GROUNDWATER MONITORING OF SHALLOW WELL NETWORKS

Ignace Pressure Data Annual Report 2022

APM-REP-01332-0411 **November 2024**

KGS Group

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Groundwater Monitoring of Shallow Well Networks – Ignace Pressure Data Annual Report 2022

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TABLE OF CONTENTS

List of Tables

List of Figures

List of Appendices

STATEMENT OF LIMITATIONS AND CONDITIONS

Limitations

This report has been prepared for Nuclear Waste Management Organization (NWMO) in accordance with the agreement between KGS Group and NWMO (the "Agreement"). This report represents KGS Group's professional judgment and exercising due care consistent with the preparation of similar reports. The information and recommendations in this report are subject to the constraints and limitations in the Agreement and the qualifications in this report. This report must be read as a whole, and sections or parts should not be read out of context.

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1.0 INTRODUCTION

1.1 Overview

The Groundwater Monitoring of Shallow Well Networks project is part of the Phase 2 Geoscientific Preliminary Field Investigations of the NWMO's Adaptive Phased Management (APM) Site Selection Phase. As part of the Phase 2 Preliminary Field Investigations, NWMO has established a shallow groundwater monitoring network at the two potential candidate sites in Canada. The sites are located in the Wabigoon Lake Ojibway Nation (WLON)-Ignace Area in Northwestern Ontario and Saugeen Ojibway Nation (SON)-South Bruce area in Southern Ontario. The objective of this project is to retrieve, on a quarterly basis, measurements of groundwater pressures and temperatures that are collected from installed dataloggers, and to collect groundwater samples for chemical analyses. The collection of this information is necessary to evaluate shallow groundwater system behaviour and characteristics.

A separate test plan was prepared for each of the two locations so that details specific to each site can be properly captured and planned for. The field work for each Site started in the beginning of the third quarter (Q3) of year 2022, i.e., in the month of July, followed by another field event in September 2022. The final field work event for the year 2022 was conducted in its fourth quarter (Q4), in the month of December.

This annual report presents the work completed and the data findings/analysis for the groundwater pressure data and results collected in 2022 from the shallow well network in the WLON-Ignace area, also referred to as the Revell Site.

1.2 Scope of Work

The objective of the groundwater monitoring and sampling program is to collect groundwater pressure measurements and baseline groundwater samples from each of the 27 permanently installed monitoring well intervals over two (2) years, starting in July 2022 until July 2024. This annual report focuses on the findings and analysis for the groundwater temperature and pressure data collected in the year 2022, which includes three field events occurring in the months of July, September, and December. A separate report will present the groundwater sampling results in 2022. Activities conducted and described in this report include:

- Mobilization of personnel and all required equipment
- Downloading of pressure and temperature data from each well interval via the Vibrating Wire Piezometer (VWP) transducers
- Summary of the monitoring data, including graphical presentation of pressure data results

Additional details regarding the work involved in completing specific activities outlined in the test plan are provided in Section 3.0 below. Task-specific activities to ensure health and safety, environment, data management, and quality assurance compliance are also described.

2.0 PROJECT LOCATION

2.1 Land Acknowledgment

It is important to acknowledge that this project was completed on the traditional territory of the Anishinaabe people of Treaty Three. KGS Group and its subcontractors are grateful for being given the opportunity to complete work within the area and are thankful for the generations of people who have taken care of the land for thousands of years.

2.2 Study Area

The Revell site is located on the Canadian Shield, approximately 43 km northwest of the Town of Ignace, 21 km southeast of the Wabigoon Lake Ojibway Nation, and 260 km northwest of Lake Superior (NWMO, 2023), Figure 1.

The ground surface elevation at the western boundary of the Revell site where the Wabigoon River lies, is at 368 metres above sea level (masl), while it increases to 554 masl at the southeastern boundary of the site (NWMO, 2023). The site area is comprised of rolling surfaces of Canadian Shield bedrock that is either covered with shallow glacial deposits or is exposed to the ground surface. This reflects an interplay between glacial action and rock resistance, with weaker rocks having been eroded to lower elevations while more resistant rocks forming the topographic highs (Renwick, 2009). The two major surface soils in the Ignace area are clay and sand of morainal, glaciofluvial or glaciolcustrial origin (Golder, 2013).

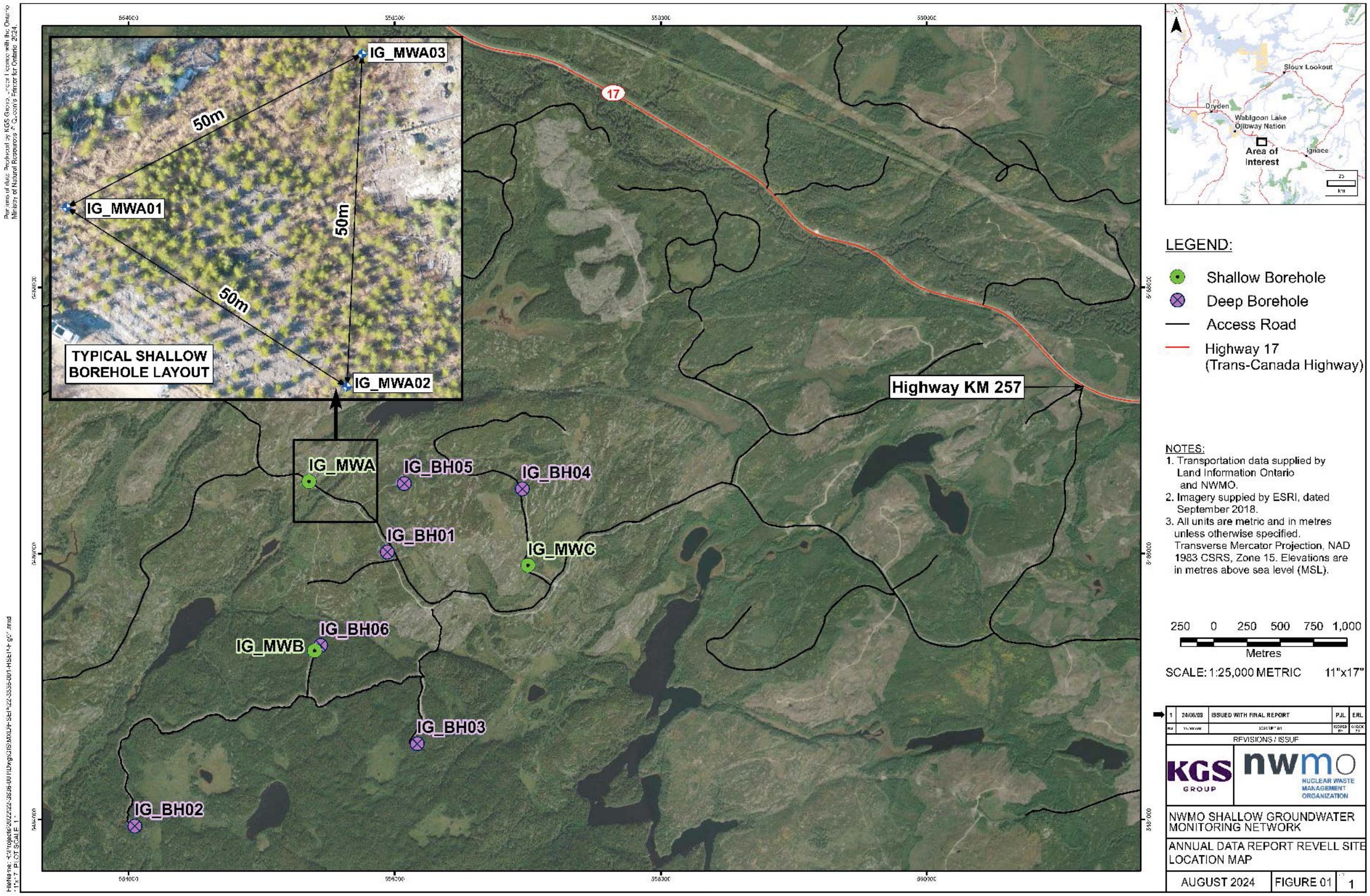
The Ignace area lies within the Superior Province of Canadian Shield and is underlain by Archean bedrock created from several ancient and tectonically stable plates, and gradually accumulated juvenile arc terranes (Card and Ciesielski, 1986). Within the Superior Province, the area is situated in the central portion of Wabigoon Subprovince which is comprised of thin greenstone belts that are separated by large felsic plutonic rock masses (Stone, 2010a). A number of granite and granodioritic batholiths dominate the bedrock geology of the Ignace area (Stone, 2010a). The geological setting of the Ignace area is discussed in detail by Golder, 2013.

There are numerous lakes in the Ignace area which are interconnected by a network of rivers such as the English, Wabigoon, and Turtle rivers. These rivers drain into the Nelson River which further flows into the Hudson Bay as its largest contributor of fresh water (NWMO, 2013). Details about the three tertiary-scale watersheds and several quaternary-scale watersheds in the Ignace area are provided in the Phase 1 Geoscientific Desktop Study by NWMO, 2013.

A total of nine (9) 100 m deep multilevel monitoring wells were drilled and installed in 2021 (KGS Group, 2023). Three multilevel monitoring wells were drilled and installed at three separate sites. Each multilevel monitoring well is comprised of three discrete depths/zones that have dedicated pressure monitoring instrumentation, to measure and record groundwater pressures and temperatures, thus, leading to a total of 27 separate monitoring well points. The three pressure monitoring instruments are connected to a datalogger on surface. Each multilevel well also has equipment for collecting groundwater samples. The three multilevel monitoring well sites include (Figure 1):

- IG_MWA
- IG_MWB
- IG_MWC

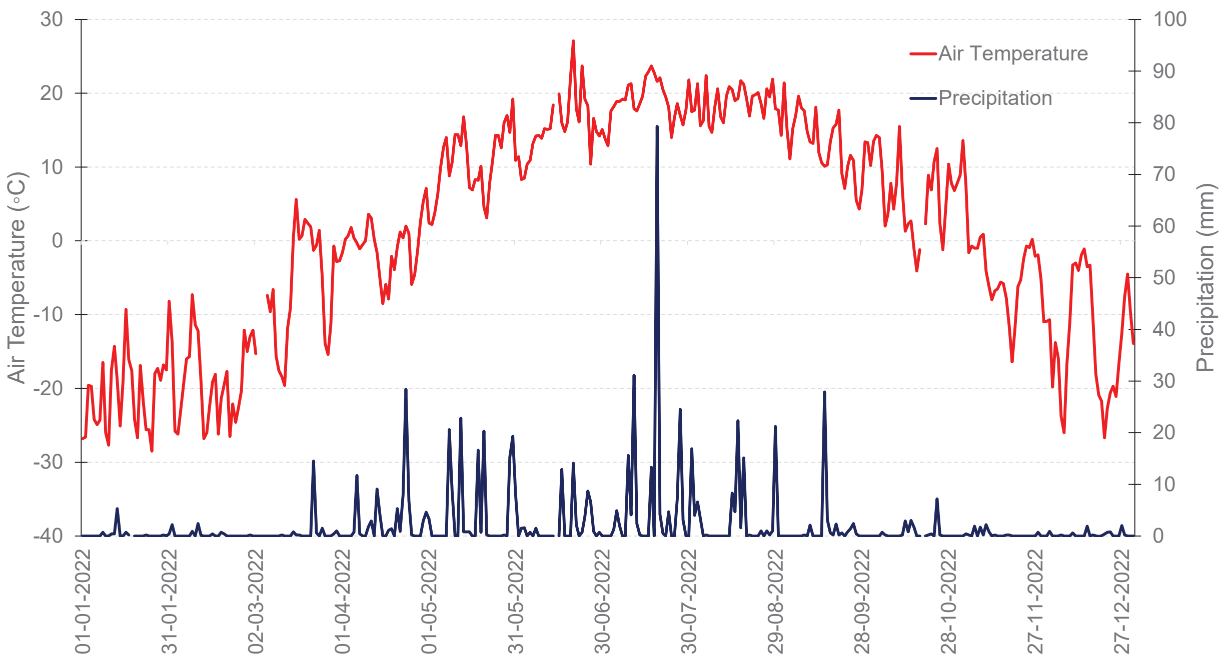
FIGURE 1 SITE LOCATION



2.3 Climate

The study area is subject to a humid continental climate of the warm summer subtype (Dfb under the Köppen climate classification defined by Kottek et al., (2006)). The closest weather station that exhibits the 1981-2010 Climate Normal Data is located in Dryden, ON, and is located approximately 49 kms Northwest of the Site (Environment and Climate Change Canada, 2017). The monthly average temperature varies from -16.8 ^{o}C in January to 18.9 ^{o}C in July as per the 1981 – 2010 Canadian Climate Normal. The area receives an average annual rainfall precipitation of 555.8 mm and 174.7 mm of snowfall precipitation, with a total annual precipitation of 719.7 mm. The wettest months are June and July (Environment and Climate Change Canada, 2017). The daily temperature and precipitation data for the year 2022 was available from the Dryden (Regional) weather station that is located at about 50 kms Northwest of the Ignace Site and is presented below on Figure 2:

FIGURE 2 SITE CLIMATE



2.4 Geology and Hydrogeology

The Ignace area comprises a number of granitic to granodioritic batholiths as described by Stone, 2010a. A number of geological units identified by Golder in their initial screening report of the Ignace area include: Indian Lake Batholith, Revell Batholith, and the White Otter Lake Batholith.

The Revell Site is located in the Revell Batholith, which was formed about 2.7 billion years ago (Percival & Easton, 2007) and is located in the western portion of the Wabigoon Sub-Province of the Superior Province. It is also surrounded by the greenstone belts that are composed of old volcanic and sedimentary rocks (Golder, 2013).

The lithology of the shallow bedrock (<101 m below ground surface) at the Revell Site was interpreted from the borehole drilling and geophysical logging of the shallow monitoring well drilling sites (IG_MWA, IG_MWB, and IG_MWC)(KGS Group, 2023).

There is minimal overburden material in the area leading to high bedrock exposure at the surface. The three main suites of plutonic rock in the Revell batholith, include (oldest to youngest): a Biotite Tonalite to Granodiorite suite, Hornblende Tonalite to Granodiorite suite, and a Biotite Granite to Granodiorite suite. The rocks of Biotite Tonalite to Granodiorite suite are present along the northeastern and southwestern margins of the Revell batholith. The main type of rock within this suite is a medium-grained, white to grey biotite tonalite to granodiorite (WSP, 2023).

The rocks in the Hornblende Tonalite to Granodiorite suite include high compositions of tonalite (igneous plutonic rock) with lower compositions of granodiorite, granite, quartz diorite and quartz monzodiorite.

The rocks in the Biotite Granite to Granodiorite suite are typically coarse grained, with white to pink in colour and are weakly to massively foliated. This suite consists of high composition of granite to lower compositions of granodiorite and tonalite rocks. The rocks of this suite are present in most of the northern, southern, and central portions of Revell batholith (WSP, 2023).

The shallow BGT (Biotite Granodiorite-Tonalite) bedrock aquifers in the region are formed within the fractured bedrock zones which occur within the upper few metres, to over 100 m of the uppermost BGT bedrock formations. Transmissive zones for groundwater flow are formed by the network of vertical to subvertical joints and horizontal bedding plane partings within the upper igneous bedrock strata. Thus, groundwater quantity and quality within the shallow bedrock aquifers varies across the region based on the different chemical and physical characteristics of the individual bedrock formations, and subregional to regional groundwater flow paths.

The borehole logs indicate that monitoring well intervals are predominately installed within the BGT formation, with six of the twenty-seven in total being installed within granite or granite amphibolite rock formation (KGS Group, 2023).

3.0 GROUNDWATER MONITORING OF SHALLOW WELL NETWORK

3.1 Overview

Monitoring and sampling activities were scheduled to be completed by KGS Group on a quarterly basis. Each quarterly monitoring event consists of checking and downloading data from all nine dataloggers at each of the multilevel monitoring wells, followed by purging select intervals, measuring water chemistry parameters and collecting groundwater samples and submitting them for laboratory analysis. The results of the groundwater sampling programs are summarized in a separate report. A detailed Test Plan for the Revell Site was prepared in advance of the first field event. The Test Plan outlines all the equipment, methodologies, criteria, and steps needed to achieve the desired outcomes of the project within the confines of the approved scope of work.

Wells to be sampled were pre-determined together with the NWMO project team in advance of the event. For each quarterly event, technical work as part of the pressure data collection scope followed the same general procedures as outline below, but were not limited to:

- Pre-mobilization equipment and material checks
- Mobilization of all personnel
- Check and download all nine dataloggers, verify that the 4-channel datalogger was functioning and in good working order, perform maintenance on the datalogger if required, field check the data, and saved data following the DMP on the field laptop (See Section 3.3).
- Store, process, and prepare the data collected from dataloggers for analysis and submission to NWMO.
- Prepare separate pressure data quarterly reports

The steps outlined above are detailed further as pre-mobilization and mobilization activities, fluid pressure and temperature monitoring, and data assessment and reporting activities. All data collected in the field was recorded directly onto approved Data Quality Confirmation Forms (DQCFs) as per the approved Project Quality Plan (PQP), the Data Management Plan (DMP), and the Test Plan.

3.2 Health, Safety and Environment Activities

As per the Health, Safety and Environment Management Plan (HSEP), developed for the project, the KGS Group project team held a pre-job meeting via MS Teams to review the HSEP and the Test Plan to ensure all team members understood their roles and the expectations given the planned scope of work.

While the field team was working on site, the Field Lead/Supervisor held daily tailgate meetings with the field crew at the beginning of their workday to review the planned work activities, the related health, safety, and environmental issues related to the planned work and specific hazards associated with each task and mitigation and control measures related to the hazards. All Job Safety Analysis (JSA) forms were updated as needed and signed off by the field team. Completed JSAs have been provided with the data package. An example of some of the specific hazards identified during the field event included:

- Heavy lifting
- Compressed gas

- Water containment
- Slips, trips, and falls
- Hand Tool Safety
- Use/handling of cleaning detergents, sample preservatives
- Highway driving
- Tire punctures from driving on gravel roads, narrow forest road access, and farm field access, etc
- Wildlife crossings/encounters
- Travel to and from the work site including safely and respectfully navigating around horse and buggies on roadways and safely approaching blind hills on the road
- Handling of preservatives when collecting samples
- Weather (e.g., heavy rain, thunderstorms, lightning protocols)

No health and safety or environmental incidents occurred during any of the field events in 2022. The field lead conducted a daily environmental inspection at each of the sites using a prescribed checklist.

3.3 Fluid Pressure and Temperature Monitoring

Fluid pressure and temperature monitoring was completed between July 15 and August 5, 2022, for the Q3 (July) event; between September 26 and October 4, 2022, for the Q3 (September) event, and between November 28 and December 6, 2022, for the Q4 2022 event. During each event, fluid pressure and temperature monitoring was facilitated by 27 permanently installed Geokon 4500SOL vibrating wire transducers (VWP) connected to a dedicated Geokon 8002-4-2 four channel datalogger (one datalogger connected to three vibrating wire transducers per multilevel monitoring well) at the Revell Site. The vibrating wire transducers and dataloggers are components of the Solinst Waterloo Multilevel system installed in 2021. Each multilevel monitoring well consisted of three discrete depth intervals, capable of measuring fluid pressure and temperature. All three intervals of the multilevel monitoring well were set up to record a measurement every 6 hours.

3.3.1 TRANSDUCER DOWNLOADS

KGS Group followed the steps outlined by the manufacturer, Geokon, for connecting and downloading data from all nine dataloggers using a field laptop and the manufacturer's supplied communication cable.

At the end of each field event, downloaded data were saved on the KGS Group File Management System (FMS) in accordance with the DMP. The unprocessed datafiles (as a CSV) were included in each quarterly data deliverable package.

Checks of the data were performed in the field to verify that the data were downloaded properly, and any errors were flagged for review by a senior reviewer. Any deviations were recorded directly onto an electronic version of *DQCF02-Datalogger Download* and were provided with each quarterly data deliverable package.

3.3.2 TRANSDUCER DATA PROCESSING

Data processing of the vibrating wire transducer data from Ignace was completed using an excel based vibrating wire conversion spreadsheet created by KGS Group. This excel conversion spreadsheet for each monitoring well was updated with all the data. The post-processed excel spreadsheet for each monitoring well was included with each quarterly data deliverable package.

The processing and analysis of each groundwater pressure dataset followed the same general procedure, outlined below:

- The downloaded data (pressure and temperature) was processed using the raw CSV downloaded from the Geokon datalogger. The raw pressure data is recorded on the Geokon datalogger as meters of water (mH20) above the VWP also referred to as hydraulic head, which was calculated by the datalogger program, based on the polynomial correction factor provided on the manufacturer's calibration certificate and is unique for each vibrating wire transducer. The equation used by the datalogger software to calculate groundwater pressures is as follows:

(psi) Linear Gauge Factor (G): -0.04000 (psi/ digit)

Polynomial Gauge Factors: **A: -1.901E-07** **B: -0.03718** **C: ______**

Thermal Factor (K): 0.03225 (psi/ °C)

Calculate C by setting P=0 and R_1 = initial field zero reading into the polynomial equation

Calculated Pressures:

$$\text{Linear, } P = G(R_1 - R_0) + K(T_1 - T_0) - (S_1 - S_0)^*$$

$$\text{Polynomial, } P = AR_1^2 + BR_1 + C + K(T_1 - T_0) - (S_1 - S_0)^*$$

*Barometric pressures expressed in MPa or psi. Barometric compensation is not required with vented transducers.

- Because the vibrating wire transducers are installed in sealed wells, it is expected that fluctuations in barometric pressure will be significantly attenuated at the depths of the transducers. Therefore, no barometric compensation has been applied.
- The hydraulic head pressure data was converted to hydraulic head elevations, calculated based on the known port elevations for each monitoring interval using the equation given below:
- Hydraulic Head Elevation = Elevation of Vibrating Wire (meters above sea level (masl)) + Hydraulic Head (mH20)
- The raw downloaded data file was not altered. KGS Group imported the raw dataset into the excel vibrating wire spreadsheet (NWMO Ignace Test Plan) and processed. Error values such as negative values (e.g., -9999) were removed. Other anomalous data points such as sudden negative or positive spikes were reviewed individually against calendar dates and times.

3.3.3 QUALITY ASSURANCE OF THE PRESSURE DATA

Raw exported data files were not altered. KGS Group imported the raw datasets into the excel Grapher hydrograph spreadsheet and the data were processed as described above. Anomalous data points such as sudden negative or positive spikes were reviewed individually against calendar dates and times to determine if there were correlations to known natural or hydrogeological events, such as weather events or aquifer pumping or if the transducer was removed from the monitoring well.

The most common type of error seen in the data were errors caused by pressure measurements outside the minimum pressure range of the vibrating wire transducer (See details in 3.3.4). This error was corrected by KGS Group with a change in the datalogger configuration setup.

3.3.4 DEVIATIONS AND CHALLENGES

The following field deviations and or challenges were identified by KGS Group field staff during the 2022 field program:

- During the Q3-July event (the first monitoring event of this program), KGS Group found that all the batteries in the dataloggers were dead, resulting in data losses dating back to December 2021, leaving a significant gap in the data set. It was found that the dataloggers had not been checked on since October 2021 and that the batteries died due to extreme cold temperatures and were found to not be the most appropriate type of battery for extreme cold weather conditions. KGS Group corrected the issue by replacing the batteries with special lithium-ion batteries that perform in extreme cold temperatures and added a battery voltage verification to the DQCF used as part of the field checks during each quarterly event. Also, the NWMO followed up with bimonthly checks of the dataloggers whenever a quarterly event was not scheduled. Since the batteries were changed to the lithium-ion types, the dataloggers have not had any battery-related issues. This is why there is a gap in the dataset indicated by a break in the x-axis of the hydrographs.
- Errors in the data (i.e. -9999 which indicates an error in the raw dataset) were observed specifically in IG_MWB01_C during Q3-July monitoring event. KGS Group troubleshooted with the help of GEOKON technical support and discovered that the datalogger model selected in the configuration setup file did not match the expected min and max output readings of the vibrating wires. This was a direct result of the shallow head conditions of the vibrating wire installed in the shallow depth C interval causing the vibrating wire transducer signals to be (in this instance) greater than what the datalogger configuration limits was expecting. The error readings are recorded by the datalogger when the frequency reading being output from the vibrating wire is greater or less than the frequency limits configured in the datalogger. When this occurred, the datalogger could not process the signal from the vibrating wire and would proceed to log the reading as an error value (e.g. -9999) in the output data. By changing the model of the datalogger in the configuration setup file of the datalogger, the datalogger was able to receive and process a wider range of high and low frequency signals output by the vibrating wire transducers, which eliminated the out-of-range (error -9999) readings from the dataset. This resolved the error readings for the shallow installed vibrating wire, but only for readings after August 5, 2022. KGS Group then proceeded to change all the datalogger configuration setup files so that all datalogger configuration files were standardized on the site and eliminate future error readings of other shallow depth vibrating wires.
- On October 1, 2022 (Q3-September event), the datalogger channel associated with IG_MWB01_C was switched from channel 1 to channel 4 within the datalogger settings. However, the datalogger export settings were not switched to match this change, resulting in missing data for IG_MWB01_C from October 1, 2022, until October 4, 2022. The export settings were corrected on October 4, 2022, and this issue was corrected for IG_MWB01_C data after October 4, 2022.
- No deviations or challenges were identified by KGS Group field staff during the Q4 program.

3.3.5 QA/QC OF FIELD DATA

KGS Group completed the QA/QC of the field data that was captured on Data Quality Confirmation Forms used to capture datalogger readings at the time of downloading (DQCF02)

This was completed as part of preparation of each quarterly data deliverable. Each DQCF was reviewed by a senior reviewer for formatting, consistency of information being recorded, errors in the values and identification of values that were outside of the expected ranges. Where an error was found that error was highlighted, and a note was made of the correction.

After the review was completed, the DQCF was signed off on by the preparer and the verifier.

Identified Errors

No errors were identified during the QA review of the field recorded data.

3.4 Hydraulic Head Results

Hydraulic heads and hydraulic head elevations were calculated for each monitoring interval using the data processing methodology described in section 3.3.2. Table 1 provides a summary of the calculated minimum and maximum hydraulic head elevations for 2022 as measured by the vibrating wire pressure transducers. Table 2 provides a summary of the quarterly hydraulic head elevations for each interval monitored. The calculated hydraulic head elevations have been plotted against time on a hydrograph for each monitoring well showing all three intervals. Each hydrograph was reviewed, and error values were filtered out and not shown on the hydrograph. Hydrographs are provided in Appendix A.

TABLE 1 HYDRAULIC HEAD ELEVATION RANGES

Interval	Hydraulic Head Elevation Ranges[1] (masl)		Interval	Hydraulic Head Elevation Ranges[1] (masl)	
	Minimum	Maximum		Minimum	Maximum
IG_MWA01_A	402.65	404.56	IG_MWB03_A	418.40	419.66
IG_MWA01_B	403.49	405.52	IG_MWB03_B	417.13	417.54
IG_MWA01_C	404.36	407.14	IG_MWB03_C	415.65	416.34
IG_MWA02_A	399.49	400.10	IG_MWC01_A	420.77	422.15
IG_MWA02_B	400.55	401.32	IG_MWC01_B	421.29	422.9
IG_MWA02_C	400.99	401.79	IG_MWC01_C	422.54	423.55
IG_MWA03_A	402.50	404.11	IG_MWC02_A	420.41	421.8
IG_MWA03_B	402.55	404.27	IG_MWC02_B	421.73	423.32
IG_MWA03_C	402.77	404.50	IG_MWC02_C	424.45	427.06
IG_MWB01_A	418.2	418.89	IG_MWC03_A	421.0	422.5
IG_MWB01_B	408.08	408.71	IG_MWC03_B	421.15	422.23
IG_MWB01_C	416.47	417.10	IG_MWC03_C	421.98	422.98
IG_MWB02_A	416.11	416.87			
IG_MWB02_B	416.91	417.66			
IG_MWB02_C	416.68	417.42			

Note: (1) As measured by the vibrating wire pressure transducers

3.4.1 HYDROGRAPH OBSERVATIONS

Hydraulic head elevations at all sites generally were stable throughout the periods with data, with slight variations in heads (e.g., <2.0 m) observed.

The nearest Environment Canada weather data for 2022 was from the Dryden station (Climate ID: 6032125), was downloaded from the Environment Canada Historical Weather online database (Environment and Climate Change Canada, 2017). The Dryden weather station is located approximately 49 kms Northwest of the Revell Site. Daily total precipitation data were plotted on the hydrographs in Appendix A, for the purpose of assessing correlations of precipitation events and hydraulic head changes. Given the distance of Dryden station from the Revell Site, limitations in interpreting hydraulic head changes (due to precipitation events) are expected.

A series of rain events were recorded between June 16 and June 27 at the Dryden weather station, with a combined precipitation of 50 mm, which is reflected in IG_MWC02_C, with an increase of 1.0 m in hydraulic head between June 14 and June 17. Later in July, an increase in the hydraulic head at IG_MWC02_C by 1.3 m was again observed after the rainfall events between July 9 and July 13 with a total rainfall precipitation of 53.4 mm.

The largest rainfall event occurred on July 19, 2022, with 79mm total precipitation measured at the weather station but was not reflected in most of the Ignace monitoring wells, except at IG_MWA01_A, IG_MWA01_B, IG_MWA01_C, and IG_MWC02_C, with small increases of 0.24 m, 0.5 m, 0.4 m and 0.4 m, respectively, were measured. It is most likely that the rain event of July 19 occurred locally near the Dryden station, and less rainfall at the Revell site.

Because the bedrock aquifer at the Revell Site is generally unconfined, the relationship between recharge areas (i.e. bedrock outcrop areas and/or areas of high bedrock elevation with limited overburden sediment cover) and local to regional precipitation/recharge events is important. It would be expected that the regional pressure response of the aquifer to short duration, high intensity summer rainfall events (for example) would be estimated to be greatest when the rainfall events are geographically active in areas of regional bedrock aquifer recharge. The hydraulic head elevation and precipitation data for this 2022 report does not capture a complete year of precipitation, primarily missing the winter months of January to March, and spring melt from March into April and will be assessed in the 2023 annual pressure data report.

Aside from the June and July rain events, changes in hydraulic head elevations were noted in response to the rain events between August 14 and August 18 (a total of 52 mm of rainfall precipitation) and after the rainfall events on September 15 and September 16 (a total of 31 mm). The hydrographs for IG_MWA01 and IG_MWA03 show a direct correlation to these rain events, with hydraulic head elevations rising between 0.3 m and 1.95 m, with largest responses measured in IG_MWA01_C (1.95 m) and IG_MWA01_B (1.31 m). A rise in hydraulic head elevation by 0.61 m was also noted in IG_MWC01_C after the rain events of September 15 and 16. These responses may be attributed to an increase in hydraulic head (via regional recharge) of the bedrock aquifers, along with a strong vertical hydraulic interconnection between the BGT bedrock aquifers. A slightly muted response in all other wells is also observed, which would be anticipated as part of the more regional overall hydraulic head response of the bedrock aquifer to the rainfall events and related to the variability of naturally occurring vertical interconnectivity of the various bedrock fracture systems and aquifer zones that exist at the Revell site.

The monitoring wells where little to no rise in hydraulic head measured during or after the above-mentioned rainfall events (throughout June to September) were IG_MWA02 (all depth intervals), IG_MWB01_A, IG_MWB02 (all depth intervals), IG_MWB03 (all depth intervals), IG_MWC01_B, IG_MWC01_C, and IG_MWC03 (all depth intervals). Although there were fluctuations observed in the hydraulic head elevations at these monitoring wells, these fluctuations are related to pumping of the interval or an interval in the multilevel monitoring well. The fact that the rainfall events did not appear to be registered within these wells is likely a result of the variability and complexity of the bedrock fracture system within the aquifer.

IG_MWA01 – (Figure A-1):

The rain event of July 19 was observed at IG_MWA01, seen in the hydraulic head response in all three monitoring well intervals. The rain events of August 14 and August 18 were also reflected in all three monitoring well intervals at this location with a larger response compared to the magnitude of hydraulic head changes observed after the July 19 event. Similarly, rises in hydraulic head elevations were also observed in all monitoring well intervals at this location after the rainfall events of September 15 and 16.

Considering the hydraulic head elevation data from the period between July and December 2022, the hydraulic head elevation in IG_MWA01_C (ranging from 404.4 to 407.1 masl) was on an average 1.8 m higher than IG_MWA01_A (between 402.7 and 404.6 masl) and 1.1 m higher than IG_MWA01_B (between 403.5 and 405.5 masl), whereas the hydraulic head elevation in IG_MWA01_B was on an average 0.74 m higher than IG_MWA01_A. Where the hydraulic head readings are outside of the stated minimum and maximum readings, these hydraulic head elevations are related to well purging for groundwater sampling, which are not included in the min/max range.

It is observed that the water level responses to rainfall events are greater in magnitude in the shallow bedrock interval (IG_MWA01_C), compared to the hydraulic head pressure responses in the deeper bedrock interval (IG_MWA01_B). It is likely a reflection of the more direct recharge to the shallow bedrock system versus the pressure response to regional recharge that enters the deeper bedrock aquifer system in regional bedrock aquifer recharge areas.

IG_MWA02 – (Figure A-2):

In this monitoring well, no direct correlation was observed between the hydraulic head elevations and precipitation.

The fact that the rainfall events did not appear to be registered within these wells is likely a result of the variability and complexity of the bedrock fracture system within the aquifer. It is likely that none or minimal preferential pathways exist between the ground surface and the bedrock aquifer at this location, such that the rainfall falling on the ground does not infiltrate into the ground and becomes runoff. This could be due to the presence of a silty clay layer above the bedrock aquifer system as shown in the borehole logs for IG_MWA02.

The hydraulic head within the shallow, intermediate, and deeper bedrock intervals (intervals C, B and A) were in a similar range throughout the year, ranging from 401.8 masl to a low of 399.5 masl.

IG_MWA03 – (Figure A-3):

The monitored intervals at this monitoring well were sampled between the July 17 and July 19 period, and due to active pumping/purging activity on these days, the hydraulic head change response due to precipitation is difficult to interpret. The August and September rain events were observed in all IG_MWA03 intervals.

Changes in hydraulic head elevations were noted in response to the rain events between August 14 and August 18 (a total of 52 mm of rainfall precipitation) and after the rainfall events on September 15 and September 16 (a total of 31 mm). The hydraulic head elevation rose by 0.45 m in IG_MWA03_C and IG_MWA03_B and by 0.31 m in IG_MWA03_A after the August precipitation events, whereas, the head elevations rose by 0.966 m, 0.92 m and by 0.77 m respectively in IG_MWA03_C, IG_MWA03_B, and IG_MWA03_A after the September rainfall events.

The hydraulic head elevation in IG_MWA03_C ranged between 402.8 to 404.5 masl, whereas in IG_MWA03_B, it ranged between 402.5 and 404.3 masl during the 2022 monitoring period. The hydraulic head elevation in IG_MWA01_A ranged between 402.5 and 404.1 masl.

IG_MWB01 – (Figure A-4):

The July, August, and September rain and hydraulic head responses were not observed in significant magnitudes in the IG_MWB01 intervals. Although some response in hydraulic head were observed in the shallow and intermediate bedrock intervals (IG_MWB01_C and IG_MWB01_B). For example, a rise in hydraulic head in IG_MWB01_C by 0.26 m was observed during the rainfall events between August 14 and August 18, whereas no response was observed in IG_MWB01_B and IG_MWB01_A during the August rainfall events. After the September 15 and 16 rainfall events, a rise in hydraulic heads were observed in IG_MWB01_C and IG_MWB01_B by 0.48 m and 0.47 m respectively, whereas no change was observed in IG_MWB01_A.

The deeper monitoring well at this site (IG_MWB01_A) had the highest hydraulic head elevations (between 418.2 and 418.9 masl) compared to the hydraulic head elevations measured in the intermediate and shallow bedrock wells. IG_MWB01_C had lower hydraulic heads (between 416.5 and 417.1 masl) than IG_MWB01_A, but higher than the intermediate monitoring interval, IG_MWB01_B (between 408.1 and 408.7 masl). It is unclear why hydraulic heads at interval IG_MWB01_B are significantly lower. A review of the drilling and geophysical logs indicate that the bedrock fracture targeted by the B interval is tighter compared to other monitoring intervals, which is supported by the hydraulic conductivity testing done in 2021 after the monitoring well was installed. The interpreted hydraulic conductivity was 5.14E-09 m/sec.

IG_MWB02 – (Figure A-5):

No direct correlation was observed between the hydraulic head elevations and precipitation in any of the monitoring wells at this site.

The hydraulic head elevation in IG_MWB02_C ranged from 416.7 to 417.4 masl, whereas it ranged within 416.9 and 417.7 m in IG_MWB02_B during the 2022 monitoring period. The hydraulic head elevation in IG_MWB02_A ranged between 416.1 and 416.9 masl.

This suggests that the hydraulic head elevations were essentially stable throughout the year and little to no connection to regional or local bedrock fracture systems.

IG_MWB03 – (Figure A-6):

No rise in hydraulic head elevations after the rainfall events of July, August, and September were observed in any of the monitored intervals of IG_MWB03.

The hydraulic head elevation in IG_MWB03_C ranged from 415.7 to 416.3 masl, whereas it ranged within 417.1 and 417.5 m in IG_MWB03_B during the 2022 monitoring period. The hydraulic head elevation in IG_MWB03_A ranged between 418.4 and 419.7 masl.

IG_MWC01 – (Figure A-7):

A rise in hydraulic head elevation by 0.61 m was noted in response to the rain events between September 15 and September 16 (a total of 31 mm) in IG_MWC01_C. There was little to no response in the intermediate (B) and deep (A) intervals at IG_MWC01 to any of the rainfall events of the year.

The hydraulic head elevation in IG_MWC01_C ranged from 422.5 to 423.6 masl, whereas it ranged within 421.3 and 422.1 m in IG_MWC01_B during the 2022 monitoring period. The hydraulic head elevation in IG_MWC01_A ranged between 420.8 and 421.7 masl.

IG_MWC02 – (Figure A-8):

A series of rain events recorded between June 16 and June 27 are reflected on the hydrograph for IG_MWC02_C. An increase of 1.0 m in hydraulic head elevation was observed in this interval between June 14 and June 17. Another increase of 1.3 m in the hydraulic head elevation was observed after the rainfall events between July 9 and July 13.

Later in August, a rise in hydraulic head elevation of 0.32 m was observed in IG_MWC02_C after the series of rainfall events happening between August 14 and August 18. Lastly, an increase in the hydraulic head elevation of 1.25 m was also observed in IG_MWC02_C after the rainfall events of September 15 and 16.

No such response was observed for the monitored intervals in the intermediate (IG_MWC02_B) and deep (IG_MWC02_A) intervals in this monitoring well.

The hydraulic head elevation in IG_MWC02_C were consistently higher than the elevations observed in intermediate and deeper bedrock intervals. The hydraulic head elevation in IG_MWC02_C ranged from 424.4 to 427.1 masl, whereas it ranged within 421.7 and 423.3 m in IG_MWC02_B during the 2022 monitoring period. The hydraulic head elevation in IG_MWC02_A ranged between 420.4 and 421.7 masl which is nearly equal to what was observed for IG_MWC01_A.

IG_MWC03 – (Figure A-8):

The hydraulic head elevations in all monitoring intervals in this monitoring well did not respond to the July, August, and September rainfall events. Hence, no direct correlation was observed between the hydraulic head elevations and precipitation.

The hydraulic head elevation in IG_MWC03_C ranged from 422.0 to 423.0 masl, whereas it ranged within 421.2 and 422.2 m in IG_MWC03_B during the 2022 monitoring period. The hydraulic head elevation in IG_MWC03_A ranged between 421.0 and 421.8 masl.

TABLE 2 HYDRAULIC HEAD MEASUREMENTS SUMMARY

Interval	Ground Elevation (masl)	Port Elevation (masl)	Test Date and Time (dd/mm/yyyy hh:mm)	Head (m above port)	Hydraulic Head Elevation (masl)	Test Date and Time (dd/mm/yyyy hh:mm)	Head (m above port)	Hydraulic Head Elevation (masl)	Test Date and Time (dd/mm/yyyy hh:mm)	Head (m above port)	Hydraulic Head Elevation (masl)
IG_MWA01_A	406.78	344.78	15-07-2022 17:20	59.72	404.50	01-10-2022 10:24	59.16	403.94	28-11-2022 14:50	58.42	403.19
IG_MWA01_B	406.78	352.18	15-07-2022 17:20	53.31	405.49	01-10-2022 10:24	52.53	404.71	28-11-2022 14:55	51.68	403.86
IG_MWA01_C	406.78	393.48	15-07-2022 17:20	13.61	407.09	01-10-2022 10:24	12.43	405.91	28-11-2022 15:00	11.35	404.83
IG_MWA02_A	404.81	316.81	15-07-2022 17:05	83.13	399.94	01-10-2022 10:40	83.14	399.95	02-12-2022 12:00	82.74	399.55
IG_MWA02_B	404.81	362.71	15-07-2022 17:05	38.56	401.27	01-10-2022 10:40	38.41	401.12	02-12-2022 12:00	37.95	400.66
IG_MWA02_C	404.81	394.31	15-07-2022 17:05	7.47	401.78	01-10-2022 10:40	7.28	401.59	02-12-2022 12:00	6.79	401.10
IG_MWA03_A	406.95	322.05	15-07-2022 17:35	81.90	403.95	01-10-2022 15:18	81.46	403.51	02-12-2022 12:15	80.65	402.70
IG_MWA03_B	406.95	366.05	15-07-2022 17:35	38.10	404.15	01-10-2022 15:18	37.52	403.57	02-12-2022 12:15	36.73	402.78
IG_MWA03_C	406.95	381.45	15-07-2022 17:35	22.92	404.37	01-10-2022 15:18	22.39	403.84	02-12-2022 12:15	21.55	403.00
IG_MWB01_A	417.62	349.22	16-07-2022 12:30	70.03	419.25	01-10-2022 13:26	69.90	419.12	29-11-2022 9:05	69.55	418.51
IG_MWB01_B	417.62	385.92	16-07-2022 12:30	22.90	408.82	01-10-2022 13:26	23.09	409.01	29-11-2022 9:05	22.62	408.28
IG_MWB01_C	417.62	409.62	16-07-2022 12:30	7.87	417.49	01-10-2022 13:26	7.71	417.33	29-11-2022 9:05	10.37	416.92
IG_MWB02_A	417.62	322.32	16-07-2022 15:21	93.90	416.22	01-10-2022 13:13	94.27	416.59	29-11-2022 12:00	94.13	416.45
IG_MWB02_B	417.62	353.62	16-07-2022 15:21	63.86	417.48	01-10-2022 13:13	63.86	417.48	29-11-2022 12:00	63.42	417.04
IG_MWB02_C	417.62	365.42	16-07-2022 15:21	51.96	417.38	01-10-2022 13:13	51.74	417.16	29-11-2022 12:00	51.36	416.78
IG_MWB03_A	418.48	333.58	16/07/202212:46	85.12	418.70	26-09-2022 13:30	86.16	419.74	29-11-2022 12:30	85.67	419.25
IG_MWB03_B	418.48	375.28	16-07-2022 12:46	42.60	417.88	26-09-2022 13:30	42.18	417.46	29-11-2022 12:30	41.94	417.22
IG_MWB03_C	418.48	395.88	16-07-2022 12:46	20.50	416.38	26-09-2022 13:30	20.15	416.03	29-11-2022 12:30	19.91	415.79
IG_MWC01_A	427.41	336.21	15-07-2022 15:15	85.32	421.53	30-09-2022 8:55	84.80	421.01	02-12-2022 13:50	84.71	420.92
IG_MWC01_B	427.41	371.71	15-07-2022 15:15	50.57	422.28	30-09-2022 8:55	49.83	421.54	02-12-2022 13:50	49.76	421.47
IG_MWC01_C	427.41	401.41	15-07-2022 15:15	22.17	423.58	30-09-2022 8:55	21.57	422.98	02-12-2022 13:50	21.40	422.81
IG_MWC02_A	431.55	337.75	20-07-2022 13:13	83.38	421.13	27-09-2022 13:30	89.94	427.69	29-11-2022 13:45	82.82	420.64
IG_MWC02_B	431.55	362.95	20-07-2022 13:13	59.86	422.81	27-09-2022 13:30	59.43	422.38	29-11-2022 13:45	59.11	421.96
IG_MWC02_C	431.55	420.05	20-07-2022 13:13	6.82	426.87	27-09-2022 13:30	5.44	425.49	29-11-2022 13:45	4.71	424.76
IG_MWC03_A	424.94	353.34	20-07-2022 13:03	68.33	421.67	28-09-2022 16:34	67.99	421.33	02-12-2022 14:15	67.89	421.23
IG_MWC03_B	424.94	362.64	20-07-2022 13:03	59.44	422.08	28-09-2022 16:34	59.08	421.72	02-12-2022 14:15	58.74	421.38
IG_MWC03_C	424.94	385.64	20-07-2022 13:03	37.18	422.82	28-09-2022 16:34	36.86	422.50	02-12-2022 14:15	36.58	422.22

3.4.2 VERTICAL HYDRAULIC HEAD GRADIENTS

Vertical hydraulic head gradients were calculated between monitoring intervals at each monitoring well location using the VW transducer-measured hydraulic head elevations. Gradients were calculated as the difference in hydraulic head elevation values between two monitoring intervals divided by the vertical distance between the middle of each interval:

$$\frac{(GW\ elev.zone\ B - GW\ elev.zone\ A)}{(middle\ of\ zone\ A\ elev. - middle\ of\ zone\ B\ elev.)}$$

Groundwater is considered to move vertically from an interval of higher hydraulic head to an interval of lower hydraulic head, except where an aquitard is present. Table 3 summarizes the vertical hydraulic head gradients between monitoring intervals at each monitoring well location. Gradients with less than 0.009 m/m are interpreted as being in a hydrostatic condition which is essentially a very low gradient and difficult to accurately measure.

Generally, vertical gradient directions remained consistent throughout 2022 with the exception of:

- IG_MWC02: downward gradient from interval B to interval A in July and December 2022, but upward gradient from interval A to interval B in September 2022

In the upper monitoring intervals (interval C) within the bedrock aquifer, the vertical gradients were downward in all wells except IG_MWB02_C and IG_MWB03_C where an upward vertical gradient existed between the intermediate monitoring interval (interval B) and the shallow interval (interval C) during all three monitoring events. The upper 100 m of bedrock unit that mostly comprises of BGT rock is understood to be as a single aquifer unit and vertical interconnection exists between the different monitoring depth intervals within the bedrock.

Generally, vertical gradients in bedrock were downward within the BGT formation from the upper monitoring interval (interval C) to the to the lower monitoring interval (interval A), with the exception of IG_MWB01_B, IG_MWB02_C, IG_MWB03_C, and IG_MWB03_B, in which the vertical gradients were upward during each monitoring event in 2022.

TABLE 3 HYDRAULIC HEAD VERTICAL GRADIENTS SUMMARY

Interval	Formation	Q3 (July) 2022			Q3 (September) 2022			Q4 (December) 2022		
		Hydraulic Head Elevation (masl)	Gradient (m/m)	Gradient Description (masl)	Hydraulic Head Elevation (masl)	Gradient (m/m)	Gradient Description (masl)	Hydraulic Head Elevation (masl)	Gradient (m/m)	Gradient Description (masl)
IG_MWA01_C	BGT	407.034	0.038	downward gradient from C to B	405.905	0.029	downward gradient from C to B	404.83	0.024	downward gradient from C to B
IG_MWA01_B	BGT	405.468	0.129	downward gradient from B to A	404.714	0.103	downward gradient from B to A	403.856	0.089	downward gradient from B to A
IG_MWA01_A	BGT	404.502			403.943			403.19		
IG_MWA02_C	Granite	401.78	0.016	downward gradient from C to B	401.586	0.015	downward gradient from C to B	401.099	0.014	downward gradient from C to B
IG_MWA02_B	Granite	401.273	0.029	downward gradient from B to A	401.123	0.026	downward gradient from B to A	400.659	0.024	downward gradient from B to A
IG_MWA02_A	Granite	399.935			399.949			399.548		
IG_MWA03_C	BGT	404.238	0.013	downward gradient from C to B	403.836	0.017	downward gradient from C to B	402.998	0.014	downward gradient from C to B
IG_MWA03_B	BGT	404.023	0.003	Hydrostatic, no vertical gradient interpreted	403.572	0.002	Hydrostatic, no vertical gradient interpreted	402.781	0.002	Hydrostatic, no vertical gradient interpreted
IG_MWA03_A	BGT	403.896			403.505			402.7		
IG_MWB01_C	BGT	417.485	0.365	downward gradient from C to B	417.327	0.351	downward gradient from C to B	416.918	0.365	downward gradient from C to B
IG_MWB01_B	BGT	408.824	-0.285	upward gradient from A to B	409.009	-0.277	upward gradient from A to B	408.279	-0.280	upward gradient from A to B
IG_MWB01_A	BGT	419.247			419.124			418.513		
IG_MWB02_C	BGT	417.383	-0.008	Hydrostatic, no vertical gradient interpreted	417.155	-0.028	upward gradient from B to C	416.78	-0.022	upward gradient from B to C
IG_MWB02_B	BGT	417.482	0.040	downward gradient from B to A	417.481	0.028	downward gradient from B to A	417.037	0.018	downward gradient from B to A
IG_MWB02_A	BGT	416.219			416.587			416.45		
IG_MWB03_C	Granite	416.379	-0.073	upward gradient from B to C	416.028	-0.069	upward gradient from B to C	415.789	-0.069	upward gradient from B to C
IG_MWB03_B	BGT	417.881	-0.020	upward gradient from A to B	417.46	-0.055	upward gradient from A to B	417.216	-0.049	upward gradient from A to B
IG_MWB03_A	BGT	418.697			419.742			419.246		
IG_MWC01_C	BGT	423.583	0.044	downward gradient from C to B	422.977	0.049	downward gradient from C to B	422.806	0.045	downward gradient from C to B
IG_MWC01_B	BGT	422.278	0.021	downward gradient from B to A	421.537	0.015	downward gradient from B to A	421.468	0.015	downward gradient from B to A
IG_MWC01_A	BGT	421.533			421.01			420.916		
IG_MWC02_C	BGT	426.713	0.067	downward gradient from C to B	425.489	0.054	downward gradient from C to B	424.764	0.049	downward gradient from C to B
IG_MWC02_B	BGT	422.882	0.064	downward gradient from B to A	422.376	-0.209	upward gradient from A to B	421.964	0.052	downward gradient from B to A
IG_MWC02_A	Granite	421.249			427.694			420.641		
IG_MWC03_C	BGT	422.939	0.034	downward gradient from C to B	422.499	0.033	downward gradient from C to B	422.218	0.036	downward gradient from C to B
IG_MWC03_B	BGT	422.156	0.048	downward gradient from B to A	421.721	0.042	downward gradient from B to A	421.381	0.016	downward gradient from B to A
IG_MWC03_A	BGT	421.711			421.333			421.229		

4.0 SUMMARY

Three groundwater monitoring events were completed in 2022, between July 15 and August 5, 2022 for the Q3 (July) event; between September 26 and October 4, 2022 for the Q3 (September) event, and between November 28 and December 6, 2022 for the Q4 2022 event. During these field programs KGS Group downloaded the data from all 27 permanently installed vibrating wire transducers (VWP) connected to dedicated four channel dataloggers. All pressure data was compiled into three separate Quarterly Data Deliverable packages along with separate Quarterly Data reports as part of the final deliverables for each quarter.

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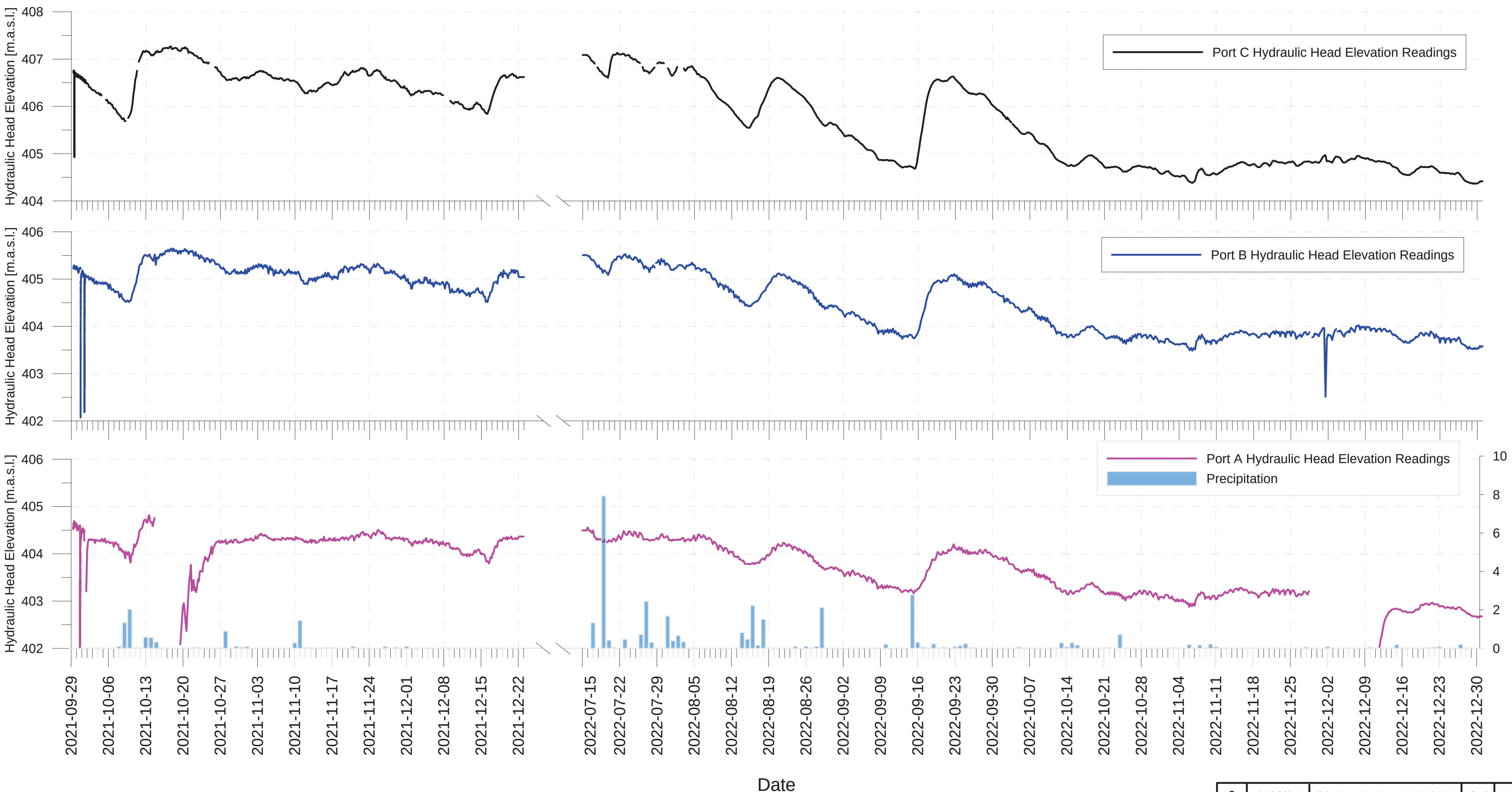
APPENDIX A

Hydrographs



Notes:
1. Port C located at 393.48 m.a.s.l.
2. Port B located at 352.18 m.a.s.l.
3. Port A located at 344.78 m.a.s.l.
4. Data gap from December 23, 2021 to July 15, 2022.

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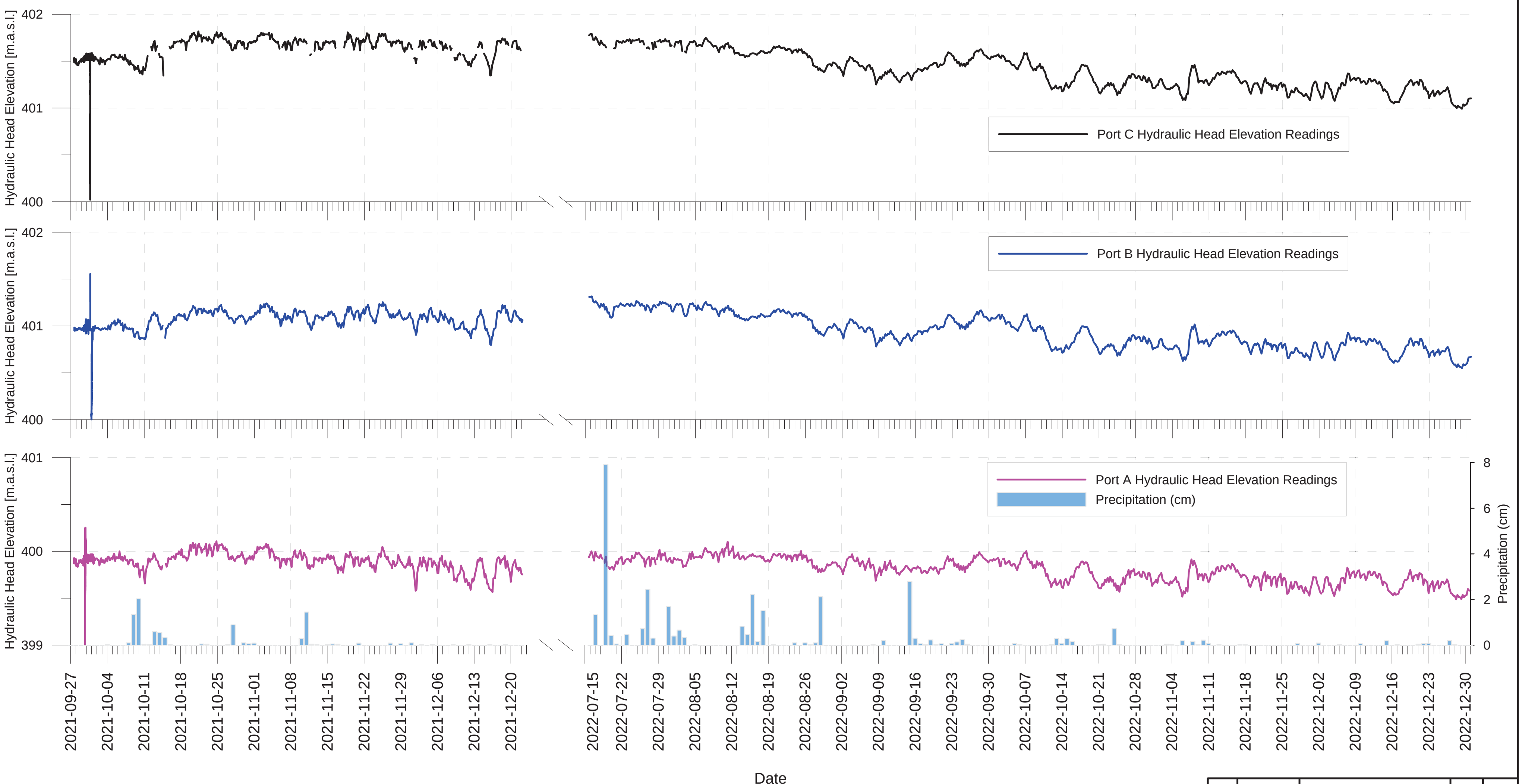
SHALLOW GROUNDWATER MONITORING NETWORK, IGNACE AREA

2022 HYDRUALIC HEAD ELEVATIONS
IG_MWA01

OCTOBER 2024 | FIGURE A-1 | REV: 0



Notes:
1. Port C located at 394.31 m.a.s.l.
2. Port B located at 362.71 m.a.s.l.
3. Port A port located at 316.81 m.a.s.l.
4. Data gap from December 23, 2021 to July 15, 2022.

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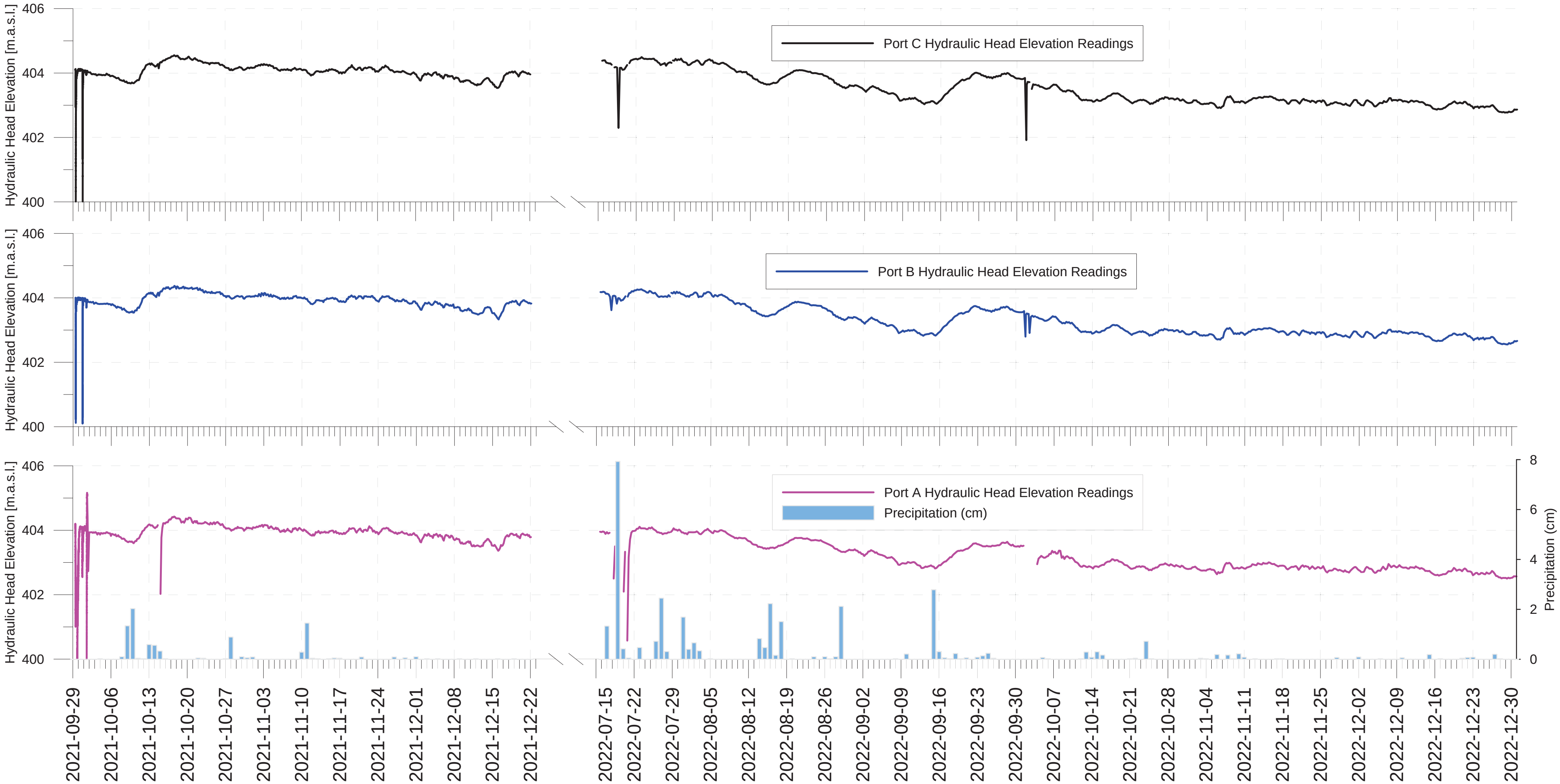
SHALLOW GROUNDWATER MONITORING NETWORK, IGNACE AREA

2022 HYDRAULIC HEAD ELEVATIONS
IG_MWA02

OCTOBER 2024 | FIGURE A-2 | REV: 0



Notes:
1. Port C located at 381.45 m.a.s.l.
2. Port B located at 366.05 m.a.s.l.
3. Port A located at 322.05 m.a.s.l.
4. Data gap from December 23, 2021 to July 15, 2022.

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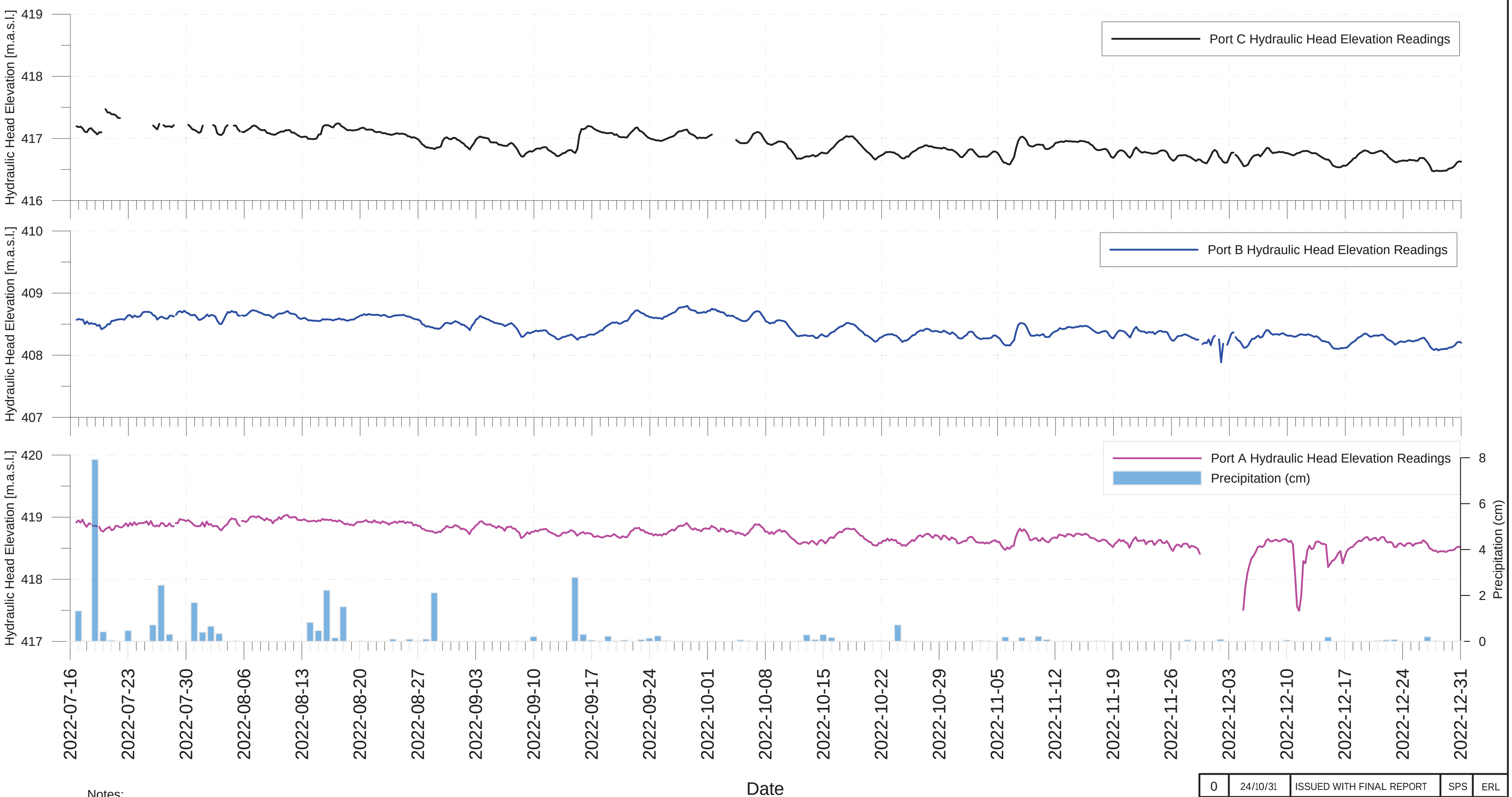
SHALLOW GROUNDWATER MONITORING NETWORK, IGNACE AREA

2022 HYDRAULIC HEAD ELEVATIONS
IG_MWA03

OCTOBER 2024 | FIGURE A-3 | REV: 0



Notes:
1. Port C located at 409.36 m.a.s.l.
2. Port B located at 385.66 m.a.s.l.
3. Port A located at 348.96 m.a.s.l.
4. Data gap from August 8, 2021 to July 16, 2022.

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nwmo NUCLEAR WASTE MANAGEMENT ORGANIZATION

SHALLOW GROUNDWATER MONITORING NETWORK, IGNACE AREA

2022 HYDRUALIC HEAD ELEVATIONS
IG_MWB01

OCTOBER 2024 | FIGURE A-4 | REV: 0

Notes:
1. Port C located at 365.42 m.a.s.l.
2. Port B located at 353.62 m.a.s.l.
3. Port A located at 322.32 m.a.s.l.
4. Data gap from August 3, 2021 to July 16, 2022.

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