Final Technical Report

Project Title:

Indiana Geological and Water Survey's Expansion and Improvement to the NGWMN

Agency Name:

Indiana Geological and Water Survey

Award Number:

G22AC00135

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Objective(s):

2B. Support persistent data service

5. Well drilling

6. Purchase equipment for continuous water-level data collection

Acknowledgements

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Overview

The Indiana Geological and Water Survey (IGWS) became a new data provider to the USGS National Ground-Water Monitoring Network (NGWMN) under the FY2016 NGWMN program announcement with agreement dates from 9/1/2016 to 8/31/2018 (Grant/Cooperative Agreement No. G16AC00360). The work completed under this agreement is the third award under the NGWMN program for an existing data provider. This report completes the work required under the FY2022 NGWMN Grant/Cooperative Agreement No. G22AC00135, (with agreement dates 9/1/2022 to 8/31/2024.)

Former awards compiled and organized data into NGWMN formats from an existing micrometeorological and groundwater monitoring network, the Indiana Water Balance Network (IWBN). The IWBN website is https://legacy.igws.indiana.edu/iwbn-dashboard/#/. New monitoring wells often complement micrometeorological networks or may be stand-alone groundwater monitoring locations. Data contributed from the IWBN to the NGWMN can be found at https://cida.usgs.gov/ngwmn/.

The goal of the IWBN and its network of monitoring wells is to gather representative monitoring of environmental activities that measure the inflow, flux, and outflow of water within various systems (atmosphere, soil, and aquifer). Developing flow paths that define the movement through the hydrosphere within a variety of physiographic settings helps to define the variations seen within these systems. By including the collection of groundwater and aquifer data at multiple depths, the dynamics of the groundwater system can be assessed. This can be a mutually beneficial effort, as it can also support the desired data collection efforts for the NGWMN. As we evaluate the groundwater in the state, we are poised to find wells that can support a national- and regional-scale data set for the assessment of important aquifers in Indiana. Our shared goals are to assess the baseline conditions and long-term trends in water levels in these aquifers and to continue to drive data collection. To that end, our monitoring network is expanding and has been redesigned to assess the best aquifers. With the wells drilled during this round, our network has grown to 15 wells that represent USGS Principal Aquifers of alluvial and glacial origin and the Mississippian Aquifer, along with secondary hydrogeologic regions of other aquifers.

NGWMN program Objective 2 (support persistent data service from an existing data provider), utilizing Part B (occasional work needed to upgrade services), was completed during this two-year project. In an effort to consolidate data from multiple programs-including the water balance monitoring network of atmospheric, soil, surface water, water table, and confined aquifer systems; the lithological description database; the sensor tracking systems; and the location and site characterization database; and all metadata—we developed a centralized data storage system to store and track these data sets along with both real-time and non-continuous monitoring data sets.

NGWMN program Objective 5 (well drilling) was completed during the project period. Installing additional groundwater monitoring wells improves the spatial distribution of NGWMN sites representing sand and gravel aquifers of the glaciated region in Indiana while addressing some water resource questions locally. One new monitoring well was drilled in southwest-central Indiana as a trend/backbone monitoring location for the NGWMN. The other monitoring well was installed in the vicinity of a buried bedrock valley of the Eel River at the border of Owen and Greene Counties (GCW) called Worthington_N (IGWS Well 602301).

NGWMN program Objective 6 (equipment purchase) was partially executed during the two-year period. Three pressure transducers were replaced at FortWayne_N1 (021602), FortWayne_N2 (021604), and Muncie_N (189103). Unfortunately, the increased cost of these non-vented pressure transducers, along with underestimated telemetry costs, made it impossible to add telemetry to the suggested wells to gain real-time data.

Support to the NGWMN as a data provider

Supporting persistent data services and timely uploads have been completed per Objective 2, including adjusting the water levels, site information, and lithology in the well registry. Accurate GPS points and elevations for each well have been completed using Trimble software, and these results have been updated in the site information. Quality assurance and quality control procedures are performed for NGWMN wells at least triennially and are updated in the water level files that are served to the web service. The Worthington well data requirements have been added to the registry per Objective 5.

Additional work done to support the NGWMN as a data provider includes migration of data from the REST API .NET and PHP programs, where data is held in comma-separated value (CSV) files and then served to the NGWMN data portal. This data was moved to a new and uniform spatial database engine (SDE). This new database houses all the NGWMN-required data and feeds it to the NGWMN data portal.

New API and network modifications

The data structure that supports the IGWS-maintained groundwater monitoring network has been transformed to a unified geodatabase (SDE) to streamline workflows and increase efficiency to deliver data to NGWMN. The initial stages for planning the geodatabase and creating data tables included the hiring of two student summer interns through the Paul Edwin Potter Scholarship Fund. The interns attended the initial planning meetings, created a database dictionary, and started ingesting data into the tables to populate the geodatabase.

While the data was being compiled, all data was updated to ensure accuracy in locations, depths, lithology, and other minimum data elements. The interns collected accurate locations using the

Trimble DA2 GPS Catalyst in conjunction with ArcGIS Field Maps. Then, with locational accuracy, elevation data was compiled using Indiana's 2016–2020 hydro-flattened bare-earth Digital Elevation Model (DEM) from IndianaMap. This data is derived from statewide QL2 Light Detection and Ranging (LiDAR) airplane imaging. This data follows USGS 3DEP standards.

The data tables were created not only to help serve real-time and discrete data to NGWMN, but also to correlate all data sets created through the IWBN. Methods presented in GWML2 were utilized to ensure that data can flow better and be shared across multiple APIs and data agencies needing data from our network.

The geodatabase was created by using ArcGIS Pro's Create Enterprise Geodatabase geoprocessing tool. Spatial feature classes (point and polygon) in ArcGIS Pro were used for relevant spatial data such as well locations. Non-spatial data tables were created using in-house schema in SQL Server Management Studio (SSMS) and ArcGIS Pro, and then these tables were registered in the geodatabase. To get data into the NGWMN-required schema, additional view tables were created in SSMS or in ArcGIS Pro and then registered within the geodatabase. The geodatabase was published in ArcGIS Enterprise and then authorized to the Web Feature Service (WFS) for reporting to NGWMN.

Water level data for the NGWMN are being updated from meters to feet to comply with the NGWMN standards in the new SDE. Values are being quality-checked for significant figures and standards to be served to the NGWMN portal.

Lithological data was updated to include gamma interpretations along with the existing core description from the borehole. The LithologyID updated during this rebuild is now associated with the pattern numbers set forth in the FGDC Digital Cartographic Standard for Geologic Map Symbolization associated with the lithological patterns of 37.1 – Sedimentary-rock lithologic patterns. This allows us to better develop cross sections of the lithology associated with the well for these reports.

The interns also took inventory of monitoring well stick-up heights, casing diameters, and verified screen lengths from well drilling records to ensure that casing and screen data were correct.

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 in field sheets, 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) 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 immediately after manual water-level measurements are taken, during routine site visits. 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

The quality assurance and quality control (QA/QC) protocol establishes the required quality standards and outlines the methods to maintain this quality throughout the project's deliverables and research processes. Following the guidelines of the NGWMN Framework Document (ACWI, 2013), continuous water-level data are calibrated using manual measurements. Water-level data are logged hourly or on minute timescales using non-vented or vented pressure transducers. Non-vented pressure transducers are downloaded in the field manually to a mobile device during site visits. Vented pressure transducer data can be downloaded directly from the datalogger source in the field or remotely using a modem. Manual depth-to-water measurements are taken during each field visit. Non-vented pressure transducer groundwater data are barometrically compensated using site-specific barometric pressure data that are logged at the same time of the submerged pressure transducer. The compensated water-level data, reported as water column depth (i.e., the height above the pressure transducer), are recorded in an Excel worksheet alongside manual measurements that are synchronized to the nearest time stamp. To convert manual depth-to-water readings to groundwater elevations, the well casing stick-up height is subtracted from the depth-to-water measurement, and this value is added to the ground elevation determined by digital elevation modeling (DEM) at the well point. To save work in the future, all the groundwater level data, including elevations and hand measurements, have been converted from meters to feet before adding this data to the new database.

The manual water elevation measurements (y-axis) are plotted against compensated water column measurements (x-axis) on a scatter plot (**fig. 1**). A linear trend line is applied, with a linear coefficient (R^2) greater than 0.85 required to confirm consistency. The equation generated from this trend line is used to calculate groundwater elevation each hour and takes the compensated height above the pressure transducer (x), multiples it by the slope (m) generated from the regression relationship, and then adds or subtracts an elevation (b). If the pressure transducer is replaced or repositioned within the well column, a new regression equation is created to recalibrate the system. A hydrograph is plotted with hourly groundwater elevations and periodic manual groundwater elevation measurements to verify that these measurements correspond well with the continuous record by doing a visual QA/QC check.

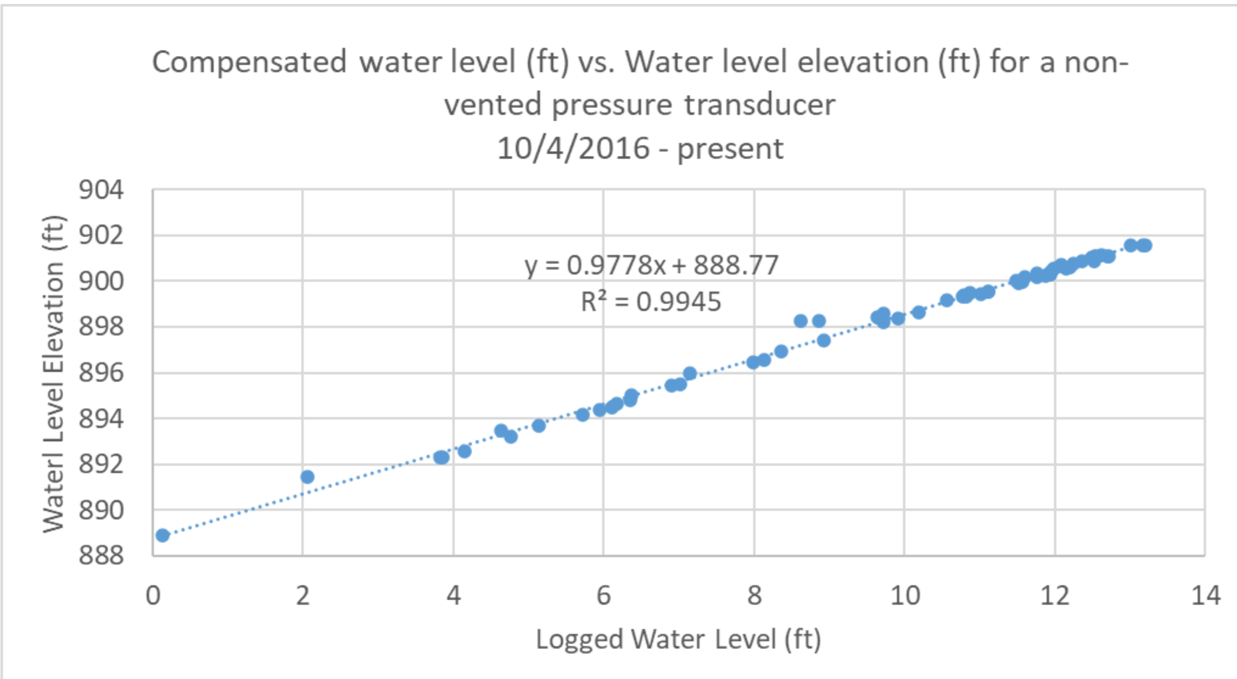


Figure 1. Example of the linear regression equation generated from the compensated pressure transducer water column reading and the manual groundwater elevation measurements at the same time. This example is from Brownsburg_N1 (531601).

A standardized data processing routine was created using spreadsheets to convert data from barometrically compensated non-vented pressure transducers and vented pressure transducers into the NGWMN web service format. The NGWMN network requires date and time to be in ISO8601 format. To achieve this, the Excel concatenate function was used to convert the date and time recorded by the pressure transducer (e.g., 8/22/2024 11:30) into the ISO8601 format (e.g., 2024-08-22T11:30:00-05:00). The value "-5:00" indicates the difference from Coordinated Universal Time (UTC), also known as Greenwich Mean Time. An example of the concatenate formula is as follows:

```
=CONCATENATE(TEXT(A8,"yyyy-mm-ddThh:MM:ss"),$J$2)
```

(cell J2 contains the value -5.0)

Accuracy values for pressure transducer measurements were sourced from the manufacturer's technical specification sheets. These accuracy values are expressed as a percentage of the pressure transducer's full scale (FS). By multiplying the accuracy percentage by the FS, the resulting value is entered into the Observation Accuracy field in the WATERLEVEL file.

Depth-to-water measurements are calculated by subtracting the groundwater elevation from the ground elevation. The rounded depth-to-water values are reported to the NGWMN for each hour. In the future, the process of QA/QC and water-level elevation computation will likely be done automatically using Python scripting to create accurate water-level data that are free from human error.

Description of site selection criteria and process

The IGWS is responsible for monitoring natural and baseline groundwater conditions, focusing on long-term water-level fluctuations throughout Indiana with little to no human impact. The Worthington_N (602301) well was selected for this purpose and aligns with the NGWMN Framework Document (ACWI, 2013). It is classified as a "trend/backbone" monitoring well, aimed at observing baseline conditions for Principal Aquifers of alluvial and glacial origins.

When selecting groundwater monitoring wells for these purposes, we assess the spatial distribution of monitoring wells across each Principal Aquifer in Indiana. We identify areas that fall below the minimum number of wells required for a Principal Aquifer, as outlined by the NGWMN framework document, and also consider regional aquifer systems and needs. Additionally, we examine variable depths within the aquifer to gain a comprehensive understanding of the entire system. **Table 1** presents the current number of wells in the NGWMN from the IGWS, including the new Worthington_N (602301) monitoring well.

Table 1 List of NGWMN wells operated by the IGWS.

Site name	Well ID	Latitude (WGS84)	Longitude (WGS84)	Altitude (ft)	Well depth (ft)	Principal aquifer
Atlanta_S	291913	40.20952	-86.02689	857.1	113.9	Other aquifers
Bloomington_N	531712	39.19399	-86.51311	759	13.4	Mississippian aquifers
Brownsburg_N1	531601	39.89448	-86.37302	912.4	39.3	Other aquifers
FortWayne_N1	021602	41.24759	-85.11812	874.8	100.8	Aquifers of alluvial and glacial origin
FortWayne_N2	021604	41.24772	-85.13912	840.1	79	Aquifers of alluvial and glacial origin
Frankfort_S	122201	40.22712	-86.43012	929.7	365.5	Other aquifers
Glenwood_N	212202	39.63908	-85.29161	1098	60	Other aquifers
Indianapolis_N	491611	39.81836	-86.20442	705.5	6.2	Other aquifers
Jasper_S	192103	38.30611	-86.86852	585.5	55	Other aquifers
LakeStation_W	459701	41.58454	-87.27534	589.8	14.5	Other aquifers
Lebanon_N	062102	40.12625	-86.41975	926.2	213	Other aquifers
Martinsville_N	552101	39.49888	-86.42708	609.4	70	Aquifers of alluvial and glacial origin
Muncie_N	189103	40.22216	-85.42320	938.1	33.1	Other aquifers
Nappanee_NE	201902	41.45389	-85.98386	871.5	157.6	Aquifers of alluvial and glacial origin
NewCastle_NE	330405	40.05339	-85.31495	1008.6	9.6	Other aquifers
Rushville_S	701201	39.57998	-85.46494	944.5	12.3	Aquifers of alluvial and glacial origin
Worthington_N*	602301	39.16823	-87.00589	528	41.4	Aquifers of alluvial and glacial origin

*New well

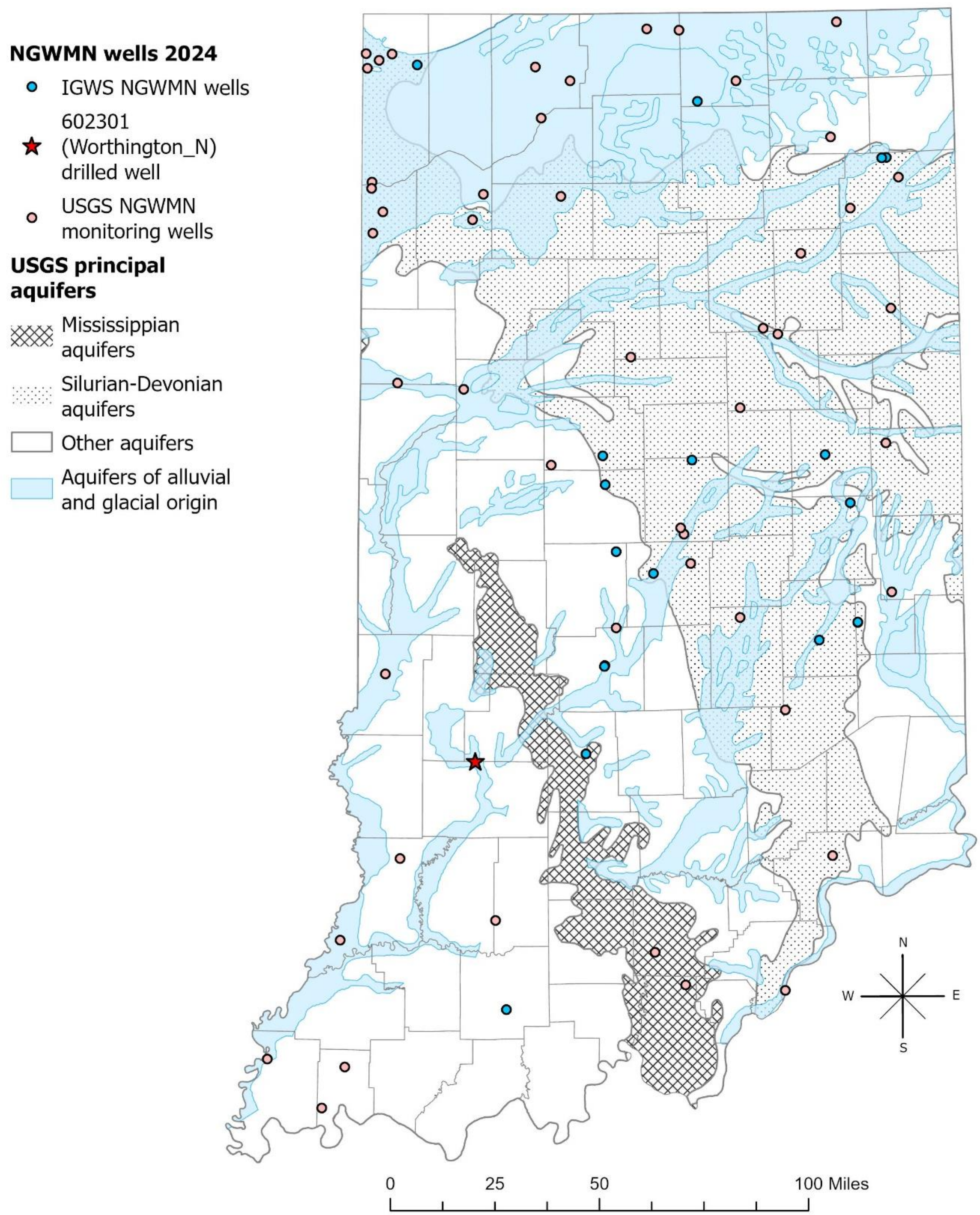


Figure 2. Map of NGWMN sites in Indiana with the red star showing the location of the new Worthington_N (602301) well. IGWS-operated wells are symbolized with a blue dot, and other monitoring wells on the NGWMN are symbolized with an orange dot.

The location for the Worthington_N well (**fig. 3**) was selected after securing landowner permissions, contacting utilities, and conducing passive seismic surveys. Finding an amenable landowner or business owner proved to be the most difficult part. Many landowners and businesses turned us down due to pervasive distrust in government in this area of the state. Fortunately, Citizens Energy Group, Johnstown Station in Worthington (3493 W. County Rd. 990 N) accepted our partnership, and we established an access, use, and indemnity agreement with them (**Appendix A)**. This location was ideal due to its proximity to the Eel River and its outwash and alluvial deposits and the fact that it is above the flood zone. The well site is 3.44 miles upgradient from the Bunge significant water withdrawal facility and 6.9 miles downgradient from the Town of Jasonville significant water withdrawal facility well field. Passive seismic surveys using a TROMINO® were completed to assess depth to bedrock with the goal of finding the thickest area of unconsolidated deposits corresponding to the thalweg of the glacial outwash aquifer (**figs. 4 and 5**). Unfortunately, we were unable to install the well in the thalweg with the thickest overlying unconsolidated units due to the lack of landowner participation in that area. However, we were still able to install a monitoring well in the outwash channel of the Eel River as planned.

The TROMINO® uses the horizontal-to-vertical spectral ratio (HSVR) method to determine peak frequency, which is related to sediment thickness through analysis of shear wave velocity. GRILLA software is used to analyze these peak frequency readings and provides an output of the summary of the criteria that indicates a reliable H/V curve and peak results. Moisture content, surface sediment density, depth to bedrock, and the proportion of sand can influence peak frequency readings. It is crucial to use high-quality data to establish a calibration curve linking sediment thickness to peak frequency. This curve is created using control data from locations where depth to bedrock (sediment thickness) is known and has passed the H/V curve and peak tests in similar geologic settings. A power function with a regression coefficient of determination (R^2) greater than .85 is considered valid and can be used to estimate depth to bedrock at various points.

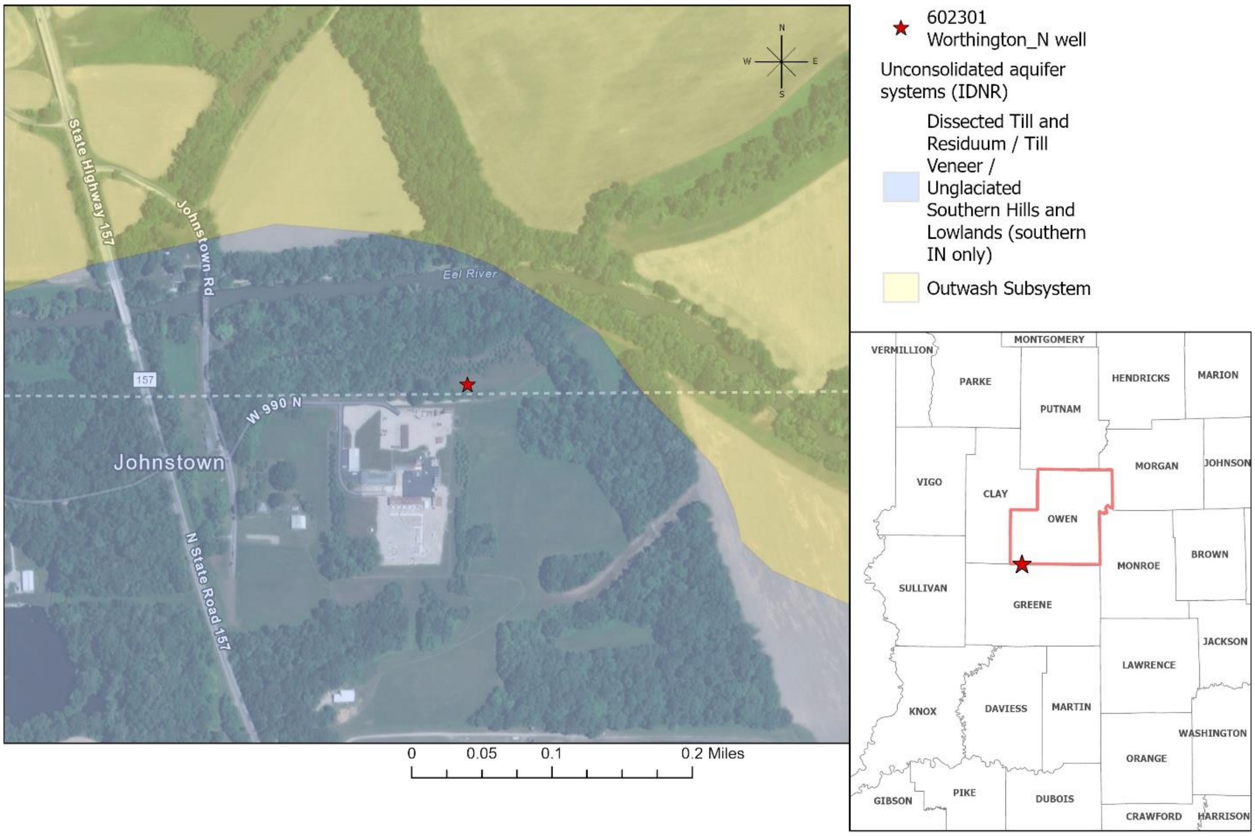


Figure 2. Map showing the new Worthington_N (602301) well location on the border of Owen and Greene Counties in Indiana. The well location was chosen due to its proximity to the Eel River. During the drilling investigation, the outwash subsystem was found instead of the dissected till and residuum that was mapped here.

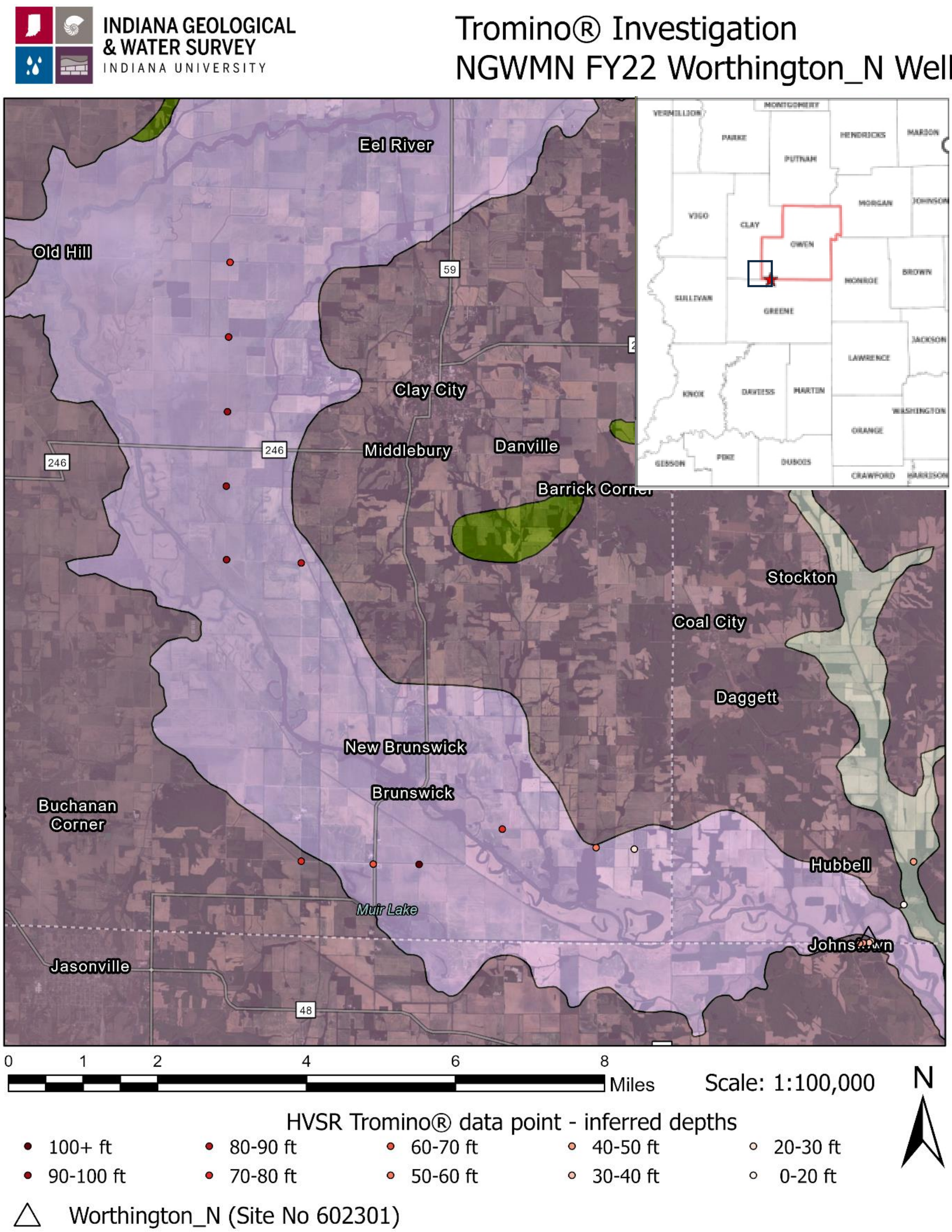


Figure 4. Map of TROMINO® investigation sites to understand the area of the buried bedrock valley. Colors grade from light red hue denoting shallow bedrock contact to deep red indicating thicker unconsolidated deposits.

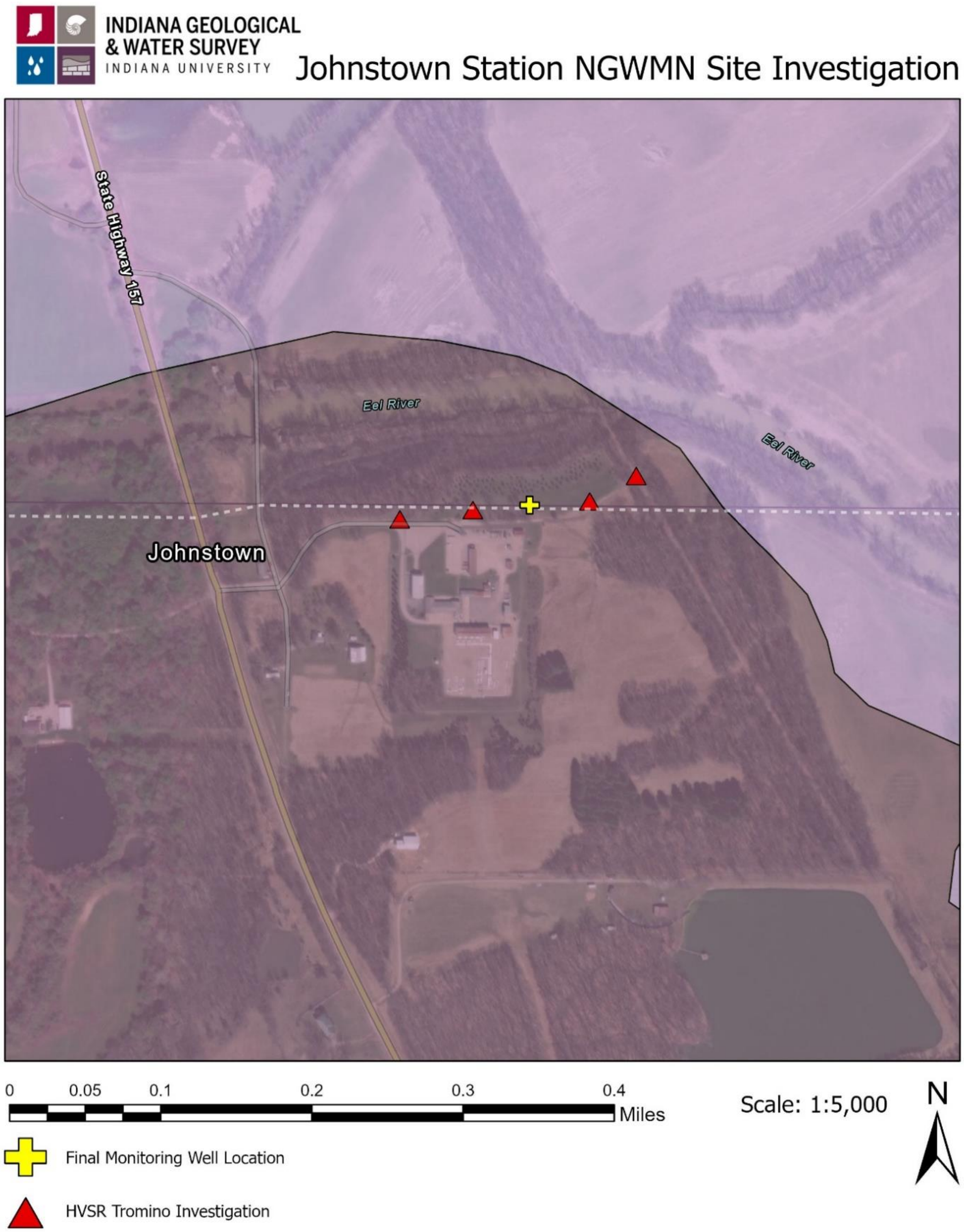


Figure 5. Map of TROMINO® points collected during the Worthington_N well placement investigation.

Placing the Worthington_N well on the border of Owen and Greene Counties was important due to a lack of monitoring wells representing sand and gravel aquifers (glaciated areas) in south-central Indiana. The Principal Aquifer Well Density Tipsheet on Well Selection Criteria for Water Levels states that the recommended number of water-level network wells for sand and gravel (glaciated regions) in Indiana is between 10 and 40 wells. While 26 wells in Indiana represent this Principal Aquifer in Indiana, none are in south-central Indiana. In Greene, Clay, and Owen Counties (1,292 square miles), the primary water source is groundwater, indicating an immediate need for a trend-monitoring well. Randy Maier from the Indiana Department of Natural Resources (personal communication, December 2021) requested that a monitoring well serve these regions.

Drilling, descriptions, and well installation methods

Drilling

Drilling was 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. Core was sampled 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. The ISGS drilled 130 ft into the bedrock for the Worthington_N well. It was decided to drill past the 50 ft of unconsolidated deposits and into the bedrock because if neither alluvial/outwash deposits nor the talweg of the unconsolidated could be monitored, any adjacent bedrock aquifer would be a good proxy for monitoring groundwater levels. Upon further information, it was determined that the alluvial system was present at this site, and the drillers backfilled the hole to seal the bedrock portion.

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 Eyles et al. (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 of the unconsolidated units were recorded using a Microsoft Access database form referred to informally as Core-nucopia.

Bedrock cores were described in detail at the IGWS Materials 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 (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 are pivotal 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 from the Federal Geographic Data Committee (FGDC) to denote rock units. The descriptions also include details for unconsolidated materials. **Appendix C** shows the comprehensive lithology description for Worthington_N (602301).

Particle size analysis (PSA)

Core sections from the Worthington borehole 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.

Portable X-ray fluorescence (PXRF)

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 bedrock portion of the Worthington core.

Well construction

After the completion of drilling and coring at the Worthington borehole, a well was installed to the appropriate depth below the surface to target the alluvial aquifer in the unconsolidated deposits. Well installation was completed on April 27, 2023. A 4-inch reamed hole was filled with a 2-inch-diameter PVC well with 0.010-inch slots for the screen. The screening interval was set from 28 to 38 ft with a well bottom of 39 ft from the ground surface. A total of 7¾ bags of sand were used as the filter pack material with a 2-ft bentonite seal. The rest of the borehole was backfilled with grout and collapsed material to a total depth of 130 ft. The well base contains a 2-ft-by-2-ft base with a well stick-up height of 2.4 ft and is cased around the PVC pipe to prevent surficial contamination. A water-proof cap was placed over the well casing. A black reference mark (i.e., crow's foot) was drawn at the top of the PVC casing 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 in **Appendix B**.

Site latitude, longitude, and elevation (GPS positions)

The location of Worthington_N was collected using the Trimble DA2 GPS Catalyst in conjunction with ArcGIS Field Maps. Using an RTK fix, we mapped this data point at sub-meter horizontal accuracy (0.671 m) for this location collected with the Trimble.

Elevation data was compiled using Indiana's 2016–2020 hydro-flattened bare-earth DEM from IndianaMap. This data is derived from statewide QL2 LiDAR Point Cloud data that follows the USGS 3DEP standards. It was determined that the elevation for Worthington_N is 528 ft.

Drilling investigation results

The Worthington_N borehole was drilled to 130 ft below grade from the unconsolidated glacial material into bedrock. Most of the core was recovered, and any gaps in the record were recorded through a gamma log. The target alluvial aquifer was not recovered in the extracted core except for a small clast of sand found in the shoe, and later, the gamma-interpreted lithologic log showed a decrease in counts around the area where deposits were found.

The unconsolidated deposits were primarily composed of till for the first 26 ft and transition to sand and gravel to about 38 ft below grade. This sand-and-gravel unit was thought to be alluvial and outwash deposits from the paleo channel of the Eel River nearby, which was the target aquifer for this investigation. The unconsolidated aquifer systems map (IDNR) shows dissected till and residuum as the primary aquifer at the borehole location, but drilling showed that the outwash deposits from the Eel River were the primary aquifer at that location. The maps should be redrawn to expand the outwash aquifer to this location. Below this sand unit rests another deposit of till until the till transitions to bedrock at around 50 ft below the surface. The bedrock was primarily composed of the Mansfield Formation of the Racoon Creek Group with silt, shale, coal, and sandstone. Most of the bedrock was composed of shale and siltstone, and another potential aquifer zone would be the sandstone that had vertical fractures from about 82 to 92 ft below surface; however, bedrock was not the target aquifer for the NGWMN well.

PSA conducted on the unconsolidated portion of the extracted core showed a mix of sediment sizes, which coincides with the description of the mixed till including sand, silt, and clay-sized particles (**Appendix B**). The screened portion of the well, which includes the alluvial outwash aquifer, was not included in the PSA analysis since there was no recovery. PXRF analysis was completed on the bedrock portion of the of the core to examine the elemental properties of the Pennsylvanian bedrock (**Appendix D**). The Pennsylvanian bedrock is characterized by interbedded sandstones and shales with high silicon and iron content. Thin calcium-rich limestone lenses and coal beds are also present. Trace elements important to groundwater studies (arsenic, cadmium, lead, and mercury) were present in expected concentrations. Arsenic concentration averaged 7 ppm in the bedrock; however, it was elevated in intervals that correlate to coal beds or iron-rich beds (75, 79, and 115 ft). Cadmium concentration was slightly elevated and averaged 2.3 ppm, which is likely a result of the organic-rich shales in the core. Lead concentration averaged 8.9 ppm, which is within the expected range. Mercury was detected in two beds which were coal beds and organic-rich sandstone (80 and 112 ft).

A Rugged BaroTROLL barometer (SN1008458) and a Rugged Troll pressure transducer (SN1009551) were added to the well on May 4, 2023, but due to an incorrect reference level, monitoring was re-initiated on July 7, 2023, with the corrected reference level. Three site visits were completed to construct the groundwater equation and for QA/QC using the hand-measurements and associated downloads. Because this well is screened in the alluvial deposits, we expect that the groundwater levels should be influenced by the nearby Eel River; however, no stream gage is present nearby to correlate. The hydrograph for Worthington_N (**fig. 6**) shows typical seasonal variations in groundwater levels. During the dry season, from late summer through winter, the alluvial aquifer has lower groundwater levels. Late winter and spring bring the wet season and higher streamflow, coinciding with periods of increased groundwater recharge in the Worthington_N well. The alluvial aquifer is influenced by surficial conditions. Further downstream within this outwash deposit is a significant water withdrawal facility which may also influence this monitoring well. A stream gage and associated weather station would be a good fit for this area to investigate the sources of variation in water levels.

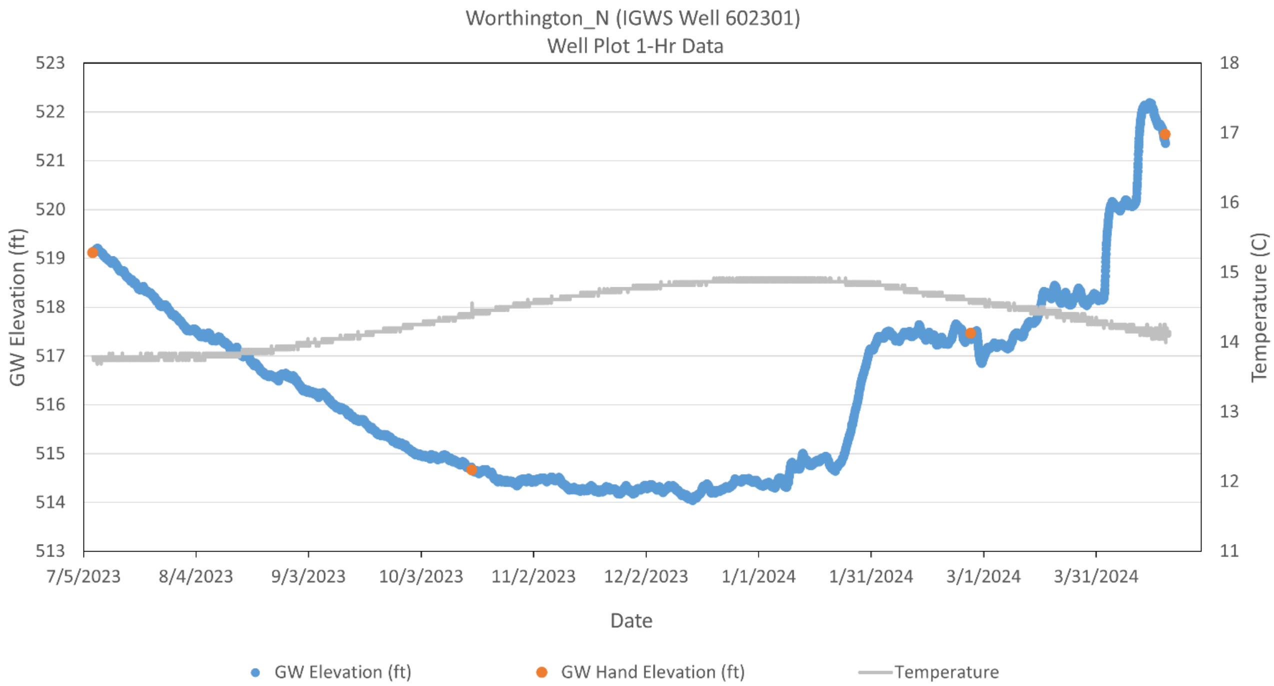


Figure 6. Hydrograph showing fluctuations in groundwater elevation and temperature each hour (blue and gray lines, respectively) at the Worthington_N well. Hand measurements for QA/QC purposes are symbolized with orange dots.

Equipment purchased and installed

FortWayne_N1 (021602), FortWayne_N2 (021604), and Muncie_N (189103) were scheduled for pressure transducer replacements because of low battery readings (below 30%). Three Rugged BaroTROLL and three Rugged TROLL pressure transducers were purchased and installed at these wells (**Table 2**).

Three wells were scheduled to receive telemetry to make them into real-time groundwater monitoring wells: Martinsville_N (552101), Indianapolis_N (491611), and NewCastle_NE (330405). It was determined that the costs to install telemetry would be much higher than the proposed $300 per station. The least expensive alternative will be to install a VuLink Datalogger and telemetry unit. Our recent quote for this tool is $1,010 plus shipping per unit. The remaining funds left for this objective were not enough to fully cover the costs of telemetry; an additional $958 was needed.

Table 2. Equipment purchased through grant No. G22AC00135.

Site No.	Depth (ft)	Principal aquifer	Unit name	Serial number
Fort Wayne_N1 (021602)	100.1	Alluvial and glacial origin	Rugged TROLL	1009206
			Rugged BaroTROLL	1005258
Fort Wayne_N2 (021604)	72.4	Alluvial and glacial origin	Rugged TROLL	1007235
			Rugged BaroTROLL	1010890
Muncie_N (189103)	33.1	Other aquifers	Rugged TROLL	1009423
			Rugged BaroTROLL	1005318

Considerations for future work and planned changes

A stream gage and weather station would be a good addition to the Greene/Owen County area to help determine the source of groundwater fluctuations. The USGS has offered the temporary installation of a colloidal borescope flow measurement system for this well. Additional partnerships like this one will be encouraged to ensure we are gathering information that help local communities gather data useful for making management decisions.

Further work on the new SDE is needed to increase the accuracy of the data, such as creating automated tables that will compute water levels based on new data entering the system from field measurements, new equipment installs, and any other changes made to the wells.

References

Advisory Committee on Water Information (ACWI), 2013, A national framework for ground-water monitoring in the United States: U.S. National Ground-Water Monitoring Network Report, 170 p.

Eyles, N., Eyles, C. H., and Miall, A. D., 1983, Lithofacies types and vertical profile models—an alternative approach to the description and environmental interpretation of glacial diamict and diamictite sequences: Sedimentology, 30, 393–410.

Thompson, T. A., and Keith, B. D., 2015, Corebook of carbonate and associated rocks in Indiana: Indiana Geological Survey Occasional Paper 74, 149 p., 7 figs.

Zambito, J. J., Haas, L. D., and Parsen, M. J., 2022, A portable X-ray fluorescence (pXRF) elemental dataset collected from Cambrian-age sandstone aquifer material, Wisconsin, U.S.A.: Data in Brief, v. 43, ISSN 2352-3409. doi: 10.1016/j.dib.2022.108411

Appendix A. Access, use, and indemity agreement

ACCESS, USE AND INDEMNITY AGREEMENT

This Access, Use and Indemnity Agreement (**"License"**) is made and entered into this 24 day of April, 2023 (the **"Effective Date"**) by and between CITIZENS GAS (the **"Owner"**); and THE TRUSTEES OF INDIANA UNIVERSITY, A BODY POLITIC AND CORPORATE OF THE STATE OF INDIANA, THROUGH THE GEOLOGICAL & WATER SURVEY USES CERTAIN MATERIALS, EQUIPMENT, AND INSTRUMENTS THAT COLLECT GROUNDWATER DATA (the **"Licensee"**).

RECITALS

A. Owner is the owner of that certain real estate located at 3493 W. 990 N., Worthington, Indiana 47471 (the "**Owner's Parcel**").

B. Licensee desires permission to enter that portion of the Owner's Parcel, as depicted in Exhibit A, attached hereto and incorporated by reference herein (the **"Property"**), to access the Owner's Parcel for the purpose of installing and maintaining Monitoring Wells on the Owner's Parcel.

C. Owner has agreed to permit the Licensee to enter upon the Property and engage in the Licensed Activity (as defined in Section 4) during the Term (as defined in Section 3), subject to the terms and conditions set forth in this License.

NOW, THEREFORE, for and in consideration of the Licensee's compliance with the terms of this License, the sufficiency of which is hereby acknowledged, the Owner and Licensee hereby agree as follows:

AGREEMENT

1. Recitals. The above recitals are true and correct, and are incorporated into this License.

2. Grant of Access to Property. Subject to the conditions set forth in this License, Owner grants to Licensee and its authorized contractors, agents, or employees, the right to enter the Property for the purpose of engaging in the Licensed Activity. Licensee shall provide to owner a work plan (**"Work Plan"**) and notice at least forty-eight (48) hours in advance of its intent to exercise its rights prior to physically access the Property. Licensee may not commence any work until Owner consents in writing to the Work Plan. Owner shall have the right to have a representative of Owner accompany Licensee or its representatives while they are engaged in the Licensed Activity.

3. Term of License. The term of this License (**"Term"**) shall commence on the Effective Date and shall terminate when Licensee removes Monitoring Wells from Owner's Parcel or Owner provides at least ninety (90) days advance written notice of any request to remove the Monitoring Wells from the Owner's Parcel. Prior to the termination of the License, Licensee agrees to enter into any necessary easements or other agreements related to the Licensed Activity as provided by Owner. Any

easements or other agreements shall be executed by Licensee and Owner and recorded by Owner.

4. Scope of Licensed Activity. Licensee shall have the right to enter the Property and install and maintain Monitoring Wells on Owner's Parcel to collect groundwater data from Owner's Parcel, as depicted on Exhibit A, which is attached hereto and incorporated by reference (**"Licensed Activity"**).

5. Performance of Licensed Activity. Licensee shall make a good faith effort to cause the Licensed Activity to be commenced, performed, and completed as expeditiously as possible. In no event shall the Licensed Activity interfere with Owner's ownership of or operations on the Property.

6. Condition of Property.

a. Licensee shall cause all debris, trash, and waste materials generated by or in connection with the Licensed Activity to be removed from the Property before the end of the Term; except that any debris, trash, and waste materials generated by or in connection with the Licensed Activity which will interfere with Owner's operations on the Property shall be immediately removed.

b. Licensee shall take all reasonable precautions to minimize damage to the Property from the Licensed Activity. In the event that Licensee, its employees, or agents shall cause any damage to the Property, then Licensee shall at its own cost and expense, restore the Property to the same condition the Property, as reasonably practicable, was in immediately prior to the commencement of the Licensed Activity.

c. Licensee's obligations in this Section 6 shall survive the termination or expiration of this License.

d. Licensee acknowledges that its entry upon the Property is at its own risk, that Owner has made no representations or warranties concerning the Property whatsoever, and that the Licensee accepts responsibility for any hazards or dangers, apparent or concealed, that may exist upon the Property.

7. Notice. All notices or other communications required or permitted to be given pursuant to this License shall be in writing and shall be considered as properly given or made: (i) upon the date of personal delivery (if notice is delivered by personal delivery); (ii) on the date of delivery, as confirmed by electronic answerback (if notice is delivered by facsimile transmission, or email); (iii) on the day one business day after deposit with a nationally recognized overnight courier service (if notice is given in such manner); or (iv) on the third (3rd) business day following mailing from within the United States by first class United States mail, postage prepaid, certified mail return receipt requested (if notice is given in such manner); and in any case addressed to the parties at the addresses set forth below (or to such other addresses as the parties may specify by due notice to the other):

If to Owner: Citizens Gas

3493 W 990 N

Worthington, Indiana 47471

Attn: Alan Waggoner, Manager of Storage Operations

Telephone: 812-798-0449

E-Mail: awaggoner@citizensenergygroup.com

If to Licensee: Indiana University

107 S. Indiana Avenue, Bryan Hall 211
Bloomington, IN 47405

Attention: **Dwayne Pinkney, Executive VP for Finance & Administration**

Telephone: **812-855-9739**

E-Mail: **vpgc@iu.edu**

8. Additional Terms and Conditions.

a. Insurance Requirements Licensee shall maintain, at Licensee's sole cost and expense, such insurance as will provide protection from claims under Workers' Compensation Acts and other employee benefit acts; from claims for damages because of bodily injury, including death, to employees and all others; from claims for damages to property (including the remediation of pollutants); and from claims for professional errors and omissions; any or all of which may arise out of or result from Licensee's operations under this Contract or product/completed operations related thereto, whether such operations or products/completed operations be by Licensee or by any subcontractor or subconsultant or anyone directly or indirectly employed by either of them.

Licensee, prior to commencement of the Work, on each anniversary date of the execution of the Contract through the periods described below, and at such other times as may be requested by Owner, shall furnish Owner with certificates of insurance, from companies satisfactory to Owner, evidencing coverage of not less than the following limits of liability and listing Owner and, to the extent any aspect of the Work relates to the Johnstown Station, Citizens Gas, as additional insureds—utilizing ISO endorsement CG2010 (11/85), ISO endorsement CG 20 10 10 01 in combination with ISO endorsement CG 20 37 10 01, or the equivalent endorsement(s) which covers ongoing and completed operations as may be approved in advance by Owner—on a primary and non-contributory basis on all policies except Workers' Compensation and Professional Liability:

Standard Workers' Compensation & Employer's Liability:

Workers Compensation	Statutory
Employer's Liability	$1,000,000/$1,000,000/$1,000,000

Commercial General Liability
(including, but not limited to, bodily injury, personal injury, property damages, premises operations, independent contractor's protective, hostile fire, demolition, excavation (including blasting), explosion, collapse and underground, broad form contractual liability, products-completed operations (with such coverage continuing for no less than three years following Final Completion of the Work), domestic certified acts of terrorism, separation of insureds and defense):

General Aggregate Liability Limit	$2,000,000
Products/Completed Operations Aggregate	$2,000,000
Personal & Advertising Injury Limit	$1,000,000
Each Occurrence Limit	$1,000,000

Comprehensive Automobile Liability
(including coverage for liability arising out of owned, non-owned, rented, leased and hired autos and for bodily injury and property damage and contractual liability):

Each Accident	$1,000,000

Other Coverages:

Umbrella Liability
(including fire legal liability) coverage in excess of and no less than concurrent with the above liability coverages:

Combined Single Limit	$1,000,000

All insurance policies required hereunder shall be endorsed to provide a 30-day written notice of cancellation to Owner, shall include waivers of subrogation in favor of Owner and CWA Authority, Inc., and shall be on an occurrence form (except, if required, Builder's Risk and Professional Liability coverages). The Comprehensive General Liability policy and the Umbrella Liability policy shall contain contractual liability coverage for any indemnity obligation undertaken herein. All deductibles and self-insured retention amounts shall be the responsibility of the Contractor.

Licensee shall require each of its subcontractors and subconsultants to carry Workers' Compensation & Employer's Liability, Commercial General Liability, Comprehensive Automobile Liability, Umbrella Liability, Pollution Liability and (where applicable) Professional Liability coverage to the same extent as is required of Contractor hereunder (including additional insured and waiver of subrogation endorsements in favor of Owner and Citizens Gas), except as may otherwise be approved in advance in writing by Owner.

b. Safety Provisions. At all times while Licensee exercises its rights under this License, Licensee shall comply with all federal, state and local laws applicable to the safe performance of the Licensed Activity on the Property.

c. Indemnification. Licensee (the **"Indemnity Party"**) shall indemnify, defend and hold Owner harmless, subject to the limitations set forth herein, against all actions, causes of action, claims, judgments, damages, demands, proceedings, penalties, fines, liabilities, liens, costs, expenses of investigation, remediation, losses, and reasonable attorneys' fees (**"Claims"**) arising from, out of or in connection with Licensee's exercise of its rights under this License, including any breach of this License by Licensee. Indemnity Party's indemnification and defense obligations in this Section 8(c) shall include Owner's consequential, incidental, special or punitive damages.

d. Permits. Licensee will obtain or caused to be obtained prior to beginning the Licensed Activity, and will maintain or cause to be maintained in full force at all times during the Term, all necessary permits, utility markings, notifications, licenses or certifications for itself and its contractors or agents.

9. Contractor. In the event Licensee decides to hire a third party to assist in performing the Licensed Activity, Licensee shall not access the property until the third party at issue agrees in writing to the terms and conditions in Section 8.

10. Miscellaneous.

a. This License constitutes the entire agreement between the parties with respect to the subject matter hereof. No modification of this License shall be effective unless it is executed in writing by Owner and Licensee.

b. This License may be executed in any number of counterparts, each of which shall be an original but all of which together shall constitute one and the same agreement.

c. In the event of any litigation arising out of this License, the prevailing party shall be entitled to receive from the losing party an amount equal to the prevailing party's costs incurred in such litigation, including, without limitation, the prevailing party's attorneys' fees, costs, and disbursements.

d. This License shall be binding upon and inure to the benefit of the parties hereto and their respective successors and assigns.

e. This License shall be governed by and construed under the laws of the State of Indiana.

f. The parties agree to cooperate fully, to execute any and all supplementary documents and take all additional actions that may be necessary or appropriate to give full force and effect to the terms and intent of this License, which are not inconsistent with its terms.

g. In resolving any conflicts or inconsistencies between this License and any other license or agreement, the document or provision thereof expressing the greater quantity or better quality or imposing the greater obligation upon Licensee and affording the greater right or remedy to Owner shall govern.

* * *

IN WITNESS WHEREOF, Owner and Licensee have caused this License to be executed on the date and year first mentioned above.

CITIZENS GAS:

By: ____________________________________

Name: [CITIZENS EMPLOYEE NAME]

Its: [CITIZENS EMPLOYEE TITLE]

LICENSING BUSINESS: Indiana University

By: Dwayne Pinkney *Electronically signed by: Dwayne Pinkney Date: May 4, 2023 14:02 EDT*

Name: Dwayne Pinkney

Its: Executive VP for Finance & Administration

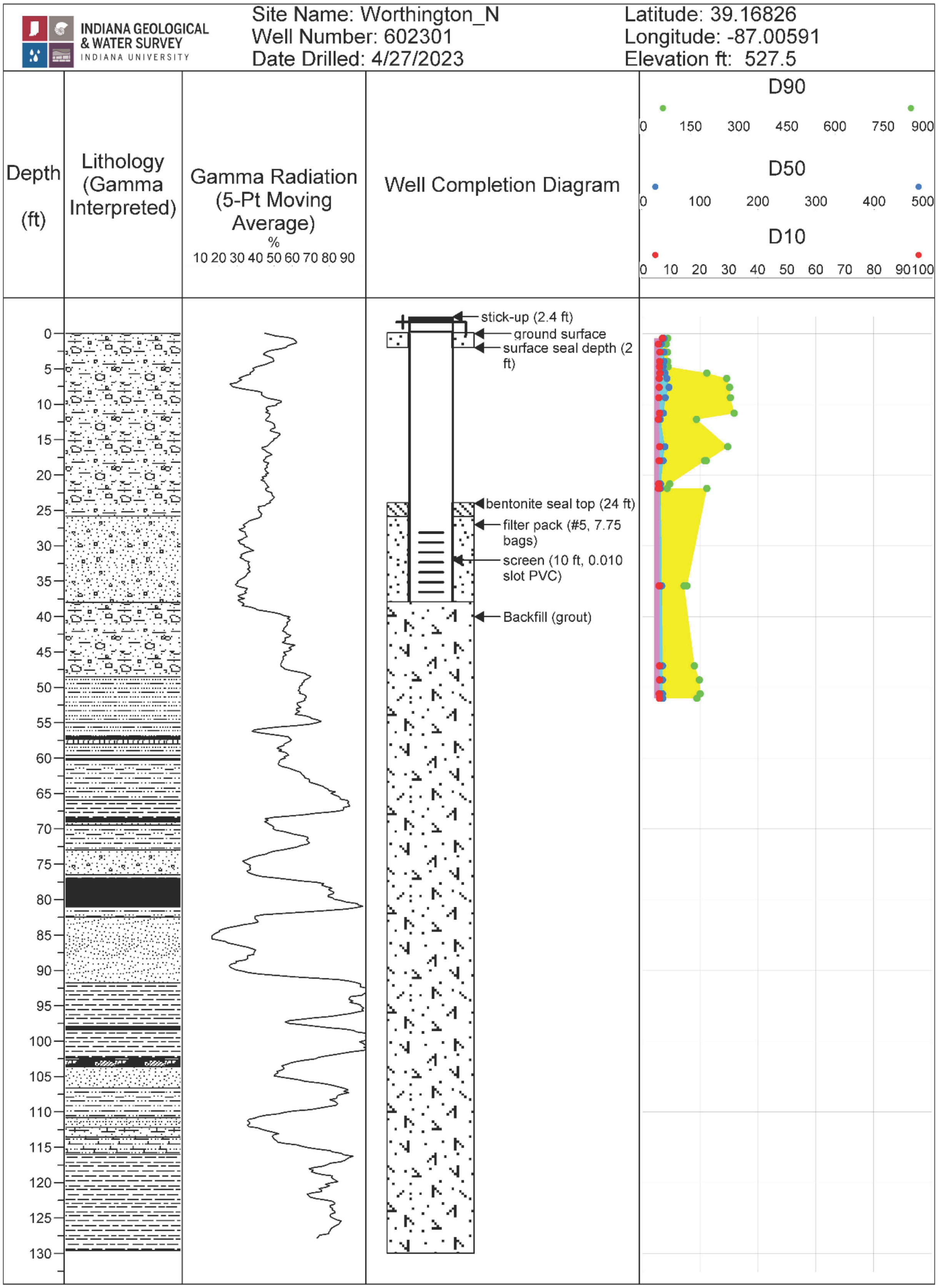
Reviewed as to form by Z.G.

EXHIBIT A

INDIANA GEOLOGICAL & WATER SURVEY
INDIANA UNIVERSITY

Johnstown Station NGWMN Site Investigation

Appendix B. Well diagram and PSA for Worthington_N (602301)



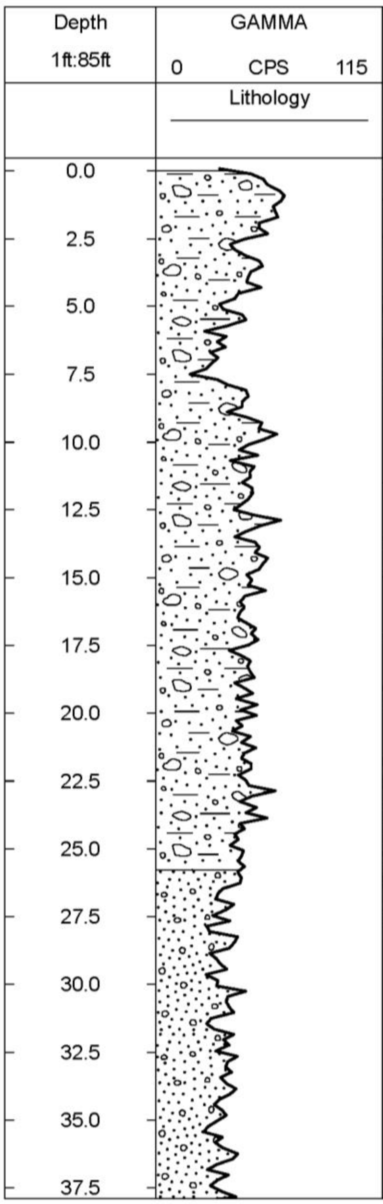
Appendix C. Lithology description for Worthington_N (602301)

INDIANA GEOLOGICAL & WATER SURVEY
INDIANA UNIVERSITY

Site ID	602301	Date	04/27/2023
Site Name	Worthington_N	Author	McKailey Sabaj
Latitude	39.16824	Elevation (ft)	527.5
Longitude	-87.005906	NGWMN well	

Legend

- Gravel or conglomerate
- Till or diamicton
- Massive sand or sandstone
- Bedded sand or sandstone
- Crossbedded sand or sandstone
- Calcareous sandstone
- Silt, siltstone or silty shale
- Calcareous siltstone
- Clay or clay shale
- Coal
- Impure coal
- Underclay
- Interbedded sandstone and siltstone
- Interbedded sandstone and shale



Description

(0-1) Silty clay loam (Fm), massive, dark brown (10YR3/3), moist, oxidized-leached, no reaction, stiff consistency, sharp lower contact, B Horizon, roots, a bone fragment, organics, insects.

(1-2.3) Silty clay (Fm), massive, dark yellowish-brown (10YR4/4), moist, oxidized-leached, no reaction, medium consistency, gradational lower contact, roots, Bt Horizon.

(2.3-4.6) Silty clay loam (Fm), massive, yellowish-brown (10YR5/6), moist, oxidized-leached, no reaction, hard consistency, gradational lower contact, few Mn concretions.

(4.6-4.8) Silty clay (Fmm) with few (6-15 %) granules (2-4 mm), massive, dark yellowish-brown (10YR5/6), moist, oxidized-leached, no reaction, stiff consistency, gradational lower contact, slightly sandy.

(4.8-6) Silt loam (Fm), massive, dark yellowish-brown (10YR4/6), moist, oxidized-leached, no reaction, stiff consistency, gradational lower contact, 5 % mottling by surface area.

(6-11.5) Sandy clay loam (Dmm), with few (16-30 %) granules (2-4 mm), massive, yellowish brown (10YR5/6), moist, oxidized-leached, no reaction, stiff consistency, fine sands up to course gravel (chert clasts). Large chert clast (.83 in). Soil turns to reddish hue at 7.25 ft indicating development of the Sangamon Formation.

(11.5-13.5) Sandy clay (Dmm), with few (16-30 %) very coarse gravel (32-64 mm), massive, yellowish-brown (10YR5/6), moist, oxidized-leached, no reaction, stiff consistency, fine sands up to coarse gravel (chert clasts)-large 3.33 cm3 clast that is fairly rounded, other clasts varying in angularity and size, sand-rich till.

(13.5-15) No recovery. Gamma-interpreted as sandy clay.

(15-17.1) Sandy clay loam (Dmm), with few (16-30 %) very coarse gravel (32-64 mm), massive, yellowish-brown (10YR5/4), moist, oxidized-leached, no reaction, very soft consistency, sharp lower contact, Sangamon Formation, Fe oxides, Mn, very light mottling, chert clasts.

(17.1-18.9) Sandy clay loam (Dmm), with few (16-30 %) coarse gravel (16-32 mm), massive, yellowish-brown (10YR5/4), moist, oxidized-unleached, strong reaction, soft consistency, sharp lower contact, clasts fairly rounded, Fe and Mn, Mn laminae (17.6-21.5 ft) fine to 1 mm thick.

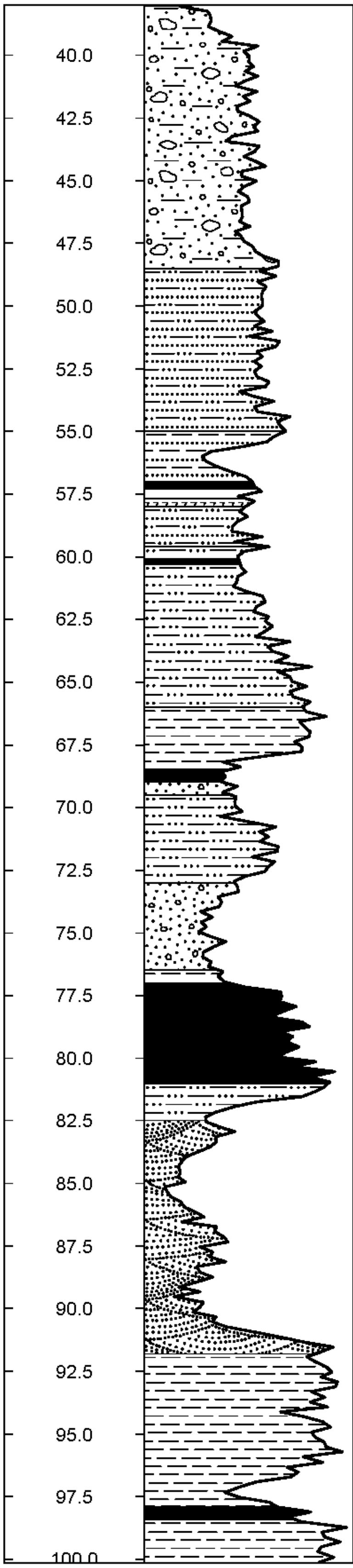
(18.9-21.5) Sandy clay (Dmm), with some (31-49 %) coarse gravel (16-32 mm), massive, yellowish-brown (10YR5/4), moist, oxidized-unleached, strong reaction, hard consistency, sharp lower contact, transition zone at top has many clasts and Mn zones (18.93-19.42 ft), mottling from 19.42-22.08 ft. Another Mn zone at 20.62-20.80 ft. Platy structures, extra platy from 20.99-21.45 ft.

(21.5-22.1) Clay loam (Dmm), with few (16-30 %) medium gravel (8-16 mm), massive, dark gray (10YR4/1), moist, unoxidized-unleached, strong reaction, very stiff consistency, sharp lower contact.

(22.1-25) No recovery. Gamma-interpreted as sandy clay loam.

(25-25.8) Sandy clay (Dmm), with some (31-49 %) very coarse gravel (32-64 mm), massive, dark gray (10YR4/1), moist, unoxidized-unleached, strong reaction, stiff consistency, large and abundant clasts, very thick till, some iron nodules (orange clasts).

(25.8-38) No recovery. Interpreted as sand and gravel unit from gamma log and from sandstone clast found in drilling shoe.



(38-41.4) Sandy clay (Dmm), with some (31-49 %) coarse gravel (16-32 mm), massive, very dark gray (10YR3/1), moist, unoxidized-unleached, strong reaction, very stiff consistency, some red shale clasts. Top 0.098 ft (3 cm) looks slightly different from below, possibly capturing sand and gravel unit shown by gamma from 25.8 to 38 ft.

(41.4-48.5) Sandy clay (Dmm) with some (31-49 %) granules to coarse (2-32 mm), massive, very dark gray (10YR3/1), moist, unoxidized-unleached, moderate reaction, very stiff consistency, sharp lower contact, sandstone clasts exhibiting weathering or poor induration.

(48.5-49.5) Saprolitic sandy siltstone indicative of Mansfield Formation, fines-silt dominated, slightly sandy, wavy bedding; oxidized zones 2-4 cm thick. Fine sand interbedded layers. Transition from unconsolidated to bedrock.

(49.5-55) Horizontal-bedded siltstone (Fthzz), saprolitic sandy siltstone. Iron-stained zones in the top 2 ft, medium gray (N5) and medium dark gray (N4).

(55-57) Bioturbated interlaminated/interbedded and horizontal-bedded shale and sandstone, with a sharp basal contact (Fs/Ssi/hbs), very fine dirty sand, some micas, small organics, medium gray (N5) and medium dark gray (N4).

(57-57.3) Coal (Orzzz); small pyrite crystals, black (N1).

(57.3-58) Massive claystone and siltstone with a gradational basal contact (Fc/Ftmzg), organic rich underclay that transitions to a clay-rich siltstone. Contains common mica and organic particles, brownish-gray (5YR 4/1).

(58-59.6) Massive siltstone (Ftmzz), hard sandstone that transitions to soft clay sandstone. Contains some organics and pyrite, light olive gray (5Y 6/1).

(59.6-60) No recovery. Gamma-interpreted as siltstone.

(60-60.1) Massive siltstone (Ftmzz), some organics and coal clasts that may be remnants from coal seam above, light olive gray (5Y 6/1).

(60.1-60.3) Coal (Orzzz), small pyrite laminations, black (N1).

(60.3-62.4) Massive siltstone with a sharp basal contact (Ftmzs), clasts and gravels increase with depth, mostly angular or subangular. Common organics. Coal clasts that are likely remnants from coal seam above, olive gray (5Y 4/1).

(62.4-66) Bioturbated horizontal-bedded siltstone and claystone (Ft/Fchbz), sandy siltstone with some claystone. Organic rich, olive gray (5Y 4/1), medium gray (N5) to dark gray (N3).

(66-67.5) No recovery. Gamma-interpreted as shale.

(67.5-69) Horizontal-bedded shale with a sharp basal contact (Fshzs), thin coal seam from 68.9-69 ft, grayish-black (N2).

(69-69.5) Massive conglomerate (Grmzz), pebble-sized clasts of chert and fine- to medium-grained sand. Some iron-rich zones, mica, and limonite. Localized minor HCl reaction, brownish-gray (5YR 4/1) and yellowish-gray (5Y 8/1).

(69.5-75) No recovery. Gamma-interpreted to be siltstone that transitions to sandstone or conglomerate around 73 ft.

(75-76.5) Intraclastic conglomerate with a gradational basal contact (Grzig), a lithic-arenite sandstone that contains fine to medium grains and large interclasts that are subangular to subrounded. Organics and iron-rich granules present. Possible chert fragments. Large sandstone clast. Coal debris at base of unit, moderate brown (5YR 4/4) and pale brown (5YR 5/2).

(76.5-77) No recovery. Gamma-interpreted as shale or coal.

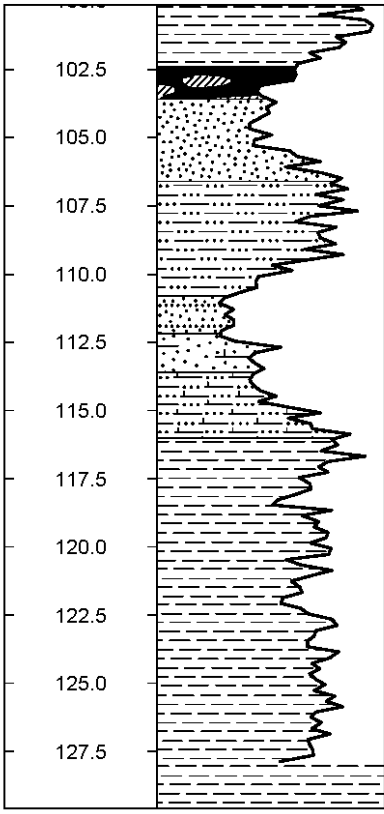
(77-81) No recovery. Some coal found at 78 ft.

(81-82.5) Disturbed-bedded horizontal-bedded siltstone with a sharp basal contact (Fthds); bedding is disturbed at base. Organic particles, light gray (N7) and medium gray (N5).

(82.5-91.8) Bioturbated and disturbed-bedded cross-bedded and horizontal-bedded sandstone (Ssx/hb/dz), lower to upper very fine sand, moderately sorted with silt laminations. Contains rare to occasional mica and minor calcareous zones. Some small organic fragments and pyrite nodules. Zones of disturbed bedding and localized dark iron-stained zone from 84-85.1 ft. Open vertical fracture, yellowish gray (5Y 8/1) and light olive gray (5Y 6/1).

(91.8-97.9) Slickensided horizontal-bedded shale with a sharp basal contact (Fshss), rare trace fossils along partings, medium dark gray (N4).

(97.9-98.4) Coal (Orzzz), poor recovery, highly damaged by core retrieval. Very small lenses of pyrite, black (N1).



(98.4-102.4) Fossiliferous and slickensided horizontal-bedded shale with a gradational basal contact (Fshf/sg), abundant plant fossils along partings. Some iron-rich zones and thin beds, medium gray (N5).

(102.4-103.6) Bioturbated horizontal-bedded coal to siltstone with a gradational basal contact (Or-Fthbg), lignite transitions to siltstone with some fine-grained sand-rich laminations. Iron cemented, sand-filled casts of plant material, grayish black (N2) to medium dark gray (N4).

(103.6-106.6) Massive sandstone with a sharp basal contact (Ssmzs), lower very fine sand to coarse silt, moderately sorted with localized iron-stained cement and organic particles/debris, medium dark gray (N4).

(106.6-110.8) Slickensided horizontal-bedded claystone to siltstone with a gradational basal contact (Fc-Fthsg). Contains iron-rich clasts, small organic debris, dark lithics (chert) and fine quartz sand throughout. Few iron-rich concretions. Greenish-gray (5G 6/1).

(110.8-112.2) Horizontal-bedded sandstone with a gradational basal contact (Sshzg), fine-grained quartz sand and dark lithics. Small organic debris. Base of unit is minorly calcareous, light olive gray (5Y 6/1).

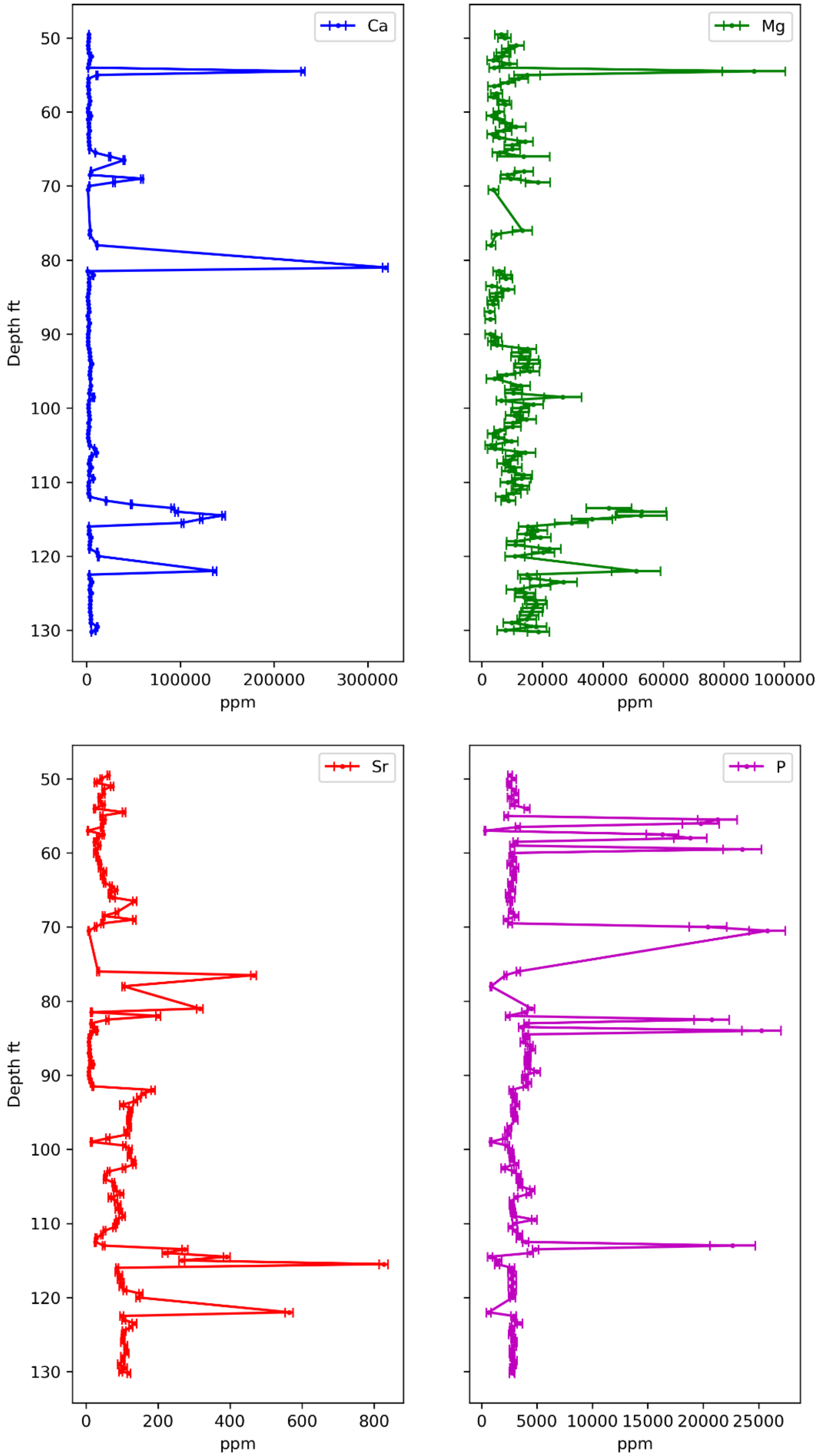
(112.2-113.6) Horizontal-bedded sandstone (Sshzz), very fine-grained quartz sandstone with dark lithics and calcareous cement. Rare to occasional mm-scale pyrite nodules, light greenish-gray (5G 8/1) and yellowish-gray (5Y 8/1).

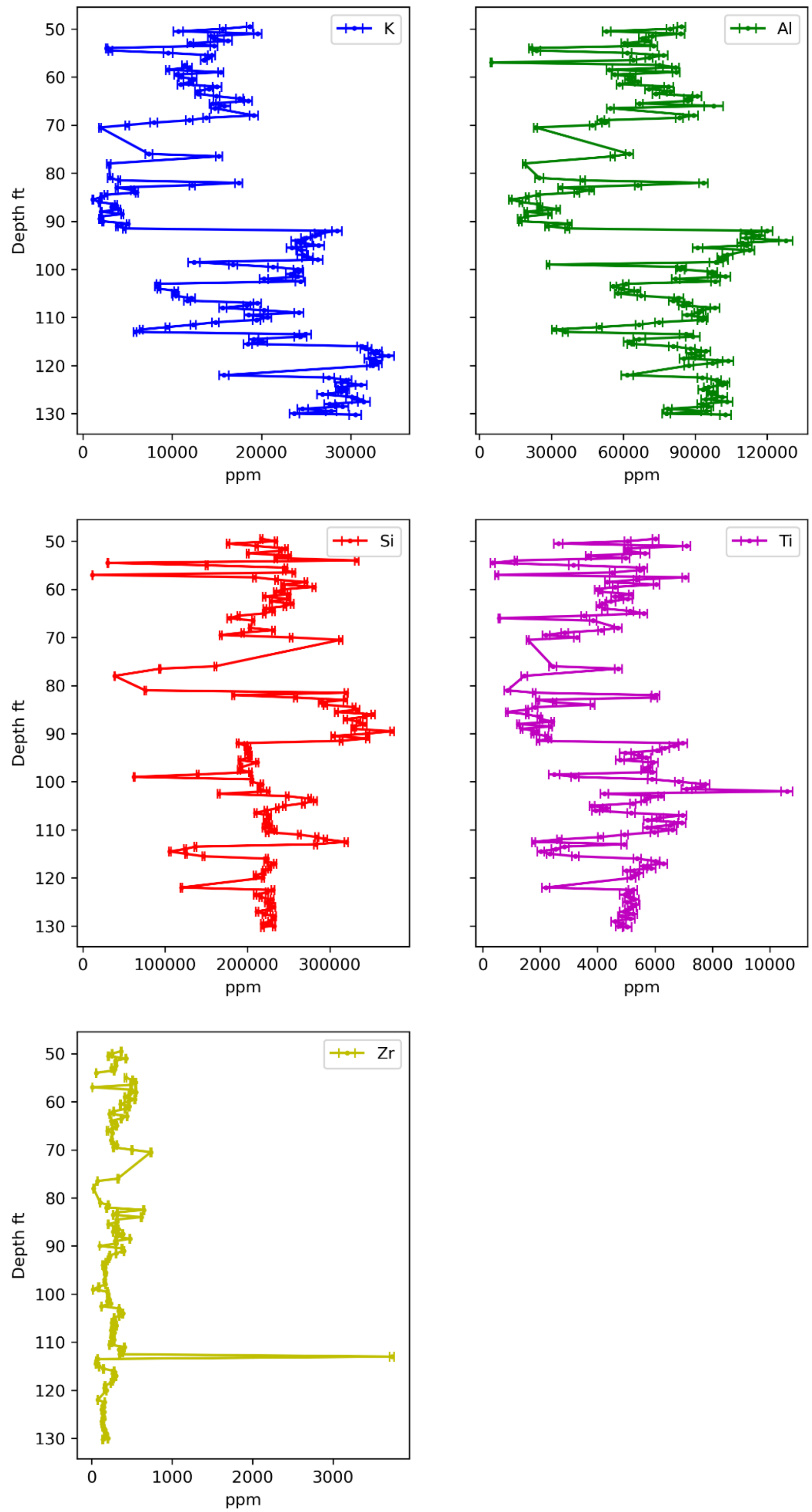
(113.6-116) Massive siltstone (Ftmzz), calcareous silt with granule-sized clasts of sandstone. Few iron-rich concretions. Poor recovery, light greenish-gray (5G 8/1).

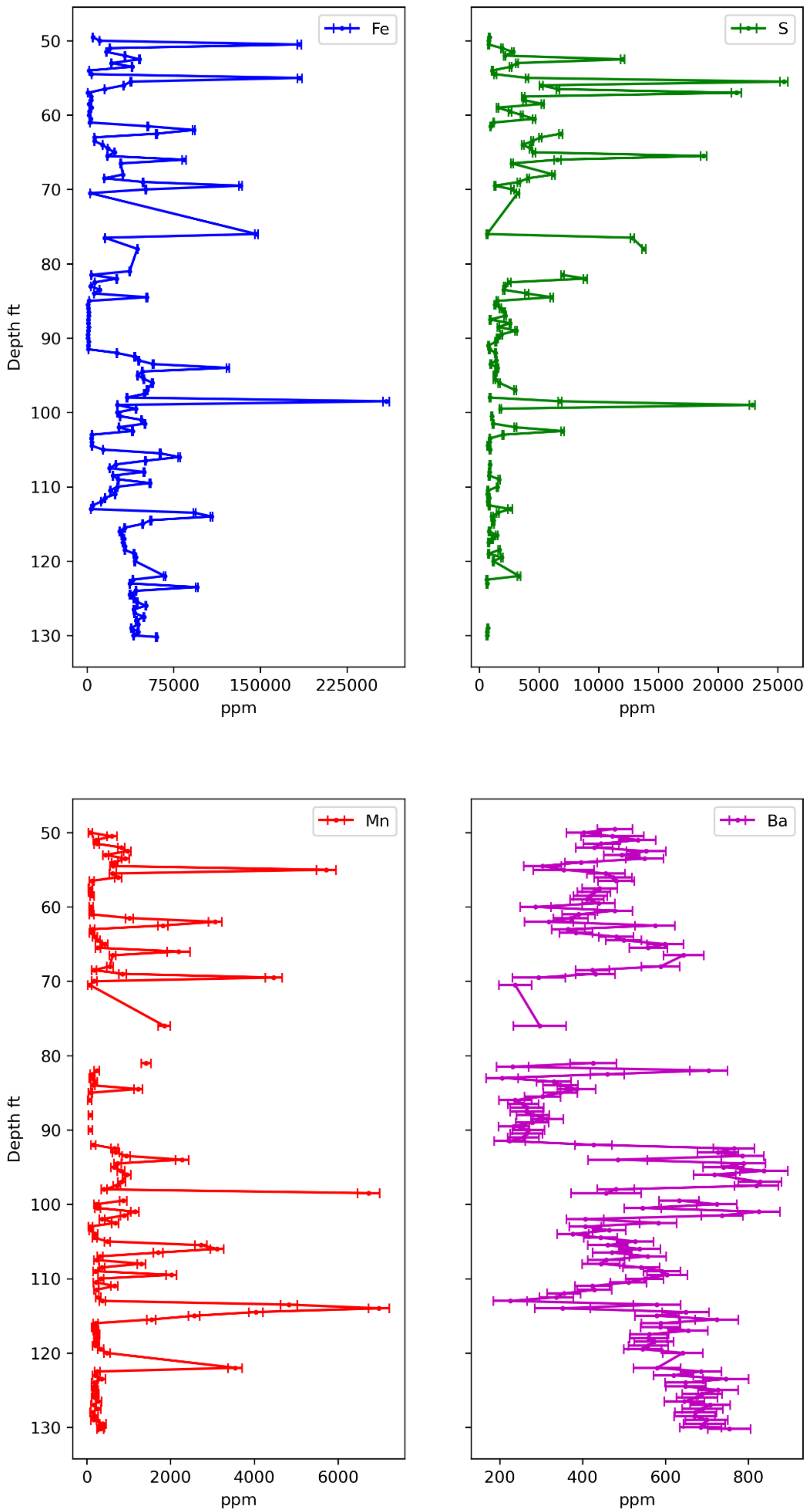
(116-120.5) Massive claystone with a sharp basal contact (Fcmzs), green shale that becomes darker with depth, greenish-gray (5GY 6/1) and dark greenish-gray (5GY 4/1).

(120.5-129.6) Slickensided horizontal-bedded shale (Fshsz), varicolored shale, medium dark gray (N4) to medium bluish-gray (5B 5/1) and grayish-red (5R 4/2).

Appendix D. pXRF results for Worthington_N (602301)




K
Al
Si
Ti
Zr
Depth ft
ppm
50
60
70
80
90
100
110
120
130
0
10000
20000
30000
30000
60000
90000
120000
100000
200000
300000
2000
4000
6000
8000
10000
1000
2000
3000


Fe
S
Mn
Ba
Depth ft
ppm
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60
70
80
90
100
110
120
130
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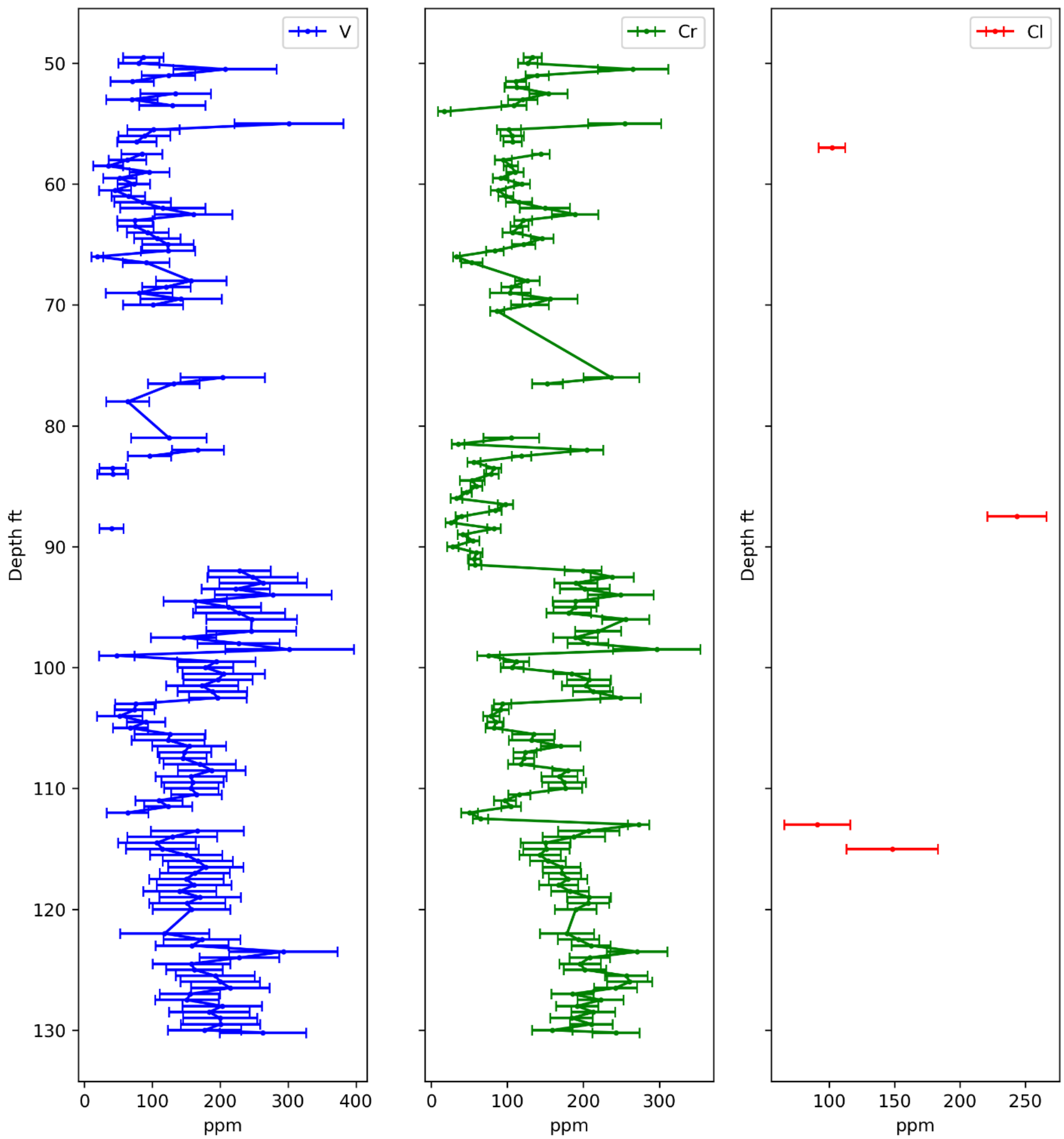
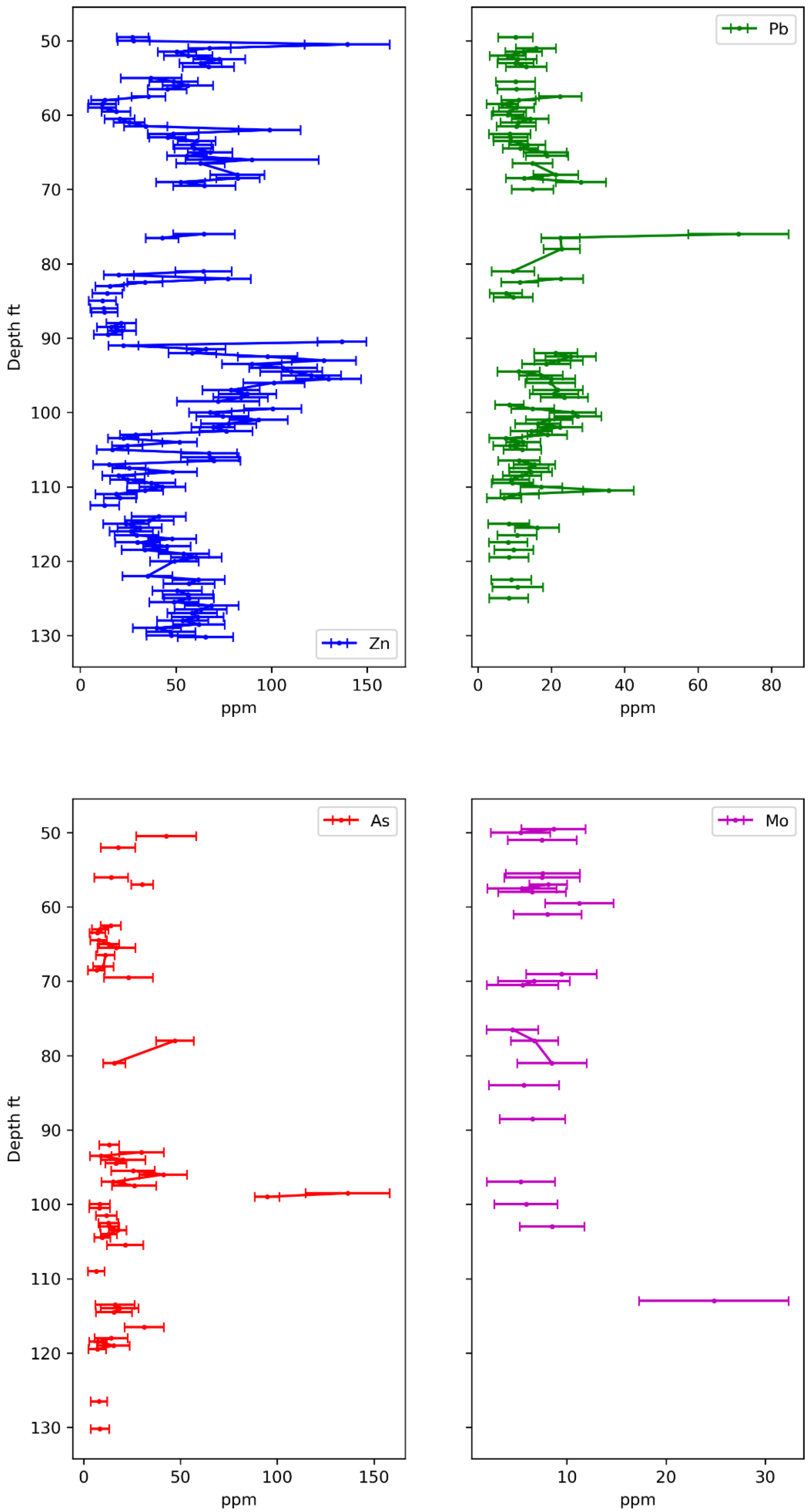
150000
225000
5000
10000
15000
20000
25000
2000
4000
6000
200
400
600
800


V
Cr
Cl
Depth ft
Depth ft
ppm
ppm
ppm
50
60
70
80
90
100
110
120
130
0
100
200
300
400
0
100
200
300
100
150
200
250


Zn
Pb
As
Mo
Depth ft
ppm
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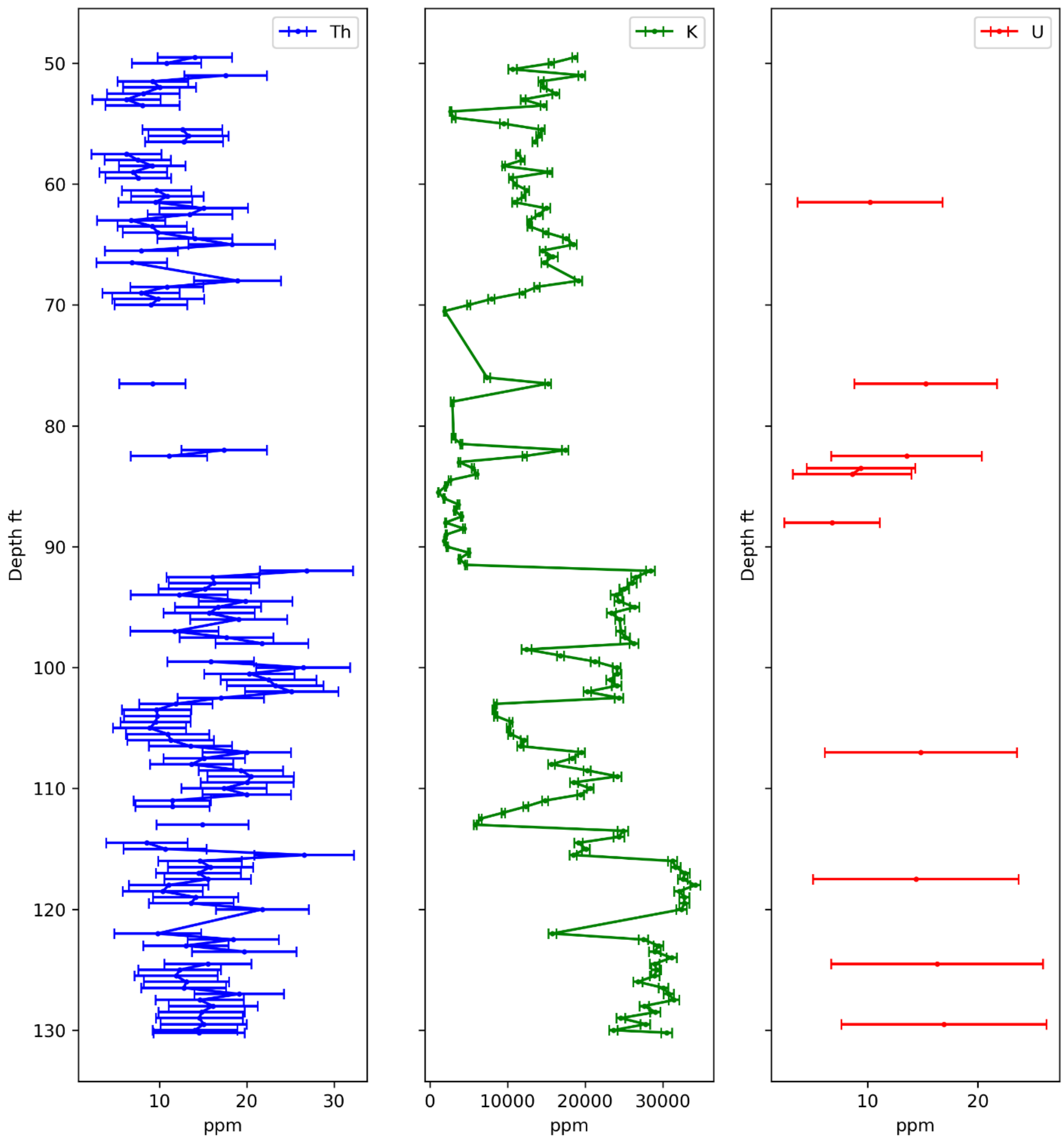
70
80
90
100
110
120
130
0
50
100
150
0
20
40
60
80
10
20
30


Th
K
U
Depth ft
ppm
ppm
ppm
50
60
70
80
90
100
110
120
130
10
20
30
0
10000
20000
30000
10
20