

● WHITEPAPER · WATER MONITORING

Uncalibrated bench characterisation of low-cost turbidity, TDS, pH and level sensors on Arduino Uno R4 WiFi

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ABSTRACT

Abstract

Dharanova is building a water-monitoring system that combines water-quality sensing with storage level. This paper reports the first bench results from four low-cost sensor modules on an Arduino Uno R4 WiFi: a KIE-TS-300B turbidity module, a generic two-needle TDS module, a PH-4502C pH module and an XKC-Y25-PNP capacitive level switch. Each was tested in one session in October 2026, in dry air and household liquids, without reference standards. All four signal chains responded to immersion. The pH module separated acidic water from near-neutral water by +0.920 V while salt water moved it only +0.044 V, the selectivity expected of a glass electrode. One turbid sample spanned 0.83 V from agitation alone. The TDS module repeated within 1.67 % on the same sample but read distilled water 6.4 times higher than RO water, against the expected order. All values are calculated from uncalibrated ADC readings. From these effects we derive six rules that the calibration protocol must follow. The work is an experimental proof of concept (TRL 3), and the paper sets out the path to TRL 4.

KEY POINT

Key findings

- **pH:** acidic lemon water moved the output +0.920 V from near-neutral water; salt water moved it only +0.044 V. The probe responds strongly to acidity and only slightly to salinity.
- **Turbidity:** one turbid sample read anywhere across a 0.83 V span depending only on how recently it was stirred. Sample agitation must be fixed before calibration.
- **TDS:** two dips into the same distilled water agreed within 1.67 %, but distilled water read 6.4 times higher than RO water, against the expected order.
- **Water level:** the switch reported dry and wet correctly with no chatter, over a single transition.
- **Protocol:** six rules for the calibration phase, each traced to a measured effect (Figure 10).
- **Readiness:** experimental proof of concept (TRL 3), with a defined path to TRL 4 (Figure 12). No reading is calibrated yet.

SECTION 1

Introduction and objective

Dharanova is building a system that monitors water quality and storage level together. Its first four sensing functions are turbidity, total dissolved solids (TDS), pH and water level. Water level is not a quality parameter, but it belongs to the same system and is reported here for completeness.

Low-cost sensor modules make affordable monitoring possible, but they come with little documentation: two of the four modules used here have no manufacturer datasheet at all. Their behaviour therefore has to be established by test before any calibration is designed. Each sensing function was built as an independent sensor node, with its own firmware, before any integration. This paper consolidates the first hardware session of each node and answers four questions:

- 1. Does each module, wired to the Uno R4 WiFi, produce a stable signal that is distinct from dry air when the probe is immersed?
- 2. Does the signal move in the physically expected direction across liquids of different clarity, conductivity or acidity?
- 3. What behaviours (settling, noise, sample handling) must a calibration and measurement protocol control?
- 4. What evidence is still missing before calibrated readings, and a TRL claim, can be made?

In scope: wiring and power-up of each module; raw ADC and voltage output (analog sensors) or digital state (level switch) in dry air and in household liquids; settling and noise behaviour as observed; firmware signal path up to the voltage or debounced state.

Out of scope: conversion to engineering units (NTU, $\mu\text{S}/\text{cm}$, mg/L , pH), temperature compensation, the filter, health, calibration, reporting and network modules (still stubs or host-tested only), the design of the combined multi-sensor node (not started), long-term drift, and environmental or EMC testing.

SECTION 2

Requirements and acceptance criteria

No measurable acceptance criteria were written before these sessions. The development plan for each node defined the bring-up step as qualitative: wire the module, upload, and log readings in dry air and liquids. Table 2.1 lists those bring-up objectives as they were evaluated afterwards.

Table 2.1: Bring-up objectives (qualitative, evaluated after testing)

ID	Objective	Applies to
B1	Module powers from the board's 5 V rail and its output reaches the board (A0 or D2)	All
B2	Immersed readings are stable and distinct from dry air	All

ID	Objective	Applies to
B3	Readings change in the physically expected direction across the liquids tested	All
B4	The ADC runs at the configured 14-bit resolution and its reference is verified	Turbidity, TDS, pH

The calibration phase will be held to measurable criteria: accuracy against certified standards, repeatability over repeat dips, settling time, level-switch reliability over repeated transitions, and ADC error against a calibrated multimeter. The numerical limits will be fixed and recorded **before** that testing starts, and published with its results (section 9).

SECTION 3

System under test

All four sensors were tested on an Arduino Uno R4 WiFi, with the sensor powered from the board's 5 V pin. Figure 1 shows the four setups as tested.

AS TESTED: FOUR SENSORS, EACH IN ITS OWN SESSION

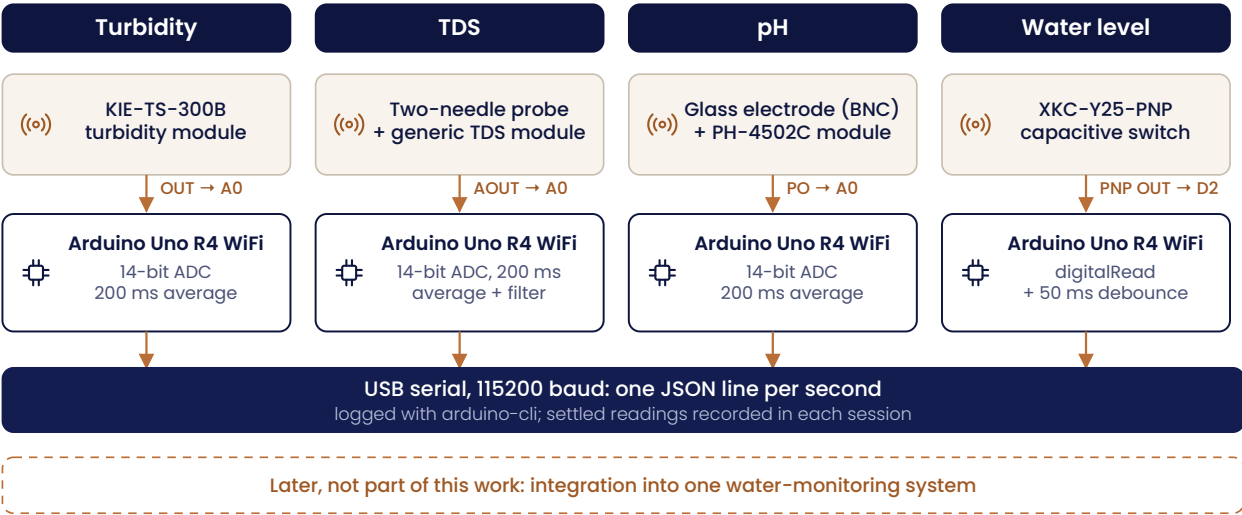


Figure 1 The four sensors as tested, each in its own session on an Arduino Uno R4 WiFi and read over USB serial.

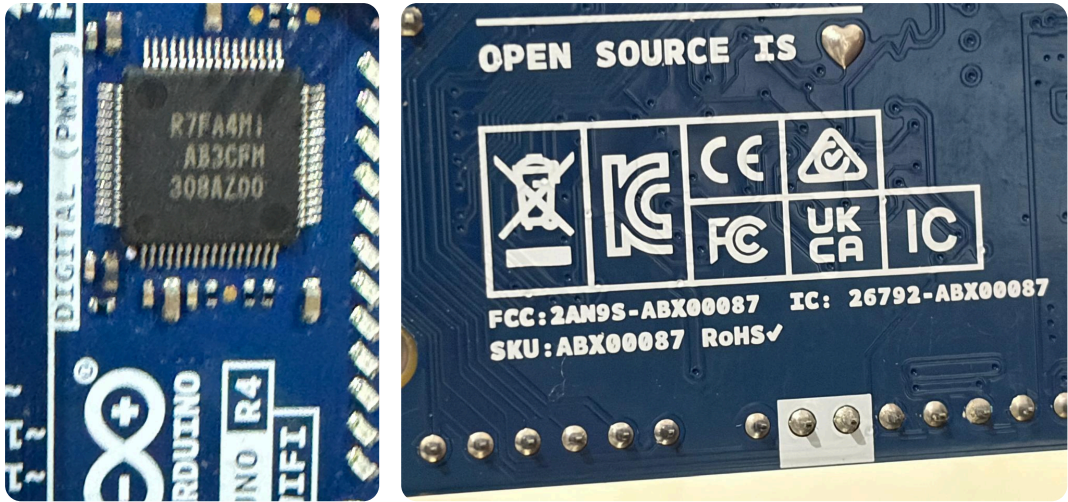


Figure 2 Board identification for the Uno R4 WiFi used in the tests, photographed on 2026-10-19. Left: the Renesas RA4M1 microcontroller (marking R7FA4M1AB3CFM) beside the UNO R4 WiFi silkscreen. Right: the underside label, SKU ABX00087. Neither side shows a board serial number.

Item	Detail
Board	Arduino Uno R4 WiFi, SKU ABX00087, Renesas RA4M1 microcontroller (R7FA4M1AB3CFM). FQBN <code>arduino:renesas_uno:unor4wifi</code>
Host connection	USB to the logging computer, port <code>/dev/ttyACM0</code> in every session. USB was also the board's power source
ADC configuration (analog sensors)	14-bit (<code>ADC_RESOLUTION_BITS</code> = 14, max count 16383), reference 5.0 V (<code>ADC_VREF_VOLTS</code>), per Arduino's UNO R4 WiFi documentation (references 9 and 10)
ADC step size	0.3052 mV per count (calculated)
Sampling (analog sensors)	Each report averages every <code>analogRead()</code> in a 200 ms window (<code>SAMPLE_WINDOW_US</code> = 200000), one report per second
Toolchain	<code>arduino-cli</code> 1.2.2, core <code>arduino:renesas_uno</code> 1.6.0, as installed on the test computer on 2026-10-19 (the day of the turbidity and pH sessions). Versions on 2026-10-17 not recorded

Table 3.1: Sensor modules

Function	Module	Interface	Wiring	Documentation
Turbidity	KIE-TS-300B ver-2.0_12227k	Analog	VCC→5V, GND→GND, OUT→A0	No manufacturer datasheet found (search, 2026-10-19; reference 11). Retailer listings for the TS-300B family give 5 V supply, 0–4.5 V analog output and <500 ms response; these are unverified seller figures, and one listing describes the product as discontinued
TDS	Generic, unbranded analog module with separate two-needle probe	Analog	VCC→5V, GND→GND, AOUT→A0	No datasheet (reference 14). Not a DFRobot SEN0244

Function	Module	Interface	Wiring	Documentation
pH	PH-4502C module with glass electrode on BNC	Analog (P0)	V+→5V, G→GND, PO→A0; T0 (temperature) and D0 (threshold) not connected	No manufacturer datasheet found. Online sources disagree on who makes the module, so the manufacturer is not identified (reference 12)
Water level	XKC-Y25-PNP non-contact capacitive point-level switch	Digital (PNP)	Brown→5V, blue→GND, yellow→D2, black (MODE) floating	Manufacturer manual found for the XKC-Y25-V family (Shenzhen Xingkechuang), which covers the PNP output variant (reference 13). Wiring cross-checked against an instruction manual and three seller listings

Firmware. Each node's sketch at the bring-up stage only printed the sensor output as one JSON line per second: `{"ms","raw","v"}` for turbidity and pH, `{"ms","raw","v","v_filtered"}` for TDS (median-of-5 + EMA filter), and `{"ms","raw","stable"}` for the level switch (time-based debounce, `DEBOUNCE_MS = 50`).

Each node's firmware is under version control. Each step was implemented, verified on hardware, recorded and committed in one sitting, and every session's commits are dated on the day of that session.

Each node's firmware is split into single-purpose modules, but at bring-up only the first one or two were implemented and in the loop (Figure 3).

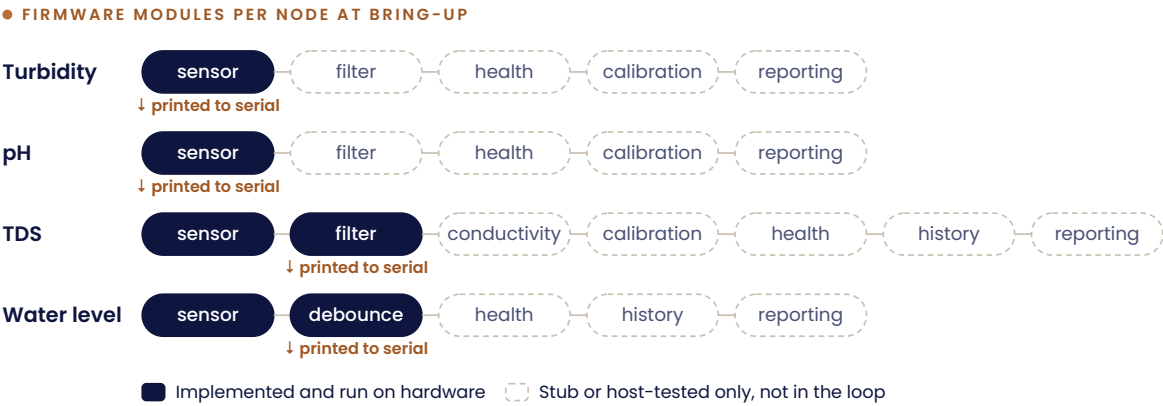


Figure 3 Firmware modules per node, from each node's firmware architecture. Filled modules were implemented and ran on hardware during these sessions; the sketch printed their output directly to serial.

SECTION 4

Test setup and method

4.1 Equipment

Instrument	Model
Board ADC (only measuring instrument, not calibrated)	Arduino Uno R4 WiFi (ABX00087), input A0
Serial monitor	arduino-cli 1.2.2 over USB at 115200 baud, port /dev/ttyACM0

No multimeter, no reference instrument (pH meter, conductivity meter, turbidimeter) and no reference standard (pH buffer, conductivity standard, formazin) was used, so no instrument traceability in the sense of ISO/IEC 17025 (reference 2) can be given.

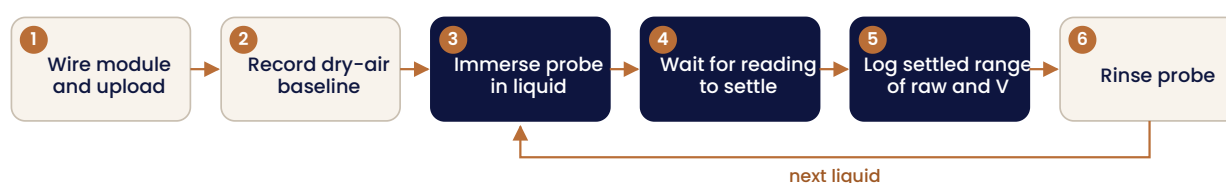
4.2 Environment

Indoor bench, laboratory-type conditions. Ambient temperature, sample temperatures and humidity were not recorded in any session. This matters most for conductivity, which the TDS firmware assumes changes by about 2 % per °C (`TEMP_COEFF_PER_C` = 0.02, a firmware assumption, not a measurement), and for pH electrode slope.

4.3 Procedure

The same procedure was used for each analog sensor, as recorded in the test logs and summarised in Figure 4:

• BRING-UP PROCEDURE, ANALOG SENSORS



Settling took 25 to 60 s for the pH probe; turbid samples never settled (section 5).

Figure 4 Bring-up procedure for the analog sensors.

1. Wire the module per Table 3.1 and upload the bring-up sketch.
2. Monitor the JSON stream over USB at 115200 baud.
3. With the probe dry, record the settled reading as the dry-air baseline.
4. Immerse the probe in each liquid in turn and wait for the reading to settle. Record the settled range of `raw` and `v` and, where noted, the settling time and how long it stayed steady.
5. Between liquids, rinse the probe: in plain water (pH), in distilled water (TDS distilled dip), or rinse and dry (turbidity).

For the level switch: power on with the sensor dry, record the dry state, then bring water to the sensor and record the transition and the wet state. The sensor's onboard LED was compared visually with the serial output.

Liquids used (none is a reference standard):

Liquid	Used on	Notes
Distilled water	Turbidity, TDS, pH	Off-the-shelf
RO water	TDS	Described as RO at the time of testing, not verified
Canned/bottled drinking water	TDS	First logged as "tap water", corrected the same day
Tap water	TDS, pH	Fresh municipal supply
Salt water	pH	Table salt dissolved in tap water
Lemon water	Turbidity, pH	Diluted lemon juice
Powder suspension	Turbidity	Powder stirred into water

These liquids serve to move each sensor in a known direction, not to give known values. The logs do not record the brand or source of the waters, the salt, lemon and powder quantities, the sample volumes or the probe immersion depth, and they do not name the containers. Photos of the turbidity setup (Figure 5) show small paper cups, with the probe held by two wooden stirrers across the rim. The containers used for the other sensors are not recorded.

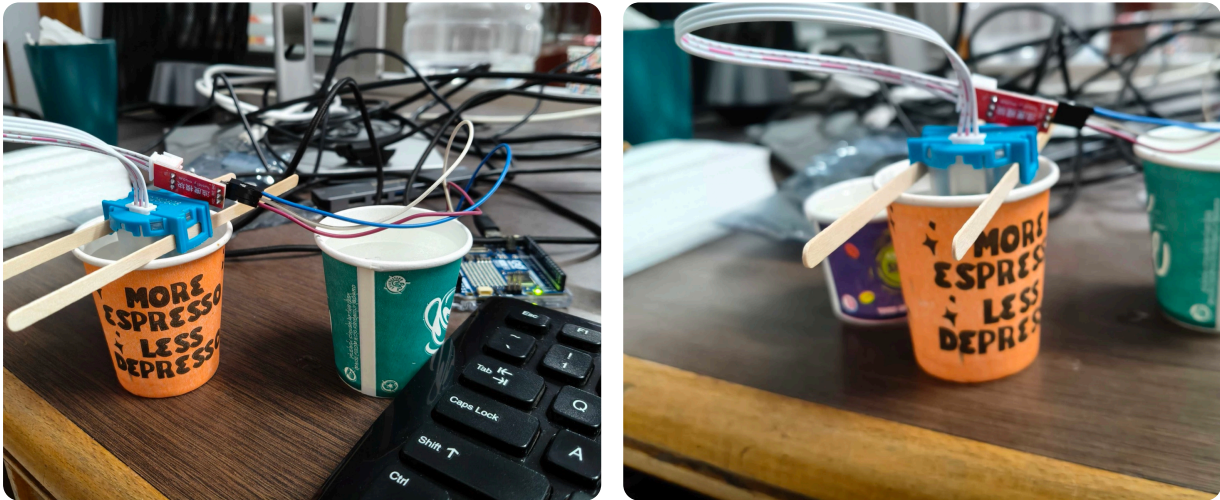


Figure 5 The turbidity bench setup. Left: the KIE-TS-300B probe (blue housing) held in a paper sample cup by two wooden stirrers, with its signal board (red) wired to the Arduino Uno R4 WiFi, visible at right. Right: the probe in its cup, from the front.

The results in section 5 are therefore comparisons within one session, not values that another laboratory could reproduce.

4.4 Runs and sample size

One session per sensor. Each condition was measured once, except TDS distilled water (two dips, with tap and RO water measured in between) and the turbidity powder suspension (four readings of the same cup in different agitation states). The logs record settled **ranges**, not individual samples, and no raw serial capture was saved in any session, so the number of samples, the standard deviation and percentiles cannot be computed.

CAUTION

Single runs only

Repeat runs are needed before any reading here can be treated as representative. No conclusion in this paper rests on a single reading being exact; the conclusions are limited to differences that are large compared with the logged ranges.

4.5 Standards followed

No standard method was followed. The methods chosen for the calibration phase are listed in section 9 and the references.

SECTION 5

Results

All voltages below are **measured** (board ADC, uncalibrated) unless marked calculated. Ranges are the settled ranges recorded during each session.

Consistency of the records. Every voltage recorded alongside an ADC count agrees with that count ($\text{raw} \times 5.0 / 16383$, calculated) to within 7.2 mV, so the recorded volts and counts are mutually consistent.

5.1 Turbidity (KIE-TS-300B, 2026-10-19)

Condition	Settled range (V)	Raw ADC (counts)	Noise / behaviour as logged
Dry air (baseline)	3.081–3.082	10096–10098	tight, <0.001 V
Distilled water	3.574–3.576	11710–11717	tight, ~0.002 V
Lemon water	3.48	11392–11426	slight, ~0.01 V
Powder suspension, dip 1	3.00–3.13	9840–10247	high, ~0.05–0.1 V, non-settling
Powder suspension, dip 2 (more powder, still mixing)	2.41–2.66	—	~±0.1–0.2 V, never settled
Powder suspension, dip 3 (unstirred, minutes later)	3.12–3.24	—	drifting upward over ~30 s
Powder suspension, continuously stirred	2.81–2.95	—	~±0.07 V

● TURBIDITY: KIE-TS-300B, 2026-10-19

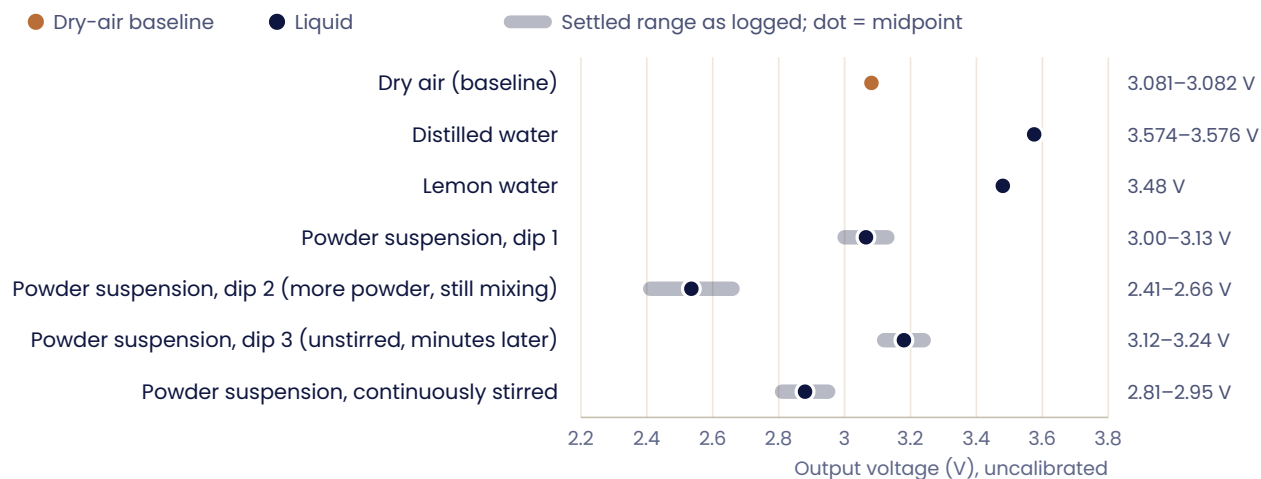


Figure 6 Turbidity module output per condition. Clear liquids read above dry air; the four powder-suspension readings of the same cup spread widely with agitation.

Calculated from these:

- Distilled water read +0.494 V above dry air, and lemon water +0.398 V above dry air.
- Powder suspension dip 1 had a mean 0.017 V *below* dry air, i.e. inside the dry-air neighbourhood. Its noise, not its mean, separates it from dry air.
- Across the four readings of the same powder suspension, readings spanned 0.83 V (2.41 V to 3.24 V) with no change in contents between dips 2 and 3.
- Continuously stirred, the suspension read 0.695 V below distilled water, with the tightest noise of any turbid reading ($\sim \pm 0.07$ V).
- Raw counts reached 11717, above the 4095 maximum of a 12-bit conversion, which confirms the 14-bit setting is active.

5.2 TDS (generic two-needle module, 2026-10-17)

Condition	Settled V	Raw ADC (counts)	Logged as steady for at least
Dry air (baseline)	0.006	21	6 s
RO water (user-described)	0.079	260	12 s
Canned/bottled drinking water	0.100–0.101	329–331 (rising slowly)	12 s
Distilled water, dip 1 (two captures)	0.507–0.508	1661–1663	10 s each
Fresh tap water	0.721	2363	14 s
Distilled water, dip 2 (after tap and RO)	0.516	1692	12 s

● TDS: GENERIC TWO-NEEDLE MODULE, 2026-10-17

● Dry-air baseline

● Liquid

— Settled range as logged; dot = midpoint

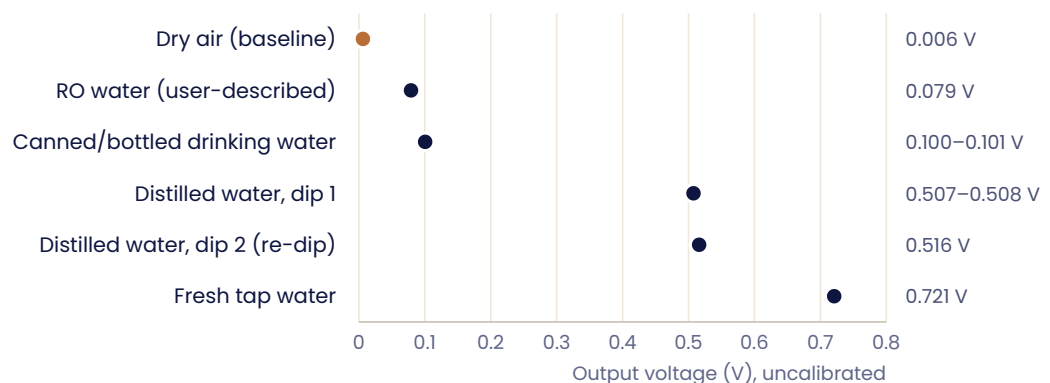


Figure 7 TDS module output per condition. RO, canned and tap water rise in the expected order; both distilled-water dips sit out of order between canned and tap water.

The order of measurement, from the log order and the board's `ms` counter: canned water, then the ADC check, distilled dip 1, tap water, RO water, and distilled dip 2.

Calculated from these:

- Tap water read +0.715 V above dry air.
- The distilled water re-dip read 1.67 % higher in volts (1.81 % in counts) than dip 1. Reproducibility on the same sample is good.
- Distilled water read 6.4 times higher than RO water. Purer water should read lower, not higher. RO < canned < tap is in the expected order. Distilled water is the only reading out of order.

CAUTION**ADC sanity check: inconclusive**

With A0 jumpered to the 5 V pin, the expected reading was near 16383 counts. The board read 3132–3146 counts (0.956–0.960 V), which is 19.1–19.2 % of full scale (calculated), rock steady across two captures, including after reseating the jumper. The cause was not found. A pin mix-up is suspected but not confirmed, as no multimeter was available. **The ADC reference and accuracy are therefore not verified.**

5.3 pH (PH-4502C, 2026-10-19)

Condition	Settled range (V)	Raw ADC (counts)	Settling time
Tap water	1.370–1.372	4495–4497	~40 s
Distilled water	1.387–1.389	4544–4550	~25 s
Salt water	1.422–1.425	4658–4664	~60 s
Dry air (baseline)	1.486	4868–4879	—
Lemon water (acidic)	2.299–2.300	7534–7536	~45 s
<i>Excluded: electrode not plugged into BNC</i>	<i>0.71–0.79, noisy</i>	—	<i>never settled</i>

● PH: PH-4502C, 2026-10-19

● Dry-air baseline

● Liquid

— Settled range as logged; dot = midpoint

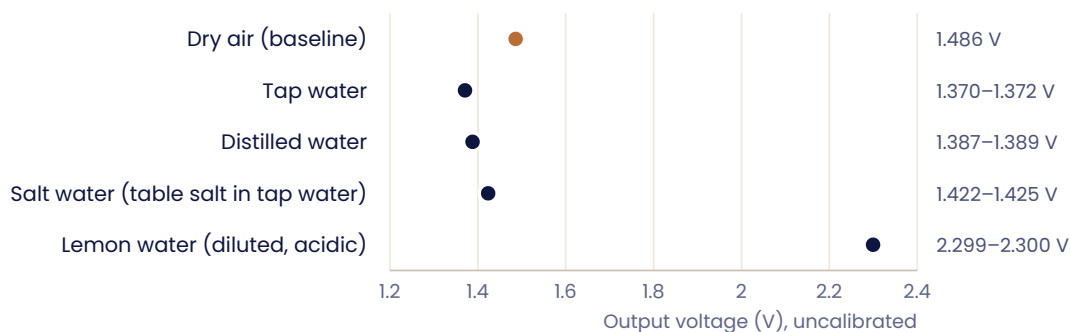


Figure 8 pH module output per condition. Tap, distilled and salt water cluster together; acidic lemon water stands well apart. The excluded unplugged-electrode reading is not shown.

Calculated from these, taking the mean of the tap and distilled midpoints as the near-neutral reference (1.3795 V):

- Lemon water read +0.920 V above the near-neutral reference.
- Salt water read +0.044 V above it. The acid response is 20.9 times the salt response.
- Dry air read +0.107 V above it, so dry air sits close to, not far from, the liquid readings.
- Tap and distilled water were separated by 0.015 V.
- The near-neutral reference is 1.121 V below the firmware's placeholder neutral voltage of 2.5 V (`PH_NEUTRAL_VOLTS`, a vendor-typical value, not a datasheet value for this unit).

5.4 Water level (XKC-Y25-PNP, 2026-10-17)

State	raw	stable	Report timestamps (ms since reset)	Duration (calculated)
Dry	0	0	33000–55000	22 s (23 reports at 1 Hz)
Water presented	1	1	56000–69000	13 s (14 reports at 1 Hz)

● WATER LEVEL: XKC-Y25-PNP, 2026-10-17

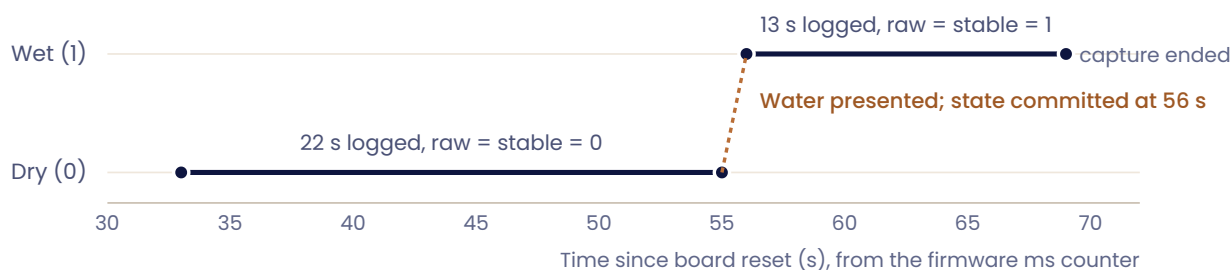


Figure 9 Debounced state of the level switch over the logged session, drawn from the first and last logged report of each state.

No chatter was seen in either state. The debounced state committed to 1 at the first report after water was presented. The sensor's onboard LED matched the serial state throughout (visual check). With MODE floating, the output is LOW when dry and HIGH when wet (normally-open

behaviour). The wet-to-dry transition was not captured because the capture ended first.

5.5 Uncertainty

A GUM-style uncertainty budget (JCGM 100:2008) **cannot be completed** from these records:

- **Type A (statistical):** not estimable. No per-sample data or repeat runs were saved. The logged settled ranges (sections 5.1 to 5.3) are the only indication of spread and should not be read as standard deviations.
- **Type B, ADC quantisation:** 0.0881 mV standard uncertainty (step / $\sqrt{12}$, calculated), negligible against every effect discussed here.
- **Type B, ADC reference and gain:** unknown. The 5 V reference is the board's supply rail, which was not measured because no multimeter was available, and the one attempt to check it was inconclusive (section 5.2).
- **Conversion to engineering units:** not applicable yet. No calibration exists.

Coverage factor: not stated, since no combined uncertainty can be given.

SECTION 6

Analysis and discussion

6.1 Against the bring-up objectives

ID	Objective	Result	Met?
B1	Powers and connects	All four modules powered from 5 V and delivered a signal. The pH electrode was at first not plugged in, which was caught before any reading was used	Met
B2	Stable and distinct from dry air	Turbidity: clear liquids yes; turbid samples never settled, and dip 1's mean overlaps dry air. TDS: yes for all liquids. pH: yes, after 25–60 s settling. Level: yes	Partly met (turbid samples)
B3	Expected direction	Turbidity: clear > turbid in mean voltage, yes. TDS: RO < canned < tap yes, distilled out of order. pH: acid clearly separated, salt barely moves, yes. Level: dry LOW, wet HIGH, yes	Partly met (TDS distilled)
B4	14-bit ADC active, reference verified	14-bit active: yes (counts above 4095). Reference verified: no (TDS check inconclusive)	Partly met

6.2 Findings per sensor

Turbidity: sample handling dominates the reading. The same cup of powder suspension read anywhere in a 0.83 V span depending only on how recently it was stirred, because the particles settle under gravity within minutes. Clear liquids, by contrast, settled to within a few mV. Two implications for the measurement protocol:

- Any turbidity calibration must fix the agitation state (for example, continuously stirred, or a fixed time after stirring stops). Continuous stirring gave the most repeatable turbid reading.

- The mean voltage alone cannot tell dry air from a partly settled turbid sample (dip 1 sat within 0.017 V of dry air). Signal variance carries information and could feed the planned health checks.

Observed voltages (2.41–3.576 V) lie inside the 0–4.5 V output range given in retailer listings for the TS-300B family. Those listings are unverified seller figures, not a datasheet for this module.

TDS: good repeatability, one unexplained sample. The module separated dry air, RO, drinking and tap water clearly. Two dips into the same distilled water agreed to within 1.67 % (calculated). But distilled water read 6.4 times higher than RO water (calculated), which contradicts the expected order. The other readings are internally consistent, so the most likely cause is the distilled water sample or its container, but this has not been tested. The plan to use this distilled water as the v1 single-point calibration should wait until a fresh, sealed sample has been measured. This re-test is already planned. Distilled water is not a conductivity standard in any case; a certified standard (for example 1413 $\mu\text{S}/\text{cm}$ at 25 °C) is needed for a real calibration.

pH: behaves like a pH electrode. The acidic sample moved the output 20.9 times as far as the salt sample did (+0.920 V against +0.044 V, calculated). A glass pH electrode should respond this way; a bare conductivity probe would have responded mainly to the salt. The small salt offset is consistent with the known ionic-strength and junction-potential effect. Two points need attention:

- The near-neutral output (1.3795 V) is 1.121 V below the 2.5 V placeholder in firmware. The placeholder must be replaced by buffer calibration. Buffer calibration, which the module's offset trimmer serves, had not started at the time of the session, and the trimmer's setting was not recorded.
- Settling took 25–60 s, depending on the liquid. The firmware's warm-up placeholder (`HEALTH_WARMUP_MS` = 500 ms) is far too short and must be set from measured settling data.

The firmware does not yet record the direction of the slope (output voltage rising as pH falls, as the lemon water suggests). This should be confirmed with buffers on both sides of pH 7.

Water level: correct behaviour, minimal evidence. The switch read dry and wet correctly, with no chatter and agreement with its own LED, and the MODE pin behaviour (floating gives normally-open) was confirmed. Only one dry-to-wet transition and no wet-to-dry transition were recorded, and the 50 ms debounce was not tested with the water held at the detection boundary.

6.3 Cross-cutting findings

- **The board's ADC is the only instrument, and it is unverified.** Every analog number in this paper depends on the Uno R4 WiFi's 5 V rail as the ADC reference. The one check of the ADC chain did not give the expected result. Until this is resolved with a calibrated multimeter, absolute voltages may carry an unknown gain error. Differences between conditions in the same session are less affected.
- **Settling time is a design input.** pH needed 25–60 s, and turbid samples never settled. The health and reporting modules need settling-aware logic.

- **Documentation is a sourcing risk.** No manufacturer datasheet could be found for the turbidity, TDS or pH modules, the pH module's manufacturer could not be identified, and one retailer lists the TS-300B as discontinued. A product built on these modules needs each one characterised in-house, and a documented equivalent identified, before the design is fixed.
- **Process discipline caught real errors.** The unplugged pH electrode and the misidentified TDS sample were both caught and corrected in the logs before any reading was used. The same discipline now needs to extend to saving raw serial captures and recording sample details.

6.4 From findings to protocol rules

Each effect above translates directly into a rule for the calibration phase. Figure 10 pairs each measured effect with the rule it implies. Together they form the core of that phase's test protocol.

• FROM MEASURED EFFECT TO PROTOCOL RULE

What the bench showed (calculated from the logs)

What the calibration protocol must do

Turbidity 0.83 V	spread in one cup of turbid water, from agitation alone	→	Fix the agitation state: stir continuously, or read at a fixed time after stirring stops
pH 25–60 s	for the pH reading to settle after immersion	→	Set warm-up from measured settling data; the 500 ms firmware placeholder is far too short
pH 1.121 V	between near-neutral output and the firmware's 2.5 V placeholder	→	Calibrate with certified buffers on both sides of pH 7 before reporting any pH value
TDS 6.4×	distilled water read higher than RO water, against the expected order	→	Take calibration constants only from certified standards, never from an unverified sample
ADC 19.1–19.2 %	of full scale with A0 jumpered to 5 V, where near 100 % was expected	→	Verify the ADC chain with a calibrated multimeter before any calibration run
Records Not saved	raw serial stream, temperatures, sample recipes and containers	→	Log the raw stream to CSV and record temperature, sample recipe, container and immersion depth

Figure 10 Six rules for the calibration protocol, each traced to an effect observed in this work. Values are calculated from the measurements in sections 5.1 to 5.3; the 2.5 V and 500 ms firmware placeholders are firmware constants.

• SECTION 7

Limitations and threats to validity

- **No reference standards.** Nothing here shows that any sensor measures NTU, conductivity, TDS or pH correctly. The results show only that the signal responds, and in which direction.
- **Household liquids of unknown composition.** Tap, RO, bottled, lemon and salt water and the powder suspension have no known turbidity, conductivity or pH. Their recipes, sources and volumes were not recorded, and the containers are known only for turbidity, from photos. The RO identity was not verified, and the bottled water was misidentified at first.
- **Single session, no saved samples.** One session per sensor, with no repeat on another day, no stored sample stream, and ranges written by hand into the logs. Statistics, drift and day-to-day repeatability are unknown.

- **Unverified ADC reference.** See section 6.3.
- **No temperature record.** Conductivity and pH both depend on temperature. Readings taken at different, unknown temperatures may not be comparable.
- **One unit of each module, board identity not recorded.** Unit-to-unit variation of these low-cost modules is unknown. Three of the four modules have no manufacturer datasheet. The board's serial number was not recorded, and whether one board served all four sessions is unknown.
- **Firmware at bring-up stage.** Only the sensor read path (and the TDS filter and level debounce) was real. The filter, health and calibration modules that will shape the reported value were not in the loop. Toolchain versions were read on 2026-10-19, after the two sessions of 2026-10-17.
- **Bench only.** No test in a tank, pipe or outdoor enclosure, and no environmental, EMC or long-duration testing.

SECTION 8

TRL assessment

TECHNOLOGY READINESS: WHERE THIS WORK SITS

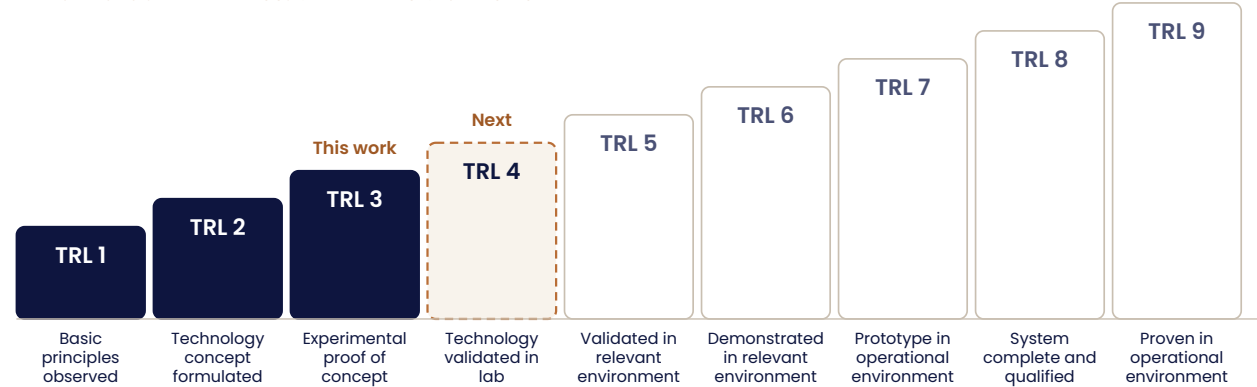


Figure 11 Where this work sits on the EU Horizon TRL scale. TRL definitions per EU Horizon, assessed with ISO 16290 criteria.

TRL demonstrated	Below TRL 4. The evidence supports an experimental proof of concept (EU Horizon TRL 3) for each of the four sensing signal chains
Integration level	Component: each sensor module on the microcontroller board, tested separately. No integrated system
Fidelity	Breadboard (off-the-shelf modules, jumper wiring, development board)
Environment	Laboratory bench. The relevant environment for this product has not yet been defined; defining it is a prerequisite for any TRL 5 claim
Evidence	Sections 5 and 6 of this paper, from the dated session records
Why not TRL 4	TRL 4 requires the component to work in the lab <i>against defined criteria</i> . No measurable criteria were defined beforehand, no reading is in engineering units, no reference standard was used, results are single-run, and the ADC chain is not verified

Gaps to TRL 4	(1) Set measurable limits before testing (section 2). (2) Verify the ADC chain with a calibrated multimeter. (3) Calibrate pH with certified buffers (at least pH 4, 7, 10), TDS/conductivity with two certified standards, and turbidity with formazin or equivalent standards under a fixed agitation protocol. (4) Repeat each test, preferably on more than one day, saving raw serial data as CSV. (5) Record sample temperature and sample details. (6) Capture both level-switch transitions over repeated trials and at the detection boundary. (7) Validate each calibration against a held-out sample, as the calibration procedure written for each node already requires
Gaps beyond TRL 4	TRL 5 needs the relevant environment defined and the sensors tested under realistic conditions (temperature, enclosure, real water). TRL 6 needs the integrated multi-sensor prototype, not yet designed, demonstrated end to end in the relevant environment

SECTION 9

Conclusions and next steps

All four low-cost modules work electrically with the Arduino Uno R4 WiFi and give stable, distinguishable, directionally sensible signals for clear liquids. The pH module shows genuine pH-electrode behaviour: a large acid response and a small salinity effect. The TDS module repeats well on the same sample but has one unexplained out-of-order reading. Turbidity readings of turbid samples are dominated by how the sample is agitated, which any protocol must control. The level switch behaves correctly with minimal evidence. None of the sensors yet gives a calibrated reading, so this is a proof of concept, below TRL 4.

The most useful output of this work is what the calibration phase must control: agitation, settling, buffer-based neutral points, certified standards in place of household samples, a verified ADC chain, and complete session records (Figure 10). Figure 12 sets out the path from here to TRL 4.

PATH FROM THIS WORK TO TRL 4

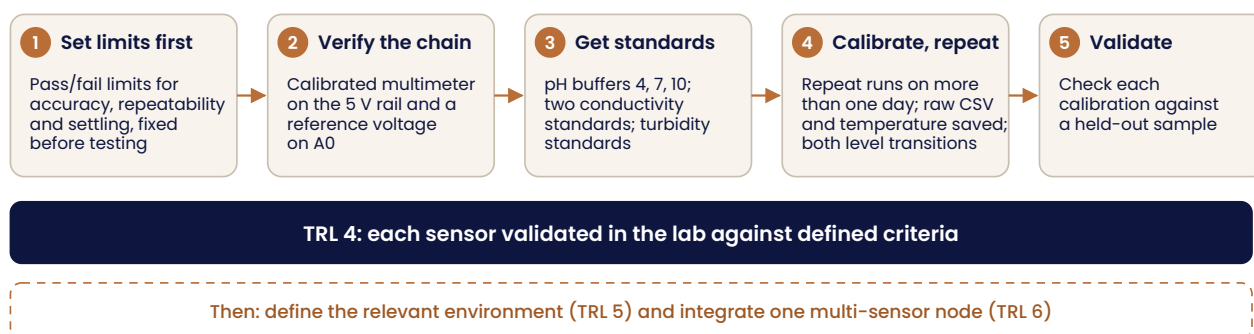


Figure 12 Path from this work to TRL 4, from the gaps listed in section 8.

Next steps, in priority order:

- 1. Save raw data and complete records.** Log the serial stream to CSV for every future session, with date, time and time zone, and fill a session sheet: temperatures, sample source and recipe, container, volume, immersion depth, board identity and power source.
- 2. Verify the measurement chain.** Resolve the A0 check with a calibrated multimeter, and measure the 5 V rail.

3. **Buy reference standards.** pH buffers (4/7/10), two conductivity standards (for example 84 and 1413 $\mu\text{S}/\text{cm}$; Indian suppliers of 1413 $\mu\text{S}/\text{cm}$ standards have already been identified), and turbidity standards. Add a temperature measurement (the TDS node's next version already includes a DS18B20 temperature sensor).
4. **Re-test the TDS distilled-water anomaly** with a fresh, sealed sample, before it becomes a calibration constant.
5. **Write the turbidity agitation protocol** (stirred or a fixed time after stirring) and time the settling.
6. **Set measurable acceptance criteria**, then run the calibration tests with repeats and publish the results as a new publication.
7. **Define the relevant environment** for the combined system, as the basis for later TRL 5 and 6 work.

Methods to follow in the calibration phase, where practical: ISO 10523 (pH), ISO 7888 (electrical conductivity), and ISO 7027-1 with IS 3025 (Part 10):2023 (turbidity). For context on target ranges, IS 10500:2012 sets drinking-water limits for all three quality parameters; the TDS firmware already uses its 500 mg/L acceptable limit for TDS as the default alert level.

SECTION 10

References

1. JCGM 100:2008, *Evaluation of measurement data: Guide to the expression of uncertainty in measurement* (GUM).
2. ISO/IEC 17025:2017, *General requirements for the competence of testing and calibration laboratories*.
3. ISO 16290:2013, *Space systems: Definition of the Technology Readiness Levels (TRLs) and their criteria of assessment*.
4. ISO 10523:2008, *Water quality: Determination of pH*.
5. ISO 7888:1985, *Water quality: Determination of electrical conductivity*.
6. ISO 7027-1:2016, *Water quality: Determination of turbidity, Part 1: Quantitative methods*.
7. IS 10500:2012, *Drinking water: Specification* (Second Revision), Bureau of Indian Standards.
8. IS 3025 (Part 10):2023, *Methods of sampling and test (physical and chemical) for water and wastewater, Part 10: Turbidity* (Second Revision), Bureau of Indian Standards.
9. Arduino, *UNO R4 WiFi ADC Resolution* tutorial, <https://docs.arduino.cc/tutorials/uno-r4-wifi/adc-resolution>.
10. Arduino, *UNO R4 WiFi Cheat Sheet*, <https://docs.arduino.cc/tutorials/uno-r4-wifi/cheat-sheet>.
11. KIE-TS-300B turbidity module: no manufacturer datasheet found (search, 2026-10-19). TS-300B family figures in Table 3.1 are from retailer listings and unverified.
12. PH-4502C pH module and glass electrode: no manufacturer datasheet found; manufacturer not identified.

13. Shenzhen Xingkechuang, manual for the XKC-Y25-V non-contact liquid-level sensor family, covering high/low-level, NPN, PNP and RS485 output variants. Document title and revision not recorded.

14. Generic two-needle TDS module: no datasheet available.

APPENDICES

Appendices

A. Firmware configuration at test time

Parameter	Value	Applies to
ADC resolution	14-bit (<code>ADC_RESOLUTION_BITS</code>)	Turbidity, TDS, pH
ADC reference	5.0 V, the board's 5 V rail (<code>ADC_VREF_VOLTS</code>)	Turbidity, TDS, pH
Sample window	200 ms per report, averaging over whole 50/60 Hz mains cycles (<code>SAMPLE_WINDOW_US</code>)	Turbidity, TDS, pH
Report interval	1 s (<code>REPORT_INTERVAL_MS</code>)	All
Filter	Median of 5, then exponential smoothing with factor 0.4 (<code>FILTER_WINDOW_SIZE</code> , <code>FILTER_SMOOTHING</code>); in the loop for TDS only	TDS
Level input and debounce	Pin D2, 50 ms time-based debounce (<code>DEBOUNCE_MS</code>)	Water level
Warm-up	500 ms placeholder (<code>HEALTH_WARMUP_MS</code>), not in the loop at bring-up	All
pH conversion	Neutral 2.5 V and slope 0.18 V per pH (<code>PH_NEUTRAL_VOLTS</code> , <code>PH_SLOPE_V_PER_PH</code>): vendor-typical placeholders, not in the loop at bring-up	pH
Temperature compensation	25 °C assumed, 2 % per °C (<code>ASSUMED_TEMP_C</code> , <code>TEMP_COEFF_PER_C</code>): not in the loop at bring-up	TDS
TDS alert default	500 mg/L, the IS 10500:2012 acceptable limit	TDS

Toolchain: `arduino-cli` 1.2.2, core `arduino:renesas_uno` 1.6.0 (see section 3).

B. Test sessions

Sensor	Date	Conditions recorded
Water level	2026-10-17	Dry baseline; one dry-to-wet transition
TDS	2026-10-17	Dry air, canned drinking water, ADC check, distilled water (two dips), tap water, RO water
pH	2026-10-19	Unplugged-electrode fault (excluded), dry air, distilled, tap, salt and lemon water
Turbidity	2026-10-19	Dry air, distilled water, lemon water, powder suspension in four agitation states

Each session was recorded as a dated test log of settled ranges and observations. Every calculated value in this paper is derived from those records.

C. Revision history

Version	Date	Author	Changes
v1.1	2026-10-21	Nanupatruni Mahesh Kumar	Wording and reference corrections; results unchanged
v1.0	2026-10-21	Nanupatruni Mahesh Kumar	First published version, reviewed by Ravi Kumar Chintalapudi. Released as Public. Retitled; board power source stated
v0.2	2026-10-19	Nanupatruni Mahesh Kumar	Added board identification and turbidity setup photos, module documentation status, IS 3025 (Part 10):2023, protocol rules and the path to TRL 4. Retitled
v0.1	2026-10-19	Nanupatruni Mahesh Kumar	First draft



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● HOW TO CITE

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