INDIANA GEOLOGICAL & WATER SURVEY
INDIANA UNIVERSITY

Final Technical Report

Project Title:

Expanding the Indiana Geological and Water Survey's contribution to the National Ground-Water Monitoring Network (NGWMN)

Name:

Indiana Geological Survey

Award Number:

G18AC00072

Award Term:

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Objectives:

2. Support persisting data service from existing data providers
5. Well drilling

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OVERVIEW OF WORK

The Indiana Geological and Water Survey (IGWS) became a new data provider to the USGS National Ground-Water Monitoring Network (NGWMN) with the agreement 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 second award under the NGWMN program for an existing data provider with the agreement under the FY2018 NGWMN program announcement with agreement dates from 9/1/2018 to 8/31/2020 (Grant/Cooperative Agreement Number: G18AC00072).

The work addresses two NGWMN program objectives during the two-year project period: 1) support persistent data services from existing data providers, and 2) install two new monitoring wells. The existing NGWMN web services for water-level data, lithology, and well construction parameters are maintained to support persistent data services. Also, in addition to the ongoing support of persistent data services, we updated our web-hosting structure during year-1 to facilitate the automated updating of web services when new data have undergone quality assurance and quality control (QA/QC) procedures. The automated updating includes data checking logic that will limit mistakes and unnecessary data handling. Finally, we installed two additional groundwater monitoring wells during project year-2 to address water-resource questions and improve the spatial distribution of NGWMN sites in Indiana.

Data was compiled and organized into NGWMN formats from a preexisting micrometeorological and groundwater monitoring network referred to as the Indiana Water Balance Network (IWBN). The IWBN web site is: https://igws.indiana.edu/CGDA/waterBalanceNetwork.cfm. Data contributed from the IWBN to the NGWMN can be found at: https://cida.usgs.gov/ngwmn/.

During the previous new data provider phase, the well registry was completed for all twelve IGWS NGWMN sites. Subsequently, Web services were developed and posted for water-level, lithology, well casing, and well screen data/metadata for sites where the necessary information was readily available. Fieldwork and data processing protocols were also documented and included herein. Persistent data services accomplished during year-2 included updates of water-level web services with new data that underwent quality assurance protocols.

As a point of clarification, The Indiana Geological Survey's (IGS) name was changed to the Indiana Geological and Water Survey (IGWS) as a result of 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.

DESCRIPTION OF EXISTING WATER-LEVEL NETWORKS

Several past projects undertaken at the IGWS resulted in the collection of continuous data related to water balance parameters (especially weather/potential evapotranspiration, soil moisture, and groundwater elevation). In lieu of removing sensors following project completion, IGWS researchers developed the Indiana Water Balance Network (IWBN) to monitor long-term trends in water loss and gain for multiple components of the hydrologic budget for 12 sites, which are representative of various hydrogeologic settings and underlying aquifer systems.

Groundwater-elevation data are collected primarily to determine how groundwater levels are changing over time (i.e., trend monitoring described in ACWI, 2013). Data from sites with continuous/high-frequency water-level records are also used to assess groundwater-recharge dynamics for the various hydrogeologic settings.

DESCRIPTION OF SITE SELECTION CRITERIA AND PROCESS

Twelve groundwater monitoring wells were chosen from 33 wells where the Indiana Geological and Water Survey (IGWS) is actively monitoring groundwater in Indiana as part of the Indiana Water Balance Network (IWBN) (Figure 1, Table 1). The groundwater monitoring sites were selected based on four primary criteria: their density/spatial distribution throughout Indiana, their depth relative to other wells in the vicinity, their unique representation of regional (IDNR, 2011) and national aquifers (ACWI, 2013), and the availability of minimum data requirements as outlined in the national groundwater monitoring framework document (ACWI, 2013). Multiple wells are present at each site, but the deeper well was typically selected for inclusion in the NGWMN because these wells could represent more extensive regional aquifers.

The focus of the IGWS groundwater monitoring program is to establish baseline conditions and track long-term water-level fluctuation trends. Hence, each of the selected wells is categorized as "trend" monitoring wells, consistent with the NGWMN framework document (ACWI, 2013).

Table 1. List of wells from the IWBN selected for NGWMN. The table includes a portion of the data provided in the Well Registry table including field names.

SiteName	DecLatVa	DecLongVa	AltVa	AltUnits	WellDepth	WellDepthUnits
Rushville_S	39.5799721	-85.4649384	287.87	m	3.08	m
FortWayne_N1	41.2476	-85.118248	266.65	m	30.5	m
FortWayne_N2	41.2477149	-85.139121	256.05	m	22.08	m
Muncie_N	40.2221534	-85.4232041	285.94	m	10.09	m
Martinsville_N	39.496509	-86.428606	184.58	m	3.34	m
Glenwood_N	39.6383908	-85.2916502	335.14	m	4.92	m
Indianapolis_N	39.818356	-86.204417	215.05	m	1.22	m
LakeStation_W	41.5845385	-87.2753423	179.76	m	2.54	m
Brownsburg_N1	39.8944763	-86.3730135	278.11	m	11.97	m
NewCastle_NE	40.053383	-85.314942	307.41	m	0.86	m
Newburgh_E	37.9480863	-87.296249	142.95	m	27.13	m
Bloomington_N	39.194058	-86.512716	231	m	3.8	m
Atlanta_S	40.20951658	-86.02688488	261.27	m	34.7	m
Nappanee_NE	41.45401042	-85.98379445	265.654	m	47.6	m

LIST OF MINIMUM DATA ELEMENTS AND HOW THEY ARE PROVIDED TO DATA PORTAL

All sites were assigned unique site number identifiers, and site names were standardized to include a geographic reference (nearest city and direction of the site relative to the city). Well construction/completion logs were gathered for groundwater monitoring wells selected for inclusion in the NGWMN. Because the deeper groundwater monitoring wells are often “wells of opportunity” that were not installed by IGWS personnel, the well construction details existed in multiple formats including geotechnical report records, Indiana Department of Natural Resources (IDNR) well driller logs, and geologist field notes. Information related to well screen and well casing characteristics were gleaned from the construction/completion logs and entered into the NGWMN Web service data structures as shown in Tables 2 and 3.

Table 2. Well casing and well screen web service data elements

Well casing web service	Well screen web service
Agency code	Agency code
Site number	Site number
Casing depth from	Screen depth from
Casing depth to	Screen depth to
Casing depth units	Screen depth units
Casing material	Hole size
Casing diameter	Hole size units
Casing diameter units	Screen material
	Screen diameter
	Screen diameter units

Lithologic data included in the NGWMN web service (Table 3) were also obtained from multiple sources used to extract well construction information (geotechnical logs, driller’s logs, and field notes) and additional resources (hydrogeologic reports, masters theses) were used to extract more detailed lithologic information. Lithologic units were standardized based on USGS conventions from the Rock Term Abbreviation table in Section 6.11.1.4 of the User’s Manual for the National Water Information System of the U.S. Geological Survey Ground-Water Site-Inventory (USGS, 2004). The textural (i.e., grain size) term was chosen that best matched the above lithologic data. Till is listed in the USGS table and is a heterogeneous mixture of clay, silt, sand, and gravel but the closest grain size term is “Sand, gravel, and clay.” Sand, gravel, and clay was selected for till or diamictons.

Groundwater-level data were compiled for the NGWMN water-level web service for the deepest monitoring wells at each monitoring location. 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, including the data elements listed in Table 3 (see Description of Data Quality and Quality Assurance Processes section for more details).

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. 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. The Indianapolis_N and Martinsville_N sites will be upgraded with new vented pressure transducers installed into recently drilled deeper wells bringing the total to three sites with vented pressure transducers. 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 using hourly time intervals. The 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.

Table 3. Lithology and water-level Web service data elements

Lithology web service	Water-level web service
Agency code	Agency code
Site number	Site number
Lithology ID	Time (ISO 8601)
Observation method	Original parameter
Lithology depth from	Original unit
Lithology depth to	Original value
Lithology depth units	Depth to water below land surface
	Observation method
	Data provided by
	Observation accuracy
	Accuracy unit

NOTES ON ANY SITES THAT HAVE MISSING REQUIRED DATA ELEMENTS

Many missing data components were located and compiled during the year-2 of the project, but some sites continue to lack the required elements. After searching through existing files and inquiring with previous monitoring coordinators, lithology logs are not currently available for the NewCastle_NE and Bloomington_N sites (see Figure 1 for locations). However, visits to these sites were not conducted during the 2019 spring/summer field season to obtain geophysical logs or cores if funds and site access (for coring) and

COVID-19 pandemic closures prevented visits during the 2020 field spring/summer field season. Geophysical logs will be attempted in an upcoming field season. Well screen details are also missing for sites NewCastle_NE and Brownsburg_N1; we plan to request funds as part of the next NGWMN funding cycle to conduct downhole camera surveys to identify screened intervals at these locations. Attempts were made to view the screened interval with an inexpensive downhole camera but were unsuccessful.

SITES THAT DO NOT MEET FRAMEWORK DOCUMENT REQUIREMENTS

As noted in the project proposal, reinstating site access for the Newburgh_E monitoring location was contingent upon successfully communicating with the landowner. Unfortunately, email attempts have thus far been unsuccessful in establishing renewed correspondence with property owners. The existing continuous monitoring record spans from 2007 to 2012, but without site access, we are unable to meet the minimum water-level measurement frequencies outlined in Table 4.5.1.1 of the NGWMN framework document (ACWI, 2013). The Newburgh_E monitoring site can be removed from the NGWMN site list due to unsuccessful attempts to contact the property owners. The Newburgh_E site has an AgencyCd (Agency code) of IN015 and a SiteNo (Site number) of 11.

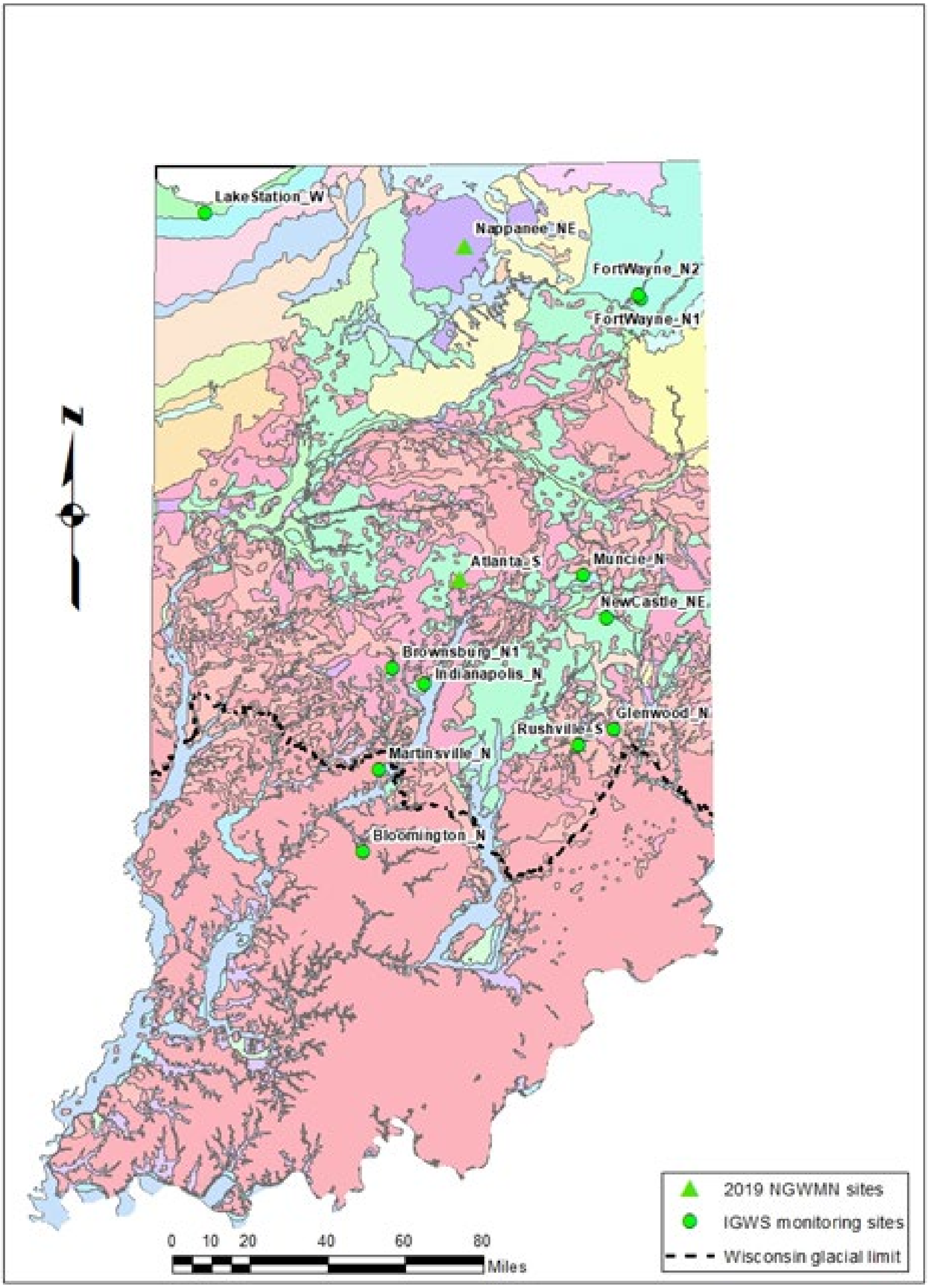


Figure 1. Map of Indiana showing IGWS groundwater monitoring sites that are included in the NGWMN. Indiana Department of Natural Resources unconsolidated aquifer boundaries (IDNR, 2011) are shown to demonstrate the complexity of glacial aquifer systems in Indiana. The IDNR aquifer types are used for local aquifer names in the "Site Info" NGWMN tables.

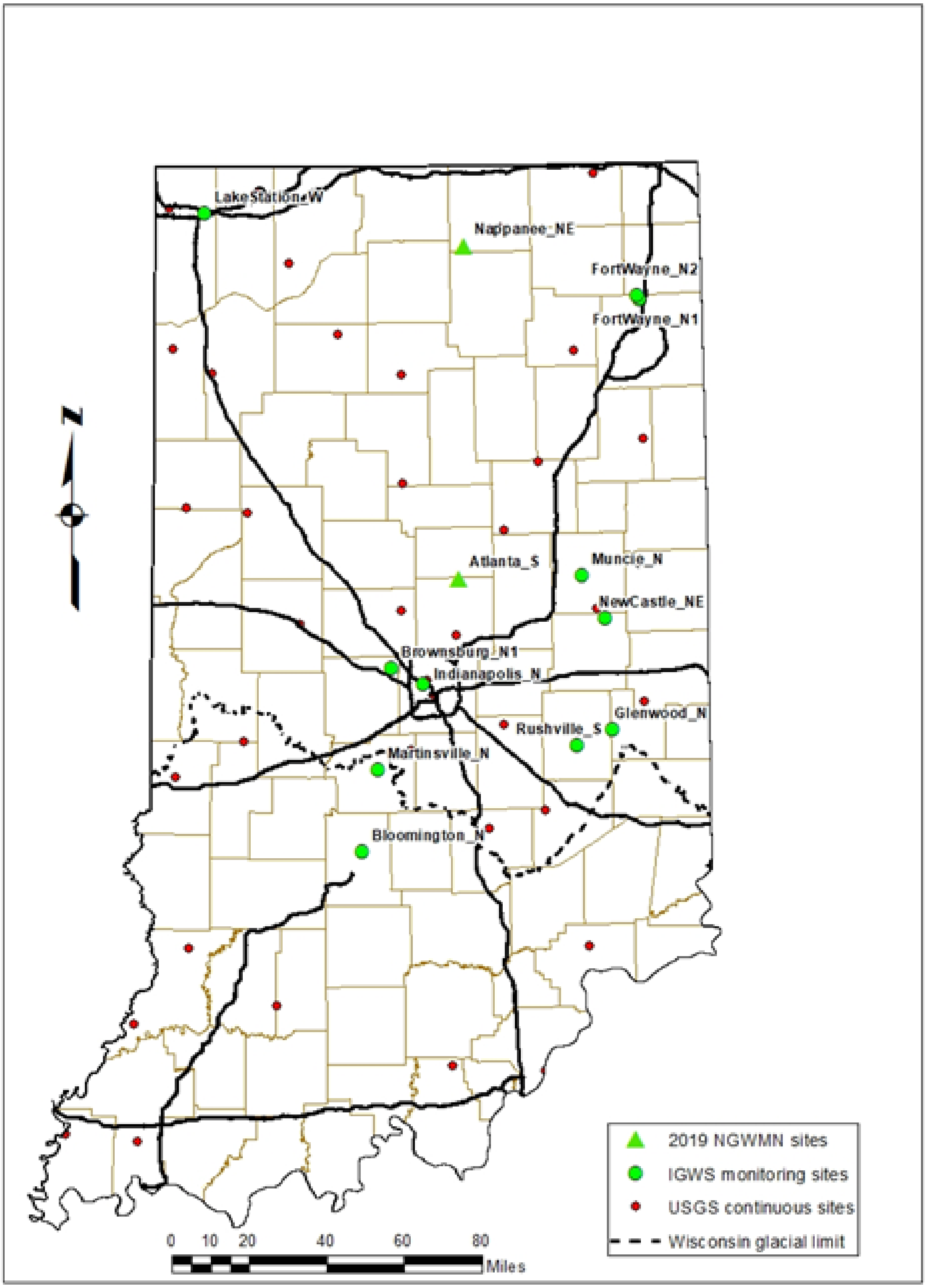


Figure 2. Map of Indiana showing IGWS groundwater monitoring sites that are included in the NGWMN relative to county boundaries and interstate highways.

Persistent data services

Support ongoing data contributions to NGWMN (Task 1)

We updated the well registry for all 11 contributing wells to NGWMN to reflect any changes at IGWS NGWMN sites. The downloaded water-level data processed and QA/QCed on at least a quarterly basis for all sites. We added two new drilled wells to the NGWMN well registry. The water level data for the new wells is available since their installation.

Upgrade IGWS web services to automate new data posting (Task 2)

A master folder is created in an IGWS internal server that contains directories for each well. These directories contain CSV files with specific keywords such as “lithology” or “water levels.” An IGWS staff updates these CSV files after every well visit.

A REST API .NET program has been developed to serve as an endpoint for general well info. An importer was also designed to automate the process of data upload to the NGWMN data portal. The importer looks within the master folder containing CSV files. These files are checked for valid column headers, and if everything checks out, they will be loaded to the SQL Server database, where they are available to the REST API .NET and will be shown on the NGWMN data portal. The importer keeps track of the last modified timestamps 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 prevents duplicate imports while also allowing for row deletions, updates, and additions over time.

Any invalid imports or errors detected by the import program will result in an automatic e-mail sent to both the project director and a member of the Information Services staff. A log file will be generated detailing the result of the import. The import occurs at 1:00 am every morning, while also being able to be run on-demand when necessary.

The importer code is as follows:

```
<?xml version="1.0" encoding="utf-8" ?>

<configuration>

  <configSections>

    <sectionGroup name="userSettings" type="System.Configuration.UserSettingsGroup, System,
Version=4.0.0.0, Culture=neutral, PublicKeyToken=b77a5c561934e089" >

      <section name="NGWMN_Importer.Properties.Settings"
type="System.Configuration.ClientSettingsSection, System, Version=4.0.0.0, Culture=neutral,
PublicKeyToken=b77a5c561934e089" allowExeDefinition="MachineToLocalUser" requirePermission="false"
/>

    </sectionGroup>

    <sectionGroup name="applicationSettings" type="System.Configuration.ApplicationSettingsGroup, System,
Version=4.0.0.0, Culture=neutral, PublicKeyToken=b77a5c561934e089" >
```

```
    <section name="NGWMN_Importer.Properties.Settings"
type="System.Configuration.ClientSettingsSection, System, Version=4.0.0.0, Culture=neutral,
PublicKeyToken=b77a5c561934e089" requirePermission="false" />

   </sectionGroup>

  </configSections>

  <startup>

   <supportedRuntime version="v4.0" sku=".NETFramework,Version=v4.6.1" />

  </startup>

  <connectionStrings>

   <add name="NGWMN" connectionString="Data Source=BL-GEOY-HALITE\dev; Initial Catalog=NGWMN;
Integrated Security=SSPI;" providerName="System.Data.SqlClient" />

  </connectionStrings>

  <userSettings>

   <NGWMN_Importer.Properties.Settings>

    <setting name="TouchedFiles" serializeAs="String">

     <value>{}</value>

    </setting>

   </NGWMN_Importer.Properties.Settings>

  </userSettings>

  <applicationSettings>

   <NGWMN_Importer.Properties.Settings>

    <setting name="DEBUGGING" serializeAs="String">

     <value>False</value>

    </setting>

    <setting name="DataPath" serializeAs="String">

     <value>\\bl-geoy-quartz\Projects\NGWMN\data</value>

    </setting>

    <setting name="ErrorEmail" serializeAs="String">

     <value>prsoni@iu.edu, bshabani@iu.edu</value>

    </setting>
```

```
    <setting name="ConfigFile" serializeAs="String">
      <value>import_directories.txt</value>
    </setting>
   </NGWMN_Importer.Properties.Settings>
  </applicationSettings>
</configuration>
```

The master folder that contains the CSV files is:

[\\bl-geoy-quartz\Projects\NGWMN\data](\\bl-geoy-quartz\Projects\NGWMN\data)

And the SQL database that the updates are copied to is:

BL-GEOY-HALITE

FIELD TECHNIQUES FOR WATER-LEVEL MEASUREMENT

Manual water-level measurements

Indiana Water Balance Network (IWBN) sites are routinely visited on average every 12 weeks to conduct maintenance and collect both 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 both paper and electronic versions of field notes.

Automated water-level measurements

Continuous groundwater-level data are collected using both vented (e.g., Druck PDCR series sensors) and unvented (e.g., In-Situ Rugged Troll 100 and Solinst 3000 series sensors) pressure transducers. The IGWS is currently working to move toward vented instruments as the standard automated measurement approach that would also facilitate real-time data service, but 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 following manual water-level measurement. Barometric pressure sensors located at the site are also downloaded and 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.

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 0.3–3 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 returns to the office:

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

DESCRIPTION OF DATA QUALITY AND QUALITY ASSURANCE PROCESSES

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

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 (Figure 3). A linear trendline is fit through the data to establish the linear relationship between the variables, and a regression coefficient of determination (R^2) 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.

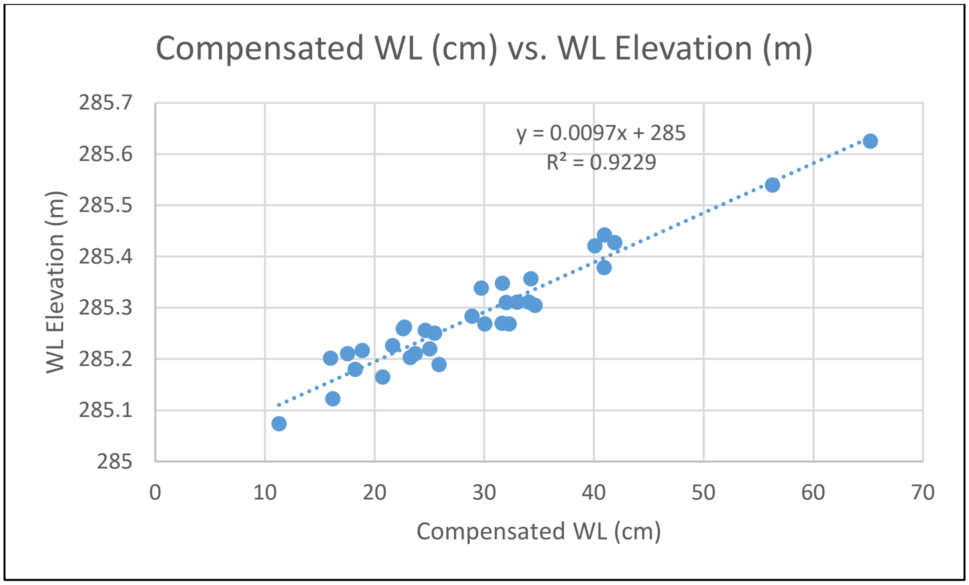


Figure 3. XY scatter plot showing compensated pressure transducer water column readings versus manual groundwater elevation measurements and linear trendline.

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.

ANALYTE LIST USED FOR SAMPLE NETWORKS / LABORATORIES

The analyte list is currently limited to water level data. IGWS staff conduct all water-level measurements and compile data; therefore, no outside laboratory is used.

Supporting persistent data services

Maintaining web services during year-2 of the project entailed QA/QC of continuous water-level data prior to posting data to the NGWMN Portal. Additional tasks completed under this objective included: maintaining the list of sites in the NGWMN Well Registry and updating site information, making routine updates to metadata, and updating web services following database changes. A groundwater hydrograph for one of the monitoring sites is shown in Figure 4 as an example of data provided by the IGWS.

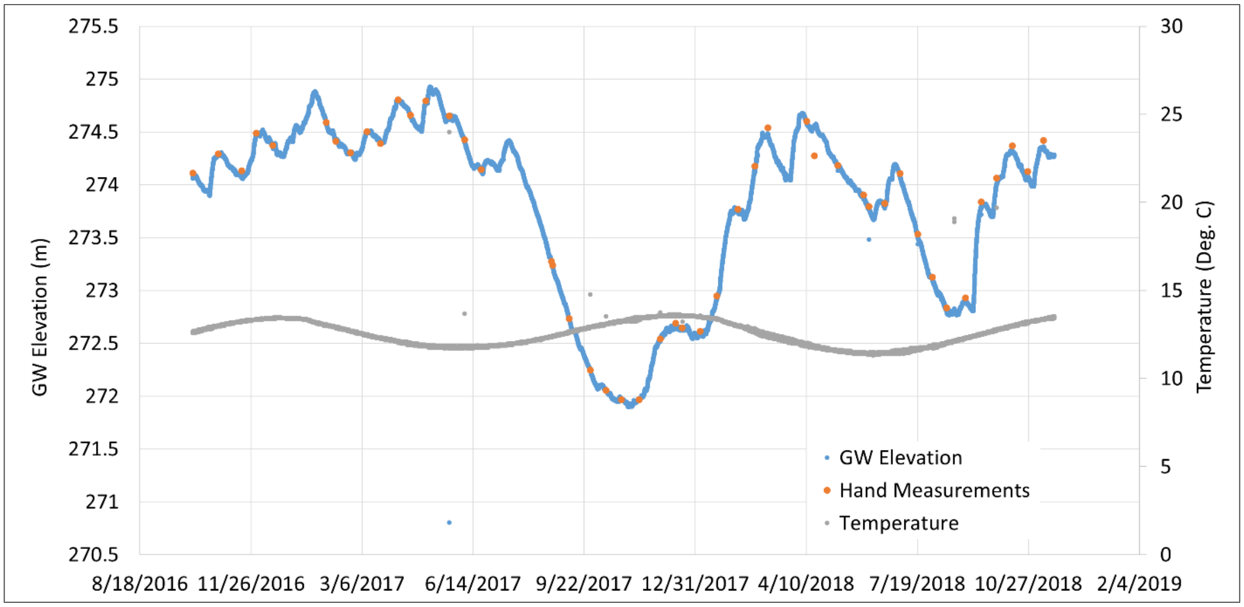


Figure 4. Groundwater hydrograph and temperature data for the Brownsburg_N2 monitoring site.

INSTALLATION OF TWO NEW MONITORING WELLS

The two new monitoring wells fill existing gaps in northern and central Indiana for trend/backbone monitoring locations in the NGWMN. The new well locations (sites Atlanta_S and Nappanee_NE) are shown in Figure 1 and summarized in Table 1. Aquifers at these well locations are generally part of the "Aquifers of alluvial and glacial origin" principal aquifer system. The spatial distribution of existing Indiana groundwater monitoring sites is improved with the Atlanta_S and Nappanee_NE well installations.

Obtaining site access for the proposed well locations proved challenging after contacting representatives or owners of several properties. Final well locations were shifted due to site access limitations. Local officials from the town of Atlanta and city of Nappanee graciously provided access to their communities' properties.

The Atlanta_S location was chosen for the monitoring well in northern Hamilton County (Figures 1 and 4) to coincide with the buried Anderson Bedrock Valley (Gray, 1991), which may represent a significant, relatively untapped aquifer for this area. The unconsolidated deposits were estimated to be approximately 275 ft thick within the center of the buried bedrock valley.

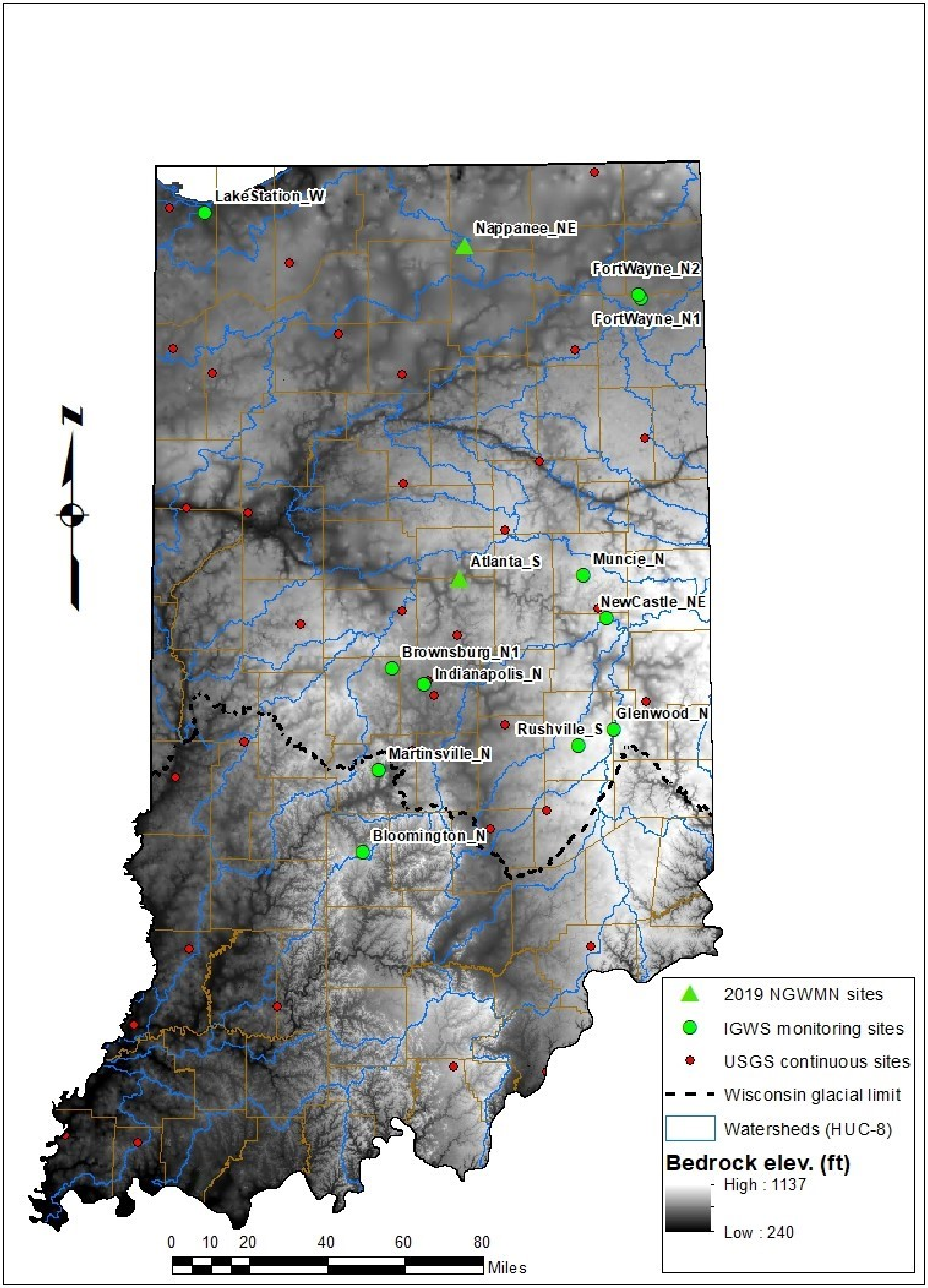


Figure 5. Map showing IWBN-NGWMN sites relative to watersheds and underlying bedrock topography.

The Nappanee_NE location was originally proposed for the aquifer(s) within the Tippecanoe River basin and to target the deeper regional aquifer that appears to coincide with a buried bedrock valley noted as an Outwash Aquifer Subsystem (over the buried valley with some potential) on the Indiana Department of Natural Resources water well web viewer. Unconsolidated deposits were estimated at more than 200 ft thick in the northeastern portion of the Tippecanoe River basin. However, due to site access challenges, the well was located in Nappanee (Figure 4), which is in the headwaters of the Saint Joseph River basin but near the headwaters of the Tippecanoe River basin. The site is also in an area of relatively thick unconsolidated deposits estimated to be approximately 280 ft thick and within a broad buried bedrock lowland (Naylor et al., 2016).

DRILLING, SOIL SAMPLING, AND WELL INSTALLATION METHODS

Drilling services were provided from the Illinois State Geological Survey (ISGS). A truck-mounted drill rig using mud rotary drilling methods and wireline coring tools were used to collect a continuous soil and bedrock core. The drilling objective was to core several feet into the underlying bedrock to verify the unconsolidated sediment to bedrock contact. 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. Poor recovery, coarse-grained intervals were collected in a food strainer, rinsed of bentonite drilling mud, reviewed for a simplified field core description, and packed into plastic bags.

Detailed core descriptions and collection of grain-size samples were conducted at the IGWS laboratory. The 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. The lithologic codes are based on the 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 includes a single-page diagram showing a combined gamma ray, well construction, and lithology symbol log, while the subsequent pages include a gamma ray log and detailed description lithologic log.

Grain size analysis, however, had not been conducted as of the report date owing to university and laboratory closures caused by the COVID-19 pandemic.

Samples of sand layers were collected, at various depths, 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 deposition back to an earlier glacial stage referred to as Illinoian, approximately 200,000 years before present (BP). For comparison, the more recent glacial stage referred to as Wisconsinan reached its greatest extent in Indiana approximately 24,000 years BP. However, OSL testing has not been completed as of the report date owing to university and laboratory closures caused by the COVID-19 pandemic.

Following core collection, a monitoring well was installed. The well installation was completed on October 3, 2019, for the Atlanta_S well and on October 10, 2019, for the Nappanee_NE well. The Atlanta_S well is also designated IGWSWell1901, and the Nappanee_NE well is also designated IGWSWell1902. 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 Atlanta_S well screen was installed from approximately 104 to 114 feet below grade to intercept sand encountered from approximately 88 to 115 feet below grade. The Nappanee_NE well screen was installed from approximately 146 to 156 feet below grade to intercept sands and gravel encountered from approximately 120 to 161 feet 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 feet above the top of well screen. Bentonite pellets were backfilled into the annulus for 1 to 2 feet 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 Atlanta_S well has a stick-up protective cover, and the Nappanee_NE well has a flush-mount protective cover. A waterproof cap was placed on the top of the well. A black reference mark (i.e., crow's foot) was drawn at the top of the PVC casing to mark the exact location for surveying the well elevation and 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.

The well locations and elevations were surveyed using real-time kinematic (RTK) GPS equipment. Location coordinates and elevations are provided in Table 1.

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. The 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 that would assist in removing debris from the slots (Figure 6).

Figure 6. Photograph showing specially constructed nozzle at the end of the compressed air line that directed compressed air at 90 degrees into the well screen slots to aid well development.

The ISGS drillers conducted gamma ray logging in the completed wells. Gamma ray logs assist with delineating stratigraphy, especially for those intervals with limited recovery. Gamma ray logs record gamma ray counts. Lower counts indicate silica-rich sediments such as sand (coarse-grained sediment) while higher counts indicate radioactive elements found in clay (i.e., fine-grained sediment). The gamma ray logs are displayed adjacent to well construction, and lithologic logs are compiled in Appendices B and C.

An In-Situ water pressure transducer and barometric pressure transducer pair were installed in each well. The pressure transducer is a Rugged TROLL 100 Data Logger, and the barometric pressure transducer is a Rugged BaroTROLL Data Logger. The sensors were installed on November 21, 2019, and continuous measurements were initiated on this date. Depth to water measurements and resulting groundwater elevations are compiled as noted in previous sections. Groundwater elevation data is updated periodically to the NGWMN web portal.

INVESTIGATION RESULTS

Atlanta_S

The Atlanta_S boring was drilled to a depth of approximately 129 feet below grade (BG). An upper sand and gravel layer is present at approximately 30 to 81 feet BG and a lower sand and gravel is present from approximately 85 to 115 feet BG. The base of the lower sand and gravel lays on the limestone bedrock surface at approximately 115 feet BG. A diamicton, present from approximately 81 to 85 feet BG, appears to separate the upper and lower sands and gravels. 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 Atlanta_S well is screened from 114 to 124 feet BG to intercept the lower sand and gravel (refer to the well construction log in Appendix B). The upper sand and gravel layer is another potential source of groundwater.

Continuous groundwater level and temperature measurements have been ongoing and five site visits have been conducted to measure the depth to groundwater since November 21, 2019. The first year of measurements includes a full water year (October to October). Figure 7 shows a graph of groundwater elevations and temperatures over time compared with the hand-measured groundwater elevations. The continuous and discrete measurements match well. 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. In addition to the seasonal differences, there is a daily difference in groundwater elevations that makes the groundwater elevation line appear thick. Groundwater temperatures range from 11.8 to 13.2 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.

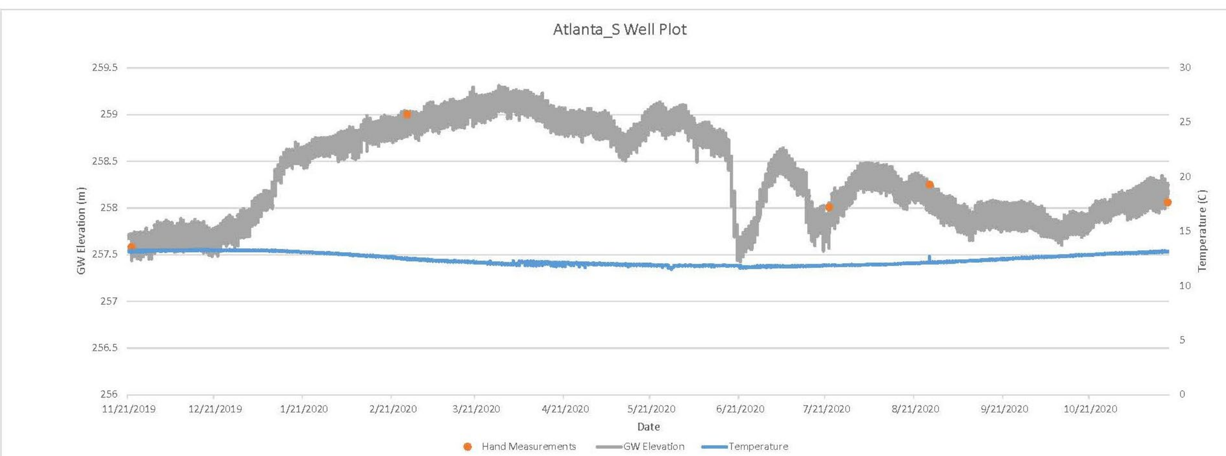


Figure 7. Graph showing groundwater elevations and temperatures over time compared with the hand-measured groundwater elevations for the Atlanta_S well.

Figure 8 shows a graph of groundwater elevations over the course of a week in November 2020, instead of a year as shown in Figure 7. Groundwater elevations vary by approximately 0.3 m (1 foot) on a nearly daily basis. The Atlanta_S well is located on the same property as the water supply well(s) for the town of Atlanta. The daily changes indicate the influence of daily pumping of the town water supply well. Groundwater levels appear to recover to nearly background levels over several hours.

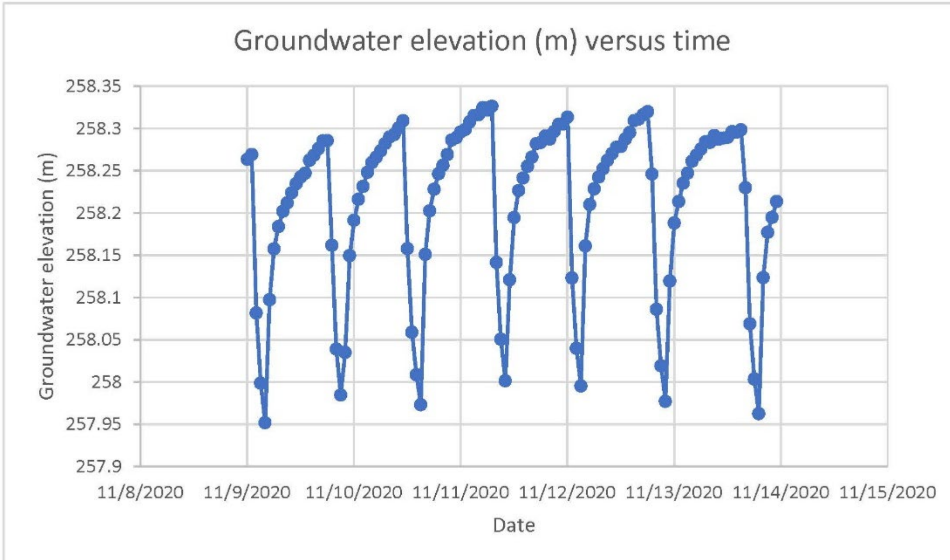


Figure 8. Graph showing groundwater elevations over the course of a week in November 2020 for the Atlanta_S well.

Nappanee_NE

The Nappanee_NE boring was drilled to a depth of approximately 288 feet BG. There are three sand and gravel layers separated by diamictons. The sand and gravel layers are present at approximately 60 to 75 feet, 120 to 160 feet, and 235 to 275 feet BG. The bedrock contact was interpreted to be present at approximately 280 feet BG. The bedrock contact was difficult to determine because the bedrock appears to be a weathered sandstone, similar in appearance to overlying sand layers. The bedrock contact was inferred from the gamma ray log and the lack of carbonates noted by the hydrochloric acid reaction test. Glacially deposited sands are typically rich in carbonates.

A reddish-brown (5YR4/3) diamicton was encountered from approximately 180 to 220 feet BG. The diamicton appears to grade from oxidized to unoxidized weathering zones at approximately 220 feet BG. This is a very thick oxidized zone and, if the interpretation is correct, may represent weathering during an older interglacial period. In addition to the reddish-brown diamicton, the ISGS drillers were able to core through a 2.3-foot-thick quartzite boulder at approximately 201 feet BG. The boulder was embedded in the reddish-brown till and is a unique example of a glacial erratic boulder (Figure 9).

Figure 9. Photograph showing a core from the Nappanee_NE boring. A quartzite boulder is shown in the foreground and the reddish-brown diamicton is shown in the background, adjacent to the ISGS drillers, A. Blacker (left) and B. Apperson (right).

The Nappanee_NE well is screened from 146 to 156 feet BG to intercept the intermediate sand and gravel layer from approximately 120 to 160 feet BG (refer to the well construction log in Appendix C). The upper and lower 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 November 21, 2019. The first year of measurements includes a full water year (October to October). Figure 10 shows a graph of groundwater elevations and temperatures over time compared with the hand-measured groundwater elevations. The continuous and discrete measurements match well. 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 near 11.7 °C. Consistent groundwater temperatures are an energy source for ground-source heat pumps.

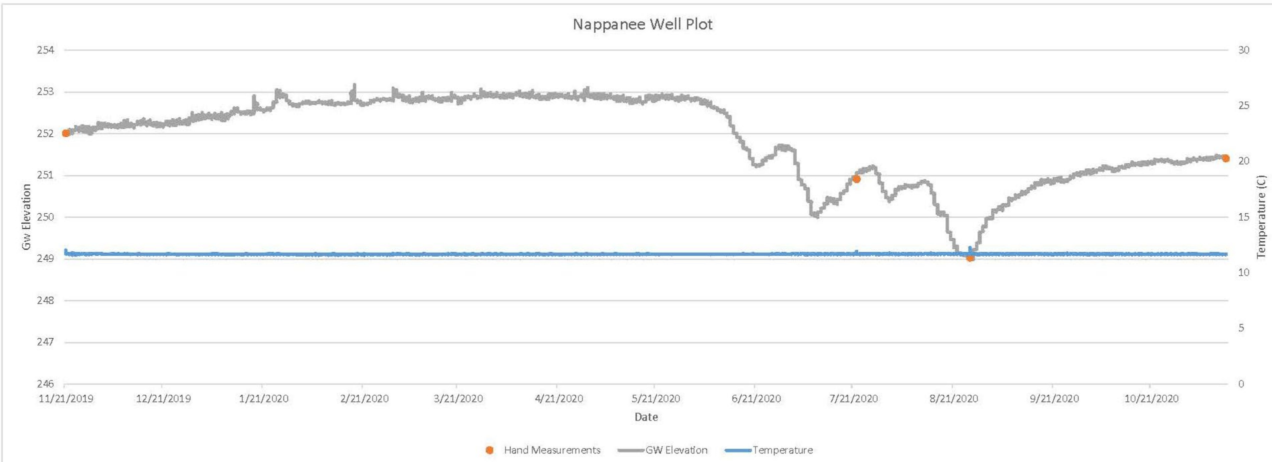


Figure 10. Graph showing groundwater elevations and temperatures over time compared with the hand-measured groundwater elevations for the Nappanee_NE well.

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., and Miall, A., 1983, Lithofacies types and vertical profile models; an alternative approach to the description and environmental interpretation of glacial diamict and diamictite sequences. Sedimentology. v. 30, Issue 3, p. 393-410. https://doi.org/10.1111/j.1365-3091.1983.tb00679.x

Indiana Department of Natural Resources (IDNR), 2011, Unconsolidated aquifer systems of Indiana, Geographic Information Systems polygon shapefile available at: https://maps.indiana.edu/layerGallery.html?category=Aquifers.

Naylor, S., Sperl, B., and Schumacher, J. 2016. Map showing thickness of unconsolidated deposits in Indiana: Indiana Geological and Water Survey Miscellaneous Map 95A. [UNCONSOLIDATED_THICKNESS_DEM_100M_IGS_IN.TIF: Unconsolidated Thickness DEM of Indiana (Indiana Geological Survey, 100-Meter TIFF Image]

U.S. Geological Survey (USGS), 2004, Ground-water Site-inventory System, National Water Information System: Open-File Report 2004-1238 v.4.3, available at: https://pubs.usgs.gov/of/2004/1238/.

Appendix A

Example Field Forms

CGDA IWBN Site Check
Field Checklist
V20200914

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 Baraloggers)

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: ____

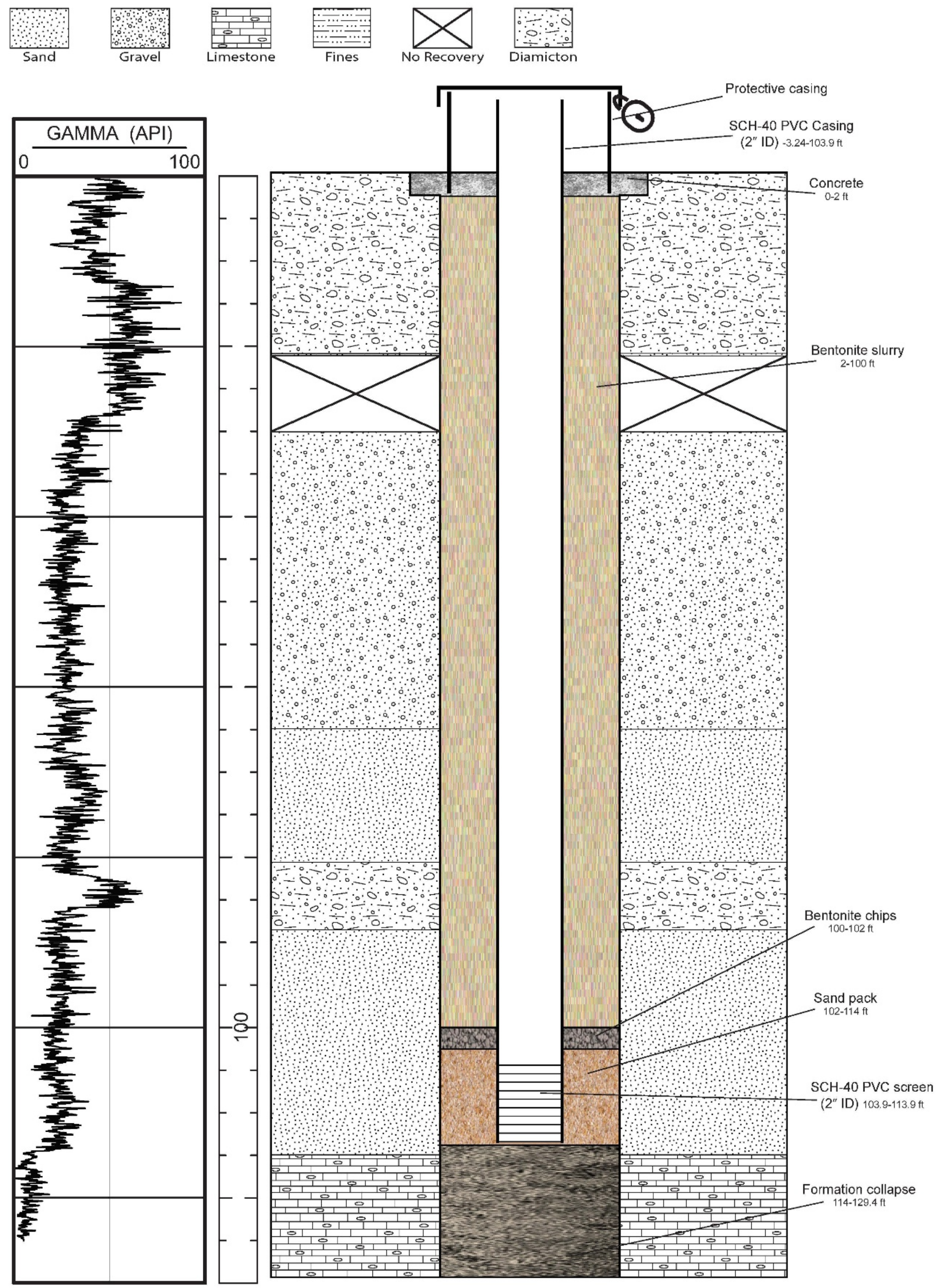
Post-field work instructions:
1. Complete and scan form into pdf document. Save pdf document to following folder: P:\GeoThermal\Monitoring_network\Data\Field_Notes. Include site name and date in pdf file name (e.g., IWBN_Site_Check_Bradford-Woods_20160522.pdf).
2. File paper copy in 3-ring binders.)
3. Download raw and compensated ptrans file(s) to P:\GeoThermal\Monitoring_network\Data\well_data > Downloads > "site name" > create folder with date in folder name (e.g., 20160509_ptrans-download)

Appendix B

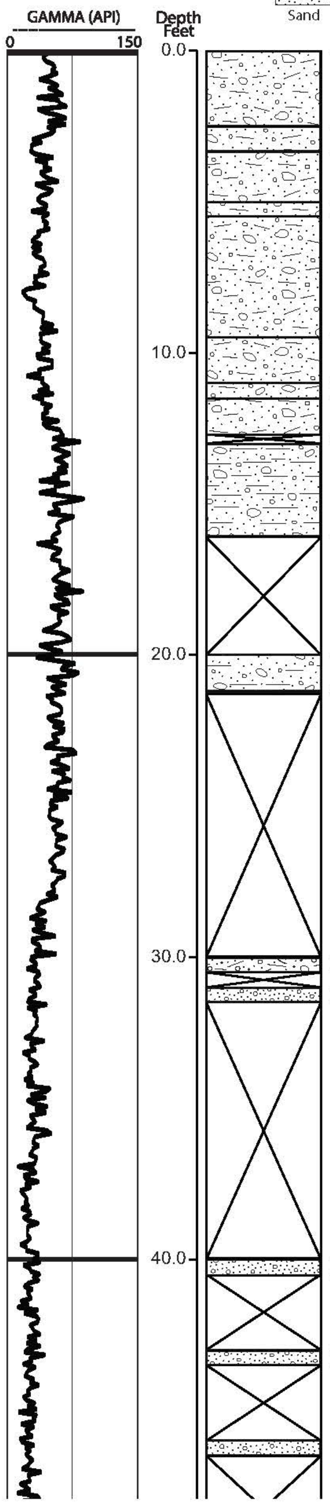
Atlanta_S IGWSWell1901

Gamma ray, well construction, and lithology logs

ID Number: IGWSWell1901	Date: 09/30/2019 - 10/03/2019
Site Name: Atlanta_S	By: Robert J. Autio and Babak Shabani
Location: Atlanta, IN	Notes: Prepared for NGWMN (G17AS00070) final report
Ground Elevation: 857.0 ft	Lat: 40.20951658, Long: -86.02688488



ID Number: IGWSWell1901	Date: 09/30/2019 - 10/03/2019
Site Name: Atlanta_S	By: Robert J. Autio and Babak Shabani
Location: Atlanta, IN	Notes: Prepared for NGWMN (G17AS00070) final report
Ground Elevation: 857.0 ft	Lat: 40.20951658, Long: -86.02688488



(0-2.5) Silt loam with trace (<5%) granules to fine (2-8 mm), massive, Black (10YR2/1), oxidized-leached, none reaction, dense, consistency, Dmm, sharp lower contact, non-calcareous, grey b/c organic matter in soil, pieces of brick and root, lower transition is a relatively sharp color contact.

(2.5-3.33) Silt loam with trace (<5%) granules to fine (2-8 mm), massive, Yellowish Brown (10YR5/8), oxidized-leached, none reaction, stiff consistency, Dmm, gradational lower contact, 50% mottled in color between primary and secondary color; non-calcareous; gradational transition in color to next interval.

(3.33-5) Silty clay loam with few (6-15%) granules to coarse (2-32 mm), massive, Light Olive Brown (2.5Y5/4), oxidized-unleached, strong reaction, stiff consistency, Dmm, strongly calcareous, some igneous rock fragments; end of box.

(5-5.45) Silt loam with few (6-15%) granules to fine (2-8 mm), massive, Light Olive Brown (2.5Y5/6), oxidized-unleached, moderate reaction, very stiff consistency, Dmm, 40% mottles of grey (2.5YR7/1)2% mottles (oxidized pebbles) decreasing in frequency with lower depth.

(5.45-9.5) Silt loam with few (6-15%) granules to coarse (2-32 mm), Light Olive Brown (2.5Y5/4), oxidized-unleached, moderate reaction, very stiff consistency, Dmm, more frequent clasts at the top of the sample, decreasing in frequency with depth; from 7.0-7.8 ft, slight change in color to a lighter version of 2.5Y5/4, due to drying out. Perhaps the greater relative dryness of this portion reflects lower clay concentration.

(9.5-11) Silty clay loam with few (6-15%) granules to fine (2-8 mm), massive, Gray (2.5Y5/1), unoxidized-unleached, moderate reaction, very stiff consistency, Dmm, occasional medium fragments of 18 mm around depth of 10.9 ft (around 2 fragments total); sample taken at 10.5 ft.

(11-11.5) Loam with few (6-15%) granules to coarse (2-32 mm), massive, Grayish Brown (2.5Y5/2), unoxidized-unleached, strong reaction, hard consistency, Dmm, gradational lower contact, large (>50 mm) fragment with drill marks; much more dried out than other parts of the core; sample at 11-11.2 feet.

(11.5-12.7) Silty clay loam with few (6-15%) granules to coarse (2-32 mm), massive, Very Dark Grayish Brown (2.5Y3/2), oxidized-unleached, strong reaction, hard consistency, Dmm, gradational lower contact, splotch of 2.5Y 8/6 (yellow) granules surrounding a fragment (5 mm); interval is brown in color, suggesting oxidization, although it is deep (oxidization from water?). Some slight lamination near the bottom on the interval (12.4-12.7 ft).

(12.7-13) No recovery.

(13-16.1) Silty clay with few (6-15%) granules to med (2-16 mm), laminated, Very Dark Gray (10YR3/1), oxidized-unleached, strong reaction, stiff consistency, Dms, more dried out with depth (dried from 15-16 ft) - due to two larger (~20 mm) fragments in that range; samples taken at 13.9 ft and 15 ft; dark grey/brown suggest possible oxidization from groundwater below (?)

(16.1-20) No recovery.

(20-21.2) Silty clay with few (6-15%) granules to med (2-16 mm), laminated, Dark Gray (10YR4/1), oxidized-unleached, strong reaction, hard consistency, Dms, sharp lower contact, very fine laminations; sample taken at 20.3-20.4 ft; sharp contact with next interval of sand (might be from other part of drive to 30 ft).

(21.2-21.3) Silty clay and sand with trace (<5%) fine gravel (4-8 mm), massive, Light Olive Brown (2.5Y5/3), oxidized-unleached, loose consistency, Dmm, sand mixed with the silty clay from the previous interval (not sure about the strat code); sample taken at 21.2 ft (small sample because the interval was very small).

(21.3-30) No recovery.

(30-30.5) Silty clay and gravel with little (16-30%) coarse gravel (16-32 mm), Dark Gray (10YR4/1), oxidized-unleached, strong reaction, loose, consistency, Dcg, muddy conglomerate: 70% gravel, 30% matrix of silt clay; polymictic gravel, medium fragments of 2-5 mm with larger fragments (20-30 mm) characterized as clasts; size of clasts increasing with depth; sample taken at 30.0 ft (might be too many large clasts?).

(30.5-31) No recovery.

(31-31.5) Gravel, massive, Yellowish Brown (10YR5/6), unoxidized-unleached, weak reaction, very loose, consistency, G, polymictic gravel: cobbles of 20-60 mm; no matrix material; colors of fragments include: GLEY1 4/5G (potentially an igneous rock), GLEY1 3/5G, 10R 6/3, 10YR 5/6; drill bit marks on largest (60 mm) cobble; sample bag volume: 2 cups (core collected in bags now).

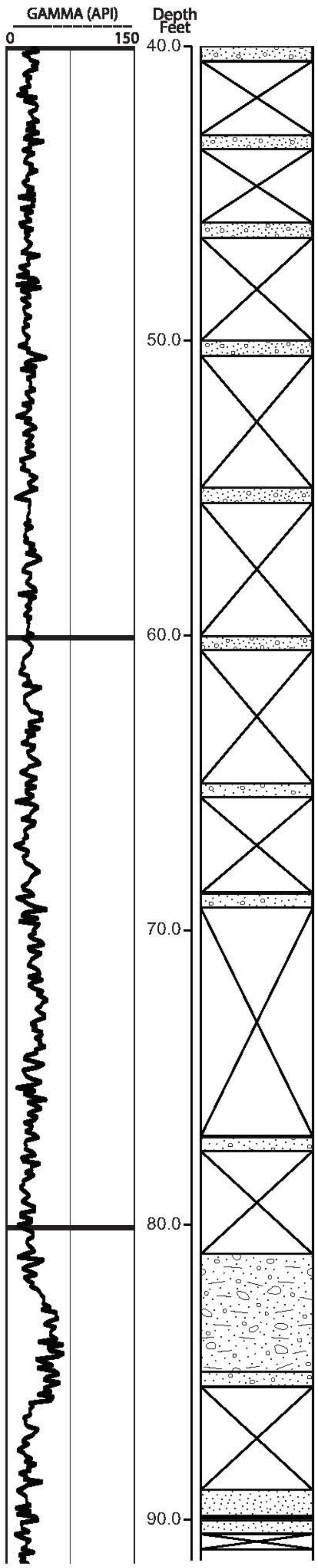
(31.5-40) No recovery.

(40-40.5) Gravel, massive, Yellowish Brown (10YR5/4), unoxidized-unleached, moderate reaction, very loose, consistency, G, Wet gravel: very fine to medium pebbles (<1 mm to 3 mm); polymictic, colors include: 10YRs and GLEYs; Sample bag volume: 0.75 cup; Total drive: 40-43 ft.

(40.5-43) No recovery.

(43-43.5) Gravel, massive, Brownish Yellow (10YR6/6), unoxidized-unleached, moderate reaction, very loose, consistency, G, wet gravel: pebbles of 2-5 mm; polymictic: colors include GLEYs and 10YRs (similar in color to previous interval, just different in grain size); sample bag volume: 2 cups; Total drive: 43-46 ft.

(43.5-46) No recovery.



(40-40.5) Gravel, massive, Yellowish Brown (10YR5/4), unoxidized-unleached, moderate reaction, very loose, consistency, G, Wet gravel: very fine to medium pebbles (<1 mm to 3 mm); polymictic, colors include: 10YRs and GLEYs; Sample bag volume: 0.75 cup; Total drive: 40-43 ft.

(40.5-43) No recovery.

(43-43.5) Gravel, massive, Brownish Yellow (10YR6/6), unoxidized-unleached, moderate reaction, very loose, consistency, G, wet gravel: pebbles of 2-5 mm; polymictic: colors include GLEYs and 10YRs (similar in color to previous interval, just different in grain size); sample bag volume: 2 cups; Total drive: 43-46 ft.

(43.5-46) No recovery.

(46-46.5) Gravel, massive, Pale Brown (10YR6/3), unoxidized-unleached, moderate reaction, very loose, consistency, G, dry gravel: pebbles of 20-60 mm (the largest showing drill bit marks); polymictic, with colors including 10R 4/6, 10YR 6/3, 10YR 4/3; no sample taken because fragments are too large (use sieve); sample bag volume: 1.25 cups; Total drive: 46-50 ft.

(46.5-50) No recovery.

(50-50.5) Gravel, massive, Black (10YR2/1), unoxidized-unleached, weak reaction, very loose consistency, G, Wet polymictic gravel: pebbles of 1-5 mm; potential plant fibers (semi-clear grass like plants); sample bag volume: 0.5 cups; Total drive: 50-55 ft.

(50.5-55) No recovery.

(55-55.5) Gravel, massive, Black (10YR2/1), unoxidized-unleached, weak reaction, very loose consistency, G, wet gravel: pebbles of (<1-6 mm); polymictic; many colors; sample bag volume: 0.5 cups; Total drive: 55-60 ft.

(55.5-60) No recovery.

(60-60.5) Granules from less than 1 mm to 5 mm; higher proportional of very fine granules in their interval than in previous.

(60.5-65) No recovery.

(65-65.5) Sandy clay loam and gravel with few (6-15%) granules (2-4 mm), Grayish Brown (2.5Y5/2), wet, unoxidized-unleached, weak reaction, loose consistency, SG, 50% gravel (coarse fragments of 7-20 mm), 35% smaller granules (logged as clasts), and 15% sandy clay loam; chunks of sandy clay loam are layered, stratified inside when opened; sample bag volume: 2 cups; Total drive: 65-68.75 ft.

(65.5-68.75) No recovery.

(68.75-69.25) Sandy loam and gravel with granules to coarse (2-32 mm), Grayish Brown (2.5Y5/2), oxidized-unleached, weak reaction, loose consistency, SG, fine/coarse sandy loam/gravel of 10-40 mm fragments; liquid in the sample bag was 10YR4/6 (dark yellowish brown) indicating oxidation; sample bag volume: 1.25 cups; Total drive: 68.75-77 ft.

(69.25-77) No recovery.

(77-77.5) Sand and gravel with some (31-49%) fine gravel (4-8 mm), massive, Yellowish Brown (10YR5/4), oxidized-unleached, weak reaction, very loose consistency, SG, 40% very coarse sand (1-2 mm) and 60% gravel of 5-10 mm; potential igneous rock fragments in the gravel conglomerate; Orange/brown color of the sample bag liquid (10YR5/4) suggests oxidation, even at depth; sample bag volume: 0.75 cup; Total drive: 77-83 ft.

(77.5-81) No recovery.

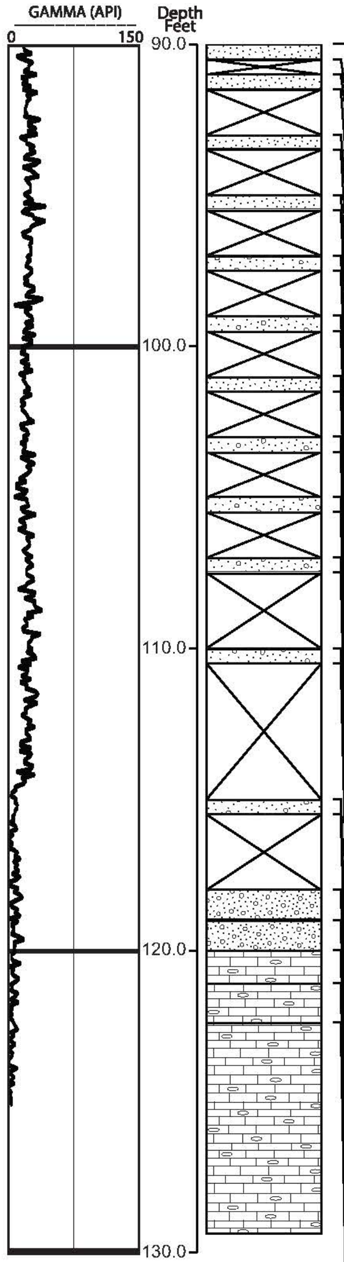
(81-85) Loam and gravel with little (16-30%) granules to fine (2-8 mm), Dmm, RJA field notes - till balls mixed with fine gravel (could be Dmm or G? - limited recovery), sediment collected with basket - layer thickness based on gamma ray log; interpreted till balls to be texture of fine-grained unit.

(85-85.5) Sand and gravel with some (31-49%) fine gravel (4-8 mm), massive, Grayish Brown (2.5Y5/2), unoxidized-unleached, weak reaction, loose consistency, SG, 50/50 mix of loamy sand and gravel (4-8 mm); sample bag volume: 0.5 cup; Total drive: 83-89 ft.

(85.5-89) No recovery.

(89-89.9) Sand, massive, Light Olive Brown (2.5Y5/3), unoxidized-unleached, weak reaction, soft consistency, S, loamy sand (forms a ball, but not a ribbon); one large (60mm) igneous rock fragment; total core drive: 89-90 ft.

(89.9-90) No recovery.



(90-90.5) Sand and gravel with some (31-49%) granules to coarse (2-32 mm), massive, Grayish Brown (2.5Y5/2), unoxidized-unleached, weak reaction, medium dense, consistency, S, Fine sand with 40% coarse fragments of granules to coarse (4-40 mm); sample bag volume: 3 cups; Total drive of 90-91 ft.

(90.5-91) No recovery.

(91-91.5) Sand, massive, Black (10YR2/1), unoxidized-unleached, weak reaction, very loose consistency, S, very coarse sand (borderline gravel granules) of 1-4 mm; shiny brown remnants in the bag 10YR3/3; sample bag volume: 0.5 cups; Total drive: 91-93 ft.

(91.5-93) No recovery.

(93-93.5) Sand, massive, Black (10YR2/1), unoxidized-unleached, weak reaction, very loose consistency, S, coarse sand and some gravel granules (0.5-3 mm); higher proportion of smallest grain sizes than previous interval; sample bag volume: 0.5 cup; Total drive: 93-95 ft.

(93.5-95) No recovery.

(95-95.5) Sand, massive, Brown (10YR4/3), wet, oxidized-unleached, very loose consistency, S, very coarse sand of 1 -4 mm, polymictic with some fragments of quartz rock (perhaps?); sample bag volume: 1 cup; Total drive of 95-97 ft.

(95.5-97) No recovery.

(97-97.5) Sand with trace (<5%) fine gravel (4-8 mm), massive, Grayish Brown (10YR5/2), wet, unoxidized-unleached, weak reaction, very loose consistency, SG, coarse sand (0.5-1 mm) with 5% coarse fragments of fine gravel/pebbles (5-8 mm); sample bag volume: 0.75 cup; Total drive: 97-99 ft.

(97.5-99) No recovery.

(99-99.5) Sand and gravel with some (31-49%) fine gravel (4-8 mm), massive, Grayish Brown (10YR5/2), wet, unoxidized-unleached, weak reaction, very loose consistency, SG, 50/50 mix of medium sand (0.25-0.5 mm) and fine gravel (4-8 mm), polymictic; sample bag volume: 1.5 cups; Total drive: 99-101 ft.

(99.5-101) No recovery.

(101-101.5) Sand with trace (<5%) fine gravel (4-8 mm), massive, Gray (10YR5/1), wet, unoxidized-unleached, weak reaction, very loose consistency, S, coarse sand with 3% coarse fragments of fine gravel (4-8 mm), polymictic and very colorful, potentially igneous rocks; sample bag volume: 2 cups; Total drive: 101-103 ft.

(101.5-103) No recovery.

(103-103.5) Sand and gravel with some (31-49%) granules (2-4 mm), massive, Brown (10YR5/3), wet, unoxidized-unleached, weak reaction, very loose consistency, SG, medium sand (0.5 mm) and fine gravel (2-5 mm) - roughly 50% fine and 50% coarse; polymictic, very colorful; sample bag volume: 1.5 cups; Total drive: 103-105 ft.

(103.5-105) No recovery.

(105-105.5) Sand and gravel with some (31-49%) granules to fine (2-8 mm), massive, Brown (10YR5/3), wet, unoxidized-unleached, weak reaction, very loose consistency, SG, medium sand (0.5mm) and fine gravel (2-8 mm) with greater proportion of coarse materials (30% fine and 70% coarse); polymictic; sample bag volume: 2 cups; Total drive: 105-107 ft.

(105.5-107) No recovery.

(107-107.5) Sand and gravel with some (31-49%) granules to fine (2-8 mm), massive, Gray (10YR5/1), wet, unoxidized-unleached, weak reaction, very loose consistency, SG, medium sand (0.5 mm) and fine gravel (2-8 mm) - 30% fine and 70% coarse; polymictic; sample bag volume: 2 cups; Total drive: 107-110 ft.

(107.5-110) No recovery.

(110-110.5) Sand and gravel with little (16-30%) fine gravel (4-8 mm), massive, Gray (10YR6/1), wet, unoxidized-unleached, weak reaction, very loose consistency, SG, coarse sand (1 mm) and fine gravel (5-10 mm), polymictic (therefore colorful) but with an overall gray tint (10Y 6/1); sample bag volume: 2.5 cups; Total drive: 110-115 ft.

(110.5-115) No recovery.

(115-115.5) Sand and gravel with some (31-49%) fine gravel (4-8 mm), massive, White (10YR8/1), wet, unoxidized-unleached, moderate reaction, very loose consistency, SG, coarse sand (0.5-1 mm) and fine gravel (5-10 mm), polymictic; small (4 mm) patch of white silty sediment (crumbles dry like very fine dust) that is also crusted on many of the granules; sample bag volume: 1.5 cups; Total drive: 115-118 ft.

(115.5-118) No recovery.

(118-119) Gravel with 16-40 mm, massive, Light Gray (10YR7/2), unoxidized-unleached, moderate reaction, very loose consistency, G, Cobbles (16-40 mm), one fragment of chert, some igneous rock, and other unidentified materials; few pieces of organic material (looks like blades of grass); polymictic, colors include 10YR 3/3 (dark brown), 10YR 5/1 (gray), GLEY2 3/10G.

(119-120) Gravel with granules to coarse (2-32 mm), massive, Light Bluish Gray (10B8/1), unoxidized-unleached, moderate reaction, very loose consistency, G, chert cobbles (5-40 mm); colors include: GLEY1s and GLEY2s; sample bag volume: 1.5 cups; Total drive: bag labelled 120 ft but assumed drive was 119-120 ft; possible weathered bedrock.

(120-121.1) Limestone, Light Bluish Gray (10B7/1), unoxidized-unleached, weak reaction, hard consistency, gradational lower contact, B, Bedrock: limestone and chert layers; veins and pockets of GLEY2 4/10B, with splotches (4%) of potential oxidization (10YR 7/8); sharp color contact with next interval.

(121.1-122.4) Limestone, Yellow (10YR7/6), oxidized-unleached, weak reaction, hard consistency, sharp lower contact, B, Bedrock (limestone with chert nodules); color mottling: surface of core is yellow/tan (10YR 7/6), mixed with the base color of GLEY2 7/10B -- mottling between the two colors 70%-30% (tan-gray); 121.3-121.35 ft: a layer of clay loam (10YR 7/6) with 30% c.

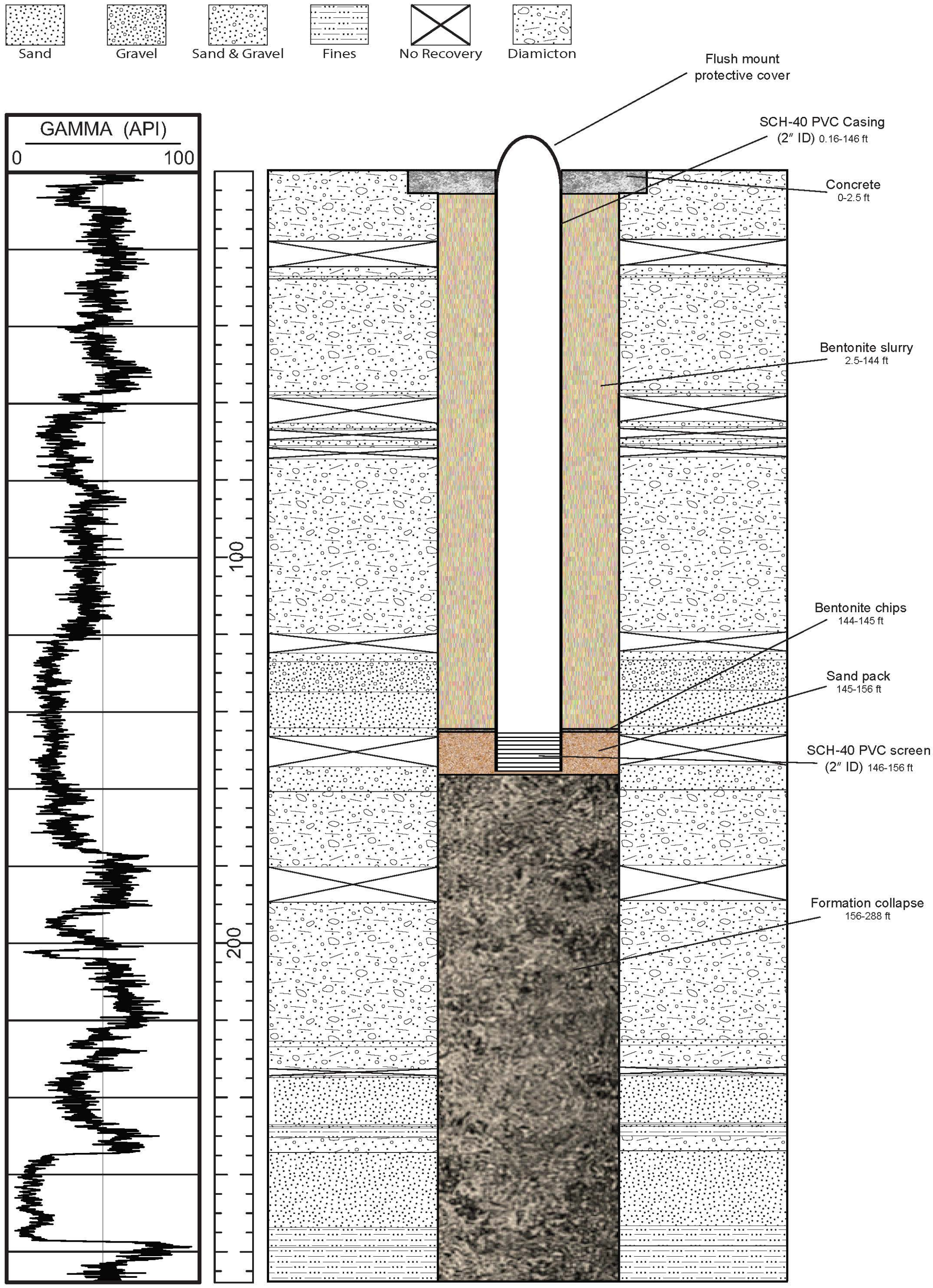
(122.4-129.35) Limestone, massive, Light Bluish Gray (10B7/1), Unoxidized-unleached, moderate reaction, hard consistency, B, Bedrock (limestone with chert nodules); frequency of chert nodules increasing slightly with depth; tan oxidization patches (10YR 7/6) on outside of core increasing with depth.

Appendix C

Nappanee_NE IGWSWell1902

Gamma ray, well construction, and lithology logs

ID Number: IGWSWell1902	Date: 10/07/2019 - 10/09/2019
Site Name: Nappanee_NE	By: Robert J. Autio and Babak Shabani
Location: Nappanee, IN	Notes: Prepared for NGWMN (G17AS00070) final report
Ground Elevation: 871.0 ft	Lat: 41.45401042, Long: -85.98379445



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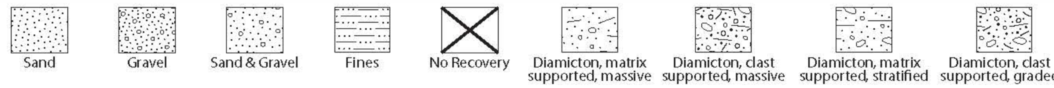
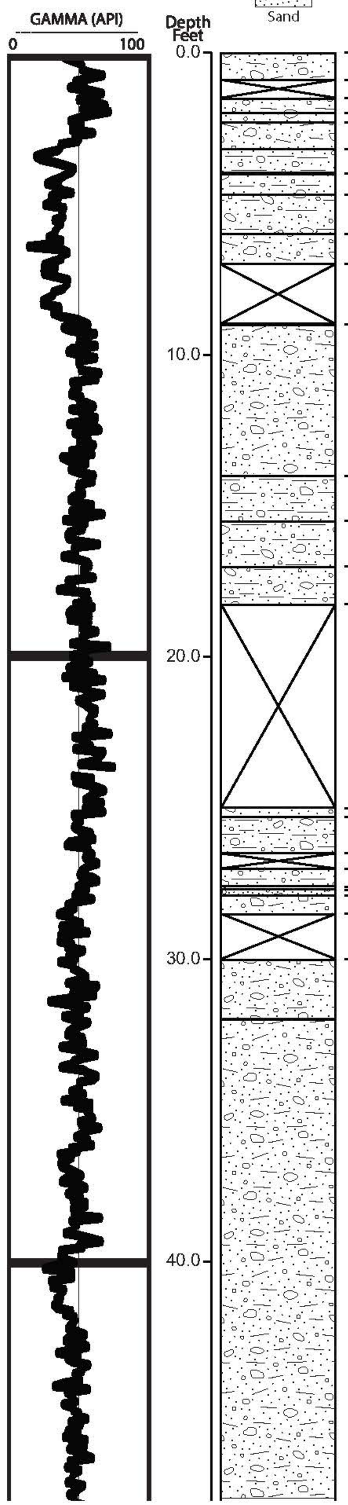




(0-0.9) Silt loam with trace (<5%) fine gravel (4-8 mm), massive, Very Dark Grayish Brown (10YR4/2), moist, oxidized-leached, none reaction, very stiff consistency, Dmm, sharp lower contact, some grass and roots throughout interval which provide some slight oxidization coloring (10YR 5/6); sample taken at 0.5 ft.

(0.9-1.5) No recovery.

(1.5-2) Silt loam with trace (<5%) granules (2-4 mm), massive, Very Dark Grayish Brown (10YR3/2), moist, oxidized-leached, none reaction, very stiff consistency, Dmm, sharp lower contact, mottled (30%) with 10YR 5/8; sample taken at 1.5 ft.

(2-2.3) Silt loam, massive, Dark Grayish Brown (10YR4/2), moist, oxidized-leached, none reaction, very stiff consistency, Dmm, sharp lower contact, Secondary color is 30% present; sample taken at 2 ft.

(2.3-3.2) Silt loam with few (6-15%) fine gravel (4-8 mm), massive, Brown (10YR5/3), moist, oxidized-leached, none reaction, very stiff consistency, Dmm, sharp lower contact, Main color: 10YR 5/3 (base); Secondary color: 10YR 3/1 (concentrated in the inside/center of core); Tertiary color: 10YR 4/6 mottled randomly outside the core of secondary color; clasts (~10%) concentrated at bottom of interval (at 3 ft); sample taken at 2.8 ft.

(3.2-4) Silt loam with trace (<5%) granules to coarse (2-32 mm), laminated, Brown (10YR5/3), moist, oxidized-unleached, moderate reaction, very stiff consistency, Dms, sharp lower contact, Line of grey/white (GLEY 1 8/N) running down (vertical, down in depth) the core; laminated; sample taken at 3.2 ft.

(4-4.7) Silt loam with trace (<5%) fine gravel (4-8 mm), laminated, Light Yellowish Brown (2.5Y6/3), moist, oxidized-unleached, moderate reaction, very stiff consistency, Dms, gradational lower contact, concentrated area of gravel in the center of the core (about 40 mm in diameter); mottled (10%) with 2.5Y 8/2.

(4.7-6) Silt loam with few (6-15%) granules to med (2-16 mm), laminated, Olive Brown (2.5Y4/4), moist, oxidized-unleached, moderate reaction, very stiff consistency, Dms, gradational lower contact, Horizontal band (10 mm wide) of white (GLEY1 8/N) then yellow (2.5Y 8/8); lamination is slightly less distinct; clasts increasing in abundance with depth.

(6-7) Loam with few (6-15%) med. gravel (8-16 mm), massive, Light Olive Brown (2.5Y5/4), dry, oxidized-unleached, strong reaction, stiff consistency, Dmm, sharp lower contact, loosely packed higher in core and moving towards more consolidation with depth; one very large coarse fragment: 10 cm diameter; sample taken at 6.3 ft.

(7-9) No recovery.

(9-14) Loam with trace (<5%) med. gravel (8-16 mm), massive, Olive Brown (2.5Y4/4), moist, oxidized-unleached, weak reaction, medium consistency, Dmm, gradational lower contact, Faint (rough) lamination present in upper core and becoming fully massive with depth; coarse fragment includes (probably) igneous rocks; sample taken at 10.3 ft.

(14-15.5) Clay loam with few (6-15%) granules (2-4 mm), laminated, Olive Brown (2.5Y4/3), moist, oxidized-unleached, weak reaction, very stiff consistency, Dms, gradational lower contact, 10% mottling in color of 10YR 5/8, increasing to 20% concentration at the bottom of the interval (~15.3-15.5 ft); ~7% coarse fragments of granules (2-5 mm), potentially igneous rock, in a variety of colors.

(15.5-17) Clay loam with few (6-15%) fine gravel (4-8 mm), laminated, Dark Gray (2.5Y4/1), moist, unoxidized-unleached, moderate reaction, very stiff consistency, Dms, gradational lower contact, ~7% coarse fragments of fine gravel (4-10 mm); 15% mottling in color of 10YR 5/8 at top of interval (15.5-15.7 ft) as part of the gradual transition from previous interval.

(17-18.25) Clay loam with few (6-15%) granules to coarse (2-32 mm), laminated, Dark Gray (5Y4/1), dry, unoxidized-unleached, moderate reaction, stiff consistency, Dms, sharp lower contact, 6% coarse fragments of granules to coarse (2-35 mm)- multiple colors and igneous looking rocks, sample taken at 17.3 ft.

(18.25-25) No recovery.

(25-25.3) Clay loam with trace (<5%) fine gravel (4-8 mm), laminated, Dark Gray (5Y4/1), moist, unoxidized-unleached, moderate reaction, very stiff consistency, Dms, sharp lower contact, 3% coarse fragments of granules to coarse (2-35 mm) - multiple colors and igneous looking rock fragments; very difficult core to split - very stiff with no natural give; relatively sharp lower transition (in color and texture); sample taken at 25 ft.

(25.3-26.5) Loam and clay loam with few (6-15%) very coarse gravel (32-64 mm), laminated, Gray (2.5Y6/1), dry, unoxidized-unleached, strong reaction, very stiff consistency, Dms, 10% clast abundance of coarse to very gravel (20-40 mm); variety of colors in the sample: Primary color present throughout - secondary color more present near the top of the interval - Horizontal band of 10R 4/6 (red) – 4 mm thick at 26.1 ft.

(26.5-27) No recovery.

(27-27.6) Clay loam with trace (<5%) fine gravel (4-8 mm), laminated, Dark Gray (2.5Y4/1), dry, unoxidized-unleached, moderate reaction, stiff consistency, Dms, sharp lower contact, -secondary color (2.5Y 6/1) mottled with primary at the top of the interval (27-27.2 ft) - dried - tertiary color (10YR 5/8) mottled with primary at the bottom of the interval (27.4-27.6 ft); sample taken at 27 ft.

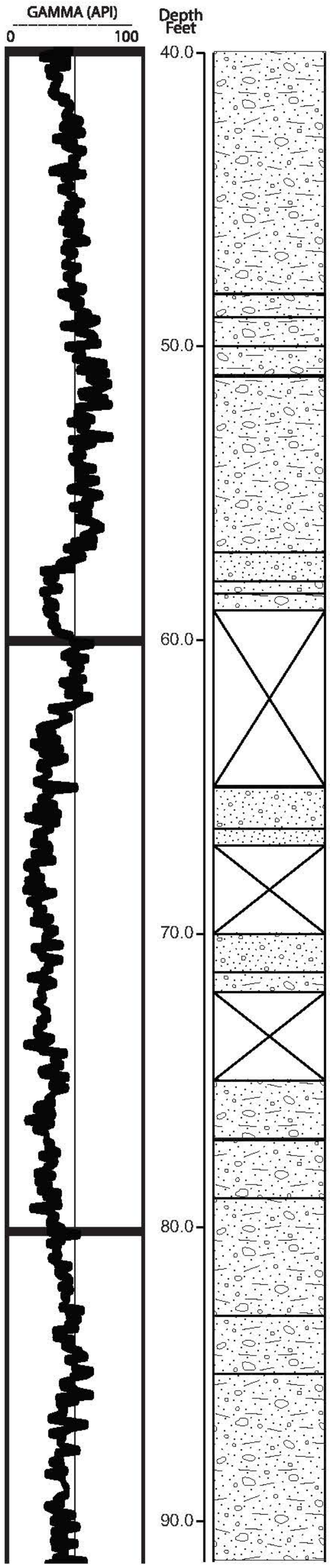
(27.6-27.7) Loam, laminated, Light Olive Brown (2.5Y5/6), dry, oxidized-unleached, strong reaction, stiff consistency, Dms, sharp lower contact, strongly laminated (fine > 1 mm), horizontal; oxidized because of yellowish color; very sharp upper and lower contact; sample taken at 27.6 ft.

(27.7-27.9) Gravel and loam, massive, Black (2.5Y2.5/1), dry, unoxidized-unleached, moderate reaction, loose, G, sharp lower contact, Gravel consist of: pebbles to cobbles (5-50 mm) with some loam between grains (10%); no sample taken (due to large size of gravel).

(27.9-28.5) Clay loam with trace (<5%) med. gravel (8-16 mm), massive, Very Dark Grayish Brown (2.5Y3/2), moist, unoxidized-unleached, strong reaction, stiff consistency, Dmm, Dry band (2 mm thick) at 28.2 ft; sample taken at 28.3 ft.

(28.5-30) No recovery.

(30-32) Clay loam with trace (<5%) med. gravel (8-16 mm), massive, Dark Grayish Brown (2.5Y4/2), moist, unoxidized-unleached, strong reaction, stiff consistency, Dmm, gradational lower contact, Band of medium to fine sand from 31.5- 31.65 ft; sample taken at 31 ft.



(32-48.2) Loam with few (6-15%) coarse gravel (16-32 mm), massive, Dark Gray (5Y4/1), moist, unoxidized-unleached, strong reaction, stiff consistency, Dmm, gradational lower contact, some color mottling (40%) at the top of interval: 32-32.8 ft of 10YR 4/6; Clasts: size of clasts increasing with depth. The granule size clasts more dominant in first 2 feet of interval. Some igneous rock fragments. Largest fragment roughly 40 mm in diameter.

(48.2-49) Loam with little (16-30%) granules to coarse (2-32 mm), massive, Dark Gray (5Y4/1), moist, oxidized-leached, none reaction, stiff consistency, Dmm, gradational lower contact, transition in color from primary (5Y 3/2) to secondary (10YR 3/4) which are finely separated by a band (0.1 ft/1 cm wide) of looser, drier sediment; the 10YR 3/4 indicates the third oxidized zone; potentially oxidized from 48.6-49 ft because of the rust.

(49-50) Clay loam with trace (<5%) granules (2-4 mm), massive, Olive Brown (2.5Y4/4), moist, unoxidized-leached, none reaction, medium consistency, Dmm, gradational lower contact, some (20%) mottling in color (of 10YR 4/6); sample taken at 49 ft; very gradual transition (in color) to the next interval.

(50-51) Clay loam with trace (<5%) granules (2-4 mm), laminated, Dark Yellowish Brown (10YR4/6), moist, oxidized-leached, none reaction, medium consistency, Dms, gradational lower contact, 2% clasts of granules; oxidized because of rust color; sample taken at 50 ft.

(51-57) Silty clay with little (16-30%) granules to coarse (2-32 mm), massive, Yellowish Brown (10YR5/4), moist, oxidized-unleached, strong reaction, Dmm, gradational lower contact, 25% coarse fragments; some circular pockets of 10YR 5/8 (10%); sample taken at 56 ft.

(57-58) Sand with little (16-30%) coarse gravel (16-32 mm), massive, Olive Brown (2.5Y4/3), moist, oxidized-unleached, strong reaction, medium dense, SG, sharp lower contact, color gradually changes from primary to secondary color with depth; fine sand becomes slightly more densely packed with depth; sample taken at 57 ft.

(58-58.4) Silty clay with few (6-15%) fine gravel (4-8 mm), massive, Dark Grayish Brown (2.5Y4/2), moist, oxidized-unleached, strong reaction, stiff consistency, Dmm, sharp lower contact, few horizontal bands (4mm wide) of 2.5 4/1 (grey) and 10YR 4/6 (dark yellowish brown); sample taken at 58 ft.

(58.4-59) Silty clay and sand with few (6-15%) granules to med (2-16 mm), massive, Dusky Red (2.5YR4/2), moist, oxidized-unleached, strong reaction, medium dense, Dmm, gradational lower contact, the medium sand is more concentrated in the middle of the interval, then continues to mix with the silty clay; one large coarse fragment of 40 mm is the exception; sample taken at 58.8 ft.

(59-65) No recovery.

(65-66.4) Sand with few (6-15%) fine gravel (4-8 mm), massive, Olive Brown (2.5Y4/4), wet, oxidized-Unleached, strong reaction, loose, SG, gradational lower contact, Color gradually shifts from primary to secondary color; sample taken at 65.5 ft.

(66.4-67) Sand with trace (<5%) granules (2-4 mm), massive, Dark Grayish Brown (2.5Y4/2), wet, unoxidized-unleached, strong reaction, medium dense, S, gradational lower contact, very fine sand; sample taken at 67 ft.

(67-70) No recovery.

(70-71.3) Sand and sand with few (6-15%) fine gravel (4-8 mm), fining upward, Dark Grayish Brown (2.5Y4/2), wet, unoxidized-unleached, strong reaction, medium dense, SG, sharp lower contact, Fining upwards (in terms of sand and grain size); chunk of gray clay at the top of the interval, likely remnants of the earlier drive that didn't have full recovery); all clasts concentrated at the bottom of the interval; sample taken at 70.5 ft.

(71.3-72) Sandy clay with little (16-30%) coarse gravel (16-32 mm), massive, Light Olive Brown (2.5Y5/3), moist, unoxidized-unleached, strong reaction, very stiff consistency, Dmm, sharp lower contact, Bands of gray (2.5Y 6/1) surrounding the coarse grains; sample taken at 72 ft.

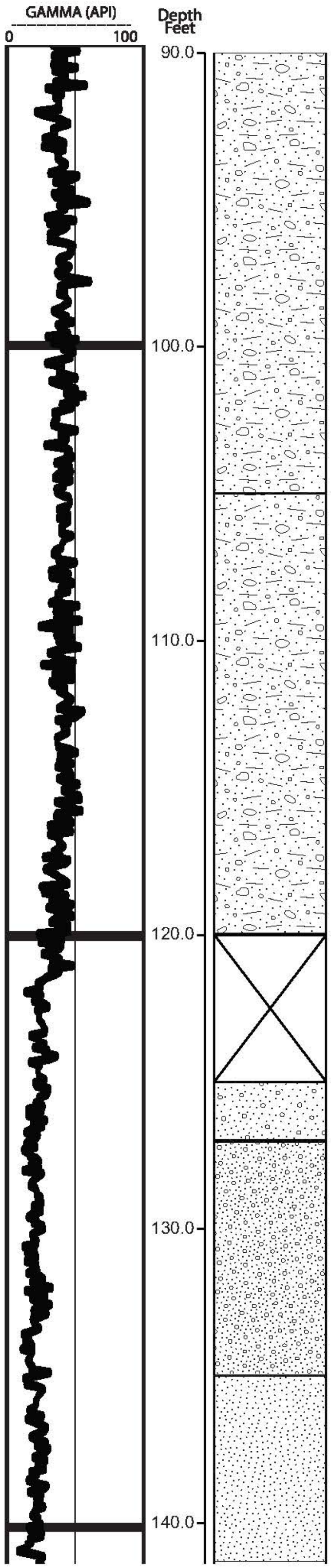
(72-75) No recovery.

(75-77) Sandy loam with few (6-15%) med. gravel (8-16 mm), massive, Olive Brown (2.5Y4/4), dry, unoxidized-unleached, strong reaction, hard consistency, Dmm, sharp lower contact, Secondary color is concentrated in the core/center of the core with the primary color surrounding the secondary color; some medium gravel comprised of igneous rocks, otherwise colorful fragments; sample taken at 76 ft.

(77-79) Sandy loam with few (6-15%) granules to coarse (2-32 mm), massive, Olive Brown (2.5Y4/3), dry, unoxidized-unleached, strong reaction, hard consistency, Dmm, sharp lower contact, some mottling (in bands) of 5YR 4/6; 15% coarse grains including igneous rock fragments; sample taken at 78 ft.

(79-83) Sandy clay loam with little (16-30%) granules to coarse (2-32 mm), massive, Dark Gray (10YR4/1), dry, unoxidized-unleached, strong reaction, very stiff consistency, Dmm, gradational lower contact, Primary color (80%) found throughout the core/center of the core, and secondary color (20%) along the edges of the core; 20% mottling in color (7.5YR 4/6) from 79-80 ft; 83-85 ft: is notably more dry, but the same color and texture; sample taken at 81 ft.

(83-85) Sandy loam with little (16-30%) granules to med (2-16 mm), massive, Dark Gray (10YR4/1), dry, unoxidized-unleached, strong reaction, very stiff consistency, Dmm, gradational lower contact, very dry sediment; sample taken at 84 ft.



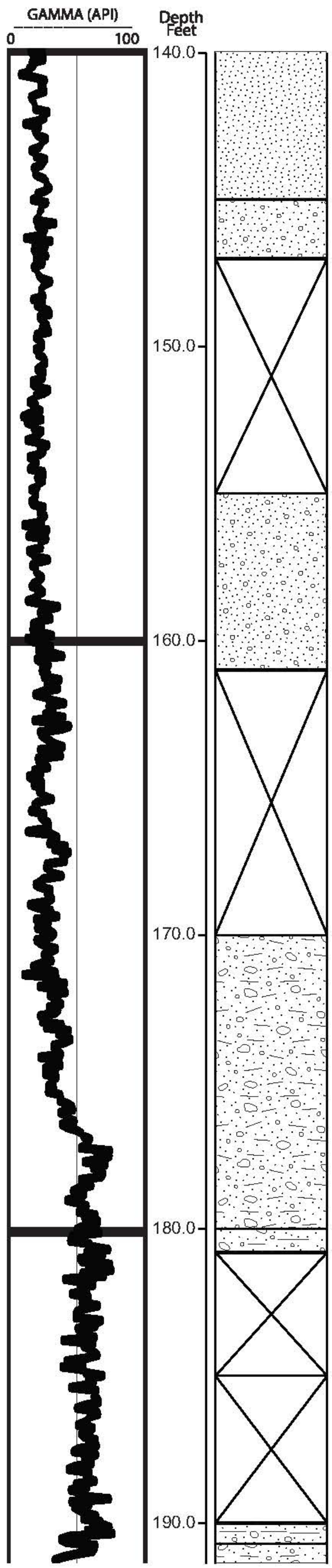
(85-105) Sandy clay with little (16-30%) granules to coarse (2-32 mm), massive, Dark Gray (10YR4/1), moist, unoxidized-unleached, strong reaction, very stiff consistency, Dmm, gradational lower contact, the box of cores (box 8) was not labelled-- so estimated the depths of the cores within the range; Misc. cores: labelled 85+ ft and a bag of rocks (coarse fragments) 85-95 ft; sample taken at 92 ft.

(105-120) Sandy loam with little (16-30%) granules to coarse (2-32 mm), massive, Dark Grayish Brown (10YR4/2), moist, unoxidized-unleached, strong reaction, stiff consistency, Dmm, 20% coarse fragments: igneous rocks, clast of 60 mm at bottom on interval (120 ft); layer of sandy clay loam from 119-119.4 ft - crumblier than the rest of core.

(120-125) No recovery.

(125-127) Sand with some (31-49%) coarse gravel (16-32 mm), massive, Dark Grayish Brown (10YR4/2), wet, unoxidized-unleached, moderate reaction, loose, SG, 40% coarse gravel up to 60 mm clasts: white, green, red, blue.

(127-135) Gravel, massive, Light Brownish Gray (2.5Y6/2), wet, unoxidized-unleached, weak reaction, very loose, G, very wet mud between the gravel; 1 bag recovered (1.5 cups in volume).



(135-145) Sand, massive, Grayish Brown (2.5Y5/2), moist, unoxidized-unleached, weak reaction, medium dense, S, 2 bags recovered (3 cups total volume).

(145-147) Sand with trace (<5%) coarse gravel (16-32 mm), massive, Olive Brown (2.5Y4/3), moist, oxidized-unleached, strong reaction, medium dense, SG, 5% coarse fragments of 8-50 mm; at 146 ft: circular mottle (40 mm diameter) of gray (5Y 5/1) encircled by 3 mm perimeter of 10YR 4/6; at 146.6 ft: faintly laminated gray clay.

(147-155) No recovery.

(155-161) Clay and sand with few (6-15%) very coarse gravel (32-64 mm), Brown (10YR4/3), moist, oxidized-unleached, strong reaction, loose, SG, 15% coarse fragments of coarse gravel (40-60 mm); oxidized by water?

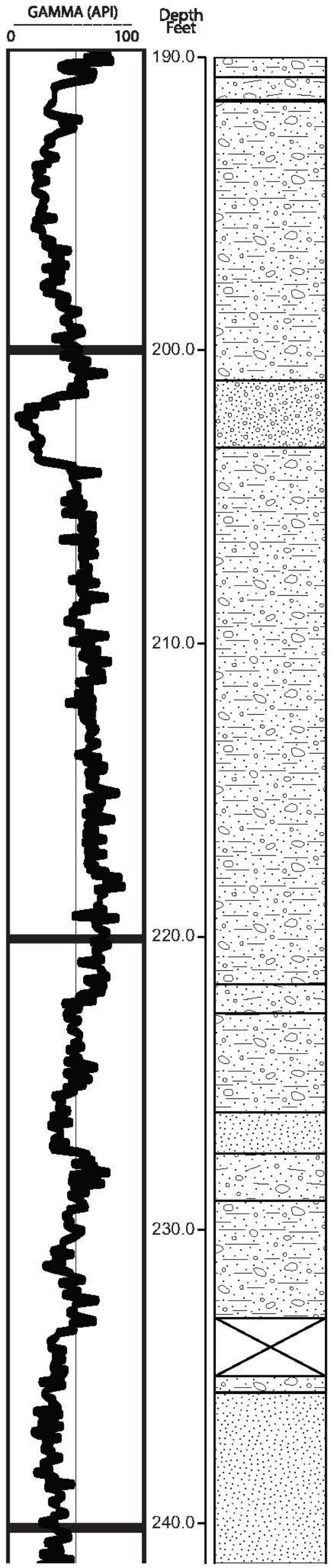
(161-170) No recovery.

(170-180) Sandy loam and sand with some (31-49%) very coarse gravel (32-64 mm), Dark Grayish Brown (2.5Y4/2), dry, unoxidized-unleached, strong reaction, stiff consistency, Dmm, 40% coarse fragments of coarse gravel to cobble (16-80 mm); 3 cups total volume recovered (1 bag); Sandy loam and clasts are non-cohesive, along with many loose fragments.

(180-180.8) Clay loam with few (6-15%) granules to coarse (2-32 mm), Dark Brown (7.5YR3/4), dry, oxidized-unleached, strong reaction, very stiff consistency, Dms, one very large clast (80 mm) with drill bit marks; grass fragments (organic layer) or surface contamination; rough lamination in parts; RJA field notes: not sure if this is an oxidized zone or if it is just the color of the till.

(180.8-185) No recovery.

(185-190) No recovery.



(190-190.7) Clay loam with trace (<5%) granules to coarse (2-32 mm), Reddish Brown (5YR4/3), moist, oxidized-unleached, strong reaction, very stiff consistency, Dms, sharp lower contact, 5% coarse fragments of granules to coarse (2-40 mm); faint laminations.

(190.7-191.5) Silty clay loam with some (31-49%) coarse gravel (16-32 mm), Reddish Brown (5YR4/3), dry, oxidized-unleached, strong reaction, very stiff consistency, Dcm, 45% coarse fragments of coarse gravel (10-40 mm) - more gravel at top of interval and cohesive silty clay loam at bottom of interval (poorly sorted).

(191.5-201) Silty clay loam with little (16-30%) granules to coarse (2-32 mm), laminated, Dark Reddish Brown (5YR4/3), dry, oxidized-unleached, moderate reaction, hard consistency, Dms, gradational lower contact, 20% coarse fragments of granules to gravel (2-45 mm) with some igneous rock fragments; some very large clasts, increasing in frequency with depth (up to 60 mm diameter); RJA field notes - 191.5-192.6 ft - unsure whether red is oxidized weathering zone or color of till.

(201-203.3) Gravel, G, RJA field notes - 201-203.3 ft - core of 2.3-foot-thick quartzite boulder - wow! - museum quality; quartzite has other clasts embedded within it - Gowganda tillite-like.

(203.3-221.6) Silty clay loam with little (16-30%) granules to coarse (2-32 mm), laminated, Reddish Brown (5YR4/3), dry, oxidized-unleached, moderate reaction, hard consistency, Dms, 20% coarse fragments of granules to gravel (2-45 mm) with some igneous rock fragments; some very large clasts, increasing in frequency with depth (up to 60 mm diameter); RJA field notes - 203.3-221.6 ft - red till - West Lebanon till? - beautiful core obtained with rock core - very dense till; possible oxidized till; 10.8 foot recovery for 215-225 ft sample.

(221.6-222.6) Clay and sandy loam with few (6-15%) granules to med (2-16 mm), laminated, Gray (2.5Y6/1), moist, unoxidized-unleached, moderate reaction, medium consistency, Dmm, gradational lower contact, 5% coarse fragments concentrated heavily in the top of the interval; large colorful mottle of 50mm: sandy (could be cut open) with inner gray (GLEY1 4/5GY) surrounded by 10YR 3/6 (rusty red); Fine/coarse textures alternative between clay (GLEY1 4/N); RJA field notes - red till appears to grade into gray till; oxidized over unoxidized zone? - over 40 feet of oxidized till, if correct - very thick; accumulation of 40-50% pebbles just below oxide/unoxide boundary.

(222.6-226) Clay and sandy loam with trace (<5%) granules (2-4 mm), laminated, Dark Gray (2.5Y4/1), moist, unoxidized-unleached, moderate reaction, medium consistency, Dms, sharp lower contact, 222.6-223 ft and 223.4-224 ft: mixing of fine sand (sandy loam) with clay, the rest of the interval is clay; laminations grows more evident with depth; 50 mm mottle at 224.7 ft that is reddish, yellowish in color, like discolored sandy soil.

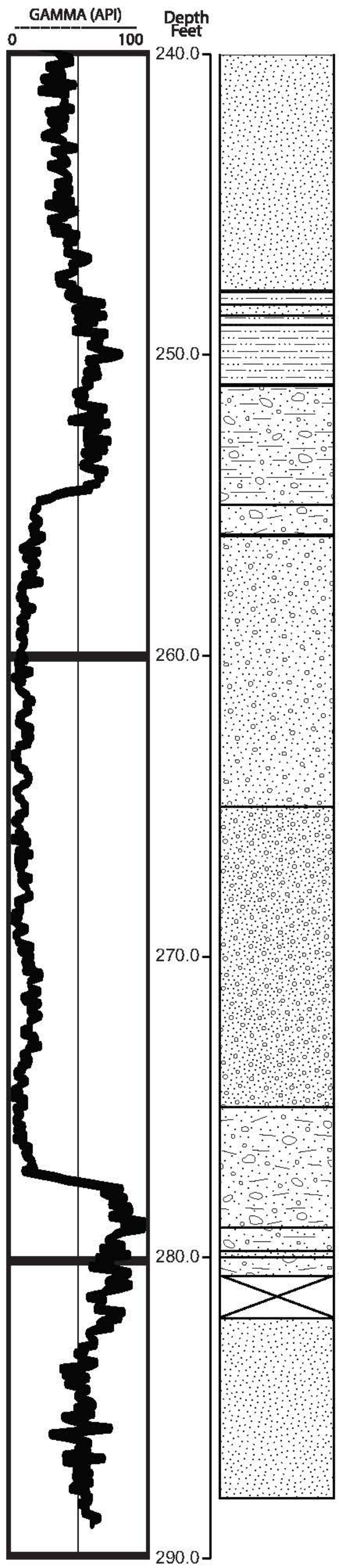
(226-227.4) Sand, laminated, Grayish Brown (2.5Y5/2), moist, unoxidized-unleached, moderate reaction, stiff consistency, S, sharp lower contact, very fine sand (bordering loamy sand); multidirectional lamination, most present at bottom on interval; some crumbly, but most is compact and moist.

(227.4-229) Clay with trace (<5%) granules (2-4 mm), laminated, Dark Gray (2.5Y4/1), moist, unoxidized-unleached, weak reaction, very stiff consistency, Dmm, gradational lower contact, GLEY1 4/N mottling for the top 0.5 ft; 3% coarse fragments (2-8 mm); thin laminations (horizontal).

(229-233) Clay with trace (<5%) granules to fine (2-8 mm), laminated, Dark Grayish Brown (2.5Y4/2), dry, unoxidized-unleached, weak reaction, very stiff consistency, Dms, gradational lower contact, 231.2-231.5 ft: 2.5Y 4/1 (grey patch); dried in the last foot of the interval (232-233 ft).

(233-235) No recovery.

(235-235.55) Silty clay with trace (<5%) granules to fine (2-8 mm), laminated, moist, unoxidized-unleached, weak reaction, Stiff consistency, Dms, sharp lower contact, GLEY1 4/N; Fine horizontal lamination; coarse grains are multi-colored.



(235.55-247.9) Sandy loam, laminated, Dark Grayish Brown (10YR4/2), moist, oxidized-unleached, moderate reaction, medium consistency, S, sharp lower contact, Slight, coarse lamination, various directions, finer lamination with depth; OSL at 240 ft and 245 ft, resulting in crumbly, dry sand.

(247.9-248.3) Clay, laminated, Dark Gray (10YR4/1), moist, unoxidized-unleached, strong reaction, stiff consistency, Fl, sharp lower contact, Diagonal (almost horizontal but not quite) laminations; slight change in color along lamination lines.

(248.3-248.7) Sandy loam with none, massive, Light Olive Brown (2.5Y5/3), moist, oxidized-unleached, strong reaction, medium consistency, S, gradational lower contact, Oxidized in color?

(248.7-249) Clay, laminated, Dark Gray (2.5Y4/1), moist, unoxidized-unleached, moderate reaction, very stiff consistency, Fl, gradational lower contact, F (because no clasts); 2 mm thick lamination horizontally.

(249-251) Clay, laminated, Very Dark Grayish Brown (10YR3/2), moist, unoxidized-unleached, moderate reaction, stiff consistency, Fl, gradational lower contact, Some color changes (due to dryness) along the lines of lamination.

(251-255) Clay with trace (<5%) granules (2-4 mm), laminated, Dark Grayish Brown (10YR4/2), moist, unoxidized-unleached, moderate reaction, very stiff consistency, Dms, Color transition is gradual with depth from primary to secondary; laminated horizontally with dryness following lines of lamination; one large chert cobble (90mm diameter).

(255-256) Silty clay with trace (<5%) granules (2-4 mm), massive, Gray (5Y5/1), dry, unoxidized-unleached, moderate reaction, very stiff consistency, Dmm, 7% circular color mottles of 10YR 4/6 (rusty red).

(256-265) Sand with few (6-15%) coarse gravel (16-32 mm), massive, Dark Grayish Brown (2.5Y4/2), moist, unoxidized-unleached, moderate reaction, loose, SG, One bag recovered: 1.5 cups total volume; one large clast (bedrock?) of 2.5Y 6/1 with a small pocket of grey clay on it; note on sample bag: sandstone (clasts?) or bedrock.

(265-275) Gravel, massive, Gray (2.5Y6/1), dry, unoxidized-unleached, strong reaction, very loose, G, one bag recovered: 1/2 cup total volume; multi-colored fragments; sample taken is full bag because there was so little recovery.

(275-279) Silty clay with trace (<5%) granules (2-4 mm), massive, dry, unoxidized-leached, none reaction, stiff consistency, Dmm, sharp lower contact, 275.5-280 ft: joint where water flowed (oxidized coloring) along with clay deposits; at 276 ft: One clast of 10YR 3/6 along with mottling of grey and black in veins; color mottling: GLEY1 5/5GY (primary) with 5Y 4/3 - the secondary color less present with depth.

(279-279.8) Clay with few (6-15%) granules to med (2-16 mm), laminated, Olive (5Y4/3), dry, unoxidized-leached, none reaction, stiff consistency, Dms, sharp lower contact, Horizontal lamination; ~10% coarse fragments concentrated at the bottom of interval - includes flat fragments, some red sandstone; secondary color: blocks of GLEY1 4/5GY.

(279.8-280) Sand, Olive (5Y4/3), moist, unoxidized-leached, loose, S, faintly laminated horizontally; some (40%) grains are red (2.5YR 3/6) - red sandstone?

(280-280.6) Clay with few (6-15%) med. gravel (8-16 mm), massive, dry, unoxidized-leached, none reaction, stiff consistency, Dmm, Primary color: GLEY1 5/10Y with 30% mottling of secondary color; clasts are red sandstone, increasing in frequency with depth - most are concentrated between 280.4-280.6 ft; weathered sandstone bedrock?

(280.6-282) No recovery.

(282-288) Sand, massive, Olive (5Y4/3), wet, unoxidized-leached, none reaction, very loose, S, collected in bag: 2 cups total volume; assumed to be weathered sandstone bedrock.