# Petrophysics of peat in the Muir-Byenup wetlands – why they dry, generate acid, and burn (Part 1)

Project progress report prepared for the South West Catchments Council (SWCC)
Project No. 022LM.5640 – Milestone 3

Jasmine Rutherford

Ecosystem Science

November 2020

Department of Biodiversity, Conservation and Attractions
GOVERNMENT OF WESTERN AUSTRALIA

Department of Biodiversity, Conservation and Attractions
Locked Bag 104
Bentley Delivery Centre WA 6983
Phone: (08) 9219 9000
Fax: (08) 9334 0498

www.dbca.wa.gov.au

Questions regarding the use of this material should be directed to:
Senior Research Scientist
Ecosystem Science
Department of Biodiversity, Conservation and Attractions
Locked Bag 104
Bentley Delivery Centre WA 6983
Phone: 9219 9505
Email: jasmine.rutherford@dbca.wa.gov.au

The recommended reference for this publication is:
Rutherford, J. (2020), Petrophysics of peat in the Muir-Byenup wetlands – why they dry, generate acid and burn (Part 1), Department of Biodiversity, Conservation and Attractions, Kensington, Western Australia.

This document is available in alternative formats on request.

Cover image reference
Tordit-Gurrup Lagoon March 2020: peat core (TGN08) (upper left); Tordit-Gurrup Lagoon depth board (upper centre); Tordit-Gurrup Lagoon peat desiccation (TGN10) (photographs by Rachael Hamilton) (upper right) and Tordit-Gurrup Lagoon July 2020 view to the west, from the eastern bank (photograph by Jasmine Rutherford)

# Contents

# Figures

## Tables

# Acknowledgments

The South West Catchment Council for funding this work through the South West (SW) RAMSAR Project; Long Term Management of SW Wetlands of International Significance.

The DBCA Warren Regional and Donnelly District staff are thanked for supporting the project. In particular Ian Wheeler, Mark Virgo and Darren Barnsby are thanked for providing help and advice during field investigations.

Local landholders, Jason and Alida Parke are thanked for providing local knowledge and assisting with access to monitoring bores.

Rachel Hamilton from Managed Recharge is thanked for the collection of soil and water data and insightful observations and photos (Figures 6, 14 and 17).

Kevin Cahill and Maria José Romero Segura are thanked for the collection of borehole NMR data in April 2015.

Staff from SoilWater Group, in particular James McMulkin, are thanked for their attention to detail in the collection, handling, photography and analysis of peat soil and sediment cores.

Dr. Grant Douglas (Senior Principal Geochemist CSIRO) and Dr. Dioni I. Cendón (Principal Geochemist ANSTO) are thanked for providing review comments on the report.

# Summary

Mapping and characterising the physical and chemical properties of peat systems in a changing climate is a global concern and is the subject of significant research.

Peat wetlands within the Muir-Byenup RAMSAR site have important ecological value as they form refugia for local flora and fauna. The Muir-Byenup Catchment is located on top of a Neogene palaeovalley with Oligocene-aged (27.8 to 33.9 Ma yrs) carbonaceous sediments identified between 10 to 20 metres below the contemporary peat wetlands. Some of these peat wetlands are undergoing deleterious drying and there is a need to understand if actions can be taken to delay or halt peat desiccation as this process tends to be concomitant with acidification and combustion.

The Department of Biodiversity, Conservation and Attractions developed a project dedicated to researching the drying and resilience of peat wetlands in the Muir-Byenup Catchment in 2015 (Project SP 2014-24). In July 2019, a project extension was facilitated through the South West Catchments Council (Project number 022LM.56) to include the research of a peat system undergoing deleterious changes. This study provides soil and water geochemistry data that improves the mapping of hydrological-geochemical process boundaries which promote acid generation (e.g. vertical and lateral movement, seasonal changes, and recycling). Data collection on this project is near completion and this report provides an interpretation of data collected since 2015.

The major findings from work are that peat within wetlands display a consistent vertical and lateral geochemical zonation that is constrained by their physical properties and hydrological process (e.g. water table fluctuation). The organic carbon component of peat generally decreases from shorelines towards the centre of the lakes. Shoreline sites store on average 50 weight percent organic carbon, which reduces to less than 20 weight percent organic carbon in desiccated areas. Preservation of carbon storage at shorelines appears to be influenced by increased groundwater availability, particularly in summer, which in turn promotes greater geochemical stability.

Declines in the water table and soil moisture promotes $O_2$ infiltration in fibric peat and $CO_2$ degassing. This process is enhanced during drought and makes fibric peat a target for combustion. Seasonal rewetting and lake inundation encourage the development of anoxic conditions and $CO_2$ accumulation in peat pore water. Sulfur and iron rich minerals identified in peat analyses include gypsum, pyrite, jarosite, goethite, haematite, and siderite. Pyrite is microbial in origin and it increases in abundance with decreasing pH; the highest concentrations located towards the centre of lakes. Redox conditions and mineralogy indicate several geochemical reaction sequences for iron and sulfur are viable. Pyrite can oxidise in the presence of carbonates to form gypsum while seasonal inundation of desiccated areas may drive the microbially mediated reduction of ferric ion, promoting the precipitation of iron carbonates.

A significant decrease in organic carbon at TGN08 suggests reductions have occurred over a long period of time.

In the past, redox conditions were known to be more anoxic in response to perennial waterlogging in the peat wetlands. This had a deleterious effect on peat wetland vegetation and also promoted the reduction of pyrite. In the presence of organic carbon this would have consumed organic carbon and produced $H_2S$ and $CH_4$ gases, as well as calcium, magnesium, and iron carbonates (e.g. as observed with TGN08 geochemistry).

In the Muir-Byenup Catchment groundwater contributes to peat wetland water balances. In Tordit-Gurrup Lagoon, one of the larger peat wetlands, there has been a reduction in rainfall recharge and groundwater flow. Mapping and characterising the hydrogeology beneath the lagoon shows that aquifers with higher porosity and permeabilities are limited to the southern area of the lagoon, where the near-surface aquitard is thin or absent. Declines in groundwater levels in this area is changing the dynamic of the Tordit-Gurrup Lagoon, from a throughflow to a recharge wetland.

The seasonal drying of lake water in Tordit-Gurrup Lagoon results in the precipitation of an evaporite crust that covers approximately 20 percent of the lake. The crust contains soluble sulfur and sodium mineral phases (e.g. halite and hexahydrite) that dissolve with winter rains and are redistributed across the lagoon. This is of concern as this is likely to reduce the internal buffering potential of the peat (e.g. consume carbonate minerals). While increases in salinity could drive geochemical reactions that will increase acidity by promoting the mobilisation of temporary storages of iron and sulfur (e.g. dissolution of siderite).

Data collection for this project will be finalised in November 2020 and results from datasets integrated. Carbon, acid and water balances will then be completed to assess potential remediation actions for drying peat wetlands in the Muir-Byenup Catchment.

# 1 Background

Mapping and characterising the physical and chemical properties of peat systems in a changing climate is a global concern and has been the subject of significant research, particularly over the past decade (e.g. Rezanezhad et. al. 2017, Young et. al. 2019).

In southwestern Australia peat soils are present in areas where the water balance enables them to retain water throughout summer. This tends to restrict their present to areas with higher rainfall and lower temperatures and evaporation. Therefore, more resilient peat systems will occur towards the coast, particularly where there are perennial surface water flows and areas where shallow aquifers are less sensitive to reductions in rainfall-recharge and increases in evapotranspiration.

Perennial wetlands have a water regime and can support peat and organic carbon rich substrates, where they are supported by vegetation (e.g. to stabilise and provide a carbon source).

Peat wetlands within the Muir-Byenup RAMSAR site have important ecological value as they form refugia for local flora and fauna (e.g. Storey 1998; Farrell and Cook 2009). The Department of Biodiversity, Conservation and Attractions (Department) developed a project dedicated to researching the drying and resilience of peat wetlands in the Muir-Byenup Catchment in 2015.

The initial three-year project (BCS project SP 2014-24) involved selecting suitable peat wetlands from an assessment of spatial datasets and local knowledge. This was followed by the installation of groundwater monitoring bores in lake/wetland shorelines and developing auger transects to map and quantify peat condition and determine hydrological threats from the shorelines to the centre of lakes.

Project SP 2014-24 has entered its reporting phase and has been extended to assess seasonal acid fluxes into the Tordit-Gurrup southern water body (near TGS01 in Figure 1). The project extension has been facilitated through funding provided by the South West Catchments Council – Project number 022LM.56, which commenced in July 2019.

The main aim of the project extension is to broaden Project SP 2014-24 conclusions by including a peat system that is currently undergoing deleterious changes. This study provides end-member soil and water geochemistry data that will improve the mapping of hydrological processes boundaries that encourage acid generation (e.g. vertical and lateral movement, seasonal changes, and recycling).

Data collection for the project extension commenced in October 2019. The investigation design and preliminary results are reported in Rutherford (2019). Data collection will be completed by November 2020. The monitoring program is outlined in Table 1 and Figures 1 and 2 show the location and nature of the data being collected.

This report integrates hydrological data from areas investigated between 2015 to 2018 with new data from the site that is showing deleterious drying (southern area of Tordit-Gurrup Lagoon).

This follows recommendations outlined in Rutherford (2019), which included;

- interpreting peat soil geochemistry data within full peat soil database.
- reviewing and interpreting water quality data to identify and map hydrological process boundaries and
- quality assuring groundwater logger data to ensure data collected are robust and can be used to construct water and solute balances to assess remediation options.

This work will ensure the following agreed project outcomes are achieved;

- Improve our understanding (conceptual model) of the key regional and local scale hydrological and hydrochemical processes that sustain the physical and chemical character of peat and organic rich substrate material within the Muir-Byenup wetlands.
- Incorporate updated conceptual models into numerical models capable of simulating the physical and geochemical behaviour of peat wetlands.
- Determine and predict the frequency and duration of current and future acidification events in Tordit-Gurrup and other Muir-Byenup peat wetlands.
- Assess remediation strategies of acidified Muir-Byenup wetlands, including recommending laboratory/mesocosm scale investigations.
- Develop a basis on which to prioritise the conservation of peat wetlands within the Muir-Byenup system based on the likely resilience of wetlands to hydrological change (Perup Management Plan Hydrology and Altered Hydrology Regime Objective).

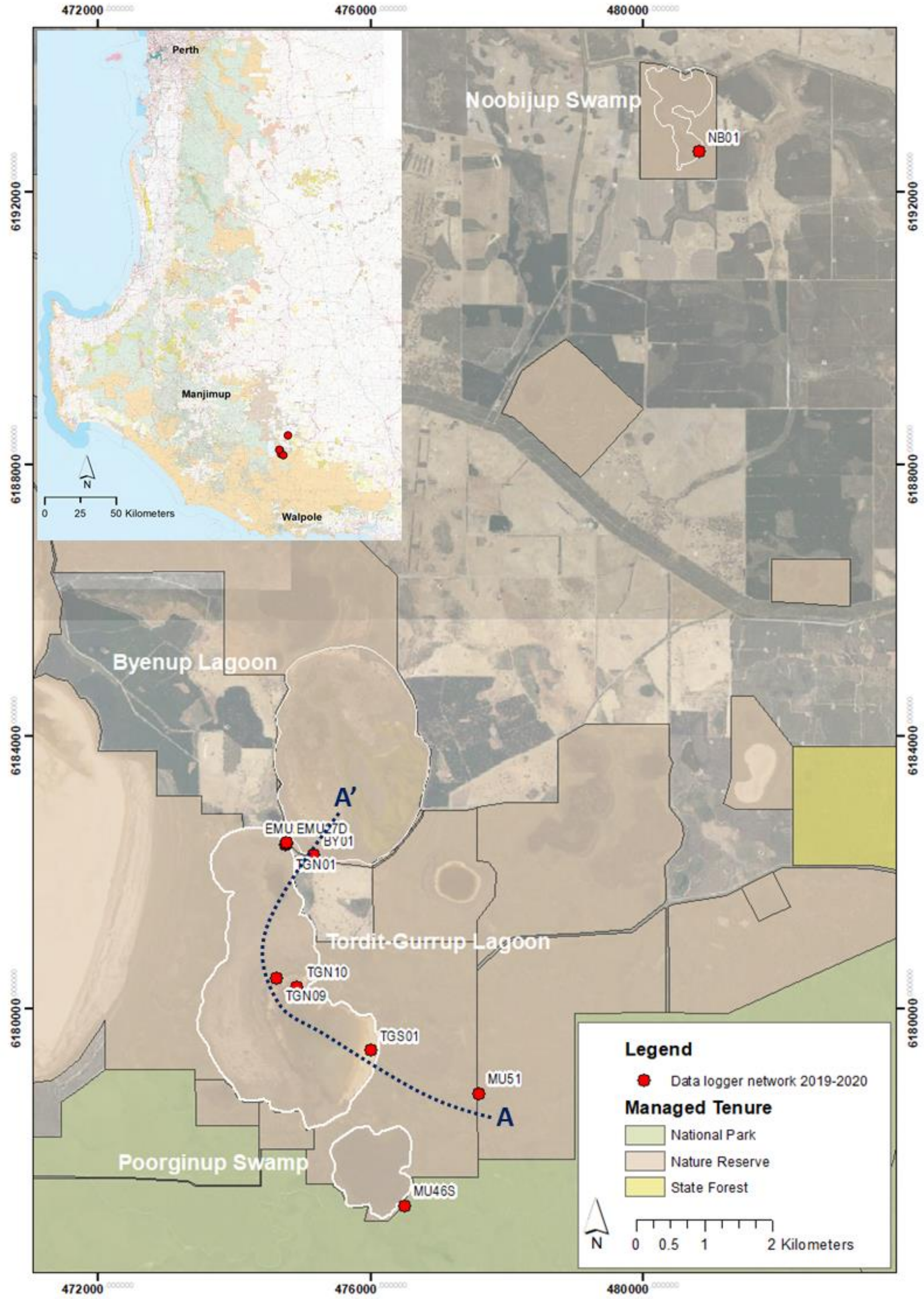


*Figure 1: Map showing the location of DBCA managed tenure in relation to the Muir-Byenup RAMSAR listed peat wetlands investigated in the DBCA peat wetlands study (2015-2018); groundwater data logger sites are in red on both the main and coarse scale inset map (A-A' marks the location of cross sections presented in this report).*

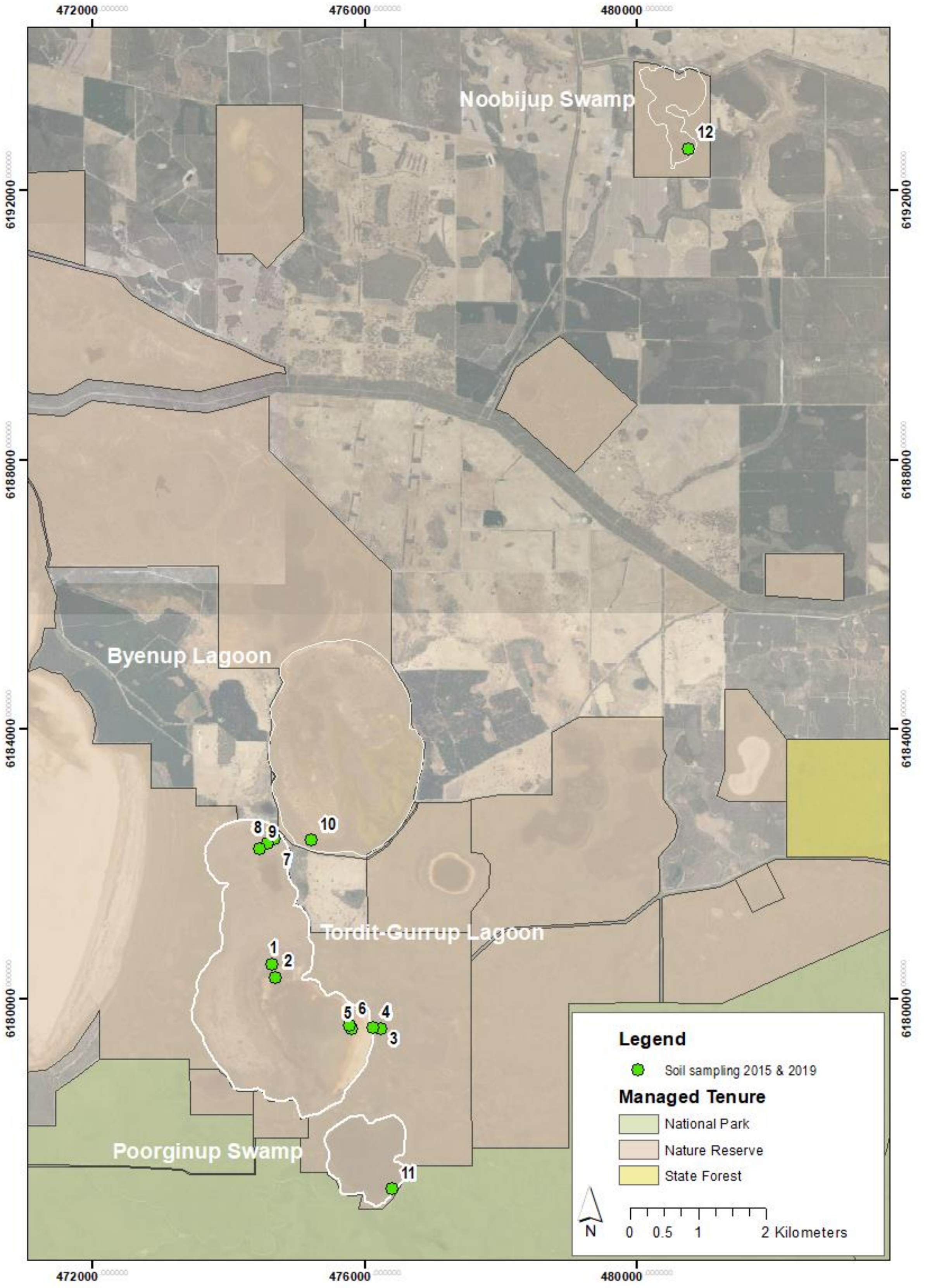


*Figure 2: Map showing the location of investigation sites dedicated to soil sampling and analyses; see Table 1 for site names.*

| Site ID | Location Monitoring Sites | | Excavation Depth & Construction | | | | | | | On-going monitoring post 9/2019 (Aprox dates/frequency) | Installation & monitoring Program |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Easting_MGA50 | Northing_MGA50 | Aprox Depth (mbgl) | ToS_mbgl | BoS_mbgl | Completion | Field water quality analyses | *Volume sample required - lab analyses | Data logger | | |
| TGN08 | 474627 | 6180509 | 0.6 | | | 2019 soil core (1) | | | | | |
| TGN09 | 474614 | 6180436 | 0.95 | 0 | 0.95 | filter sock; no backfill | Field pH,Temp, EC & alkalinity (as CaCO3) | ~1100mL | Y (CTD Diver) | 1/20; 3/20; 5/20; 7/20; 9/20 | Data logger |
| TGN10 | 474922 | 6180311 | 1.0 | 0 | 1 | filter sock; no backfill | Field pH,Temp, EC & alkalinity (as CaCO3) | ~1100mL | Y (CTD Diver) | 1/20; 3/20; 5/20; 7/20; 9/20 | Data logger |
| TGN11_12 | 474687 | 6180305 | 0.1 | | | 2019 soil core (2) | | | | 3/20 | Soil/lake water grap sample |
| TGS03 | 476234 | 6179540 | 0.31 | | | 2019 soil core (3) | | | | | |
| TGS04 | 476116 | 6179556 | 0.56 | | | 2019 soil core (4) | | | | | |
| TGS07 | 475808 | 6179541 | 0.1 | | | 2019 soil core (5) | | | | 3/20 | Soil/lake water grap sample |
| TGS05 | 475771 | 6179598 | 0.1 | | | 2020 soil core (6) | | | | 3/20 | Soil/lake water grap sample |
| TGS01 | 476005 | 6179371 | 6 | 0.5 | 6 | Existing bore | Field pH,Temp, EC & alkalinity (as CaCO3) | ~1100mL | Y (CTD Diver) | 1/20; 5/20; 9/20 | Data logger |
| TGN01 | 474754 | 6182394 | 6 | 0.5 | 6 | Existing bore | Field pH,Temp, EC & alkalinity (as CaCO3) | ~1100mL | Y (CTD Diver) | 1/20; 5/20; 9/20 | Data logger |
| TGN04 | 474670 | 6182361 | 1.9 | | | 2015 soil core (7) | | | | | |
| TGN05 | 474572 | 6182293 | 1.9 | | | 2015 soil core (8) | | | | | |
| TGN06 | 474458 | 6182218 | 1.8 | | | 2015 soil core (9) | | | | | |
| BY04 | 475217 | 6182343 | 1.8 | | | 2015 soil core (10) | | | | | |
| Poor01 | 476399 | 6177160 | 1.05 | | | 2015 soil core (11) | | | | | |
| NB04 | 480766 | 6192629 | 1.35 | | | 2015 soil core (12) | | | | | |
| BY01 | 475170 | 6182247 | 6 | 0.5 | 6 | Existing bore | Field pH,Temp, EC & alkalinity (as CaCO3) | ~1100mL | Y (CTD Diver) | 1/20; 5/20; 9/20 | Data logger |
| EMU27D | 474773 | 6182424 | 20 | 14 | 20 | Existing bore | Field pH,Temp, EC & alkalinity (as CaCO3) | ~1100mL | Y (CTD Diver) | 1/20; 5/20; 9/20 | Data logger |
| EMU27S | 474773 | 6182426 | 2 | 1 | 2 | Existing bore | Field pH,Temp, EC & alkalinity (as CaCO3) | ~1100mL | Y (CTD & Baro Diver) | 1/20; 5/20; 9/20 | Data logger |
| MU51 | 477584 | 6178735 | 20 | 17.8 | 19.8 | Existing bore | Field pH,Temp, EC & alkalinity (as CaCO3) | ~1100mL | Y (CTD Diver) | 1/20; 5/20; 9/20 | Data logger |
| MU46S | 476500 | 6177082 | 27 | 20 | 26 | Existing bore | Field pH,Temp, EC & alkalinity (as CaCO3) | ~1100mL | Y (CTD Diver) | 1/20; 5/20; 9/20 | Data logger |
| NB01 | 480825 | 6192604 | 6 | 0.5 | 6 | Existing bore | Field pH,Temp, EC & alkalinity (as CaCO3) | ~1100mL | Y (CTD Diver) | 1/20; 5/20; 9/20 | Data logger |

*major ions (500 mL, unfiltered); minor ions and REE (125mL, filtered & pre-acidified); nutrients (125mL, unfiltered);  nutrients (125mL, filtered); ferrous iron (60ml; unfiltered); reactive silica (125 mL, filtered); stable water isotopes (20ml, unfiltered (clear glass or HDPE))

*Table 1 Muir-Byenup peat wetland acid release investigation and monitoring program*

# 2 Mapping geology and aquifers

This section describes techniques and results in mapping fine scale changes in the Muir-Byenup geology that relates to the study area. A conceptual model of the geology was presented in Rutherford (2019). This has been updated to reflect recent laboratory results in Figure 3. Coarse, catchment and palaeovalley scale detail, is available in Smith (2010) and Rutherford (in prep).

As discussed in Rutherford (2019) the Muir-Byenup Catchment is located on top of a Neogene palaeovalley with a history of supporting peat wetlands. Results from spores and pollen confirm Oligocene (27.8 to 33.9 Ma yrs), aged carbonaceous sediments exist at around 10 to 20 metres below contemporary peat wetlands. This confirms that carbonaceous sediments develop periodically and are separated by lengthy periods where they don't form or haven't been preserved.

The drying of the contemporary systems requires research to understand if actions can be taken to delay or halt peat desiccation. One of the key hydrogeological questions is the degree of connection of the peat with underlying aquifers.

As discussed in Rutherford (2019), it is likely that in some areas of Muir-Byenup Catchment, the substrate beneath the peat leaks and resultant mixing helps buffer acidic water. Where underlying sediments have a lower permeability gravity induced drainage of peat soil water will be reduced which helps peat maintain soil moisture and limit redox driven geochemical reactions occurring in the peat.

This section discusses the approach used to assess and integrate information on the physical and chemical properties (petrophysics) of the peat and underlying sediments.

## 2.1 Borehole Nuclear Magnetic Resonance (NMR)

To map the porosity permeability of the aquifers a borehole nuclear magnetic resonance (NMR) survey was carried out using the VistaClara Dart™ NMR logging system as part of the initial investigation for DBCA SP-2014-24. NMR data were acquired for a total of seven bores in April 2015; four peat wetland shoreline bores installed in March 2015 and three existing bores where their construction was suitable to acquire NMR data (e.g. NMR acquired for all bores, apart from MU46S in Figure 1 and Table 1).

All data were acquired using the Dart probe, which has an outer diameter of 4.45cm, nominal vertical resolution of 0.25m, and a nominal sensitive diameter of 15.2cm. The NMR logging method measures fluid hydrogen in groundwater. Magnets in the down hole probe polarize fluid hydrogen, and radio-frequency coils within the probe excite and measure the NMR response from the hydrogen. The initial amplitude of the signal directly reflects the volumetric quantify of hydrogen or the volumetric water content (porosity if saturated). The decay time of the signal ($T_2$) indicates whether the water is "bound" in small pores (e.g. clay or silt) or is mobile in large pores (e.g. sand).

The $T_2$ distribution provides an indication of the relative pore-size distribution. Short $T_2$ values associated with smaller, and longer $T_2$ values, larger pores.

The configuration of the Dart NMR logging tool allows data to be acquired in a dual-frequency mode. Data acquired using a lower RF frequency (245kHz) is sensitive to water at a radial distance of 7.6cm from the tool (diameter 15.25cm). Data acquired using a higher RF frequency (290kHz) is sensitive to water at a lesser radial distance of 7.2cm (diameter 14.6cm). In most cases, the formation is sufficiently homogeneous that data at these different radial distances are identical. As such, these two datasets are combined by averaging to generate a dual-frequency log with higher signal-to-noise. It is also important to note that the low operating frequency of the Dart tool minimises artifacts associated with paramagnetic geology, which is important in the areas with widespread ferricrete, such as the Muir-Byenup Catchment.

In NMR data the fraction of water that is “mobile”, “capillary bound”, or “clay bound”, is estimated based on the fraction of water with different $T_2$ ranges. Water with $T_2$ longer than 33ms is estimated as “mobile water”; water with $T_2$ between 3ms and 33ms is estimated as “capillary bound” water; and water with $T_2$ less than 3ms is estimated as “clay bound” water. These cutoff times are taken as standard values used for NMR logging in reservoir sandstones and need to be verified with local laboratory data. Without laboratory calibration, the pore size information should be considered qualitatively as likely to be “more bound” versus “more mobile”.

NMR measurements are sensitive to both porosity (via the signal amplitude) and pore size (via the decay time $T_2$) and can therefore be used to estimate hydraulic conductivity. In areas characterised by low hydraulic conductivities the Schlumberger Doll Research Equation ($K_{SDR}$) below is used to estimate K using NMR estimated porosity (from the initial amplitude $S_0$) and the mean-log $T_2$ decay time in the $T_2$ distribution. A calibration coefficient b is included and derived from NMR and physical data from unconsolidated aquifers.

$$K_{SDR} = b_{SDR} T_{2ml}^{2} S_0$$

Noting that care must be taken in partially saturated zones where K estimates are not reliable.

NMR total water content (separated into mobile, capillary and clay fractions) and hydraulic conductivity results, for five of the seven bores surveyed are shown in Figures 4 and 5. NMR Data for the four shoreline bores (TGN01, TGS01/02, BY01 and NB01) are presented in Appendix 1. Figure 4c shows the relationship between laboratory volumetric water content and NMR total water content.

Overall, the results show that the total water content is generally around or less than 50% and tends to be bound in silts and clays rather than in sands (Figure 4). Higher water content with more mobile water occurs within and near the base of the sapric peat in TGN01 and BY01 respectively and in sediments with greater sand sized material in MU51 and TGS01/02 (Figure 4 and Appendix 1).

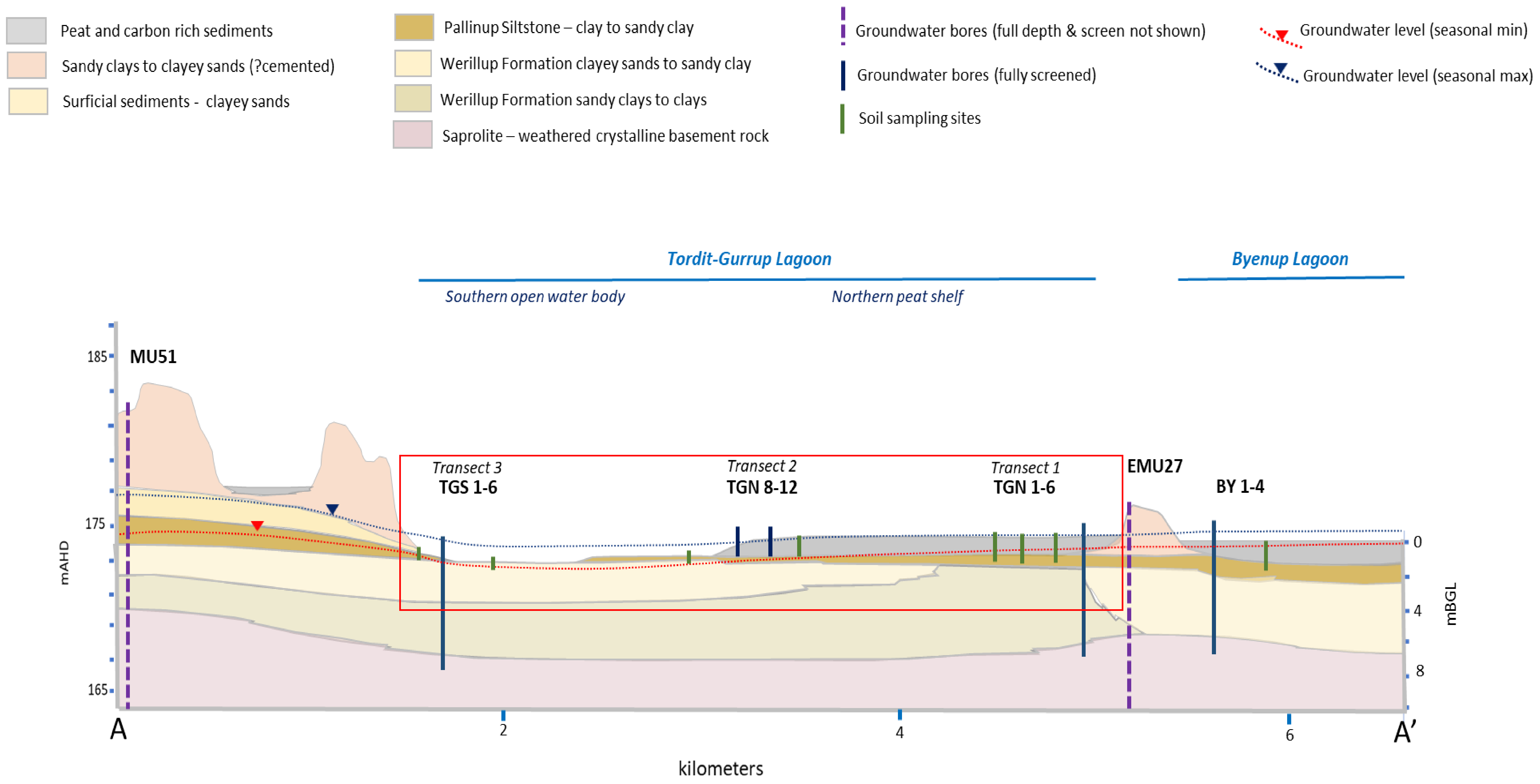


*Figure 3: Geological Cross section A-A' following the direction of decreasing landscape elevation, showing the location of investigation transects in Tordit-Gurrup Lagoon (Note: red outline represents fine scale cross sections presented in this report.*

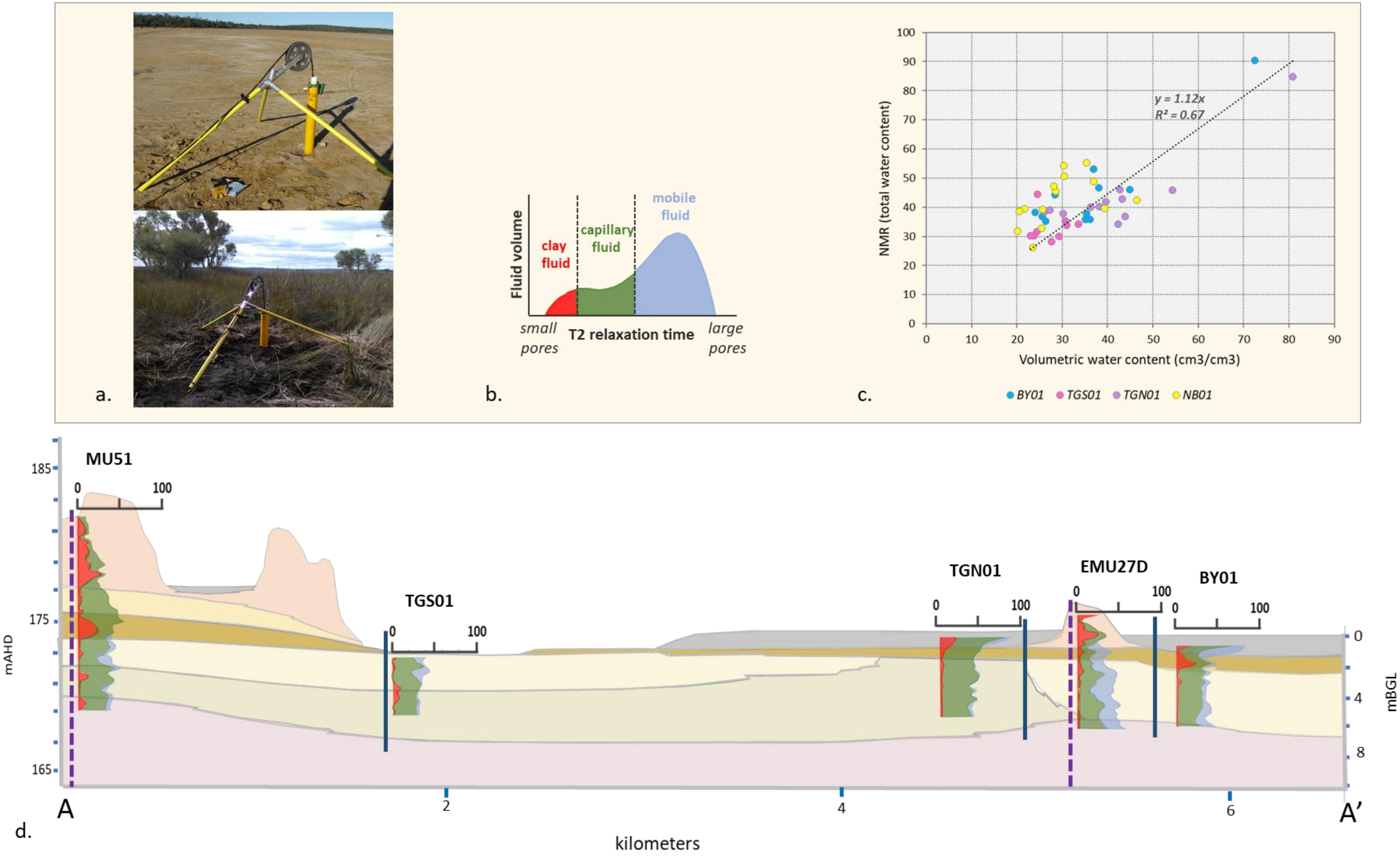


*Figure 4: Muir-Byenup Borehole NMR logging; a. NMR logging of TGS01/02 and BY01 (April 2015); b. schematic showing the relationship between measured NMR decay times and pore size; c. comparison laboratory soil core volumetric water content against NMR total water content and d. NMR total water content results for bores logged across transect A-A'.*

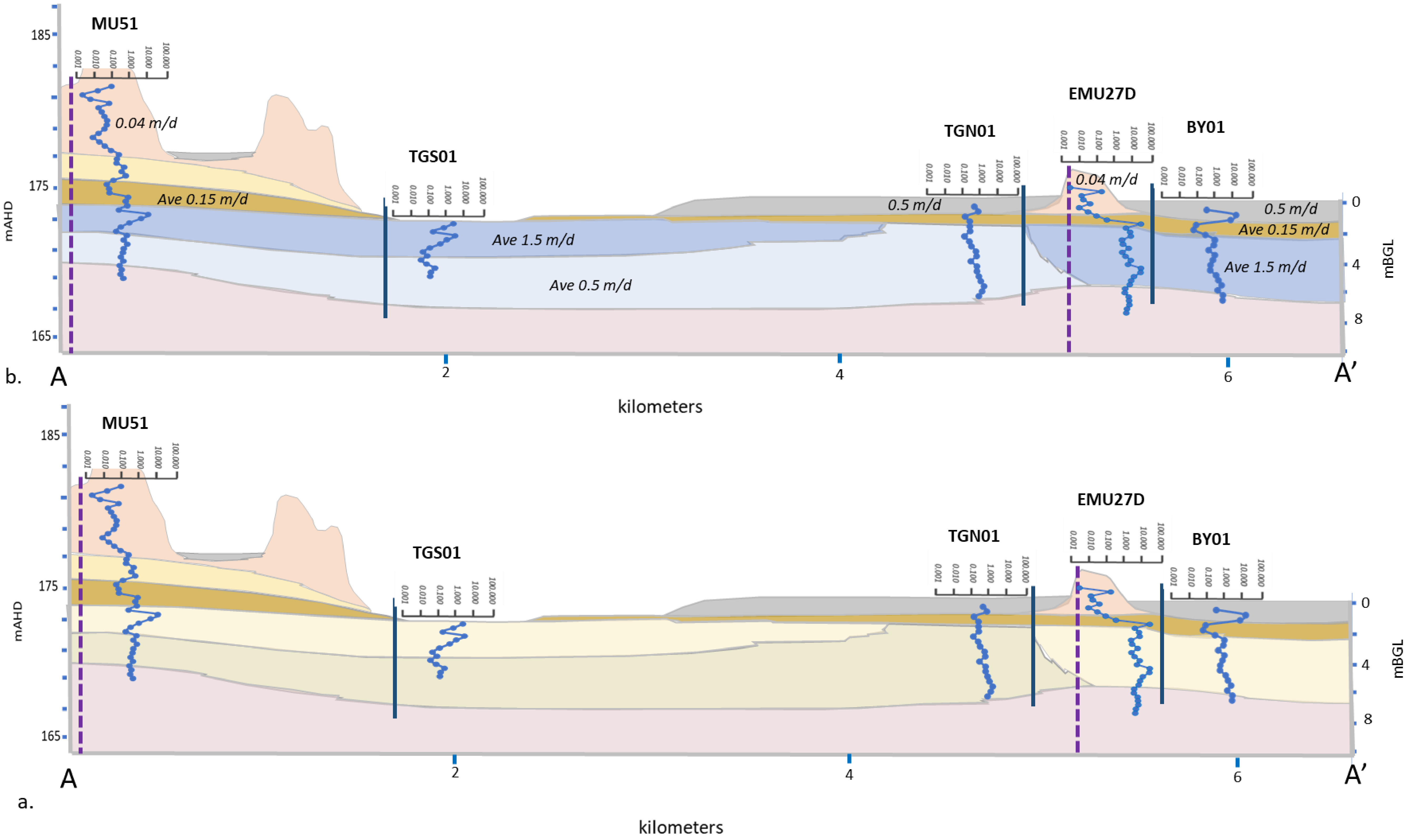


*Figure 5: Borehole NMR hydraulic conductivity ($K_{SDR}$) (m/day) results for bores logged across transect A-A’; a. NMR data overlain on Figure 3 geology and b. interpretation of the average hydraulic conductivity values for underlying aquifers (shaded blue), the overlying aquitard, peat and ?cemented dunes.*

Elevated mobile water content for bore EMU27D (below ~173mAHD; Figure 4d) are associated with NMR measurements with higher noise levels, and therefore lower confidence. Low vadose zone total water content in MU51 (~177 to 181mAHD; Figure 4d) occurs within a fining up sequence. NMR responses in these partially saturated materials are like where they are saturated (e.g. EMU27D ~173 to 175mAHD; Figure 4d) providing confidence in the results.

Elevated clay bound water occurs below and in the sapric peat (TGN01 and BY01) and at or below the water table in MU51 (around 174mAHD; Figure 4d).

A comparison of volumetric water content and NMR total water content data shows they produce similar results across the 25 to 45% water content range. Some of the variation can be explained by the timing of the core sampling and NMR logging. The drilling and coring took place in March 2015 and the NMR logging following early rainfall towards the end of April. Rain recharged partially saturated near surface sediments prior to the NMR logging in April 2015. This is most noticeable where particle size analysis data indicate the sand fraction to be unsaturated in the volumetric water content analyses (Appendix 1).

Hydraulic conductivity (K) results in sapric peat is higher than expected (Figure 5), possibly influenced by secondary as well as primary porosity. The peat contains mobile, capillary and clay bound water, but in this case the clay term relates to organic carbon size material rather than clay minerals (see Appendix 1). Underlying the peat an aquitard characterised by a lower K can delay gravity induced drainage of peat soil water into deeper aquifers. Although these conditions change to the south in Figure 4 (towards TGS01) where the aquitard is discontinuous and can promote leakage where the aquitard becomes thin or absent.

Porosity driving the mobile water NMR response is likely to be a combination of secondary porosity (e.g. development of cracks within the peat) and the presence of quartz sands at the base of the sapric peat. Noting that mineral matter within the peat is mainly composed of disseminated quartz, gypsum, and pyrite. The drying and cracking of the peat is noticeable across Tordit-Gurrup Lagoon, with fracture density and depth increasing from the north to the south of the lagoon (Figure 6).

Scanning electron microscopy (SEM) data showing diatoms and sponge spicules represent a major component of the siliceous material (Rutherford in prep). As the underlying aquitard also contains these microfossils and is alkaline, the lithology is described here as the Pallinup Siltstone, although it may include reworked Pallinup sediments and be geologically younger (Figure 3).

Beneath the aquitard, Werillup Formation sands to clayey sands and sandy clays occur as a coarsening up sequence to the south of Tordit-Gurrup Lagoon (TGS01 and MU51) and fining upwards on the southern margin of Byenup Lagoon (BY01). The change in distribution of materials across these lagoons may occur due to a sharp change in the depositional environment or in response to the down faulting of the geology in Byenup Lagoon. This is covered in more detail in Rutherford (in prep).

The average horizontal saturated hydraulic conductivity distribution is shown in Figure 5b and forms a framework to explain the direction and rates of vertical and lateral movement of groundwater and peat soil water. These results are now compared with spatial variation in the peat soil and sediment geochemistry.

*Figure 6: Tordit-Gurrup Lagoon spatial changes in peat desiccation from north (Transect 1) to south (Transect 2) (photos left to right).*

| ***Analyses*** | ***Measurement*** | ***Test description*** | ***Compliance: Test method*** | ***Laboratory*** |
|---|---|---|---|---|
| 1 | Salinity (EC) | EC1:5 soil/water extract | AS 1289.4.3.1 | SWG |
| 2 | Soil pH | pH1:5 soil/water extract | AS 1289.4.3.1 | SWG |
| 3 | Potential acidity | pHfox | ASSMAC 21Bf | SWG |
| 4 | Potential acidity | Chromium Reducible Sulfur ($S_{CR}$) | ASSMAC 22B | ALS |
| 5 | Moisture content | Gravimetric water content | AS 1289.2.1 | SWG |
| 6 | Bulk density | Intact core | SPMILE 503.01 | SWG |
| 7 | Volumetric water content | calculated from analyses 4 and 5 results | | |
| 8 | Sedimentation | Pipette method (% Sand;% Silt;% Clay) | AS 4816.1-2002 | SWG |
| 9 | Water retention characteristics | Pressure plate method (10kPa; 33kPa; 100kPa;1,500kPa) | SPMILE 504.02 | SWG |
| 10 | Mineralogy (including silicates) | X-Ray diffraction (semi-quantitative) | Relevant Aust Standards | Microanalysis |
| 11 | Mineralogy | ASD spectrometer (SWIR-VNIR) (semi-quantitative) | Relevant Aust Standards | Portable Spectral Services (PSS) |
| 12 | Mineralogy & element chemistry | Scanning electron microscopy (SEM) | Relevant Aust Standards | Microanalysis |
| 13 | Element chemistry | X-Ray fluorescence (pXRF) and (lab - calibration) | Relevant Aust Standards | PSS & ALS |
| 14 | Carbon and Nitrogen (wt %) | δ15N [‰ AIR] & δ13C [‰ VPDB] | Peer reviewed publications | UWA Biogeochemistry Centre |

AS = Australian Standard; SPMILE = Soil Physical Measurement and Interpretation for Land Evaluation; ASSMAC = Acid Sulphate Soil Management Advisory Council

*Table 2: Peat soil and sediment analyses*

# 3 Peat soil and sediment analyses

In May 2015 DBCA designed an investigation program to install lake shoreline bores and collect approximately 54 meters of core across four peat wetlands using a Geoprobe 7822DT push probe drill rig and Dormer gouge and split tube samplers (Rutherford 2019). Rockwater and SoilWater (SWC) Group were contracted to supervise bore construction, collect soil and water data, install data loggers and report the initial results (Rockwater 2015).

NMR data and initial lithology logs were used to develop a laboratory peat soil and sediment analysis program (Table 2). Results for all sites where soil/sediment analyses can be displayed with sample depth are compiled in Appendix 1, Figure 7 shows results for site TGN01.

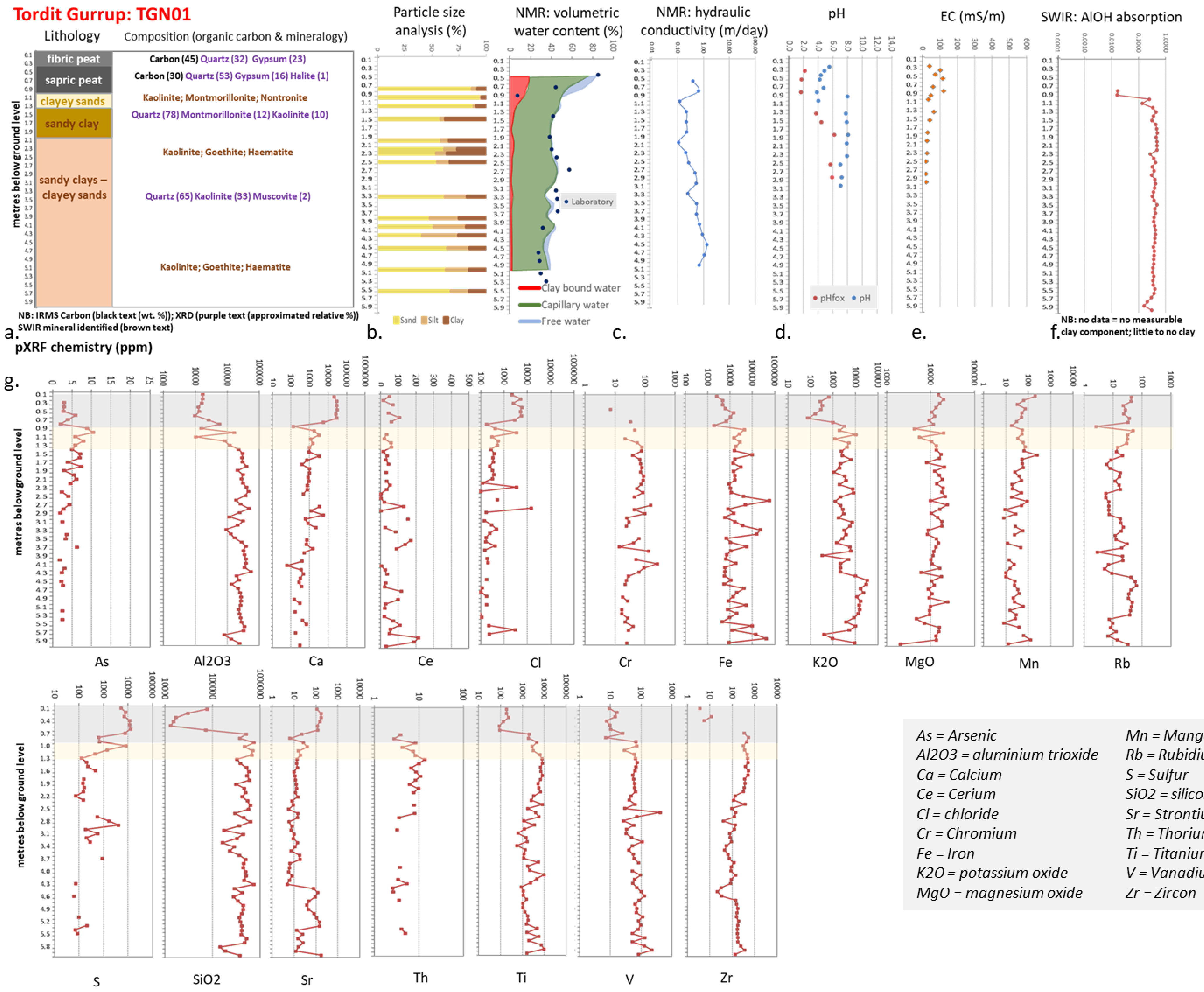
## 3.1 Lithology, mineral mapping and texture

Coarse scale lithological boundaries were determined at the time of drilling and iterated following NMR logging and interpretation of particle size analyses and mineralogical data from X-Ray Diffraction and spectrometric data. Additional quality assurance for textural data was provided by a relative measure of clay abundance that was determined from the short-wave infrared (SWIR) AlOH absorption. This provides an independent check that clay size material in the fibric and sapric peat is organic matter rather than clay minerals. Lithology, mineral composition, texture and SWIR AlOH data are displayed respectively for bore TGN01 in Figure 7a, 7b and 7e.

## 3.2 Moisture content and hydraulic conductivity

An objective logging approach was applied to gravimetric moisture measurements where data were collected at regular 40 to 50 mm intervals for all core. Bulk density data were measured at major changes in lithology identified in NMR and textural data. Fibric and sapric peat bulk density was measured at 0.13 and 0.2 to 0.22 g/cm$^3$ respectively and underlying sediments ranged from 1.0 to 1.6 g/cm$^3$. Noting that hemic peat zone didn't appear to be present and therefore wasn't sampled. At the southern end of Tordit-Gurrup Lagoon, where the peat shelf is desiccated, the bulk density increased to 0.3 to 0.6 g/cm$^3$ at depths of around 20 to 60mm below ground level. This increase corresponds with an approximate 50% decrease in organic carbon content (see Section 3.5). Bulk density data were required to calculate carbon storage in g/kg units (Rutherford in prep). Both gravimetric water content and bulk density were used to calculate volumetric water content and results are superimposed on NMR volumetric water content in Figure 7c (e.g. blue markers).

Results show peat has the highest volumetric water content (e.g. 70 to 100%) and this drops to 20 to 60% in the underlying sediments. Apart from coring in March 2020, both peat and the underlying sediments were saturated at the time of sampling. There is a good relationship between NMR water content and laboratory measured textural (e.g. particle size) and volumetric water content (Figure 7c and Appendix 1).



As = Arsenic
Al2O3 = aluminium trioxide
Ca = Calcium
Ce = Cerium
Cl = chloride
Cr = Chromium
Fe = Iron
K2O = potassium oxide
MgO = magnesium oxide
Mn = Manganese
Rb = Rubidium
S = Sulfur
SiO2 = silicon dioxide
Sr = Strontium
Th = Thorium
Ti = Titanium
V = Vanadium
Zr = Zircon

*Figure 7: Physical and chemical analysis summary from TGN01 drill core (see Appendix 1 for core analyses from all push-probe rig and auger sites).*

## 3.3 Electrical conductivity and pH

Electrical conductivity (EC) and pH were measured in soil water 1:5 extracts. Additional pH measurements were collected undertaking a partial digest with peroxide to assess potential acidity (pHfox) (Figure 7e and Appendix 1).

Results are relatively consistent across all cores with elevated EC and lower pH occurring in the fibric and sapric peat. Partial digest results (pHfox) show the buffering capacity of the peat and sediments that directly underly the peat is low. However, sediments below this zone appear to have greater buffering capacity. This is discussed further in Section 3.5.

As part of the quality control process EC results from different laboratories and methods were compared. Results from EC water and soil/sediment extracts were graphed against laboratory total dissolved solids (TDS) data sampled from bore screens (Figure 8a). Note that the full laboratory dataset is displayed to show the data range.

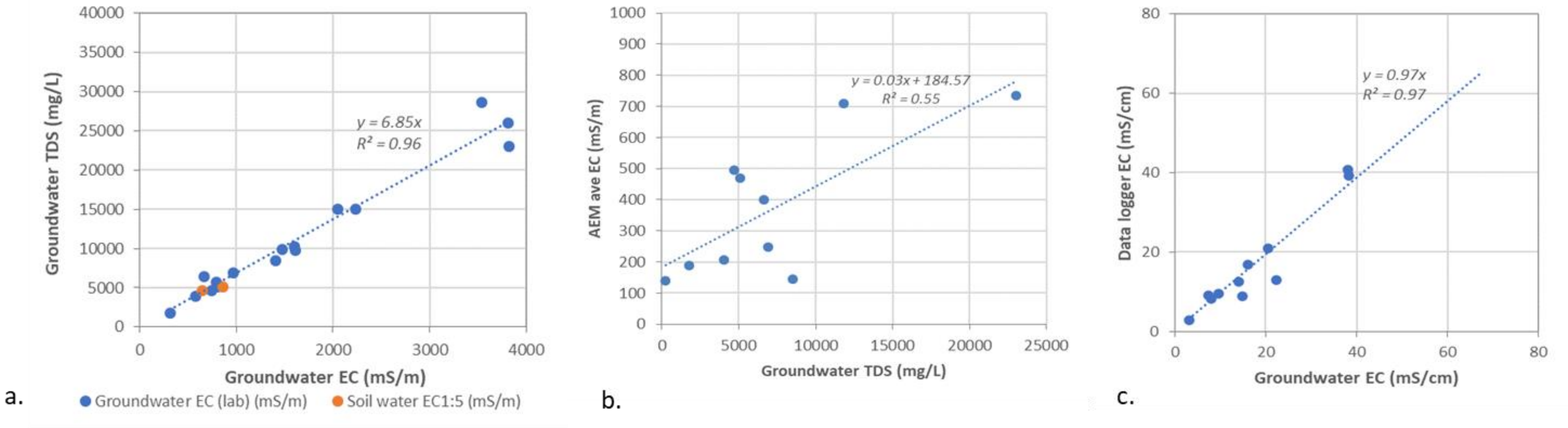


*Figure 8: Calibration of electrical conductivity and groundwater measurements; a. groundwater EC )bore and EC1:5) (mS/m) vs groundwater TDS (mg/L); b. groundwater TDS (mg/L) vs airborne EM ave EC (mS/m) and c. groundwater EC (mS/cm) vs groundwater data logger EC (mS/cm) at time of sampling.*

## 3.4 X-Ray fluorescence – metals and metalloids

Data obtained from portable X-Ray fluorescence (pXRF) measurements tend to have a higher integrity where elements have a greater atomic weight. Therefore, the approach taken here was to interpret trends in pXRF data and assess relative changes in elements, in relation to borehole depth, and along transects. The sampling frequency of pXRF data with depth was on average around 10cm. This sampling frequency proved to be effective at resolving lithological zonation in the geochemistry data to discriminate between the peat and the underlying sediments. Where concentrations were within instrument error they were not graphed and interpreted.

Peat is a complex material to analyse by pXRF, with data collected being influenced by matrix effects (e.g. high bound moisture, texture, and organic material). Verification of pXRF data was achieved by undertaking XRF fusion analyses. These results were compared showing relationships for alkalis and alkaline earths to be sound (Appendix 1).

Data presented for TGN01 in Figure 7e shows that compared to underlying sediments, the upper meter of fibric and sapric peat is characterised by higher hydraulic conductivity (K), EC and pXRF measured Ca, Cl, S and Sr, which exist in the minerals mapped by XRD and spectrometric methods (e.g. gypsum, aragonite and halite). The peat has lower pH, pH(fox) and concentrations of As, $Al_2O_3$, Fe, $K_2O$, $SiO_2$, Ti, V and Zr. Low buffering capacity due to limited or no clay minerals and carbonates. Concentrations of Ce, MgO, Mn, Rb are similar throughout the profile indicating potential mixing and similar geochemical conditions with respect to these elements.

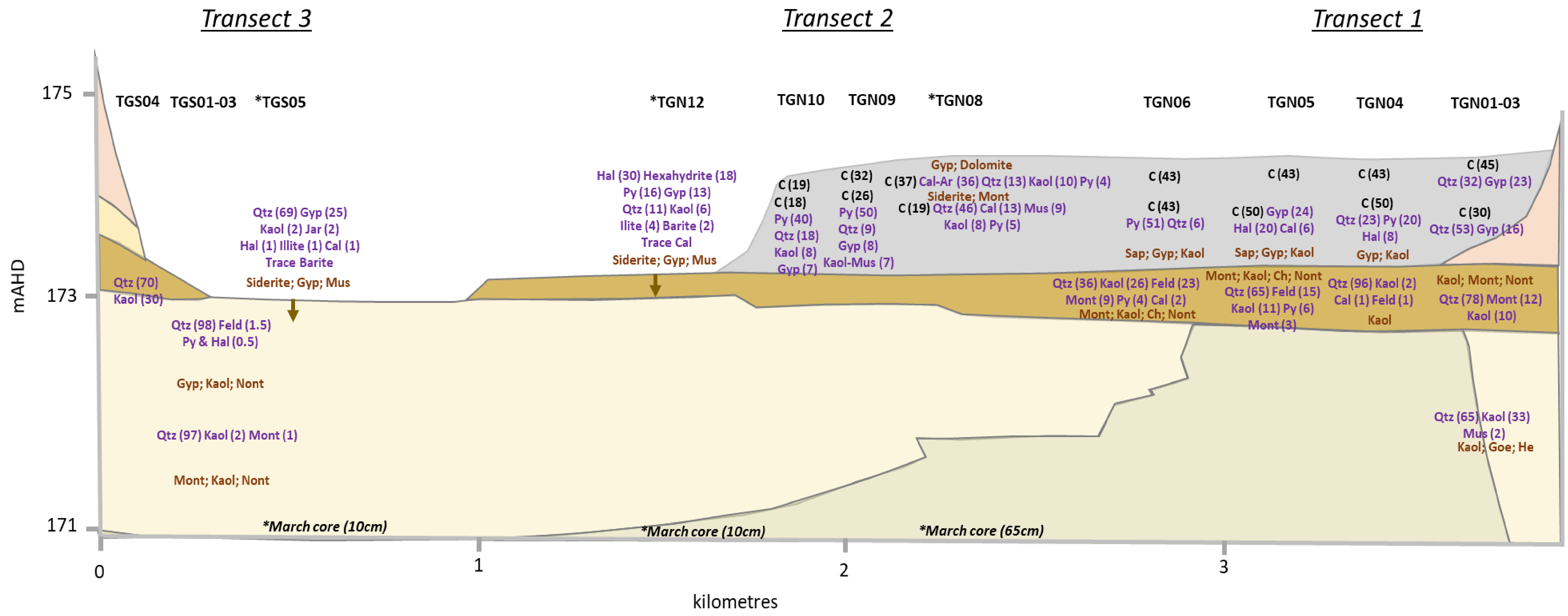
Similar pXRF trends are observed across other soil sampling sites, with the most noticeable change being peat exhibiting a decrease in Ca, S, Sr, Rb and Mn with distance from the shoreline (e.g. TGN05 and TGN06; Appendix 1). Greatest geochemical change occurs in core at the southern end of Tordit-Gurrup Lagoon, where the peat shelf is desiccated. Core sampled in March 2020 (TGN08; see Appendix 1) has elevated Al2O3, Ca, Ce, Cr, Fe, $K_2O$, Mn, $SiO_2$, Sr and Ti compared with TGN06 (Appendix 1).

Potential hydrological and geochemical processes controlling these changes are discussed in Section 3.5.

## 3.5 Spatial trends and process interpretation

Data collection across the three transects within Tordit-Gurrup Lagoon is designed to gain a better understanding of spatial and temporal controls on the release and fate of acid stores within and beneath the peat. This is discussed in more detail in Rutherford (2019).

Results presented here show that the geochemical stratification within the peat can be resolved and mapped along the three transects studied (Figure 9). Peat soil classified here as containing between 30 to 100% organic matter, (Lindsay 2010).



*Ar = aragonite (calcium carbonate)*
*Barite = barium sulfate*
*C = organic carbon*
*Cal = calcite (calcium carbonate)*
*Ch = chlorite (magnesium iron phyllosilicate)*
*Dolomite = calcium magnesium carbonate*
*Feld = feldspar (potassium sodium calcium tectosilicates)*
*Goe = goethite (iron oxyhydroxide)*
*Gyp = gypsum (calcium sulfate)*
*Hal = halite (sodium chloride)*
*He = haematite (iron oxide)*
*Hexahydrite = magnesium sulfate*
*Illite = potassium magnesium iron phyllosilicate*
*Jar = jarosite (potassium iron sulfate)*
*Kaol = kaolinite (alumina phyllosilicate)*
*Siderite = iron carbonate*
*Nont = nontronite (iron alumina phyllosilicate (smectite))*
*Mont = montmorillonite (sodium calcium magnesium alumina phyllosilicate (smectite))*
*Mus = muscovite (potassium phyllosilicate)*
*Py = pyrite (iron sulphide)*
*Qtz = quartz (silicon oxide)*
*Sap = saponite (calcium magnesium iron alumina phyllosilicate (smectite))*

*Figure 9: Geological cross section for Transects 1 to 3, annotated with semi-quantitative X-Ray Diffraction analyses (purple text), ASD spectrometer (SWIR-VNIR) mineralogy (brown text) and carbon IRMS weight % results (black text) (see Appendix 1 for individual site details) (Note location of analyses is not to scale and X-Ray Diffraction data adjusted and combined with IRMS carbon data to show approximate compositions of organic and mineral matter).*

Analyses show that peat has the highest elemental and mineralogical concentrations of sulfur. Metals expected to be present due to their association with organics, such as U, Hg, Cu, Pb, Zn, Ni and Co, are not evident in high concentrations in pXRF data. Sediments below the peat also have low concentrations of these metals suggesting vertical hydrological processes and inheritance may play a role. Also, humic acids within the peat could be influencing heavy metals to remain in the dissolved phase, and when dried and analysed they have not been resolved.

To assess the presence of organic, as well as pH, redox and salinity induced reactions, mineralogical data acquired across Transects 1, 2 and 3 are combined to form a continuum in Figure 9. Results confirm that gypsum is the main mineralogical sink for sulfur at the northern lagoon shoreline (TGN01). This association changes to pyrite towards the central and southern desiccated area of the lagoon (e.g. TGN04 to TGN06 (March 2015) and TGN09 and TGN10 (Oct-Nov 2019). Minor calcite is also present in this area.

These mineralogical patterns are also present in other peat wetlands studied; see Appendix 1. Shoreline coring at Poorginup Swamp mimics Tordit-Gurrup Lagoon northern shoreline's organic carbon and mineral matter composition (Poor01; Appendix 1). Limited sampling at Poorginup Swamp measures low organic carbon. Byenup Lagoon and Noobijup Swamp (e.g. BY04 and NB04; Appendix 1) peat cores were collected approximately 100 and 50 metres from their respective lake shorelines (Figure 2). Organic and mineral matter composition analyses confirm carbonates and pyrite are present, with organic carbon decreasing with distance from the shoreline at Byenup. Noobijup shows a different trend as peat development in this lake's shoreline is limited (Appendix 1).

Scanning electron microscopy (SEM) data confirm that pyrite has a microbial origin, existing as framboids and frequently pseudo-morphing existing plant root material (Rutherford 2019 and Rutherford in prep). Under the current climate and lake hydrology the sequential oxidation and reduction of pyrite is likely as the water table fluctuates to levels that seasonally wet and dry the peat profile. At Tordit-Gurrup Lagoon, field reduction potential (Eh) and dissolved oxygen (DO mg/L) measurements are lower at the end of summer compared to winter when the lake is inundated (Appendix 4). Declines in the water table and soil moisture promotes $O_2$ to infiltrate fibric peat and $CO_2$ degassing, particularly in drought. Seasonal rewetting and lake inundation encourage anoxic conditions and $CO_2$ accumulation in peat pore water (Estop-Aragonés et. al. 2011).

Geochemically, redox conditions and mineralogy indicate several reaction sequences for iron and sulfur are viable. Pyrite could oxidise in the presence of carbonates to form gypsum (Ritsema and Groenberg 1993) and seasonal inundation of desiccated areas may drive the microbially mediated reduction of ferric ion, which promotes the precipitation of iron carbonates (Burton et. al. 2008). The significant reduction in organic carbon at TGN08 suggests reductions in organic carbon have occurred over a long period of time.

Redox conditions were known to be more anoxic in the past and resulted in perennial waterlogging. Waterlogging and subsequent salinisation has had a deleterious effect on peat wetland vegetation (e.g. Gibson and Keighery 1999) and promoted the reduction of pyrite. In the presence of organic carbon this would have consumed organic carbon and produced $H_2S$ and $CH_4$ gases, as well as calcium, magnesium, and iron carbonates (e.g. TGN08 geochemistry) (Thiel et. al. 2019).

Beneath the peat sediments comprising high percentages of sands, then clays, are present and are laterally continuous. High cation exchange capacity clays (e.g. montmorillonite, nontronite and saponite and iron oxides are identified using SWIR-VNIR methods and indicate there is potential to buffer peat soil water if it drains vertically. Gley colouration of sediments beneath the peat suggest a reducing/anoxic environment (see TGN08 Appendix 1). In this zone montmorillonite and nontronite clays occur at the shoreline and saponite and illite towards the centre of the lake (Figure 9).

On the lagoon water body margins remnants of the organic material in the peat is evident and this overlies sediments of variable physical integrity. Sampling and analysis of the upper 10cm of the dry lagoon bed in March 2020 shows the geochemistry is dominated by a thin crust of chloride and magnesium and calcium sulfates (e.g. halite, hexahydrite and gypsum; TGN12 Figure 9). Hexahydrite is also observed at shallow sampling site TGN05, overlying iron rich precipitates (Jarosite and illite), with quartz and gypsum dominating the mineralogy (Figures 9 and 10).

The precipitation of a sulfate crust over such a large area, approximately 20% of the lagoon (~1km$^2$), indicates seasonal cycling of soluble evaporite minerals is likely. Less visible temporary sinks for sulfur (e.g. monosulfidic black ooze) are also identified at shallow depths beneath the lake surface, on the southwest and southeast margins of the lagoon (Steve Appleyard pers. comm). Recent manganese and likely iron precipitates are noted on older ferricrete on the margins of the lagoon (e.g. Figure 11 & Appendix 4). These complexes can assist in the temporary storage of sulfur, dependent on redox, pH, salinity, and microbiological activity.

pH and salinity (EC) are important controls on acidity their spatial distributions across Transects 1,2 and 3 are examined in Figure 12. These data are then reviewed in relation to spatial changes in physical properties (Figure 13). Results show EC and pH produce similar, but different, patterns (Figure 12), indicating they are constrained by different near-surface hydrological and geochemical processes. pH is higher where secondary porosity development in the peat is less developed (e.g. desiccation cracks) and the aquitard integrity is higher (e.g. Transect 1; Figure 13b). High EC tends to correspond with low pH and occurs in areas where peat water drains into the lagoon water body and evaporates. The lower pH reflecting the low buffering capacity of sediments in this area (Figure 13a&b). EC increases with depth, and this reflects the current hydrological condition of the wetland, as reductions in average rainfall increases seasonal ponding and evaporation.

*Figure 10: Tordit-Gurrup Lagoon surface water body evaporite crust March 2020; left to right photos show the physiographic contrast between the surficial sands and evaporite crust (southern Tordit-Gurrup, view to the east), soil sample TGS05 (see Figure 9 for mineralogy) and close up of Hexahydrite crystals (see Figure 9 for mineralogy).*

*Figure 11: Surface precipitates on and near the central eastern margin of Tordit-Gurrup Lagoon July 2020; left to right photos show manganese precipitate on older (Cenozoic) ferricrete (purple-black precipitate at the tree line), decomposed fibric peat with organic and mineral matter located between the eastern shoreline and TGN10 (see Figure 9 TGN08 for mineralogy) and inundation of TGN10 showing dissolution of surface precipitates (e.g. halite, magnesium and calcium sulfates; Figure 6) (Note that the desiccation cracks are not visible, but remain open beneath the lake water).*

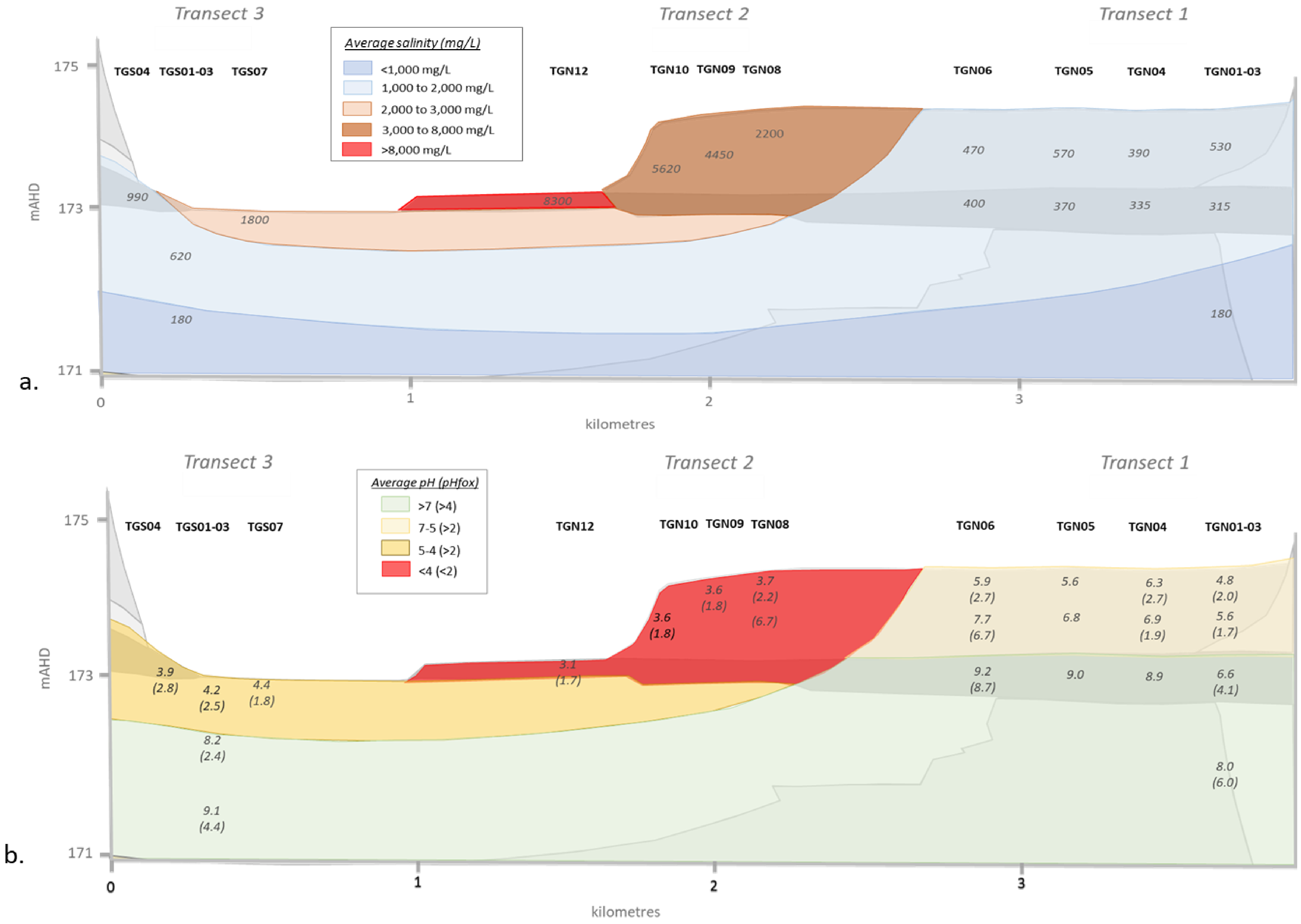


*Figure 12: Geological cross section for Transects 1 to 3, annotated with a. average salinity data and interpreted spatial extents (Appendix 1 EC1:5 data converted to mg/L using relationship in Figure 8a) and b. average pH and interpreted spatial extents. (Note location of analyses is not to scale).*

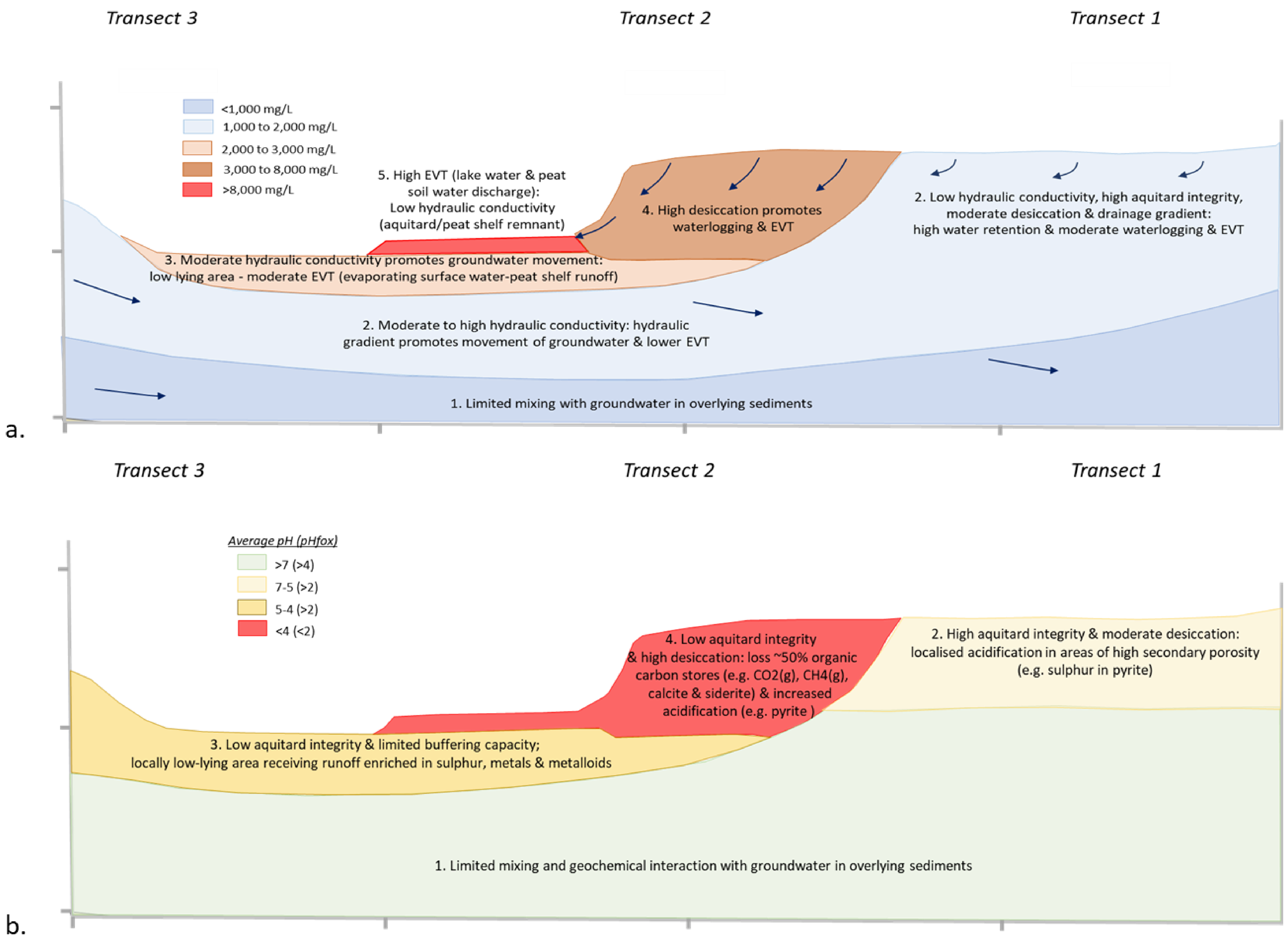


*Figure 13: Geological cross section for Transects 1 to 3, annotated with a. interpreted hydrological processes constraining average salinity and b. interpreted hydrological processes constraining average pH. (Note location of analyses is not to scale).*

The dissolution and redistribution of soluble sulfur and sodium evaporite minerals in winter is likely to reduce the internal buffering potential of the peat (e.g. consume carbonate minerals). Increases in salinity may encourage geochemical reactions that will increase acidity by promoting the mobilisation of temporary storages of iron and sulfur (e.g. dissolution of siderite; Cullen et. al. 2017).

# 4 Upscaling results using airborne geophysics

Results from Section 3 confirm that higher salinities characterise peat wetlands that are maintaining high water retention and minimal drying (e.g. Poorginup Swamp) as well as those that are experiencing desiccation (e.g. Tordit-Gurrup Lagoon). Underlying sediments tend to have lower salinities, which means that mapping peats based on salinity requires the use of a method that can resolve change in the uppermost one to two metres (e.g. thickness of the peat is between 0.5 to 1.5 metres in the peat wetlands examined here (Appendix 1).

To assist in the mapping and characterising of processes in peat wetlands airborne electromagnetic (AEM) data acquired over the Muir-Byenup Catchment in 2008 was reprocessed and inverted to enhance near surface conductivity variability (Søerensen et. al. 2019). One metre interval conductivity-depth images were produced for 0 to 10 metres below ground level (Appendix 2).

Wetlands with peat substrates in Muir-Byenup Catchment are generally located in broad, or local scale topographically low-lying areas (Figure 14). Peat wetlands in the contemporary valley floor can connect under different rainfall regimes (intensity and longevity). It is thought that most wetlands in this area previously had a peat or carbon rich substrate. Identification of the remaining peat wetlands in Figure 14 was determined from maps in Gibson and Keighery (1999) and updated in (2015) from information provided by previous DBCA Regional Ecologist Roger Hearn. Smaller peat wetlands, like Noobijup or Poorginup Swamp, have discrete catchment areas and less natural connectivity with other wetlands. The dynamics of the surface water processes affecting these systems are explored in Rutherford (in prep).

AEM derived solute storage, for the uppermost 2 metres of peat and sediments, was calculated using relationships shown in Figure 8b. These are displayed in Figure 15 (in mg/L). Figure 15 details the relative salinity for different peat wetlands, with highest salinities observed in Byenup Lagoon. Elevated groundwater levels following winter rains occurs in wetlands and within the valley floor, which encourages widespread evapotranspiration. As a result, high salinity is present in wetlands and lakes that do or do not have peat substrates. This confirms that salinity data cannot be used in isolation to map peat wetlands in the Muir-Byenup Catchment.

Other physical properties that allow peat to be discriminated from other wetland substrates are its bulk density and pH (Section 3). Geochemically peat is like underlying sediments but generally displays a muted response, probably due to humic acids assisting metals to remain in a dissolved state. Elevated sulfur and calcium and strontium are potential diagnostic elements.

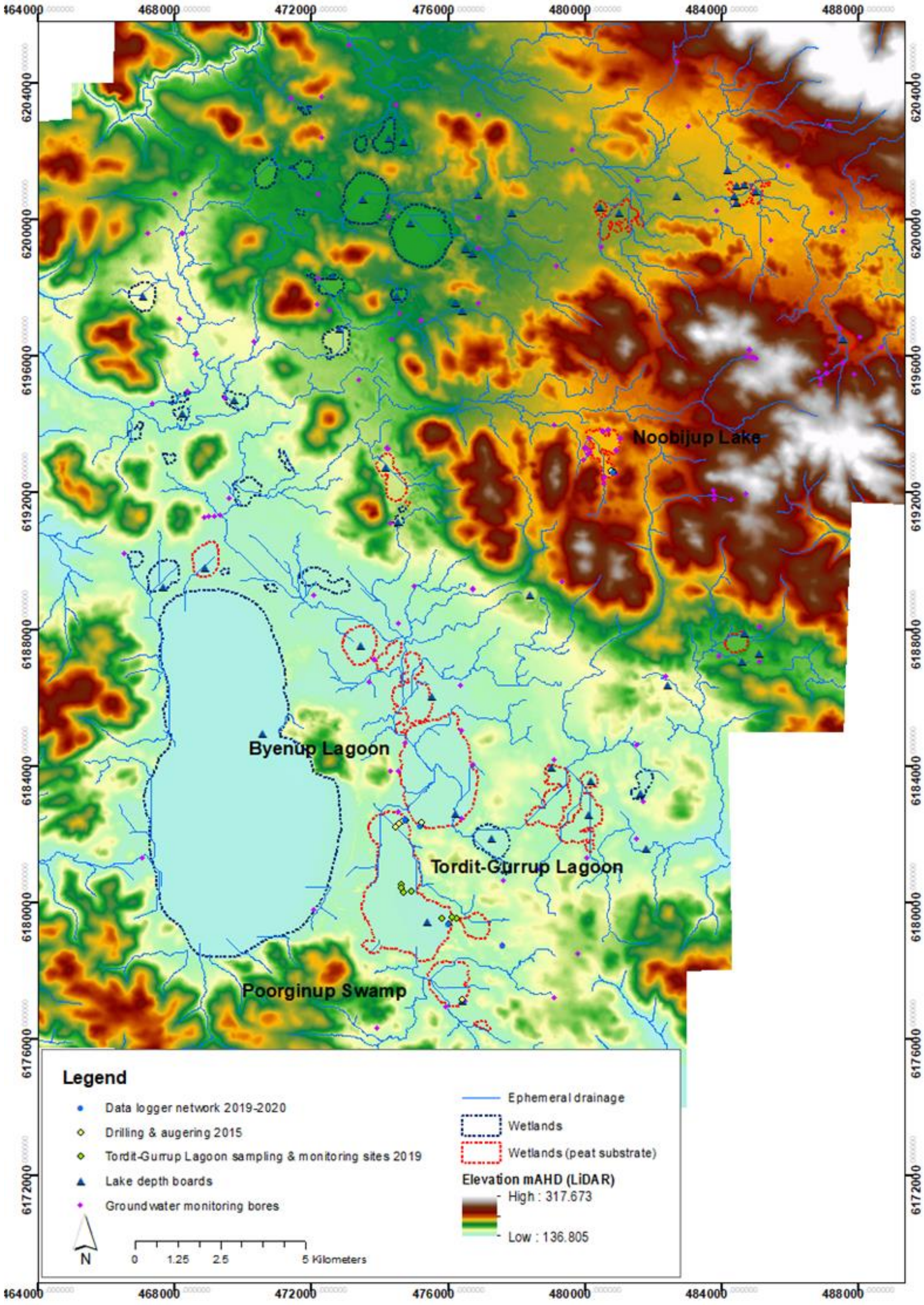


*Figure 14: Muir-Byenup RAMSAR site topography (LiDAR data) with modelled drainage network and location of wetlands with and without peat substrates.*

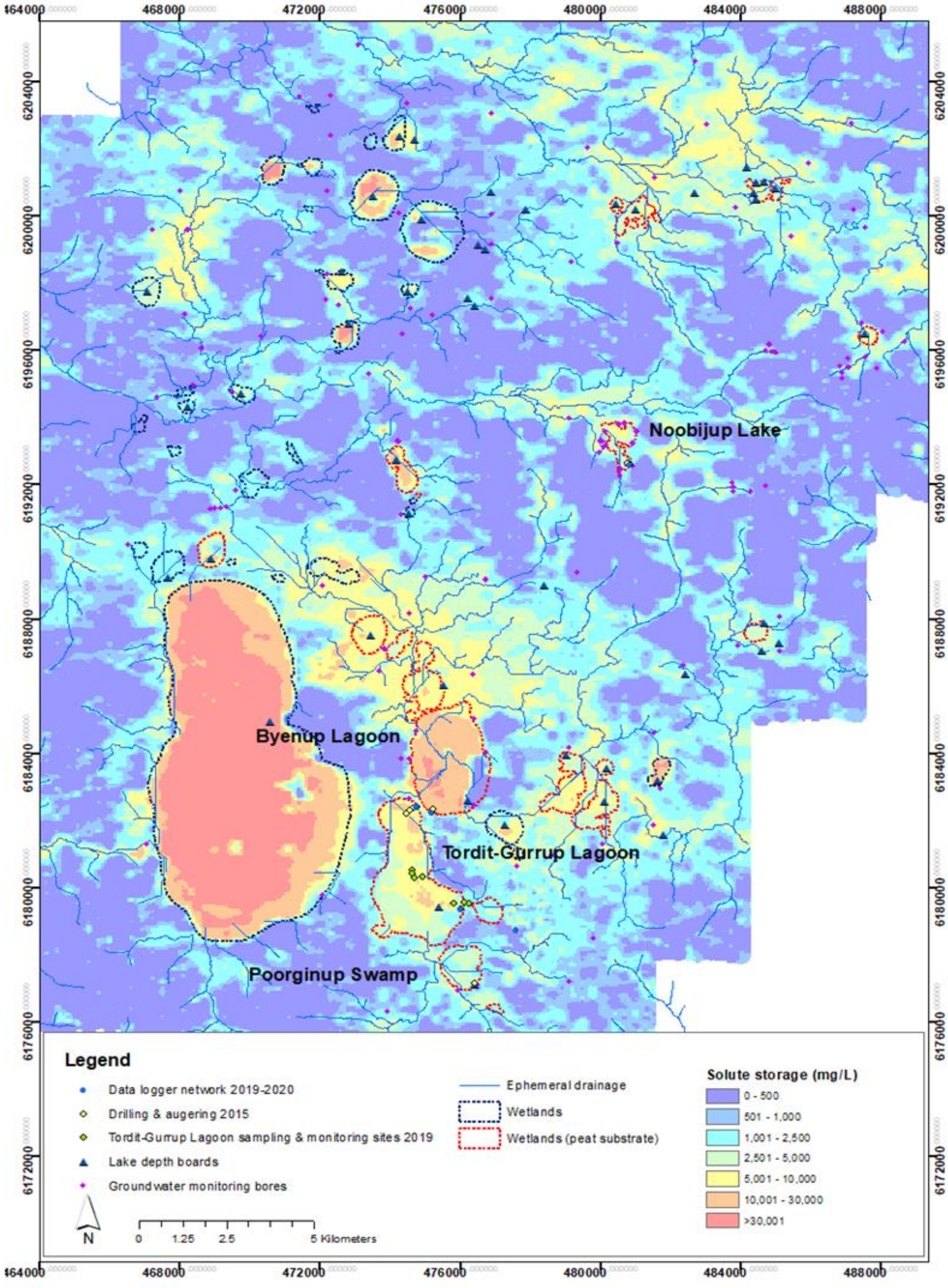


*Figure 15: Muir-Byenup RAMSAR site airborne electromagnetic (AEM) conductivity depth image for solute storage (0 to 2 metres below ground level) (converted to mg/L using relationship in Figure 8b*

Strontium and calcium are geochemically associated with thorium, which makes the Th channel of airborne radiometric data a potential mapping tool. However, maps of airborne radiometric data (e.g. K (potassium), Th (Thorium) and U (Uranium) acquired in 2013 display a relatively uniform low response across the valley floor and don’t appear to resolve or map contrasts that represent peat wetlands in the Muir-Byenup Catchment (Appendix 3).

The generally widespread low radiometric response of peat and sediments within the Muir-Byenup palaeovalley suggests the peat substrates do not provide a mappable contrast with other sediments. Therefore, undertaking further processing (e.g. ratioing or combining data) is unlikely be effective at delineating peat wetlands.

Fingerprinting the physico-chemical signature of the peat and assessing broadscale approaches to mapping it in the Muir-Byenup Catchment with continue in work reported in Rutherford (in prep).

# 5 Hydrogeochemistry and groundwater flow

Monitoring groundwater levels and quality continued from the 3rd to the 6th March 2020, with Managed Recharge contracted to undertake the pumping and sampling of groundwater and downloading of dataloggers (see Table 1).

Where dataloggers were installed within the desiccated peat at Tordit-Gurrup (e.g. TGN09 and TGN10; Figure 1), groundwater excavations were used to sample groundwater (Figure 16). This was anticipated, as in summer groundwater levels drop to the base of the sapric peat within the basal clayey sands, and the mini-piezometers constructed at TGN09 and TGN10 are not designed to maintain accurate groundwater levels, as well as provide the volume of water for the end of summer laboratory chemical analyses.

Groundwater samples from other bores were obtained with a Geotech peristaltic low-flow pump and a YSI water quality sampling meter (Figure 16). Samples were taken once physico-chemical parameters stabilised, which was generally around 30 minutes. Chain of custody documentation for the different laboratories, field physico-chemistry results and tabled, quality assured, and graphed hydrogeochemistry data are compiled in Appendices 4, 5 and 6.

As detailed in Rutherford (2019), field laboratory pH tends to be higher than field measurements, the latter showing more realistic values compared with soil pH and soil metal storages. Laboratory pH is generally around 0.7 of a pH unit greater than field measurements (Appendix 4). Field alkalinity was measured with a HACH alkalinity test kit (Figure 16) and these data were used to quality assure laboratory results. Taking this approach geochemical charge balance errors for the 17 water samples collected in Oct-Nov 2019 and March 2020 were generally less than 5%; 4 samples (~23%) were greater; MU51 5.5%; TGS01/02 6.1%, NB01 9.8% and TGS06 5.6% (Appendix 4).

Groundwater surface water interactions for data collected in October and November 2019 and March 2020 are further assessed by plotting the data within the broader dataset collected between 2015 and 2017 (Appendices 4, 5 & 6).

### 5.1.1 Major ion chemistry

Major ion data are displayed in Appendix 4 as bivariate plots of different major ion concentrations (mmol/L) against chloride as chloride tends to be conservative (e.g. stay in solution). Ratios of ions against chloride provides a useful model to assess change in the ionic composition of samples against the ionic composition of rainfall.

As reported in Rutherford (2019), similar trends are present when groundwater and peat soil water data are plotted with surface water data collected in lakes. There is a higher degree of scatter/variation within and between the peat soil water and groundwater data. The main trends show that calcium (Ca) increases in peat soil water, particularly in Poorginup Swamp shoreline, as well as shallow groundwater sampled in Tordit-Gurrup Lagoon (TGN01 and TGS01) and upgradient of Poorginup Swamp (MU46S).

*Figure 16: March 2020 data collection (left to right); shallow excavation to sample desiccated peat soil water at the end of summer; pumping and sampling groundwater (BY01) and alkalinity testing (TGS01/0)*

Elevated magnesium (Mg) also exists in Poorginup and Tordit-Gurrup Lagoon's northern shoreline (TGN01), with other samples showing minor depletion against rainfall. Potassium (K) and sulfate ($SO_4$) exhibits greater depletion, indicating a mineralogical sink exists (e.g. jarosite, illite, gypsum, pyrite; Figure 9). Elevated sulfate ($SO_4$) occurs in shoreline samples of peat at Poorginup Swamp groundwater in Tordit-Gurrup and Byenup Lagoons (TGN01 and BY01). Graphs of sulfate against calcium confirm gypsum dissolution is common and pyrite dissolution occurs, which supports data presented in Figure 9. These relationships will be explored further in Rutherford (in prep).

### 5.1.2 Metals, metalloids and REE

Bivariate plots of metal, metalloid and rare earth element (REE) concentrations were examined against chloride and pH to assess preliminary trends, sampling gaps and identify dominant hydrogeochemical and hydrological processes (Appendices 5 and 6).

Results and a preliminary interpretation show similar observations reported in Rutherford (2019). Some metals and metalloids correlate with increases in chloride (e.g. sequential evaporation and dissolution (recycling) or increases in salinity driving geochemical reactions that release particular metals) and/or pH (linked with redox changes), particularly when groundwater and peat soil water were treated as separate populations. Increased salinity appearing to be an important geochemical process in the release of B, Fe, Li, Mn, Pb Rb, Se and Sr in peat (Appendix 5). Reductions in pH driving geochemical changes that increase peat soil water in Al, Co, Li, Mn, and U (Appendix 5).

REE concentrations generally increase with decreasing pH, weak but inconclusive trends apparent in bivariate plots for individual analytes (Appendix 6). The relationship with pH improves when normalised heavy rare earth element (HREE) data peat and sediment groundwater are graphed with pH (Figure 17). Indicating a common process controls the release of HREE in groundwater and peat soil water.

### 5.1.3 Stable water isotopes ($\delta^2$H vs $\delta^{18}$O)

Stable water isotope analyses were undertaken to provide an independent environmental tracer dataset to assess evaporation and mixing in groundwater and lake water. Results are plotted in Figure 18a and show that enrichment in $\delta^2$H and $\delta^{18}$O occurs with increased potential evaporation (e.g. lake water, peat soil water and shallow groundwater generally exhibiting elevated values compared to samples collected from deeper bores).

Comparing peat soil water sampling from desiccated peat that occurs marginal to the Tordit-Gurrup Lagoon water body resolves seasonal trends (e.g. enriched values at the end of summer that approach lake water concentrations (Figure 18b). This indicates that the lake water develops from the discharge and evaporation of desiccated peat soil water. Peat soil water sampled closer to lake shorelines showing less isotopic enrichment (Figure 18a).

Figure 17a plots peat groundwater HREE against $\delta^{18}$O. Increases in HREE and $\delta^{18}$O indicates both are concentrating through evaporation.

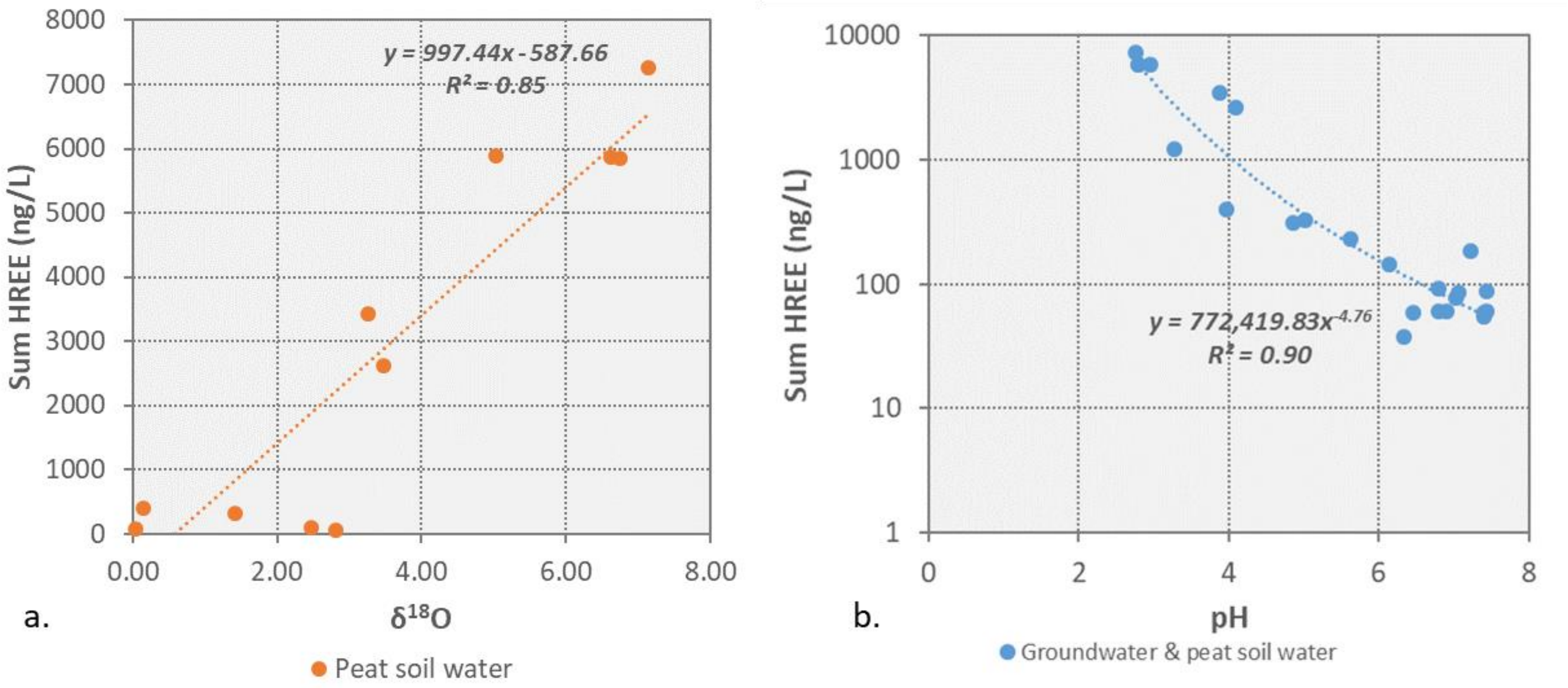


*Figure 17: Bivariate plots of normalized Post Archaean Australian Shale (PAAS) heavy rare earth elements (HREE) graphed against a. δ$^{18}$O and b. pH.*

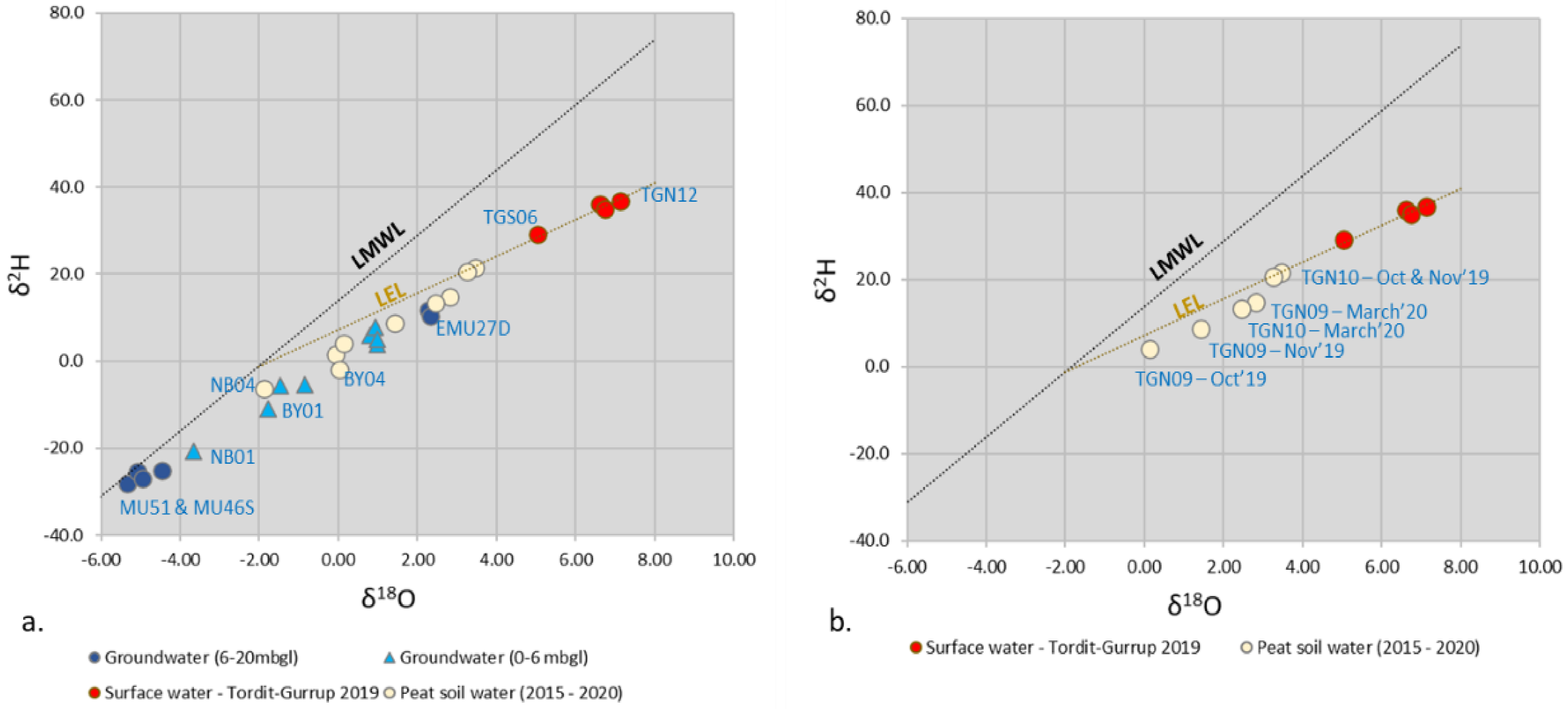


*Figure 18: Bivariate plot of of a. δ$^{2}$H vs δ$^{18}$O, showing local meteroic water line (LMWL) from Hearn (2011) unpublised data (4yr study; 2009-2012; n=118) and local evaporation line (LEL) derived from data interpreted in this report; (a) all data and b. data from Transect 2 and 3 (2019; a.. to 2020).*

### 5.1.4 Groundwater level and quality (data loggers)

Groundwater level and water quality data from data loggers were downloaded in March 2020. A trip planned in May 2020 (Table 1) was delayed due to travel restrictions in regional Western Australia. Data logger downloads also occurred on July 29th and 30th, but the trip occurred after a storm and some forest roads were blocked, which prohibited access to bores MU46, MU51 and TGS01/02. TGN09 could not be accessed due to safety reasons.

High frequency groundwater level and salinity data are collected to review and verify groundwater gradients, recharge and surface water and groundwater interactions. In Muir-Byenup high frequency groundwater level and water quality data are collected using Diver CTD data loggers. Once data are downloaded, data are processed to compensate for barometric pressures and graphed to quality assure against manual measurements and past data collected (Appendix 7). Appendix 7 also includes a table with data logger compliance information; individual graphs for each bore/data logger showing groundwater levels (hourly and manual measurements) metres below ground level (mbgl) and salinity (mS/cm) on separate axes and separate groundwater level and salinity graphs for the period Oct/Nov 2019 to Aug 2020.

To ensure datal logger salinity data were providing reliable measurements they were compared against laboratory electrical conductivity measurements in Figure 8c. The results show an improvement in the relationship reported in Rutherford (2019) and confirm they can be used with confidence to estimate groundwater salinity.

Abrupt changes in data logger groundwater level and salinity data collected in Oct-Nov 2019 or March 2020 are due to pumping and sampling and are generally short lived (Appendix 7). Overall, the bores show the same groundwater level trends, with a seasonal increase in groundwater levels producing a maximum level in October 2019 and a minimum near the end of March 2020. Bore TGN01 displays around a 1.5m seasonal change in groundwater levels, with slightly lower seasonal changes exhibited by bores other peat wetland shoreline bores BY01 and NB01.

Data logger installed at TGS01/02 was unable to be downloaded in July 2020, but data collected to date show elevated groundwater level responses compared with the northern shoreline bore TGN01 (Appendix 7). Peat soil water bore TGN10 was downloaded in July 2020 and data indicate groundwater levels were below the base of the mini-piezometer construction for four months, from Dec 2019 to March 2020. Providing four months for the desiccated peat in this area to dry and geochemical reactions to take place.

The most interesting salinity data collected to date are provided by TGN10, as the data show increases and decreases in salinity in response to isolated rainfall events in Dec 2019 and spring and winter rainfall received from March to July 2020. Data presented in Appendix 7 and Figure 8 showing an average salinity change of around 7 mS/cm (4,000 to 10,000 mg/L), which agrees with AEM solute storage data (Figure 19). Salinisation is identified in Section 3.5 as a major threat to driving reactions that consume organic carbon and acidify soils and sediments.

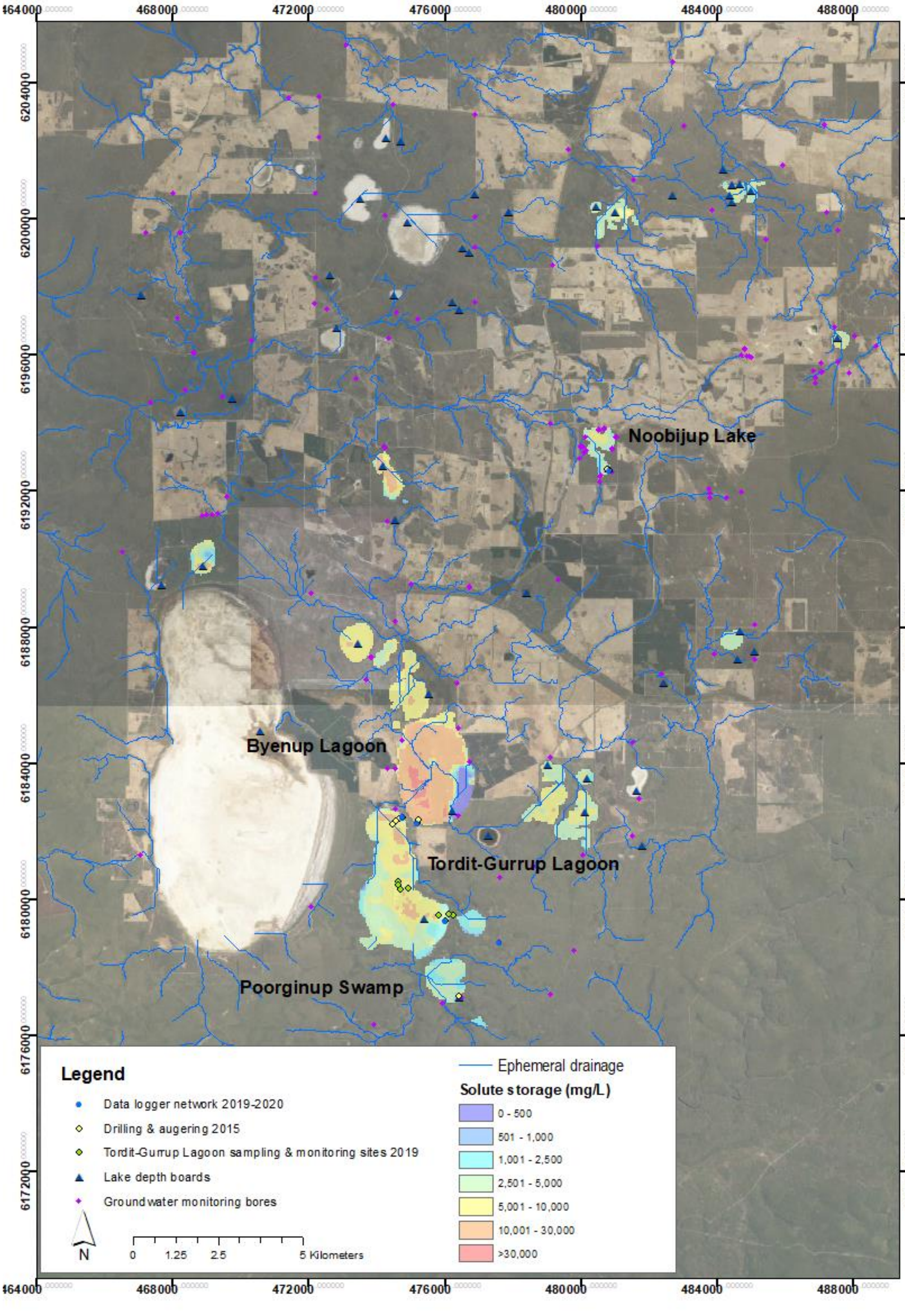


*Figure 19: Muir-Byenup RAMSAR site airborne electromagnetic (AEM) conductivity depth image for solute storage (0 to 2 metres below ground level) (see Figure 13) clipped to mapped peat wetlands.*

Integrating information obtained from data logger groundwater levels and salinity, with rainfall and stable water isotope results will help estimate the quantity of water required to re-saturate peat and carbonaceous soils in Tordit-Gurrup Lagoon. This work will be progressed when all data loggers have been downloaded in November 2020 and reported in Rutherford (in prep).

Groundwater level and salinity data from peat shoreline bores BY01, TGN01 and NB01 shows that under the current climate groundwater levels are at, or within 0.5m of the ground surface, for around 9, 5 and 6 mths respectively ((Appendix 7). High volumetric water content and water retention of peat will delay deep drainage and reduce fire risk, particularly where underlying aquitards have high physical integrity.

Secondary porosity development in peat that dries and becomes desiccated encourages deep drainage when groundwater levels decline. This increases the likelihood of acidification and burning, the latter where sufficient organic carbon, that can be considered a fire risk, remains in the desiccated profile.

# 6 Summary and discussion

Research questions posed have been progressed by undertaking the further work identified in Rutherford (2019). These tasks are outlined below.

- Monitoring has continued, as outlined in Table 1 (Rutherford (2019) and this report).
- Peat soil geochemistry data collected for SWCC Project No. 022LM.5640 has been incorporated and interpreted within the larger, existing peat soil database acquired for DBCA project SP 2014-24.
- Groundwater logger data have been reviewed to ensure they are delivering fit for purpose data to interpret hydrological processes and incorporate into a water balance assessment (model) and
- Water quality data (salinity) have been reviewed and interpreted to identify hydrological process boundaries.

Additional work undertaken includes.

- Borehole geophysical data (nuclear magnetic resonance (NMR)) have been interpreted to produce a 2.5-D physical model of the hydrogeology beneath Tordit-Gurrup and Byenup Lagoons.
- Airborne electromagnetic (AEM) data have been calibrated, using groundwater salinity data, to assess the current condition within peat wetlands (e.g. identify peat wetlands with elevated salinities that may represent drying, e.g. fire and/or acidification risk) and
- Soil and sediment geochemistry data have been reviewed within the 2.5D physical model of the hydrogeology, in order to assess spatial variation in hydrological processes.

## 6.1 Further work

Activities to complete agreed project outcomes by June 2021 are outlined below.

- Complete final monitoring and decommission temporary infrastructure (e.g. remove data loggers and mini piezometers TGN09 and TGN10) in November 2020.
- Process, interpret and combine results (e.g. water and soil geochemistry) to refine hydrological process and geochemical reaction boundaries.
- Produce a 3-D hydrogeological model to use as a framework for the carbon, acid, and water balance assessments (models).
- Report results.

# 7 References

Burton, E.D., Bush, R.T., Sullivan, L.A., Johnston, S.G. and Hocking, R.K. (2008). Mobility of arsenic and dissolved metals during reflooding of iron- and organic-rich acid-sulfate soil. Chemical Geology, v 253. 64-73.

Cullen, M.D., Phillips-Lander, C.M. and Elwood Madden, M.E. (2017) Siderite dissolution kinetics in Mars-Analog Brines. Lunar and Planetary Science XLVIII. 2p.

Estop-Aragonés C., Knorr, K. and Blodau, (2012) Controls on in situ oxygen and dissolved inorganic carbon dynamics in peats of a temperate fen. Journal of Geophysical Research. v. 117. P. 1-14. G02002, doi:10.1029/2011JG001888

Farrell C. & Cook B. (2009) Ecological character description of the Muir-Byenup System RAMSAR site south-west Western Australia. Report prepared for the Department of Environment and Conservation. Centre of Excellence in Natural Resource Management, University of Western Australia.

Geological Survey of Western Australia (GSWA), 2012. Satellite ASTER GEoscience Produce Notes for Australia: Geological Survey of Western Australia, 26p.

Gibson, N. & Keighery, G.J. (1999) Assessment of the nature conservation values of the Byenup-Muir peat swamp system, south western Australia: flora and vegetation, Unpublished report for Environment Australia prepared by Department of Conservation and Land Management.

Lindsay, R. (2010) Peat Bogs and Carbon, A Critical Synthesis. Report for RSPB Scotland by the University of East London 344p.

Rockwater (2015) Muir-Byenup peat wetland investigation – bore completion and wetland analyses report. Report for Department of Parks and Wildlife.

Rezanezhad, R., Price, J.S., Quinton, W.L., Lennartz, B., Milojevic, T., and Van Cappellen, P. (2017) Structure of peat soils and implication for water storage, flow and solute transport: A review update for geochemists. Chemical Geology. v. 429. p. 75-84.

Ritsema, C.J. and Groenenberg, J.E. (1993) Pyrite oxidation, carbonate weathering, and gypsum formation in a drained potential acid sulfate soil. Soil Science of America Journal, v. 57. 968-976.

Rutherford, J. (2019), Muir-Byenup peat wetland acid release investigation design and initial monitoring results, Department of Biodiversity, Conservation and Attractions, Kensington, Western Australia.

Rutherford, J. (in prep), Petrophysics of peat in the Muir-Byenup wetlands – why they dry, generate acid and burn (Part 2), Department of Biodiversity, Conservation and Attractions, Kensington, Western Australia.

Smith, M. (2010) Hydrogeology of the Lake Muir–Unicup Catchment, Western Australia: an ecologically important area experiencing hydrologic change. Curtin University Department of Applied Geology, unpublished Doctor of Philosophy Thesis 274p

Søerensen, C., Munday, T.J., and Rutherford, J.L. (2019) Lake Muir SkyTEM Airborne EM Data: Phase 2-Data processing and inversion results, CSIRO Technical Report. CSIRO, Australia. EP 198698, 36pp.

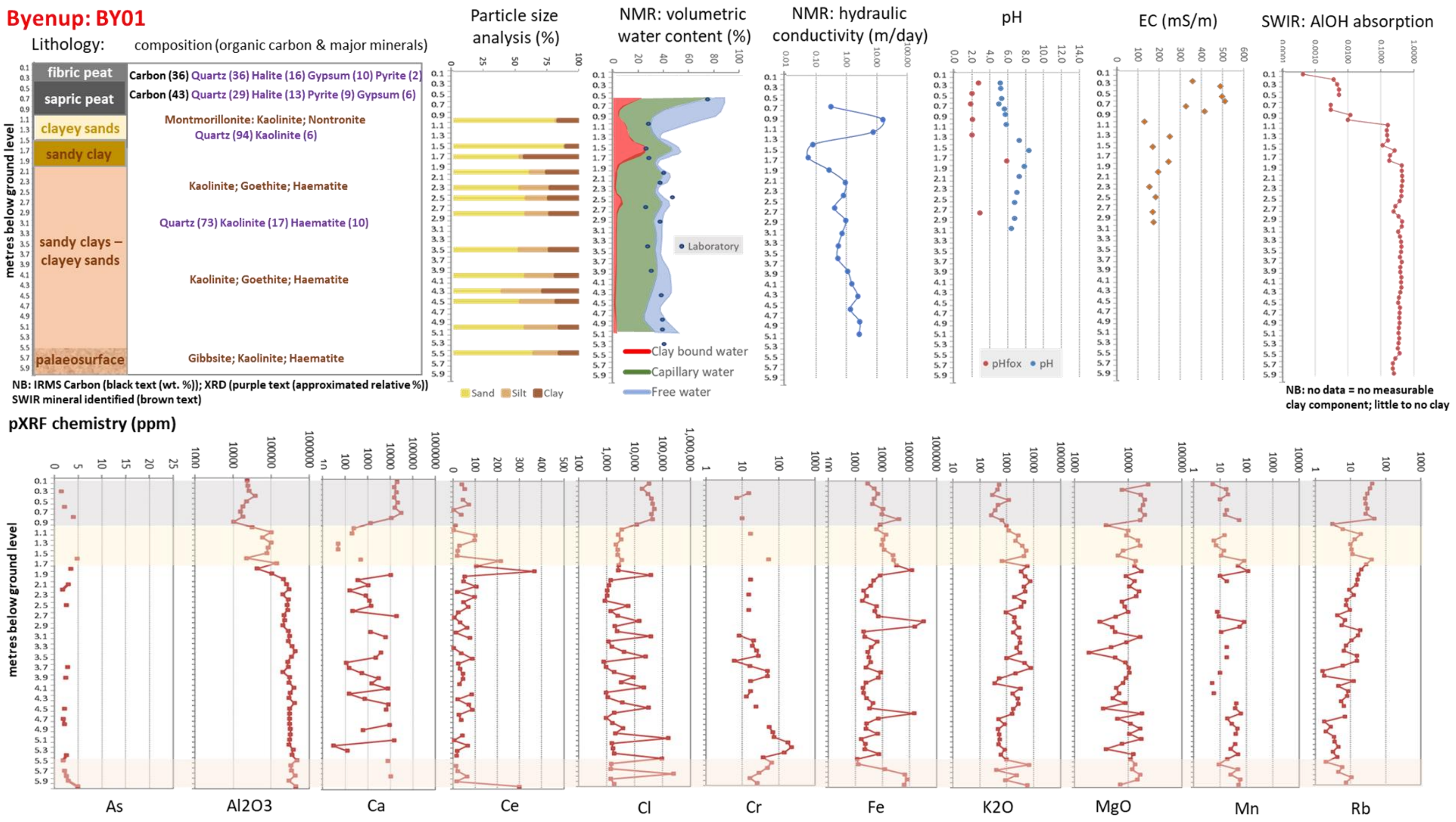
Storey A.W. (1998) Assessment of the Nature Conservation Values of the Byenup-Muir Peat Swamp System, South-western Australia: Physico-chemistry, Aquatic Macroinvertebrates and Fishes. An Unpublished Report for the Department of Conservation and Land Management. Wetland Research and Management, Perth.

Thiel, J., Byrne, J.M., Kappler, A., Schink, B. and Pester, M. (2019) Pyrite formation from FeS and $H_2S$ is mediated through microbial redox activity. PNAS - Proceedings of the National Academy of Sciences of the United States of America, v. 116, no. 14 p. 6897-6902.

Young, D.M., Baird, A.J., Charman, D.J., Evans, C.D., Gallego-Sala, A.V., Gill, P.J., Hughes, P.D.M., Morris, P.J., and Swindles, G.T. (2019) Misinterpreting carbon accumulation rates in records from near-surface peat. Scientific Reports. 9:17939.

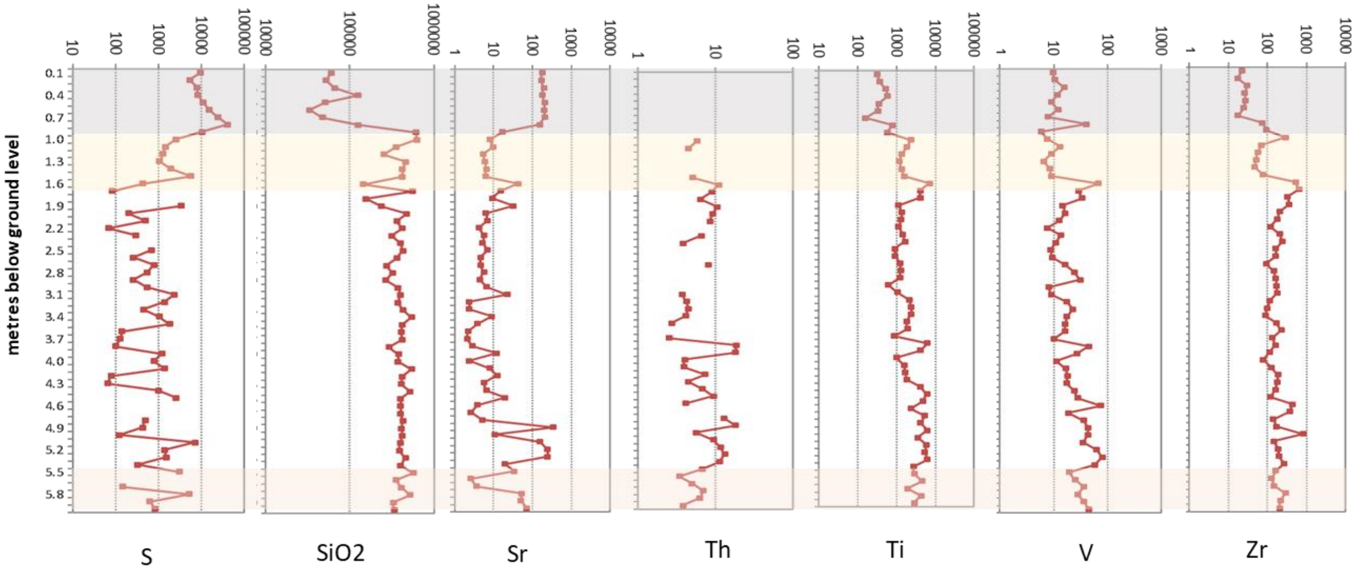
# Appendices

# Appendix 1 Sediment core: field and laboratory data summaries

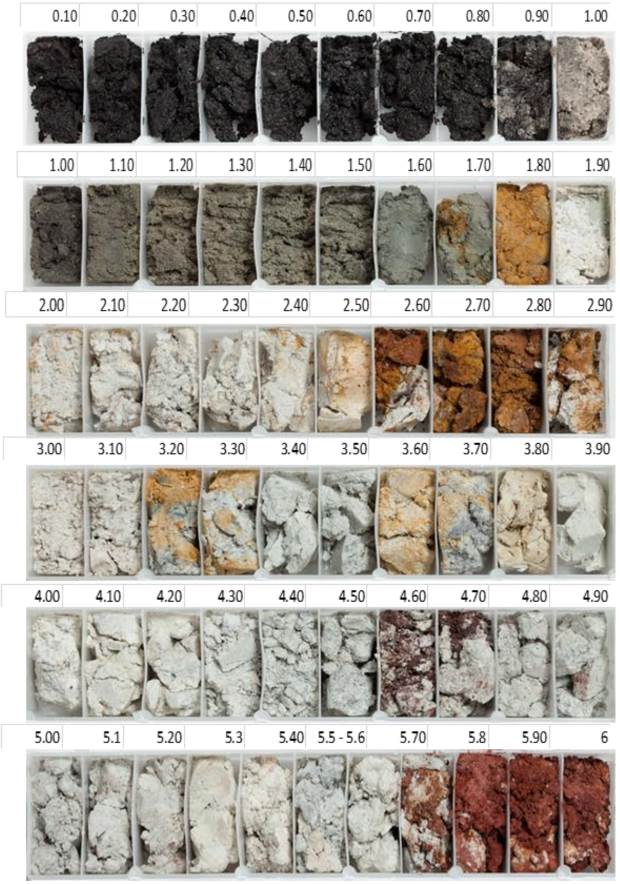


## Byenup: BY01

**pXRF chemistry (ppm)**

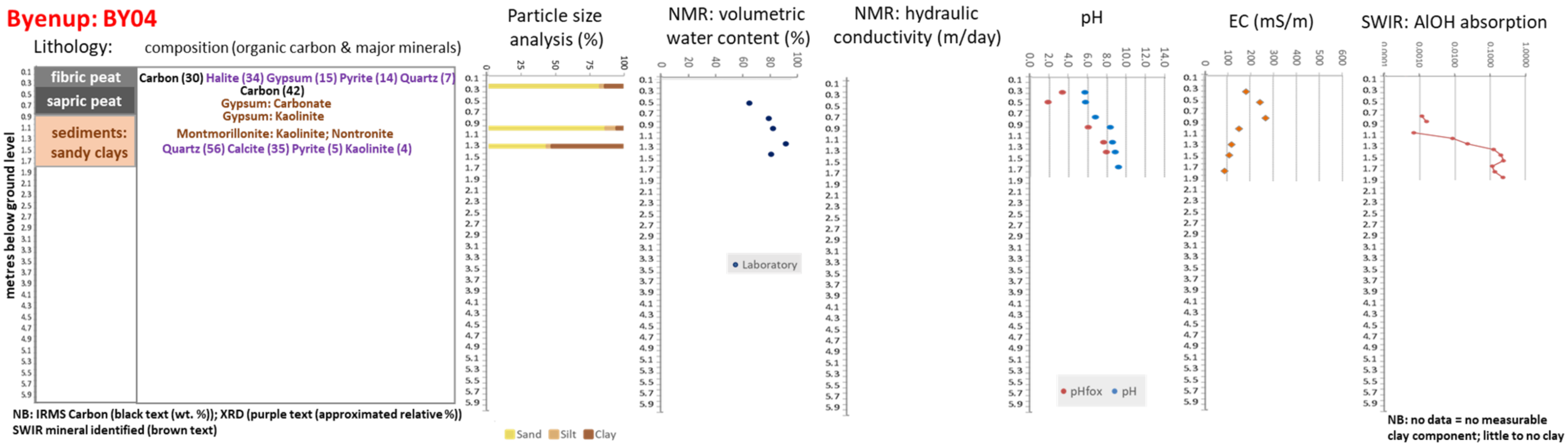


## Drill core chip tray photos (m BGL)



Note: samples 0.1 to 1.00 from BY03
(separate hand augered hole in close proximity to BY01)

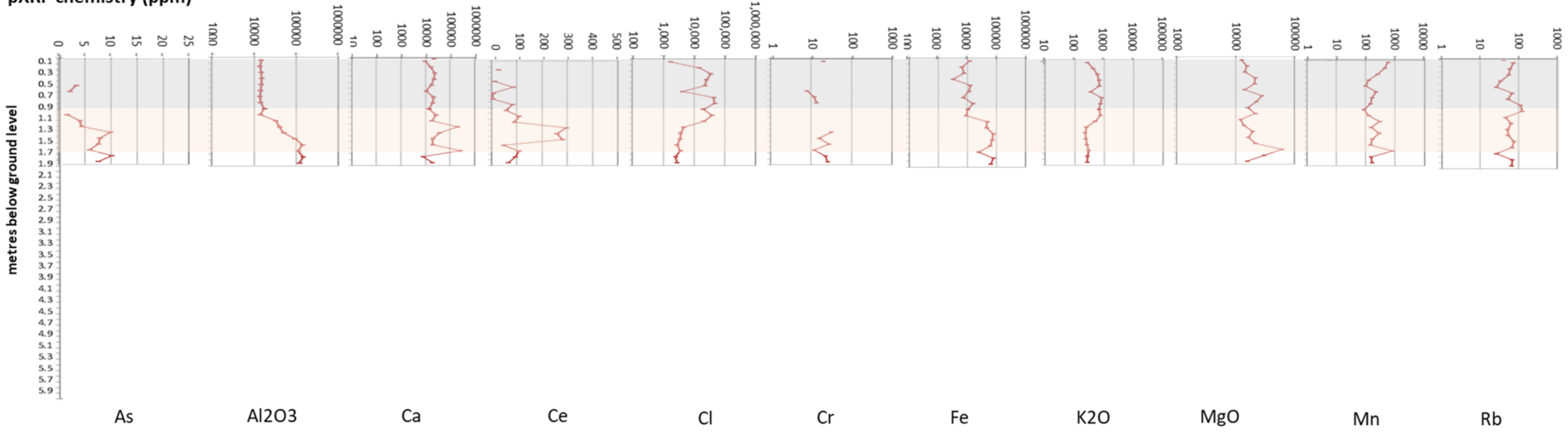
## Byenup: BY04



NB: IRMS Carbon (black text (wt. %)); XRD (purple text (approximated relative %))
SWIR mineral identified (brown text)

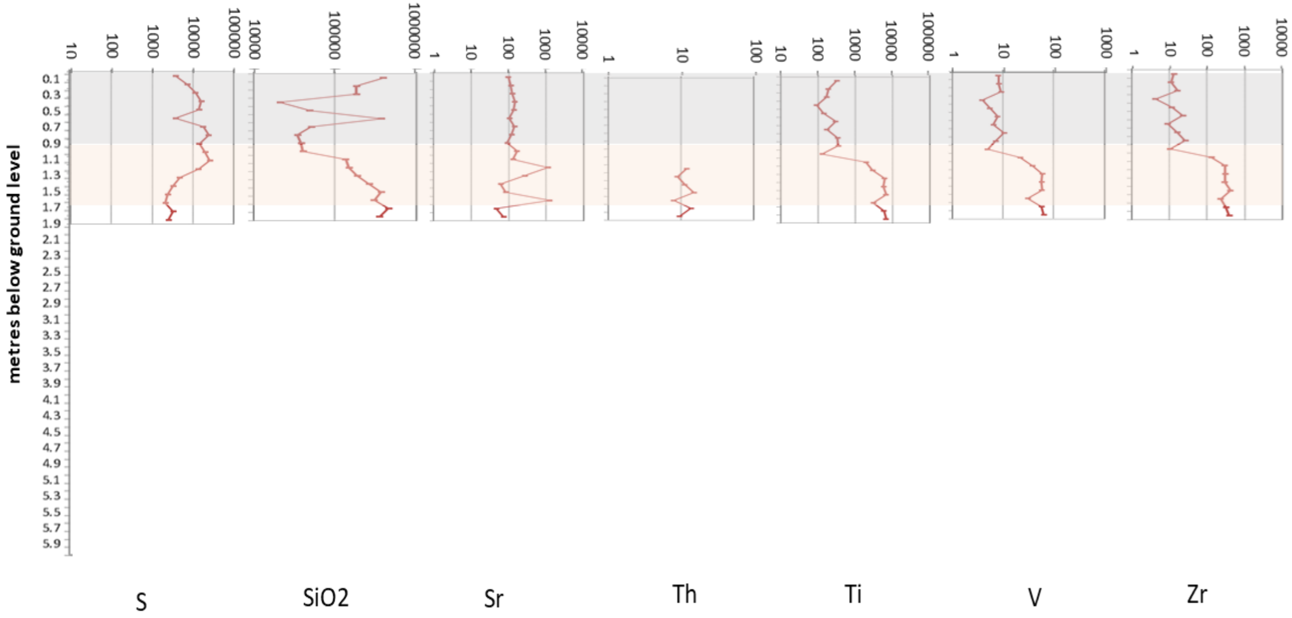
NB: no data = no measurable clay component; little to no clay

### pXRF chemistry (ppm)

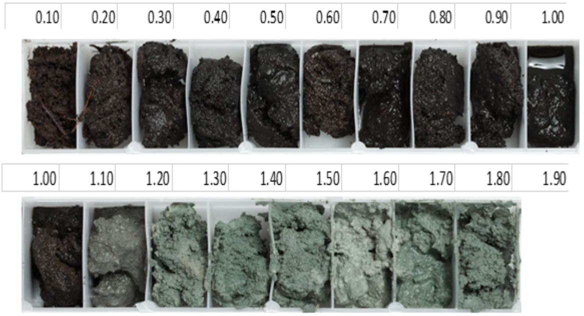


## Byenup: BY04

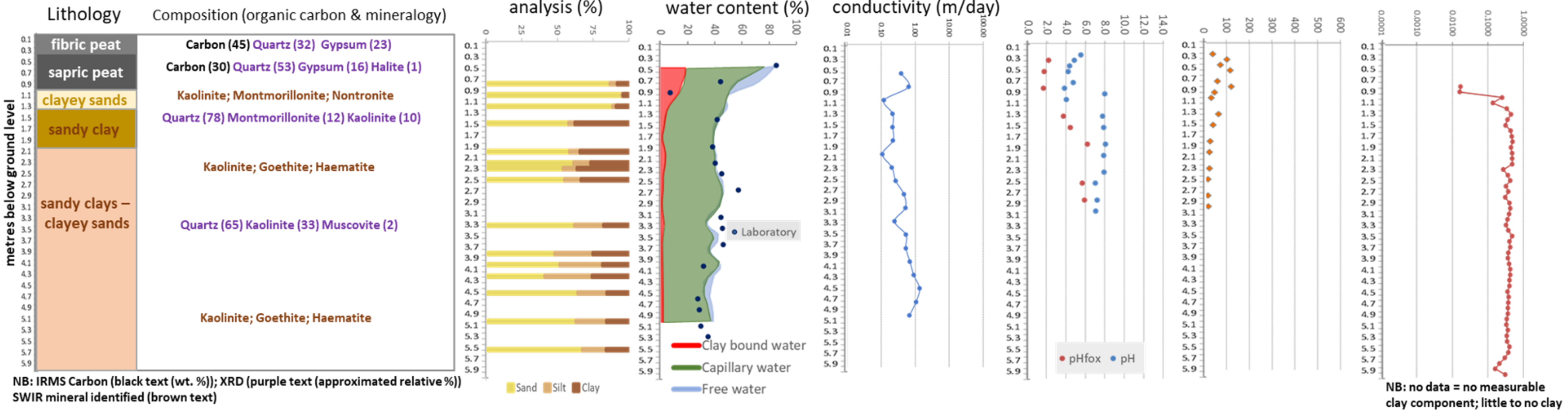
### pXRF chemistry (ppm)



## Drill core chip tray photos (m BGL)



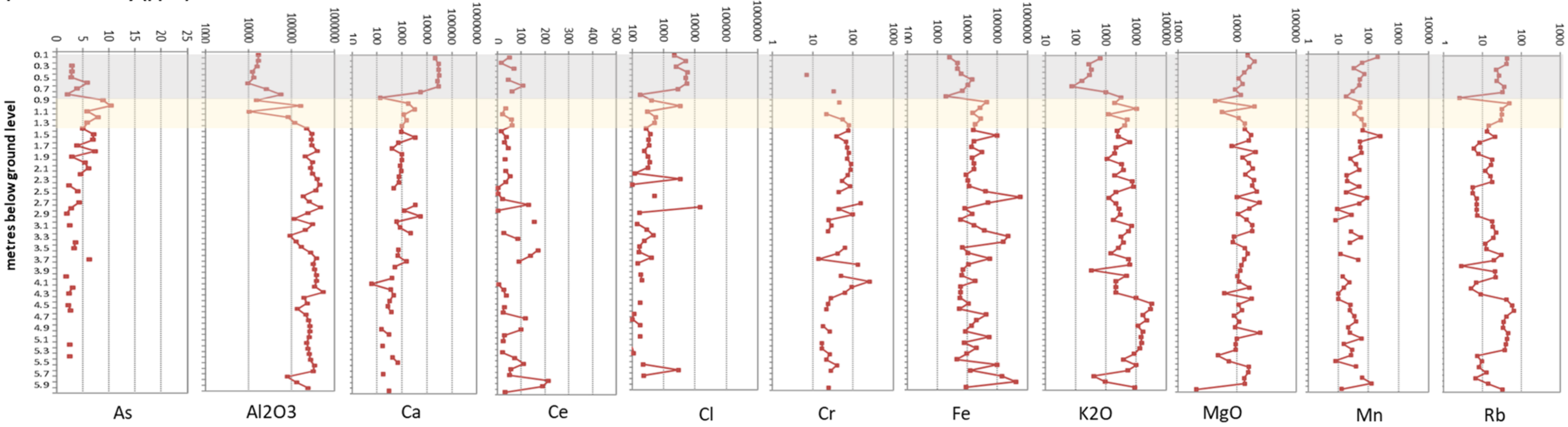
## Tordit Gurrup: TGN01



NB: IRMS Carbon (black text (wt. %)); XRD (purple text (approximated relative %))
SWIR mineral identified (brown text)

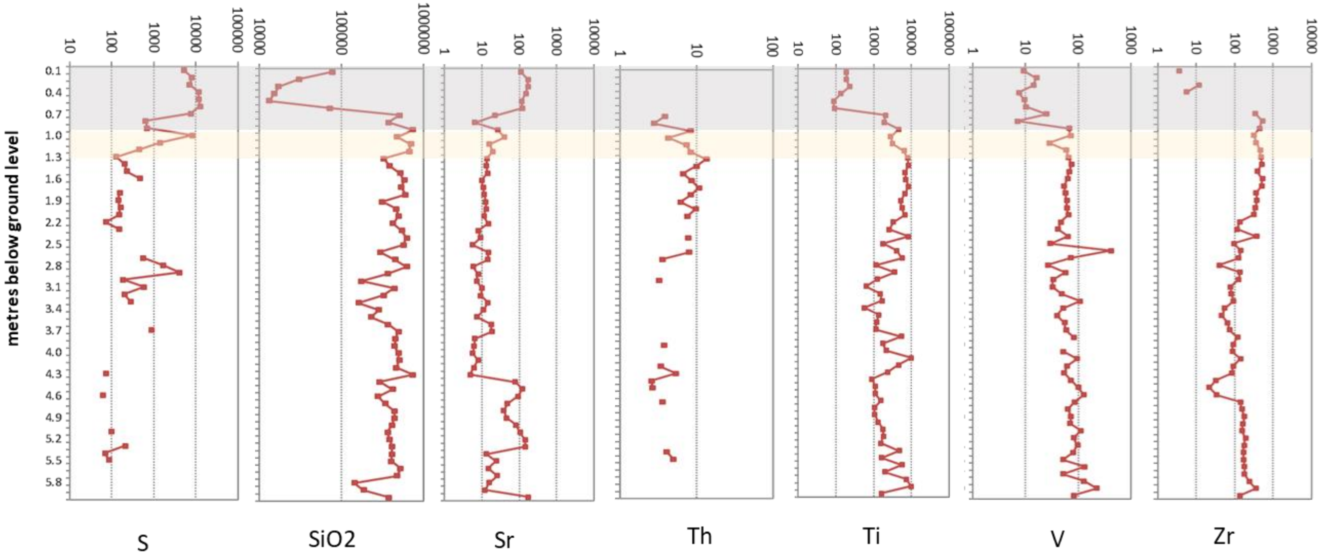
NB: no data = no measurable clay component; little to no clay

### pXRF chemistry (ppm)

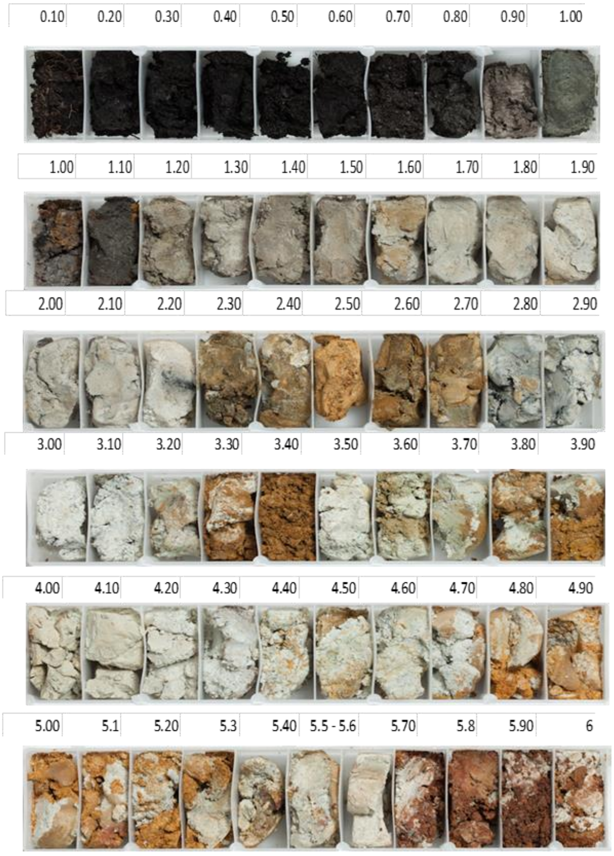


## Tordit Gurrup: TGN01

**pXRF chemistry (ppm)**

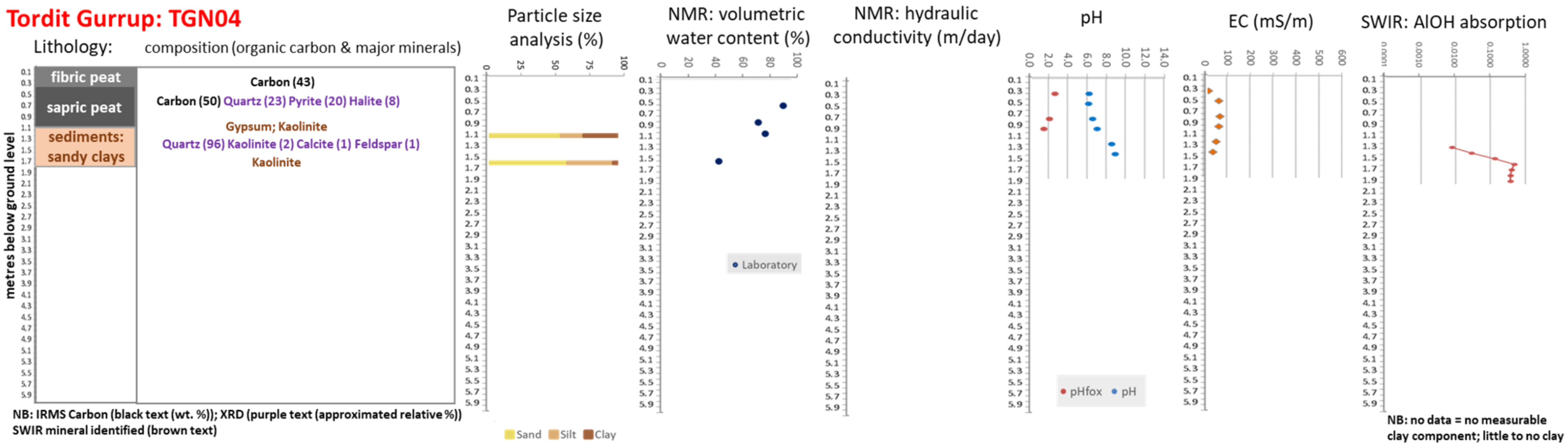


## Drill core chip tray photos (m BGL)



Note: samples 0.1 to 1.00 from TGN03
(separate hand augered hole in close proximity to TGN01)

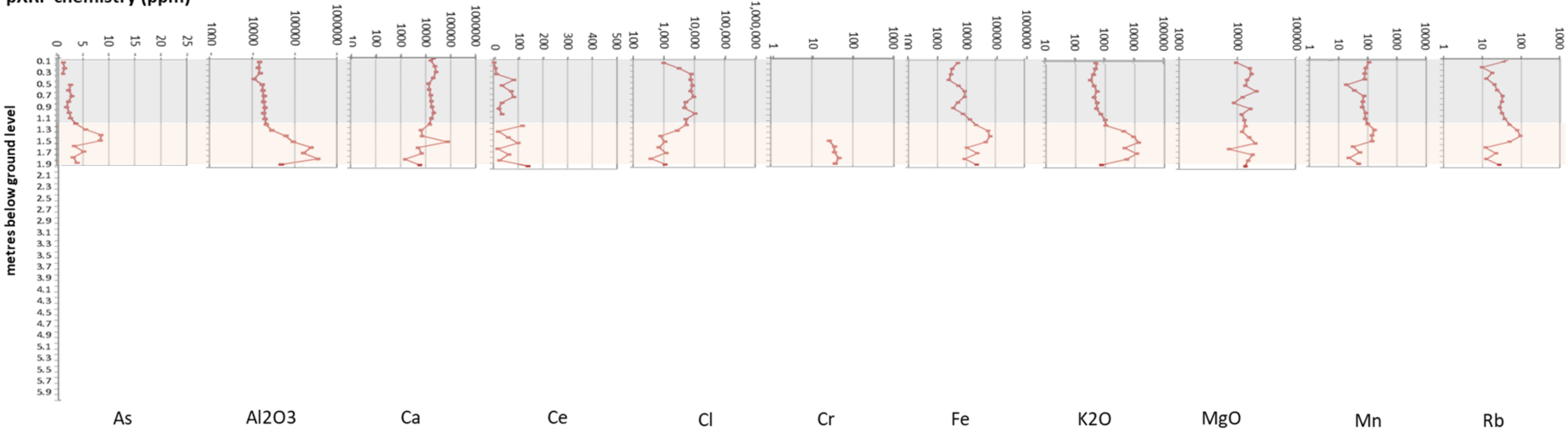
## Tordit Gurrup: TGN04



NB: IRMS Carbon (black text (wt. %)); XRD (purple text (approximated relative %))
SWIR mineral identified (brown text)

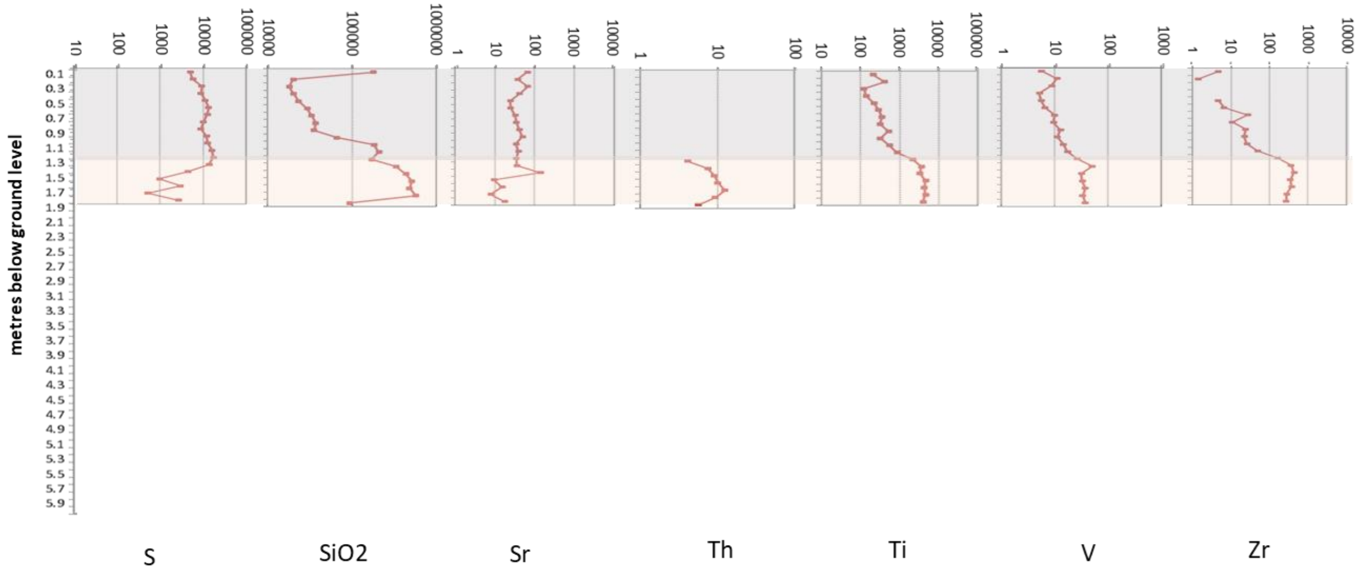
NB: no data = no measurable clay component; little to no clay

### pXRF chemistry (ppm)

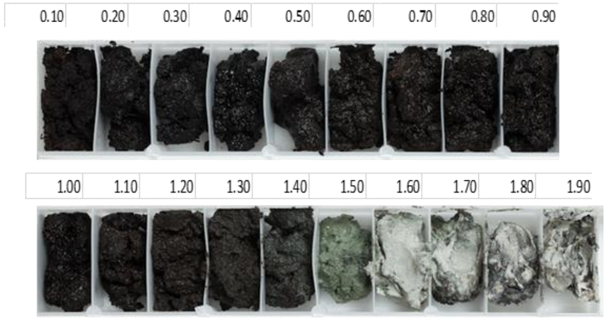


## Tordit Gurrup: TGN04

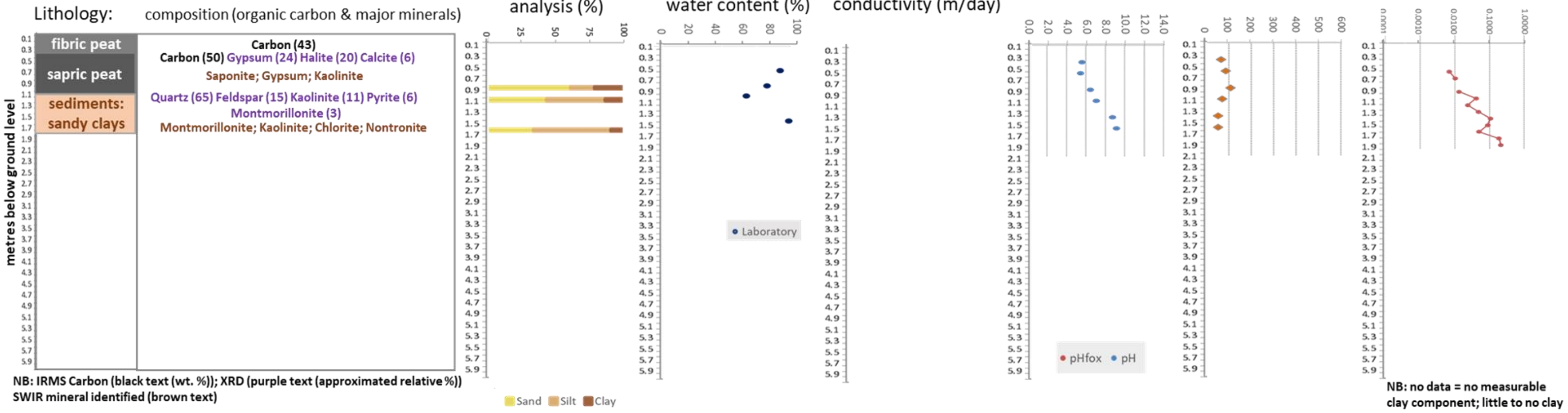
**pXRF chemistry (ppm)**



## Drill core chip tray photos (m BGL)



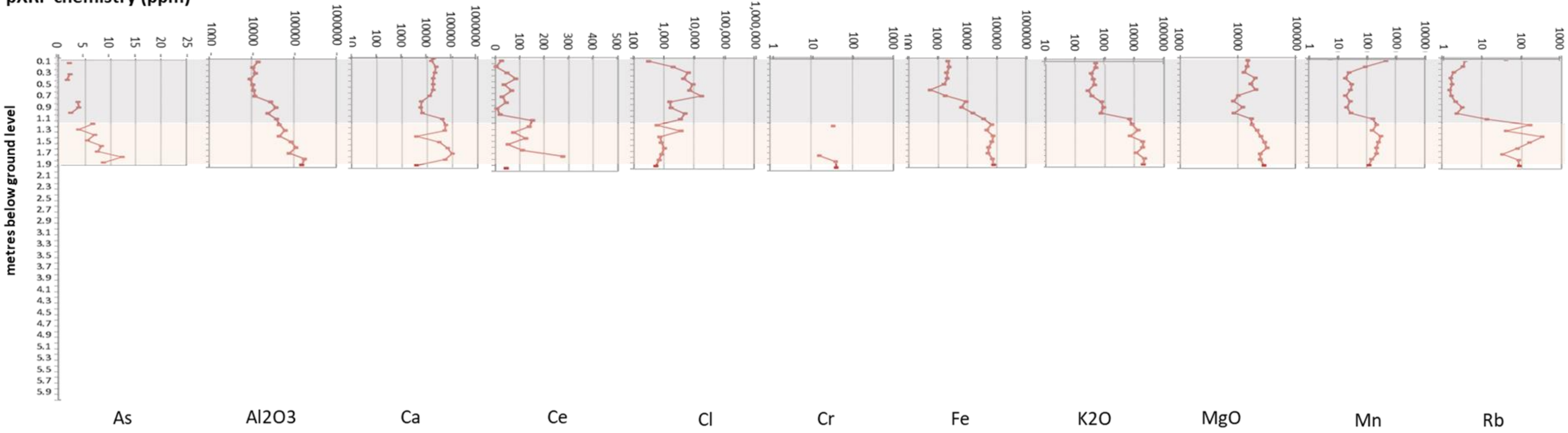
## Tordit Gurrup: TGN05



NB: IRMS Carbon (black text (wt. %)); XRD (purple text (approximated relative %))
SWIR mineral identified (brown text)

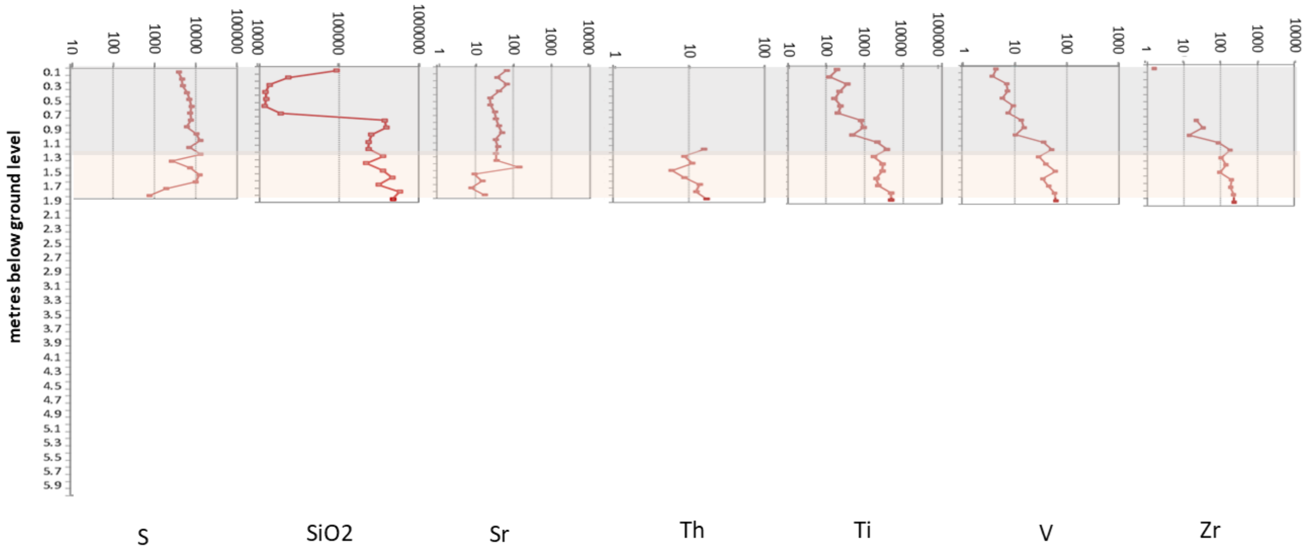
NB: no data = no measurable clay component; little to no clay

**pXRF chemistry (ppm)**

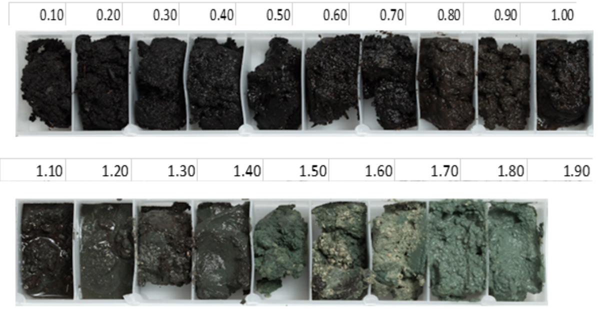


## Tordit Gurrup: TGN05

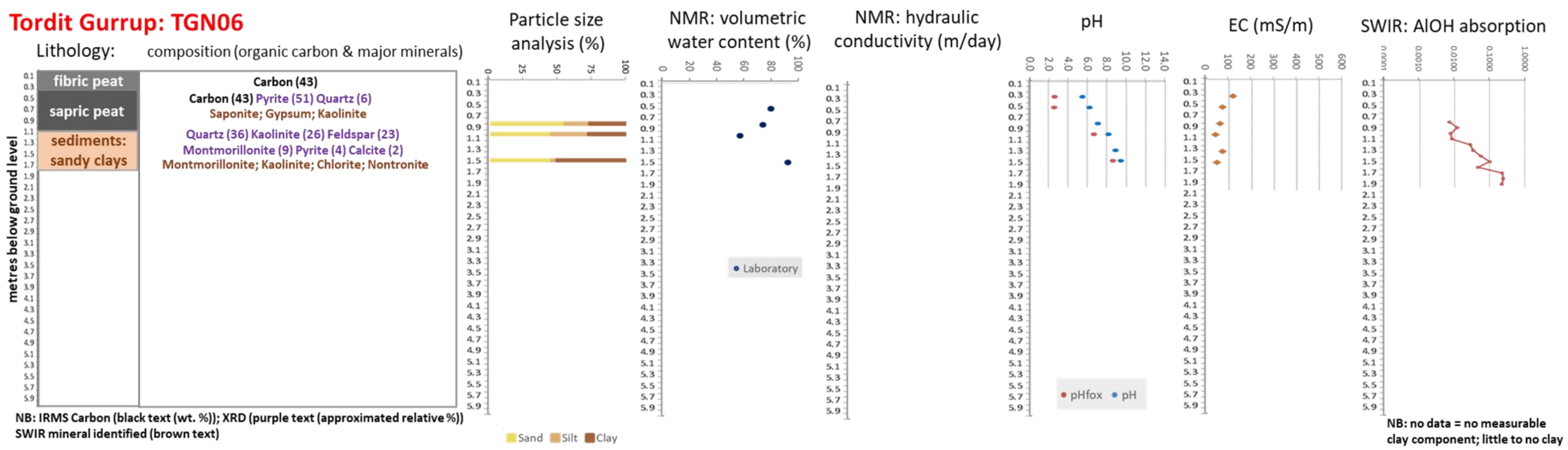
**pXRF chemistry (ppm)**



## Drill core chip tray photos (m BGL)



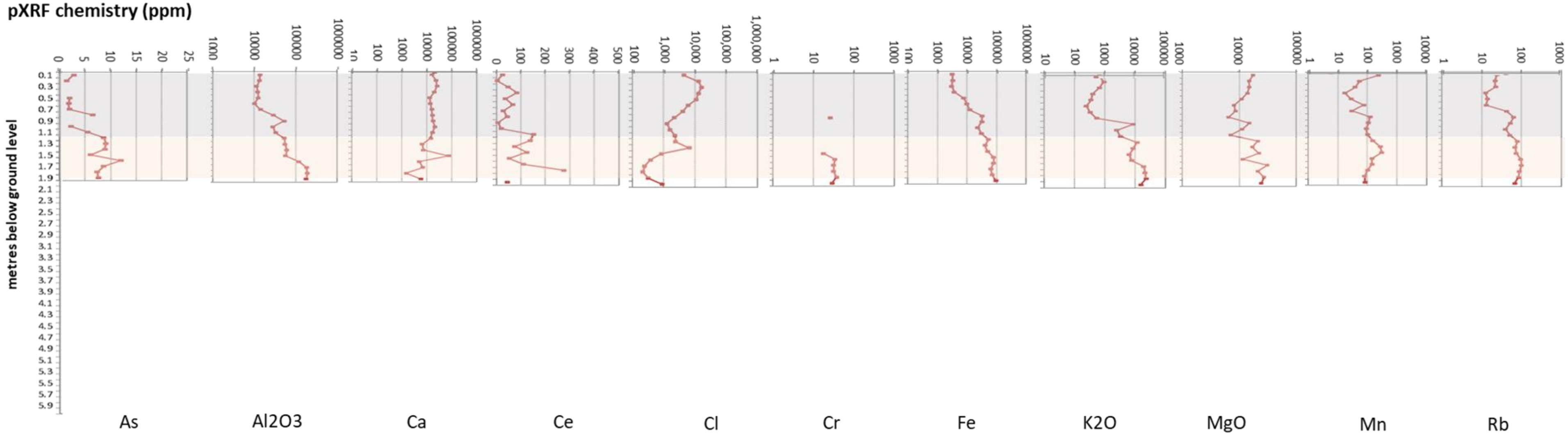
## Tordit Gurrup: TGN06



NB: IRMS Carbon (black text (wt. %)); XRD (purple text (approximated relative %))
SWIR mineral identified (brown text)

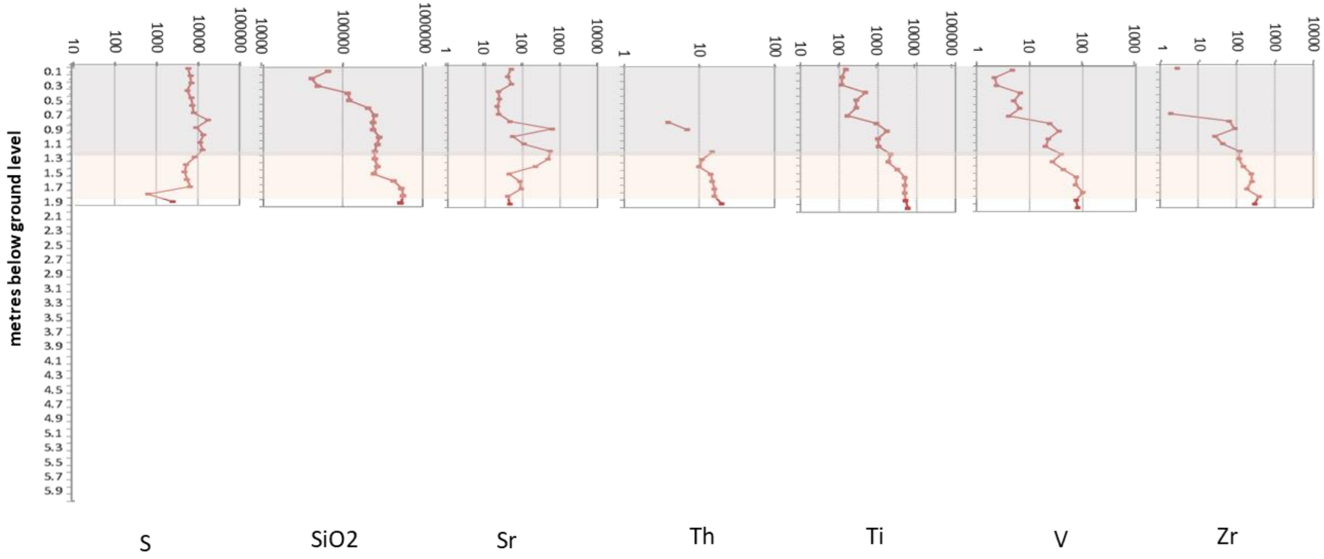
NB: no data = no measurable clay component; little to no clay

**pXRF chemistry (ppm)**

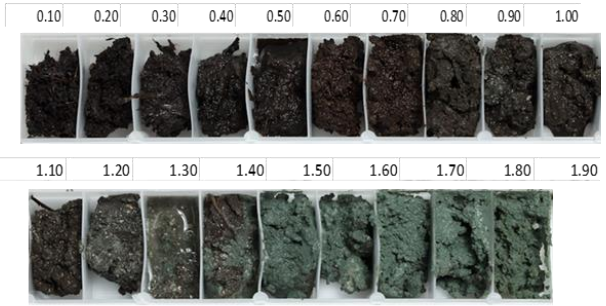


## Tordit Gurrup: TGN06

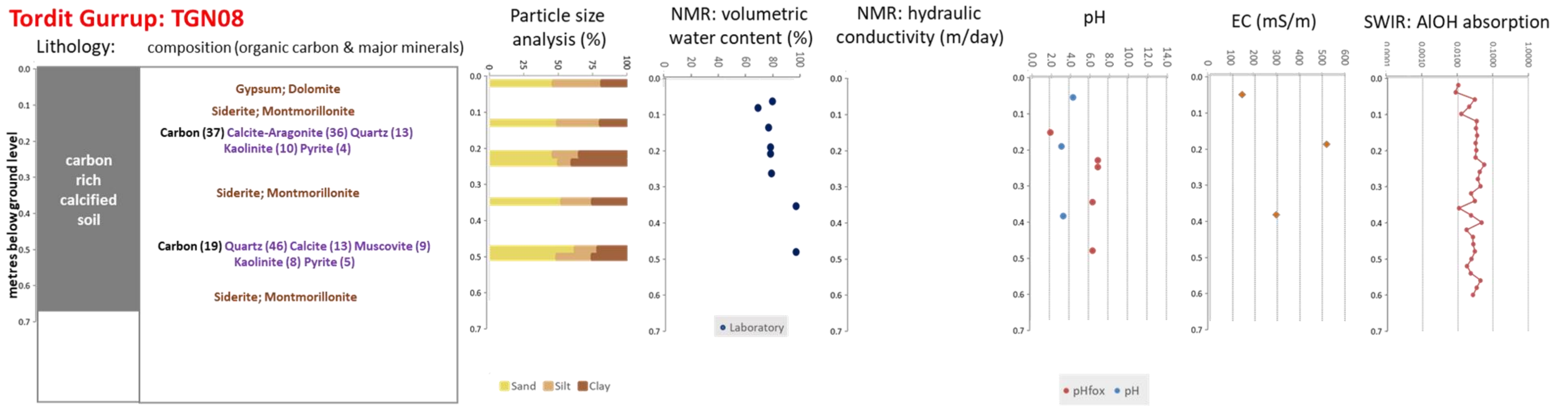
### pXRF chemistry (ppm)



## Drill core chip tray photos (m BGL)



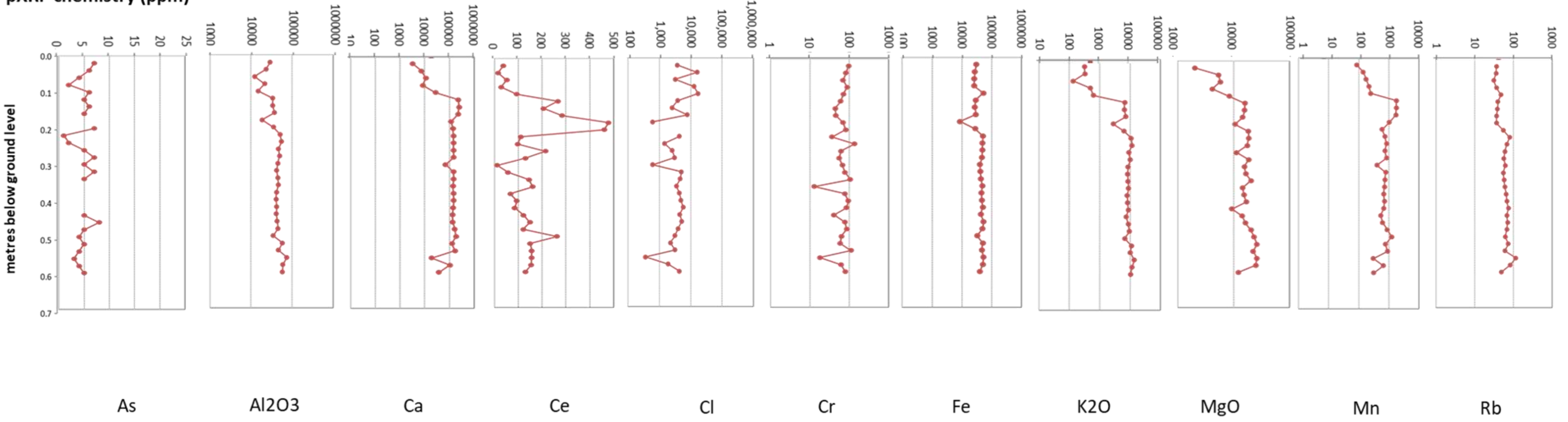
## Tordit Gurrup: TGN08



**NB: IRMS Carbon (black text (wt. %)); XRD (purple text (approximated relative %))**
**SWIR mineral identified (brown text)**

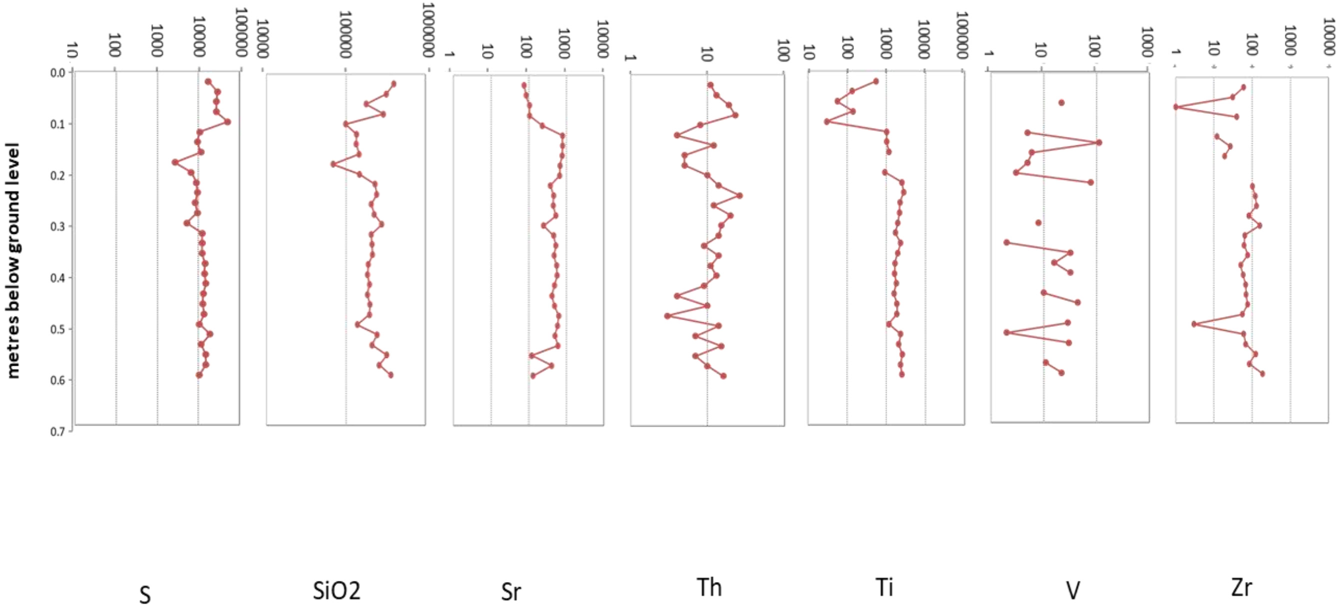
**NB: no data = no measurable clay component; little to no clay**

### pXRF chemistry (ppm)

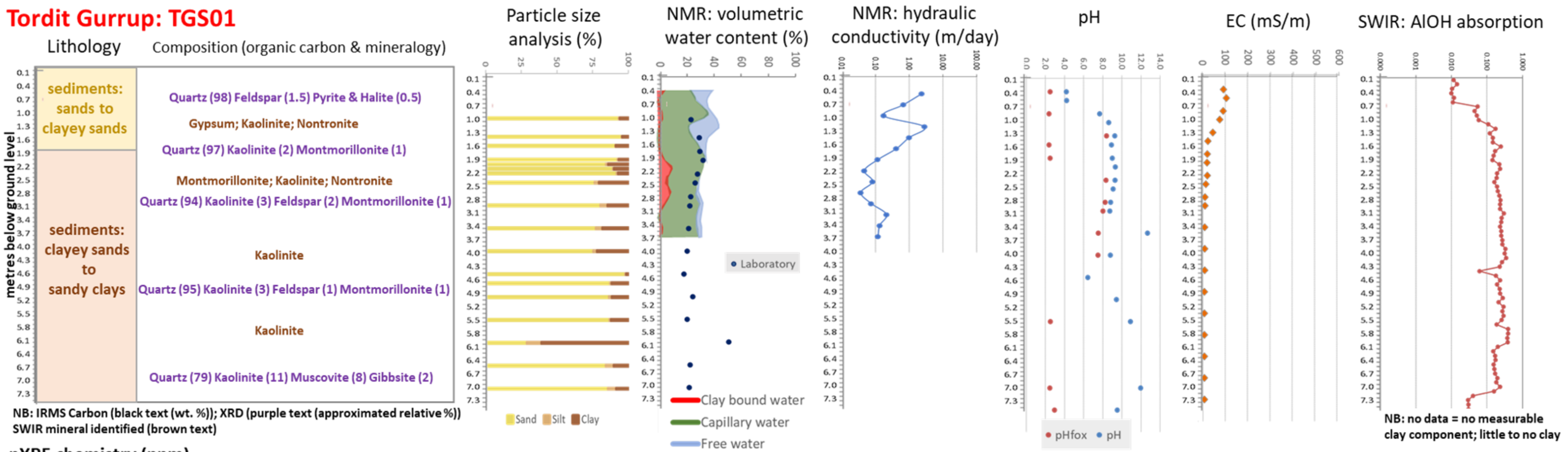


## Tordit Gurrup: TGN08

**pXRF chemistry (ppm)**



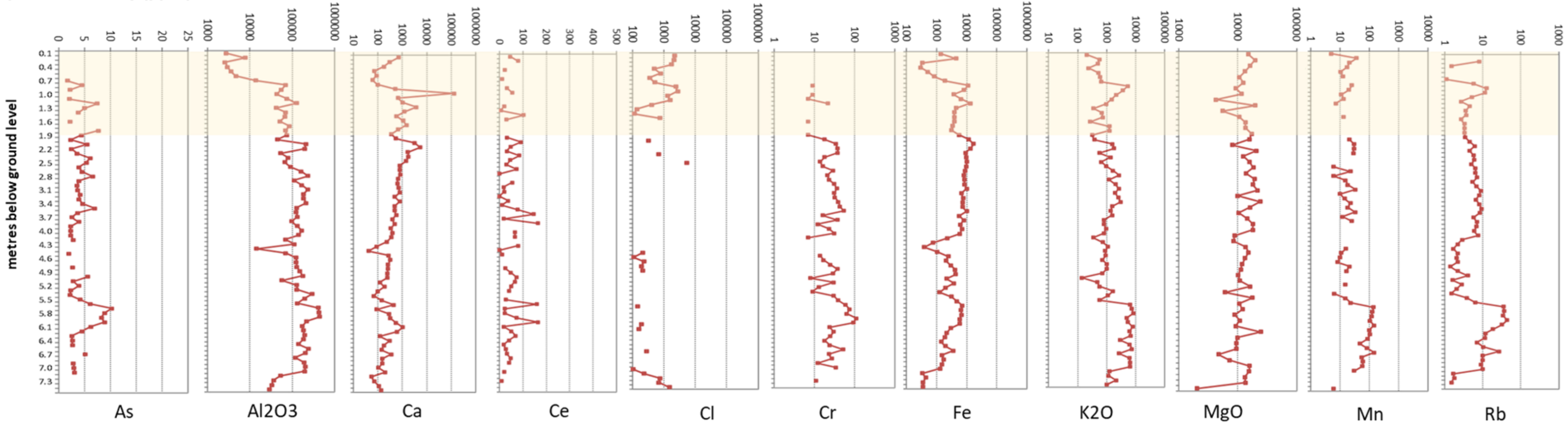
## Tordit Gurrup: TGS01



NB: IRMS Carbon (black text (wt. %)); XRD (purple text (approximated relative %))
SWIR mineral identified (brown text)

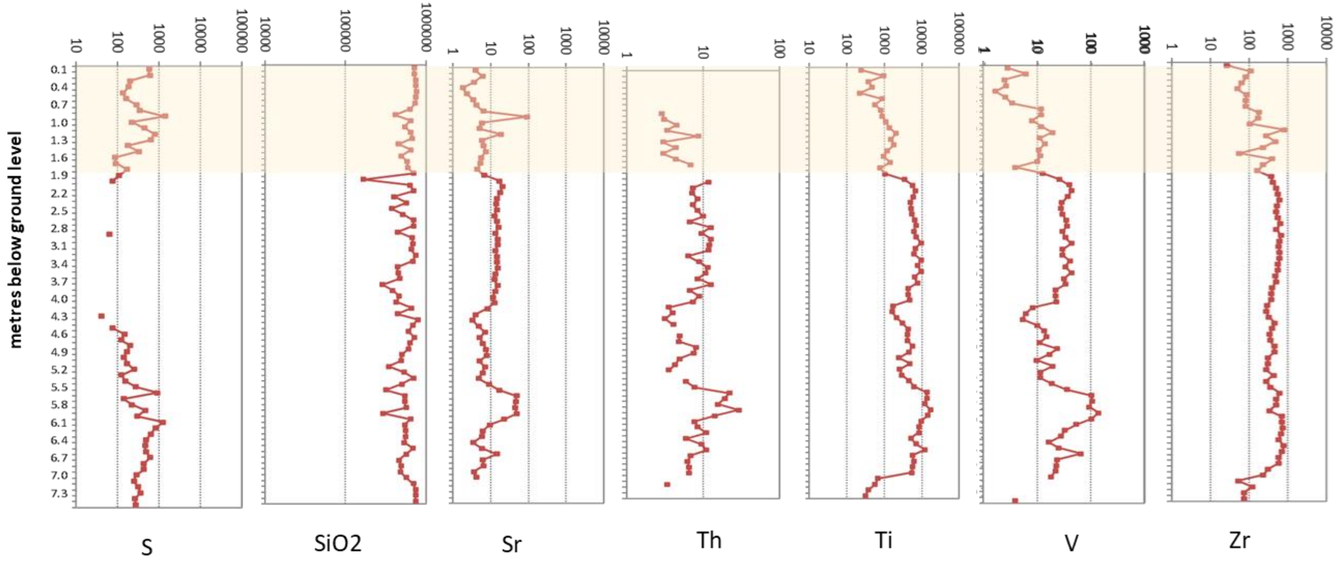
NB: no data = no measurable clay component; little to no clay

pXRF chemistry (ppm)

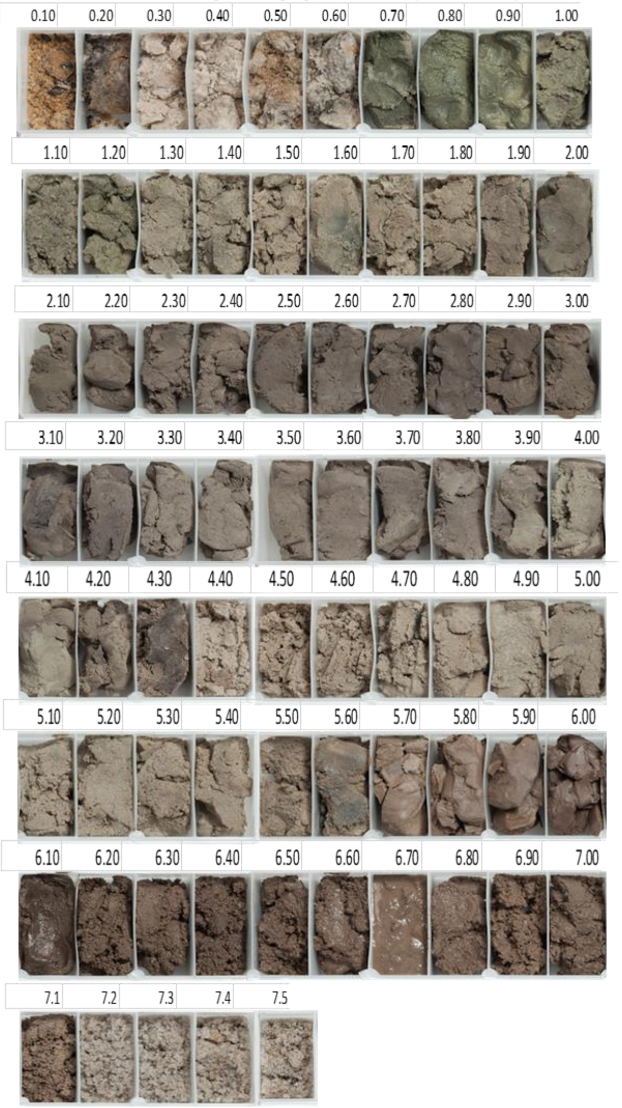


## Tordit Gurrup: TGS01

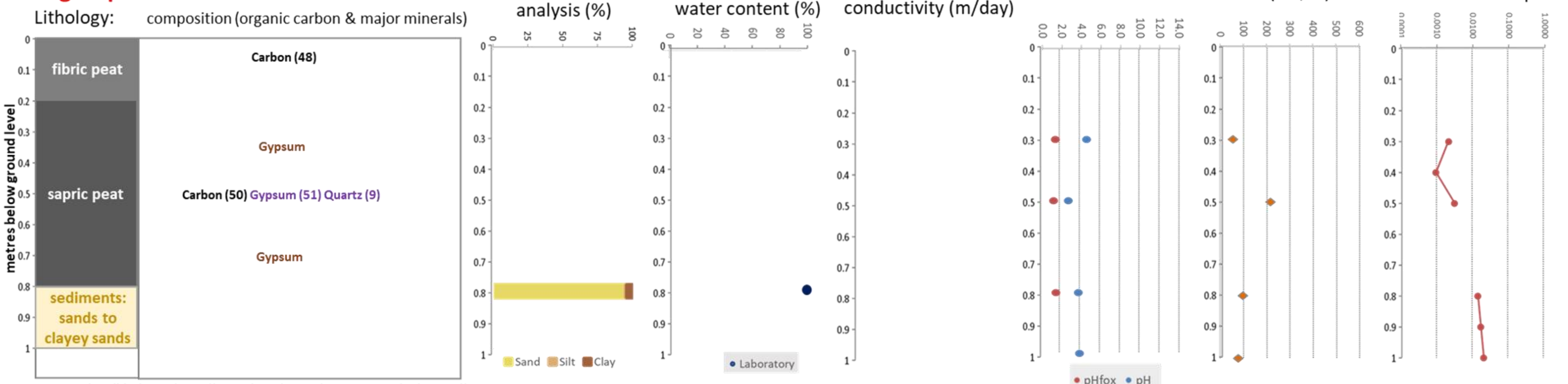
### pXRF chemistry (ppm)



## Drill core chip tray photos (m BGL)



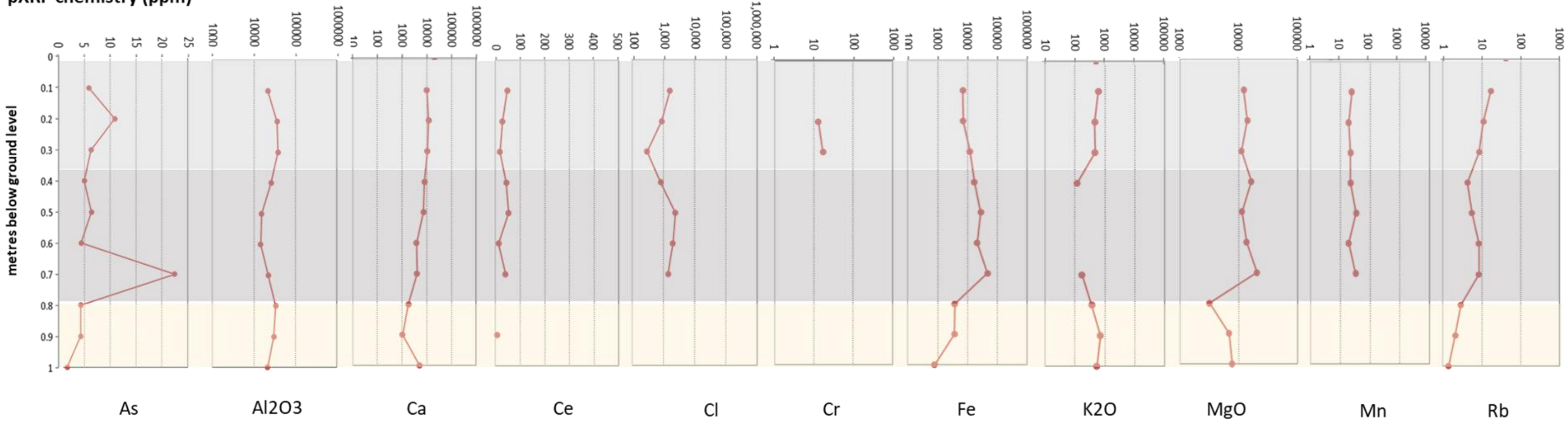
## Poorginup: POOR01



NB: IRMS Carbon (black text (wt. %)); XRD (purple text (approximated relative %))
SWIR mineral identified (brown text)

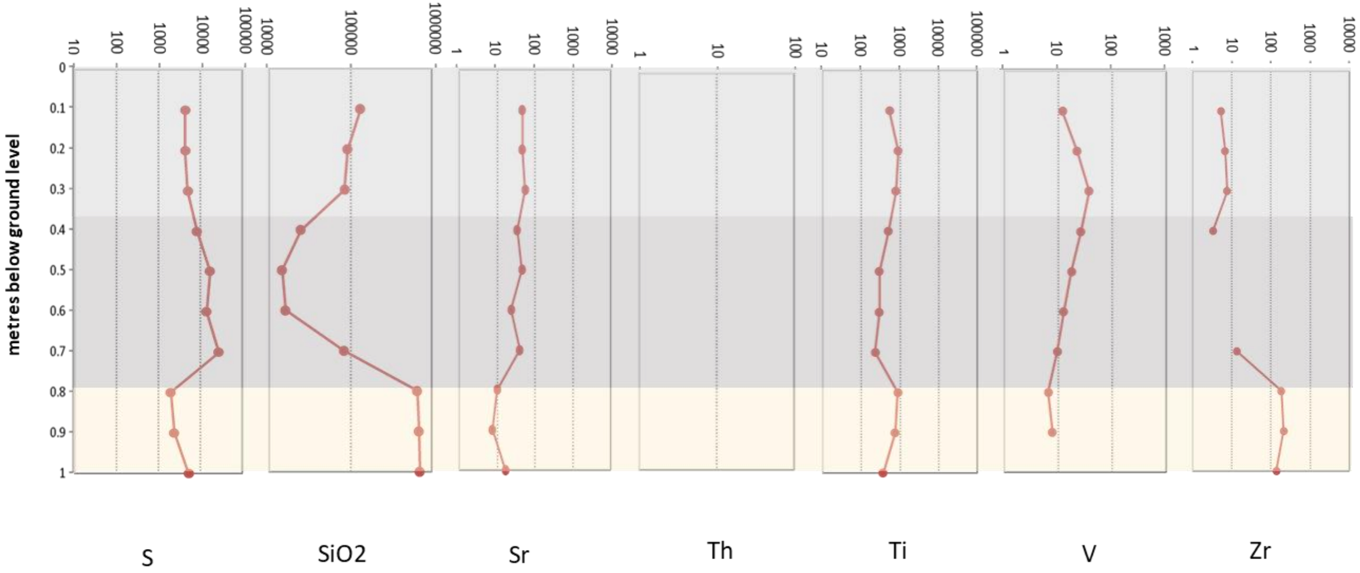
NB: no data = no measurable clay component; little to no clay

### pXRF chemistry (ppm)

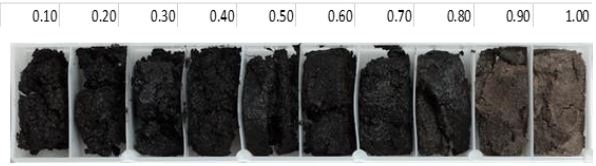


## Poorginup: POOR01

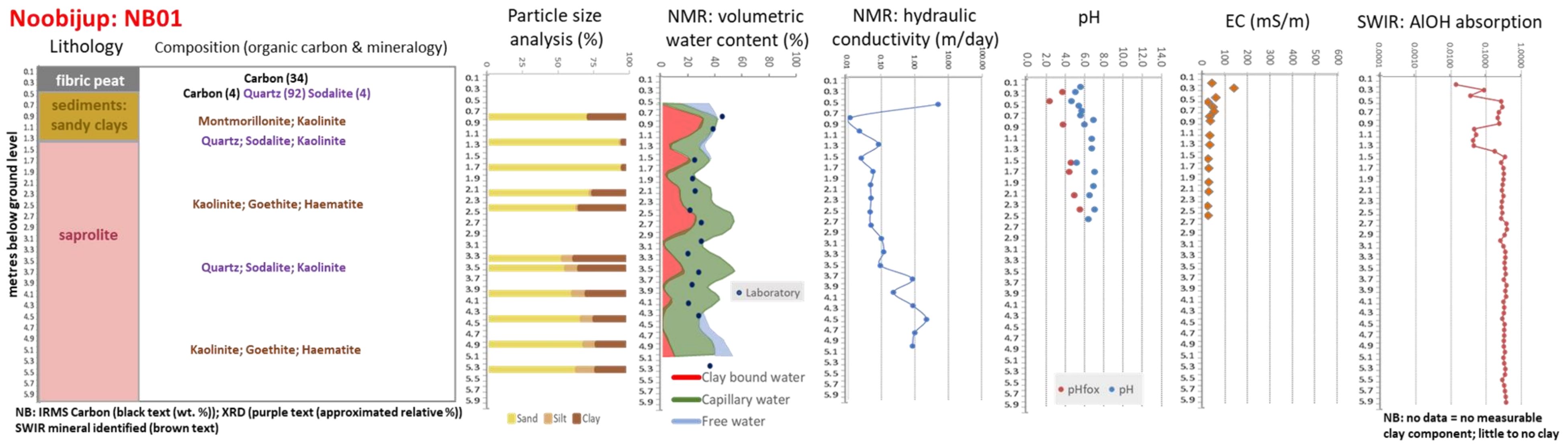
### pXRF chemistry (ppm)



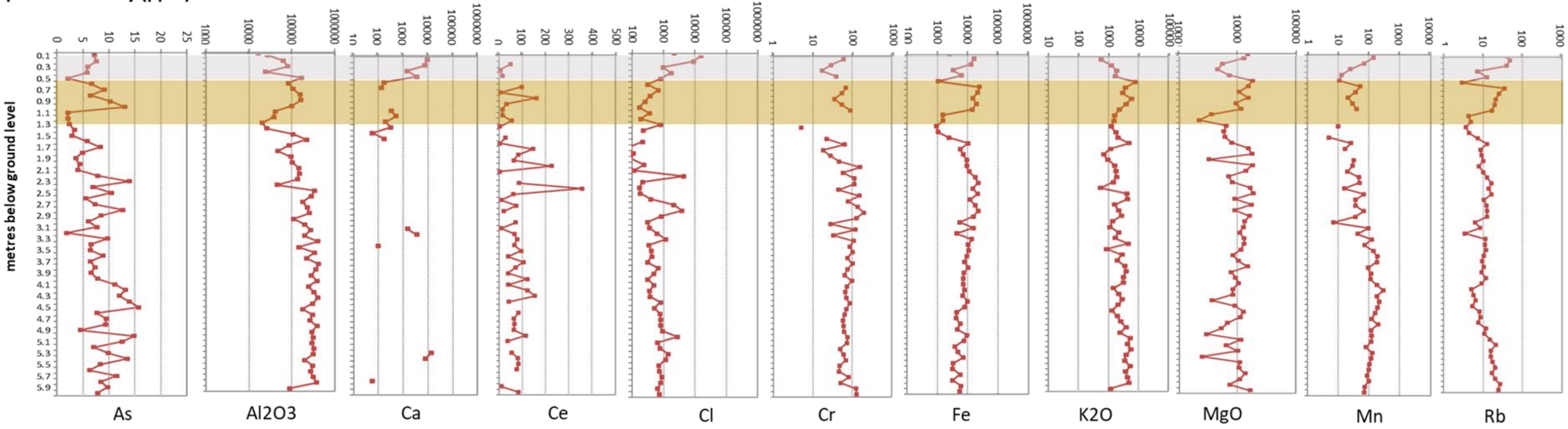
## Drill core chip tray photos (m BGL)



## Noobijup: NB01

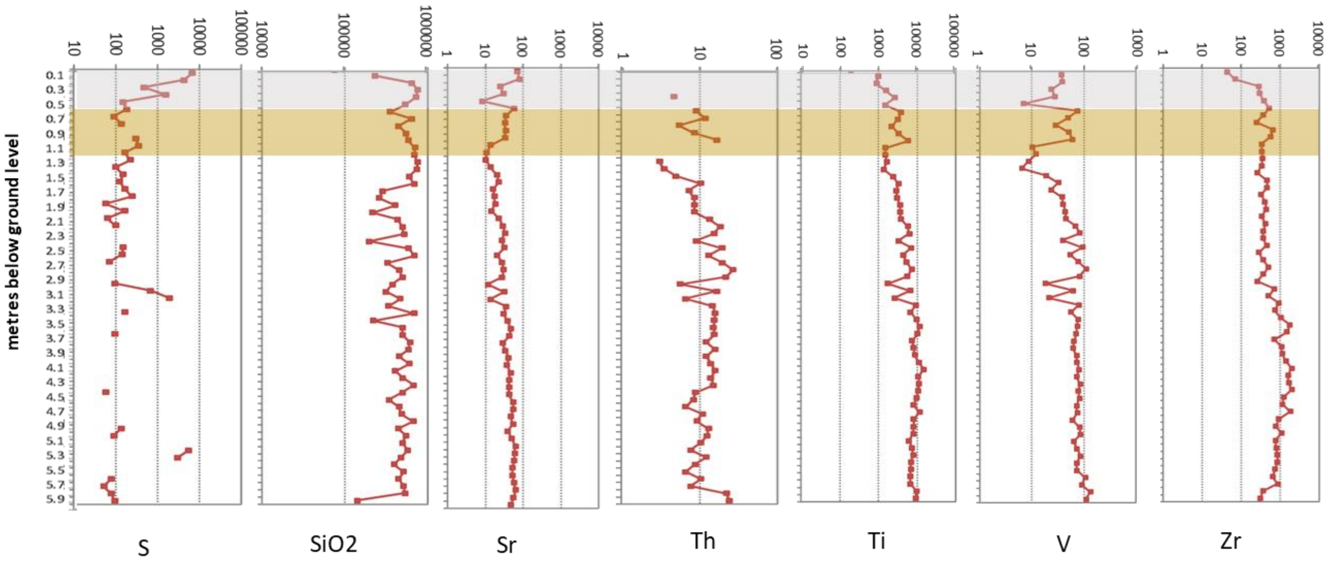


**pXRF chemistry (ppm)**

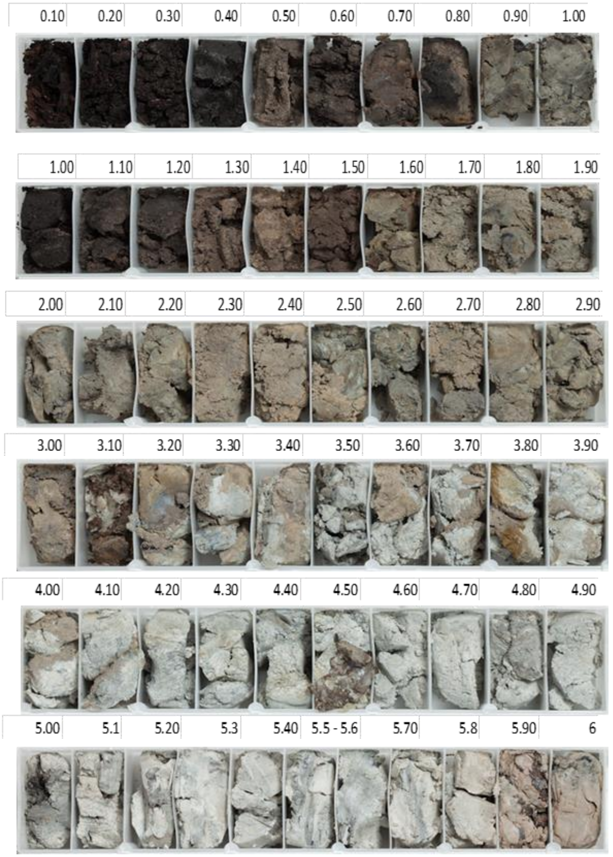


## Noobijup: NB01

**pXRF chemistry (ppm)**

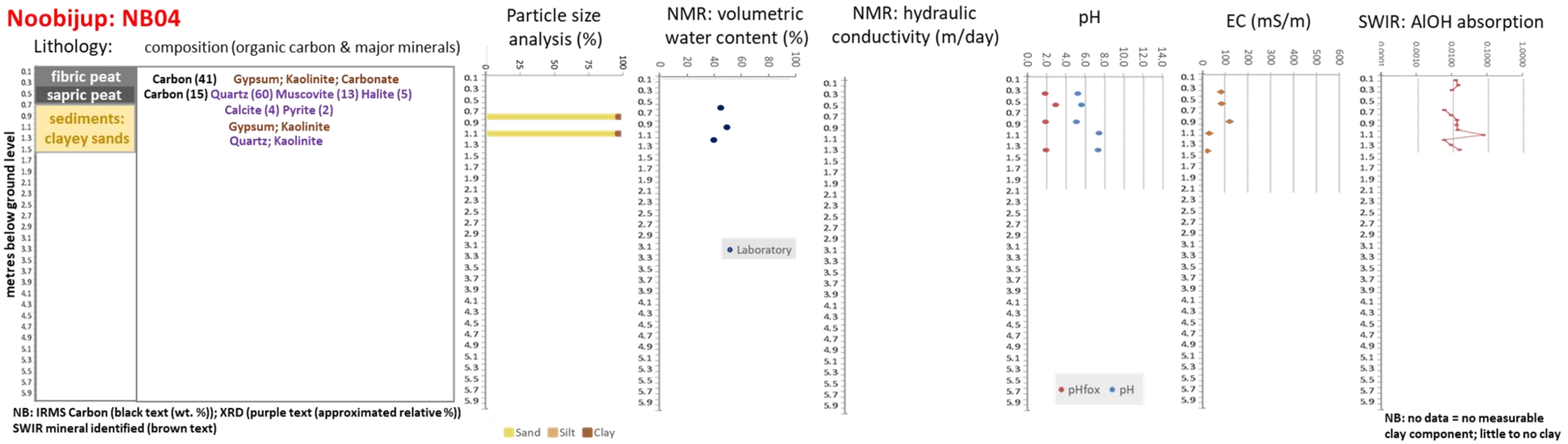


## Drill core chip tray photos (m BGL)



Note: samples 0.1 to 1.00 from NB03
(separate hand augered hole in close proximity to NB01)

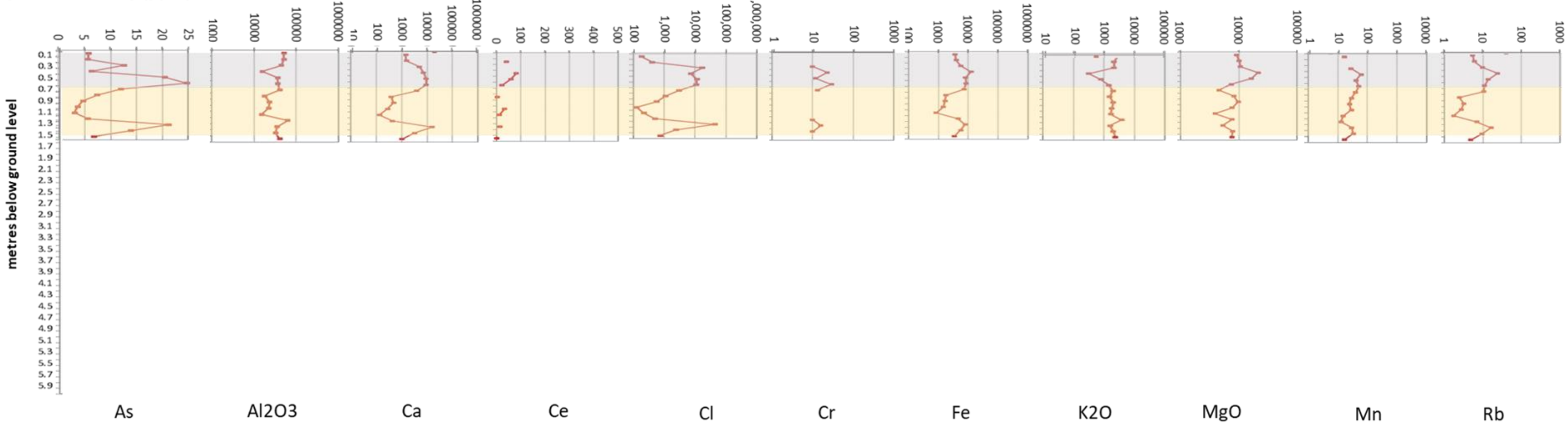
## Noobijup: NB04



NB: IRMS Carbon (black text (wt. %)); XRD (purple text (approximated relative %))
SWIR mineral identified (brown text)

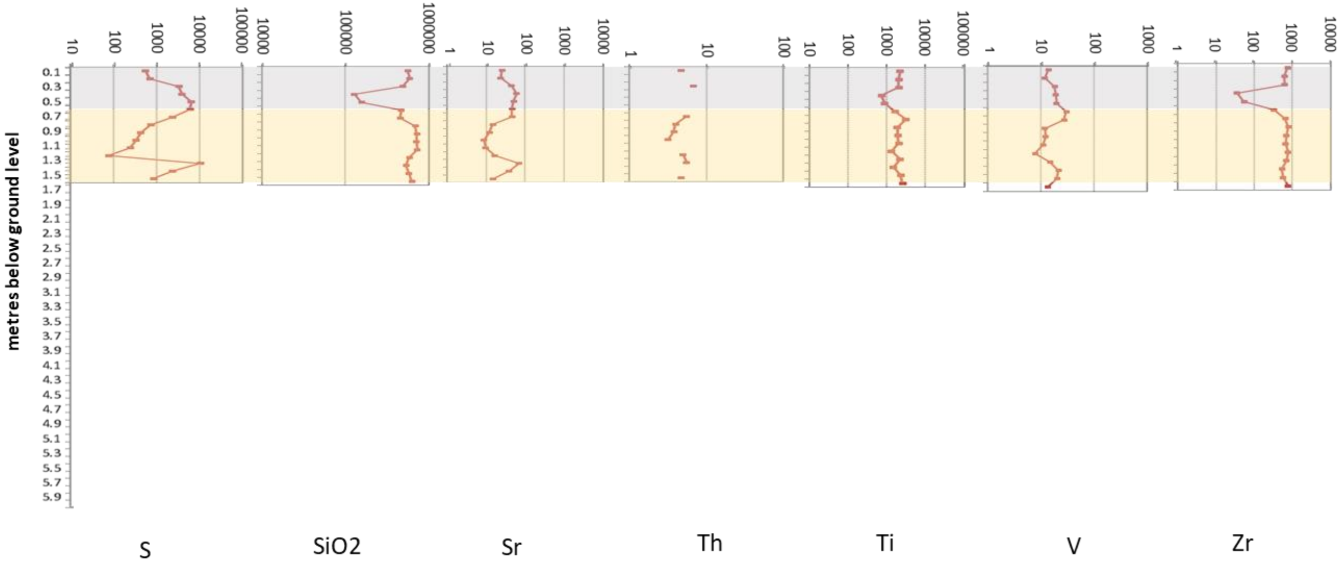
NB: no data = no measurable clay component; little to no clay

**pXRF chemistry (ppm)**

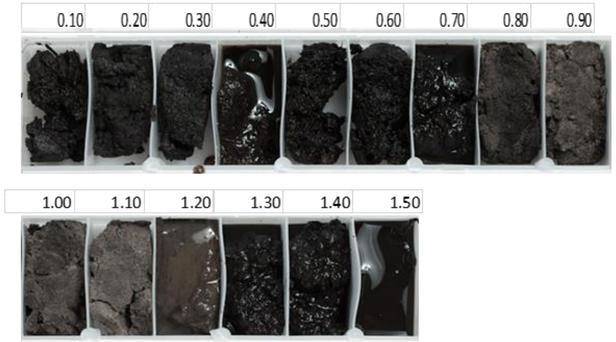


## Noobijup: NB04

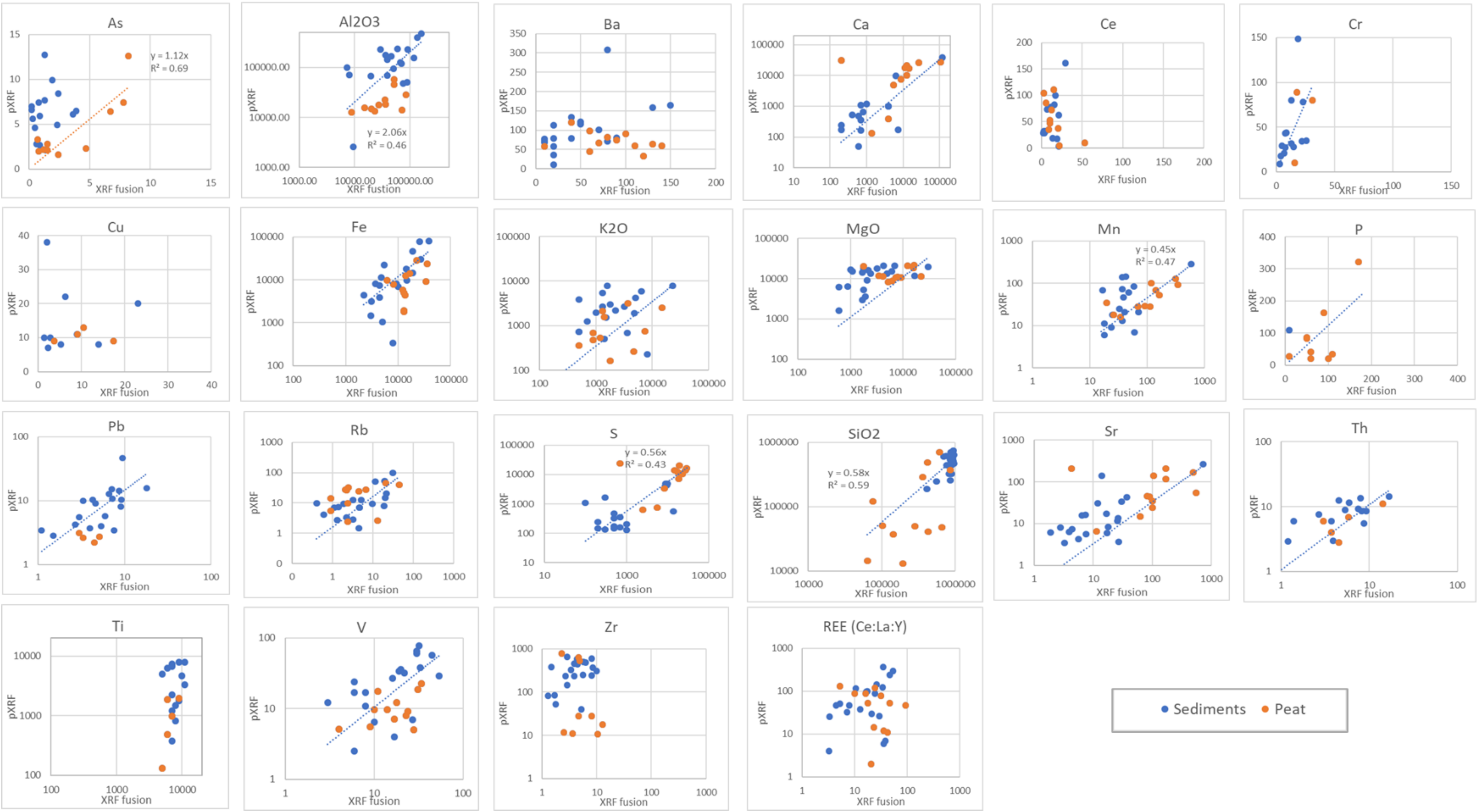
**pXRF chemistry (ppm)**



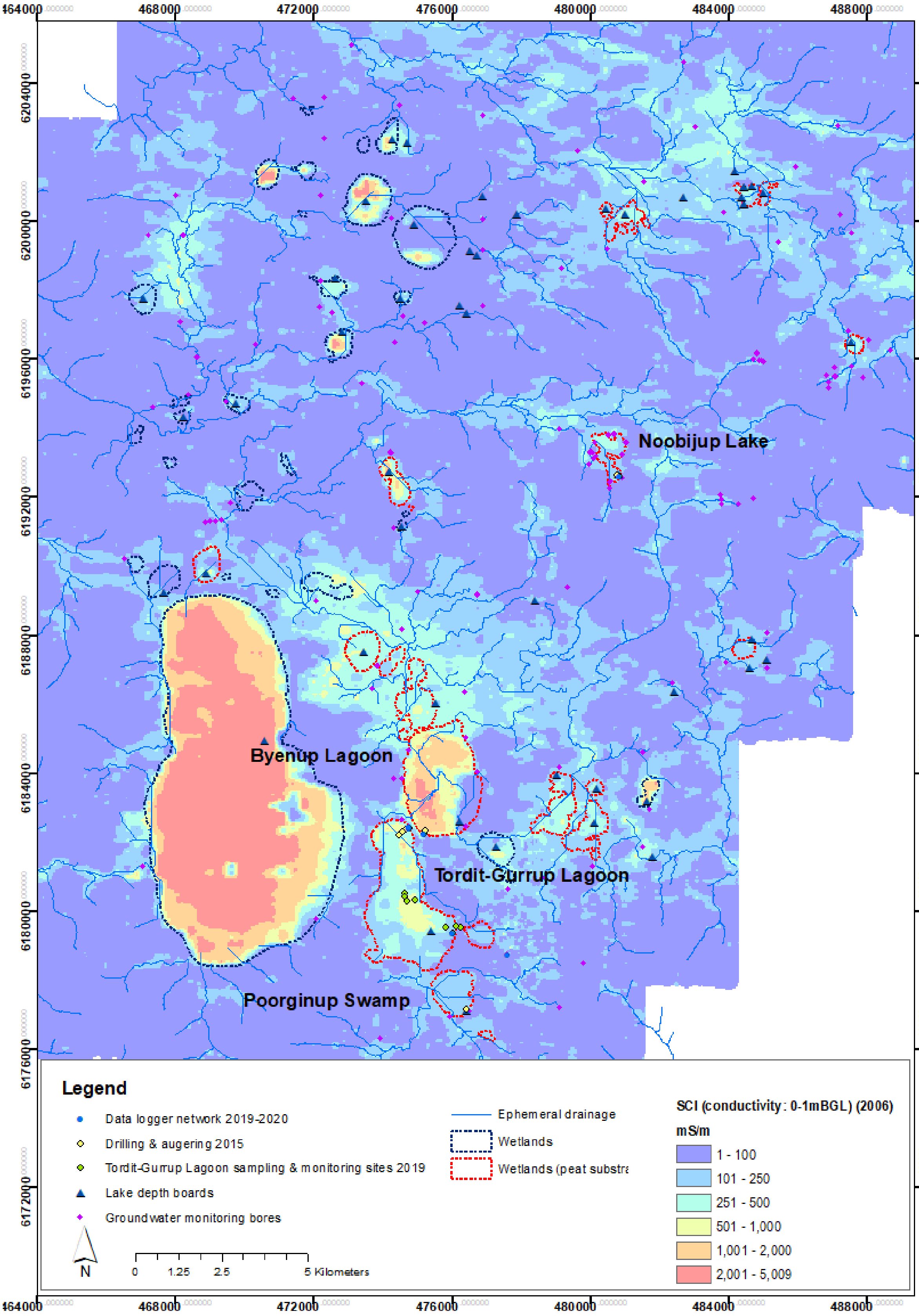
## Drill core chip tray photos (m BGL)

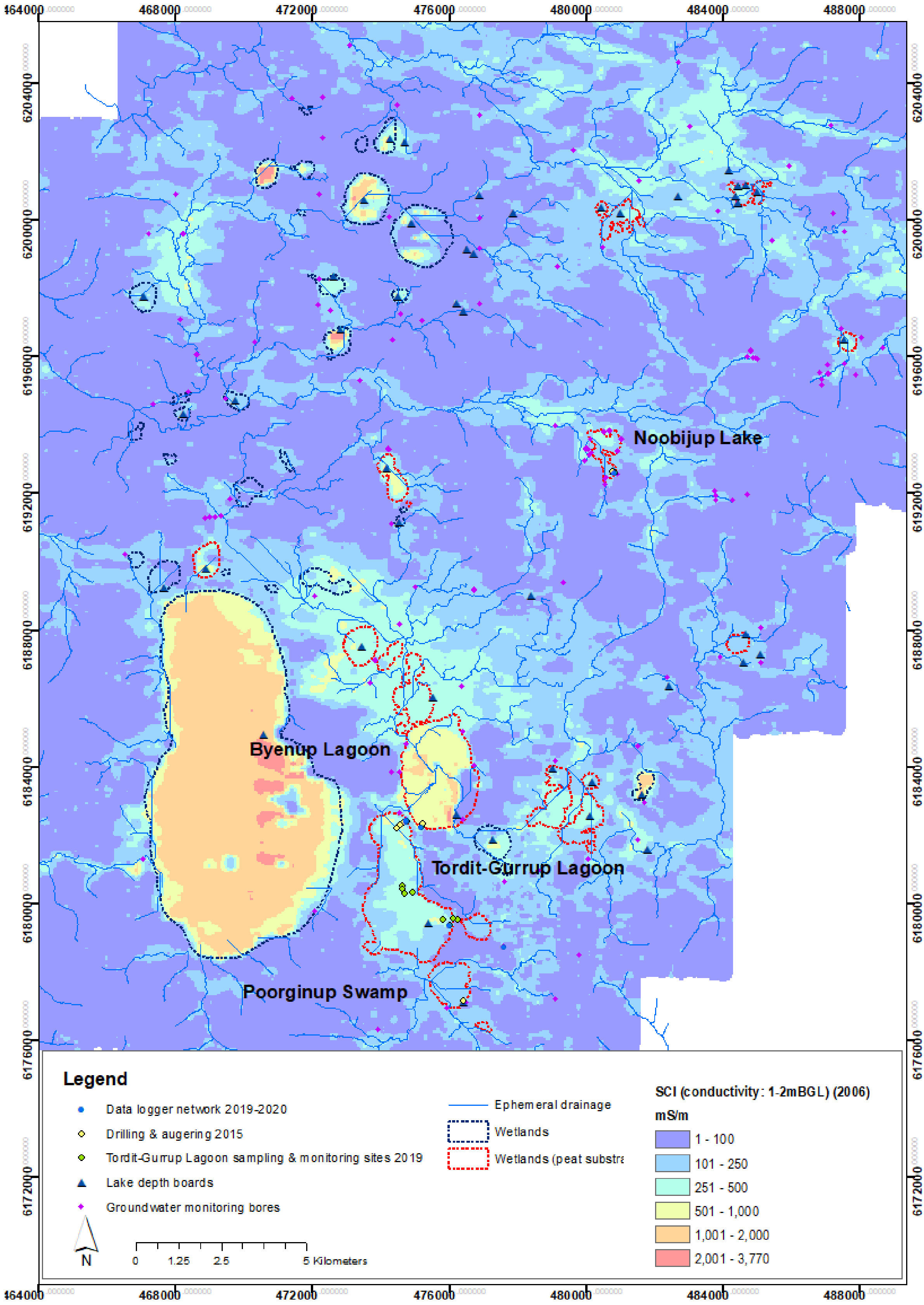


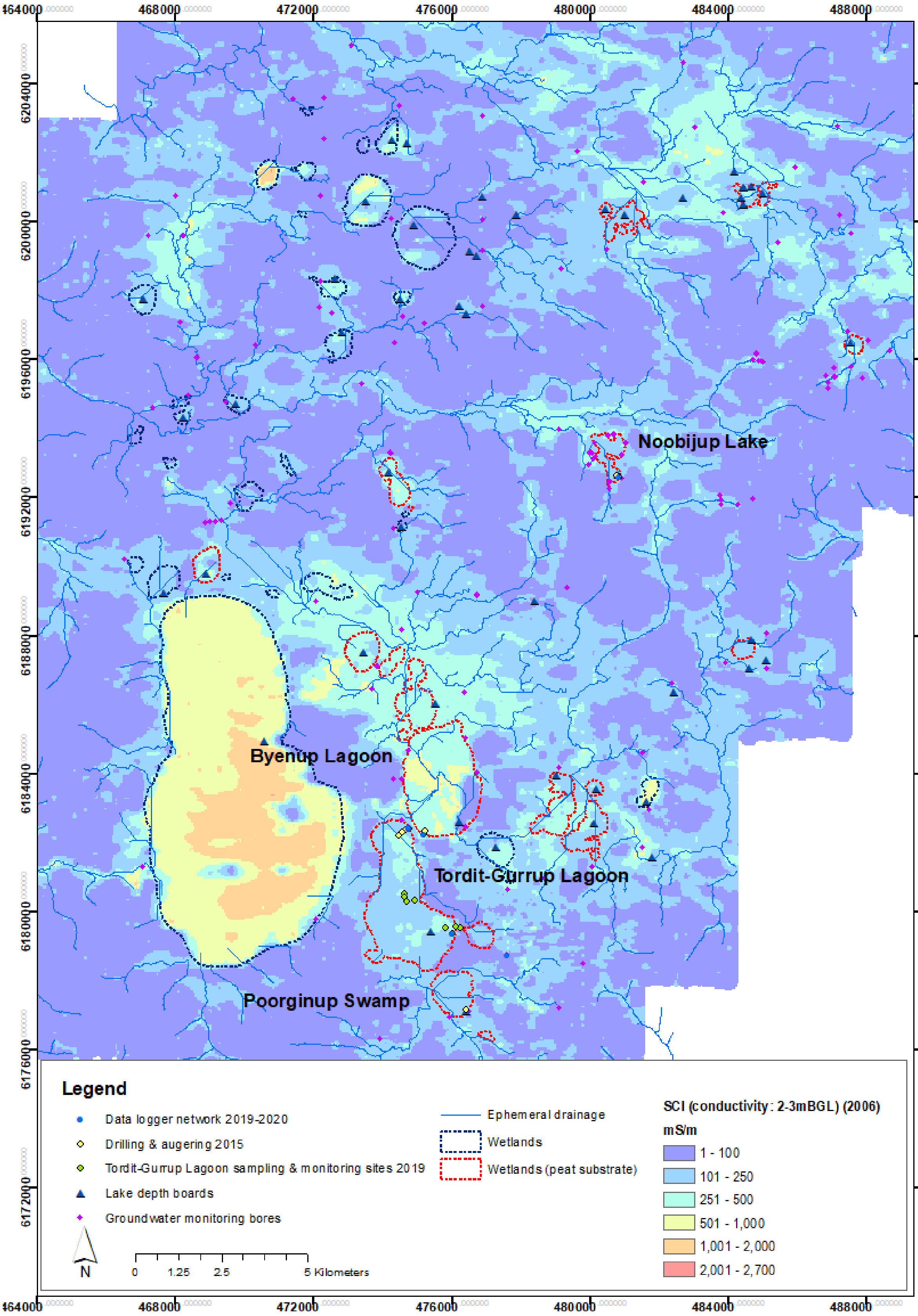
Calibration graphs of laboratory XRF data (n=33; acquired ALS June 2017 - ME-XRF26 whole rock fusion & ME-MS41 ICP-MS) against pXRF (n=395; acquired PSS Nov 2016 - Olympus Delta Premium 6000 (soil calibration) & April 2018 / March 2020 Bruker Titan 800 (Geo Exploration))

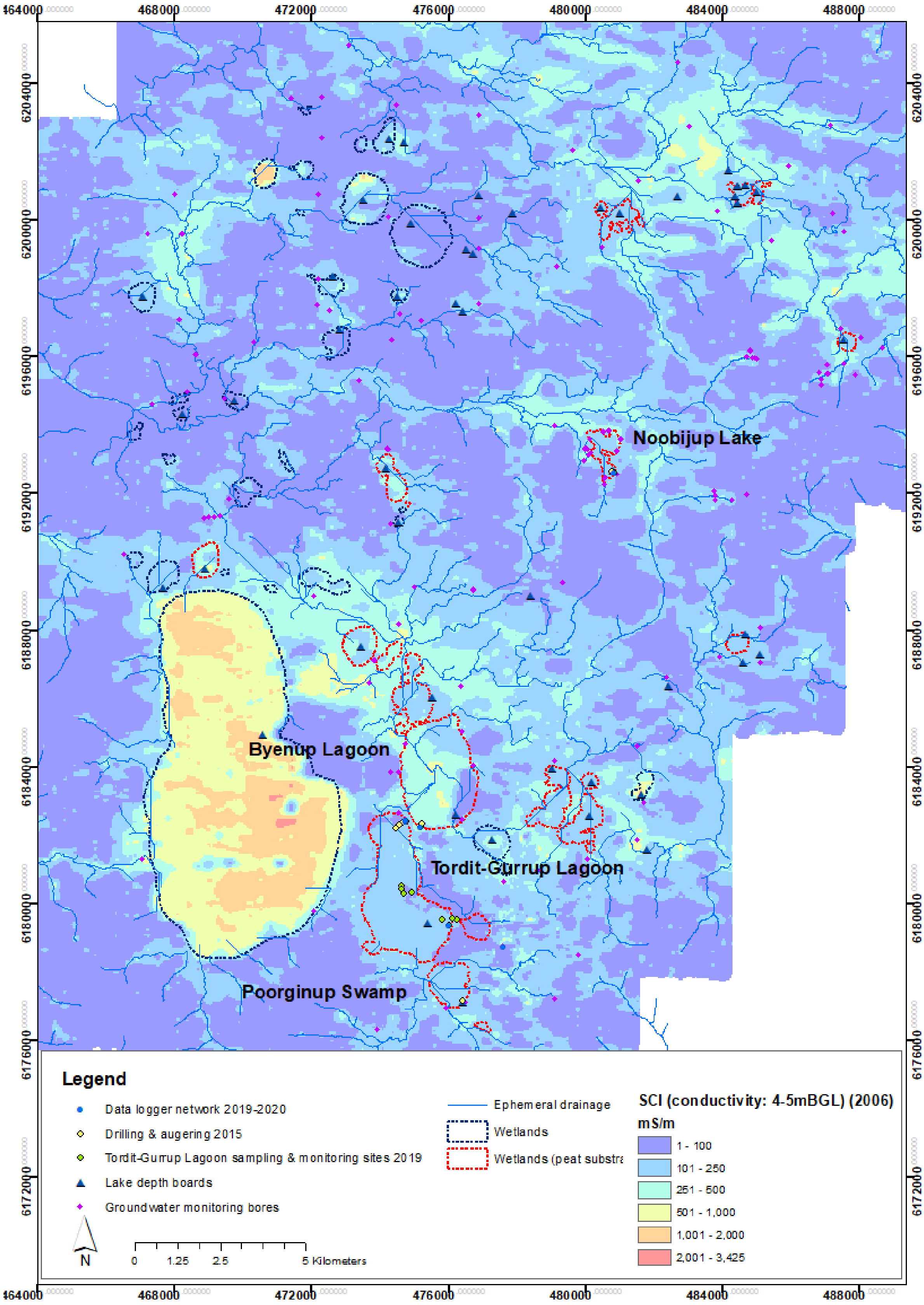


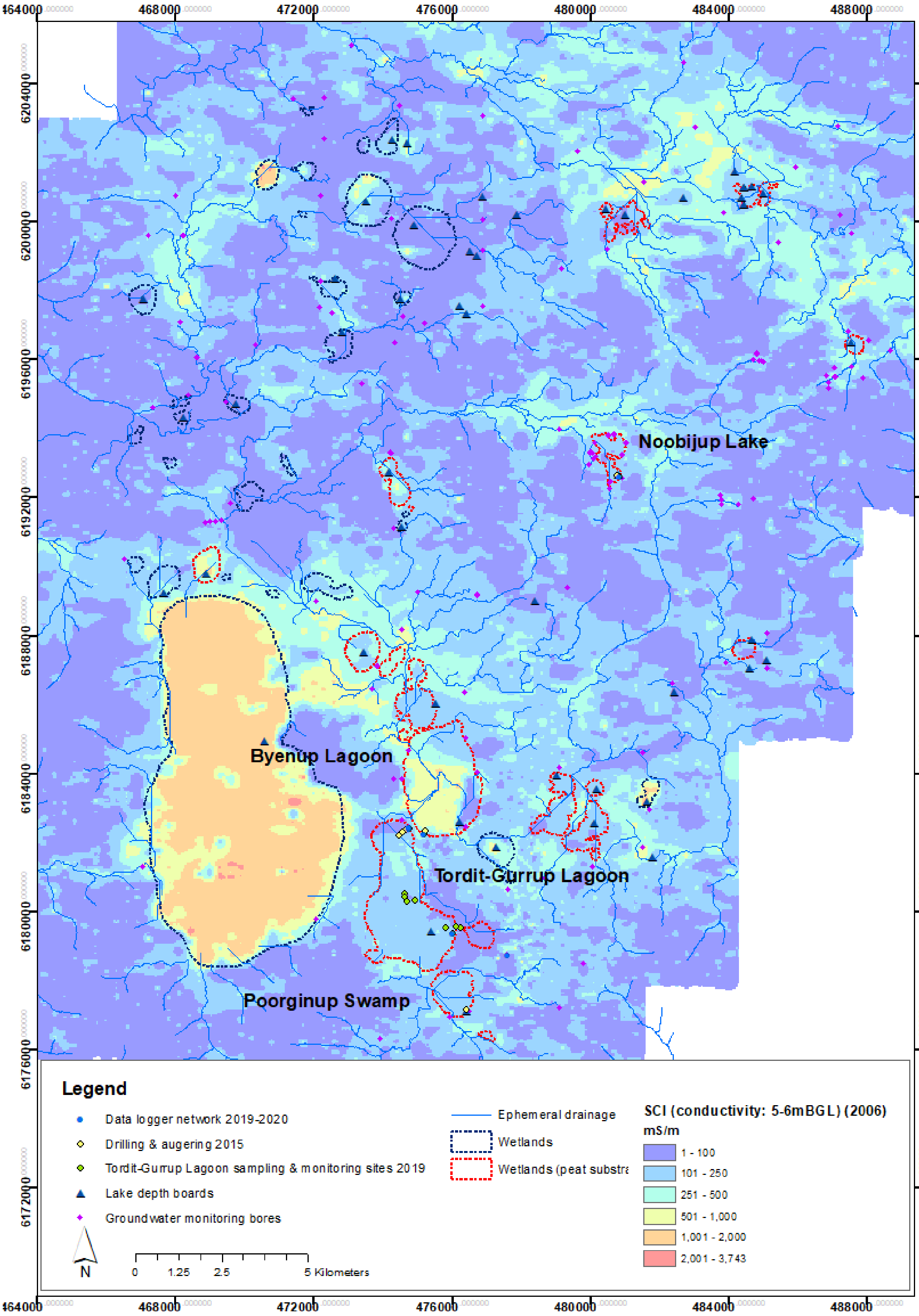
# Appendix 2 AEM conductivity depth images

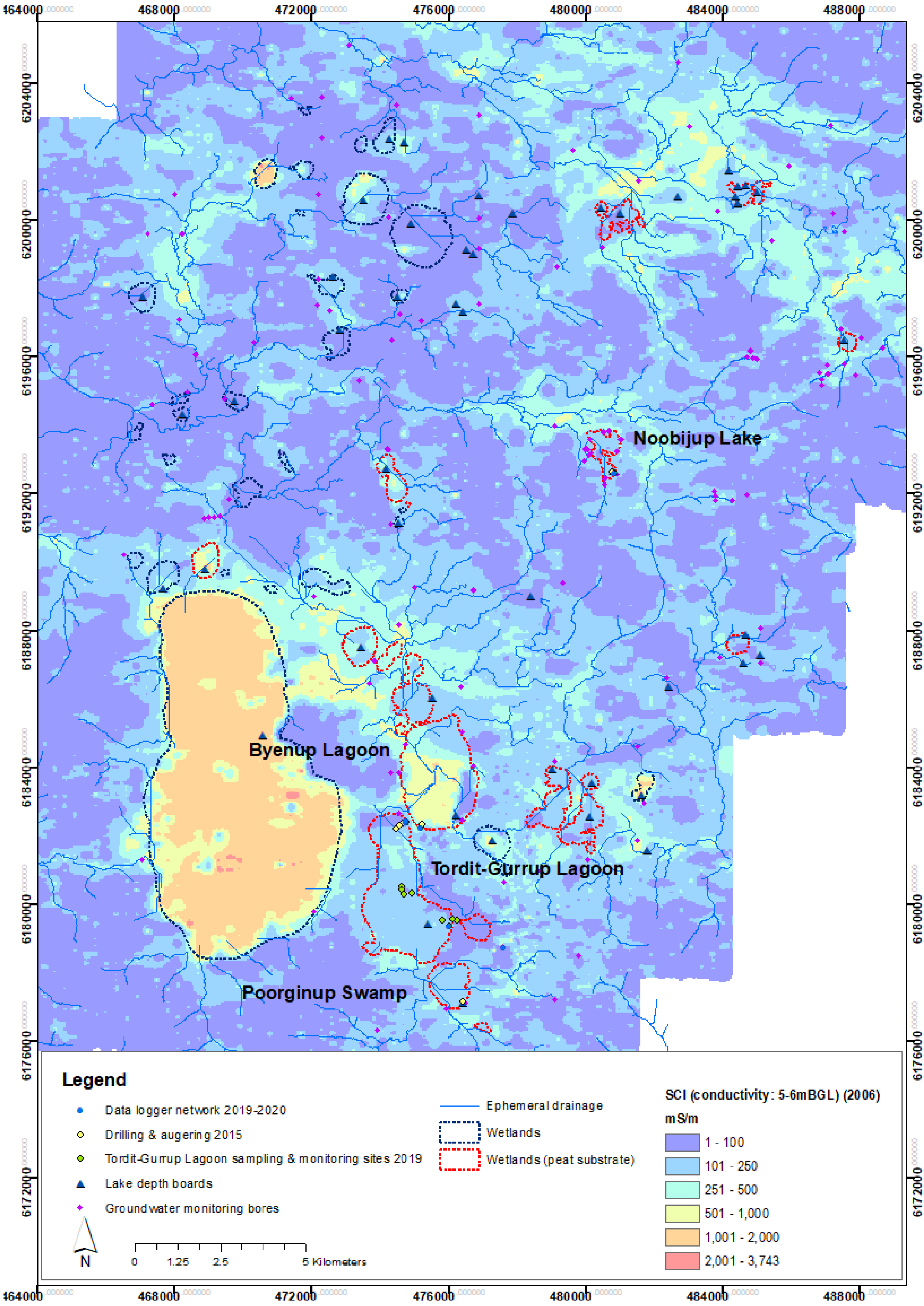


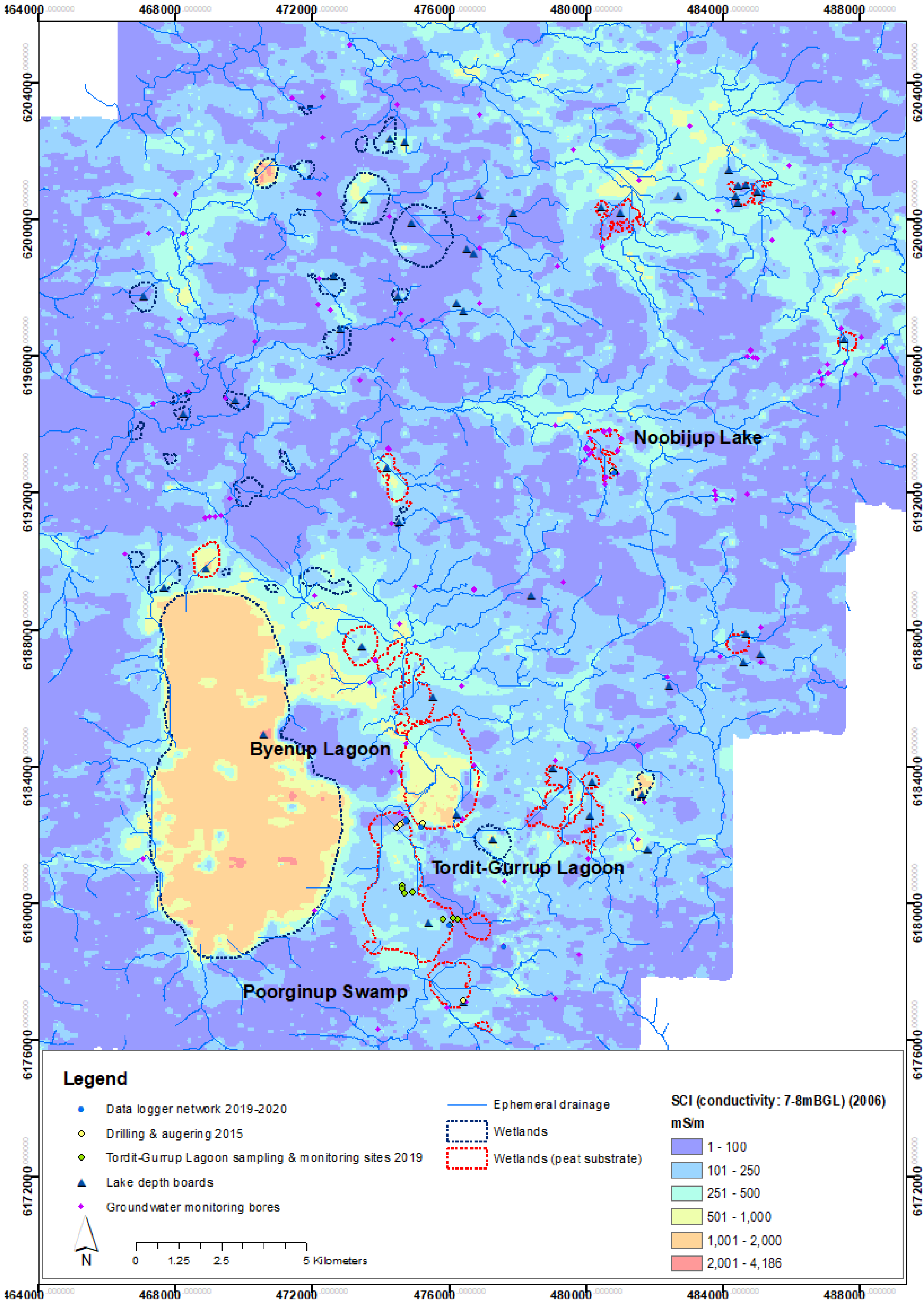

464000
468000
472000
476000
480000
484000
488000
6204000
6200000
6196000
6192000
6188000
6184000
6180000
6176000
6172000
Noobijup Lake
Byenup Lagoon
Tordit-Gurrup Lagoon
Poorginup Swamp
Legend
Data logger network 2019-2020
Drilling & augering 2015
Tordit-Gurrup Lagoon sampling & monitoring sites 2019
Lake depth boards
Groundwater monitoring bores
Ephemeral drainage
Wetlands
Wetlands (peat substra
SCI (conductivity: 1-2mBGL) (2006)
mS/m
1 - 100
101 - 250
251 - 500
501 - 1,000
1,001 - 2,000
2,001 - 3,770
N
0
1.25
2.5
5 Kilometers

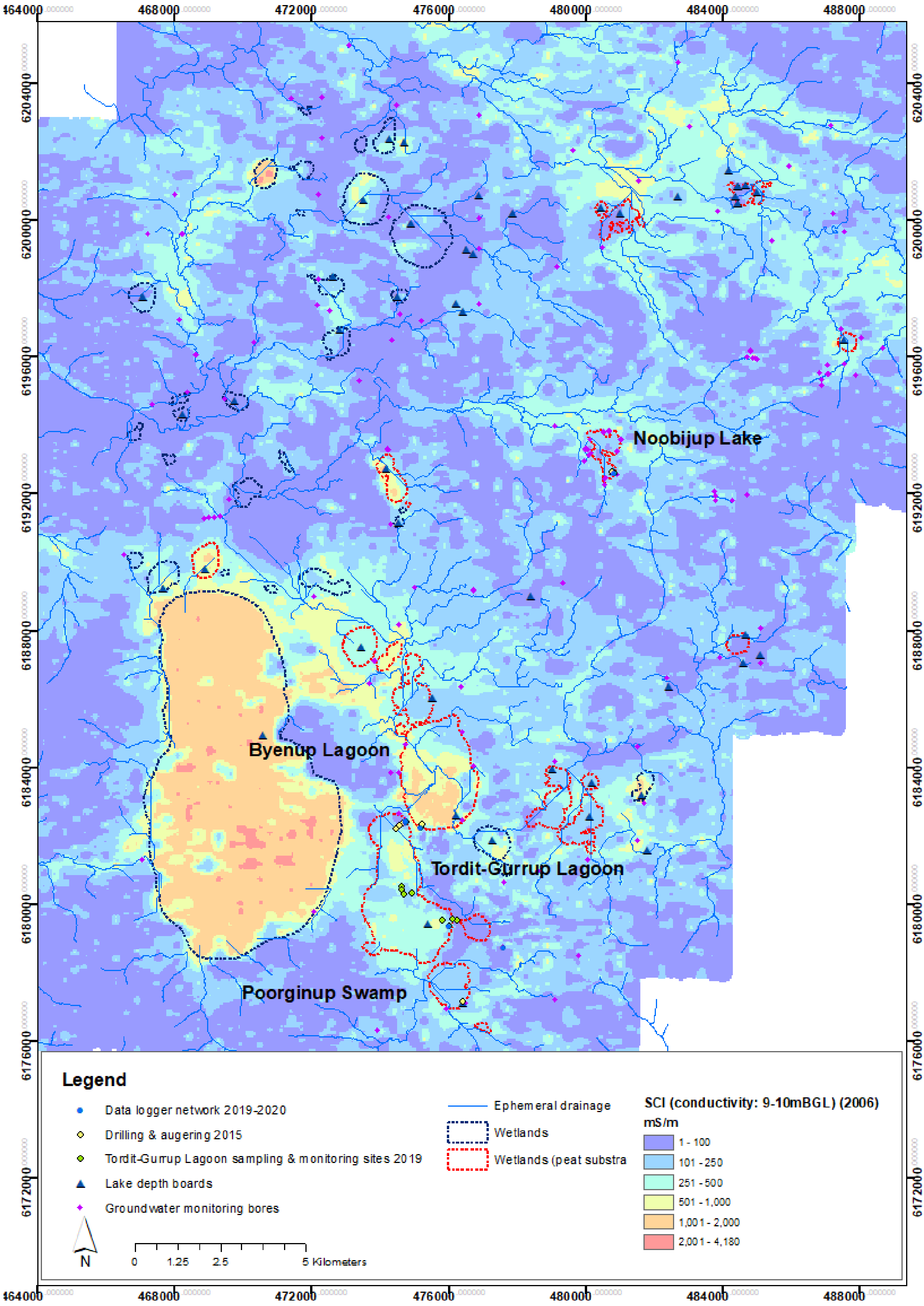

464000
468000
472000
476000
480000
484000
488000
6204000
6200000
6196000
6192000
6188000
6184000
6180000
6176000
6172000
Noobijup Lake
Byenup Lagoon
Tordit-Gurrup Lagoon
Poorginup Swamp
Legend
Data logger network 2019-2020
Drilling & augering 2015
Tordit-Gurrup Lagoon sampling & monitoring sites 2019
Lake depth boards
Groundwater monitoring bores
Ephemeral drainage
Wetlands
Wetlands (peat substrate)
SCI (conductivity: 2-3mBGL) (2006)
mS/m
1 - 100
101 - 250
251 - 500
501 - 1,000
1,001 - 2,000
2,001 - 2,700
N
0
1.25
2.5
5 Kilometers


464000
468000
472000
476000
480000
484000
488000
6204000
6200000
6196000
6192000
6188000
6184000
6180000
6176000
6172000
Noobijup Lake
Byenup Lagoon
Tordit-Gurrup Lagoon
Poorginup Swamp
Legend
Data logger network 2019-2020
Drilling & augering 2015
Tordit-Gurrup Lagoon sampling & monitoring sites 2019
Lake depth boards
Groundwater monitoring bores
Ephemeral drainage
Wetlands
Wetlands (peat substra
SCI (conductivity: 4-5mBGL) (2006)
mS/m
1 - 100
101 - 250
251 - 500
501 - 1,000
1,001 - 2,000
2,001 - 3,425
N
0
1.25
2.5
5 Kilometers

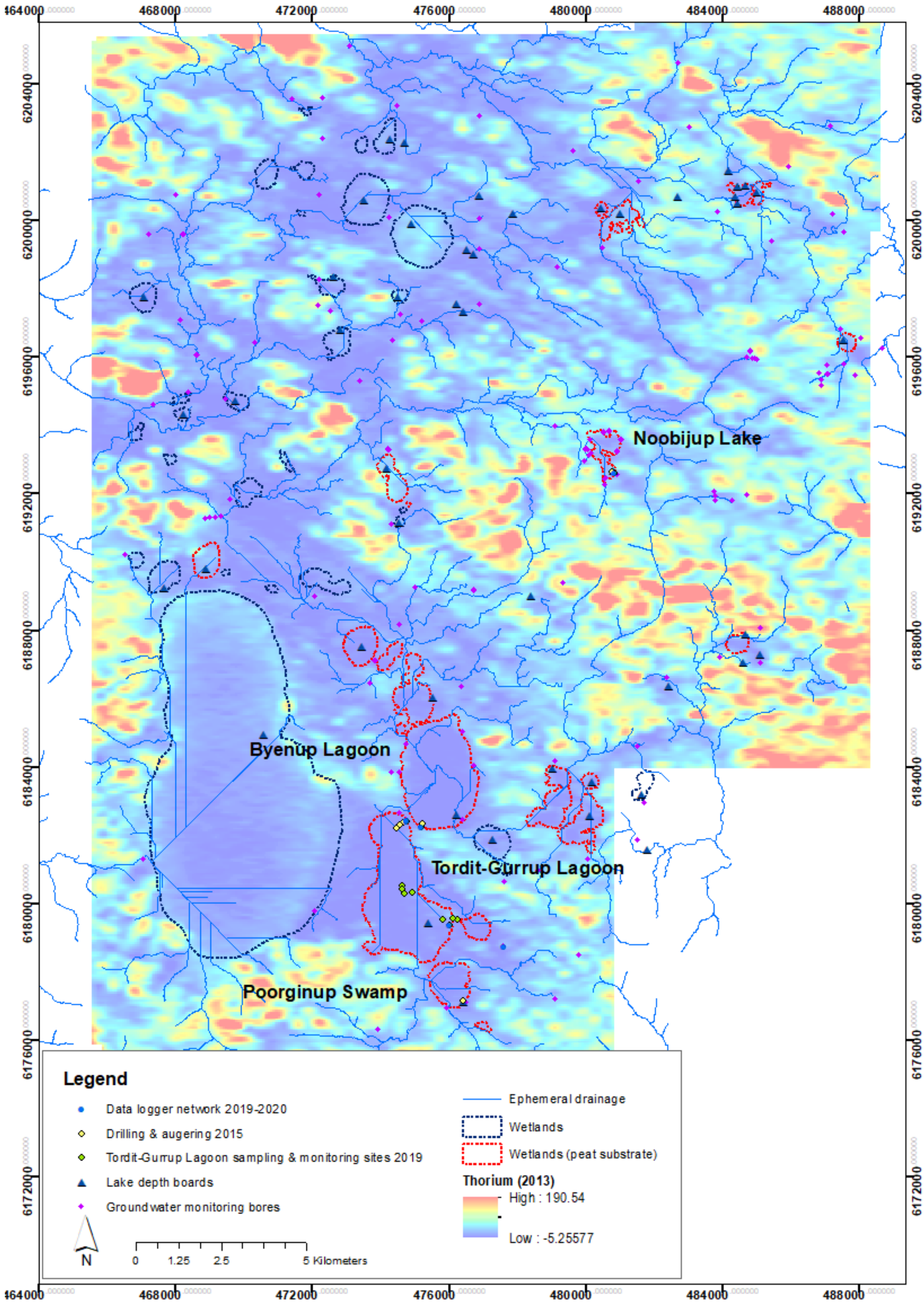

464000
468000
472000
476000
480000
484000
488000
6204000
6200000
6196000
6192000
6188000
6184000
6180000
6176000
6172000
Noobijup Lake
Byenup Lagoon
Tordit-Gurrup Lagoon
Poorginup Swamp
Legend
Data logger network 2019-2020
Drilling & augering 2015
Tordit-Gurrup Lagoon sampling & monitoring sites 2019
Lake depth boards
Groundwater monitoring bores
Ephemeral drainage
Wetlands
Wetlands (peat substra
SCI (conductivity: 5-6mBGL) (2006)
mS/m
1 - 100
101 - 250
251 - 500
501 - 1,000
1,001 - 2,000
2,001 - 3,743
N
0
1.25
2.5
5 Kilometers

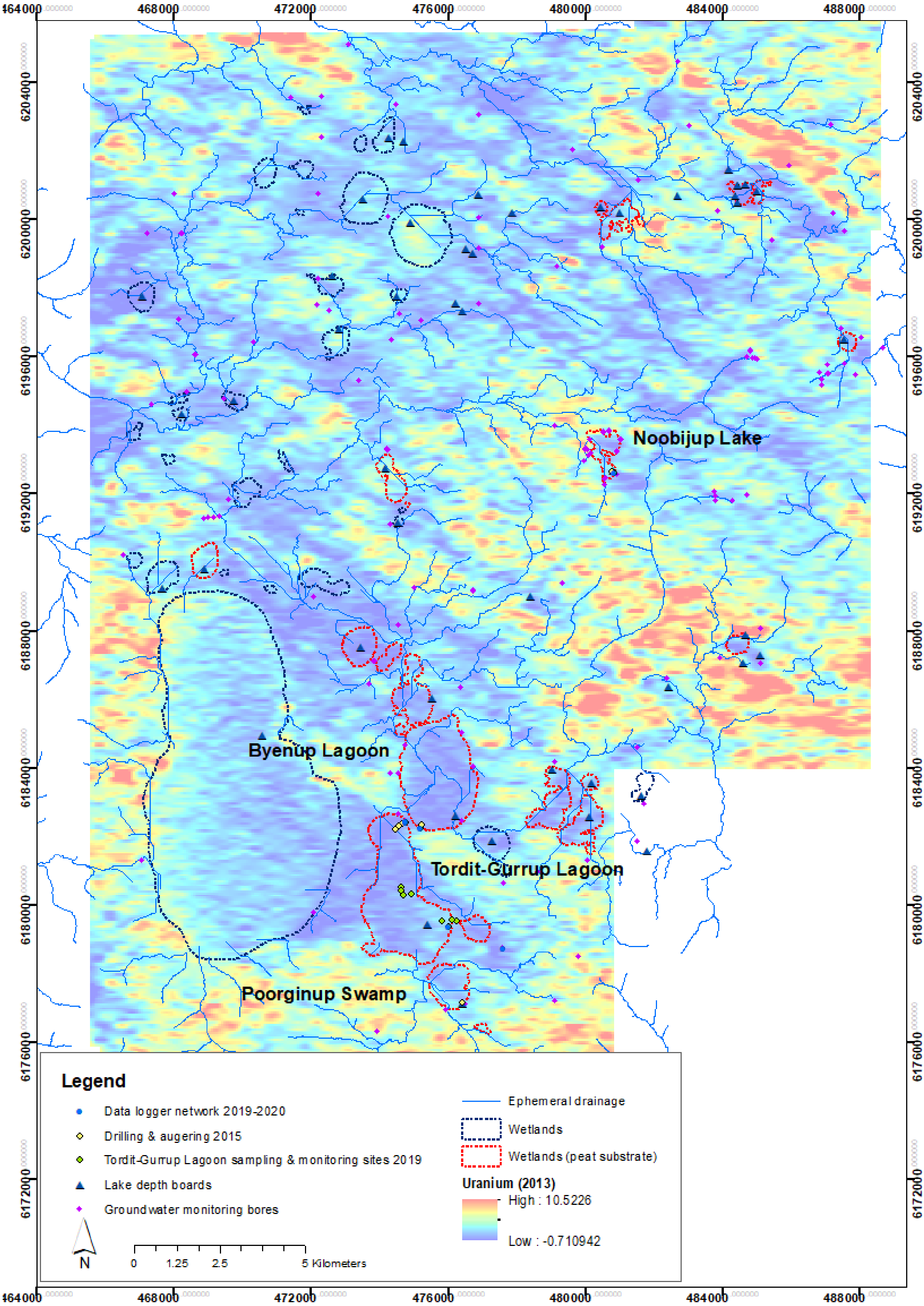

464000
468000
472000
476000
480000
484000
488000
6204000
6200000
6196000
6192000
6188000
6184000
6180000
6176000
6172000
Noobijup Lake
Byenup Lagoon
Tordit-Gurrup Lagoon
Poorginup Swamp
Legend
Data logger network 2019-2020
Drilling & augering 2015
Tordit-Gurrup Lagoon sampling & monitoring sites 2019
Lake depth boards
Groundwater monitoring bores
Ephemeral drainage
Wetlands
Wetlands (peat substrate)
SCI (conductivity: 5-6mBGL) (2006)
mS/m
1 - 100
101 - 250
251 - 500
501 - 1,000
1,001 - 2,000
2,001 - 3,743
N
0
1.25
2.5
5 Kilometers

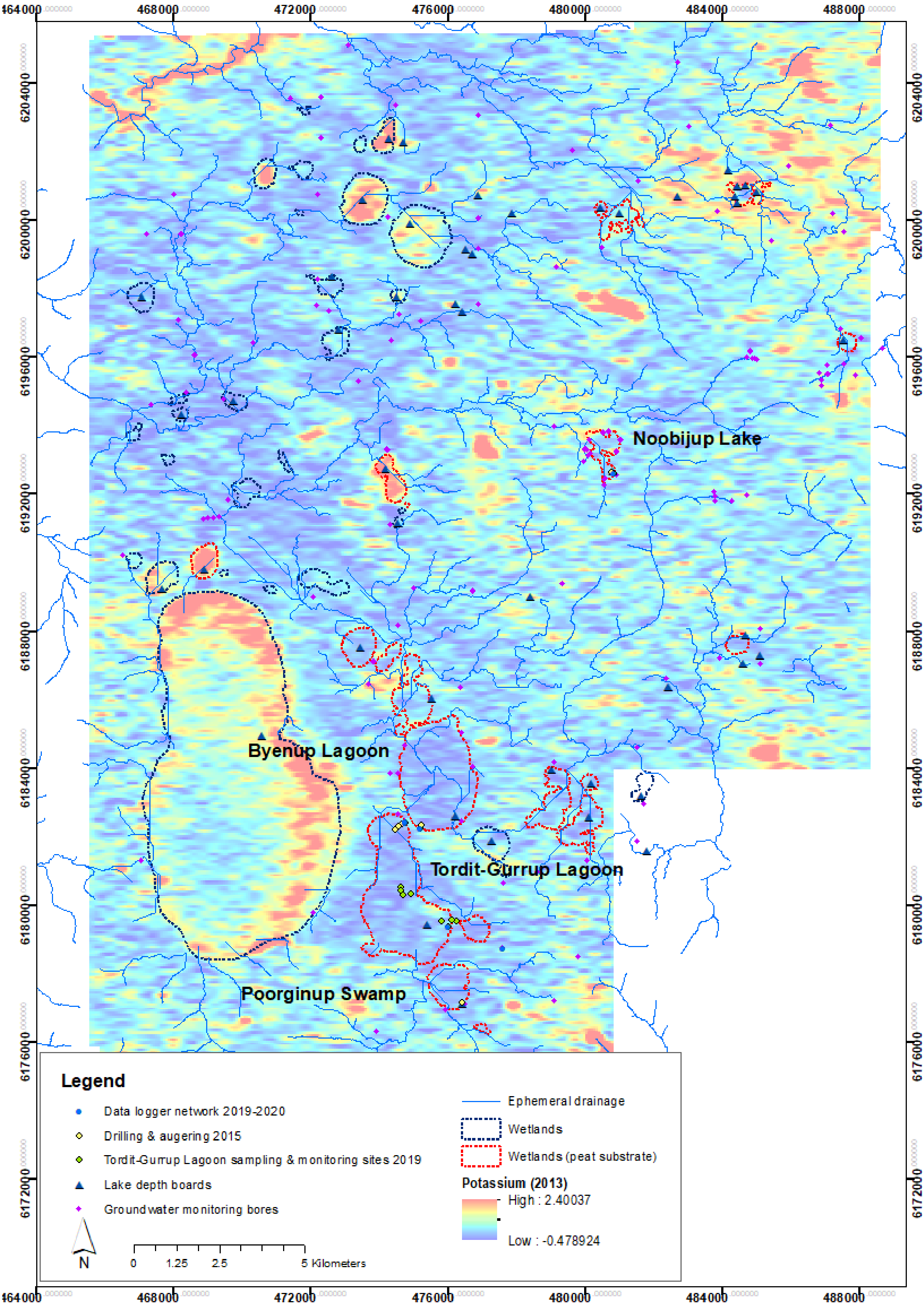

464000
468000
472000
476000
480000
484000
488000
6204000
6200000
6196000
6192000
6188000
6184000
6180000
6176000
6172000
Noobijup Lake
Byenup Lagoon
Tordit-Gurrup Lagoon
Poorginup Swamp
Legend
Data logger network 2019-2020
Drilling & augering 2015
Tordit-Gurrup Lagoon sampling & monitoring sites 2019
Lake depth boards
Groundwater monitoring bores
Ephemeral drainage
Wetlands
Wetlands (peat substrate)
SCI (conductivity: 7-8mBGL) (2006)
mS/m
1 - 100
101 - 250
251 - 500
501 - 1,000
1,001 - 2,000
2,001 - 4,186
N
0
1.25
2.5
5 Kilometers

464000
468000
472000
476000
480000
484000
488000
6204000
6200000
6196000
6192000
6188000
6184000
6180000
6176000
6172000
Noobijup Lake
Byenup Lagoon
Tordit-Gurrup Lagoon
Poorginup Swamp
Legend
Data logger network 2019-2020
Drilling & augering 2015
Tordit-Gurrup Lagoon sampling & monitoring sites 2019
Lake depth boards
Groundwater monitoring bores
Ephemeral drainage
Wetlands
Wetlands (peat substra
SCI (conductivity: 9-10mBGL) (2006)
mS/m
1 - 100
101 - 250
251 - 500
501 - 1,000
1,001 - 2,000
2,001 - 4,180
N
0
1.25
2.5
5 Kilometers

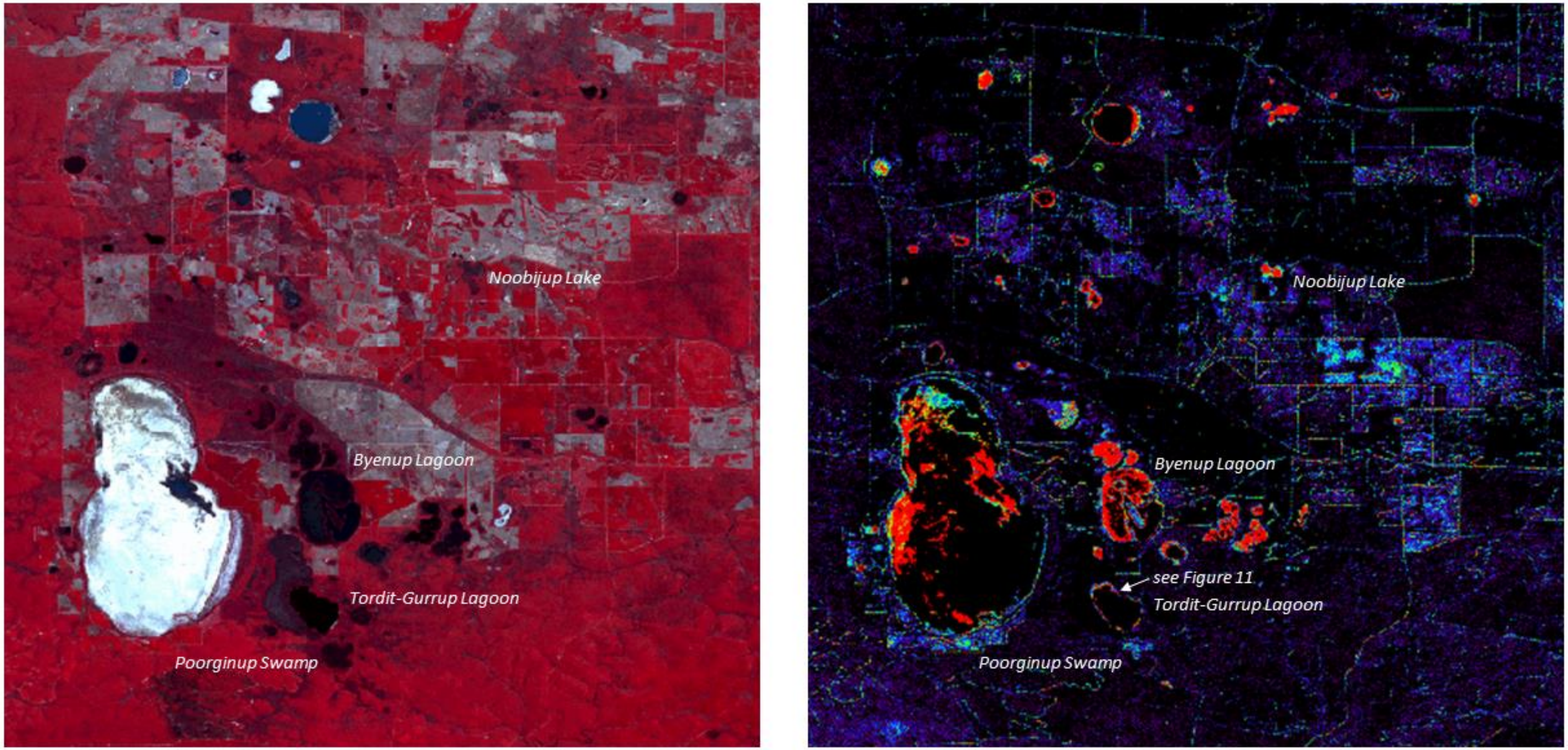
# Appendix 3 ASTER imagery & radiometric data



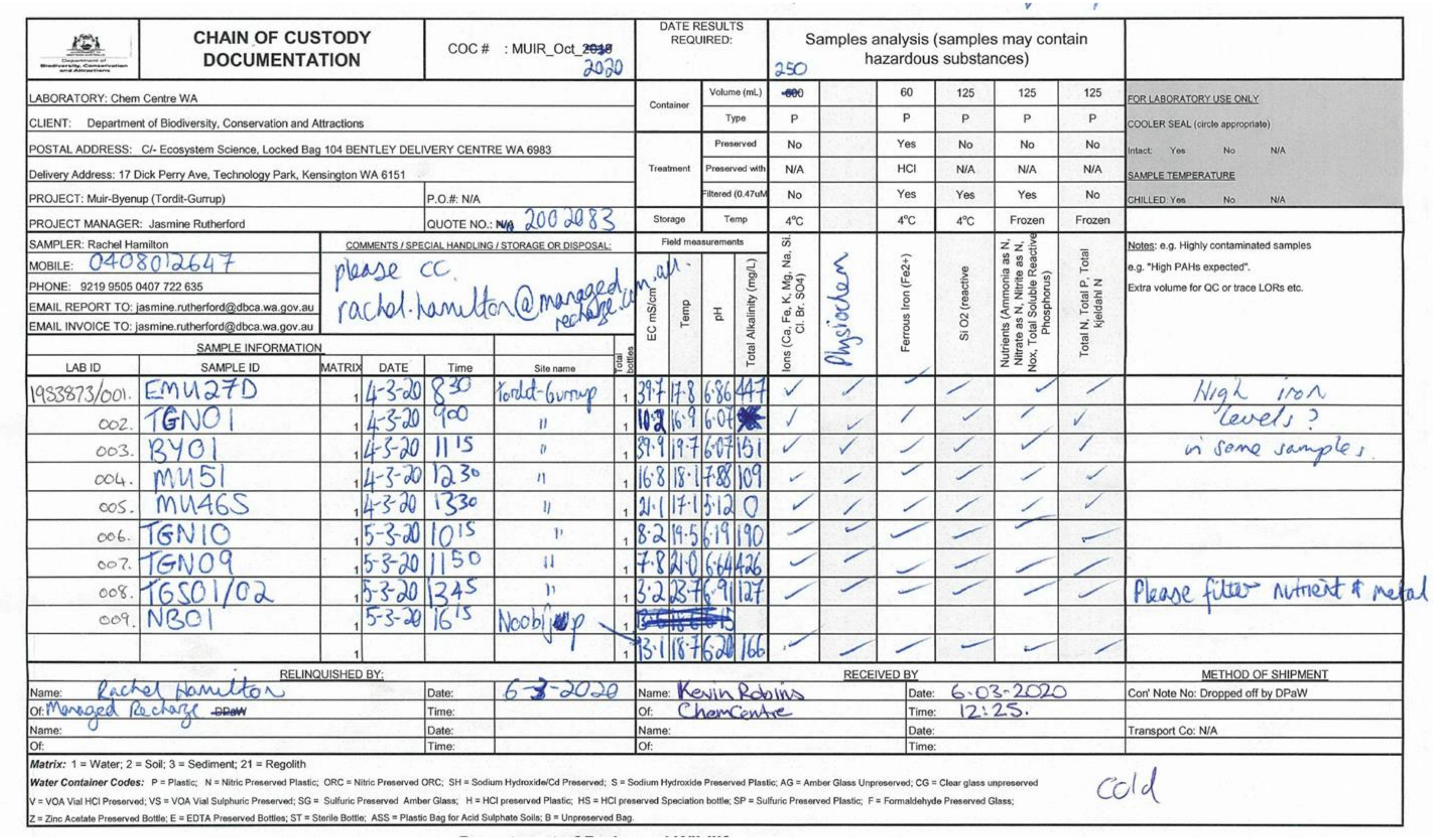

464000
468000
472000
476000
480000
484000
488000
6204000
6200000
6196000
6192000
6188000
6184000
6180000
6176000
6172000
Noobijup Lake
Byenup Lagoon
Tordit-Gurrup Lagoon
Poorginup Swamp
Legend
Data logger network 2019-2020
Drilling & augering 2015
Tordit-Gurrup Lagoon sampling & monitoring sites 2019
Lake depth boards
Groundwater monitoring bores
Ephemeral drainage
Wetlands
Wetlands (peat substrate)
Uranium (2013)
High : 10.5226
Low : -0.710942
N
0
1.25
2.5
5 Kilometers


464000
468000
472000
476000
480000
484000
488000
6204000
6200000
6196000
6192000
6188000
6184000
6180000
6176000
6172000
Noobijup Lake
Byenup Lagoon
Tordit-Gurrup Lagoon
Poorginup Swamp
Legend
Data logger network 2019-2020
Drilling & augering 2015
Tordit-Gurrup Lagoon sampling & monitoring sites 2019
Lake depth boards
Groundwater monitoring bores
Ephemeral drainage
Wetlands
Wetlands (peat substrate)
Potassium (2013)
High : 2.40037
Low : -0.478924
N
0
1.25
2.5
5 Kilometers

ASTER VNIR-SWIR imagery (GSWA 2012): Left; False colour infrared composite, with red areas representing vegetation, water bodies are dark grey to black and dry lakes containing Evaporite minerals are bright white-blue and Right; Opaque index; red areas represent areas with high concentrations of manganese oxides, maghemite gravels or carbon.



# Appendix 4 Field and laboratory chemistry compliance and data (tabled & graphed): physical and major and minor ions



**CHAIN OF CUSTODY DOCUMENTATION**

COC # : MUIR_Oct_~~2018~~ 2020

DATE RESULTS REQUIRED:

Samples analysis (samples may contain hazardous substances)

LABORATORY: Chem Centre WA
CLIENT: Department of Biodiversity, Conservation and Attractions
POSTAL ADDRESS: C/- Ecosystem Science, Locked Bag 104 BENTLEY DELIVERY CENTRE WA 6983
Delivery Address: 17 Dick Perry Ave, Technology Park, Kensington WA 6151
PROJECT: Muir-Byenup (Tordit-Gurrup)
P.O.#: N/A
PROJECT MANAGER: Jasmine Rutherford
QUOTE NO.: ~~N/A~~ 2002083
SAMPLER: Rachel Hamilton
MOBILE: 0408012647
PHONE: 9219 9505 0407 722 635
EMAIL REPORT TO: jasmine.rutherford@dbca.wa.gov.au
EMAIL INVOICE TO: jasmine.rutherford@dbca.wa.gov.au

COMMENTS / SPECIAL HANDLING / STORAGE OR DISPOSAL:
please cc. rachel.hamilton@managedrecharge.com.au.

| | | Ions (Ca, Fe, K, Mg, Na, Si. Cl. Br. SO4) | Physiochem | Ferrous Iron (Fe2+) | Si O2 (reactive | Nutrients (Ammonia as N, Nitrate as N, Nitrite as N, Nox, Total Soluble Reactive Phosphorus) | Total N, Total P, Total kjeldahl N |
|---|---|---|---|---|---|---|---|
| Container | Volume (mL) | ~~600~~ 250 | | 60 | 125 | 125 | 125 |
| | Type | P | | P | P | P | P |
| Treatment | Preserved | No | | Yes | No | No | No |
| | Preserved with | N/A | | HCl | N/A | N/A | N/A |
| | Filtered (0.47uM | No | | Yes | Yes | Yes | No |
| Storage | Temp | 4°C | | 4°C | 4°C | Frozen | Frozen |

FOR LABORATORY USE ONLY
COOLER SEAL (circle appropriate)
Intact: Yes No N/A
SAMPLE TEMPERATURE
CHILLED Yes No N/A

Notes: e.g. Highly contaminated samples
e.g. "High PAHs expected".
Extra volume for QC or trace LORs etc.

SAMPLE INFORMATION

| LAB ID | SAMPLE ID | MATRIX | DATE | Time | Site name | Total bottles | EC mS/cm | Temp | pH | Total Alkalinity (mg/L) | Ions | Physiochem | Ferrous Iron (Fe2+) | Si O2 | Nutrients | Total N, Total P | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1953873/001. | EMU27D | 1 | 4-3-20 | 830 | Tordit-Gurrup | 1 | 39·7 | 17·8 | 6·86 | 447 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | High iron |
| 002. | TGN01 | 1 | 4-3-20 | 900 | " | 1 | 10·2 | 16·9 | 6·07 | [illegible] | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | levels ? |
| 003. | BY01 | 1 | 4-3-20 | 1115 | " | 1 | 39·9 | 19·7 | 6·07 | 151 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | in some samples. |
| 004. | MU51 | 1 | 4-3-20 | 1230 | " | 1 | 16·8 | 18·1 | 7·88 | 109 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |
| 005. | MU46S | 1 | 4-3-20 | 1330 | " | 1 | 21·1 | 17·1 | 5·12 | 0 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |
| 006. | TGN10 | 1 | 5-3-20 | 1015 | " | 1 | 8·2 | 19·5 | 6·19 | 190 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |
| 007. | TGN09 | 1 | 5-3-20 | 1150 | " | 1 | 7·8 | 21·0 | 6·64 | 426 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |
| 008. | TGS01/02 | 1 | 5-3-20 | 1345 | " | 1 | 3·2 | 23·7 | 6·91 | 127 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | Please filter nutrient & metal |
| 009. | NB01 | 1 | 5-3-20 | 1615 | Noobijup | 1 | ~~13·6~~ | ~~18·6~~ | ~~6·15~~ | | | | | | | | |
| | | 1 | | | | 1 | 13·1 | 18·7 | 6·20 | 166 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |

RELINQUISHED BY:
Name: Rachel Hamilton
Of: Managed Recharge ~~DPaW~~
Date: 6-3-2020
Time:
Name:
Of:
Date:
Time:

RECEIVED BY
Name: Kevin Robins
Of: ChemCentre
Date: 6-03-2020
Time: 12:25.
Name:
Of:
Date:
Time:

METHOD OF SHIPMENT
Con' Note No: Dropped off by DPaW
Transport Co: N/A

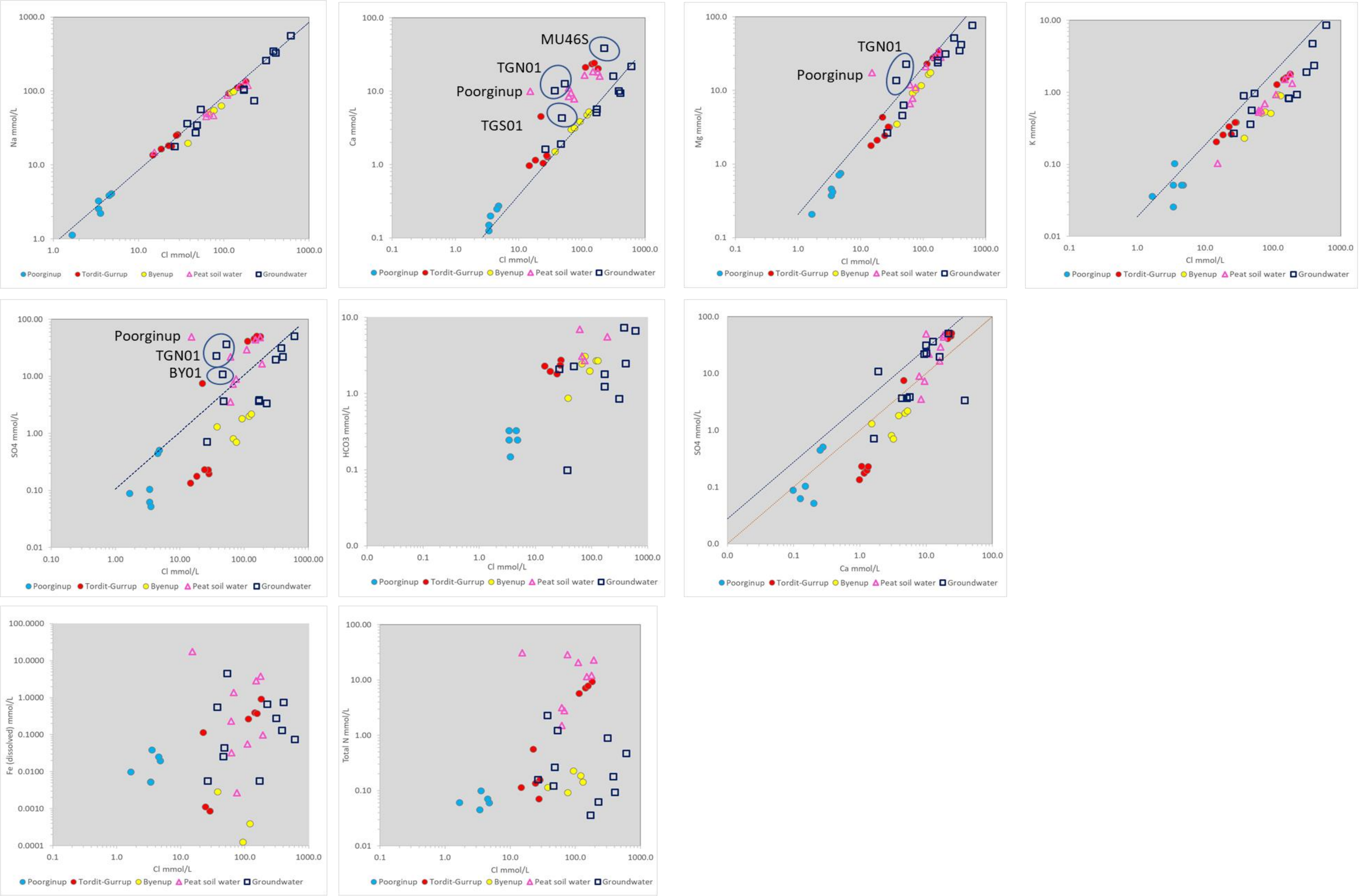
**Matrix:** 1 = Water; 2 = Soil; 3 = Sediment; 21 = Regolith
**Water Container Codes:** P = Plastic; N = Nitric Preserved Plastic; ORC = Nitric Preserved ORC; SH = Sodium Hydroxide/Cd Preserved; S = Sodium Hydroxide Preserved Plastic; AG = Amber Glass Unpreserved; CG = Clear glass unpreserved
V = VOA Vial HCl Preserved; VS = VOA Vial Sulphuric Preserved; SG = Sulfuric Preserved Amber Glass; H = HCl preserved Plastic; HS = HCl preserved Speciation bottle; SP = Sulfuric Preserved Plastic; F = Formaldehyde Preserved Glass;
Z = Zinc Acetate Preserved Bottle; E = EDTA Preserved Bottles; ST = Sterile Bottle; ASS = Plastic Bag for Acid Sulphate Soils; B = Unpreserved Bag.

Cold

| Field parameters (YSI meter) | | | | | | | | | | | | Laboratory parameters | | QAD | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site ID | Date | Time | EC (mS/m) | pH | Temp (°C) | ORP (mV) | Eh (V) | DO (%) | *DO (mg/L) | Turbidity (FNU) | Alkalinity | EC (mS/m) | pH | EC % change | pH % change |
| TGN12 | 30/10/2019 | 14:30 | 1960 | 2.95 | 22.9 | 486 | 0.69 | 104.7 | 8.2 | | 0 | | | | |
| TGN12 | 20/11/2019 | 10:00 | 2310 | 2.8 | 19.1 | 480.7 | 0.68 | 102.2 | 8.5 | 5.89 | 0 | 2240 | 3 | -3 | 7 |
| TGS06 | 30/10/2019 | 9:30 | 1690 | 2.79 | 18 | 487.4 | 0.69 | 97.1 | 8.5 | | 0 | | | | |
| TGS06 | 19/11/2019 | 14:30 | 2100 | 2.76 | 21.3 | 486.1 | 0.69 | 91.9 | 7.4 | 2.04 | 0 | 2020 | 2.9 | -4 | 5 |
| TGN09 | 16/10/2019 | 13:35 | 690 | 3.97 | 17.9 | 341.1 | 0.54 | 100.7 | 9.1 | | 0 | | | | |
| TGN09 | 20/11/2019 | 12:15 | 1519 | 4.86 | 17.9 | 213.4 | 0.41 | 79.8 | 7.0 | 852 | 0 | 1480 | 4.1 | -3 | -16 |
| TGN09 | 5/03/2020 | 11:50 | 778 | 6.6 | 21 | -42.5 | 0.16 | 35.3 | 3.0 | 43.3 | 426 | 742 | 7.4 | -5 | 11 |
| TGN09 | 28/10/2020 | 13:35 | 816 | 7.4 | 18 | 111.8 | 0.31 | 82.5 | 7.4 | 25.2 | | | | | |
| TGN10 | 29/10/2019 | 14:30 | 1960 | 4.11 | 18.9 | 205.7 | 0.41 | 61.2 | 5.2 | | 0 | | | | |
| TGN10 | 20/11/2019 | 12:30 | 2180 | 3.88 | 21.7 | 273.1 | 0.47 | 79 | 6.3 | 314 | 0 | 2230 | 3.2 | 2 | -18 |
| TGN10 | 5/03/2020 | 10:15 | 823 | 6.2 | 19.5 | -11.7 | 0.19 | 25.8 | 2.3 | 75.6 | 190 | 805 | 6.8 | -2 | 10 |
| TGN10 | 29/07/2020 | 16:30 | 1362 | 4.1 | 14.6 | 124.4 | 0.32 | 34.5 | 3.3 | 101.5 | 0 | | | | |
| TGN10 | 28/10/2020 | 13:30 | 1398 | 4.7 | 20.8 | 185.6 | 0.39 | 36.7 | 3.1 | 36.7 | | | | | |
| BY01 | 4/03/2020 | 11:15 | 3990 | 6.1 | 19.7 | 3.7 | 0.20 | 7.7 | 0.6 | 38.7 | 151 | 3820 | 6.8 | -4 | 12 |
| EMU27D | 4/03/2020 | 8:30 | 3970 | 6.9 | 17.8 | -78.5 | 0.12 | 4.1 | 0.3 | | 447 | 3810 | 7.4 | -4 | 8 |
| MU51 | 4/03/2020 | 12:30 | 1680 | 7.9 | 18.1 | 38.8 | 0.24 | 66.3 | 5.8 | 7.12 | 109 | 1610 | 7.8 | -4 | -1 |
| NB01 | 5/03/2020 | 16:15 | 1308 | 6.2 | 18.7 | -8.8 | 0.19 | 9.7 | 0.9 | 210.7 | 166 | 1410 | 6.9 | 8 | 11 |
| TGN01 | 4/03/2020 | 9:00 | 1020 | 6.1 | 16.9 | -95.2 | 0.10 | 8.5 | 0.8 | 8.56 | 144 | 969 | 5.9 | -5 | -3 |
| TGS01/02 | 5/03/2020 | 13:45 | 324 | 6.9 | 23.7 | -51.6 | 0.15 | 67.4 | 5.5 | 1362 | 127 | 316 | 7.8 | -2 | 13 |
| MU46S | 4/03/2020 | 13:30 | 2110 | 5.1 | 17.1 | 140.2 | 0.34 | 3.2 | 0.3 | 20.93 | 0 | 2050 | 3.8 | -3 | 26 |

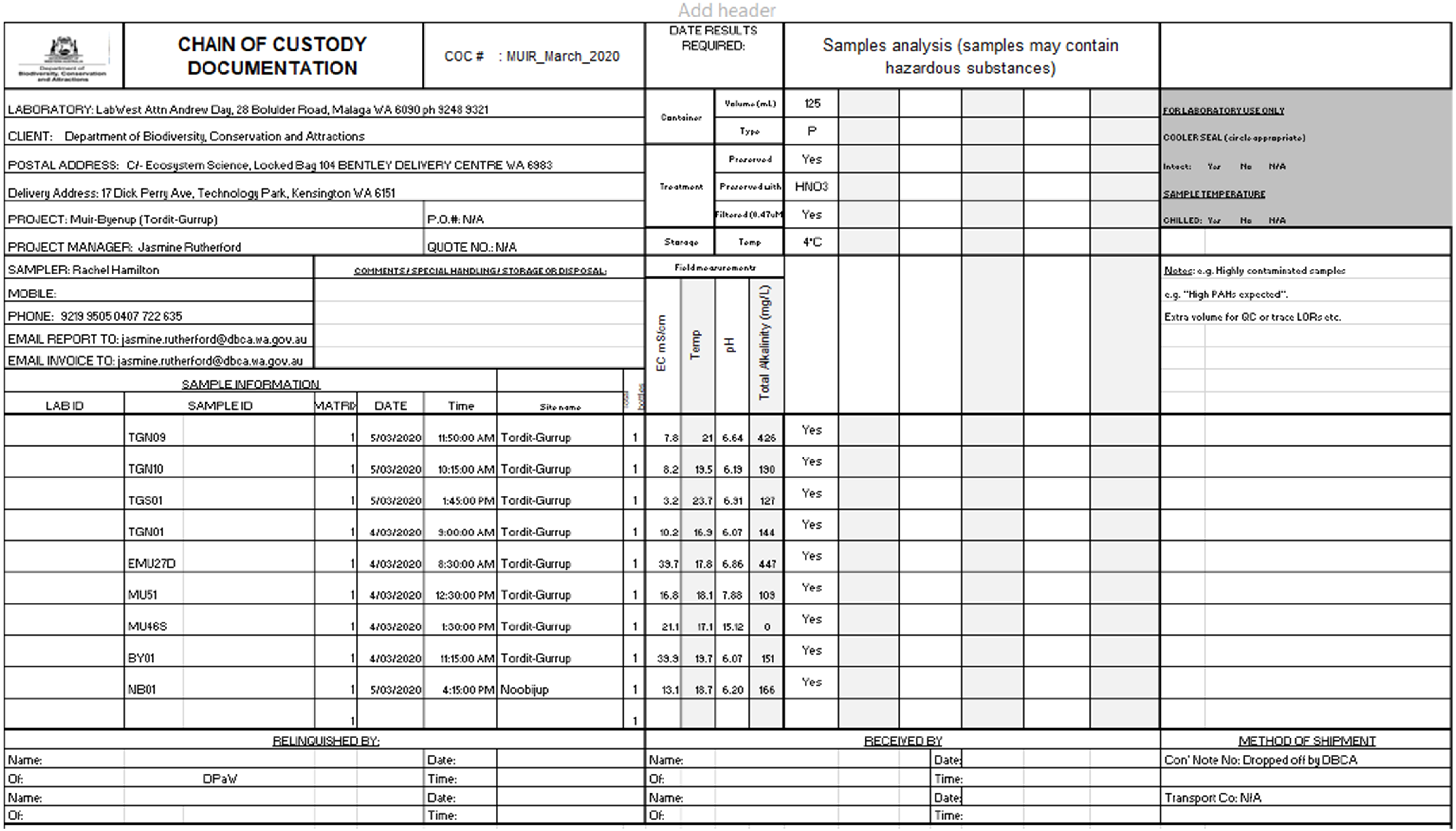
*DO(mg/L) calculated using USGS DOTABLES (https//water.usgs.gov/cgi-bin/dotables) & field Temp/Salinity/Pressure data; data in red appear erroneous

| | | | CBE | Alkalin | Br | Ca | Cl | ECond | Fe | FeII | HCO3 | K | Mg | N_NH3 | N_NO2 | N_NO3 | N_NOx | N_TK | N_total | Na | P_SR | P_total | SO4 | Si | SiO2 | TDS_grav | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Method Code | Charge Balance Error | iALK1WATI | iANIO1WAIC | iMET1WCICP | iCO1WCDA | iEC1WZSE | iMET1WCICP | iCO1WCDA | iALK1WATI | iMET1WCICP | iMET1WCICP | iNPSi1SFAA | iNPSi1SFAA | iNPCALC4 | iNPSi1SFAA | iNPCALC1 | iNPT1SFAA | iMET1WCICP | iNPSi1SFAA | iNPT1SFAA | iCO1WCDA | iMET1WCICP | iNPSi1SFAA | iSOL1WDGR | iPH1WASE |
| | | *Limits of Reporting* | | *1* | *0.1* | *0.1* | *1* | *0.2* | *0.005* | *0.05* | mg/L | *0.1* | *0.1* | *0.01* | *0.01* | *0.01* | *0.01* | *0.025* | *0.025* | *0.1* | *0.005* | *0.005* | *1* | *0.05* | *0.002* | *10* | *0.1* |
| | | Units | | mg/L | mg/L | mg/L | mg/L | mS/m | 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 | mg/L | mg/L | mg/L | mg/L | |
| Site ID | DateSampled | ChemCentre Id | | | | | | | | | | | | | | | | | | | | | | | | | |
| EMU27D | 4/03/2020 | 19S3873-001 | -1.5 | 447 | 19 | 401 | 13600 | 3810 | 7.3 | 0.42 | 545.3 | 185 | 840 | 2 | <0.010 | 0.08 | 0.077 | 2.4 | 2.5 | 7940 | <0.005 | 0.055 | 3000 | 13 | 28 | 26000 | 7.4 |
| TGN01 | 4/03/2020 | 19S3873-002 | 4.2 | | 3.1 | 506 | 1900 | 969 | 250 | 240 | | 37.8 | 549 | 13 | 0.033 | 0.01 | 0.047 | 17 | 17 | 1300 | 0.028 | 0.042 | 3500 | 18 | 36 | 6900 | 5.9 |
| BY01 | 4/03/2020 | 19S3873-003 | -2.1 | 151 | 24 | 375 | 14400 | 3820 | 41 | 39 | 184.2 | 92.4 | 1020 | 1.3 | <0.010 | 0.02 | 0.023 | 1.3 | 1.3 | 7510 | <0.005 | 0.029 | 2100 | 2.8 | 6.1 | 23000 | 6.8 |
| MU51 | 4/03/2020 | 19S3873-004 | -5.5 | 109 | 15 | 205 | 6070 | 1610 | <0.05 | 0.43 | 133.0 | 32.3 | 579 | 0.086 | <0.010 | 0.28 | 0.28 | 0.22 | 0.5 | 2360 | 0.006 | 0.025 | 350 | 24 | 55 | 9800 | 7.8 |
| MU46S | 4/03/2020 | 19S3873-005 | -3.9 | 0 | 15 | 1540 | 8040 | 2050 | 37 | 35 | 0.0 | 36.3 | 762 | 0.85 | <0.010 | 0.02 | 0.021 | 0.85 | 0.87 | 1700 | <0.005 | 0.022 | 320 | 4.4 | 9.3 | 15000 | 3.8 |
| TGN10B | 5/03/2020 | 19S3873-006 | 2.7 | 190 | 3.6 | 378 | 2390 | 805 | 77 | 89 | 231.8 | 21.9 | 190 | 39 | <0.010 | 0.02 | 0.024 | 39 | 39 | 1130 | <0.005 | 0.03 | 700 | 21 | 42 | 5100 | 6.8 |
| TGN09B | 5/03/2020 | 19S3873-007 | 1.0 | 426 | 3.1 | 337 | 2200 | 742 | 1.8 | 18 | 519.7 | 21.9 | 160 | 21 | <0.010 | 0.01 | 0.01 | 21 | 21 | 1040 | <0.005 | 0.024 | 340 | 25 | 53 | 4700 | 7.4 |
| TGS01/02 | 5/03/2020 | 19S3873-008 | -6.1 | 127 | 1.7 | 64.9 | 944 | 316 | 0.31 | 0.081 | 154.9 | 10.5 | 64.4 | 1.8 | 0.01 | 0.04 | 0.052 | 2.2 | 2.2 | 407 | <0.005 | 0.01 | 68 | 13 | 28 | 1800 | 7.8 |
| NB01 | 5/03/2020 | 19S3873-009 | -9.8 | 166 | 15 | 142 | 5190 | 1410 | 86 | 48 | 202.5 | 17.6 | 514 | 0.7 | <0.010 | 0.01 | 0.014 | 0.7 | 0.71 | 1750 | <0.005 | 0.014 | 390 | 9.2 | 20 | 8500 | 6.9 |
| T6N09C | 16/10/2019 | 19S1659/001 | -2.7 | | 3.5 | 442 | 2190 | | 13 | 0.12 | | 20.6 | 287 | 41 | <0.010 | <0.01 | 0.015 | 44 | 44 | 1160 | 0.015 | 0.094 | 2100 | 12 | 27 | | |
| TGN09C | 20/11/2019 | 19S2195/004 | -0.4 | <1 | 5.7 | 660 | 3910 | 1480 | 3.1 | 3.1 | | 36.2 | 503 | 60 | <0.010 | 0.05 | 0.052 | 290 | 290 | 2020 | 0.031 | 2.1 | 2800 | 19 | 43 | | 4.1 |
| TGN10B | 29/10/2019 | 19S1852/001 | -3.0 | | 7.4 | 738 | 5330 | | 160 | 160 | | 58.7 | 696 | 110 | <0.010 | <0.01 | 0.01 | 160 | 160 | 2650 | 0.049 | 0.16 | 4200 | 17 | 43 | | |
| TGN10B | 20/11/2019 | 19S2195/003 | -2.7 | <1 | 9.1 | 730 | 6310 | 2230 | 210 | 210 | | 69.8 | 832 | 130 | <0.010 | 0.06 | 0.064 | 170 | 170 | 3140 | 0.024 | 0.84 | 4600 | 22 | 46 | | 3.2 |
| TGN12 | 29/10/2019 | 19S1852/002 | -2.7 | | 6.6 | 946 | 5080 | | 22 | 5.8 | | 59.2 | 663 | 99 | <0.010 | <0.01 | <0.010 | 100 | 100 | 2570 | 0.041 | 0.12 | 4400 | 11 | 29 | | |
| TGN12 | 20/11/2019 | 19S2195/002 | -4.5 | <1 | 8.6 | 817 | 6370 | 2240 | 51 | 18 | | 70.3 | 820 | 120 | <0.010 | <0.01 | <0.010 | 130 | 130 | 3120 | <0.005 | 0.015 | 4800 | 16 | 37 | | 3 |
| TGS06 | 30/10/2019 | 19S1852/003 | -2.3 | | 5.5 | 847 | 4040 | | 15 | 3.9 | | 50.3 | 552 | 80 | <0.010 | <0.01 | <0.010 | 80 | 80 | 2150 | 0.024 | 0.038 | 4000 | 6.9 | 17 | | |
| TGS06 | 19/11/2019 | 19S2195/001 | -5.6 | <1 | 7.1 | 967 | 5540 | 2020 | 21 | 5.8 | | 62.5 | 702 | 100 | <0.010 | <0.01 | <0.010 | 110 | 110 | 2660 | <0.005 | 0.02 | 4900 | 9.5 | 20 | | 2.9 |



Bivariate plots; changing concentration (mmol/L) major cations & anions with respect to chloride; surface water data from Tordit-Gurrup & Byenup Lagoons & Poorginup Swamp (1998 to 2020); groundwater and peat soil water includes Noobijup Swamp (2015 to 2020) (NB dashed blue line represents seawater evaporation line (chloride plots); SO4/Ca plot orange and blue dashed lines represent respective gypsum & pyrite dissolution), where measurements were below detection limits they are not plotted (e.g. no measurable alkalinity / HCO3 in Oct/Nov 2019 & 2020)

# Appendix 5 Laboratory chemistry compliance and data (tabled & graphed): minor ions and stable water isotopes



Add header

**CHAIN OF CUSTODY DOCUMENTATION**

COC # : MUIR_March_2020

DATE RESULTS REQUIRED:

Samples analysis (samples may contain hazardous substances)

LABORATORY: LabWest Attn Andrew Day, 28 Bolulder Road, Malaga WA 6090 ph 9248 9321

CLIENT: Department of Biodiversity, Conservation and Attractions

POSTAL ADDRESS: C/- Ecosystem Science, Locked Bag 104 BENTLEY DELIVERY CENTRE WA 6983

Delivery Address: 17 Dick Perry Ave, Technology Park, Kensington WA 6151

PROJECT: Muir-Byenup (Tordit-Gurrup)

P.O.#: N/A

PROJECT MANAGER: Jasmine Rutherford

QUOTE NO.: N/A

SAMPLER: Rachel Hamilton

MOBILE:

PHONE: 9219 9505 0407 722 635

EMAIL REPORT TO: jasmine.rutherford@dbca.wa.gov.au

EMAIL INVOICE TO: jasmine.rutherford@dbca.wa.gov.au

COMMENTS / SPECIAL HANDLING / STORAGE OR DISPOSAL:

| | | |
|---|---|---|
| Container | Volume (mL) | 125 |
| | Type | P |
| Treatment | Preserved | Yes |
| | Preserved with | HNO3 |
| | Filtered (0.47uM | Yes |
| Storage | Temp | 4°C |

FOR LABORATORY USE ONLY

COOLER SEAL (circle appropriate)

Intact: Yes No N/A

SAMPLE TEMPERATURE

CHILLED: Yes No N/A

Notes: e.g. Highly contaminated samples

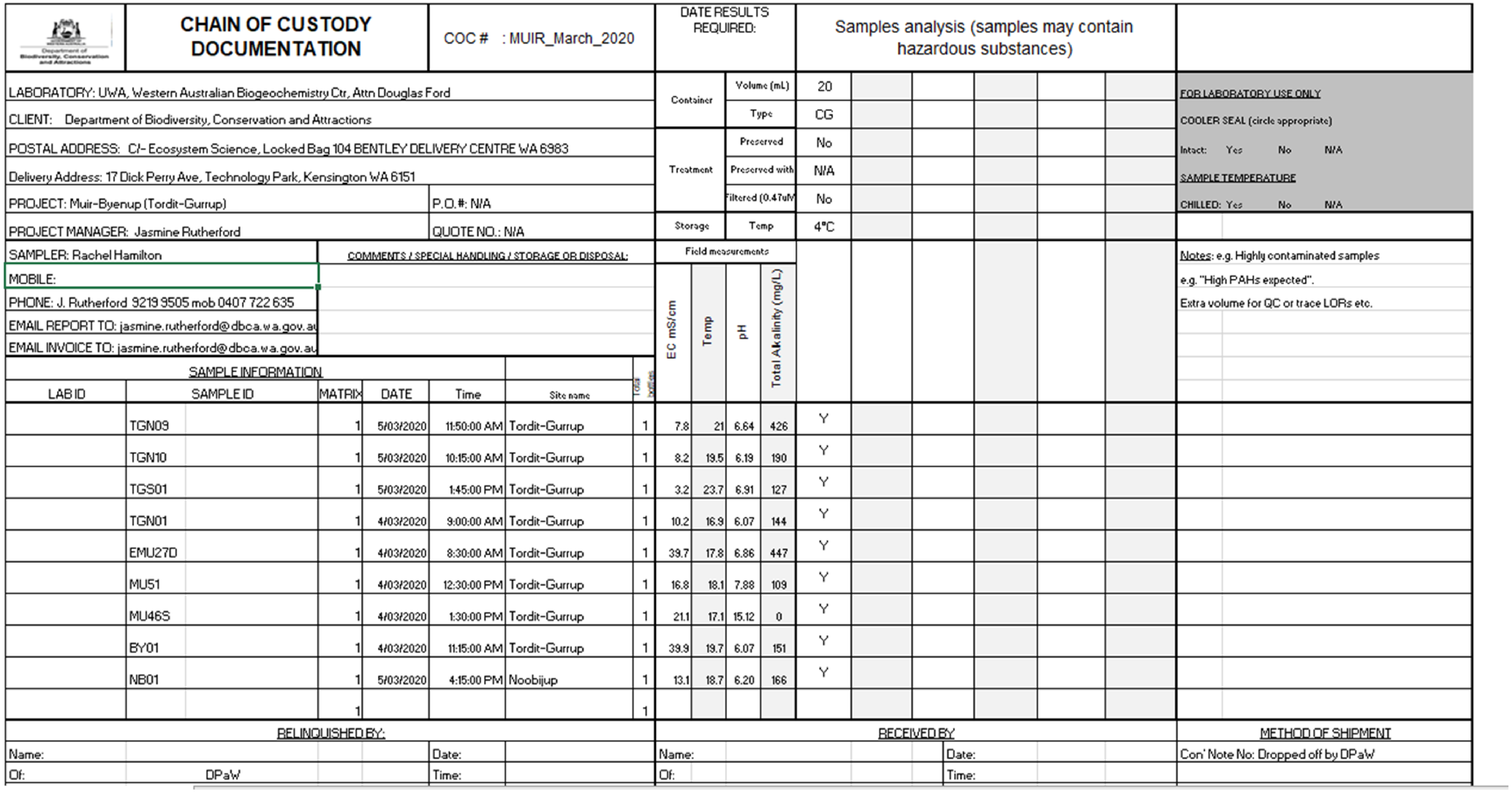
e.g. "High PAHs expected".

Extra volume for QC or trace LORs etc.

SAMPLE INFORMATION

| LAB ID | SAMPLE ID | MATRIX | DATE | Time | Site name | Total bottles | Field measurements EC mS/cm | Temp | pH | Total Alkalinity (mg/L) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | TGN09 | 1 | 5/03/2020 | 11:50:00 AM | Tordit-Gurrup | 1 | 7.8 | 21 | 6.64 | 426 | Yes |
| | TGN10 | 1 | 5/03/2020 | 10:15:00 AM | Tordit-Gurrup | 1 | 8.2 | 19.5 | 6.19 | 190 | Yes |
| | TGS01 | 1 | 5/03/2020 | 1:45:00 PM | Tordit-Gurrup | 1 | 3.2 | 23.7 | 6.91 | 127 | Yes |
| | TGN01 | 1 | 4/03/2020 | 9:00:00 AM | Tordit-Gurrup | 1 | 10.2 | 16.9 | 6.07 | 144 | Yes |
| | EMU27D | 1 | 4/03/2020 | 8:30:00 AM | Tordit-Gurrup | 1 | 39.7 | 17.8 | 6.86 | 447 | Yes |
| | MU51 | 1 | 4/03/2020 | 12:30:00 PM | Tordit-Gurrup | 1 | 16.8 | 18.1 | 7.88 | 109 | Yes |
| | MU46S | 1 | 4/03/2020 | 1:30:00 PM | Tordit-Gurrup | 1 | 21.1 | 17.1 | 15.12 | 0 | Yes |
| | BY01 | 1 | 4/03/2020 | 11:15:00 AM | Tordit-Gurrup | 1 | 39.9 | 19.7 | 6.07 | 151 | Yes |
| | NB01 | 1 | 5/03/2020 | 4:15:00 PM | Noobijup | 1 | 13.1 | 18.7 | 6.20 | 166 | Yes |
| | | 1 | | | | 1 | | | | | |

| RELINQUISHED BY: | | | | RECEIVED BY | | | | METHOD OF SHIPMENT |
|---|---|---|---|---|---|---|---|---|
| Name: | | Date: | | Name: | | Date: | | Con' Note No: Dropped off by DBCA |
| Of: | DPaW | Time: | | Of: | | Time: | | |
| Name: | | Date: | | Name: | | Date: | | Transport Co: N/A |
| Of: | | Time: | | Of: | | Time: | | |



**CHAIN OF CUSTODY DOCUMENTATION**

COC # : MUIR_March_2020

DATE RESULTS REQUIRED:

Samples analysis (samples may contain hazardous substances)

LABORATORY: UWA, Western Australian Biogeochemistry Ctr, Attn Douglas Ford

CLIENT: Department of Biodiversity, Conservation and Attractions

POSTAL ADDRESS: C/- Ecosystem Science, Locked Bag 104 BENTLEY DELIVERY CENTRE WA 6983

Delivery Address: 17 Dick Perry Ave, Technology Park, Kensington WA 6151

PROJECT: Muir-Byenup (Tordit-Gurrup)

P.O.#: N/A

PROJECT MANAGER: Jasmine Rutherford

QUOTE NO.: N/A

SAMPLER: Rachel Hamilton

MOBILE:

PHONE: J. Rutherford 9219 9505 mob 0407 722 635

EMAIL REPORT TO: jasmine.rutherford@dbca.wa.gov.au

EMAIL INVOICE TO: jasmine.rutherford@dbca.wa.gov.au

COMMENTS / SPECIAL HANDLING / STORAGE OR DISPOSAL:

| | | |
|---|---|---|
| Container | Volume (mL) | 20 |
| | Type | CG |
| Treatment | Preserved | No |
| | Preserved with | N/A |
| | Filtered (0.47uM | No |
| Storage | Temp | 4°C |

FOR LABORATORY USE ONLY

COOLER SEAL (circle appropriate)

Intact: Yes No N/A

SAMPLE TEMPERATURE

CHILLED: Yes No N/A

Notes: e.g. Highly contaminated samples

e.g. "High PAHs expected".

Extra volume for QC or trace LORs etc.

SAMPLE INFORMATION

| LAB ID | SAMPLE ID | MATRIX | DATE | Time | Site name | Total bottles | EC mS/cm | Temp | pH | Total Alkalinity (mg/L) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | TGN09 | 1 | 5/03/2020 | 11:50:00 AM | Tordit-Gurrup | 1 | 7.8 | 21 | 6.64 | 426 | Y |
| | TGN10 | 1 | 5/03/2020 | 10:15:00 AM | Tordit-Gurrup | 1 | 8.2 | 19.5 | 6.19 | 190 | Y |
| | TGS01 | 1 | 5/03/2020 | 1:45:00 PM | Tordit-Gurrup | 1 | 3.2 | 23.7 | 6.91 | 127 | Y |
| | TGN01 | 1 | 4/03/2020 | 9:00:00 AM | Tordit-Gurrup | 1 | 10.2 | 16.9 | 6.07 | 144 | Y |
| | EMU27D | 1 | 4/03/2020 | 8:30:00 AM | Tordit-Gurrup | 1 | 39.7 | 17.8 | 6.86 | 447 | Y |
| | MU51 | 1 | 4/03/2020 | 12:30:00 PM | Tordit-Gurrup | 1 | 16.8 | 18.1 | 7.88 | 109 | Y |
| | MU46S | 1 | 4/03/2020 | 1:30:00 PM | Tordit-Gurrup | 1 | 21.1 | 17.1 | 15.12 | 0 | Y |
| | BY01 | 1 | 4/03/2020 | 11:15:00 AM | Tordit-Gurrup | 1 | 39.9 | 19.7 | 6.07 | 151 | Y |
| | NB01 | 1 | 5/03/2020 | 4:15:00 PM | Noobijup | 1 | 13.1 | 18.7 | 6.20 | 166 | Y |
| | | 1 | | | | 1 | | | | | |

RELINQUISHED BY:

Name:

Of: DPaW

Date:

Time:

RECEIVED BY

Name:

Of:

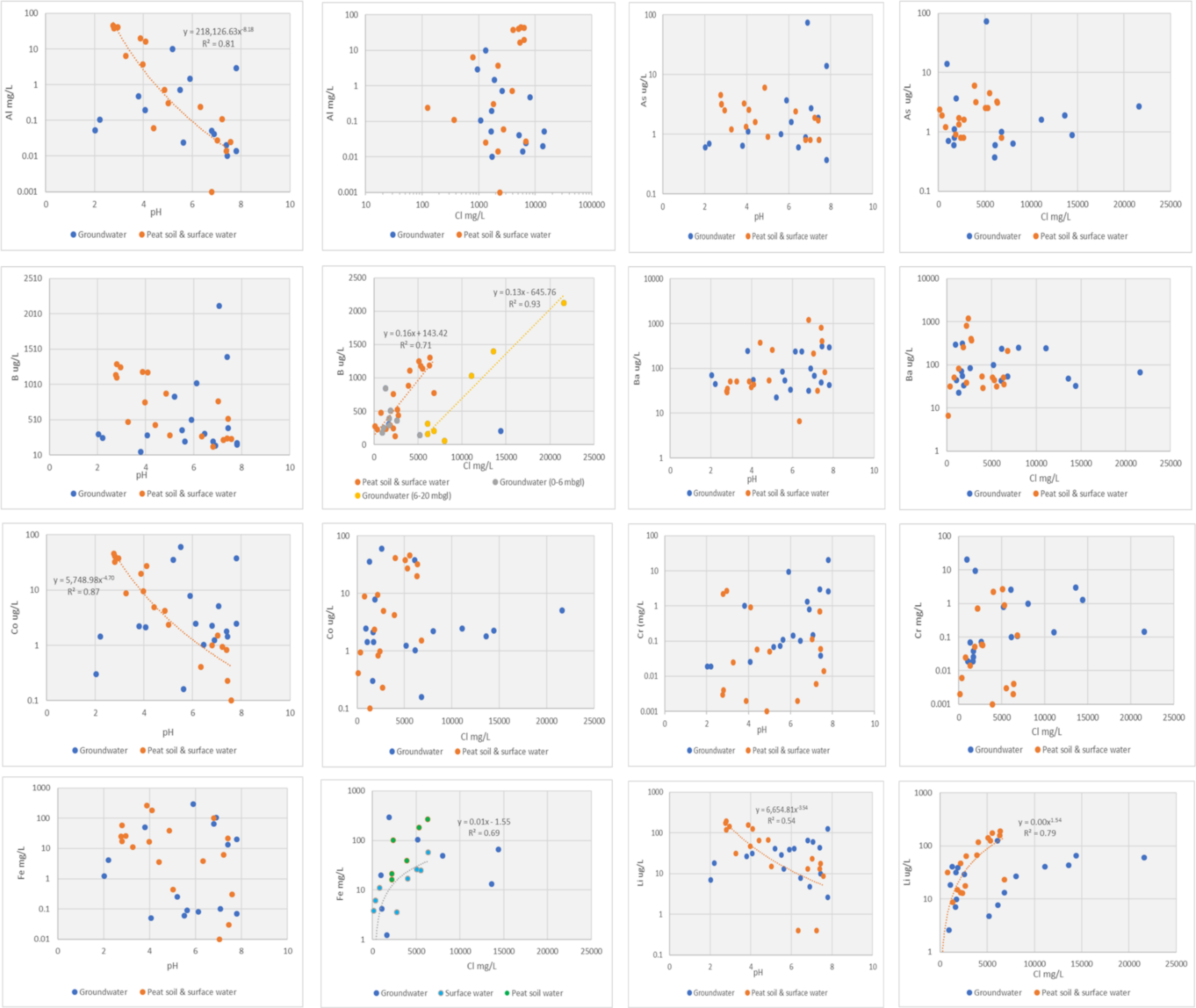
Date:

Time:

METHOD OF SHIPMENT

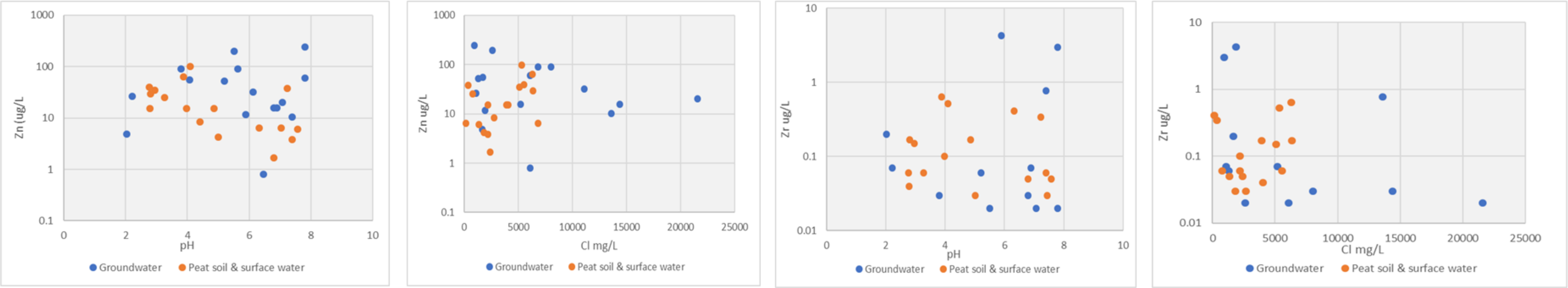
Con' Note No: Dropped off by DPaW

| Element | Date sampled | Al | As | B | Ba | Co | Cr | Cs | Cu | Fe | Li | Mn | Ni | Pb | Rb | Se | Sr | U | V | Zn | Zr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Units | | mg/L | ug/L | ug/L | ug/L | ug/L | mg/L | ug/L | ug/L | mg/L | ug/L | ug/L | ug/L | ug/L | ug/L | ug/L | mg/L | ug/L | ug/L | ug/L | ug/L |
| DL | | 0.001 | 0.5 | 5 | 0.05 | 0.02 | 0.001 | 0.01 | 0.1 | 0.01 | 0.1 | 0.05 | 0.2 | 0.1 | 0.01 | 0.5 | 0.01 | 0.02 | 0.01 | 0.5 | 0.02 |
| Method | | | | | | | | | | | | | | | | | | | | | |
| ClientID/Scheme | | ENV04 | ENV04 | ENV04 | ENV04 | ENV04 | ENV04 | ENV04 | ENV04 | ENV04 | ENV04 | ENV04 | ENV04 | ENV04 | ENV04 | ENV04 | ENV04 | ENV04 | ENV04 | ENV04 | ENV04 |
| EMU27D | 4/03/2020 | 0.02 | 1.89 | 1400 | 48.1 | 1.8 | 3 | 0.02 | 0.9 | 13.24 | 43.2 | 266 | 30.7 | 0.1 | 20.4 | 18 | 7.06 | 1.42 | 0.9 | 10.3 | 0.77 |
| MU51 | 4/03/2020 | 0.014 | 0.37 | 160 | 42.7 | 37.5 | 2.6 | 0.02 | 3.7 | 0.071 | 124 | 3170 | 3020 | | 4.46 | 11.5 | 1.78 | 0.02 | 0.37 | 59.5 | 0.02 |
| MU46S | 4/03/2020 | 0.466 | 0.64 | 58 | 246 | 2.21 | 1 | 1.26 | 3 | 49.64 | 26.5 | 1710 | 55.3 | 1.1 | 53.9 | 15 | 8.94 | | 0.19 | 90.5 | 0.03 |
| BY01 | 4/03/2020 | 0.051 | 0.88 | 206 | 32 | 2.24 | 1.3 | 0.21 | 2.4 | 65.4 | 65.5 | 526 | 27.9 | | 31.8 | 21.7 | 7.06 | 0.01 | 0.6 | 15.7 | 0.03 |
| TGN01 | 4/03/2020 | 1.46 | 3.66 | 506 | 33.6 | 7.77 | 9.4 | 0.09 | 0.2 | 292.5 | 38.7 | 481 | 23.5 | 0.4 | 18 | 3.8 | 2.9 | 0.07 | 19.3 | 11.7 | 4.3 |
| NB01 | 5/03/2020 | 0.041 | 73.2 | 144 | 98 | 1.24 | 0.8 | 0.08 | 91.4 | 103.9 | 4.7 | 1300 | 20 | | 5.82 | 11.5 | 1.43 | 0.04 | 0.75 | 15.7 | 0.07 |
| TGS01 | 5/03/2020 | 2.88 | 13.9 | 179 | 295 | 2.44 | 20.3 | 0.08 | 19.3 | 20.07 | 2.6 | 236 | 14.5 | 69.9 | 4.88 | 1.4 | 0.27 | 1.13 | 22.2 | 243 | 2.96 |
| TGN12 | 29/10/2019 | 40.3 | 2.52 | 1250 | 51.1 | 37.5 | 2.7 | 1.29 | 2.7 | 26.36 | 143 | 10300 | 44.7 | 3.3 | 77.8 | 11 | 7.38 | 0.31 | 0.52 | 34.9 | 0.15 |
| TGN12 | 20/11/2019 | 42.6 | 3.14 | 1300 | 35.2 | 32.4 | 0.004 | 1.02 | 18.1 | 57.89 | 191 | 15900 | 65.3 | 1.4 | 70.2 | 5.9 | 9.67 | 0.19 | 0.33 | 29.7 | 0.17 |
| TGS06 | 30/10/2019 | 38 | 3.19 | 1110 | 29.2 | 41.3 | 2.2 | 1.13 | 1.2 | 17.08 | 118 | 8080 | 30.5 | 1.9 | 70.5 | 6.5 | 6.6 | 0.23 | 0.17 | 15.3 | 0.04 |
| TGS06 | 19/11/2019 | 44.9 | 4.54 | 1140 | 31.2 | 45.2 | 0.003 | 0.96 | 35.4 | 25 | 174 | 13300 | 63.7 | 1.6 | 65.6 | 10.7 | 9.38 | 0.23 | 0.17 | 39.3 | 0.06 |
| TGN09 | 16/10/2019 | 3.72 | 1.34 | 758 | 38.1 | 9.46 | | 0.54 | 0.7 | 16.41 | 47.1 | 4640 | 6.2 | 0.5 | 26.2 | 1.4 | 2.98 | 0.05 | 0.25 | 15.1 | 0.1 |
| TGN09 | 20/11/2019 | 0.706 | 6.06 | 879 | 53.9 | 4.24 | 0.001 | 0.48 | 0.5 | 39.21 | 66.7 | 11700 | 12 | 0.4 | 33.2 | 6.7 | 4.92 | | 3.76 | 15.1 | 0.17 |
| TGN09 | 5/03/2020 | 0.014 | 1.71 | 243 | 813 | 0.83 | 0.7 | 0.04 | 3.6 | 21.37 | 13.2 | 2150 | 17.5 | 0.4 | 7.17 | 4.1 | 1.47 | 0.1 | 0.16 | 3.8 | 0.06 |
| TGN10 | 5/03/2020 | 0.001 | 0.8 | 130 | 1190 | 0.99 | < 0.5 | 0.1 | 1.5 | 100.8 | 12.9 | 3500 | 21.9 | 0.1 | 11 | 3.7 | 1.84 | 0.02 | 0.08 | 1.7 | 0.05 |
| TGN10 | 29/10/2019 | 16.4 | 2.54 | 1180 | 44.1 | 27.1 | 0.9 | 1.35 | 1.7 | 183.9 | 124 | 12300 | 77.7 | 2 | 78 | 7.9 | 6.57 | 0.04 | 2.16 | 99.3 | 0.52 |
| TGN10 | 20/11/2019 | 19.6 | 3.25 | 1190 | 50.5 | 19.8 | 0.002 | 1.21 | 4.7 | 266.7 | 157 | 16500 | 51.2 | 1.9 | 65.4 | 11.8 | 7.61 | 0.21 | 10.7 | 63.4 | 0.64 |



Bivariate plots; concentration (pH units, mg/L or µg/L) minor ions (metals & metalloids) with respect to pH and chloride; surface water data from five lakes and groundwater & peat soil water from four lakes within the Muir-Byenup Ramsar site (2015 to 2020) (NB trendlines & correlation coefficients are present where relationships were observed)

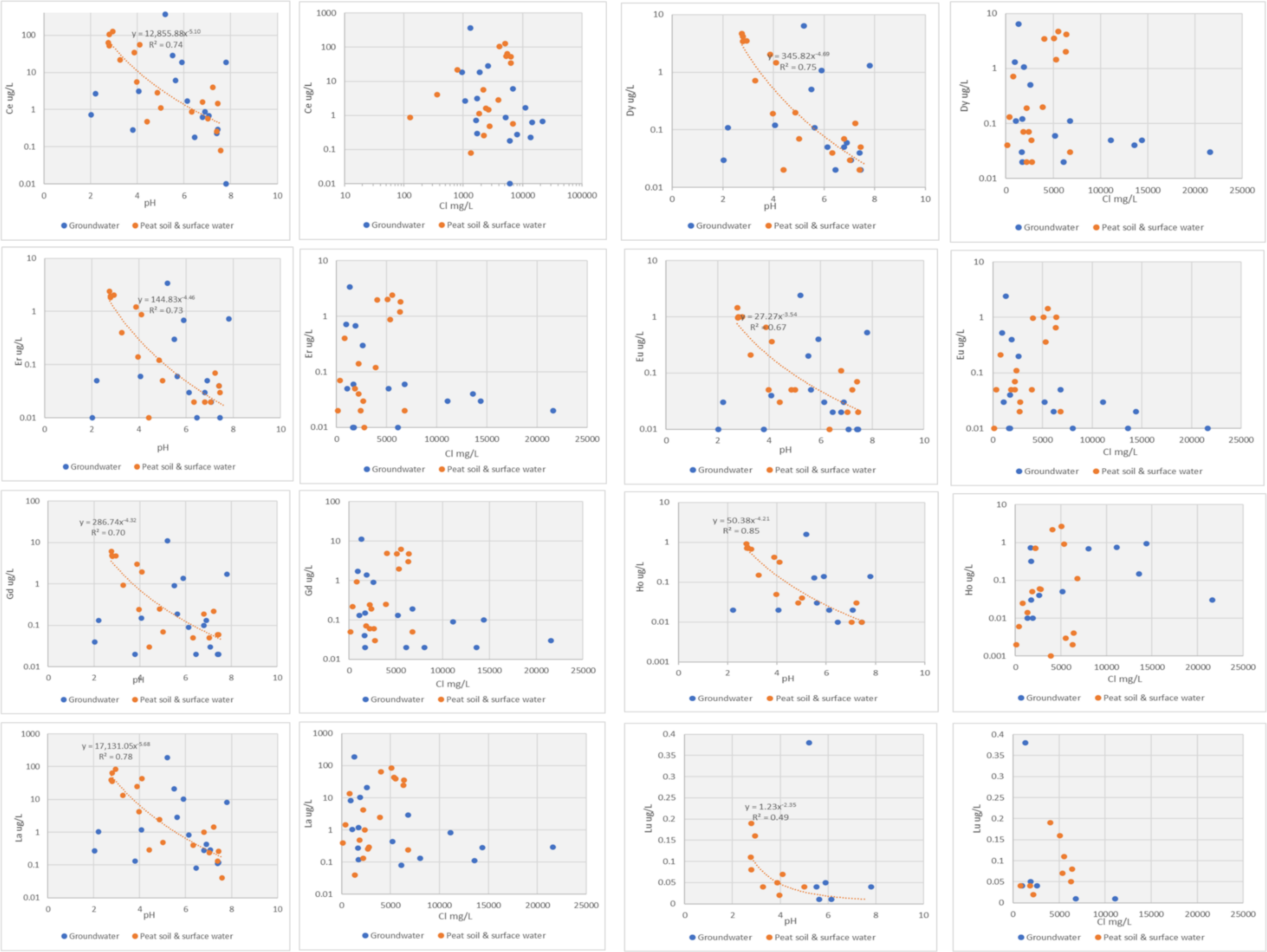
Bivariate plots; concentration (pH units, mg/L or µg/L) minor ions (metals & metalloids) with respect to pH and chloride; surface water data from five lakes and groundwater & peat soil water from four lakes within the Muir-Byenup Ramsar site (2015 to 2020) (NB trendlines & correlation coefficients are present where relationships were observed)



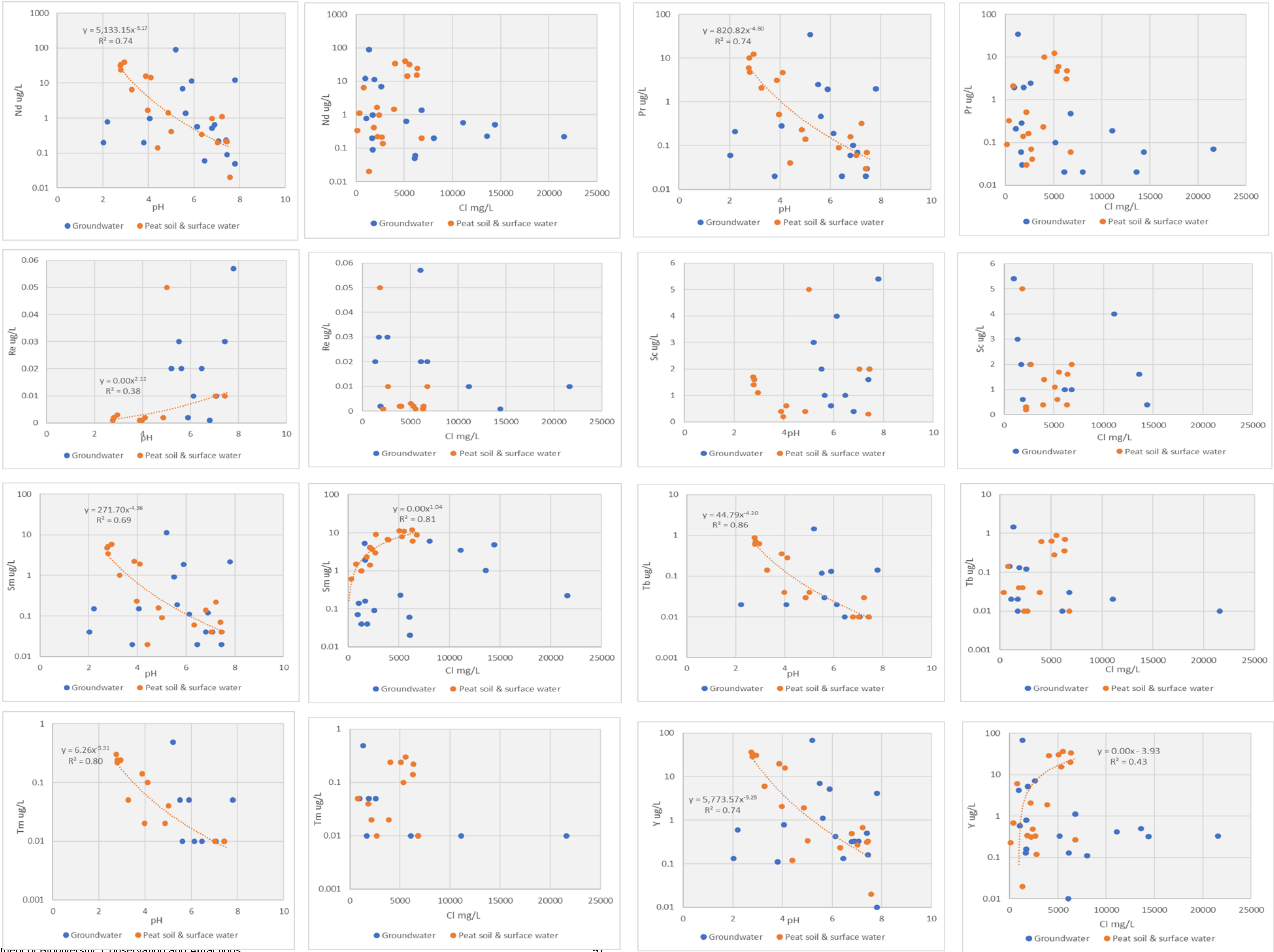
Bivariate plots; concentration (pH units, mg/L or µg/L) minor ions (metals & metalloids) with respect to pH and chloride; surface water data from five lakes and groundwater & peat soil water from four lakes within the Muir-Byenup Ramsar site (2015 to 2020) (NB trendlines & correlation coefficients are present where relationships were observed)

# Appendix 6 Laboratory chemistry compliance and data (tabled & graphed): REE

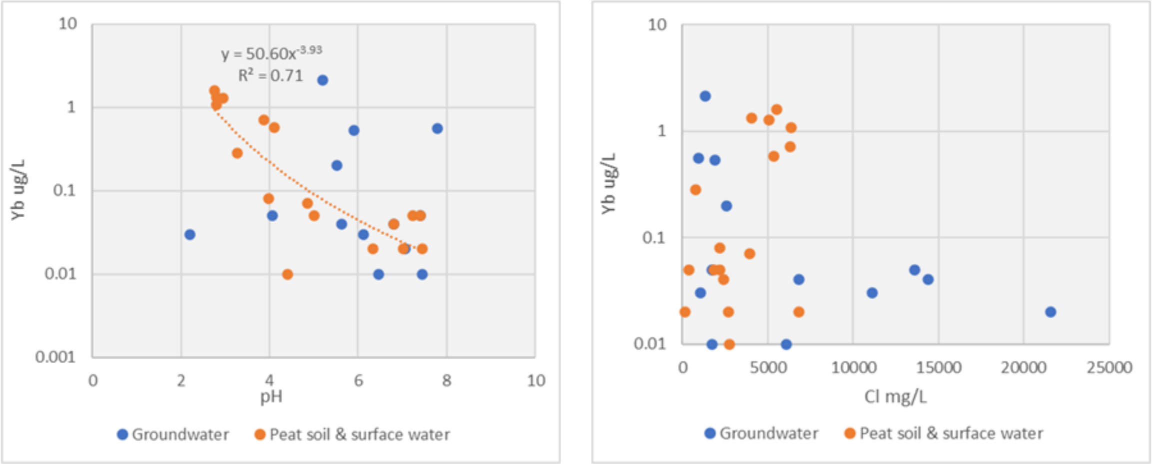
| Element | Date sampled | Ce | Dy | Er | Eu | Gd | Ho | La | Lu | Nd | Pr | Re | Sc | Sm | Tb | Tm | Y | Yb |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Units | | ug/L | ug/L | ug/L | ug/L | ug/L | ug/L | ug/L | ug/L | ug/L | ug/L | ug/L | ug/L | ug/L | ug/L | ug/L | ug/L | ug/L |
| DL | | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 1 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| Method | | | | | | | | | | | | | | | | | | |
| ClientID/Scheme | | ENV04 | ENV04 | ENV04 | ENV04 | ENV04 | ENV04 | ENV04 | ENV04 | ENV04 | ENV04 | ENV04 | ENV04 | ENV04 | ENV04 | ENV04 | ENV04 | ENV04 |
| EMU27D | 4/03/2020 | 0.23 | 0.04 | 0.04 | 0.01 | 0.02 | < 0.01 | 0.11 | < 0.01 | 0.23 | 0.02 | < 0.001 | 1.6 | < 0.01 | < 0.01 | < 0.01 | 0.5 | 0.05 |
| MU51 | 4/03/2020 | 0.01 | < 0.01 | < 0.01 | < 0.01 | < 0.01 | < 0.01 | < 0.01 | < 0.01 | 0.05 | < 0.01 | 0.057 | < 0.1 | < 0.01 | < 0.01 | < 0.01 | 0.01 | < 0.01 |
| MU46S | 4/03/2020 | 0.28 | < 0.01 | < 0.01 | 0.01 | 0.02 | < 0.01 | 0.13 | < 0.01 | 0.2 | 0.02 | < 0.001 | < 0.1 | 0.02 | < 0.01 | < 0.01 | 0.11 | < 0.01 |
| BY01 | 4/03/2020 | 0.62 | 0.05 | 0.03 | 0.02 | 0.1 | < 0.01 | 0.28 | < 0.01 | 0.51 | 0.06 | 0.001 | 0.4 | 0.04 | < 0.01 | < 0.01 | 0.32 | 0.04 |
| TGN01 | 4/03/2020 | 18.6 | 1.07 | 0.68 | 0.4 | 1.38 | 0.14 | 10.2 | 0.05 | 11.4 | 1.93 | 0.002 | 0.6 | 1.88 | 0.13 | 0.05 | 5.14 | 0.53 |
| NB01 | 5/03/2020 | 0.88 | 0.06 | 0.05 | 0.03 | 0.13 | < 0.01 | 0.43 | < 0.01 | 0.64 | 0.1 | < 0.001 | < 0.1 | 0.12 | < 0.01 | < 0.01 | 0.33 | < 0.01 |
| TGS01 | 5/03/2020 | 18.7 | 1.3 | 0.72 | 0.52 | 1.72 | 0.14 | 8.08 | 0.04 | 12.2 | 1.96 | < 0.001 | 5.4 | 2.16 | 0.14 | 0.05 | 4.18 | 0.56 |
| TGN12 | 29/10/2019 | 128 | 3.53 | 2.03 | 1 | 4.76 | 0.68 | 83.5 | 0.16 | 39.8 | 12.2 | 0.003 | 1.1 | 5.9 | 0.63 | 0.24 | 30.7 | 1.28 |
| TGN12 | 20/11/2019 | 52.2 | 4.18 | 1.84 | 1 | 4.7 | 0.75 | 35.3 | 0.08 | 24.2 | 4.78 | 0.002 | 1.6 | 3.42 | 0.7 | 0.22 | 33.5 | 1.08 |
| TGS06 | 30/10/2019 | 104 | 3.44 | 1.96 | 0.97 | 4.87 | 0.72 | 65 | 0.19 | 34.1 | 10 | 0.002 | 1.4 | 5.16 | 0.61 | 0.24 | 28.9 | 1.33 |
| TGS06 | 19/11/2019 | 63.6 | 4.71 | 2.42 | 1.45 | 6.13 | 0.93 | 39.8 | 0.11 | 31.5 | 5.97 | 0.001 | 1.7 | 4.79 | 0.88 | 0.3 | 36.6 | 1.59 |
| TGN09 | 16/10/2019 | 5.59 | 0.19 | 0.14 | 0.05 | 0.24 | 0.05 | 4.18 | 0.02 | 1.66 | 0.51 | 0.001 | 0.2 | 0.23 | 0.04 | 0.02 | 2.06 | 0.08 |
| TGN09 | 20/11/2019 | 2.83 | 0.2 | 0.12 | 0.05 | 0.25 | 0.03 | 2.45 | | 1.44 | 0.23 | 0.002 | 0.4 | 0.16 | 0.03 | 0.02 | 1.9 | 0.07 |
| TGN09 | 5/03/2020 | 0.26 | 0.02 | 0.04 | 0.07 | 0.06 | < 0.01 | 0.13 | < 0.01 | 0.22 | 0.03 | < 0.001 | 0.3 | 0.07 | < 0.01 | < 0.01 | 0.31 | 0.05 |
| TGN10 | 5/03/2020 | 1.6 | 0.07 | 0.02 | 0.11 | 0.19 | < 0.01 | 0.99 | < 0.01 | 0.98 | 0.16 | < 0.001 | < 0.1 | 0.14 | 0.01 | < 0.01 | 0.49 | 0.04 |
| TGN10 | 29/10/2019 | 55.2 | 1.46 | 0.88 | 0.36 | 1.96 | 0.32 | 42.8 | 0.07 | 14.5 | 4.64 | 0.002 | 0.6 | 1.89 | 0.28 | 0.1 | 15.6 | 0.58 |
| TGN10 | 20/11/2019 | 34.6 | 2.03 | 1.21 | 0.65 | 3.03 | 0.42 | 24.6 | 0.05 | 15.6 | 3.1 | 0.001 | 0.4 | 2.21 | 0.35 | 0.14 | 19.9 | 0.71 |



Bivariate plots; concentration rare earth elements (REE) with respect to pH and chloride; surface water data from five lakes and groundwater & peat soil water from four lakes within the Muir-Byenup Ramsar site (2015 to 2020) (NB trendlines & correlation coefficients are present where relationships were observed)



Bivariate plots; concentration rare earth elements (REE) with respect to pH and chloride; surface water data from five lakes and groundwater & peat soil water from four lakes within the Muir-Byenup Ramsar site (2015 to 2020) (NB trendlines & correlation coefficients are present where relationships were observed)

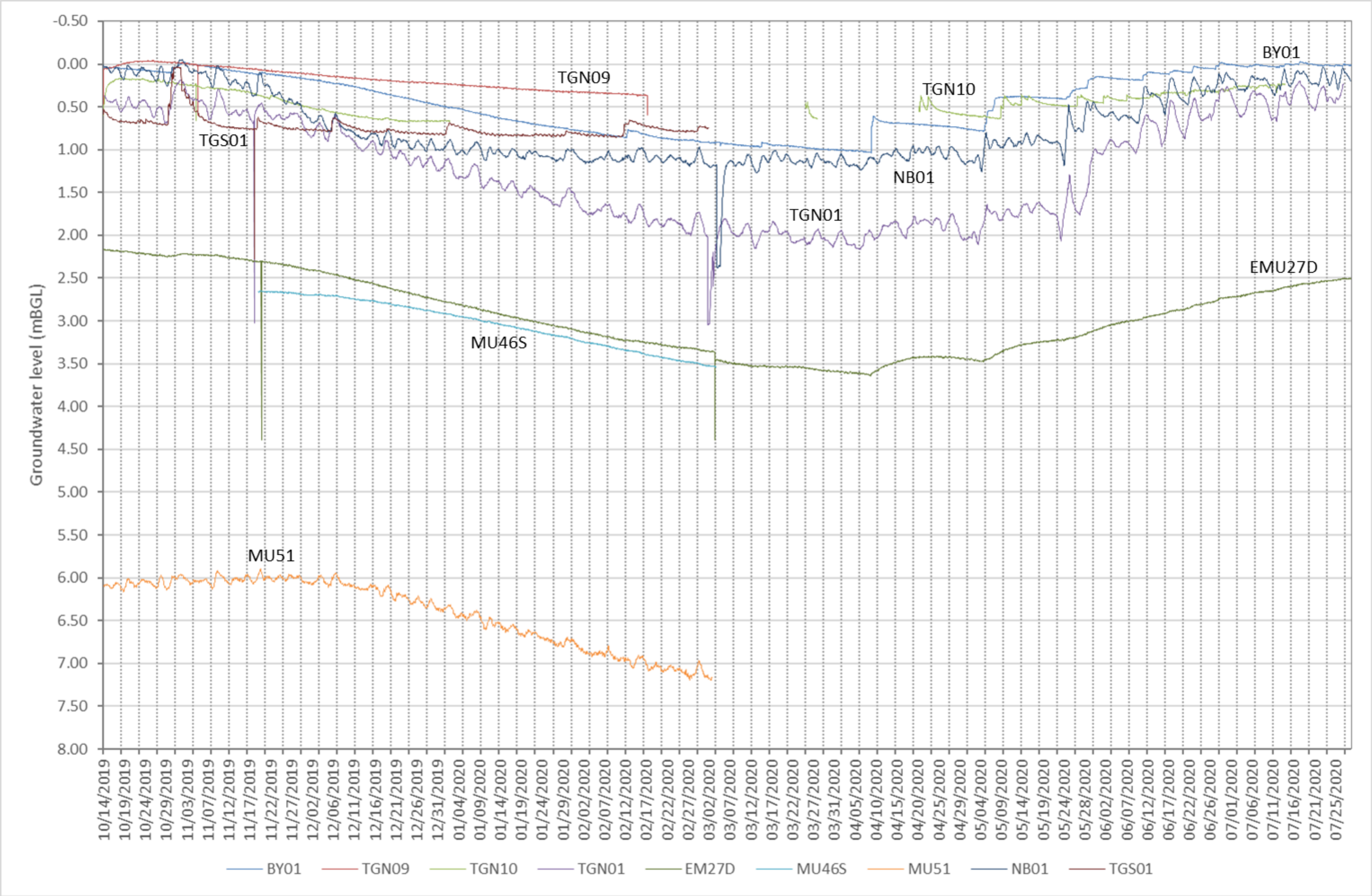


Bivariate plots; concentration rare earth elements (REE) with respect to pH and chloride; surface water data from five lakes and groundwater & peat soil water from four lakes within the Muir-Byenup Ramsar site (2015 to 2020) (NB trendlines & correlation coefficients are present where relationships were observed)

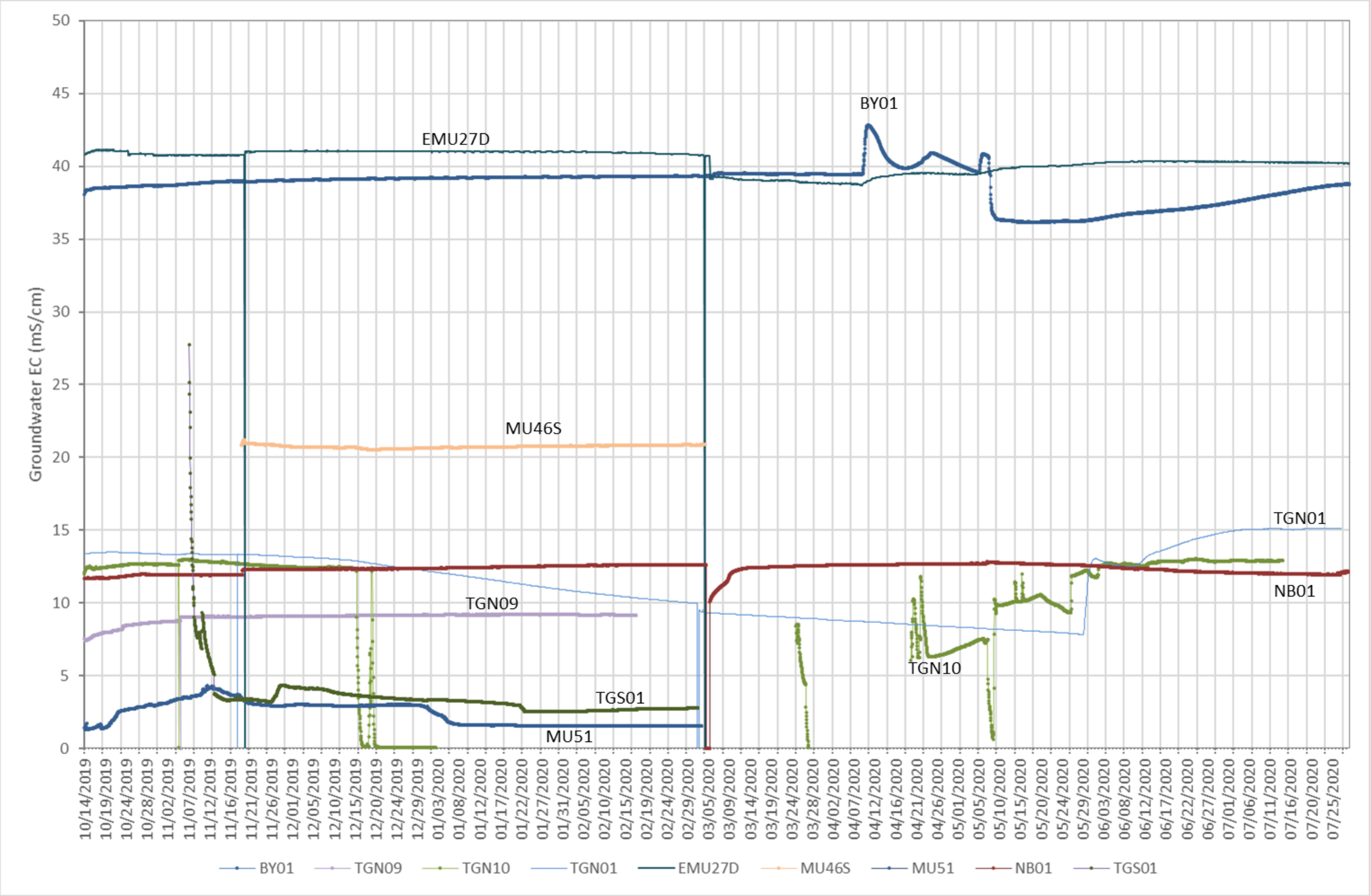
# Appendix 7 Groundwater level and water quality compliance & graphs

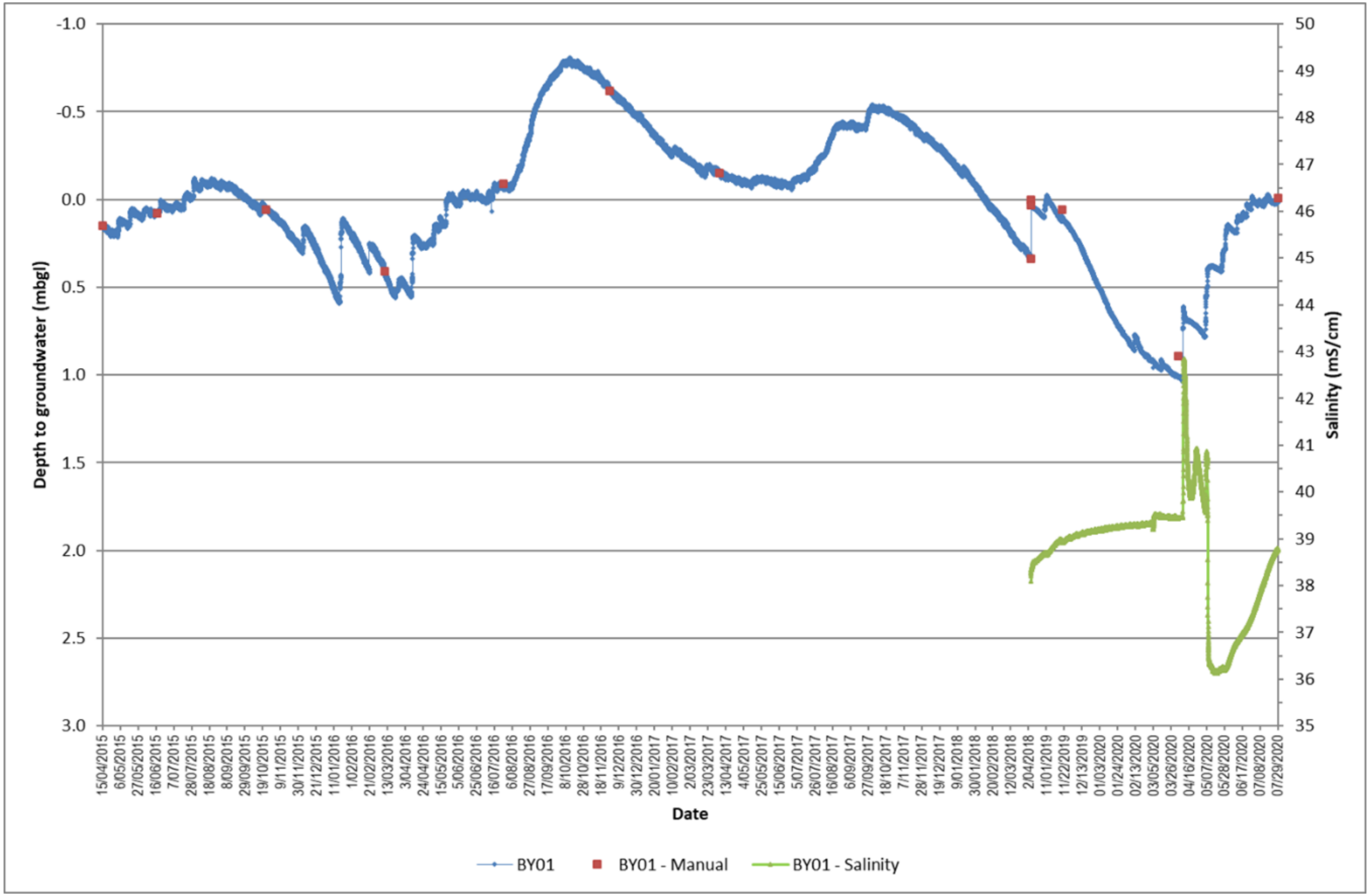
| Site ID | Easting MGA50 | Northing MGA50 | Date: Data logger installed | Date: last manual groundwater level measurement | Time: last manual groundwater level measurement | Ground elevation (mAHD) | Depth drilled (mbgl) | Top of bore screen (mbgl) | Base of bore screen (mbgl) | Top of casing height (TOC) (stick-up) (m) | Groundwater level (mTOC) | Groundwater level (mbgl) | Groundwater level (mAHD) | Diver CDT/Baro data Logger Serial No | Frequency Data Logger Measurements | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NB01 | 480825.0 | 6192604.0 | 15/10/2019 | 30/07/2020 | 8:00 | 219.90 | 6.00 | 0.50 | 6.00 | 0.75 | 0.79 | 0.04 | 219.86 | V9849 | Hourly | |
| MU51 | 477584.0 | 6178735.0 | 15/10/2019 | 4/03/2020 | 12:00 | 181.40 | 20.00 | 17.80 | 19.80 | 0.63 | 8.19 | 7.17 | 174.23 | K6618 | Hourly | unable to access and download in July 2020 |
| MU46S | 476500.2 | 6177082 | 19/11/2019 | 4/03/2019 | 12:50 | 177.32 | 27.00 | 20.00 | 26.00 | 0.62 | 4.40 | 3.77 | 173.55 | X0055 | Hourly | unable to access and download in July 2020 |
| TGS02 | 476005.0 | 6179371.0 | 15/10/2019 | 3/03/2019 | 16:10 | 173.60 | 5.00 | 0.50 | 5.00 | 0.86 | 1.60 | 0.74 | 172.86 | K5037 | Hourly | unable to access and download in July 2020 |
| *TGN10b | 474922.3 | 6180310.6 | 29/10/2019 | 29/07/2020 | 16:00 | 173.50 | 0.95 | 0.10 | 1.10 | 1.10 | 1.34 | 0.24 | 173.26 | V9883 | Hourly | |
| *TGN09b | 474613.8 | 6180435.7 | 29/10/2019 | 20/11/2019 | 10:13 | 174.00 | 0.10 | 0.10 | 1.10 | 1.10 | 1.33 | 0.23 | 173.77 | V9179 | Hourly | unable to access and download in July 2020 |
| TGN01 | 474754.0 | 6182394.0 | 16/10/2019 | 29/07/2020 | 15:00 | 174.61 | 6.00 | 0.50 | 6.00 | 0.71 | 1.00 | 0.29 | 174.32 | V8794 | Hourly | |
| EMU27D | 474773.0 | 6182424.0 | 14/10/2019 | 29/07/2020 | 15:30 | 176.10 | 20.00 | 14.00 | 20.00 | 0.61 | 3.03 | 2.48 | 173.62 | K6593 | Hourly | |
| EMU27S | 474773.0 | 6182426.0 | 30/10/2019 | 29/07/2020 | 15:30 | 176.15 | 2.00 | 1.00 | 2.00 | 0.54 | dry | dry | | V5452 | Hourly | |
| BY01 | 475170.0 | 6182247.0 | 14/10/2019 | 29/07/2020 | 15:00 | 174.18 | 6.00 | 0.50 | 6.00 | 0.63 | 0.62 | -0.01 | 174.19 | V6918 | Hourly | |
| BARO (EMU27S) | 474773.0 | 6182426.0 | 14/10/2019 | 20/11/2019 | 8:00 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | BN998 | Hourly | |

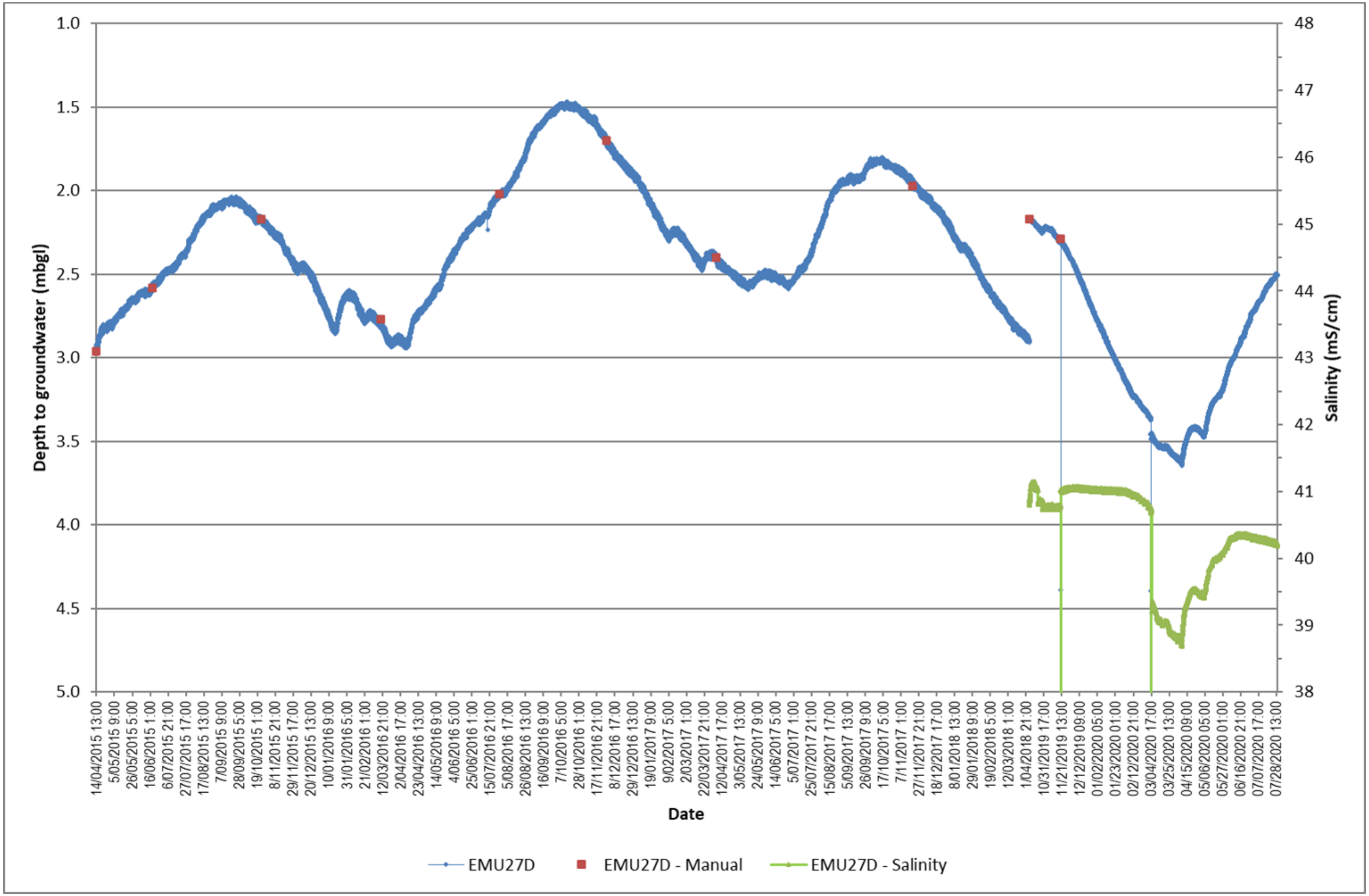
*Note TGN09b and TGN10b have not been surveyed

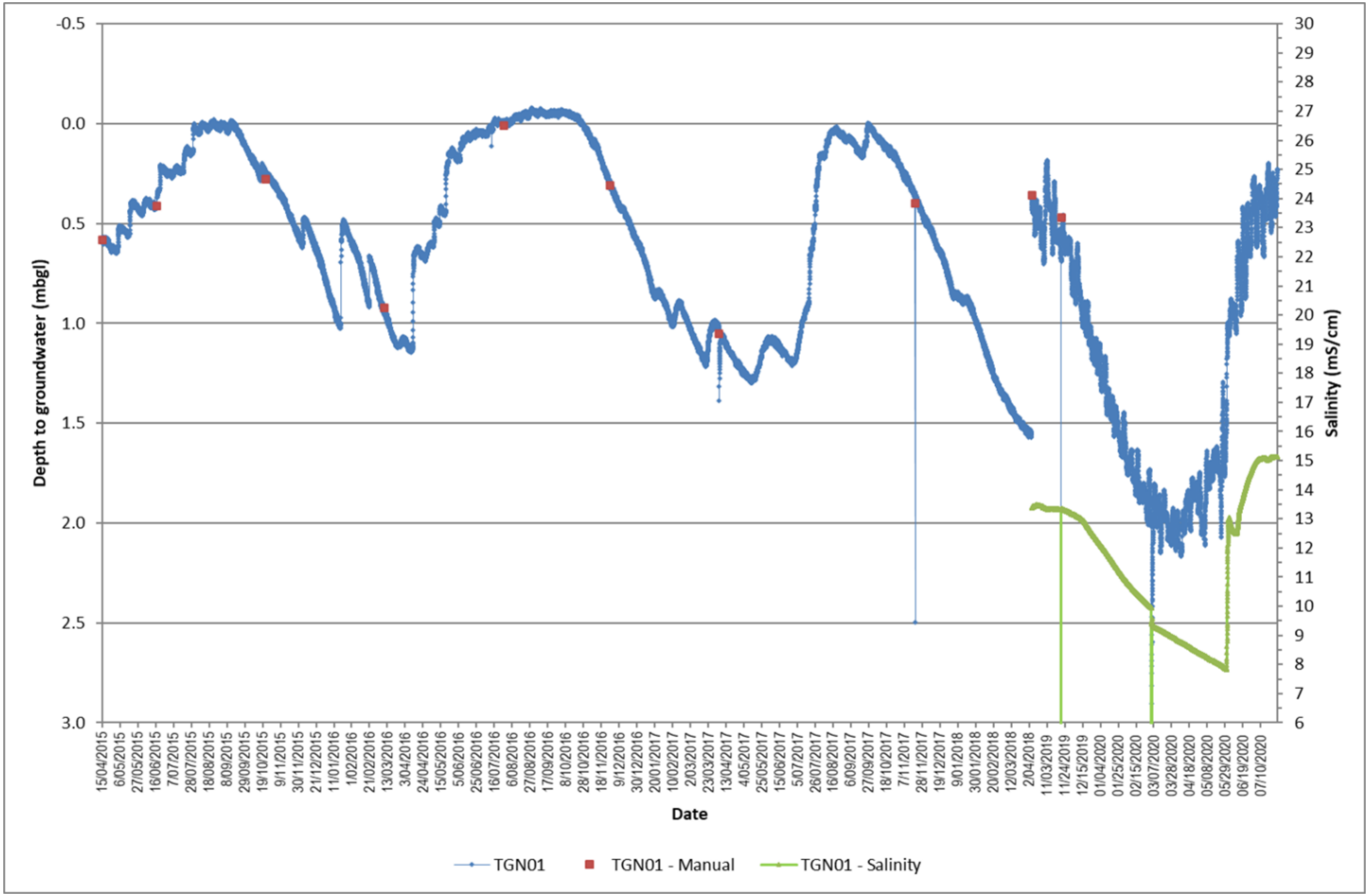


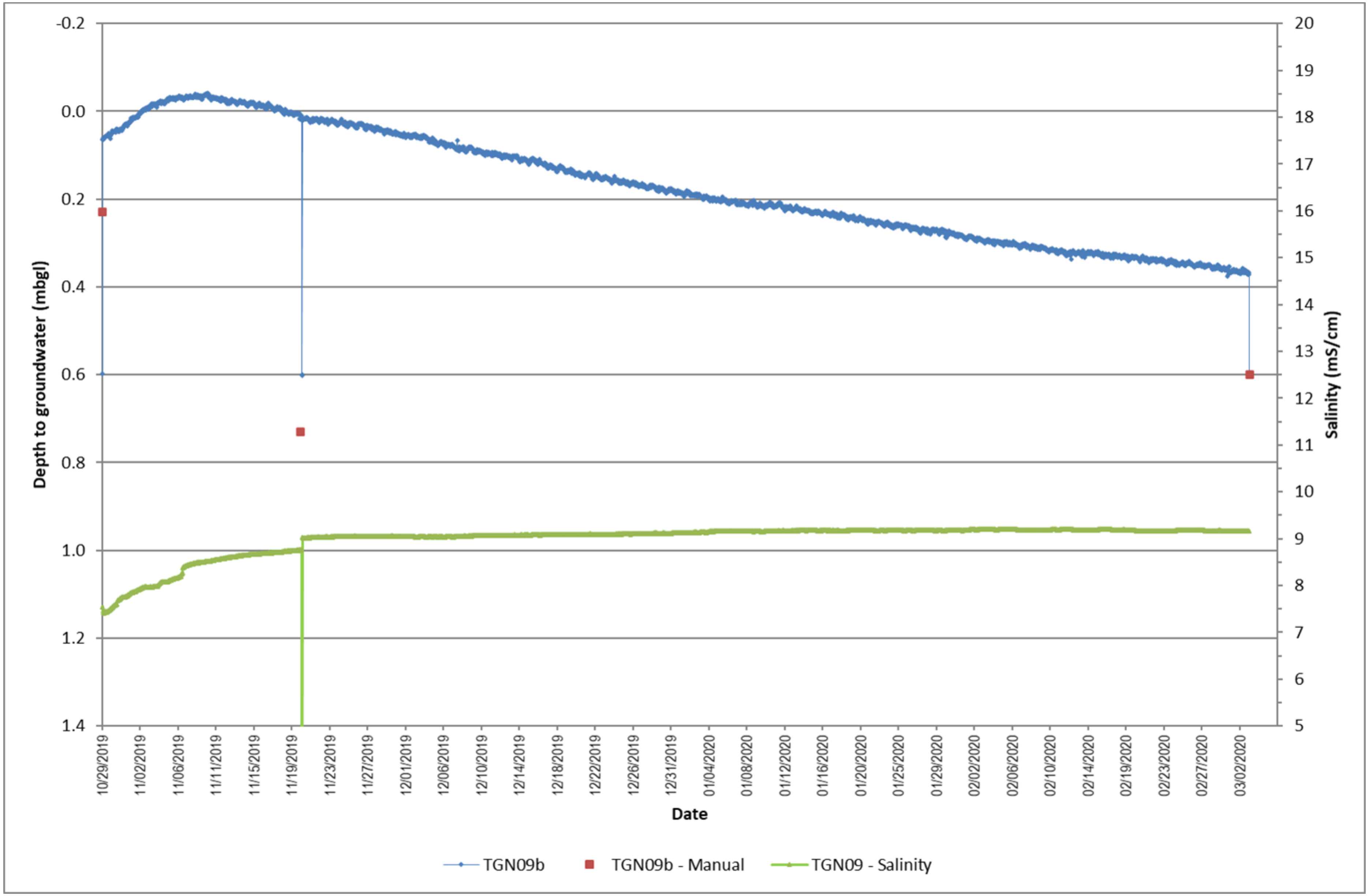
Groundwater level (mBGL)
-0.50
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
5.50
6.00
6.50
7.00
7.50
8.00
BY01
TGN09
TGN10
TGS01
NB01
TGN01
EMU27D
MU46S
MU51
10/14/2019
10/19/2019
10/24/2019
10/29/2019
11/03/2019
11/07/2019
11/12/2019
11/17/2019
11/22/2019
11/27/2019
12/02/2019
12/06/2019
12/11/2019
12/16/2019
12/21/2019
12/26/2019
12/31/2019
01/04/2020
01/09/2020
01/14/2020
01/19/2020
01/24/2020
01/29/2020
02/02/2020
02/07/2020
02/12/2020
02/17/2020
02/22/2020
02/27/2020
03/02/2020
03/07/2020
03/12/2020
03/17/2020
03/22/2020
03/27/2020
03/31/2020
04/05/2020
04/10/2020
04/15/2020
04/20/2020
04/25/2020
04/29/2020
05/04/2020
05/09/2020
05/14/2020
05/19/2020
05/24/2020
05/28/2020
06/02/2020
06/07/2020
06/12/2020
06/17/2020
06/22/2020
06/26/2020
07/01/2020
07/06/2020
07/11/2020
07/16/2020
07/21/2020
07/25/2020
BY01
TGN09
TGN10
TGN01
EM27D
MU46S
MU51
NB01
TGS01

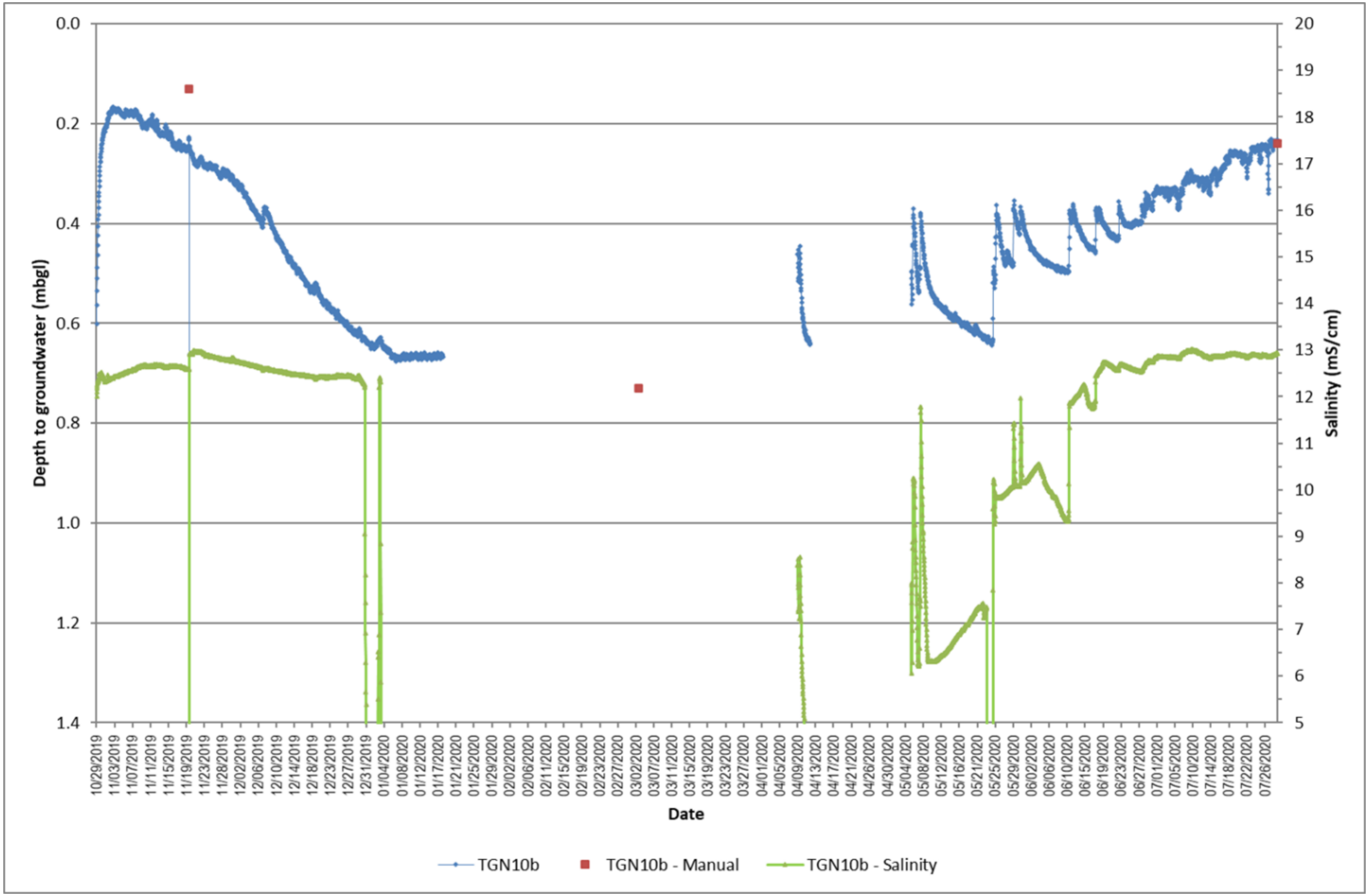

Groundwater EC (mS/cm)
50
45
40
35
30
25
20
15
10
5
0
BY01
EMU27D
MU46S
TGN01
TGN09
NB01
TGN10
TGS01
MU51
10/14/2019
10/19/2019
10/24/2019
10/28/2019
11/02/2019
11/07/2019
11/12/2019
11/16/2019
11/21/2019
11/26/2019
12/01/2019
12/05/2019
12/10/2019
12/15/2019
12/20/2019
12/24/2019
12/29/2019
01/03/2020
01/08/2020
01/12/2020
01/17/2020
01/22/2020
01/27/2020
01/31/2020
02/05/2020
02/10/2020
02/15/2020
02/19/2020
02/24/2020
02/29/2020
03/05/2020
03/09/2020
03/14/2020
03/19/2020
03/24/2020
03/28/2020
04/02/2020
04/07/2020
04/12/2020
04/16/2020
04/21/2020
04/26/2020
05/01/2020
05/05/2020
05/10/2020
05/15/2020
05/20/2020
05/24/2020
05/29/2020
06/03/2020
06/08/2020
06/12/2020
06/17/2020
06/22/2020
06/27/2020
07/01/2020
07/06/2020
07/11/2020
07/16/2020
07/20/2020
07/25/2020
BY01
TGN09
TGN10
TGN01
EMU27D
MU46S
MU51
NB01
TGS01

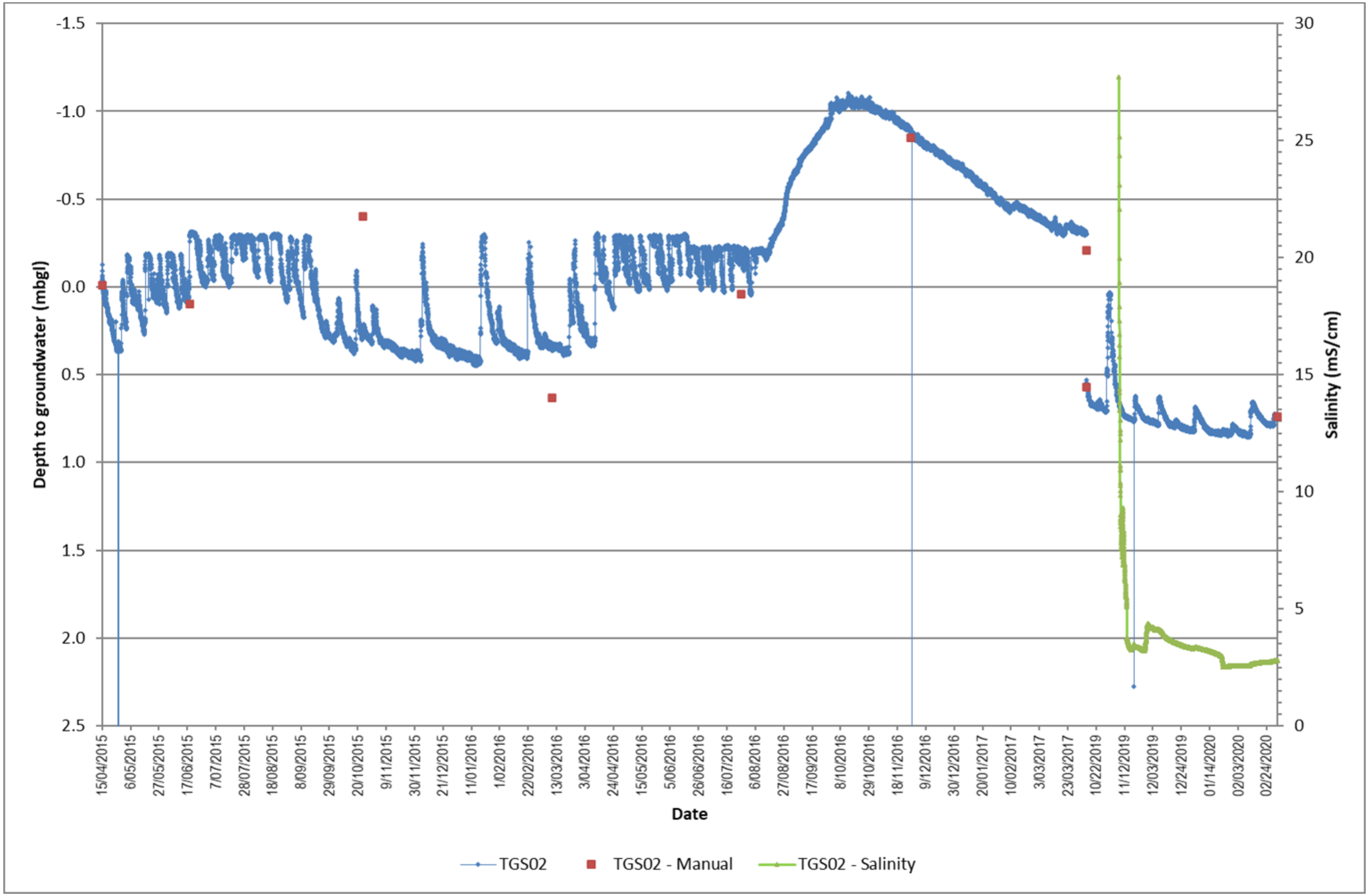

-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Depth to groundwater (mbgl)
50
49
48
47
46
45
44
43
42
41
40
39
38
37
36
35
Salinity (mS/cm)
15/04/2015
6/05/2015
27/05/2015
16/06/2015
7/07/2015
28/07/2015
18/08/2015
8/09/2015
29/09/2015
19/10/2015
9/11/2015
30/11/2015
21/12/2015
11/01/2016
1/02/2016
21/02/2016
13/03/2016
3/04/2016
24/04/2016
15/05/2016
5/06/2016
25/06/2016
16/07/2016
6/08/2016
27/08/2016
17/09/2016
8/10/2016
28/10/2016
18/11/2016
9/12/2016
30/12/2016
20/01/2017
10/02/2017
2/03/2017
23/03/2017
13/04/2017
4/05/2017
25/05/2017
15/06/2017
5/07/2017
26/07/2017
16/08/2017
6/09/2017
27/09/2017
18/10/2017
7/11/2017
28/11/2017
19/12/2017
9/01/2018
30/01/2018
20/02/2018
12/03/2018
2/04/2018
11/01/2019
11/22/2019
12/13/2019
01/03/2020
01/24/2020
02/13/2020
03/05/2020
03/26/2020
04/16/2020
05/07/2020
05/28/2020
06/17/2020
07/08/2020
07/29/2020
Date
BY01
BY01 - Manual
BY01 - Salinity

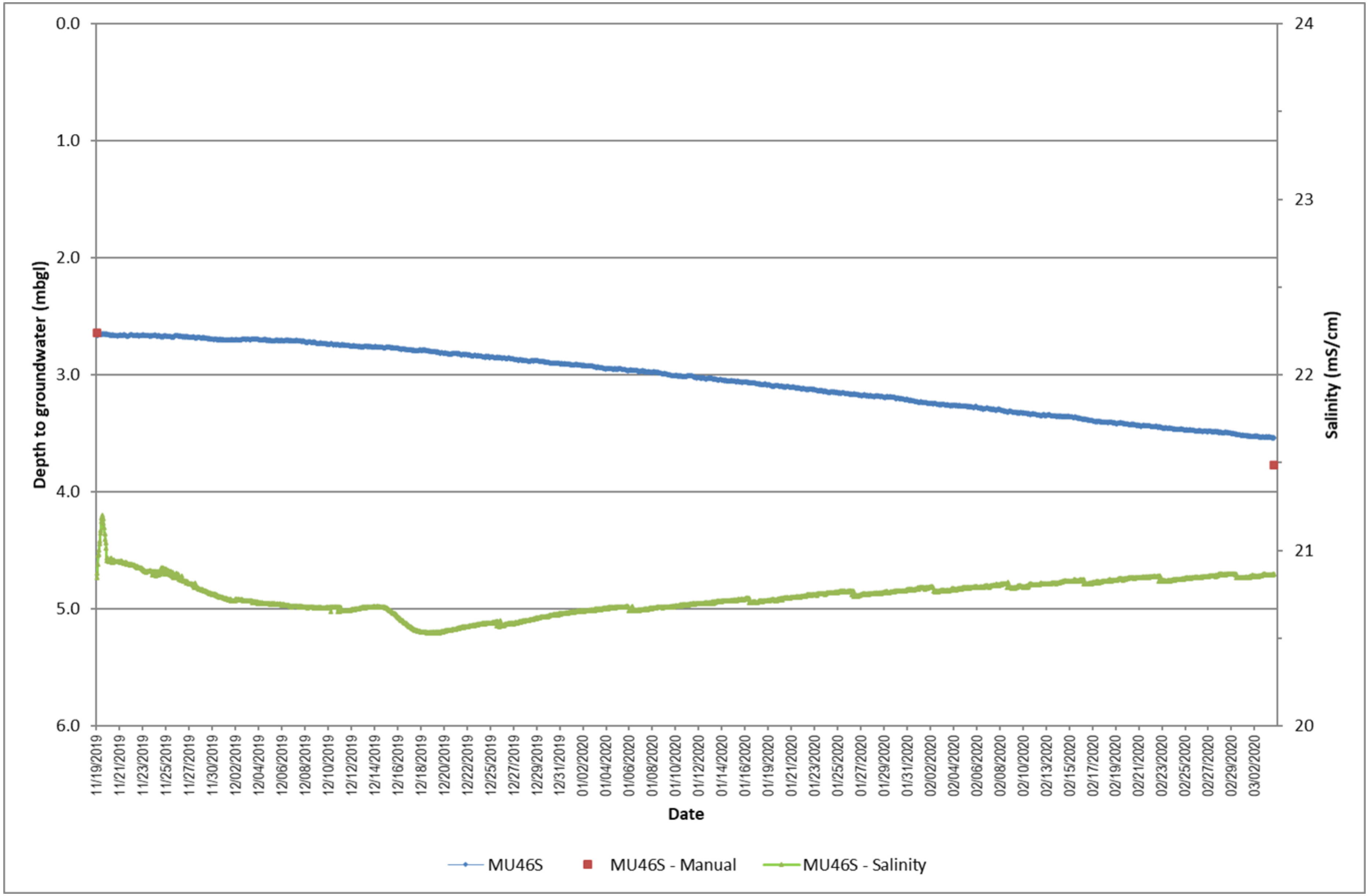

1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Depth to groundwater (mbgl)
48
47
46
45
44
43
42
41
40
39
38
Salinity (mS/cm)
14/04/2015 13:00
5/05/2015 9:00
26/05/2015 5:00
16/06/2015 1:00
6/07/2015 21:00
27/07/2015 17:00
17/08/2015 13:00
7/09/2015 9:00
28/09/2015 5:00
19/10/2015 1:00
8/11/2015 21:00
29/11/2015 17:00
20/12/2015 13:00
10/01/2016 9:00
31/01/2016 5:00
21/02/2016 1:00
12/03/2016 21:00
2/04/2016 17:00
23/04/2016 13:00
14/05/2016 9:00
4/06/2016 5:00
25/06/2016 1:00
15/07/2016 21:00
5/08/2016 17:00
26/08/2016 13:00
16/09/2016 9:00
7/10/2016 5:00
28/10/2016 1:00
17/11/2016 21:00
8/12/2016 17:00
29/12/2016 13:00
19/01/2017 9:00
9/02/2017 5:00
2/03/2017 1:00
22/03/2017 21:00
12/04/2017 17:00
3/05/2017 13:00
24/05/2017 9:00
14/06/2017 5:00
5/07/2017 1:00
25/07/2017 21:00
15/08/2017 17:00
5/09/2017 13:00
26/09/2017 9:00
17/10/2017 5:00
7/11/2017 1:00
27/11/2017 21:00
18/12/2017 17:00
8/01/2018 13:00
29/01/2018 9:00
19/02/2018 5:00
12/03/2018 1:00
1/04/2018 21:00
10/31/2019 17:00
11/21/2019 13:00
12/12/2019 09:00
01/02/2020 05:00
01/23/2020 01:00
02/12/2020 21:00
03/04/2020 17:00
03/25/2020 13:00
04/15/2020 09:00
05/06/2020 05:00
05/27/2020 01:00
06/16/2020 21:00
07/07/2020 17:00
07/28/2020 13:00
Date
EMU27D
EMU27D - Manual
EMU27D - Salinity


-0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Depth to groundwater (mbgl)
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
Salinity (mS/cm)
15/04/2015
6/05/2015
27/05/2015
16/06/2015
7/07/2015
28/07/2015
18/08/2015
8/09/2015
29/09/2015
19/10/2015
9/11/2015
30/11/2015
21/12/2015
11/01/2016
1/02/2016
21/02/2016
13/03/2016
3/04/2016
24/04/2016
15/05/2016
5/06/2016
25/06/2016
16/07/2016
6/08/2016
27/08/2016
17/09/2016
8/10/2016
28/10/2016
18/11/2016
9/12/2016
30/12/2016
20/01/2017
10/02/2017
2/03/2017
23/03/2017
13/04/2017
4/05/2017
25/05/2017
15/06/2017
5/07/2017
26/07/2017
16/08/2017
6/09/2017
27/09/2017
18/10/2017
7/11/2017
28/11/2017
19/12/2017
9/01/2018
30/01/2018
20/02/2018
12/03/2018
2/04/2018
11/03/2019
11/24/2019
12/15/2019
01/04/2020
01/25/2020
02/15/2020
03/07/2020
03/28/2020
04/18/2020
05/08/2020
05/29/2020
06/19/2020
07/10/2020
Date
TGN01
TGN01 - Manual
TGN01 - Salinity

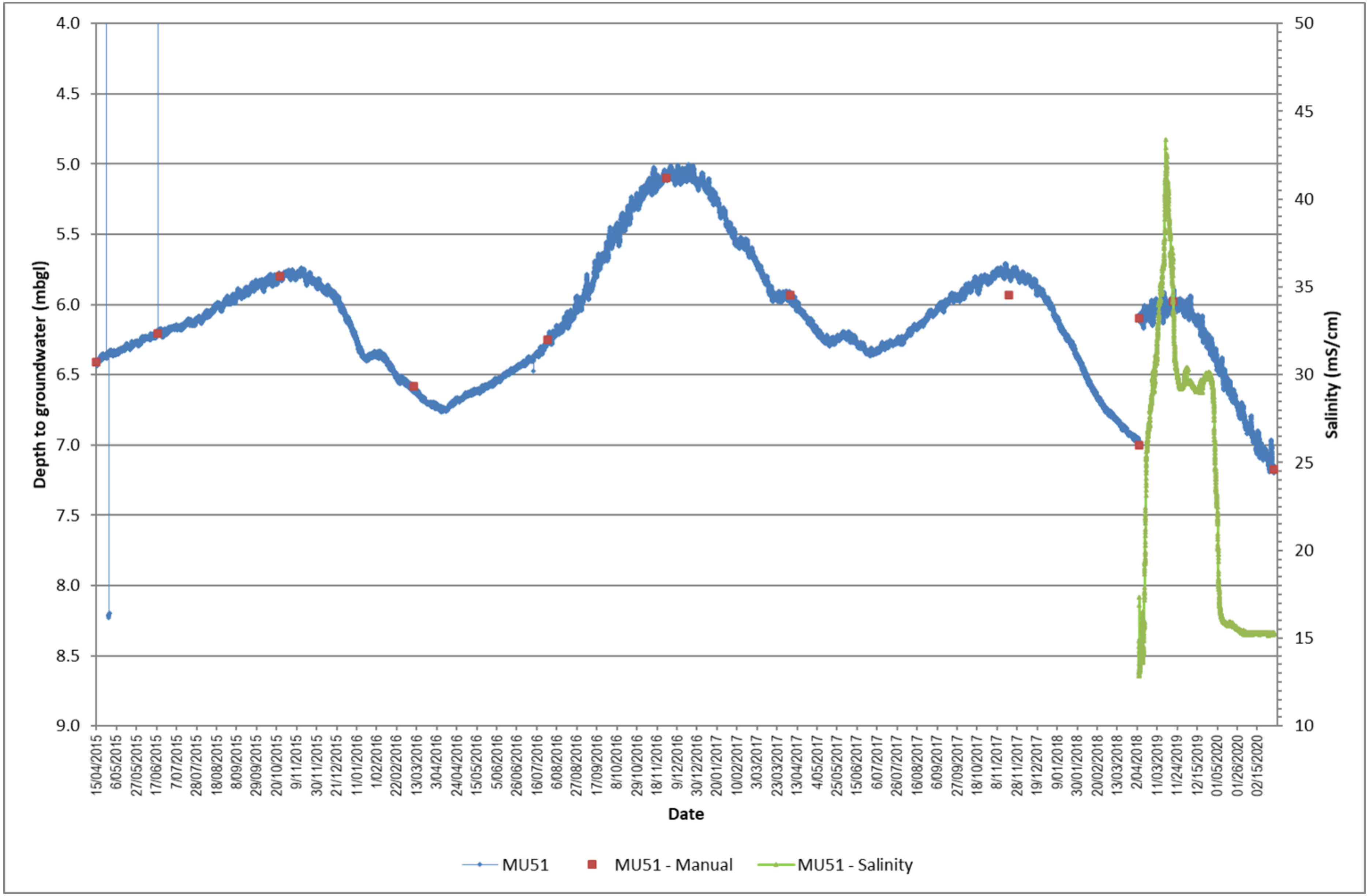

Depth to groundwater (mbgl)
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
Salinity (mS/cm)
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
10/29/2019
11/02/2019
11/06/2019
11/11/2019
11/15/2019
11/19/2019
11/23/2019
11/27/2019
12/01/2019
12/06/2019
12/10/2019
12/14/2019
12/18/2019
12/22/2019
12/26/2019
12/31/2019
01/04/2020
01/08/2020
01/12/2020
01/16/2020
01/20/2020
01/25/2020
01/29/2020
02/02/2020
02/06/2020
02/10/2020
02/14/2020
02/19/2020
02/23/2020
02/27/2020
03/02/2020
Date
TGN09b
TGN09b - Manual
TGN09 - Salinity

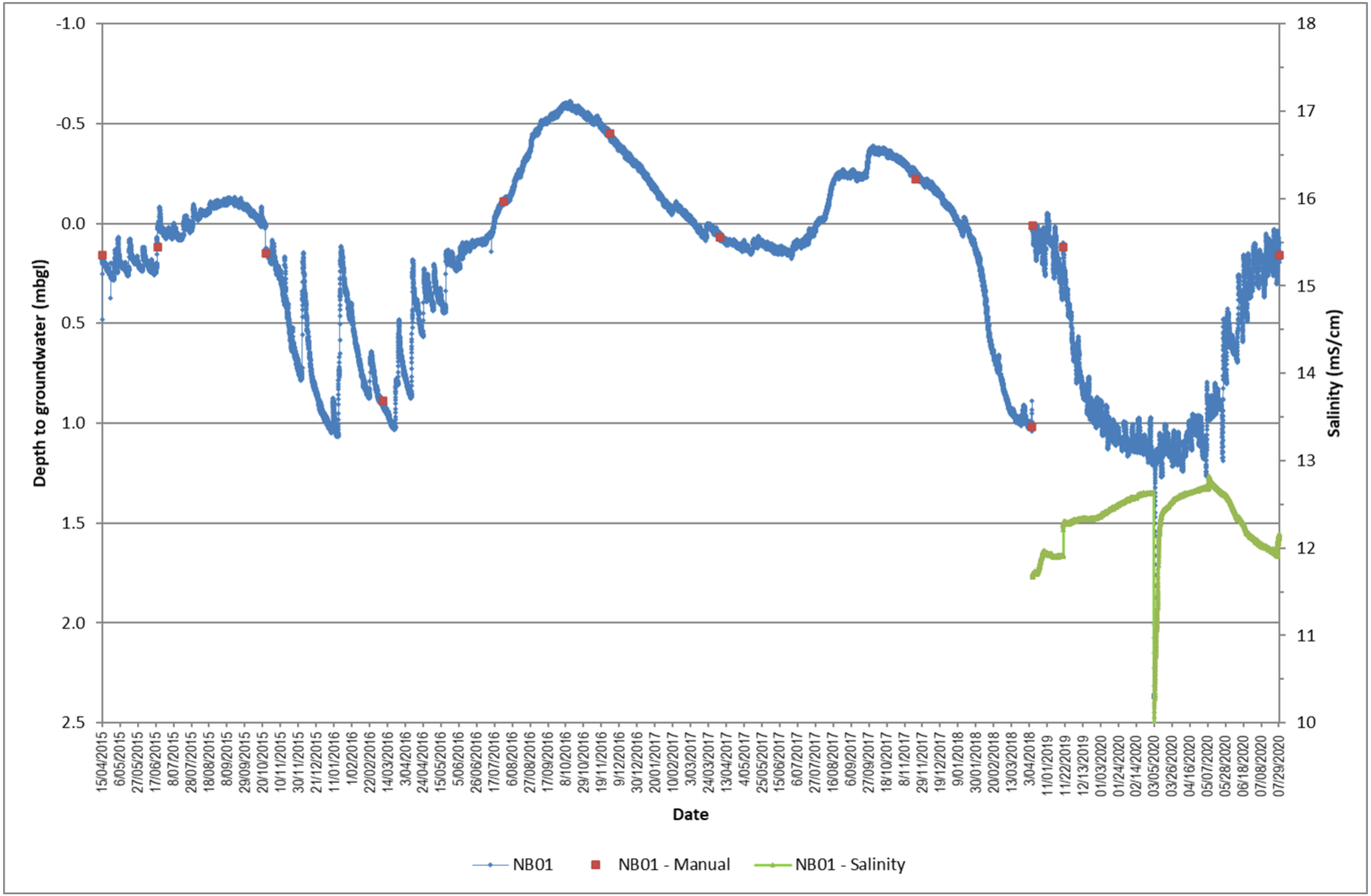

Depth to groundwater (mbgl)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
Salinity (mS/cm)
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
Date
10/29/2019
11/03/2019
11/07/2019
11/11/2019
11/15/2019
11/19/2019
11/23/2019
11/28/2019
12/02/2019
12/06/2019
12/10/2019
12/14/2019
12/18/2019
12/23/2019
12/27/2019
12/31/2019
01/04/2020
01/08/2020
01/12/2020
01/17/2020
01/21/2020
01/25/2020
01/29/2020
02/02/2020
02/06/2020
02/11/2020
02/15/2020
02/19/2020
02/23/2020
02/27/2020
03/02/2020
03/07/2020
03/11/2020
03/15/2020
03/19/2020
03/23/2020
03/27/2020
04/01/2020
04/05/2020
04/09/2020
04/13/2020
04/17/2020
04/21/2020
04/26/2020
04/30/2020
05/04/2020
05/08/2020
05/12/2020
05/16/2020
05/21/2020
05/25/2020
05/29/2020
06/02/2020
06/06/2020
06/10/2020
06/15/2020
06/19/2020
06/23/2020
06/27/2020
07/01/2020
07/05/2020
07/10/2020
07/14/2020
07/18/2020
07/22/2020
07/26/2020
TGN10b
TGN10b - Manual
TGN10b - Salinity


-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
Depth to groundwater (mbgl)
30
25
20
15
10
5
0
Salinity (mS/cm)
15/04/2015
6/05/2015
27/05/2015
17/06/2015
7/07/2015
28/07/2015
18/08/2015
8/09/2015
29/09/2015
20/10/2015
9/11/2015
30/11/2015
21/12/2015
11/01/2016
1/02/2016
22/02/2016
13/03/2016
3/04/2016
24/04/2016
15/05/2016
5/06/2016
26/06/2016
16/07/2016
6/08/2016
27/08/2016
17/09/2016
8/10/2016
29/10/2016
18/11/2016
9/12/2016
30/12/2016
20/01/2017
10/02/2017
3/03/2017
23/03/2017
10/22/2019
11/12/2019
12/03/2019
12/24/2019
01/14/2020
02/03/2020
02/24/2020
Date
TGS02
TGS02 - Manual
TGS02 - Salinity



Depth to groundwater (mbgl)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
Salinity (mS/cm)
24
23
22
21
20
Date
11/19/2019
11/21/2019
11/23/2019
11/25/2019
11/27/2019
11/30/2019
12/02/2019
12/04/2019
12/06/2019
12/08/2019
12/10/2019
12/12/2019
12/14/2019
12/16/2019
12/18/2019
12/20/2019
12/22/2019
12/25/2019
12/27/2019
12/29/2019
12/31/2019
01/02/2020
01/04/2020
01/06/2020
01/08/2020
01/10/2020
01/12/2020
01/14/2020
01/16/2020
01/19/2020
01/21/2020
01/23/2020
01/25/2020
01/27/2020
01/29/2020
01/31/2020
02/02/2020
02/04/2020
02/06/2020
02/08/2020
02/10/2020
02/13/2020
02/15/2020
02/17/2020
02/19/2020
02/21/2020
02/23/2020
02/25/2020
02/27/2020
02/29/2020
03/02/2020
MU46S
MU46S - Manual
MU46S - Salinity


4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
Depth to groundwater (mbgl)
50
45
40
35
30
25
20
15
10
Salinity (mS/cm)
15/04/2015
6/05/2015
27/05/2015
17/06/2015
7/07/2015
28/07/2015
18/08/2015
8/09/2015
29/09/2015
20/10/2015
9/11/2015
30/11/2015
21/12/2015
11/01/2016
1/02/2016
22/02/2016
13/03/2016
3/04/2016
24/04/2016
15/05/2016
5/06/2016
26/06/2016
16/07/2016
6/08/2016
27/08/2016
17/09/2016
8/10/2016
29/10/2016
18/11/2016
9/12/2016
30/12/2016
20/01/2017
10/02/2017
3/03/2017
23/03/2017
13/04/2017
4/05/2017
25/05/2017
15/06/2017
6/07/2017
26/07/2017
16/08/2017
6/09/2017
27/09/2017
18/10/2017
8/11/2017
28/11/2017
19/12/2017
9/01/2018
30/01/2018
20/02/2018
13/03/2018
2/04/2018
11/03/2019
11/24/2019
12/15/2019
01/05/2020
01/26/2020
02/15/2020
Date
MU51
MU51 - Manual
MU51 - Salinity



-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
Depth to groundwater (mbgl)
18
17
16
15
14
13
12
11
10
Salinity (mS/cm)
15/04/2015
6/05/2015
27/05/2015
17/06/2015
8/07/2015
28/07/2015
18/08/2015
8/09/2015
29/09/2015
20/10/2015
10/11/2015
30/11/2015
21/12/2015
11/01/2016
1/02/2016
22/02/2016
14/03/2016
3/04/2016
24/04/2016
15/05/2016
5/06/2016
26/06/2016
17/07/2016
6/08/2016
27/08/2016
17/09/2016
8/10/2016
29/10/2016
19/11/2016
9/12/2016
30/12/2016
20/01/2017
10/02/2017
3/03/2017
24/03/2017
13/04/2017
4/05/2017
25/05/2017
15/06/2017
6/07/2017
27/07/2017
16/08/2017
6/09/2017
27/09/2017
18/10/2017
8/11/2017
29/11/2017
19/12/2017
9/01/2018
30/01/2018
20/02/2018
13/03/2018
3/04/2018
11/01/2019
11/22/2019
12/13/2019
01/03/2020
01/24/2020
02/14/2020
03/05/2020
03/26/2020
04/16/2020
05/07/2020
05/28/2020
06/18/2020
07/08/2020
07/29/2020
Date
NB01
NB01 - Manual
NB01 - Salinity