INDIANA GEOLOGICAL & WATER SURVEY
INDIANA UNIVERSITY

Final Technical Report

Project Title:

Supporting the IGWS contribution to the NGWMN with new wells in central and southern Indiana

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Indiana Geological and Water Survey

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Objective(s):

Objective 2- Support persistent data service

Objective 4- Well maintenance

Objective 5- Well drilling

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OVERVIEW OF WORK

The Indiana Geological and Water Survey (IGWS) started serving the USGS National Ground-Water Monitoring Network (NGWMN) as a new data provider with an agreement under the FY2016 NGWMN program announcement and Grant/Cooperative Agreement Number G16AC00360. The work completed in this report is the fourth award related to this project, under the FY2020 NGWMN program and Grant/Cooperative Agreement Number G20AC00183 with agreement dates from 9/1/2020 to 8/31/2022.

The IWBN is a network of micrometeorological and groundwater monitoring data established in 2012 that can be viewed through public portal https://legacy.igws.indiana.edu/iwbn-dashboard/#/. Monitoring wells and micrometeorological networks complement one another or may be stand-alone groundwater monitoring locations.

The goal of the IWBN, also referred to as “the network,” is to monitor long-term trends through the hydrosphere by acquiring weather, soil moisture, and groundwater data to measure atmosphere, soil, and aquifer changes. The IWBN achieves this by having weather stations with associated wells scattered across Indiana. The network can show flow paths through the hydrosphere over variable physiographic settings. Wells are set at various depths in multiple aquifers at each station to also assess dynamics of the groundwater systems. The groundwater data in relation to the weather and soil moisture conditions can show aquifer storage changes such as the influx, outflux, and outflow of water. The IWBN complements the NGWMN by having a shared goal of analyzing baseline conditions and long-term trends in water levels for important aquifers in Indiana. Because of this effort, the monitoring network is expanding and redesigning to assess the aquifers that are most likely to be utilized and have drinking water potential. We now have 18 monitoring wells in the network that represent principal aquifers of alluvial and glacial origin and the Mississippian Aquifer, along with secondary hydrogeologic regions of other aquifers.

NGWMN program Objective 4, maintenance activities, was conducted on wells to ensure connectivity to the aquifer, ensure accuracy in water level measurements, inspect for additional concerns, and safeguard the well from mechanical equipment failure. A total of 11 wells were developed during the project cycle to clean buildup of fines and ensure screens are connected to the aquifer by increasing the competency of the screen. Pneumatic slug tests were completed after well development to determine the efficiency of the well in prime condition, the success of development, and to measure hydraulic conductivities to compare with local aquifer properties. This will help to establish baseline conditions for future well maintenance, trigger development efforts, and assist with assessing well degradation. Reflective taped poles were added to three flush-mount wells to ensure that wells could be located and were protected from heavy equipment.

NGWMN program Objective 5, well drilling, was completed by adding two new wells to the network and drilling one replacement well. The two new trend/backbone wells provide critical data for expanding the network to include Clinton County and Dubois County. Gaps have been identified in the monitoring of levels in aquifers used for drinking water. The Frankfort_S well (IGWS ID 122201) in Clinton County was installed April 5, 2022, and the Jasper_S well (IGWS ID 192103) in Dubois County was installed Sept. 30, 2021. The replacement well allows us to monitor the deep aquifer system in addition to the previous shallow well to analyze groundwater recharge dynamics. This replacement well for Glenwood_N (IGWS ID 212202) was completed April 15, 2022.

DESCRIPTION OF WORK DONE TO SUPPORT THE NGWMN AS A DATA PROVIDER FOR EACH OBJECTIVE

NGWMN program Objective 2, support of persistent data services, was reached by updating and adding data to the well registry for all wells contributing to the NGWMN. Uploads were made to the water level, site, casing, and screen files to update changes or improvements to data knowledge at IGWS NGWMN sites and to add data from new wells. Quality assurance and quality control are performed for stations at least quarterly to present the most accurate data. Currently, data from our sites are incorporated into the NGWMN using a web service and API connection. We added two new wells to the NGWMN well registry and replaced one well with another in the same general location. We utilize non-vented pressure transducers and barometric pressure sensors in the wells to record water level data.

Our previously developed REST API .NET program is the endpoint for general well info. An importer automates the process of data upload to the NGWMN data portal. The importer looks within the master folder containing comma-separated value (CSV) files. These files are checked for valid column headers and then loaded to the SQL server database, where they are available to the REST API .NET. Our web service then allows the transfer of the data from the REST API .NET to the NGWMN data portal. The importer keeps track of the last modified time stamps for these files and imports them again only if they have changed. Updates to these processes have been made to include the new wells and transfer information for replacement wells.

DESCRIPTION OF SITE SELECTION CRITERIA AND PROCESS

Part of the job of the Indiana Geological and Water Survey (IGWS) is to monitor natural and baseline groundwater conditions as outlined by the IWBN. We are interested in monitoring long-term water-level fluctuations across Indiana with little to no influence from anthropogenic sources. Hence, each of the selected wells are also consistent with the NGWMN framework document (ACWI, 2013) and are categorized as "trend/backbone" monitoring wells with the shared goal of monitoring baseline conditions for major aquifers.

Groundwater monitoring wells are selected by determining the spatial density of monitoring sites for each primary aquifer system in Indiana. We identify areas that have less than the minimum required number of wells for a national primary aquifer as defined by the NGWMN framework document, and regional aquifer systems. Additionally, we look at variable depths within the aquifer to get a more accurate understanding of the whole aquifer system. **Table 1** shows the current number of wells from the IWBN selected for the NGWMN with the addition of the three new wells drilled for this project, and **Figure 1** shows the locations of the Frankfort_S (Clinton County well CCW), Jasper_S (Dubois County well DCW), and Glenwood_N (IN015-6R) wells.

Table 1. List of NGWMN sites operated by the IGWS for the State of Indiana

Site Name	NGWMN #	Latitude (WGS84)	Longitude (WGS84)	Altitude (ft)	Well Depth (ft)	Principal Aquifer
Rushville_S	1	39.579972	-85.464938	944.5	10.1	Aquifers of Alluvial and Glacial Origin
FortWayne_N1	2	41.2476	-85.118248	874.8	100.1	Aquifers of Alluvial and Glacial Origin
FortWayne_N2	3	41.247715	-85.139121	840.1	72.4	Aquifers of Alluvial and Glacial Origin
Muncie_N	4	40.222153	-85.423204	938.1	33.1	Other Aquifers
Martinsville_N	5	39.496509	-86.428606	605.6	10.9	Aquifers of Alluvial and Glacial Origin
Glenwood_N	6 (211609)	39.638391	-85.291650	1099.5	16.1	Other Aquifers
Indianapolis_N	7	39.818356	-86.204417	705.5	4.0	Other Aquifers
LakeStation_W	8	41.584538	-87.275342	589.8	8.8	Other Aquifers
Brownsburg_N1	9	39.894476	-86.373013	912.4	39.2	Other Aquifers
NewCastle_NE	10	40.053383	-85.314942	1008.6	2.8	Other Aquifers
Bloomington_N	12	39.193990	-86.513105	759.0	13.1	Mississippian Aquifers
Frankfort_S*	122201	40.227089	-86.430064	929.7	365.5	Other Aquifers
Jasper_S*	192103	38.306542	-86.868494	584	56.3	Other Aquifers
Glenwood_N*	212202	39.639096	-85.291602	1098	58.8	Other Aquifers

*New wells

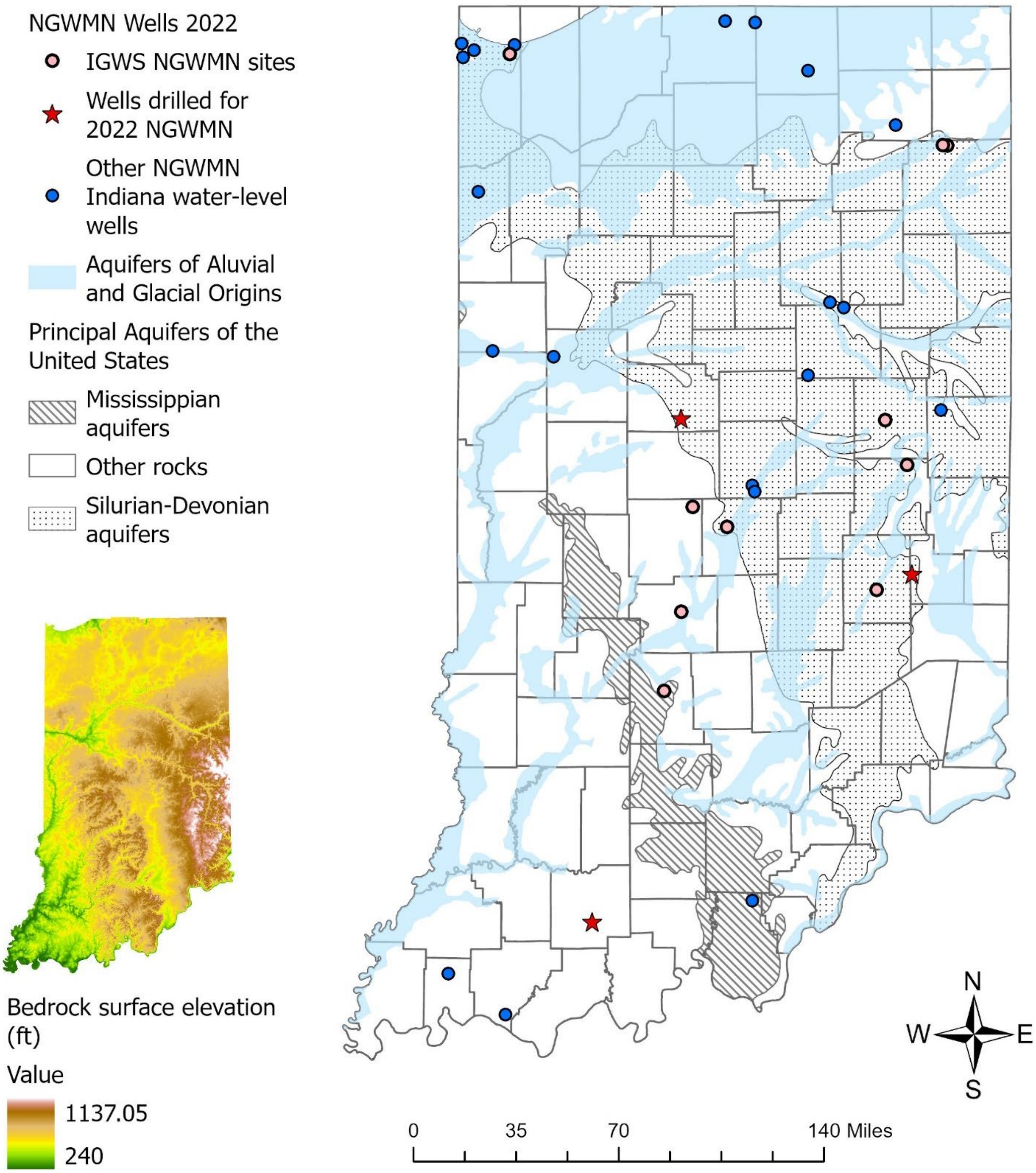

Figure 1. NGWMN wells in Indiana including IGWS well sites indicated by pink circles, wells drilled for this project indicated by red stars, and other non-IGWS wells in the NGWMN indicated by blue circles. The figure also shows the location of principal aquifers and a subset map of the bedrock surface.

Well drilling started with site reconnaissance. A passive seismic geophysical survey of the area was conducted following best practices (Voytek, 2012) to map the surface of the buried bedrock valley in the Clinton County area and for the replacement well at the Glenwood IWBN station. Our attempts to find a deeper valley terrane system for the Glenwood well area were fruitful. We were able to uncover additional sites for deeper valley terrane monitoring wells; however, landowner permissions could not be obtained. Transects were run perpendicular to the landforms or along gridded roads. to determine the direction of buried valley thalwegs. Tromino® data, using the horizontal-to-vertical spectral ratio (HVSR) method, allows for analysis of the HVSR peak frequency. HVSR peak frequency can be related to sediment thickness through analysis of shear wave velocity. The peak frequency reading, analyzed in GRILLA software, can be influenced by factors besides the depth to bedrock, like moisture content, surface sediment density, and the proportion of sand. GRILLA provides an output of the peak frequency and a summary of the criteria that indicate reliable H/V curve and H/V peak results. This allows the user to assess the trace for accuracy and quality. A calibration curve must be constructed with quality data to associate sediment thickness with a peak frequency. Control data collected at locations with known depth to bedrock (sediment thickness) in similar geologic settings that passed the H/V curve and H/V peak tests were used to create a calibration curve. The power function of the curve with a regression coefficient of determination (R^2) greater than 0.85 is considered acceptable and can then be applied to the transect's HVSR peak frequency to approximate sediment thickness at that point. With this data, we selected sites with the lowest HSVR peak frequency, which is associated with the deepest bedrock surfaces.

Frankfort_S

The Frankfort well site (122201) was chosen because there were only 19 wells in the network representing sand and glacial aquifers (glaciated regions) in Indiana. The NGWMN Tip Sheet on Well Selection Criteria for Water Levels recommends 10 and 40 wells for these aquifers. Additionally, almost all water in Clinton County (405 mi^2) is sourced from glacial aquifers, and there were no NGWMN wells or other monitoring wells in this area.

The placement goal for the Clinton County well was to be above the bedrock valley of Anderson Branch, a tributary of the Teays buried river valley, to gain understanding of the hydrogeology of the area. This data is crucial to monitor water availability in the region and support the Central Indiana Water Study (Indiana Finance Authority, 2019).

During the reconnaissance period, a sister program through the Indiana Finance Authority (IFA) was being conducted to investigate the water-supply potential that resulted in the report, "Hydrogeologic Assessment of the Anderson Valley, Clinton County Indiana" (January 2023). The IFA subcontractor, Intera Inc., along with the IGWS coordinated efforts to ensure cooperation between agencies and to combine efforts. The IFA-funded study investigated a 20-square-mile area southwest of Frankfort in Clinton County. Reconnaissance included HVSR analysis and 22 sonic rig borehole investigations. Of the 22, two became production wells for aquifer tests, 11 became monitoring wells, and six became test wells for quality considerations. The IGWS looked at upgradient and downgradient locations from this investigation as good places to monitor long-term impacts from any public water supply production wells placed in the area. We decided to look for a monitoring well location upgradient of this study location to avoid direct influence from any future production wells. Monitoring of the aquifer for baseline assessment cannot be located near pumping wells. If pumping wells are located in the area, we will want to see what effects it has on this aquifer system. Looking downgradient would help to assess properties of the aquifer if a water withdraw facility is placed in this area.

HVSR analysis was gathered in three cross sections supplemented by the IFA study HVSR sites to try and define the main channel of the Frankfort Lowland Section as seen in Bluer (1989) at the base of the Anderson Valley which has been only approximately mapped. Figure 2 shows the HSVR collection points to determine well placement for Frankfort_S. Site selection was narrowed to three possible areas based on the HVSR analysis and land ownership, along with the goal to stay upgradient from the study area and any new production wells. Obtaining site access for many of the proposed locations proved to be challenging, as usual. Many owners were very hesitant to provide their property but more specifically to provide government access to their waters due to fears surrounding the sister IFA project. Ultimately, we were able to find a grain elevator owner, Ty Brown, who allowed us to place the well on his property. This was a bit further north from what appeared to be the deepest portion of the channel, but drilling showed evidence that we succeeded in capturing the full channel lithology package. The final well placement relative to the area and the bedrock surface can be seen in Figure 3.

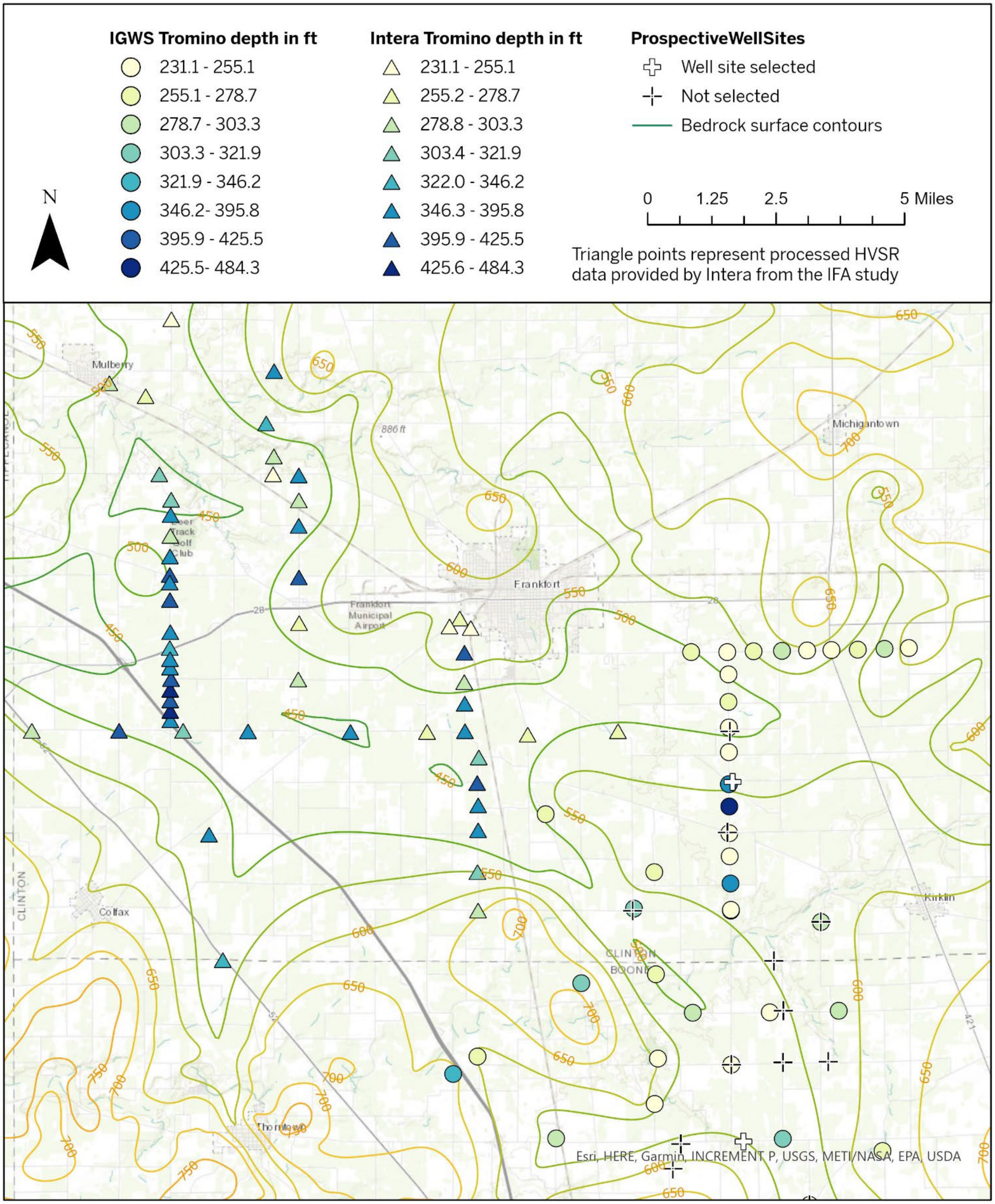

Figure 2. Map of HVSR collection points for investigation into the Anderson Valley deep bedrock channel, including the proposed and final well selection points (white crosses) for the Clinton County Well (CCW) and Frankfort_S (IGWS Well 122201).

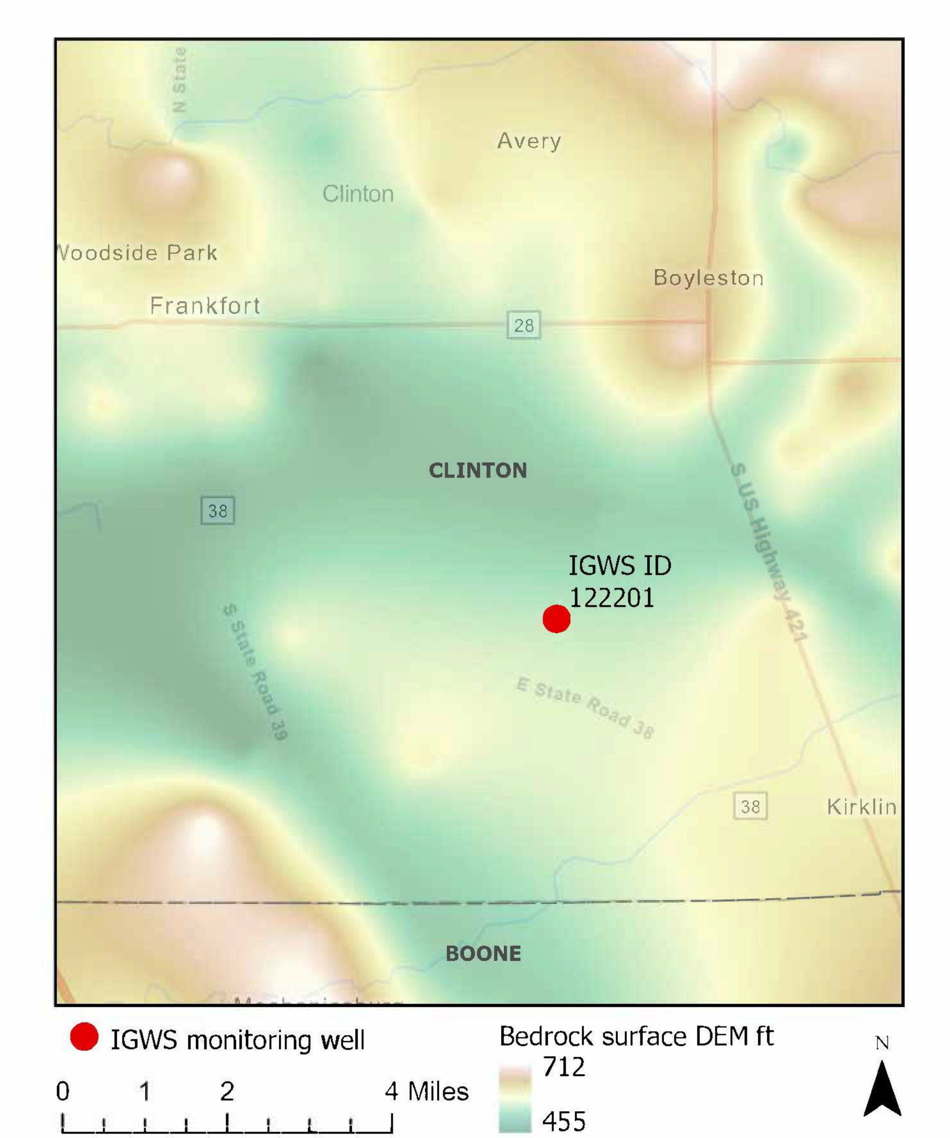

Figure 3. Map of southern Clinton County showing bedrock surface elevations and the location of IGWS groundwater monitoring well Frankfort_S (IGWS Well 122201), relative to county boundaries and interstate highways.

Jasper_S

The Jasper well is intended to close a large gap in data for the Pennsylvanian bedrock aquifer in Indiana. Only one well in the NGWMN represented this aquifer system for Indiana, and the NGWMN Tip Sheet recommends having between seven and 28 wells. The NGWMN also had no existing wells in Dubois County (435 mi^2). The Dubois County well was to be placed in the bedrock aquifers of the Mansfield formation of the Raccoon Creek Group that represents a significant bedrock aquifer utilized in southern Indiana. No HVSR analysis was conducted in this area due to the near-surface bedrock nature of the well installation. During the reconnaissance period, we also considered this well site for placement of new meteorological and soil moisture sensors for the IWBN network. An area school, Cedar Crest Intermediate in Huntingburg had asked about getting a weather station, and the school's location fit our needs for meteorological and soil moisture collection as well as well placement (fig. 4).

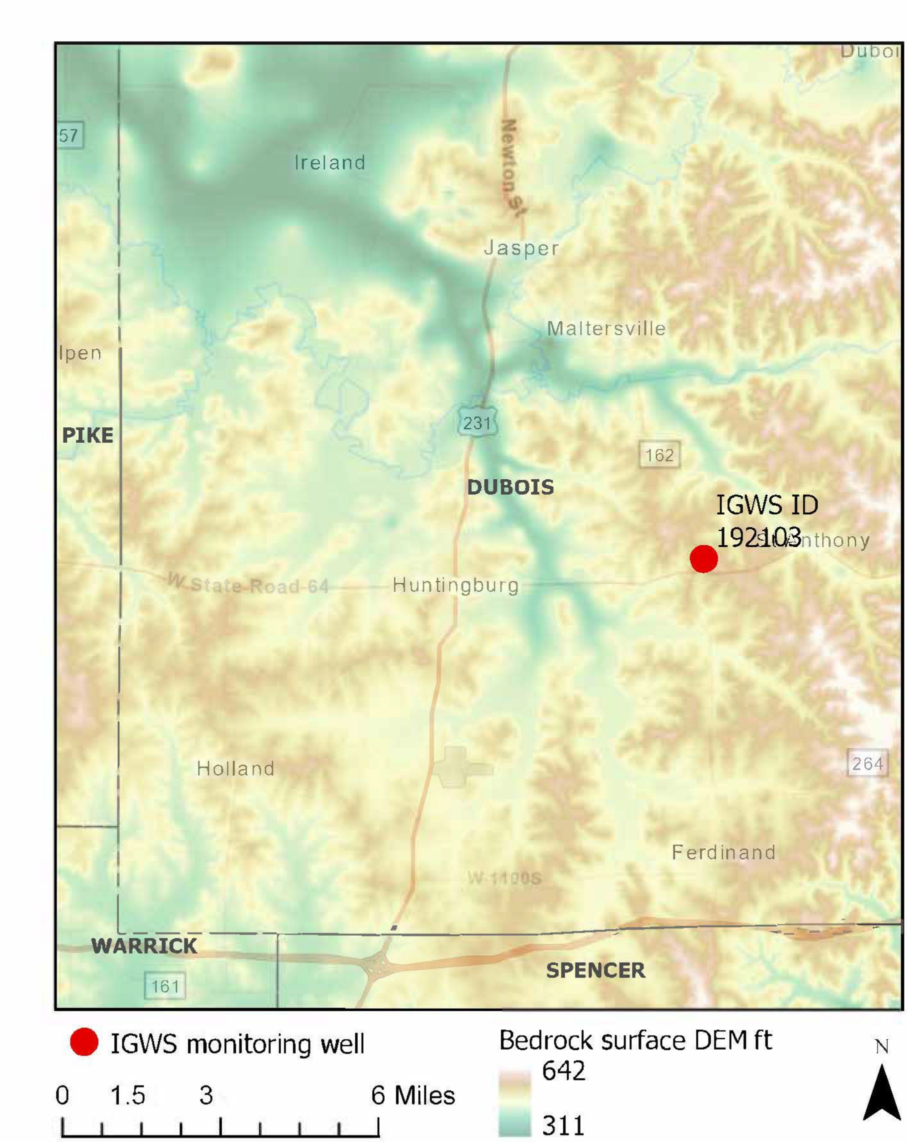

Figure 4. Map of southern Dubois County showing bedrock surface elevations and the location of IGWS groundwater monitoring well Jasper_S (IGWS Well 192103), relative to county boundaries and interstate highways.

Glenwood_N replacement well

The replacement well near the Glenwood weather station (originally IN15-06, renamed and marked IGWS Well 211609) was to be placed below the Indiana Department of Natural Resources (IDNR) residential well drillers' code (35 ft) and in unconsolidated aquifers. Our goal was to install the replacement north of the current well where two sequences of water-bearing glacial sand and gravel sequences have been seen in other well logs for the area. The previous monitoring well (NGWMN #6, 211609) has a depth of about 16 ft, and the new well has a depth of 58.8 ft, giving a good range of depth data for this aquifer. The new location (fig. 5) provides an improved understanding of the White River watershed; such data is needed for water resource planning in this watershed (IFA, 2019). Having both shallow and deep wells in the region helps to show recharge dynamics in the watershed.

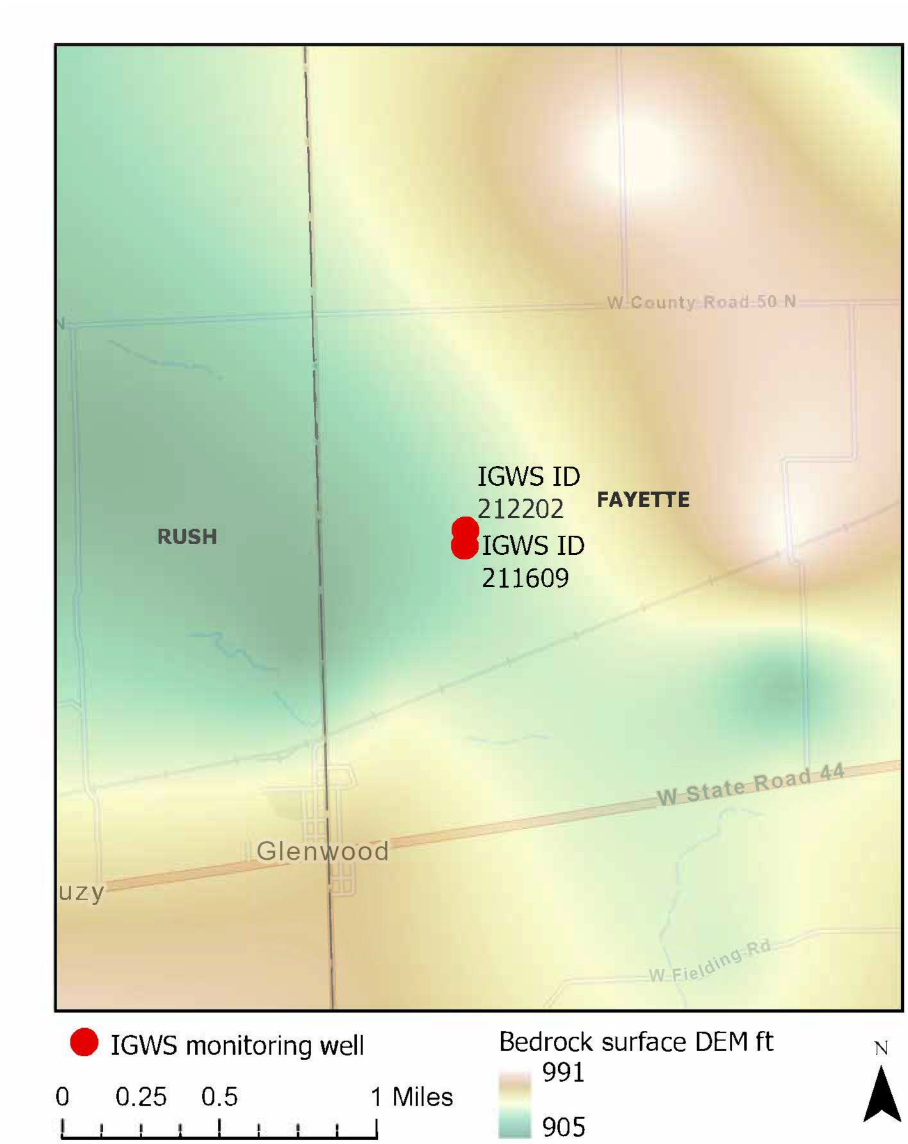

Figure 5. Map of western Fayette County showing bedrock surface elevations, the location of the new IGWS groundwater monitoring well Glenwood_N (IGWS Well 212202) and the original, shallow Glenwood_N NGWMN well (IN015-6, renamed and marked IGWS Well 211609), relative to county boundaries and interstate highways.

DRILLING, DESCRIPTIONS, AND WELL INSTALLATION METHODS

Drilling

Drilling services were contracted from the Illinois State Geological Survey (ISGS). A truck-mounted drill rig using mud rotary drilling methods and wireline coring tools was used to collect continuous soil and bedrock core. The objective at the Frankfort_S site (IGWS Well 122201) was to core several feet into the bedrock to verify the unconsolidated-sediment-to-bedrock contact. At the Glenwood_N site (IGWS Well 212202), the goal was to access the intermediate aquifer in the area to fill out our understanding of the multiple aquifer sets in this portion of the state. At the Jasper_S site (IGWS Well 192103), the goal was to drill as deep as possible into the bedrock within the budgeted time and to access a frequently used aquifer for the region. Core from all three bores was obtained in 10-ft lengths, when possible. Better core recovery was possible within the fine-grained sediments versus coarse-grained sediments like sand and gravel in the unconsolidated bores due to the nature of mud rotary drilling. Cores were discharged from the core barrel onto a half PVC pipe, rinsed to clean off the bentonite drilling mud, reviewed for a simplified field description, and packed into core boxes. Core boxes were labeled with the site identification number and core depths. Coarse-grained samples from intervals of poor recovery were collected from the mud circulation pit in a food strainer, rinsed of bentonite drilling mud, reviewed for a simplified field core description, and packed into plastic bags.

Core description

Detailed unconsolidated core descriptions and grain-size sample collections were conducted at the IGWS sediment laboratory. The description for the unconsolidated deposits includes the U.S. Department of Agriculture (USDA) texture with additional description for pebbles greater than 2 mm, Munsell color, hydrochloric acid reaction, lithologic code, and any miscellaneous features. Lithologic codes are based on a paper by Eyles, Eyles, and Miall (1983). The codes of F for fines (silt/clay), S for sand, G for gravel, and SG for sand and gravel are self-explanatory. D for diamicton is a poorly sorted mixture of clay, silt, sand, and gravel, up to boulder sizes. Tills are one common type of diamicton assumed to have been deposited from melting glacial ice. Given the amount of silt and clay in Indiana tills, they have a relatively fine-grained matrix. The detailed descriptions were recorded using a Microsoft Access database form referred to informally as Core-nucopia.

Bedrock cores were described in detail at the IGWS Material Testing Facility. Color identification and description were determined after wetting the core and using the coding system in Thompson and Keith (2015). Bedrock is described first by the dominant lithology (such as sandstone, siltstone, shale, etc.), followed by an examination of transition zones between rock units, weathering patterns, grain size, grain shape, grain sorting, bedding, presence of fossils, and organic deposits. Transition zones may exhibit gradual or abrupt contacts, while weathering manifestations can encompass oxidation, reduction (e.g., iron staining), and core condition indicators like fractures and faults. Grain size, shape, and sorting play pivotal roles in delineating aquifer characteristics and understanding water movement dynamics. Furthermore, bedding, fossils, and organic materials serve as crucial indicators for identifying specific formations and lithologic groups. After the description, the stratigraphic column is created using the Windows™.NET program Column (v. 1.02).

Unconsolidated and bedrock lithologic descriptions are subsequently compiled using WellCAD™ software and plotted alongside gamma radiation data, including standard USGS symbology to denote rock units. The descriptions also include details for unconsolidated materials. Appendix B, C, and D present the comprehensive descriptions for Frankfort_S (IGWS Well 122201), Glenwood_N (IGWS Well 212202), and Jasper_S (IGWS Well 192103), respectively.

Particle size analysis

Core sections from Frankfort_S (IGWS Well 122201) and Glenwood_N (IGWS Well 212202) were subsampled at visually and physically discernible textural zones for laser-assisted particle size analysis. Using a solution of H_2O and $Na_6[(PO_3)_6]$, a small, representative sample was suspended, sonicated, and evaluated through laser diffraction using the Malvern Mastersizer 3000. This process enables the calculation of approximate particle/grain size, allowing the IGWS to generate detailed grain size distributions for precise sedimentological records (see Appendix C for the Frankfort_S well and Appendix D for the Glenwood_N well with grain size distribution and associated well diagram with gamma radiation). Grain size analysis was not conducted on the Jasper_S well (IGWS Well 192103), but the well diagram and gamma are still provided in Appendix B.

Portable X-ray fluorescence

Portable X-ray fluorescence (pXRF) uses high-intensity x-ray fluorescence, which detects the amount of light that certain chemicals give off from absorbing radiation, to determine the relative abundance of elements in a core sample. Data from pXRF can be used for 1) chemostratigraphy, 2) understanding subsurface geochemical properties; 3) characterizing subsurface aquifers/aquitards; 4) identifying naturally occurring groundwater trace metal contaminants; and 5) aiding geologists in making inferences on mineralogic change within bedrock core (Zambito et al., 2022). In this case, pXRF was used to determine elements that persist in the aquifer material and the elements and minerals that will interact with the groundwater where the well is screened. PXRF analysis was conducted on the Jasper_S bedrock core, and the screened interval for the well is highlighted in yellow on each plot (Appendix F).

Well construction

After core collection, monitoring wells were installed at each site. Installation was completed on Sept. 30, 2021, for the Jasper_S well (IGWS Well 192103), on April 5, 2022, for the Frankfort_S well (IGWS Well 122201), and on April 15, 2022, for the Glenwood_N well (IGWS Well 212202). Wells were installed in the same boreholes used for coring. The target depth for the well screens was chosen to intercept the sand and gravels (Frankfort_S and Glenwood_N) or bedrock aquifers (Jasper_S). A 20-foot-long, 0.010-inch slot, 2-inch inside-diameter PVC well screen, and a PVC bottom plug were installed at the target depth for Jasper_S. A 10-foot-long, 0.010-inch slot, 2-inch inside-diameter PVC well screen, and a PVC bottom plug were installed at the target depths at Frankfort_S and Glenwood_N. At each site, a 2-inch inside-diameter PVC casing was installed from the top of the well screen up to grade. A No. 5 global sand pack was backfilled into the annulus around the well screen to a depth of 1 to 2 ft above the top of the screen. Bentonite pellets were backfilled into the annulus for 1 to 2 ft above the sand pack to create an annular seal. The remaining annulus was tremie-grouted from the pellets to the ground surface with a mixture of Benseal and EZ mud. A concrete surface seal and a well protective cover were installed at grade. The Jasper_S well has a stick-up protective cover while the Frankfort_S and Glenwood_N wells were installed with flush-mount protective covers. Waterproof caps were placed on the top of the well casing. Black reference marks (i.e., crow's foot) were drawn at the top of the PVC casings to denote the consistent location for surveying the well elevation and obtaining depth-to-water and total depth measurements. Well construction details are displayed adjacent to a gamma-interpreted lithologic description and particle size analysis (if applicable) below lithologic descriptions in Appendices B, C, and D.

Table 1. List of wells added to the NGWMN from the IWBN's recent drilling efforts. The table includes a portion of the data provided in the well registry table, including field names.

Site name	New or replace	Lat.	Long.	Site No.	Altitude (ft)	Principal aquifer	Well depth (ft)
Glenwood_N	Replace	39.6391	-85.2916	6 (original) 212202	1098	Other aquifers	60
Frankfort_S	New	40.22707	-86.4301	122201	929.7	Other aquifers	365.5
Jasper_S	New	38.30654	-86.8685	192103	585.5	Other rocks	55

Site latitude, longitude, and elevation (GPS positions)

With the increase of cellphone capabilities and coverage, locations were collected utilizing an Android app called UTM GEO Map 3.9.3 which utilizes the built-in GPS and compass in the phone to determine latitude and longitude. This app was used because at the time of data collection, we were awaiting on Trimble GPS systems to arrive after significant inventory challenges. We believe that the GPS location collected with the cellphone was as accurate as possible at the time and was plotted correctly in relation to visual features on projected orthoimagery.

DATA COLLECTION METHODS

Manual water level measurements

IWBN sites are visited, on average, every quarter (3 months) to conduct maintenance and collect manual and automated water-level data. Manual measurements of groundwater level and total well depth are made from the well reference point, typically the top of the well casing marked by an indelible marker, using a Geotech ET electronic-tape meter (accuracy = +0.01 ft). The measurement, date, and time are recorded on field sheets (Appendix A), and well sediment accumulation is noted, if present. Measurements are transferred to a well metadata spreadsheet when field personnel return to the office. Field sheets are scanned into pdf format and saved to a network directory to provide paper and electronic versions of field notes.

Automated water-level measurements

Continuous groundwater-level data are collected using vented (e.g., Druck PDCR series or Campbell Scientific CS451 sensors) and non-vented (e.g., In-Situ Rugged Troll 100 and Solinst 3000 series sensors) pressure transducers. The IGWS is working toward using vented instruments as the standard automated measurement approach, which would also facilitate real-time data service; however, the transition is constrained due to budget limitations, including the need for multiplexers to expand to the required number of IWBN site datalogger terminals.

Monitoring wells instrumented with non-vented (i.e., absolute) pressure transducers with internal memory are downloaded during routine site visits immediately after manual water-level measurements are taken. Barometric pressure sensors at the site are also downloaded; raw water-level data are compensated for barometric effects using sensor manufacturer software. The uncorrected water-level, barometric, and compensated water-level data are stored on a field laptop hard drive and then transferred to a network directory upon field personnel's return to the office.

DESCRIPTION OF DATA QUALITY AND QUALITY ASSURANCE PROTOCOLS

Converting compensated water column thickness measurements to water level depth and elevation

The Quality Assurance and Quality Control (QA/QC) Protocol defines the acceptable level of quality and describes how the project will ensure this level of quality in its deliverables and research processes. In accordance with the NGWMN framework report (ACWI, 2013), continuous water level data are calibrated against manual water level determinations. Compensated water level data, reported as water column depth, are entered into an Excel worksheet along with manual measurements that are temporally coincident to the nearest hour. The manual depth-to-water measurements are converted to groundwater elevation by subtracting depth-to-water measurements and well casing riser heights from the RTK GPS-determined ground elevation (meters) at the well. Compensated water column measurements are plotted on the x-axis of an XY scatter plot, and manually determined groundwater elevations are expressed on the y-axis (fig. 4). A linear trend line is fit through the data to establish the linear relationship between the variables, and a regression coefficient of determination (R2) greater than 0.85 is used to ensure a consistent relationship. If the pressure transducer is replaced or moved within the well column, a new regression equation is generated to update the calibration.

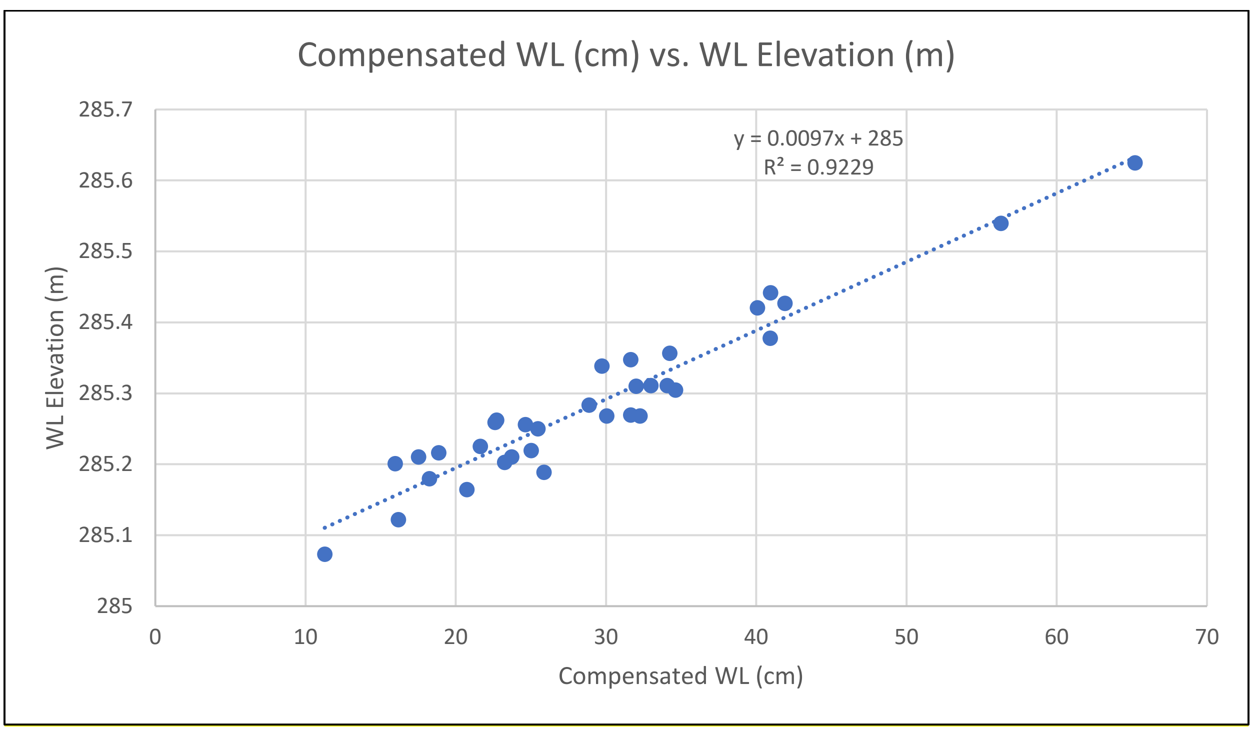

Figure 4. XY scatter plot and linear regression showing compensated pressure transducer water column readings versus manual groundwater elevation measurements.

The resulting linear transform equation is used to convert hourly compensated water column depth readings to groundwater elevations relative to the ground surface in a separate worksheet. Data are plotted to show the groundwater hydrograph for the entire monitoring period, and a visual QA/QC check is done to verify that the periodic manual measurements correspond well with the continuous record.

A standardized data processing routine was developed using spreadsheets, wherein data from barometrically compensated non-vented pressure transducers and vented pressure transducers could be translated into the NGWMN web service format.

The NGWMN network requires date and time in an ISO8601 time format. The concatenate function in Excel was used to convert the date and time recorded by the pressure transducer (e.g., 8/28/2012 14:35) into the ISO8601 format (e.g., `2012-08-28T14:35:37-05:00`). The -5.00 value is the difference from Coordinated Universal Time (UTC), also referred to as Greenwich Mean Time. An example concatenate formula is as follows:

=CONCATENATE(TEXT(A8,"yyyy-mm-ddThh:MM:ss"),J2)

(cell J2 contains the value -5.0)

Groundwater-level data are typically logged on hourly time intervals using non-vented pressure transducers and downloaded to a laptop computer during site visits. The Glenwood_N replacement well (IGWS Well 212202) and the Frankfort_S well (IGWS Well 122201) have non-vented pressure transducers. The Jasper_S well (IGWS Well 192103) has a vented pressure transducer connected to a datalogger, which can be downloaded directly using a laptop computer or remotely via a modem. Manual depth-to-water measurements are collected during site visits. Example field forms for the site visit are included in Appendix A. The manual depth-to-water measurements are converted to a groundwater elevation value by subtracting the depth-to-water and well riser stickup from the GPS-surveyed reference elevation at the ground surface. Non-vented pressure transducer groundwater-level data are barometrically compensated using site-specific barometric pressure data that are also logged hourly. Pressure transducer data are converted from water column depth measurements (i.e., the height of water above the pressure transducer) to groundwater elevations based on a linear relationship established using matched pairs of manual-measured groundwater elevations and compensated pressure transducer water column data. The daily groundwater elevation data are compiled and stored in spreadsheets, and hydrographs are plotted along with hand-measured groundwater elevations for QA/QC purposes. The depth to water below grade is calculated by subtracting the pressure transducer groundwater elevation from the ground surface elevation.

Accuracy values for pressure transducer measurements were obtained from the transducer manufacturer’s technical specification sheets. The accuracy value is a percentage of the full scale (FS) of the pressure transducer. The accuracy value multiplied by the FS is the value populated into the Observation Accuracy field in the WATERLEVEL file.

WELL MAINTENANCE RESULTS AND DISCUSSION

Camera investigations and reflective post installations

A borehole camera was used to examine the well screen integrity of Muncie_N and Brownsburg_N1. This was necessary because these wells were installed long before they were added to the IGWS network.

Reflective posts were installed for the flush-mount well at the Rushville_S site, the deep NGWMN well at the FortWayne_N1 site, and the well at the FortWayne_N2 site. These posts were added to identify the wells, as the areas are covered with grass and vegetation, making them difficult to locate.

Well development

Well development and redevelopment are often the only times the aquifer is ensured connection with the well. Studies conducted by the state of Michigan concluded that wells that were properly developed had fewer problems with positive coliform bacteria tests and that no-flow areas (e.g. zones clogged with drilling fluids) near the screen are locations for enhanced bacterial growth (Hanna, 2023). Thus, wells that are not properly developed tend to have biofouling problems more frequently than properly developed wells.

We completed well development to remove fine-grained sediment from the well screen, well bottom, and filter pack. This is accomplished by using compressed air that pumps the sediment-rich water to the surface and out of the well. This process is necessary for accurate water level and total depth measurements and well efficiency.

Each well was developed using compressed air-lift surging and pumping, except for NewCastle_NE, which used the bailer method. Compressed air was directed down to the well screen through a line equipped with a specialized cap that jets air horizontally into the screen slots and surrounding filter pack, effectively removing sediment. Several cycles of jetting and pumping were required for some of the wells. Total well depths were measured prior to and after development to document the thickness of sediment removed. The following table (**Table 2**) reports the results of the well development and maintenance work done.

Slug tests

Slug tests were conducted to ensure proper aquifer connections to the wells for 10 sites, excluding the Fort Wayne_N2 well due to construction at the site and encroachment issues. For pneumatic slug tests, a well head apparatus was fixed to the top of the well casing, and air pressure was added and released from the wells to monitor changes in water levels. For wells with a diameter other than what the well head apparatus could accommodate, a known volume of water was added to the well after recording the initial water level. Water levels were then measured at sub-second intervals in the beginning and then logarithmically increased intervals for pneumatic and non-pneumatic slug tests. A few wells failed because they were dry (water level was below the screen interval) or the well could not hold any pressure.

Slug test data was processed using industry standard aquifer test software (AQTESOLV®) to plot the data and estimate hydraulic conductivity (Appendix E). Saturated aquifer thickness was estimated by looking at nearby well records accessed from the Indiana Department of Natural Resources Water Well Viewer: https://indnr.maps.arcgis.com/apps/webappviewer/index.html?id=4b4f37e1dde744ce865e1be4d157ac93.

Rushville_S

The well was developed and was purged dry after three flushes. Five gallons of water were added to the well; however, there was no change in total depth, indicating that no sediment buildup was removed, if any existed. A pneumatic slug test was attempted, but it failed because pressure could not be held in the well. The protective steel casing covering the well casing popup (polyvinyl chloride-PVC) was too narrow to accommodate the slug. It is recommended that a pneumatic slug test be reapplied using an extended PVC pipe. A reflective post was added to mark the flush-mount well location (fig. 5).

Figure 5. Photograph of the reflective post added at Rushville_S site next to the flush-mount well.

FortWayne_N1

The well was successfully developed and 1.6 ft of sediment was removed. A single-well slug test was conducted because the pneumatic slug test apparatus could not fit the casing diameter. Approximately 3000 mL of water was added to the well to initiate the test. This well has a total depth of about 102 ft. The estimated thickness of the aquifer was 22.5 ft based on nearby wells with IDNR reference numbers: 105660 (27 ft), and 346069 (18 ft). The Bouwer-Rice straight-line method was applied to analyze the results of the falling-head slug test for a confined aquifer. A reflective post was added for this well (fig. 6).

Figure 6. Photograph of the reflective post installed next to the FortWayne_N1 deep well for the NGWMN.

FortWayne_N2

This well was developed on September 20, 2021, and 0.13 ft of sediment was removed while making the connection to the aquifer through the screen. Local residential development prevented the slug test and reflective post installations because land disturbance made the stick-up height too high to accommodate a slug head apparatus. There were also uncertainties with continued land access.

Muncie_N

This well was developed on September 22, 2021, and 3.9 ft of sediment was removed while making the connection to the aquifer through the screen. A pneumatic slug test was completed using 20 psi. A double straight-line effect was observed, so the Bouwer-Rice analysis for a confined aquifer was used. The aquifer thickness was estimated to be 14 ft (IDNR record 14628); the well depth is 41.34 ft. A downhole camera investigation was conducted but the screen interval was not able to be determined due to suspended particles (likely from well development), so it is recommended that another one be done with better resolution. The casing appeared to be in good condition (fig. 7).

Figure 7. Image of the casing integrity for Muncie_N from the camera investigation.

Martinsville_N

This well was developed on September 13, 2021, and 0.27 ft of sediment was removed while making the connection to the aquifer through the screen. No water was added to complete the well development.

The old NGWMN Martinsville well was not tested; instead, the new NGWMN Martinsville well (IGWS well 2101) was used for conducting a pneumatic slug test. During the test, 50 psi of pressure was applied to the well. Unlike the old NGWMN well, this new well is confined and has an estimated aquifer thickness of 13 ft based on a nearby well (IDNR 405050) with a similar lithographic profile. This new Martinsville well has a total borehole depth of 70 ft and was screened between 29.9 to 39.9 ft. The old NGWMN well was shallow, with a depth of only 11 ft to monitor shallow groundwater and surface interactions.

To analyze the data from the new Martinsville well, a curve-type approach was employed using the KGS model solution since the data exhibited a non-linear change in head over time, as represented by a curve.

Glenwood_N

This well was developed on September 21, 2021, and was purged dry and 1 gallon of water was added. A total of 0.28 ft of sediment was removed to reconnect to the aquifer through the screen.

The old NGWMN Glenwood well (6, 211609) did not pass the pneumatic slug test because it was unable to hold pressure. A pneumatic slug test was applied to the replacement well (IGWS Well 212202) and its results are reported in the table below. Approximately 30 psi of pressure was applied to the well. We then waited for 17 minutes for the water to return to its original depth-to-water value, but the water level did not return. This slug test failed, indicating a problem with the screen or casing. Sediment was reported in field notes at the bottom, so it is likely that the well needs to be redeveloped.

Indianapolis_N

This well was developed on March 10, 2023; however, no additional depth was recovered. It was not necessary to add additional water to complete the reconnection to the aquifer through the screen. A pneumatic slug test failed due to the shallow nature of the well; it is only 4 ft below the surface and the water level was below the top of the screen, so a slug test could not be applied.

LakeStation_W

Well development was completed on October 11, 2021, and the well was purged dry. No water was added. The sediment grew courser with each development, indicating that the screen slot size was too large for the aquifer sediment surrounding the well; fine sands were moving through it. The total depth of the well remained the same after development, indicating that material removed was replaced with new material. This well would benefit from a scope to ensure the screen is still fully intact.

A pneumatic slug test was carried out, during which 20 psi of pressure was applied. This well is shallow and unconfined, with an estimated aquifer thickness of 22.5 ft based on well records nearby (IDNR 387324-18 ft and IDNR 299730-27 ft) and a well depth of 13.88 ft. A Bouwer-Rice model for unconfined aquifers was used. Due to the oscillatory behavior (underdamped) observed in this unconfined well, it appears that the screen and casing are in good connection to the aquifer. We now have a baseline for future slug tests to compare for determining degradation.

This site contains many large phragmites and grasses, so a reflective post was added to this well (fig. 8).

Figure 8. Photograph of the reflective post installed next to LakeStation_W well for the NGWMN.

Brownsburg_N1

Well development was conducted on September 21, 2021, and 0.4 ft of sediment was removed. A pneumatic slug test failed, as we were unable to apply and maintain pressure in the well. It is possible that the diameter and depth of the well exceeded the capabilities of our test equipment. In subsequent attempts, we will employ a bail test method to measure the hydraulic conductivity. A downhole camera investigation was conducted, and the screen interval was determined to be from 36.5 ft to 37.11 ft from the top of the casing (fig. 9). The casing and screen appear to be intact, but there were a lot of particles and sediments that seemed to coat the well. A reflective post was added to this site (fig. 10).

Figure 9. Image of the camera investigation shows the beginning of the screen interval and the condition of the screen pre-development. The post-development camera investigation was too turbid.

Figure 10. Photograph of the reflective post installed next to Brownsburg_N1 well for the NGWMN.

NewCastle_NE

Well development was conducted on February 15, 2023, using the bailer method here. Frost action of the wetland soil has caused heaving to occur in the well and the casing has become loose and lifted. A total of 0.31 ft of sediment was removed from the bottom of the well. It started as mud transitioning to silt, then sand, and finally clean quartz gravel. The well casing was able to be pushed down to the original stickup height, but further well maintenance will be needed to retain this well in the network. A pneumatic slug test was attempted; however, the well was not competent enough for a successful test. The aquifer is unconfined and relatively shallow.

Bloomington_N

This well was developed on March 9, 2023, and purged dry, and 6 gallons of water was added. Very little (0.01 ft) of sediment was removed from the system. The well went clear and then became turbid after the second flush, indicating a possible problem with the screen. It is recommended that this well be examined and assessed for continued use in the network.

A single-well slug test was conducted by adding approximately 3000 mL of water to the well to initiate the test. The aquifer is unconfined with an estimated thickness of 1 ft since this aquifer is a fracture within the bedrock. The well is screened in the contact zone between two different units, and this zone is located at a depth of 15.4 ft within the well. The Bouwer-Rice double straight-line method was employed to analyze the results obtained from this unconfined aquifer.

Table 2. Well Maintenance Conducted

Site Name	Site ID	Slug Test	Well Development	Sediment Thickness Change (ft)	Camera Investigation	Reflective Post Added
Rushville_S	1	Failed	Completed	0		Completed
FortWayne_N1	2	Successful	Completed	1.6		Completed
FortWayne_N2	3	N/A	Completed	0.13		
Muncie_N	4	Successful	Completed	3.9	Completed	
Martinsville_N	552101	Successful	Completed	0.27		
Glenwood_N	212202	Failed	Completed	0.28		
Indianapolis_N	7	Failed	Completed	0		
LakeStation_W	8	Successful	Completed	1.24		Completed
Brownsburg_N1	9	Failed	Completed	0.4	Completed	Completed
NewCastle_NE	10	Failed	Completed	0.31		
Bloomington_N	12	Successful	Completed	0.01		

CONSIDERATIONS FOR FUTURE WORK AND PLANNED CHANGES

Pneumatic slug test results showed that further maintenance will be needed, such as well development by air or submersible pump, for most of the wells in the network. Camera investigations will also be useful in determining the screen and casing interval and the condition of wells that were not able to be checked otherwise.

INVESTIGATION RESULTS

Frankfort_S

The Frankfort_S (IGWS Well 122201, CCW) borehole was drilled to 400 ft below grade into unconsolidated glacial material to the top of bedrock. Over half of the core was not recovered. A gamma log accounted for the loss of core; it indicated till deposits consistent with most of the stratigraphic column. The gamma-interpreted lithologic units are shown in the well diagrams.

The majority of the core recovered consisted of till that was sandy with thin layers of sand and gravel (<5 ft thick), and the layers influence recharge dynamics. At 345 ft below grade, a sand and gravel unit was identified and the gamma log showed that it continues down to bedrock at 392 ft. The well was screened in the sand and gravel unit from about 355 to 365 ft due to the thickness of this unit of sand and gravel compared to the relatively thin units above. The aquifer is capped by a thick deposit of silt. This well is significant since the well is screened deeper than most wells in the region and significant growth is occurring nearby, prompting the utilization of these aquifers in the Clinton County region. The bedrock consists of dolomite/dolostone and was present within the last 8 ft of core from 392 to 400 ft below grade.

Particle size analysis showed that most subsurface materials were very fine-grained and that silt deposits dominated, likely in the thick till deposits. About 10 instances showed sand dominating based on the median grain size (Φ) and likely correlated with sandy till layers and sand and gravel units.

Continuous groundwater levels and temperature have been recorded since 10/27/2022 when the non-vented pressure transducer was installed. Three site visits are needed to construct the well equation for quality assurance and quality control using hand measurements and downloads (fig. 11). Water levels and temperature remain relatively constant throughout the year with only about a foot difference in water level and a 0.1°C difference in temperature. Water levels increase in the spring and summer and decrease in the fall and winter. These small variations in water level are likely a result of wellbore effects and aquifer pressures that are common in deep and confined to semi-confined aquifers.

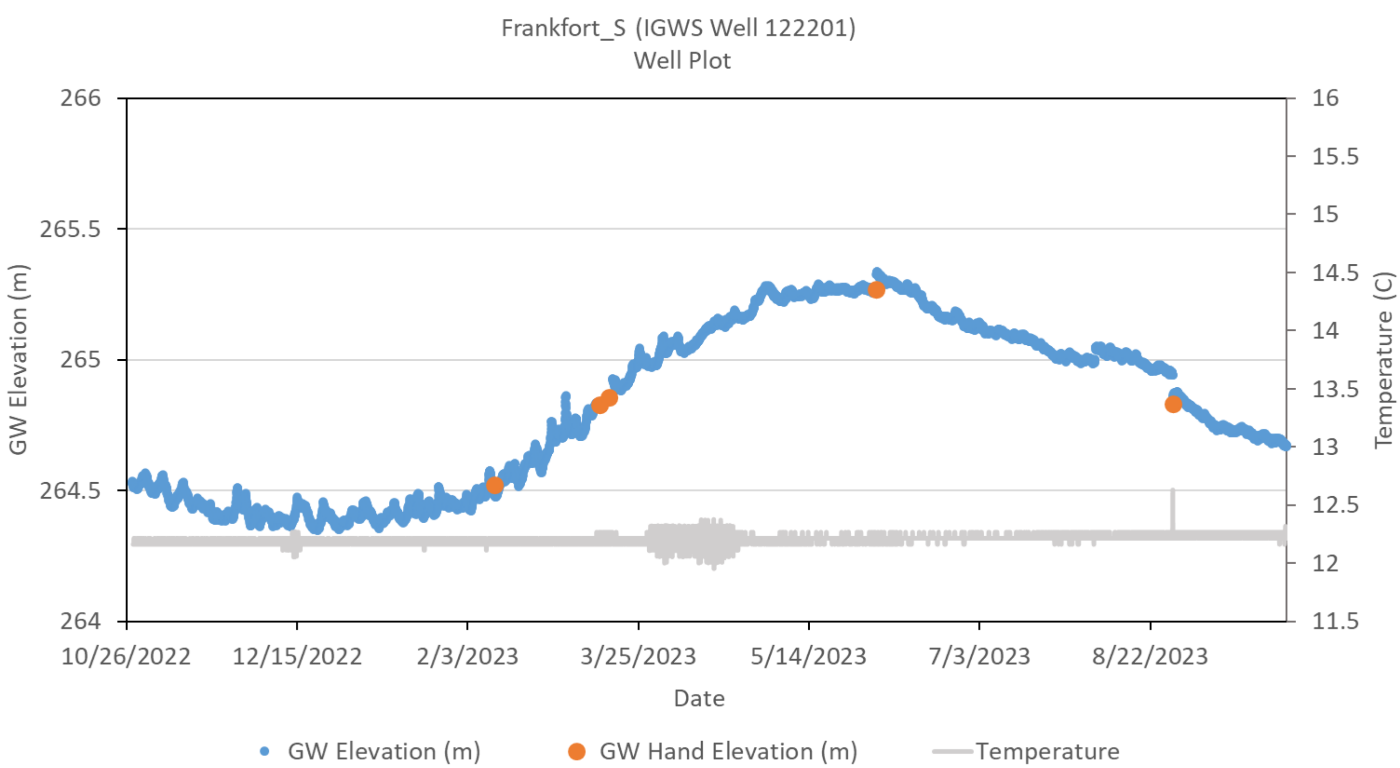

Figure 11. Hydrograph showing groundwater elevations and temperatures over time compared to hand-measured groundwater elevations for the Frankfort_S well.

Jasper_S

The Jasper_S (IGWS Well 192103, DCW) was drilled to 150 ft below grade, targeting the Pennsylvanian bedrock. Only one zone of core about 3.4-6.3 ft below grade was not recovered. Gamma ray logging was used to identify that zone and correspond to lithologic descriptions.

The lithology is primarily composed of the Pennsylvanian Raccoon Creek Group, Mansfield Formation consisting of sandstone with areas of crossbedding, breccia layers, and carbonaceous shales (Hutchison, 1970; Hutchison and Hasenmueller, 1986). PXRF can aid in identifying lithologies that look similar within a formation. When looking at pXRF data from the screened interval of 35 to 55 ft below grade, the elemental makeup changes within that unit. The sandstone changes from horizontal-bedded to flaser-bedded. Organics are found from 36.4 to 55.3 ft of the screened material. From 35.1 to 36.4 ft, the sandstone was gray and likely unoxidized, and from 36.4 to 51.3 ft there was iron-oxide staining which gradually lessens from 51.3 to 55.3 ft. Coal stringers became more abundant with depth in this screened interval. The concentration of iron in the screened zone was low and the sulfur concentration was variable, increasing with depth. The increasing sulfur content could correlate with the increase in organics and coal. The pXRF results also showed that calcium and magnesium content varied in the screened zone, but they were correlated with one another. These spikes could indicate interaction with the rare limestone clasts found in the screened unit. The pXRF results also showed varying peaks of arsenic concentration in the screened interval, likely corresponding to the coal if it is pyrite rich.

Continuous groundwater levels and temperature have been recorded since 3/4/2022 when the vented pressure transducer was installed. Three site visits are needed to construct the well equation for quality assurance and quality control using hand measurements and downloads (fig. 12). Groundwater does not vary much throughout the year, with less than a foot in change; Temperature does fluctuate seasonally with a difference of 1.25°C. The small variations in water level are likely a result of wellbore effects and aquifer pressures that are common in confined to semi-confined aquifers.

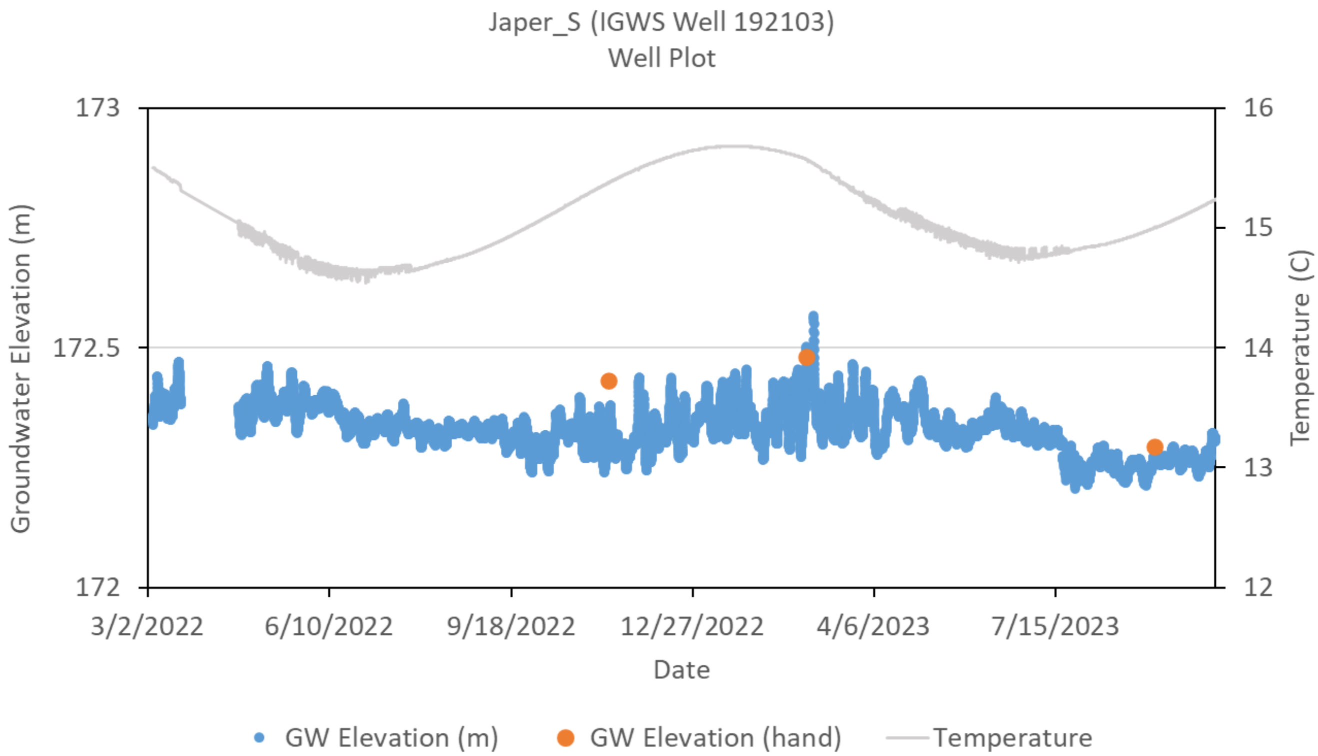

Figure 12. Hydrograph showing groundwater elevations and temperatures over time compared to hand-measured groundwater elevations for the Jasper_S well.

Glenwood_N-R

The Glenwood_N replacement well (IGWS ID 212202, IN015-R) was installed and screened from 50 to 60 ft below grade to capture a sand unit from 49 ft to 64 ft below grade. The total depth reached 155 ft. Only about 50 percent of the core was recovered. A gamma log was provided to account for the poor recovery and these interpretations were added to the lithologic descriptions and filled in with the well diagram.

The aquifer was described as a sand to sandy loam with silt and clay (diamicton) deposits above 49 ft and below 62.7 ft below grade. In comparison, the old NGWMN well (6) was 15.48 ft deep. In the replacement well, from 15 to 23 ft below grade was a zone of no recovery that was gamma-interpreted to be sandy gravel mixed with till that likely correlates to where the old well is screened. These two different screened aquifers can pinpoint recharge dynamics between them and differences in water quantity and quality.

Particle size analysis showed that most of the subsurface column contained silt-sized grains, with fine to medium sand-sized grains dominating in the screened portion of the aquifer based on the median grain size (Φ). Where silt was more abundant correlates to the glacial till deposits.

Continuous groundwater levels and temperature have been recorded since 07/06/2022 when the non-vented pressure transducer was installed. Three site visits are needed to construct the well equation for quality assurance and quality control using hand measurements and downloads (fig. 13). Data indicates that groundwater in this aquifer is influenced by seasons and experiences recharge in relation to surface infiltration.

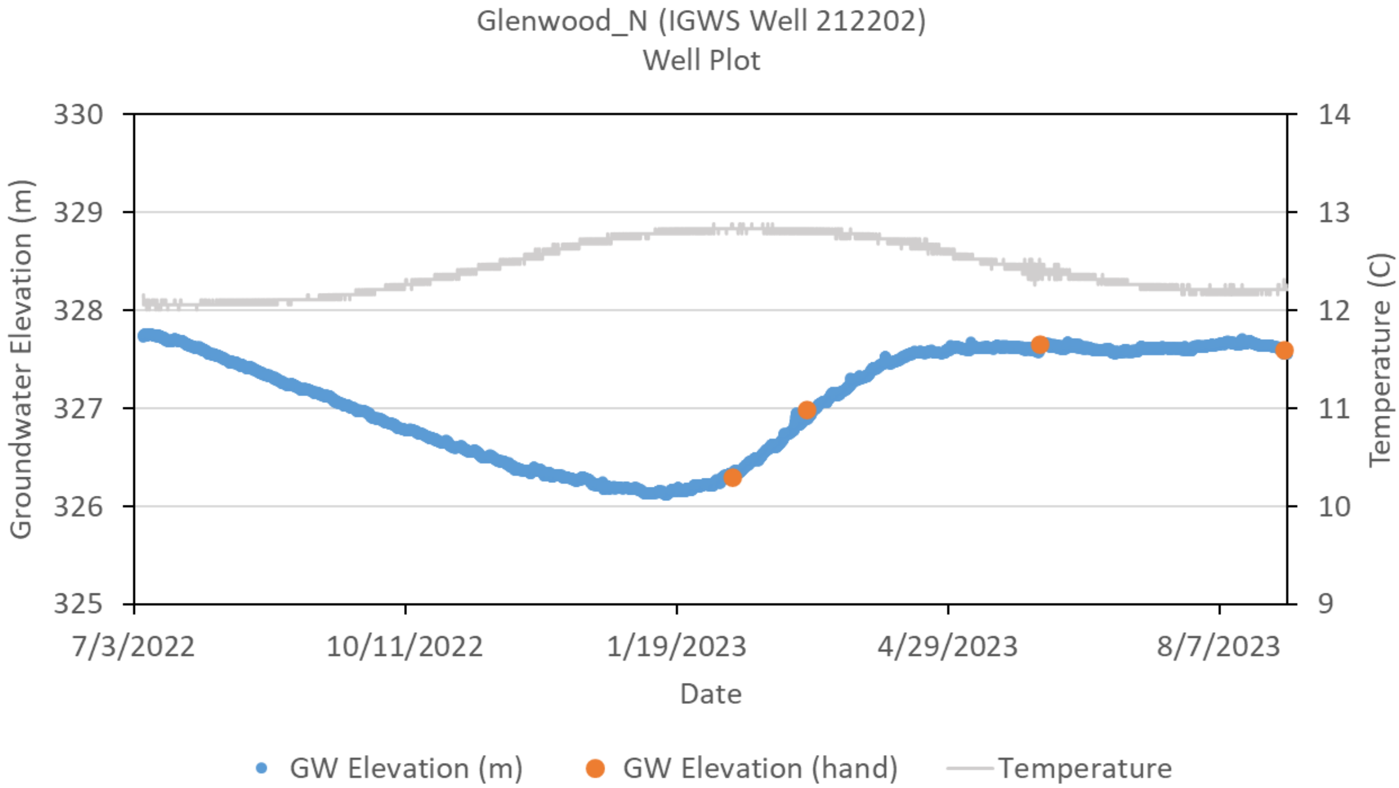

Figure 13. Hydrograph showing groundwater elevations and temperatures over time compared to hand-measured groundwater elevations for the replacement Glenwood_N well.

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APPENDIX A

Example field forms

Indiana Geological and Water Survey

MONITORING WELL DEVELOPMENT

Project Name	County	Well Name
Monitoring Site	Unique Well Number	IGS Well ID

1. Can this well be purged dry? ☐ Yes ☐ No

2. Well development method
   - surged with bailer and bailed ☐
   - surged with bailer and pumped ☐
   - surged with block and bailed ☐
   - surged with block and pumped ☐
   - surged with block, bailed and pumped ☐
   - compressed air ☐
   - bailed only ☐
   - pumped only ☐
   - pumped slowly ☐
   - Other ____________

3. Time spent developing well ____ min.

4. Depth of well (from top of well casisng) ___ . _ ft.

5. Inside diameter of well __ . __ in.

6. Volume of water in filter pack and well casing (if known) ___ . _ gal.

7. Volume of water removed from well (if known) ___ . _ gal.

8. Volume of water added (if any) ___ . _ gal.

9. Source of water added ____________

10. Analysis performed on water added? ☐ Yes ☐ No (If yes, attach results)

		Before Development	After Development
11. Depth to Water (from top of well casing)	a.	___ . __ ft.	___ . __ ft.
Date	b.	__/__/____ m m d d y y y y	__/__/____ m m d d y y y y
Time	c.	__:__ ☐ a.m. ☐ p.m.	__:__ ☐ a.m. ☐ p.m.
12. Total well depth		__ . _ feet	__ . _ feet
13. Sediment thickness		__ . _ feet	
14. Water clarity		Clear ☐ Turbid ☐ (Describe) ____	Clear ☐ Turbid ☐ (Describe) ____

Fill in if drilling fluids were used and well is at solid waste facility:

	Before Development	After Development
14. Total suspended solids	____ . _ mg/l	____ . _ mg/l
15. COD	____ . _ mg/l	____ . _ mg/l

16. Well developed by: Name (first, last) and Firm

First Name: Last Name:

17. Additional comments on development:

I hereby certify that the above information is true and correct to the best of my knowledge.

Signature: ____________

Print Name: ____________

Firm: ____________

IWBN Site Check
Field Checklist
V20221221

Site name: ____
Staff: ____
Weather: cloudy – partly sunny; ______mph; ______°F

1. Extech AN340 Calibration

(Start recording ON THE HOUR, plus or minus 10 minutes)

Start: _________________________________ Stop: _____________________________________

2. Weather station:

Anemometer	Level?	Y	N	N/A	
	Spinning?	Y	N	N/A	
Pyranometer	Level?	Y	N	N/A	
	Clear?	Y	N	N/A	
Net Radiometer	Level?	Y	N	N/A	
	Clear?	Y	N	N/A	
Rain Gauge	Level?	Y	N	N/A	
	Funnel clear?	Y	N	N/A	
Strong Box	Moisture?	Y	N	N/A	
	Wires taunt?	Y	N	N/A	
	Replace desiccants?	Y	N	N/A	
Vegetation	Type?				
	Height?			ft	

3. Well and Weir checks:

Name:	Name:	Name:
Depth to Water (ft): Total Depth(ft): Time (24hr):	Depth to Water (ft): Total Depth(ft): Time (24hr):	Depth to Water (ft): Total Depth(ft): Time (24hr):
Notes:		
Name:	Name:	Name:

Depth to Water (ft): Total Depth(ft): Time (24hr):	Depth to Water (ft): Total Depth(ft): Time (24hr):	Depth to Water (ft): Total Depth(ft): Time (24hr):
Notes:		

4. Download Data:
(Pressure transducers AND Baryloggers)

Name	Serial Number	Battery Level	Memory Level	Notes

*Note: compensate the data on site, in case of issues. Record compensated file name/location here:
____

5. Photographs:
- Obtain photos from at least 2 sides of weather station – note surrounding and state of station
- Include site name label in bottom of picture

Notes	**Additional Tasks Required**

Signature: ____

Date: ____

APPENDIX B Jasper_S (IGWS Well 192103) Lithology and Well Construction

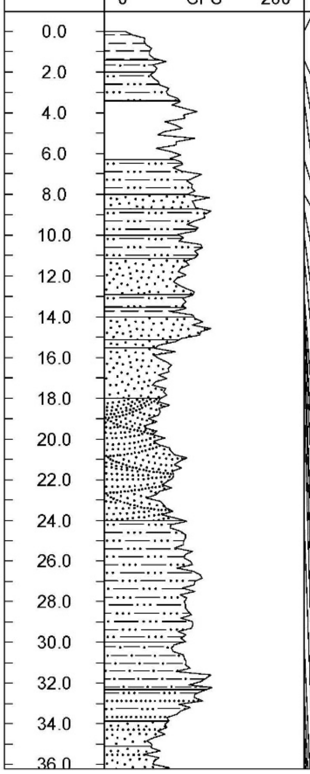
INDIANA GEOLOGICAL & WATER SURVEY
INDIANA UNIVERSITY

Site ID: 192103	Date: 2/11/2022
Site Name: Jasper_S	Authors: Ginger Davis, McKailey Sabaj
Latitude: 38.306542	Elevation (ft): 584
Longitude: -86.868494	NGWMN well

Legend

- Breccia
- Massive sand or sandstone
- Bedded sand or sandstone
- Crossbedded sand or sandstone
- Silt, siltstone or silty shale
- Sandy or silty shale
- Clay or clay shale
- Calcareous shale or marl
- Interbedded sandstone and siltstone
- Interbedded sandstone and shale

Depth 1ft:100ft	Lithology / Gamma (CPS, 0–200)	Description



(0-1.4) Silty clay loam (Ulzzz), small A Horizon organic present, trace grains of 2mm sand followed by a massive moisture very stiff B Horizon at 0.62 ft; 0.62-0.89 ft mottled platy compaction B Horizon; 0.89-1.4 ft C Horizon massive hard platy and dry with rock clasts from lower, maybe R horizon, (10 YR 5/4) yellowish-brown.

(1.4-2) Siltstone, sandstone and shale (Ft/Ss/Fszzz), RACCOON CREEK - Mansfield Formation, highly damaged by core retrieval. Few thin coal laminations. Orange-brown.

(2-3.4) Massive siltstone (Ftmzz), RACCOON CREEK - Mansfield Formation, some large clasts (some iron-stained), limestone debris, dark organic particles. Possibly cavings from bore hole. Light brown and light gray.

(3.4-6.3) Not present/recovered.

(6.3-8) Siltstone (Ftzzz), RACCOON CREEK - Mansfield Formation, some sand grains and iron staining. Light yellow-brown.

(8-8.7) Disturbed-bedded and mottled horizontal-bedded sandstone, with a sharp basal contact (Sshd/ms), RACCOON CREEK - Mansfield Formation, very fine, subangular, poorly sorted, quartz sand with iron-stained silica cement. Light gray and light orange.

(8.7-10) Siltstone (Ftzzz), RACCOON CREEK - Mansfield Formation, some very fine sand grains, iron-stained bedding planes, some large dark organic particles. Light yellow-brown.

(10-11.2) Horizontal-bedded siltstone with a sharp basal contact (Fthzs), RACCOON CREEK - Mansfield Formation, sandy siltstone. Very fine sand, poorly sorted. Some mica and dark organic particles. Light orange and gray.

(11.2-12.9) Disturbed-bedded and slickensided and mottled horizontal-bedded sandstone with a sharp basal contact (Sshd/s/ms), RACCOON CREEK - Mansfield Formation, upper fine to lower medium, rounded to subangular, poorly sorted sand. Some coal particles and seams. Iron-stained grains and cement. Orange, gray, maroon.

(12.9-13.6) Disturbed-bedded and slickensided massive siltstone with a sharp basal contact (Ftmd/ss), RACCOON CREEK - Mansfield Formation, sandy siltstone (lower very fine sand), well-lithified and iron-stained. Light gray and light orange.

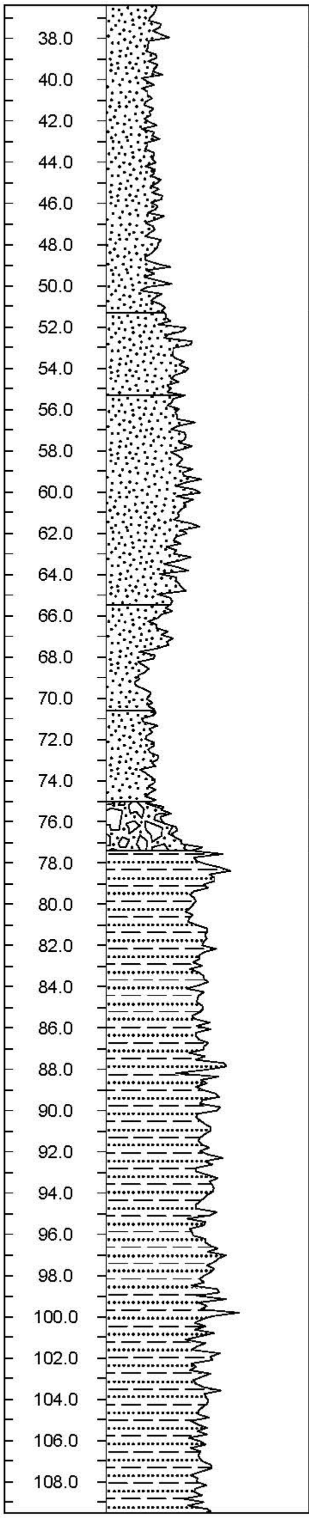
(13.6-14) Disturbed-bedded massive mudstone with a sharp basal contact (Fmmds), RACCOON CREEK - Mansfield Formation, organic-rich laminations, iron-stained sand grains and natural fractures. Gray.

(14-15.1) Disturbed-bedded horizontal-bedded sandstone with a sharp basal contact (Sshds), RACCOON CREEK - Mansfield Formation, very fine to lower medium sand, poorly sorted. Organic particles and laminations. Large mudclasts which contain slickensides. Gray, orange, and maroon.

(15.1-15.5) Disturbed-bedded horizontal-bedded sandstone with a sharp basal contact (Sshds), RACCOON CREEK - Mansfield Formation, very fine sand with some mica grains, dark organic particles and organic-rich laminations. Possible iron cement. Maroon, orange, and purple.

(15.5-18) Horizontal-bedded to cross-bedded sandstone with a gradational basal contact (Ssh-xzg), RACCOON CREEK - Mansfield Formation, upper very fine to lower fine sand, moderately sorted, subrounded grains. Inclined bedding. Thick iron-stained laminations. Gray-orange and tan.

(18-24) Cross-bedded to horizontal-bedded sandstone with a gradational basal contact (Ssx-hzg), RACCOON CREEK - Mansfield Formation, very fine to upper fine sand. Very porous with dark organic particles. Iron-stained laminations. Inclined bedding. Zones of thin laminations. Gray, tan, and orange.



(24-30) Horizontal-bedded siltstone with a gradational basal contact (Fthzg), RACCOON CREEK - Mansfield Formation, slightly dolomitic, some fine sand grains. Yellow-tan, gray, and yellow-gray.

(30-32.3) Bioturbated interlaminated/interbedded siltstone and shale and sandstone with a gradational basal contact (Ft/Fs/Ssibg), RACCOON CREEK - Mansfield Formation, lower very fine to upper very fine sand-rich laminations. Gray.

(32.3-33.9) Bioturbated interlaminated/interbedded sandstone and siltstone with a sharp basal contact (Ss/Ftibs), RACCOON CREEK - Mansfield Formation, lower very fine sand and silt. Gray.

(33.9-35.1) Horizontal-bedded sandstone with a gradational basal contact (Sshzg), RACCOON CREEK - Mansfield Formation, upper very fine, well sorted, subrounded sand with thinly laminated coal and organic-rich stringers. Light gray.

(35.1-36.4) Horizontal-bedded sandstone with a gradational basal contact (Sshzg), RACCOON CREEK - Mansfield Formation, lower to upper fine sand, moderately sorted, subrounded. Heavily damaged zone from 35.9 to 36.1 ft. Gray.

(36.4-51.3) Horizontal-bedded and flaser-bedded sandstone with a gradational basal contact (Ssh/fzg), RACCOON CREEK - Mansfield Formation, lower to upper fine, moderately sorted, subrounded sand. Common to abundant plant fossils and organic material. Iron-rich clasts 1 mm up to 3.5 cm (siderite). Rare limestone clasts. Few iron-stained beds. Gray and orange-gray.

(51.3-55.3) Horizontal-bedded sandstone with a sharp basal contact (Sshzs), RACCOON CREEK - Mansfield Formation, lower to upper very fine sand, moderately sorted, subrounded grains. Coal laminations, quartz and dark lithics (organics). Some sand is iron-stained. Thick shale laminations at 59.5 and 61.5 ft. Gray and tan-gray.

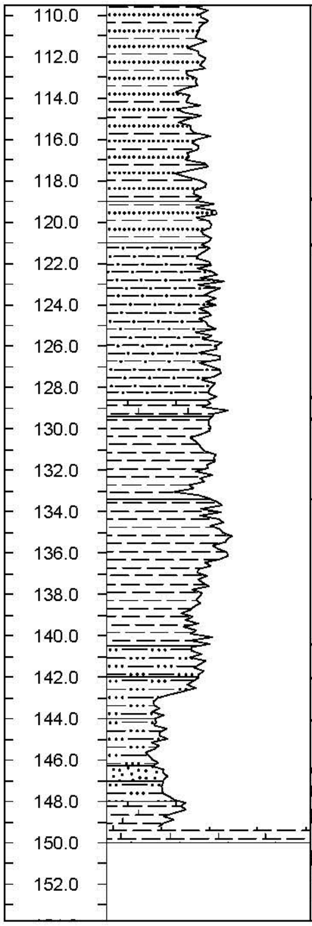
(55.3-65.5) Bioturbated wavy-bedded to flaser-bedded and interlaminated/interbedded sandstone and coal with a gradational basal contact (Ss/Orw-f/ibg), RACCOON CREEK - Mansfield Formation, lower very fine to lower medium, poorly sorted, subrounded sand. Coal stringers and laminations. Sand size varies between laminations. Gray and tan-gray.

(65.5-70.6) Disturbed-bedded wavy-bedded sandstone (Sswdz), RACCOON CREEK - Mansfield Formation, very fine to lower medium, poorly sorted, subrounded sand. Coal lamination 2 mm thick at 66 ft. Coal and iron-rich concretions (siderite) and laminations. Some plant fossils have been replaced with siderite and/or pyrite. Gray-black and brown.

(70.6-75) Massive sandstone with a gradational basal contact (Ssmzg), RACCOON CREEK - Mansfield Formation, lower very fine to upper fine sand. Quartz and dark lithics. Organic-rich stringers and coal. Clay and organic-rich clasts up to 2 cm increase in occurence with depth. Gray.

(75-77.4) Massive breccia with a sharp basal contact (Brmzs), RACCOON CREEK - Mansfield Formation, silt with shale clasts ranging from <5 mm to +10 cm. Some clasts are sidierite, some organic-rich and some coal. Gray.

(77.4-119) Bioturbated interlaminated/interbedded and wavy-bedded sandstone and shale with a gradational basal contact (Ss/Fsi/wbg), RACCOON CREEK - Mansfield Formation, lower very fine to upper fine, moderately sorted, subrounded sand and silt. Organic-rich particles and laminations. Few microfaults. Minor iron staining throughout. Some sand beds are cross-bedded. Iron-rich beds occur between 93 and 111 ft. Possible siderite grains. Light gray, dark gray and black.



(119-121) Bioturbated interlaminated/interbedded and lenticular-bedded to wavy-bedded shale and sandstone with a gradational basal contact (Fs/Ssi/l-wbg), RACCOON CREEK - Mansfield Formation, upper very fine sand. Some sands are cross-bedded. Minor iron staining throughout. Dark gray and light gray.

(121-128.6) Bioturbated lenticular-bedded shale with a sharp basal contact (Fslbs), RACCOON CREEK - Mansfield Formation, siderite-rich beds. Sand-filled burrows and laminations. Very fine sand and organic fragments. Rare iron concretions. Dark gray and orange-brown.

(128.6-129.4) Horizontal-bedded shale with an irregular and sharp basal contact (Fshzi/s), RACCOON CREEK - Mansfield Formation, very fissile. Rare siderite lamination. Zone of deformation at base. Dark gray.

(129.4-133.4) Disturbed-bedded and slickensided mudstone with a sharp and irregular basal contact (Fmzd/ss/i), RACCOON CREEK - Mansfield Formation, plant fossils and siderite concretions. Highly deformed. Numerous fractures and slickensides. Becomes more cohesive with depth. Iron-stained cement 132.6-133.4 ft. Light green-gray and maroon.

(133.4-140.5) Slickensided horizontal-bedded mudstone to shale (Fm-Fshsz), RACCOON CREEK - Mansfield Formation, mudstone transitions to shale and becomes more organic-rich with depth. Some iron-rich cement and laminations. Few very fine sand laminations. Gray and maroon.

(140.5-142) Wavy-bedded siltstone with a gradational basal contact (Ftwzg), RACCOON CREEK - Mansfield Formation, some very fine sand. Clay drapes. Light gray.

(142-144) Bioturbated wavy-bedded siltstone (Ftwbz), RACCOON CREEK - Mansfield Formation, clay stringers and laminations. Quartz silt and sand and dark lithics. Light gray and gray.

(144-146.3) Bioturbated and disturbed-bedded wavy-bedded sandstone with a sharp and irregular basal contact (Sswb/ds/i), RACCOON CREEK - Mansfield Formation, silty sandstone with irregular, patchy iron-rich cement 144.1-144.8 ft. Clay laminations increase with depth. Heavily iron-stained. 145.6 -146.15 ft not recovered. Light orange and maroon.

(146.3-147) Mottled massive sandstone with a sharp and irregular basal contact (Ssmms/i), RACCOON CREEK - Mansfield Formation, heavily cemented (obscures grain size and shape). Vuggy porosity. Iron-rich. Maroon and orange-brown.

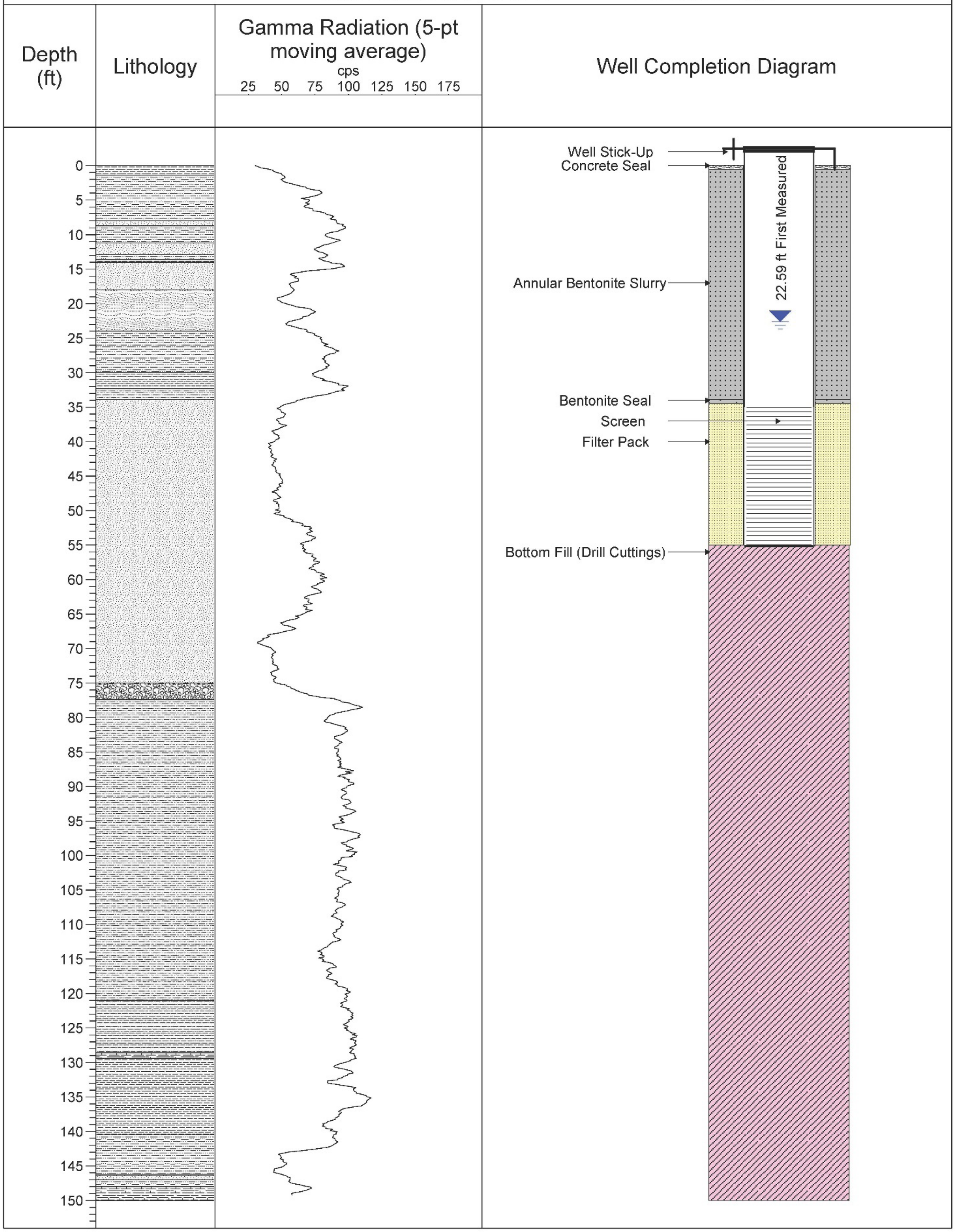
(147-148) Massive siltstone with a sharp and irregular basal contact (Ftmzs/i), RACCOON CREEK - Mansfield Formation, some lower very fine sand. Quartz and dark lithics. Gray.

(148-150) Bioturbated lenticular-bedded shale (Fslbz), RACCOON CREEK - Mansfield Formation, lower very fine sand and silt-filled burrows. Fissile. Damaged by core retrival. Siderite rich laminations 0.5 mm thick. Black.

INDIANA GEOLOGICAL & WATER SURVEY
INDIANA UNIVERSITY

Well Number: 192103
Site Name: Jasper_S
Date Drilled: 02/11/2022

Latitude: 38.306542
Longitude: -86.868494
Elevation: 584



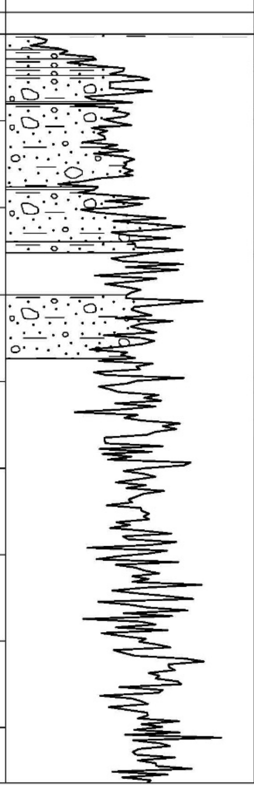
APPENDIX C Frankfort_S (IGWS Well 122201) Lithology and Well Construction

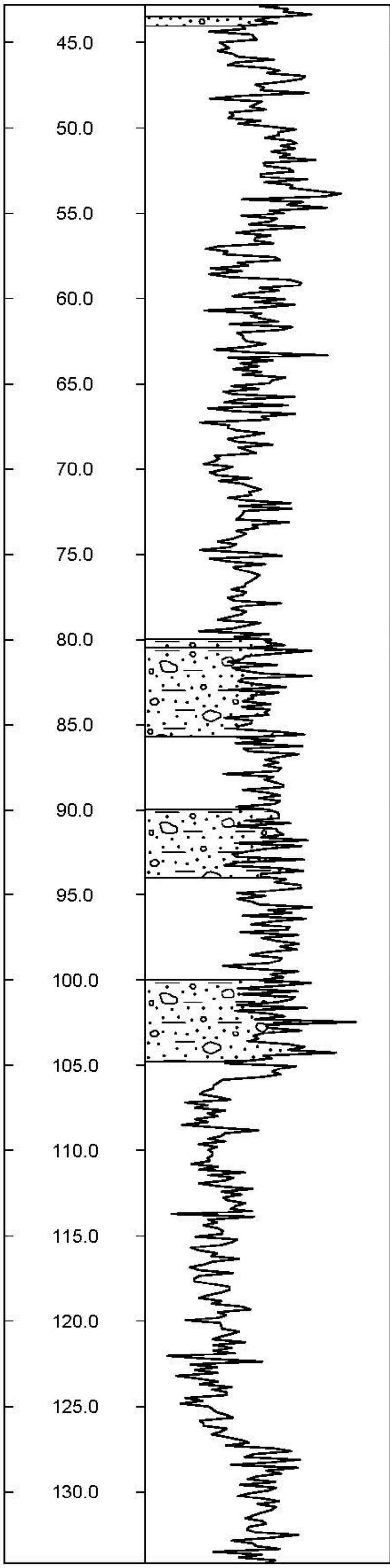
INDIANA GEOLOGICAL & WATER SURVEY
INDIANA UNIVERSITY

Site ID: 122201	Date: 04/05/2022
Site Name: Frankfort_S	Authors: Ginger Davis, McKailey Sabaj
Latitude: 40.22707274	Elevation (ft): 929.7
Longitude: -86.43013546	NGWMN flushmount well

Legend

- Gravel or conglomerate
- Till or diamicton
- Massive sand or sandstone
- Silt, siltstone or silty shale
- Dolomite
- Argilaceous or shaly dolomite
- Cherty dolomite
- Interbedded sandstone and siltstone

Depth 1ft:125ft	Lithology / Gamma Ray (0 CPS 100)	Description
0.0, 5.0, 10.0, 15.0, 20.0, 25.0, 30.0, 35.0, 40.0		(0-0.9) Clay loam and gravel (Dmm) with some (31-49%) very coarse gravel (32-64 mm), massive, very dark grayish-brown (10YR3/2), moist, oxidized-leached, no reaction, loose, medium consistency, sharp lower contact, A Horizon (disturbed) over gravel fill, anthropogenic evidence.
		(0.9-1.4) Clay loam (Dmm), with trace (<5%) medium gravel (8-16 mm), massive, black (10YR2/1), moist, oxidized-leached, no reaction, very soft consistency, sharp lower contact, A Horizon (buried) with clay tile clasts.
		(1.4-1.9) Clay loam (Dmm), with trace (<5%) fine gravel (4-8 mm), massive, brown (10YR4/3), moist, oxidized-leached, no reaction, loose, very soft consistency, gradational lower contact, B Horizon, some organics (roots or worms), changes to till with pebbles.
		(1.9-2.4) Sandy clay (Sm) with little (16-30%) granules to coarse (2-32 mm), massive, yellowish-brown (10YR5/4), moist, oxidized-unleached, moderate reaction, loose, very soft consistency, gradational lower contact, Bt soil layer.
		(2.4-3.9) Sandy clay (Sm), with little (16-30%) granules to coarse (2-32 mm), massive, yellowish-brown (10YR5/4), moist, oxidized-leached, no reaction, loose, very soft consistency, gradational lower contact.
		(3.9-4) No recovery.
		(4-8.8) Clay loam and gravel (Dmm) with little (16-30%) granules to coarse (2-32 mm), massive, brown (10YR5/3), moist, oxidized-unleached, moderate reaction, very soft consistency, sharp lower contact, secondary weathering, iron oxidation, trace amount of nodules. Pebbles scattered throughout: schist, shale, granite. Manganese concretion around some clast.
		(8.8-9) No recovery.
		(9-12) Silty clay loam and gravel (Dmm) with little (16-30%) fine gravel (4-8mm), massive, yellowish-brown (10YR5/4), wet, oxidized-unleached, moderate reaction, medium dense consistency, gradational lower contact. First 15 cm, driller's lubricant inside core. Few (6-15%) iron nodules throughout.
		(12-12.6) Sandy clay and gravel (Dmm) with few (6-15%) medium gravel (8-16 mm), massive, dark gray (10YR4/1), wet, oxidized-unleached, moderate reaction, loose consistency, gradational lower contact, gray till, possible lodgement till incorporated from meltout.
		(12.6-15) No recovery.
		(15-18.7) Silty clay (Dc) with little (16-30%) coarse gravel (16-32 mm), massive, dark grayish-brown (2.5Y4/2), moist, reduced, strong reaction, very soft consistency, sharp lower contact, dark gray clay, little clasts (16-30%) from granules to medium gravel.
		(18.7-43.5) No recovery.



(43.5-44) Sand and gravel (SG) with some (31-49%) fine gravel (4-8 mm), dark grayish-brown (2.5Y4/2), moist, moderate reaction, very loose consistency, small sample of 43.5-50 ft section due to poor recovery.

(44-80) No recovery.

(80-80.5) Sandy loam and gravel (Dmm) with few (6-15%) medium gravel (8-16 mm), massive, dark grayish-brown (2.5Y4/2), moist, reduced-unleached, moderate reaction, hard consistency, sharp lower contact.

(80.5-85.7) sandy clay loam and gravel (Dmm), with some (31-49%) very coarse gravel (32-64 mm), massive, dark gray (2.5Y4/1), moist, oxidized-leached, weak reaction, very dense, hard consistency, gradational lower contact, clast-rich, large clasts of granite, subangular clasts.

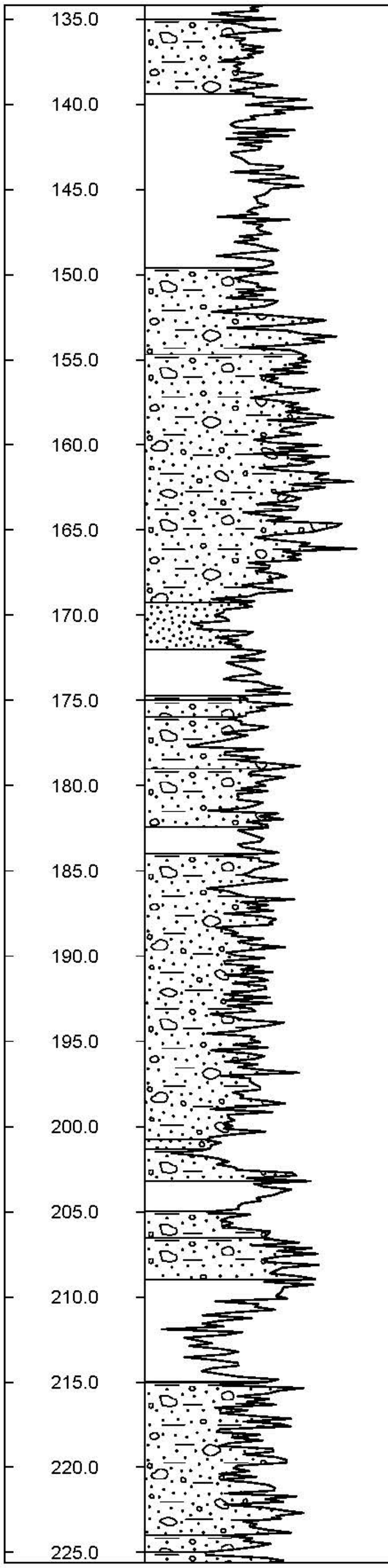
(85.7-90) No recovery.

(90-94) Sandy clay loam and gravel (Dmm) with some (31-49%) granules to coarse (2-32 mm), massive, dark gray (2.5Y4/1), moist, oxidized-leached, weak reaction, hard consistency, gradational lower contact, section more moist than others, still clast-rich, very dense.

(94-100) No recovery.

(100-104.8) Clay and gravel (Dmm) with few (6-15%) fine gravel (4-8 mm), massive, dark gray (10YR4/1), moist, oxidized-leached, weak reaction, dense consistency, sharp lower contact, large clast 3 cm wide.

(104.8-135) No recovery.



(135-139.4) Sandy clay loam and gravel (Dmm) with some (31-49%) fine gravel (4-8 mm), massive, dark gray (5YR4/1), moist, oxidized-unleached, weak reaction, dense consistency, gradational lower contact, more green than before, many clasts: granite, pebbles up to 3 cm, blue and orange concretions in trace amounts.

(139.4-149.6) No recovery.

(149.6-154.7) Sandy clay loam and gravel (Dmm) with little (16-30%) fine gravel (4-8mm), massive, dark gray (5Y4/1), moist, oxidized-leached, moderate reaction, medium dense consistency, sharp lower contact, large shale clast (16 mm), other sedimentary rocks.

(154.7-169.3) Silty clay loam and gravel (Dmm) with few (6-15%) granules (2-4 mm), massive, very dark gray (5Y3/1), dry, oxidized-leached, weak reaction, very dense consistency, some iron concretions throughout, granite clasts, much drier than before, clasts of shale, wood and granite, green nodule about 8 mm, organic bands from 167-169.3 ft.

(169.3-172) Sand (S) with trace (<5%) granules (2-4 mm), massive, moist, loose consistency, gradational lower contact.

(172-174.7) No recovery.

(174.7-175) Silt and gravel (Dmm) with trace (<5%) fine gravel (4-8 mm), massive, dark grayish-brown (10YR4/2), moist, oxidized-leached, weak reaction, medium consistency, gradational lower contact.

(175-176) Silty clay loam and gravel (Dmm) with trace (<5%) granules (2-4 mm), massive, dark gray (5Y4/1), moist, oxidized-leached, weak reaction, medium consistency, gradational lower contact.

(176-179) Sandy clay loam and gravel (Dmm) with little (16-30%) granules to coarse (2-32 mm), massive, dark gray (5Y4/1), moist, oxidized-leached, weak reaction, medium consistency, gradational lower contact, area with large (up to 25 mm) clasts at 178.35 ft, some sandy zones.

(179-182.4) Sandy loam and gravel (Dmm) with some (31-49%) granules to coarse (2-32 mm), massive, dark grayish-brown (2.5Y4/2), moist, oxidized-leached, weak reaction, stiff consistency, gradational lower contact, large clasts throughout, iron concretion about 14 mm large, more brown than gray.

(182.4-184) No recovery.

(184-200.8) Sandy loam and gravel (Dmm) with little (16-30%) granules to coarse (2-32 mm), massive, dark grayish-brown (2.5Y4/2), moist, oxidized-leached, weak reaction, stiff consistency, gradational lower contact, some areas more sandy than others. Many clasts throughout: granite, quartz, shale, other sedimentary rocks.

(200.8-201.3) Sand and gravel (SGm) with some (31-49%) fine gravel (4-8 mm), massive, moist, weak reaction, medium consistency, gradational lower contact.

(201.3-203.2) Silty clay loam and gravel (Dmm) with little (16-30%) granules to medium (2-16 mm), massive, dark gray (2.5Y4/1), moist, oxidized-leached, weak reaction, stiff consistency, gradational lower contact.

(203.2-205) No recovery.

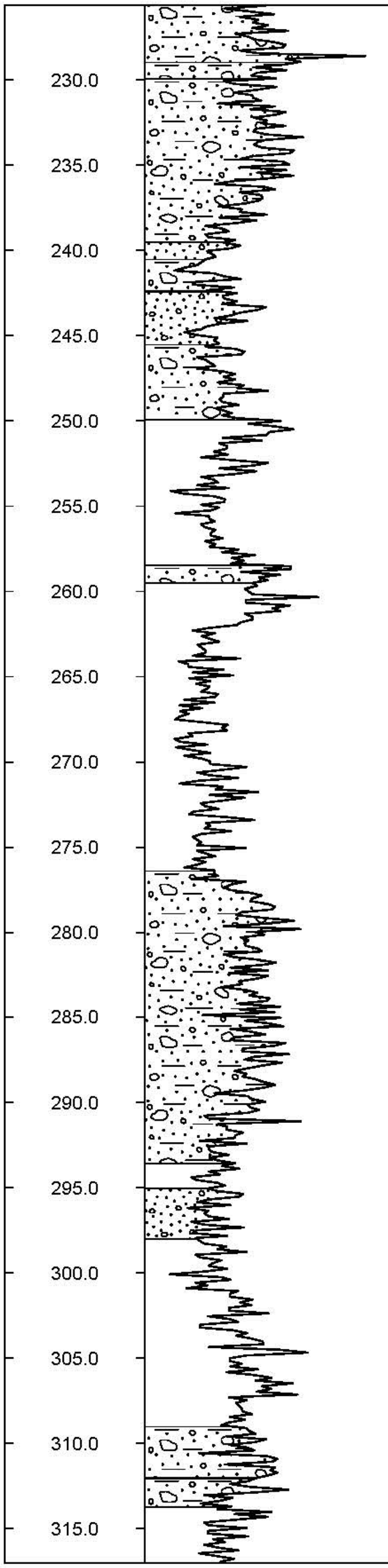
(205-206.5) Silt and gravel (Dmm) with little (16-30%) granules to medium (2-16 mm), massive, grayish-brown (2.5Y5/2), moist, oxidized-leached, weak reaction, medium consistency, gradational lower contact.

(206.5-209) Silty clay loam and gravel (Dmm) with little (16-30%) granules to medium (2-16 mm), massive, dark gray (2.5Y4/1), moist, oxidized-leached, weak reaction, medium consistency, gradational lower contact.

(209-215) No recovery.

(215-224) Sandy clay loam and gravel (Dmm) with some (31-49%) granules to coarse (2-32 mm), massive, dark gray (2.5Y4/1), dry, oxidized-leached, weak reaction, dense consistency, sharp lower contact, (2.5Y 5/2) from 220-223 ft, some larger clasts (up to 24 mm), more dry than previously, small sand bed at 217.3 ft.

(224-225) Sandy loam and gravel (Dmm) with few (6-15%) granules to medium (2-16 mm), massive, dark gray (2.5Y4/1), moist, oxidized-leached, weak reaction, medium dense consistency, gradational lower contact.



(225-229) Sandy clay loam and gravel (Dmm) with little (16-30%) granules to medium (2-16 mm), massive, dark gray (2.5Y4/1), moist, oxidized-leached, weak reaction, medium dense consistency, gradational lower contact, some green concretions up to 7 mm.

(229-230) Silt and gravel (Dmm) with trace (<5%) granules to fine (2-8 mm), massive, dark gray (2.5Y4/1), moist, oxidized-leached, weak reaction, medium consistency, gradational lower contact.

(230-239.5) Sandy loam and gravel (Dmm) with some (31-49%) granules to coarse (2-32 mm), massive, dark gray (2.5Y4/1), moist, oxidized-leached, weak reaction, dense consistency, gradational lower contact, large granite clasts up to 25 mm, one shale clast (5 mm).

(239.5-240.5) Sand and gravel (SGm) with some (31-49%) granules to coarse (2-32 mm), massive, dark gray (2.5Y4/1), moist, oxidized-leached, weak reaction, loose consistency, gradational lower contact.

(240.5-242.4) Sandy clay loam and gravel (Dmm) with little (16-30%) granules to coarse (2-32 mm), massive, dark gray (2.5Y4/1), moist, oxidized-leached, weak reaction, medium dense consistency, gradational lower contact, some sandy beds up to 1 cm, one sand and gravel bed 4 cm thick.

(242.4-245.5) Sand and gravel (SGm) with some (31-49%) granules to coarse (2-32 mm), massive, dark gray (2.5Y4/1), moist, oxidized-leached, weak reaction, loose consistency, gradational lower contact, iron concretion (6 mm), some possible clay (red color) 6 mm.

(245.5-249.9) Sandy loam and gravel (Dmm) with some (31-49%) granules to coarse (2-32 mm), massive, dark gray (2.5Y4/1), moist, oxidized-leached, weak reaction, medium consistency, gradational lower contact, some sandy beds and silt loam throughout.

(249.9-258.5) No recovery.

(258.5-259.5) Sandy loam and gravel (Dmm) with little (16-30%) granules to coarse (2-32 mm), massive, very dark grayish-brown (2.5Y3/2), dry, oxidized-leached, weak reaction, very dense consistency, gradational lower contact, some quartz, shale clasts among other types.

(259.5-276.4) No recovery.

(276.4-293.6) Sandy loam and gravel (Dmm) with some (31-49%) granules to medium (2-16 mm), very dark grayish-brown (2.5Y3/2), moist, oxidized-leached, weak reaction, medium dense consistency, gradational lower contact, gravel interval at top (3 cm), more sand less gravel from 292-293 ft, more color variation between two colors, manganese concretion at 293 ft, small iron concretion, shale is notable among clasts.

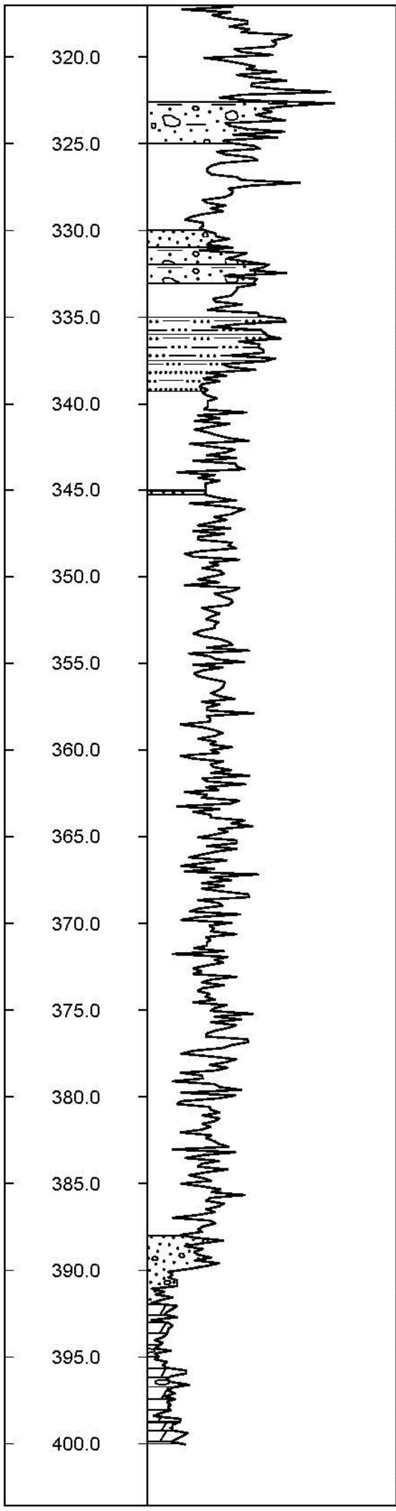
(293.6-295) No recovery.

(295-298) Sand and gravel (SGm) with few (6-15%) granules to medium (2-16 mm), massive, very dark grayish-brown (2.5Y3/2), wet, oxidized-leached, weak reaction, very loose consistency, gradational lower contact.

(298-309) No recovery.

(309-312) Silty clay loam and gravel (Dmm) with some (31-49%) granules to coarse (2-32 mm), massive, dark grayish-brown (2.5Y4/2), wet, oxidized-leached, weak reaction, medium dense consistency, gradational lower contact, large gravel for 8 cm at the beginning of interval. More gray than previously.

(312-313.7) Sandy loam and gravel (Dmm) with few (6-15%) fine gravel (4-8 mm), massive, dark gray (2.5Y4/1), wet, oxidized-leached, weak reaction, soft consistency, gradational lower contact, very fine-grained sand beds at bottom of interval.



(313.7-322.6) No recovery.

(322.6-325) Sandy clay loam and gravel (Dmm) with few (6-15%) granules to medium (2-16 mm), massive, dark gray (2.5Y4/1), moist, oxidized-leached, weak reaction, medium consistency, gradational lower contact, small sand beds throughout.

(325-330) No recovery.

(330-331) Sand and gravel (SGm), with trace (<5%) granules to fine (2-8 mm), massive, dark gray (2.5Y4/1), moist, oxidized-leached, weak reaction, very loose consistency, sharp lower contact.

(331-332) Silty clay loam and gravel (Dmm), with few (6-15%) granules to medium (2-16 mm), massive, dark gray (2.5Y4/1), moist, oxidized-leached, weak reaction, stiff consistency, sharp lower contact, wood. Large area of (2.5Y3/1).

(332-333) Silt loam and gravel (Dmm) with little (16-30%) granules to medium (2-16 mm), massive, dark gray (2.5Y4/1), moist, oxidized-leached, moderate reaction, soft consistency, gradational lower contact.

(333-335) No recovery.

(335-336) Silt (Fm), with trace (<5%) granules (2-4 mm), massive, dark gray (2.5Y4/1), wet, oxidized-leached, moderate reaction, soft consistency, gradational lower contact.

(336-337.5) Silt (Fm), with trace (<5%) granules (2-4 mm), thinly bedded, dark gray (2.5Y4/1), wet, oxidized-leached, moderate reaction, soft consistency, sharp lower contact, some organic bedding, darker color (2.5Y 3/1).

(337.5-339.3) Silt and sand (Sm) with trace (<5%) granules (2-4 mm), massive, dark gray (2.5Y4/1), wet, oxidized-leached, moderate reaction, soft consistency, gradational lower contact, no more bedding, more sand than above silt layers, area of wood, very dark in color from 338.5-338.8 ft.

(339.3-345) No recovery.

(345-345.2) Sand and gravel (SG), very loose consistency, mostly chert, some other sedimentary and igneous clasts present.

(345.2-388) No recovery.

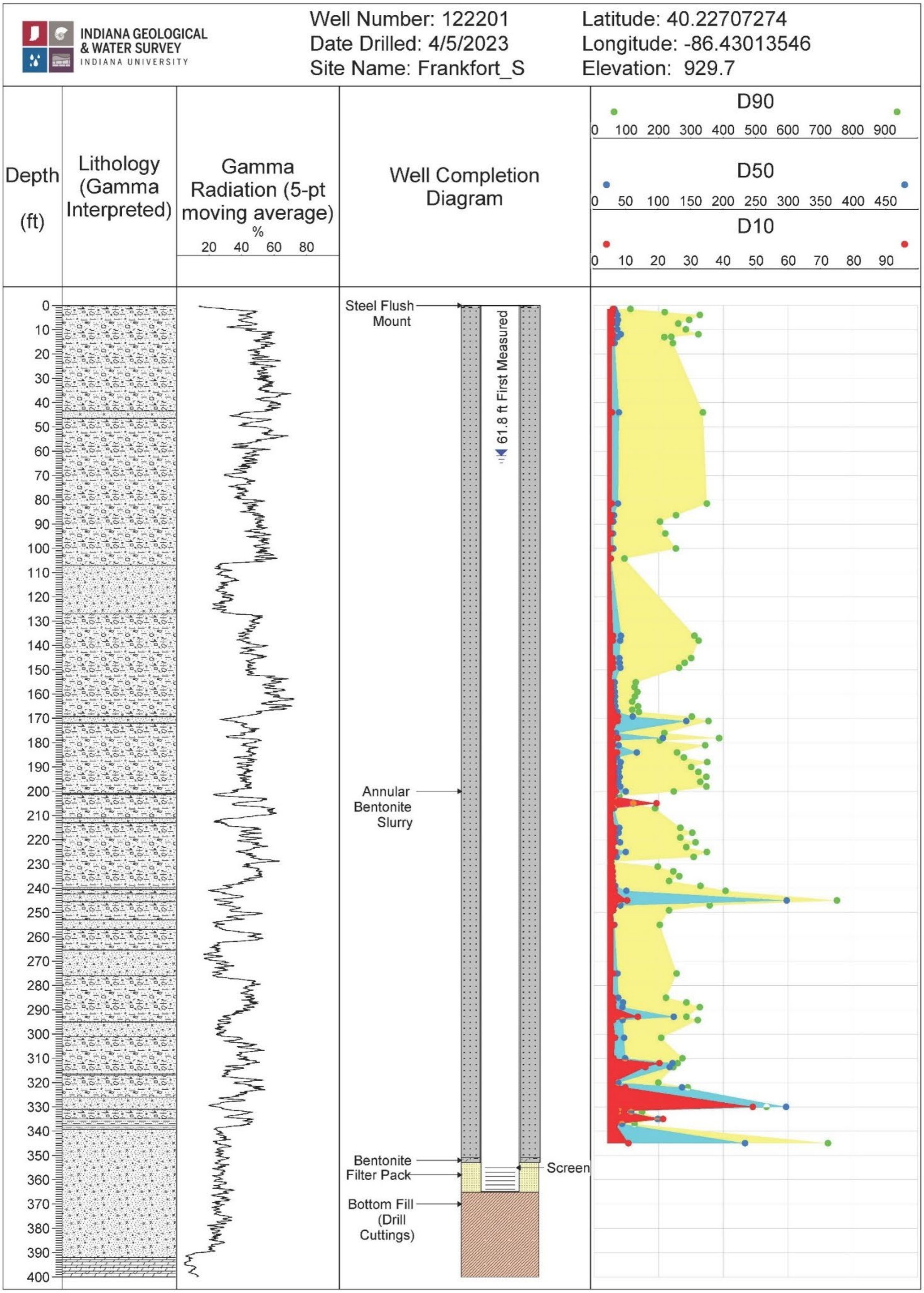
(388-392) Sand and gravel (SG) with granules to coarse (2-32 mm), coarsening upward, very loose consistency, gradational lower contact.

(392-393) Dolostone/dolomite crystallized, oxidation due to weathering front (orange), vuggy porosity, secondary fracture filled with drillers mud, light reaction to acid, crinoid stems present very small, glauconite sparsely present throughout.

(393-398.8) Dolostone/dolomite, vuggy porosity, alternating gray/buff, fine grained with drapped or bioturbated layers increasing with depth, Archimedes found at 398.4 ft, frequency of chert clasts increasing slightly with depth.

(398.8-399.3) Dolostone/dolomite, argillaceous dolostone with large chert nodules. Buff color with stylolites consitsting of shales.

(399.3-400) Dolostone/dolomite, vuggy porosity, alternating gray/buff, fine grained with draped or bioturbated layers increasing with depth.


INDIANA GEOLOGICAL & WATER SURVEY
INDIANA UNIVERSITY
Well Number: 122201
Date Drilled: 4/5/2023
Site Name: Frankfort_S
Latitude: 40.22707274
Longitude: -86.43013546
Elevation: 929.7
Depth (ft)
Lithology (Gamma Interpreted)
Gamma Radiation (5-pt moving average)
%
20 40 60 80
Well Completion Diagram
D90
0 100 200 300 400 500 600 700 800 900
D50
0 50 100 150 200 250 300 350 400 450
D10
0 10 20 30 40 50 60 70 80 90
Steel Flush Mount
61.8 ft First Measured
Annular Bentonite Slurry
Bentonite
Filter Pack
Screen
Bottom Fill (Drill Cuttings)
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 270 280 290 300 310 320 330 340 350 360 370 380 390 400

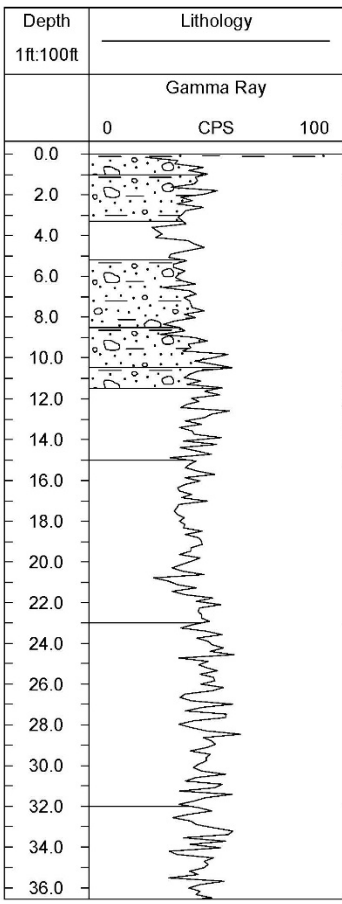
APPENDIX D Glenwood_N Replacement (IGWS Well 212202) Lithology and Well Construction

INDIANA GEOLOGICAL & WATER SURVEY
INDIANA UNIVERSITY

Site ID: 212202	Date: 04/15/2022
Site Name: Glenwood_N Replacement	Authors: Ginger Davis, McKailey Sabaj
Latitude: 39.639096	Elevation (ft): 1098
Longitude: -85.291602	NGWMN Flushmount Well

Legend

- Gravel or conglomerate
- Till or diamicton
- Massive sand or sandstone
- Silt, siltstone or silty shale
- Calcareous siltstone



Description

(0-1.1) Silt loam and gravel (Dmm) with trace (<5%) fine gravel (4-8 mm); massive; dark grayish-brown (10YR3/2); dry; oxidized-leached; no reaction; stiff consistency; gradational lower contact; A horizon; roots, worms, and other organics.

(1-3.3) Sandy clay loam and gravel (Dmm) with few (6-15%) granules to med (2-16 mm); massive; dark yellowish-brown (10YR4/4); dry; oxidized-unleached; moderate reaction; stiff consistency; gradational lower contact; Bt horizon developed in till; igneous clasts.

(3.3-5.2) No recovery; gamma interpretation: sand and gravel.

(5.2-8.5) Sandy loam and gravel (Dmm) with trace (<5%) granules to med (2-16 mm); massive; yellowish-brown (10YR5/4); dry; oxidized-unleached; moderate reaction; medium consistency; sharp lower contact; organic-rich bed at 3.31 ft (101-103 cm); thin (4 cm) bed of higher sand content at 4.26 ft (130-134 cm).

(8.5-10.5) Sandy loam and gravel (Dmm) with trace (<5%) granules to med (2-16 mm); massive; brown (10YR4/3); moist; oxidized-unleached; moderate reaction; soft consistency; gradational lower contact; increase in silt in the last 4 cm; coarse gravel subangular slate clast; organic layer; roots; weak hydrogen peroxide reaction; secondary color dark gray (10YR 4/1) in mottling.

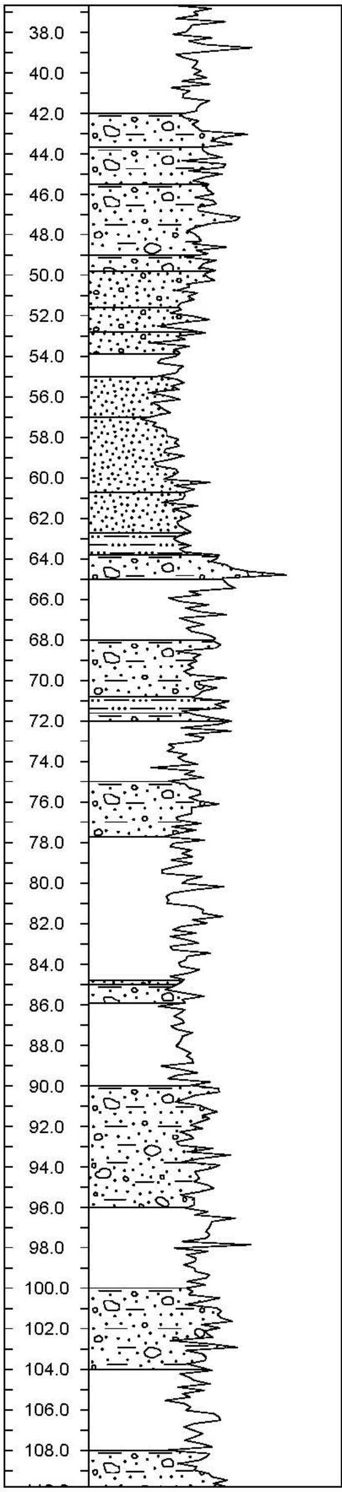
(10.5-11.5) Loam and gravel (Dmm) with trace (<5%) granules to med (2-16 mm); massive; gray (10YR5/1); moist; unoxidized-unleached; moderate reaction; medium consistency; sharp lower contact; igneous clasts.

(11.5-15) No recovery; gamma interpretation: dense till; driller cuttings, till balls.

(15-23) No recovery; gamma interpretation: sandy gravel mixed in till, increasing coarse content with depth.

(23-32) No recovery; gamma interpretation: dense till; (30-35 ft) drilling cuttings collected.

(32-42) No recovery; gamma interpretation: dirty sand and gravel; (30-35 ft) drilling cuttings collected; (40-45 ft) interpreted as fine to medum sand with granules.



(42-43.7) Sandy clay loam and gravel (Dmm) with trace (<5%) granules to med (2-16 mm); massive; dark gray (10YR4/1); moist; unoxidized-unleached; moderate reaction; soft consistency; gradational lower contact; gradual increase in density toward bottom; course gravel; subrounded sedimentary clast exhibiting secondary weathering at contact.

(43.7-45.5) Silt loam and gravel (Dmm) with trace (<5%) granules to coarse (2-32 mm); massive; olive gray (5Y4/2); dry; oxidized-leached; no reaction; stiff consistency; gradational lower contact; rounded to sub-angular igneous clasts; redox features mostly in the joints; secondary color of very dark gray (2.5Y 3/1); some manganese stringers; marked decrease in redox features beyond upper contact.

(45.5-49) Silty clay loam and gravel (Dms) with trace (<5%) granules (2-4 mm); thinly bedded; multicolored; dry; unoxidized-leached; no reaction; very stiff consistency; gradational lower contact; banded bedding with high organic (darker olive gray 5Y4/2) 0.5 cm thick and lower organic (lighter dark yellowish-brown 10YR 4/4) 1 cm thick, alternating sets; sorted at bottom before transition; some beds near bottom are gley 1 5G5/2

(49-49.8) Sandy loam and sand (Dms) with trace (<5%) granules (2-4 mm); thinly bedded; olive gray (5Y4/2); dry; unoxidized-leached; no reaction; medium consistency; gradational lower contact; dark yellowish-brown (10YR 4/4) oxidation on 1 cm-thick laminea, alternating olive gray (5Y 2.5/2) with olive gray (5Y4/2); no hydrogen peroxide reaction; sandy 1 cm beds with high oxidation surrounding from 49 to 49.5 ft.

(49.8-51.6) Sand to sandy loam and gravel (SGms) with some (31-49%) granules to fine (2-8 mm); fining upward; multicolored; dry; unoxidized-leached; no reaction; dense consistency; gradational lower contact; dark yellowish-brown (10YR3/6) incorporated into the olive gray (5Y4/2) matrix with some strong brown (7.5YR 4/6); underlying sands and increase of sand in this unit may be allowing for increased oxidation; gravel percent decrease upward; variety of gravel rock types.

(51.6-52.8) Sand to sandy loam and gravel (SGm) with little (16-30%) granules to fine (2-8 mm); massive; dark yellowish-brown (10YR4/4); dry; oxidized-leached; no reaction; medium dense; gradational lower contact; sand are fining upward; sedimentary, igneous, and metamorphic rock types.

(52.8-53.9) Sand and sandy loam (Sms) with trace (<5%) granules (2-4 mm); thinly bedded; dark yellowish-brown (10YR4/6); dry; oxidized-leached; no reaction; medium consistency; sharp lower contact; bedding laminea are clay-rich; little gravel in the last 10 cm at contact.

(53.9-55) No recovery; gamma interpretation: sand (clean).

(55-57) Sand and sandy loam (Sm) ; massive; dark yellowish-brown (10YR4/6); moist; oxidized-leached; no reaction; soft consistency; sharp lower contact; silty bed of sand with a greyish color (10YR 5/3) from 56.1-56.5 ft.

(57-60.7) Sand (Sm); massive; yellowish-brown (10YR5/4); moist; oxidized-unleached; weak reaction; medium consistency; gradational lower contact; fine to medium; well sorted.

(60.7-62.7) Silt and sand (Sms); massive; yellowish-brown (10YR5/6); moist; oxidized-unleached; moderate reaction; medium consistency; gradational lower contact; two varieties of interbedding toward the top beds of sand alternating with 10YR 3/3 silt horizontal bedding, appear to be some crossbeds toward the bottom.

(62.7-63.8) Silty clay (Fm) with trace (<5%) granules to med (2-16 mm); massive; grayish brown (2.5Y5/2); dry; unoxidized-unleached; moderate reaction; stiff consistency; sharp lower contact; some oxidized interbedded layers; platy structure.

(63.8-65) Clay and sand (Dmm); massive; dark grayish-brown (2.5Y4/2); moist; unoxidized-unleached; strong reaction; stiff consistency; sharp lower contact; gray till.

(65-68) No recovery; gamma interpretation: till.

(68-70.8) Sandy loam with gravel (Dmm) with few (6-15%) granules to coarse (2-32 mm); massive; dark grayish-brown (2.5Y4/2); dry; unoxidized-unleached; strong reaction; dense; sharp lower contact; secondary color 2.5Y 3/1; clasts appear to be igneous mostly with some tabular sedimentary clasts; clasts are poorly sorted.

(70.8-71.6) Silt and clay (Fms) with trace (<5%) granules (2-4 mm); startified; very dark grayish-brown (10YR3/2); moist; unoxidized-unleached; moderate reaction; stiff consistency; gradational lower contact; bedding or stratification of organics approx. 10YR 3/1, very common in this interval; lake silt.

(71.6-72) Sand and sandy loam (Dcm) with few (6-15%) granules (2-4 mm); massive; dark grayish-brown (10YR4/2); dry; unoxidized-unleached; moderate reaction; dense; sharp lower contact; very sandy unit.

(72-75) No recovery; gamma interpretation: sandy unit mixed in till.

(75-77.7) Silty sand and gravel (Dmm) with little (16-30%) granules to fine (2-8 mm); massive; dark grayish-brown (10YR4/2); dry; oxidized-unleached; moderate reaction; dense; sharp lower contact; till.

(77.7-84.8) No recovery; gamma interpretation: sand and gravel units mixed in till.

(84.8-85) Sand and gravel (Gm) with few (6-15%) granules to fine (2-8 mm); massive; brown (10YR4/3); dry; oxidized-unleached; moderate reaction; very stiff consistency; sharp lower contact.

(85-85.9) Silt and sand (Dmm) with trace (<5%) granules (2-4 mm); massive; dark grayish-brown (10YR4/2); moist; unoxidized-unleached; moderate reaction; medium consistency; sharp lower contact.

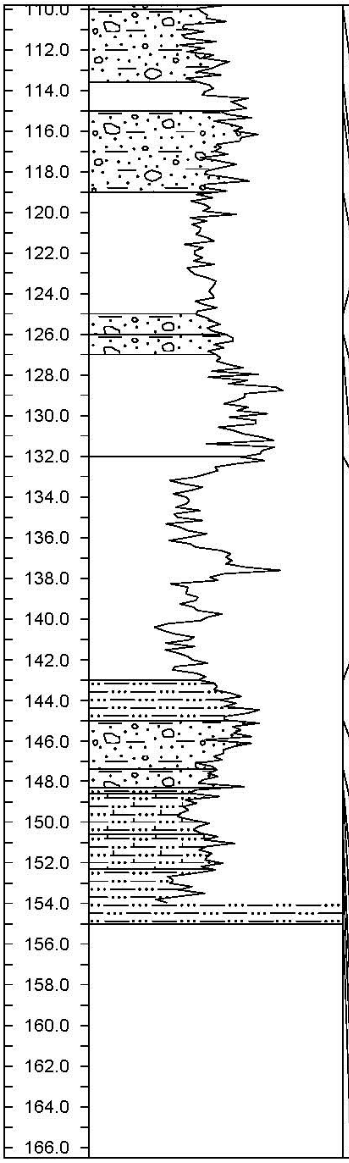
(85.9-90) No recovery; gamma interpretation: sand and gravel units mixed in till.

(90-96) Silt and gravel (Dmm) with little (16-30%) granules to coarse (2-32 mm); massive; dark grayish-brown (10YR4/2); dry; unoxidized-unleached; moderate reaction; stiff consistency; sharp lower contact; clasts of carbonate, igneous, and metamorphic; secondary color of 5Y 5/2.

(96-100) No recovery; gamma interpretation: till.

(100-104) Sandy loam (Dmm) with few (6-15%) granules to coarse (2-32 mm) and trace (<5%) cobble; massive; dark grayish-brown (10YR4/2); dry; unoxidized-unleached; weak to moderate reaction; stiff to very stiff consistency; sharp lower contact; platy structure with some blocky.

(104-108) No recovery; gamma interpretation: sandy till unit; driller: slow drilling.



(108-110) Silt loam (Dmm) with trace (<5%) granules to fine (2-8 mm); massive; dark gray (2.5Y4/1); dry; unoxidized-unleached; weak to moderate reaction; medium consistency; gradational lower contact; weathering/oxidation rhine at the top of this interval; fining downward toward a silt- and clay-rich loam; feldspar clast.

(110-113.6) Sandy loam (Dmm) with few (6-15%) granules to fine (2-8 mm); massive; very dark grayish-brown (10YR3/2); moist; oxidized-unleached; weak reaction; very stiff consistency; lower contact missing; secondary color of light brownish-gray (10YR 6/2) comes from two clay-rich joints that start at 111.6 ft and go to 112 ft within this interval; metamorphic clast.

(113.6-115) No recovery; gamma interpretation: till.

(115-119) Loam (Dmm) with little (16-30%) granules to coarse (2-32 mm); massive; dark gray (2.5Y4/1); dry; unoxidized-unleached; weak reaction; very stiff consistency; sharp lower contact; pebbles/gravel fining and sorting downward; fairly similar to interval above no-data zone with marked increase in clast abundance.

(119-125) No recovery; gamma Interpretation: sand and gravel-rich sandy loam.

(125-126) Sandy loam (Dmm) with trace (<5%) granules to fine (2-8mm); massive; dark gray (10YR4/1); moist; reduced-unleached; moderate reaction; stiff consistency; gradational lower contact; laminea as a reduction feature increasing in the downward direction; small percentage of clay; interpreted as a oxidation feature from a sand in gravel (gamma indicated) below causing the oxidation

(126-127) Silt loam (Dmm) with trace (<5%) granules to coarse (2-32 mm); massive; dark gray (2.5Y4/1); moist; oxidized-leached; no to weak reaction; very stiff consistency; sharp lower contact; secondary color of brownish-yellow (10YR 6/8) is oxidized color; chert, rhyolite, other igneous rock clasts; heavily oxidized especially at the bottom; very weak reaction to hcl increased reaction down the core, indicating surficial leaching; paleosol.

(127-132) No recovery; gamma interpretation: diamicton, clay loam.

(132-143) No recovery; gamma interpretation: sand and gravel with layer till (136-138 ft); driller: crystalline limestone with geode stuck in shoe; small amounts of till on clasts.

(143-145) Silty clay (Fm); massive; light yellowish-brown (2.5 YR 6/4) with light greenish-gray (5BG 7/1); dry; unoxidized-unleached; moderate to strong reaction; stiff consistency; sharp lower contact; calcarious silt and silty clay; secondary weathering at the top and bottom of the section interpreted as rip-up clast from bedrock below; mottling (oxidized-leached).

(145-147.4) Silty clay loam (Dmm) with trace (<5%) granules to coarse (2-32 mm); massive; dark greenish-gray (10Y3/1); dry; reduced-leached; no reaction; very stiff consistency; gradational lower contact; coarse gravel clasts of chert; dense compacted clay; banding of colors near transition to more traditional diamicton below; diamicton interpreted as clay-rich till.

(147.4-148.3) Silty clay loam (Dmm) with little (16-30%) granules to coarse (2-32 mm) and cobble; massive; greenish-gray (10Y5/1); dry; reduced-leached; no reaction; very stiff consistency; sharp lower contact; clast-rich; platy structure; lightening of gray toward bottom to a Light greenish-gray (10YR 7/1); diamicton interpreted as till

(148.3-148.6) Silty clay (Fm) with trace (<5%) v. fine sand(<0.125 mm); massive; light yellowish-brown (2.5 YR 6/4) with light greenish-gray (5BG 7/1); moist; oxidized-unleached; moderate to strong reaction; very stiff consistency; sharp lower contact; calcarious silt and silty clay; extensive mottling (oxidized-leached); interpreted as saprolith of calcarious siltstone.

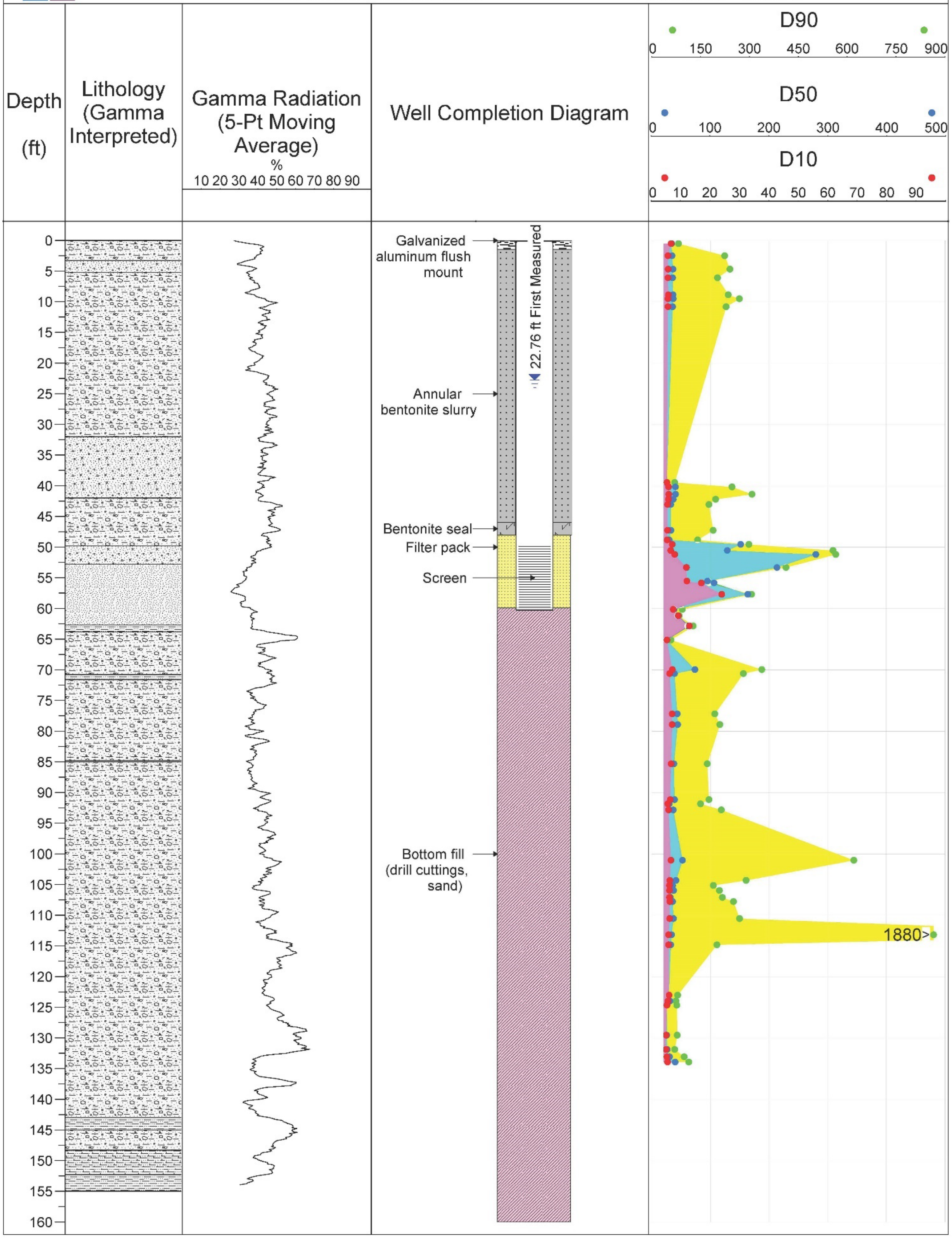
(148.6-150.6) Saprolite with trace (<5%) v. fine sand(<0.125 mm); massive; olive yellow (2.5Y6/6); dry; oxidized-leached; moderate to strong reaction; very dense; poorly indurated; sharp lower contact; parent material calcarious sandy siltstone with very fine-grained sand; red oxidized areas likely from water flow which may be source of calcarious cement in surrounding siltstone.

(150.6-152.3) Calcarious sandy siltstone with trace (<5%) v. fine sand (<0.125 mm); massive; light yellowish-brown (10YR 6/4) with brownish-yellow (10YR 6/6) and yellowish-brown (10YR 5/8); moderate to strong reaction; moderately indurated; interbedded 2-inch greenish gray (10Y 6/1) beds of non-calcarious sandy siltstone.

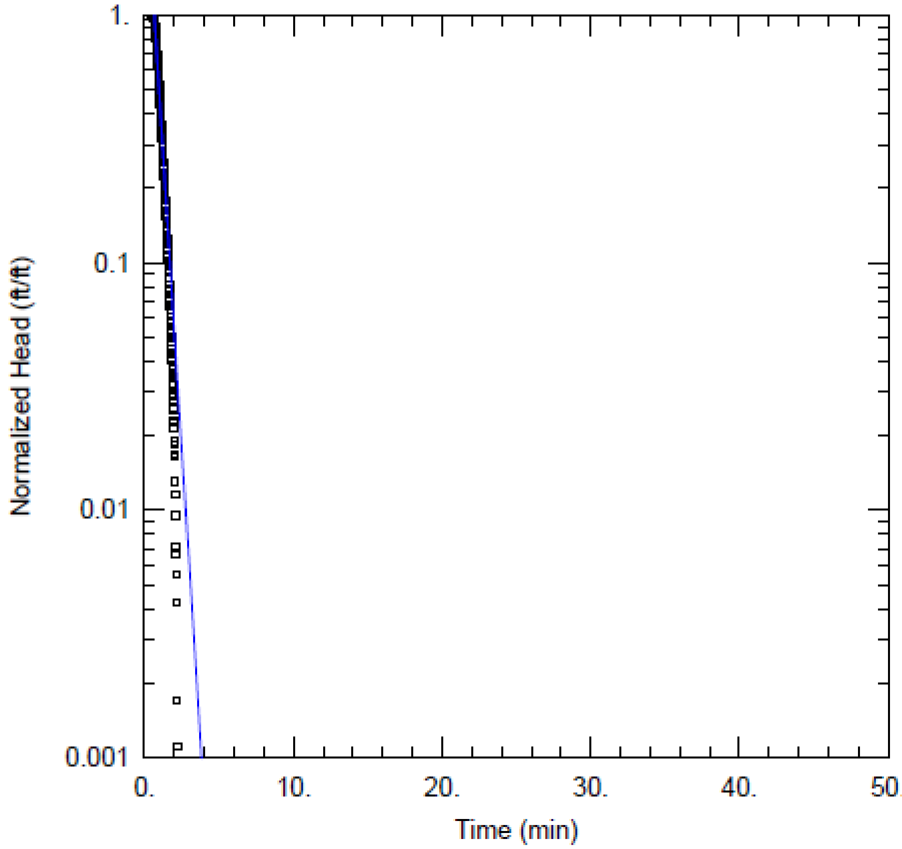
(152.3-155) Sandy siltstone with some(31-49%) v. fine sand (<0.125 mm); massive; greenish-gray (10Y6/1); dry; no reaction; well indurated; sharp lower contact; sandy siltstone with very fine-grained sand; some thin (<1 mm) organic-rich laminea; non-calcarious; well indurated; 2-inch zones of dolostone at 153.5 ft and 154.5 ft; Mississinewa Shale Member, Wabash Formation.

Site Name: Glenwood_N Replacement
Well Number: Glenwood_N_R
Date Drilled: 04/15/2022

Latitude: 39.639096
Longitude: -85.291602
Elevation: 1098 ft



APPENDIX E Slug Test Results



WELL TEST ANALYSIS

PROJECT INFORMATION

Company: IGWS
Test Well: Fort Wayne_N1

AQUIFER DATA

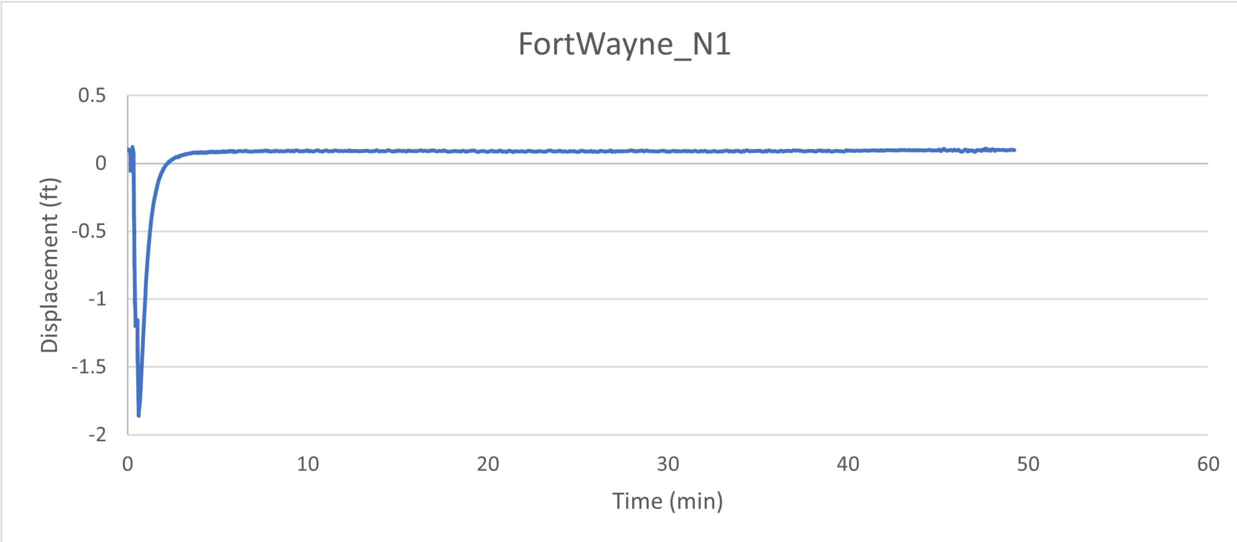
Saturated Thickness: 22.5 ft
Anisotropy Ratio (Kz/Kr): 1.

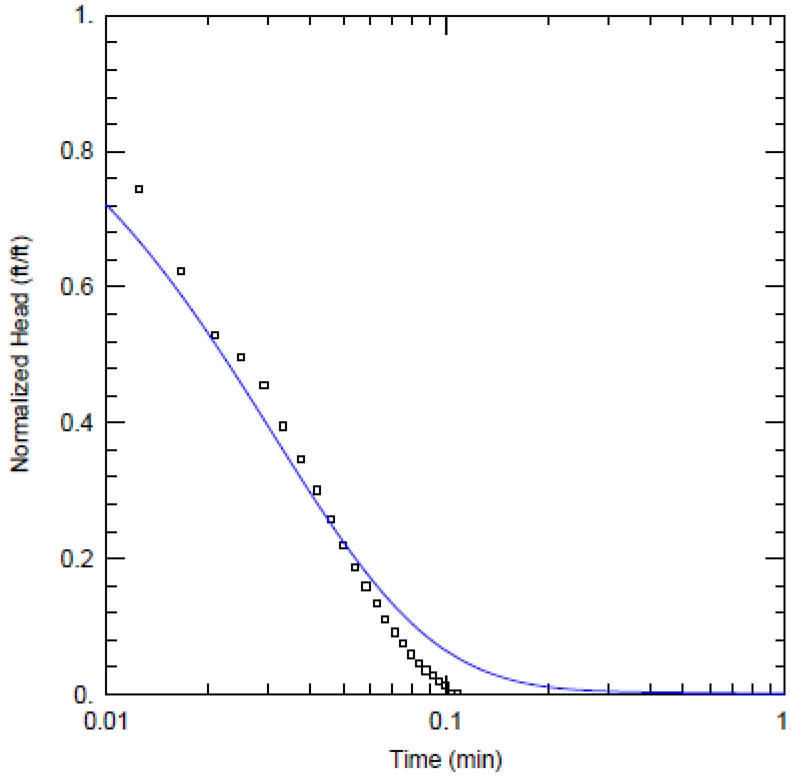
WELL DATA (Fortwayne_N1)

Initial Displacement: 1.859 ft
Total Well Penetration Depth: 30.95 ft
Casing Radius: 0.166 ft
Static Water Column Height: 30.95 ft
Screen Length: 10. ft
Well Radius: 0.166 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.01164 ft/min
y0 = 7.914 ft


FortWayne_N1
Displacement (ft)
0.5
0
-0.5
-1
-1.5
-2
0
10
20
30
40
50
60
Time (min)



WELL TEST ANALYSIS

PROJECT INFORMATION

Company: IGWS
Test Well: Martinsville_N

AQUIFER DATA

Saturated Thickness: 13. ft

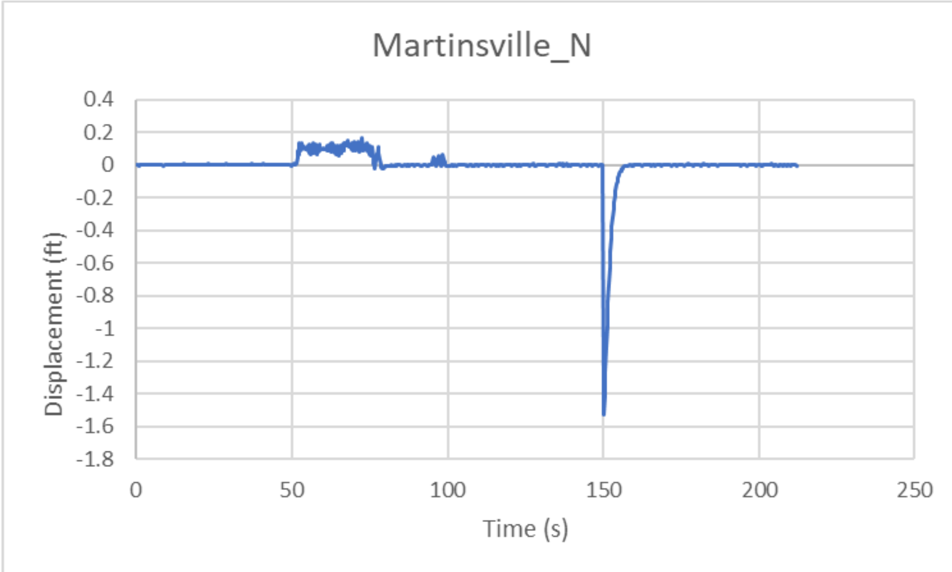
WELL DATA (Martinsville_N)

Initial Displacement: 3.661 ft
Total Well Penetration Depth: 37.03 ft
Casing Radius: 0.0835 ft
Static Water Column Height: 56.83 ft
Screen Length: 10. ft
Well Radius: 0.0875 ft

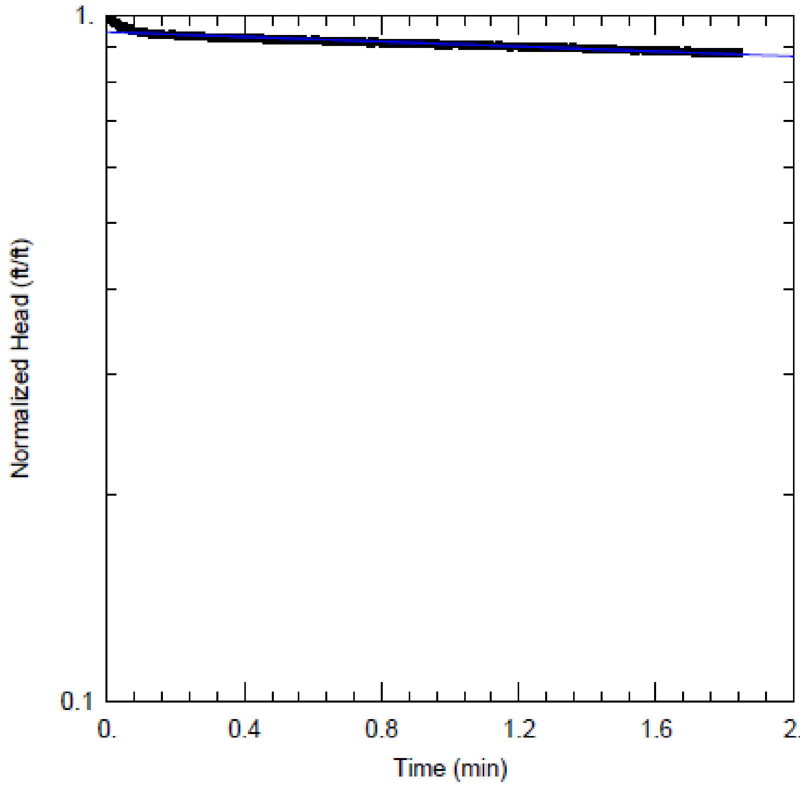
SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.1176 ft/min
Ss = 1.78E-12 ft^{-1}
Kz/Kr = 1.



Martinsville_N
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
-1.8
Displacement (ft)
0
50
100
150
200
250
Time (s)



WELL TEST ANALYSIS

PROJECT INFORMATION

Company: IGWS
Test Well: Muncie_N

AQUIFER DATA

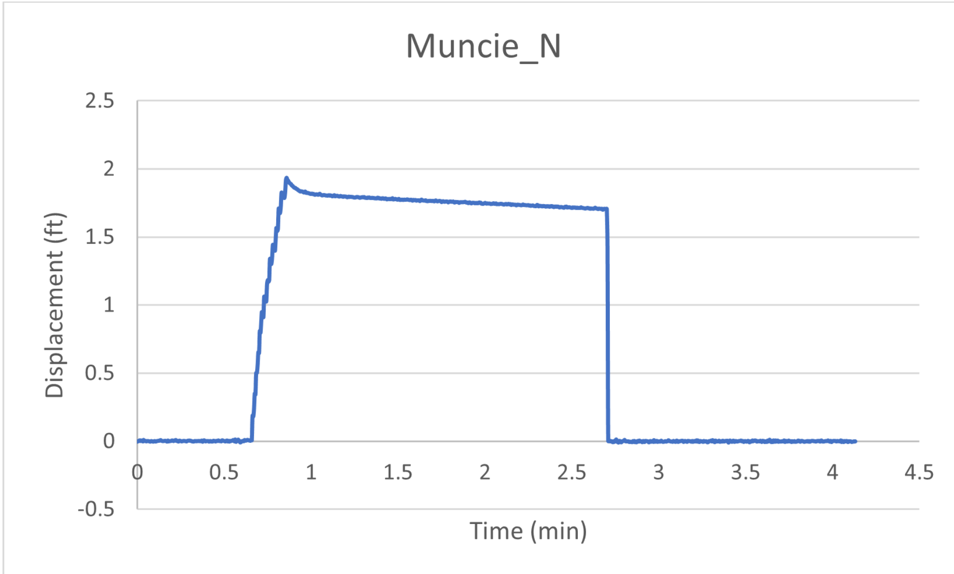
Saturated Thickness: 14. ft
Anisotropy Ratio (Kz/Kr): 1.

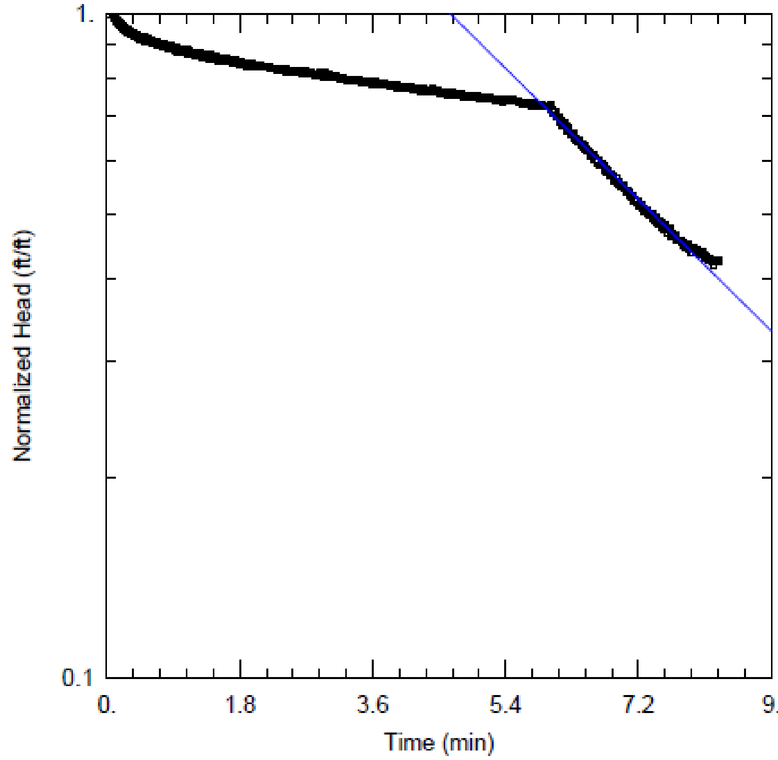
WELL DATA (Muncie_N)

Initial Displacement: 1.935 ft
Total Well Penetration Depth: 26.94 ft
Casing Radius: 0.0835 ft
Static Water Column Height: 26.94 ft
Screen Length: 3. ft
Well Radius: 0.0875 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.000187 ft/min
y0 = 1.831 ft


Muncie_N
Displacement (ft)
Time (min)
2.5
2
1.5
1
0.5
0
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5



WELL TEST ANALYSIS

PROJECT INFORMATION

Company: IGWS
Test Well: Glenwood_N

AQUIFER DATA

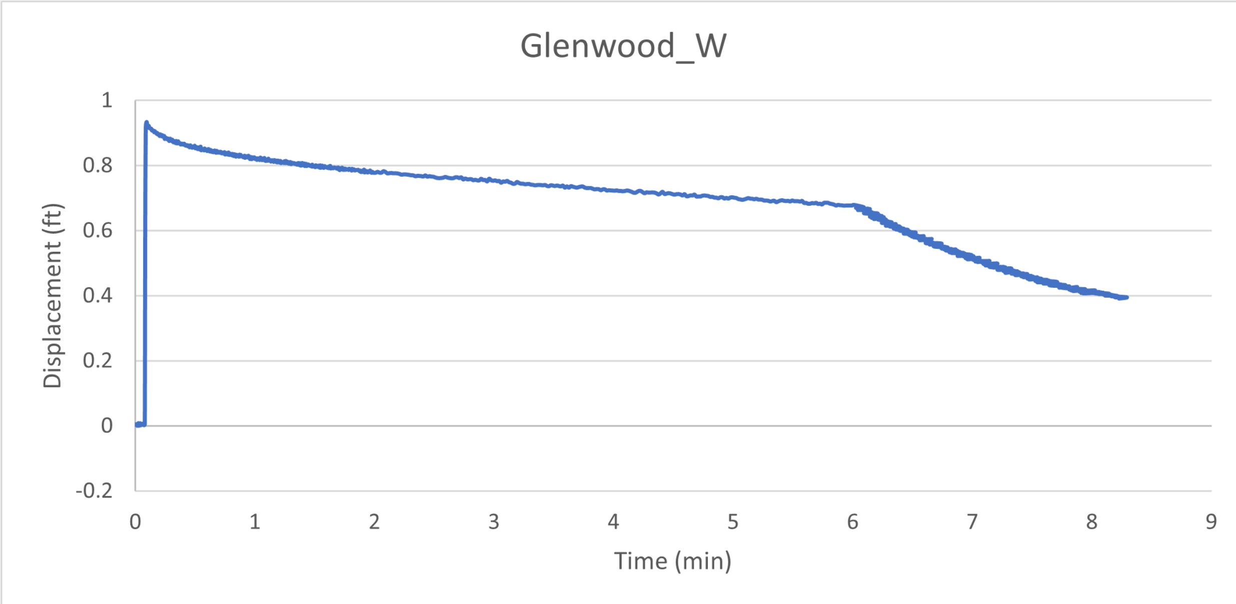
Saturated Thickness: 11. ft
Anisotropy Ratio (Kz/Kr): 1.

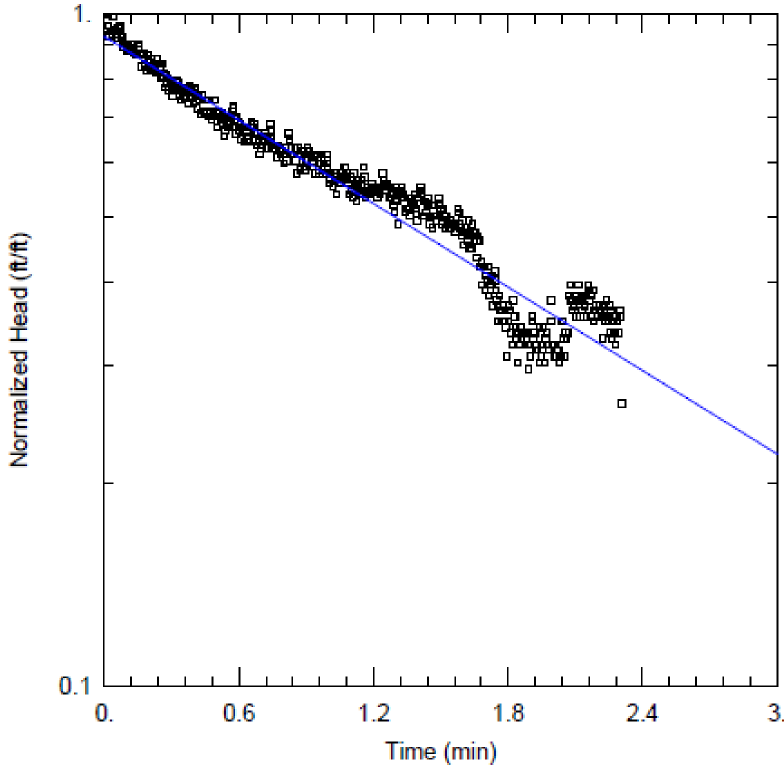
WELL DATA (Glenwood_N)

Initial Displacement: 0.9334 ft
Total Well Penetration Depth: 29.28 ft
Casing Radius: 0.0859 ft
Static Water Column Height: 30.72 ft
Screen Length: 10. ft
Well Radius: 0.09895 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.0003941 ft/min
y0 = 3.022 ft


Glenwood_W
Displacement (ft)
1
0.8
0.6
0.4
0.2
0
-0.2
0
1
2
3
4
5
6
7
8
9
Time (min)



WELL TEST ANALYSIS

PROJECT INFORMATION

Company: IGWS
Test Well: Lake Station_W

AQUIFER DATA

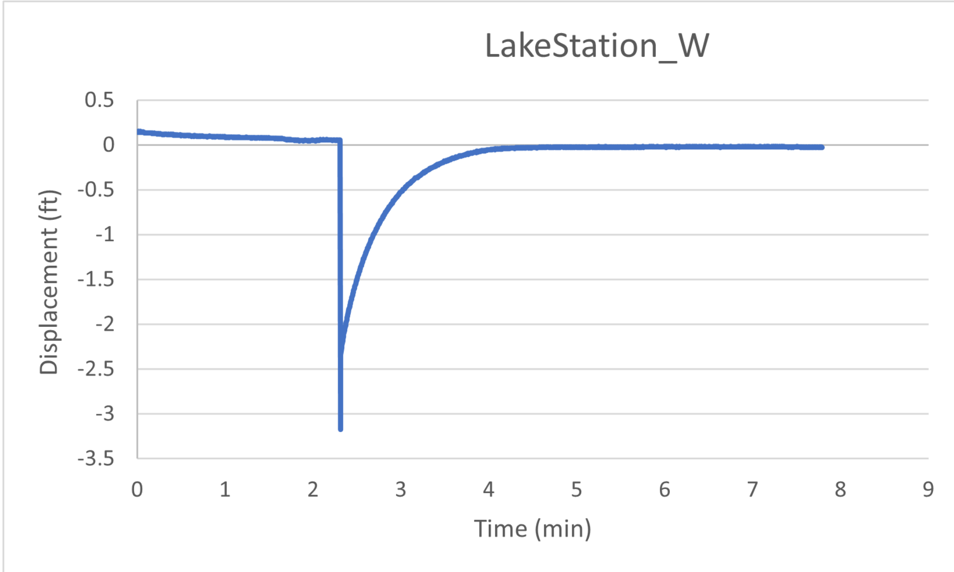
Saturated Thickness: 22.5 ft
Anisotropy Ratio (Kz/Kr): 1.

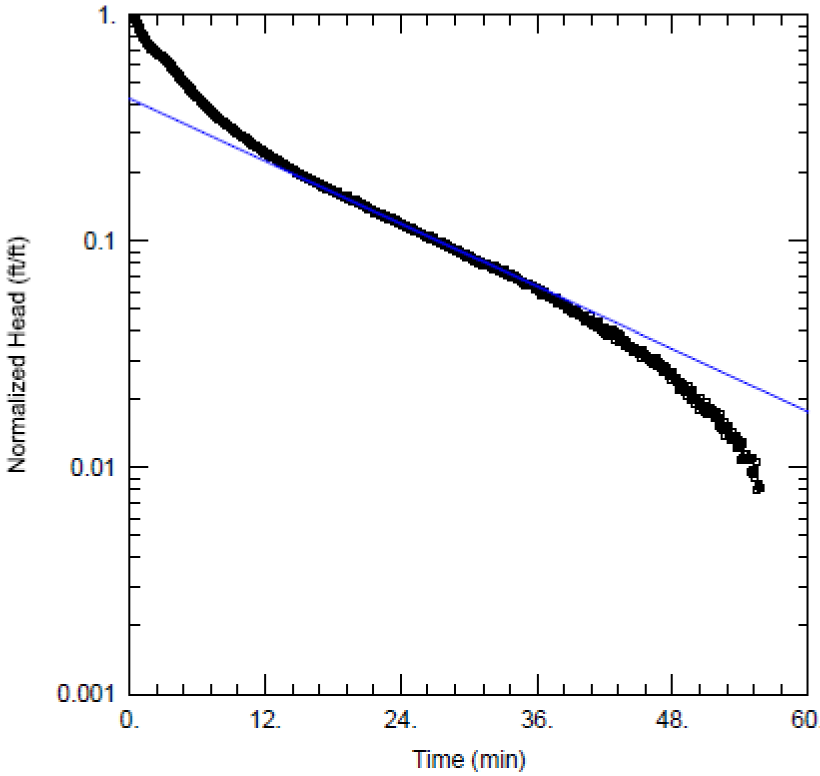
WELL DATA (Lake Station_N)

Initial Displacement: 0.152 ft
Total Well Penetration Depth: 6. ft
Casing Radius: 0.083 ft
Static Water Column Height: 11. ft
Screen Length: 5. ft
Well Radius: 0.0875 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.0008956 ft/min
y0 = 0.1405 ft


LakeStation_W
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
Displacement (ft)
0
1
2
3
4
5
6
7
8
9
Time (min)



WELL TEST ANALYSIS

PROJECT INFORMATION

Company: IGWS
Test Well: Bloomington_N

AQUIFER DATA

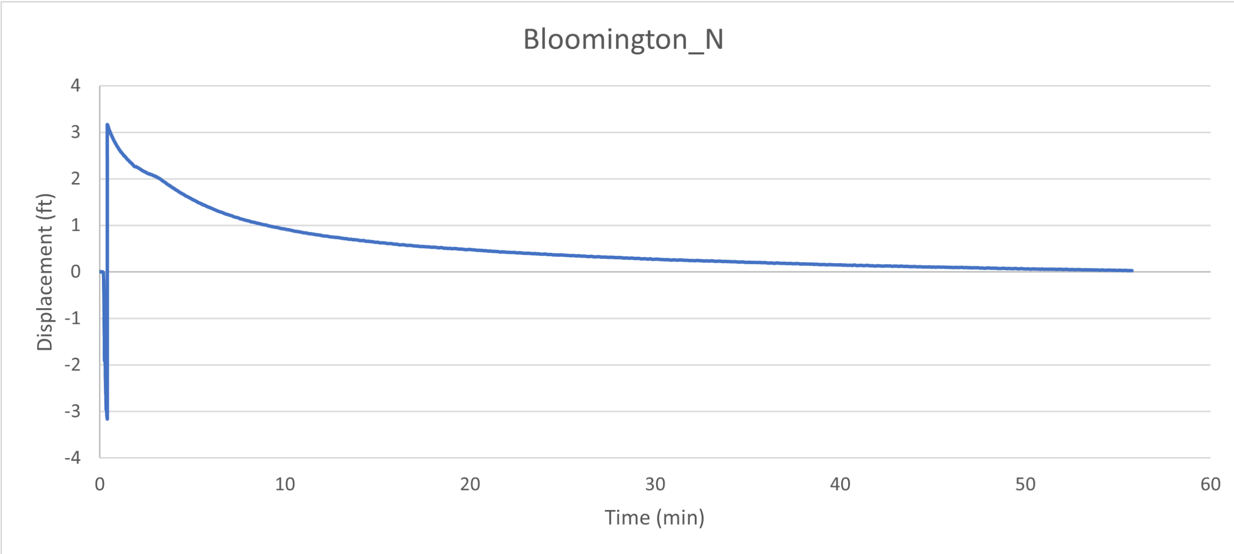
Saturated Thickness: 1. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (Bloomington_N)

Initial Displacement: 3.167 ft
Static Water Column Height: 0.48 ft
Total Well Penetration Depth: 5.1 ft
Screen Length: 5.1 ft
Casing Radius: 0.1167 ft
Well Radius: 0.0833 ft

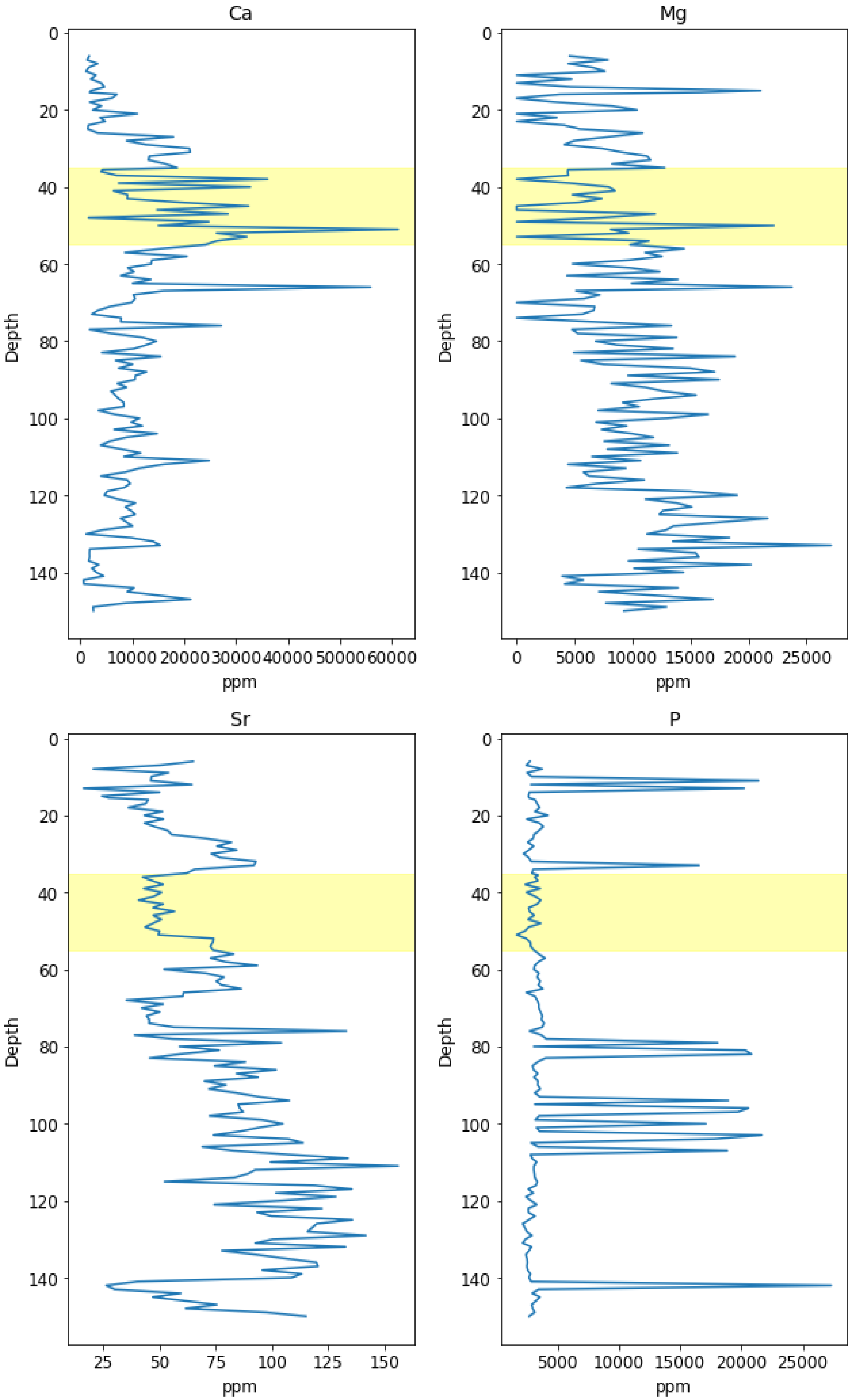
SOLUTION

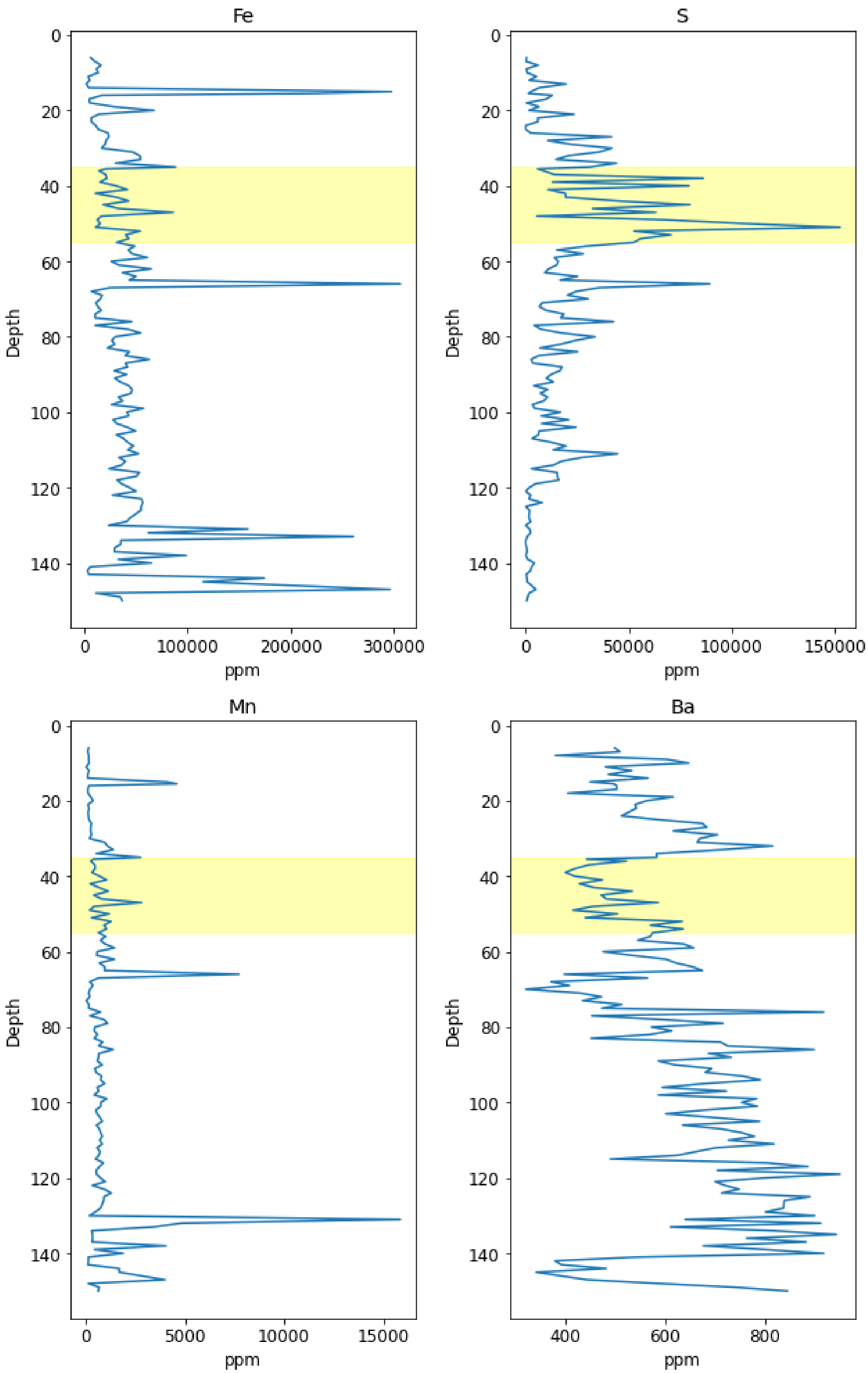
Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.0009457 ft/min
y0 = 1.355 ft

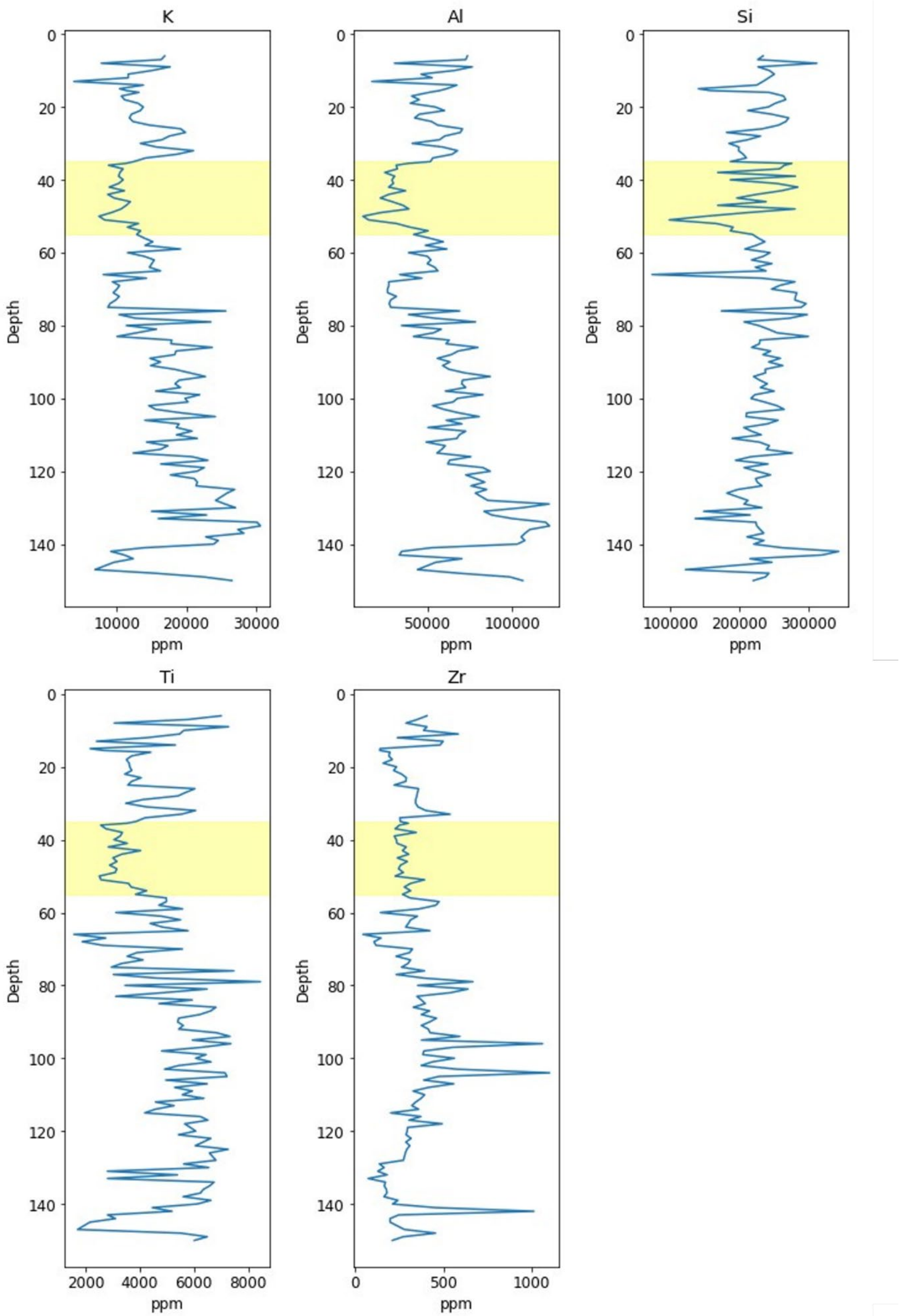


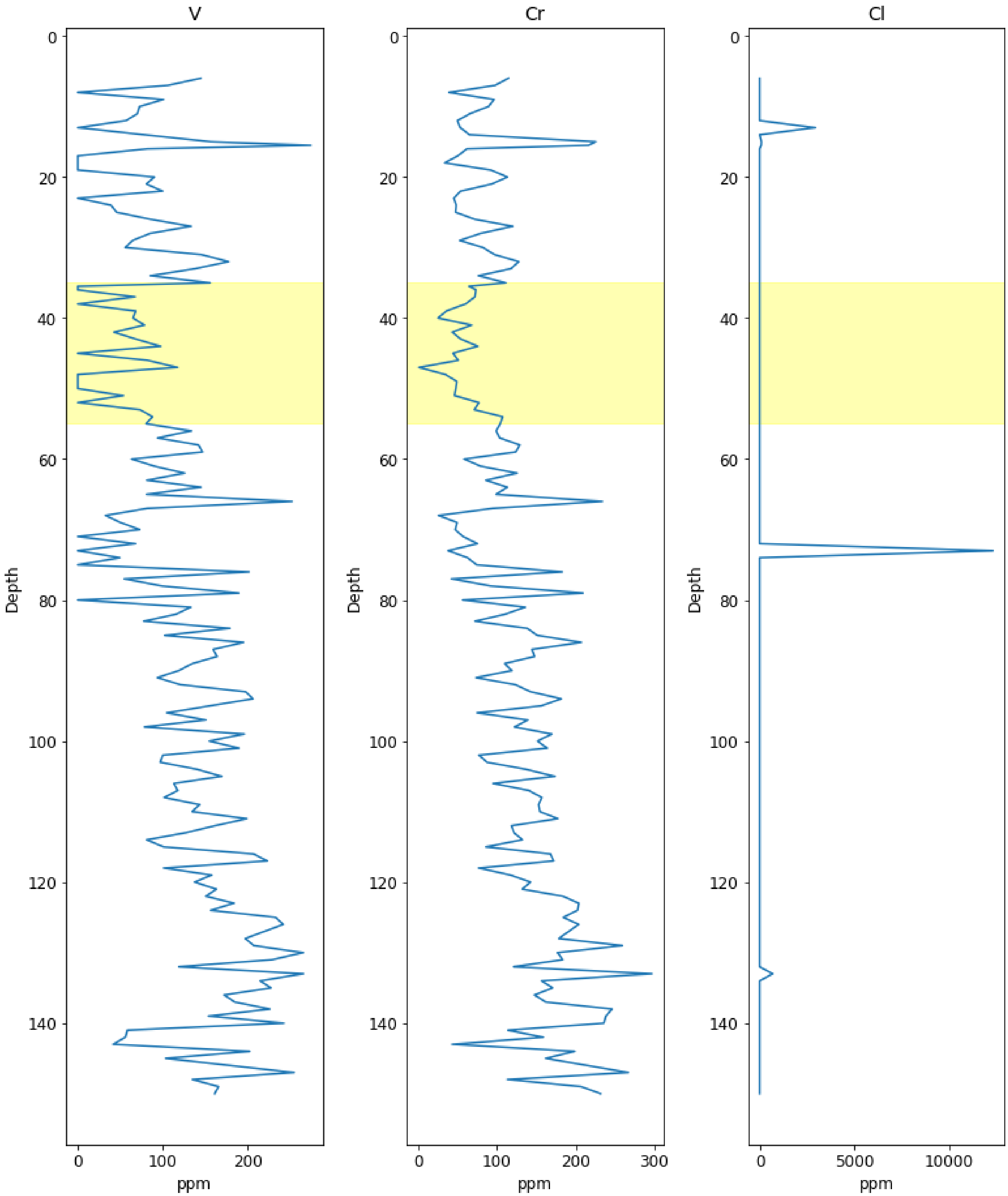
Bloomington_N
4
3
2
1
0
-1
-2
-3
-4
Displacement (ft)
0
10
20
30
40
50
60
Time (min)

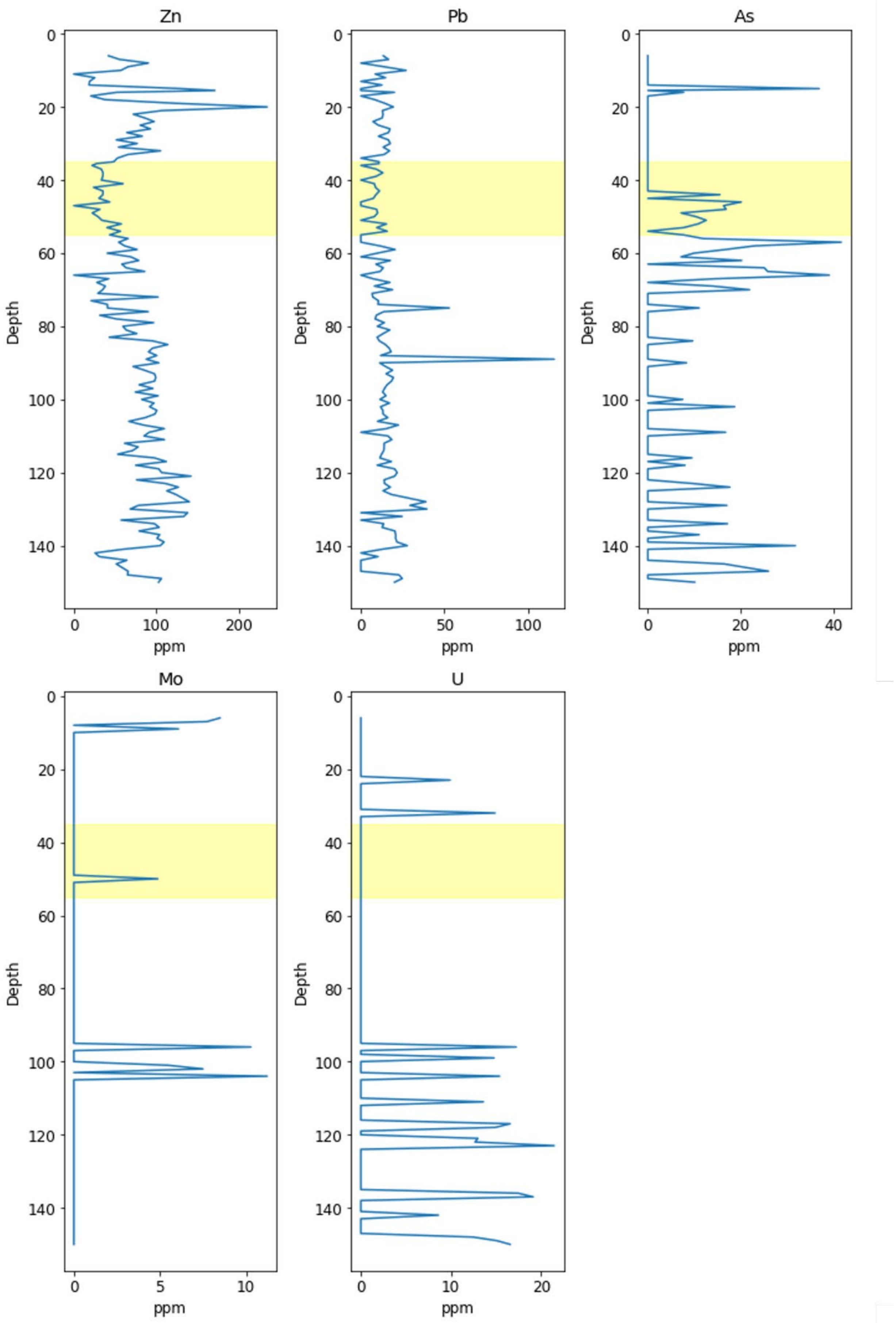
Appendix F PXRF for Jasper_S (IGWS Well 192103) (Yellow bands show location of screened interval)




Fe
S
Mn
Ba
Depth
ppm
0
20
40
60
80
100
120
140
100000
200000
300000
50000
150000
5000
10000
15000
400
600
800


K
Al
Si
Ti
Zr
Depth
ppm


V
Cr
Cl
Depth
ppm
0
20
40
60
80
100
120
140
100
200
300
5000
10000


Zn
Pb
As
Mo
U
Depth
ppm
0
20
40
60
80
100
120
140
0
100
200
0
50
100
0
20
40
0
5
10
0
10
20