



New Jersey Geological and Water Survey near-surface geophysics program

The New Jersey Geological and Water Survey (NJGWS) uses a wide variety of near surface geophysical tools to understand the subsurface. These tools are easy to use, fast to deploy, and less expensive than a traditional subsurface investigation, which may require the drilling and monitoring of several wells over a long period of time. Specifically, these tools assist with finding buried items (old tanks, lost graves, old roads, or abandoned wells) and in understanding the underlying geology (sediment type, rock type, depth to bedrock, the location of caves, or aquifer properties). Near surface geophysical tools show physical and chemical variations in subsurface materials and locate anomalies. Once the approximate locations of subsurface features are known, they must be ground-truthed. For studies of aquifer properties, geophysical tools can guide hydrogeologists in the design of a traditional groundwater study. For example, the information gained from a near surface geophysical survey can be used to choose optimal locations for the placement of boreholes and wells for hydrologic studies or to correlate geology between wells and boreholes. The information derived from near surface geophysics is also used to reduce the risk of drilling into buried tanks, drums and underground piping.

Geophysical Tools and Common Uses

Ground Penetrating Radar (GPR) images the subsurface by sending radar pulses into the ground. These pulses are produced by a control unit, amplified by the antenna, and sent into the ground at a chosen frequency, measured in kilohertz (kHz) (figure 1). Low frequencies have greater depth penetration, but lower resolution than higher frequencies. The GPR unit records the strength (watts) and the return time (seconds), of these radar signals. It compiles a series of these measurements into a profile. Notable reflections are produced when the energy pulse encounters a material with a different dielectric permittivity (a measurement of a material's ability to carry an electric current). Differences in dielectric permittivity reflect variability in water content and the presence of metallic objects (GSSI, undated a). Thus, GPR is most often used to locate the water table, find buried metallic objects, or locate highly compacted material. GPR should not be used in wet or clayey conditions or used to solely differentiate between lithologies (i.e. different rock or sediment layers) (NJDEP, 2005).

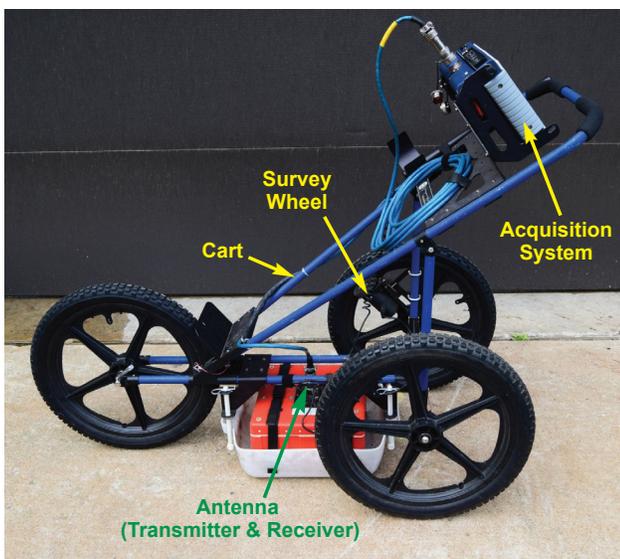


Figure 1. Typical ground penetrating radar (GPR) survey equipment configuration. Photo by M. Spencer

Electromagnetic Induction (EM) measures conductivity, a material's ability to transport an electrical current, in the subsurface. EM instruments are made up of two coils which are electrically connected and spaced at a fixed distance (figure 2). The transmitter coil generates a primary electromagnetic field at a chosen frequency (kHz). This primary field induces an electric current that flows through conductive materials in the subsurface. The flow of current in the subsurface generates a secondary magnetic field that is picked up by the receiver coil. The equipment measures the difference in strength (W) between the primary magnetic field generated by the transmitter coil and the secondary magnetic field picked up by the receiver coil (GSSI, undated b). Typical applications for EM are locating metal objects and groundwater investigations. EM is especially useful in groundwater studies of delineating salt plumes as salt is highly conductive and its extent can be determined. EM is useful only in very near surface applications and should not be used in wet conditions (NJDEP, 2005).

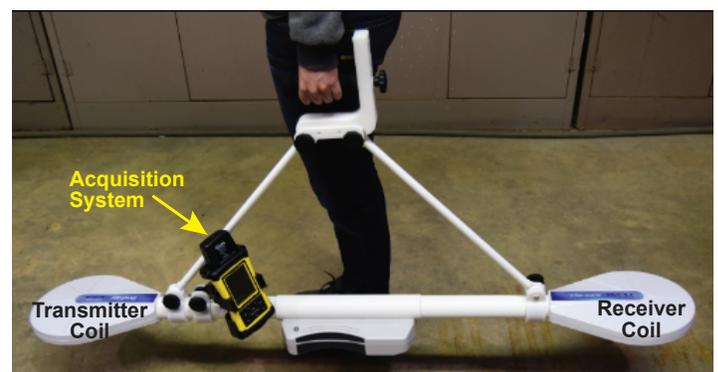


Figure 2. Electromagnetic Induction (EM) Profiler, showing typical carry height of deployment. Photo by M. Spencer

Electrical Resistivity, measured in ohm-meters, is the resistivity of a material to carrying an electric current, which is measured in amps. Resistivity measurements are made using an automated multi-electrode resistivity meter, which sends DC current into the ground and records the loss of current (voltage or potential) between electrodes (figure 3). The voltage drop indicates the extent

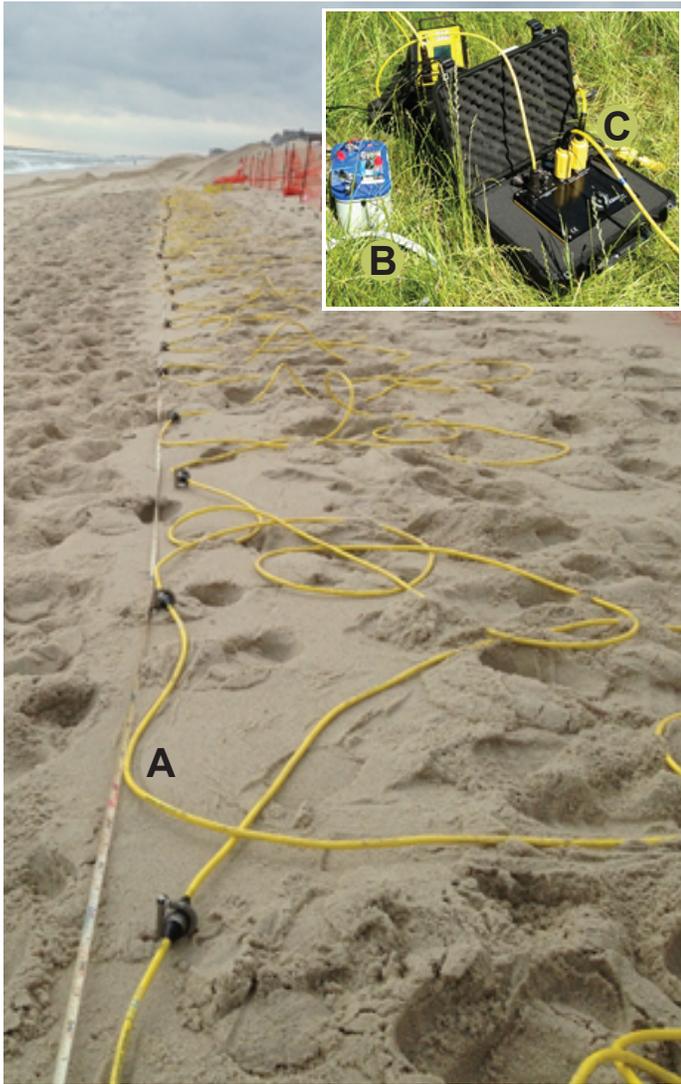


Figure 3. Electrical resistivity survey setup showing (A) electrode-cable deployed on a beach, (B) power supply/battery and (C) recording devices. *Photo by M. Spencer*

to which a material resists carrying an electrical current (amps) – the resistivity of the material. The pattern of sending and receiving current is controlled by the electrode configuration, which is set up in advance and is dependent upon the local geology, the desired target, and the desired depth of penetration. Depth penetration and electrode spacing are directly related, so as spacing increases so does depth penetration, however there is a loss of resolution with increase in electrode spacing. From the chosen array, a two-dimensional profile is generated, showing variations in resistivity with depth. Electrical resistivity is typically used to locate and delineate particularly resistive materials such as bedrock or particularly conductive materials such as metal objects or salt plumes. Resistivity should not be used in wet conditions or near background electrical currents and cannot be solely relied on to differentiate between lithologies (NJDEP, 2005).



Figure 4. Magnetometer. *Photo from Geometrics*

Magnetometer surveys pick up slight, localized variations in Earth's magnetic field (i.e. magnetic anomalies). Magnetometers used in geophysical surveys measure changes in proton rich, positively charged fluids, which are surrounded by an electric coil and measured by a sensor (figure 4). When a current is applied, the protons temporarily become polarized (redistributed in alignment with the magnetic field generated by the coil). When the current is removed, the protons realign according to the Earth's local magnetic field. Measurements across an area are combined into magnetic anomaly maps (Ghatge, 2004). Magnetic anomalies

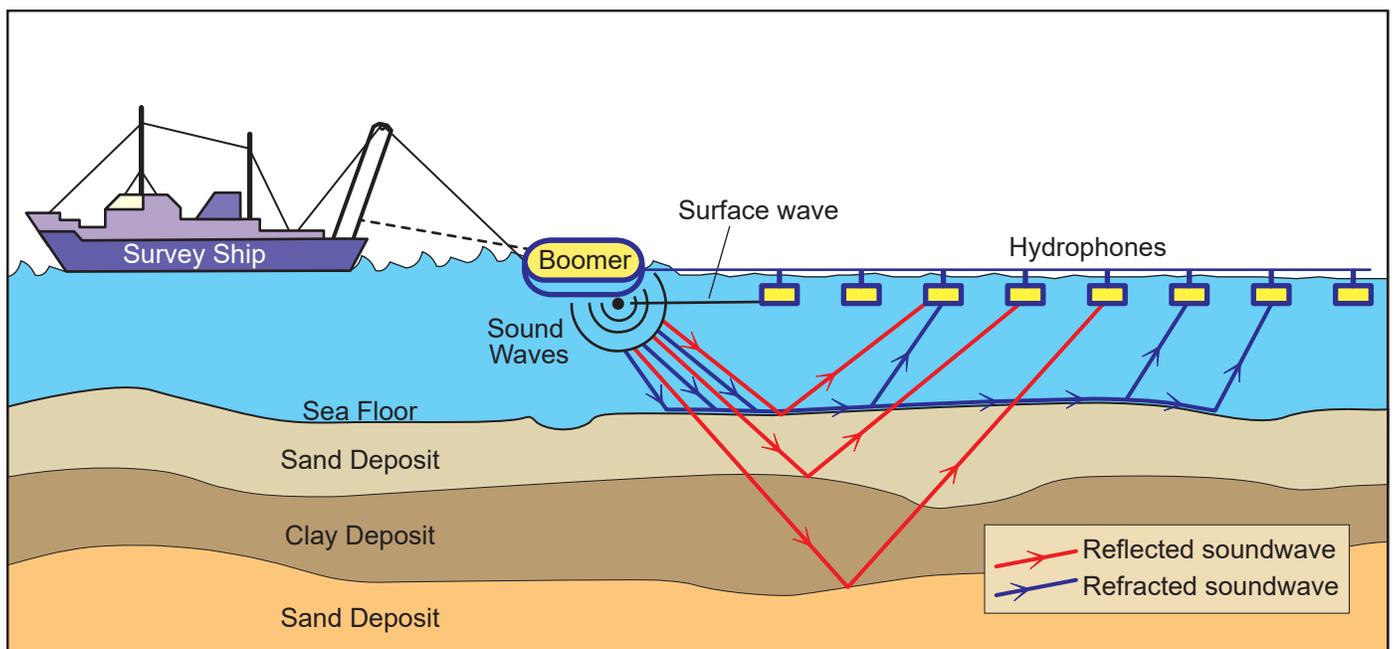


Figure 5. Marine Seismic survey diagram. The boomer generates a sound pulse, which reflects and refracts off the surface of each new material. Seismic waves are measured by the hydrophones being dragged behind the boat. *Figure adapted from EPA website.*

occur above magnetic ore bodies, igneous rocks, and buried steel objects (Subsurface Geotechnical, undated a). Larger magnetic features in magnetometer surveys often obscure subtle features (NJDEP, 2005).



Figure 6. LaCoste & Romberg Model G Gravity Meter. Photo by M. Gagliano

Seismic Reflection and Refraction surveys use a controlled source of energy (i.e. explosion, sledge hammer impact, boomer or chirp) to send sound waves, measured in decibels (dB) into the subsurface. The sound waves reflect and refract at each subsurface layer. These changes are recorded by geophones (on land) or hydrophones (in water, figure 5), which measure the two-way travel times of either reflected or refracted sound waves (NJDEP, 2005). Seismic reflection surveys are best for depths greater than 50 feet, have higher horizontal resolution, and are more expensive and time consuming than refraction surveys. Refraction surveys are best for depths less than 100 feet and often only show the top few subsurface layers. Both reflection and refraction surveys are useful for identifying the depth to bedrock, geologic features, and offshore sand resources. Seismic data can be time consuming to collect and process (Enviroscan, Inc., undated a).

Gravity surveys measure small, local variations in acceleration due to Earth's gravity in milligals (mGal). A gravity meter (figure 6) consists of a mass, measured in milligrams (mg), on a spring. The amount of spring stretch is used to calculate the gravity at each location. These gravity values are then combined in a map to show variations in gravity through the area of investigation (Ghatge, 2004a and b). Because elevation influences gravity measurements precise elevation data from either traditional surveying or LIDAR imaging are necessary. Gravity surveys can be used to find abandoned mines, caverns, sinkholes, bedrock topography or buried fractures and faults. The collection of gravity data is time consuming, and access to precise location and elevation data is a necessity (NJDEP, 2005).

Spontaneous Potential (SP) measures the naturally occurring potential difference between two points. Small potentials are caused by two different electrolytic concentrations in direct

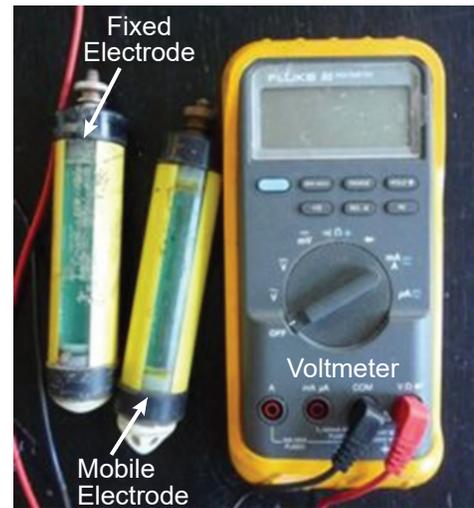


Figure 7. Spontaneous potential. Photo from Enviroscan, Inc.

contact, and by the flow of groundwater through porous materials. Larger potentials can be caused by conductive mineralized ore bodies partly immersed below the water table (Subsurface Geotechnical, undated a). SP surveying is typically done using one fixed electrode and one mobile electrode (figure 7). The mobile electrode is moved a fixed distance between each measurement in a series. SP is used for investigating seepage in dams, noting groundwater flow through porous materials, or locating large conductive ore bodies (Enviroscan, undated b).

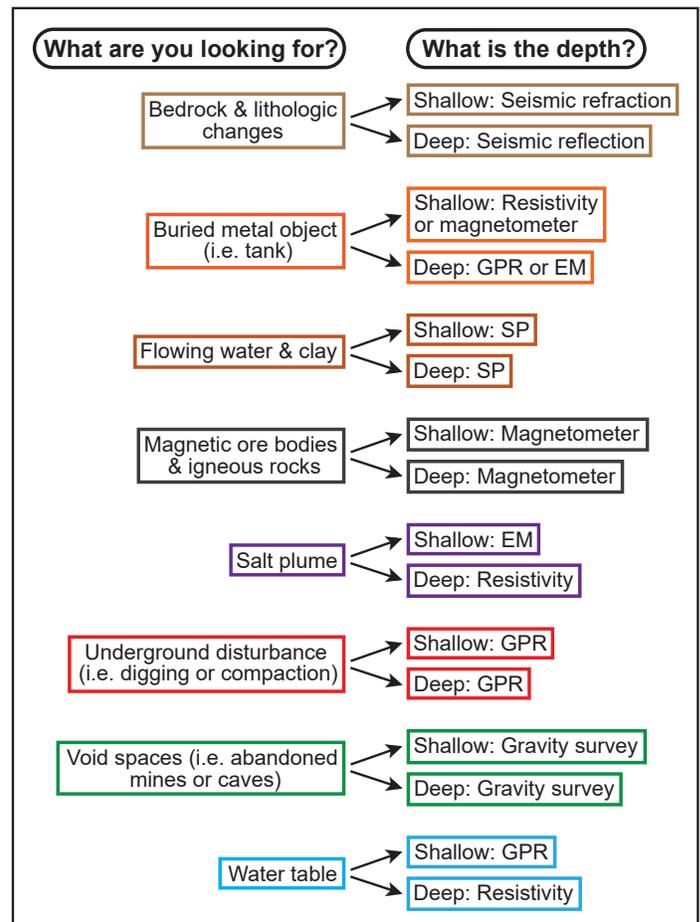


Figure 8. Near surface geophysical tools flow chart showing the process NJGWS uses to determine the appropriate tool for a project.

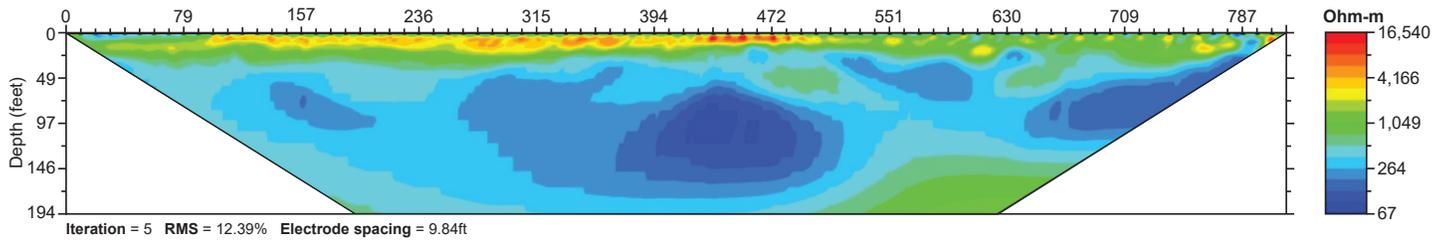


Figure 9. Resistivity profile image of the salt plume investigated by the NJGWS. Red indicates high resistivity and low conductivity, whereas blue indicates low resistivity and high conductivity. The highly conductive salt plume is indicated by deep blue in the center of the profile.

Tool Selection

Each near surface geophysical method has its advantages and limitations. Determining the best near surface tool for a particular application requires an in-depth understanding of how each tool operates and its capabilities, knowledge of the local geology, and the properties of the anticipated target. Figure 8 shows general criteria that are used to determine the most appropriate tool for a given application. Factors in the decision process include the project objective, required depth, resolution, and time requirements including survey design, data collection, and data interpretation. This sequence of qualifications allows for the most efficient and effective project design and implementation.

Examples of Projects

The NJGWS used the electrical resistivity method to locate a possible salt plume, a highly conductive target. This method was chosen instead of electromagnetic induction (EM) because the depth of the plume was unknown and the resistivity method would provide greater depth resolution. The survey was conducted by placing electrodes every 9.84 feet to measure a horizontal profile distance of approximately 800 feet to a depth penetration of approximately 200 feet. The salt plume, shown in deep blue on figure 9, was found in the center of the profile at an approximate depth between 75 and 150 feet.

For another study, ground penetrating radar (GPR) was used to locate an old wagon trail through a cemetery, as well as the

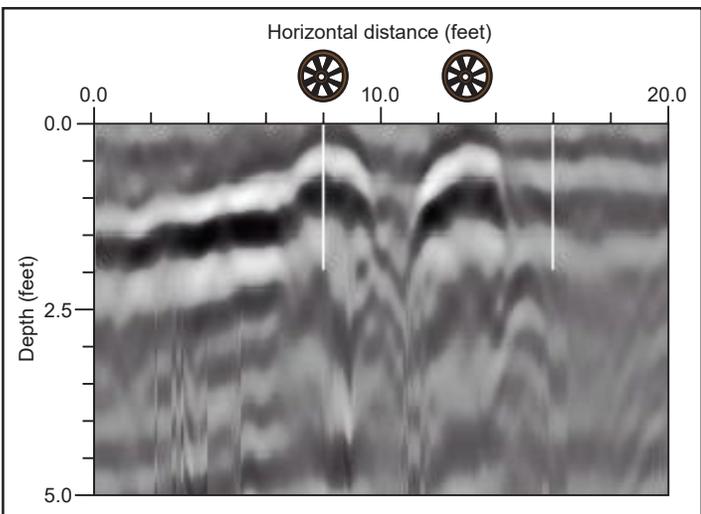


Figure 10. Ground Penetrating Radar (GPR) profile line across the wagon trail. The two "n" shaped bumps show soil compacted by repeated contact with wagon wheels. The white lines are marks made by the NJGWS every 8 feet to calibrate the distance.

possible locations of missing graves and an old church foundation on the same property. GPR was utilized for all three investigations as the depth of investigation was shallow, large amounts of groundwater were not anticipated, and differences in soil density were expected due to the digging of graves and soil compaction beneath the wagon tracks. Figure 10 shows the GPR data collected across the wagon trail. Two tracks of compaction just below the surface, presumably caused by wagon wheels, are clearly visible as bump like disturbances in the normal profile just below the surface. For the church foundation, the target was the presence

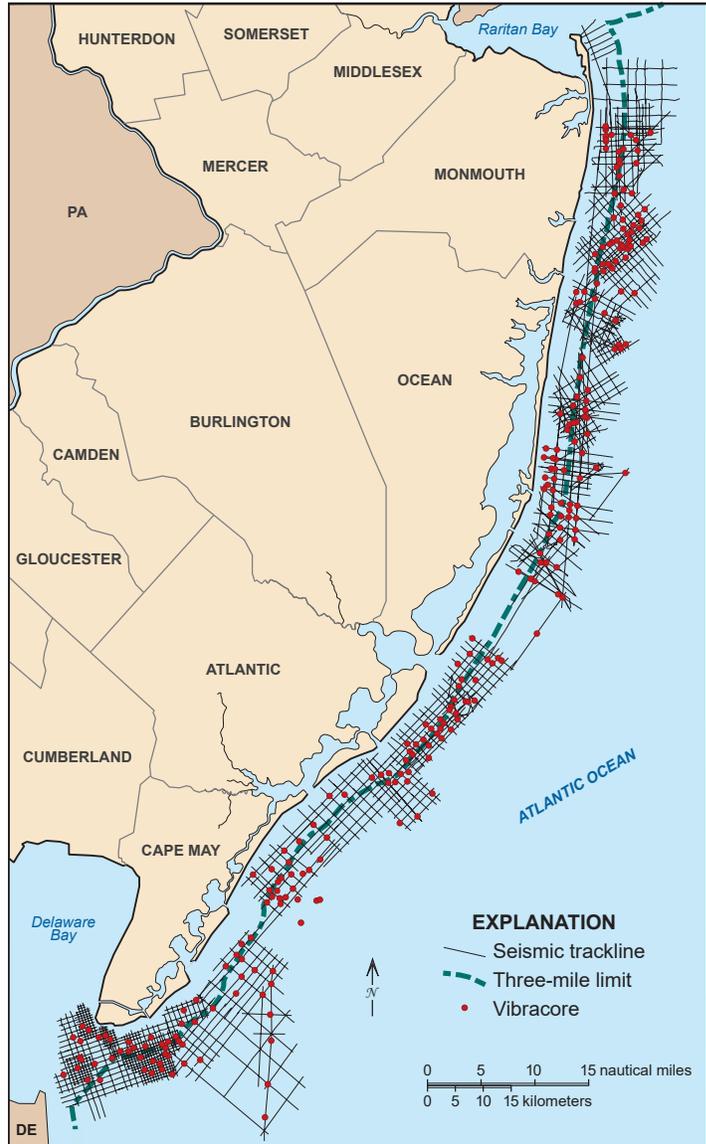


Figure 11. New Jersey Geological and Water Survey seismic and vibracore data from 1996 to 2017. Data spans from Monmouth County to Cape May and is typically between 1 nm and 8 nm offshore.

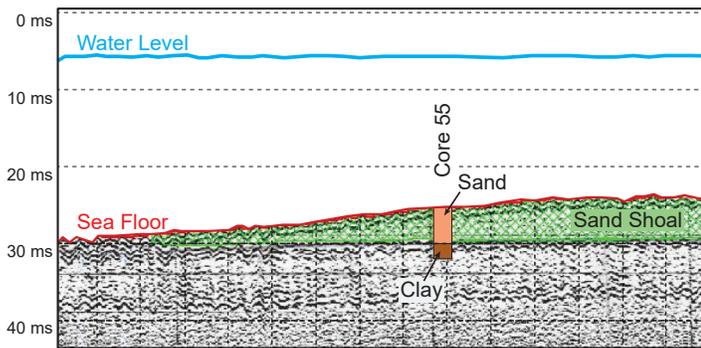


Figure 12. Seismic Line 9440 and Vibracore 55 analyzed to determine the location and extent of a sand shoal.

of building stone a few feet below the surface. No anomaly was noted, so it was presumed that the old church foundation was no longer buried in the cemetery. So, stonework at the new church, located on the same property, was examined. At the new church, two distinct stone types were found, one in the foundation and base presumably from the old church and one on top purchased for the construction of the new church. Thus, the old foundation was likely dug up in order to build the new church. To find the missing graves – as it was unlikely caskets would have been used – soil disturbances were assumed to be indicative of digging and refilling of soil. We compared this data with survey lines collected over known grave locations. The known graves produced clear anomalies, whereas the missing graves did not. Thus, the specific locations of the missing graves could not be located, supporting the conclusion that the individuals were either buried in another section of the cemetery or somewhere else entirely.

In 1996, the NJGWS began an on-going investigation to locate and delineate offshore sand resources for beach replenishment (figure 11). Ideally offshore sand usable for beach replenishment is found in sand shoals at least 10 feet thick. The entire seafloor is not coated with sand, however; there are somewhat discrete layers of sand, clay, and gravel. Thus, finding and delineating usable sand shoals requires accurate differentiation of lithologies, a task best completed by a seismic reflection survey. Biennially, the NJGWS staff spends 2-3 weeks on a vessel collecting offshore marine seismic reflection data. The remainder of the year is spent processing and analyzing the data for possible sand shoals. In alternate years, staff collects vibracores, 20-foot sediment cores, to ensure that a shoal of interest contains usable sand and to confirm the thickness of the shoal (figure 12). Once the composition of the shoal is determined, the sand volumes are calculated, mapped, and given to the U.S. Army Corps of Engineers, the agency responsible for determining which sand shoals are suitable for dredging. Since the projects inception, New Jersey beaches all along the coast have received beach replenishment sand identified by the NJGWS.

References

- Enviroscan, Inc., undated a, [Seismic reflection versus refraction](#), accessed August 23, 2018.
- Enviroscan, Inc., undated b, [Spontaneous potential](#), accessed August 23, 2018.
- Geometrics, undated a, [G-858 magmapper](#), accessed August 23, 2018.
- Geophysical Survey Systems, Inc. (GSSI), undated a, [Ground penetrating radar explained](#), accessed August 23, 2018.
- Geophysical Survey Systems, Inc. (GSSI), undated b, [Electromagnetic induction explained](#), accessed August 23, 2018.
- Ghatge, S.L., 2004a, Bouguer Gravity Anomaly Map of New Jersey and Vicinity. New Jersey Geological and Water Survey OFM 55.
- Ghatge, S.L., 2004b, Magnetic Anomaly Map of New Jersey and Vicinity. New Jersey Geological and Water Survey OFM 57.
- GWR Instruments, Inc., undated, [iGRAV gravity sensors](#), accessed August 23, 2018.
- New Jersey Department of Environmental Protection (NJDEP), 2005, [Field Sampling Procedures Manual \(FSPM\)](#), Chapter 8: Geophysical Techniques, updated April 11, 2011, accessed August 23, 2018.
- Reynolds, John M, 2011, An introduction to applied and environmental geophysics, 2nd Edition: Hoboken, NJ, John Wiley & Sons Ltd, 695 p.
- Subsurface Geotechnical, undated a, Geophysical survey fact file, [magnetic method](#), accessed August 23, 2018.
- Subsurface Geotechnical, undated b, Geophysical survey fact file, [self potential surveys](#), accessed August 23, 2018.
- United States Environmental Protection Agency Marine Seismic Methods, undated (USEPA), [Environmental geophysics, marine seismic methods](#), accessed August 23, 2018.

Additional Resources

- Bambrick, T.C. and Jagel, D.L., 1988, Seismic Refraction and Gravity Investigation of Topography at Lakeland Regional High School, Wanaque, Passaic County, New Jersey. NJGWS TM 88-1.
- Castelli, M.C., Latini, D., Uptegrove J., Waldner, J.S., Hall, D.W. and Friedman, A.L., 2015, Significant Sand Resource Areas in State and Federal Waters offshore Monmouth County, New Jersey. NJGWS GMS 15-3.
- Ghatge, S.L. and Hall, D.W., 1989, Geophysical Investigations to Determine Bedrock Topography in the East Hanover-Morristown Area, Morris County, New Jersey. NJGWS GSR 17.

Ghatge, S.L., Pasicznyk, D.L., Sandberg S.K., Hall, D.W. and Groenewold, J.C., 1989, Determination of Bedrock Topography and Geology Using Various Geophysical Techniques. NJGWS TM 89-2.

Ghatge, S.L. and Hall, D.W., 1991, Bedrock Topography Map of the Millburn-Springfield Area, Essex and Union Counties, New Jersey. NJGWS GMS 91-4.

Ghatge, S.L. and Waldner, J.S., 1991, Detection of an Abandoned Mine Using High-Resolution Geophysical Methods in Randolph Township, Morris County, New Jersey. NJGWS OFR 91-1.

Ghatge, S.L., Jagel, D.L. and Herman G.C., 1992, Gravity Investigation to Delineate Subsurface Geology in the Beemerville Intrusive Complex Area, Sussex County, New Jersey. NJGWS GMS 92-2.

Ghatge, S.L., 1993, Microgravity Method for the Detection of Abandoned Mines in New Jersey. Bulletin of the Association of Engineering Geologists, v. 30, no. 1, p. 79-85.

Ghatge, S.L., 1993, Microgravity Method for the Detection of Abandoned Shafts of the Schuyler Mine in Northeastern New Jersey *in* Proceedings of the Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP 1993), April 18-22, 1993, San Diego, California, v. 1, p. 195-207.

Hall, D.W. and Pasicznyk, D.P., 1987, Application of Seismic Refraction and Terrain Conductivity Methods at a Ground Water Pollution Site in North-Central New Jersey *in* Proceedings of the First National Outdoor Action Conference in Aquifer Restoration, Ground Water Restoration and Geophysical Methods, National Water Well Association, May 18-21, 1987, Las Vegas, Nevada, p. 505-524.

Sandberg, S.K., Hall, D.W., Gronberg, J.M. and Pasicznyk, D.L., 1996, Geophysical Investigation of the Potomac-Raritan-Magothy Aquifer System and Underlying Bedrock in Parts of Middlesex and Mercer Counties, New Jersey. NJGWS GSR 37.

Uptegrove, J., Waldner, J., Stanford, S., Monteverde, D., Sheridan, R.E. and Hall, D.W., 2012, Geology of the New Jersey offshore in the vicinity of Barnegat Inlet and Long Beach Island. NJGWS GMS 12-3

Waldner, J.S. and Hall, D.W., 1991, A Marine Seismic Survey to Delineate Tertiary and Quaternary Stratigraphy of Coastal Plain Sediments offshore to Atlantic City, New Jersey. NJGWS GSR 26.

Waldner, J.S., Bambrick, T.C. and Groenewold, J.C., 1988, Seismic Refraction and Electrical Resistivity Surveys, West Milford Township, Passaic County, New Jersey. NJGWS TM 88-5.

STATE OF NEW JERSEY
Philip D. Murphy, *Governor*
Sheila Y. Oliver, *Lieutenant Governor*

Department of Environmental Protection
Catherine R. McCabe, *Commissioner*

New Jersey Geological and Water Survey
Jeffrey L. Hoffman, *State Geologist*



Prepared by Fern Beetle-Moorcroft

2018

Comments or requests for information are welcome

Mail: New Jersey Geological and Water Survey
P.O. Box 420, Mail Code 29-01
Trenton, NJ 08625-0420

Phone: 609-292-1185

On-line: <http://www.njgeology.org/comments.html>

Note: Any use of trade, product or firm names in this publication is for descriptive purposes only and does not imply endorsement by the New Jersey state government.

Banner photograph: Electromagnetic induction survey of salt pile, Knowlton Township, Warren County. *Photo by M. Spencer*