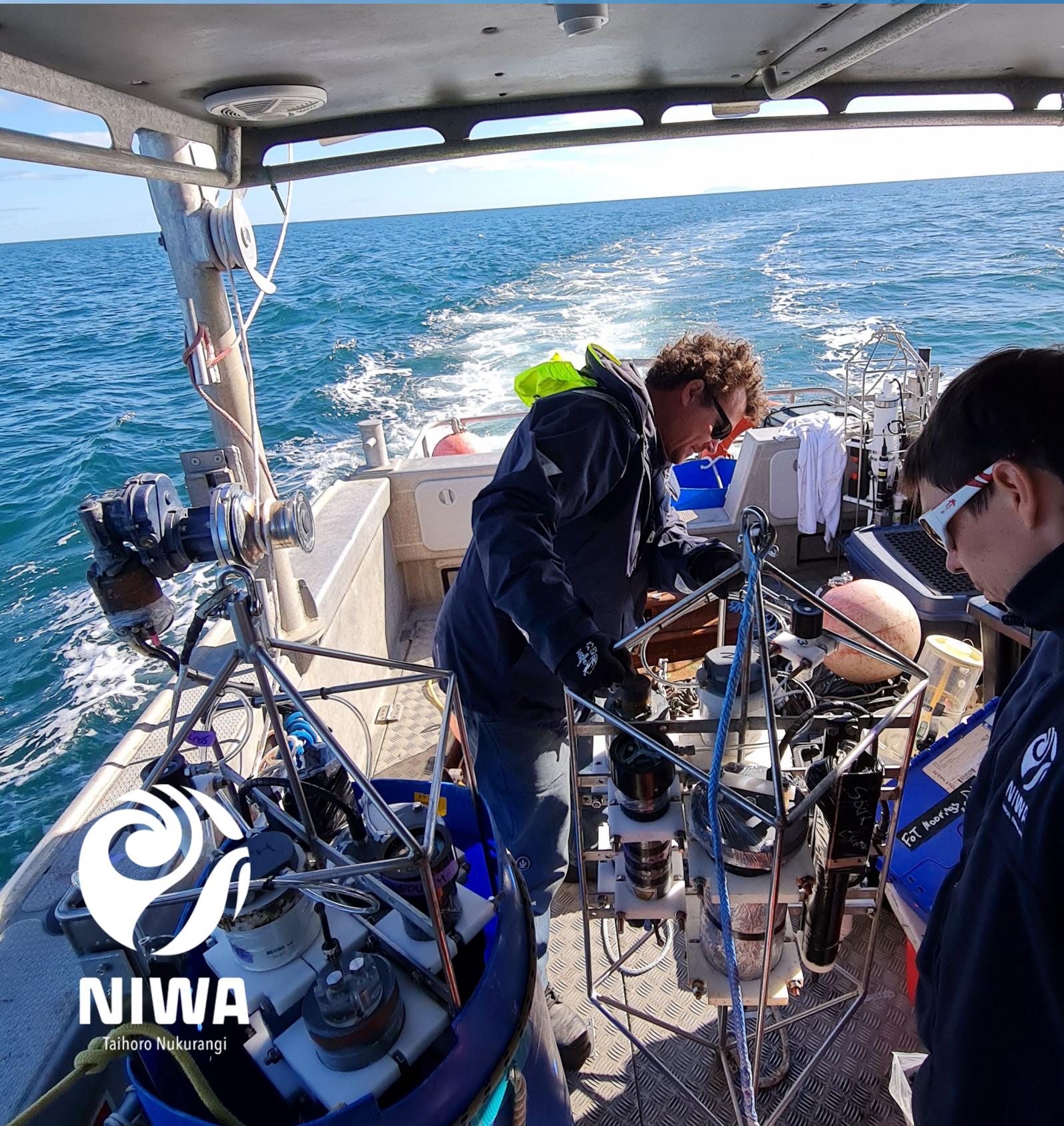


# ELECTRICAL CONDUCTIVITY SENSOR SELECTION



**NIWA**  
Tairāhoro Nukurangi

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**Front cover: Rangatahi III underway on the Firth of Thames [Rod Budd, NIWA].**

**Back cover: Temporary multiparameter sonde deployment on a bridge pier [Garry de Rose, NIWA].**

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## ABSTRACT

Electrical conductivity (EC) sensor use is well established in Aotearoa New Zealand for environmental monitoring of rivers, lakes and estuaries. Although high frequency conductivity sensors have been operated for decades, it can be challenging to select the right sensor for a particular site. Commercially available EC sensors suitable for unattended in-situ deployments use several different principles and these affect their performance, data quality and suitability for different waters.

This chapter provides information to help people select a sensor. It describes the basic types of EC sensors, compares sensor hardware and software, summarises key sensor selection questions, and showcases the variety of deployments undertaken across New Zealand. Often conductivity measurement is included on combined sensors, such as CTDs or multiparameter sondes. Most field sites are unattended and visited on a regular schedule (commonly monthly), which creates extra challenges that do not occur at attended sites or with field meters. This chapter does not address field maintenance, data editing or verification procedures in detail.

## BACKGROUND

Obtaining information about water quality dynamics over short time scales (such as daily cycles, or during a storm or rain event lasting a few days) using conventional discrete samples or field measurements may be costly and logistically challenging to undertake frequently. Fortunately, high frequency water quality (HFWQ) sensors can be deployed on site to measure indicators (e.g., nitrate, dissolved oxygen) and provide detailed insights into water quality dynamics at scales of interest (minutes to hours). However, these HFWQ sensors create can different technical challenges, and unattended deployments can be resource hungry. Monitoring projects are more likely to succeed if they have (1) clearly defined objectives, (2) robust data collection systems, and (3) well thought-out methods for managing raw data and converting it into knowledge for decision-making.

This chapter provides detailed guidance on EC sensor selection. It sits alongside guidance chapters on HFWQ Use Cases, Resourcing, Sensor Selection and Automated Anomaly Detection as part of the *High Frequency Water Quality Monitoring Guidance* project.

## PURPOSE AND SCOPE

This chapter provides information on sensor selection for measuring EC in-situ and at high frequency in rivers, lakes and estuaries. It will help regional council staff to shorten the learning curve for new users, support them to make good sensor selection decisions, and help them accelerate the collection of high-quality EC data.

## RELATED RESOURCES

Useful reading that expands on the detail in this chapter can be found in the following documents:

- A technical overview of fouling management, focused on coastal waters, in Delgado et al. (2021).
- US Geological Survey research and guidance documents, such as McCleskey et al. (2023) and U.S. Geological Survey (2019).
- A complete overview of EC units and conversions in coastal waters in IOC et al. (2015).
- A detailed technical overview of conductivity sensors is available in Thirstrup and Deleebeek (2021). Detailed explanations of the physics of toroids, capacitance and conductors are available in University Physics Volume 2 (Ling et al. 2016b).
- Many useful documents can be found at Ocean Best Practices ([oceanbestpractices.org](http://oceanbestpractices.org)), Integrated Marine Observing System ([imos.org.au](http://imos.org.au)), National Estuarine Research Reserve System ([noaa.gov](http://noaa.gov)), Integrated Ocean Observing Systems ([ioos.noaa.gov](http://ioos.noaa.gov)).

## SENSOR SELECTION STEPS

Sensor selection involves a sequence of steps (Figure 1). Figure 1 also links this chapter to several other guidance chapters. Many factors must be considered when selecting an EC sensor suitable to meet a user’s monitoring objectives.

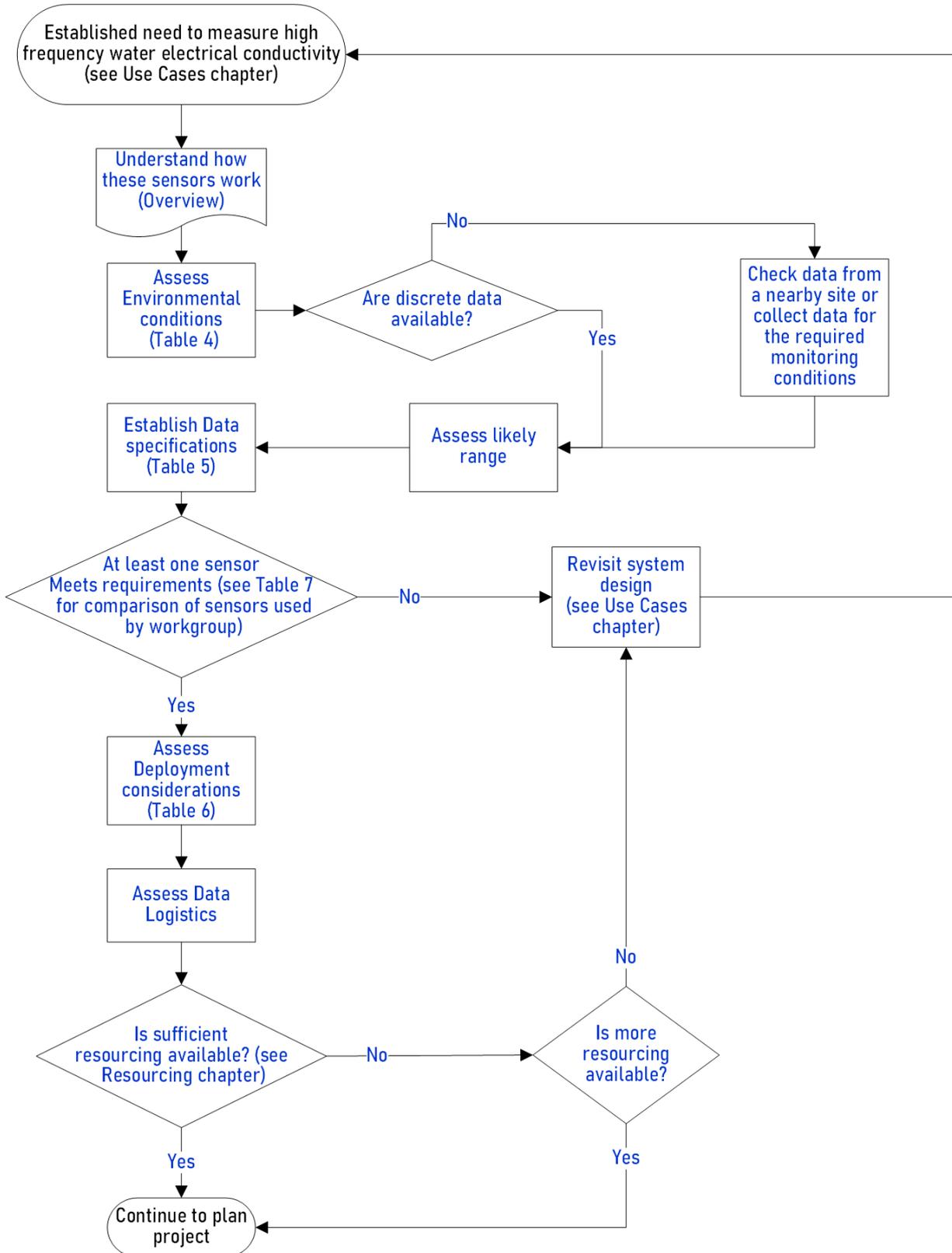


Figure 1. Suggested sequence of steps to guide electrical conductivity sensor selection.

## ELECTRICAL CONDUCTIVITY SENSOR OVERVIEW

Electrical conductivity (EC) sensors measure the ability of water to conduct an electric current. A basic electrical conductivity sensor consists of:

- a method to create an electrical current or field,
- a method to measure the current or field,
- a micro-controller to convert the output (current or volts) to a digital value, and
- data storage and/or communications capability.

Understanding the sensor technology is a key step in sensor selection. With a basic understanding of the different types of electrical conductivity sensors, a user can then assess sensor suitability aspects such as range, measurement challenges, and sensitivity to fouling.

### Ions

The ability of water to conduct an electrical current depends on the mobility of separated (dissociated) ions in the solution. The ions carry the electric charge through the solution. Distilled water is a very poor conductor of electricity since it has few ions, so little charge can flow. Natural waters, such as seawater, contain more dissociated ions and can conduct electric charge.

Electrical conductivity is a function of the number of ions, their valence and elementary charge (mobility of positive and negative ions). Some ions contribute significantly to the conductivity of natural waters (e.g., hydron,  $H^+$ ; sodium,  $Na^+$ ; magnesium,  $Mg^{2+}$ ; calcium,  $Ca^{2+}$ ; nitrate,  $NO_3^-$ ; potassium,  $K^+$ ; and sulphate,  $SO_4^{2-}$ ) and are essential for accurate measurement. Other ions only contribute a moderate (e.g., copper,  $Cu^{2+}$ ) or small amount (e.g., bromide,  $Br^-$ ) to conductivity. More detailed information on electrical conductivity and ions in natural waters – geothermal waters, seawater, dilute mountain waters, and river water impacted by municipal wastewater – can be found in McCleskey et al. (2011).

Temperature alters conductivity values through its influence on the ion mobility. It is common to correct the temperature to a reference temperature ( $T_0$ ), most commonly 25 °C. The change per °C is the temperature coefficient ( $\alpha_0$ ), and conductivity increases by 0.5 to 3 % per °C. The precise increase depends on the ionic species present in the water (see McCleskey et al. 2011). Most sensors use linear conversions (1.9 to 2 % per °C), but many also offer non-linear temperature compensation algorithms (see Table 7 for more details on individual sensors). The conductivity ( $\kappa_0$ ) at the measured water temperature ( $T_t$ ) is converted to specific conductivity ( $\kappa$ ) using:

$$\kappa = \kappa_0 [1 + \alpha_0 (T_t - T_0)] \quad \text{Equation 1}$$

Temperature compensation is typically accurate to  $\pm 5$  % for waters with a pH between 4 and 11 over the temperature range of 5 to 35 °C. However, for waters with low pH (< 4), the standard temperature coefficients can result in specific conductivity errors as large as 50 % (see McCleskey et al, 2011).

### Units

Values measured by EC sensors can be converted to several different indicators: electrical conductivity, specific conductance, salinity and total dissolved solids (Table 1).

Salinity is defined as the mass of salts dissolved in water. Sea water contains about 32 g/kg salt, of which 90 % is sodium chloride. Salinity is determined in the lab by drying out samples of water and weighing the remaining salts. Electrical conductivity sensors estimate salinity, but there are several different approaches.

Oceanographers have a well-documented salinity manual which provides guidance on standard units and conversions (IOC et al. 2015). One of these units, the Practical Salinity Scale (PSS-78) method, calculates

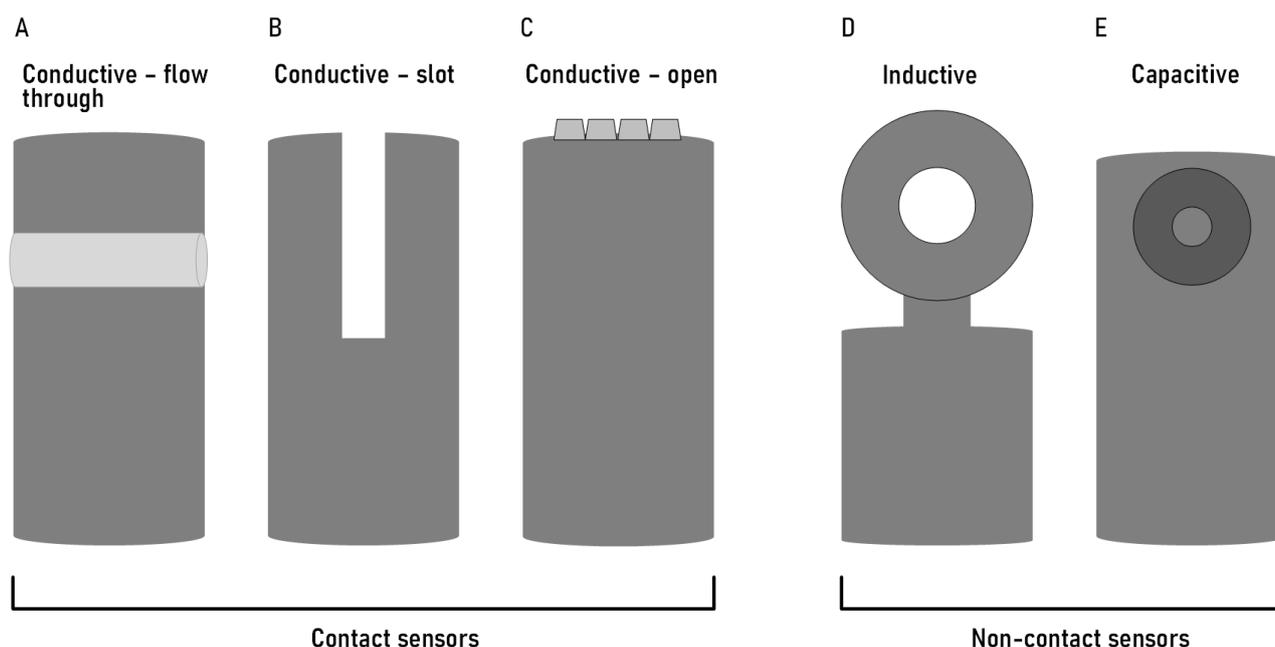
salinity from EC, temperature and pressure using well-established equations. The PSS is designed to measure the salinity of seawater (chloride-rich waters) and defined only in the range 2 to 42. The equations define Practical Salinity ( $S_p$ ) as the ratio of seawater EC at atmospheric pressure and 15 °C to the EC of a potassium chloride solution containing 32.4365 g KCl in a mass of 1 kg of solution at the same temperature and pressure. Practical Salinity is a ratio, so it is a unitless quantity. Although sometimes convenient, it is technically incorrect to quote Practical Salinity in “psu”; rather it should be quoted as a value “on the Practical Salinity Scale PSS-78”.

**Table 1. Electrical conductivity units.**

Indicator	Description	Formal definition	Units
Electrical conductivity	Not temperature corrected	Electrical conductance of a 1 cm <sup>3</sup> of liquid at a specified temperature.	μS cm <sup>-1</sup>
Specific conductance	Temperature corrected	Electrical conductance of 1 cm <sup>3</sup> of liquid at 25 °C.	μS cm <sup>-1</sup> at 25 °C
Salinity		Mass of dissolved salts in a given mass of solution.	mg/L or ppt
Practical Salinity	Relative to a standard & temperature corrected	Salinity relative to a standard KCl solution at 15 °C (PSS-78).	Unitless (but psu often used)

## SENSING PRINCIPLES

Two main groups of EC sensors exist: (1) contact sensors with electrodes in direct contact with the water (using the conductive principle), and (2) non-contact sensors which do not have electrodes (these operate using inductive and capacitive principles; Figure 2). Conductive sensors have two or more electrodes that tend to be located inside a tube or slot (Figure 2 A & B), although some designs use an open (or flat) face (Figure 2 C). Inductive sensors have a unique doughnut shape and use water to link two coils in a transformer (Figure 2 D). Capacitive sensors (Figure 2 E) are also non-contact sensors and measure a static electric field.



**Figure 2. Common conductivity sensor forms. (A, B & C) Conductive sensors with electrodes in direct contact with the water. (D & E) Non-contact sensors without electrodes.**

## Conductive sensors

Many EC sensors have electrodes which measure the resistance of the water to conducting the current – there is direct contact between the electrode and water matrix. When an electrical current is applied to water, ions move, and an electrical potential is measured. The sensors create a known current in the water and by alternating the current direction at an extremely high frequency, ions migrate. The positive ions (cations) move towards the cathode (negatively charged), and negative ions (anions) move towards the anode (positively charged). By switching the cathode and anode with the alternating current, ions migrate backwards and forwards between the electrodes. The conductivity is a function of the speed of ion migration, the charges and concentrations of ions, and any interactions between the ions.

Resistance is calculated using Ohm's law. Ohm's law (Equation 2) states that the resistance ( $R$ , ohms) is the ratio of electrical potential ( $E$ , V) to electrical current ( $i$ , amps).

$$R = \frac{E}{i} \quad \text{Equation 2}$$

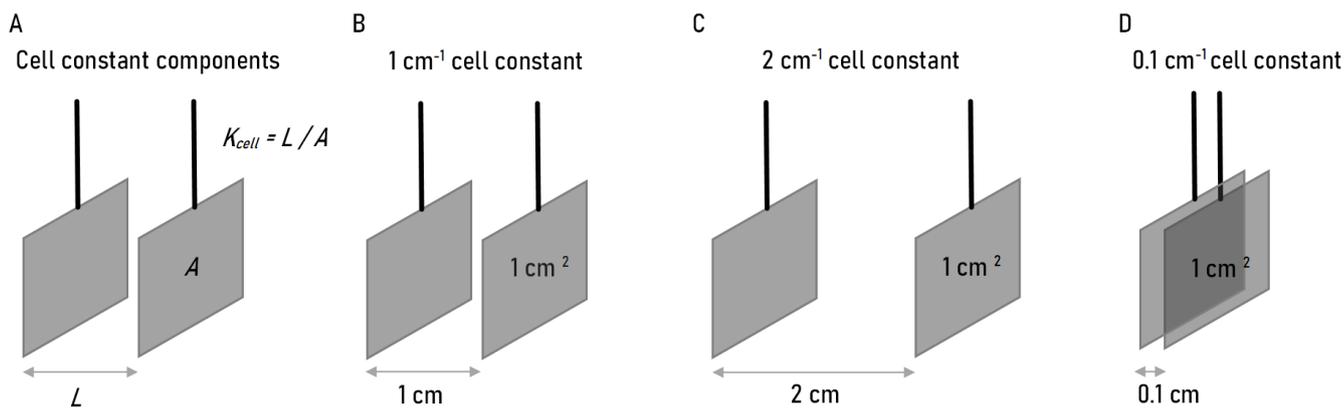
Conductance ( $G$ , measured in  $\text{ohm}^{-1}$  or more commonly siemens, S) is the reciprocal of resistance ( $R$ , Equation 3). Conductance is measured between spatially fixed and chemically inert electrodes. The conductance of a liquid is directly proportional to the electrode surface area,  $A$  ( $\text{cm}^2$ ), and inversely proportional to the distance between the electrodes ( $L$ , cm).

$$G = \frac{1}{R} \quad \text{Equation 3}$$

The conductivity ( $\kappa$ , microsiemens per centimetre,  $\mu\text{S cm}^{-1}$ ) is a property of the solution between the electrodes and is the conductance multiplied by the cell constant (Equation 4). The cell constant ( $K_{cell}$ ) is the ratio of the distance between the two electrodes ( $L$ ) and their area ( $A$ ) and has units of  $\text{cm}^{-1}$  (Figure 3 A). To compare conductivities, values of  $\kappa$  are reported relative to electrodes, with  $A = 1 \text{ cm}^2$  and  $L = 1 \text{ cm}$  with a volume of  $1 \text{ cm}^3$  (Figure 3 B) and normalised to  $25 \text{ }^\circ\text{C}$  (see units in Table 1).

$$\kappa = G K_{cell} = \frac{L}{R A} \quad \text{Equation 4}$$

In a theoretical sensor with  $1 \text{ cm}^2$  electrodes placed  $1 \text{ cm}$  apart (Figure 3 B), the cell constant is  $1 \text{ cm}^{-1}$  and the conductance ( $G$ ) value in  $\mu\text{S}$  is numerically equal to the conductivity value in  $\mu\text{S/cm}$ . For low conductivity solutions, the electrodes are usually closer together (reducing  $L$ ) and these sensors have cell constants between  $0.01$  and  $0.1 \text{ cm}^{-1}$ . A smaller cell constant raises the conductance between the electrodes and makes it easier for the electronic circuitry to measure a value. Similarly, for high conductivity solutions,  $L$  can be increased to give a cell constant of  $10 \text{ cm}^{-1}$  or more.



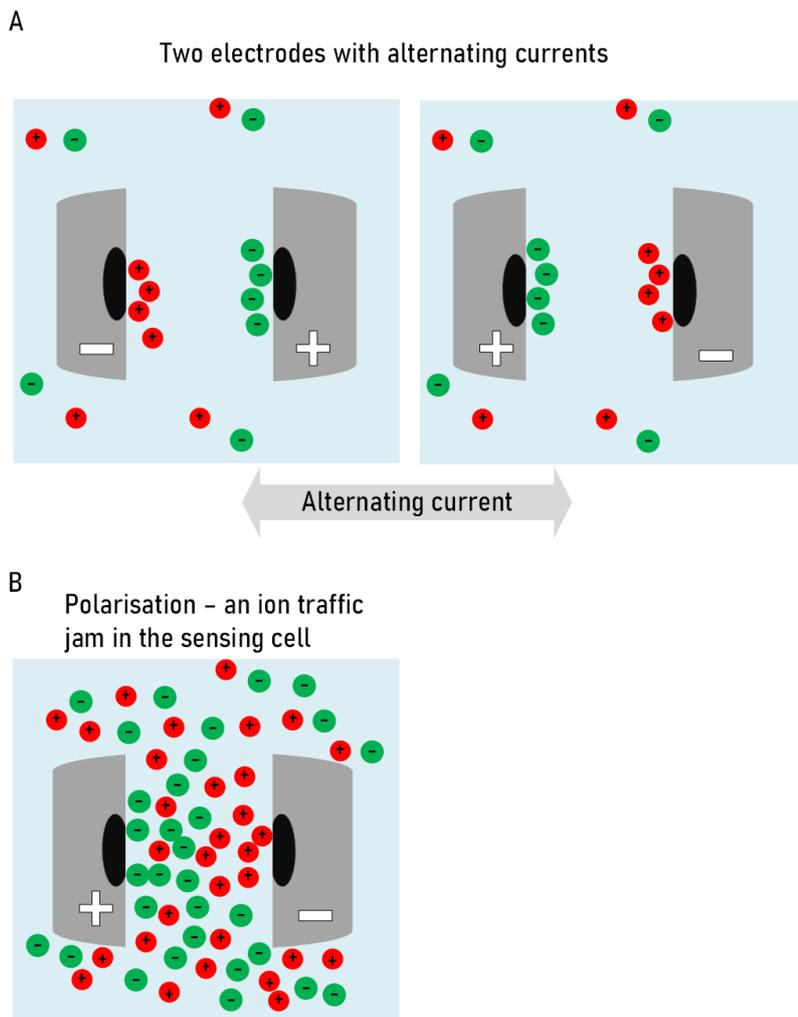
**Figure 3. Theoretical conductive conductivity sensors. (A) Cell constant components. (B) Standard conductivity cell (with volume  $1 \text{ cm} \times 1 \text{ cm}^2 = 1 \text{ cm}^3$ ) and a cell constant of  $1 \text{ cm}^{-1}$ . (C) A larger cell constant, suitable for high conductivity solutions. (D) Smaller cell constant ( $0.1 \text{ cm}^{-1}$ ), suitable for low conductivity solutions.**

Conductive EC sensor cell geometries vary (see Table 7 for examples), and it is not always practical or convenient to design a measurement cell with exact dimensions or a cubic shape. A sensor's cell geometry is determined by calibrating the sensor's value to an accepted standard (commonly potassium chloride).

Users should carefully consider the suitability of different types of conductive EC sensors, particularly the number of electrodes and the sensor form. Conductive sensors for environmental monitoring typically have two, three or four electrodes, but designs with more electrodes are available. Three forms are common – open face, slot or flow-through (Figure 2 A, B & C). Wipers can be used on sensors with a slot or open face, but the sensing volume is partly external. Electrodes in flow-through EC sensors tend to be inside borosilicate glass tubes, and the current is contained internally. In natural waters, flow-through EC sensors may benefit from pumps (e.g., Sea-Bird MicroCAT) to ensure the conductivity cell is well-flushed.

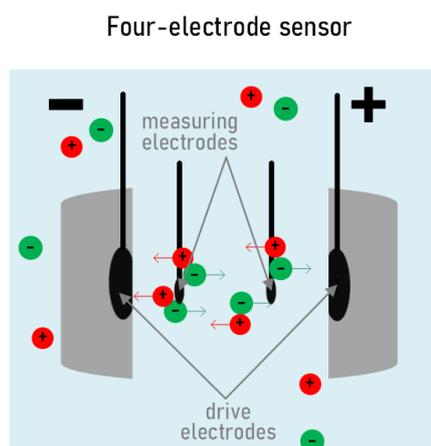
Conductive sensor electrodes are typically graphite, platinum or platinum-iridium (see Table 7 for electrode details on commonly used sensors). Some sensors have stainless steel electrodes (e.g., Meter Hydros21). Other metals are not commonly used at the sensor head as they will alter electrical currents, but they can be used for the sensor body. Epoxy or plastic (e.g., ABS, Delrin) are common sensor body materials.

Two-electrode conductivity sensors have the simplest design and are most suitable for low conductivity waters (distilled water through to surface water). The electrodes are often graphite, and the cell constant is small (in the order of  $0.1 \text{ cm}^{-1}$ ). Two-electrode conductivity sensors can be sensitive to fouling and are prone to polarisation. Even a thin layer of fouling on the electrodes can alter the calibration, so four-electrode sensors are preferable in fouling-prone environments. Polarisation is a phenomenon that occurs when there is a drag effect on the ions – i.e., there are too many ions trying to migrate when the current alternates – and it means the measured conductivity tends to underestimate the actual value. Polarisation restricts the use of the two-electrode design to lower conductivity waters ( $< 300 \mu\text{S/cm}$ ).



**Figure 4. (A) Ion movement under an alternating current in a two-electrode conductive sensor. (B) Polarisation occurs when too many ions are trying to migrate.**

Four-electrode EC sensors are often used to overcome the effects of polarisation and reduce sensitivity to fouling. Adding two small measuring electrodes between the two main drive electrodes (Figure 5) enables the current to be increased until a voltage can be measured. A thin fouling layer or coating on the main drive electrodes will not impact on the measuring circuit (Figure 5). Four-electrode sensors perform well in a wide range of waters – freshwater through to seawater. Sensor designs vary and the range of cell constants is large (see Table 7 for examples), so a critical evaluation of each sensor’s design and suitability is important.



**Figure 5. Addition of measuring electrodes in a four-electrode conductivity sensor.**

## Inductive sensors

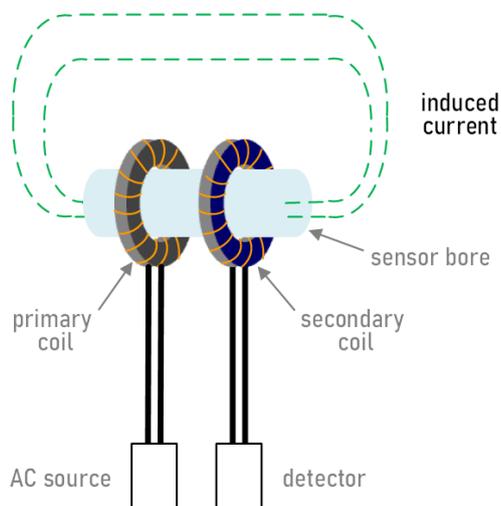
Inductive EC sensors used for HFWQ have a distinctive doughnut-shaped head (Figure 2 D). Inductive conductivity sensors operate according to Faraday's law of induction, and the sensor head contains two transformers or a toroidal coil. A toroid is a closely wound doughnut-shaped coil of one continuous wire.

The sensor applies an alternating current to the primary coil, creating a magnetic flux and a resulting circular electrical field which induces a current in the water. The current travels through and around the cell in closed loops, and back into the cell (Figure 6). The current loops are dense inside the cell and spread out around the sensor. The resulting current around the primary coil induces a current around the secondary coil. The current measured by the second cell is proportional to the resistance of the water, which is inversely proportional to conductivity.

Inductive sensors are suitable for sea water and some freshwaters. They are electrically isolated from the water so can be used in corrosive environments and waters with high suspended particulate matter. Inductive conductivity sensors are less sensitive to fouling, although macrofouling by biota can still occur. They are robust, have good linearity and are able to withstand shock, freezing and impact. Inductive conductivity sensors are commonly made from plastic and include a ceramic tube lining the transformers to ensure the cell geometry is stable.

Inductive sensors tend to have a large cell geometry ( $> 1 \text{ cm}^{-1}$ ). Note that due to the casing around the toroids, the cell geometry of an inductive sensor does not strictly follow the definition of a cell constant; despite this, the term cell constant is commonly used.

Proximity effects can be significant for inductive EC sensors. The current loops occupy a sensing volume beyond the sensor (Figure 6), and metal objects can affect the sensor calibration and sensor accuracy. If conducting materials (e.g., shields, guards, antenna) are going to be within the sensing volume, they must be included in calibration.



**Figure 6. Basic components of an inductive conductivity sensor and resulting external current.**

## Capacitive sensors

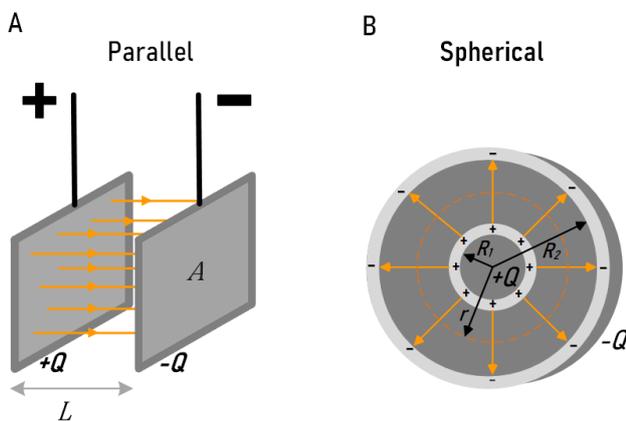
Capacitive EC sensors are less commonly used for HFWQ sensing. A capacitor stores electrical charge and energy. It consists of at least two capacitor plates separated by a space, which is filled with an insulating material known as a dielectric (with low conductivity and high insulating properties). The capacitance is a function of the cell geometry and the dielectric's properties (its permittivity). The permittivity of the dielectric substance varies with the conductivity of the water.

When a voltage is applied, the water and sensor create a resistor-capacitor circuit. A static electric field,  $Q$ , forms across the dielectric when a voltage ( $V$ ) is applied between the plates, which causes an electrical charge to build up. The capacitance ( $C$ ) is determined by the area of the conductors ( $A$ ), the distance between them ( $d$ ) and the electrical properties of the dielectric substance, the permittivity,  $\epsilon$ .

$$C = \frac{\epsilon A}{d} = \frac{Q}{V} \quad \text{Equation 5}$$

Capacitors are commonly explained using the simple parallel-plate model (Figure 7 A), but they can have other forms, including spherical (Figure 7 B), rolled, and cylindrical. A spherical capacitor consists of two concentric conducting spheres (Figure 7) with an inner shell (radius  $R_1$ ) and an outer shell (radius  $R_2$ ). The electrical field is directed outwards from the inner shell towards the outer shell. The magnitude of the field is determined using Gauss' law over the spherical surface of radius  $r$ . The capacitance ( $C$ ) is calculated using the radii of the fields ( $R_1$  and  $R_2$ ) and the permittivity,  $\epsilon$  (Equation 6):

$$C = \frac{Q}{V} = 4\pi\epsilon \frac{R_1 R_2}{R_2 - R_1} \quad \text{Equation 6}$$

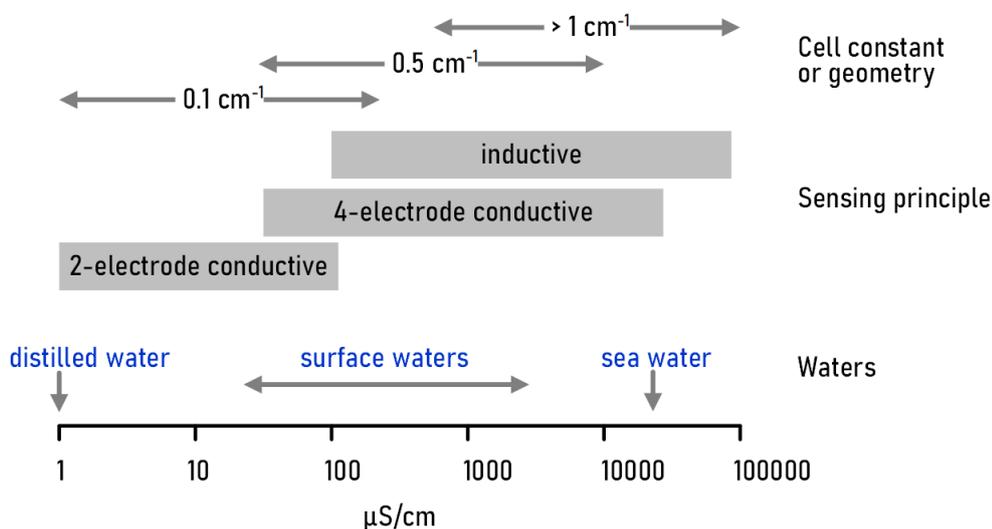


**Figure 7. Simple models of capacitors. (A) A parallel-plate capacitor. (B) A spherical capacitor [after Ling et al. (2016a)].**

Capacitive sensors are suitable for both sea water and freshwater. However, they can suffer from sensor drift (e.g., HOBO U24 drifts up to 12 % per month, exclusive of fouling drift) and require frequent calibration.

## Summary of sensing principles

Selecting the most appropriate sensing principle for your project is critical (Figure 8). When the sensing principles overlap, it's important to consider the advantages and disadvantages of each (Table 2). Key factors to consider include range, polarisation, sensitivity to fouling, ability to withstand corrosion, and proximity effects.



**Figure 8. Typical cell constant or geometry and sensing principles across the range of waters and conductivities measured in lakes, rivers and estuaries.**

**Table 2. Comparison of sensing principles**

Sensor principle	Advantages	Disadvantages
Two-electrode conductive sensors	<ul style="list-style-type: none"> <li>- Simple.</li> <li>- Suitable for low conductivity waters.</li> </ul>	<ul style="list-style-type: none"> <li>- Small cell geometry, sensitive to fouling by biota.</li> <li>- Prone to polarisation.</li> </ul>
Four-electrode conductive sensors	<ul style="list-style-type: none"> <li>- Less sensitive to fouling than a two-electrode conductive sensor.</li> <li>- Wide EC measuring range.</li> <li>- No polarisation.</li> <li>- Small sensor dimensions.</li> </ul>	<ul style="list-style-type: none"> <li>- May have a small cell geometry, sensitive to fouling by biota.</li> </ul>
Inductive sensors	<ul style="list-style-type: none"> <li>- Less sensitive to fouling due to large sensing volume.</li> <li>- Separation of measuring components from the solution, so suitable for corrosive environments.</li> <li>- Water freely flushes the sensor bore (typically short and wide).</li> <li>- No polarisation.</li> <li>- Robust.</li> </ul>	<ul style="list-style-type: none"> <li>- Sensitive to proximity effects due to external sensing volume.</li> <li>- Care may be required during calibration to overcome proximity effects.</li> <li>- Cannot be fitted with a wiper.</li> <li>- Not suitable for low conductivity waters.</li> <li>- Sensor bore may become fouled.</li> </ul>
Capacitance sensors	<ul style="list-style-type: none"> <li>- Suitable for corrosive environments.</li> <li>- Small sensor dimensions.</li> </ul>	<ul style="list-style-type: none"> <li>- Prone to sensor drift (in addition to fouling drift).</li> </ul>

## SENSOR PERFORMANCE

The performance of EC sensors is determined by many factors, including:

- sensor hardware (including the sensing principle used, temperature measurement and analog-to-digital convertor specifications),
- instrument noise (such as fluctuations in voltage in the electrical circuitry),
- sensor deployment (e.g., fouling management),
- sensor software and firmware,
- integration with data loggers.

The workshop participants identified design suitability, fouling, calibration, thermistor performance, and proximity as key factors affecting EC sensor performance during unattended deployments. Sensor software and firmware and integration are discussed in Logistics – getting the data.

### Design suitability

Some users have stopped using inductive EC sensors in freshwater. The key problems identified with the deployments were managing gross fouling, and the temperature sensor not meeting manufacturer specifications (on some sensors). Replacing them with four-electrode conductive EC sensors enabled these users to overcome the challenges and obtain high quality EC data.

### Fouling

Fouling alters the cell geometry, reducing sensor accuracy and introducing anomalies (e.g., drift, spikes). The impact of fouling varies with EC sensor design. Two-electrode conductive sensors are more sensitive to fouling because the cell constants are small and fouling alters the sensing cell geometry. The design of four-electrode sensors largely overcomes the influence of micro-fouling on the primary electrodes. Inductive sensors are typically larger and have a large sensing volume, so a thin layer of micro-fouling may be tolerated.

Macro-fouling is a major challenge for unattended in-situ deployments. In freshwater environments, sludge, algae or biota (e.g., mud snails, barnacles or eels) will alter values. Some EC sensors have wiper systems to reduce fouling (e.g., YSI EXO wiped C/T, In-Situ Aqua TROLL). New Zealand mud snails (*Potamopyrgus antipodarum*) are often found inside conductivity sensor cells in rivers, and their presence alters the cell geometry and affects the sensor calibration. In coastal waters, EC sensors on moorings can suffer from gross fouling by barnacles, seaweed and molluscs, which alter cell geometries. More information on actively managing fouling is available in the Fouling management section.

A



B



**Table 3. Examples of fouling. (A) YSI EXO non-wiped C/T sensor fouled during an estuary deployment [Chris Eager, WRC]. (B) In-Situ Aqua TROLL fouled during a coastal lagoon deployment [Hamish Carrad, ECan].**

### Calibration

Conductivity sensor calibration is a key performance and sensor selection factor. EC sensors must be checked or calibrated before every deployment to ensure the sensor is working properly. Sensors are typically calibrated with potassium chloride (KCl) standards. The workgroup identified four calibration issues relevant to sensor selection: (1) the recommended and actual frequency of calibration, (2) ease of calibration, (3) available calibration options, and (4) ability to store and switch between several calibrations.

Experienced users highlighted several calibration issues:

- Manufacturer recommendations vary with sensor principle. For example, In-Situ recommend a factory calibration after 12 months for their Aqua TROLL EC sensor, while Onset HOB0 recommend monthly calibration to manage instrument drift (excluding fouling drift) for their U24 capacitive sensor. Details of recommended calibration frequency are included in Table 7.
- Less frequent calibrations may be required for groundwaters due to light fouling, while EC sensors in rivers and lakes may require monthly calibrations. For example, Horizons Regional Council operates E+H Memosens SE 615 sensors in groundwater wells; the sensors do not show drift over 3-month calibration intervals.
- Some sensor software limits users to 1-point calibrations (see Table 7). Experienced users are wary of the errors this could introduce, as only the slope can be adjusted with a 1-point linear calibration. Many sensors allow users to enter multipoint calibrations into the software.
- Users operating a sensor fleet across waters with different conductivities (e.g., freshwater and sea water) should carefully check how and where calibrations are stored. Some sensors can store several calibrations, and the user is able to select the appropriate calibration in the field (e.g., Sea-Bird CTDs). In contrast, other sensors need a new calibration before moving between fresh and sea waters (e.g., YSI EXO).
- Some industrial-style sensors can store and run two calibrations simultaneously. This enables more precise calibration of the low range, while ensuring these sensors can also measure the full range.

### Thermistors

Electrical conductivity varies with water temperature, so all conductivity sensors have an electrical thermometer. Thermistors (see Water Temperature Sensor Selection Guidance chapter) are commonly

used and are usually placed as close to the conductivity cell as possible to ensure they are sensing the same water volume. Thermistor accuracy should also be checked; some experienced users have stopped using some brands of EC sensors after finding the thermistors were not accurate.

Thermistor location is an important factor to consider if your sensor will also be used for profiling applications or used on a lake buoy with a profiler. An offset between the thermistor and conductivity cell may require a time offset to remove spikes. For more information on correcting profiles, refer to Halverson et al. (2017).

## Proximity

Users also identified proximity effects as a key factor affecting performance. This is important for inductive sensors, which have an external sensing volume (see Figure 6). For example, around 20 % of the electric field created by the RBR conductivity cell is external to the cell, and lab experiments show that objects within 15 cm of the cell can affect measurements (Halverson et al. 2017, Halverson et al. 2020).

## ADVICE FOR NEW USERS

We asked experienced users to share their advice for new users, and to highlight one thing they wish they'd known earlier:

- Understand the sensing method used in a sensor.
- Actively manage fouling by using a wiper or antifouling system. If an automatic antifouling system is not possible, ensure manual cleaning is frequent.
- Check the temperature sensor performance. An inaccurate temperature sensor will affect the conversion of EC to specific conductance and can be hard to detect without testing.
- Take care with calibrations:
  - Budget in regular calibrations.
  - Complete calibrations in the office or lab.
  - Check the quality of calibration solution, including expiry date.
  - Consider swapping field sensors for a clean and recently calibrated sensor (you will need more sensors).
- Check the cell constant (if it changes, check for fouling).
- EC sensors are simple (compared to optical HFWQ sensors), so consider how a sensor works within your fleet.

## FOULING MANAGEMENT

Active fouling management can:

- Reduce interferences on the sensor electrodes. Fouling is a major cause of drift in conductivity sensors. Drift may be sporadic as fouling may be episodic.
- Make cleaning and re-deployment easier.
- Reduce macro-fouling. Macro-fouling could (1) alter the cell constant (e.g., mud snails, oysters), or (2) drift around the sensor head and intermittently alter values (e.g., strands of filamentous algae entering the sensing cell).

### Recommendations

Fouling should be managed during most deployments. Even a slight build-up on the sensing cell will degrade the sensor's ability to return accurate values. Fouling reduces the cell geometry, which alters the calibration relationship.

For freshwater deployments, experienced users suggest:

- Regular maintenance, particularly in spring and summer, including hand-cleaning of sensor and sensor face with the supplied brush or a lint-free swab/wipe and DI water.
- Use an EC sensor with a wiper (where possible) – but don't assume the wiper will always be adequate. Telemetry can allow users to identify fouling drift and adjust wiping frequency.
- Thoroughly clean the sensor cell and housing (inside and outside) to remove fouling. Some sensors come with special brushes for thoroughly cleaning the EC cell.

For coastal deployments, advanced anti-fouling methods are required:

- Users should consider using a combination of wipers, biocides, copper tape and guards.
- Also consider fouling on structures supporting the sensor.
- More detailed information on marine fouling systems can be found in Delgado et al. (2021).

### Fouling tools

EC sensors can be sorted into two groups – those with a proprietary fouling management system and those without. Sensors with proprietary fouling systems have unique patented designs (cell geometries, wipers, pumped flow, etc.) or dispensations (e.g., Sea-Bird's use of a biocide). Fitting third-party anti-fouling systems to EC sensors is not common practice.

### Wipers

The design of many EC sensors includes protected electrodes, which prevents the use of wipers. Some EC sensors, particularly on sondes, can be wiped by brushes. For example, the YSI EXO sonde wiped CT sensor has a U-shaped cell geometry which allows the central wiper to clean the sensor (Figure 9 B). In contrast, the same brand's standard CT sensor has a slot which cannot be wiped with the central wiper and must be manually cleaned with a brush. The In-Situ Aqua TROLL has a open-faced EC sensor which is wiped by the central wiper and protected by fins (which define the cell geometry and protect the electrodes from external interferences).

For telemetered EC sensors it is good practice to telemeter wiper performance values when they are available. These values can help identify if the wiper has failed, is parked incorrectly across a sensor face, is buried or is struggling to clear debris.

If you can add a wiper to an EC sensor (e.g., open-face or open slot design), consider the wiper design, including materials (scraper, sponge, or bristles), controller, and power (cabled or standalone). Refer to the Optical DO Sensor Selection Guidance chapter for more information on selecting a wiper.



**Figure 9 (A) Sea-Bird SBE 37-SMP encrusted with barnacles and fouling after a marine deployment [Rod Budd, NIWA]. (B) Oyster growing on a YSI EXO sonde C/T sensor [Chris Eager, WRC]. (C) Sea-Bird MicroCATs wrapped in tape and painted with biocide ready for deployment [Chris Eager, WRC]. (D) YSI EXO sonde post-deployment with sensors wrapped in copper tape [Chris Eager, WRC].**

## Copper

Copper can slow the growth of biofouling by releasing dissolved copper ions into the water. However, as copper is a conductor it can't be used within the sensing volume of EC sensors. Some manufacturers supply copper guards or mesh, and these may offer some protection and slow the fouling rate. Copper tape can also be used (Figure 9 D), but when applying copper tape near an EC sensor, ensure it is outside of the sensing volume so the sensor calibration is not altered.

## Biocides

In marine environments, where macro-fouling is heavy and service intervals can be long, biocides are often required. A more detailed discussion on the use of biocides (and alternatives) to manage fouling can be found in Delgado et al. (2021).

Chlorine or bromine solutions can be used to reduce fouling. A chlorine injection was available on some Sea-Bird instruments (e.g., discontinued Sea-Bird WQM) and a small volume of bleach was pumped into the EC cell. Similar systems have been developed by others, including NIWA's Squirtek, which squirts bromine for 15 s every 3 hours.

Several of the Sea-Bird CTD range with internal and pumped EC sensors can be deployed with anti-fouling plugs, which contain TBTO (tributyltin oxide). The plugs are placed at the external ends of the cell (both entrance and exit) and work to minimise fouling without altering the cell geometry. The pumped system contains poisoned water when the sensor is not sampling. TBTO was banned by the International Marine Organisation in 2008 as it is considered an environmental toxicant, but Sea-Bird continues to obtain approval for its use for this application. The Argo float programme identified accidental leakage of TBTO onto the conductivity cells followed by gradual decontamination, which is a potential source of error users should be aware of (Wong et al. 2024).

## Antifouling paints

Paints designed for boat hulls can be used to slow fouling on sensors in coastal waters (Figure 9 A). Paints such as Pettit Hydrocoat or International Trilux 33 contain copper and/or biocides and degrade over time. These paints are not suitable for freshwater deployments. Many of these paints contain toxic chemicals, so use good workplace safety practices.

## Coatings

Coatings that create a slick surface that prevents organisms from adhering may be useful, but for unattended deployments they may be inadequate. Coatings may be added at the factory or by users, but both versions are generally designed to reduce rather than eliminate adhesion. For example, the Onset HOBO U24 comes with an inert titanium pentoxide coating, which is marketed as an aide to cleaning rather than an antifouling solution.

Users can apply coatings, but only to non-sensing surfaces. For example, YSI markets *C-spray*, a non-toxic, nano-polymer spray, to cover exposed surfaces such as the sensor body (do not apply to sensor faces). An alternative product, which BOPRC uses to protect non-sensing surfaces, is a New Zealand lanoline-based product, Prolan.

## Tapes

Many experienced sensor users routinely use duct tape to cover the bodies of sensors and sondes to reduce post-deployment cleaning effort. Some users combine duct tape with PVC film (e.g., cling wrap, sandwich wrap; see Front cover).

## KEY QUESTIONS TO CONSIDER WHEN SELECTING AN ELECTRICAL CONDUCTIVITY SENSOR

Each EC sensor should be considered against the monitoring objectives and deployment requirements. Key questions are grouped into environmental considerations (Table 4), data specifications (Table 5) and deployment considerations (Table 6).

### Environmental considerations

**Table 4. Environmental considerations: Considerations and challenges to help guide sensor selection.**

Key questions	Consequences	Possible solutions
What is the site's conductivity range?	<ul style="list-style-type: none"> <li>- Loss of sensitivity.</li> <li>- Inappropriate sensor selected.</li> </ul>	<ul style="list-style-type: none"> <li>- Select a sensor that spans the range of possible conductivities.</li> <li>- Consider the sensor principle and cell geometry suitability (see Figure 2).</li> </ul>
What is the site's pH?	<ul style="list-style-type: none"> <li>- Standard temperature correction algorithms may introduce errors.</li> </ul>	<ul style="list-style-type: none"> <li>- If the site's pH is &lt; 4 or &gt; 11, temperature compensation requires additional checking to ensure standard temperature compensation approaches are adequate and do not introduce error. For these ranges, the in situ specific conductance should be compared to that of a sample equilibrated to 25 °C. See McCleskey et al. (2023) or U.S. Geological Survey (2019).</li> </ul>
What is the site's temperature?	<ul style="list-style-type: none"> <li>- Inability to measure temperature required for unit conversions.</li> </ul>	<ul style="list-style-type: none"> <li>- Most sensors have an operating range of 0–50 °C, but some, particularly inductive sensors, can operate below zero.</li> </ul>
How rapidly will the temperature change?	<ul style="list-style-type: none"> <li>- Thermistors on EC sensors may not represent temperature changes.</li> </ul>	<ul style="list-style-type: none"> <li>- Check the sensor response time specifications carefully &amp; identify where the electrical thermometer is located on the EC sensor. Refer to the temperature sensor response times of commonly used sensors in Table 7.</li> </ul>
What is the maximum depth?	<ul style="list-style-type: none"> <li>- Potential damage to sensors and possible water ingress.</li> </ul>	<ul style="list-style-type: none"> <li>- Check maximum sensor depths (Table 7) to ensure the sensor housing will withstand the pressure.</li> <li>- Check recommended cable lengths for the sensor type.</li> </ul>
What is the minimum depth?	<ul style="list-style-type: none"> <li>- Sensor out of water and unable to measure.</li> </ul>	<ul style="list-style-type: none"> <li>- Ensure the EC sensor will be submerged across the range of conditions.</li> </ul>
How will you manage fouling, including burial?	<ul style="list-style-type: none"> <li>- Inaccurate values.</li> </ul>	<ul style="list-style-type: none"> <li>- Consider the planned frequency of sensor maintenance. Will it need to vary seasonally?</li> <li>- Consider selecting an EC sensor which comes with a fouling management system, such as a wiper (check it wipes the conductivity sensor), copper guard or biocide.</li> <li>- Consider installing a pumped flow through system with the sensor well-protected from light to reduce biological growth rates.</li> </ul>
How robust is the sensor?	<ul style="list-style-type: none"> <li>- Sensor damage from vibrations or knocks.</li> </ul>	<ul style="list-style-type: none"> <li>- Use a sensor which can withstand knocks &amp; vibrations.</li> </ul>
Is the environment corrosive?	<ul style="list-style-type: none"> <li>- Sensor damage.</li> </ul>	<ul style="list-style-type: none"> <li>- Consider choosing a non-contact sensor (inductive or capacitive).</li> </ul>

## Data specifications

**Table 5. Data specifications: Considerations and challenges to help guide sensor selection.**

Key questions	Consequences	Possible solutions
What performance is required?	- Data will not meet requirements for decision-making.	- Check sensor performance specifications (particularly range, accuracy & response time) against project requirements. Ask the manufacturer if information is not available in brochures or manuals. - Check sensor specifications against standards (e.g., NEMS).
What is the required response time?	- Lag in temperature data may cause unit conversion errors.	- Select a sensor with a suitable response time for your project. - Check response time information carefully. Understand the terminology used (see Electrical conductivity sensor overview selection chapter). - Check the response time of the temperature sensor in a water bath before deploying an EC sensor. Some users have observed differences in thermistor performance between individual sensors of the same model (particularly for lower cost sensors). - Contact the manufacturer if details are not available in the sensor brochure or manual.
Are real-time data required?	- No real-time data available for decision making.	- Choose a sensor which can be connected to a logger with telemetry.
Do you need to measure EC variation with depth?	- Surface EC may not meet data requirements in lakes or coastal waters.	- Consider using a mooring. Mooring design will depend on resourcing and monitoring objectives. Fixed depth sensors are useful for understanding physical processes and can return high frequency data (minutes). For understanding biological or chemical processes, profiling systems might be more suitable as they can carry more complex sensors (at reasonable cost) but return less frequent data (hours).
Does the combined sensor & logging system have the required performance?	- Loss of data resolution. - Inadequate temperature range. - Insufficient accuracy.	- Consider how the EC sensor will be logged and whether it will be integrated into an existing system. - Check the performance of the combined sensor and logger system prior to deployment. Most new loggers will have 16 or 24-bit analog-to-digital convertors (ADC) on the analog channels, but if you're using an older model, check the ADC convertor specifications.
Are data gaps acceptable?	- Consequences for analysis, particularly if large periods are missing or poor quality.	- If a complete record is required, compare the resourcing required for telemetry and rapid troubleshooting versus operating a backup sensor. A backup sensor would ideally be adjacent to the primary sensor. - Consider the consequences of a data gap for decision-making.
Is averaging user controlled?	- Smoothed data may look good but might not include transient maximum or minimum values.	- Check how on-board averaging works and the ability of the user to fully configure averaging. On some sensors you can turn averaging off, while on others all data is averaged.
Is long-term deployment of the sensor at a site required?	- Sensor may need replacing. - Challenges detecting drift.	- Consider resourcing & availability of replacement sensors. Stationarity of record requires that bias is not introduced with a change in instruments. - Consider telemetry to ensure data loss risk is minimised and troubleshooting is prompt. - Consider operating a primary and backup EC sensor to identify drift and other data quality issues. - Select an EC sensor type which is less susceptible to drift and comes with an anti-fouling system.

## Deployment considerations

**Table 6. Deployment considerations: Considerations and challenges to help guide sensor selection.**

Key questions	Consequences	Possible solutions
How will you access the sensor across the range of environmental conditions?	<ul style="list-style-type: none"> <li>- Poor access may make downloading a sensor with internal logging difficult.</li> <li>- Unable to check if sensor is operating.</li> </ul>	<ul style="list-style-type: none"> <li>- Consider if access to the sensor is required during bad weather. One option is to select a telemetered sensor so you can frequently check the data continuity and quality.</li> <li>- If you plan to use a sensor with a cable, select a sensor model/option with a waterproof connector so it's simple to disconnect cable from sensor for checks or replacement.</li> </ul>
What are the data download options?	<ul style="list-style-type: none"> <li>- Inability to download.</li> <li>- Slow download speed.</li> <li>- Inability to recover data.</li> </ul>	<ul style="list-style-type: none"> <li>- Assess if the user can access/swap an internal SD card (if applicable). With access to an internal SD card, it may be possible to recover data without sending the instrument to the manufacturer.</li> <li>- Check data transfer speed from sensor to device or computer.</li> </ul>
Proximity to conducting materials	<ul style="list-style-type: none"> <li>- Calibration and accuracy compromised.</li> </ul>	<ul style="list-style-type: none"> <li>- Inductive and capacitive sensors require a large (10-15 cm) sensing volume clear of conducting materials. Ensure this is possible for your sensor deployment.</li> </ul>
Is the deployment location representative?	<ul style="list-style-type: none"> <li>- Poor representation of local conditions.</li> </ul>	<ul style="list-style-type: none"> <li>- Consider the deployment site carefully and check it is representative. Some of the key risks to representativeness include: (1) stagnant water, (2) exposure to air, and (3) burial.</li> </ul>
What is the interval between calibrations?	<ul style="list-style-type: none"> <li>- Resourcing overspend.</li> </ul>	<ul style="list-style-type: none"> <li>- Check manufacturer and experienced user-recommended calibration intervals (see Table 7). Select a sensor which holds its calibration well and does not require frequent calibration.</li> </ul>
Will the sensor battery meet needs?	<ul style="list-style-type: none"> <li>- Data loss or gaps due to power failure.</li> </ul>	<ul style="list-style-type: none"> <li>- Check the battery specifications. In addition to battery lifespan, consider if it is a special type (high cost, low availability), and if the operating environment may reduce battery performance.</li> </ul>
Will cable length affect accuracy?	<ul style="list-style-type: none"> <li>- Long cables can add resistance or increase settling errors in voltage measurement.</li> </ul>	<ul style="list-style-type: none"> <li>- Check maximum cable length.</li> <li>- Purchase sensor with required cable length.</li> <li>- Check with manufacturer about cable extensions; some sensors need to be sent back to the manufacturer for cable lengthening.</li> </ul>
Does this sensor integrate into existing systems?	<ul style="list-style-type: none"> <li>- Loss of data resolution.</li> <li>- Overspend resourcing allocation.</li> </ul>	<ul style="list-style-type: none"> <li>- Use a sensor which integrates with existing data collection platforms. Test the integration prior to field deployment.</li> <li>- Check the sensor cable length to ensure it can reach the logger.</li> </ul>
How does the sensor fit within the fleet?	<ul style="list-style-type: none"> <li>- Fleet management and spare parts issues.</li> <li>- Training.</li> <li>- Field calibrations.</li> </ul>	<ul style="list-style-type: none"> <li>- Consider how a sensor fits within the fleet and current Standard Operating Procedures. Additional training may be required.</li> <li>- Consider the need to move the sensor between sites. Can multiple calibrations (sea and freshwater) be stored on the sensor? See Table 7.</li> </ul>
Is there existing site infrastructure?	<ul style="list-style-type: none"> <li>- Time and resources required to install a new site.</li> </ul>	<ul style="list-style-type: none"> <li>- If site infrastructure is not available, select a sensor with sufficient on-board memory (with redundancy in case the sensor cannot be accessed).</li> </ul>
What is your anticipated site visit schedule?	<ul style="list-style-type: none"> <li>- Data loss if the sensor has a fault.</li> </ul>	<ul style="list-style-type: none"> <li>- Check NEMS data processing requirements, and if you are using a sonde, check the relevant NEMS.</li> <li>- Consider operating a backup sensor or telemeter the data. A larger fleet of sensors may be required to avoid data gaps.</li> </ul>
Do you have sufficient technical expertise & support?	<ul style="list-style-type: none"> <li>- Unknown data quality.</li> </ul>	<ul style="list-style-type: none"> <li>- Ensure SOPs are developed and maintained because, for example, calibration errors may result in data gaps.</li> <li>- Select a sensor which is widely used.</li> <li>- Seek training – online or in-person.</li> </ul>
How user-friendly is the software interface?	<ul style="list-style-type: none"> <li>- Discouraged users and more time spent setting up &amp; downloading sensors.</li> </ul>	<ul style="list-style-type: none"> <li>- Check the software interface (and experienced user comments about software interfaces in Table 7).</li> <li>- What is the format of downloaded data? Text, csv or a proprietary format?</li> </ul>
Availability of sensors in NZ?	<ul style="list-style-type: none"> <li>- Data gaps.</li> </ul>	<ul style="list-style-type: none"> <li>- Consider if you can source a replacement sensor at short notice.</li> </ul>

## CASE STUDY 1 – COMPARING SONDE EC SENSORS

Taranaki Regional Council (TRC) undertook a comparison of two brands of multiparameter sonde. TRC uses the YSI EXO platform for State of Environment (SoE) monitoring and wanted to assess the suitability of the In-Situ Aqua TROLL platform for compliance monitoring.

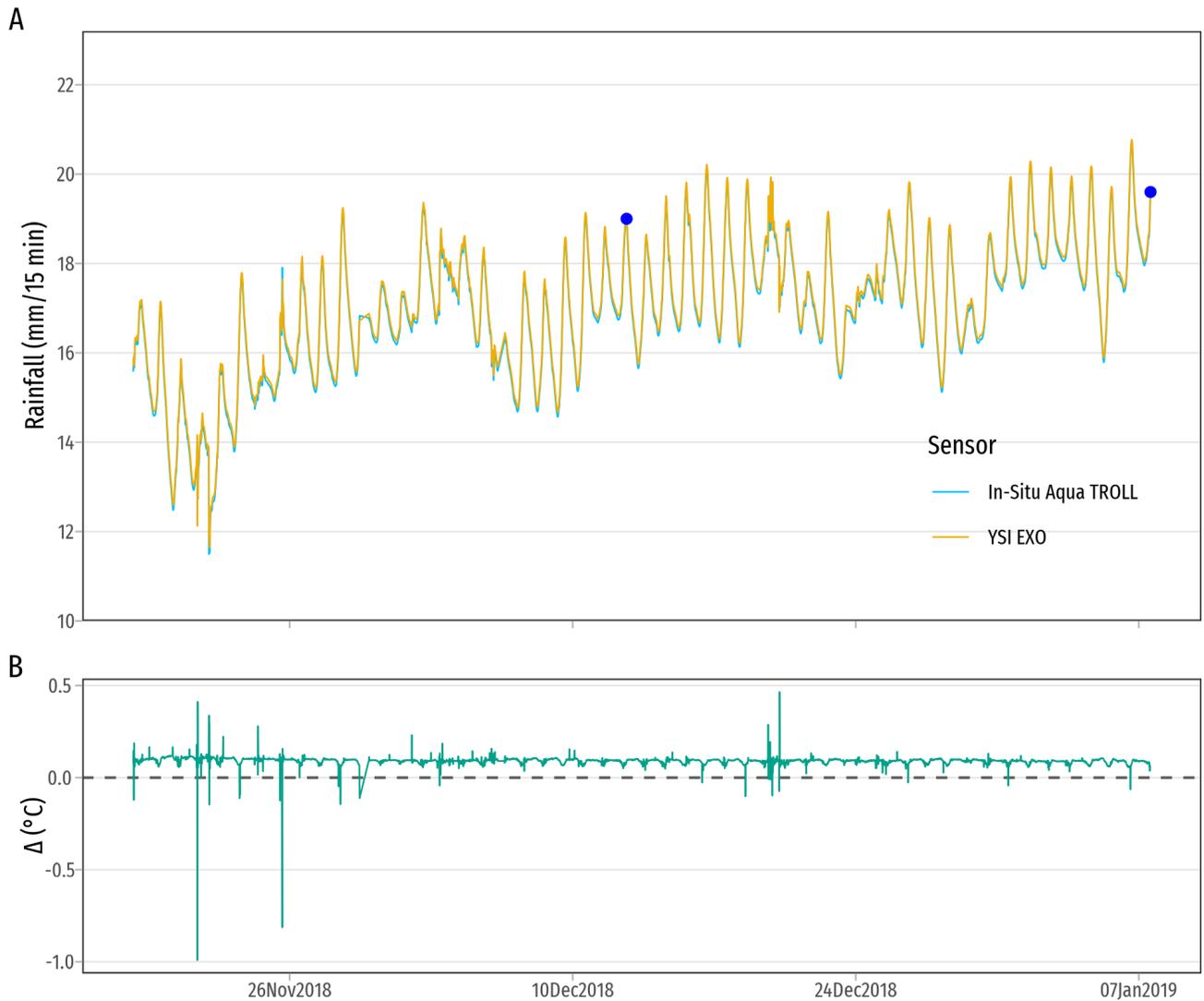
The Mangati Stream drains through the northern New Plymouth suburb of Bell Block. The short stream (5 km) discharges to the sea and has a small, narrow catchment (6.1 km<sup>2</sup>). The stream's headwaters are pastoral and horticultural, the mid-section has industrial land use, and the lower section (below SH3) is urban residential. The Bell Block industrial area has 15 discharge consents that grant permission to discharge stormwater, wash water and cooling water with a range of conditions. TRC has operated a multiparameter sonde for continuous monitoring of pH, conductivity, turbidity, dissolved oxygen and fDOM since 2016 to assess the cumulative effects of the discharge consents on stream water quality. Flow and rainfall are also measured at SH3.

Two sondes, a YSI EXO3 and an In-Situ Aqua TROLL 600, were deployed side-by-side on the Mangati Stream at SH3 in November 2018 (see Figure 10). The side-by-side deployment ended in early January 2019. The sondes, sensors and wipers were used instruments and were checked thoroughly prior to use. A non-wiped conductivity/temperature sensor (599870) was deployed on the EXO3. The Aqua TROLL instrument was loaned by Thermo Fisher Scientific NZ for the comparison. The sensors were calibrated by TRC according to the manufacturer's instructions using a 1413  $\mu\text{S}/\text{cm}$  standard. The Aqua TROLL was installed adjacent to the EXO sonde (< 20 cm apart) in PVC housing (see Figure 10). The EXO sonde data was telemetered, while the Aqua TROLL logged data internally in its internal memory and on an SD card. Instantaneous data was recorded at 15-minute intervals. Field meter readings (YSI ProDSS) were collected during the deployment to verify sensor values.



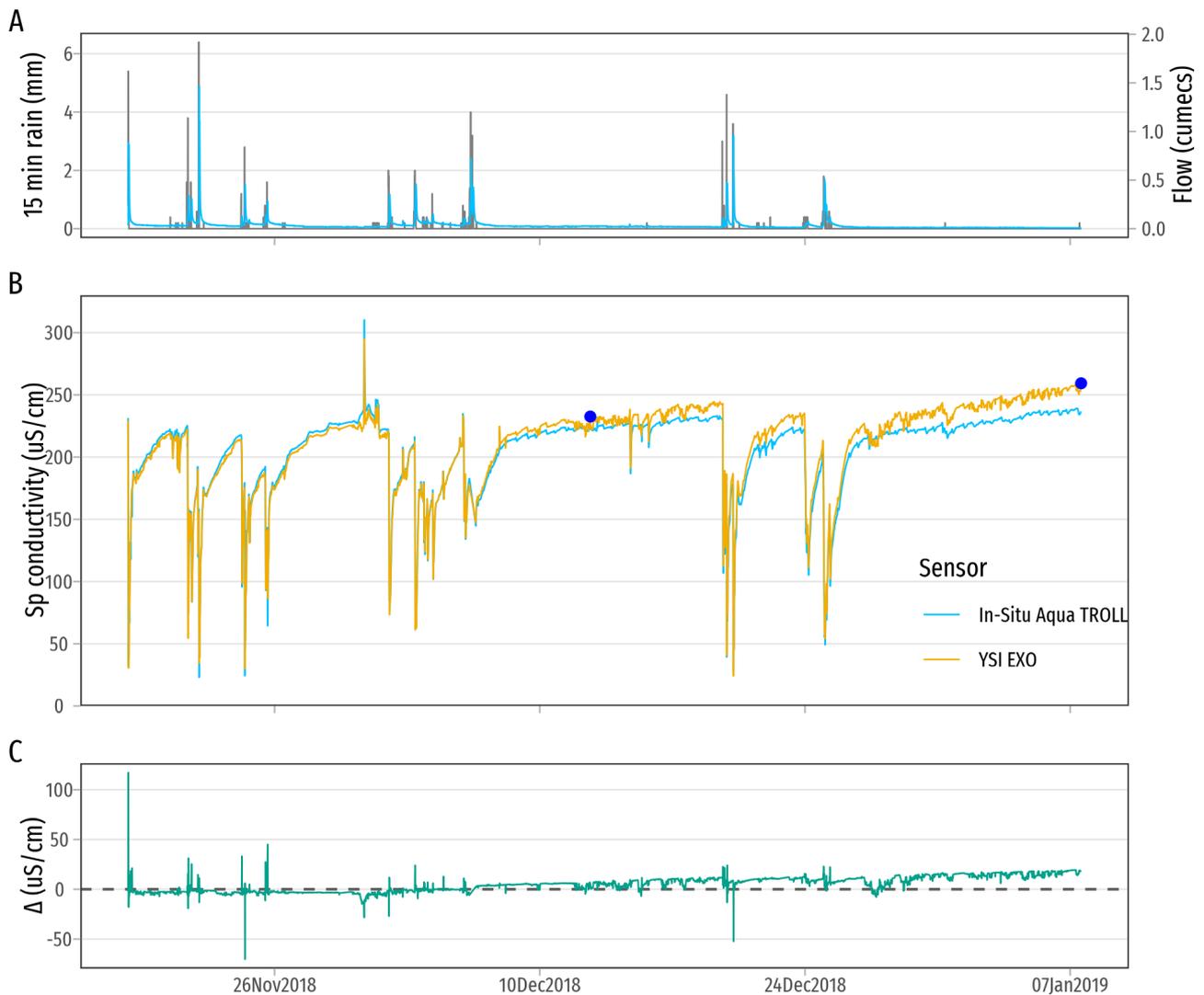
**Figure 10. EXO sonde and Aqua TROLL installed at Mangati Stream. (A) Sensors deployed beside culvert. (B) Sensors inside PVC housings bolted to timber [TRC].**

This case study focuses on the performance of the EC and temperature sensors on the sondes. The temperature sensors returned similar values (Figure 11 A), albeit with a consistent offset of  $\sim 0.1\text{ }^{\circ}\text{C}$  (Figure 11 B).



**Figure 11. (A) Time series plot of water temperature at Mangati Stream at SH3. (B) Difference between EXO and Aqua TROLL water temperature values at each 15-min time step.**

The EC sensor values tracked closely for the first few weeks (Figure 12 A). After 8 Dec 2018, the Aqua TROLL sensor started to drift and was returning lower raw values than the EXO sonde; a drift correction of the Aqua TROLL data would reduce the difference between the two sensors.



**Figure 12. Time series plots for Mangati Stream (A) Rainfall and flow. (B) Time series plot of raw data for specific conductivity with field meter readings (blue dots). (C) Difference between raw EXO3 and Aqua TROLL water specific conductivity values at each 15-min time step.**

As a result of the sensor comparison, TRC recommends the In-Situ Aqua TROLL for compliance monitoring. The Aqua TROLL, with more plastic parts and a lower cost wiper (~ \$2000), has a lower initial capital cost than the YSI EXO platform (see Table 7). For long-term SoE monitoring, TRC continues to operate the YSI EXO platform. TRC now uses the wiped conductivity/temperature sensor on the EXO platform to reduce fouling drift and extend field visit intervals.

## SENSOR COMPARISON TABLE

**Table 7. Comparison of EC sensors used by the workgroup in 2023 (arranged left to right by EC sensors, CTD, then multiparameter sondes). At least one sensor user contributed to each column. All costs in NZD. See notes below table for detailed additional comments on each sensor. To evaluate a different sensor, gather equivalent information from brochures, manuals, manufacturer and other users.**

	Memosens SE 615	Unidata 6536D	Onset HOBO U24-001	Seametrics CT2X	Meter Hydros21 CTD	Sea-Bird SBE 37 MicroCAT	RBRconcerto <sup>3</sup>	YSI EXO C/T	YSI EXO Wiped C/T	In-Situ Aqua TROLL 600
Cost (\$ <1K, \$\$ < 3K, \$\$\$ < 10K, \$\$\$\$>10K)	\$ (+ \$\$)	\$\$	\$\$	\$\$	\$	\$\$\$\$	\$\$\$\$	\$(+\$\$\$\$)	\$(+\$\$\$\$)	\$(+\$\$\$)
<b>Sensor basics</b>										
Original manufacturer	Yes					Yes	Yes	Yes		Yes
Type (conductive, inductive, capacitive)	2-electrode conductive	4-electrode conductive	Capacitive	4-electrode conductive	4-electrode conductive	3-electrode conductive, tube	Inductive	4-electrode conductive; tube	4-electrode conductive; slot	4-electrode conductive, open
Pumped or passive	Passive	Passive	Passive	Passive	Passive	Pumped	Passive	Passive		Passive
Electrode materials	Graphite	Graphite	-	Graphite	Stainless steel	Platinum		Nickel	Graphite	Graphite
Sensor versions			002 saline			CTD options	Many models	2 (see right)	2 (see left)	
Cell constant (cm <sup>-1</sup> )	1 cm <sup>-1</sup>	0.475 cm <sup>-1</sup>					Large	C/T: 5.1. cm <sup>-1</sup>	0.469 cm <sup>-1</sup>	0.7 to 1.3 cm <sup>-1</sup>
Bundle or solo	Solo	Solo	Solo	CT, optional D	CTD	CTD	CTD	Sonde	Sonde	Sonde
Suited environments	Surface water, Groundwater	Coastal, Surface water	Surface water, Groundwater	Surface water, Groundwater	Surface water, Groundwater	Coastal, Surface water	Brackish, Coastal	Any	Any	Any
Body materials	Plastic	Plastic	Plastic, epoxy	Plastic & SS or Ti	Plastic	Plastic, Ti options	Plastic, ceramic	Plastic/SS	Plastic/SS	Plastic
Comms interface	Yes	No	Yes	No	No		No	Options <sup>e</sup>	Options <sup>e</sup>	Options
Communications output	4–20 mA	SD1-12 <sup>u</sup>	USB, optical shuttle	SD1-12; RS-485 Modbus	SDI-12, serial	RS-232, RS-485	USB-C, Wi-Fi, RS-232	SDI-12, Modbus, RS-232	SDI-12, Modbus, RS-232	RS-485/Modbus, SDI-12, Bluetooth <sup>at</sup>
Data logger options	External	External	Internal	External	External	Both	Internal	Both	Both	Both
Cable options	Options to 20 m	Options to 20 m	NA	30 m	10, 20, 40m	Options	Various end caps	Various	Various	Various to 60 m
Detachable sensors	Yes	No	NA	No	No	No	Yes	Yes	Yes	Yes
Diameter (as deployed)	~15 mm	21.7 mm	31.8 mm	19 mm	34 mm	> 103 mm	63.3 mm	68 mm	68 mm	47 mm
Max depth	40 m	20 m	70 m	< 600 m	10 m	350 m plastic	20–6000 m	250 m	250 m	
Minimum log interval		5 s	1 s	0.25 s	<0.6 s	2–3 s <sup>sb</sup>	0.5 s			2 s
Power source	External	External	Internal	Both	External	Internal	Internal or both	Both	Both	Both
Battery life			3 y @ 1 s; factory	1 y @ 15 min		2 y @ 2.5 min		90 d @ 15 min	90 d @ 15 min	6 mo with wiping
Thermistor location	Internal	External	External	External	Internal	Internal	External	External	External	External
Warranty	1 y	1 y	1 y	2 y	2 y	5 y	1 y	2 y	2 y	2 y
<b>Manufacturer specs</b>										
Cond range (μS/cm)	10–20,000	0–200,000	0–10,000	0–300,000	0–20,000	0–70,000	0–85,000	0–200,000	0–100,000	0–350,000
Gain setting (user sensitivity adjustment)	No	Yes, low range	Yes low range 0 – 1000 <sup>h</sup>	No	No	No	No	No	No	No
Cond resolution (μS/cm)		10 to 1000	1	0.1	1	0.1	1	0.1 to 10		0.1
Cond accuracy (μS/cm)		0–100 K ± 0.5 %	<1000: 3 % or 5, <10K: 3 % or 25	0–100 K: ± 0.5 %	greater of ± 10 μS/cm or 10 % <sup>hy</sup>	3	3	<100 K ± 5 %, >100 K ± 1 %	± 1 % or 2	<100 K: ±0.5 + 1 100 K–200 K: 1%
Cond response time (s)			T90: 1 s			T63: 0.06 s	T63: < 10 ms	T63: < 2 s	T63: < 2 s	T63<1s, T90 <3s
Temperature type	Thermistor	Thermistor	Pt RTD	Thermistor	Thermistor	Thermistor <sup>sb</sup>	Thermistor	Thermistor	Thermistor	Thermistor
Temp range (°C)	-5 to 80	-20 to 60	-2 to 36	-5 to 40	0 to 50 °C	-5 to 45	-5 to 35	-5 to 50	-5 to 50	-5 to 50
Temp accuracy (°C)		± 0.1	0.1 at 25 °C	± 0.25	± 1	± 0.002	± 0.002	-5 to 35: ± 0.01	± 0.2	0.1
Temp resolution (°C)		0.0612	0.01	0.1	0.1	0.0001	< 0.00005	0.001	0.001	0.01

	Memosens SE 615	Unidata 6536D	Onset HOBO U24-001	Seametrics CT2X	Meter Hydros21 CTD	Sea-Bird SBE 37 MicroCAT	RBRconcerto <sup>3</sup>	YSI EXO C/T	YSI EXO Wiped C/T	In-Situ Aqua TROLL 600
Temp response time (s)							T63: < 1 s (std)	T63 < 1 s	T95 < 30 s	T63 < 2 s, T90 < 15 s
Default temp corr (/ °C)	Linear	2.00 %	2.1 %	2.1 %	1.9 %		1.91 %	1.91 %	1.91 %	1.91 %
User linear correction	Yes		Yes, 0–3 % / °C	Yes		Yes	Yes			Yes
Non-linear correction	ISO7888, user defined		EN27888, PSS-78	Yes		Yes	PSS-78	ISO7888	ISO7888	?
Units available	µS/cm, ohm.cm, etc.	µS/cm		mS/cm, µS/cm, PSU	µS/cm	Many options	µS/cm, PSU	mS/cm, µS/cm, PSU	mS/cm, µS/cm, PSU	µS/cm, PSU, ohm.cm
<b>User experience</b>										
Durability with field use	Robust	Robust	Robust	Robust	Robust	Robust; take care with glass cell	Robust	Robust	Robust, hard on wiper <sup>e</sup>	Robust, good guard
Ease of calibration or validation	Easy	Cable adds time	Validate - easy <sup>h</sup>	Cable adds time	Factory cal	Validate	Validate	Easy	Easy	Easy
Calibration frequency	1–3 months <sup>m</sup>	Validate monthly	Monthly			Before and after, factory cal 2 y	Validate; factory cal	Regularly	Regularly	Validate; factory cal 1 y
User calibration possible	Yes	Yes, but not recommended	No <sup>h</sup>	Yes	Yes	No	Yes, but not recommended	Yes <sup>e</sup>	Yes	Yes
Calibration options	2 pt			1 or 2 pt	Multipoint	Multipoint	Multipoint	1 pt		1 or 2 pt
Antifouling supplied	No	No	No, but coating <sup>h</sup>	No <sup>sm</sup>	No	Biocide (TBTO)	No	No	Wiper <sup>e</sup>	Yes – wiper <sup>at</sup>
Software required	MemoSuite	Any logging software	HOBOWare <sup>h</sup>	Any logging software	Any logging software	Fathom replaces SeaSoft <sup>sb</sup>	Ruskin, Ruskin App <sup>r</sup>	Kor/Kor2	Kor/Kor2	WinSitu or VuSitu App
Software user friendliness	Good		Good			SeaSoft - powerful but command line	Excellent	Good	Good	Good. App easy to use
Data offload speed	NA					Depends on file	Quick	Long for large files	Long for large files	
Manual quality	Good	OK	Good	Good	OK <sup>hy</sup>	Comprehensive	Good	Good	Good	Good
NZ support	Yes	Yes	Yes, but limited	Yes	No	No, Aust supplier	No, Aust suppl.	Yes	Yes	No
Training advisable						Yes - not straightforward.	Yes - proximity effects	Yes - cleaning	Yes - cleaning	Yes
Free online training			Videos			Sea-Bird Uni, tech notes	Webinars, application notes	YSI Uni, webinars, tech notes	YSI Uni, webinars, tech notes	Videos, tech notes

<sup>at</sup> Aqua TROLL notes: (1) Modbus RS-232 also available but requires third party convertor. (2) Wiper has a good slip clutch but can be tricky to adjust.

<sup>e</sup> YSI EXO sonde notes: (1) Depth - may be less with pressure transducer. (2) Various comms interfaces – DCP for SDI-12, Modbus interface. (3) Users note slight calibration variability at 53,000 µS/cm. (4) Kor2 only allows 1 pt calibration which alters the slope, so error will be magnified if the calibration is slightly off. (5) Users note a wiped C/T sensor loads the wiper with extra resistance. Use a cable tie around the sensors to reduce sensor splay.

<sup>h</sup> HOBO notes: (1) Coated with Titanium pentoxide to reduce corrosion and make easy to clean. (2) Can log both high range and low range – but doubles memory required. (3) Calibration is not possible – “calibration” in HOBOWare is a drift correction, and “calibration” in U24 manual is verification against field or lab conductivity meter. (5) Requires 2.5 cm clearance from conducting materials. (6) HOBOWare Pro license required to convert units, licenses cannot be shared.

<sup>hy</sup> Hydros notes: (1) Accuracy reduced < 10 µS/cm and > 100,000 µS/cm. (2) Works well with METER logger and Mayfly. (3) May require an interface for serial comms to computer. (4) Custom cable up to 75 m available. (5) Users note that the manual is basic but there is plenty of third-party information available.

<sup>m</sup> Memosens notes: (1) Low-cost sensor designed for water and wastewater treatment, would require protection in a river or suits a pumped system. (2) Videos available. (3) Experienced users suggest calibration frequency varies between 1 and 3 months depending on environment.

<sup>r</sup> RBR notes: (1) Powered models run on internal memory and SD card which automatically log all data. (2) Requires 15 cm clearance from conducting materials. (3) Python code available for data processing.

<sup>sb</sup> Sea-Bird notes: (1) Sea-Bird use the same 3-electrode sensor in all units; older units may have 2 electrodes. (2) Pump timing varies with model, but typically 2–3 seconds. (3) Borosilicate glass cell can crack with incorrect handling during calibration and cleaning or rough handling in the field (e.g., hitting the bed). (4) New Fathom software (2024) available for MicroCAT 37, also Python code available for CTD data processing.

<sup>sm</sup> Seametrics notes: (1) Galvanic corrosion if metals nearby & in strong electrolyte. (2) Fouling can be an issue in some environments.

<sup>u</sup> Unidata notes: (1) Model D has a low range setting, 0–65,535 µS/cm (2 byte). Current model is F which has 4 gain settings and ModBus RS-485 and SDI-12.

## LOGISTICS – GETTING THE DATA

Most EC sensors output values of electrical conductivity and specific conductance. Some sensors, particularly oceanographic sensors, offer the user a wide range of units and correction methods (see Table 7).

Internal logging is a feature of many sonde and CTD models, but internal logging is less common for sensors only measuring EC (see Table 7). The use of internal logging requires robust consideration of the consequences of data loss, while the adoption of telemetry may require additional resourcing. The key advantages and disadvantages of using sensors with internal logging or telemetry are summarised in Table 8.

**Table 8. Advantages and disadvantages of data communication systems (after Wagner et al., 2006).**

<b>Data capture system</b>	<b>Advantages</b>	<b>Disadvantages</b>
<b>Telemetry</b>	<ul style="list-style-type: none"> <li>- Data secure once transmitted.</li> <li>- Data can be viewed at any time, including on public websites.</li> <li>- Real-time decision-making is possible.</li> <li>- Systems can be monitored remotely and fault servicing can be carried out in a timely manner.</li> </ul>	<ul style="list-style-type: none"> <li>- May require additional resourcing.</li> <li>- More complex system and more faults are possible.</li> <li>- Telecommunications protocol may need to be updated (satellite/mobile system switch-off).</li> <li>- Site may attract vandals – particularly solar panels.</li> </ul>
<b>Internal logging</b>	<ul style="list-style-type: none"> <li>- Deployment options are flexible.</li> <li>- Vandalism may be reduced due to absence of site infrastructure, particularly solar panels.</li> <li>- Sensor theft may be reduced if the sensor can be well-hidden.</li> <li>- Sensors can be installed and replaced rapidly (reducing resourcing).</li> <li>- Small, battery-powered sensors may be less likely to catch flood debris.</li> </ul>	<ul style="list-style-type: none"> <li>- Real-time decision-making not possible.</li> <li>- Data are only available during site visits.</li> <li>- Migrating channels or bank erosion may require adjustment to sensor placement.</li> <li>- Status of equipment can only be checked during servicing.</li> <li>- Data cannot be viewed without a site visit.</li> <li>- Loss of data is unknown until site visit.</li> <li>- Sensor may lose power.</li> </ul>

Sensors with the capability to connect to data loggers use a range of communication protocols (see Table 7). Workgroup recommendations include:

- If possible, connect using Modbus or SDI-12. Experienced users have had problems using analog signals. If using an analog signal, carefully check the specifications of the logger’s Analog-to-Digital Convertor (ADC).
- While it can be useful to have a proprietary controller in the lab, you can use a computer to communicate with most sensors (software may be required).

## DEPLOYMENT OVERVIEW

This project does not cover deployment in detail; however, good quality data depends on careful deployment design. The photos on this page demonstrate the range of deployments undertaken in New Zealand.



Divers cleaning an RBRconcerto on a moored pontoon in the Firth of Thames [Iain MacDonald, NIWA]



Field verification sensor (wrapped in pink tape) alongside a field sonde (in PVC housing) in a Hamilton stream [Gareth van Assema, NIWA]



Sea-Bird CTD on an estuarine mooring [Rod Budd, NIWA]

## SUPPORT FOR NEW USERS

All New Zealand sensor reps are helpful and approachable; some will be able to give detailed operational guidance, while others will need to defer to colleagues.

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