Large-Scale Cover Trial of Tailings Dam, Heap Leach Facility and PAF Waste Dump at Nifty Copper Operation

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Abstract

Nifty Copper Operation has three waste landforms with highly saline materials: tailings dam, heap leach facility and a PAF waste dump. Once rehabilitated, potential exists for salts from these wastes to rise via capillary action into the cover material. Two large-scale trial plots were installed on each of these landforms in June 2015 following preliminary water and solute balance modelling. The objectives of the cover trial are to measure the actual movement of water and salts within the cover layers and the underlying in situ materials.

Plots were established with different cover thicknesses on each landform. Specialised monitoring equipment was installed on each plot to monitor climate and soil moisture and salt movements through the cover profiles. Data was collected via wireless and cloud-based systems. Simulated rainfall was applied to the plots to expedite data collection and reduce the risk that insufficient rainfall events would occur during the short available trial period. Physical samples of the materials' salinity and moisture (along with a suite of other measures) were taken to validate the data recorded by the electronic monitoring equipment.

These data provide a validation dataset used to complete long-term water and solute movement modelling, and in turn identify the cover design that would most effectively manage potential salt movement in the long term. Additionally, the data has been used to calibrate water-solute balance models, with outputs used to assess the long-term performance of the cover design. This case study details the initial modelling, cover trial set up, and a summary of the data collected.

Introduction

The Nifty Copper Operation (NCO), located in the East Pilbara, Great Sandy Desert, has three main closure landforms that may require covering for rehabilitation at mine closure – a waste dump, tailings storage facility (TSF) and heap leach facility (HLF). The broad expectation for the closure and rehabilitation of mine waste landforms is that they are left safe, stable, non- polluting, and capable of sustaining vegetation consistent with ongoing land uses. Shale waste rock, tailings, and heap leach material at Nifty are by various characteristics and to various degrees hostile to revegetation; drainage from such materials, if not adequately prevented or contained, can impact on surrounding soils, vegetation and habitats. Closure and rehabilitation typically requires some form of cover, comprising an inert material to encapsulate adverse wastes and prevent salts and metals from migrating to surface, overlain by a growth medium to support revegetation.

Many cover designs for mine waste landforms would incorporate the use of hard rock to armour the tops and slopes of the constructed covers to minimise erosion, and would utilise a blocky material as a capillary break between the mine waste and cover materials which would prevent water and any dissolved metals or salts from migrating upwards in the cover profile towards the surface. If upwards migrating salts and metals from the mine waste were able to express themselves on the surface of the cover system, this could cause vegetation death and pollution to the environment.

The Nifty waste dump is approximately 150 hectares in size and is comprised of black shale waste rock and white oxide waste rock. The black shales generally have high sulphur content and are classified as potentially acid forming (PAF). The white oxide waste rock material is low in sulphur, neutral to slightly alkaline, has low to high salinity and is classified as non-acid forming (NAF). The oxide material is highly erosive and prone to tunnelling due to its high silt and fine sand content. The TSF is approximately 100 hectares in size and the tailings are moderately saline, slightly alkaline and classified as NAF. The HLF is also approximately 100 hectares in size, is acidic (due to its historical irrigation with sulphuric acid for copper heap leaching), saline and high in various metals, including copper.

Challenges for closure

Due to the closure landform characteristics, potential exists for salts and metals to rise from the various underlying in situ waste materials to the surface materials that are placed as part of cover layers to rehabilitate the site. One of the main challenges with designing covers for the closure landforms at Nifty is that there is no hard rock at Nifty. The only material that is present that could be utilised as a clean cover material is the white oxide material from the waste dump. Because there is no rocky material which could be utilised in the construction of a capillary break, a capillary break will need to be constructed via use of an appropriate thickness of cover – i.e. the cover has to be thick enough to sufficiently prevent the upward movement of salts and metals to the cover surface.

Nifty was purchased by Metals X Pty Ltd in 2016, and since has increased the life of mine (LOM) to well over six years. Under the previous operator, the LOM was significantly less as the mine was being run towards closure. Therefore, when the cover design work commenced in 2013, conducting scientifically defendable mine closure planning in a short amount of time was of paramount importance.

It was apparent from the early stages that no amount of lab work, materials characterisation and desktop modelling would ever give us sufficient confidence in cover designs for the closure landforms which would minimise the risk of long term failure. As a result, trial plots were established on three locations at Nifty - the TSF, the HLF and the PAF waste dump. It was assumed that the primary goal would be to limit the upward movement of salts from the underlying in situ materials. A total of 6 cover options were implemented in the field trial.

The cover trials involved placement of a known depth of cover material over in situ wastes, and the installation of appropriate instruments to monitor changes in soil water and salinity status in response to wetting by rain and drying by evaporation. In order to consider the effectiveness of a cover system in the long-term, computer modelling is necessary. This is because only a short period of time was available in which data could be collected, and computer models are able to extend a short period of monitored performance to a much longer period to include a wider range of climatic conditions. To this end, the goal of the cover trials were:

- to provide time-series data of rainfall, infiltration, and drainage of water into the cover and the underlying materials, and
- to provide data on the movement of salts in the underlying in situ materials and how salts interact with the applied cover layer materials in response to rainfall events and profile drying.

Given the short period over which the trial could be run, it is critical that as many wetting and drying events were captured in the time available, and that changes in soil water and salinity profiles in response to these events are measured. A review of rainfall data in the Nifty region indicated that a large proportion of rain falls in very few events, and that much of the rain in a given year occurs as a result of fewer than 5 events. Further, a cover system is likely to be most useful when extreme events occur. It is these events that will cause deep wetting that would most likely translate into movement of water and salts. The probability of these extreme events occurring is low. For example, for any given year, there is only a 1% chance of getting a rain event with a return interval of 100 years; and there is an even smaller chance of getting more than one such event in the period available to collect data. The trials sought to capture data for 10-15 wetting events from which the models would be calibrated, and there is essentially no chance that this could be achieved without augmenting natural rain with the application of additional watering events.

It is not essential that only data measured from ‘natural’ rainfall events be used, and the application of simulated rain events through irrigation provides considerable advantages in that the timing of events can be controlled, the volumes and durations of events can be manipulated, and the required number or wetting events can be guaranteed within the allotted time for the trial.

Therefore, the scope of works was further developed with the understanding that the site has a limited timeframe before closure activities must commence, and climate variability poses a significant risk in terms of Nifty collecting the required information from long-term field-based trial plots.

Initial data review and preliminary water-solute modelling

Preliminary water-solute modelling was conducted using laboratory based data for a range of cover systems configurations. The intent of this modelling was to provide information about the configurations that should be adopted in the field-based cover trials. In order to complete the preliminary modelling, the following information was required:

- Moisture retention curves;
- Saturated hydraulic conductivity;
- Solute concentration (including salt profiles for in situ materials);
- Water content profiles for in situ materials; and
- Bulk density

Nifty already had significant quantities of historical characterisation data that had been acquired from various studies. A gap analysis was conducted and further data that needed to be sourced for the modelling was determined. From the above data requirements, Nifty had to collect bulk density, and solute and moisture profiles of the closure domains at Nifty. This was done by the Nifty Environment staff on site utilising a backhoe to access the profiles of the HLF, TSF and waste dump.

The Hydrus 1-D model was used to undertake water and solute balance modelling. The intent of this work was not to define the final cover layer systems required, but to provide a basis from which a range of potential cover layers could be chosen for inclusion in a field-scale trial. Capillary rise of salts was considered by assessing predicted solute concentrations at the interface between the cover and the TSF, HLF or PAF waste dump. An increase in solute concentrations at that point over time would indicate a rise in salts into the cover. Solute concentrations above 2.0dS/m were assumed to not be acceptable to plant growth.

The preliminary modelling of cover layer options recommended the following configurations be trialled:

- 0.4m oxide over tailings,
- 0.8m oxide over tailings,
- 0.4m oxide over heap leach material,
- 0.8m oxide over heap leach material,
- 0.5m oxide over PAF material, and
- 1.0m oxide over PAF material.

Given the free draining nature of the TSF, a cover of 1.0m of oxide is predicted to not cause rise of salts to within 0.3m of the surface. However, a 0.5m thick cover may be sufficient as only a small amount of salinity increase is predicted to occur at 0.3m when this thickness is adopted. Simulations of placement of oxide over the HLF material predicted that a thickness of 0.5m can effectively mitigate the salinisation of the surface 0.3m of the cover. Use of 1.0m provides further benefits in terms of reducing salinity in the surface materials. However, the additional benefit of slightly reducing salinity is countered by having to supply twice as much oxide to create this cover. Simulations of placement of oxide over the waste dump PAF material predicted that a thickness of 1.0m can effectively mitigate the excessive salinisation of the surface 0.3m of the cover. Use of only 0.5m thickness of cover is predicted to cause a rise of salts at 0.3m depth in the medium term.

Importantly, given that oxide is likely to be a key component to all cover systems, if high EC oxide is used within the cover, the cover will commence with high salinity. Higher EC oxides may be encountered as they are excavated from depths >2m (below the typical wetting front of rainfall) as they are sourced from the waste dump for rehabilitation activities. Therefore, the cover depths suggested do not necessarily indicate depths of cover that will always support vegetation, rather they are depths of cover for which increasing salt levels are not predicted to occur in materials near the surface.

Once the trials are completed and all data has been collected, this will produce a validation dataset that will be used to complete long-term water and solute movement modelling, and in turn identify the cover design that will most effectively manage potential salt movement in the long term. Additionally, the data will be used to calibrate water-solute balance models, with outputs used to assess the long-term performance of the cover design.

Configuration of the field plots

Plot construction

A total of six cover layer plots were implemented in the field trial. Two plots were established on flat surfaces no more than 30m apart on each of the waste dump, TSF and HLF. Placement and compaction of the cover materials was completed using earth moving machines similar to those to be employed during the eventual capping of the landforms, in order to replicate real life rehabilitation techniques. Plots at each site were established adjacent to each other enabling dual use of the logger enclosure that housed some of the monitoring equipment as shown in Figure 2. All plots were constructed to be square and surrounded with small bunds (~0.4m high) to enclose water and eliminate runoff from adjacent mining areas entering the plot area, ensuring that only recorded precipitation was able to permeate or evaporate on the plot surface. The plot areas were surrounded with the oxide cover material to allow safe vehicle access to the plots and reduce edge effects. The surface of the individual plots was to be as flat as possible with an elevation difference of <70mm achieved. This was done to ensure even distribution of the water across the plot, reducing areas of preferential ponding and infiltration.

Electronic monitoring equipment and communications

Salinity and soil moisture measurements for the soil profile were needed so that the movement of salts in response to soil wetting and drying could be monitored. Two Enviropro soil water and salinity sensors were installed within each plot (Figure 2). The HLF and waste dump plots were instrumented with 1,600mm long probes, and the TSF was instrumented with 1,200mm long probes due to sensor availability. All sensors were installed vertically into the cover layer and upper region of the underlying material, enabling measurement of both layers and the interface between the layers. All sensors were connected to a logger on the surface between the two plots that continually records soil temperature, soil moisture and salinity levels at 10cm depth increments every 30 minutes.

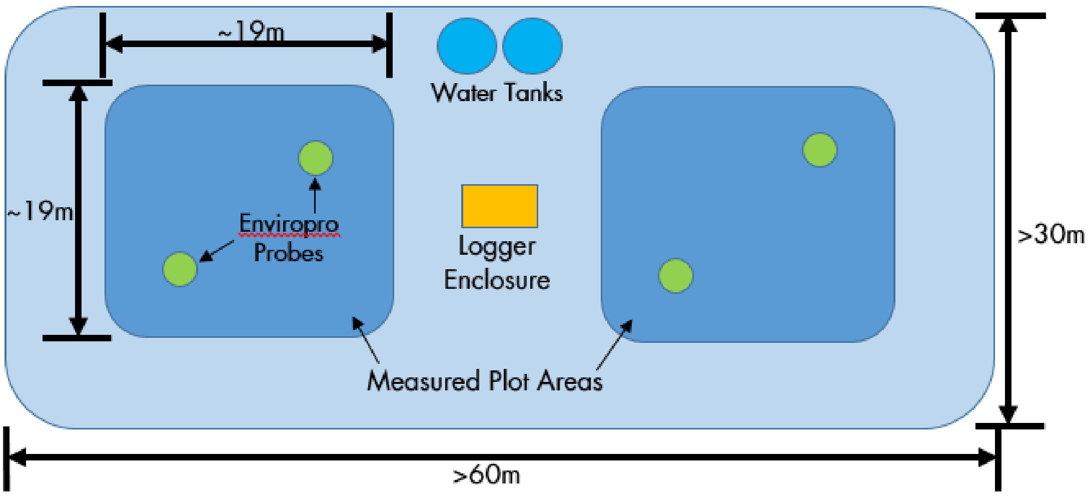


Figure 1: Schematic drawing of plot configurations.

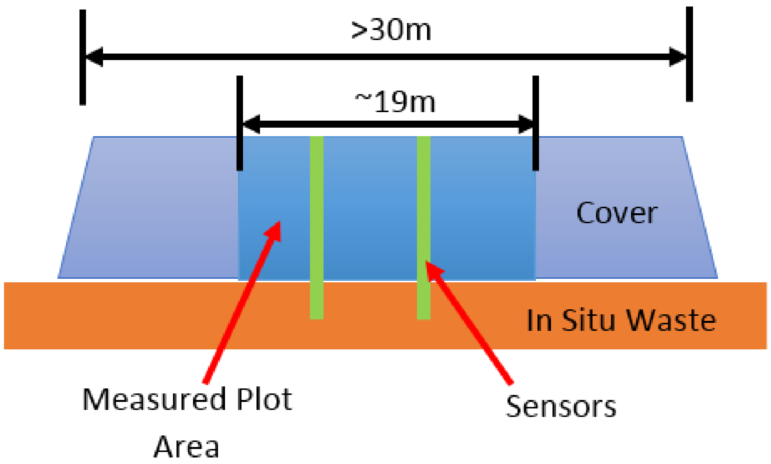


Figure 2: Schematic drawing of Enviropro soil sensors installed through the cover layer and upper region of the underlying material.

Rainfall is highly variable in the Nifty region. Therefore, pluviometers (rainfall intensity instruments) were installed at all sites to record precipitation amounts and intensities, and account for the variation in precipitation across the site. A full weather station at one site was installed to record data at 5 minute intervals for:

- temperature;
- wet bulb temperature;
- dew point;
- relative humidity;
- air pressure;
- wind speed and direction; and
- precipitation (amount, duration, intensity and type).

At each site the loggers, pluviometers and weather station were connected to a GSM modem. The data was then automatically uploaded to a secure internet website, enabling remote access to the data and the equipment's functional status. This lead to reduced maintenance site visits, and reduced costs and repair times for malfunctioning equipment.

Irrigation

Water tanks and a portable irrigation system were installed in order to apply water treated by reverse osmosis (i.e. low salinity) to the plot surface (Figure 3). This process had the benefit of speeding up natural processes and simulating as many rain events as possible on the plots.

Figure 3: Irrigation event using the portable irrigation system at the TSF

The optimal spacing and type of sprinklers was determined prior to deployment of the portable irrigation system. Radial leg data (measure irrigation depth as it varies with distance from the sprinkler head) was collected by spacing rain gauges at known distances from an operating sprinkler at a known pressure (240kPa), and measuring the incremental depths of accumulated water over a given period. The irrigation design software SpacePRO was then used to assess the spacings between sprinklers that achieved the highest uniformity. In this case, a 6.0m sprinkler spacing was shown to achieved an 89% distribution uniformity when the sprinklers were placed in a square (as opposed to an offset) pattern. A high irrigation distribution uniformity across the cover trial plots was important to create an even distribution of water and infiltration across the plot surface, reducing ponding and preferential infiltration. A range of simulated rainfall events up to a maximum of 120mm in a single event was applied to the cover trial plots.

Evaporation rates are high at Nifty. Evaporation pans were installed at each plot. Evaporation rates were measured and recorded following irrigation events as a means of calculating how much water was being lost to evaporation and therefore how much water was infiltrating into the plot surfaces.

Data and sample collection

Initial sampling

Samples of the overlying oxide and the underlying material were taken from the materials adjacent to the 2 probes during installation. The samples were processed for the following parameters:

- Material $pH_{1:5}$;
- Electrical conductivity ($EC_{1:5}$);
- Exchangeable cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, and Al^{3+});
- Effective cation exchange capacity (ECEC);
- Exchangeable sodium percentage (ESP);
- Particle size distribution of the coarse fraction (rock, pebbles, coarse gravel, gravel, coarse sand, fine sand, silt, clay); and
- Rock density and water absorption.

In addition, a subset of the samples for both the overlying oxide and underlying material from both of the probe pits on each plot were combined and processed for the following parameters:

- EC Saturated Extract;
- Saturated hydraulic conductivity values; and
- Moisture retention curves.

Periodic sampling

A maximum of 8 sampling events per plot have currently been taken over the duration of the project. A minimum of 3 soil core samples per plot of the overlying material were taken to a maximum depth of 1m with a handheld soil auger for each sampling event. A hand auger was used in order to reduce the use of vehicles within the plot area and preserve the undisturbed plot surface. Each soil core was divided into 3 different depth intervals for analysis. The samples from each depth interval were then combined and assessed for the following parameters:

- pH
- Electrical conductivity ($EC_{1:5}$); and
- Moisture Content (%).

A subset of these samples was assessed in more detail for a range of additional parameters:

- Exchangeable cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, and Al^{3+});
- Effective cation exchange capacity (ECEC);
- Exchangeable sodium percentage (ESP);
- Particle size distribution of the fine fraction (coarse fragments, coarse sand, fine sand, silt, clay);
- NAG (pH 4.5 and pH 7.0);

- ANC (as H2SO$_4$ and $CaCO_3$);
- Total Soluble Salts;
- Sulphate as SO_4^{2-};
- Total Sulfur as S; and
- Total metals (As, Be, Ba, Cd, Cr, Co, Cu, Pb, Mn, Ni, Se, V, Zn, B and Hg).

To date, only the salinity ($EC_{1:5}$) and moisture data has been analysed and used to calibrate the monitoring equipment. The remaining data is currently still being evaluated.

Summary of calibrated data

The installed probes log both soil moisture and soil salinity, and the raw value reported by each probe was calibrated using measures of actual soil moisture and salinity. Figures 4-9 below show the collected salinity data only for each of the probes and cover systems.

Tailings storage facility

The salinity of the tailings initially is actually low (0.3-0.5dS/m) as seen in Figures 4 and 5 in the initial salinity values at 1.0m for the thicker oxide cover plot and 0.7m for the thinner oxide cover plot. For the thicker oxide plot (Figure 4), one of the probes (Probe 3) does measure a general though slight rise of salinity within the oxide at 0.7m and within the tailings at 1.0m until September 2017 when the salinity levels decrease in response to a large irrigation event. A similar pattern is seen in the other probe (Probe 4) installed in this cover system.

For the thinner oxide plot (Figure 5), a more variable response to application of water has been observed, with one probe (Probe 1) showing only minor variation in salinity even though significant volumes of water have been applied. A more pronounced change in salinity was observed for Probe 2. This probe is behaving consistently with Probes 3 and 4 on the thicker plot with observed increases in salinity, throughout the measurement period, followed by a decrease in salinity in response to a rainfall event in late February 2018. The lack of response in Probe 1 on the thinner plot is likely due to its position on the plot relative to where the water is ponding and infiltrating. The data for this probe requires further scrutiny.

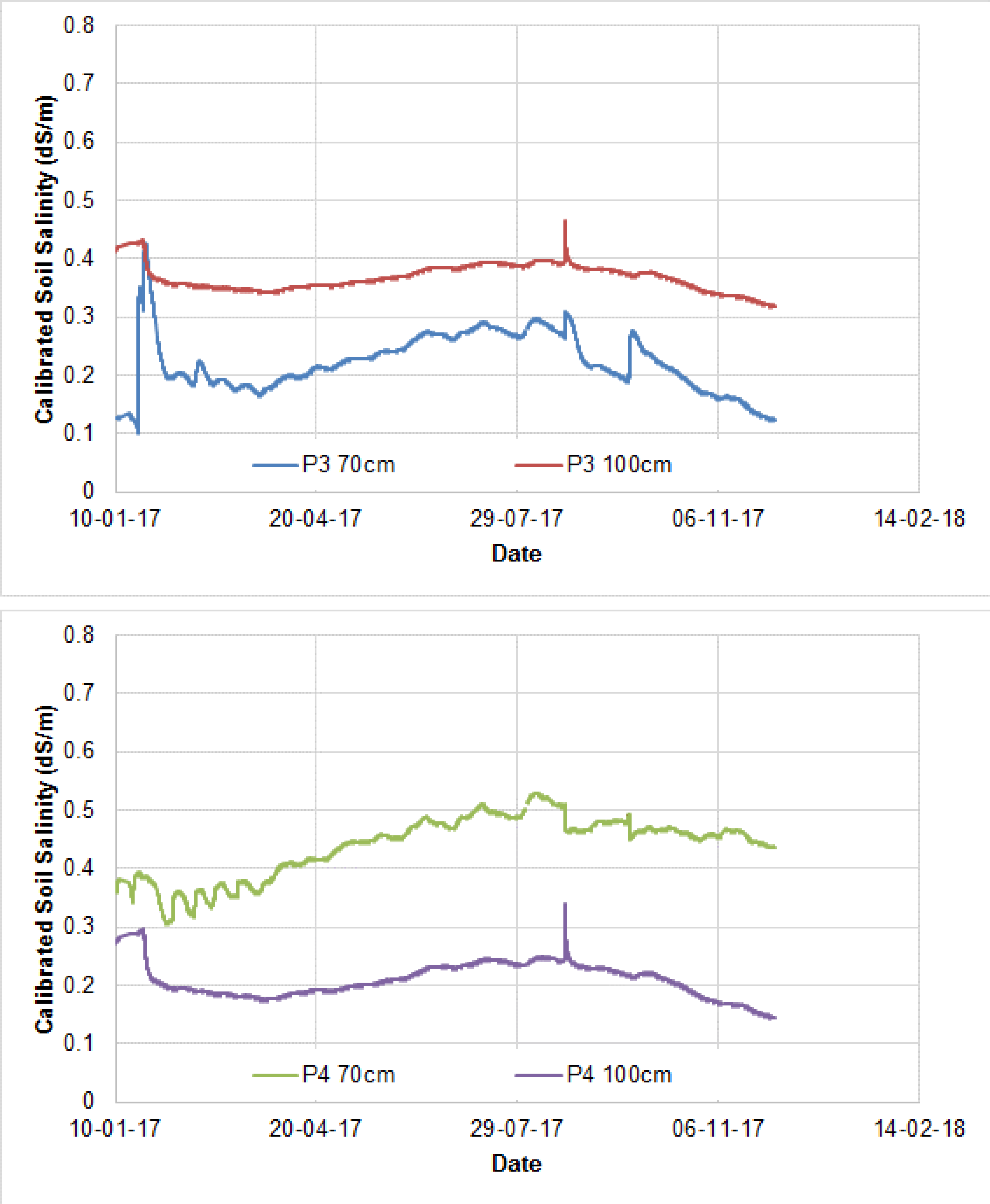
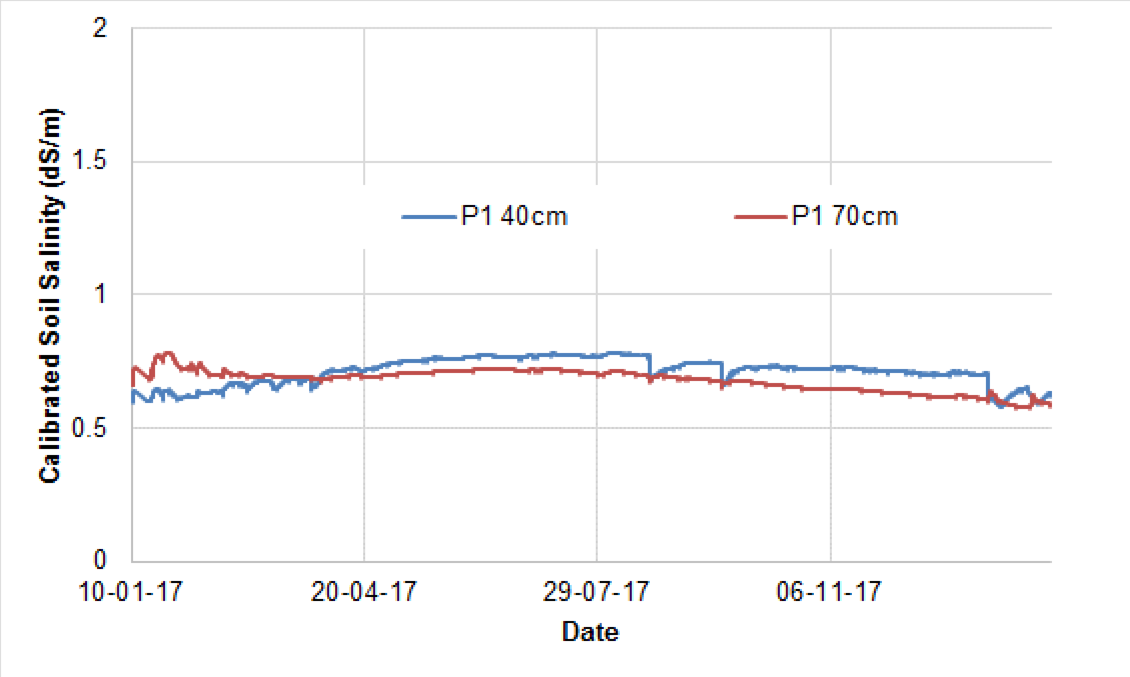


Figure 4: Soil salinity for the thicker cover (0.8m) over the TSF at profile depths of 70cm, and 100cm. Probe 3 (top) and Probe 4 (bottom).



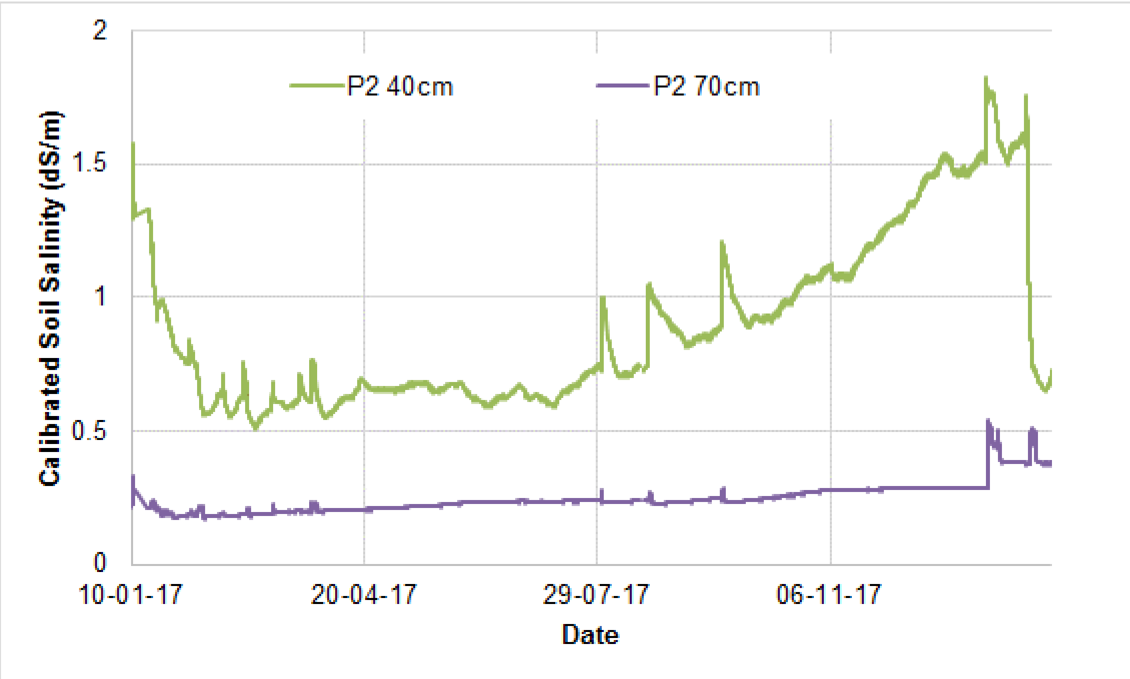


Figure 5: Soil salinity for the thinner cover (0.4m) over the TSF at profile depths of 40cm and 70cm. Probe 1 (top) and Probe 2 (bottom)

Heap Leach

Both probes on the thicker plot (Probes 1 and 2) show a trend of increasing salinity over time in response to multiple wetting and drying events over the course of the trial. A similar trend is also seen for Probe 4 on the thinner oxide cover though the increase is slight. A more variable response to wetting and drying was observed for Probe 3 in the thinner cover, and the data from this probe requires further scrutiny, though it appears the heap leach material is more free-draining in the area in which the probe was installed. Be that as it may, the general trend for the other three probes is an increase in salinity over time. Importantly, application of significant rainfall and irrigation events is not acting to stop the trend towards increasing salinity.

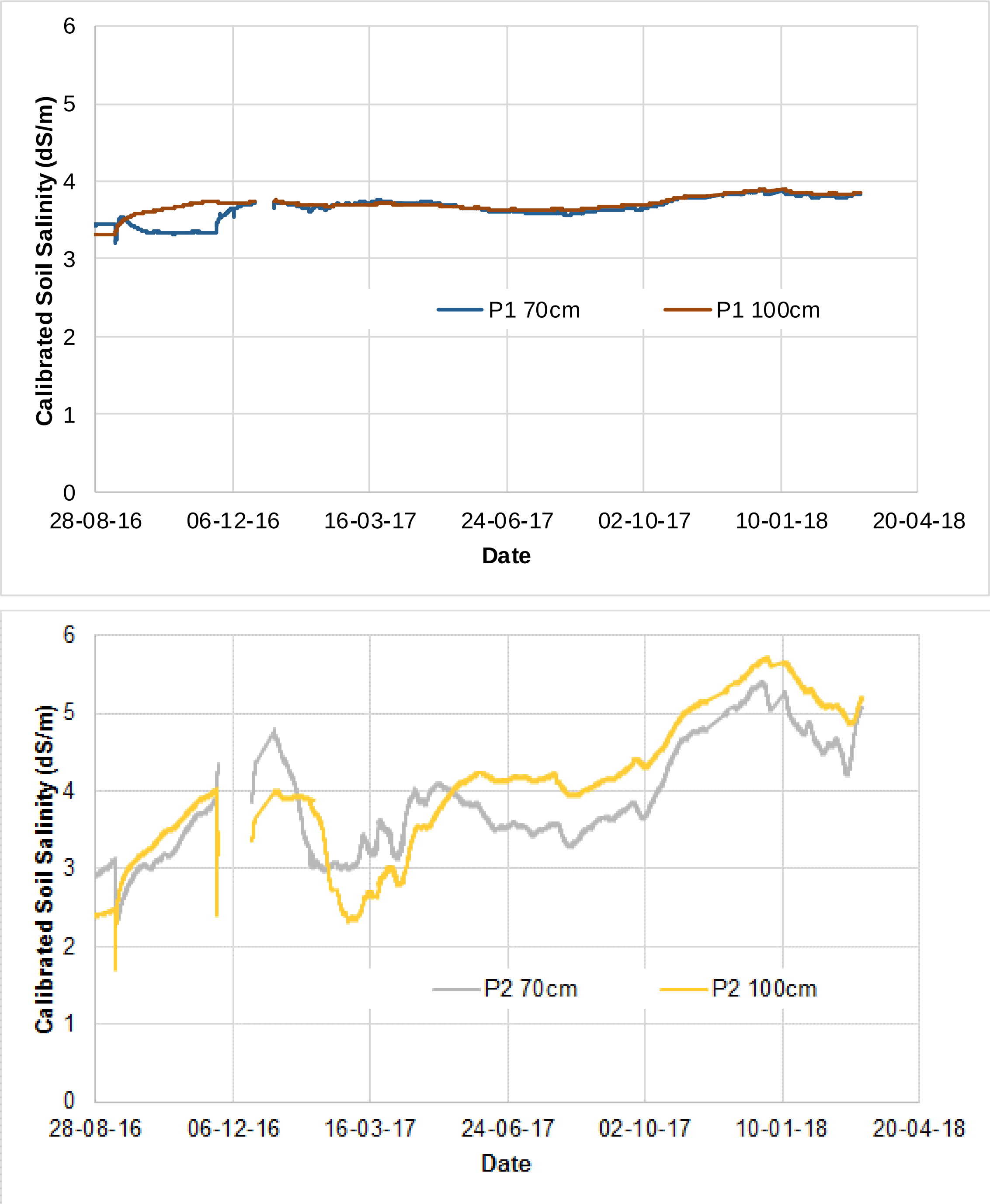


Figure 6: Soil salinity for the thicker cover (0.8m) over the heap leach pad at profile depths of 70cm and 100cm. Probe 1 (top) and Probe 2 (bottom)

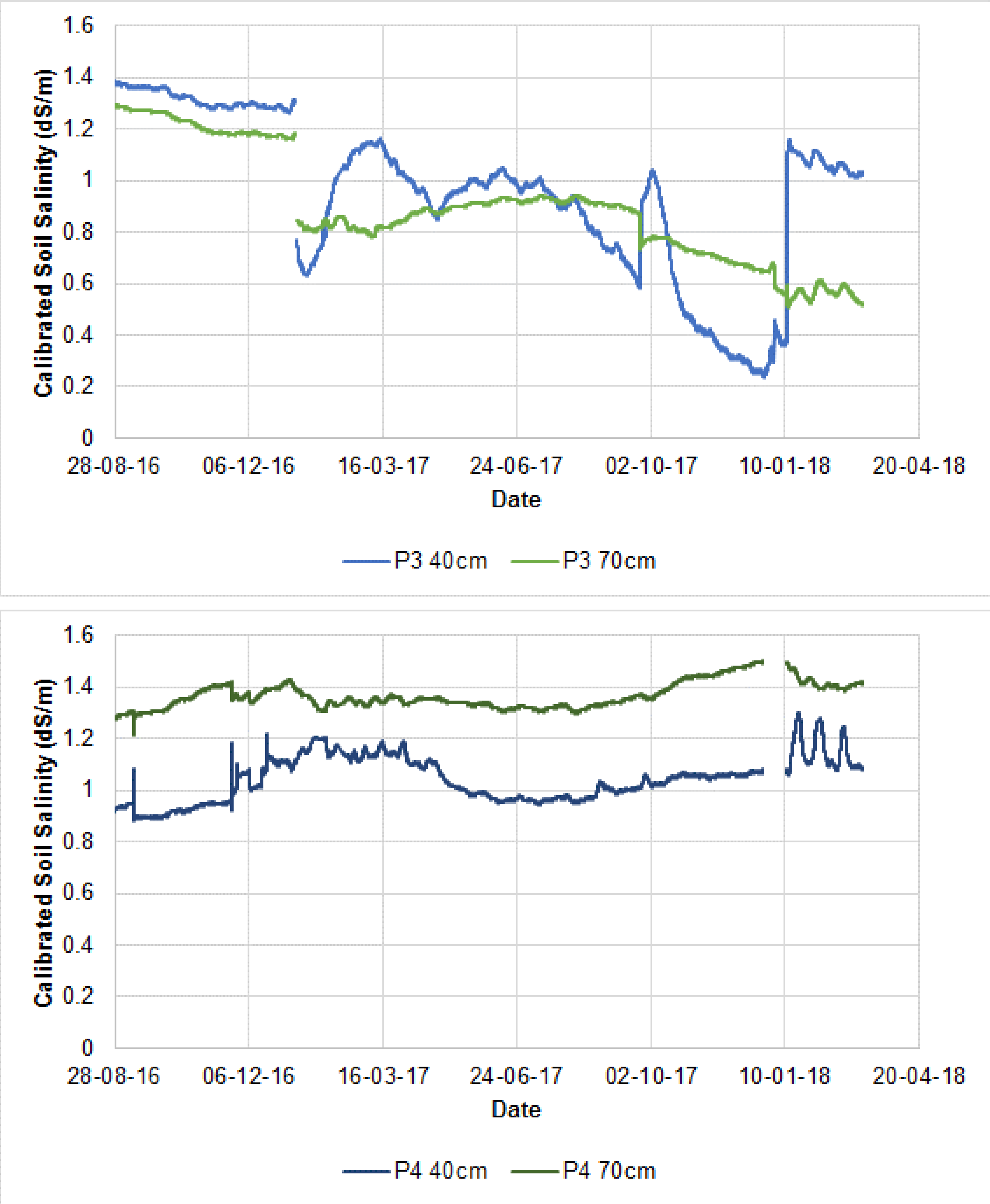


Figure 7: Soil salinity for the thinner cover (0.4m) over the heap leach pad at profile depths of 20cm, 70cm, and 100cm. Probe 3 (top) and Probe 4 (bottom)

PAF waste dump

For all probes installed in the PAF waste dump, there is a general trend towards increasing salinity, though the rate and magnitude of the response does vary between probes. This is not unexpected given the heterogeneity of the materials being measured. As was observed for the heap leach pad, application of wetting events is not translating into reductions in salinity within the oxide, suggesting that salts may well rise within even the thicker cover layer over time.

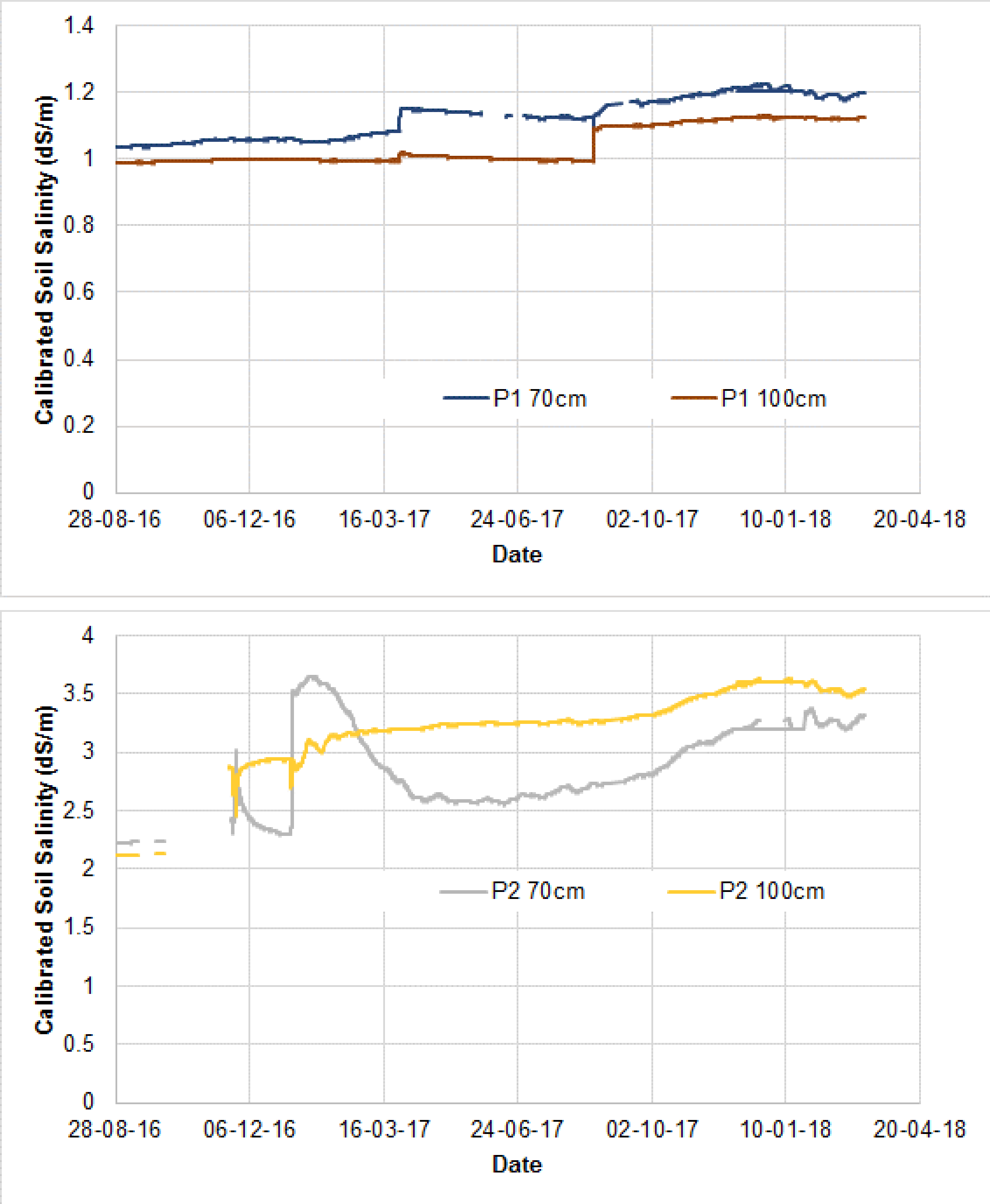
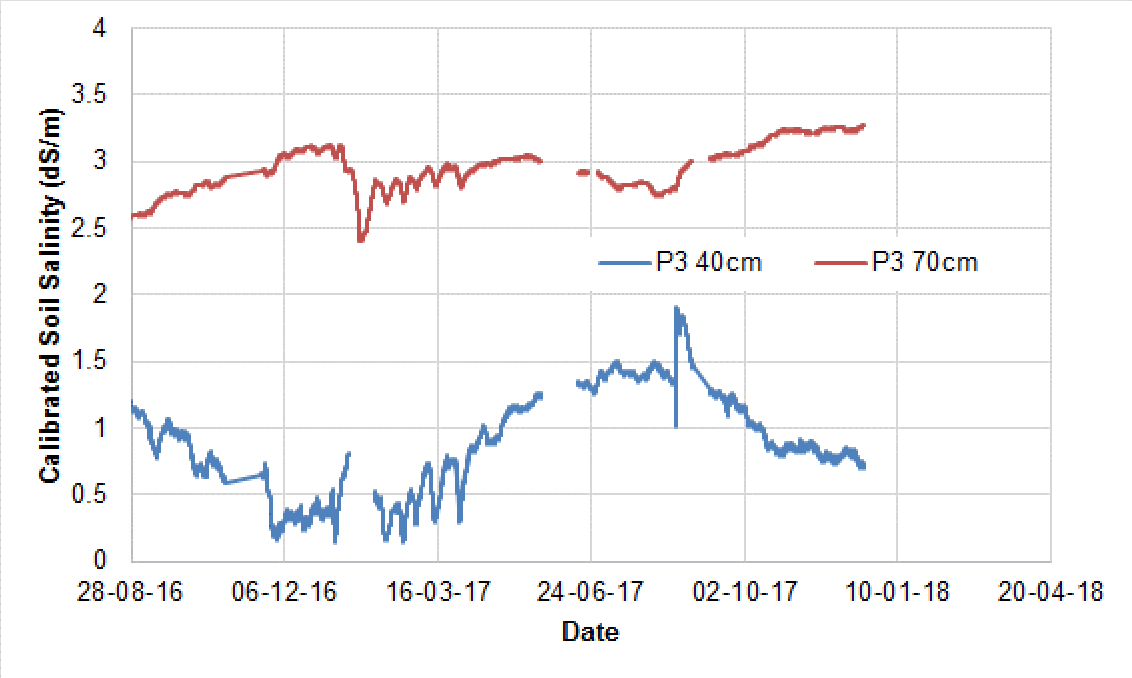


Figure 8: Soil salinity for the thicker cover (1.0m) over the PAF waste dump at profile depths of 70cm, and 100cm. Probe 1 (top) and Probe 2 (bottom)



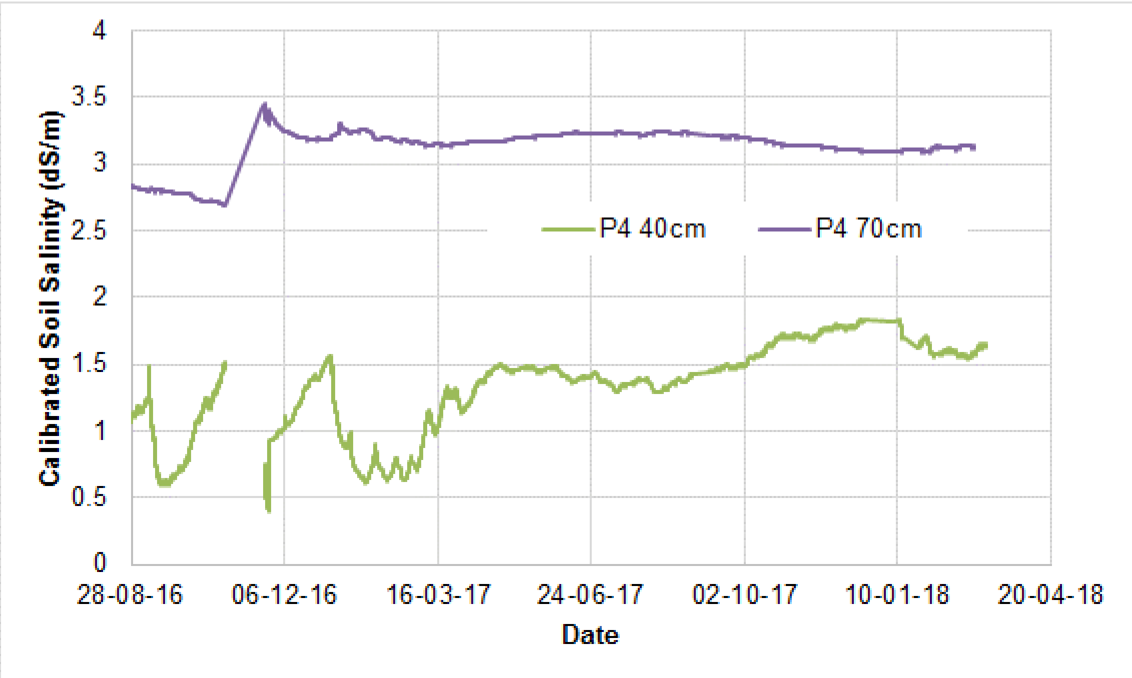


Figure 9: Soil salinity for the thinner cover (0.5m) over the PAF waste dump at profile depths of 70cm, and 100cm. Probe 3 (top) and Probe 4 (bottom)

Discussion

In general, salinity is observed to rise within the oxide overlying to tailings. However, significant rainfall events have been observed to flush these rising salts and lower salinity in the oxide. This indicates that the tailings are free draining, and will likely be less prone to capillary rise of salts as a result.

For the heap leach pad material, there is a general trend towards increasing salinity. However, application of wetting events does not appear to flush these salts to the same decrease as was observed for the tailings. This indicates that the risk of rise of salts from the heap leach, even with the 0.8m cover may be unacceptable. This is to be considered in planned water-solute modelling of this cover using these calibrated data as validation datasets.

Similarly, for the PAF waste dump, here is a general trend towards increasing salinity, with both the thinner and thicker cover observed to increase in salinity through time. The impact of this increase on possible salinity levels in the surface layers will be considered as part of the planned water-solute balance modelling.

Planned water-solute modelling

For all three landforms considered, the oxides have been observed to be able to move salts upwards, with the drainage properties of the underlying materials influencing how they respond to flushing with large rainfall events. The planned water-solute modelling yet to be undertaken will be critical to consider the role the often large and infrequent rainfall events at Nifty in flushing salts (or not) in the long term. However, it is likely that thicker layers will need to be considered if the stated long-term condition of the cover is to be achieved (i.e. low salinity in the surface 0.3m). As part of the modelling, there is also scope to consider what the long-term salinity of the surface layers would be if thinner cover layer is applied, and whether this salinity level would remain suitable for more salt-tolerant species.

Conclusion

Based on our thorough materials characterisation data sets, the initial modelling suggested that covers ranging in depths of between 0.3 m – 1.0 m would all perform such that the net movements of salinity and trace metals would be downward through the cover systems, and would not accumulate on the surfaces. The results of these large-scale trials counter that initial modelling. Further long term modelling based on our results will now be undertaken in order to verify an appropriate cover design for the three closure domains. It is apparent that no amount of *lab work*, *materials characterisation*, and *desktop modelling* would ever give us (or the State of WA) sufficient confidence in cover designs for the closure landforms which would minimise the risk of long term failure – only large scale field trials would ever be sufficient to provide this type of assurance and minimise closure risks. Mine closure plans should not be accepted unless there is a concrete plan for such trials to occur at all mine sites in Western Australia.