

Geoarchaeological Survey Methods for Enhanced Decision Making in the Ohio Department of Transportation's Project Development Process



Prepared by:
Seth Van Dam, MA, RPA; David M. Crowell, MS, RPA;
Jeff Laswell, MS, RPA; Mike Striker, MA, RPA

Prepared for:
The Ohio Department of Transportation,
Office of Statewide Planning & Research

Project ID Number: 11457

February 2023

Final Report



Technical Report Documentation Page

| | | | |
|---|--|---|-----------|
| 1. Report No. | 2. Government Accession No. | 3. Recipient's Catalog No. | |
| FHWA/OH-2022/36 | | | |
| 4. Title and Subtitle | | 5. Report Date | |
| Draft Report for Geoarchaeological Survey Methods for Enhanced Decision Making in the Ohio Department of Transportation's Project Development Process | | February 2023 | |
| | | 6. Performing Organization Code | |
| | | 20-3701.001 | |
| 7. Author(s) | | 8. Performing Organization Report No. | |
| Seth Van Dam, MA, RPA David Crowell, MS, RPA Jeff Laswell, MS, RPA Mike Striker, MS, RPA | | | |
| 9. Performing Organization Name and Address | | 10. Work Unit No. (TRAIS) | |
| Gray & Pape, Inc. 1318 Main Street Cincinnati, Ohio 45202 | | | |
| | | 11. Contract or Grant No. | |
| | | 34887 | |
| 12. Sponsoring Agency Name and Address | | 13. Type of Report and Period Covered | |
| Ohio Department of Transportation 1980 West Broad Street Columbus, Ohio 43223 | | Final Report | |
| | | 14. Sponsoring Agency Code | |
| | | | |
| 15. Supplementary Notes | | | |
| This report utilizes the term geophysical survey to describe the specific survey methods this research project is addressing. | | | |
| 16. Abstract | | | |
| The Ohio Department of Transportation (ODOT) Office of Statewide Planning & Research, Research Section contracted Gray & Pape, Inc., to conduct research to provide a comparison of geophysical survey methods, instruments, equipment, and associated software to determine what instrument or combination of instruments works best in different scenarios. The goal of the research is to provide the recommendations necessary for the Office of Environmental Services (OES) to establish a geophysical survey program. Gray & Pape, Inc., conducted a literature review, and the results provide two main conclusions: 1) the rate of success of a geophysical survey increases as more technologies are used; and 2) the more diverse the types of geophysical equipment used on a particular project, the more likely it is that the geophysical surveys will yield quality data that can be used to help guide future decisions. Gray & Pape, Inc., recommends that the ODOT's Unmanned Aircraft Systems Center (UAS) operate the geophysical survey program under a cooperative agreement with OES, and with the support of archaeologists from that office. Leveraging in-house capabilities will make the geophysical program operational, sustainable, and successful; save labor and expense costs under this research project that can be allocated for more investment into reconfiguring and upgrading in-house instruments; and purchase new instruments, software, and licensing, which will ultimately provide a higher return on investment and a more operationally sound, sustainable, and successful program than thought possible as this research project was originally conceived—to build the geophysical survey program capacity within OES alone. | | | |
| 17. Keywords | | 18. Distribution Statement | |
| Archaeology, Ecoregions, Electrical Magnetic Susceptibility/Gradient, Electrical Resistivity/Conductivity, Geoarchaeological Survey, Geophysical Survey, Gradiometer, Ground Penetrating Radar, Historic, Magnetometer, Noninvasive, Office of Environmental Services, Pre-Historic, Remote Sensing | | No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161 | |
| 19. Security Classification (of this report) | 20. Security Classification (of this page) | 21. No. of Pages | 22. Price |
| Unclassified | Unclassified | 79 | |

Credits and Acknowledgments

Prepared in cooperation with the Ohio Department of Transportation and the United States Department of Transportation, Federal Highway Administration

The contents of this report reflect the views of the author(s) who is (are) responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Ohio Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

This final report was made possible by the time, assistance, support, and cooperation of the Technical Advisory Committee on this project: Jill Martindale, District Research Coordinator and Jennifer Sprigs, Project Coordinator, Office of Statewide Planning & Research, Research Programs; Erica Schneider, Assistant Environmental Administrator and Jason Watkins, Archaeologist, Office of Environmental Services; Thomas Grooms, Archaeology Transportation Reviews Manager, Ohio History Connection; and Jamie Davis, Data Manager, and Helen McCreary, Program Analyst, Unmanned Aircraft Systems Center. Special acknowledgement goes to the Office of Environmental Services archaeology staff whose willingness and enthusiasm and the hard work they put in to learn completely new concepts, methods, and skills.

Table of Contents

| | | |
|-----|---|----|
| 1.0 | Problem Statement | 6 |
| 2.0 | Research Background | 7 |
| 2.1 | Foundational Texts..... | 7 |
| 2.2 | Literature Review..... | 8 |
| 3.0 | Research Approach..... | 10 |
| 3.1 | Environmental Factors..... | 10 |
| 3.2 | Literature Review and Geophysical Survey Assessment..... | 11 |
| 4.0 | Research Findings and Conclusions | 13 |
| 4.1 | Literature Review..... | 13 |
| 5.0 | Recommendations for Implementation | 38 |
| 5.1 | Geophysical Survey Program | 38 |
| 5.2 | Instruments, Equipment, and Software..... | 39 |
| 5.3 | Geophysical Equipment Purchase, Set-up, and Testing..... | 40 |
| 6.0 | Results of the Geophysical Training Surveys and Processing..... | 42 |
| 6.1 | Orientation..... | 42 |
| 6.2 | Geophysical Survey | 42 |
| 6.3 | Post-Field Processing | 43 |
| 6.4 | Training Results and Recommendations..... | 44 |
| 6.5 | Factsheet and Practical Application Guide | 45 |
| 7.0 | Bibliography | 46 |
| | Appendix A. Foundational Text Bibliography | |
| | Appendix B. Geophysical Surveying Practical Application Guide | |
| | Appendix C. Geonics EM-38MK2 User Manual | |
| | Appendix D. Bartington Instruments Grad 601-2 User Manual | |
| | Appendix E. GSSI SIR 4000RADA User Manual | |

List of Figures

| | |
|--|----|
| Figure 1. Cultural site types that were the subject of geophysical surveys. | 14 |
| Figure 2. Specific cultural site types that were the subject of geophysical surveys. | 15 |
| Figure 3. Location of geophysical surveys throughout Ohio's ecoregions. | 16 |
| Figure 4. Number of geophysical surveys per ecoregion. | 17 |
| Figure 5. Location and success ratings of magnetic gradient surveys throughout Ohio's ecoregions. | 19 |
| Figure 6. Success of magnetic gradient geophysical surveys across Ohio's ecoregions. | 20 |
| Figure 7. Location of electrical magnetic susceptibility surveys throughout Ohio's ecoregions. | 21 |
| Figure 8. Success of electrical magnetic susceptibility geophysical surveys across Ohio's ecoregions. | 22 |
| Figure 9. Location of ground-penetrating radar surveys throughout Ohio's ecoregions. | 23 |
| Figure 10. Success of ground-penetrating radar geophysical surveys across Ohio's ecoregions. | 24 |
| Figure 11. Location of electrical resistivity surveys throughout Ohio's ecoregions. | 25 |
| Figure 12. Success of electrical resistivity geophysical surveys across Ohio's ecoregions. | 26 |
| Figure 13. Location of electrical magnetic conductivity surveys throughout Ohio's ecoregions. | 27 |
| Figure 14. Success of electrical magnetic conductivity geophysical surveys across Ohio's ecoregions. | 28 |
| Figure 15. Magnetic gradiometer and ground-penetrating radar success chart. | 29 |
| Figure 16. Dual technological methods. | 32 |
| Figure 17. Dual technological methods success chart. | 33 |
| Figure 18. Three technological methods. | 35 |
| Figure 19. Three technological methods success chart. | 36 |

1.0 Problem Statement

The approach to archaeological studies and investigations, especially within a regulatory compliance framework, has remained largely static. Generally, these follow a phased, sequential approach, which requires a fair amount of labor and varying levels of effort to complete. This approach largely consists of one or all the following: background research, literature review, and desktop assessment of previously conducted archaeological investigations and previously identified archaeological resources within a project boundary and a predetermined study radius. Predictive modelling, based on the results of the background research and environmental and geophysical attributes of a project and study area, is often the next step. Fieldwork may include: archaeological reconnaissance studies consisting of visual inspection and limited, discretionary sub-surface shovel testing, generally to confirm previous ground disturbance, and/or inundated/wetland soils; an archaeological identification survey, either through walkover survey over exposed soils and/or subsurface testing via a random stratified sampling strategy (i.e., shovel testing); archaeological site-boundary delineation and site testing to ascertain the areal (horizontal and vertical) extent of the site and the nature and context of the archaeological and cultural deposits; and, finally, the archaeological excavation of a site, often framed as mitigation or data recovery if a project is unable to avoid impacts to the archaeological site. All these approaches are labor intensive, inherently destructive, and imperfect because they all rely on a sampling strategy, which leaves to chance that only a portion of an archaeological site is being investigated and smaller sites, or dispersed archaeological features, may not be identified at all.

Geophysical surveys are one approach to identify archaeological resources and sites that reduces the level of effort and high labor costs. Geophysical surveys are nonintrusive, nondestructive, and often may offer a clearer representation of the nature and extent of an archaeological site and its component features. The objective of this geophysical technical research was to aid the Ohio Department of Transportation's (ODOT) Office of Environmental Services' (OES) knowledge to provide a baseline understanding of geophysical techniques and their applications to various types of archaeological investigative situations, and to provide recommendations for the implementation of a geophysical survey program. The ODOT staff have been exposed to geophysical techniques and applications with the equipment they purchased. Overall, the OES staff have been able to develop a baseline understanding of geophysical survey methods, which should grow with an increased use of the equipment and programs. The OES staff would also benefit from additional training with the providers of the accompanying software programs; these could be online and/or in person.

2.0 Research Background

The objective of this research project was to provide a baseline understanding of geophysical techniques and their applications to diverse types of archaeological investigative situations. A myriad of geophysical technologies exists; however, only a few have proven worthwhile with regard to archaeological terrestrial applications. The three groups of appropriate geophysical technologies are based upon the scientific principles of surrounding radar waves, electrical magnetics, and electrical currents, more commonly referred to as Ground Penetration Radar (GPR), electrical magnetic susceptibility/gradient (Mag-Sus and Mag-G), and electrical resistivity/conductivity (ER and EC), respectively. Each of these techniques have their strengths and weaknesses; this literature review will show which technique provides the strongest results given the site conditions of the project.

This research project aimed to create and implement a geophysical survey program within ODOT and train an in-house, operationally independent team that is an integral part of ODOT's Project Development Process (PDP). The geophysical survey team can be deployed, in the appropriate scenarios and field conditions, during the Project Initiation Package (PIP), Field Review, and other processes during the Planning phase of ODOT's PDP. The geophysical survey results and recommendations can be used to generate specific scopes in Draft and Final PIPs. With the geophysical study programmed early in the planning phases of a project, it will inform the planning itself and be built into the Preliminary Engineering Phase of the PDP, including design and alternative selections. This literature review is the first step of this research project, and the results and recommendations will lay the groundwork for the execution of the rest of the project.

Geophysical studies have helped define the scopes of archeological field investigations by highlighting areas within an Area of Potential Effects (APE) that have geophysical anomalies. This information has allowed field efforts to focus in clearly defined areas and most plausibly reduce the level of traditional archaeological excavation. Geophysical surveying methods on transportation projects are extremely valuable investments in most localities and field conditions. Geophysical survey may obtain larger sample sizes, with less field time and personnel than traditional archaeological methods, although traditional archaeological excavations will never be totally replaced by geophysical methods. Geophysical survey strives to provide guidance for subsequent archaeological efforts, with the goals of greater efficiency and efficacy in the identification and evaluation of archaeological resources. Geophysical field data results also act as another important dataset detailing the existing conditions of an area prior to new or further development from ODOT projects, these additional datasets would be available for research by the Ohio History Connection (OHC).

2.1 Foundational Texts

The foundational texts were chosen to provide both the theoretical laws and the operating principles behind each geophysical technology covered in this literature review. Many of these texts also offer guides and manuals of how to properly operate different types of geophysical survey instruments and equipment in specific environments and on specific types of sites. These texts help establish baseline knowledge and standard operational procedures and practices to achieve the greatest level of accuracy of data collection by geophysical survey methods. A complete list of the foundational texts is presented in The references cited in this document and the annotated bibliography from Gray & Pape, Inc.'s (Gray & Pape), include additional helpful references.

The basic principles behind each of the geophysical equipment types covered in this literature review are as follows.

Archaeological Mag-Sus surveys passively map the contrasting values of buried or invisible anthropogenic activities characterized through magnetic susceptibility, thermoremanent magnetism, and ferrous materials. Many cultural actions can change the magnetic susceptibility of an area from its natural state; some examples of these are earth-moving activities, cooking fires, and the introduction of ferrous objects, but many other types of human processes can be responsible when magnetometers identify magnetic variations within the surveyed area (Lowrie 2007).

A Mag-G survey operates under the same principle as Mag-Sus meter; however, it employs the use of two magnetic susceptibility sensors positioned at a known fixed distance from each other, usually in the vertical configuration for archaeological prospecting. Then, the different measurements between the two probes are compared in the vertical configuration and the upper sensor is subtracted from the lower sensor, thus removing the background noise caused by the Earth's magnetic field. If no anomalies are present below the sensors, the value will be near zero; however, if an anomaly is present, the sensor closest to the ground would have a value that was significantly different than the upper sensor and, hence, detect the subsurface anomaly (Lowrie 2007).

GPR is a geophysical method that uses broad radio wave frequency spectrums to probe ground conditions and distinguish between different materials by the dielectric loss, because earths materials are composed of many chemical components. The GPR method of geophysical surveying is an active method of data collection requiring extremely precise and accurate antennas, one transmitting a pulse into the ground and another receiving that signal, measuring the distance and intensity of the reflection of the original pulse as it passes through objects in the ground of the surveyed area (Conyers 2004).

The EC meters actively measure both soil conductivity and magnetic susceptibility and map the contracting values characterized by electromagnetism. The instrument can locate buried anthropogenic activities that have changed the soil's conductivity and magnetic susceptibility of an area from its natural state; some samples of these actions are earth moving activities, fires, and the introduction of ferrous objects, but many other types of human processes can be responsible for these fluctuations (Clay 2006).

ER meters are an active geophysical method and the opposite of an electrical magnetic conductivity meter. As soil is comprised of three parts, air, water, and minerals, this composition allows the movement of an electrical charge. The method requires the placing of probes in the ground and injecting a current between them, which in turn is measured by a data collector. If the material easily transmits the electric charge, it is considered conductive; if it does not, it is resistant. This instrument distinguishes anthropogenic activities that have disturbed or otherwise changed the natural homogenous soil properties within local areas (Somers 2006).

2.2 Literature Review

The OES provided 17 geophysical technical reports for the literature review. These reports include the results of geophysical surveys conducted in support of transportation projects, primarily in the southern half of the state. Gray & Pape identified 60 additional geophysical

technical reports from the Digital Archaeological Record/National Archaeological Database (tDAR/NADB) and the database of the OHPO, who provided copies of the reports. These reports contained the results of geophysical surveys conducted in support of a variety of other undertakings, from infrastructure projects to cemetery surveys, to meeting permitting requirements. In total, these reports provide a robust sample of different geophysical survey methods and instruments employed on various types of projects, including transportation-related projects, and with a wide distribution across the state's ecoregions. This diverse sample of a total of 77 reports was critical to understanding what noninvasive remote-sensing methods and instruments were successful and unsuccessful in the identification of archaeological resources on different types of projects, and within different types of environmental contexts.

3.0 Research Approach

Geophysical surveys are best when they are deliberate, meaning utilizing the proper methods and equipment for the identification and evaluation of a given archaeological resource. In other words, the equipment and methods employed for the suspected presence of a historical foundation buried near the ground surface, will differ for an ephemeral deeply buried prehistoric hearth. No geophysical technological method is applicable to all field conditions; however, the literature research aims to show that several techniques have viable applications throughout the state of Ohio and are consistent with the needs of ODOT's archaeological investigations within the PDP.

3.1 Environmental Factors

Environmental conditions are a significant factor in the efficacy of geophysical surveys within the context of archaeological investigations. It is important to have a basic environmental context for the geophysical surveys included in this literature review. More importantly, a more nuanced and holistic comprehension of the specific environmental conditions at each project location is critical to assess the success or failure of the methods and instruments employed on a particular project. An environmental metric and a spatial framework that takes into consideration the interplay of all the different environmental conditions, and how those conditions influenced the results of the geophysical surveys, is critical. By using an environmental framework that helps to identify the most successful methods and instruments, and using that data to inform the conclusions of this literature review, the best recommendations for the ODOT OES geophysical program can then be made. Gray & Pape used the concept of ecoregions in this literature review to provide this key environmental metric from which to perform the review and assessment (Commission for Environmental Cooperation 1997). Ecoregions are areas of generally comparable ecosystems and the type, quality, and quantity of environmental resources (Commission for Environmental Cooperation 1997).

3.1.1 Ecoregions

The multinational Commission for Environmental Cooperation has divided North America into ecoregions, which are useful for illustrating the ecological diversity of the area (Commission for Environmental Cooperation 1997). As described by the United States Environmental Protection Agency (EPA)

Ecoregions are identified by analyzing the patterns and composition of biotic and abiotic phenomena that affect or reflect differences in ecosystem quality and integrity (Omernik 1987, 1995). These phenomena include geology, landforms, soils, vegetation, climate, land use, wildlife, and hydrology. The relative importance of each characteristic varies from one ecological region to another regardless of the hierarchical level (EPA 2020).

The ecoregion approach is differentiated from more traditional approaches to environmental classification, such as physiographic analysis, ecological zones, etc., by the fact that it incorporates as many factors as possible in combination. The ecoregion approach recognizes that all these factors are interrelated and may combine in unexpected ways.

Four levels of ecoregion, each of increasing ecological specificity, are described below.

Level I and II Ecoregions

The Level I Ecoregion for the entire study area is the Eastern Temperate Forest. This is a region in which dense broadleaf deciduous forests, with beech-maple, maple-basswood, oak-hickory, and oak-hickory-pine forests, predominate (Commission for Environmental Cooperation 1997). Stretching from eastern Texas to New Brunswick, and from Minnesota to Florida, the Level I Ecoregion is too broad to be useful in describing the area in terms of climate and flora. However, broadly speaking, fauna is consistent across the area, with variations in the climatic extremes in the north and south, and with regional variations in population sizes (Commission for Environmental Cooperation 1997:25).

Four Level II Ecoregions are present in the study area: the Mixed Wood Plains, the Central USA Plains, the Southeastern USA Plains, and the Ozark-Ouachita-Appalachian Forests. These are broad divisions that account for climatic differences and variations in species distribution not accounted for in the Level I Ecoregions (Commission for Environmental Cooperation 1997:25) yet remain too broad for application on this research project.

Level III and IV Ecoregions

The Level III and Level IV Ecoregions are the most specific and are best at characterizing the environmental variability of Ohio. This includes five Level III Ecoregions: the Erie/Ontario Drift and Lake Plain, the Huron/Erie Lake Plains, the Eastern Corn Belt Plains, the Interior Plateau, and the Western Allegheny Plateau. Each of the Level III Ecoregions is subdivided into Level IV Ecoregions. Twelve Level IV Ecoregions contain project locations included in this literature review, with three others that cover multiple ecoregions.

3.2 Literature Review and Geophysical Survey Assessment

The five geophysical equipment types being evaluated in this literature review are: EC, ER, GPR, Mag-G and Mag-Sus.

The analysis of the geophysical techniques represented in the literature review was based upon the ability of each type of geophysical equipment used to acquire quality datasets at a particular site in a particular equipment configuration. More specifically, the assessment of each technology was evaluated individually based on the type of equipment used, what configuration was employed at a particular location, what sampling strategy was used, and what the end results of the survey were. The configuration and sampling strategies are compared to recommended industry standards for each geophysical equipment type. The individual geophysical equipment types are assessed individually and evaluated on how they operated and contributed to the end results of each survey.

Each geophysical equipment type used within a particular report was given a single rating in a five-step ranking system including, 1) Unsuccessful, 2) Very Limited Successful, 3) Limited Success, 4) Successful, or 5) Very Successful. The ranking system is defined as follows.

1. Unsuccessful: A technological method was unsuccessful in either producing a usable dataset due to field conditions and/or operator errors. The methods may or may not be sound and/or the equipment did not work in the environment at all.
2. Very Limited Success: A technological method was able to produce useable datasets; however, the datasets are extremely limited and suspected of having errors due to

factors ranging from inadequate equipment setting to environmental conditions (i.e., operator errors). The methods may or may not be sound and/or the equipment worked very poorly in the environment.

3. Limited Success: A technological method was able to produce useable datasets; however, the datasets do not identify the specific cultural resource believed to be within the project area. These tend to be inconclusive results from a particular survey, even when standard operation procedures were adhered to in a particular environmental condition. The methods are sound, but the results are unclear.
4. Successful: A technological method was able to produce useable datasets that identify archaeological cultural features of some kind, although they may or may not be the features sought out in a particular project. The methods and results are clear.
5. Very Successful: A technological method was able to produce useable datasets that clearly identify archaeological cultural features of some kind. The technological method identified the presumed cultural resources in a very clear and compelling way. The methods and results are very clear.

The success rate is measured from the consideration that only a ranking of successful and very successful are considered a successful application of the technology at a particular site, as all other categories less than successful have a myriad of issues associated with the project.

4.0 Research Findings and Conclusions

4.1 Literature Review

The OES provided 17 geophysical technical reports for the literature review. These reports included the results of geophysical surveys conducted in support of transportation projects, primarily in the southern half of the state. Gray & Pape identified 60 additional geophysical technical reports from the tDAR/NADB and OHPO, who provided copies of the reports. These reports contained the results of geophysical surveys conducted in support of a variety of other undertakings, from infrastructure projects to cemetery surveys, to meeting permitting requirements for transportation and non-transportation projects. In total, these reports provide a robust sample of different geophysical survey methods and instruments employed on various types of projects, including transportation related, and with a wide distribution across the state's ecoregions. This diverse sample of a total of 77 reports was critical to understanding what noninvasive remote sensing methods and instruments were successful and unsuccessful in the identification of archaeological resources on different types of projects, and within different types of environmental contexts.

4.1.1 Types of Sites

This literature review consisted of 77 projects in which research areas represented distinct cultural periods and archaeological resources; of these, 25 were conducted on historical sites, 31 on prehistoric sites, 13 on multicomponent sites, 7 historic cemetery sites and 1 geological (historical/modern) study (Figure 1). The geological study was an outlier and was included in this study as it is a GPR project survey, with a sound methodology in which it was encumbered by the historical and modern features in the landscape within the project area. The literature review's sample included an even representation of historical and prehistoric archaeological sites, with 59.7 percent and 57.1 percent, respectively.

The literature review's 77 projects cover a diverse sample of distinct types of important archaeological resources that are commonly subjected to geophysical surveying techniques throughout Ohio, which offer specific insight into projects with successful techniques and methods. These archaeological resources include prehistoric earthworks and mounds, historical structures, and historical burials/cemeteries (Figure 2). These geophysical surveys occurred at known or suspected archaeological sites, essential conducted just before a Phase II or III investigation or pre-Phase I near a known important archaeological site.

4.1.2 Ecoregions

Of the 20 ecoregions that are present within Ohio (Figure 3), this literature review found a representative sample for 14 samples spread throughout the state (Figure 4). Each of these ecozones have different associated qualities associated and will have different effects upon geophysical equipment.

The natural environment or ecoregion in which a dataset is collected has effects upon the success of a particular method within a particular project area. The effects from the ecoregion can be large or small, depending upon the technology employed in the research. While the field conditions defined by the ecoregion of a particular project area is important, it is equally important to be aware of any modern manmade manipulations or activities within the general

vicinity of the project area, which can have a greater influence upon a successful result depending upon the technology being utilized.

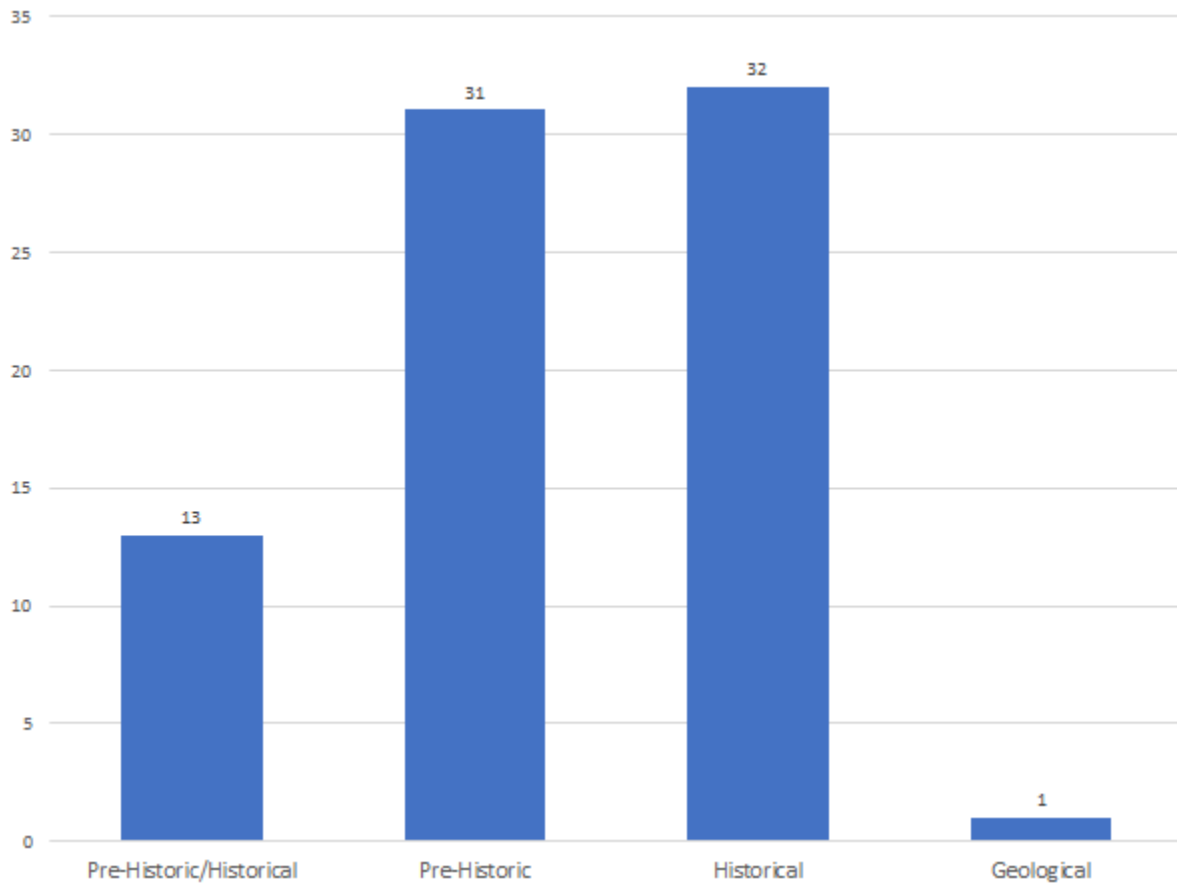


Figure 1. Cultural site types that were the subject of geophysical surveys.

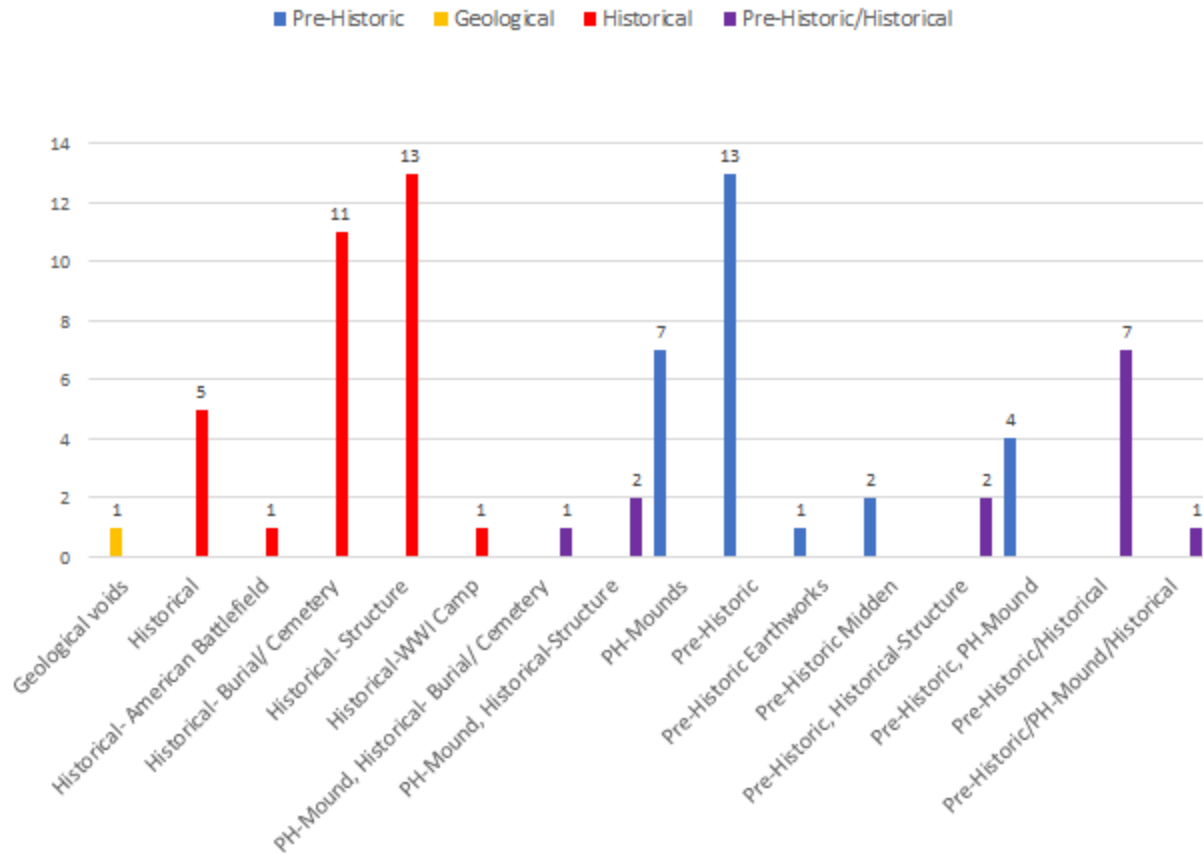


Figure 2. Specific cultural site types that were the subject of geophysical surveys.

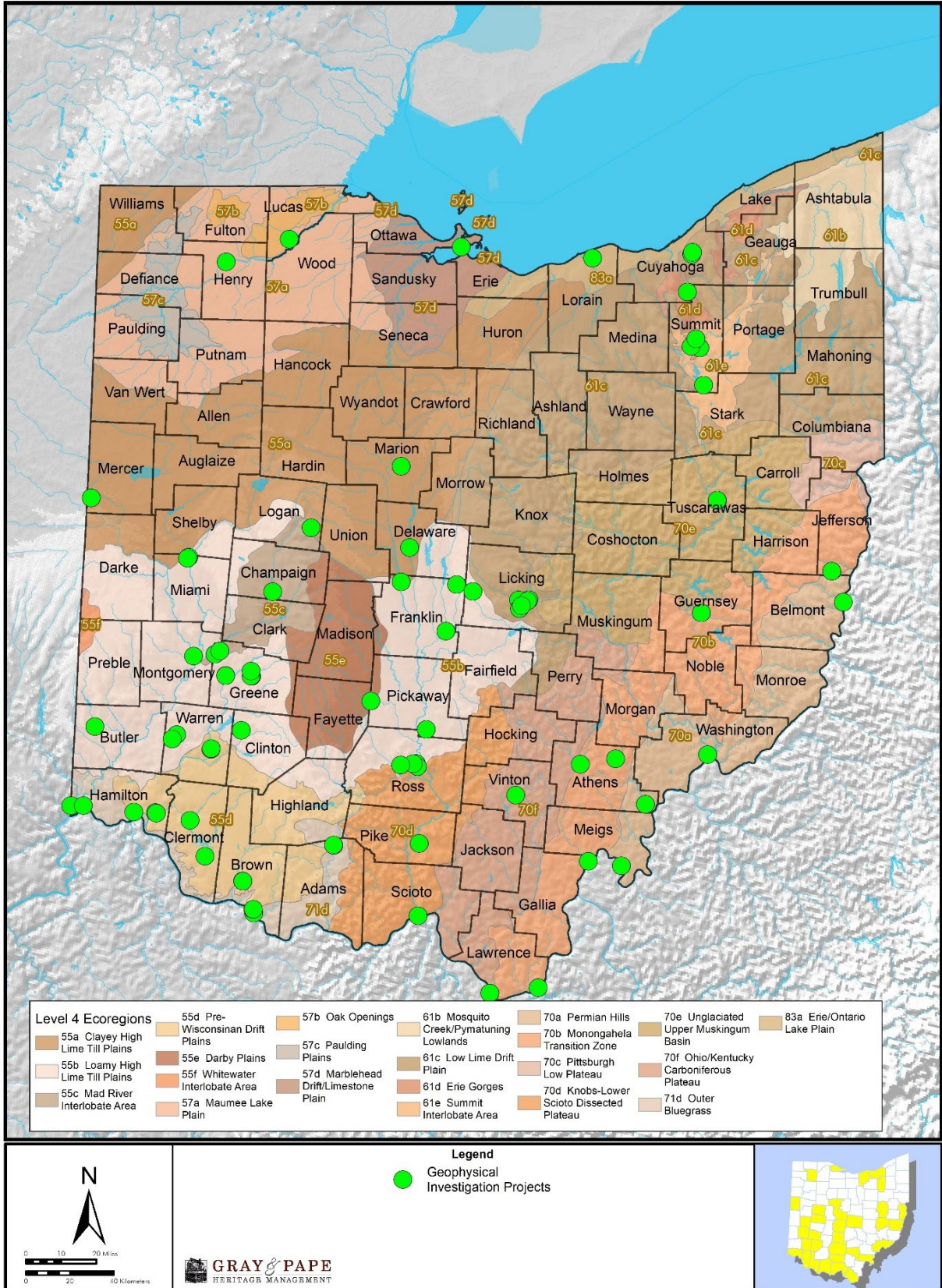


Figure 3. Location of geophysical surveys throughout Ohio's ecoregions.

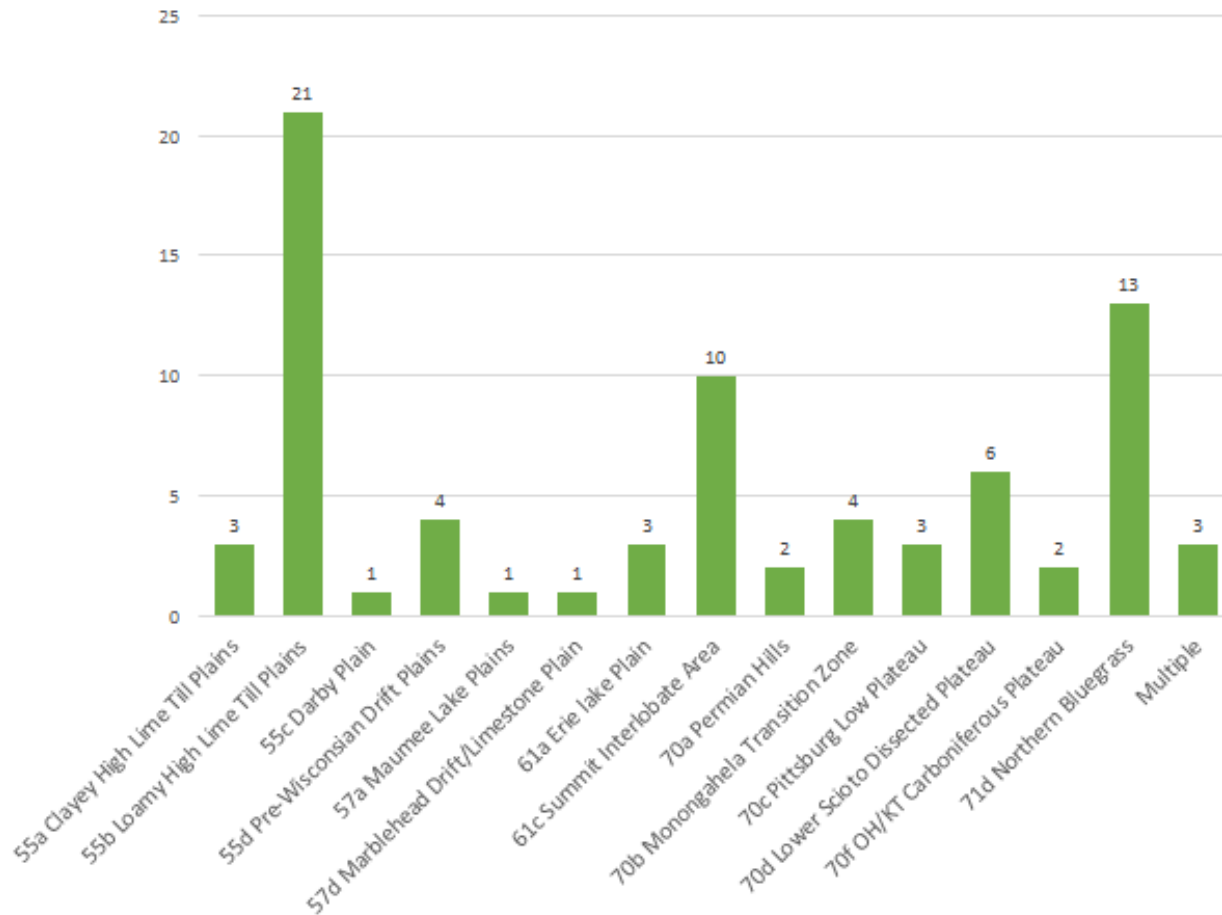


Figure 4. Number of geophysical surveys per ecoregion.

The two geophysical technological methods that are affected the least by the natural effects of an ecoregion are Mag-Sus and Mag-G, as these two technologies are affected by magnetics and the laws of electrical magnetism. Little exists in the natural environment that could have an adverse effect upon a magnetic survey as the few naturally occurring magnetic phenomena, such as magnetic rocks or lightning strikes, are generally both distinctive and low-range magnetic anomalies. These effects could possibly complicate the analysis of a prehistoric site's magnetic survey but would not be the cause of an unsuccessful survey. These two geophysical technological methods are vastly more affected by a site's history, especially its recent modern manmade manipulations or activities within the general vicinity of the project area. Large modern metal objects and buried infrastructural elements can and often do have significant effects upon a magnetic survey. The presence of metal within or near the location of the survey will have a vastly greater potential of rendering a magnetic survey unsuccessful. This is especially prevalent when working within an urban environment or near large industrial buildings and/or busy roads.

The other three geophysical technological methods (GPR, ER, and EC), are greatly affected by the natural effects of an ecoregion because they are heavily influenced by the presence of water and the chemical composition of the soil within the project area.

The Ecoregion Success Chart is color coded as follows:

- **Black** color represents Unsuccessful (U),
- **Very Dark Gray** colors represent Very Limited Success (VLS),
- **Light Gray** colors represent Limited Success (LS),
- **Green** colors represent Successful (S),
- **Blue** colors represent Very Successful (VS).

Magnetic gradation was used 66 times in 14 different ecoregions, and it had a successful rate of 77.3 percent (Figure 5 and Figure 6). As already stated, the success rate of the Mag-G has less to do with a particular ecoregion and more to do with the cultural features being sought after within specific modern interferences affecting local field conditions.

Electrical magnetic susceptibility was used eight times in four different ecoregions and had a successful rate of 100.0 percent (Figure 7 and Figure 8). As already stated, the success rate of the Mag-Sus has less to do with a particular ecoregion, and more to do with the cultural features being sought after within specific modern interferences affecting local field conditions and the success rate reflects this relationship.

Ground-penetrating radar was used 41 times in nine different ecoregions and had a success rate of 65.8 percent (Figure 9 and Figure 10). Most of the sample sizes within a particular ecoregion are too small to make sweeping judgements about the overall effectiveness of a GPR within a particular ecoregion; however, two regions do have a large enough sample size. Sixteen projects are in the Loamy High Lime Till Plain (55b) and eight are in the Northern Bluegrass (71d). The success rate for this technique in these ecoregions is 50.0 percent for Loamy High Lime Till Plain (55b) and 87.5 percent for Northern Bluegrass (71d). While it could be assumed that GPR works well in Northern Bluegrass (71d), the volatile variability in Loamy High Lime Till Plain (55b) suggests that some known local issues are affecting the success rate of a GPR survey. This could be as simple as different weather conditions around the field collection dates, as water moisture has a significant effect upon the success of a GPR survey.

Electrical resistivity was used 18 times across five different ecoregions, and had a success rate of 72.2 percent (Figure 11 and Figure 12). Most of the sample sizes within a particular ecoregion are too small to make sweeping recommendations about the overall effectiveness of an ER within a particular ecoregion; however, the five projects in Loamy High Lime Till Plains (55b) and the six projects in Summit Interlobate Area (61c) are trending in a positive direction, with success rates of 80.0 percent and 83.3 percent, respectively.

Electrical magnetic conductivity was used 11 times across four different ecoregions, and had a success rate of 36.4 percent (Figure 13 and Figure 14). While most of the sample sizes within a particular ecoregion are too small to make sweeping recommendations about the overall effectiveness of an EC within a particular ecoregion, the overall trend of the effectiveness of EC is leaning towards Limited Success. This geophysical survey method should be further studied with a larger sample size to ensure that it is ecoregion conditions affecting the overall success rate and not operator errors skewing this trend. Several of the current sample projects had associated operator errors associated.

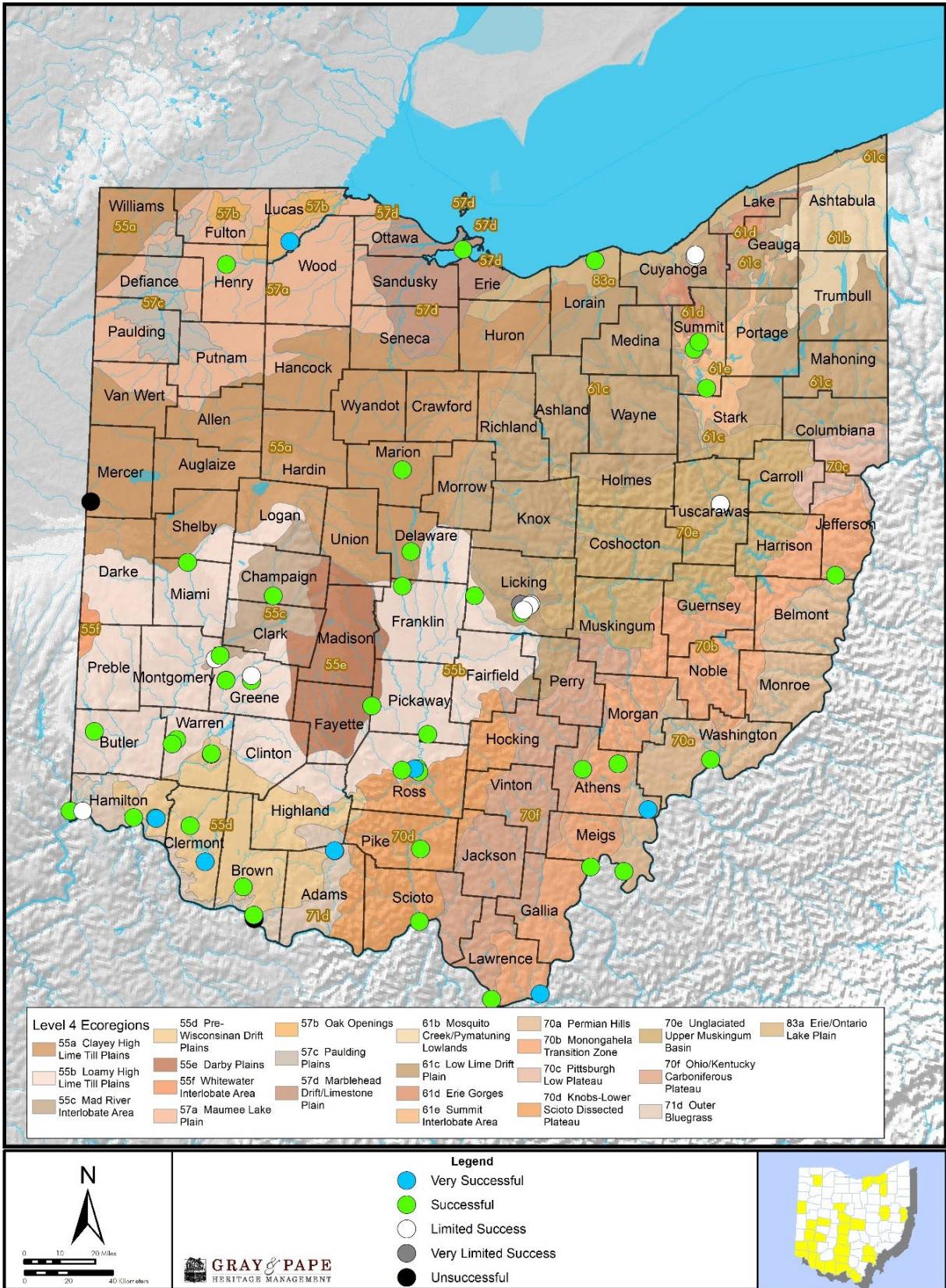


Figure 5. Location and success ratings of magnetic gradient surveys throughout Ohio's ecoregions.

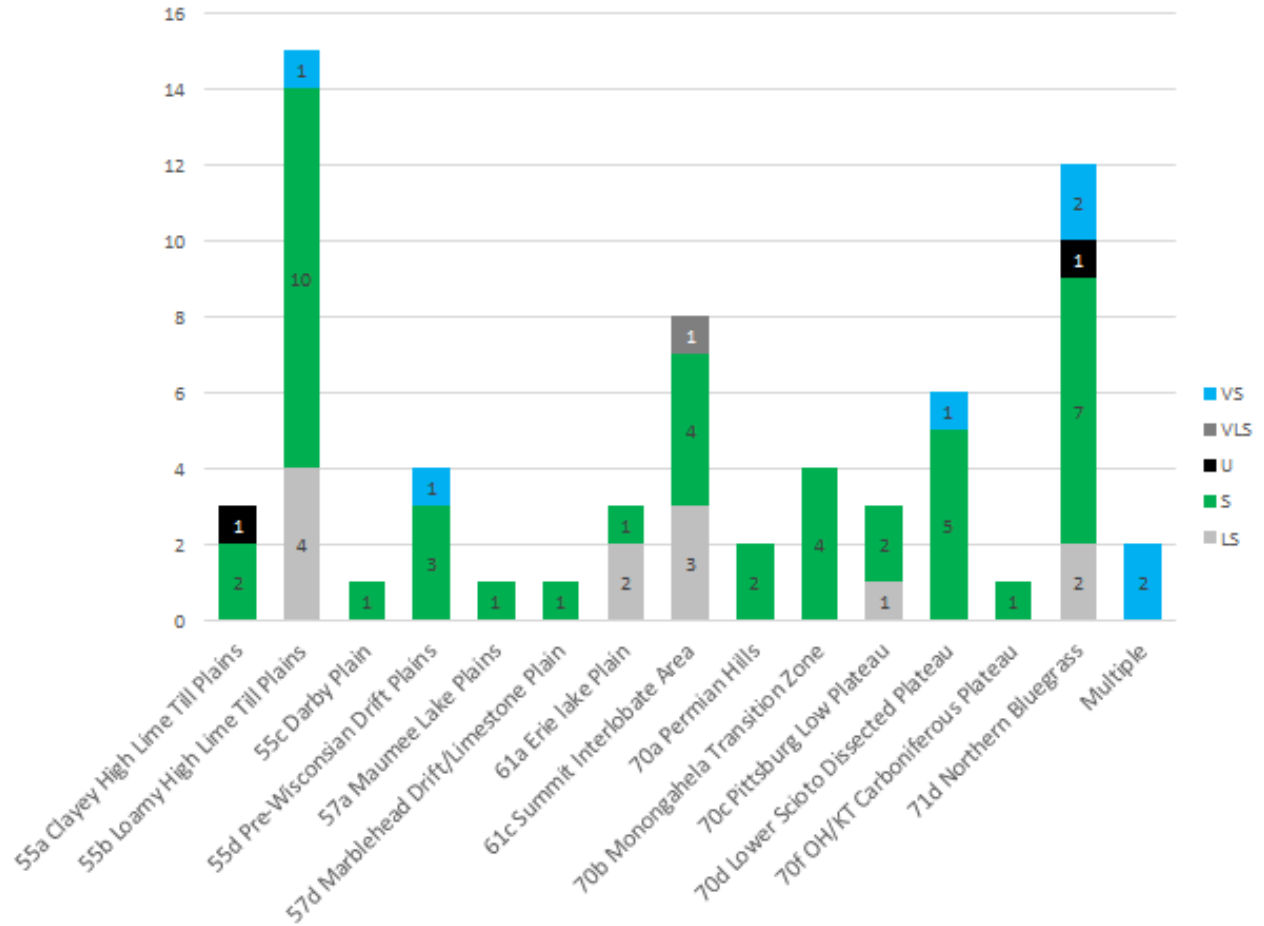


Figure 6. Success of magnetic gradient geophysical surveys across Ohio's ecoregions.

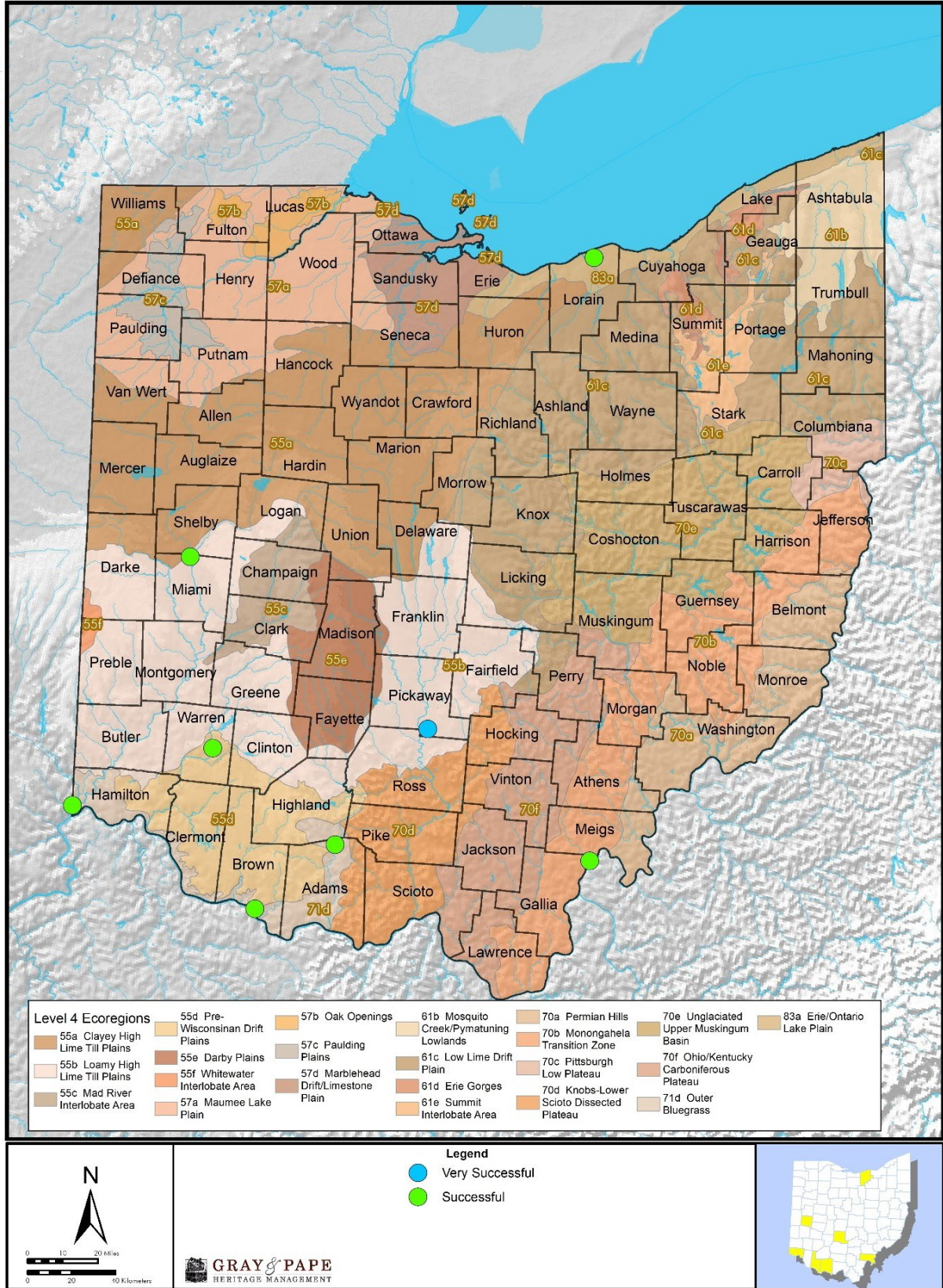


Figure 7. Location and success rating of electrical magnetic susceptibility surveys throughout Ohio's ecoregions.

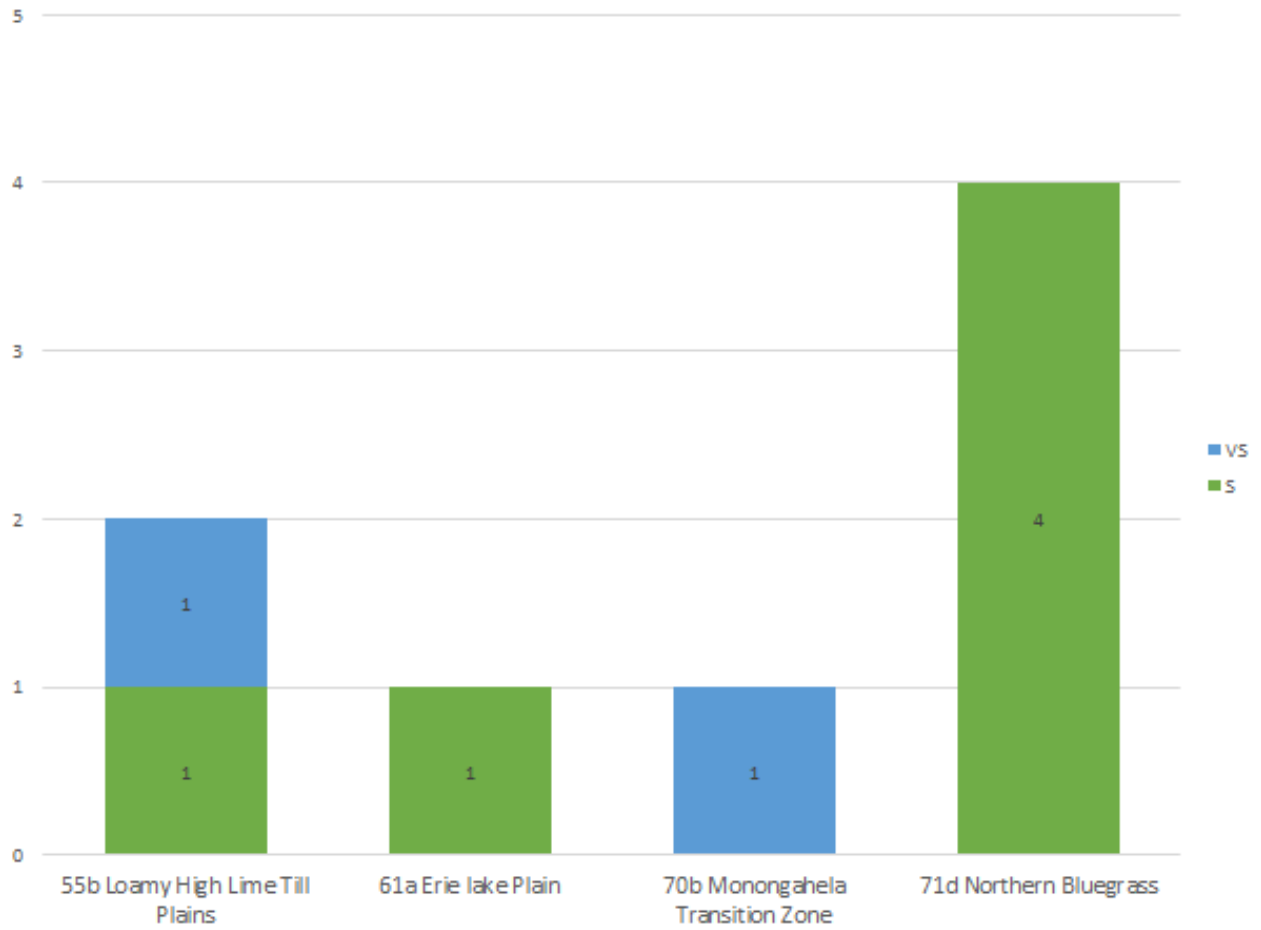


Figure 8. Success of electrical magnetic susceptibility geophysical surveys across Ohio's ecoregions.

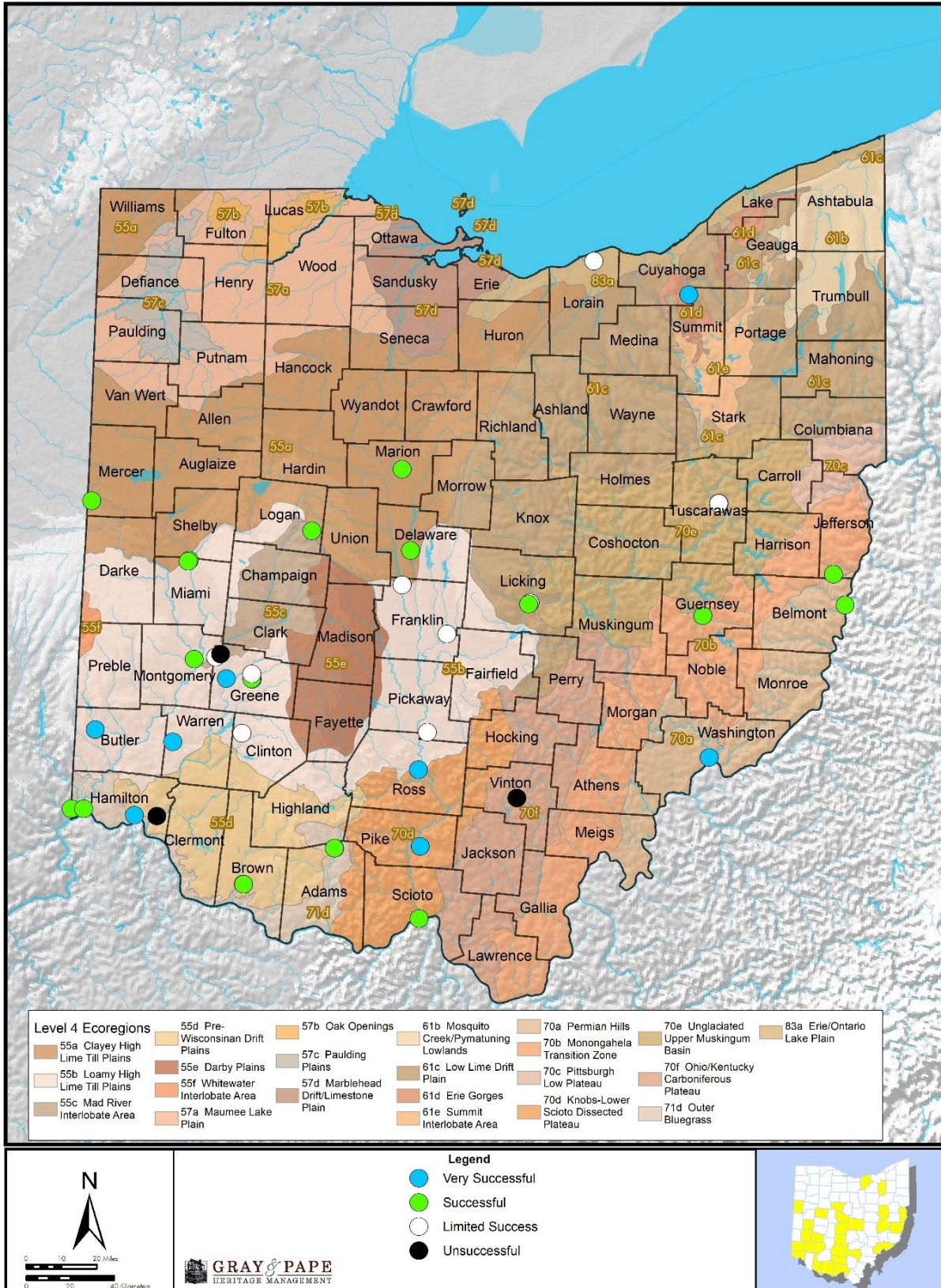


Figure 9. Location and success rating of ground-penetrating radar surveys throughout Ohio's ecoregions.

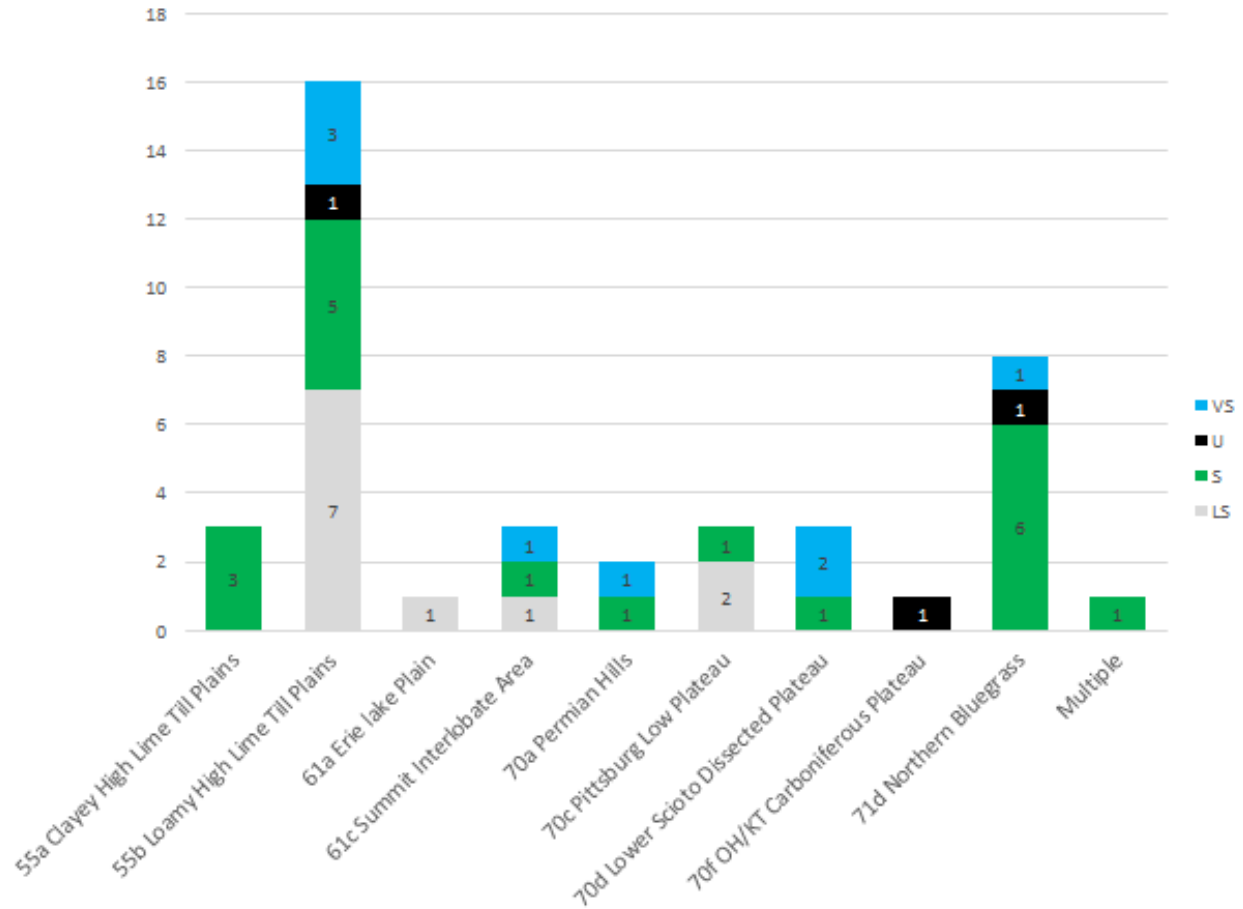


Figure 10. Success of ground-penetrating radar geophysical surveys across Ohio's ecoregions.

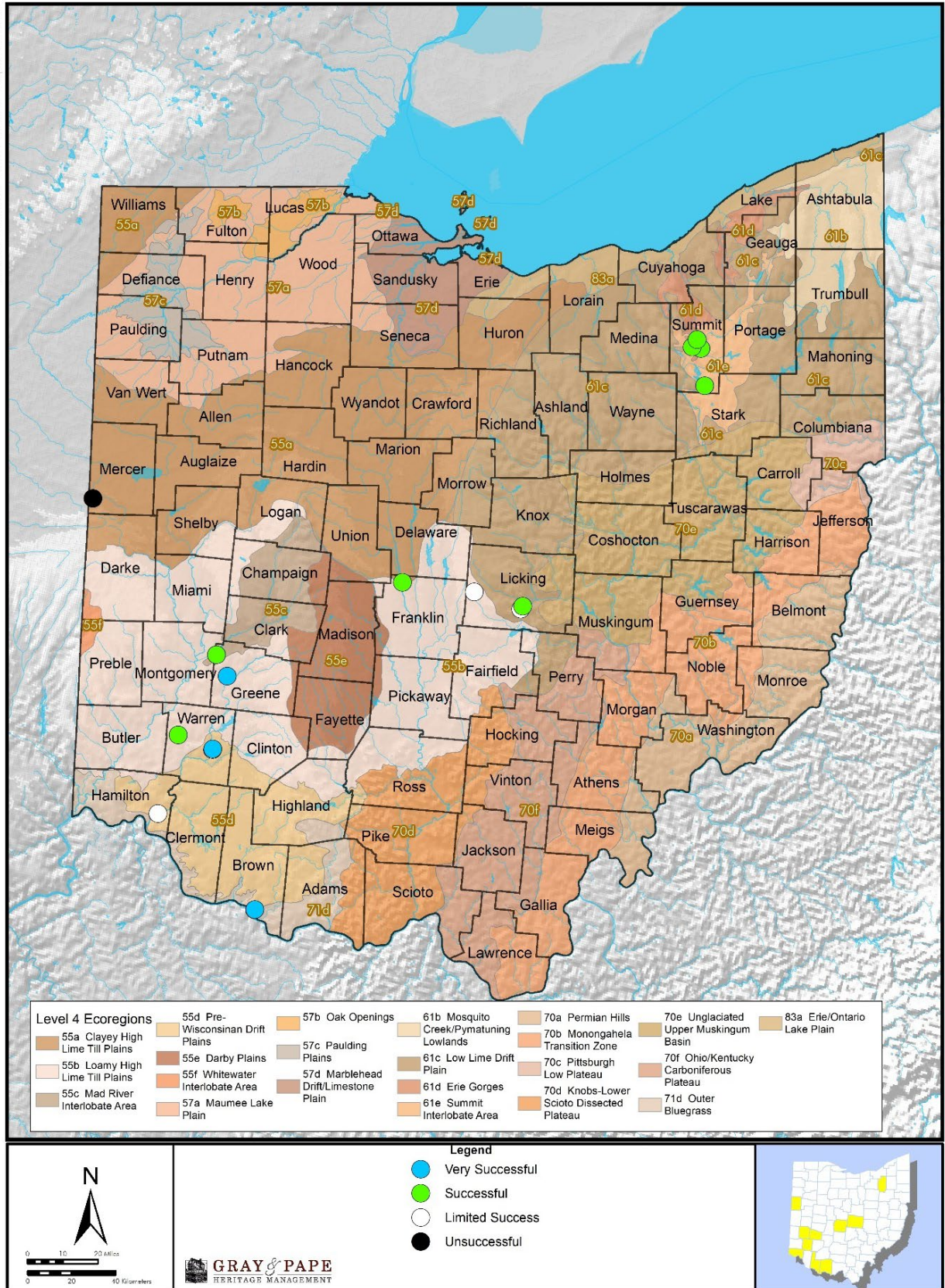


Figure 11. Location and success rating of electrical resistivity surveys throughout Ohio’s ecoregions.

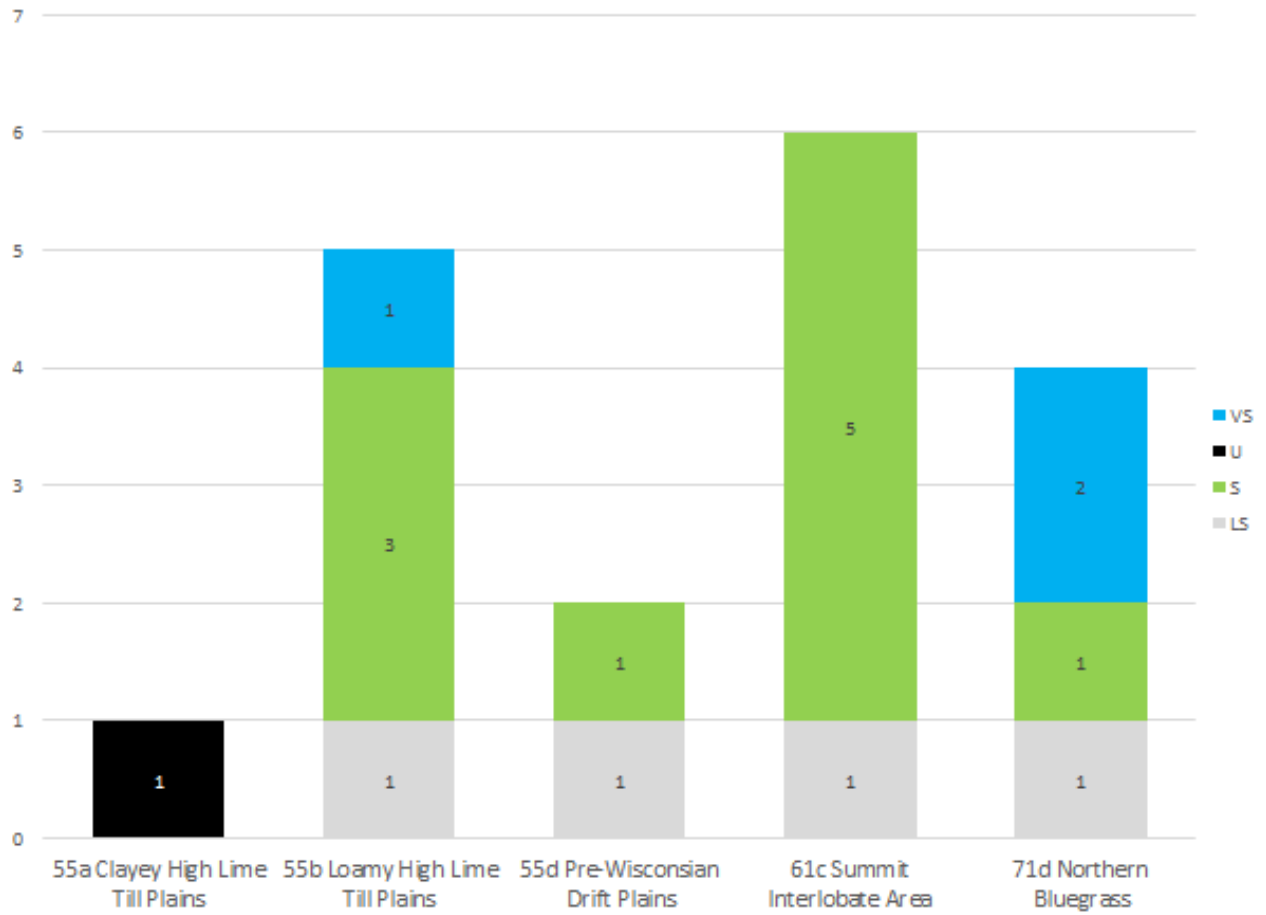


Figure 12. Success of electrical resistivity geophysical surveys across Ohio’s ecoregions.

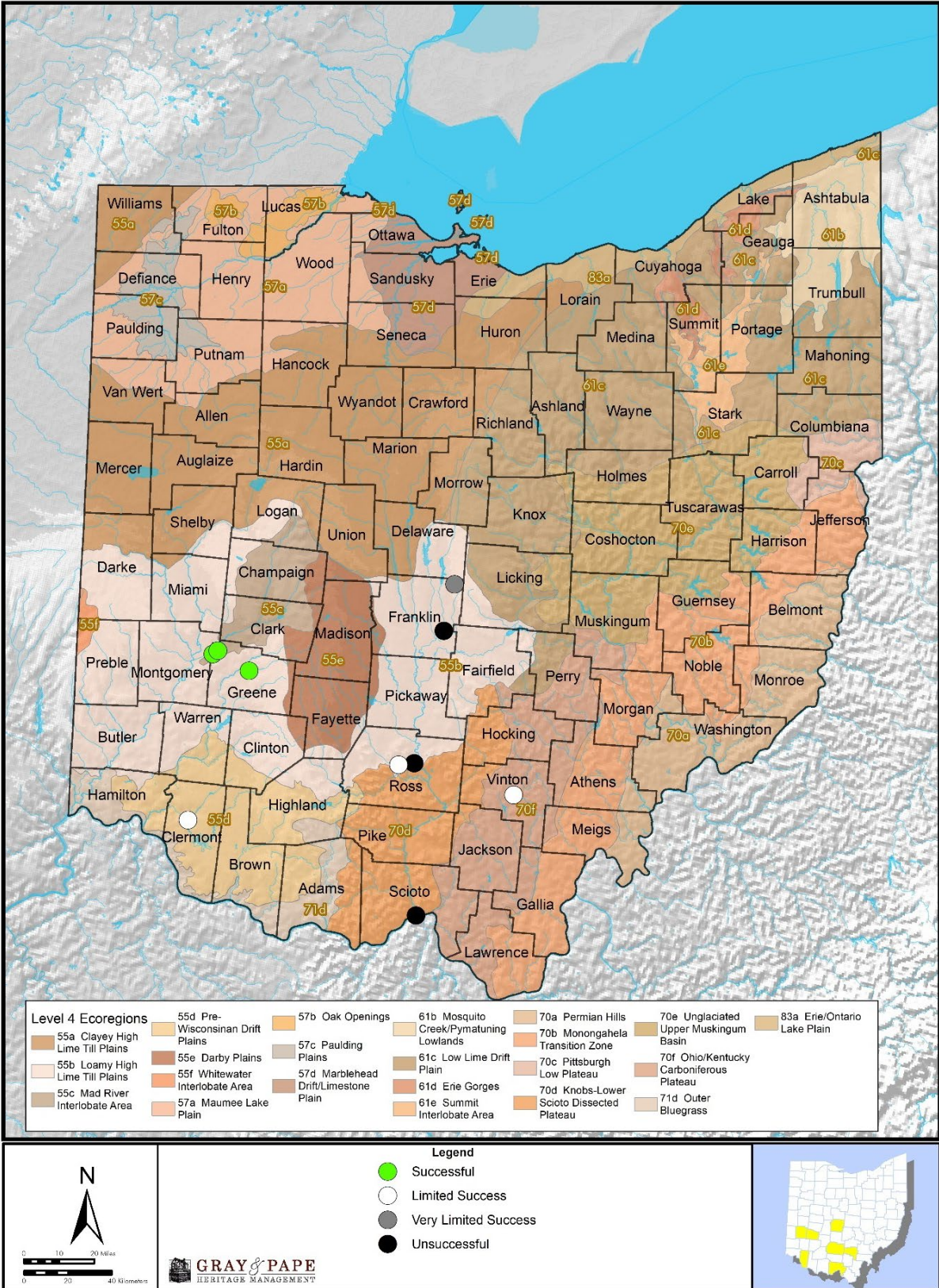


Figure 13. Location and success rating of electrical magnetic conductivity surveys throughout Ohio's ecoregions.

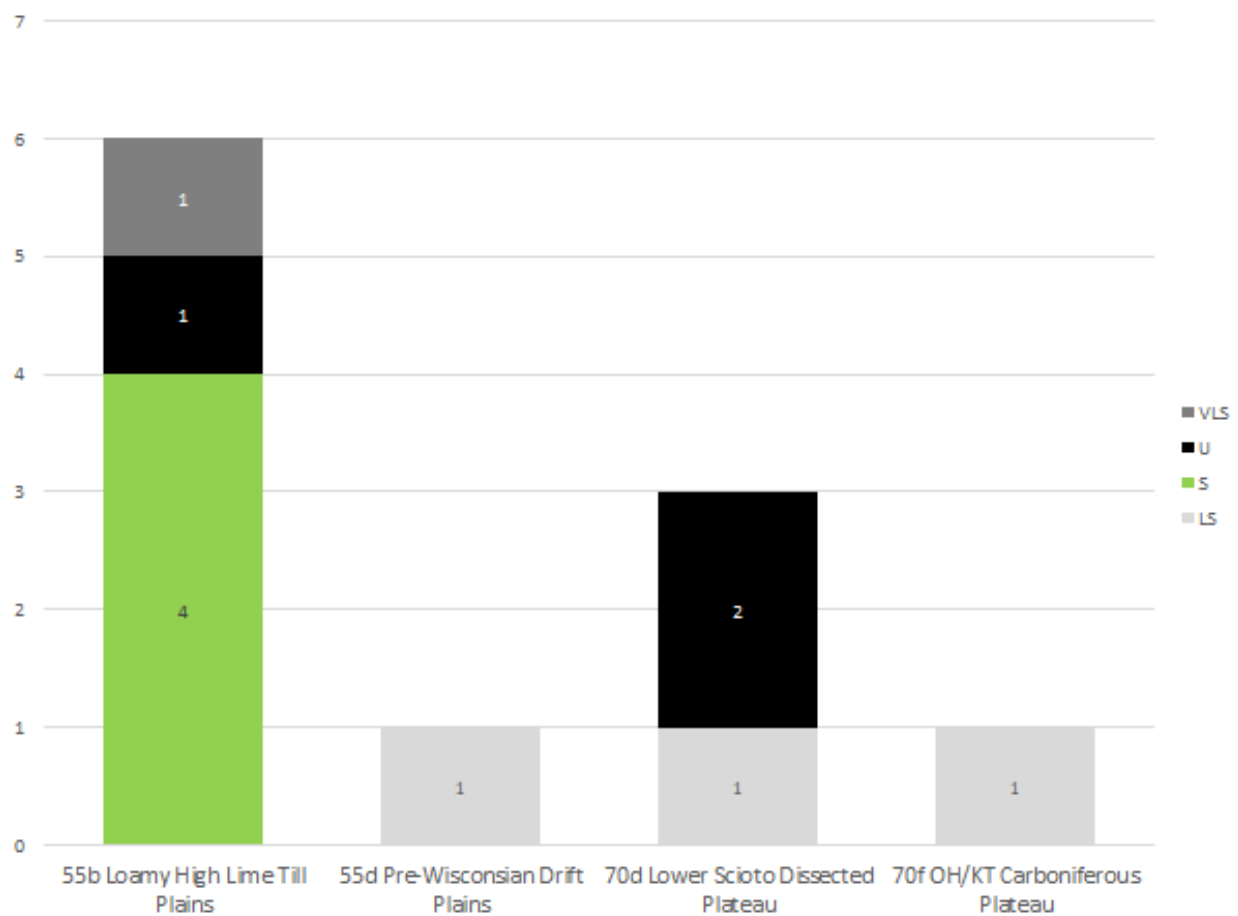


Figure 14. Success of electrical magnetic conductivity geophysical surveys across Ohio's ecoregions.

4.1.3 Instrument Performance

The literature review of a total of 77 geophysical reports covered the three branches of geophysical surveying most associated with archaeological surveying. These are based upon the scientific principles of radar waves, electrical magnetics, and electrical currents. This literature review across the 77 projects produced a diverse variety of methods and combinations between the uses of these five different types of geophysical technological equipment. As some projects focused upon one technological method, while others used two, three, or four different technological methods to complete their study.

Of the 77 projects used for this study, 26 used a single technological method and 51 used multiple technological methods. Of the 51 multi-technological methods, 37 used two technological methods, 12 used three technological methods, and two used four technological methods (Figure 15). The types of technologies employed during these projects are dominated by Mag-G and GPR, with the Mag-G being used in 66, or 85.7 percent, and GPR used in 41, or 53.2 percent, of the projects. The other three technological methods were used more sparingly. Magnetic susceptibility was used in eight projects, or 10.4 percent; ER was used in 18 projects, or 23.4 percent; and EC was used in 11 projects, or 14.3 percent, of the projects.

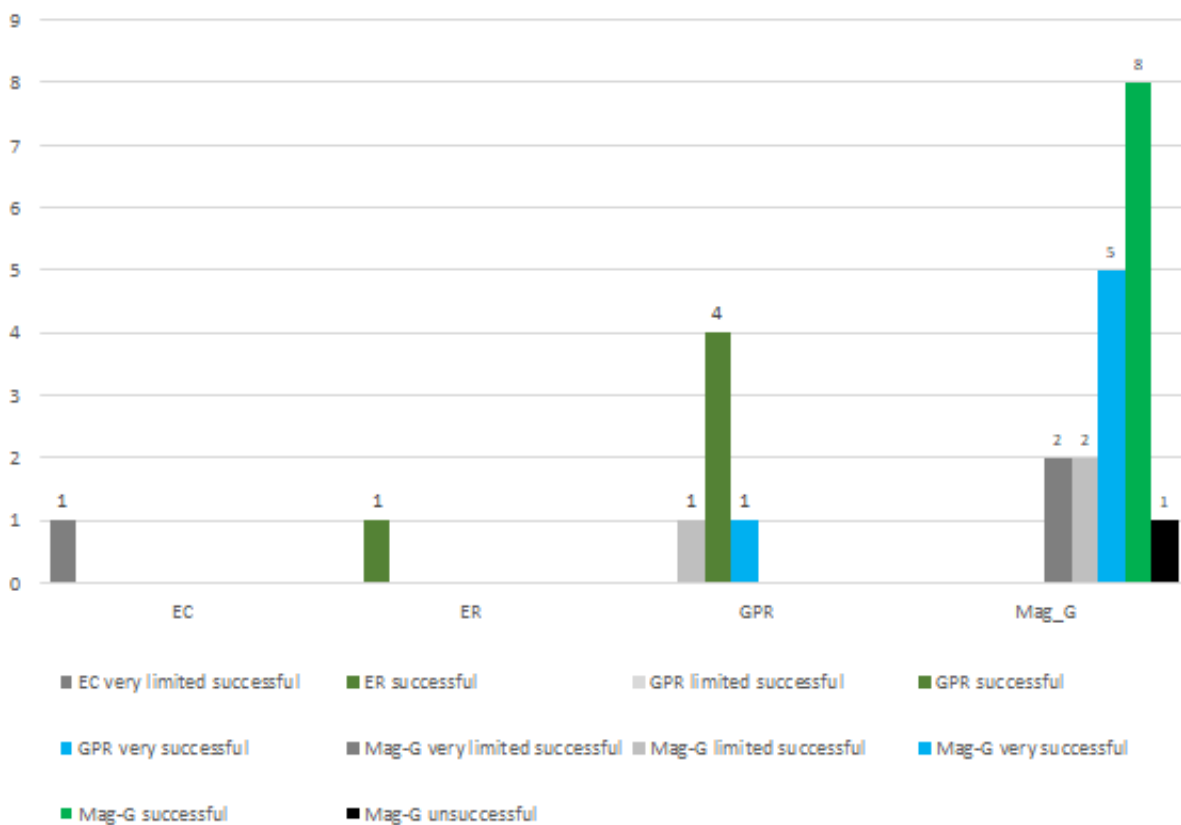


Figure 15. Success ratings of geophysical surveys reviewed by this study.

Of the 26 instances of the use of a single technological method, 18 were Mag-G, six were GPR, one was EC meter, and one was ER. Overall, the success rate for a single method was 76.0

percent successful. This number is highly skewed as the use of a single technological method was not evenly distributed among the technologies. The single technological method was heavily weighed to using either a GPR or Mag-G, as both equipment types are fully appropriate as standalone technologies for certain cultural sites in certain environmental conditions. The success rate for the GPR and Mag-G, those being 83.3 percent and 72.2 percent, respectively.

The use of a single technological method does occur often in geophysical surveying. Significant risks exist when relying upon a single method, especially if the operator is not significantly versed in the chosen equipment type and local field conditions. That is why it is critically important to know which methods are appropriate to locate different cultural resources in different environments.

The single use of EC, while standard for soil science and geological-based projects, is unusual for archaeological projects. This is especially true if the Mag-Sus data is not included in the report's final analysis, as was the case in the reference report in this literature review. Most EC units collect both an EC dataset and Mag-Sus dataset simultaneously in one pass of the instrument. This technological method has the potential to be used as a single method for archaeological surveying and evaluating both historical and prehistoric sites. This method is a relatively fast data-collection method; however, field conditions are a major factor with this technology. Soil conditions should not be too dry or too saturated; thus, a Goldilocks Zone exists for ideal EC data. This technological method is further limited to medium to very large features created by earth-moving activities, such as structures, ditches, mounds, old roads/paths, and graves. This method is often used as the first method in a multi-technological approach to help guide a geophysical survey.

The single use of ER is an odd choice as it is a very intensive field survey method. This method is usually reserved for areas that have already been identified by other technological methods. This method can be used in both historical and prehistoric sites and is best used in environments where the soils are well saturated. This technological method is limited to medium to very large features created by earth-moving activities, such as structures, ditches, mounds, old roads/paths, and graves.

The single use of GPR unit is very common. A GPR unit has many different configurations and settings; it is vitally important that the correct configuration and setting are used in a particular environment. The most common GPR unit configuration used for archaeological surveying is a 400 to 500 MHz antenna mounted in a cart system. This configuration is limited to medium to very large features created by earth-moving activities, such as structures, ditches, mounds, old roads/paths, and graves. Therefore, GPRs are often used to locate graves in cemeteries and structural remains at a site. While the GPR unit works best in dry to nearly dry soils, units can have their setting adjusted to wet to saturated soils. If the soils are too saturated, the depth of the radar wave's penetration will be severely diminished, and a quality dataset may not be obtained.

The single use of Mag G is very common, especially on prehistoric sites. This technology is very sensitive to the near-surface field conditions, which make it an ideal technology for locating prehistoric sites, as the sensitivity of a magnetic gradiometer measures magnetic variations in nonmetallic objects and soils. These magnetic variations occur in the environment both naturally due to chemical and temperature effects, but are most often due to human manipulation. This technological method is unlimited in the size of a feature, only the intensity of magnetic variations. A Mag-G unit can find an individual object or earth-moving activities,

such as structures, ditches, mounds, old roads/paths, graves, etc. This technique is only limited by the effects of modern activities within a historical site and historical/modern activities in a prehistoric site, as the more recent activities are usually larger than the preceding events and involve metals that often obscure the features possibly associated with the earliest activities.

The single use of Mag Sus for a project in an uncombined EC survey context is very unusual, and no example of this method occurred in this research study. This technology is very limited in its ability to locate features smaller than large to very large features created by earth moving activities, such as villages, structures, ditches, mounds, and old roads. Although a Mag-Sus unit measures magnetic variation much like a Mag-G unit, a Mag-Sus unit is about 100 times less sensitive than a Mag-G unit and often has a much smaller data sampling size, as well. This lower sensitivity can aid a Mag-Sus's ability to achieve a successful data collection in a project area where a Mag-G unit was unsuccessful due to surface conditions and modern magnetic interferences. Mag-Sus is one of the fastest data collection methods available and a Mag-Sus survey, with or without a combined EC unit, is often the first geophysical survey method used in a multi-technological approach.

Of the 77 geophysical surveys, 37 were dual technological methods (Figure 16); the combinations of equipment used were two EC/GPR, three Mag-G/EC, 10 Mag-G/ER, 20 Mag-G/GPR, 1 Mag-G/Mag-Sus and 1 was Mag-Sus/GPR. Overall, the success rate of the dual technological method was 94.7 percent, and 84.2 percent when adjusted to only rating of Successful or Very Successful (Figure 17). The dual technological method combinations were dominated by the combination of Mag-G/GPR at 20 uses, or 54.0 percent, of the total sample and in these surveys the Mag-G usage was 80.0 percent Successful and the GPR usage was 80.0 percent Successful; this combination was overall 85.0 percent Successful. The second most common combination was Mag-G/ER with 10 uses, or 26.3 percent, of the total sample. In these surveys the Mag-G was 40.0 percent Successful and the ER was 80.0 percent; this combination was overall 90.0 percent Successful. The two most popular combinations had a successful rate of 86.6 percent with their surveys. The worst combination was EC/GPR with a 0 percent Successful rate. However, this combination only had a sample size of two uses in this study and, thus, is too small of a sample size to on which to base recommendations. More study into this combination is warranted before making the recommendations that this combination not to be relied on in Ohio.

The most heavily relied upon technology as one of the components of the dual technological method was a Mag-G unit, with it being utilized 35, or 94.7 percent, on projects in various combinations with other equipment, with an 80.0 percent Success rate of use.

The Dual Technological Success Chart is color coded as follows:

- Gray colors represent that both technologies were either unsuccessful or only one technology was Limited Success;
- Yellow colors represent that both technologies were Limited Success;
- Light Green colors represent that one technology was Successful while the second technology was only Limited Success;
- Dark Green colors represent that both technologies were Successful;
- Blue colors represent that one technology was Very Successful and the other was Limited Success;
- Dark Blue colors represent that one technology was Very Successful and the other was Successful.

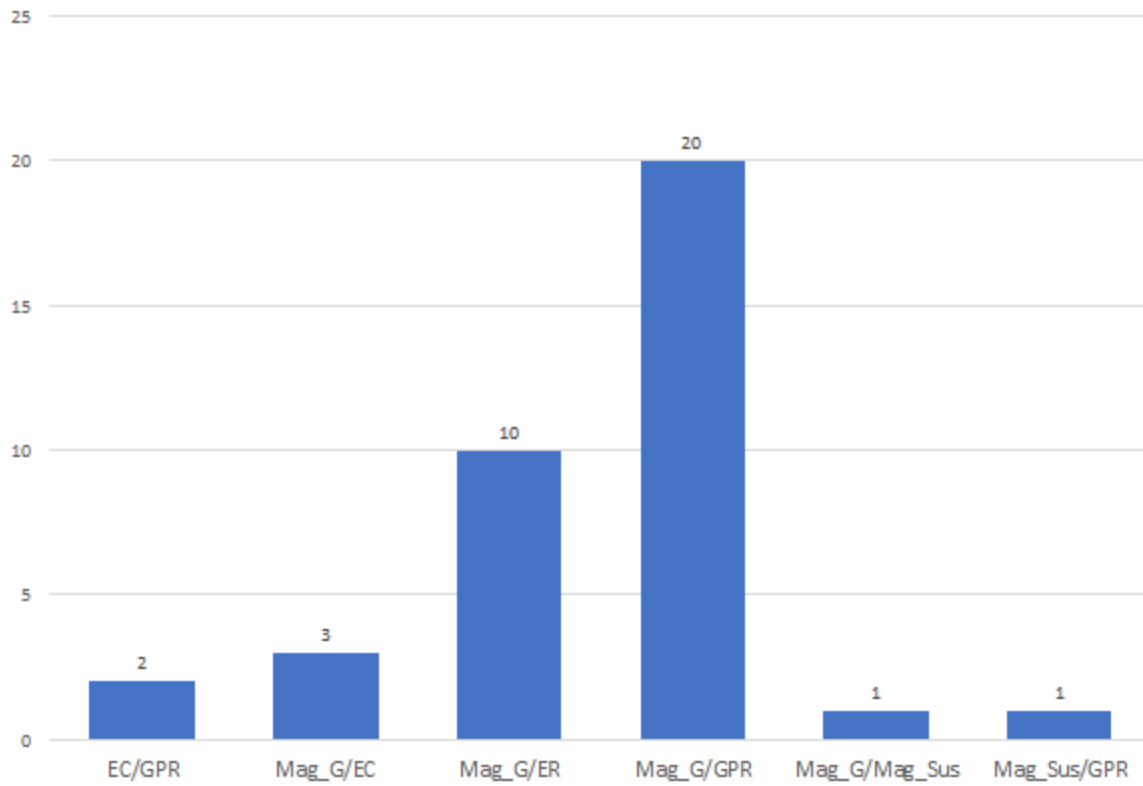


Figure 16. Number of surveys identified using dual technological methods.

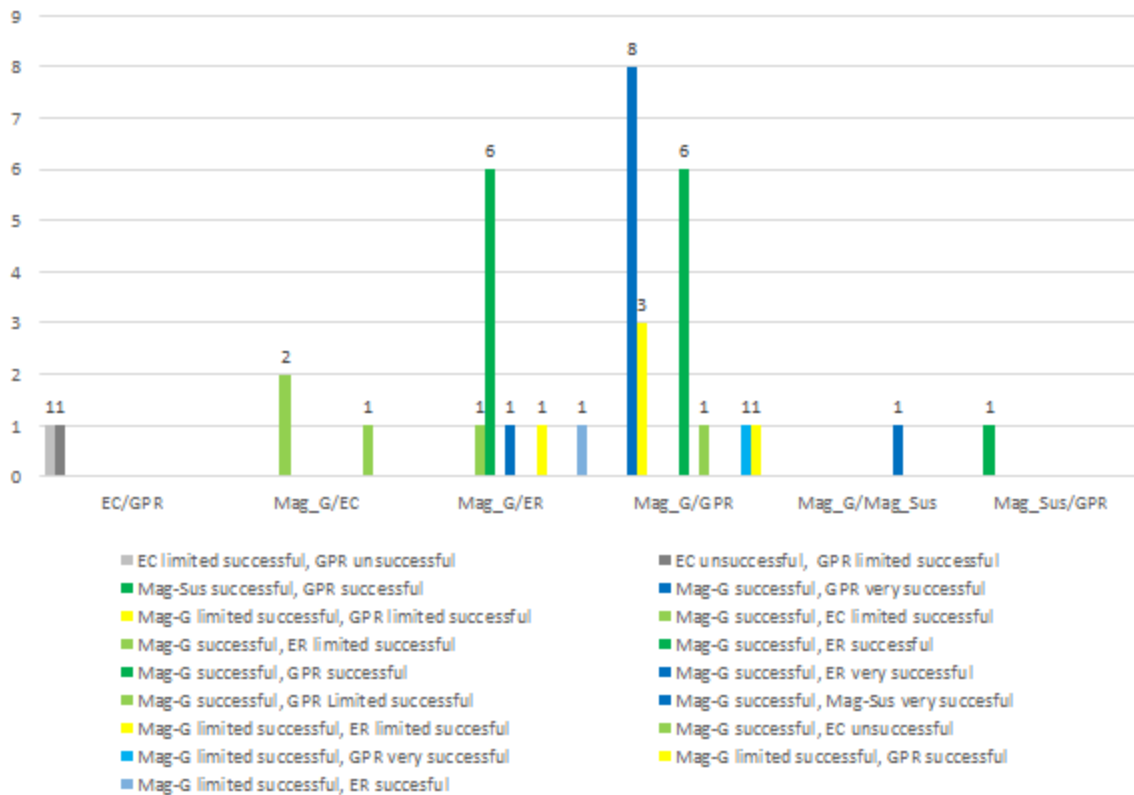


Figure 17. Dual technological methods success chart.

Of the 77 geophysical surveys, 12 used three technological methods (Figure 18); the combinations of equipment used were 3 using Mag-G/EC/GPR, 3 using Mag-G/ER/GPR, 2 using Mag-G/Mag-Sus/ER, and 4 using Mag-G/Mag-Sus/GPR. Overall, the success rate of the three technological method was 100.0 percent as at least one of the three methods employed in each project area was Successful or Very Successful (Figure 19) in discovering archaeological features of some kind, and most located the assumed archaeological feature within the project area. The most common technique was Mag-G/Mag-Sus/GPR, with four applications; however, this combination did not use the three different branches of geophysical equipment types. These surveys used two branches, with one branch at two different levels of sensitivity. This application is riskier as, if a project location is poorly suited for magnetometry methods, then it is possible that both Mag-G and Mag-Sus could fail to collect quality datasets. Six of the 12 projects, or half of the representative sample, ran that risk, but local field conditions allowed these surveys to be highly successful endeavors.

The Three Technological Success Chart is color coded as follows:

- **Gray** colors represent that two technologies were Unsuccessful, and one technology was Successful;
- **Yellow** colors represent that one technology was Unsuccessful, and the other two technologies were Successful;
- **Pink** colors represent that one technology was Unsuccessful, one was Very Successful, and the last technology employed was either Limited Successful or Successful;
- **Light Green** colors represent that two technology were Successful, while the third technology was only Limited Successful;
- **Dark Green** colors represent that all three technologies were Successful;
- **Blue** colors represent that one technology that was Very Successful, and the other two were Limited Successful or Successful;
- **Dark Blue** colors represent that one technology was Very Successful and the other two were Successful.

Of the 77 geophysical surveys, two used four technological methods. Both projects used the same combination of equipment, which was Mag-G/ER/EC/GPR. Both had a 100 percent success rate, with the combination of Mag-G Limited Successful/EC Successful/ER Successful/GPR Limited Successful.

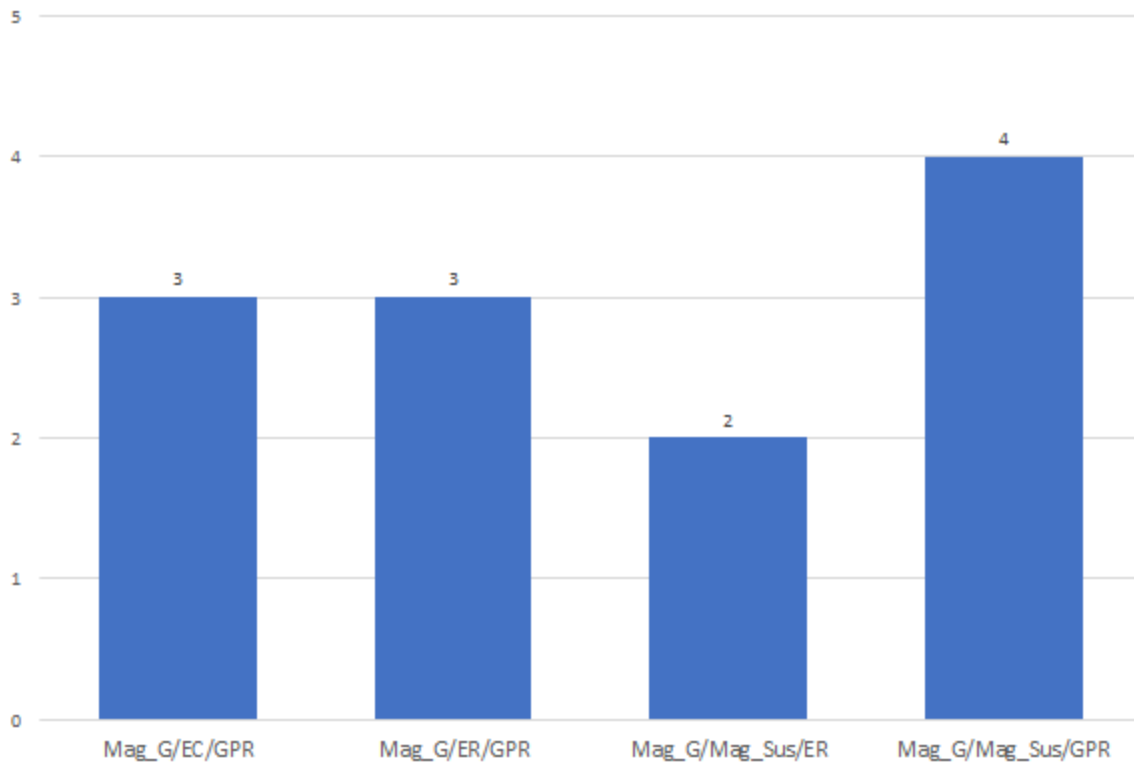


Figure 18. Number of surveys identified using three technological methods.

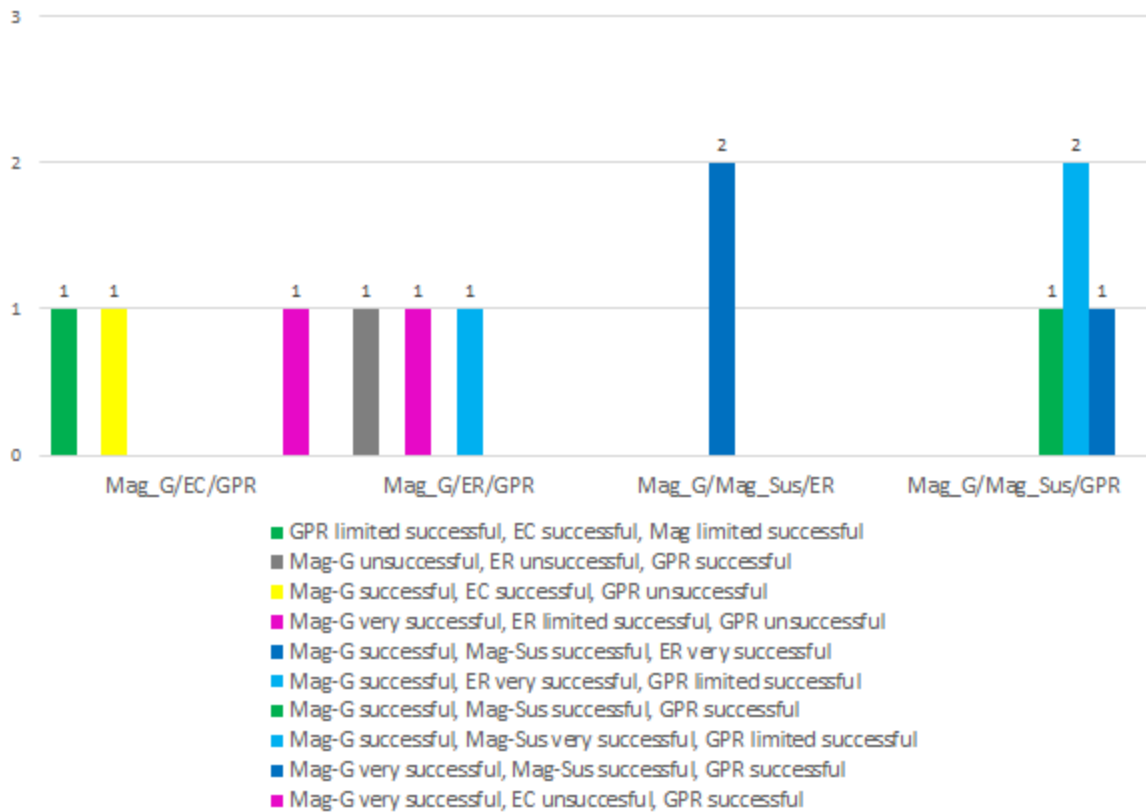


Figure 19. Three technological methods success chart.

4.1.4 Results of Assessment

The goal of this geophysical literature review was to add to the ODOT OES' knowledge of geophysical techniques and their applications to diverse types of archaeological investigative situations. This research consisted of an analysis of 77 geophysical reports conducted throughout Ohio. The reports used one or more of the three groups of appropriate geophysical technologies that are based upon the scientific principles of surrounding radar waves, electrical magnetics, and electrical currents, more commonly referred to as Ground Penetration Radar (GPR), electrical magnetic susceptibility/gradient and electrical resistivity/conductivity, respectively. Each of these techniques has its strengths and weaknesses.

The analysis of the results of the literature review of geophysical survey methods had two main conclusions. First, that the rate of success of a geophysical survey increases as more technologies are used. Second, the more diverse the types of geophysical equipment used on a particular project, the more likely it is that the geophysical surveys will yield quality data that can be used to help guide future decisions through ODOT's PDP, archaeological excavation, and/or general resource planning.

The success rate of geophysical methods is as follows:

- Single Methods: 73.0 percent successful,
- Dual Methods: 84.2 percent successful,
- Three Methods: 100 percent successful and
- Four Methods: 100 percent successful.

It is always recommended that more than a single geophysical technological method should be employed at a particular site. However, when a single geophysical technological method is selected for a particular project area, it should only be selected after careful consideration of the cultural resources assumed to be in the project area, the local ecoregion within which the project lies, and the recent/modern history and current local weather/field conditions.

Though several geophysical technological combinations can be used, some combinations are generally more successful than others. For dual technological methods, the best combination is Mag-G and GPR. This method had an 85.0 percent success rate and was closely followed by the Mag-G and ER combination, with a success rate of 80.0 percent. For three technological methods, all tested combinations were 100.0 percent successful; however, the Mag-G, ER, and GPR combination has the broadest use of the three branches of terrestrial geophysical survey methods associated with archaeological prospecting. This combination offers the best chance for near 100.0 percent of a geophysical survey overcoming local field conditions and producing quality data that can help guide future archaeological excavations or large-scale decisions affecting a potential archaeological site. The use of four methods, while always recommended, is unrealistic in practice as time and cost constraints of a project often limit the scope of geophysical survey methods, except in high-profile, or culturally important, site locations.

5.0 Recommendations for Implementation

This research project aimed to create and implement a geophysical survey program within OES and train an in-house, operationally independent team that is an integral part in ODOT's PDP. Specifically, OES planned to use the geophysical survey program to augment their in-house cultural resources surveys on mid- to low-level projects. Some examples of these types of projects are strip right-of-way takes that are manageable by current OES staff and interns. Other types of applicable projects may include intersection improvements, bridge/culvert replacements, and minor roadway realignments. OES also plans to use the geophysical survey program to investigate archaeological sites identified during research or preliminary survey to reduce the time-and labor-intensive work of traditional archaeological methods, such as subsurface testing and/or assessment-level survey, both of which are inherently invasive and destructive. A geophysical survey program would allow OES to avoid unnecessary excavations on archaeological sites, an important concern Tribal consulting partners have consistently expressed. A geophysical survey program allows OES to gather information in a nonintrusive way, and specifically target areas for limited, but intensive, excavation. These methods may also be employed in areas where testing revealed very little in terms of cultural deposits, but where land-use and archaeological models suggest a high likelihood for intensive use/occupation. OES planned to continue contracting consultants to perform geophysical surveys on the large, major, new projects, such as large roadway realignments, new roadways, and new interchanges.

During the project start-up meeting in December 2020, the ODOT District Research Coordinator identified the Unmanned Aircraft Systems (UAS) Center as another potential member of the Technical Advisory Committee (TAC), with the goal of leveraging capabilities, expertise, and resources already present within ODOT. Among all the services and agency support the UAS Center provides, they also provide aerial geophysical and remote-sensing services. A natural synergy exists between the UAS Center, the OES, the Research Program, and the goals of this research project. Gray & Pape's literature review was undertaken partly with the knowledge these organizations, all within ODOT, and under this research project, would converge to form the geophysical program, as originally conceived in the Request for Proposal (RFP). A primary goal of this research project was to make recommendations to ODOT that not only addressed the objective and goals of the project, but do this in a cost-effective and efficient manner, and one that provides ODOT with the highest return on investment.

5.1 Geophysical Survey Program

Gray & Pape had recommended that the UAS Center should continue to help assist ODOT's operation of the geophysical survey program, under a cooperative agreement with OES, to ensure the OES environmental and cultural resources goals for initiating this research project for a geophysical survey program were met. OES archaeologists were trained in the basics of geophysical survey methods and post-field processing under this research project, with ongoing training from the UAS Center to support the program. This approach allowed ODOT to leverage the already present in-house geophysical survey capabilities and expertise of the UAS Center, and with the OES archaeologists, to build the capacity for both organizations to use these methods and instruments for enhanced decision-making in ODOT's PDP. The cooperation between the UAS Center and OES would extend to the OHC, who is also a partner on this project.

5.2 Instruments, Equipment, and Software

As demonstrated by the two main conclusions from the literature review and assessment, the rate of success of a geophysical survey increases when more technologies and types of equipment are utilized. By following this guidance, it becomes more likely that the geophysical surveys will yield quality data that can be used to help guide future decisions through ODOT's PDP, archaeological excavation, and/or general resource planning. Therefore, Gray & Pape recommended the following multiple technological methods approach, through a new suite of instruments, equipment, and software.

The UAS Center has several airborne instruments and equipment that either have proven successful when deployed on archaeological investigations and/or have been reconfigured to meet the OES' terrestrial geophysical survey needs. During this literature review, the UAS Center has identified additional airborne instruments that would be valuable to archaeological investigations; however, the recommendation here focuses on terrestrial geophysical survey instruments and equipment. The goal of this research project was a geophysical survey program that the OES can use independently for enhanced decision making, which needs to be done through terrestrial geophysical surveys. It is important to note that just as a multiple technological methods approach is recommended for the terrestrial geophysical survey program, using the appropriate array of UAS airborne survey methods is also recommended.

5.2.1 GPR

The UAS Center has one Radar Systems Zond-12E drone, with a 500a GPR system - 500 MHz antenna, which has proven success on archaeological geophysical surveys. The UAS Center was attempting to acquire a terrestrial cart for their GPR to be mounted upon.

For the OES to be able to operate completely independently from the UAS Center, Gray & Pape recommended, and the OES purchased, a Geophysical Survey Systems, Inc. (GSSI) SIR 4000 datalogger cart system, with a 350 MHz antenna. This system came with GPR-processing software RADAN 7.0.

Gray & Pape also recommended the purchase of the following

- Juniper Geode GPS receiver, as it was a sub-meter accurate GPS and could be used with other geophysical equipment. However, the UAS Center suggested that a Emlid Reach was better because it had greater accuracy. The Emlid Reach was purchased, but due to its size and weight can only be used with the GPR cart system.

5.2.2 Magnetic Gradiometer

As included in the budget of this project, Gray & Pape also recommended and the OES purchase a Bartington Instruments Grad 601-2 magnetic gradiometer kit; this was a dual-sensor system that came with the downloading program, Grad601. The device developer Bartington relies upon a third-party vender for the processing of the data that this unit collects, which required OES to purchase two lifetime licenses of the processing program TerraSurveyor. Two licenses were purchased, so that one could be in the field with the device, while not inhibiting the processing of other projects' datasets.

5.2.3 Simultaneous Conductivity and Magnetic Susceptibility Meter

Gray & Pape made every effort to identify United States vendors and manufacturers of the geophysical equipment so the project remains in compliance with Buy America provisions that specifically apply to the transportation sector, which are procurements funded by grants provided to state, municipal, or other organizations, including transit authorities, through the Federal Transit Authority (FTA), Federal Highway Administration (FHWA), and Federal Rail Administration (FRA). One instrument, the Simultaneous Conductivity and Magnetic Susceptibility Meter, was not available from a United States-based vendor. Prior to being discontinued in 2016-2017, a domestically manufactured instrument, the GSSI Profiler, was sold by a United States vendor, GSSI. Gray & Pape researched alternatives to Geonics, the Canadian vendor for the conductivity and magnetic susceptibility meter, and this research found the only comparable systems commercially available were the Dualem 21, also made in Canada, and a GF Instruments S.R.O CM-031, made in the Czech Republic. Gray & Pape has recently purchased a Geonics EM38-MK2, under a federal contract, for a field office of the Natural Resources Conservation Service (NRCS) in the United States Department of Agriculture (USDA) for a project like this one, and this purchase was in full compliance with Buy America provisions. In addition to the Geonics product being the superior instrument, the past success using federal funds to purchase the equipment was another reason Gray & Pape selected this vendor for ODOT.

Gray & Pape also recommended the OES purchase an EM38-MK2 Electrical Conductivity Meter (EM) kit, which included the EM device, a secondary MESA 3 datalogger, and a Juniper Geode GPS unit, which was eventually purchased, once the OES staff saw that the Emlid Reach GPS unit was not appropriate for use with the EM38-MK2. The kit also included four software programs, DAT38WIN, EM38MK2win, Nav38MK2, and TrackMaker38MK2.

Gray & Pape recommended the purchase of the following software:

- SURFER Mapping Software V.16 (For more info visit www.goldensoftware.com), but there was confusion between the OES and the UAS Center, as the UAS Center already had a license and said they could help the processing of data. This, however, did not happen as the UAS Center's current workloads inhibit their ability to aid OES. Therefore, the OES is currently seeking purchase of several licenses of this software so to be independent of the UAS Center.

5.3 Geophysical Equipment Purchase, Set-up, and Testing

Gray & Pape authorized by ODOT, solicited quotes, at a government rate (where applicable), for geophysical surveying instruments and associated electronics and equipment within the last year to purchase the OES-approved geophysical survey instruments and equipment. Gray & Pape recommended the in-person orientation and training to directly transition to the geophysical surveys and processing, to avoid multiple mobilizations and demobilizations. Based on the project schedule, most of the equipment was purchased by September 2021. A secondary purchase of equipment extras (e.g., a GPS unit, cables, connectors, ext.) was completed by April 2022.

5.3.1 Geophysical Survey Site Selection

In addition to the final report and other project deliverables the ODOT team (UAS Center, OES) had an application guide (Appendix B) to conduct operationally independent geophysical surveys with each type of geophysical instrument. To ensure maximum understanding of the

equipment in local terrains, Gray & Pape recommended the sites selected by ODOT and OHC should best represent a cross section of Ohio's prehistoric and historical resources. Gray & Pape provided guidance during the survey site-selection process to help ensure feasibility of the geophysical surveys. The site-selection process was complete after the purchase of the geophysical equipment, set-up, and testing phase of this project. However, due to travel restrictions, the ODOT team decided that they needed to choose site locations within approximately one-hour driving distance of the ODOT headquarters in Columbus, Ohio. The ODOT team selected Union Village, Fort Ancient, Fort Jefferson, and the State of Ohio, State New Insane Cemetery located near or on the ODOT headquarters campus as their testing sites for geophysical surveying training areas. While these selected areas were able to provide the staff with geophysical surveying experiences on pre-contact, post-contact, and cemetery sites, it did limit the staff to working in only two Ecozones, the Loamy High Lime Till Plains (55b) and Darby Plains (55e).

Sites selected represented a broad range of cultural periods within Ohio, but did not represent a strong sample of the types of environmental site conditions located in the state.

- Union Village, Turtlecreek Township, Warren County was a Shaker Village settlement (~1805-1870).
- Fort Ancient, Lebanon Township, Warren County is a pre-contact site (1000-1750 CE).
- Fort Jefferson, Neave Township, Darke County was a fortification erected in 1791 during the Northwest Indian War.
- The State of Ohio, State New Insane Cemetery (1934-1986), Columbus, Franklin County.

6.0 Results of the Geophysical Training Surveys and Processing

Gray & Pape conducted an active orientation process through the collection of geophysical field data using the equipment ODOT purchased. The geophysical survey fieldwork occurred directly after the initial orientation, to avoid multiple mobilizations and demobilizations, and to maximize the value of each training. Gray & Pape proposed a wide schedule window, but a narrow window within which to complete the orientation and training including travel between survey site locations. Two separate two week-long mobilizations were scheduled, one in November 2021 and another one in August 2022. Each mobilization consisted of the first week in the field gathering geophysical data at the selected sites, while the second week was spent processing the gathered datasets. The first mobilization was spent working at Union Village and Fort Ancient. The second mobilization was spent working on Fort Jefferson and the State of Ohio, State New Insane Cemetery.

Gray & Pape provided the trainings with significant support to establish a baseline understanding of geophysical survey, by immersing the OES archaeologists, who, in turn, will support the geophysical survey program. The trainings also provided the opportunity for the UAS Center and OES to work cooperatively, develop best practices, standard operating procedures (SOP), and establish the working organizational relationship that will define the geophysical survey program moving forward.

6.1 Orientation

During the first mobilization (November 2021), Gray & Pape conducted a two-day, in-person orientation and training at ODOT headquarters prior to commencing the geophysical surveys. The two-day orientation and training session included basic orientation of each type of geophysical equipment purchased, how to select and prepare a site for geophysical survey (as only sections of each site will be prepared for field collection), instruction on how to collect useful data, and how to process data/interpret each dataset. Completion of the two-day orientation session also supplied ODOT with an established test grid with known datasets, which will provide a readily available test grid for continued practice.

6.2 Geophysical Survey

After conducting the two-day in-person orientation, the ODOT staff moved to Union Village for a one-day field test of the equipment, followed by one day of processing datasets acquired in the field. The following week ODOT staff conducted a three-day field test at Fort Ancient, followed by one day of data processing. Gray & Pape's Geophysical Program Manager led the field data collection and guided the ODOT team through the various processes. This included survey area selection within each site, setting up the geophysical survey, performing data collection, methods of proper note taking while using each type of equipment, field analysis, and preliminary processing of the field data. A post-fieldwork meeting occurred at the end of the last processing day to review the equipment and software programs covered during the training.

During the second mobilization (August 2022), Gray & Pape directed the ODOT staff in a one-day reorientation of the geophysical equipment, and Gray & Pape formally turned over all

equipment to ODOT during this time. The training next continued with a three-day field test at Fort Jefferson. The second week was composed of a one-day field test of the State of Ohio, State New Insane Cemetery, followed by a three-day processing seminar going over all the datasets that were collected during both mobilizations. Again, a post-fieldwork meeting occurred at the end of the last processing day to review the equipment and software programs covered during both trainings, and what types of additional aid the OES staff still needed going forward.

6.3 Post-Field Processing

Gray & Pape guided the post-field processing to build OES archaeologists' basic knowledge of processing geophysical survey field data from different types of geophysical equipment, as well as conducting an analysis of those datasets acquired in the field; this occurred immediately after data collection were completed. This guided post-field processing served to familiarize the OES staff with the new instruments and software. Gray & Pape conducted thorough reviews and follow-up on the field data collection and post-processing training, discussion of the results, a question-and-answer session, and a final guided check of equipment and software.

6.4 Challenges/ Limitations of the Research Project

Overall, the research project was a resounding success, however there were some challenges and limitations that occurred during the course of implementing the research project.

The first challenges was the scheduling of when the training session would occur.

Although, initially, the mobilizations were scheduled to be closer together to avoid loss of knowledge gained from the first training, environmental, logistical, and public health and safety variables made scheduling and completing this phase of the project challenging. Scheduling conflicts for the ODOT team required a longer-than-ideal separation between training mobilizations.

Another issue was the duration of the sessions were restricted, because the ODOT staff were confined to work-hour restrictions, which required members of the ODOT staff to only work their 40 hours during their normal work weeks. This requirement caused the trainings to only be scheduled Monday through Thursday. This administrative inflexibility greatly limited the OES staff of critical hands-on/face-to-face training with the Gray & Pape Geophysical Program Manager.

The involvement with the ODOT computer technology department (Tech) was another huge issue, from the acquiring of the laptop computers to installing the geophysical programs' software, maneuvering around ODOT's firewalls and making sure that all the programs were in good working order took an exceptionally large amount of time to accomplish. Even though the Tech department was involved early in the process of acquisition of the geophysical equipment, there were miscommunications and misunderstandings between the Tech department and OES staff which cost valuable training session time to resolve.

Gray & Pape originally proposed for this project a follow-up, intensive, post-processing training session, with the goal of building an independent, stand-alone geophysical survey program within OES. Gray & Pape first thought of eliminating this additional training because the UAS Center already has the expertise in-house to conduct the post-field processing, analysis, and

interpretation. However, the current workload of the UAS Center has inhibited its ability to support the OES staff in terms of guidance and support. This support includes ongoing coordination with OES archaeologists working through final post-field processing of all the field datasets gathered during the training mobilizations. It was Gray & Pape who initially thought that by eliminating the follow-up training and leveraging the in-house expertise of the UAS Center and newly trained OES archaeologists, the geophysical survey program would be effectively implemented. The program capacity could begin immediately, becoming fully operational, while Gray & Pape completed the remaining project deliverables, although this was not the case. The elimination of labor costs associated with the follow-up training freed up funds in the research budget to be reinvested back into the geophysical research program. However, in retrospect, the funds should have gone to additional follow-up training as it became apparent that the OES staff could use more support during the processing of datasets, post-process graphic creation, and proper report structure. Little time was left to go over these last two steps during the two training mobilizations. OES staff has been unable to supply the results of the geophysical surveys at the test sites to Gray & Pape for inclusion in the research report.

6.5 Training Results and Recommendations

Many challenges exist to building an ODOT geophysical survey program from the ground up within OES, the least of which is the intensive, hands-on, and on-going training needed to get the program operational, sustainable, and successful. It was presumed that by leveraging the geophysical capabilities and expertise already present within ODOT, labor and expense costs under this research project could be allocated for more investment into reconfiguring and upgrading the instruments the UAS Center currently uses, in addition to new instruments, software, and licensing. An investment in the current UAS Center geophysical survey program, cooperatively with OES, would ultimately provide ODOT a higher return on investment and a more operationally sound, sustainable, and successful program than what this research project was originally conceived, which was to build a stand-alone program within OES. However, as this project went forward, it slowly became clear that its original design was correct.

While some coordination with the UAS Center would help OES to continue to establish the geophysical survey program, it was more critical to build, maintain, and improve the program if OES could operate individually from the UAS Center. OES archaeologists need continuity and immersion in geophysical equipment and survey methods to be successful with their program's development. The overarching goal of this research project is for the OES staff to be able to take a geophysical survey project from the cradle to the grave utilizing their own in-house abilities. These abilities are still in the development phase for OES participants.

Gray & Pape recommends a follow-up, intensive, post-processing training for OES staff. OES staff could greatly benefit from additional support during the processing of datasets, post-process graphic creation, and proper report structure. Little time remained to instruct on these last two steps during the two training mobilizations. Perhaps the UAS Center can provide this training, but if their current workload still prevents this aid, then Gray & Pape is willing to supply this support. However, no funds in this current contract remain for added trainings. Gray & Pape also recommends that the OES staff should attempt to attend online and/or in-person trainings that are provided by the software vendors, as each of these programs are expansive and tend to be overwhelming, especially to individuals' developing their skill sets. This extra support would be highly beneficial to all the OES participants, as well as the program overall.

6.6 Factsheet and Practical Application Guide

Gray & Pape prepared a research report that incorporates the results of this literature review, technical approach of the conducted trainings, survey site descriptions, and conclusions of the trainings and recommendations. Instead of a single factsheet for ODOT's Research Project, three reference manuals were prepared, one for each of the geophysical equipment types purchased for submission with this report (Appendices B-E),. The Factsheet can be found in Appendix F.

Finally, Gray & Pape developed a practical application guide for ODOT's geophysical survey program that documents the best uses of and applications of the equipment, as well as the best combinations of datasets for different field conditions. The practical application guide provides ODOT and OHC decision-making paths and SOPs for conducting and reviewing geophysical surveys.

If requested, Gray & Pape will conduct a Research Results Presentation that provides an overview of the project, including in-depth discussion and analysis that examines the technical aspects, research, and implementation of the geophysical survey and data collection, the training, the results of the project, and the conclusions and recommendations.

7.0 Bibliography

Clay, Rudolf Berle

2005 Conductivity (EM) Survey: A Survival Manual. *Remote Sensing in Archaeology*. 2006:79-107.

Commission for Environmental Cooperation

1997 *Ecological Regions of North America: Toward a Common Perspective*. Commission for Environmental Cooperation, Montreal, Quebec, Canada. 71p. Map (scale 1:12,500,000). Revised 2006.

Conyers, Lawrence B.

2004 *Ground-Penetrating Radar for Archaeology*. Rowman & Littlefield Publishers, Inc., Altamira Press, Lanham, Maryland.

Lowrie, William

2007 *Fundamentals of Geophysics*. Cambridge University Press, Cambridge, England.

Omernik, J.M.

1987 Ecoregions of the conterminous United States. Map (scale 1:7,500,000). *Annals of the Association of American Geographers* 77(1):118-125.

1995 Ecoregions: A Spatial Framework for Environmental Management. In *Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making*. Edited by Davis, W.S., and T.P. Simon. Lewis Publishers: Boca Raton, Florida.

Somers, Lewis

2005 Resistivity Surveys. *Remote Sensing in Archaeology* 2006:109-129.

United States Environmental Protection Agency (EPA)

2020 *Ecoregions*. Electronic document, <https://www.epa.gov/eco-research/ecoregions>, accessed February 2021.

Appendix A. Foundational Text Bibliography

- Aitken, M.J.
1961 *Physics and Archaeology*. Interscience Publishers, Inc.: New York.
- Bevan, Bruce
1983 Electromagnetic for mapping Earth Features. *Journal of Field Archaeology*, 10(1):47-54.
1998 *Geophysical Exploration for Archaeology: An Introduction to Geophysical Exploration. Report No. 1*. Midwest Archaeological Center: Lincoln, Nebraska.
- Bigman, Daniel P
2012 The Use of Electromagnetic Induction in Locating Graves & Mapping Cemeteries: An Example from Native North America. *Archaeological Prospection* 19:31-39.
- Burks, Jarrod
2009 *Large Scale Magnetic Gradient and Magnetic Susceptibility Survey at sites 36 AD500 and 36 AD501, Near Gettysburg, PA*. *Ohio Valley Archaeology, Inc.* Submitted to R. Goodwin & Associates, Inc., Contract No. #2009-23. Ohio Valley Archaeology, Inc., Columbus, Ohio.
- Campana, Stefano & Piro, Salvatore (editor)
2009 *Seeing the Unseen Geophysics and Landscape Archaeology*. Taylor & Francis Group, London.
- Clark, Anthony
1996 *Seeing Beneath the Soil: Prospecting Methods in Archaeology*. B.T. Batsford Ltd.: London, England.
- Clay, Rudolf Berle
2001 Complementary Geophysical Survey Techniques: Why Two Ways Are Always Better Than One. *Southwestern Archaeology* 20(1):31-43.
2005 Conductivity (EM) Survey: A Survival Manual. *Remote Sensing in Archaeology* 2006:79-107.
- Conyers, Lawrence B.
2004 *Ground-Penetrating Radar for Archaeology*. Rowman & Littlefield Publishers, Inc., Altamira Press, Lanham, Maryland.
2006 Ground-Penetrating Radar Techniques to Discover and Map Historic Graves. *Historical Archaeology* 40(3):64-73.
2012 *Interpreting Ground-penetrating Radar for Archaeology*. Left Coast Press, Inc., Walnut Creek, California.

- Dalan RA, De Vore SL, & Clay RB
2010 Geophysical Identification of Unmarked Historic Graves. *Geoarchaeology-An International Journal* 25(5):572-601.
- Evans, Michael E., and Friedrich Heller
2003 *Environmental Magnetism: Principles and Applications of Environmagnetics*. Academic Press, New York.
- Fassbinder, J.W.E., H. Stanjek, and H Vali
1990 Occurrence of Magnetic Bactia in Soil. *Nature* 343:161-163.
- Goodman, D., Y. Nishimura, and J.D Rogers,
1995 GPR Time Slices in Archaeology Prospection. *Archaeological Prospection* 2:85-89.
- Goodson, Ricky A., John C. Morgan, Dwaih K Butler, Morris P Fields, Hollis H Bennett, Jr., and Tere A Demoss.
2009 *Unexploded Ordnance (UXO) Data Analysis System (DAS)*. Environmental Laboratory, United States Army Corps of Engineers. Project # ERDC\EL TR-09-16. Copies available from United StatesArmy Corps of Engineers, Washington D. C.
- Johnson, Jay K. (editor)
2006 *Remote Sensing for Archaeology*. University of Alabama Press. Tuscaloosa, Alabama.
- Johnson, William J., Donald W. Johnson, Marcella G. Johnson, & Tanya E Raymond
2015 Looking for Lost Graves. *FastTIMES Archaeological Geophysics* 20(2):20-31.
- Jones, Geoffrey, and David L. Maki
2005 Lightning-Induced Magnetic Anomalies on Archaeological Sites. *Archaeological Prospection* 12:191-197.
- Jol, Harry M. (editor)
2009 *Ground Penetrating Radar: Theory and Applications*. Elsevier: Oxford, England.
- Kvamme, Kenneth L.
2003 Geophysical Surveys as Landscape Archaeology. *American Antiquity* 68(3):437-457.

2006 Magnetometry: Nature's Gift to Archaeology. In *Sensing in Archaeology: An Explicitly North American Perspective*, edited by Jay K. Johnson, University of Alabama Press, Tuscaloosa.
- Kvamme, Kenneth L. and Stanley A. Ahler
2007 Integrated Remote Sensing and Excavation at Double Ditch State Historic Site, North Dakota. *American Antiquity* 72(3):539-561.

- Lillesand, Thomas M., Ralph W. Kiefer, and Jonathan W. Chipman.
2008 *Remote Sensing and Image Interpretation*. John Wiley & Son, Inc.: Hoboken, New Jersey.
- Lowrie, William
2007 *Fundamentals of Geophysics, 2nd ed.* Cambridge University Press: Cambridge, England.
- Milsom, J.
2003 *Field Geophysics: Geological Field Guide Series, 3rd edition*. Wiley: Chichester, England.
- Olhoeft, Gary R.
2002 Applications & Frustrations in Using Ground Penetrating Radar. *IEEEES AESS Systems Magazine* February 2002.
- Schellentrager GW, Doolittle JA. Calhoun TE & Wettstein CA.
1988 Using Ground-Penetrating Radar to Update Soil Survey Information. *Soil Science Society of America Journal* 53(3):46-752.
- Schultz, John J.
2012 *Detecting Buried Remains Using Ground-Penetrating Radar*. Department of Anthropology, University of Central Florida. Submitted to National Institute of Justice, Office of Justice Programs, Award No.: 2008-DN-BX-K132. National Institute of Justice, Office of Justice Programs, Washington D.C.
- Scollar, Irwin
1990 *Archaeological Prospecting & Remote Sensing*. Cambridge University Press: Cambridge, England.
- Somers, Lewis
2005 Resistivity Surveys. *Remote Sensing in Archaeology* 2006:109-129.
- Wentao Li, Xihong Cui, Li Guo, Jin Chen, Xuehong Chen & Xin Cao
2016 Tree Root Automatic Recognition in Ground Penetrating Radar Profiles Based on Randomized Hough Transform. *Remote Sensing*. 8:430-446.
- Wiseman, James & Farouk El-Baz. (editors)
2007 *Remote Sensing in Archaeology*. Springer Science + Business Media, LLC.: New York, New York.
- Witten, A. J.
2006 *Handbook of Geophysics and Archaeology*. Equinox Publishing Ltd.: London, England.

Appendix B. Geophysical Surveying Practical Application Guide

Geophysical Surveying Practical Application Guide

There is a practical application to geophysical surveying, as not all methods are appropriate for use in all situations on suspected archaeological sites. This guide details industry standards for equipment and its use on known or suspected archaeological sites, as well as recommendations for which equipment to use and in what order to utilize the equipment.

Prior to data collection, it is important to be aware of local weather forecasts for the project area and note when the last rain event occurred and how many inches fell, since water greatly effects ground-penetrating radar (GPR), electrical resistivity (ER), and electrical conductivity (EM) surveys. For GPR surveys, it is best to only collect new data for a site with unknown local soil conditions at least 24 to 36 hours after a significant rain event has stopped. For ER and EM surveys, it is best to conduct the survey within 6 hours of a rain event stopping, as rain will increase the conductivity of the soil. Rainwater has no effect upon magnetic surveys.

It is also recommended that one becomes familiar with the local soil conditions of the area to be surveyed in advance, as dry sandy soils require different settings than wet clayey soils. Individuals should consult the United States Department of Agriculture (USDA) Web Soil Map.

(<https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx>).

Layout of the survey grids does not need to be any particular length, but 20-by-20 meter (m) grids are often used, especially when Mag-G, or ER is being used on the same project. A 20-by-20-m grid is usually the default layout that operators utilize. As 20-by-20-m grid is recommended for people. This grid size provides a large enough sample to capture anomalies and plausible features, but is not too large to make it difficult to recollect, if issues arise during the initial collection phase. Once the operator is more comfortable with the equipment, the transects can be expanded to greater lengths, usually around 40 m. However, it is recommended that transect lengths do not exceed 100 m as the data files get very large in size (several dozen if not hundreds of them), which will likely cause the processing to be slow and the program may crash frequently. Lastly, even though you can collect data in any direction, it will complicate processing if you don't start in the southwest corner.

Geophysical Technology Collection Standards

These are the industry standards minimum samples/meter for data collection with each type of near surface geophysical instrument.

Magnetic Susceptibility (Mag-Sus): Data density is generally low. The industry standards are 1 sample/5 m, at 5-m spaced transects (unless it was collected with an EM unit).

Electrical Magnetic Conductivity (EM or EC): The industry standards are still 4 samples/meter at 1-meter spaced transects. However, the technology plus GPS, has increased this to a denser dataset of ~10 samples/m and most EMs collect 4 datasets simultaneously, 2 EM & 2 Mag-Sus. For graves, it is recommended that transect spacing be decreased to 0.5 m.

Electrical Resistivity (ER): The industry standards are 2 samples/m at 0.5-m spaced transects.

Magnetic Gradiometer (Mag-G): The industry standards are 8 samples/m at 0.5-m spaced transects.

Ground-Penetrating Radar (GPR): The industry standards are 40 samples (or traces)/m and a sampling rate of 512 scans per m at 0.5-m spaced transects for antennas that are 300–500MHz. For graves/human remains features, the transect spacing is decreased to 0.25 m.

Geophysical Technology of Particular Site Types

When considering initiating a geophysical survey for an archaeological site, it is important to choose the correct equipment for each type of suspected archaeological resource. Not all methods are appropriate for use in all situations and are dependent upon particular site conditions. Overall, it is best practice to use at least two geophysical survey methods, but in some ideal environmental conditions one methodology could be employed as a standalone technology.

When researchers have access to all the forms of near-surface geophysical equipment (ER, EM, GPR, Mag-Sus, and Mag-G,) and are faced with a project area that is generally unknown archaeologically, it is recommended that most, if not all, of the geophysical techniques be employed as long as time and budget allows. It is recommended that the first collection dataset is with the EM, as it is the fastest and requires the least grid/area preparation. In addition, the instrument collects two different types of datasets (conductivity and Mag-Sus) at the same time. This method can identify hot spots for the focus of other methodologies. Next, Mag-G should follow, as it is the second-fastest technique and requires only moderate grid/area preparation. The third method to be employed is GPR, as it requires significant grid/area preparation, and can reach great depths with impressive resolution. The last method is usually the ER, as it is the slowest to gather data with and requires moderate grid/area preparation. It usually is used for small areas where a known feature(s) are present, or in areas where the GPR has difficulty collecting data. There are sites and situations in which the recommended order of equipment implementation may shift, due to particular site associations and industry standards.

Pre-Contact Sites: The industry standard for pre-contact sites is magnetic surveys (Mag-Sus, Mag-G, and EM), all of which have the ability to detect subtle magnetic signatures emanated by these types of archaeological resources. Mag-Sus and EM surveys are great first techniques to use, as they can locate hot spots for other equipment to focus on, but are almost never used as standalone techniques, especially Mag-Sus instruments (non-EM) since they lack data density.

GPR and ER surveys are great secondary technologies to incorporate into a survey, but they cannot be a standalone technique, unless the pre-contact site is an earthen mound. The only possible standalone technique is Mag-G, if ideal surface conditions exist. Surface conditions must be excellent (void of large surface metal, both historical and modern), as the sensitivity of the equipment can detect the smallest magnetic changes in soils. That said, Mag-G may also be washed out by even the smallest ferrous debris.

Post-Contact Sites: The industry standard for post-contact sites is GPR and Mag-G. Depending upon the archaeological resource, either one of these methods could be used as a standalone technique. For architectural remains (foundation, pathways, wells, privies, etc.), the GPR is the preferred standalone technique. However, ground water and soil types can easily cause this method to have mixed results. That is why it is most commonly paired with Mag-G, as it is not affected by ground water and works particularly well at locating historical waste. The main limitation for Mag-G is modern surface trash, large metal objects (e.g., parked cars, fire hydrants, signposts, etc.), and underground utility lines. EM, Mag-Sus, and ER are great secondary and tertiary techniques to use. Magnetic susceptibility is great to provide information over a large area quickly, and requires almost no site preparation, as do EM surveys. EM surveys are less affected by modern magnetic objects that washout Mag-G systems. ER work well in areas where known features are present and the GPR had difficulty collecting quality data.

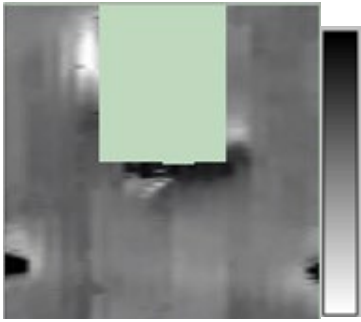
Graves/Human Remains: The industry standard for graves/human remains features/sites is GPR. Depending upon the ground water and soil types, GPR could be used as a standalone technique. However, it is still recommended that another technique be employed, which would be an ER or Mag-G. ER works particularly well, as it will often work best in places where the GPR performed poorly. Both ground water and rain events can adversely affect the GPR's ability to detect anomalies, while the opposite is true with the ER instrument's functionality under the same conditions. Mag-G can be useful for detecting graves/human remains but is dependent upon the intrinsic magnetic nature of the surface soil and the different subsoils located in the area. Also, the area must be void of large surface metal, both historical and modern, so as not to be washed out by small or large ferrous debris. EM is less affected by modern magnetic objects. Mag-G and can provide information about the overall soil conditions, but has difficulty locating small features, such as grave/human remains features/sites. Under certain field conditions, Mag-G can identify them, though it is unrealistic to depend upon this equipment as a standalone technique. Mag-sus meters are not used in the location of graves/human remains, as the sample size is too small to identify them.

Geophysical Technology Color Standards for Reporting

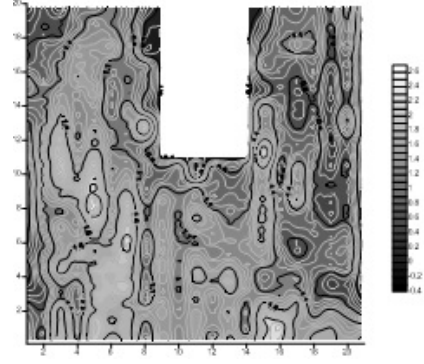
All near-surface geophysical technologies for archaeology (GPR, Mag-Sus, Mag-G, EC, and ER) can be represented in black/white-gray scale, mainly due to publication restrictions. The issue is when multiple technologies are being employed at the same site and the images overlap.

Mag-Sus and Mag-G: Both Mag-Sus and Mag-G surveys are displayed in black/white-gray scale. Since this technology measures magnetic polarity in terms of positive and negative, it is represented in black/white-gray scale. In other industries, it was adopted by the developers of the magnetic processing software (Geoscan, TerraSurveyor, and MagMap). *Blue and green colors are a dummy log placeholder, no data.

Samples:



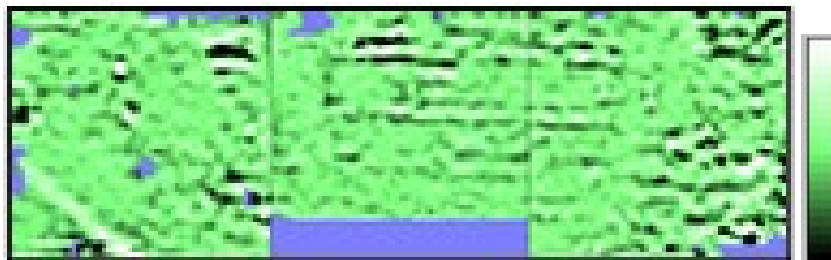
*Magnetic Gradiometer**



Magnetic Susceptibility

Electromagnetic Resistivity: ER is represented in black/white and green scale. The main reason for this is that black/white-gray scale was already taken, and the main developers of the ER data processing selected this scale (Geoscan), and it worked well with the overlapping of the different datasets.

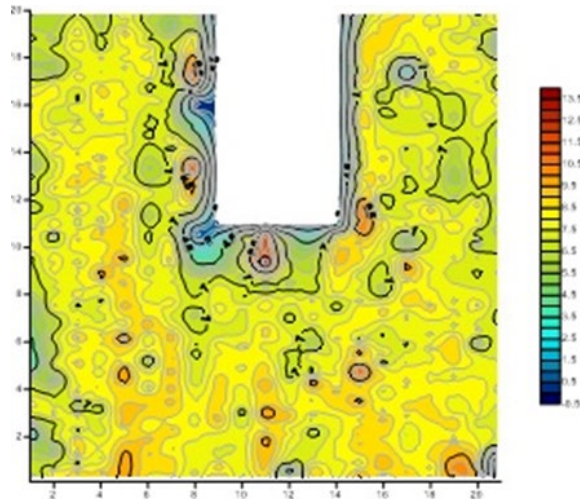
Sample:



*Electromagnetic Resistivity**

Electromagnetic Conductivity: EC is represented in a red to blue rainbow scale as it was selected by individuals in their publications, and it worked well with the overlapping of the different datasets.

Sample:

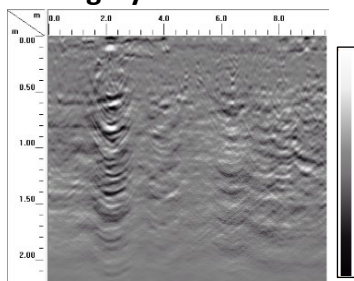


Electromagnetic Conductivity

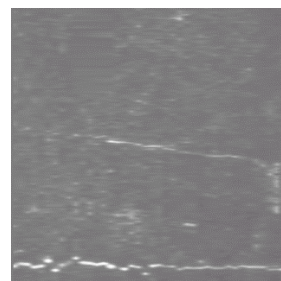
Ground-penetrating Radar: GPR has some variability, mainly based upon the three main developers of the GPR software for archaeology in the United States, GPR Slice, Dr. Lawrence Conyer's GPR Viewer, and RADAN (Sensor & Software and Mala GPR have a smaller market share in the US and they follow the other 3). GPR software has two visual components, the vertical radargram profiles, and the horizontal amplitude slice maps. **All programs will generally represent the radargrams in black/white-gray scale.** The software default variabilities are generally, more for the horizontal amplitude slice maps. The default for images created by GPR Slice is Industrial Blue; the default for GPR Viewer/Surfer is Blue to Red; the default for RADAN is black/white-gray scale and the black/white-gray scale, with extreme poles of blue and red is also acceptable, as it is a mix of the RADAN default and the GPR Viewer defaults.

Samples:

Black/White-gray scale

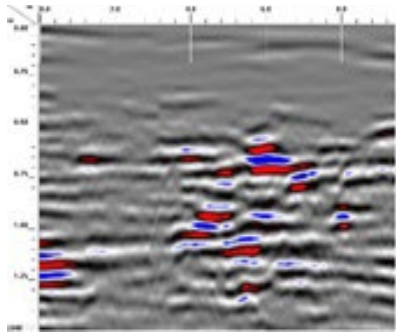


Gray Scale Radargram

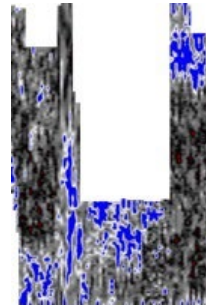


Gray Scale Amplitude Map

Black/White-Gray Scale with Blue and Red Poles

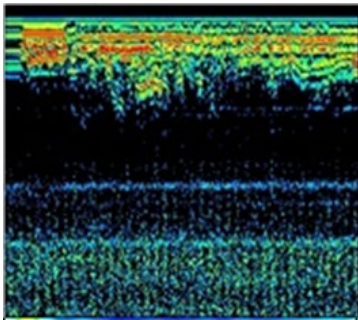


Blue and Red Poles Radargram

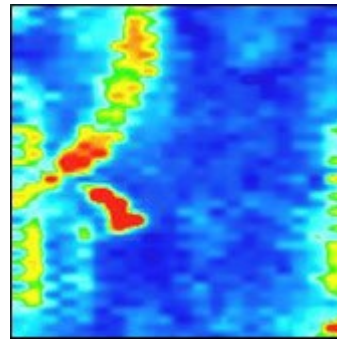


Blue and Red Poles Amplitude Map

Industrial Blue Scale

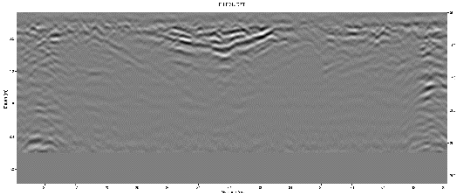


GPR Slice Radargram

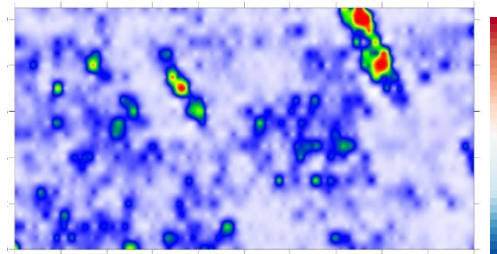


GPR Slice Amplitude Map

Red to Blue Scale



GPR Viewer Radargram



GPR Viewer Amplitude Map

Appendix C. Geonics EM-38MK2 User Manual

Geonics EM-38MK2 User Manual

When referring to this appendix, users should already be familiar with the provided Geonics User's Manuals.

While collecting data with the EM-38MK2 (EM-38), it is always recommended that data is collected within an established grid. This is especially critical if analog mode (non-GPS) is utilized. The data should be collected along a north-south axis and begun from the southwest corner of the grid.

Section 1: Field Collection

1. Make sure the Juniper Geode GPS unit, the MESA data collector, and the EM-38MK2 all have been properly charged and that the operator is metal free (especially the shoes).
2. To get the EM-38 to connect to the GPS unit, first turn on the Juniper Geode and let it warm up (~5 mins) then turn on the MESA data collector.
3. Turn the EM-38 switch to "1m" and walk around and find an area that is near 0 Q/P or at least not fluxing greatly (<20-50 Q/P). Once an area that meets these specifications is found, let the EM-38 warm up there ~15 min.
4. Well away from the EM-38 at least >3-4m away, start the pairing of the GPS and the data collector. On the MESA, in the search menu, type "*Geode Connect*", open the program. In the drop-down menu click on the "Connect Device" and then click the Geode device # (# is on the bottom of the Geode) and the two computers should be paired.
5. Calibrate the EM-38. (See Below, *Section 2*)
6. Open the program "EM38MK2win". Click on "*Survey Settings*" and make sure "Survey Line" and "Start Station" are set to 1, as these both carry over the last settings from previous projects. Make sure the "Line Sequence" is Alternate and the Direction is correct (usually North). ***Note:*** These are not important if the dataset is going to be GPS enabled but, if analog mode is being used, then this is important.
7. Open "*Logging*", click "*Data File*" and name the project and where you want to store the data. Position the EM-38 and click "GO(log data)", if you need to pause for any reason click the large "Pause" button, if you are collecting in a grid pattern, it is recommended that you use the "New Line" button to create new datasets on separate lines. ***Note:*** These are not as important if the GPS is enabled, but if analog mode is being used then it is important.
8. Once all the data is collected, click "Exit", confirm "Yes". Exit the program.

9. Open "DAT38MK2", click "Covert", "Covert EM38-MK2 Raw(N38) Files to Data38MK2 (M38) File", click "Input", find the dataset you just created in the field, click "Convert".
10. Click "File", "Open Profile File", find the dataset you just created and open the file.
11. A. For GPS datasets, click "2D Layout", "Create GPS Based XYZ File" => In the next window that opens up, make sure your settings are correct for how that data was collected and what type of datasets you want to have exported. Usually "Selected Component" is Both, "Dipole Mode" is Vertical, "Separation" is Both, "Options" (all boxes checked), "XYZ Format" should be either Surfer or CSV, "Column Delimiter" should be comma, "Coordinates (Datum WGS84)" should be UTM meters.
 - The GPS settings are based upon the actual unit used for the Juniper Geode. They should be set as follows: "GPS Time Gap" 5 seconds, "GPS Connections" AGPS, "HDOP Mask" 3 HDOP and "System Time Constant Delay" 0 seconds. Once everything is satisfactory, click "File" and name the file to be created, click "Proceed".
- 11.B.1 For analog datasets (no GPS), First save the file as a new file, usually something like Original File Name_ *edit*.M38.
- 11.B.2 Next, remove any lines that needs to be removed, click "Display".
Select Survey Lines, select all but the lines you want to delete and click Delete Lines and click "OK".
- 11.B.3 Click "Edit Geometry", "Set Line Limits", click "Select all" and "Set Line Limits" to 1 and 20 (For a 20-by-20-meter grid), click "OK".
- 11.B.4 Click "Display", "Set Display Parameters", Stations From: 1, TO: 20 (For a 20-by-20-meter grid), click "OK".
- 11.B.4 Click "2D Layout", Create Grid Based XYZ File, the setting are usually: "Select Survey Line Direction" North- South, "Components" Both, "Dipole Mode" Vertical, "Coil Separation" Both, "File Format" Surfer, "Column Delimiter" Comma, "Options" all boxes checked). Click "Output File" and chose the place and file name for the file to be exported. Click, "Create XYZ".
12. Copy the exported data files created on the MESA on a flash drive and export it to your processing computer.
13. Open the program *Surfer* by Golden Software. This is a very powerful mapping software program that can process field data and create all sorts of maps. To get familiar with this program, it is recommended that individuals watch a few YouTube videos on how to use

the software and/or take a beginner course provided by the software developers. (Basic Processing in *Section 3*).

Section 2: Calibration of the EM-38

****WARNING****

Never toggle the switch to Q/P. It is how the factory calibrated the coils and requires special equipment to correct.

1. Turn the toggle switch to “BAT”, to do a battery test, if the reading is over 500 then the battery is ready. If under 500, it should be replaced. Next, turn the toggle switch to “1m” and let warm up for ~15 minutes.
2. Next, extend the calibration rod to ~1.5-meters in height, place the EM-38 on the calibration rod. The toggle switch should still be in the “1m” position. While the EM-38 is in the vertical position, unlock the 1-meter calibration adjusters.
3. While in the vertical position move the I/P calibration adjustment knob until it reads 0. Next move the Q/P calibration adjustment knob until it reads 1–2, then shift the EM-38 into the horizontal position and the Q/P should read 2–4 or twice what it was reading in the vertical position. Lock the calibration adjustment knobs.
4. Place the EM-38 back into the vertical position and unlock the 0.5-m calibration adjustment knobs and toggle the switch to 0.5-m. Move the I/P calibration adjustment knob until it reads 0. Next move the Q/P calibration adjustment knob until it reads 1–2, then shift the EM-38 into the horizontal position and the Q/P should read 2–4 or twice what it was reading in the vertical position. Lock the calibration adjustment knobs.
5. ***Note:*** If the project area is located in a magnetic/electric noisy area, such as being located near modern metal structures, then it will be necessary to calibrate the 1-m and the 0.5-m at the same time. ****Example:**** The local area is creating a fluctuation of ± 100 Q/P, then the user would have to adjust the 1-m calibration adjustment knob until it was ± 50 Q/P or half of the fluctuation rate. Then adjust the 0.5-m calibration adjustment knobs until it was ± 50 Q/P or half of the fluctuation rate. Then repeat the process always reducing the fluctuation rate by half. The EM-38 most likely would never reach 0 in this type of location, but should be in the 10–20 Q/P range which is fine for this type of project area.
6. The final step to calibrate the EM-38 is to place the EM-38 on the ground in the vertical position and toggle the switch to I/P and adjust the I/P 1m calibration adjustment knob so that it reads 0. Lock the knob. The EM-38 is calibrated.

Section 3: Basic Processing in Surfer

Remember the goal of processing is to clean and clear up the dataset—not to create new data.

1. Open the program *Surfer* by Golden Software. This is a very powerful mapping software program that can process field data and create all sorts of maps. It is recommended that to best get familiar with this program. Individuals should watch a few YouTube videos on how to use the software and/or take a beginner course provided by the software developers.
2. To simplify the mapping process, it is best to first open the .dat file that was created on the MESA. On the menu bar at the top, select “File” and then scroll down to the “Open...” or use the Open file shortcut path to where the new file is stored and open the file.
3. Next, save the file as Original File Name_ *edit*.dat, then remove the first row and save the file. This is removing the Header that states in what UTM Zone the data was collected. It is valuable information, but gets in the way when creating maps.
4. On the menu bar at the top, select “Grid” and scroll down to select “Data”, path to where the field data is being stored and select the .dat file that was created on the MESA.
5. In the pop-up menu that appears, you will have to change the Z: drop-down menu to Cond./V/1.0m. Make sure the box “Blank grid outside convex hull data” is checked. Click the output Grid File and save the data Original File Name_ *Cond_1m*. and click save. Uncheck “Grid Report”. Make sure the Gridding Method is set to “Kriging” and click “OK”.
6. Next on the menu bar at the top, select “Map” and then scroll down to the “New” and then scroll over to select “Contour Map”. Select the file you just created.
7. Select the map that appears in the workspace below, the “Property Manager” window should appear, click the “Level”, check Fill Contours. Change the “Fill colors” by clicking the “...” and then select the “Preset” dropdown menu, scroll up to Rainbow6. ****Note:**** Black/white is ok if this map is going to be published in an article, but since there are at least two different datasets being expressed in the report, it is best to change conductivity data color pallets, as magnetic data is always shown in black/white scale.
8. On the menu bar at the top, select “Grid” and scroll down to select “Filter”, path to the file, Original File Name_ *Cond_1m*, select Low-pass Filter Gaussian (3x3), click “Output Grid File”, add LPF to the end of the file. Ex. Original File Name_ *Cond_1m_LPF*, click

“Save”. You can repeat this process a second time. Just add a “2” to the end of the datafile name. Ex. Original File Name_*Cond_1m_LPF2*.

9. Next on the menu bar at the top, select “Map” and then scroll down to the “New” and then scroll over to select “Contour Map”. Select the file you just created (Original File Name_*Cond_1m_LPF2*).
10. Select the map that appears in the workspace below, the “Property Manager” window should appear, click the “Level”, check Fill Contours. Change the “Fill colors” by clicking the “...” and then select the “Preset” dropdown menu, scroll up to Rainbow6.
11. Compare the two maps. It is best that you keep track of your maps by labeling them. You can label the maps in two ways, one is through the Object Manager and the other is by adding Text boxes and placing them close to the maps. The labels should reflect the filename and the processed or raw data being shown.
12. You can continue to process the data by using other filters such as High Pass Filters such as Mean Removal, High Pass 1–3, or experiment with the various other filters. Processing on a whole is to only remove background noise and other factors that may be obscuring the field data. Therefore, it is always recommended to perform the least number of processes on the datasets to ensure the data has not been overprocessed. Remember, the goal of processing is to clean and clear-up the dataset and not to create new data.
13. If everything looks correct, generate the other three maps from the datasets that were created in the field. You will have to repeat the process for Inphase/V/1.0m, Cond./V/0.5m & Inphase/V/0.5m.

Appendix D. Bartington Instruments Grad 601-2 User Manual

Bartington Instruments Grad 601-2 User Manual

When referring to this appendix, user should already be familiar with the provided Bartington Instruments user manuals.

While collecting data with the Bartington Grad 601-2, it is always recommended that the data is collected within an established grid. This is especially critical if the analog mode (non-GPS) is used. If the analog mode is employed, it is also highly recommended that the data is collected along the north-south axis, beginning from the southwest corner of the grid. Even though you can collect any direction, it will complicate processing if you don't start in the southwest corner heading north (Figure 1).

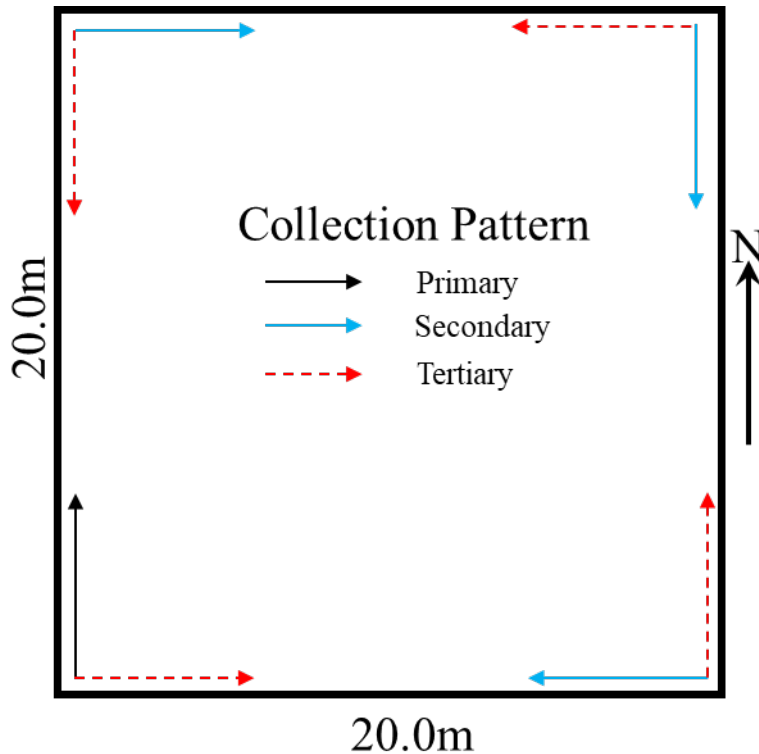


Figure 1

Section 1: Field Collection

14. Make sure the Bartington Grad 601-2 has been properly charged and that the operator is metal free (especially the shoes).
15. Turn on the Bartington Grad 601-2 and let it warm up (~5 mins).
16. Push the button switch to "Grid Mode" and then select "Start Scan" and press "Enter". It will begin to click, as now it is in prospect mode. Walk around and find an area that is near 0 nT or at least not fluxing greatly (<20–50 nT). Only look at the left or right reading as they will not be calibrated yet and they will be very different for one another.

17. Click “Esc” to stop the scanning. Next, click “Grid Mode” and then “Start Survey”. Next, scroll down to “Set Parameters”. In this menu you can select various fields for any given survey, “Pace, Gridsize, Start, Pattern, Lines/m, Sample/m Range, Audio and Volume”. The most important attributes being “Gridsize”, “Pattern” and “Start”. These will determine the size and direction of the data collection. “Pace” is the walking pace, or how fast the data collection will be 0.5 to 2 meters (m)/second (s) and is personal preference. Under “Gridsize,” you can select 10-by-10-, 20-by-20-, 30-by-30- or 40-by-40-m. The default is 20-by-20-m and is usually the grid size that is recommended. It is a large enough sample size to see anomalies and features, but not too large to make it difficult to collect data, given that most pacing lines consist of 20-m grids. “Pattern” is how the data is going to be collected. Either mono-directional (Parallel) or bi-directional (ZigZag). “Start” is the starting direction of the first transect. The default is north, though you can select north, northeast, east, southeast, south, southwest, west, or northwest. Users should always try to start with a northern heading starting from the southeast corner of the grid. However, the overall shape of the site, and various obstructions in the way, may prevent this. If the user must collect in a different direction other than north, it is recommended to stick to the three other cardinal directions, east, west, and south, and begin the collection as depicted in Figure 1. This will simplify the processing of the datasets. The processed images can be georectified in ArcGIS later to its true azimuth. “Line/m” is data lines per meter, and for a dual sensor it is 1. “Samples/m”, the industry standard, is eight samples/m. “Range” will set the sensitivity of the unit and the data range of the sample. The scales are 100nT (sensitivity 0.03nT) or 1000nT (sensitivity 0.1nT) with 100nT for prehistoric and most historical sites, while 1000nT is for modern, and some magnetically noisy, sites. “Audio and Volume” are both personal preferences, but it is recommended that they are used, until the user gets familiar with the equipment.
18. Once an area that meets these specifications is found, let the Bartington Grad 601-2 continue to warm up at that location for ~15 min.
19. Calibrate the Bartington Grad 601-2 (See Below, *Section 2*)
20. Collect the data, for 0.5-m transects (from the southwest corner heading north). Start the left sensor on 0.5 m walking up and down on the full meter mark. Pay attention to the obstructions and the grids. The grids will be numbered automatically in the data collector as Grid 1, 2, 3, and so on. Once the data has been downloaded, it can be renamed to represent the true name of the grids collected. Keep notes associating the default grids to their true designations.

Section 2: Calibration

1. It is best to calibrate the Bartington Grad 601-2 on a plastic bucket or step stool, just ensure it doesn't have any metal on it. Know which way is facing north and the other cardinal directions, as you will be required to face each of the directions.

- Once on the bucket, the user will follow the calibration sequence. Select “Grid Mode”, “Start Survey”, “Adjust Gradiometer”.
 - Calibration Procedure:
2. From the main menu, once “Adjust Gradiometer” is selected. The initial display will prompt the operator to *Point arrows North and Then Press Enter/PB*.
 3. Align the assembly so the sensor arrows point north, and the sensors are vertical, then press the green push button. When the button is pressed, the instrument will take readings from the sensors. It will then bleep and prompt the operator with the message *Point arrows South and Then Press Enter/PB*.
 4. Rotate the gradiometer to point the arrows south. Press the green button when stable. The gradiometer will then take a series of measurements and make corrections to the sensors in turn.
 5. Point the sensor arrows east and west, as prompted by the display.
 - When prompted to invert the sensor, face west and rotate the beam so that the tops of the sensors are now pointing vertically downward and press the green button.
 - When prompted, restore the sensors to the normal position with the arrows pointing west. At this point, both the vertical error and offset are adjusted.
 - Point the sensor arrows east, south, and north again as prompted, while further corrections are made.
 - If all is well, the display will show *Set-up finished* and prompt the operator to press the *ENTER* key or push button. If there is an issue, the procedure will need to be repeated.
 6. Calibration should happen twice a day to avoid desloping.

Section 3: Downloading

1. Make sure the program Grad 601 has been uploaded to the computer, and make sure you upload the driver for the Serial Port to USB.
2. Select the USB port that will act as the main uploading port. Plug in the Serial to USB adapter. In “Control Panel”, “Device Manager”, “Ports” you will see the Serial adapter, not the COM #.
3. Set up a file on the computer where you want the field data to be saved.

4. Start the program Grad 601 and turn on the Bartington Grad 601-2 data logger. Select the correct COM #. Also set the Dummy Data value to something uncollectable. For the 100nT range, 150 is suggested, for the 1000nT range, 1500 is suggested.
5. On the Bartington Grad 601-2, select "Grid Mode", "Output Data" and press "Enter". In the program Grad 601, click "Start" the datalogger should be sending the data.
6. Once the transfer is complete, the "Save" prompt will appear. Select "Save All Grids". Select the pathway to where you want the files saved. You may also add a Prefix to the grids, if wanted. Select comma separated and two Files in spreadsheet. The Header and the dataset will be on separate files with different filename extension.
7. If a prefix was not added during the download, the downloaded grid files may be renamed from Grid 1, Grid 2, Grid 3... to something more relevant such as Grid A, Grid B2, Grid C3... for an alphanumeric grid or whatever naming system has been decided upon.

Section 4: Processing in TerraSurveyor 3.0

It is recommended that individuals first click on the help window "Help Contents" to get familiar with the various processing functions within the program. However, remember this software is made to process several different types of geophysical equipment and many of the processors will never be used for magnetic data. As for the processing of data, it is very site specific, and this manual only gets into the basic processes that most occur on most magnetic datasets. Some sites will require more advanced processing to be complete.

1. Make sure TerraSurveyor has been downloaded and is running on your computer. Remember, the dongle will need to be in the computer's USB to run the program.
2. Create a new site on the "Navigation Bar" select "New Site", name the site, click "OK". The "Site Data" window will appear. You can add more details about the site in the Location, Map Refs, or Comments field, if desired. Click "Save" when ready.
3. TerraSurveyor likes to work out of the file it created when it was first downloaded. That file is on the Documents/TerraSurveyor Sites/"New Site Name". When you create a new site, it will automatically create a file of the same name, and add three sub files: comps, graphics, and grids.
4. Transfer a copy of the downloaded grid file to the file named "grids" located in the Documents/TerraSurveyor Sites/"New Site Name" directory. ****Note:**** Transfer only a copy of the grid data that was collected and downloaded. Those files should also be archived as many government agencies will want the raw data files when reports are filed. Plus, TerraSurveyor is a specialty form of software developed by a small firm in the Netherlands, some agencies internal firewalls may attack the program and wipe the files out. Other small software firms may have these types of security contingencies for as well,

so be aware. The TerraSurveyor root file should be backed up from time-to-time on a separate storage space.

5. In the “Navigation Bar,” select the pathway to the new site folder. It should be a yellow-green colored folder, and click “Import”, select Bartington Grad 601- Basic (Z.dat), click “Next”, select the grids that you need to import and select “Next”; you can add a prefix if you want or just select Next. The files will be imported, and “Grid Assembly” will appear.
6. Once in “Grid Assembly”, you can also click “Assemble Grid”. Click the “Adjust Survey Size” to shrink or expand the size of the grid, as needed, by using the blue arrows. The center button will change the function to expand or shrink. Place the grids in their proper place. Note, that the north is pointed to the right (this is a European convention). At this point, you will see a preview of the datasets and you will be able to see if any mistakes were made, such as, forgetting to change the “Direction” setting on the Grad 601-2. The data can be rotated or flipped, if needed, in this window. When ready, click “Save As,” and chose an appropriate name for the new file.
7. All data processing occurs in the composite files (.cmp) that were just created. Grid files (.grd) are never adjusted, processed, or written over in any way.
8. The goal to processing the data is to do the least amount of processing and limiting any manipulation of the raw field data, as possible. The main objective of processing is to remove operator errors and to merge grid files that may have been collected by different operators. If, for any reason, the user needs to remove a process that has been completed, select “Modify” and you will see the list of all process that have occurred. You may turn them on and off or delete a process (layer). You can also shift processes up and down if the operator accidentally did something out of order. Also, it is good to save frequently, usually after completing a process action, by clicking “Save Composite: in the “Navigation Bar” as the program doesn’t autosave. Complicated processes, or large grids, will often make the program crash.
9. If the grids need to be further aligned, areas can be moved by first selecting the area that needs to be shifted and the pressing “Move”. A sub-window will appear and then you can move the area up, down, left, or right. You also have the option to overwrite or merge the data (usually you want to overwrite).
10. The first operation after the correct placement of all the grids is to search and replace all the dummy logged areas. Select “Replace” under replace, click “Exactly,” put 150 in the box, and under “With” select “Dummy”. Click “OK.”
11. Common operator errors occur with pacing and the zigzag data collection. Striping white and black bands are caused by zigzag collecting and can be fixed by “Destripe”.
 - If mono-directional data collection was used, skip to the next process, otherwise select “Destripe” in apply to select “Traverses”, in method, select “Mean”, in

Threshold select “Std Dev. 2”. The other setting will affect the data differently, you can experiment with the other functions. Just remember to only select one.

12. Minor pacing errors can be fixed by clicking “Destagger”. Select the offset (usually >12.5, but no >25 centimeters [cm]). Any more than 25 cm means the collection was done poorly. If you have to de-stagger more than 25 cm, the grid should be collected, because you are only going to get general information and you will not be able to properly place identified anomalies in the field. If no pacing error occurred, skip to the next process.
13. If the Grad601-2 was not calibrated often enough, desloping may need to be required. Select the grids that need to be desloped and click “Deslope”. Under method, select “Polynomial Best Fit”. Under orientation, click the direction the data was collected (example. for a grid collected north it would be “Horizontal”, because the north-south axis is horizontal).
14. If there are large metal objects in the dataset, they will washout out not only the area near the object, but the whole dataset, so it is always good to despiking. Click “Despike” under Window Size, select X & Y diameter 3, under Threshold select “3.0”. Under Center Value, select “Mean,” and under Replace with “Mean”. This process can be repeated once.
15. If no more pacing/collection errors need to be fixed, it is time to smooth the data for export. Click “Interpolate”. Under Axis, click the opposite axis the data was collected in (e.g., for a grid collected north it would be “Y”, because the north-south axis is horizontal, so the data was collected along the X-axis). Under Factor, click “Double”. This will create more data points to smooth the data and make it less pixelated. This process can be repeated once.
16. To help small magnetic anomalies be seen better, it is best to use a Low Pass Filter (LPF). Click H/L Pass, then under Filter select “Low Pass”. Under weight, select “Gaussian”, and under Window Size, select X & Y diameter 3. This process will also smooth the dataset. This process can be repeated once.
17. Now the magnetic data is processed and ready for export. TerraSurveyor can publish images, but it is a bit cumbersome, so it is best to use other programs, such as PowerPoint and Adobe Illustrator. Export an image by clicking “File”, “Save Image...”, In Save As, type click “.PNG” and make sure “Transparent Background” is selected. The image is automatically going to the subfile “Graphics” that was created when the new site was created. You also can export it as an ESRI grid file, which can be useful if it needs to be georeferenced. Click “File”, “Export”, and in Format. select “ESRI Grid File.” Click “Omit Dummy Values” and click “Save As”. A new subfolder (Export) will be created in the same root directory. Several other types of file formats can be exported, as well.

Appendix E. GSSI SIR 4000RADA User Manual

GSSI GPR SIR 4000 & RADAN User's Manual Appendix

When referring to this appendix, the user should already be familiar with the provided GSSI User manuals. GSSI also provides technical support and classes for their equipment and software. The ground-penetrating radar (GPR) unit collects vertical profiles/radargrams for each transect and each transects' radargram will be saved as its own file.

While collecting data with the GSSI GPR unit, or any other GPR unit, it is always recommended that the data is collected within an established grid. This is especially critical if analog mode (non-GPS) is being used and if analog mode is being employed. It is also recommended that the data is collected from starting in the southwest corner of the grid. Even though you can collect any direction, it will complicate processing if another directional corner is used (Figure 1).

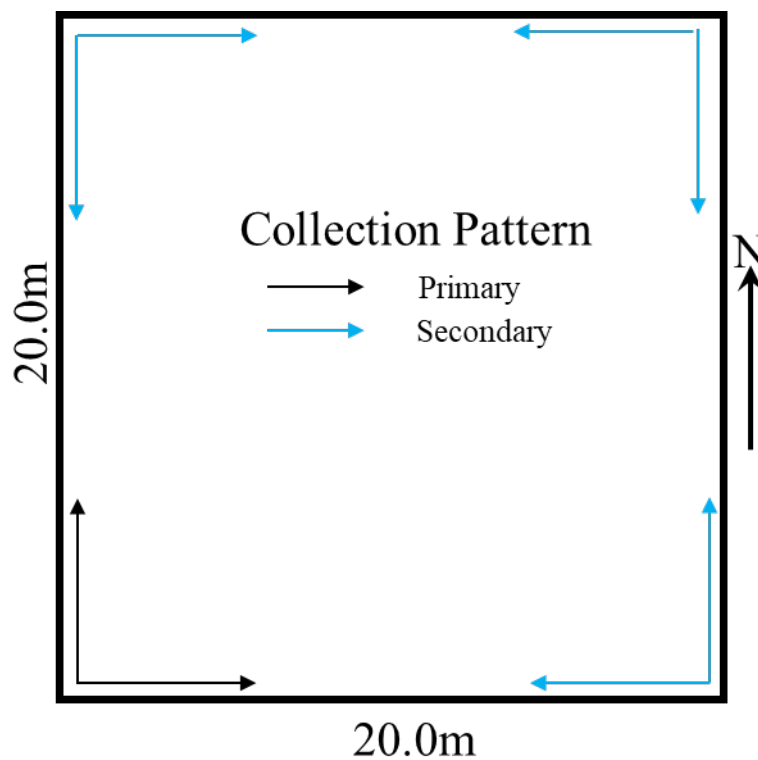


Figure 1

Section 1: Field Collection

21. Make sure the GSSI SIR 4000 datalogger is properly charged and that the operator's phone has been turned to airplane mode or off; radios should be turned off, as well. These devices may have negative affects to the data, especially with specific antenna wave lengths.
22. Prior to data collection, it is important to pay attention to the local weather forecast for the project area and note when the last rain event occurred and how many inches fell, as water greatly effects radar waves. It is best to only collect new data for a site with unknown local soil conditions at least 24 to 36 hours after a significant rain event has

stopped. It is also recommended that the user become familiar with the local soil conditions of the area to be surveyed, as dry sandy soils require very different settings than wet clayey soils. Individuals should consult the United States Department of Agriculture (USDA) Web Soil Map. (<https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx>).

23. Layout of grids does not need to be any particular length, but 20-by-20-meters (m) are often used, especially when gradiometry is being used on the same project. The 20-by-20-m grid size is usually the default operators utilize. A 20-by-20-m grid is recommended for users who are novices and developing their skills. It is a large enough sample size to see anomalies and plausible features, but not too large of a sample to make it difficult to recollect, if issues arise. Once the operator becomes more familiar with the equipment the transects can be expanded to greater lengths, usually around 40 m, but it is recommended that the transect lengths do not exceed 100 m. Transects larger than 100 m create large data files that will likely cause the processing to be slow and the program may crash frequently.
24. Turn on SIR-4000, in the introduction screen make sure the top row icon is in “Expert Mode”, then use the buttons to navigate to “New Project”, and name your project and click “Save”. Then let the radar antenna warm up ~10–15 minutes. While waiting for the antenna to warm up, find a spot to calibrate the antenna and a spot to calibrate the wheel. These may not be in the same location as the wheel calibration requires a somewhat flat area and the antenna calibration requires an area clear of known features, both archaeological and modern (utilities, roads, concrete pathways, etc.).
25. Calibrate the antenna and wheel (see Section 2a & 2b)
26. Collect the data along transects; each transect collected will be saved as its own file. Pay attention to obstructions, and keep extremely good notes, as many mistakes in the field can be corrected, if the notes are organized and complete. They should include who is collecting the data, what equipment is being used, the grid that is being surveyed, the gain setting, the starting direction, where you started from, if both directions are being used, and if the data is being collected mono-directional or bi-directional. Sketch maps are useful to draw the grid and make notes where the first transect started, and if any changes occur during collection. Notes for transects should be organized as follows:

| File# | X-Start | X-End | Y-Start | Y-End | Transect # | Comments |
|-------|---------|-------|---------|-------|------------|----------|
|-------|---------|-------|---------|-------|------------|----------|

Note: Transect # is mostly for breaks in transects, which requires more than one file to complete, it will help the data processing if it is filled out. Grids with no obstructions that break a transect, means that column will have no entries.
27. Position the center of the antenna on the baseline of your grid. The antenna has black lines on it that mark the center.

28. To begin data collection, press the green “Start” button one time.
29. At the end of each profile, press the red “Stop” button one time. You will be prompted to save the file. Before saving the file, reposition your antenna so that it is in place to begin collecting the next profile. Once the antenna is in position, select “Save”.
30. Repeat steps 1–3 until finished with the grid.
31. At the end of your last transect, push, and hold down the red “Stop” button to stop data collection and return to the “Collect Setup” screen. The profile will be saved and can be viewed in “Playback” mode.

Section 2a: Calibration of the Antenna

To calibrate the antenna, it would be best to push the cart around while it is in prospect mode, while the antenna is still warming up. In prospect mode, the antenna will be firing a radar wave into the ground, but no data will be collected. While in this mode, you can push the cart around looking at the soil conditions. Look at the screen for an area that is relatively quiet, a place where only horizontal lines are seen in the datalogging screen, and no large hyperbolas, parabolas, or large stratigraphic transitions are appearing. Once this area is found, it means that area is in a relatively natural state and that is the best place to calibrate the antenna, let the antenna continue to warm up (~10 mins). Many attribute fields will be automatically set based upon the type of antenna being used and thus will not require adjustment. All attribute fields that are changed/adjusted should be recorded in the notes/field book.

1. From the “Setup” menu use the knob to select “Radar”, then scroll down to make sure the “Samples/Scan” are correct, for a 350–500 MHz antenna, the samples should be at least 40/scan, but 50 are recommended. Next scroll down to “Dielectric”, this function will adjust the pulse of the radar in regard to local soil conditions at a scale of 1 to 81 where 1 is air and 81 is salt water. If the operator is familiar with the local soil conditions and comfortable with selecting a number then do so, otherwise the operator can use the “Soil Type” function and the data collector will auto select a number. Once done, back out of the menu.
2. Next from the “Setup” menu use the knob to select “Process”, then scroll down to “Gain Mode”, click “Manual,” and then reselect “Auto”; repeat this process two or three times allowing a minute delay in between. This will allow the antenna to apply gains to the data that reflect the local soil conditions. Leave the “Gain Mode” in the “Auto” position.
3. Next, scroll down to “Edit Gain Curve”. The default is 5 gain points. Use the button to add points 8–10 in total. Use the control knob to select each point and shift the curve (red line) and wiggle (black line) so that it causes the edges of the wiggle to almost touch the two vertical lines, but not go over. Once satisfied with the gain curve, click the button “Save and Exit”, the antenna is calibrated.

Section 2b: Calibration of the Wheel

To calibrate the wheel, find an area that is generally flat where you can lay out a 10-m line tape. It is good to place a marker of some type at the 0.0 and the 10.0-m mark. The operator should know which direction they are facing. The calibration should be recorded in the notes/field book with each calibration attempt label by direction and the number of units/ticks. The 3-wheeled cart system will be in negative numbers, and the 4-wheeled cart system will be positive numbers.

1. In the “System” menu, select “Calibrate SW”; the “Quadrature” should already be selected, and the distance should be 10 m but, if not, select “Quadrature” and punch in 10 m.
2. The default distance is 10 m. The longer the calibration distance, the more accurate the calibration should be, but 10 m is fine to use.
3. Position Antenna on the Start mark. The antenna or system can be positioned anywhere at the start as long as you use the same point on the antenna or system when you stop, but it is recommended that you use the center of the antenna.
4. Press the “Start” button. This is the green “Start” button located on the keypad of the SIR 4000.
5. Move antenna to the Stop mark. This should match the same location on the antenna or system where you started, usually the center of the antenna.
6. Press the “Stop” button. This is the red “Stop” button located on the keypad of the SIR 4000.
7. Write down this number (for the 3-wheeled cart system it should be in the -1785 range)
8. Repeat 3–7 until the numbers begin to be semiregular and an average could be determined, (usually 2 to 3 up and down passes). Once the next number that appears that is within 10 units of the average, stop.
9. Select “Apply” to save the current calibration setting. The wheel has been calibrated.

Section 3: Downloading

1. Turn on SIR 4000 or, if already running, stop all collection and playback functions prior to continuing.
2. Insert USB memory stick into the back of the SIR 4000.

3. Select the mode you used to collect the data (Expert).
4. From either the Introduction or Setup screens, select “Choose Path.” Choose the folder you want to download, use the control button, and select the project folder.
5. Select the files you wish to transfer by using the Control knob to navigate and pressing the Control Knob to select a file. You can select multiple files from the list.
6. To copy the files, select the “Copy to USB” control button. This will copy the selected files to the USB memory stick and maintain a copy on the SIR 4000 internal memory. A progress bar will appear on the screen showing the status of the copied files.
7. To copy the files to the USB memory stick and remove them from the SIR 4000, press the “Move to USB” Command key. A progress bar will appear on the screen showing the status of the copied files. ***Note:*** It is best not to delete the files from the SIR-4000 until the data has been successfully transferred to the processing computer.
8. The field files should be downloaded onto the processing computer, in the RADAN directory. The directory file was created when the program was first downloaded onto the computer, the project file should be placed into the /Documents/RADAN/ProjectFileName. As RADAN likes to work out of this directory. and to avoid excessive crashing. it is highly recommended that this directory is used.

Section 4: Processing in RADAN 7.0

It is recommended that individuals first review the user guide found in the “Help” window (click “Help”, “Index”) to get familiar with much of the various processing functions this program has, but remember this software is made to process several different types of GPR antennas’ datasets. It is likely that many processors will never be used for a 350–500 MHz antenna. The processing of data is site specific, and this manual only details the basic processes that occur most often on GPR datasets. Some sites will require move advanced processing to complete and this manual does not cover those situations.

1. Before RADAN is even turned on, look at the collected radargram files. If a transect/s were broken, errors were made, or different directions were used during the collection of the grid, create subfolders, and label them as such. *Trash*, for radargrams that were collected with known issues, do not delete the files, as they may still be useful. *X-Axis* and *Y-axis*, for radargrams collected in those directions. *Mono* and *Duo*, for areas that maybe collected differently. *Breaks*, for transects that have more than one radargram associated with it. The *Break* folder maybe a sub, subfolder if more than one direction was used; there also may be more than one (example: *Y_Axis/BreakN* and *BreakS* for data collected north-south). When dealing with breaks, only place the extra sections of the transect in the break folder. Leave the starting radargram for that transect in place.

2. Upon opening RADAN, first click "Colors Tables" and select table 11, 12, 17, 28 or 30. Even though there are several other choices, most are not appropriate for archaeological reporting. Usually Grayscale with Red/Blue poles (11) Grayscale (12) and True Gray (17) are the most appropriate, unless other geophysical methods are being used in the same report. Then 28 or 30 should be used.
3. Next click, "Color Xforms" and select either 03, 06 or 07, as these are closest to the linear migration of the color palette being used.
4. Prior to opening any data set from the Source Directory, click "Global Settings", "Source Directory," and path to where the data files are located and click "OK".
5. Click the "GSSI Button" (the big G at the top left corner), "Assemble Data File", "3D File".
6. Choose the location for the 3D Grid file.
7. Enter a filename for the Grid being created and click "Save". Next the "3D Grid Options" window will appear and allow you to place the data files where they belong, mirroring how the transects were gathered in the field.
8. The "Grid Options" window will have many 3D Grid Options: Enter the grid parameters.
 - **3D Filename:** This is the file name created in Step 5 and will automatically be loaded.
 - **Files in X/Y Direction:** Fill in the tabs as appropriate. For some grids data may be collected in both the X and Y Direction so both tabs need to be filled out.
 - **Starting (units):** Both the X and Y Direction start at X = 0 and Y = 0., but if you have multiple grids you might want to put in the grid coordinate of the SW corner of the associated grid.
 - **X-Length/Y-Length:** Is the size of the grid collected in both directions.
 - **# Profile Lines:** The number of transects (ex. 21 individual radargrams (transects) are collected for a standard 20-by-20-m, with 0.5-m spaced transects).
 - **Line Spacing:** This is automatically created by the # Profile Lines and the line length. Use this to check for errors in the input parameters.
 - **Line Order:** Chose where the collecting started and if the transects were collected in a zigzag or mono-directional pattern.
 - **Working Folder:** This is where data are stored. Clicking this button will open a browser to select a different directory. Select the folder for X or Y Direction files depending upon which tab is being filled out.
 - **Auto Load Files:** Check this box to automatically load files from either the X or Y file folder. When all field are completed click "OK"
9. Next the "3-D File Creation" window will appear, this window shows the locations and orientations of the individual transects. Edit individual transects in this view, if necessary.

One can add or delete lines if they were not auto filled in the correct order. This is where one can add additional radargrams to specific transects. Once every radargram is in the correct place, click "OK". RADAN will now create the grid appending all the radargram files together.

10. Once a radargram image appears in the main window, you are ready to begin to process the data. The goal of processing the data is to do the least amount of processing possible to be as close to the raw field data, as possible. The main objective of processing is to remove operator errors and environmental conditions that cloud collected datasets. The first three processes happen to almost all datasets. First, scroll through the radargrams to find one with some type of obvious anomaly, like a large hyperbola to better see how the processes are affecting the dataset.

- Set all start distances to 0.0 m click "Tables", next click the window "Profile" next in the column "Starting Distance" set all start distances to 0.0 m.
- First process: click on "Processes" button, "Time Zero". Then grab the first Positive Peak of the scan trace and adjust it to the top. The peak of the first positive wave will be bisected by the horizontal line at 0.0. Click on "Apply" to test the correction and once satisfied with the result click OK.
- Second process: "Background Removal", noise often seen as horizontal banding, may be removed using a filter. Always perform Time Zero Correction prior to Background Removal. Click on the "Processes" button, "Filter", Background Removal". Click on "Apply" to test the correction and once satisfied with the result click "OK".
- Third process is "Range Gain" Click on "Processes" button, "Gain", "Range Gain". Select Gain Type: Exponential, Enter Number of Points (the same number of Gain Points used in the field, work well to adjust the Time Variable Gain curve). Grab boxes to adjust the gain, the gains maybe be similar as to they were in the field but not necessarily. Click on "Apply" to test the process and "OK" when satisfied with the results. ***Note:*** The overall shape of the gain curve should resemble a pregnant woman or a fat man.

These three processes may be all that is needed to fully process a site's dataset. There are situations where more processing will be required, but this manual does not cover those situations. Please refer to the GSSI manual for more examples of different processes.

11. To see the data in 3D, click the "3D-View" box and it will appear. From the "3D Volume Options" tab, you will be able to shift the horizontal slices to whatever depth desired, as well as have radargrams cutting through the slice.

12. More options for the 3D window are located in the “Window Settings” button on the “Home” tab, just make sure to click on the 3D window once you have shifted to the Home screen.

13. You can export an image by either clicking on the 3D window once you have shifted to the home screen and then click “Copy” and paste the image to PowerPoint, Adobe Illustrator, or some other image manipulation program. You can export individual radargrams if you click the radargram window and then click “Copy” and paste the image. You can export all the radargrams at once if you use “GSSI Button”, “Export”, “Custom Image Export”. Just select in Select Image Window, “Linescan” and in Select Image Size, “Entire File”. All exported files will be in the exported to the processing folder that was auto created when the first process was completed (in the project folder where the data is located).