# GROUNDWATER MONITORING OF SHALLOW WELL NETWORKS - SOUTH BRUCE PRESSURE DATA ANNUAL REPORT 2022

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KGS Group

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# Groundwater Monitoring of Shallow Well Networks – South Bruce Pressure Data Annual Report 2022

# APM-REP-01332-0419

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# 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 South Bruce area.

## 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 26 permanently installed monitoring well intervals over eight (8) quarters, starting in July 2022 ending in Q1 2024. This annual report focuses on the findings and analysis for the 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 includes:

- Mobilization of personnel and all required equipment
- Downloading of pressure and temperature data at each interval from the non-vented pressure transducers and barologger
- 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 the Saugeen Treaty 45 1/2, 1836. 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 South Bruce site is located approximately 7 km north-west of the Town of Teeswater in southwestern Ontario (Figure 1). This area is in the Western St. Lawrence Lowland that comprises of a gently undulating land surface and occupies much of southwestern Ontario. The area is covered with a surficial layer of glacial sediments. The land surface ranges from a maximum of 249 meters above sea level (masl) in the southeast corner of the Municipality of South Bruce to a minimum of 176 masl along the shore of Lake Huron in the Township of Huron-Kinloss. The regional topography shows a general slope down towards Lake Huron from southeast to northwest. The municipality of South Bruce and the surrounding areas are landscaped predominantly with an agricultural land use with terrestrial features such as valley lands, along with watercourses and wetlands. The Teeswater River is the predominant drainage feature in the area that flows from east to west in the Municipality of South Bruce, and bends to flow in the north direction to eventually discharge into the Saugeen River at Paisley (NWMO, 2022).

Within the South Bruce site, a total of seven (7) shallow groundwater monitoring well groups were drilled and installed in 2021/2022. The seven (7) groups consist of MW01, MW02, MW03, MW04, MW05, MW06, and MW07. Monitoring well group MW06 contains a separate redrilled well which is designated MW09 and should be considered as part of the MW06 group. MW09 was drilled as a replacement for a compromised interval in MW06, located approximately 50m away. It was constructed in late December 2022 and was therefore not included in the 2022 field events. MW08 was a potential monitoring well group that did not proceed with drilling and testing, and therefore will not be further discussed. Six (6) of the monitoring well groups (MW02 through MW07) consist of a standalone overburden monitoring well and three nested bedrock monitoring wells installed in a single borehole at various depth intervals. One site (MW01) consists of a single overburden monitoring well and a single six-inch open bedrock well.

Each monitoring well was instrumented with a non-vented, Solinst Levellogger pressure transducer to measure and record groundwater pressures and temperatures, and Waterra tubing installed with foot valves. A single barologger is installed at site SB_MW01 to measure and record barometric pressures for compensation of the non-vented pressure transducers. In total, the seven well groups subject to this project include (Figure 1):

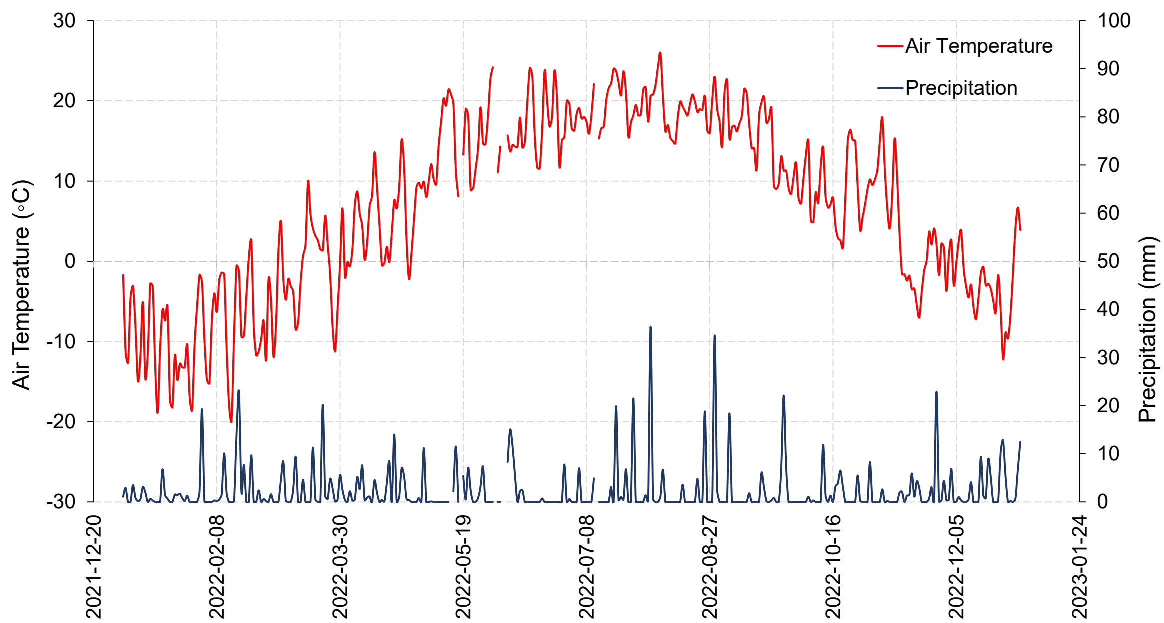
- SB_MW01
- SB_MW02
- SB_MW03
- SB_MW04
- SB_MW05
- SB_MW06 (includes MW09)
- SB_MW07

## 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, (Natural Resources Canada, 1957). The closest weather station that exhibits the 1981-2010 Climate Normal Data is located in Hanover, ON, and is located approximately 14 kms Northeast of the South Bruce Site. The monthly average temperature varies from -6.8 $^{o}$C in January to 19.6 $^{o}$C in July as per the 1981 – 2010 Canadian Climate Normal (Environment Canada, 2017). The area receives an average annual rainfall precipitation of 819.7 mm and 271.3 mm of snowfall precipitation, with a total annual precipitation of 1087.1 mm. The wettest months are July and September. The daily temperature and precipitation data for the year 2022 was available from the Mount Forest (AUT) weather station that is located at about 31 kms Southeast of the South Bruce Site and is presented below on Figure 2.

FIGURE 2 SITE CLIMATE




## 2.4 Geology and Hydrogeology

The South Bruce Site is located on the eastern portion of the Michigan Basin that consists of laterally extensive sedimentary rock formations deposited during the Cambrian (540 to 485 million years ago), Ordovician (485 to 443 million years ago), Silurian (443 to 416 million years ago) and Devonian (360 - 419 million years ago) periods. As the name suggests, the Michigan Basin is centered in the Michigan State of U.S. and extends across southern Ontario, where its thickness at the South Bruce Site is eventually reduced for the geological layers above the underlying Precambrian (older than 540 million years) basement granitic rock. The bedrock is overlain with Quaternary sediments that are sand, clays and soil deposits (NWMO, 2022).

The shallow bedrock aquifers within the area comprise the upper few metres to over 100 m of bedrock formations. Water quantity and quality within the shallow bedrock aquifers can vary across the area based on the different chemical and physical characteristics of the individual bedrock formations.

The carbonate bedrock aquifers of the Lucas, Amherstburg and Bois Blanc formations are important sources of drinking water in the area and is the primary source for municipal water supplies. The borehole logs suggests that the overburden wells consist of sand, gravel, till and clay deposits, whereas the bedrock wells are drilled in the Lucas (dolostone), Amherstburg (limestone) and Bois Blanc (limestone) formations.

# 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 event consisted of measuring static water levels, checking and downloading all 27 pressure transducers (26 Solinst Leveloggers (water level and temperature) and 1 Solinst Barologger (barometric pressure)), followed by purging select intervals, measuring water chemistry parameters and collecting groundwater samples and submitting them for laboratory analysis. A detailed Test Plan for the South Bruce 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. Seven (7) overburden and nineteen (19) bedrock wells were drilled and installed at the South Bruce Site in 2021 under NWMO's supervision, with the addition of a replacement well MW09 installed in December 2022.

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.
- Manually measured the depth to water level before removing and downloading all 27 Leveloggers, verification that they were in good working condition, field verification of the data, and saved data following the DMP requirements on the field laptop (See Section 3.3).
- Stored, processed, and prepared transducer data for analysis and submission to NWMO.
- Prepared 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.
- Generator and Hydrolift Pump use including fuel handling and storage.
- 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.
- All-Terrain Vehicle Use (where required).
- 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. The completed checklist was included in the data package.

## 3.3 Fluid Pressure and Temperature Monitoring

Fluid pressure and temperature monitoring was completed between July 26 and July 28, 2022 for the Q3 (July) event; between September 12 and September 19, 2022 for the Q3 (September) event, and between December 13 and December 17, 2022 for the Q4 2022 event. During each event, the depth to groundwater in each of the groundwater monitoring wells (Table 2 – Groundwater Elevation Measurements) was measured and the pressure transducer data from each of the 26 Solinst Leveloggers and 1 Solinst Barologger were downloaded and checked. To calculate the depth to groundwater below ground surface, the well stick-up height was subtracted from the groundwater depth, measured from top of casing of each well. The groundwater elevations at each well (except SB_MW01) were calculated using the Top of Casing (TOC) elevation (meters above sea level masl) and the ground surface elevation (masl) data. Survey data was provided by NWMO for use in calculating water level elevations. The elevations survey data for SB_MW01 was taken from the well completion report.

### 3.3.1 TRANSDUCER DOWNLOADS

To download the pressure transducers, KGS Group followed the steps outlined by the manufacturer (Solinst), for connecting and downloading all 26 of the pressure transducers and 1 barlogger using the manufacturer's supplied docking station connected to a field laptop with the Solinst Levelogger Software installed on it.

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 pressure transducer data from South Bruce was completed using the manufacturer provided software to compensate for barometric pressure using the data collected by the Barologger. Data were then exported and used in an excel based spreadsheet that was created by KGS Group to be used as source files for Grapher (a graphing software) to generate hydrographs of the transducer data for each well. The post-processed excel spreadsheet for each monitoring well was included with the 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) were processed using the raw CSV file downloaded from the Solinst Levelogger and compensated for barometric pressure using the data downloaded at the Solinst Barologger. The raw pressure data are recorded on the Solinst Levelogger as pressure measured in kilo-pascals (kPa), which assumes that the density of the fluid is fresh water.
- The Solinst Levelogger transducers are non-vented units, which are suspended in the monitoring well on aircraft cable. Because most of the monitoring wells (except for SB_MW03 wells) are open to the atmosphere, barometric compensation is required. As noted above, all data are processed for barometric pressures using data collected from the Solinst Barologger deployed on site (SB_MW01_BR-A), compensating the well pressure data to the barometric pressure data using the compensation wizard function in the Solinst software.
- The pressures measured in kPa is converted to pressure head using the following conversion:
  - 1 kPa = 0.101972 mH2O
- Then, pressure head data were converted to groundwater elevations or hydraulic heads, calculated based on the surveyed top of casing (TOC) elevations and manual depth to water (DTW) measurements for each monitoring well using the calculation given:
  - Hydraulic Head or Groundwater Elevation (masl) = Transducer Elevation (masl) + Pressure Head (mH20))
- To calculate the transducer elevation, the depth of the pressure transducer must be determined and verified every time it is removed from the monitoring well.
  - Pressure Transducer depths are determined and verified in the post processing of the data. This is important to verify each time the pressure transducer is removed from the monitoring well because the water level elevation calculations are based on the depth of the pressure transducer. In order to verify the depth of the pressure transducer in the monitoring well (from which all pressure measurements are taken), a manual measurement of the depth to water at a known time is added to the most recent pressure head reading (downloaded from the transducer). This assumes that the most recent pressure reading by the pressure transducer before being removed has not changed significantly since the depth to water was measured. This verification is done using the calculation given below:
    - Transducer Depth (m below TOC)= DTW (m below TOC) + Most Recent Pressure Head (mH2O)

- The transducer elevation is then able to be calculated using:
  - Transducer Elevation (masl)= Elevation of TOC (masl) – Transducer Depth (m)

### 3.3.3 MANUAL DEPTH TO WATER MEASUREMENTS

Manual depth to water measurements were measured from the Top of Casing (TOC) at each monitoring well using a calibrated electronic sensor water level meter. The manually measured hydraulic head elevations are included on the hydrographs as verification of the transducer data. Hydraulic head elevation or groundwater elevation is calculated using the calculation:

- Hydraulic Head Elevation or Groundwater Elevation (masl) = TOC Elevation (masl) - DTW (from TOC)

Hydraulic head elevations were calculated for each well and for each quarter and shown on Table 2 below. All manual water level measurements collected during each field event were recorded on DQCF02 which was provided with each quarterly data deliverable.

### 3.3.4 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 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 from human interferences such as aquifer pumping or displacement in the water column induced from moving the transducer.

The most common type of error seen in the data were pressure measurements while the transducer was not installed in the monitoring well, essentially a measurement of atmospheric pressure. Any non-atmospheric compensated value approximate to 100 kPa (+/- 3 kPa) was considered as atmospheric and removed from the dataset used to generate the hydrographs.

Another type of anomalous data point observed and assessed would only be identified after the processed data set was graphed to generate the hydrographs. The assessor would identify breaks or shifts in the data to be investigated. The most common issue to review, was related to a shift in the data set either upwards or downwards whenever the transducer was removed for downloading and well sampling and then replaced.

As mentioned above, the pressure transducers are suspended in the monitoring well on an aircraft cable and need to be removed from the well to download the data and to conduct water sampling. The cable is fixed to the outside of the well casing in all monitoring wells, except for wells at SB_MW03, where there are 3.0 m (10-feet) long Margo-plugs installed with the transducer fixed to the bottom of the plugs on a length of aircraft cable. Margo-plugs are used to seal a well from surface, preventing the wells from flowing uncontrollably. Re-installing the transducers follows the opposite process to removing them, with care needed to ensure no twists or bends are in the cable and the transducer can hang freely inside the monitoring well.

### 3.3.5 DEVIATIONS AND CHALLENGES

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

- The measurement recording intervals of the pressure transducers were changed from 1hr intervals during the period of April 2022 to July 2022, to 6-hour intervals as part of the Q3(July) field event. This change was done to ensure the transducer internal memory was sufficient to not lose data between quarterly downloads. This affects the frequency of symbols visually displayed on the hydrographs only (Appendix A).
- Downloaded data from SB_MW05_BR-B during the Q3-July event was incorrectly named during the field download. This affects data from April 2022 to July 28, 2022. During the saving of the data file, the incorrect file was selected and renamed incorrectly in the field.
- The Solinst Levelogger transducers are suspended from aircraft cable and re-installation elevations can vary if not carefully placed exactly as before removal.
- It is not possible to record Real Time pressures because the Leveloggers are deployed on aircraft wire and without direct read cables, therefore some interpretation is required to best fit the data to create groundwater elevation hydrographs.
- SB_MW03 wells are sealed with packers based on historical artesian conditions observed in the wells and Solinst Levelogger transducers are suspended below the packer seals. The potential for artesian conditions below the packers as well as inability to directly read the transducer pressures while in place create challenges for interpretation of the data. Manual DTW readings after removal of the packers is used to best interpret the Levelogger data collected.
- Due to the artesian and near to surface static water levels observed at SB_MW03 bedrock intervals, the Margo-plugs are installed into the water column. When the Margo-plug is removed from the well, it induces a displacement of the water column. This impacts both the manual water level measurements and the pressure transducer readings and is visually represented as either an upward or downward shift in the data set and manual water level measurements that do not match exactly to the water levels measured by the pressure transducers as seen on hydrograph Figure A-3.
- SB_MW06 was not monitored during the Q4-December event due to construction in the area happening at the same time as the monitoring event. Groundwater elevation data could still be shown from September to December using data downloaded in 2023, but manual groundwater elevation measurements could not be completed and used for adjustment of elevation data, development of groundwater contours, or determination of vertical gradients in Q4 2022.

### 3.3.6 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 both the preparer and the verifier.

**Identified Errors**

During the review of the downloaded data, KGS Group identified the following issues:

Q4-2022

- The transducer data retrieved from SB_MW06_BR-B before the well was decommissioned on December 12, 2022, is not representative of the hydraulic heads for this interval. The hydraulic heads for this period were approximately 1 m higher compared to before the Q3-September monitoring event (when the casing failure was identified) and after the replacement well was installed December 13 and 14, 2022. This is highlighted on Figure A-6.

Q3-September 2022

- While updating the hydrographs for the Q3-September report, a file naming error of a raw dataset was identified for the Q3-July 2022 download of the datalogger from SB_MW05_BR-B. At the time of download, the incorrect file name was given when saving the data.

Q3-July 2022

- There is a small shift and gap in the water level data on April 5, 2022 in the following monitoring wells: SB_MW04_BR-A, SB_MW04_BR-B, SB_MW04_BR-C, SB_MW04_OB-INT, SB_MW05_BR-C, SB_MW06_BR-A, SB_MW06_BR-B, SB_MW06_BR-C, SB_MW06_OB-INT, SB_MW07_BR-C and SB_MW07_OB-INT. This is most likely due to the pressure transducers being removed from the well and not returned to the exact same depth.
- There is a large decrease in hydraulic head between April 5 and April 23, 2022 in SB_MW02_BR-B, that is not consistent with changes observed in other monitoring wells, including other SB_MW02 wells that responded similarly the rest of the year. This is most likely related to issues with the well construction and well development and the reason why a replacement well, SB_MW02_BR_R-B was required to be installed in June 2022.

## 3.4 Hydraulic Head Results

Hydraulic heads were calculated for each monitoring interval using the data processing methodology described in section 3.3.2. Table 1 below provides a summary of the measured minimum and maximum groundwater elevations for 2022 as measured by the pressure transducers. Table 2 below provides a summary of the calculated hydraulic head elevations for each monitoring well. The calculated hydraulic head elevations have been plotted against time on a hydrograph for each monitoring well and site. Each hydrograph was reviewed, and out-of-range data points were filtered out from the graph data set and not shown on the hydrograph. Hydrographs are provided in Appendix A.

TABLE 1 GROUNDWATER HYDRAULIC HEAD RANGES

| Interval | Hydraulic Head Ranges[1] | | |
|---|---|---|---|
| | Minimum (masl) | Maximum (masl) | Range (m) |
| **SB_MW01_BR-A** | 278.53 | 279.45 | 0.93 |
| **SB_MW01_OB-INT** | 283.61 | 285.09 | 1.48 |
| **SB_MW02_BR-A** | 285.68 | 287.35 | 1.66 |
| **SB_MW02_BR-B** | 286.15 | 289.52 | 3.36 |
| **SB_MW02_BR-C** | 286.15 | 287.93 | 1.78 |

| Interval | Hydraulic Head Ranges[1] | | |
|---|---|---|---|
| | Minimum (masl) | Maximum (masl) | Range (m) |
| SB_MW02_OB-INT | 286.19 | 287.94 | 1.75 |
| SB_MW03_BR-A | 283.39 | 285.28 | 1.88 |
| SB_MW03_BR-B | 282.51 | 283.93 | 1.42 |
| SB_MW03_BR-C | 280.87 | 282.96 | 2.09 |
| SB_MW03_OB-INT | 280.27 | 281.72 | 1.45 |
| SB_MW04_BR-A | 280.15 | 281.40 | 1.26 |
| SB_MW04_BR-B | 278.90 | 280.24 | 1.34 |
| SB_MW04_BR-C | 278.29 | 279.72 | 1.44 |
| SB_MW04_OB-INT | 278.34 | 279.89 | 1.55 |
| SB_MW05_BR-A | 275.46 | 276.41 | 0.95 |
| SB_MW05_BR-B | 275.13 | 275.67 | 0.54 |
| SB_MW05_BR-C | 274.85 | 275.79 | 0.94 |
| SB_MW05_OB-INT | 273.81 | 274.73 | 0.92 |
| SB_MW06_BR-A | 276.18 | 277.42 | 1.24 |
| SB_MW06_BR-B | 276.20 | 277.42 | 1.23 |
| SB_MW06_BR-C | 276.11 | 277.48 | 1.37 |
| SB_MW06_OB-INT | 275.86 | 276.89 | 1.03 |
| SB_MW07_BR-A | 292.85 | 294.31 | 1.46 |
| SB_MW07_BR-B | 292.98 | 294.35 | 1.37 |
| SB_MW07_BR-C | 292.84 | 294.21 | 1.37 |
| SB_MW07_OB-INT | 293.85 | 295.15 | 1.29 |
| SB_MW09_BR-B | 276.41 | 276.68 | 0.28 |

Note: (1) As measured by the pressure transducers

### 3.4.1 HYDROGRAPH OBSERVATIONS

Hydraulic head elevations at most sites generally decreased through the spring and summer months, then began to increase slowly beginning in September and continuing through the fall months. However, in SB_MW01 and SB_MW04, the decreases in hydraulic head elevations were observed from April to August 2022 when the rate of decreasing hydraulic head slowed to becoming static by the end of 2022.

The nearest Environment Canada weather data for 2022 from the Goderich station (Climate ID: 6122847), was downloaded from the Environment Canada Historical Weather online database (Environment Canada, 2022). The Goderich weather station is located approximately 42 km southwest of the South Bruce site . Daily total precipitation data were plotted on the hydrographs in Appendix A, for the purposes of assessing any correlations of precipitation events and hydraulic head changes. Given the distance of Goderich station from the South Bruce site, limitations in interpreting hydraulic head changes (due to precipitation events) are expected. There was a large rain event on August 3 with 63mm total precipitation measured at the weather station that is not reflected in the South Bruce hydrographs. It is possible that this rain event occurred locally around the Goderich station, with little to no rainfall at the South Bruce site. Because the bedrock aquifer at the South Bruce site is confined, 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. 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 does not extend through an entire year of precipitation, primarily missing the winter months of January to March, and spring melt from March into April. The spring melt would also be expected to contribute to increases in groundwater hydraulic head in the bedrock and overburden aquifers. Spring recharge events would typically not cause a sudden increase in hydraulic head within the bedrock, such as seen with precipitation in the form of short duration and high intensity rainfall events. Spring recharge would be observed throughout an entire monitoring period that covers a season, or a portion of the full calendar year, with gradual increases and decreases over several weeks or months, as the ground thaws, and recharge enters the regional bedrock aquifer system within bedrock aquifer recharge zones, resulting in more gradual bedrock aquifer pressure responses. This is analogous but opposite to a relatively low precipitation period, such as through a dry summer/fall season, where gradually decreasing bedrock aquifer hydraulic head conditions are typically observed over the ensuing weeks to months.

Aside from the August 3 rain event, the largest rain event through the 2022 monitored period occurred between June 5 and June 9, 2022, with a peak daily precipitation of 53 mm measured on June 6. All hydrographs show a direct correlation to this rain event, with water level elevations raising between 0.1 m and 0.4 m, with the largest responses measured in SB_MW02_BR-C and SB_MW02_OB-INT. This response may be attributed to an increase in pressures (via regional recharge) of the bedrock aquifers, along with a strong vertical hydraulic interconnection between the limestone bedrock aquifers and the overlying sand and gravel overburden aquifers. A slightly muted response in the deeper bedrock wells is also observed, which would be anticipated as part of the more regional overall pressure response of the bedrock aquifer to the rainfall event, and also related to the variability of naturally occurring vertical interconnectivity of the various bedrock fracture systems and aquifer zones that exist at the South Bruce site.

An earlier notable period of precipitation occurred during the month of April (18 to 25) where five days had >= 2.0 mm of precipitation totaling 30 mm for that span of time. This precipitation is reflected on most of the hydrographs with a relatively small magnitude though steady incremental rise in the bedrock hydraulic heads. The monitoring wells where little to no rise was measured during this April event included SB_MW02_BR-B and all monitored intervals at SB_MW04. While the April 2022 data at SB_MW02_BR-B data appears to be an artefact of a well affect, the fact that the April precipitation event did not appear to be registered within the other bedrock intervals at SB_MW04 is likely a result of the variability and complexity of the bedrock fracture system within the aquifer at this well location. Notably, the much larger magnitude June 2022 event at SB_MW04 is of less overall amplitude and the well interval data demonstrated a relative lag in pressure response in comparison to (for example) SB_MW02 and SB_MW03, thus supporting this interpretation.

Two other notable multi-day rain events occurred between September 25-27 and October 12-20, with a hydraulic response observed in all monitoring wells except for SB_MW01 (all intervals) and SB_MW04 (all intervals). Persistent precipitation was observed from the end of September through November and December, which is reflected in the hydrographs as an increase in hydraulic head in most monitoring intervals through the fall months.

**SB_MW01 – (Figure A-1):** The April rain events (Between April 18 to 25) was observed very slightly at SB_MW01, seen in the hydraulic response in both monitoring intervals. The rain event in June 2022 was reflected in both wells at Site SB_MW01, with a larger hydraulic response observed in the overburden monitoring interval. October rainfall was reflected in SB_MW01_OB-INT, but with little evidence of influence in SB_MW01_BR-A.

Water levels are approximately 5.5 m higher in the overburden well at SB_MW01, compared to the deep bedrock well monitoring interval, ranging from 283.5 to 285 masl, compared to a range of 278.5 to 279.5 masl in the bedrock. Generally, the water level responses are quicker to respond to rainfall events and with greater magnitude in the overburden well, compared to the hydraulic head pressure responses in the deep bedrock well, likely a reflection of the more direct recharge to the overburden aquifer system versus the pressure response to regional recharge that enters the bedrock aquifer system in regional bedrock aquifer recharge areas.

**SB_MW02 – (Figure A-2):** The April rain event (April 18 to 25) was observed in intervals A, C, and OB-INT at SB_MW02, but not in interval B. Interval SB_MW02_BR-B shows an anomalous decrease in hydraulic head from the point of installation on April 7, 2022 until approximately April 18, 2022. The reasons for this anomalous hydraulic head response is unknown. What is apparent is that by May of 2022, and for all data collection thereafter, this well interval and its instrument recorded detailed pressure conditions within the bedrock that are in step and accurate, based on comparison to the other monitored bedrock intervals at this installation site. The hydraulic response in SB_MW02_BR-B matches very closely the response in all other monitoring intervals at SB_MW02 for the rest of 2022, with no other similar sudden increases or decreases observed.

The precipitation event in June 2022 rain event had the greatest response measured in the wells at Site SB_MW02 compared to other sites. Hydraulic head increased approximately 0.5 m in each of the monitoring intervals at SB_MW02 following the June precipitation.

Hydraulic heads increased in all SB_MW02 monitoring intervals during the fall precipitation.

Hydraulic head within the overburden and upper bedrock intervals (intervals C and B) were similar in level and response throughout the year, ranging from 287.9 masl in April to a low of 286.2 masl in September. The deepest monitoring interval, SB_MW02_BR-A was consistently 0.5 m lower in elevation than the other intervals monitored.

**SB_MW03 – (Figure A-3):** The April and June rain events were observed in all the SB_MW03 wells. The two shallowest wells (SB_MW03_BR-C and SB_MW03_OB-INT) and to a lesser degree in the deeper monitoring wells, show daily fluctuations in the water levels, seen as a distinct “sawtooth” pattern on the hydrograph, between May 15 and 29, June 6 and 19, July 3 and August 27, and between September 12 and 26. This could be a direct result of the installation of the packers, which are used to seal the well and keep it from flowing due to the artesian conditions observed in the wells at SB_MW03. When the well becomes sealed to the atmosphere, the in-casing pressure responses become more sensitive to barometric fluctuations, and other regional confined aquifer pressure changes, as seen in the hydrograph.

The fall precipitation was observed less in SB_MW03 wells compared to others, with only a slight overall increase. However obvious small spikes in the hydrograph were observed around precipitations events occurring roughly September 25 and October 19.

The hydrograph shows a strong upward hydraulic gradient within the bedrock intervals from the deepest to the shallowest zones. Hydraulic heads in all bedrock intervals are greater than the overburden water table elevation interval. SB_MW03_BR-A demonstrates a hydraulic head range of 283.5 to 285.2 masl, compared to the shallowest overburden interval monitored in SB_MW03_OB-INT which had water elevations ranging from 280.5 to 281.7 masl.

During each monitoring event, the static depth to water was measured, with this measurement used to adjust past data based on a known fixed transducer position at the time of monitoring. There are several discrepancies in the manual elevation measurements and transducer data for SB_MW03, especially in intervals A, B, and C, and less so in the overburden well. These discrepancies may be attributed to the artesian conditions observed at SB_MW03, and the packer installation preventing artesian flow during the majority of data collection, which is not the case when manual measurements are acquired. By removing the packers to manually measure groundwater elevation, confined pressure is relieved and the hydraulic conditions during collection of manual measurements are different from those being monitored via the pressure transducers the remainder of the time while packers are installed. The perceived sudden changes in hydraulic head, or shifts in data traces, observed at SB_MW03 could also possibly be due to small incremental changes in transducer installation depths within the well between monitoring events, along with the variability in build-up of confined pressures within the wells that occur over time following re-installation of the well packers.

**SB_MW04 – (Figure A-4):** The April rain and hydraulic response observed at other monitoring well locations was not observed in SB_MW04 wells. There was a shift observed in early April where the hydraulic head changed suddenly from increasing to decreasing, with a sudden drop observed on April 6. Presumably, this was caused when the pressure transducers were being installed and is most likely related to adjustments made to the transducer depth.

The June rain event was observed in all the SB_MW04 wells with an increase in hydraulic head of approximately 0.2 m in each well.

Like the conditions observed at Site 3, SB_MW04_BR-A has higher water elevations than measured in the intermediate and shallow bedrock wells. SB_MW04_BR-B has lower hydraulic head than SB_MW04_BR-A, but higher than the upper monitoring intervals. There is very little difference between the water elevations of SB_MW04_BR-C and SB_MW04_OB-INT.

**SB_MW05 – (Figure A-5):** The April and June rain events were reflected in all wells at SB_MW05. The hydrograph shows a relatively strong upward gradient from the deepest to the shallowest monitoring wells, with SB_MW05_BR-A having a water elevation range of 275.6 to 276.4 masl, compared to the shallowest interval monitored in SB_MW05_OB-INT with water elevations ranging from 273.9 to 274.7 masl observed.

Fall precipitation from September to December was not reflected as an increase in hydraulic head in SB_MW05 monitoring wells, rather relative stability was maintained from October through December following a general decrease in hydraulic head from installation in April through the summer months until the end of September.

See section 3.3.6 for explanation of the missing Q3-July water levels.

**SB_MW06 – (Figure A-6):** The rain events from April and June 2022 were reflected in all the SB_MW06 wells as sudden increases in hydraulic head around April 23 and June 12. Fall precipitation was reflected in all

SB_MW06 wells, with a slight increase in hydraulic head starting at the end of September and continuing through December. Relatively sharp increases in hydraulic head were observed around September 30 and October 25.

The bedrock water level elevations were essentially the same as one another throughout the year. This indicates a strong hydraulic connection between the three monitoring wells. The overburden well had groundwater elevations consistently lower than the nested bedrock wells, with hydraulic head lower by approximately 0.5 m at the beginning of 2022 and approximately 0.3 m at the end of the year.

**SB_MW07 – (Figure A-7):** The rain events from April and June 2022 were reflected in all the SB_MW07 wells as increases in hydraulic head around April 23 and June 12. Fall precipitation was reflected in all SB_MW07 wells, with increases in hydraulic head starting at the end of September and continuing through December. Relatively sharp increases in hydraulic head were observed between September 30 and October 25.

Interestingly, the water level elevations in SB_MW07_OB-INT were consistently higher than bedrock water level elevations, ranging from 0.6 to 1.0 m higher. Hydraulic head values did not show the same minor fluctuations in SB_MW07_OB-INT as what is observed in the bedrock wells, (i.e., the hydrograph line is muted). This could indicate a perched water table condition, potentially isolated from the pressures in the bedrock.

## TABLE 2 GROUNDWATER LEVEL MEASUREMENTS SUMMARY

| Interval | Ground Elevation (masl) | TOC Elevation (masl) | Q3 (July) 2022 | | | Q3 (September) 2022 | | | Q4 2022 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Test Date and Time (dd/mm/yyyy hh:mm) | Water Level (mbgs) | Groundwater Elevation (masl) | Test Date and Time (dd/mm/yyyy hh:mm) | Water Level (mbgs) | Groundwater Elevation (masl) | Test Date and Time (dd/mm/yyyy hh:mm) | Water Level (mbgs) | Groundwater Elevation (masl) |
| SB_MW01_BR-A | 288.69 | 289.59 | 7/28/2022 8:10 | 9.94 | 278.75 | 12/09/2022 09:37 | 10.07 | 278.62 | 14/12/2022 09:55 | 9.92 | 278.77 |
| SB_MW01_OB-Int | 288.75 | 289.70 | 7/28/2022 8:15 | 4.96 | 283.80 | 12/09/2022 09:42 | 5.08 | 283.68 | 14/12/2022 10:00 | 4.72 | 284.03 |
| SB_MW02_BR-A | 291.37 | 291.75 | 7/27/2022 10:16 | 5.13 | 286.24 | 16/09/2022 12:30 | 5.59 | 285.79 | 13/12/2022 11:00 | 5.21 | 286.16 |
| SB_MW02_BR-B | 291.37 | 291.76 | 7/27/2022 10:17 | 4.64 | 286.74 | 16/09/2022 12:35 | 5.18 | 286.19 | 13/12/2022 11:15 | 4.61 | 286.76 |
| SB_MW02_BR_R-B | 291.37 | 291.76 | | (1) | | | (1) | | 13/12/2022 11:20 | 4.54 | 286.76 |
| SB_MW02_BR-C | 291.37 | 291.77 | 7/27/2022 10:18 | 4.63 | 286.74 | 16/09/2022 12:37 | 5.13 | 286.24 | 13/12/2022 11:25 | 4.60 | 286.77 |
| SB_MW02_OB-Int | 291.75 | 292.50 | 7/27/2022 10:15 | 4.60 | 287.15 | 16/09/2022 12:41 | 5.50 | 286.25 | 13/12/2022 11:30 | 4.93 | 286.82 |
| SB_MW03_BR-A | 282.30 | 284.08 | 7/27/2022 20:35 | -1.12 | 283.42 | 15/09/2022 13:00 | 0.014 | 282.29 | 15/12/2022 11:30 | 0.31 | 281.99 |
| SB_MW03_BR-B | 282.30 | 284.76 | 7/27/2022 20:30 | -0.43 | 282.73 | 15/09/2022 13:05 | -0.19 | 282.49 | 15/12/2022 11:45 | -0.68 | 282.98 |
| SB_MW03_BR-C | 282.30 | 284.88 | 7/27/2022 20:36 | 0.55 | 281.75 | 15/09/2022 13:10 | 1.15 | 281.15 | 15/12/2022 11:55 | 1.11 | 281.19 |
| SB_MW03_OB-Int | 282.36 | 283.16 | 7/27/2022 19:55 | 1.95 | 280.41 | 15/09/2022 13:15 | 1.95 | 280.41 | 15/12/2022 12:10 | 1.46 | 280.90 |
| SB_MW04_BR-A | 284.66 | 285.54 | 7/28/2022 9:04 | 5.35 | 279.31 | 13/09/2022 09:42 | 4.42 | 280.24 | 14/12/2022 15:25 | 4.33 | 280.33 |
| SB_MW04_BR-B | 284.66 | 285.56 | 7/28/2022 9:15 | 4.59 | 280.07 | 13/09/2022 09:40 | 5.58 | 279.08 | 14/12/2022 15:30 | 5.65 | 279.01 |
| SB_MW04_BR-C | 284.66 | 285.49 | 7/28/2022 9:15 | 5.83 | 278.83 | 13/09/2022 09:44 | 6.12 | 278.54 | 14/12/2022 15:35 | 6.27 | 278.39 |
| SB_MW04_OB-Int | 284.43 | 285.29 | 7/28/2022 12:52 | 5.58 | 278.85 | 13/09/2022 09:50 | 5.89 | 278.54 | 14/12/2022 15:40 | 6.02 | 278.41 |
| SB_MW05_BR-A | 277.78 | 278.46 | 7/28/2022 9:50 | 2.09 | 275.69 | 13/09/2022 16:10 | 2.23 | 275.55 | 15/12/2022 13:47 | 2.00 | 275.78 |
| SB_MW05_BR-B | 277.78 | 278.44 | 7/28/2022 9:51 | 2.67 | 275.11 | 13/09/2022 16:12 | 2.54 | 275.25 | 15/12/2022 13:50 | 2.38 | 275.40 |
| SB_MW05_BR-C | 277.78 | 278.47 | 7/28/2022 9:52 | 2.75 | 275.03 | 13/09/2022 16:14 | 2.88 | 274.90 | 15/12/2022 13:54 | 2.68 | 275.10 |
| SB_MW05_OB-Int | 277.92 | 278.70 | 7/28/2022 9:53 | 3.93 | 273.99 | 13/09/2022 17:46 | 3.98 | 273.94 | 15/12/2022 14:00 | 3.77 | 274.15 |
| SB_MW06_BR-A | 286.29 | 287.05 | 7/27/2022 12:40 | 9.84 | 276.45 | 14/09/2022 12:50 | 10.06 | 276.23 | | (2) | |
| SB_MW06_BR-B | 286.29 | 287.04 | 7/27/2022 12:48 | 9.85 | 276.44 | 14/09/2022 12:55 | 10.09 | 276.20 | | (2) | |
| SB_MW06_BR-C | 286.29 | 287.10 | 7/27/2022 12:51 | 9.87 | 276.43 | 14/09/2022 13:00 | 10.09 | 276.20 | | (2) | |
| SB_MW06_OB-Int | 286.46 | 287.37 | 7/27/2022 12:52 | 10.43 | 276.03 | 14/09/2022 13:05 | 10.60 | 275.86 | | (2) | |
| SB_MW07_BR-A | 301.65 | 302.14 | 7/26/2022 9:36 | 8.37 | 293.29 | 17/09/2022 12:05 | 9.20 | 292.94 | 16/12/2022 15:30 | 8.79 | 293.35 |
| SB_MW07_BR-B | 301.65 | 302.16 | 7/26/2022 9:40 | 8.23 | 293.42 | 17/09/2022 12:09 | 9.09 | 293.07 | 16/12/2022 15:34 | 8.67 | 293.49 |
| SB_MW07_BR-C | 301.65 | 302.14 | 7/26/2022 9:43 | 8.37 | 293.28 | 17/09/2022 12:15 | 9.21 | 292.93 | 16/12/2022 15:39 | 8.79 | 293.35 |
| SB_MW07_OB-Int | 301.96 | 302.69 | 7/26/2022 9:46 | 7.64 | 294.32 | 17/09/2022 12:19 | 8.75 | 293.94 | 16/12/2022 15:45 | 8.56 | 294.13 |

Notes: (1) DTW not measured during field event. (2) Site not available due to drilling of replacement well SB_MW09_BR-B.

### 3.4.2 VERTICAL GROUNDWATER GRADIENTS

Vertical groundwater gradients were calculated between monitoring intervals at each monitoring well location using the manually measured groundwater elevations. Gradients were calculated as the difference in groundwater 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 below summarizes the vertical groundwater gradients between monitoring intervals at each monitoring well location.

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

- SB_MW03: upward gradient from interval A to interval B in July 2022, but downward gradient from interval B to interval A in September and December 2022
- SB_MW04: downward gradient from interval B to interval A in July 2022, but upward gradient from interval A to interval B in September and December 2022
- SB_MW06: upward gradient from interval B to interval C in July 2022, but downward gradient from interval C to interval B in September 2022.

In the upper monitoring intervals between overburden and bedrock, vertical gradients were downward in the higher groundwater elevation areas along the south of the site (i.e. an overburden to bedrock recharge condition, where vertical interconnection might allow for this to occur). In the lower groundwater elevation monitoring areas to the north of the site, vertical gradients were upward between bedrock and overburden (intervals C to OB; i.e. a bedrock aquifer discharge condition, where vertical interconnection might allow for this to occur).

Generally, vertical gradients in bedrock were upward from the Bois Blanc formation to the Amherstburg formation, and upward from the Amherstburg formation to the Lucas formation, with the exception of SB_MW02, in which vertical gradients were downward between all monitoring intervals during each monitoring event in 2022. Vertical gradients between monitoring intervals within the Amherstburg formation alone were not consistent between monitoring well locations and events.

Since SB_MW06 was not monitored in Q4 2022, manual groundwater elevations were not measured, and vertical groundwater gradients for that location were not determined.

## TABLE 3 GROUNDWATER VERTICAL GRADIENTS SUMMARY

| Interval | Geological Formation | Q3 (July) 2022 | | | Q3 (September) 2022 | | | Q4 2022 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Groundwater Elevation (masl) | Groundwater Gradient (m/m) | Gradient Description (masl) | Groundwater Elevation (masl) | Groundwater Gradient (m/m) | Gradient Description (masl) | Groundwater Elevation (masl) | Groundwater Gradient (m/m) | Gradient Description (masl) |
| SB_MW01_OB-Int | Overburden | 283.795 | 0.1624 | downward gradient from OB to A | 283.675 | 0.1628 | downward gradient from OB to A | 284.026 | 0.1693 | downward gradient from OB to A |
| SB_MW01_BR-A | Lucas Formation | 278.753 | | | 278.622 | | | 278.770 | | |
| SB_MW02_OB-Int | Overburden | 287.151 | 0.0484 | downward gradient from OB to C | 286.250 | 0.0013 | downward gradient from OB to C | 286.824 | 0.0062 | downward gradient from OB to C |
| SB_MW02_BR-C | Lucas Formation | 286.742 | 0.0001 | Hydrostatic, no vertical gradient interpreted | 286.239 | 0.0010 | downward gradient from C to B | 286.772 | 0.0003 | Hydrostatic, no vertical gradient interpreted |
| SB_MW02_BR-B | Amherstburg Formation | 286.735 | 0.0356 | downward gradient from B to A | 286.188 | 0.0288 | downward gradient from B to A | 286.757 | 0.0425 | downward gradient from B to A |
| SB_MW02_BR-A | Bois Blanc Formation | 286.237 | | | 285.785 | | | 286.162 | | |
| SB_MW03_OB-Int | Overburden | 280.414 | -0.1480 | upward gradient from C to OB | 280.406 | -0.0821 | upward gradient from C to OB | 280.900 | -0.0321 | upward gradient from C to OB |
| SB_MW03_BR-C | Lucas Formation | 281.750 | -0.0638 | upward gradient from B to C | 281.147 | -0.0876 | upward gradient from B to C | 281.190 | -0.1164 | upward gradient from B to C |
| SB_MW03_BR-B | Amherstburg Formation | 282.730 | -0.0322 | upward gradient from A to B | 282.492 | 0.0096 | downward gradient from B to A | 282.976 | 0.0461 | downward gradient from B to A |
| SB_MW03_BR-A | Amherstburg Formation | 283.420 | | | 282.286 | | | 281.988 | | |
| SB_MW04_OB-Int | Overburden | 278.850 | 0.0014 | downward gradient from OB to C | 278.542 | 0.0003 | Hydrostatic, no vertical gradient interpreted | 278.413 | 0.0016 | downward gradient from OB to C |
| SB_MW04_BR-C | Lucas Formation | 278.830 | -0.0752 | upward gradient from B to C | 278.538 | -0.0330 | upward gradient from B to C | 278.389 | -0.0375 | upward gradient from B to C |
| SB_MW04_BR-B | Amherstburg Formation | 280.070 | 0.0229 | downward gradient from B to A | 279.083 | -0.0352 | upward gradient from A to B | 279.007 | -0.0401 | upward gradient from A to B |
| SB_MW04_BR-A | Bois Blanc Formation | 279.314 | | | 280.243 | | | 280.331 | | |
| SB_MW05_OB-int | Overburden | 273.988 | -0.0543 | upward gradient from C to OB | 273.943 | -0.0497 | upward gradient from C to OB | 274.150 | -0.0497 | upward gradient from C to OB |
| SB_MW05_BR-C | Lucas Formation | 275.030 | -0.0035 | upward gradient from B to C | 274.897 | -0.0155 | upward gradient from B to C | 275.103 | -0.0133 | upward gradient from B to C |
| SB_MW05_BR-B | Amherstburg Formation | 275.109 | -0.0238 | upward gradient from A to B | 275.245 | -0.0125 | upward gradient from A to B | 275.402 | -0.0154 | upward gradient from A to B |
| SB_MW05_BR-A | Bois Blanc Formation | 275.689 | | | 275.550 | | | 275.777 | | |
| SB_MW06_OB-Int | Overburden | 276.033 | -0.0129 | upward gradient from C to OB | 275.860 | -0.0113 | upward gradient from C to OB | - | - | - |
| SB_MW06_BR-C | Amherstburg Formation | 276.425 | -0.0006 | Hydrostatic, no vertical gradient interpreted | 276.204 | 0.0003 | Hydrostatic, no vertical gradient interpreted | - | - | - |
| SB_MW06_BR-B | Amherstburg Formation | 276.443 | -0.0005 | Hydrostatic, no vertical gradient interpreted | 276.197 | -0.0025 | upward gradient from A to B | - | - | - |
| SB_MW06_BR-A | Bois Blanc Formation | 276.449 | | | 276.229 | | | - | | |
| SB_MW07_OB-Int | Overburden | 294.317 | 0.0416 | downward gradient from OB to C | 293.942 | 0.0406 | downward gradient from OB to C | 294.130 | 0.0314 | downward gradient from OB to C |

| Interval | Geological Formation | Q3 (July) 2022 | | | Q3 (September) 2022 | | | Q4 2022 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Groundwater Elevation (masl) | Groundwater Gradient (m/m) | Gradient Description (masl) | Groundwater Elevation (masl) | Groundwater Gradient (m/m) | Gradient Description (masl) | Groundwater Elevation (masl) | Groundwater Gradient (m/m) | Gradient Description (masl) |
| **SB_MW07_BR-C** | Lucas Formation | 293.283 | -0.0043 | upward gradient from B to C | 292.932 | -0.0045 | upward gradient from B to C | 293.350 | -0.0045 | upward gradient from B to C |
| **SB_MW07_BR-B** | Amherstburg Formation | 293.417 | 0.0051 | downward gradient from B to A | 293.073 | 0.0050 | downward gradient from B to A | 293.490 | 0.0054 | downward gradient from B to A |
| **SB_MW07_BR-A** | Amherstburg Formation | 293.285 | | | 292.944 | | | 293.350 | | |

### 3.4.3 GROUNDWATER HYDRAULIC HEADS AND LOCAL GROUNDWATER FLOW

Groundwater hydraulic heads  were determined through manual measurements during each field event, as described in section 3.3.3. Groundwater elevations were plotted on a site map, with groundwater hydraulic head elevation contours developed across the site, as seen on Figures B-1 to B-6 in Appendix B. Two contour maps were generated for each of the three monitoring events in 2022, one showing groundwater elevations in the overburden, and a second showing groundwater elevations in the bedrock specifically in the Amherstburg Formation. Where two monitoring intervals are within the Amherstburg Formation, as is the case for MW03_BR-A and MW03_BR-B; MW06_BR-B and MW03_BR-C; and MW07_BR-A and MW07_BR-B, an average of the groundwater elevation from both intervals was used. Geological formations and groundwater elevations for each monitoring well and monitoring event are included in Table 2.

Since SB_MW01_BR-A is within the Lucas Formation and there are no deeper bedrock monitoring intervals at the SB_MW01 site, the location was not considered in generating the bedrock groundwater contour maps. Since SB_MW06 was not monitored during the Q4 2022 event in December2022, groundwater elevations at that location were not considered in generating either the Q4 2022 overburden groundwater contour map or the Q4 2022 bedrock groundwater contour map.

Generally, overburden groundwater contours follow the topography across the site, with topographic highs at SB_MW07 and SB_MW02 correlating with higher overburden groundwater elevations, and topographic lows at SB_MW03, SB_MW04, and SB_MW06 correlating with lower overburden groundwater elevations. Overburden groundwater flow is generally northward, with northeastward flow toward Teeswater River at the west of the site, and northwestward flow toward Teeswater River and a topographic low (from SB_MW04 to SB_MW05) at the east of the site. The Teeswater River flows north in the region, ultimately discharging to the Saugeen River at Paisley, Ontario.

Bedrock groundwater flow follows the same trends as seen in the overburden groundwater flow. Bedrock groundwater flows generally northerly across the site, with localized northeasterly flow at the west of the site and localized northwesterly flow at the east of the site.

There is little variation in groundwater contours between monitoring events measured during 2022. Groundwater contours between July and September are nearly identical within overburden (Figures B-1 and B-3) and within the bedrock (Figures B-2 and B-4). Q4-December groundwater contours appear slightly different for both overburden (Figure B-5) and bedrock (Figure B-6), likely due to SB_MW06 groundwater elevations being omitted in the contour development since SB_MW06 was not monitored in December 2022.

# 4.0 SUMMARY

Three groundwater monitoring events were completed in 2022, between July 26 and July 28, 2022 for the Q3 (July) event; between September 12 and September 19, 2022 for the Q3 (September) event, and between December 13 and December 17 2022 for the Q4 2022 event. During these field programs KGS Group downloaded all 26 pressure transducers and one barologger. 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.

# 5.0 REFERENCES

Environment Canada, 2017. Canadian Climate Normals. 1981-2010 Station Data.

Environment Canada, 2022. Daily Data Reports for Goderich Weather Station, Climate ID: 6122847 (https://www.climate.weather.gc.ca/climate_data/)

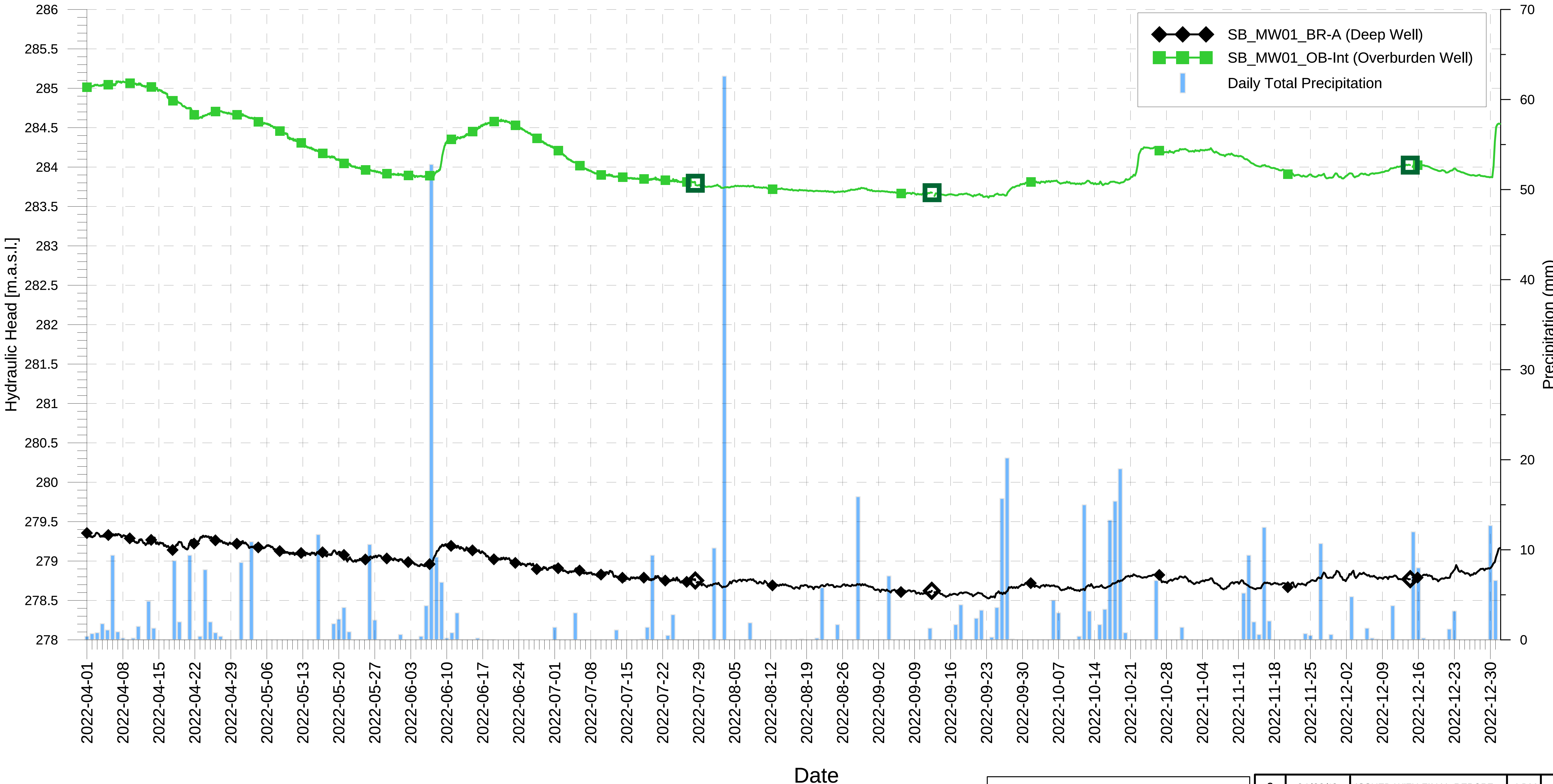
GEOFIRMA, 2023, APM-REP-01332-0360, Shallow Groundwater Monitoring Well Network Installation at the South Bruce Site. Project Data Report for Shallow Groundwater Monitoring Well Network Installation, Rev 3. Table 8 Details of Monitoring Well Hydrualic Testing and Analysis.

Natural Resources Canada, 1957, Atlas of Canada, 3rd Edition, (1921 to 1950 inclusive)

Nuclear Waste Management Organization (NWMO), 2022. Confidence in Safety – South Bruce Site. NWMO-TR-2022-15

# APPENDIX A

Hydrographs




Notes:
1. SB_MW01_BR-A transducer installed at 269.48 m.a.s.l. as of September 12, 2022.
2. SB_MW01_OB-Int transducer installed at 281.87 m.a.s.l. as of September 12, 2022.
3. Precipitation data collected from Environment Canada Goderich Station, located approximately 42 km southwest of the site.

| NO. | YY/MM/DD | DESCRIPTION | DESIGN BY | CHECKED BY |
|---|---|---|---|---|
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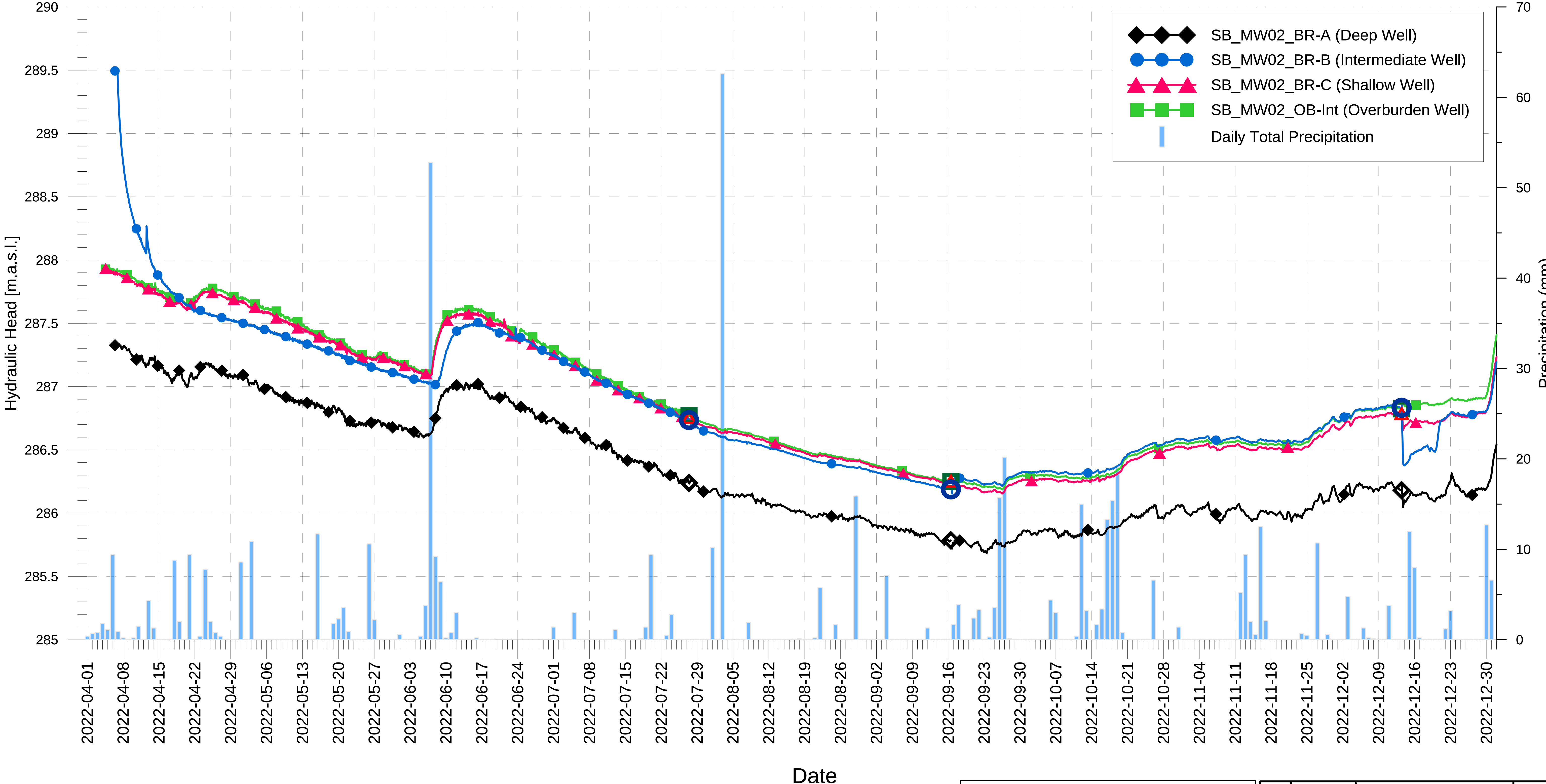
SHALLOW GROUNDWATER MONITORING NETWORK, SOUTH BRUCE AREA

2022 HYDRAULIC HEADS AT SB_MW01 WELL NEST

FEBRUARY 2024 | FIGURE A-1 | REV: 0




SB_MW02_OB-Int Manual GW elevation
SB_MW02_BR-C Manual GW elevation
SB_MW02_BR-B Manual GW elevation
SB_MW02_BR-A Manual GW elevation

Notes:
1. SB_MW02_BR-A transducer installed at 276.90 m.a.s.l. as of September 16, 2022.
2. SB_MW02_BR-B transducer installed at 278.26 m.a.s.l. as of September 16, 2022.
3. SB_MW02_BR-C transducer installed at 276.91 m.a.s.l. as of September 16, 2022.
4. SB_MW02_OB-Int transducer installed at 282.56 m.a.s.l. as of September 16, 2022.
5. Precipitation data collected from Environment Canada Goderich Station, located approximately 42 km southwest of the site.

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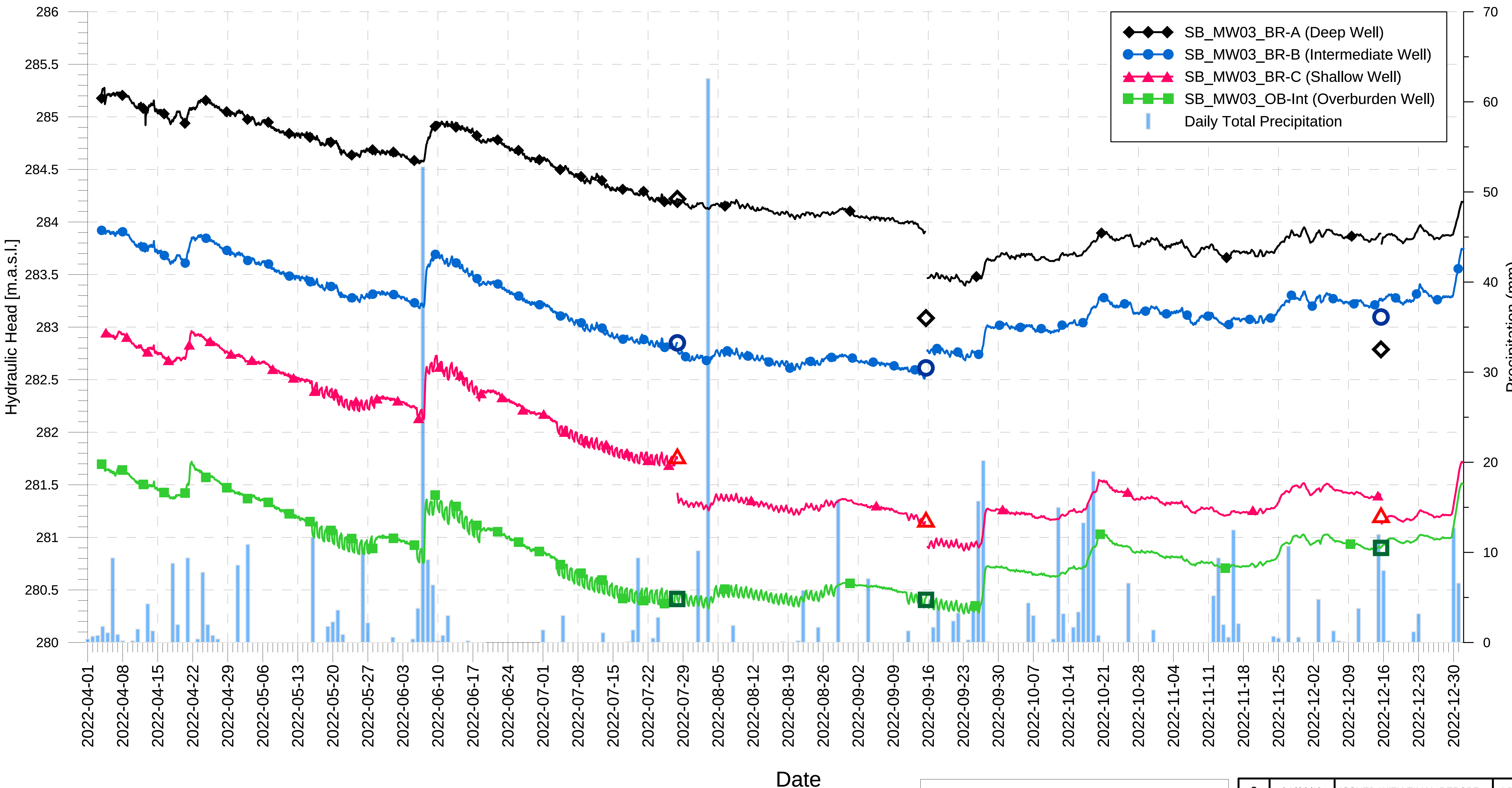
2022 HYDRAULIC HEADS AT SB_MW02 WELL NEST

FEBRUARY 2024 | FIGURE A-2 | REV. 0




SB_MW03_BR-A Manual GW elevation
SB_MW03_BR-B Manual GW elevation
SB_MW03_BR-C Manual GW elevation
SB_MW03_OB-Int Manual GW elevation

Notes:
1. SB_MW03_BR-A transducer installed at 271.96 m.a.s.l. as of September 15, 2022.
2. SB_MW03_BR-B transducer installed at 273.17 m.a.s.l. as of September 15, 2022.
3. SB_MW03_BR-C transducer installed at 272.88 m.a.s.l. as of September 15, 2022.
4. SB_MW03_OB-Int transducer installed at 276.11 m.a.s.l. as of September 15, 2022.
5. Precipitation data collected from Environment Canada Goderich Station, located approximately 42 km southwest of the site.

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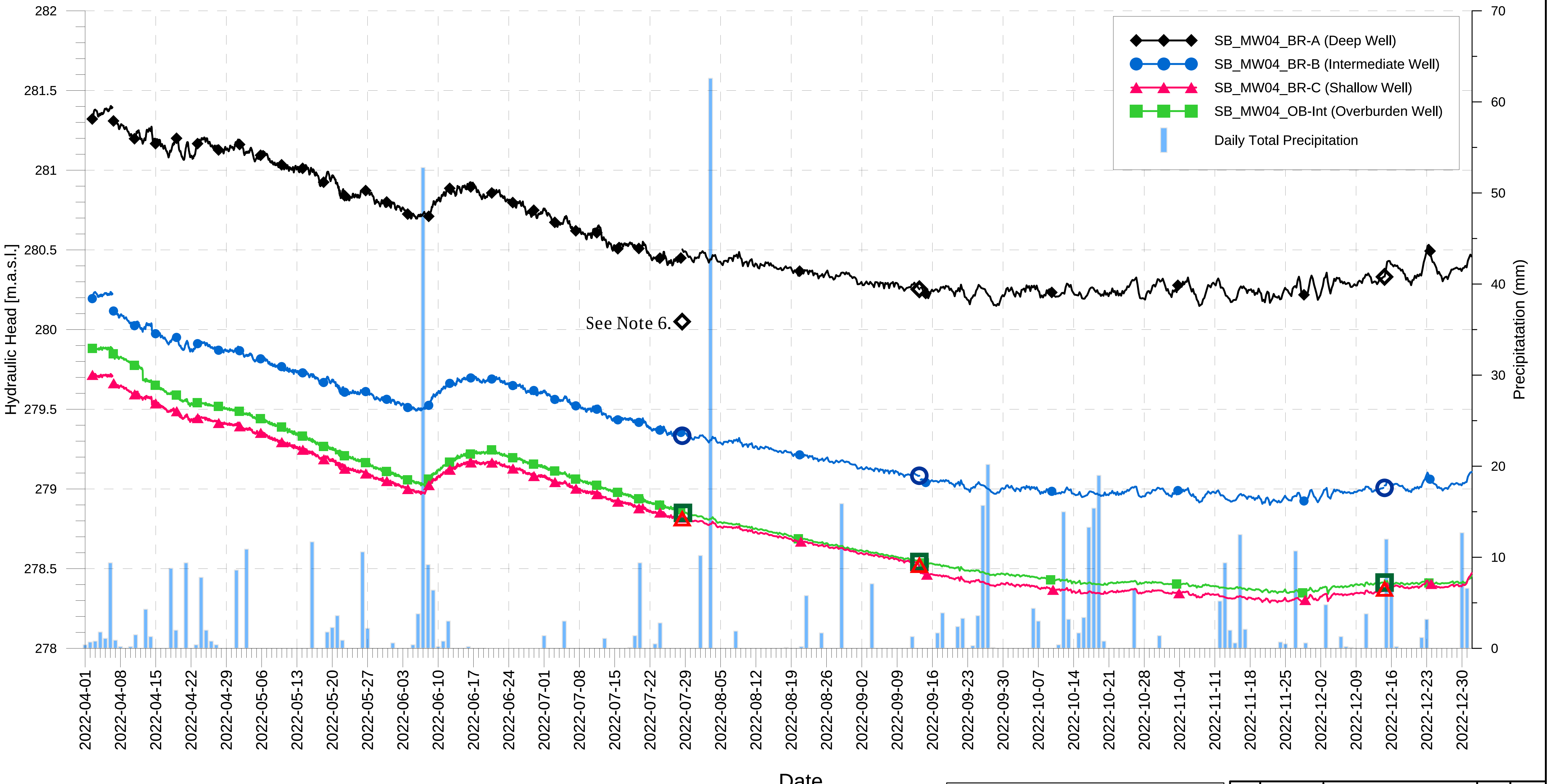
2022 HYDRAULIC HEADS AT SB_MW03 WELL NEST

FEBRUARY 2024 | FIGURE A-3 | REV. 0




Notes:
1. SB_MW04_BR-A transducer installed at 270.54 m.a.s.l. as of September 13, 2022.
2. SB_MW04_BR-B transducer installed at 269.33 m.a.s.l. as of September 13, 2022.
3. SB_MW04_BR-C transducer installed at 268.61 m.a.s.l. as of September 13, 2022.
4. SB_MW04_OB-Int transducer installed at 274.31 m.a.s.l. as of September 13, 2022.
5. Precipitation data collected from Environment Canada Goderich Station, located approximately 42 km southwest of the site.
6. Manual water level measurement is a suspected field error.

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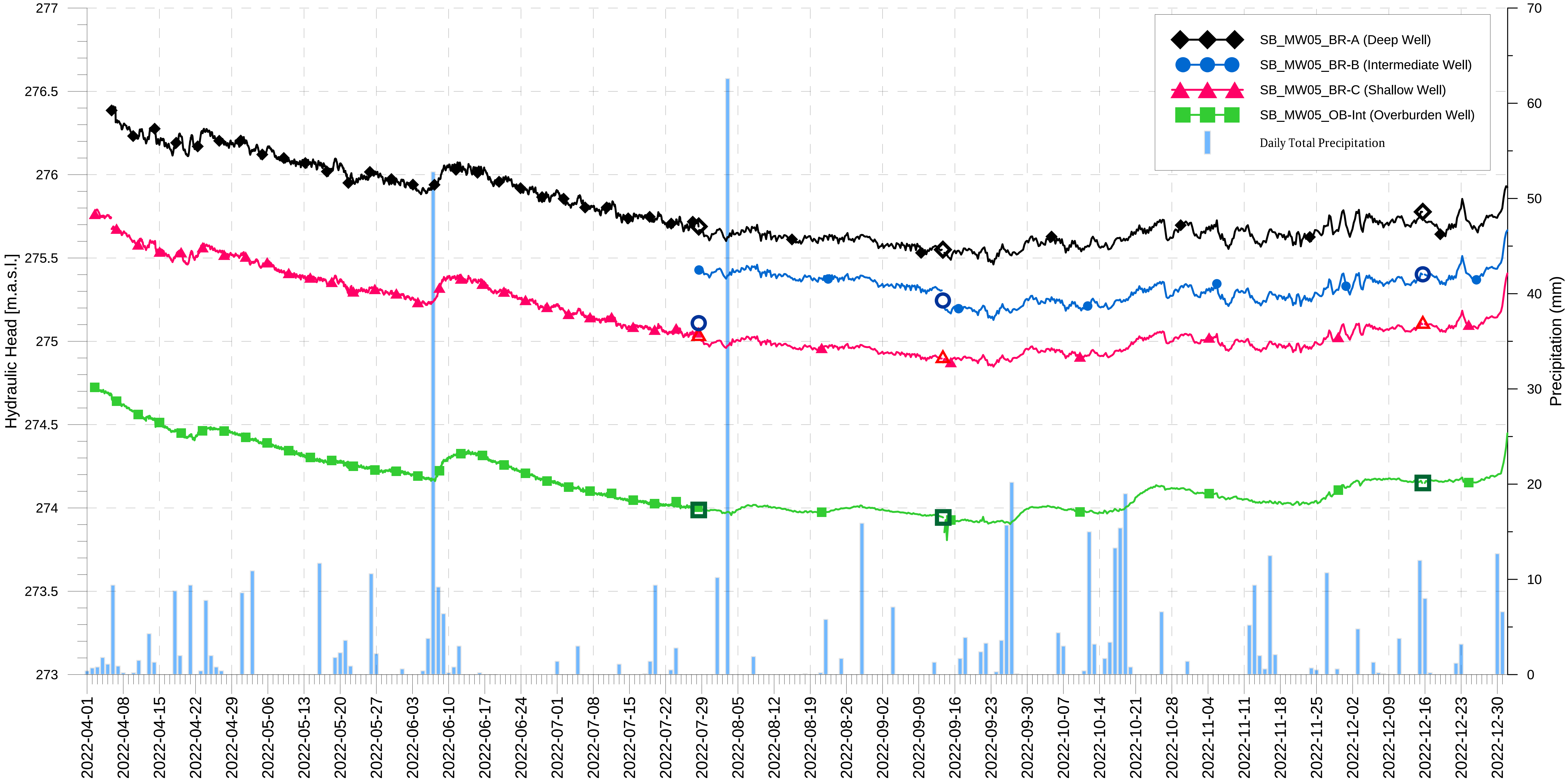
2022 HYDRAULIC HEADS AT SB_MW04 WELL NEST

APRIL 2024 | FIGURE A-4 | REV: 1




Notes:
1. SB_MW05_BR-A transducer installed at 266.33 m.a.s.l. as of September 13, 2022.
2. SB_MW05_BR-B transducer installed at 265.45 m.a.s.l. as of September 13, 2022.
3. SB_MW05_BR-C transducer installed at 265.50 m.a.s.l. as of September 13, 2022.
4. SB_MW05_OB-Int transducer installed at 269.69 m.a.s.l. as of September 13, 2022.
5. Precipitation data collected from Environment Canada Goderich Station, located approximately 42 km southwest of the site.

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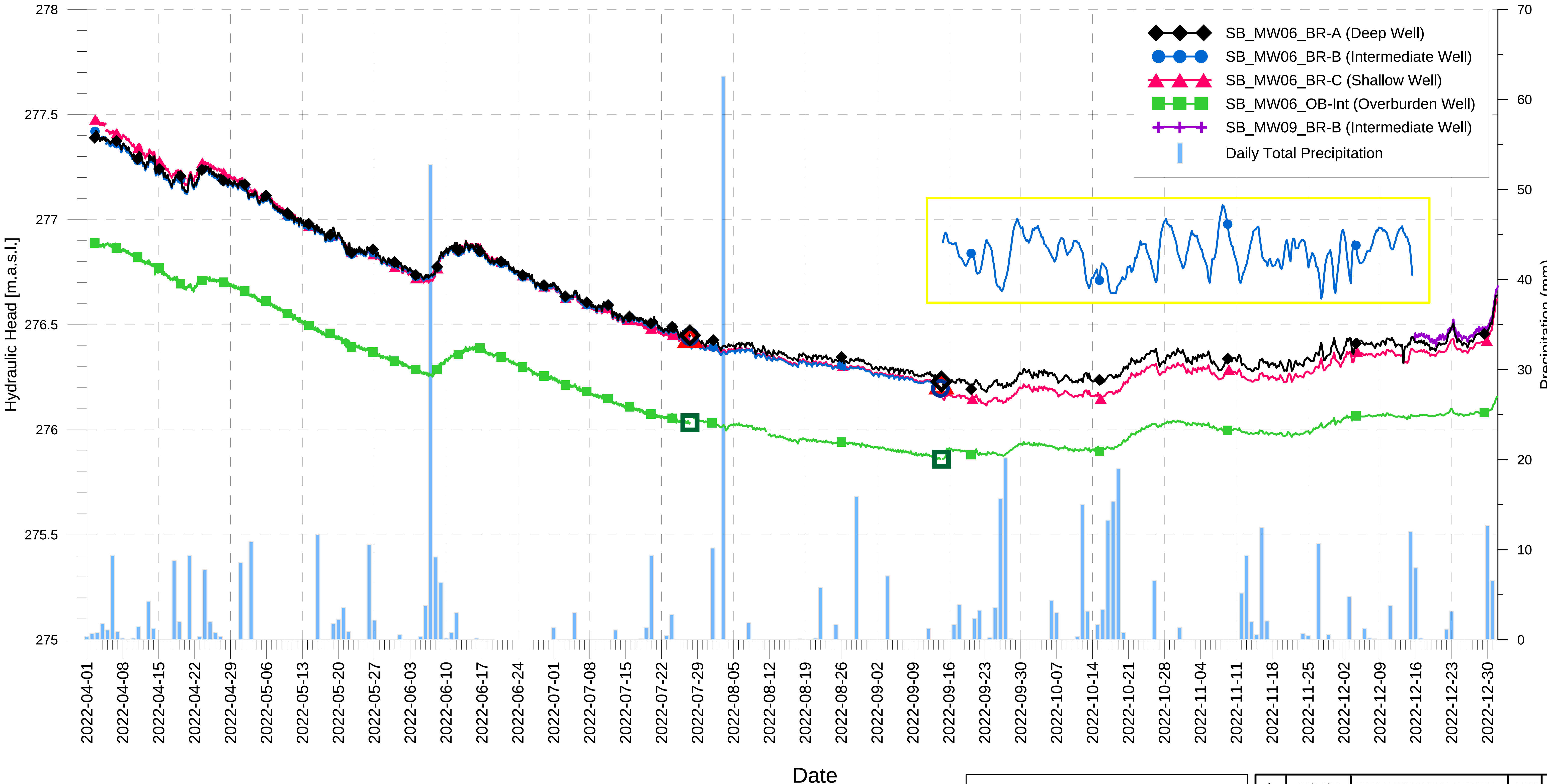
2022 HYDRAULIC HEADS AT SB_MW05 WELL NEST

FEBRUARY 2024 | FIGURE A-5 | REV. 0




Notes:
1. SB_MW06_BR-A transducer installed at 266.93 m.a.s.l. as of September 14, 2023.
2. SB_MW06_BR-B transducer installed at 266.84 m.a.s.l. as of September 14, 2023.
3. SB_MW06_BR-C transducer installed at 266.94 m.a.s.l. as of September 14, 2023.
4. SB_MW06_OB-Int transducer installed at 273.62 m.a.s.l. as of September 14, 2023.
5. Precipitation data collected from Environment Canada Goderich Station, located approximately 42 km southwest of the site.
6. SB_MW06_BR-B decommissioned on December 12, 2022.
7. SB_MW09_BR-B installed December 13 to 14, 2022 to replace SB_MW06_BR_B.
8. Highlighted Data from transducer in SB_MW06_BR-B between September and December is not representative of the groundwater conditions outside of the well. Errors caused by collapsed well casing.

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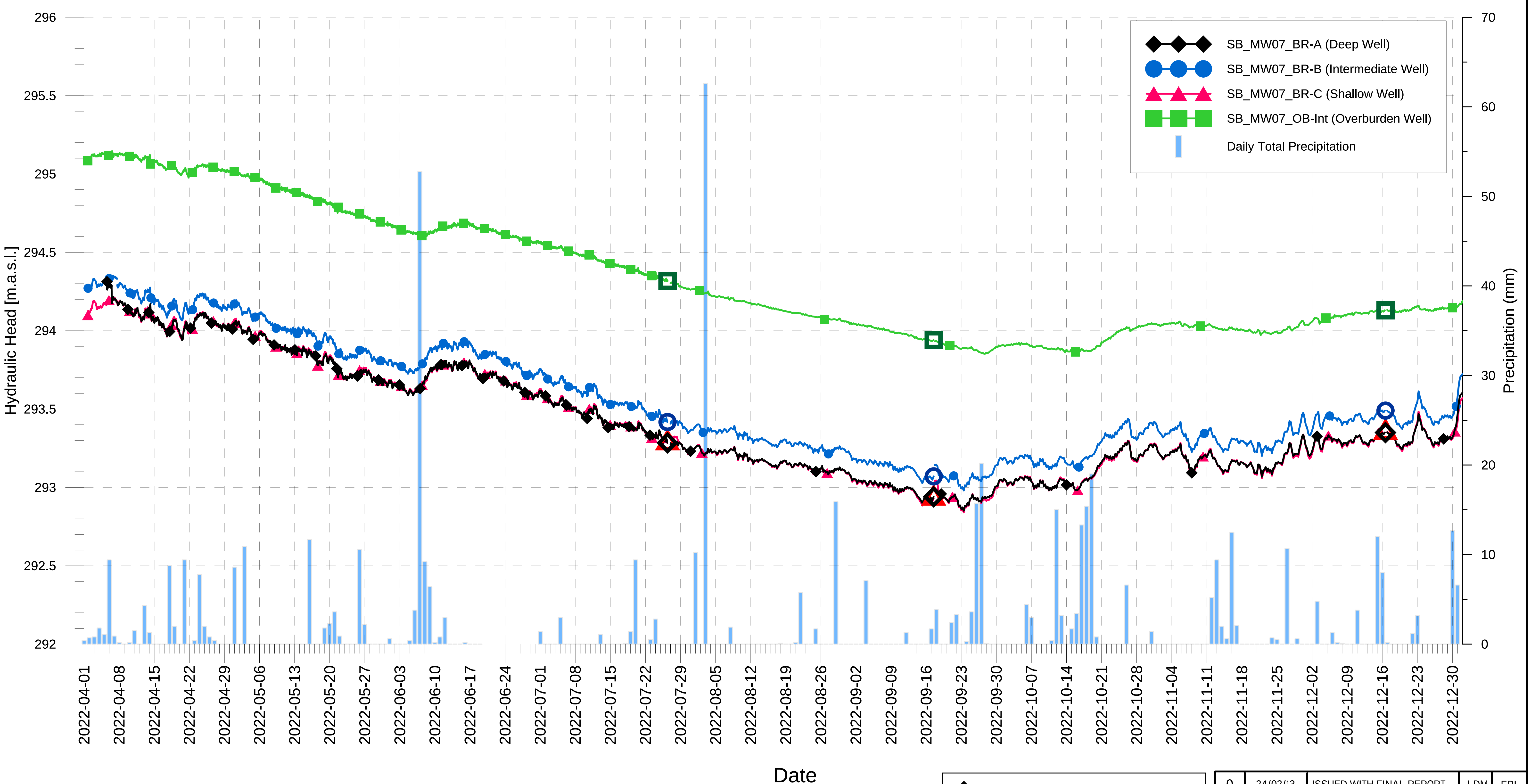
2022 HYDRAULIC HEADS AT SB_MW06 WELL NEST

| | | |
|---|---|---|
| APRIL 2024 | FIGURE A-6 | REV: 1 |




SB_MW07_BR-A Manual GW elevation
SB_MW07_BR-B Manual GW elevation
SB_MW07_BR-C Manual GW elevation
SB_MW07_OB-Int Manual GW elevation

Notes:
1. SB_MW07_BR-A transducer installed at 283.24 m.a.s.l. as of September 17, 2022.
2. SB_MW07_BR-B transducer installed at 284.21 m.a.s.l. as of September 17, 2022.
3. SB_MW07_BR-C transducer installed at 283.20 m.a.s.l. as of September 17, 2022.
4. SB_MW07_OB-Int transducer installed at 292.94 m.a.s.l. as of September 17, 2022.
5. Precipitation data collected from Environment Canada Goderich Station, located approximately 42 km southwest of the site.

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2022 HYDRAULIC HEADS AT SB_MW07 WELL NEST

FEBRUARY 2024 | FIGURE A-7 | REV: 0

# APPENDIX B

Groundwater Contours



**KEY MAP:**

**LEGEND:**

- SB_MW01 MONITORING WELL
- GROUNDWATER CONTOUR
- FLOW DIRECTION
- TEESWATER RIVER

**NOTES:**

1. IMAGERY SOURCE: GOOGLE EARTH (2023)
2. ALL UNITS ARE METRIC AND IN METRES UNLESS OTHERWISE SPECIFIED. TRANSVERSE MERCATOR PROJECTION, NAD 1983, ZONE 17. ELEVATIONS ARE IN METRES ABOVE SEA LEVEL (MSL).

250 0 250 500 750m

SCALE: 1:10000 METRIC

| NO. | YY/MM/DD | DESCRIPTION | ISSUED BY | CHECK BY |
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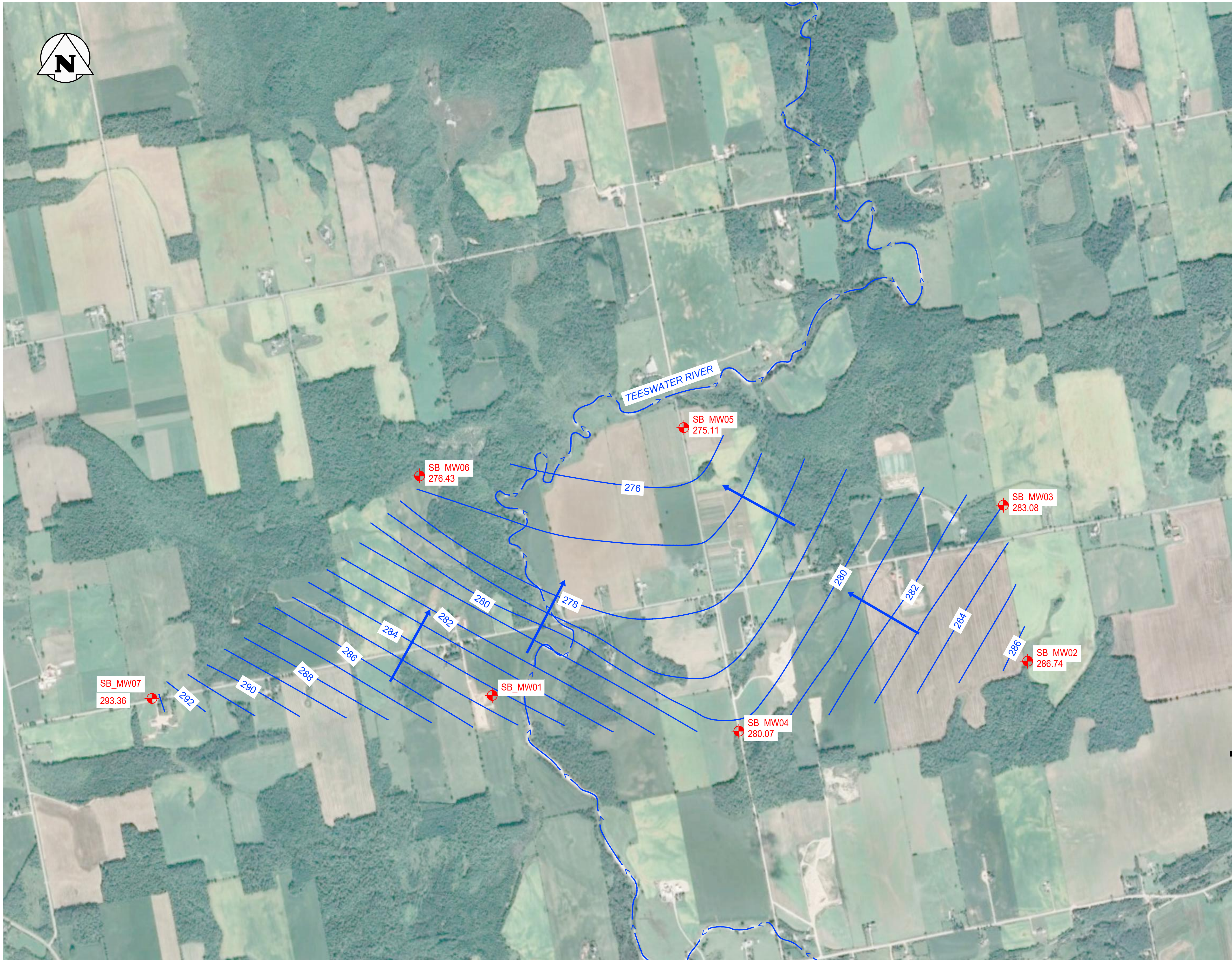
SOUTH BRUCE PRESSURE DATA ANNUAL REPORT

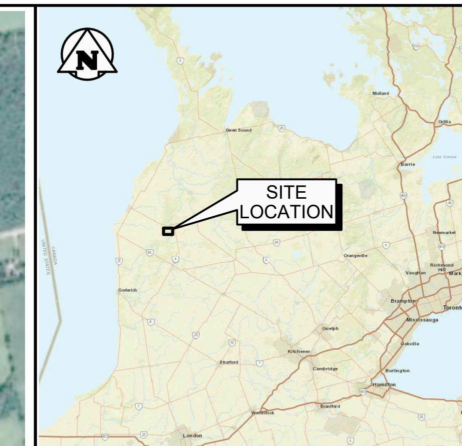
Q3 (JULY) 2022 OVERBURDEN GROUNDWATER CONTOURS

AUGUST 2024

FIGURE B1

REV: 1




**KEY MAP:**

**LEGEND:**

- SB_MW01 MONITORING WELL
- BEDROCK GROUNDWATER CONTOURS
- FLOW DIRECTION
- TEESWATER RIVER

**NOTES:**

1. IMAGERY SOURCE: GOOGLE EARTH (2023)
2. ALL UNITS ARE METRIC AND IN METRES UNLESS OTHERWISE SPECIFIED. TRANSVERSE MERCATOR PROJECTION, NAD 1983, ZONE 17. ELEVATIONS ARE IN METRES ABOVE SEA LEVEL (MSL).

250 0 250 500 750m

SCALE: 1:10000 METRIC

| NO. | YY/MM/DD | DESCRIPTION | ISSUED BY | CHECK BY |
|---|---|---|---|---|
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| 1 | 24/08/09 | RE-ISSUED WITH FINAL REPORT | PJL | ERL |
| 0 | 24/08/08 | ISSUED WITH FINAL REPORT | ERL | PJL |

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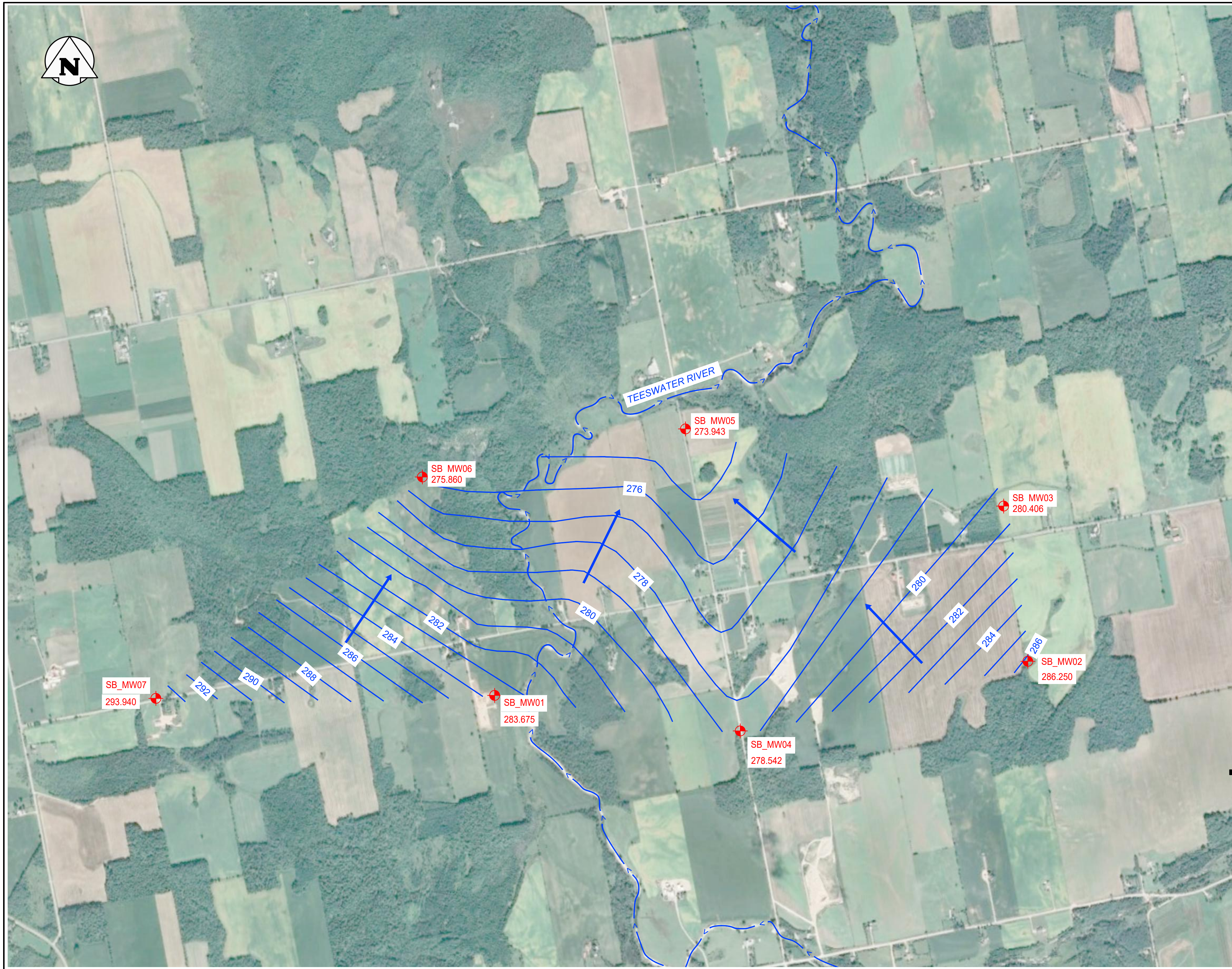
SOUTH BRUCE PRESSURE DATA ANNUAL REPORT

Q3 (JULY) 2022 BEDROCK GROUNDWATER CONTOURS (AMHERSTBURG FORMATION)

AUGUST 2024 | FIGURE B2 | REV: 2





**KEY MAP:**

**LEGEND:**

- SB_MW01 MONITORING WELL
- GROUNDWATER CONTOUR
- FLOW DIRECTION
- TEESWATER RIVER

**NOTES:**

1. IMAGERY SOURCE: GOOGLE EARTH (2023)
2. ALL UNITS ARE METRIC AND IN METRES UNLESS OTHERWISE SPECIFIED. TRANSVERSE MERCATOR PROJECTION, NAD 1983, ZONE 17. ELEVATIONS ARE IN METRES ABOVE SEA LEVEL (MSL).

250 0 250 500 750m

SCALE: 1:10000 METRIC

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SOUTH BRUCE PRESSURE DATA ANNUAL REPORT

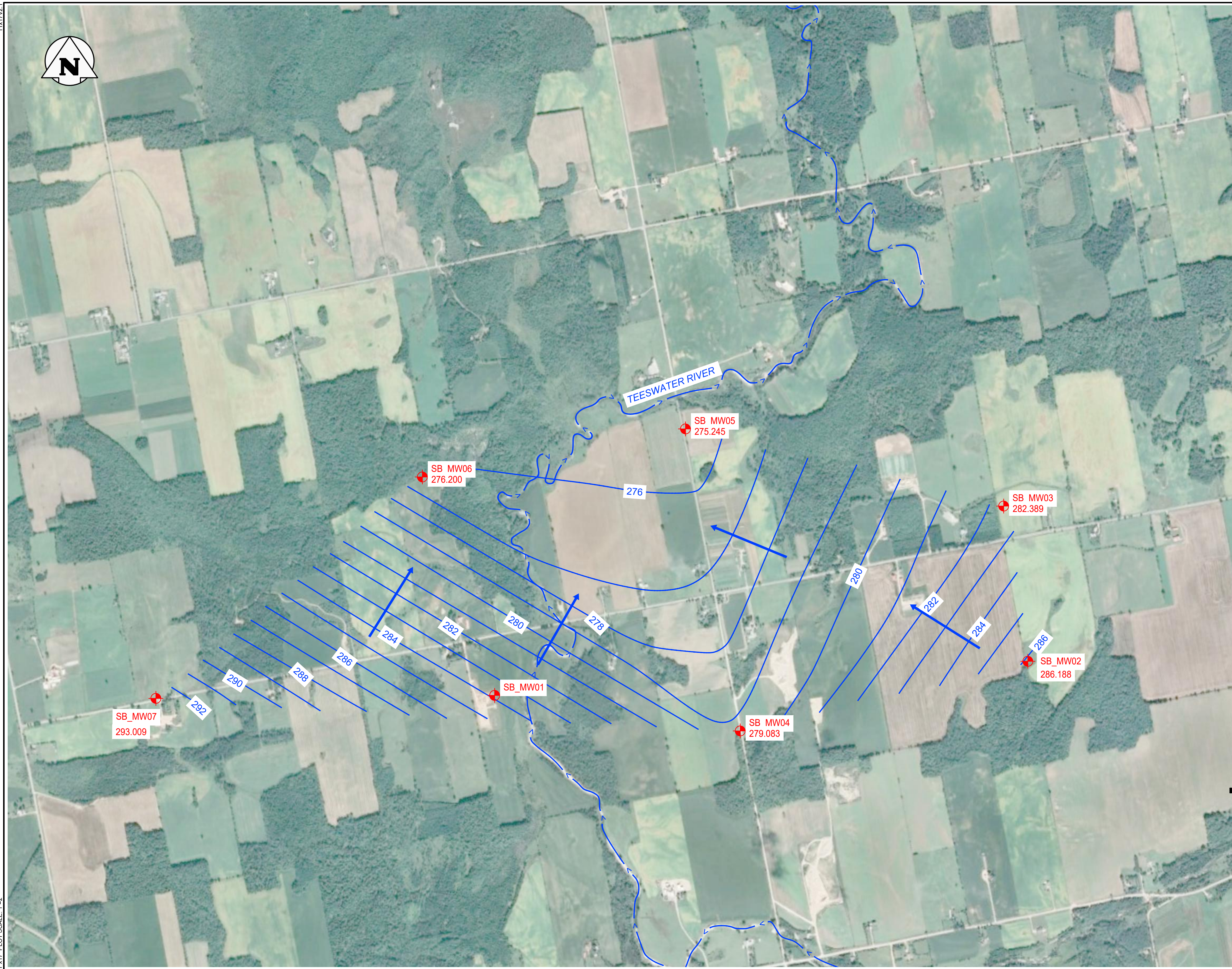
Q3 (SEPTEMBER) 2022 OVERBURDEN GROUNDWATER CONTOURS

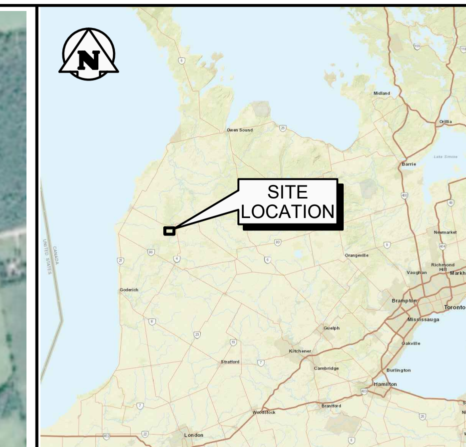
AUGUST 2024

FIGURE B3

REV: 1

11x17V2.1




**KEY MAP:**

**LEGEND:**

SB_MW01 MONITORING WELL

BEDROCK CONTOURS

FLOW DIRECTION

TEESWATER RIVER

**NOTES:**

1. IMAGERY SOURCE: GOOGLE EARTH (2023)
2. ALL UNITS ARE METRIC AND IN METRES UNLESS OTHERWISE SPECIFIED. TRANSVERSE MERCATOR PROJECTION, NAD 1983, ZONE 17. ELEVATIONS ARE IN METRES ABOVE SEA LEVEL (MSL).

250 0 250 500 750m

SCALE: 1:10000 METRIC

| NO. | YY/MM/DD | DESCRIPTION | ISSUED BY | CHECK BY |
|---|---|---|---|---|
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SOUTH BRUCE PRESSURE DATA
ANNUAL REPORT

Q3 (SEPTEMBER) 2022
BEDROCK GROUNDWATER CONTOURS
(AMHERSTBURG FORMATION)

FEBRUARY 2024 | FIGURE B4 | REV: 0

Filename: \\kgs-file\r-data\Projects\2022\22-3836-001\Dwg\Env\22-3836-001_FIGB4 - Tab:Rev0 Plotted By: Ivanwent 24/02/13 [Tue 1:08pm]
11"x17" PLOT SCALE: 1"=2"



**KEY MAP:**

**LEGEND:**

SB_MW01 MONITORING WELL

OVERBURDEN CONTOUR

FLOW DIRECTION

TEESWATER RIVER

**NOTES:**

1. IMAGERY SOURCE: GOOGLE EARTH (2023)
2. ALL UNITS ARE METRIC AND IN METRES UNLESS OTHERWISE SPECIFIED. TRANSVERSE MERCATOR PROJECTION, NAD 1983, ZONE 17. ELEVATIONS ARE IN METRES ABOVE SEA LEVEL (MSL).

250 0 250 500 750m

SCALE: 1:10000 METRIC

| NO. | YY/MM/DD | DESCRIPTION | ISSUED BY | CHECK BY |
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SOUTH BRUCE PRESSURE DATA ANNUAL REPORT

Q4 2022 OVERBURDEN GROUNDWATER CONTOURS

FEBRUARY 2024 | FIGURE B5 | REV: 0

11x17V2.1

Filename: \\kgs-file\r-data\Projects\2022\22-3836-001\Dwg\Env\22-3836-001_FIGB5 - Tab:Rev0 Plotted By: lvanwert 24/02/13 [Tue 1:08pm]

11"x17" PLOT SCALE: 1"=2"



**KEY MAP:**

**LEGEND:**

- SB_MW01 MONITORING WELL
- BEDROCK CONTOURS
- FLOW DIRECTION
- TEESWATER RIVER

**NOTES:**

1. IMAGERY SOURCE: GOOGLE EARTH (2023)
2. ALL UNITS ARE METRIC AND IN METRES UNLESS OTHERWISE SPECIFIED. TRANSVERSE MERCATOR PROJECTION, NAD 1983, ZONE 17. ELEVATIONS ARE IN METRES ABOVE SEA LEVEL (MSL).

250 0 250 500 750m

SCALE: 1:10000 METRIC

| NO. | YY/MM/DD | DESCRIPTION | ISSUED BY | CHECK BY |
|---|---|---|---|---|
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SOUTH BRUCE PRESSURE DATA ANNUAL REPORT

Q4 2022 BEDROCK GROUNDWATER CONTOURS (AMHERSTBURG FORMATION)

FEBRUARY 2024 | FIGURE B6 | REV: 0

11x17V2.1

Filename: \\kgs-file\r-data\Projects\2022\22-3836-001\Dwg\Env\22-3836-001_FIGB6 - Tab:Rev0 Plotted By: tvanwent 24/02/13 [Tue 1:07pm]
11"x17" PLOT SCALE: 1"=2"