TSRA Groundwater Monitoring:

Final Report 2022

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Report No. 22/46

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TSRA Groundwater Monitoring: Final Report 2022, incorporating Technical Report 2021.

A Report for Torres Strait Regional Authority

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EXECUTIVE SUMMARY

The Torres Strait groundwater monitoring program is a joint initiative between James Cook University's Centre for Tropical Water and Aquatic Ecosystem Research (TropWATER) , Townsville, and the Torres Strait Island Regional Authority. The program included rangers from four Island communities in the Torres Strait - Saibai, St Paul's, Warraber, and Masig Islands, who were trained in methods for monitoring water quality.

The rangers collected water samples from groundwater wells on all four Islands and these were analysed for contaminants at a laboratory in Cairns. Results from the laboratory analysis were compared to Australian drinking water guidelines and there was found to be variable results between the wells. The pesticides dimethoate and malathion were detected at Buthu May Well on Saibai Island, though these were at concentrations lower than health and aesthetic guideline values. Buthu May Well also exceeded health guideline values for Escherichia coli (E. coli) and exceeded aesthetic guideline values for ammonium, iron (total and dissolved), aluminium, and turbidity. Thelma Billy Well on Masig Island showed an anomalously high turbidity, also exceeding guideline values. Kurrsarr Well at St Paul's exceeded health guideline values for E. coli and arsenic and Alwal Well and MGNM Well at Warraber exceeded health guideline values for E. coli.

There were no pesticides detected at any wells other than Buthu May on Saibai Island.
There were no total petroleum hydrocarbons, perfluoroalkyl or polyfluoroalkyl substances, or herbicides detected in any of the groundwater wells. Hydrochemical analysis on water sample results was conducted to understand groundwater chemistry and detect seawater intrusion. There is evidence of seawater intrusion to Kurrsarr Well on St Paul's Island and Meriba Ged Ngalpan Mab Well (MGNM) on Warraber Islet. There is also potential for seawater intrusion at Saibai Buthu May Well and Masig Mothers Well. The extent of seawater intrusion should be closely monitored.

Rangers installed dataloggers into wells to monitor for water depth, temperature, and electrical conductivity. The logger program was partially successful but had problems throughout. These included loggers being removed from the well or not being installed below the water level on many occasions. There were large amounts of data loss throughout the length of the monitoring program.
When data was captured, there was a clear alignment between groundwater recharge and the wet season rains. Water temperature was fairly consistent across the different Wells, with water temperatures ranging from ~ 26°c in July to ~ 30°c in January.

Electrical conductivity measured within the wells indicated that groundwater was mostly 'fresh', with values not exceeding 1500 µS cm^{-1}. There were some short periods in the wet season where Thelma Billy Well reached 2000 µS cm^{-1} however this would still be considered fresh.

Recommendations going forward include increasing training for Rangers, community engagement regarding safe use of groundwater, investigating new wells and expanding water sampling to other existing wells, and continued monitoring for contaminants. Ideally, consider in engaging in the process of producing a groundwater quality management plan for Torres Strait Island communities following the Water Quality Australia 'Guidelines for groundwater protection in Australia: National Water Quality Management Strategy'.

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1 INTRODUCTION

The Torres Strait Islands are remote and low-lying islands located on the shallow continental shelf between Papua New Guinea and Cape York, Australia (Figure 1). Of the 300 islands, 17 are inhabited by the Torres Strait Islander Peoples, with a total resident population of approximately 8700 (TSRA). Being highly exposed to the physical impacts of weather, Torres Strait communities are under multiple threats due to climate change, including sea level rise, storm surges, changes to the ocean environment, hotter days, more intense rainfall, and longer dry seasons. Sea levels in Torres Strait are rising at a rate of 6-9 mm annually and this trend is expected to continue (Green et al., 2009). While seawalls can be constructed to stop coastal inundation, ingress into groundwater is more difficult to control. Further, contamination from pollutants such as hydrocarbons, pesticides, sewerage, plastics, and landfill increase potential impacts to groundwater. With communities often reliant on groundwater wells for fresh drinking water, irrigation of crops, and replenishment of the streams and wetlands that support fish, ensuring the quality and quantity of this source of water is a priority for the health and wellbeing of the communities.

Figure 1: Map of Torres Strait Island communities which are part of the TSRA groundwater monitoring program. (Basemap Image: ESRI online)

Project background

In 2018, a desk-based review of groundwater prospects across 15 island communities serviced by the Torres Strait Island Regional Council (TSIRC) was finalised (Project 276, Rob Lait and Associates Pty Ltd).

Recommendations of the review were that long-term field investigations and ongoing monitoring were required to fully define and monitor groundwater resources.
A subsequent plan was developed between the Torres Strait Regional Authority (TSRA) and the Centre for Tropical Water and Aquatic Ecosystems (TropWATER) at James Cook University (JCU) to work with the Traditional Owners in the implementation of a groundwater monitoring program. The project focus was on three specific outcomes

1. Establish baseline water quality conditions of groundwater on nine islands in the Torres Strait.

2. Establish monitoring program of groundwater quality, including ranger training

3. Communication of groundwater monitoring plan and outcomes to island communities.

2 METHODOLOGY

Ranger training

TSRA program coordinator and a scientist from JCU TropWATER visited Saibai, Boigu, and Moa/St Paul's in November 2019 to train TSRA rangers in how to go about installing and maintaining dataloggers and collecting water samples from wells. Training for rangers at Warraber, Masig, and Hammond Island in 2020 and 2021 was conducted over virtual 'Teams' videoconferencing, with the TSRA program coordinator visiting each community and teleconferencing with a JCU scientist in Townsville.

The following rangers undertook training for the groundwater program:
Laura Pearson, Young Billy, Aken Baragud, and Kevin Levi (Warraber). Jackson Ware, George Saveka, and Freddie Wapau (St Paul's, Moa Island). Jehemess Waia, and David Garama (Saibai). Edna Nai, and Francis Nai (Masig), and Richard Gela + TSIRC staff (Keriri).

Site establishment

The rangers decided on which wells in their communities to include in the program with guidance from the TSRA project coordinator and a JCU scientist. Two sites were selected at Aiwal Well and Meriba Ged Ngalpan Mab (MGNM) Well on Warraber Islet (Figure 2). One site was selected at Buthu May Well on Saibai Island (Figure 3). One site was selected at Kurrsarr Well in the St Paul's community on Moa Island (Figure 4). Two sites were selected at Mother's Well and Thelma Billy Well on Masig Island (Figure 5). There were no suitable wells identified on Boigu to include in the program. A site named Francis Road Well at Keriri (Hammond Island) has recently been added to the program (Figure 6) and a site is soon to be selected at Mer (Murray Island).

Figure 2: Location of Aiwal Well and Meriba Ged Ngalpan Mab (MGNM) Well on Warraber Islet

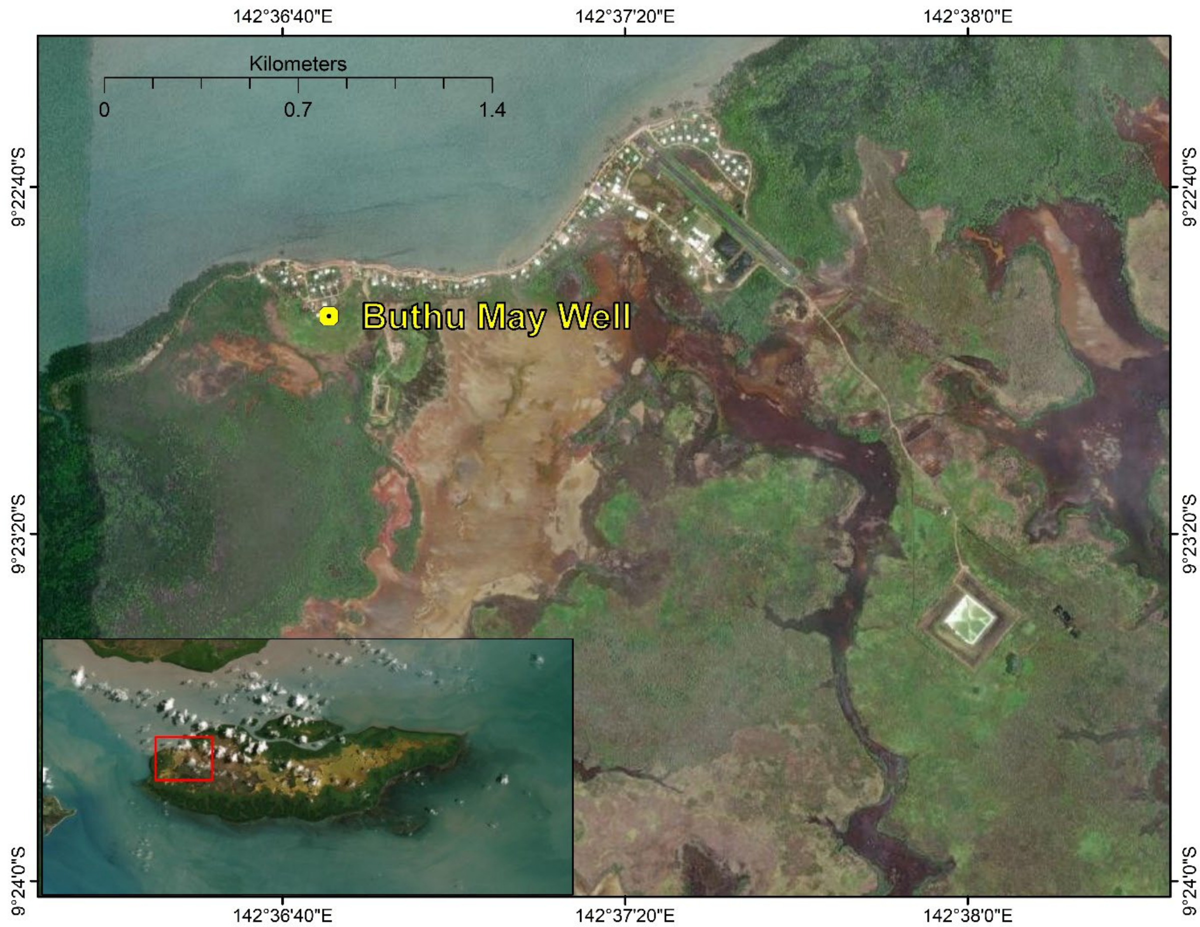

Figure 3: Location of Buthu May Well on Saibai Island

Figure 4: Location of Kurrsarr Well at St Paul's on Moa Island

Figure 5: Location of Mothers Well and Thelma Billy Well on Masig Island

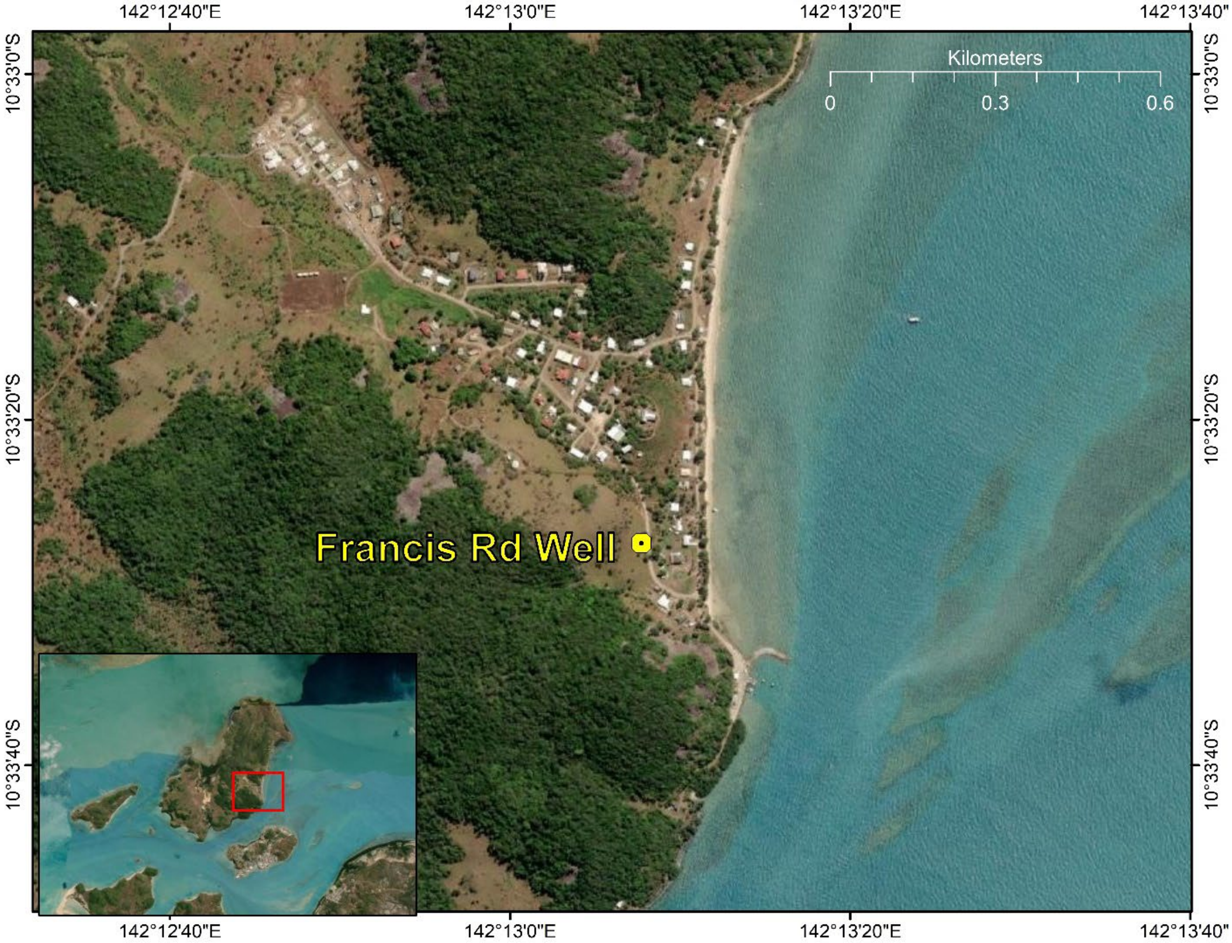

Figure 6: Location of Francis Road Well on Keriri (Hammond Island).

Data loggers

Each well was equipped with a pair of dataloggers to record depth, temperature, and electrical conductivity of the well water. Each pair consisted of a HOBO U20L-01 Water Level datalogger and a HOBO U24-001 Fresh Water Conductivity datalogger (Onset Computer Corporation, Massachusetts USA) (Figure 7). The data loggers were affixed inside the well with a length of stainless-steel wire or nylon cord at a set depth.

Logger files were received in .hobo, .hproj, and .csv format. All files were inspected for valid data and extracted to individual .csv files. The start and end of each logger file was masked to remove the period when the logger was actively recording data but not installed in the well. Logger files were combined per site/well and the overall dataset assessed for completeness and validity.

Figure 7: HOBO dataloggers used to measure conductivity (salinitiy) and water depth in the groundwater wells.

Pressure measurements recorded by the water depth loggers were converted to depth below surface. The depth was barometrically compensated with surface air pressure readings collected from nearby weather stations maintained by the Australian Institute of Marine Science (AIMS). Barometric compensation improves the accuracy of the calculated depth from the HOBO pressure sensor, although ideally the atmospheric sensor should be close to the depth sensor. Differences in atmospheric pressure between the weather station and well location will introduce error to the depth measurement. Summary plots of relevant data extracted from the weather stations are included in the ‘weather and climate’ section below.

Water sampling

Water sampling kits prepared by Cairns Regional Council Laboratory Services were sent to each community. Rangers collected water sample from the groundwater well with a clean bucket and filled each of the bottles. Nitrile gloves were worn while collecting the samples and handling sample bottles. Samples which required filtering (dissolved metals) were syringe filtered on-site with combined sterile 0.8 µm pre-filter and 0.45 µm filter. Samples were immediately packed into an esky and kept cool with an ice brick. The esky was then transported to the Cairns Regional Council Laboratory Services for analysis. Where there was a delay between collecting the water sample and transport to the laboratory, the water samples were refrigerated, with the nutrient sample stored frozen.

All water samples were forwarded to Cairns Regional Council Water and Waste Laboratory Services for analysis. The following analysis suites were requested: Organics, Microbiology, Metals, PFOS/PFOA and AFFF, Physical properties, Nutrients and Anions. A full list of analytes within each suite and their detection limits is contained in the results section.

Water samples were sorted into hydrochemical facies based on their cation and anion chemistry. Cations and anions were converted from reported concentrations (mg L^{-1}) to milliequivalents (mEq) and plotted onto a piper diagram (Piper, 1944). Hydrochemical facies are used to characterise groundwater ‘type’ and identify sources of dissolved constituents in water. Seawater intrusion to the groundwater wells was assessed by the interpretation of the piper diagram. A Chadha diagram was produced to further compare the results between water types at the various bores (Chadha, 1999)

Potential groundwater contaminants such as heavy metals, pesticides and hydrocarbons were tabulated and assessed against the Australian Drinking Water Guidelines (NHMRC, 2011) and Guidelines for Recreational Water Quality and Aesthetics within the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG, 2018). Each of the guidelines give health and aesthetics guideline values (GV's).

Weather and climate

Data presented in this report covers the period 01 November 2019 to 30 July 2022 (where available). Daily mean air temperature and daily rainfall recorded at AIMS weather stations across the region are shown in figures 8-11. Note that during this period, AIMS reduced the number of weather stations in the Torres Strait and only Masig Island and Thursday Island have weather data available after July 2021.

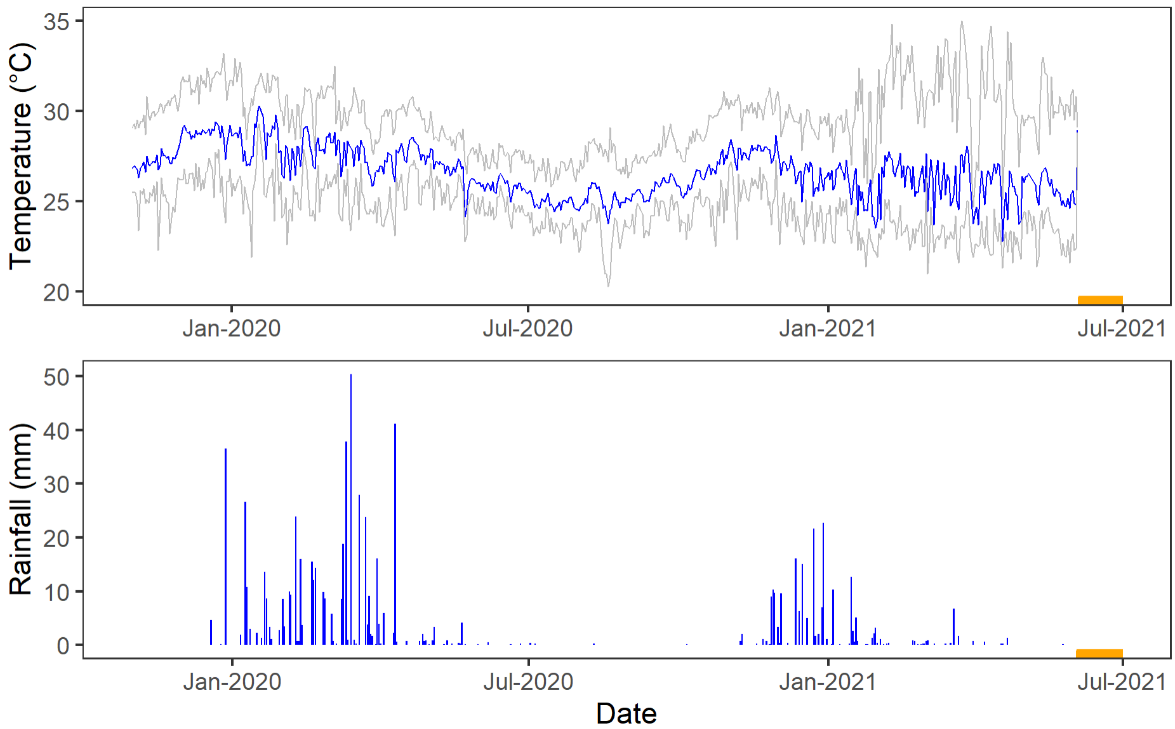

Figure 8: Daily mean air temperature (blue line), maximum/minimum air temperature (grey lines), and daily rainfall (blue bars) recorded at Badu. The orange strip at the bottom of each panel indicates periods of missing data. Based on Australian Institute of Marine Science data (http://data.aims.gov.au/).

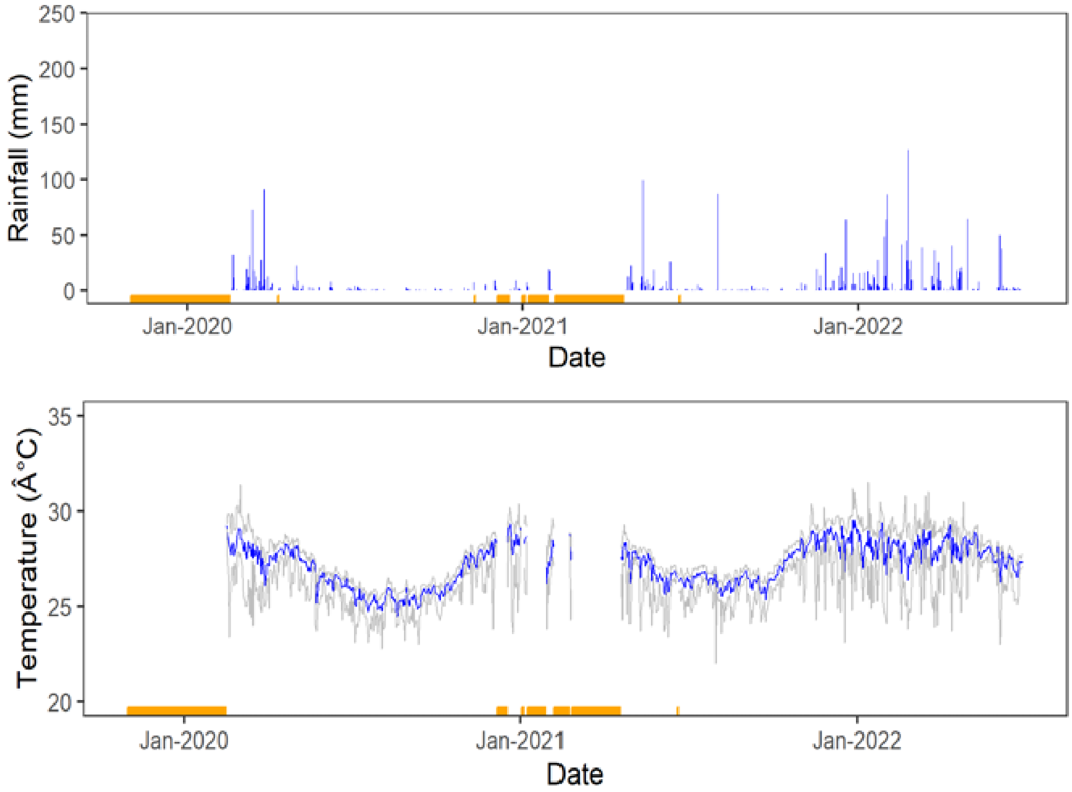

Figure 9: Daily mean air temperature (blue line), maximum/minimum air temperature (grey lines), and daily rainfall (blue bars) recorded at Masig. The orange strip at the bottom of each panel indicates periods of missing data. Based on Australian Institute of Marine Science data (http://data.aims.gov.au/).

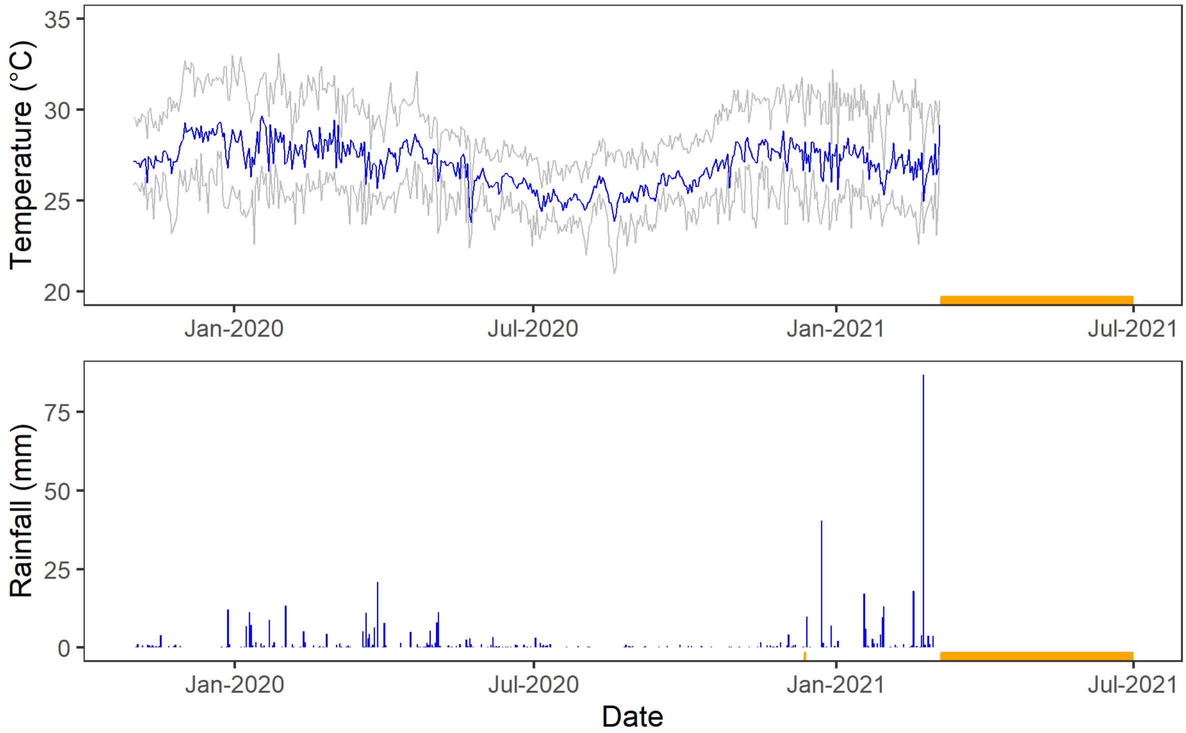

Figure 10: Daily mean air temperature (blue line), maximum/minimum air temperature (grey lines), and daily rainfall (blue bars) recorded at Saibai Island. Based on Australian Institute of Marine Science data (http://data.aims.gov.au/).

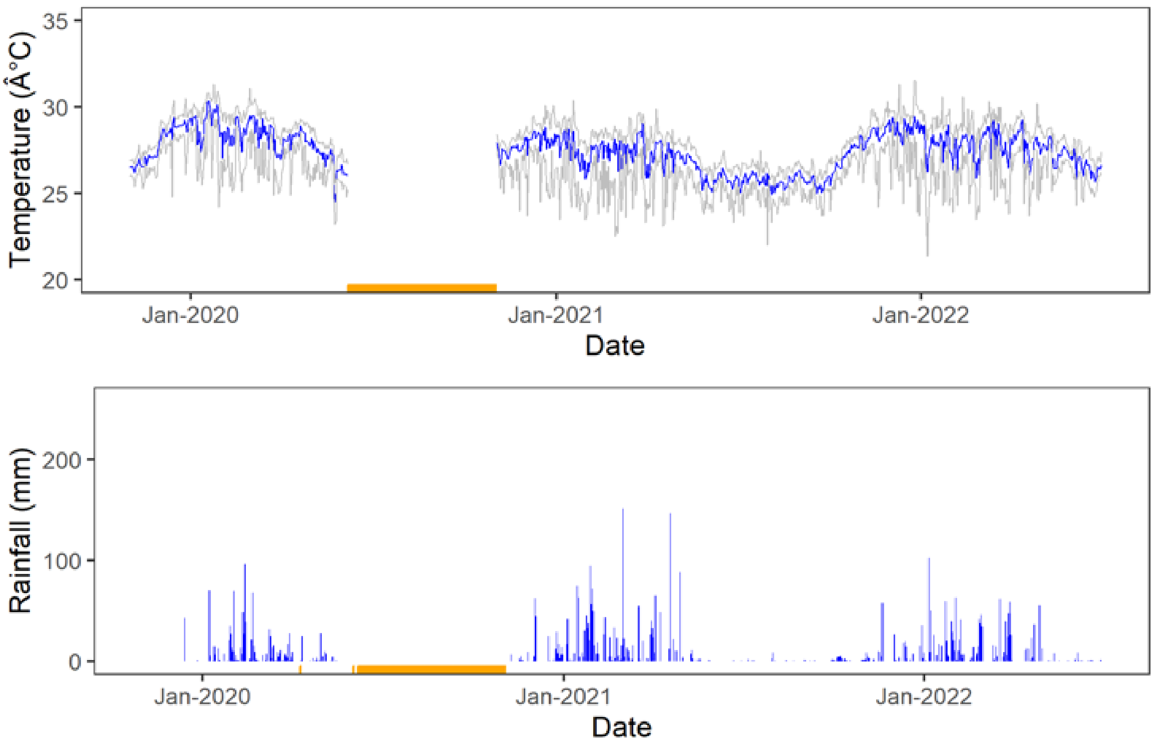

Figure 11: Daily mean air temperature (blue line), maximum/minimum air temperature (grey lines), and daily rainfall (blue bars) recorded at Thursday Island. The orange strip at the bottom of each panel indicates periods of missing data. Based on Australian Institute of Marine Science data (http://data.aims.gov.au/).

Barometric pressure was highly seasonal, with higher pressure during the cooler months, and lower pressure recorded during the warmer / wet season months (Figure 12-15).

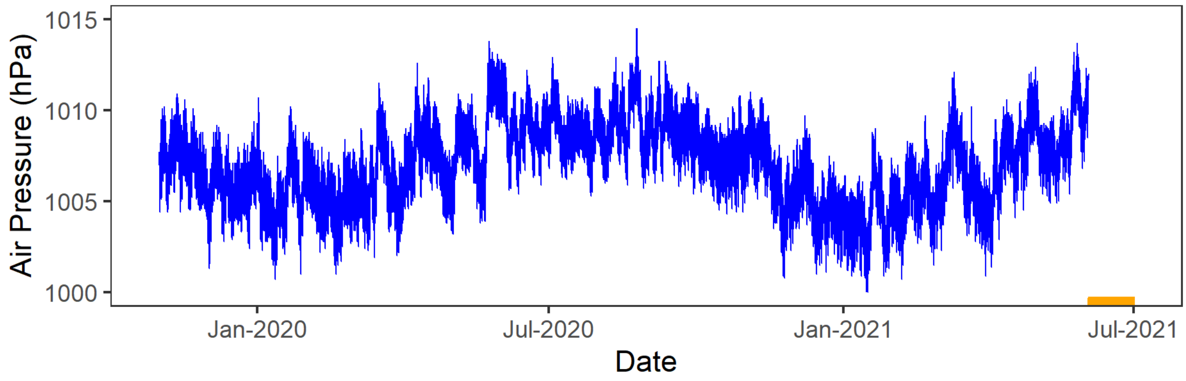

Figure 12: Barometric air pressure recorded at Badu and used to calculate barometric compensated depth from the HOBO depth loggers deployed in St Paul's Kurrsarr Well and Aiwal Well at Warraber. The orange strip at the bottom of the panel indicates periods of missing data. Based on Australian Institute of Marine Science data (http://data.aims.gov.au/).

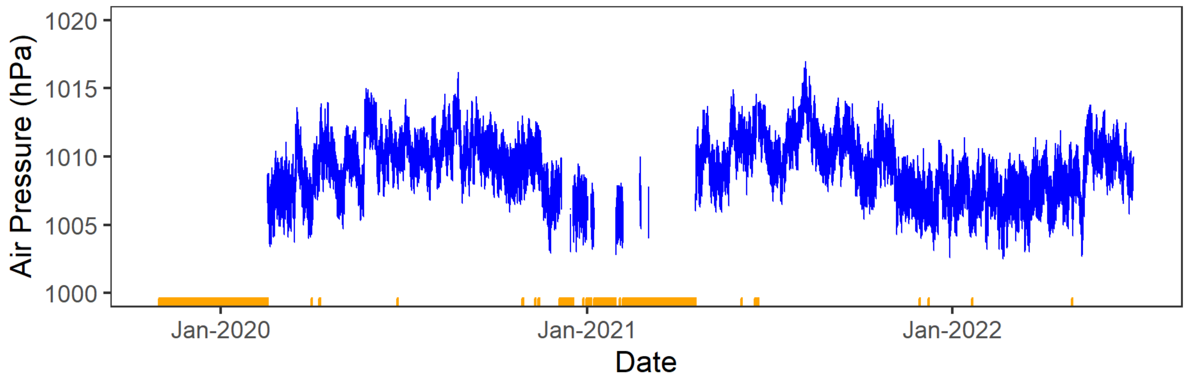

Figure 13: Barometric air pressure recorded at Masig Island and used to calculate barometric compensated depth from the HOBO depth loggers deployed in Mother's Well and Thelma Billy Well. The orange strip at the bottom of the panel indicates periods of missing data. Based on Australian Institute of Marine Science data (http://data.aims.gov.au/).

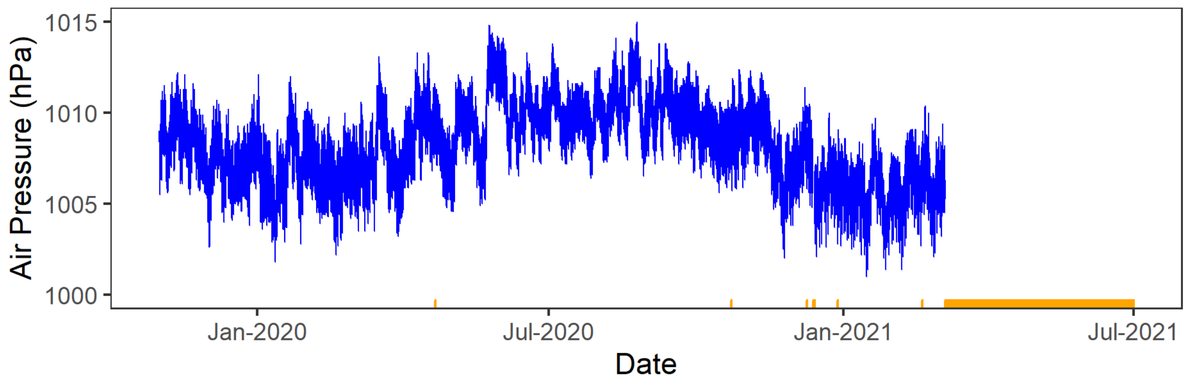

Figure 14: Barometric air pressure recorded at Saibai Island and used to calculate barometric compensated depth from the HOBO depth logger deployed in Buthu May Well. The orange strip at the bottom of the panel indicates periods of missing data. Based on Australian Institute of Marine Science data (http://data.aims.gov.au/).

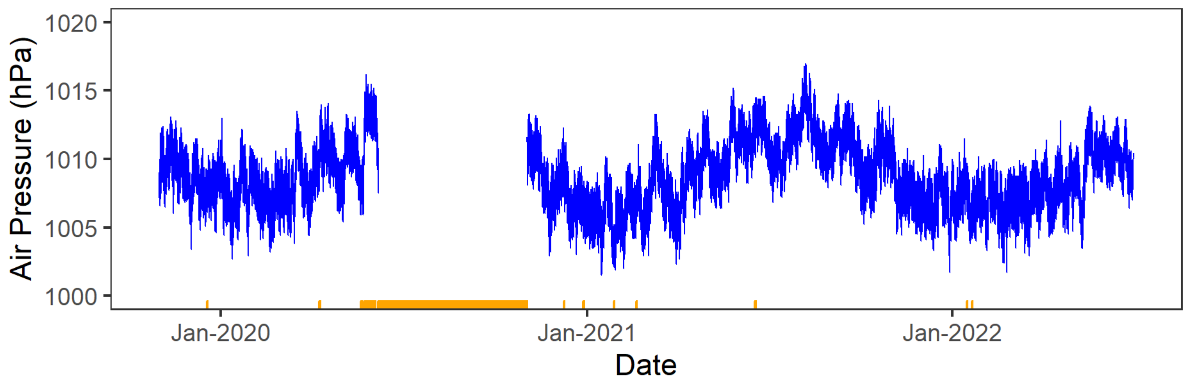

Figure 15: Barometric air pressure recorded at Thursday Island. The orange strip at the bottom of the panel indicates periods of missing data. Based on Australian Institute of Marine Science data (http://data.aims.gov.au/).

3 RESULTS AND DISCUSSION

Data loggers

Warraber: Aiwal Well

Aiwal Well was established as a sampling site in October 2020. The well had recently undergone maintainence, with a new corrugated iron cover, fencing, and signage installed (Figure 16). TSRA Rangers took measurements of the well dimensions and installed dataloggers near the base of the well (Table 1). All measurements were taken from the top of the well casing. Measurements were then converted to depth below ground level (bgl).

Table 1: Dimensions of Warraber's Aiwal Well measured by TSRA Rangers at time of groundwater quality program establishment and calculated depths below ground level (bgl).

Parameter	*Value*
Total depth (m)	3.04
Casing height (m)	0.15
Well diameter (inner) (m)	1.56
Water depth (m)	2.84
Well depth (m bgl)	2.89
Water depth (m bgl)	2.69
Depth logger depth (m bgl)	3.04
Cond logger depth (m bgl)	3.03

Figure 16: Warraber's Aiwal Well is a concrete lined square well with a total depth of 2.89 m bgl.

Logger data downloaded from this well covered the period from 10/10/2020 to 03/06/2021 (Figure 17). The depth logger recorded data between 10/10/2020 and 16/10/2020 which appears to be a period prior to the logger's installation in the well. The temperature sensor showed high daily range which indicates the logger was out of the water for that period. Inspection of the logger data indicates that the logger was installed in the well on the afternoon of 17/10/2021. The logger recorded data covering the period 17/10/2021 to 03/06/2021. Over that period the groundwater depth ranged from 2.2 to 2.5 m bgl and groundwater temperature ranged from 26.5 to 28.5 °C. No data was returned from the conductivity logger.

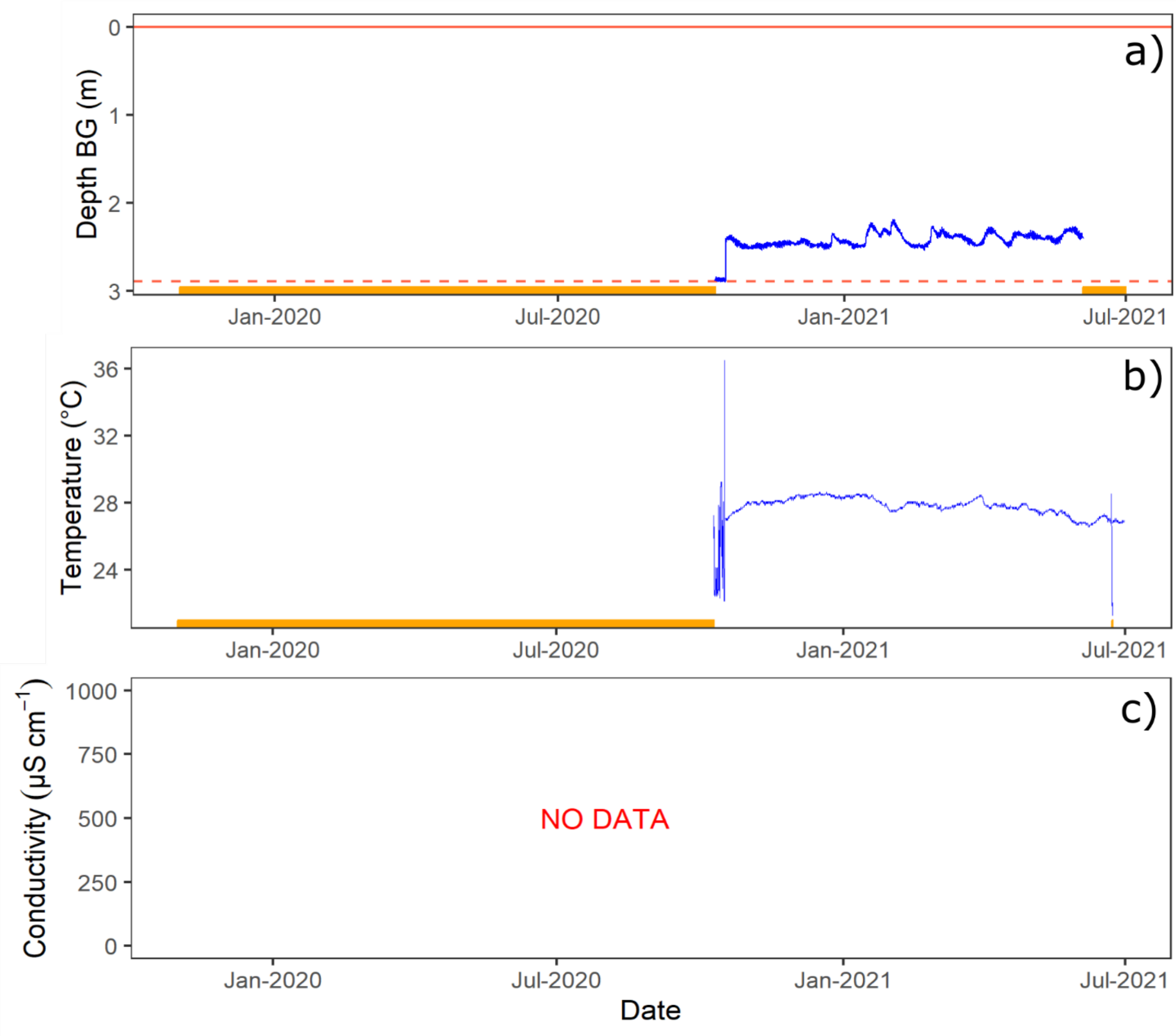

Figure 17: Data recorded by submerged dataloggers at Warraber's Aiwal Well. a) water depth below ground level. The red horizontal line at 0 m indicates ground level, red dashed line represents the bottom of the well. b) water temperature, and c) Electrical conductivity. Conductivity values are reported in microsiemens per centimeter ($\mu S\ cm^{-1}$). The orange strip at the bottom of each panel indicates periods of missing data.

Warraber: Meriba Ged Ngalpan Mab Well

Meriba Ged Ngalpan Mab Well (MGNM) was established as a sampling site in October 2020 (Figure 18). This well currently supplies water to Meriba Ged Ngalpan Mab nursery. TSRA Rangers took measurements of the well dimensions and installed dataloggers near the base of the well (Table 2). All measurements were taken from the top of the well casing. Measurements were then converted to depth below ground level (bgl). Rangers commented that the well containd "*bit dirty water*". No logger data was returned for this well as the two loggers which were assigned to this well malfunctioned.

Table 2: Dimensions of Warraber's MGNM Well measured by TSRA Rangers at time of groundwater quality program establishment and calculated depths below ground level (bgl).

Parameter	*Value*
Total depth (m)	3.73
Casing height (m)	0.65
Well diameter (inner) (m)	1.75
Water depth (m)	3.19
Well depth (m bgl)	3.08
Water depth (m bgl)	2.54
Depth logger depth (m bgl)	3.73
Cond logger depth (m bgl)	3.65

Figure 18: Meriba Ged Ngalpan Mab Well at Warraber

Saibai: Buthu May Well

Buthu May well is a traditional hand dug well (Figure 19). As this is an 'undeveloped' well, there is no infrastructure to tether the dataloggers to. The rangers improvised and attached the logger to base of star picket driven into the well. Well dimensions were measured in the field but were not saved on the fulcrum form (Table 3).

Table 3: Dimensions of Saibai's Buthu May Well measured by TSRA Rangers at time of groundwater quality program establishment and calculated depths below ground level (bgl). *Note: Casing height measured as top of star picket to water surface.

Parameter	*Value*
Total depth (m)	-
Casing height* (m)	1.48
Well diameter (inner) (m)	11.50
Water depth (m)	0.14
Well depth (m bgl)	-
Water depth (m bgl)	-
Depth logger depth (m bgl)	-
Cond logger depth (m bgl)	-

Figure 19: Buthu May Well on Saibai Island is a traditional hand dug well which historically supplied water to nearby community gardens.

Logger data downloaded from this well covered the period from 25/11/2019 to 19/04/2021 (Figure 20). There was an extra period of data collected from 22/11/2021 to 25/05/2022 (Figure A 2). The logger data for this well was difficult to interpret as it is evident that the depth logger was not positioned consistently throughout the year. Temperature data indicates that the logger may have been moved out of the water for the duration of the periods 26/11/2019 to 10/01/2020 and 30/10/2020 to 03/02/2021. The daily temperature range is high during those periods as the logger was exposed to air and hence recorded ambient air temperature for that period. There were numerous sharp 'breaks' in the water depth which indicate that the logger was interfered with and moved on 14/01/2020, 13/08/2020, 01/09/2020, 01/10/2020, 30/10/2020, 04/02/2021, and 28/02/2021. The electrical conductivity logger initially recorded values in the range of 800 µS cm^{-1} in early December 2019 and ranged from approximately 700 to 200 µS cm^{-1} from February to April 2021. Conductivity reduced slightly during the November 2021 to May 2022 logging period, with values ranging from 500 to 200 µS, with the logger again being removed from the water several times during April 2022 (Figure A 2). Conductivity values less than 1500 µS cm^{-1} are considered freshwater.

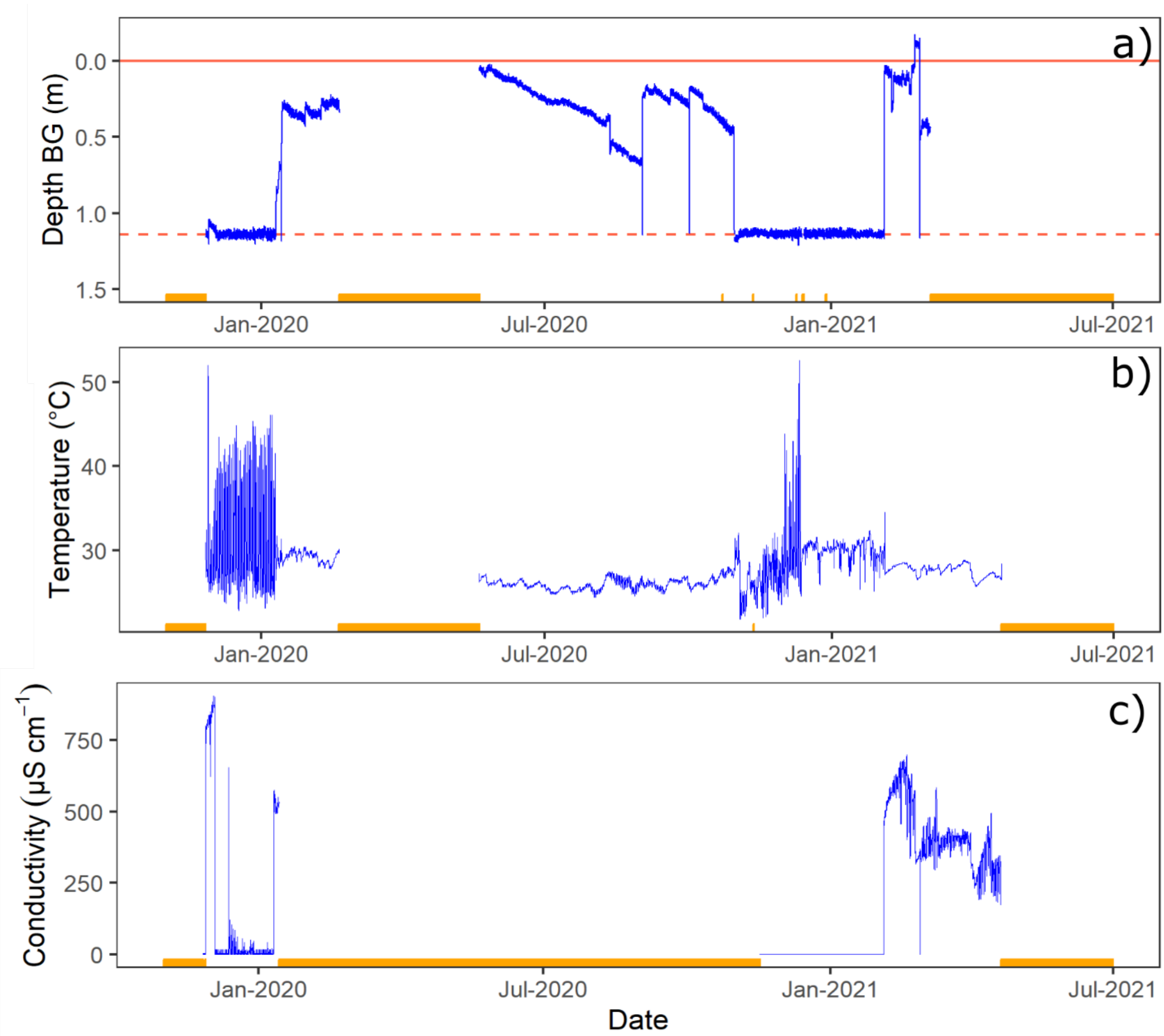

Figure 20: Data recorded by submerged dataloggers at Saibai Island's Buthu May Well. a) water depth below ground level. The red horizontal line at 0 m indicates ground level, red dashed line represents the bottom of the well. b) water temperature, and c) Electrical conductivity. Conductivity values are reported in micro Siemens per centimetre (µS cm^{-1}). The orange strip at the bottom of each panel indicates periods of missing data.

St Paul's: Kurrsarr Well

Kurrsarr well was established as a sampling site in November 2019 (Figure 21). The well is located nearby to the historical community garden and adjacent to a traditional hand dug well but is now in disuse. The well was near empty at the time of establisment, with the water depth measured to be 1.97 m below ground (Table 4).

Table 4: Dimensions of St Paul's Kurrsarr Well measured by TSRA Rangers at time of groundwater quality program establishment and calculated depths below ground level (bgl).

Parameter	*Value*
Total depth (m)	2.85
Casing height (m)	0.63
Well diameter (inner) (m)	1.20
Water depth (m)	2.60
Well depth (m bgl)	2.22
Water depth (m bgl)	1.97
Depth logger depth (m bgl)	2.85
Cond logger depth (m bgl)	NR

Logger data downloaded from this well covered the period from 29/11/2019 to 16/02/2021 (Figure 22). There was also an extra period of data collected between 13/12/2021 and 26/05/2022 (Figure A 3). Depth logger data indicates that the well commenced filling for the wet season in February 2020 (02/02/2020) and was full two weeks later (14/02/2020) (Figure 22a). Following this there was a period from March to May 2020 when the loggers indicated that the water depth was above ground level. This seems unlikely and possibly an artefact of incorrect measurement of the well's total depth or the installed position of the logger, or the logger itself has been moved at some time over the course of deployment. This period could be interpreted with caution as the well being 'full'. The date recording ended on 21/04/2020 and recommenced on 25/09/2020. Depth logger indicated that the well dried out completley in November 2020 this is supported by the temperature logger, which shows high daily variability in temperature over that period as would be expected with the logger being out of water. The well commenced filling again in mid-December 2020 (16/12/2020). The logger ceased to record data on 16/02/2021 with no further data collected until December 2021, when the well again appeared to be full (Figure A 3). It appears that there is significant between-year variability in the timing of aquifer recharge at Kurrsarr Well, with the aquifer filling comparitively late in the 2019-2020 wet season (recharge commenced February 2020), and towards the start of the 2020-2021 wet season (recharge commenced mid-December 2020).

Figure 21: St Paul's Kurrsarr Well is a concrete lined circular well located adjacent to the community gardens. The well has a total depth of 2.22 m bgl.

Groundwater temperature measured in the well was fairly stable, with water temperature generally between 27 and 28 °C for the 2019-2020 wet season (Figure 22b). The temperature logger appears to have been out of water for the November to mid-December 2020 period coinciding with when the depth logger indicated the well was dry, hence measurements recorded during that period were of ambient air temperature within the well rather than groundwater temprature. Water temeterature was in the range of 27 to 28 °C for the mid-December 2020 to mid-February 2021 period. There was not data recorded beyond when the logger stopped recording data on 16/02/2021.

The electrical conductivity logger recorded measurements over the 2019-2020 wet season, but did not return any data for the 2020-2021 dry and wet seasons (Figure 22c). Electrical conductivity of groundwater in Kurrsarr Well ranged from 240 to 840 µS cm^{-1}, indicating that the aquifer contained freshwater. The February 2020 filling event coincided with a spike in electrical conductivity of 840 µS cm^{-1} measured in the well on 06/02/2020, likely from where salts from the surrounding soil profile were flushed through the well. The near-zero conductivity readings between 20/12/2019 and 13/01/2020 were probably due to the conductivity logger sensor measuring in air above the water during this period. There was no conductivity recorded after April 2020.

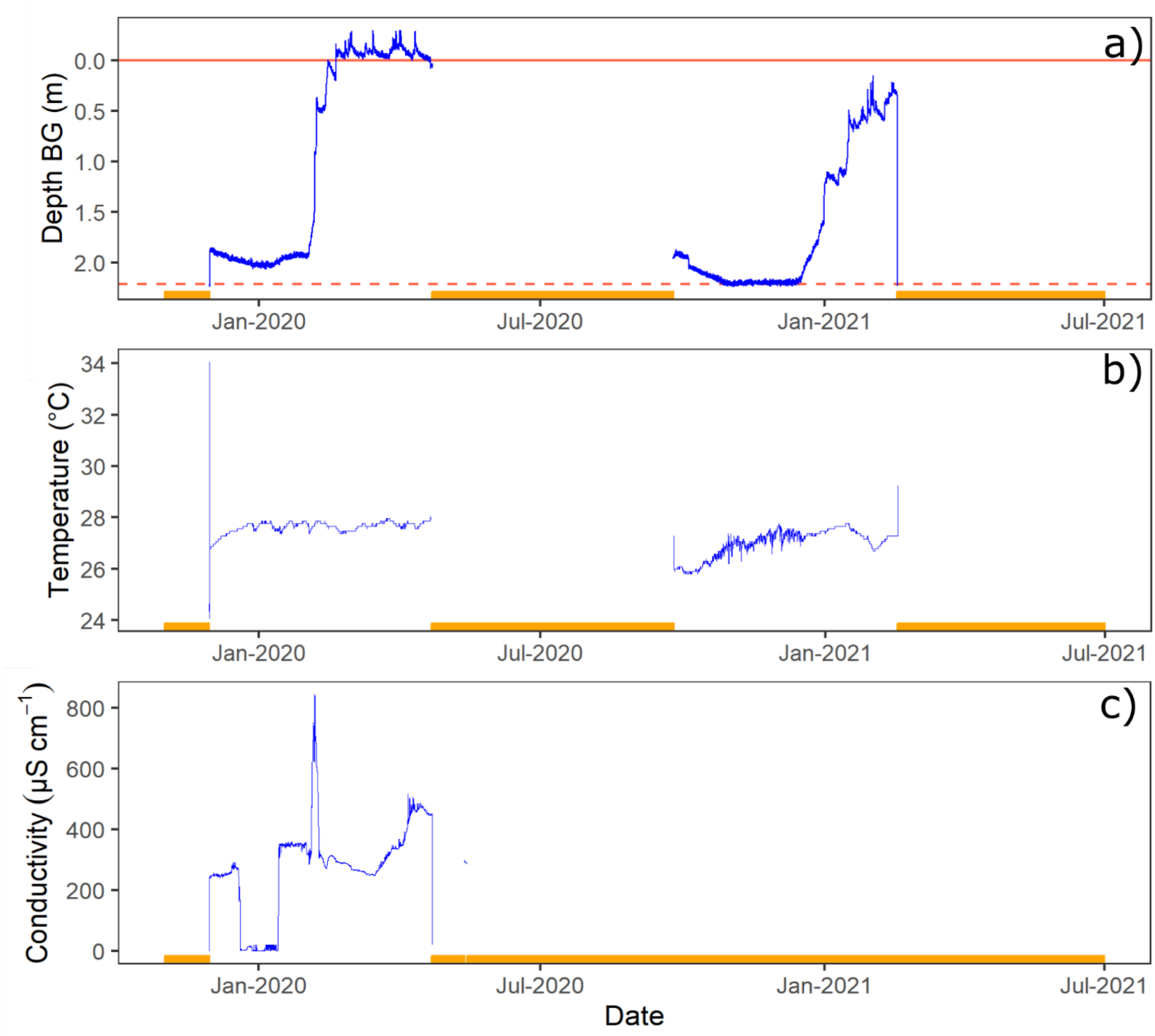

Figure 22: Data recorded by submerged dataloggers at St Paul's Kurrsarr Well. a) water depth below ground level. The red horizontal line at 0 m indicates ground level, red dashed line represents the bottom of the well. b) water temperature, and c) Electrical conductivity. Conductivity values are reported in microsiemens per centimeter (μS cm^{-1}). The orange strip at the bottom of each panel indicates periods of missing data.

Masig: Mother's Well

Mother's well was established as a sampling site in December 2020 (Figure 23). Mother's Well is a concrete lined circular well located on Masig Island at the Mothers Well Nursery. The well has an electric pump which is used to extract water for the nursery. The well has a total depth of 6.0 m bgl.

Table 5: Dimensions of Masig's Mother's Well measured by TSRA Rangers at time of groundwater quality program establishment and calculated depths below ground level (bgl).

Parameter	*Value*
Total depth (m)	6.50
Casing height (m)	0.50
Well diameter (inner) (m)	2.03
Water depth (m)	1.30
Well depth (m bgl)	6.00
Water depth (m bgl)	0.80
Depth logger depth (m bgl)	6.00
Cond logger depth (m bgl)	5.70

Figure 23: Mother's Well is a concrete lined circular well located on Masig Island at the Mothers Well Nursery. The well has a total depth of 6.0 m bgl.

The data recoded by submerged dataloggers at Masig Island's Mother's Well is presented in Figure 24. Logger data downloaded from this well covered the period from 06/02/2021 to 18/02/2021. There was no data recovered from the depth logger. A short period of data was recovered from conductivity logger (06/02/2021 to 18/02/2021). The logger initially recorded a conductivity value of approximately 1500 µS cm^{-1} at the start of the deployment then steadily declined to approximately 1200 µS cm^{-1} over the following days. Conductivity values in this range are typical of freshwater. Temperature ranged from 28.5 to 29 °c throughout the period.

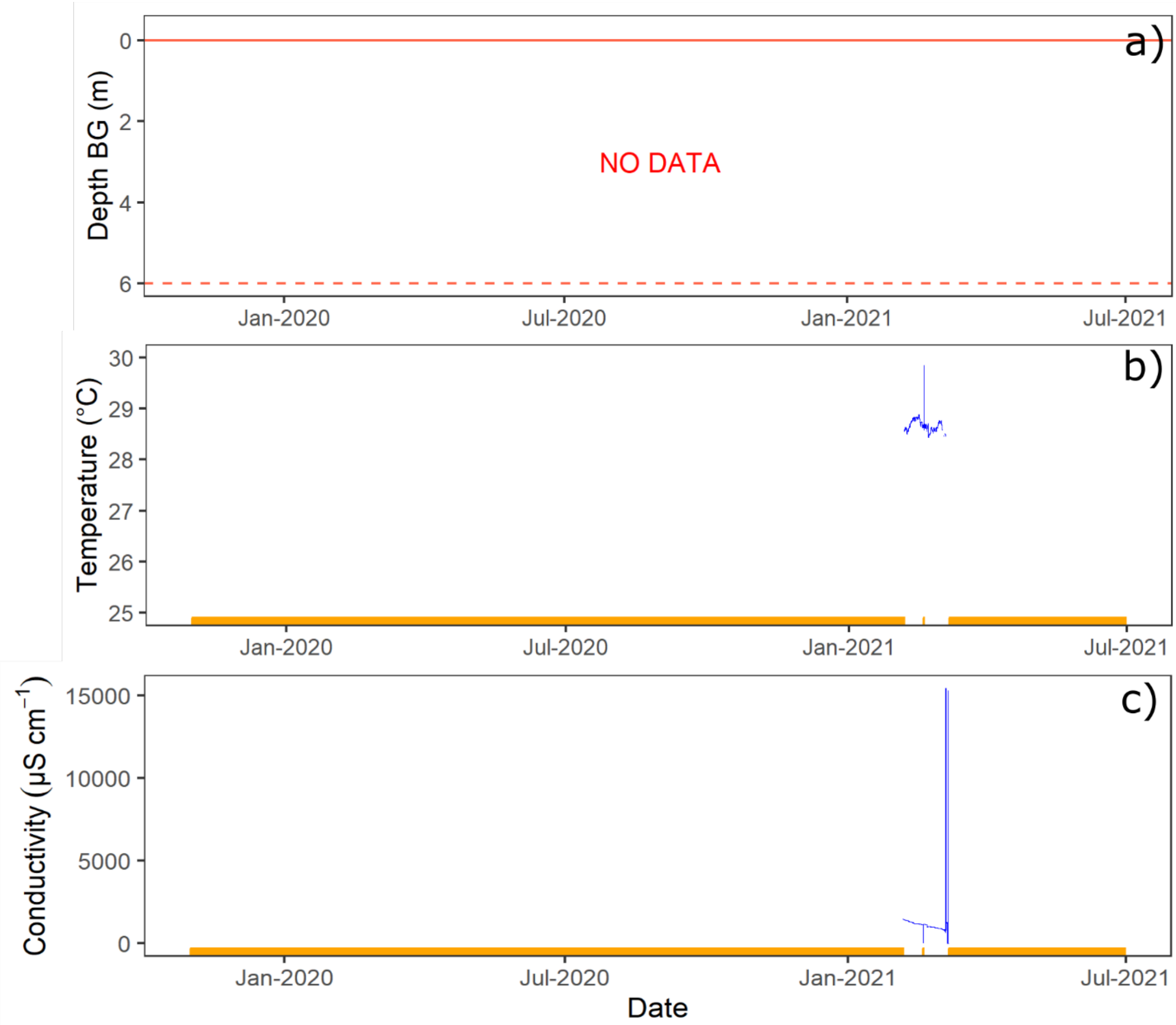

Figure 24: Data recorded by submerged dataloggers at Masig Island's Mother's Well. a) water depth below ground level. The red horizontal line at 0 m indicates ground level, red dashed line represents the bottom of the well. b) water temperature, and c) Electrical conductivity. Conductivity values are reported in microsiemens per centimeter (µS cm^{-1}). The orange strip at the bottom of each panel indicates periods of missing data.

Masig: Thelma Billy Well

Thelma Billy Well was established as a sampling site in December 2020 (Figure 25). The rangers commented on the fulcrum form that "*the water is low and quality is dirty*". Well dimensions were not recorded on the fulcrum form.

Figure 25: Thelma Billy Well is a concrete lined circular well located on Masig Island.

A short period of data was recovered from conductivity logger (09/12/2020 to 02/04/2021) (Figure 26). There was no data recovered from the depth logger. The logger recorded conductivity value of 0 µS cm^{-1} for the first month of deployment, indicating that the logger was most probably positioned above water. The conductivity sensor began showing sporadic values from 10/01/2021, and likely coincides with the aquifer filling. The conductivity sensor began to show 'real' data from 25/01/2021 in the range of 1500 to 1800 µS cm^{-1}. Conductivity values in this range are indicative of freshwater with slightly elevated salts. The temperature sensor also showed patterns typical of the sensor being exposed to air, with larger daily range than expected when submerged. Temperature stabilized from 25/01/2021 and showed groundwater temperature to be in the range of 29.5 to 30.2 °C.

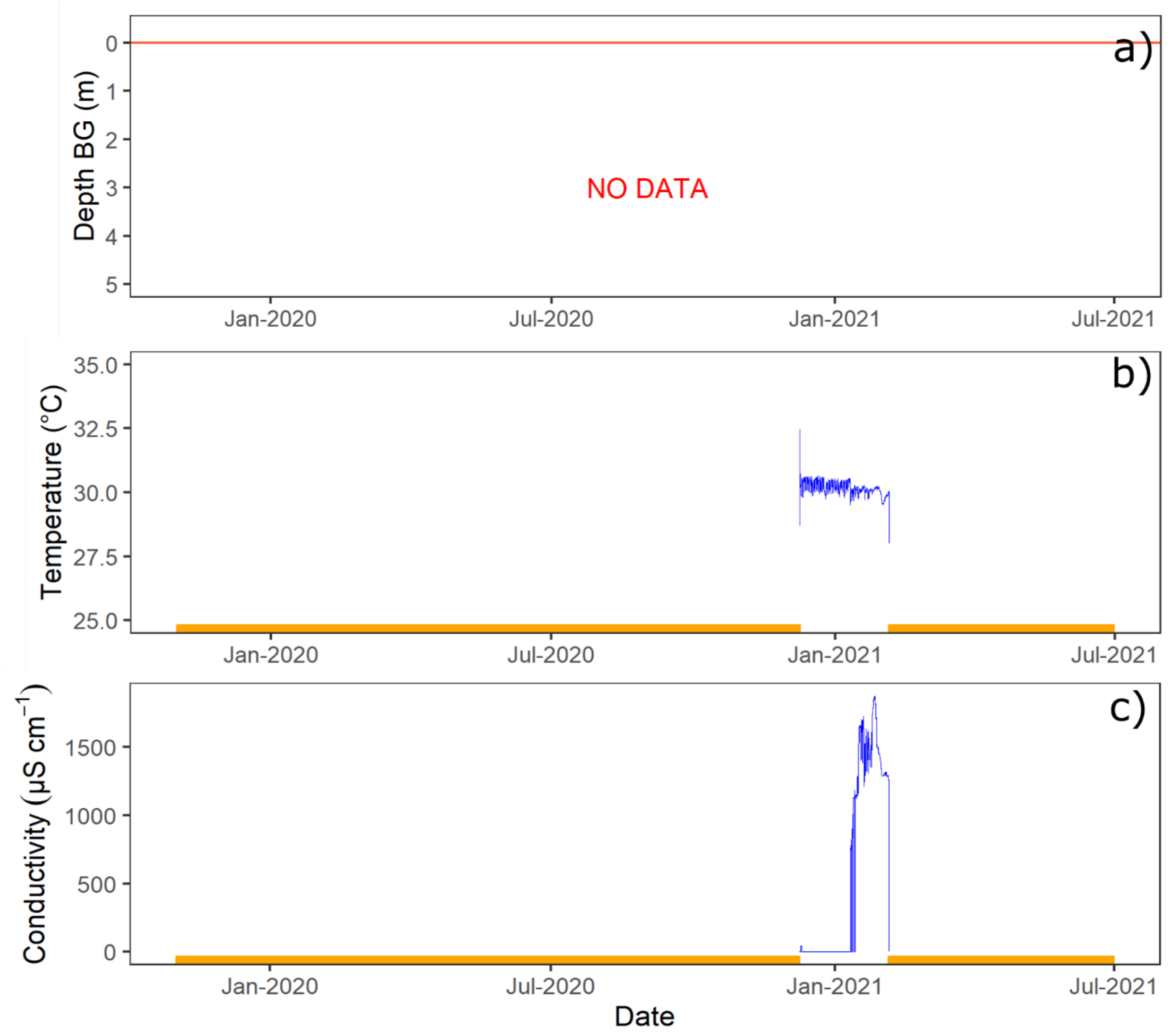

Figure 26: Data recorded by submerged dataloggers at Masig Island's Thelma Billy Well. a) water depth below ground level. The red horizontal line at 0 m indicates ground level. b) water temperature, and c) Electrical conductivity. Conductivity values are reported in microsiemens per centimeter (µS cm^{-1}). The orange strip at the bottom of each panel indicates periods of missing data.

Water chemistry

Anions and cations

Water samples were sorted into hydrochemical facies using a Piper diagram (Figure 27).

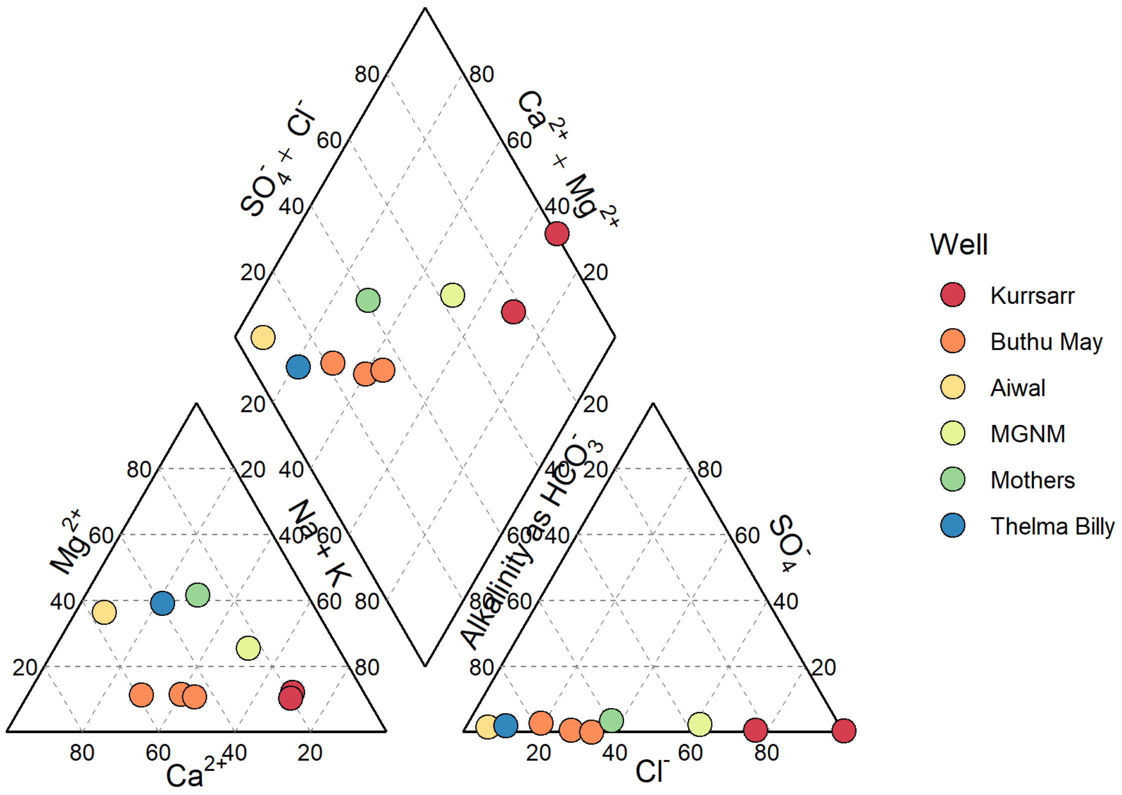

Figure 27: Piper diagram representing the major dissolved constituents (major cations and anions) of groundwater in Torres Strait Island wells. The dominant cation and anion fields are shown in the lower triangles and Hydrochemical Facies in the upper diamond

There is evidence of saltwater intrusion at the Kurrsarr Well (St Pauls) and MGNM Well (Warraber), with these wells falling into the sodium chloride type waters class that are typical of marine and deep ancient ground water. Groundwater from wells located on Warraber (Aiwal Well), Saibai (Buthu May Well), and Masig (Thelma Billy & Mothers Well) were classed as calcium/magnesium bicarbonate type waters which are typical of shallow fresh ground water.

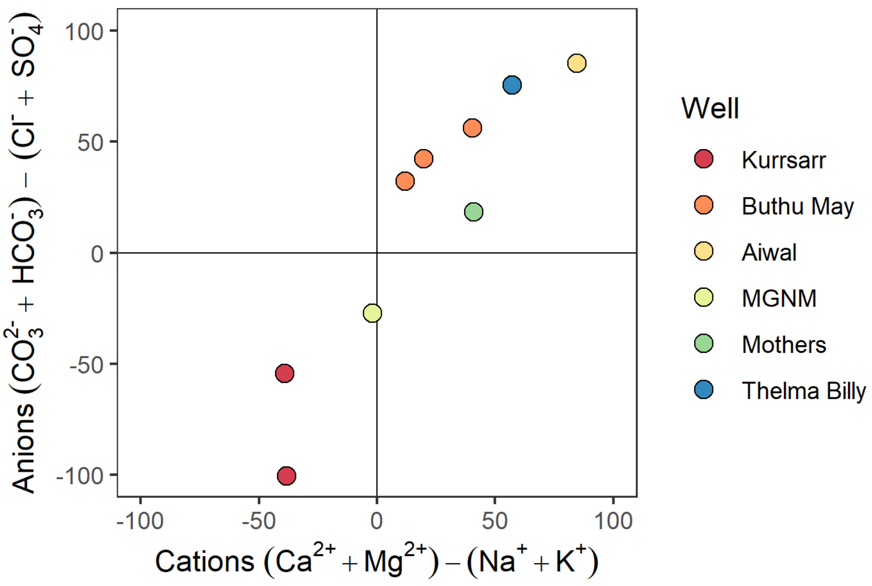

Figure 28: Chadha diagram of water collected from groundwater wells. The x-axis shows the difference in milliequivalent percentages between alkaline earths (calcium and magnesium) and alkali metals (sodium and potassium). The y-axis shows the difference between weak acidic anions (carbonate and bicarbonate) and strong acidic anions (chloride and sulphate).

A Chadha diagram was prepared to further classification of well water based on its hydrochemistry (Figure 28).

The waters collected from Kurrsarr Well are plotted in the bottom-left quadrant of the diagram indicating they contain alkali metals exceeding alkaline earths and strong acidic anions exceeding weak acidic anions. Waters falling into this category create salinity problems for both irrigation and drinking (Chadha, 1999).

Waters from MGNM (Warraber Islet) display strong acidic anions exceeding weak acidic anions and are borderline alkali metals exceeding alkaline earths, indicating that this groundwater source may display permanent hardness and be unsuitable for domestic use.

The remainder of the wells fell into the category indicating that alkaline earths and weak acidic anions exceed both alkali metals and strong acidic anions, respectively. According to Chadha (1999), such water has only temporary hardness that can be removed by boiling, with the carbonates precipitating out.

Nutrients

Nutrient concentrations in the six groundwater wells were mostly below Australian Drinking Water Guideline values, apart from ammonia levels at Buthu May well in 2019 (Table 6).

Table 6: Total Phosphorus (TP), Total Nitrogen (TN), Total Oxidised Nitrogen (NOx), Orthophosphate (PO4), Ammonia, Nitrite, and Nitrate at six wells in the Torres Strait Islands. Highlighted cells indicate values above Australian Drinking Water Guidelines.

Location		Date	TP	TN	TON	OP	Ammonia	Nitrite	Nitrate
			(mg L^{-1})	(mg L^{-1})	(mg L^{-1})	(mg L^{-1})	(mg L^{-1})	(mg L^{-1})	(mg L^{-1})
Masig									
	Mother's	9/12/2020	<0.05	0.18	0.07	0.03	<0.02	<0.01	0.07
	Thelma Billy	9/12/2020	0.19	28	27	<0.01	<0.02	0.09	27
Saibai									
	Buthu May	27/11/2019	0.09	2.9	0.05	<0.01	0.83	<0.01	0.05
	Buthu May	24/07/2020	0.05	0.88	<0.01	0.01	<0.02	0.01	<0.01
	Buthu May	3/06/2021	<0.05	0.59	0.02	0.01	0.02	0.01	0.01
	Buthu May	1/12/2021	0.06	1.4	0.01	<0.01	<0.02	<0.01	0.01
St Paul									
	Kurrsarr	29/11/2019	0.08	0.77	0.01	0.03	0.34	<0.01	0.01
	Kurrsarr	3/09/2020	<0.05	0.31	<0.01	<0.01	<0.02	<0.01	<0.01
	Kurrsarr	14/12/2021	0.05	0.56	<0.01	0.01	0.06	<0.01	<0.01
Warraber									
	Aiwal	12/11/2020	0.09	0.24	0.16	0.09	<0.02	<0.01	0.15
	MGNM	12/11/2020	<0.05	0.1	0.03	0.01	<0.02	0.01	0.03
	MGNM	3/11/2021	<0.05	0.28	0.16	0.02	<0.02	0.01	0.15
	Aiwal	2/12/2021	0.07	0.23	0.13	0.06	<0.02	<0.01	0.13

Biological

Results of biological counts are reported in Table 7. Buthu May Well at Saibai Island exceeded health guideline values for E. Coli. Kurrsarr Well at St Paul's exceeded health guideline values for E. Coli. Aiwal Well and MGNM Well at Warraber exceeded health guideline values for E. Coli.

Turbidity

Turbidity levels recorded in nephelometric turbidity units (NTU) are displayed in Table 7. Turbidity levels at Buthu May and Thelma Billy bores exceeded aesthetic guideline values for groundwater.

Table 7: E.coli and Total coliforms in groundwater from six wells on four Torres Strait Islands. Highlighted cells indicate levels regarded as medium risk under Australian Guideline Standards for Drinking Water. NR = not reported

Location		Date	E. coli (CFU/100 mL)	Total coliforms (CFU/100 mL)	Turbidity (NTU)
Masig					
	Mother's	9/12/2020	NR	NR	0.2
	Thelma Billy	9/12/2020	NR	NR	150
Saibai					
	Buthu May	27/11/2019	est 30	94000	28
	Buthu May	24/07/2020	240	>10000	5.9
	Buthu May	3/06/2021	est 50	3300	5.4
	Butha May	1/12/2021	est 10	15000	NR
St Paul					
	Kurrsarr	29/11/2019	<10	5000	3.1
	Kurrsarr	3/09/2020	<10	17000	2.6
	Kurrsarr	14/12/2021	est 10	1600	NR
Warraber					
	Aiwal	12/11/2020	est 70	12000	0.2
	MGNM	12/11/2020	est 10	8000	0.7
	MGNM	19/11/2021	16	8800	NR
	Aiwal	1/12/2021	240	2600	NR

Hydrocarbons
There were no hydrocarbons above the limit of detection in any of the water samples analysed.

Pesticides
The pesticides dimethoate and malathion were detected at Saibai Buthu May Well in June 2021. The concentration of each pesticide did not exceed the health guideline value of 0.007 mg L^{-1} for dimethoate and 0.07 mg L^{-1} for malathion. Australian drinking water guideline factsheets for dimethoate and malathion have been included in appendix A.. Dimethoate and malathion are insecticides found in commercial products to treat for sucking insects such as fruit flies, mites, fleas, and ticks. These chemicals may have entered the well via spray drift or leaching into groundwater from neighboring gardens. A list of products containing dimethoate and malathion is included in appendix A.3.

Herbicides
No herbicides were detected above the limits of detection in any of the groundwater samples.

PFOS
There were no perfluoroalkyl or polyfluoroalkyl substances detected in any of the groundwater wells

Metals
There were some metals found above Australian Drinking Water Guideline Values These included iron and aluminium at Buthu May Well and arsenic at Kurrsarr Well (Table 8).

Table 8: Metals found in groundwater at four Torres Strait Island Wells. Highlights indicate levels above Australian Guideline Standards for Drinking Water (NHMRC 2011; https://www.nhmrc.gov.au/sites/default/files/documents/reports/aust-drinking-water-guidelines.pdf)

Location	Well	Date	Al (diss)	Sb (diss)	As (diss)	Ba (diss)	Be (diss)	Bo (diss)	Cd (diss)	Cr (diss)	Co (diss)	Cu (diss)	Fe (diss)	Pb (diss)	Mn (diss)
			mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Masig															
	Mother's	9/12/2020	<0.015	<0.001	0.0011	0.002	<0.0001	0.139	<0.0001	<0.0005	<0.0005	<0.001	<0.015	<0.0005	0.0005
	Thelma Billy	9/12/2020	<0.015	<0.001	0.0019	0.008	<0.0001	0.12	<0.0001	0.0007	<0.0005	0.001	<0.015	<0.0005	0.0006
Saibai															
	Buthu May	3/06/2021	0.02	<0.001	0.0019	0.008	<0.0001	0.063	<0.0001	<0.0005	<0.0005	0.001	1.56	<0.0005	0.0139
	Buthu May	27/11/2019	<0.015	<0.001	0.0042	0.028	<0.0001	0.178	<0.0001	0.0006	<0.0005	<0.001	0.187	<0.0005	0.0476
	Buthu May	24/07/2020	0.036	<0.001	0.0013	0.008	<0.0001	0.102	<0.0001	0.0007	<0.0005	0.002	0.48	<0.0005	0.0027
St Paul															
	Kurrsarr	29/11/2019	0.034	<0.001	0.013	0.03	<0.0001	<0.05	<0.0001	0.0023	<0.0005	0.001	0.17	<0.0005	0.0063
	Kurrsarr	3/09/2020	0.081	<0.001	0.0019	0.042	<0.0001	<0.05	<0.0001	0.0004	<0.0005	<0.001	0.785	<0.0005	0.0471
Warraber															
	Aiwal	12/11/2020	<0.015	<0.001	0.0025	0.013	<0.0001	<0.05	<0.0001	0.0005	<0.0005	0.001	<0.008	<0.0005	0.0004
	MGNM	12/11/2020	<0.015	<0.001	0.0026	0.003	<0.0001	0.187	<0.0001	<0.0002	<0.0005	<0.001	0.014	<0.0005	0.0021

Location	Well	Date	Mo (diss)	Ni (diss)	Se (diss)	Ag (diss)	Tl (diss)	Th (diss)	Sn (diss)	Ti (diss)	Ur (diss)	Va (diss)	Zn (diss)	Hg (Diss)	Hg
			mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	µg/L	µg/L
Masig															
	Mother's	9/12/2020	0.0016	<0.0005	<0.002	<0.0002	<0.0005	<0.002	<0.001	<0.001	0.0008	0.004	<0.008	<0.06	<0.06
	Thelma Billy	9/12/2020	0.0007	<0.0005	<0.002	<0.0002	<0.0005	<0.002	<0.001	<0.001	0.0021	0.0034	<0.008	<0.06	<0.06
Saibai															
	Buthu May	3/06/2021	0.0007	<0.0005	<0.002	<0.0002	<0.0005	<0.002	<0.001	<0.001	0.0001	0.0006	0.034	<0.06	<0.06
	Buthu May	27/11/2019	0.0014	<0.0005	<0.002	<0.0002	<0.0005	<0.002	<0.001	<0.001	0.0005	0.0009	0.116	<0.06	<0.06
	Buthu May	24/07/2020	0.0018	0.0005	<0.002	<0.0002	<0.0005	<0.002	<0.001	<0.001	0.0007	0.001	<0.008	<0.06	<0.06
St Paul															
	Kurrsarr	29/11/2019	<0.0005	<0.0005	<0.002	<0.0002	<0.0005	<0.002	<0.001	<0.001	0.0001	0.0001	0.114	<0.06	<0.06
	Kurrsarr	3/09/2020	<0.0005	<0.0005	<0.002	<0.0002	<0.0005	<0.002	<0.001	<0.001	0.0001	0.0001	0.021	<0.06	<0.06
Warraber															
	Aiwal	12/11/2020	<0.0005	<0.0005	<0.002	<0.0002	<0.0005	<0.002	<0.001	<0.001	0.0008	0.0011	0.032	<0.06	<0.06
	MGNM	12/11/2020	0.0013	0.0026	<0.002	<0.0002	<0.0005	<0.002	<0.001	<0.001	0.0013	0.0006	<0.008	<0.06	<0.06

Location	Well	Date	Al	Sb	As	Ba	Be	Bo	Cd	Cr	Co	Cu	Fe	Pb	Mn
			mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Masig															
	Mother's	9/12/2020	<0.015	<0.001	0.0011	0.002	<0.0001	0.147	<0.0001	<0.0005	<0.0005	<0.001	<0.015	<0.0005	0.0006
	Thelma Billy	9/12/2020	0.14	<0.002	0.0023	0.011	<0.0002	0.117	<0.0002	0.0028	<0.001	0.002	0.118	<0.001	0.0143
Saibai															
	Buthu May	3/06/2021	<0.03	<0.002	0.0021	0.008	<0.0002	<0.1	<0.0002	<0.001	<0.001	0.024	2.11	<0.001	0.0171
	Buthu May	27/11/2019	0.2	<0.001	0.0057	0.03	<0.0001	0.179	<0.0001	0.0011	<0.0005	0.001	3.25	0.0006	0.052
	Buthu May	24/07/2020	0.868	<0.001	0.0029	0.012	0.0001	0.111	<0.0001	0.0029	<0.0005	0.002	2.41	0.0016	0.0086
St Paul															
	Kurrsarr	29/11/2019	0.069	<0.001	0.0142	0.031	<0.0001	<0.05	<0.0001	0.0027	<0.0005	0.001	0.54	<0.0005	0.0244
	Kurrsarr	3/09/2020	0.085	<0.001	0.0019	0.04	<0.0001	<0.05	<0.0001	0.0004	<0.0005	<0.001	0.776	<0.0005	0.0464
Warraber															
	Aiwal	12/11/2020	<0.015	<0.001	0.0026	0.013	<0.0001	<0.05	<0.0001	0.0005	<0.0005	0.001	<0.015	<0.0005	0.0006
	MGNM	12/11/2020	<0.015	<0.001	0.003	0.003	<0.0001	0.184	<0.0001	0.0057	<0.0005	0.001	0.115	<0.0005	0.0033

Location	Well	Date	Mo	Ni	Se	Ag	Tl	Th	Sn	Ti	Ur	Va	Zn
			mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Masig													
	Mother's	9/12/2020	0.0016	<0.0005	<0.002	<0.0002	<0.0005	<0.002	<0.001	<0.001	0.0009	0.0042	0.008
	Thelma Billy	9/12/2020	<0.001	<0.001	<0.004	<0.0004	<0.001	<0.004	<0.002	<0.002	0.0025	0.0038	<0.016
Saibai													
	Buthu May	3/06/2021	<0.001	<0.001	<0.004	<0.0004	<0.001	<0.004	<0.002	<0.002	<0.0002	0.0007	<0.016
	Buthu May	27/11/2019	0.0013	0.0005	<0.002	<0.0002	<0.0005	<0.002	<0.001	0.002	0.0006	0.0026	0.083
	Buthu May	24/07/2020	0.0011	0.0007	<0.002	<0.0002	<0.0005	<0.002	<0.001	0.004	0.0011	0.0057	0.012
St Paul													
	Kurrsarr	29/11/2019	<0.0005	<0.0005	<0.002	<0.0002	<0.0005	<0.002	<0.001	0.001	0.0001	0.0002	0.169
	Kurrsarr	3/09/2020	<0.0005	<0.0005	<0.002	<0.0002	<0.0005	<0.002	<0.001	<0.001	0.0001	0.0001	0.024
Warraber													
	Aiwal	12/11/2020	<0.0005	<0.0005	<0.002	<0.0002	<0.0005	<0.002	<0.001	<0.001	0.0006	0.0012	0.033
	MGNM	12/11/2020	0.0014	0.0031	<0.002	<0.0002	<0.0005	<0.002	<0.001	<0.001	0.0013	0.0008	0.009

4 DISCUSSION

The Torres Strait Groundwater Monitoring program has been a collaboration between the Torres Strait Regional Authority and scientists from James Cook University's Centre for Tropical Water and Aquatic Ecosystem Research (TropWATER). The program has determined that overall, the water in the groundwater wells is fresh and suitable for domestic and irrigation use. However, there were some instances where wells exceeded Australian drinking water health and aesthetic guidelines for metals, nutrients, turbidity, and pesticides, as well as E.coli. There was also evidence of potential seawater incursion in some wells.

Hydrochemical facies analysis indicated that there is evidence of seawater intrusion to Kurrsarr Well on St Paul's Island and Meriba Ged Ngalpan Mab Well (MGNM) on Warraber Islet. There is also potential for seawater intrusion at Saibai Buthu May Well and Masig Mothers Well. The extent of seawater intrusion should be closely monitored.

Kurrsarr Well at St Paul's exceeded guideline values for arsenic in November 2019 with levels of 14.2 µg L^{-1} , almost 50% above safe levels for drinking water (Table 8). Arsenic (As) in groundwater can be a natural occurrence or can come from industrial sources such as fertilisers and pesticides. The most common symptoms resulting from drinking As-contaminated well water include respiratory problems, skin lesions, hyperkeratosis (calloused palms and heels) and hyperpigmentation (Shahid et al., 2009), however serious effects including cancer, particularly lung cancer (Celik et al., 2006; D'Ippoliti et al., 2015) and skin cancer (Karagas et al., 2015) have been widely reported with long term exposure. Further, it is known that As-contaminated groundwater that is used for crop irrigation also forms a human health hazard as the substance accumulates in soils and plants over time (Brammer and Ravenscroft, 2009).
While the Torres Strait Island Regional Council has a Drinking Water Quality Management Plan that includes 6-monthly sampling for a range of contaminants, the annual reports indicate that testing for arsenic is not conducted (TSIRC). The concentration of arsenic at Kurrsarr Well was back within health guideline values at the following sampling occasion in September 2020 (Table 8) and it is recommended that regular testing for this groundwater contaminant is performed and filtration systems that remove arsenic are used.

The Buthu May Well on Saibai is a hand dug well without a casing, making it more susceptible to contamination from surface run-off (Figure 19). The well, which has traditionally been used for irrigation, did contain the pesticides Dimethoate and Malathion, as well as exceeding aesthetic values for aluminium on one sampling occasion, and aesthetic values for iron on all sampling occasions. Iron levels at the Buthu May Well were consistently 7 to 10 times greater than the aesthetic guideline value for drinking water. Iron is widely considered to be safe in elevated amounts, and while there is a known association between iron accumulation and Parkinson's Disease, a causative link is yet to be established (Mochizuki and Yasuda, 2020). The main concern with iron in groundwater is the increased growth of bacteria that forms slimy coatings in water pipes as well as severe staining that leads to negative perceptions of groundwater within communities (Demlie et al., 2014). Likewise with aluminium (Al), there is uncertainty surrounding the human health data, mostly due to the many confounding factors controlling aluminium absorption and toxicity, and only an aesthetic guideline for Al concentration exists. Despite this, the WHO (1997) acknowledges the positive relationship between aluminium intake and Alzheimer's disease and recommends taking action to reduce concentrations in drinking water to below 0.1 mg L^{-1}. The concentration at Buthu May Well in July 2020 was more than 8 times this guideline value (Table 8).

E.coli was found in several water samples. Buthu May Well exceeded health guideline values for E.coli in all years (2019-2021) and exceeded heath guidelines for ammonia in 2021, indicating potential fecal contamination. Both wells on Warraber Islet (Aiwal Well and MGNM Well) also exceeded health guidelines for E.coli on multiple sampling occasions in 2020 and 2021, with Aiwal Well testing in the 'high risk' level, at more than 20 times the safe amount. It is important that precautions are taken to protect the community from consuming this water untreated.

While there have been some clear results for determining the quality of groundwater in the wells of Saibai, Warraber, St Paul's and Masig Island, there were some problems with the logger deployments that could potentially be addressed with increased training of the Torres Strait Island Rangers and education within the Torres Strait communities. Here we propose several recommendations for improving the outcomes of a Torres Strait Island Groundwater Monitoring Program going forward.

Recommendations

- Consider engaging in the process of producing a groundwater quality management plan for Torres Strait Island communities following the Water Quality Australia 'Guidelines for groundwater protection in Australia: National Water Quality Management Strategy' as a combined venture with Torres Strait Regional Authority, Torres Strait Island Regional council, and James Cook University.
- Provide increased frequency of training to Rangers and engage in community education programs to improve the 'citizen science' outcomes of the program.
- Repeat metals analysis and monitor for arsenic contamination, particularly at Kurrsarr Well, and for aluminium contamination at Buthu May Well.
- Include electrical conductivity as a parameter in future water sample collection and analysis as a backup in the case of conductivity logger data loss.
- Improvements to how loggers are deployed.
    - Attach loggers to a semi-permanent structure with known depth. This will also help to avoid interference form curious people. improves accuracy of the depth measurement.
    - Paired pressure/depth loggers (1 underwater and 1 atmosphere) – one atmospheric logger per island is sufficient if there are multiple wells. Having paired pressure sensors improves the precision of the depth calculation.
    - Ensure loggers are working correctly prior to deployment and leave loggers deployed for 6-month periods before data is retrieved.
- Document where all wells are located, their character (type, location, size, use, custodian, history), and:
    - Expand water sampling to additional wells in each community.
    - Collect water samples, well dimension and water depth measurements only in new wells. No need for data loggers in all wells.
    - Investigate the potential for building new wells.

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A APPENDICES

A.1 Australian drinking water guideline factsheets for dimethoate and malathion

PHYSICAL AND CHEMICAL CHARACTERISTICS –
FACT SHEETS

Dimethoate

(endorsed 2011)

GUIDELINE

Based on human health concerns, dimethoate in drinking water should not exceed 0.007 mg/L.

RELATED CHEMICALS

Dimethoate (CAS 60-51-5) belongs to the organophosphate class of chemicals. There are many other pesticides in this class, which includes acephate, chlorpyrifos, diazinon, dichlorvos, fenitrothion, omethoate, profenofos and trichlorfon (Tomlin 2006).

HUMAN RISK STATEMENT

With good water quality management practices, the exposure of the general population is expected to be well below levels that may cause health concerns.

If present in drinking water as a result of a spillage or through misuse, dimethoate would not be a health concern unless the concentration exceeded 0.007 mg/L. Excursions above this level even for a short period are of concern, as the health-based guideline is based on short-term effects.

With good water quality management practices, pesticides should not be detected in source waters used for drinking water supplies. Persistent detection of pesticides may indicate inappropriate use or accidental spillage, and investigation is required in line with established procedures in the risk management plan for the particular water source.

GENERAL DESCRIPTION

Uses: Dimethoate is a broad use systemic insecticide and acaricide (miticide) for the control of insects and mites in the home garden and in agricultural crops.

There are registered products that contain dimethoate in Australia. These products are intended for professional and/or home garden use and are available in aerosol formulation or concentrated solutions. Agricultural products for professional use are intended for application as a dilute or concentrated spray using hand-held, ground boom, mist machine or aerial spray equipment, or application as a diluted seed dressing or concentrated pre-planting or post-harvest dip. Home garden products are intended for application as an aerosol spray or concentrated spray using hand-held equipment. Data on currently registered products are available from the Australian Pesticides and Veterinary Medicines Authority.

Exposure sources: The main sources of public exposure to dimethoate are the use of home garden products and residues in food. Omethoate is an environmental degradant of dimethoate and thus the residue definition for dimethoate is "sum of dimethoate and omethoate, expressed as dimethoate". Residue levels of dimethoate and omethoate in food produced according to good agricultural practice are generally low.

Agricultural use of dimethoate may potentially lead to contamination of source waters through processes such as run-off, spray drift or entry into groundwater.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

No data on the occurrence of dimethoate in Australian waters could be found. In Canadian waters, dimethoate was not detected in drinking water (<0.6 µg/L) or in surface waters (<0.5 µg/L) (Health Canada 1986). The United States Environmental Protection Agency predicted surface water concentration after application is 0.44 to 33.4 µg/L, depending on use pattern (USEPA 2008).

TREATMENT OF DRINKING WATER

Dimethoate appears to be very well removed by chlorination but is likely to be transformed into omethoate in the process (Ormad *et al.* 2008). Activated carbon is partially effective for the removal of dimethoate (Ormad *et al.* 2008).

MEASUREMENT

Dimethoate can be measured by routine gas chromatography–mass spectrometry analysis, with a limit of reporting of 0.1 µg/L (Queensland Health 2007).

HISTORY OF THE HEALTH VALUES

The current acceptable daily intake (ADI) for dimethoate is 0.02 mg per kg of bodyweight (mg/kg bw), based on a no-observed-effect level (NOEL) of 0.2 mg/kg bw/day from a short-term (57-day) human volunteer study. The NOEL is based on cholinesterase inhibition. The ADI incorporates a safety factor of 10 and was established in 1988.

The previous health value was 0.05 mg/L (NHMRC and NRMMC 2004).

HEALTH CONSIDERATIONS

Since omethoate is an environmental degradant of dimethoate, the toxicity of omethoate needs to be considered in the context of the health impact of dimethoate in drinking water. A separate fact sheet is available for omethoate.

Metabolism: Dimethoate is well absorbed via the gastrointestinal tract and distributed rapidly to the tissues, accumulating in the liver and kidneys. It is slowly excreted as metabolites (85-91% of the dose within 5 days), primarily in the urine. The major metabolites were thiophosphate and phosphate esters, and omethoate (1-6%). The parent compound represented 1-2% of the excreted dose.

Acute effects: Dimethoate has moderate acute oral toxicity, and low acute dermal toxicity. It is not a skin sensitiser.

Short-term effects: Short-term dietary studies in rats and dogs reported the main effect to be on the nervous system, with reduced erythrocyte and brain cholinesterase activity from the lowest dose of 2.48 mg/kg bw/day (rats) and 2.2 mg/kg bw/day (dogs). From 40 mg/kg bw/day, severe clinical signs consistent with cholinesterase inhibition were observed. In addition, increased mortality occurred in dogs at high doses.

Short-term (57-day) volunteer studies in humans reported inhibition of cholinesterase in whole blood at doses of 0.4 mg/kg bw/day and above. The NOEL from this study was 0.2 mg/kg bw/day and is the basis for the current ADI.

Long-term effects: Long-term dietary studies in mice, rats and dogs showed the most sensitive effects to be on the nervous system. In mice, erythrocyte cholinesterase inhibition was reported at 3.6 mg/kg bw/day and above. In rats, erythrocyte and brain cholinesterase were inhibited at 0.23 mg/kg bw/day and above. In dogs, brain and erythrocyte cholinesterase were inhibited at 0.125 mg/kg bw/day and above.

At higher dose levels, there were changes in haematological parameters and clinical chemistry, as well as organ weight changes. Clinical neurological signs consistent with cholinesterase inhibition were observed at 50 mg/kg bw/day.

Carcinogenicity: Based on long-term dietary studies in mice, rats and dogs, there was no evidence of carcinogenicity associated with dimethoate.

Genotoxicity: Dimethoate is not considered to be genotoxic, based on *in vitro* and *in vivo* short-term studies.

Reproductive and developmental effects: A two-generation reproduction study in rats and developmental toxicity studies in rats and rabbits did not produce evidence of effects on reproductive parameters or foetal development. A developmental neurotoxicity study in rats reported increased post-natal mortality and cholinesterase inhibition in pups dosed *in utero* and post-natally at 0.5 mg/kg bw/day and above, in the absence of maternal toxicity. The NOEL from this study is 0.1 mg/kg bw/day. The potential effects of dimethoate on foetal development are the subject of a current review.

Poisons Schedule: Dimethoate is included in Schedule 6 of the *Standard for the Uniform Scheduling of Medicines and Poisons No.1, 2010* (the Poisons Standard)(DoHA 2010). Current versions of the Poisons Standard should be consulted for further information.

DERIVATION OF THE HEALTH-BASED GUIDELINE

The health-based guideline of 0.007 mg/L for dimethoate was determined as follows:

$$0.007 \text{ mg/L} = \frac{0.2 \text{ mg/kg bodyweight/day} \times 70 \text{ kg} \times 0.1}{2 \text{ L/day} \times 100}$$

where:

- 0.2 mg/kg bw/day is the NOEL based on a short-term (57-day) human volunteer study.
- 70 kg is taken as the average weight of an adult.
- 0.1 is a proportionality factor based on the assumption that 10% of the ADI will arise from the consumption of drinking water.
- 2 L/day is the estimated maximum amount of water consumed by an adult.
- 100 is the safety factor applied to the NOEL derived from human studies. This safety factor incorporates a factor of 10 for intraspecies (human) variation, with an additional safety factor of 10 to account for the uncertainty in the ADI (which is likely to be lower as a result of the current review).

The World Health Organization has a health-based guideline value of 0.006 mg/L for dimethoate (WHO 2004).

REFERENCES

NOTE: The toxicological information used in developing this fact sheet is from reports and data held by the Department of Health, Office of Chemical Safety.

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USEPA (United States Environmental Protection Agency) (2008). Revised Interim Reregistration Eligibility Decision for Dimethoate. USEPA.

WHO (World Health Organization) (2006). *Guidelines for Drinking-water Quality*. 3rd Edition, WHO, Geneva, Switzerland.

PHYSICAL AND CHEMICAL CHARACTERISTICS –
FACT SHEETS

Maldison (Malathion)

(endorsed 2011)

GUIDELINE

Based on human health concerns, maldison in drinking water should not exceed 0.07 mg/L.

RELATED CHEMICALS

Maldison (malathion)(CAS 121-75-5) belongs to the organophosphate class of chemicals. There are many other pesticides in this class, including fenthion, parathion, profenofos and ethoprophos (Tomlin 2006).

HUMAN RISK STATEMENT

With good water quality management practices, the exposure of the general population is expected to be well below levels that may cause health concerns.

If present in drinking water as a result of a spillage or through misuse, maldison would not be a health concern unless the concentration exceeded 0.07 mg/L. Minor excursions above this level would need to occur over a significant period to be a health concern, as the health-based guideline is based on long-term effects.

With good water quality management practices, pesticides should not be detected in source waters used for drinking water supplies. Persistent detection of pesticides may indicate inappropriate use or accidental spillage, and investigation is required in line with established procedures in the risk management plan for the particular water source.

GENERAL DESCRIPTION

Uses: Maldison is an insecticide and parasiticide for the control of various insect pests such as fruit fly and locusts on various crops, and in grain storage facilities. It is also used on dogs and cats and in aviaries for treatment of lice, brown dog tick and mange.

There are registered products containing maldison in Australia. The products are intended for both professional and home garden/veterinary use. Products are formulated as liquid concentrates (to be diluted and sprayed), dusts, lures/traps and insecticidal washes. Aerial ultra-low volume (ULV) application is permitted, as well as ground-based ULV application. Data on currently registered products are available from the Australian Pesticides and Veterinary Medicines Authority.

Exposure sources: The main sources of public exposure to maldison and its metabolites are the use of home garden and home veterinary products, and residues in food. Residue levels in food produced according to good agricultural practice are anticipated to be generally low.

Agricultural use of maldison may potentially lead to contamination of source waters through processes such as run-off, spray drift (especially from aerial and ULV application) or entry into groundwater.

REPORTED VALUES IN AUSTRALIAN WATERS

No data were found on maldison in Australian waters. Maldison was not detected in surveys of municipal and private drinking-water supplies conducted in Canada between 1971 and 1986 (Health Canada 1989). It was detected in 4 of 949 stream samples in southern Ontario agricultural watersheds at concentrations of 0.24 to 1.8 µg/L (Health Canada 1989). In the USA, maldison has been reported in surface water at levels up to 0.18 µg/L and in drinking-water at 0.1 µg/L (ATSDR 2000, WHO 2004a).

TREATMENT OF DRINKING WATER

There is insufficient information on the treatment of maldison in drinking water, but it is expected that advanced treatment methodologies such as ozonation and advanced oxidation would be effective. Maldison has been shown to have relatively high removal rates when water undergoes advanced oxidation with iron-catalysed ultraviolet irradiation and peroxide (Fenton reaction) (Huston and Pignatello 1999).

MEASUREMENT

Maldison can be measured by routine gas chromatography–mass spectrometry analysis, with a limit of reporting of 0.1 µg/L (Queensland Health 2007).

HISTORY OF THE HEALTH VALUES

The current acceptable daily intake (ADI) for maldison is 0.02 mg per kg of bodyweight (mg/kg bw), based on a no-observed-effect level (NOEL) of 2 mg/kg bw/day from a 2-year dietary study in rats. This NOEL is based on inhibition of red blood cell cholinesterase. The ADI incorporates a safety factor of 100 and it was established in 2005.

The previous ADI was 0.02 mg/kg bw/day, based on a NOEL of 0.26 mg/kg bw/day for inhibition of red blood cell and plasma cholinesterase in a human study and a safety factor of 10. The NOEL in this study was not maintained due to the absence of information regarding the purity of the material tested.

The acute reference dose (ARfD) of 1.5 mg/kg bw/day for maldison was established in 2005, based on a NOEL of 15 mg/kg bw/day from an acute dietary study in humans. The ARfD incorporates a safety factor of 10.

The previous health value was 0.05 mg/L (NHMRC and NRMMC 2004).

HEALTH CONSIDERATIONS

Metabolism: Maldison is rapidly and extensively absorbed from the gastrointestinal tract. Metabolism is extensive, with oxidation to malaoxon, and further hydroxylation to another six to eight metabolites. Maldison has a low potential for accumulation, with <1% of the dose present in blood and tissues after 72 hours.

Acute effects: Maldison has low acute oral and dermal toxicity. It is not a skin sensitiser in guinea pigs, although there is some evidence of skin sensitisation in humans.

Short-term and long-term effects: Short-term and long-term dietary studies in rats report cholinesterase inhibition as the main toxicological effect. In a 3-month study, cholinesterase inhibition occurred at 34 mg/kg bw/day and above. In a 2-year study, inhibition of red blood cell cholinesterase occurred at 29 mg/kg bw/day and above. The NOEL of 2 mg/kg bw/day in this rat study is the basis for the current ADI.

A 56-day human study reported inhibition of red blood cell cholinesterase at a dose of 0.4 mg/kg bw/day.

Carcinogenicity: Adenomas were reported in the liver in mice and rats and in the thyroid in rats at high dose levels, but these were considered rodent-specific. There was no other evidence of carcinogenicity for maldison.

Genotoxicity: Maldison is not considered to be genotoxic, based on *in vitro* and *in vivo* short-term studies.

Reproductive and developmental effects: A 2-generation reproduction study in rats and developmental studies in rats and rabbits reported no evidence of effect on reproductive parameters or foetal development.

Neurotoxicity: Maldison did not cause delayed neurotoxicity in hens.

Poisons Schedule: Maldison (Malathion) is included in Schedule 3, 5 and 6 of the *Standard for the Uniform Scheduling of Medicines and Poisons No.1, 2010* (the Poisons Standard)(DoHA 2010), depending on its concentration and use. Current versions of the Poisons Standard should be consulted for further information.

DERIVATION OF THE HEALTH-BASED GUIDELINE

The health-based guideline of 0.07 mg/L for maldison was determined as follows:

$$0.07 \text{ mg/L} = \frac{2 \text{ mg/kg bodyweight/day} \times 70 \text{ kg} \times 0.1}{2 \text{ L/day} \times 100}$$

where:

- 2 mg/kg bw/day is the NOEL based on a long-term (2-year) dietary study in rats.
- 70 kg is taken as the average weight of an adult.
- 0.1 is a proportionality factor based on the assumption that 10% of the ADI will arise from the consumption of drinking water.
- 2 L/day is the estimated maximum amount of water consumed by an adult.
- 100 is the safety factor applied to the NOEL from animal studies. The safety factor of 100 incorporates a factor of 10 for interspecies extrapolation and 10 for intraspecies variation.

The World Health Organization has not established a health-based guideline value for malathion and it is excluded from the list of agricultural chemicals guideline value derivation because it “occurs in drinking-water at concentrations well below those at which toxic effects may occur” (WHO 2004b).

REFERENCES

NOTE: The toxicological information used in developing this fact sheet is from reports and data held by the Department of Health, Office of Chemical Safety.

ATSDR (Agency for Toxic Substances and Disease Registry) (2000). Toxicological profile information sheet – Malathion. Draft for public comment. Atlanta, GA, US Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry.

DoHA (2010) *The Poisons Standard; Schedule 1-Standard for the Uniform Scheduling of Medicines and Poisons*, Department of Health and Ageing, Commonwealth of Australia, Canberra.

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Huston PL, Pignatello JJ (1999). Degradation of selected pesticide active ingredients and commercial formulations in water by the photo-assisted Fenton reaction. *Water Research* 33(5):1238-1246.

NHMRC (National Health and Medical Research Council), NRMMC (Natural Resources Management Ministerial Council) (2004). *Australian Drinking Water Guidelines.* National Water Quality Management Strategy, Paper 6. NHMRC and NRMMC.

Queensland Health (2007). Organochlorine, organophosphorous and synthetic pyrethroid pesticide, urea and triazine herbicides and PCBs in water. QHFSS SOP 16315.

NOTE: Important general information is contained in PART II, Chapter 6

Tomlin CD (ed) (2006). *The Pesticide Manual: a world compendium*, 14th Edition, British Crop Production Council, UK.

WHO (World Health Organization) (2004a). Malathion in Drinking-water. Background document for development of WHO Guidelines for Drinking-water Quality. WHO.

WHO (World Health Organization) (2004b). *Guidelines for Drinking-water Quality*. 3rd Edition, WHO, Geneva, Switzerland.

A.3 List of products containing dimethoate and/or malathion

The following list of products containing dimethoate and/or malathion was generated from the Australian Pesticides and Veterinary Medicines Authority PubCRIS database (https://portal.apvma.gov.au/pubcris).

No	Name	Company	Actives
55441	4FARMERS DIMETHOATE 400 SYSTEMIC INSECTICIDE	4 FARMERS AUSTRALIA PTY LTD	DIMETHOATE
63470	ACCENSI DIMETHOATE 400 SYSTEMIC INSECTICIDE	ACCENSI PTY LTD	DIMETHOATE
39239	ADAMA DIMETHOATE 400 INSECTICIDE	ADAMA Australia Pty Limited	DIMETHOATE
70165	APPARENT DECIMATOR 400 INSECTICIDE	Titan Ag Pty Ltd	DIMETHOATE
59469	AW DIMETHOATE 400 SYSTEMIC INSECTICIDE	AGRI WEST PTY LIMITED	DIMETHOATE
54285	BOB MARTIN SINCE 1892 FLEA & TICK CONTROL FOR DOGS, CATS & AVIARIES MALAWASH	BOB MARTIN (AUSTRALIA) PTY LTD	MALATHION
90037	Choice Di Met 400 Insecticide	GROW CHOICE PTY LIMITED	DIMETHOATE
58374	CROPRO STALK INSECTICIDE	PCT HOLDINGS PTY LTD	DIMETHOATE
56454	DANADIM INSECTICIDE	FMC AUSTRALASIA PTY LTD	DIMETHOATE
62242	DAVID GRAYS FRUIT FLY GARDEN SPRAY	DAVID GRAY & CO PTY LIMITED	MALATHION
58968	DAVID GRAYS MALATHION AND WHITE OIL INSECTICIDE	DAVID GRAY & CO PTY LIMITED	MALATHION | PETROLEUM OIL
42035	DAVID GRAYS MALATHION GARDEN SPRAY	DAVID GRAY & CO PTY LIMITED	MALATHION
50110	DAVID GRAYS MALATHION GRAIN DUST INSECTICIDE	DAVID GRAY & CO PTY LIMITED	MALATHION
42267	DAVID GRAYS POULTRY DUST	DAVID GRAY & CO PTY LIMITED	MALATHION
80465	Dimethoate	Shandong Rainbow International Co Ltd	DIMETHOATE
67003	DIMETHOATE	AGROGILL CHEMICALS PTY LTD	DIMETHOATE
66494	DIMETHOATE	Farmalinx Pty Ltd	DIMETHOATE
66093	DIMETHOATE	Farmalinx Pty Ltd	DIMETHOATE
65605	DIMETHOATE	SINON AUSTRALIA PTY LIMITED	DIMETHOATE
44043	DIMETHOATE	FMC AUSTRALASIA PTY LTD	DIMETHOATE
54320	DIMETHOATE MANUFACTURING CONCENTRATE	FMC AUSTRALASIA PTY LTD	DIMETHOATE
44566	DIMETHOATE MANUFACTURING CONCENTRATE	FMC AUSTRALASIA PTY LTD	DIMETHOATE
81676	Dimethon Insecticide	INDUSTRIAL QUIMICA KEY, S.A.	DIMETHOATE
63032	ECO-LURE MALE QLD FRUIT FLY WICK	DULUXGROUP (AUSTRALIA) PTY LTD	4-(P-ACETOXYPHENYL)-2-BUTANONE | MALATHION
64309	FARMALINX DIMETHOLINX INSECTICIDE	Farmalinx Pty Ltd	DIMETHOATE
62194	FYFANON 1000 EC INSECTICIDE	FMC AUSTRALASIA PTY LTD	MALATHION
51150	FYFANON 440 EW INSECTICIDE	FMC AUSTRALASIA PTY LTD	MALATHION

No	Name	Company	Actives
69529	FYFANON PREMIUM INSECTICIDE	FMC AUSTRALASIA PTY LTD	MALATHION
49539	FYFANON ULV INSECTICIDE	FMC AUSTRALASIA PTY LTD	MALATHION
80540	GENFARM DIMETHOATE 400 INSECTICIDE	Nutrien Ag Solutions Limited	DIMETHOATE
57860	HALLEY DIMETHOATE 400 SYSTEMIC INSECTICIDE	HALLEY INTERNATIONAL ENTERPRISE (AUSTRALIA) PTY LTD	DIMETHOATE
48992	HY-MAL INSECTICIDE	NUFARM AUSTRALIA LIMITED	MALATHION
69555	IMTRADE DIMETHOATE 400 EC INSECTICIDE	IMTRADE AUSTRALIA PTY LTD	DIMETHOATE
37201	INCA MALABAN WASH CONCENTRATE	INCA (FLIGHT) CO PTY LTD	MALATHION
85466	KATAR INSECTICIDE	ARYSTA LIFESCIENCE AUSTRALIA PTY LTD	DIMETHOATE
87713	Malathion	Tagros Chemicals India Private Limited	MALATHION
46160	MALDISON	GULMOHAR CHEMICALS PTY LTD	MALATHION
44350	MALDISON	FMC AUSTRALASIA PTY LTD	MALATHION
32962	NUFARM DIMETHOATE SYSTEMIC INSECTICIDE	NUFARM AUSTRALIA LIMITED	DIMETHOATE
33021	PHARMACHEMICAL MALDISON 50 INSECTICIDE	BOCKO P/L & FLEXSKY P/L IN PARTNERSHIP	MALATHION
42727	Q FLY WICK	BUGS FOR BUGS PTY LTD	4-(P-ACETOXYPHENYL)-2-BUTANONE | MALATHION
83009	RELYON DIMETHOATE 400 INSECTICIDE	Nutrien Ag Solutions Limited	DIMETHOATE
65259	ROVER SYSTEMIC INSECTICIDE	SIPCAM PACIFIC AUSTRALIA PTY LTD	DIMETHOATE
63456	SAINT BERNARD PETCARE MALDISON WASH INSECTICIDE	Vet Med IP Pty Ltd	MALATHION
50589	SEARLES FRUIT FLY WICK ATTRACTANT AND INSECTICIDE	J C & A T SEARLE PTY LTD	4-(P-ACETOXYPHENYL)-2-BUTANONE | MALATHION
55495	SUPERWAY DIMETHOATE 400 SYSTEMIC INSECTICIDE	Pooma Fertilizers Pty Ltd	DIMETHOATE
62511	TITAN DIMETHOATE 400 SYSTEMIC INSECTICIDE	Titan Ag Pty Ltd	DIMETHOATE

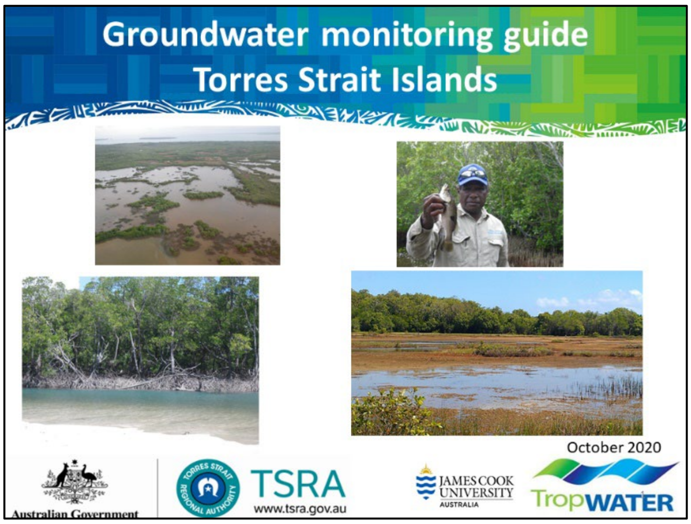
A.3 Laboratory reports

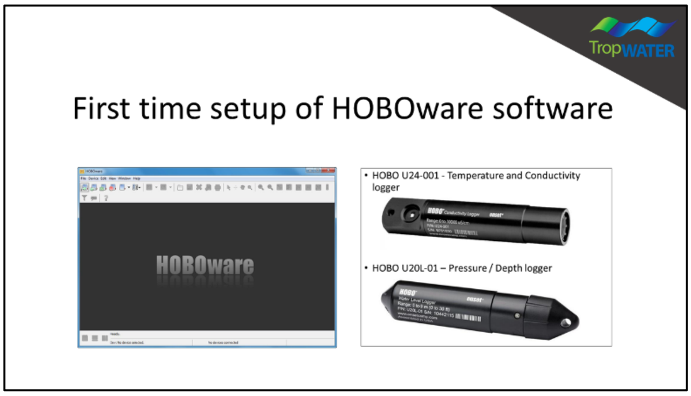
The following laboratory reports were provided for water samples collected from groundwater wells by TSRA Rangers.

Location	Well	Original Sample	Date Sampled	Report Number	CRC Sample Acknowledgement	CRC Certificate of Analysis	ALS Certificate of Analysis	ALS results spreadsheet
St Paul	Kurrsarr	783434	3/09/2020	100824	100824_SAMACK.pdf	100824-00040501-F.pdf	100824_ALSsup.pdf	100824_eresults.csv
Saibai	Buthu May	785107	24/07/2020	100938	100938_SAMACK.pdf	100938-00039900-F.pdf	100938_ALSsup.pdf	100938_eresults.csv
Warraber	Aiwal	785115	12/11/2020	100939	100939_SAMACK.pdf	100939-00041690-F.pdf	100939_ALSsup.pdf	100939_eresults.csv
Warraber	MGNM	785123	12/11/2020	100940	100940_SAMACK.pdf	100940-00041691-F.pdf	100940_ALSsup.pdf	100940_eresults.csv
St Paul	Kurrsarr	785131	29/11/2019	100941	100941_SAMACK.pdf	100941-00037289-F.pdf	100941_ALSsup.pdf	100941_eresults.csv
Saibai	Buthu May	785139	27/11/2019	100942	100942_SAMACK.pdf	100942-00037290-F.pdf	100942_ALSsup.pdf	100942_eresults.csv
Saibai	Buthu May	912974	3/06/2021	107159	107159_SAMACK.pdf	107159-00045099-F.pdf	107159_ALSsup.pdf	107159_BASIC_eresults.csv
Masig	Mothers	913015	9/12/2020	107163	107163_SAMACK.pdf	107163-00042154-F.pdf	107163_ALSsup.pdf	107163_eresults.csv
Masig	Thelma Billy	913025	9/12/2020	107164	107164_SAMACK.pdf	107164-00042147-F.pdf	107164_ALSsup.pdf	107164_eresults.csv

A.4 Training material

The training material consisted of three powerpoint presentations developed for face-to-face or remote online training for the TSRA groundwater monitoring program. The 'monitoring and reporting' presentation introduces the program, gives background on issues surrounding groundwater contamination, and includes community specific slides for purpose of selecting or confirming well sites to include in the program. The 'monitoring guide' details how to go about collecting water samples, measuring well dimensions, and installing HOBO dataloggers. The 'setup guide' details how to install and setup the HOBOware program which communicates with the dataloggers.





A.5 Raw logger data

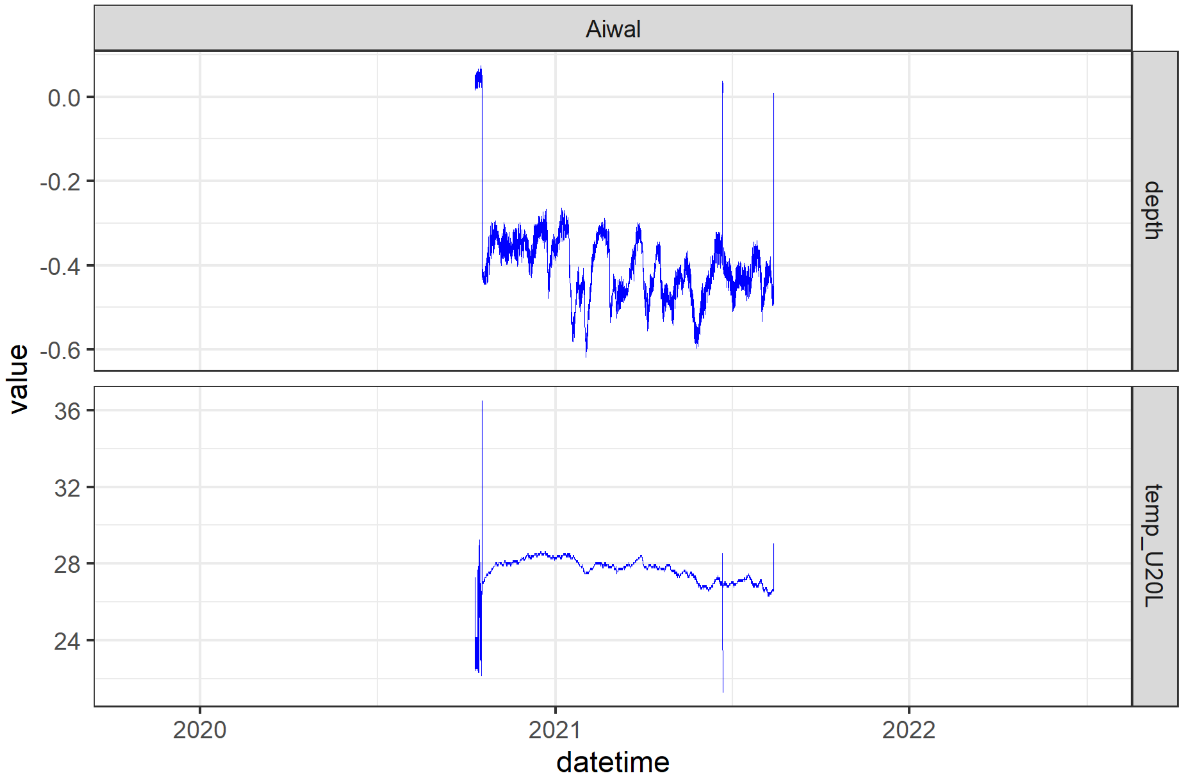


Figure A 1: Depth and temperature from logger data at Aiwal Well on Warraber Islet.

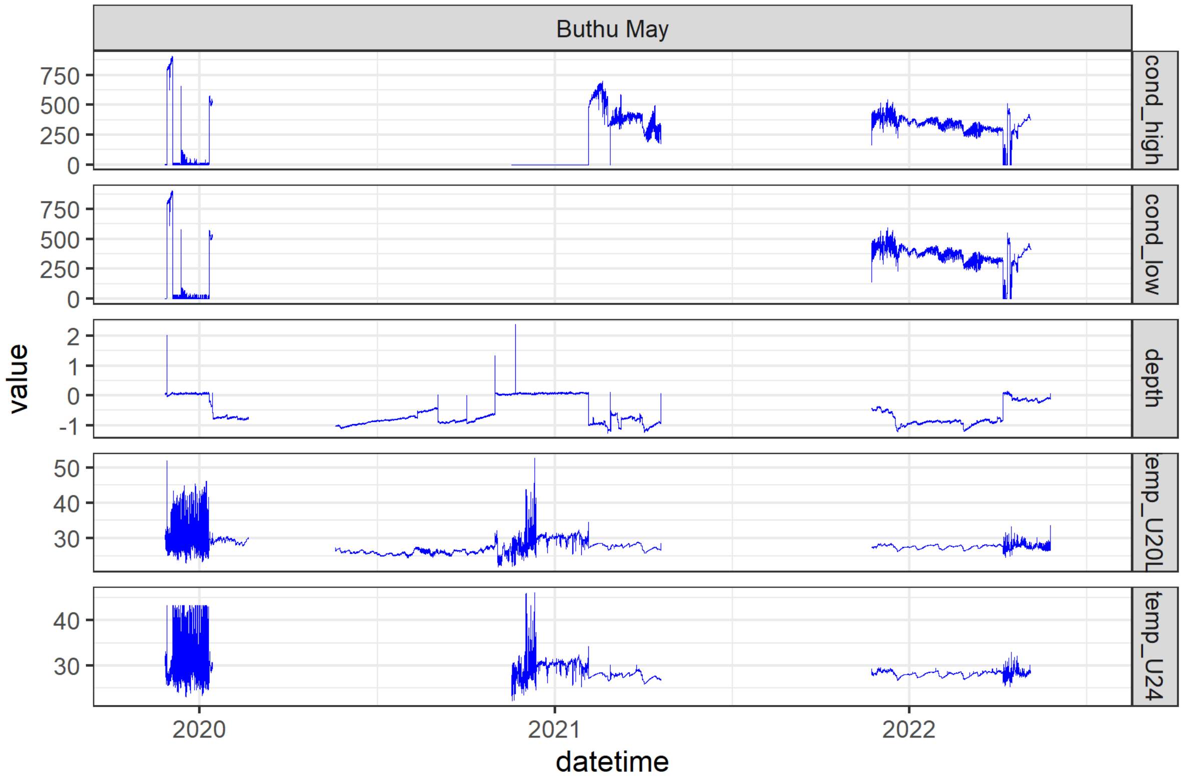


Figure A 2: Conductivity, depth, and temperature at the Buthu May Well on Saibai.

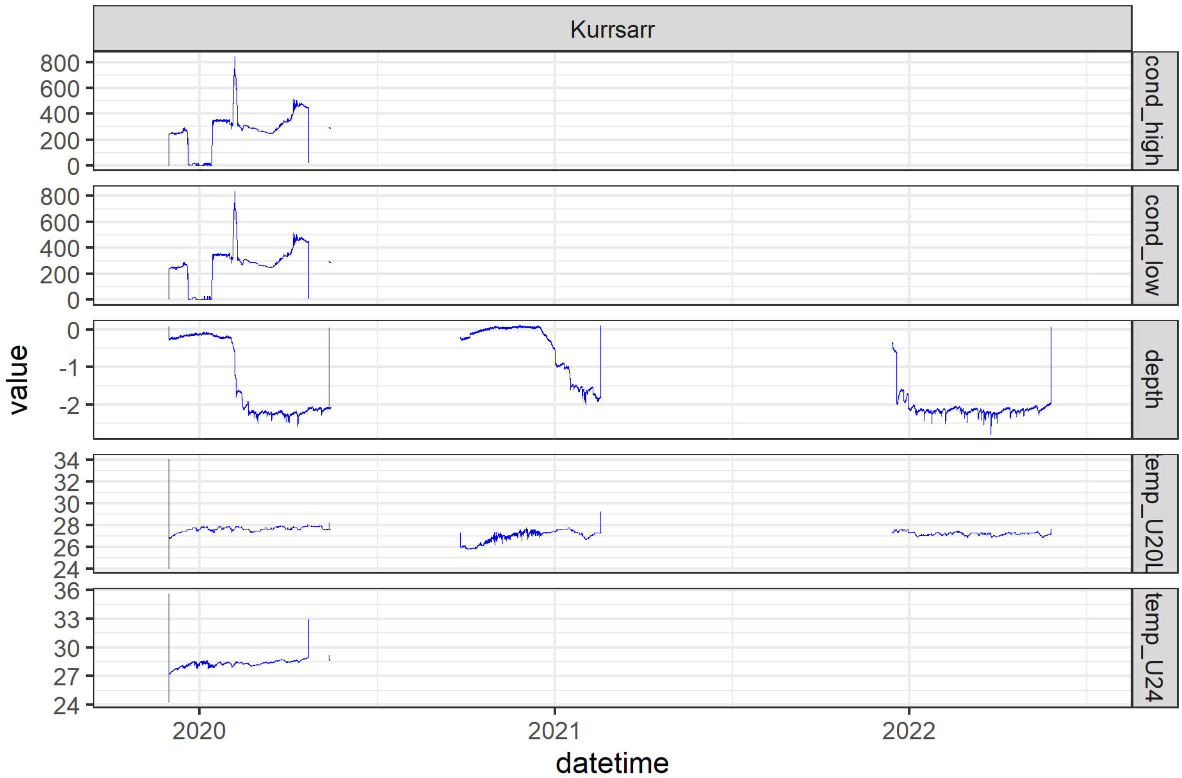


Figure A 3: Conductivity, depth, and temperature at the Kurrsarr Well at St Paul's.

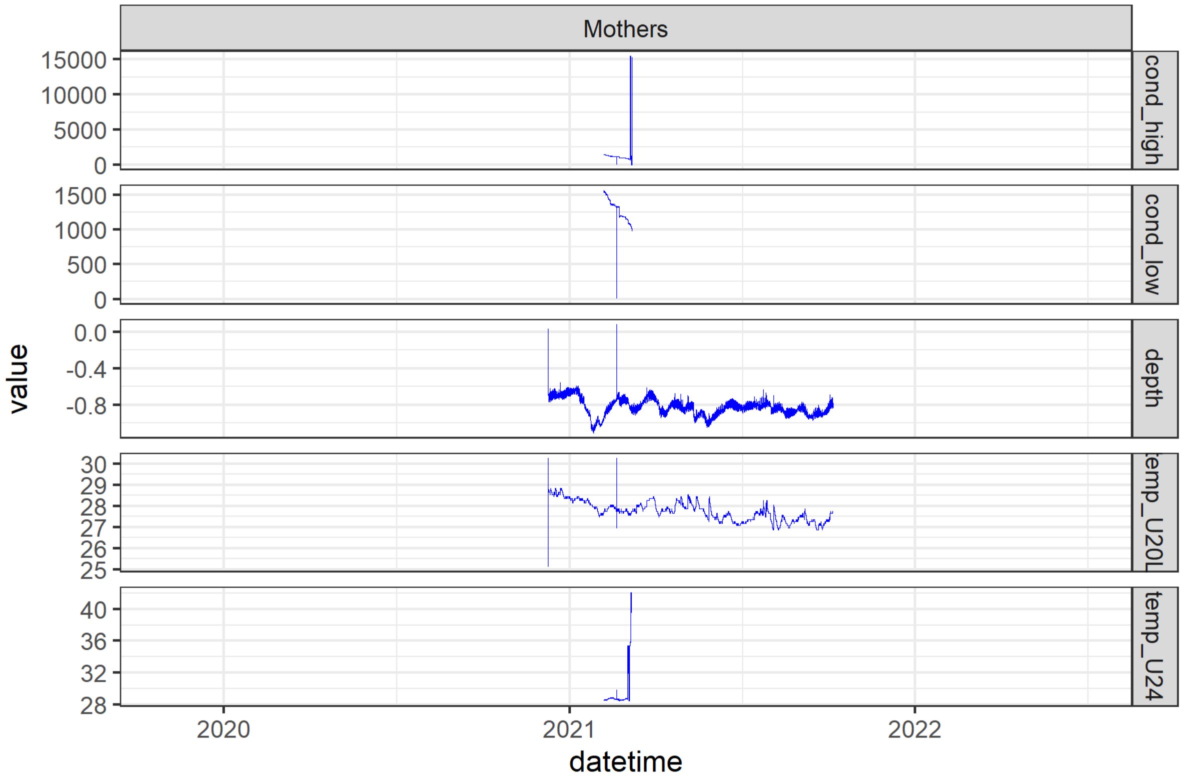


Figure A 4: Conductivity, depth, and temperature at the Mothers Well on Masig Island.

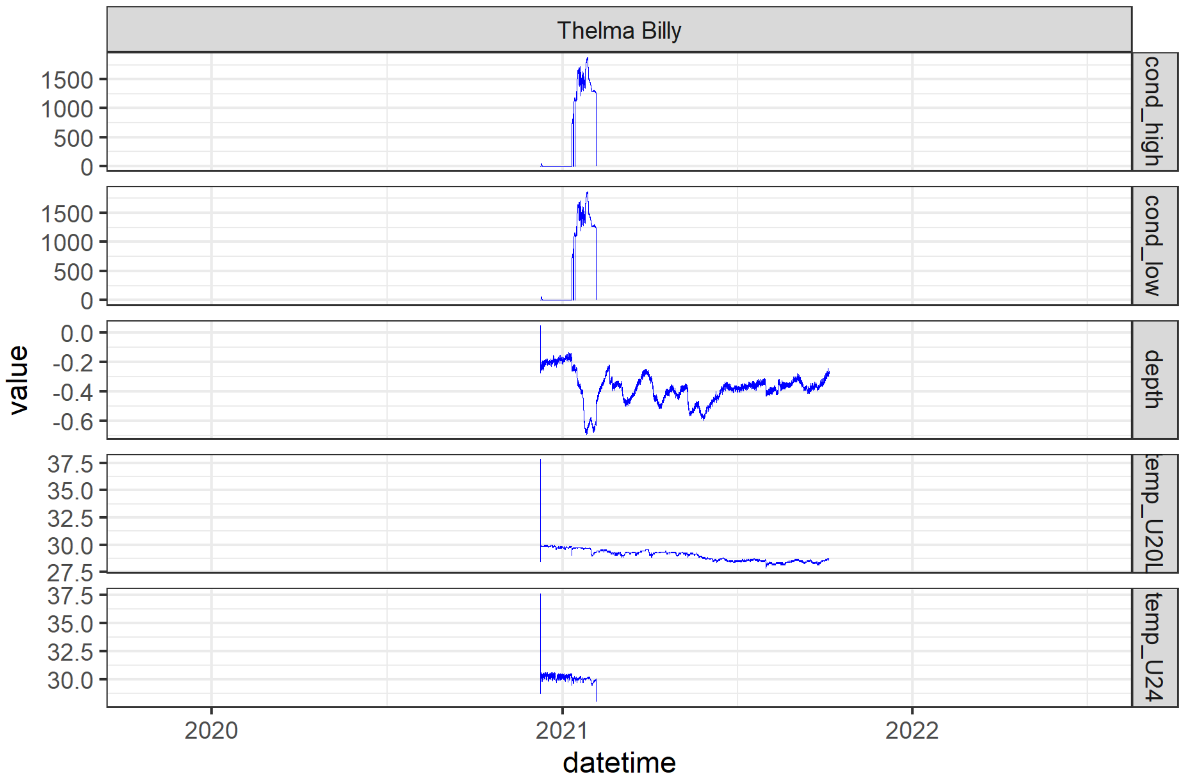


Figure A 5: Conductivity, depth, and temperature at the Thelma Billy Well on Masig Island.