Support of Logging of Monitoring Wells for the National Ground-Water Monitoring Network in Illinois.

Illinois State Geological Survey
Award #G20AC00377

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Grant Award Term:
16 November 2020 – 15 November 2021
(Extension granted through 15 November 2022)

Final Technical Report Submitted 10 February 2023

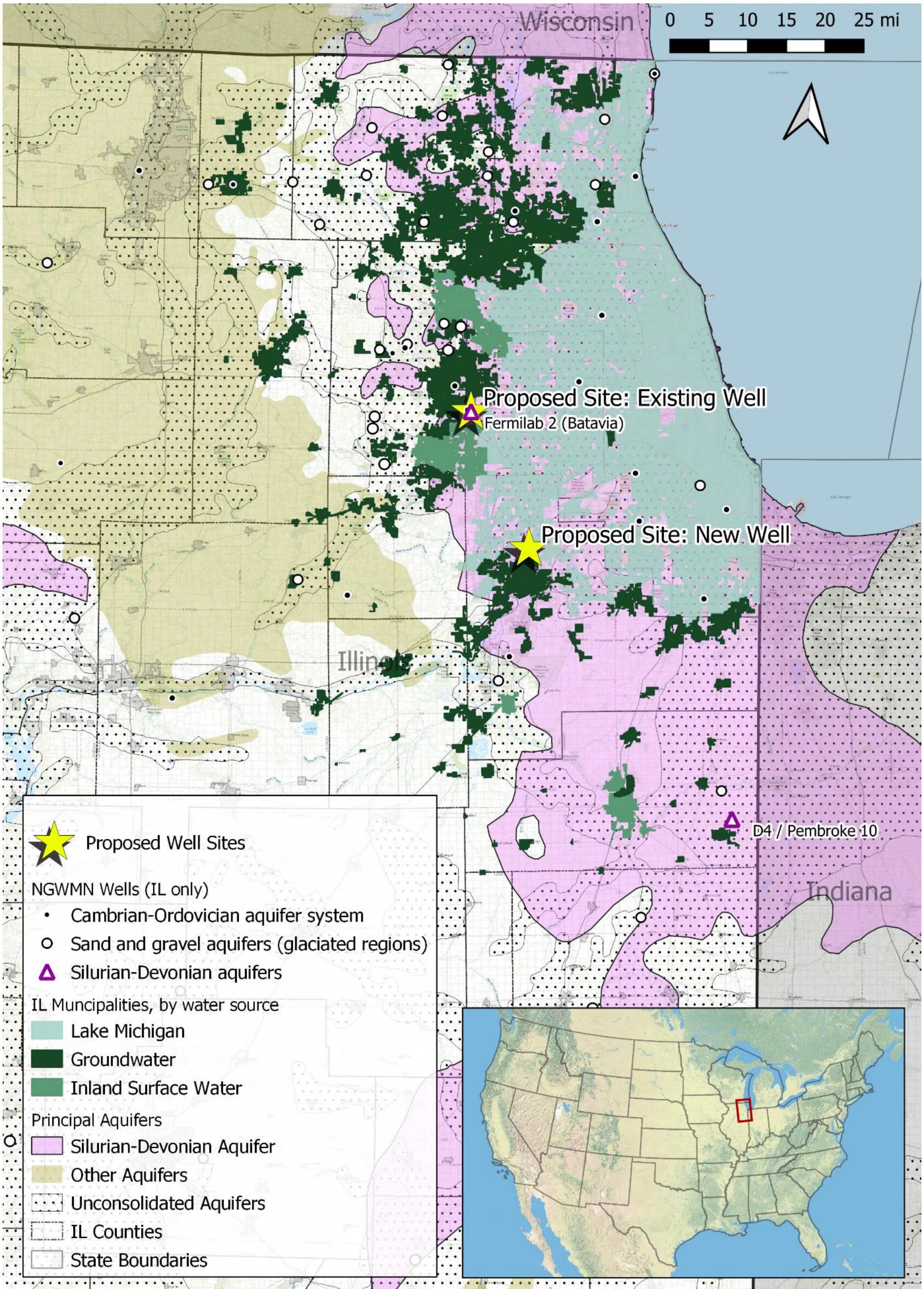

Figure 1. Wells in the National Groundwater Monitoring Network. Stars indicate the wells for which geophysical logging was performed under this grant.

Overview

Overview of the work planned and accomplished during the project.

The Illinois State Geological Survey (ISGS) performed included two components: 1) surface and downhole geophysics at one potential drill site for a new well in the National Groundwater Monitoring Network (NGWMN), and 2) downhole geophysics at an existing network well. The purpose of both components of this award is to fill in data gaps within the existing NGWMN subnetworks managed by the Illinois State Water Survey (ISWS). These activities fall within the bounds of NGWMN's Objective 3: Filling gaps in information at NGWMN sites.

The contract award term was originally 16 November 2020 – 15 November 2021, and a one-year extension was requested for the award term until 15 November 2022. This extension was necessary due to delays from Covid restrictions and supply chain issues associated with maintenance and repair of equipment used towards fulfillment of grant activities. There was also a significant delay for acquisition of downhole data at Site 2 (see Table 1) since the drilling of this well (associated with another NGWMN award) was also delayed. The award granted was $17,875.79. Final expenditures of the award totaled $10,508.16.

Description of Grant Activities

Introduction

Two sites were identified as part of the work associated with this contract (Table 1). These sites were selected due to their important locations with respect to water use and to their applicability to fulfilling Objective 3 of the request for proposals (Filling gaps in information at NGWMN sites). Both wells are located in communities that depend on groundwater, but which are adjacent and peripheral to communities where surface water from Lake Michigan is used. These sites also have high potential for providing a more comprehensive and detailed understanding of characteristics of the Silurian-Devonian aquifer. Site 1 (see Table 1) is the location of an existing well that is uncased through portions of bedrock and has a high potential to provide an understanding of the extent of the fracturing and weathering that contribute to groundwater flow in this region. There were only very sparse records available for this well, which only included a general location, drilling date, and sparse details such as (incomplete) casing information. Site 2 fills in a large spatial gap in monitoring network in an area that is vital to understanding the availability of groundwater for residents of the region (see Table 1). Precise (1-3 m accuracy) GPS coordinates were acquired for the wells at both sites and are included below.

Table 1. Well sites

Site	Site Name	API No.	Latitude (NAD83)	Longitude (NAD83)	Status	Aquifer	Geophysical Methods
1	Fermilab #2	120430206300	41.842825	-88.250177	Existing	Silurian-Devonian	Downhole: Gam, EM*, ATV†, FT&R‡
2	Romeoville: Veteran's Woods FP	121974725000	41.673366	-88.057924	Drilled in contract term	Silurian-Devonian	Surface: TEM, HVSR Downhole: Gam, EM*, ATV†, FT&R‡

Gam = Gamma; EM = EM conductivity/resistivity; ATV = Acoustic Televiewer, FT&R = fluid temperature and resistivity, TEM=Transient Electromagnetics, HVSR = Horizontal/Vertical Spectral Ratios

* Performed only in uncased or screened portions of well

† Performed in portions of well that are uncased or cased with PVC

‡ Performed in portions of well with water

Site 1 consists of a well drilled in 1970 located on the campus of the Argonne National Lab. Limited information existed about the well at Site 1 prior to this project. The ISGS and ISWS only had an inventory form in their possession from the time of the well construction that contained little more than the drill date and location of the well. As a part of this work, more data from supplementary forms were obtained at the site that has now been added to the ISGS and ISWS records (see Appendix B). This is in addition to the data from the downhole geophysics work carried out. At Site 1, data acquisition included gamma, EM conductivity, Acoustic Televiewer (ATV), fluid temperature, and fluid resistivity data.

Site 2 is located in Romeoville, IL in the Veteran's Woods Forest Preserve in the Forest Preserve District of Will County, IL. Site 2 includes a well drilled in the fall of 2022. Surface geophysics data was acquired at Site 2 prior to drilling of the well to help determine if the site was suitable and to help the drillers with siting of the well within the site. The surface geophysics also helped the drillers understand what they might encounter during the drilling process. These data were also used to help interpret the downhole geophysical data that was acquired after the drilling process, and vice versa. Some of the surface geophysics data also continued at depth beyond the downhole geophysics data.

For both sites, maps and data are included in Appendices A and B, respectively.

Geophysical Activities

Surface Geophysics

Surface geophysics were carried out at Site 2 before the well drilling associated with another NGWMN award. Surface geophysical methods included Time-domain Electromagnetics (TEM or WalkTEM) and analysis of ambient seismic data to estimate bedrock depth using the Horizontal to Vertical Spectral Ratio (HVSR) method.

Time-Domain Electromagnetic Methods (TEM)

The surface electromagnetic survey was conducted using an ISGS-owned WalkTEM system (ABEM Instruments AB, Sweden) to collect local time-domain electromagnetic (TEM) data. The TEM data helped to expand the spatial and electrical characterization of the local geological variability than allowed by mere geophysical logging (see Figure 2a). The TEM data also helped to distinguish the contact between the different geological materials at Site 2 (e.g., unconsolidated material and Silurian-Devonian aquifer, as well as at least one lower bedrock formation). Lithological information extracted from the TEM data helped to improve the *a priori* understanding of the geology at the site, with the purpose of informing the drilling location, depth, and expectations to achieve optimal well performance in the future.

The WalkTEM system operates using a transmitter coil and two receiver coils. During a WalkTEM survey all three coils are placed in concentric rings on the ground for data collection. An electrical current is sent through the transmitting coil, then immediately turned off. This flux creates a pulse of magnetic field, which in turn induces secondary electrical and magnetic fields in the subsurface. The amplitude and decay of these secondary fields are measured by the receiver coils over time. The nature of the field and its decay is analyzed and inverted to produce a 1D geologic model of the earth, down to several hundred meters. The measured 1-D TEM data is known as a "sounding."

The benefits of using TEM data at this site is that it gives the drillers a preview of what they can expect to see in the subsurface at depth (e.g., the depth to bedrock, an estimate of the grain size of layers unconsolidated sediment they might find above bedrock, the thickness of the aquifer, etc.).

TEM requires a large area per sounding, and the site must be relatively flat and unforested (the largest coil is 40m x 40m and requires an approximately 80-meter radius from the center that is free of metal or electrical infrastructure). The general area selected for the well site could only accommodate one sounding for more than 1 mile in all directions due to industry, property access, or high voltage power lines. Even so, the singular location of the TEM proved useful for site selection and drilling expectations. Data, plots, and interpretations from the TEM sounding are included in Appendix B. A site map showing the location of the sounding in relation to the other data at the site is included in Appendix A.

Horizontal-Vertical Spectral Ratio (HVSR) 1-D Seismic Method

The Horizontal-Vertical Spectral Ratio (HVSR) method makes use of ambient seismic “noise” in the environment to estimate depth to different strata, usually bedrock. A single, portable, 3-component seismometer records ground vibrations over a period of 20-30 minutes. The background vibrations are produced by a combination of wind, long-period ocean waves, industrial activity, vehicular traffic, and other nearby surface activities. The data appears to be random seismic noise, but using advanced signal processing techniques, we can glean useful geologic data.

To extract the signal from the noise, the seismic recordings are first converted to power spectral densities. The amplitudes of the three components are compared, frequency-by-frequency. Over most of the spectrum the signal is noise: the amplitudes of the horizontal and vertical components are relatively similar. At a specific frequency there is resonance in the horizontal (N-S and E-W) seismometer components; at this frequency, the amplitude of spectral power of the horizontal components becomes greater than the vertical component. This wavelength of this resonant peak is often a proxy for depth to a change in the subsurface material. The most abrupt changes seismic character in Illinois are often at the interface between bedrock and the overlying unconsolidated material. This is expected at the sites in this proposal, given the regional geology.

HVSR data was collected and analyzed at four stations near where the well would eventually be drilled at Site 2. These four sites include the same location as the WalkTEM sounding and the eventual location of the well itself, as well as two other sites in between. The four sites were all analyzed, and—in addition to providing actionable information about bedrock depth to the drillers before well drilling—allow for the tracing of the bedrock surface from the eventual well location to the TEM sounding, helping to connect the data for better interpretation and to get a better understanding of how the groundwater might interact both with the well and the surrounding subsurface. Data, plots, and interpretations from the HVSR and TEM soundings are included in Appendix B and are summarized below. A site map showing the location of the sounding in relation other data at the site is included in Appendix A.

The four HVSR sites were separated by about 240 feet (~73 meters) on average, with a total distance of about 720 ft (~220 meters) separating the furthest sites. The furthest northeast HVSR site was within a few feet of where the well would eventually be drilled. The furthest southwest HVSR site was co-located with the center of the TEM loops. See Appendix A for a map of the sites.

The HVSR data revealed quite similar results at each site, with the calculated bedrock depth varying at most 5 feet between all points. The standard deviation of the frequency peak measurement corresponded to an approximate variation of ±4 feet bedrock depth. The surface topography was also quite flat at this site, with all surface elevations being within two feet of each other vertically. The deepest bedrock depth derived from the HVSR measurements was 79.7 feet (24.3 meters) and the shallowest bedrock depth was 74.7 feet (22.7 meters). Calibrating the HVSR frequency peak to local data provided better results than using a regional calibration with a much larger number of points.

The TEM sounding produced similar results, though it has much coarser resolution and deeper penetration. The inverted TEM sounding curve modeled a resistivity peaking around 65-82 feet (20-25 meters) below the ground surface. This high resistivity layer would be expected for dolomite/dolomitic limestone, like what is expected at the bedrock surface here. However, the presence of a high resistivity sandy layer just above the bedrock and the expected weathering of the top of bedrock meant that the top of bedrock did not create as clear a signal as it might be in other contexts. Still, the TEM corresponded quite closely to the HVSR sounding data, and closely matched the drilling information and downhole geophysical data. See appendices for actual data and maps showing the sites where surface geophysical data was collected.

Downhole Geophysics

Downhole logging to determine lithology and other characteristics of the subsurface was carried out at the wells at both sites. For each well, ten data types were acquired (see Table 2), however, borehole conditions limited the extent to which each data type could be collected within the well. For example, at Site 2, only about 10 feet of several data types (types 2-9 in Table 2 below) could be collected due to the water level in relation to the bottom of the well. The extent and type of grout as well as the screening intervals also affected the data quality and ability of different probes to gather data. Additionally, telemetry and other equipment at the top of the well at Site 1 prevented the installation of adequately sized centralizers, reducing the effectiveness of the Acoustic Televiewer (ATV) Probe. Still, about 100 feet of usable data were able to be extracted in that case. The downhole geophysical data are included in Appendix B.

At both sites and with both surface and downhole geophysical data, the activity associated with this grant enabled much better understanding of the aquifer and the monitoring wells themselves. An understanding of the geologic context surrounding these monitoring wells and a refined understanding of the characteristics of the wells themselves were important outcomes of the work. Additionally, communication between stakeholders involved in this work brought to light information about the existing well at Site 1 that was previously not filed in the associated database at ISGS.

Table 2. Downhole data types and descriptions

Data type		Probe	Description
1	Gamma	Poly Gamma-Resistivity	Counts per second of natural gamma radiation
2	Spontaneous potential (SP)		Natural potential from electrochemical differences
3	Single point resistance		Qualitative measure of resistance to surface
4	Conductivity/Resistivity: 8		Resistivity of formation (8-inch electrode spacing)
5	Conductivity/Resistivity: 16		Resistivity of formation (16-inch electrode spacing)
6	Conductivity/Resistivity: 32		Resistivity of formation (32-inch electrode spacing)
7	Conductivity/Resistivity: 64		Resistivity of formation (64-inch electrode spacing)
8	Fluid temperature	Fluid temperature & resistivity	Temperature in ^{o}C of well fluid
9	Fluid conductivity/resistivity		Conductivity of well fluid (and inverse resistivity)
10	Acoustic imagery	Acoustic Televiewer	Acoustic sounding of borehole for imaging

Appendix A
Maps, Site Photos, and Figures

Site 1: Argonne National Lab

Fermilab Well #2 (API: 120430206300)

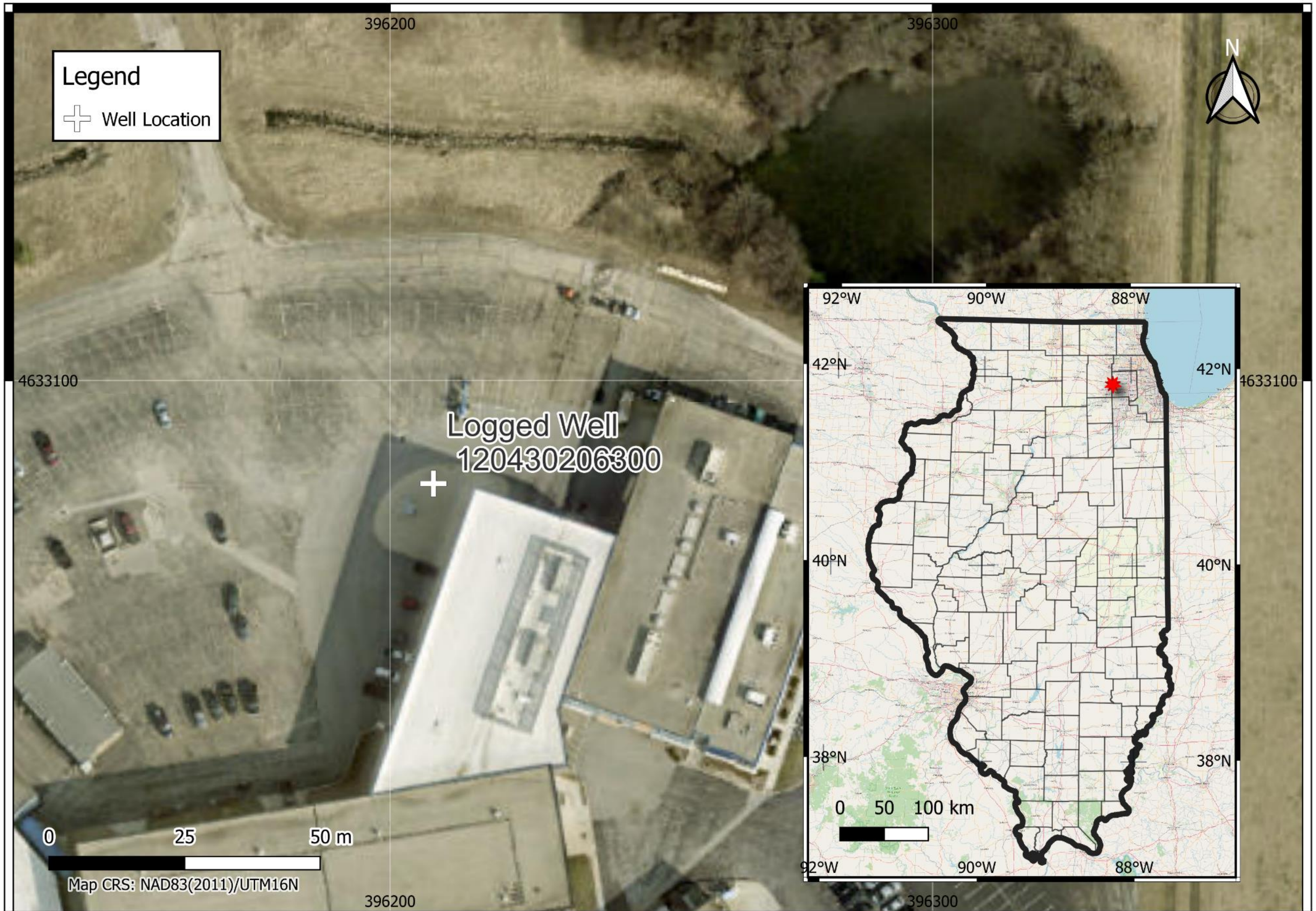

FIGURE A2. MAP OF SITE 1 LOCATED ON CAMPUS OF ARGONNE NATIONAL LAB.

Figure A3. Fermilab Well #2 (API 120430206300) at site 1 surrounded by protective bollards.

Figure A4. Closeup (left) and wider (right) view of the wireline log acquiring data at Fermilab Well #2 at site 1.

FIGURE A5. OTHER IMAGES OF DATA ACQUISITION AT FERMILAB WELL #2 AT SITE 1.

Site 2: Romeoville: Veteran's Woods Forest Preserve

Well API: 121974725000

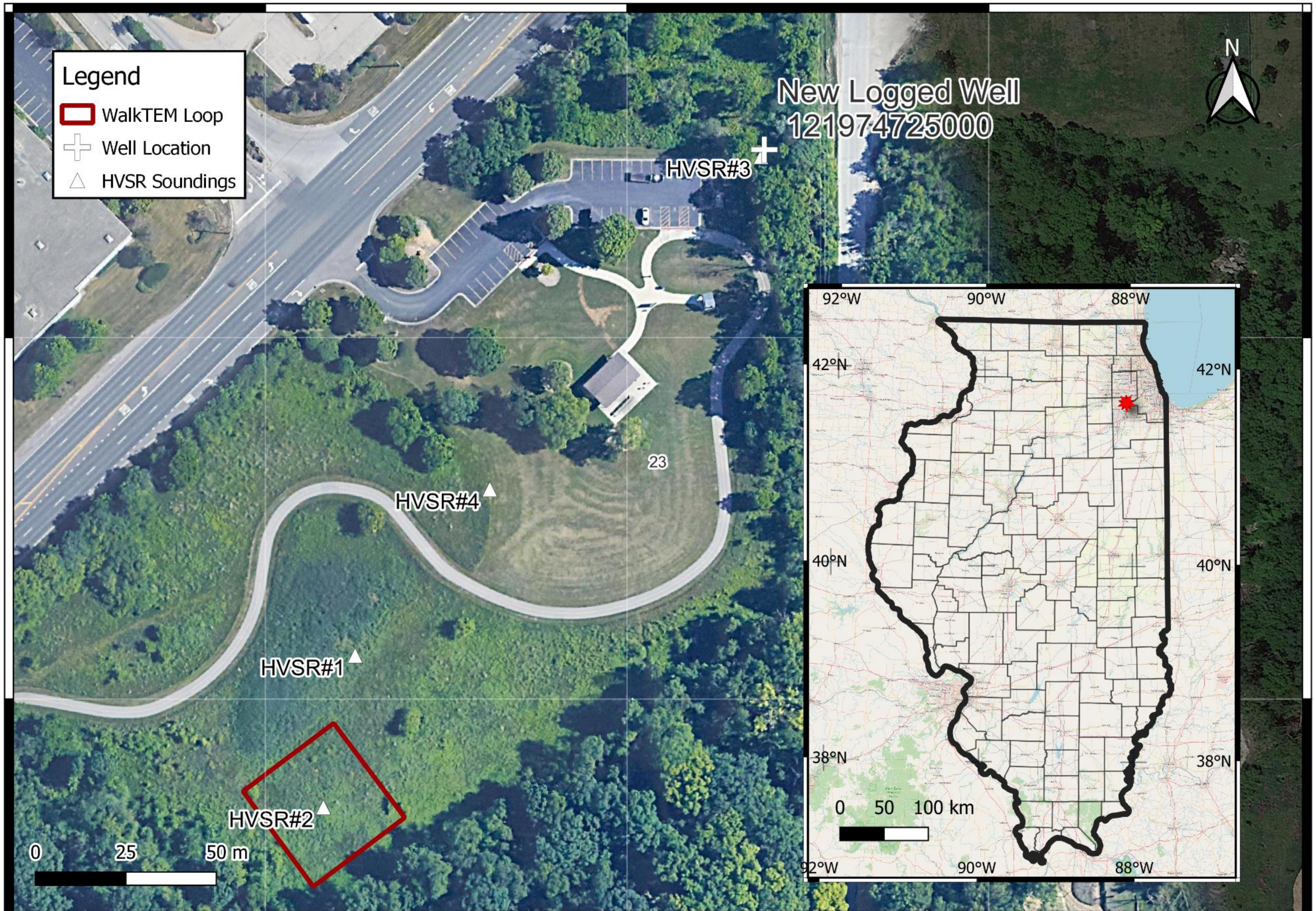

Figure A6. Map of Site 2: Romeoville: Veteran's Woods Forest Preserve

Figure A7. WalkTEM setup at Site 2. Barely visible is red transmission loop extending to right and left from orange reel.

Figure A8. HVSR Setup at HVSR#2, co-located with the center of the WalkTEM Loops

Figure A9. HVSR Site #3, approximately co-located with one potential future well site, denoted with the white flag.

Figure A10. The well at Site 2 looking southwest (left) and northeast (right)

FIGURE A11. THE WELL WITH THE ACOUSTIC TELEVIEWER PROBE (LEFT) AND THE WATER LEVEL METER AND FLUID TEMPERATURE AND RESISTIVITY PROBE (RIGHT)

Appendix B
Geophysical Data

Site 1: Argonne National Lab

Fermilab Well #2 (API: 120430206300)

Well Information

Feet		Feet	Description
0	to	5	Topsoil.
5	to	30	Gray clay, with boulders.
30	to	64	Gravel, sand and boulders.
64	to	70	Broken limestone.
70	to	205	Gray limestone, medium.
205	to	217	Gray limestone, with shale streaks.
217	to	235	Blue shale.
235	to	245	Shale, with limestone streaks.
245	to	290	Gray shale.
290	to	305	Very soft, muddy gray shale.
305	to	310	Gray shale, with limestone streaks.
310	to	326	Gray and blue shale.

Figure B12. The well information imaged here was previously not documented with the well and has since been submitted for inclusion in the appropriate ISGS databases.

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TYPE LOG
NATURAL GAMMA,
8-16-32-64 INCH NORMAL RESISTIVITY,
SP & SPR
Fluid Temperature and Resistivity
Acoustic Televiewer

API #:	120430206300
SYSTEM:	MGXII #1
ACQ SER #:	1190
PROBE:	2PGA/2PEA-1000; 2WQA-1000; ABI-40
PROBE SER #:	3342, 3897
PERMIT #	

COMPANY	Illinois State Geological Survey		
OWNER	Fermilab		
WELL	Fermilab #2		
PROJECT	National Groundwater Monitoring Network		
COUNTY	Dupage	STATE	IL
LATITUDE	41.842841	LONGITUDE	-88.2501880
DATUM	NAD83		
ADDRESS	Rd D Horseshoee, Warrenville, IL 60555		
LOCATION	~30 ft. WNW from NW corner of building		
SECTION	19	TWP 39N	RGE 9E

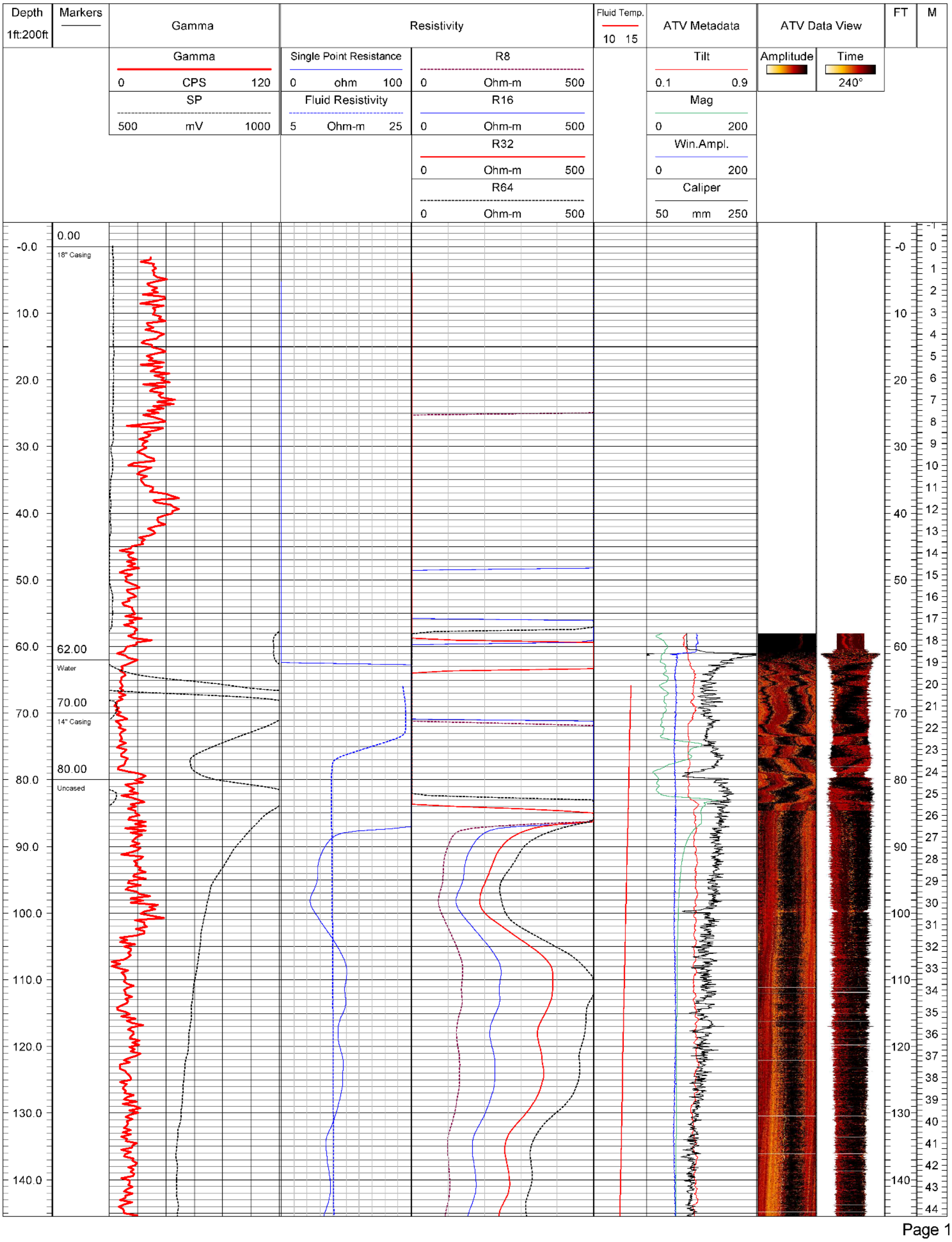
OTHER INFORMATION
Location in Riverside Industrial Park

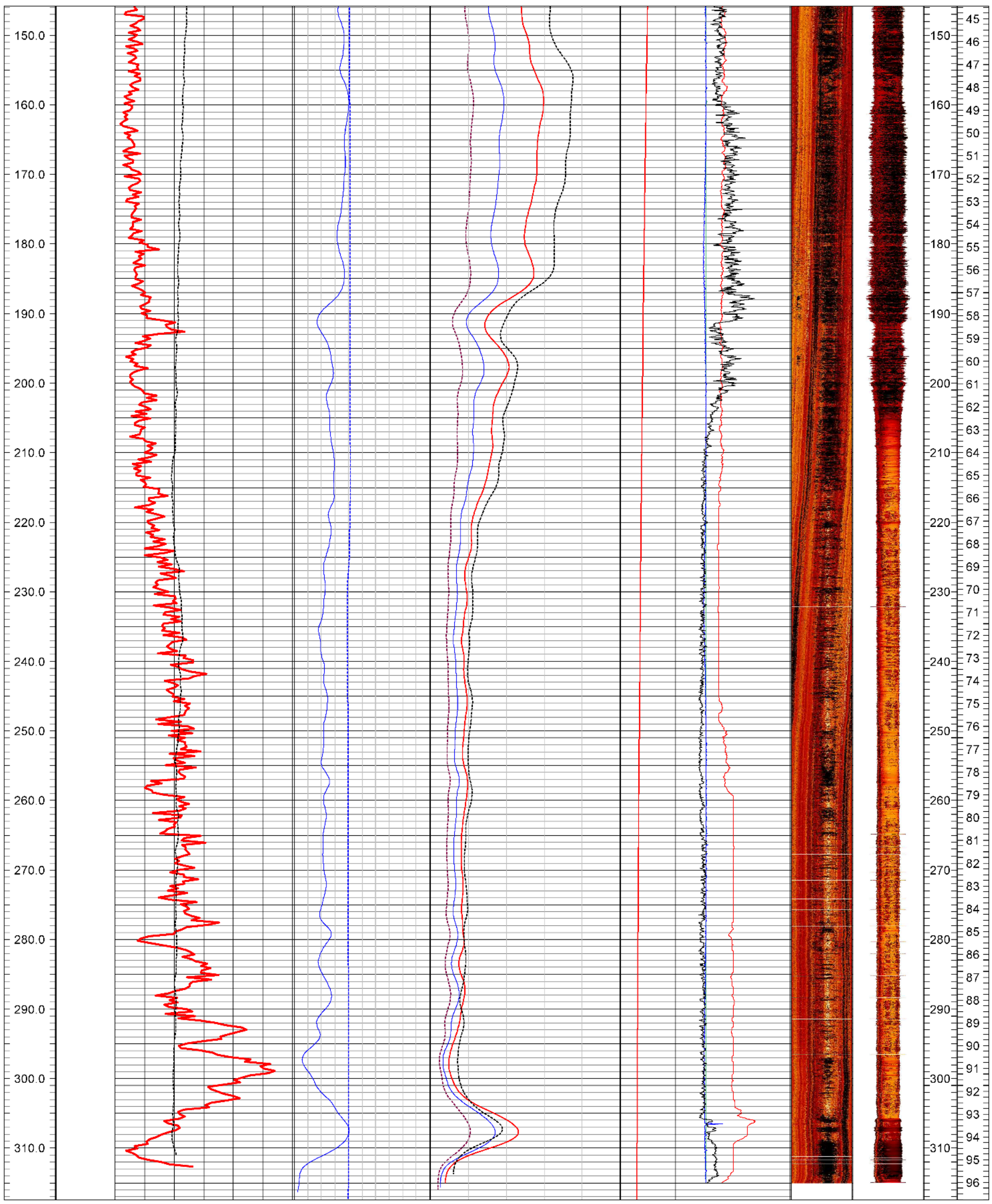
DATE LOGGED	November 4, 2022 (ATV on Nov 14)	G.S. ELEVATION	743' AMSL
RUN NUMBER	1-3	ELEVATION SOURCE	2017 Lidar DTM
DRILLER DEPTH	326' BGS		
LOGGER DEPTH	~318' BGS		
LOGGED INTERVAL	~0' BGS TO~320' BGS	TYPE FLUID IN HOLE	Formation H2O
DEPTH REFERENCE	Top of Casing	SALINITY	[Text]
HEIGHT ABOVE G.S.	0.875' AGS	DENSITY	[Text]
START DOWN DEPTH	~2-5' BGS	LEVEL	Ground Surface
START RECORD DEPTH	~317' BGS	MAX. REC. TEMP.	[Text]
END RECORD DEPTH	~60' BGS		
LOG FILE NAME	120430206300_PolyGamRes_2022-11-04.rd	120430206300_FluidTempRes_2022-11-04.rd	120430206300_ATV_2022-11-04.rd
WELL/HOLE TYPE	Groundwater Monitoring Well		
RECORDED BY	R. Balikian		
WITNESSED BY	S. Sargent		

BOREHOLE RECORD			CASING RECORD			
BIT DIAM (IN.)	FROM (FT BGS)	TO (FT BGS)	I.D. (IN.)	TYPE & GAUGE	FROM (FT BGS)	TO (FT BGS)
18	0.0	70	14	Steel	0.0	80
14	0	80	[Text]	[Text]	[Text]	[Text]
[Text]	[Text]	[Text]	[Text]	[Text]	[Text]	[Text]

Figure B13. Header form for downhole geophysical data.

Downhole Geophysics Data




150.0
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Site 2: Romeoville: Veteran’s Woods Forest Preserve
New well drilled the week of 11 Nov 2022 (API: 121974725000)

Surface Geophysics Data

Data summary

Transient Electromagnetic (TEM) sounding data and ambient seismic data using the Horizontal Vertical Spectral Ratio (HVSR) technique were acquired at Site 2 (Romeoville: Veteran’s Woods Forest Preserve) to better understand bedrock depth and potential geologic layering in anticipation of drilling and logging of a monitoring well at or near the surface geophysical sites.

TEM was used to calculate a 1D conductivity/resistivity data at depth. The data was processed and inverted using Aarhus’s GeoSoftware SPIA processing and inversion software. Because the data is inverted, a 1D layered model created with a discrete number of depth layers/time intervals. The layers and inverted resistivity values are shown in Figure 14.

In general, the grain size of unconsolidated sediment usually is positively related to resistivity. That is to say, clay tends to have a very low resistivity and sand and gravel tend to have much higher resistivities. Bedrock like sandstone and limestone tend to have very high resistivity values, where bedrock like shale can have resistivity values as low as clay. Characteristics like water saturation, mineral composition, cementation, and weathering in the bedrock can also affect resistivity values of geologic materials.

In the data shown below, the resistivity curve begins at a fairly low resistivity, then increases to a quite high resistivity where it levels off around 20-25 meters (65-82 feet) below the ground surface. The high resistivity layer(s) continue until about 50 meters depth (about 165 feet), where it begins to transition to a lower resistivity zone at depth. This low resistivity zone continues beyond the depth of investigation.

The initial low resistivity is likely too high to be pure clay, but too low to be sandy. This is interpreted as a clay-rich till. There is a somewhat gradual and consistent increase in resistivity from about 8 – 12 meters (25 – 40 feet) depth to 20 – 25 meters (65 – 82 feet) depth. Based on data from nearby wells in the region, this appears to be two layers that cannot be easily delineated, given the relatively coarse thickness of the model layers. First, there appears to be a sand-rich till. Below that, the geology appears to coarsen, to something like sand and gravel. Around 65 – 82 feet deep there appears to be a distinct bedrock boundary, which, given the surrounding well data, is likely limestone. The amount of weathering in this layer of bedrock is not clear in the TEM data. The green horizontal line indicates the maximum depth of interpretation for this dataset, and the black dotted horizontal lines indicate interpretated geologic layers.

The HVSR data as processed here is more limited in its scope. We use the HVSR to make bedrock picks along a transect encompassing most of the potential well locations at this site. The furthest southwest HVSR point aligned with the TEM sounding, and the furthest northeast HVSR point aligned closely with the eventual well location.

The peak resonant frequencies calculated from the HVSR points were quite similar, as shown in Figure B15. Table B3 shows the parameters calculated from the ambient seismic data relevant to this work. Parameters modified from HVSR and well data regional and local to the site were used to convert from a peak frequency to depth in meters, which is also converted to feet for ease of reference. Like the TEM data, the depth to bedrock calculated from HVSR is about 68 – 83 feet (20 – 25 meters) below the ground surface. There is little variation across the site. The approximately 5 feet (1.5 meters) difference between the deepest and shallowest bedrock is close to the standard deviation of the calculations.

The surface geophysics, in summary, reveal that bedrock is significantly shallower than 100 feet below the ground surface. Since depth in this formation is often a proxy for whether weathering will be sufficient for the extraction of water, this also implies that the top part of bedrock is likely to be weathered enough to serve as an aquifer.

WalkTEM (Time-domain Electromagnetics)

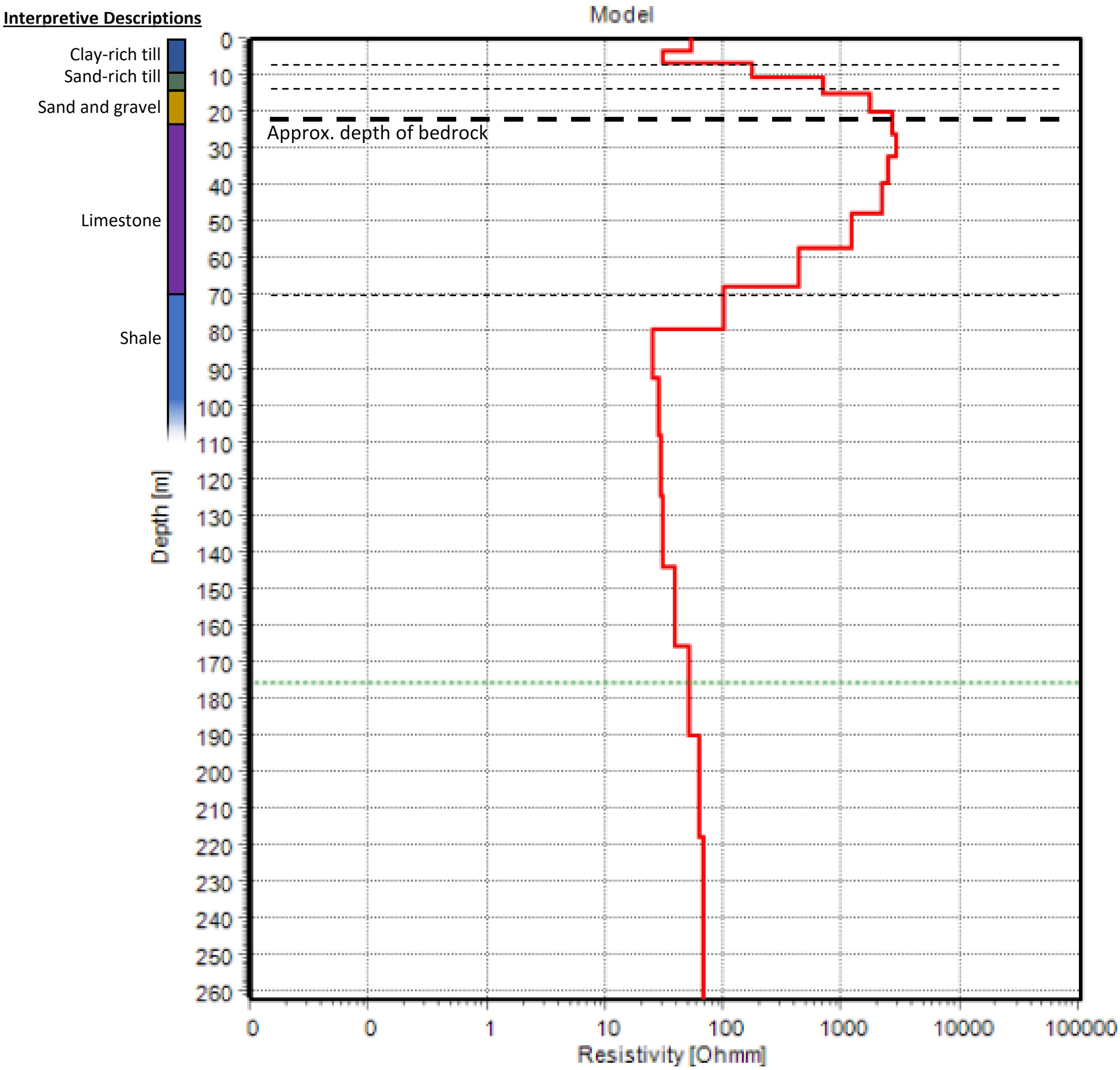

FIGURE B14. PROCESSED TEM DATA AT SITE 2.

Horizontal-Vertical Spectral Ratio (Seismic)

Table B3. Summary of HVSR data collected at Site 2: Romeoville/Veteran's Wood Forest Preserve

Site Name	Acquisition Date	Longitude (NAD83)	Latitude (NAD83)	Peak Frequency Hz	Peak Freq. St. Dev. Hz	Conversion Equation	Calculated Bedrock Depth: Feet	(± StDev)	Meters	(+ StDev)
ROM01	3 Nov 2022	-88.059263	41.672093	4.63	± 0.24	$142.95x^{-1.23}$	69.1	68.0 – 77.2	21.05	20.7 – 23.5
ROM02	3 Nov 2022	-88.059362	41.671714	4.38	± 0.22		74.0	72.9 – 82.4	22.56	22.2 – 25.1
ROM03	3 Nov 2022	-88.057935	41.673348	4.38	± 0.05		74.0	76.3 – 78.5	22.56	23.3 – 23.9
ROM04	3 Nov 2022	-88.058823	41.672511	4.38	± 0.22		74.2	73.1 – 82.6	22.62	22.3 – 25.2

The equation to convert peak frequency, following Ibs-von Seht and Wohlenberg, 1999 with parameters derived from other data collected regionally

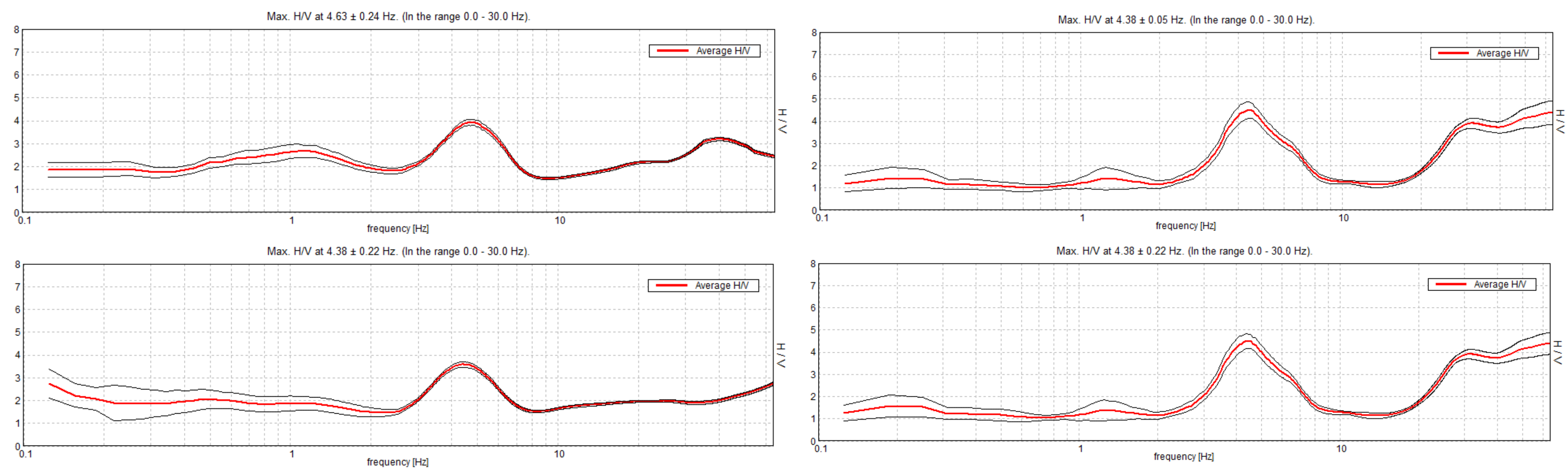

Figure B15. H/V Spectral Amplitude/Ratio Charts. Top Left: ROM01, Bottom Left: ROM02, Top Right: ROM03, Bottom Left: ROM04

Well Information

ILLINOIS
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TYPE LOG
NATURAL GAMMA,
8-16-32-64 INCH NORMAL RESISTIVITY,
SP & SPR
Fluid Temperature and Resistivity
Acoustic Televiewer

API #:	121974725000
SYSTEM:	MGXII #1
ACQ SER #:	1190
PROBE:	2PGA/2PEA-1000; 2WQA-1000; ABI-40
PROBE SER #:	3342, 3897
PERMIT #	

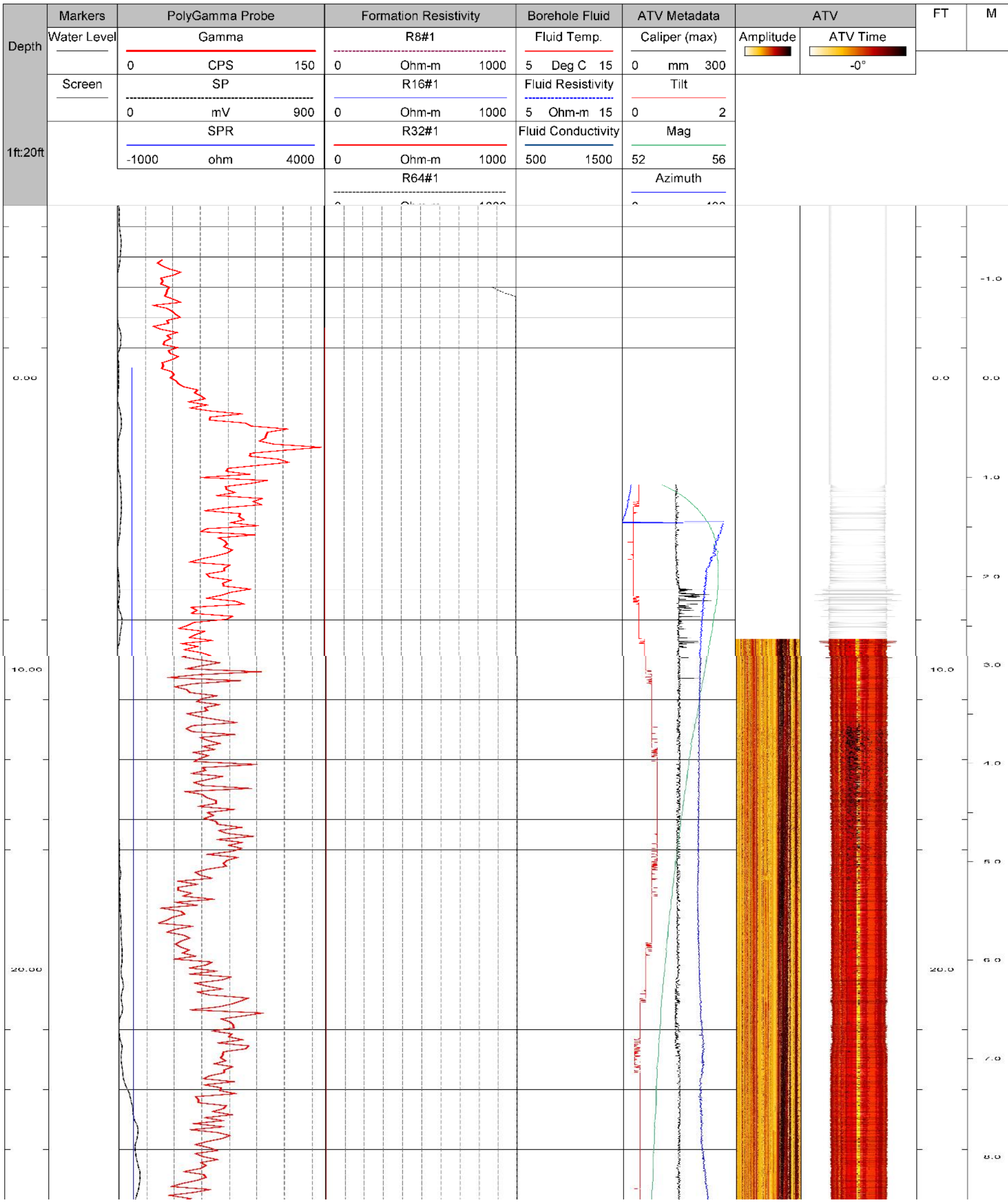
COMPANY	Illinois State Geological Survey
OWNER	Will County Forest Preserve District
WELL	Veteran Woods FP
PROJECT	National Groundwater Monitoring Network
COUNTY	Will
STATE	IL
LATITUDE	41.67364785
LONGITUDE	-88.05807135
DATUM	NAD83
ADDRESS	1371 S Joliet Rd., Romeoville, IL 60446
LOCATION	~240 ft. SSW from corner of Joliet Rd and Vulcan Way
SECTION	23
TWP	37N
RGE	10E
OTHER INFORMATION	Location in Riverside Industrial Park

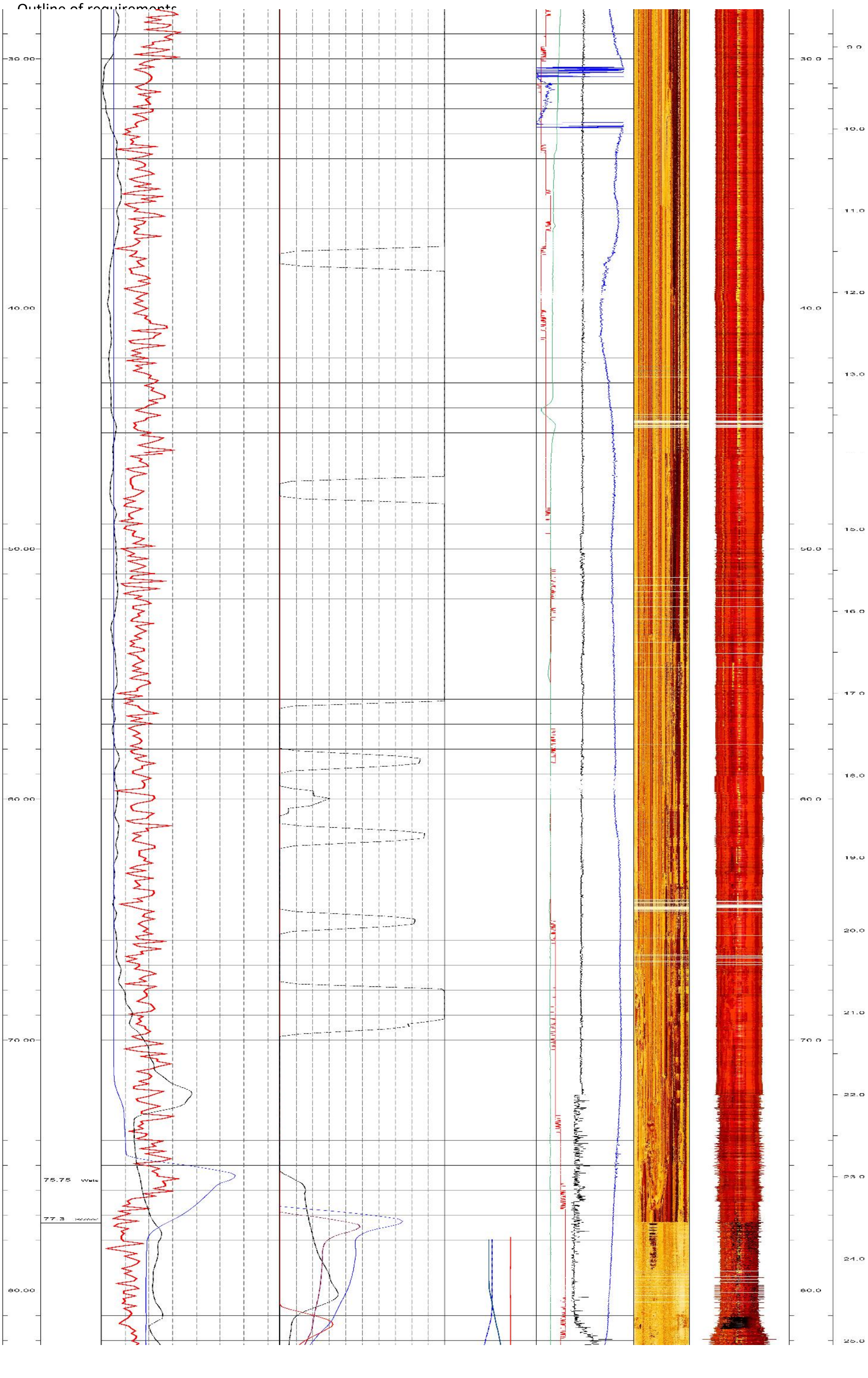
DATE LOGGED	November 14, 2022	G.S. ELEVATION	698' AMSL
RUN NUMBER	1-3	ELEVATION SOURCE	2021 Lidar DTM
DRILLER DEPTH	87.3' BGS		
LOGGER DEPTH	~85' BGS		
LOGGED INTERVAL	~0' BGS TO~85' BGS	TYPE FLUID IN HOLE	Formation H2O
DEPTH REFERENCE	Top of Casing	SALINITY	[Text]
HEIGHT ABOVE G.S.	2.75' AGS	DENSITY	[Text]
START DOWN DEPTH	0-5' BGS	LEVEL	Ground Surface
START RECORD DEPTH	-0.775' BGS and ~87' BGS	MAX. REC. TEMP.	[Text]
END RECORD DEPTH	~3.5' BGS and ~85' BGS		
LOG FILE NAME	VetWoods_PolyGamRes.rd	VetWoods_FluidTempRes.rd	VetWoods_ATV.rd
WELL/HOLE TYPE	Groundwater Monitoring Well		
RECORDED BY	R. Balikian		
WITNESSED BY	S. Sargent		

BOREHOLE RECORD			CASING RECORD			
BIT DIAM (IN.)	FROM (FT BGS)	TO (FT BGS)	I.D. (IN.)	TYPE & GAUGE	FROM (FT BGS)	TO (FT BGS)
3	0.0	77.3	2	Schedule 40 PVC	0.0	77.3
			2	Screened PVC	77.3	87.3
[Text]	[Text]	[Text]	[Text]	[Text]	[Text]	[Text]

Figure 16. Header information for downhole geophysical data for well at Site 2 (Veteran Woods Forest Preserve)

Downhole Geophysics Data

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9.0
10.0
11.0
12.0
13.0
15.0
16.0
17.0
18.0
19.0
20.0
21.0
22.0
23.0
24.0
25.0

Outline of requirements