Trench Test Analysis Report

Mackay Potash Project

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All attachments are being transmitted as separate electronic files.

Abbreviations

Agrimin	Agrimin Limited
ATO	adaptive time-stepping
bgs	below ground surface
cm	centimeters
DFS	Definitive Feasibility Study
DTW	depth to water
km	kilometer(s)
L/s	Liters per second
m	meter
m/day	meters per day
mm	millimeters
MFSF	Modflow-Surfact Version 4.0 (MFSF).
MPP	Mackay Potash Project
PCG5	MODFLOW PGC solver
PEST	Parameter ESTimation
PFS	Pre-feasibility Study
Stantec	Stantec Consulting International LLC
USGS	United States Geological Survey

1.0 INTRODUCTION

This report details the analysis performed by Stantec Consulting International LLC (Stantec)on pump testing of prototype trenches by Agrimin Limited (Agrimin) at Lake Mackay, Western Australia.

1.1 PROJECT HISTORY

Agrimin Limited (Agrimin) is developing the Mackay Potash Project (MPP) on and near Lake Mackay in Western Australia. The project is based on extracting brine from trenches on the Lake. Several groundwater models have been developed historically for this brine extraction process. These models have been used to progress the MPP through the Pre-feasibility Study (PFS) stage.

1.2 ANALYSIS OBJECTIVES

The MPP is currently moving to the Definitive Feasibility Study (DFS) stage of project development. This requires refinement of the hydrogeological understanding of the lake and the proposed on-lake trench network. A series of 100 meter (m) long trenches were excavated on the lake, and short-term trench pumping tests have been conducted to evaluate hydraulic properties of the lake sediments. Long-term production tests are currently being conducted at two of these trenches (T02A and T13).

This report documents the short-term trench testing and analyses and preliminary analyses of the long term testing at T02A and T13. The long-term trench tests at T02A and T13 will be documented in detail in a separate report.

1.3 REPORT ORGANIZATION

This report is organized into nine chapters, including this introductory chapter. Chapter 2 gives a generic trench test description. Chapter 3 summarizes the external data (barometric pressure, precipitation, and evapotranspiration) that impact the test analysis. Chapter 4 presents the analysis approach for a trench test. Chapter 5 summarizes the trench test execution. Chapter 6 summarizes the trench test analysis results. Conclusions and recommendations are presented in Chapter 7, and limitations of the analysis are presented in Chapter 8. Cited references are presented in Chapter 9. Individual trench test analysis summaries are attached as appendices.

2.0 GENERIC TRENCH TEST DESCRIPTION

This section describes the general approach to conducting a trench test and the data gathered. There were 17 trench tests undertaken. The trench test locations are shown on Figure 2-1, in Appendix B.

2.1 TRENCH CONSTRUCTION

The trenches were constructed with an excavator. The excavator moved across the lake to a pre-determined test location. Several days were spent constructing the trench and installing monitoring piezometers. The trenches were generally 100 m long, 6 m wide at the surface, 1 m wide at the base, and 6 m deep. Individual trench construction was field modified to adjust to site conditions.

Each trench construction was documented with a short summary report. These reports generally included a post-construction summary table, notes on lithology and ground conditions, construction notes, site photographs, piezometer installation summary, observations of the hydraulic behavior of the trench during construction, trench location, and if a trench pump out test was conducted or planned.

The trench construction summary reports were the basis for construction of the groundwater flow models for analysis of trench pump out tests. The individual trench construction reports are included in the attachments summarizing the analysis of that trench test.

2.2 TRENCH PUMPING TESTING

During trench construction, groundwater flowing into the trench was controlled and removed by pumping or removal by construction equipment. This created an initial cone of depression around the trenches. Following construction, the groundwater was given time to equilibrate prior to the trench test being initiated.

2.2.1 Monitoring Set Up

Water levels were monitored with recording pressure transducers in the surrounding piezometers. Before a test began, transducers were installed in the piezometers and in the trench to quantify the pressure changes at those locations. The data was typically logged at 15 minute intervals in the trench and every 6 hours in the monitoring piezometers. Piezometer water levels were recorded at 15 minute intervals for the first few tests.

A pump was installed in the trench with an in-line flow meter installed in the discharge line. Flow rates were reported, and for some tests the total volume of water produced at discrete intervals was recorded. The change in flow meter totalizer readings indicated the volume of water that had been pumped since the previous reading.

2.2.2 Test Procedure

The test was initiated by pumping water from the trench and discharging at distance of 400 to 500 m from the trench to reduce the possibility of recharging the aquifer in the vicinity of the trench. The pumping rate was generally decreased after an initial trench water level pump-down. The test sites were visited at one to three-day intervals as the test was conducted to take measurements and ensure the test equipment was functioning.

After the pumping rates and observed water levels appeared to stabilize, pumping was terminated. The water level recovery was monitored for a period after pumping for all of the tests. Following recovery, the transducers and other equipment were recovered from the site.

3.0 EXTERNAL IMPACTS ON TRENCH TESTS

The primary data gathered from the tests were changes in water pressure recorded by transducers and volumes of water extracted. The changes in observed water pressure are influence by factors besides the pumping of water from the trench (barometric pressure, precipitation, and evapotranspiration). This section describes these factors and the approach taken to account for these factors in analysis of the trench tests.

3.1 BAROMETRIC PRESSURE

Changes in atmospheric pressure can produce large fluctuations in pressure transducer readings in wells or piezometers. The effect of barometric pressure was removed from all piezometer data based on regional barometric data recorded at the Walungurru Air Station located in Kintore, Northern Territory approximately 80 kilometers (km) southeast of Lake Mackay. An example of barometric pressures recorded at the Kintore station are shown on Figure 3-1, in Appendix B.

3.2 PRECIPITATION

Precipitation at the site is generally low with a mean annual rainfall of approximately 281 mm/year in the Lake area (Knight Piesold, 2018). Precipitation occurs in isolated events with high variability in precipitation amounts. Most of the precipitation occurs over the November to March period with lower mean precipitation over the April to October period.

Precipitation can impact the observed groundwater levels due to recharge of the water table as precipitation infiltrates through the lakebed surface. This mechanism is currently being quantified with various recharge specific experiments at several locations across Lake Mackay.

For the purpose of the trench test analysis, the periods of reported precipitation were compared with the period over which each test was conducted. This was done for both data from the on-site weather station located near pilot ponds (Figure 3-2, in Appendix B) and, in some cases, trench specific precipitation monitoring. The correlation of the precipitation and changes in observed water levels was examined. If there was no precipitation during or right before the test period, recharge was not considered in the test analysis. If there was a correlation between precipitation and observed water levels, the amount of recharge was estimated from the water level changes.

3.3 EVAPOTRANSPIRATION

Lake Mackay is a terminal lake, meaning that the amount of water coming into the lake surface and subsurface and leaving the surface and subsurface is either in balance or results in longer-term changes in water levels. In most instances, the water budget appeared to be in balance.

Mean annual evaporation is approximately 3,270 millimeters (mm) and is greatest during the months of November, December, and January. The mean annual evaporation is an order of magnitude larger than the mean annual rainfall.

4.0 TRENCH TEST ANALYSIS

The standard trench test analysis approach is described in this section. The goal of the analysis was to identify composite properties for a trench in that area of the lakebed. There is considerable heterogeneity, especially in the vertical direction as the trench completion reports demonstrate. While it is possible to over-parametrize a numerical model and achieve a better fit to observations, it is important to focus on the questions the model is being used to answer. In this case, the trench pumping tests were being conducted to investigate the long-term potential for trenches to produce brine across the lakebed at a scale of 100 m in length or larger. The parameters obtained from this analysis are reflective of the overall performance of a trench.

The following sections describe the data used to construct local scale groundwater models for each trench location. A sensitivity analysis was conducted to identify a likely range of parameter values. The models were then analyzed with the PEST (Parameter ESTimation) program starting from the current best parameter fit of the model results to the observed water level responses in the monitoring piezometers.

4.1 DATA USED

Stantec was provided with a completion report of the trench construction, raw data logger files, photos, and processed data for each trench test including flow rate and totalizer readings and water levels in the piezometers. Meteorological data was available from the pilot pond weather station and the Kintore weather station.

4.2 MODEL CODE

A numerical model framework was developed using Modflow-Surfact Version 4.0 (MFSF). This is an enhanced version of the a publicly available groundwater flow simulation program MODFLOW developed by the United States Geological Survey (USGS) and is designed to simulate three-dimensional groundwater flow using the finite-difference method. The program was selected for this study, in part, because it is thoroughly documented, widely used by consultants, government agencies, and researchers, and is consistently accepted in regulatory and litigation proceedings.

In addition to its attributes of widespread use and acceptance, MFSF was selected because of its versatile simulation features. MFSF can simulate transient or steady-state saturated groundwater flow in one, two, or three dimensions and offers a variety of boundary conditions, including specified head, areal recharge, hydraulic barriers, injection or extraction wells, evapotranspiration, drains, and rivers or streams. Aquifers simulated by MFSF can be confined or unconfined, or convertible between confined and unconfined conditions. MFSF's three-dimensional capability and boundary condition versatility are essential for the simulation of groundwater flow conditions given the complex hydrostratigraphy of the Study Area, which consists of a multi-layered geologic system with variable unit thicknesses and the hydrogeologic framework necessitates the inclusion of a variety of boundary conditions. MFSF has an advanced version of the MODFLOW PGC solver (PCG5) which utilizes adaptive time-stepping (ATO) which was required to efficiently solve the groundwater flow model finite-difference equations. The parameter estimation code, PEST, was used in the calibration of the models.

4.3 MODEL DISCRETIZATION

Model grids were developed to facilitate representation of the physical trench dimensions. The base model domain is 1,000 m wide by 1,000 m long and 6 m thick. It is divided into 114 rows, 144 columns, and 5 active model layers. The trench is oriented north to south in the middle of the model grid with columns being 1m wide in this area to accurately capture the changes in the trench width with depth. There are five model layers with the first four being 1 m thick and the fifth being 2 m thick. Model grid spacing is 10 m wide in the area of the trench so that the 100 m long trench covers 10 rows. Grid spacing reduces to 5 m at the north and south end of the trench to increase the model resolution for piezometers located along the main trench axis.

The model domain is bordered with constant head or general head boundary conditions. These were set to the same elevation as the initial water levels in the model. This reflects a groundwater system near equilibrium prior to the pumping test and reflects the ability of water to flow to the trench over greater distances.

Figure 4-1, in Appendix B shows the model grid and trench layout over both the whole model domain and a closeup of the trench area.

Trenches are represented by model cells of higher hydraulic conductivity and specific yield in the model to reflect the water-filled trench. The trench width in each model layer was based on the trench completion report and cells reflecting this width are given trench properties for the corresponding layer. This enables matching the amount of water available in the trench at the start of the pumping test so that water yield from the formation can be better estimated. The calculated water production was removed from the model by well boundary conditions set to the correct pumping rates for that model stress period. This enabled the model to extract the correct volume of water for each model stress period.

4.4 TRENCH PUMPING

The test pumping data consisted of spot flow rate readings and, in some cases, totalizer readings. Based on the processed data received, the time of the start of the test was identified, and the pumping rate changes over time noted as the test progressed. These periods of pumping rate changes were assigned individual stress periods in the model time discretization. A daily pumping rate in cubic meters per day was identified for each stress period of the model, and the rate was distributed proportionally in each trench cell using well boundary conditions along the trench length. A new stress period started when a significant change in the reported pumping rate occurred.

4.5 OBSERVATION DATA

The trench tests were monitored by recording changes in water level (or depth to water) using transducers at five or more piezometers that were installed either along the trench axis or perpendicularly away from the trench near the middle (50 m) of the length of the trench. In general, the trenches were oriented north to south, so the perpendicular piezometers were labeled east (E) or west (W) along with the distance from the trench center (commonly 20, 50, or 100 m). The wells along the trench axis were labeled north (N) or south (S) along with the distance from the trench end. To maintain consistency in the analysis approach, in the few instances where the trench was oriented east to west (T22 and T10) the trench was rotated for the model analysis so that the piezometers located perpendicular to the trench axis were represent in the model as east or west piezometers instead of the reported north or south locations.

Water levels in the trench and piezometers were recorded using pressure transducers supplemented by manual depth to water (DTW) measurements. The processed data was reported and plotted as depth to water and plotted in the processed data workbooks. An example of this is shown on Figure 4-2, in Appendix B.

Observed changes in water level were small enough such that they could be masked by changes in barometric pressure. To reduce this uncertainty, the changes in water level from the start of the test were adjusted by the changes in barometric pressure since the start of the test. A typical result of this barometric correct procedure is shown in Figure 4-3, in Appendix B. The data in this figure shows the pressure changes being smoother and more distinct after correction for barometric effects.

The observed changes in water level at the piezometers were used as targets for the trench test model calibration. The changes in water levels at the trench were reviewed for consistency with the reported trench pumping rates and overall changes in water level at the trench. The changes in trench water levels were not used as calibration targets for the model. The observed water levels in the trench could be impacted by skin effects of the trench walls or other localized phenomena, while the test analysis was focused on matching the water level response for the larger aquifer as represented by water level responses in the piezometers. The responses in water levels were converted to water level drawdown time series and the magnitude of observed drawdowns over time are the primary model calibration target.

Spreadsheets containing processed field data and barometric data and analysis are included in the digital data accompanying this report.

5.0 TRENCH TEST EXECUTION SUMMARY

The section describes the number of trenches constructed, the tests conducted, and test parameters such as pumping rates and observed inflows.

5.1 TRENCH LOCATIONS

A total of 24 locations where trench construction was planned are shown on Figure 2-1, in Appendix B. The trenches and testing periods are summarized on Table 5-1, in Appendix A.

5.2 PUMPING TESTS CONDUCTED

Pumping tests were conducted at 17 of the proposed 24 trenches. The testing program was flexible and responded to field observation and operational needs. The testing for each of the trenches is summarized on Table 5-1, in Appendix A. Fifteen of the 17 trench pumping tests are described in this report. Preliminary results of the long-term tests conducted at Trenches T02A and T13 are described in this report. More detailed analyses of the T02A and T13 testing will be reported separately.

6.0 TRENCH TEST ANALYSIS RESULTS

The section summarizes the trench test analysis results. Attachments 1 through 23 contain electronic files (if applicable) with the trench construction report, the processed data file, analyzed data, the model set up file, and the model file associated with the trench test analysis. The trench tests can be broadly grouped into five categories. These are: 1) standard test length without significant precipitation, 2) earlier tests prior to rainfall information being available, 3) standard test length with significant precipitation, 4) trenches that were abandoned or did not have tests conducted, and 5) longer-term pumping tests. Each group is covered in a separate section in this chapter.

6.1 STANDARD TEST LENGTH WITHOUT SIGNIFICANT PRECIPITATION

This group is comprised of tests on trenches with little to no precipitation reported during the tests. This group comprises T01, T03, T06, T18, and T20.

6.1.1 T01

Trench 01 was constructed from June 17, 2018 to June 23, 2018. The observed brine inflow was reported as low. The trench was pumped from August 6, 2018 to August 9, 2018. The pumping rate was initially 2 liters per second (L/s) which dropped to an average of 0.3 L/s over three days of pumping.

Water level monitoring data was recorded at two piezometers (20mE and 50mE). Calibration of the numerical model with PEST resulted in bulk parameter estimates of 0.46 meters per day (m/day) for horizontal hydraulic conductivity, 0.013 for specific yield, and 2.04 x 10^{-4} m^{-1} for specific storage which are consistent with the low water production rates for this test. The processed data spreadsheet, groundwater modeling files, and model calibration plots from the test are included in Attachment 1.

6.1.2 T03

A pumping test was conducted for Trench 03 from July 6, 2018 to July 15, 2018. The pumping rate began at 2.38 L/s and dropped on the second day of the test to 0.6 L/s. After three days, the pumping rate dropped to 0.22 L/s where it remained for the duration of the test.

The calibration of the numerical model for the test improved with PEST, and bulk parameters were estimated as 1.53 m/day for horizontal hydraulic conductivity, 0.122 for specific yield, and 4.95 x 10^{-3} m^{-1} for specific storage. The processed data, model work up spreadsheet, calibration targets spreadsheet, calibration spreadsheet, and model files are included in Attachment 3.

6.1.3 T06

Trench 06 was constructed from October 22, 2017 to October 28, 2017. The observed brine inflow was reported as high. Abundant brine inflow was reported at approximately 1.9 m below ground surface (bgs).

A pumping test was conducted on this trench from March 11, 2018 until April 7, 2018. Water level recovery was monitored, and a second pumping test was started on April 11, 2018. The second test had equipment challenges, so the analysis focused on the first test. Minor precipitation (0.7 mm on March 10, 2018 and 0.1 mm on March 11, 2018) was reported from the pilot pond weather station prior to the beginning of the test. This corresponded to a rise in the average piezometer water level (DTW on 79.9 centimeters (cm) on March 9, 2018 to 66.1 cm on March 11, 2018 at the start of the test). It appears that this volume of precipitation would be unlikely to create such a rise in the water table. Field personnel noted that a significant atmospheric pressure low moved through the area during this period, but there was very little rain at the T06 test location. This low atmospheric pressure may have passed over the Kintore station (80 km distant) at different time which may account for this water level change.

The numerical model results using PEST indicated an effective hydraulic conductivity of 24.3 m/day, a specific yield of 0.025, and a specific storage of 4.04×10^{-6} m^{-1}. This parameter estimation performed differently from the other models. PEST sought to decrease the specific yield and storage much lower than seen in other simulations. The specific yield reached the lower bound of 0.025 used for the modeling and parameter estimates reflect this. Low specific yield and specific storage would be consistent with the field observation of over 10 cm of water level increase for a small precipitation event as discussed previously, however, this appears to be inconsistent with the high effective hydraulic conductivity. The trench construction report, processed data spreadsheet, model setup spreadsheet, drawdown target spreadsheet, model file, and calibration plots are included in Attachment 6.

6.1.4 T18

Trench 18 was constructed from June 17, 2018 to June 23, 2018. The observed brine inflow was reported as low with brine inflow primarily occurring from a zone at 3 to 4 m bgs.

A pumping test was conducted on this trench from July 21, 2018 until August 8, 2018. Minor precipitation (0.3 mm on August 2, 2018 and 1.1 mm on August 3, 2018) was reported from the pilot pond weather station during the pumping test.

Pumping rates started at approximately 1 L/s and were maintained at this level for 5 days. The pumping rate then dropped over time to approximately 0.6 L/s at the end of the test.

The numerical model results using PEST indicated an effective hydraulic conductivity of 6.34 m/day, a specific yield of 0.14, and a specific storage of 6.54×10^{-4} m^{-1}. The trench construction report, processed data spreadsheet, model setup spreadsheet, drawdown target spreadsheet, model file, and calibration plots are included in Attachment 18.

6.1.5 T20

Trench 20 was constructed from October 28, 2017 to October 30, 2017. The observed brine inflow was reported as low-moderate.

A pumping test was conducted on this trench from March 11, 2018 to April 20, 2018. Minor precipitation (0.7 mm on March 10, 2018 and 0.1 mm on March 11, 2018) were reported from the pilot pond weather station near the beginning of the test. Pumping rates started at 3 L/s and were maintained at this level for six days. The pumping rate then dropped to approximately 1 L/s for the next 16 days. The next 17 days continued with a pumping rate of approximately 1 L/s interspersed with three intervals of zero pumping due to equipment difficulties.

The numerical model results using PEST indicated an effective hydraulic conductivity of 2.85 m/day, a specific yield of 0.150, and a specific storage of 1.50 x 10^{-3} m^{-1}. The trench construction report, processed data spreadsheet, model setup spreadsheet, drawdown target spreadsheet, model file, and calibration plots are included in Attachment 20.

6.2 EARLIER TESTS WITHOUT PRECIPITATION INFORMATION

This group is comprised of tests on trenches earlier in the program prior to precipitation records being available. This group consists of T02, T05, T14, T16, and T22.

6.2.1 T02

Trench 02 was constructed from August 6, 2017 to August 11, 2017. The observed brine inflow was reported as moderate. A trench pumping test was conducted from September 4, 2017 to September 9, 2017. No pumping rate was reported, and the completion report states the data was of little value. Without the pumping rate, a numerical model was not developed. The completion report and processed data spreadsheet are included in Attachment 2.

6.2.2 T05

Trench 05 was constructed from August 21, 2017 to August 26, 2017. The observed brine inflow was described as moderate to low. All of the observed inflow was between 1.5 and 1.8m bgs.

A pumping test was conducted at this trench from October 13, 2017 to November 6, 2017. It began with an initial pumping rate of 6 L/s which dropped to under 1 L/s by the second day of the test. For the last 12 days of the test a pumping rate of 0.3 L/s was reported.

The numerical model results indicated an effective hydraulic conductivity of 2.81 m/day, a specific yield of 0.109, and a specific storage of 5.00 x 10^{-3} m^{-1}. The trench construction report, processed data spreadsheet, model setup spreadsheet, drawdown target spreadsheet, model file, and calibration plots are included in Attachment 5.

6.2.3 T14

Trench 14 was constructed from August 1, 2017 to August 5, 2017. The observed brine inflow was moderate to high. All of the observed inflow into the trench was between 0.5 and 1.9 m bgs.

Two pumping tests were conducted at this trench. The second pumping test was from November 26, 2017 to December 17, 2017. Based on the more complete data set for this test and reported precipitation of 4.4 mm on December 15, 2017 at the pilot pond weather station, the second test was analyzed for this work. A steady pumping rate of 0.5 L/s was reported for the duration of this test.

The drawdown targets for this test do not correspond very well to the expected behavior based on the reported constant pumping rate. The eight monitoring piezometers all show little drawdown or an increase in reported water levels during the first few days of the test. This could potentially be due to a precipitation event, but the precipitation data set does not cover this period. This poor match reduces the confidence in the parameter values from the PEST modeling.

The numerical model results using PEST indicated an effective hydraulic conductivity of 17.3 m/day, a specific yield of 0.167, and a specific storage of 3.23 x 10^{-3} m^{-1}. The trench construction report, processed data spreadsheet, model setup spreadsheet, drawdown target spreadsheet, model file, and calibration plots are included in Attachment 14.

6.2.4 T16

Trench 16 was constructed from July 24, 2017 to July 26, 2017. The observed brine inflow was moderate to high. Observed brine ingress was in the form of diffuse flow within the top 2.5 m. Persistent flow was reported between 1 m and 2.5 m in depth.

A pumping test was conducted on this trench from August 4, 2017 to September 30, 2017. Pumping rates were calculated from the totalizer readings. The pumping rated started at 4.57 L/s and then dropped to 2.82 L/s through day 6 of the test. The pumping rate then dropped to approximately 1.6 L/s for the remainder of the test with four periods on the order of one day where the pump was not operating. Water levels at piezometer 20mE showed an unexplained rise in the water levels later in the test. For this reason, this piezometer was not used in the model calibration.

The numerical model results using PEST indicated an effective hydraulic conductivity of 19.5 m/day, a specific yield of 0.062, and a specific storage of 2.34 x 10^{-4} m^{-1}. The trench construction report, processed data spreadsheet, model setup spreadsheet, drawdown target spreadsheet, model file, and calibration plots are included in Attachment 16.

6.2.5 T22

Trench 22 was constructed from September 9, 2017 to September 15, 2017. This trench was not initially planned and was constructed after a test pit displayed promising hydrogeological properties. The trench was constructed in an area of very soft ground and observed brine ingress was recorded as very moderate-to-high, but with significant spatial variability along the trench for areas of deeper inflows. The completion report for this trench is included in Attachment 22.

Two pumping tests were conducted at this trench. The first test was conducted from October 12, 2017 to November 6, 2017. It began with an initial pumping rate of 6 L/s which dropped to 5 L/s and maintained for approximately five days. A very high pumping rate of 36 L/s was reported on the second day of the test with the assistance of two flex drives. The modeling was not able to match this pumping rate and observed drawdowns. Since the duration of this pumping rate was not well delineated, the modeling used approximately a 20% increased rate for an entire day. This test showed higher inflow rates that were still on the order of 1.5 L/s at the end of the test. The calibration of the numerical model for the test improved with PEST, and bulk parameters were estimated as 9.33 m/day for horizontal hydraulic conductivity, 0.295 for specific yield, and 5.44 x 10^{-4} m^{-1} for specific storage. The model work up spreadsheet, processed data spreadsheet, drawdown targets spreadsheet, calibration spreadsheet, and model files are included in Attachment 22.

The second test was conducted from November 11, 2017 to December 18, 2017. The second test was analyzed as a verification for the first test analysis. Unfortunately, the observed piezometer drawdowns were inconsistent with the reported pumping rates. A pumping rate of 4 L/s was reported for 17 days. The piezometer drawdowns increased at the start of the test which is consistent with the pumping rates. They then recovered while the pumping presumably was still occurring. It is clear the analysis is missing either an additional source of water such as a large precipitation event or a change in the pumping rates. Due to this discrepancy, no further work was conducted on the second test for this trench.

6.3 STANDARD TEST LENGTH WITH SIGNIFICANT PRECIPITATION

This group is comprised of tests on trenches with significant precipitation reported during the tests. This group comprises T08, T09, T10, T11, and T23.

6.3.1 T08

Trench 8 was constructed from September 2, 2017 to September 9, 2017. The observed brine inflow was reported as low.

A pumping test was conducted on this trench from January 14, 2018 to January 28, 2018. Approximately 62 mm of precipitation was reported from the pilot pond weather station in the five days prior to the test (January 9, 2018 to January 13, 2018). Minor precipitation (0.1 mm on January 14, 2018, 0.3 mm on January 15, 2018, and 2.5 mm on January 20, 2018) was reported during the test and a larger precipitation events of 20.6 mm was reported on the last day of the test from the pilot pond weather station.

The test began with three days of pumping at 2.2 L/s. The following day had no pumping followed by days at 2 and 1.6 L/s before the test settled into a constant pumping rate of 1 L/s for the duration of the test.

Pumping in the model for the test stopped on January 28, 2018 at 12:00 pm with a final period of 0.76 days without pumping. This showed the predicted water level recovery using the calibrated model parameters.

The numerical model results using PEST indicated an effective hydraulic conductivity of 6.69 m/day, a specific yield of 0.082, and a specific storage of 2.37 x 10^{-4} m^{-1}. The trench construction report, processed data spreadsheet, model setup spreadsheet, drawdown target spreadsheet, model file, and calibration plots are all contained in Attachment 8.

The actual water levels recovered very quickly on January 27, 2018 with water levels rising on the order of 40 to 80 cm over the six hours between 6:00 pm and midnight. The modeling (without recharge) showed a minor recovery during the same period. The reported precipitation for this period was 2.06 cm at the pond weather station. This amount of recharge would be expected to raise the water level on the order of 25 cm for the estimated specific yield of 0.082. This suggests a very high percentage of the precipitation became recharge at this trench for this event, and it appears that there may have been more precipitation near Trench 08 than that seen at the weather station. Field personnel noted that the trench was inundated with surface water flow from this precipitation event which may account for higher than expect water level rise in the piezometers.

6.3.2 T09

Trench 9 was constructed from October 2, 2017 to October 9, 2017. The observed brine inflow was reported as moderate to high and dominated by conduit inflow between 1.5 and 3 m bgs.

A pumping test was conducted on this trench from January 13, 2018 to February 24, 2018. Approximately 62 mm of precipitation was reported from the pilot pond weather station in the five days prior to the test (January 9, 2018 to January 13, 2018). Eleven precipitation events were recorded during the test at the pilot pond weather station. Six of these reported more than 1.0 mm of precipitation (2.5 mm on January 20, 2018, 20.6 mm on January 28, 2018, 6.7 mm on February 12, 2018, 3.6 mm on February 27, 2018, and 3.2 mm on February 28, 2018).

The reported pumping rate for the test was 5 L/s or greater for all but one day of the test. A zero L/s pumping rate was recorded on January 20, 2018 due to pump problems. Examining the daily notes and the totalizer on the volumes pumped showed an incrementally lower pumping rate and a second period where the pump was not functioning. The timing of the pump failure was estimated from the recorded trench water levels, allowing for some more resolution of when the water levels were able to recover. The test was calibrated to the period before the January 28, 2018 precipitation event.

The numerical model results using PEST indicated an effective hydraulic conductivity of 65.92 m/day, a specific yield of 0.170, and a specific storage of 1.05 x 10^{-4} m^{-1}. The trench construction report, processed data spreadsheet, model setup spreadsheet, drawdown target spreadsheet, model file, and calibration plots are included in Attachment 9.

An estimate of the percentage of recharge can be made using the estimated specific yield, precipitation amounts, and recorded rises in water level. For the January 28, 2018 event with 20.6 mm of precipitation, four of the five piezometers recorded an average rise in water level for the period between 14.25 and 15.25 days into the test of 5.125 cm. Piezometer 20mN had the water level drop from time 14.75 to 15.0 days into the test. Multiplying the 5.125 cm water level rise by the estimated specific yield of 0.17 gives an average recharge volume of 0.87 cm which is approximately 36% of the 2.4 cm of the precipitation reported at the T09 location for this period.

The February 1, 2018 event with 20.8 mm of precipitation was reflected in a rise in water level at each of the piezometers between 18.5 and 19.25 days into the pumping test. The water level rises averaged

1.8 cm which gives and average recharge of 0.3 cm which is approximately 15% of the 2.08 cm of precipitation reported for this period.

6.3.3 T10

Trench 10 is a replacement for T19 which was abandoned when the pump and discharge equipment plugged up with precipitated salts a few hours into pumping. Trench 10 was constructed from July 28, 2018 to August 5, 2018. The observed brine inflow was reported as moderate to high.

A pumping test was conducted on this trench from August 20, 2018 to September 19, 2018 followed by three days of recovery. One minor precipitation event (0.3 mm on August 31, 2018) was reported during the test and one significant precipitation event (8.9 mm on September 21, 2018) was reported from the pilot pond weather station during the test recovery period.

The reported pumping rate for the test ranged from 4.8 L/s to 22.5 L/s.

The numerical model results using PEST indicated an effective hydraulic conductivity of 171 m/day, a specific yield of 0.116, and a specific storage of 8.76×10^{-4} m^{-1}. The trench construction report, processed data spreadsheet, model setup spreadsheet, drawdown target spreadsheet, model file, and calibration plots are included in Attachment 10.

6.3.4 T11

Trench 11 was constructed from October 30, 2017 to November 3, 2017. The observed brine inflow was reported as moderate to high primarily by conduit flow between 1.5 and 3 m bgs.

A pumping test was conducted on this trench from January 12, 2018 to February 24, 2018. Approximately 62 mm of precipitation was reported from the pilot pond weather station in the five days prior to the test (January 9, 2018 to January 13, 2018). Eleven precipitation events were recorded during the test at the pilot pond weather station. Six of these reported more than 1.0 mm of precipitation (2.5 mm on January 20, 2018, 20.6 mm on January 28, 2018, 6.7 mm on February 12, 2018, 3.6 mm on February 27, 2018, and 3.2 mm on February 28, 2018.

The reported pumping rate for the test started at approximately 3 L/s. This rate slowly dropped over time with the final reported pumping rate being 1 L/s on February 24, 2018 or greater for all but one day of the test. A 0 L/s pumping rate was recorded on January 17, 2018 due to pump problems. The test was calibrated to the period before the January 28, 2018 precipitation event.

The numerical model results using PEST indicated an effective hydraulic conductivity of 6.57 m/day, a specific yield of 0.163, and a specific storage of 5.00×10^{-3} m^{-1}. The trench construction report, processed data spreadsheet, model setup spreadsheet, drawdown target spreadsheet, model file, and calibration plots are included in Attachment 11.

An estimate of the percentage of recharge can be made using the estimated specific yield, precipitation amounts, and recorded rises in water level. For the January 28, 2018 event with 20.6 mm of precipitation, eight of the nine piezometers recorded an average rise in water level for the period between 15.00 and

16.25 days into the test of 5.0 cm. Piezometer 20mS had the water level drop slightly. Multiplying the 5.0 cm water level rise by the estimated specific yield of 0.163 give an average recharge volume of 0.81 cm which is approximately 39% of the 2.06 cm of the precipitation reported for this period.

The February 1, 2018 event with 20.8 mm of precipitation was reflected in a rise in water level in five of the nine piezometers between 19.25 and 20.25 days into the pumping test. The water level rises averaged 2.6 cm which gives and average recharge of 0.42 cm which is approximately 20% of the 2.08 cm of precipitation reported for this period.

6.3.5 T23

Trench 23 was constructed from August 30, 2018 to September 2, 2018. The observed brine inflow was reported as low.

A pumping test was conducted on this trench from September 6, 2018 to September 22, 2018 followed by five days of recovery. One precipitation event (8.9 mm on September 21, 2018) was reported from the pilot pond weather station during the test.

The pumping rate for the test started at approximately 2 L/s for four days with short periods when the pump was not on. The rate was set to approximately 0.8 L/s for the end of the test. The pumping was turned off on September 22, 2018, and the water levels were allowed to recover.

The numerical model results using PEST indicated an effective hydraulic conductivity of 6.86 m/day, a specific yield of 0.11, and a specific storage of 2.31×10^{-4} m^{-1}. The trench construction report, processed data spreadsheet, model setup spreadsheet, drawdown target spreadsheet, model file, and calibration plots are included in Attachment 23.

6.4 TRENCH LOCATIONS WITHOUT PUMPING TESTS

This group consists of trenches that were not completed or where tests were not conducted, or testing was abandoned during the test. This group comprises T04, T07, T12, T15, T17, T19, and T21.

6.4.1 T04

Trench 04 want not constructed. There are no files to include in Attachment 4.

6.4.2 T07

Trench 07 construction began on August 30, 2017. Only minor seepage observed in the first 20 m constructed. The full trench excavation was not continued. The completion report for this trench is included in Attachment 7.

6.4.3 T12

The construction report for trench 12 is included in Attachment 12. The trench was constructed, but no pumping test was conducted. Brine ingress was reported in the form of diffusive flow on the contact of the upper sand horizon and lower clay margins. Almost no brine inflow was observed deeper than 2 m. The collective brine ingress for this trench was recorded as very low to low. The upper 1 m sequence is likely to have high specific yield properties.

6.4.4 T15

Trench 15 was abandoned due to very sloppy conditions making construction difficult. The trench total length was about 30 m. Water and precipitated salts are visible in the trench construction photographs. No further work was done on this trench and Attachment 15 is empty. Trench 21 was constructed as a replacement for Trench 15 in the test program.

6.4.5 T17

Trench 17 was constructed from July 28, 2017 to July 31, 2017. Low brine inflow was reported for the trench and it was not pump tested. The completion report for Trench 17 is included in Attachment 17.

6.4.6 T19

Trench 19 was constructed from July 15, 2018 to July 19, 2018. Very low brine inflow was reported, and no pumping test was conducted. The completion report for Trench 19 is included in Attachment 19.

6.4.7 T21

Trench 21 was constructed from August 15, 2017 to August 19, 2017 as a replacement for Trench 15. The completion report states it was in an area of very soft ground with soil failures during construction. Approximately 1 m of very loose unconsolidated silt sand and gypsum sand overlays a very firm homogeneous red brown clay. Inflows were surprising low given the nature of the surface features, but the trench and surrounding bucket depressions from the excavator did make water.

A pumping test was attempted, but salt precipitation blocked the pump inlet and values within 2 to 3 hours, and the test was abandoned. The completion report for this trench is included in Attachment 21.

6.5 LONG-TERM TRENCH TESTS

Two long-term trench tests are currently ongoing at the Mackay Potash Project at locations T02A and T13. Groundwater flow models were constructed for these tests for a preliminary assessment of bulk hydraulic properties of the shallow lakebed sediments at these locations. Results of this preliminary modeling is described below. Detailed analyses of testing at the T02A and T13 locations including flow and mass transport modeling in the unsaturated zone and analysis of recharge and evapotranspiration will be described in a separate report.

6.5.1 T2A

Trench 02A was constructed from November 17, 2018 to November 19, 2018. Approximately 0.5 m of clayey evaporitic silty sand with a thin (1 mm) evaporitic crust overlays a moderately firm clay at this location. Brine ingress was observed from small conduit features at approximately 2.5 m bgs. The rate on ingress was low, yet consistent, and the trench filled in under 48 hours post-construction.

Trench pumping began on December 2, 2018, and the test was shut in on June 27, 2019. The initial pumping rate was approximately 2.8 L/s reducing to a sustained long term pumping on the order of 0.6 L/s.

Preliminary numerical model results using PEST indicate an effective hydraulic conductivity of 5.22 m/day, a specific yield of 0.023, and a specific storage of 2.16 x 10^{-4} m^{-1}. The trench construction report, processed data spreadsheet, model setup spreadsheet, drawdown target spreadsheet, model file, and calibration plots are included in Attachment 02A.

6.5.2 T13

Trench 13 was constructed from August 18, 2018 to August 20, 2018. Approximately 1 m of evaporitic coarse grained sand overlays 0.5 m of evaporitic sand with a silty-clay matrix overlaying a clay with cobble grade evaporite nodules at this location. Moderate to high brine ingress was observed from distinct conduit associated with the evaporite nodules at about 2 m bgs.

Trench pumping began on December 3, 2018, and the test was shut in on June 2, 2019. The initial pumping rate was approximately 2 L/s reducing to a sustained long term pumping on the order of 1 to 1.2 L/s.

Preliminary numerical model results using PEST indicate an effective hydraulic conductivity of 6.76 m/day, a specific yield of 0.112, and a specific storage of 1.61 x 10^{-4} m^{-1}. The trench construction report, processed data spreadsheet, drawdown target spreadsheet, model file, and calibration plots are included in Attachment 13.

7.0 CONCLUSIONS

Local scale groundwater flow models were constructed to analyze trench pumping tests conducted by Agrimin personnel at the Mackay Potash Project. Models were discretized to represent the area and aquifer thickness affected by trench pumping. The models were calibrated to drawdowns observed in nearby piezometers, and trench tests were analyzed for bulk hydraulic properties (hydraulic conductivity, specific yield, and specific storage) of the shallow lakebed sediments.

Hydraulic conductivity estimates from the trench test analyses ranged from 0.45 m/d to 171 m/d; specific yield estimates ranged from 0.013 to 0.295, with most estimates on the order of 0.10 to 0.15; and specific storage estimates ranged from $4x10^{-6}$ m^{-1} to $5x10^{-3}$ m^{-1}.

A high-level assessment was conducted to compare spatial distribution of hydraulic conductivity and specific yield with the assumptions for these parameters used in the PFS groundwater modeling. The PFS groundwater model assumed a uniform spatial distribution of hydraulic conductivity and specific yield based on the geometric mean of available data at specific depth intervals. The models developed to analyze the trench test data in this report assume bulk hydraulic conductivity and specific yield for the upper 6 m of lakebed sediments to develop site specific values for these parameters at each trench location.

To compare the results of the local scale trench modeling with the PFS model results, the layered aquifer formula for hydraulic conductivity and a thickness weighted average of specific yield from the PFS over the saturated interval from 0.5 m to 6 m depth were applied (hydraulic conductivity = 7.8 m/day and specific yield = 6.2%). A preliminary spatial distribution of these parameters from the trench test analyses was developed by projecting the results on a 200 m x 200 m grid spacing over an area roughly covering the outline of the trench tests within the lake boundary (note that this preliminary projection does not incorporate information such as geologic boundaries and gradations or the island outlines which will be incorporated in the final distribution of parameters in the DFS groundwater and mine planning models).

The area in which the specific yield and hydraulic conductivity in the preliminary spatial parameter distribution exceeds the PFS thickness weight averages for these parameters over an area approximately 84% of the area which would be drained by the PFS trench network assuming an area of influence extending one kilometer from the PFS trenches. These areas are on the order of 20% to 25% of the total area encompassing the 12 Agrimin Exploration Licenses.

The percentage recharge estimates were derived based on water level changes due to rainfall events and specific yield results at the trench location. These estimates are on the same order as the PFS assumption of recharge (37% of rainfall).

This high-level assessment using the data and inputs noted above suggests that the DFS mine planning effort will be able to meet or exceed the production predicted in the PFS modeling. Additional work remains to complete the DFS groundwater model and mine planning. The hydraulic property estimates from these trench test analyses along with ongoing long-term trench testing, field and lab recharge experiments, resource drilling and sampling, and lab estimates of physical properties will inform the construction of a lake-scale groundwater flow and mass transport model for use in mine planning and reserves estimates for the current program to bring the project to DFS level of accuracy.

8.0 MODEL LIMITATIONS

The trench pumping test models were based on the available data and with the objective of identifying larger-scale bulk hydrogeologic parameters that reasonably matched the test observations. The models are well-calibrated within the objectives of the analysis. Even with this, there is always uncertainty associated with the numerical simulation of groundwater flow. The simulated systems represent simplified versions of the conceptual model of a complex hydrogeologic system. Therefore, even though the trench pump test models are considered calibrated, prudence should be used in the application of the results as a planning tool. For predictive simulations, there is a potential that the forecasting information used to evaluate future scenarios may be insufficient.

It is expected that some the trench pump test models may be revisited following the completion and analysis of the recharge field work being conducted on the lake. In addition, if data becomes available that was not utilized in this analysis, the interpretation of the pumping tests could change and should be revisited.

9.0 REFERENCES

Knight Piesold, 2018. Mackay SOP Project – Pre-Feasibility Study.

APPENDIX A
TABLES

5-1. Trenches and Testing Periods

6-1. Trench Tests and Estimated Parameters

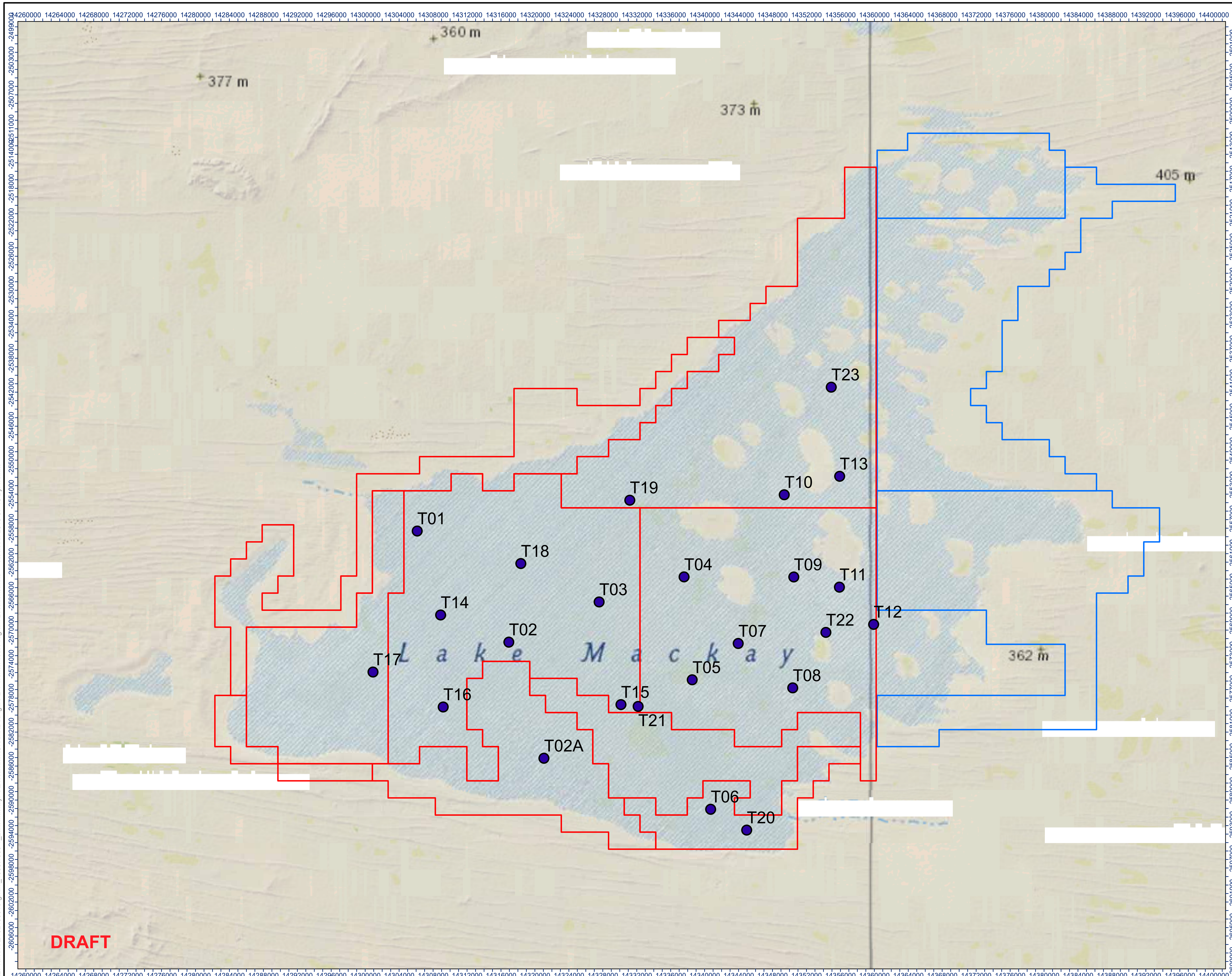
Table 5-1. Draft Trenches and Testing Periods

Trench	Trench Construction	Testing Period		Notes
		Start	End	
T01	June 17-23, 2018	August 6, 2018	August 9, 2018	
T02	August 6-11, 2017	September 4, 2017	September 9, 2017	"Pump out test completed but data of little value"
T02A		December 2, 2018	June 5, 2019	Long term pumping test
T03		July 6, 2018	July 15, 2018	
T04	Not constructed - Replaced by T23			
T05	August 21-26, 2017	August 21, 2017	November 6, 2017	
T06	October 22-28, 2017	March 11, 2018	April 7, 2018	
T07	August 30, 2017	n/a	n/a	absence of inflow in first 20 meters, abandoned trench
T08	September 2-9, 2017	January 8, 2018	January 28, 2018	
T09	October 2-9, 2017	January 13, 2018	February 24, 2018	
T10	July 28-August 5, 2018	August 20, 2018	September 19, 2018	
T11	September 30 - October 3, 2017	January 12, 2018	February 26, 2018	
T12	September 24-27, 2017	n/a	n/a	not pumped
T13	September 18-20, 2018	December 3, 2018	May 28, 2019	Long term pumping test
T14	August 1-5, 2017	November 26, 2017	December 17, 2017	Dates are for second pumping test
T15	July 15-19, 2018	n/a	n/a	Abandoned due to very sloppy conditions. Total length was about 30 m.
T16	July 24-26, 2017	August 4, 2017	September 30, 2017	
T17	July 28-31, 2017	n/a	n/a	not pumped
T18	June 17-23, 2018	July 18, 2018	August 8, 2018	
T19	July 15-19, 208			not pumped
T20	October 28-30, 2018	March 11, 2018	April 20, 2018	
T21	August 15-19, 2017			Replaced T15. Tried to pump it but salt precipitation blocked the pump inlet and valves within 2-3hrs. Test abandoned.
T22	September 9-15, 2017	October 12, 2017	November 6, 2017	Dates are for first pumping test.
T23	August 30 to September 2, 2018	September 6, 2018	September 28, 2018	

Table 6-1. Draft Trench Test Summary and Parameter Estimates

Trench	Approximate Volume Pumped (m^3)	Observed Brine Inflow Rate (Low/Moderate/High)	Model Scaled RMS (%)	Estimated Parameters: Horizontal Conductivity (m/day)	Specific Yield (-)	Specific Storage (m^{-1})
Group 1 - Standard Length Without Significant Precipitation Reported						
T01	450	Low	37.5	0.46	0.013	1.28×10^{-4}
T03	350	n/a	9.97	1.53	0.122	4.95×10^{-3}
T06	5,050	High	6.54	24.3	0.025	4.04×10^{-6}
T18	1,200	Low	5.93	6.34	0.140	6.54×10^{-4}
T20	3,000	Low/Moderate	7.27	2.85	0.150	1.50×10^{-3}
Group 2 - Earlier Tests Without Precipitation Information						
T02	unknown	Moderate	n/a	n/a	n/a	n/a
T05	950	Moderate/Low	4.5	2.81	0.109	5.00×10^{-3}
T14	900	Moderate/High	13.6	17.3	0.167	3.23×10^{-3}
T16	7,800	Moderate	10.6	19.5	0.062	2.34×10^{-4}
T22	4,500	Moderate/High	6.2	9.33	0.295	5.44×10^{-4}
Group 3 - Standard Length With Significant Precipitation Reported						
T08	1,500	Low	19.6	6.69	0.082	2.37×10^{-4}
T09	17,500	Moderate/High	12.9	65.92	0.17	1.05×10^{-4}
T10	20,000	Moderate/High	13.9	171	0.116	8.76×10^{-4}
T11	6,800	Moderate/High	4.7	6.57	0.163	5.00×10^{-3}
T23	1,650	Low	8.2	6.86	0.11	2.31×10^{-4}
Group 4 - Longer Term Tests						
T02A	1,500	Low	13.1	5.22	0.023	2.16×10^{-4}
T13	13	Moderate/High	3.6	6.76	0.112	1.61×10^{-4}

APPENDIX B
FIGURES



Stantec

CLIENT LOGO - MUST NOT EXTEND BEYOND THE LEFT & RIGHT EDGES OF THIS BOX

AGRIMIN WA TENEMENTS

AGRIMIN NT TENEMENTS

Trench Locations

0 8,700 17,400 metres

(At original document size of 11x17)
1:459,097

Notes

1. Coordinate System: WGS 1984 Web Mercator Auxiliary Sphere
2. Data Sources:
3. Background: Content may not reflect National Geographic's current map policy. Sources: National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, increment P Corp.

Project Location
T11N, R12E, S05
T. of Dane, Dane Co., WI

Prepared by SKB on 2019-06-17
TR by SO on 2019-06-17

Client/Project
Client: Agrimin
Project: Lake Mackay
Report

Figure No.
2-1 **DRAFT**

Title
Trench Test Program Locations

Revised: 2019-07-18 By: mreinke

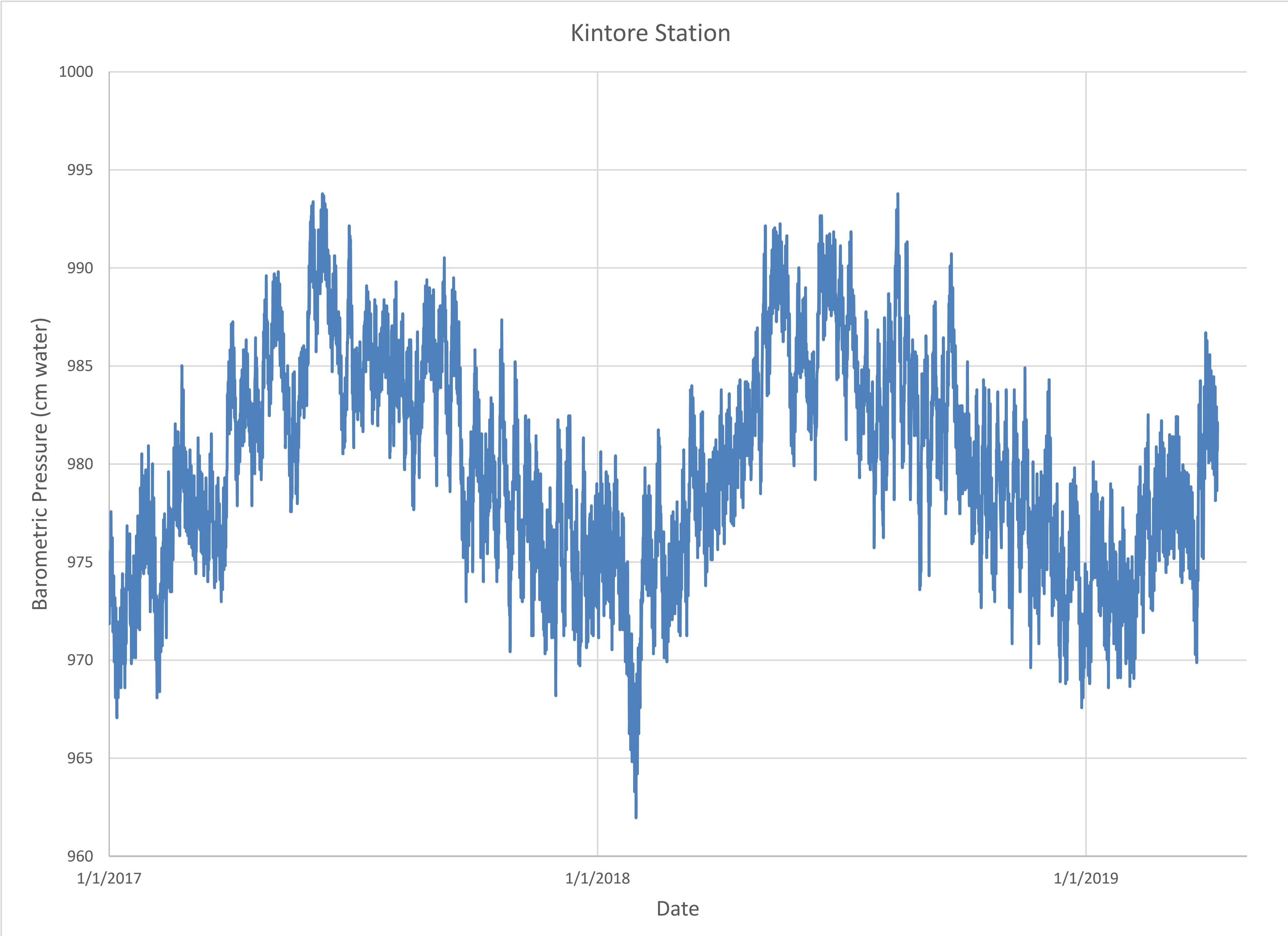


Figure 3-1. Barometric Pressure at Kintore Station

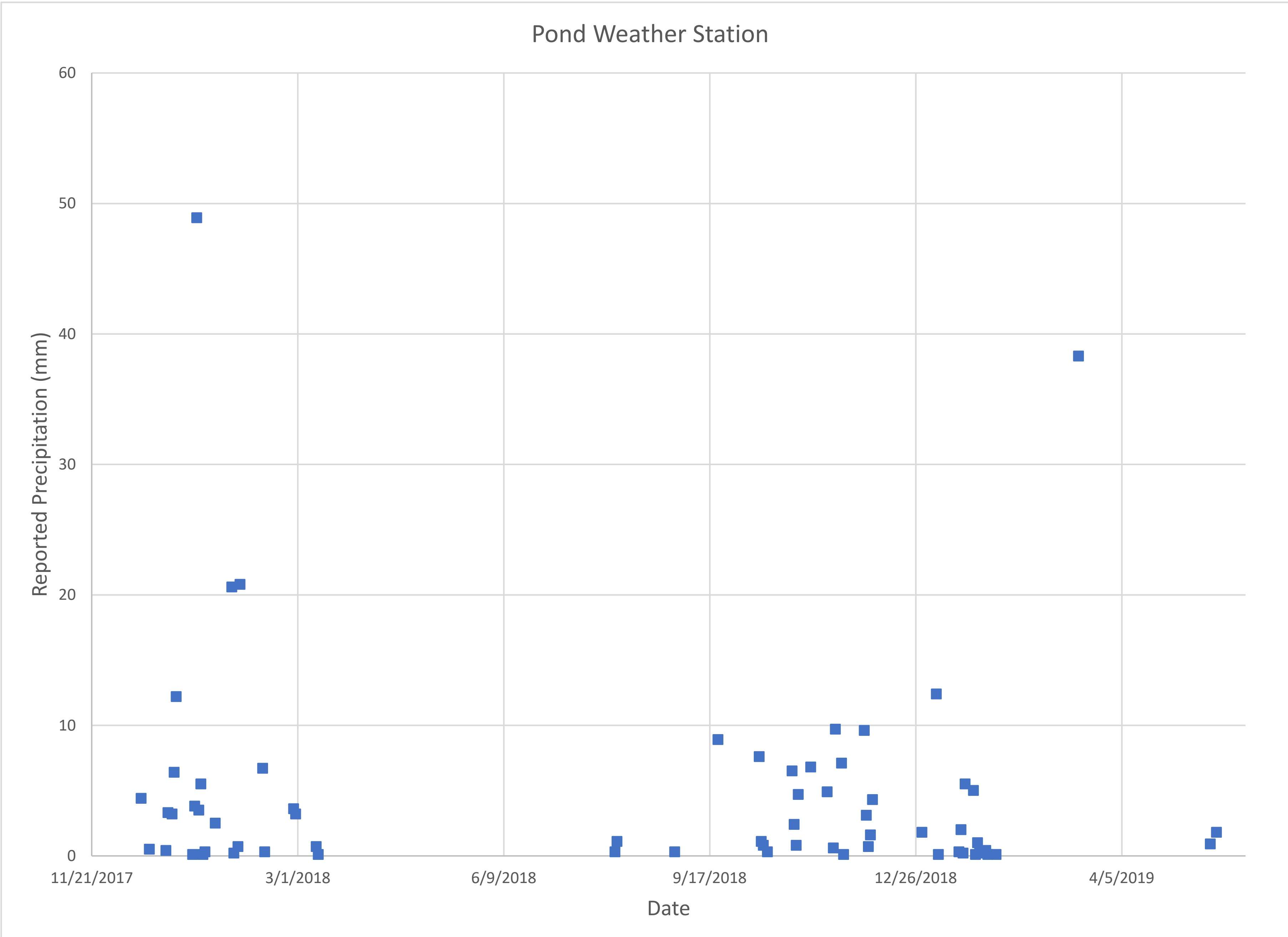


Figure 3-2. Pond Weather Station Precipitation Events

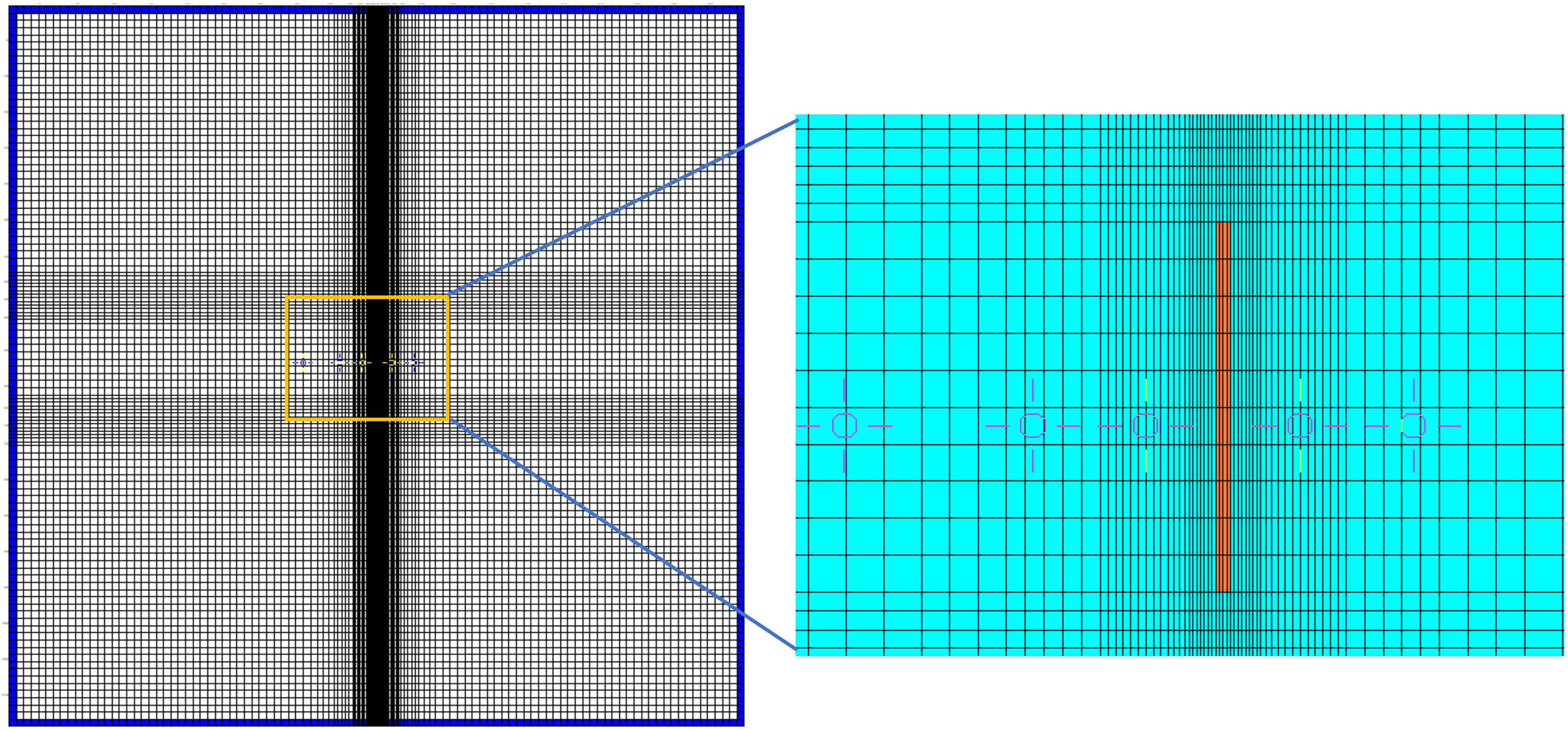


Figure 4-1. Model Grid and Trench Layout

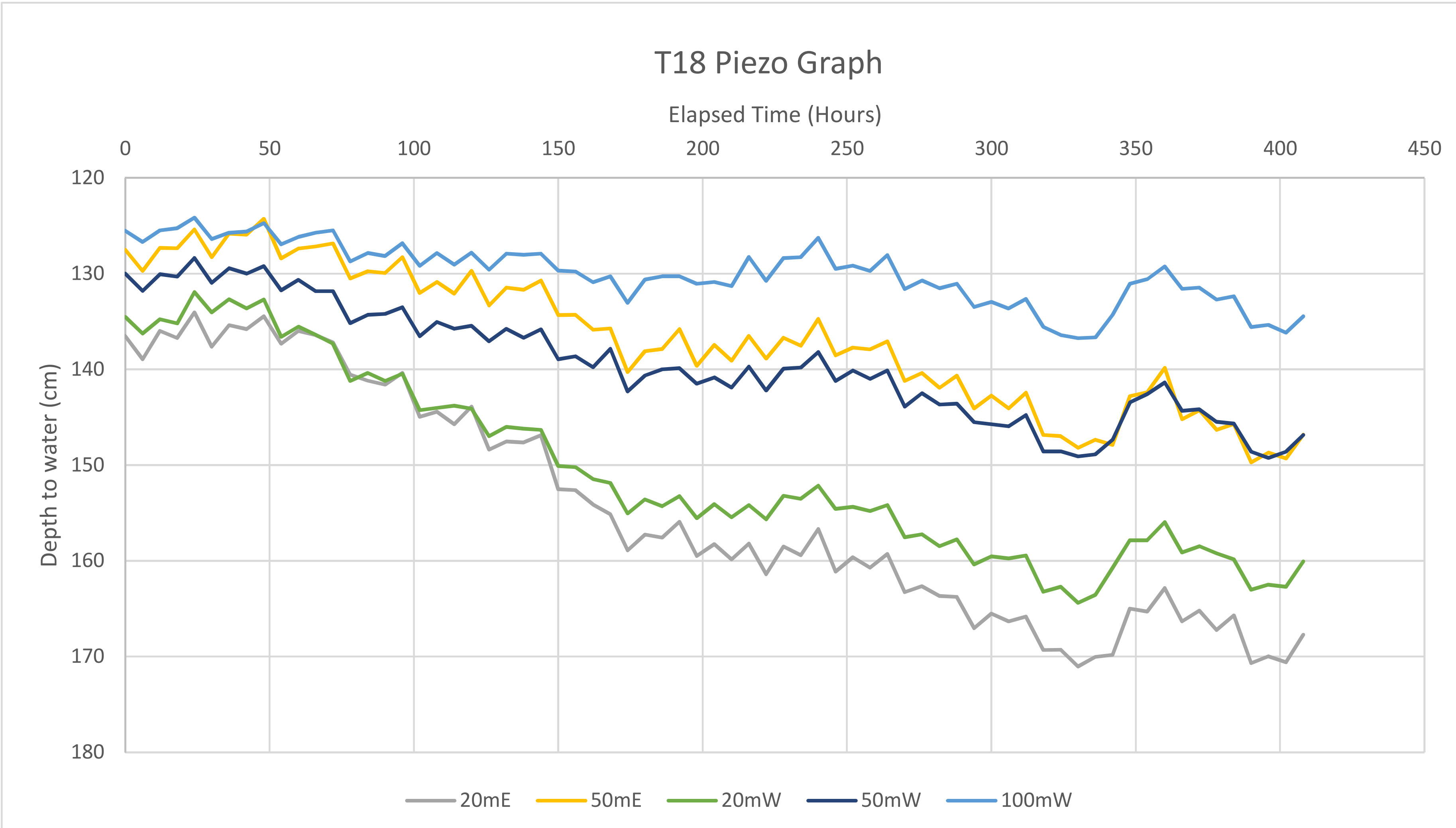


Figure 4-2. Monitoring Data Without Barometric Adjustment

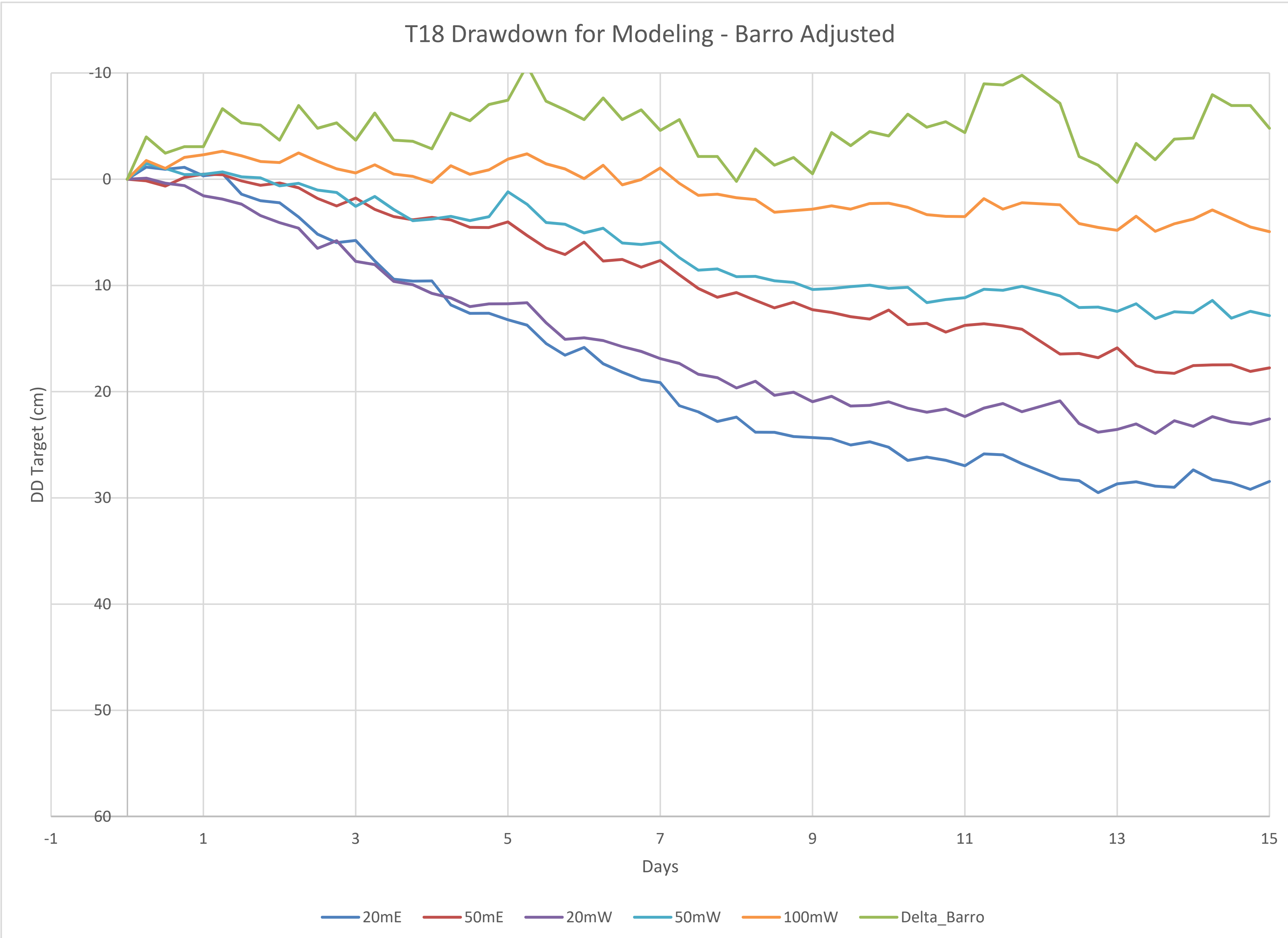


Figure 4-3. Monitoring Data With Barometric Adjustment

ATTACHMENTS

All attachments are being transmitted as separate electronic files.