Final Technical Report

Project Title:

Expanding the Indiana Geological and Water Survey's Contribution to the NGWMN: New monitoring wells in central Indiana

Agency Name:

Indiana Geological and Water Survey

Award Number:

G19AC00278

Award Term:

December 31, 2019, through December 29, 2021

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Report Date:

December 22, 2022

Objective(s):

Objective 5 - Well drilling

ACKNOWLEDGEMENTS

The author would like to acknowledge the contributions of several colleagues who worked on this project, including Jose Luis Antinao, Alex Crookshanks, Addie Jenkinson, Henry Loope, Garrett Marietta, Robin Rupp, and Babak Shabani. We also thank Bradford Woods management and Morton Family Farm for hosting the new monitoring wells.

OVERVIEW OF WORK

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 Number: G16AC00360). The work completed under this agreement is the third award under the NGWMN program for an existing data provider under the FY2019 NGWMN program announcement with agreement dates from 12/20/2019 to 12/29/2021 (Grant/Cooperative Agreement Number: G19AC00278).

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://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 dataset 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 continue to drive the data collection. To that end, our monitoring network is expanding and redesigned to assess the best aquifers. With the additional wells drilled during this round, our network has grown to 15 wells that represent Principal Aquifers of Alluvial and Glacial Origin and the Mississippian Aquifer, along with Secondary Hydrogeologic Regions of Other Aquifers.

NGWMN program Objective 5, well drilling, was completed during the two-year project period. Installing additional groundwater monitoring wells improves the spatial distribution of NGWMN sites in Indiana while addressing some water resource questions locally. Two new monitoring wells were drilled in central Indiana as trend/backbone monitoring locations in the NGWMN. One of the wells, Martinsville_N (IGWS Well 552101), is a replacement well installed near the original monitoring well (IN015-5) at an Indiana Geological and Water Survey (IGWS) IWBN monitoring station near Martinsville, Indiana. This well is deeper than the original well and intercepts at depth the regional valley-train outwash aquifer. An additional monitoring well was installed in the vicinity of a buried bedrock valley in northern Boone County (NBC) called Lebanon_N (IGWS Well 062102).

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

To incorporate data from our sites into the NGWMN, our data services have been maintained with connections via a web service and API to provide the data gathered from the stations. We updated, or added, the well registry for all 15 contributing wells to the NGWMN to reflect any changes at IGWS NGWMN sites or to add new sites' data. As staff transitions and COVID-related work location challenges have occurred, some of the frequency of quality assurance and quality control (QA/QC) protocols for the stations had to be adjusted. The downloaded water-level data is processed and put through QA/QC protocols (see related section below for specifics) at least annually for all sites; we plan to increase frequency as additional staff support is stabilized and positions are filled. We added two new wells to the NGWMN well registry, including all required data elements. Sensors also were installed to record and report water level data for the new wells. This data is currently available for ingest by the NGWMN.

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

Well drilling activities started with site reconnaissance. Passive seismic geophysical survey of the area was conducted following best practices (Voytek, 2012) to map the bedrock surface of the buried bedrock valley. Two valleys were investigated at each of the drill sites. The northern Boone County well placement goal was to be above the bedrock valley of Anderson Branch, a tributary of the Teays buried river valley. The second replacement well near Martinsville_N station (IN15-05) was to be placed further into the known bedrock channel filled with the valley-train outwash aquifer. Transects were run perpendicular to the landforms or along grided roads to determine the direction of buried valley thalwegs. The horizontal-to-vertical spectral ratio (HVSR) method collected with the use of Tromino® 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.

The northern Boone County (Lebanon_N) drill location was narrowed down to six possible sites based on HVSR analysis and existing land use. Obtaining site access for the proposed well locations proved challenging after contacting representatives or owners of several properties. The final well location was successfully obtained at the Morton Family Farm grain elevator and workshop. The Martinsville_N location was more easily obtained because it was being added to the network at an existing site with permissions gained before the grant application. Bradford Woods graciously allowed continued access to their property and granted further drilling.

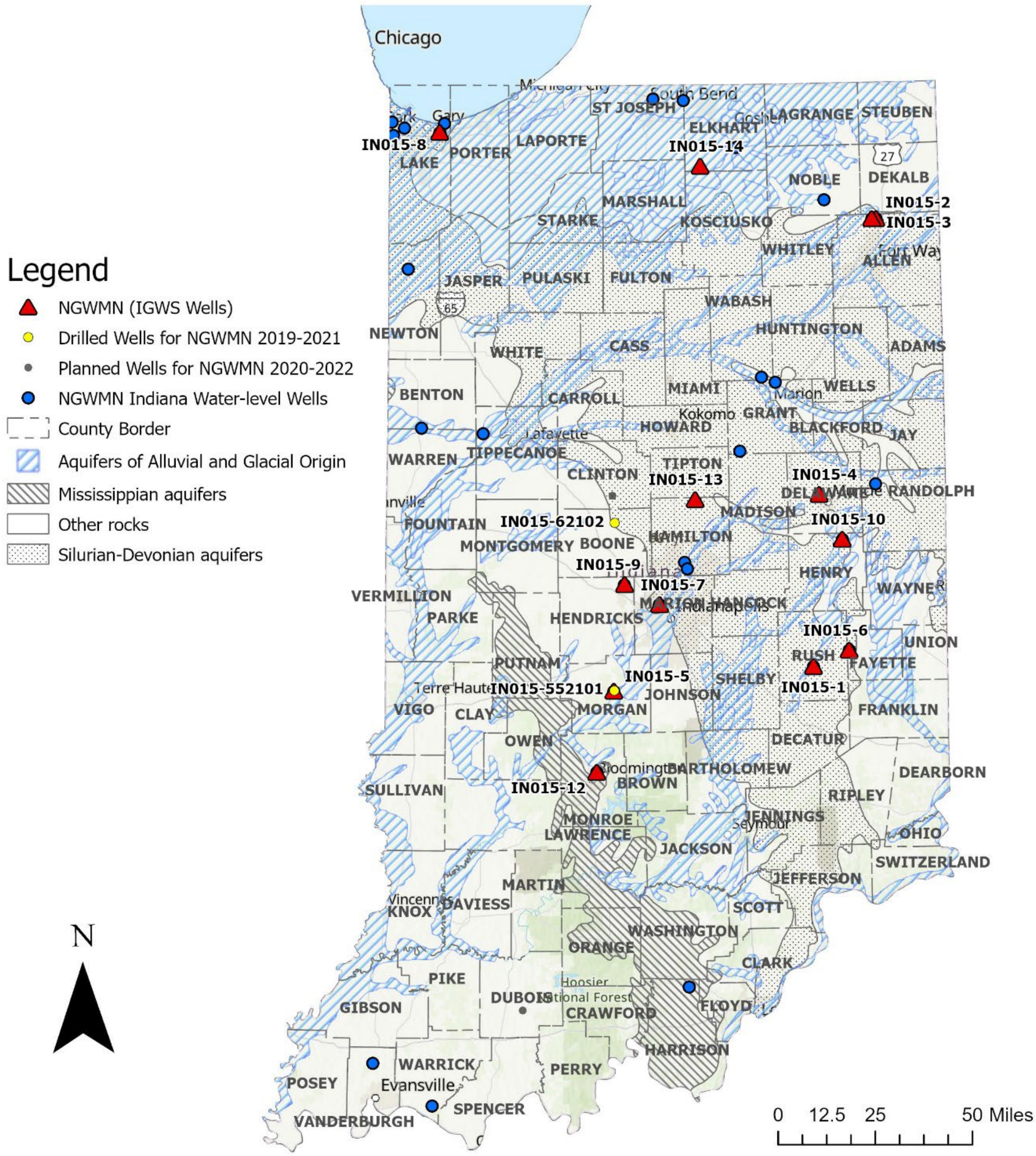

Figure 1. Map of Indiana showing IGWS groundwater monitoring sites that are included in the NGWMN.

The Lebanon_N location was chosen for the monitoring well in northern Boone County (Figs. 1 and 2), as continued exploratory drilling in the area has been conducted to locate useable quantities of water for the communities of Thorntown, Lebanon, and Frankfort. This well was established to provide a long-term record of groundwater levels in an area where trend monitoring is otherwise absent. The site was chosen to map the thalweg of the deepest portion of the buried bedrock valley, but we were only budgeted to drill to a depth of 235 ft. This allowed our geologists to interpret the glacial setting and reach usable aquifers but did not allow us to determine the full depth to bedrock. This area coincides with a tributary of the buried Anderson Bedrock Valley (Gray, 1991), which may still represent a significant, relatively untapped aquifer for this area. Unconsolidated deposits were estimated to be approximately 325 ft thick in the center of the buried bedrock valley and deeper sand and gravel.

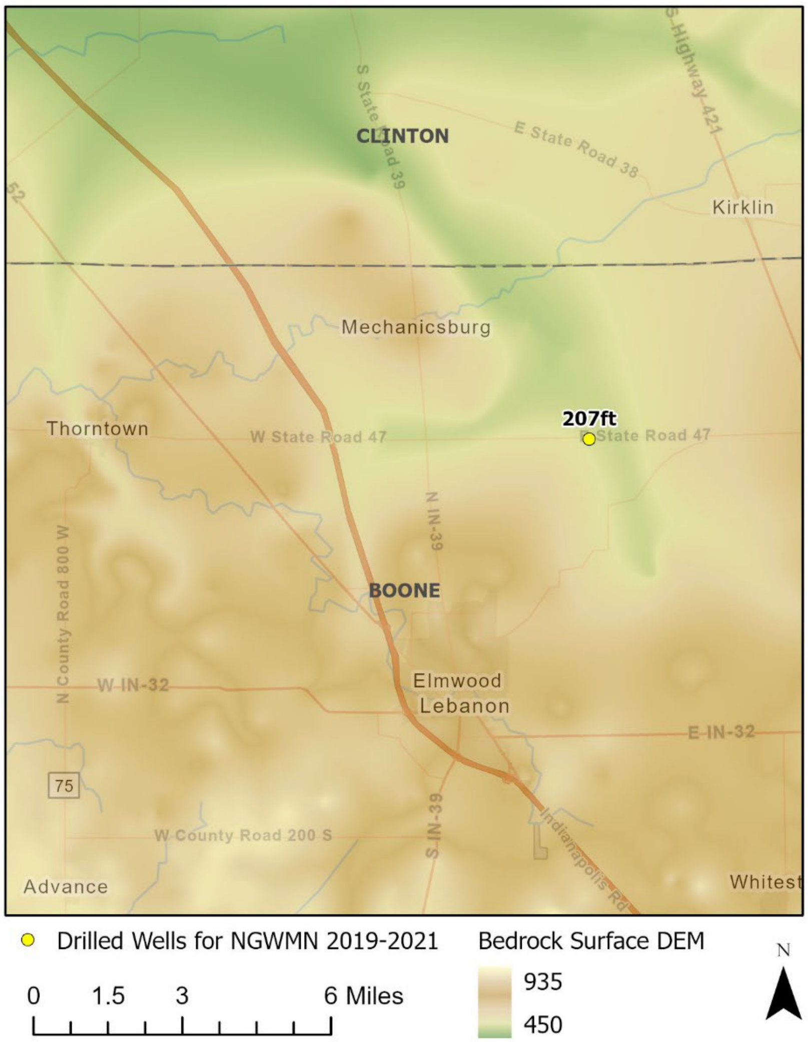

Figure 2. Map of northern Boone County showing bedrock surface elevation and IGWS groundwater monitoring site Lebanon_N (IGWS Well 062102) included in the NGWMN, relative to county boundaries and interstate highways.

The existing wells at Martinsville_N station include three shallow wells (less than 11 feet deep). To improve our understanding of water resource availability and to improve the assessment of aquifers that support public and residential wells, a deeper replacement well was added to this station that extends monitoring to the state driller's code (minimum depth for residential wells at 35 ft). The deep well was placed in the vicinity of the shallow well system to facilitate a better understanding of surface water and groundwater interactions.

The location chosen for the proposed replacement monitoring well at Martinsville_N ended up being significantly further away than initially expected; analysis of the HVSR indicated that the bedrock valley did not drop off appreciably near the existing shallow well (Fig. 3). The bedrock valley wall exists to the south of the site and is exposed at the ground surface in the form of non-aquifer Borden siltstone/shale sequences. We presumed it deepened closer to the existing site (within 100 ft). In fact, we had to drill 960 ft away to get to a deeper portion of the unconsolidated aquifer valley. Unconsolidated deposits at 64.5 ft were found above the shale within the Borden Formation buried bedrock valley at the final location.

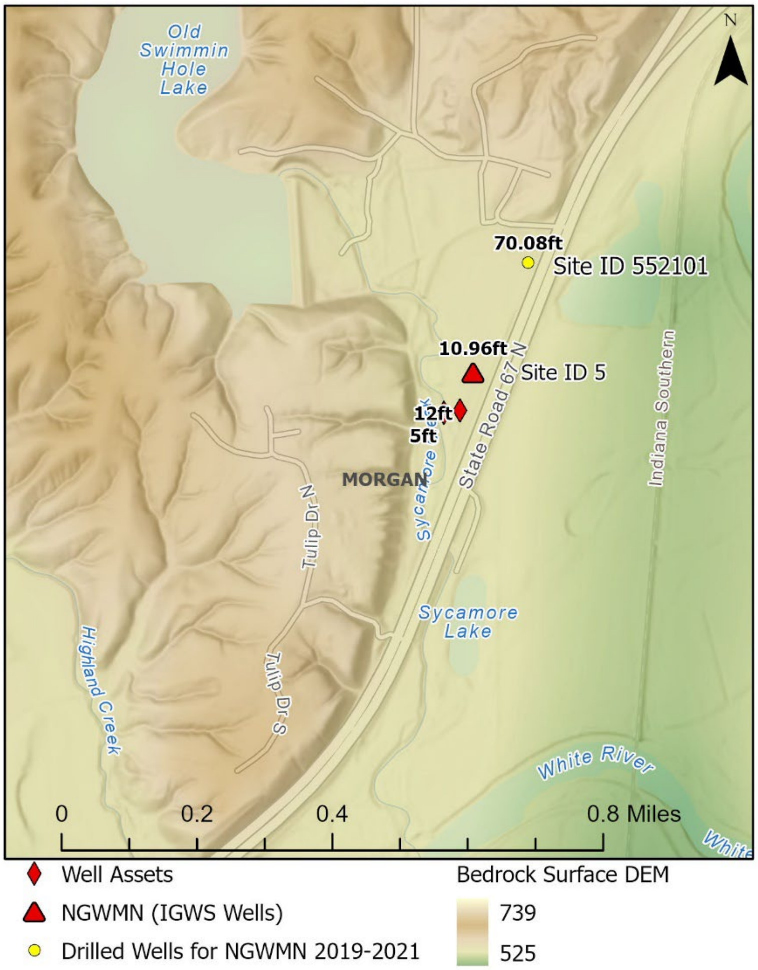

Figure 3. Map of Martinsville_N station location showing monitoring wells and depths over the colored bedrock surface elevation. Map indicates the previous NGWMN monitoring well (Site ID IN15-05) as a red triangle and the replacement NGWMN well (IGWS Well 552101) as a yellow circle relative to other IGWS groundwater monitoring wells and relative to interstate highways.

DRILLING, SOIL SAMPLING, 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 a continuous soil and bedrock core. The objective was to core several feet into the underlying bedrock to verify the unconsolidated-sediment-to-bedrock contact at the Martinsville site (IGWS Well 552101). At the Lebanon_N site (IGWS Well 062102), the goal was to get as deep as possible within the budgeted time while accessing a frequently used aquifer for the region. The core was obtained in 10-ft lengths. Longer lengths of core (i.e., better core recovery) was possible within the fine-grained sediments versus coarse-grained sediments like sand and gravel. 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 site identification and core depths. Coarse-grained samples from intervals of poor recovery were collected in a food strainer, rinsed of bentonite drilling mud, reviewed for a simplified field core description, and packed into plastic bags.

Core description

Detailed core descriptions and grain-size sample collections were conducted at the IGWS laboratory. Each description includes the U.S. Department of Agriculture (USDA) texture with additional description for greater than 2 mm pebbles, 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. However, 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 descriptions were recorded using a Microsoft Access database form referred to informally as Core-nucopia. Detailed lithologic description logs are included in Appendices B and C. The first page in Appendices B and C contains a single-page diagram showing a combined gamma ray, well construction, lithology symbol log, and particle size analysis (where available), while the subsequent pages include a gamma ray log and detailed description lithologic log.

Particle size analysis

Sections of core from Lebanon_N site (IGWS Well 062102) were subsampled at visually and physically discernible textural zones for laser-assisted particle size analysis. By suspending a small, representative sample in an H_20 and $Na_6[(PO_3)_6]$ solution, sonicating, and assessing laser diffraction as contact with individual grains is made, the Malvern Mastersizer 3000 is able to calculate approximate particle/grain size. Through this, the IGWS can produce dense grain size distributions that provide highly precise sedimentological records (see Appendix C for the Lebanon_N well with grain size distribution). Grain size analysis, however, could not have been conducted on the Martinsville_N core (IGWS Well 552101), as we only had about 20 % recovery on that core.

Optically-stimulated luminescence

Samples of sand layers were collected for optically-stimulated luminescence (OSL) testing. A method to date the time of deposition of the sand layer, OSL has the potential to date sediment back to an earlier glacial stage referred to as Illinoian, approximately 200,000 years before the present (BP). For comparison, the more recent glacial stage, referred to as Wisconsin, reached its greatest extent in Indiana approximately 24,000 years BP. During core collection in the field, Lebanon_N (IGWS Well 062102) core was subsampled within the 225 to 231.6-ft interval for OSL. This section was chosen for its grain size, depth within the core, and features observed in the core indicating soil development. The IGWS uses OSL dating techniques in the forms of blue light stimulation (BSL), infrared stimulation (IRSL), and post-infrared infrared stimulation (PIRIRSL). In tandem with OSL measurements, samples are split and shipped to ALS labs in Reno, Nev., for ICPMS measurements to determine natural irradiation rates. This is a necessary part of the OSL dating process, as mineral luminescence is a byproduct of radioactively stimulated electrons moving and becoming trapped in the crystalline lattice of individual grains. For Lebanon_N samples, quartz and feldspar fractions were obtained, which are apt for BSL and IRSL/PIRIRSL dating, respectively. As of 12/15/22, only dates for quartz BSL have been recovered. The data obtained from the IGWS OSL lab indicates that the date of burial for the subsample taken from Lebanon_N at 225 to 231.6 ft (115-120 cm) was 226.549 ka ± 7.876 ka. These values were calculated in the following manner:

$$Age(ka) = \frac{0.128\ \left(\frac{Gy}{\text{sec}}\right) * Dose\ Seconds\ (sec)}{Environmental\ Dose\ (\frac{Gy}{ka})}$$

The current rate of irradiation for the IGWS OSL reader is 0.128 Gy/sec, and the environmental dose for this sample was determined to be 1.13 Gy/ka. A set of 40 OSL discs containing 10 to 20 grains of quartz each (20 % of which, on average, should be luminescent) was processed, allotting for approximately 120 luminescent grains.

Well construction

After core collection, monitoring wells were installed. Installation was completed on May 25, 2021, for the Martinsville_N replacement well (IGWS Well 552101) and on June 3, 2021, for the Lebanon_N well (IGWS Well 062102). Monitoring wells were installed in the same boreholes used for coring. The target depth for the well screens was chosen to intercept the sands and gravels. 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. The Martinsville_N well screen was installed from 29.8 to 39.8 ft below grade to intercept gravel encountered from approximately 29 to 41 ft below grade. The Lebanon_N well screen was installed from approximately 197 to 207 ft below grade to intercept sands and gravel encountered from approximately 197 to 217 ft below grade. 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 approximately 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 for 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 Martinsville_N and Lebanon_N wells both have stick-up protective covers. Waterproof caps were placed on the top of the wells. Black reference mark (i.e., crow's foot) were drawn at the top of the PVC casings to mark the exact location for surveying the well elevation and a consistent location for obtaining depth-to-water and total depth measurements. Well construction details are displayed adjacent to the lithologic logs compiled in Appendices B and C.

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

Site name	New/ replace	Lat.	Long.	Site No.		Principal aquifer	Well depth	Depth units
Martinsville_N	Replace	39.49887	-86.4271	5 (original) 552101		Alluvial and Glacial Origin	70.08	ft
Lebanon_N	New	40.12625	-86.4196	062102		Other rocks	207	ft

Site latitude, longitude, and elevation (GPS positions)

Well locations are established using a differentially corrected Real-Time Kinematic (RTK) global positioning system (GPS) unit. A Leica Viva GNSS GS12 receiver and Leica controller capable of 8 mm horizontal and 15 mm vertical baseline accuracy are used to establish horizontal and vertical positions. The controller is set to record positions after a 4-cm, three-dimensional (3D) accuracy tolerance is met to ensure a minimum accuracy is obtained and 3D coordinate quality (3D CQ) values are commonly in the range of 0.3 to 3 cm.

Locations are determined for the top of the well casing (TOC), the ground surface immediately adjacent to the well, and the top of the protective well cover (if present). GPS location data are stored in the Leica controller, and the following information is transferred to a well metadata spreadsheet when field personnel return to the office:

- Point ID
- Northing
- Easting
- Elevation
- Accuracy (3D CQ)
- Notes

Well development

The wells were developed using compressed air, surging the water out of the well until all evidence of drilling mud was removed and surged water was relatively clear. Illinois State Geological Survey (ISGS) drillers used a specially constructed nozzle at the end of the compressed air line that directed compressed air at 90 degrees into the well screen slots and would assist in removing debris from the slots.

Data collection methods

Manual water level measurements

IWBN sites are visited, on average, every 18 weeks 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 = $\pm$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 a 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 sensors) and nonvented (e.g., In-Situ Rugged Troll 100 and Solinst 3000 series sensors) pressure transducers. The IGWS is working to move toward 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 nonvented (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 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.

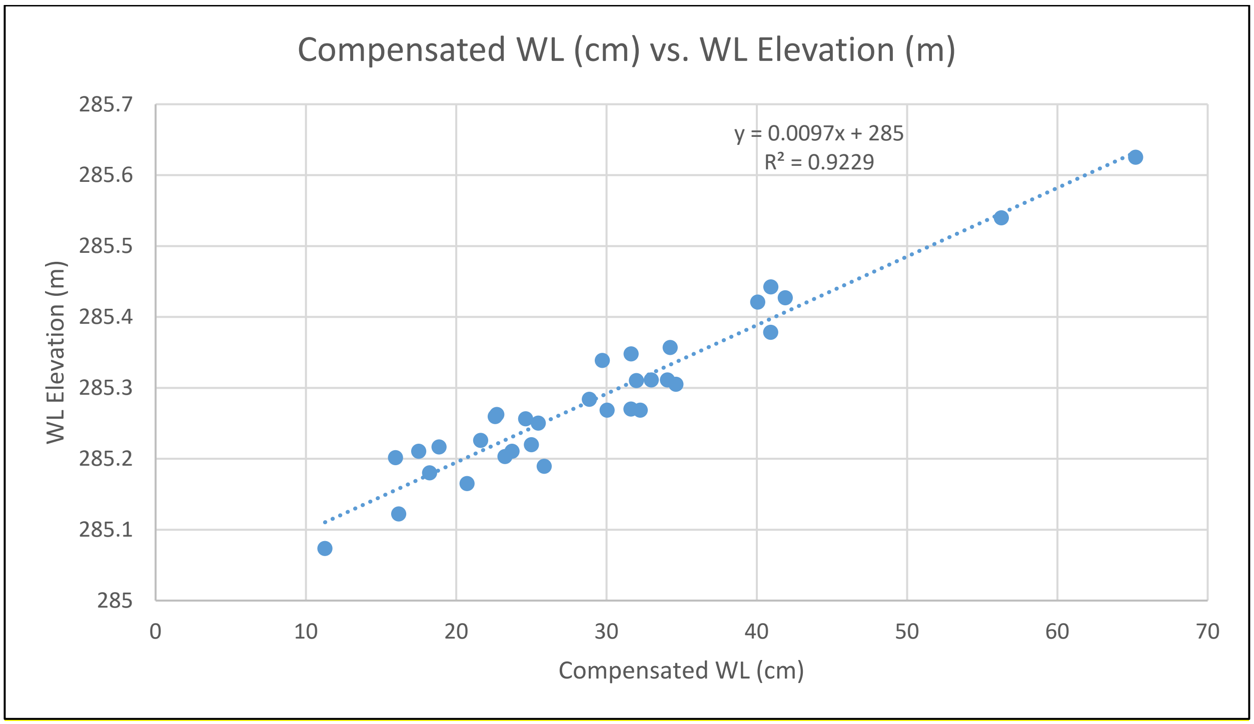

Figure 4. XY scatter plot and linear regression showing compensated pressure transducer water column readings versus manual groundwater elevation measurements.

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 both barometrically compensated nonvented 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 nonvented pressure transducers and downloaded to a laptop computer during site visits. The Martinsville_N replacement well (IGWS Well 552101) and the Lebanon_N well (IGWS Well 062102) have nonvented pressure transducers. Two sites, Indianapolis_N and NewCastle_NE, have vented pressure transducers connected to a datalogger, which can be downloaded either directly using a laptop computer or remotely via a modem. Manual depth-to-water measurements are also 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. Nonvented 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 ObservationAccuracy field in the WATERLEVEL file.

CONSIDERATIONS FOR FUTURE WORK AND PLANNED CHANGES

Unique identifiers for our water assets have not been created. Factors that have hampered that effort include staff changes, entity name changes[1], migration of projects, merging of databases, and an evolution of the purpose of the network. We also have added wells of opportunity, drilled new wells, and adopted other groundwater assets (springs), which has complicated the processes, inventory, and numbering systems already in place. The lack of unique identifiers is creating an inventory problem that is spilling into the NGWMN assets. We plan to standardize well asset inventories.

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[1] The Indiana Geological Survey's (IGS) name was changed to the Indiana Geological and Water Survey (IGWS) as a result of enacted Indiana Senate Bill 416 that took effect on July 1, 2017. The name change required minor revisions to the data files submitted to the NGWMN, but name instances have not completely been changed in all databases, allowing for the lingering IGS stamps echoing around in the networks.

Additional challenges have come in the form of discrepancies between databases for field data, downloaded data, analyzed data, QA/QC data, and served data, along with web API and other coded processes.

The IGWS maintains groundwater data that have undergone quality control procedures in CSV files, while the web API for the NGWMN uses an SQL database. A computer program automatically handles the CSV-to-SQL data import processes and NGWMN web-service data posting. A master location of file directories allows the importer program to look within these directories for CSV files with file names containing NGWMN web-service keywords such as "lithology" or "water levels." These files are checked for valid column headers, and if everything checks out, they are uploaded into the web service. The program keeps track of the last-modified time stamps for these files and imports them again only if they have changed. The files are structured to include data for only one given site. Based on this structure, the program can clear the database of any preexisting data for that site and refresh it with the incoming data. This process prevents duplicate imports.

Currently, there are two APIs to retrieve groundwater data at the IGWS: an older one written in .NET and a newer one written in PHP. The new API uses a real-time data feed between the monitoring stations/wells and the database. The older API relies on ingesting data that is manually retrieved (by IGWS staff) at specific intervals into a database. The two APIs currently pull data from separate databases. To keep the two databases synchronized, text data (CSV) is exported at regular intervals from the database hosting the real-time data, and then that text data is loaded into the other database. As the newer API is just becoming available, the NGWMN website is configured to use the older API. The work for the FY2023 NGWMN is to centralize data storage in a single database by importing both real-time and noncontinuous data into the same tables. These tables will support data collected hourly and daily. This effort will ensure that the most current data is being published to the NGWMN and will simplify updates to the network.

INVESTIGATION RESULTS

Martinsville_N

The Martinsville_N (IGWS Well 552101) boring was drilled to a depth of approximately 70 ft below grade (BG). Recovery of the core from this drill hole was poor, with only 20 % of the material recovered. The gamma log data allows for some additional interpretation of the subsurface units. An upper 4.5 feet of capping silty clay loam overlies a sand and gravel layer present from approximately 4.5 to 23 ft BG. A diamicton layer, present from approximately 23 to 29 ft BG, appears to separate the upper and lower sands and gravels. A lower sand and gravel layer is present from approximately 29 to 41 feet BG. A diamicton layer likely exists from 41 ft BG down to bedrock at 65 ft BG based on gamma log analysis; however, recovery of core indicated gravel was present at this interval. The diamicton was interpreted to be present based on a limited sample volume, balls of diamicton collected in a strainer, and a fine-grained layer noted on the gamma-ray log. The base of this lower unit lies on the shale bedrock surface at approximately 65 ft BG.

The Martinsville_N well is screened from 29.8 to 39.8 ft BG to intercept the lower sand and gravel layer (refer to the well construction log in Appendix B). The upper sand and gravel layer is likely the unit intercepted in the original well at this location.

Continuous groundwater level and temperature measurements have been ongoing, and three site visits have been conducted to measure the depth to groundwater since July 7, 2021. The first measurements were conducted at the installation of the pressure transducer on July 7, 2021 and the last was June 29, 2022. The continuous and discrete measurements match well (Fig. 5). The water levels show seasonal trends of higher groundwater elevations during the winter and spring and lower groundwater elevations in the summer and fall. There is a seasonal difference of approximately 1.5 m in groundwater elevations. Groundwater temperatures range from 12.5 to 12.8 degrees Centigrade (°C). Consistent groundwater temperatures are an energy source for ground-source heat pumps. Changes in temperatures lag slightly behind changes in groundwater elevations.

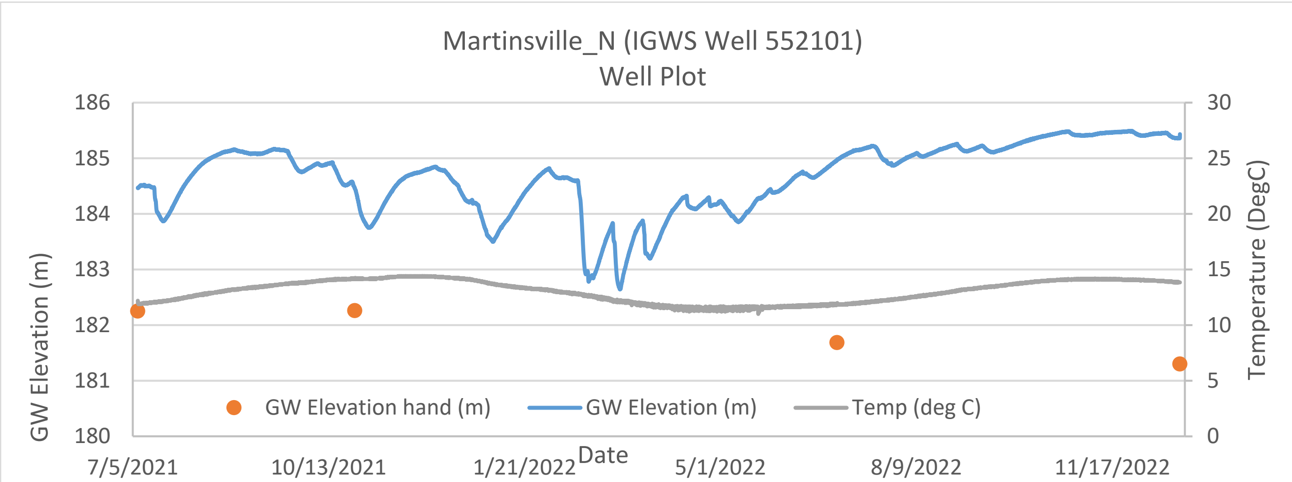

Figure 5. Graph showing groundwater elevations and temperatures over time compared with the hand-measured groundwater elevations for the Martinsville_N well (IGWS Well 552101).

Lebanon_N

The Lebanon_N (IGWS Well 062102) boring was drilled to a depth of approximately 235 ft BG. Primarily, three main sand and gravel layers separated by diamicton are seen within this well. The sand and gravel layers are present at approximately 60 to 100 ft, 120 to 140 ft, and 195 to 220 ft BG. Users of water within a 5-mile radius include residential and agricultural, and golf courses that depend on aquifers at similar depths to these units, with the majority in the upper or middle units. Bedrock contact was not encountered at this location.

A reddish-brown (5YR4/3) diamicton was encountered from approximately 227 to 235 ft BG. The diamicton appears to abruptly change from unoxidized to oxidized weathering zones at approximately 220 ft BG. This is a very thick oxidized zone and, if the interpretation is correct, may represent weathering during an older interglacial period.

The Lebanon_N well is screened from 197 to 207 ft BG to intercept the intermediate sand and gravel layer from approximately 195 to 220 ft BG (refer to the well construction log in Appendix C). The two upper sand and gravel layers are other potential sources of groundwater.

Continuous groundwater level and temperature measurements have been ongoing, and four site visits have been conducted to measure the depth to groundwater since August 5, 2021. The first year of measurements includes almost a full water year (October to October). The continuous and discrete measurements match well (Fig. 6). The graph shows seasonal trends of higher groundwater elevations during the winter and spring and lower groundwater elevations in the summer and fall. There is a seasonal difference of approximately 1.5 m in groundwater elevations. Groundwater temperatures are consistently 12.5 to 12.8 °C. Consistent groundwater temperatures are an energy source for ground-source heat pumps.

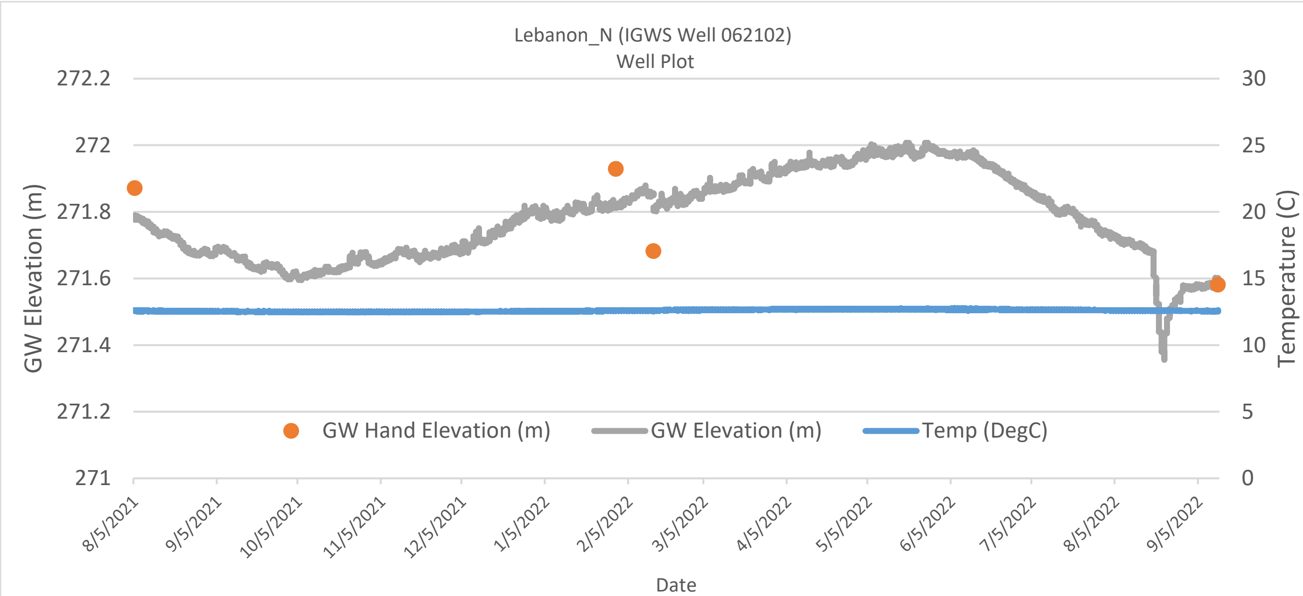

Figure 6. Graph showing instrument-read groundwater elevations and temperatures over time compared with hand-measured groundwater elevations for the Lebanon_N well (IGWS Well 062102).

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.

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Appendix A

Example field forms

CGDA IWBN Site Check
Field Checklist
V20211213

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:		

4. Download Data:
(Pressure transducers AND Barologgers)

Name	Serial Number	Site Name	Log Name	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: ____

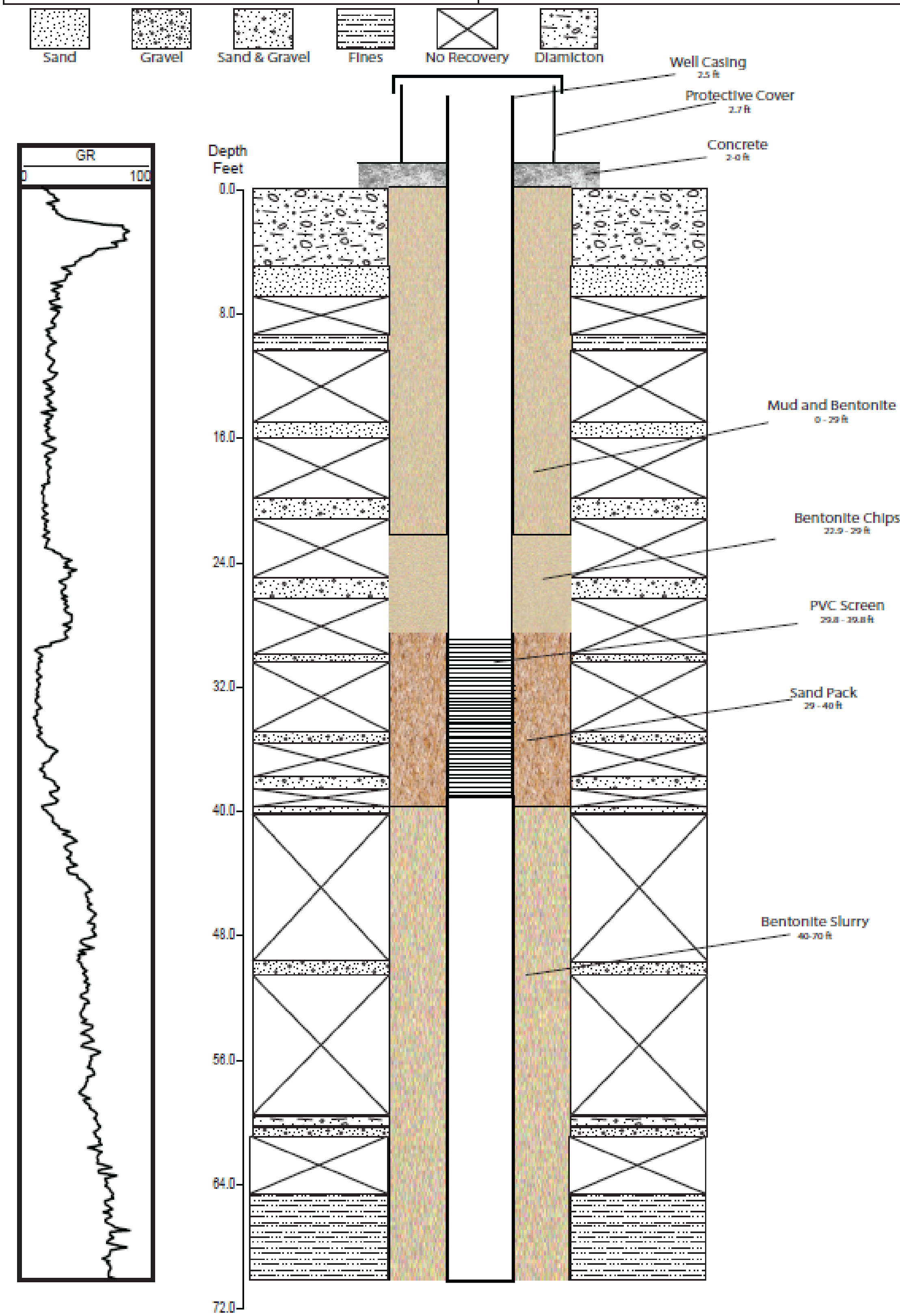
Post-field work instructions:
1. Complete and scan form into pdf document. Save pdf document to following folder: P:\565_IWBN\data downloads\Field notes. Include site name and date in pdf file name (e.g., 20200127_Site_Check_Bradford-Woods_IWBN.pdf).
2. Download raw and compensated ptrans file(s) to P:\565_IWBN\data downloads\groundwater well data\"site name", create folder with date in folder name (e.g., 20160509_ptrans-download))
3. Download Extech files into P:\565_IWBN\data downloads\Extech downloads\"site name"
4. Upload photos into P:\565_IWBN\Photographs
5. Update IWBN_schedule
6. File paper copy in 3-ring binder associated with each site.

Appendix B

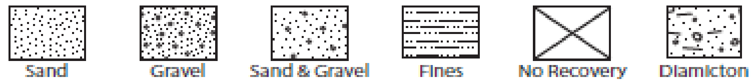
Martinsville_N (IGWS Well 552101)

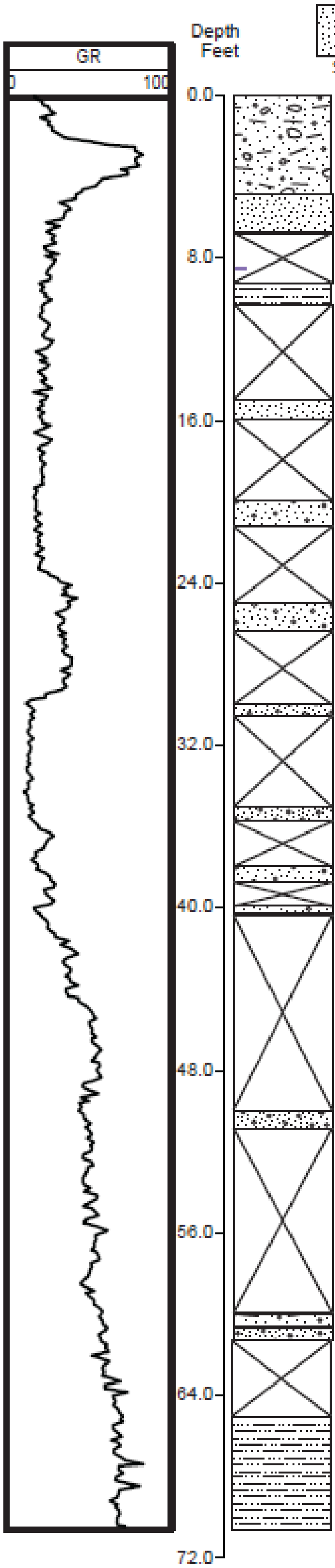
Gamma ray, well construction, and lithology logs

ID Number	IGWS Well 552101	Date:	5/24/2021-5/25/2021
Site Name	Martinsville_N	By:	Ginger Davis & Addie Jenkinson
Location:	Martinsville IN	Notes:	Prepared for NGWMN final report
Ground Elevation:	606.95 ft	Lat: 39.49887	Long: -86.4271



ID Number	IGWS Well 552101	Date:	5/24/2021-5/25/2021
Site Name	Martinsville_N	By:	Ginger Davis & Addie Jenkinson
Location:	Martinsville IN	Notes:	Prepared for NGWMN final report
Ground Elevation:	606.95 ft	Lat: 39.49887	Long: -86.4271





(0-4.4) Silty clay loam (Fm), massive, dark yellowish-brown (10YR3/4), moist, oxidized-leached, none HCl reaction, stiff consistency, gradational lower contact, dark brown soil. No clasts. Uniform in color and texture. Medium-sized roots in the first 33 cm and fine roots in the first 60 cm. Grass on top. Massive structure on the first 80 cm and then a thin, platy structure emerges.

(4.4-4.7) Sandy loam and gravel (Dmm), with some (31-49 %) granules (2-4 mm), massive, dark brown (10YR3/3), moist, oxidized-leached, none HCl reaction, medium dense consistency, gradational lower contact, cohesive sandy/loam/gravel layer. Transition/mixing layer between silty loam soil and sand below.

(4.7-5.5) Sand (Sm), with trace (<5 %) granules (2-4 mm), massive, dark yellowish-brown (10YR4/6), dry, oxidized-leached, none HCl reaction, dark yellowish-brown sand. Noncohesive. Coarse/medium sand.

No Recovery

(8.5-8.58) Silty clay (Dmm), with few (6-15 %) granules (2-4 mm), massive, dark yellowish-brown (10YR4/4), wet, reduced-unleached, weak HCl reaction, soft consistency, outside of core quickly reduced in storage. Olive brown/greyish on the inside. Inside reacts weakly to HCl. Brown does not react to HCl.

No Recovery

(15-16) Sand (SG), with little (16-30 %) granules to med (2-16 mm) massive, moist, reduced-unleached, strong HCl reaction, loose consistency. No lower transition. Gravel layer. Mostly non-cohesive. One cohesive clump (~8 cm) held together by olive brown (2.5Y4/4) clay. Some parts are semi-cohesive, but loose. Gravel is 70 % granule/fine sized with 30 % medium gravel.

No Recovery

(20-21.3) Sandy clay and gravel (Gms), with little (16-30 %) coarse gravel (16-32 mm), massive, olive brown (2.5Y4/4), wet, reduced-unleached, strong HCl reaction, medium dense consistency, gravel layer with various sized gravel. 15 % coarse gravel - loose from matrix, 50 % granule/fine gravel - some loose some cohesive within matrix, 35 % sandy clay. Cohesive. Olive brown with slight amounts of light gray mottling.

No Recovery

(25-26.4) Sand and gravel (SG), with trace (<5 %) very coarse gravel (32-64 mm), massive, moist, reduced-unleached, strong HCl reaction, very loose consistency.

No Recovery

(30-30.5) Gravel (G), medium-sized (8-16 mm), massive, dry, reduced-unleached, strong HCl reaction, very loose consistency, loose gravel layer.

No Recovery

(35-35.7) Gravel (G), massive, dry, reduced-unleached, strong HCl reaction, very loose consistency. Gravel averages 8-20 mm, small amounts of dark grey/olive clay coating gravel. Reactive to HCl.

No recovery.

(38-38.7) Sand and gravel (SG), massive, moist, reduced-unleached, strong HCl reaction, very loose consistency, no fine matrix.

No Recovery

(40-40.3) Sand and gravel (SG), massive, moist, reduced-unleached, strong HCl reaction, very loose consistency, no fine matrix.

No Recovery

(50-50.8) Gravel (G), massive, wet, reduced-unleached, strong HCl reaction, very loose consistency, slight matrix of soupy fine-grained sediment (maybe drilling clay). Sludge is dark grayish-brown.

No Recovery

(60-60.6) Silty clay and gravel (Gms), massive, dark gray (Gley1 4/10Y), moist, reduced-unleached, strong HCl reaction, very loose consistency, 85 % loose large rocks (~3-5 cm) in a bag. 15 % Silty clay. Gley1 4/10Y.

(60.6-61.2) Gravel (G), massive, moist, reduced-unleached, strong HCl reaction, very loose consistency.

No Recovery

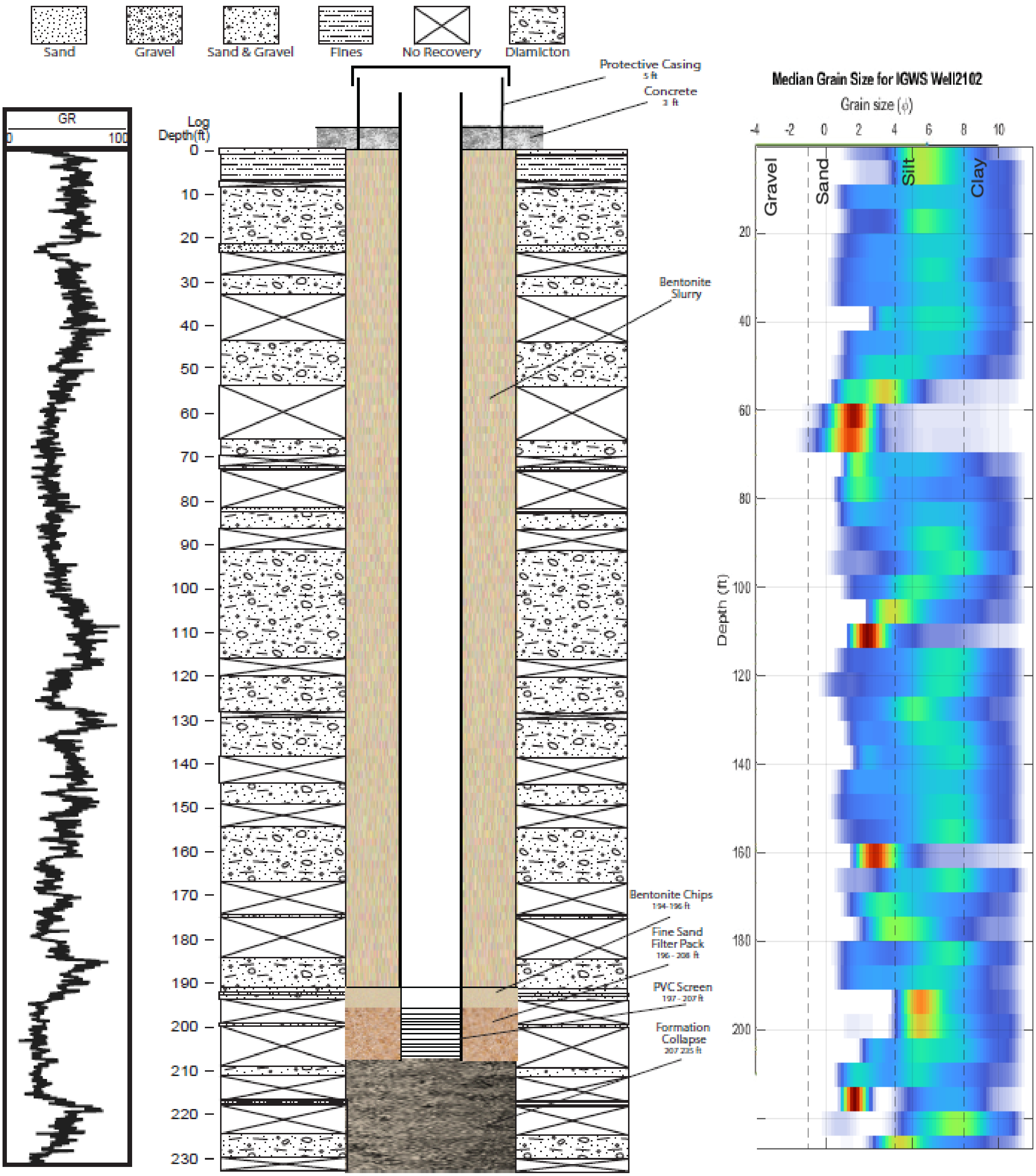
(65-70.6) Shale bedrock (Fl), laminated, very dark gray (Gley1 3/5GY), dry, reduced-unleached, moderate HCl reaction, very stiff consistency. Laminated structure that breaks off into plates. Few large clasts, inclusions in shale weathering seen on clasts.

Appendix C

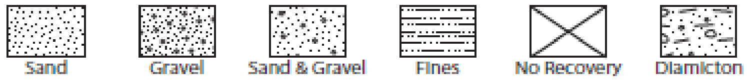
Lebanon_N (IGWS Well 062102)

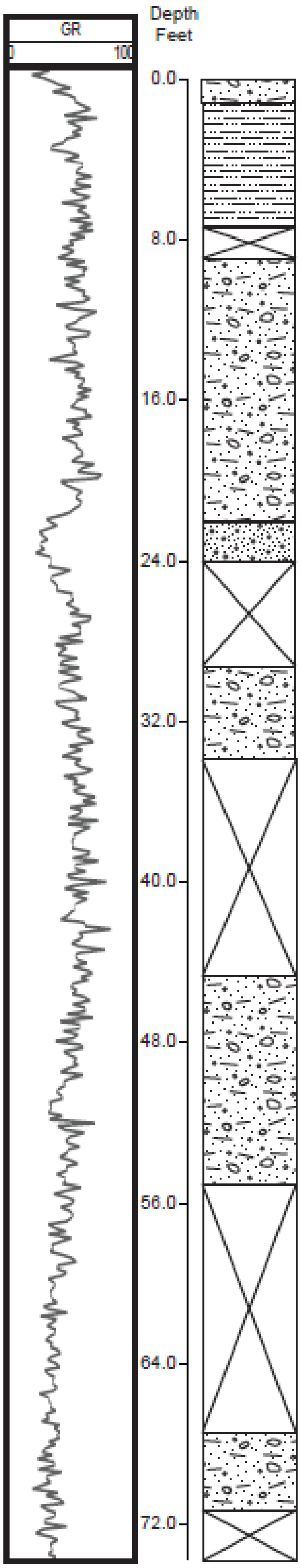
Gamma ray, well construction, particle size analysis, and lithology logs

ID Number:	IGWS Well 062102	Date:	6/2/202 - 6/3/2021
Site Name:	Lebanon_N	By:	Ginger Davis & Addie Jenkinson
Location:	Lebanon IN	Notes:	Prepared for NGWMN final report
Ground Elevation:	926.25 ft	Lat: 40.1262505	Long: -86.4196828



ID Number:	IGWS Well 062102	Date:	6/2/202 - 6/3/2021
Site Name:	Lebanon_N	By:	Ginger Davis & Addie Jenkinson
Location:	Lebanon IN	Notes:	Prepared for NGWMN final report
Ground Elevation:	926.25 ft	Lat: 40.1262505	Long: -86.4196828





(0-1.2) Sandy loam (Dmm), with trace (<5 %) med. gravel (8-16 mm), massive, very dark grayish-brown (10YR3/2), moist, oxidized-leached, no HCl reaction, sharp lower contact, non-calcareous, pieces of grass root. Lower transition is a relatively sharp color contact. May be anthropogenic.

(1.2-2.9) Silty clay (Dmm), with trace (<5 %) granules (2-4 mm), massive, dark brown (10YR3/3), moist, oxidized-leached, no HCl reaction, gradational lower contact, gradual transition zone between colors. 30 % sec color value with increasing frequency lower in core, 70 % primary color hue. Translocation of organic material through roots or between peds. Small amount of roots.

(2.9-4.3) Silty clay (Dmm), with trace (<5 %) granules (2-4 mm), massive, dark brown (10YR3/3), moist, oxidized-leached, no HCl reaction, gradational lower contact. Drilling error from 124-131 cm interrupts lower transition. Oxidized soil 45 % primary color, 45 % secondary color in uniform distribution ~ 10 % yellow and orange hues.

(4.3-7.3) Silty clay (Dmm), with trace (<5 %) granules (2-4 mm), massive, brown (10YR4/3), moist, oxidized-leached, no HCl reaction, sharp lower contact, 25 % secondary color hue in gradual decreasing amounts down the profile, oxidized, non-calcareous soil. Sharp lower transition into denser clay.

No Recovery

(8.9-14.2) Sandy clay (Dmm), with few (6-15 %) med. gravel (8-16 mm), massive, brown (10YR5/3), wet, oxidized-, strong reaction to HCl, sharp lower contact, very dense clay. ~98 % 10YR 5/3 with small (1-2 mm) infrequent spots of oxidized red. 138-143 cm very wet (mud); @10 ft drilling clay pellets in the core.

(14.2-15) Sandy clay (Dmm), with few (6-15 %) fine gravel (4-8 mm), few (6-15 %) clast ranging in size from granules to a few cobbles, massive, dark gray (5Y4/1), uniform in color, moist, reduced, strong reaction to HCl, sharp lower contact.

(15-22) Sandy clay (Dmm), with few (6-15 %) fine gravel (4-8 mm), few (6-15 %) clast ranging in size from granules to a few cobbles, massive, dark gray (5Y4/1), uniform in color, moist, reduced, strong reaction, sharp lower contact, same sandy clay as above.

(22-24) Gravel (G), with granules to coarse (2-32 mm), trace amounts of clay and sand.

No Recovery

(29.2-30) Sandy clay (Dmm), with little (16-30 %) granules to coarse (2-32 mm), massive, olive brown (2.5Y4/3), moist, reduced, strong reaction to HCl, yellow/greenish gray clay with various sized clasts (granules to very coarse). Thin line of dark gray at the upper transition.

(30-33.9) Sandy clay (Dmm), with few (6-15 %) granules to coarse (2-32 mm), massive, dark gray (10YR4/1), uniform in color and texture, moist, reduced-unleached, strong reaction to HCl, very gritty high sand content. Occasional clasts of various size (granule to coarse gravel). Calcareous clasts.

No Recovery

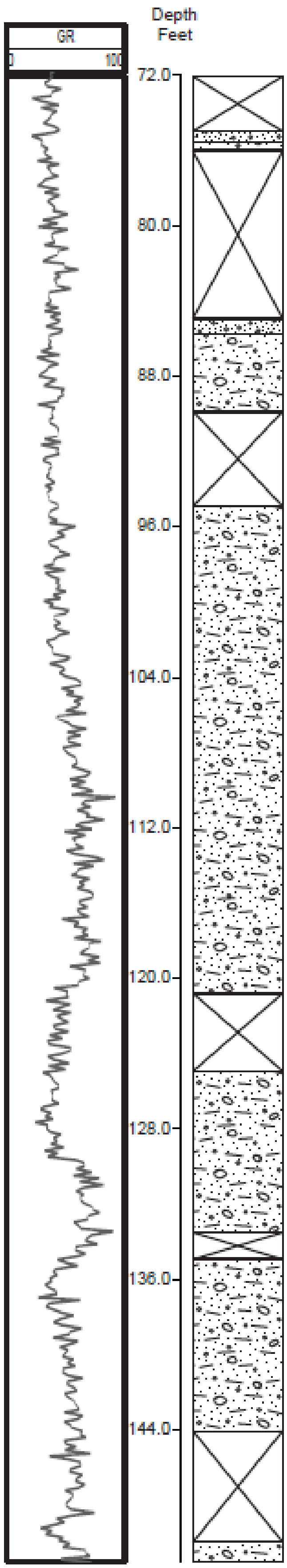
No Recovery

(44.6-50) Sandy clay (Dmm), with few (6-15 %) granules to coarse (2-32 mm), massive, dark gray (10YR4/1), uniform in color and texture, moist, reduced-unleached, strong reaction to HCl, very gritty, high sand content. Occasional clasts of various size (granule to coarse gravel). Calcareous clasts.

(50-55) Sandy clay (Dmm), with few (6-15 %) granules to coarse (2-32 mm), massive, very dark grayish-brown (10YR3/2), moist, reduced-unleached, strong reaction to HCl, very stiff consistency. Very gritty/sandy, calcareous, and uniform in color and texture, core topped with a 19 cm rock clast in core.

No Recovery

(67.4-68) Sandy clay loam (Dmm), with trace (<5 %) granules (2-4 mm), massive, olive brown (2.5Y4/3), wet, reduced -unleached, strong reaction to HCl, medium dense consistency, wet sand. Fairly cohesive especially when dry. Uniform olive brown color, but individual sand granules can still be seen as well. Calcareous.



No Recovery

(75-75.6) Gravel (G), massive, moist, reduced-unleached, strong reaction to HCl, loose consistency, gradational lower contact, layer of loose coarse gravel. Gradational transition to the clay layer below.

(75.6-76.1) Sandy clay (Dmm), with some (31-49 %) fine gravel (4-8 mm), dark gray (2.5Y4/1), moist, reduced-unleached, strong reaction to HCl, stiff consistency. Clay in cohesive clumps rather than one cohesive unit. 31-49 % fine gravel and granules dispersed evenly throughout the layer.

No Recovery

(85-85.9) Gravel (G), massive, moist, moderate reaction to HCl, loose consistency.

(85.9-89.9) Sandy clay loam (Dmm), with little (16-30 %) granules to coarse (2-32 mm), massive, dark gray (10YR4/1), moist, reduced-leached, strong reaction to HCl, very stiff consistency, high plasticity and able to form a medium ribbon. Feels very gritty. Uniform color and texture. Calcareous clasts range in size, 95 % granules and fine gravel.

No Recovery

(95-118) Sandy clay (Dmm), with few (6-15 %) granules to coarse (2-32 mm), massive, dark gray (10YR4/1), moist, reduced-unleached, strong reaction to HCl, very stiff consistency. Uniform in texture and color. Clasts ranging in size, 50 % granules, 50 % coarse sand.

(118-118.5) Sandy clay (Dmm), with trace (<5 %) fine gravel (4-8 mm), massive, olive gray (5Y4/2), moist, reduced-leached, no reaction to HCl, very stiff consistency, gradational lower contact, gradational transitional layer from olive sandy clay into brown loam. Olive sandy clay dominates 75-80 %. Increasing sand content with decreasing depth. Trace amounts of fine gravel.

(118.5-120.8) Clay loam (Dmm), with trace (<5 %) coarse gravel (16-32 mm), olive brown (2.5Y4/4), moist, reduced. Top half of unit has no HCl reaction while bottom half has a strong reaction, medium consistency, olive brown clay loam. Uniform in color and texture, no clasts throughout unit except for one layer of coarse gravel ~3-4 cm long at the bottom.

No Recovery

(125-128.1) Sandy loam (Dmm), massive, olive brown (2.5Y4/3), moist, reduced-unleached, strong reaction to HCl, medium consistency, sharp lower contact, fining upward. Grading to coarse sand within matrix followed by a sharp gravel-rich layer at base.

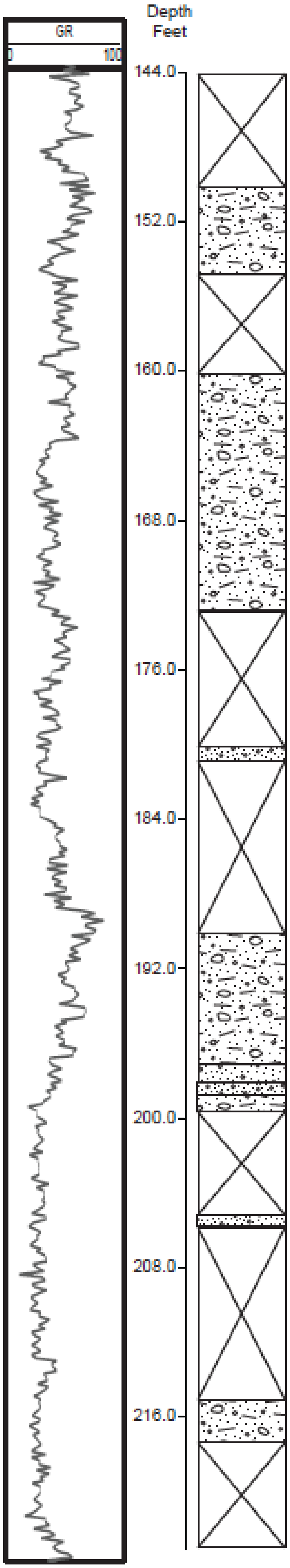
(128.1-128.8) Sandy clay (Dmm), with few (6-15 %) granules to coarse (2-32 mm), massive, uniform texture, olive brown (2.5Y4/4), moist, reduced-unleached, strong reaction to HCl, medium consistency, sharp lower contact, sandy clay transition zone. 80 % olive brown color with 29 % dark gray mottles at the lower transition.

(128.8-132.9) Sandy clay (Dmm), with few (6-15 %) med. gravel (8-16 mm), massive, very dark grayish-brown (2.5Y3/2), moist, reduced-unleached, no reaction to HCl, very stiff consistency, sharp lower contact. Uniform in color and texture. Very dense, clast abundance and size is uniform throughout, sharp lower transition to brown clay.

(132.9-133.6) Sandy clay (Dmm), with trace (<5 %) granules (2-4 mm), massive, olive brown (2.5Y4/4), moist, reduced-unleached, strong reaction to HCl, very stiff consistency. Sand content increases with depth. Some horizontal gray banding. Density decreases with increasing depth. No lower transition.

No Recovery

(135-136.5) Sandy loam and gravel (SGmg), with some (31-49 %) fine gravel (4-8 mm), massive, olive brown (2.5Y4/4), wet, reduced-unleached, moderate reaction to HCl, medium dense consistency, gradational lower contact. Gravel is semi-cohesive and concentrated at the bottom of the layer. Sand is cohesive ~3-4 cm of a gley 2.5/5GY sand concentration at the bottom of the layer.



(143.3-144.1) Sandy clay (Dmm), with some (31-49 %) boulder (>256 mm), massive, very dark grayish-brown (10YR3/2), moist, reduced-unleached, strong reaction to HCl, very stiff consistency, no lower transition.

No Recovery

(150-154.8) Sandy clay (Dmm), with few (6-15 %) med. gravel (8-16 mm), massive, very dark grayish-brown (10YR3/2), moist, reduced-unleached, strong reaction to HCl, very stiff consistency, No lower transition. Uniform in texture. Color becomes slightly more olive toned around 154 ft (4693 cm). Uniform clast abundance throughout.

No Recovery

(160-163.3) Sandy clay (Dmm), with few (6-15 %) granules to coarse (2-32 mm), massive, dark gray (10YR4/1), moist, reduced-unleached, strong reaction to HCl, very stiff consistency. No lower transition. Dark gray sandy clay with high sand content (very gritty). Very dense. Bottom 20 cm of section has mottling of light 10YR5/1 and dark 10YR3/1 clay. No sand in mottled zones.

(170-171.1) Sandy loam (Dmm), with trace (<5 %) fine gravel (4-8 mm), massive, olive brown (2.5Y4/3), moist, reduced-unleached, moderate reaction to HCl, medium consistency, cohesive sandy loam layer. Very fine sand. No lower transition. Clasts fairly uniform in size.

(171.1-172.1) Sandy clay (Dmm), with trace (<5 %) med. gravel (8-16 mm), massive, dark grayish-brown (2.5Y4/2), moist, reduced-unleached, strong reaction to HCl, very stiff consistency, sharp lower contact. Clay is not excessively gritty, suggests low sand content or fine-grained sand. Uniform in texture and color. Clast distribution is more frequent near the bottom. Sharp transition into a lighter shade clay.

(172.1-172.1) Sandy clay loam (Dmm), massive, light brownish-gray (2.5Y6/2), moist, reduced-unleached, strong reaction to HCl, very stiff consistency, sharp lower contact, Very small sandy clay loam layer. Noticeably sandier and lighter in color than the layers above and below.

(172.1-172.7) Silty clay (Fm), gray (10YR5/1), moist, reduced-unleached, strong reaction to HCl, very stiff consistency, sharp lower contact. Trace amounts of sand. Small inclusions of light gray clay. No larger clasts. First 5 cm are a cohesive, very stiff unit. The remaining section is looser.

No Recovery

(180-180.6) Gravel (G), moist, strong reaction to HCl, very loose consistency. Clasts average 2-4 cm in size. Clay is about 2.5Y3/2 in color, but is nonuniform. Sandy clay texture.

No Recovery

(190-197) Sandy clay (Dmm), with little (16-30 %) fine gravel (4-8 mm), massive, dark yellowish-brown (10YR4/4), moist, reduced-unleached, strong reaction to HCl, very stiff consistency, sharp lower contact. Very dense. Sparse orange banding starts to occur at 193.5 ft depth.
At 193.2 ft there is ~1 inch of very dense, dry, pale brown clay.

(197-198.1) Sand and gravel (SGm), massive, moist, reduced-unleached, strong reaction to HCl, medium dense consistency, cohesive sand and gravel layer. 50 % gravel, 50 % sandy loam - 10YR4/4 and moderate plasticity, no lower transition.

(198.1-198.6) Gravel (G), dry, strong reaction to HCl, very loose consistency. Clasts average 2-5 cm.

(198.6-199.5) Sandy loam (Dmm), with few (6-15 %) fine gravel (4-8 mm), massive, olive brown (2.5Y4/4), wet, reduced-unleached, moderate reaction to HCl, medium dense consistency. Cohesive. Slight plasticity and able to hold shape when formed. Small concentrations of gray clay at the top of the section. Resembles drilling clay.

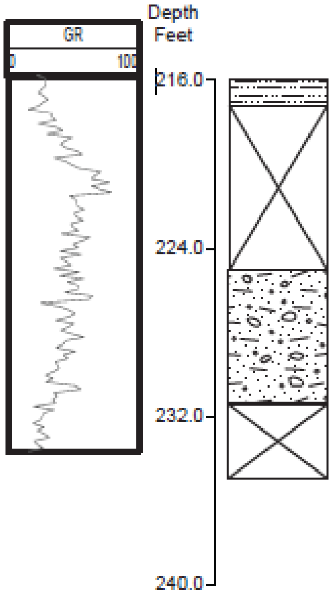
No Recovery

(205-205.6) Gravel (G), moist, strong reaction to HCl, very loose consistency. Gravel layer with a little bit of clay on rocks. Clasts average 2-4 cm. Clay is about 2.5Y3/2 in color, but is nonuniform. Sandy clay texture.

No Recovery

(215-215.9) Sandy loam (Dmm), with few (6-15 %) granules (2-4 mm), olive brown (2.5Y4/4), moist, reduced-unleached, moderate reaction to HCl, medium dense consistency, sharp lower contact, sandy layer. Majority medium/coarse sand, but able to hold shape when squeezed. Uniform matrix color and uniform clast distribution.

(215.9-216.2) Silty clay (Fl), laminated, light olive brown (2.5Y5/4), moist, reduced-unleached, strong reaction to HCl, medium consistency, sharp lower contact, banded layers of silty clay. 75 % primary color, 25 % secondary color of bands, uniform texture. Semi dense.



(215.9-216.2) Silty clay (Fl), laminated, light olive brown (2.5Y5/4), moist, reduced-unleached, strong reaction to HCl, medium consistency, sharp lower contact, banded layers of silty clay. 75 % primary color, 25 % secondary color of bands, uniform texture. Semi dense.

(216.2-216.3) Silty clay (Fl), laminated, dark grayish-brown (2.5Y4/2), moist, reduced-unleached, strong reaction to HCl, medium consistency, bands of silty clay. Semi-dense. Uniform in texture. 50 % light gray, 50 % dark gray, lower transition is unknown. It occurs during a cut between two cores, could be missing.

(216.3-217.2) Sandy clay (Dmm), with few (6-15 %) granules to med (2-16 mm), massive, olive brown (2.5Y4/4), moist, reduced-unleached, strong reaction to HCl, stiff consistency, gradational lower contact, cohesive sandy clay with uniform texture throughout. 60 % primary color, 40 % secondary color. Larger clasts at the bottom of the section.

No Recovery

(225-226.4) Sandy clay (Dmm), with few (6-15 %) fine gravel (4-8 mm), massive, dark grayish-brown (10YR4/2), moist, reduced-unleached, strong reaction to HCl, very stiff consistency, sharp lower contact, dark gray/brown sandy clay. Uniform in texture. Color uniform except for the lower transition where there is ~2 cm of dark blue/green sand.

(226.4-226.6) Silty clay (Fl), massive, dark brown (10YR3/3), moist, oxidized-leached, no reaction to HCl, medium consistency, sharp lower contact. Thick silty clay layer, dark brown in color. Sharp upper and lower transition. Slight horizontal platy structure.

(226.6-227) Silty clay loam (Fl), massive, dark yellowish-brown (10YR3/6), moist, oxidized-leached, no reaction to HCl, medium consistency. Brown silty clay loam. Uniform in color and texture. Very thin plates forming.

(227-230.8) Sandy clay (Dmm), with some (31-49 %) granules to med (2-16 mm), massive, dark reddish-brown (5YR3/4), moist, oxidized-leached, no reaction to HCl, very stiff consistency, sharp lower contact, dark red sandy clay. Very gritty/coarse sand texture. Large number of clasts. Occasional large clasts (3-5cm), Large amount of olive brown spots (2-8mm) of clasts that have been weathered into spots. Large amount of various colored granules/fine gravel.

(230.8-231.4) Sandy loam (Sm), massive, dark reddish-brown (5YR3/4), moist, oxidized-leached, no reaction to HCl, dense consistency. Dark red sandy loam. Sand medium-grained.

No Recovery