Teck Alaska, Inc. - Red Dog Mine
4th Quarter & 2018 Annual Report
Waste Management Permit No. 2016DB0002
Reclamation Plan Approval F20169958

February 28th, 2019

Teck

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Introduction

This report has been prepared to fulfill the 4th quarter and annual reporting requirements of Teck Alaska Incorporated's (TAK) obligations under the State of Alaska Waste Management Permit No. 2016DB0002 and the Red Dog Mine Reclamation Plan Approval F20169958.

This report addresses mine water management, biomonitoring, waste rock management, tailings management, permafrost and groundwater monitoring, water load balance, Class III waste landfill, mining and milling activities, reclamation activities, land disturbance and wildlife interactions for the reporting period.

Biomonitoring Program

Annual Biomonitoring Report

The annual biomonitoring report will be submitted with the 2019 2nd quarter report. The report when completed will be listed as Appendix A within this report.

Annual Summary of Biomonitoring Water Quality Sampling

Analytical results of samples collected for biomonitoring water quality for the last five years are attached with the electronic file, *Red Dog Analytical Data 2018.xlsx*. Sampling concluded the last week of September, one week after discharge ended for the year.

Permafrost and Sub-permafrost Groundwater Monitoring

Permafrost and Subsurface Temperature Monitoring

Piezometer and thermistor measurements were completed for the 4th quarter, no issues noted.
The 2018 annual Long-Term Permafrost and Groundwater Monitoring Report is included with this report under Appendix B.

Significant activities in Permafrost and Sub-permafrost Groundwater Monitoring

A new piezometer and digital thermistor well was scheduled to be completed during the fall of 2018, due to complications related to the drilling contractor well construction was postponed. The EPA Region 10 was notified of the delay, it is anticipated the new well will be completed by this summer. No changes to the previously approved work plan are anticipated at this time.

The new well will be constructed in the same vicinity as piezometer well P-96-013 (located on the Kivalina Overburden stockpile). P-96-013 will remain active and continue to be monitored and results compared to the new well once it is completed. The new well will include both a shallow and deep piezometers along with a digital thermistor string which will be used to correlate any temperature differences with thermistor T-96-013 (next to P96-013) which utilizes an older type analog thermistor string.

Mine Water Management

Mine water flows

Table 1 lists mine water volumes transferred from mine areas during the reporting period. The table also includes a summation of volumes transferred for the report year. All flow monitoring stations operated normally with no problems noted for the period.

Table 1 - Water Management Volumes

	Volume in Gallons			
Mine Water Monitoring Stations	October	November	December	2018 Total
Bon's Creek Total Flow	9,197,000	7,281,000	10,100,000	168,588,000
Mine Water Sump Total Flow[1]	45,010,000	37,410,000	16,850,000	574,860,000
Main Dam Seepage Pumpback	20,250,000	18,150,000	17,670,000	273,890,000
Reclaim Flow to Mill	261,500,000	225,800,000	268,400,000	3,237,500,000
WTP #1 Influent from Reclaim	0	0	0	0
WTP #1 Influent from Mine Sump	0	0	0	282,681,994
WTP #1 Clarifier Sludge To Tails	0	0	0	0
WTP #2 Influent from Reclaim	9,567	2,526	1,824	2,010,413,917
WTP #2 Sludge To Tails	0	0	0	71,031,169
Discharge to Red Dog Creek	0	0	0	1,402,650,000
WTP #3 Influent from MWD	2,574,000	2,335,000	2,426,000	58,789,000
WTP #3 Influent from Mine Sump	0	0	0	60,423,000
WTP #3 Total Effluent	2,574,000	2,335,000	0	119,212,000
East Overburden Sump	214,900	31,800	85,600	10,381,800
West Overburden Sump	2,200	0	400	12,199,800
Main Waste ARD to Main Pit	0	0	0	436,317
Treated Water to Main Pit	0	0	0	0
Tailings Water Supernatant (calc.)	390,100,000	207,210,000	307,458,000	2,980,000,000
Mill Pad Runoff	161,646	2494	87	1,335,894

Notes: [1] Includes Main Pit water pumped back to Tailings Storage Facility

Mine water quality

A Mine water spreadsheet *Red Dog Analytical Data 2018.xlsx* is attached with this report which includes data for the last five years. The spreadsheet includes all data used to generate the charts data for Appendixes C, D, E and F within this report.

Mine Water Quality Trend Charts

Mine water quality trend charts are provided in Appendixes C, D, E, and F of this report. Water quality Profile I and II (*"Monitoring Plan, Jan 2018")* constituents for the Mine Water, Mine Drainage, Bons Creek and APDES stations are illustrated for a five year period ending with the 4th quarter. Only the Mine Water Quality charts (Profile II) were sampled during the 4th quarter since the discharge season ended on September 22nd, 2018. No significant trends were noted for the Mine Water 4th quarter monitoring results.

The Kaviqsaaq "seep" area upstream of station 145 will be investigated during 2019. Teck is in the process of obtaining a consultant (most likely Golder Associates Inc.) to evaluate the area and determine the source. The consultant's report is expected to be completed by the end of the 2nd quarter. A copy of the report will be submitted to appropriate agencies once it is complete.

Visual Monitoring of Mine Water Management Systems

Red Dog diversion ditches, seepage collection and treated water discharge lines were monitored during the quarter. All mine water management systems operated without incident during the reporting period.

Fish weir inspections

The fish weir was inspected on October 16th, 2018, no major issues were identified. The system is operating as designed. A written report was submitted to US EPA Region 10 on October 17th, 2018.

Figure 1 - Photo of Fish Weir

Fish weir: Looking west across east abutment and weir notch

Water and Load Balance

A mine water balance computer simulation program is maintained using GoldSim software. Viewing the model requires the GoldSim version 11.1 player software. An updated data file spreadsheet *RedDog_GoldSimModel_Input_Database.xlsx* is included with this report. No changes were made to the model during the 2018 year. As mentioned in previous quarterly reports a new model has been developed though is still being reviewed and not yet released. It is anticipated the new model will be released during the 2019 year, an electronic copy will provided to agencies when completed.

A Total Dissolved Solids (TDS) load balance spreadsheet is provided for major mine water areas and the Tailings Storage Facility. The load balance model results are listed in Appendix G of this report. The TDS load balance spreadsheet depicts a 5,100 tonnes reduction of TDS load in the Tailings Storage Facility for the 2018 year when compared to the previous year. Continuous year round wastewater treatment and a successful discharge season attributed to this reduction. The Tailings Storage Facility contained an estimated 3.446 billion gallons of free water (end of 2018) compared to 3.718 billion gallons for the previous year.

Approximately 574 million gallons was pumped from the Main Pit and Red Dog Creek Pumpback water to the Tailings Storage Facility during 2018. The Main Pit and Red Dog Creek Diversion water transferred to the Tailings Storage Facility accounted for the majority of TDS loading to the Tailings Storage Facility during 2018.

The Acid Rock Drainage (ARD) water collection system treated approximately 59 million gallons for 2018. The volume was less compared to previous years due mainly to an ARD collection sump being decommissioned during 2017. A new design to replace the decommissioned collection sump was reviewed and approved during 2018. Construction of the new sump is expected be commence during 2019 with the sump becoming operational the same year. An estimated 11,600 tonnes of TDS was removed from ARD water treated during the 2018 year.

Significant reagents consumed for wastewater treatment during 2018:

- Total quantity of flocculant used in Waste Treatment Plant 2 (WTP2) and WTP1 was 109.2 metric tonnes, the majority being used in WTP2
- Total quantity of lime used in WTP2 is not tracked individually, though the total lime used in WTP1, WTP2 and WTP3 was 13,191 metric dry tonnes
- Total quantity of sodium sulfide used in WPT1 and WTP2 was 289.8metric tonnes, utilized to precipitate cadmium
- Total quantity of flocculants used in WTP3; - none
- Quantity of any other chemicals used in significant quantities in WTP2; - Gypsum 3,946.3 metric tonnes

Significant activities in mine water management

The Main Waste Dump synthetic cover pilot test construction was monitored for movement and moisture infiltration during 2018. Meteoric water is not infiltrating below the liner and that the cover is functioning as designed. Survey monument monitoring was conducted during 2018 and will continue for the 2019 year. A copy of the entire report is included in Appendix H of this report.

Figure 2 - Photos of MWD Synthetic Cover Project

Photo 1 – Geosynthetic test, aerial southern end of MWD looking NW.

Photo 2 – Geosynthetic test, aerial looking south over the MWD

Waste Rock Management

Quantities, placement locations and analysis of waste rock

Results of waste rock geochemical monitoring

Other than blast hole analyses, no additional geochemical monitoring was conducted on waste rock during the reporting period. Geochemical blast hole monitoring results are included within the Waste Rock Production Summary report listed in Appendix I of this report.

Visual monitoring of waste rock facilities

Weekly waste dump inspections were conducted on both inactive and active waste rock dumps with no adverse findings noted. Dig face inspections were carried out on waste shots to confirm waste characteristics and suitability for designated stockpile locations. All waste material was placed in suitable waste storage stockpiles.

The primary waste dump areas utilized for the 4th quarter have been the Main Pit Dump (MPD4 and MPD5), Oxide / Main Waste Dump, Copper Waste Dump, Landfill, Cover, MWD, Kivalina Overburden and Oxide Ore Stockpile). A total of 774,324 tonnes of waste rock were hauled from Aqqaluk pit and a total of 559,720 tonnes of waste rock were hauled from Qanaiyaq pit.

Main Pit Dump Area

For the fourth quarter of 2018 a total of 510,728 tonnes of waste were hauled to the Main Pit Stockpile Area.

- 96,923 tonnes of Ikalukrok, Siksikpuk “Other Waste” were hauled to MPD4.
- 7,525 tonnes of Ikalukrok and Siksikpuk “Most Reactive Waste” were hauled to MPD4.
- 230,876 tonnes of Ikalukrok, Otuk, Siksikpuk, Kivalina “Other Waste” were hauled to MPD5.
- 175,404 tonnes of Ikalukrok and Siksikpuk “Most Reactive Waste” were hauled to MPD5.

Main Waste Dump Area

For the fourth quarter of 2018 a total of 350,940 tonnes were hauled to the Main Waste Stockpile Area.

- 3,327 tonnes of Ikalukrok “most reactive waste” were hauled to the landfill.
- 257,939 tonnes of Ikalukrok, Siksikpuk and Mixed “Other Waste” were hauled to the Main Waste Dump (MWD).
- 89,674 tonnes of Ikalukrok “Most Reactive Waste” were hauled to the Main Waste Dump

Copper Waste Dump

- 26,090 tonnes of Ikalukrok “Most Reactive Waste” were hauled to the Copper stockpile dump

Oxide Ore Stockpile

- 111,269 tonnes of Ikalukrok “Most Reactive Waste” were hauled to the Oxide Ore Stockpile

Construction Material

- 518 tonnes of Siksikpuk “Most Reactive Waste” were hauled to the Crusher Pad to patch the bench.

Kivalina Overburden

- 53,742 tonnes of topsoil were hauled to the Kivalina Overburden Area topsoil stockpile location on the west end of the dump.

Cover Material at Main Waste Dump

- 280,757 tonnes of Cover Material were hauled to the Cover Dump (COV). Appendix J includes a more detailed report for the 4th quarter reporting period. Table 2 lists amount of cover material stockpiled onsite.

Table 2 - Cover Material Amount

	Tonnes Hauled per Month			Total Tonnes Report Period	Tonnes Stockpiled
Cover Stockpile Location	Oct	Nov	Dec		
Ramp to Nowhere (RNC)	74,758	91,590	114,409	280757	1,671,382
Oxide 2 Cover Dump (OX2)	0	0	0	0	39,694
Oxide Cover Dump (OCD)	0	0	0	0	27,880
North Oxide (NOX)	0	0	0	0	553,245
South Oxide Top Soil (SOT)	0	0	0	0	81,094
				0	2,373,295

Significant activities in waste rock management

No significant activities reported for the 4th quarter. Test pits were dug for the Main Waste Dump extension to gather geotechnical data and samples. Golder Associates Inc. is currently working on a dump design for the extension, this is expected to be completed by the end of April 2019.

Teck

Red Dog Operations
Waste Rock, Stockpile and New Construction
Site Map
Aerial acquired Sept 2018

Red Dog Mine

Figure 3

file location
G:\Enviro\SRCE\waste rock dumps.mxd

Drawn: FEB

Date: 12/18/18

Quantities and analysis of tailings

Table 3 depicts the dry tonnes of tailings generated and the average lead, zinc and iron concentrations in the tailings solids for the 4th quarter and summation and average concentrations for the 2018 report year.

Table 3 - Tailings Generated

		Analysis		
Month	Dry Tonnes Tailings	% Pb	% Zn	% Fe
Oct	409,911	2.0	3.0	5.6
Nov	224,459	2.1	2.6	5.2
Dec	322,281	1.9	2.8	5.3
Annual sum/avg.	3,184,544	2.1	2.8	5.8

Tailings Storage Facility and Main Pit Dump water elevation

Table 4 depicts the surveyed Tailings Storage Facility and Main Pit water levels during the reporting period. The current dam permits allow for a crest elevation of 986 feet amsl or 981 amsl freeboard. The Tailings Storage Facility water level for the 4th quarter was maintained below the freeboard limit. The Main Pit Dump was maintained below an elevation of 850 feet amsl.

Table 4 - Tailings Storage Facility and Main Pit Water Elevations

Tailings Storage Facility Elevation			Main Pit Dump		
Date	Elevation	Comment	Date	Elevation	Comment
10/3/2018	972.88	Weekly H2O	10/3/2018	837.70	Weekly H2O
10/16/2018	973.15		10/16/2018	836.87	lake
10/25/2018	973.15	weekly h2o	10/24/2018	837.90	Lake
11/3/2018	973.41	Weekly H2O	11/3/2018	837.08	Lake
11/17/2018	973.80	Top of ICE	11/17/2018	838.18	Lake
11/23/2018	973.62	Top of ICE	11/23/2018	837.80	Lake Top of ICE
11/28/2018	973.98	Top of ICE	11/28/2018	837.99	Lake Top of ICE
12/6/2018	974.10	Top of ICE	12/6/2018	836.91	Lake Top of ICE
12/12/2018	974.12	Top of ICE	12/12/2018	836.83	Lake Top of ICE
12/17/2018	974.17	H2O by barge	12/17/2018	836.68	Lake Top of Ice
12/28/2018	974.45	H2O near barges	12/28/2018	836.70	Lake Top of ICE

Visual monitoring of tailings facilities

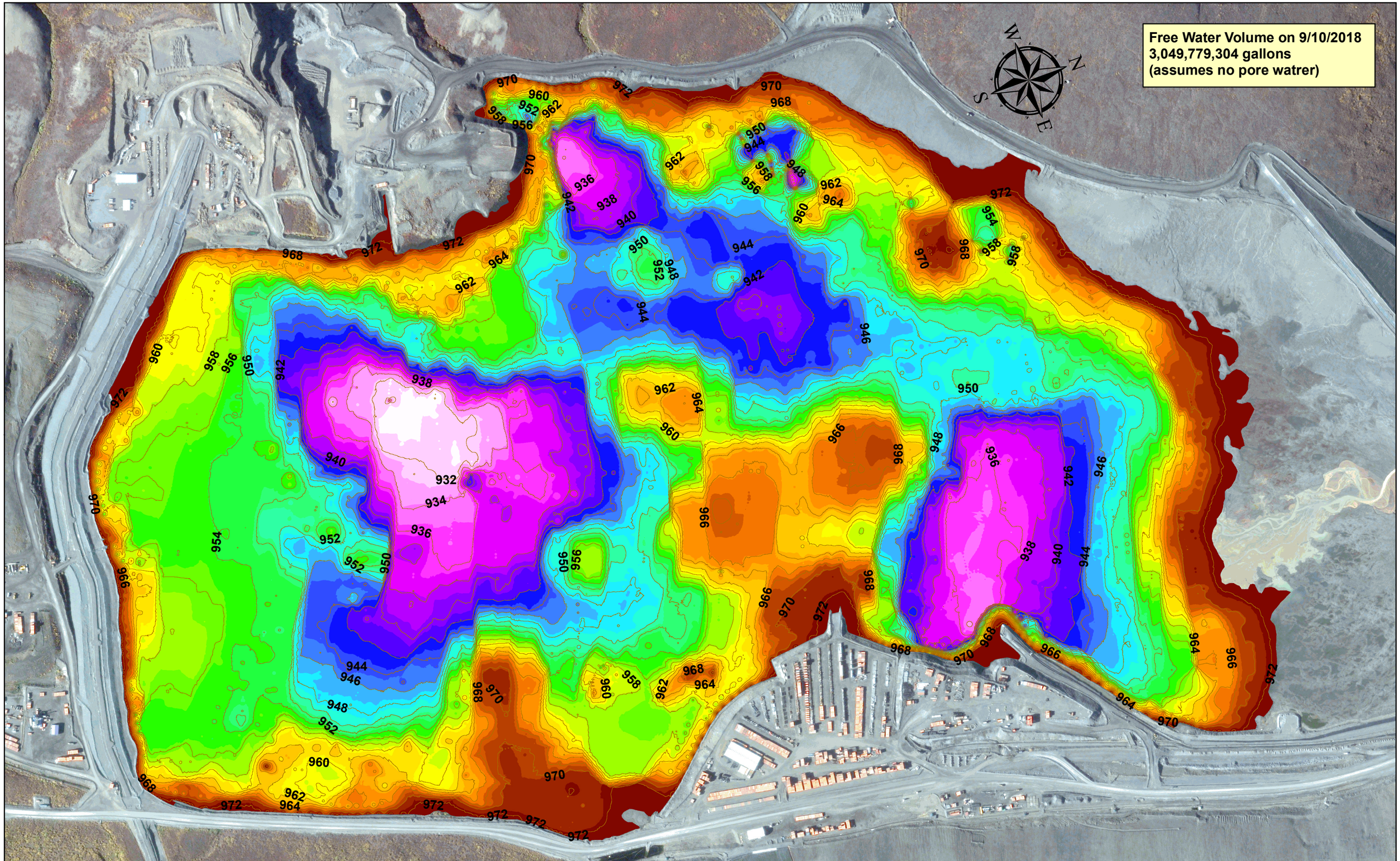
Visual monitoring inspections of the tailings storage facilities were completed during the 4th quarter. All systems operated as designed with no findings. Eight daily dam inspections could not be located for the 4th quarter, it is not known if these were not completed possibly due to weather conditions or

other factors. The daily dam hardcopy inspection forms recently transitioned to an electronic “I-pad” tablet using “i-auditor software” which will allow for quicker data access and easier review of completed inspections by supervisors.

Significant activities in tailings management

Tailings were deposited in several areas of the Tailings Storage Facility during the 4th quarter, mainly along the west and northwest portions of the Tailings Storage Facility.

Bathymetry surveys were completed on September 9th and 10th, 2018 for the Tailings Storage Facility and the Main Pit. A bathymetry map for each area was generated and depicted in Figures 4 and 5.



Teck

Red Dog Mine

1 inch = 500 feet

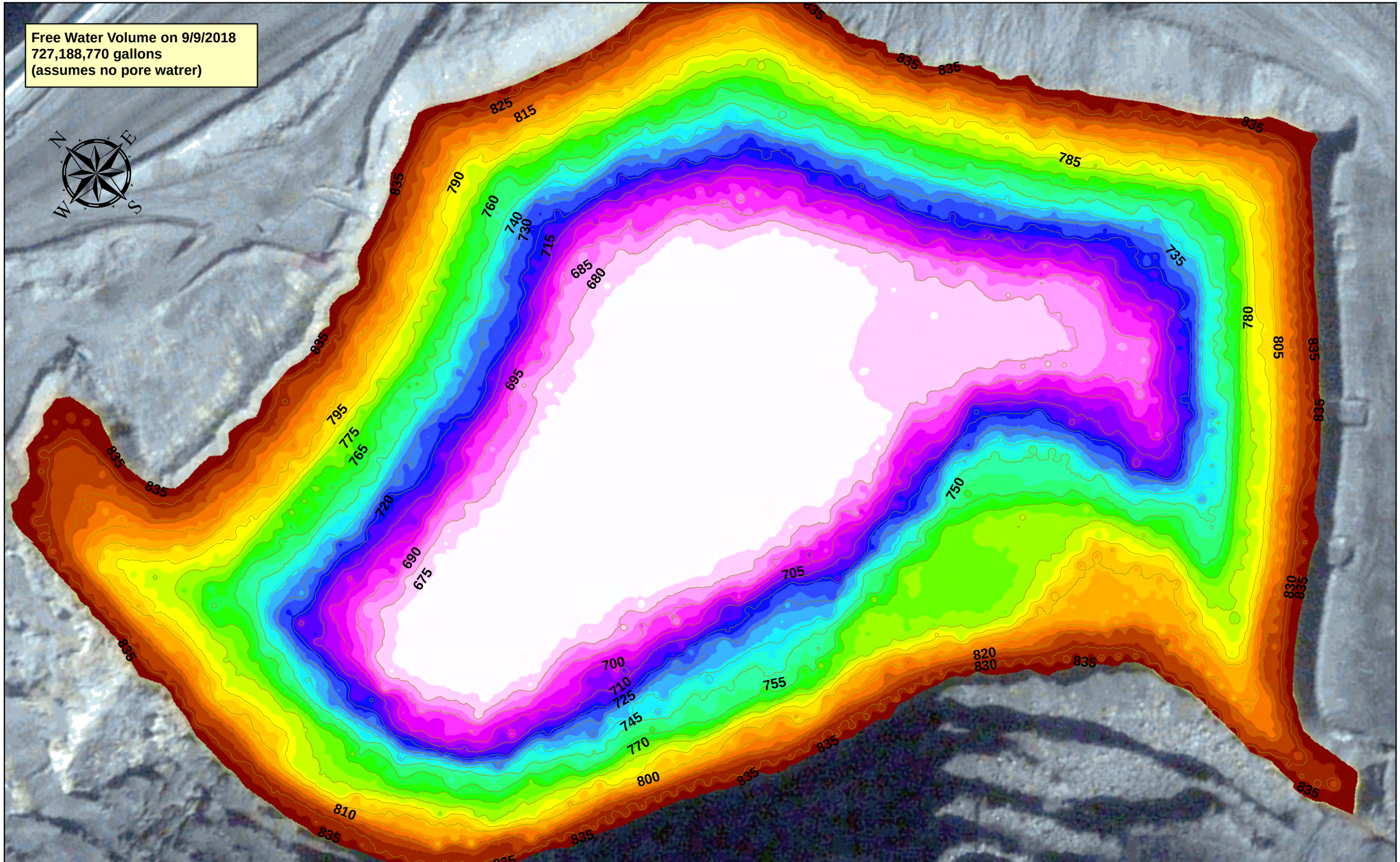
0 250 500 1,000 1,500 2,000 Feet

Coordinate System: NAD 1927 StatePlane Alaska 7 FIPS 5007
Projection: Transverse Mercator
Datum: North American 1927

Satellite Image acquired Sept 14th, 2018
Survey data Sept 9, 2018

Figure 4

Title: 2018 TSF Bathymetry Map
Drawn: FEB, 12/8/2018



Teck

1 inch = 100 feet

0 50 100 200 300 400 Feet

Coordinate System: NAD 1927 StatePlane Alaska 7 FIPS 5007
Projection: Transverse Mercator
Datum: North American 1927

Satellite Image acquired Sept 14th, 2018
Survey data Sept 9, 2018

Figure 5

Title: 2018 Main Pit Bathymetry Map
Drawn: FEB, 12/8/2018

Class III Municipal Solid Waste Landfill

Visual inspections were conducted at the landfill and random inspections conducted on bins of refuse waste prior to being hauled to the landfill. No incidents were reported during the 4th quarter.

The annual mine incinerator composite (3-week) ash sample was collected on September 9th and analyzed for metals using EPA 1311 Toxicity Characteristics Leaching Procedure (TCLP), 6010C, 7470A and ASTM D2974 methods. The results were all below RCRA levels, a copy of the analytical lab report was submitted to Neil Lehner with ADEC – Fairbanks office on November 11th, 2018.

Quantities of inert solid waste for the reporting year

The Red Dog survey department performed a LiDAR scan of the landfill on 9 September 2018 and calculated a total volume of 29,391 cubic yards (12,165 cubic yards of waste rock used as cover) placed for the period from September 2017 through to September 2018. Approximately 17,226 cubic yards of refuse was placed in the landfill during the 2018 year.

Significant activities in solid waste landfill and waste management

Red Dog Operations implemented many improvements to the recycling program for the 2018 year, some are listed below. Opportunities to enhance recyclables will continue into 2019.

- Approximately 70 small 40 gallon trash can collection points were added to the mine and port facilities to collect and recycle plastic and aluminum cans.
- 38 scrap metal bins (40 cubic yards) were acquired to improve the collection and recycling of scrap metals generated from the mine and port facilities.
- 3 cardboard hydraulic balers were purchased to improve upon cardboard recycling throughout the facility. Compacted cardboard bales are being shipped offsite for recycling.
- A pallet wood grinder is being reviewed which would generate a mulch type product to be used for reclamation. This could potentially eliminate approximately 85% of the landfill volume.

Landfill Use Plan

For the 2019 year, refuse will continue to be placed within the northern end of the lower cell. This is expected to continue until later 2019 the lower cell is expected to become full, a new lift begin on the southern end if required. Figure 5 - 2019 Landfill Use Plan Map depicts the areas of use for 2019.

Figure 6 - 2019 Landfill Use Plan Map

Mining and Milling Activities

Mining quantities

Table 5 lists the tonnes of ore hauled to the mill stockpile each month during the reporting period and also provides a total amount produced for the 2018 year. This does not include marginal ore which was placed within the Marginal Ore Stockpile.

Table 5 - Ore Mined

Date	Ore Mined, tonnes
Oct	386,322
Nov	318,753
Dec	407,056
Annual	**4,471,406**

Milling Quantities

Table 6 lists the tonnes of ore processed through the mill facilities each month during the reporting period.

Table 6 - Ore Processed through Mill

Date	Ore Milled, tonnes
Oct	561,729
Nov	297,948
Dec	435,575
Annual	**4,428,535**

Significant activities in mining and milling

There were no significant activities in mining and milling during the quarter.

Reclamation

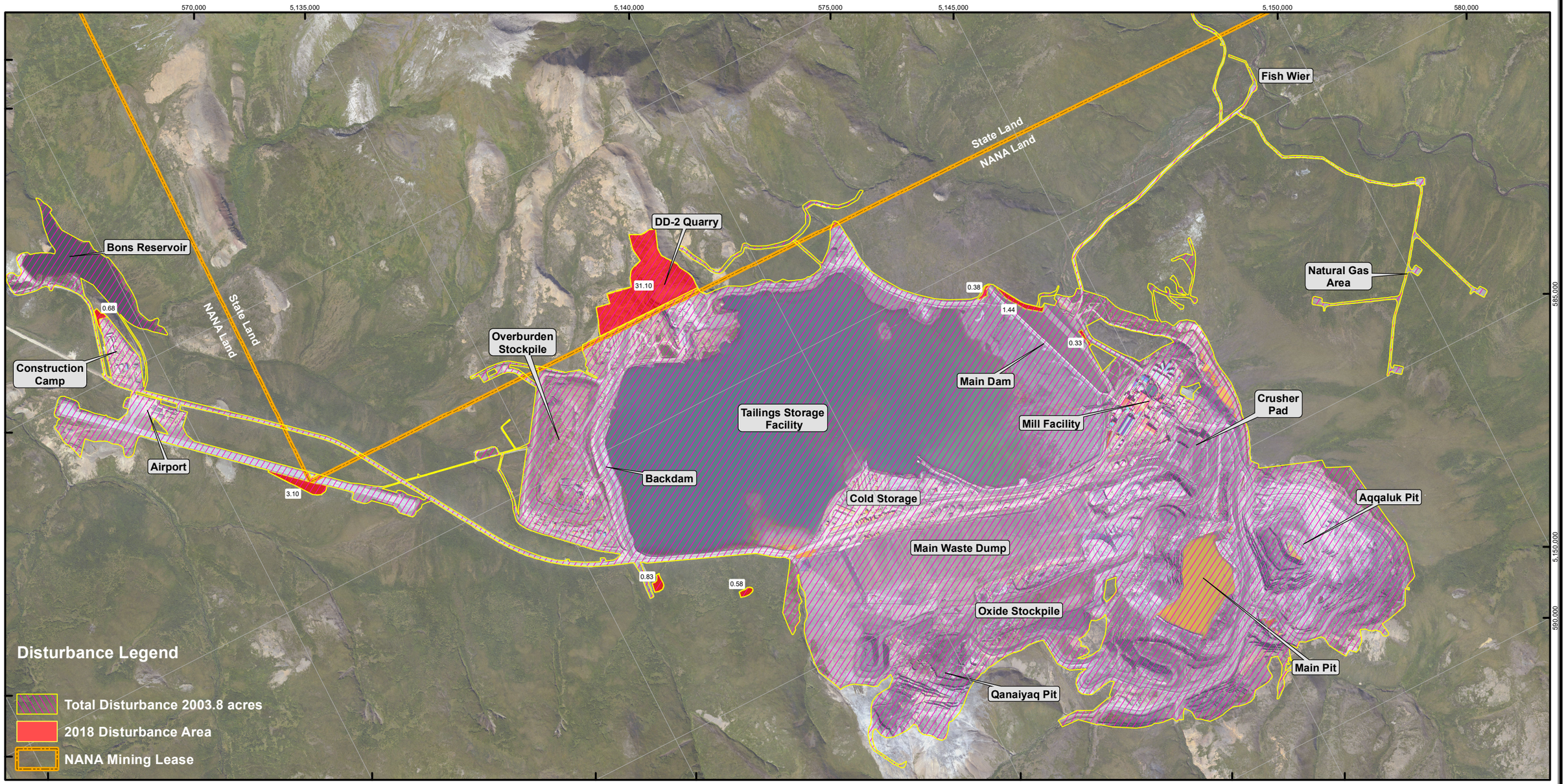
Reclamation Activities

Area Disturbed and Reclaimed

A map of new land disturbance for the mine site is shown in Figure 4 – Red Dog Operations 2018 Land Disturbance Map. Table 7 list new disturbed acreage for 2018. No areas were reclaimed during the reporting period. Top soil recovered from newly disturbed areas was stockpiled for future use.

Table 7 - Area Disturbed in 2018

2018 New Disturbance Area	Acres
DD2 quarry pit and access road	31.1
MWD extension test geo pits	1.4
Airport stripping	3.1
Tent camp clearing	0.7
Main dam clearing	2.2



2018 Land Disturbance	Acres
DD2 Quarry Site (State Land only)	31.1
Airport, SE of runway	3.1
Wetlands (2 areas), S of MWD Extension	1.4
Construction Camp W Pad Extension	0.7
Main Dam Roads	2.2
Total 2018 Land Disturbance (State + NANA)	38.5
Total 2018 NANA Land Disturbance	7.4

Teck

Red Dog Operatons
2018 Land Disturbance Map
Aerial acquired September 2018

Red Dog Mine

0 425 850 1,700 2,550 3,400 Feet
1 inch = 1,700 feet

Figure 7

file location
Y:\Minetech\Inter\MAPS\Land_Use\Drawings\disturbance\2018 Disturbance.mxd

Drawn: FEB,CLR

Date: 01/12/19

Reclamation Research

In 2017, Teck, NANA, and the Alaska Plant Materials Center (PMC) collaborated to develop and install revegetation test plots ("test plots") on the geomembrane pilot study area to evaluate revegetation success on the cover rock. The purpose of the study was to:

- Evaluate the success of a various grass and forb seed mixtures, fertilizer, and various mulch additions
- Evaluate the success of several locally harvested, locally adapted seed species
- Develop a revegetation strategy to apply to the entire Main Waste Dump that incorporates locally harvested arctic-adapted forbs.

The report documents the construction of the test plots in 2017 and the growth observed though 2018. The complete report is located in Appendix K: Main Waste Dump Revegetation Test Plots.

Reclamation Monitoring

No monitoring was completed for the reporting year.

Significant reclamation activities

No reclamation activities took place during the 2018 reporting year.

Dust

Dust monitoring activities

The 2018 Risk Management Plan Annual Report is not completed. The report should be finalized and submitted by the end of the 2nd quarter and submitted as Appendix L in this report.

Wildlife

Wildlife interactions

No wildlife interactions occurred during this 4th quarter reporting period.

Financial Assurance

TAK increased the reclamation bond for Reclamation Plan Approval (F20169958) by $6,472,393 to account for inflation based on the Anchorage Consumer price Index (CPI). The total bond amount is $569,289,193. The adequacy of the bond is sufficient for current operations and conditions.

2021 Renewal of the Waste Management Permit (WMP) and the Reclamation and Closure Plan (RCP)

Red Dog Mine will begin reviewing other closure options for significant changes to the Reclamation Closure Plan prior to the September 2021 renewal of the WMP and RCP. Closure options which will be reviewed include a dry cover for the Tailings Storage Facility and a synthetic cover over the Main Waste Dump.

2019 Mine Plan

No significant changes are planned for 2019, Qanniyaq pit will continue to be mined during 2019. A 2019 Mine Plan is included with the annual report and listed within Appendix M. References to grades and pricing have been redacted from the plan.

Closing

Please accept this report as required under the State of Alaska Waste Management Permit No. 2016DB0002 and Reclamation Plan Approval F20169958. If there are any questions, please contact Frank Bendrick at (907) 754-5138 or myself at (907) 754-5127.

Based on information and belief formed after reasonable inquiry, I certify that the statements and information in and attached to this document are true, accurate and complete.

Sincerely,
Teck Alaska Incorporated

for LY 2/28/2019

Les Yesnik
General Manager

cc:

Tim Pilon, ADEC, Fairbanks;
Marty Lentz, ADNR, Anchorage
Brent Martellaro, ADNR, Fairbanks
Mike Gonzales, Red Dog Mine
Lance Miller, NANA
DNR Water Reports
Jim Vohden, ADNR
Audra Brase, ADF&G, Fairbanks

Appendix A: Biomonitoring Report (pending 2nd quarter)

Appendix B: Long-Term Permafrost and Groundwater Monitoring Program for the Tailing Impoundment

Red Dog Mine
Long-Term Permafrost and Groundwater Monitoring Program for the Tailing Impoundment
2018 Annual Report

March 2019

Submitted to:
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Anchorage, Alaska 99517

Submitted by:
Kuna Engineering, LLC
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Appendix B Thermistor Plots

Appendix C Piezometer Plots

Appendix D Quality Control/ Quality Assurance

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Introduction

The Long-term Permafrost and Groundwater Monitoring Program (the Monitoring Program) was established as an outcome of the Supplemental Environmental Project (SEP) and the Consent Decree between Cominco Alaska, Inc. (now Teck Alaska Incorporated) and the United States Environmental Protection Agency (EPA), entered on November 25, 1997 (US v. Cominco Alaska Incorporated, Civil Action A97-267CV). The Monitoring Program was developed to monitor and predict potential effects of the Tailings Impoundment on permafrost and groundwater in the areas of the tailings Main Dam, Overburden Stockpile, and background locations downgradient of the Tailings Impoundment within the Red Dog Creek and Bons Creek drainages. A specific contract deliverable is the submission of an annual report which includes a data collection summary, a quality assurance and quality control (QA/QC) summary, and a description of the status of the monitoring program.

A review of the data from 2018 did not show any significant changes or trends. Improved quality checks and maintenance are starting to show improvement in data acceptance rates.

Background

The Red Dog Mine is a lead-zinc mine located in northwestern Alaska approximately 50 miles northeast of Kotzebue, Alaska and 107 miles north of the Arctic Circle within the DeLong Mountains. The mine is owned by NANA Regional Corporation and operated by Teck Alaska (TAK). Figures 1 and 2 illustrate the regional setting and layout of the mine and its support facilities. As illustrated on Figure 2, the mine consists of two open pits and support facilities. The open pits are used for the extraction of zinc and lead bearing ore. The support facilities include an ore milling and a concentration facility, an employee housing area, a construction camp, an asphalt paved runway, a power generation facility, and a tailings area. There are approximately 300 acres of waste rock piles and a tailings pond behind two earthen dams. The pond receives drainage from the open pit areas, natural surface run-off, and process waters from the milling operation.

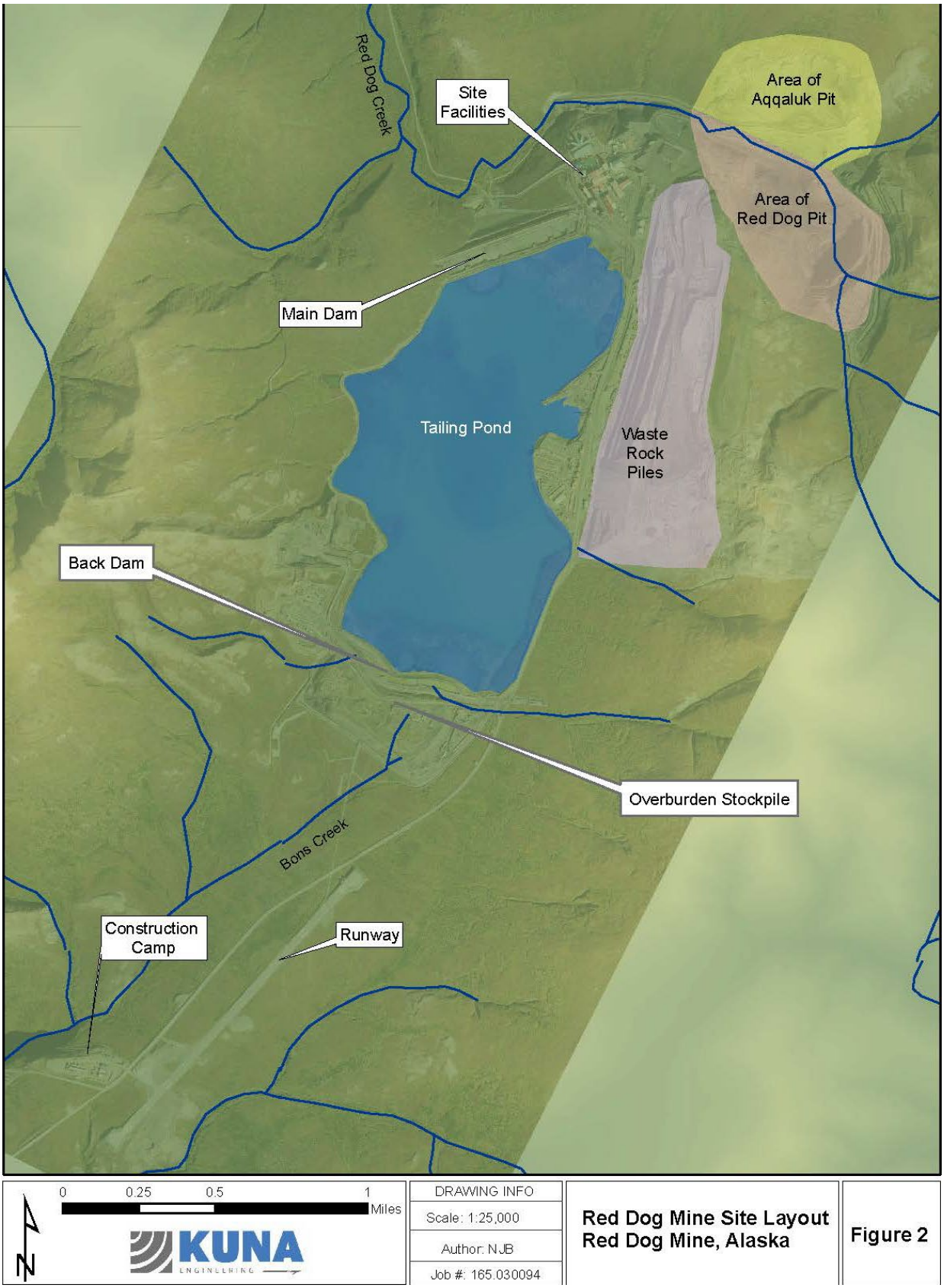
The tailings pond has the potential to affect both permafrost and groundwater in one or more adjacent drainages. To document this, a ground temperature/groundwater level monitoring program began in the mid-1990s as part of the Groundwater Monitoring Supplemental Environmental Project. Results from this project are documented in Water Management Consultants, Inc. (WMCI 2001) report and form the basis for the Long-Term Permafrost and Groundwater Monitoring Plan.

The key elements of the Monitoring Program are:

- The quarterly monitoring of sixteen thermistors at background sites, overburden stockpile, and main dam area;
- The quarterly monitoring of nine piezometers at background sites and main dam area;
- Data reduction, presentation, and management;
- Annual data reporting; and,
- Assessment of data trends on a five year basis.

Figure 1 Red Dog Mine and Vicinity

Figure 2 Red Dog Mine Site Layout



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2018 Data Collection

TAK emailed Kuna Engineering (Kuna), the raw 2018 readings from the project thermistors and piezometers for data reduction, presentation, and management. A table of all the raw data is presented in Appendix A.

Ground temperatures and water levels were monitored beneath the main dam and overburden stockpile for graphical comparison to the background sites.

Thermistor Data

Kuna plotted the ground temperature measurements collected from the 15 thermistor monitoring locations. The Red Dog Mine thermistor monitoring locations are illustrated on Figure 3 (northern portion), Figure 4 (central portion), and Figure 5 (southern portion).

The ground temperature monitoring data is depicted using two types of graphical plots which are presented in Appendix B, and summarized below:

- Temperature trumpet plot of data for all years (separate color for each year); and
- Temperature trumpet plot of data for 2018.

For each graphic plot, the measurements are presented as auto range and scale limited. The auto range plots represents all measurements which have passed the database QA/QC process described in the Data Management section of this report. For visual clarity, scale limited plots only include data within a limited range and excludes most outliers. Note the outliers are individual nodes that are likely caused by intermittent connections and therefore do not represent true changes in temperature at depth.

Table 1 Summary of the 2018 Quarterly Thermistor Data Collection

Thermistors	Associated Figure	General Location	Sampling Dates			
			1st Quarter	2nd Quarter	3rd Quarter	4th Quarter
T-96-015	Figure 3	Red Dog Creek	1/15/18	4/8/18	7/12/18	10/20/18
T-95-005	Figure 3	Dam Area	1/15/18	4/8/18	7/12/18 20 of 24	10/20/18
T-96-010	Figure 3	Dam Area	Error	4/8/18 2 of 24	7/12/18	10/20/18 2 of 24
T-97-028	Figure 3	Dam Area	Error	Error	7/12/18	10/20/2018 9 of 24
T-97-029	Figure 3	Dam Area	Error	4/8/18 7 of 24	7/12/18	10/20/18 4 of 24
T-97-030	Figure 3	Dam Area	Error	4/8/18 2 of 24	7/12/18	10/20/18 3 of 24
T-14-110	Figure 4	Tailing Impoundment	Error	4/8/18	7/12/18	10/20/18
T-95-004	Figure 4	Dam area	Error	Error	7/12/18 20 of 24	10/20/18 21 of 24
T-05-061	Figure 4	Dam area	Error	4/8/18	7/12/18	10/20/18
T-95-008 #2	Figure 5	Overburden Stockpile	1/17/18	Error	7/12/18	10/20/18
T-96-013	Figure 5	Overburden Stockpile	Error	4/8/18	7/12/18	10/20/18
T-96-021	Figure 5	Overburden Stockpile	Error	4/8/18	7/12/18	10/20/18
T-96-022	Figure 5	Overburden Stockpile	1/15/18	4/8/18 2 of 24	7/24/18 3 of 24	10/20/18 3 of 24
T-96-023	Figure 5	Overburden Stockpile	Error	4/8/18 7 of 24	7/12/18 8 of 24	10/20/18 8 of 24
T-96-012	Figure 5	Bons Creek	Error	4/8/18	7/12/18	10/20/18
T-96-012s	Figure 5	Bons Creek	Error	4/8/18	7/12/18 1 of 24	10/20/18

Note: Dates listed for date of collection, second line, if present, indicates number of nodes out of total number of nodes that were missing. For example first quarter thermistor T-96-010, two of twenty four nodes had no results reported.

Figure 3 Red Dog Mine Long-Term Thermistor and Piezometer Monitoring Locations (Northern portion)

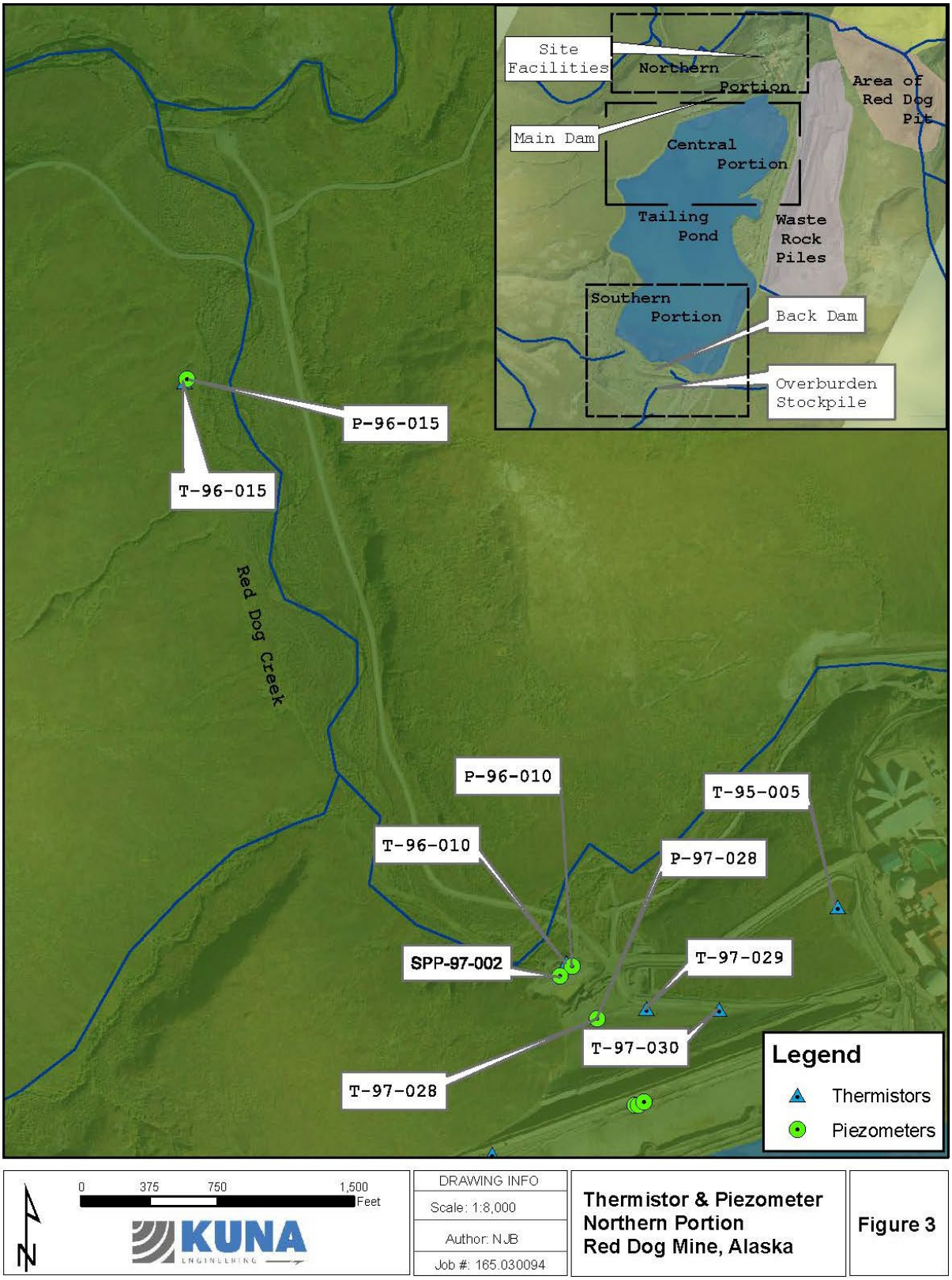


Figure 4 Red Dog Mine Long-Term Thermistor and Piezometer Monitoring Locations (Central portion)

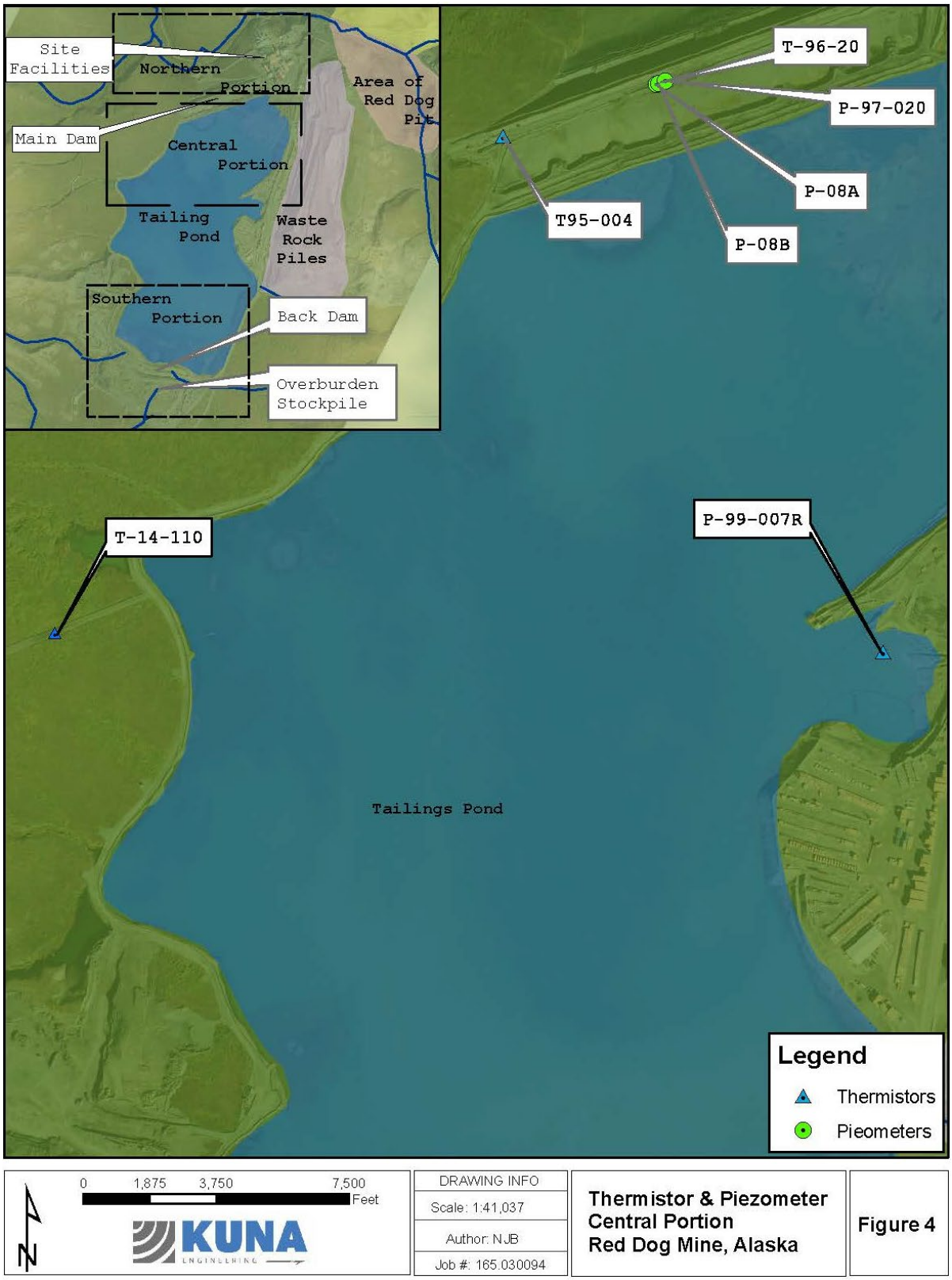
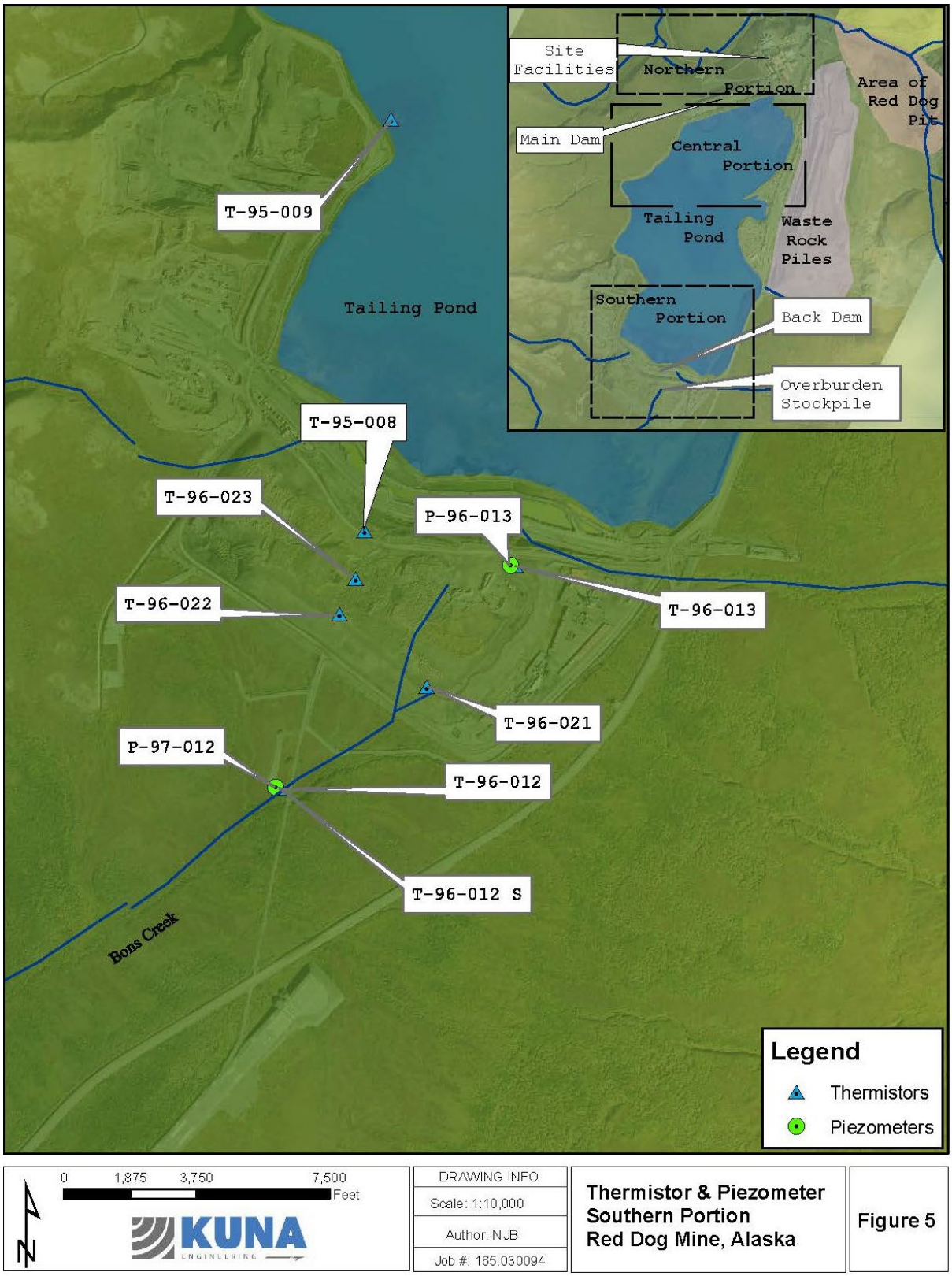


Figure 5 Red Dog Mine Long-Term Thermistor and Piezometer Monitoring Locations (Southern portion)



Piezometer Data

The Red Dog Mine piezometers are illustrated on Figure 3 (northern portion), Figure 4 (central portion), and Figure 5 (southern portion). The 2018 quarterly piezometer data was collected by TAK and submitted to Kuna which prepared a graphical time series plots of groundwater elevation. This data is presented in Appendix C.

Table 2 Summary of the 2018 Quarterly Piezometer Data Collection

Piezometer	Associated Figure	General Location	Sampling Dates			
			1st Quarter	2nd Quarter	3rd Quarter	4th Quarter
P-96-015	Figure 3	Red Dog Creek	1/15/18	4/8/18	7/12/18	10/20/18
P-96-010	Figure 3	Dam Area	1/15/18	4/8/18	7/12/18	10/20/18
P-97-028	Figure 3	Dam Area	1/15/18	4/8/18	7/12/18	10/20/18
SPP-97-002	Figure 3	Dam Area	1/15/18	4/8/18	7/12/18	10/20/18
P-08A	Figure 4	Dam Area	1/15/18	4/8/18	7/12/18	10/20/18
P-08B	Figure 4	Dam Area	1/15/18	4/8/18	-	10/20/18
P-97-020	Figure 4	Dam Area	1/15/18	4/8/18	7/12/18	10/20/18
P-96-013	Figure 5	Overburden Stockpile	1/15/18	4/8/18	7/12/18	10/20/18
P-97-012	Figure 5	Bons Creek	1/15/18	4/8/18	7/12/18	10/20/18

Note:

- Hyphen (-) denotes data was not collected

Data Management

The 2018 thermistors and piezometers data collection was performed by TAK personnel in accordance with the Red Dog Mine Long Term Groundwater Monitoring Plan's standard operating procedure (WMCI 2001). This data was provided to Kuna to update the TAK Red Dog Mine Database. Microsoft Access™ and Excel™ software were used to generate graphical plots of the data.

Data collected from the thermistor cables was measured in resistance as kilo-ohms (kohms) using a Dryden Instrumentation T5KMUK Automated Thermistor String Reader. The measured resistance values were converted to temperature using calibration coefficients for each thermistor sensor. A calibrated digital temperature acquisition cable was used to measure ground temperature at replacement site T-14-110. Data was reviewed for errors and omission, and then uploaded to the Red Dog Mine Database.

Ground temperature measurements that were not representative of true measurements (i.e., less than zero (0) kohms or greater than 300 kohms) were deleted before uploading to the Red Dog Mine Database. The deleted values are shaded red in the raw data table presented in Appendix A.

TAK provided Kuna the piezometer's vibrating wire measurements and barometric pressure measurements collected on-site. The vibrating wire transducer measurements were converted to groundwater elevation using the calibration coefficients, site elevation, and barometric pressure. Calibration of the vibrating wire transducers was determined during installation. The 2018 data was reviewed for errors and omissions and then uploaded to the Red Dog Ming Database.

Summary of Data QA/QC and System OM

Starting in 2017 Kuna developed and began using a "Quarterly Report Data Checklist", copies of which are included in Appendix D. The Checklist was developed to do a first order review of the data received from TAK. The completed checklists were transmitted to TAK to allow them to make corrections or if possible re-collect missing data. Standard operating procedures developed for the monitoring program included taking duplicate measurements to ensure different operators and or equipment would not impact representativeness of the data. QA/QC measurements for quarterly thermistors and piezometers data are attached in Appendix D.

A site visit by Kuna personnel to the Red Dog Mine, was performed on March 22-24, 2018. We met with all the TAK technicians and went over procedures and all the equipment being used. We were able to determine that one of the two Dryden Instrumentation T5KMUK data loggers was not operating properly. It was recommended that that one unit be returned to the manufacturer for repair or replacement. We visited multiple sites and collected data using both the data logger and the manual switch box and multi-meter. We experienced typical

winter difficulty in getting to sites and one site (T-96-4) was so badly frozen in, we could not get to cable to collect data.

Thermistor QA/QC

Duplicate measurements were collected from the Dryden Instrumentation T5KMUK data logger and the Dryden Switchbox Fluke multimeter system to ensure repeatability and concurrence with the automated data logger system. Variations in the thermistor measurements were also compared to previously collected data and trends. Thermistor QA/QC data is presented in Table 3.

Table 3 Summary of 2018, QA/QC Thermistors Data Collection

Quarter	Date	Thermistor	Multi-meter Start Time	Comments
1st Quarter	1/15/18	T-96-012	1517 hours	Two open readings Nodes 1 & 6
2nd Quarter	4/8/18	T-96-15	1519 hours	One open reading Node 15
3rd Quarter	7/12/18	T-95-05	1529 hours	Nodes 10 & 12-16 "jumpy"
4th Quarter	10/20/18	T-96-10	1702 hours	Nodes 9-11 & 24 fluctuating

Piezometer QA/QC

Piezometer QA/QC data is presented in Table 4.

Table 4 Summary of 2018, QA/QC Piezometer Data Collection

Quarter	Date	Piezometer	Comments
1st Quarter	1/15/18	P-97-012	0 PSI reading on packer
2nd Quarter	4/8/18	P-96-15	
3rd Quarter	7/13/18	P-96-05	
4th Quarter	10/20/18	P-96-10	

Thermistor System Maintenance

Thermistor measurements indicate that several are malfunctioning and require replacement. A program has been setup to replace surface connector cables as needed. Photographs of this being done at one thermistor are included in Appendix D.

Piezometer System Maintenance

Vibrating wire transducers are functioning with few erroneous measurements collected from the sensors. Some of the piezometer wells have pneumatic packers installed in them to separate shallow from deep groundwater zones. It was noted in 2017, the pressure readings in some of these packers were very low so they were re-pressurized with nitrogen.

Piezometer P96-013 is planned to be replace in 2019. Reading from the current piezometer are suspect.

References

Water Management Consultants, Inc. (WMCI), 2001, Red Dog Mine – Long-Term Permafrost and Groundwater Monitoring Plan for the Tailing Impoundment, March, 2001.

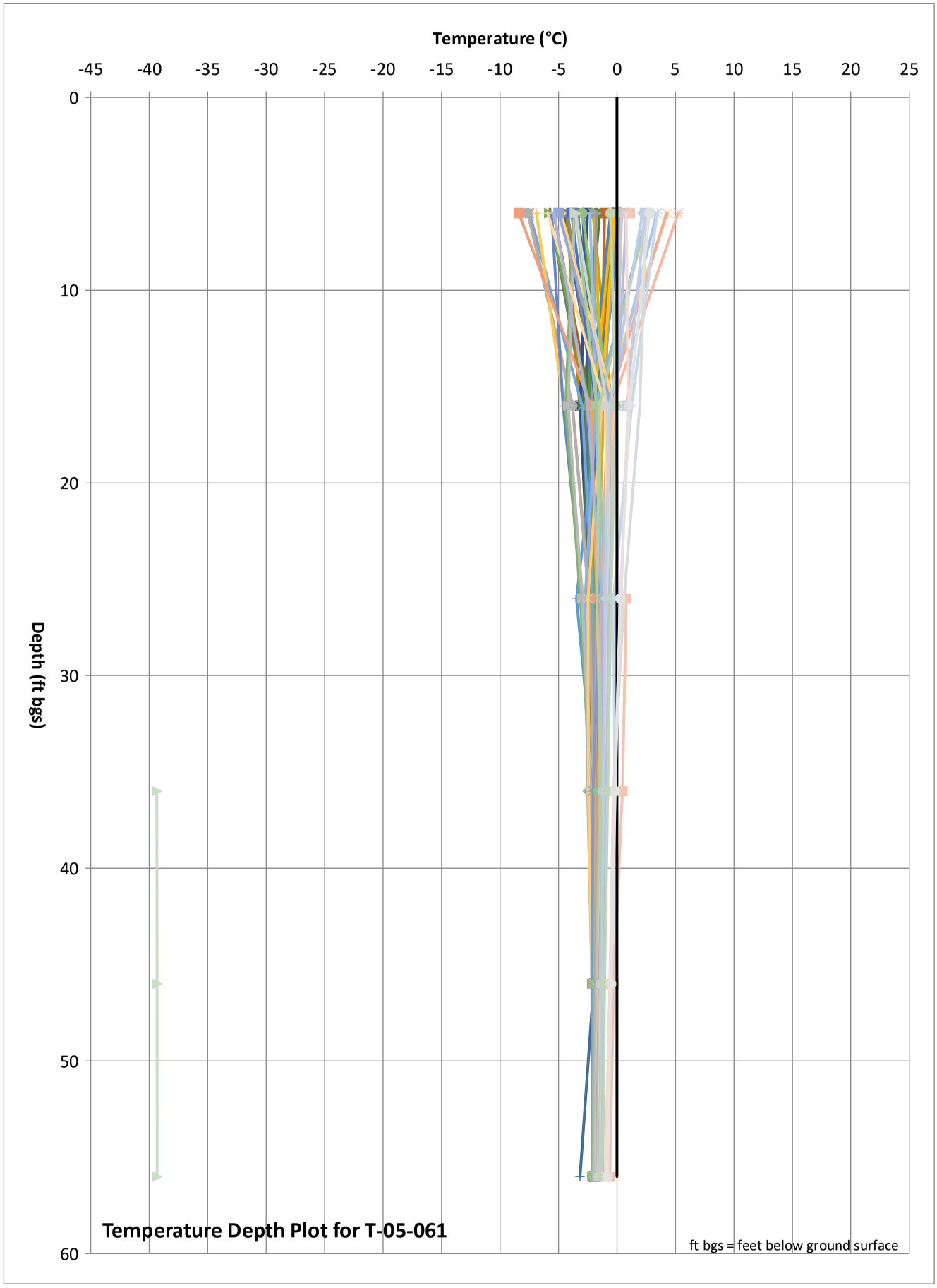
Appendix A
Raw Data

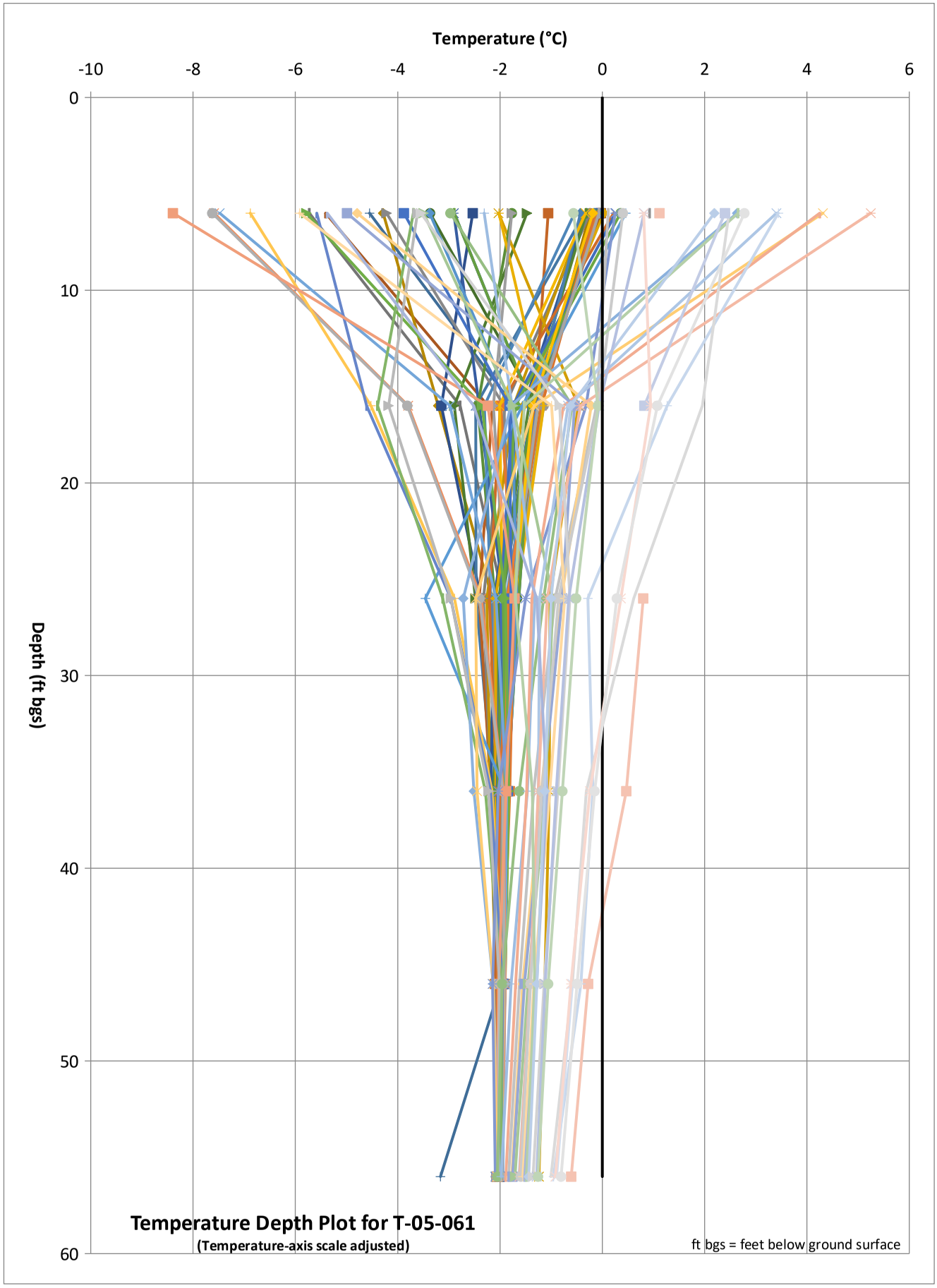
Raw Data Table (Thermistor)

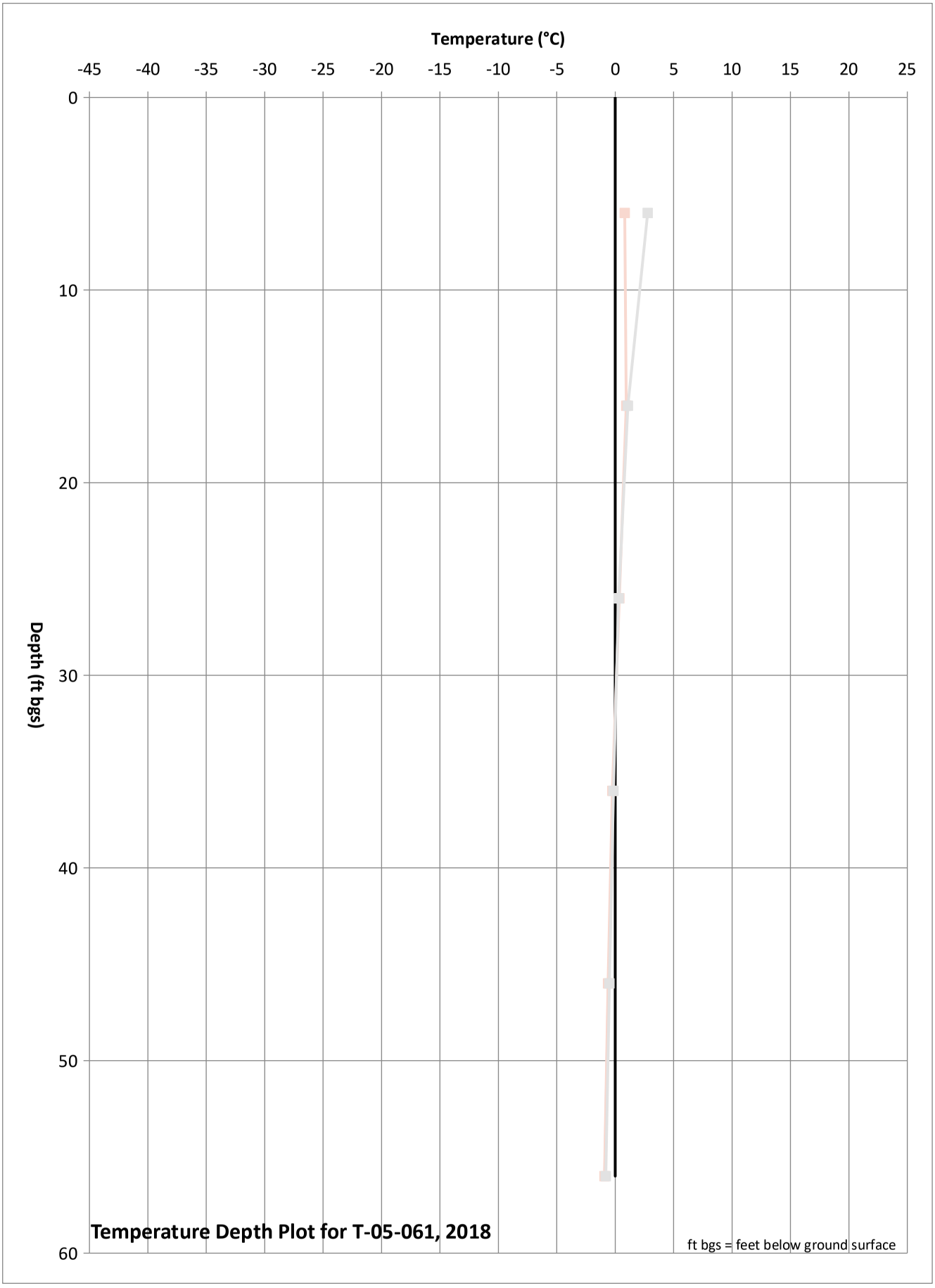
Site ID	Num Therm	Date/Time	pt-01	pt-02	pt-03	pt-04	pt-05	pt-06	pt-07	pt-08	pt-09	pt-10	pt-11	pt-12	pt-13	pt-14	pt-15	pt-16	pt-17	pt-18	pt-19	pt-20	pt-21	pt-22	pt-23	pt-24
T05-61	6	1/15/18 5:23 PM	5.59	5.87	6.34	6.77	16.85	17.13																		
T05-61	6	4/8/18 4:05 PM	15.73	15.61	15.99	16.58	16.87	17.15																		
T05-61	6	7/12/18 4:25 PM	6.26	6.26	6.38	6.68	6.88	7.06																		
T05-61	6	10/20/18 5:45 PM	14.24	15.51	16.05	16.50	16.77	17.05																		
T95-4	24	7/12/18 4:30 PM	5.28	-5.11	-5.20	-5.48	-5.33	-25.41	6.16	-6.03	-5.26	-6.09	-5.54	-5.53	-5.86	6.30	-5.24	-5.34	-5.67	-5.59	-5.74	5.95	-5.29	-38.73	-5.28	-5.30
T95-4	24	10/20/18 5:41 PM	-13.44	-13.40	-14.02	-13.68	-13.70	-42.82	15.58	-15.14	-14.00	-14.97	-13.96	-13.50	-15.17	-15.24	-13.20	-12.44	-14.16	-14.77	-14.74	15.05	-14.08	14.09	-13.81	-13.71
T95-5	24	1/15/18 5:36 PM	15.61	15.47	15.91	16.15	16.12	16.22	16.19	16.19	16.35	16.32	16.32	16.41	16.24	7.20	16.67	16.61	16.56	16.42	16.29	16.12	15.99	15.81	15.64	15.35
T95-5	24	4/8/18 4:18 PM	16.29	16.08	16.33	16.59	16.66	16.77	16.82	16.85	16.87	16.89	16.90	16.85	16.83	16.81	16.75	16.69	16.65	16.50	16.38	16.21	16.08	15.91	15.75	15.58
T95-5	24	7/12/18 3:26 PM	5.07	6.48	-5.88	-6.13	-5.63	-5.72	-5.91	-4.63	-1.83	-5.14	-4.24	6.53	-3.34	6.86	6.83	6.80	6.77	-83.59	6.59	5.60	6.40	-2.54	6.19	6.05
T95-5	24	10/20/18 3:16 PM	13.12	14.98	16.00	16.26	16.44	16.63	16.25	16.74	16.66	16.83	16.74	16.73	16.75	16.78	16.72	16.68	16.63	16.44	16.37	16.17	16.07	15.86	15.74	15.56
T95-8 #2	24	1/17/18 10:57 AM	16.77	16.77	16.83	16.94	16.94	16.96	16.94	16.92	17.01	17.02	17.02	16.99	17.00	17.07	17.02	17.06	17.06	17.06	17.08	17.11	17.10	17.10	17.15	17.19
T95-8 #2	24	7/12/18 11:46 AM	5.75	6.90	6.87	6.95	6.95	6.97	6.95	6.95	7.00	7.00	7.00	6.99	6.99	7.04	7.01	6.77	7.03	7.03	7.04	7.06	7.06	7.06	7.08	7.11
T95-8 #2	24	10/20/18 10:53 AM	15.05	16.76	16.80	16.93	16.94	16.96	16.94	16.92	17.01	17.01	17.02	16.98	17.00	17.06	17.02	17.05	17.06	17.04	17.07	17.10	17.10	17.08	17.14	17.17
T96-10	24	1/15/18 5:11 PM	6.48	6.60	14.62	6.44	6.39	6.38	6.37	6.29	6.28	6.24	6.53	6.17	6.09	6.84	8.56	5.78	5.86	6.81	5.60	-5.36	5.50	5.53	12.18	-132.50
T96-10	24	4/8/18 3:34 PM	16.90	16.31	29.84	16.13	16.06	16.03	16.03	15.89	15.89	15.82	16.29	15.70	15.60	16.78	19.62	15.05	15.22	16.60	14.74	-13.77	14.67	14.53	25.57	-809.90
T96-10	24	7/12/18 3:03 PM	6.33	6.57	14.98	6.43	6.38	6.36	6.36	6.28	6.28	6.24	6.54	6.16	6.09	19.70	8.72	5.76	5.85	6.83	5.60	-5.36	5.51	5.53	12.34	-161.40
T96-10	24	7/12/18 3:04 PM	6.33	6.57	14.98	6.43	6.38	6.36	6.36	6.28	6.28	6.24	6.54	6.16	6.09	-23.64	8.72	5.76	5.85	6.84	5.60	-5.36	5.51	5.53	12.34	-135.60
T96-10	24	10/20/18 5:02 PM	13.91	15.93	30.60	16.08	16.02	15.99	16.00	15.85	15.87	15.80	16.30	15.68	15.59	16.82	19.87	15.01	15.21	16.64	14.72	-13.76	14.69	14.54	25.92	-419.10
T96-12	24	1/15/18 3:09 PM	6.62	6.87	7.00	7.04	7.09	7.12	7.14	7.17	7.16	7.14	7.16	7.10	7.04	7.05	6.96	6.92	6.87	6.79	6.70	6.60	161.76	6.46	6.36	6.28
T96-12	24	4/8/18 2:52 PM	16.45	16.79	17.00	17.07	17.16	17.20	17.23	17.27	17.25	17.23	17.26	17.18	17.08	17.08	16.95	16.89	16.81	16.68	16.54	16.39	-9999.00	16.16	16.02	15.88
T96-12	24	7/12/18 10:58 AM	0.95	0.26	0.08	2.13	3.72	6.06	6.61	6.71	6.72	6.79	6.81	6.73	6.84	6.84	6.86	6.89	6.83	6.94	6.94	6.79	6.74	7.01	6.98	6.77
T96-12	24	10/20/18 11:32 AM	17.11	17.15	17.33	16.47	15.69	15.41	15.86	16.30	16.52	16.64	16.70	16.71	16.75	16.73	16.78	16.80	16.86	16.89	16.90	16.82	16.90	16.99	17.02	16.96
T96-12s	24	1/15/18 3:10 PM	7.36	7.77	8.17	7.71	6.99	6.66	6.65	6.71	6.75	6.82	6.84	6.87	6.88	6.87	6.90	6.91	6.95	6.96	6.96	6.97	6.99	7.01	7.03	7.00
T96-12s	24	4/8/18 2:53 PM	14.56	21.45	19.35	17.76	17.09	16.52	16.47	16.55	16.58	16.70	16.74	16.76	16.79	16.78	16.82	16.85	16.90	16.94	16.94	16.96	16.99	17.03	17.06	17.01
T96-12s	24	7/12/18 11:00 AM	6.57	6.85	6.98	7.03	7.09	7.11	7.13	7.16	7.15	7.14	7.15	7.10	7.03	7.05	6.97	6.93	6.86	6.79	6.70	6.61	161.45	6.45	6.36	6.28
T96-12s	24	10/20/18 11:33 AM	17.05	16.74	16.96	17.02	17.13	17.15	17.21	17.25	17.24	17.21	17.25	17.16	17.06	17.02	16.90	16.85	16.75	16.46	16.46	16.34	-1844.00	16.13	15.99	15.86
T96-13	24	1/15/18 2:32 PM	6.20	6.62	6.21	6.72	6.84	6.90	7.06	6.98	7.05	7.07	7.11	7.14	7.89	7.89	7.52	7.12	7.14	7.03	8.08	6.91	6.85	6.77	6.71	6.61
T96-13	24	4/8/18 2:19 PM	16.57	16.78	15.78	16.57	16.75	16.86	17.10	16.98	17.08	17.12	17.19	17.23	18.46	18.48	17.85	17.20	17.24	17.05	18.77	16.87	16.77	16.66	16.56	16.39
T96-13	24	4/8/18 2:22 PM	16.56	16.76	15.76	16.56	16.74	16.85	17.10	16.97	17.07	17.12	17.19	17.22	18.45	18.45	17.82	17.18	17.20	17.01	18.74	16.86	16.76	16.64	16.55	16.38
T96-13	24	7/12/18 11:10 AM	2.98	6.73	6.13	6.71	6.84	6.90	7.06	6.98	7.03	7.07	7.11	7.14	7.94	7.97	7.54	7.12	7.14	7.02	8.13	6.90	6.85	6.77	6.71	6.61
T96-13	24	9/28/18 9:43 AM	11.55	15.65	15.64	16.55	16.74	16.85	17.11	16.96	17.06	17.11	17.18	17.21	18.53	18.61	17.88	17.18	17.23	17.04	18.83	16.86	16.77	16.65	16.56	16.38
T96-13	24	10/20/18 10:57 AM	12.92	15.47	15.61	16.55	16.74	16.85	17.11	16.96	17.06	17.10	17.17	17.21	18.55	18.63	17.89	17.18	17.22	17.04	18.84	16.86	16.76	16.64	16.56	16.38
T96-15	14	1/15/18 4:49 PM	16.78	17.01	16.93	16.91	16.80	16.72	16.66	16.58	16.53	16.52	16.42	16.35	16.29	16.24										
T96-15	14	4/8/18 3:13 PM	16.77	17.01	16.95	16.93	16.82	16.74	16.68	16.60	16.55	16.53	16.44	16.36	16.30	16.25										
T96-15	14	7/12/18 2:47 PM	6.88	6.98	6.95	6.95	6.88	6.82	6.79	6.73	6.71	6.70	6.63	6.58	6.54	6.61										
T96-15	14	10/20/18 5:28 PM	16.76	16.96	16.93	16.91	16.81	16.72	16.67	16.58	16.54	16.52	16.43	16.35	16.30	16.24										
T96-21	24	1/15/18 2:42 PM	7.12	7.86	5.85	5.24	4.89	5.01	4.79	4.89	5.02	5.18	5.34	5.57	5.81	6.09	6.24	6.44	6.69	6.76	6.80	6.86	6.89	6.91	6.94	6.98
T96-21	24	4/8/18 2:32 PM	12.12	19.08	16.47	15.16	14.30	14.21	13.66	13.65	13.76	14.03	14.34	14.72	15.13	15.56	15.80	16.13	16.53	16.63	16.70	16.79	16.84	16.88	16.92	16.98
T96-21	24	7/12/18 11:40 AM	-0.20	1.58	3.51	4.78	5.28	5.52	5.13	5.03	5.04	5.17	5.34	5.57	5.81	6.07	6.22	6.15	6.69	6.76	6.80	6.86	6.89	6.91	6.94	6.98
T96-21	24	9/28/18 9:47 AM	15.17	12.99	11.23	11.68	12.58	13.66	13.76	13.93	14.05	14.26	14.51	14.83	15.19	15.57	15.80	16.12	16.52	16.62	16.68	16.77	16.83	16.86	16.90	16.96
T96-21	24	10/20/18 11:04 AM	17.69	15.30	12.28	11.98	12.46	13.43	13.59	13.85	14.03	14.28	14.53	14.85	15.20	15.58	15.80	16.12	16.52	16.62	16.68	16.78	16.82	16.86	16.90	16.96
T96-22	24	1/15/18 2:46 PM	17.31	17.14	9999.90	14.68	14.41	14.58	14.98	15.35	15.79	16.13	16.45	16.69	16.76	16.82	9999.90	16.93	17.04	17.00	17.06	17.09	17.10	17.17	14.19	17.26
T96-22	24	4/8/18 2:35 PM	17.10	17.65	9999.90	15.39	14.96	14.96	15.19	15.42	15.80	16.12	16.45	16.69	16.77	16.82	9999.90	16.93	17.04	17.01	17.07	17.09	17.11	17.18	13.92	17.27
T96-22	24	4/8/18 2:36 PM	17.04	17.63	-8275.00	15.36	14.94	14.94	15.16	15.40	15.77	16.09	16.42	16.67	16.75	16.80	-7486.00	16.90	17.00	16.96	17.04	17.07	17.06	17.15	13.90	17.24
T96-22	24	7/12/18 11:34 AM	-0.55	2.22	161.53	5.61	5.90	6.00	6.11	161.53	6.39	6.52	6.64	6.80	6.84	6.89	161.53	6.75	7.02	6.99	7.03	7.05	7.06	7.10	4.80	7.07
T96-22	24	9/28/18 9:51 AM	15.47	13.59	-9999.00	12.87	13.96	14.85	15.41	9999.90	16.00	16.20	16.44	16.68	16.76	16.81	-9999.00	16.92	17.03	16.99	17.06	17.08	17.10	17.16	13.41	16.82
T96-22	24	10/20/18 11:08 AM	17.32	15.57	9999.90	12.94	9999.90	-9999.00	17.32	15.57	-9999.00	12.94	13.72	14.60	15.28	-18.29	15.98	16.21	16.44	16.67	16.76	16.81	9999.90	16.92	17.03	16.99
T96-23	24	1/15/18 2:49 PM	161.47	161.47	6.53	6.02	5.98	6.08	6.11	6.33	-4.94	-5.75	6.65	6.78	6.89	6.93	-6.15	-5.76	-6.06	6.70	7.07	7.10	6.97	-5.70	-6.66	7.17
T96-23	24	4/8/18 2:38 PM	-9999.00	9999.90	16.52	16.09	15.84	15.92	15.96	16.21	-13.69	-14.84	16.59	16.77	16.84	16.89	-15.41	-13.77	-15.35	16.19	17.11	17.15	16.86	-13.97	-16.35	17.28
T96-23	24	4/8/18 2:40 PM	-9999.00	-9999.00	16.52	16.09	15.83	15.92	15.95	16.21	-13.70	-14.83	16.59	16.77	16.83	16.88	-15.41	-13.75	-15.34	16.18	17.11	17.14	16.84	-13.96	-16.35	17.28
T96-23	24	7/12/18 11:30 AM	161.51	161.51	2.38	5.39	5.78	5.96	5.91	6.10	-4.74	-5.37	6.76	6.85	6.89	6.93	-6.28	-5.49	-5.65	6.99	6.89	7.08	6.91	-5.34	6.71	7.16
T96-23	24	9/28/18 9:54 AM	9999.90	9999.90	13.25	13.85	14.52	14.93	14.95	15.23	-13.30	-13.97	16.09	16.75	16.83	16.87	-15.56	-13.23	-13.95	15.92	17.05	17.14	16.80	-13.87	16.46	17.26
T96-23	24	10/20/18 11:11 AM	9999.90	-9999.00	15.12	14.23	14.71	15.01	14.98	15.32	-13.47	-14.10	16.13	16.57	16.83	16.87	15.63	-13.55	-13.91	16.15	17.10	17.13	16.68	-13.93	16.46	17.26
T97-28	24	1/15/18 5:30 PM	14.12	-12.96	-12.53	13.35	-11.97	-10.58	-9.05	-10.85	-11.37	-13.46	-13.71	14.85	-19.61	16.23	15.18	15.07	-11.55	15.19	15.17	-12.88	14.67	15.06	-11.72	-15.46
T97-28	24	7/12/18 3:15 PM	5.64	-5.37	5.66	5.40	5.48	5.42	5.37	5.43	5.32	-5.28	-5.42	5.76	-10.21	5.90	5.94	5.99	-3.78	5.95	5.99	-5.43	5.84	6.01	5.93	-8.02
T97-28	24	10/20/18 4:41 PM	13.81	13.70	13.64	13.75	13.93	13.94	13.92	13.93	13.94	13.98	14.11	14.32	14.56	14.64	14.80	14.93	15.12	15.12	15.23	15.26	15.37	2676.30	3949.80	15.29
T97-28	24	10/23/18 5:24 PM	14.78	-12.85	14.67	14.54	14.72	14.53	14.47	14.36	14.16	-13.91	-14.46	14.70	-19.14	9999.90	15.31	-114.70	-11.45	15.04	15.41	-13.60	15.09	15.33	15.28	-20.30
T97-29	24	1/15/18 5:15 PM	12.62	5.43	14.07	14.39	14.61	14.96	15.19	15.37	15.51	15.53	15.61	-14.08	15.43	-18.79	16.43	16.87	15.81	15.50	15.51	-14.12	15.16	15.78	-16.62	-15.73
T97-29	24	4/8/18 4:13 PM	13.76	14.53	14.18	19.49	15.34	-77.32	15.28	-28.06	-25.19	15.65	16.06	-14.67	16.08	16.18	-38.53	16.21	15.95	23.51	15.86	23.98	20.63	30.81	-42.55	-14.21
T97-29	24	4/8/18 4:14 PM	13.75	13.83	14.16	14.45	14.70	15.01	15.24	15.40	15.53	15.64	15.84	-14.45	16.06	16.09	16.08	16.06	15.96	15.28	15.70	-14.03	15.29	15.57	-14.34	-14.05
T97-29	24	7/12/18 3:11 PM	4.95	4.93	5.12	5.31	5.37	5.60	5.74	5.85	5.91	6.01	6.08	-5.19	-9.33	6.40	6.38	6.38	6.23	6.08	6.10	-4.96	6.08	5.99	-5.53	-5.30
T97-29	24	10/23/18 5:25 PM	14.13	14.14	14.33	14.48	14.61	14.60	15.09	15.07	15.37	15.27	15.68	-14.21	15.78	16.08	16.07	16.08	15.94	15.28	15.65	-13.67	-34.79	15.59	-44.40	14.31
T97-30	24	1/15/18 5:17 PM	13.63	13.52	13.45	13.52	13.66	13.73	13.77	13.86	13.90	13.96	14.07	14.27	14.52	14.61	14.77	14.91	15.10	15.11	15.23	15.26	15.37	-2584.00	3278.00	15.30
T97-30	24	4/8/18 4:09 PM	13.76	13.61	13.47	13.61	13.77	13.81	13.81	13.87	13.91	13.97	14.10	14.30	14.55	14.64	14.79	14.94	15.13	15.13	15.25	15.28	15.39	-2896.00	-3405.00	15.32
T97-30	24	4/8/18 4:11 PM	13.76	13.60	13.47	13.61	13.77	13.80	13.81	13.87	13.91	13.97	14.10	14.30	14.54	14.62	14.78	14.93	15.12	15.13	15.24	15.28	15.39	-2725.00	-2969.00	15.31
T97-30	24	7/12/18 3:08 PM	4.87	4.79	4.77	4.88	4.98	4.99	4.96	4.99	5.01	5.05	5.13	5.27	5.42	5.48	5.57	5.67	5.79	5.79	5.87	5.89	5.95	-151.10	152.30	5.91
T97-30	24	10/20/18 4:45 PM	14.78	-12.89	14.64	14.50	14.70	14.50	14.45	14.33	14.11	-13.88	-14.43	14.67	-19.05	15.16	15.11	15.15	-11.50	15.03	15.37	-13.62	15.07	15.29	15.25	-20.20
T97-30	24	10/23/18 5:27 PM	13.97	13.76	13.70	13.81	13.99	14.00	13.98	13.99	14.00	14.04	14.17	14.38	14.62	14.70	14.86	14.99	15.18	15.18	15.29	15.32	15.43	-2034.00	-3871.00	15.35

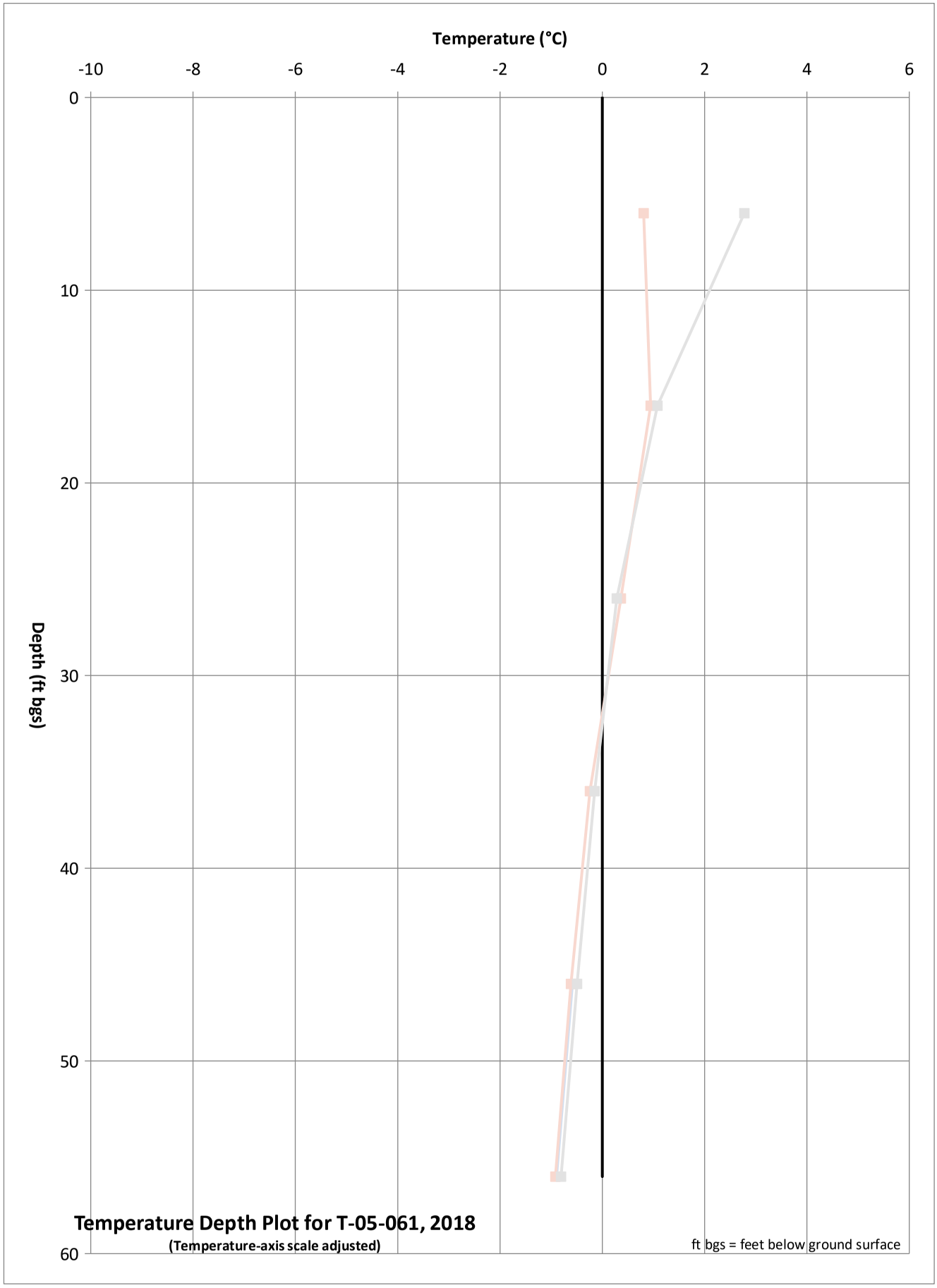
Note:
Num of Therms = total number of thermistors at each site
Date/Time = mm/dd/yy hh:mm
Measurements are shown in kohms
Red highlighted data represent measurements that are outside of database criteria and omitted from the database.

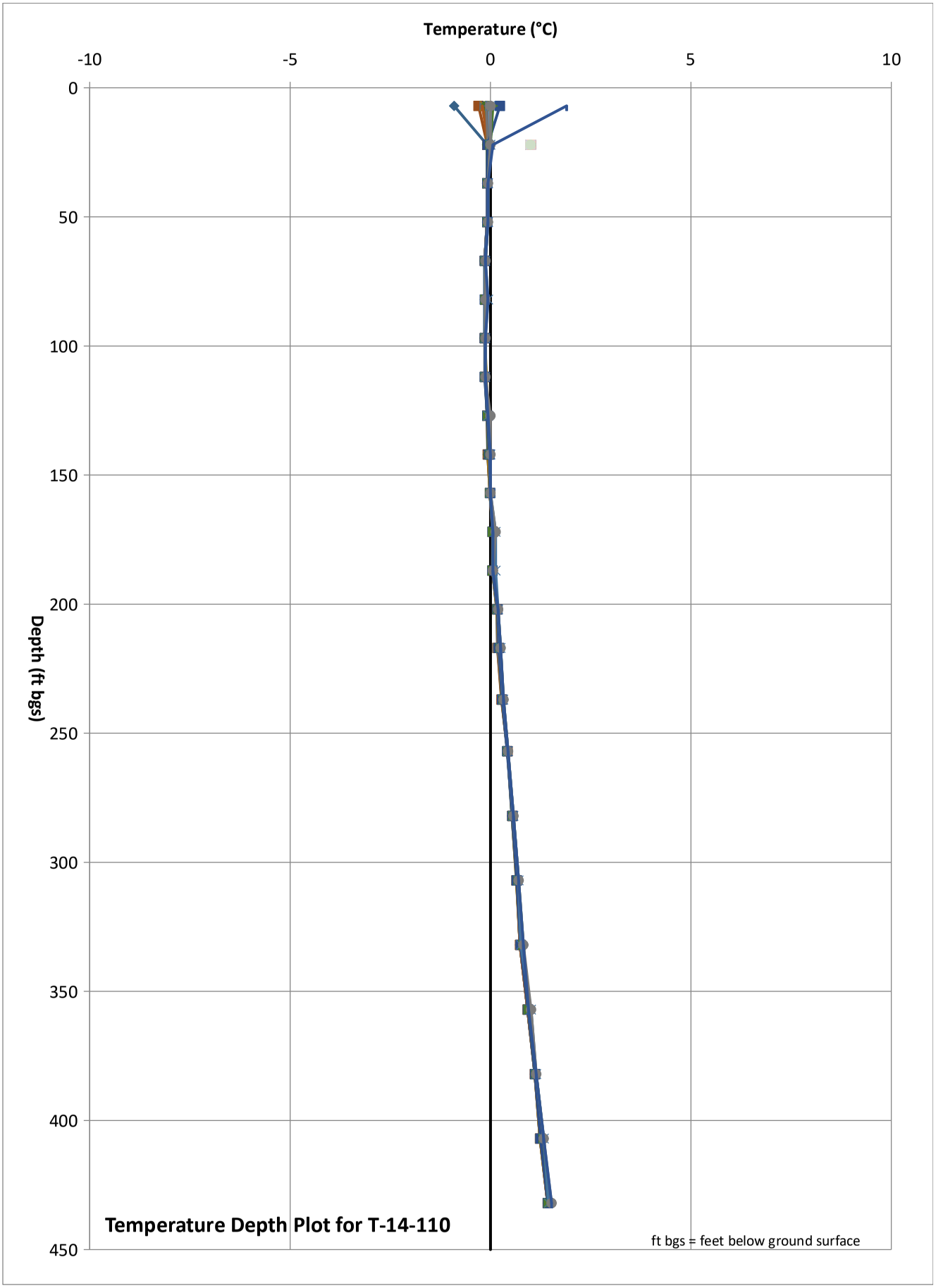
Appendix B
Thermistor Plots

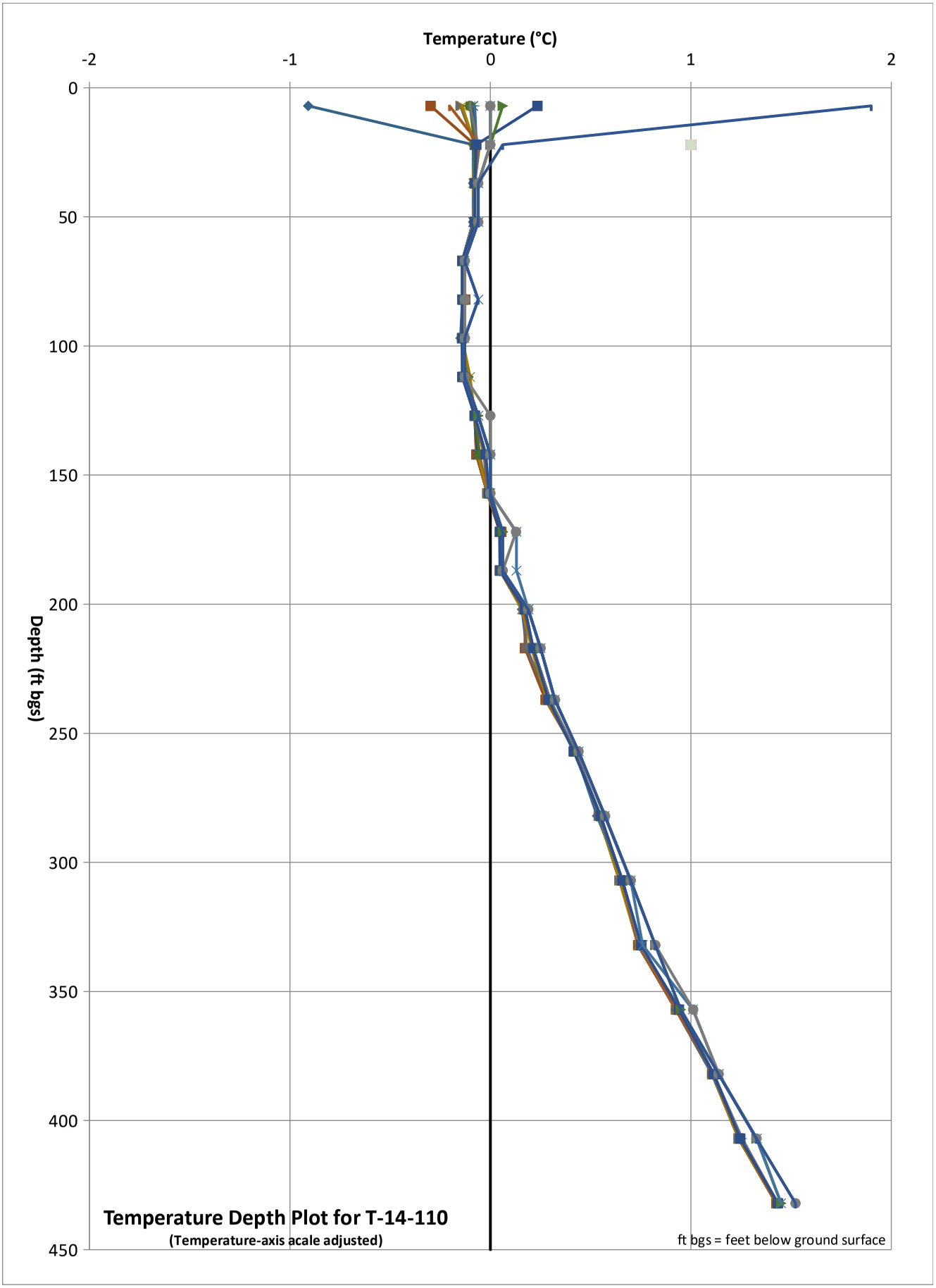

Temperature (°C)
-45
-40
-35
-30
-25
-20
-15
-10
-5
0
5
10
15
20
25
Depth (ft bgs)
0
10
20
30
40
50
60
Temperature Depth Plot for T-05-061
ft bgs = feet below ground surface

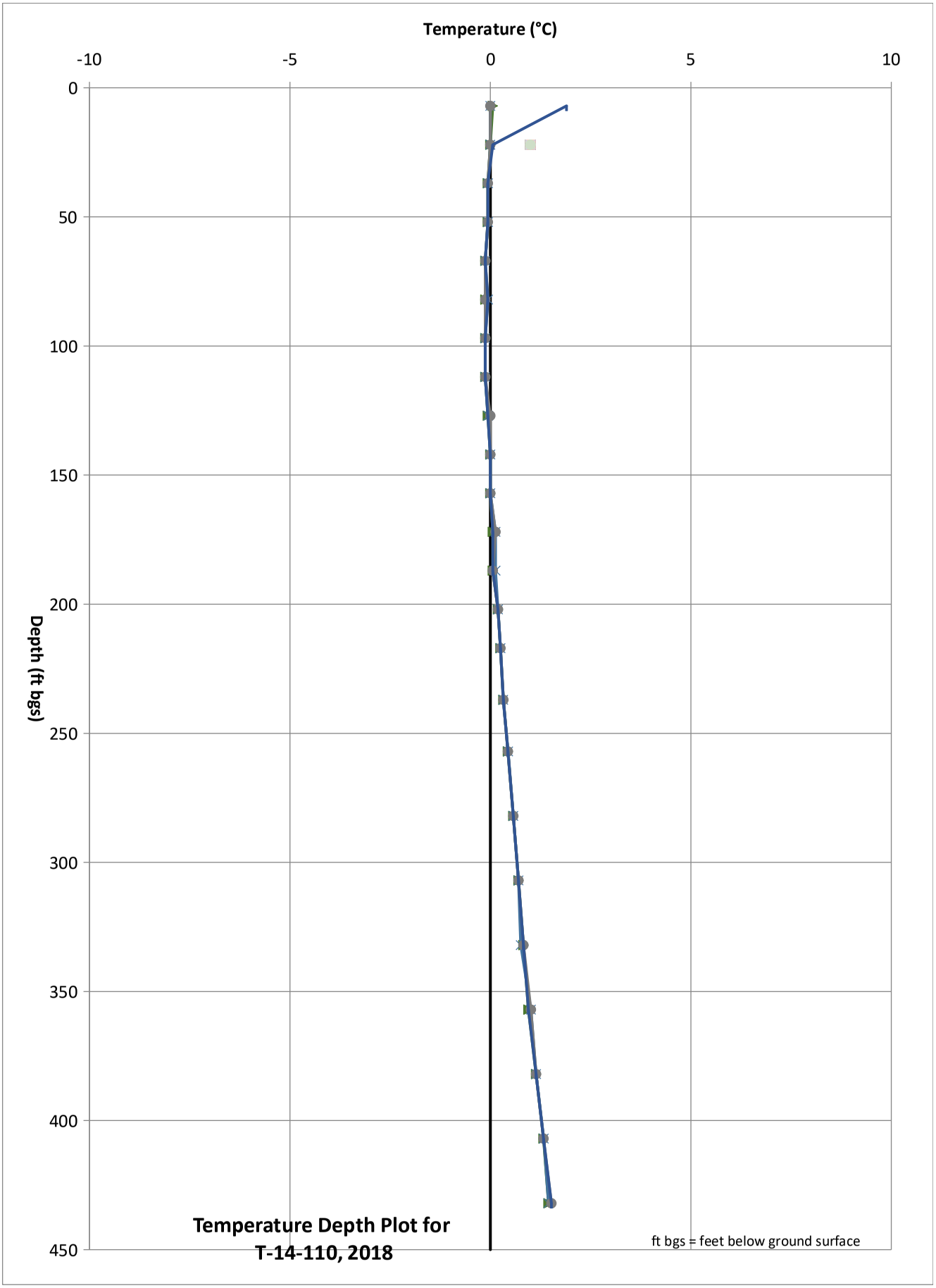

Temperature (°C)
-10
-8
-6
-4
-2
0
2
4
6
0
10
20
30
40
50
60
Depth (ft bgs)
Temperature Depth Plot for T-05-061
(Temperature-axis scale adjusted)
ft bgs = feet below ground surface

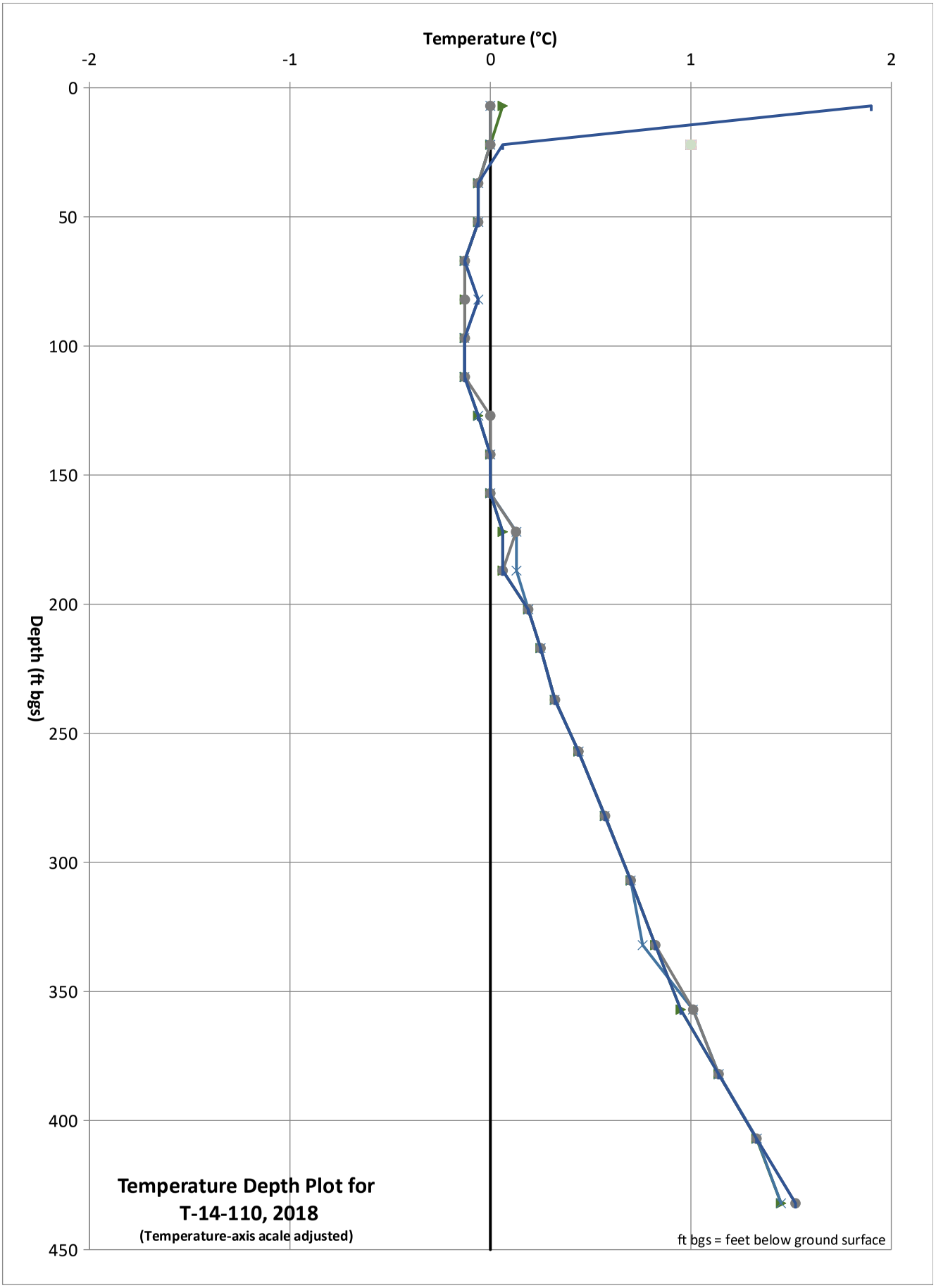

Temperature (°C)
-45
-40
-35
-30
-25
-20
-15
-10
-5
0
5
10
15
20
25
Depth (ft bgs)
0
10
20
30
40
50
60
Temperature Depth Plot for T-05-061, 2018
ft bgs = feet below ground surface

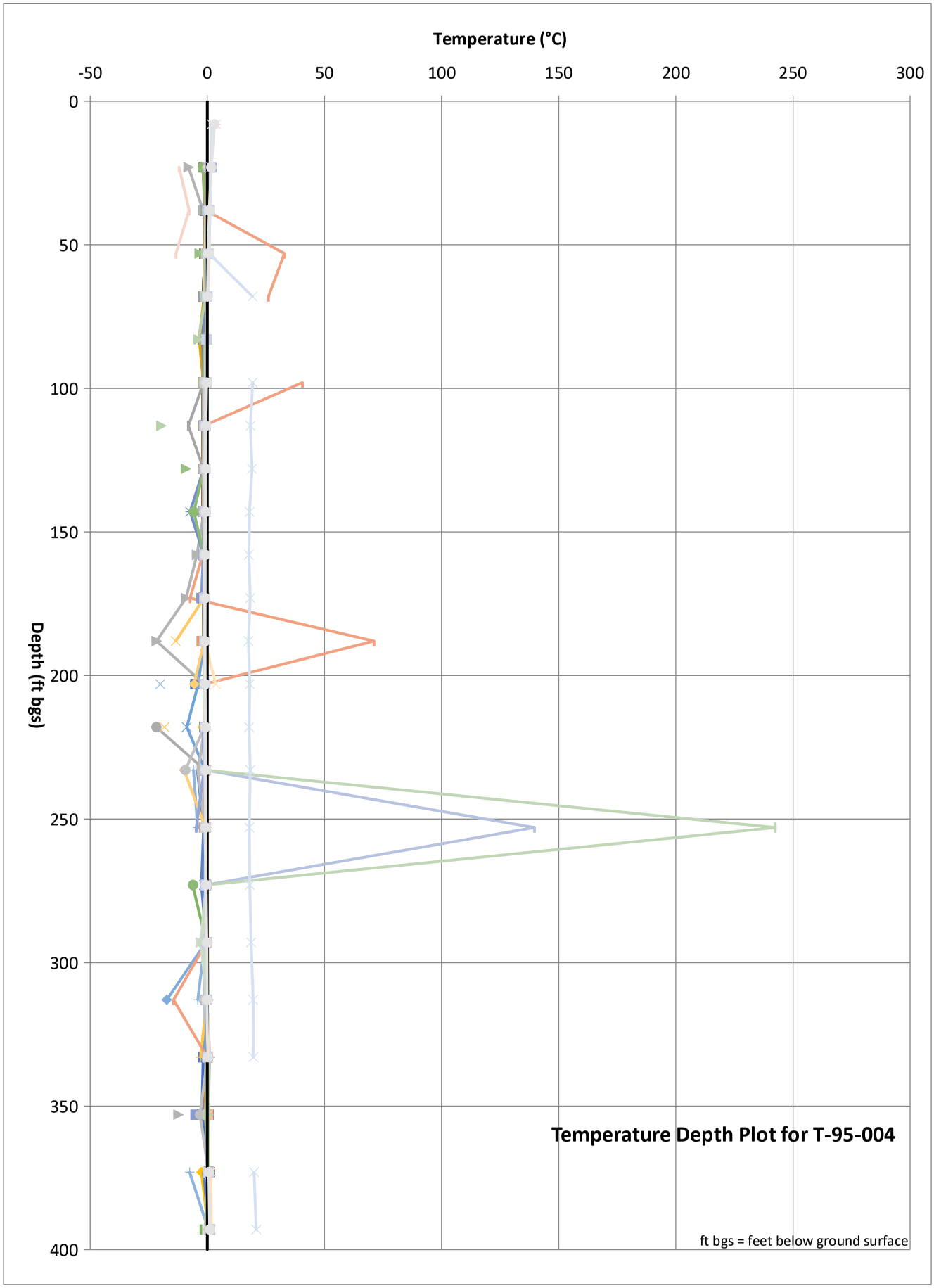

Temperature (°C)
-10
-8
-6
-4
-2
0
2
4
6
0
10
20
30
40
50
60
Depth (ft bgs)
Temperature Depth Plot for T-05-061, 2018
(Temperature-axis scale adjusted)
ft bgs = feet below ground surface

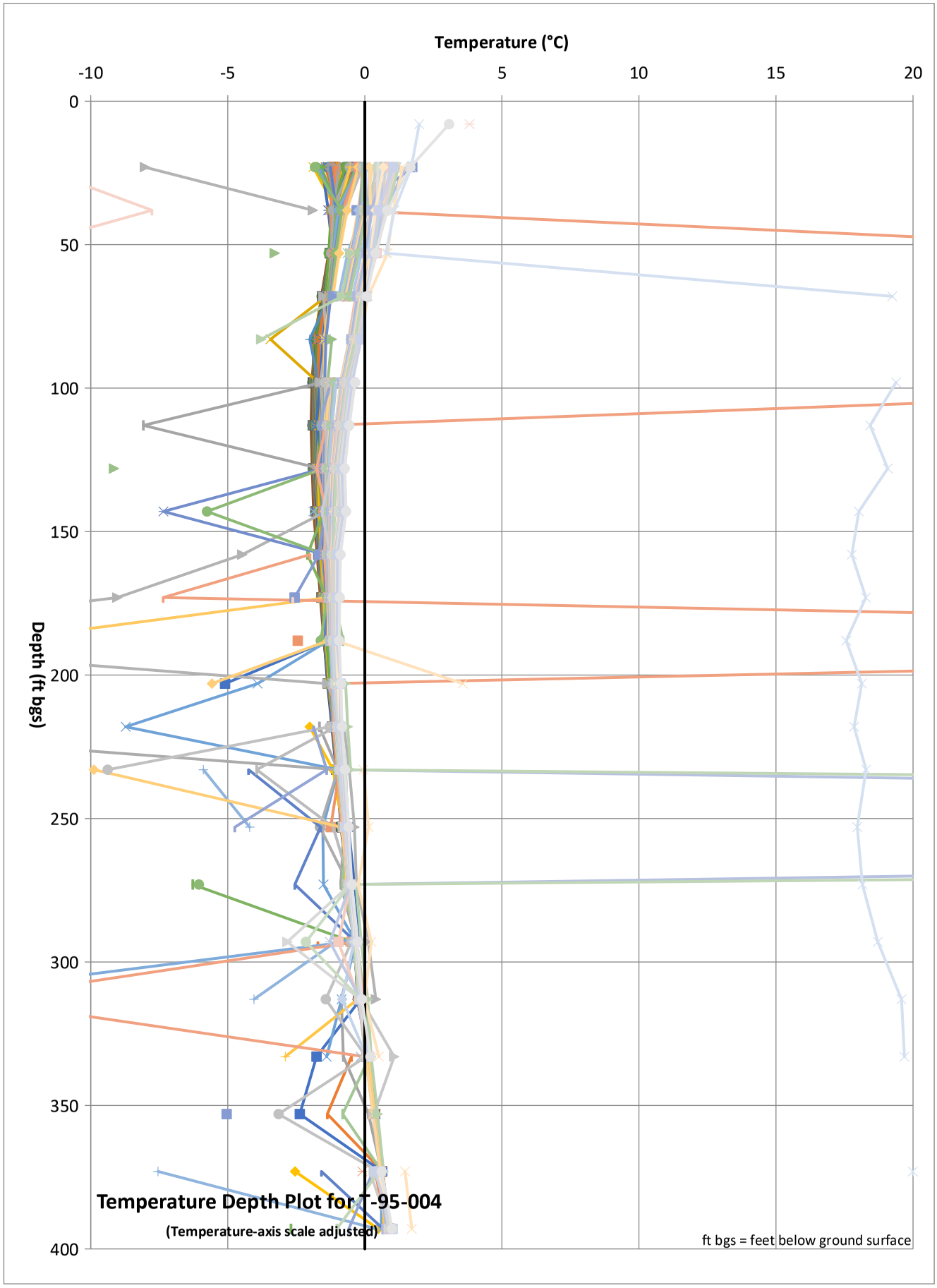

Temperature (°C)
-10
-5
0
5
10
0
50
100
150
200
250
300
350
400
450
Depth (ft bgs)
Temperature Depth Plot for T-14-110
ft bgs = feet below ground surface

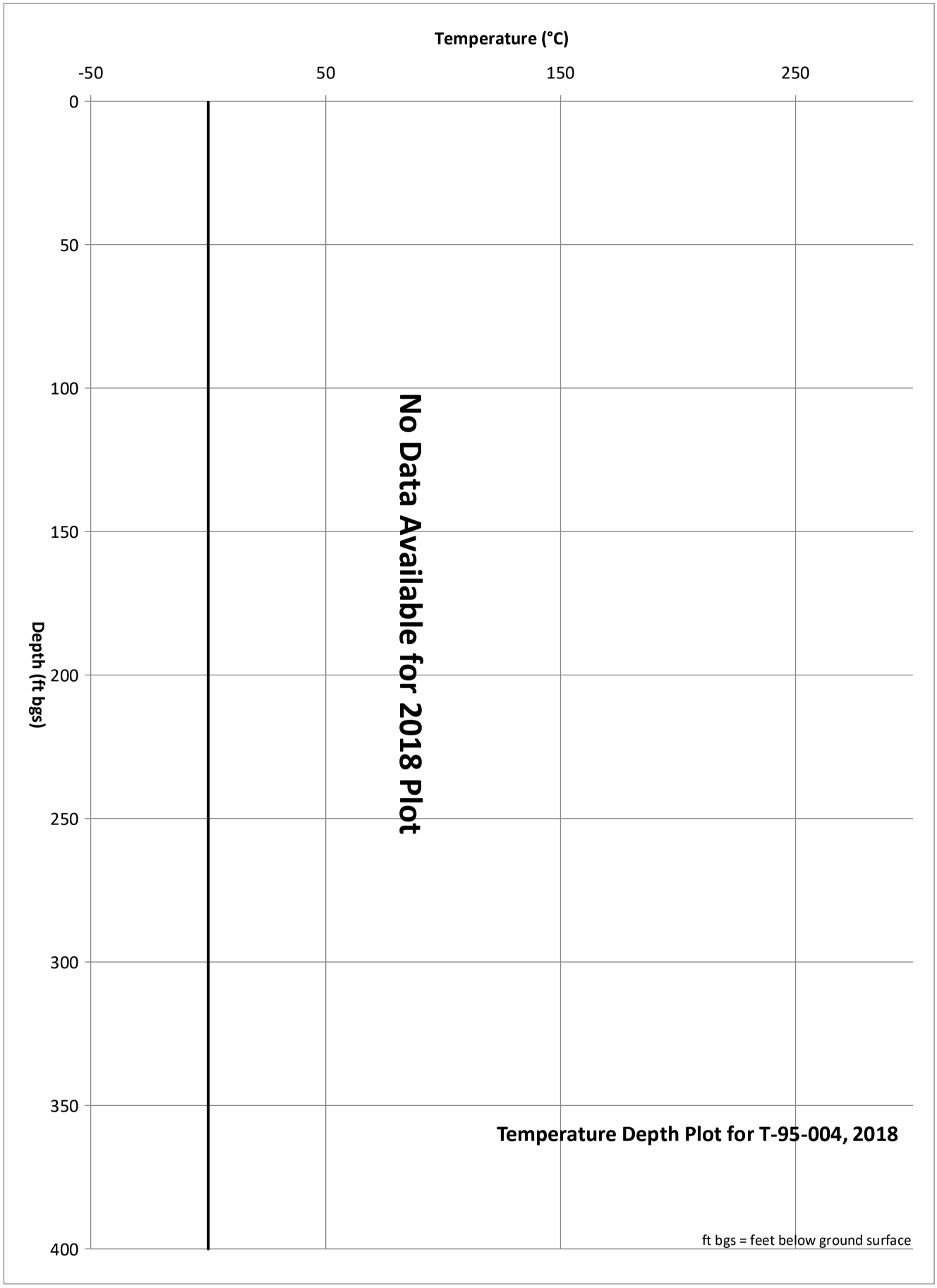

Temperature (°C)
-2
-1
0
1
2
0
50
100
150
200
250
300
350
400
450
Depth (ft bgs)
Temperature Depth Plot for T-14-110
(Temperature-axis acale adjusted)
ft bgs = feet below ground surface

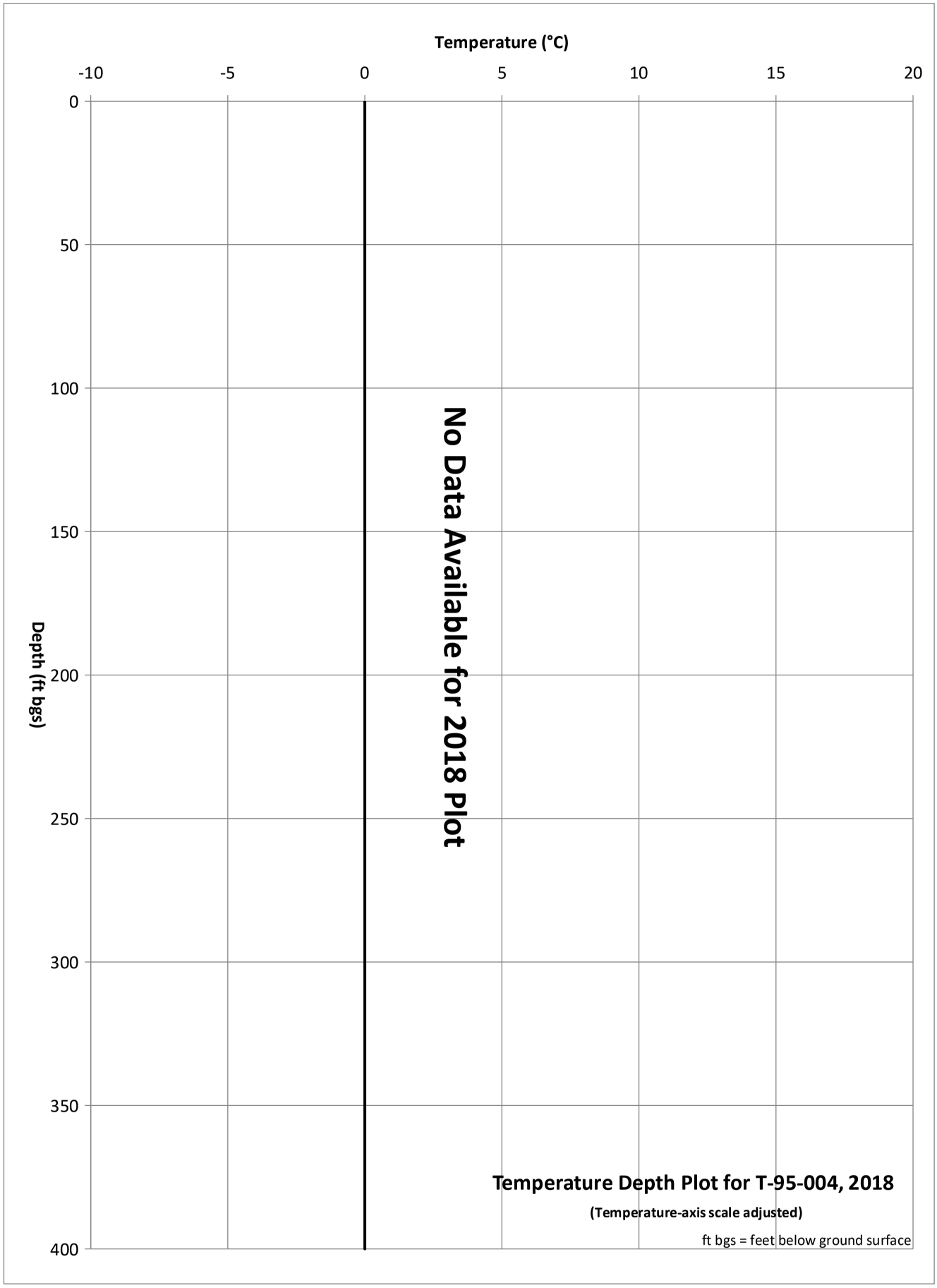

Temperature (°C)
-10
-5
0
5
10
0
50
100
150
200
250
300
350
400
450
Depth (ft bgs)
Temperature Depth Plot for
T-14-110, 2018
ft bgs = feet below ground surface

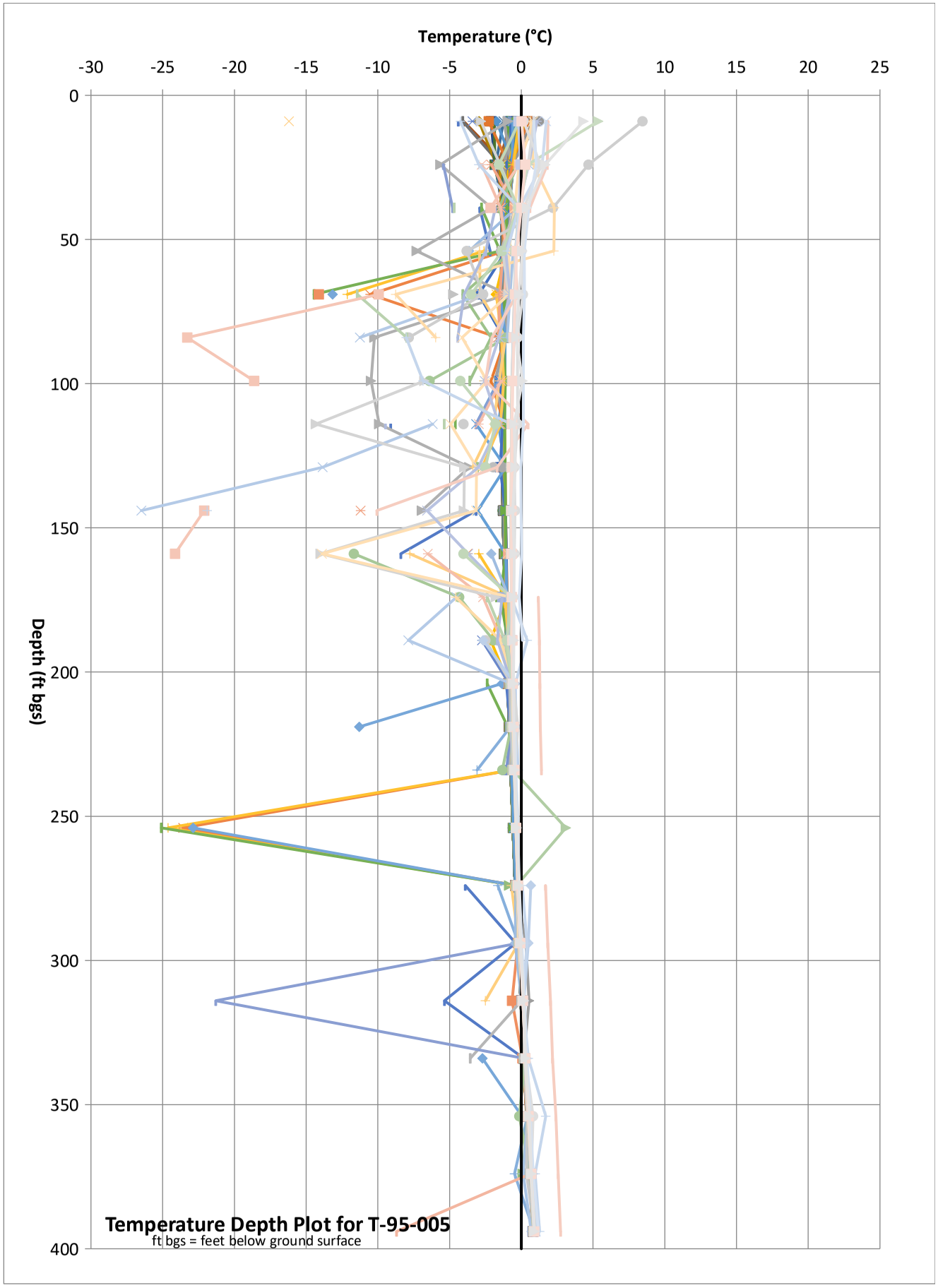

Temperature (°C)
-2
-1
0
1
2
0
50
100
150
200
250
300
350
400
450
Depth (ft bgs)
Temperature Depth Plot for
T-14-110, 2018
(Temperature-axis acale adjusted)
ft bgs = feet below ground surface

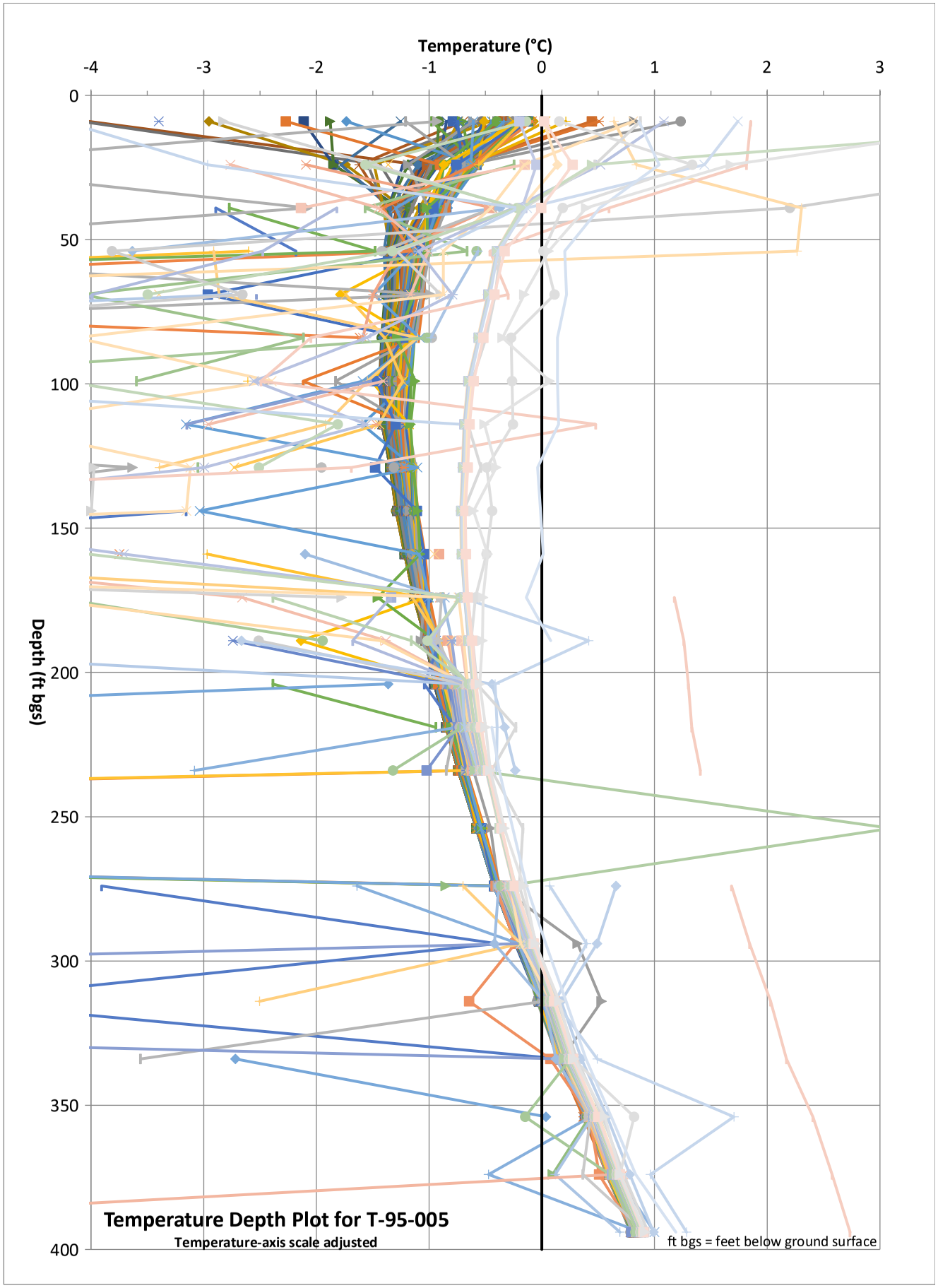

Temperature (°C)
-50
0
50
100
150
200
250
300
Depth (ft bgs)
0
50
100
150
200
250
300
350
400
Temperature Depth Plot for T-95-004
ft bgs = feet below ground surface

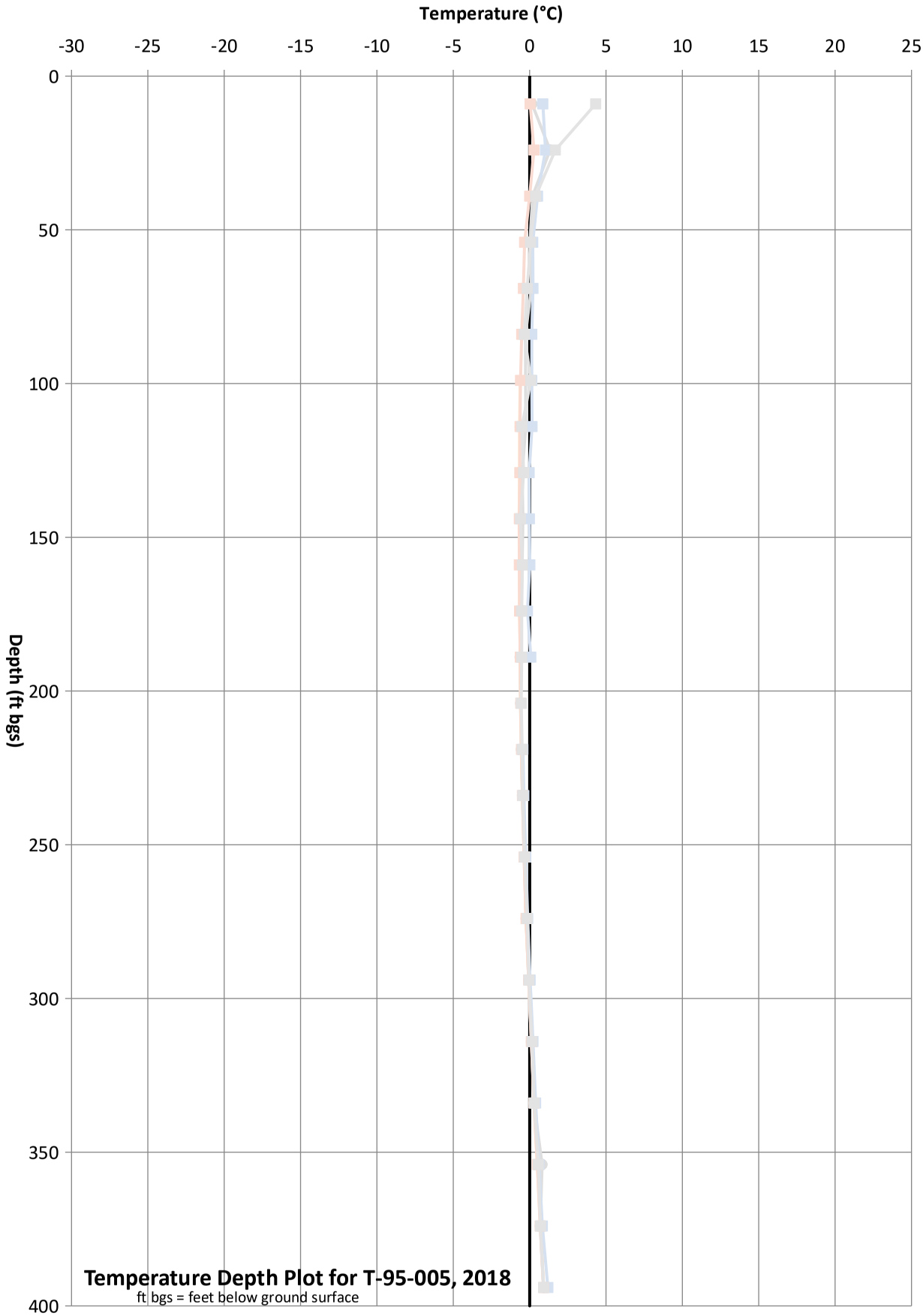

Temperature (°C)
-10
-5
0
5
10
15
20
Depth (ft bgs)
0
50
100
150
200
250
300
350
400
Temperature Depth Plot for T-95-004
(Temperature-axis scale adjusted)
ft bgs = feet below ground surface

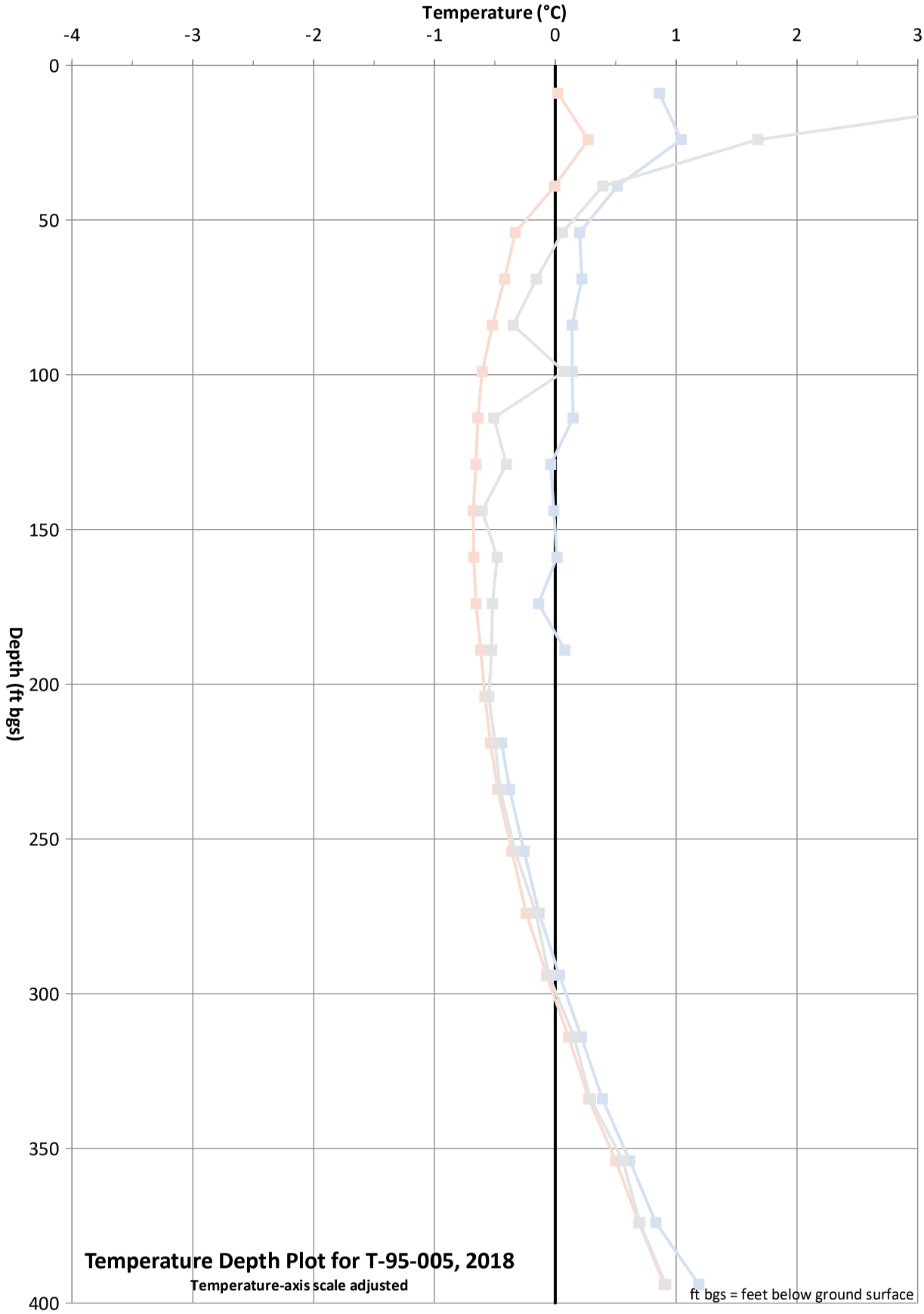

Temperature (°C)
-50
50
150
250
0
50
100
150
200
250
300
350
400
Depth (ft bgs)
No Data Available for 2018 Plot
Temperature Depth Plot for T-95-004, 2018
ft bgs = feet below ground surface

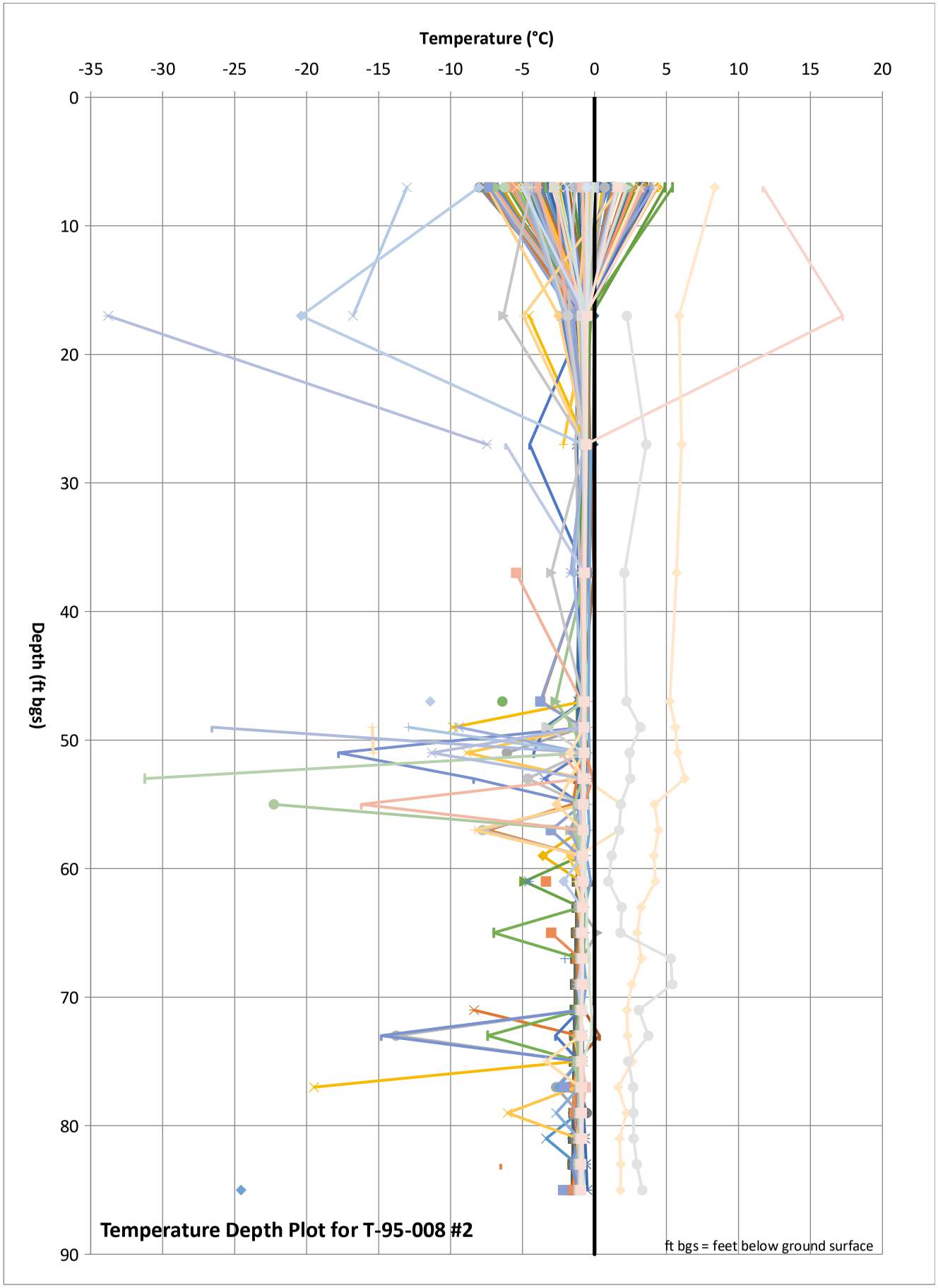

Temperature (°C)
-10
-5
0
5
10
15
20
0
50
100
150
200
250
300
350
400
Depth (ft bgs)
No Data Available for 2018 Plot
Temperature Depth Plot for T-95-004, 2018
(Temperature-axis scale adjusted)
ft bgs = feet below ground surface

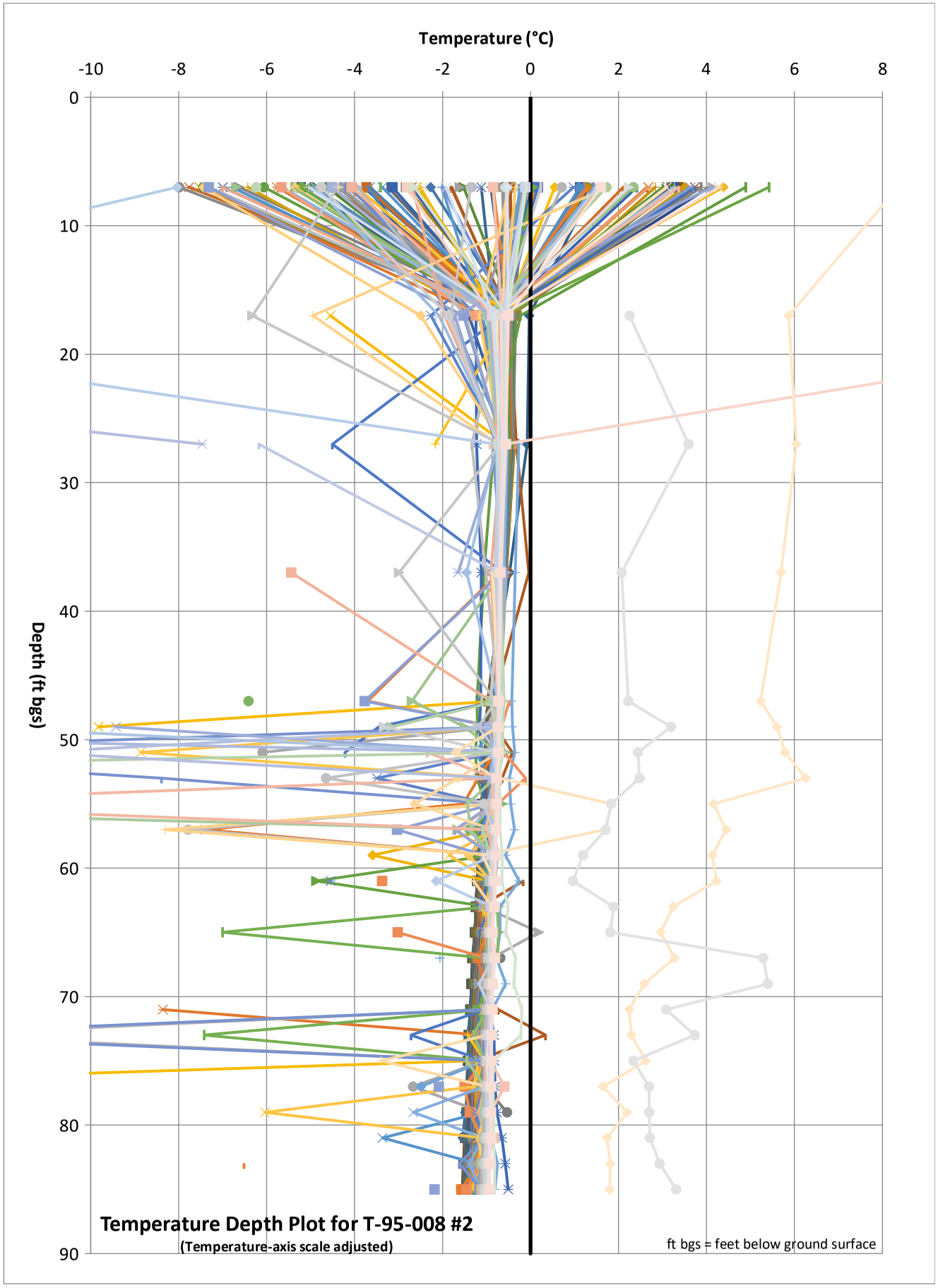

Temperature (°C)
-30
-25
-20
-15
-10
-5
0
5
10
15
20
25
Depth (ft bgs)
0
50
100
150
200
250
300
350
400
Temperature Depth Plot for T-95-005
ft bgs = feet below ground surface

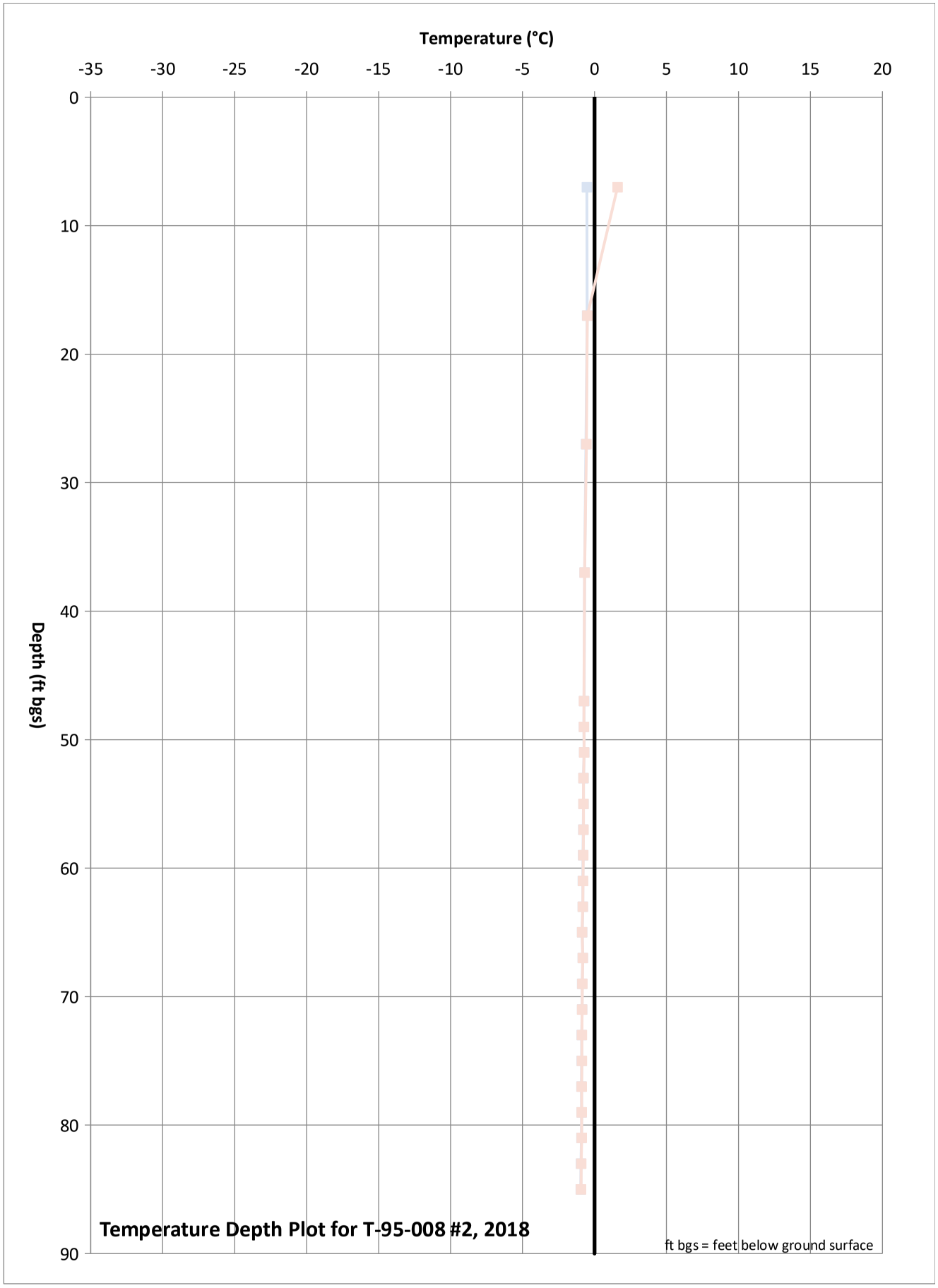

Temperature (°C)
-4
-3
-2
-1
0
1
2
3
0
50
100
150
200
250
300
350
400
Depth (ft bgs)
Temperature Depth Plot for T-95-005
Temperature-axis scale adjusted
ft bgs = feet below ground surface

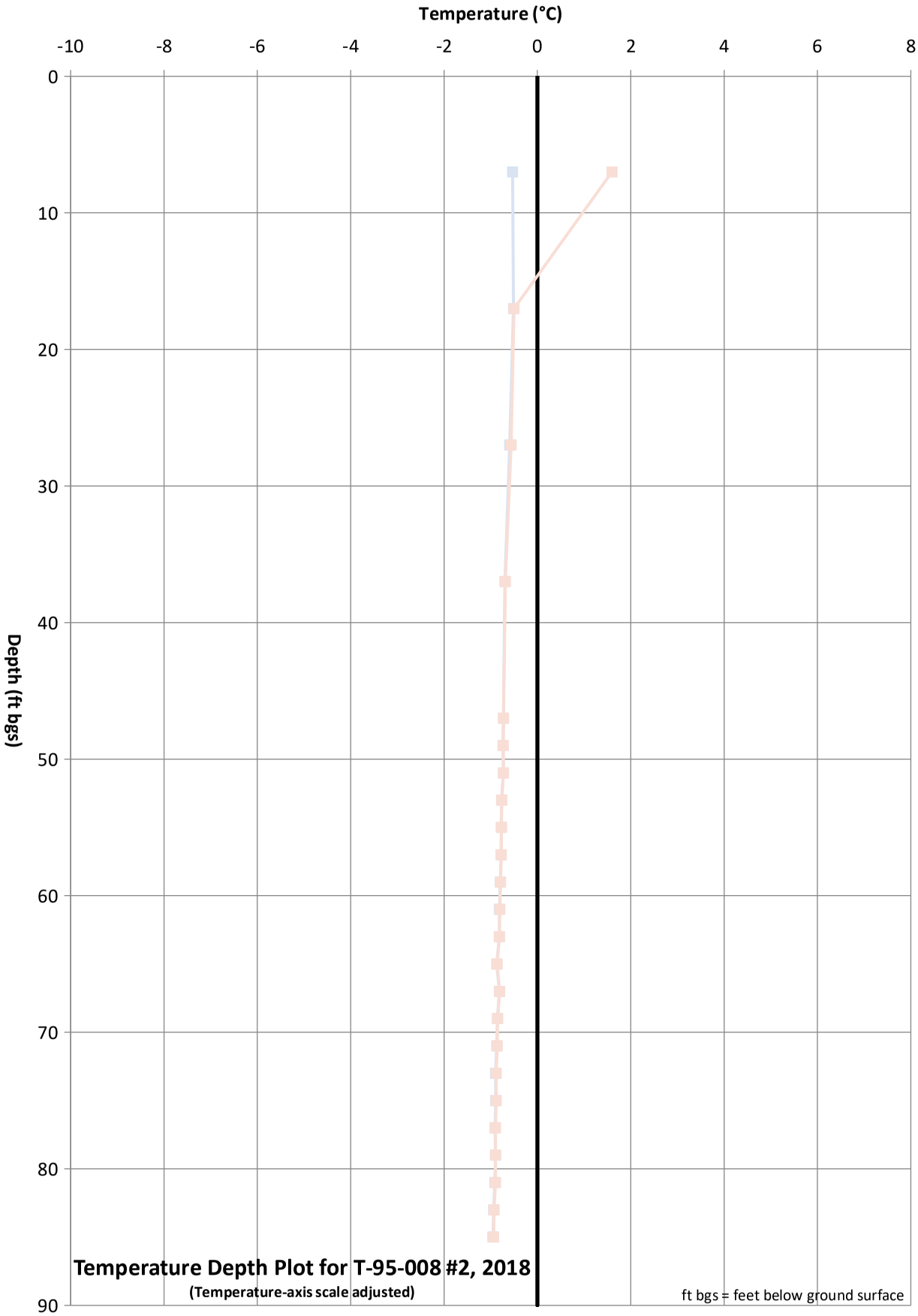

Temperature (°C)
-30
-25
-20
-15
-10
-5
0
5
10
15
20
25
Depth (ft bgs)
0
50
100
150
200
250
300
350
400
Temperature Depth Plot for T-95-005, 2018
ft bgs = feet below ground surface

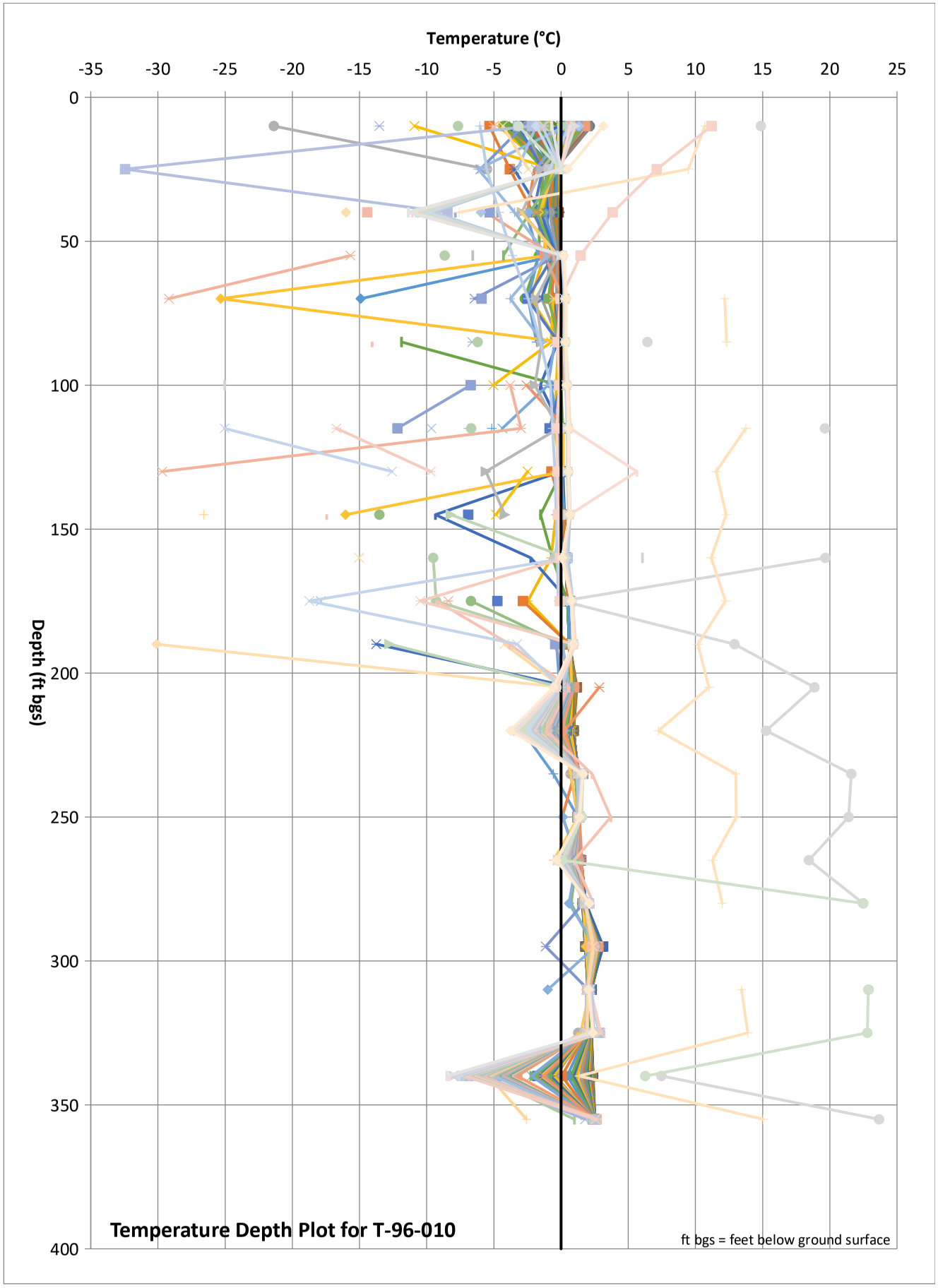

Temperature (°C)
-4
-3
-2
-1
0
1
2
3
0
50
100
150
200
250
300
350
400
Depth (ft bgs)
Temperature Depth Plot for T-95-005, 2018
Temperature-axis scale adjusted
ft bgs = feet below ground surface

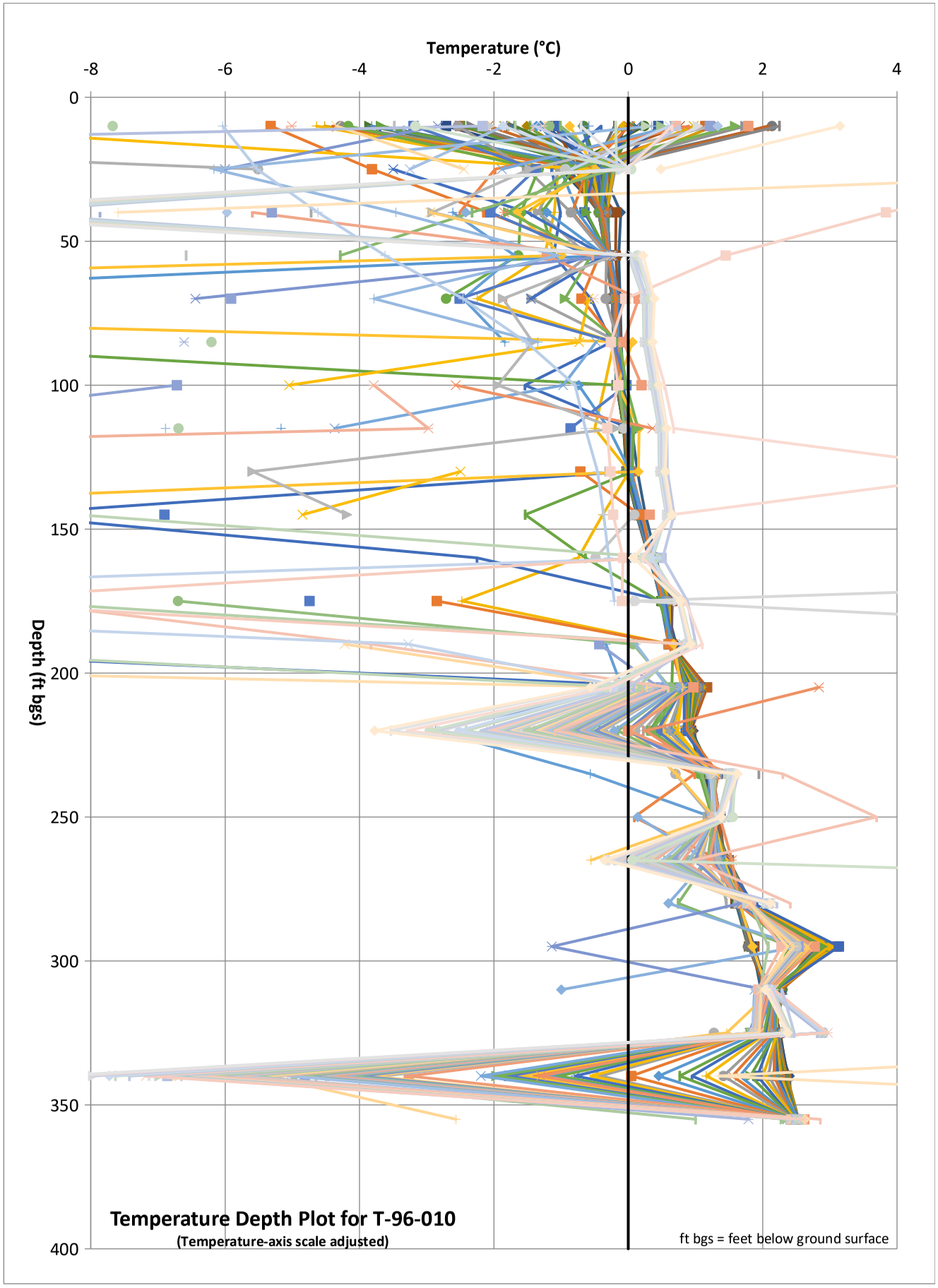

Temperature (°C)
-35
-30
-25
-20
-15
-10
-5
0
5
10
15
20
Depth (ft bgs)
0
10
20
30
40
50
60
70
80
90
Temperature Depth Plot for T-95-008 #2
ft bgs = feet below ground surface

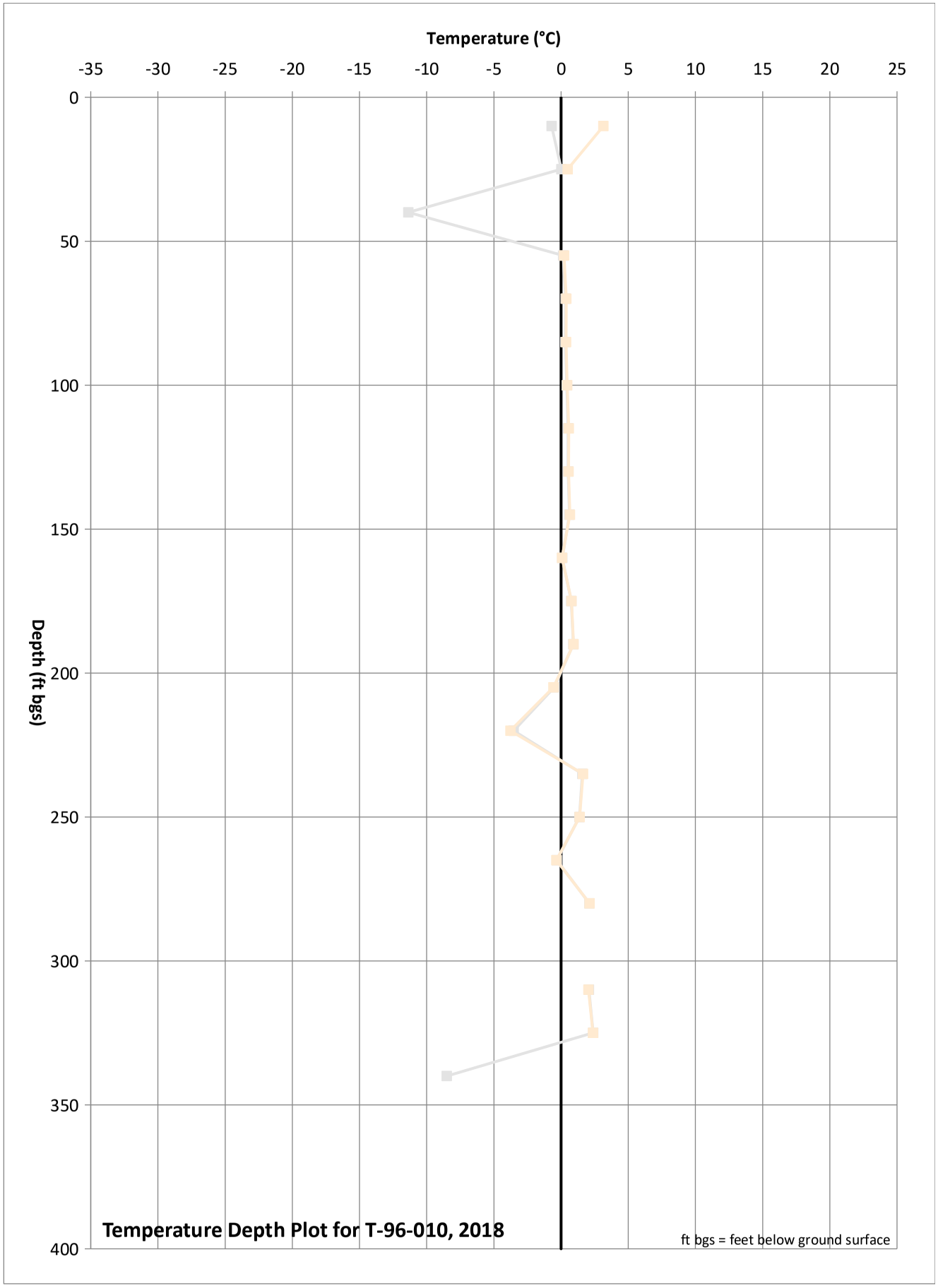

Temperature (°C)
-10
-8
-6
-4
-2
0
2
4
6
8
Depth (ft bgs)
0
10
20
30
40
50
60
70
80
90
Temperature Depth Plot for T-95-008 #2
(Temperature-axis scale adjusted)
ft bgs = feet below ground surface

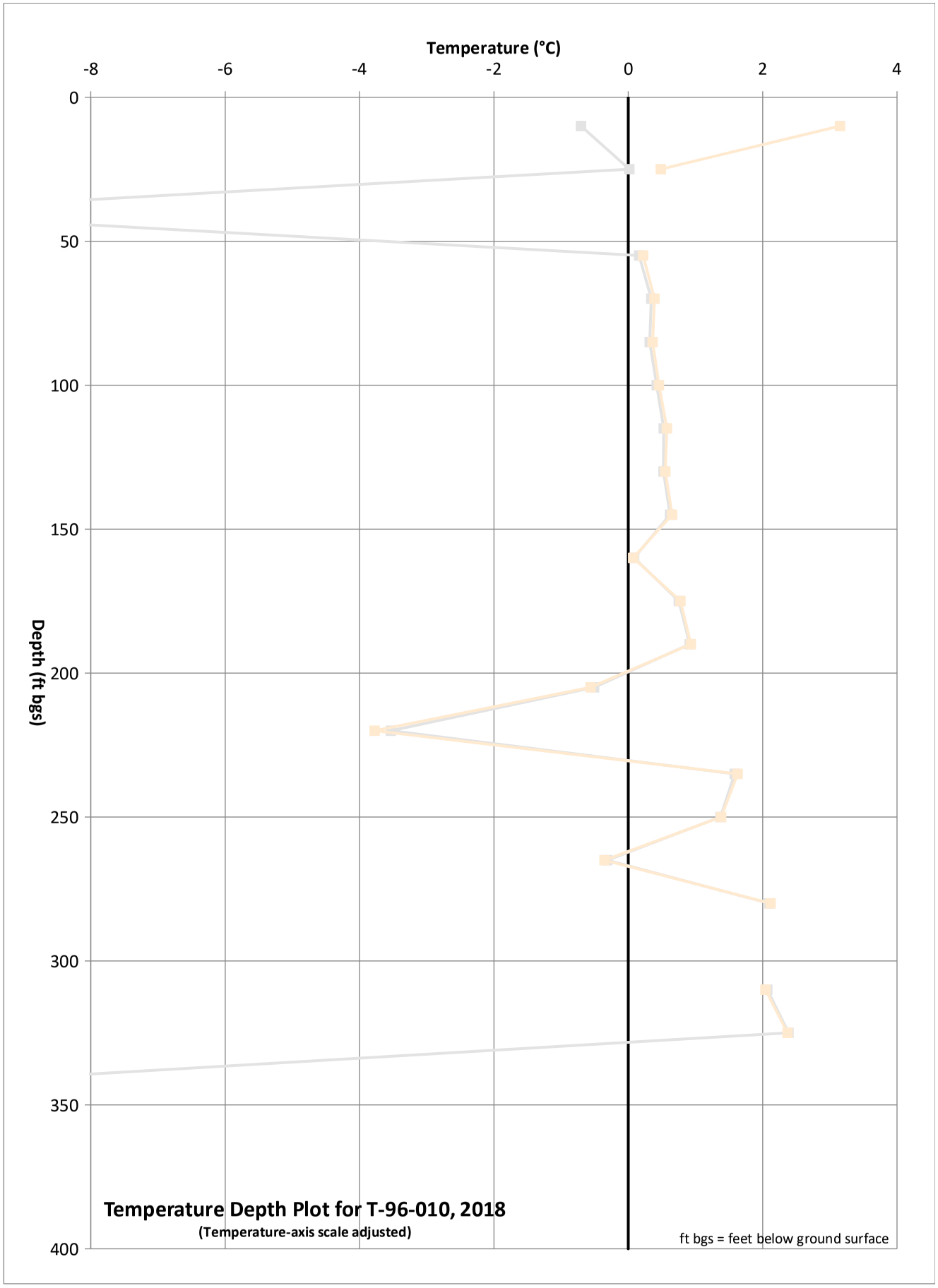

Temperature (°C)
-35
-30
-25
-20
-15
-10
-5
0
5
10
15
20
Depth (ft bgs)
0
10
20
30
40
50
60
70
80
90
Temperature Depth Plot for T-95-008 #2, 2018
ft bgs = feet below ground surface

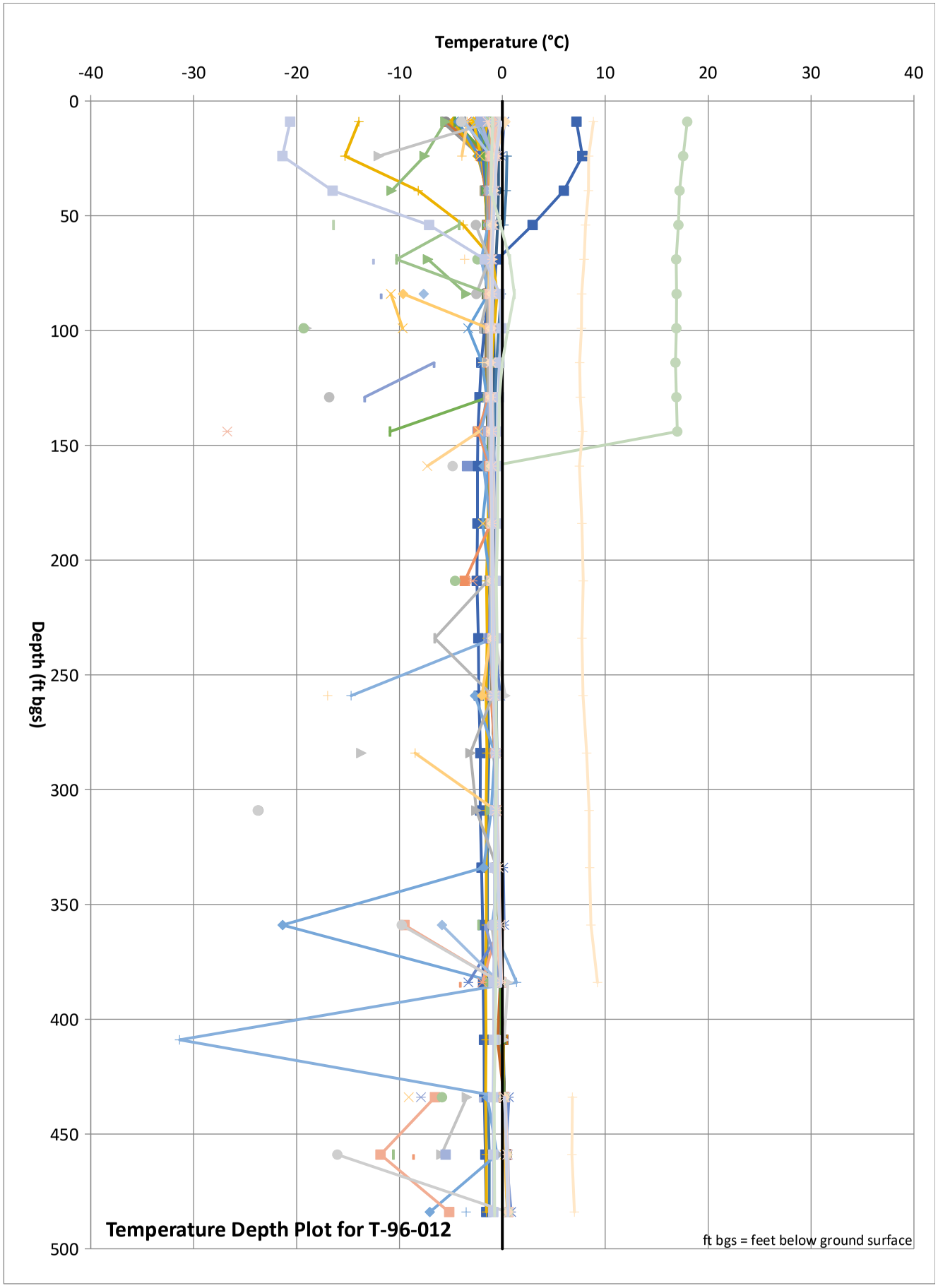

Temperature (°C)
-10
-8
-6
-4
-2
0
2
4
6
8
0
10
20
30
40
50
60
70
80
90
Depth (ft bgs)
Temperature Depth Plot for T-95-008 #2, 2018
(Temperature-axis scale adjusted)
ft bgs = feet below ground surface

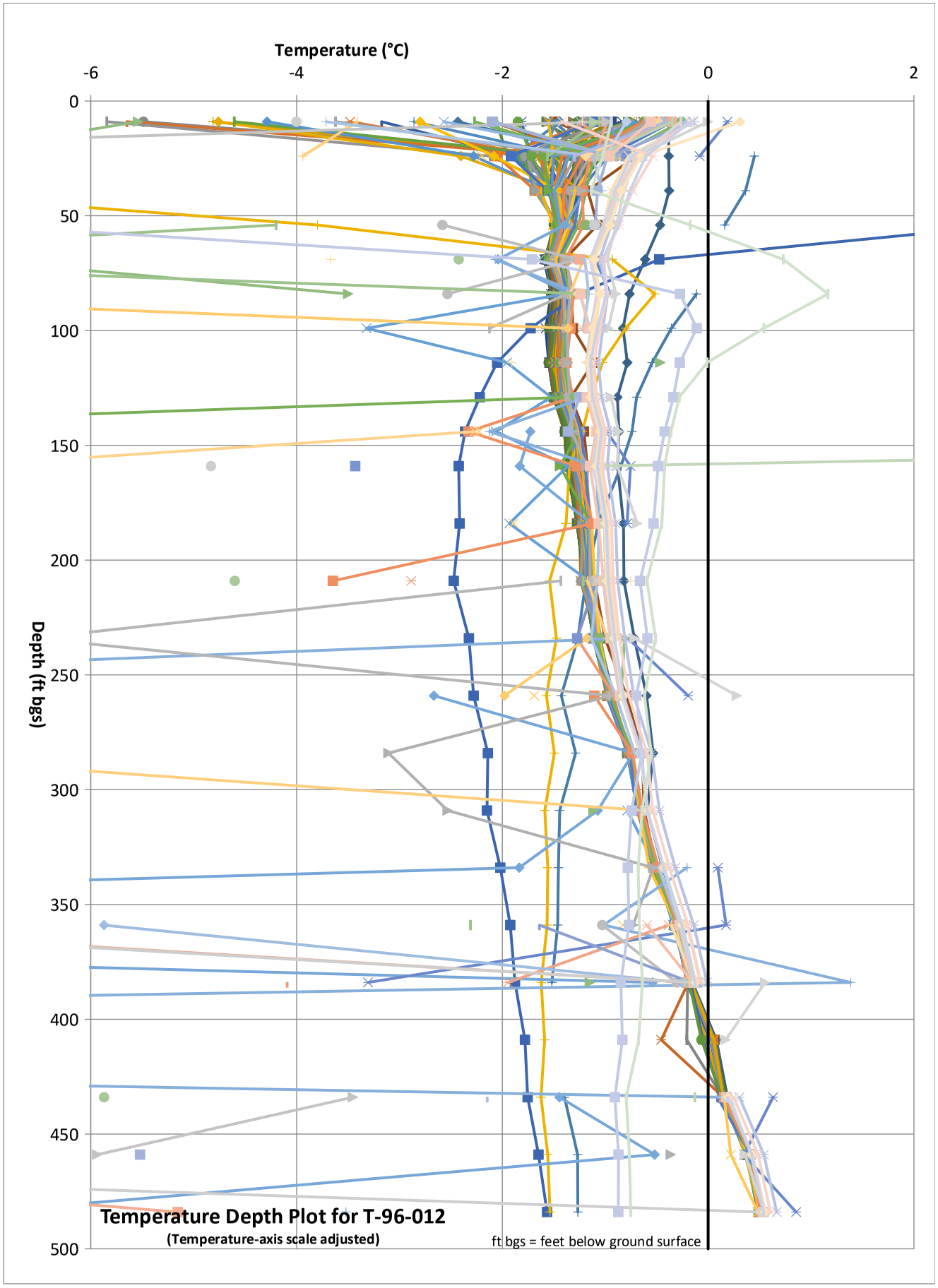

Temperature (°C)
-35
-30
-25
-20
-15
-10
-5
0
5
10
15
20
25
Depth (ft bgs)
0
50
100
150
200
250
300
350
400
Temperature Depth Plot for T-96-010
ft bgs = feet below ground surface

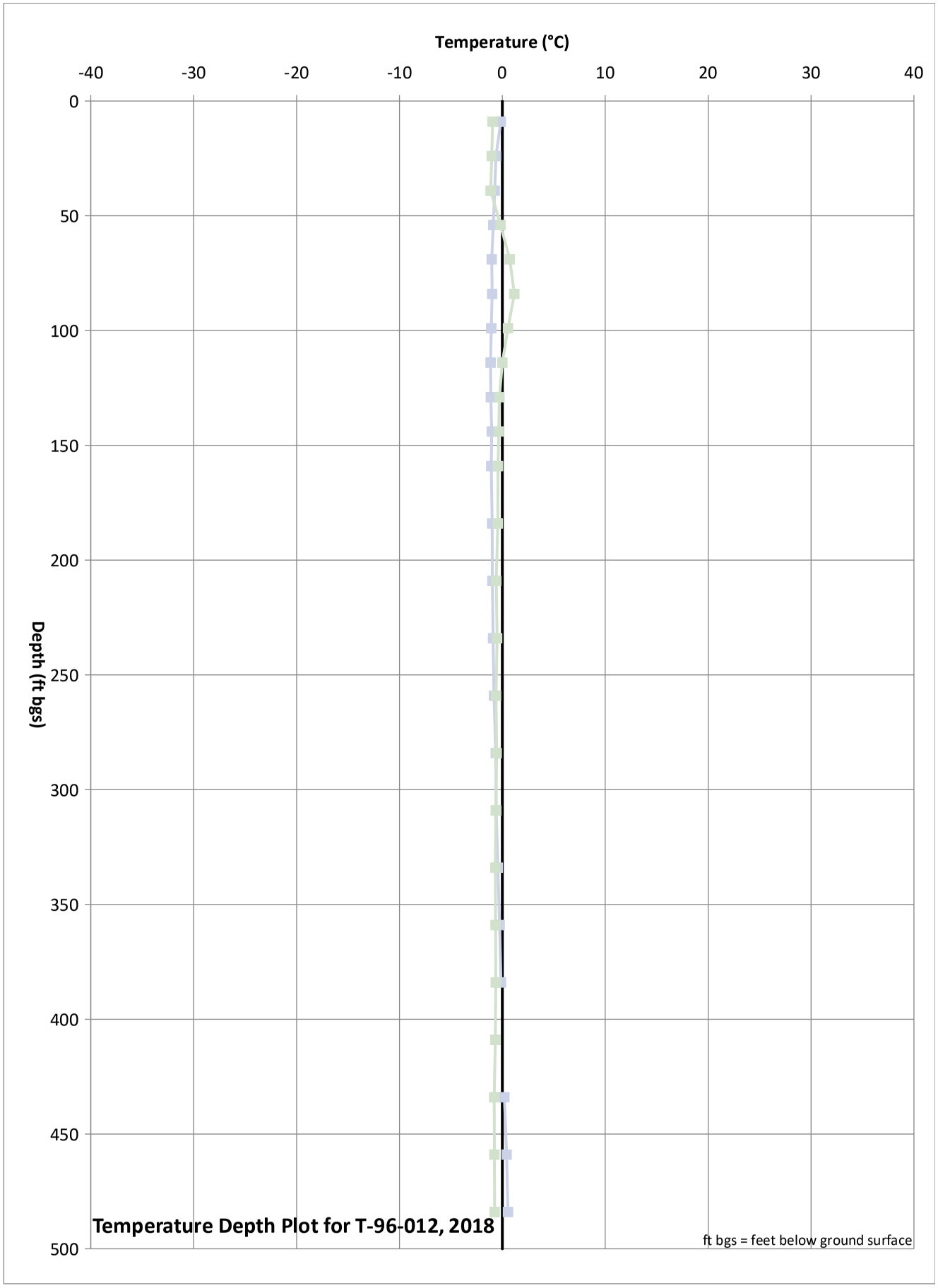

Temperature (°C)
-8
-6
-4
-2
0
2
4
0
50
100
150
200
250
300
350
400
Depth (ft bgs)
Temperature Depth Plot for T-96-010
(Temperature-axis scale adjusted)
ft bgs = feet below ground surface

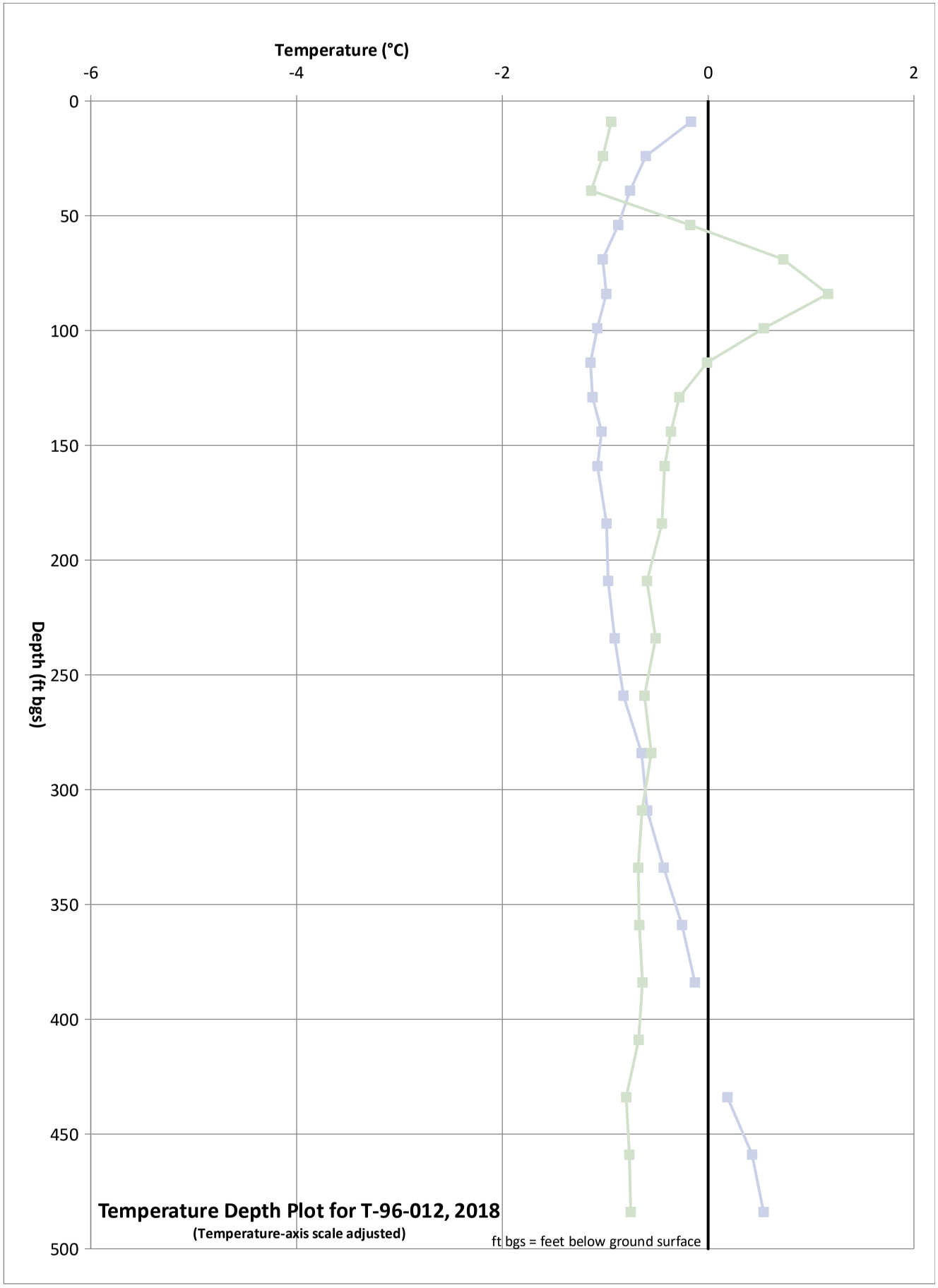

Temperature (°C)
-35
-30
-25
-20
-15
-10
-5
0
5
10
15
20
25
Depth (ft bgs)
0
50
100
150
200
250
300
350
400
Temperature Depth Plot for T-96-010, 2018
ft bgs = feet below ground surface

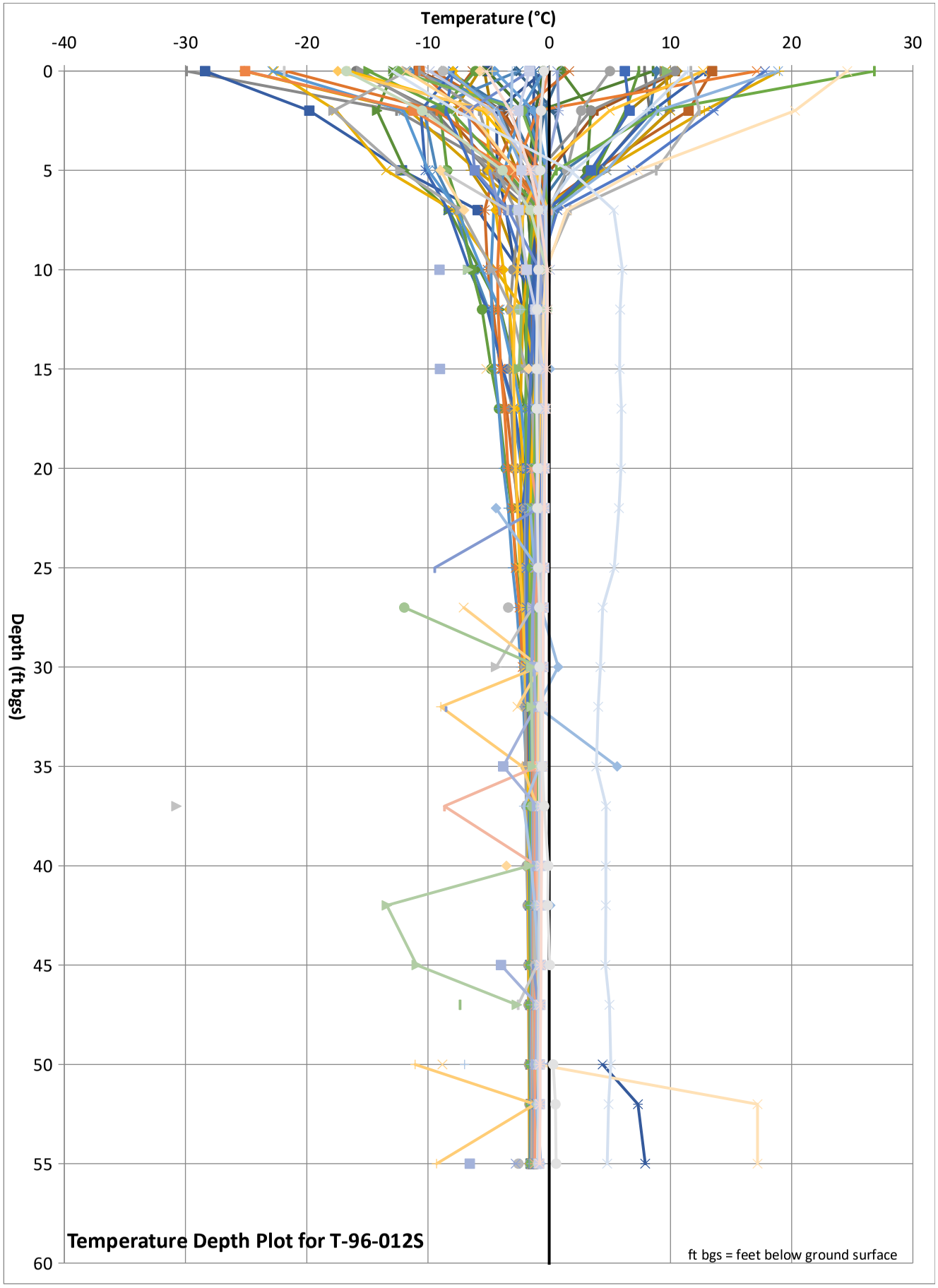

Temperature (°C)
-8
-6
-4
-2
0
2
4
0
50
100
150
200
250
300
350
400
Depth (ft bgs)
Temperature Depth Plot for T-96-010, 2018
(Temperature-axis scale adjusted)
ft bgs = feet below ground surface

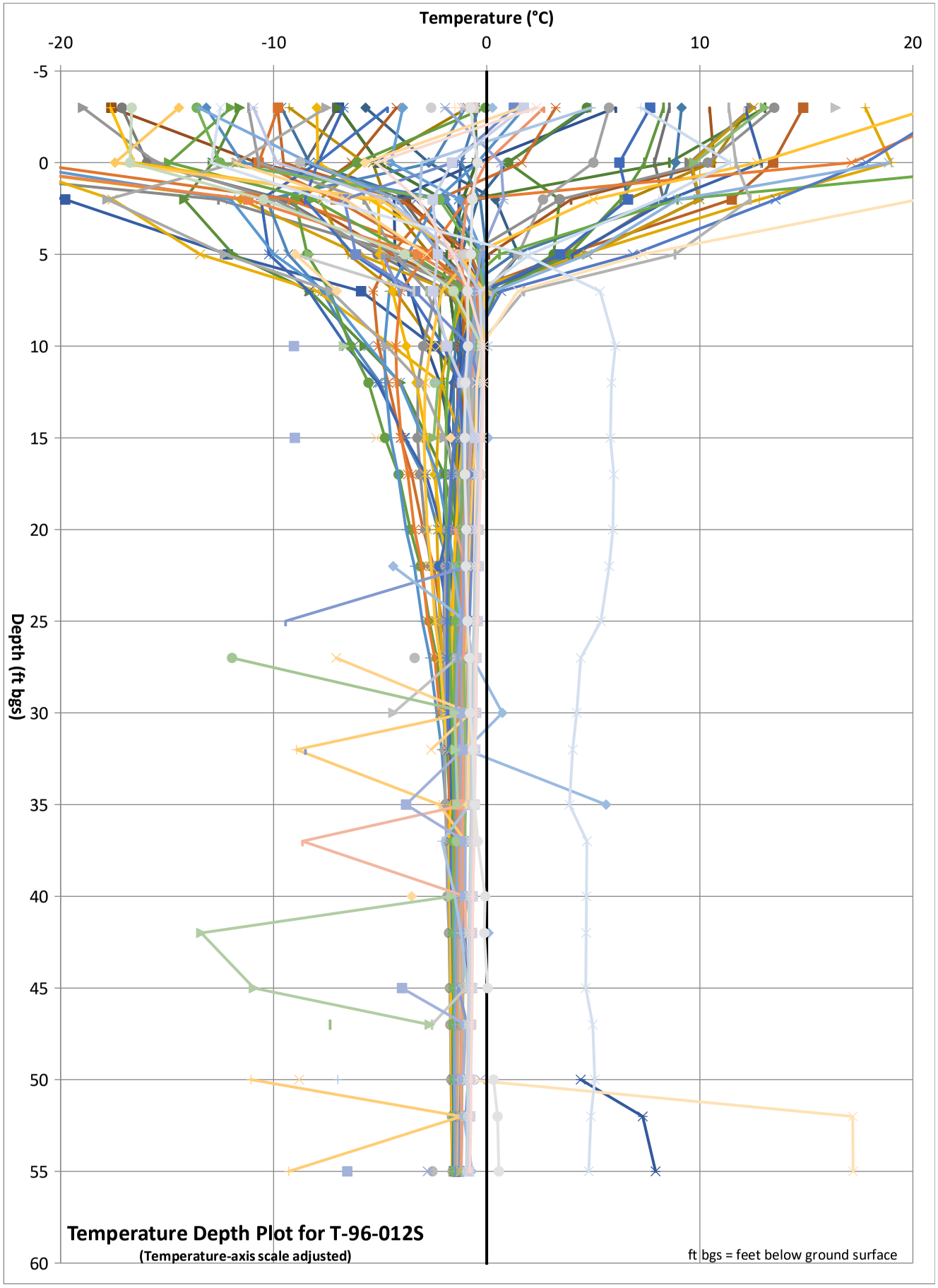

Temperature (°C)
-40
-30
-20
-10
0
10
20
30
40
Depth (ft bgs)
0
50
100
150
200
250
300
350
400
450
500
Temperature Depth Plot for T-96-012
ft bgs = feet below ground surface

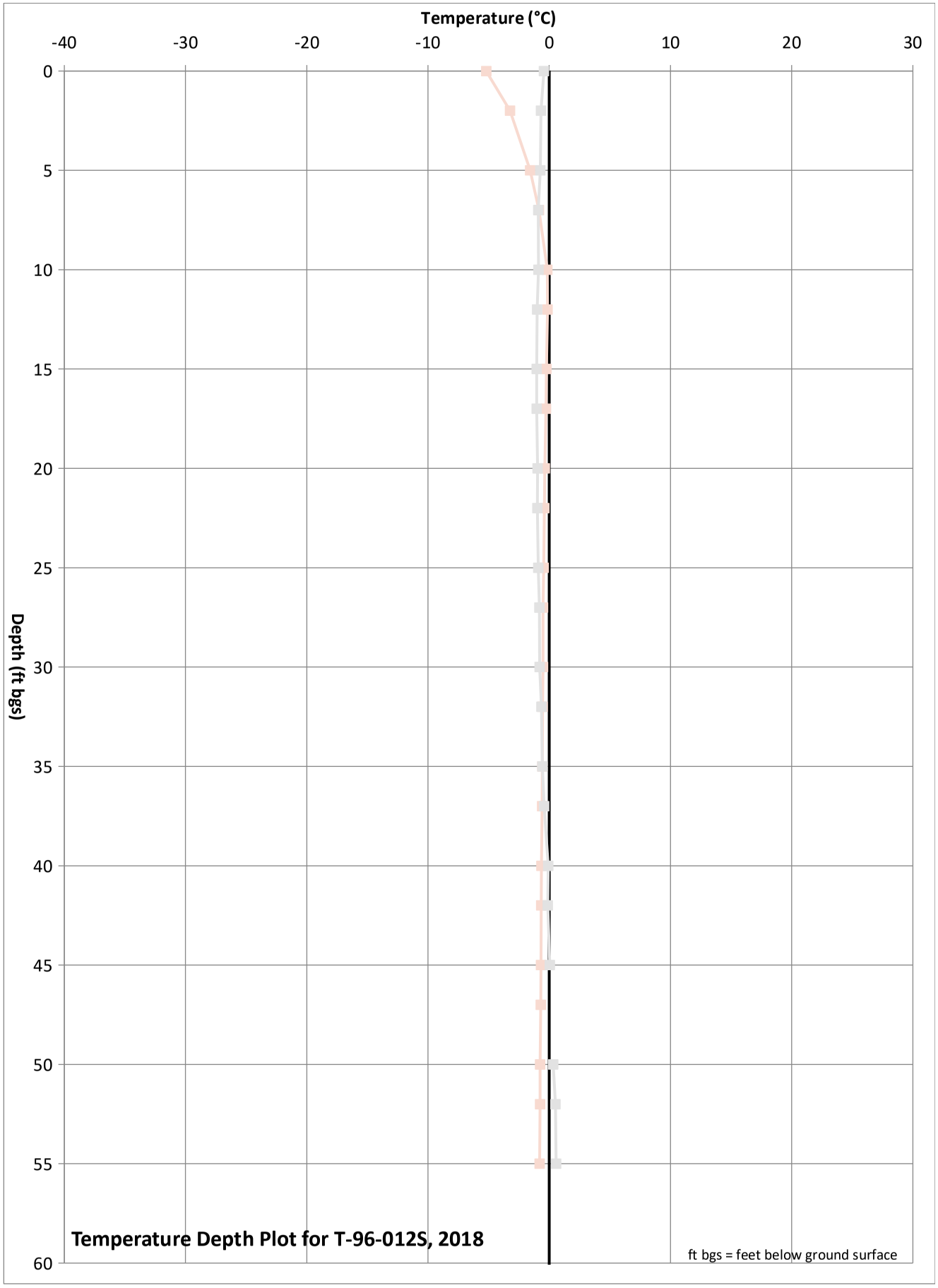

Temperature (°C)
-6
-4
-2
0
2
0
50
100
150
200
250
300
350
400
450
500
Depth (ft bgs)
Temperature Depth Plot for T-96-012
(Temperature-axis scale adjusted)
ft bgs = feet below ground surface

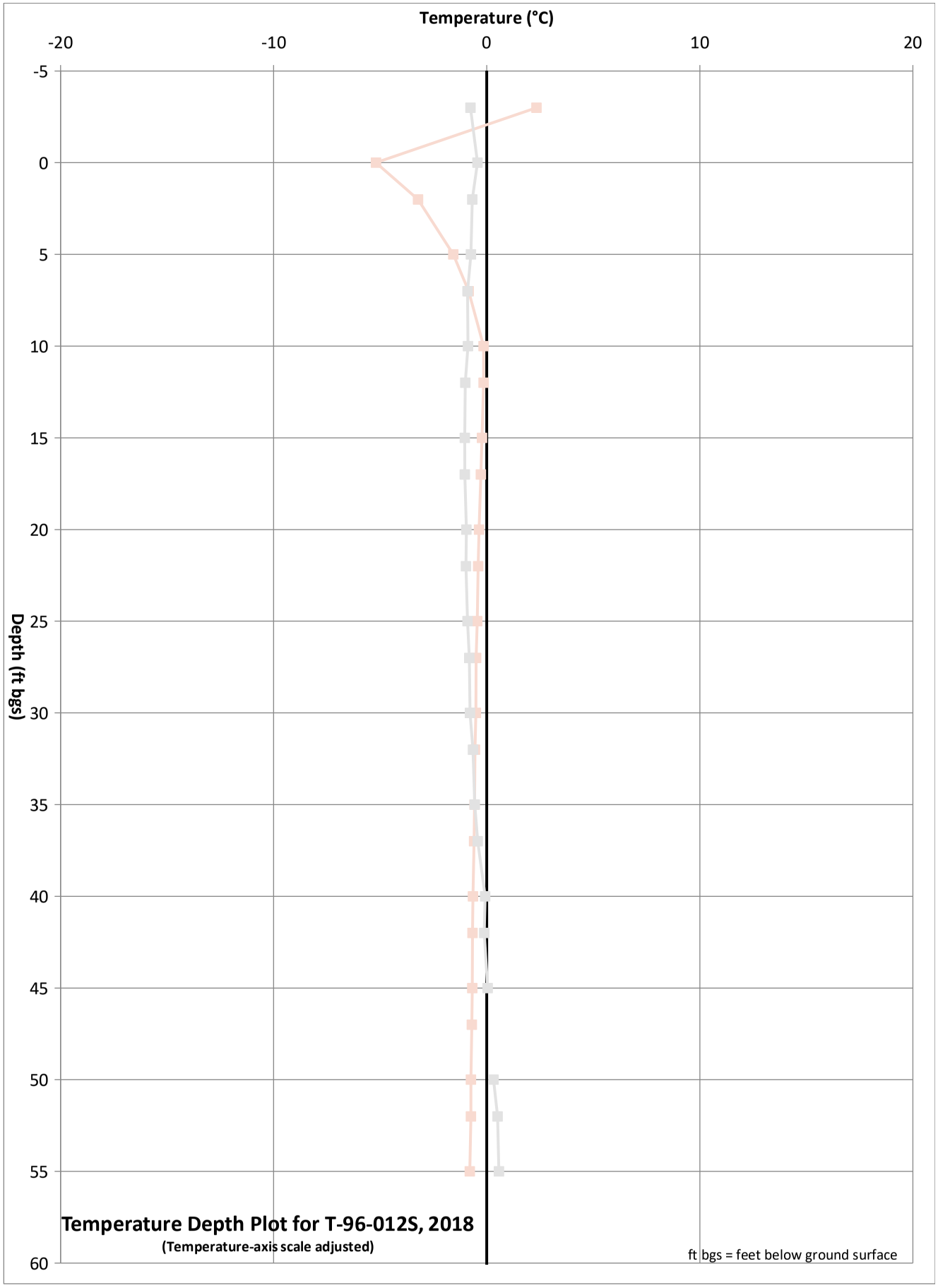

Temperature (°C)
-40
-30
-20
-10
0
10
20
30
40
Depth (ft bgs)
0
50
100
150
200
250
300
350
400
450
500
Temperature Depth Plot for T-96-012, 2018
ft bgs = feet below ground surface

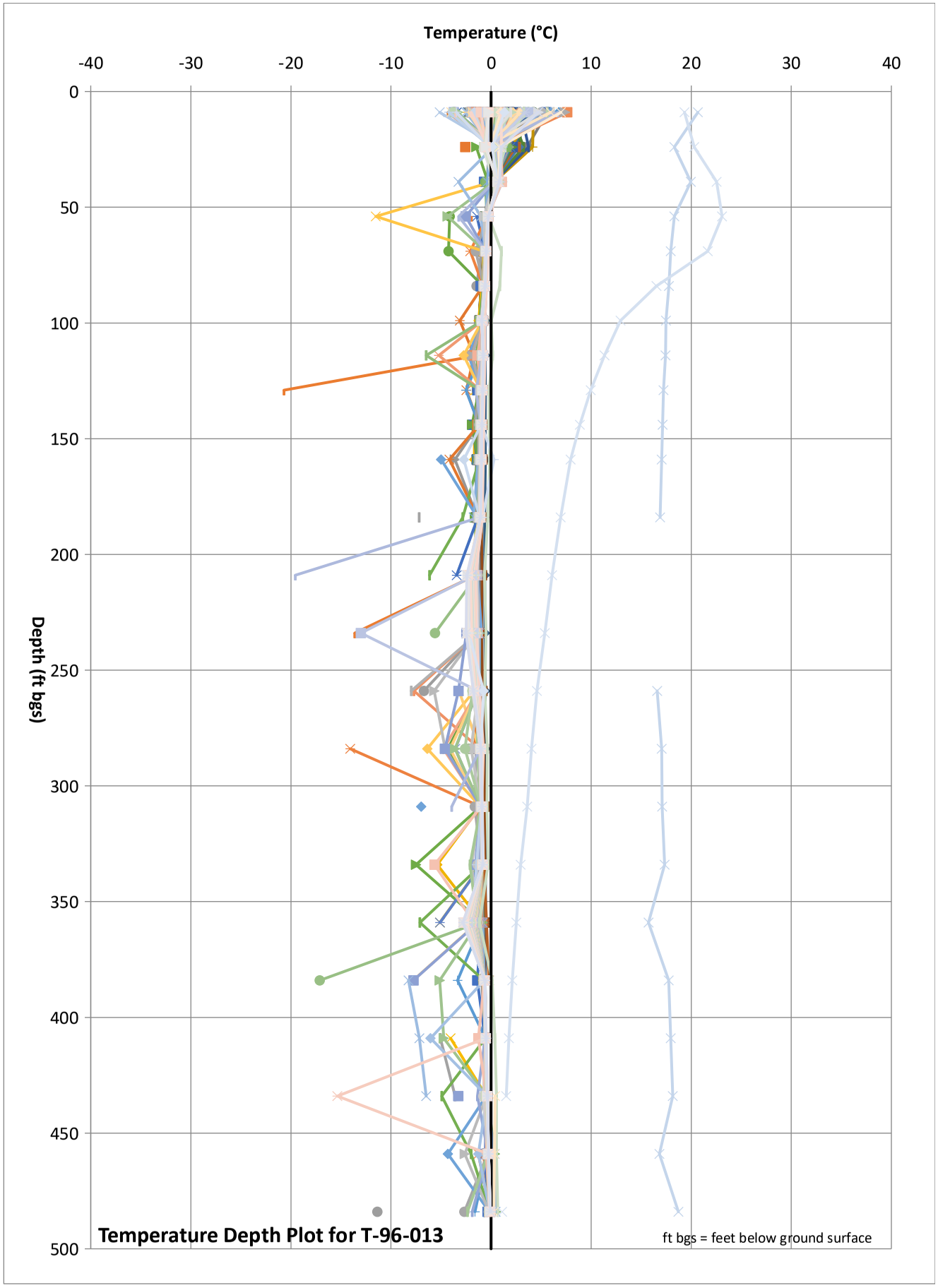

Temperature (°C)
-6
-4
-2
0
2
0
50
100
150
200
250
300
350
400
450
500
Depth (ft bgs)
Temperature Depth Plot for T-96-012, 2018
(Temperature-axis scale adjusted)
ft bgs = feet below ground surface

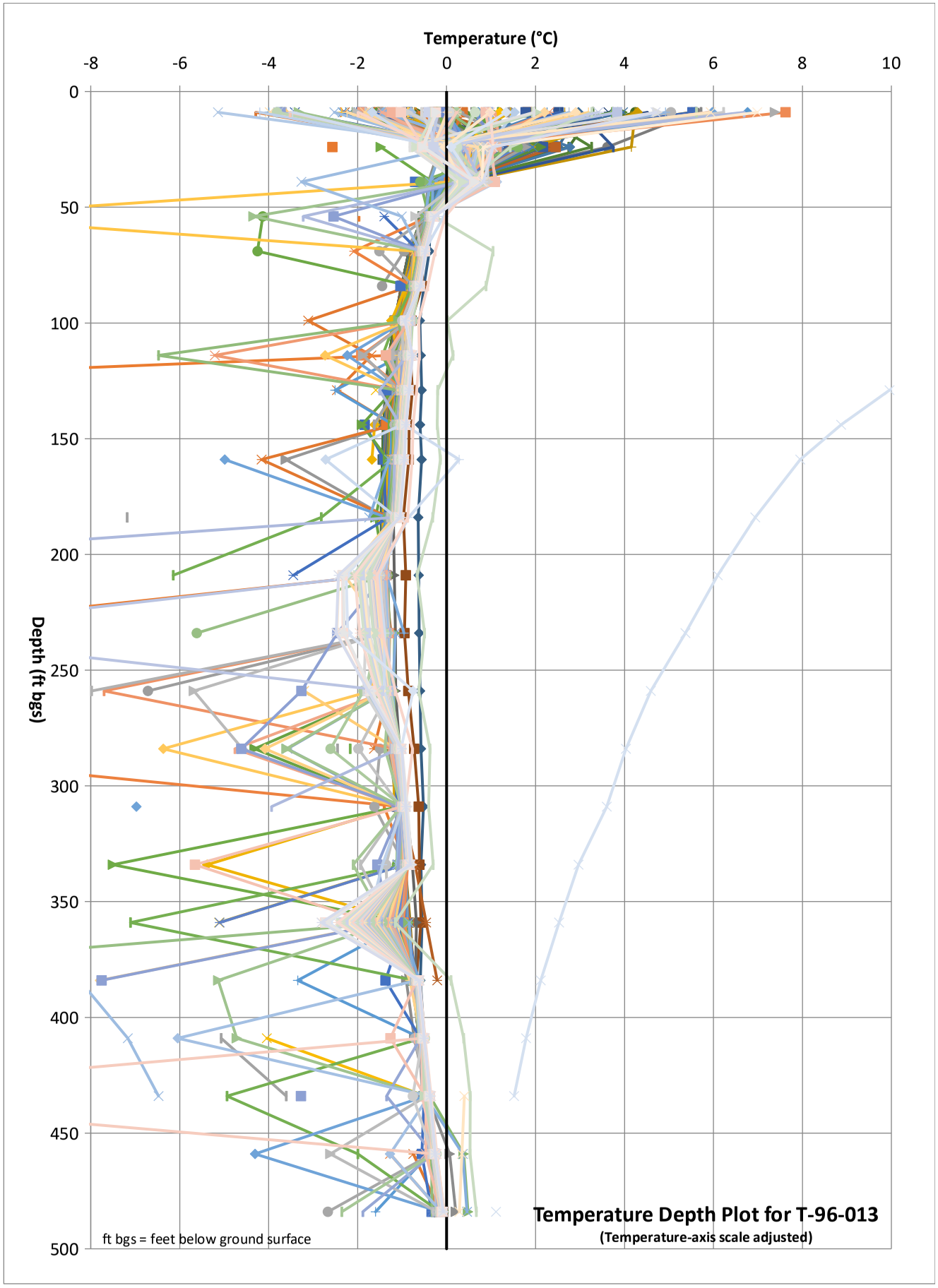

Temperature (°C)
-40
-30
-20
-10
0
10
20
30
Depth (ft bgs)
0
5
10
15
20
25
30
35
40
45
50
55
60
Temperature Depth Plot for T-96-012S
ft bgs = feet below ground surface

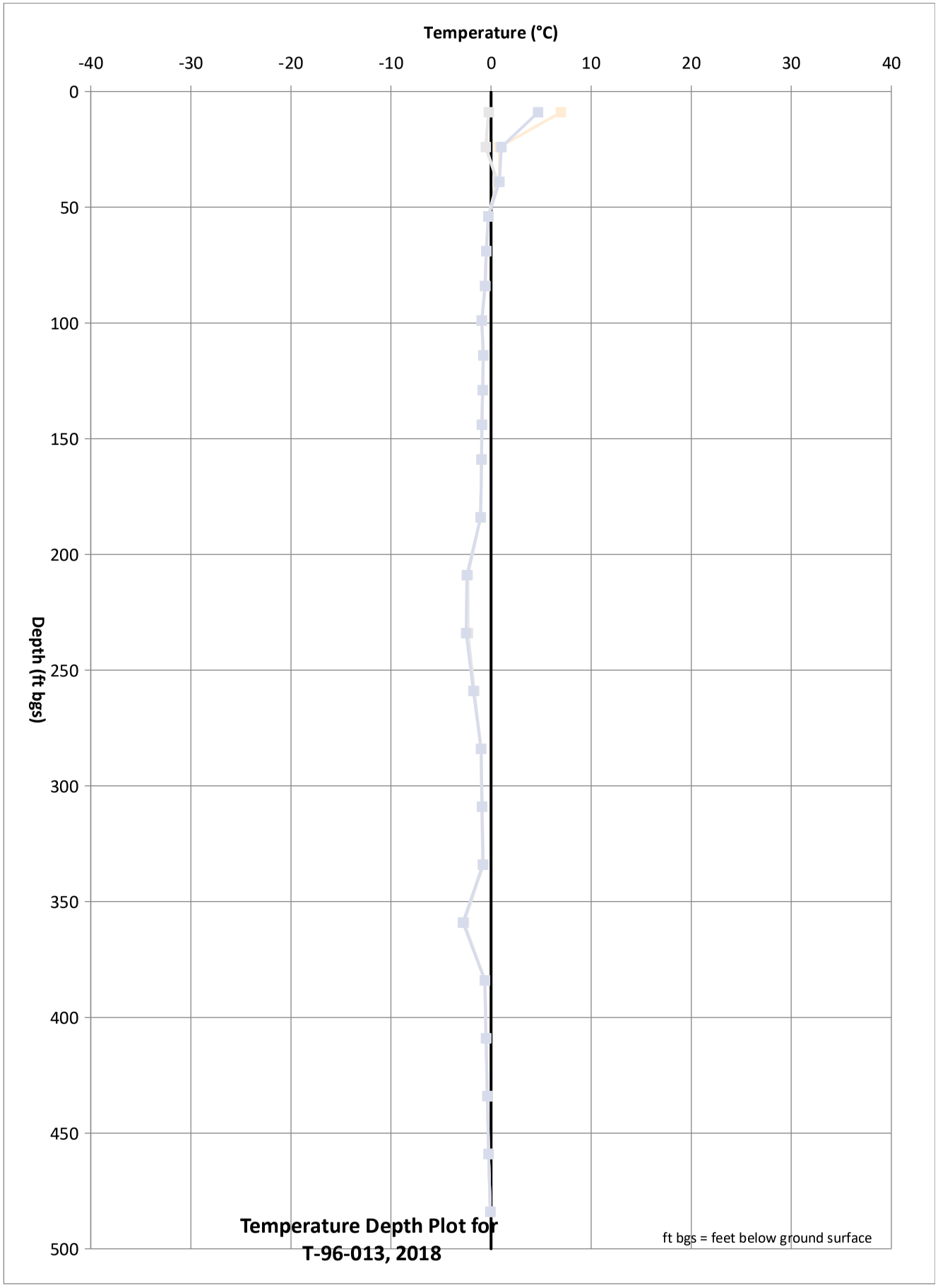

Temperature (°C)
-20
-10
0
10
20
Depth (ft bgs)
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
Temperature Depth Plot for T-96-012S
(Temperature-axis scale adjusted)
ft bgs = feet below ground surface

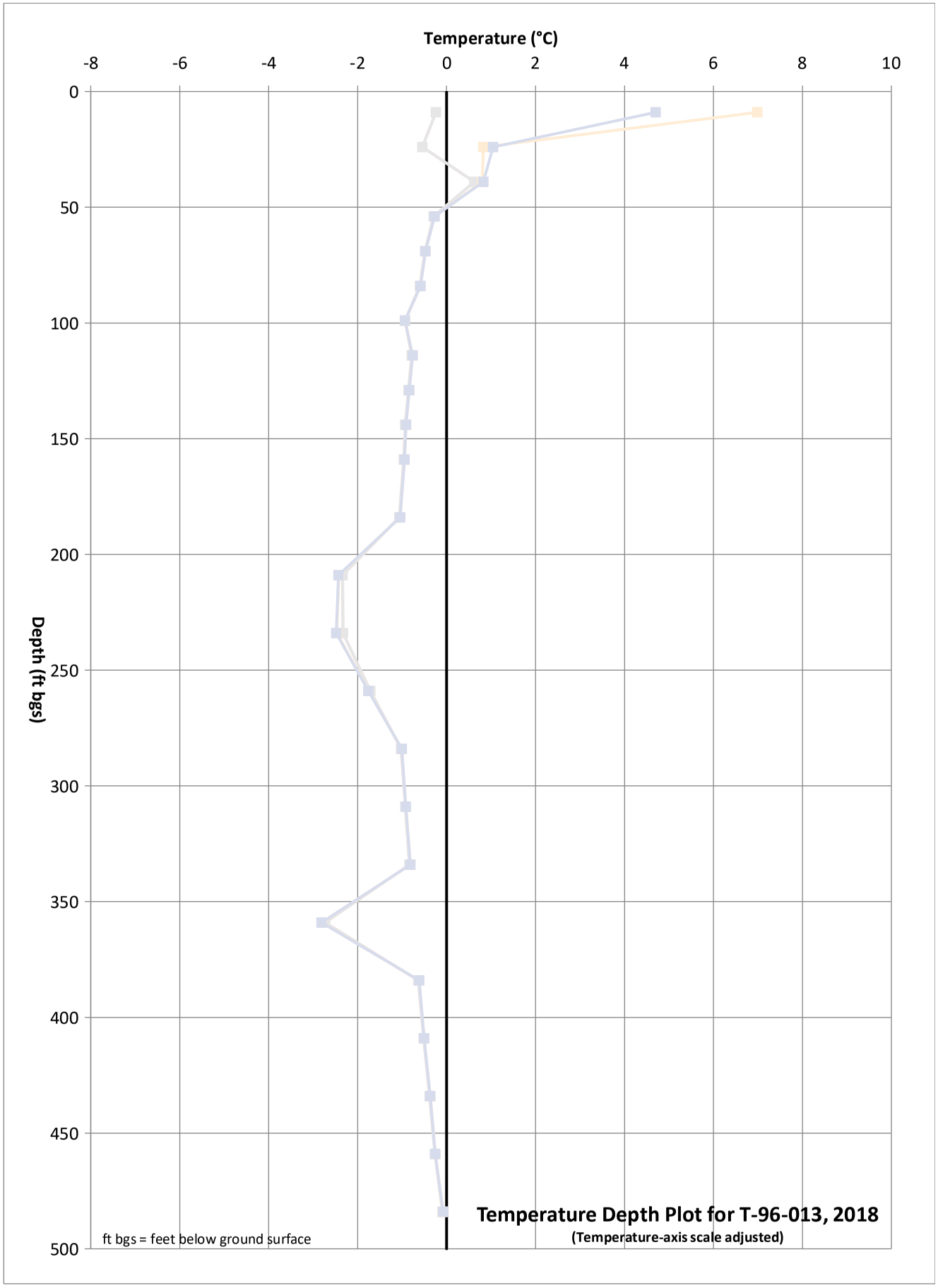

Temperature (°C)
-40
-30
-20
-10
0
10
20
30
Depth (ft bgs)
0
5
10
15
20
25
30
35
40
45
50
55
60
Temperature Depth Plot for T-96-012S, 2018
ft bgs = feet below ground surface

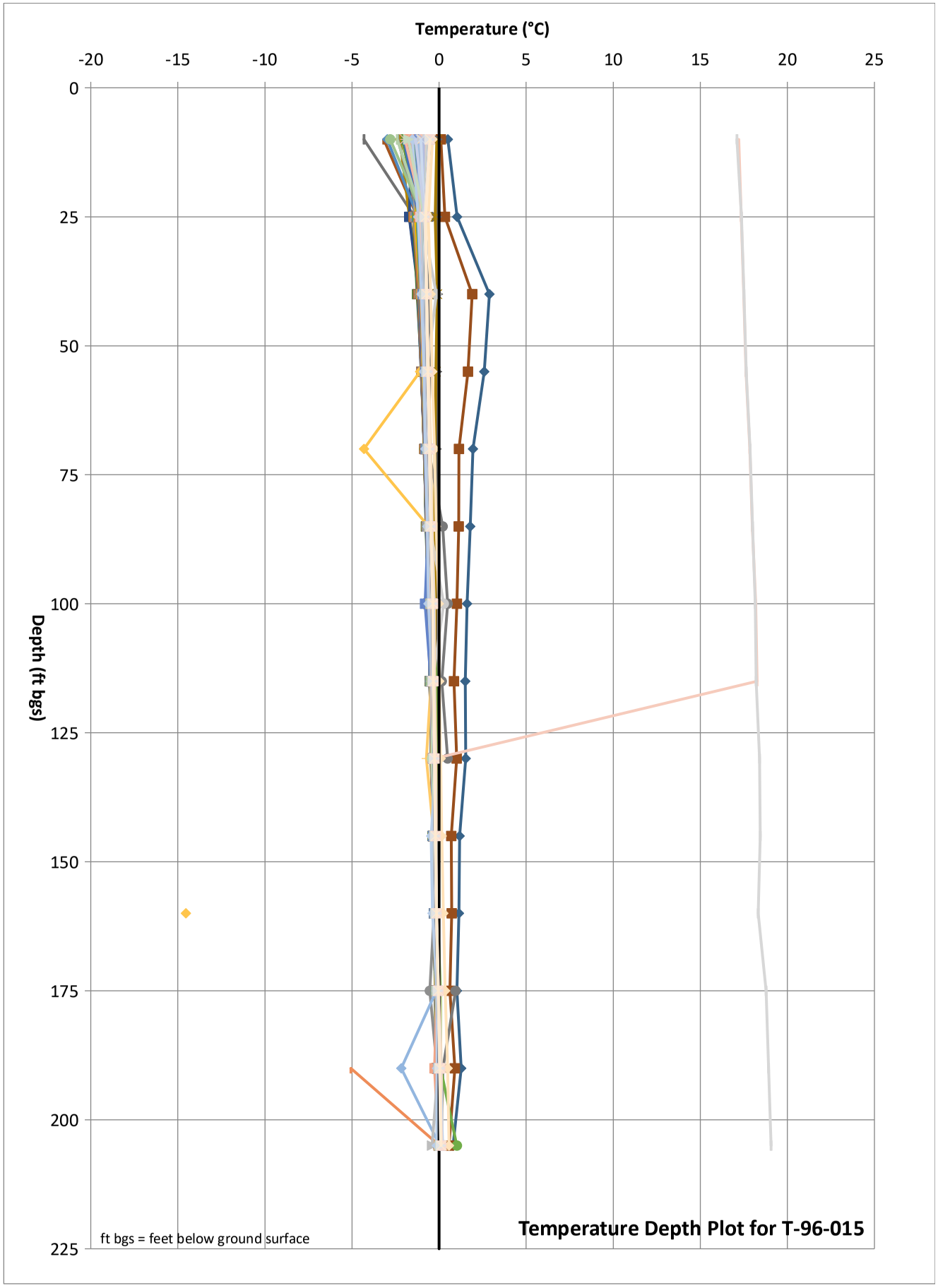

Temperature (°C)
-20
-10
0
10
20
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
Depth (ft bgs)
Temperature Depth Plot for T-96-012S, 2018
(Temperature-axis scale adjusted)
ft bgs = feet below ground surface

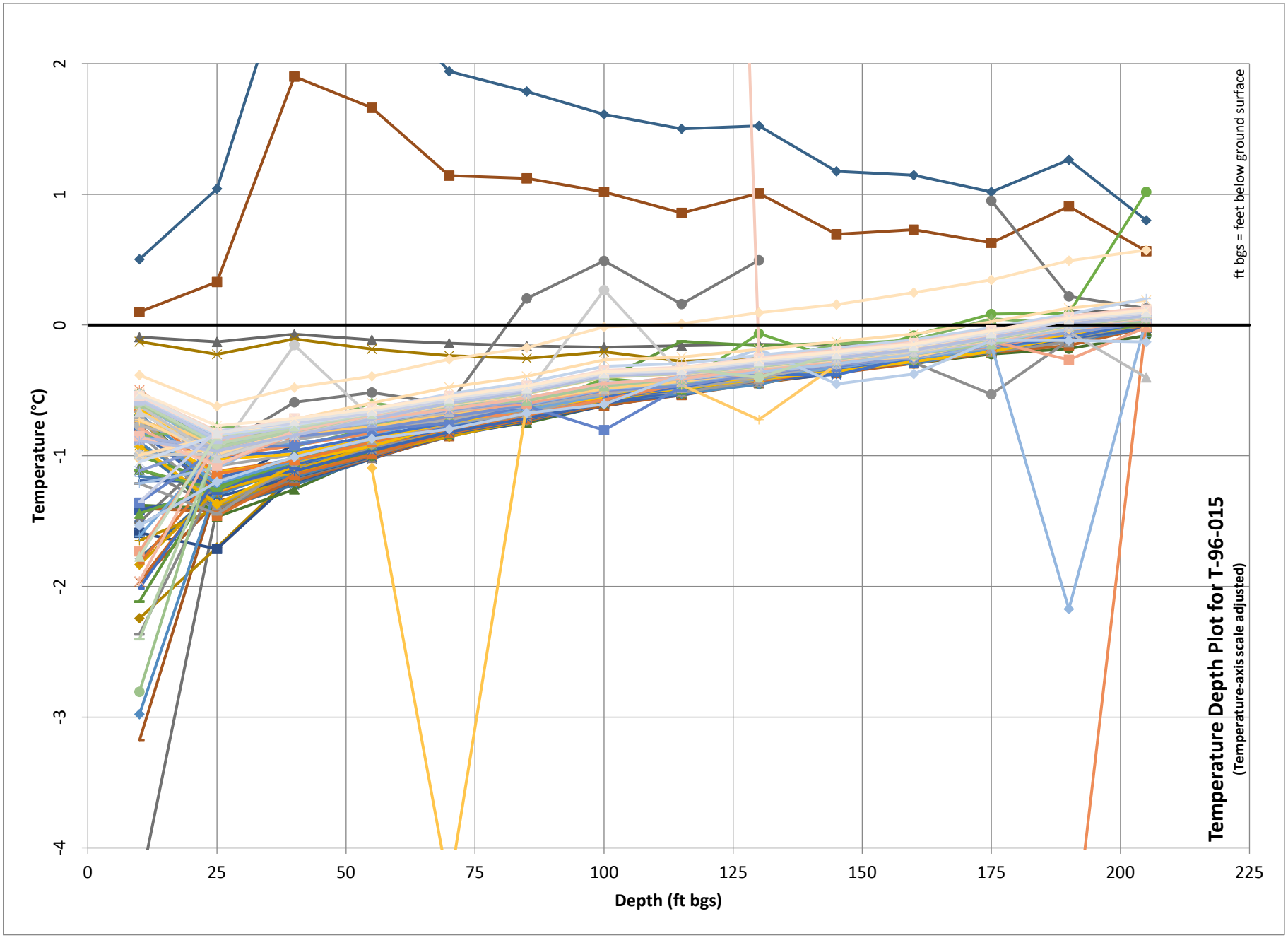

Temperature (°C)
-40
-30
-20
-10
0
10
20
30
40
Depth (ft bgs)
0
50
100
150
200
250
300
350
400
450
500
Temperature Depth Plot for T-96-013
ft bgs = feet below ground surface

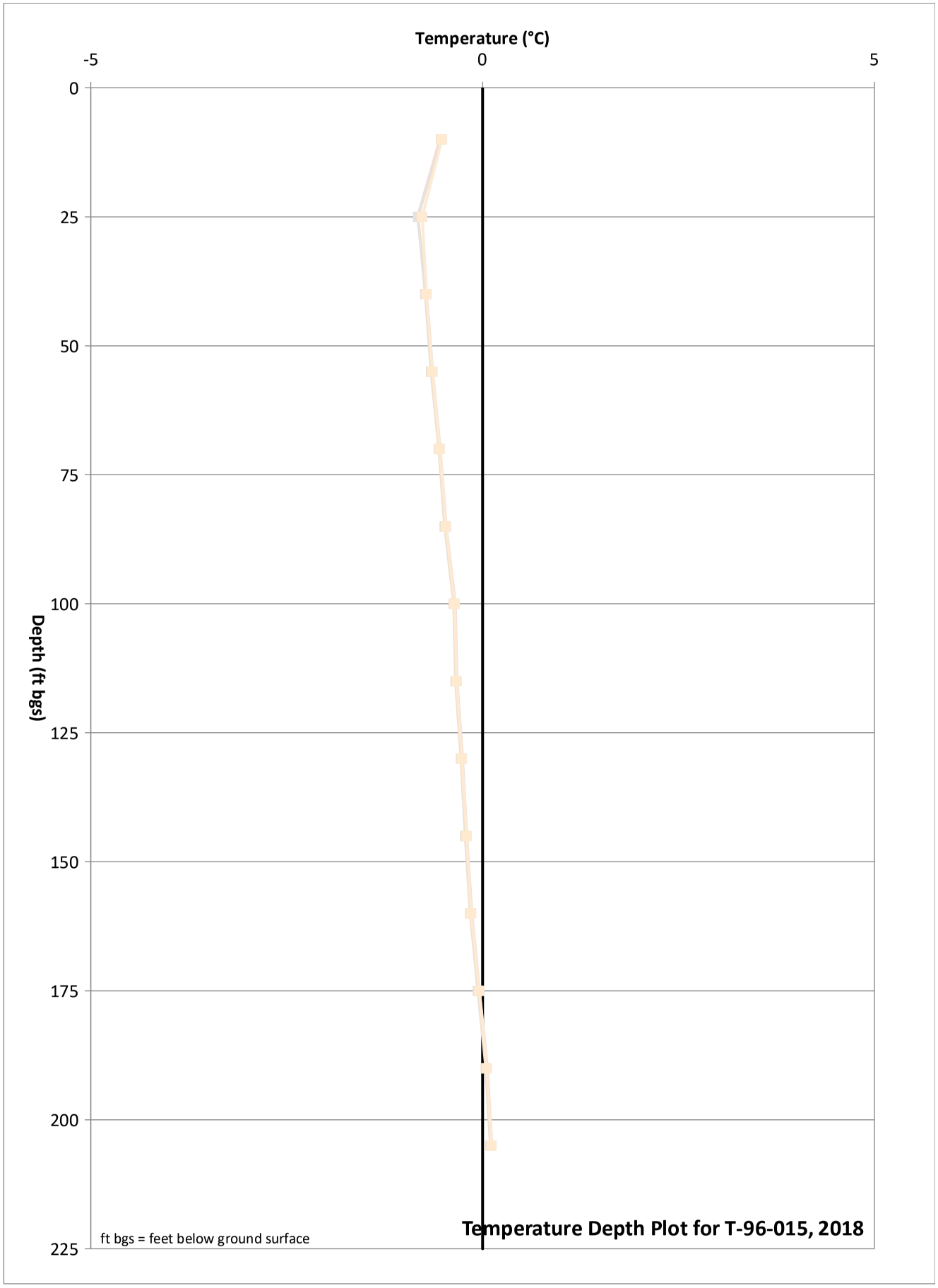

Temperature (°C)
-8
-6
-4
-2
0
2
4
6
8
10
Depth (ft bgs)
0
50
100
150
200
250
300
350
400
450
500
ft bgs = feet below ground surface
Temperature Depth Plot for T-96-013
(Temperature-axis scale adjusted)

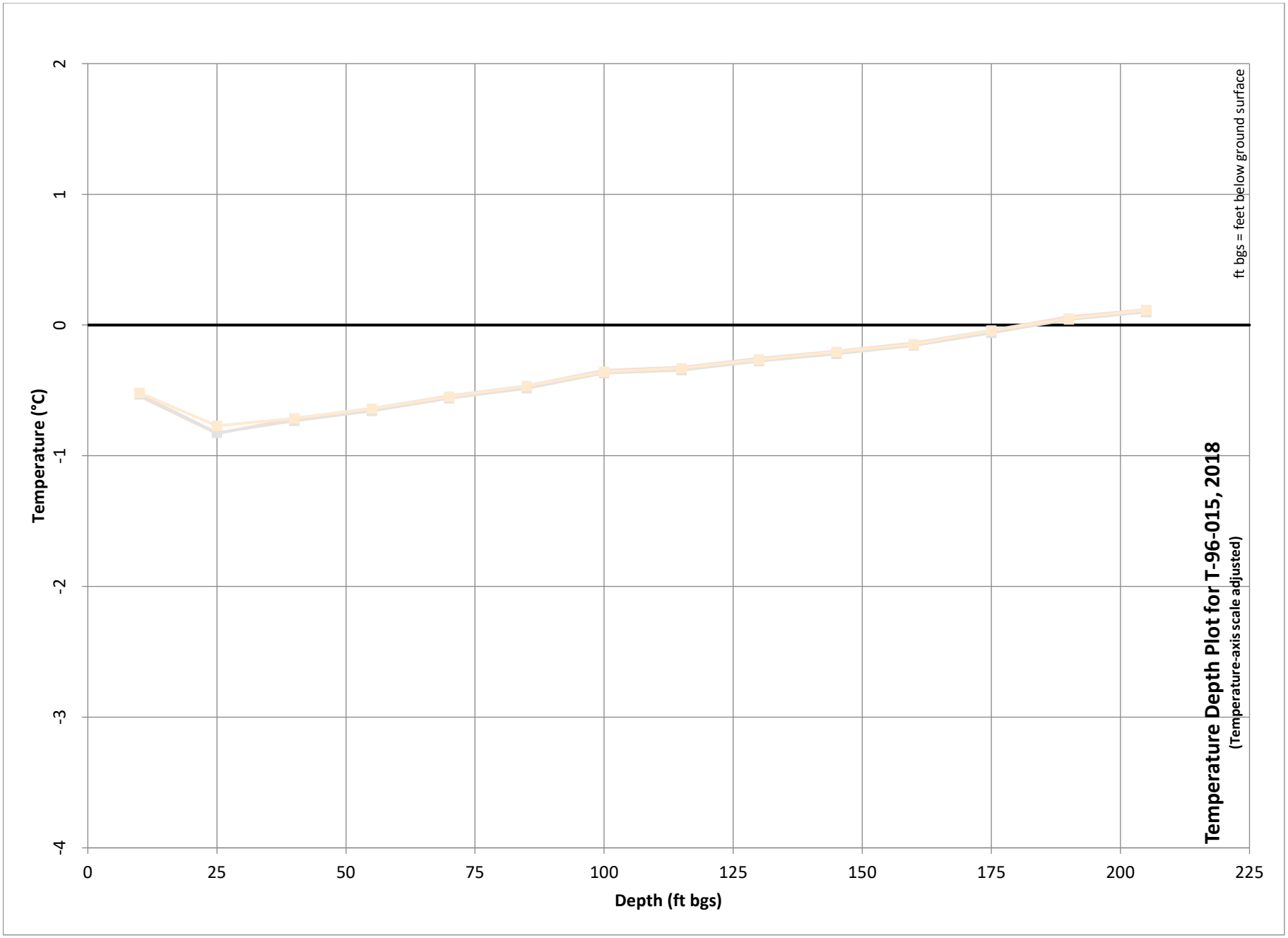

Temperature (°C)
-40
-30
-20
-10
0
10
20
30
40
Depth (ft bgs)
0
50
100
150
200
250
300
350
400
450
500
Temperature Depth Plot for
T-96-013, 2018
ft bgs = feet below ground surface

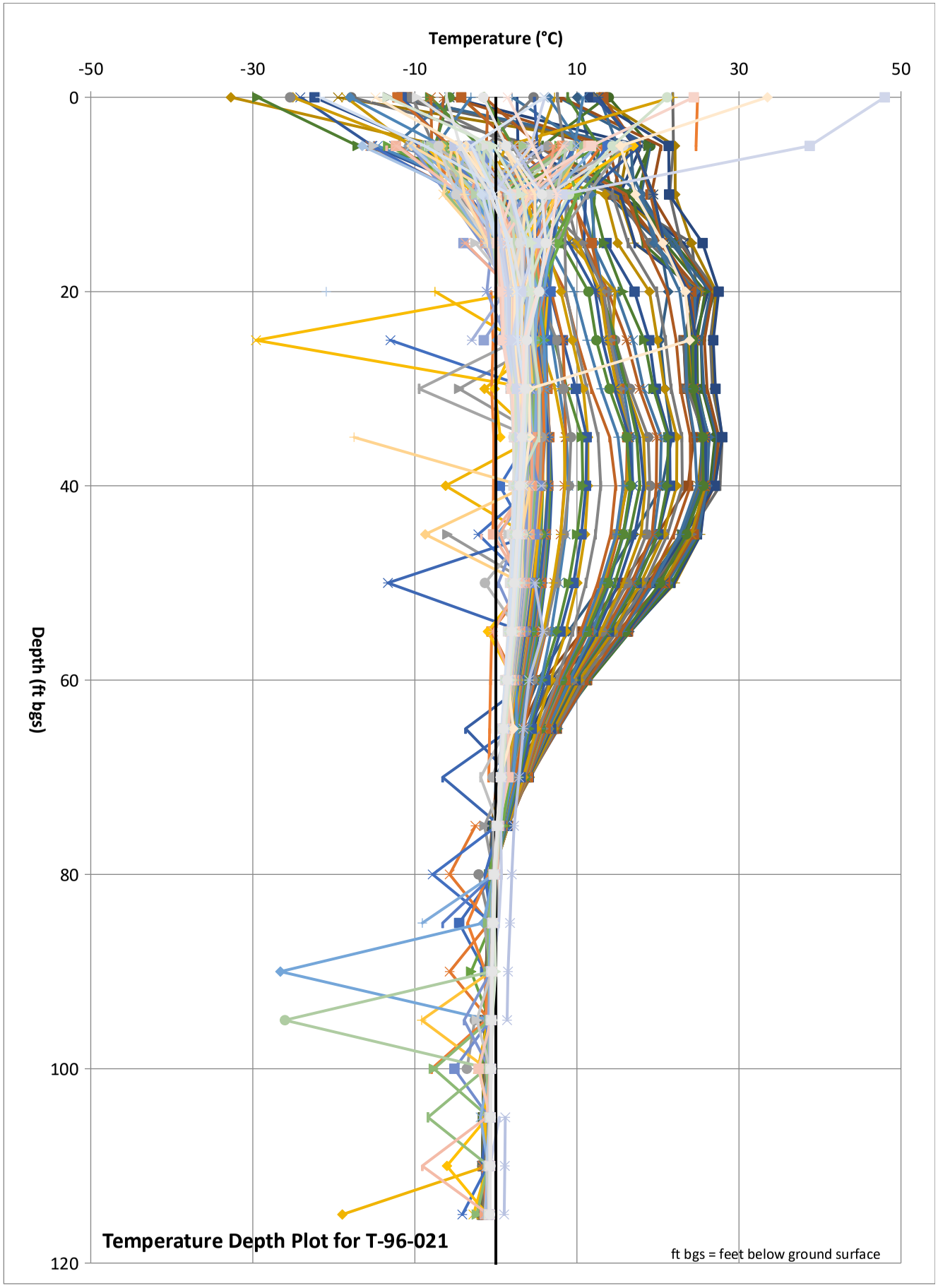

Temperature (°C)
-8
-6
-4
-2
0
2
4
6
8
10
Depth (ft bgs)
0
50
100
150
200
250
300
350
400
450
500
ft bgs = feet below ground surface
Temperature Depth Plot for T-96-013, 2018
(Temperature-axis scale adjusted)

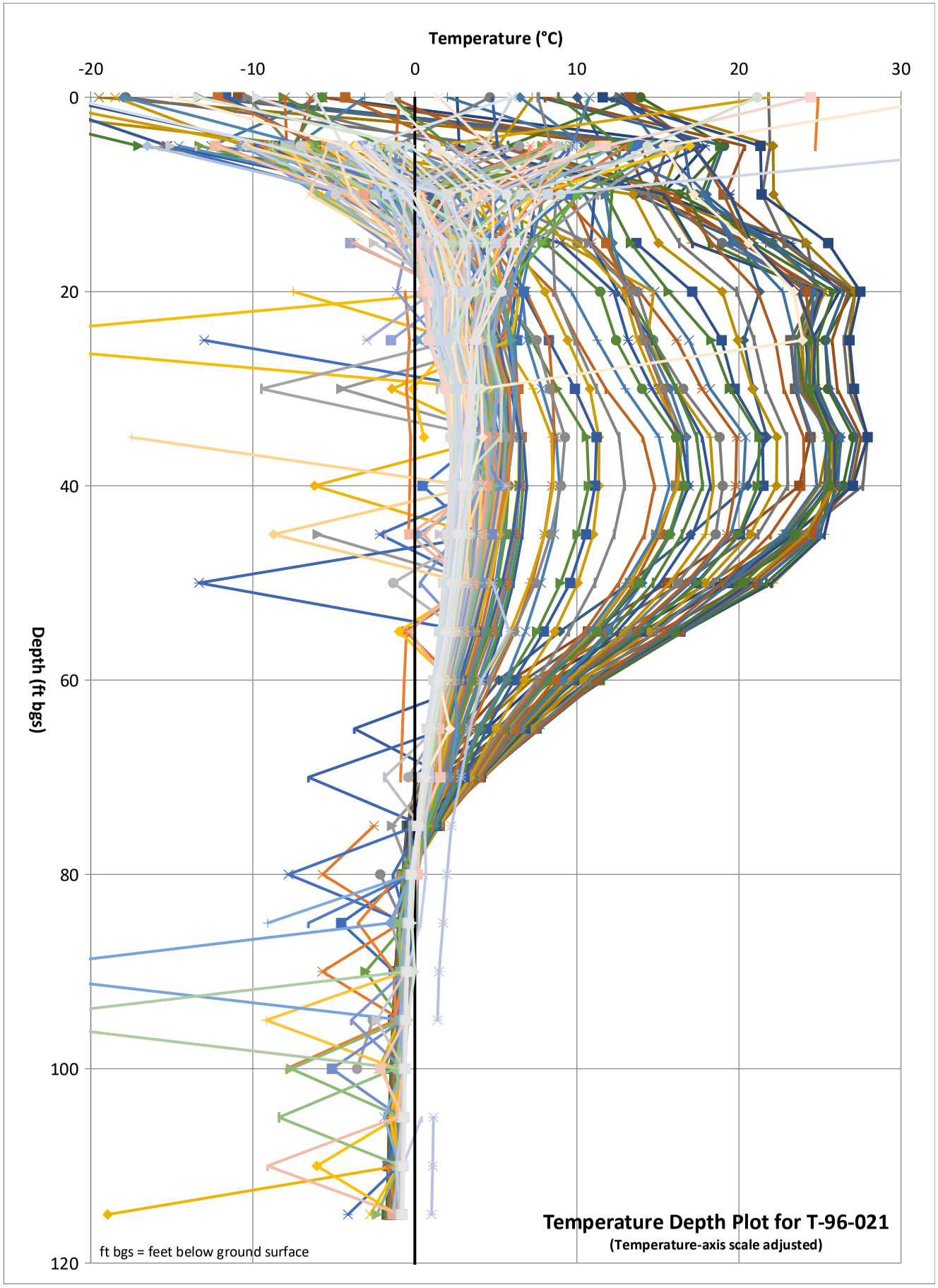

Temperature (°C)
-20
-15
-10
-5
0
5
10
15
20
25
Depth (ft bgs)
0
25
50
75
100
125
150
175
200
225
ft bgs = feet below ground surface
Temperature Depth Plot for T-96-015

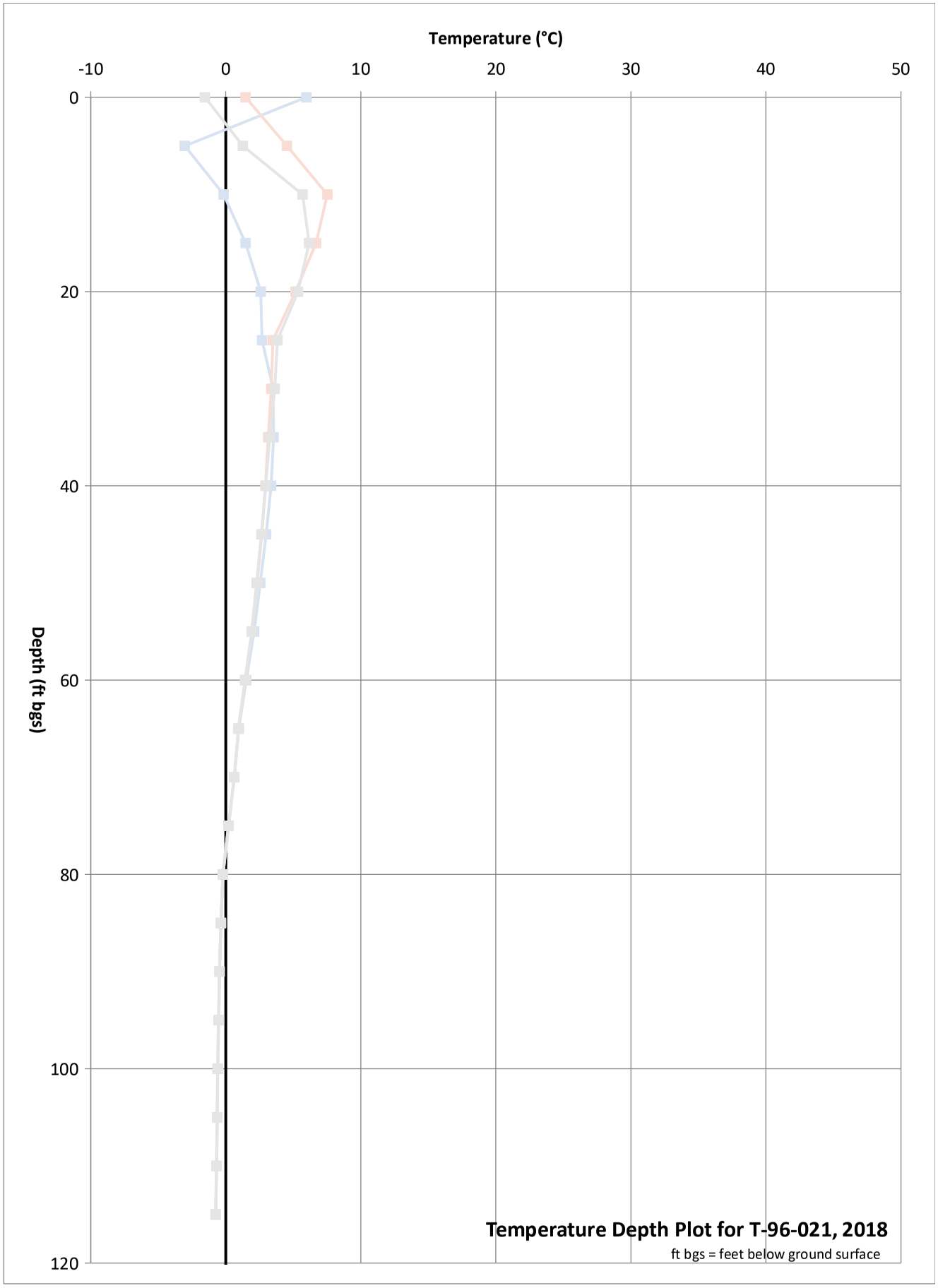

Temperature Depth Plot for T-96-015
(Temperature-axis scale adjusted)
ft bgs = feet below ground surface
Temperature (°C)
2
1
0
-1
-2
-3
-4
Depth (ft bgs)
0
25
50
75
100
125
150
175
200
225

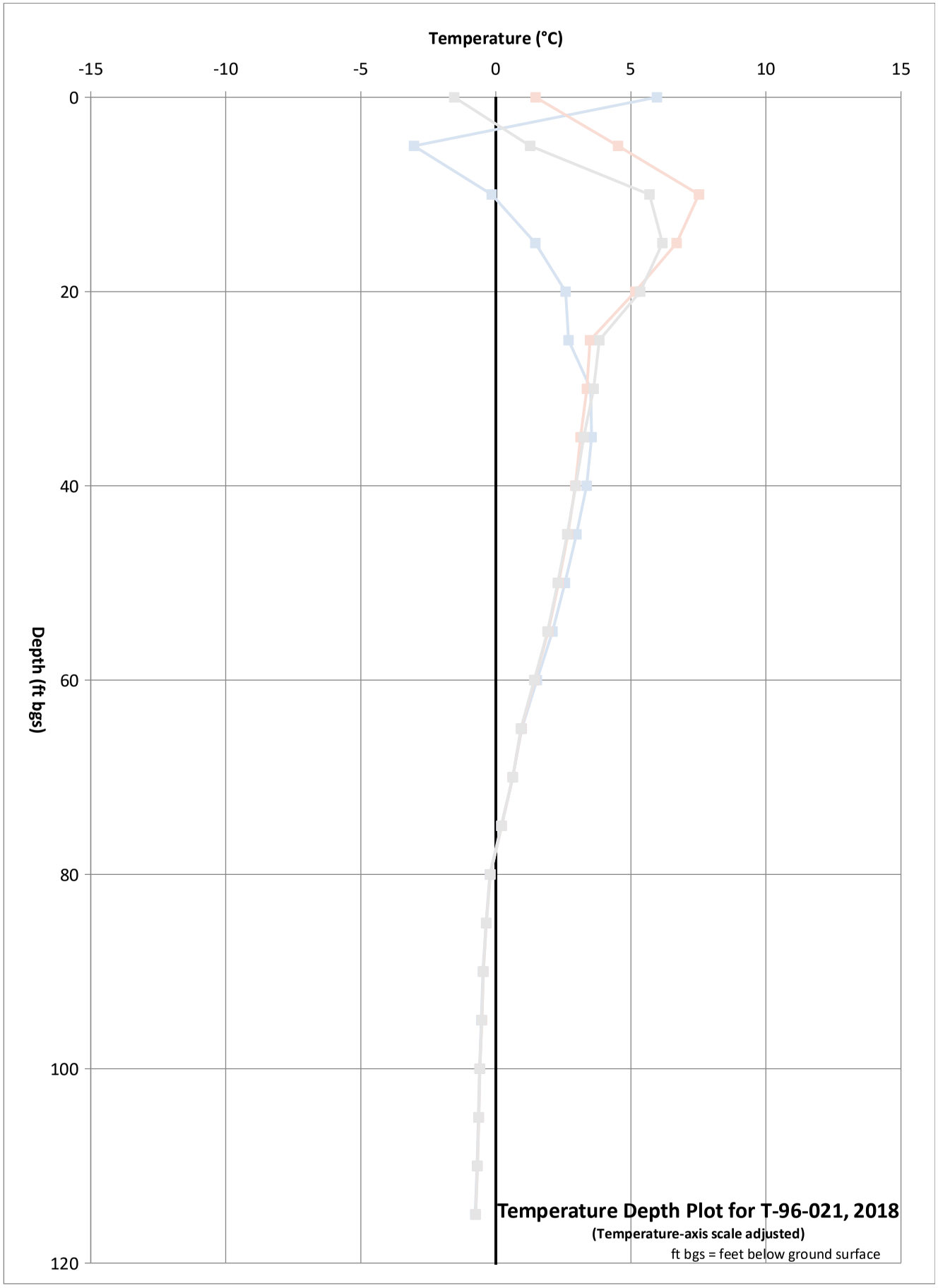

Temperature (°C)
-5
0
5
0
25
50
75
100
125
150
175
200
225
Depth (ft bgs)
ft bgs = feet below ground surface
Temperature Depth Plot for T-96-015, 2018

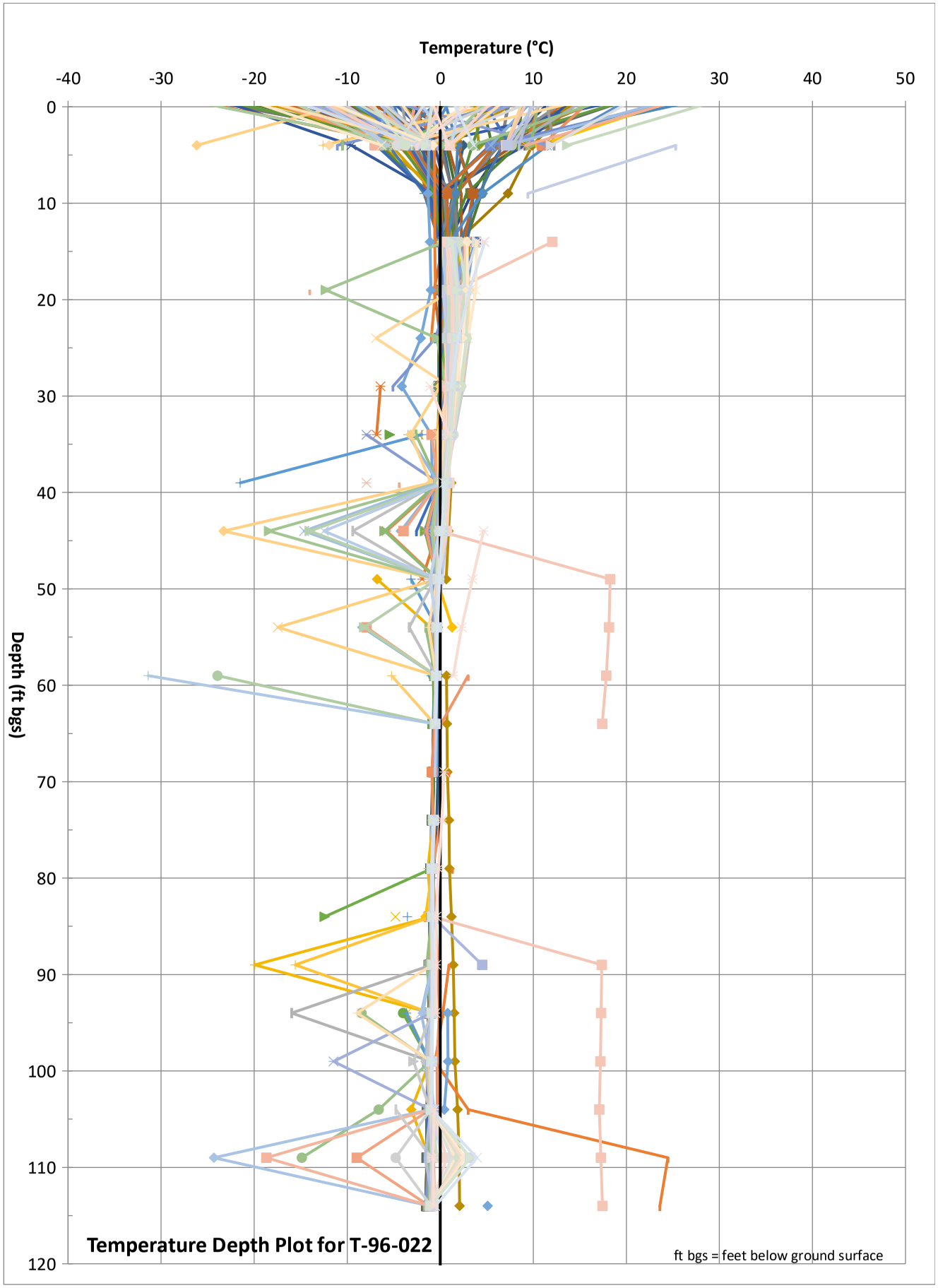

Temperature Depth Plot for T-96-015, 2018
(Temperature-axis scale adjusted)
ft bgs = feet below ground surface
Temperature (°C)
2
1
0
-1
-2
-3
-4
Depth (ft bgs)
0
25
50
75
100
125
150
175
200
225

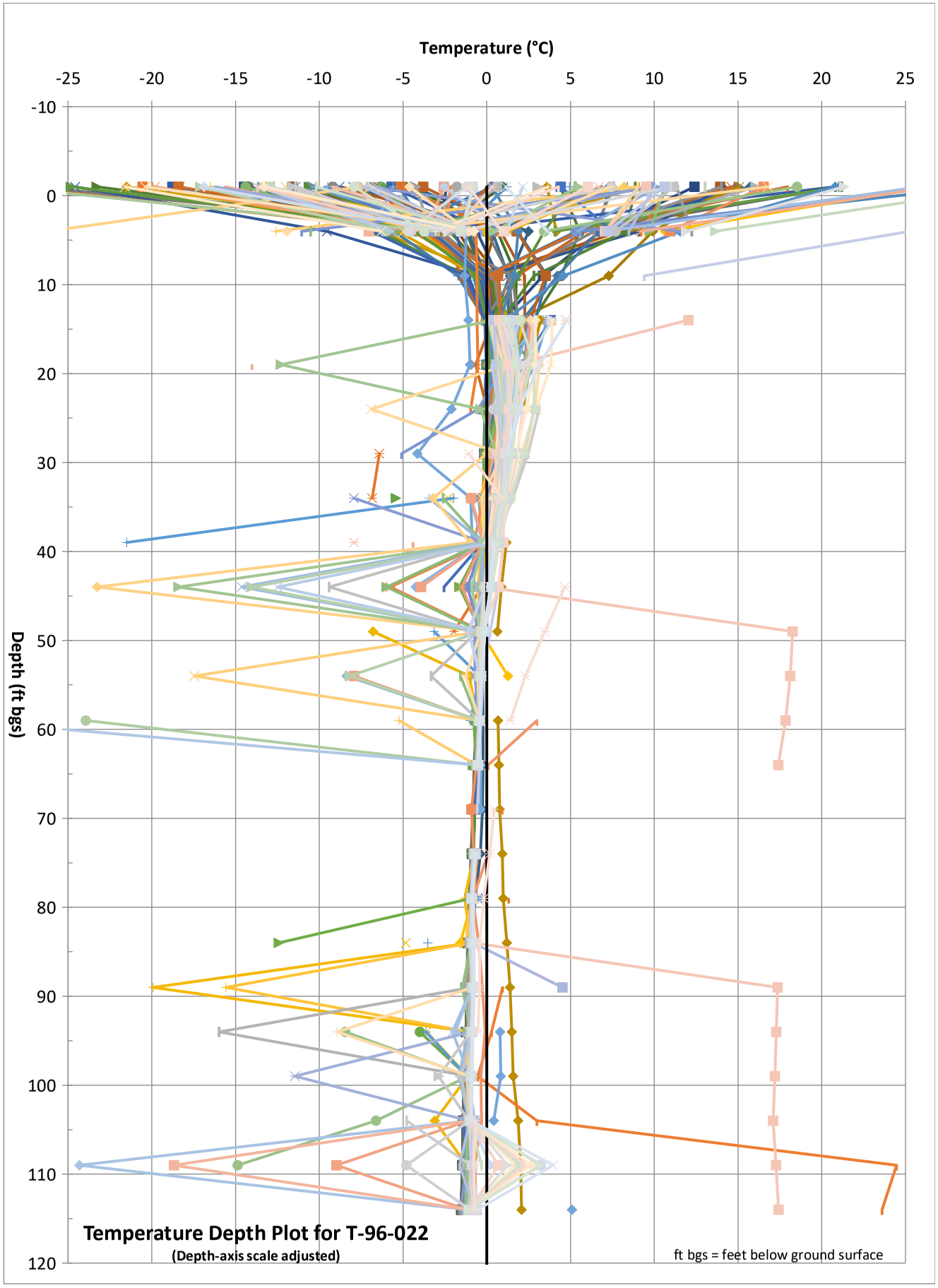

Temperature (°C)
-50
-30
-10
10
30
50
0
20
40
60
80
100
120
Depth (ft bgs)
Temperature Depth Plot for T-96-021
ft bgs = feet below ground surface

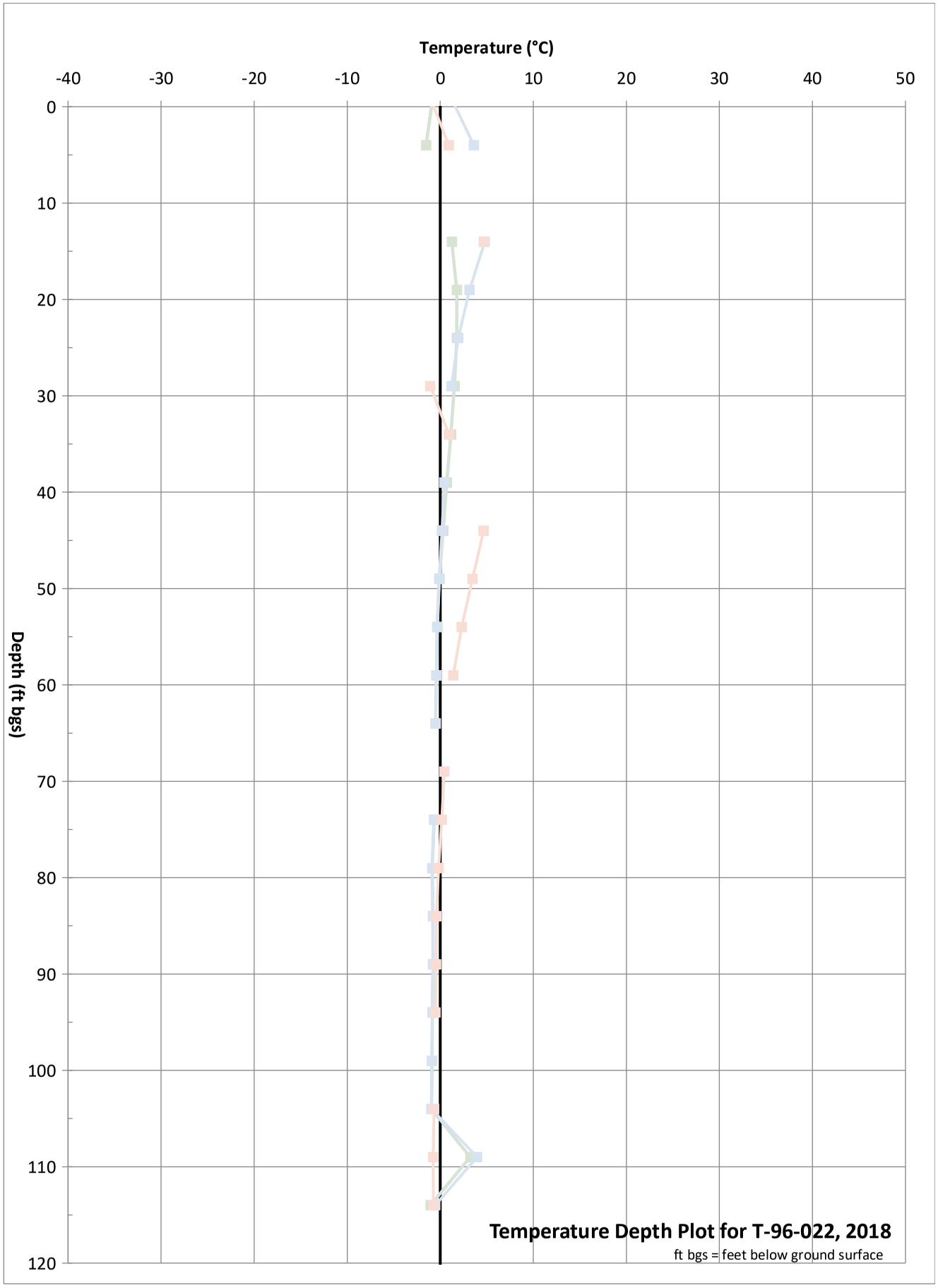

Temperature (°C)
-20
-10
0
10
20
30
0
20
40
60
80
100
120
Depth (ft bgs)
ft bgs = feet below ground surface
Temperature Depth Plot for T-96-021
(Temperature-axis scale adjusted)

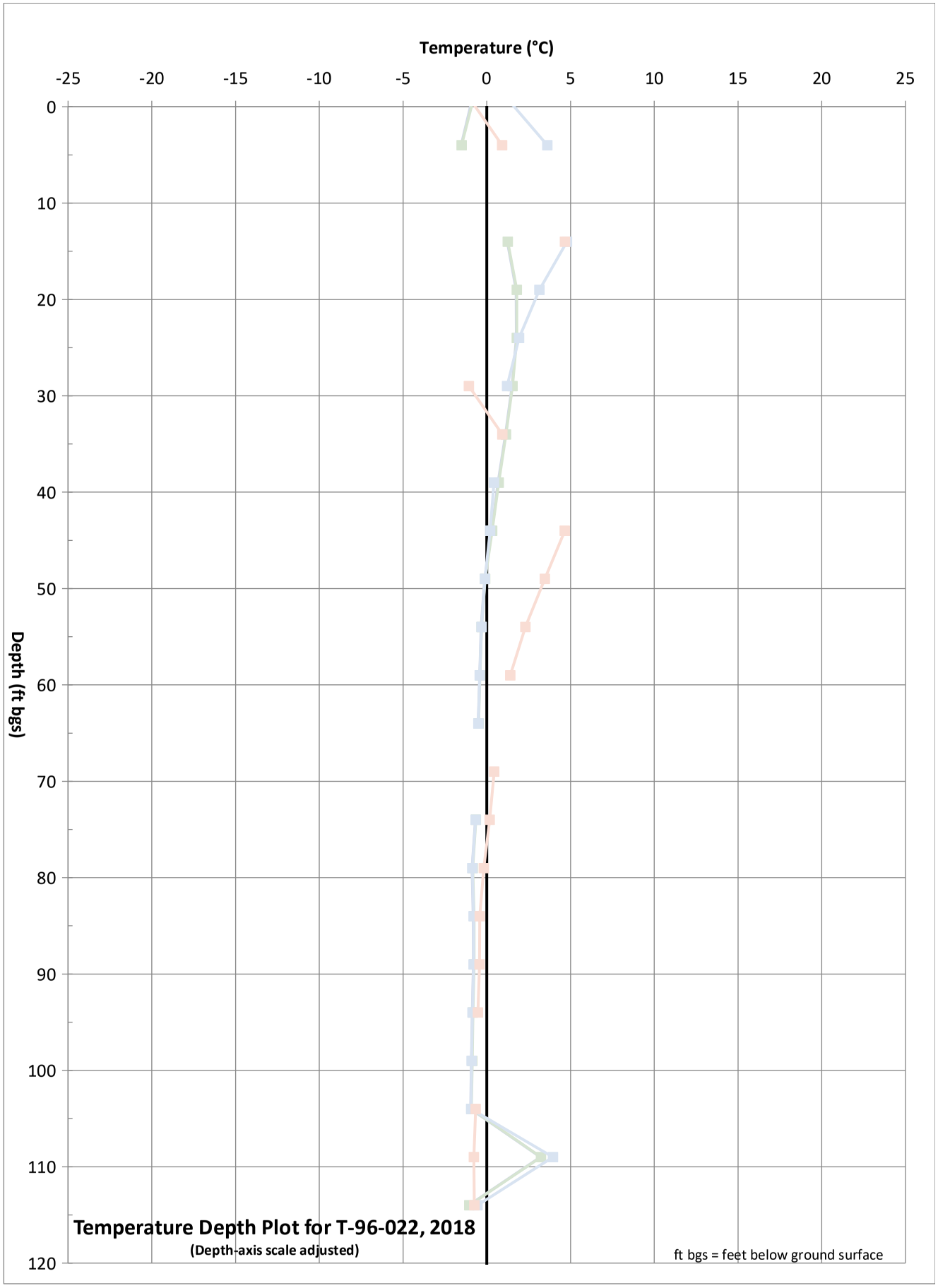

Temperature (°C)
-10
0
10
20
30
40
50
Depth (ft bgs)
0
20
40
60
80
100
120
Temperature Depth Plot for T-96-021, 2018
ft bgs = feet below ground surface

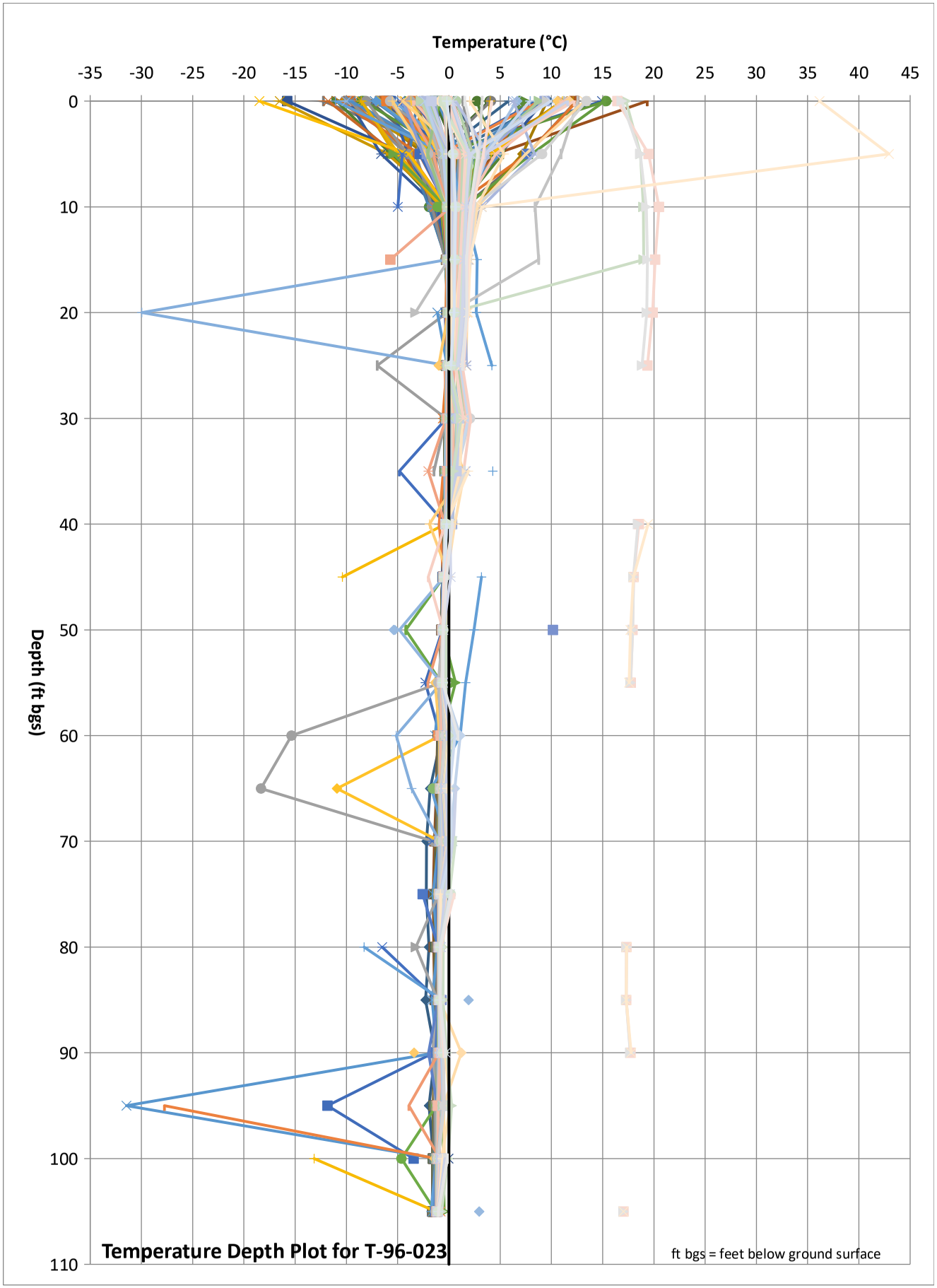

Temperature (°C)
-15
-10
-5
0
5
10
15
0
20
40
60
80
100
120
Depth (ft bgs)
Temperature Depth Plot for T-96-021, 2018
(Temperature-axis scale adjusted)
ft bgs = feet below ground surface

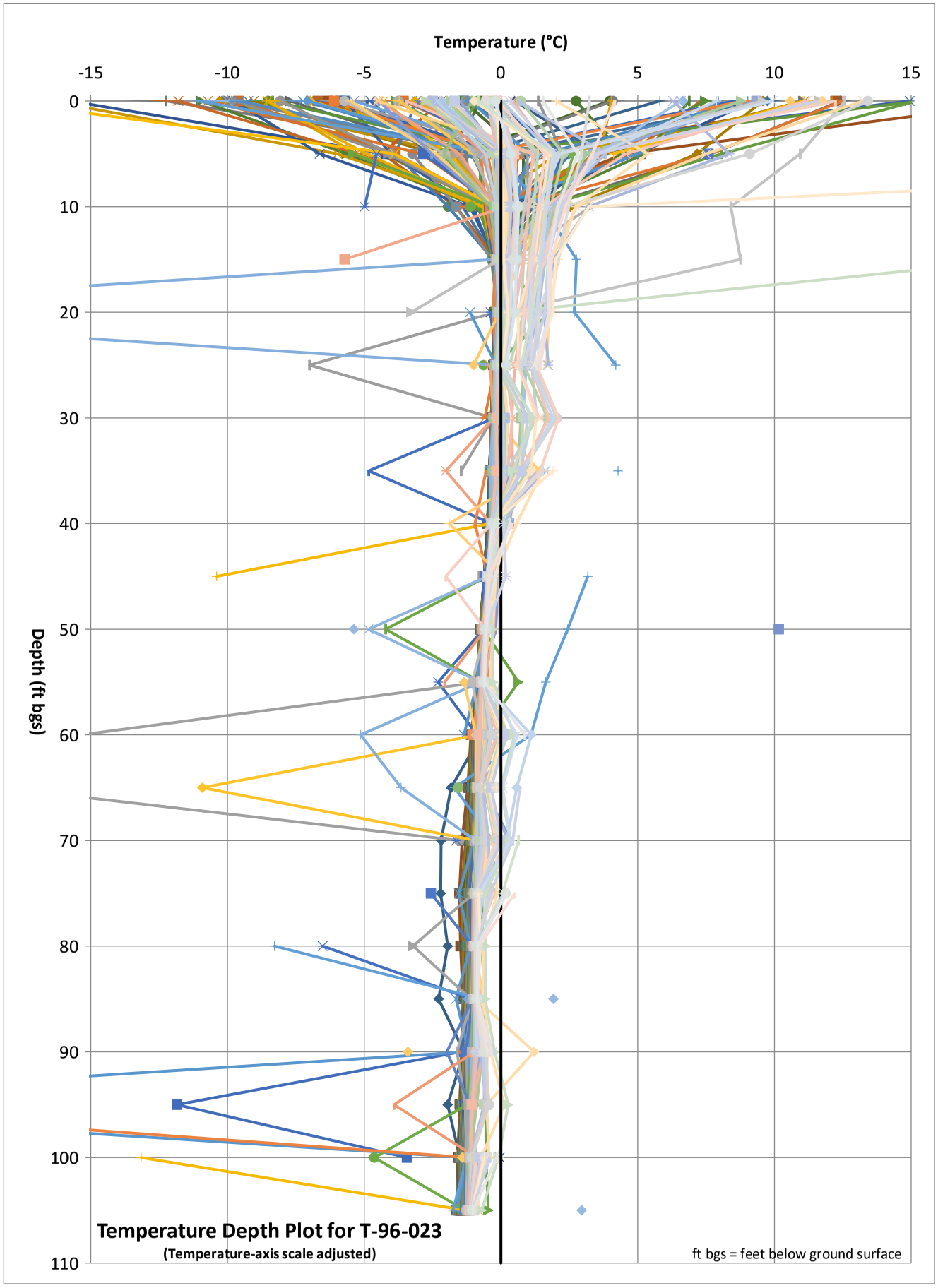

Temperature (°C)
-40
-30
-20
-10
0
10
20
30
40
50
Depth (ft bgs)
0
10
20
30
40
50
60
70
80
90
100
110
120
Temperature Depth Plot for T-96-022
ft bgs = feet below ground surface

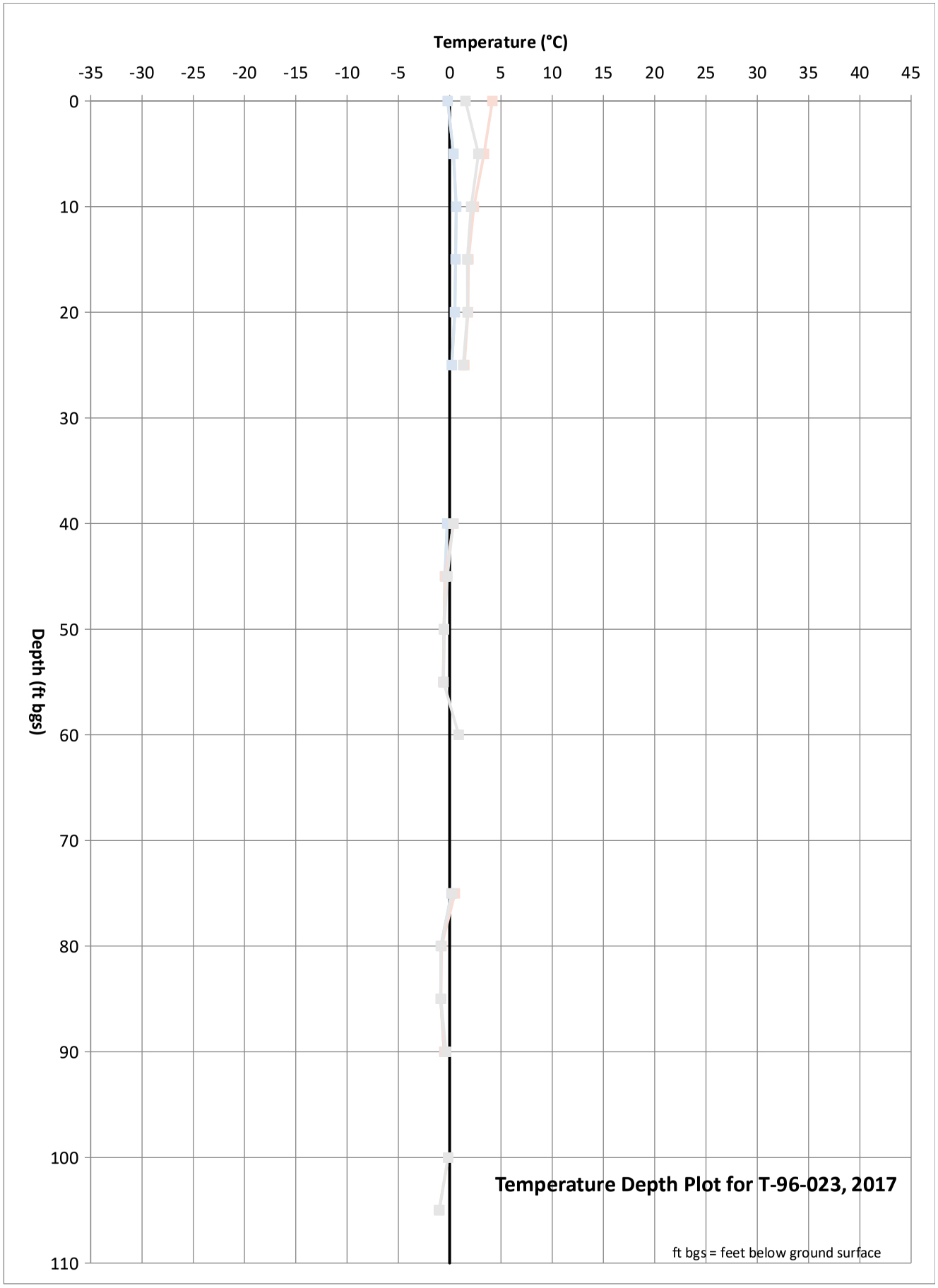

Temperature (°C)
-25
-20
-15
-10
-5
0
5
10
15
20
25
Depth (ft bgs)
-10
0
10
20
30
40
50
60
70
80
90
100
110
120
Temperature Depth Plot for T-96-022
(Depth-axis scale adjusted)
ft bgs = feet below ground surface

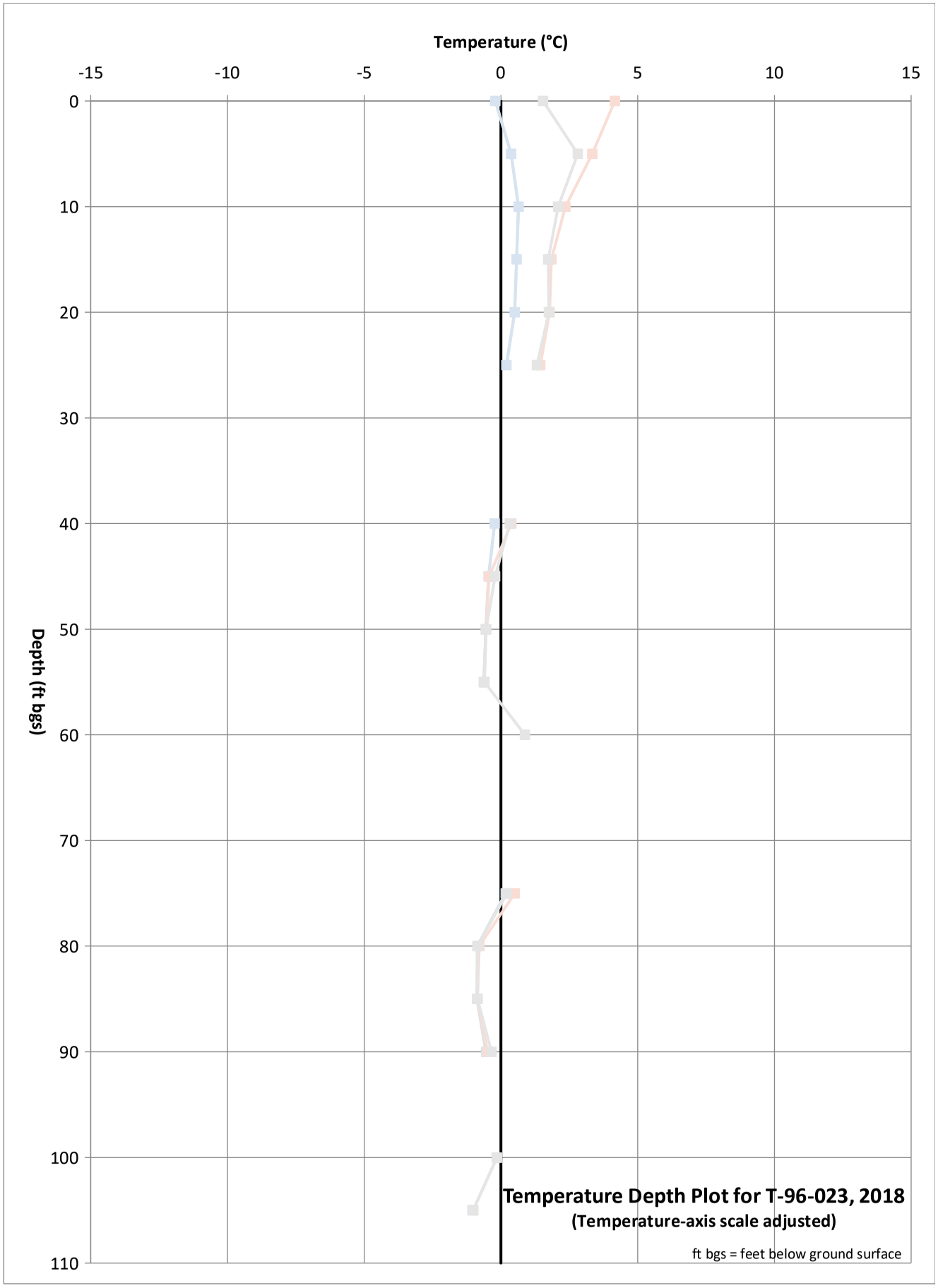

Temperature (°C)
-40
-30
-20
-10
0
10
20
30
40
50
Depth (ft bgs)
0
10
20
30
40
50
60
70
80
90
100
110
120
Temperature Depth Plot for T-96-022, 2018
ft bgs = feet below ground surface

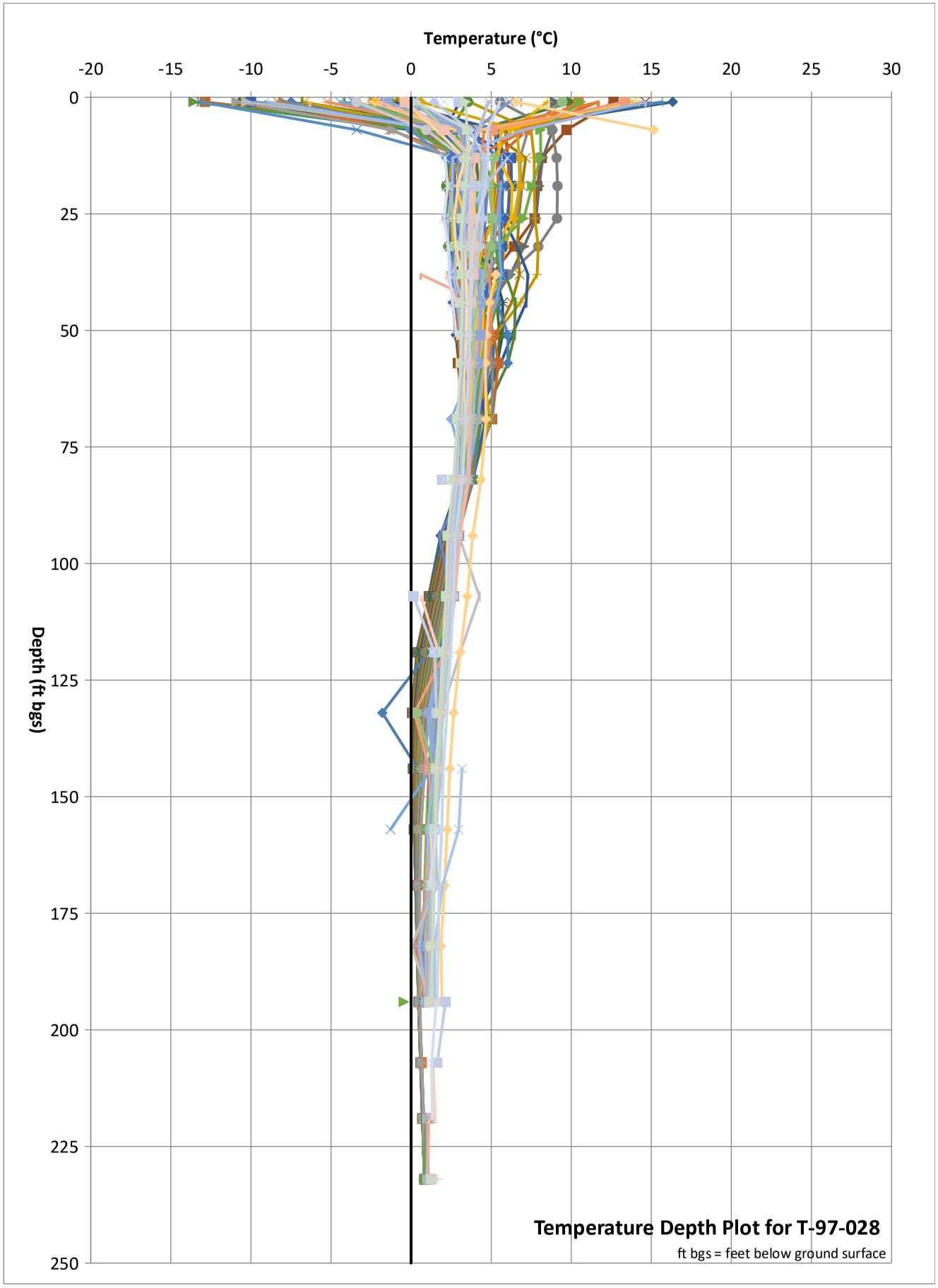

Temperature (°C)
-25
-20
-15
-10
-5
0
5
10
15
20
25
Depth (ft bgs)
0
10
20
30
40
50
60
70
80
90
100
110
120
Temperature Depth Plot for T-96-022, 2018
(Depth-axis scale adjusted)
ft bgs = feet below ground surface

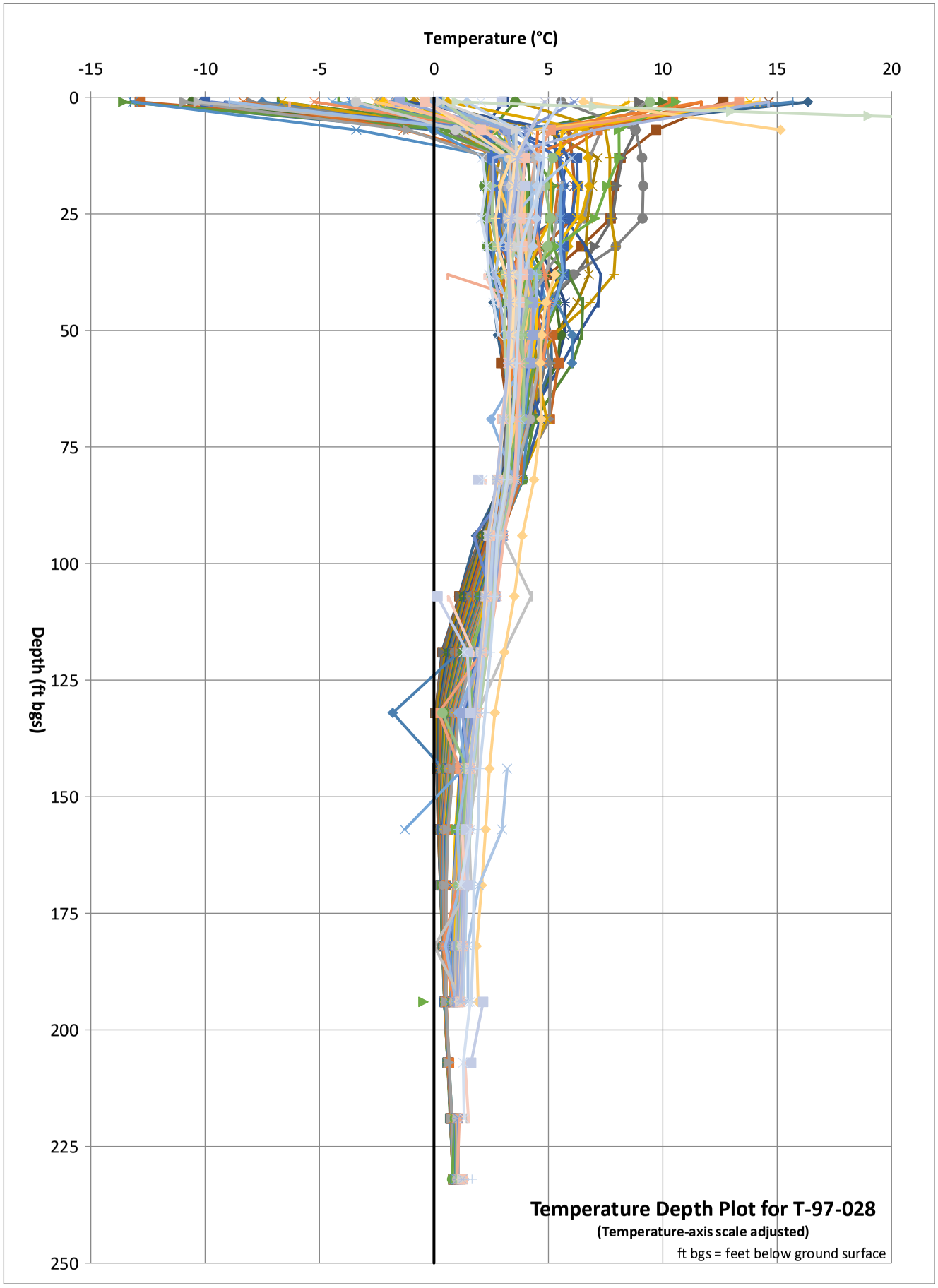

Temperature (°C)
-35
-30
-25
-20
-15
-10
-5
0
5
10
15
20
25
30
35
40
45
Depth (ft bgs)
0
10
20
30
40
50
60
70
80
90
100
110
Temperature Depth Plot for T-96-023
ft bgs = feet below ground surface

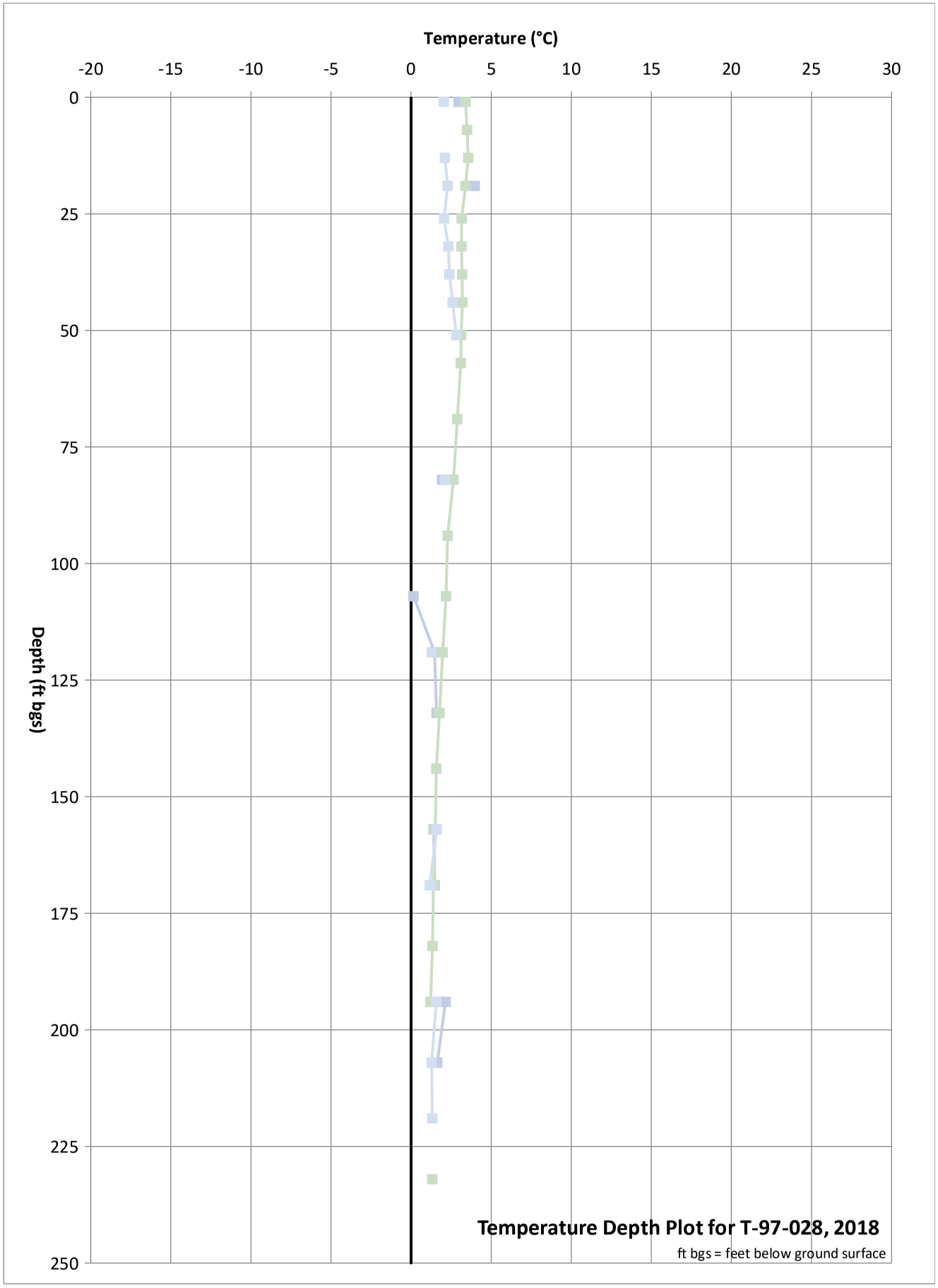

Temperature (°C)
-15
-10
-5
0
5
10
15
Depth (ft bgs)
0
10
20
30
40
50
60
70
80
90
100
110
Temperature Depth Plot for T-96-023
(Temperature-axis scale adjusted)
ft bgs = feet below ground surface

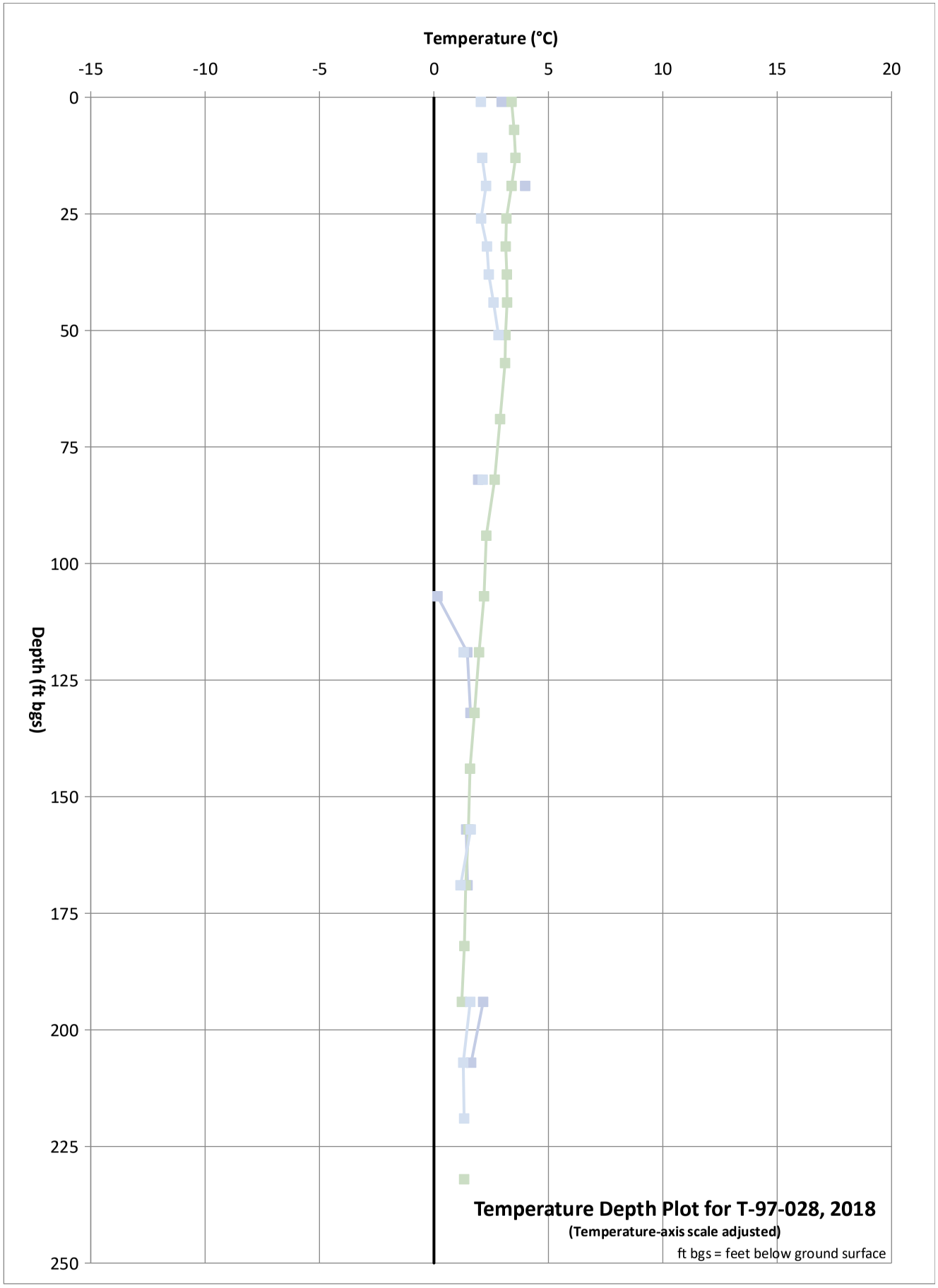

Temperature (°C)
-35
-30
-25
-20
-15
-10
-5
0
5
10
15
20
25
30
35
40
45
Depth (ft bgs)
0
10
20
30
40
50
60
70
80
90
100
110
Temperature Depth Plot for T-96-023, 2017
ft bgs = feet below ground surface

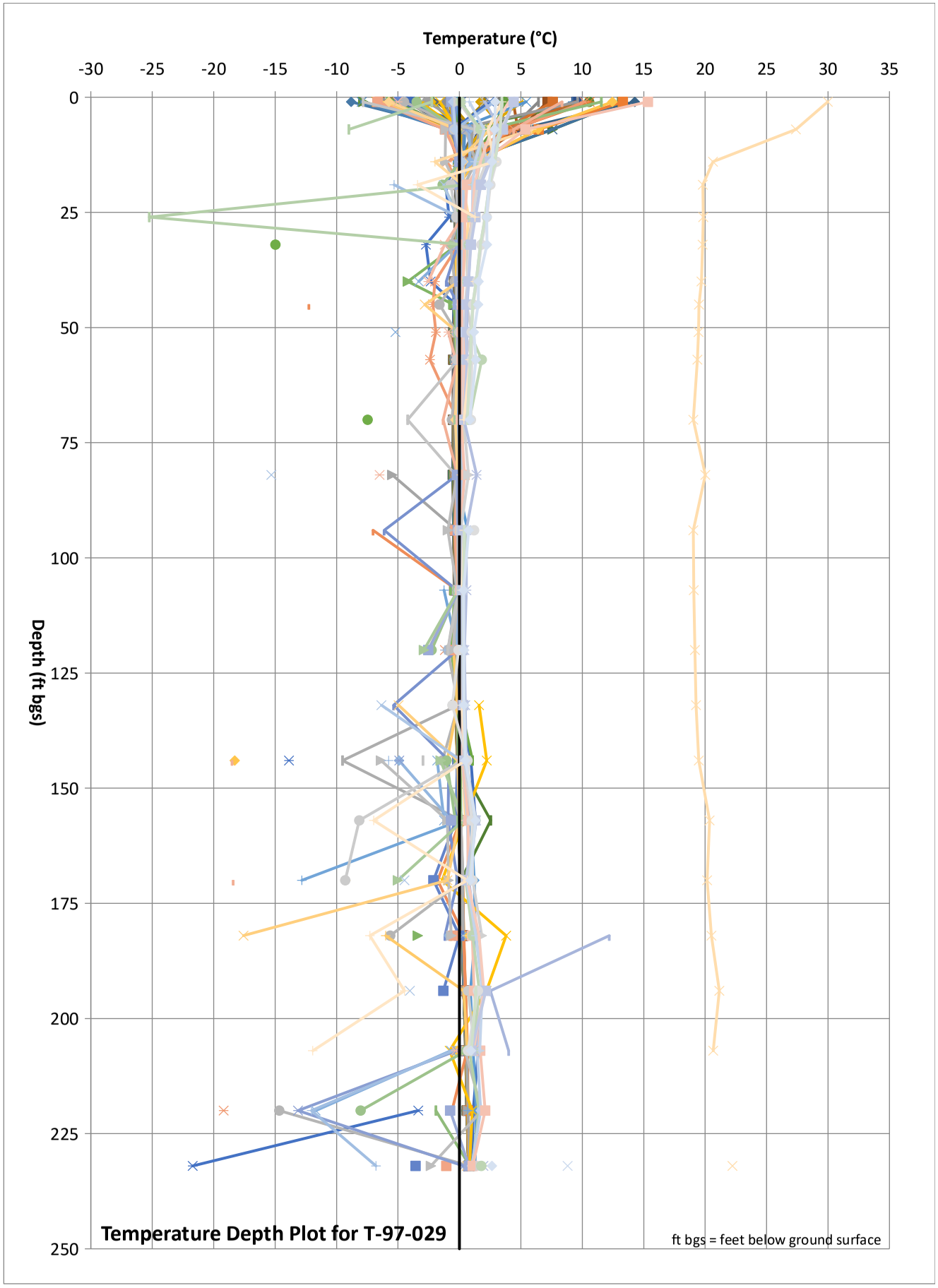

Temperature (°C)
-15
-10
-5
0
5
10
15
Depth (ft bgs)
0
10
20
30
40
50
60
70
80
90
100
110
Temperature Depth Plot for T-96-023, 2018
(Temperature-axis scale adjusted)
ft bgs = feet below ground surface

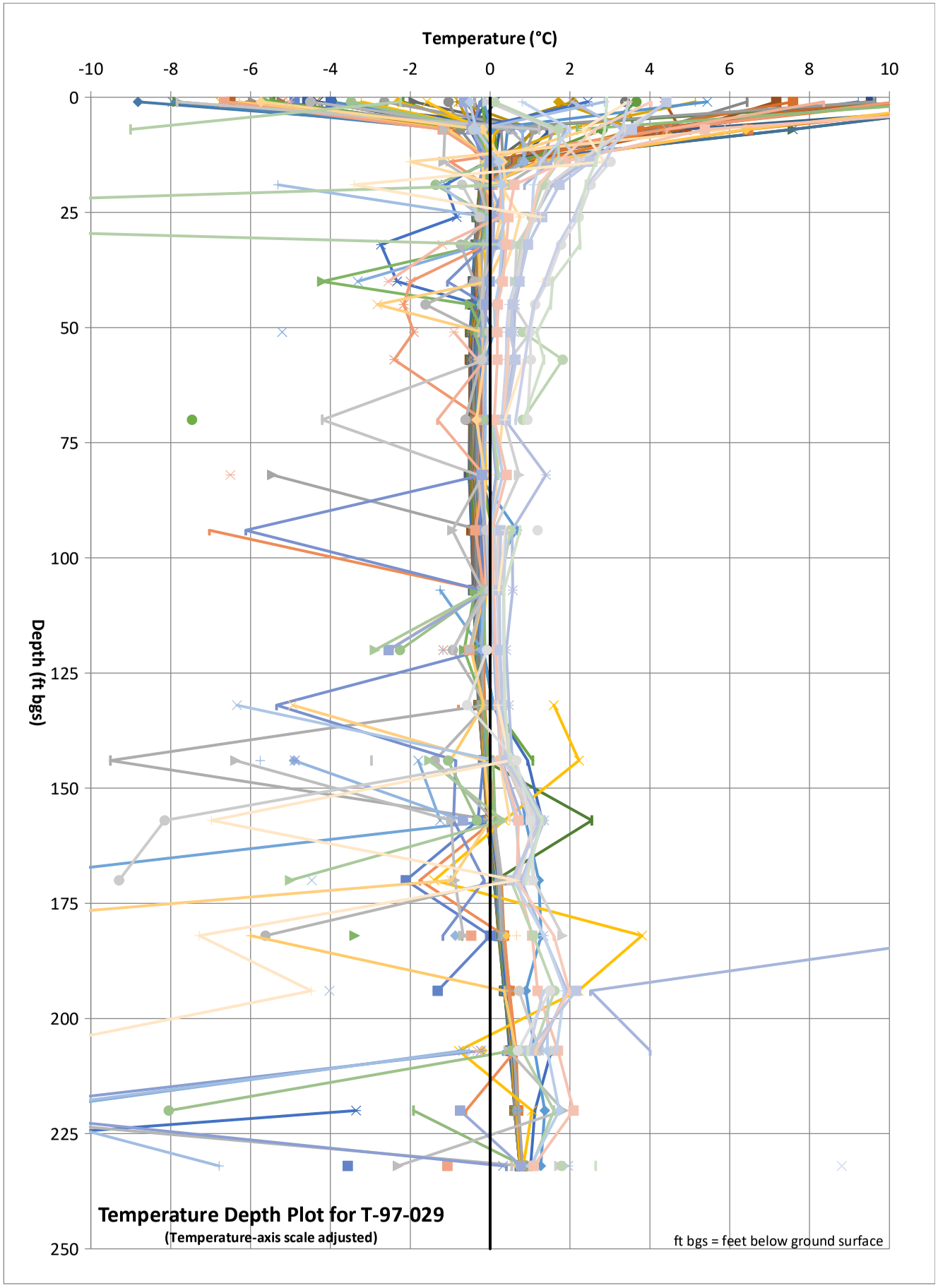

Temperature (°C)
-20
-15
-10
-5
0
5
10
15
20
25
30
Depth (ft bgs)
0
25
50
75
100
125
150
175
200
225
250
Temperature Depth Plot for T-97-028
ft bgs = feet below ground surface

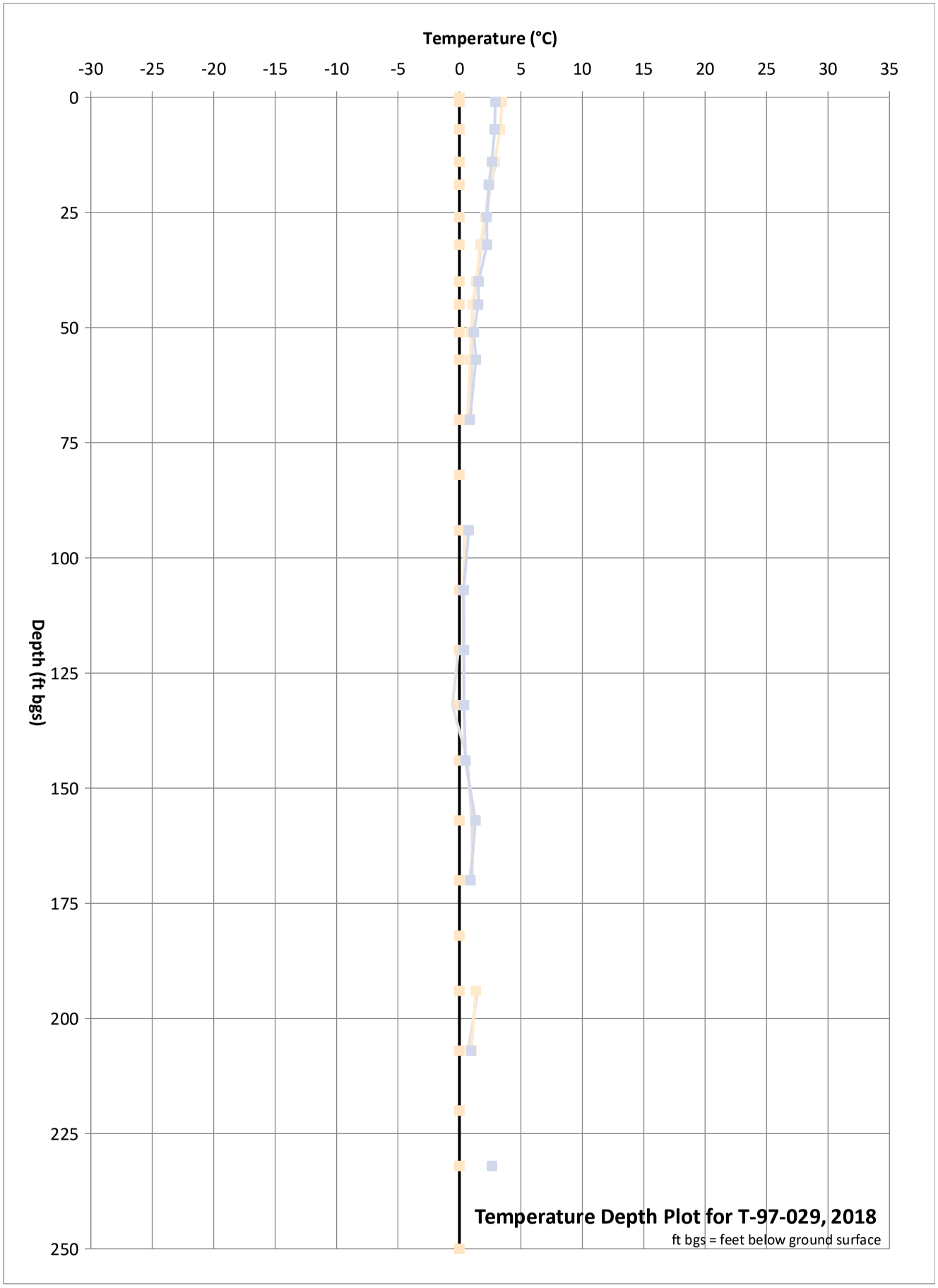

Temperature (°C)
-15
-10
-5
0
5
10
15
20
Depth (ft bgs)
0
25
50
75
100
125
150
175
200
225
250
Temperature Depth Plot for T-97-028
(Temperature-axis scale adjusted)
ft bgs = feet below ground surface

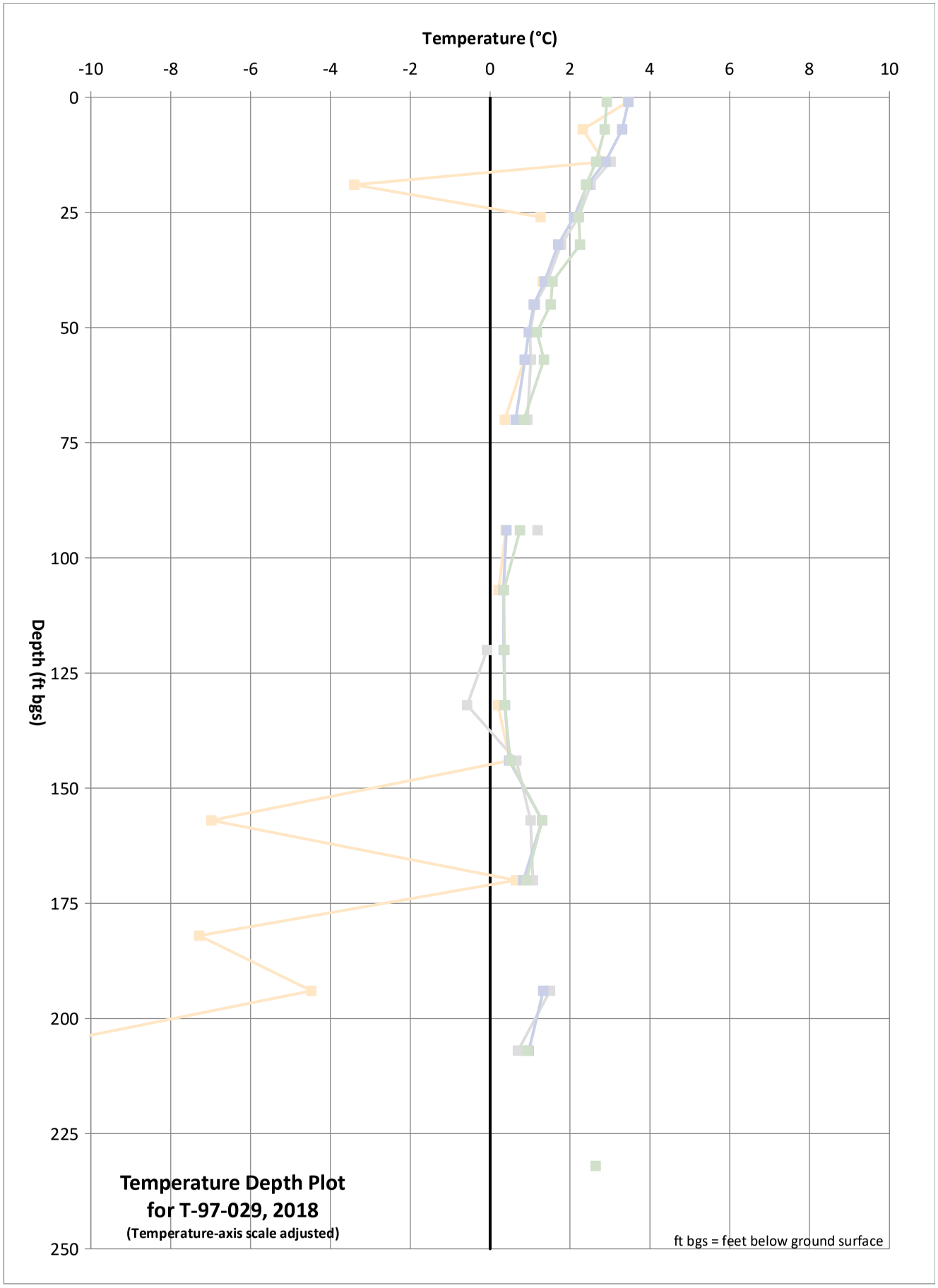

Temperature (°C)
-20
-15
-10
-5
0
5
10
15
20
25
30
Depth (ft bgs)
0
25
50
75
100
125
150
175
200
225
250
Temperature Depth Plot for T-97-028, 2018
ft bgs = feet below ground surface

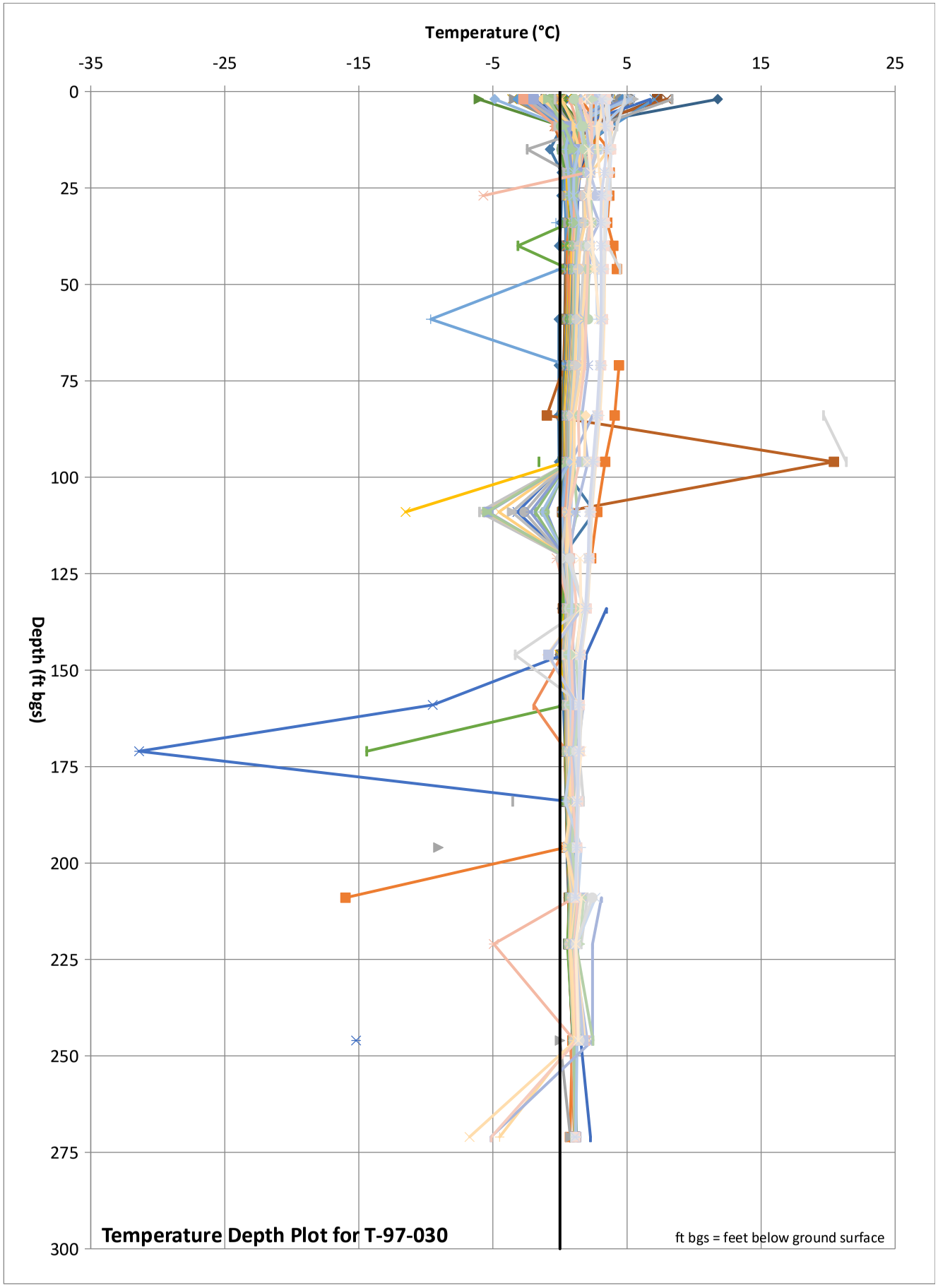

Temperature (°C)
-15
-10
-5
0
5
10
15
20
Depth (ft bgs)
0
25
50
75
100
125
150
175
200
225
250
Temperature Depth Plot for T-97-028, 2018
(Temperature-axis scale adjusted)
ft bgs = feet below ground surface

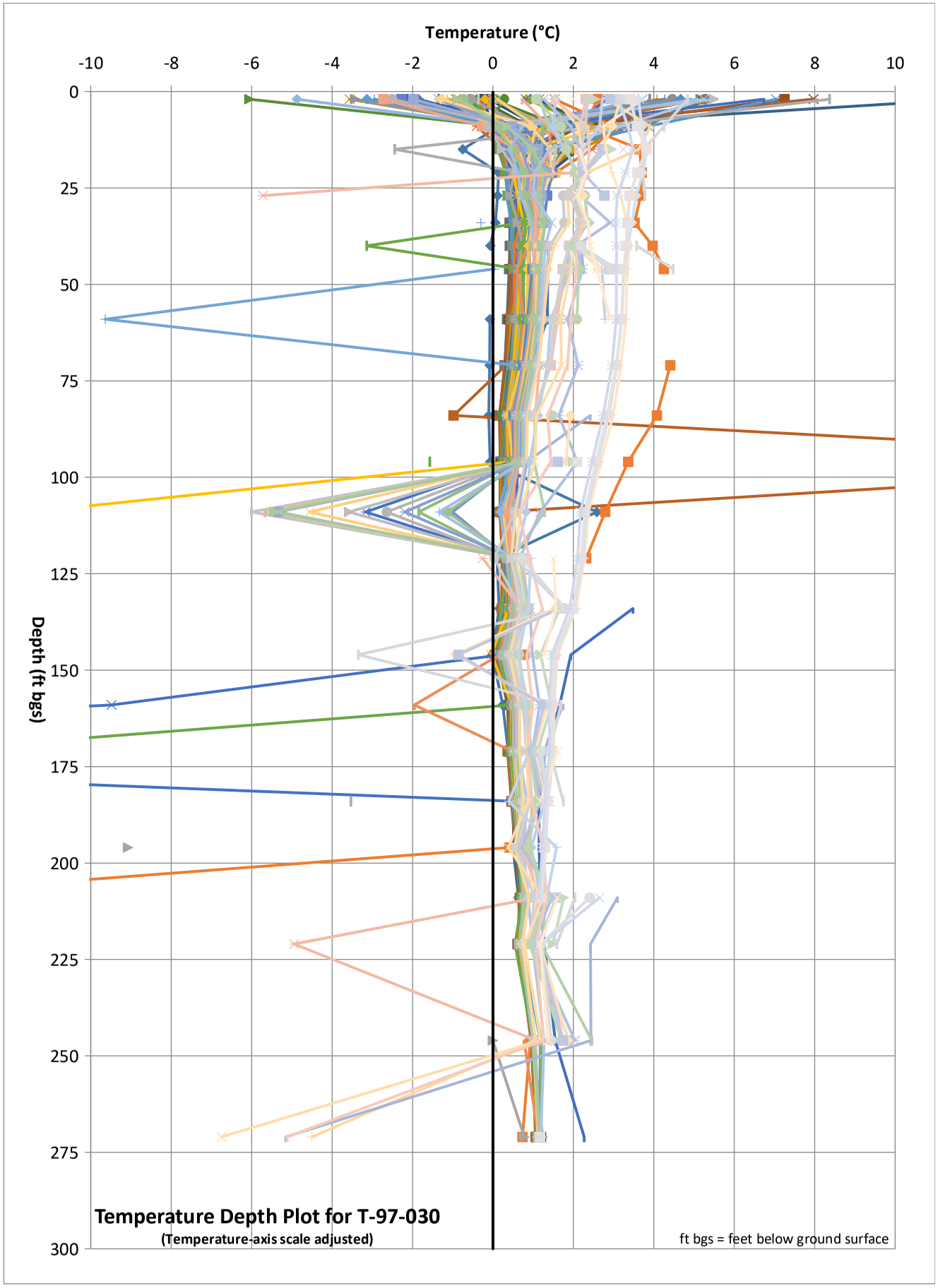

Temperature (°C)
-30
-25
-20
-15
-10
-5
0
5
10
15
20
25
30
35
Depth (ft bgs)
0
25
50
75
100
125
150
175
200
225
250
Temperature Depth Plot for T-97-029
ft bgs = feet below ground surface

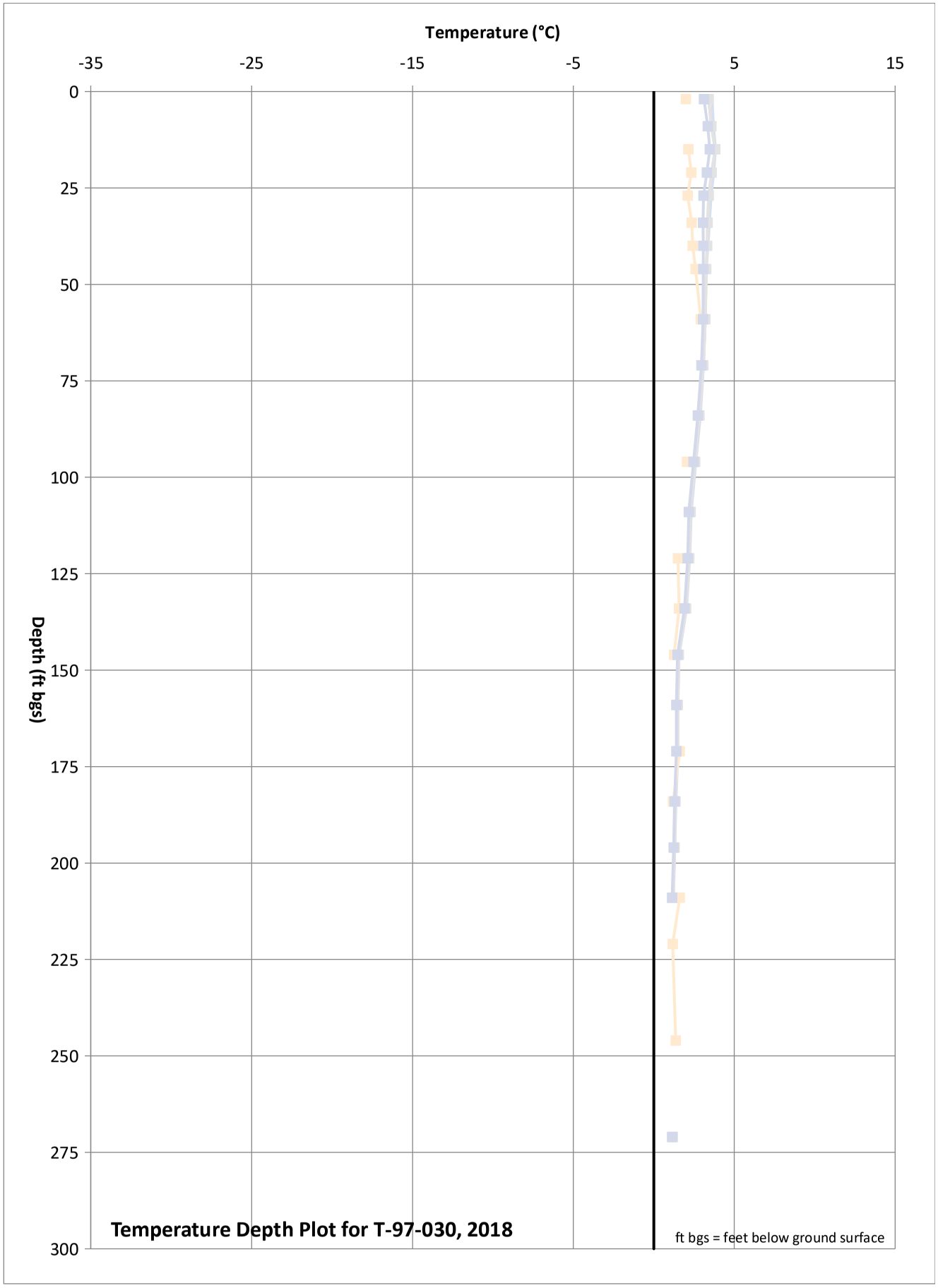

Temperature (°C)
-10
-8
-6
-4
-2
0
2
4
6
8
10
Depth (ft bgs)
0
25
50
75
100
125
150
175
200
225
250
Temperature Depth Plot for T-97-029
(Temperature-axis scale adjusted)
ft bgs = feet below ground surface

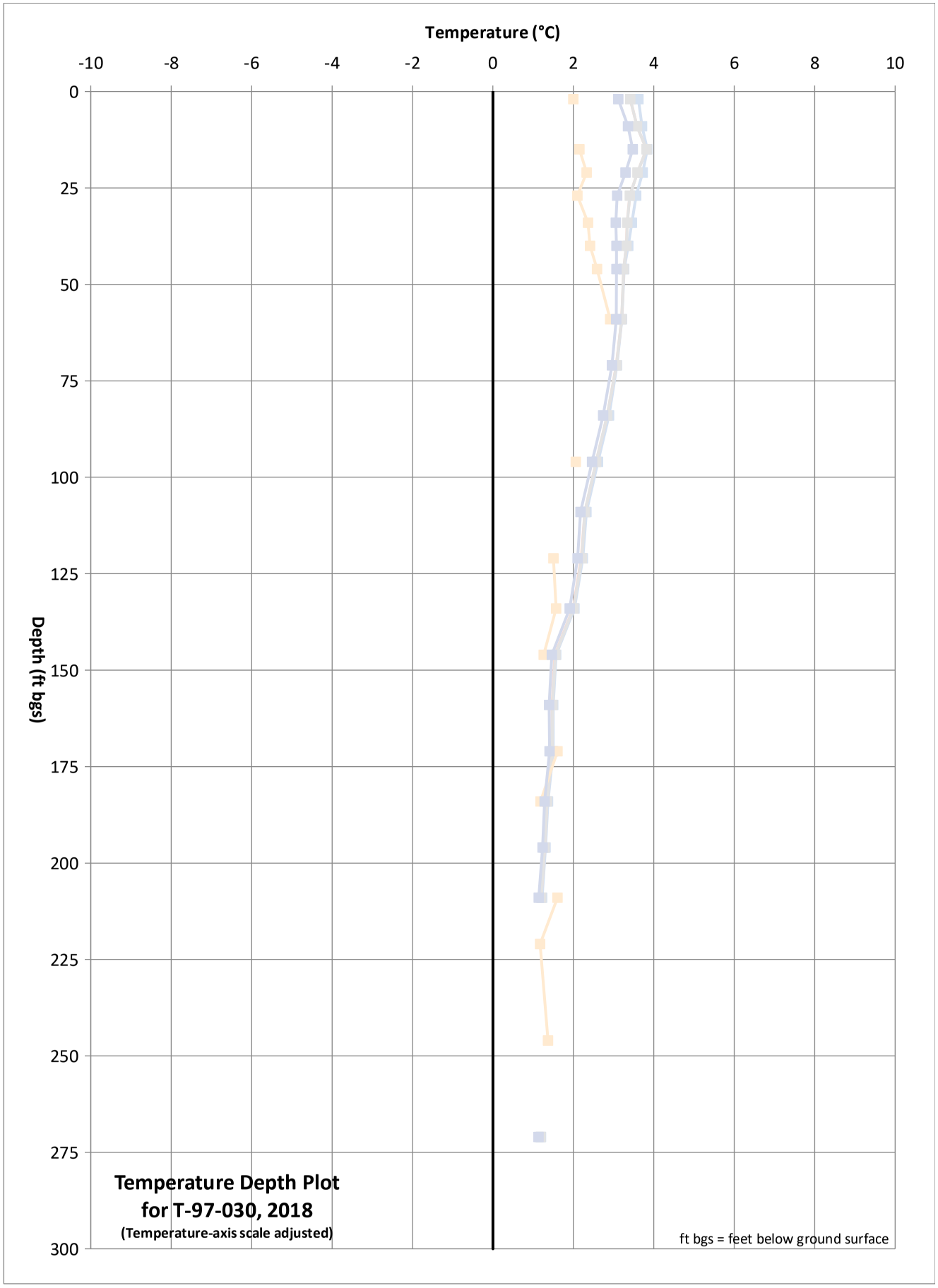

Temperature (°C)
-30
-25
-20
-15
-10
-5
0
5
10
15
20
25
30
35
Depth (ft bgs)
0
25
50
75
100
125
150
175
200
225
250
Temperature Depth Plot for T-97-029, 2018
ft bgs = feet below ground surface


Temperature (°C)
-10
-8
-6
-4
-2
0
2
4
6
8
10
Depth (ft bgs)
0
25
50
75
100
125
150
175
200
225
250
Temperature Depth Plot
for T-97-029, 2018
(Temperature-axis scale adjusted)
ft bgs = feet below ground surface

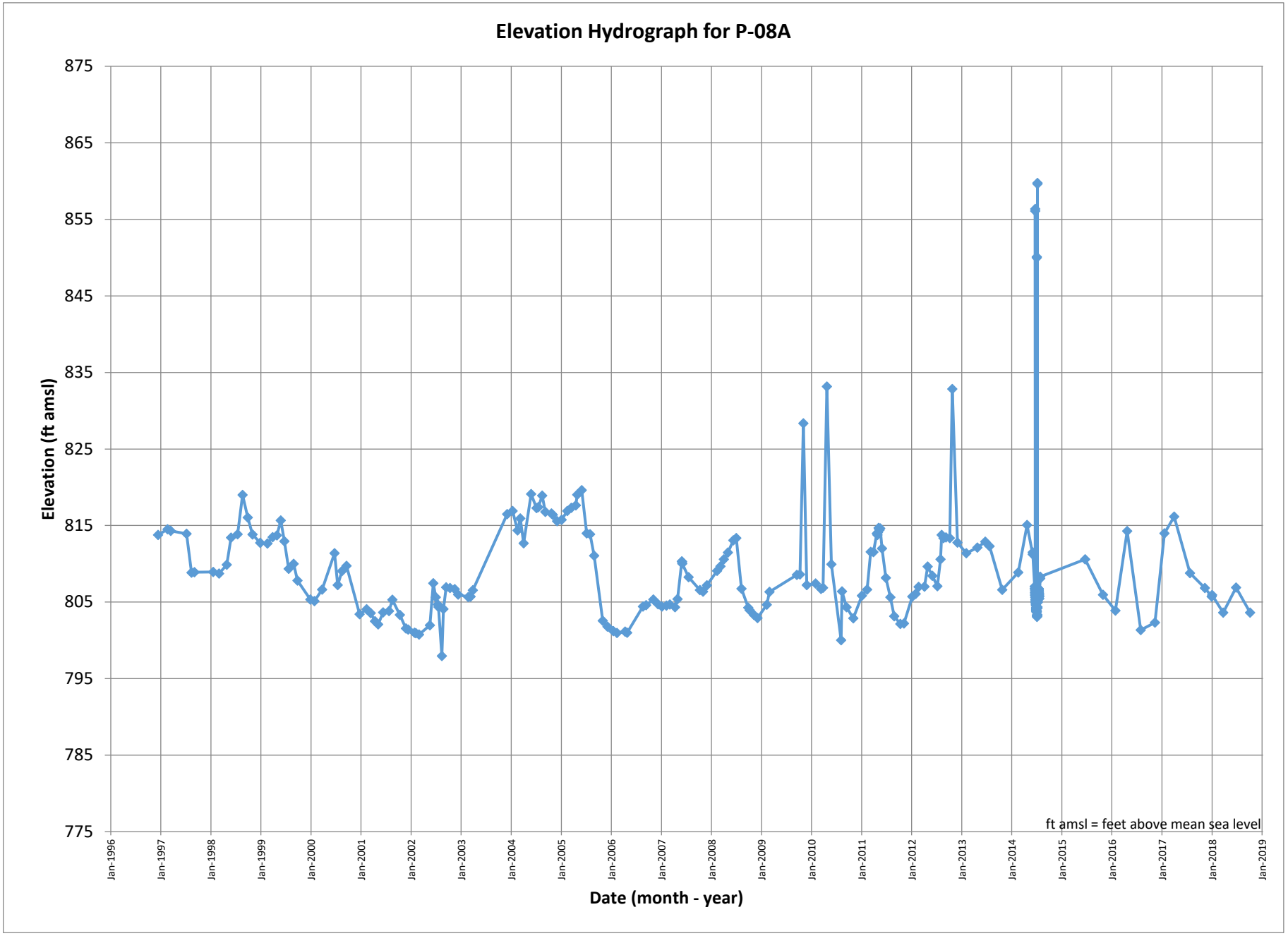

Temperature (°C)
-35
-25
-15
-5
5
15
25
0
25
50
75
100
125
150
175
200
225
250
275
300
Depth (ft bgs)
Temperature Depth Plot for T-97-030
ft bgs = feet below ground surface

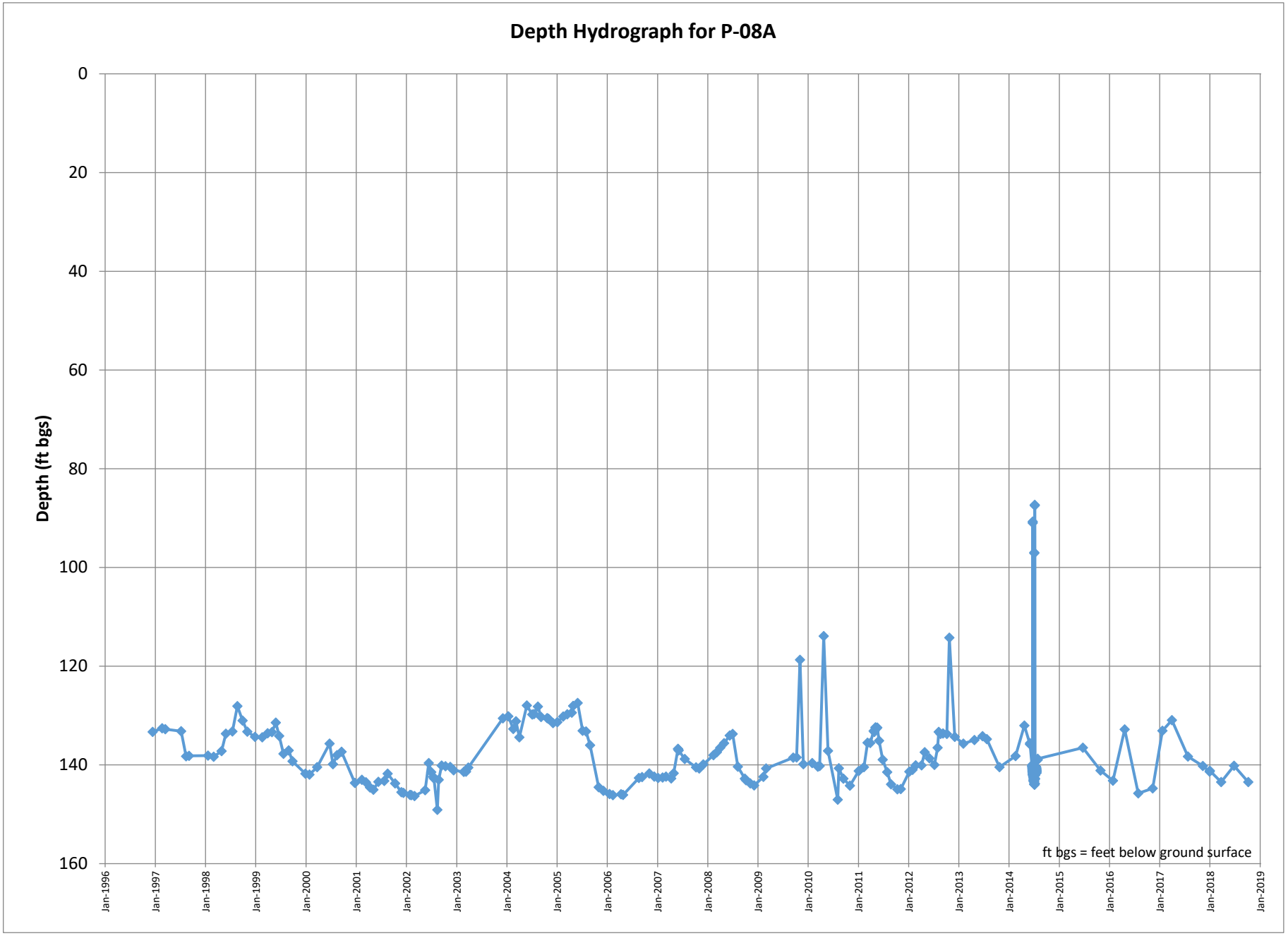

Temperature (°C)
-10
-8
-6
-4
-2
0
2
4
6
8
10
Depth (ft bgs)
0
25
50
75
100
125
150
175
200
225
250
275
300
Temperature Depth Plot for T-97-030
(Temperature-axis scale adjusted)
ft bgs = feet below ground surface

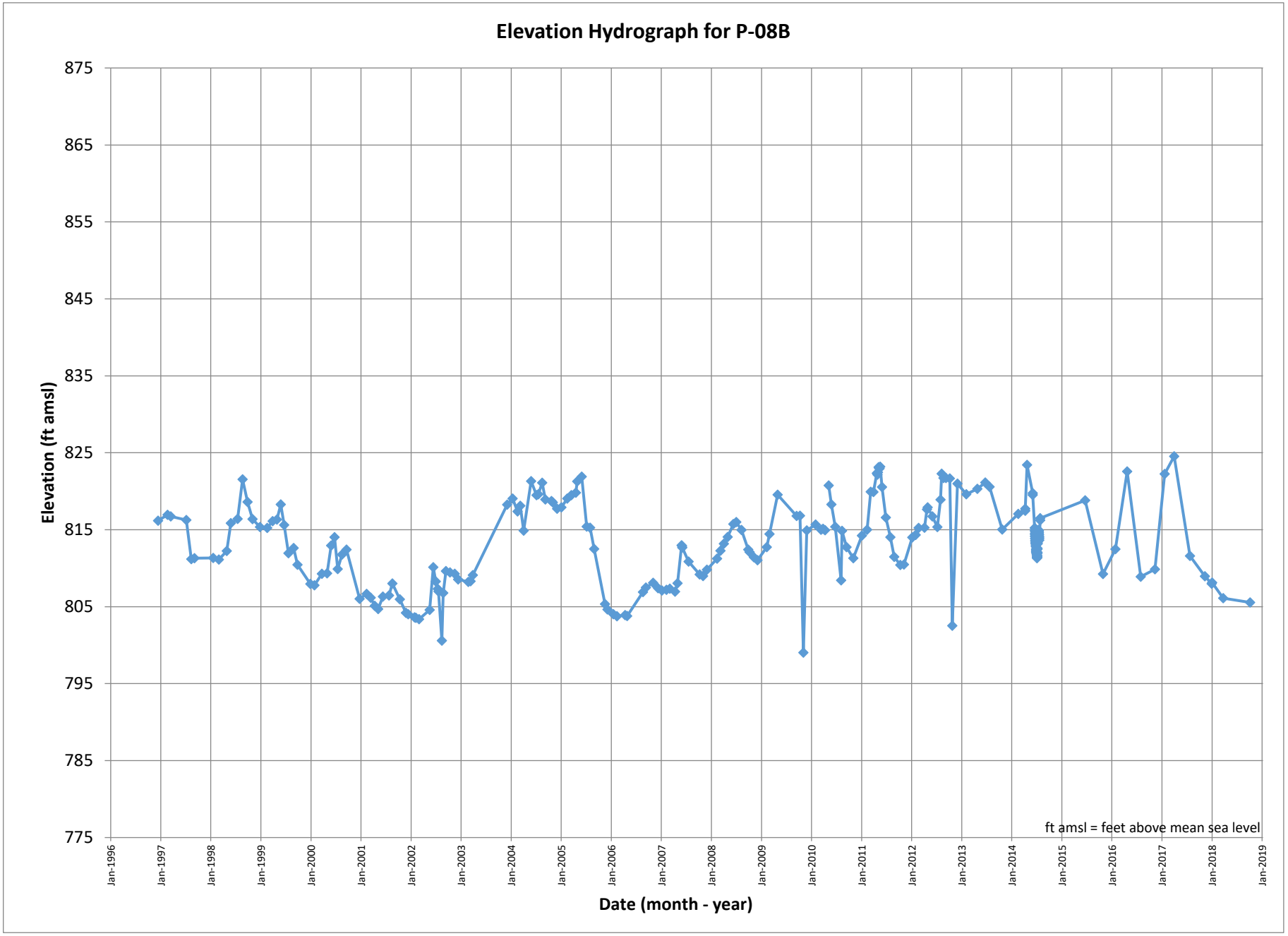

Temperature (°C)
-35
-25
-15
-5
5
15
0
25
50
75
100
125
150
175
200
225
250
275
300
Depth (ft bgs)
Temperature Depth Plot for T-97-030, 2018
ft bgs = feet below ground surface

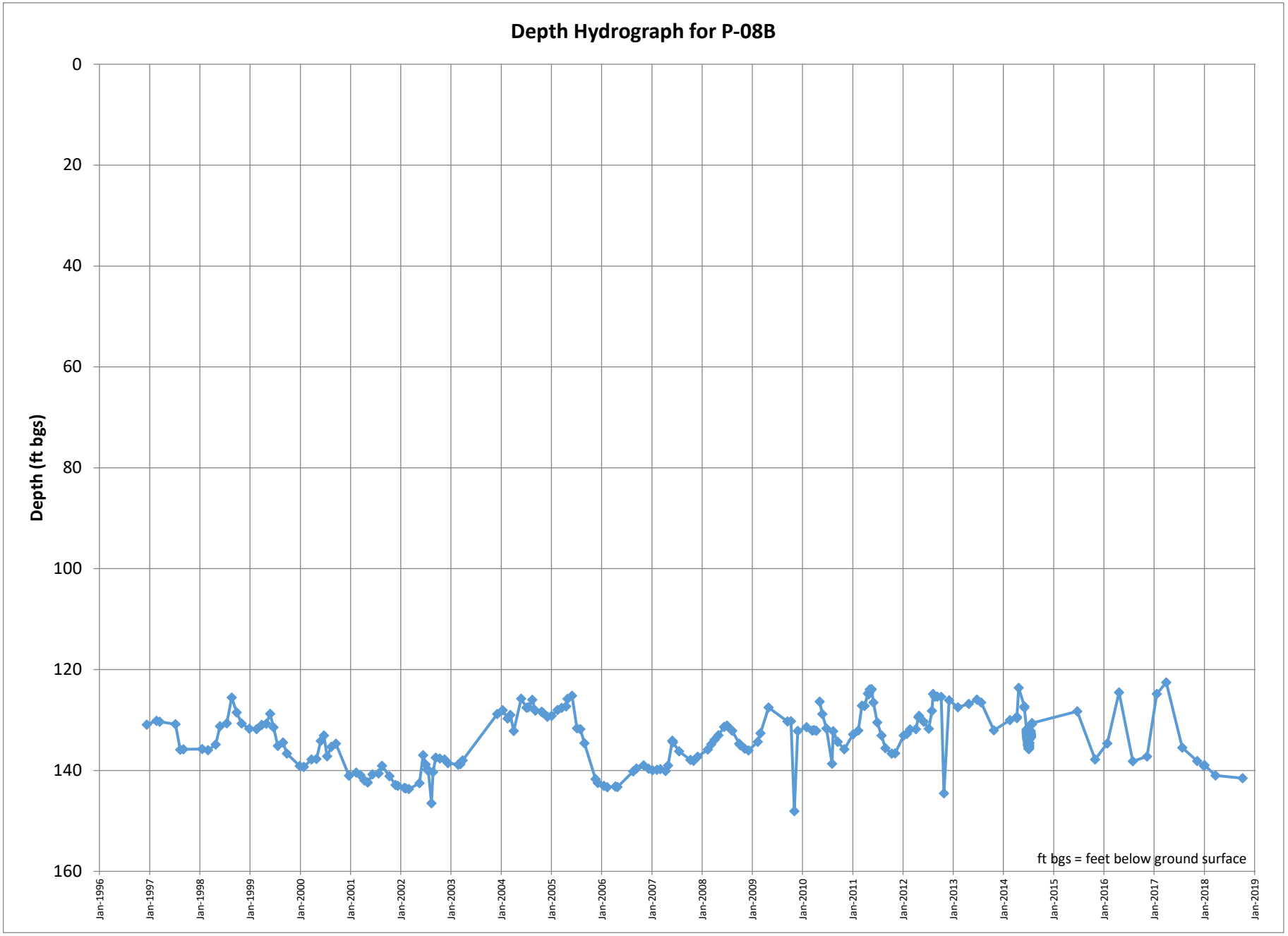

Temperature (°C)
-10
-8
-6
-4
-2
0
2
4
6
8
10
Depth (ft bgs)
0
25
50
75
100
125
150
175
200
225
250
275
300
Temperature Depth Plot
for T-97-030, 2018
(Temperature-axis scale adjusted)
ft bgs = feet below ground surface

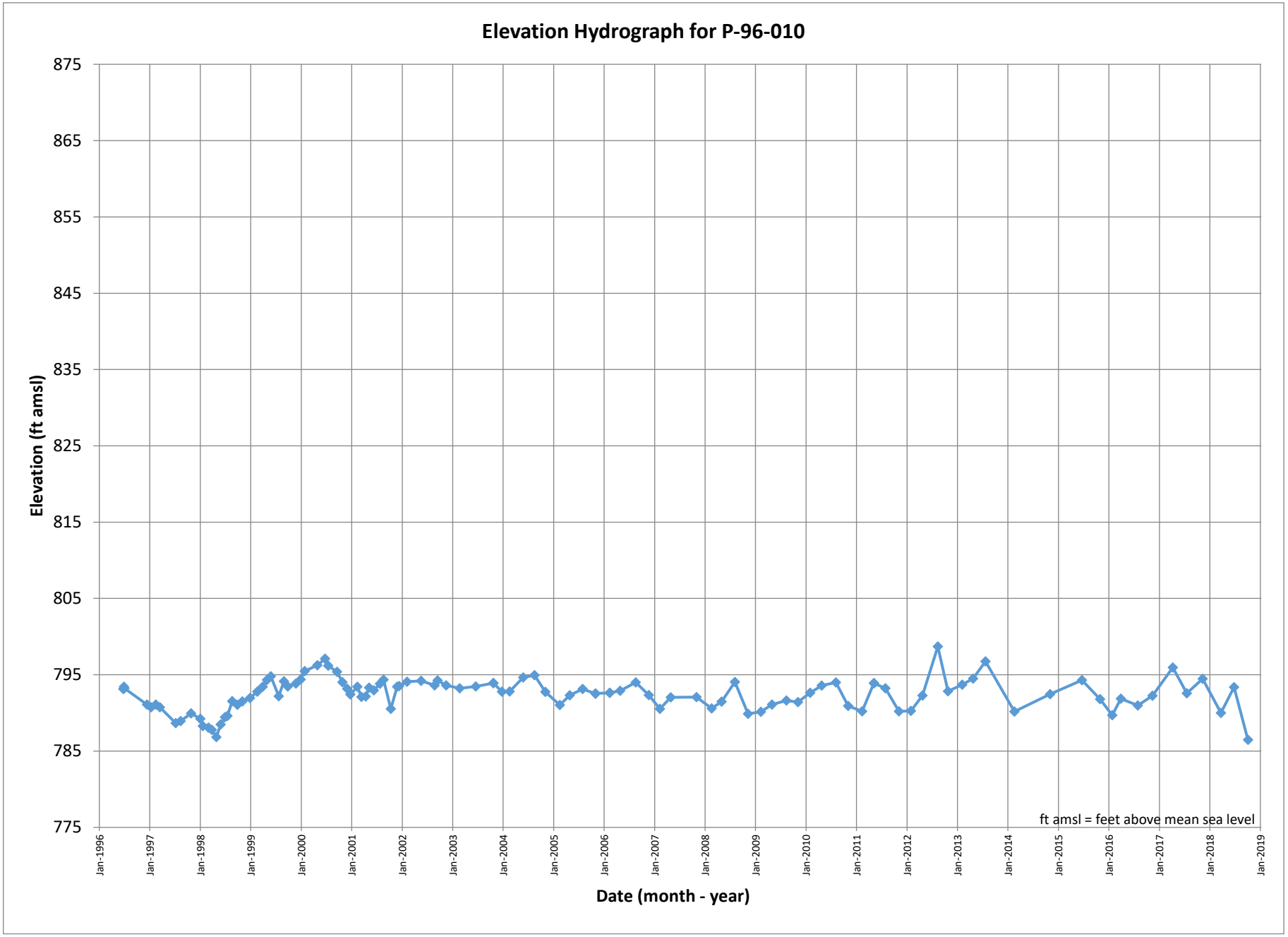
Appendix C
Piezometer Plots

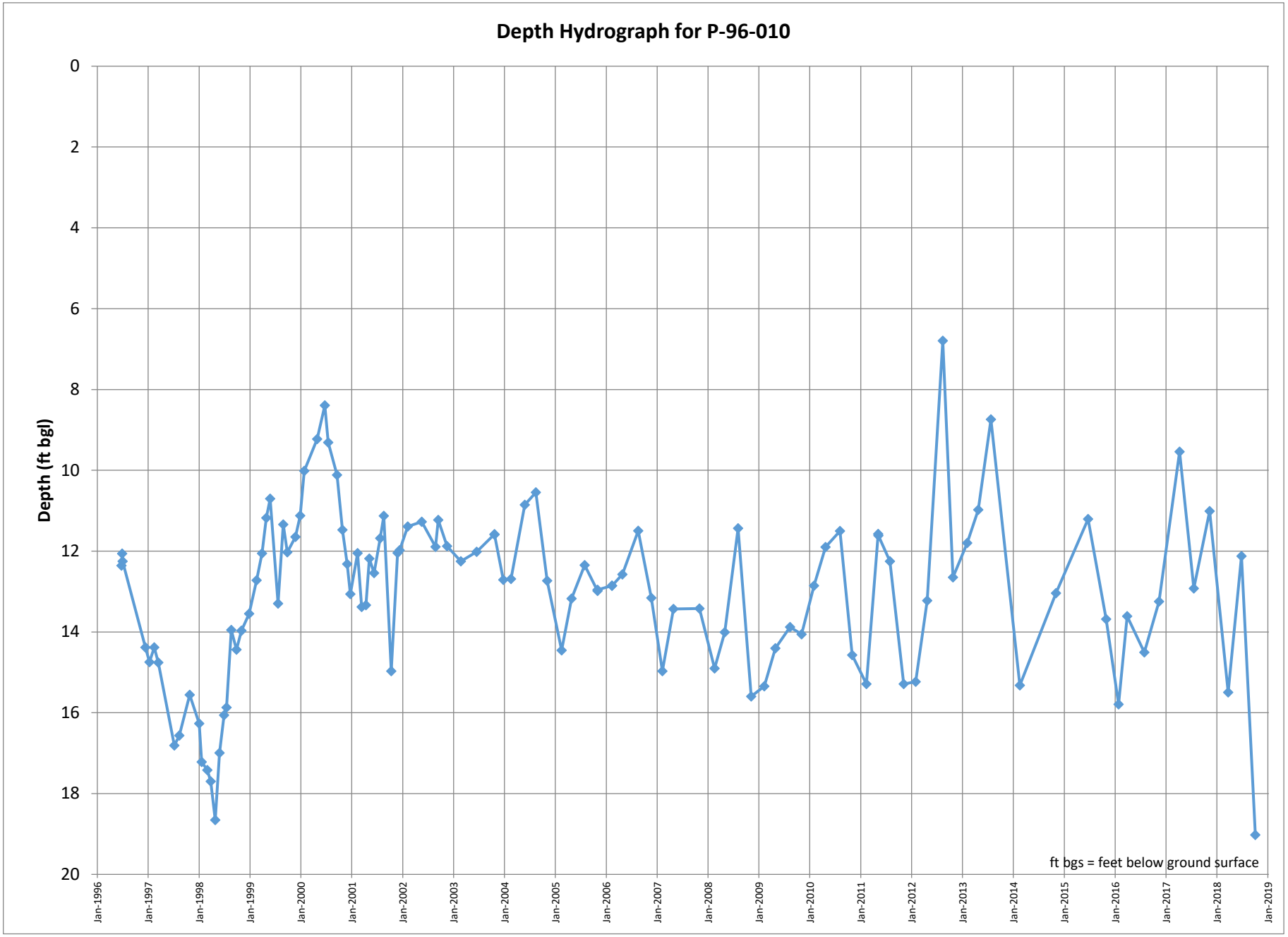

Elevation Hydrograph for P-08A
875
865
855
845
835
825
815
805
795
785
775
Elevation (ft amsl)
Jan-1996
Jan-1997
Jan-1998
Jan-1999
Jan-2000
Jan-2001
Jan-2002
Jan-2003
Jan-2004
Jan-2005
Jan-2006
Jan-2007
Jan-2008
Jan-2009
Jan-2010
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016
Jan-2017
Jan-2018
Jan-2019
Date (month - year)
ft amsl = feet above mean sea level

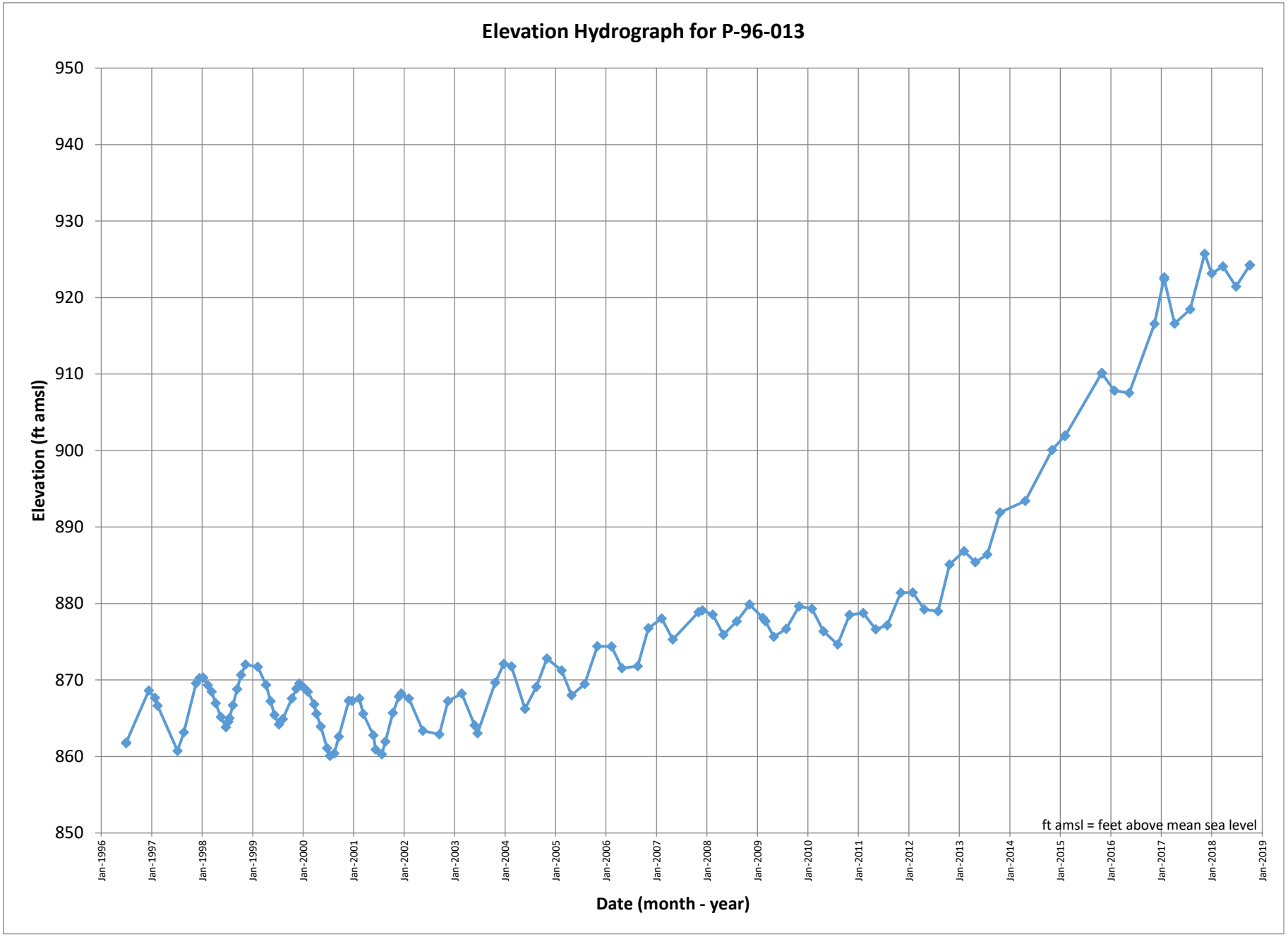

Depth Hydrograph for P-08A
Depth (ft bgs)
0
20
40
60
80
100
120
140
160
Jan-1996
Jan-1997
Jan-1998
Jan-1999
Jan-2000
Jan-2001
Jan-2002
Jan-2003
Jan-2004
Jan-2005
Jan-2006
Jan-2007
Jan-2008
Jan-2009
Jan-2010
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016
Jan-2017
Jan-2018
Jan-2019
ft bgs = feet below ground surface

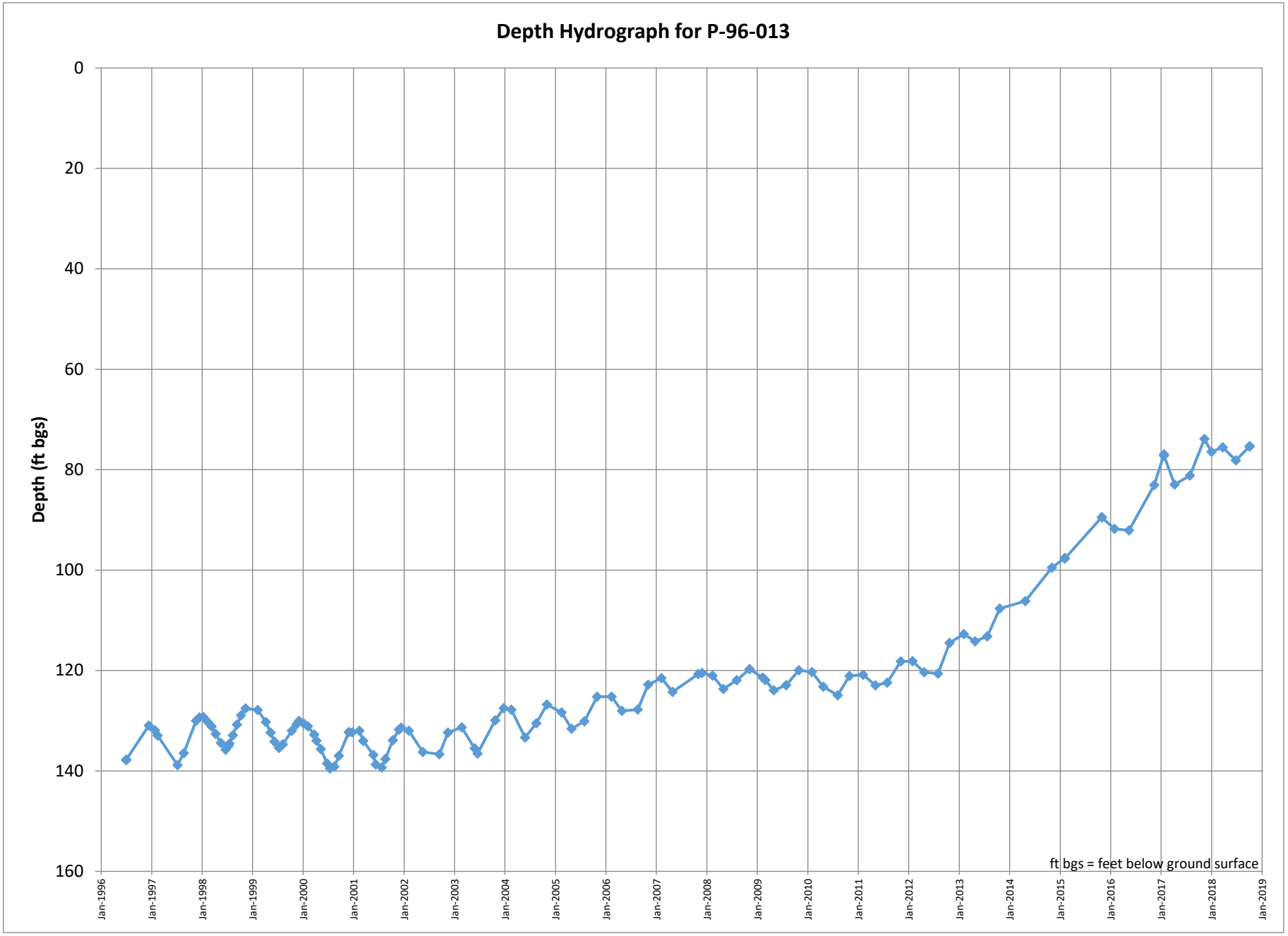

Elevation Hydrograph for P-08B
875
865
855
845
835
825
815
805
795
785
775
Elevation (ft amsl)
ft amsl = feet above mean sea level
Jan-1996
Jan-1997
Jan-1998
Jan-1999
Jan-2000
Jan-2001
Jan-2002
Jan-2003
Jan-2004
Jan-2005
Jan-2006
Jan-2007
Jan-2008
Jan-2009
Jan-2010
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016
Jan-2017
Jan-2018
Jan-2019
Date (month - year)

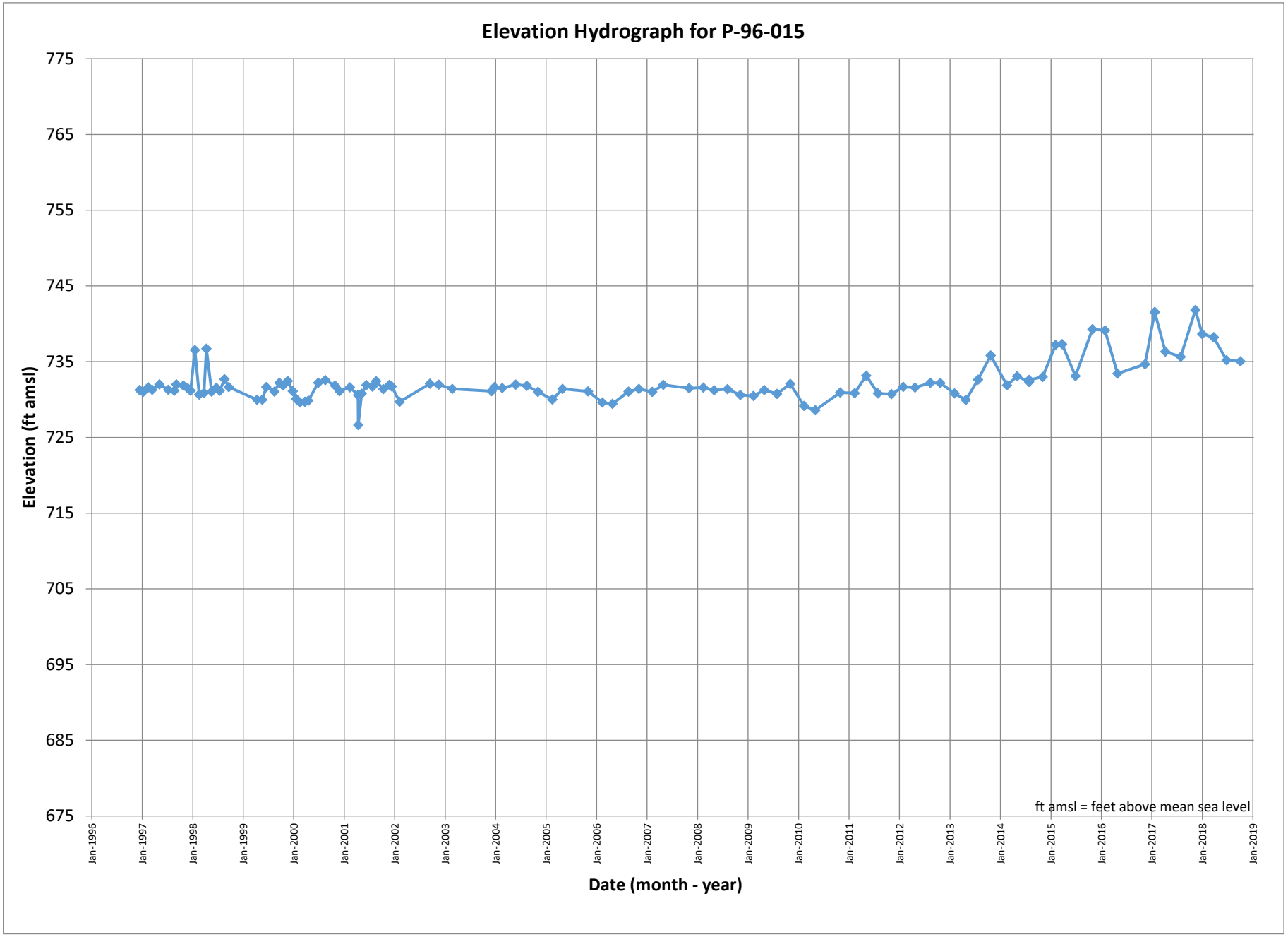

Depth Hydrograph for P-08B
Depth (ft bgs)
0
20
40
60
80
100
120
140
160
Jan-1996
Jan-1997
Jan-1998
Jan-1999
Jan-2000
Jan-2001
Jan-2002
Jan-2003
Jan-2004
Jan-2005
Jan-2006
Jan-2007
Jan-2008
Jan-2009
Jan-2010
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016
Jan-2017
Jan-2018
Jan-2019
ft bgs = feet below ground surface

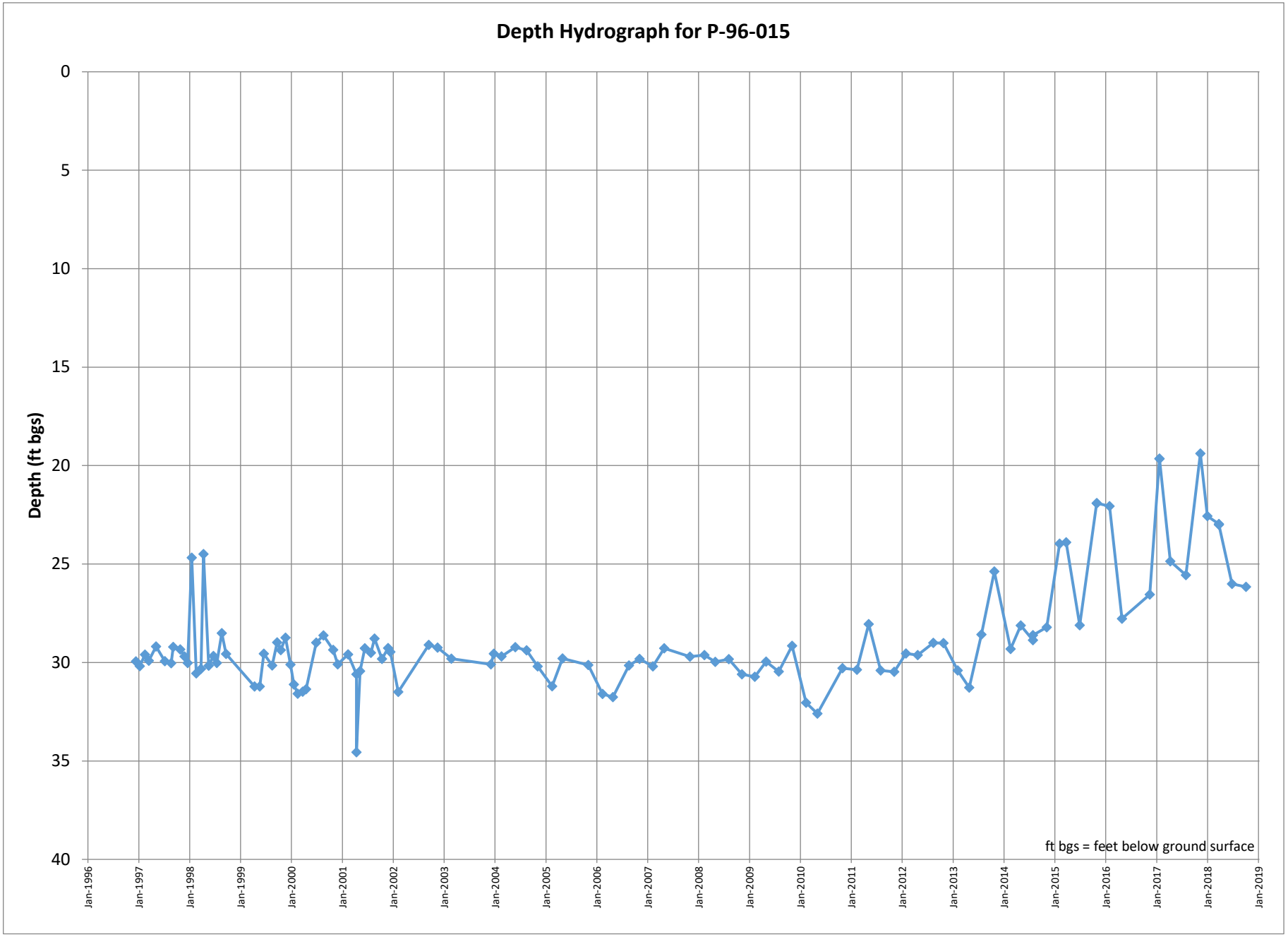

Elevation Hydrograph for P-96-010
875
865
855
845
835
825
815
805
795
785
775
Elevation (ft amsl)
Jan-1996
Jan-1997
Jan-1998
Jan-1999
Jan-2000
Jan-2001
Jan-2002
Jan-2003
Jan-2004
Jan-2005
Jan-2006
Jan-2007
Jan-2008
Jan-2009
Jan-2010
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016
Jan-2017
Jan-2018
Jan-2019
Date (month - year)
ft amsl = feet above mean sea level

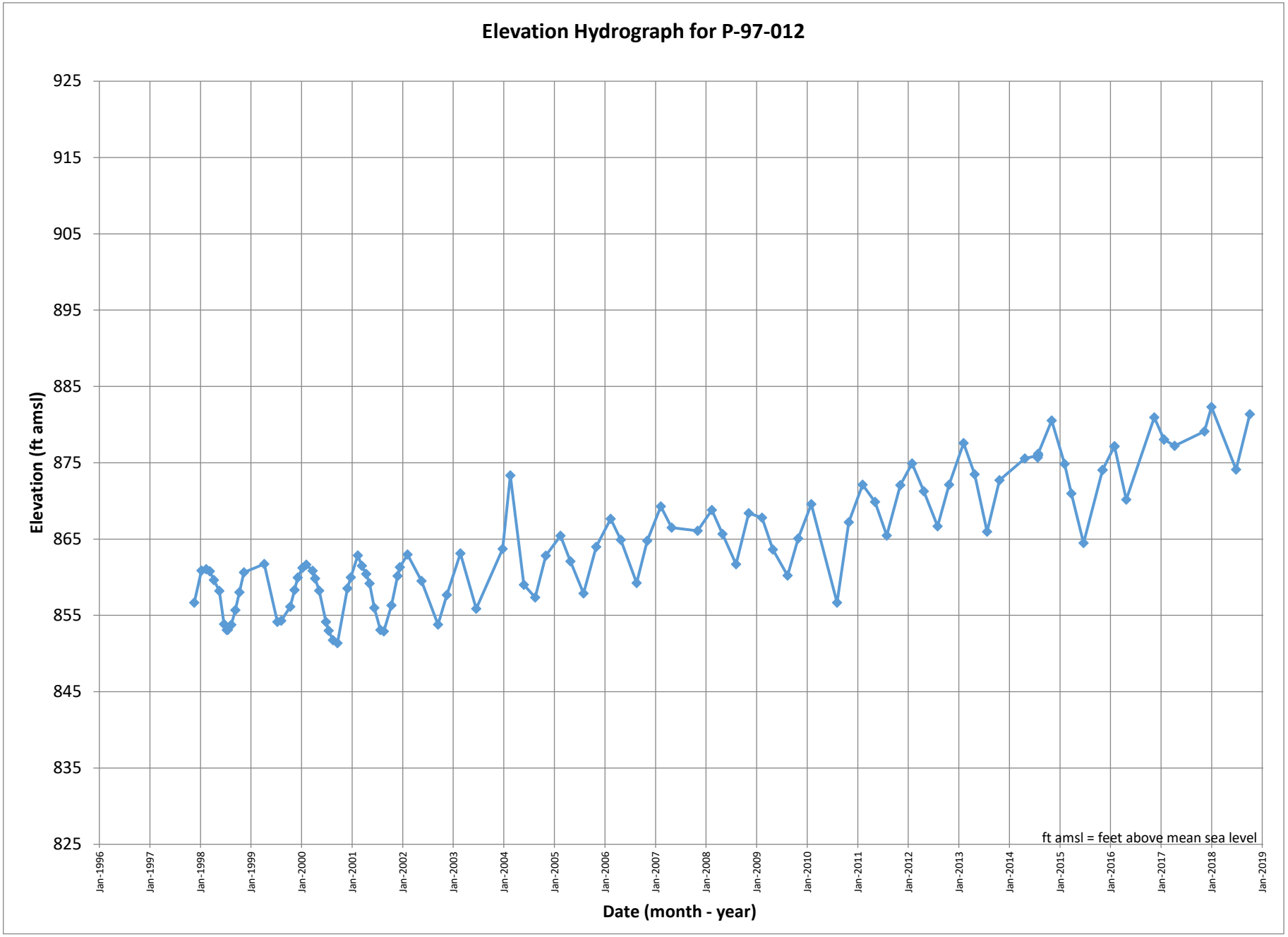

Depth Hydrograph for P-96-010
Depth (ft bgl)
0
2
4
6
8
10
12
14
16
18
20
Jan-1996
Jan-1997
Jan-1998
Jan-1999
Jan-2000
Jan-2001
Jan-2002
Jan-2003
Jan-2004
Jan-2005
Jan-2006
Jan-2007
Jan-2008
Jan-2009
Jan-2010
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016
Jan-2017
Jan-2018
Jan-2019
ft bgs = feet below ground surface

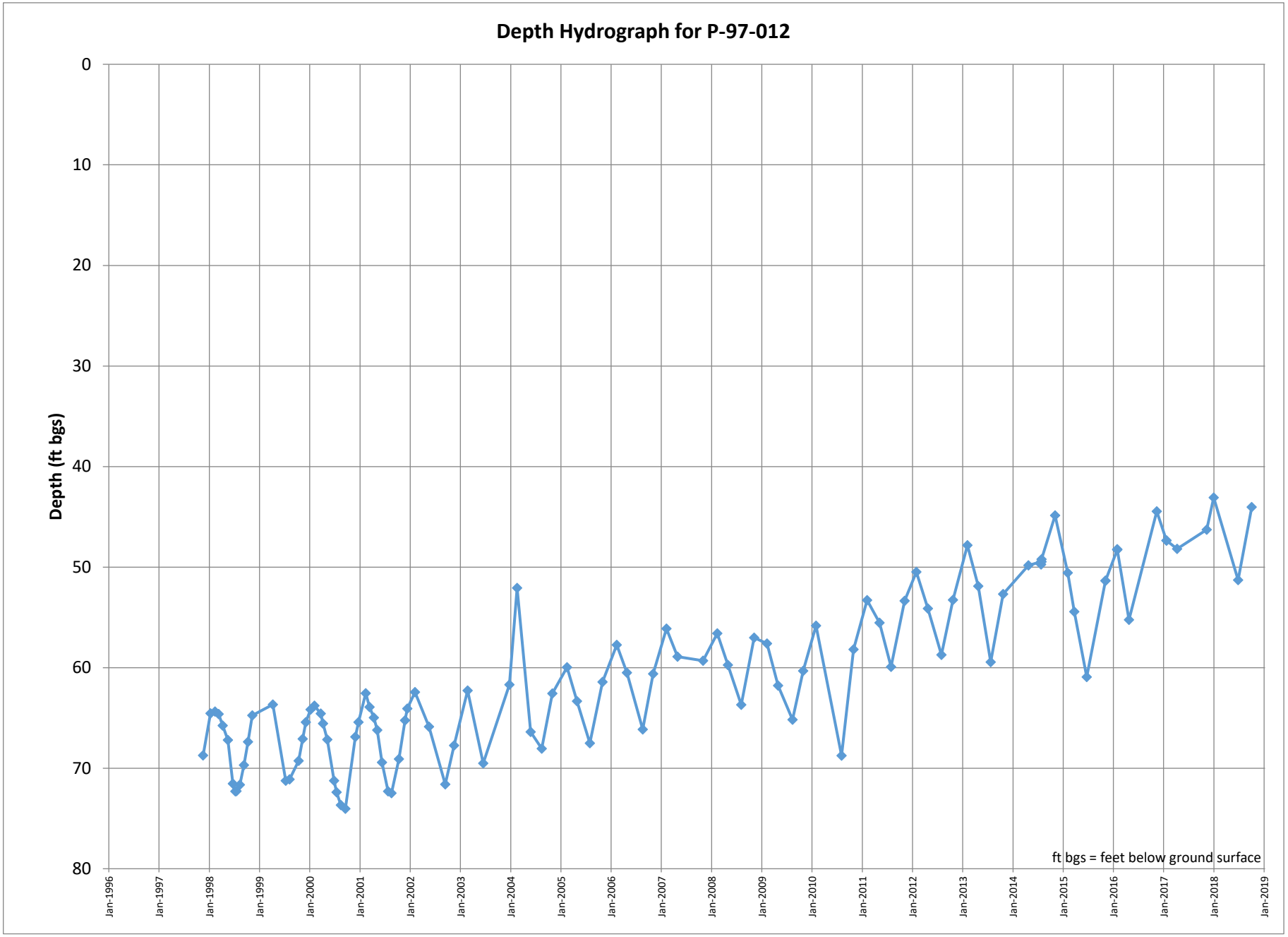

Elevation Hydrograph for P-96-013
Elevation (ft amsl)
950
940
930
920
910
900
890
880
870
860
850
Jan-1996
Jan-1997
Jan-1998
Jan-1999
Jan-2000
Jan-2001
Jan-2002
Jan-2003
Jan-2004
Jan-2005
Jan-2006
Jan-2007
Jan-2008
Jan-2009
Jan-2010
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016
Jan-2017
Jan-2018
Jan-2019
Date (month - year)
ft amsl = feet above mean sea level

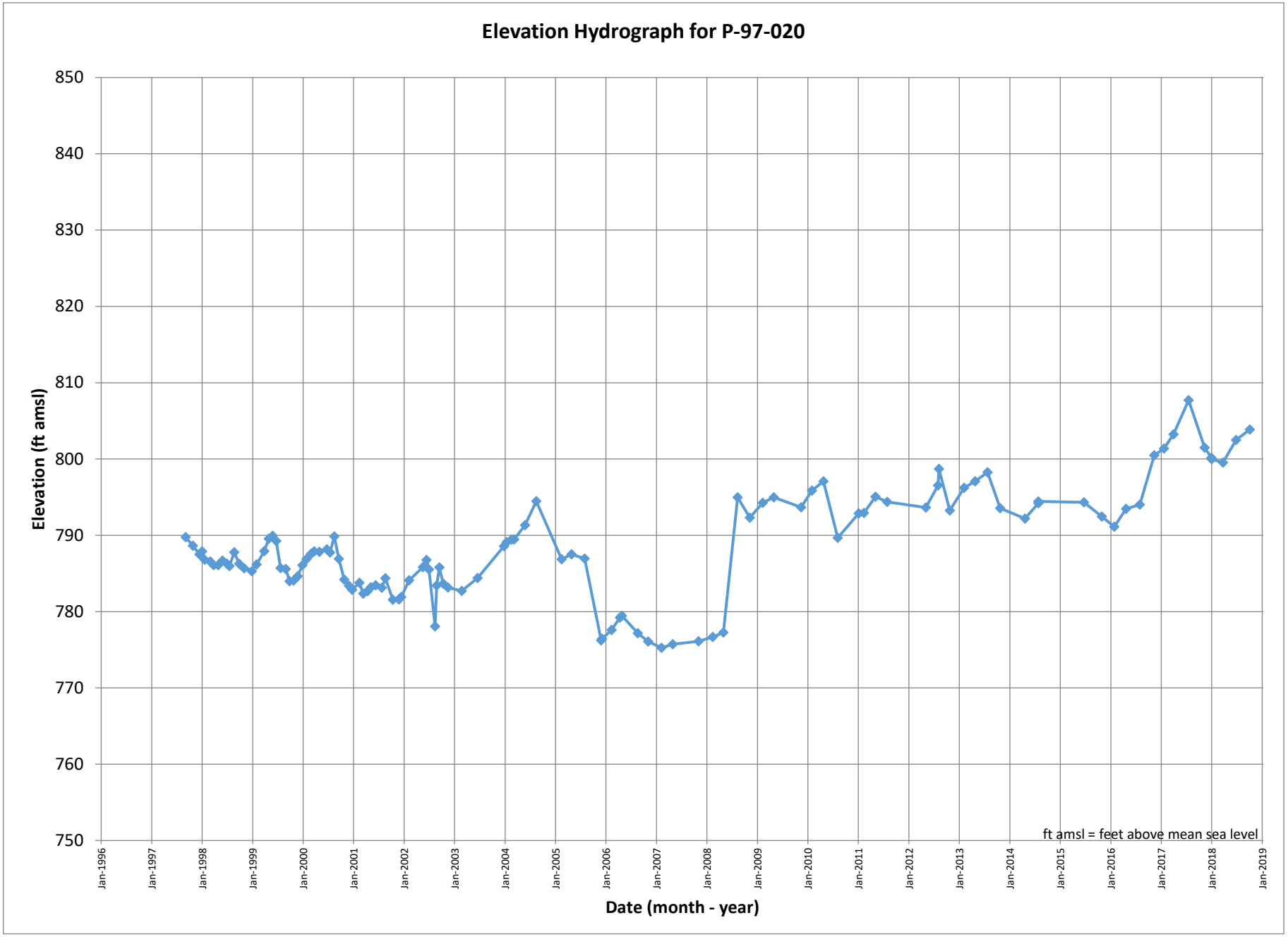

Depth Hydrograph for P-96-013
Depth (ft bgs)
0
20
40
60
80
100
120
140
160
Jan-1996
Jan-1997
Jan-1998
Jan-1999
Jan-2000
Jan-2001
Jan-2002
Jan-2003
Jan-2004
Jan-2005
Jan-2006
Jan-2007
Jan-2008
Jan-2009
Jan-2010
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016
Jan-2017
Jan-2018
Jan-2019
ft bgs = feet below ground surface

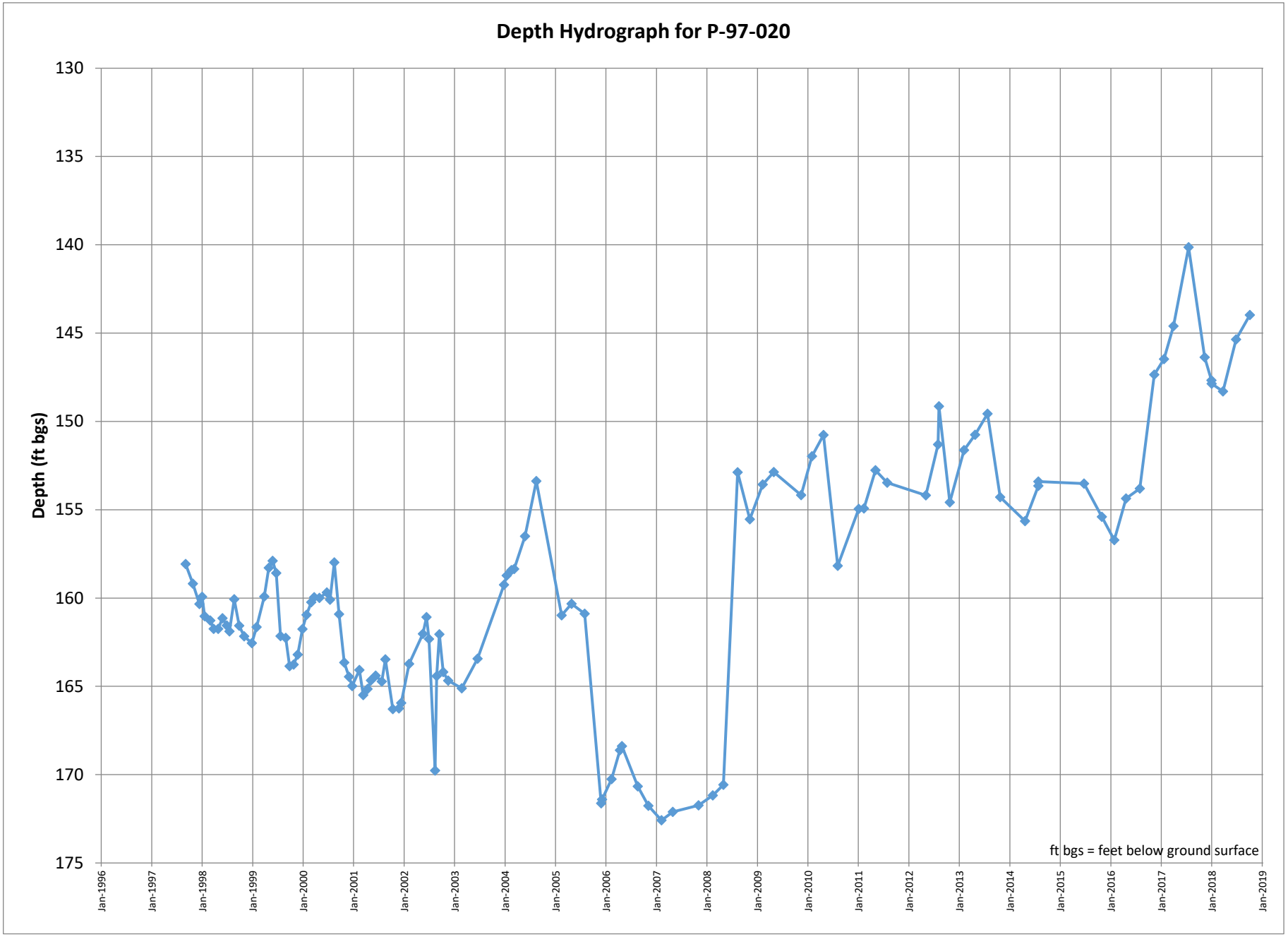

Elevation Hydrograph for P-96-015
775
765
755
745
735
725
715
705
695
685
675
Elevation (ft amsl)
ft amsl = feet above mean sea level
Jan-1996
Jan-1997
Jan-1998
Jan-1999
Jan-2000
Jan-2001
Jan-2002
Jan-2003
Jan-2004
Jan-2005
Jan-2006
Jan-2007
Jan-2008
Jan-2009
Jan-2010
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016
Jan-2017
Jan-2018
Jan-2019
Date (month - year)

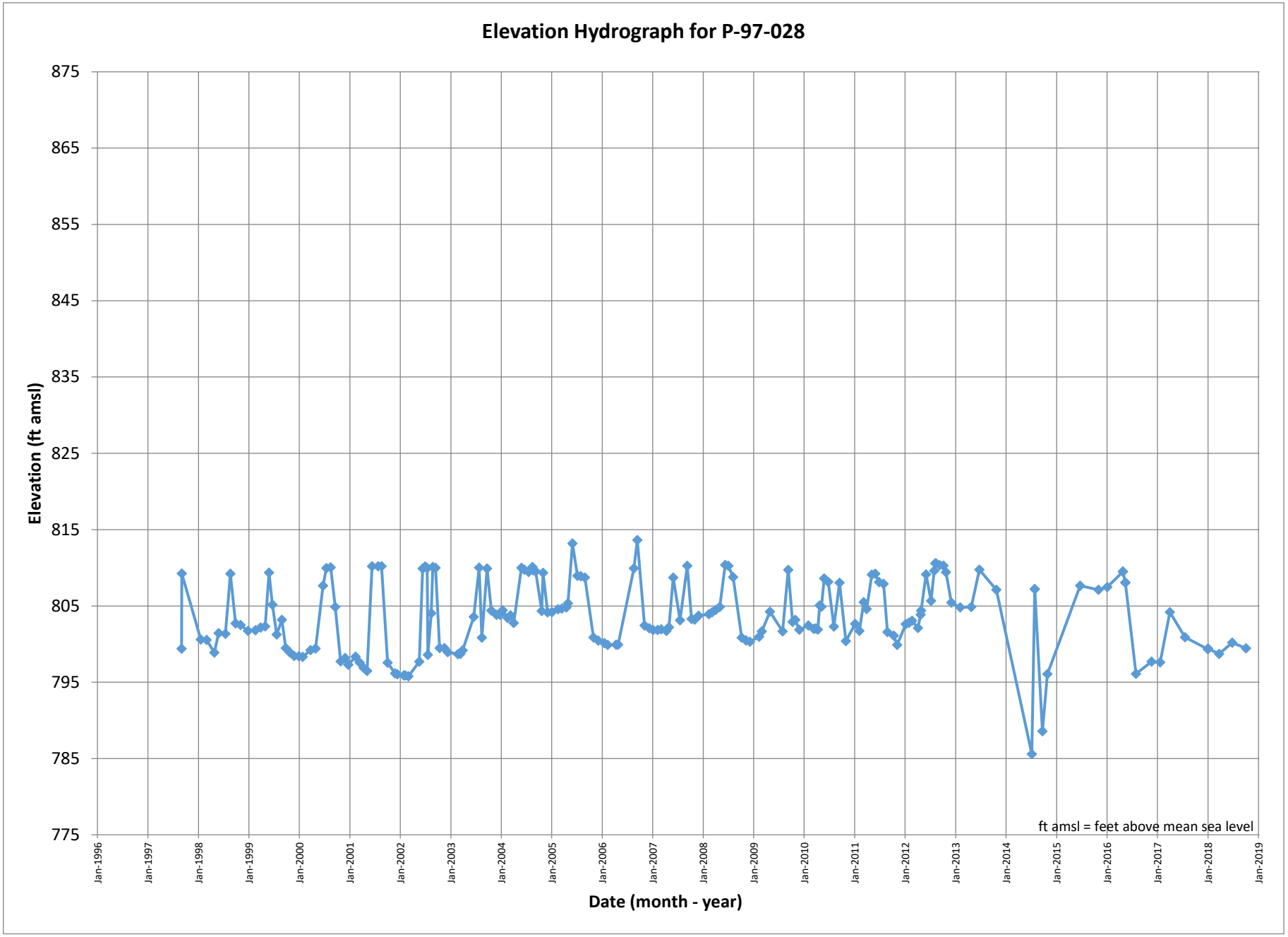

Depth Hydrograph for P-96-015
Depth (ft bgs)
0
5
10
15
20
25
30
35
40
Jan-1996
Jan-1997
Jan-1998
Jan-1999
Jan-2000
Jan-2001
Jan-2002
Jan-2003
Jan-2004
Jan-2005
Jan-2006
Jan-2007
Jan-2008
Jan-2009
Jan-2010
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016
Jan-2017
Jan-2018
Jan-2019
ft bgs = feet below ground surface

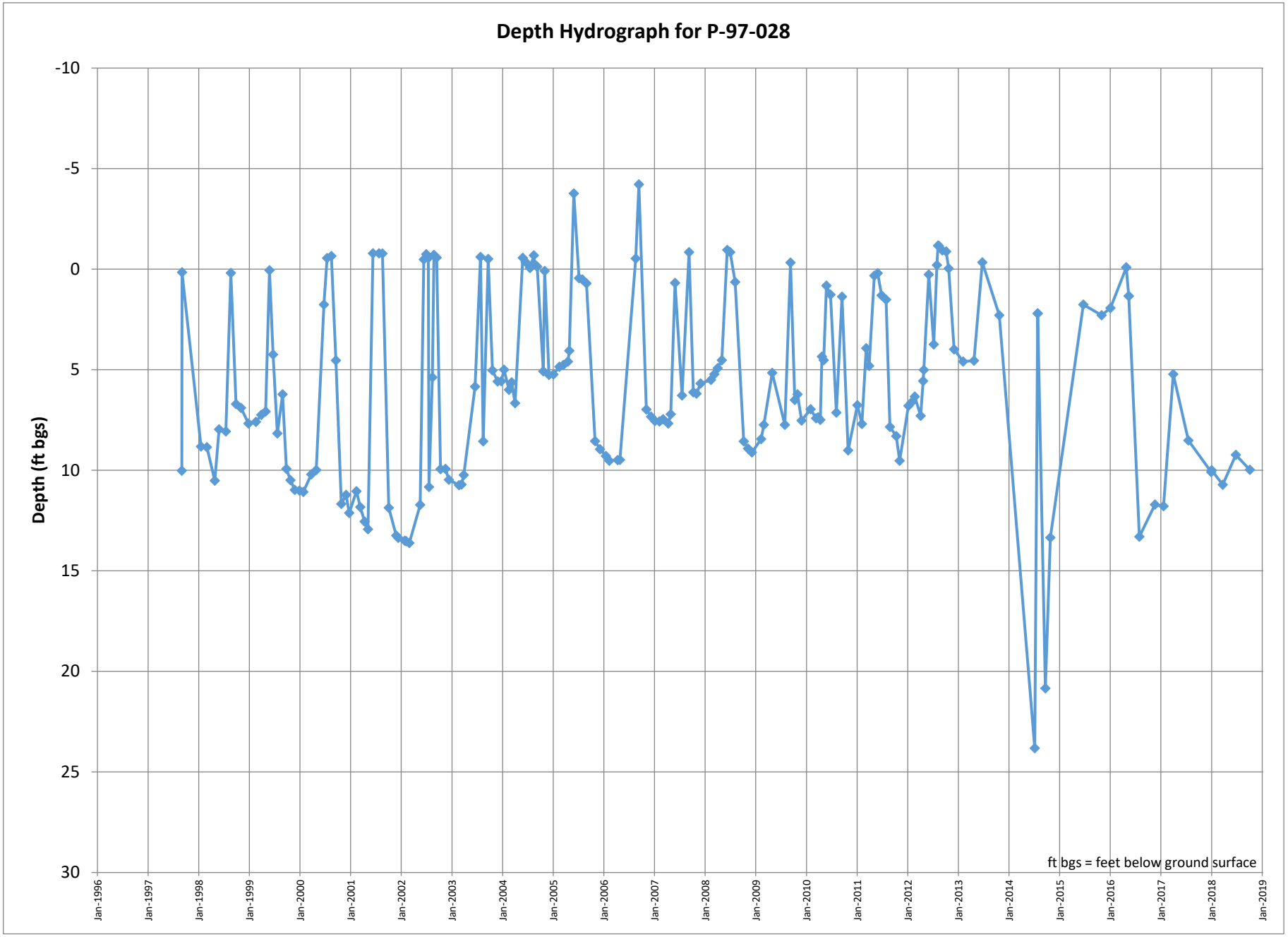

Elevation Hydrograph for P-97-012
Elevation (ft amsl)
925
915
905
895
885
875
865
855
845
835
825
Jan-1996
Jan-1997
Jan-1998
Jan-1999
Jan-2000
Jan-2001
Jan-2002
Jan-2003
Jan-2004
Jan-2005
Jan-2006
Jan-2007
Jan-2008
Jan-2009
Jan-2010
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016
Jan-2017
Jan-2018
Jan-2019
Date (month - year)
ft amsl = feet above mean sea level

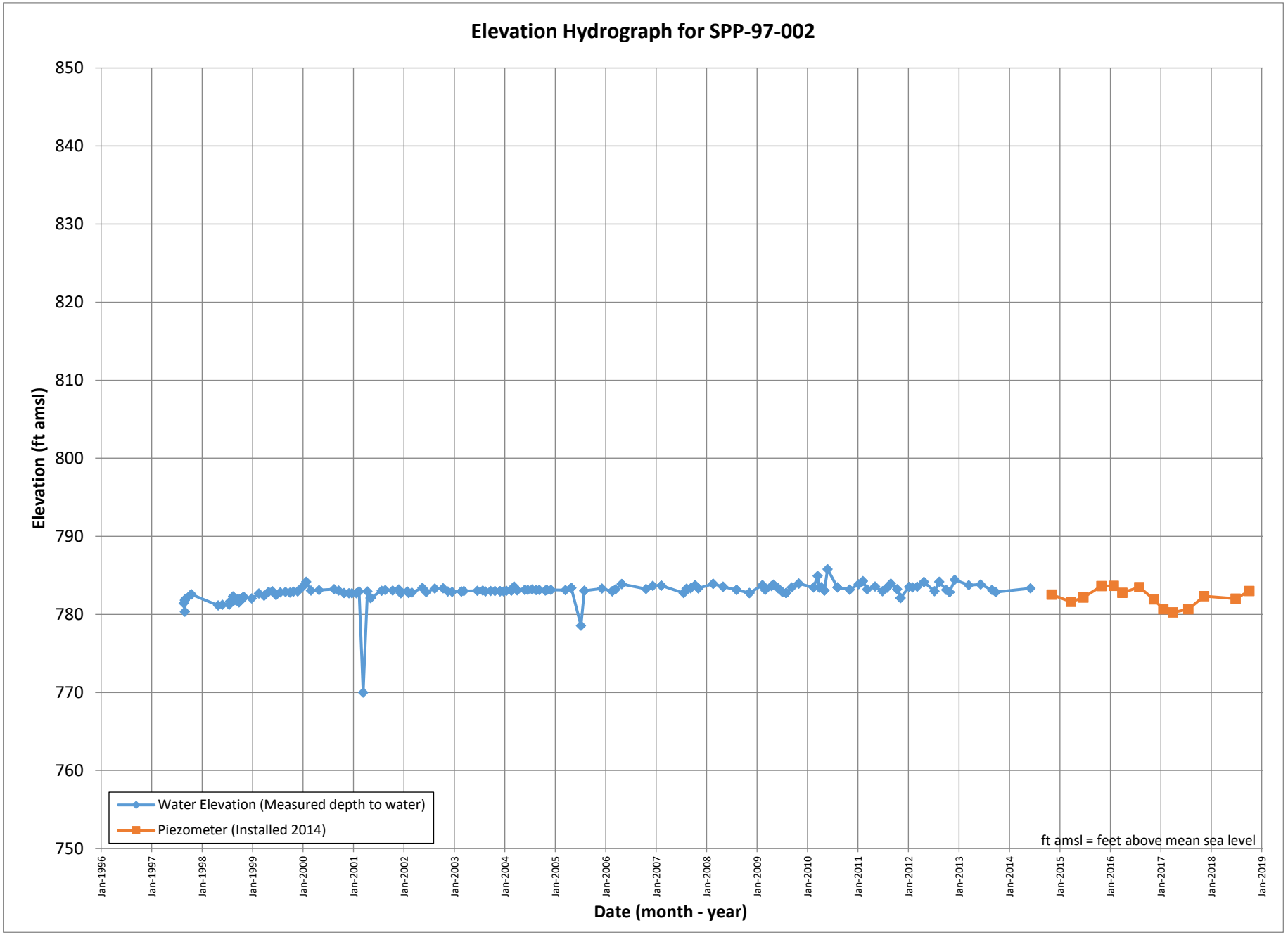

Depth Hydrograph for P-97-012
Depth (ft bgs)
0
10
20
30
40
50
60
70
80
Jan-1996
Jan-1997
Jan-1998
Jan-1999
Jan-2000
Jan-2001
Jan-2002
Jan-2003
Jan-2004
Jan-2005
Jan-2006
Jan-2007
Jan-2008
Jan-2009
Jan-2010
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016
Jan-2017
Jan-2018
Jan-2019
ft bgs = feet below ground surface

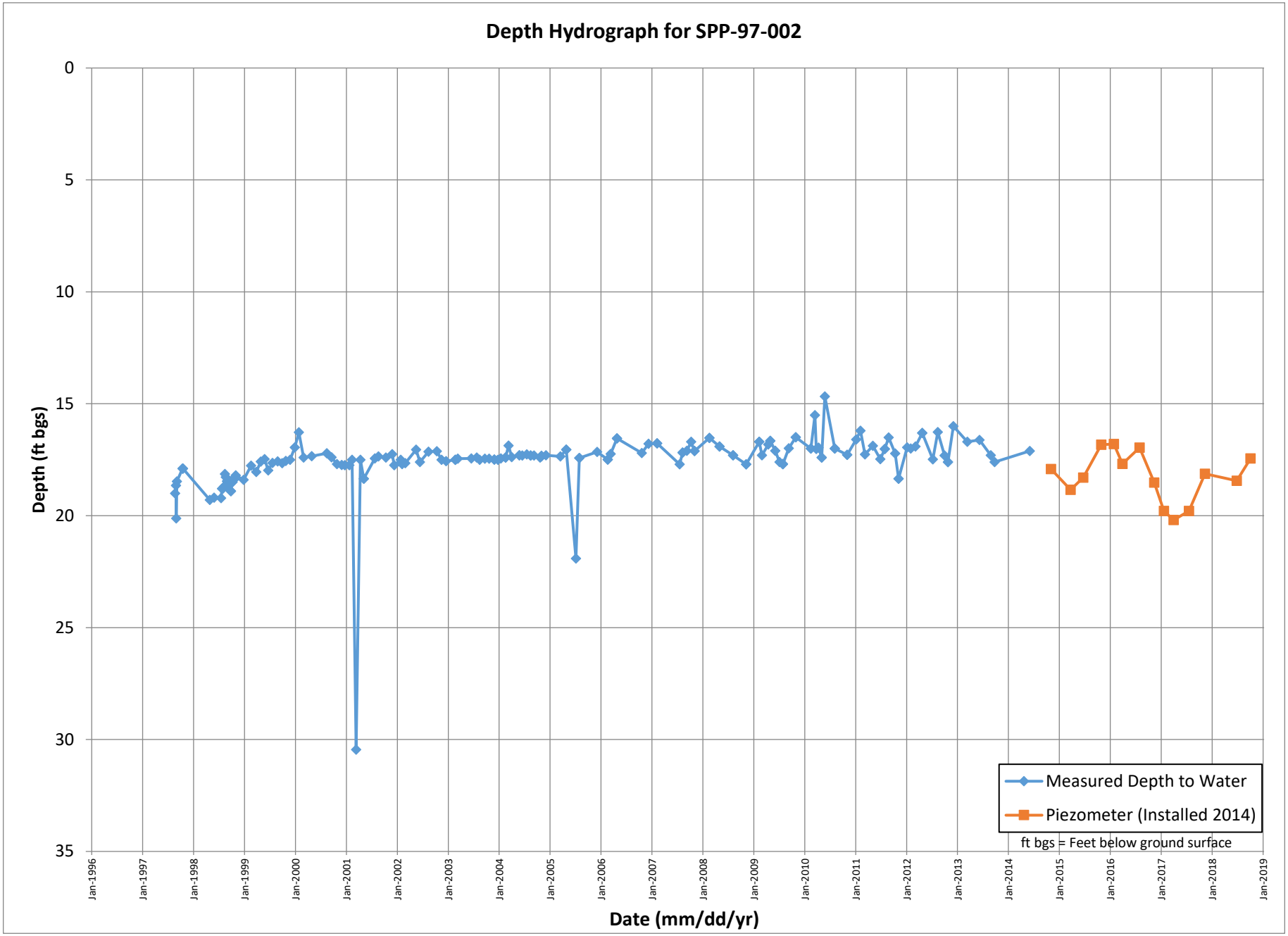

Elevation Hydrograph for P-97-020
Elevation (ft amsl)
850
840
830
820
810
800
790
780
770
760
750
Jan-1996
Jan-1997
Jan-1998
Jan-1999
Jan-2000
Jan-2001
Jan-2002
Jan-2003
Jan-2004
Jan-2005
Jan-2006
Jan-2007
Jan-2008
Jan-2009
Jan-2010
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016
Jan-2017
Jan-2018
Jan-2019
Date (month - year)
ft amsl = feet above mean sea level


Depth Hydrograph for P-97-020
Depth (ft bgs)
130
135
140
145
150
155
160
165
170
175
Jan-1996
Jan-1997
Jan-1998
Jan-1999
Jan-2000
Jan-2001
Jan-2002
Jan-2003
Jan-2004
Jan-2005
Jan-2006
Jan-2007
Jan-2008
Jan-2009
Jan-2010
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016
Jan-2017
Jan-2018
Jan-2019
ft bgs = feet below ground surface


Elevation Hydrograph for P-97-028
Elevation (ft amsl)
875
865
855
845
835
825
815
805
795
785
775
Jan-1996
Jan-1997
Jan-1998
Jan-1999
Jan-2000
Jan-2001
Jan-2002
Jan-2003
Jan-2004
Jan-2005
Jan-2006
Jan-2007
Jan-2008
Jan-2009
Jan-2010
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016
Jan-2017
Jan-2018
Jan-2019
Date (month - year)
ft amsl = feet above mean sea level


Depth Hydrograph for P-97-028
Depth (ft bgs)
-10
-5
0
5
10
15
20
25
30
Jan-1996
Jan-1997
Jan-1998
Jan-1999
Jan-2000
Jan-2001
Jan-2002
Jan-2003
Jan-2004
Jan-2005
Jan-2006
Jan-2007
Jan-2008
Jan-2009
Jan-2010
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016
Jan-2017
Jan-2018
Jan-2019
ft bgs = feet below ground surface


Elevation Hydrograph for SPP-97-002
Elevation (ft amsl)
850
840
830
820
810
800
790
780
770
760
750
Jan-1996
Jan-1997
Jan-1998
Jan-1999
Jan-2000
Jan-2001
Jan-2002
Jan-2003
Jan-2004
Jan-2005
Jan-2006
Jan-2007
Jan-2008
Jan-2009
Jan-2010
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016
Jan-2017
Jan-2018
Jan-2019
Date (month - year)
Water Elevation (Measured depth to water)
Piezometer (Installed 2014)
ft amsl = feet above mean sea level


Depth Hydrograph for SPP-97-002
Depth (ft bgs)
0
5
10
15
20
25
30
35
Jan-1996
Jan-1997
Jan-1998
Jan-1999
Jan-2000
Jan-2001
Jan-2002
Jan-2003
Jan-2004
Jan-2005
Jan-2006
Jan-2007
Jan-2008
Jan-2009
Jan-2010
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016
Jan-2017
Jan-2018
Jan-2019
Date (mm/dd/yr)
Measured Depth to Water
Piezometer (Installed 2014)
ft bgs = Feet below ground surface

Appendix D
Quality Control / Quality Assurance

Quarterly Thermister & Piezometer

Date 1-15-18, 1-17-18 Row: Technician: DJS/JWM

Well	Location	Col. Row #Ports	Collection Method Instrument	(Nodes) Time	Date
Backdam Piezo	Backdam	16	Nautiz Geokon logger	No data since	last Collection
T15-135	Backdam	1	Archer Beaded Stream	17:02	1-17-18
T15-136	Backdam	1	Archer Beaded Stream	16:56	↓
T15-138	Backdam	1	Archer Beaded Stream	16:52	↓
T15-139	Backdam	1	Archer Beaded Stream	16:47	↓
T15-140	Backdam	1	Archer Beaded Stream	16:41	↓
T15-141	Backdam	1	Archer Beaded Stream	16:35	↓
T15-143	Backdam	1	Archer Beaded Stream	16:28	↓
T15-144	Backdam	1	Archer Beaded Stream	16:22	↓
T12-106	Backdam	1	Archer Beaded Stream	16:12	↓
T12-107	Backdam	1	Archer Beaded Stream	16:17	↓
T12-108	Backdam	1	Archer Beaded Stream	16:06	↓
T12-109	Backdam	1	Archer Beaded Stream	15:58	↓
*T95-08	Over Burden	26	Yellow box Thermister	(24) 10:56	↓
*P96-13	Over Burden	25	Geokon Piezometer	14:34	1-15-18
*T96-13	Over Burden	29	Yellow box Thermister	(24) [illegible]	↓
T96-13S	Over Burden	30	Yellow box Thermister	(24) [illegible]	↓
*T96-21	Over Burden	31	Yellow box Thermister	(24) 14:37	↓
*T96-22	Over Burden	32	Yellow box Thermister	(24) 14:47	↓
*T96-23	Over Burden	33	Yellow box Thermister	(24) 14:49	↓
T96-24	Over Burden	34	Yellow box Thermister	(24) 14:52	↓
*P97-12	Blast Road	24	Geokon Piezometer	15:24	QAQC
*T96-12	Blast Road	27	Yellow box Thermister	(24) ~~15:20~~ 15:20	QAQC
*T96-12S	Blast Road	28	Yellow box Thermister	(24) 15:20	↓
T98-33	Cold Storage	12	Yellow box Thermister	(10) buried	1-17-18
T98-34	Cold Storage	13	Yellow box Thermister	(11) 11:11	↓
T98-35	Cold Storage	14	Yellow box Thermister	(11) 11:15	↓
T11-91	ARD Toe	145	Yellow box Thermister	(12) 16:02	1-15-18
T11-92	ARD Toe	146	Yellow box Thermister	(11) 15:56	↓
T11-93	ARD Toe	147	Yellow box Thermister	(9) 15:52	↓
T11-94	ARD Toe	148	Yellow box Thermister	(12) 15:45	1-17-18
~~T11-95~~	~~ARD Toe~~	~~149~~	~~Yellow box Thermister~~	~~(12) 15:56~~	
P05-67	By "3 Way"	1	Nautiz Geokon logger	15:20	1-17-18
T05-67	By "3 Way"	133	Yellow box Thermister	(8) 15:20	↓
~~WingWall~~	Power House	4	Nautiz Geokon logger		

Well	Location	Col. Row #Ports	Collection Method Instrument	(Nodes) Time	Date
~~P16-148AB~~	Powerhouse	2	Nautiz Geokon logger		
~~P16-149AB~~	S. of Powerhouse	2	Nautiz Geokon logger		
~~P16-150~~	S. of Powerhouse	1	Nautiz Geokon logger		
P05-63	Zn Thickener	1	Nautiz Geokon logger	11:37	1-17-18
T05-63	Zn Thickener	129	Yellow box Thermister	(8) 11:35	↓
T05-64	By CSB	130	Yellow box Thermister	(7) 11:31	↓
T05-66	South of CSB	132	Yellow box Thermister	(8) 11:27	↓
*T95-05	By sandfilter	70	Yellow box Thermister	(24) 17:33	1-15-18
*T05-61	TDAM (end)	127	Yellow box Thermister	(8) 17:24	↓
*T95-04	TDAM (end)	69	Yellow box Thermister	(24) bad	1-17-18
~~*T14-110~~	W. Tails Pond	1	Archer Beaded Stream	(24)	
~~Riglet & 12A~~	TDAM	4	Nautiz Geokon logger		
~~TailingsCPT~~	TDAM	16	Nautiz Geokon logger		
~~P14-134~~	TDAM	1	Nautiz Geokon logger		
~~P06-74~~	TDAM	1	Nautiz Geokon logger		
~~The Hog~~	TDAM	4	Nautiz Geokon logger		
~~Warthog~~	TDAM	16	Nautiz Geokon logger		
~~*SS-16 prt~~	TDAM	16	Nautiz Geokon logger		
~~P16-151AB~~	TDAM Slope	1	Nautiz Geokon logger		
~~P14-131~~	TDAM Slope	1	Nautiz Geokon logger		
~~P05-62~~	Buttress	1	Nautiz Geokon logger		
~~P14-132~~	Buttress	1	Nautiz Geokon logger		
~~P05-69~~	Buttress	1	Nautiz Geokon logger		
*T97-28	Buttress	~~75~~ 76	Yellow box Thermister	(24) 17:30	1-15-18
*T97-29	Buttress	~~76~~ 77	Yellow box Thermister	(24) 17:16	↓
*T97-30	Buttress	~~77~~ 78	Yellow box Thermister	(24) 17:17	↓
*P96-10	Seepage Dam	1	Nautiz Geokon logger	14:30	1-17-18
*T96-10	Seepage Dam	71	Yellow box Thermister	(24) 17:12	1-15-18
TDAM T7	Seepage Dam	65	Yellow box Thermister	17:05	↓
*SPP97-2	Seepage Dam	1	Nautiz Geokon logger	14:35	1-17-18
*P96-15	Lower RDC	23	Geokon Piezometer	16:50	1-15-18
*T96-15	Lower RDC	44	Yellow box Thermister	(14) 16:49	↓
~~DODO~~	By OF_001	1	Nautiz Geokon logger	~~16:50~~ DJS	
~~P16-147~~	By OF_001	1	Nautiz Geokon logger		
RDD Piezo	RDC Dam	16	Nautiz Geokon logger	14:53	1-17-18 changed batteries

Comments: 6191.2, -18.4°C @ 15:24 – T96-12 QA/QC, P-11-92 is buried in a snow Pile
T11-95 not accessible. Reread RDD Piezo on 1-18-18 @ 10:30

*SEP Piezometer. QC: Duplicate Reading with Geokon to be taken within 5 min. of each other, Quarterly.

*SEP Thermister. QC: CR850 & Multimeter readings to be taken within 5 min. of each other, Quarterly.

Quarterly Thermistor QA / QC

Location: T96-12 Date: 1-15-18

Technician: DVS/VWM Start Time: 15:17 Stop Time: 15:20

Node	Ohms	Comments	Node	Temperature
Test	16.34		Test	
1		OL	1	
2	15.91		2	
3	16.04		3	
4	16.18		4	
5		OL	5	
6	16.42		6	
7	16.57		7	
8	16.71		8	
9	16.84		9	
10	16.92		10	
11	16.99		11	
12	17.12		12	
13	17.1		13	
14	17.22		14	
15	17.3		15	
16	17.26		16	
17	17.29		17	
18	17.3		18	
19	17.27		19	
20	17.23		20	
21	17.2		21	
22	17.11		22	
23	17.04		23	
24	16.84		24	
Test	16.35		Test	

Read these locations on noted month.

Month	Location
Feb-17	T 95-04
May-17	T 96-21
Aug-17	T96-22
Nov-17	T 96-23
Feb-18	T 96-12
May-18	T 95-15
Aug-18	T 96-05
Nov-18	T 96-10
Feb-19	T 97-28
May-19	T 97-29
Aug-19	T 97-30
Nov-19	T 95-8
Feb-20	T 96-13
May-20	T 96-21
Aug-20	T 96-22

Make a comment if reading jumps around and takes a long time to stabilize.
QA / QC readings to be done on 5% of SEP required thermistors - see above schedule.
Record test readings before and after other readings.
CR850 & multimeter readings are to be taken within 5 minutes of each other.

Teck

WHP QUARTERLY REPORT DATA CHECKLIST **Quarter** Q1 2018 **Date** 3/29/2018

For Teck/RedDog Longterm Groundwater and Permafrost monitoring

- ☐ **YES / NO** Quarterly data received from Teck. Date received: 3/29/2018
- ☐ **YES / NO** Data received for 16 Thermistors
- ☐ **YES / NO** Data received for 9 Piezometers
- ☐ **YES / NO** QA/QC Forms received for both Thermistors and Piezos
- ☐ **YES / NO** Is data complete for all Thermistors? If "No" make note of data gaps:

  No data received for T-14-110 or T-95-004

- ☐ **YES / NO** Is data complete for all Piezometers? If "No" make note of data gaps:

  _____

- ☐ **YES / NO** Field Notes for the Quarter. Are data gaps/irregularities addressed?

Additional Comments: _____

Data for All thermistors EXCEPT T96-022, T96-015, T95-005, and T95-008 should be reread.

Resistance readings appear to have been taken with data logger that was giving

erroneous readings (SN 19977)

QA/QC readings did not correlate with datalogger readings for T96-012

No data received for T114-110 or T95-004

QUARTER Q1 2018 **DATE** 03/29/2018

Thermistor	Data Received? Y / N	Comments
T-96-015	**Y**	
T-05-061	**Y**	Erroneous data, please reread
T-95-005	**Y**	
T-96-010	**Y**	Erroneous data, please reread
T-97-028	**Y**	Erroneous data, please reread
T-97-029	**Y**	Erroneous data, please reread
T-97-030	**Y**	Erroneous data, please reread
T-14-110	**N**	
T-95-008 #2 (manually add "#2")	**Y**	
T-96-013	**Y**	Erroneous data, please reread
T-96-021	**Y**	Erroneous data, please reread
T-96-022	**Y**	
T-96-023	**Y**	Erroneous data, please reread
T-96-012	**Y**	Noted as QAQC. Erroneous data, please reread
T-96-012s	**Y**	Erroneous data, please reread
T-95-004	**N**	

Piezometer	Data Received? Y / N	Comments
P-96-015	**Y**	
P-08A	**Y**	
P-08B	**Y**	
P-96-010	**Y**	
P-97-020	**Y**	
P-97-028	**Y**	
SPP-97-002	**Y**	
P-96-013	**Y**	
P-97-012	**Y**	Noted as QAQC

Quarterly Thermistor Piezometer Readings

Technician(s): Dennis J. Sheldon, Tristen S. Pattee

CR 850 SN: 18976
Geokon SN: 06-13815
Nautiz SN: 1610410537

General Weather Conditions: Overcast, 20°F, light winds

Date: 4-8-18

29-06 inHg

Col. Row #Ports	Well	Location	Collection Method Instrument	Nodes	Comments & Maintenance
26	*T95-08	Overburden	CR850 Data Logger	24	buried in snow
25	*P96-13	Overburden	Geokon Piezometer		~~Read. Cleaned reread~~ 235 psi
29	*T96-13	Overburden	CR850 Data Logger	24	Read. Cleaned reread
30	T96-13S	Overburden	CR850 Data Logger	24	good
31	*T96-21	Overburden	CR850 Data Logger	24	good
32	*T96-22	Overburden	CR850 Data Logger	24	Cleaned w/contact cleaner reread
33	*T96-23	Overburden	CR850 Data Logger	24	Cleaned w/contact cleaner. Reread
34	T96-24	Overburden	CR850 Data Logger	24	Cleaned w/contact cleaner. Plastic Brush. Reread
24	*P97-12	Blast Road	Geokon Piezometer		No Temp reading
27	*T96-12	Blast Road	CR850 Data Logger	24	Errors. New connector. Did not clean
28	*T96-12S	Blast Road	CR850 Data Logger	24	Errors. " " " "
12	T98-33	Cold Storage	CR850 Data Logger	10	buried in Snow
13	T98-34	Cold Storage	CR850 Data Logger	11	read. cleaned w/contact cleaner, Plastic brush, re-read. Broken wires
14	T98-35	Cold Storage	CR850 Data Logger	11	buried in snow
1	P05-67	By "3 Way"	Nautiz Geokon logger		buried in Snow
133	T05-67	By "3 Way"	CR850 Data Logger	8	Error. Cleaned. Reread. Good
4	WingWall	Power House	Nautiz Geokon logger		Gone? buried? Water level Rising from Mill Discharge into Tailing Pond
1	P05-63	Zn Thickener	Nautiz Geokon logger		ID Mismatch
129	T05-63	Zn Thickener	CR850 Data Logger	8	No Errors but Connector was dirty. Cleaned. Reread
130	T05-64	By CSB	CR850 Data Logger	7	Errors. Cleaned. Reread. Good
132	T05-66	South of CSB	CR850 Data Logger	8	No errors
70	*T95-05	By sandfilter	CR850 Data Logger	24	Damaged Pin in Connector
127	*T05-61	TDAM (end)	CR850 Data Logger	6	No Errors
69	*T95-04	TDAM (end)	CR850 Data Logger	24	in Frozen slurry
1	*T14-110	W. Tails Pond	Beaded Stream Datalogger	24	Excel Sheet
75	*T97-28	Buttress	CR850 Data Logger	24	Buried in Snow
76	*T97-29	Buttress	CR850 Data Logger	24	Errors. Cleaned. Reread
77	*T97-30	Buttress	CR850 Data Logger	24	Errors. Cleaned. Reread
1	*P96-10	Seepage Dam	Nautiz Geokon logger		ID mismatch
71	*T96-10	Seepage Dam	CR850 Data Logger	24	Error
65	TDAM T7	Seepage Dam	CR850 Data Logger		Cleaned w/contact cleaner. Reread
1	*SPP97-2	Seepage Dam	Nautiz Geokon logger		Good
23	*P96-15	Lower RDC	Geokon Piezometer		0 psi QA/QC
44	*T96-15	Lower RDC	CR850 Data Logger	14	good QA/QC
1	P16-147	By OF_001	Nautiz Geokon logger		No DataLogger

*SEP Thermister. QC: CR850 Multimeter readings to be taken within 5 min. of each other, Quarterly.

*SEP Piezometer. QC: Duplicate Reading with Geokon to be taken within 5 min. of each other, Quarterly.

Quarterly Thermistor QA / QC

Location: T 96-15 Date: 4-8-18

Technician: DJS/TSP Start Time: 15:19 Stop Time: 15:21

Node	Ohms	Comments	Node	Temperature
Test	16.35		Test	
1	16.8		1	
2	17.02		2	
3	16.97		3	
4	16.95		4	
5	16.85		5	
6	16.76		6	
7	16.74		7	
8	16.63		8	
9	16.57		9	
10	16.55		10	
11	16.46		11	
12	16.39		12	
13	16.33		13	
14	16.28		14	
15	OL		15	
16			16	
17			17	
18			18	
19			19	
20			20	
21			21	
22			22	
23			23	
24			24	
Test	16.35		Test	

Read these locations on noted month.

Month	Location
Feb-17	T 95-04
May-17	T 96-21
Aug-17	T96-22
Nov-17	T 96-23
Feb-18	T 96-12
May-18	T 95-15
Aug-18	T 96-05
Nov-18	T 96-10
Feb-19	T 97-28
May-19	T 97-29
Aug-19	T 97-30
Nov-19	T 95-8
Feb-20	T 96-13
May-20	T 96-21
Aug-20	T 96-22

Make a comment if reading jumps around and takes a long time to stabilize.
QA / QC readings to be done on 5% of SEP required thermistors - see above schedule.
Record test readings before and after other readings.
CR850 & multimeter readings are to be taken within 5 minutes of each other.

Teck

WHP QUARTERLY REPORT DATA CHECKLIST **Quarter** Q2 2018 **Date** 18 April, 2018

For Teck/RedDog Longterm Groundwater and Permafrost monitoring

- ☐ **YES / NO** Quarterly data received from Teck. Date received: 18 April, 2018
- ☐ **YES / NO** Data received for 16 Thermistors
- ☐ **YES / NO** Data received for 9 Piezometers
- ☐ **YES / NO** QA/QC Forms received for both Thermistors and Piezos
- ☐ **YES / NO** Is data complete for all Thermistors? If "No" make note of data gaps:

  No data for three thermistors. Explination in field notes

- ☐ **YES / NO** Is data complete for all Piezometers? If "No" make note of data gaps:

  No temp reading for P97-12. Noted in field notes

- ☐ **YES / NO** Field Notes for the Quarter. Are data gaps/irregularities addressed?

Additional Comments:

Field notes were great. All gaps in in data collection were noted or addressed.

QUARTER Q2 **DATE** 18 April, 2018

Thermistor	Data Received? Y / N	Comments
T-96-015	**Y**	
T-05-061	**Y**	
T-95-005	**Y**	
T-96-010	**Y**	Field notes comment: "Error" Errors at 2 of 24 nodes.
T-97-028	**N**	Field notes comment: "buried in snow"
T-97-029	**Y**	Field notes comment: "Errors. Cleaned. Reread" Read twice. One time had errors at 7 of 24 nodes.
T-97-030	**Y**	Field notes comment: "Errors. Cleaned. Reread" Errors at 2 of 24 nodes.
T-14-110	**Y**	
T-95-008 #2 (manually add "#2")	**N**	Field notes comment: "buried in snow."
T-96-013	**Y**	
T-96-021	**Y**	
T-96-022	**Y**	Field notes: "Cleaned with contact cleaner reread." Errors at 2 of 24 nodes.
T-96-023	**Y**	Field notes: "Cleaned with contact cleaner reread." Errors at 7 of 24 nodes.
T-96-012	**Y**	
T-96-012s	**Y**	
T-95-004	**N**	Field notes comment: "in Frozen slurry."

Piezometer	Data Received? Y / N	Comments
P-96-015	**Y**	
P-08A	**Y**	
P-08B	**Y**	
P-96-010	**Y**	
P-97-020	**Y**	
P-97-028	**Y**	
SPP-97-002	**Y**	
P-96-013	**Y**	
P-97-012	**Y**	Field notes comment "No temp reading"

Quarterly Thermistor Piezometer Readings

19771 Logs Laurbrook 2018

Technician(s): Nicole Shellbarger, James Mills

Geokon Row: 1

Date: 7-12-18

Geokon Serial #: 392

Thermrdr Serial #: 19976, 19977

General Weather Conditions: 19976 | 19977

Col. Row #Ports	Well	Location	Collection Method Instrument	Nodes	Piezo PSI Therm Error	Date	Comments	
26	*T95-08	Overburden	Yellow box Thermistor	24		7-12-18	Err 0 71.3	Err 0 34.9
25	*P96-13	Overburden	Geokon Piezometer		235 PSI	7-12-18		
29	*T96-13	Overburden	Yellow box Thermistor	24		7-12-18	Err 0 99°	Err 0 46.8
30	T96-13S	Overburden	Yellow box Thermistor	24		7-12-18	Err 3 183	Err 3 62°
31	*T96-21	Overburden	Yellow box Thermistor	24		7-12	Err 3 Nan	Err 0 68.3
32	*T96-22	Overburden	Yellow box Thermistor	24		7-12	Err 3 Nan reread	Err 3 71.9
33	*T96-23	Overburden	Yellow box Thermistor	24		7-12	Err 3 -34.8	Err 3 -13.1
34	T96-24	Overburden	Yellow box Thermistor	24		7-12	Err 3 175.3	Err 3 80.2
24	*P97-12	Blast Road	Geokon Piezometer		No Gauge	7-12-18		
27	*T96-12	Blast Road	Yellow box Thermistor	24		7-12	Err 3 153°	Err 0 59°
28	*T96-12S	Blast Road	Yellow box Thermistor	24		7-12	Err 3 66°	Err 3 32°
12	T98-33	Cold Storage	Yellow box Thermistor	10		7-12	Err 3 567.6 Exposed cables	Err 3 66.5
13	T98-34	Cold Storage	Yellow box Thermistor	~~11~~ 7		7-12	Err 3 45.8 "	" Err 3 16.9
14	T98-35	Cold Storage	Yellow box Thermistor	~~11~~ 7		7-12	Err 0 125.6 "	" Err 0 54.2
133	T05-67	By "3 Way"	Yellow box Thermistor	8		7-12-18	Err 0 74.6	Err 0 36.6
4	WingWall	Power House	Nautiz Geokon logger	?				
1	P05-63	Zn Thickener	Nautiz Geokon logger			7-12-18	37 Arrays	
129	T05-63	Zn Thickener	Yellow box Thermistor	8		7-12-18	Err 0 81.2	Err 0 37.7
130	T05-64	By CSB	Yellow box Thermistor	7		7-12-18	Err 3 60.7	Err 3 28.9
132	T05-66	South of CSB	Yellow box Thermistor	8		7-12-18	Err 3 -38.8	Err 0 35.9
70	*T95-05	By sandfilter	Yellow box Thermistor	24		7-12-18	Err 3 76.4 Needs New pigtail	Err 3 83.2
127	*T05-61	TDAM (end)	Yellow box Thermistor	6		7-12-18	Err 0 67.9	Err 0 33.1
69	*T95-04	TDAM (end)	Yellow box Thermistor	24			Err 3 74.8	Err 3 32.0
1	*T14-110	W. Tails Pond	Beaded Stream Datalogger	24			Logger	
75	*T97-28	Buttress	Yellow box Thermistor	24		7-12-18	Err 3 72.1	Err 3 35.3
76	*T97-29	Buttress	Yellow box Thermistor	24		7-12-18	Err 3 77.4	Err 3 37.9
77	*T97-30	Buttress	Yellow box Thermistor	24		7-12-18	Err 3 78.1	Err 3 38.2
71	*T96-10	Seepage Dam	Yellow box Thermistor	24		7-12-18	Err 3 67.4 Reread	Err 3 32.8
65	TDAM T7	Seepage Dam	Yellow box Thermistor			7-12-18	Err 3 221.5	Err 0 63.9
23	*P96-15	Lower RDC	Geokon Piezometer		0 PSI	7-12-18	~~Err 0 64.2~~	
44	*T96-15	Lower RDC	Yellow box Thermistor	14		7-12-18	Err 0 64.2	Err 0 31.0

*SEP Thermister. QC: CR850 Multimeter readings to be taken within 5 min. of each other, Quarterly.

07/12/2018

*SEP Piezometer. QC: Duplicate Reading with Geokon to be taken within 5 min. of each other, Quarterly.

Quarterly Thermistor QA / QC

Location: T95-05 Date: 7-12-18

Technician: MMJWM Start Time: 15:29 Stop Time: 15:43

Node	Ohms	Comments	Node	Temperature
Test	16.34		Test	
1	16.62		1	
2	15.54		2	
3	15.40		3	
4	15.86		4	
5	16.10		5	
6	16.21		6	
7	16.39		7	
8	OL		8	
9	16.67		9	
10	unstable	Jumpy	10	
11	16.68		11	
12	5.9	unstable	12	
13	16.65		13	
14	15.21	Long	14	
15	7.59		15	
16	12.58		16	
17	16.66		17	
18	15.77		18	
19	16.00		19	
20	16.06		20	
21	16.37		21	
22	15.75	Long	22	
23	15.07		23	
24	15.48		24	
Test	16.34		Test	

Read these locations on noted month.

Month	Location
Feb-17	T 95-04
May-17	T 96-21
Aug-17	T96-22
Nov-17	T 96-23
Feb-18	T 96-12
May-18	T 95-15
Aug-18	T 96-05
Nov-18	T 96-10
Feb-19	T 97-28
May-19	T 97-29
Aug-19	T 97-30
Nov-19	T 95-8
Feb-20	T 96-13
May-20	T 96-21
Aug-20	T 96-22

Make a comment if reading jumps around and takes a long time to stabilize.
QA / QC readings to be done on 5% of SEP required thermistors - see above schedule.
Record test readings before and after other readings.
CR850 & multimeter readings are to be taken within 5 minutes of each other.

Teck

WHP QUARTERLY REPORT DATA CHECKLIST **Quarter** Q3 2018 **Date** 08 Aug, 2018

For Teck/RedDog Longterm Groundwater and Permafrost monitoring

- ☐ **YES / NO** Quarterly data received from Teck. Date received: 02 Aug, 2018
- ☐ **YES / NO** Data received for 16 Thermistors
- ☐ **YES / NO** Data received for 9 Piezometers
- ☐ **YES / NO** QA/QC Forms received for both Thermistors and Piezos
- ☐ **YES / NO** Is data complete for all Thermistors? If "No" make note of data gaps:

  _____

- ☐ **YES / NO** Is data complete for all Piezometers? If "No" make note of data gaps:

  No barometer temperature included with 20180712 piezo readings
  "Bad reading" reported for P-08B

- ☐ **YES / NO** Field Notes for the Quarter. Are data gaps/irregularities addressed?

Additional Comments: _____

_____

_____

_____

_____

_____

_____

QUARTER Q3 **DATE** 08Aug, 2018

Thermistor	Data Received? Y / N	Comments
T-96-015	Y	
T-05-061	Y	
T-95-005	Y	Error at 20 of 24 nodes
T-96-010	Y	
T-97-028	Y	
T-97-029	Y	
T-97-030	Y	
T-14-110	Y	
T-95-008 #2 (manually add "#2")	Y	
T-96-013	Y	
T-96-021	Y	
T-96-022	Y	Error at 3 of 24 nodes
T-96-023	Y	Error at 8 of 24 nodes
T-96-012	Y	
T-96-012s	Y	Error at 1 of 24 nodes
T-95-004	Y	Error at 20 of 24 nodes

Piezometer	Data Received? Y / N	Comments
P-96-015	Y	Need barometer **Temperature** reading.
P-08A	Y	
P-08B	**N**	
P-96-010	Y	
P-97-020	Y	
P-97-028	Y	
SPP-97-002	Y	
P-96-013	Y	
P-97-012	Y	

Date 10/20/18 and 10-23-18 **Quarterly Thermistor Piezometer Readings**

Technician: Tristen Pattee/Darren Jones Dennis J. Sheldon Thermrdr: 2/19977 Geokon Row: 1 Barometric Pressure 28.57 in Hg General Weather: 28°F, N wind, 9mph

Col. Row #Ports	Well	Location	Collection Method Instrument	Nodes	Piezo PSI Therm Error	Date	Comments
26	*T95-08	Overburden	Yellow box Thermistor	24	0	10/20	
25	*P96-13	Overburden	Geokon Piezometer		✓	✓	✓
29	*T96-13	Overburden	Yellow box Thermistor	24	0		Short
30	T96-13S	Overburden	Yellow box Thermistor	24	3		Long
31	*T96-21	Overburden	Yellow box Thermistor	24	0		
32	*T96-22	Overburden	Yellow box Thermistor	24	3		
33	*T96-23	Overburden	Yellow box Thermistor	24	3		
34	T96-24	Overburden	Yellow box Thermistor	24	3		
24	*P97-12	Blast Road	Geokon Piezometer		✓	✓	
27	*T96-12	Blast Road	Yellow box Thermistor	24	0		Short
28	*T96-12S	Blast Road	Yellow box Thermistor	24	3		Long
12	T98-33	Cold Storage	Yellow box Thermistor	10	✓	✓	✓
13	T98-34	Cold Storage	Yellow box Thermistor	11	✓		7 nodes
14	T98-35	Cold Storage	Yellow box Thermistor	~~11~~ 7 DJS	✓		7 nodes, Not 11 as noted
133	T05-67	By "3 Way"	Yellow box Thermistor	8	✓		
4	WingWall	Power House	Nautiz Geokon logger				Gone?
1	P05-63	Zn Thickener	Nautiz Geokon logger		✓		Wireless Tx
129	T05-63	Zn Thickener	Yellow box Thermistor	8	✓		
130	T05-64	By CSB	Yellow box Thermistor	7	✓		
132	T05-66	South of CSB	Yellow box Thermistor	8	✓		
70	*T95-05	By sandfilter	Yellow box Thermistor	24	✓		
127	*T05-61	TDAM (end)	Yellow box Thermistor	6	✓		
69	*T95-04	TDAM (end)	Yellow box Thermistor	24	✓		
1	*T14-110	W. Tails Pond	Beaded Stream Datalogger	24	✓		
75	*T97-28	Buttress	Yellow box Thermistor	24	✓		Reread on 10-23-18
76	*T97-29	Buttress	Yellow box Thermistor	24			~~Reread~~ DJS Read on 10-23-18
77	*T97-30	Buttress	Yellow box Thermistor	24	✓		ReRead on 10-23-18
71	*T96-10	Seepage Dam	Yellow box Thermistor	24	✓		QAQC Error on Node 24/45psi on P96-10
65	TDAM T7	Seepage Dam	Yellow box Thermistor		✓		
23	*P96-15	Lower RDC	Geokon Piezometer		✓		0 psi
44	*T96-15	Lower RDC	Yellow box Thermistor	14	✓		

*SEP Thermister. QC: CR850 Multimeter readings to be taken within 5 min. of each other, Quarterly.

08/19/2018

*SEP Piezometer. QC: Duplicate Reading with Geokon to be taken within 5 min. of each other, Quarterly.

Switchbox 16325
Multimeter Morris 57060

Quarterly Thermistor QA / QC

Location: T 96-10 Date: 10-20-18

Technician: DJS/TSP Start Time: 17:02 Stop Time: 17:15

Node	Ohms	Comments	Node	Temperature
Test	16.29		Test	
1	13.77		1	
2	15.95		2	
3	30.65		3	
4	16.06		4	
5	16.0		5	
6	15.98		6	
7	15.98		7	
8	15.84		8	
9	16.06 ~~16.28~~ DJS	Fluctuating ±50Ω Reread	9	
10	16.13 ~~24.7~~ DJS	Fluctuating badly Reread	10	
11	17.8 ~~27.1~~ DJS	Fluctuating	11	
12	15.5m		12	
13	15.57		13	
14	16.86		14	
15	19.87		15	
16	15.16		16	
17	15.20		17	
18	16.91		18	
19	14.97		19	
20	15.36		20	
21	14.75		21	
22	14.89		22	
23	26.18		23	
24	3.5m	Fluctuating	24	
Test	16.29		Test	

Read these locations on noted month.

Month	Location
Feb-17	T 95-04
May-17	T 96-21
Aug-17	T96-22
Nov-17	T 96-23
Feb-18	T 96-12
May-18	T 95-15
Aug-18	T 96-05
Nov-18	T 96-10
Feb-19	T 97-28
May-19	T 97-29
Aug-19	T 97-30
Nov-19	T 95-8
Feb-20	T 96-13
May-20	T 96-21
Aug-20	T 96-22

Make a comment if reading jumps around and takes a long time to stabilize.
QA / QC readings to be done on 5% of SEP required thermistors - see above schedule.
Record test readings before and after other readings.
CR850 & multimeter readings are to be taken within 5 minutes of each other.

Teck

KUNA ENG. QUARTERLY REPORT DATA CHECKLIST **Quarter** Q4 **Date** 9 Nov, 18

For Teck/RedDog Longterm Groundwater and Permafrost monitoring

☐ **YES / NO** Quarterly data received from Teck. Date received: 26 Oct,18

☐ **YES / NO** Data received for 16 Thermistors

☐ **YES / NO** Data received for 9 Piezometers and barometer readings

☐ **YES / NO** QA/QC Forms received for both Thermistors and Piezos

☐ **YES / NO** Is data complete for all Thermistors? If "No" make note of data gaps:

T95-04's data has negative values for 21 of 24 nodes.
6 other thermistors have errors at 2-9 nodes

☐ **YES / NO** Is data complete for all Piezometers? If "No" make note of data gaps:

☐ **YES / NO** Field Notes for the Quarter. Are data gaps/irregularities addressed?

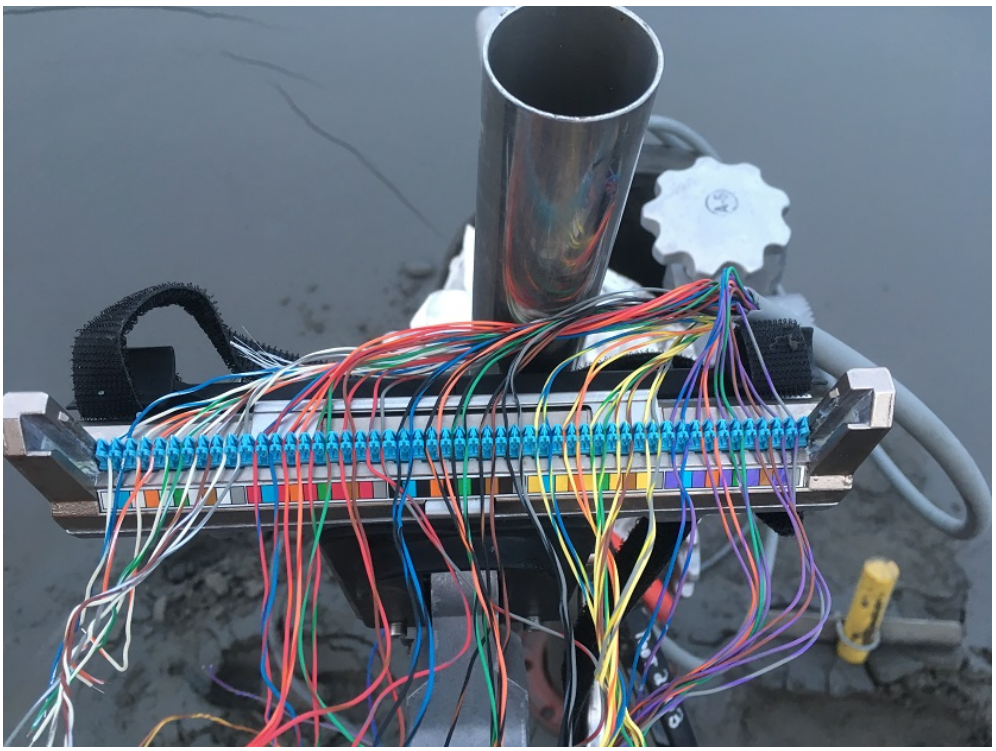
Additional Comments:

QUARTER Q4, 2018 **DATE** 9 Nov, 2018

Thermistor	Data Received? Y / N	Comments
T-96-015	**Y**	
T-05-061	**Y**	
T-95-005	**Y**	
T-96-010	**Y**	Errors at 2 of 24 nodes
T-97-028	**Y**	Errors at 9 of 24 nodes
T-97-029	**Y**	Errors at 4 of 24 nodes
T-97-030	**Y**	Errors at 7 of 24 nodes on 10/20, 3 of 24 on 10/23
T-14-110	**Y**	
T-95-008 #2 (manually add "#2")	**Y**	
T-96-013	**Y**	
T-96-021	**Y**	
T-96-022	**Y**	Errors at 3 of 24 nodes on 9/28 reading, 6 of 24 on 10/20
T-96-023	**Y**	Errors at 8 of 24 nodes on 9/28, 7 of 24 on 10/20
T-96-012	**Y**	
T-96-012s	**Y**	
T-95-004	**Y**	Errors at 21 of 24 nodes

Piezometer	Data Received? Y / N	Comments
P-96-015	**Y**	
P-08A	**Y**	
P-08B	**Y**	
P-96-010	**Y**	
P-97-020	**Y**	
P-97-028	**Y**	
SPP-97-002	**Y**	
P-96-013	**Y**	
P-97-012	**Y**	

Wire splicing jig on well head.

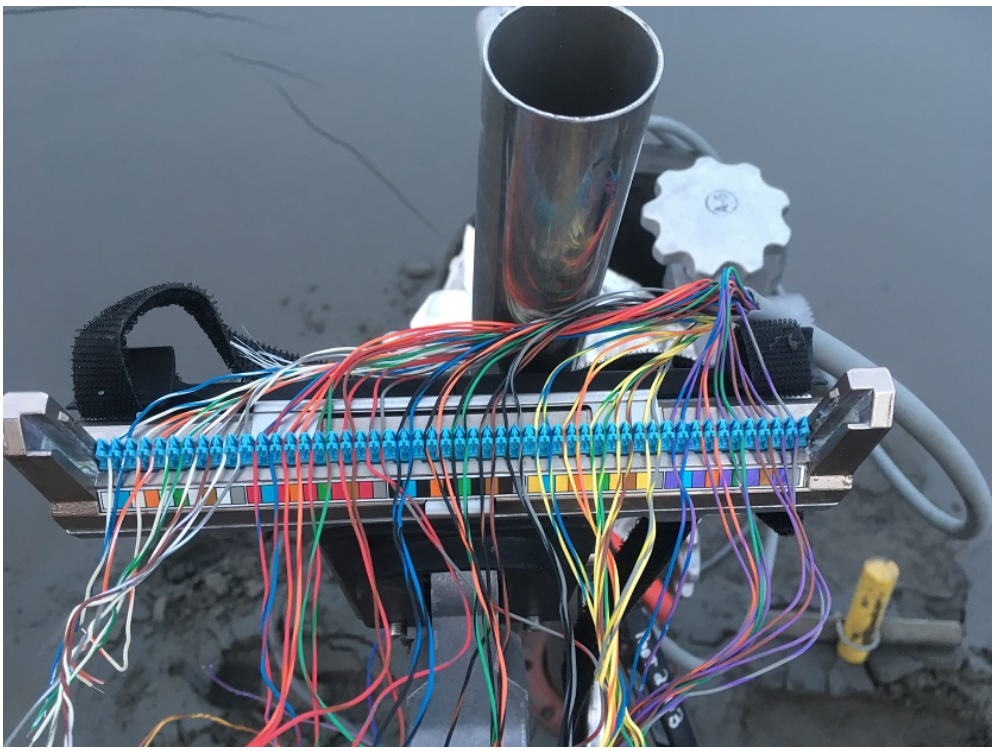


Spicing in new pigtail.

Sealing up new splice

New splice all sealed.

Wire splicing jig on well head.



Spicing in new pigtail.

Sealing up new splice

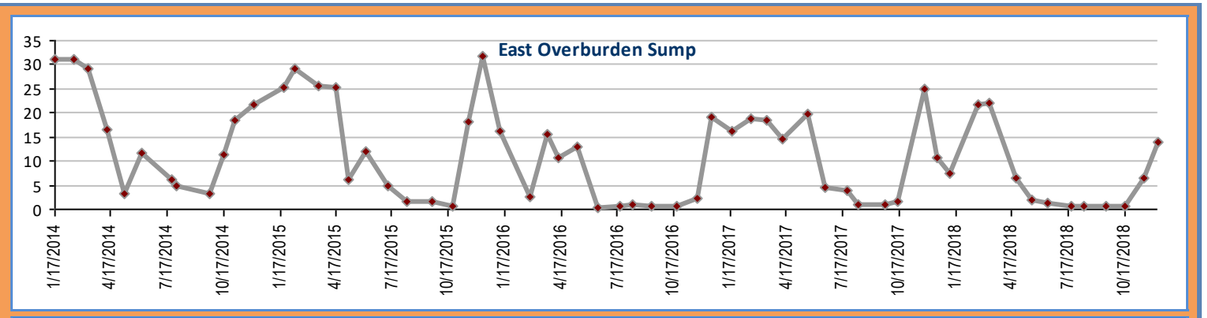
New splice all sealed.

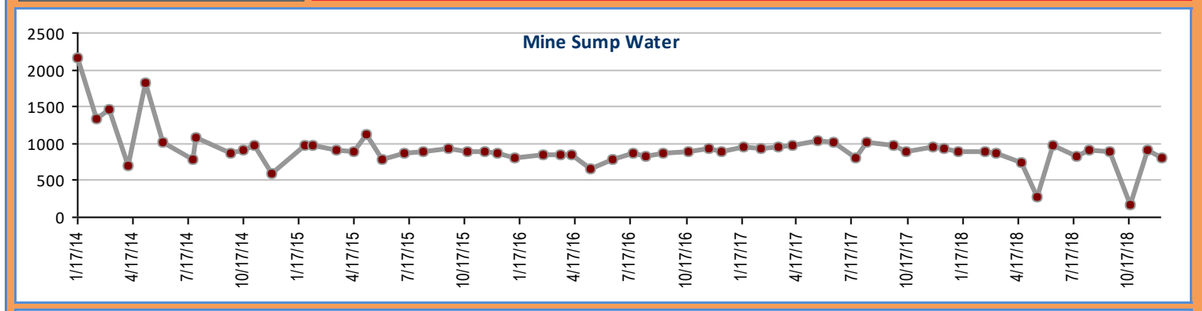
Appendix C: Water Quality Profile II Charts – Mine Water Monitoring Stations

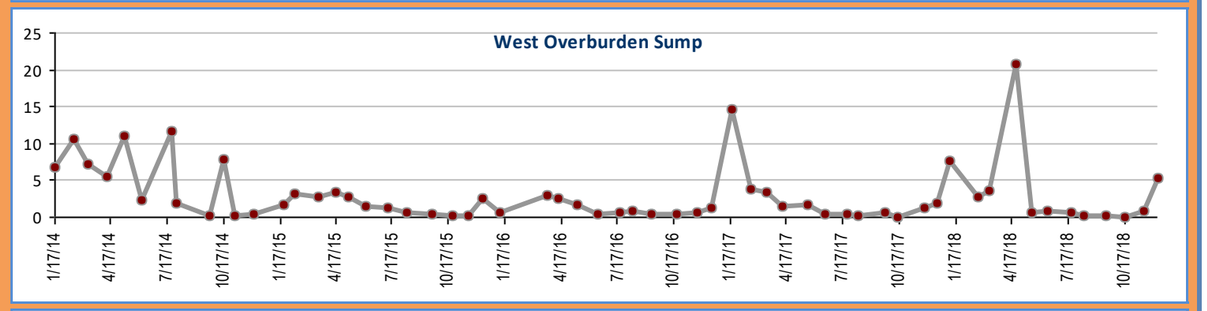
RED DOG MINE

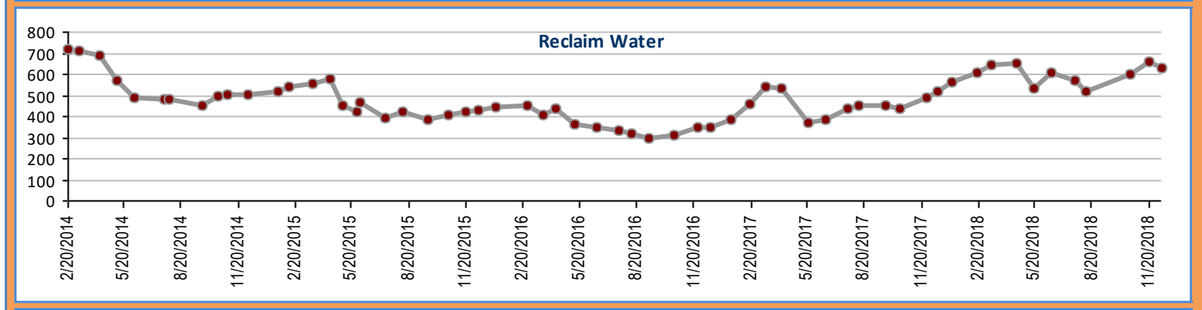
Mine Water Monitoring - Water Quality Profile II, Trend Charts

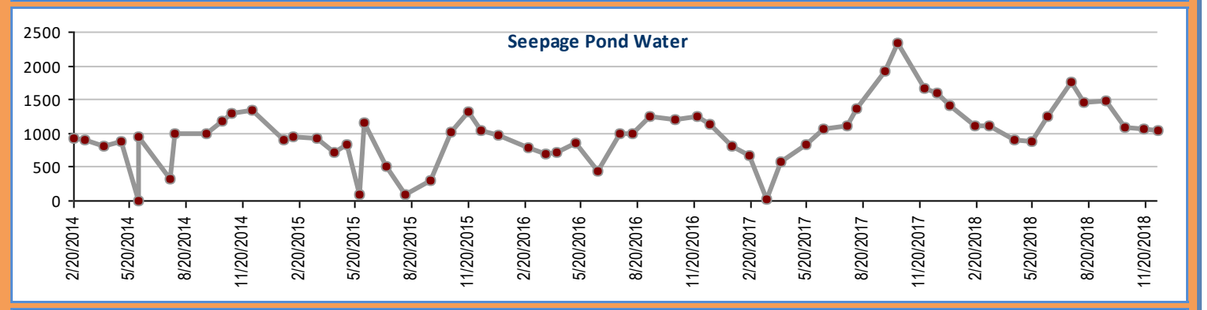
Zinc, dissolved, units, mg/L

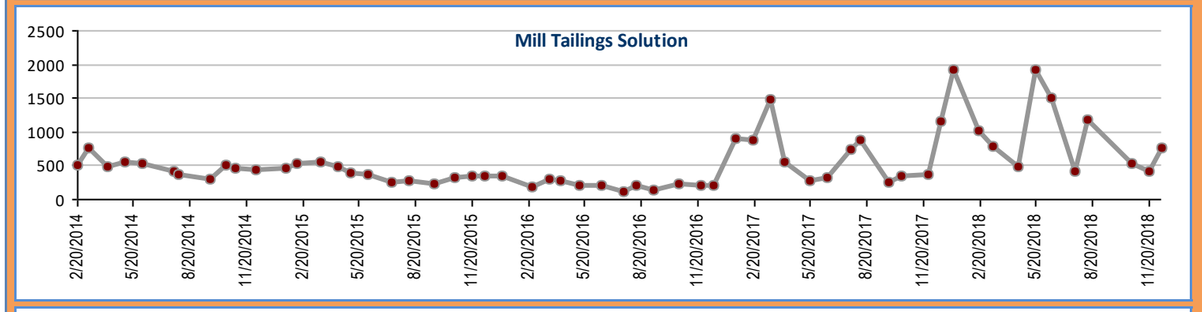


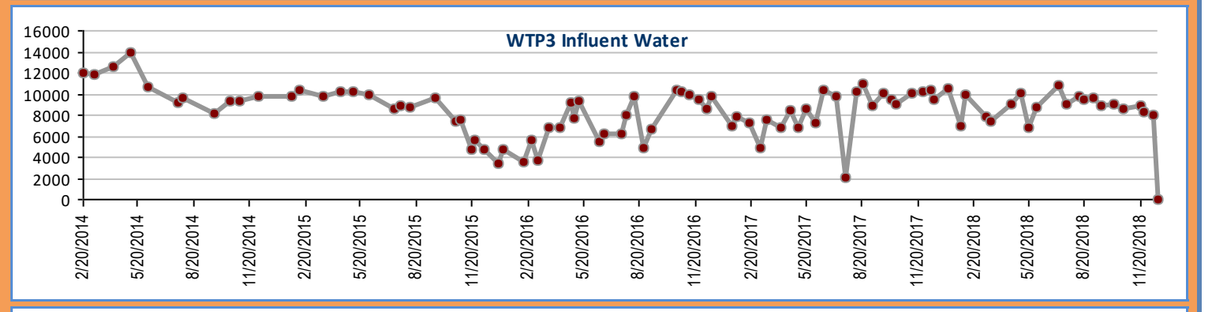


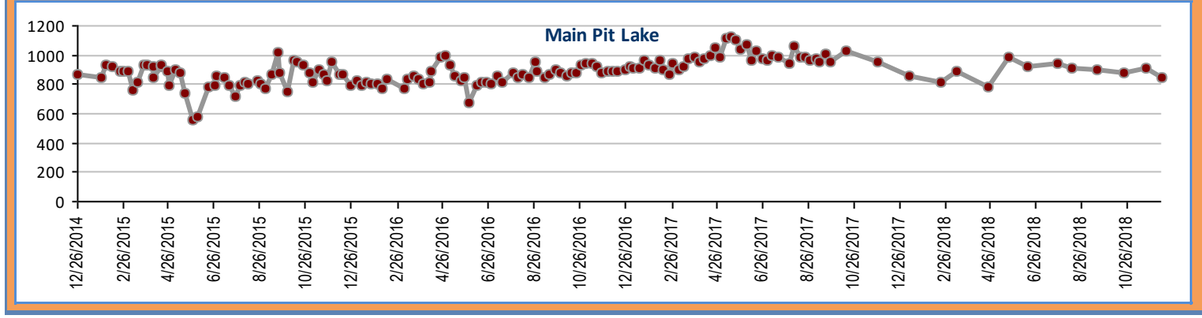


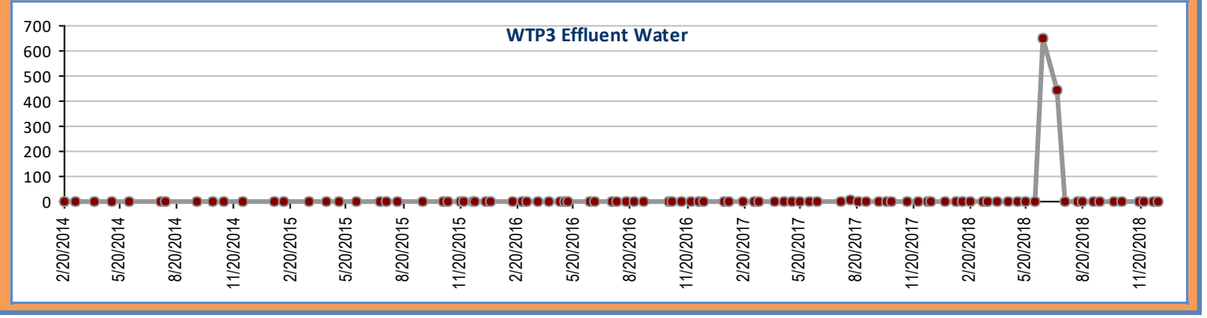








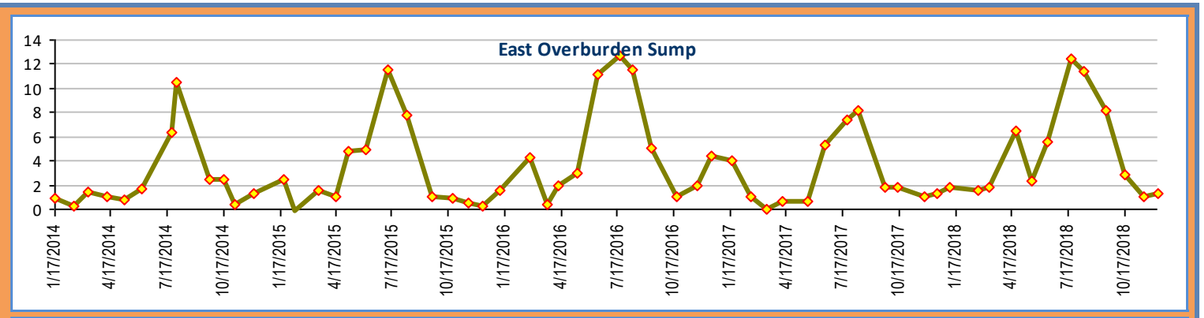


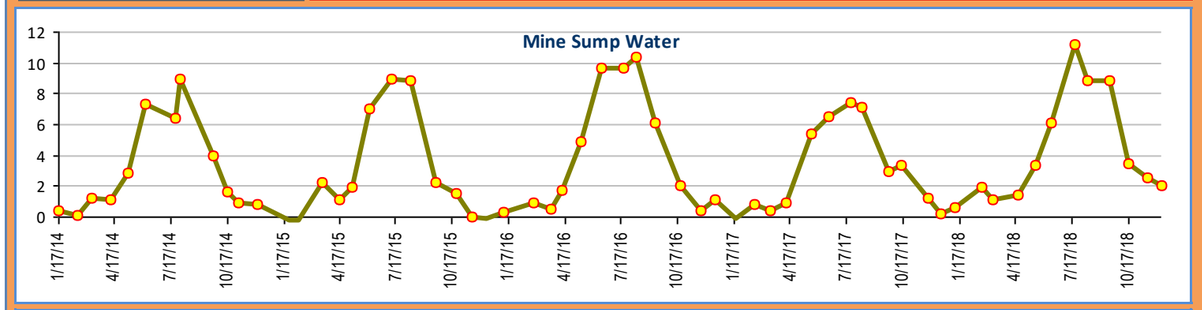


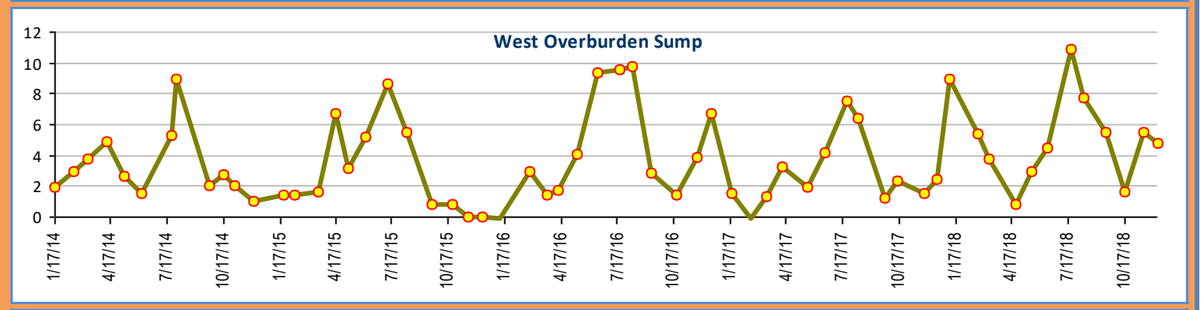
RED DOG MINE

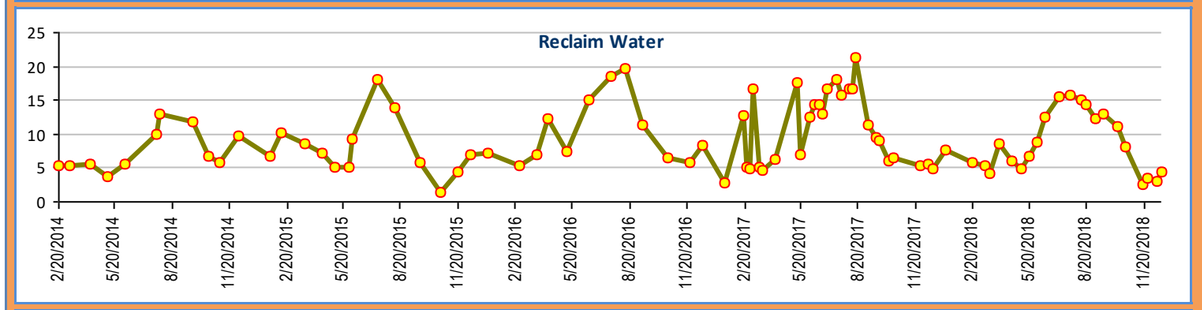
Mine Water Monitoring - Water Quality Profile II, Trend Charts

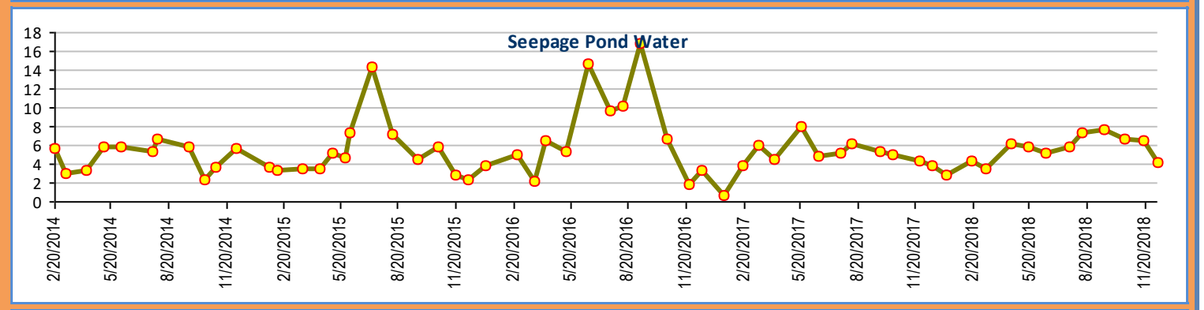
Temperature, Celsius

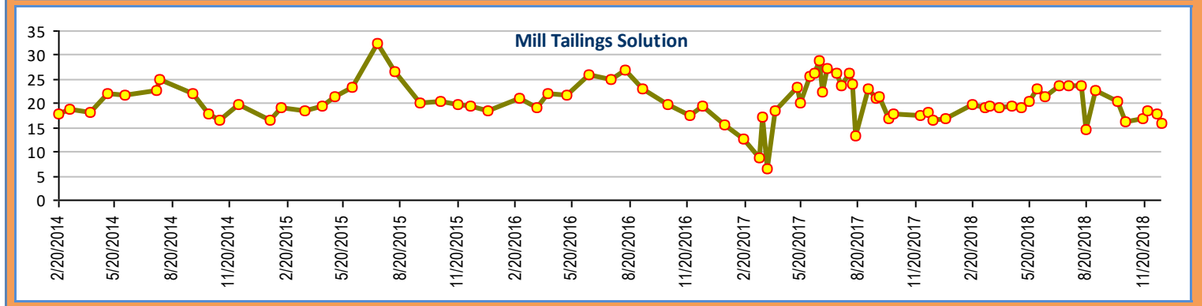


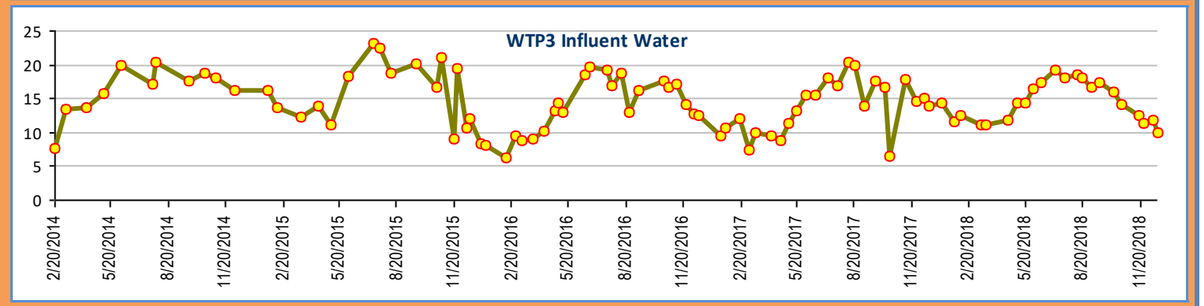


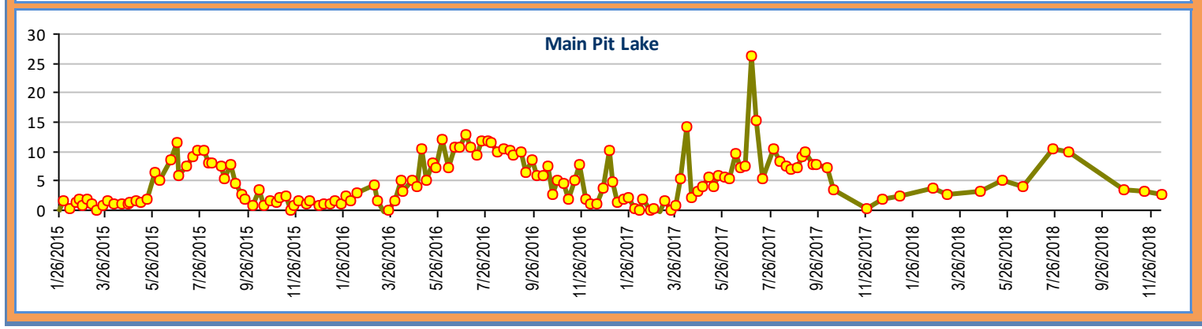


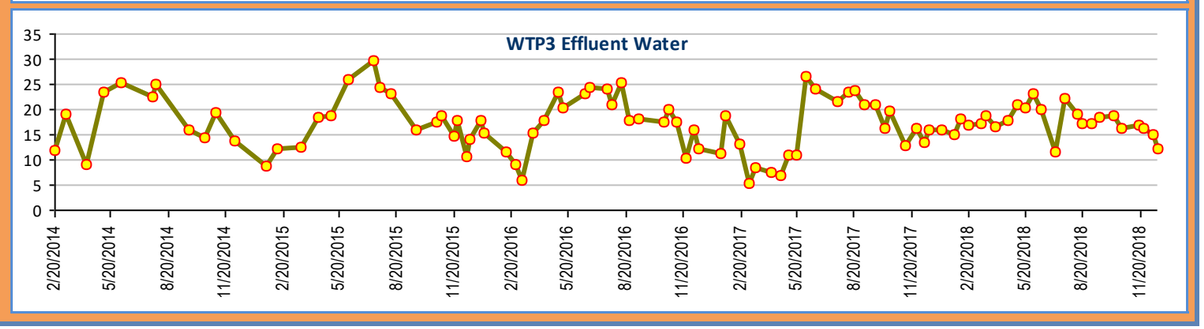








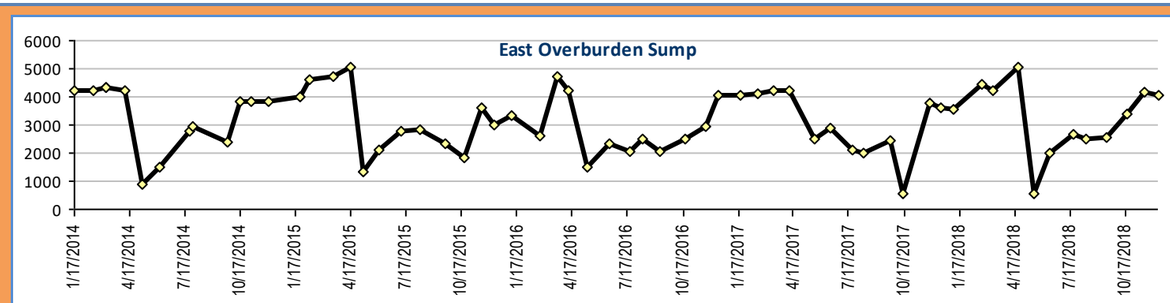


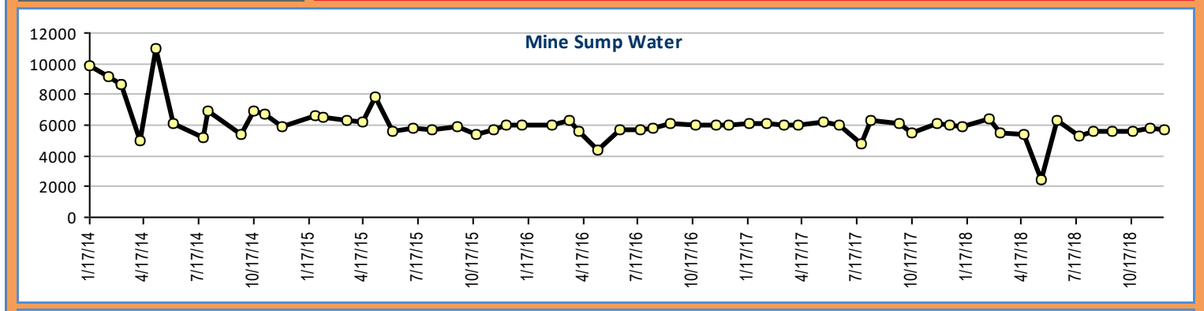


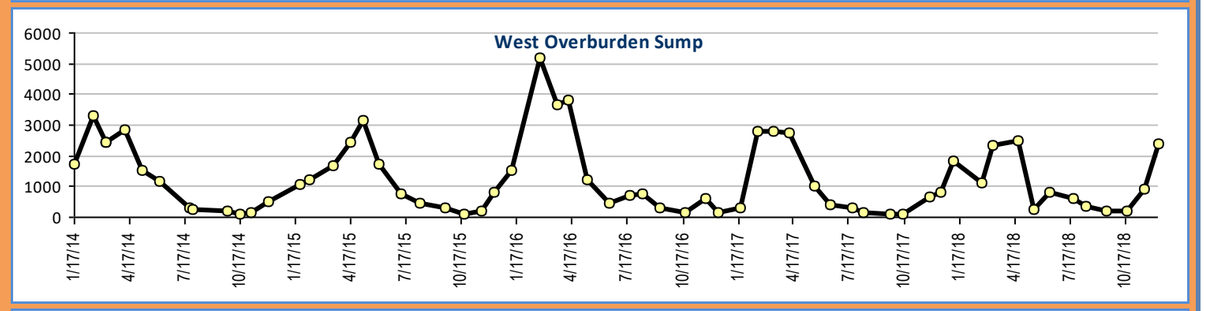
RED DOG MINE

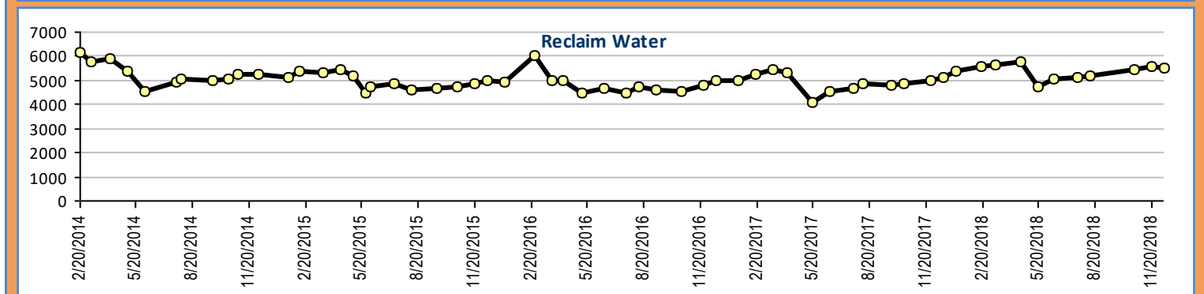
Mine Water Monitoring - Water Quality Profile II, Trend Charts

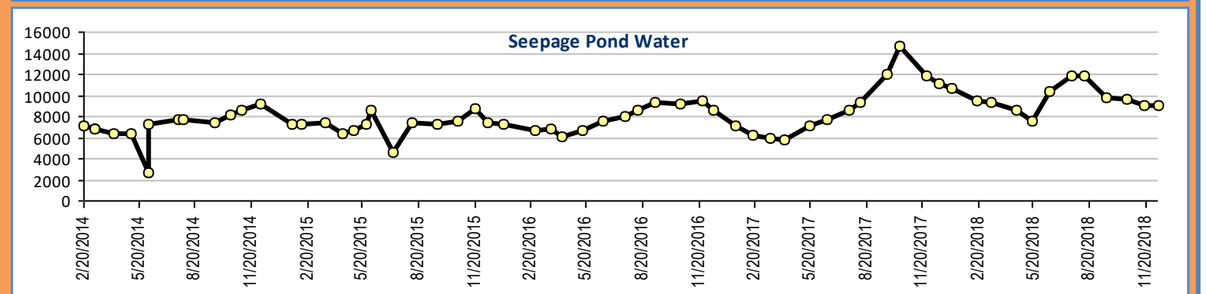
Total Dissolved Solids, units, mg/L

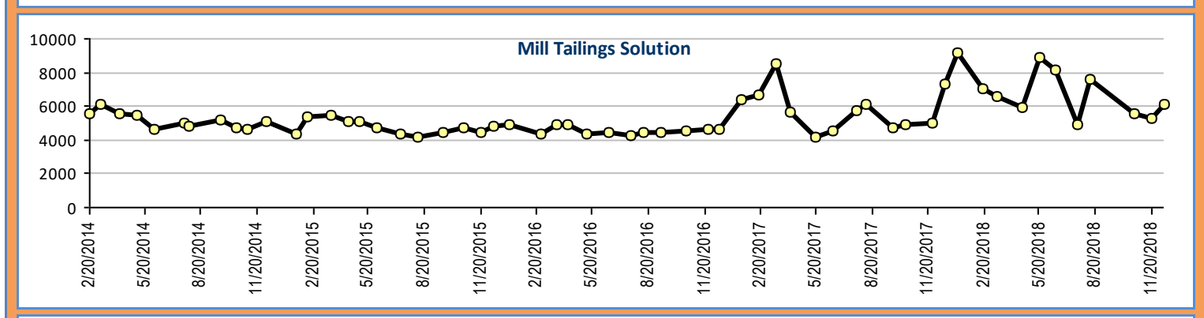


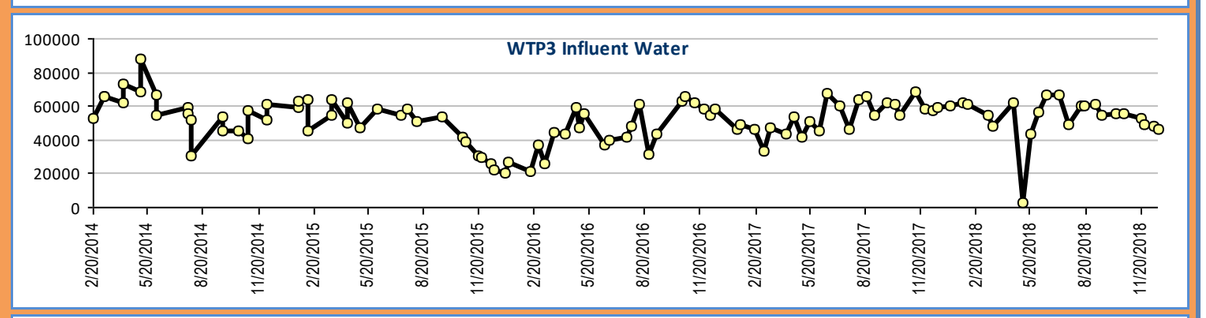


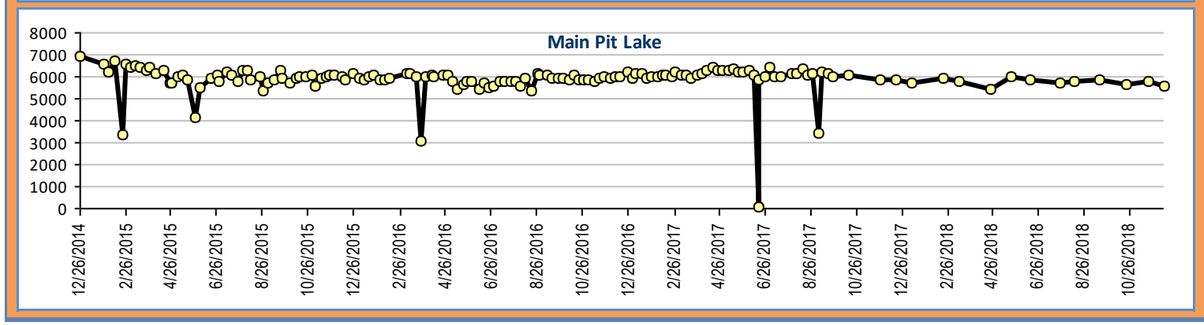


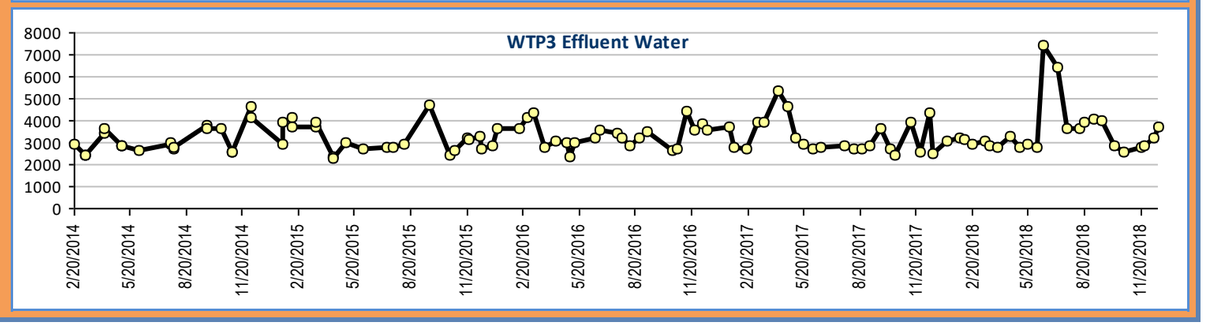








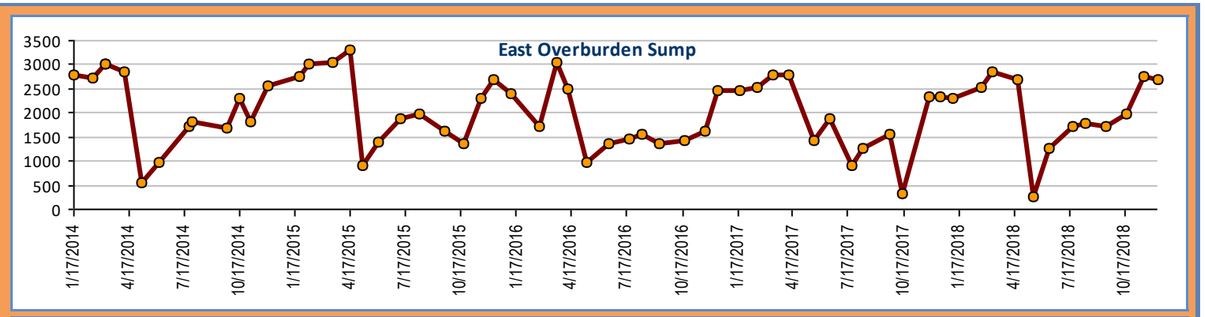


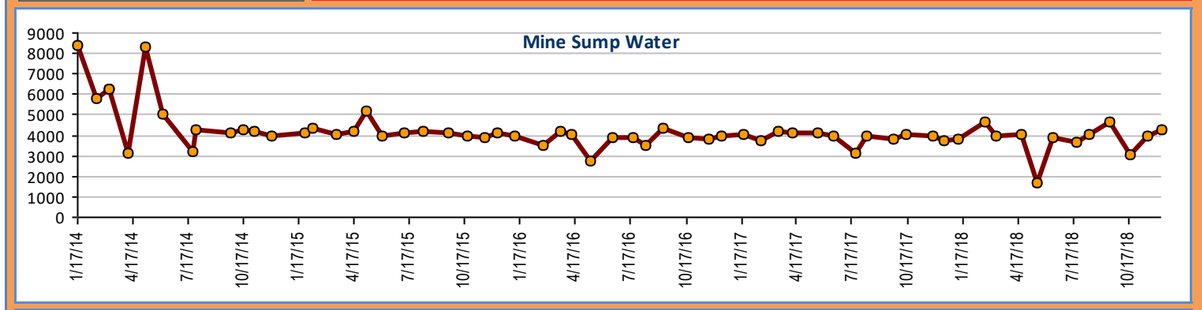


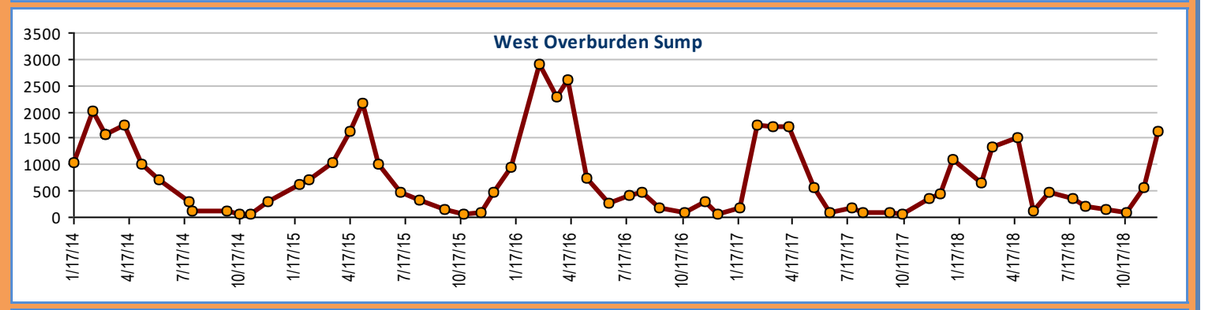
RED DOG MINE

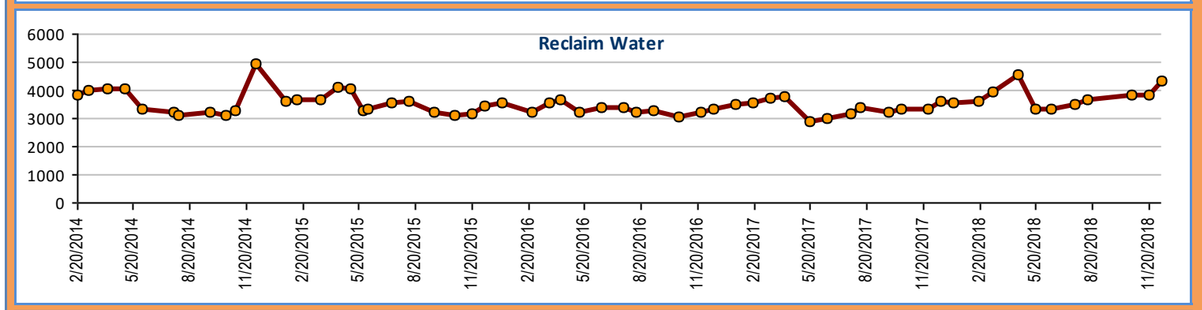
Mine Water Monitoring - Water Quality Profile II, Trend Charts

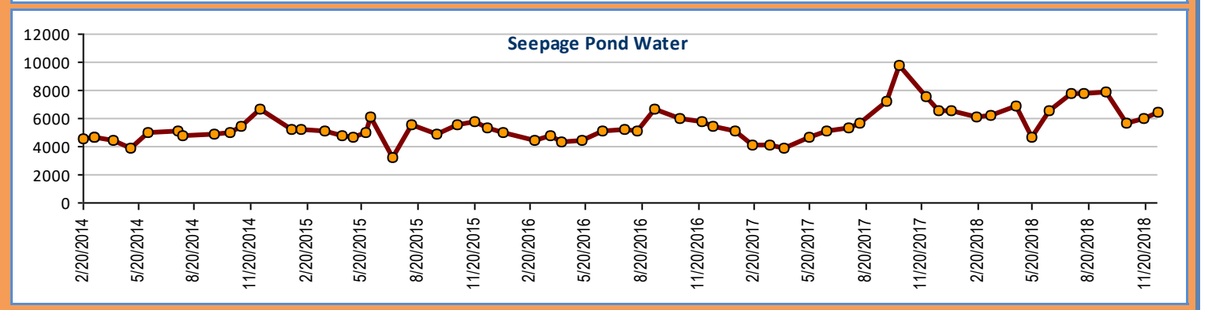
Sulfate, units mg/L

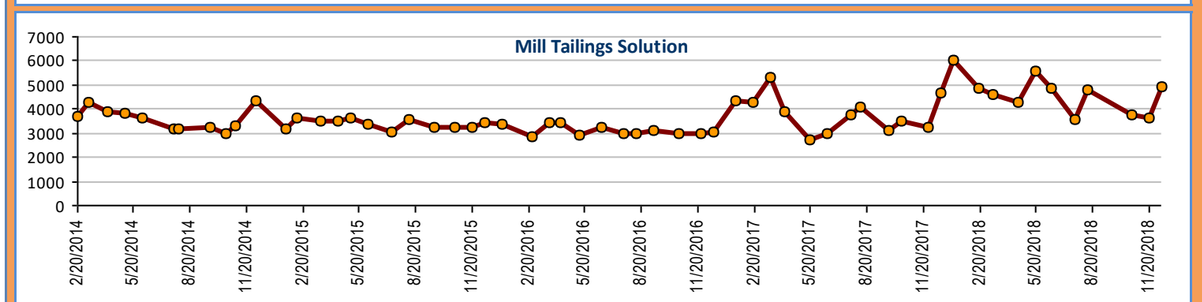


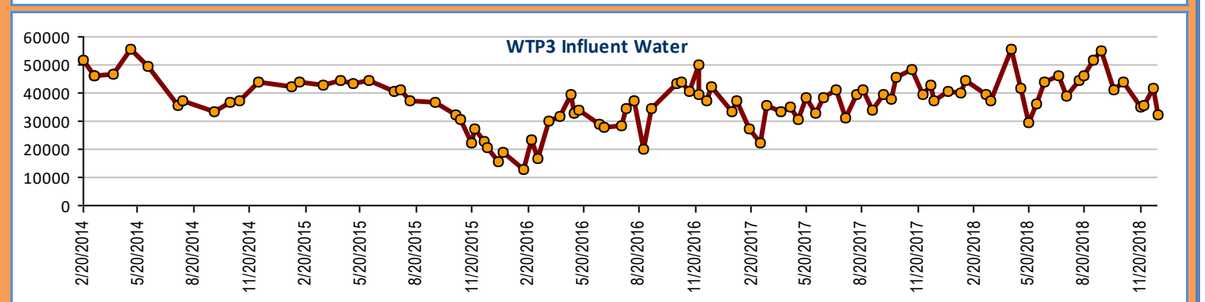


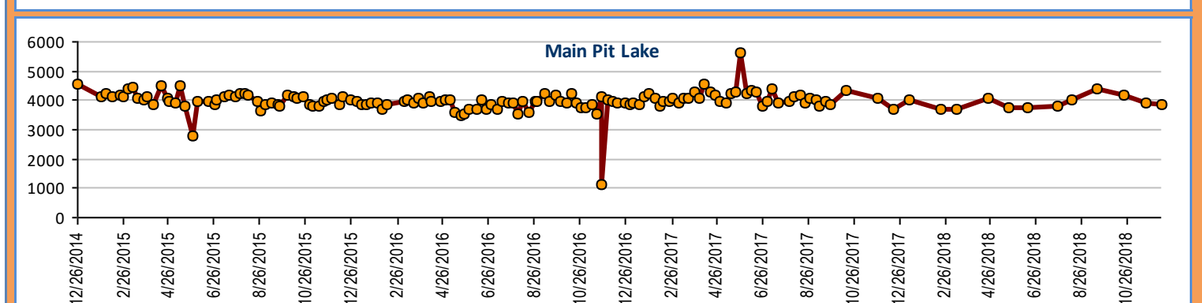


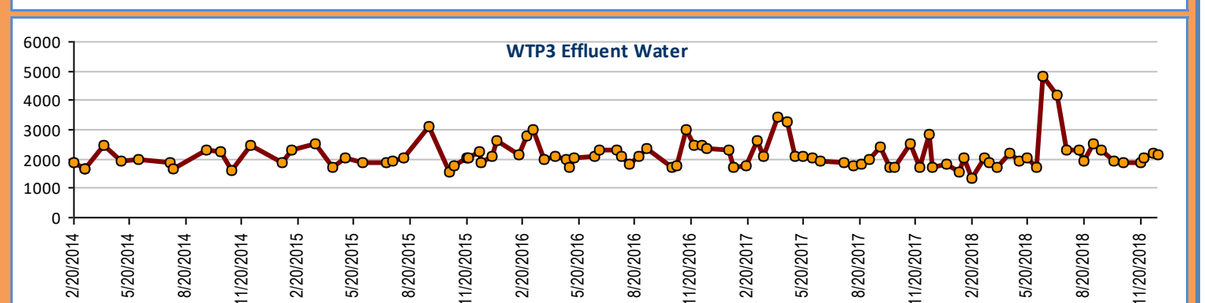








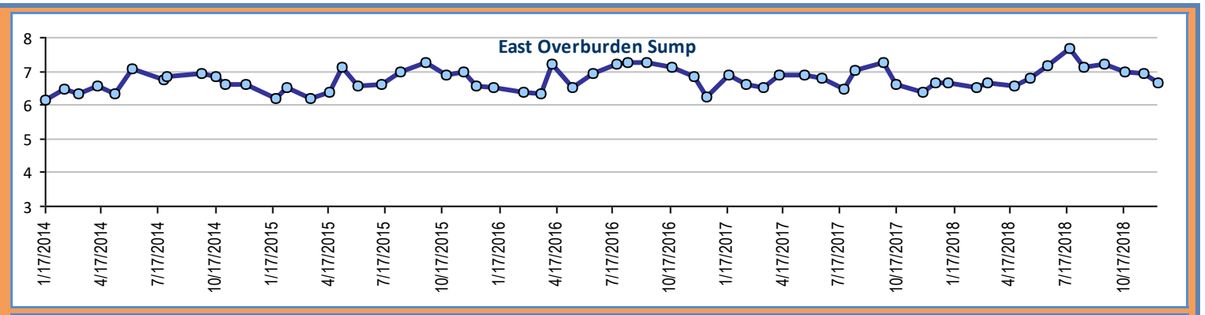


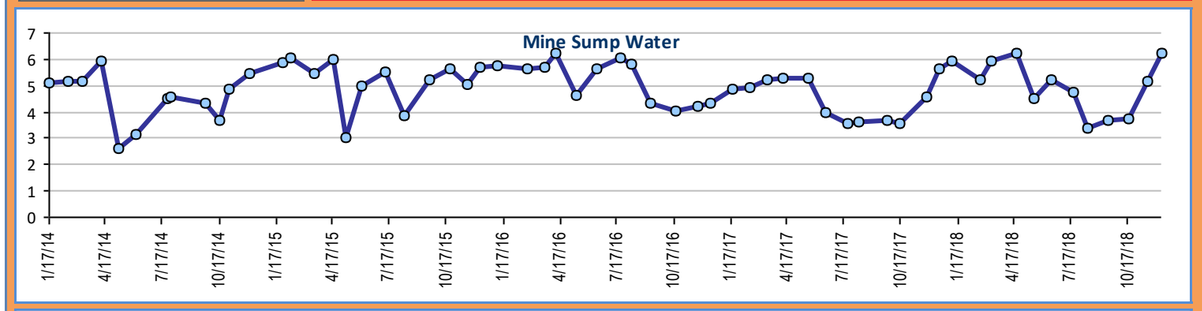


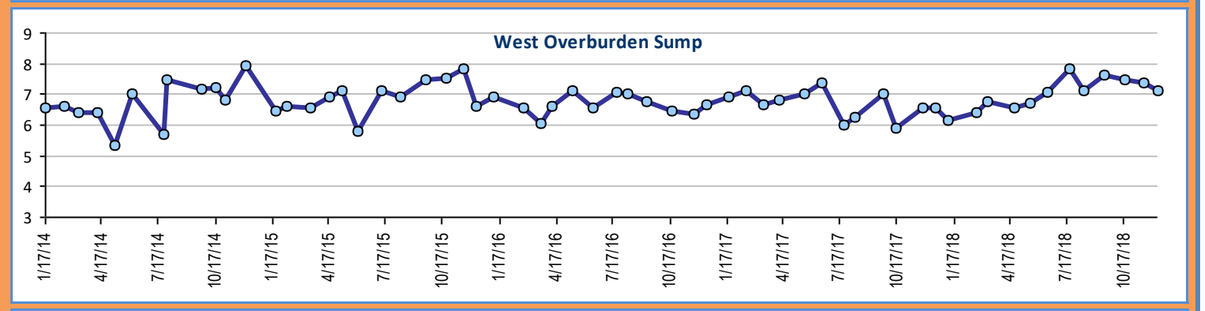
RED DOG MINE

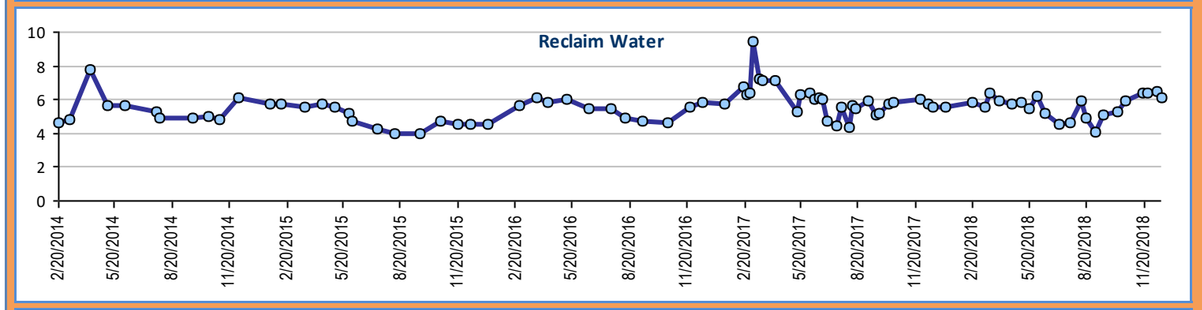
Mine Water Monitoring - Water Quality Profile II, Trend Charts

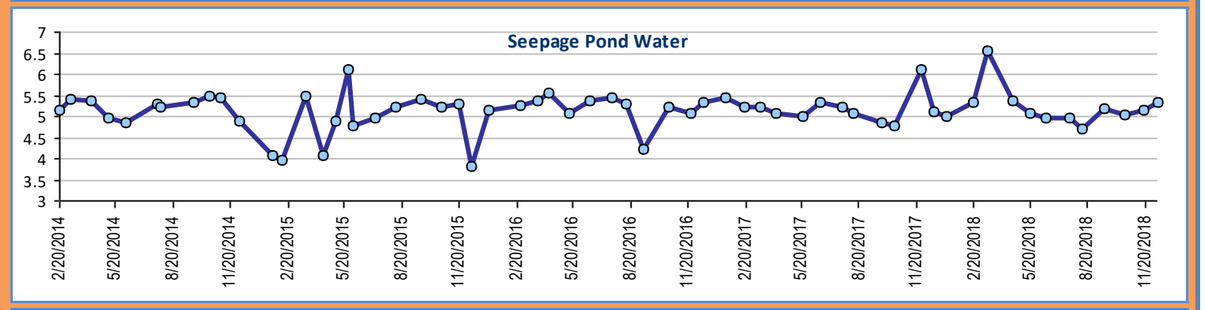
pH, units

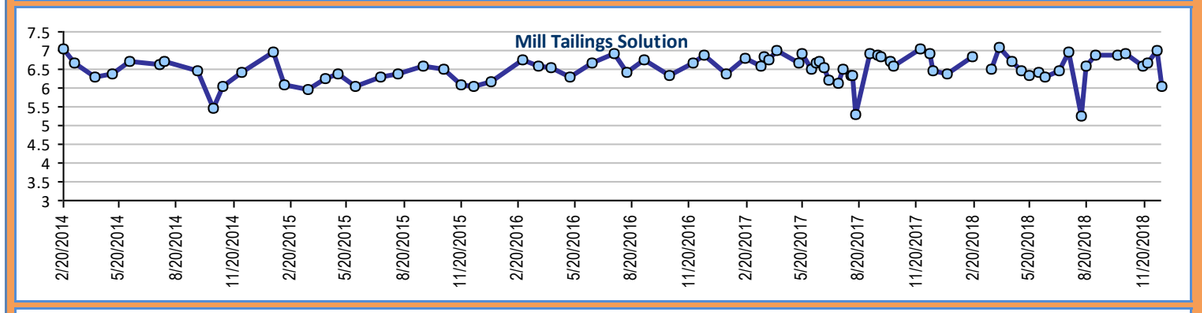


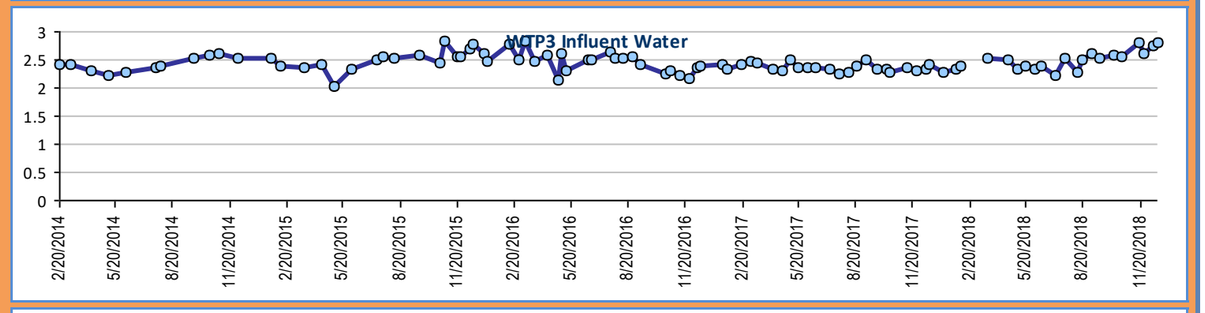


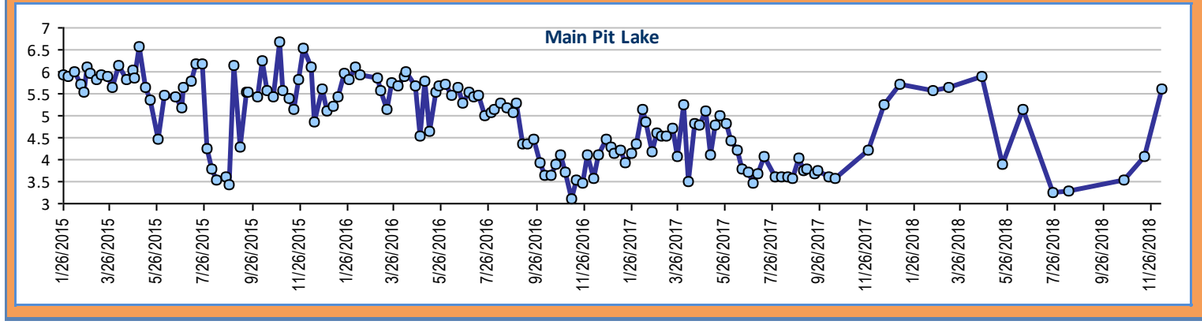


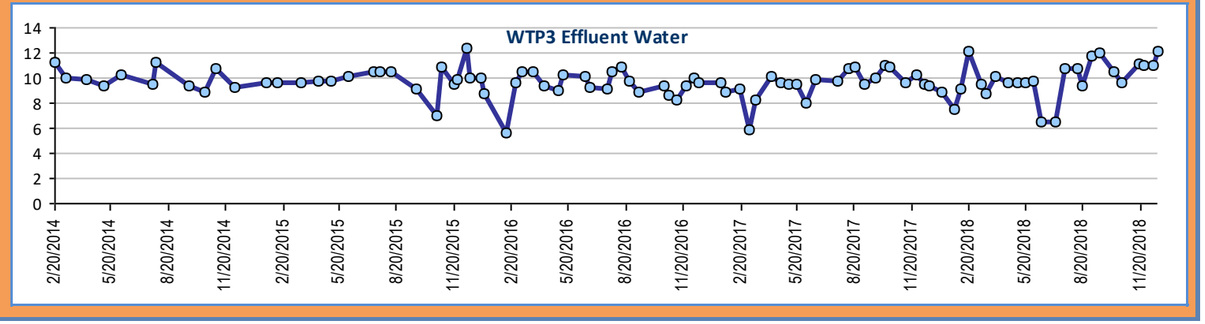








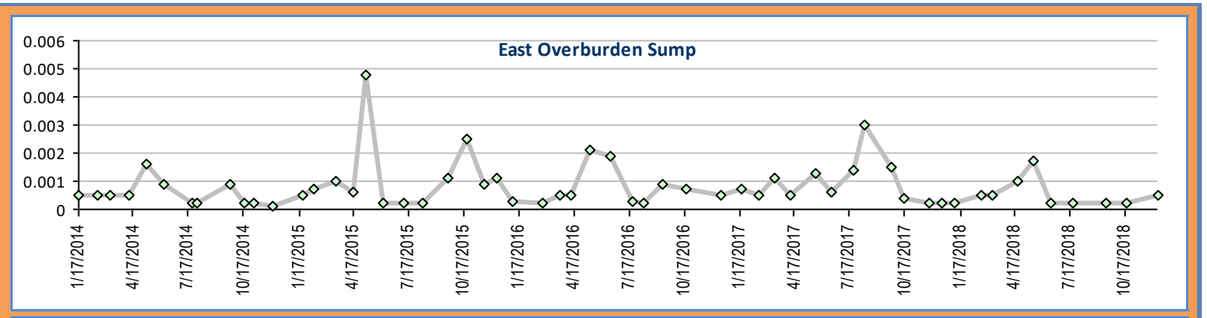


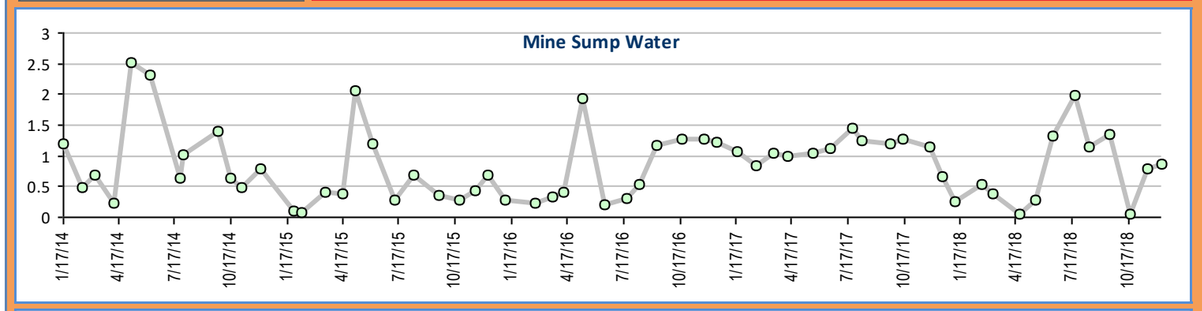


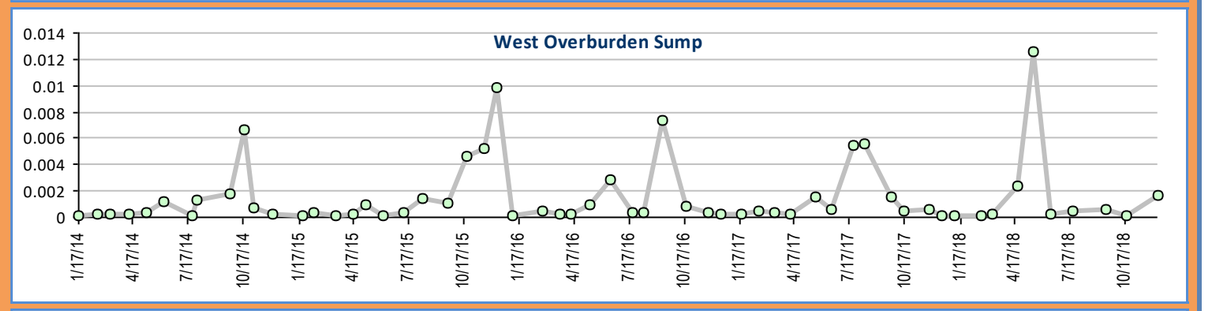
RED DOG MINE

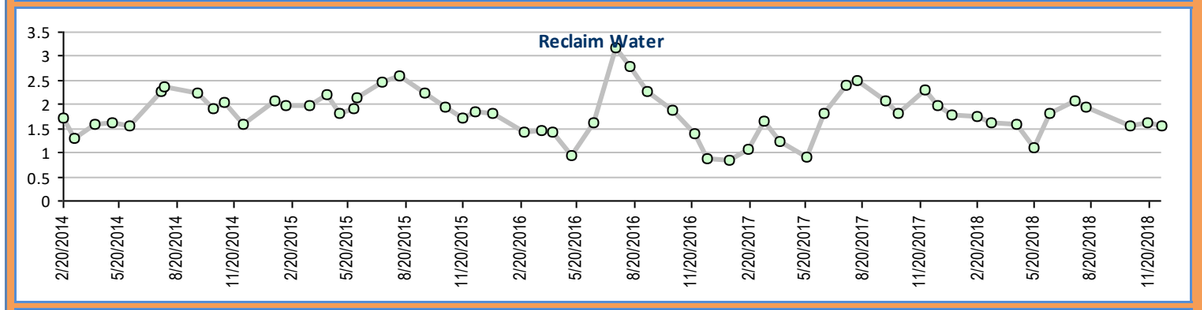
Mine Water Monitoring - Water Quality Profile II, Trend Charts

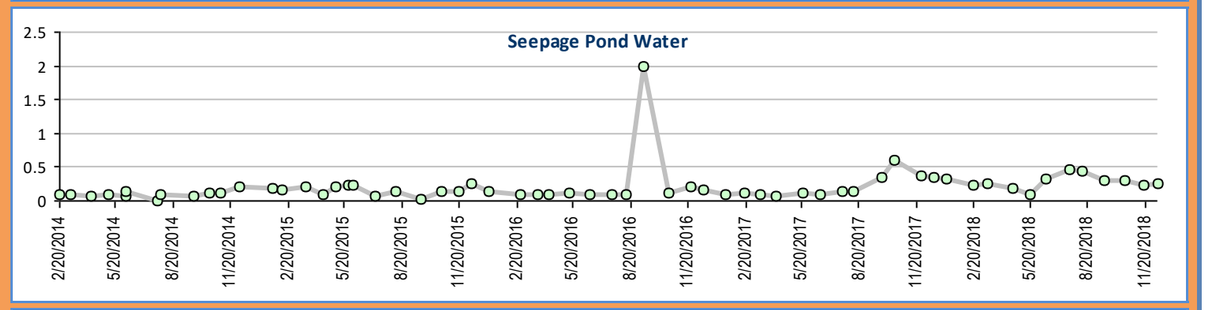
Lead, dissolved, units mg/L

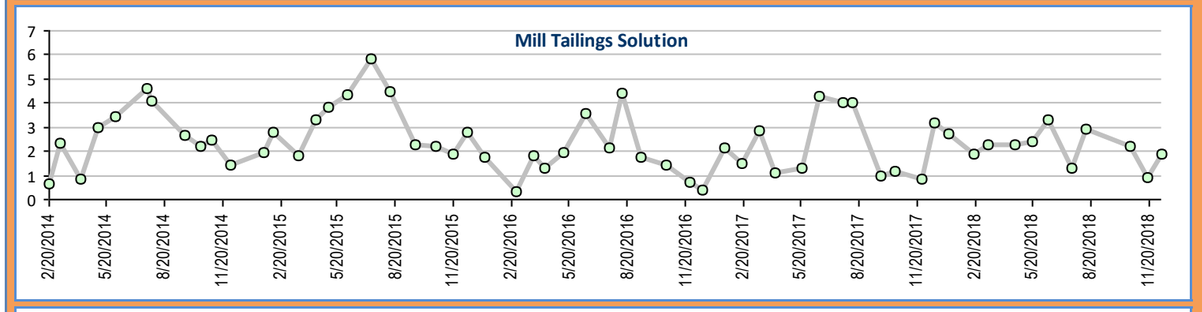


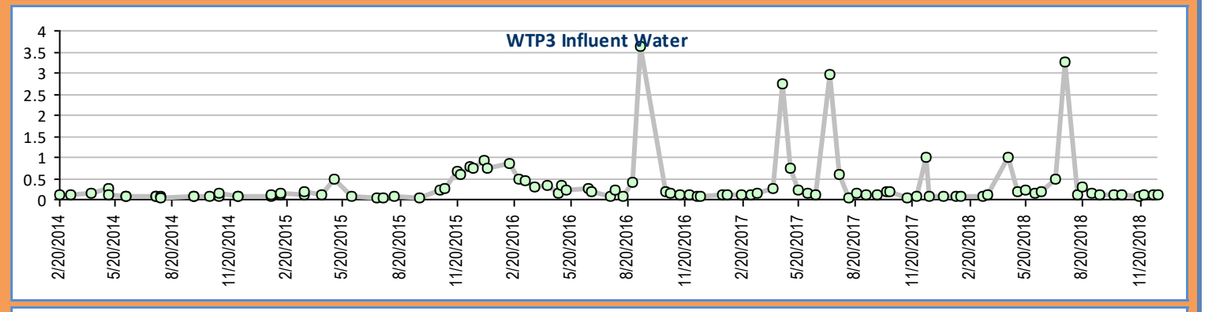


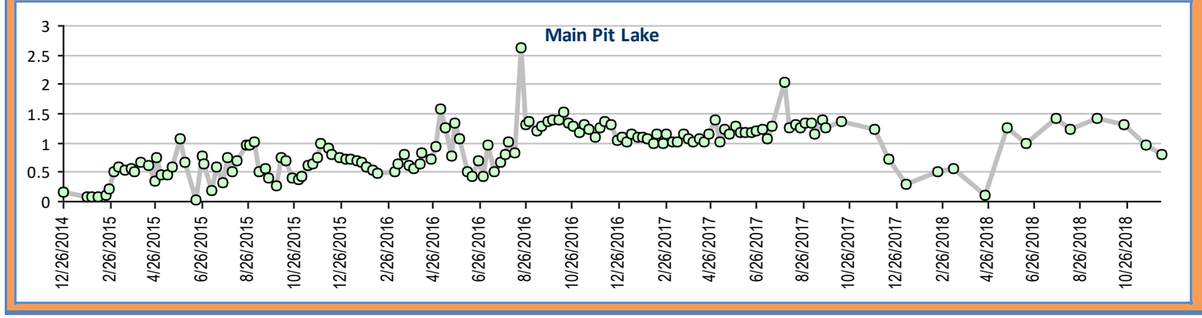


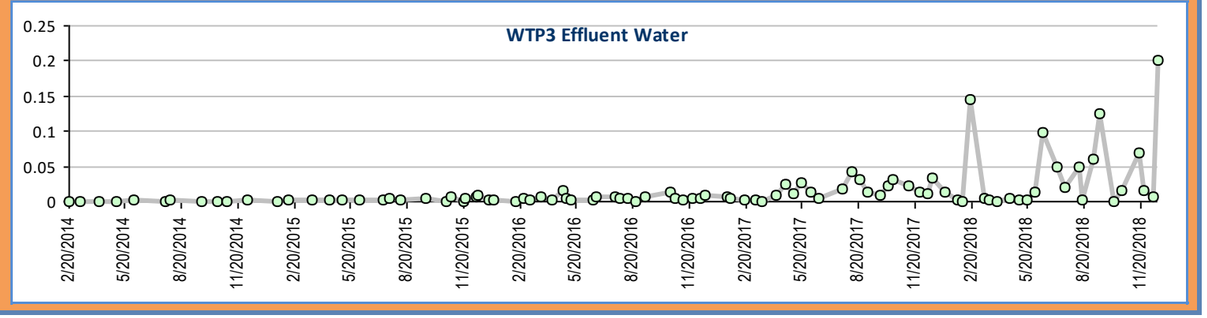








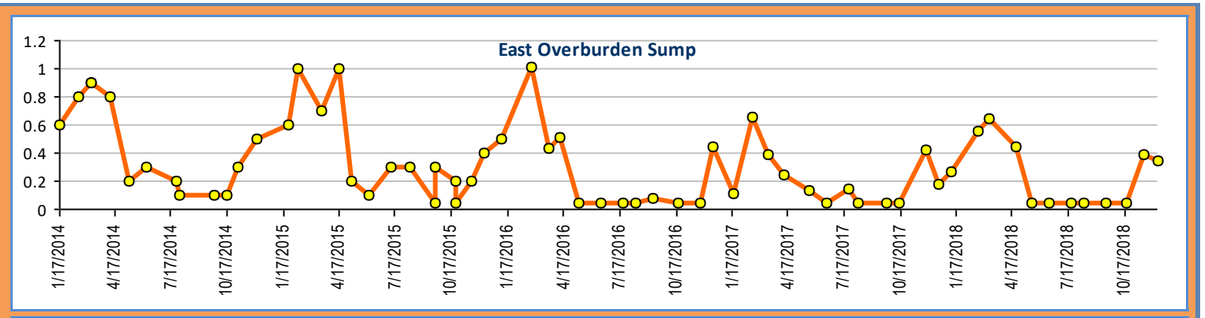


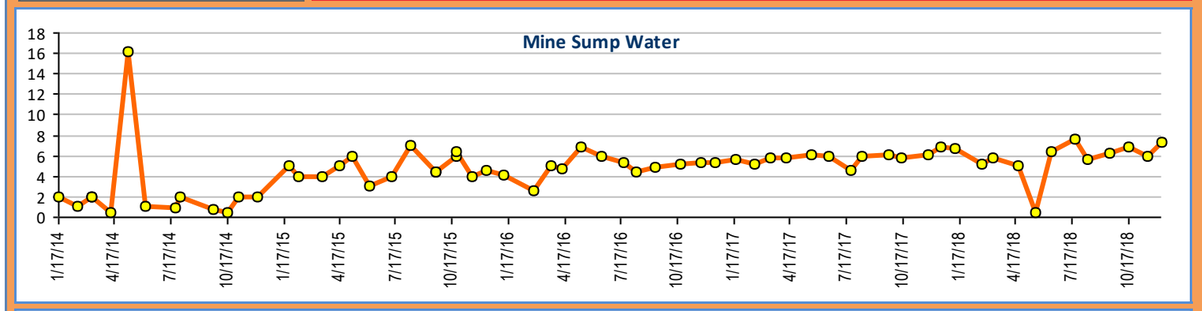


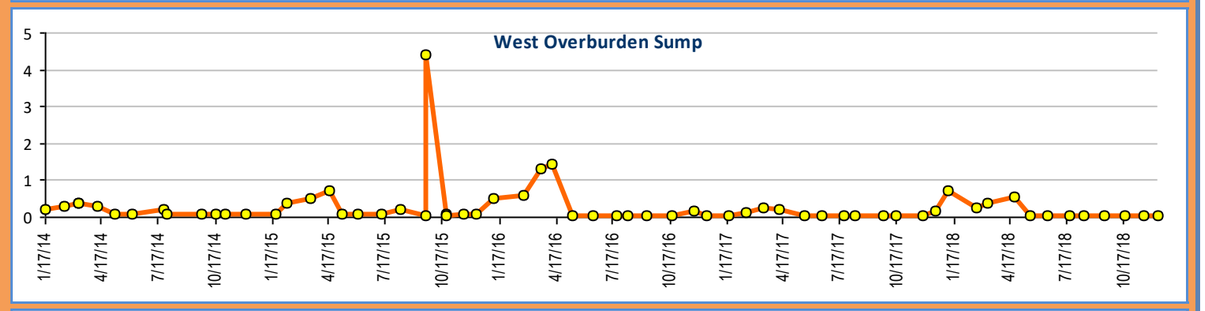
RED DOG MINE

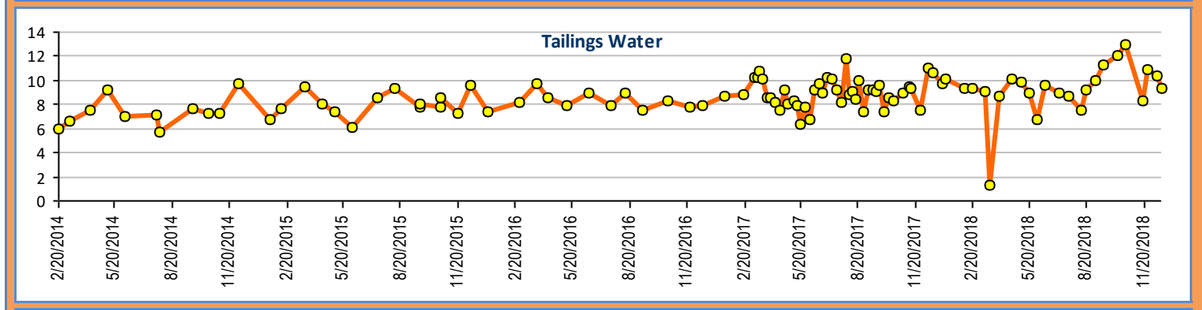
Mine Water Monitoring - Water Quality Profile II, Trend Charts

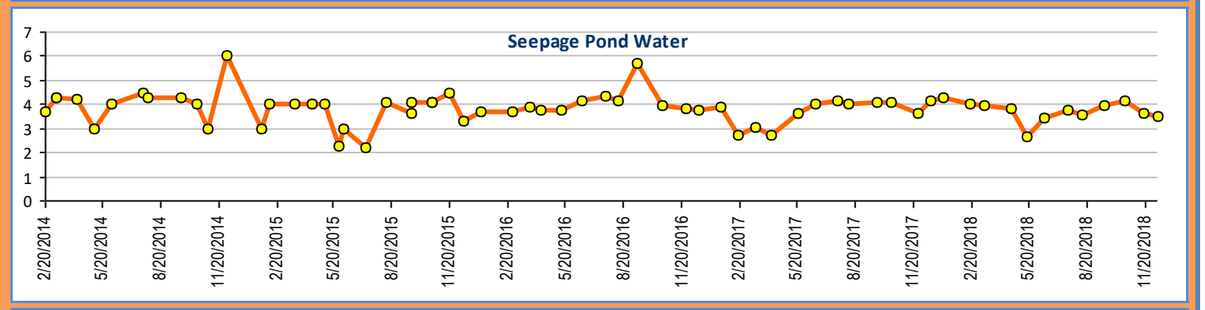
Ammonia as N, units mg/L

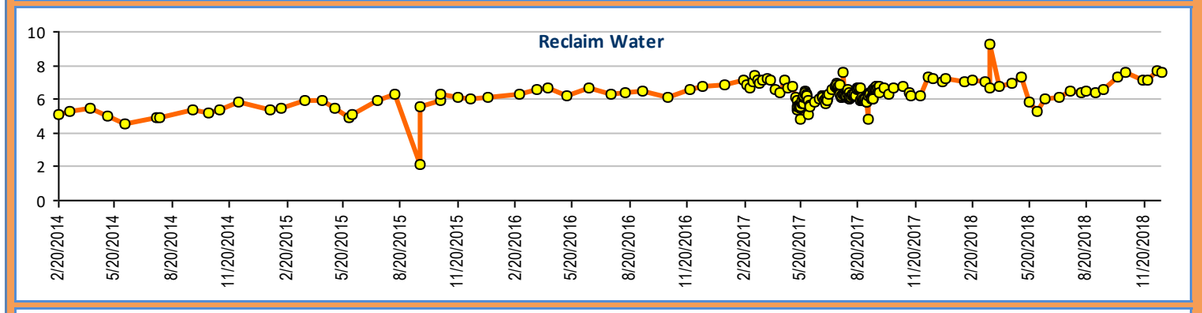


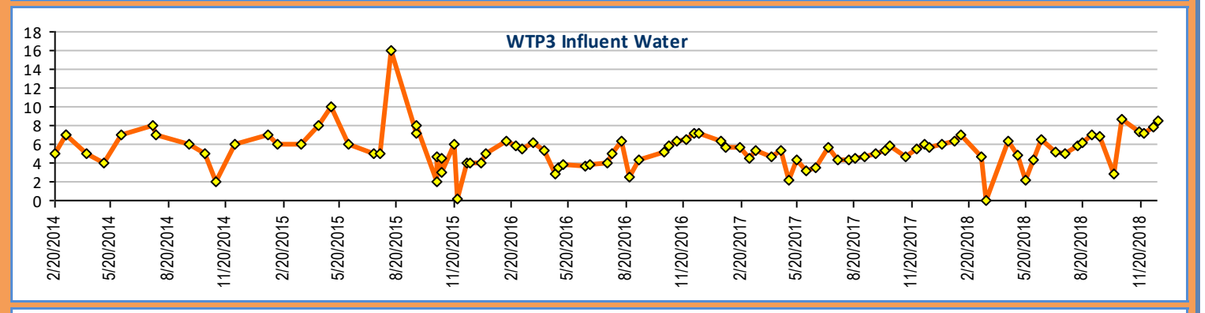


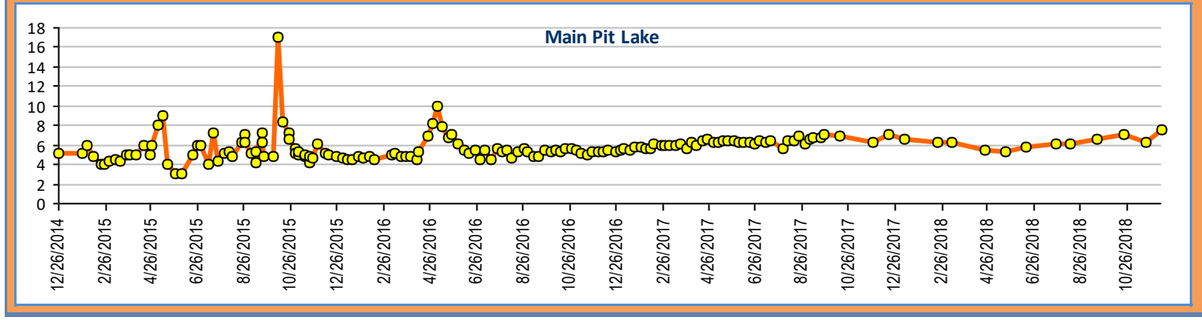


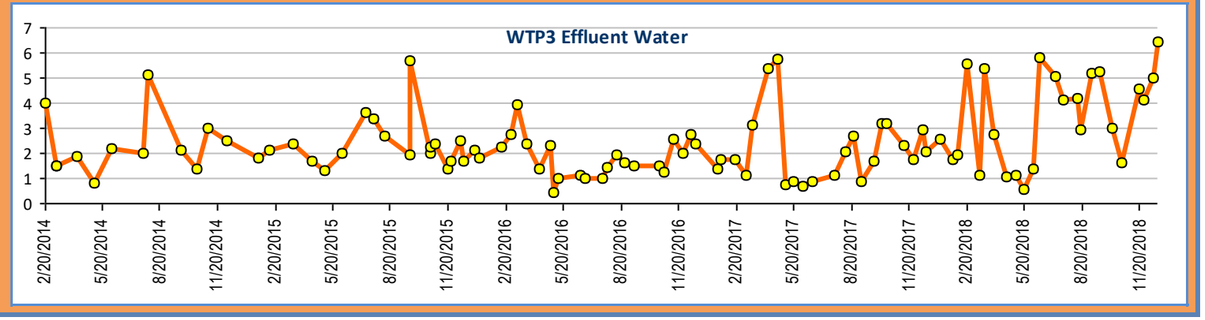








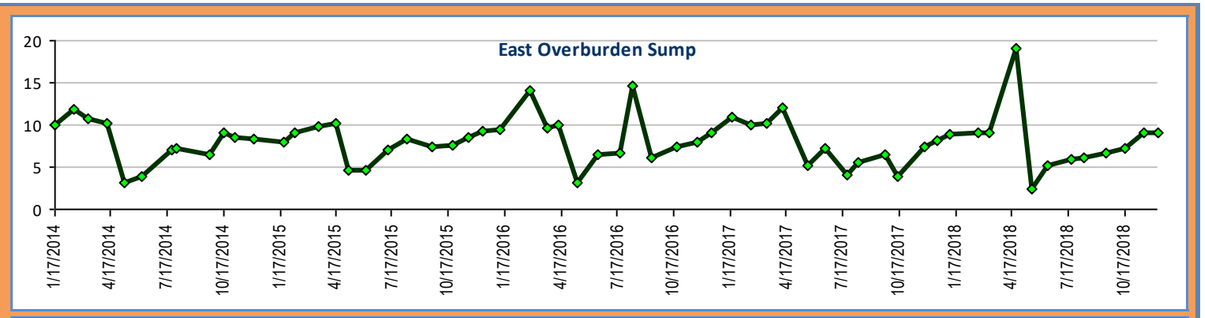


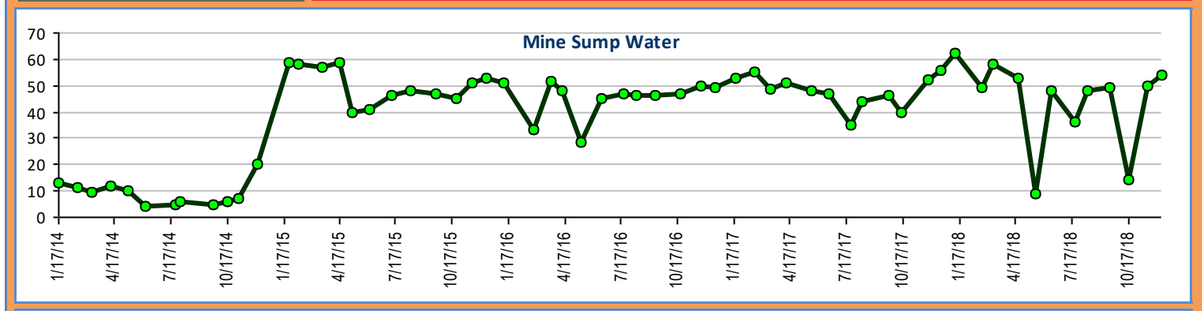


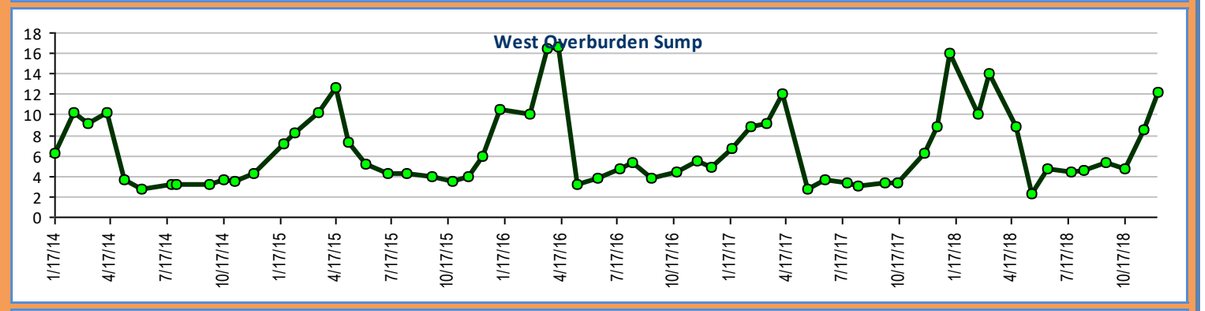
RED DOG MINE

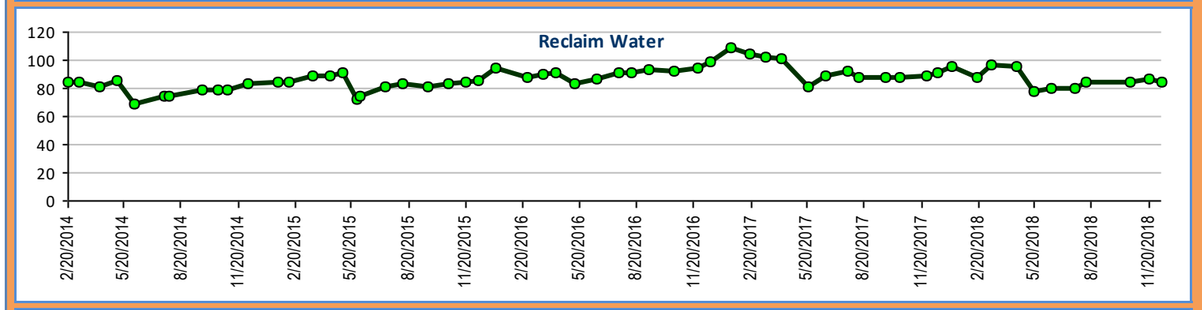
Mine Water Monitoring - Water Quality Profile II, Trend Charts

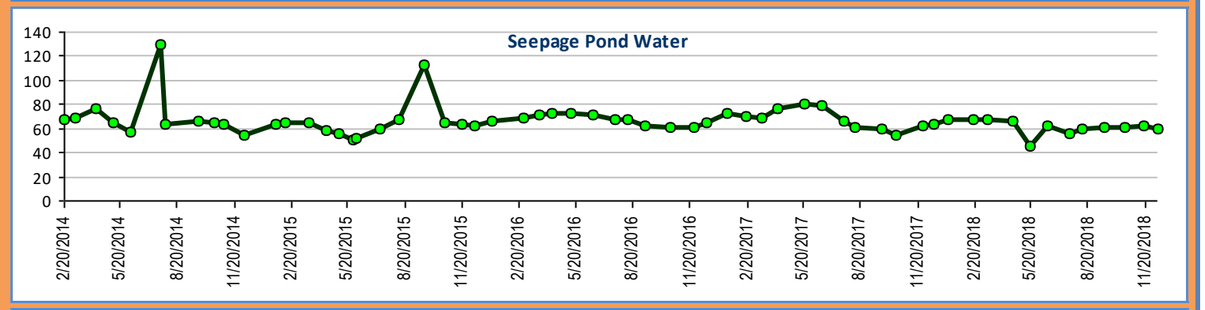
Sodium, dissolved, units mg/L

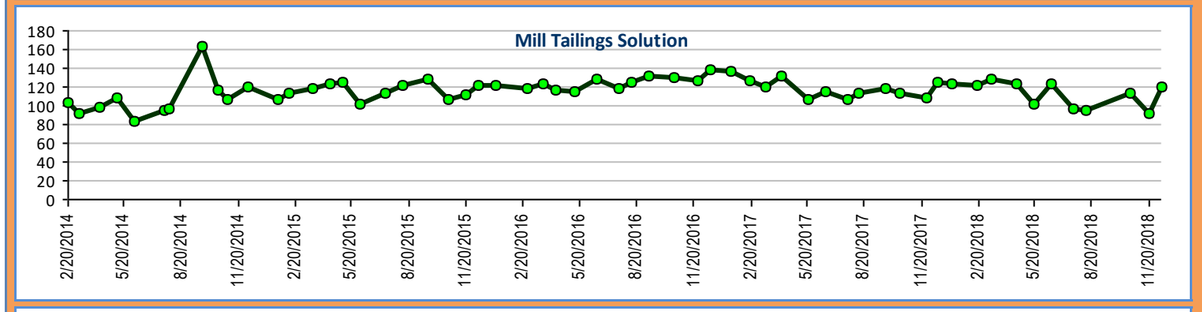


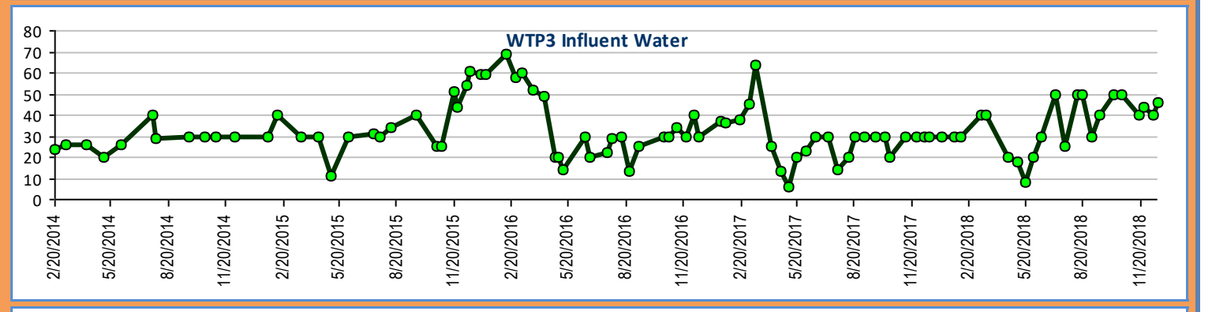


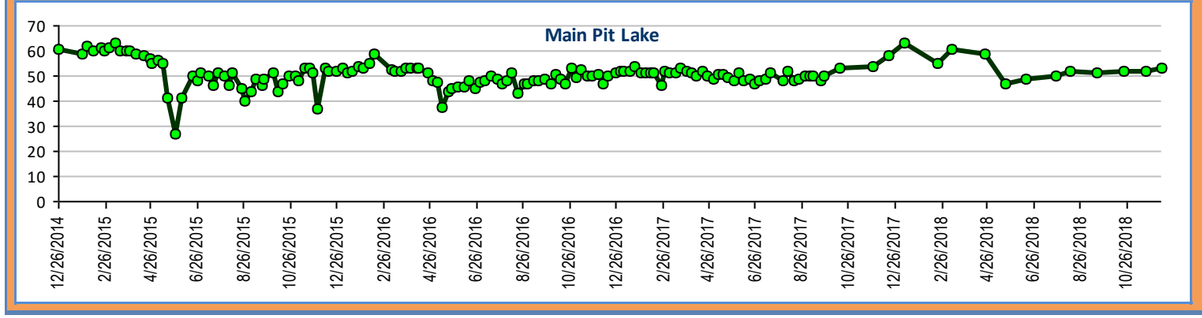


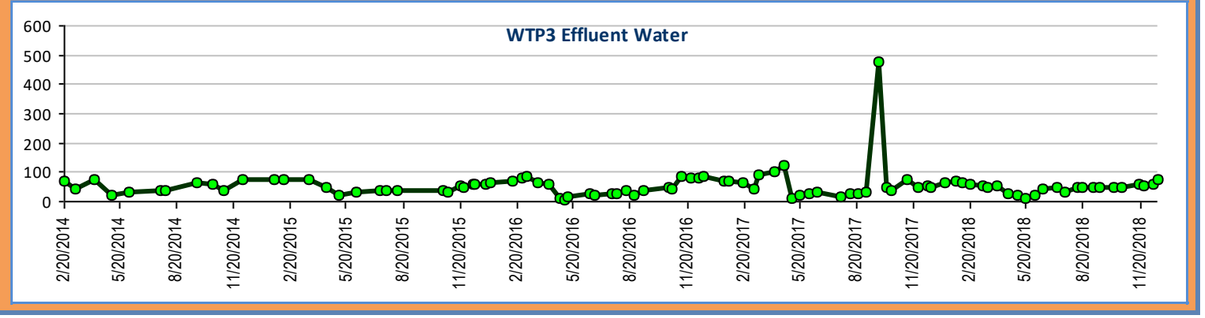








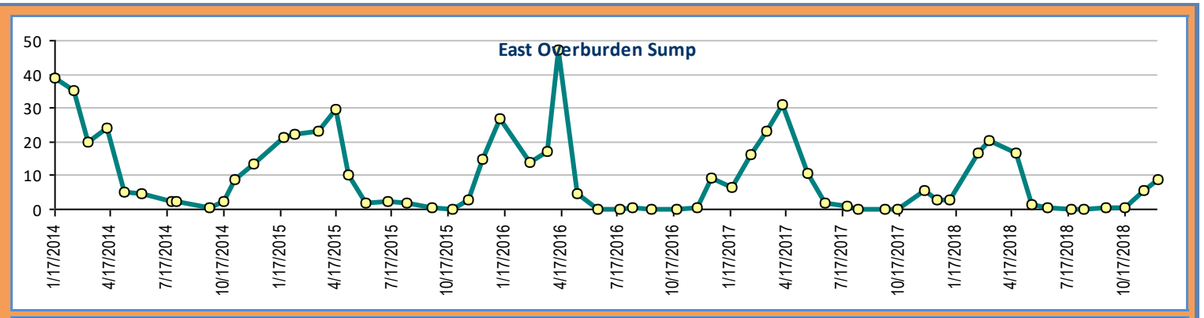


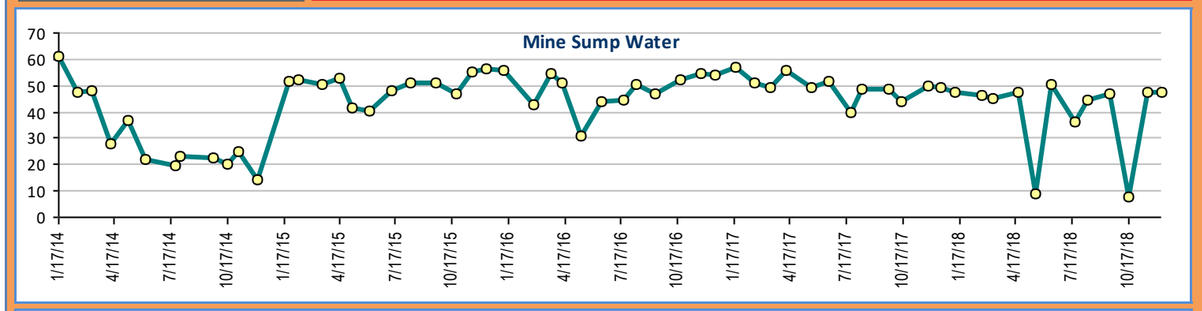


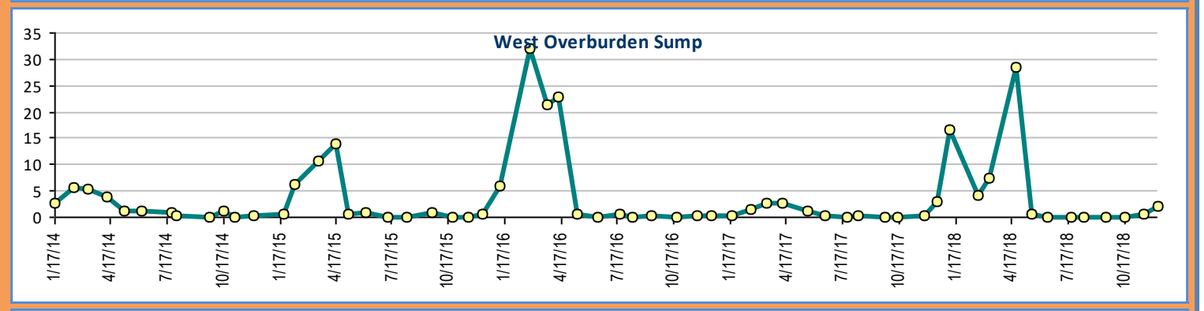
RED DOG MINE

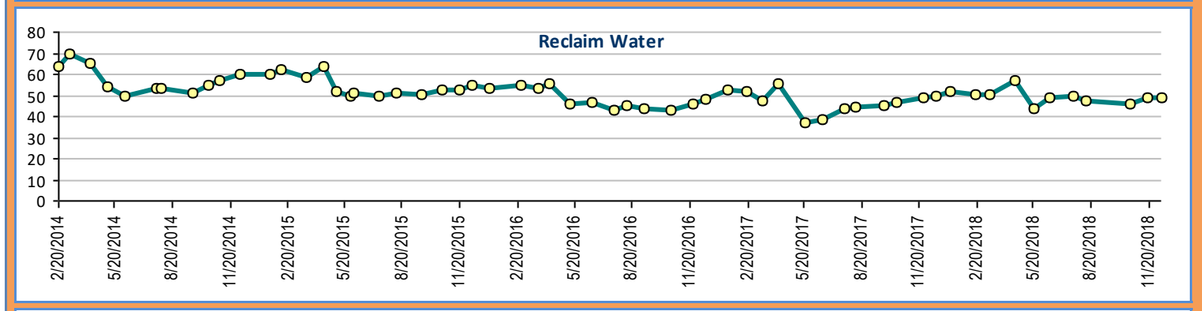
Mine Water Monitoring - Water Quality Profile II, Trend Charts

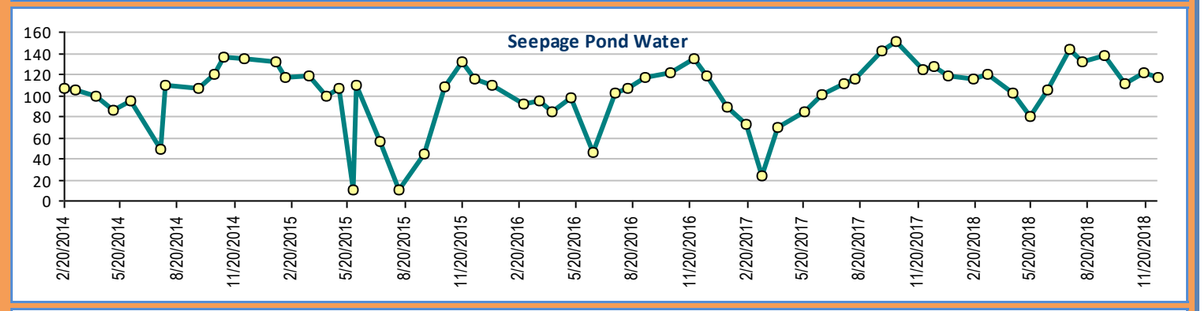
Manganese, dissolved, units mg/L

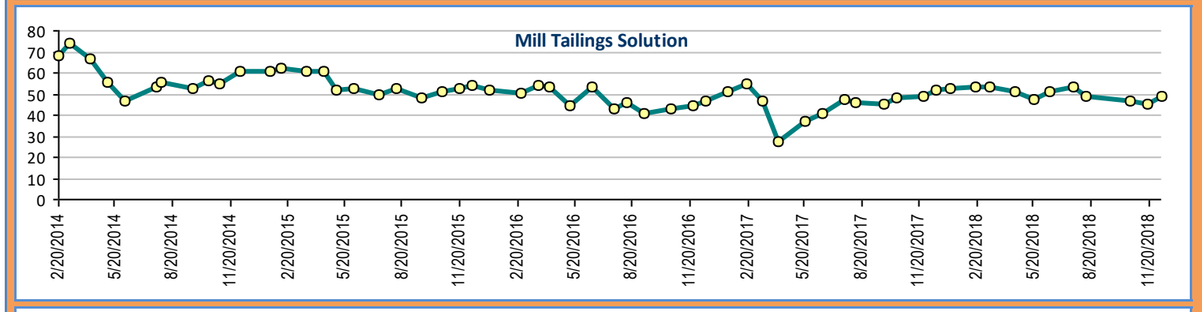


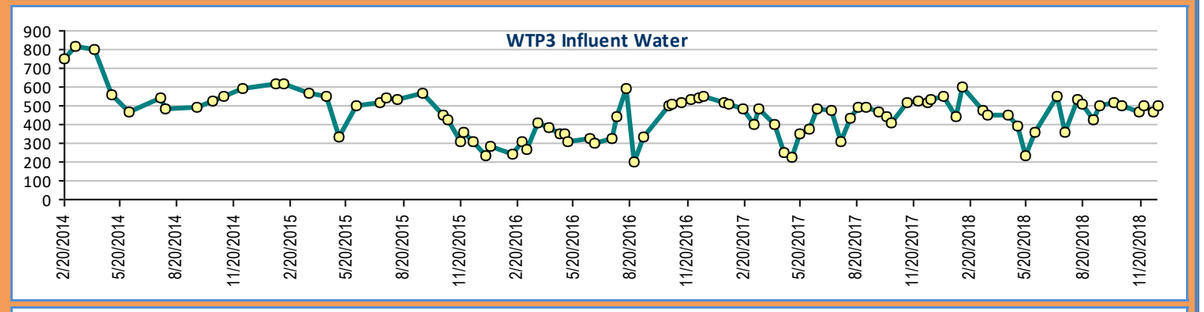


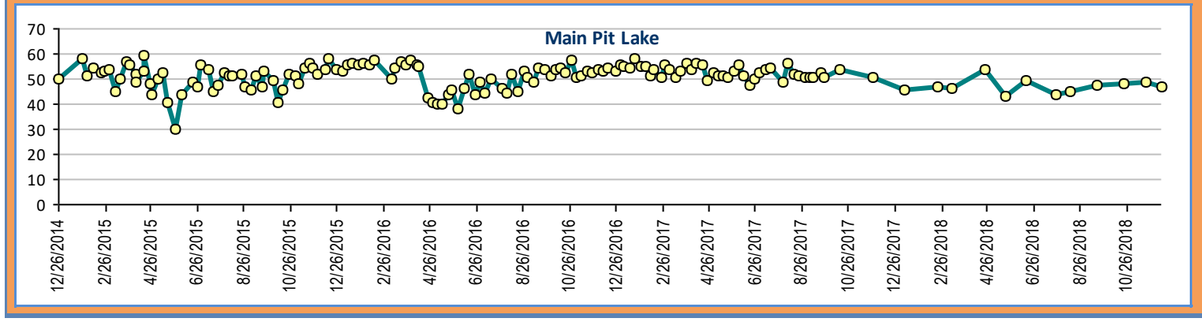


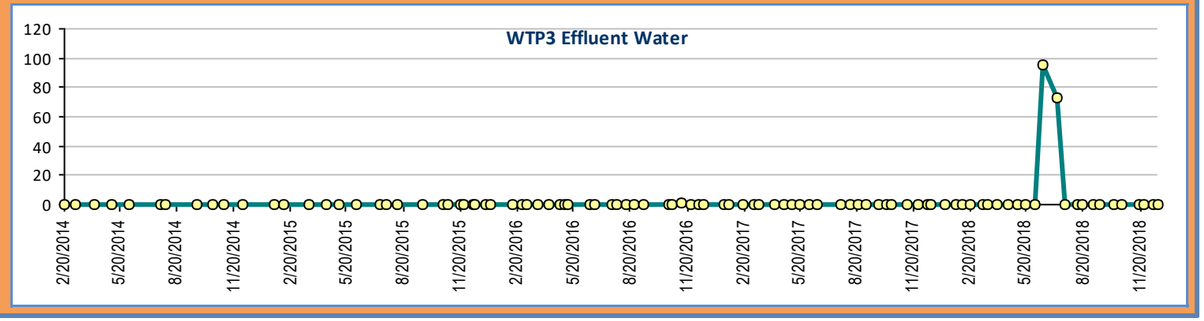








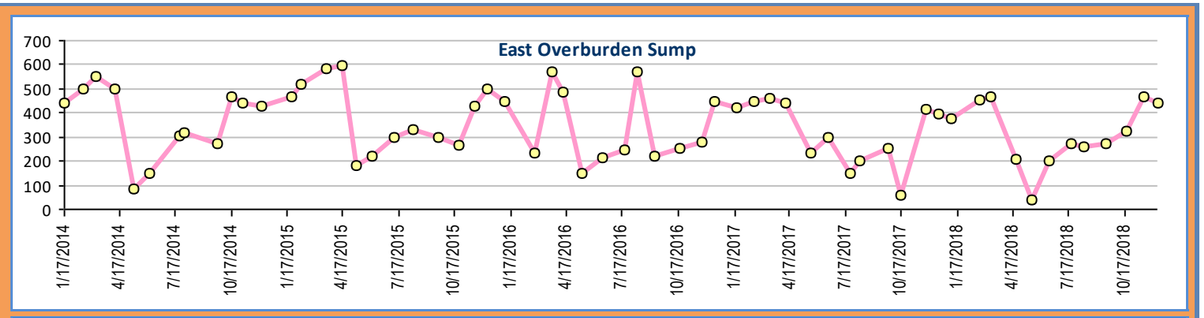


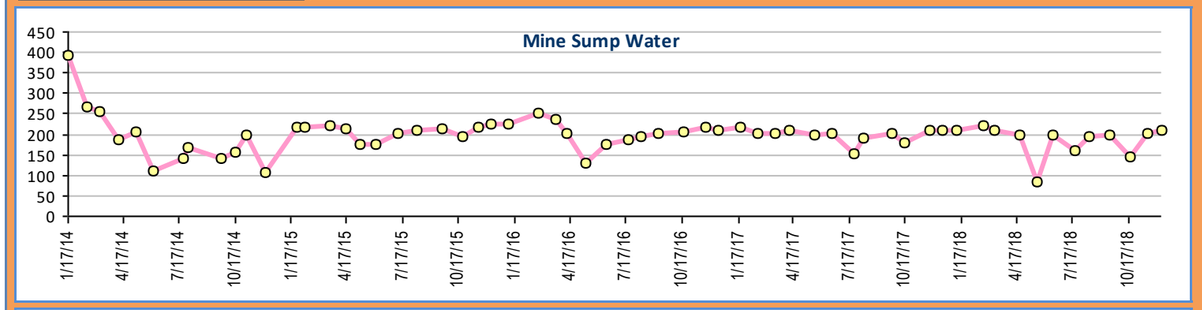


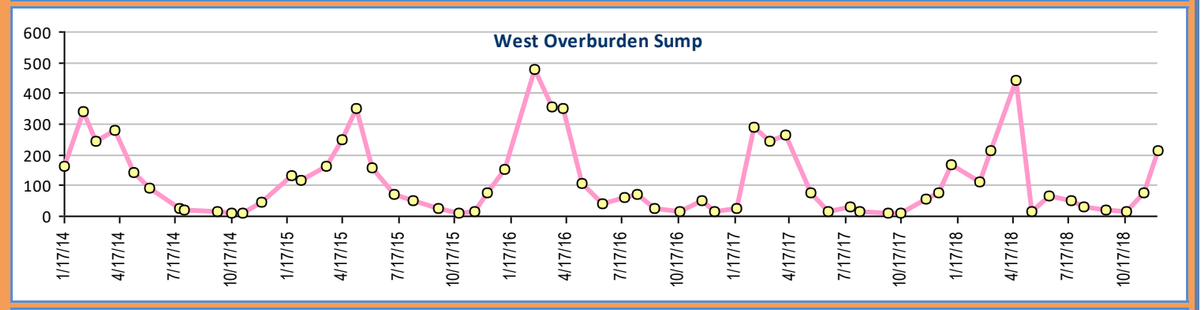
RED DOG MINE

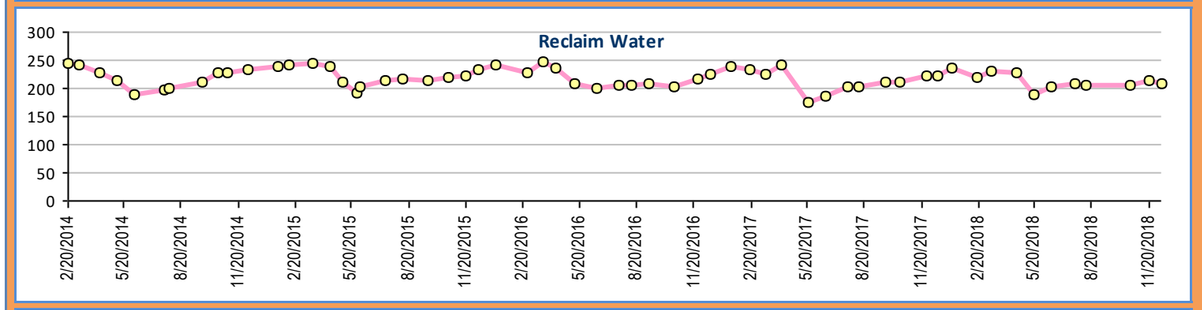
Mine Water Monitoring - Water Quality Profile II, Trend Charts

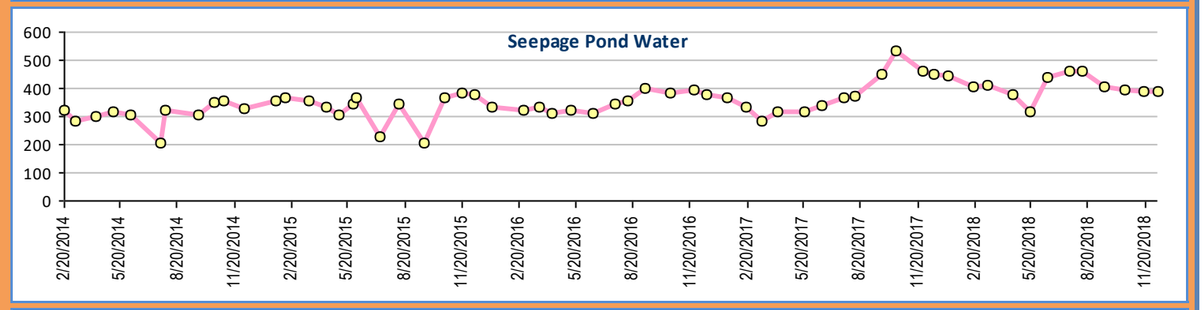
Magnesium, dissolved, units mg/L

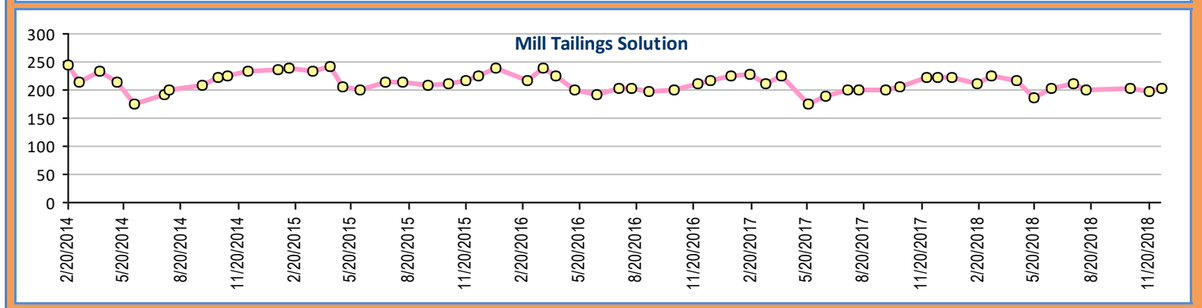


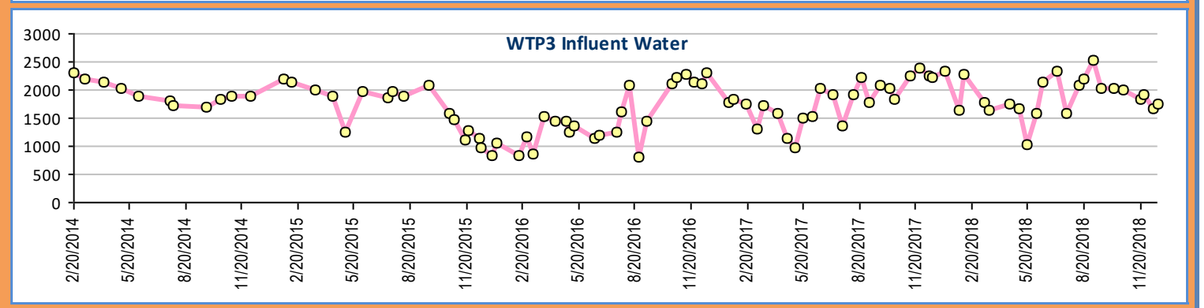


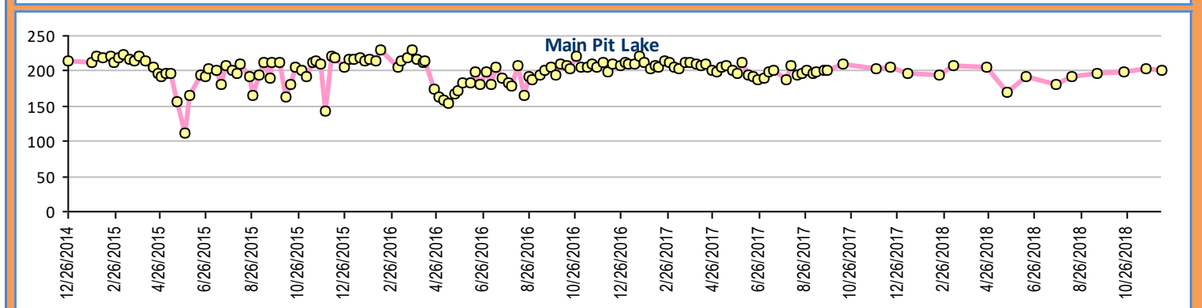


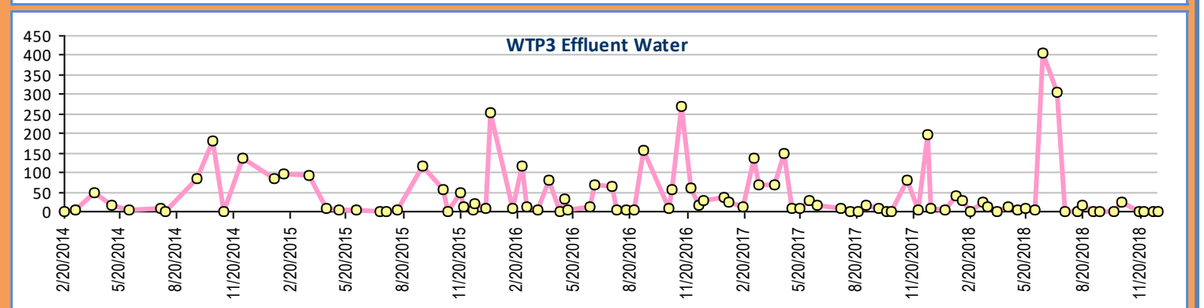








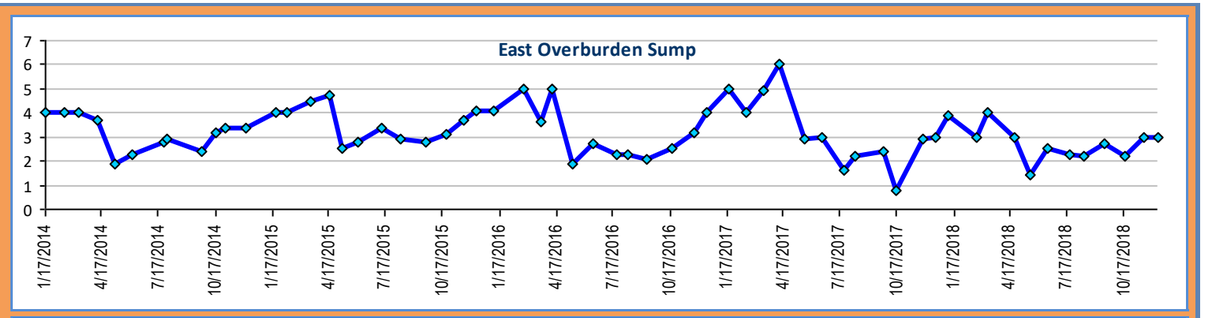


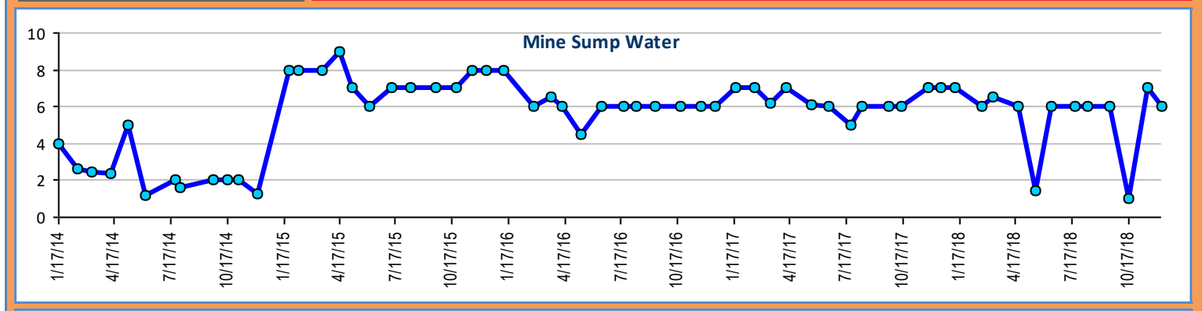


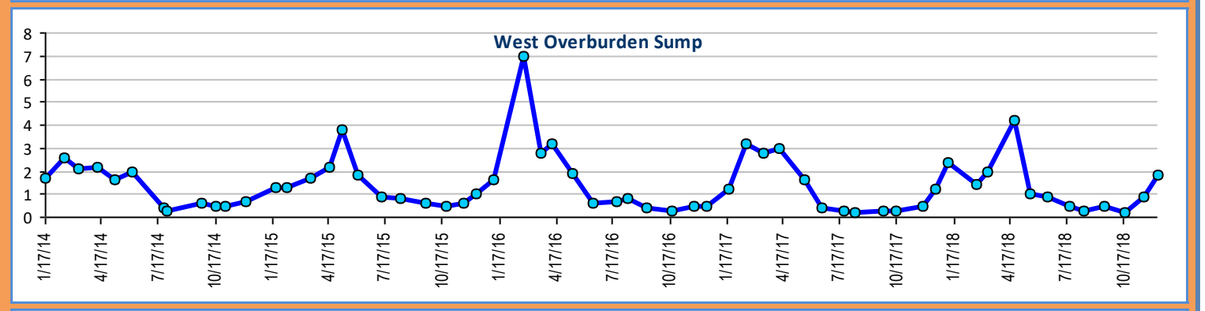
RED DOG MINE

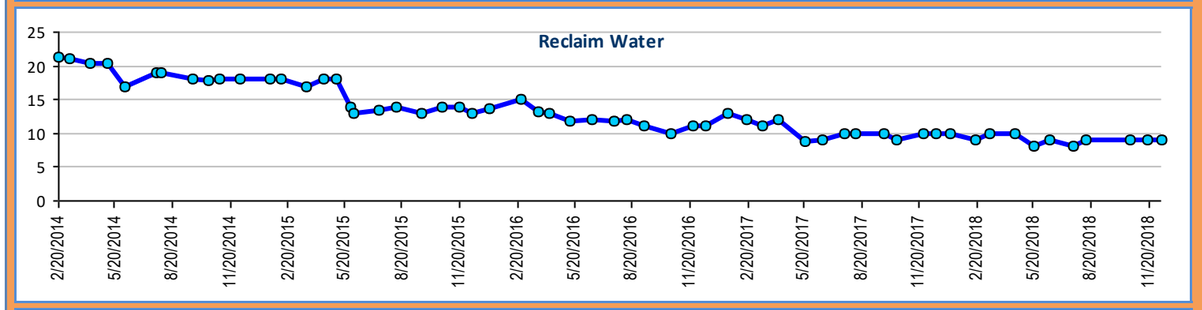
Mine Water Monitoring - Water Quality Profile II, Trend Charts

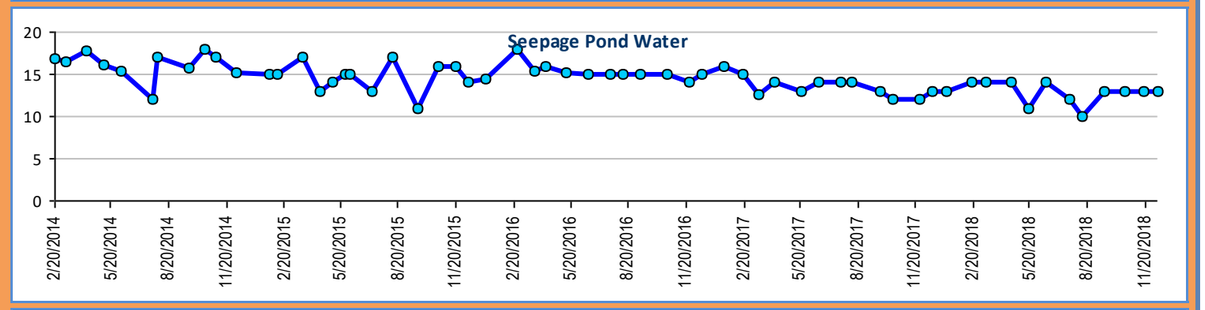
Potassium, dissolved, units mg/L

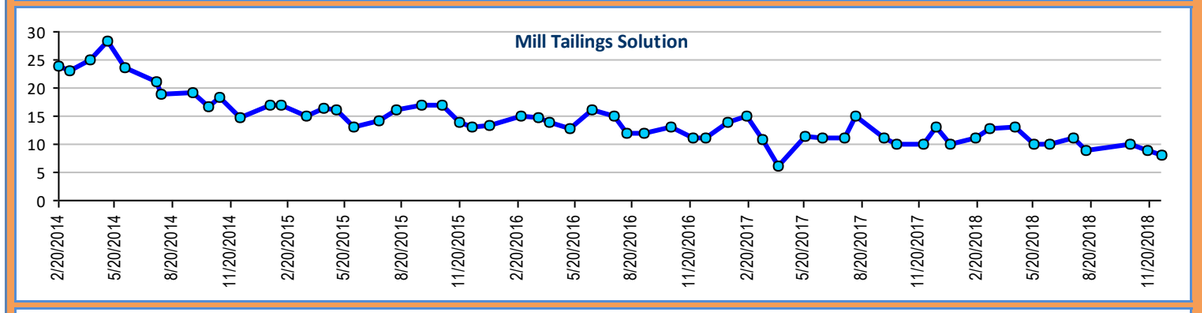


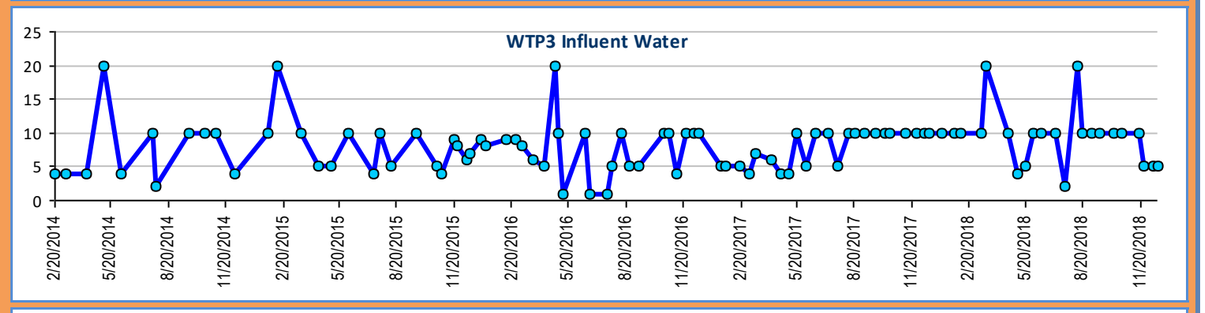


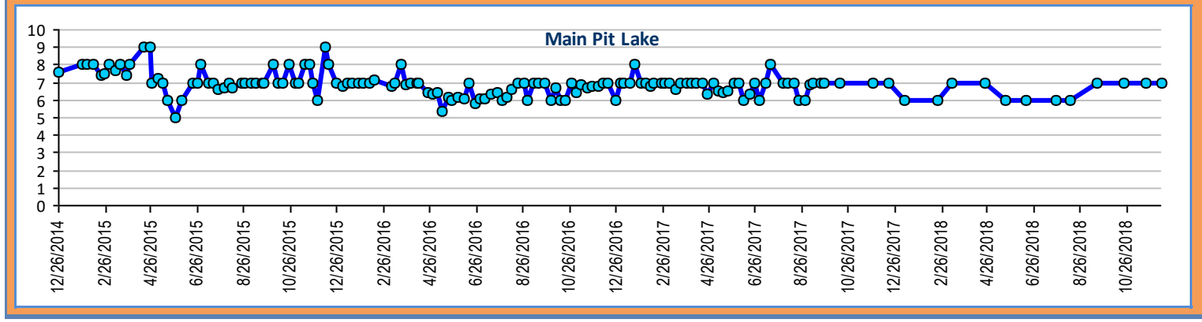


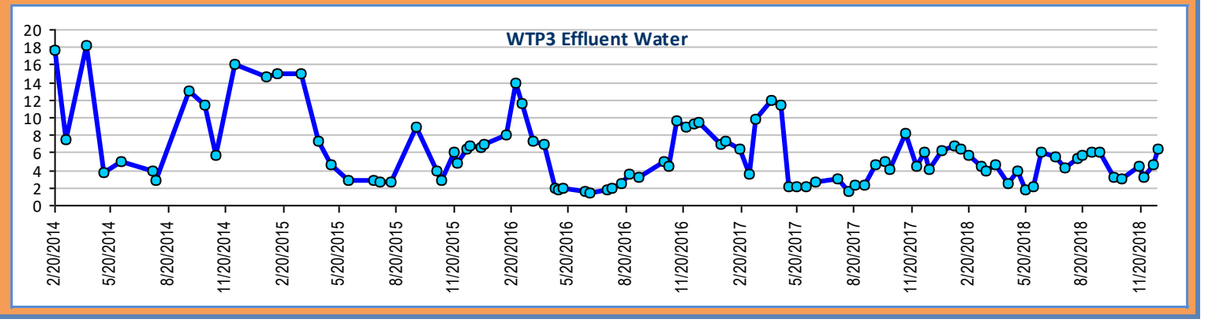








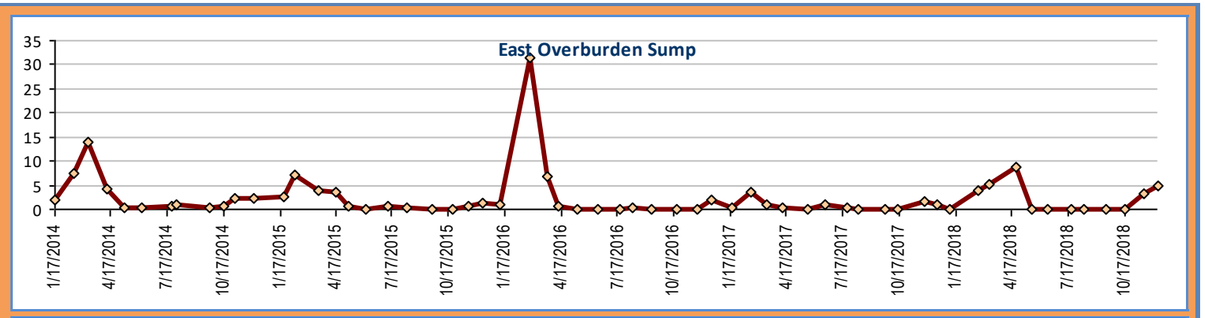


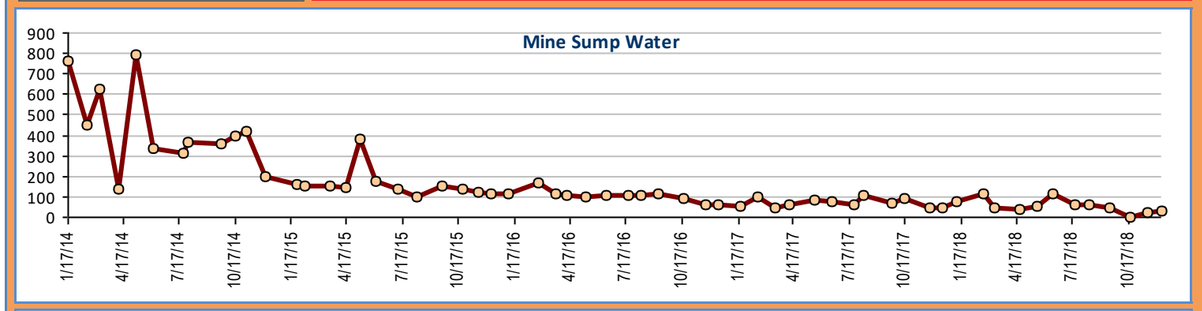


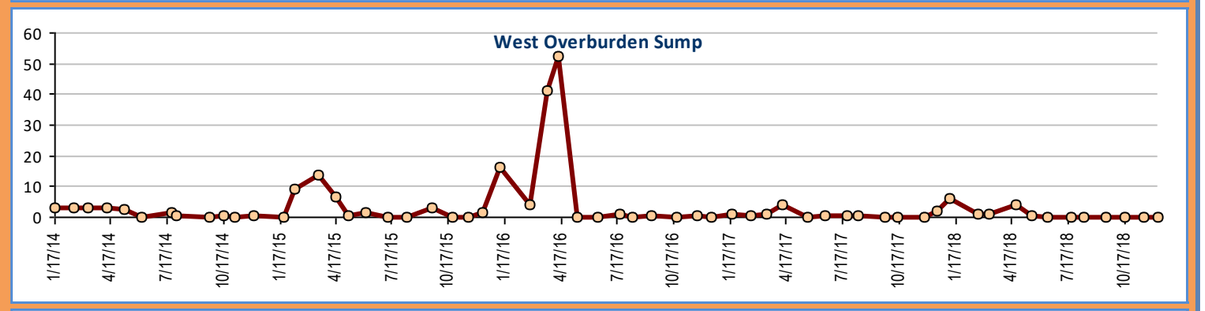
RED DOG MINE

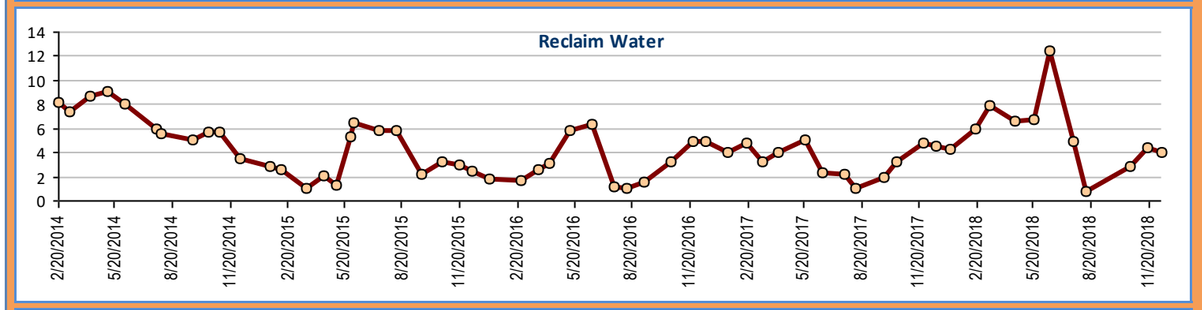
Mine Water Monitoring - Water Quality Profile II, Trend Charts

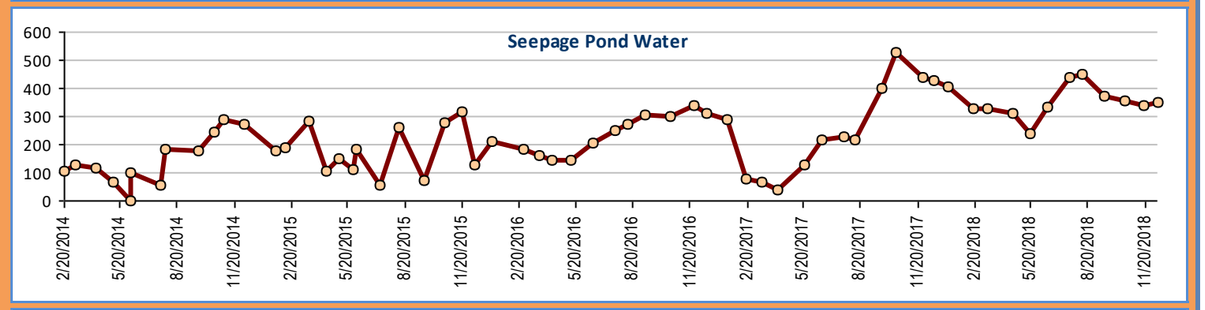
Iron, dissolved, units mg/L

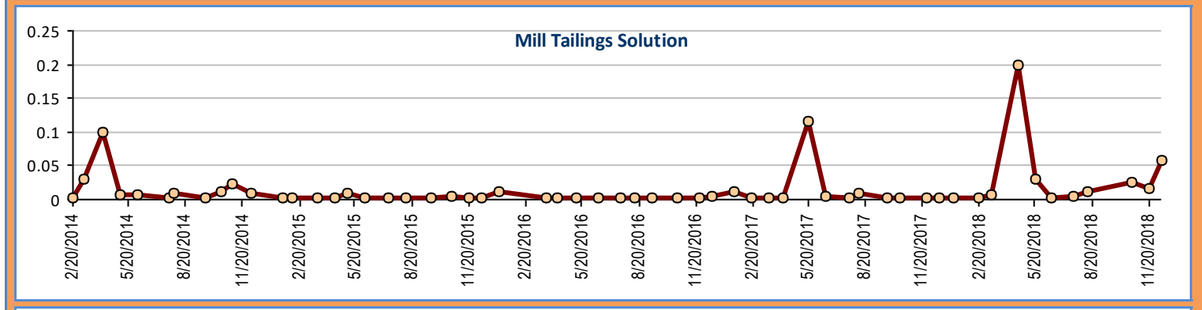


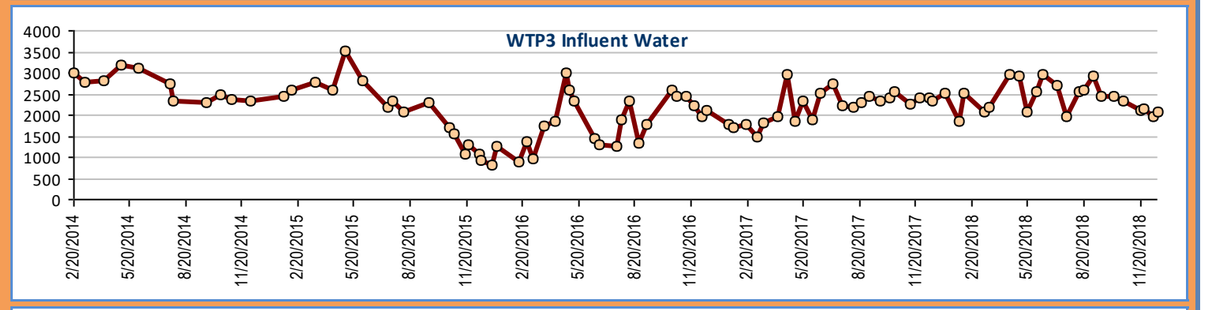


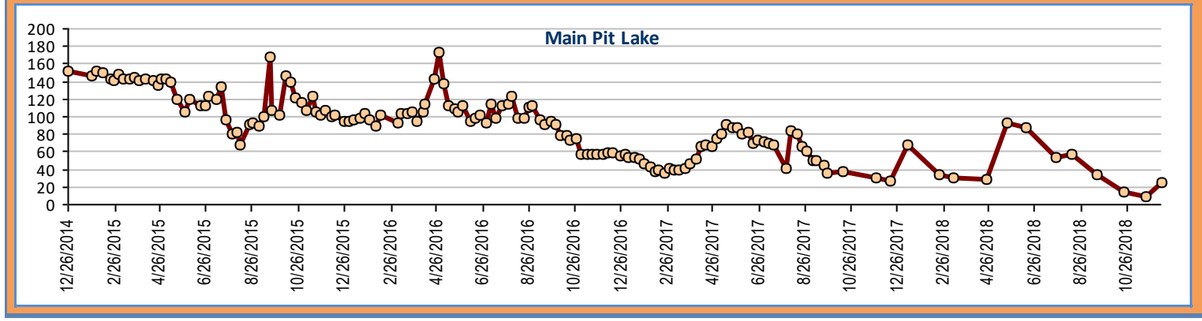


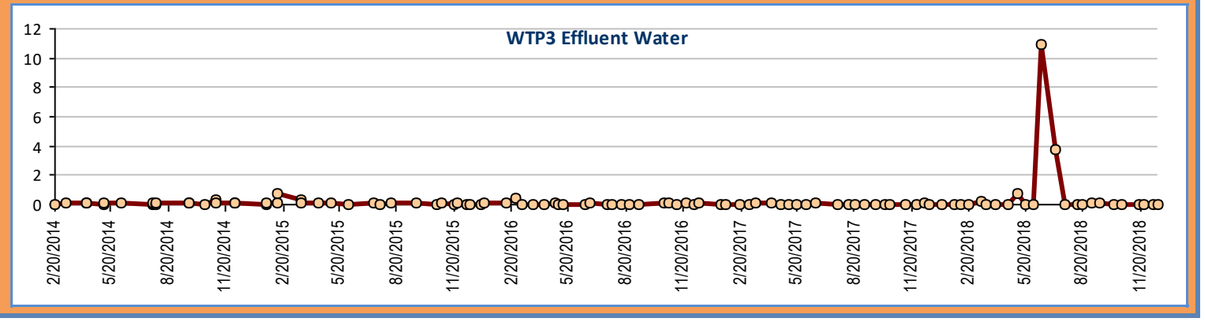








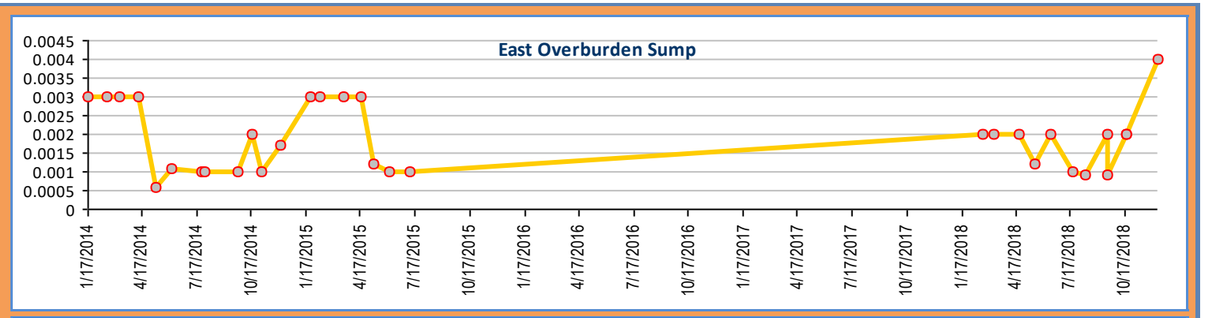


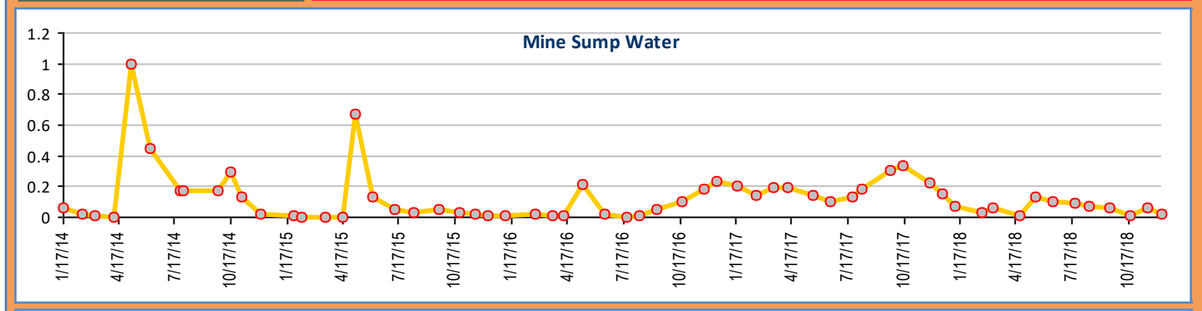


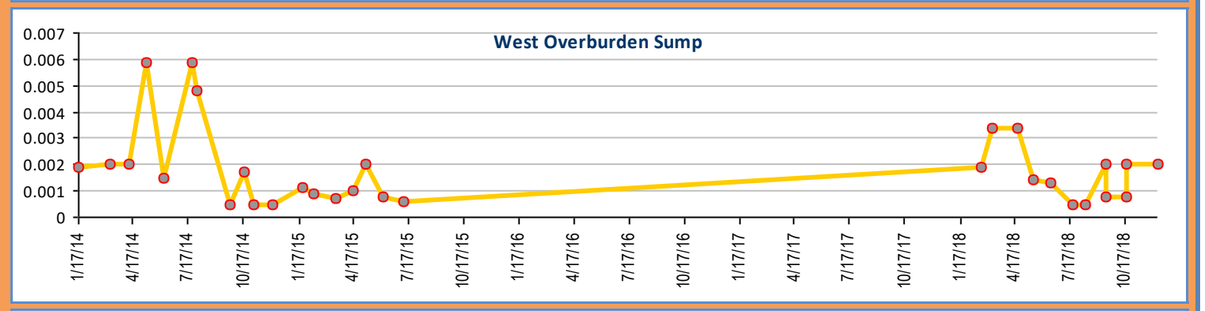
RED DOG MINE

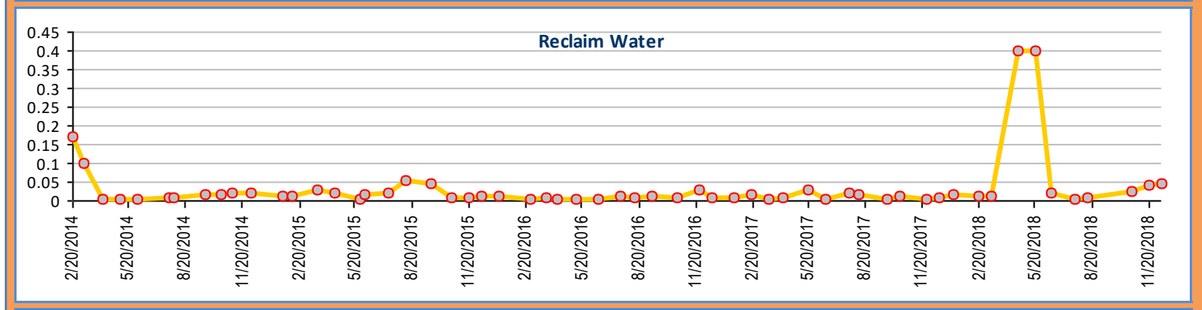
Mine Water Monitoring - Water Quality Profile II, Trend Charts

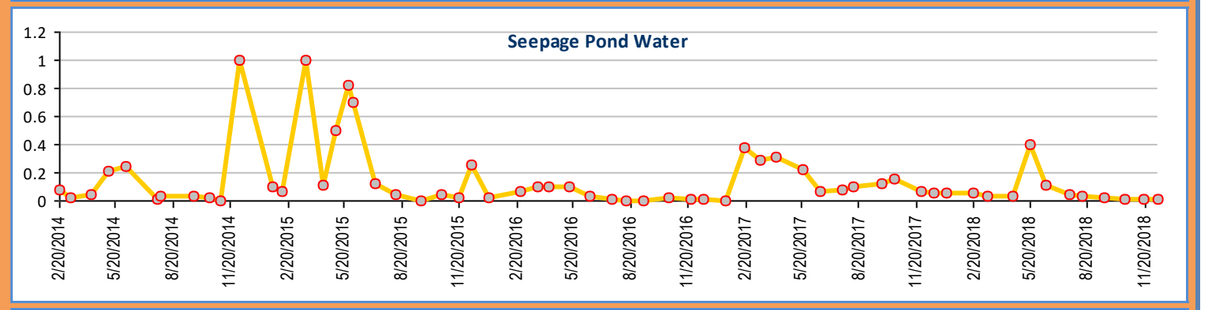
Copper, dissolved, units mg/L

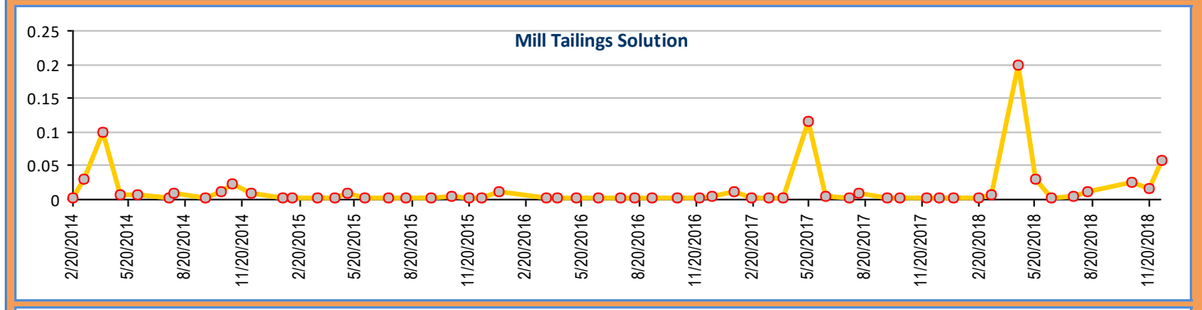


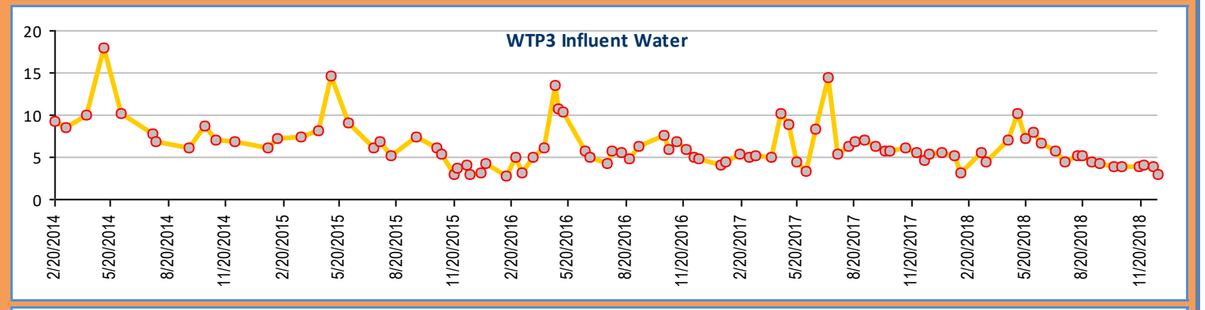


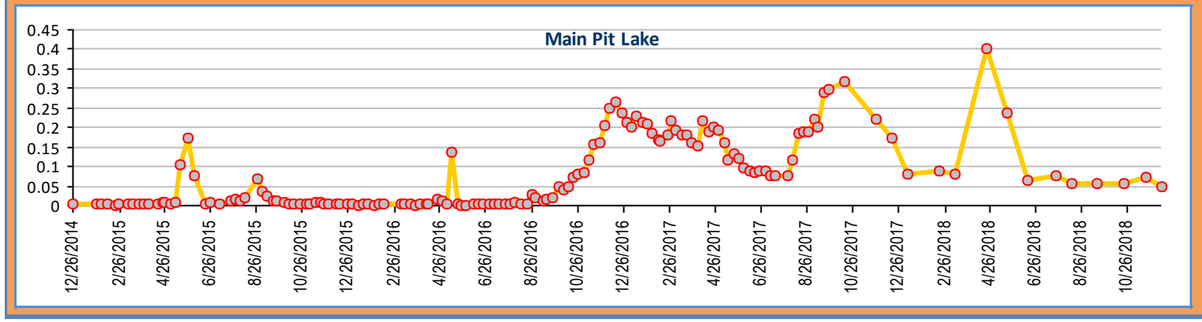


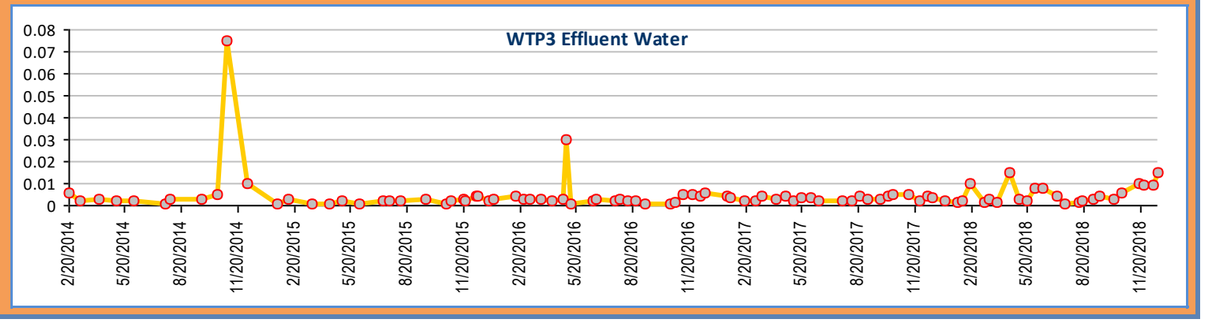








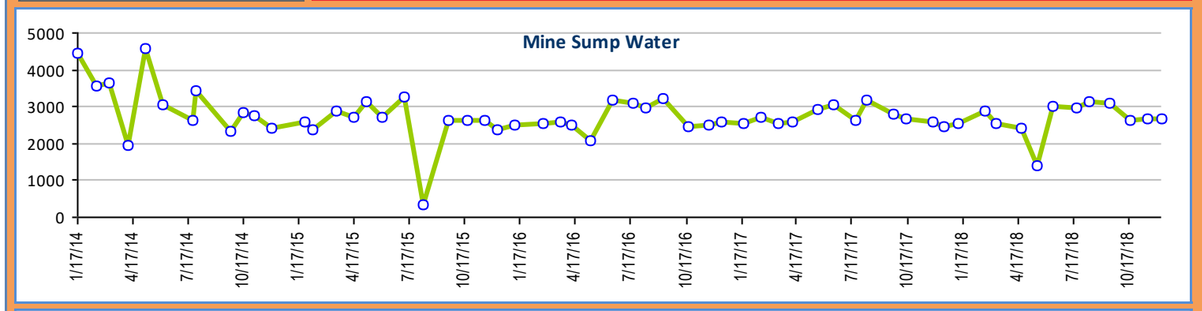


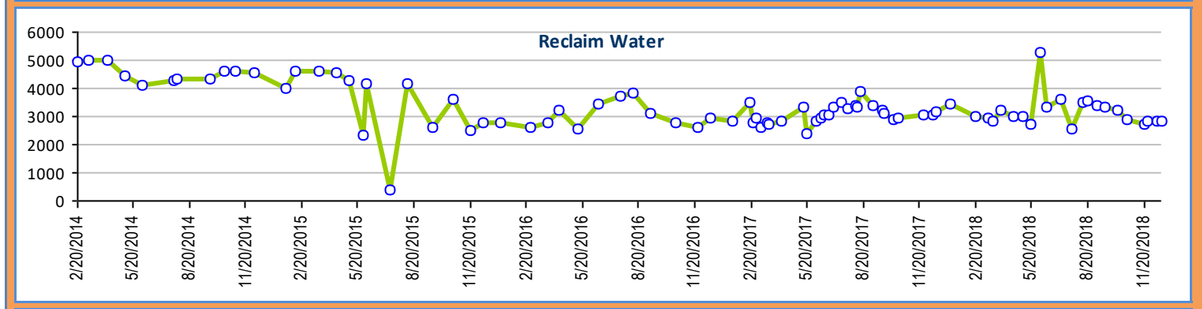


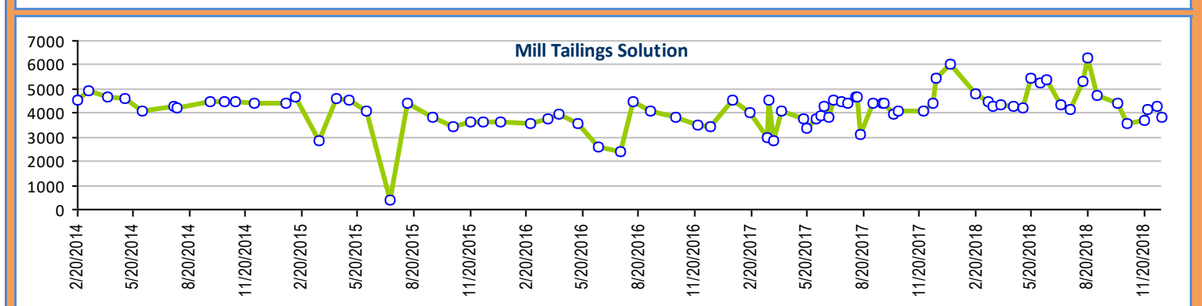
RED DOG MINE

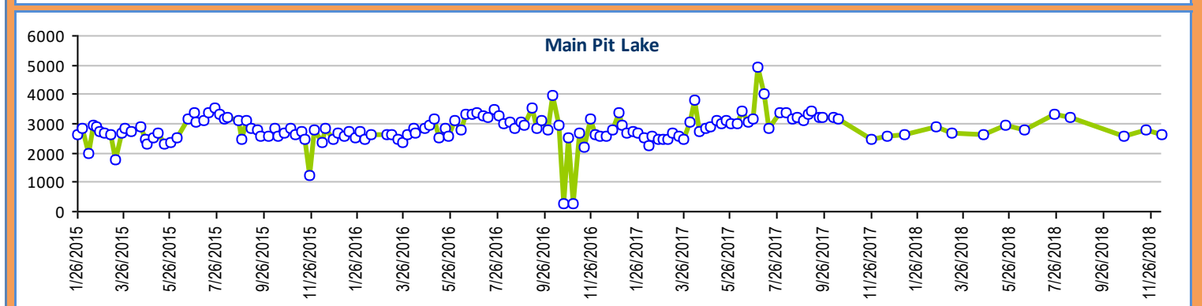
Mine Water Monitoring - Water Quality Profile II, Trend Charts

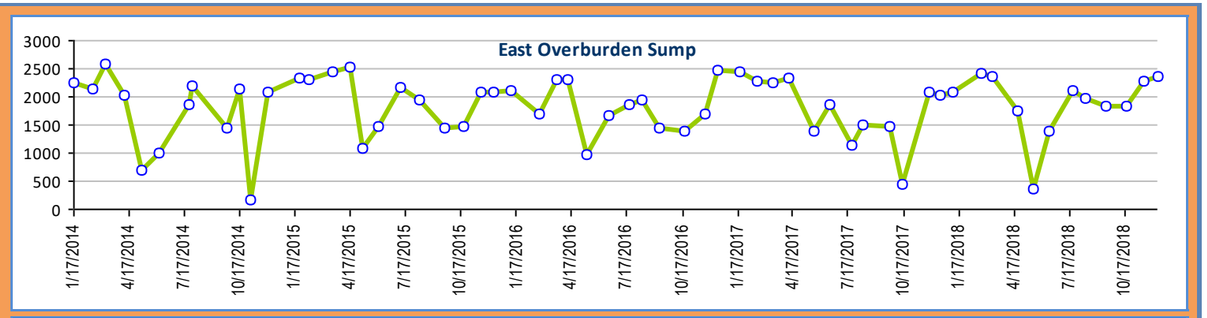
Conductivity, units uS/cm

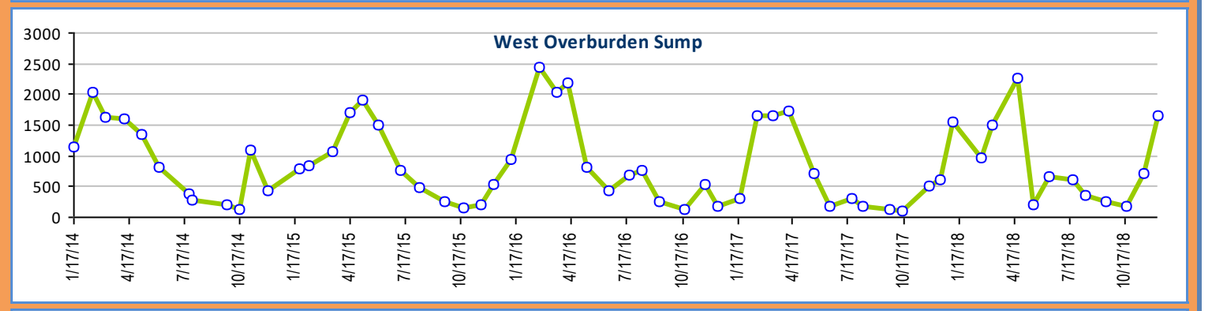


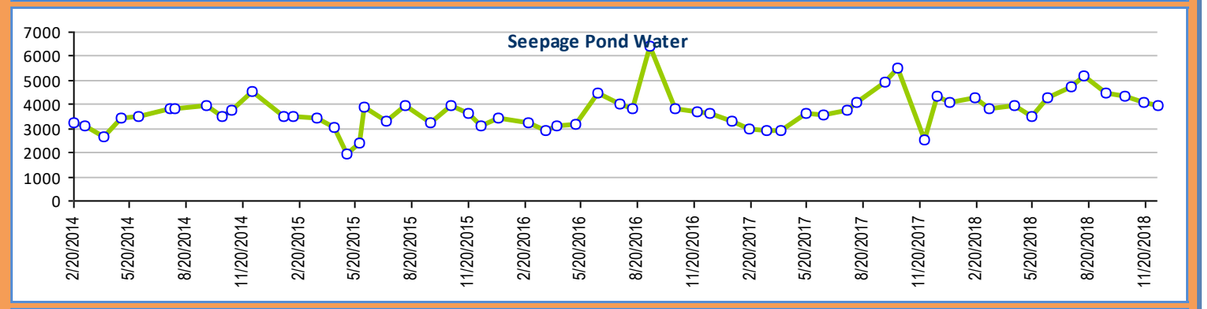


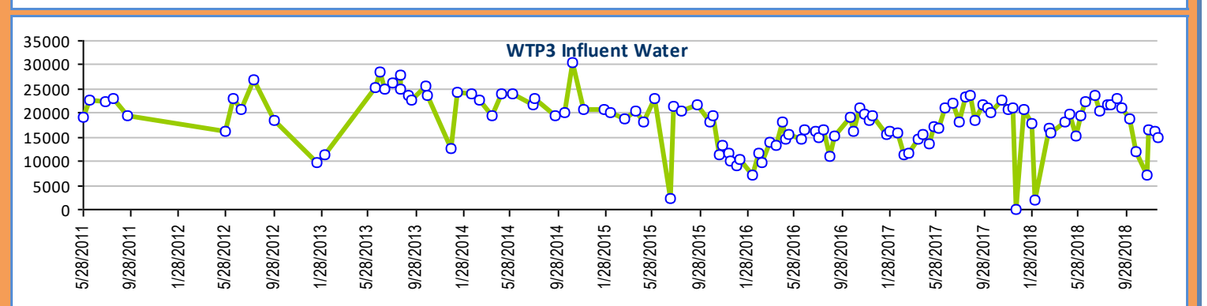


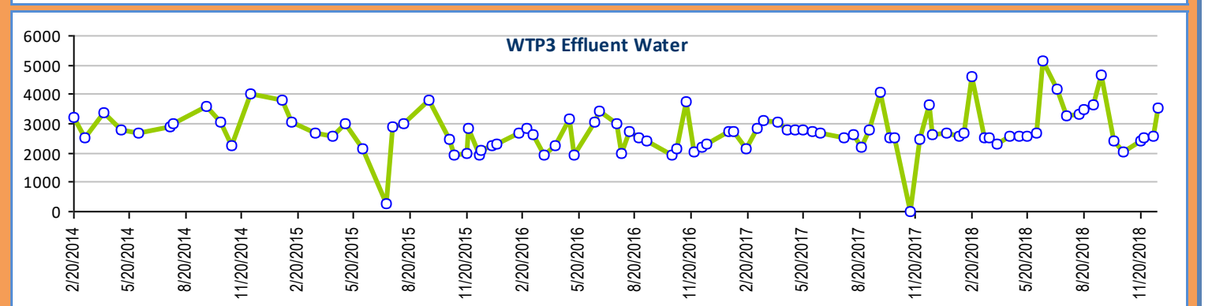








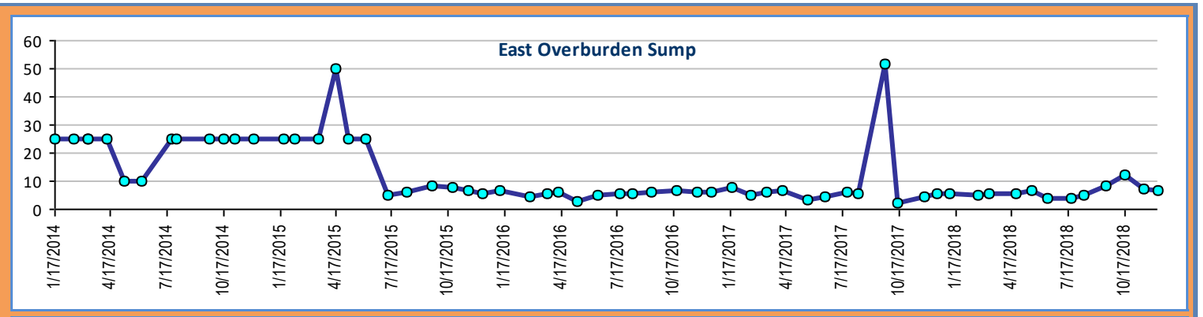


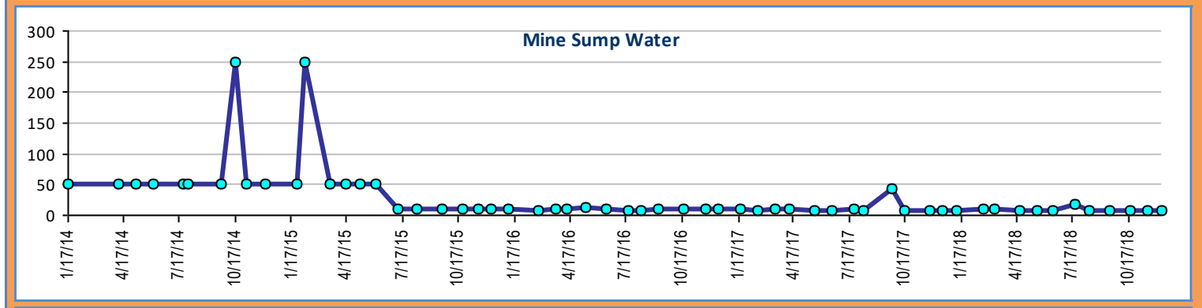


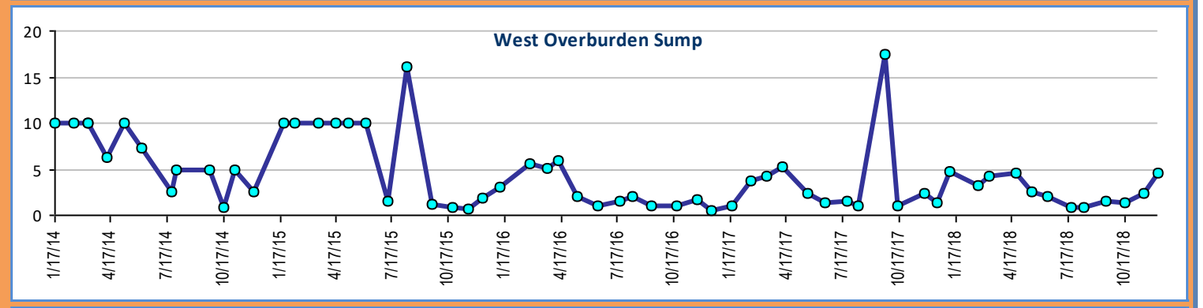
RED DOG MINE

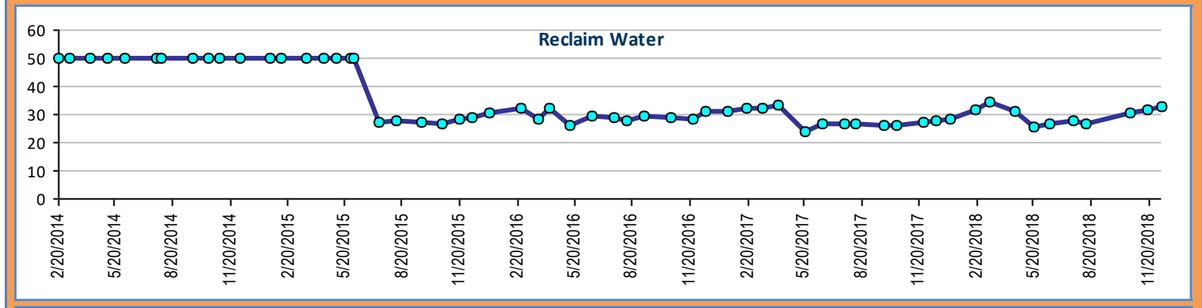
Mine Water Monitoring - Water Quality Profile II, Trend Charts

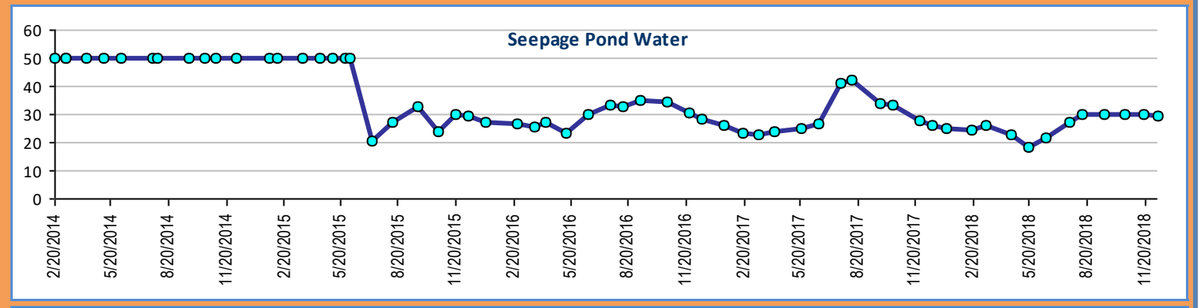
Chloride, dissolved, units mg/L

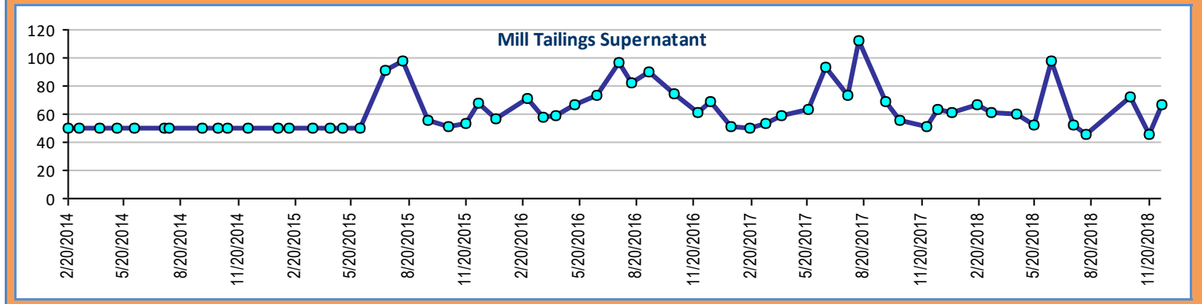


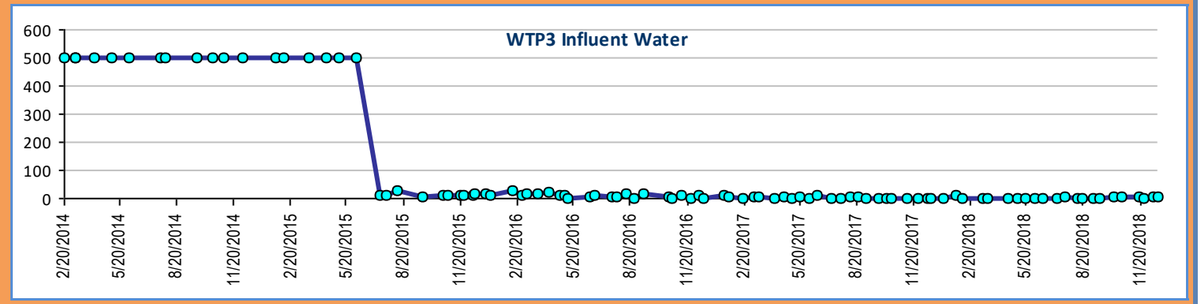


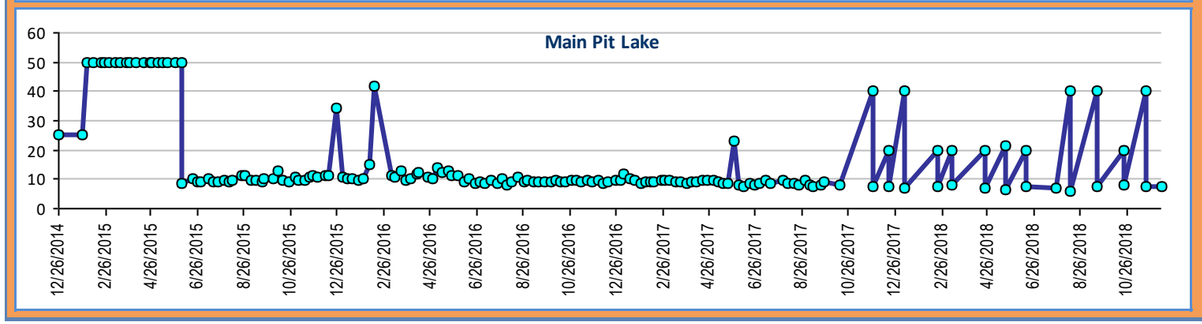


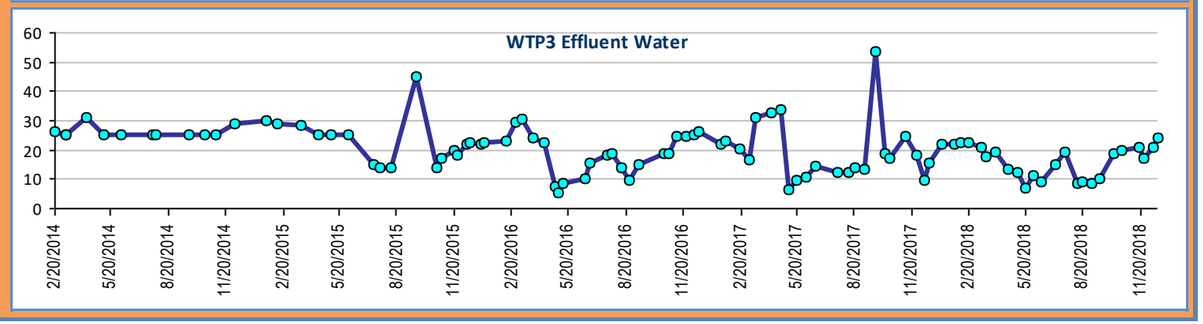








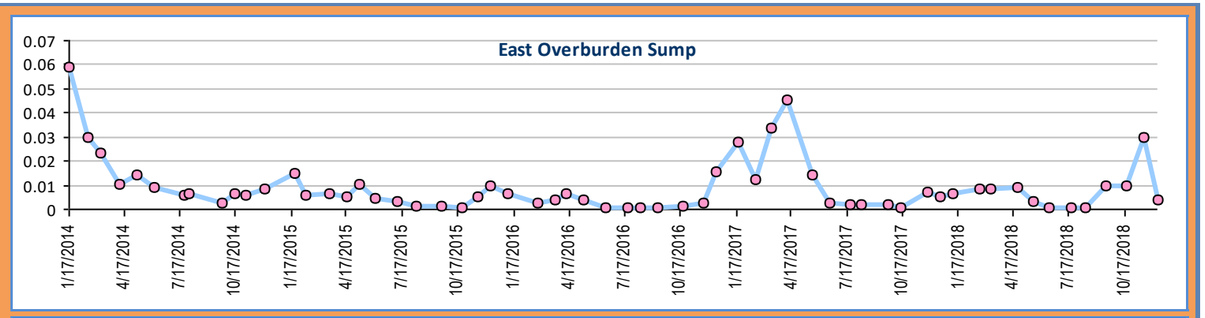


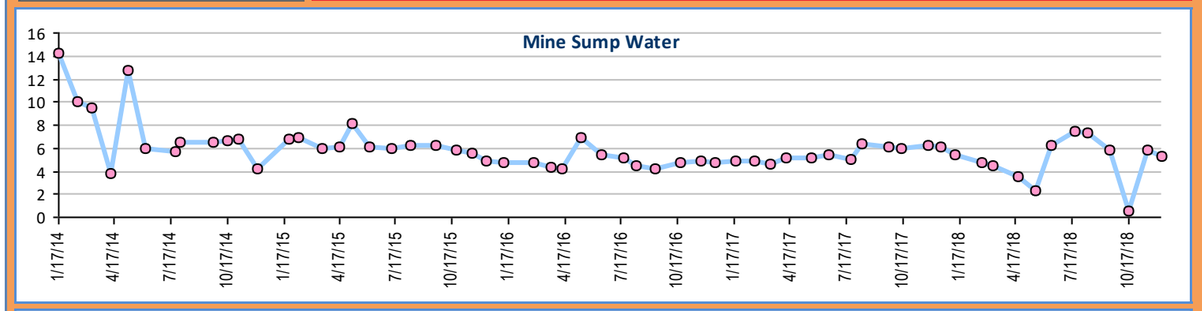


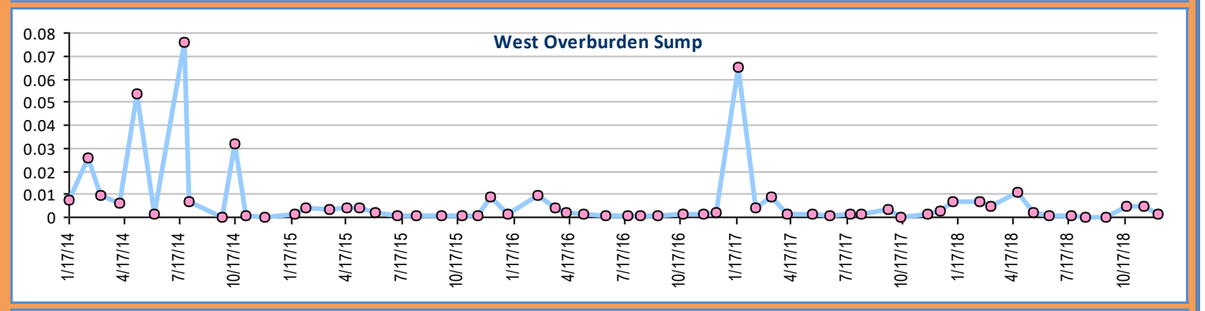
RED DOG MINE

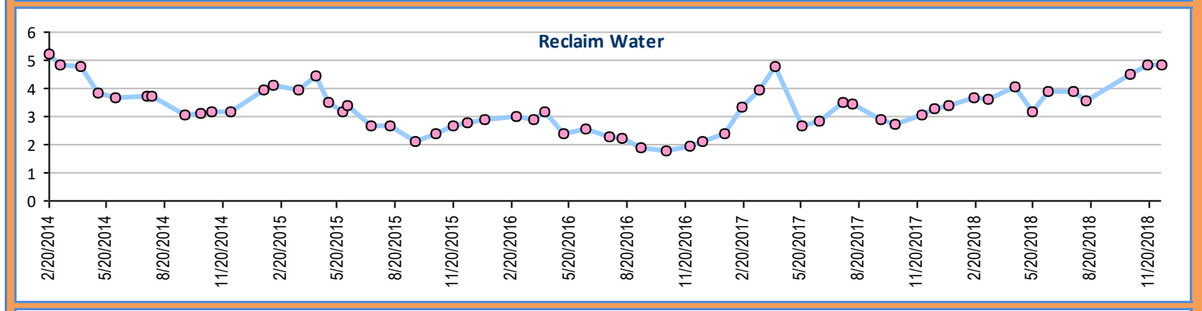
Mine Water Monitoring - Water Quality Profile II, Trend Charts

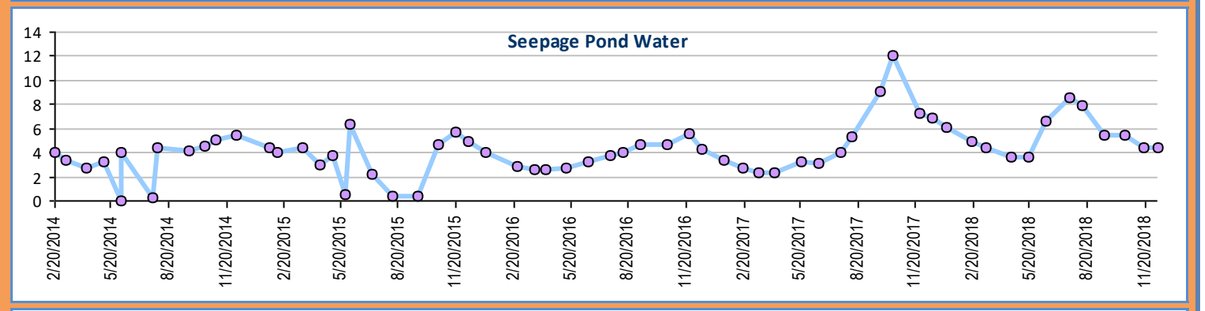
Cadmium, dissolved, units mg/L

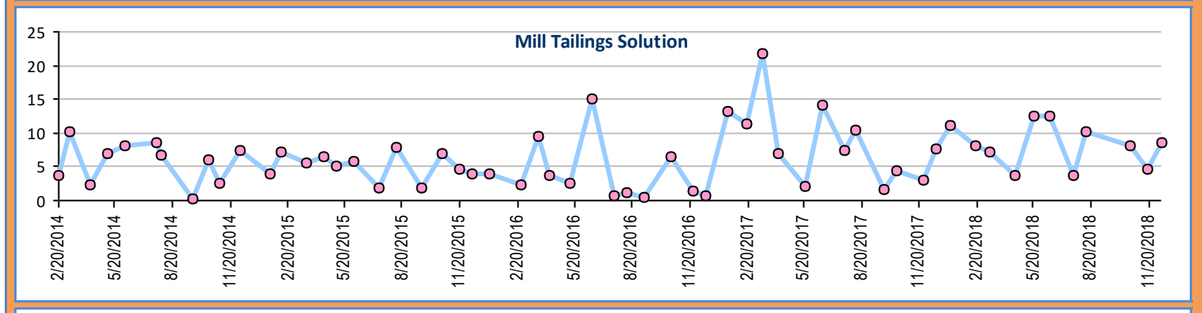


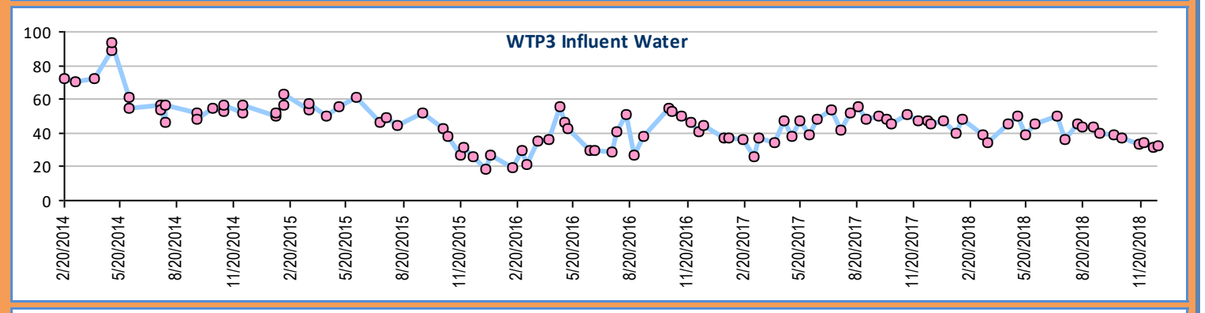


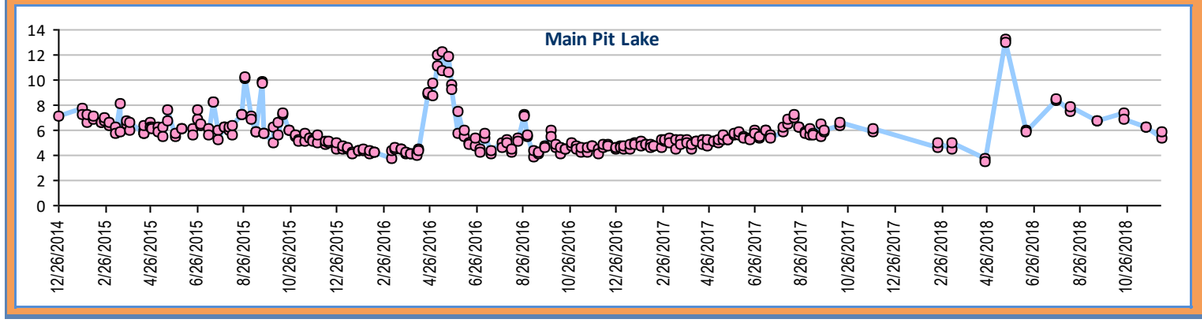


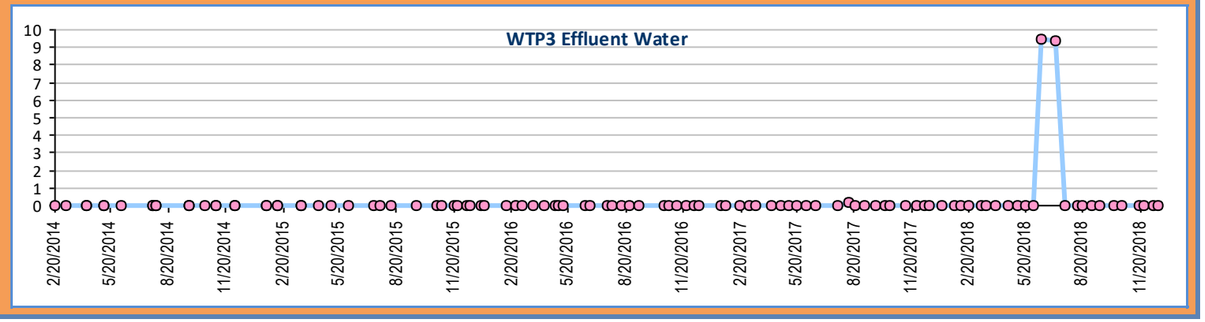








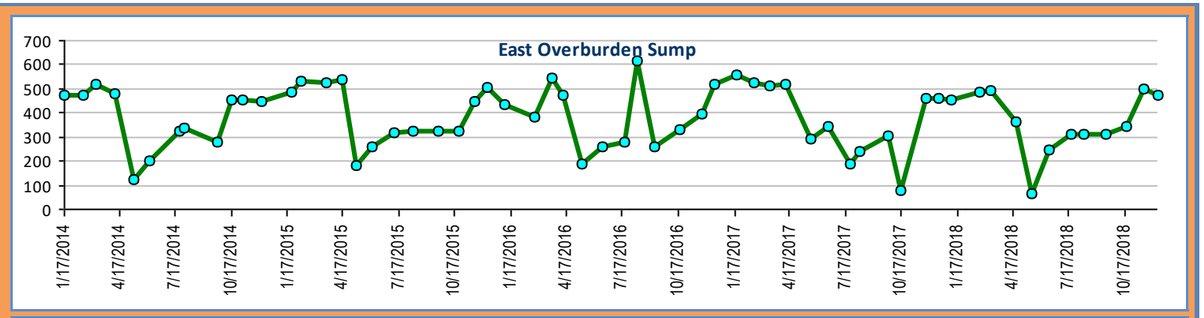


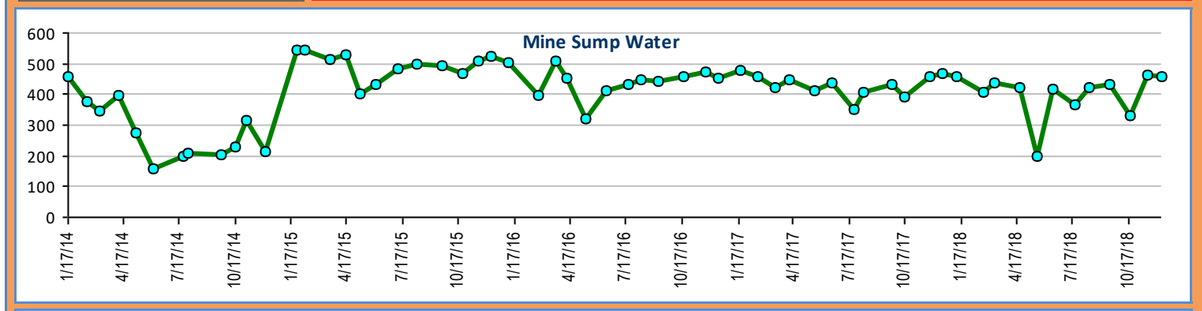


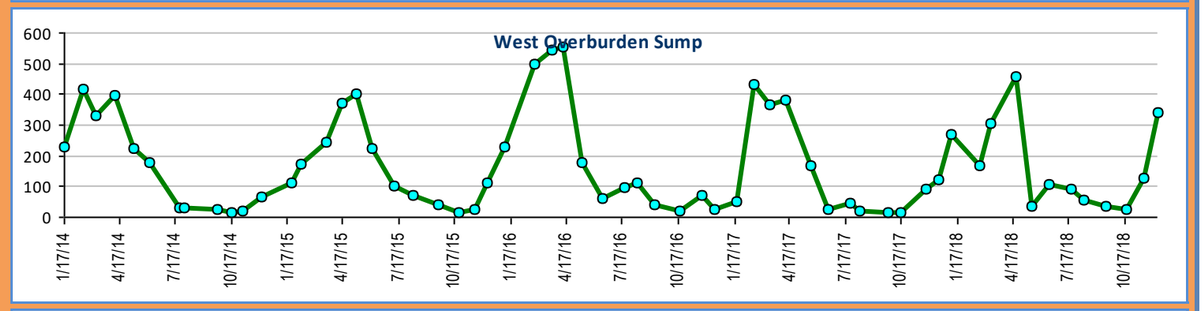
RED DOG MINE

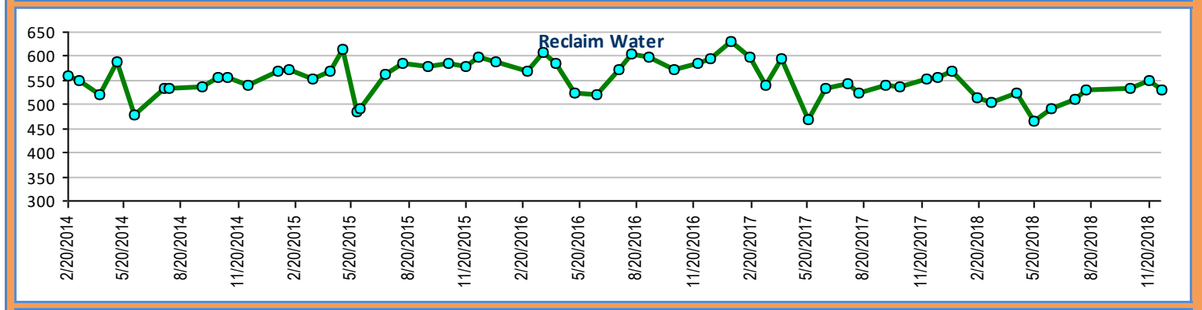
Mine Water Monitoring - Water Quality Profile II, Trend Charts

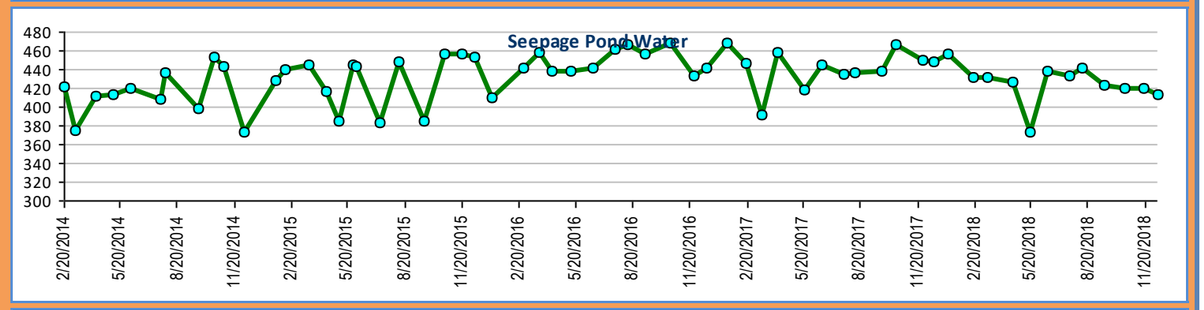
Calcium, dissolved, units mg/L

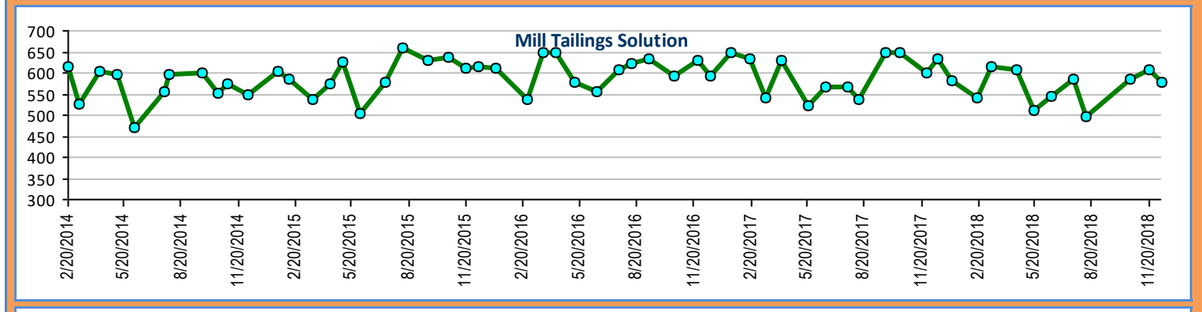


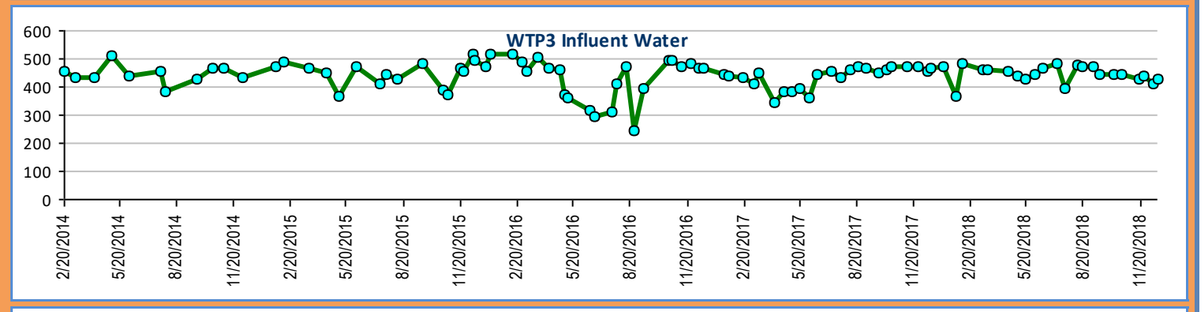


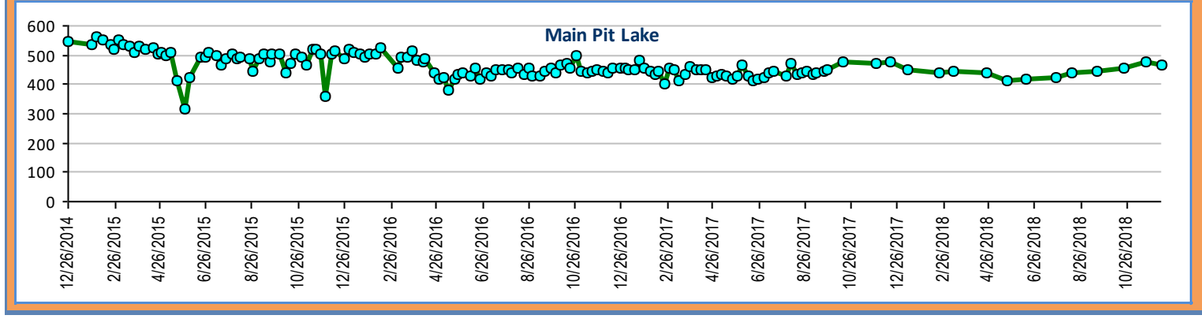


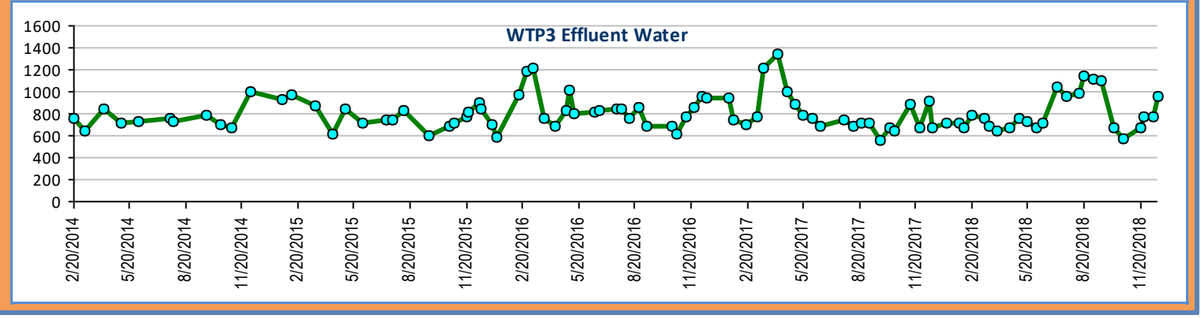








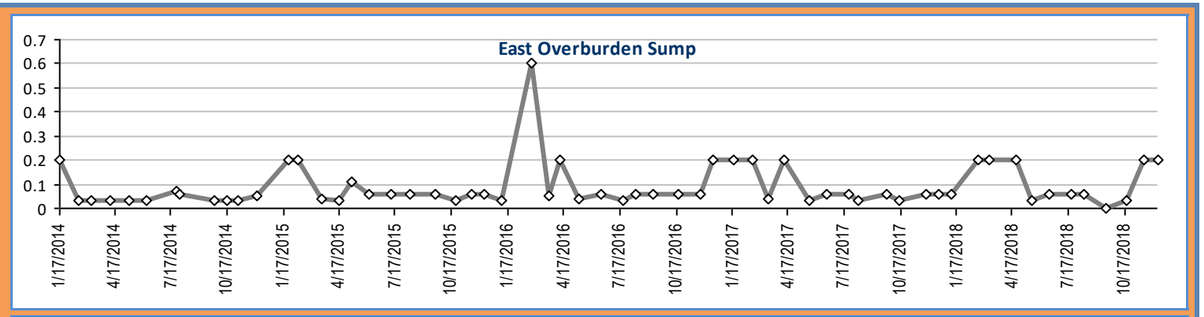


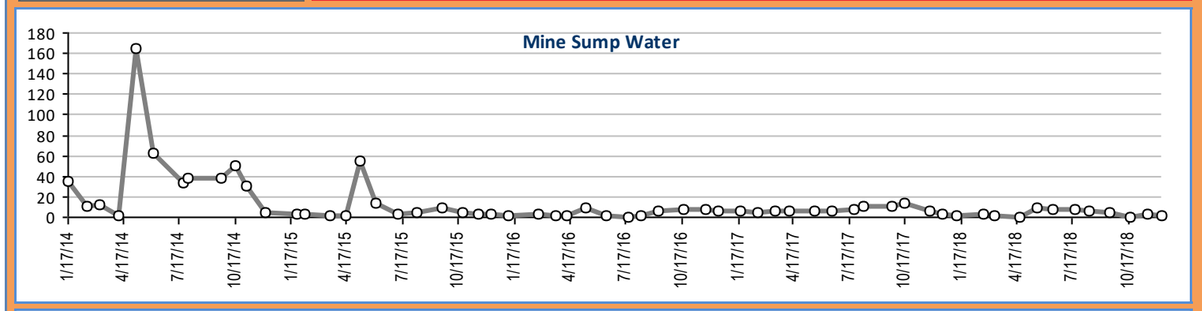


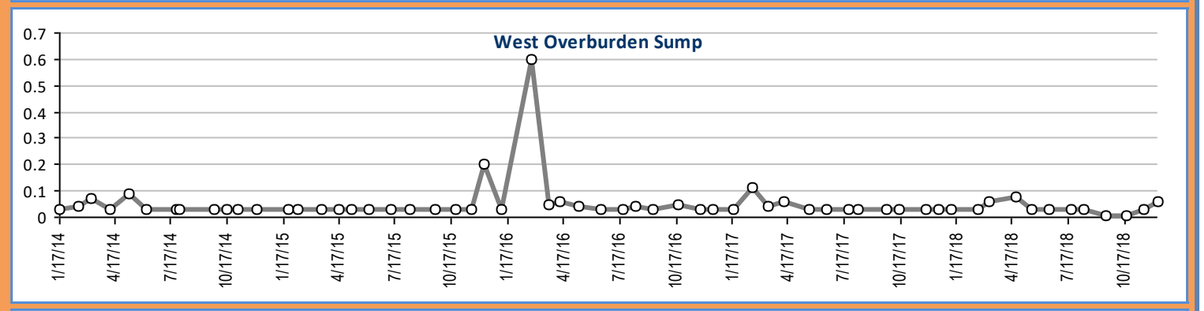
RED DOG MINE

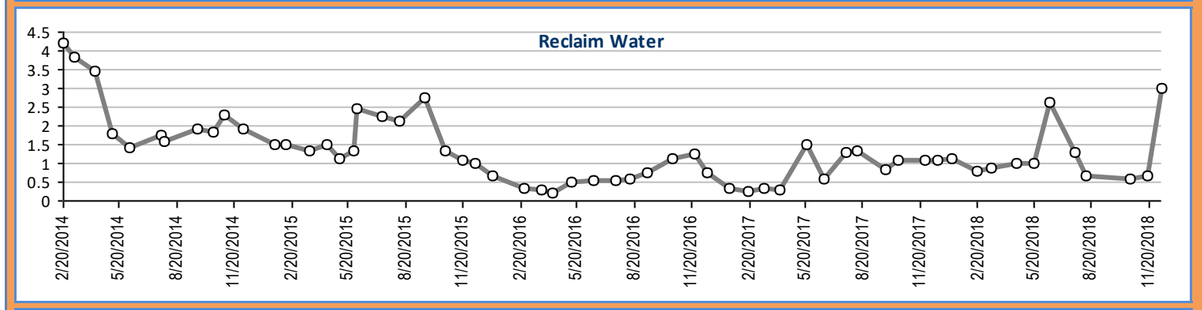
Mine Water Monitoring - Water Quality Profile II, Trend Charts

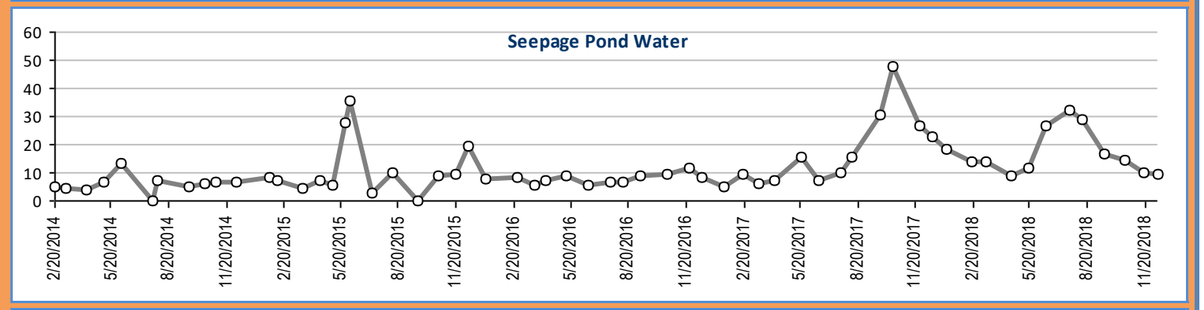
Aluminum, dissolved, units mg/L

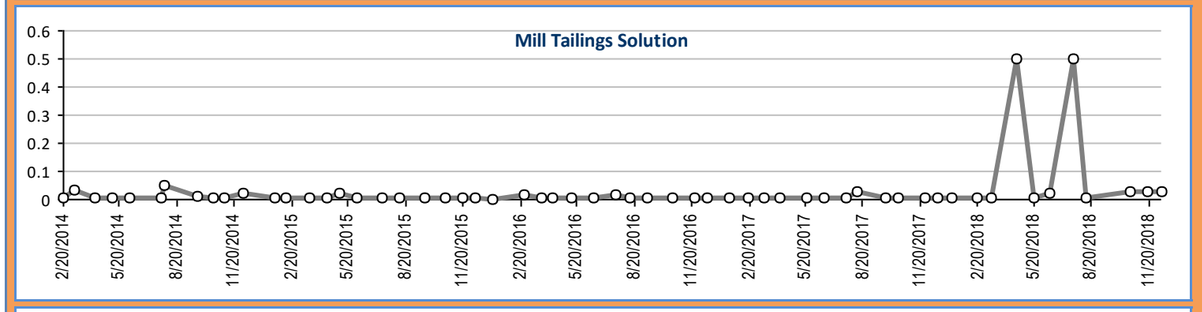


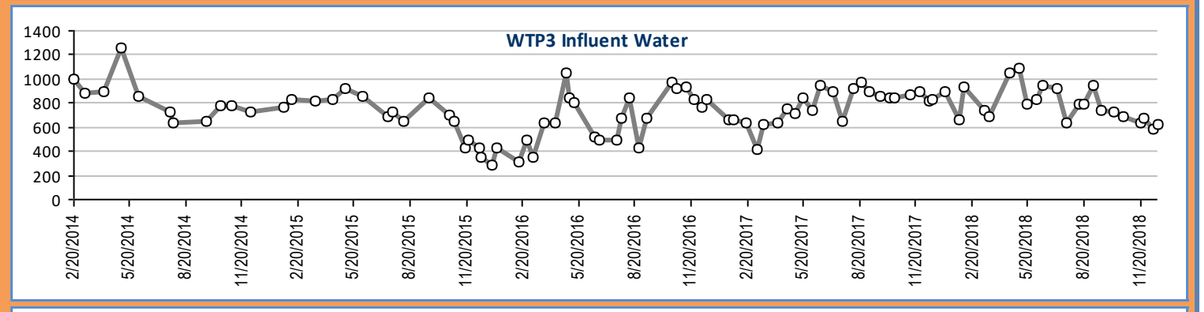


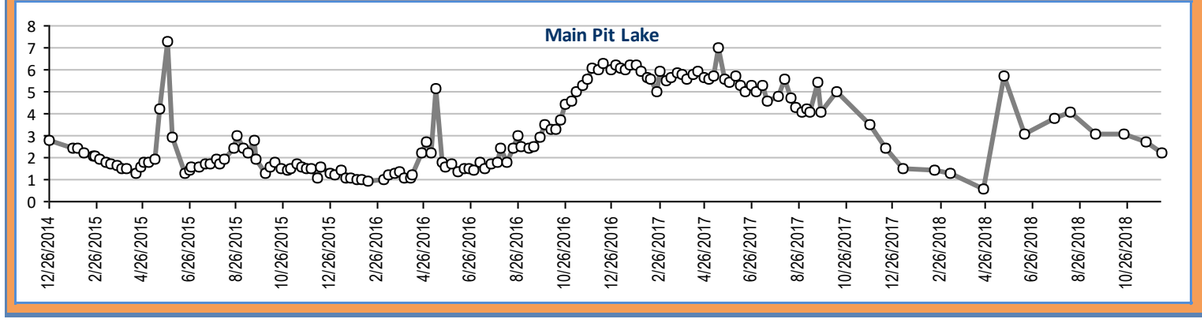


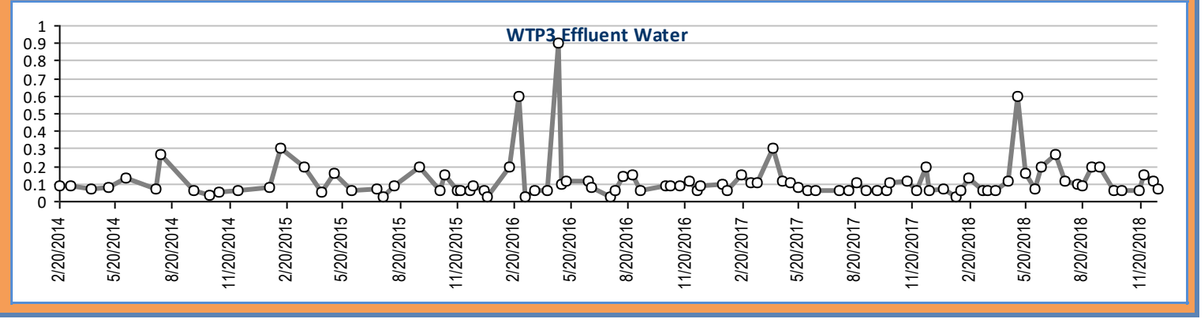








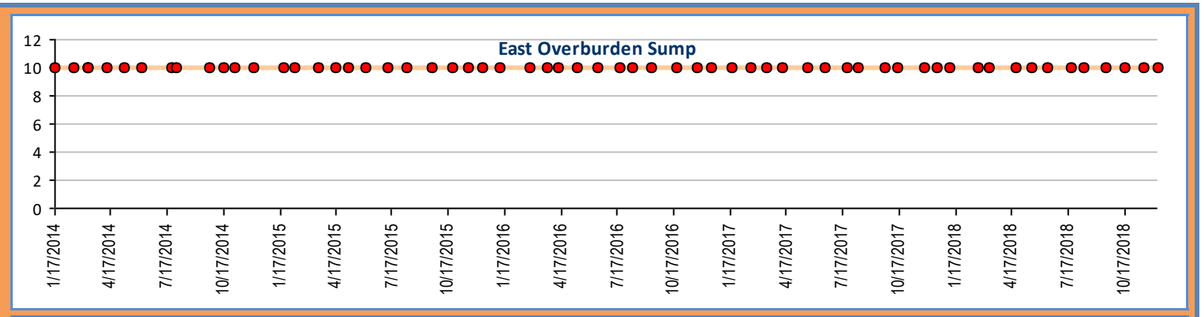


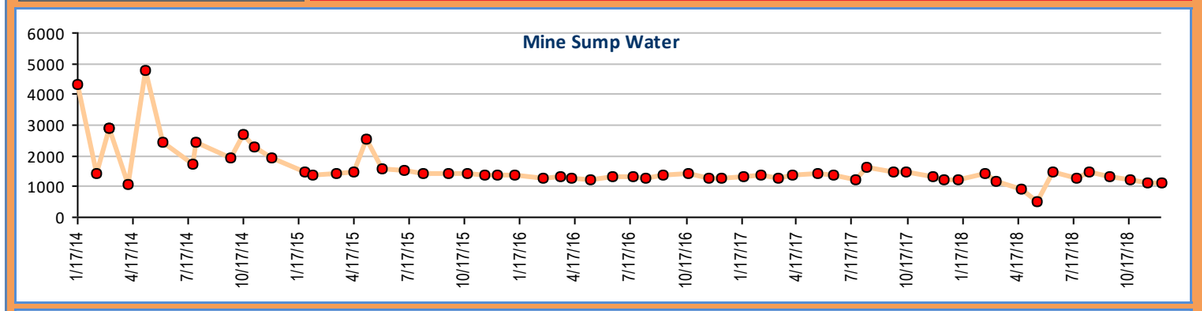


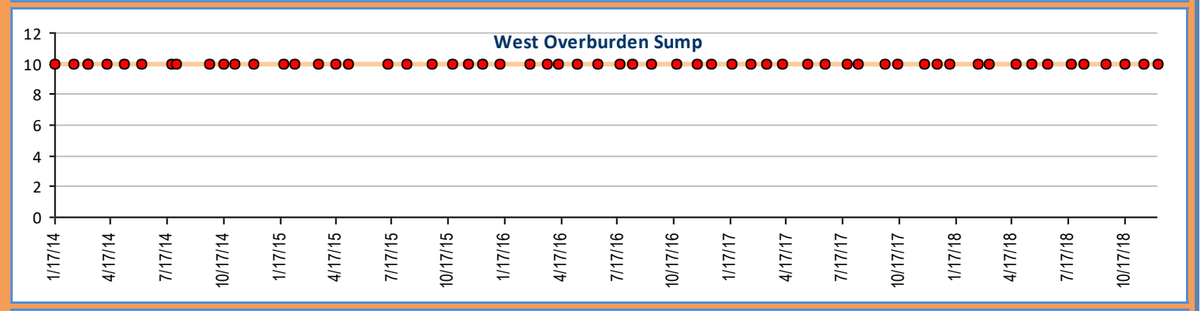
RED DOG MINE

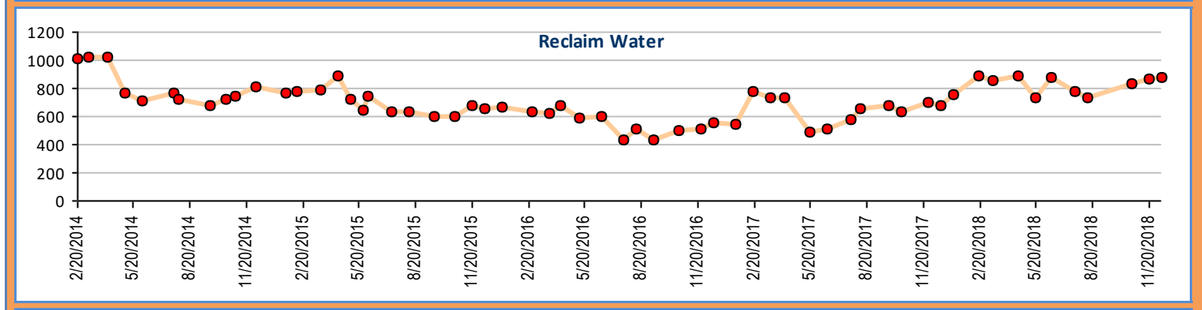
Mine Water Monitoring - Water Quality Profile II, Trend Charts

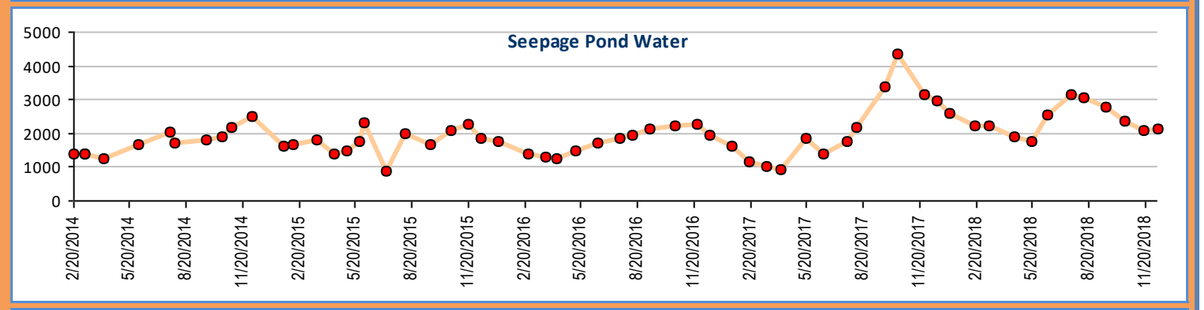
Acidity as CaCO3, units mg/L

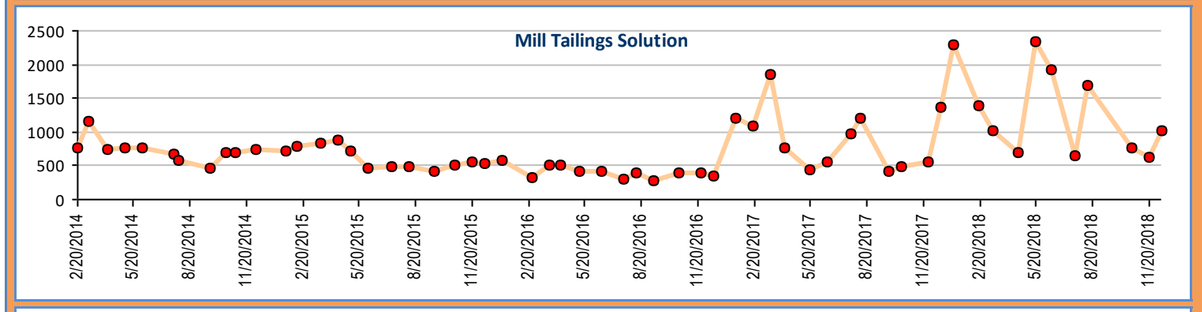


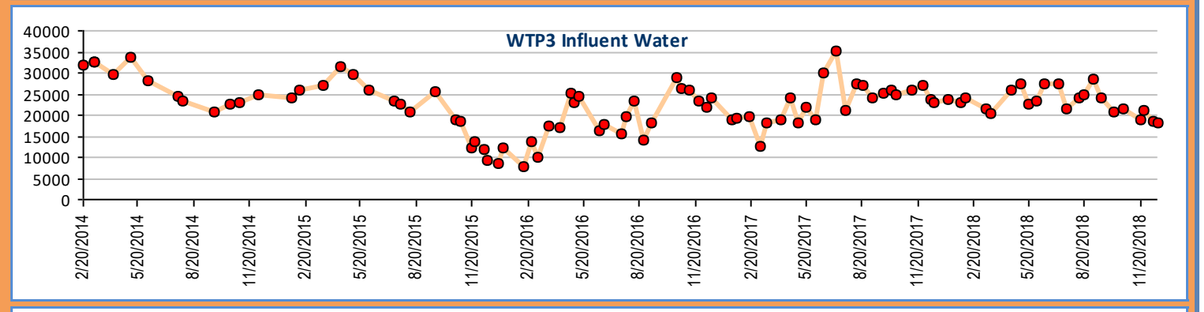


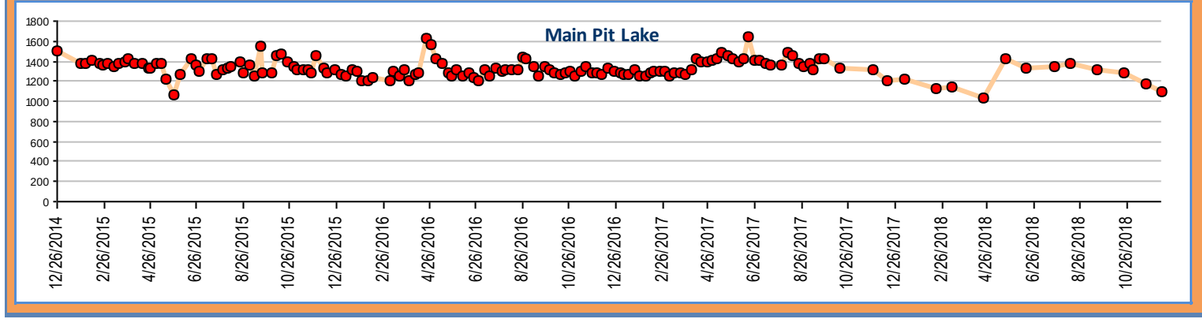


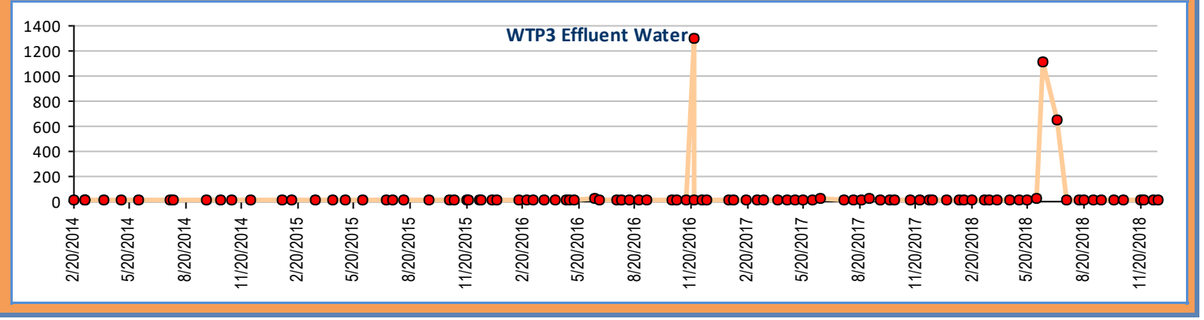












Appendix D: Water Quality Profile I Charts – Mine Drainage Monitoring Stations

RED DOG MINE

Water Monitoring Drainage
Water Quality Profile I , 5-Year Trend Charts

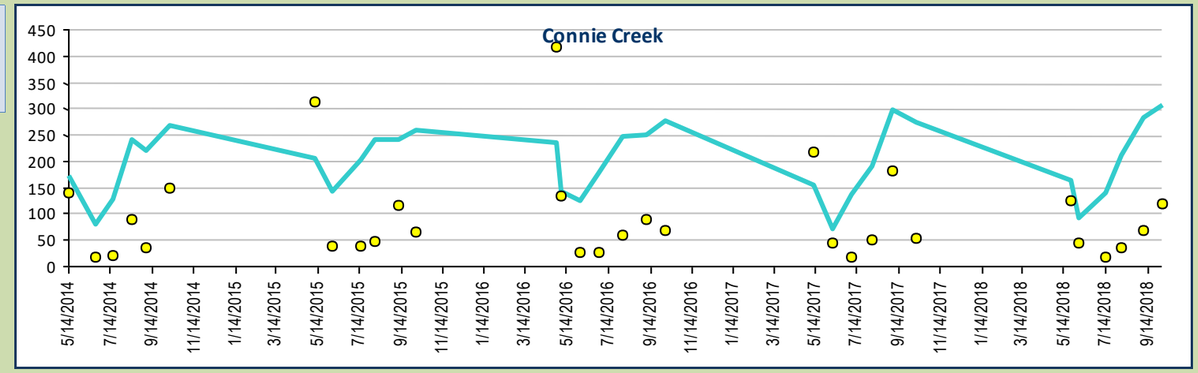
Zinc, Total Recoverable, units ug/L

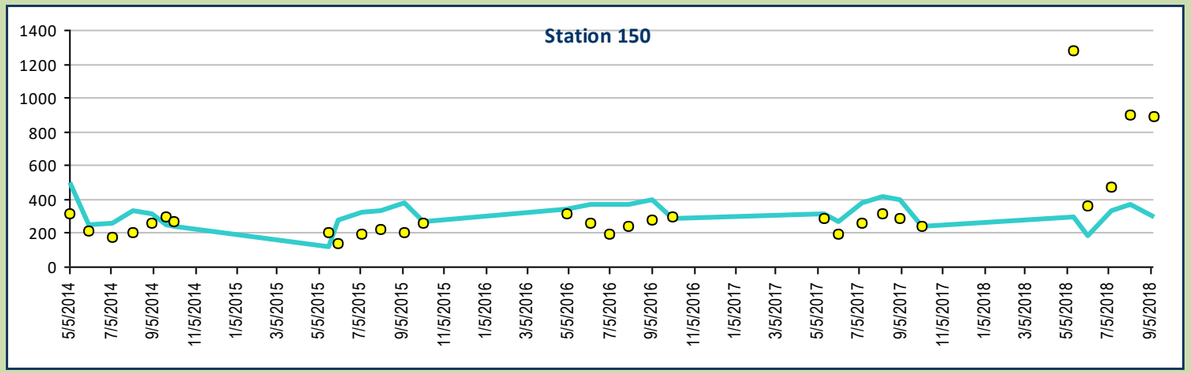
Aquatic Life - Fresh Water Acute WQS ug/L

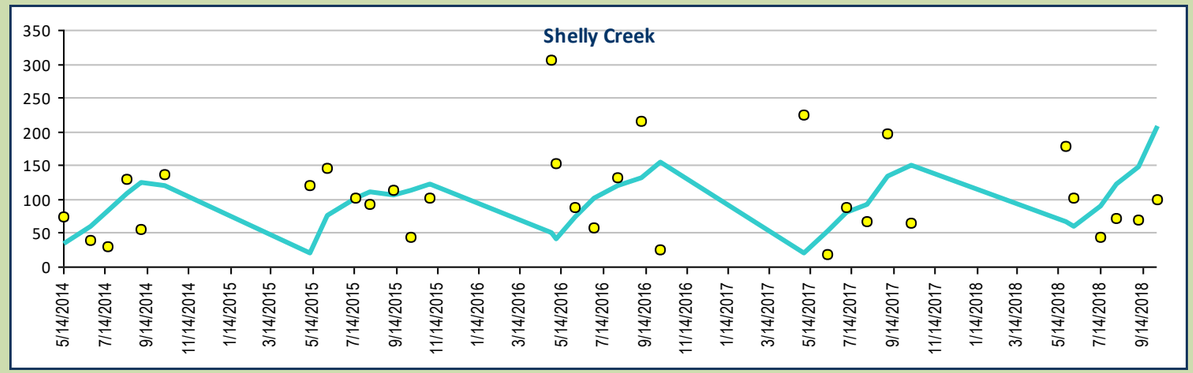
Hardness Dependent Calculation

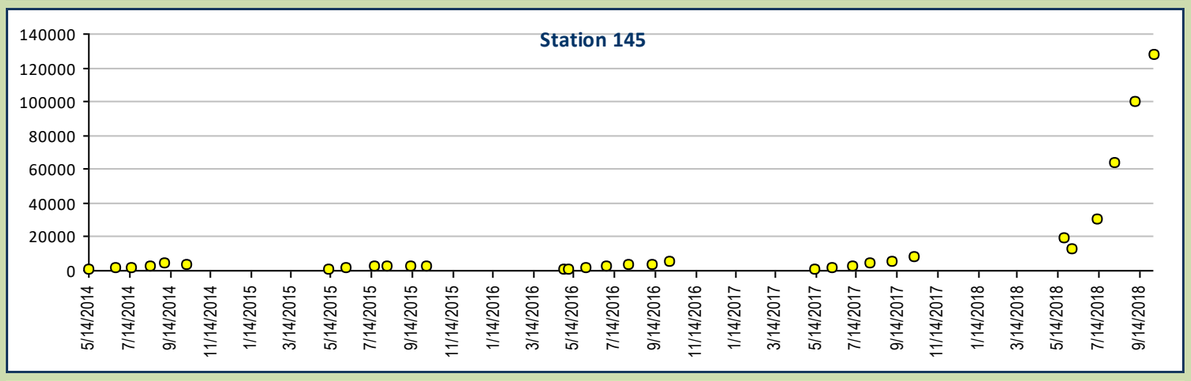
=EXP(0.8473*(LN(*hardness))+0.884)

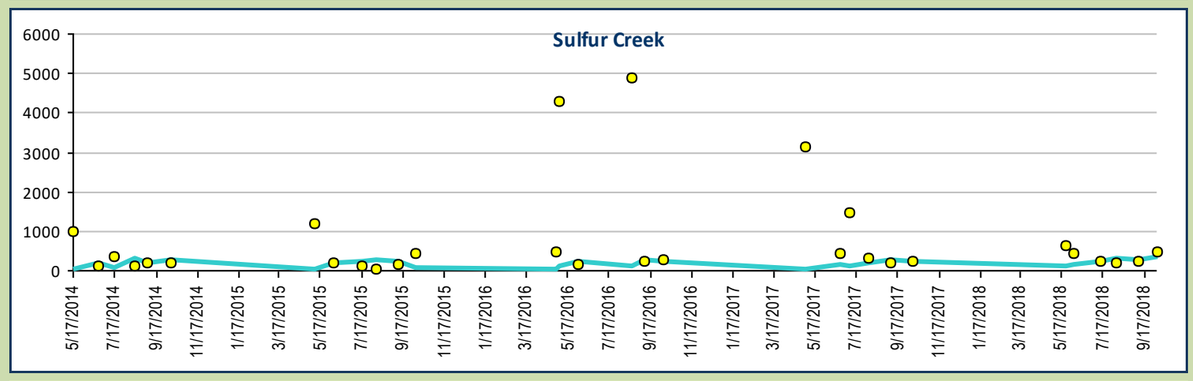
* Calculated using Standard Methods 2340B

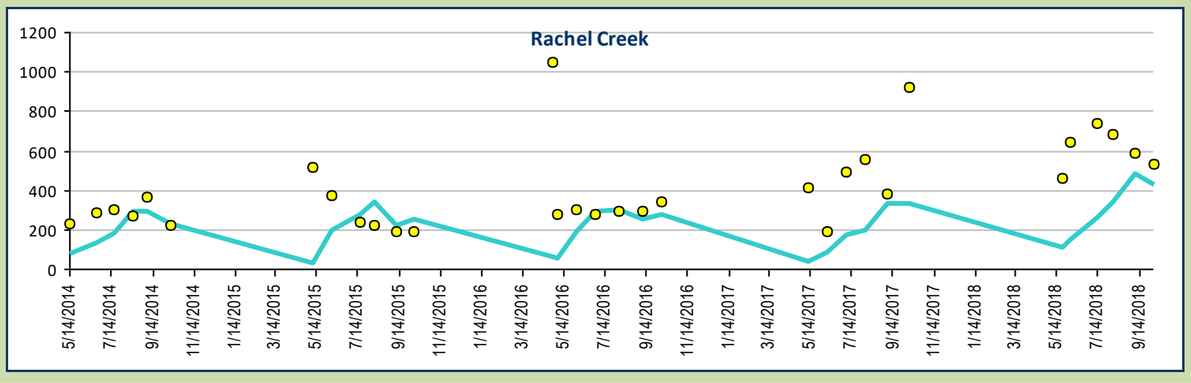


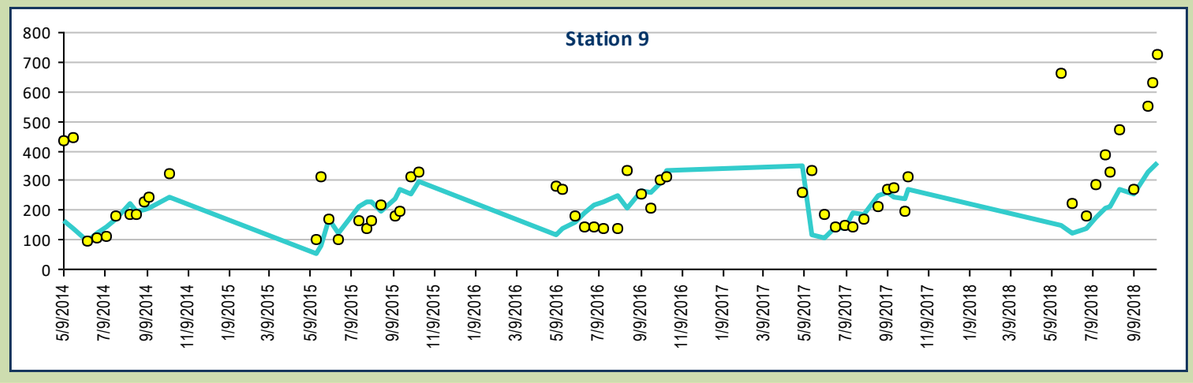






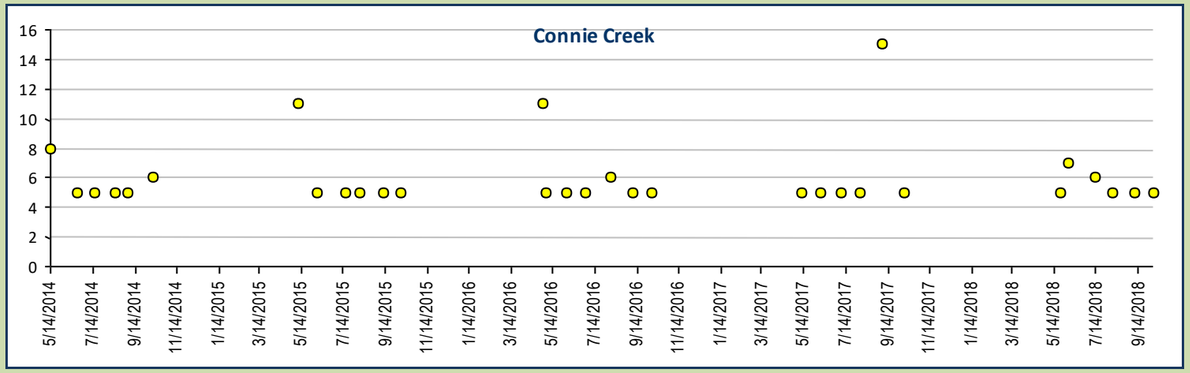


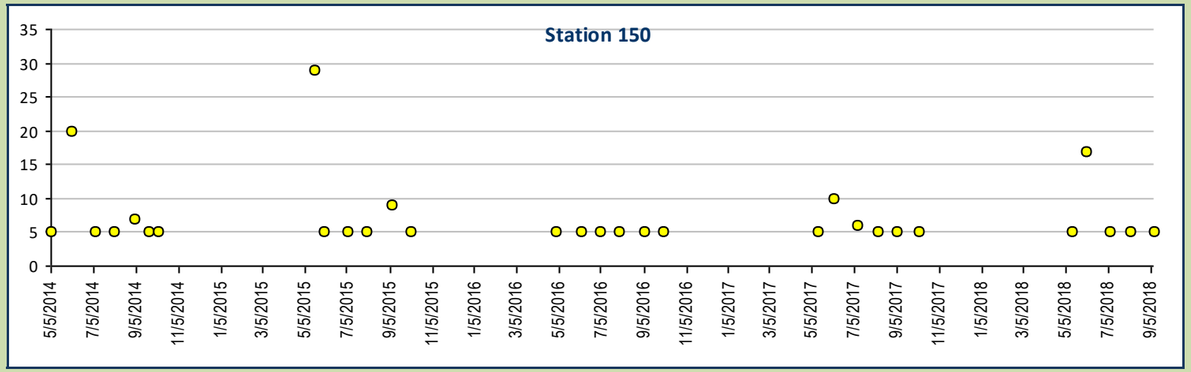


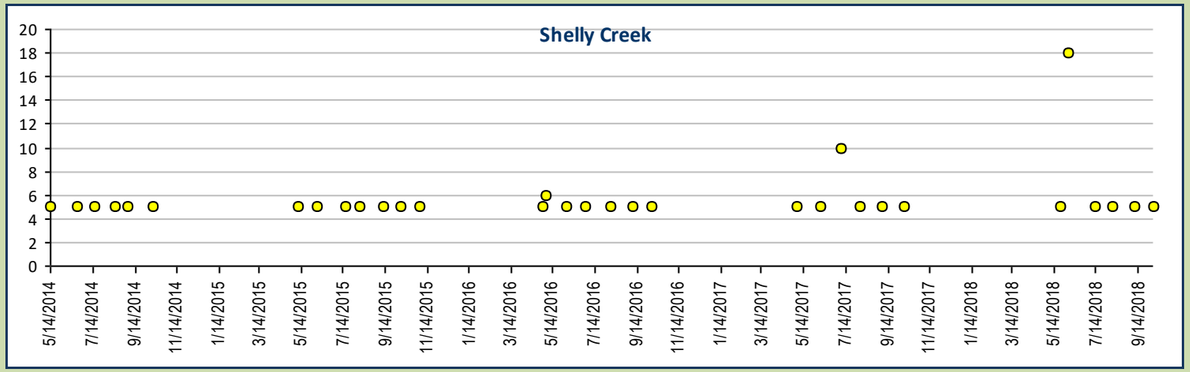


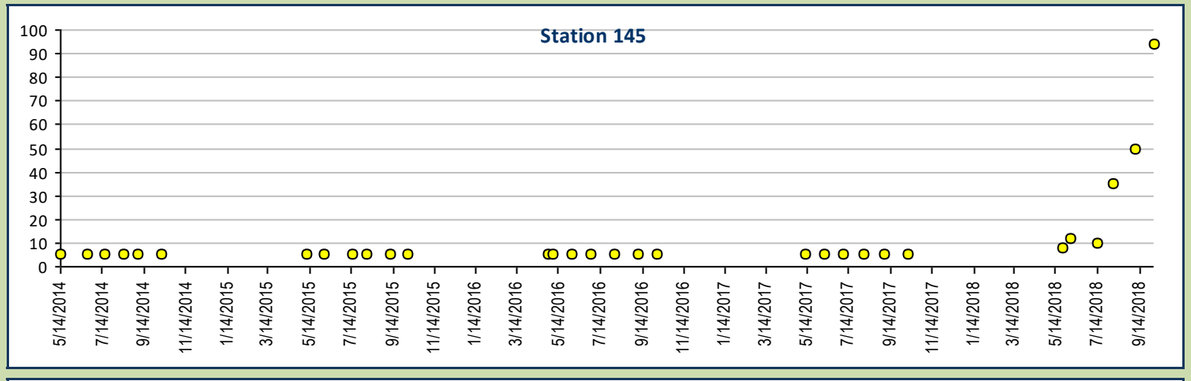
Water Monitoring Mine Drainage
Water Quality Profile I , 5-Year Trend Charts

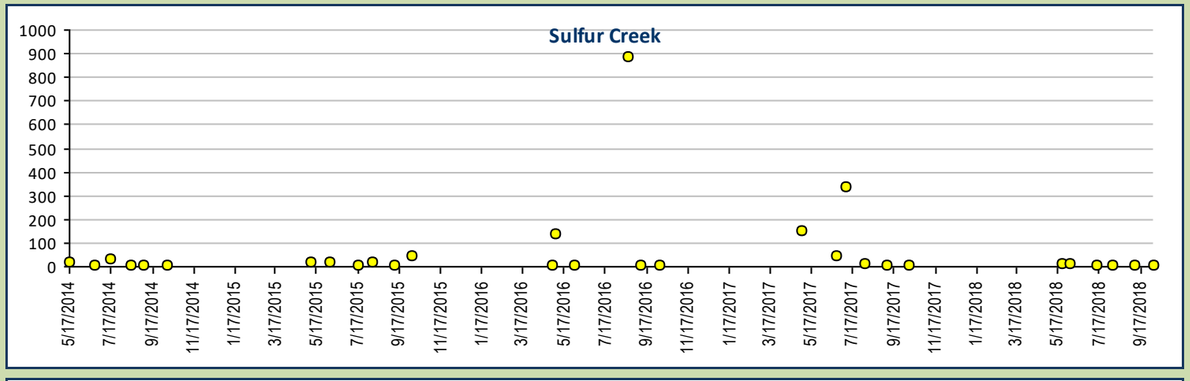
Total Suspended Solids, units mg/L

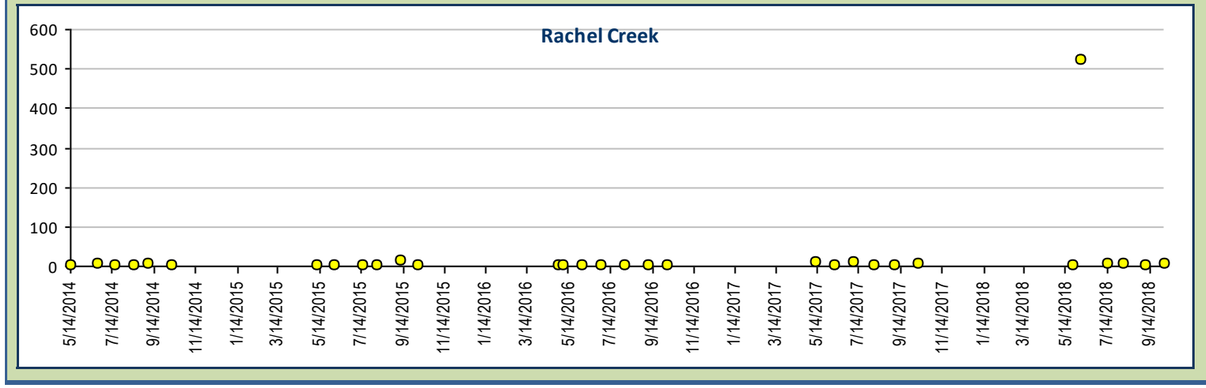


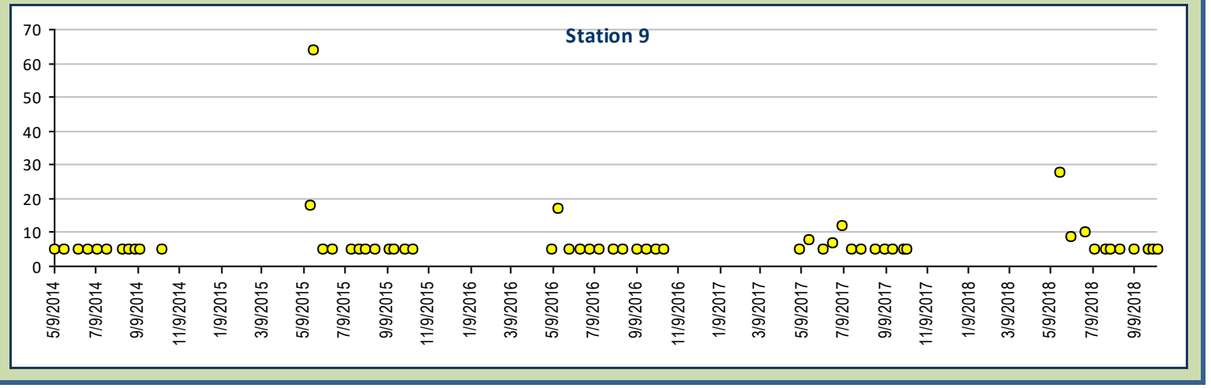










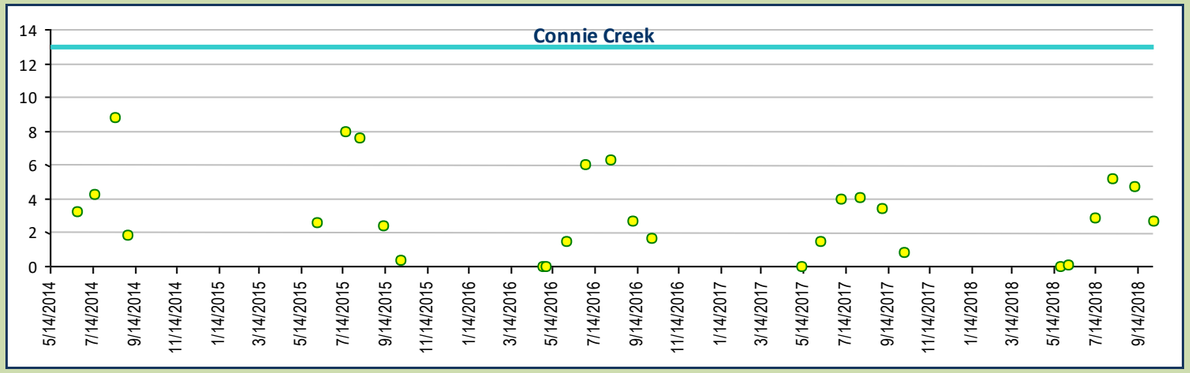


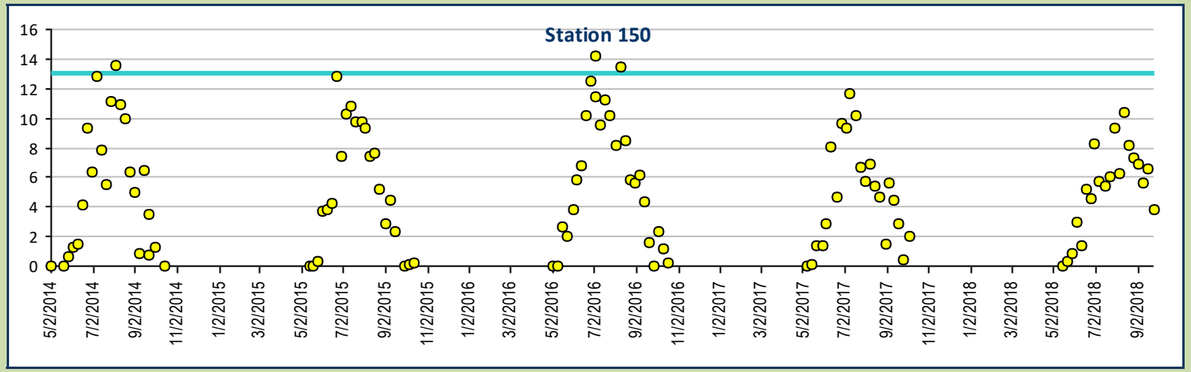
Water Monitoring Mine Drainage
Water Quality Profile I , 5-Year Trend Charts

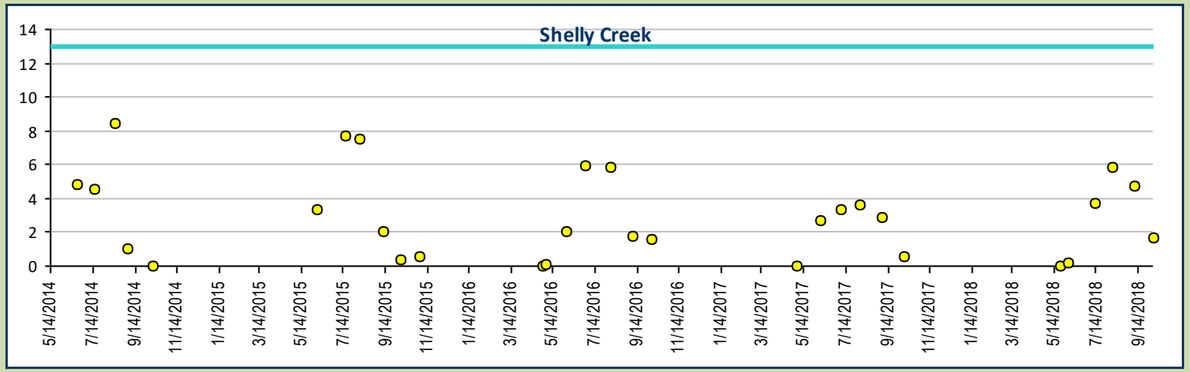
Temperature Field, Celsius

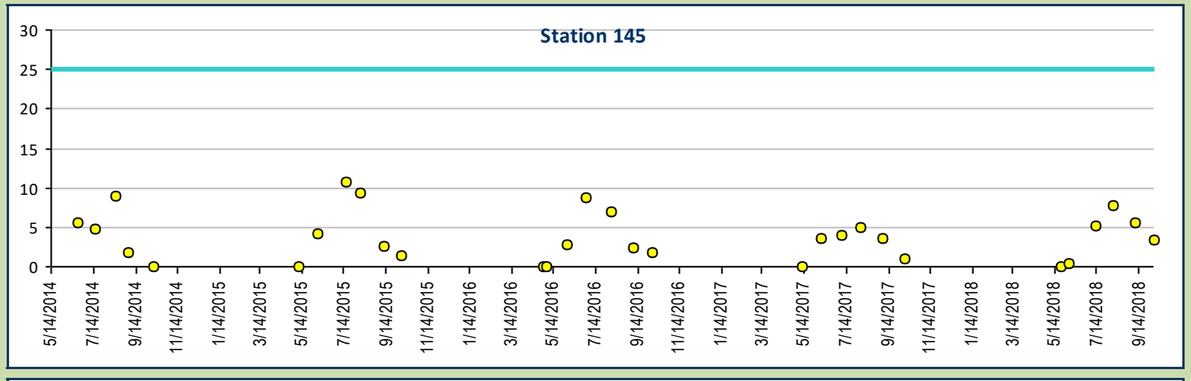
Site Specific WQS mg/L

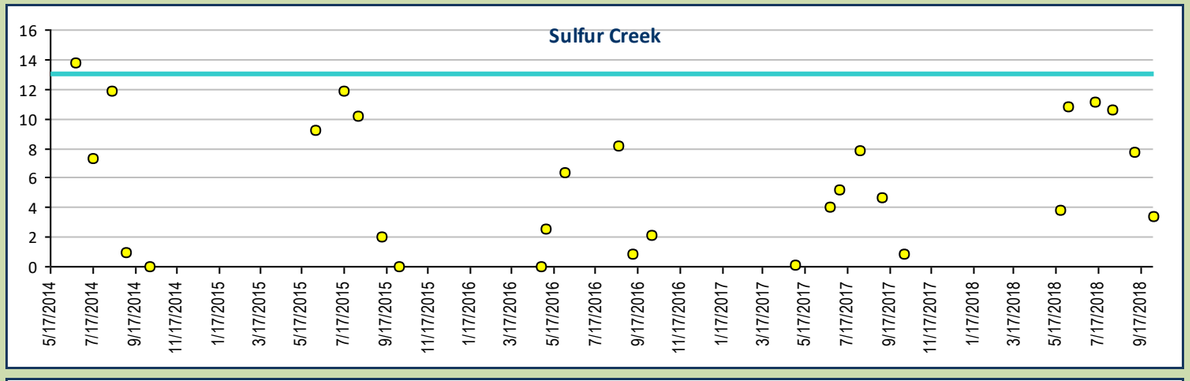
13 Celsius

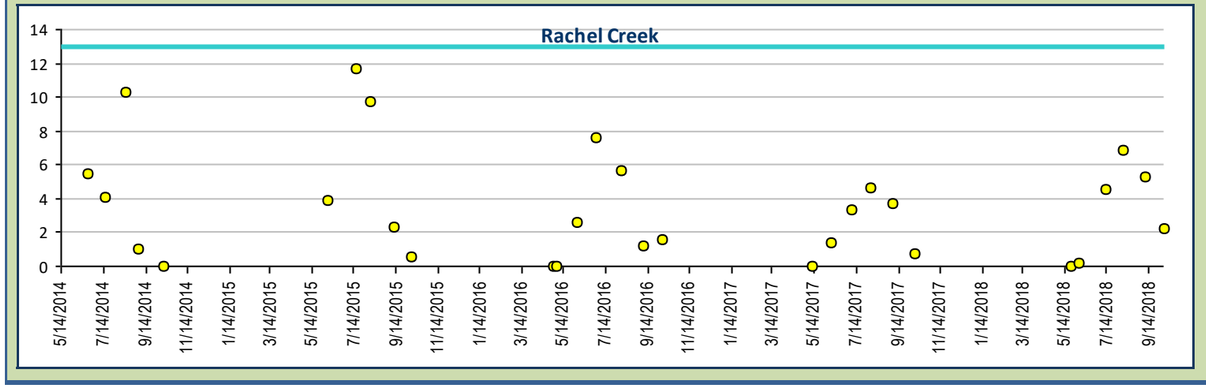


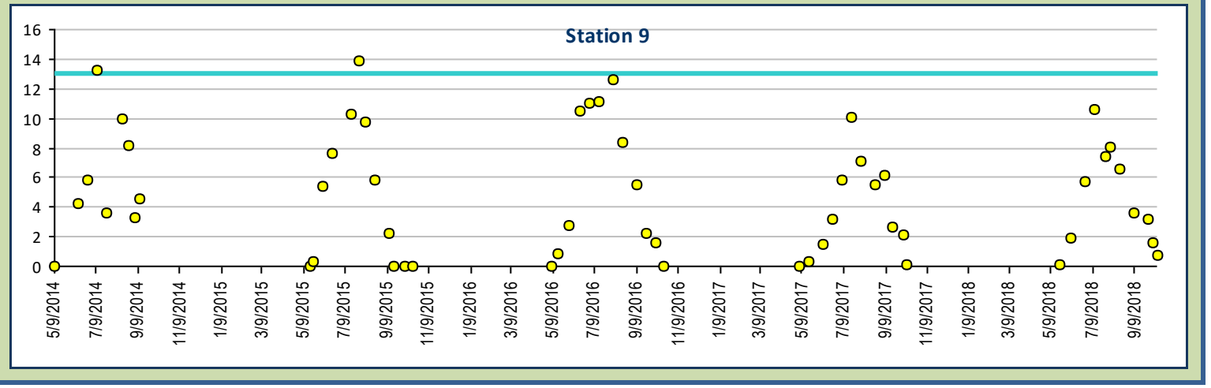










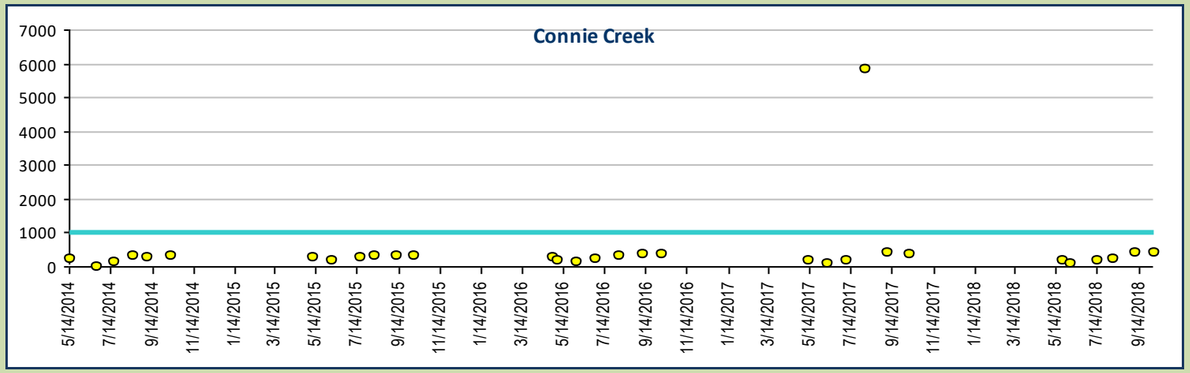


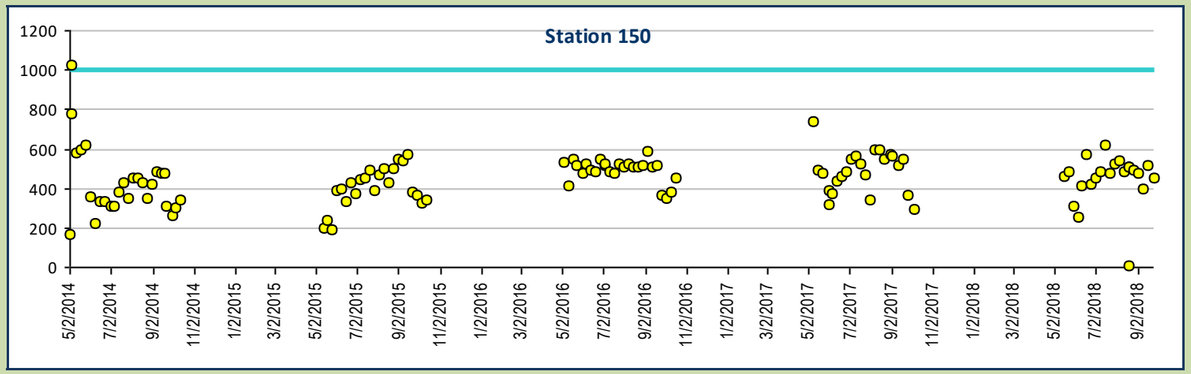
Water Monitoring Mine Drainage
Water Quality Profile I , 5-Year Trend Charts

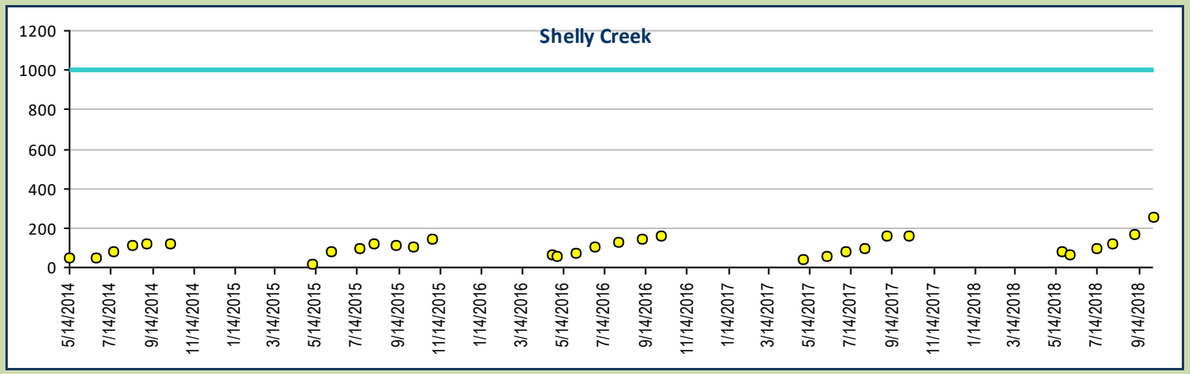
Total Dissolved Solids, units mg/L

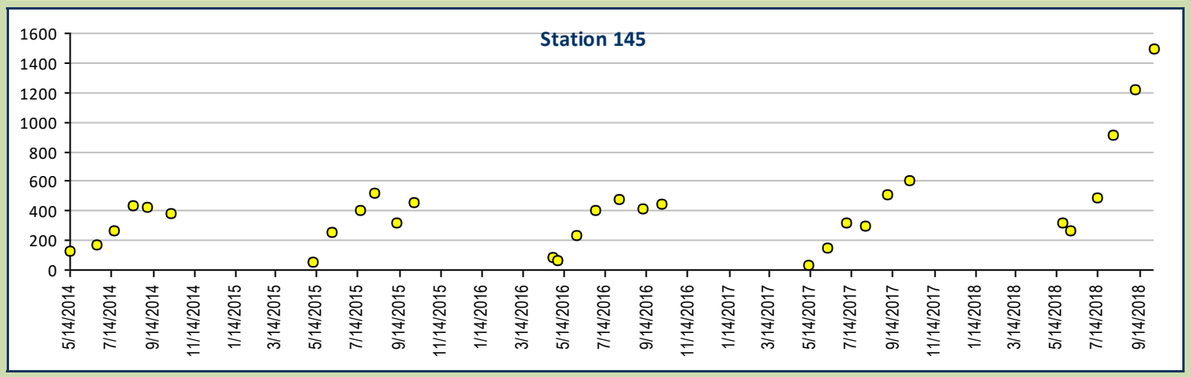
Site Specific WQS mg/L

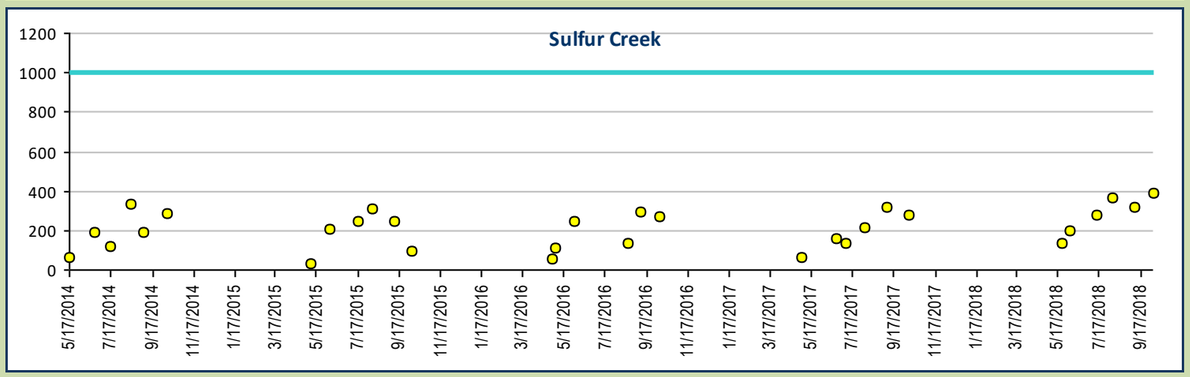
1000 mg/L

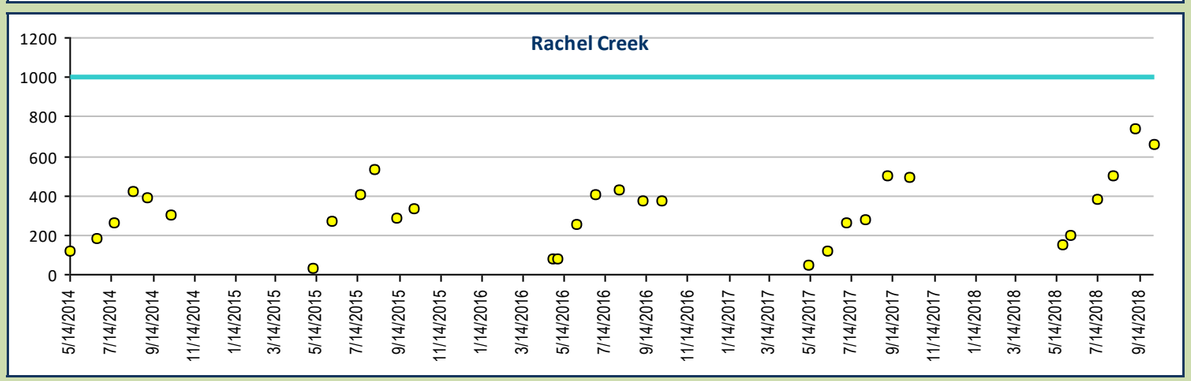


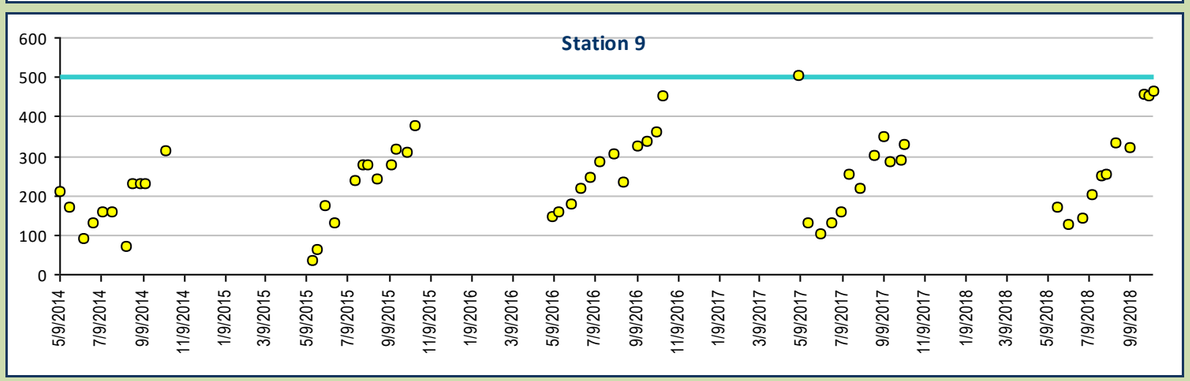








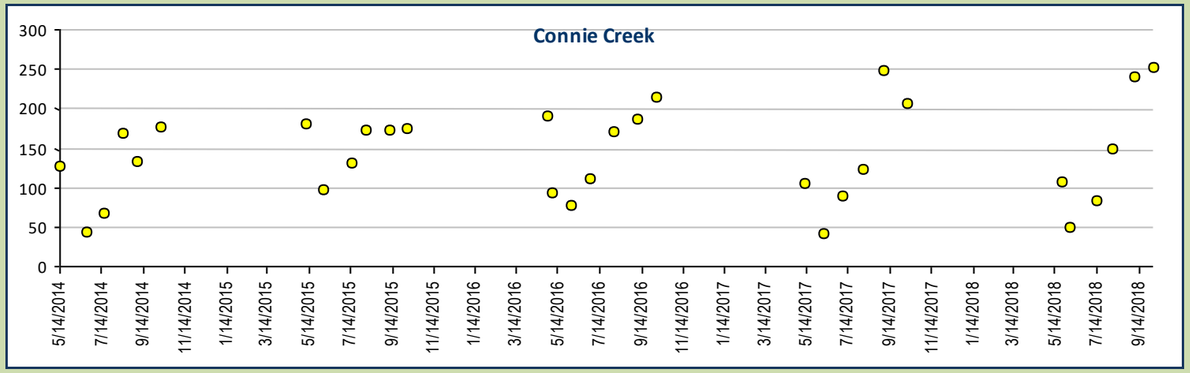


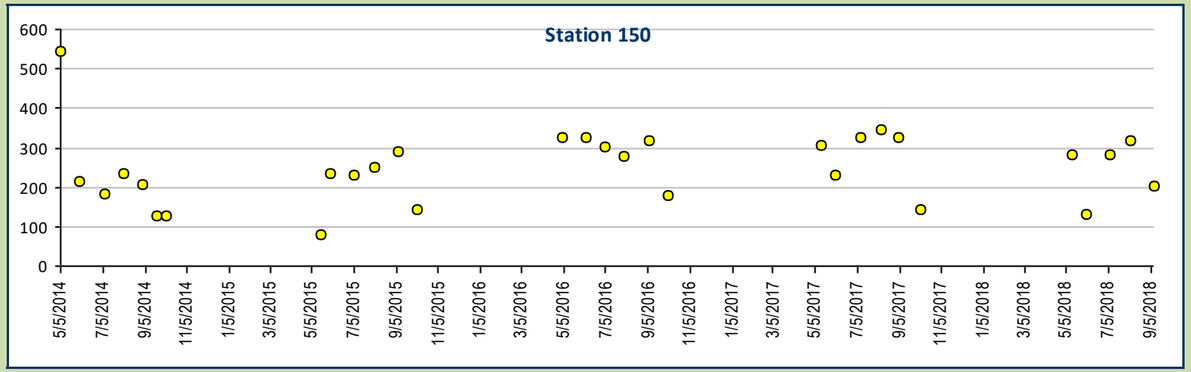


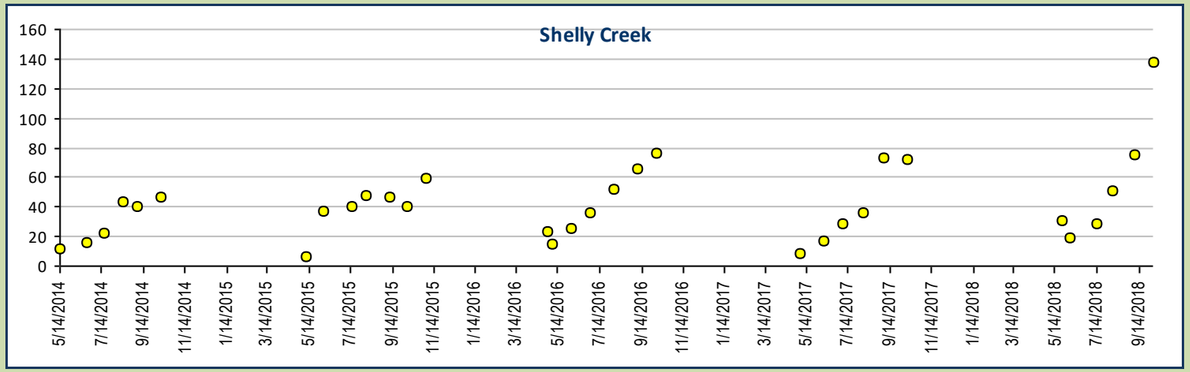
RED DOG MINE

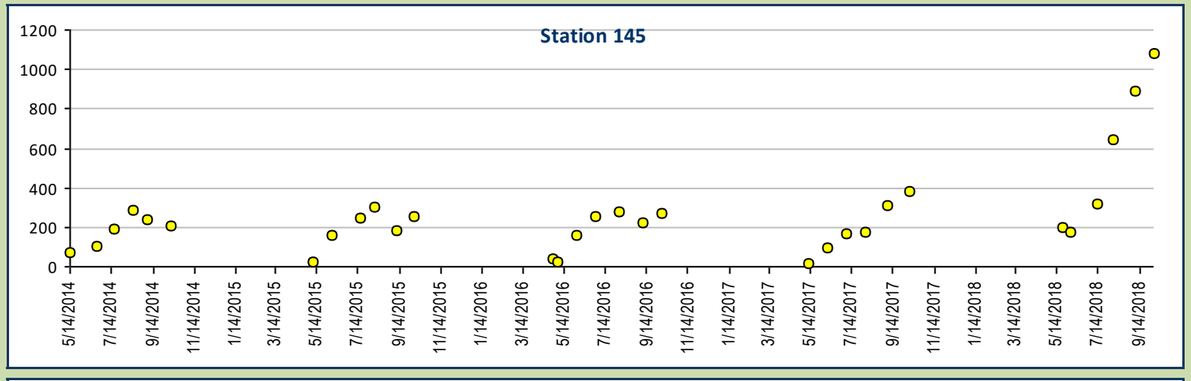
Water Monitoring Mine Drainage
Water Quality Profile I , 5-Year Trend Charts

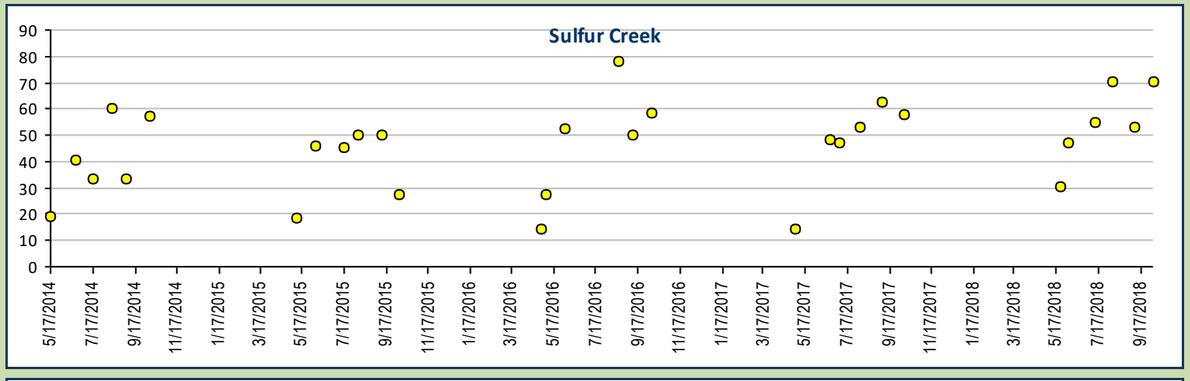
Sulfate, units mg/L

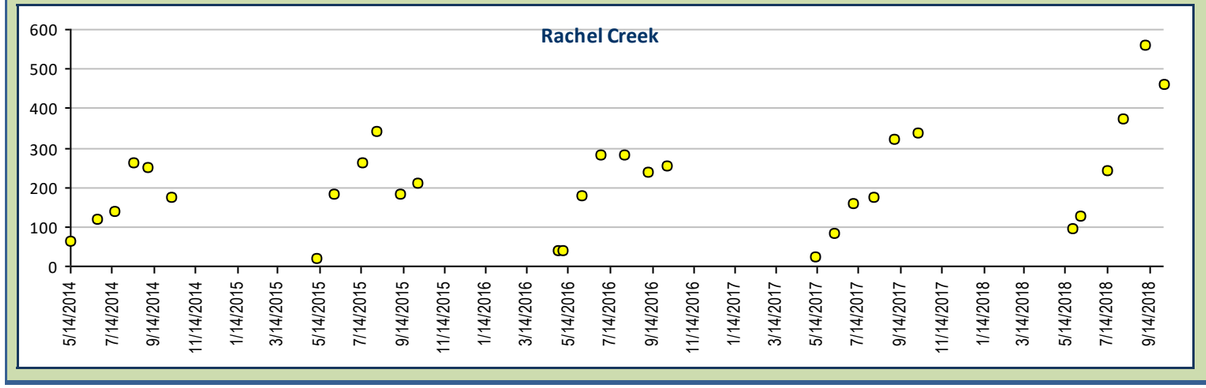


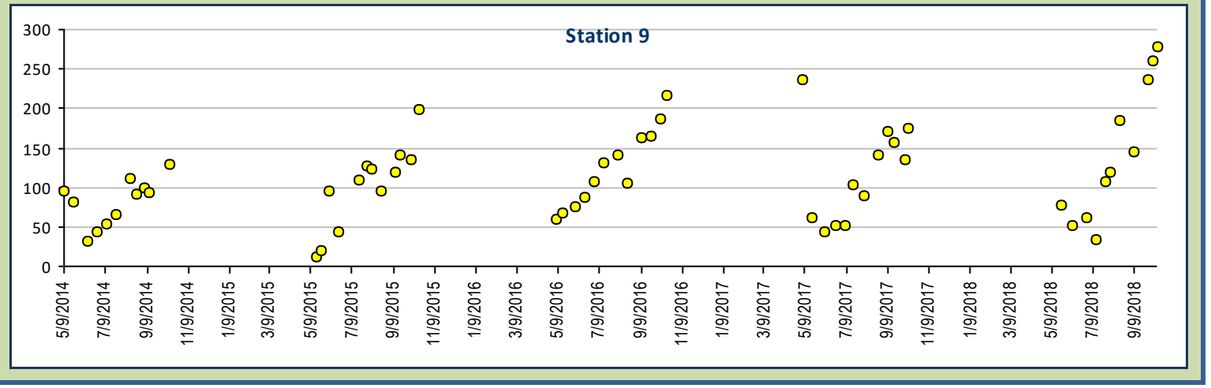










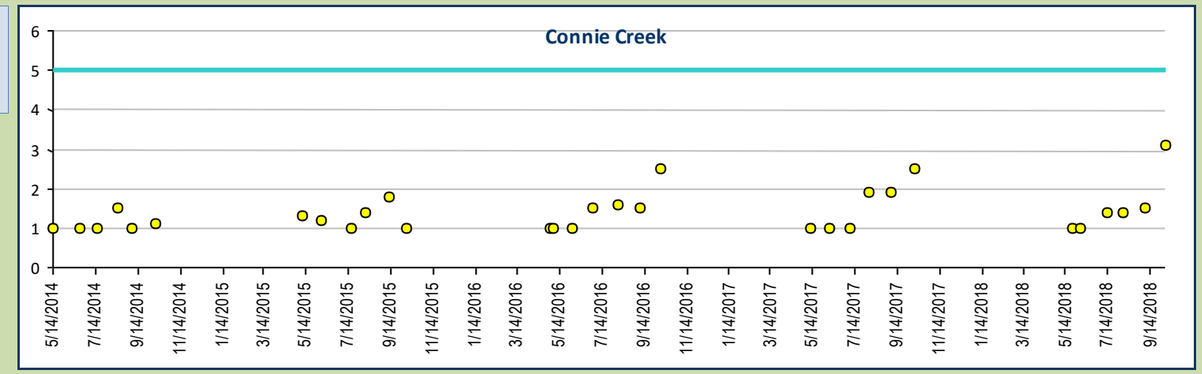


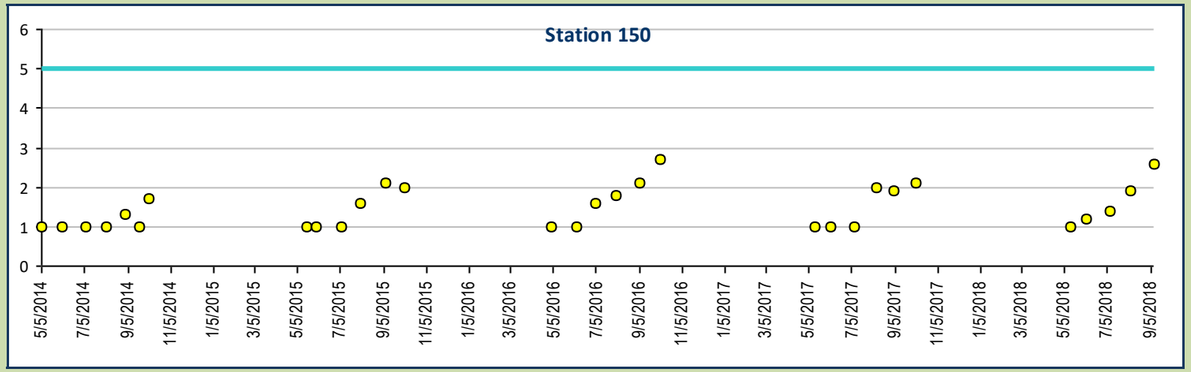
Water Monitoring Mine Drainage
Water Quality Profile I , 5-Year Trend Charts

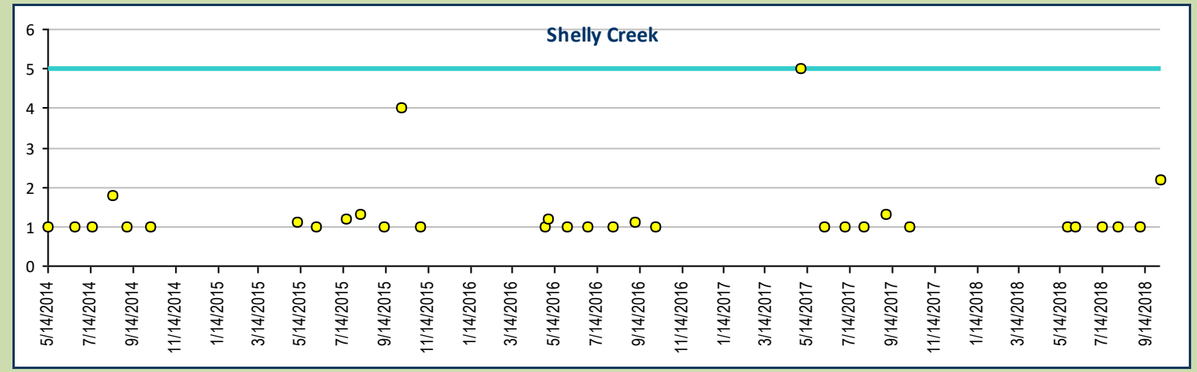
Selenium, Total Recoverable, units ug/L

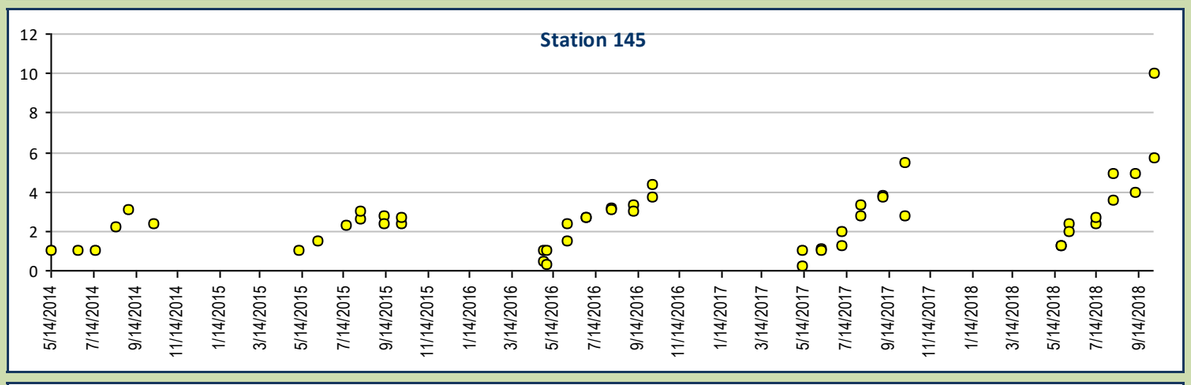
Aquatic Life - Fresh Water Chronic WQS ug/L

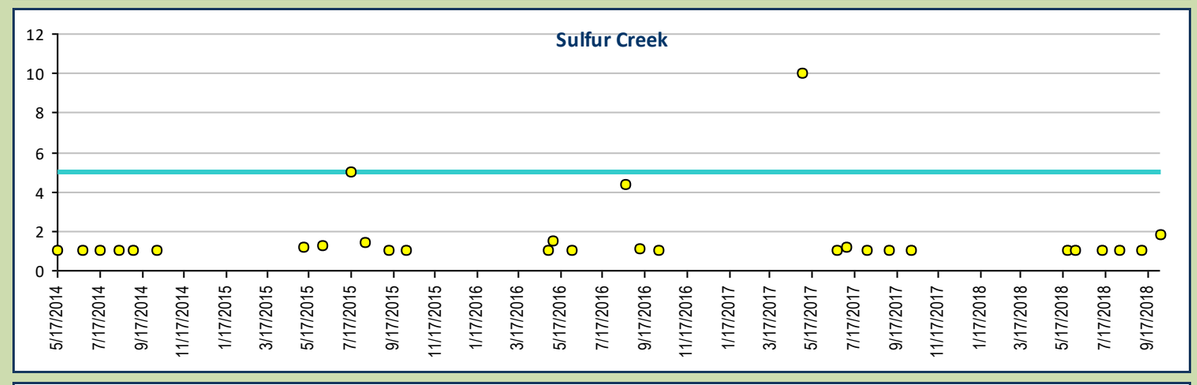
5 ug/L

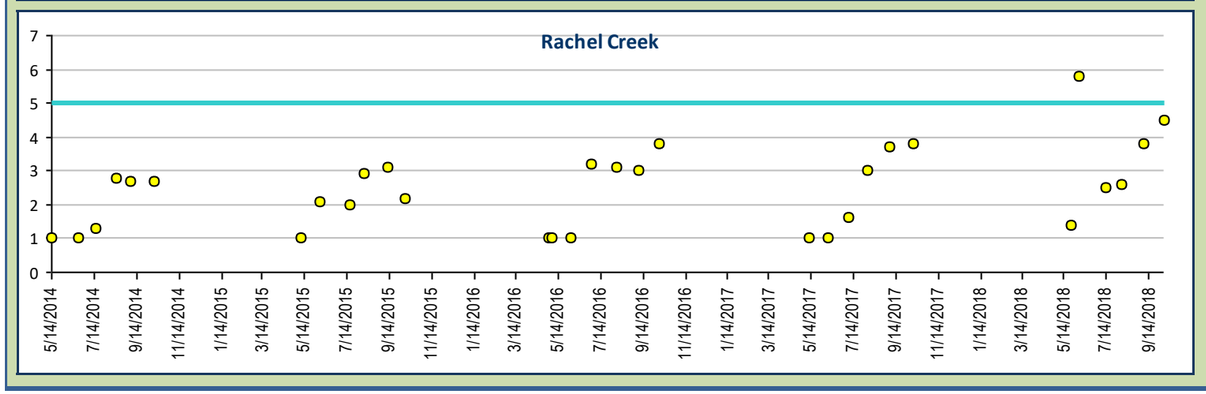


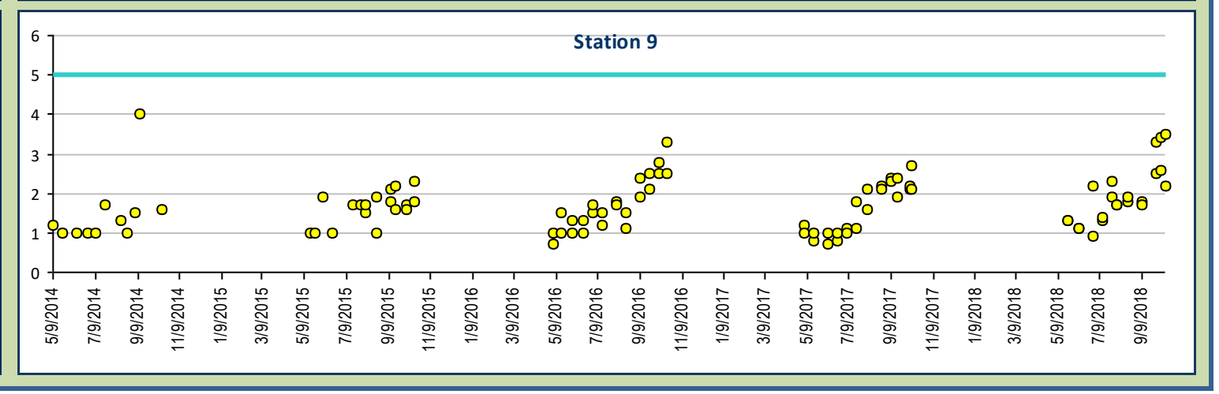








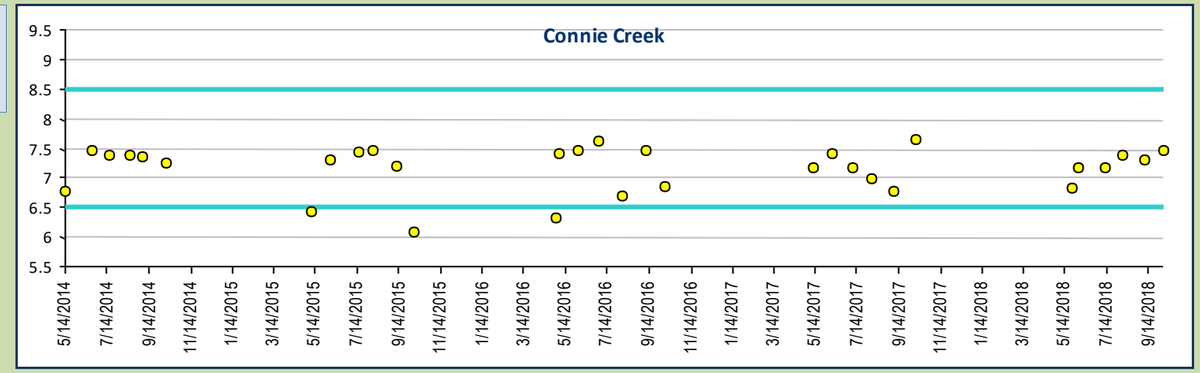


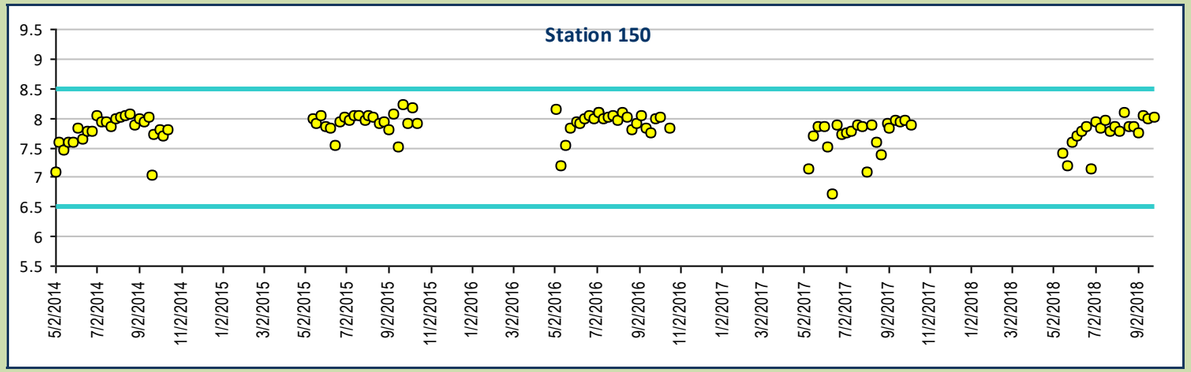


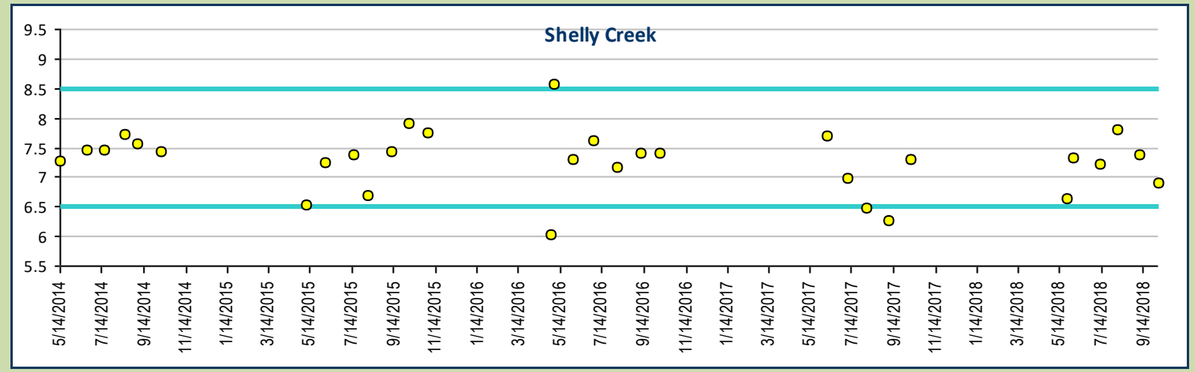
Water Monitoring Mine Drainage
Water Quality Profile I , 5-Year Trend Charts

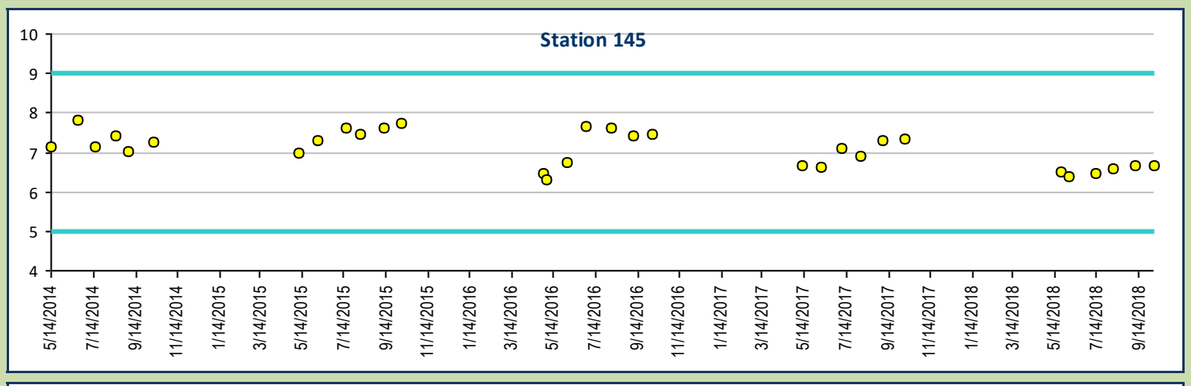
pH

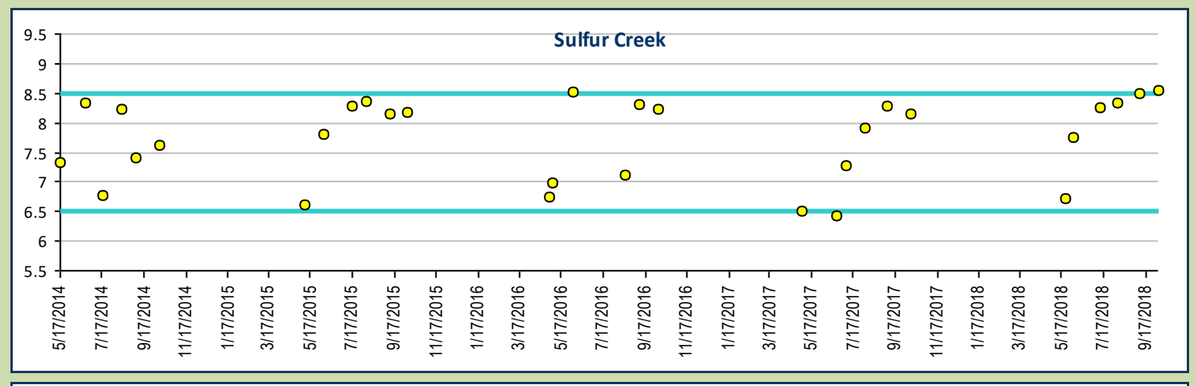
Site Specific WQS pH units

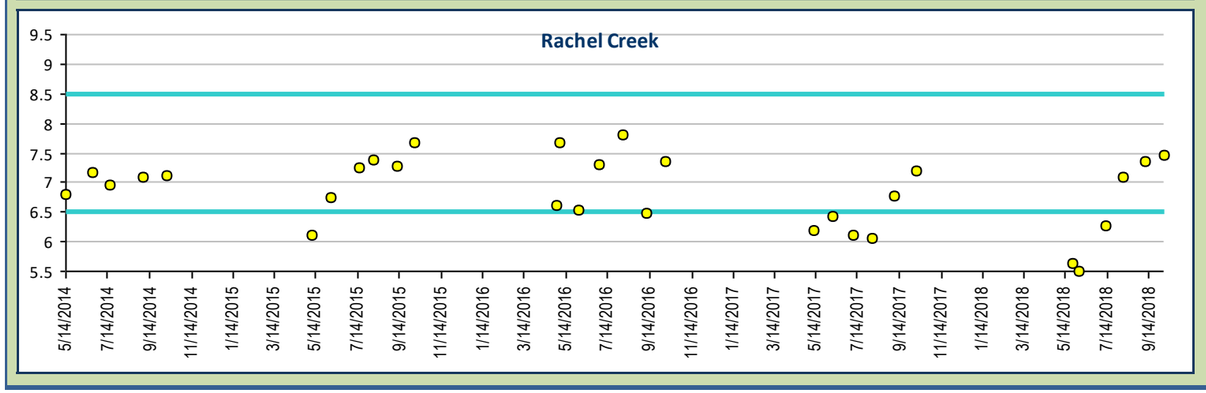


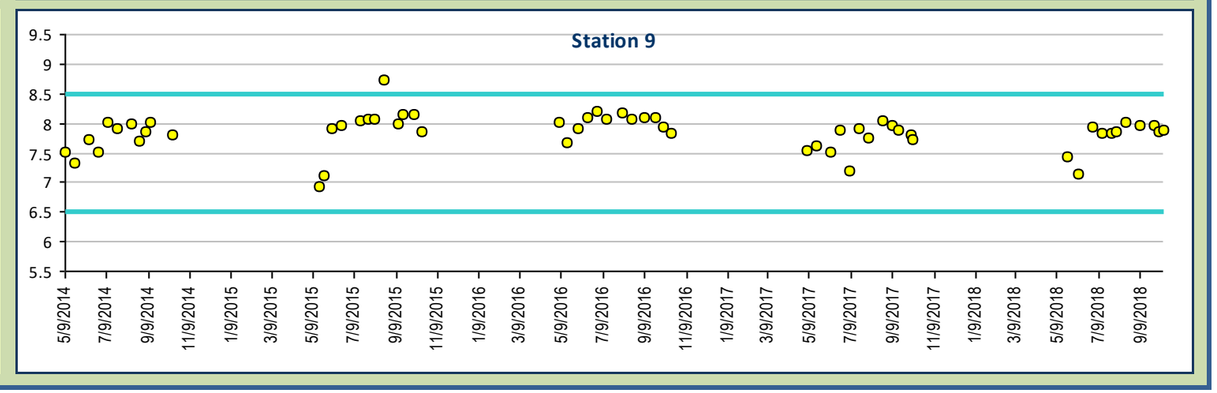












Water Monitoring Mine Drainage
Water Quality Profile I , 5-Year Trend Charts

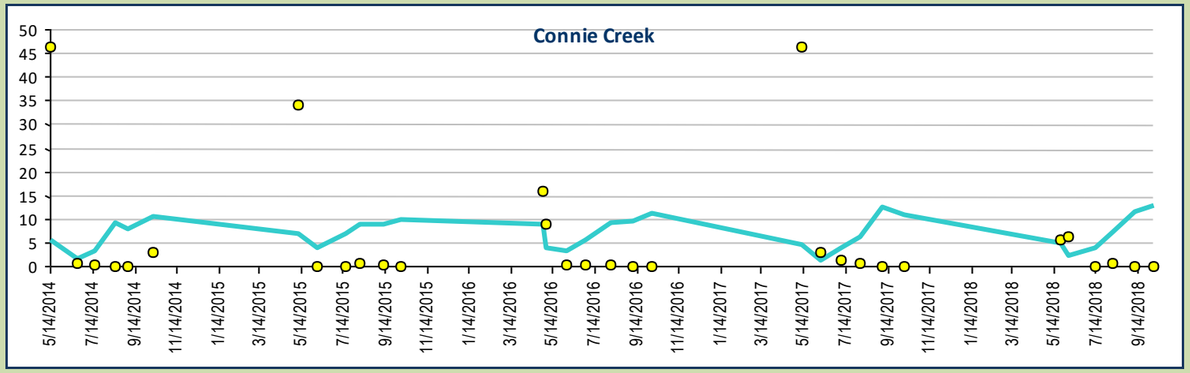
Lead, Total Recoverable, units ug/L

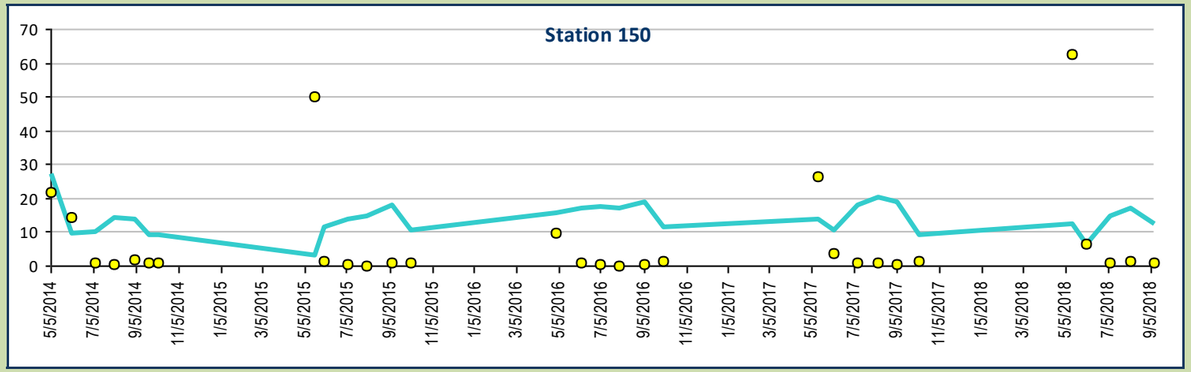
Aquatic Life - Fresh Water Chronic WQS ug/L

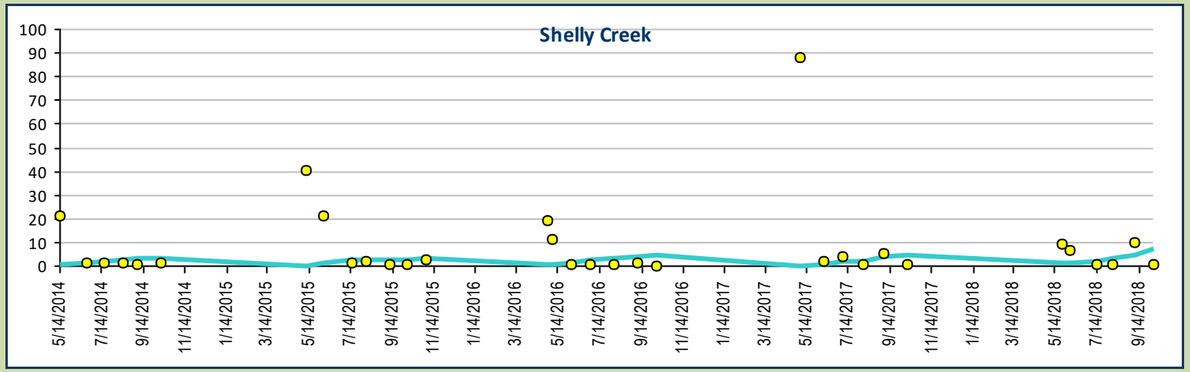
Hardness Dependent Calculation

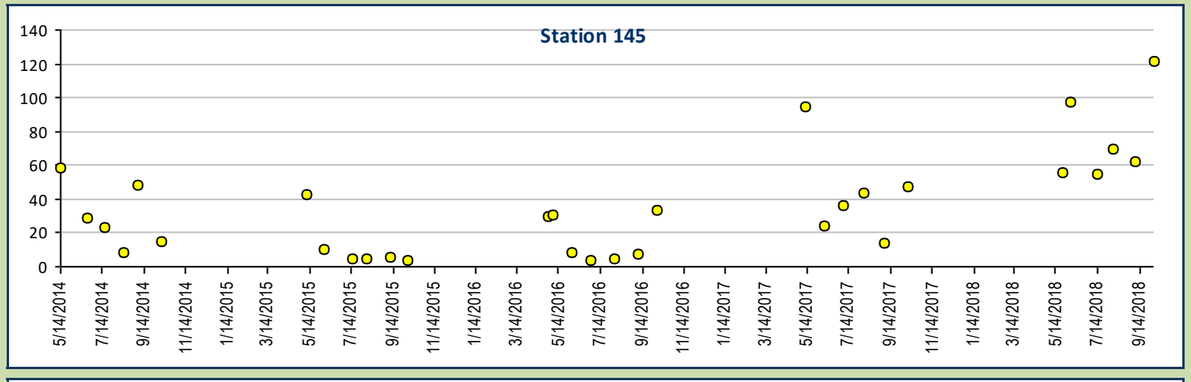
=EXP(1.273*(LN(calc *hardness))-4.705)

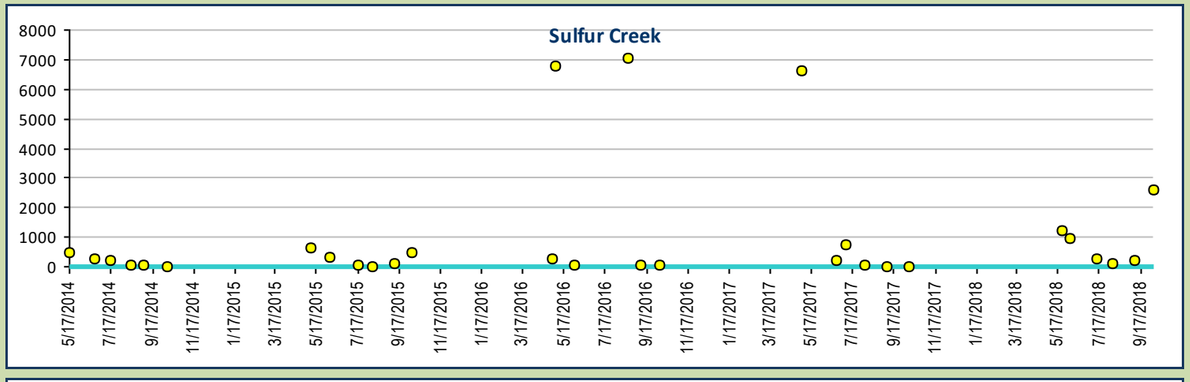
* Calculated using Standard Methods 2340B

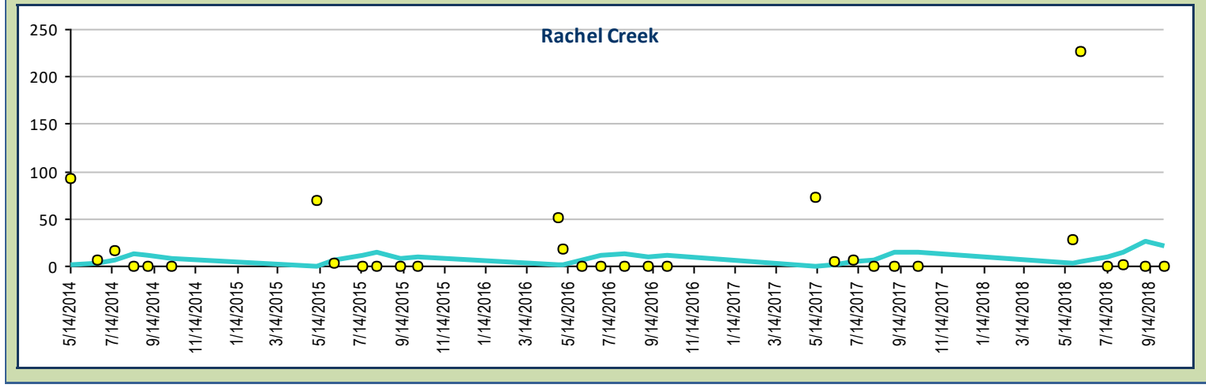


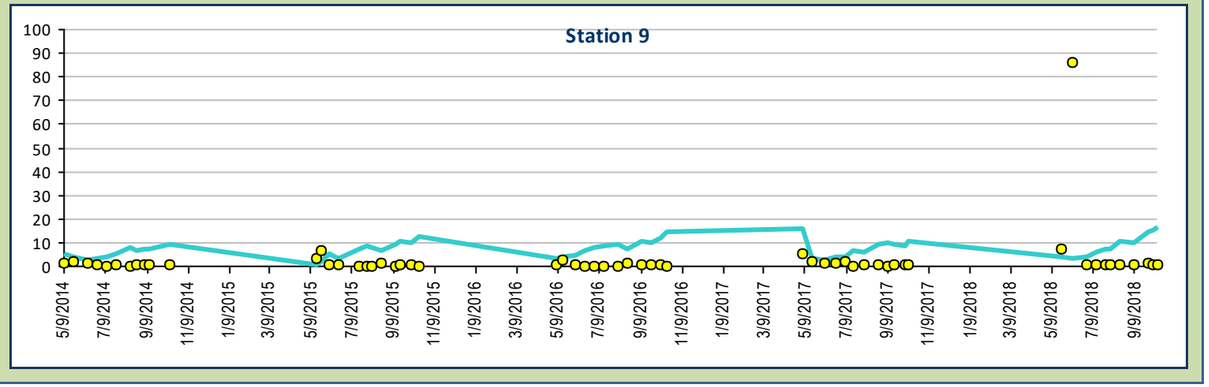






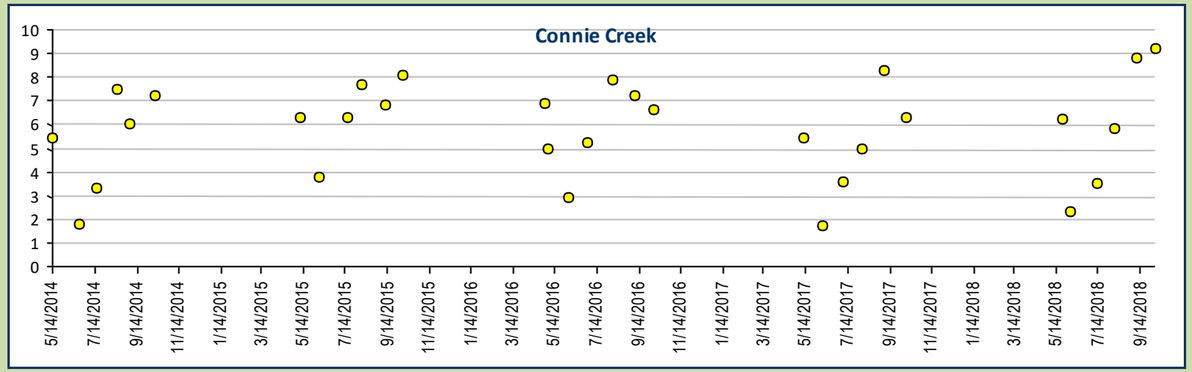


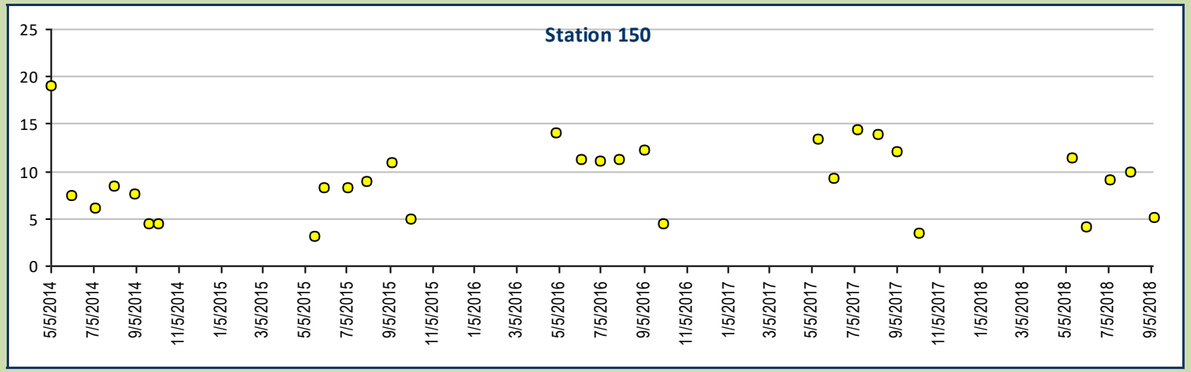


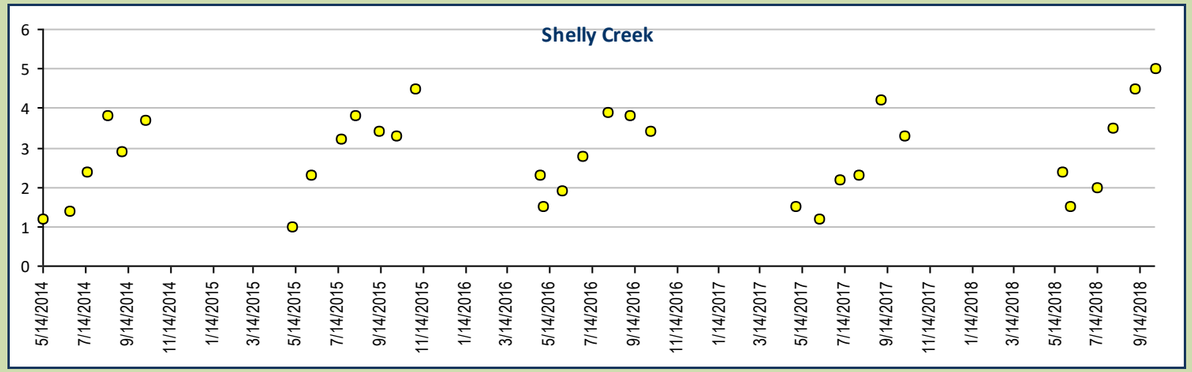


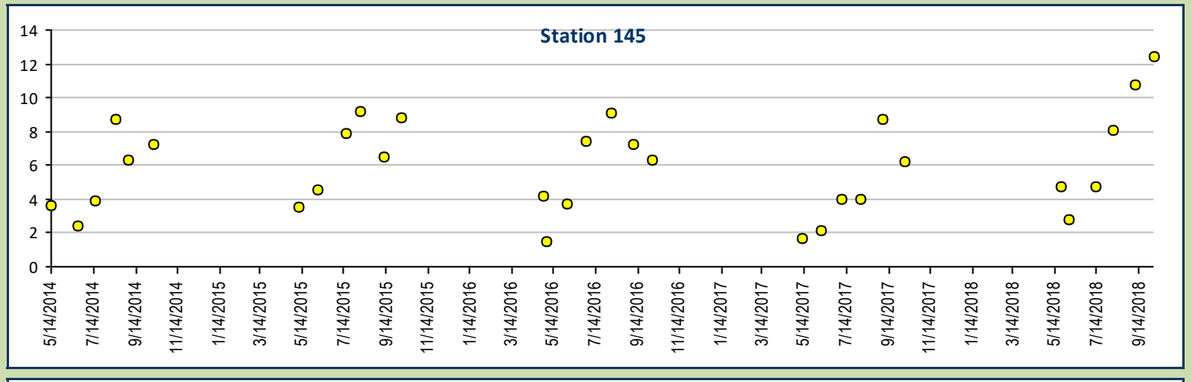
Water Monitoring Mine Drainage
Water Quality Profile I , 5-Year Trend Charts

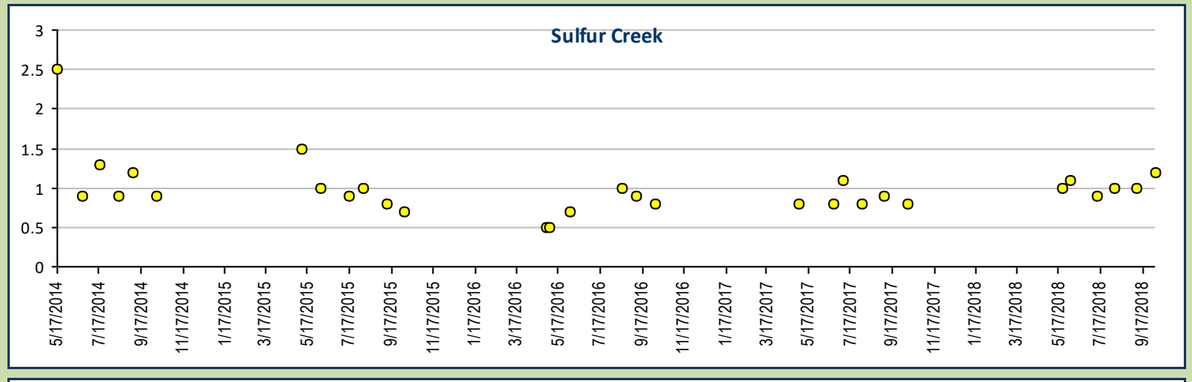
Sodium, Total Recoverable, units mg/L

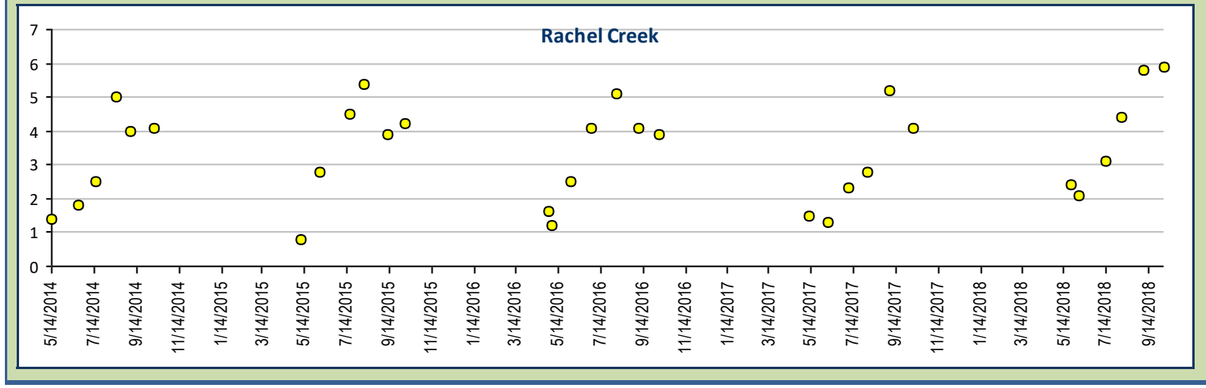


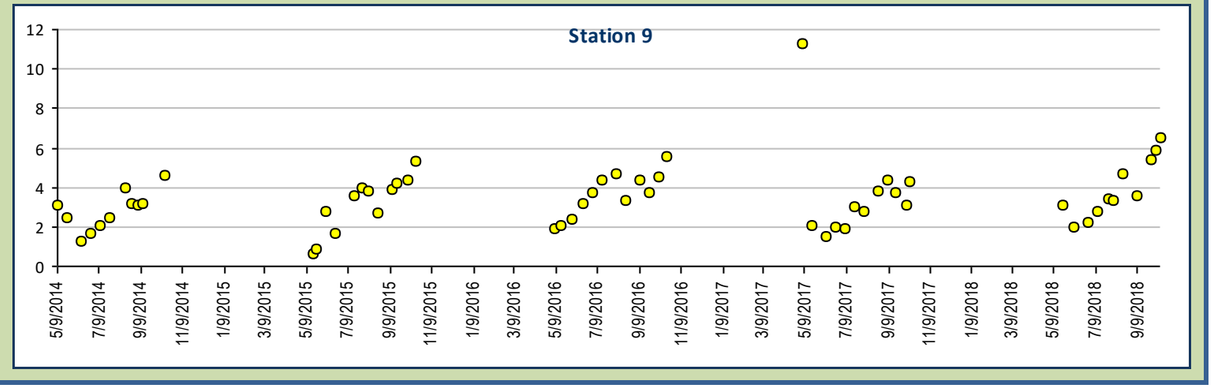








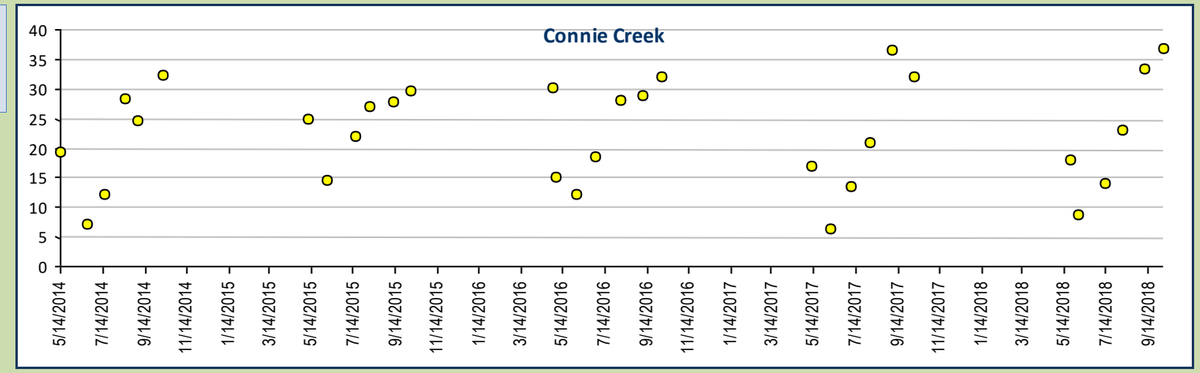


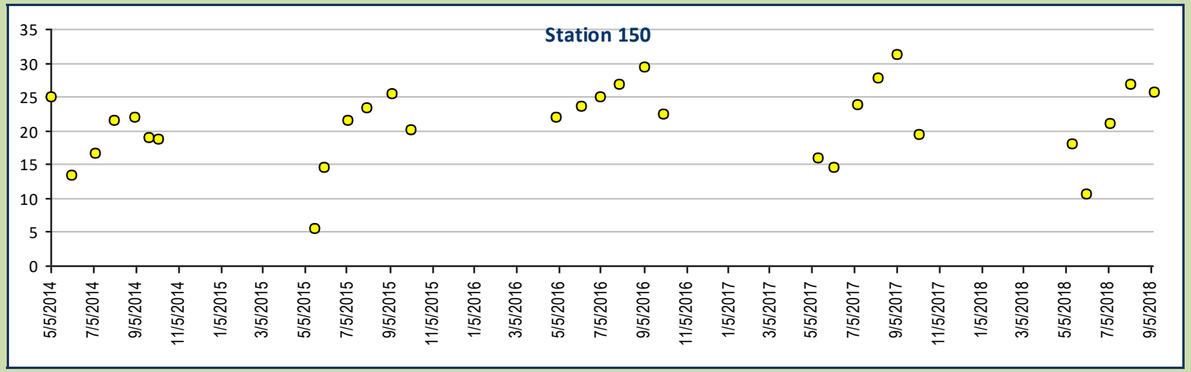


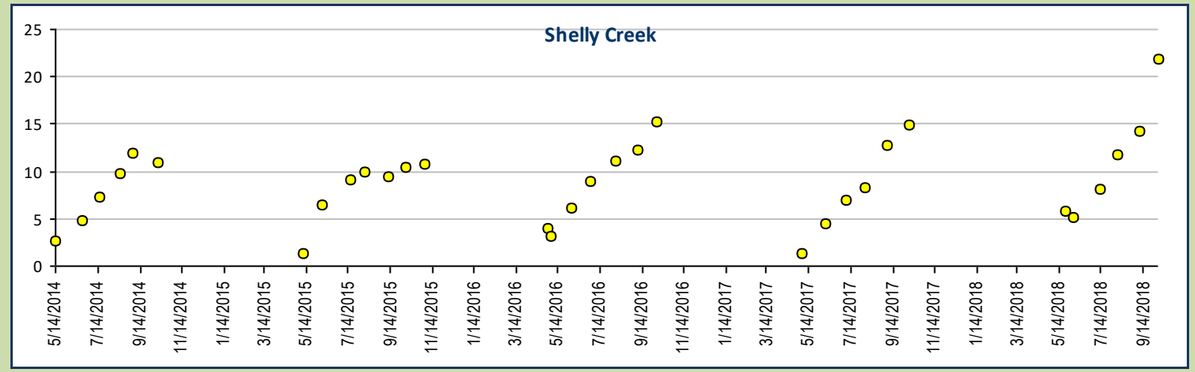
RED DOG MINE

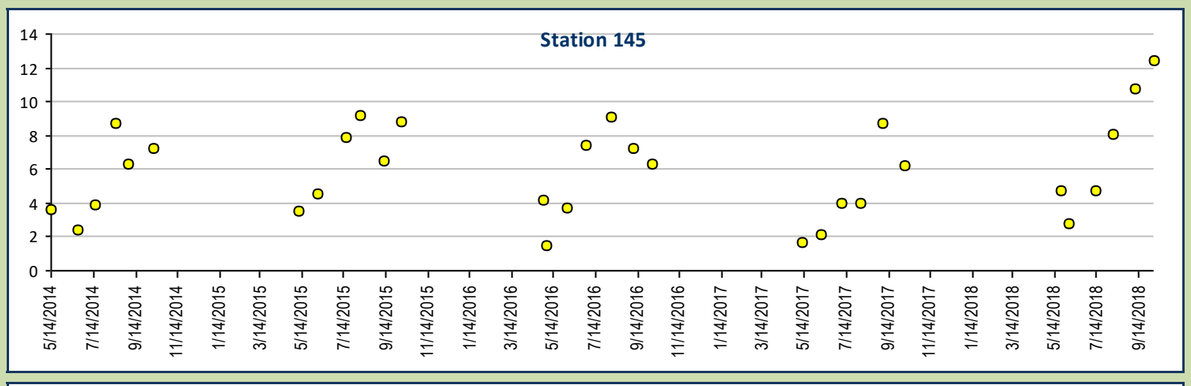
Water Monitoring Mine Drainage
Water Quality Profile I , 5-Year Trend Charts

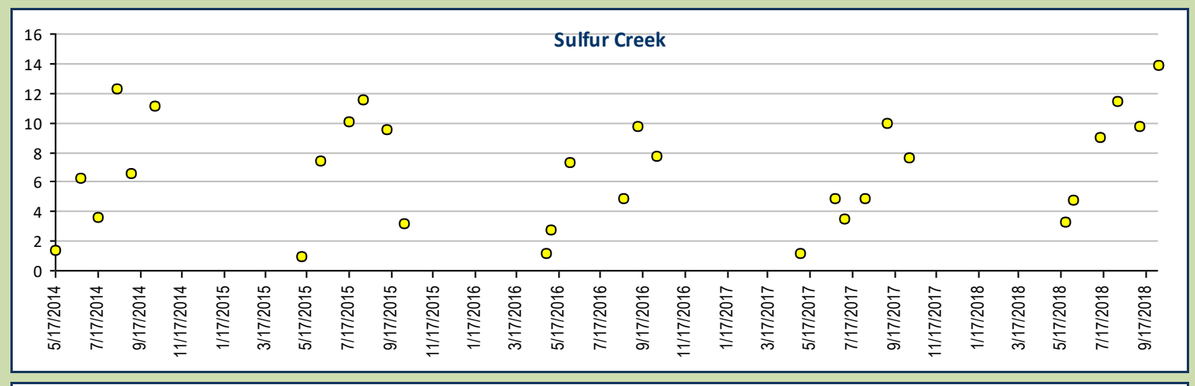
Magnesium, Total Recoverable, units mg/L

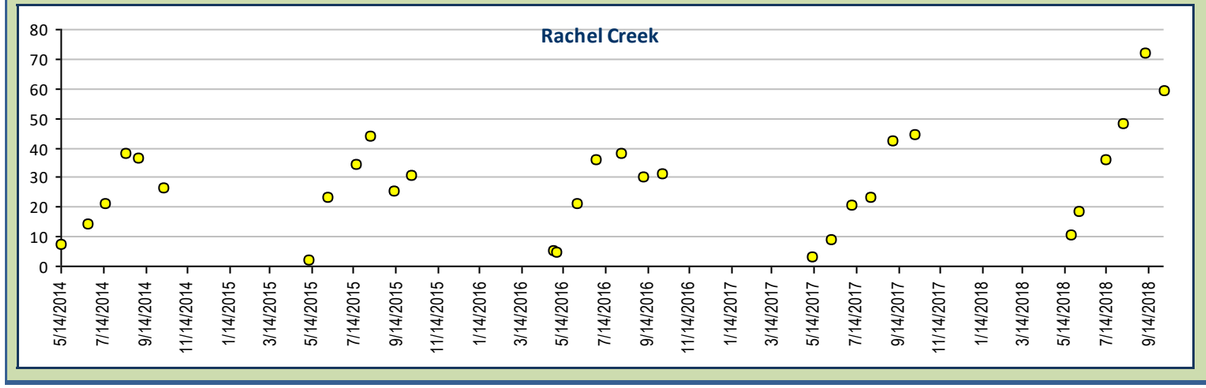


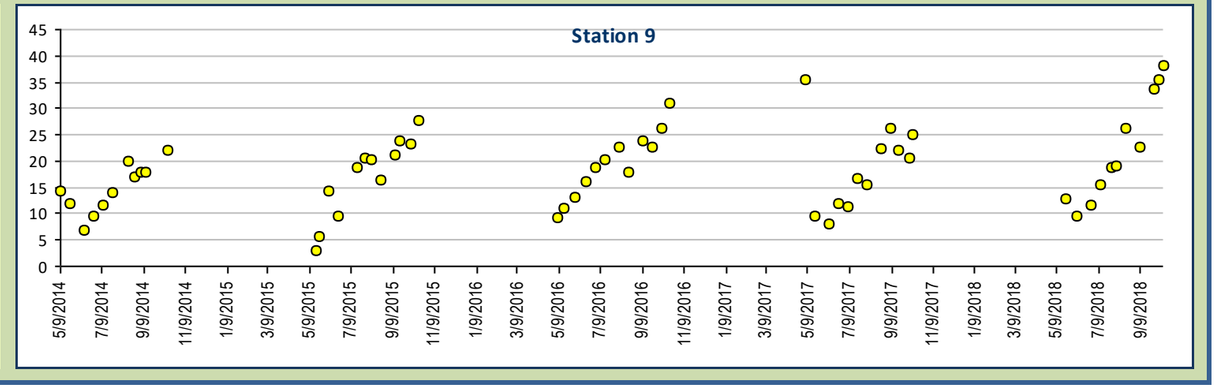






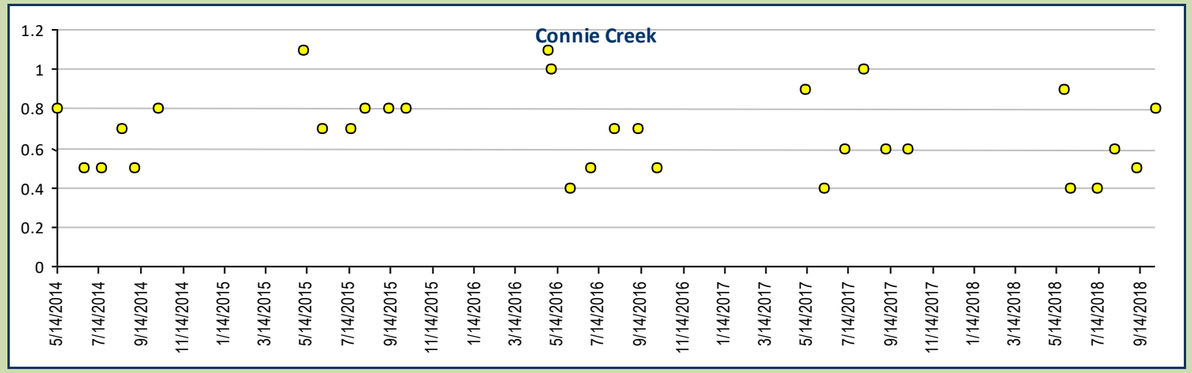


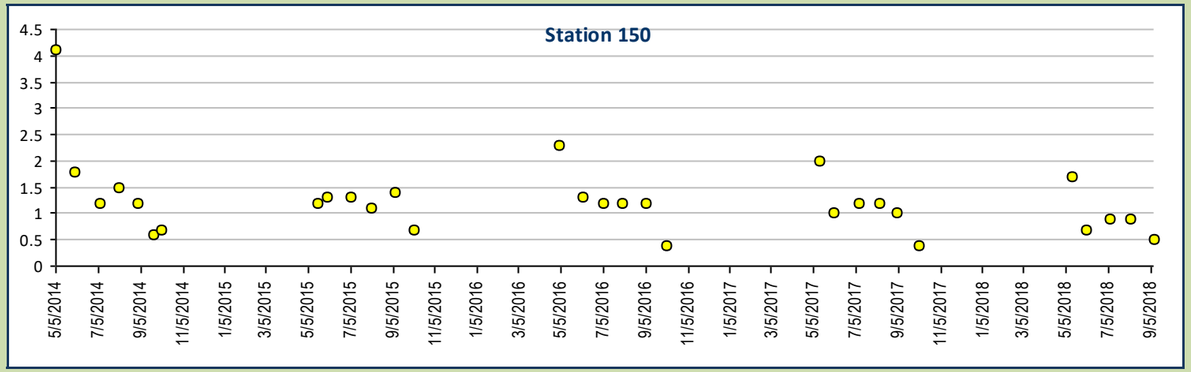


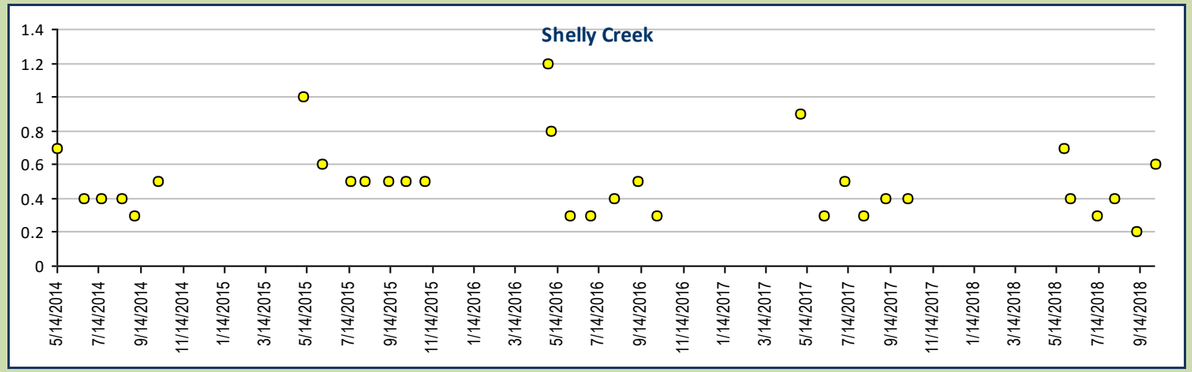


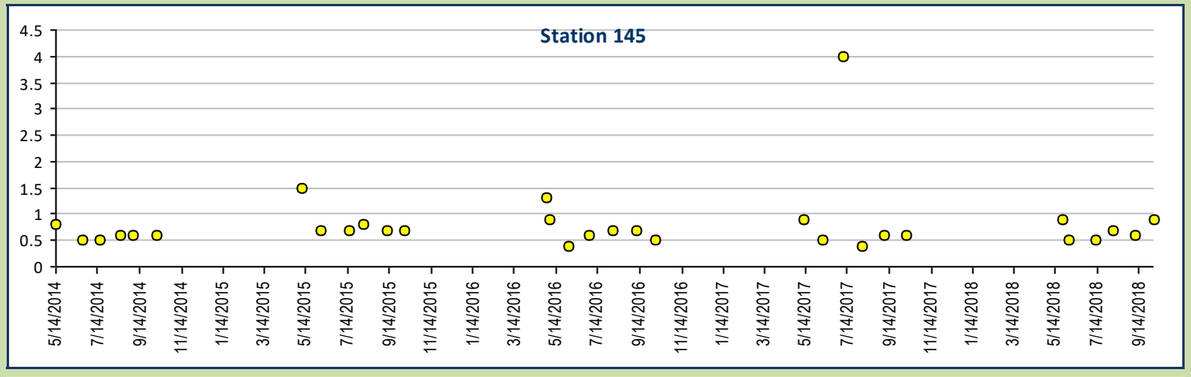
Water Monitoring Mine Drainage
Water Quality Profile I , 5-Year Trend Charts

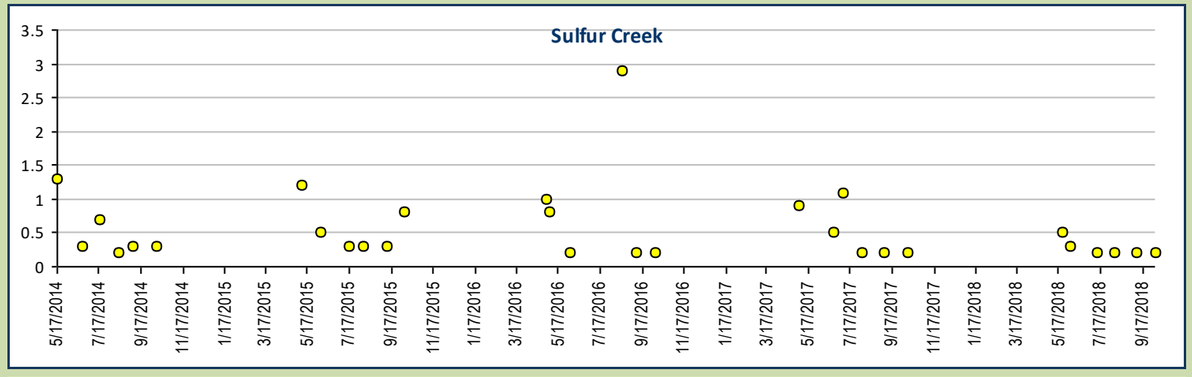
Potassium, Total Recoverable, units mg/L

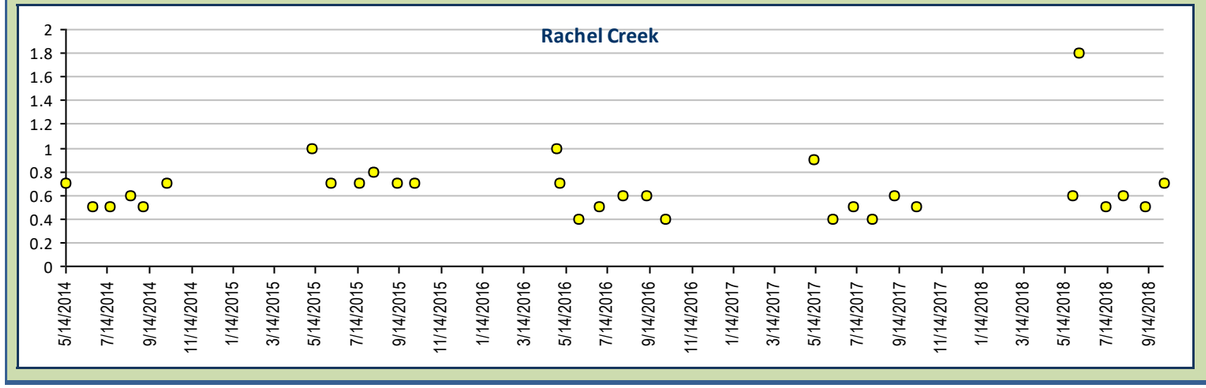


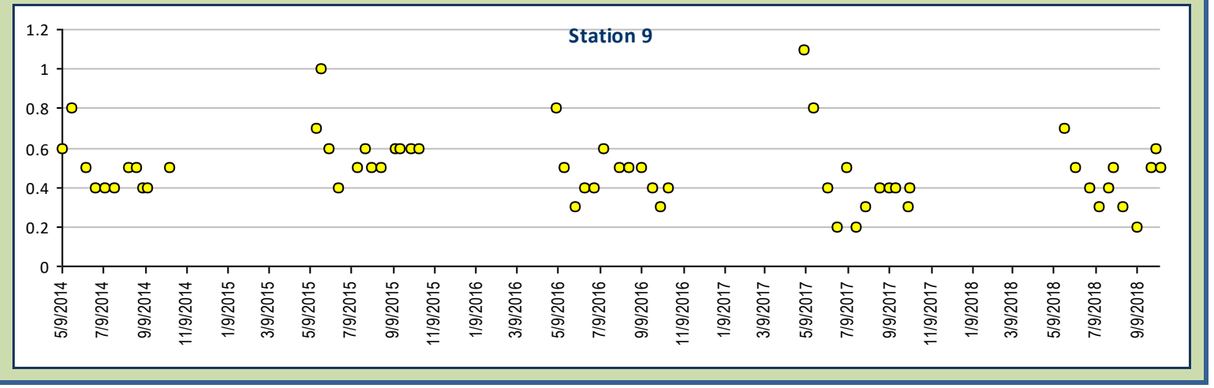










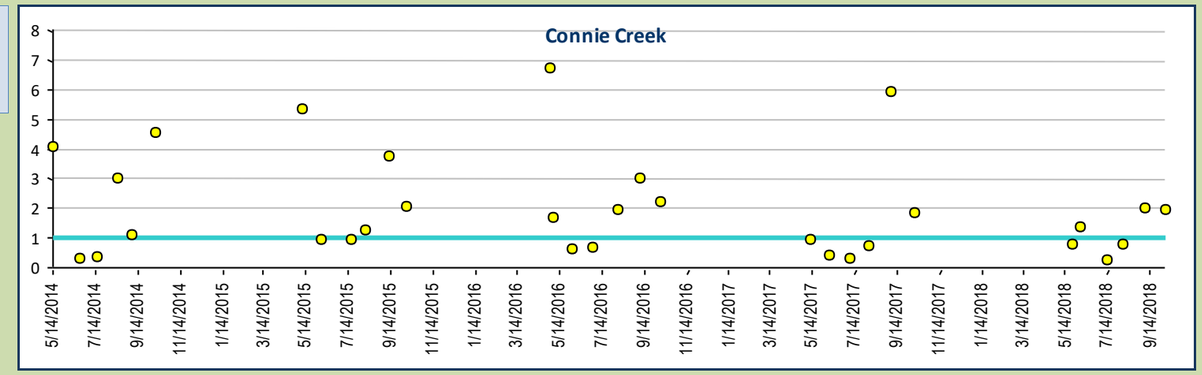


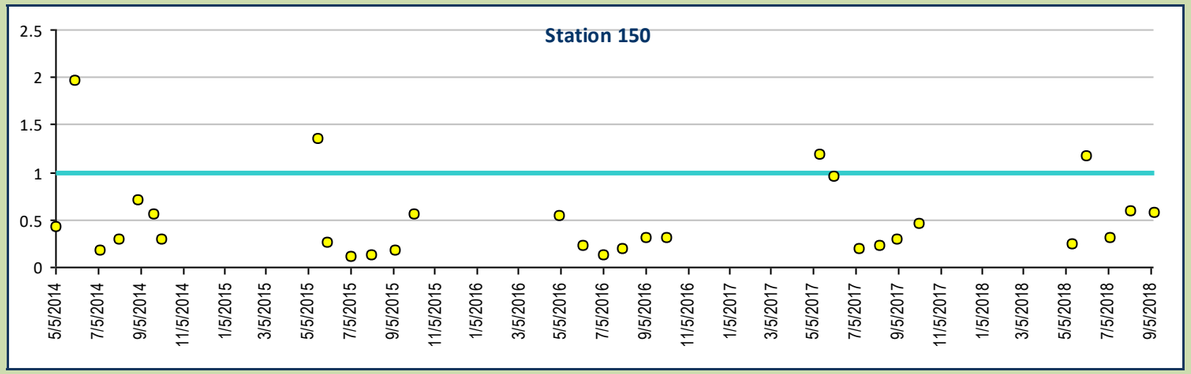
Water Monitoring Mine Drainage
Water Quality Profile I , 5-Year Trend Charts

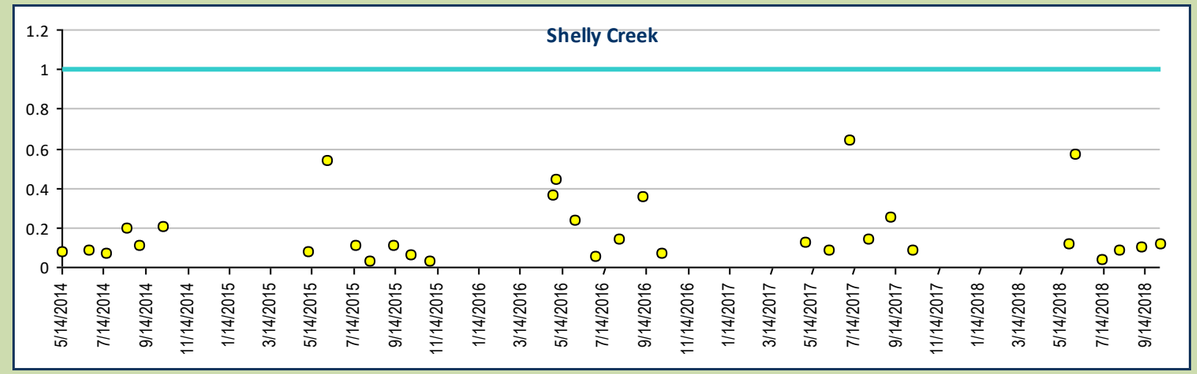
Iron, Total Recoverable, units mg/L

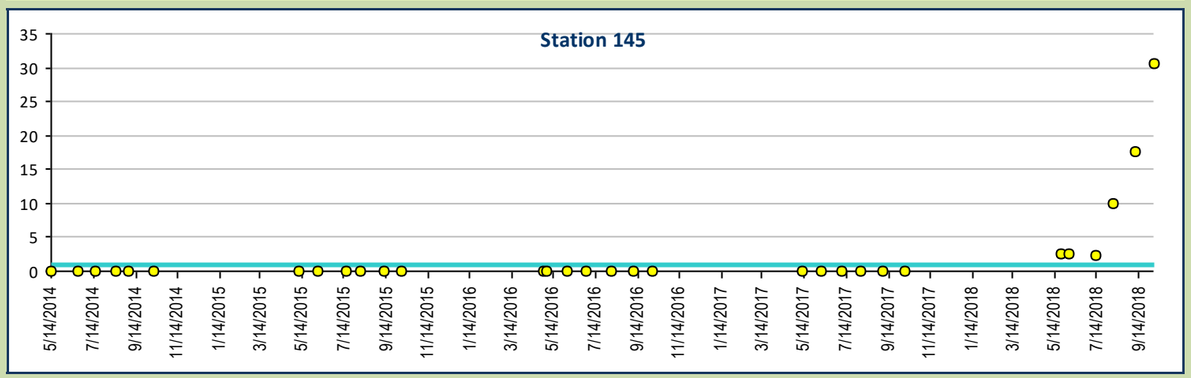
Aquatic Life - Fresh Water Chronic WQS mg/L

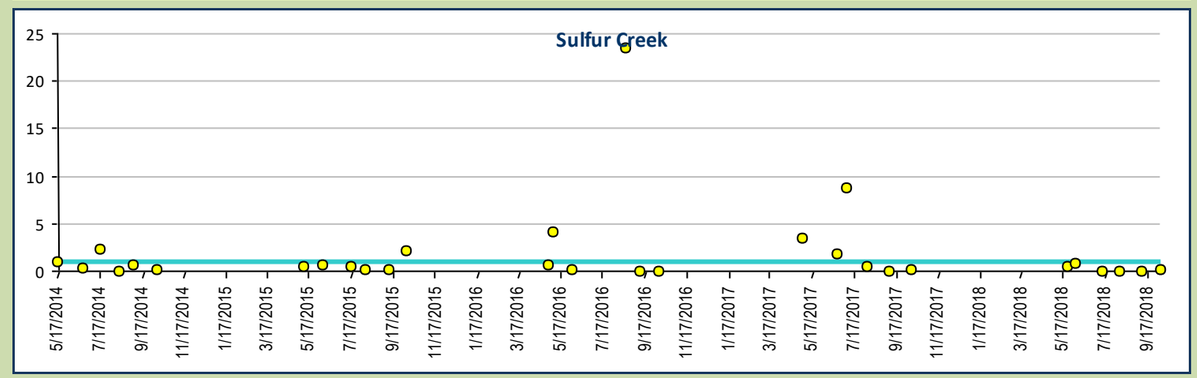
1.0 mg/L

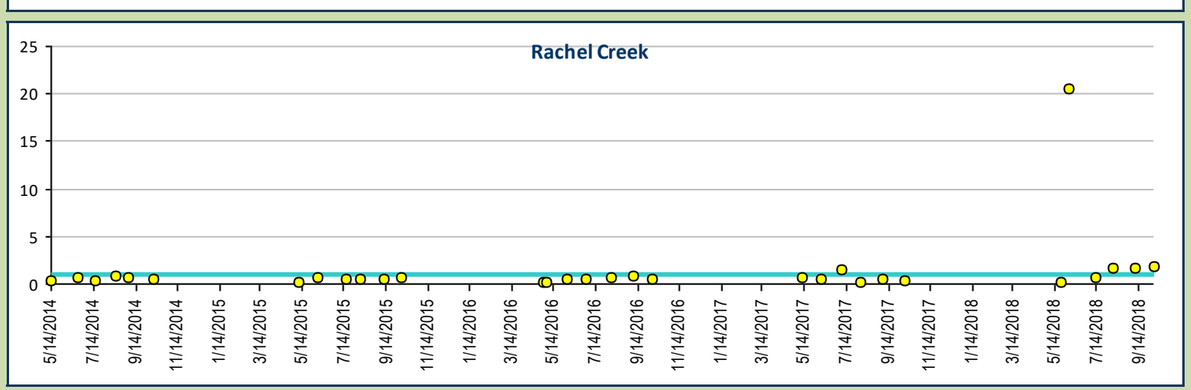


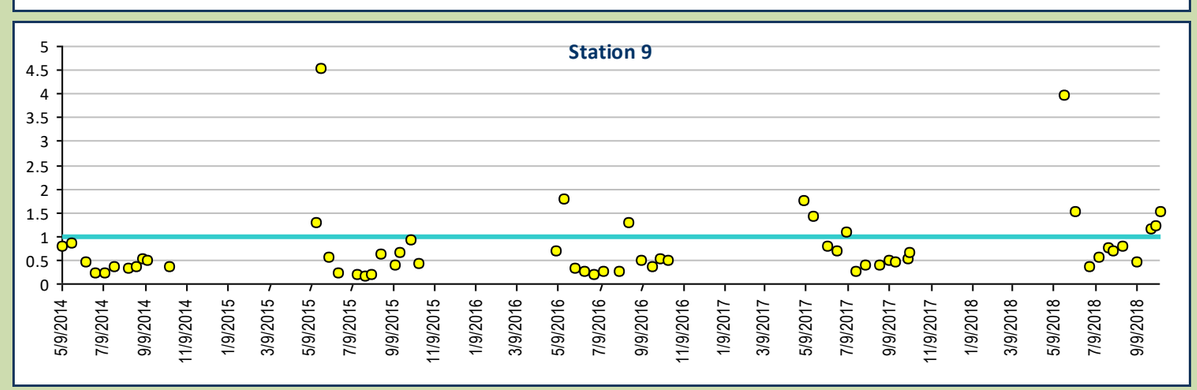








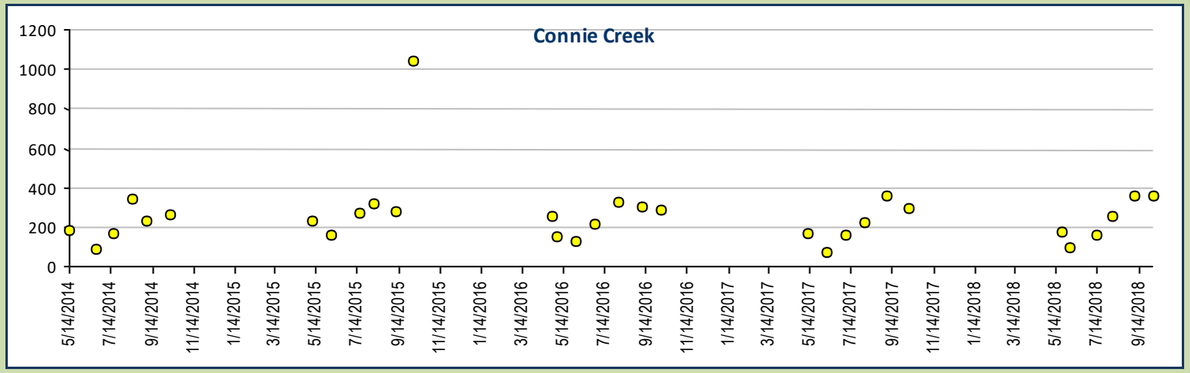


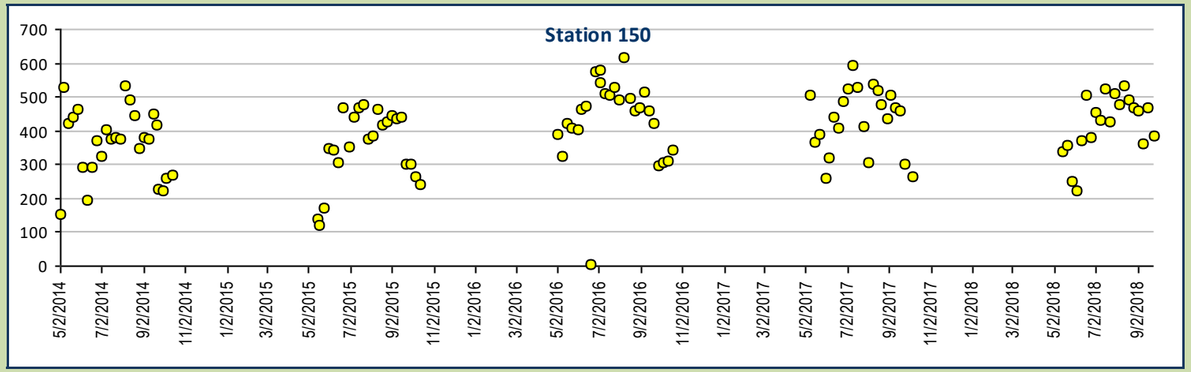


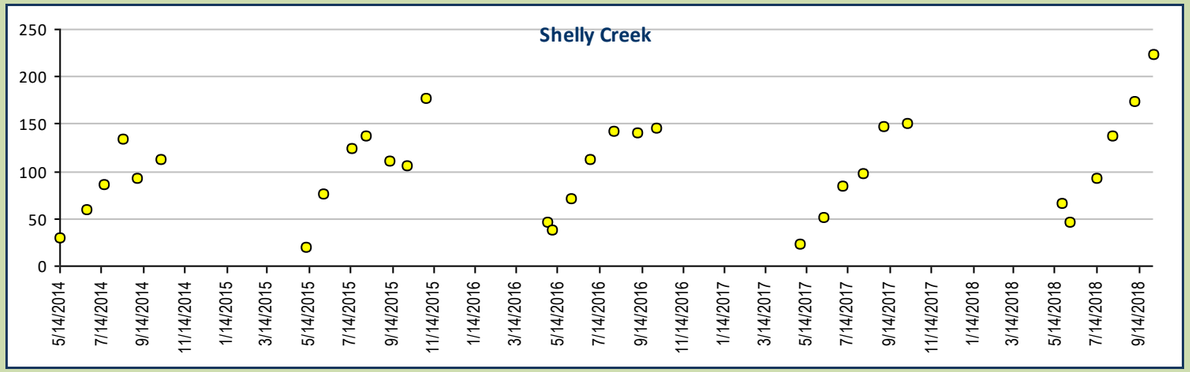
RED DOG MINE

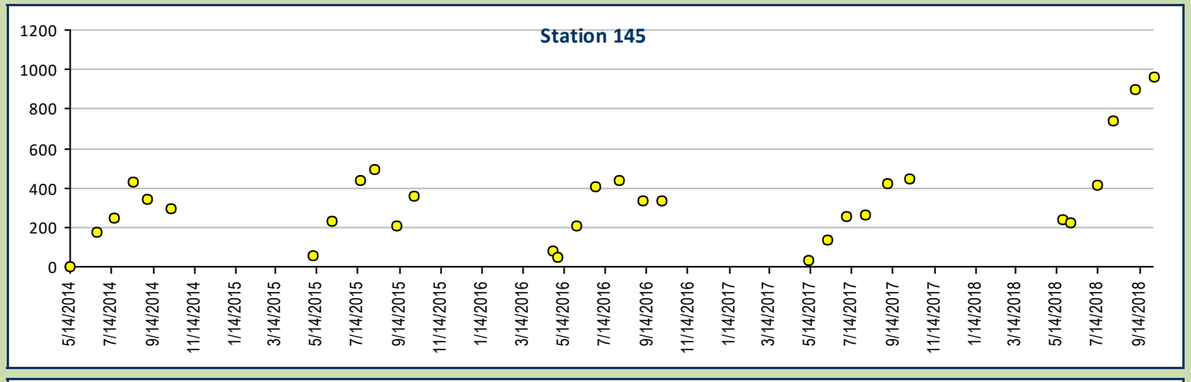
Water Monitoring Mine Drainage
Water Quality Profile I , 5-Year Trend Charts

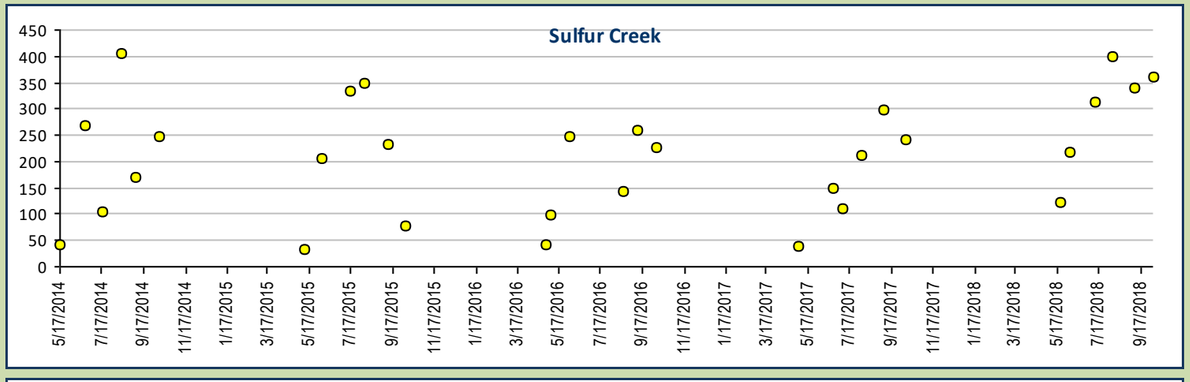
Conductivity, units uS/cm

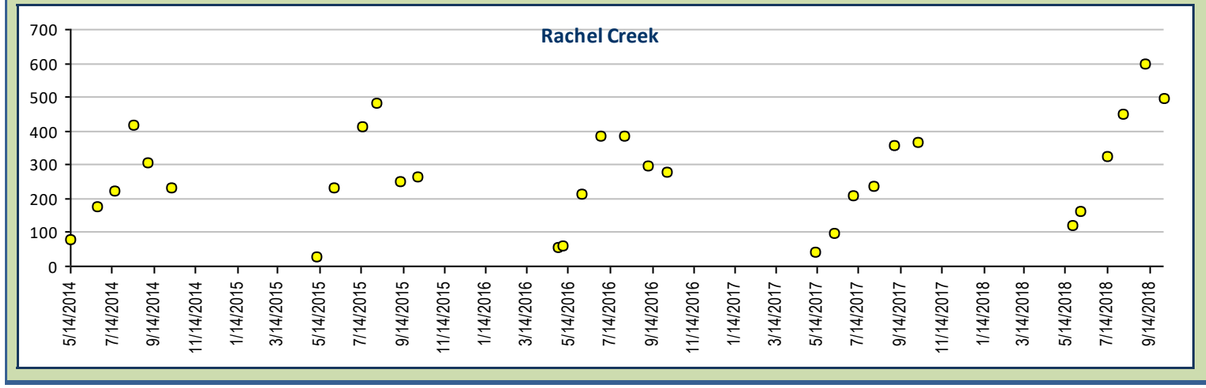


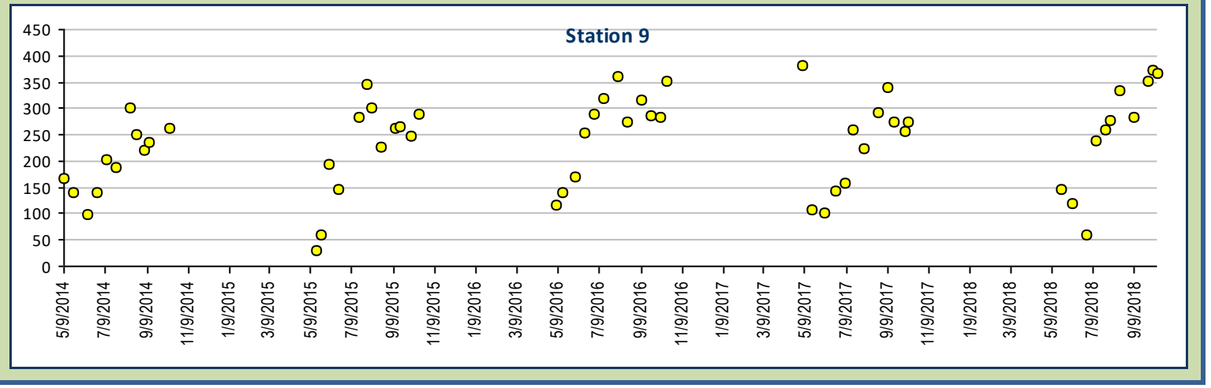










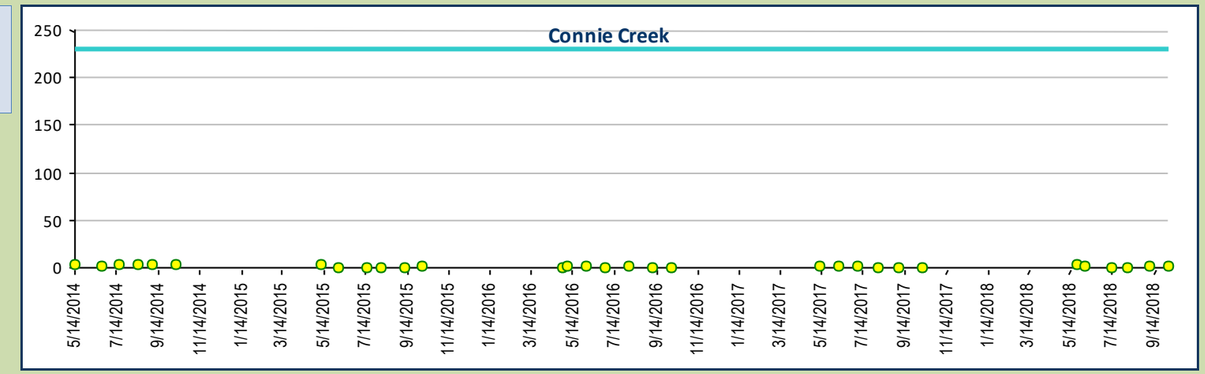


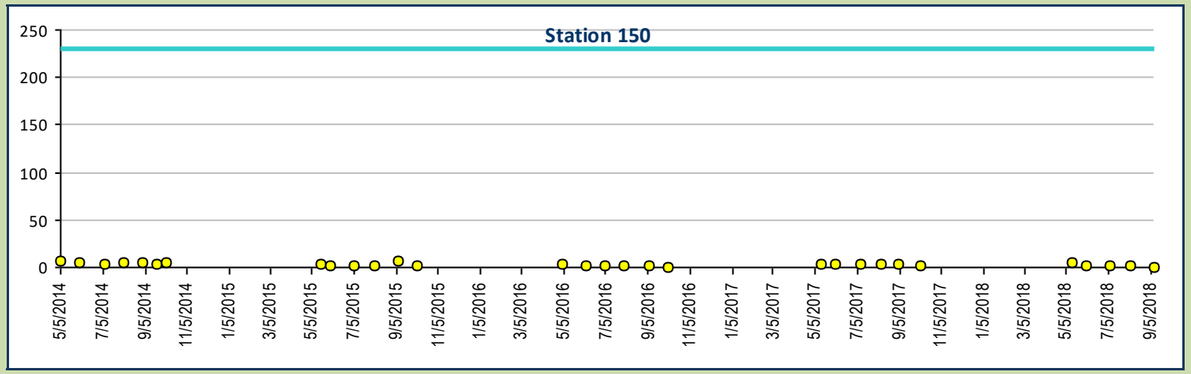
Water Monitoring Mine Drainage
Water Quality Profile I , 5-Year Trend Charts

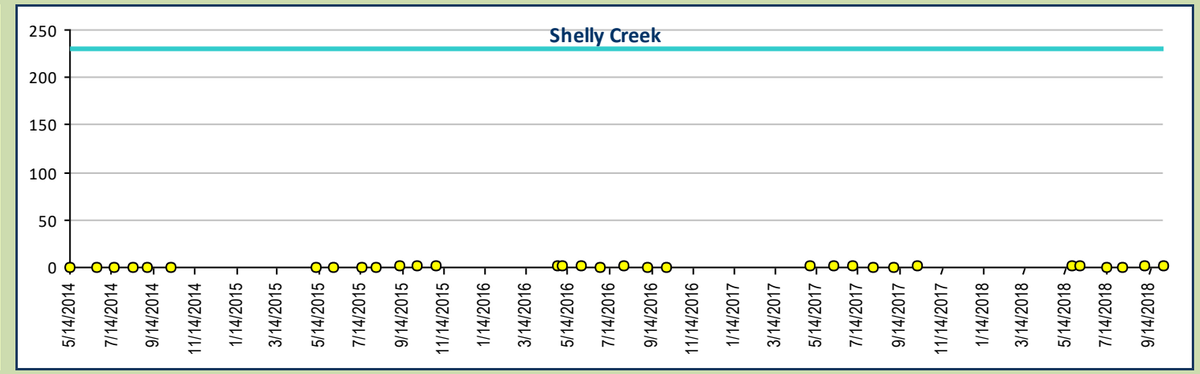
Chloride, Total Recoverable, units mg/L

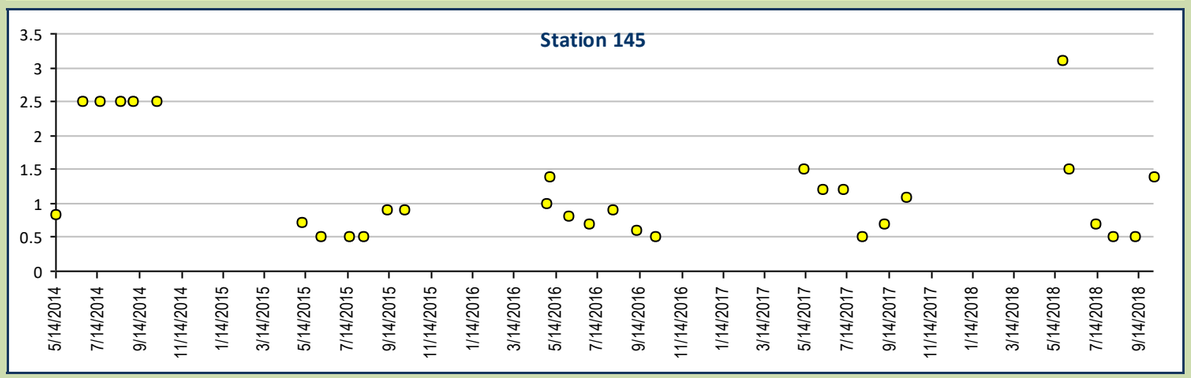
Aquatic Life - Fresh Water Chronic WQS mg/L

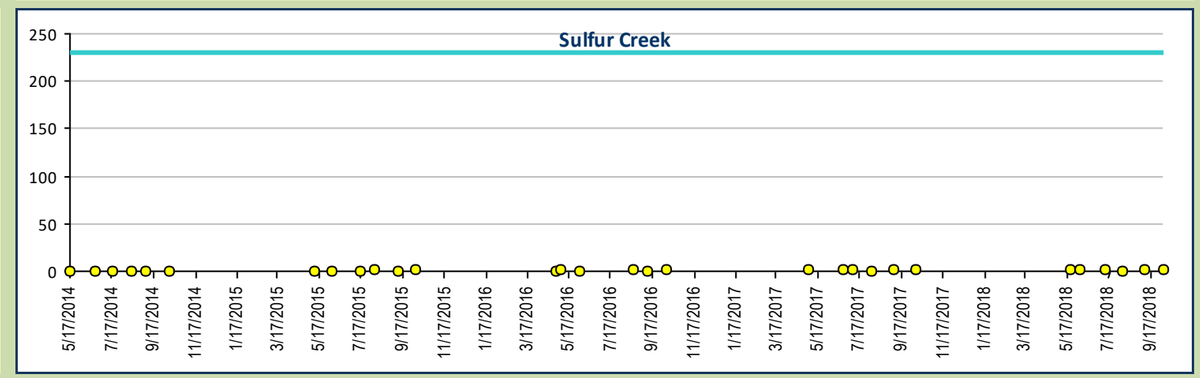
230 mg/L

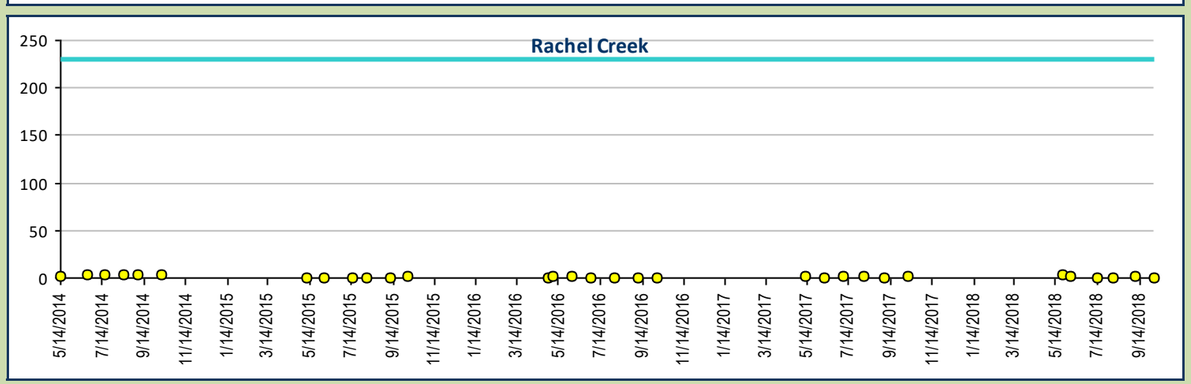


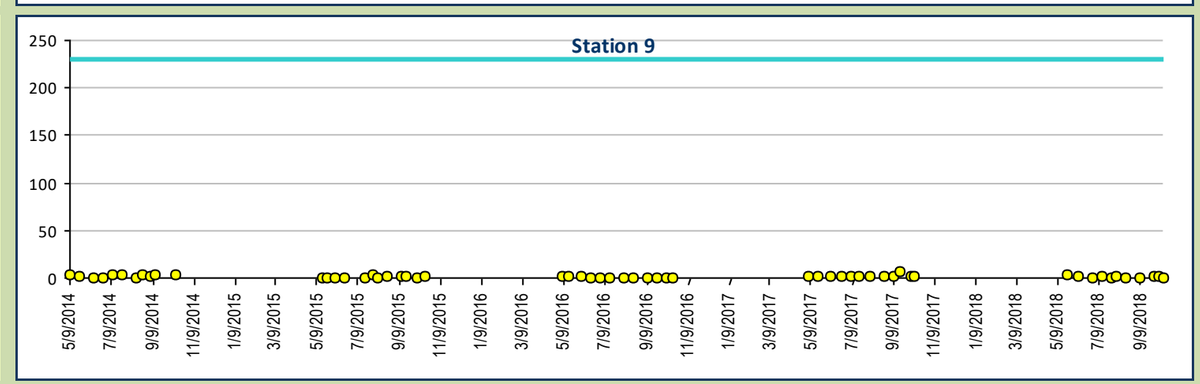












Water Monitoring Mine Drainage
Water Quality Profile I , 5-Year Trend Charts

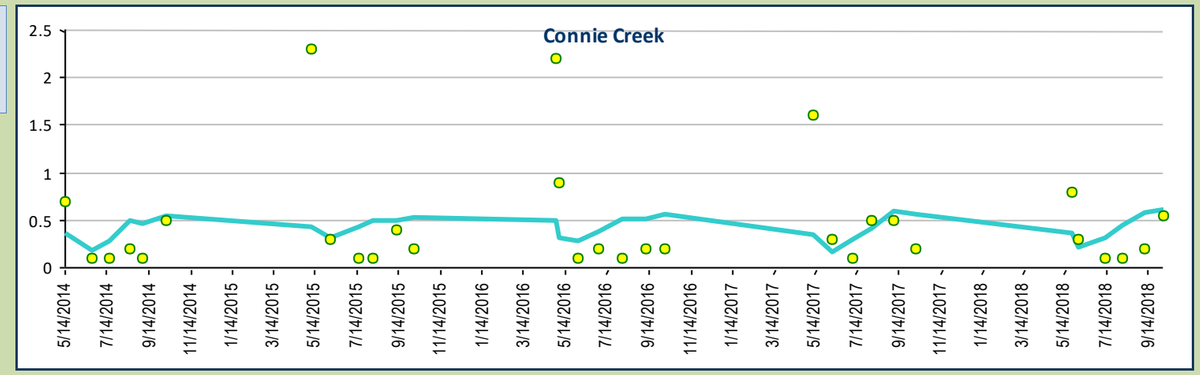
Cadmium, Total Recoverable, units ug/L

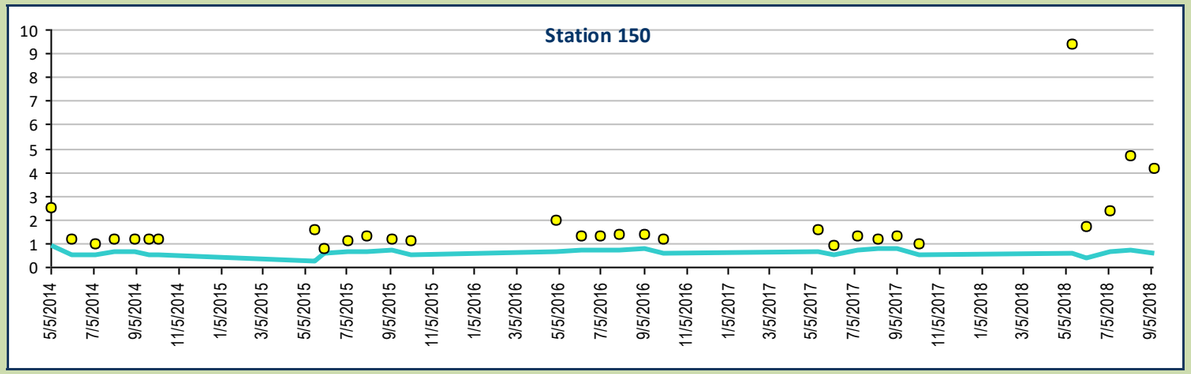
Aquatic Life - Fresh Water Chronic WQS ug/L

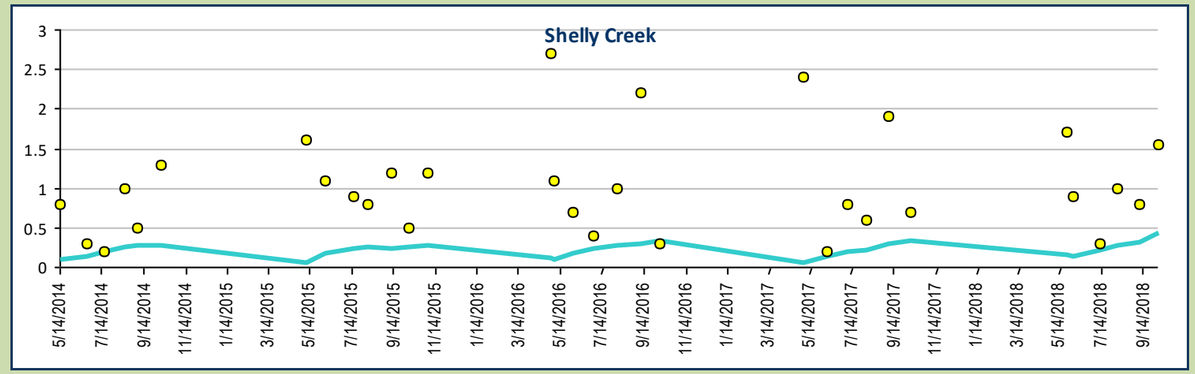
Hardness Dependent Calculation

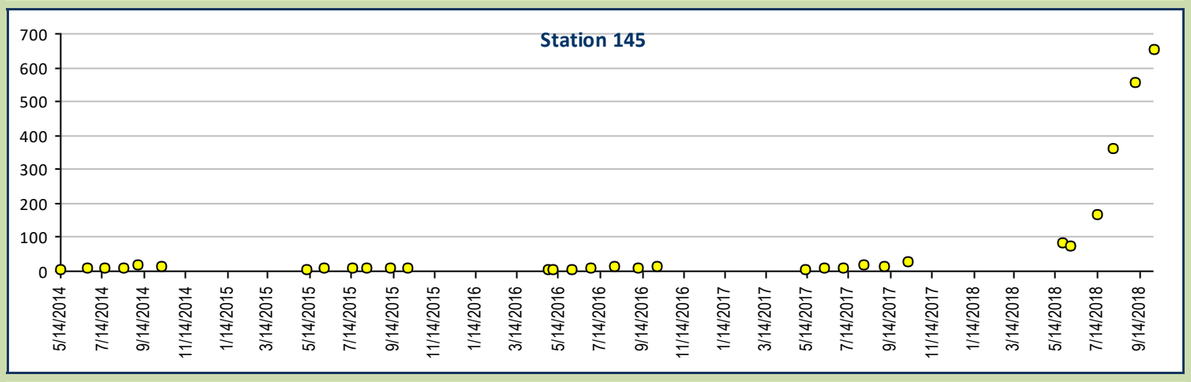
=EXP(0.7409*(LN(calc *hardness))-4.719)

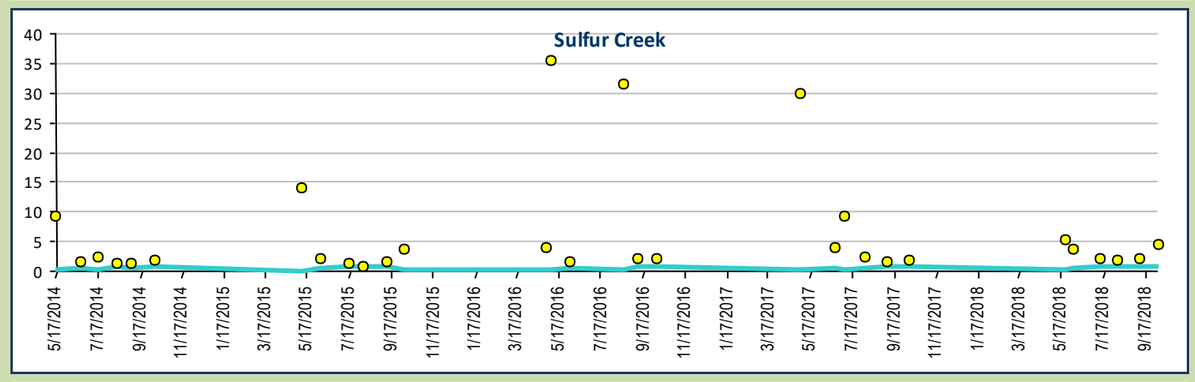
* Calculated using Standard Methods 2340B

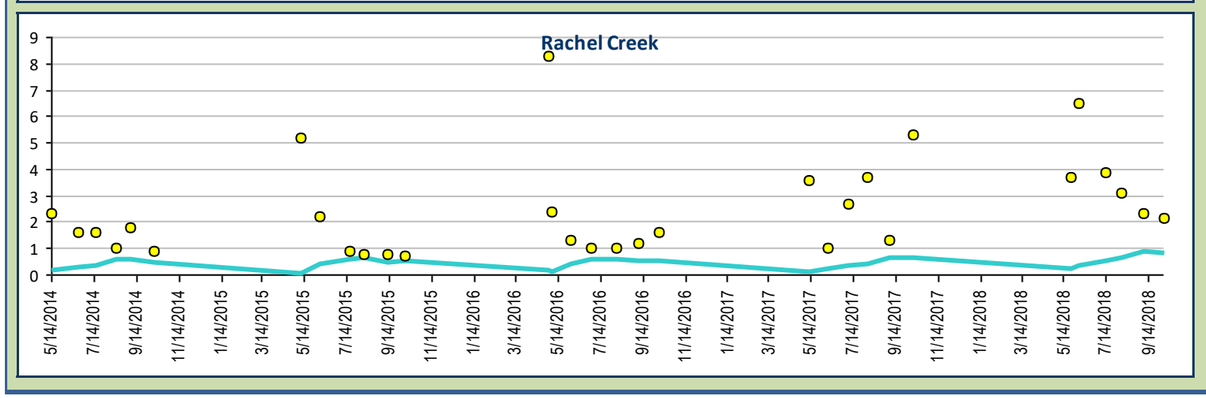


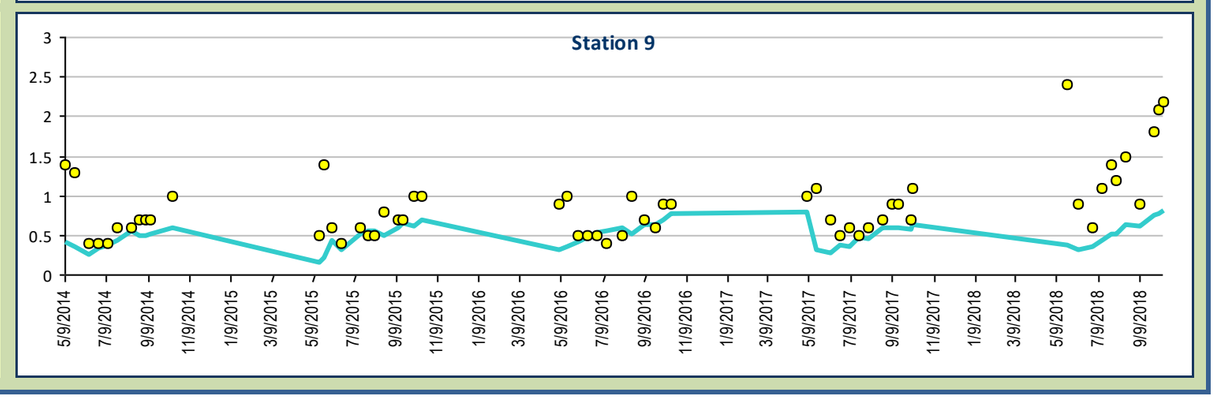






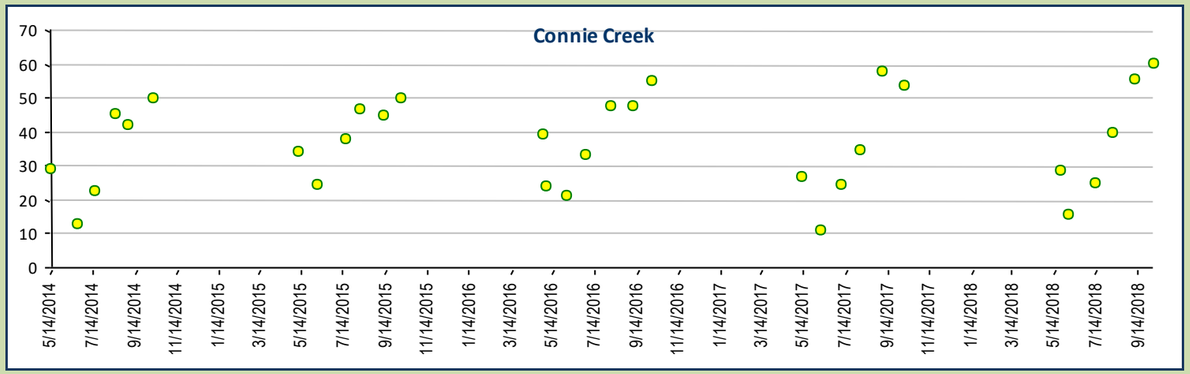


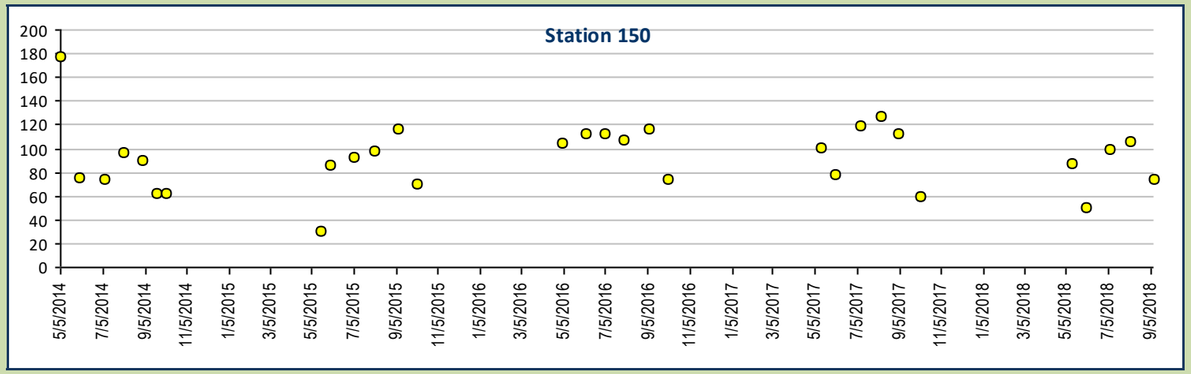


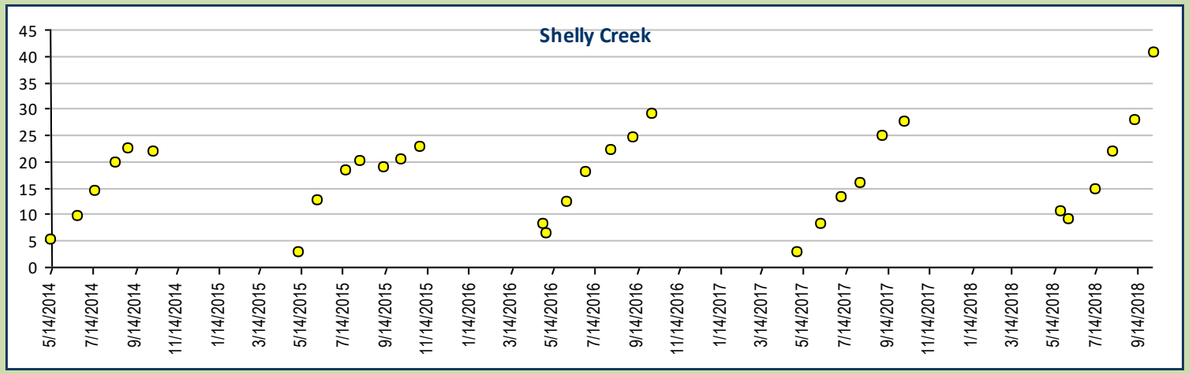


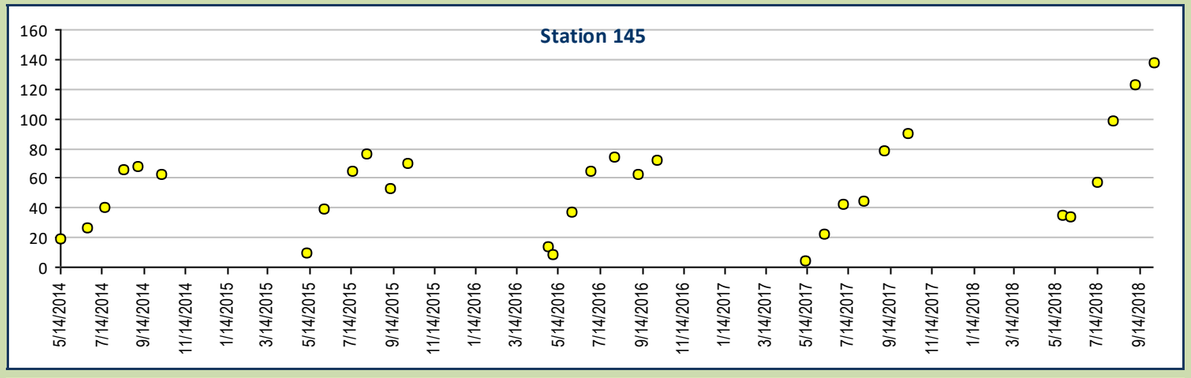
Water Monitoring Mine Drainage
Water Quality Profile I , 5-Year Trend Charts

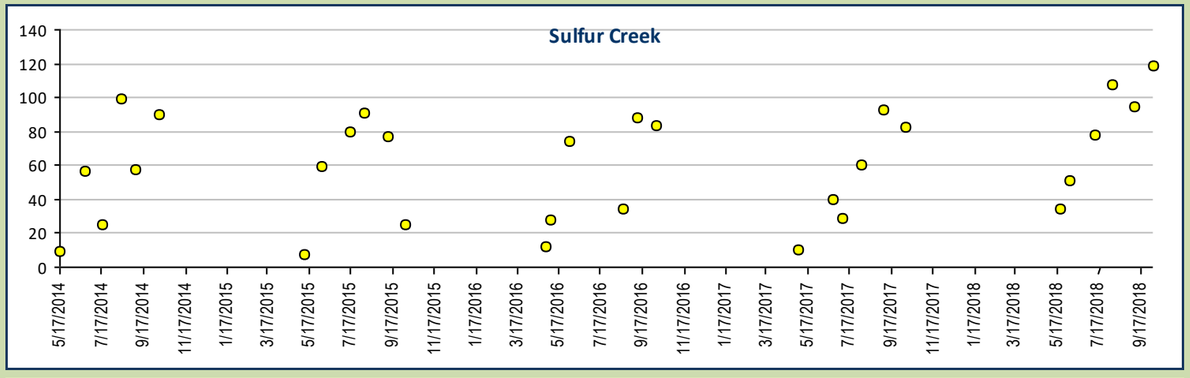
Calcium, Total recoverable, units mg/L

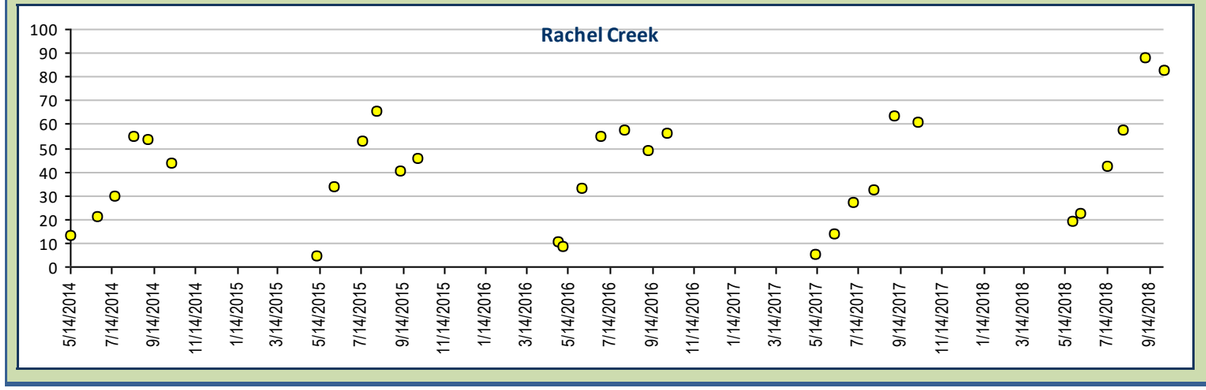


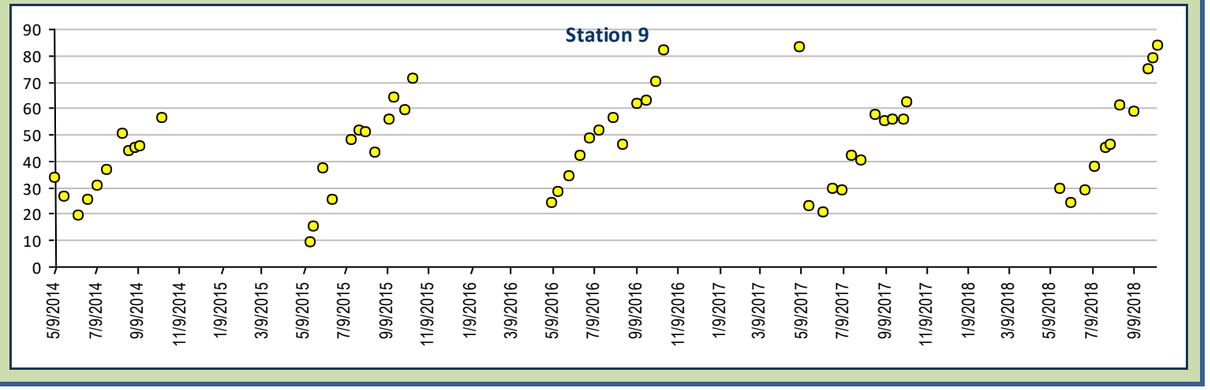










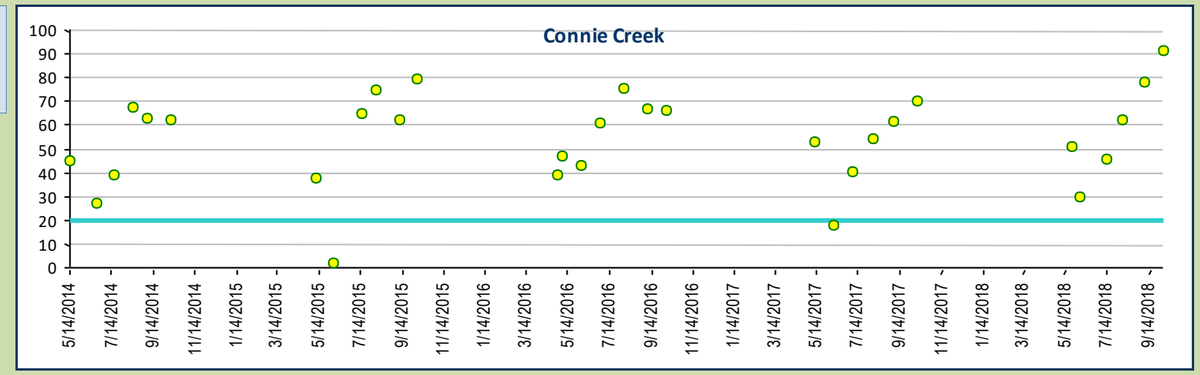


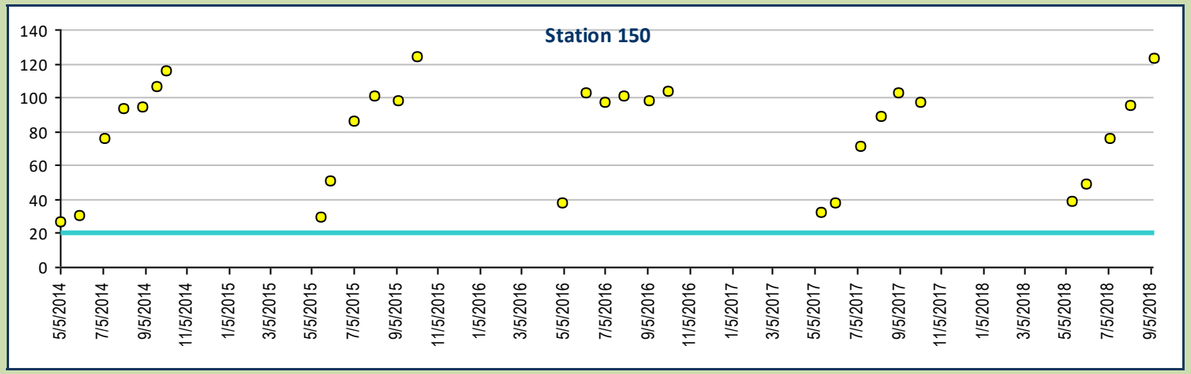
Water Monitoring Mine Drainage
Water Quality Profile I , 5-Year Trend Charts

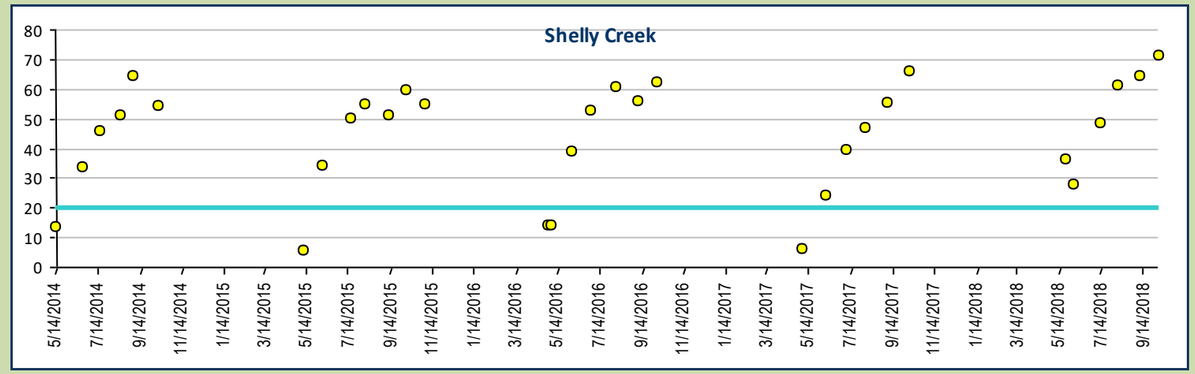
Alkalinity as CaCO3, units mg/L

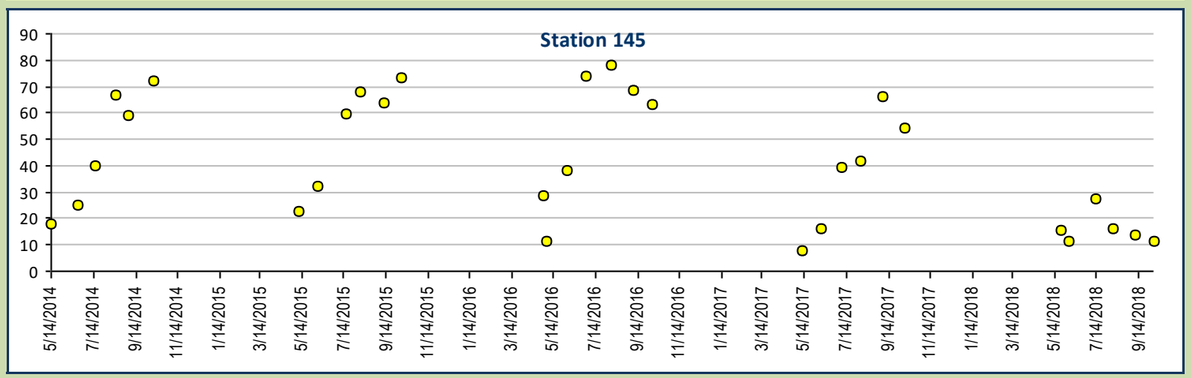
Aquatic Life - Fresh Water Chronic WQS mg/L

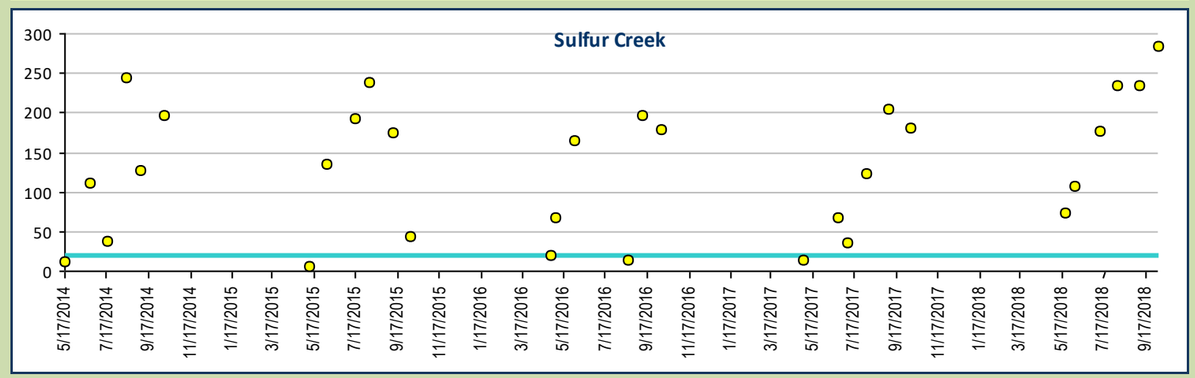
20 mg/L minimum

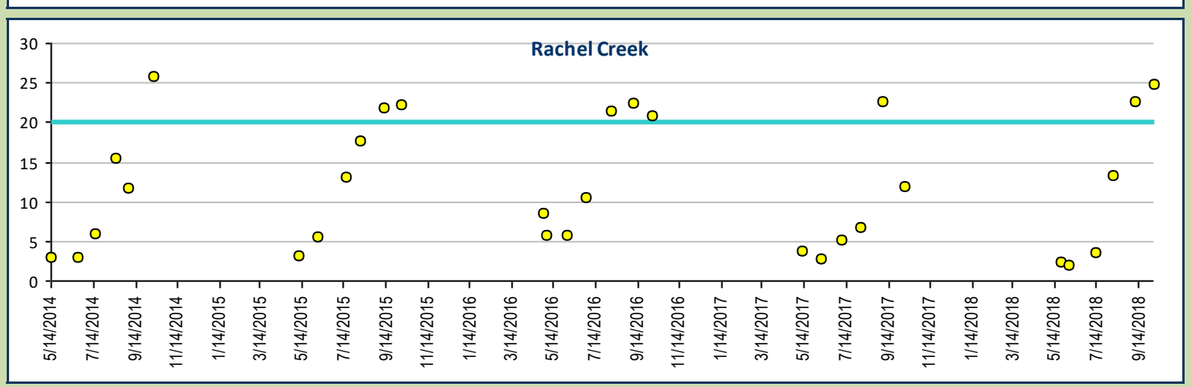


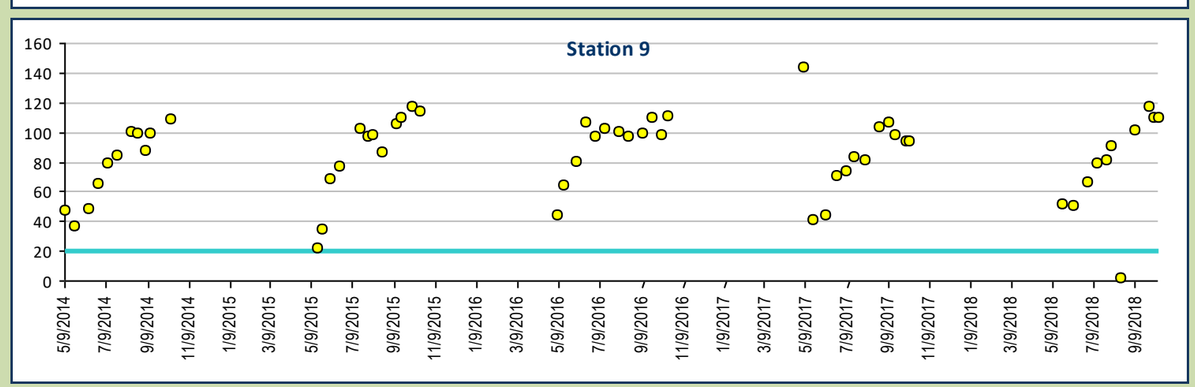










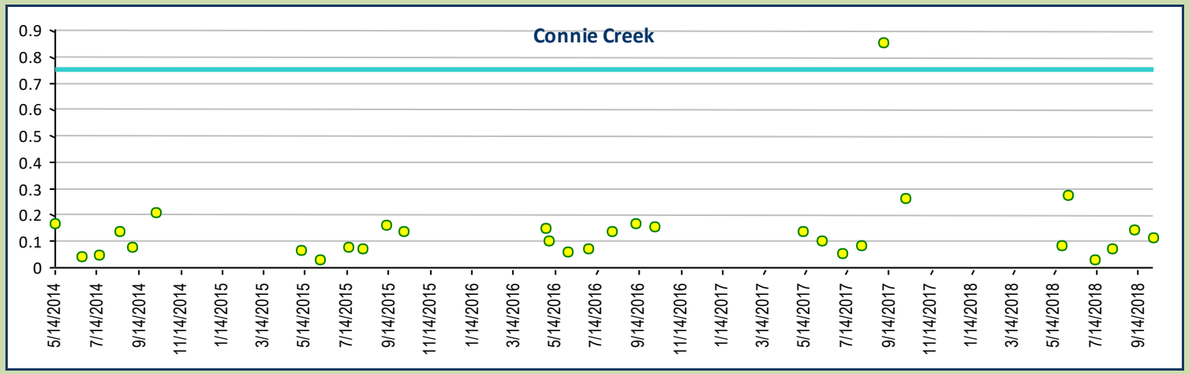


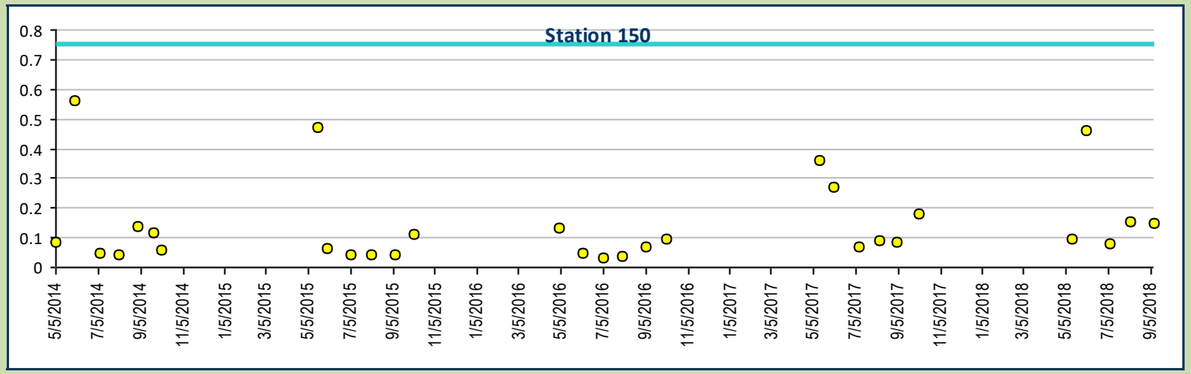
Water Monitoring Mine Drainage
Water Quality Profile I , 5-Year Trend Charts

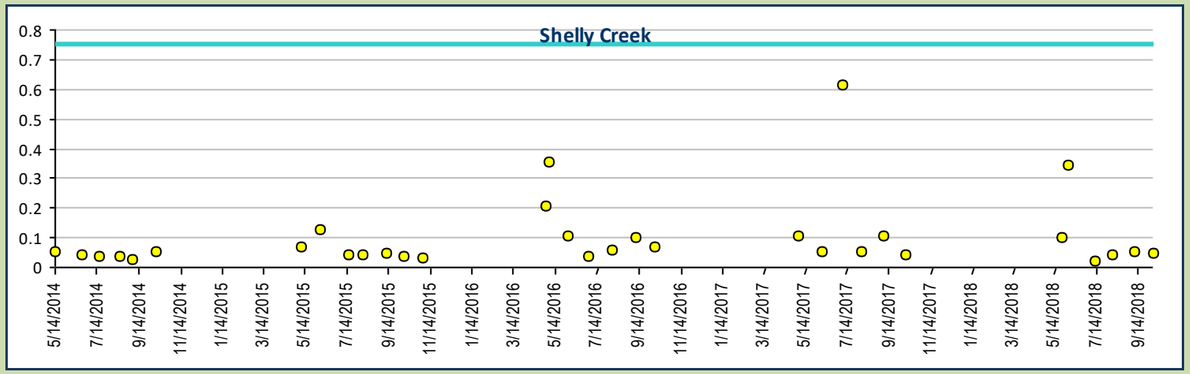
Aluminum, Total recoverable, units mg/L

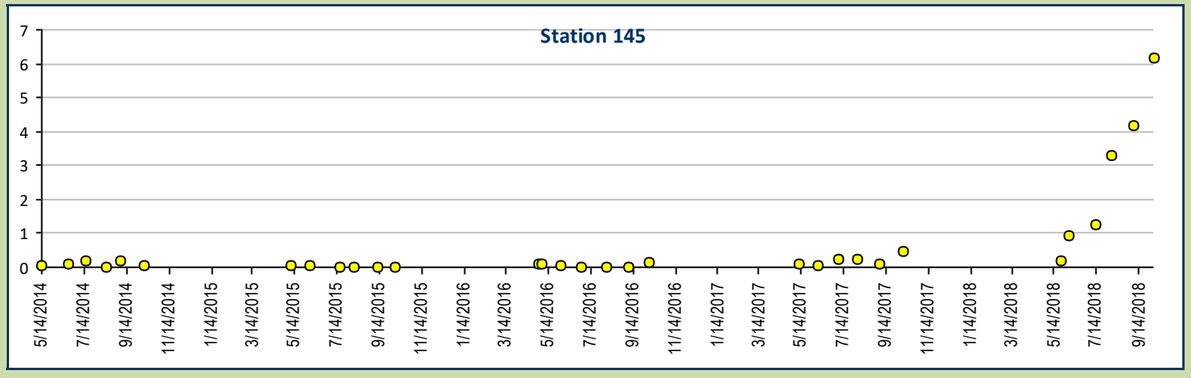
Aquatic Life - Fresh Water Chronic WQS mg/L

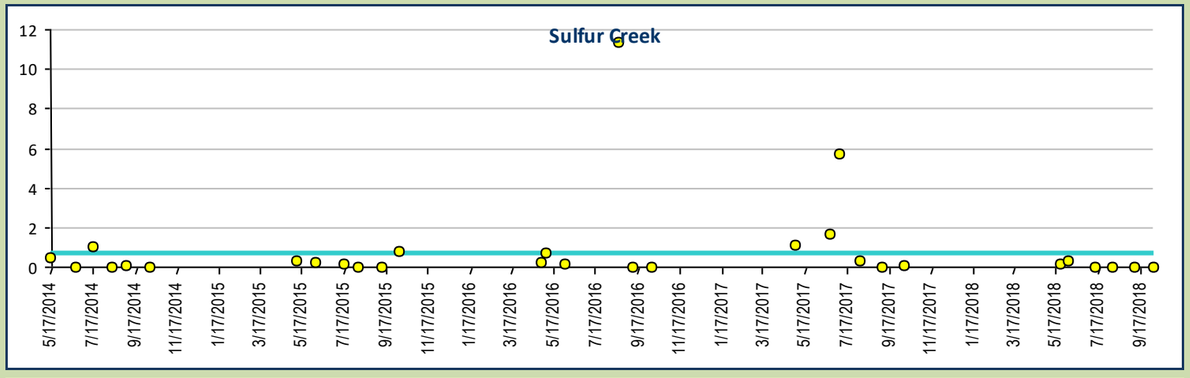
If pH > 7 and hardness > 50. then WQS = 0.75mg/l

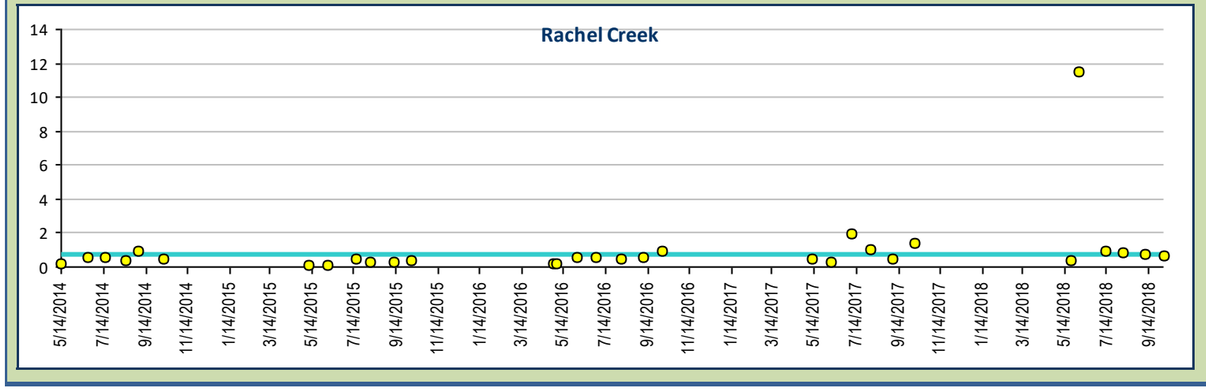


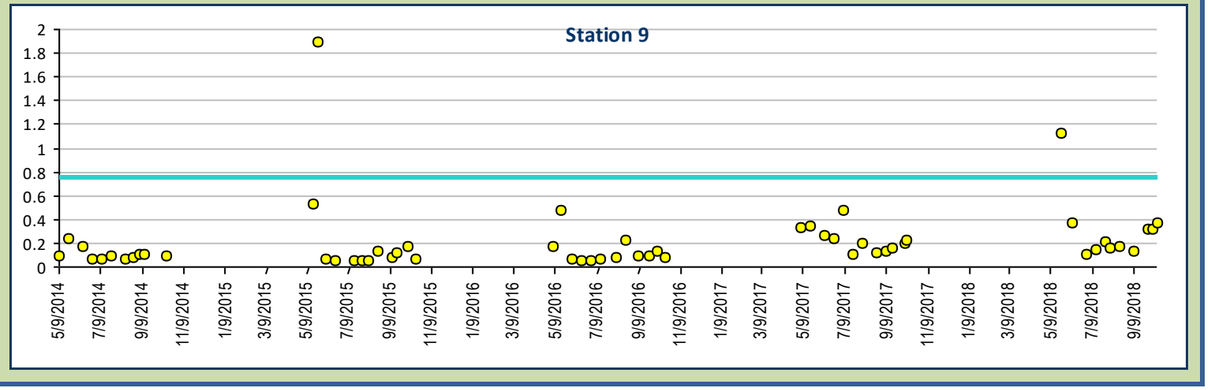












Appendix E: Water Quality Profile I Charts – Bons Creek Monitoring Stations

RED DOG MINE

Water Monitoring Bons Creek Drainage
Water Quality Profile I , 5-Year Trend Charts

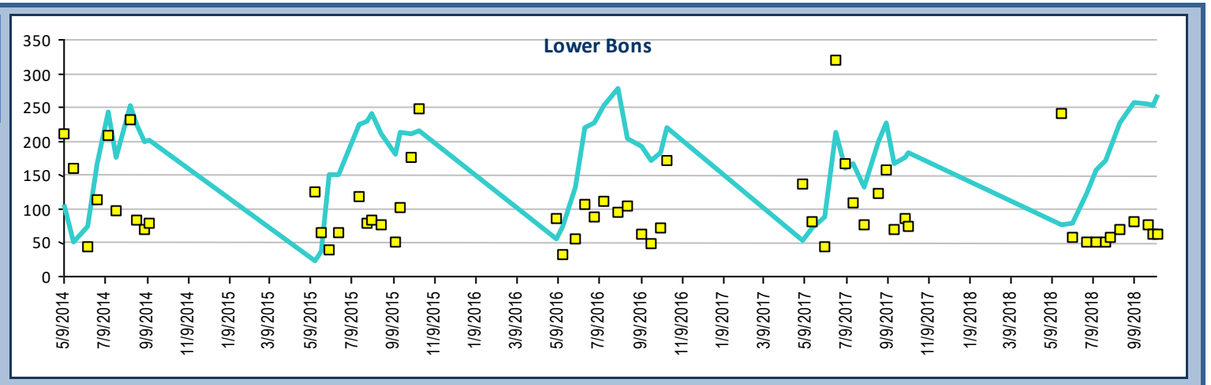
Zinc, Total Recoverable, units ug/L

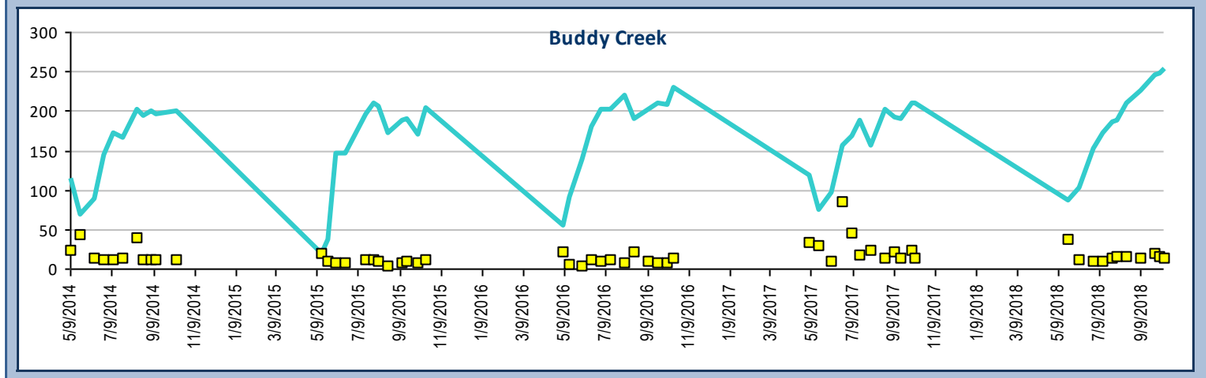
Aquatic Life - Fresh Water Acute WQS ug/L

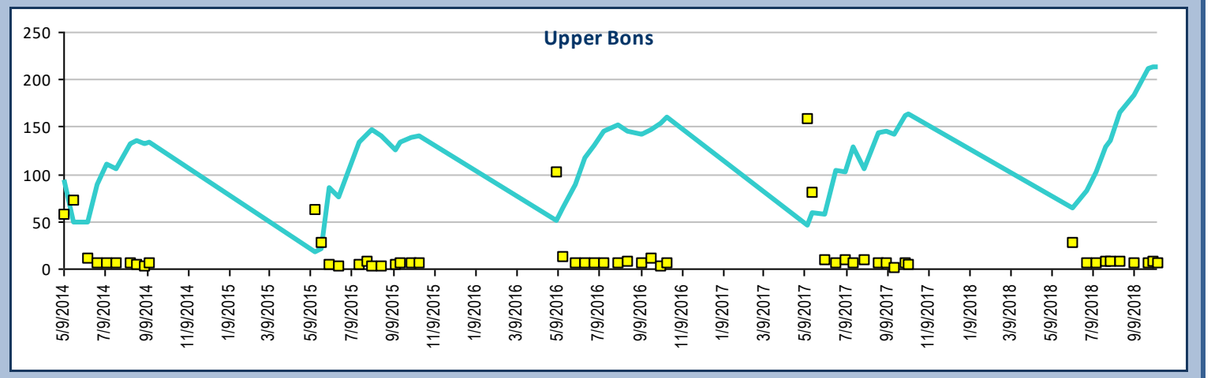
Hardness Dependent Calculation

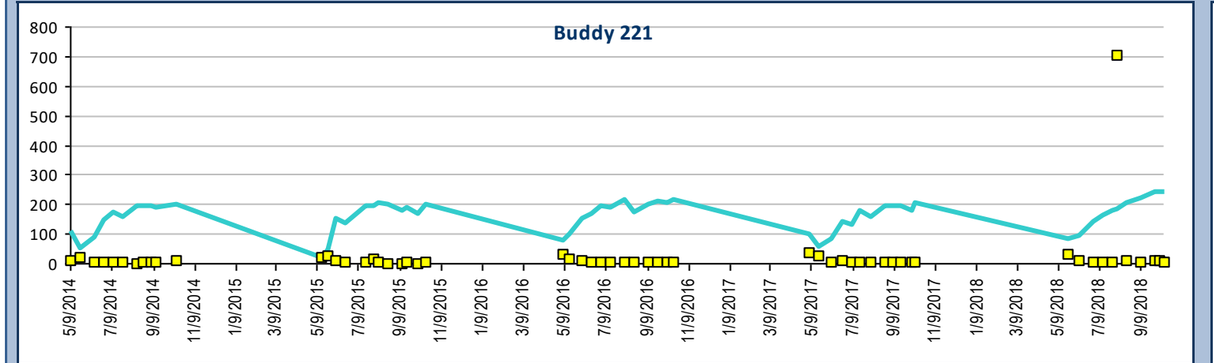
=EXP(0.8473*(LN(*hardness))+0.884)

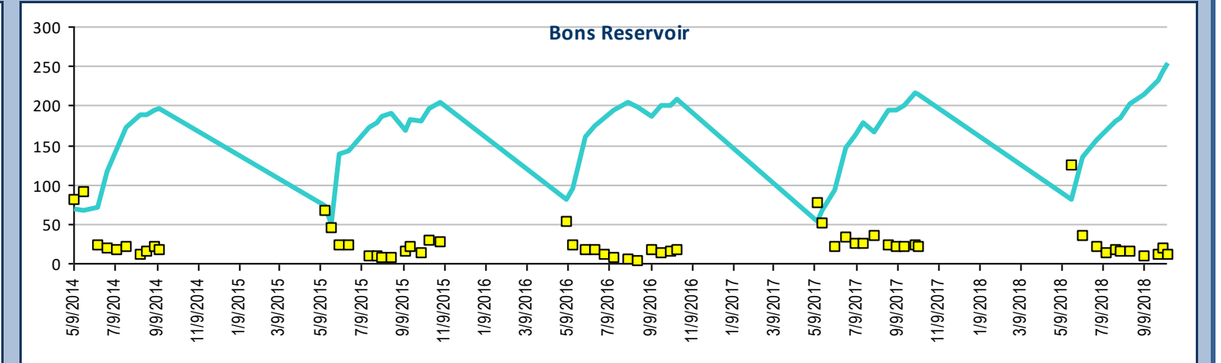
* Calculated using Standard Methods 2340B

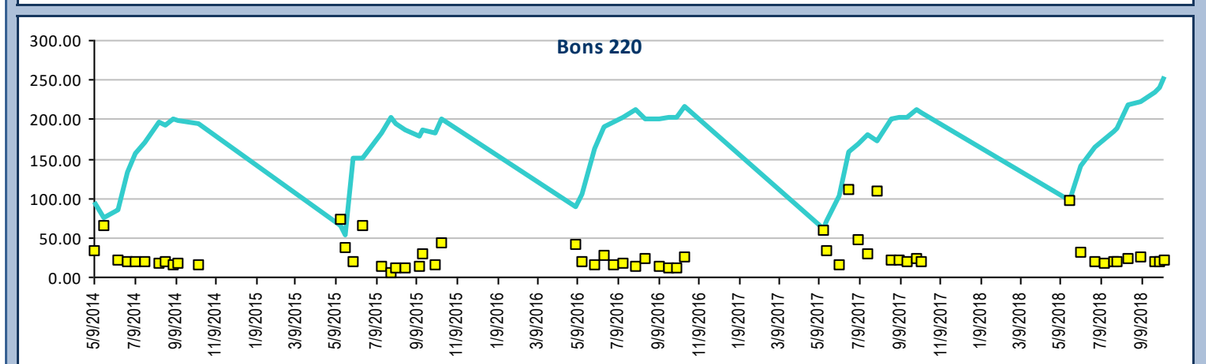


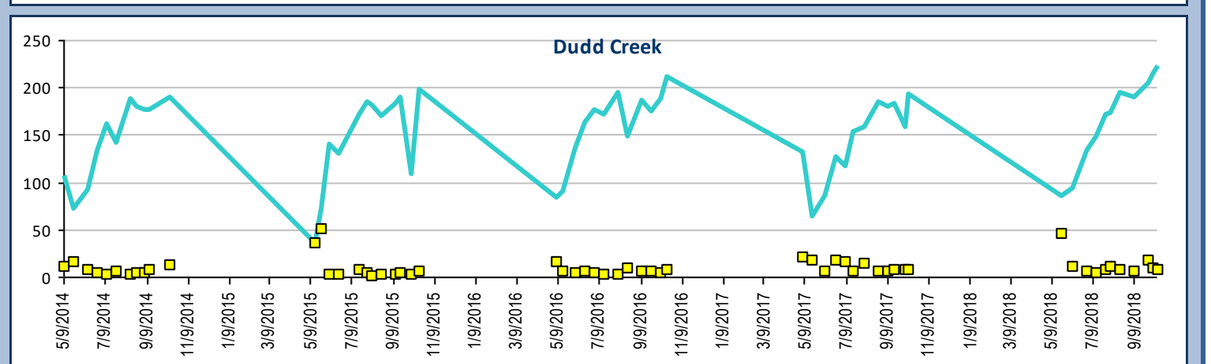






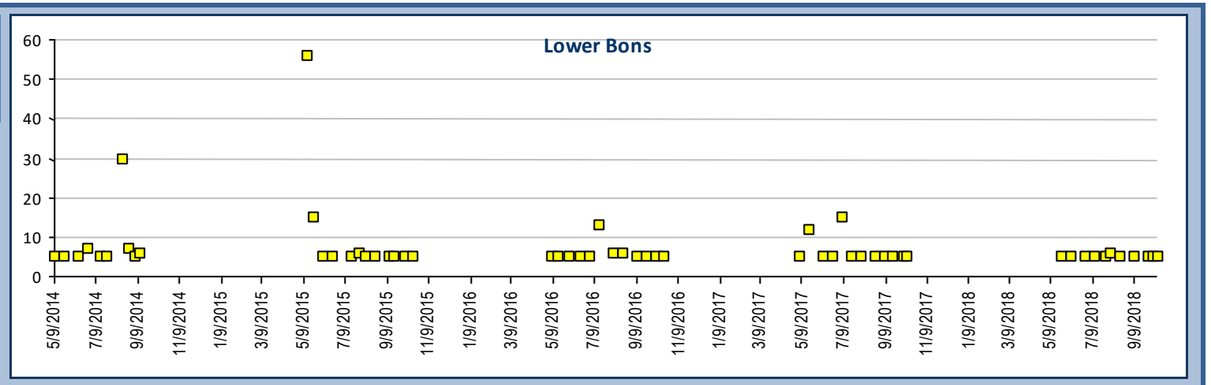


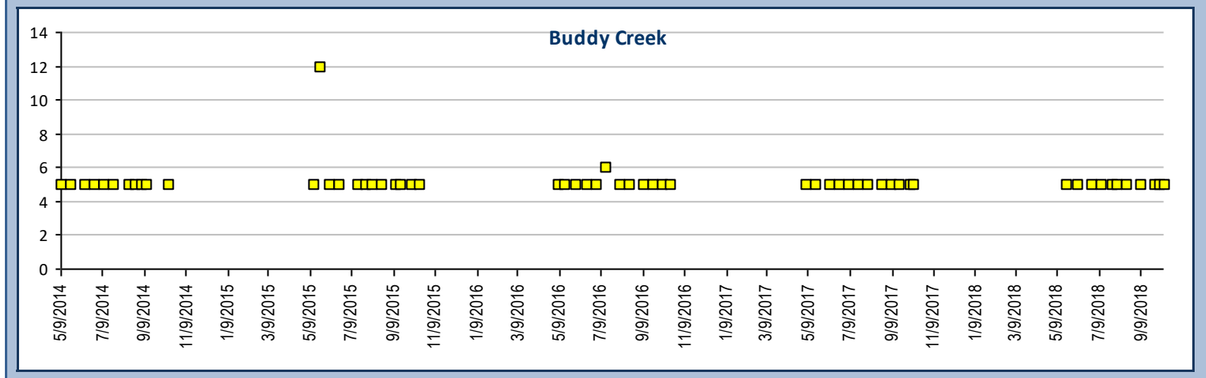


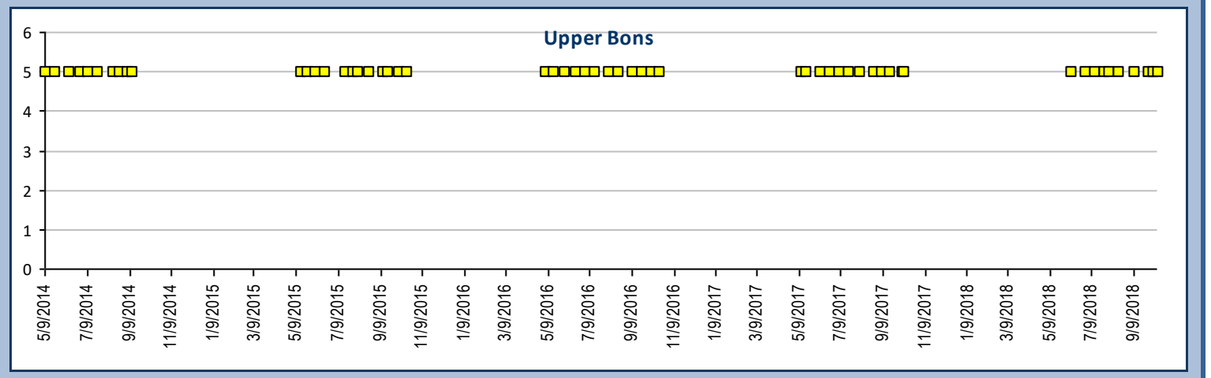


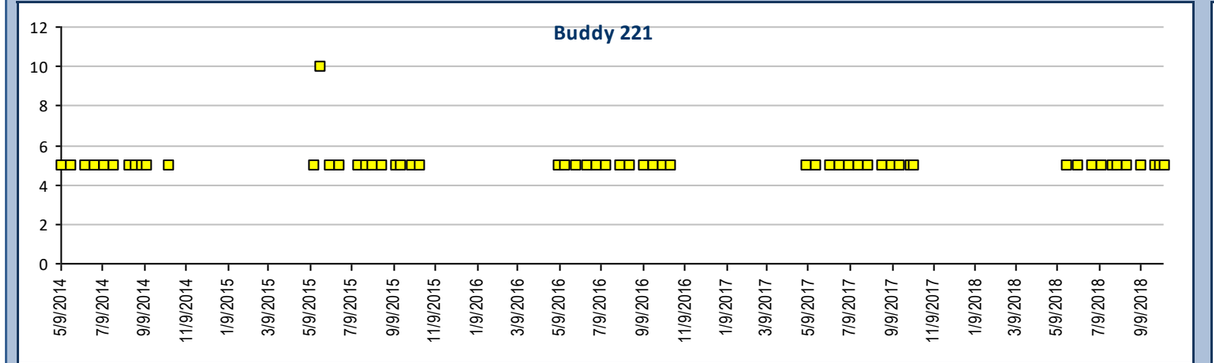
Water Monitoring Bons Creek Drainage
Water Quality Profile I , 5-Year Trend Charts

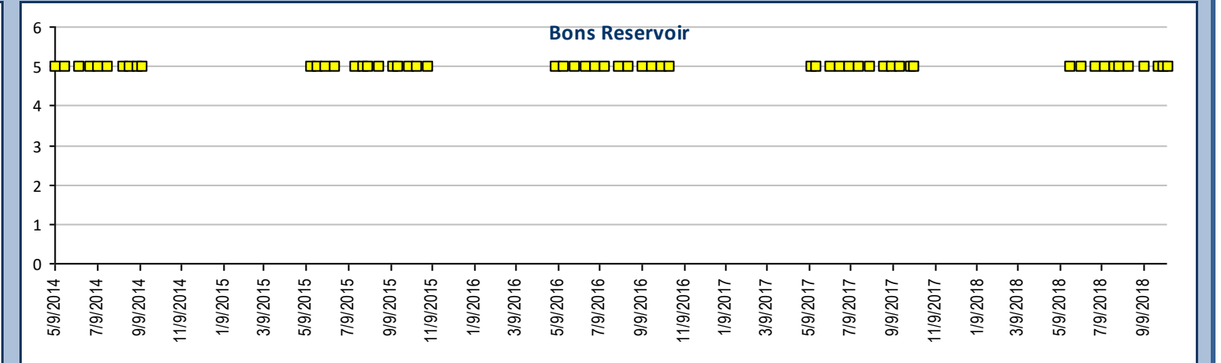
Total Suspended Solids, units mg/L

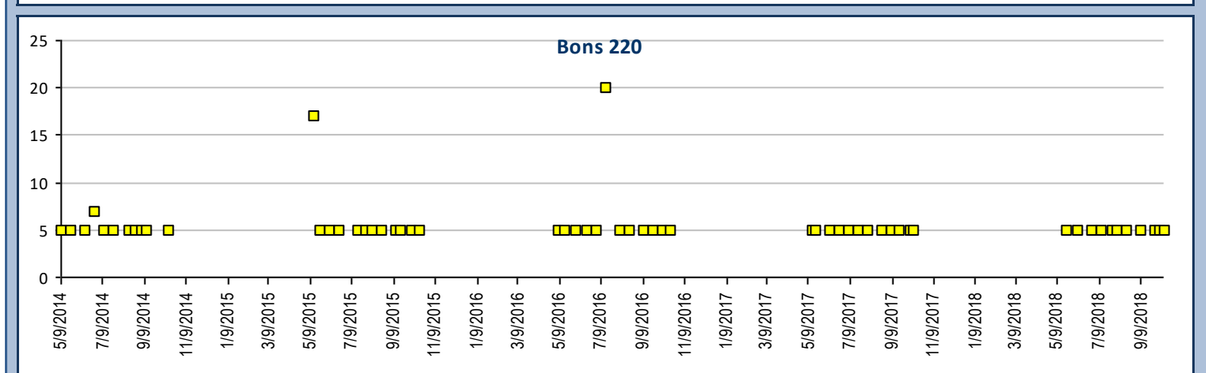


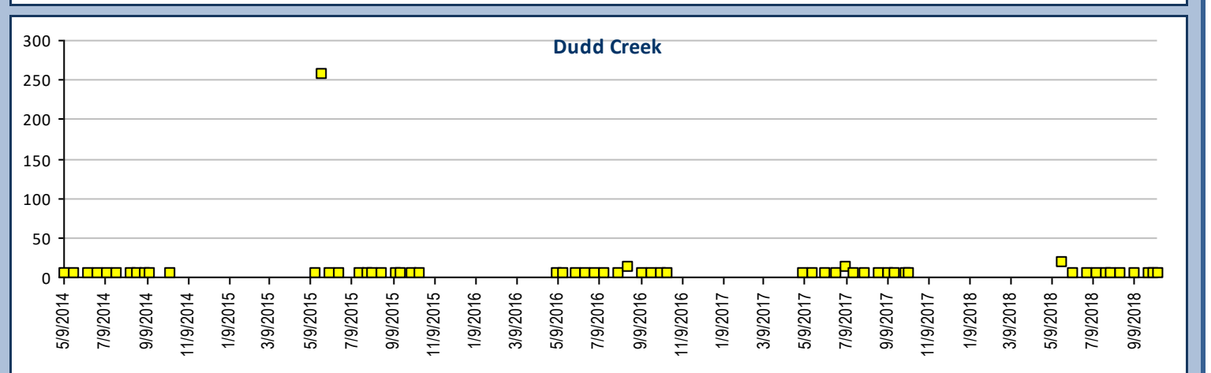










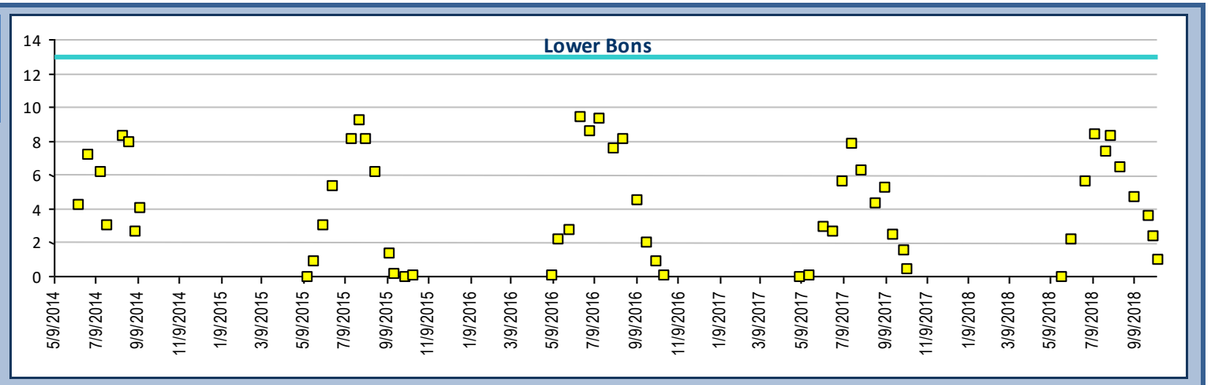


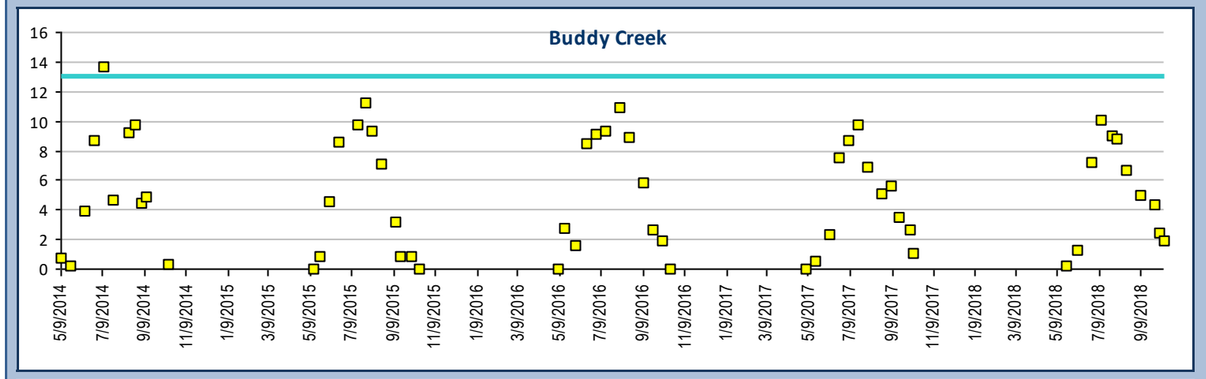
Water Monitoring Bons Creek Drainage
Water Quality Profile I , 5-Year Trend Charts

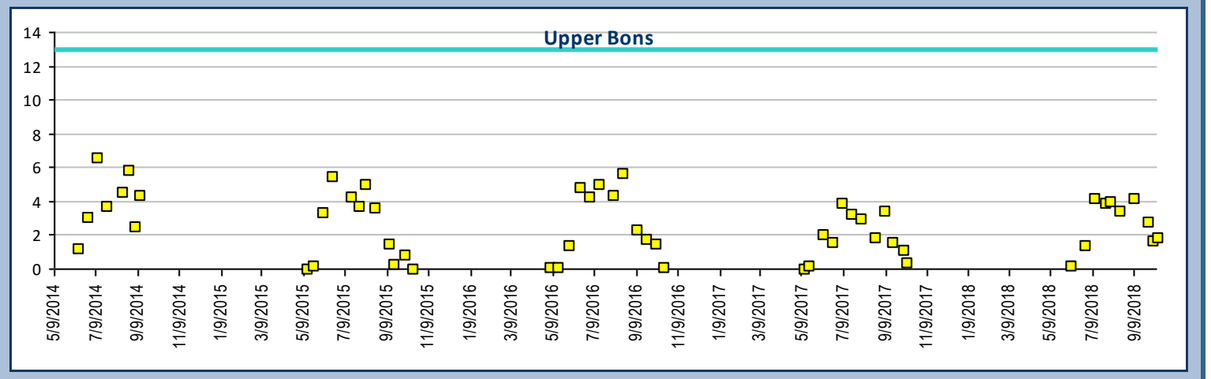
Temperature Field, units Celsius

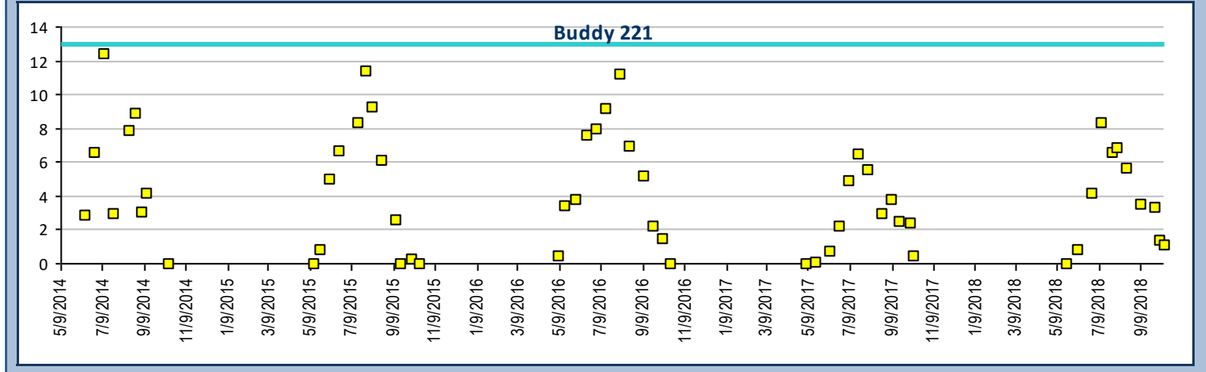
Site Specific WQS mg/L

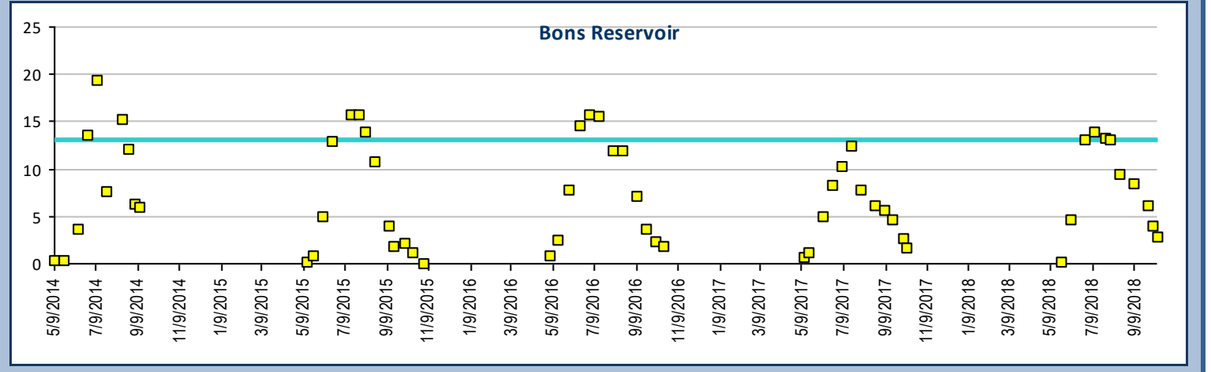
13 Celsius

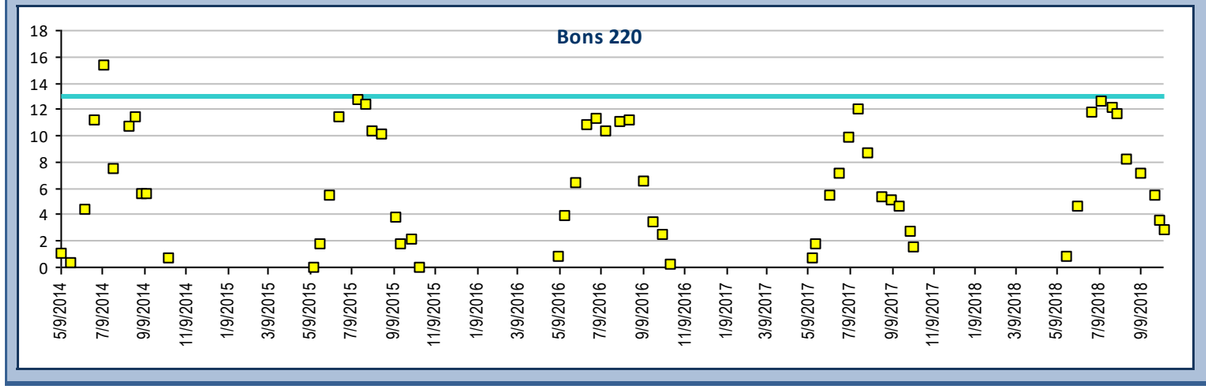


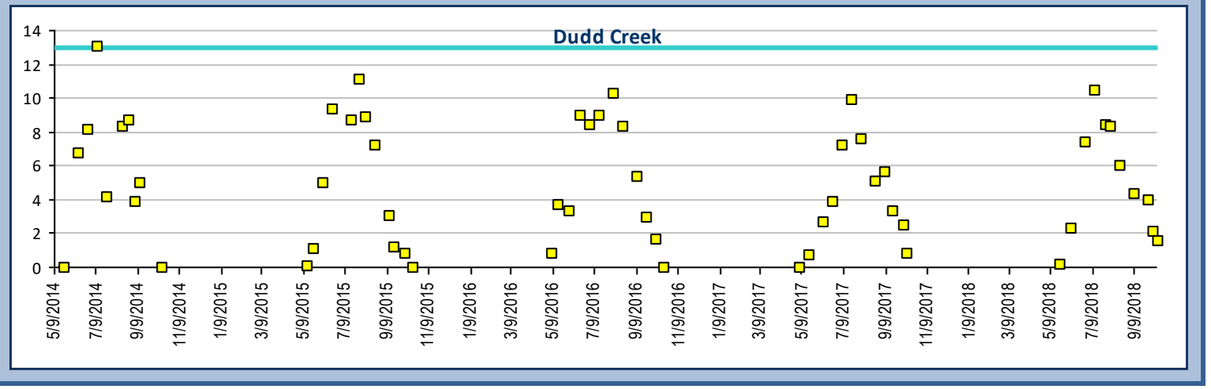










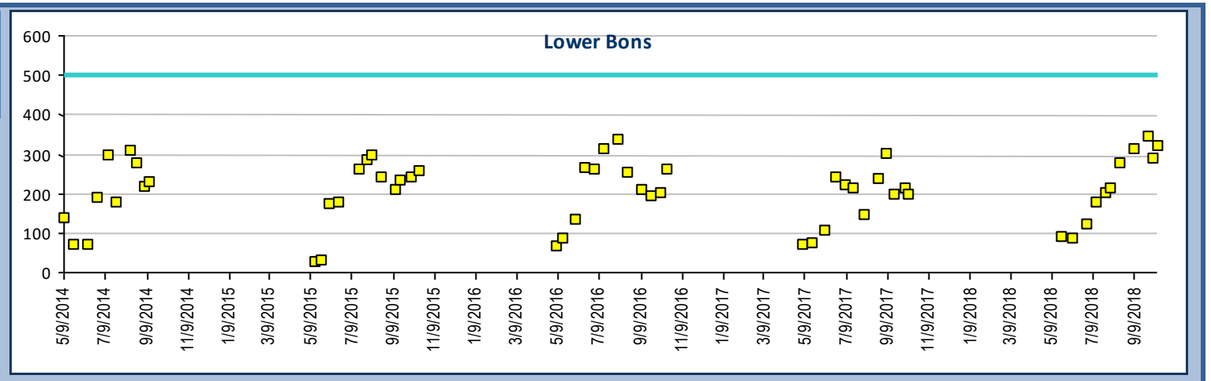


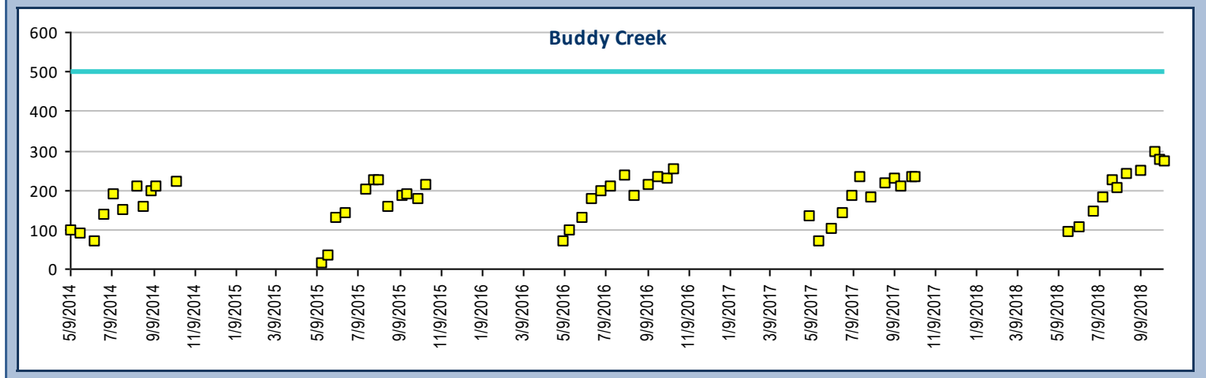
Water Monitoring Bons Creek Drainage
Water Quality Profile I , 5-Year Trend Charts

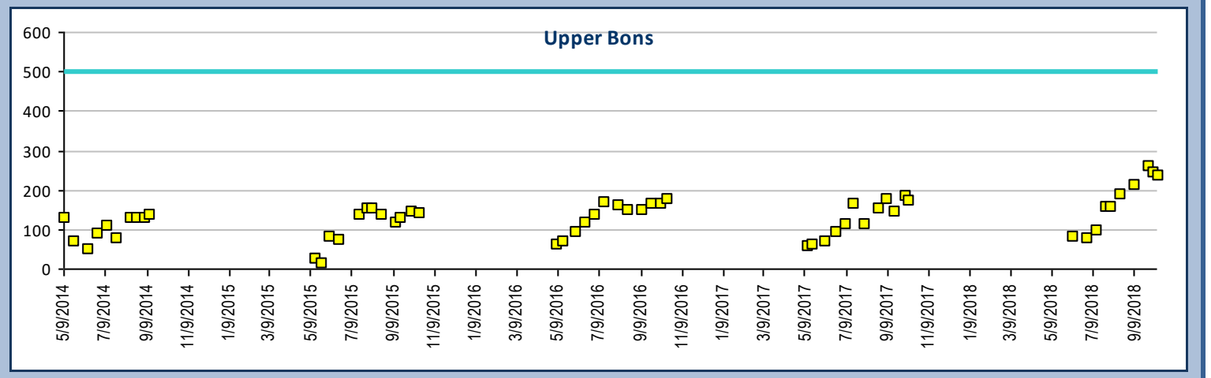
Total Dissolved Solids, units mg/L

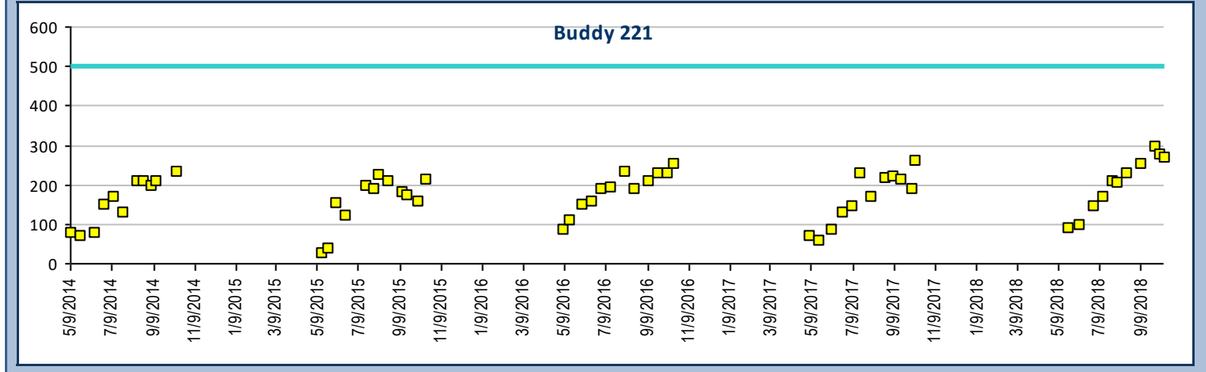
Site Specific WQS mg/L

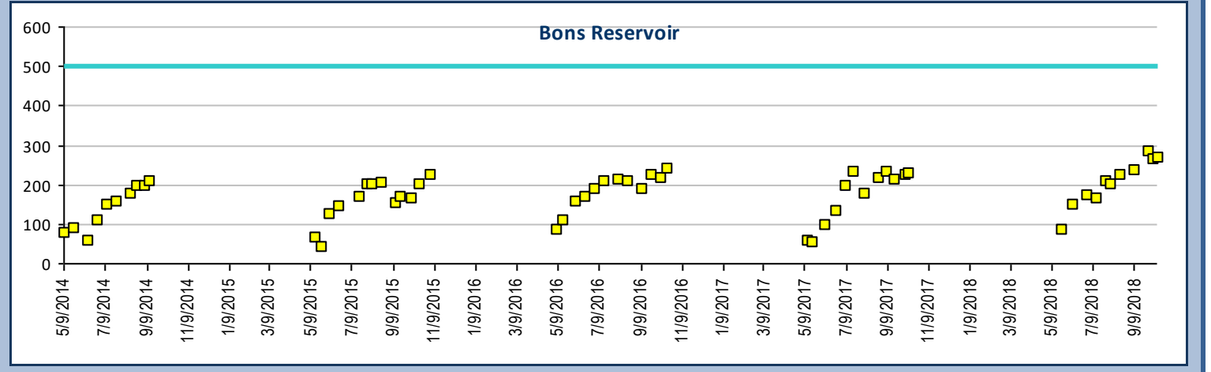
500 mg/L

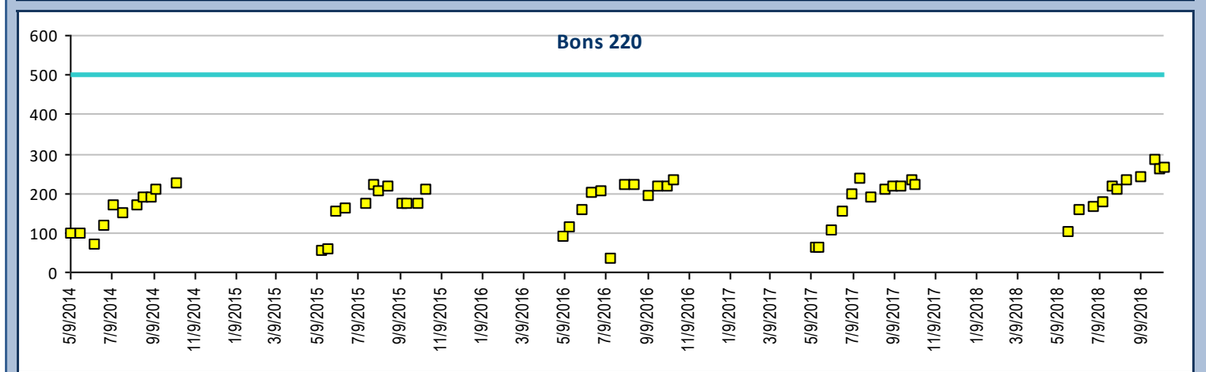


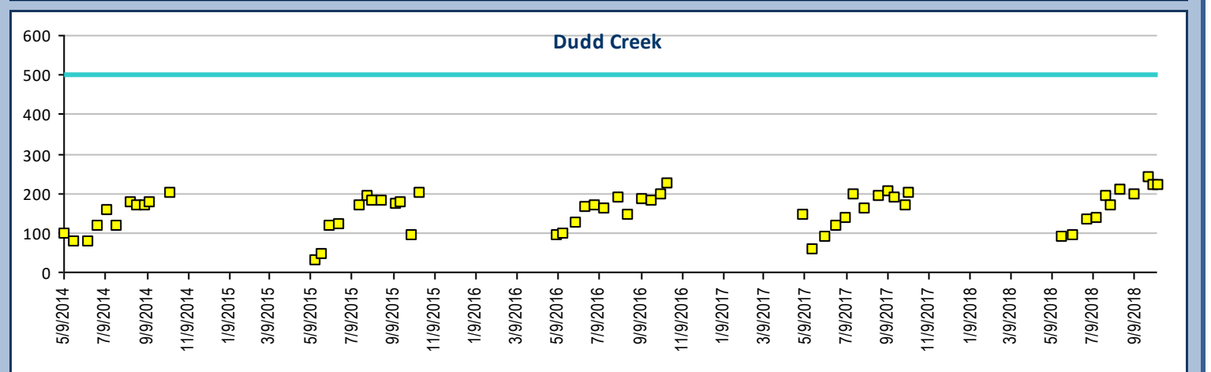






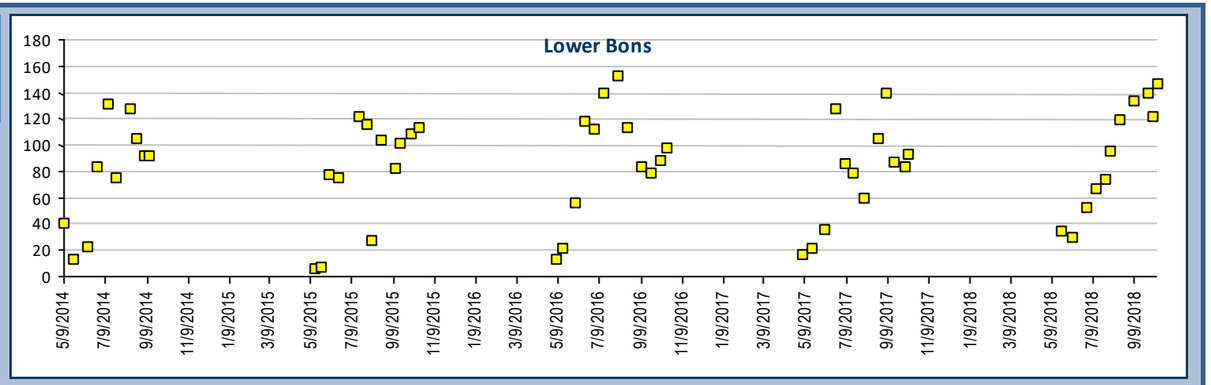


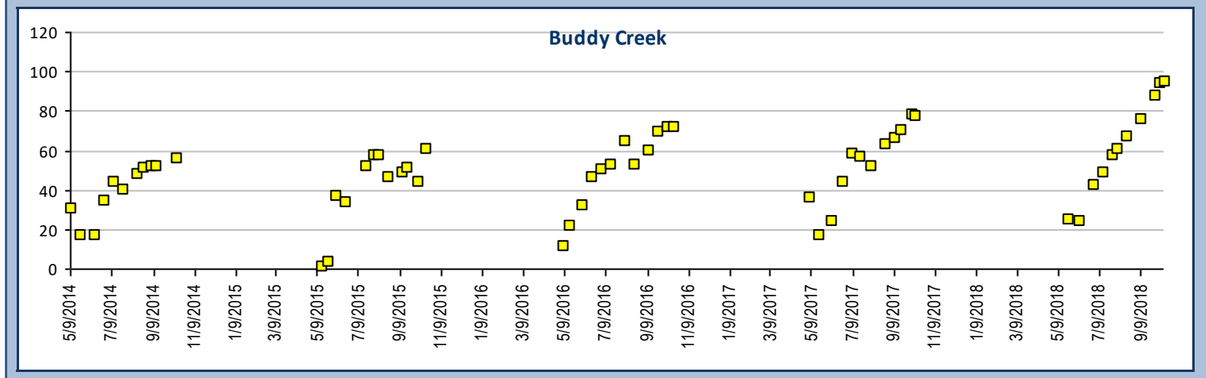


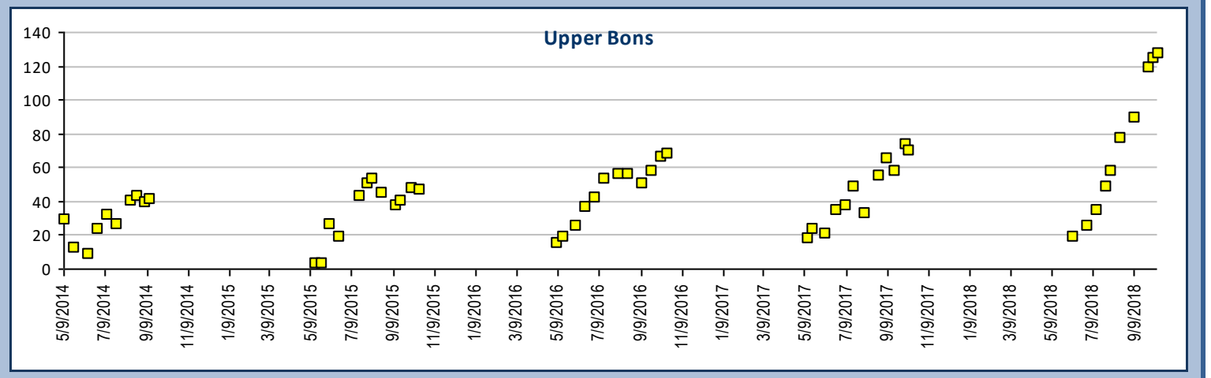


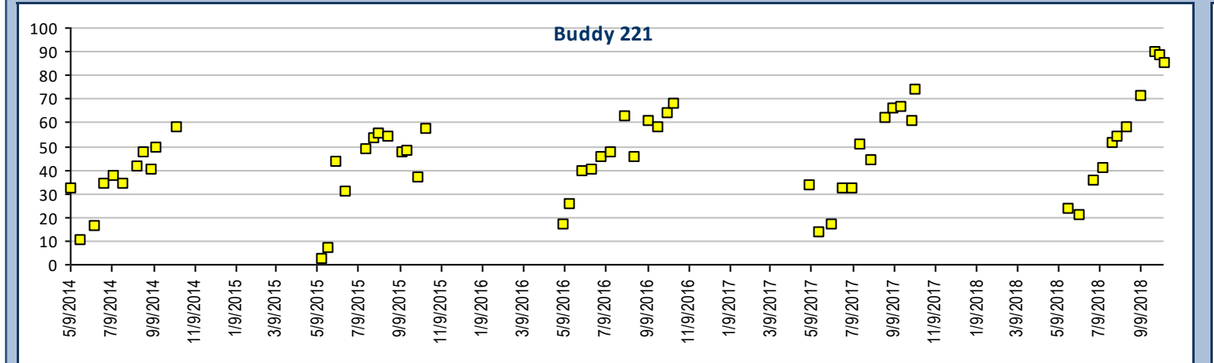
Water Monitoring Bons Creek Drainage
Water Quality Profile I , 5-Year Trend Charts

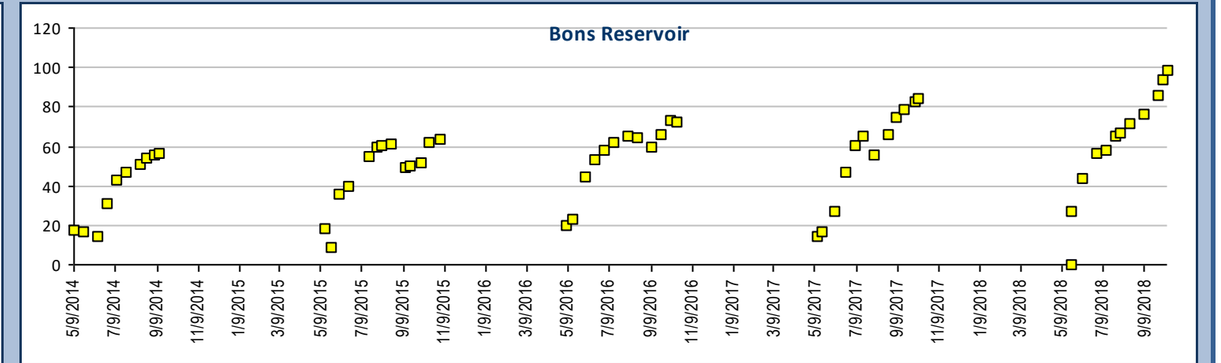
Sulfate, Total recoverable, units mg/L

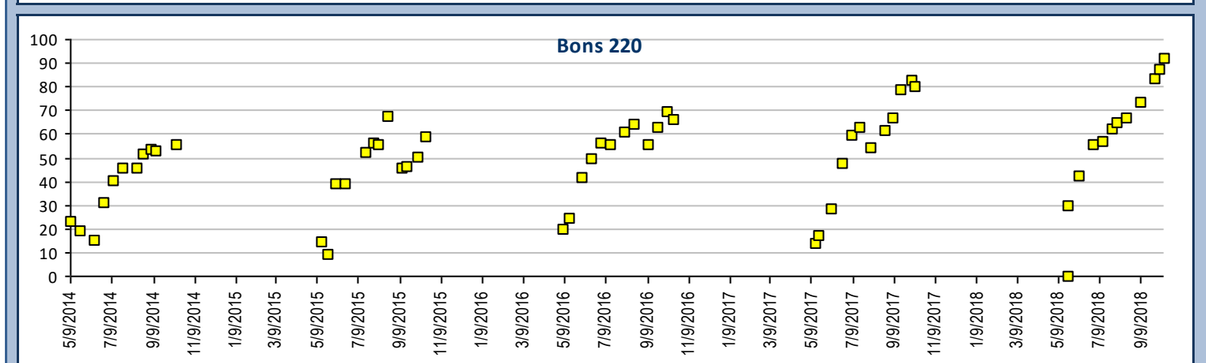


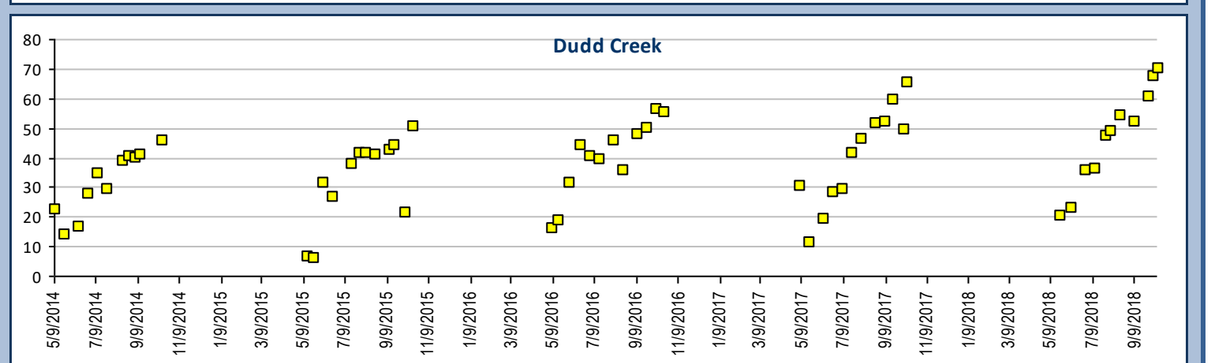










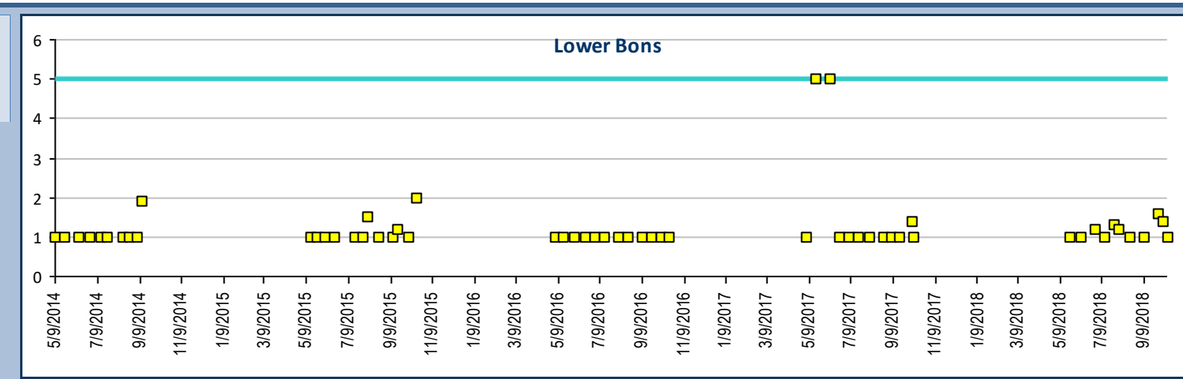


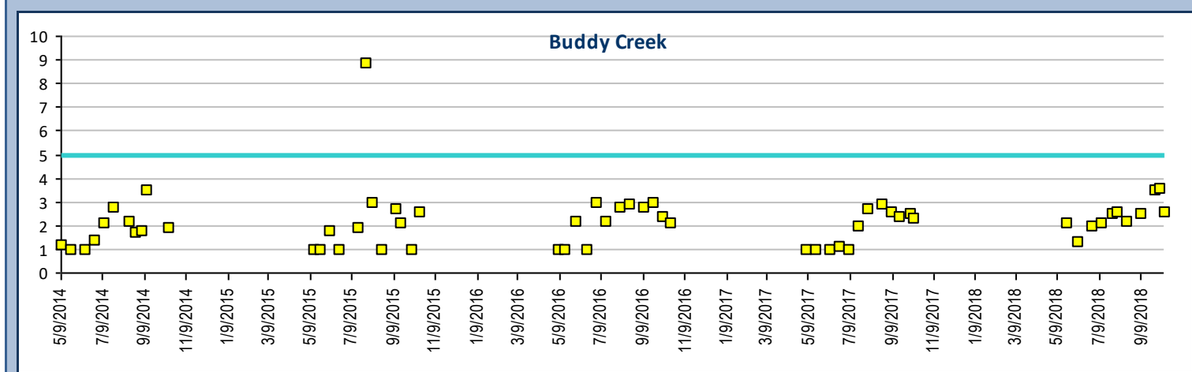
Water Monitoring Bons Creek Drainage
Water Quality Profile I , 5-Year Trend Charts

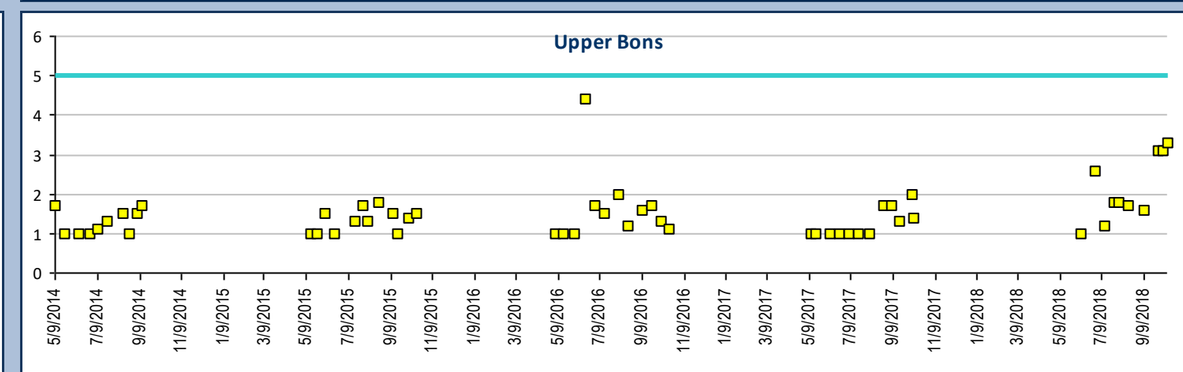
Selenium, Total Recoverable, units ug/L

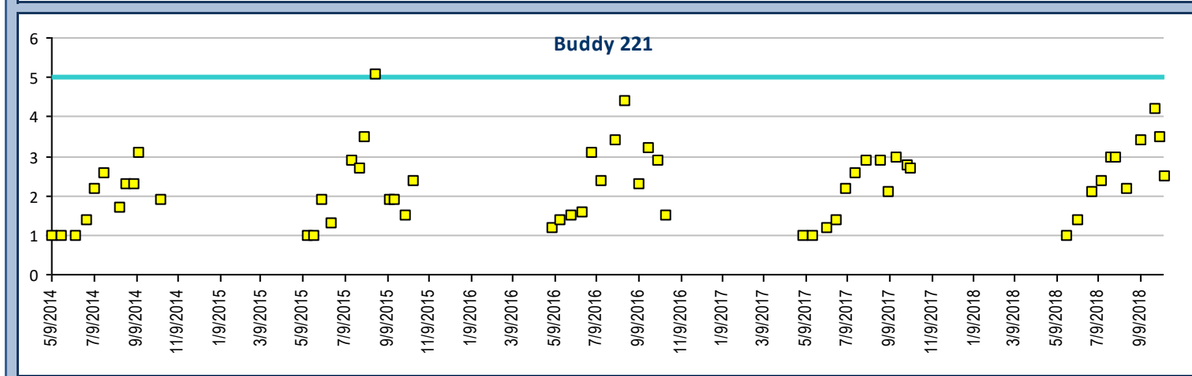
Aquatic Life - Fresh Water Chronic WQS ug/L

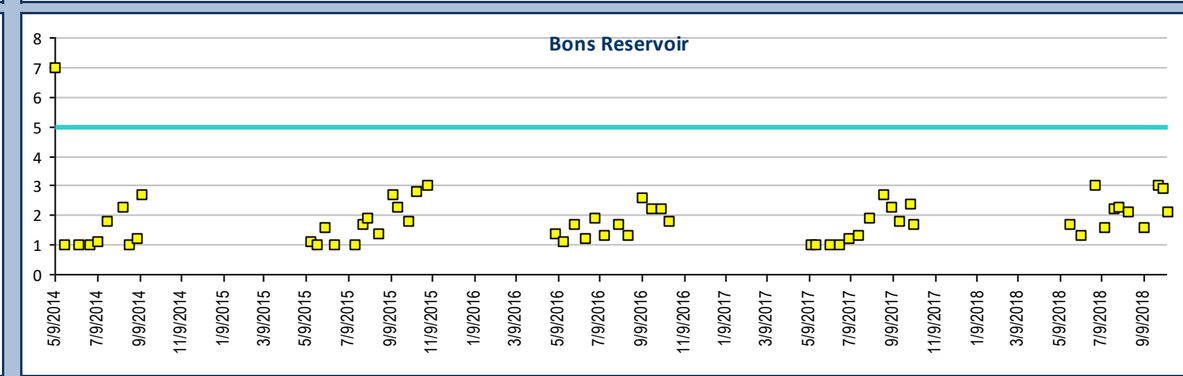
5 ug/L

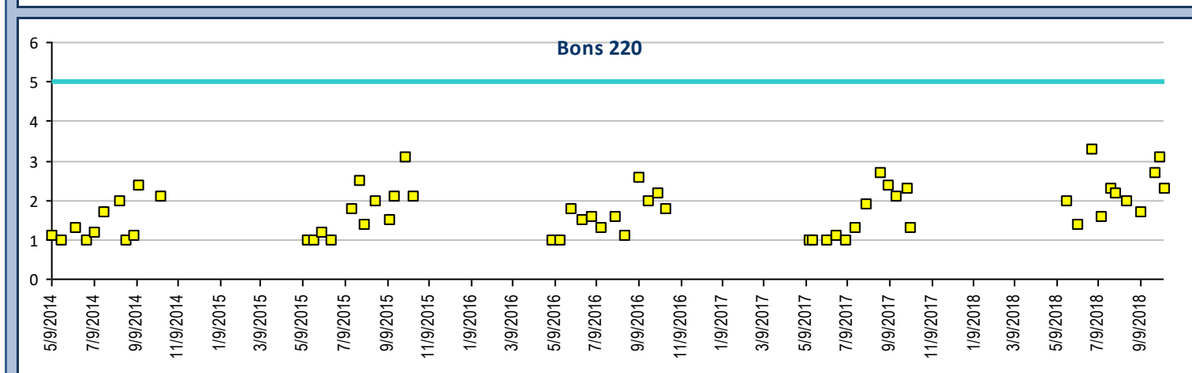


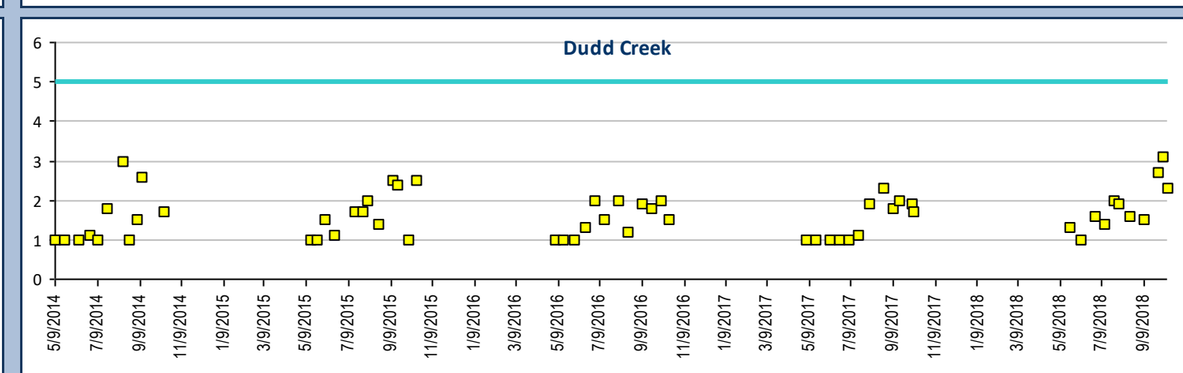










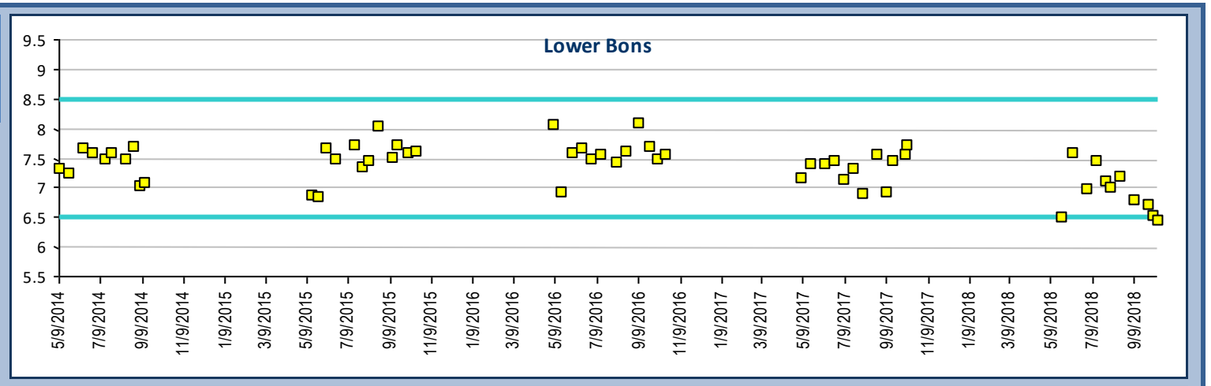


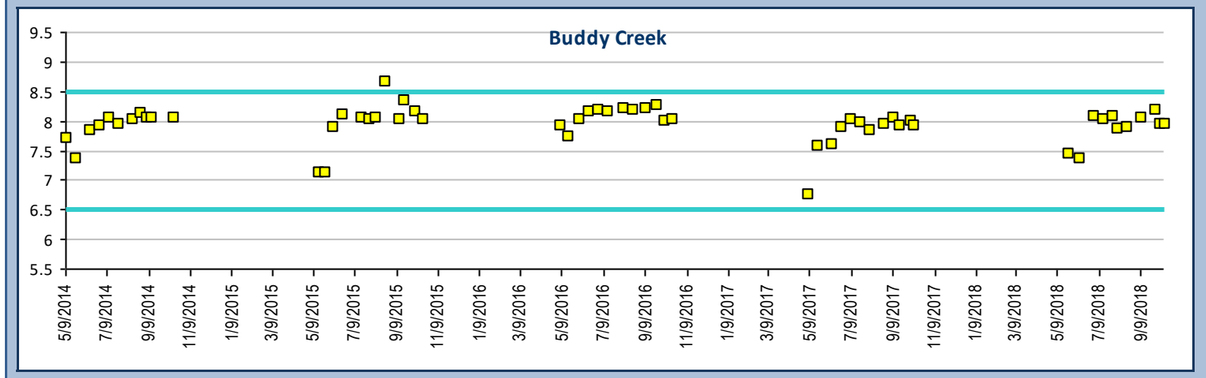
RED DOG MINE

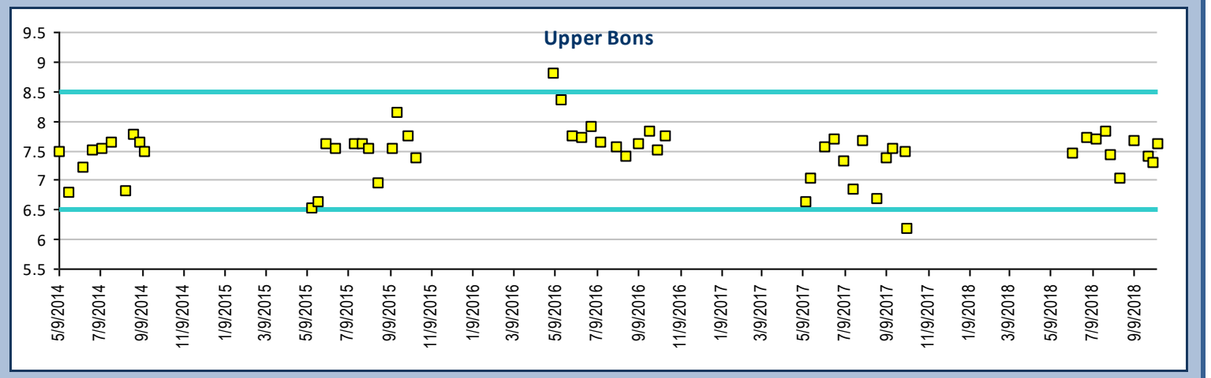
Water Monitoring Bons Creek Drainage
Water Quality Profile I , 5-Year Trend Charts

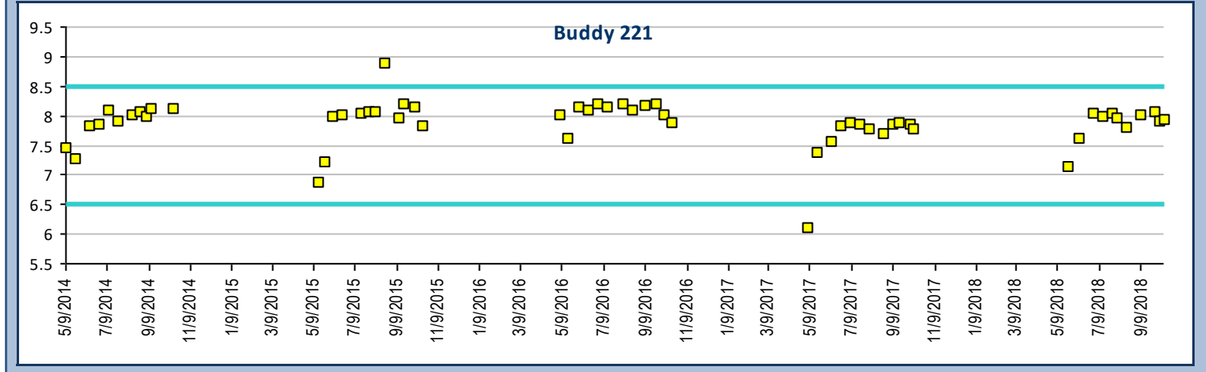
pH

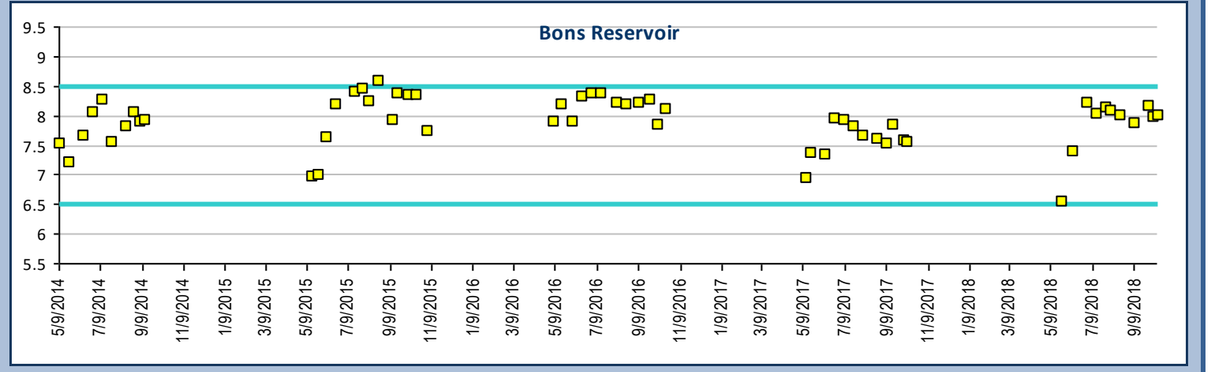
Site Specific WQS between 6.5 and 8.5

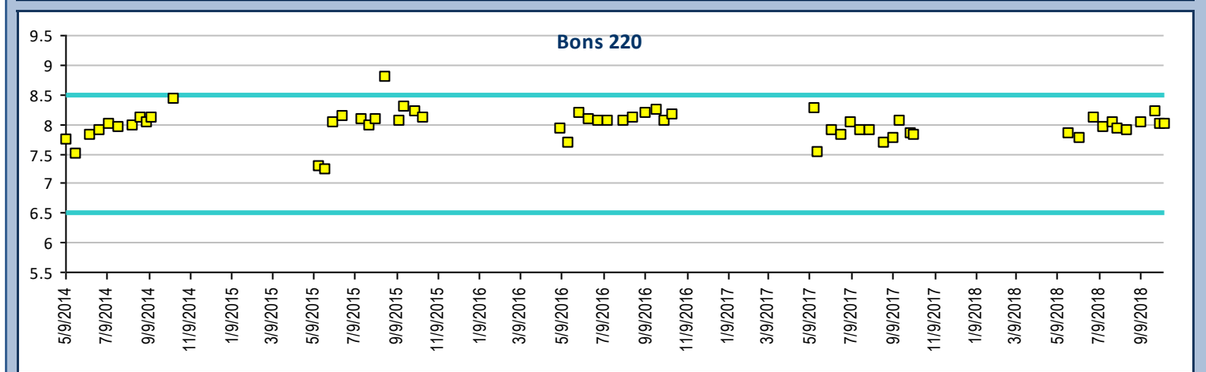


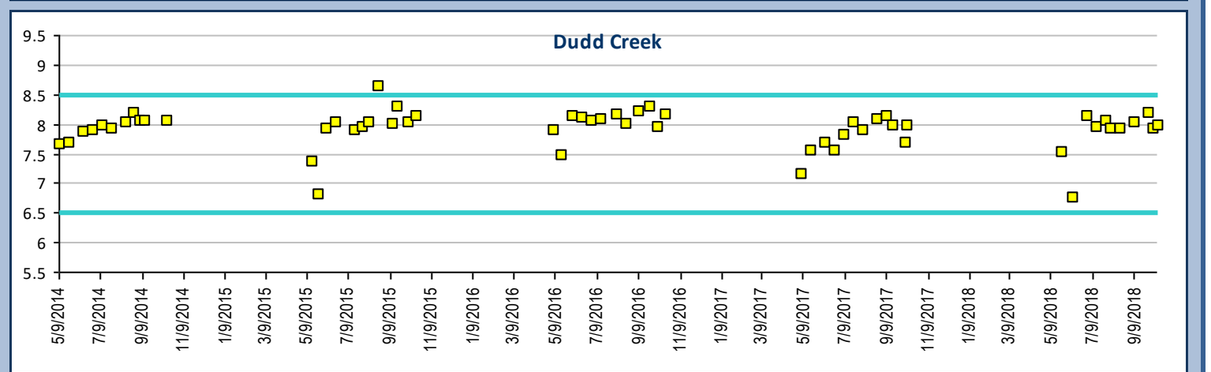












Water Monitoring Bons Creek Drainage
Water Quality Profile I , 5-Year Trend Charts

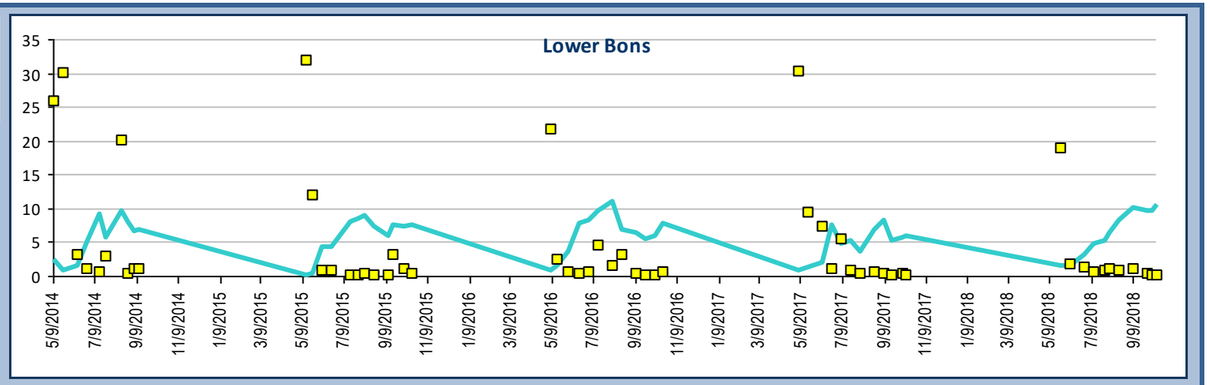
Lead, Total recoverable, units ug/L

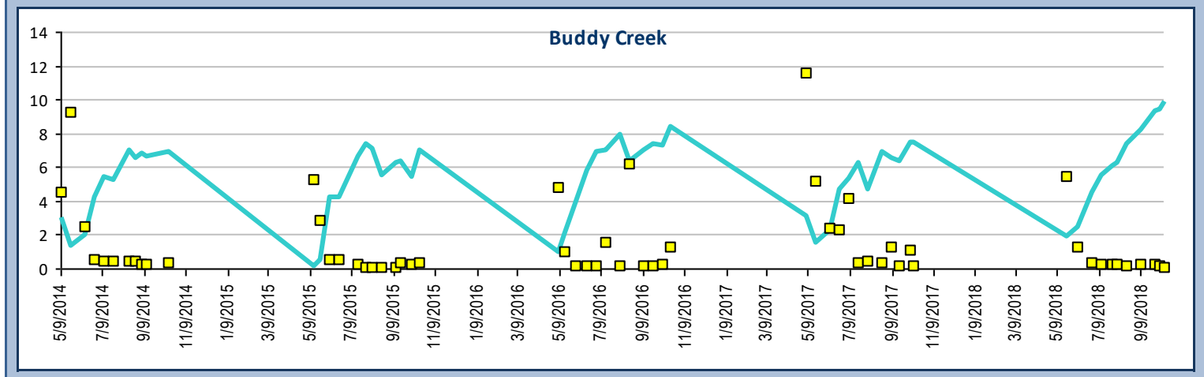
Aquatic Life - Fresh Water Chronic WQS ug/L

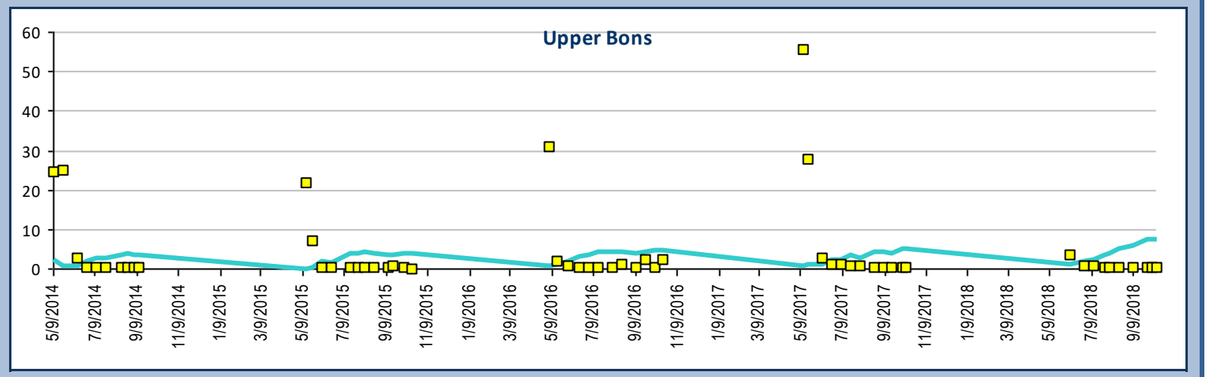
Hardness Dependent Calculation

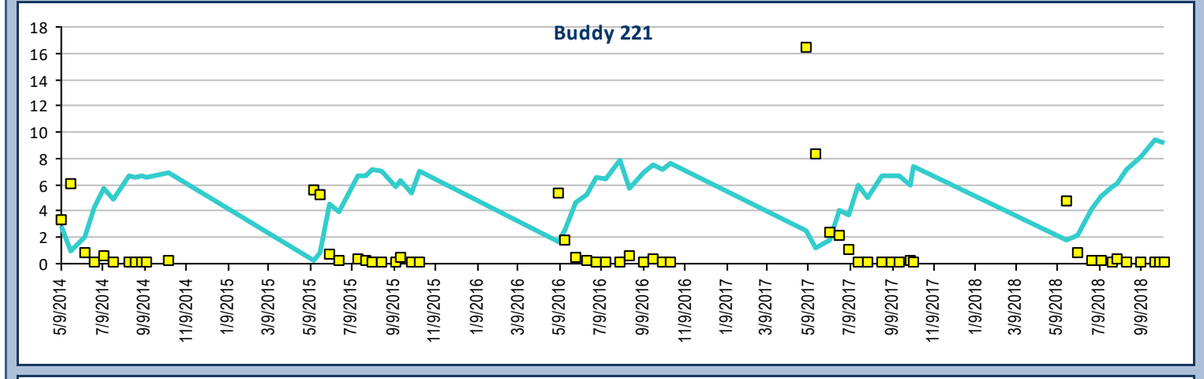
=EXP(1.273*(LN(calc *hardness))-4.705)

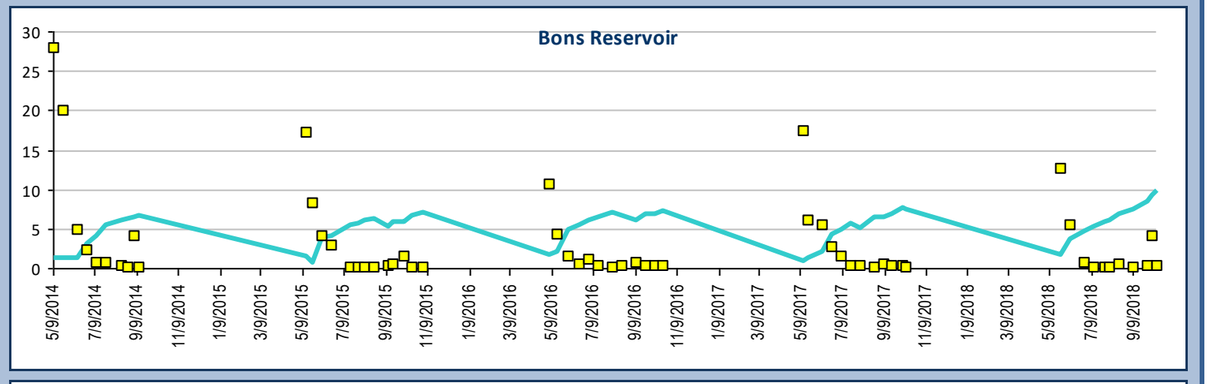
* Calculated using Standard Methods 2340B

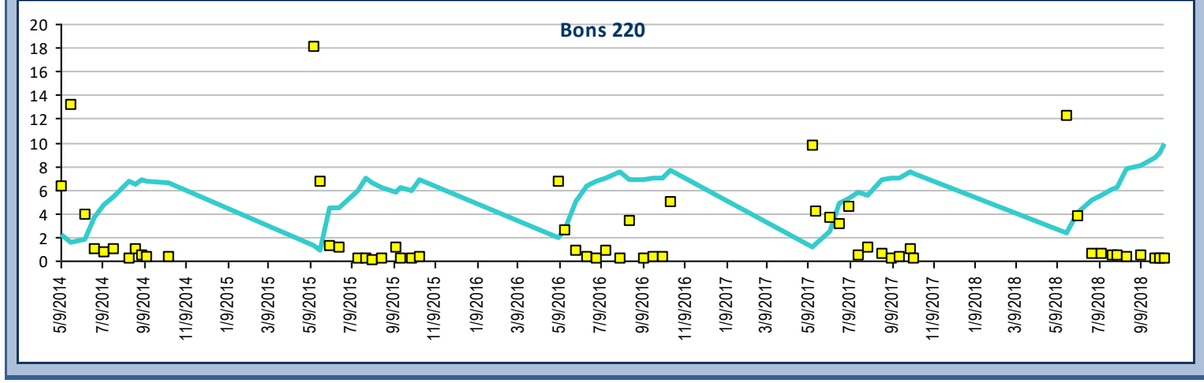


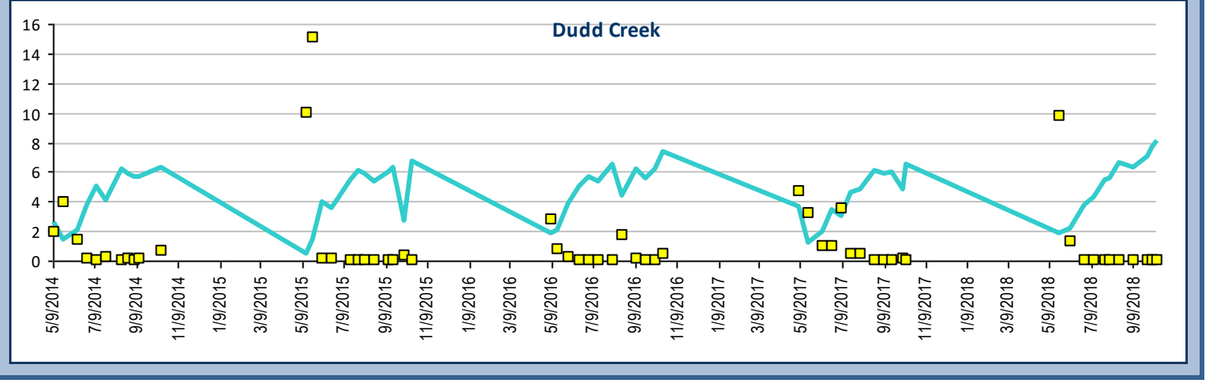








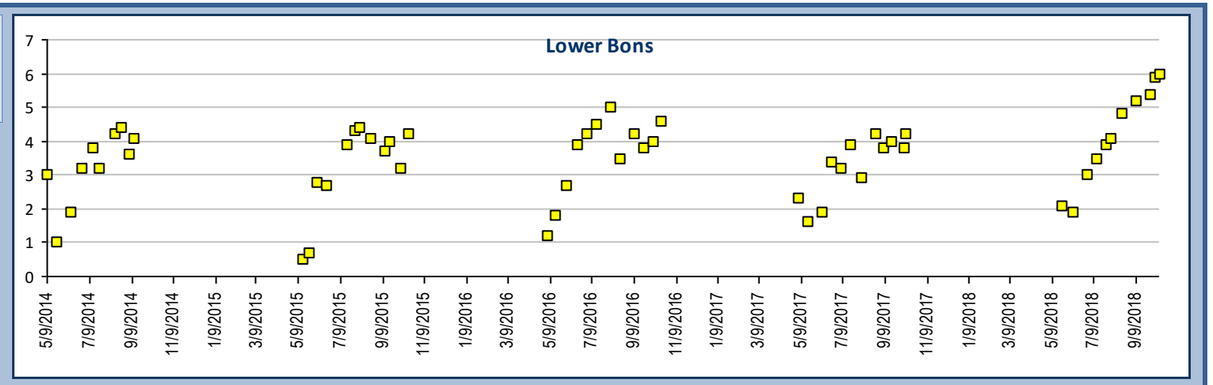


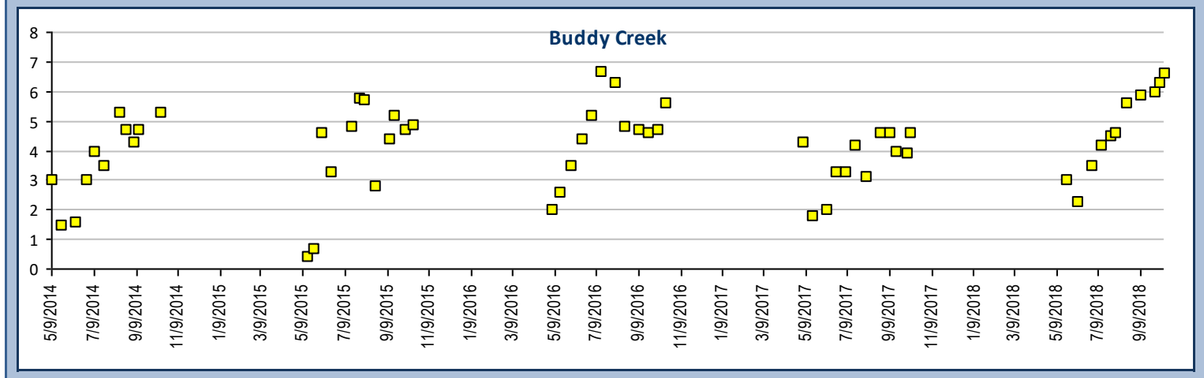


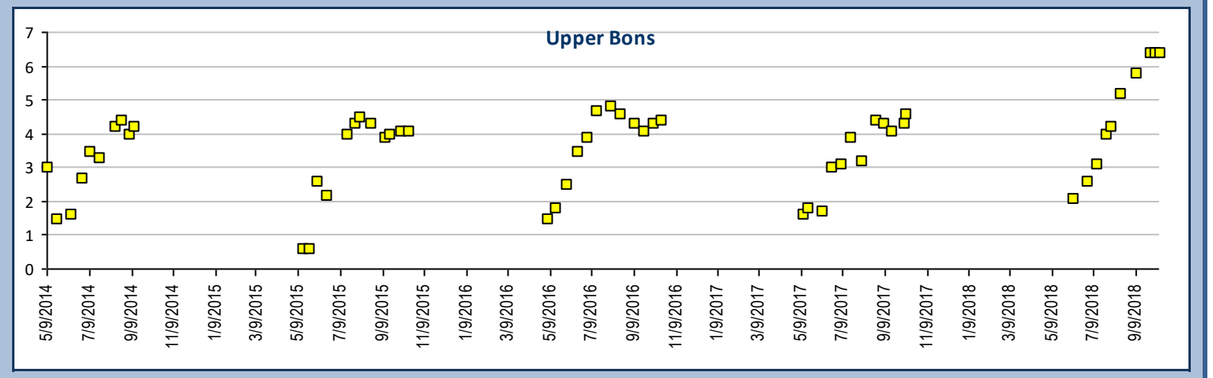
RED DOG MINE

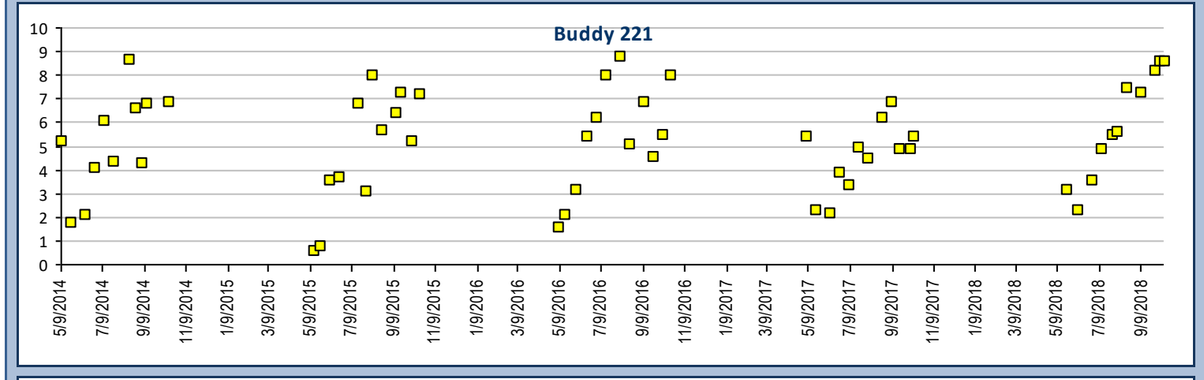
Water Monitoring Bons Creek Drainage
Water Quality Profile I , 5-Year Trend Charts

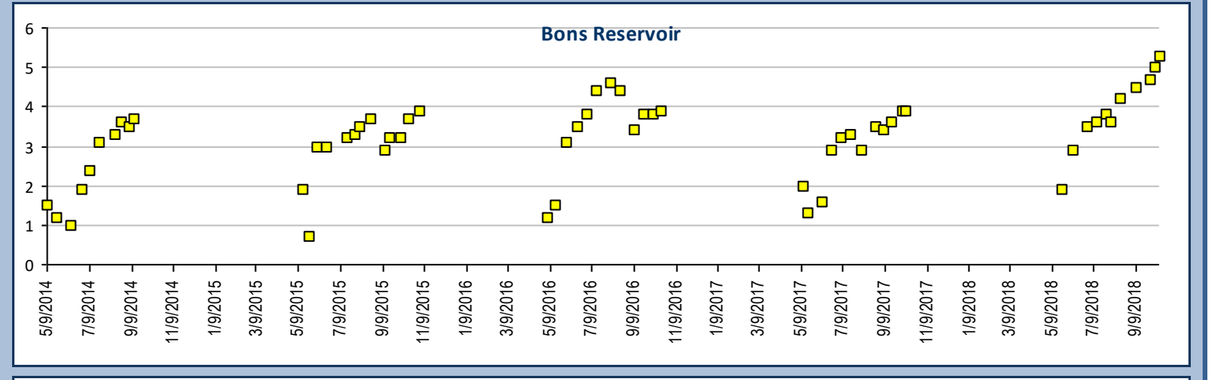
Sodium, Total Recoverable, units mg/L

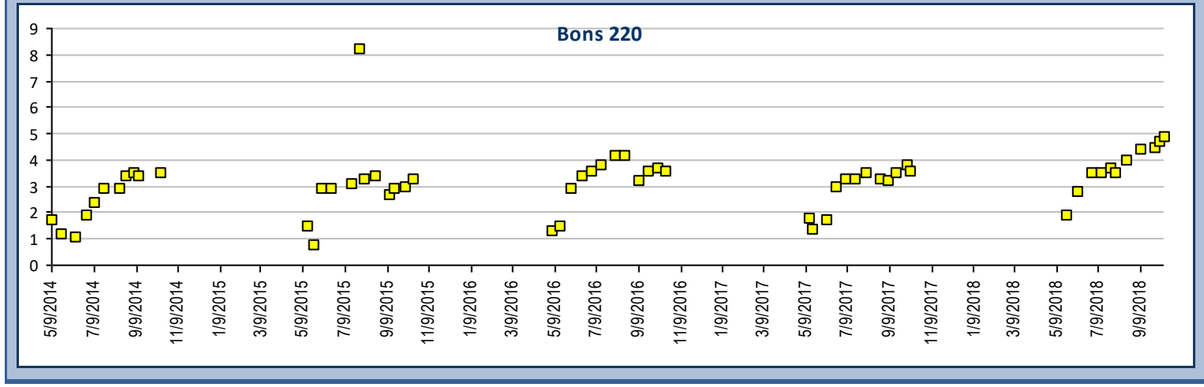


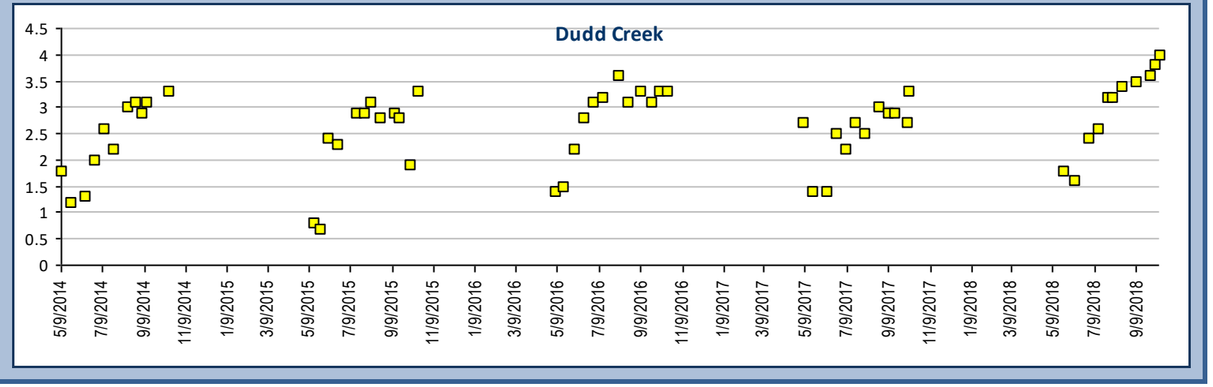






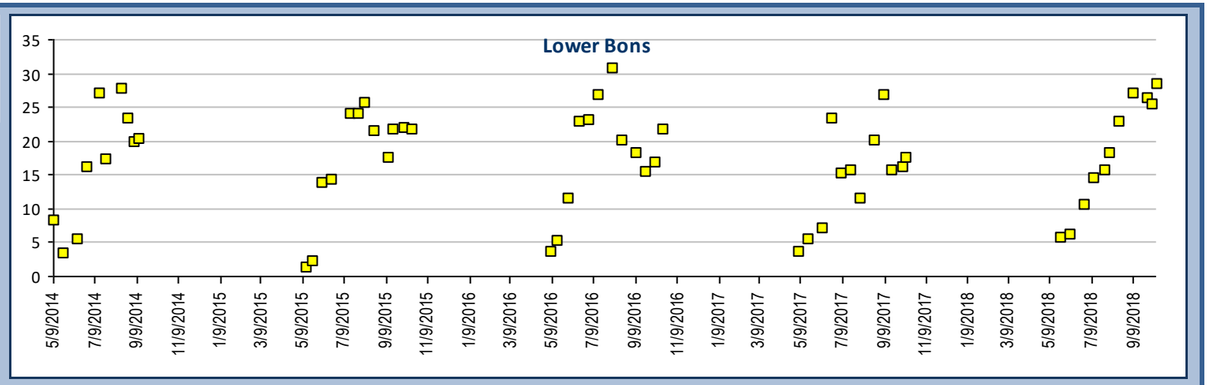


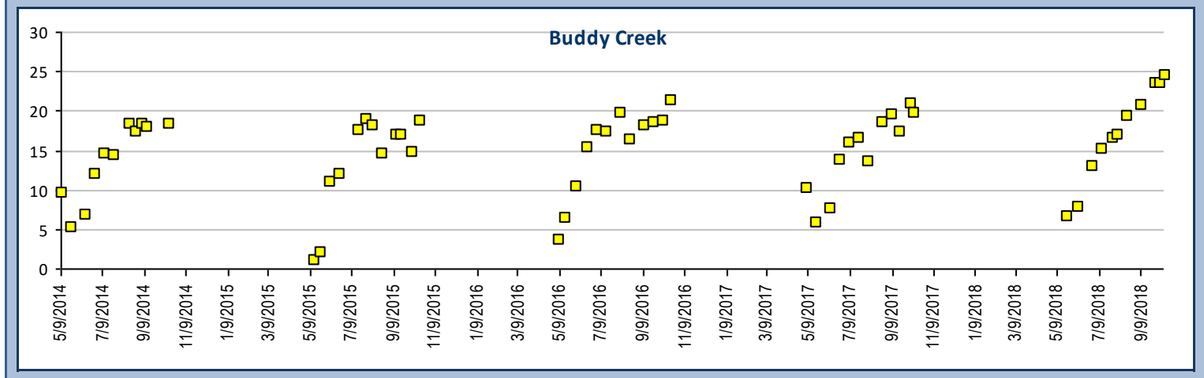


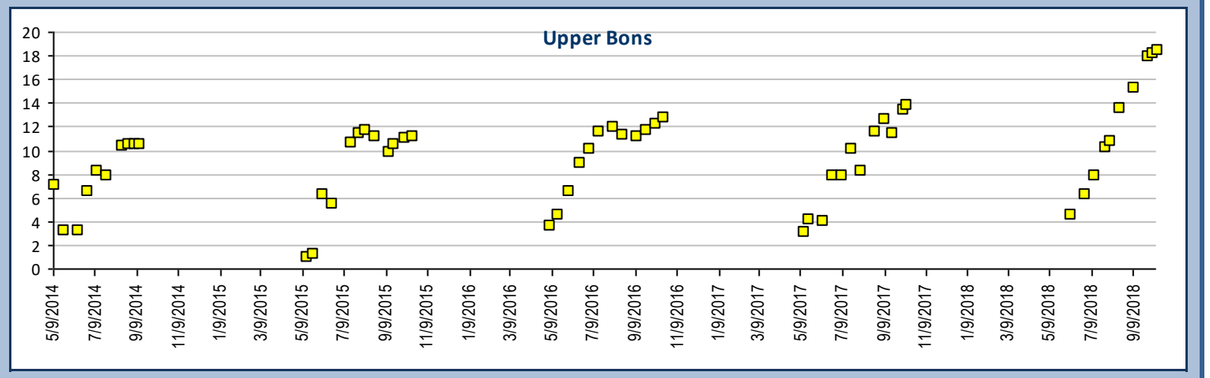


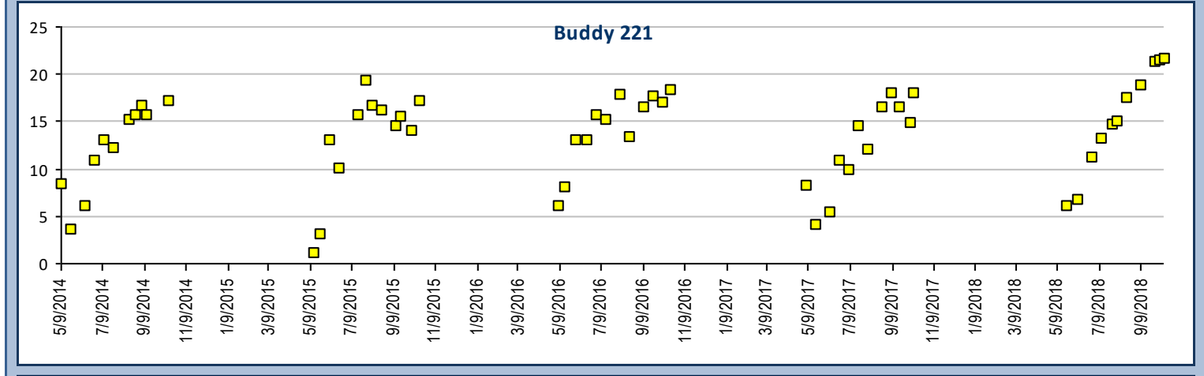
Water Monitoring Bons Creek Drainage
Water Quality Profile I , 5-Year Trend Charts

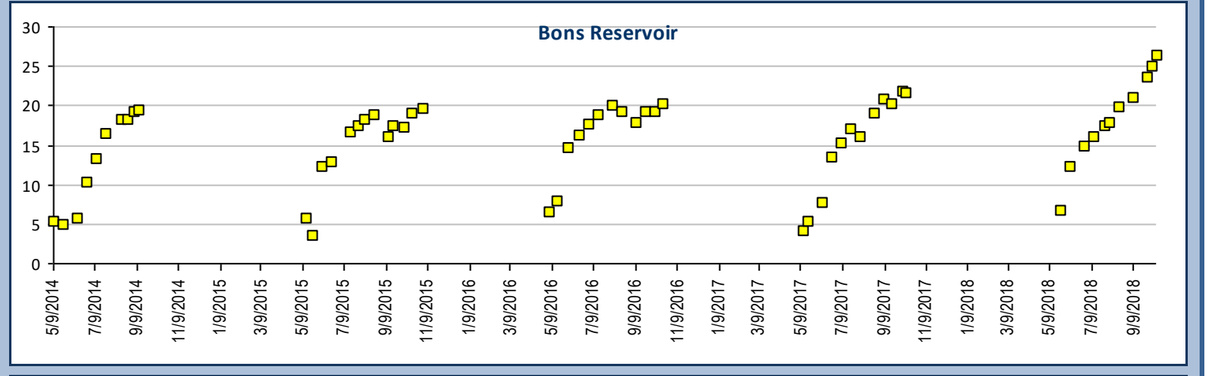
Magnesium, Total Recoverable, units mg/L

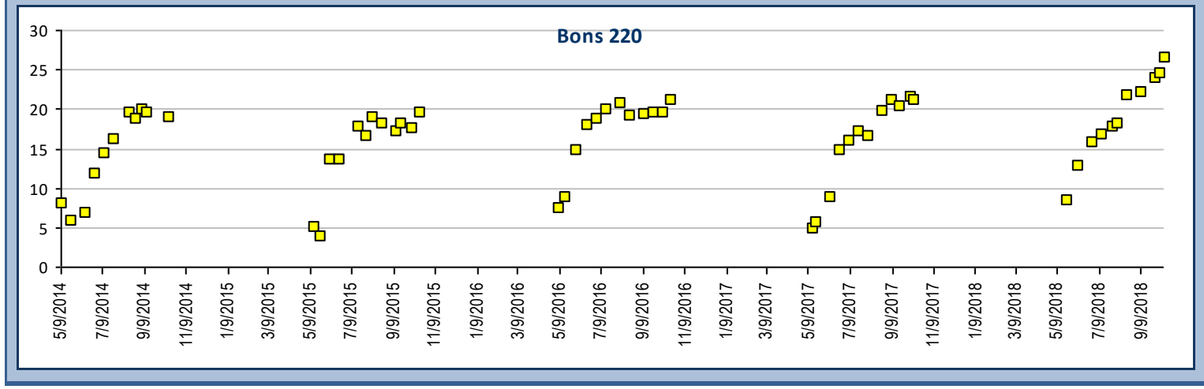


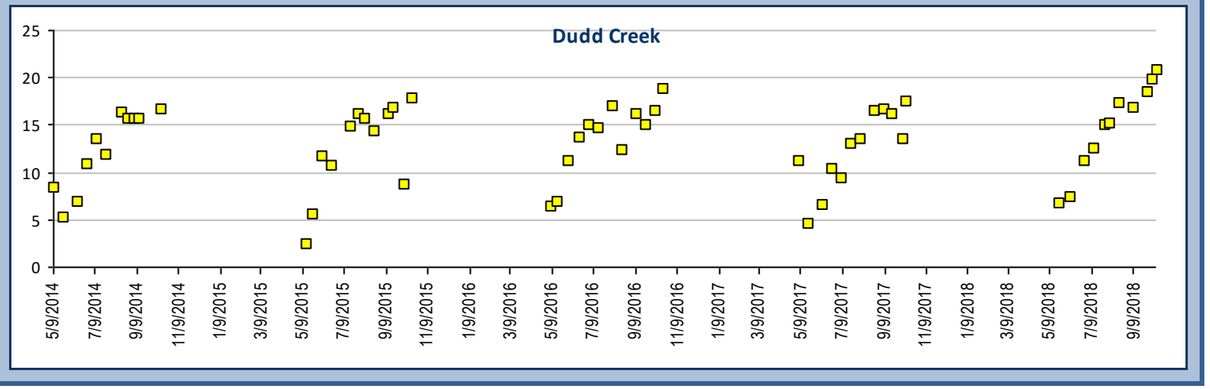






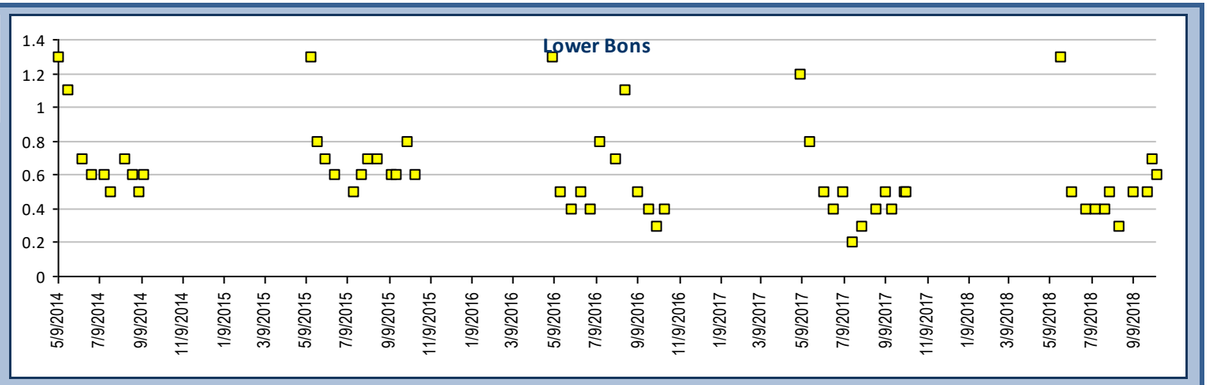


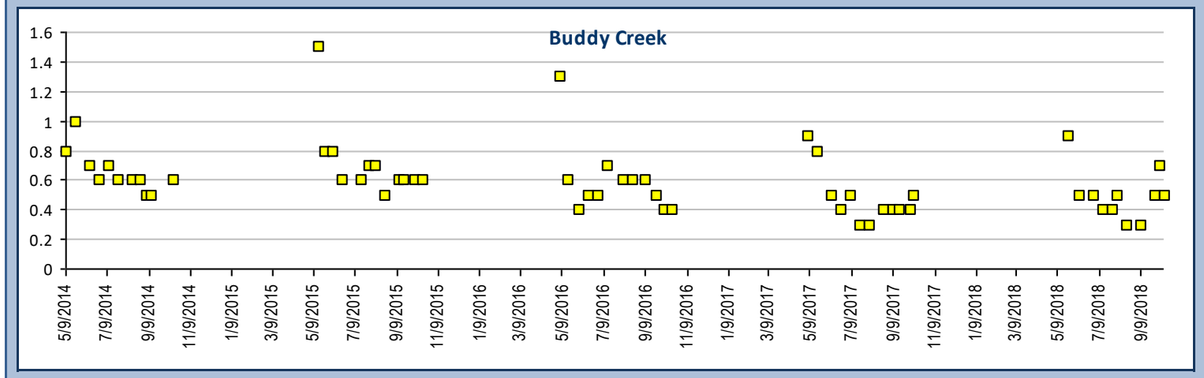


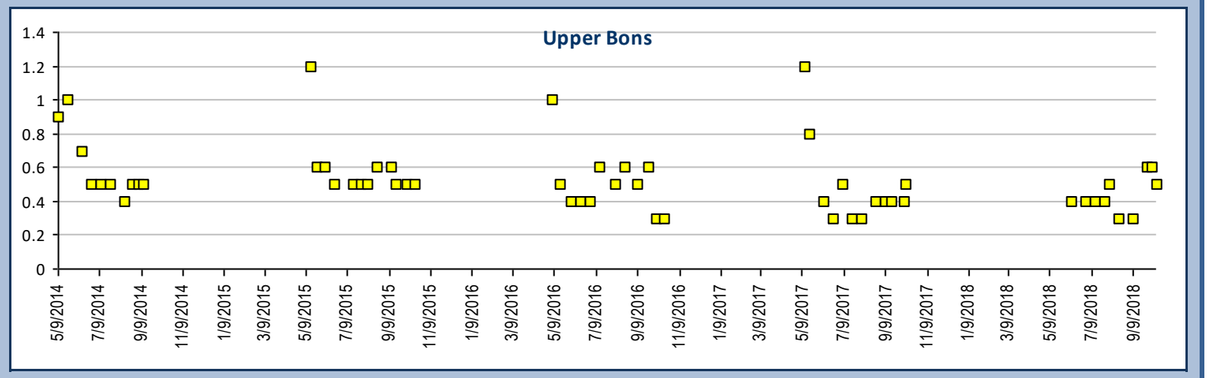


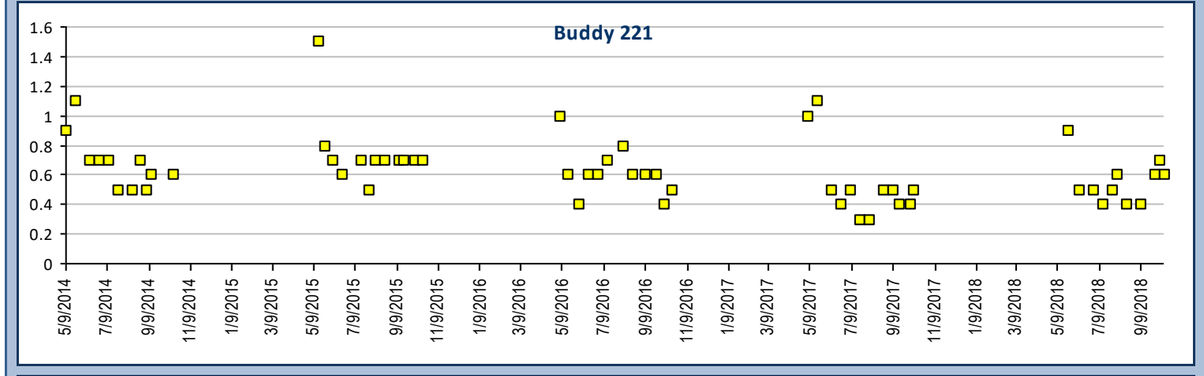
Water Monitoring Bons Creek Drainage
Water Quality Profile I , 5-Year Trend Charts

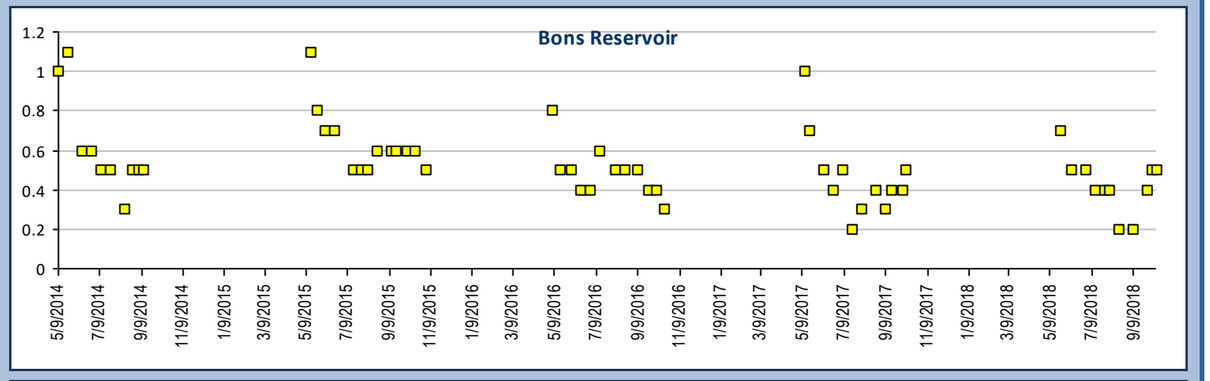
Potassium, Total Recoverable, units mg/L

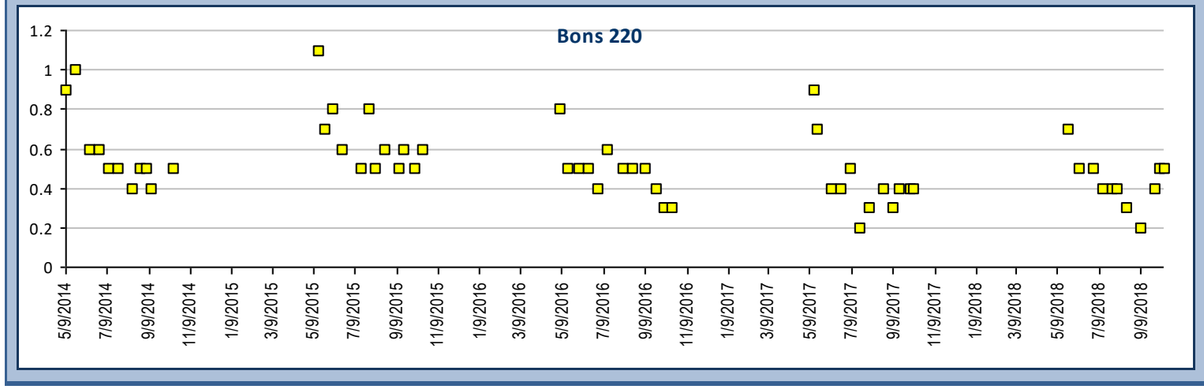


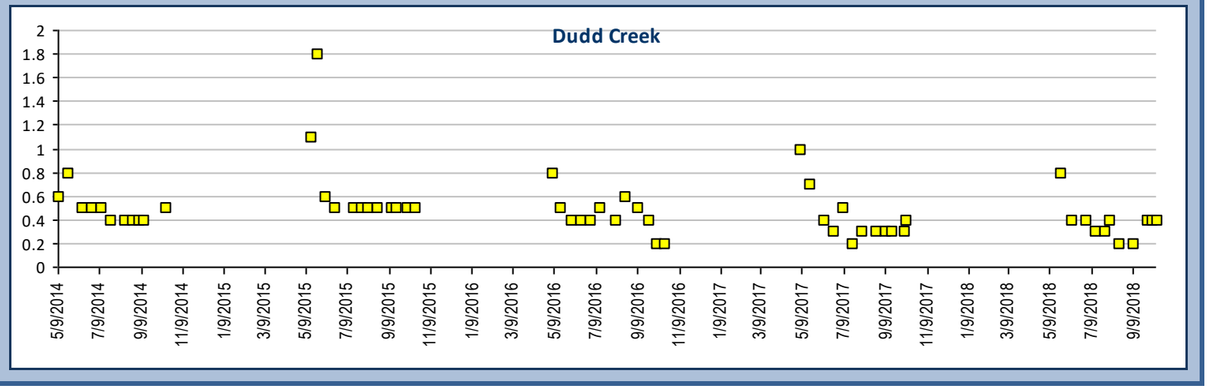










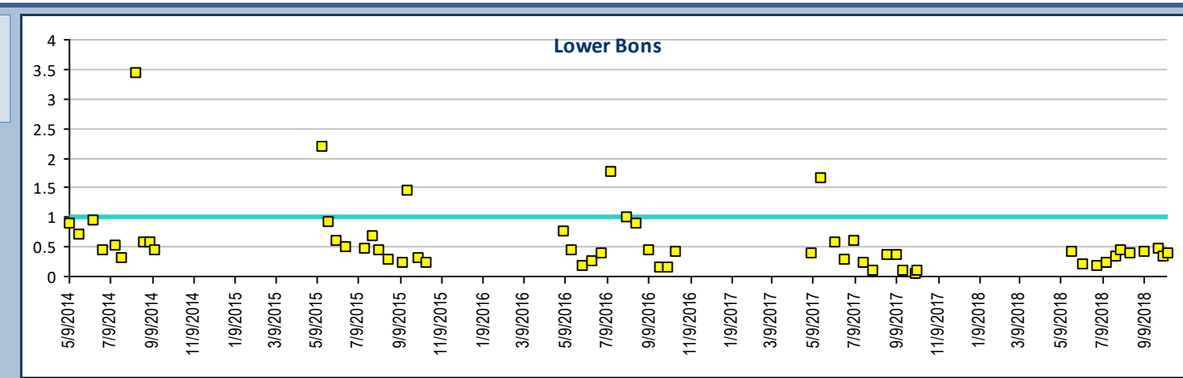


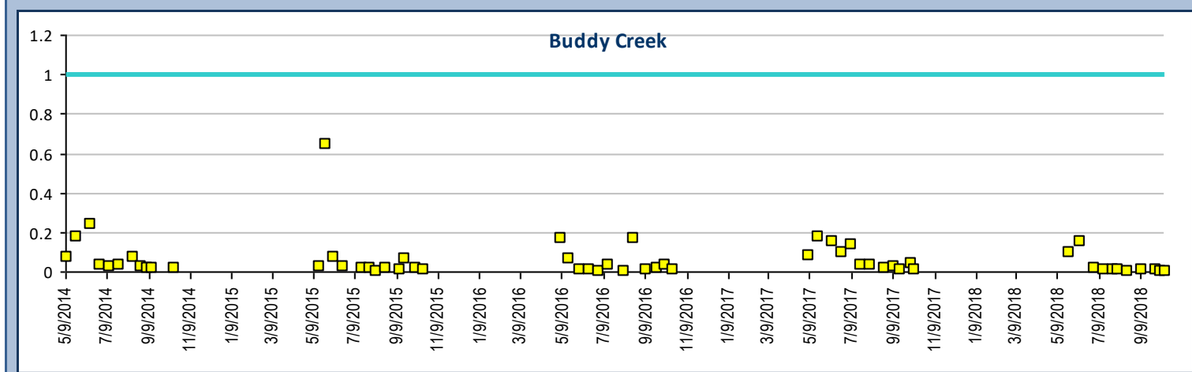
Water Monitoring Bons Creek Drainage
Water Quality Profile I , 5-Year Trend Charts

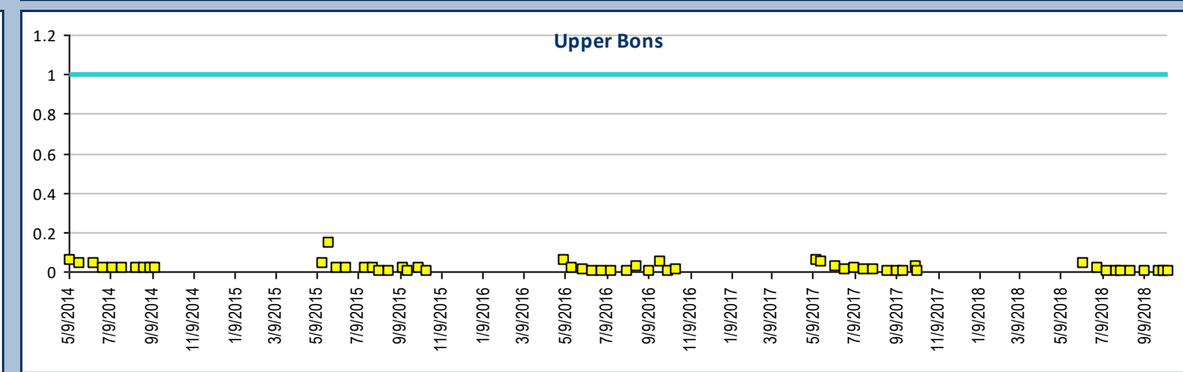
Iron, Total Recoverable, units mg/L

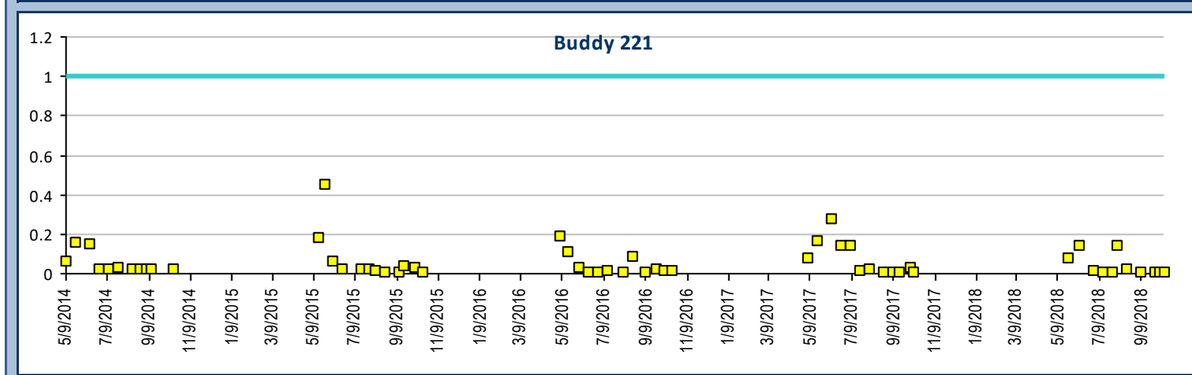
Aquatic Life - Fresh Water Chronic WQS mg/L

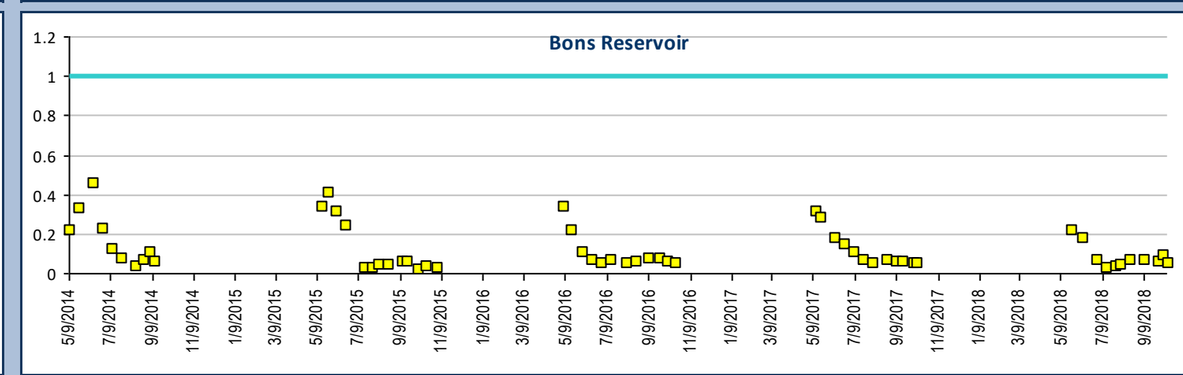
1.0 mg/L

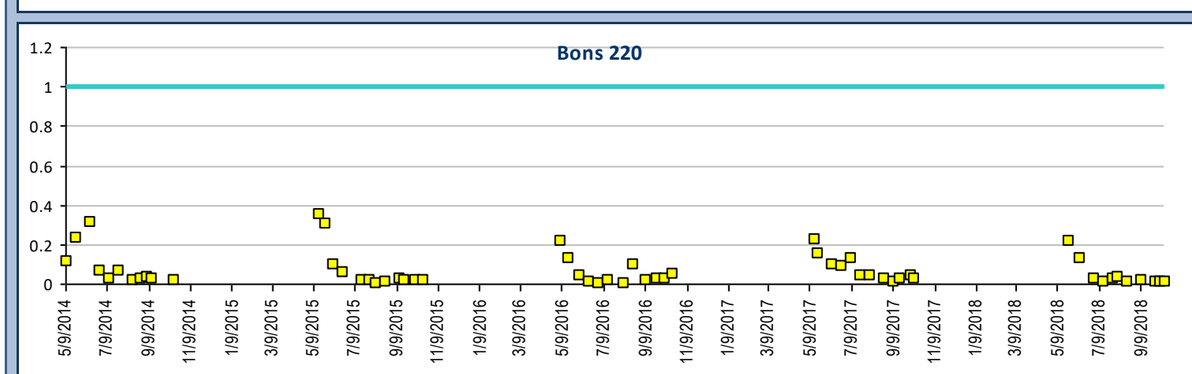


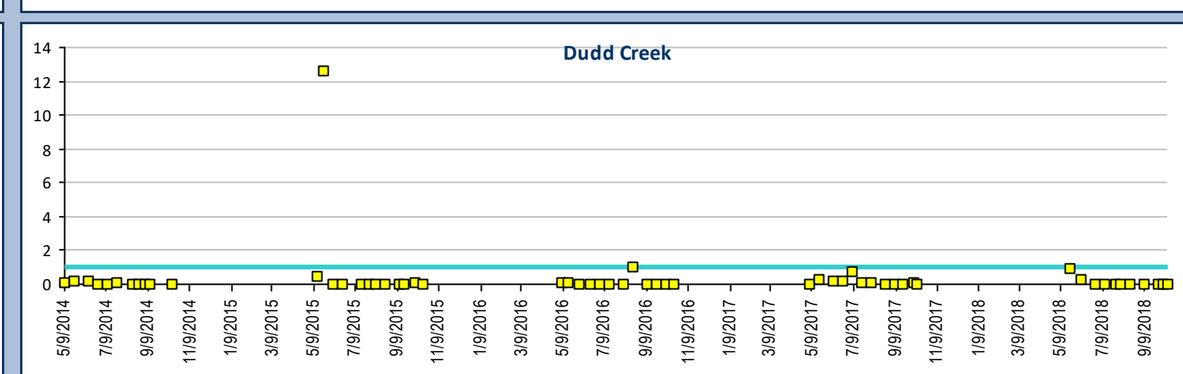








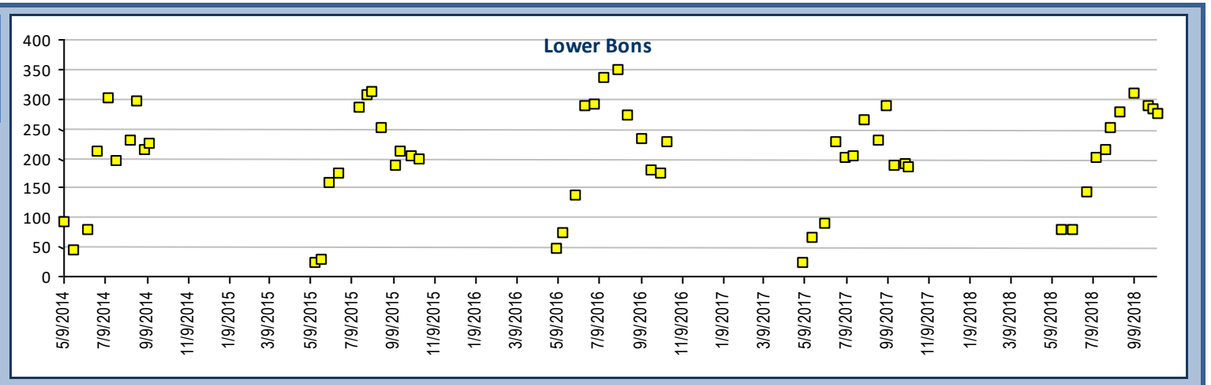


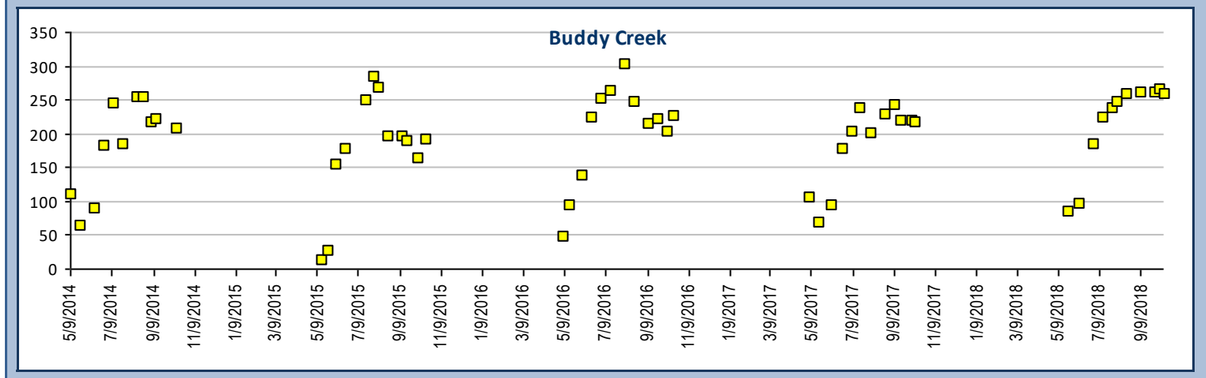


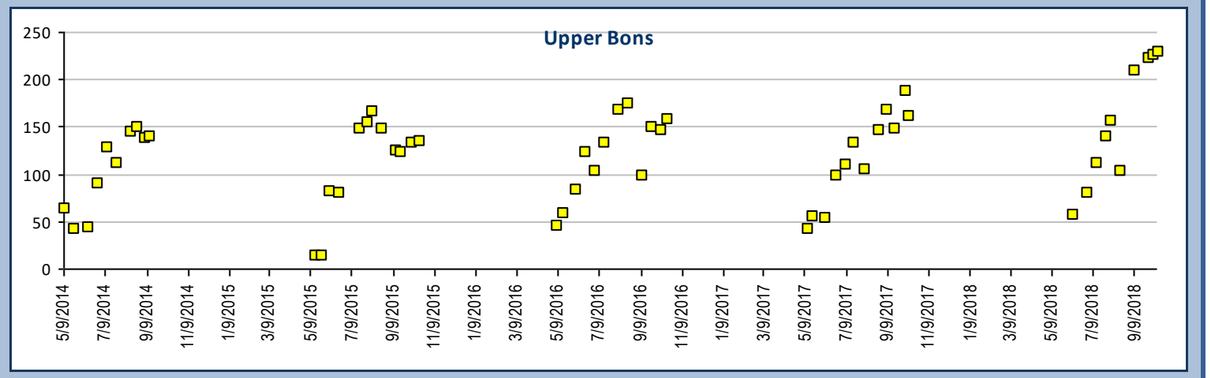
RED DOG MINE

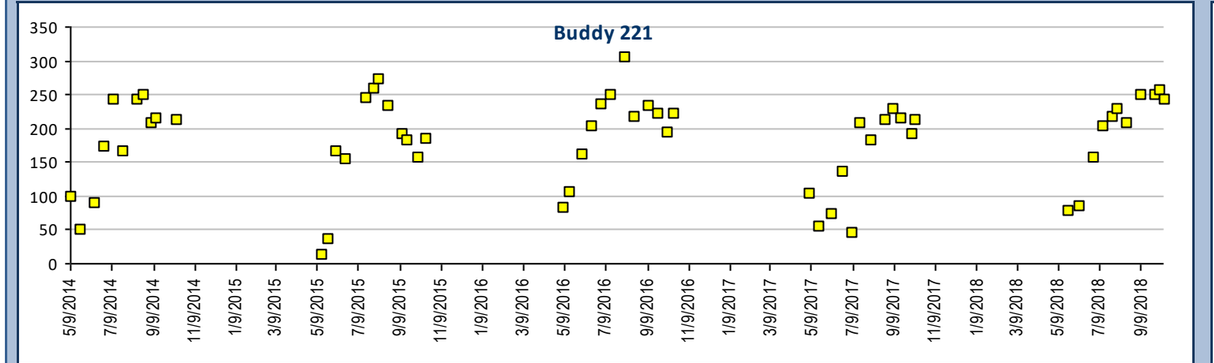
Water Monitoring Bons Creek Drainage
Water Quality Profile I , 5-Year Trend Charts

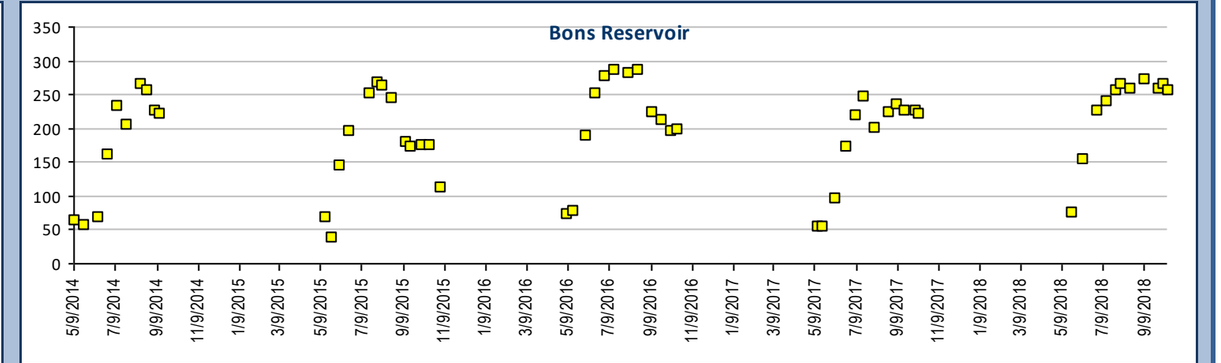
Conductivity, units uS/cm

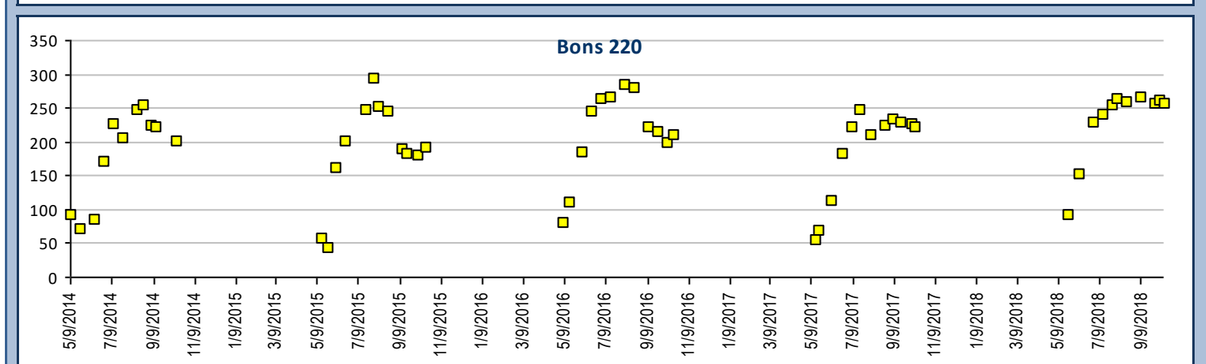


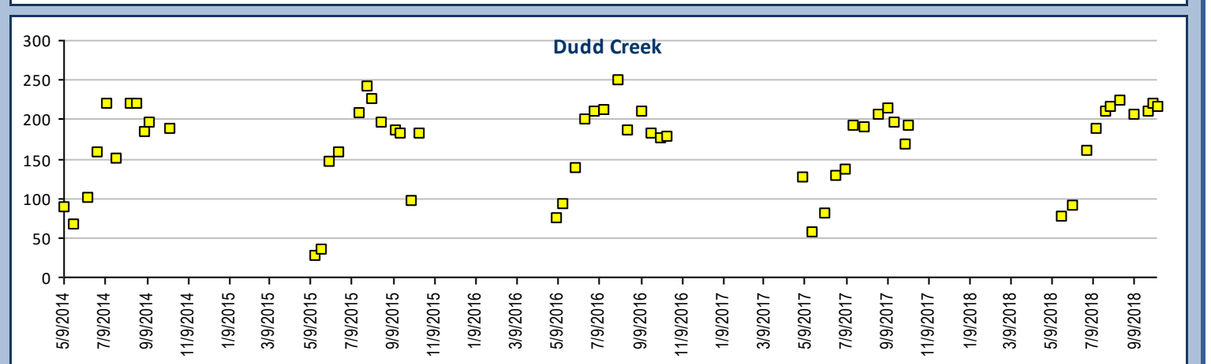










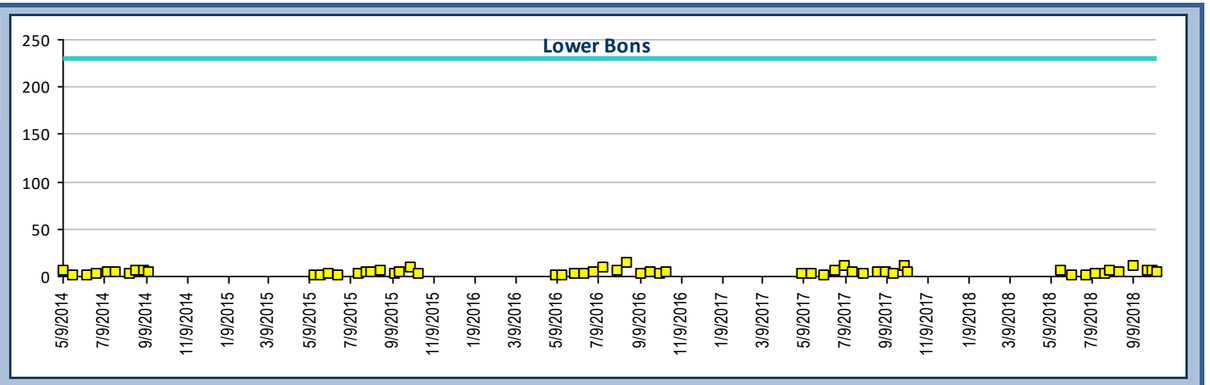


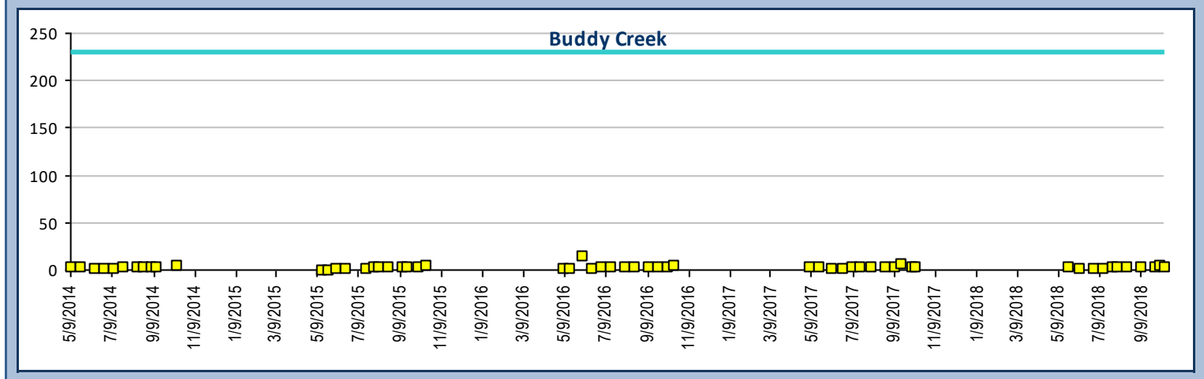
Water Monitoring Bons Creek Drainage
Water Quality Profile I , 5-Year Trend Charts

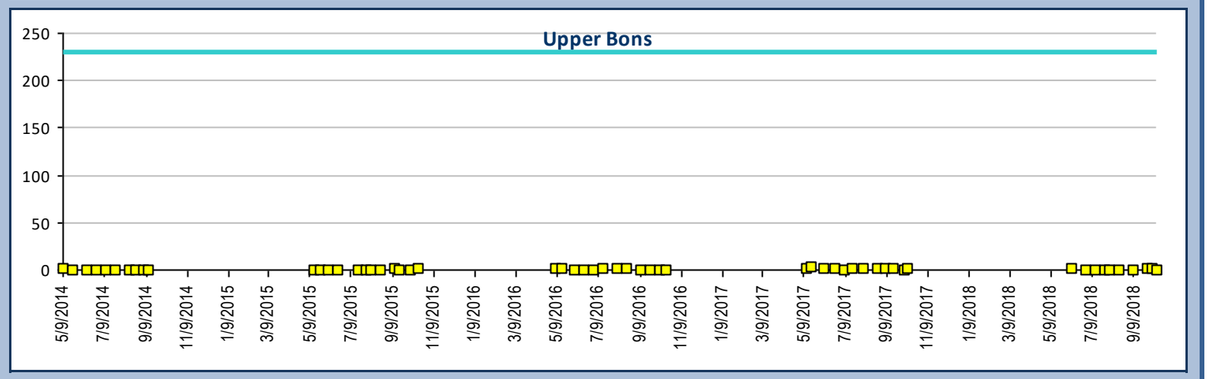
Chloride, Total recoverable, units mg/L

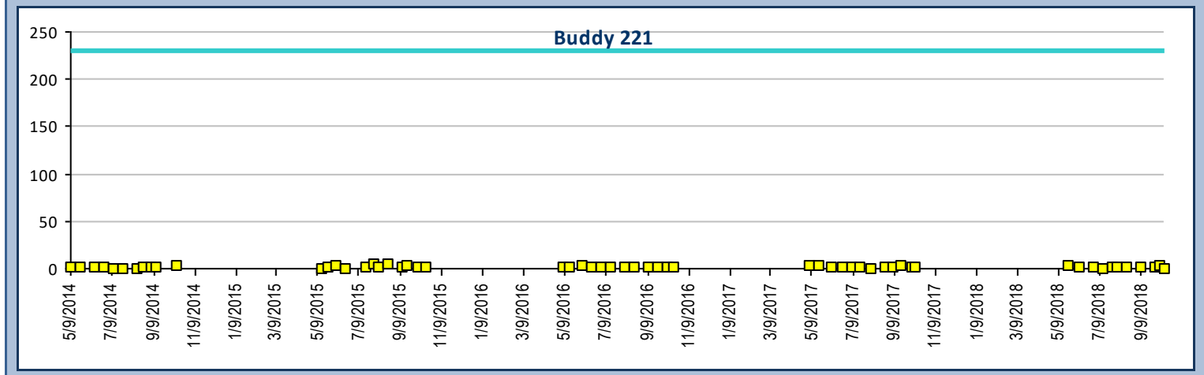
Aquatic Life - Fresh Water Chronic WQS mg/L

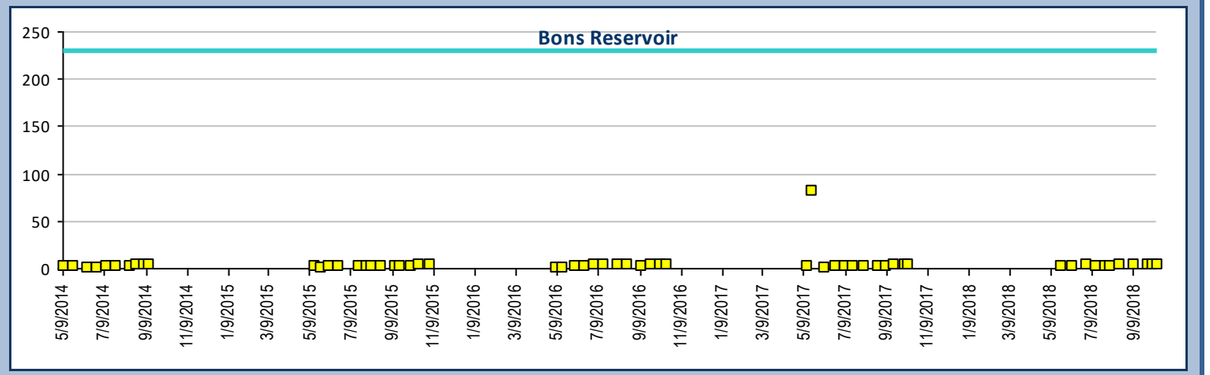
230 mg/L

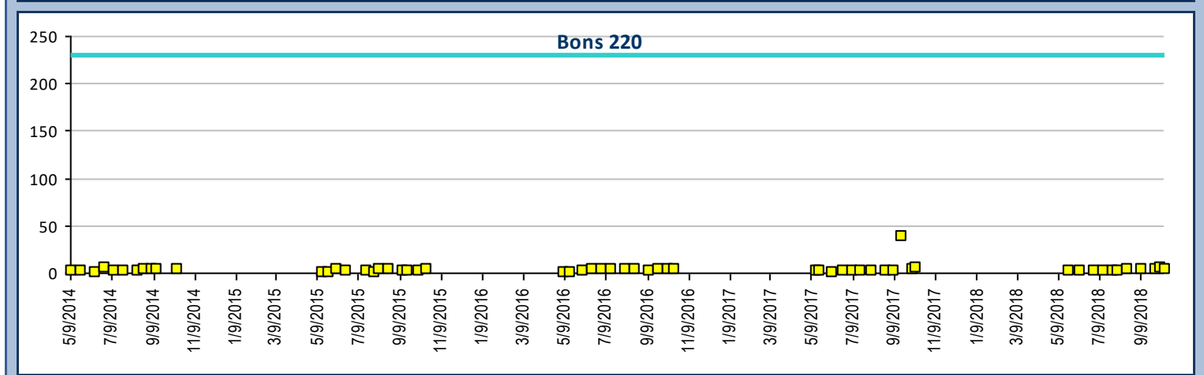


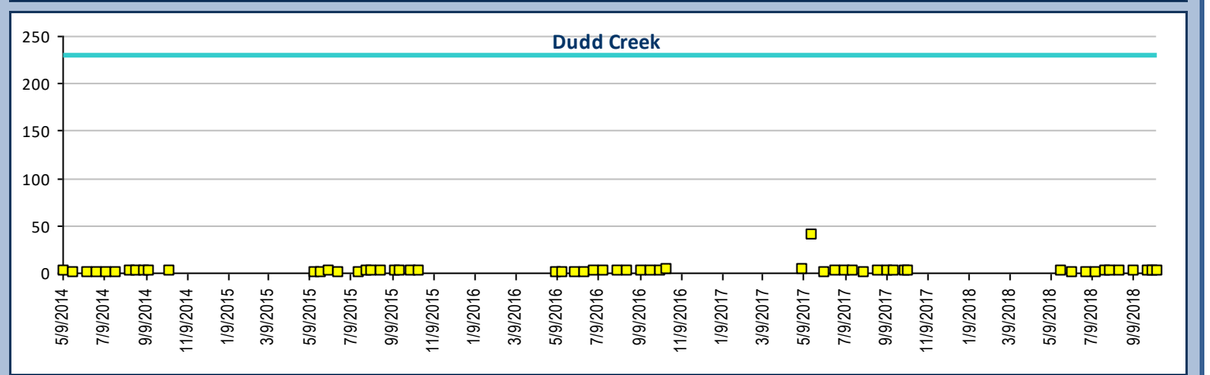












Water Monitoring Bons Creek Drainage
Water Quality Profile I , 5-Year Trend Charts

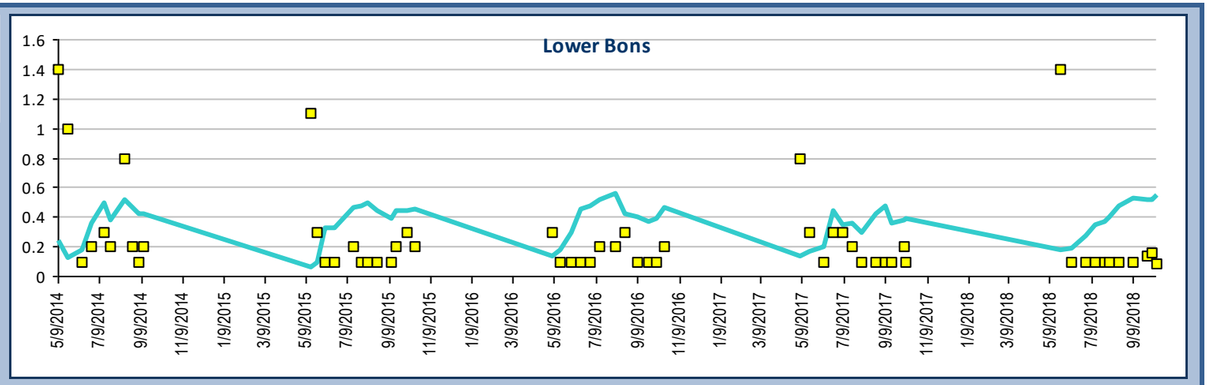
Cadmium, Total Recoverable, units ug/L

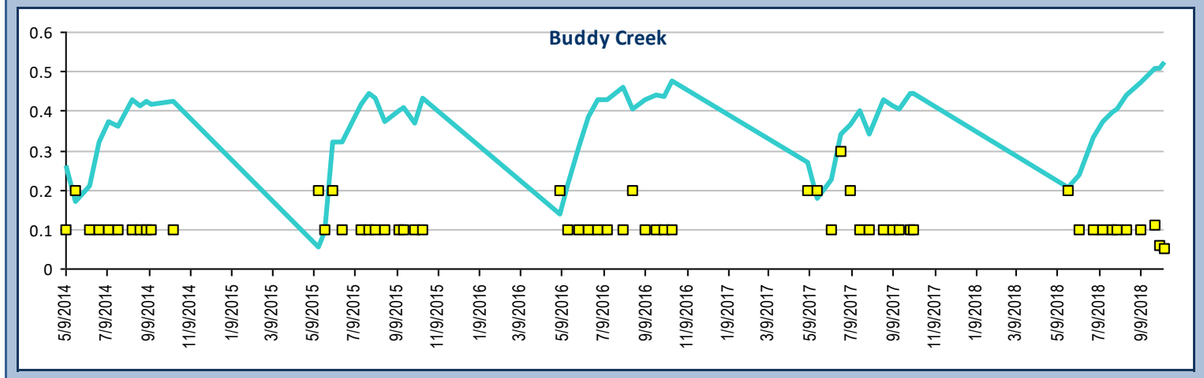
Aquatic Life - Fresh Water Chronic WQS ug/L

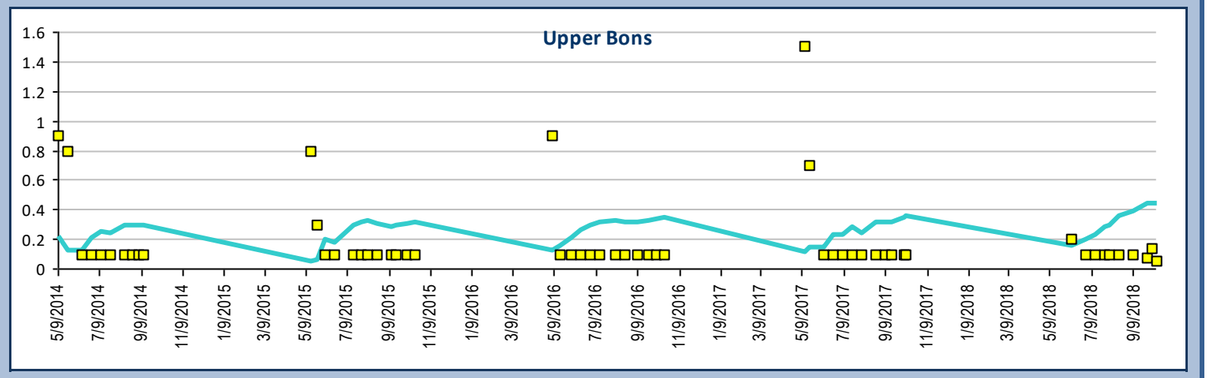
Hardness Dependent Calculation

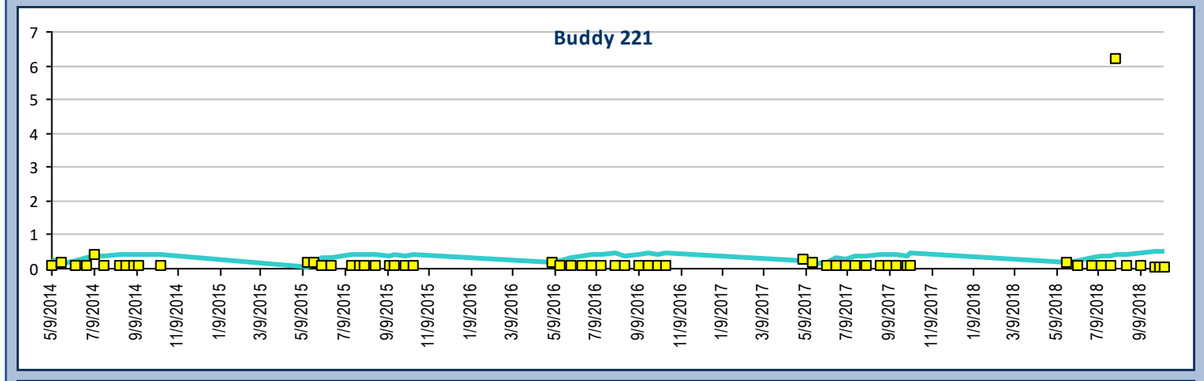
=EXP(0.7409*(LN(calc *hardness))-4.719)

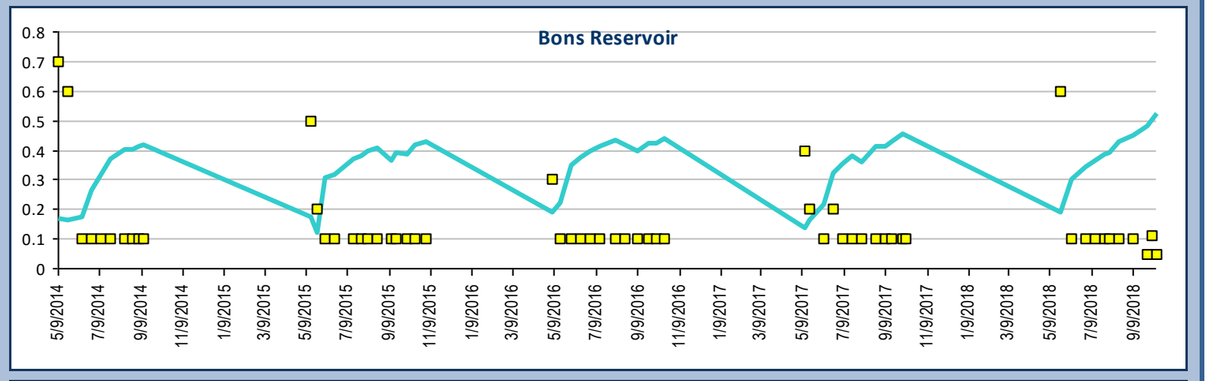
* Calculated using Standard Methods 2340B

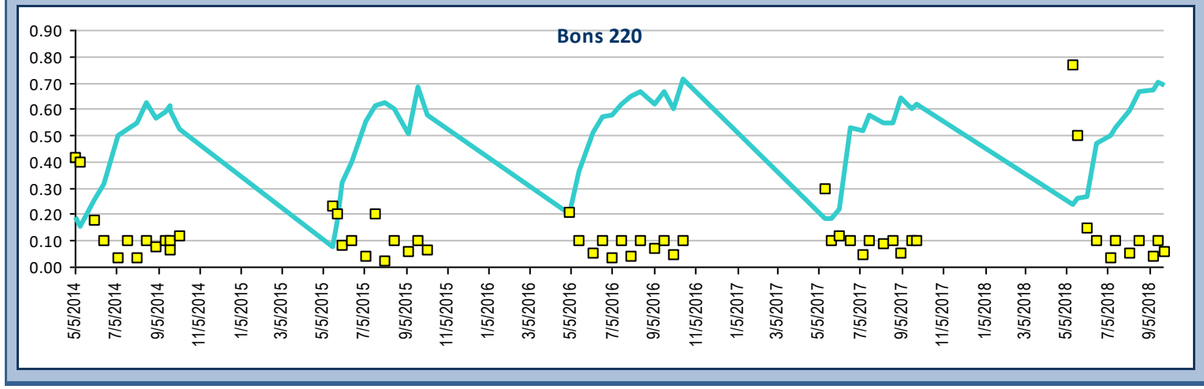


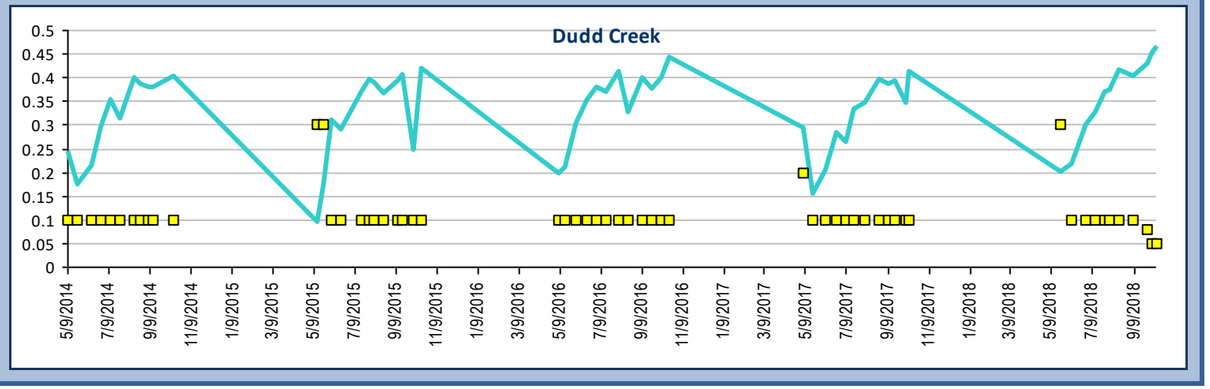






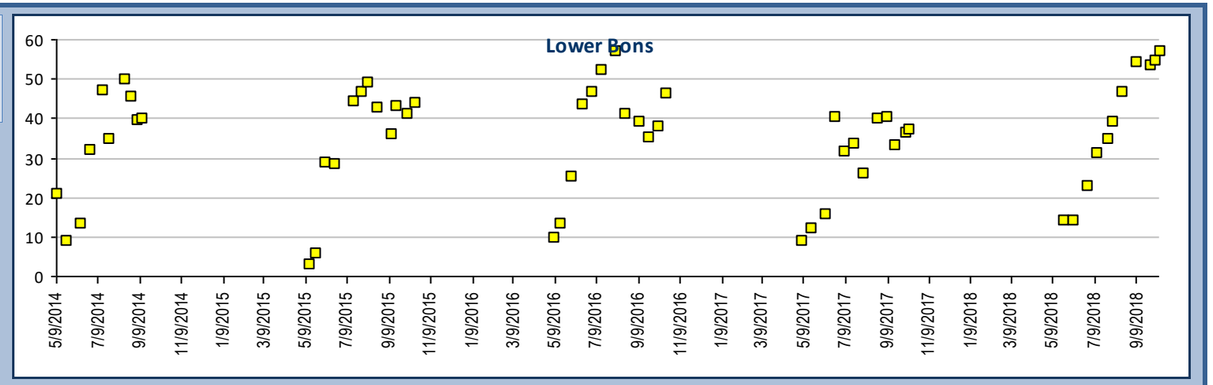


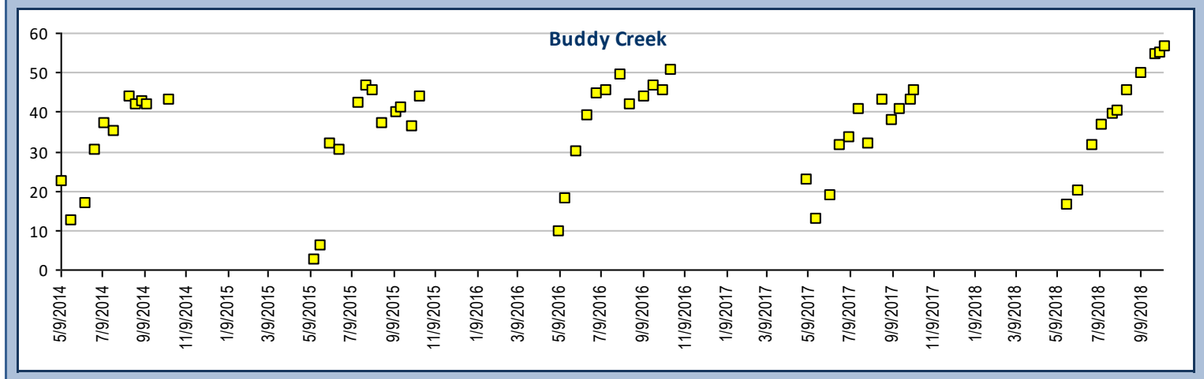


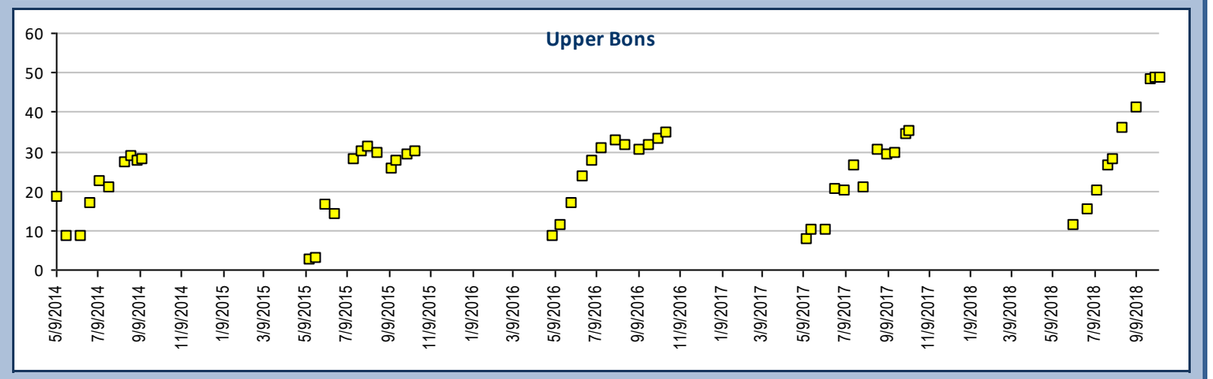


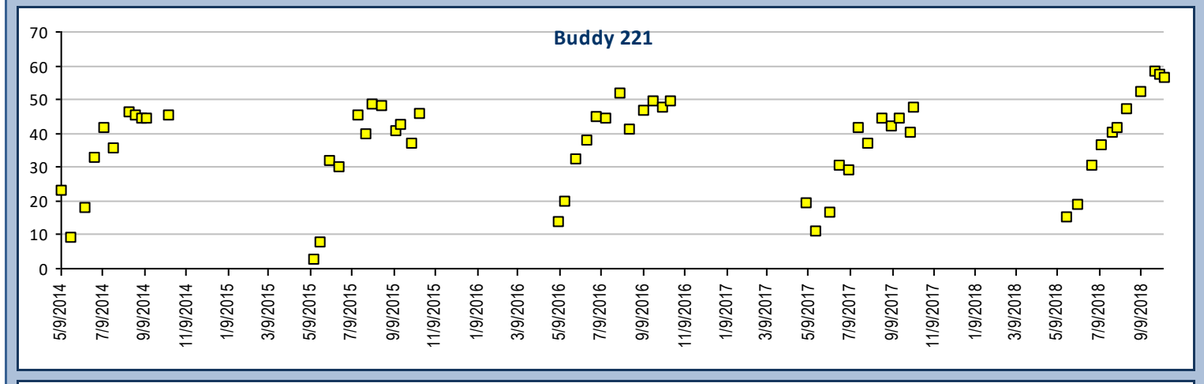
Water Monitoring Bons Creek Drainage
Water Quality Profile I , 5-Year Trend Charts

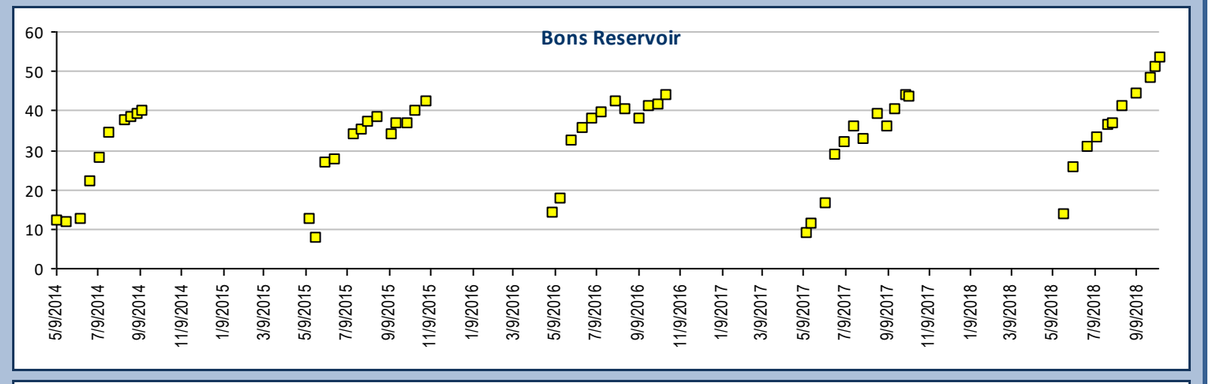
Calcium, Total Recoverable, units mg/L

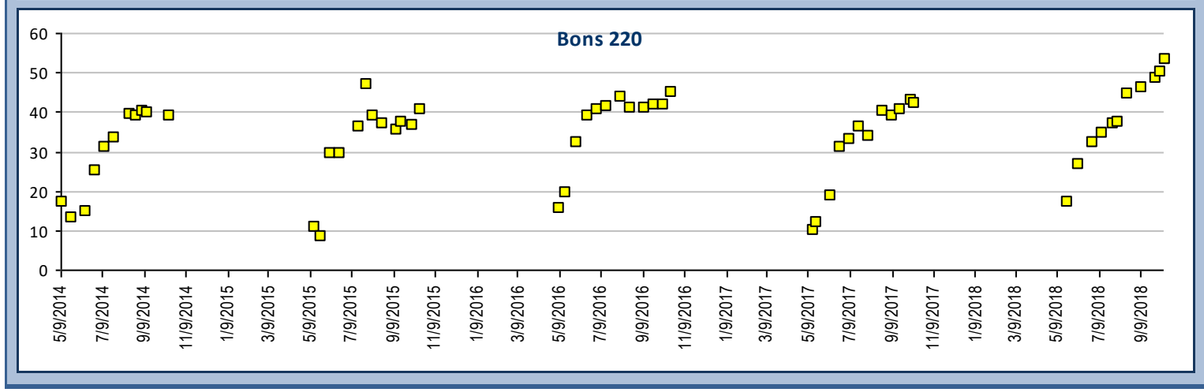


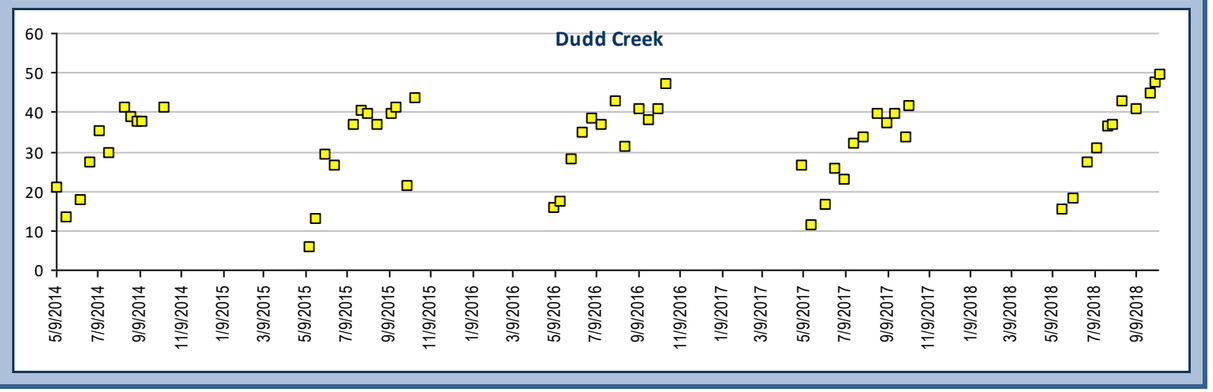










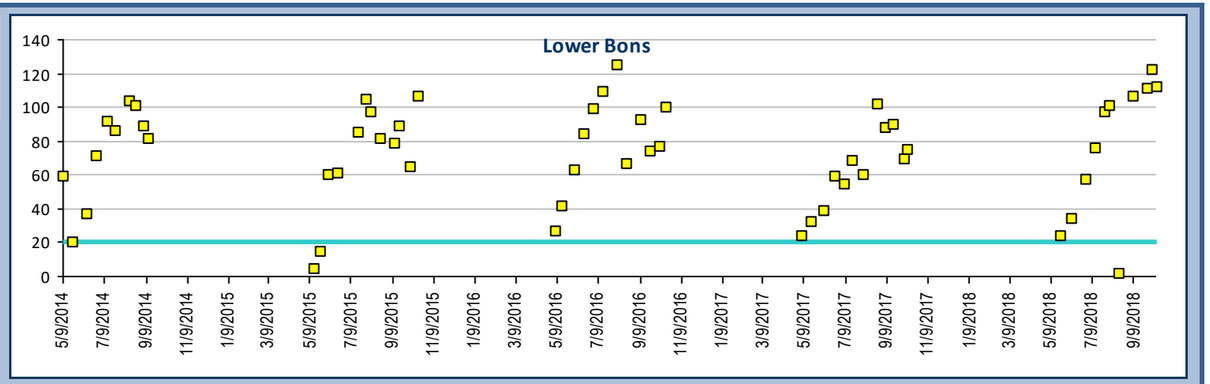


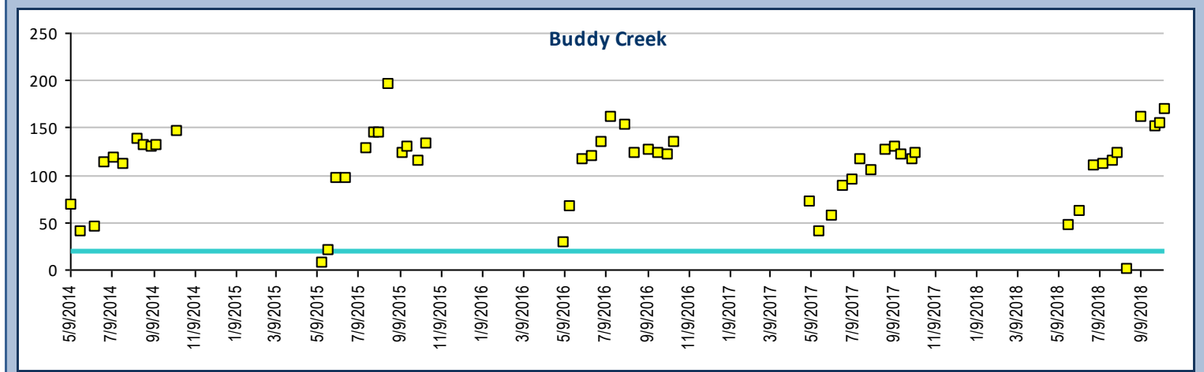
Water Monitoring Bons Creek Drainage
Water Quality Profile I , 5-Year Trend Charts

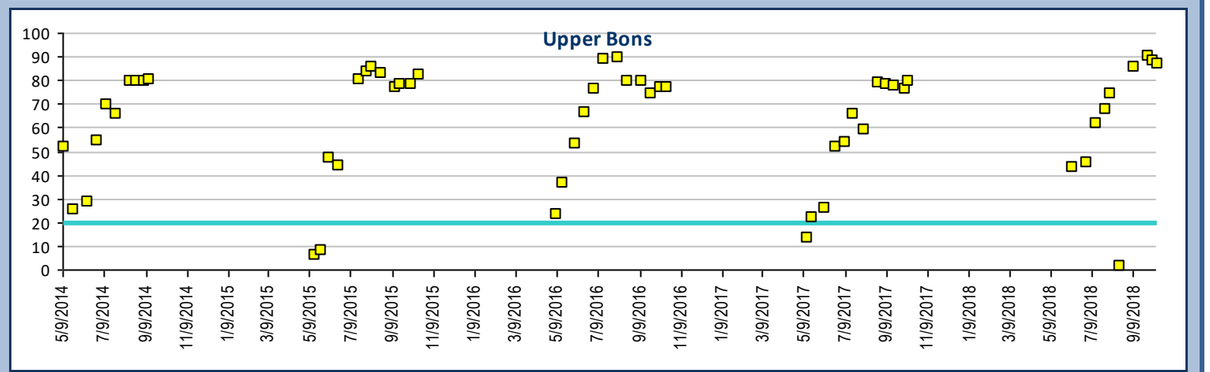
Alkalinity (as CaCO3), units mg/L

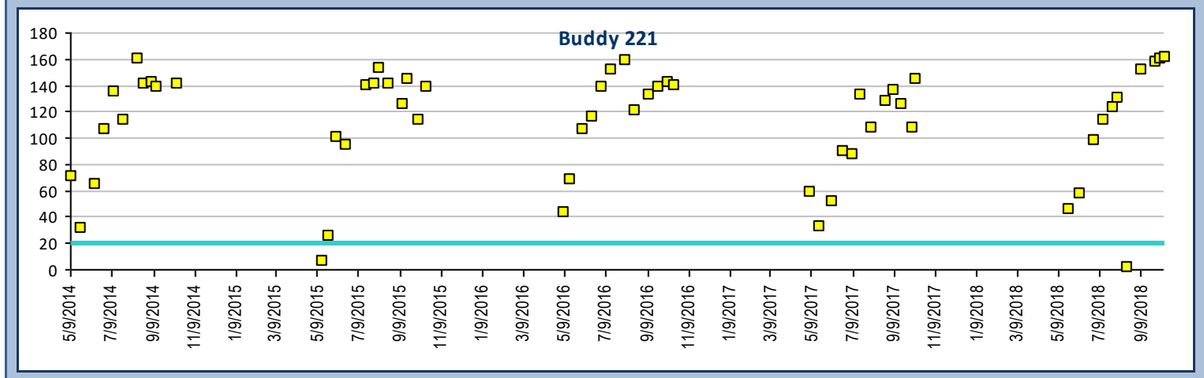
Aquatic Life - Fresh Water Chronic WQS mg/L

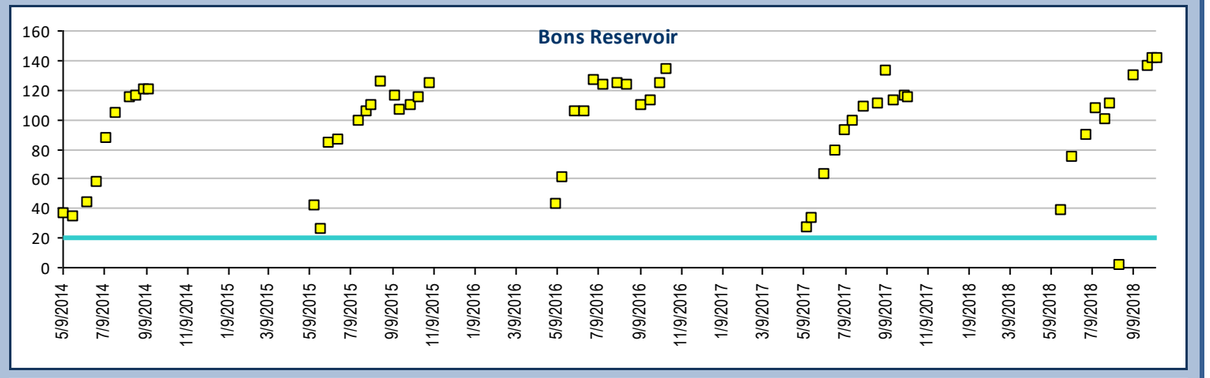
20 mg/L minimum

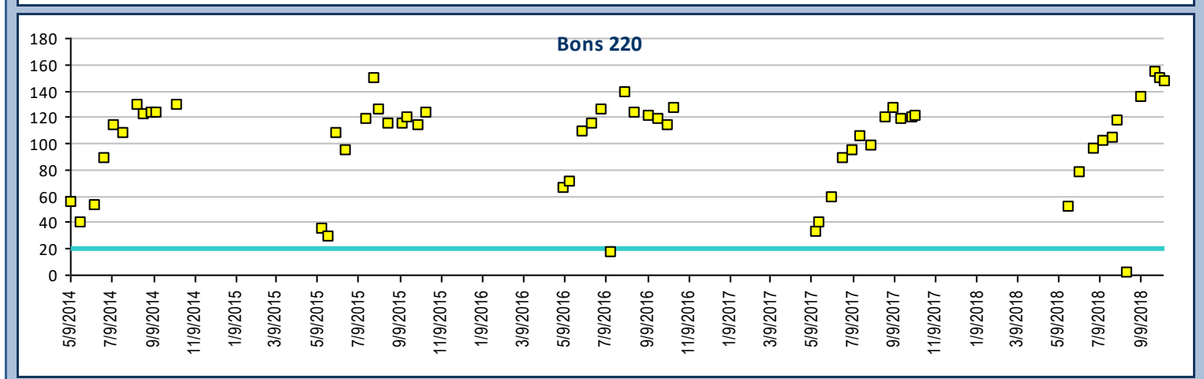


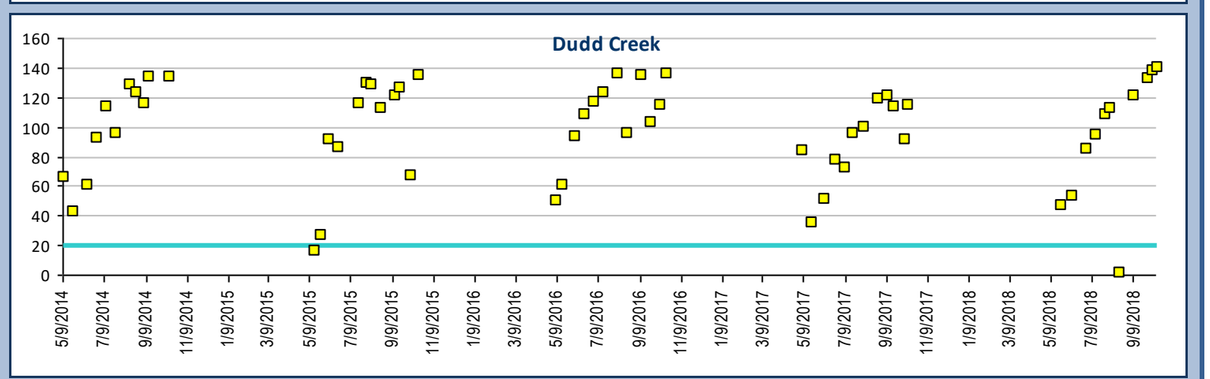










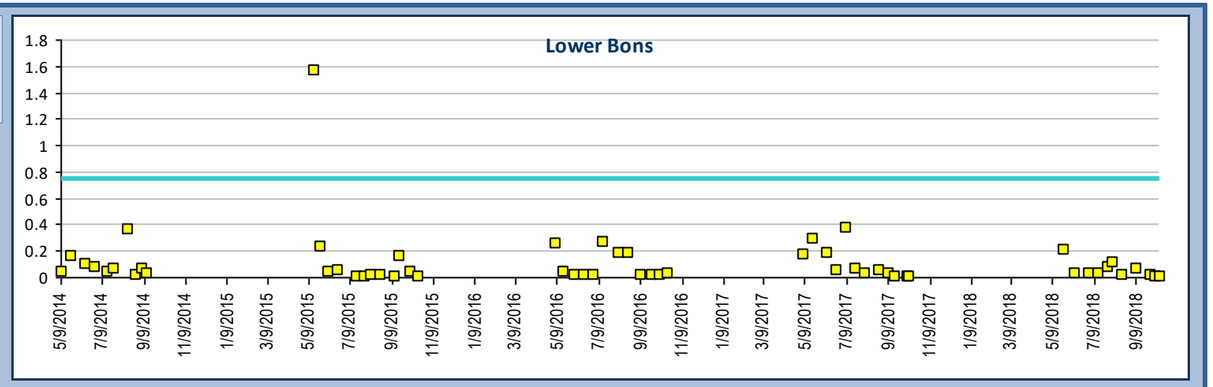


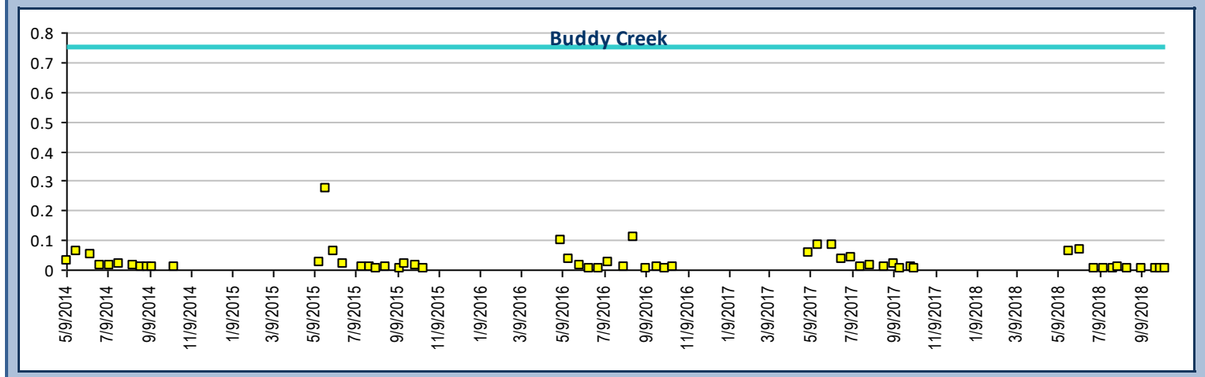
Water Monitoring Bons Creek Drainage
Water Quality Profile I , 5-Year Trend Charts

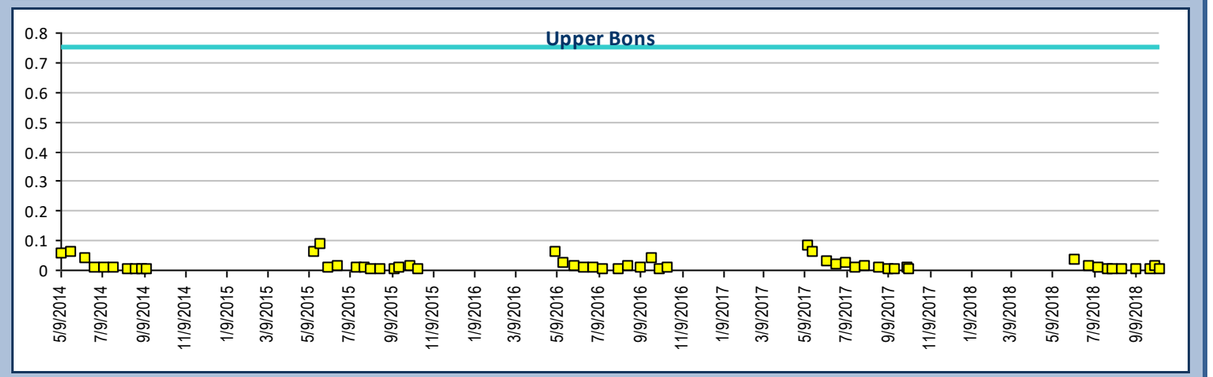
Aluminum, Total Recoverable, units mg/L

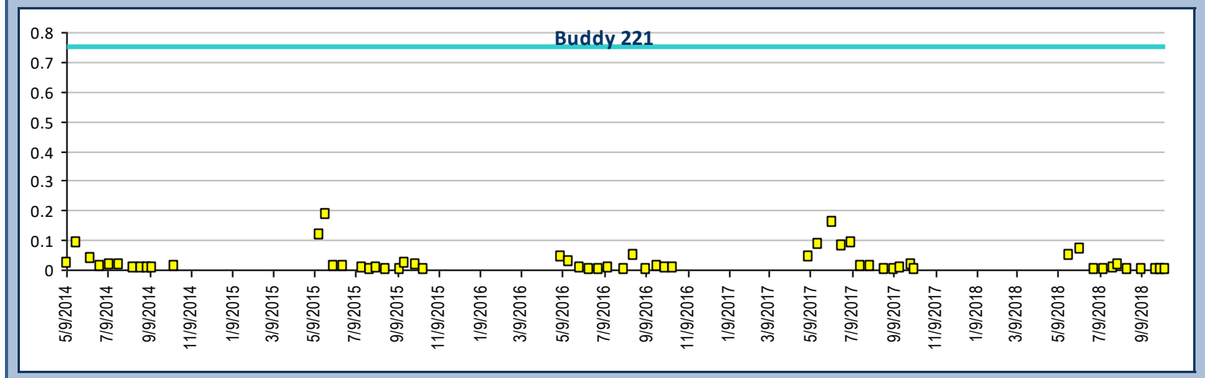
Aquatic Life - Fresh Water Chronic WQS mg/L

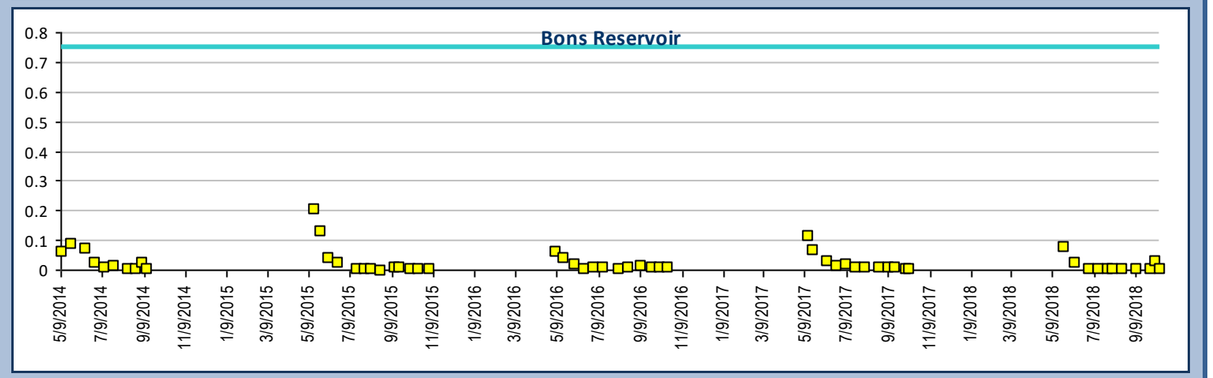
If pH > 7 and hardness > 50. then WQS = 0.75mg/l

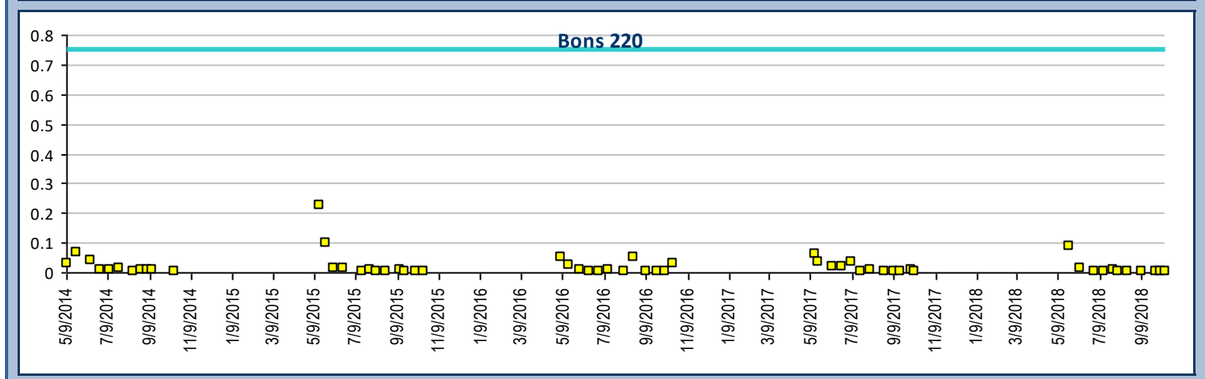


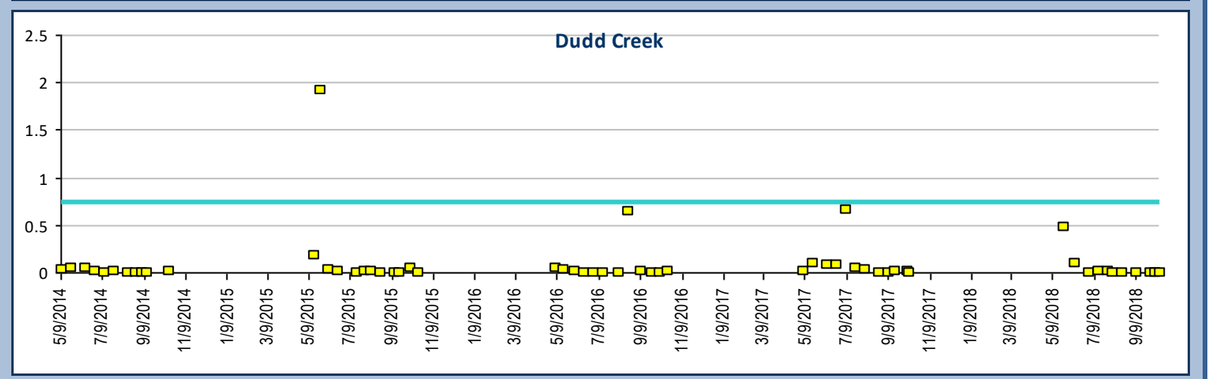










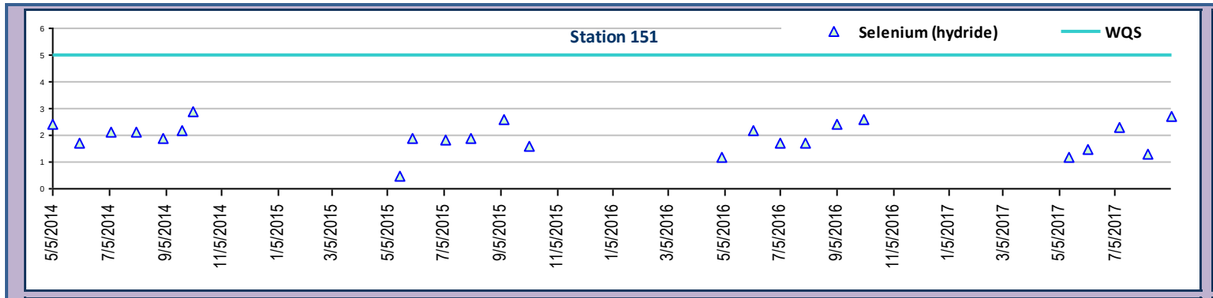


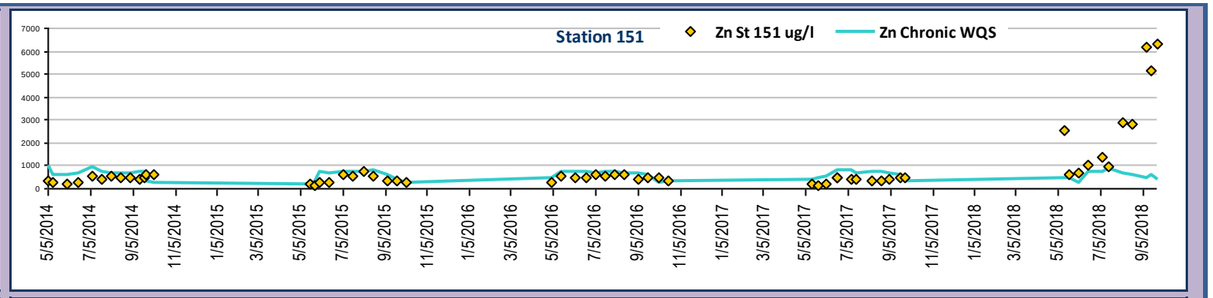
Appendix F: Water Quality Profile I Charts – APDES Monitoring Stations

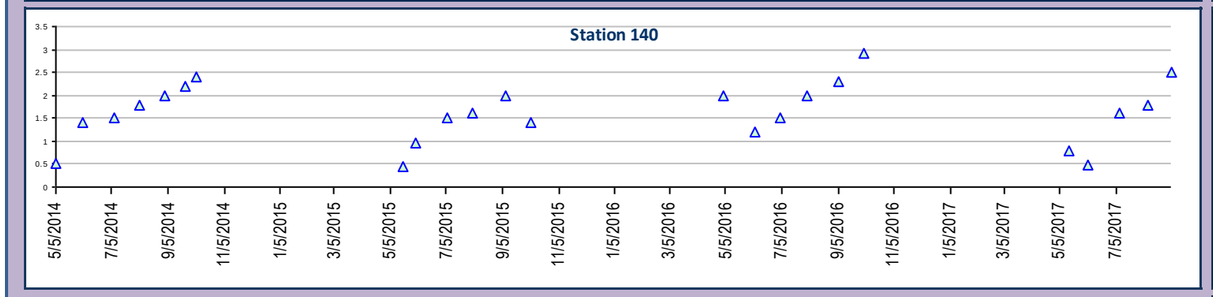
APDES Stations : Selenium, units, ug/l - 5 Year Trend

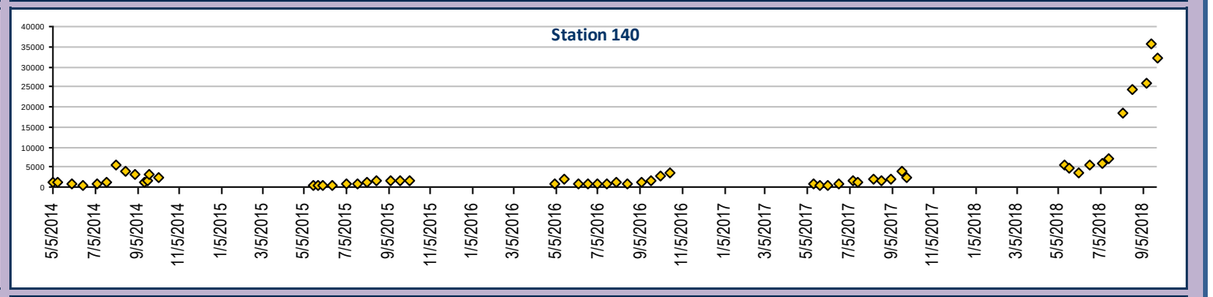
APDES Stations : Zinc, Total, units ug/l - 5 Year Trend

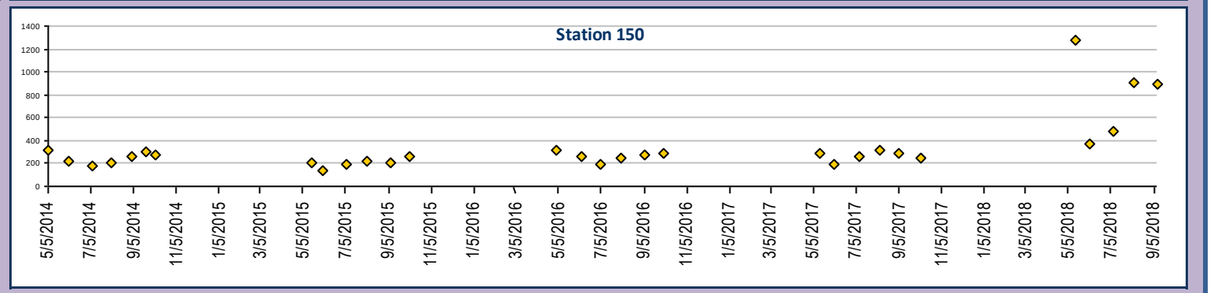
Teck

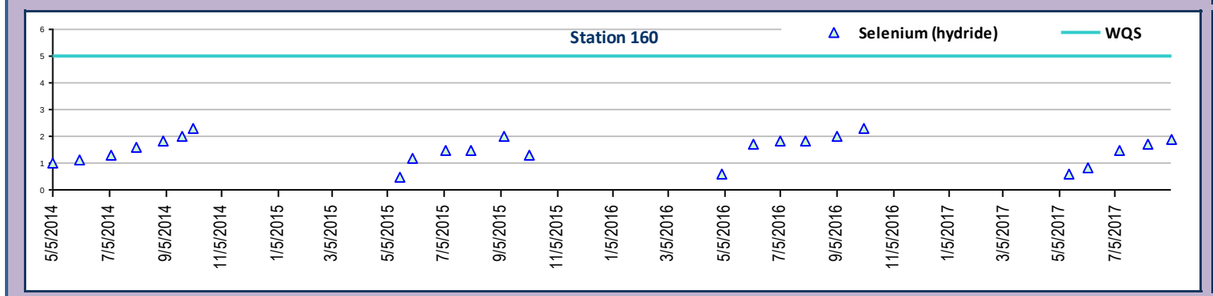


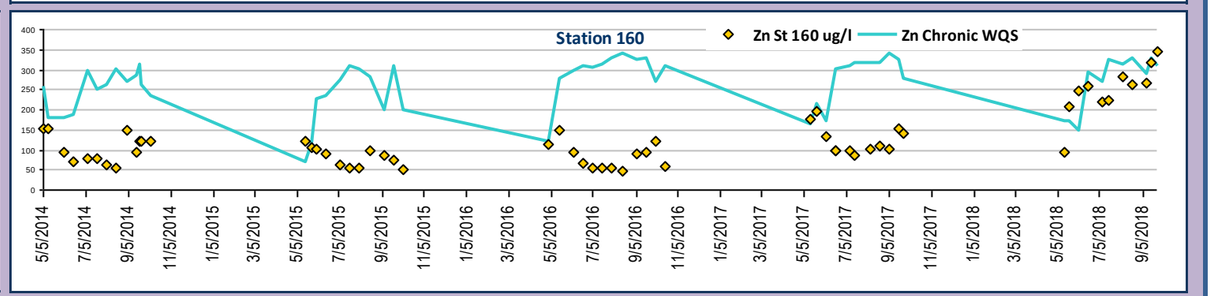


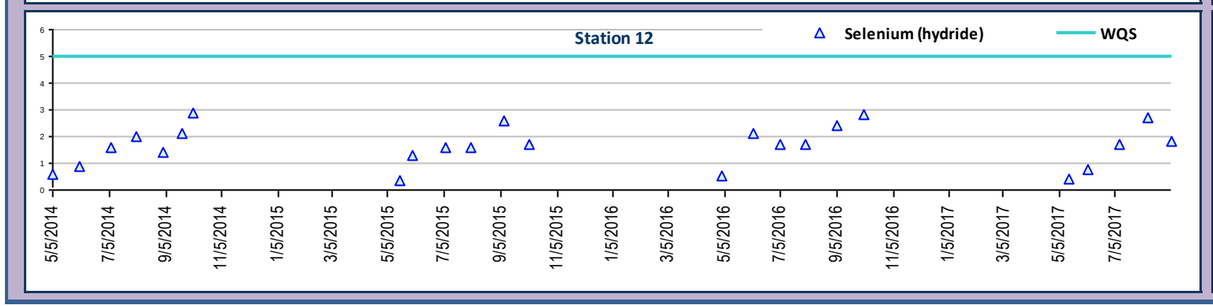


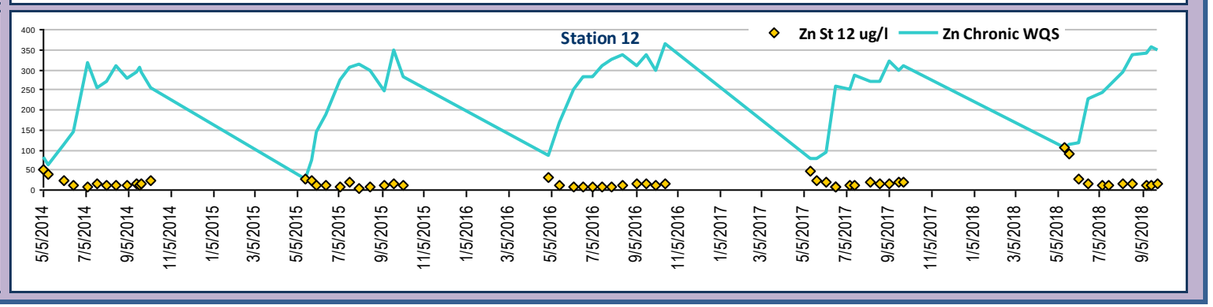








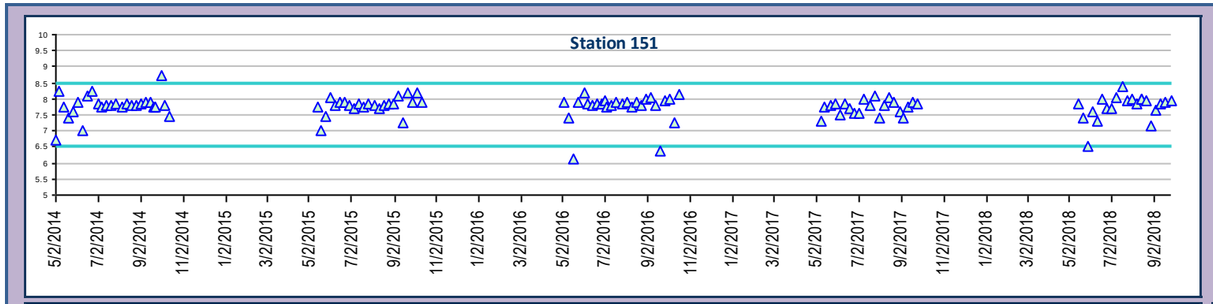


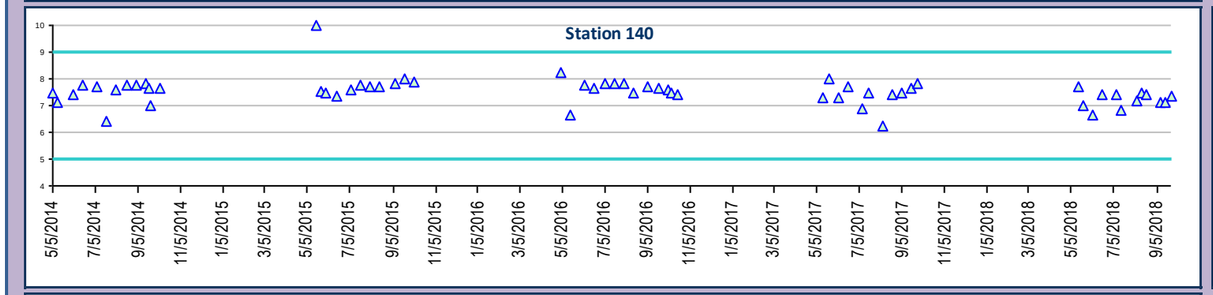


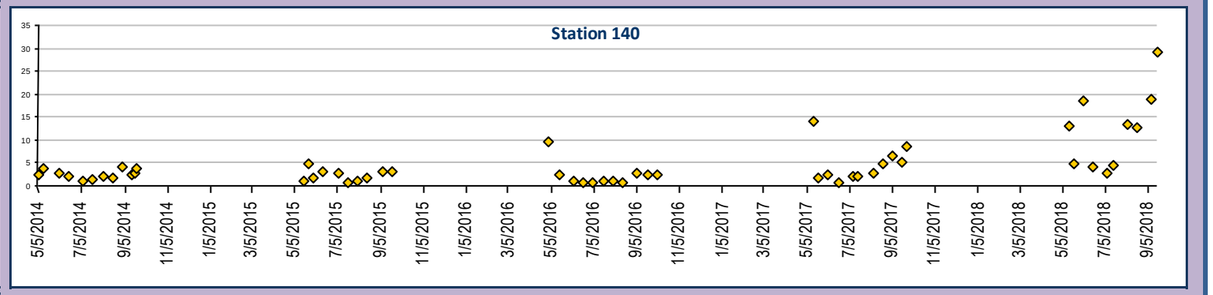
APDES Stations : pH, units - 5 Year Trend

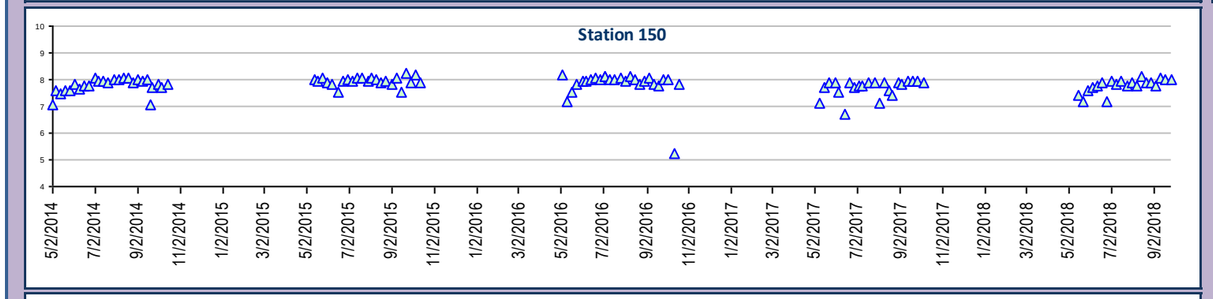
APDES Stations : Turbidity, Total, units NTU - 5 Year Trend

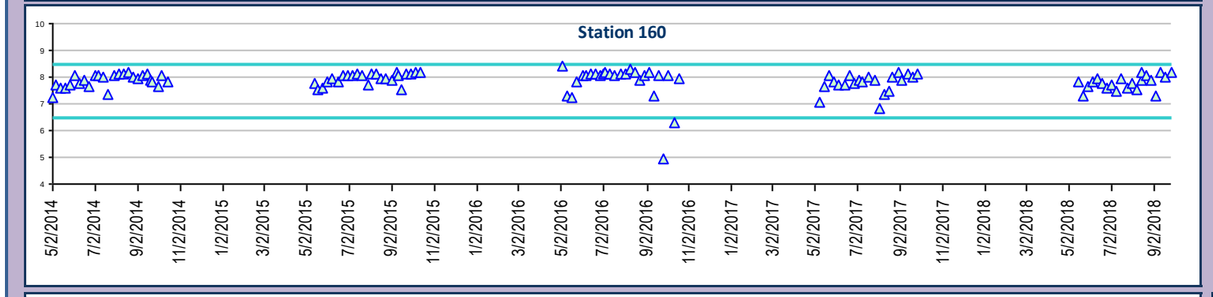
Teck

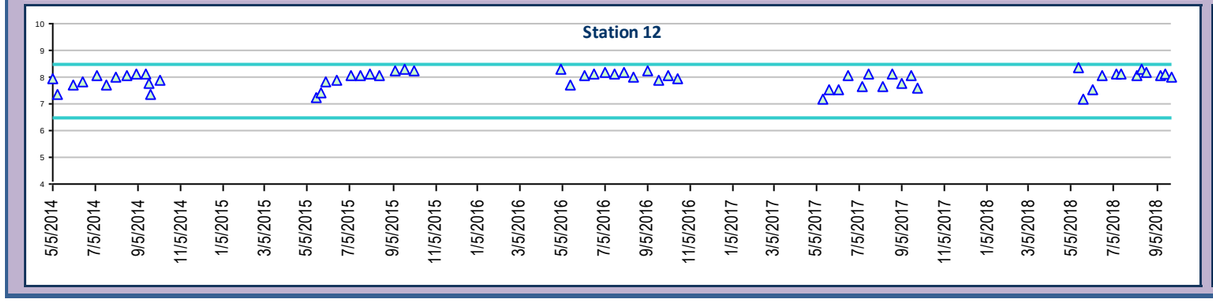


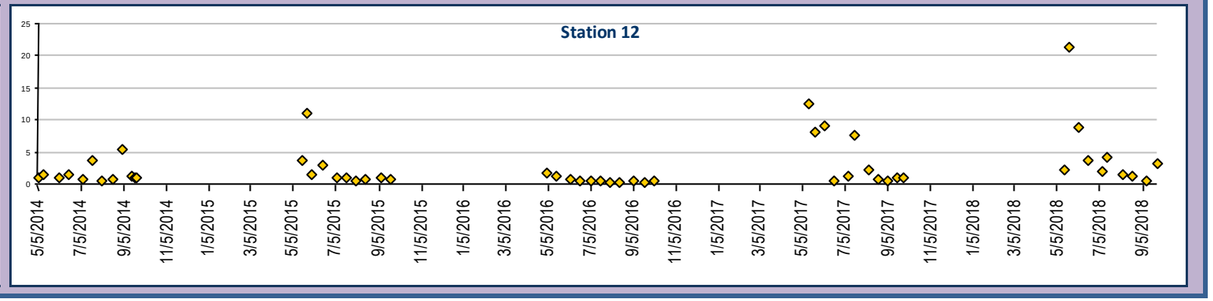








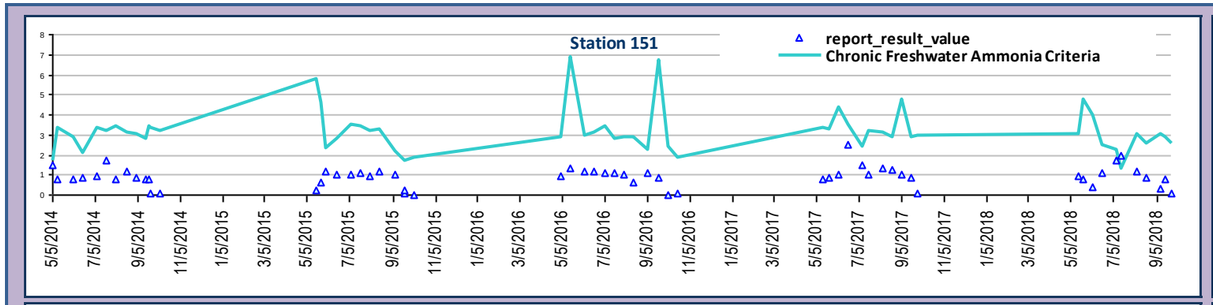


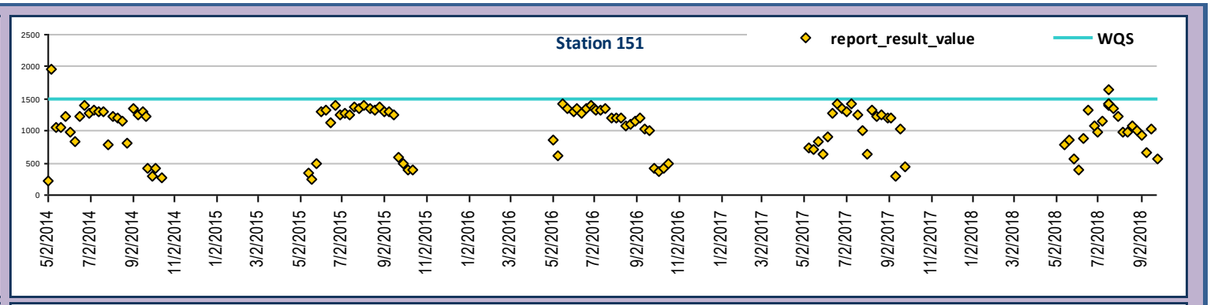


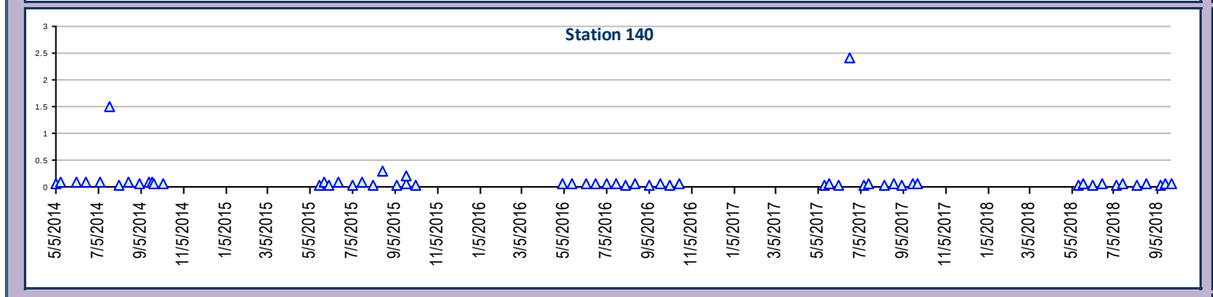
APDES Stations : NH3-N, Total, units mg/l - 5 Year Trend

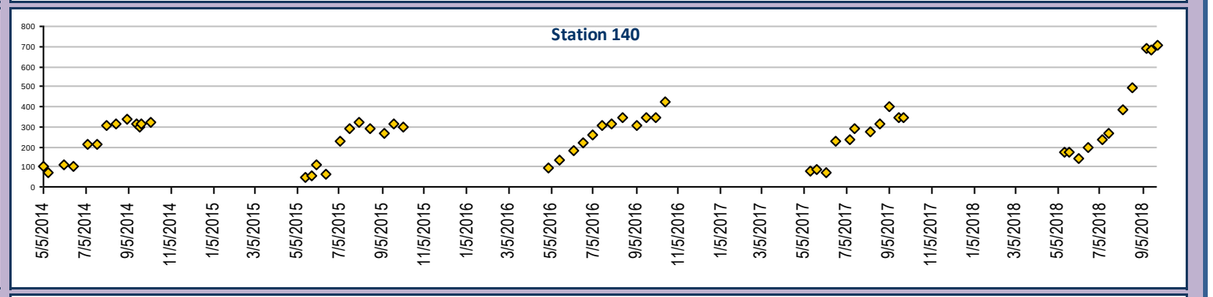
APDES Stations : TDS, units mg/l - 5 Year Trend

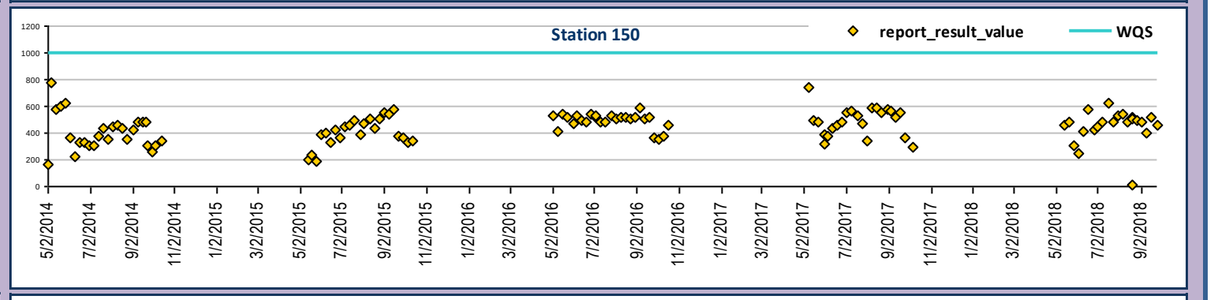
Teck

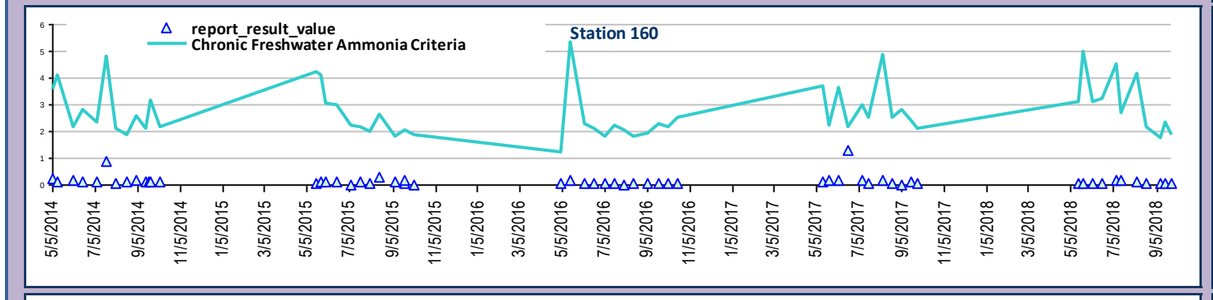


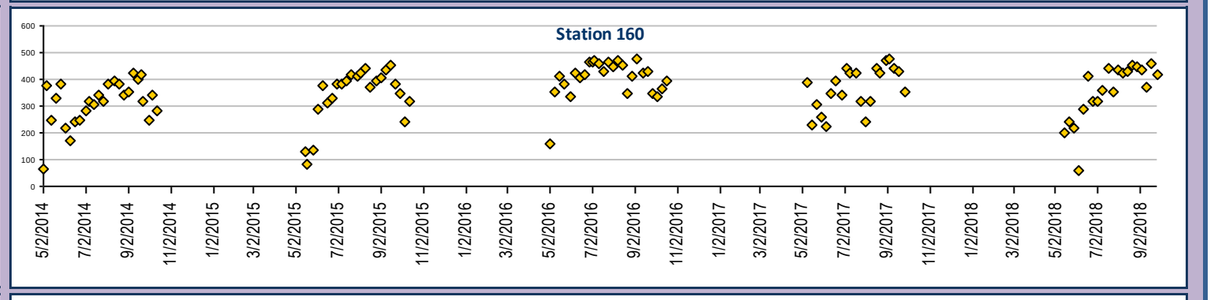


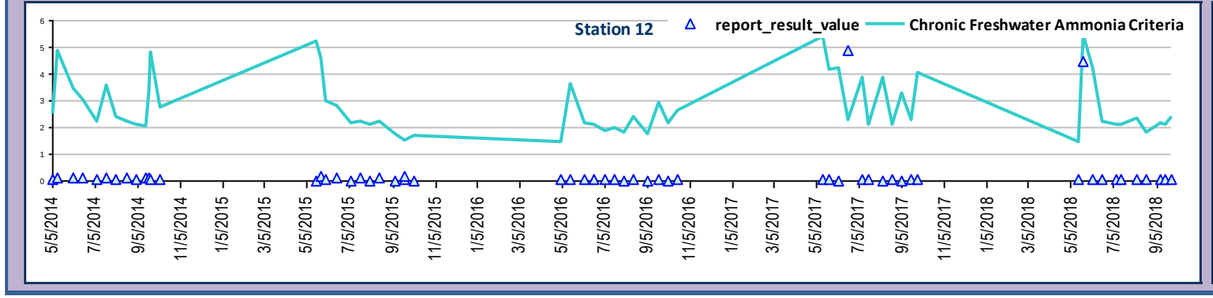


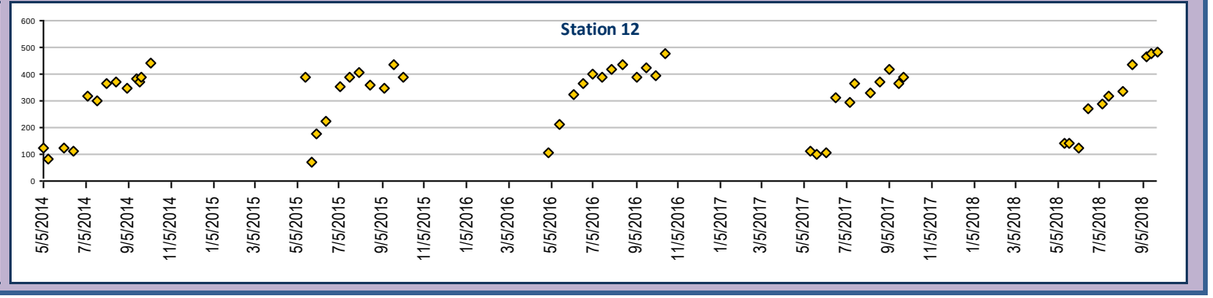








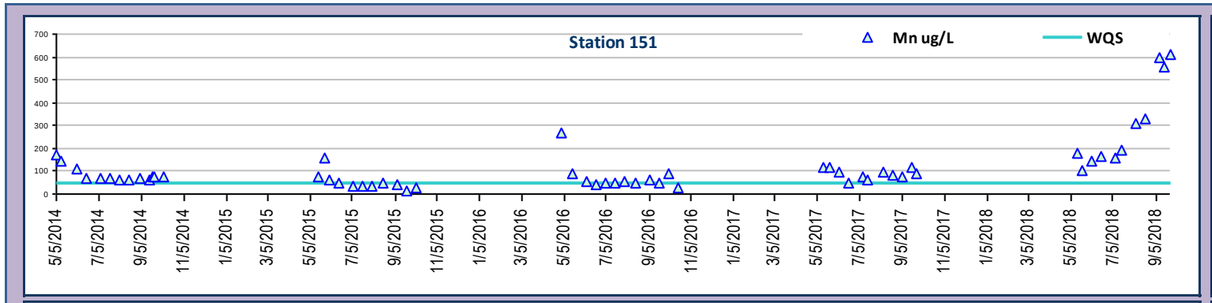


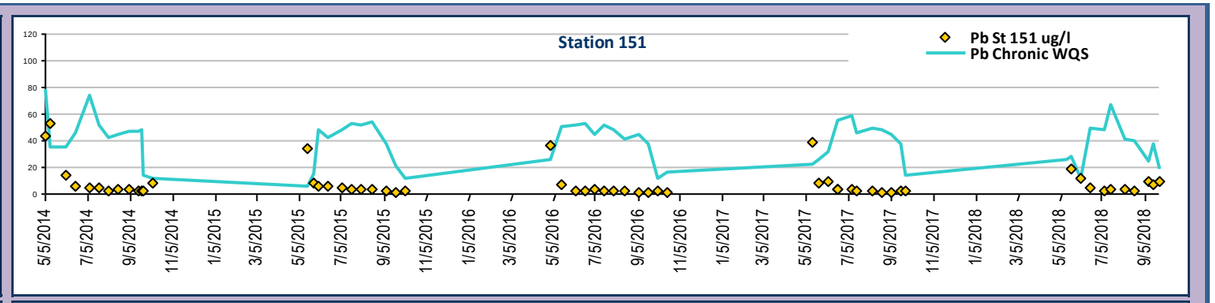


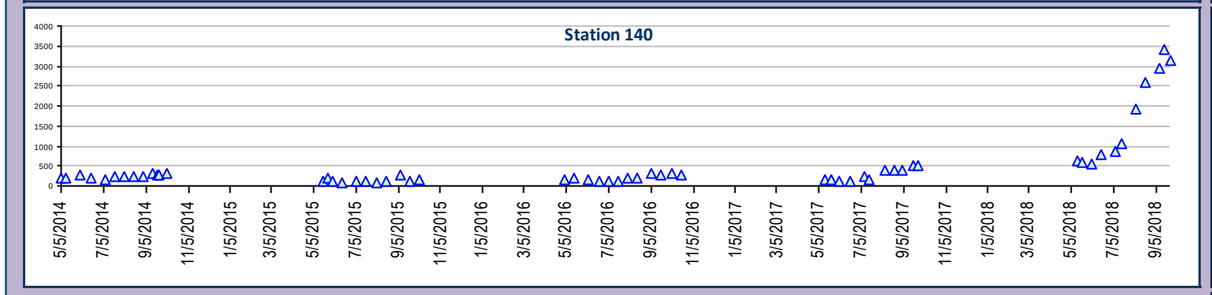
APDES Stations : Manganese, Total, units ug/L - 5 Year Trend

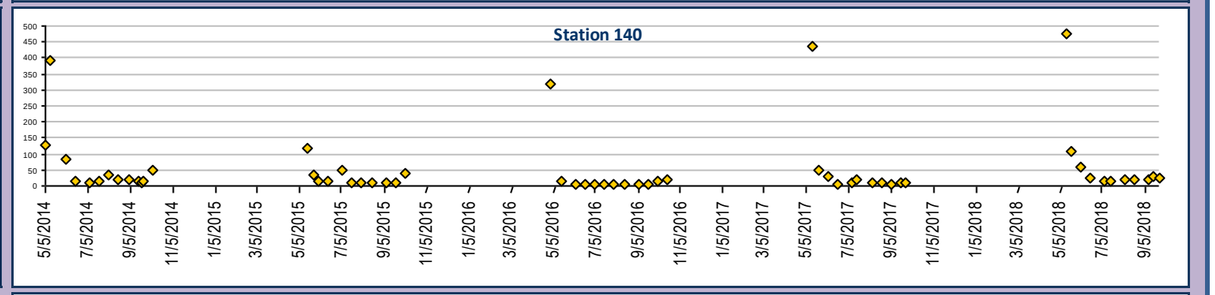
APDES Stations : Lead, Total, units, ug/L - 5 Year Trend

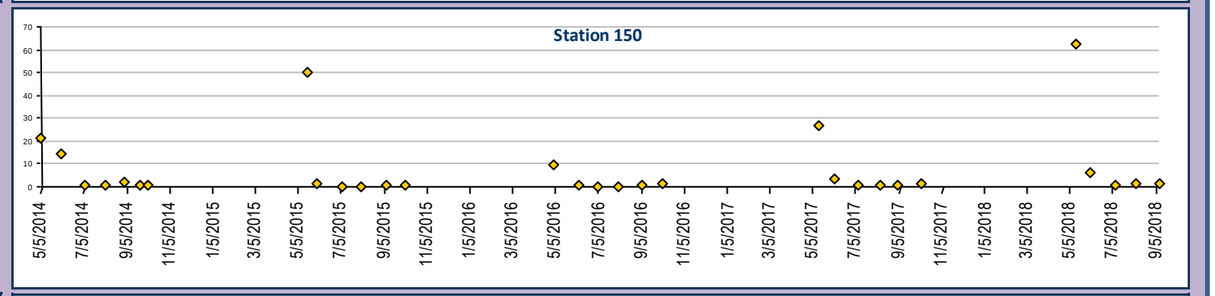
Teck

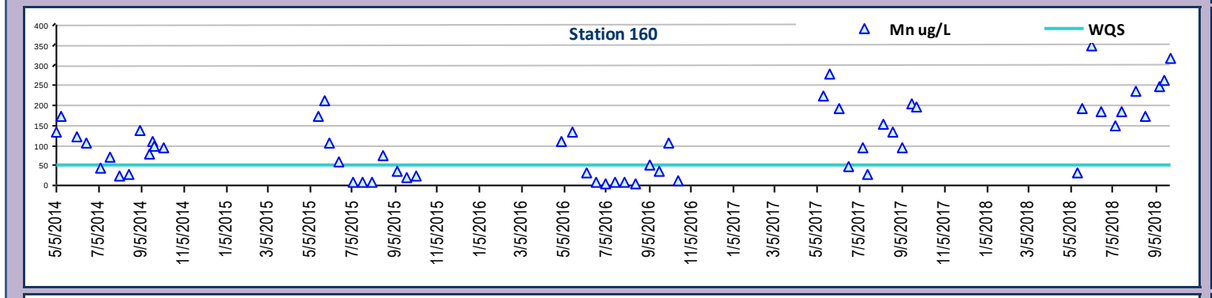


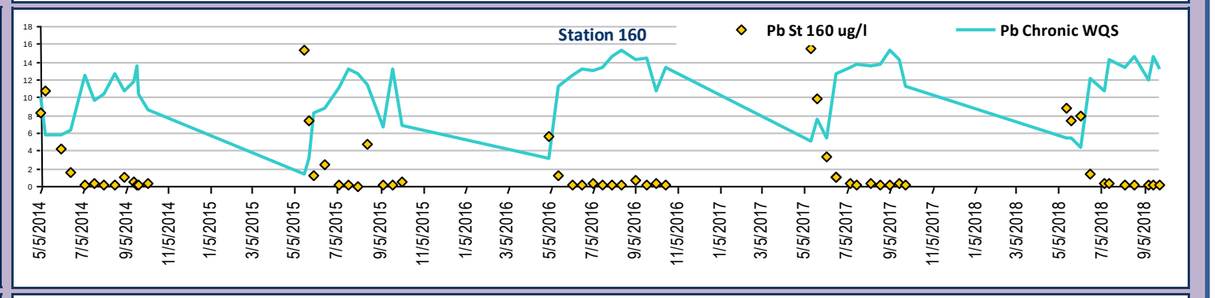


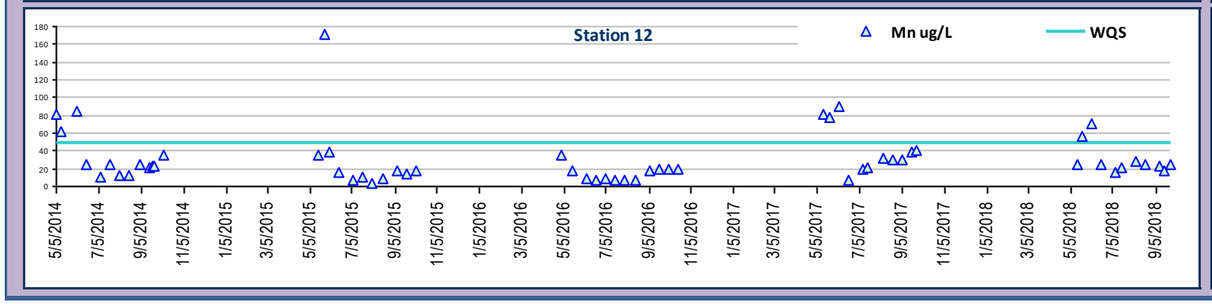


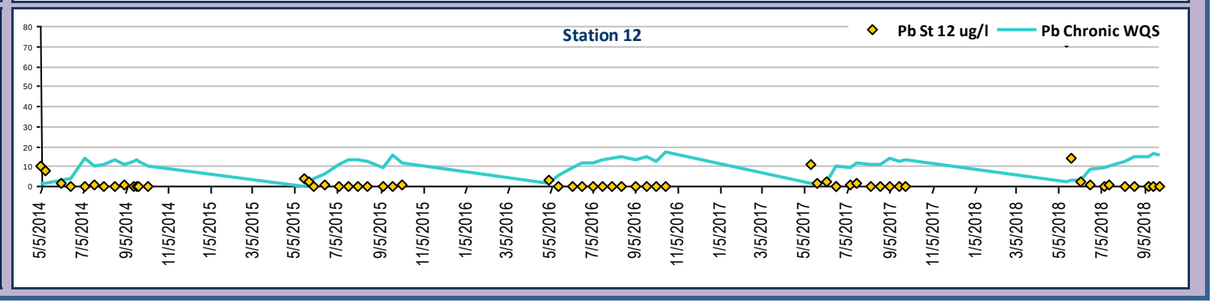












APDES Stations : Mercury, Total, units ug/L - 5 Year Trend

APDES Stations : Nickel, Total, units, ug/L - 5 Year Trend

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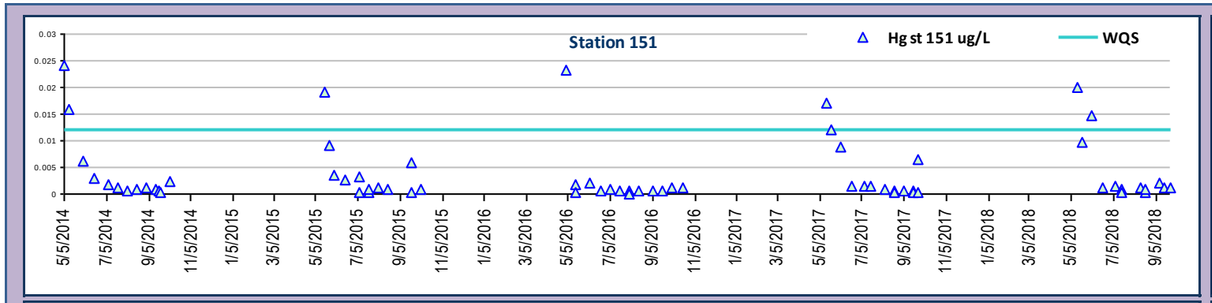
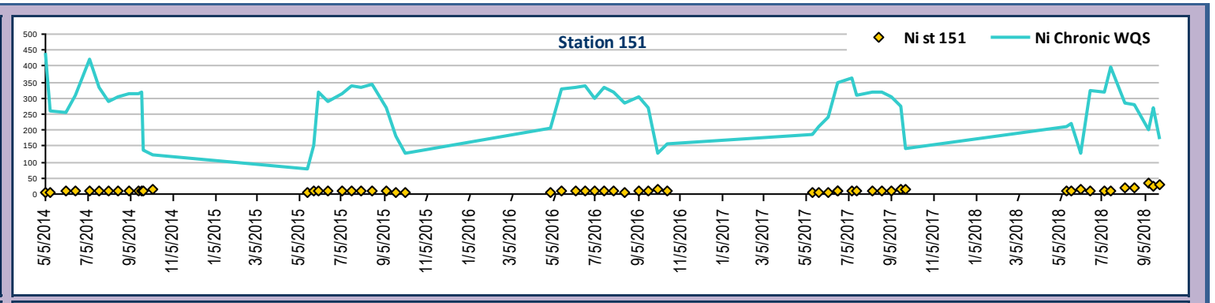
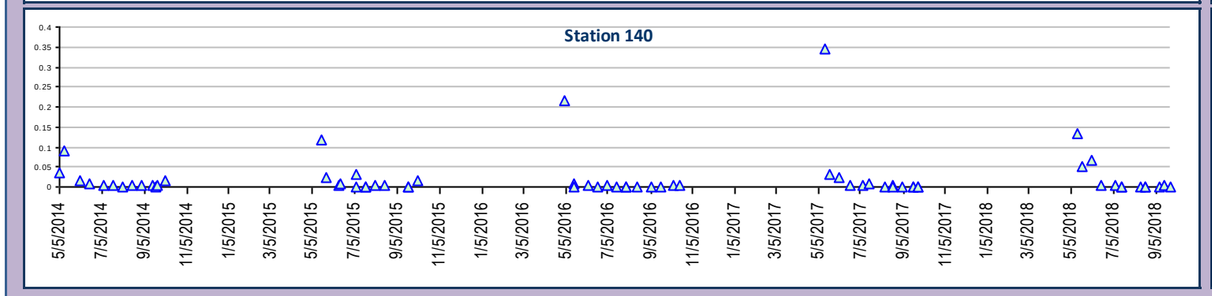
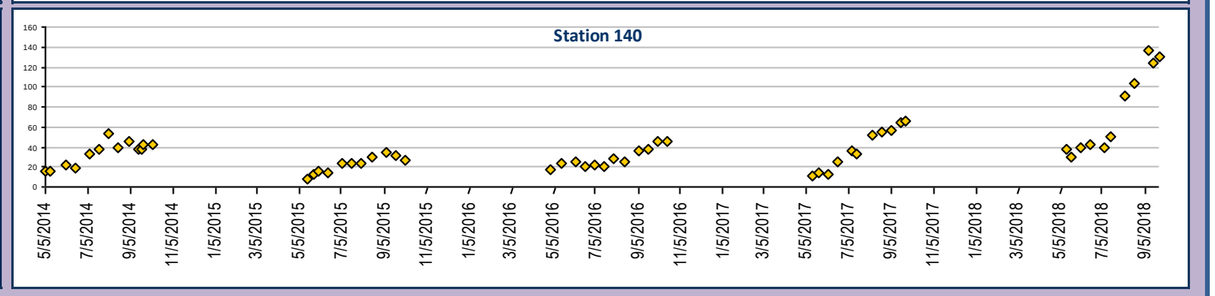
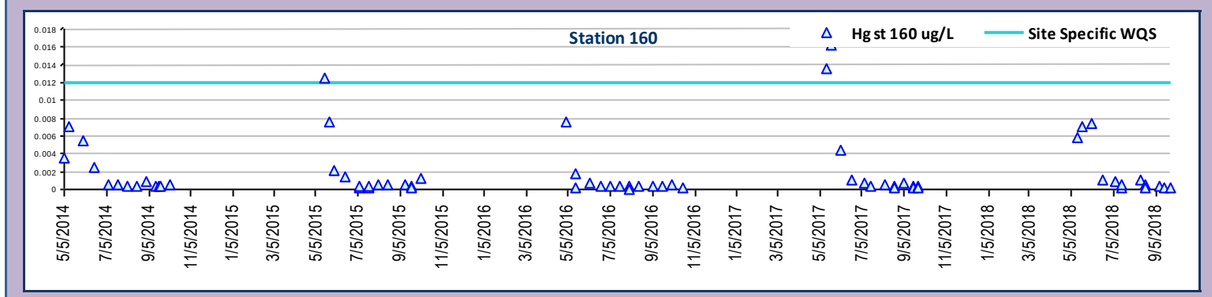
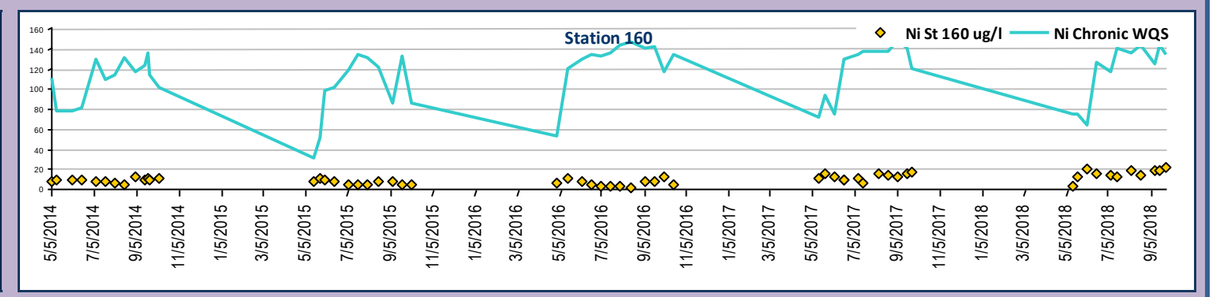


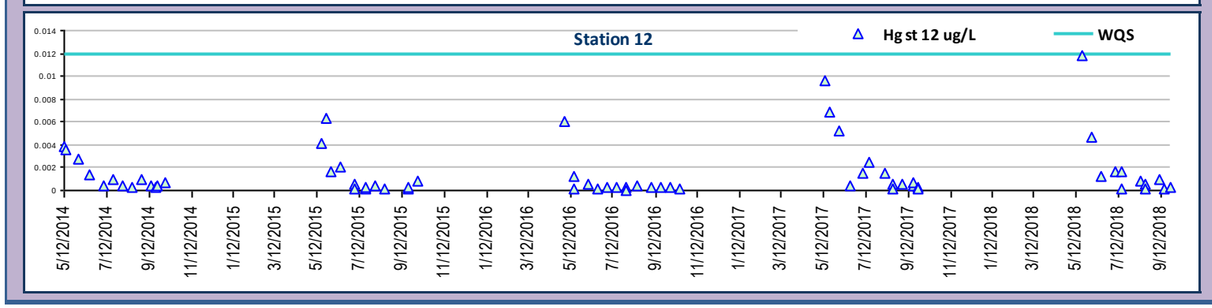


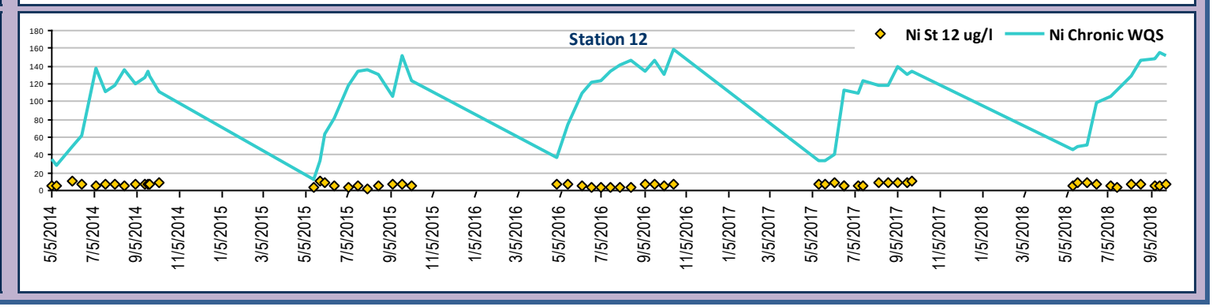








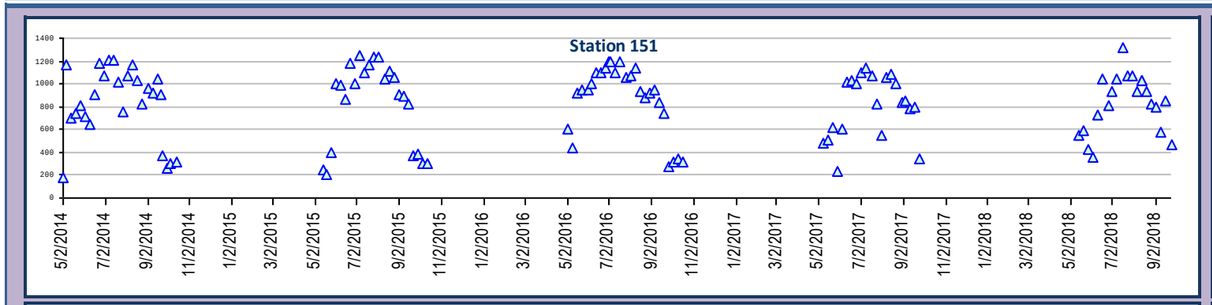


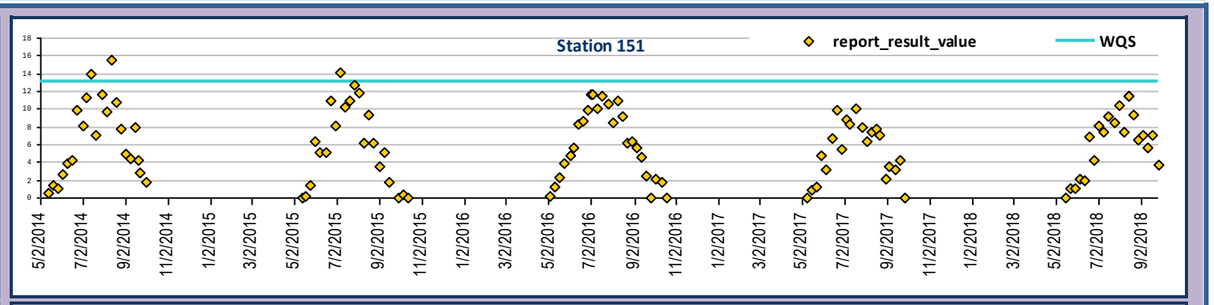


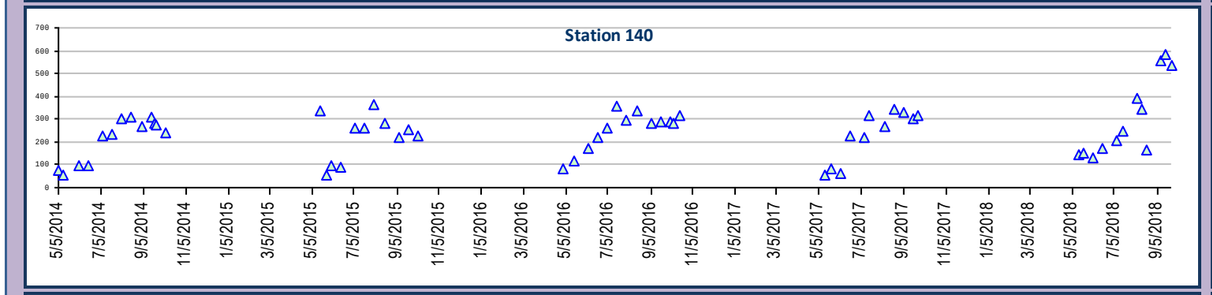
APDES Stations : Conductivity, Total, units uS/cm - 5 Year Trend

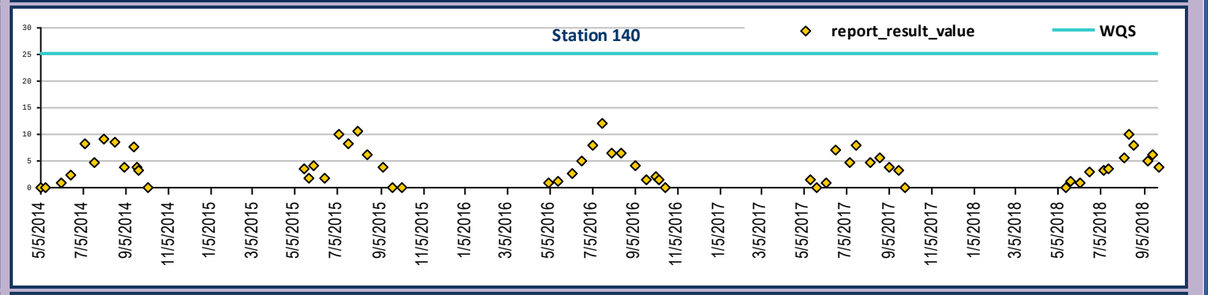
APDES Stations : Temperature, units Celsius - 5 Year Trend

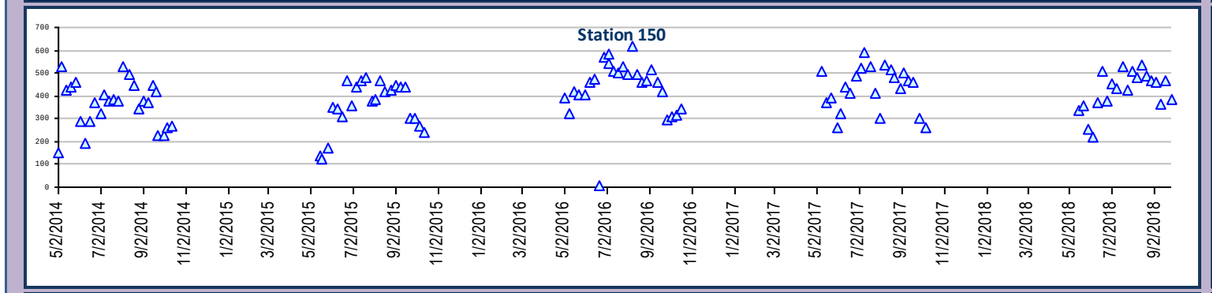
Teck

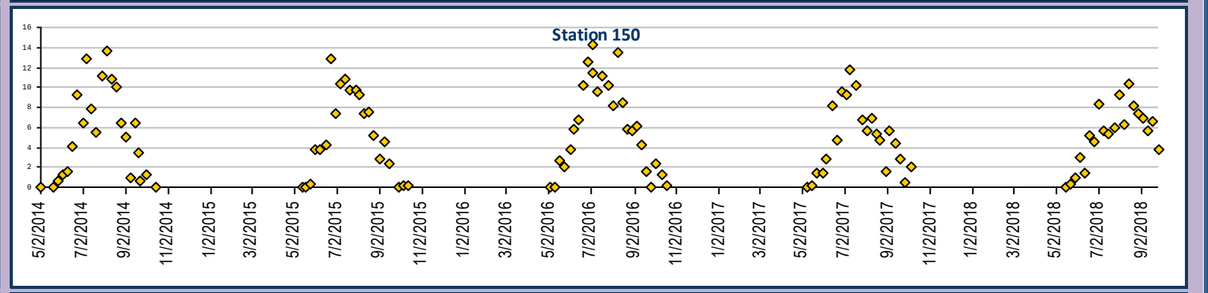


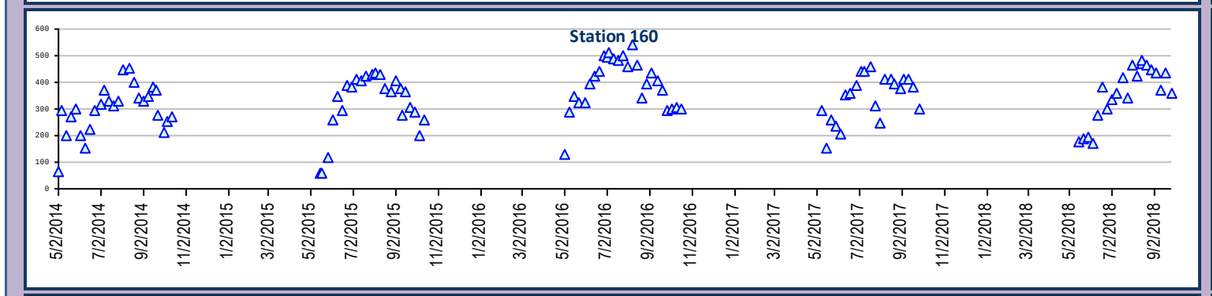


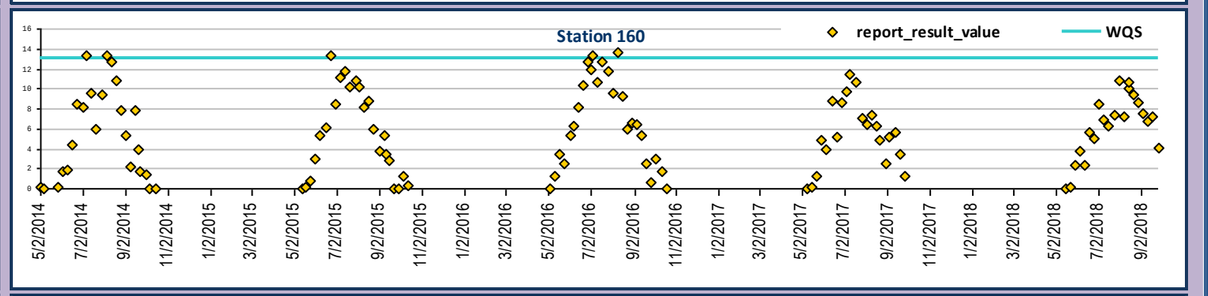


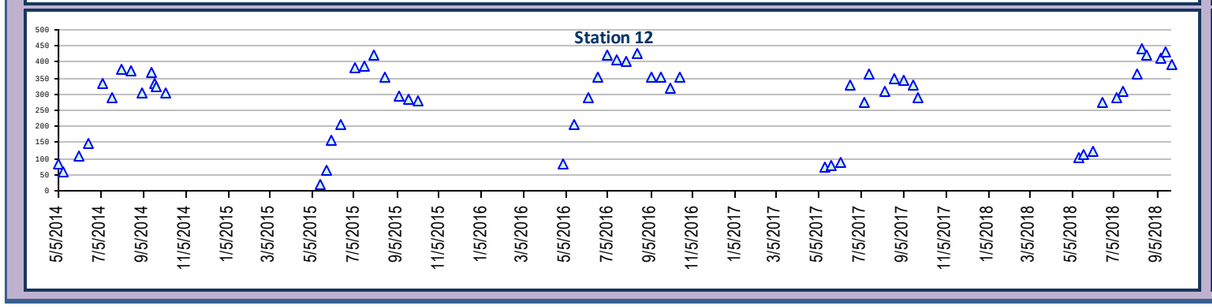


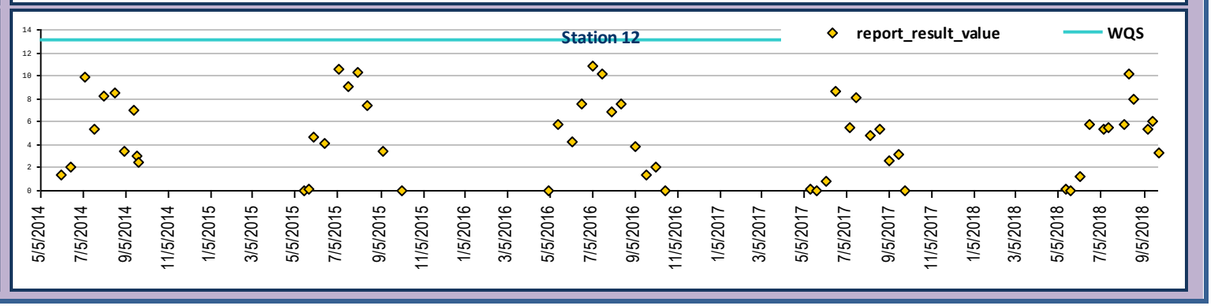




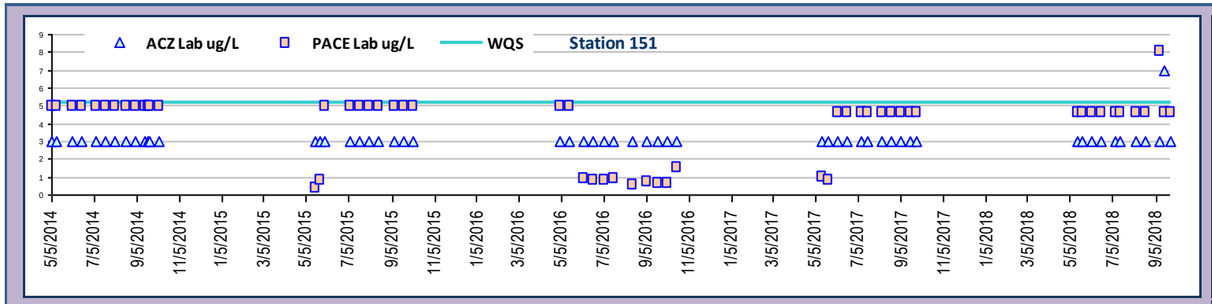






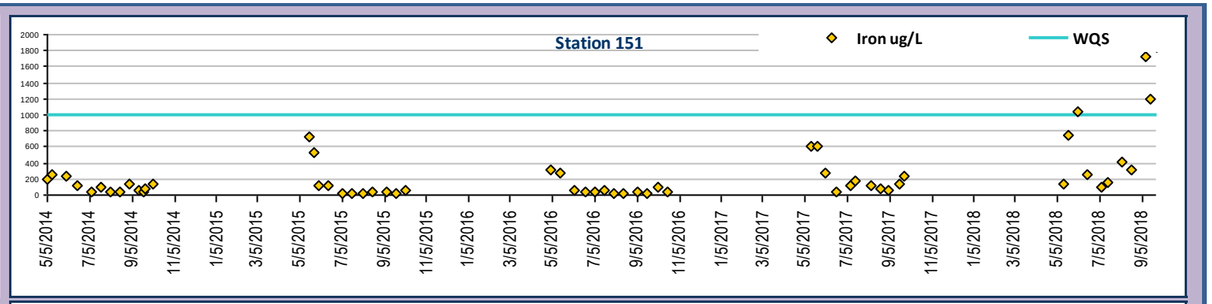


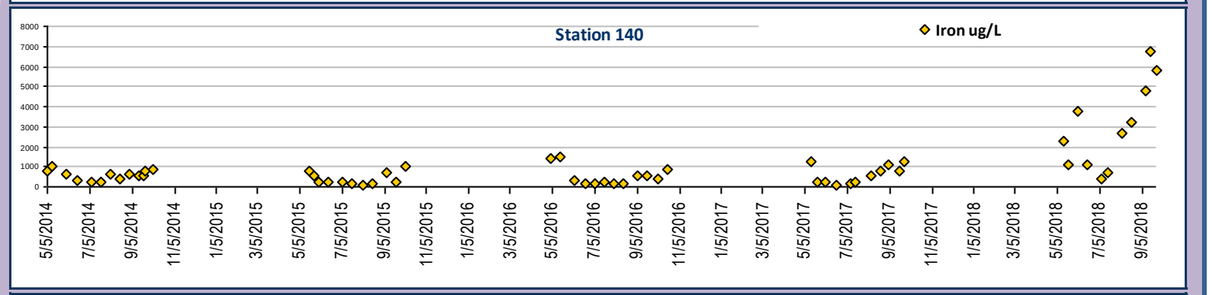
APDES Stations : Cyanide, WAD, units ug/L - 5 Year Trend

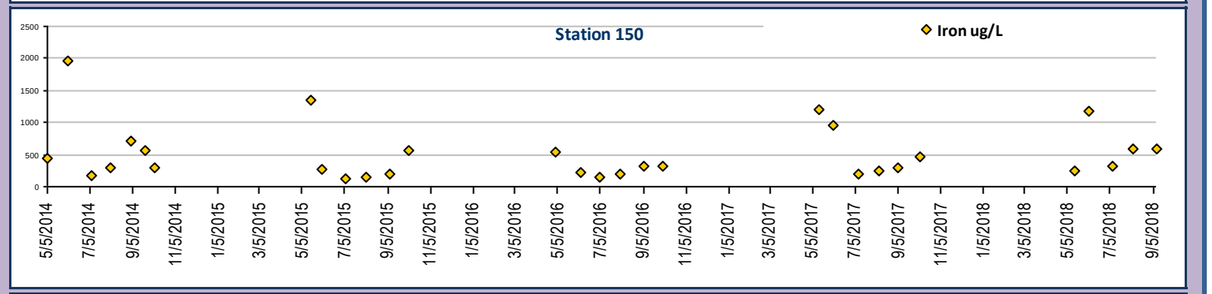


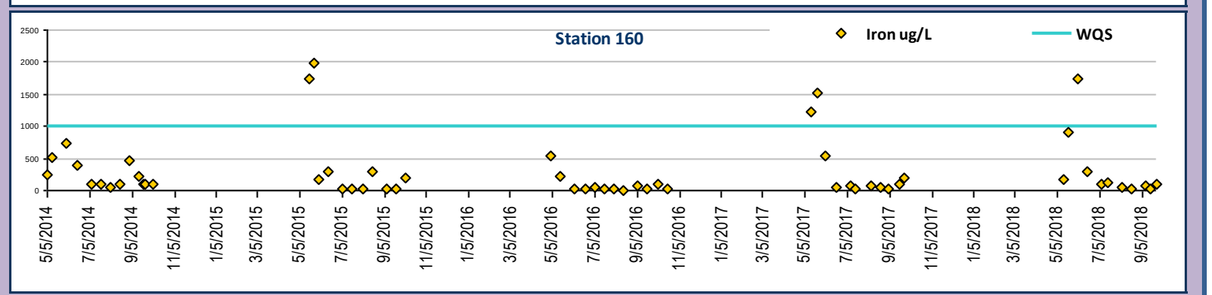
APDES Stations : Iron, Total, units, ug/L - 5 Year Trend

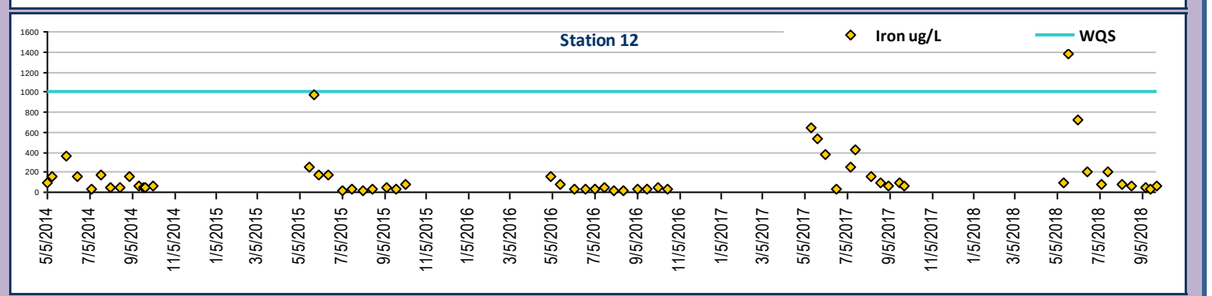
Teck







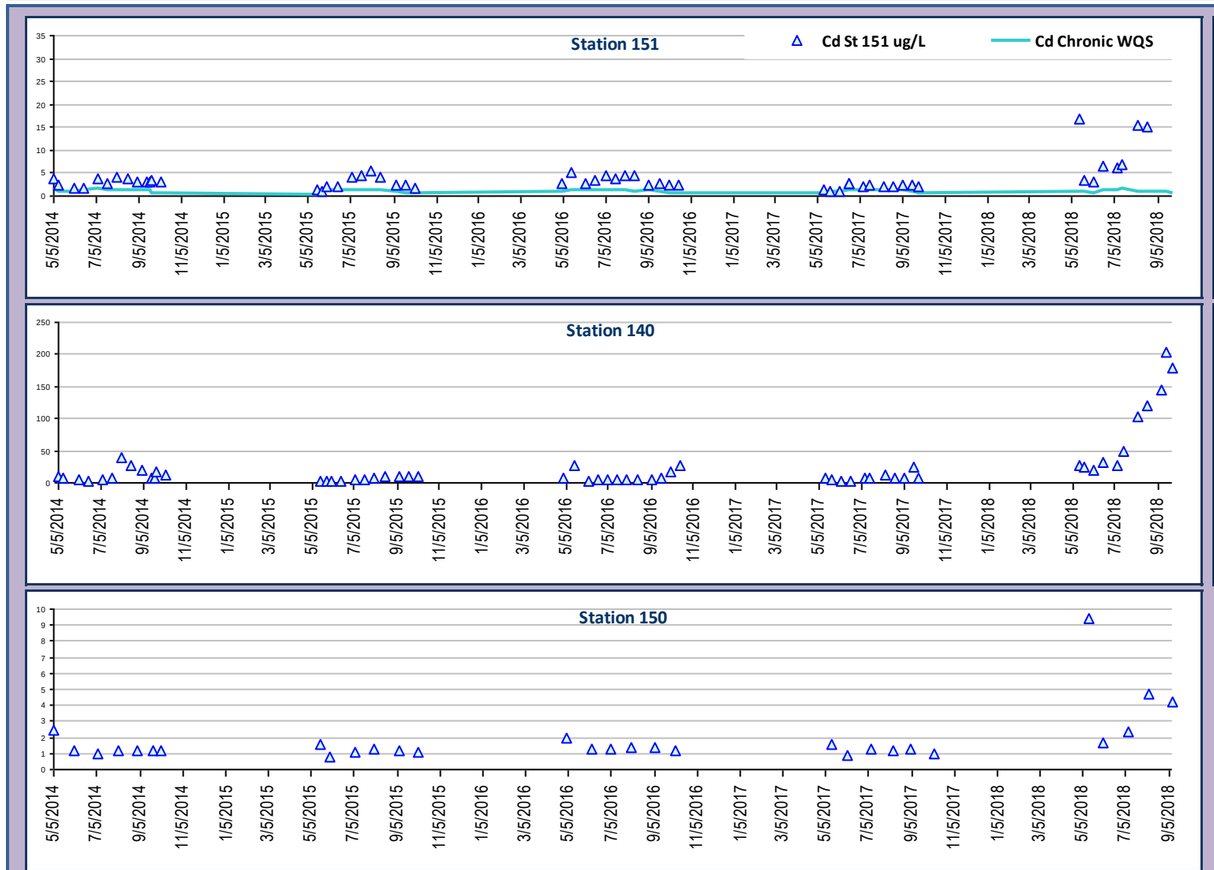


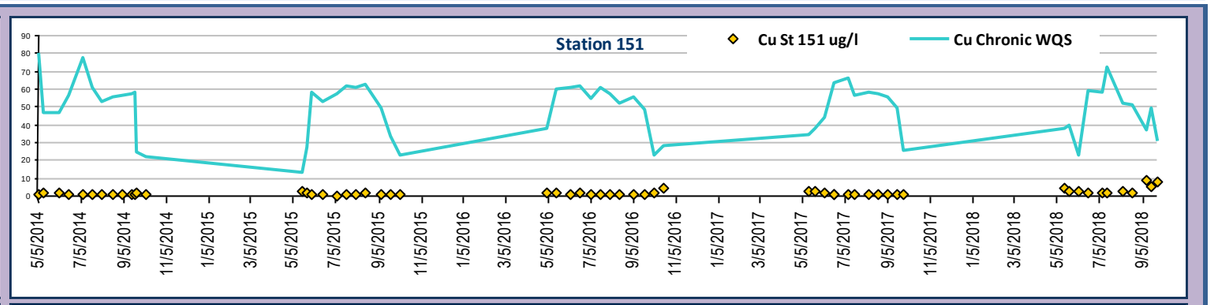


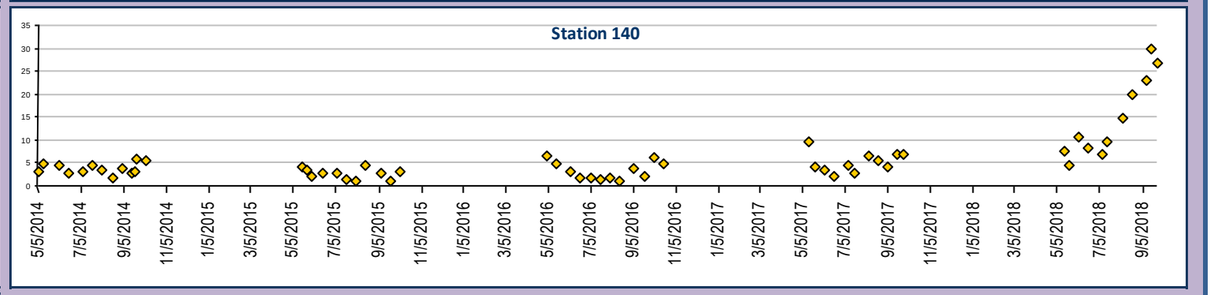
APDES Stations : Cadmium, Total, units ug/L - 5 Year Trend

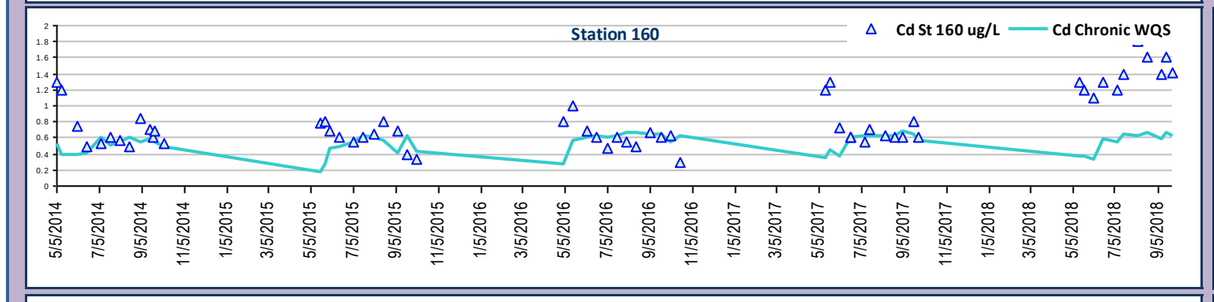
APDES Stations : Copper, Total, units, ug/L - 5 Year Trend

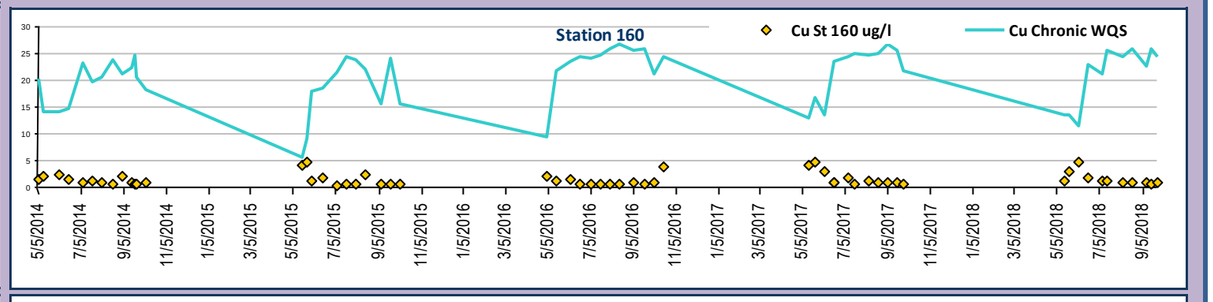
Teck

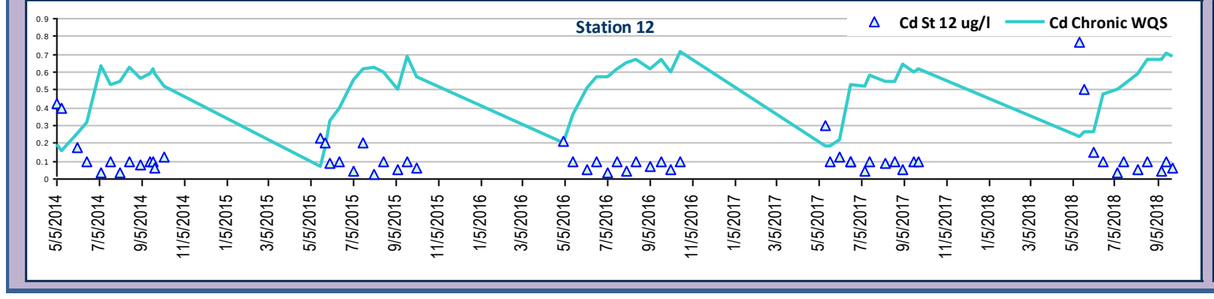


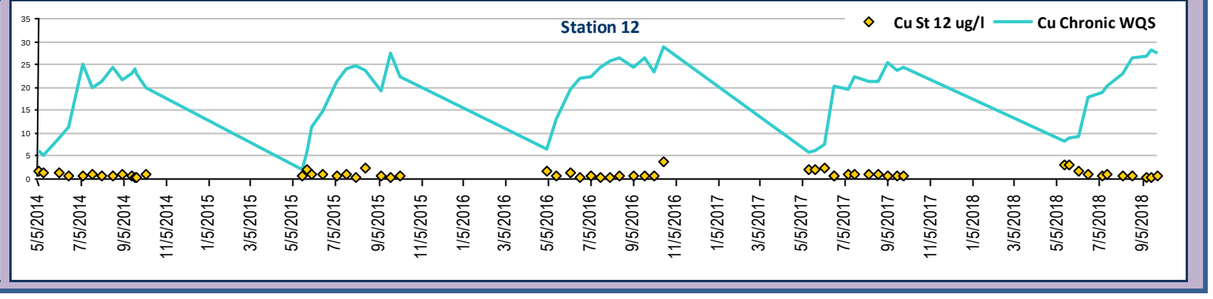








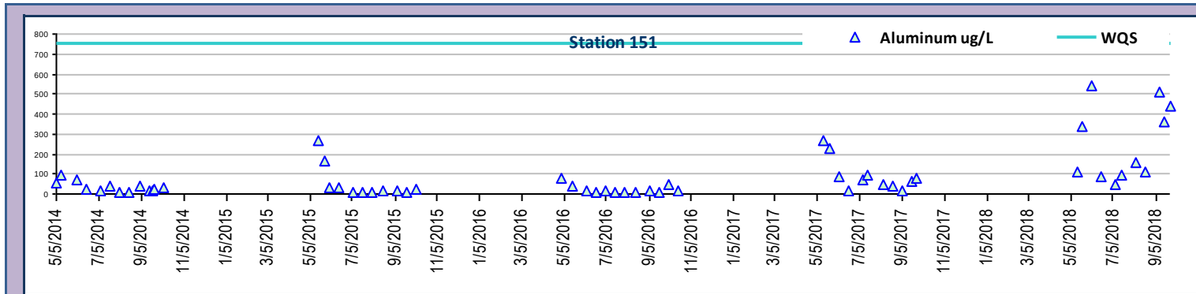


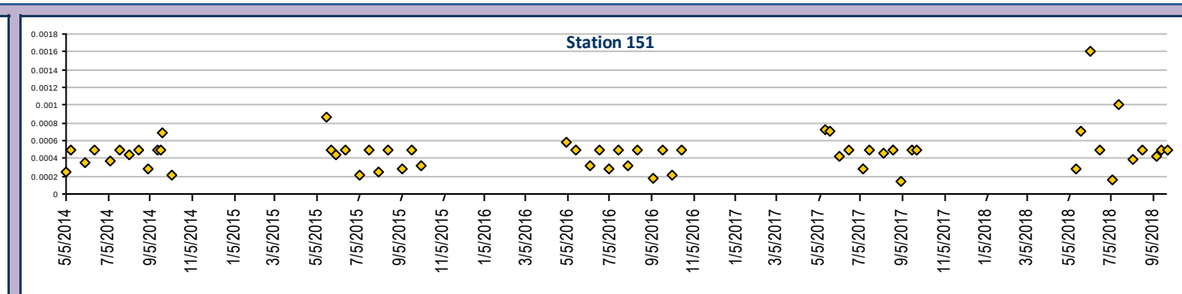


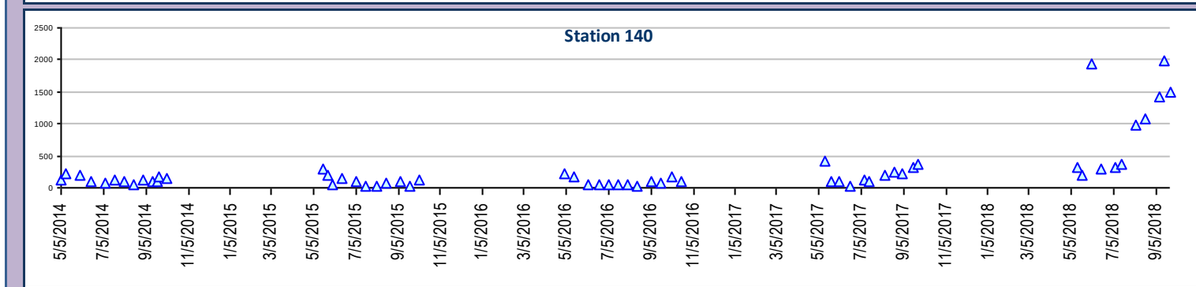
APDES Stations : Aluminum, Total, units ug/L - 5 Year Trend

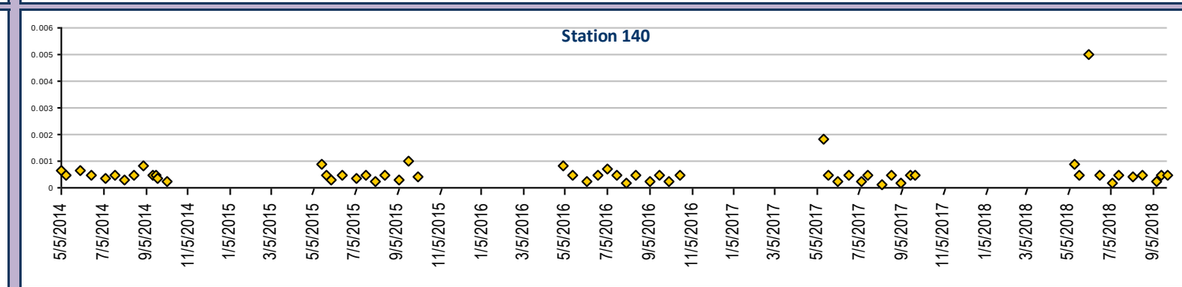
APDES Stations : Chromium, Total, units mg/L - 5 Year Trend

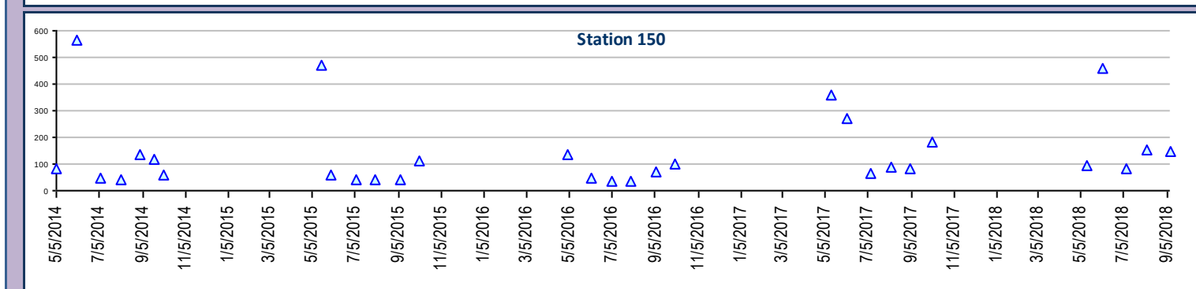
Teck

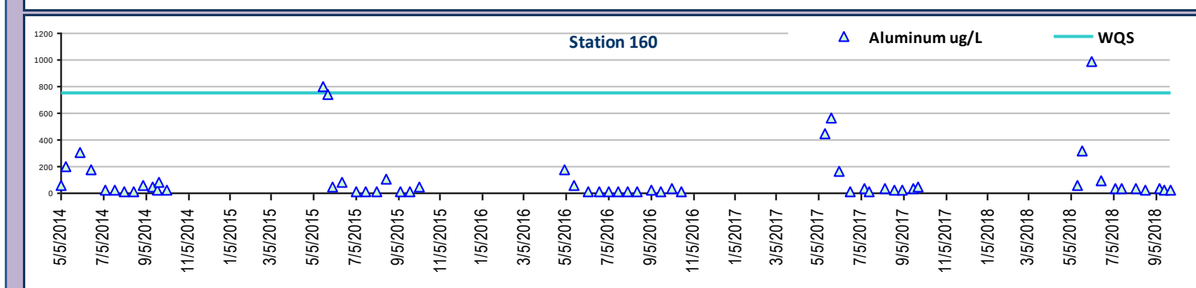


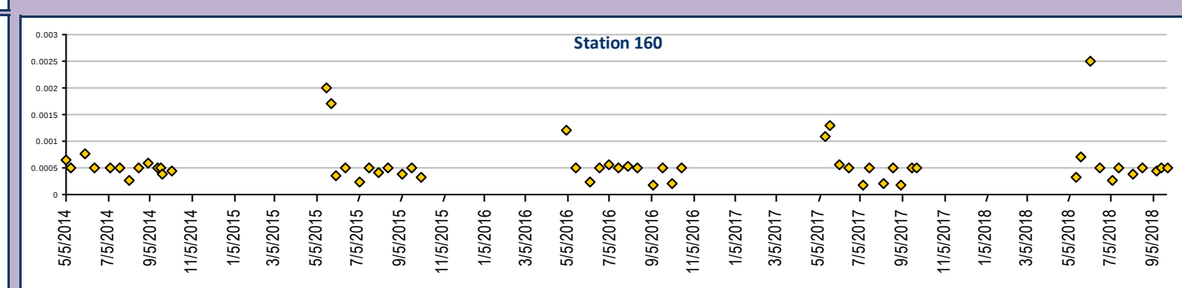


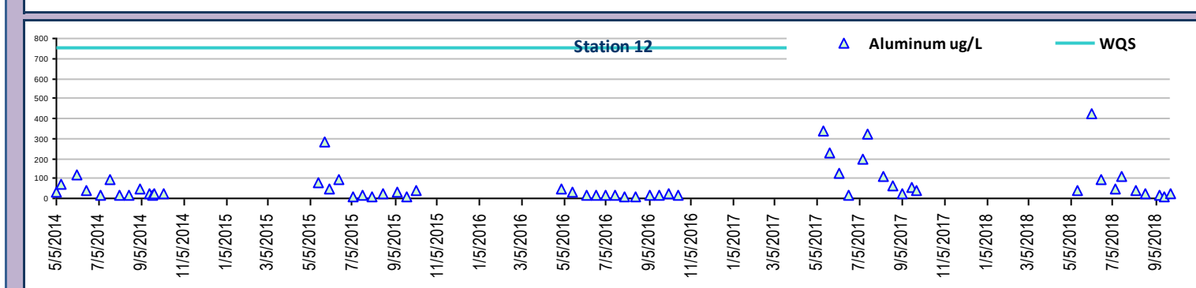


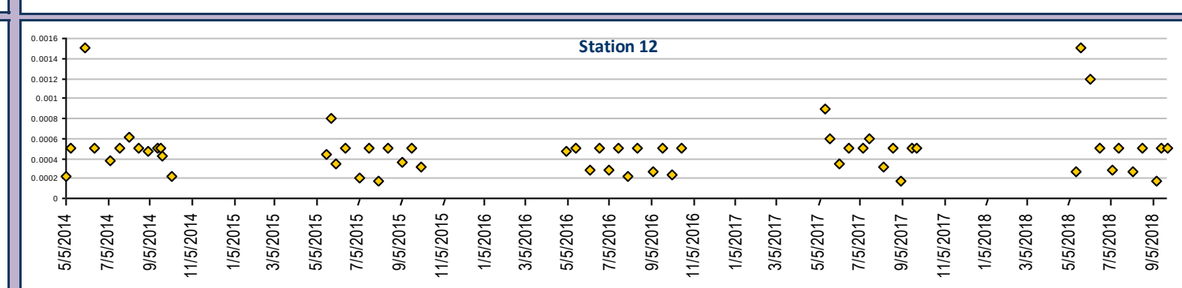












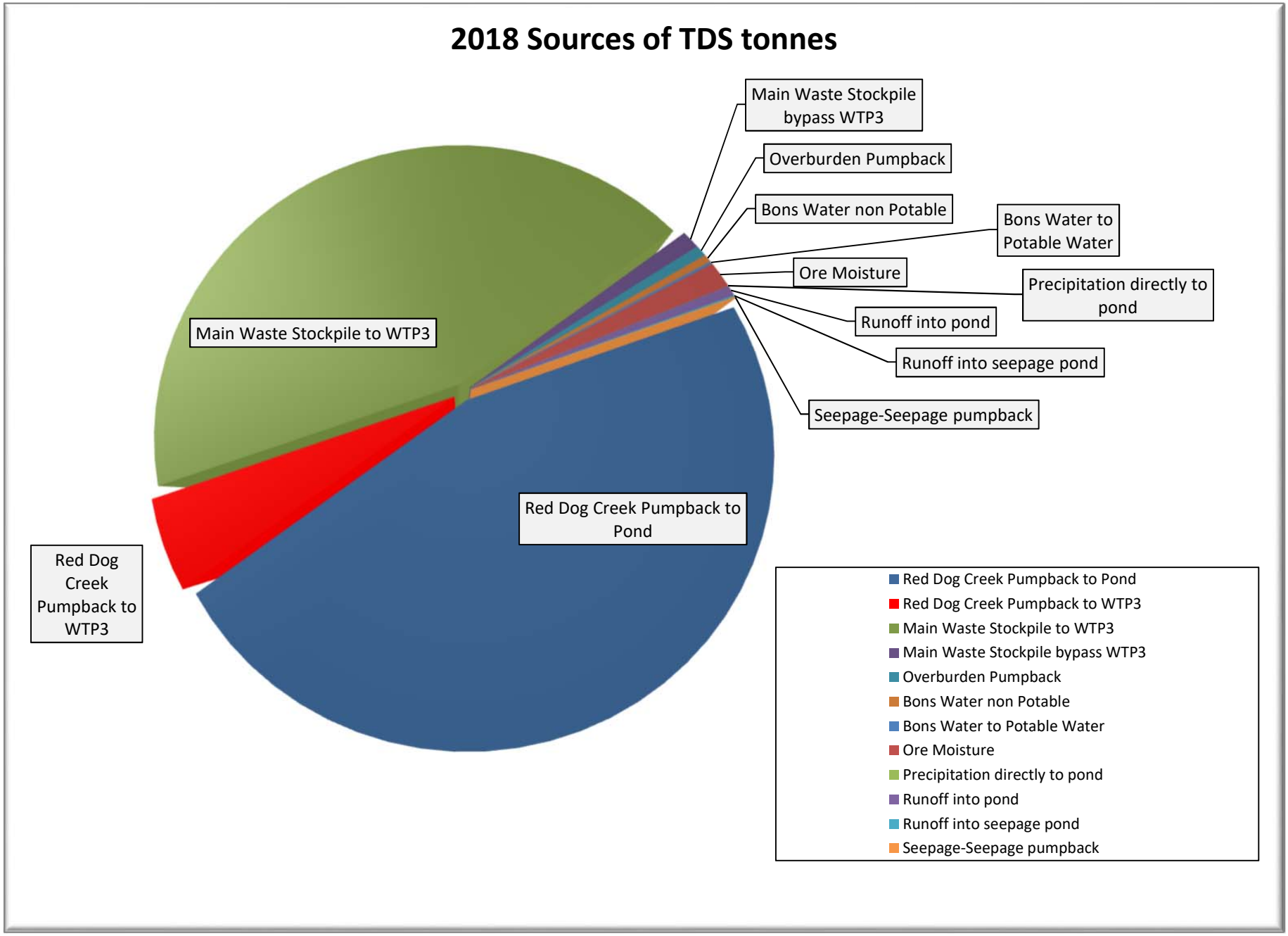
Appendix G: Red Dog Mine Tailings Basin Water Mass Balance

Major Flows for Red Dog Tailings Basin Water Mass Balance 2018

	Flow	*Concentrations*									
Location	*2018 Flow Mgal*	*Ca mg/L*	*Cu mg/L*	*Zn mg/L*	*Mg mg/L*	*Mn mg/L*	*Fe mg/L*	*Al mg/L*	*SO_4 mg/L*	*TDS mg/L*	*Comment*
Red Dog Creek Pumpback to Pond	574.80	441.8	0.1	887.7	194.9	47.1	44.7	2.7	3,929.2	5,759.2	Avg 2018 data
Red Dog Creek Pumpback to WTP3	60.42	441.8	0.1	887.7	194.9	47.1	44.7	2.7	3,929.2	5,759.2	Avg 2018 data
Main Waste Dump to WTP3	58.79	446.6	5.2	8,889.5	1,898.6	466.1	2,405.9	789.3	41,763.6	56,019.0	Avg 2018 data, Flow to WTP 3 and 1 from MWD
Main Waste Dump bypass WTP3	1.43	446.6	5.2	8,889.5	1,898.6	466.1	2,405.9	789.3	41,763.6	56,019.0	
Overburden Pumpback	22.58	265.6	0.0	5.3	217.1	5.5	1.6	0.1	1,365.1	2,198.0	2018 data,average of east/west sump, Cu from 2015
Bons Water non Potable	168.60	37.9	0.0	0.0	18.3	0.0	0.1	0.0	67.6	207.6	Avg from 2018 data
Bons Water to Potable Water	50.10	37.9	0.0	0.0	18.3	0.0	0.1	0.0	67.6	207.6	Avg from 2018 data
Ore Moisture	19.90	441.8	0.1	887.7	194.9	47.1	44.7	2.7	3,929.2	5,759.2	Assumed to be the same as mine pumpback water
Precipitation directly to pond	463.96	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Runoff into pond	119.30	48.0	0.0	15.4	28.6	1.7	3.0	1.0	246.5	377.7	avg data 2018, from station 140 values
OB Runoff pumpback	18.50	48.0	0.0	15.4	28.6	1.7	3.0	1.0	246.5	377.7	avg data 2018, from station 140 values
Seepage-Seepage pumpback	1.48	375.5	0.0	403.3	227.4	49.7	92.9	0.2	3,085.4	4,460.5	Avg from 2017 data
Seepage Pond Pumpback	273.87	423.0	0.1	1,196.8	405.4	116.7	349.6	17.0	6,540.0	9,658.2	Avg from 2018 data, includes some runoff
Reclaim Water to Mill	3237.50	520.1	0.1	598.7	213.1	49.3	5.5	1.2	3,772.7	5,363.6	Avg from 2108 data
Reclaim Water to WTP2/Pond	608.00	804.6	0.1	0.1	122.6	0.1	0.0	0.0	2,612.0	3,392.0	Avg from 2108 data
Reclaim Water to WTP2/Discharge	1402.60	804.6	0.1	0.1	122.6	0.1	0.0	0.0	2,612.0	5,363.6	Avg from 2108 data
Reclaim Water to WTP1	0.00	520.1	0.1	598.7	213.1	49.3	5.5	1.2	3,772.7	5,363.6	Avg from 2108 data
WTP2 effluent to pond	71.03	565.9	0.0	48.0	106.0	0.1	0.5	0.0	2,972.8	4,310.4	No new samples in 2018
WTP3 effluent	57.78	801.9	0.0	46.1	37.3	7.0	0.7	0.1	2,192.1	3,504.2	Avg from 2018 data
WTP1 effluent	282.60	749.0	0.0	38.6	14.6	0.0	0.7	0.2	1,786.0	3,763.8	No new samples in 2018
Tailings water	2989.00	568.5	0.0	996.1	207.1	50.3	0.1	0.1	4,620.0	6,833.6	Same as concentrate water, avg data from 2018
Evaporation	93.23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
WTP2 Discharge Water	1402.60	804.6	0.1	0.1	122.6	0.1	0.0	0.0	2,612.0	3,392.0	2018 dasta
Retained pore water	306.46	520.1	0.1	598.7	213.1	49.3	5.5	1.2	3,772.7	5,363.6	Assume same concentration as reclaim
Concentrate water	33.59	568.5	568.5	568.5	568.5	568.5	568.5	568.5	568.5	568.5	Assume same concentration as tailings
Seepage from T-pond	273.89	520.1	0.1	598.7	213.1	49.3	5.5	1.2	3,772.7	5,363.6	Assume same concentration as reclaim
Pond water end 2017 (12/31/17)	3718.00	541.0	0.0	468.3	210.8	46.8	3.8	1.0	3,382.0	4,945.0	Avg data from 2017
Pond water end 2018 (12/31/18)	3446.00	520.1	0.1	598.7	213.1	49.3	5.5	1.2	3,772.7	4,945.0	Avg from 2018 data

Major Flows for Red Dog Tailings Basin Water Mass Balance 2018

	Flow	Loads								
Location	*2018 Flow M^3x10^6*	*Ca tonnes*	*Cu tonnes*	*Zn tonnes*	*Mg tonnes*	*Mn tonnes*	*Fe tonnes*	*Al tonnes*	*SO4 tonnes*	*TDS tonnes*
Red Dog Creek Pumpback to Pond	*2.18*	961	0	1,932	424	102	97	6	8,549	12,531
Red Dog Creek Pumpback to WTP3	*0.23*	101	0	203	45	11	10	1	899	1,317
Main Waste Stockpile to WTP3	*0.22*	99	1	1,978	423	104	535	176	9,294	12,467
Main Waste Stockpile bypass WTP3	*0.01*	2	0	48	10	3	13	4	226	303
Overburden Pumpback	*0.09*	23	0	0	19	0	0	0	117	188
Bons Water non Potable	*0.64*	24	0	0	12	0	0	0	43	132
Bons Water to Potable Water	*0.19*	7	0	0	3	0	0	0	13	39
Ore Moisture	*0.08*	33	0	67	15	4	3	0	296	434
Precipitation directly to pond	*1.76*	0	0	0	0	0	0	0	0	0
Runoff into pond	*0.45*	22	0	7	13	1	1	0	111	171
Runoff into seepage pond	*0.07*	3	0	1	2	0	0	0	17	26
Seepage-Seepage pumpback	*0.01*	2	0	2	1	0	1	0	17	25
Total Infow	5.83	1,273	1	4,235	963	224	661	187	19,548	27,583
Seepage Pond Pumpback	*1.04*	439	0	1,241	420	121	362	18	6,780	10,013
Reclaim Water to Mill	*12.26*	6,374	1	7,337	2,612	604	67	15	46,235	65,732
Reclaim Water to WTP2/Pond	*2.30*	1,852	0	0	282	0	0	0	6,012	7,807
Reclaim Water to WTP2/Discharge	*5.31*	4,272	1	0	651	0	0	0	13,868	28,478
Reclaim Water to WTP1	*0.00*	0	0	0	0	0	0	0	0	0
WTP2 effluent to pond	*0.27*	152	0	13	29	0	0	0	799	1,159
WTP3 effluent	*0.22*	175	0	10	8	2	0	0	479	766
WTP1 effluent	*1.07*	801	0	41	16	0	1	0	1,911	4,026
Tailings water	*11.31*	6,432	0	11,270	2,343	569	1	1	52,273	77,319
Evaporation	*0.35*	0	0	0	0	0	0	0	0	0
WTP2 Discharge Water	*5.31*	4,272	1	0	651	0	0	0	13,868	18,010
Retained pore water	*1.16*	603	0	695	247	57	6	1	4,377	6,222
Concentrate water	*0.13*	72	72	72	72	72	72	72	72	72
Seepage from T-pond	*1.04*	539	0	621	221	51	6	1	3,911	5,561
Total Outflow	*7.99*	*5,487*	*73*	*1,388*	*1,191*	*181*	*84*	*75*	*22,229*	*29,865*
Pond water end 2017 (12/31/17)	*14.07*	7,614	0	6,590	2,967	659	54	13	47,599	69,597
Pond water end 2018 (12/31/18)	*13.04*	6,784	1	7,810	2,780	643	72	16	49,213	64,505
δ Pond water	-1.030	-830	1	1,220	-187	-16	18	2	1,614	-5,092


2018 Sources of TDS tonnes
Main Waste Stockpile bypass WTP3
Overburden Pumpback
Bons Water non Potable
Bons Water to Potable Water
Ore Moisture
Precipitation directly to pond
Runoff into pond
Runoff into seepage pond
Seepage-Seepage pumpback
Main Waste Stockpile to WTP3
Red Dog Creek Pumpback to Pond
Red Dog Creek Pumpback to WTP3
Red Dog Creek Pumpback to Pond
Red Dog Creek Pumpback to WTP3
Main Waste Stockpile to WTP3
Main Waste Stockpile bypass WTP3
Overburden Pumpback
Bons Water non Potable
Bons Water to Potable Water
Ore Moisture
Precipitation directly to pond
Runoff into pond
Runoff into seepage pond
Seepage-Seepage pumpback

	Flow	Load								
	2018 Flow M^3x10^6	*Ca tonnes*	*Cu tonnes*	*Zn tonnes*	*Mg tonnes*	*Mn tonnes*	*Fe tonnes*	*Al tonnes*	*SO4 tonnes*	*TDS tonnes*
Reclaim Water to WTP1	0.0	0	0	0	0	0	0	0	0	0
WTP1 effluent	1.1	801	0	41	16	0	1	0	1911	4026
WTP1 Net to Pond		801	0	41	16	0	1	0	1,911	4,026

	Flow	Load								
	2018 Flow M^3x10^6	*Ca tonnes*	*Cu tonnes*	*Zn tonnes*	*Mg tonnes*	*Mn tonnes*	*Fe tonnes*	*Al tonnes*	*SO4 tonnes*	*TDS tonnes*
Reclaim Water to WTP2/Pond	2.3	1,852	0	0	282	0	0	0	6,012	7,807
WTP2 effluent to pond	0.3	152	0	13	29	0	0	0	799	1,159
WTP2 Net to Pond		-1,700	0	13	-254	0	0	0	-5,212	-6,648

	Flow	Load								
	2016 Flow M^3x10^6	*Ca tonnes*	*Cu tonnes*	*Zn tonnes*	*Mg tonnes*	*Mn tonnes*	*Fe tonnes*	*Al tonnes*	*SO4 tonnes*	*TDS tonnes*
Reclaim Water to WTP2/Discharge	5.3	4,272	1	0	651	0	0	0	13,868	28,478
WTP2 Discharge Water	5.3	4,272	1	0	651	0	0	0	13,868	18,010
WTP2 Net to Discharge		0	0	0	0	0	0	0	0	-10,468

	Flow	Load								
	2018 Flow M^3x10^6	*Ca tonnes*	*Cu tonnes*	*Zn tonnes*	*Mg tonnes*	*Mn tonnes*	*Fe tonnes*	*Al tonnes*	*SO4 tonnes*	*TDS tonnes*
Red Dog Creek Pumpback to WTP3	0.2	101	0	203	45	11	10	1	899	1,317
Main Waste Stockpile to WTP3	0.2	99	1	1,978	423	104	535	176	9,294	12,467
WTP3 effluent	0.2	175	0	10	8	2	0	0	479	766
WTP3 Net to Pond		-25	-1	-2,171	-459	-113	-545	-176	-9,714	-13,018

	Flow	Load									
	2018 Flow M^3x10^6	*Ca tonnes*	*Cu tonnes*	*Zn tonnes*	*Mg tonnes*	*Mn tonnes*	*Fe tonnes*	*Al tonnes*	*SO4 tonnes*	*TDS tonnes*	
Reclaim Water to Mill	12.255	6,374	1	7,337	2,612	604	67	15	46,235	65,732	
Ore Moisture	0.075	33	0	67	15	4	3	0	296	434	
Bons Water non Potable	0.638	24	0	0	12	0	0	0	43	132	
Tailings water	11.315	6,432	0	11,270	2,343	569	1	1	52,273	77,319	
Concentrate water	0.127	72	72	72	72	72	72	72	72	72	
Used Bons Water non Potable	1.527	58	0	0	28	0	0	0	103	317	Assume no change in chemistry because no data
Net Mill to pond		131	71	3,939	-194	34	3	59	5,874	11,410	

	Flow	Load								
	2018 Flow M^3x10^6	*Ca tonnes*	*Cu tonnes*	*Zn tonnes*	*Mg tonnes*	*Mn tonnes*	*Fe tonnes*	*Al tonnes*	*SO4 tonnes*	*TDS tonnes*
Seepage from T-pond	1.04	539	0	621	221	51	6	1	3,911	5,561
Runoff into seepage pond	0.07	3	0	1	2	0	0	0	17	26
Seepage-Seepage pumpback	0.01	2	0	2	1	0	1	0	17	25
Seepage from Seepage Pond	0.00	0	0	1	0	0	0	0	5	8
Seepage Pond Pumpback	1.04	439	0	1,241	420	121	362	18	6,780	10,013
Seepage System Net to pond		-106	0	618	196	70	356	16	2,840	4,409

Red Dog Tailings Basin Water Mass Balance 2018

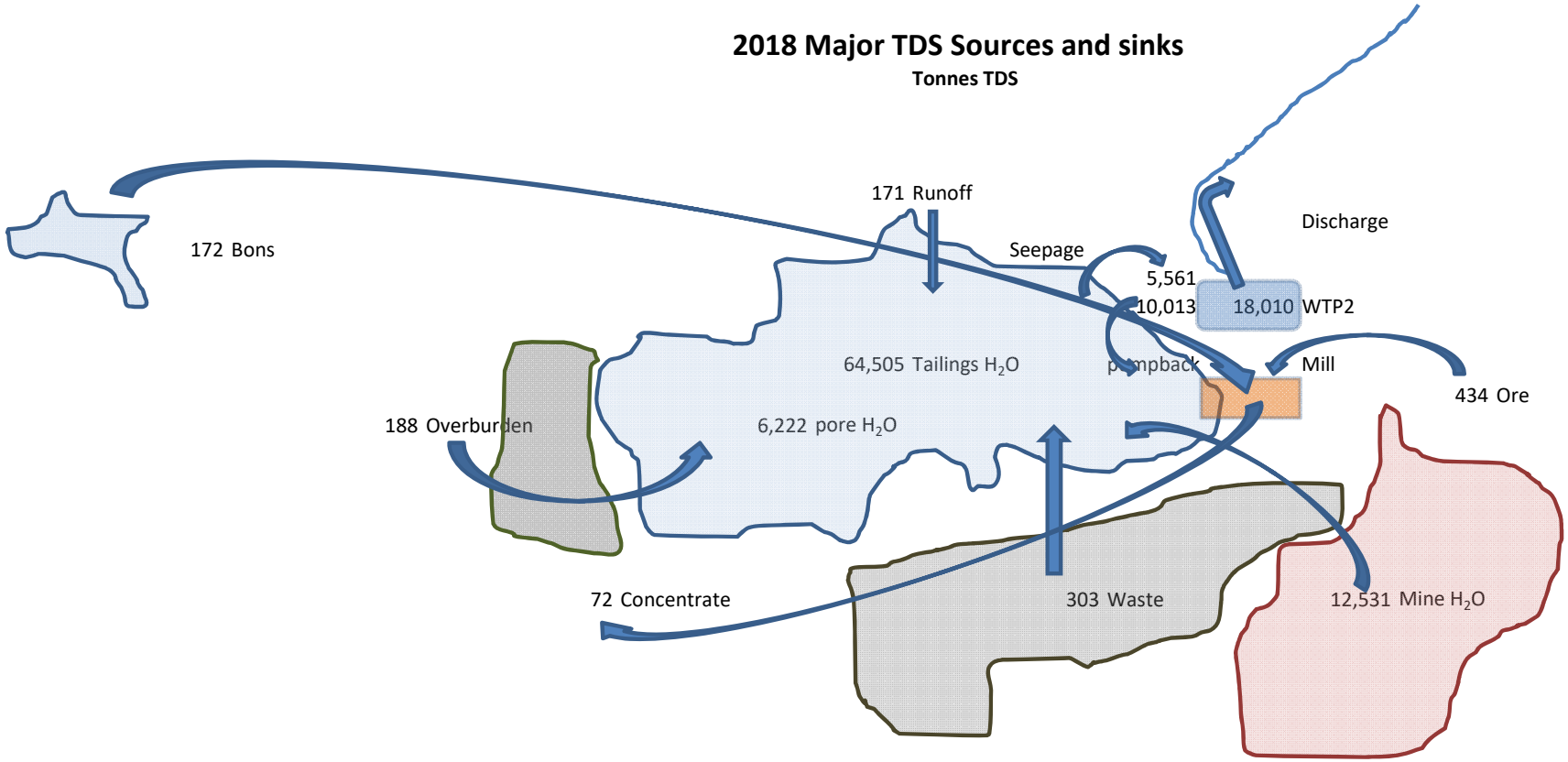
	Load								
	Ca tonnes	*Cu tonnes*	*Zn tonnes*	*Mg tonnes*	*Mn tonnes*	*Fe tonnes*	*Al tonnes*	*SO4 tonnes*	*TDS tonnes*
WTP1 Net to Pond	801	0	41	16	0	1	0	1,911	4,026
WTP2 Net to Pond	-1,700	0	13	-254	0	0	0	-5,212	-6,648
WTP3 Net to Pond	-25	-1	-2,171	-459	-113	-545	-176	-9,714	-13,018
Net Mill to pond	131	71	3,939	-194	34	3	59	5,874	11,410
Red Dog Creek Pumpback to Pond	961	0	1,932	424	102	97	6	8,549	12,531
Main Waste Stockpile bypass WTP3	2	0	48	10	3	13	4	226	303
Overburden Pumpback	23	0	0	19	0	0	0	117	188
Runoff into pond	22	0	7	13	1	1	0	111	171
Seepage System Net to pond	-106	0	618	196	70	356	16	2,840	4,409
Reclaim Water to WTP2/Discharge	-4,272	-1	0	-651	0	0	0	-13,868	-28,478
Retained pore water	-603	0	-695	-247	-57	-6	-1	-4,377	-6,222
Net Change in Tailings Pond loads	-4,765	69	3,731	-1,127	39	-80	-92	-13,543	-21,327

Change in Pond Chemistry Load Calculation

	Load								
	Ca tonnes	*Cu tonnes*	*Zn tonnes*	*Mg tonnes*	*Mn tonnes*	*Fe tonnes*	*Al tonnes*	*SO4 tonnes*	*TDS tonnes*
Pond water end 2017 modeled	7,614	0	6,590	2,967	659	54	13	47,599	69,597
Pond water end 2018 modeled	6,784	1	7,810	2,780	643	72	16	49,213	64,505
Annual Change Pond water loads	-830	1	1,220	-187	-16	18	2	1,614	-5,092

2018 Major TDS Sources and sinks

Tonnes TDS



Appendix H: Test plot Monitoring Main Waste Stockpile Cover System

Geosyntec consultants

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www.geosyntec.com

17 December 2018

Mr. Tyler Oester, P.E.
Senior Engineer, Tailings and Water
Teck Alaska Incorporated
Red Dog Mine, Alaska

Subject: Summary of 2018 Test Plot Monitoring
Main Waste Stockpile Cover System
Red Dog Mine
Northwest Arctic Borough, Alaska

Dear Mr. Oester:

Geosyntec Consultants (Geosyntec) is pleased to submit this report to Teck Alaska, Inc. (TAK) that summarizes activities and results associated with test plot monitoring for the Main Waste Stockpile (MWS) cover system at Red Dog Mine (site) during 2018.

PROJECT DESCRIPTION

During 2016, Geosyntec designed a geosynthetic cover system for the MWS that consisted of a geomembrane, a geocomposite drainage layer, corrugated polyethylene piping, drainage aggregate, and onsite cover material. During the Summer of 2016, TAK constructed an approximately 2.1-acre Test Plot of the cover system that encompasses a portion of the slope and a portion of the top deck of the MWS. As a part of the 2016 Test Plot, TAK installed moisture monitoring plots to evaluate the performance of the cover system by monitoring the moisture content profile in the cover system. TAK also installed survey hubs to monitor movement of the cover system.

MOISTURE MONITORING PLOTS

TAK installed two moisture monitoring plots as part of the 2016 Test Plot. Each moisture monitoring plot consists of a test plot area and a control area. The test plot areas are located on the 2016 Test Plot (i.e. above and below the liner) and the control areas (i.e. installed within placed cover material only) are located just south of the 2016 Test Plot where the cover system was not installed. One moisture monitoring plot is located near the toe of the 2016 Test Plot on the 3H:1V (Horizontal:Vertical) slope (Test Plot #1 and Control #1) and one is located at the top deck of the MWS (Test Plot #2 and Control #2).

Test Plot #1 and Test Plot #2 contain six CS650 Water Content Reflectometers (moisture probes), manufactured by Campbell Scientific, Inc, buried in three different locations. At each location, one probe is located approximately 12-inches below the geomembrane and one probe is buried approximately 12-inches below the surface of the cover material. At Control #1 and Control #2, six probes were installed in a similar fashion, with one probe approximately 24-inches below the ground surface and one probe approximately 12-inches below the ground surface. This results in an upper and lower probe for each location. Figure 1 presents the approximate locations of the probes.

Each probe is identified by its area, location, and whether it is an upper or lower probe. For example, "TP2-2L" is in the Test Plot #2 area and is the lower probe in location 2.

The lower probes were installed by TAK during construction of the 2016 Test Plot. Installation of the lower probes was not observed by Geosyntec. The upper probes were installed by Geosyntec on 8 June 2017.

Each of the probes is connected to a CS800 datalogger (manufactured by Campbell Scientific, Inc.) programmed to collect soil water content and temperature readings from the probes every six hours. The data is stored in the datalogger and downloaded periodically by Geosyntec or TAK personnel.

2018 MONITORING

TAK personnel re-installed the dataloggers and batteries after being stored for the 2017/2018 winter on 1 June 2018 for Test Plot #1 and Control #1 and 26 June 2018 for Test Plot #2 and Control #2. Geosyntec and TAK removed the dataloggers and batteries for winter on 16 October 2018. Water content readings from the instruments were recorded as volumetric water content (volume/volume) and converted to gravimetric moisture content (mass/mass) assuming an average bulk density of the cover material of 122.7 pounds per cubic foot (pcf) obtained from previous laboratory testing.

In addition to the water content and temperature data collected, TAK provided meteorological data for the monitoring period from the BONS Weather Station and National Oceanic and Atmospheric Administration (NOAA) precipitation gauge located near the BONS Weather Station at the site.

Error Readings

Two of the CS650 moisture probes (TP1-3U and C1-1L) experienced error readings during the 2018 monitoring period. The error readings show up as NAN values in the data output. NAN values can have multiple root causes including wiring issues, and measurements of dielectric

permittivity or electrical conductivity outside the range of normal values. The cause of the NAN values is unknown and will be investigated when the dataloggers are re-installed for the 2019 monitoring period.

Water Content Results

Attachment A includes Figures A-1 through A-6 which present the data from Test Plot #1 and Control #1 and Figures A-7 through A-12 which present data from Test Plot #2 and Control #2. Figures A-1, A-2, A-7, and A-8 present the water content data for each of the probes, as well as the precipitation data for the site. Figures A-3, A-4, A-9, and A-10 present the temperature data for each of the probes, as well as daily average air temperatures for the site. Figures A-5 and A-11 present the average water content data for each probe location (upper and lower on the test plot and control plot) and Figures A-6 and A-12 present average temperature data for each instrument location (upper and lower on the test plot and control plot).

Figures A-1 and A-7 show no appreciable change in water content over time for the instruments installed below the liner (labeled as the "L" instruments). One minor exception is sensor TP2-2L, which is presented on Figure A-7, that showed a moisture content increase of approximately 0.7% beginning 9 July 2019. The moisture content began decreasing around 25 July 2018 and did not show another moisture content increase associated with a precipitation event during the 2018 monitoring period. Sensor TP-2L will be monitored closely during the 2019 monitoring period. The instruments installed above the liner (labeled as the "U" instruments) show changes in moisture content that closely mirror precipitation events, as expected.

Figures A-2 and A-8 show that both the upper and lower probes for the control plots are affected by precipitation because of the absence of the liner, as expected.

The observed patterns in water content for Test Plot #1 and Test Plot #2 indicate that meteoric water is not infiltrating below the liner installed as part of the 2016 Test Plot for the MWS cover system and that the cover system is functioning as designed.

Other Moisture Content Monitoring Observations

The water content values and temperature values for individual instruments installed at the same depth at one location (i.e. TP1-1U, TP1-2U, and TP1-3U) would be expected to record very similar values over the monitoring period. However, some data shows significant differences in the individual values recorded, but changes in the data follow similar and expected trends. These differences in individual values can likely be attributed to two main factors:

- Lack of material specific calibration for the instruments; and

- Heterogeneity and large particle sizes in the cover soil/rock material located around the instruments.

For the purposes of the moisture monitoring of the 2016 Test Plot, the exact water content values are of less importance than the overall trends of increasing or decreasing water contents; therefore, differences in individual values are not considered a concern.

Figures A-9, A-10, and A-12 indicate relatively high average temperatures for the Test Plot #2 and Control #2 probes (near 35 degrees Celsius) and generally 20 to 25 degrees Celsius above the average daily temperature. Geosyntec suspects that these readings are anomalous and will continue to monitor them and perform field verifications, if necessary.

Survey Monument Monitoring

TAK installed three survey monument hubs on the surface of the 2016 cover system slope to monitoring cover system movement. The hubs were surveyed on 27 August 2018 and showed 0.24 to 0.47 feet of change in the downslope direction along with 0.07 to 0.08 feet of vertical settlement. The hubs should be surveyed again in 2019 after the winter snow melts to assess if additional movement has occurred since August 2018 and the results should be submitted to Geosyntec.

CLOSURE

Geosyntec appreciates this opportunity to provide professional services to TAK. If you have any questions regarding this report, please contact Mr. Jay Griffin at (510) 285-2689 or Mr. Greg Corcoran at (858) 716-2905.

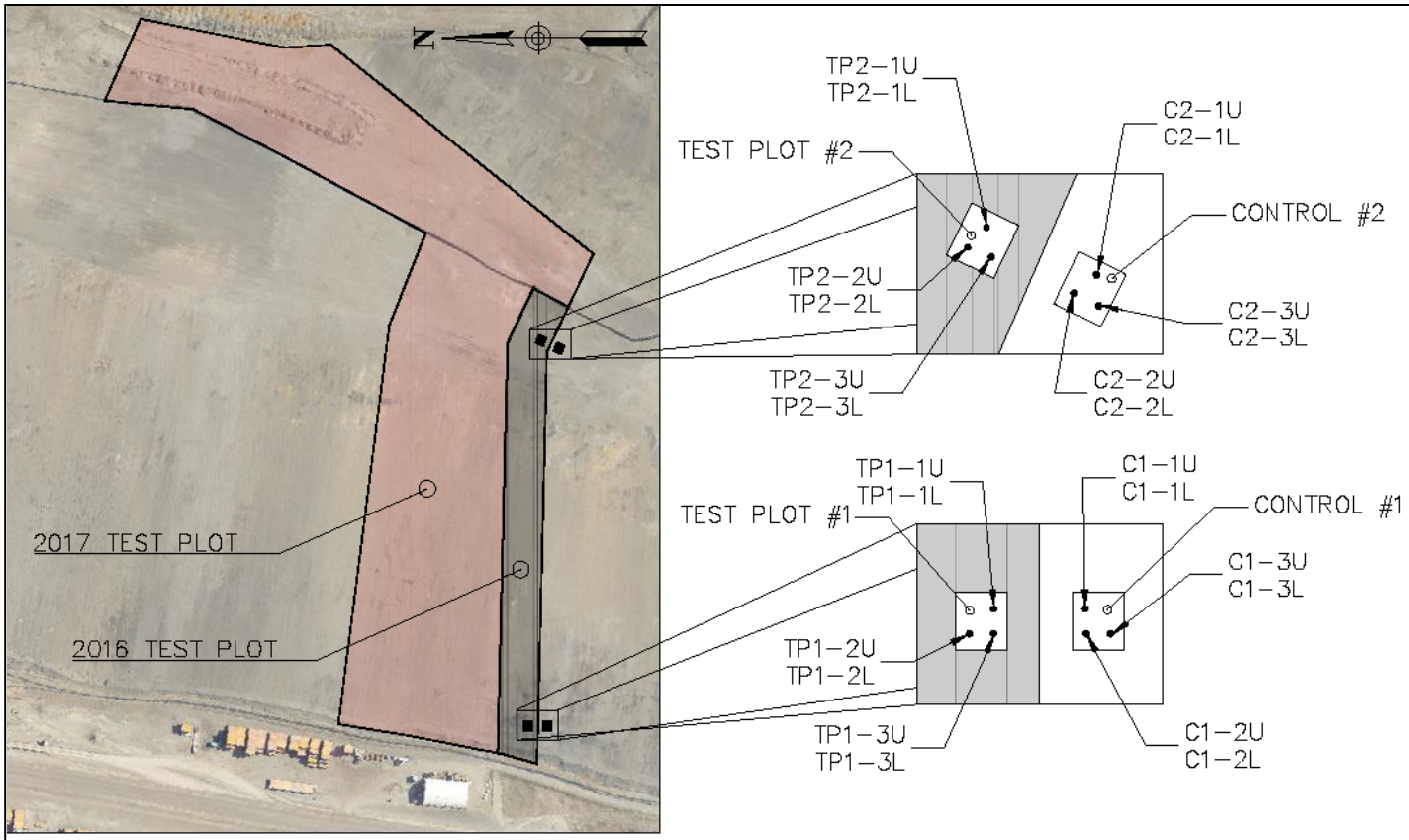
Sincerely,

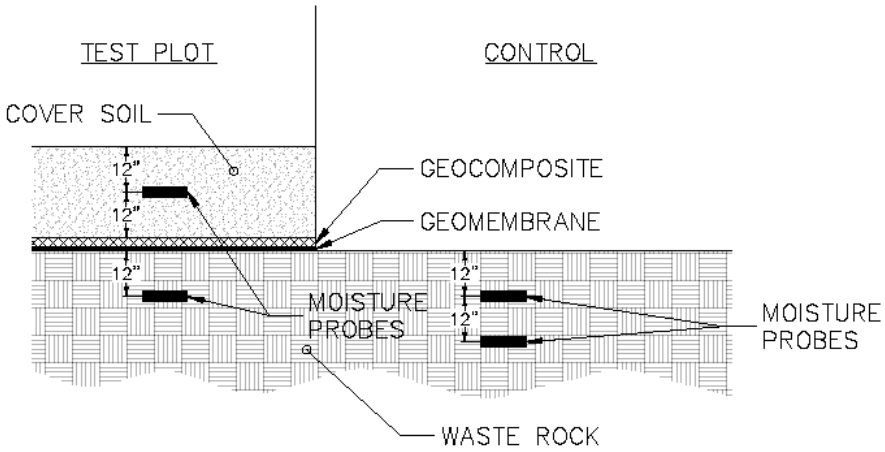
Jay L. Griffin, P.E. (AK, CA, OR)
Project Engineer

Gregory T. Corcoran, P.E. (AZ, CA, ID, OR, UT)
Senior Principal Engineer

Figure 1: Approximate Instrument Locations

Attachment A: Collected Data





MOISTURE PROBE CROSS SECTION

Approximate Moisture Probe Locations
Main Waste Stockpile Cover

Geosyntec consultants

DATE	**DECEMBER 2018**	**FIGURE 1**
PROJECT NO.	**WG2516**	

Attachment A

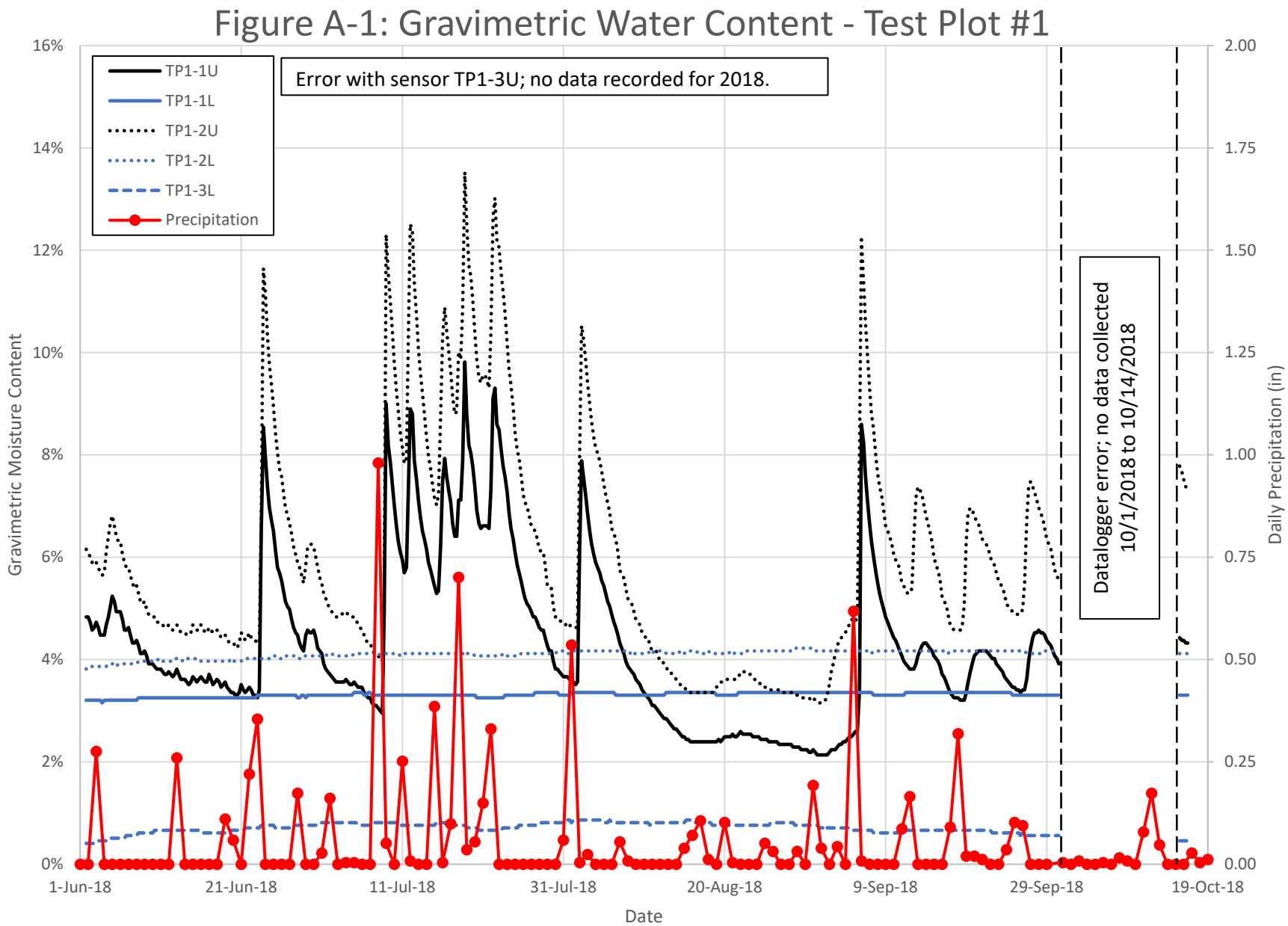


Figure A-1: Gravimetric Water Content - Test Plot #1
TP1-1U
TP1-1L
TP1-2U
TP1-2L
TP1-3L
Precipitation
Error with sensor TP1-3U; no data recorded for 2018.
Datalogger error; no data collected 10/1/2018 to 10/14/2018
Gravimetric Moisture Content
Daily Precipitation (in)
Date
16%
14%
12%
10%
8%
6%
4%
2%
0%
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
1-Jun-18
21-Jun-18
11-Jul-18
31-Jul-18
20-Aug-18
9-Sep-18
29-Sep-18
19-Oct-18

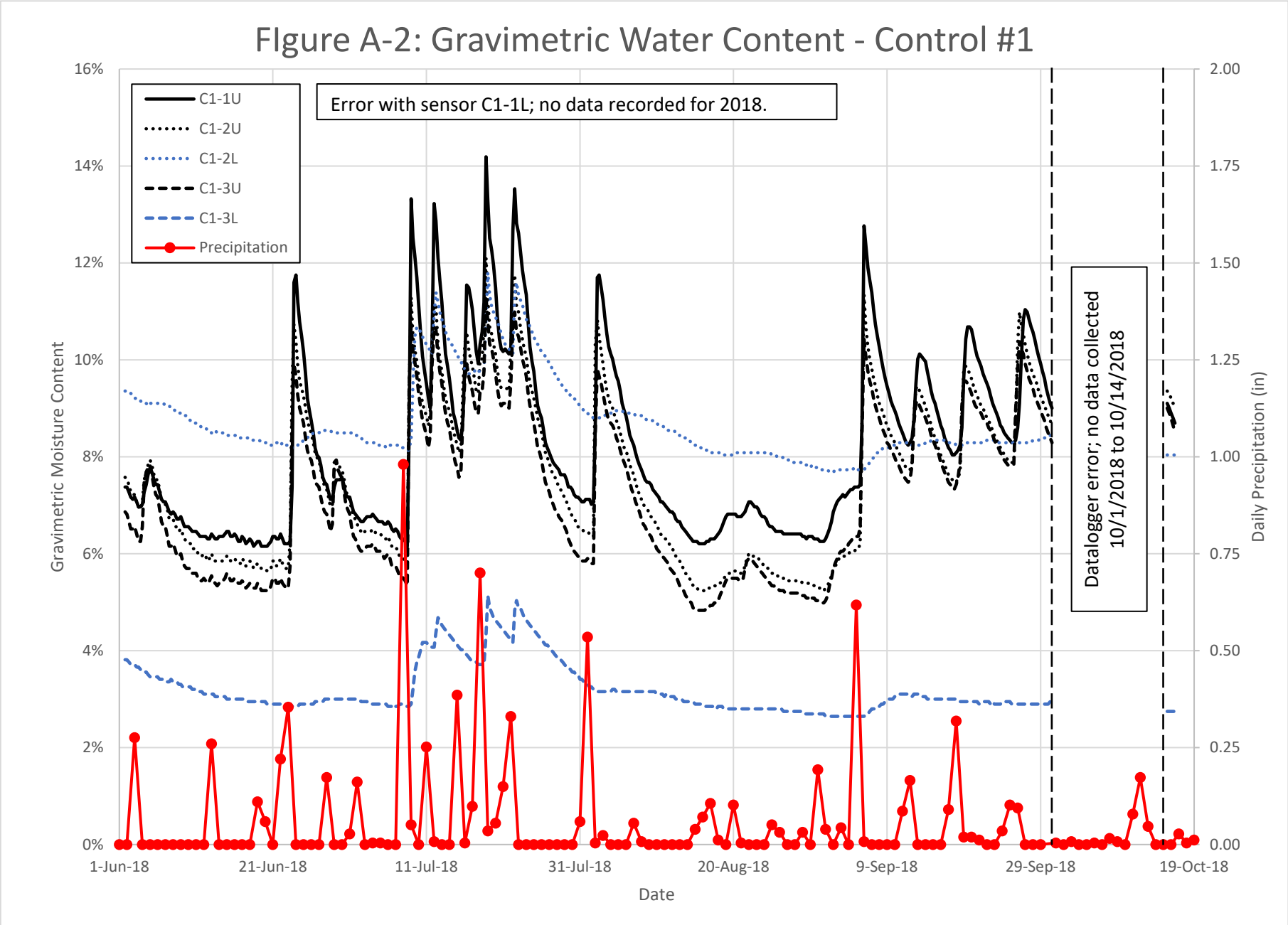


FIgure A-2: Gravimetric Water Content - Control #1
C1-1U
C1-2U
C1-2L
C1-3U
C1-3L
Precipitation
Error with sensor C1-1L; no data recorded for 2018.
Datalogger error; no data collected 10/1/2018 to 10/14/2018
Gravimetric Moisture Content
Daily Precipitation (in)
Date
16%
14%
12%
10%
8%
6%
4%
2%
0%
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
1-Jun-18
21-Jun-18
11-Jul-18
31-Jul-18
20-Aug-18
9-Sep-18
29-Sep-18
19-Oct-18

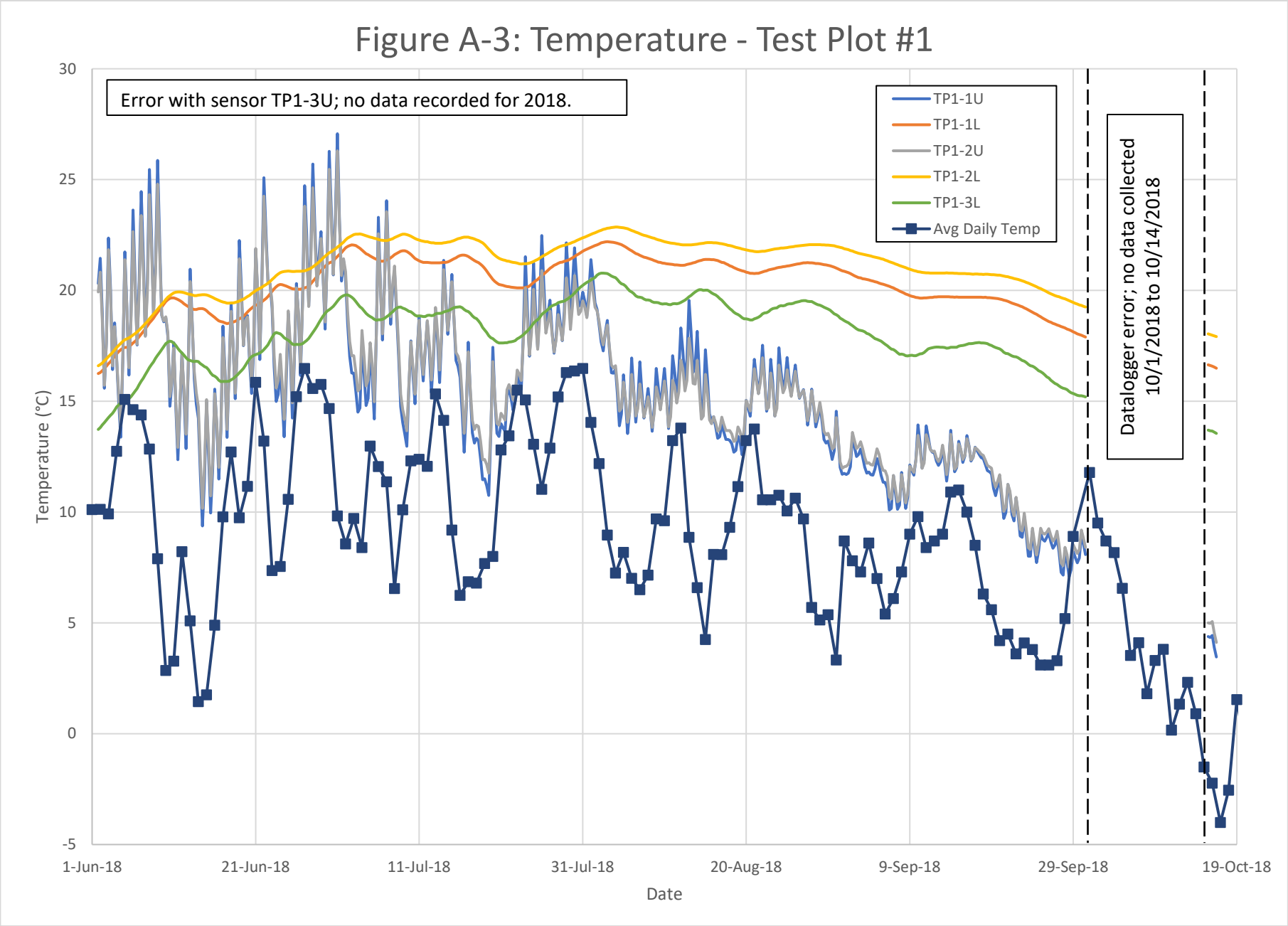


Figure A-3: Temperature - Test Plot #1
Error with sensor TP1-3U; no data recorded for 2018.
TP1-1U
TP1-1L
TP1-2U
TP1-2L
TP1-3L
Avg Daily Temp
Datalogger error; no data collected 10/1/2018 to 10/14/2018
Temperature (°C)
30
25
20
15
10
5
0
-5
1-Jun-18
21-Jun-18
11-Jul-18
31-Jul-18
20-Aug-18
9-Sep-18
29-Sep-18
19-Oct-18
Date

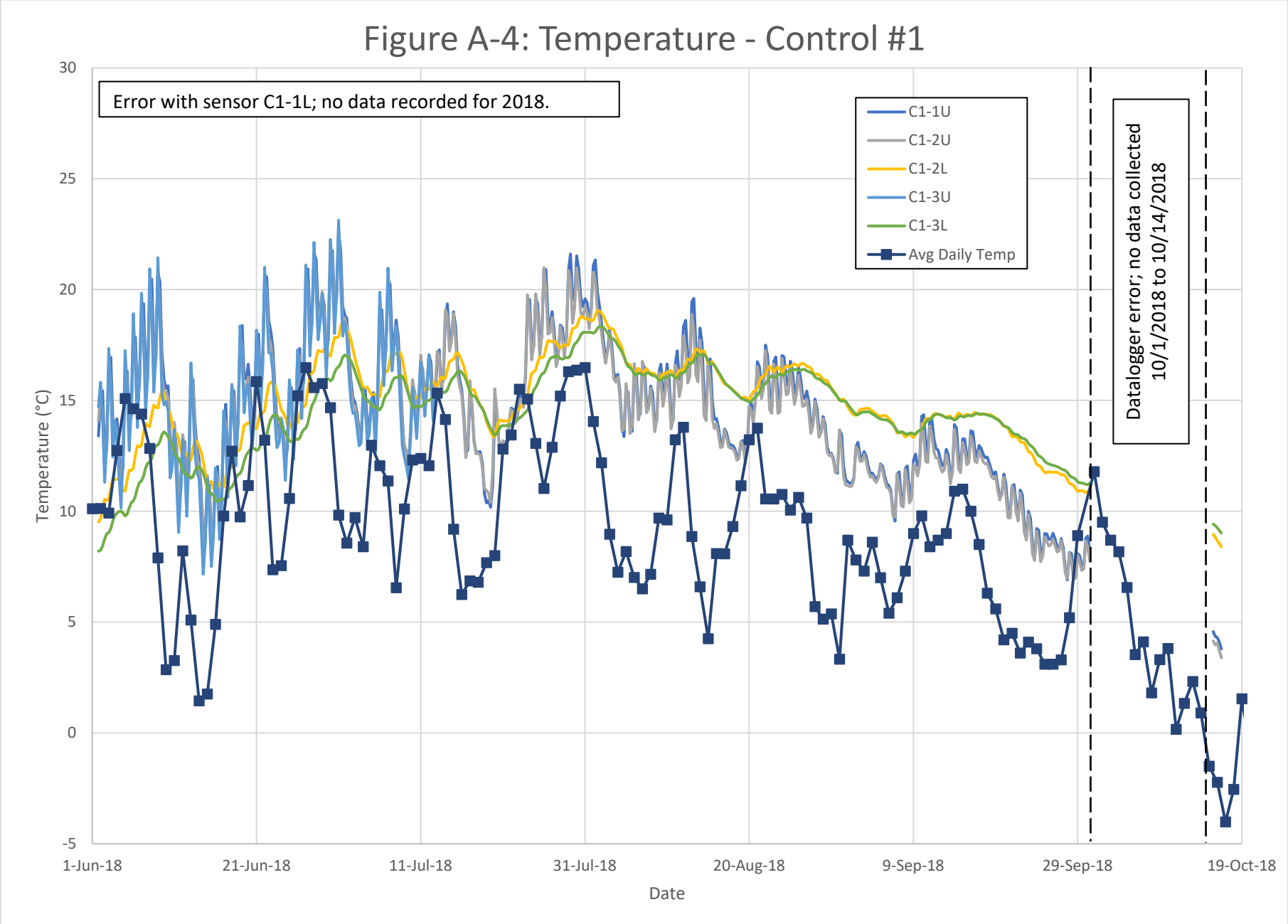


Figure A-4: Temperature - Control #1
Error with sensor C1-1L; no data recorded for 2018.
C1-1U
C1-2U
C1-2L
C1-3U
C1-3L
Avg Daily Temp
Datalogger error; no data collected 10/1/2018 to 10/14/2018
Temperature (°C)
30
25
20
15
10
5
0
-5
1-Jun-18
21-Jun-18
11-Jul-18
31-Jul-18
20-Aug-18
9-Sep-18
29-Sep-18
19-Oct-18
Date

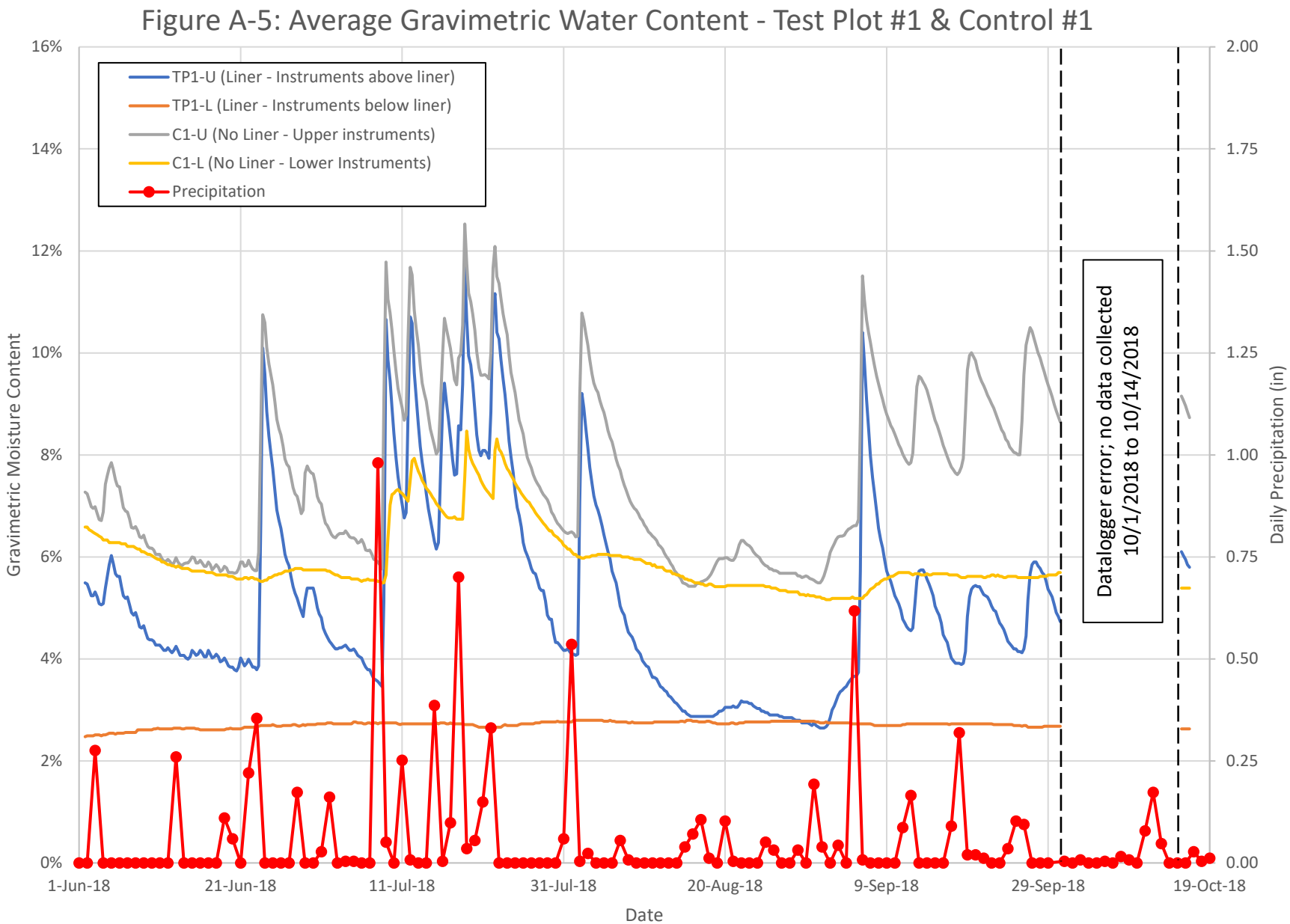


Figure A-5: Average Gravimetric Water Content - Test Plot #1 & Control #1
TP1-U (Liner - Instruments above liner)
TP1-L (Liner - Instruments below liner)
C1-U (No Liner - Upper instruments)
C1-L (No Liner - Lower Instruments)
Precipitation
Datalogger error; no data collected 10/1/2018 to 10/14/2018
Gravimetric Moisture Content
Daily Precipitation (in)
Date
16%
14%
12%
10%
8%
6%
4%
2%
0%
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
1-Jun-18
21-Jun-18
11-Jul-18
31-Jul-18
20-Aug-18
9-Sep-18
29-Sep-18
19-Oct-18

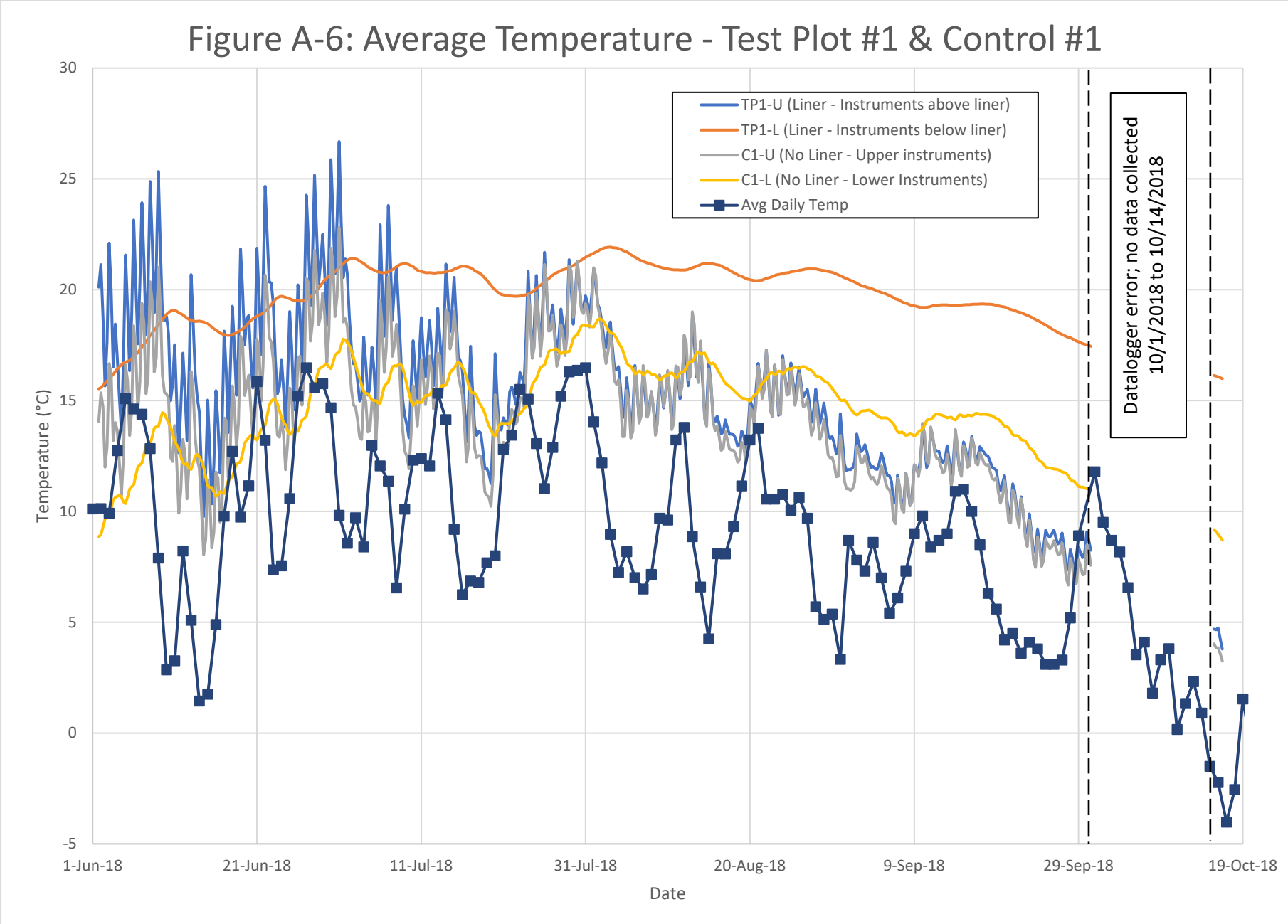


Figure A-6: Average Temperature - Test Plot #1 & Control #1
TP1-U (Liner - Instruments above liner)
TP1-L (Liner - Instruments below liner)
C1-U (No Liner - Upper instruments)
C1-L (No Liner - Lower Instruments)
Avg Daily Temp
Datalogger error; no data collected 10/1/2018 to 10/14/2018
Temperature (°C)
30
25
20
15
10
5
0
-5
1-Jun-18
21-Jun-18
11-Jul-18
31-Jul-18
20-Aug-18
9-Sep-18
29-Sep-18
19-Oct-18
Date

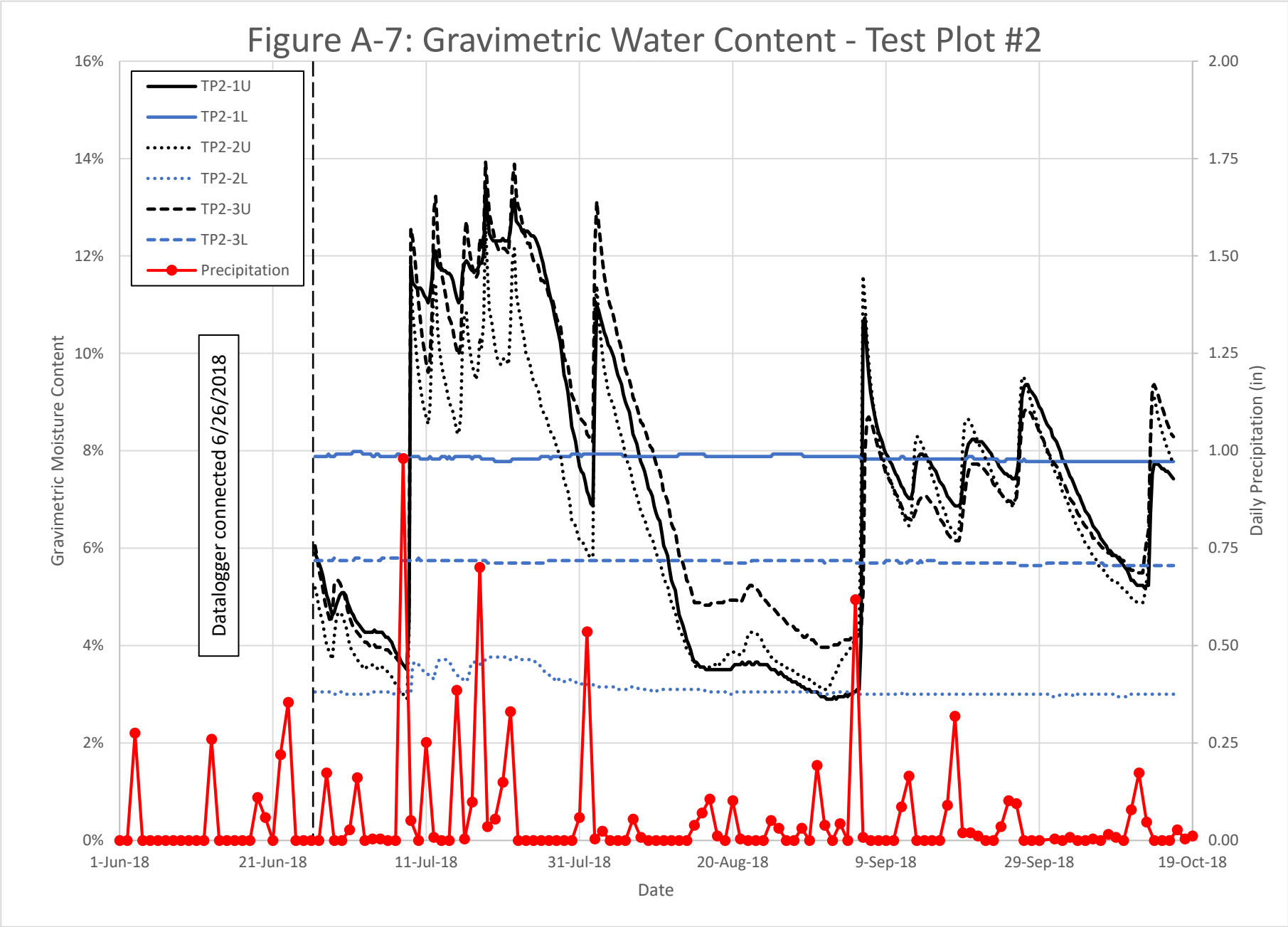


Figure A-7: Gravimetric Water Content - Test Plot #2
TP2-1U
TP2-1L
TP2-2U
TP2-2L
TP2-3U
TP2-3L
Precipitation
Datalogger connected 6/26/2018
Gravimetric Moisture Content
Daily Precipitation (in)
Date
16%
14%
12%
10%
8%
6%
4%
2%
0%
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
1-Jun-18
21-Jun-18
11-Jul-18
31-Jul-18
20-Aug-18
9-Sep-18
29-Sep-18
19-Oct-18

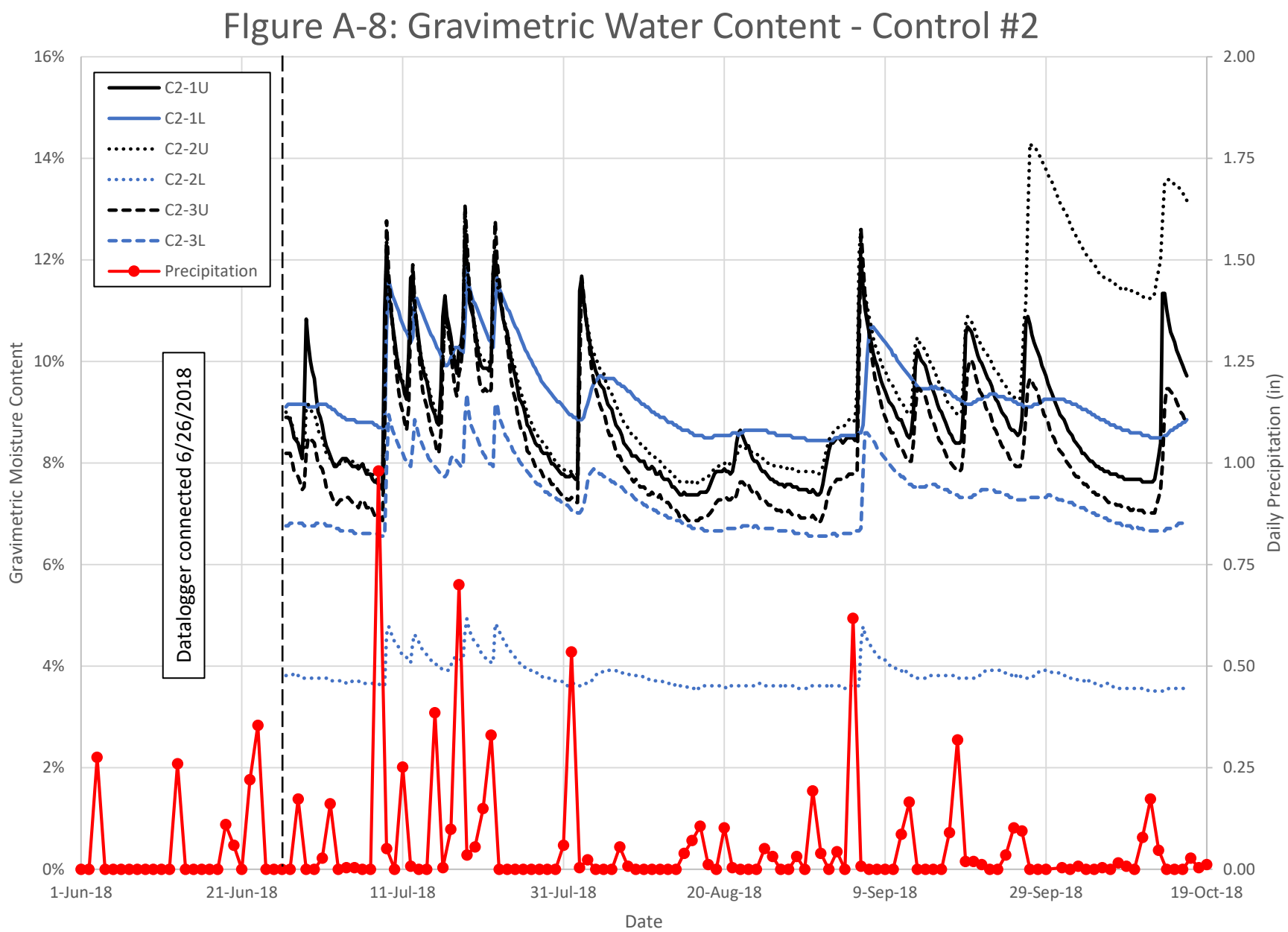


FIgure A-8: Gravimetric Water Content - Control #2
C2-1U
C2-1L
C2-2U
C2-2L
C2-3U
C2-3L
Precipitation
Datalogger connected 6/26/2018
Gravimetric Moisture Content
Daily Precipitation (in)
Date
16%
14%
12%
10%
8%
6%
4%
2%
0%
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
1-Jun-18
21-Jun-18
11-Jul-18
31-Jul-18
20-Aug-18
9-Sep-18
29-Sep-18
19-Oct-18

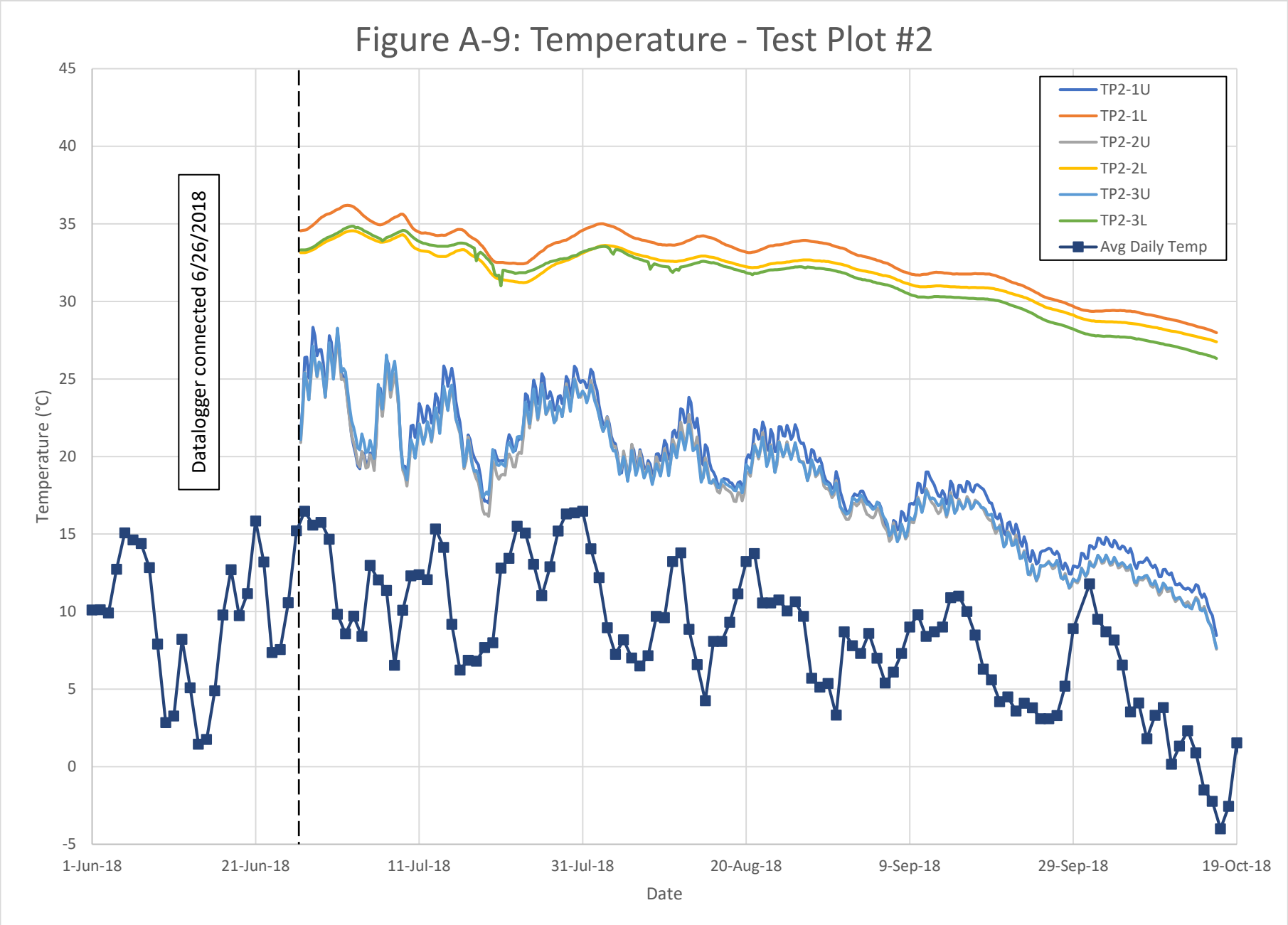


Figure A-9: Temperature - Test Plot #2
Datalogger connected 6/26/2018
TP2-1U
TP2-1L
TP2-2U
TP2-2L
TP2-3U
TP2-3L
Avg Daily Temp
Temperature (°C)
45
40
35
30
25
20
15
10
5
0
-5
1-Jun-18
21-Jun-18
11-Jul-18
31-Jul-18
20-Aug-18
9-Sep-18
29-Sep-18
19-Oct-18
Date

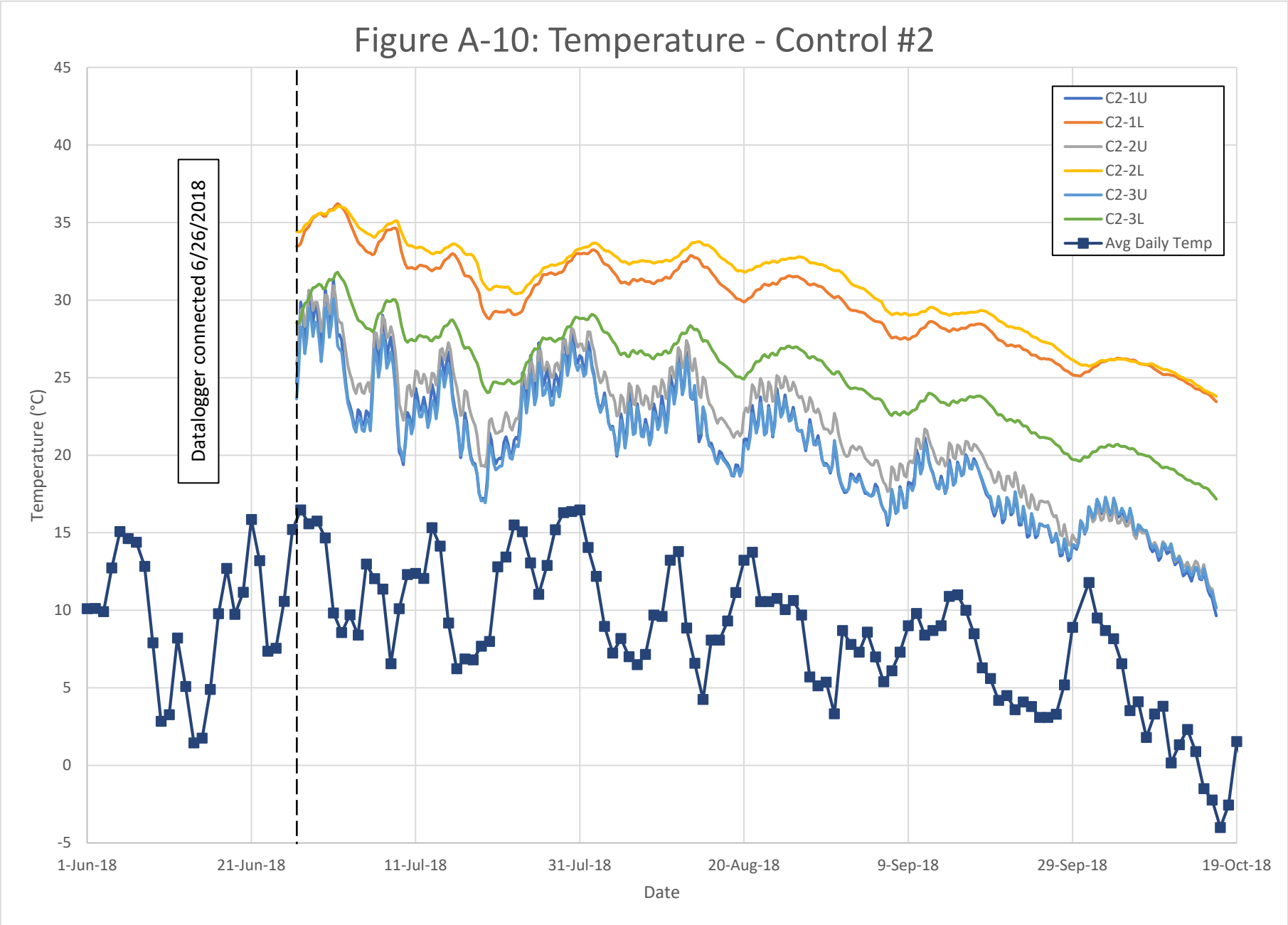


Figure A-10: Temperature - Control #2
Datalogger connected 6/26/2018
C2-1U
C2-1L
C2-2U
C2-2L
C2-3U
C2-3L
Avg Daily Temp
Temperature (°C)
45
40
35
30
25
20
15
10
5
0
-5
1-Jun-18
21-Jun-18
11-Jul-18
31-Jul-18
20-Aug-18
9-Sep-18
29-Sep-18
19-Oct-18
Date

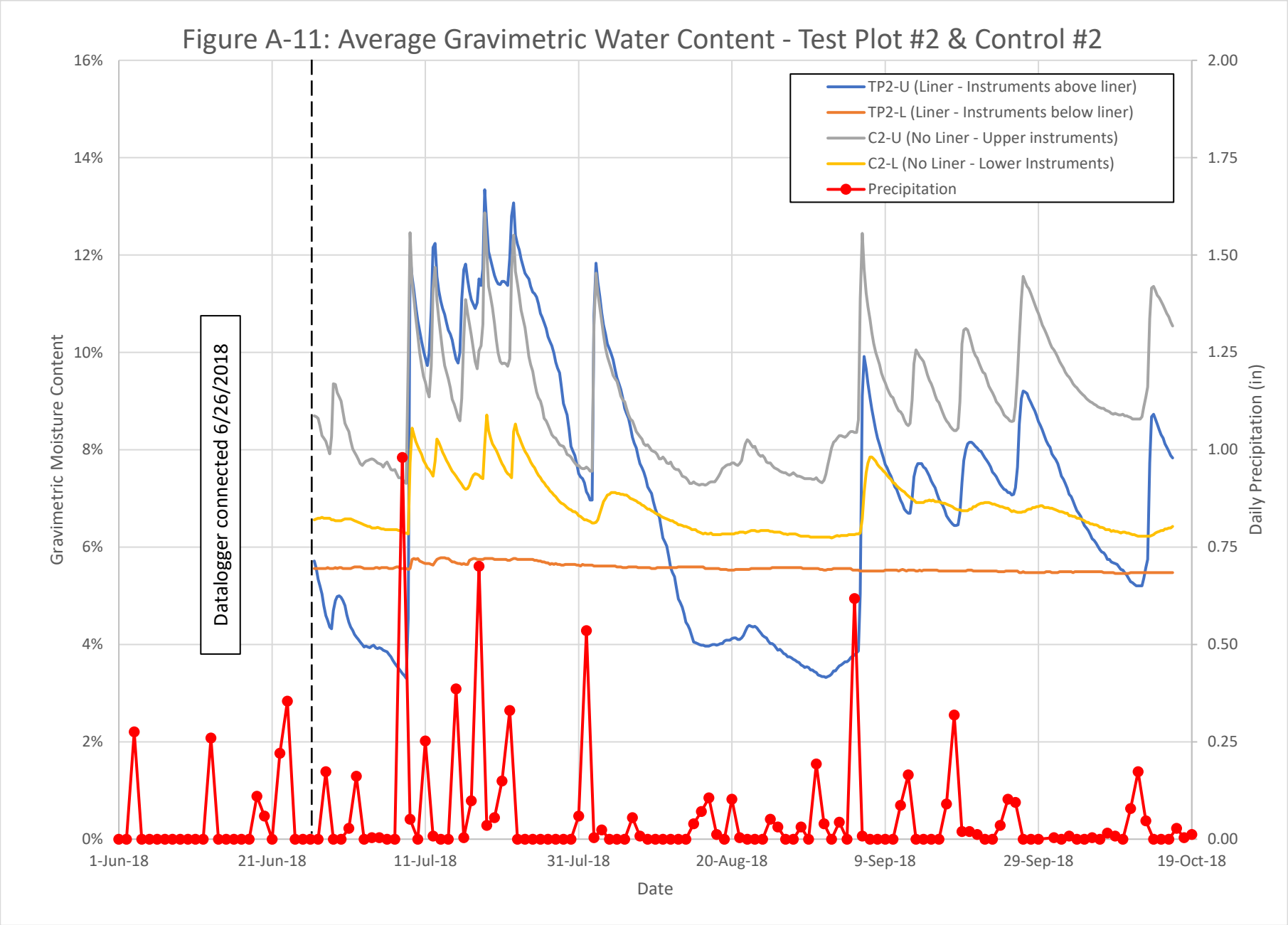


Figure A-11: Average Gravimetric Water Content - Test Plot #2 & Control #2
TP2-U (Liner - Instruments above liner)
TP2-L (Liner - Instruments below liner)
C2-U (No Liner - Upper instruments)
C2-L (No Liner - Lower Instruments)
Precipitation
Datalogger connected 6/26/2018
Gravimetric Moisture Content
Daily Precipitation (in)
Date
16%
14%
12%
10%
8%
6%
4%
2%
0%
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
1-Jun-18
21-Jun-18
11-Jul-18
31-Jul-18
20-Aug-18
9-Sep-18
29-Sep-18
19-Oct-18

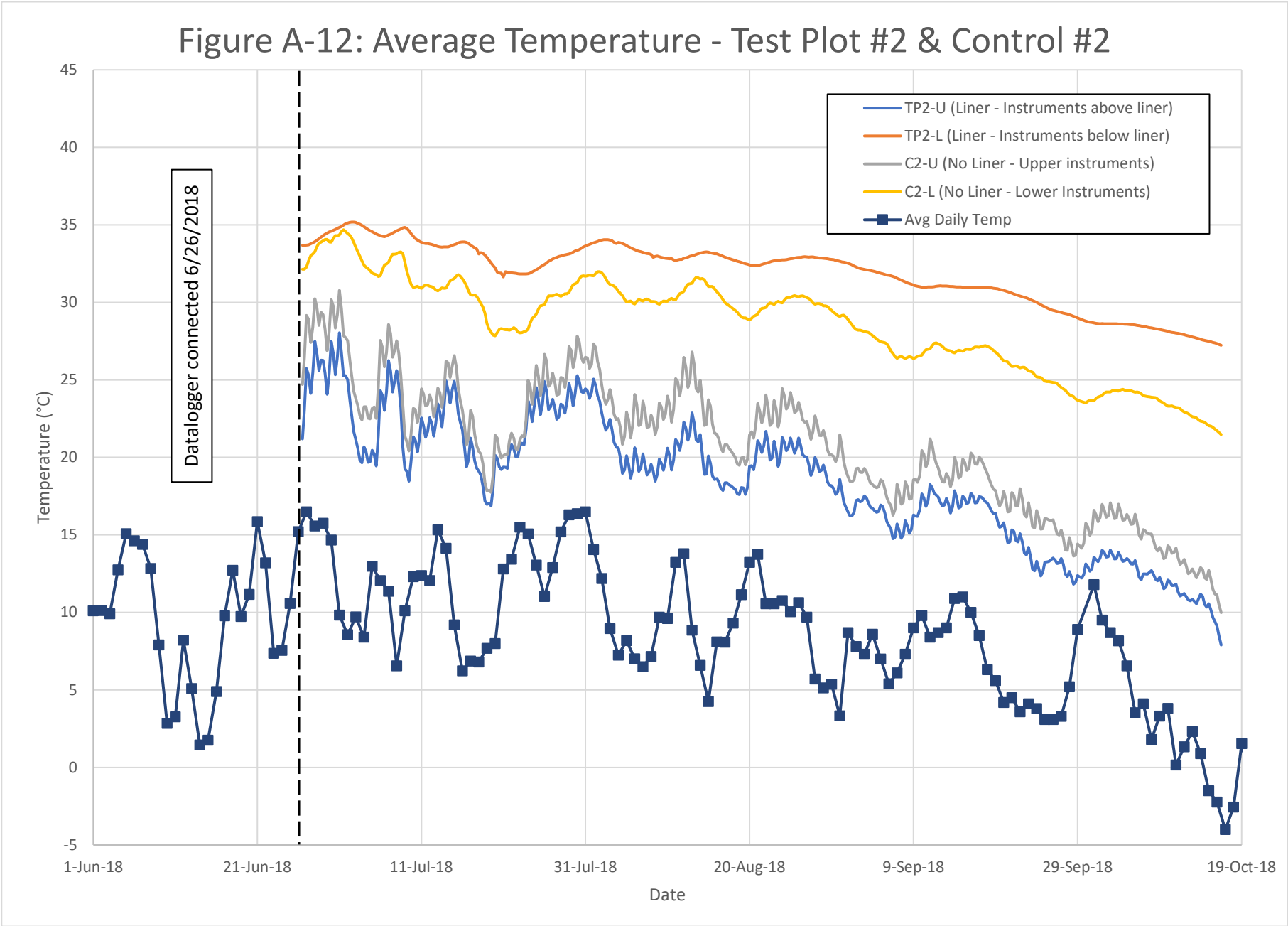


Figure A-12: Average Temperature - Test Plot #2 & Control #2
Datalogger connected 6/26/2018
TP2-U (Liner - Instruments above liner)
TP2-L (Liner - Instruments below liner)
C2-U (No Liner - Upper instruments)
C2-L (No Liner - Lower Instruments)
Avg Daily Temp
Temperature (°C)
45
40
35
30
25
20
15
10
5
0
-5
1-Jun-18
21-Jun-18
11-Jul-18
31-Jul-18
20-Aug-18
9-Sep-18
29-Sep-18
19-Oct-18
Date

Appendix I: Waste Rock Production Summary

Quarterly Waste Rock Production Report

Teck

Production Month **October 2018**

Waste Type: Cover Material	**Tonnes**	**Avg Zn%**	**Avg Fe%**	**Avg Pb%**
Formation: Kayak				
Placed Location				
Cover Dump	8,150	0.10%	3.90%	0.30%
Formation: Kivalina				
Placed Location				
Cover Dump	66,608	0.18%	3.68%	0.18%
Placed Location				
KOB	3,904	0.00%	0.00%	0.00%
Formation: Topsoil				
Placed Location				
KOB	44,180	0.03%	0.03%	0.03%
Waste Type Subtotal	**122,842**			

Waste Type: Most Reactive Waste	**Tonnes**	**Avg Zn%**	**Avg Fe%**	**Avg Pb%**
Formation: Ikalukrok				
Placed Location				
Landfill @MWD	3,327	2.60%	3.70%	3.40%
Placed Location				
Main Pit Dump 5	9,184	1.78%	4.22%	2.32%
Placed Location				
Main Waste Dump	18,137	6.68%	7.52%	3.39%
Placed Location				
Oxide Ore Stockpile	12,782	0.40%	5.40%	12.10%
Formation: Siksikpuk				
Placed Location				
Main Pit Dump 5	120,961	0.10%	5.30%	0.10%
Placed Location				
Crusher Pad	518	0.10%	5.30%	0.10%
Waste Type Subtotal	**164,909**			

Waste Type: Other Waste	**Tonnes**	**Avg Zn%**	**Avg Fe%**	**Avg Pb%**
Formation: Ikalukrok				
Placed Location				
Oxide Ore Stockpile	43,520	0.29%	2.36%	11.87%
Placed Location				
Main Waste Dump	78,201	0.33%	2.53%	4.29%
Placed Location				
Main pit dump 4	2,141	0.10%	0.90%	3.30%
Placed Location				
Main Pit Dump 5	3,291	1.60%	1.50%	4.30%
Formation: Kivalina				
Placed Location				
Main Pit Dump 5	62,384	0.10%	3.60%	0.10%
Formation: Mixed				
Placed Location				
Main Waste Dump	2,791	1.20%	2.80%	1.80%
Formation: Siksikpuk				
Placed Location				
Main pit dump 4	2,247	0.10%	3.20%	0.00%

Placed Location				
Main Pit Dump 5	10,245	0.45%	3.20%	0.21%
Waste Type Subtotal	**204,820**			
Total tonnes for month	**492,571**			

Production Month **November 2018**

Waste Type: Cover Material	**Tonnes**	**Avg Zn%**	**Avg Fe%**	**Avg Pb%**
Formation: Kayak				
Placed Location				
Cover Dump	1,318	0.00%	1.00%	0.00%
Formation: Kivalina				
Placed Location				
Cover Dump	90,272	0.00%	1.24%	0.00%
Formation: Topsoil				
Placed Location				
KOB	5,658	0.10%	0.10%	0.10%
Waste Type Subtotal	**97,248**			

Waste Type: Most Reactive Waste	**Tonnes**	**Avg Zn%**	**Avg Fe%**	**Avg Pb%**
Formation: Ikalukrok				
Placed Location				
Oxide Ore Stockpile	24,371	0.20%	5.50%	17.80%
Placed Location				
Main Pit Dump 5	26,911	2.30%	5.10%	2.50%
Placed Location				
Copper Waste Dump	10,604	16.52%	8.29%	3.36%
Formation: Siksikpuk				
Placed Location				
Main Pit Dump 5	12,222	0.10%	5.30%	0.10%
Waste Type Subtotal	**74,108**			

Waste Type: Other Waste	**Tonnes**	**Avg Zn%**	**Avg Fe%**	**Avg Pb%**
Formation: Ikalukrok				
Placed Location				
Main Pit Dump 5	10,596	1.64%	2.34%	1.69%
Placed Location				
Main Waste Dump	106,831	1.01%	1.97%	2.07%
Placed Location				
Oxide Ore Stockpile	6,296	1.50%	2.80%	12.00%
Formation: Otuk				
Placed Location				
Main Pit Dump 5	51,636	0.00%	4.40%	0.00%
Formation: Siksikpuk				
Placed Location				
Main Pit Dump 5	92,724	0.00%	4.40%	0.00%
Placed Location				
Main Waste Dump	34,089	1.13%	3.21%	1.65%
Waste Type Subtotal	**302,172**			
Total tonnes for month	**473,528**			

Production Month **December 2018**

Waste Type: Cover Material	**Tonnes**	**Avg Zn%**	**Avg Fe%**	**Avg Pb%**
Formation: Kivalina				
Placed Location				
Cover Dump	114,409	0.00%	0.97%	0.00%
Waste Type Subtotal	**114,409**			

Waste Type: Most Reactive Waste	**Tonnes**	**Avg Zn%**	**Avg Fe%**	**Avg Pb%**
Formation: Ikalukrok				
Placed Location				
Oxide Ore Stockpile	24,300	1.40%	4.70%	9.30%
Placed Location				
Main Waste Dump	57,213	2.50%	4.27%	2.33%
Placed Location				
Main Pit Dump 5	6,126	6.97%	9.27%	2.26%
Placed Location				
Copper Waste Dump	15,486	15.76%	7.07%	4.14%
Placed Location				
Main pit dump 4	7,525	4.78%	8.21%	1.73%
Formation: Siksikpuk				
Placed Location				
Main Waste Dump	14,324	2.43%	4.67%	2.42%
Waste Type Subtotal	**124,974**			

Waste Type: Other Waste	**Tonnes**	**Avg Zn%**	**Avg Fe%**	**Avg Pb%**
Formation: Ikalukrok				
Placed Location				
Main pit dump 4	48,595	0.92%	3.50%	2.16%
Placed Location				
Main Waste Dump	94	2.40%	2.50%	1.20%
Formation: Kivalina				
Placed Location				
Main pit dump 4	2,241	0.40%	3.80%	1.60%
Formation: Siksikpuk				
Placed Location				
Main Waste Dump	35,933	0.60%	3.30%	1.30%
Placed Location				
Main pit dump 4	41,699	0.35%	3.72%	0.81%
Waste Type Subtotal	**128,562**			
Total tonnes for month	**367,945**			

Total Waste Rock tonnes for period **1,334,044**

Appendix J: Cover Material Stockpile Summary

Waste Rock Cover Material Monitoring Report

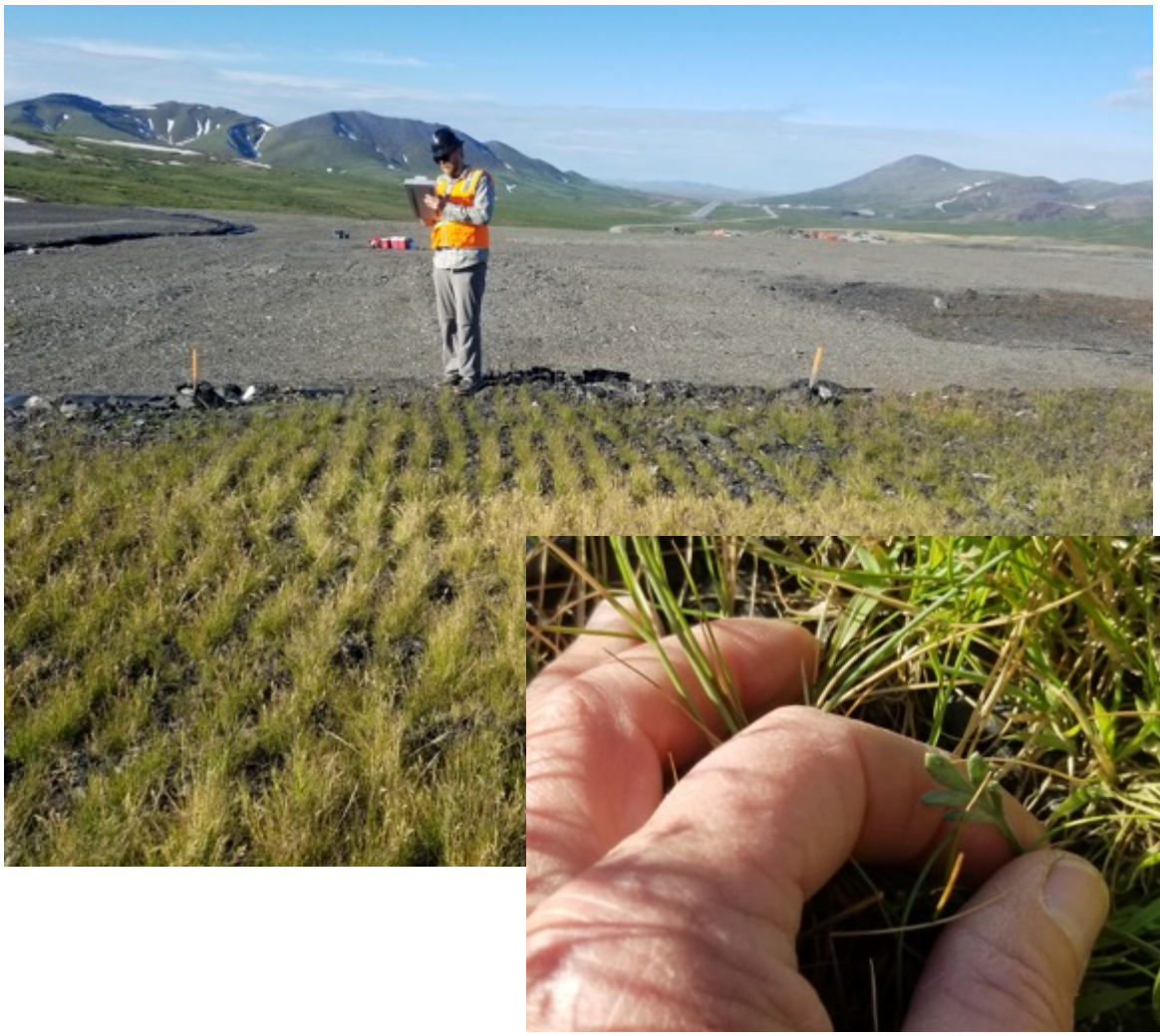
Teck

	Date Stockpiled	Waste Rock Type	Tonnes	Formation	Zinc_%	Stockpile Code
October 2018						
	10/2/2018	Cover Material	9,153	Kivalina	0.20	COV
	10/3/2018	Cover Material	22,866	Kivalina	0.20	COV
	10/4/2018	Cover Material	8,150	Kayak	0.10	COV
	10/4/2018	Cover Material	5,740	Kivalina	0.20	COV
	10/4/2018	Cover Material	1,047	Kivalina	0.00	KOB
	10/5/2018	Cover Material	2,857	Kivalina	0.00	KOB
	10/5/2018	Cover Material	7,794	Kivalina	0.20	COV
	10/5/2018	Cover Material	545	Topsoil	0.00	KOB
	10/5/2018	Cover Material	1,444	Kivalina	0.20	COV
	10/6/2018	Cover Material	2,982	Topsoil	0.00	KOB
	10/6/2018	Cover Material	381	Kivalina	0.20	COV
	10/7/2018	Cover Material	1,711	Topsoil	0.00	KOB
	10/9/2018	Cover Material	6,910	Topsoil	0.00	KOB
	10/9/2018	Cover Material	587	Kivalina	0.20	COV
	10/10/2018	Cover Material	78	Kivalina	0.20	COV
	10/10/2018	Cover Material	4,738	Topsoil	0.00	KOB
	10/16/2018	Cover Material	11,091	Kivalina	0.10	COV
	10/24/2018	Cover Material	2,895	Kivalina	0.20	COV
	10/26/2018	Cover Material	10,291	Topsoil	0.10	KOB
	10/27/2018	Cover Material	2,033	Kivalina	0.20	COV
	10/27/2018	Cover Material	2,905	Topsoil	0.10	KOB
	10/28/2018	Cover Material	2,546	Kivalina	0.20	COV
	10/28/2018	Cover Material	7,473	Topsoil	0.00	KOB
	10/29/2018	Cover Material	6,340	Topsoil	0.00	KOB
	10/30/2018	Cover Material	285	Topsoil	0.00	KOB
November 2018						
	11/11/2018	Cover Material	3,368	Kivalina	0.00	COV
	11/12/2018	Cover Material	3,520	Kivalina	0.00	COV
	11/13/2018	Cover Material	7,096	Kivalina	0.00	COV
	11/14/2018	Cover Material	641	Topsoil	0.10	KOB
	11/15/2018	Cover Material	3,337	Topsoil	0.10	KOB
	11/16/2018	Cover Material	1,680	Topsoil	0.10	KOB
	11/17/2018	Cover Material	10,991	Kivalina	0.00	COV
	11/19/2018	Cover Material	9,878	Kivalina	0.00	COV
	11/20/2018	Cover Material	3,251	Kivalina	0.00	COV

	Date Stockpiled	Waste Rock Type	Tonnes	Formation	Zinc_%	Stockpile Code
	11/21/2018	Cover Material	14,134	Kivalina	0.00	COV
	11/22/2018	Cover Material	2,356	Kivalina	0.00	COV
	11/23/2018	Cover Material	402	Kivalina	0.00	COV
	11/24/2018	Cover Material	2,159	Kivalina	0.00	COV
	11/25/2018	Cover Material	4,400	Kivalina	0.00	COV
	11/26/2018	Cover Material	6,261	Kivalina	0.00	COV
	11/28/2018	Cover Material	1,318	Kayak	0.00	COV
	11/28/2018	Cover Material	4,498	Kivalina	0.00	COV
	11/29/2018	Cover Material	8,300	Kivalina	0.00	COV
	11/30/2018	Cover Material	9,658	Kivalina	0.00	COV
December 2018						
	12/1/2018	Cover Material	2,484	Kivalina	0.00	COV
	12/2/2018	Cover Material	11,222	Kivalina	0.00	COV
	12/7/2018	Cover Material	12,831	Kivalina	0.00	COV
	12/9/2018	Cover Material	7,280	Kivalina	0.00	COV
	12/10/2018	Cover Material	10,991	Kivalina	0.00	COV
	12/11/2018	Cover Material	12,953	Kivalina	0.00	COV
	12/12/2018	Cover Material	11,488	Kivalina	0.00	COV
	12/15/2018	Cover Material	5,258	Kivalina	0.00	COV
	12/16/2018	Cover Material	1,003	Kivalina	0.00	COV
	12/16/2018	Cover Material	6,491	Kivalina	0.00	COV
	12/28/2018	Cover Material	11,981	Kivalina	0.00	COV
	12/29/2018	Cover Material	20,427	Kivalina	0.00	COV
		Total	**334,499**			

Appendix K: Main Waste Dump Revegetation Test Plots Study

Red Dog Mine Main Waste Dump Revegetation Test Plots, 2018 Monitoring: Year 2



December 2018

Prepared by fuse & traverse, llc for:

Teck Alaska, Inc.

3105 Lakeshore Boulevard, Anchorage, Alaska 99517

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1 Introduction

Teck Alaska, Inc. (Teck) operates the Red Dog Mine in northwest Alaska. NANA Regional Corporation (NANA) owns the surface and subsurface estate associated with Red Dog Mine including the Red Dog Main, Aqqaluk, and Qanaiyaq deposits. The mine produces approximately zinc and lead concentrate and generates approximately 6 million tons of waste rock annually (Red Dog Operations, August 2016).

Through approximately 2012, the waste rock was disposed in the Main Waste Dump (MWD) at Red Dog Mine. The MWD consists of an approximately 190-acre tetrahedron-shaped stockpile located on the side of a shallow sloping hill the east of the Tailings Storage Facility. It contains mineralized waste rock with the potential to generate acid-rock drainage (ARD). The 1982 Operating Agreement ("Agreement") between NANA and Teck requires that "to the extent practicable, disturbed areas shall, through seeding, fertilizing, and other appropriate means, be revegetated with a diverse vegetative cover of species native to the area and similar to that on adjoining areas (Cominco American Incorporated, 1982)."

Per the 2016 Reclamation and Closure Plan (SRK Consulting (U.S.), Inc., August 2016), the final cover of the MWD consists of one 18-inch layer of compacted weathered shale overlain with 18-inches of lightly compacted weathered shale. The material consists of broken shale that is porous and low in organic material, and therefore limited in its capacity to support vegetation without amendments (fertilizer).

In 2009, Teck revegetated the reclaimed Oxide Dump with a prescribed seed mix as described in the 2013 Oxide Dump monitoring report (Cedar Creek Associates, February 2013). The prescribed seed mix was applied annually through 2012 and consisted of seven grasses and three forbs. As of 2012, vascular plant cover on the Oxide Dump ranged from a minimum of 12.8% (west face) to 45.6%. 47.0% and 50.8%, respectively, on the east, top, and north surfaces of the Oxide Dump. Per Teck staff, plant cover continued to decrease over time. No additional treatments were applied to the Oxide Dump until it was fertilized in the spring of 2017. Teck sought to improve upon these results with an updated revegetation plan for the future revegetation projects.

In 2016, Teck implemented a Geomembrane Pilot Study (see Introduction) to evaluate the stability of a synthetic geomembrane cover system and its potential to reduce infiltration to the MWD and ARD discharge to the TSF. The synthetic geomembrane was overlain with approximately 24-inches of Kivalina/Key Creek shale that was "track-walked with a dozer to provide nominal compaction and minimize surface erosion (Geosyntec Consultants, 2016)."

In 2017, Teck, NANA, and the Alaska Plant Materials Center (PMC) collaborated to develop and install revegetation test plots ("test plots") on the shale cover of the geomembrane pilot study area to evaluate revegetation success on the MWD cover. The purpose of the study was to:

- Evaluate the success of a various grass and forb seed mixtures[1], fertilizer, and mulch treatments
- Evaluate the success of several locally harvested, locally adapted seed species
- Assess the potential for the Main Waste Dump to support vegetation
- Develop a revegetation strategy to apply to the entire Main Waste Dump that incorporates locally harvested arctic-adapted forbs.

This report documents the installation of the test plots in 2017 ("Year 1") and the growth observed in Year 1 and Year 2 (2018).

[1] The seed mix was restricted to grasses and forbs, i.e., non-woody plants. Willow (*Salix spp*.) staking and alder (*Alnus spp.*) transplants have demonstrated limited success in low-moisture environments (e.g., the main Waste Dump) and are relatively costly to implement.

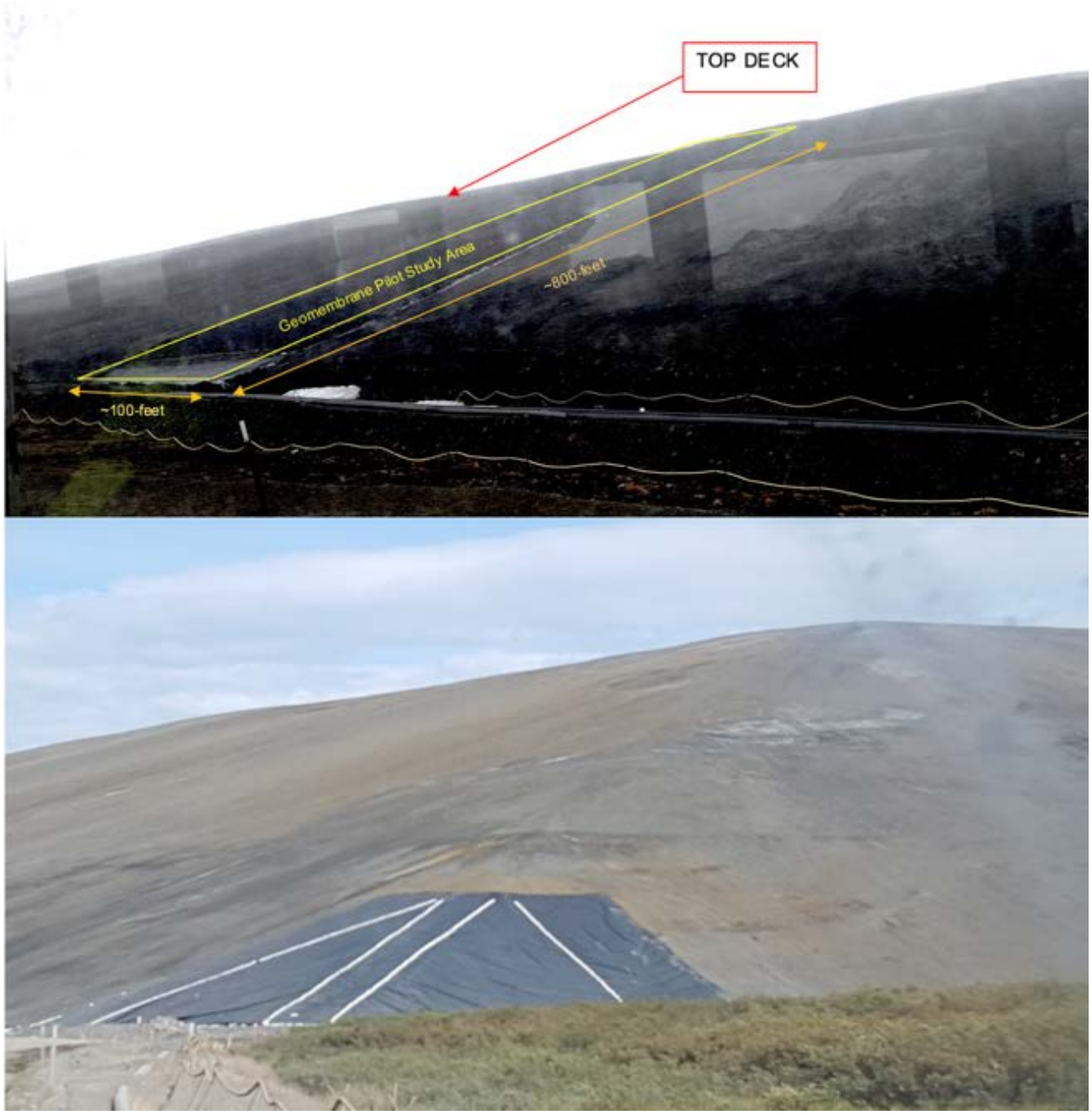


Photo 1: (Top) Geomembrane Pilot Study Area; dimensions are approximately 950-feet long by approximately 350-feet wide. (Bottom) The test plots were constructed on the flat Top Deck of the MWD.

2 Objectives

The objectives of the revegetation test pilot study were to:

- Evaluate the potential for grass-only (G) and grass-with-forbs (G+F) seed mixes to establish long-term growth on the shale cover;

- Compare the performance of plots treated with commercial mulch to un-mulched plots;
- Evaluate variable fertilizer application rates;
- Evaluate the success of locally-harvested forbs, by species, to grow on the shale cover; and
- Develop recommendations for effective revegetation of material stockpiles and, potentially, other disturbed areas at the mine.

3 Limitations

Due to the following circumstances, the 2017 plots were potentially compromised.

3.1 Early-season Seed and Fertilizer Application

On June 5, 2017, Teck seeded and fertilized the entire area that had been designated for the test plots. Teck applied seed they had found in the Environment conex that was assumed to be "dead seed," since it had been in cold storage for an unknown period of time and exposed to seasonal temperature variations. The study team observed unsprouted seed and residual fertilizer (see Photo 2 and Photo 3) throughout the entire proposed test plot area and the adjacent slopes, as well as a large "dump" of seed that the helicopter ejected.

Table 1: Early season (6/5/2017) seed and fertilizer application data (F. Bendrick, personal communication, July 24, 2018)

Treatment	Description	Application Rate
Grass seed mix[2]	4-grass mix: Red fescue, tundra bluegrass, alpine bluegrass, tufted hairgrass	40-45 #/acre
Fertilizer	20-20-10	~400 to 450 #/ac

[2] This is the same mix that was applied to the test plots, minus the addition of Wainwright wheatgrass. See Section 5.1.1. See also Photo 36.

Photo 2: Fertilizer beads (white and red “beads”) and grass seed present from Teck’s June 5, 2017 seed and fertilizer application.

Photo 3: A large pile of grass seed (center-left, in photo) remained that had been ejected from the helicopter after the June 5, 2017 fertilizer and seed application.

3.1.1 Potential Impacts to Seed

The early season grass seed application effectively doubled the seed application from a proposed treatment application rate of approximately 40-pounds per acre to an effective application rate of 80-pounds per acre. In addition, the early season seed mix did not contain one of the test plot species (*Elymus trachycaulus*, a.k.a. Wainwright or "slender" wheatgrass). The relative under-seeding of wheatgrass as well as competition with species seeded at a higher rate may inhibit the abundance of the wheatgrass.

It is not possible to determine what portion of the observed grass seed growth can be attributed to the early season application versus the test plot treatment application.

3.1.2 Potential Impacts to Fertilization

Residual fertilizer from the early season fertilizer application was not anticipated, as it was expected to percolate into the subsurface cover and, eventually, to the synthetic geomembrane, where it could enter into the Main Waste Dump acid rock drainage (ARD) collection wells. To confirm this, the study team collected grab and composite samples of the surface material to analyze for residual fertilizer and to establish the baseline soil conditions. See Section 4.

3.2 Limited Fertilizer

Due to the potential for fertilizer to percolate through the highly porous and low organic content soil, the test plots were to be fertilized in three applications at approximately one-third the prescribed rate, as follows:

- Initial application (plot construction): 150-pounds per acre
- Second application (approximately two weeks later): 150-pounds per acre
- Final application (No later than July 31): 150-pounds per acre

Red Dog staff were not available to complete the second and third prescribed fertilizer treatments. Therefore, the plots may have received insufficient fertilizer to support all of the grass and forb species in the mix.

3.3 Limited Water

Teck has limited watering capacity and lacked the resources to water the test plots during the growing season. The mulched test plots received a single water application via the mulch mix at construction. Thereafter, the mulched plots relied on local precipitation for water throughout the rest of the growing season. Local precipitation provided the only source of water for the un-mulched test plots. The net water gain from precipitation, corrected for temperature and evaporation, during the three months following plot construction is shown in

Table 2. The same information for 2018 indicates that precipitation was low, as shown in Table 3.

Table 2: Net water gain at Red Dog Mine in July, August, and September 2017

Month	Precipitation (in)	Average Temperature (°C)	Evaporation (in)	Net H2O Gain (in)
July 2017	5.0	12.5	-2.2	7.2
August 2017	3.1	6.7	1.4	1.7
September 2017	3.1	3.6	-1.7	4.8

Table 3: Net water gain at Red Dog Mine in June, July, and August 2018

Month	Precipitation (in)	Average Temperature (°C)	Evaporation (in)	Net H2O Gain (in)
June 2018	1.5	10.4	-2.8	-1.3
July 2018	3.3	11.6	No data	No data[3]
August 2018	1.3	9.1	0.7	0.6

3.4 Plot Damage

The test plots were located on a portion of the Top Deck that was closed to Operations. Sometime prior to snow-fall in 2017, Teck identified evidence of equipment damage (tracked dozer) on the northeast corner of the test plot area (F. Bendrick, personal communication, February 22, 2018). The survey lath that had been used to identify the western limit of the test plots had been driven over and no longer present.

The potential damage occurred when Operations added new cover material to extend the existing cover. The traffic potentially impacted two test plots, G100 and GF100 (see Section 5). Track marks were evident where the equipment damage occurred, and the cover material and vegetation appeared compacted, potentially impacting growth.

3.5 Limited Monitoring

Due to site access and staff limitations, it was not possible to implement a robust monitoring plan. Monitoring in 2017 was limited to area-wide photo documentation that occurred weekly during July 2017 and monthly in August and September 2017. Monitoring in 2018 consisted of a single monitoring event in June that consisted of one transect per subplot. The transect monitoring occurred early in the growing season and

[3] Data quality issue in the field rendered data set invalid for July 2018.

was not repeated in 2018. Therefore, data were not available to compare growth throughout the 2018 season. See Section 6.

4 Baseline Soil Conditions

The cover material on the Main Waste Dump consists of weathered shale from the Kivalina and Key Creek formations that do not contain the high concentrations of zinc and lead mineralization that are found in the Red Dog Plate (SRK Consulting (U.S.), Inc., 2016). The material includes large cobble to gravel-sized fragments and some fines. Similar material was used to cover the Oxide Dump.

Based on observations of the material profile in a shallow trench dug into the Oxide Dump cover, the material is expected to weather quickly and compress into smaller particles within several years. However, the current material is very porous and water

Photo 4: (Top and bottom) July 1, 2017. Evidence of weathered cover material breakdown observed in a test pit of the Oxide Dump, approximately 10-years after the cover was installed. Similar results are expected for the Main Waste Dump cover

and fertilizer applied to the test plots may be lost via leaching.

Photo 5: July 1, 2017. Advancing a soil test pit at the Oxide Dump. The Oxide Dump cover was installed and revegetated in 2008. The Oxide Dump cover material consists of Kivalina shale and is similar to the cover material on the Main Waste Dump.

Due to the potential for residual seed and fertilizer treatments to contaminate the test plots (see Section 3.1), the test plots were sampled prior to the application of seed,

fertilizer, and/or mulch treatments defined for the test plots. Soil samples were collected to estimate the potential for residual nitrogen, phosphorus, and potassium (NPK) from the early-season (June 5, 2017) application and to establish baseline soil health. Two

Photo 6: (Left) Close-up view of Main Waste Dump cover material collected for the baseline soil samples (cobble in photo is approximately 5-inches at the widest dimension). Note presence of seed from early-season (June 5, 2017) seed application. (Right) Landscape view of the cover material on the Main Waste Dump.

samples were collected from each of the three test plots (GF50, GF100, G100) prior to any test plot treatments. The samples consisted of a single, discrete grab sample and one three-part composite sample collected from each test plot.

PMC submitted the samples to Brookside Laboratories, Inc. for baseline soil analyses. In general, the soil analyses indicated relatively poor growing conditions and that the availability in the test plots of residual nutrients from the June 2017 fertilizer application was low. Soil sample data are summarized in Table 4 and discussed in the following sections. Laboratory data are included in Appendix A.

Table 4: Baseline Soil Analyses (June 5 2017)

Analysis	Units	Minimum	Maximum	Mean	Mean - Std Dev	Mean + Std Dev	Soil Health Indicator
Total Exchange Capacity	meq/100g	46.65	65.18	59.25	52.10	66.39	Very Good
pH	pH units	7.5	7.8	7.67	7.56	7.77	Good
Organic matter	%	0.29	0.53	0.43	0.35	0.52	Poor
Anions							

Analysis	Units	Minimum	Maximum	Mean	Mean - Std Dev	Mean + Std Dev	Soil Health Indicator
Soluble sulfur	ppm	691	1182	1000.83	792.38	1209.28	
Phosphorus (P_2O_5) (Mehlich III)	ppm	3	46	16.83	1.91	31.75	Poor[4]
Exchangeable Cations							
Calcium	ppm	8619	12073	11011.00	9665.07	12356.93	
Magnesium	ppm	173	235	201.50	180.45	222.55	
Potassium	ppm	69	112	93.67	78.83	108.51	
Sodium	ppm	13	16	14.00	12.74	15.26	
Base Saturation							
Calcium	%	92.38	93.15	92.91	92.58	93.24	Very high
Magnesium	%	2.67	3.09	2.85	2.67	3.02	
Potassium	%	0.28	0.62	0.42	0.30	0.53	
Sodium	%	0.09	0.12	0.11	0.09	0.12	
Other							
NO_3-N	ppm	33.00	58.60	50.20	40.35	60.05	Good
NH_3-N	ppm	1.10	23.30	5.55	0	14.32	Good
Total N availability (NO_3-N + NH_3-N)	ppm	34.10	81.90	55.75	N/A	N/A	Good
BRAY I P	ppm	<1	<1	<1	N/A	N/A	N/A

[4] Based on the University of Delaware fertility index value (FIV) for the Mehlich II (lb/A) and Bray I (ppm) methods (Shober, Gartley, & Sims, 2017).

Photo 7: Baseline soil samples included two samples from each test plot for a total of three discrete samples (top) and three composite samples (bottom).

4.1 Total Exchange Capacity and Base Saturation

Cation exchange capacity (CEC) describes the capacity of the soil to absorb cations that are beneficial to plant growth (nutrients), such as ammonium, calcium and, potassium, and the soil's ability to release those nutrients from the soil to the plant. CEC generally increases with increasing pH and is therefore lower in acidic soils than it is in alkaline soils. A CEC of 5 milliequivalents (meq) per100-grams or less is typical of sandy soils with low organic content. A CEC of 15 meq/100g is typical of loamier soils with high organic content.

The base saturation measures the "basic" cations, such as Ca and Mg, in the total CEC. As soil pH decreases, "acidic" cations, such as hydrogen and aluminum, become more available to the plants and may reach concentrations that inhibit or prevent plant growth.

The CEC in all of the samples was high (mean = 59.25 meq/100g), which was inconsistent with the field observations of the soil[5]. The samples consisted of large (gravel-sized) particles. The lab was required to crush and screen to particle sizes to less than 2-mm and placed in solution. Based on the high calcium content in the sample, PMC speculated that the larger shale particles may have settled from the sample, leaving dissolved clay particles in the analyzed sample solution. The resulting sample solution would have a high clay – and calcium – content, which is consistent with the high calcium base saturation (mean = 92.91%).

[5] Per Teck, the Kivalina shale cover material is net-neutralizing and the high CEC may be consistent with this material.

4.2 pH

The soil pH in all samples was approximately neutral and slightly basic (mean = 7.7).

4.3 Soil Organic Matter and Qualitative Moisture Content

The soil organic matter (SOM) is very low (mean = 0.35%), consistent with the porous, rapidly draining shale in the test plots. The low SOM in the soil may limit moisture retention, increase nutrient (fertilizer) leachate, and limit the conversion of ammonia to nitrate.

A hand-held qualitative moisture probe[6] was used to evaluate baseline moisture content in the soil at each composite sample point. The qualitative soil moisture readings indicated the material was “dry.”

4.4 Plant-available Nitrogen

There are two forms of plant-available nitrogen: ammonia ($N\text{-}NH_3$) and nitrate ($N\text{-}NO_3$). The nitrogen in the fertilizer was approximately 4% $N\text{-}NO_3$ and approximately 16% $N\text{-}NH_3$.

Nitrate is the preferred nitrogen source, as plants uptake nitrate directly. If soil conditions support plant growth, then $N\text{-}NH_3$ is typically converted to $N\text{-}NO_3$, resulting in relatively low $N\text{-}NH_3$ concentrations. Soil $N\text{-}NO_3$ concentrations in excess of 25 ppm are generally considered sufficient to support optimal yield, without fertilizer, for corn. However, this may be low for soils subject to heavy rainfall or high-porosity soils prone to nutrient leaching (Camberato & Nielson, 2017) due to the lack of organic material in the Main Waste Dump cover. The organic material helps to retain highly mobile nutrients, such as nitrogen, near the plant roots for uptake and release and decay during plant growth and senescence.

The $N\text{-}NH_3$ concentrations in the test plots are consistent with this pattern, ranging from 1.4 to 4.3 ppm, with a single sample result of 23 ppm, which may have resulted from a “nugget” of fertilizer from the July 2017 application. With the exception of the single elevated result, the $N\text{-}NH_3$ concentrations are typical (Horneck, Sullivan, Owen, & Hart, 2011).

Estimated nitrogen release indicates the amount of nitrogen released when organic matter is broken down in the soil substrate. The estimated nitrogen release is used to determine the fertilizer application rate for the following season. The estimated nitrogen release in the baseline soil samples ranged from 8 to 14 pounds per acre (lb/A). For optimal growth, the recommended estimated nitrogen release for cool season grasses is 1.8 pounds per square foot (77.4 lb/A) (McLachlan, 2013); this equates to 387 lb/A of 20-20-10 fertilizer (20% N). Fertilizer should be applied in multiple applications to reach the best end results for plant growth.

[6] Active-Air Model MGMP-1 2-way moisture/pH meter, battery-powered.

4.5 Phosphorus

Phosphorus supports general plant healthy including the root systems, seed quality, and improved yield. Soil phosphorus was analyzed by the Mehlich III (mean = 17 ppm) and Bray I (mean = <1 ppm) methods. Both the Bray I and the Mehlich III methods use a multi-element extraction and chelation process to remove phosphorus, primarily from aluminum and iron phosphates in acidic to neutral soils, and measures phosphorus as phosphate (P_2O_5). The Mehlich III method can also be used to extract exchangeable cations (Ca, Mg, K, Na) and micro-nutrients (copper, iron manganese, zinc).

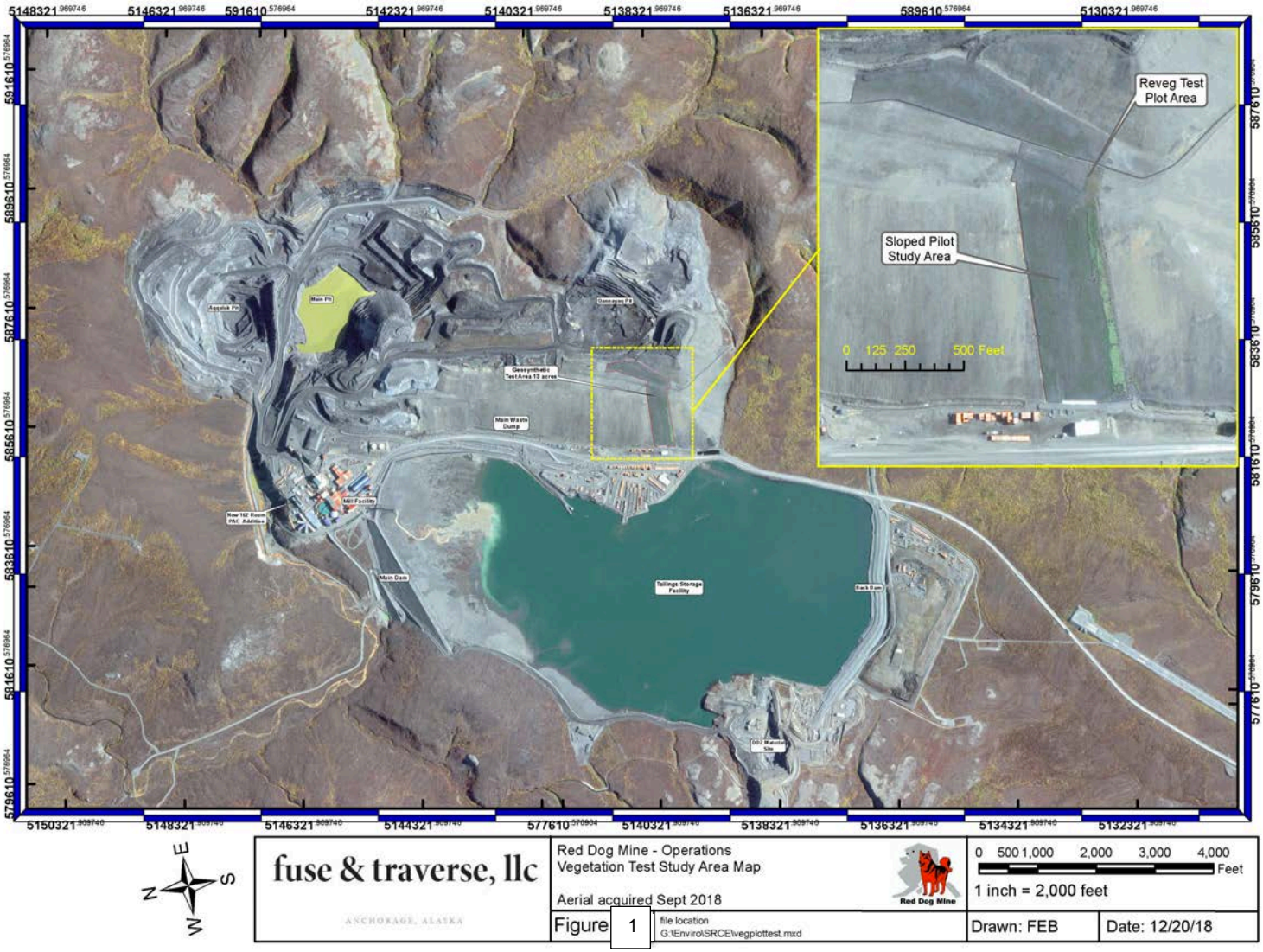
The Bray I method may underestimate phosphate concentrations in calcareous soils, such as those in the test plots, and when the soil pH exceeds 7.4, as observed in all of the samples (pH range: 7.5 to 7.8). Therefore, the data from the Mehlich III analyses are expected to more accurately represent the phosphate concentrations in the test plot soil. Both the Mehlich II and Bray I phosphate results are indicative of poor soil conditions.

4.6 Sulfur

Plant-available sulfur must be mineralized, by microbes, to sulfate for plant uptake. The baseline soil sulfur content is used to infer how much sulfur is available in the soil prior to amendment to convert to sulfate, and to determine the fertilizer ratio. The high porosity and low percentage of organic matter in the soil is a limiting environment for soil microbes and is therefore conducive to low soil sulfur concentrations. The sulfur concentration in the soil samples was high (mean = 1,000-ppm). Although mineralization in the Kivalina and Key Creek shale cover material on the test plots is low, sulfur is present in the Kivalina shale.

5 Test Plot Construction and Design

The study team constructed three test plots in an approximately 100-feet by 100-feet area located on the Top Deck of the Main Waste Dump, at the eastern-most limit of the geomembrane test area (see Figure 1).


Reveg Test Plot Area
Sloped Pilot Study Area
0 125 250 500 Feet
Main Pit
Aggulak Pit
Geosynthetic Test Area 12 acres
Main Waste Dump
Mill Facility
Main Dam
Tailings Storage Facility
Back Dam
DOJ Waste Site
fuse & traverse, llc
ANCHORAGE, ALASKA
Red Dog Mine - Operations
Vegetation Test Study Area Map
Aerial acquired Sept 2018
Figure 1
file location
G:\Enviro\SRCE\vegplottest.mxd
Red Dog Mine
0 500 1,000 2,000 3,000 4,000 Feet
1 inch = 2,000 feet
Drawn: FEB
Date: 12/20/18

- A temporary access road defined the approximately western limit of the test plots and separated the plots from the rest of the geomembrane pilot study area.
- A linear surface water diversion structure (Smart Ditch) defined the approximately eastern limit of the test plots.
- The approximately southern and northern limits of the test plot area were defined by the approximately 2-feet vertical difference between the pre-existing MWD cover and the new cover material where the test plots were constructed.

Each test plot was approximately 15-feet wide by approximately 60-feet long, or 900-ft^2 and was subdivided into two approximately equal 450-ft^2 subplots. The subplots were established to compare the application of mulch in one subplot to the absence of mulch from the other subplot.

The original plan included an approximately 15-feet by 60-feet buffer, or “control” plot, between each of the treatment plots. However, the GF50 plot was accidentally seeded with a single forb (see Section 5.1.2), which resulted in the loss of control plot between the GF50 plot and the adjacent treated plot. This forb-seeded area was established as a single-species test plot (see Table 5 and Table 6).

Table 5: Test plot layout and treatment (from approximately west to east)

Road/throughway

Edge of pad	GF50: grass + forb, no mulch	GF50: grass + forb, mulch @ 50% MAR
	ASTR: forb only, no mulch	ASTR: forb only, no mulch
	Control: no treatments	Control: no treatments
	GF100: grass + forb, no mulch	GF100: grass + forb, mulch @ 100% MAR
	Control: no treatments	Control: no treatments
	G100: grass only, no mulch	G100: grass only, mulch @ 100% MAR
Edge of pad		

Smart Ditch

The test plots were treated with:

- Grass seed (G100), or forb seed (ASTR), or a grass and forb seed mix (GF50, GF100).
- Mulch applied at 50% (GF50) or 100% (G100, GF100) of the manufacturer’s recommended application rate (MAR), or with no mulch at all (ASTR and one subplot in each of GF50, GF100, and G100).
- 20-20-10 fertilizer

plots located between G100 and GF100 and between GF100 and ASTR, as well as on to the un-mulched subplots and untreated areas outside the test plots. PMC recommended a minimum of 25-feet between test plots to minimize encroachment but there was not sufficient area on the Main Waste Dump to accommodate a larger buffer. PMC recommended a minimum of 25-feet between test plots to minimize encroachment but there was not sufficient area on the Main Waste Dump to accommodate a larger buffer.

The treatments are listed in Table 6 and are discussed in detail in the Introduction and sections 5.2, and 5.3.

Table 6: Revegetation Test Plot Treatment Applications

Plot Name	Seed Type	Estimated Area (ft^2)	20-20-10 Fertilizer Application Rate, lb/acre	Mulch: % of Manufacturer's Application Rate
G100	Grass	450	150	None applied
G100	Grass	450	150	100%
GF100	Grass + Forb	450	150	None applied
GF100	Grass + Forb	450	150	100%
GF50	Grass + Forb	450	150	None applied
GF50	Grass + Forb	450	150	50%
ASTR	Forb	450	150	None applied
ASTR	Forb	450	150	None applied

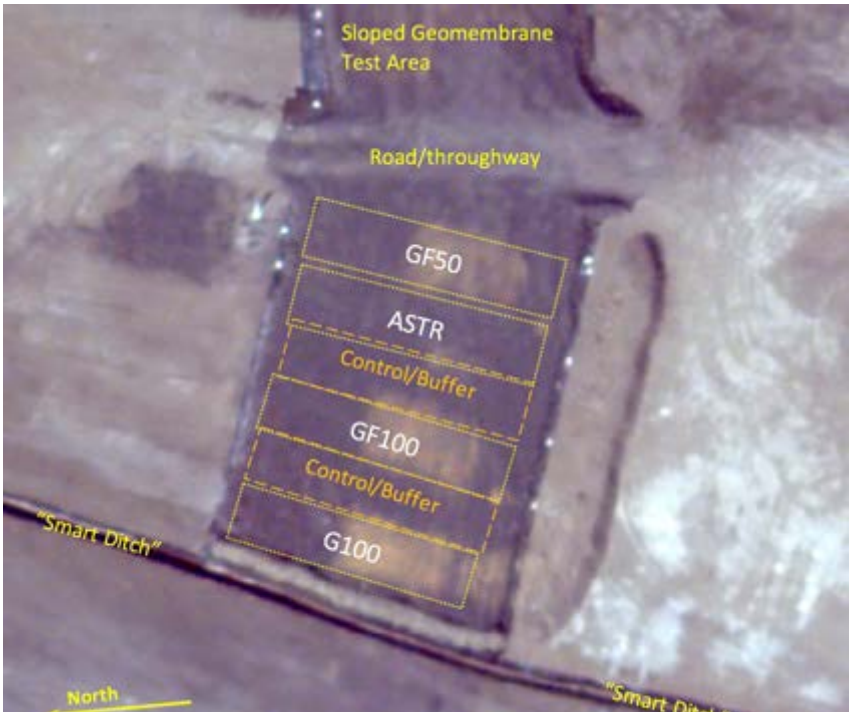


Photo 8: Aerial view of the 2017 test plots (photo: 6/29/2018). Note that 2018 growth is evident, and seed has encroached upon the adjacent control/buffer plots and unseeded areas.

5.1 Treatment: Grass and Forb Seed

The grass seed mixes were stored in a weather-resistant conex located on the Top Deck of the Main Waste Dump. Teck stored the forb seed in an on-site desiccator at Red Dog Mine dedicated to seed storage. The grass was weighed on site to the nearest 0.1-pound with a Measuretek Model PS-103-75 digital balance. Forb seed was weighed at the Red Dog Mine Assay Lab using a digital reagent balance the nearest 0.01-grams. On June 30, 2017, the grass and forb seed were mixed on site at the test plots and applied manually with a hand-operated broadcast seed spreader[7].

Photo 9: Grass seed and fertilizer storage conex at the Main Waste Dump. Grass seed and fertilizer were measured on site with a Measuretek Model PS-103-75 digital balance.

5.1.1 Grasses

The grasses were prescribed by the PMC to include dry-tolerant arctic species. The grass mix was prepared by Alaska Mill & Feed. The mix that was onsite at Red Dog Mine was a different mix that PMC had prescribed to revegetate spill areas, including

[7] EarthWay Ev-n-Spread 3100 professional hand-crank broadcast seed spreader.

wetlands. Thus, the grass mix applied to the test plots included Gruening alpine bluegrass, a wetlands grass species that was not expected to perform well in the dry, porous material on the Main Waste Dump. The other species in the mix were appropriate for the conditions and were expected to provide sufficient soil binding, erosion control, and seed entrapment to support longer-term plant growth.

The prepared seed mix included the first four species shown in Table 7 (tufted hairgrass, red fescue, tundra bluegrass, and alpine bluegrass). The wheatgrass was not included in the purchased mix and was added in the field.

The mass of each grass type was applied as "pure, live, seed." For example, the wheatgrass label indicated the seed was 94.86% pure and the germination rate was 80%. Therefore, one pound of pure, live seed (PLS) was equal to 12.2-ounces of pure, live wheatgrass.

PMC combined the following to yield pound of grass seed that was applied to each of the three test plots:

- 3.2-ounces of wheatgrass, and
- 12.8-ounces of tufted hairgrass, red fescue, tundra bluegrass, and alpine bluegrass mix

The total grass seed application rate was 0.84-pounds of pure, live seed per test plot, or 41-pounds of pure, live grass seed per acre. The grass species, mass applied, and pure, live seed equivalents are shown in Table 7.

Table 7: Test plot grass seed mix

Common Name	Species Name	Maturity	Origin	Percent of mix	Germination	PLS mass applied: #/plot	Application Rate: #/acre
Notran Tufted Hairgrass	*Deschampsia caespitosa*	Late season	AK	28.87%	83%	0.19	9.3
Boreal Red Fescue	*Festuca rubra*	Early to mid-season	CAN	19.67%	85%	0.13	6.5
Glaucous Tundra Bluegrass	*Poa glauca*	Late season	AK	23.87%	95%	0.18	8.8
Gruening Alpine Bluegrass	*Poa alpina*	Early season	AK	24.52%	94%	0.18	8.9
Wainwright ("slender") Wheatgrass	*Elymus trachycaulus*	Late season	AK	18.99%	80%	0.15	7.4

5.1.2 Forbs

All forbs applied to the test plots were local, native seed species harvested in Noatak, Alaska by community members trained to identify and harvest seed (fuse & traverse, LLC, March 2017). The seed was harvested in 2016. PMC cleaned the seed and tested it for purity and germination.

The forb seed consisted of four species:

- Indian milkvetch (Astragalus aboriginum)
- Low-lying stinkweed (Artemisia arctica)
- Dwarf fireweed (Chamerion latifolium)
- Masu (masru)/Potato (Hedysarum alpinum)

The forb seed mix included equal masses (25%) of all four species applied at a rate of 5.67 grams per plot, per species (9.6-pounds per acre, per species), for a total forb seed application of approximately 38.5-pounds per acre (all forb species).

Table 8: Test plot forb seed mix

Common Name	Species Name	Maturity	Origin	Percent of mix	Germination	Purity	PLS mass applied: lb/plot	Application Rate: #/acre
Indian milkvetch	*Astragalus aboriginum*	Late season	Noatak	25%	91%	98%	0.01	0.54
Stinkweed (low-lying)	*Artemisia arctica*	Late season	Noatak	25%	87%	100%	0.01	0.53
Dwarf Fireweed	*Chamerion latifolium*	Late season	Noatak	25%	83%	99%	0.01	0.50
Masu/potato	*Hedysarum alpinum*	Late season	Noatak	25%	75%	96%	0.01	0.44

5.2 Treatment: Fertilizer

The soil conditions on the Main Waste Dump required fertilizer to support to support cation exchange capacity and nitrogen retention in the soil.

The original workplan prescribed applying 20:20:10 NPK at a rate of approximately 450-pounds per acre, divided into three separate applications (see Section 3.2).

On June 28, 2017, 20-20-10 N-P-K fertilizer[8] was applied at a rate of approximately 150-pounds per acre (approximately 3.1-pounds per 900-ft^2 plot). The fertilizer was applied, by hand, with a broadcast seed spreader.

Due to limited accommodations for contractors and schedule constraints, Teck planned to apply the second and third fertilizer doses, to achieve a total fertilizer application rate of 450-pounds per acre (9.3-pounds per test plot) for the season.

- The second fertilizer application was due once the first tiller[9] was observed. Based on photos provided by Teck, first tiller likely occurred between July 20, 2017 and August 4, 2017. However, Teck was not able to apply the fertilizer.
- The third fertilizer application was due after first tiller was observed but no later than August 15, 201710 to allow growth to enter dormancy in the fall. However, Teck was not able to apply the fertilizer.

The test plots received a total application of 150-pounds per acre (3.1-pounds per plot) of fertilizer, which was approximately 33% of the amount recommended by PMC.

5.3 Treatment: Commercial Mulch

The test plots consisted of porous, well-drained soil with low organic matter and limited fines to retain moisture. Water was not available at the Main Waste Dump and the test plots would not receive water other than from local precipitation. Mulch was recommended to provide an initial water application, to retain moisture, and to retain seed. However, mulch is labor-intensive and mulching the entire Main Waste Dump is expected to be cost-prohibitive. Therefore, Hydromulch1000® (Conwed Fibers, 2017), a commercially-prepared wood fiber mulch, was only applied to one-half (the "subplots") of each of the three test plots to compare the same seed and fertilizer treatments with and without mulch.

The manufacturer's application rate (MAR) for Hydromulch1000® applied to slopes less than 4-to-1 (horizontal-to-vertical) is 2,000-pounds per acre (approximately 0.05-lb/ft^2), prepared by mixing 50-pounds of mulch in 100-gallons of water (0.5-lb/gal).

Five bags (250-pounds) of mulch and 2-cups of Earthbound TerraNovo® tackifier (Terra Novo, Inc., 2012) were mixed with 900-gallons of site water (approximately 0.25 pounds per gallon) in a Finn T120 Hydro-seeder (Finn, Corporation, 2014), to yield a mulch mixture at approximately 50% MAR. The mulch was prepared at 50% MAR to allow for mulch application at 50% MAR and 100% MAR.

- Two plots (G100, GF100) received 100% MAR Hydromulch1000®
- One plot (GF50) received 50% MAR Hydromulch1000®

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[8] United Agri Products (UAP) (Fremont, NE) 20-20-10 fertilizer, derived from muriate of potash, ammonium sulfate, ammonium nitrate, diammonium phosphate, treble super phosphate. Guaranteed analysis: Total Nitrogen 20% (16.02% ammonia-N, 3.98% nitrate-N); available phosphate (P_2O_5) 20%; chlorine ≤ 7.83%; sulfur 2.54%.

[9] The first tiller stage, a.k.a, the "flag-leaf" stage occurs when the vegetation have two or more leaves and indicates that the vegetation is "established."

[10] Per PMC, complete fertilizer applications at least two weeks before the first killing frost.

- One plot (ASTR) received 0% MAR, i.e., was not treated with mulch.

The hydro-seeder was not equipped with a meter or volume control. The volume of mulch applied to each test plot could not be measured and was estimated using a dip-stick to estimate the volume in the hydro-seeder tank. For mulch application purposes, the subplots were estimated to be 500-ft^2.

- Approximately 80-gallons of mulch mixture was applied to the G100 and GF100 subplots, to yield approximately 20-pounds of mulch per subplot, or approximately 100% MAR.
- Approximately 40-gallons was applied to plot GF50, to yield approximately 10-pounds of mulch per subplot, or approximately 50% MAR.

Table 9: Hydromulch1000® preparation and application rates

MAR	Plot Size (ft^2)	Mulch (#/plot)	Mulch Concentration (#/gal)	Mulch Volume (gal/plot)
100%	450	20	0.25	80
50%	450	10	0.25	40

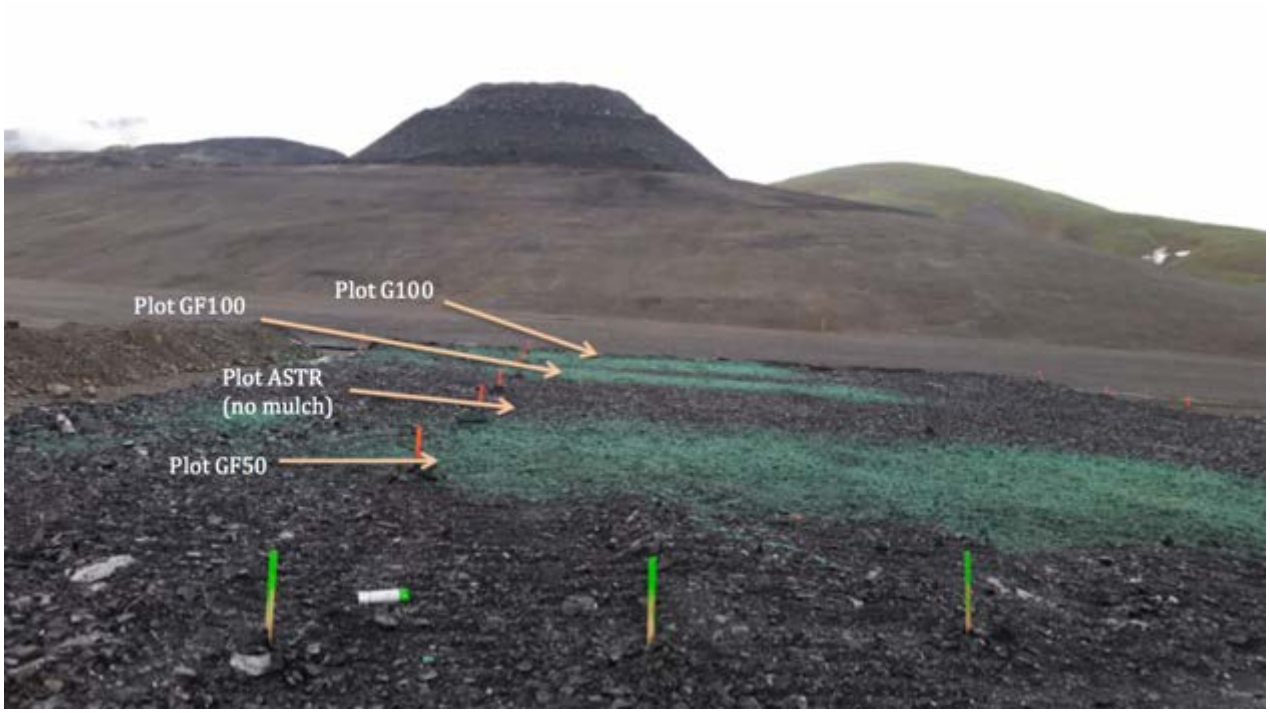

Photo 10: View looking approximately south from the Geomembrane Pilot Study area toward the test plots. Mulch was applied on one subplot (the left) of each test plot. Plots G100 and GF100 received 100% MAR mulch application. Plot GF50, in the foreground, received 50% MAR mulch application (note lighter coverage). No mulch was applied to the ASTR plot.

6 Monitoring

6.1 Year 1 (2017)

There were multiple large-scale construction projects scheduled at the mine during the 2017 construction season. Camp space and charter seats were not available for the study team after the plots were constructed. Therefore, the monitoring plan prescribed that Teck would collect weekly photo-documentation of all plots. The team used survey paint to establish 1-meter "quadrants" in each of the six sub-plots (two subplots in each of the three test plots). Aerial and overview photos were collected at each subplot quadrant periodically throughout the season.

Due to staff rotations, photo-documentation was only available on July 13, July 20, August 4, August 19, and September 8, 2017.

All vegetative cover estimates were inferred from the limited photos, are subjective, and are estimates for gross comparison purposes only.

6.1.1 GF50 Subplots

Two weeks after the test plots were constructed on July 1, 2017, emerging grass was observed that was attributed to the June 5, 2017 early-season (June 5, 2017) helicopter seed application. By July 20, 2017, vegetation was evident in the mulched subplot. However, the growth was immature, could not be positively identified. By late August, vegetative cover reached approximately 40% in the mulched subplot, with lower coverage in the un-mulched subplot. Photo quality was not sufficient to key grasses from forbs.

Photo 11: Note the emerging growth (assumed to be grasses) between the rocks in the mulched GF50 subplot.

The last photos of these season were obtained on September 8, 2017. The photos were not labeled, but the GF50 SE marker was observed in one photo, identifying the un-mulched GF50 subplot. Vegetative cover in this area was estimated at 30% and consisted of 100% grasses with a trace of at least one species of forb. The forb could not be positively keyed in the photo but appeared to be *Astragalus aboriginum*.

Photo 12: Photos taken on July 13, 2017 indicate no growth in the un-mulched GF50 (left) plot or the GF50 with 50% MAR mulch (right).

Photo 13: July 20, 2017 photos indicated emerging grasses in the mulched (right) subplot, and no growth observed in the un-mulched GF50 (left) plot.

Photo 14: August 4, 2017 photos indicated increased growth in the un-mulched (left) and mulched (right) GF50 subplots. Vegetation appeared to be more abundant in the mulched subplot.

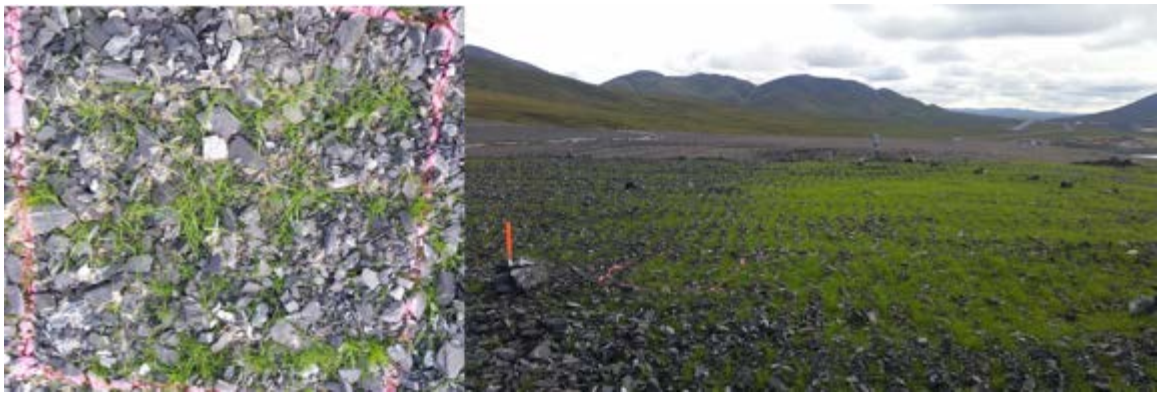

Photo 15: August 19, 2017. (Left) close-up of GF50 subplot with approximately 40% cover. Photos were not obtained for the un-mulched subplot. (Right) Over view of GF50 plot looking from the mulched towards the un-mulched subplot.

6.1.2 GF100 Subplots

The first detectable growth was observed in the mulched GF100 subplot on July 20, 2017 and consisted of grass that may have been from either the early-season or test plot seed applications. The August 4, 2017 photos indicated vegetative cover approaching 10% in both the mulched and un-mulched subplots. By August 19, 2017 the last set of photos for this test plot indicated that vegetative cover in the mulched subplot approached 50%, with less vegetative cover in the un-mulched subplot (approximately 40%). At least one species of forb was observed in the mulched GF100 subplot. The forb could not be positively identified but appeared to be *Artemisia arctica*.

Photo 16: Photos taken July 13, 2017 indicate no growth in the un-mulched GF100 (left) plot or the GF100 with 100% MAR mulch (right).

Photo 17: July 20, 2017. (Left) No growth was observed in the un-mulched GF100 subplot. (Right) Several shoots were observed in the mulched (right) GF100 subplot.

Photo 18: August 4, 2017. Vegetative cover in both GF100 subplots appeared to approach 10%.

Photo 19: August 19, 2017. Vegetative cover in the mulched GF100 subplot (foreground) appeared to approach 50%, with vegetative cover in the un-mulched subplot (background) slightly lower, at approximately 40%.

Photo 20: Forb (center of photo) observed in the GF100 mulched subplot (8/19/2017).

6.1.3 G100 Subplots

Growth in this test plot appeared to be somewhat slower than in the other test plots. No detectable growth was observed until August 4, 2017 and could only be confirmed in the mulched subplot (approximately 10%). By August 19,2017, vegetative cover was extensive and demonstrated a significant difference in vegetative cover between the mulched subplot (approximately 75%) and the un-mulched subplot (approximately 25%).

Photo 21: Photos taken July 13, 2017 indicate no growth in the un-mulched G100 (left) plot or the G100 with 100% MAR mulch (right).

Photo 22: July 20, 2017. No detectable growth was observed in the un-mulched (left) or mulched (right) G100 subplots.

Photo 23: August 4, 2017. The photo quality was insufficient to infer vegetative cover in the un-mulched G100 subplot (left). Vegetative cover in the mulched G100 subplot (right) approached 10%. All growth was assumed to be grasses; photo quality was not sufficient to determine if forbs were present.

Photo 24: August 19, 2017. Growth in the mulched G100 subplot (foreground) was established and demonstrated significantly greater cover than in the un-mulched subplot (background).

6.1.4 Astragalus Test Plot

Photos were only taken on August 19, 2017. There are no subplots, as no mulch was applied on this test plot. Overall cover in this test plot was low, and consistent with the application of a single forb, *Astragalus aboriginum*. Forbs were present in higher number than observed in the other plots, which may have been due to lack of competition from grasses and other forbs.

A control plot was established between this test plot and the adjacent GF 50 test plot. Some grasses were present, most likely from the early-season helicopter seed application or windblown from the adjacent plot.

Photo 25: August 19, 2017. (Left) Overview of the ASTR test plot on the left side of photo, with heavy growth on the G100 test plot visible on the right. (Right) Close-up of forbs in the ASTR test plot.

6.1.5 Other Observations

A limited number of forbs were observed outside the test plot area, indicating natural transplantation of forbs from the surrounding native vegetation to the Main Waste Dump may have occurred. The forbs were observed east of and across the “Smart Ditch” from the test plot area. The Oxide Dump is the nearest revegetation project. The surrounding native vegetation and, possibly, the Oxide Dump are potential sources of natural transplantation that may have occurred from the surrounding native vegetation.

Grasses were also observed at a relatively mature growth stage, indicating they may have established prior to the early season seed application (6/5/2017).

Photo 26: June 29, 2017. Forbs and grasses have begun to populate the upper slope of the Main Waste Dump, located east of and across the “Smart Ditch” from the test plots.

Photo 27: June 29, 2017. (Left) Natural colonization of forbs (willow shrubs) observed on the slope east of and across the "Smart Ditch" from the test plots. (Right) Mature grasses (with seed heads) were also observed and probably established prior to the early season seed application (6/5/2017).

6.2 Year 2 (2018)

The study team conducted a single monitoring event on June 28, 2018. The raw data sheets are included in Appendix B.

A flexible cord, 1-meter quadrant was cast into each subplot. The area occupied by the flexible quadrant was photographed and evaluated for the following qualitative conditions:

- Total percent cover, visual estimate
- Grasses, % cover, visual estimate
- Forbs, % cover, visual estimate
- Shrubs, % cover, visual estimate[11]
- Species present, count

[11] The seed mix included grasses and forbs, i.e., non-woody species, but shrubs, if observed, were recorded shrubs to document the presence of shrubs that may have cast naturally from the adjacent slopes

The qualitative monitoring data are summarized in Table 10. The following sections include a discussion for each of the test plots.

6.2.1 GF50 Subplots

Photo 28: (Left) GF50 un-mulched subplot. (Right) GF50 mulched subplot.

Total percent cover was estimated at approximately 45% in the un-mulched subplot and approximately 85% in the mulched subplot, indicating that, as observed in Year 1, the mulched plot supported more abundant plant growth.

Photo 29: *Artemisia arctica* observed in the GF50 mulched subplot.

- Grasses accounted for 100% of the estimated total cover in both subplots.
- The dominant grasses were the alpine and tundra bluegrasses, and a trace of wheatgrass was also observed.
- A trace of Timothy (*Phleum spp*), a grass that was not prescribed in the seed mix, was observed in both subplots.
- A trace amount of one forb, *Artemisia arctica*, was observed in the mulched subplot.
- No forbs were observed in the un-mulched subplot.

6.2.2 GF100 Subplots

Total percent cover was estimated at approximately 80% in the un-mulched subplot and approximately 85% in the mulched subplot. The difference in growth between the mulch treatment was insignificant and no effect was inferred due to the presence or absence of mulch.

- Grasses accounted for 99% of the estimated total cover in the un-mulched subplot. The dominant grasses were the alpine and tundra bluegrasses and the tufted hairgrass.
- Grasses accounted for approximately 100% of the estimated total cover in the mulched subplot. The dominant grasses were the alpine and tundra bluegrasses.
- A trace of wheatgrass was observed in both subplots.
- A trace of Timothy[12] (*Phleum spp*), a grass that was not prescribed in the seed mix, was observed in the mulched subplot.
- Forbs (*Artemisia arctica* and, possibly, *Astragalus aboriginum*) accounted for approximately 1% of the total cover in the un-mulched subplot.
- A trace amount of *Artemisia arctica* was observed in the mulched subplot.

The forbs were too young to key positively. Both bluegrasses were positively keyed in this plot.

The un-mulched plot included an area (approximately 2-ft x 5-ft) of stressed grasses characterized by yellow, desiccated seed heads. The stressed vegetation may be the result of standing water (observed), the fertilizer spill from the helicopter (6/5/2017), or some other factor.

Photo 30: (Left) GF100 un-mulched subplot. (Right) GF100 mulched subplot.

[12] Timothy (Phleum spp.) is native to Alaska but it is not native to the mine area and was not prescribed in the seed mix. Prepared seed mixes typically contain a certain percentage of "other species." PMC expects this was the source fo the seed.

Photo 31: Stressed vegetation observed in GF100 test plot. Note yellowed vegetation.

6.2.3 G100 Subplots

Total percent cover was estimated at approximately 75% in the un-mulched subplot and approximately 90% in the mulched subplot. The difference in growth between the mulch treatment was measurable and may indicate a mulch effect.

- Grasses accounted for approximately 100% of the estimated total cover in the both subplots.
- The dominant grasses in both subplots were the alpine and tundra bluegrasses.
- A trace of Timothy (*Phleum spp*), a grass that was not prescribed in the seed mix, was observed in both subplots.
- A trace of wheatgrass was observed in both subplots.
- No forbs were observed in either subplot.

The bluegrasses were too young to key positively. However, the presence of both bluegrasses in the GF100 plot supports the presence of both species in this test plot.

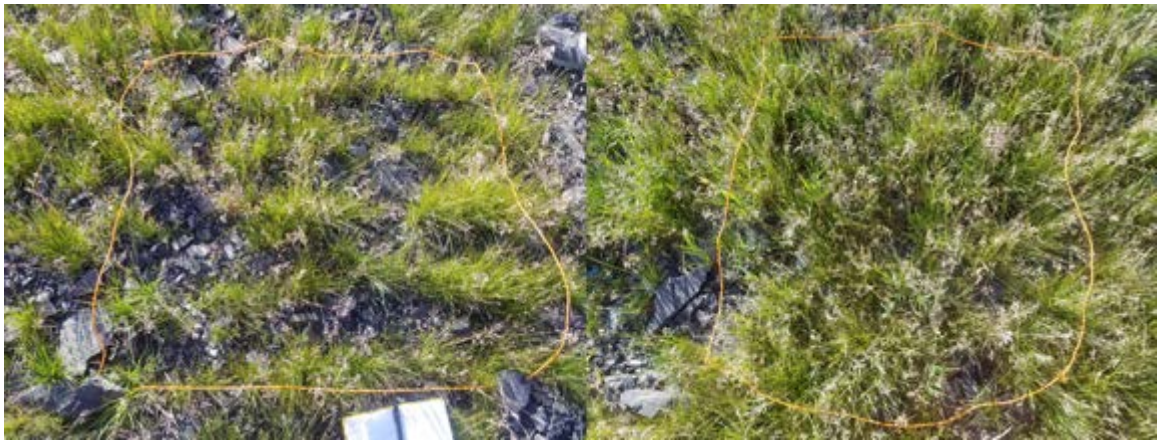

Photo 32: (Left) Un-mulched G100 subplot. (Right) Mulched G100 subplot.

As reported by Teck, equipment was accidentally driven on the mulched subplot, and disrupted growth. The vegetation appeared stressed in some spot of this test plot, with grasses characterized by wide-open panicles and yellowed and desiccated seed heads.

Photo 33: Equipment traveled on the mulched (foreground) G100 subplot, which may have contributed to the yellow, desiccated vegetation in a portion of the subplot.

6.2.4 ASTR Test Plot

No mulch was applied to this test plot, but both “subplots” were monitored. Total percent cover was estimated at approximately 50% in the southern subplot and approximately 60% in the northern subplot. The difference in growth between the subplots may be due to effects from the adjacent GF50 plot, the early-season seed application, or some other effect.

- Grasses accounted for approximately 99% of the estimated total cover in the both subplots.
- The dominant grasses in the southern subplot were the alpine bluegrass and tufted hairgrass. Tundra bluegrass appeared to be absent.
- A trace of wheatgrass was observed in both subplots.
- A trace of Timothy (*Phleum spp*), a grass that was not prescribed in the seed mix, was observed in the southern subplot.
- A trace of *Hordeum jubatum* (United States Forest Service, 2004), a weed species (foxtail) that was not prescribed in the seed mix, was observed in the northern subplot[13]. The ranking for *H. jubatum* in the Alaska Exotic Plants Information Clearinghouse (AKEPIC) is 63, indicating it poses a moderate threat to native ecosystems (Zero (0) indicates "no threat to native ecosystems" and 100 indicates "a major threat to native ecosystems.") (Alaska Center for Conservation Science, 2011). The weed was pulled anywhere that it was observed within the test plot area.
- Forbs accounted for 1% of the total cover; both Astragalus aboriginum and Artemisia arctica were present.
- Of note is that a different forb, *Potentilla spp.*, was present. The specimen was too young to positively identify. This forb was not present in the forb seed mix but may have been weed species present in the grass mix.

This area was not seeded with any grass. The heavy grass growth is probably from the early-season seed application and drift from the adjacent grass-forb plot (GF50).

Photo 34: (Left) Southern ASTR subplot. (Right) Northern ASTR subplot.

[13] Members of the 2018 Moss Study team observed the presence of *Hordeum jubatum.* In several areas along the DMTS road and suggested Teck conduct a weed pull while the population is relatively low.

Photo 35: (Left) *Potentilla spp*. observed in ASTR subplots. (Right) *Astragalus aboriginum* seedling observed in ASTR test plot.

Table 10: 2018 test plot monitoring observations

Plot Name	Description	Total Cover	Grasses	TBG	ABG	THG	BRF	SWG	Forbs	AA	HA	AT	CL	Shrub
G100-U	Grass only; no mulch	75%	75%	DOM	DOM	0%	0%	Trace	0%	0%	0%	0%	0%	0%
G100-M	Grass only; mulch=100% MAR	90%	90%	DOM	DOM	0%	0%	Trace	0%	0%	0%	0%	0%	0%
Buffer	Untreated	--	--	--	--	--	--	--	--	--	--	--	--	0%
GF100-U	Grass and forb; no mulch	80%	79%	DOM	DOM	DOM	0%	trace	1%	POSS	0%	1%	0%	0%
GF100-M	Grass and forb; mulch=100% MAR	85%	85%	DOM	DOM	0%	0%	trace	trace	0%	0%	trace	0%	0%
Buffer	Untreated	--	--	--	--	--	--	--	--	--	--	--	--	0%
ASTR-U	Astragalus only; no mulch	50%	49%	0%	DOM	DOM	0%	trace	1%	0.5%	0%	0.5%	0%	0%
ASTR-M	Astragalus only; no mulch	60%	59%	DOM	DOM	0%	0%	trace	1%	1%	0%	0%	0%	0%
GF50-U	Grass and forb; no mulch	45%	45%	DOM	DOM	0%	0%	trace	--	--	--	--	--	0%
GF50-M	Grass and forb; mulch=50% MAR	85%	85%	DOM	DOM	0%	0%	trace	trace	0%	0%	trace	0%	0%

DOM (dominant) indicates the species present in the highest concentration
POSS (possible) indicates the possible species of a plant that was not sufficiently developed to key accurately.

Grasses		**Forbs**	
TBD	Tundra bluegrass	AA	Astragalus aboriginum
ABG	Alpine bluegrass	HA	Hedysarum alpinum
THG	Tufted hairgrass	AT	Artemisia arctica
BRF	Boreal red fescue	CL	Chamerion latifolium
SWG	Wainwright wheatgrass		

7 Outcomes

7.1 Grasses

Overall growth was slow but successful during Year 1 considering the limited fertilizer application, limited water availability, and the potential plot damage from equipment traffic. It was not possible to distinguish growth from the early-season seed application in 2017 from the prescribed seed application on the test plots.

Overall growth in Year 2, as observed at the end of June 2018, indicated successful grass and forb regrowth. Photo-monitoring indicated that growth in the mulched plots measurably out-performed un-mulched plots in two of the test plots by 20% (G100) to 90% (GF50). However, growth in the forb-only subplots also differed by 20% with no mulch application to either subplot. The monitoring data consisted of photo-monitoring only (2017) and a single monitoring event of one transect in each subplot (2018) which is not sufficient to perform statistically robust comparisons between the treatment applications.

The growth pattern of the low-lying grasses appeared to be in their first year of growth in 2018 and had likely remained dormant over the winter of 2017-2018. The taller seed-head grasses indicated more established plants that were indicative of second-year growth from 2017.

Additional observations included:

- The early season seed event appears to have affected overall outcomes for the test plots.
- Two grasses Timothy (*Phleum spp.*) and *Hordeum jubatum*) were observed in the test plot area that were not in the prescribed seed mix. *Phleum pretense L.* is a native arctic species of Timothy (Alaska Natural Heritage Program, 2011) but the growth phase was too early to key to the species level. PMC expects that Timothy may have been one of the “other crops” (0.84%) listed on the seed mix label. The seed label also indicated weed seed (0.13%) but certified that “no noxious weeds” were in the mix. *H. judaicum* is a non-native plant and is ranked “63” in the AKEPIC ranking system.
- PMC was able to key both species in at least one plot (G100) confirming the presence of both tundra and alpine bluegrass (*Poa glauca* and *Poa arctica*). The two bluegrasses dominated the grass cover.
- The density of wheatgrass (*Elymus trachycaulus*) in the test plots was low, which may be due to the absence of this species from the early-season seed mix. Wheatgrass represented approximately 20% of the seed mix applied to the test plots compared to 0% of the early-season seed mix and may have been outcompeted by other grasses.
- Although red fescue represented approximately 25% of the early season seed mix, and approximately 20% of the seed mix applied to the test plots, the limited monitoring data indicate that red fescue was not present. Some of the young tufts of grasses may have included Red fescue that could not be keyed at that growth stage.

- There were no annual grasses applied to the test plots. The draft workplan prescribed that annual rye grass (*Lolium multiflorum*) would comprise 5% of the seed mix applied to the test plots. The incorrect mix was delivered for the test plots and included alpine bluegrass (*Poa arctica*) a wetlands grass, instead of rye grass.

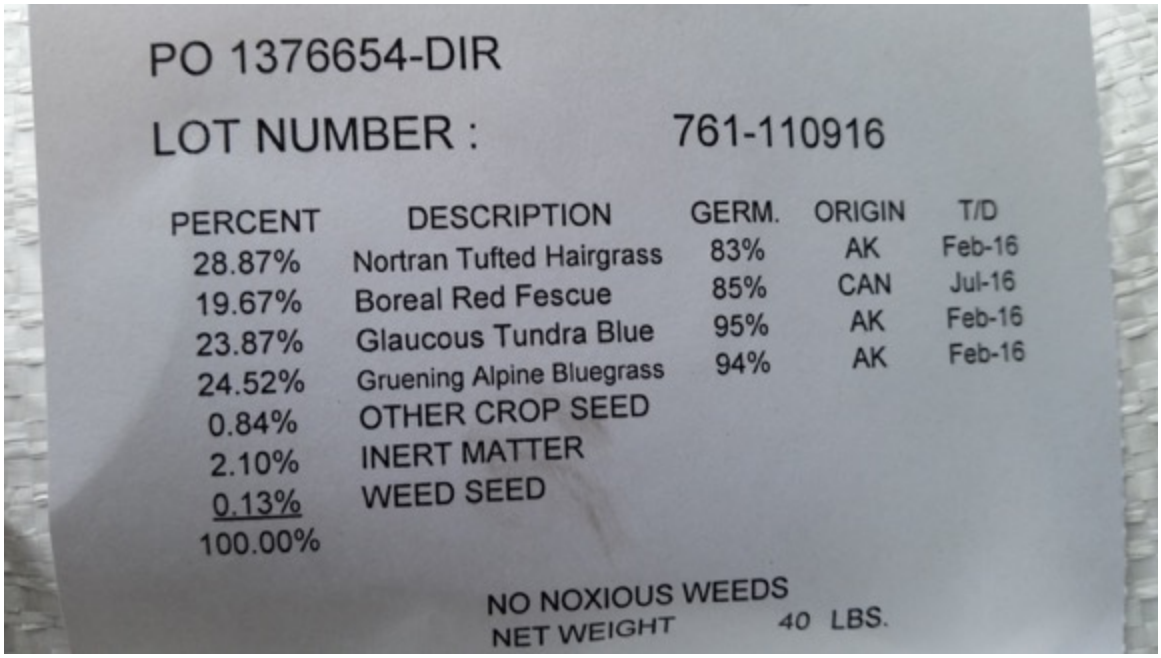

Photo 36: Label for the four-seed mix applied to the test plots in 2017. Note the presence of weeds (0.13%) but that "no noxious weeds" are present.

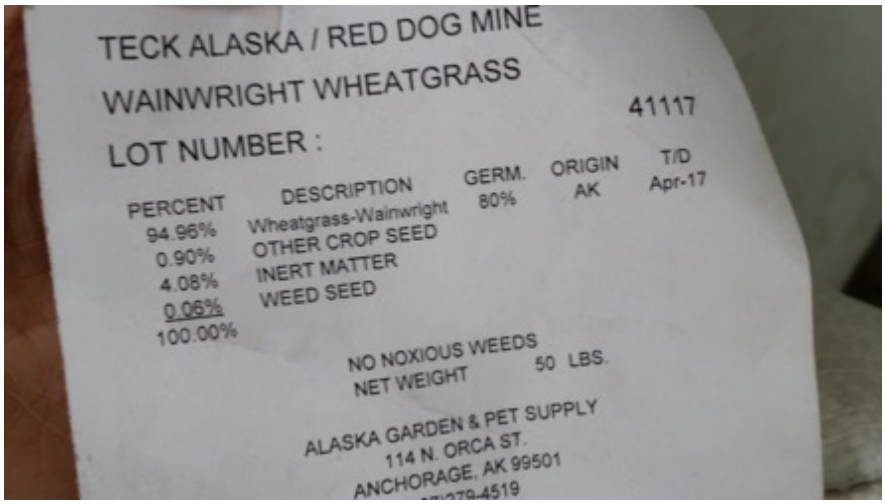

Photo 37: Label for the slender wheatgrass seed applied to the test plots in 2017. Note the presence of weeds (0.06%) but that "no noxious weeds" are present.

7.2 Forbs

Two of the four forb species, the low low-lying stinkweed (*Artemisia arctica*) and the Indian milkvetch (*Astragalus aboriginum*) that were harvested from Noatak appeared to

have successfully emerged in the test plots. The milkvetch's distinctive straight purple stem differentiated it from the dusty grey stems of the stinkweed seedlings.

- The vetches were too young to key the masu (*Hedysarum alpinum*) from the milkvetch. The vetch seedlings observed were assumed to be milkvetch based on the seedlings observed in the ASTR plot, which was seeded only with *A. aboriginum*.
- Observations during seed harvest in Noatak indicated that masu (*H. alpinum*) and milkvetch (*A. aboriginum*) may thrive under different climatic conditions, such as rainfall and saturation of the root zone that may occur during high water events in riverine areas. Masu was plentiful and well-harvested during 2015 while milkvetch plants were less abundant and appeared stressed. In 2016, the opposite was observed. Local knowledge reports indicated that 2016 was a very dry spring and break-up had been more extensive, encroaching further up the river banks. Under these conditions, masu plants were few, stressed, and produced limited and poorly formed seed pods, whereas milkvetch was abundant and produced large quantities of vigorous seed. The dry conditions on the Main Waste Dump may favor milkvetch and may not support masu.
- Precipitation data for 2017 indicated that July was relatively wet (7.2-inches net precipitation gain) and August was comparatively dry (1.7-inches net precipitation gain). September received an intermediate amount of rainfall (4.8-inches net precipitation gain. Precipitation data for 2018 show that June was relatively dry (-1.3-inches net precipitation gain), as was August (0.6-inches net precipitation gain). Data were not available for July or September 2018. Local precipitation may provide more favorable conditions for one vetch species over the other.
- The initial germination results were very poor (8%) for the milkvetch seed that was harvested in Noatak in 2016. PMC treated the seed with acid to scarify (soften) the seed coat, which increased the germination rate to 91%. The masu seed was not treated to enhance germination[14] and may be dormant without some type of treatment

Monitoring data indicated that dwarf fireweed (*Chamerion latifolium*) were not present. Per the PMC, dwarf fireweed can be challenging to grow from seed under healthy growing conditions (good soil, adequate water).

- The Main Waste Dump growing conditions may not be adequate to support dwarf fireweed.
- Teck may consider applying "dwarf fireweed mulch" to improve water and seed retention, and as a potential soil amendment.

The early season seeding in 2017 may have impacted the success of forbs in the test plots.

[14] The germination rate for *H. alpinum* harvested in Noatak in 2016 was 75%, which is lower than the treated *A. aboriginum* seed (91%), but much high than the untreated *A. aboriginum* seed (8%).

- No grasses were planted on the test plots, but the high density of grasses in the ASTR (forb-only) plot indicates that grasses present were a result of the 6/5/17 seed application.
- The high density of grasses may out-compete the forbs.
- The presence of stinkweed (*A. arctica*) on the ASTR plot demonstrates that buffer zones (un-seeded areas) were absent (as between ASTR and GF50) or inadequate (as between ASTR and GF100).

8 Recommendations

8.1 Dwarf Fireweed Mulch

Fireweed can be harvested whole, including the stalk, leaves, and seed and applied as surface mulch to meet multiple goals cost-effectively:

- Plant fireweed seed
- Add organic matter to the soil
- Retain seed and moisture in place

Fireweed mulch is not currently available on the commercial market. However, it can be harvested in bundles from Noatak or several places near the mine and transported easily from the harvest source.

8.2 Rye Grass

The PMC recommends adding rye grass to the grass mix (5%). Rye grass is robust in the first year and helps prevent erosion and retain seed in place. Then, it decreases in following years as self-seeding declines, allowing for other species to establish in its place.

8.3 On-site Wood Mulch/Compost Test Plots

As detailed in this report, mulch resulted in improved plot success in the first two years by assisting with erosion control, improving seed retention, retaining moisture, and reducing fertilizer loss due to leaching. Mulch is not expected to directly affect soil nutrition (e.g., nitrogen, sulfur) but is expected to provide conditions that support soil health and development. However, the materials and the labor to install the mulch are costly. Site-made mulch from wood waste (pallets, excess dimensional lumber, etc.) could reduce the cost of the mulch. Teck purchased a pallet grinder in 2018 and plans to establish revegetation test plots using the resulting mulch.

8.4 Restrict Access to Test Areas

Site control is a significant challenge to the success of the test plots. Unauthorized traffic and seed and fertilizer applications interfered with the success of the test plots. Teck will need to work directly with all operations groups to prohibit traffic on test plots and may be able to achieve success with a communication plane, early planning, and a written commitment from all managers.

8.5 Slow-release fertilizer

Due to limited resources at the mine to apply fertilizer throughout the growing season, the PMC suggests that slow-release fertilizer (20-20-10 or as necessary to yield the desired estimated nitrogen release (see Section 4.4) may be used to provide nutrients that may be lost to leaching. Slow-release fertilizer is available from Alaska Mill and Feed. The fertilizer is prepared to order.

8.6 Improve Buffers

The buffer distance between the test plots was insufficient to isolate and clearly delineate growth between the plots. Future test plots should be allotted sufficient area to allow for a minimum 20-feet buffer between test plots.

9 Bibliography

Alaska Center for Conservation Science. (2011, February 7). *Alaska Exotic Plant Information Clearinghouse database*. (U. o. Anchorage, Producer) Retrieved October 31, 2018, from Alaska Center for Conservation Science: http://aknhp.uaa.alaska.edu/apps/akepic/

Alaska Natural Heritage Program. (2011, February 8). *University of Alaska Anchorage: Alaska Center for Conservation Science.* Retrieved from timothy Phleum pratense L.: http://accs.uaa.alaska.edu/files/invasive-species/Phleum_pratense_BIO_PHPR3.pdf

Alaska Plant Materials Center. (1986, Nov 25). *Notice of Naming and Release of 'Gruening' Alpine Bluegrass (Poa alpina).* Retrieved July 25, 2018, from Alaska Plant Materials Center: http://plants.alaska.gov/pdf/GrueningAlpineBluegrass.pdf

Alaska Plant Materials Center. (2007, July 20). *'Nortran' Tufted Hairgrass Deschampsia caespitosa.* Retrieved July 25, 2018, from Alaska Plant Materials Center: http://plants.alaska.gov/pdf/plant-flyers/NortranTuftedHairgrass.pdf

Alaska Plant Materials Center. (2008, January 9). *Wainwright Germplasm slender wheatgrass.* Retrieved July 25, 2018, from Alaska Plant Materials Center: http://plants.alaska.gov/pdf/plant-flyers/WainwrightWheatgrass.pdf

Camberato, J., & Nielson, R. (2017, June). *Soil Sampling to Assess Current Soil N Availability.* Retrieved from Purdue Agronomy Home Page: https://www.agry.purdue.edu/ext/corn/news/timeless/assessavailablen.html

Cedar Creek Associates. (February 2013). *Red Dog Mine 2012 Revegetation Monitoring: Oxide Stockpile.* Fort Collins, CO.

Cedar Creek Associates, Inc. (February 2013). *Red Dog Mine 2012 Revegetation Monitoring Oxide Stockpile.* Fort Collins, CO: Cedar Creek Associates, Inc.

Cominco American Incorporated. (1982, October 11). Development and Operating Agreement between NANA Regional Corporation and Cominco American Incorporated. Anchorage, Alaska, United States.

Conwed Fibers. (2017, January 1). Conwed Fibers Hydro Mulch 1000 with TriFlo. *GHS SAfety Data Sheet: SDS Number CON052*. Buffalo Grove, Illinois, USA: Profile Products, LLC.

Elrashidi, M. (No date). *Selection of an Appropriate Phosphorus Test for Soils.* Retrieved from Natural Resource Conservation Service: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_051918.pdf

Finn, Corporation. (2014, Feruary 10). Finn HydroSeeder Series II Model T120. Fairfield, Ohio, USA: FinnCorp.com. Retrieved from Finn Corporation.

fuse & traverse, LLC. (March 2017). *Final Report: Noatak Seed Source Pilot Study, Year 2.* Anchorage, AK: fuse & traverse, LLC.

Geosyntec Consultants. (2016). *2016 Test Plot Work Plan, Main Waste Stockpile Cover System, Red Dog Mine, Alaska.* San Diego, CA: Geosyntec Consultants.

Geosyntec Consultants. (April 2016). *2016 Test Plot Work Plan, Main Waste Stockpile Cover System, Red Dog Mine, Alaska.* San Diego, CA: Geosyntec Consultants.

Horneck, D., Sullivan, D., Owen, J., & Hart, J. (2011, July). *Soil Test Interpretation Guide (EC 1478).* Retrieved from Michigan State University College of Agriculture and Natural Resources: http://www.canr.msu.edu/foodsystems/uploads/files/soil_test_interpretation.pdf

McLachlan, W. (2013, April 11). *How Much Fertilizer Do I Need To Fertilize My Lawn?* Retrieved from University of Maryland Extension: https://extension.umd.edu/learn/how-much-fertilizer-do-i-need-fertilize-my-lawn

Potassium Nitrate Association. (2018). *Nitrate (NO3-) versus ammonium (NH4+).* Retrieved from Potassium Nitrate Association: http://www.kno3.org/product-features-a-benefits/nitrate-no3-versus-ammonium-nh4

Red Dog Operations. (August 2016). *Life of Mine Plan (2017-2033).* Red Dog ine, Alaska: Teck Alaska, Inc.

Red Dog Operations. (August 2016). *Life-of-Mine Plan (2017-2033).* Red Dog Mine, AK: Teck Alaska, Inc.

Shober, A., Gartley, K., & Sims, J. (2017, March). *Interpreting Soil Phosphorus and Potassium Tests.* Retrieved from University of Delaware Cooperative Extension: http://extension.udel.edu/factsheets/interpreting-soil-phosphorus-and-potassium-tests/

Sonon, L. S., Saha, U. K., & Kissel, D. E. (2014, February 24). *Cation Exchange Capacity and Base Saturation.* Retrieved from University of Georgia Extension: http://extension.uga.edu/publications/detail.html?number=C1040&title=Cation%20Exchange%20Capacity%20and%20Base%20Saturation

Spargo, J., Allen, T., & Kariuki, S. (2013, July 1). *Interpreting Your Soil Test Results.* Retrieved from The Center for Agriculture, Food, and the Environment: https://ag.umass.edu/soil-plant-nutrient-testing-laboratory/fact-sheets/interpreting-your-soil-test-results

SRK Consulting (Canada), Inc. (2005). *Supporting Document F Reclamation and Revegetation: Mine Area Closure Studies - Summary of Cover Options.* Vancouver, BC: SRK Consulting (Canada), Inc.

SRK Consulting (U.S.), Inc. (2016, August 5). Evaluation of Borrow Sources. *Memo to Project 329100.030*. Anchorage, Alaska, United States: SRK Consulting (U.S.), Inc.

SRK Consulting (U.S.), Inc. (August 2016). *Reclamation and Closure Plan Red Dog Mine, Alaska, USA.* Teck Alaska, Inc. Anchorage, AK: SRK Consulting (U.S.), Inc.

SRK Consulting. (May 2009). *Red Dog Mine Closure and Reclamation Plan.* Anchorage, AK: SRK Consulting.

St. John, L., Tilley, D., Hunt, P., & Wright, S. (2012). *Plant Guide: Red Fescue.* Retrieved July 25, 2018, from United States Department of Agriculture: https://plants.usda.gov/plantguide/pdf/pg_feru2.pdf

Teck Alaska, Inc. (January 2014). *Life of Mine Plan (2014-2030).* Red Dog Operations. Red Dog, Alaska: Teck Alaska, Inc.

Terra Novo, Inc. (2012, November 13). EarthBound Mulch Tackifier Specifications. *Earthbound Soil Stabilizer and Mulch Tackifier*. Terra Novo, Inc.

United States Forest Service. (2004). *Selected Invasive Plants of Alaska (R10-TP-130B).* Retrieved from United States Department of Agriculture: https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5320150.pdf

Waltz, C., Ayers, E., Sikora, F., & Miller, R. (2014, February 26). *Cation Exchange Capacity and Base Saturation.* Retrieved from University of G2014eorgia Extension: http://extension.uga.edu/publications/detail.html?number=C1040&title=Cation%20Exchange%20Capacity%20and%20Base%20Saturation#What

Wright, S. J. (August 2008). *A Revegetation Manual For Alaska.* Palmer, Alaska: Alaska Plant Materials Center.

Appendix A Soil Analytical Data

SAMPLE CHAIN OF CUSTODY FORM

PROJECT NAME

Red Dog Mine Main Waste Dump Reveg TestPlots

Client **TECK ALASKA INC.**

Copy to **NANA REGIONAL CORP**

LABORATORY

Alaska Plant Materials Center

Frank Bendrick Frank.Bendrick@Teck.com 907.745.5138

Alison Kelley Alison.Kelley@NANA.com 907.301.8486

Item	LAB ID *LAB USE ONLY*	DATE SAMPLED	TIME SAMPLED	SAMPLED BY	SAMPLE ID	Matrix	# of Containers	ANALYSIS/PARAMETER: Moisture Content	Soil nutrients (N:P:K)	Cation Exchange Capacity (CEC)	pH	REMARKS
1		6/30/17	11:30	P. Johnson	G100-G1	Soil	1/Ziploc Bag	X	X	X	X	Single grab, pre-seed/fertilizer/mulch
2		6/30/17	11:40	P. Johnson	GF100-G1	Soil	1/Ziploc Bag	X	X	X	X	Single grab, pre-seed/fertilizer/mulch
3		6/30/17	11:45	P. Johnson	AST-G1	Soil	1/Ziploc Bag	X	X	X	X	Single grab, pre-seed/fertilizer/mulch
4		6/30/17	11:45	A. Kelley	G100-C1	Soil	1/Ziploc Bag	X	X	X	X	3-part composite, pre-seed/fert./mulch
5		6/30/17	11:55	A. Kelley	GF100-C1	Soil	1/Ziploc Bag	X	X	X	X	3-part composite, pre-seed/fert./mulch
6		6/30/17	12:10	A. Kelley	AST-C1	Soil	1/Ziploc Bag	X	X	X	X	3-part composite, pre-seed/fert./mulch

Relinquished by (Print)	Relinquished by (sign)	Date/Time	Received by (Print)	Received by (sign)	Date/Time
Alison Kelley		7/1/17	Pete Johnson		7/1/17
~~Pete Johnson~~	~~[illegible]~~	~~7/1/17~~			

lb/A

BROOKSIDE LABORATORIES, INC.

76195-5

SOIL AUDIT AND INVENTORY REPORT

Name Peter Johnson City Palmer State AK

Independent Consultant Home Office Date 07/13/2017

Sample Location	MAIN WASTE STUDY	PLOT 1	PLOT 1	PLOT 2	PLOT 2
Sample Identification		4 in	4 in COMP	4 in	4 in COMP
Lab Number		1467-1	1468-1	1469-1	1470-1
Total Exchange Capacity (ME/100 g)		65.18	63.17	46.65	62.11
pH (H_2O 1:1)		7.5	7.7	7.6	7.7
Organic Matter (360°C LOI) %		0.38	0.47	0.53	0.45
Estimated Nitrogen Release	lb/A	10	13	14	12
ANIONS: SOLUBLE SULFUR*	ppm	1182	788	1110	1071
PHOSPHORUS: MEHLICH III	lb/A P as P_2O_5	43	43	140	43
	ppm of P	14	14	46	14
BRAY II	lb/A P as P_2O_5				
	ppm of P				
OLSEN	lb/A P as P_2O_5				
	ppm of P				
EXCHANGEABLE CATIONS: CALCIUM*	lb/A	16097	15691	11492	15425
	ppm	12073	11768	8619	11569
MAGNESIUM*	lb/A	313	271	231	265
	ppm	235	203	173	199
POTASSIUM*	lb/A	136	123	149	133
	ppm	102	92	112	100
SODIUM*	lb/A	17	19	17	17
	ppm	13	14	13	13
BASE SATURATION PERCENT					
Calcium	%	92.61	93.15	92.38	93.13
Magnesium	%	3.00	2.68	3.09	2.67
Potassium	%	0.40	0.37	0.62	0.41
Sodium	%	0.09	0.10	0.12	0.09
Other Bases	%	3.90	3.70	3.80	3.70
Hydrogen	%	0.00	0.00	0.00	0.00
EXTRACTABLE MINORS					
Boron* (ppm)		0.28	0.21	0.24	0.28
Iron* (ppm)		382	394	355	404
Manganese* (ppm)		64	60	53	64
Copper* (ppm)		2.20	2.01	4.00	2.57
Zinc* (ppm)		69.79	48.71	76.58	89.20
Aluminum* (ppm)		8	13	13	5
OTHER TESTS: Soluble Salts (mmhos/cm)					
Chlorides (ppm)					
NO_3-N (ppm)		55.2	52.1	57.8	58.6
NH_4-N (ppm)		1.4	4.3	23.3	1.7
Bray I P (ppm)		< 1	< 1	11	< 1

d - specific a - alkaline

* Mehlich III Extractable

lb/A

BROOKSIDE LABORATORIES, INC.

76195-5

SOIL AUDIT AND INVENTORY REPORT

Name Peter Johnson City Palmer State AK

Independent Consultant Home Office Date 07/13/2017

Sample Location		MAIN WASTE STUDY	PLOT 3	PLOT 3			
Sample Identification			4 in	4 in COMP			
Lab Number			1471-1	1472-1			
Total Exchange Capacity (ME/100 g)			54.85	63.51			
pH (H_2O 1:1)			7.8	7.7			
Organic Matter (360°C LOI) %			0.47	0.29			
Estimated Nitrogen Release		lb/A	13	8			
ANIONS	SOLUBLE SULFUR*	ppm	691	1163			
ANIONS – PHOSPHORUS	MEHLICH III	lb/A P as P_2O_5	31	9			
		ppm of P	10	3			
	BRAY II	lb/A P as P_2O_5					
		ppm of P					
	OLSEN	lb/A P as P_2O_5					
		ppm of P					
EXCHANGEABLE CATIONS	CALCIUM*	lb/A	13607	15776			
		ppm	10205	11832			
	MAGNESIUM*	lb/A	251	281			
		ppm	188	211			
	POTASSIUM*	lb/A	116	92			
		ppm	87	69			
	SODIUM*	lb/A	20	21			
		ppm	15	16			
BASE SATURATION PERCENT							
	Calcium	%	93.03	93.15			
	Magnesium	%	2.86	2.77			
	Potassium	%	0.41	0.28			
	Sodium	%	0.12	0.11			
	Other Bases	%	3.60	3.70			
	Hydrogen	%	0.00	0.00			
EXTRACTABLE MINORS							
	Boron* (ppm)		0.36	0.35			
	Iron* (ppm)		392	460			
	Manganese* (ppm)		54	65			
	Copper* (ppm)		2.47	2.59			
	Zinc* (ppm)		58.36	61.01			
	Aluminum* (ppm)		8	5			
OTHER TESTS	Soluble Salts (mmhos/cm)						
	Chlorides (ppm)						
	NO_3-N (ppm)		44.5	33.0			
	NH_4-N (ppm)		1.1	1.5			
	Bray I P (ppm)		< 1	< 1			

d - specific a - alkaline

* Mehlich III Extractable

Appendix B Field Monitoring Data Sheets

Red Dog

~~[illegible]~~ Reveg Study

Date: 6/28/18

Location/Aspect: [illegible]

Plot #: ASTR

Seed mix: Ast abo

Collected By: AK, PS

Condition of Plot: Good

Vegetative Cover

Grass	Forb	Shrub
Cover %: 69	Cover %: 1 %	Cover %: None
Notes: Des ces, Poa spp, Ely tra 1.5%, Phleum 2.4%	Notes: Ast abo, Art arc, Pot bim ?!	Notes:

Total Cover %: 50

Grass Mix (G) Total 1.5 lb per 1500' plot		Grass Mix (G+F) Total 1.6 lb per 1500' plot	
Festuca rubra 'Arctared' Red Fescue	20%	*Artemisia arctica* Boreal sagebrush	1.25%
Lolium perenne Annual Ryegrass	5%	*Astragalus aboriginum* Indian Milk Vetch	1.25%
Elymus trachycaulus 'Wainwright' Slender Wheatgrass	25%	*Chamerion latifolium* Dwarf fireweed	1.25%
Poa glauca 'Tundra' Bluegrass	25%	*Hedysarum alpinum* Eskimo potato	1.25%
Deschampsia cespitosa 'Nortran' Tufted Hairgrass	25%		

Possible Stephan Cinquefoil - See Pic

Red Dog

~~Dem~~ Reveg Study

Date: 6/28/18 Location/Aspect: Mulch

Plot #: AstR Seed mix: Ast abo

Collected By: AK, PJ Condition of Plot: Good

Vegetative Cover

Grass	Forb	Shrub
Cover %: 59	Cover %: 1	Cover %:
	Ast abo	
Notes:	Notes:	Notes:
Poa spp		
Des ces		
Ely trac		
1 Hwr Sub		

Total Cover %: 60

Grass Mix (G) Total 1.5 lb per 1500' plot		Grass Mix (G+F) Total 1.6 lb per 1500' plot	
Festuca rubra 'Arctared' Red Fescue	20%	*Artemisia arctica* Boreal sagebrush	1.25%
Lolium perenne Annual Ryegrass	5%	*Astragalus aboriginum* Indian Milk Vetch	1.25%
Elymus trachycaulus 'Wainwright' Slender Wheatgrass	25%	*Chamerion latifolium* Dwarf fireweed	1.25%
Poa glauca 'Tundra' Bluegrass	25%	*Hedysarum alpinum* Eskimo potato	1.25%
Deschampsia Cespitosa 'Nortran' Tufted Hairgrass	25%		

Red Dog

[redacted] Reveg Study

Date: 6/28/18

Location/Aspect: un mulch

Plot #: GF 50

Seed mix: GF

Collected By: AK, PS

Condition of Plot: Good

Vegetative Cover

Grass	Forb	Shrub
Cover %: 15%	Cover %: Ø none	Cover %:
Notes: Poa Phleum Deschamp Elytrig	Notes:	Notes:

Total Cover %: 15%

Grass Mix (G) Total 1.5 lb per 1500' plot		Grass Mix (G+F) Total 1.6 lb per 1500' plot	
Festuca rubra 'Arctared' Red Fescue	20%	*Artemisia arctica* Boreal sagebrush	1.25%
Lolium perenne Annual Ryegrass	5%	*Astragalus aboriginum* Indian Milk Vetch	1.25%
Elymus trachycaulus 'Wainwright' Slender Wheatgrass	25%	*Chamerion latifolium* Dwarf fireweed	1.25%
Poo glauca 'Tundra' Bluegrass	25%	*Hedysarum alpinum* Eskimo potato	1.25%
Deschampsia Cespitosa 'Nortran' Tufted Hairgrass	25%		

Red Dog
~~[illegible]~~ Reveg Study

Date: 6/28/18 Location/Aspect: Mulch

Plot #: GF50 Seed mix: GF

Collected By: AK, PJ Condition of Plot: Good

Vegetative Cover

Grass	Forb	Shrub
Cover %: 85	Cover %: Trace	Cover %:
	Art arc	none
Notes:	Notes:	Notes:
Poa spp		
Des ces		
Ely tra-trace		
Phleum-trace		

Total Cover %: 85

Grass Mix (G) Total 1.5 lb per 1500' plot		Grass Mix (G+F) Total 1.6 lb per 1500' plot	
Festuca rubra 'Arctared' Red Fescue	20%	*Artemisia arctica* Boreal sagebrush	1.25%
Lolium perenne Annual Ryegrass	5%	*Astragalus aboriginum* Indian Milk Vetch	1.25%
Elymus trachycaulus 'Wainwright' Slender Wheatgrass	25%	*Chamerion latifolium* Dwarf fireweed	1.25%
Poa glauca 'Tundra' Bluegrass	25%	*Hedysarum alpinum* Eskimo potato	1.25%
Deschampsia Cespitosa 'Nortran' Tufted Hairgrass	25%		

Red Dog

[redacted] Reveg Study

Date: 6/28/18

Location/Aspect: UN - Mulch

Plot #: G100

Seed mix: Ely tre, Des cas, Fes rub, Poa gla, Hpa alo

Collected By: AK, PJ

Condition of Plot: _____

Vegetative Cover

Grass	Forb	[redacted] Shrub
Cover %: 75%	Cover %: None	Cover %: None
Notes: Dominated by Poa & Deschampsia Trace Ely tre Trace Phleum	Notes:	Notes:

Total Cover %: 75%

Grass Mix (G) Total 1.5 lb per 1500' plot		Grass Mix (G+F) Total 1.6 lb per 1500' plot	
Festuca rubra 'Arctared' Red Fescue	20%	*Artemisia arctica* Boreal sagebrush	1.25%
Lolium perenne Annual Ryegrass	5%	*Astragalus aboriginum* Indian Milk Vetch	1.25%
Elymus trachycaulus 'Wainwright' Slender Wheatgrass	25%	*Chamerion latifolium* Dwarf fireweed	1.25%
Poa glauca 'Tundra' Bluegrass	25%	*Hedysarum alpinum* Eskimo potato	1.25%
Deschampsia Cespitosa 'Nortran' Tufted Hairgrass	25%		

Red Dog

~~UGM~~ Reveg Study

Date: 6/28/18

Location/Aspect: Mulch

Plot #: G1000

Seed mix: _____

Collected By: AK, PJ

Condition of Plot: Good

Vegetative Cover

Grass	Forb	Shrub
Cover %: 90	Cover %: None	Cover %: None
Notes: Poa & Des dominate 1% Elytra Trace Phleum	Notes:	Notes:

Total Cover %: 90

Grass Mix (G) Total 1.5 lb per 1500' plot		Grass Mix (G+F) Total 1.6 lb per 1500' plot	
Festuca rubra 'Arctared' Red Fescue	20%	*Artemisia arctica* Boreal sagebrush	1.25%
Lolium perenne Annual Ryegrass	5%	*Astragalus aboriginum* Indian Milk Vetch	1.25%
Elymus trachycaulus 'Wainwright' Slender Wheatgrass	25%	*Chamerion latifolium* Dwarf fireweed	1.25%
Poa glauca 'Tundra' Bluegrass	25%	*Hedysarum alpinum* Eskimo potato	1.25%
Deschampsia Cespitosa 'Nortran' Tufted Hairgrass	25%		

Red Dog

[redacted] Reveg Study

Date: 6/08/18

Location/Aspect: [redacted] Non-mulch

Plot #: CF100SW

Seed mix: CHF

Collected By: AK, PS

Condition of Plot: Stress area on South side, yellow sand head

Vegetative Cover

Grass	Forb	Shrub
Cover %: 79	Cover %: 1	Cover %:
		None
Notes: Poa > Dominate Des Ely trace No Phleum Poa Seems Stressed	Notes: Art arc	Notes:

Total Cover %: 80

Grass Mix (G) Total 1.5 lb per 1500' plot		Grass Mix (G+F) Total 1.6 lb per 1500' plot	
Festuca rubra 'Arctared' Red Fescue	20%	*Artemisia arctica* Boreal sagebrush	1.25%
Lolium perenne Annual Ryegrass	5%	*Astragalus aboriginum* Indian Milk Vetch	1.25%
Elymus trachycaulus 'Wainwright' Slender Wheatgrass	25%	*Chamerion latifolium* Dwarf fireweed	1.25%
Poa glauca 'Tundra' Bluegrass	25%	*Hedysarum alpinum* Eskimo potato	1.25%
Deschampsia Cespitosa 'Nortran' Tufted Hairgrass	25%		

Red Dog

[redacted] Reveg Study

Date: 6/28/18 Location/Aspect: Mulch

Plot #: GF100 Seed mix: G+F

Collected By: AK, PT Condition of Plot: Good

Vegetative Cover

Grass	Forb	Shrub
Cover %: 85	Cover %: trace	Cover %: none
Notes:	Notes:	Notes:
Ely trachycaulus trace		
Poa glauca		
Poa pratensis		
Phleum trace		

Total Cover %: 85%

Grass Mix (G) Total 1.5 lb per 1500' plot		Grass Mix (G+F) Total 1.6 lb per 1500' plot	
Festuca rubra 'Arctared' Red Fescue	20%	*Artemisia arctica* Boreal sagebrush	1.25%
Lolium perenne Annual Ryegrass	5%	*Astragalus aboriginum* Indian Milk Vetch	1.25%
Elymus trachycaulus 'Wainwright' Slender Wheatgrass	25%	*Chamerion latifolium* Dwarf fireweed	1.25%
Poa glauca 'Tundra' Bluegrass	25%	*Hedysarum alpinum* Eskimo potato	1.25%
Deschampsia Cespitosa 'Nortran' Tufted Hairgrass	25%		

Where's the fescue?

Appendix L: Risk Management Plan (RMP) Fugitive Dust (pending, 2nd quarter)

Appendix M: Red Dog One Year Mine Plan 2019

Red Dog Operations

Alaska, USA

ONE YEAR MINE PLAN – 2019 (REVISED)

December 2018

Teck

ONE YEAR MINE PLAN - 2019

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Distribution List

Red Dog Operations, Teck Alaska Inc.

Vice President – Shehzad Bharmal
General Manager – Les Yesnik
Assistant General Manager – John Egan
Operating Manager – Mark Smith
Mine Superintendent – Todd Smith
Mine General Supervisor – Robert Merculieff
Chief Engineer – Chris Ryan
Chief Geologist – Kevin Palmer

Short Range Planning (2)
Long Range Planning (2)
Projects (1)
Geology (1)
NANA (1)
Spares (4)

ONE YEAR MINE PLAN - 2019

Prepared by:

Mark Helms, Mine Engineer	Date

Approved by:

Chris Ryan, Chief Engineer	Date
Kevin Palmer, Chief Geologist	Date
Robert Merculieff, Mine General Supervisor	Date
Todd Smith, Mine Superintendent	Date

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SECTION 1. SUMMARY

1.1. Introduction

Utilizing Red Dog Mine's current stockpile blending criteria and equipment capabilities, a 12-month mine production plan for 2019 has been developed. The 2019 One Year Mine Plan has an estimated production of 1,018 kt of zinc concentrate and 162 kt of lead concentrate, yielding 553 kt of zinc metal and 89 kt of lead metal. These estimates are based upon mill recovery formulas in the mine block model, with adjustments made by Mill Technical based on projected mill feed grades and mill feed tonnes The average mill throughput is 531 tonnes per operating hour. Increasing throughput above 531 tpoh will require feeding material that is planned for stockpiling, and will result in a reduction of average mill feed grades. All production will be mined from the Aqqaluk and Qanaiyaq deposits, and the waste will primarily be dumped back into the Main Pit. The production total for 2019 is forecast to be 11,813 kt, of which 5,685 kt is ore and 6,128 kt is waste.

1.2. Mine Planning Parameters

The mine plan is based on two distinct block models; one for the Aqqaluk and the Qanaiyaq deposits respectively. Planning for the Aqqaluk Pit is based on the RED2017-A model, issued in February 2018, and uses the Aqq17 pit shell. Planning for the Qanaiyaq Pit is based on the QAN2012-O model, issued in February 2018, and uses the Qan12f pit shell. An update to the geologic shape model for the Qanaiyaq pit is underway, and is expected to improve model accuracy. The anticipated rollout of this model will be in Q1 2019. The drilling and metallurgical understanding of both the Aqqaluk and Qanaiyaq deposits is sufficient for reserves classification.

February 2018 Reserve & Resource metal prices ($1.10/lb. Zn, $0.90/lb. Pb and $20.00/tr. oz. Ag) were used to calculate revenue and generate ore/waste cutoff values. Net value per tonne is converted to net value per second, using throughput formulae from the Teck sponsored AMIRA GeM mineral texture project, to account for ore throughput variability. An operating, rather than breakeven cutoff is utilized by Red Dog in order to provide a higher NPV mining schedule than that obtainable on a breakeven cutoff basis. A net value per second of $[redacted]/s is used as the operating cutoff to classify High Grade Ore. For the duration of this plan, only High Grade Ore is fed into the mill. Medium Grade Ore, from $[redacted]0/s up to $[redacted]5/s, and Low Grade Ore, from $0.00/s up to $[redacted]/s, are stockpiled for processing later in the mine life. A separate cutoff grade was developed for Low Grade Possibly Reactive (LG-PR) Ore. LG-PR Ore above $4[redacted]/s is classified as High Grade Ore and will be fed into the mill. LG-PR Ore below $[redacted]/s is considered waste and handled accordingly. Due to sulfide reactivity, only the fraction of Low Grade Ore (that is classified as non-reactive) is stockpiled. Once ore and waste reserves were determined, the ore was scheduled by grade and grade ratios according to the Red Dog Operations mill stockpile blending criteria.

Total production tonnage is considered a function of available truck hours. The first priority was to determine the total truck hours required to achieve mill feed and critical projects (e.g. Tailings Storage Facility (TSF) infrastructure). These hours were then subtracted from the total available truck hours to determine the tonnage of waste able to be hauled. An average Physical Availability of 76.8.0%, Use of Availability of 86.3%, and Operating Efficiency of 87.0% were used to calculate the total truck hours available for 2019. All production is in line with the 2018 5-Year Mine Plan commitments.

1.3. Mine Production

In 2019, Red Dog is anticipating 11,813 kt of total mine production from the Aqqaluk Pit and Qanaiyaq Pit as shown in Table 1.3-1. 4,218 kt of High Grade Ore at [redacted]1% Zn and [redacted]% Pb, 1,467 kt of Low Grade & Medium Grade Ore, plus 6,128 kt of waste is forecasted. Of the total ore production, the Aqqaluk Pit contributes 79.6% and the Qanaiyaq Pit 20.4%.

Table 1.3-1 2019 Summary

2019	Aqqaluk Pit	Qanaiyaq Pit	Total
Total (tonne)	8,267,201	3,546,274	11,813,475
HG Ore (tonne)	3,359,542	858,752	4,218,294
Zn (%)	[redacted]	[redacted]0	[redacted]1
Pb (%)	[redacted]	[redacted]1	[redacted]5
Ba (%)	15.3	2.3	12.7
SiO2 (%)	n/a	19.3	n/a
LG & MG Ore	1,391,373	75,600	1,466,973
Total Waste	3,516,286	2,611,922	6,128,208
SR	1.05	3.04	1.45

1.4. Equipment Fleets

The oldest haul truck (77-07) and the oldest loader (92-07) in the fleet will remain in service until the end of 2018, and then will be decommissioned. Two new trucks will be commissioned in Q3 2019. Two old trucks will be decommissioned, one when the new trucks join the fleet, and the other at the end of 2019. The 2019 equipment schedule is shown in Table 1.4-1.

Table 1.4-1 2019 Equipment Schedule

Equipment	Description	Q1	Q2	Q3	Q4
Drills	DML	3	3	3	3
Trucks	777	10	10	10	11
Loaders	992/993	5	5	5	5
Dozers	D9/D10	4	4	4	4

1.5. Risks and Opportunities

Risks

1) Aqqaluk Pit Highwall Stability
2) Qanaiyaq Summer Production
3) Main Pit Dump (MPD) Stability
4) Selenium (Se) Leaching
5) Low Fleet Availabilities
6) Ammonia Levels in Main Pit Water Reservoir (MPWR)

Opportunities

1) Mobile Equipment Monitoring
2) Haul Road and Pit Bench Maintenance

1.6. Project Lists

Pit Dewatering

1) Aqqaluk Pit Dewatering
2) Qanaiyaq Pit Dewatering

Environmental Related Projects

1) Fugitive Dust Control

Other Projects

1) Aqqaluk South Wall Seepage Mitigation
2) DD2 Development
3) Qanaiyaq Haul Road Realignment
4) West Tails Road Realignment

Project Support

1) Stage IV Back Dam Construction
2) Crushing
3) Reclaim Barge Raise

SECTION 2. MINE PLANNING PARAMETERS

Red Dog's ability to blend its highly variable run-of-mine zinc grade into stockpiles with a consistent feed grade (± 1% Zn) has been essential to optimizing concentrate production. The challenge for short-range mine planners is to create an achievable mine plan utilizing a variety of zinc and lead grades to aid stockpile blending. The following assumptions, standards, and methods have been applied to the 2019 One Year Mine Plan.

2.1. Tonnage and Shot Calculations

With MineSight Interactive Planner (MSIP), Red Dog Engineering has divided and sequenced the 5-Year Mine Plan into mineable drill patterns for 2019. Beginning with the predicted 2018 end-of-year topography, shot boundaries ("cuts") were scheduled into a reasonable mining sequence based on ore grades, required waste stripping and haulage access. These cuts are also generated to achieve the designed pit phases. Once the mining sequence was determined, production was reported based on the block model and the scheduled cut geometries.

The 2019 One Year Mine Plan is based on the RED2017-A and QAN2012-O models (both issued in February 2018). Relevant grade items used for planning include:

- STZN – Zinc % based on diamond drill hole core
- STPB – Lead % based on diamond drill hole core
- STFE – Iron % based on diamond drill hole core
- STBA – Barium % based on diamond drill hole core
- TOC – Total organic carbon based on diamond drill hole core
- SiO_2 – Calculated silica value

In addition to interpolated geologic information, the model also stores calculated data to value each block and to estimate recoveries for planning purposes. To balance Red Dog's polymetallic deposit, Red Dog's ore/waste cutoff is based on value (net smelter recovery) per second. Value is defined as the amount of revenue generated by the recoverable metal produced per second of mill operating time. Teck's long-range price forecast (February 2018) was utilized in determining the estimated revenue per block. Price assumptions include:

- Zinc - $1.10/lb.
- Lead - $0.90/lb.
- Silver - $20.00/tr. oz.

Along with mill recoveries (calculated from historical geologic and mill data), the reserve prices are used to code each block in the model with a value per tonne. For each block in the block model, the site breakeven cost is subtracted from the Net Smelter Return (NSR) to determine the net value per tonne. This is then multiplied by the throughput to calculate the net value per second, which is used as the basis for the mine cutoffs. For the Two Year Mine Plan, the operating cutoff is $[redacted]5/s for High Grade Ore, and $[redacted]00/s for Medium Grade Ore. All blocks whose value exceeds the High Grade operating cutoff cost are tagged as Mill Feed for the plan. Of the remaining blocks, those whose value exceeds the breakeven (or mill) cutoff are tagged as Low Grade Ore. Low Grade Possibly Reactive (LG-PR) Ore above a $[redacted]0/s cutoff is classified as High Grade Ore, and below this cutoff is classified as waste. As of 2015, the Non-Reactive classified fraction of the Low Grade Ore is being stockpiled separately at the north end of the

MWD for potential milling at the end of mine. Beginning in 2019, Medium Grade Ore will be stockpiled on the Methanol Pad for future milling. Remaining blocks are considered waste.

In addition to the ore and waste tonnages, the MineSight Interactive Planner reports % zinc, % lead, silver ounces per ton, % iron, % barium, total organic carbon, silica, and calculated mill recoveries for each cut. The cuts, their geologic data, and their recoveries are compiled and used to design stockpiles and estimate mill output.

2.2. Waste Segregation Criteria

In order to select the disposal method required for waste material, waste rock is further classified as Non-Reactive (NR) or Possibly Reactive (PR). Waste with a Self-Heating Capacity (SHC) risk of four or below is considered NR whereas waste with a SHC risk of five or above is considered PR.

The current procedure for handling PR waste rock requires placing, whenever possible, into dump lifts at or below the planned closure water elevation of excavated open pits. Currently only the Main Pit is available. As the closure water level is planned at the 850 ***ft.*** elevation, PR waste would be placed into the 850' lift subzones for as long as these remained unfilled. The possibility will exist in the future to dump PR waste into pit closure water level dump lifts in the Aqqaluk and Qanaiyaq Pits. However, the designs for these pits and modeling of their hydrological regimes are still ongoing.

2.3. Stockpile and Mill Criteria

Historical experience building blended stockpiles from Red Dog's Main Pit deposit created a workable standard to optimize the deposit's highly rich and variable zinc grades. Once the cuts are run against the models, they are ordered and sequenced to be both mineable and blended to meet predetermined stockpile criteria. Optimizing mill feed requires blending weathered, baritic and siliceous ore types from both the Aqqaluk and Qanaiyaq deposits into stockpiles that meet the criteria set forth by the mill.

Ore cuts are sequenced and organized into roughly 190 kt stockpiles that are built in seven lifts on the crusher pad. The stockpiles are designed such that the lifts, when mined in strips across the face, create a relatively consistent feed grade profile (Figure 2.3-1). Currently, a stockpile should meet the following requirements to optimize mill throughput and recoveries, listed roughly in order of importance (Revision 19: February 2, 2018):

- Stockpile average +/- 1.0% Zn quarter average
- Barite: as close to quarter avg as possible and >= 9%
- Zinc/Iron ratio: as close to quarter avg. as possible and >= 2.0
- TOC: <= 0.50%
- Soluble Pb <[redacted]%
- Type 5 <[redacted]%; Type 8 <[redacted]
- Qanaiyaq weathered ore < 15% total ore feed
- Qanaiyaq ore < 30% total ore feed

Mill feed for the 2019 One Year Mine Plan is planned from the Aqqaluk and Qanaiyaq deposits.

When building blended stockpiles it is preferred to free dump the coarser, often higher grade ore, on the odd numbered lifts as it has a higher angle of repose in truck dumped piles (Figure 2.3-1, blue). The finer, more variable sized rock (typically lower grade, baritic ores) is positioned on the even numbered dozed lifts. This blending concept is adjusted as production blast hole assays and pit progression drives

stockpile planning. The mine plan attempts to create a sequence that reflects the separation and recovery efforts of Ore Control and Mine Operations.

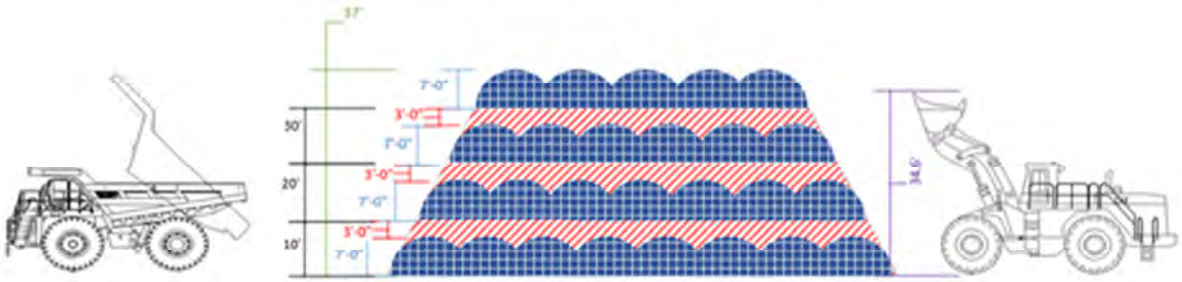


Figure 2.3-1 Ideal Stockpile Lift Sequence

The historical data comparison between mine stockpile release and actual mill feed (dry mass-balanced data from the Gencid 480 report) from January 2017 to December 2018 is shown in Table 2.3-1.

Table 2.3-1 Historical Stockpile Comparison (January 2017 to December 2018)

Stockpile	Stockpile Release					480 Mass Balance Report					Variance				
	Tonnes	Zn	Pb	Fe	Ba	Tonnes	Zn	Pb	Fe	Ba	Tonnes	Zn	Pb	Fe	Ba
484	163,997	[redacted]	[redacted]	[redacted]	[redacted]	172,370	[redacted]	[redacted]	[redacted]	11.4	(8,373)	1.3%	-6.8%	-8.0%	26.9%
485	172,691	[redacted]	[redacted]	[redacted]	[redacted]	160,148	[redacted]	[redacted]	[redacted]	12.1	12,543	-1.7%	-7.3%	-8.9%	0.1%
486	168,708	[redacted]	[redacted]	[redacted]	[redacted]	149,800	[redacted]	[redacted]	5.9	11	18,908	2.4%	1.7%	-1.7%	6.5%
487	172,287	[redacted]	[redacted]	[redacted]	[redacted]	161,566	[redacted]	[redacted]	[redacted]	11.2	10,721	-5.5%	6.4%	-11.6%	13.2%
488	162,401	[redacted]	[redacted]	[redacted]	[redacted]	130,250	[redacted]	[redacted]	[redacted]	12.4	32,151	-11.5%	-5.4%	-1.4%	4.9%
489	157,052	[redacted]	[redacted]	[redacted]	[redacted]	177,919	[redacted]	[redacted]	[redacted]	12.5	(20,867)	3.9%	3.0%	-4.4%	-1.7%
490	161,683	[redacted]	[redacted]	[redacted]	[redacted]	164,872	[redacted]	[redacted]	[redacted]	15.1	(3,189)	2.0%	3.1%	1.5%	-8.0%
491	165,303	[redacted]	[redacted]	[redacted]	[redacted]	159,501	[redacted]	[redacted]	4.7	14.8	5,802	0.0%	1.4%	-3.5%	7.6%
492	161,965	[redacted]	[redacted]	[redacted]	12.5	213,254	[redacted]	[redacted]	6.4	13	(51,289)	0.6%	1.5%	4.1%	-3.6%
493	163,026	[redacted]	[redacted]	[redacted]	12.0	163,359	[redacted]	[redacted]	7.7	13.1	(333)	2.4%	6.1%	1.5%	-9.2%
494	190,174	[redacted]	[redacted]	[redacted]	15.9	199,127	[redacted]	[redacted]	7.3	16.1	(8,953)	3.2%	2.8%	1.6%	-1.5%
495	178,063	[redacted]	[redacted]	[redacted]	14.3	178,220	[redacted]	[redacted]	8.2	13.6	(157)	-2.2%	-2.3%	-11.7%	4.8%
496	193,659	[redacted]	[redacted]	[redacted]	14.3	172,587	[redacted]	[redacted]	7.5	14.1	21,072	-0.7%	-2.3%	-11.9%	1.6%
497	183,835	[redacted]	[redacted]	[redacted]	14.5	173,949	[redacted]	[redacted]	6.8	15.8	9,886	6.0%	2.0%	-8.4%	-8.7%
498	197,261	[redacted]	[redacted]	[redacted]	10.8	192,289	[redacted]	[redacted]	7.6	11.7	4,972	-4.4%	-1.2%	-7.3%	-7.9%
499	199,641	[redacted]	[redacted]	[redacted]	10.1	207,396	[redacted]	[redacted]	8.3	14	(7,755)	-0.6%	-3.2%	-7.0%	-38.0%
500	174,181	[redacted]	[redacted]	[redacted]	10.6	169,726	[redacted]	[redacted]	5.9	11.6	4,455	8.7%	8.4%	0.1%	-9.5%
501	187,779	[redacted]	[redacted]	[redacted]	13.6	179,089	[redacted]	[redacted]	4.5	14.1	8,690	7.4%	10.4%	-1.5%	-3.8%
502	203,246	[redacted]	[redacted]	[redacted]	12.1	227,520	[redacted]	[redacted]	6.1	16.2	(24,274)	-1.7%	-9.7%	-3.9%	-33.9%
503	188,134	[redacted]	[redacted]	[redacted]	11.0	209,829	[redacted]	[redacted]	6.7	12.4	(21,695)	-3.3%	-13.5%	-8.0%	-12.9%
504	184,835	[redacted]	[redacted]	[redacted]	9.2	203,375	[redacted]	[redacted]	7.4	9.4	(18,540)	10.9%	2.2%	-7.7%	-2.4%
505	200,754	[redacted]	[redacted]	[redacted]	11.4	198,853	[redacted]	[redacted]	7.8	11.7	1,901	5.1%	4.0%	-5.8%	-2.9%
506	185,381	[redacted]	[redacted]	[redacted]	12.4	190,769	[redacted]	[redacted]	7.1	12.9	(5,388)	7.3%	1.0%	-8.2%	-4.4%
507	169,905	[redacted]	[redacted]	6.1	12.8	161,957	[redacted]	[redacted]	6.6	13.6	7,948	5.6%	5.6%	-9.0%	-5.9%
508	191,942	[redacted]	[redacted]	7.0	12.4	180,652	[redacted]	[redacted]	7.2	12.9	11,290	6.0%	0.2%	-3.3%	-4.2%
509	177,820	[redacted]	[redacted]	5.3	14.4	186,039	[redacted]	[redacted]	5.9	14.1	(8,219)	3.0%	-0.4%	-11.9%	2.0%
510	143,023	[redacted]	[redacted]	4.0	13.3	142,140	[redacted]	[redacted]	4.9	12.8	883	3.4%	-1.1%	-21.1%	3.9%
511	180,413	[redacted]	[redacted]	4.7	11.9	149,418	[redacted]	[redacted]	4.8	11.9	30,995	3.1%	2.4%	-2.2%	0.2%
512	186,982	[redacted]	[redacted]	5.8	12.9	177,543	[redacted]	[redacted]	5.8	12	9,439	5.2%	3.2%	-0.2%	6.9%
513	184,761	[redacted]	[redacted]	7.9	11.9	179,581	[redacted]	[redacted]	8.3	12.9	5,180	4.9%	4.8%	-4.6%	-8.6%
514	185,416	[redacted]	[redacted]	6.1	13.0	180,829	[redacted]	[redacted]	6.2	14.5	4,587	7.3%	3.2%	-1.3%	-11.5%
515	184,392	[redacted]	[redacted]	6.3	11.8	179,806	[redacted]	[redacted]	6.5	12.1	4,586	9.2%	0.0%	-3.2%	-2.5%
516	205,371	[redacted]	[redacted]	5.7	12.9	210,813	[redacted]	[redacted]	5.7	12.7	(5,442)	4.4%	0.0%	0.0%	1.6%
517	188,270	[redacted]	[redacted]	6.9	12.7	198,775	[redacted]	[redacted]	6.4	13.6	(10,505)	7.4%	-1.9%	7.2%	-7.3%
518	191,186	[redacted]	[redacted]	5.2	13.6	186,372	[redacted]	[redacted]	4.9	13.9	4,814	3.4%	2.1%	5.7%	-1.9%
519	193,489	[redacted]	[redacted]	5.2	14.0	178,667	[redacted]	[redacted]	4.7	13.4	14,822	6.6%	5.6%	10.5%	4.5%
520	203,978	[redacted]	[redacted]	5.2	13.9	199,578	[redacted]	[redacted]	5.1	1.9	4,400	-3.2%	2.7%	2.6%	86.3%
521	197,632	[redacted]	[redacted]	4.0	14.3	177,760	[redacted]	[redacted]	4	1.9	19,872	9.6%	10.7%	0.0%	86.7%
522	190,079	[redacted]	[redacted]	5.1	14.1	188,648	[redacted]	[redacted]	4.7	1.9	1,431	12.4%	30.4%	7.6%	86.6%
523	177,938	[redacted]	[redacted]	5.7	12.3	189,648	[redacted]	[redacted]	5	1.9	(11,710)	0.5%	32.5%	11.7%	84.6%
524	204,829	[redacted]	[redacted]	6.5	10.8	195,697	[redacted]	[redacted]	6.1	1.9	9,132	4.0%	9.3%	6.0%	82.4%
525	181,380	[redacted]	[redacted]	4.3	12.7	209,255	[redacted]	[redacted]	4.7	1.9	(27,875)	4.1%	2.5%	-8.6%	85.0%
526	184,038	[redacted]	[redacted]	5.0	12.8	201,273	[redacted]	[redacted]	5.3	1.9	(17,235)	-1.1%	-7.2%	-5.6%	85.2%
527	184,959	[redacted]	[redacted]	5.3	15.6	169,330	[redacted]	[redacted]	5.3	16.1	15,629	1.9%	-7.0%	0.7%	-3.0%
528	207,064	[redacted]	[redacted]	[redacted]	[redacted]	214,309	[redacted]	[redacted]	4.7	17.8	(7,245)	8.6%	2.6%	8.3%	-13.4%
529	187,867	[redacted]	[redacted]	5.6	15.7	222,962	[redacted]	[redacted]	5.1	14.9	(35,095)	2.7%	-1.2%	9.0%	4.9%
SUBTOTALS	8,418,789	[redacted]	[redacted]	6.0	13.0	8,436,820	[redacted]	[redacted]	6.2	11.5	(18,031)	3.1%	2.2%	-2.3%	10.7%

Equipment Operating Metrics

Physical availability (A) is calculated as:

$$\%\ Availability = \frac{Total\ Hrs.in\ Period - Maintenance\ Hrs.}{Total\ Hrs.in\ Period}$$

Use of Availability (UA) or Utilization is calculated as:

$$\%\ Use\ of\ Availability = \frac{Total\ Hrs.\ \ in\ period - Maintenance\ Hrs. - Standby\ Hrs.}{Total\ Hrs.in\ Period - Maintenance\ Hrs.}$$

Operating Efficiency (OE) is calculated as:

$$\%\ Operating\ Efficiency = \frac{Total\ Hrs.\ \ in\ period - Maintenance\ Hrs. - Standby\ Hrs. - Delay\ Hrs.}{Total\ Hrs.in\ Period - Maintenance\ Hrs. - Standby\ Hrs.}$$

Asset Utilization (AU) is calculated as:

$$\%\ Asset\ Utilization = \%\ Availability\ x\ \%\ Use\ of\ Availability\ x\ \%\ Operating\ Efficiency$$

Production hours are calculated as:

$$Production\ Hrs. = Total\ Hrs.\ \ in\ Period\ \times \%\ Asset\ Utilization$$

The current mine fleet operating metrics for 2018 year-to-date as of October 31st are listed in Table 2.4-1.

Table 0-1 Current Fleet Operating Metrics

Equipment	Description	Units Available	Physical Availability	Use of Availability	Operating Efficiency	Asset Utilization
Drills	DML	3	82.1%	60.2%	76.4%	37.8%
Trucks	777	11	73.3%	81.8%	84.2%	50.5%
Loaders	993/992	6	61.8%	75.9%	88.2%	41.4%
Dozers	D9/D10	4	79.6%	54.0%	100.0%	43.0%

2.4. Haul Cycle and Production Assumptions

Total production is based on the haul truck hours available per year and productivity per hour for each material to be moved. Productivities per hour for ore, waste and reclaim are calculated from the weighted average haul times from Wenco and target tonnages for each material.

Currently Red Dog has a fleet of four 777D, five 777F and two 777G CAT haul trucks available for haulage duty. These trucks are rated at 91 tonnes (100 short tons). Truck capacity based on material and deposit is shown in Table 2.5-1.

Table 2.4-1 Truck Capacity by Material (tonnes/load)

Model	Units	SP Reclaim		Ore		Waste	
		Aqqaluk	Qanaiyaq	Aqqaluk	Qanaiyaq	Aqqaluk	Qanaiyaq
777D/F/G	tonnes/load	90	90	90	90	85	85

The truck capacity and the average haul cycle time are used to determine the average productivity (tonnes/hour) for ore and waste production in the Aqqaluk and Qanaiyaq pits and for hauling stockpiled ore to the crusher. The productivity is calculated as:

$$Productivity = \frac{Payload\ (mt)}{average\ haul\ cycle\ (hrs.)}$$

Productivities for other equipment are based on historic data and are summarized in Table 2.5-2. The respective productivities are divided by the scheduled tonnes per period and the required operating hours compiled by fleet.

Table 2.4-2 Loader, Drill, and Dozer Productivities

	Productivity (tonnes/operating hour)				
Equipment	Ore	SP Reclaim	COSP	Marginal Ore	Waste
993 Loader	869	869	-	-	869
DM-L Drill	1,078	-	-	1,078	1,748
D9/D10 dozer	8,730	2,493	5,180	-	1,412

SECTION 3. MINE PRODUCTION

3.1. Overview

The 2019 One Year Mine Plan production is divided into nine material classes: High Grade Ore (Mill Feed), Non-Reactive Low Grade Ore, Possibly Reactive Low Grade Ore, Possibly Reactive Waste, Non-Reactive Waste, Construction Rock, Cover Rock, Non-Sulphide Ore, and Weathered High Copper Ore. The plan assumes all production is from the Aqqaluk and Qanaiyaq Pits. Waste will primarily backfill the Main Pit, though a significant amount of non-mineralized material will also be stockpiled on the Main Waste Dump for future reclamation. Ore production for the plan is forecast to meet or exceed the ore required to produce the forecasted zinc metal tonnes in the 2018 LOM Plan. The average mill throughput is 531 tonnes per operating hour. Attaining an average throughput above 531 tpoh requires feeding material that is planned for stockpiling, and will result in a reduction of average mill feed grades.

3.2. 2019 Mine Schedule

In 2019, the plan currently schedules 11,813 kt total mine production from Aqqaluk Pit and Qanaiyaq Pit as shown in Table 3.2-1. Of the total High Grade Ore production (4,218 kt at [redacted]% Zn and [redacted]% Pb), the Aqqaluk Pit contributes 79.6% and the Qanaiyaq Pit 20.4%. Non-Reactive Low Grade Ore production is estimated at 804 kt and Medium Grade Ore production at 663 kt. Waste production is estimated at 6,128 kt, which includes 333 kt of Possibly Reactive Low Grade Ore, 110 kt of Non-Sulphide Ore, 272 kt of Possibly Reactive Waste, 4,963 kt of Non-reactive Waste, 0 kt of Construction Rock, 297 kt of Cover Rock, and 153 kt of Weathered High Copper Ore (Table 3.2-2).

Table 3.2-1 2019 Summary

2019	Aqqaluk Pit	Qanaiyaq Pit	Total
Total (tonne)	8,267,201	3,546,274	11,813,475
HG Ore (tonne)	3,359,542	858,752	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
Pb (%)	[redacted]	[redacted]	[redacted]
Ba (%)	[redacted]	[redacted]	[redacted]
SiO2 (%)	n/a	19.3	n/a
LG & MG Ore	1,391,373	75,600	1,466,973
Total Waste	3,516,286	2,611,922	6,128,208
SR	1.05	3.04	1.45

The average monthly ore production is 352 kt for 2019 (compared with 338 kt for 2017). The monthly waste production averages are:

- 490 kt in Quarter 1, 2019
- 479 kt in Quarter 2, 2019
- 554 kt in Quarter 3, 2019
- 520 kt in Quarter 4, 2019

The monthly One Year Mine Plan summary for 2019 is shown in Table 3.2-2.

The quarterly One Year Mine Plan summary for 2019 is shown in Table 3.2-3.

Table 3.2-2 2019 Monthly Summary

Mine Plan Production Schedule -Total

		2019												
Description / Activity	**Units**	**M01**	**M02**	**M03**	**M04**	**M05**	**M06**	**M07**	**M08**	**M09**	**M10**	**M11**	**M12**	**2019 Total**
Days	Days	31	28	31	30	31	30	31	31	30	31	30	31	365
Mine Production Summary														
Ore														
High Grade	t	**355,895**	**320,550**	**317,044**	**338,775**	**344,437**	**348,792**	**361,965**	**370,339**	**370,085**	**361,309**	**365,045**	**364,058**	**4,218,294**
Medium Grade	t	141,196	22,096	23,234	104,607	4,696	1,171	48,416	45,118	124,998	52,660	75,165	20,086	663,443
Low Grade - Non-reactive	t	81,070	2,723	9,383	119,550	55	29,720	69,664	109,065	97,087	12,567	28,082	244,564	803,530
Total Ore	t	578,161	345,369	349,661	562,932	349,188	379,683	480,045	524,522	592,170	426,536	468,292	628,708	5,685,267
Waste														
Low Grade - Possibly Reactive	t	5,326	-	-	18,852	34,199	-	113,299	22,804	23,129	71,074	34,260	10,510	333,453
Non-sulphide Ore	t	-	-	42,889	49	8,720	14,387	-	-	-	-	6,517	37,180	109,742
Waste - Possibly Reactive	t	6,684	366	25,762	8,274	57,232	2,071	51,476	25,977	-	7,693	83,857	2,819	272,211
Waste - Non-reactive	t	394,709	519,786	426,200	250,461	440,357	416,496	392,049	442,027	381,661	439,902	463,620	396,030	4,963,298
Waste - Construction	t	-	-	-	-	-	-	-	-	-	-	-	-	-
Waste - Cover	t	21,072	-	-	35,909	-	120,937	-	119,057	8	-	-	-	296,983
Weathered High Zn-Cu	t	3,519	15,702	7,555	23,909	-	4,410	11,013	26,483	52,475	7,351	68	36	152,521
Total Waste	t	431,310	535,854	502,406	337,454	540,508	558,301	567,837	636,348	457,273	526,020	588,322	446,575	6,128,208
Waste/Mill Feed Ratio	-	1.21	1.67	1.58	1.00	1.57	1.60	1.57	1.72	1.24	1.46	1.61	1.23	***1.45***
Total Mine Production	t	**1,009,471**	**881,223**	**852,067**	**900,386**	**889,696**	**937,984**	**1,047,882**	**1,160,870**	**1,049,443**	**952,556**	**1,056,614**	**1,075,283**	**11,813,475**
% Qanaiyaq Mined	%	**19.6%**	**21.7%**	**22.4%**	**22.5%**	**22.2%**	**20.1%**	**19.6%**	**18.2%**	**17.8%**	**21.8%**	**18.3%**	**20.8%**	**20.4%**
% Qanaiyaq Weathered Mined	%	**12.8%**	**13.7%**	**16.1%**	**16.7%**	**10.5%**	**4.3%**	**14.0%**	**2.4%**	**5.2%**	**7.3%**	**12.0%**	**11.5%**	**10.4%**
Production by Pit Phase														
A1	t	-	-	-	-	-	-	-	-	-	-	-	-	-
A2	t	109,066	145,878	145,881	162,212	188,035	163,833	153,516	58,146	83,150	48,760	124,477	133,521	1,516,475
A3	t	429,661	212,867	138,342	261,962	84,623	251,394	376,240	621,064	590,102	464,349	511,213	525,249	4,467,066
A4	t	232,325	112,227	152,327	223,343	232,925	345,256	174,038	266,714	196,576	143,050	130,857	74,022	2,283,660
Q1	t	238,419	410,251	294,280	252,869	384,113	177,501	344,088	214,946	179,615	296,397	290,067	342,491	3,425,037
Q2	t	-	-	121,237	-	-	-	-	-	-	-	-	-	121,237

Table 3.2-3 2019 Quarterly Summary

Mine Plan Production Schedule -Total (by QTR)

		2019				
Description / Activity	**Units**	**Q1**	**Q2**	**Q3**	**Q4**	**Total**
Days	Days	90	91	92	92	365
Mine Production Summary						
Ore						
High Grade	**t**	**993,489**	**1,032,004**	**1,102,389**	**1,090,412**	**4,218,294**
Medium Grade	t	186,526	110,474	218,532	147,911	663,443
Low Grade - Non-reactive	t	93,176	149,325	275,816	285,213	803,530
Total Ore	t	1,273,191	1,291,803	1,596,737	1,523,536	5,685,267
Waste						
Low Grade - Possibly Reactive	t	5,326	53,051	159,232	115,844	333,453
Non-sulphide Ore	t	42,889	23,156	-	43,697	109,742
Waste - Possibly Reactive	t	32,812	67,577	77,453	94,369	272,211
Waste - Non-reactive	t	1,340,695	1,107,314	1,215,737	1,299,552	4,963,298
Waste - Construction	t	-	-	-	-	-
Waste - Cover	t	21,072	156,846	119,065	-	296,983
Weathered High Zn-Cu	t	26,776	28,319	89,971	7,455	152,521
Total Waste	t	1,469,570	1,436,263	1,661,458	1,560,917	6,128,208
Waste/Mill Feed Ratio	-	1.48	1.39	1.51	1.43	***1.45***
Total Mine Production	t	**2,742,761**	**2,728,066**	**3,258,195**	**3,084,453**	**11,813,475**
% Qanaiyaq Milled	%	**21.2%**	**21.6%**	**18.5%**	**20.3%**	**20.4%**
% Qanaiyaq Weathered Milled	%	**14.2%**	**10.4%**	**7.1%**	**10.3%**	**10.4%**
Production by Pit Phase						
AQQ PH1	t	-	-	-	-	-
AQQ PH2	t	400,825	514,080	294,812	306,758	1,516,475
AQQ PH3	t	780,870	597,979	1,587,406	1,500,811	4,467,066
AQQ PH4	t	496,879	801,524	637,328	347,929	2,283,660
QAN Q1	t	942,950	814,483	738,649	928,955	3,425,037
QAN Q2	t	121,237	-	-	-	121,237

3.2.1. Phases and Benches Mined

There are four phases in the Aqqaluk Pit, starting at the highest grade pit (A1) and ending at the ultimate pit (A4). There are two phases in the Qanaiyaq Pit, the starter (Q1) and the ultimate pit (Q2).

A summary of the benches mined by month for 2019 is shown in Table 3.2-4. A graphical summary of all the phases by material type by month for 2019 is shown in Figure 3.2-1.

Total materials mined for 2019:

- 0.0% is mined from AQQ A1,
- 12.8% is mined from AQQ A2,
- 37.8% is mined from AQQ A3,
- 19.3% is mined from AQQ A4,
- 29.0% is mined from QAN Q1,
- 1.0% is mined from QAN Q2.

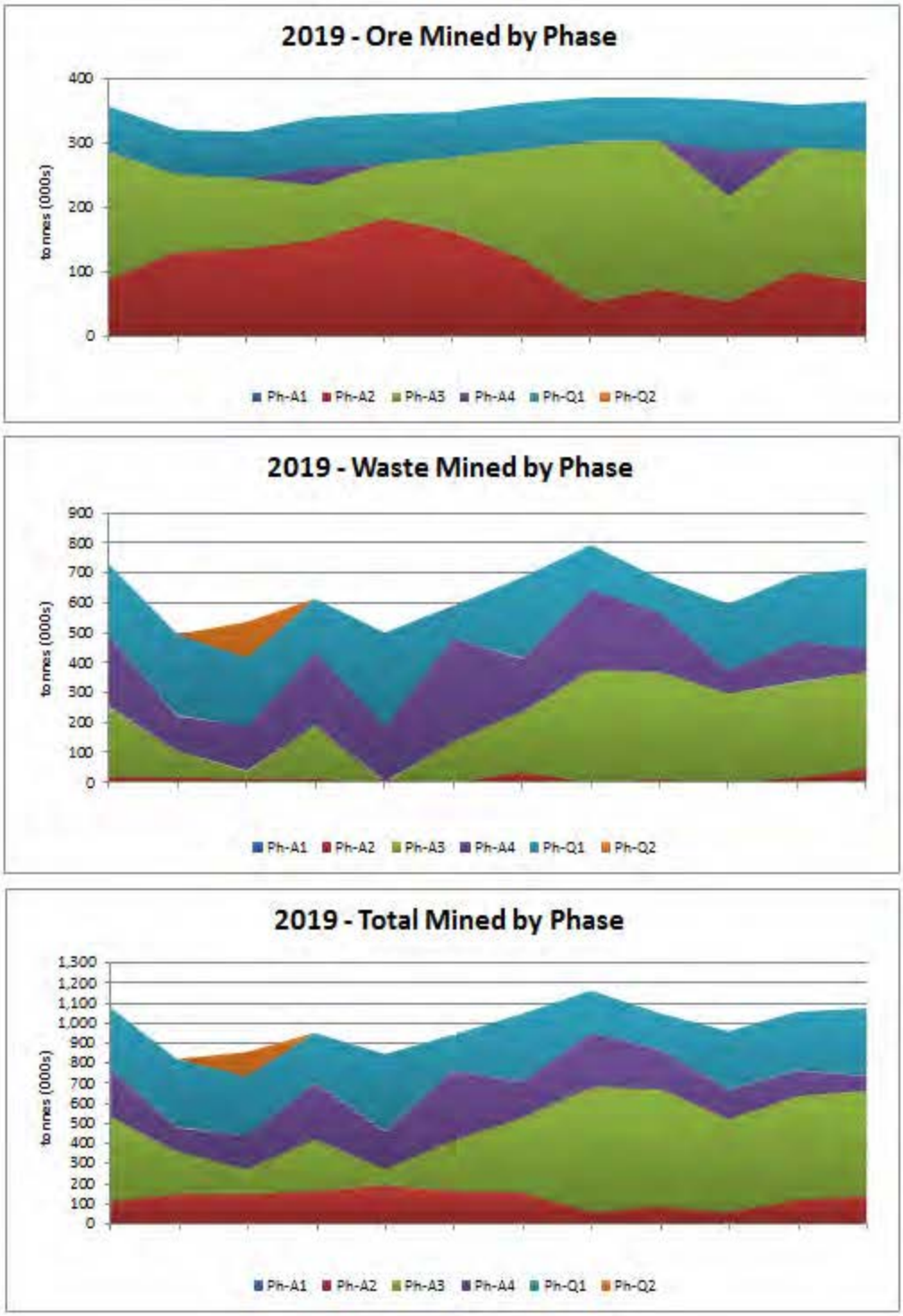
Table 3.2-4 2019 Monthly Material Mined by Benches

2019

Bench	Aqqaluk (kt)												
	M01	M02	M03	M04	M05	M06	M07	M08	M09	M10	M11	M12	Total
1150						124							124
1125								127	133				260
1100													
1075													
1050													
1025													
1000													
975	232	113	158	93									596
950				188	183	224							594
925							174	140	63	143			520
900	167										157	74	397
875	263	212	133	255	85	114	210	158	84				1,513
850						107	143	371	325	61	114	72	1,194
825						30	58	98	193	403	315		1,096
800	49	52									83	502	686
775		50	95	126									271
750					157	53							211
725						108	47						155
700							72	52	38				163
675									34	49	57		139
650											42	84	126
625	60	43	51	36	31								222
Total	771	471	437	698	456	760	704	946	870	656	767	733	8,045

Bench	Qanaiyaq (kt)												
	M01	M02	M03	M04	M05	M06	M07	M08	M09	M10	M11	M12	Total
1475			121										121
1450													
1425													
1400													
1375													
1350													
1325													
1300													
1275		267		74									341
1250	308	73	137	73	333		222	136	5				1,286
1225			158	106	51	178	123	79	175	296	290	199	1,654
1200												143	143
1175													
Total	308	340	416	253	384	178	344	215	180	296	290	342	3,546

Figure 3.2-1 2019 Material Mined by Phase



3.2.2. Material Movement Classification

Material mined is classified as ore (mill feed), low-grade ore (non-reactive and possibly reactive), possibly reactive waste, non-reactive waste, construction rock and cover rock. Figure 3.2-2 shows the material mined by class by month. Figure 3.2-3 shows the total material moved by destination (stockpile and waste dump) by month.

Figure 3.2-2 2019 Material Mined by Class

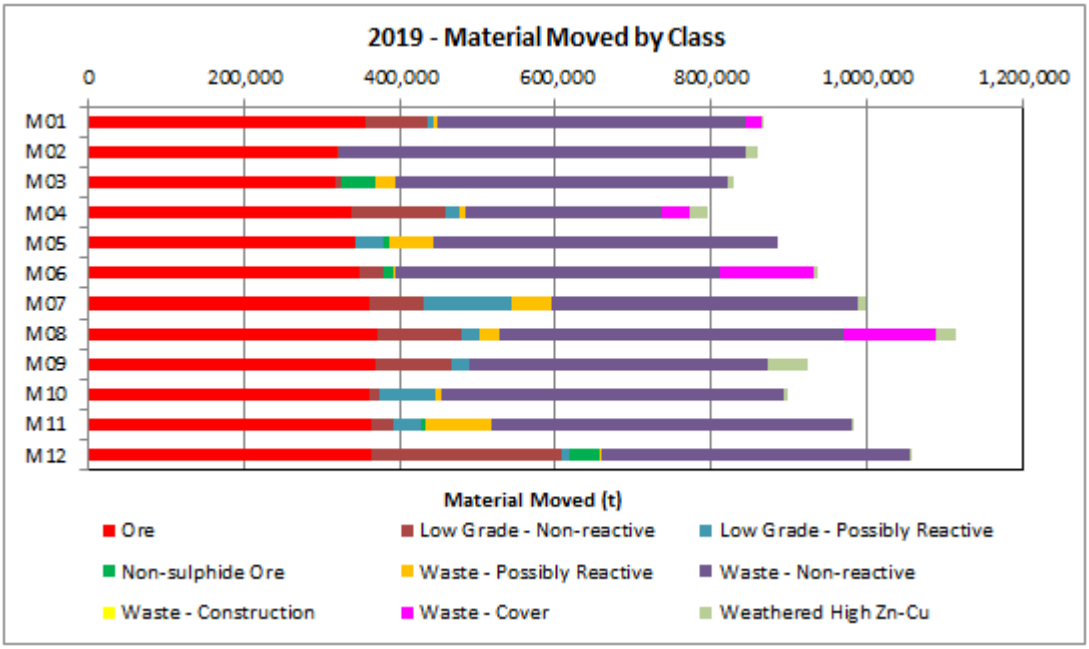
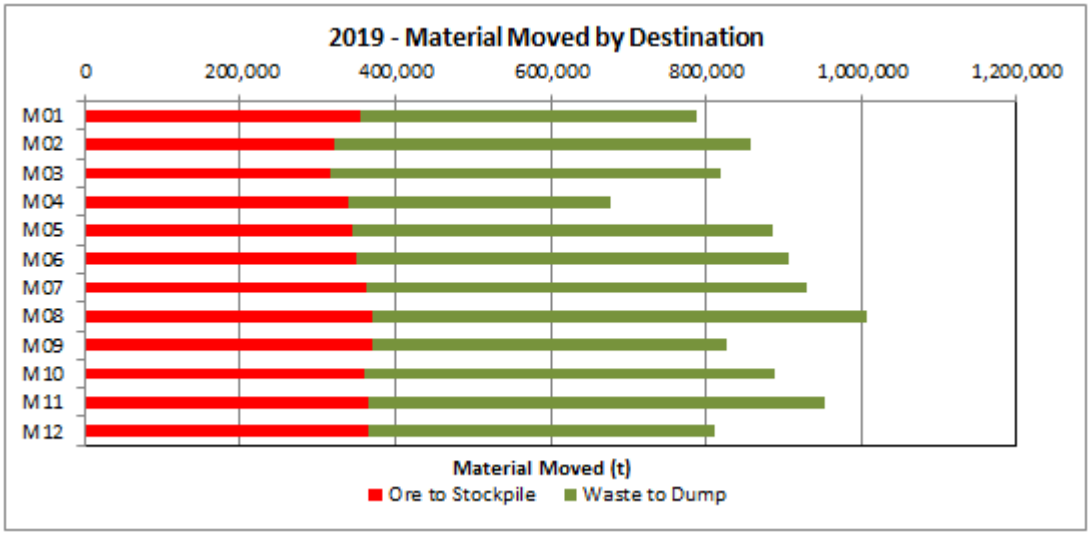


Figure 3.2-3 2019 Material Mined by Destination



3.2.3. Monthly Plans

3.2.3.1. 2019 1st Quarter

Total production is 2,743 kt for the 1st quarter of 2019. Total ore production is 1,273 kt and total waste production is 1,470 kt. Table 3.2-5 gives the 2019 1st quarter mine schedule. Monthly pit progression maps are located in Appendix 7.1.

January 2019
Total January mine production is 1,009 kt. High Grade Ore production is 356 kt at [redacted]% Zn and [redacted]% Pb.

February 2019
Total February mine production is 881 kt. High Grade Ore production is 321 kt at [redacted]% Zn and [redacted]% Pb.

March 2019
Total March mine production is 852 kt. High Grade Ore production is 317 kt at [redacted]% Zn and [redacted]% Pb.

Table 3.2-5 2019 1st Quarter Mine Schedule (by Cuts)

2019 Q1	Prediction			Jan-19			Feb-19			Mar-19		
	Ore	Waste	Total	Ore	Waste	Total	Ore	Waste	Total	Ore	Waste	Total
Total Production	1,273,191	1,469,570	2,742,761	355,895	653,576	1,009,471	320,550	560,673	881,223	317,044	535,023	852,067
A625-104	60,369	0	60,369	60,369	0	60,369						
A800-225	27,591	21,066	48,657	27,591	21,066	48,657						
A875-387	5,765	61,829	67,594	5,765	61,829	67,594						
A875-388a	61,669	8,503	70,172	61,669	8,503	70,172						
A875-391	37,516	34,954	72,470	37,516	34,954	72,470						
A875-394	32,664	20,259	52,923	32,664	20,259	52,923						
A900-391	44,689	42,163	86,852	44,689	42,163	86,852						
A900-392	15,705	63,985	79,690	15,705	63,985	79,690						
A975-286	0	232,325	232,325	0	232,325	232,325						
Q1250-500Ramp	47	17,053	17,100	47	17,053	17,100						
Q1250-520	38,175	18,396	56,571	38,175	18,396	56,571						
Q1250-522a	31,705	37,569	69,274	31,705	37,569	69,274						
Q1250-533	0	95,474	95,474	0	95,474	95,474						
Q1250-533	0	70,000	70,000				0	70,000	70,000			
A625-105	40,932	2,474	43,406				40,932	2,474	43,406			
A775-181	50,179	0	50,179				50,179	0	50,179			
A800-224	38,781	13,512	52,293				38,781	13,512	52,293			
A875-383Ramp	0	18,994	18,994				0	18,994	18,994			
A875-388b	16,667	3,429	20,096				16,667	3,429	20,096			
A875-389	72,301	1,002	73,303				72,301	1,002	73,303			
A875-396	21,981	68,127	90,108				21,981	68,127	90,108			
A975-287	0	112,593	112,593				0	112,593	112,593			
Q1250-522b	21,674	0	21,674				21,674	0	21,674			
Q1250-523a	31,535	3,124	34,659				31,535	3,124	34,659			
Q1275-500Ramp	0	28,250	28,250				0	28,250	28,250			
Q1275-532	0	98,568	98,568				0	98,568	98,568			
Q1275-533	0	42,545	42,545				0	42,545	42,545			
Q1275-534	0	46,517	46,517				0	46,517	46,517			
Q1275-535	0	51,538	51,538				0	51,538	51,538			
A875-391	10,000	0	10,000				10,000	0	10,000			
Q1250-520	16,500	0	16,500				16,500	0	16,500			
A625-106	41,702	9,376	51,078							41,702	9,376	51,078
A775-182	43,686	0	43,686							43,686	0	43,686
A775-183	49,515	1,602	51,117							49,515	1,602	51,117
A875-390	101,042	21,632	122,674							101,042	21,632	122,674
A975-288	0	75,174	75,174							0	75,174	75,174
A975-290	0	82,821	82,821							0	82,821	82,821
Q1225-502	1,892	62,021	63,913							1,892	62,021	63,913
Q1225-503	0	93,634	93,634							0	93,634	93,634
Q1250-521	0	53,170	53,170							0	53,170	53,170
Q1250-523b	52,575	14,488	67,063							52,575	14,488	67,063
Q1475-003	132	121,105	121,237							132	121,105	121,237
A875-391	10,000	0	10,000							10,000	0	10,000
Q1250-520	16,500	0	16,500							16,500	0	16,500

3.2.3.2. 2019 2nd Quarter

Total production is 2,728 kt for the 2nd quarter of 2019. Total ore production is 1,292 kt and total waste production is 1,436 kt. Table 3.2-6 gives the 2019 2nd quarter mine schedule. Monthly pit progression maps are located in Appendix 7.1.

<u>April 2019</u>
Total April mine production is 900kt. High Grade Ore production is 339 kt at [redacted]% Zn and [redacted] Pb.

<u>May 2019</u>
Total May mine production is 890 kt. High Grade Ore production is 344 kt at [redacted]% Zn and [redacted] Pb.

<u>June 2019</u>
Total June mine production is 938 kt. High Grade Ore production is 349 kt at [redacted]% Zn and [redacted]% Pb.

Table 3.2-6 2019 2nd Quarter Mine Schedule (by Cuts)

2019 Q2	Prediction			Apr-19			May-19			Jun-19		
	Ore	Waste	Total	Ore	Waste	Total	Ore	Waste	Total	Ore	Waste	Total
Total Production	1,291,803	1,436,263	2,728,066	338,775	561,611	900,386	344,437	545,259	889,696	348,792	589,192	937,984
A652-107a	29,567	1,440	31,007	29,567	1,440	31,007						
A775-185	63,277	2,370	65,647	63,277	2,370	65,647						
A775-195	52,472	8,086	60,558	52,472	8,086	60,558						
A875-387Ramp	865	20,547	21,412	865	20,547	21,412						
A875-392a	36,532	0	36,532	36,532	0	36,532						
A875-395	8,301	76,786	85,087	8,301	76,786	85,087						
A875-397	39,891	72,018	111,909	39,891	72,018	111,909						
A950-332	26,598	111,087	137,685	26,598	111,087	137,685						
A975-289	0	92,680	92,680	0	92,680	92,680						
Q1225-504	76,058	29,969	106,027	76,058	29,969	106,027						
Q1250-524	214	72,688	72,902	214	72,688	72,902						
Q1275-536	0	73,940	73,940	0	73,940	73,940						
A625-106	5,000	0	5,000	5,000	0	5,000						
A950-332	0	50,000	50,000				0	50,000	50,000			
A625-107b	30,912	44	30,956				30,912	44	30,956			
A750-136	51,183	1,373	52,556				51,183	1,373	52,556			
A750-137	57,711	2,015	59,726				57,711	2,015	59,726			
A750-138	43,489	1,308	44,797				43,489	1,308	44,797			
A875-392b	84,623	0	84,623				84,623	0	84,623			
A950-333	0	182,925	182,925				0	182,925	182,925			
Q1225-505a	51,333	4	51,337				51,333	4	51,337			
Q1250-526	25,186	22,538	47,724				25,186	22,538	47,724			
Q1250-530	0	135,109	135,109				0	135,109	135,109			
Q1250-535	0	149,943	149,943				0	149,943	149,943			
A1150-107	0	55,414	55,414							0	55,414	55,414
A1150-108	0	68,366	68,366							0	68,366	68,366
A725-131	53,766	0	53,766							53,766	0	53,766
A725-132	54,524	0	54,524							54,524	0	54,524
A750-139	53,472	0	53,472							53,472	0	53,472
A825-265	2,745	27,283	30,028							2,745	27,283	30,028
A850-294	0	107,045	107,045							0	107,045	107,045
A875-398	114,321	0	114,321							114,321	0	114,321
A950-334	0	94,121	94,121							0	94,121	94,121
A950-335	0	56,272	56,272							0	56,272	56,272
A950-336	0	73,154	73,154							0	73,154	73,154
Q1225-505b	69,964	5,240	75,204							69,964	5,240	75,204
Q1225-521	0	102,297	102,297							0	102,297	102,297

3.2.3.3. 2019 3rd Quarter

Total production is 3,258 kt for the 3rd quarter of 2019. Total ore production is 1,597 kt and total waste production is 1,661 kt. Table 3.2-7 gives the 2019 3rd quarter mine schedule. Monthly pit progression maps are located in Appendix 7.1.

July 2019
Total July mine production is 1,048 kt. High Grade Ore production is 362 kt[redacted] Zn and [redacted] Pb.

August 2019
Total August mine production is 1,161 kt. High Grade Ore production was 370 kt at [redacted]% Zn and [redacted]% Pb.

September 2019
Total September mine production is 1,049 kt. High Grade Ore production was 370 kt at [redacted]% Zn and [redacted]% Pb.

Table 3.2-7 2019 3rd Quarter Mine Schedule (by Cuts)

2019 Q3	Prediction			Jul-19			Aug-19			Sep-19		
	Ore	Waste	Total	Ore	Waste	Total	Ore	Waste	Total	Ore	Waste	Total
Total Production	1,596,737	1,661,458	3,258,195	361,965	685,917	1,047,882	370,339	790,531	1,160,870	370,085	679,358	1,049,443
A700-115	37,275	0	37,275	37,275	0	37,275						
A700-116	35,208	0	35,208	35,208	0	35,208						
A725-133	46,571	0	46,571	46,571	0	46,571						
A825-246	20,959	36,885	57,844	20,959	36,885	57,844						
A850-289	17,840	56,141	73,981	17,840	56,141	73,981						
A850-290	40,759	28,538	69,297	40,759	28,538	69,297						
A875-358Ramp	0	33,651	33,651	0	33,651	33,651						
A875-393	2,224	45,142	47,366	2,224	45,142	47,366						
A875-400	90,106	38,401	128,507	90,106	38,401	128,507						
A925-341	51	174,043	174,094	51	174,043	174,094						
Q1225-507	9,743	69,003	78,746	9,743	69,003	78,746						
Q1225-508	26,916	16,901	43,817	26,916	16,901	43,817						
Q1250-528	25,725	59,664	85,389	25,725	59,664	85,389						
Q1250-531	0	76,834	76,834	0	76,834	76,834						
Q1250-534	3,588	50,714	54,302	3,588	50,714	54,302						
Q1250-523b	5,000	0	5,000	5,000	0	5,000						
A1125-133	0	126,718	126,718				0	126,718	126,718			
A700-114	52,259	0	52,259				52,259	0	52,259			
A825-247	1,386	96,818	98,204				1,386	96,818	98,204			
A850-291	93,707	5,996	99,703				93,707	5,996	99,703			
A850-292	0	127,915	127,915				0	127,915	127,915			
A850-293	0	55,605	55,605				0	55,605	55,605			
A850-295	33,584	54,253	87,837				33,584	54,253	87,837			
A875-399	95,801	12,060	107,861				95,801	12,060	107,861			
A875-401b	26,058	23,768	49,826				26,058	23,768	49,826			
A925-342	0	139,996	139,996				0	139,996	139,996			
Q1225-509	62,544	16,127	78,671				62,544	16,127	78,671			
Q1250-525	0	67,070	67,070				0	67,070	67,070			
Q1250-532	0	64,205	64,205				0	64,205	64,205			
Q1250-523b	5,000	0	5,000				5,000	0	5,000			
A1125-134	0	133,425	133,425							0	133,425	133,425
A675-117	33,745	0	33,745							33,745	0	33,745
A700-117	38,285	0	38,285							38,285	0	38,285
A825-248	0	104,994	104,994							0	104,994	104,994
A825-249	35,438	52,078	87,516							35,438	52,078	87,516
A850-287	67,707	20,020	87,727							67,707	20,020	87,727
A850-288	31,446	30,995	62,441							31,446	30,995	62,441
A850-296	7,393	76,430	83,823							7,393	76,430	83,823
A850-297	39,431	51,754	91,185							39,431	51,754	91,185
A875-401a	50,904	32,624	83,528							50,904	32,624	83,528
A925-344	0	63,159	63,159							0	63,159	63,159
Q1225-510	60,736	21,810	82,546							60,736	21,810	82,546
Q1225-511	0	92,069	92,069							0	92,069	92,069
Q1250-523b	5,000	0	5,000							5,000	0	5,000

3.2.3.4. 2019 4th Quarter

Total production is 3,084 kt for the 4th quarter of 2019. Total ore production is 1,524 kt and total waste production is 1,561 kt. Table 3.2-8 gives the 2019 4th quarter mine schedule. Monthly pit progression maps are located in Appendix 7.1.

October 2019
Total October mine production is 953 kt. High Grade Ore production is 361 kt at [redacted]% Zn and [redacted]% Pb.

November 2019
Total November mine production is 1,057 kt. High Grade Ore production is 365 kt at [redacted] Zn and [redacted] Pb.

December 2019
Total December mine production is 1,075 kt. High Grade Ore production is 364 kt at [redacted] Zn and [redacted] Pb.

Table 3.2-8 2019 4th Quarter Mine Schedule (by Cuts)

2019 Q4	Prediction			Oct-19			Nov-19			Dec-19		
	Ore	Waste	Total	Ore	Waste	Total	Ore	Waste	Total	Ore	Waste	Total
Total Production	1,523,536	1,560,917	3,084,453	361,309	591,247	952,556	365,045	691,569	1,056,614	364,058	711,225	1,075,283
A675-118	48,760	0	48,760	48,760	0	48,760						
A825-245	1,215	73,005	74,220	1,215	73,005	74,220						
A825-250	54,654	15,426	70,080	54,654	15,426	70,080						
A825-251	0	107,196	107,196	0	107,196	107,196						
A825-252	10,226	58,683	68,909	10,226	58,683	68,909						
A825-253	51,323	13,704	65,027	51,323	13,704	65,027						
A825-265Ramp	0	17,502	17,502	0	17,502	17,502						
A850-398a	47,287	14,128	61,415	47,287	14,128	61,415						
A925-343	69,247	73,803	143,050	69,247	73,803	143,050						
Q1225-512	0	72,021	72,021	0	72,021	72,021						
Q1225-516a	66,638	3,797	70,435	66,638	3,797	70,435						
Q1225-518	6,710	81,170	87,880	6,710	81,170	87,880						
Q1225-522	5,249	60,812	66,061	5,249	60,812	66,061						
A675-118	5,000	0	5,000				5,000	0	5,000			
A650-112	41,688	0	41,688				41,688	0	41,688			
A675-119	51,798	0	51,798				51,798	0	51,798			
A800-226	5,889	76,764	82,653				5,889	76,764	82,653			
A825-254	23,632	35,247	58,879				23,632	35,247	58,879			
A825-255	73,459	19,137	92,596				73,459	19,137	92,596			
A825-256	0	85,834	85,834				0	85,834	85,834			
A825-257	0	77,298	77,298				0	77,298	77,298			
A850-298b	40,576	0	40,576				40,576	0	40,576			
A850-303a	50,559	22,818	73,377				50,559	22,818	73,377			
A900-393	5,761	151,087	156,848				5,761	151,087	156,848			
Q1225-514	57,078	22,017	79,095				57,078	22,017	79,095			
Q1225-516b	9,198	289	9,487				9,198	289	9,487			
Q1225-519	18	86,008	86,026				18	86,008	86,026			
Q1225-523	389	115,070	115,459				389	115,070	115,459			
A650-113	51,518	0	51,518							51,518	0	51,518
A650-114	32,748	0	32,748							32,748	0	32,748
A800-227	40,384	66,415	106,799							40,384	66,415	106,799
A800-228	72,706	4,921	77,627							72,706	4,921	77,627
A800-229	1,130	76,338	77,468							1,130	76,338	77,468
A800-230	17,642	66,221	83,863							17,642	66,221	83,863
A800-231	0	156,547	156,547							0	156,547	156,547
A850-229a	55,308	0	55,308							55,308	0	55,308
A850-298c	16,892	0	16,892							16,892	0	16,892
A900-394	0	74,022	74,022							0	74,022	74,022
Q1200-042	2,509	72,177	74,686							2,509	72,177	74,686
Q1200-051	20,392	48,383	68,775							20,392	48,383	68,775
Q1225-506	0	54,921	54,921							0	54,921	54,921
Q1225-515	23,542	26,007	49,549							23,542	26,007	49,549
Q1225-517	29,287	28,604	57,891							29,287	28,604	57,891
Q1225-524	0	36,669	36,669							0	36,669	36,669

SECTION 4. EQUIPMENT FLEETS

4.1. Summary

Equipment required to achieve the 2019 One Year Mine Plan is mostly similar to 2018. Haul truck 77-07, originally scheduled for retirement, will be operated through to the end of 2018, and then will be decommissioned. Similarly, the 992 loader will also remain part of the active production fleet through 2018, and then will be decommissioned.

The current major equipment fleets and associated operating metrics is listed in Table 4.1-1. The current truck fleet detail is shown in Table 4.1-2.

Table 4.1-1 Current Fleet Equipment Availability YTD as of Oct. 31, 2018

Equipment	Description	Units Available	Physical Availability	Use of Availability	Operating Efficiency	Asset Utilization
Drills	DML	3	82.1%	60.2%	76.4%	37.8%
Trucks	777	11	73.3%	81.8%	84.2%	50.5%
Loaders	993/992	6	61.8%	75.9%	88.2%	41.4%
Dozers	D9/D10	4	79.6%	54.0%	100.0%	43.0%

Table 4.1-2 Current Truck Fleet

Fleet	Model	Description	Year	Operating Hours (Mar. 12th, 2018)
77-07	CAT 777D	777-D 100-T HAUL TRUCK	2000	75,803
77-12	CAT 777D	777-D 100-T HAUL TRUCK	2004	64,062
77-13	CAT 777D	777-D 100-T HAUL TRUCK	2004	72,584
77-14	CAT 777D	777-D 100-T HAUL TRUCK	2004	71,814
77-15	CAT 777D	777-D 100-T HAUL TRUCK	2005	69,701
77-17	CAT 777F	777-F 100-T HAUL TRUCK	2008	52,164
77-18	CAT 777F	777-F 100-T HAUL TRUCK	2008	52,165
77-19	CAT 777F	777-F 100-T HAUL TRUCK	2010	44,279
77-20	CAT 777F	777-F 100-T HAUL TRUCK	2010	43,023
77-21	CAT 777F	777-F 100-T HAUL TRUCK	2010	42,959
77-22	CAT 777G	777-G 100-T HAUL TRUCK	2017	3,718
77-23	CAT 777G	777-G 100-T HAUL TRUCK	2017	2,257

4.2. 2019 Equipment Requirements

All planned project hours and forecasted production hours have been considered when determining the fleet requirements for the 2019 One Year Mine Plan. Table 4.2-1 gives the equipment hours needed for non-production projects in 2019.

Table 4.2-1 2019 Monthly Non-Production Project Hours

Monthly Projects Hours

Projects	Jan-19	Feb-19	Mar-19	Apr-19	May-19	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19	2019 Total
	31	28	31	30	31	30	31	31	30	31	30	31	365
Non-Capital Project													
Drill hours	72	72	72	0	0	0	0	0	0	0	0	0	216
Loader hours	0	44	44	0	0	0	0	0	0	0	0	0	88
Haultruck hours	0	176	176	0	0	0	0	0	187	0	0	0	539
Dozer hours	185	185	185	0	0	0	0	0	0	0	0	0	555
Quarry and Crush (DD2 / MS)													
Drill hours	90	90	180	180	0	0	0	0	0	0	0	0	539
Loader hours	177	177	338	322	0	0	0	0	0	0	0	0	1013
Haultruck hours	318	318	635	635	0	0	0	0	0	0	0	0	1905
Dozer hours	76	80	170	179	0	0	0	0	0	0	0	0	505
Back Dam & Main Dam													
Drill hours	0	0	0	0	180	180	180	180	180	0	0	0	898
Loader hours	0	0	0	0	90	71	52	44	36	0	0	0	292
Haultruck hours	0	0	0	0	171	133	95	79	64	0	0	0	543
Dozer hours	0	0	0	0	128	152	56	56	56	0	0	0	448
West Tails Road (1006 elev)													
Drill hours	0	0	0	0	0	0	0	0	0	0	0	0	0
Loader hours	0	0	0	0	0	0	0	0	0	0	0	0	0
Haultruck hours	0	0	0	0	0	0	0	0	0	866	300	866	2032
Dozer hours	0	0	0	0	0	0	0	0	0	160	55	160	375
Total													
Drill hours	162	162	252	180	180	180	180	180	180	0	0	0	1653
Loader hours	177	221	382	322	90	71	52	44	36	0	0	0	1392
Haultruck hours	318	494	811	635	171	133	95	79	251	866	300	866	5019
Dozer hours	261	265	355	179	128	152	56	56	56	160	55	160	1883

Atlas Copco DML Drills

Three Atlas Copco DML drills will be required through the duration of the One Year Plan. Three DML drills are currently in service. Besides production drilling, the drills will be required to produce 980,000 cu. Yds of broken quarry rock for the back dam raise and the main dam embankment project. Also, 154,000 cu. Yds of broken quarry rock will be needed for gravel requirements, including a shot at MS-9 and MS-2. This increased workload for the drills will be managed by spreading out the DD2 work over Q1, Q2, and Q3 of 2019.

Caterpillar 992G/993K Production Loaders

One 992 loader and five 993 loaders are currently in service. The 992 loader, the oldest in the fleet, will be decommissioned at the end of 2018. Five loaders are scheduled for 2019. It should be noted that loader hours are maxed out for nine out of twelve months in 2019. This schedule will require an average loader availability of 77.7% (versus 61.8% YTD – Oct. 31st 2018). Most hours are allocated for pit production, but some support will be required for development of DD2, especially in March/April of 2019.

Caterpillar 777D/F/G Haul Trucks

Twelve 777 haul trucks are currently in service although one unit has been converted to a water truck. The oldest unit (77-07) is decommissioning at the end of the 2018. Ten Caterpillar 777 haul trucks will be required through 2019, until Q4, which requires 11 trucks. Two new trucks will be commissioned in Q3 2019. Two old trucks will be decommissioned, one when the new trucks join the fleet, and the other at the end of 2019 to accommodate the additional truck needed in Q4. In 2019, truck hours are maxed out for eight of twelve months. This schedule will require an average haul truck availability of 77.8% (versus 73.3% YTD – October 31st 2018). Truck hours for project support are heavy in March/April, supporting DD2 development, and again in Q4, supporting the realignment of West Tails Road.

Caterpillar D9 and D10 Dozers

Two D9 dozers and two D10 dozers are currently in service. Four Caterpillar dozers will be required in 2019. Notable projects requiring dozer support hours include the expansion of DD2, the realignment of the Qanaiyaq haul road, and the realignment of the West Tails Road.

Table 4.2-2 contains details on the number of units required in 2019 and the tasks for which those hours will be used. Truck hour availabilities for the months of January and February are taken from the December 90 Day Plan rather than the 2019 Budget.

Table 4.2-2 2019 Monthly Equipment Performance Forecast

Equipment Performance Forecast

		2019												
	Units	M01	M02	M03	M04	M05	M06	M07	M08	M09	M10	M11	M12	2019 Total
DM-L Drill														
Units Available	ea	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Units Required	ea	2.5	2.6	2.6	2.4	2.5	2.6	2.8	2.9	2.7	2.1	2.8	2.9	2.7
Hours Available per unit	op hrs	342	307	340	329	340	329	340	340	329	340	266	246	***3,850***
Hours Used per unit	op hrs	284	268	293	268	285	288	318	328	301	239	252	241	***3,366***
HG Ore Drilling Hours Required	op hrs	330	297	294	314	320	324	336	344	343	335	339	338	***3,913***
LG / MG Drilling Hours Required	op hrs	211	23	30	225	36	29	215	164	227	126	128	255	***1,670***
Waste Drilling Hours Required	op hrs	117	292	269	54	287	302	192	263	121	223	258	98	***2,476***
Redrilling Hours Required	op hrs	33	30	33	32	33	32	33	33	32	33	32	33	***387***
Project Hours Required	op hrs	162	162	252	180	0	0	0	0	0	0	0	0	***755***
Main Dam Hours	op hrs	0	0	0	0	180	180	180	180	180	0	0	0	***898***
Drilling Hours Required	***op hrs***	***852***	***804***	***878***	***805***	***855***	***865***	***955***	***983***	***903***	***717***	***756***	***724***	***10,099***
Availability	%	81.8%	81.3%	81.3%	81.3%	81.3%	81.3%	81.3%	81.3%	81.3%	81.3%	65.7%	58.7%	78.1%
Use of Availability	%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%
Operating Efficiency	%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%
Asset Utilization	%	46.0%	45.7%	45.7%	45.7%	45.7%	45.7%	45.7%	45.7%	45.7%	45.7%	37.0%	33.0%	44.0%
993/992G Loader														
Units Available	ea	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Units Required	ea	4.8	5.0	5.0	5.0	4.8	5.0	5.0	5.0	5.0	4.7	5.0	5.0	4.9
Hours Available per unit	op hrs	419	371	409	404	373	361	390	414	381	373	376	383	***4,654***
Hours Used per unit	op hrs	403	369	407	402	358	361	386	411	379	354	374	382	***4,586***
HG Ore Hours Required	op hrs	410	369	365	390	396	401	417	426	426	416	420	419	***4,854***
LG / MG Hours Required	op hrs	256	29	38	258	5	36	136	177	256	75	119	305	***1,688***
Reclaim Hours Required	op hrs	446	403	446	432	446	432	446	446	432	446	432	446	***5,250***
Waste Hours Required	op hrs	496	617	578	388	622	642	653	732	526	605	677	514	***7,052***
Non-pit Hours Required	op hrs	229	207	229	221	229	221	229	229	221	229	221	229	***2,694***
Project Hours Required	op hrs	177	221	382	322	0	0	0	0	0	0	0	0	***1,101***
Main Dam Hours	op hrs	0	0	0	0	90	71	52	44	36	0	0	0	***292***
Loading Hours Required	***op hrs***	***2,013***	***1,844***	***2,037***	***2,011***	***1,788***	***1,803***	***1,932***	***2,054***	***1,896***	***1,771***	***1,869***	***1,912***	***22,931***
Availability	%	79.6%	74.6%	79.6%	74.9%	79.6%	79.6%	75.1%	75.1%	74.9%	79.6%	79.6%	79.6%	77.7%
Use of Availability	%	84.0%	88.0%	82.0%	89.0%	75.0%	75.0%	83.0%	88.0%	84.0%	75.0%	78.0%	77.0%	81.5%
Operating Efficiency	%	86.0%	86.0%	86.0%	86.0%	86.0%	86.0%	86.0%	86.0%	86.0%	86.0%	86.0%	86.0%	86.0%
Asset Utilization	%	57.5%	56.5%	56.1%	57.4%	51.3%	51.3%	53.6%	56.8%	54.1%	51.3%	53.4%	52.7%	54.4%
777 Haul Trucks														
Units Available	ea	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Units Required	ea	9.9	9.9	10.1	10.0	9.3	9.4	9.5	9.9	9.9	10.0	10.9	10.9	10.1
Hours Available per unit	op hrs	421	412	430	415	408	393	441	445	421	461	398	461	***5,105***
Hours Used per unit	op hrs	418	407	435	414	379	368	419	440	417	459	435	504	***5,094***
HG Ore Hours Required	op hrs	1,096	986	974	1,041	1,058	1,074	1,115	1,142	1,142	1,111	1,126	1,120	***12,985***
LG / MG Hours Required	op hrs	727	83	115	721	15	99	406	496	714	210	332	878	***4,796***
Reclaim Hours Required	op hrs	382	345	382	369	382	369	382	382	369	382	369	382	***4,495***
Waste Hours Required	op hrs	1,549	2,074	1,964	1,269	2,058	1,907	2,084	2,199	1,589	1,918	2,124	1,686	***22,421***
Non-pit Hours Required	op hrs	104	94	104	101	104	101	104	104	101	104	101	104	***1,226***
Project Hours Required	op hrs	318	494	811	635	171	133	95	79	251	866	300	866	***5,019***
Hauling Hours Required	***op hrs***	***4,176***	***4,075***	***4,350***	***4,136***	***3,789***	***3,684***	***4,186***	***4,403***	***4,165***	***4,590***	***4,352***	***5,036***	***50,942***
Availability	%	73.7%	81.8%	75.3%	75.1%	75.7%	75.5%	81.7%	80.7%	80.7%	80.7%	72.2%	80.7%	77.8%
Use of Availability	%	90.0%	88.0%	90.0%	90.0%	85.0%	85.0%	85.0%	87.0%	85.0%	90.0%	***90.0%***	90.0%	87.9%
Operating Efficiency	%	87.0%	87.0%	87.0%	87.0%	87.0%	87.0%	87.0%	87.0%	87.0%	87.0%	87.0%	87.0%	87.0%
Asset Utilization	%	57.7%	62.6%	58.9%	58.8%	56.0%	55.9%	60.4%	61.0%	59.6%	63.1%	56.5%	63.1%	59.5%
D9 & D10 Dozers														
Units Available	ea	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Units Required	ea	3.8	4.0	4.0	3.6	4.0	3.5	3.4	3.6	3.5	3.5	3.5	3.8	3.5
Hours Available per unit	op hrs	330	290	317	309	324	309	319	319	309	319	309	319	***3,774***
Hours Used per unit	op hrs	316	288	316	274	325	273	271	290	267	280	269	302	***3,471***
HG Ore Hours Required	op hrs	41	37	36	39	39	40	41	42	42	41	42	42	***483***
LG / MG Hours Required	op hrs	157	18	23	159	3	22	84	109	157	46	73	187	
Reclaim Hours Required	op hrs	155	140	155	150	155	150	155	155	150	155	150	155	***1,830***
COSP Hours Required	op hrs	69	62	61	65	66	67	70	71	71	70	70	70	***814***
Waste Hours Required	op hrs	305	380	356	239	383	395	402	451	324	373	417	316	***4,340***
Other Mining Hours Required	op hrs	250	226	250	242	500	242	250	250	242	250	242	250	***3,193***
Non-pit Hours Required	op hrs	25	23	25	25	25	25	25	25	25	25	25	25	***300***
Non-Capital Projects	op hrs	185	185	185	0	0	0	0	0	0	0	0	0	***555***
Quarry & Crushing	op hrs	76	80	170	179	0	0	0	0	0	0	0	0	***505***
DD2 Pushback	op hrs	0	0	0	0	0	0	0	0	0	0	0	0	-
Back Dam & Main Dam	op hrs	0	0	0	0	128	152	56	56	56	0	0	0	***448***
B-Pad Stripping & Road Building	op hrs	0	0	0	0	0	0	0	0	0	0	0	0	-
West Tails Road Building	op hrs	0	0	0	0	0	0	0	0	0	160	55	160	***375***
Airport Tundra Stripping	op hrs	0	0	0	0	0	0	0	0	0	0	0	0	-
Dozing Hours Required	***op hrs***	***1,264***	***1,150***	***1,262***	***1,098***	***1,301***	***1,094***	***1,084***	***1,161***	***1,068***	***1,121***	***1,074***	***1,207***	***13,883***
Availability	%	80.8%	74.6%	69.5%	80.8%	80.8%	80.8%	80.8%	80.8%	80.8%	80.8%	80.8%	80.8%	79.3%
Use of Availability	%	67.0%	71.0%	75.0%	65.0%	66.0%	65.0%	65.0%	65.0%	65.0%	65.0%	65.0%	65.0%	66.6%
Operating Efficiency	%	84.0%	84.0%	84.0%	84.0%	84.0%	84.0%	84.0%	84.0%	84.0%	84.0%	84.0%	84.0%	84.0%
Asset Utilization	%	45.5%	44.5%	43.8%	44.1%	44.8%	44.1%	44.1%	44.1%	44.1%	44.1%	44.1%	44.1%	44.4%

SECTION 5. RISKS AND OPPORTUNITIES

The key risks and opportunities relevant to the 2019 One Year Plan are described herein.

5.1. Risks

1) Aqqaluk Pit Highwall Stability

Certain zones within Aqqaluk pit have been identified as Geotechnical Hazard Zones (GHZ). If not properly monitored and/or managed, these zones could destabilize and present an imminent risk to pit operations. Of particular note is the south wall where water is entering the pit from the Main Pit Water Reservoir. In the event that these zones cannot be effectively managed with the current pit design, changes to the pit walls may be required which will have a significant impact on the Aqqaluk ore reserves. Golder Associates (Golder) are presently enlisted as the third party reviewers of the pit designs. Golder are also actively involved with the stability evaluation of the south wall and analysis of mitigation options.

2) Qanaiyaq Summer Production

The 2017 wet summer season resulted in a number of problems that hindered production. Cut-off blast patterns and an increased amount of unloaded holes resulted in excessive high bottoms and uneven ground for haulage equipment. This also resulted in a significant amount of unplanned dozer work for ripping through unshot ground, leveling the pit floor, repeatedly doing clearing limits, and managing mud. In 2018, key learnings were employed to minimize disruption. The Drill & Blast team has become more proficient in using Sonotubes to reduce the number of unloaded holes and decrease the chance of a cutoff pattern. The Mine Operations team has put forth more effort in maintaining roads, particularly applying strategic placement of overlays. A “Pit Road Condition” map and the rollout of MEMS has facilitated the identification and communication of road improvement opportunities. Aided by a dryer summer in 2018, efforts proved effective as is reflected by improved production and fleet reliability compared with the summer before.

3) Main Pit Dump (MPD) Stability

The continuous availability of the MPD areas is critical to execution of the 2019 One Year Mine Plan. Destabilization of the dumps could result in the inability to deposit waste rock in Main Pit, with little alternate dump space available elsewhere on site. Currently, material quality is monitored and blended to ensure that poor quality waste rock is kept in the upper (dry) lifts, while material that is more competent is deposited below water level. Golder Associates (Golder) are presently enlisted as the third party reviewers of the dump designs.

4) Selenium (Se) Leaching

Dissolved selenium levels have risen due to mining of weathered overburden and ore in the upper benches of the Aqqaluk Pit and Qanaiyaq Pit. Laboratory testing of various Qanaiyaq rock types, limiting the ore and waste mining rates for the deposit, and modelling the extraction based on this plan was undertaken to determine the quantity of selenium that could be produced. The result did not indicate that the quantity would be excessive. However, scaling from the laboratory to the outdoor environment introduces some uncertainty. Selenium solubility may require methods of mitigation in the Tailings Pond and Main Pit Water Reservoir.

Mitigation of selenium release from the ore will primarily be controlled by limiting the milling rates of the Qanaiyaq ore to 850k tonnes per year or less. To minimize the amount of selenium release from waste rock, Qanaiyaq weathered waste material will be placed in the MPD above 850 ft. elevation to keep it out the water, layered and covered. Potential cover methods are under investigation.

5) Low Fleet Availabilities

The production fleet had experienced low availabilities in 2017. Efforts in 2018 for a more robust pit road maintenance program helped to improve haul truck availability. Initiatives in the HE Shop helped improve drill and dozer availability, while loader availability decreased further in 2018. The Maintenance Department is confident that the operating statistics provided for the 2019 Mine Plan are achievable by the HE Shop. Nonetheless, the 2019 Mine Plan will be more difficult to achieve if equipment availabilities fall short of target.

6) Ammonia Levels in Main Pit Water Reservoir (MPWR)

In 2018, there were several trials using the DN11L surfactant in the emulsion. This surfactant increases emulsion viscosity, thereby reducing seepage of emulsion and reducing inefficiently or undetonated product. The trials saw a reduction in the ammonia levels in the MPWR. Consequentially, going forward, production of all emulsion will use DN11L surfactant. Close monitoring of ammonia levels will continue to ensure discharge within permitted limits.

5.2. Opportunities

1) Mobile Equipment Monitoring

Implementation of Mobile Equipment Monitoring (MEM) on the haul truck and loader fleets was completed in the third quarter of 2018. This system utilizes the data from the Vital Information Monitoring System (VIMS) onboard the units to provide real-time operating data to the Maintenance, Mine Operations and Reliability groups. Information from the MEM system provides critical feedback to the Maintenance and Reliability groups in order to monitor the operating condition of equipment. There may be opportunities to better utilize this information for the purposes of understanding equipment damage/wear.

2) Haul Road and Pit Bench Maintenance

In 2018, several initiatives launched to improve haul road conditions. Firstly, a system was developed for communicating pit road conditions via map and magnets. This resides outside the Pit Shifter's office. Also, the new MEM heat maps report high strut pressure events as well as average truck speeds. Similarly, this is used to pin point rough road conditions. Next, an additional grader arrived to site, bringing the fleet count to five graders. This will facilitate road maintenance, especially during the wet summer months. Finally, actions from quarterly road & ramp audits are being executed and reviewed. It will be critical to follow through with these initiatives to continue to see improvements in haul road conditions. Efforts will see continued improvement in equipment availabilities.

SECTION 6. PROJECTS

6.1. Dewatering

6.1.1. Aqqaluk Pit Dewatering

Dewatering efforts in the Aqqaluk deposit for 2019 will include maintaining a dry working area for mining activity on the 650 to 900 benches, and removal of surface and substrate inflows. Dewatering mainly depends on two electrical pumps (140HP and 58HP) in the 775-bench pump station, through an insulated and heat traced six-inch HDPE pipe along the southeast side of pit connected to the main 16-inch HDPE heat-traced dewatering line on the 900 ft. elevation reporting to the Main Pit Water Reservoir (MPWR). A 6 in. diesel driven pump delivers water from the 650-bench sump. A 14-inch uninsulated HDPE dewatering line is also available from the 775-pump station to the main 16-inch reporting to the MPWR when higher dewatering demands are required.

The main 16-inch line runs underground through MPD3 and flows to the Main Pit Water Reservoir (MPWR).

With the required relocation of the dewatering system due in Q3 2019, an evaluation of the entire Aqqaluk dewatering system is underway to determine alternative solutions to improve the efficiency and versatility of the system and make the system as maintenance free as possible. Currently the design for the planned upgraded dewatering system is approximately 90% complete with the finalization of electrical feeds and the new discharge pipe ramp remaining. The design and scope of work for contractors is overdue and to be completed as soon as possible.

The projected end of 2018 configuration of existing system is shown in Figure 6.1-1.

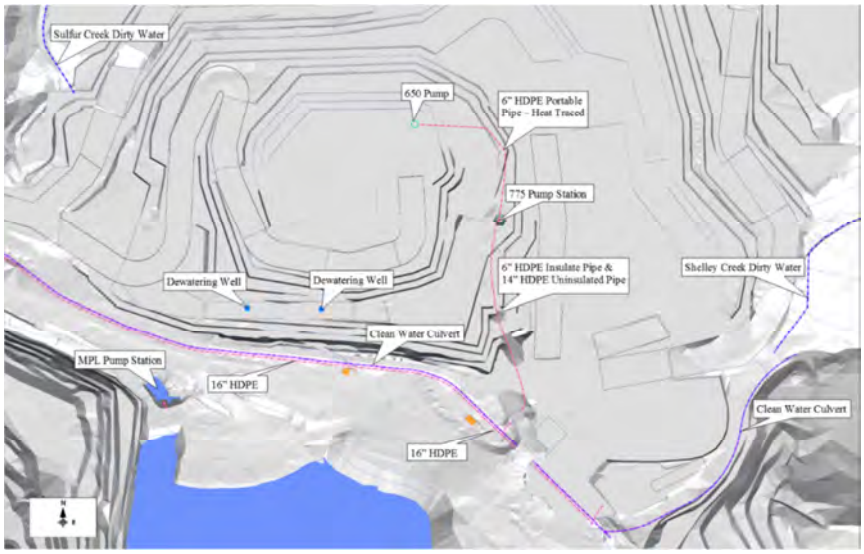


Figure 6.1-1 End of Year 2018 Dewatering

6.1.2. Qanaiyaq Pit Dewatering

This summer, a temporary sump, ditches, pump, and piping system were established to manage water on the 1275 & 1250 benches. Water discharges into the catchment south of the pit where it eventually flows to the ARD system. A plan to re-route this pipe to the top of the main haul road where water can drain into the MPWR has been developed. This route is more complicated with one major road crossing; however, selenium will be managed more effectively.

A plan for a long-term system to dewater the Qanaiyaq pit has been developed. This includes system improvements to make it a more robust dewatering platform and is expected to be installed in early 2019 for the freshet season.

6.2. Environmental Related Projects

6.2.1. Fugitive Dust Control

Fugitive dust comes from the construction and reclamation of the ore stockpiles located in front of the gyratory crusher. The prevailing winds are from the NE, thus carrying dust from stockpile activity to the tundra located south and west of the tailings pond. Evaluation of options for mitigating the impact of dust from stockpiles will continue in 2019.

6.2.1.1. Water Truck Fill Station

To improve the control of fugitive dust from the active mining areas, a new water truck fill station is being commissioned adjacent to the main haul road into Aqqaluk Pit, across from the lower entrance to the gyratory crusher. This project will reduce the cycle time of the water truck and increase the capacity of water spread on the haul roads when required. Paa River Construction has installed the main HDPE pipe run from the Sand Filter Building to the water tank. Remaining work includes the installation of electric actuated valves and communication systems to control the valves and pump. Materials including a PLC, radio, two 6” valves, remote control, and some small fittings need to be ordered to finish the project. The planned project completion date is Q2 2019.

6.2.1.2. Test Application of Dust Suppressant for Stockpile Pad and Mine Roads

Dust suppressant (e.g. calcium chloride) has been applied to the mine roads and is planned to be utilized as needed. Testing of effects of calcium chloride entering the mill are planned to be run prior to applying to the stockpiles to evaluate potential impacts to the milling process.

6.3. Other Projects

6.3.1.1. Aqqaluk South Wall Mitigation Efforts

Depressurization of the Aqqaluk Pit South Wall is critical to prevent further seepage of water from the MPWR into the pit. Golder Associates Ltd. (GA) set a threshold hydraulic gradient of 0.3 ft./ft. (Golder 2017). However, hydraulic gradients have crossed this threshold. If mitigation efforts are not in place by the end of 2018, the increased hydraulic gradients will lead to further seepage and potential destabilization of the South Wall. To prevent destabilization of the South Wall, RDO started working on mitigation efforts in January 2018. Mitigation efforts to date have included the following:

- Piezometer data and hydraulic gradient monitoring (six piezometers on the pillar)
    - Additional instrumentation installations including two piezometers on the 700 ft bench in the Aqqaluk Pit (May 2018) – **PHASE I, completed**
- Slope stability monitoring
    - Visual inspections
    - 19 active prisms on the South Wall
- Established a Trigger Action Response Plan (TARP) for proper management of the South Wall

Future mitigation efforts are as follows:

- Continued slope stability, piezometer data, and hydraulic gradient monitoring
    - The radar will be connected to the network by the end of October 2018 for continuous, real-time geotechnical monitoring.

- **PHASE II**
    - Drilling of two depressurization wells on the South Wall, and installation of plumbing and electrical infrastructure to support the wells.
    - Drilling of ten piezometer drill holes and installation of 30 piezometers sensors (3 in each drill hole).

Phase II will be completed from August to December 2018.

6.3.1.2. DD2 Development

In 2018, the DD2 material site met its previously designed pit extents. The pit was expanded west in Phase 1 of a two phase pit expansion to meet life-of-mine project material requirements. Also, a new portable crusher pad was established that will remain for the entire life-of-mine.

Due to significant construction material requirements in 2019, seen below in **Table 6.3-1**, the current phase 1 pit expansion will continue to be mined throughout 2019.

Table 6.3-1 2019 DD2 Material Requirements

Year	Project	Material Type	Quantity (lcyd.)
2019			
	Tailings Back Dam	DD2 Pit Run	101,000
	Tailings Main Dam	DD2 Pit Run	800,000
	Tailings Seepage Pond	DD2 Pit Run	25,000
	Tailings Seepage Pond	Armoring Boulders	2,500
	West Tailings Road	DD2 Reject/Mine Waste	20,000
	All Crushing	DD2 Pit Run	125,000
	Total		**1,073,500**

In order to meet material demand in the summer months while minimizing impacts to Aqqaluk and Qanaiyaq pit production, Mine Operations will develop the pit expansion at DD2 year-round. Construction material will be stockpiled in the bottom of the existing pit from January through to the beginning of May; Figure 6.3-1 DD2 Pit Development Q2 2019Figure 6.3-1 shows pit expansion progression by mid-Q2 2019 as well as stockpiled material in the pit bottom.

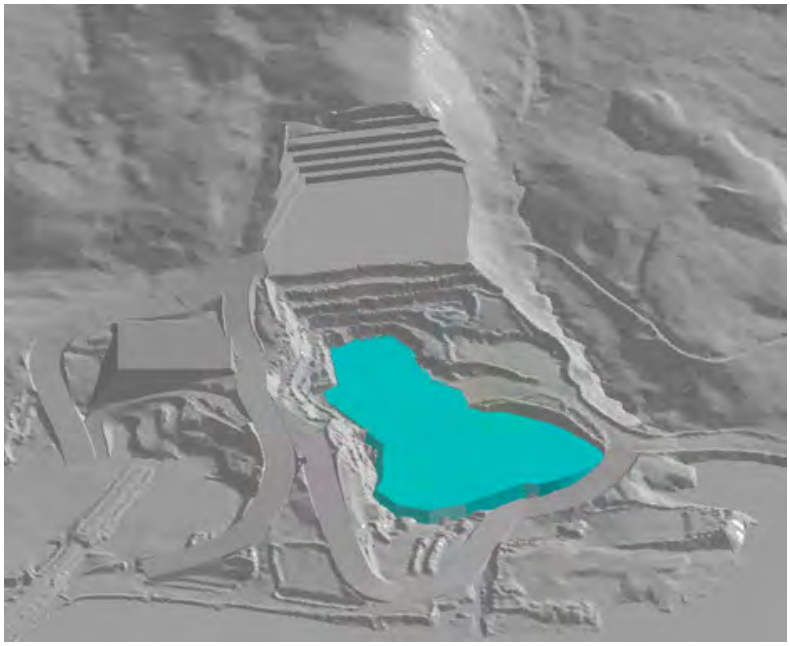


Figure 6.3-1 DD2 Pit Development Q2 2019

As the Tailings Storage Facility dam work begins on-site, contactors will take over material haulage responsibilities from Mine Operations. Mine Operations will continue carrying out drilling and blasting work. Contractor haulage will vary between the progressing benches of the pit expansion and the stockpiled material at the pit bottom in order to maintain a steady feed of material for project development.

As the project season ends in late fall, Mine Operations will work to establish a pioneering road and the first bench for Phase 2 of the DD2 pit expansion, as seen in Figure 6.3-2.

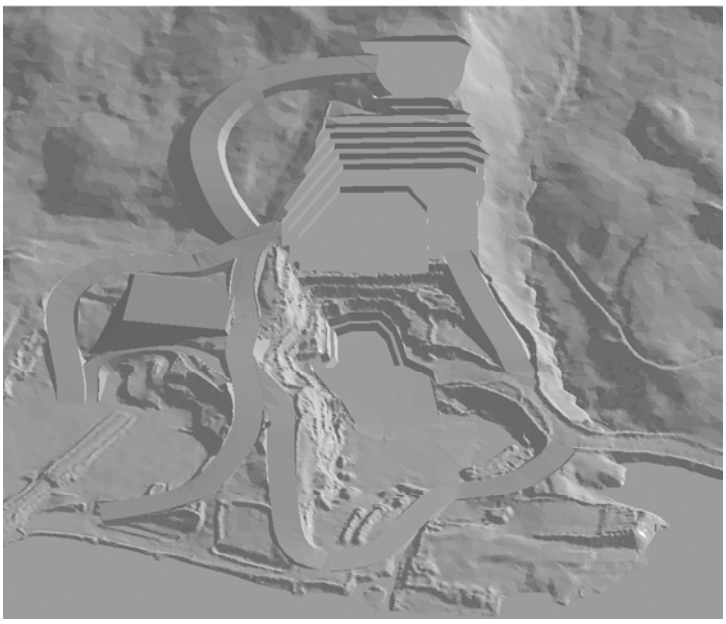


Figure 6.3-2 DD2 Pit Development EOY 2019

Progression of Phases 1 and 2 of the DD2 pit expansion will continue in 2020 with focus on developing Phase 2. The broader material specifications associated with the West Tails Road raise in 2020 presents an opportunity to utilize the normally out-of-spec material found in the first few benches below original ground, as well as material intersected by a fault on the north side of the pit. A summary of the DD2 material requirements for 2020 is shown below in Table 6.3-2.

Table 6.3-2 2020 DD2 Material Requirements

Year	Project	Material Type	Quantity (lcyd.)
2020			
	Tailings Main Dam	DD2 Pit Run	203,100
	Tailings Main Dam Crushing	DD2 Pit Run	136,000
	West Tails Road Raise	DD2 Reject/Mine Waste	410,000
	Yearly Crushing	DD2 Pit Run	90,000
	Total		**839,100**

Figure 6.3-3 shows the pit progression at the end of 2020. Access to the Phase 1 pit will be established on the north side, while Phase 2 satisfies the majority of remaining material requirements.

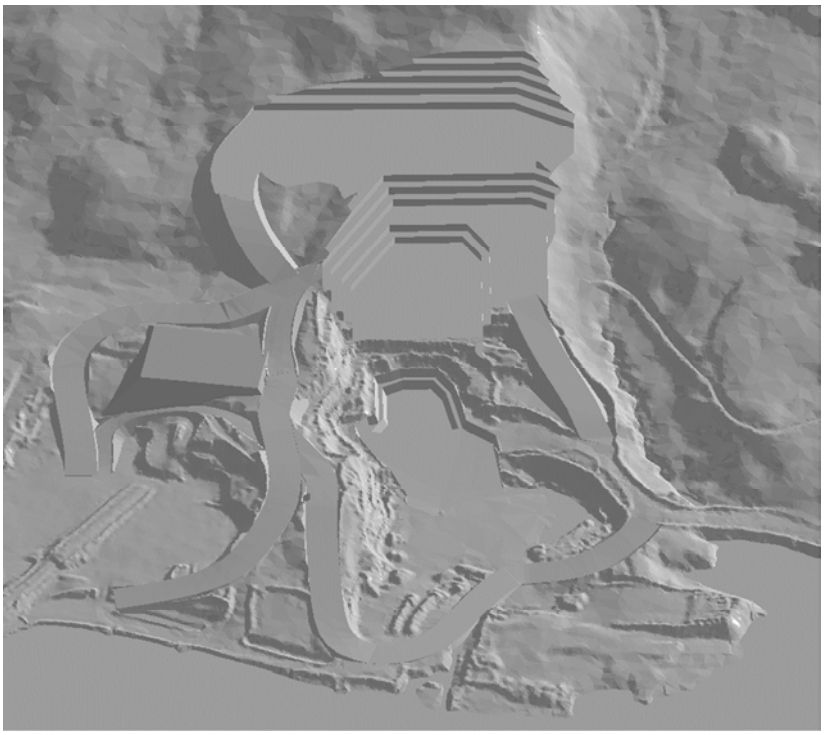


Figure 6.3-3 DD2 Pit Development EOY 2020

6.3.1.3. Qanaiyaq Haul Road Realignment

In Q1 2019, the Qanaiyaq Haul Road will need to be re-aligned to open up additional dumping space for the LG stockpile and the Weathered High Zn-Cu stockpile. The road re-alignment involves moving 377 kt of material, approximately 90% of which will require blasting (est. 216 drill hours; 88 loader hours; 353 truck hours). The majority of the material will be pushed over the Main Pit highwall (est. 454 dozer hours). Additionally, the ramp to the cover dump will need re-grading (est. 103 dozer hours) in order to tie-in with the new road.

6.3.1.4. West Tails Road Realignment

Around freshet of 2020, the current West Tails Road will be underwater. Consequentially, a new road, at a higher elevation (1006 feet) will need to be built. The project will require tundra stripping (est. 409 dozer hours) and haulage of stripped “topsoil” material to Kivalina (est. 351 loader hours; 756 truck hours; 351 dozer hours). The road will be constructed with suitable waste material from the Aqqaluk pit (est. 2,599 truck hours; 481 dozer hours). The project is scheduled to begin in Q4 2019, and for completion in Q1 2020.

6.3.2. Project Support

6.3.2.1. Stage IV Back Dam Construction

In 2019, work will begin on the Main Dam in order to complete a raise to the 996 elevation by the end of 2020. Also in 2019, a raise on the Back Dam to the 996 elevation will be completed. Combined, both projects require approximately 976k cu. Yds of DD2 pit run material, 40k cu. Yds of DD2 crushed product, and 89k cu. Yds of suitable mine waste from Aqqaluk. Mine Operations will be responsible for drilling and blasting to provide broken rock (est. 1,437 drill hours; 953 dozer hours) for this project. To achieve these significant quantities of broken rock will require stockpiling of blasted material (est. 1,304 loader hours; 2,448 truck hours). Maintaining a larger supply of broken DD2 inventory through the duration of the project will reduce the risk of a setback. Contractors will be responsible for moving and placing the material at its final destination. A more detailed plan of the DD2 development is provided in Section 6.3.1.2.

6.3.2.2. Crushing

Quarrying and crushing are typically carried out from May to September. In 2019, approximately 154,000 bank cubic yards of material will be blasted (Table 6.3-3) for crushing. Crusher products include material for yards and road gravel, main dam & back dam lift construction, and drill & blast stemming. Some haulage will be required to remove crushed material to remote stockpiles. Drilling is to be done with the mine production drills.

Table 6.3-3 Estimated Crushed Rock Quantities for 2019

Product Size Required	Project/Code	Amount (cyd)	Quarry Location
3/4" Select	Dams	30,000	DD2
1-1/2" minus (Type 3)	Dams	25,000	DD2
3/8" minus (Type 4)	Dams	3,000	DD2
2" minus	Yards & Roads	4,000	DD2
3/4" minus	Yards & Roads	2,000	DD2
1" minus	MS-9 Port Road	25,000	MS-9
1" minus	MS-2 Port Road	25,000	MS-2
3" minus	Mine Road Sand	20,000	Mine
1" - 1/2" minus	Mine Drill & Blast Stemming	20,000	Mine
	Total Crushed Rock	**154,000**	**CYD**

6.3.2.3. Reclaim Barge Raise

In Q3 2019, the Reclaim Barge finger will be raised. This project will require an estimated 188 kt of suitable Aqqaluk waste rock. Mine Operations will deliver the rock to a staging area near A-Pad (647 truck hours). Contractors will place the material and construct the new finger.

SECTION 7. APPENDICES

7.1. 2019 One Year Mine Plan and Waste Dump 3D View Maps

Table 7.1-1 Legend for 2019 Maps

Type	Legend	VALS Range ($/s)
Ore		
Low Grade Ore		$0.00-$7.00
Medium Grade Ore		$7.00-$20.00
High Grade Ore		$20.01 - $40.00
High Grade Ore		>$40.00
Dumps		
MPD 850 Elevation		
MPD 904 Elevation		
MPD 1015 Elevation		
MPD 1125 Elevation		

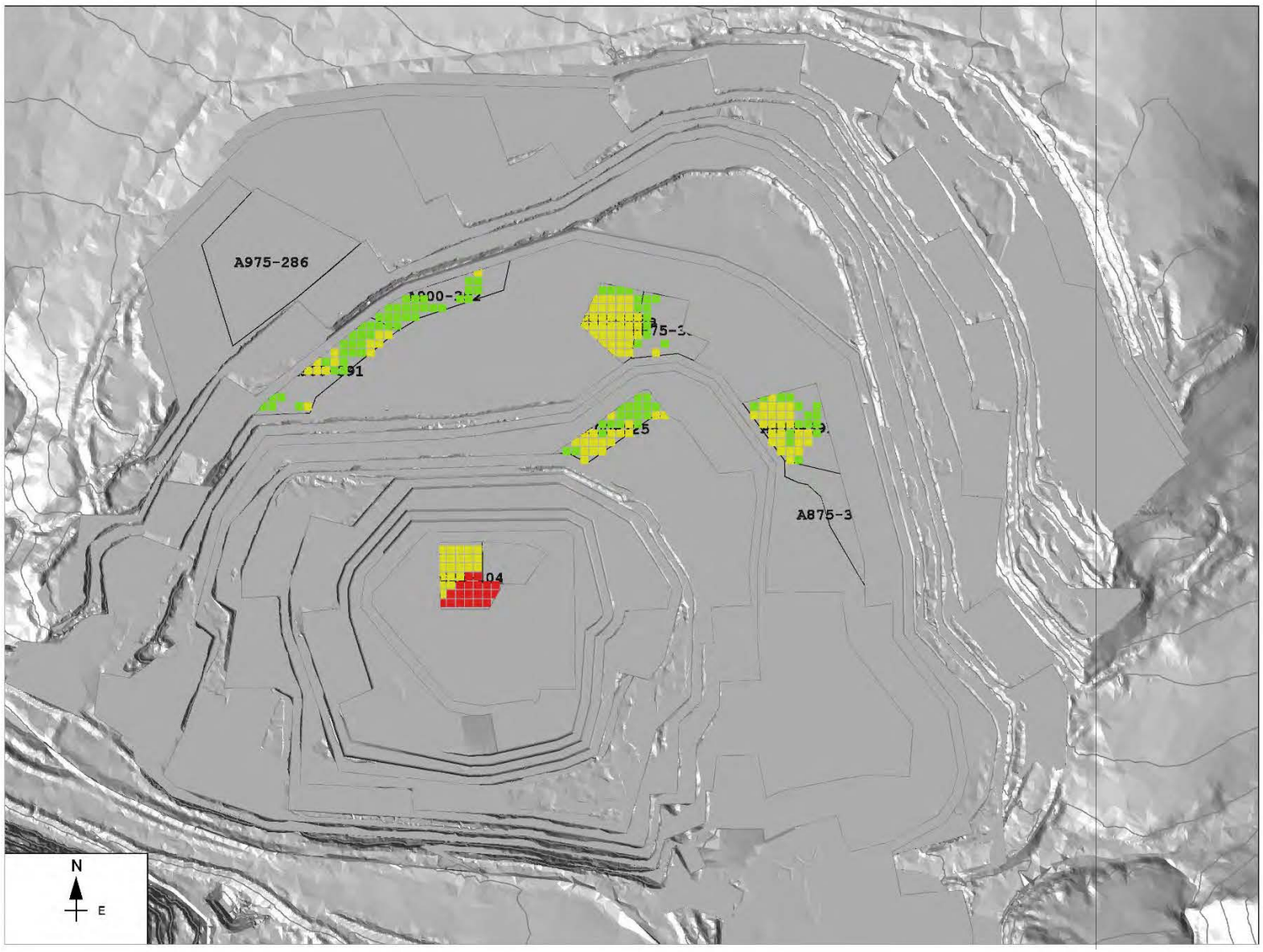


Figure 7.1-1 January 2019 Mine Plan 3D View (AQQ)

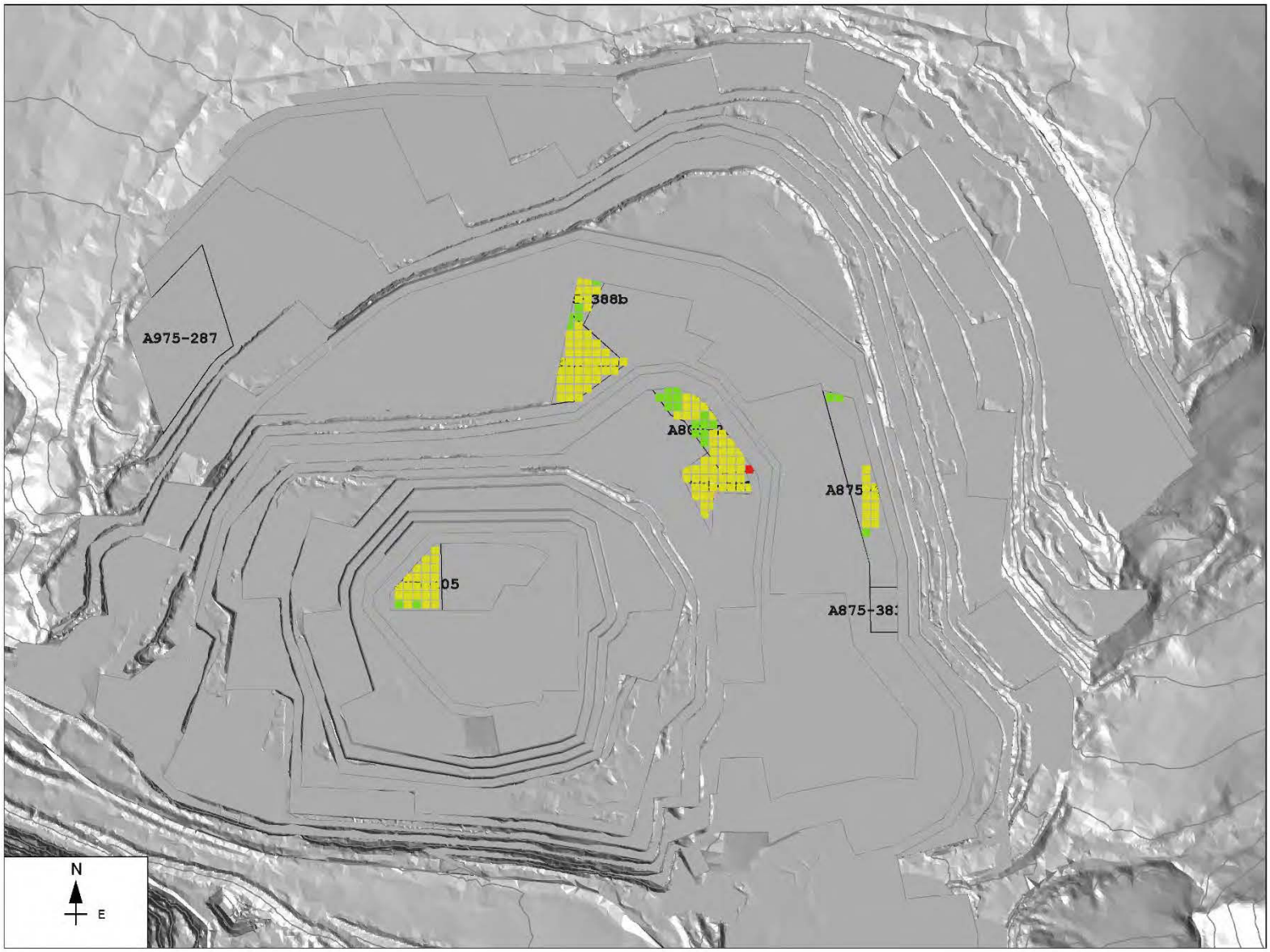


Figure 7.1-2 February 2019 Mine Plan 3D View (AQQ)

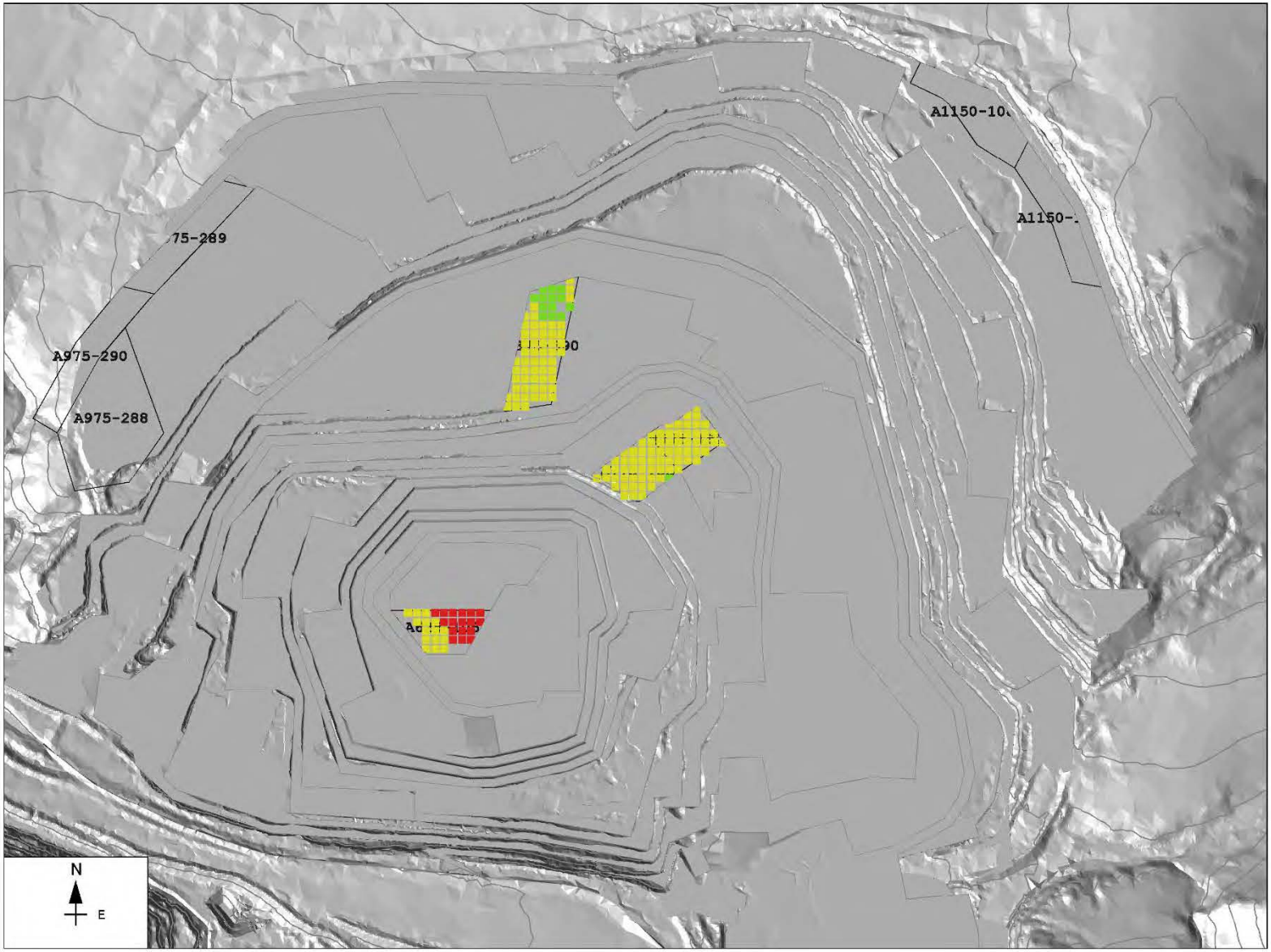


Figure 7.1-3 March 2019 Mine Plan 3D View (AQQ)

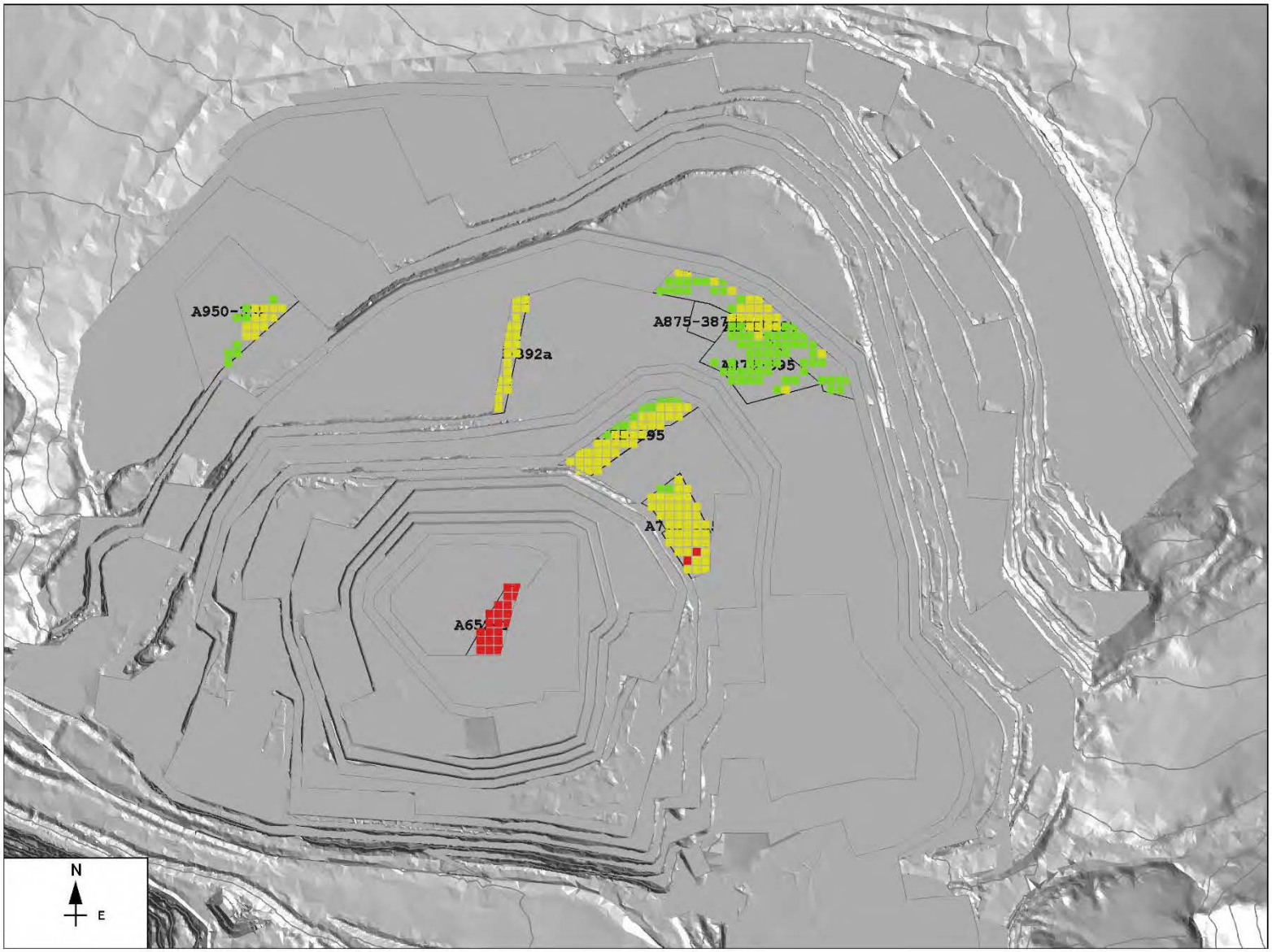


Figure 7.1-4 April 2019 Mine Plan 3D View (AQQ)

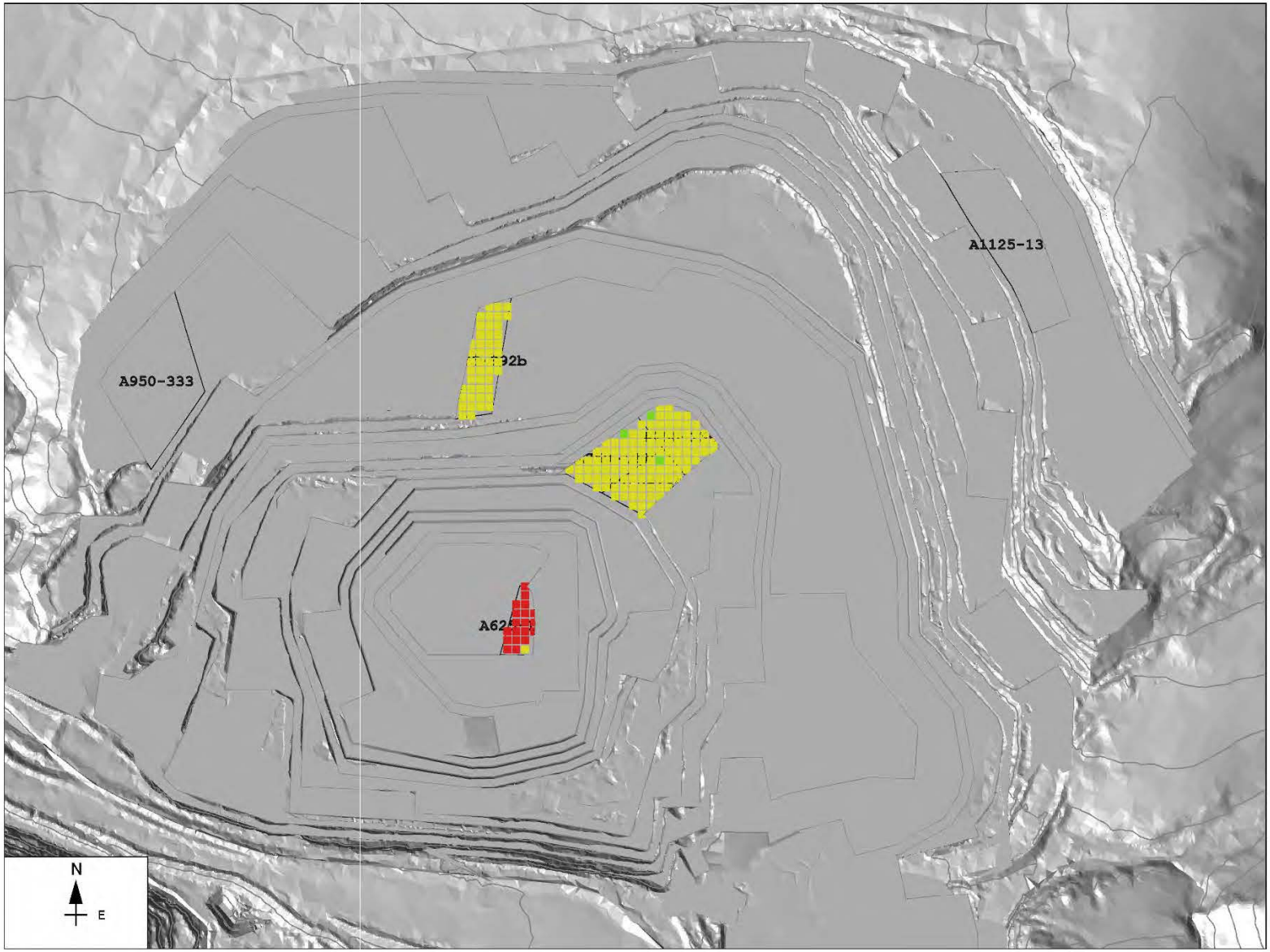


Figure 7.1-5 May 2019 Mine Plan 3D View (AQQ)

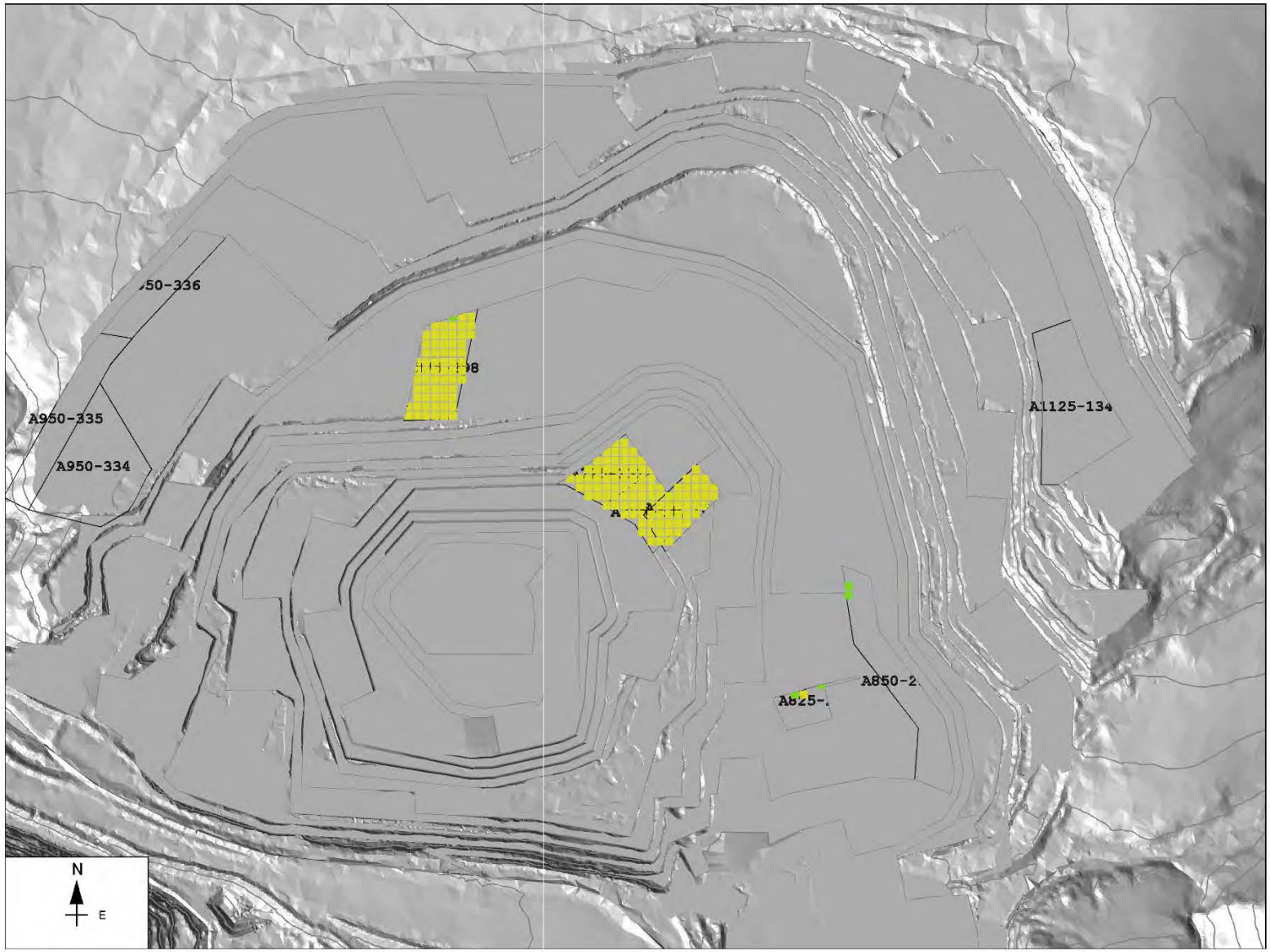


Figure 7.1-6 June 2019 Mine Plan 3D View (AQQ)

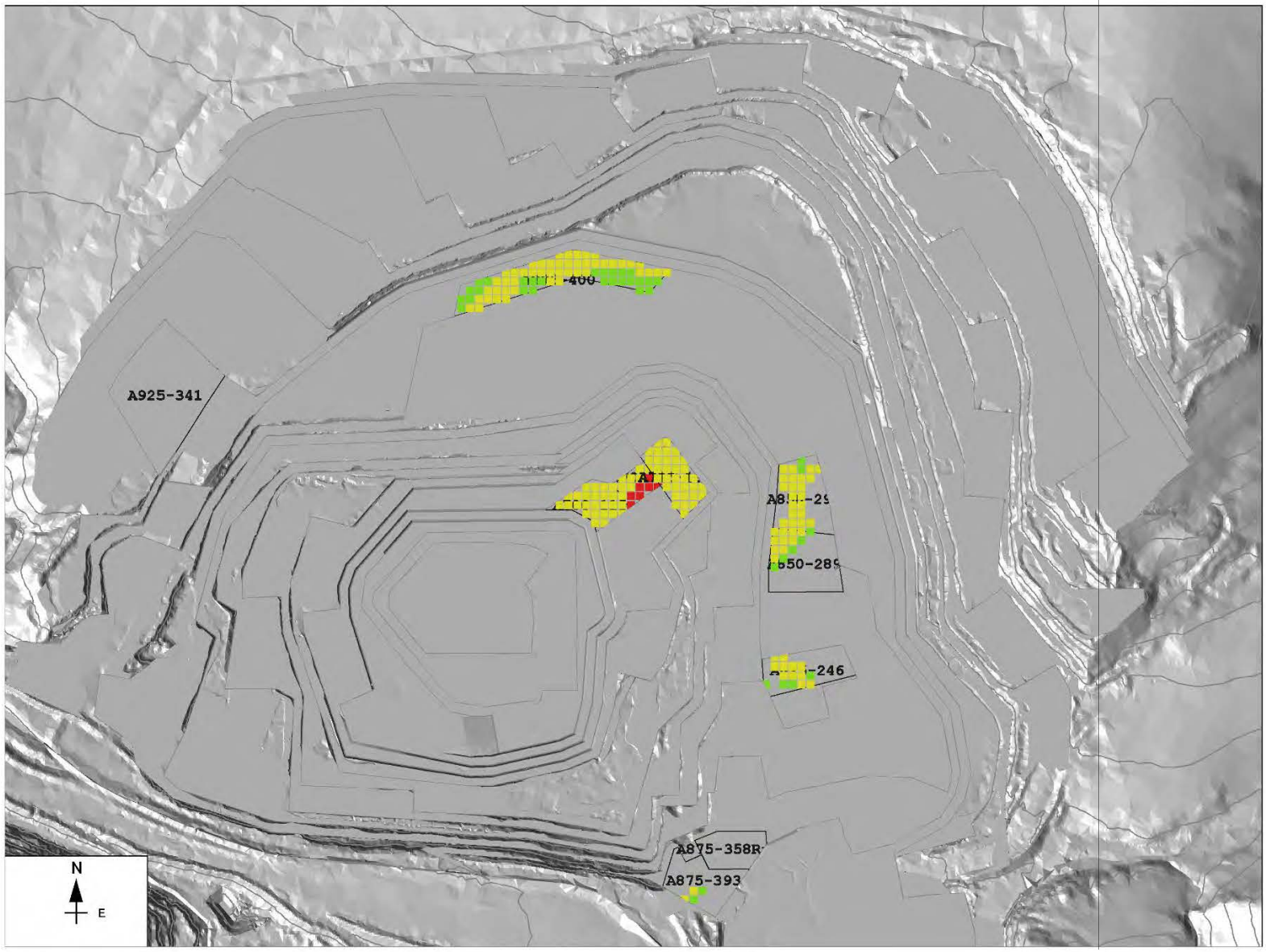


Figure 7.1-7 July 2019 Mine Plan 3D View (AQQ)

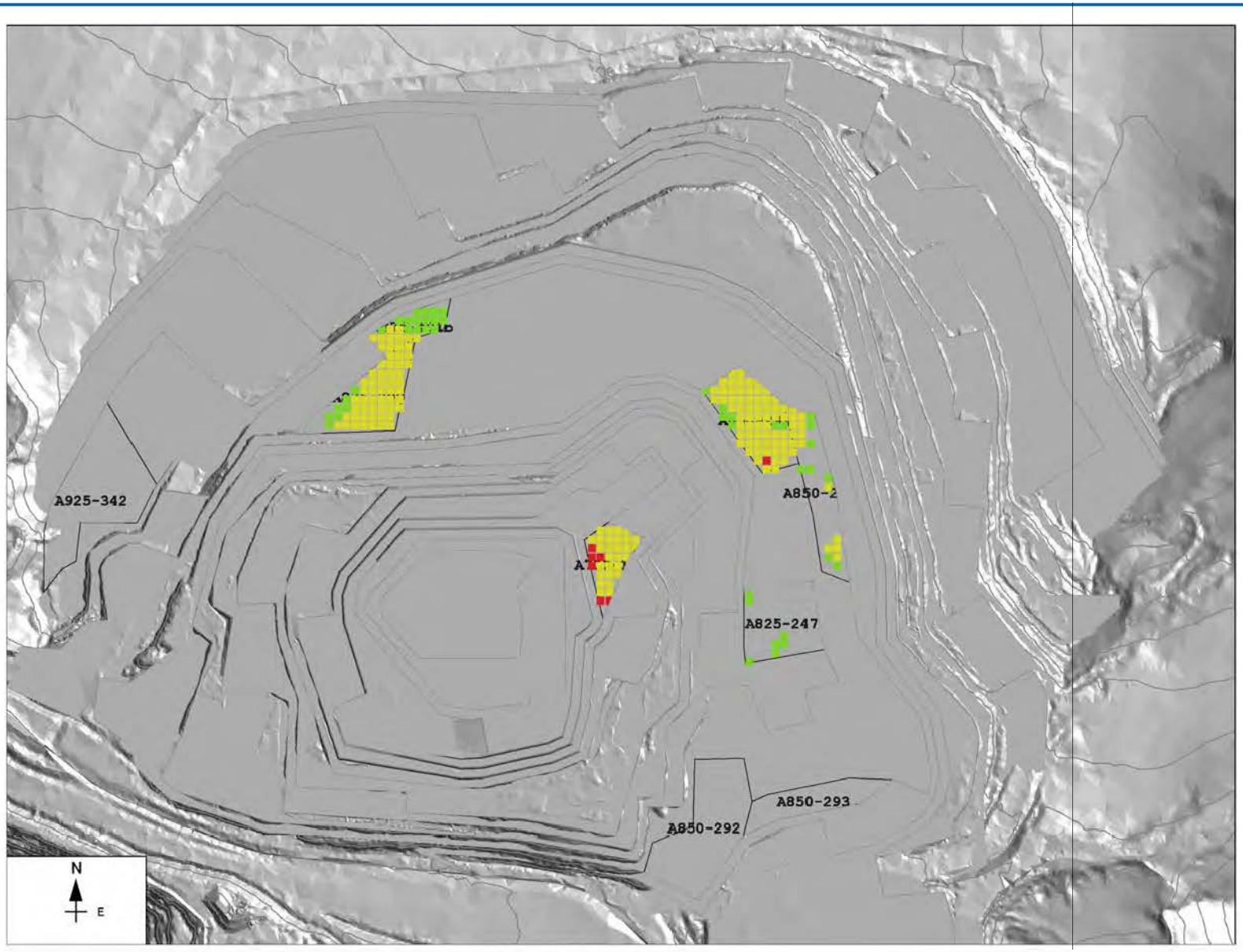


Figure 7.1-8 August 2019 Mine Plan 3D View (AQQ)

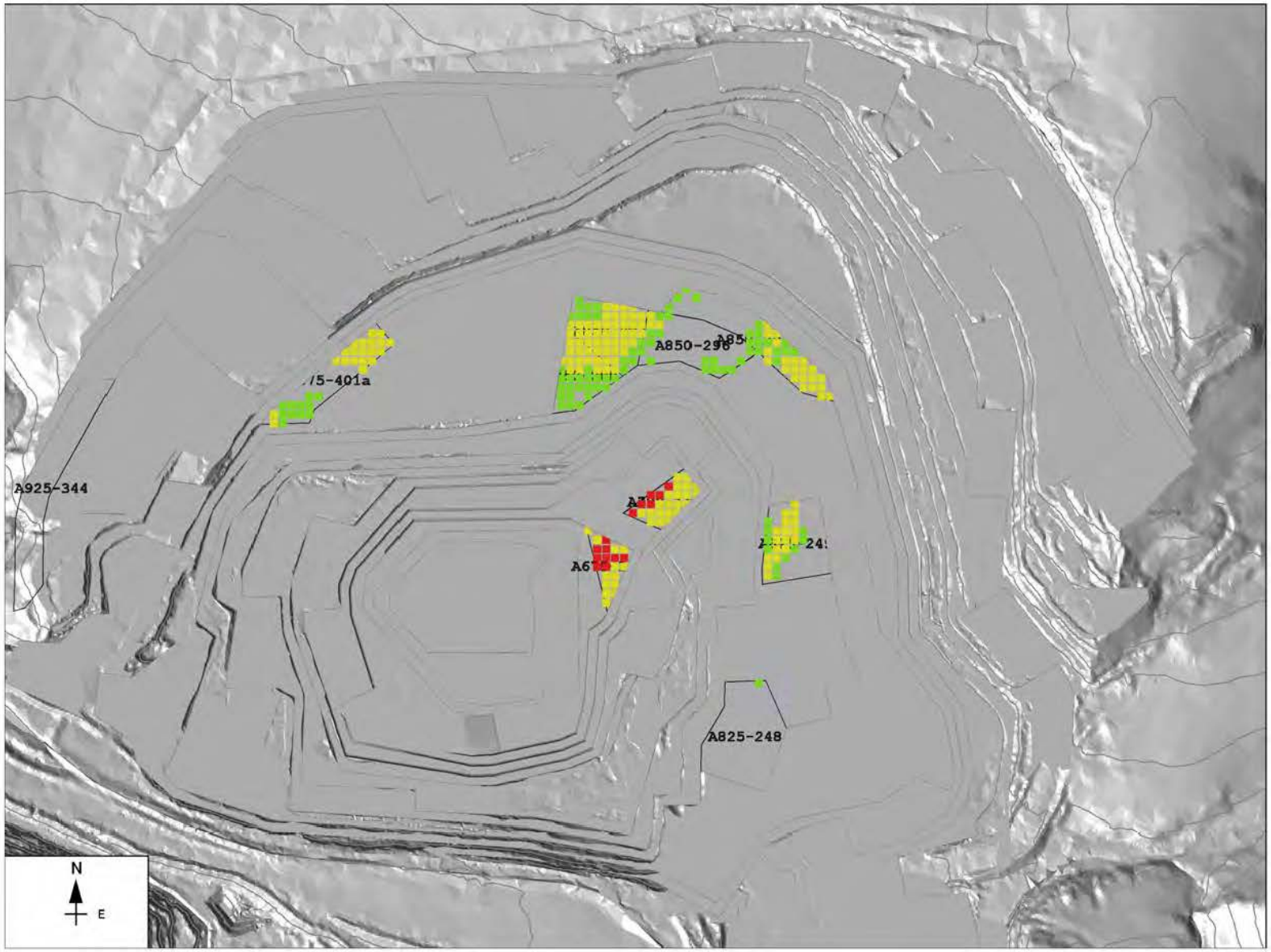


Figure 7.1-9 September 2019 Mine Plan 3D View (AQQ)

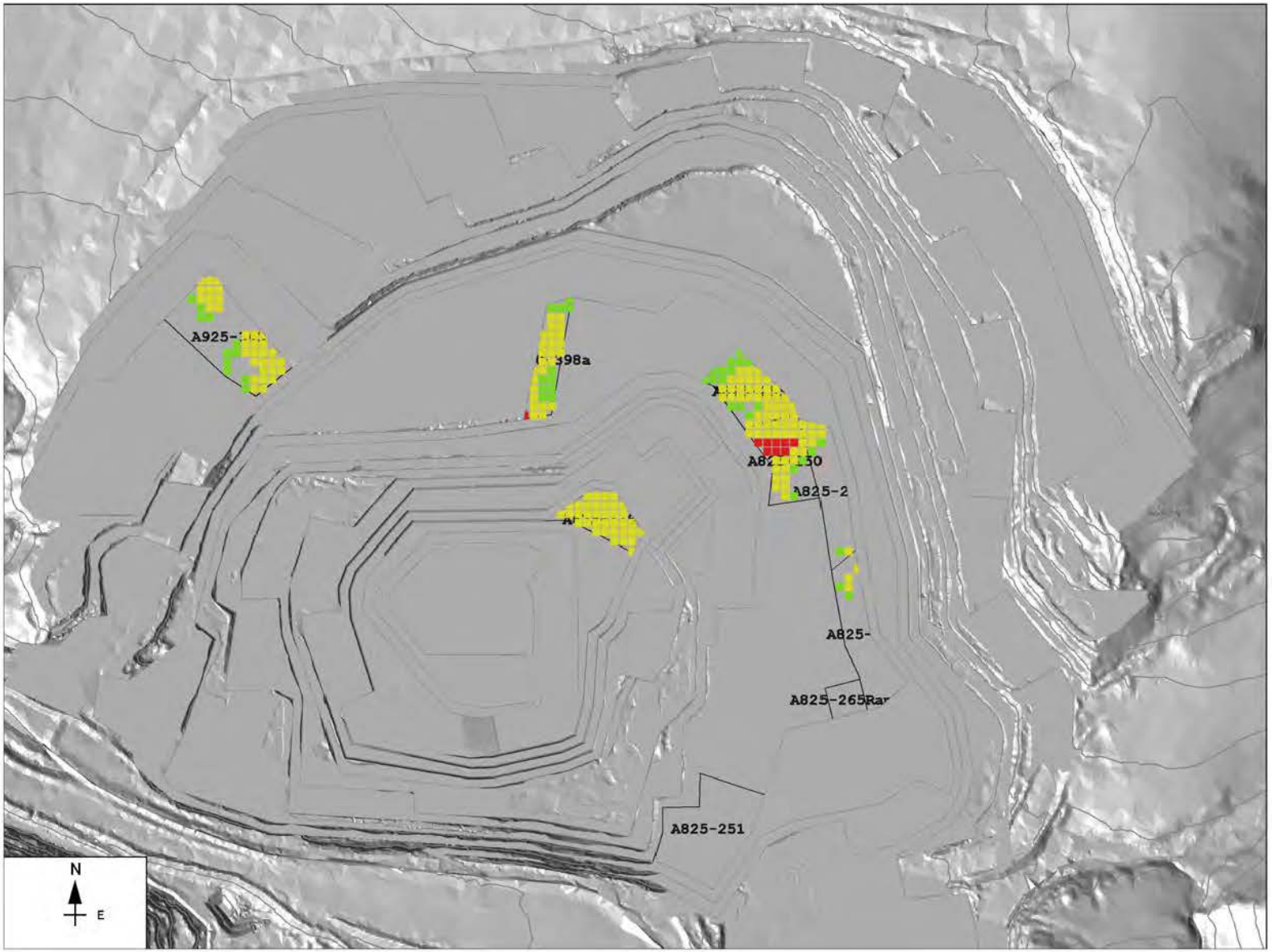


Figure 7.1-10 October 2019 Mine Plan 3D View (AQQ)

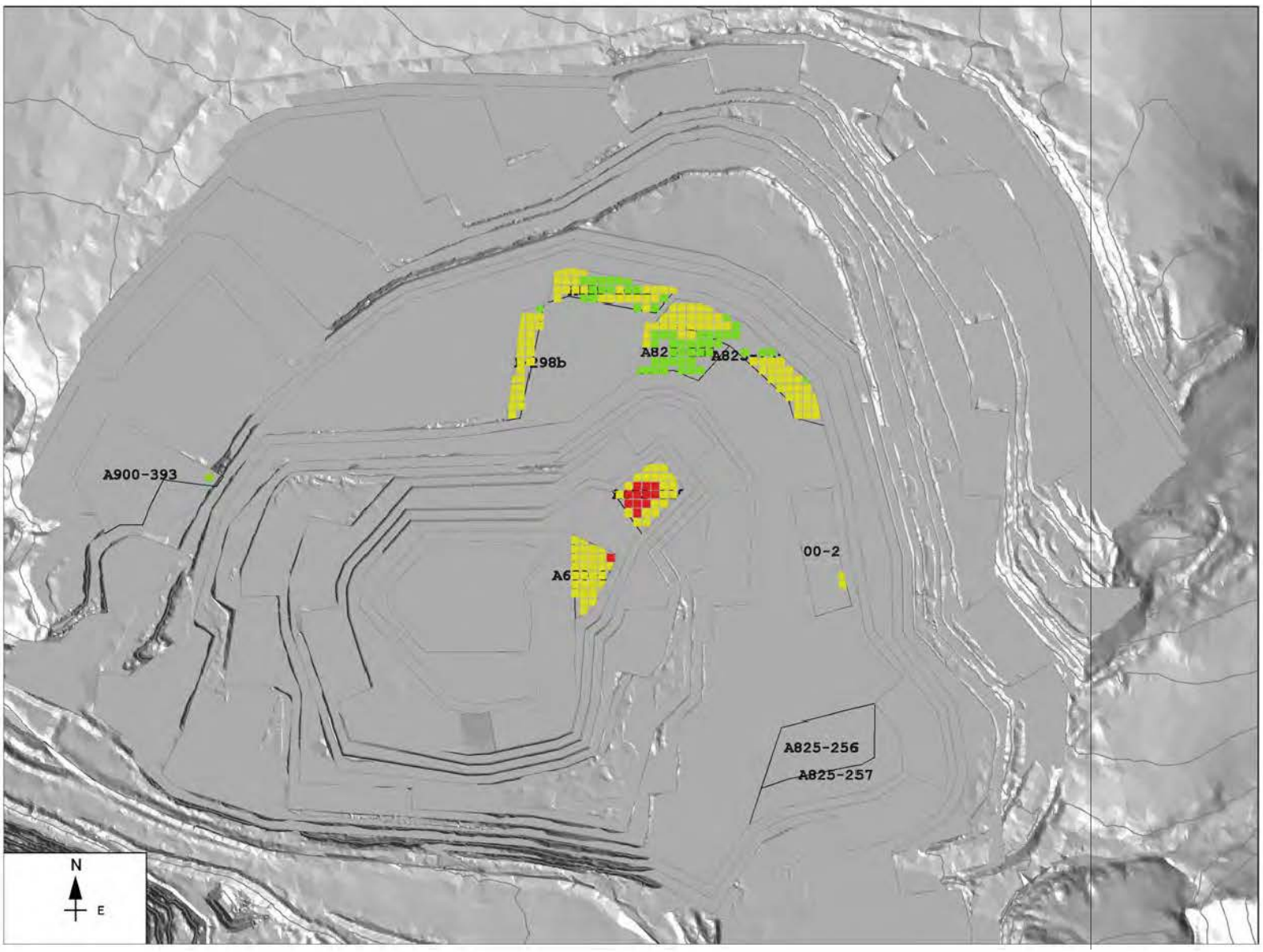


Figure 7.1-11 November 2019 Mine Plan 3D View (AQQ)

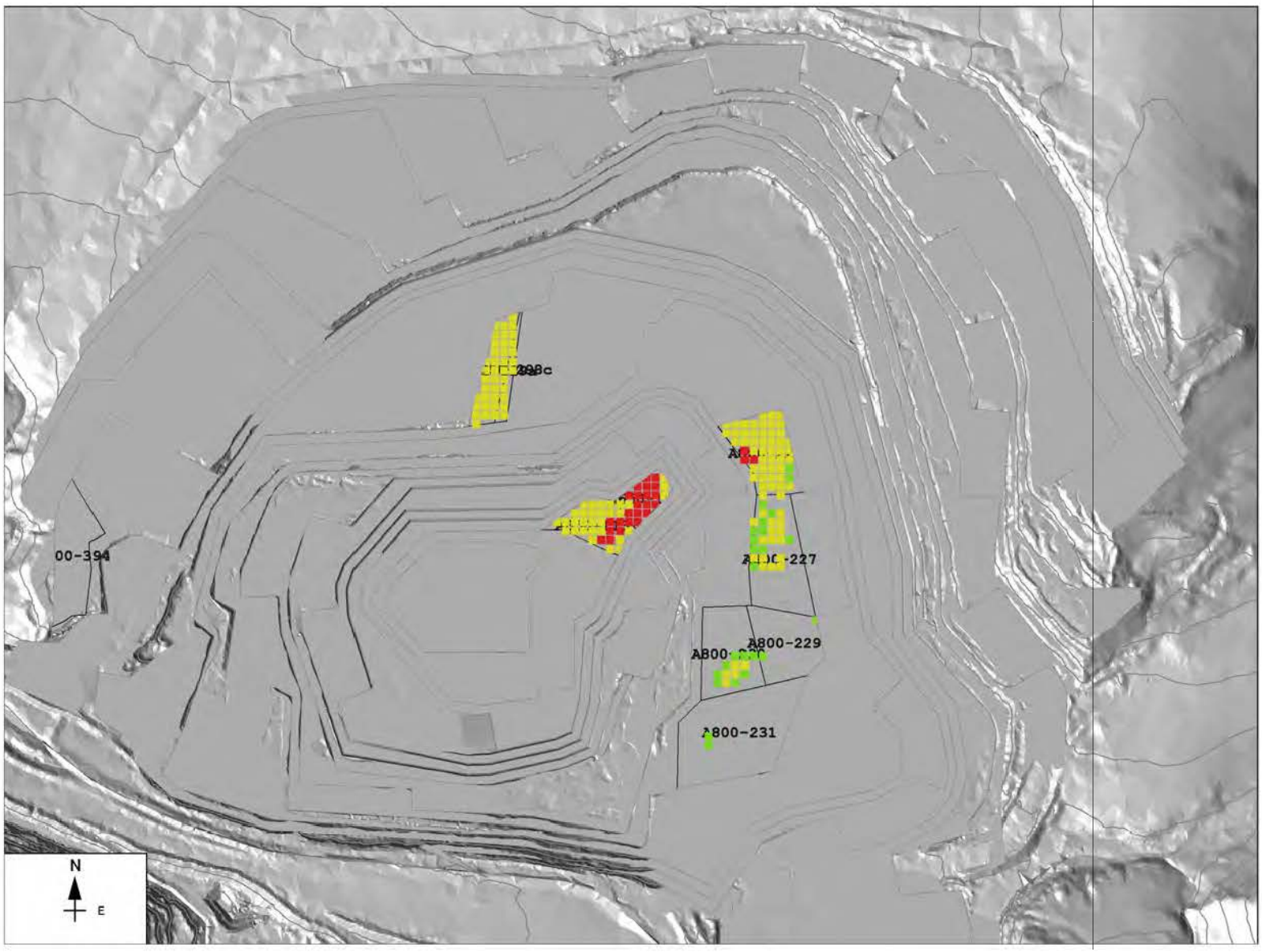


Figure 7.1-12 December 2019 Mine Plan 3D View (AQQ)

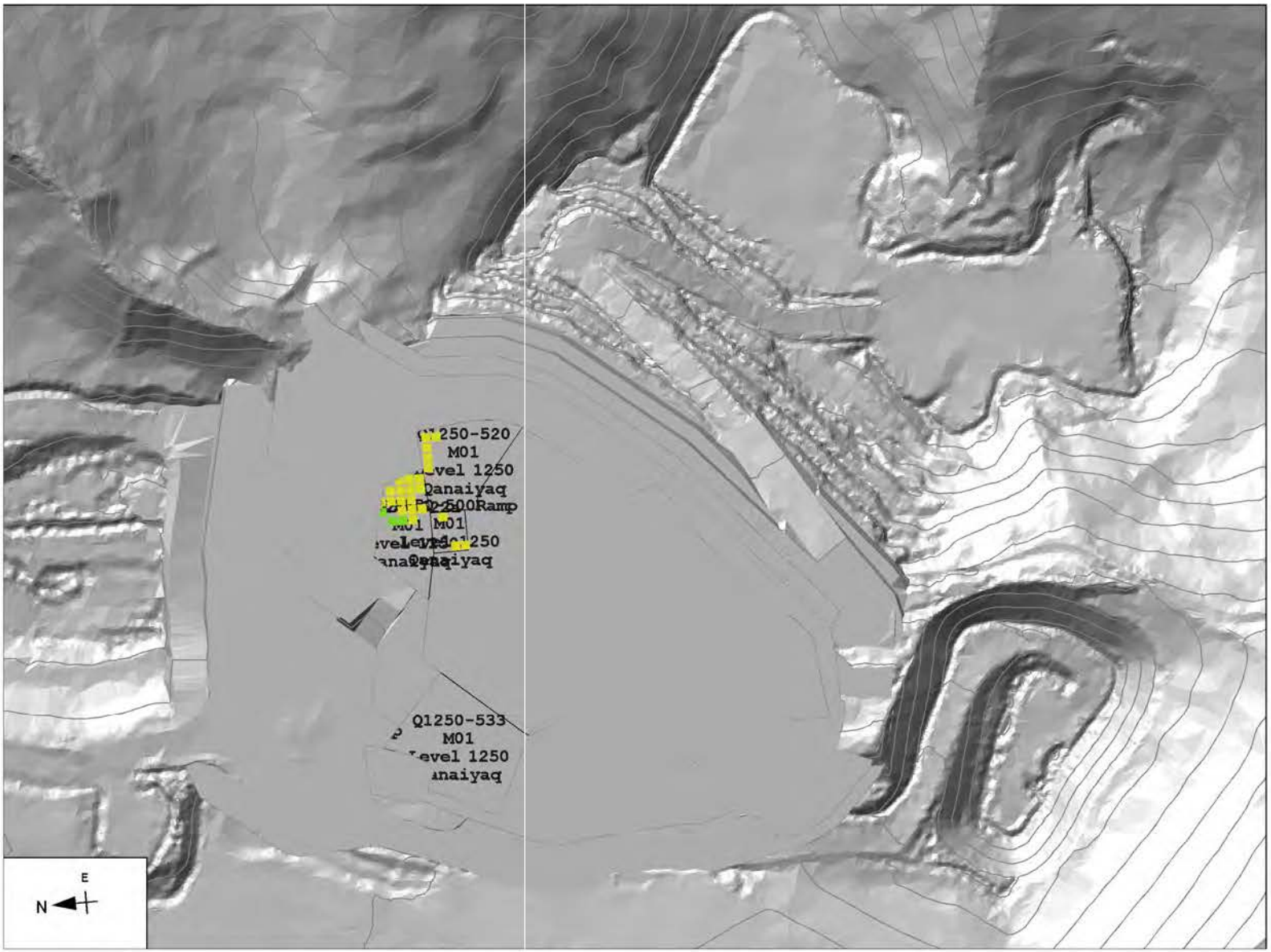


Figure 7.1-13 January 2019 Mine Plan 3D View (QAN)

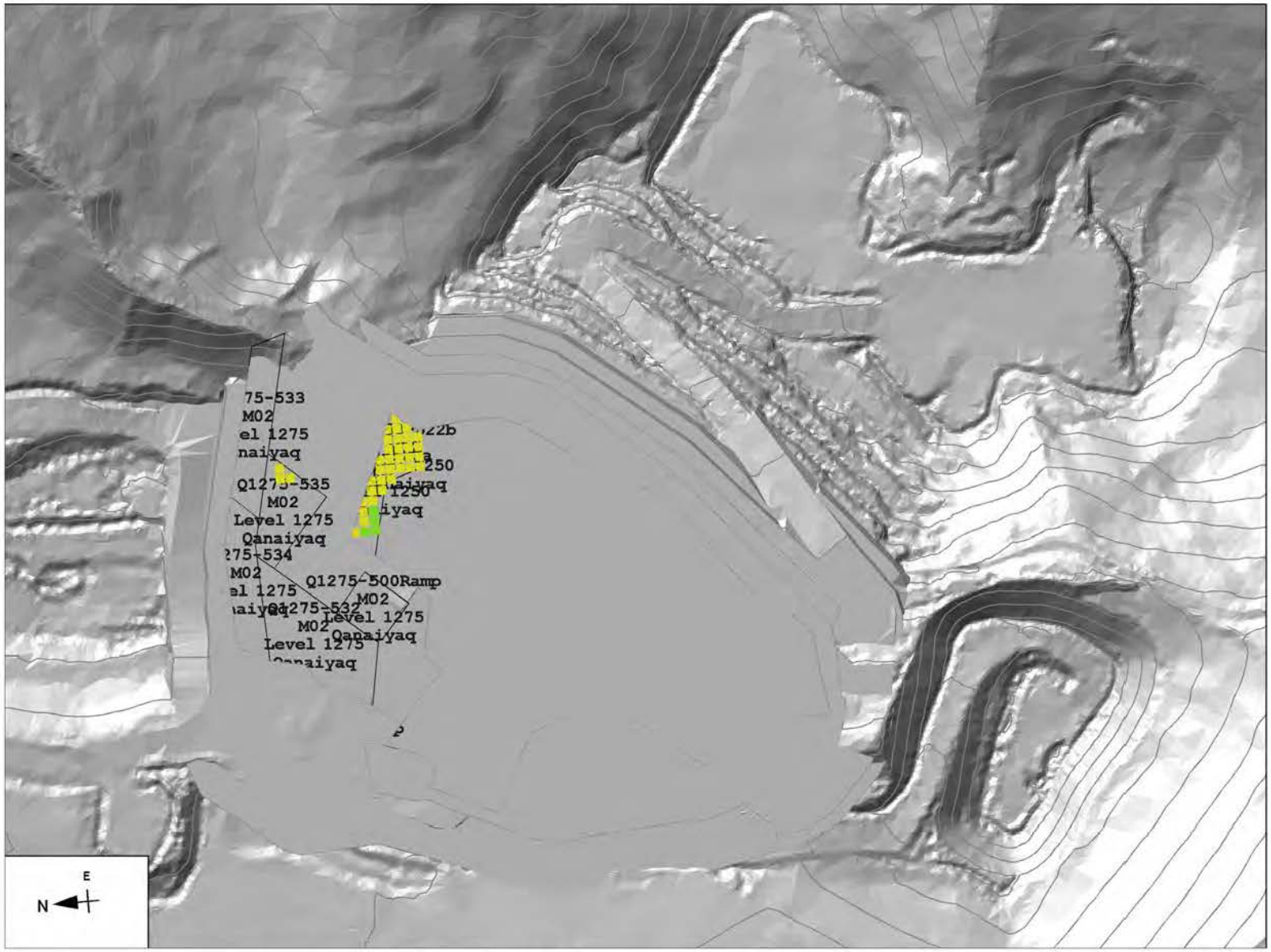


Figure 7.1-14 February 2019 Mine Plan 3D View (QAN)

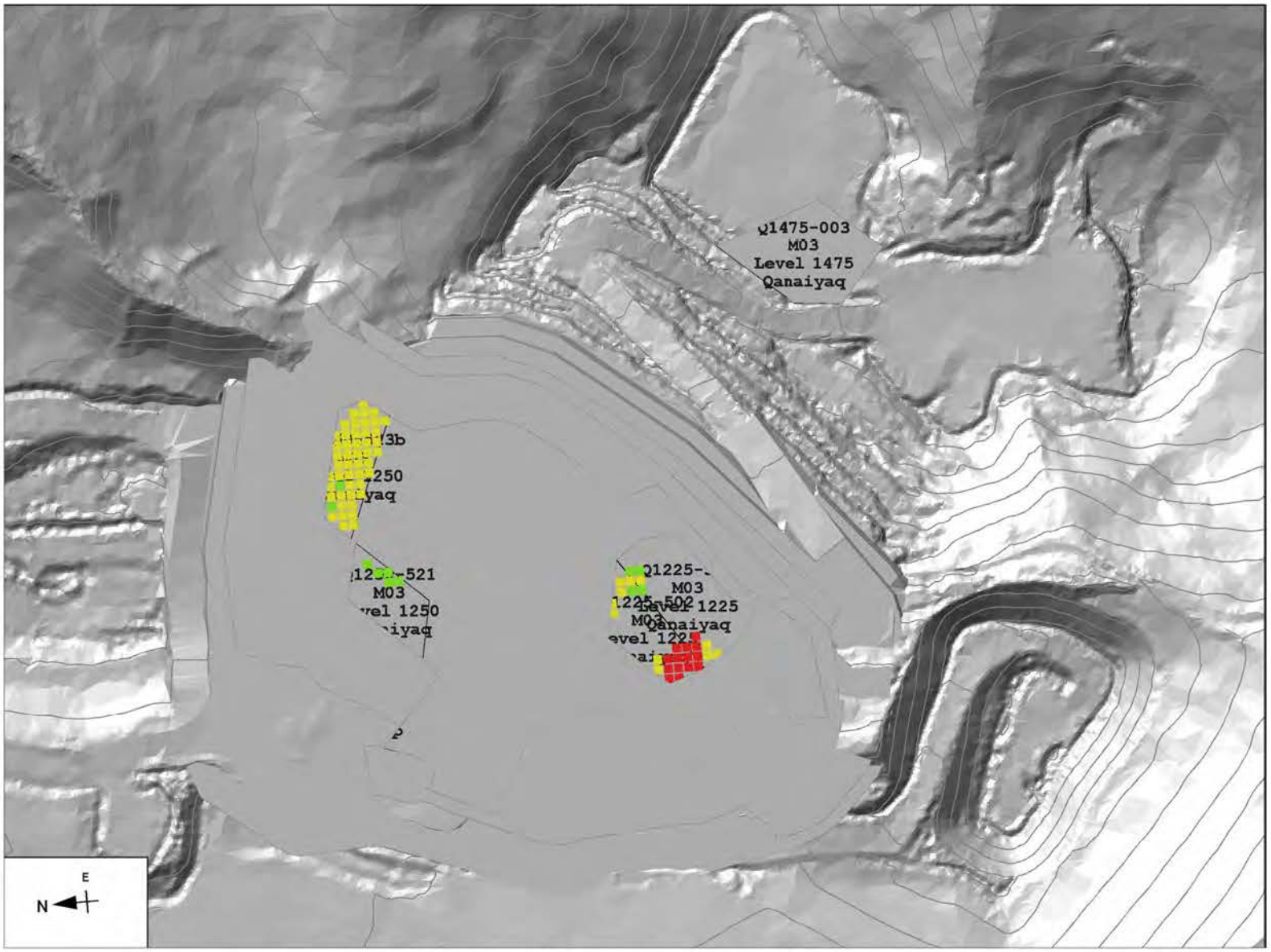


Figure 7.1-15 March 2019 Mine Plan 3D View (QAN)

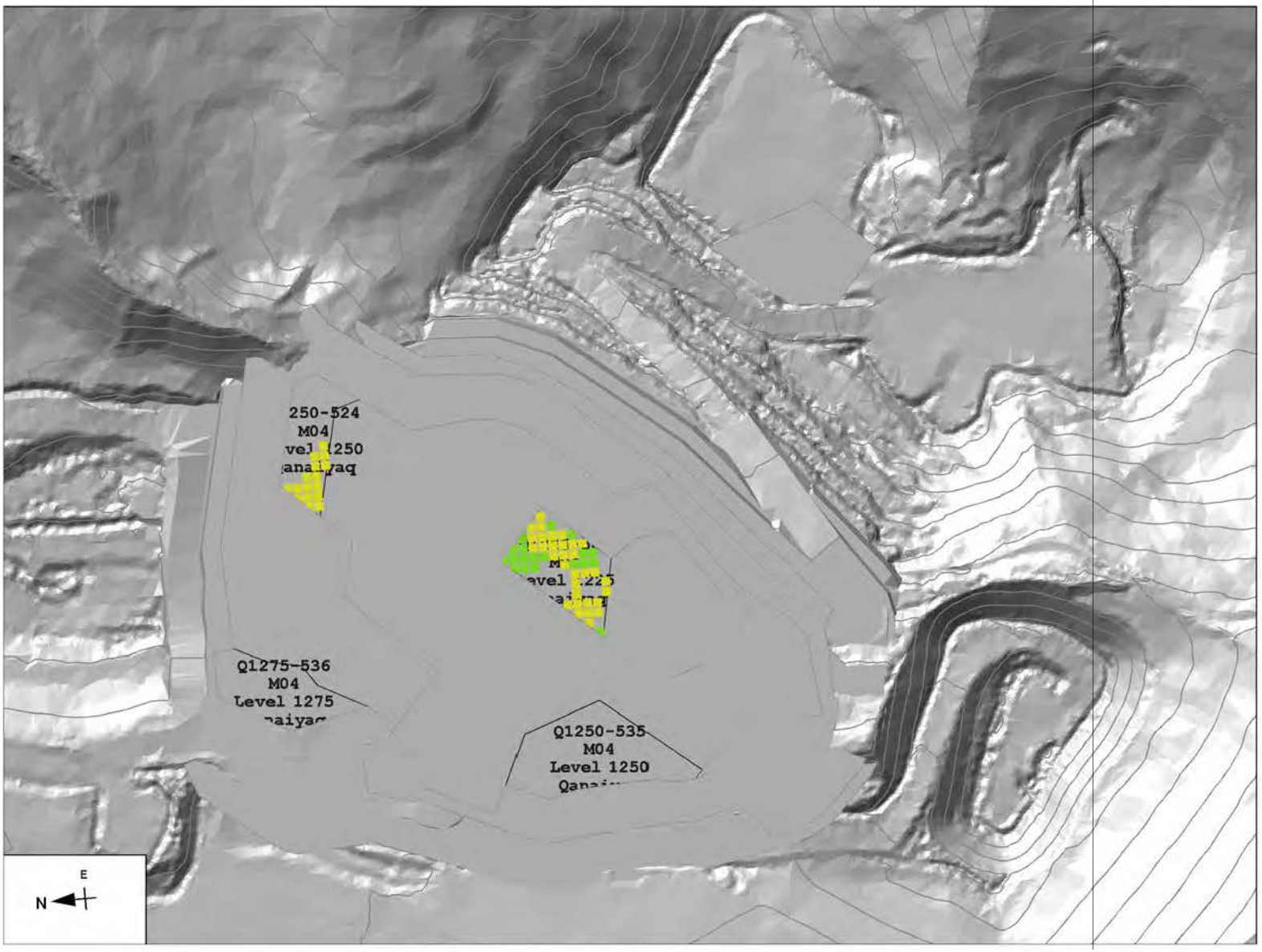


Figure 7.1-16 April 2019 Mine Plan 3D View (QAN)

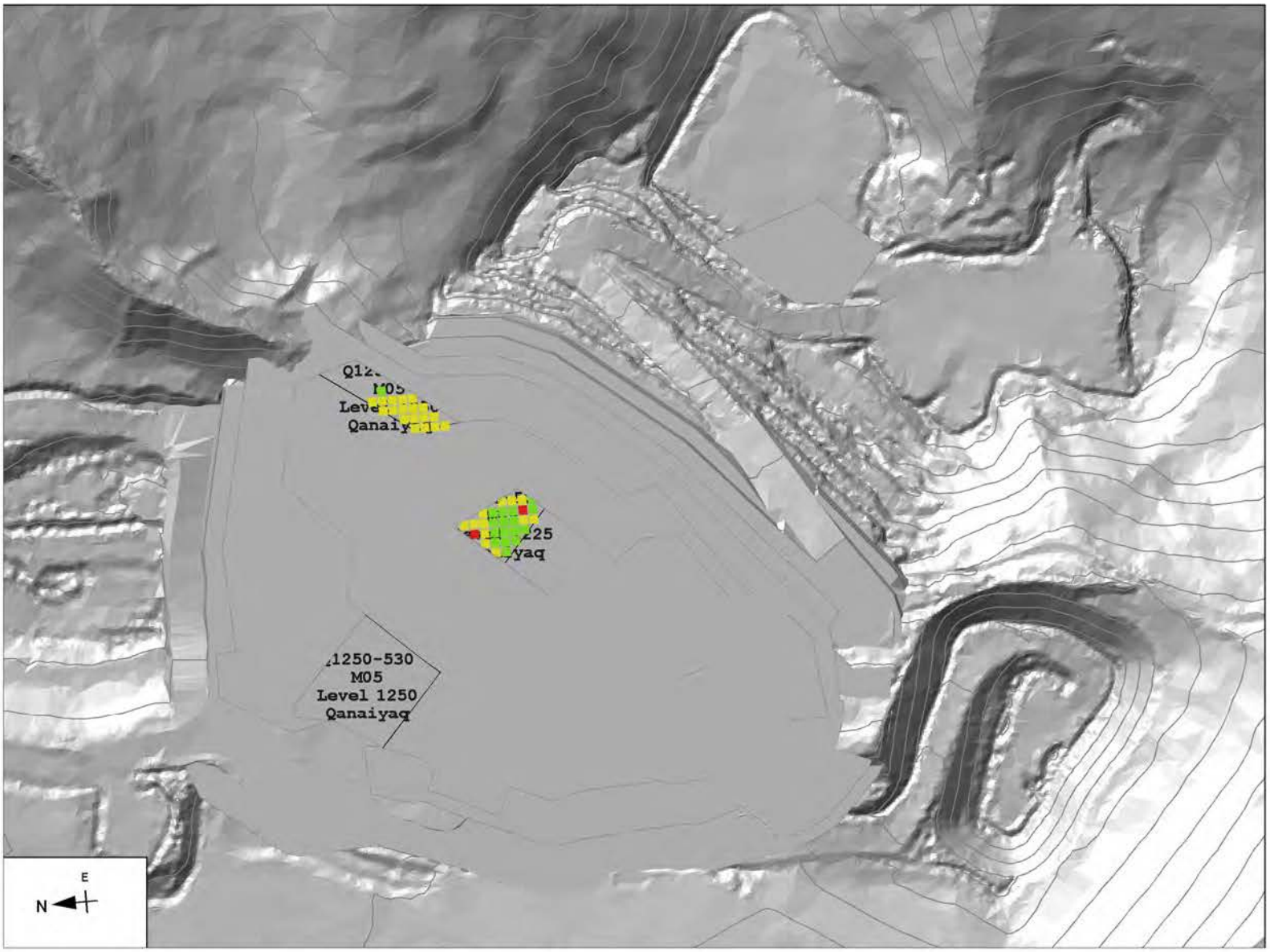


Figure 7.1-17 May 2019 Mine Plan 3D View (QAN)

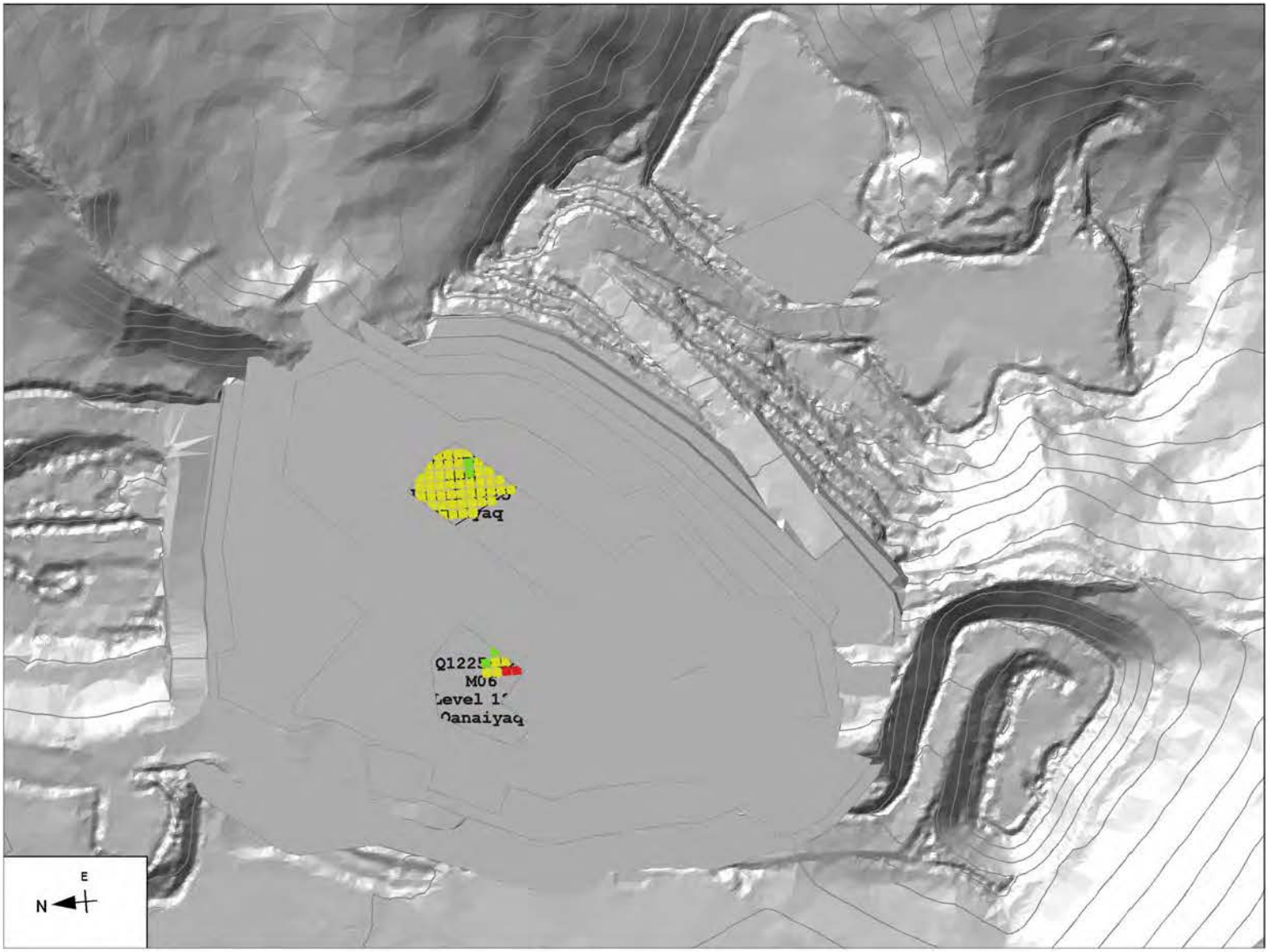


Figure 7.1-18 June 2019 Mine Plan 3D View (QAN)

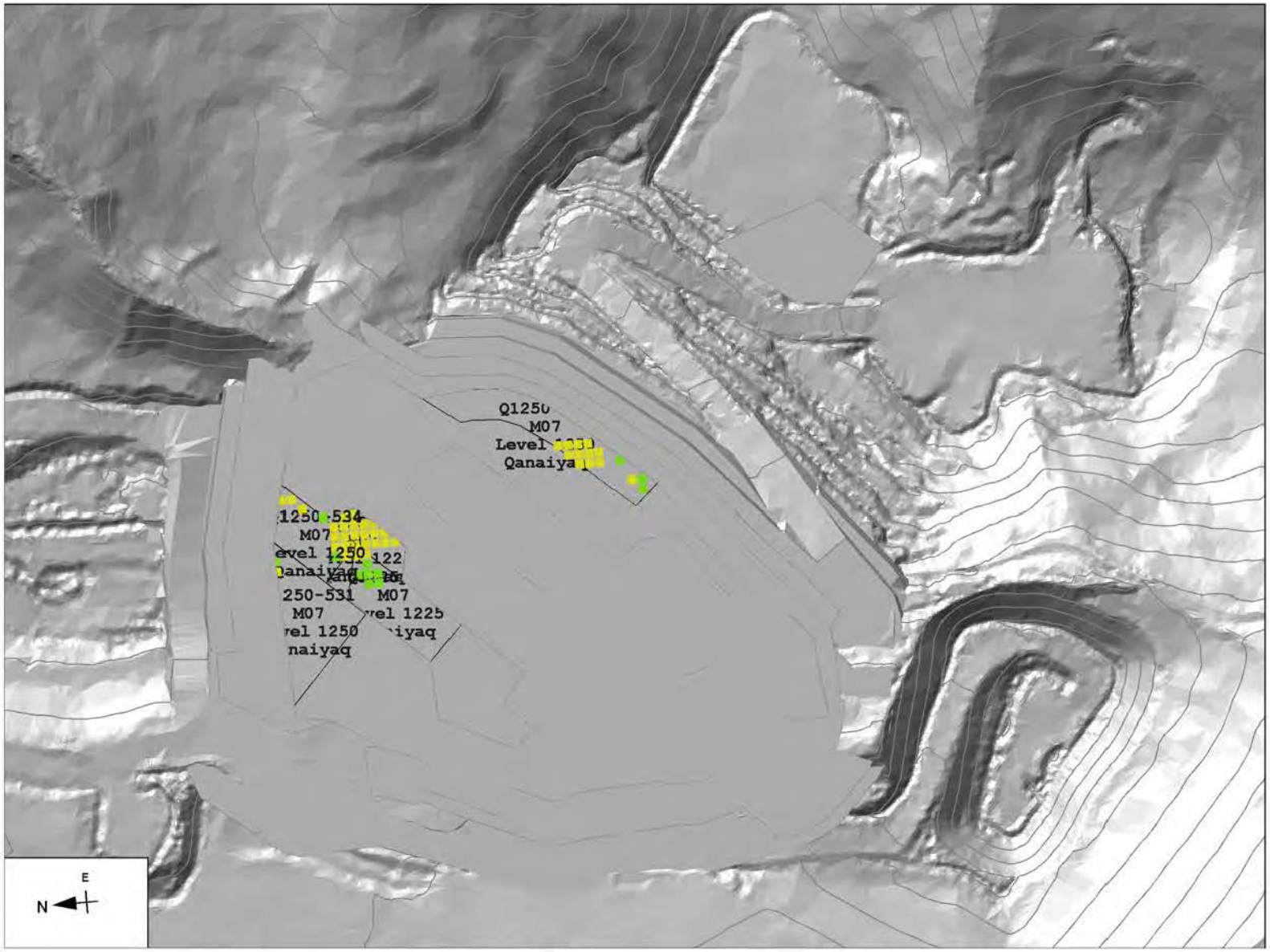


Figure 7.1-19 July 2019 Mine Plan 3D View (QAN)

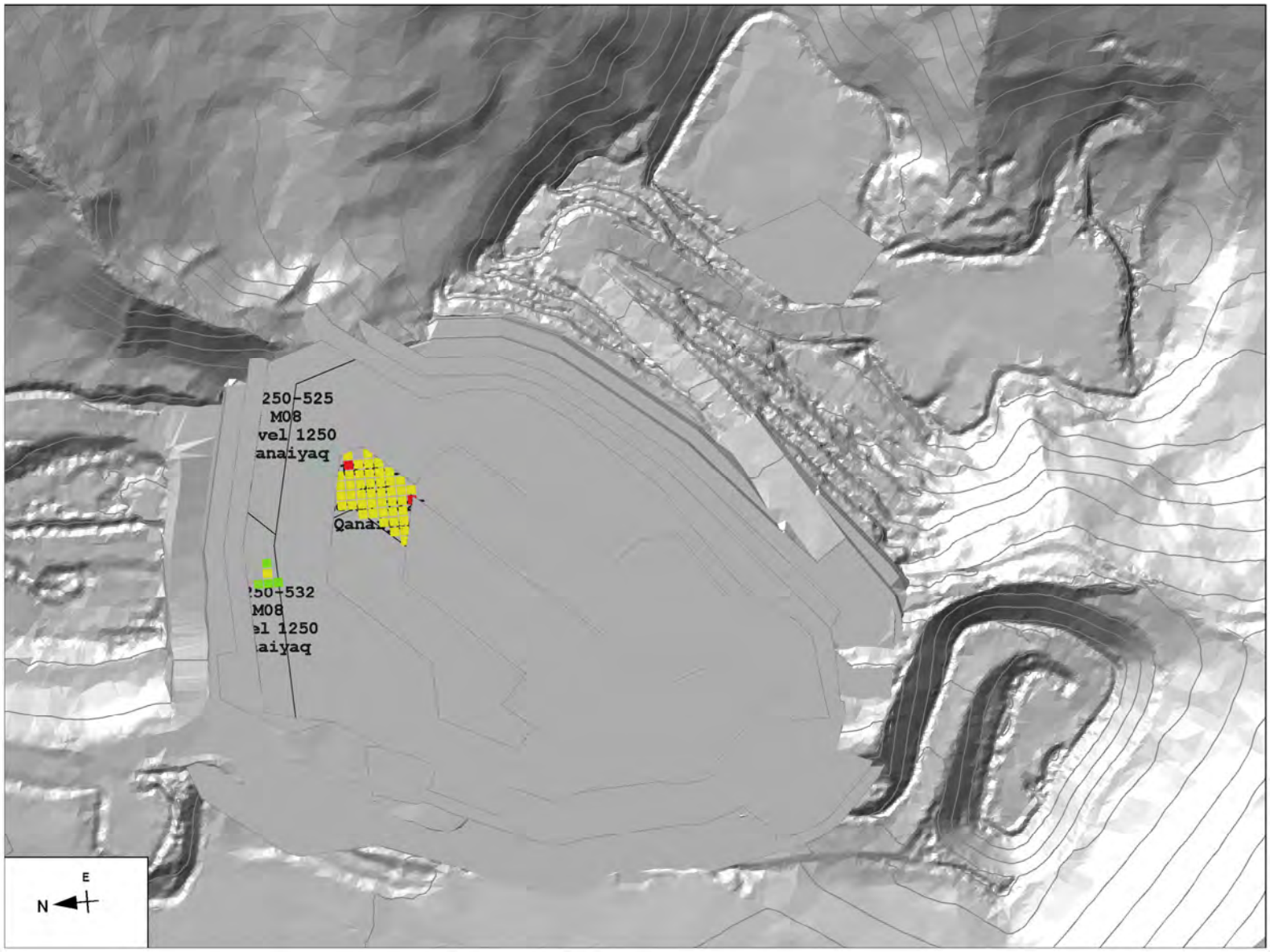


Figure 7.1-20 August 2019 Mine Plan 3D View (QAN)

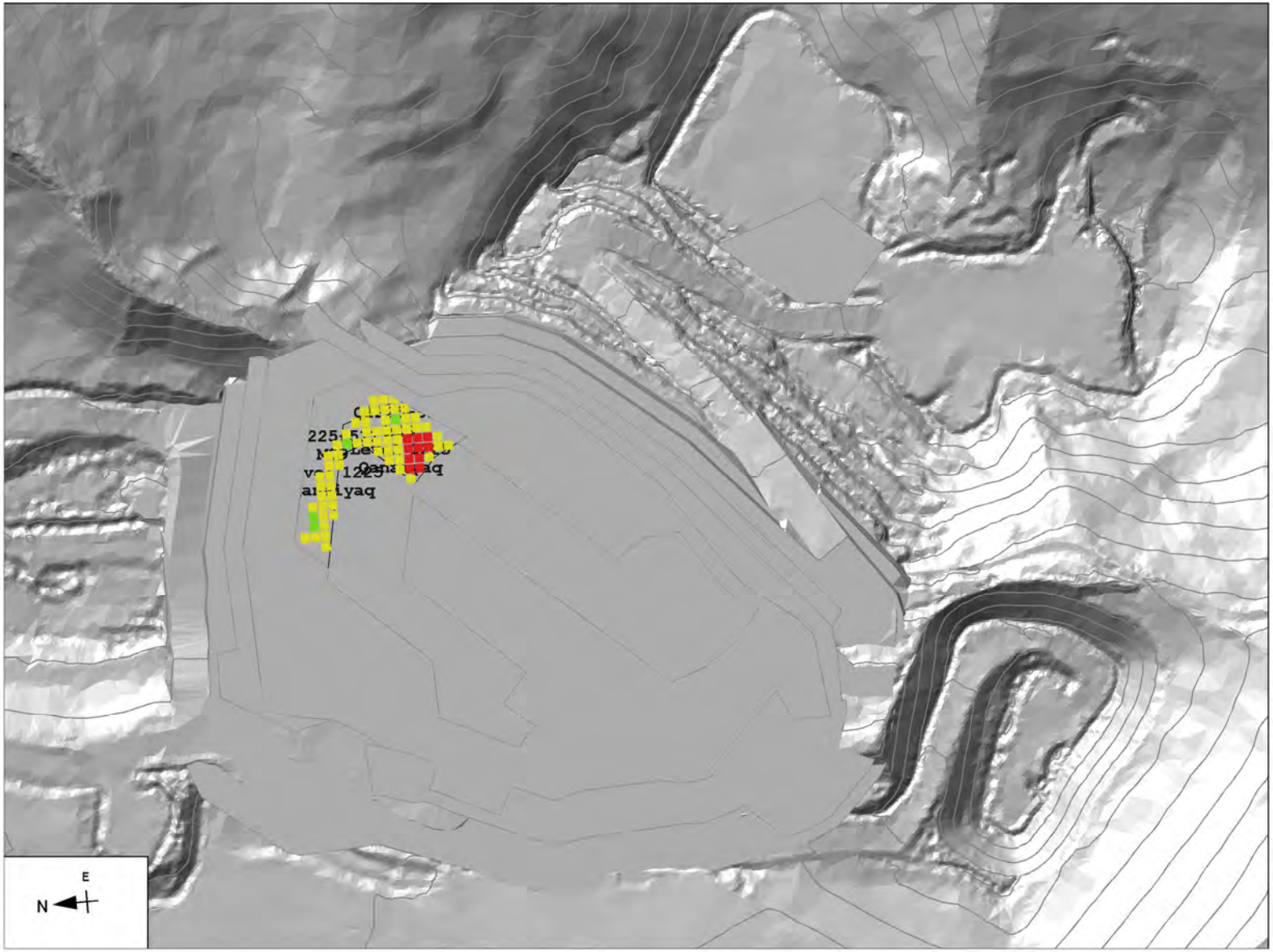


Figure 7.1-21 September 2019 Mine Plan 3D View (QAN)

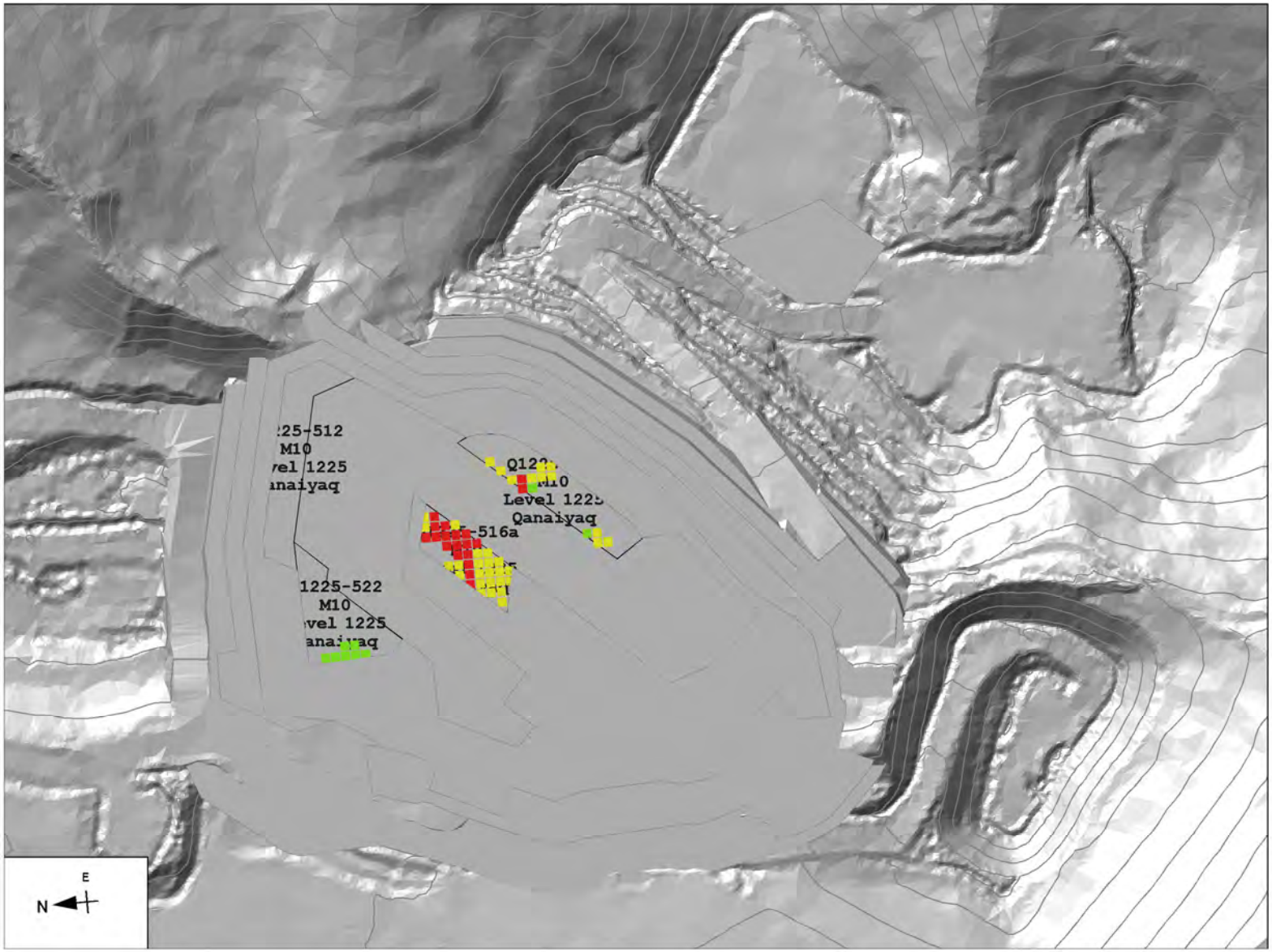


Figure 7.1-22 October 2019 Mine Plan 3D View (QAN)

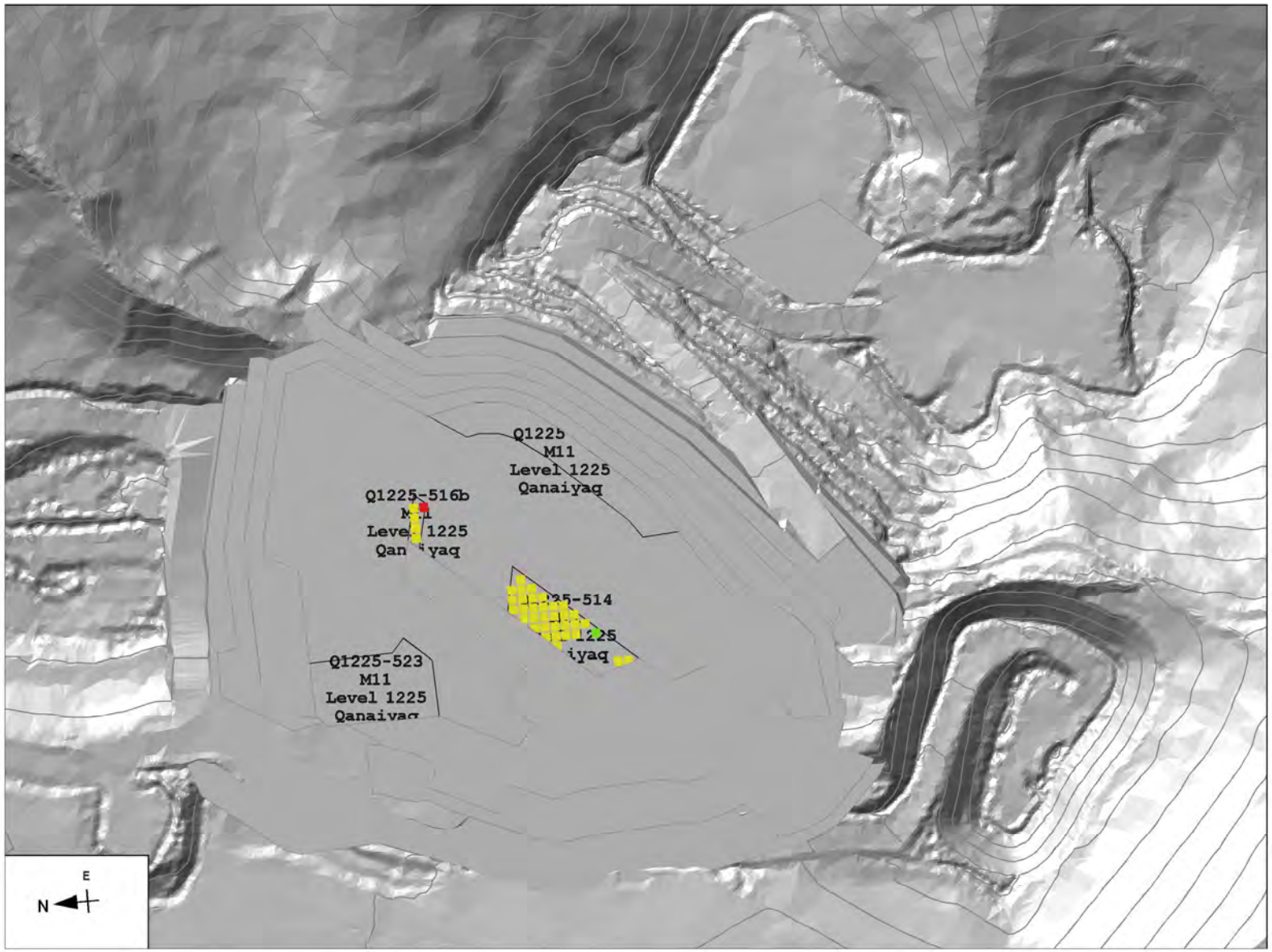


Figure 7.1-23 November 2019 Mine Plan 3D View (QAN)

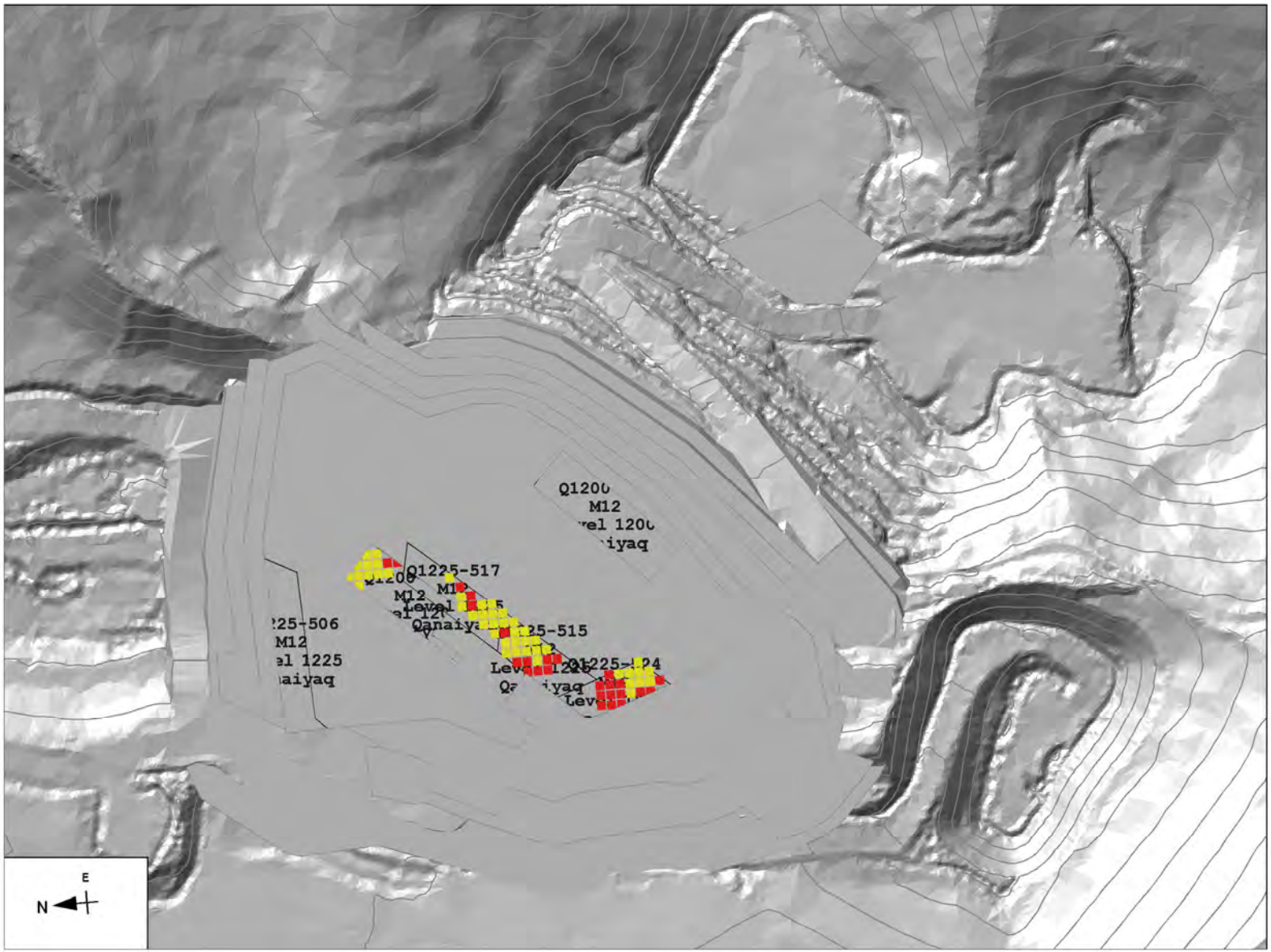


Figure 7.1-24 December 2019 Mine Plan 3D View (QAN)

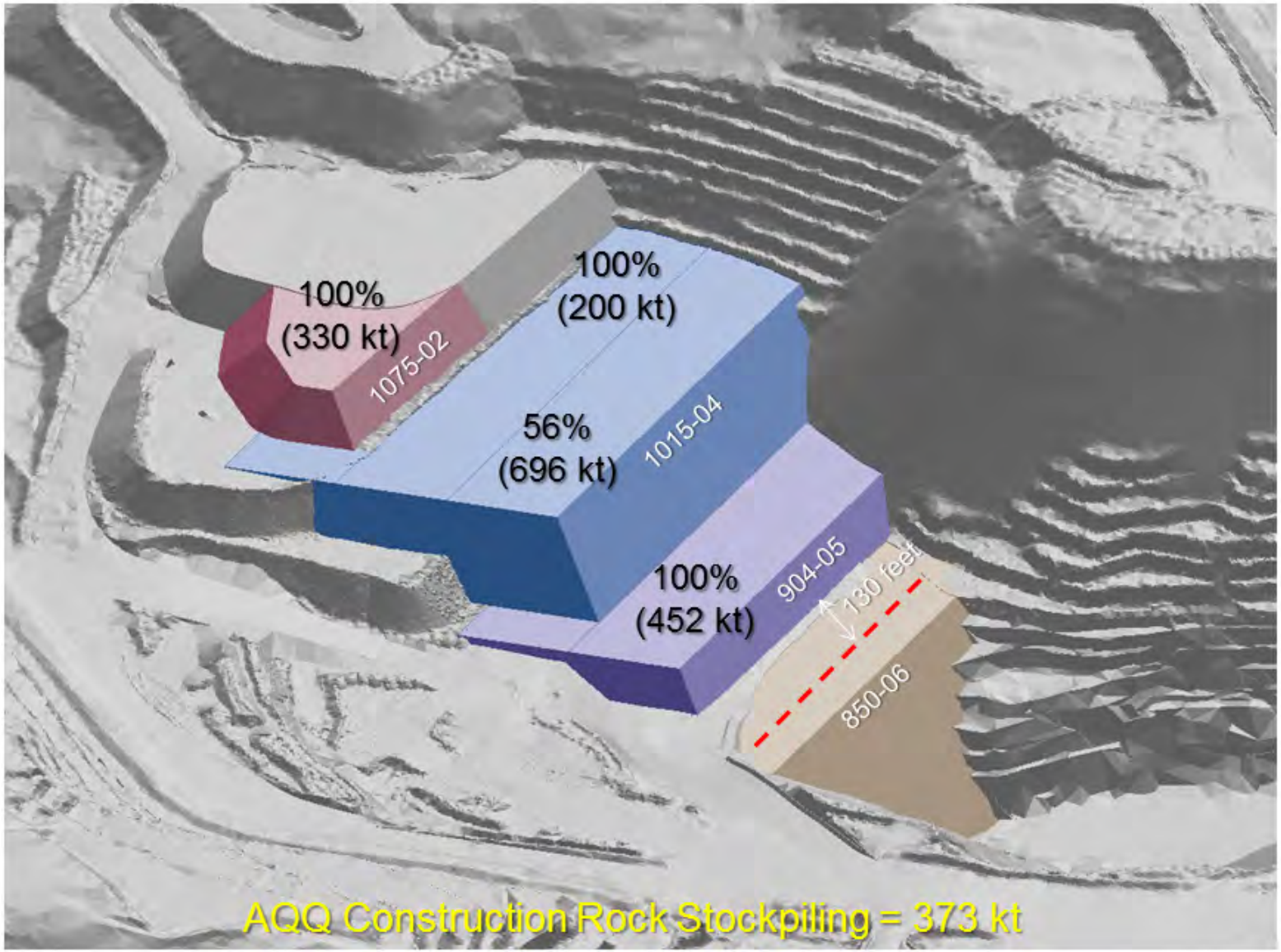


Figure 7.1-25 MPD Progression, End of May 2019

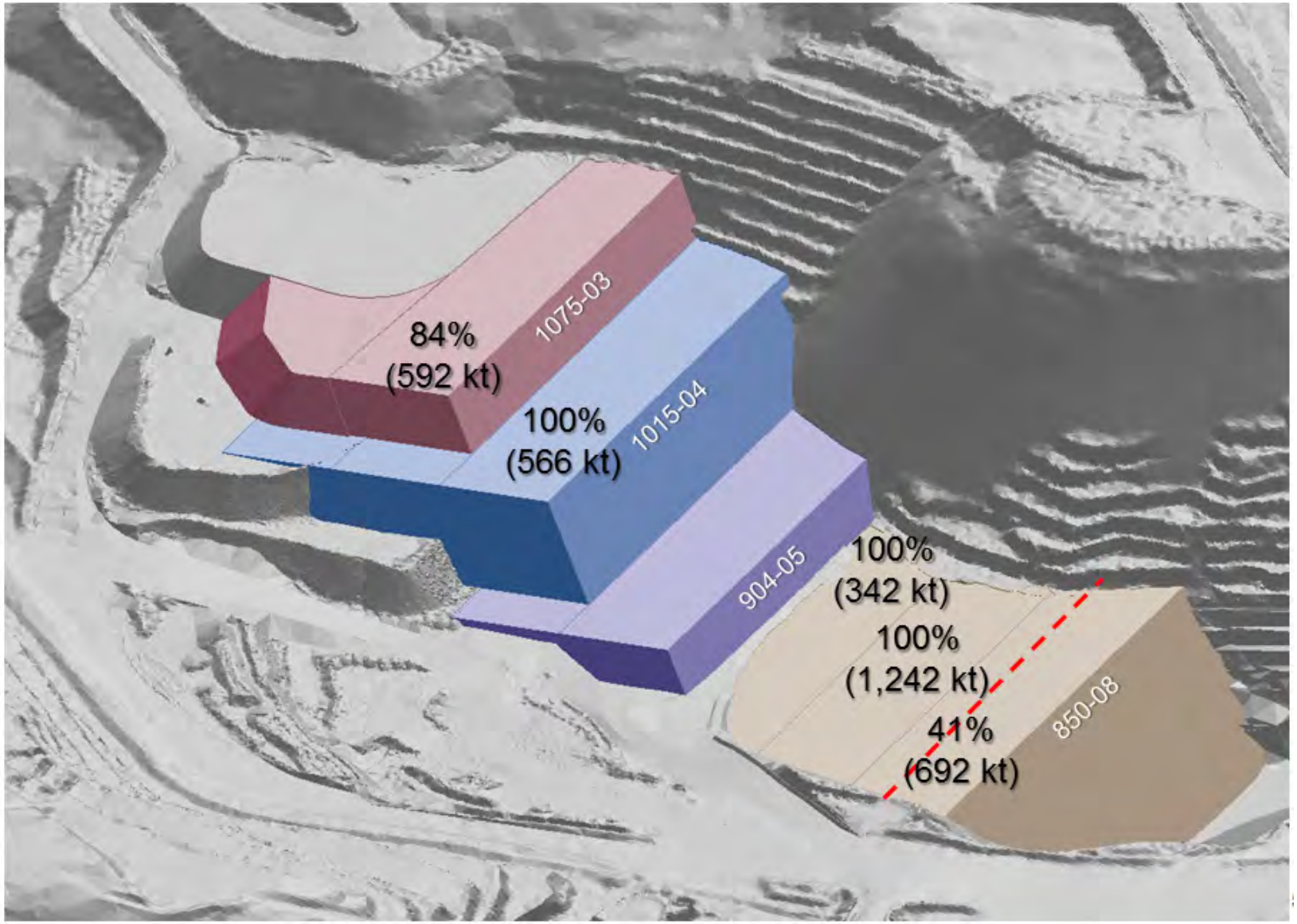


Figure 7.1-26 MPD Progression, End of December 2019