HULL

Environment / Energy / Infrastructure

August 3, 2018

Mr. David Savage
Open Road Renewables
1105 Navasota Street
Austin, Texas 78702

Re: Groundwater Hydrogeological and Geotechnical Desktop Document Review Summary Report for the Proposed Willowbrook Solar Farm Project Located in Highland County, Ohio; ORR005.0002.

Dear Mr. Savage:

Hull & Associates, Inc. (Hull) is pleased to provide Open Road Renewables, LLC (Client) with this Desktop Document Review of readily available geologic, hydrogeologic, and geotechnical information that was reviewed for the proposed Willowbrook Solar Farm Project located in Highland County and Brown County, Ohio (Project). The Client is pursuing the development of a solar powered electric generation facility that includes construction of associated infrastructure.

For this summary report, the following definitions have been used when describing the project pursuant to the Ohio Power Siting Board's (OPSB's) current Ohio Administrative Code (OAC) rules (Chapter 4906-1-01):

- **Project Area:** "all land within a contiguous geographic boundary that contains the facility, associated setbacks, and properties under lease or agreement that contain any components of the facility" (OAC 4906-1-01(GG)).

- **Facility:** "the proposed major utility facility and all associated facilities" (OAC 4901-1-01(W)).

- The **Study Area:** is defined by Hull to better describe the region both inside and outside of the Project Area that was included during database searches of available public information. The Study Area includes all of Highland County, as well as adjacent counties, whose physical characteristics could globally impact the Project Area (ie: floodplains, faults and geophysical anomalies).

PROJECT APPROACH

The Desktop Document Review was completed to gather the applicable geologic, hydrogeological, and geotechnical information specified in the OPSB's current OAC rules (Chapter 4906-4) concerning certificate applications for electric generation facilities. The information was gathered by completing a literature search of existing and readily available documents related to the hydrogeological and geotechnical conditions of the Study Area. This information was then reviewed to develop a generalized understanding of the suitability of conditions within the Study Area for the proposed construction within the Project Area. The information summarized below was obtained from available on-line databases and/or documents maintained or produced by the following federal, state and local agencies:

1. Federal Emergency Management Agency (FEMA);
2. Ohio Department of Agriculture (ODA);
3. Ohio Department of Natural Resources (ODNR);
4. Ohio Environmental Protection Agency (Ohio EPA);
5. Ohio Department of Transportation District 9 (ODOT);
6. The Ohio State University, Agricultural Extension Office;
7. Office of the Highland County Engineer;
8. Office of the Broun County Engineer;

9. United States Department of Agriculture (USDA) Soil Conservation Service Soil Survey of Highland County; and
10. United States Geological Survey (USGS).

No environmental studies or structural evaluations were performed as part of this scope of work, and therefore no recommendations relative to environmental or structural issues are included in this report.

PROJECT LOCATION

The proposed Project Area consists of approximately 2,034 acres located in Concord, White Oak and Eagle Townships and Highland and Broun Counties, Ohio. The currently proposed Project Area is shown on Figure 1and subsequent figures discussed below.

INFORMATION REVIEW AND ANALYSIS

The following provides a summary of the information reviewed and its applicability to the proposed Project.

<u>Geology and Seismology</u>

The Project Area lies entirely within the Illinoian Till Plain Region of the Till Plains Section of the Central Lowland Physiographic Province. The Illinoian Till Plain Region is characterized as a rolling ground moraine of older till, lacking ice-constructional features (i.e., moraines, kames and eskers). The region has many buried valleys and modern valleys alternating between floodplains and bedrock gorges. Elevations in the region range from 600 to 1100 feet above mean sea level (msl) and the region has moderately low relief; less than 50 feet (Ohio Division of Geological Survey, 1998) locally. The Project Area is relatively flat and has minimal relief features.

The surface topography within the Project Area is the result of ice-deposited ground moraine resulting in a relatively flat surficial topography. The surface deposits are characterized by loess (wind-blown sediment) over thin till on ridge tops and thick colluvium on slopes. The loess, and till deposits are underlain by Ordovician and Silurian-age carbonate rocks and calcareous shales (Ohio Division of Geology, 2005). The area was passed over by Illinoian age glaciers.

The most prominent uppermost bedrock units of the Project Area are the Preacherville Member of the Drakes Formation and the Waynesville and Arnheim Formations (see Figure 2). The Preacherville Member of the Drakes Formation (Oda) is composed of shale, limestone, and dolomite. It is commonly interbedded and exhibits gray to maroon colors in the upper portions of the formation. These rocks typically weather yellowish-gray to light-gray, have thin to thick bedding, and are wavy, irregular, and nodular. The Waynesville Formation is composed of interbedded (70%) shale and (30%) limestone and is approximately 90 to 120 feet thick. The Arnheim Formation is composed of interbedded (60%) shale and (40%) limestone and is approximately 50 to 100 feet thick. Both formations are gray to blue in color and have thin to thick bedding. However, the Arnheim Formation bedding is wavy, irregular, and nodular. Additionally, the Arnheim Formation contains multiple sedimentary cycles of shale and limestone.

Other bedrock units within the Project Area include the Drowning Creek Formation (north-central and southern portions) and the Estill Shale (northeastern and southern portions). The Drowning Creek Formation (Sd) is composed of interbedded limestone and shale. The limestone of this formation typically exudes shades of blue, green, and yellowish-gray and weathers light gray to shades of red. Beds are thin to thick and exhibit planar to nodular features. Fossils are common in the limestone of the Drowning Creek Formation. The shale of the Drowning Creek Formation is greenish-gray to bluish-gray and contains thin, silty beds. The Estill Shale (Se) is composed of shale with minor interbedded dolomite beds. The formation typically exudes a reddish to greenish-gray color and weathers to light gray. It exhibits planar to irregular bedding and contains thin to thick beds. The formation is 30 to 180 feet thick. Diagnostic features include dominance of shale beds and susceptibility to be unstable on slopes and cause landslides.

The bedrock topographic surface is shown on Figure 3. ODNR water well logs indicate bedrock has been encountered during the installation of several domestic water wells in the northern portion of the Project Area at depths ranging between 8 and 28 feet below ground surface (bgs). In the southern portion of the Project Area, bedrock was reportedly encountered at depths ranging between 12 and 20 feet bgs. Based on the inferred bedrock topography within the Project Area, the depth to bedrock appears to vary between approximate depths of 8 and 28 feet.

Information obtained from ODNR, Division of Geological Survey, indicates the Project Area lies in the Ordovician Uplands and Dissected Niagara Escarpment Karst Areas, and that portions of the eastern and southeastern ends of the Project Area lie within probable karst areas. Probable karst areas and known karsts are presented in Figure 4. The Ohio Geological Survey indicates that the Study Area contains carbonate-rich members of the Waynesville and Arnheim Formations that are most prone to karstification. The Ohio Geological Survey also completed mapping and field verifications of karst features and depths of karst depressions within Highland County for the Hillsboro, New Market, New Vienna, and Leesburg Quadrangles (2015) and the Belfast and Sugar Tree Ridge Quadrangles (2016). These in-depth studies produced detailed karst maps of 2-km^2 tiles of the quadrangles and cover portions of the Project Boundary. The studies are presented in Appendix A.

Geologic structural and seismic information were evaluated for the Study Area. Structural features and earthquake epicenters within the region are shown on Figure 5. A review of the information indicated that no epicenters are present within the Project Area. The nearest fault, the W. Hickman Creek-Bryan Station Fault, is located approximately 15 miles south of the Project Area. Additionally, the Serpent Mound Disturbance, the Plum Run Quarry Fault and an un-named fault are located greater than 18 miles east of the Project Area. The Ohio Anomaly is located approximately 45 miles west of the Project Area. Recorded seismic information shows that no earthquake epicenters have occurred within the Project Area, and only two earthquakes have ever originated in Highland County. The closest seismic event to the Project Area was a 2.9-magnitude earthquake that occurred in August of 1881, with an epicenter located approximately 10 miles north of the Project Area. The second nearest seismic event was a 3.6-magnitude earthquake that occurred in February of 1995, with an epicenter located approximately 13 miles east of the Project Area.

Hydrology and Hydrogeology

Surface water flow within the Project Area is generally to the south. The entire Project Area is located within the Ohio River Drainage Basin. Surface water bodies present within the Project Area include several small streams, ditches and ponds. The streams generally flow from the north to the south. The majority of the surface water runoff inside the Project Area flows into Plum Run, located in the west-central portion of the Project Area. This water flows into East Fork White Oak Creek before discharging to White Oak Creek, and eventually recaching the Ohio River. Several small un-named tributaries in the southeastern portion of the Project Area, connect with West Fork Ohio Brush Creek, before discharging into the Ohio River.

Figure 6 was prepared using information obtained from the ODNR and FEMA and shows that there are no 100-year floodplains located inside the Project Area or in the surrounding areas. Several small wetlands and streams registered with the National Wetlands Inventory are located in the western and southeastern portions of the Project Area.

The principal groundwater source within the Project Area is an interbedded limestone and shale aquifer. Groundwater yields seldom exceed three (3) gallons per minute (gpm). Water present in the bedrock usually occurs in the upper few feet of the formation where the strata has been weathered. Domestic wells installed in this formation are commonly pumped dry. Overlying glacial cover that contains sand and gravel will supply limited yields. Sand and gravel formations located along stream valleys may produce up to 10 gpm (Schmidt, 1991).

The Anderson Thin Upland Aquifer overlies the bedrock aquifer for the majority of the Project Area. This aquifer yields less than 3 gpm. The Anderson Complex Aquifer makes up the remaining portion of the Project

Area aquifer, and is located in the eastern and southern portions of the Project Area. The aquifer parallels Sterling Run and yields less than 3 gpm. The aquifer locations are shown on Figure 7.

The Project Area lies within a rural area. Property owners within the Project Area utilize private wells to supply potable water. Locations of these water wells are shown in Figure 7. Water well location information was provided by ODNR, Ohio EPA, and the Highland County Health Department. Additionally, several oil and gas wells are present on properties within the northwestern portion of the Project Area, as shown in Figure 7.

The presence of Source Water Protection Areas (SWPAs) for public water systems within the Project Area was evaluated. SWPAs are areas defined and approved by the Ohio EPA for the purpose of protecting drinking water resources. A study of available resources from the Ohio EPA shows that there are no SWPAs located within the Project Area.

The nearest SWPA is a Corridor Management Zone (CMZ) located approximately 6 miles south of the Project Area at Lake Waynoka. The Waynoka Regional Water and Sewer District operates a community public water system that serves a population of approximately 1,400 people. The primary source of water for the water treatment system is Sycamore Run Reservoir. Lake Waynoka has been used as an emergency water source on at least one occasion. The next closest SWPA is a CMZ located north of Mt. Orab approximately 10 miles west of the Project Area. This CMZ extends 1,000 feet from each bank of Sterling Run. The Mt. Orab Inland Surface Water Protection Area encompasses Sterling Run, which serves as the surface water source for the village of Mt. Orab. From Mt. Orab's surface water intake, Sterling Run is approximately 8.45 miles long and has a drainage area of 18.97 square miles, it flows into White Oak Creek before discharging into the Ohio River.

Environmental regulatory programs within the Ohio EPA, as well as other regulatory agencies such as the Ohio Bureau of Underground Storage Regulations (BUSTR), have adopted regulations that restrict specific activities within SWPAs. These activities include concentrated animal feeding operations, wastewater treatment land application systems, industrial, municipal and residual waste landfills, leaking underground storage tanks (LUSTs) and voluntary action program (VAP) cleanups. The restrictions typically apply to SWPAs relying on groundwater as their drinking water source. Hull has reviewed the range of programs which have adopted rules related to the presence of SWPAs and has concluded that construction of the proposed solar farm facility will not constitute an activity that would be restricted within either a surface water or groundwater SWPA.

Well Survey

Hull mailed a brief survey to the property owners within the Project Area that were under contract with the Client at the time the hydrogeology review commenced in March 2018. A list of names and addresses for the property owners was provided to Hull by the Client. The survey included multiple questions regarding the number, depth, installation date and construction of the wells. Additional information was requested regarding the aquifer type, depth to water and yield of each well. The survey also requested information regarding any problems experienced by the property owners with their wells.

The survey was mailed to nine separate property owners in the Project Area. At the time this Desktop Document Review was completed, Hull had received eight responses to the survey. Copies of the well surveys are attached in Appendix B.

Of the eight survey respondents, one (1) respondent had no wells on their property. Three (3) respondents had one well on their property, while two respondents noted two wells, and two reported three or more wells. The wells provide potable water and irrigation for the residents and several respondents indicated that their wells are no longer used. Four respondents indicated that they were connected to a municipal water supply.

Approximately half of the respondents who indicated that they had a well on their property were able to provide information regarding the well diameter, total depth, and depth to water. One respondent reported a hand-dug well approximately 3 to 4 feet wide and 12 feet deep. Two respondents indicated they have drilled wells, approximately 6" to 8" wide and depths of about 60 feet below ground surface. None of the respondents knew the specific formation their wells were set in. The respondent with the hand-dug well indicated that the well water depth was approximately 8 feet below ground surface.

Respondents were asked on the survey whether they had ever experienced problems with their wells related to the water table being lowered or poor yield. None of the respondents indicated they experienced lowering water tables or poor yield.

Soil Survey

The USDA Soil Conservation Service Soil Survey of Highland County was reviewed (USDA, 1973). Soil surveys furnish surface soil maps and provide general descriptions and potentials of the various soil types to support specific uses, and can be used to compare the suitability of large areas for general land uses. The majority of the surface soils within the Project Area are comprised of the Avonburg Silt Loams (AvA and AvB) covering approximately 30.1% of the Project Area. The Rossmoyne Silt Loams (RpA, RpB, RpB2, and RpC2) cover approximately 27%, the Clermont Silt Loam (Cm) covers approximately 14.6%, and the Atlas Silt Loams (AtB, AtB2, AtC2, and AtC3) cover approximately 10.5 % of the Project Area. The remainder of the Project Area is covered by various silt loams as presented in the soils map, Figure 8.

The soil survey information suggests the Avonburg Silt Loams have slopes ranging from 0 to 2% and 2 to 6% and are somewhat poorly drained soils. The permeability of the soil is moderate in the upper part, and very slow in the lower part. The water capacity is high (10.1 to 10.7 inches) and the depth to the water table is 6 to 18 inches bgs. The Rossmoyne Silt Loams have a 2 to 6% slope and are moderately well drained soils. The permeability of the soil is moderately slow to slow and the available water capacity is medium. The Clermont Silt Loams have a 0 to 1% slope and are poorly drained soils. The permeability of the soil is very slow, the available water capacity is high (11.5 inches) and the depth to the water table is 0 to 6 inches bgs. The Atlas Silt Loams have slopes ranging from 2 to 6% and are somewhat poorly drained soils. The permeability of the soil is very slow and the available water capacity is medium. The soil survey indicates that these soils do not frequently flood, however the Shoals Silt Loam (Sh) and Algiers Silt Loam (Ag), which make up a minor portion of the Site (4.5%), located in drainage pathways, do flood frequently.

Underground and Surface Mines

Information obtained from the ODNR, Division of Geological Survey, and phone discussions with ODOT District 9 and the Highland County Engineer's Office indicated that there is no information available that suggests that underground mines are located within the Project Area. Soil survey information provided by the USDA indicates that there are no surface mine quarries located in the Project Area. However, one surface mine, the Hanson Eagle Quarry, is located approximately 0.5 miles south of the Project Area. Several additional surface mines are located greater than 10 miles away to the north and west of the Project Area. Figure 9 illustrates that no known coal, underground, abandoned or surface mines are located within the Project Area.

PROJECT AREA RECONNAISSANCE

In addition to the desktop study, Hull completed a field reconnaissance on April 18, 2018 at representative points within the Project Area to observe geotechnical-related conditions including topography, surface geologic features, and surface water conditions. The areas within proximity of the Project Area predominantly consist of agricultural fields. In general, the Project Area appears to be nominally drained. Surface water from a recent rain event appeared to be draining towards low lying areas and roadside ditches. Based on phone conversations with ODOT, rockfalls or landslides are not present within the Project Area. Based on a review of the existing topography of the Project Area and the visual observations completed by Hull during the reconnaissance, it is anticipated that the potential for rockfalls and landslides is very low due to the relative flatness of the Project Area. In addition, Hull did not observe sinkholes, depressions, or other evidence of karst topography within the Project Area. Representative photographs from the site reconnaissance are presented in Appendix C to illustrate the general Project Area conditions.

AGENCY INTERVIEWS

Hull contacted ODOT District 9 in order to discuss typical maintenance issues encountered in the area. Dan Nartker, Transportation Administrator for Highland County, indicated that ODOT does not encounter major geotechnical issues and that their work is typically focused on routine maintenance such as resurfacing, vegetation clearing, and ditch cleaning.

Hull contacted the Highland County Engineer's Office and Brown County Engineer's Office regarding their knowledge and experience of previous construction projects, subsurface conditions, and reoccurring maintenance history within the Project Area. Dean Otworth, Highland County Engineer and Todd Cluxton, Brown County Engineer were contacted on several occasions, however did not respond to any of our inquiries.

PRELIMINARY CONSTRUCTION CONSIDERATIONS

Based on our experience with earthwork in the region and our understanding that solar array equipment is lightly loaded; conventional, helical piles are typical for supporting solar modules and resisting wind uplift. However, this assumption will need to be confirmed by a detailed geotechnical exploration and evaluation for each solar array site (e.g., each solar module and associated access road locations). If it is determined that helical piles are not suitable for structural support, extended foundation systems, such as driven H-piles or rammed aggregate pier systems, may be necessary to bear in suitable material or on bedrock. Additionally, other suitable foundation types may be utilized depending on their compatibility with the geotechnical parameters of the specified solar array. The geotechnical engineer, or a designated representative, should examine foundation designs and compatibility with the supporting soils and approve the work prior to placement of foundation components.

Based on the information collected to date, it is anticipated that there will be limited risk associated with construction concerns related to the access roads. Like any preparation work related to access roads, localized subgrade areas may need to be stabilized by undercutting, chemical stabilization, geogrid reinforcement, etc. However, this assumption will need to be confirmed by a detailed geotechnical exploration and evaluation of each access road location.

Adequate surface water run-off drainage should be established at each solar array, access road, and the switchyard location to minimize any increase in the moisture content of the subgrade material. Positive drainage of each solar array site and access road location should be created by gently sloping the surface toward existing or proposed drainage swales. Surface water runoff should be properly controlled and drained away from the work area. It should be noted that the subgrade soils are subject to shrinking and swelling with variation in seasonal moisture content and consideration should be given during constructability reviews to determine how best to deal with potential moisture fluctuations.

The contractors should be prepared to deal with any seepage or surface water that may accumulate in excavations. Site dewatering may be required during construction if excavations extend below the water table, or significant precipitation events occur when the foundation excavations are exposed. The contractor should be able to minimize the amount of excavation exposed at one time, especially when precipitation is forecasted. Fluctuations in the groundwater level may occur seasonally due to variations in rainfall, construction activity, surface runoff, and other factors. Because such variation is anticipated, we recommend that design drawings and specifications accommodate such possibilities and that construction planning be based on the assumption that such variation can occur.

It is understood that the foundations and excavations are to be designed by the Client's structural designer. The contractor should be solely responsible for constructing stable, temporary excavations and should shore, slope, or bench the sides of the excavations as required to maintain stability of both the excavation sides and bottom. All excavations should comply with applicable local, state, and federal safety regulations including the current Occupational Safety and Health Administration (OSHA) Excavation and Trench Safety Standards (29 CFR Part 1926).

As mentioned above, due to the glacial history within the Study Area, the depth to bedrock varies by approximately 8 to 28 feet, resulting in relatively shallow bedrock depths throughout the Project Area as shown in Figure 3. Consequently, foundation considerations may vary depending on the location of each solar array. Based on a review of the soil survey information and our experience with earthwork in the Study Area, the soils should be suitable for grading, compaction, and drainage when each solar array is prepared as discussed in the Geotechnical Engineering Report. These assumptions must be confirmed with geotechnical test borings prior to construction.

Additional considerations relative to site preparation, suitability of fill materials, fill placement and weather limitations are presented in Appendix D for reference. These considerations are provided as general guidelines and may not be applicable to site-specific conditions. The contractor is responsible for selecting and implementing the most appropriate construction techniques (e.g., construction means, methods, sequences or procedures, and safety precautions or programs) for each site-specific condition(s).

SUMMARY

Based on the information reviewed to date and the field reconnaissance, it does not appear that the local geology and/or hydrogeology will be prohibitive regarding construction of the proposed solar modules, access roads, and/or switchyard. Likewise, based on Hull's knowledge of typical solar module foundation construction, it does not appear that the construction of the proposed solar array will have a significant impact on the local geology and/or hydrogeology of the Project Area.

Although the exact location of each potable use well cannot be determined with the information obtained to date, it is assumed that the potable wells are located in close proximity to each property owners' residence. Therefore, based on the information presented herein and the associated analysis, construction of the solar arrays, or other project components, are not anticipated to result in any significant negative impact to the property owners' wells.

Based on the information reviewed and the field reconnaissance, it appears that the primary geotechnical challenges for the solar arrays, access roads and switchyard location that should be considered during construction is variable subsurface conditions (i.e., depth to bedrock and karst) and the need for drainage improvements for the relative flatness and poor drainage characteristics of the surface soils within the Project Area. As previously discussed, adequate surface water drainage should be established at each Project Area, access road and substation location to minimize any increase in the moisture content of the subgrade material. Surface water drainage can be managed by implementing techniques such as surface water swales, drainage berms, etc. Furthermore, foundation system design for each solar array should consider the findings and recommendations of the geotechnical subsurface investigation and laboratory testing.

Site-specific geotechnical information should be obtained by the Client prior to design of the solar array foundations, and prior to preparation of construction specifications and design plans. This may require, but not be limited to, completion of geotechnical explorations to further evaluate the *in-situ* materials at each module. A generalized scope of work template for the geotechnical explorations has been provided in Appendix D which can be used to prepare detailed Requests for Proposals for the solar array.

The conclusions included in this Desktop Document Review are based on general summaries available through the resources previously listed. There may be anomalies in the hydrogeology or geotechnical conditions of a specific Facility that cannot be resolved at the scale of the publicly available data used in this study. As noted previously, site-specific geotechnical information should be obtained prior to final solar array foundation design.

STANDARD OF CARE

Hull has performed its services using that degree of care and skill ordinarily exercised under similar conditions by reputable members of its profession practicing in the same or similar locality at the time of service. No other warranty, expressed or implied, is made or intended by our proposal or by our oral or written reports. The work does not attempt to evaluate past or present compliance with federal, state, or local environmental or land use laws or regulations. Conclusions presented by Hull regarding the area within the Project Area are consistent with the Scope of Work, level of effort specified, and investigative techniques employed. Reports, opinions, letters, and other documents do not evaluate the presence or absence of any condition not specifically analyzed and reported. Hull makes no guarantees regarding the completeness or accuracy of any information obtained from public or private files or information provided by subcontractors.

If you have any questions regarding the summary and conclusions presented in this Desktop Document Review, please do not hesitate to contact either of the undersigned at your convenience.

Sincerely,

Cory E. Schoonover
Project Manager

Shawn D. McGee, P.E.
Geotechnical Practice Leader

REFERENCES

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10. United States Department of Agriculture, Soil Conservation Service, *Soil Survey of Highland County,* 1977.

FIGURES

Notes:
The aerial photo was acquired through the ESRI Imagery web service. Aerial photography dated 2015.

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Open Road Renewables, LLC

Project Area

Highland County, Ohio

Figure 1

Produced using ArcGIS 10.5

File Name: ORR005_01_Fig01_Review.mxd

Edited: 8/3/2018 By: rkaip

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Figure 2

Bedrock Geology

Highland County, Ohio

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Bedrock Topography

Highland County, Ohio

Figure
3

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Figure 4

Karst Features

Highland County, Ohio

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File Name: ORR005_01_Fig04_Karst.mxd

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Structural and
Seismic Features

Highland County, Ohio

Figure
5

File Name: ORR005_01_Fig05_Geophysical.mxd

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Notes:
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Open Road Renewables, LLC

Surface Water, Floodplain, and Wetland Information

Highland County, Ohio

Figure 6

File Name: ORR005_01_Fig06_Eco.mxd

Edited: 8/3/2018 By: rkaip

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Figure 7

Aquifers and Wells

Highland County, Ohio

File Name: ORR005_01_Fig07_Wells.mxd

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Desktop Document Review Summary Report
Proposed Willowbrook Solar Project
Open Road Renewables, LLC

Soil Types

Highland County, Ohio

Figure 8

Produced using ArcGIS 10.5

File Name: ORR005_01_Fig08_Soils.mxd

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Produced using ArcGIS 10.3

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Underground and Suface Mines in Study Area

Highland County, Ohio

Figure 9

File Name: ORR005_01_Fig09_Mines.mxd

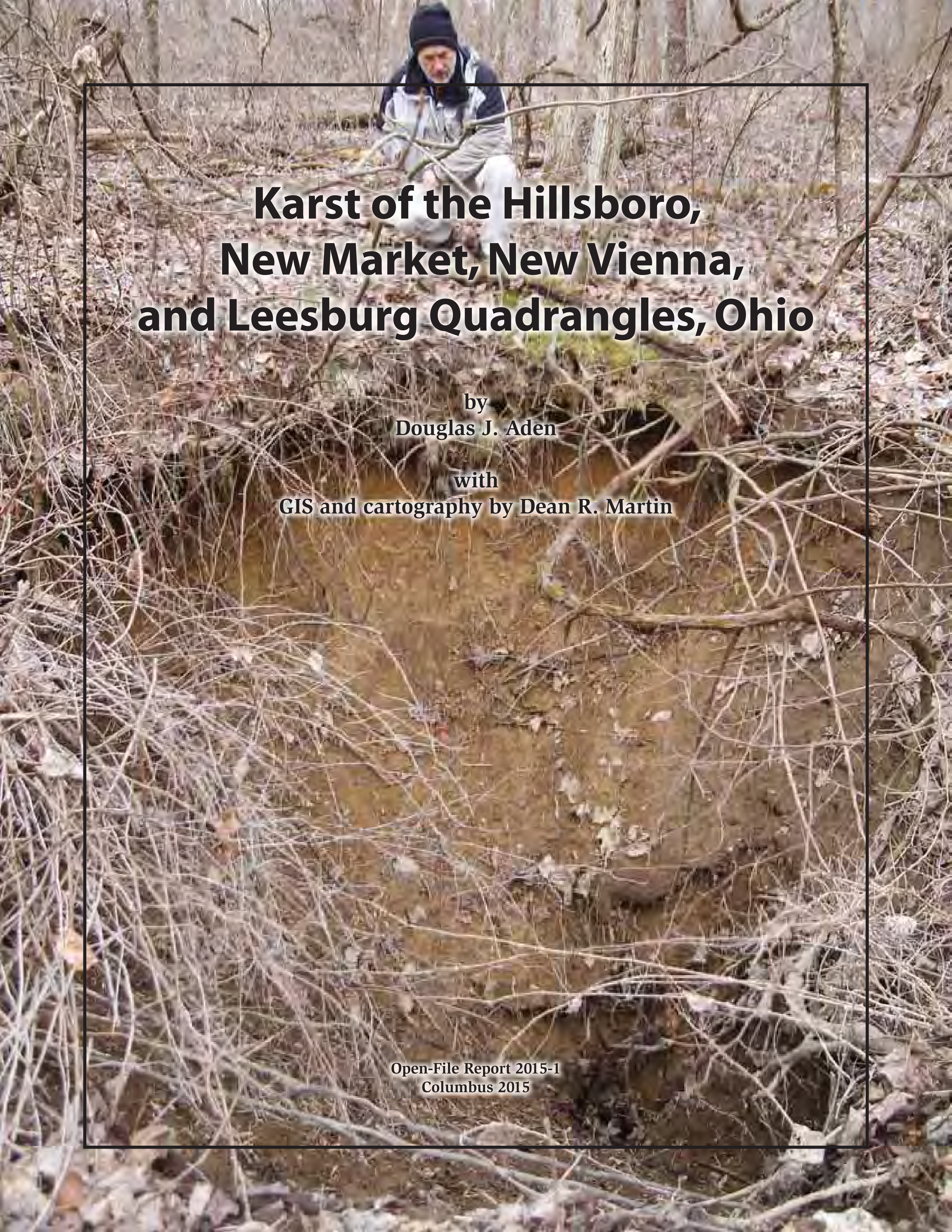
Edited: 8/3/2018 By: rkaip

APPENDIX A

Karst Studies:

Karst of the Hillsboro, New Market, New Vienna, and Leesburg Quadrangles, OH (Aden, 2015)

Karst of the Belfast and Sugar Tree Ridge 7.5-Minute Quadrangles, OH (Aden, 2016)



Karst of the Hillsboro, New Market, New Vienna, and Leesburg Quadrangles, Ohio

by
Douglas J. Aden

with
GIS and cartography by Dean R. Martin

Open-File Report 2015-1
Columbus 2015

DISCLAIMER

The information contained herein has not been reviewed for technical accuracy and conformity with current ODNR Division of Geological Survey standards for published or open-file materials. The ODNR Division of Geological Survey does not guarantee this information to be free from errors, omissions, or inaccuracies and disclaims any responsibility or liability for interpretations or decisions based thereon.

Cover image: At approximately 9 ft deep, this classically funnel-shaped sinkhole shows signs of recent collapse and has an open and active throat at the bottom; it was only 2 ft deep according to 2006 LiDAR data and has grown quickly since. The sinkhole is found within a much larger, older collapse that formed as two separate depressions merged. The larger sinkhole is 8 ft deep, 755 ft long, and 475 ft wide and irregularly shaped. This area is surrounded by trees and other plants, which will slow erosion and reduce further collapse. A large, active spring nearby runs brown with sediment after heavy rains, indicating connections to surface water and likely this sinkhole. An aerial view of this area is found on Tile 157.

Recommended citation: Aden, D.J., 2015, Karst of the Hillsboro, New Market, New Vienna, and Leesburg Quadrangles, Ohio: Columbus, Ohio Department of Natural Resources, Division of Geological Survey Open-File Report 2015-1, 4 p., 71 maps.

Karst of the Hillsboro, New Market, New Vienna, and Leesburg Quadrangles, Ohio

by

Douglas J. Aden, with GIS and cartography by Dean R. Martin

Introduction

Karst terrain forms by dissolution of carbonate rocks, such as limestone or dolomite, or evaporites, such as gypsum or salt, and is characterized by features including sinkholes, disappearing streams, caves, and springs. *Sinkholes* (or *sinks*) are enclosed depressions that do not usually hold water; they often have a "throat" or opening at the bottom where they drain to the subsurface. When a stream flows into a sinkhole, it is known as a *disappearing stream* or *losing stream*. Water flowing into the ground can cause solution enlargement of natural fractures in the rock and eventually can grow into caves. The Ohio Revised Code defines a *cave* as "…a naturally occurring void, cavity, recess, or system of interconnecting passages beneath the surface of the earth or within a cliff or ledge…" (State of Ohio, 1989).

The many passageways formed in karst terrain allow for high connectivity between the land surface and the water table. These passageways permit water to bypass soil and rock layers that filter out contaminants. Consequently, when compounds such as fertilizers, pesticides, and waste enter sinkholes, they are rapidly transported to the water table and quickly pollute water wells, streams, and rivers. When water exits these solutional features, a *spring* is formed. Such springs enable release of these contaminants at the surface.

The different types of karst features may pose infrastructure complications; roads, utilities, houses, and other facilities built in karst areas are at risk of subsidence, collapse, or other damage. In order to provide a reference for future planning on both the local and regional scale, the Ohio Geological Survey has produced this map book identifying the known and suspected karst areas in the vicinity of Hillsboro, Ohio.

Previous Work

Karst areas have been studied in Ohio for many years. During the 1980s and 1990s, karst was researched for the proposed Superconducting Super Collider and was mapped statewide to determine areas suitable for storage of low-level nuclear byproducts. Ohio's preliminary map of karst features (Pavey and others, 1999) was completed in 1997 and released in 1999; it since has been updated with new data in 2003, 2005, and 2007 and will be updated again in the near future.

In the spring of 2008, severe karst-related flooding occurred in Bellevue and led to concern among residents of the area regarding Ohio's geologic hazards (Raab and others, 2009; Pavey and others, 2012). From 2011 to 2012, karst was mapped in the Delaware County region (Aden and others, 2011) and in the Springfield and Donnelsville 7.5-minute quadrangles (Aden, 2012). Next, from fall 2012 to spring 2014 karst was mapped in the Bellevue 7.5-minute quadrangle and parts of the Clyde and Castalia quadrangles (Aden, 2013) and the Fireside, Flat Rock, and the remaining portion of the Clyde quadrangle (Aden, 2014). With the majority of the northern and central karst areas complete, the Ohio Geological Survey shifted focus to southern Ohio. From fall 2014 to spring 2015, karst was mapped in the Hillsboro, New Market, New Vienna, and Leesburg quadrangles.

Methodology

A digital elevation map (DEM), generated from LiDAR (Light Detection and Ranging) data, was used to create a map layer that identified low, enclosed areas. To locate potential sinkholes, these low spots were cross referenced with known karst points, bedrock geology, aerial photography of multiple sources and ages, soil maps, glacial drift thickness maps, and water well logs. Suspect locations were then visited in the field, evaluated, and photographed. Through this process some of the LiDAR-derived depressions were found not to be sinkholes; features such as building foundations, broken field tiles, steep-walled streams, road culverts, and glacial features often produced enclosed areas similar in shape to sinkholes. Many of these misleading features were eliminated remotely using both 6-inches-per-pixel aerial photography and experience from past field verification. However, many points remained that could not be distinguished remotely and these were visited in the field.

Results

The resulting karst feature data set was overlain on four different geologic data sets—the Land Surface, the Bedrock Geology, the Bedrock Topography, and the Drift Thickness maps—to show how the features are related to the local geology. The first of these is the Land Surface map (p. 5), which shows the 173 two-km² tiles and the 7.5-minute quadrangles that form the project area overlain on the DEM of the land surface. The Hillsboro quad was the core project area. However, three adjacent quads - New Market, New Vienna, and Leesburg - were mapped to define the edge of the karst region. The Land Surface map shows that in Hillsboro, sinks are concentrated near the break in slope at the tops of hills and often occur in clusters. One particularly unusual sinkhole was discovered in a cluster of 9 sinkholes—an 8 ft x 8ft square shaft formed in bedrock (exposed at the ground surface) approximately 20 ft deep with an additional 5-ft-deep fracture at bottom, likely indicating the presence of a cave. This sinkhole extends west for about another 10 ft with an additional deep, open collapse in soil. A strong directional trend (as was seen in the previous years' project [Aden, 2014]) was not observed in this project area at the 7.5-minute quadrangle scale; however, karst features do increase in frequency from north to south.

On the Land Surface map, tiles outlined in red contain the karst features identified through this project. No karst was identified in tiles outlined in black. In total, there are 644 karst features, including 42 springs, in 173 tiles. Note that the project area is restricted to the 7.5-minute quadrangle boundaries and not the tile boundaries (especially along the southern border). At the top left of each aerial imagery page (p. 9-74), a Tile Number references the corresponding numbered tile on the four overlay maps.

There are four types of karst features identified on each map:

- Red circles indicate field-verified features, i.e., those that have been visited in the field and confirmed as karst.
- Orange circles indicate sites that were visited but could not be verified at the time, for example a suspicious depression that is flooded or that lacks an active sink throat and cannot be clearly classified.
- Yellow circles represent areas with suspect characteristics, such as a subtle LiDAR depression, a location where access to the property could not be gained, or where there was not enough time to field check the point.
- Blue squares represent springs, where water was found flowing from the subsurface.

The next overlay map is the Bedrock Geology map (p. 6). This map shows that the karst features are forming primarily by dissolution of Silurian-age rocks, namely the Peebles, Lilley, and Bisher Dolomites. In the Hillsboro region, most well-developed karst is expressed as steep-walled, cone-shaped depressions with active sinking and an active sink throat where water drains. It should be noted that according to this map, there are sinks on shale, which indicates that either the shale is very thin and the sinks are forming through it, or the bedrock map needs to be refined. There are also springs located on shale; this is to be expected since water percolating down through vuggy limestone is impeded by shale and moves horizontally until it reaches the land surface.

Four hundred and thirty nine of the 644 karst features are within the Peebles Dolomite, Lilley Formation, and Bisher Formation undivided (**Splb** on the Bedrock Geology map) and 179 are within the Tymochtee Dolomite, Greenfield Dolomite, Peebles Dolomite, Lilley Formation, and Bisher Formation undivided (**St-b**).The 26 remaining points are comprised mostly of springs within the Estill Shale (**Se**) and a few sinkholes in the Greenfield Dolomite (**Sg**). These formations and the others on the Bedrock Geology map are buried in many places by surficial glacial materials. The elevation of the bedrock below the surficial materials is called Bedrock Topography and is shown on page 7. The elevations of the bedrock surface were subtracted from the DEM (p. 5) to create the Drift Thickness map (p. 8). Knowing the drift thickness is useful because where the drift is shallow—about 25 ft or less—sinkholes are commonly expressed. Other sinkholes may exist but were either buried beneath the glacial drift or prevented from forming by thick drift. The Drift Thickness map clearly shows that in the Hillsboro area, the sinkholes are concentrated along areas of thin glacial drift.

Following the four overlay maps are the detailed two-km^2 map tiles (p. 9-74) that contain specific point locations. Also included on these maps are karst depressions represented by yellow to red topographic lines. Each concentric ring represents a one-foot drop in elevation toward the low point of an internally drained area.

Conclusions

Of the 644 mapped karst features, 424 have photos (from multiple angles for interesting features) and 402 appear on the LiDAR-derived sink layer. Many springs were located in this area and are generally found associated with clusters of sinkholes (see tiles 111, 114, 116, 124, 126, 132, 137, 157, 160, 168, and 172). Springs do not typically show up as depressions unless a catch basin was built and subsequently failed, thus many were located during field work by spotting springhouses. The large number of sinks found without LiDAR attests to the need for spending time in the field near known karst areas, looking for new features, and talking to the public. For example, 35 of 88 features in tile 172 and 20 of 45 features in the cluster on tile 160 were not located via the LiDAR. Farmers and other land holders are still one of the best sources of local information, particularly for historical features, such as drained ponds, old mill races, and even sinkholes that have been periodically or historically filled in.

In addition to this map book, a DVD containing the GIS data, metadata, LiDAR depressions, and photographs of many of the features is available. The GIS data contains details such as the location of each point and a brief description of what was found there. The metadata provides information on the sources and quality of the data used in this project. The LiDAR depressions layer records the depths and areas for many of the sinkholes. In addition, the collection of photographs captured for many of these features can be used to monitor the growth of preexisting sinkholes and development of new karst features, as well as assisting in identification. Identification is important because karst regions are highly susceptible to pollution and structures built near them may subside. The maps in this report will allow areas of land development near karst features to be better planned and maintained.

Acknowledgments

This project was funded by the Great Lakes Geologic Mapping Coalition surficial mapping grant program.

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Aden, D.J., 2012, Karst of Springfield, Ohio: Ohio Department of Natural Resources, Division of Geological Survey Open-File Report 2012-2, 3 p., 25 maps, accessible at <http://geosurvey.ohiodnr.gov/portals/geosurvey/PDFs/OpenFileReports/OFR_2012-2.pdf>.

Aden, D.J., 2013 Karst of the Bellevue Quadrangle and portions of the Clyde and Castalia Quadrangles, Ohio: Ohio Department of Natural Resources, Division of Geological Survey Open-File Report 2013-1, 4p., 59 maps, accessible at <http://geosurvey.ohiodnr.gov/portals/geosurvey/PDFs/OpenFileReports/OFR_2013-1.pdf>.

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Aden, D.J., Powers, D.M., Pavey, R.R., Jones, D.M., Martin, D.R., Shrake, D.L., and Angle, M.P., 2011, Karst of the western Delaware County, Ohio, region: Ohio Department of Natural Resources, Division of Geological Survey Open-File Report 2011-4, 2 p., 35 maps, accessible at <http://geosurvey.ohiodnr.gov/portals/geosurvey/PDFs/OpenFileReports/OFR_2011-4.pdf>.

Pavey, R.R., Angle, M.P., Powers, D.M., Swinford, E.M., 2012, Karst flooding in Bellevue, Ohio, and vicinity—2008: Ohio Department of Natural Resources, Division of Geological Survey Map EG-5, scale 1:24,000, accessible at <http://geosurvey.ohiodnr.gov/digital-map-series-pgs/eg-5-map-of-bellevue-ohio-karst-flooding-2008>.

Pavey, R.R., Hull, D.N., Brockman, C.S., Schumacher, G.A., Stith, D.A., Swinford, E.M., Sole, T.L., Vorbau, K.E., Kallini, K.D., Evans, E.E., Slucher, E.R., and Van Horn, R.G., 1999, Known and probable karst in Ohio: Ohio Department of Natural Resources, Division of Geological Survey Map EG-1, scale 1:500,000. [Revised 2002, 2004, 2007.]

Raab, James, Haiker, Bill, Jones, Wayne, Angle, Michael, Pavey, Rick, Swinford, Mac, and Powers, Donovan, 2009, Ground water induced flooding in the Bellevue, Ohio area, spring and summer 2008:

Ohio Department of Natural Resources, Division of Water Technical Report of Investigation 2009-1, 19 p., accessible at <http://geosurvey.ohiodnr.gov/portals/geosurvey/PDFs/Karst/Bellevue_Final_Report.pdf>.

State of Ohio, 1989, Ohio Revised Code 1517.21 Cave definitions, in chap. 1517 of Title 15, Conservation of Natural Resources: State of Ohio, Ohio Revised Code, accessible at <http://codes.ohio.gov/orc/1517.21>.

Further Reading

For more information on karst in Ohio, visit the Ohio Geological Survey website, **OhioGeology.com.** The following resources also provide additional information on karst and its effects in Ohio and beyond.

American Geological Institute

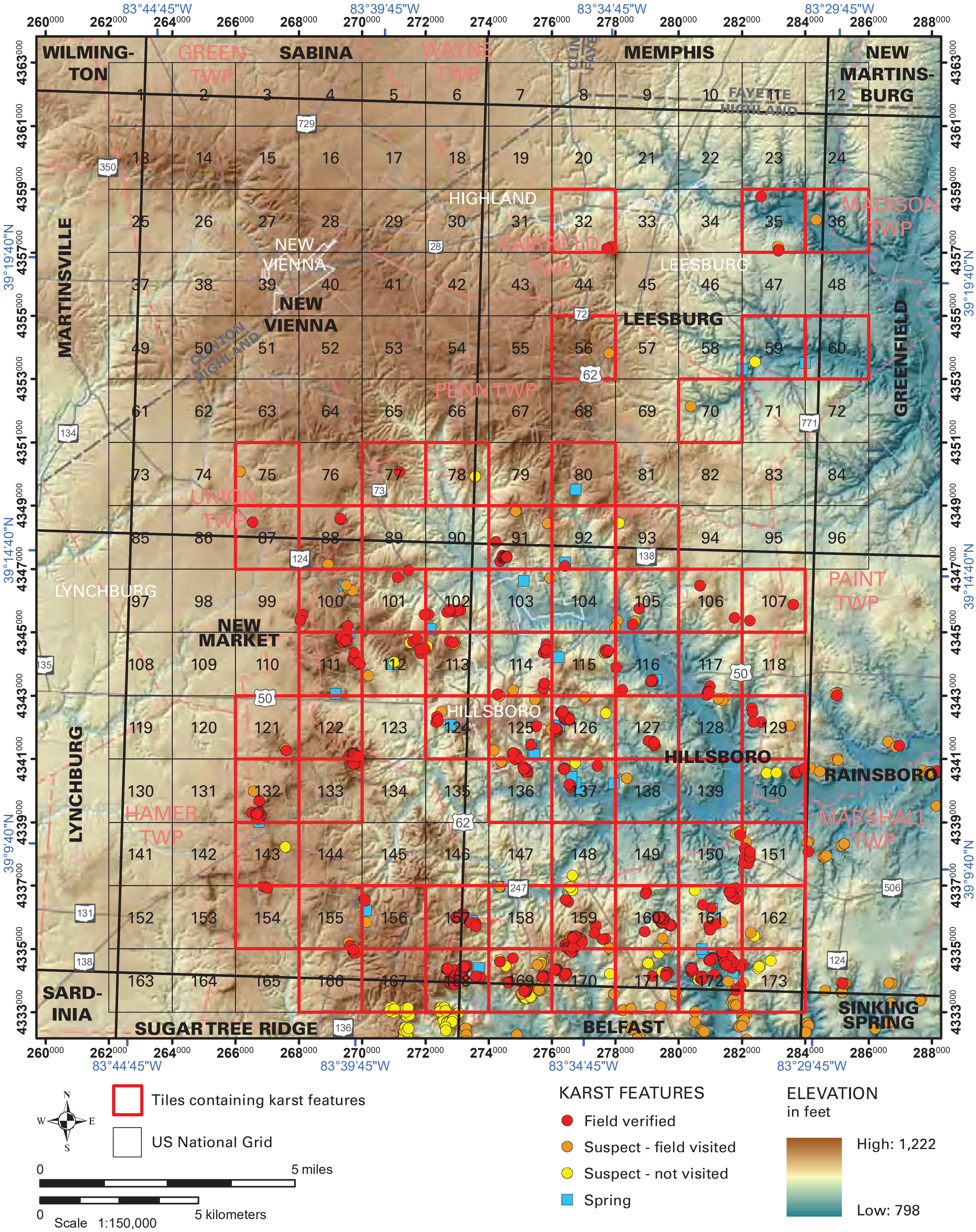
Living with Karst—A Fragile Foundation, AGI Environmental Awareness Series, no. 4, accessible at <http://www.agiweb.org/environment/publications/karst.pdf>.

National Speleological Society

Hobbs, H.H., III, 2009, The Glaciated Central Lowlands—Ohio, *in* Palmer, A.N., and Palmer, M.V., eds., Caves and Karst of the USA: National Speleological Society, p. 136–140.

U.S. Geological Survey

USGS Groundwater Information, Karst and the USGS, accessible at <http://water.usgs.gov/ogw/karst/>.



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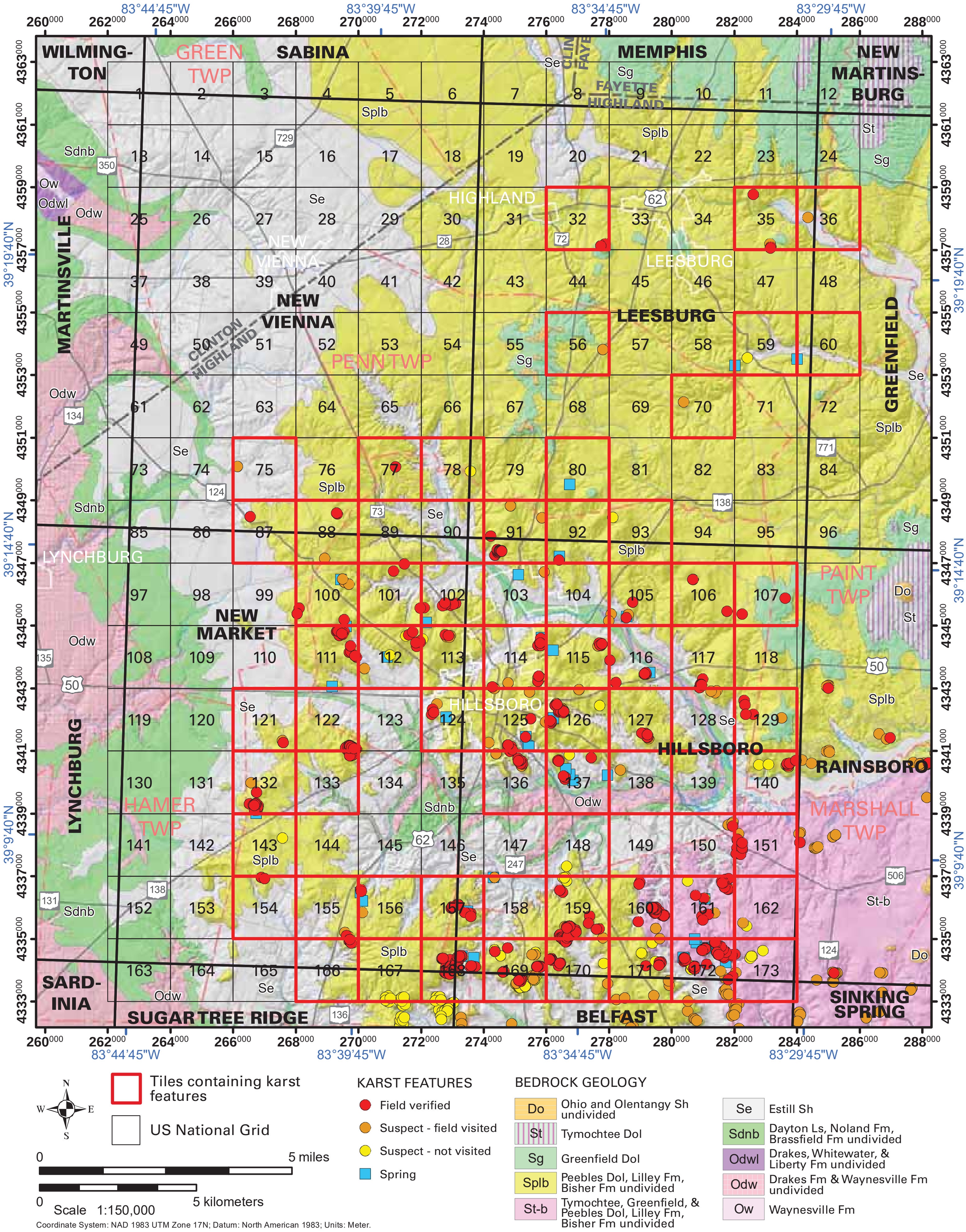
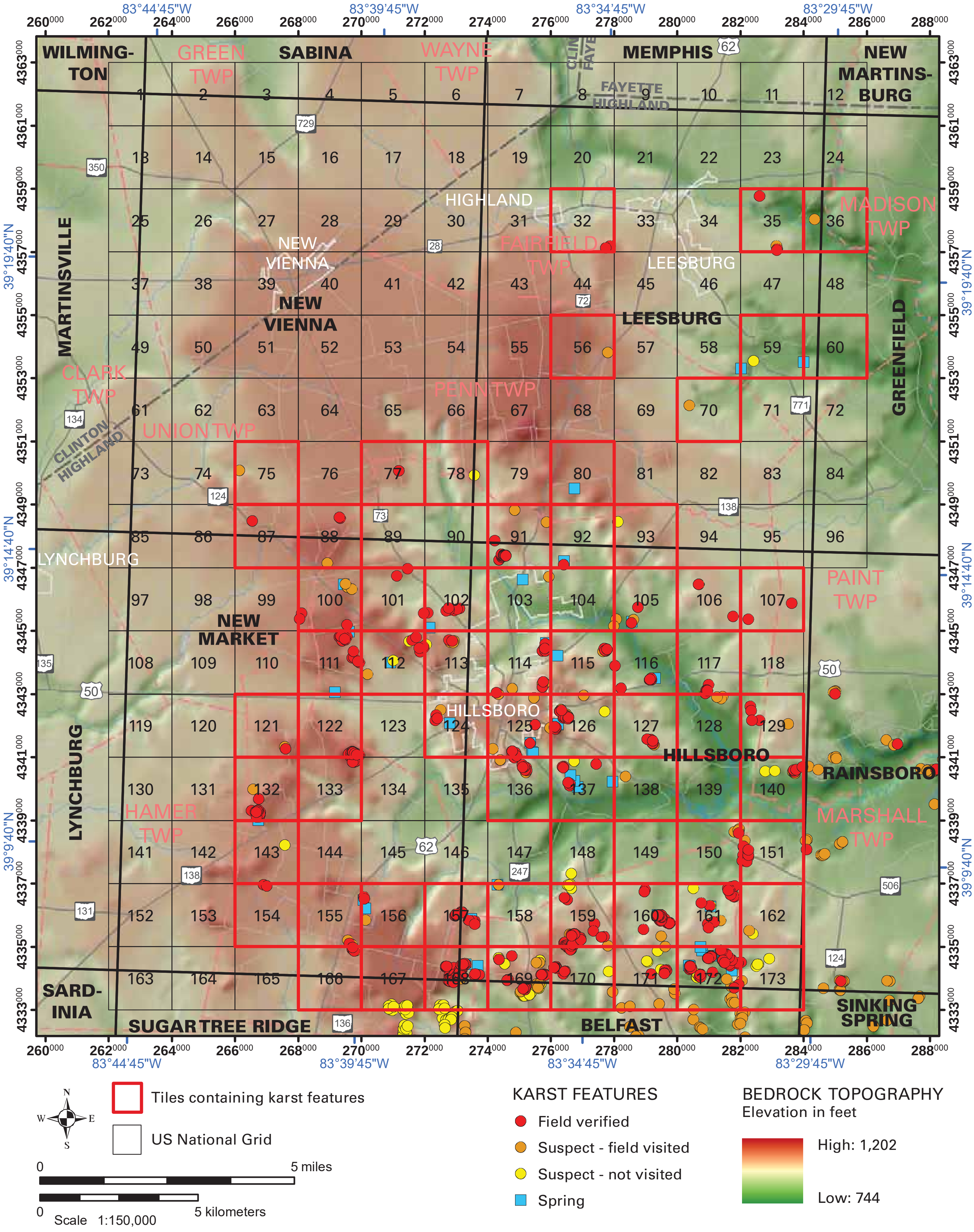
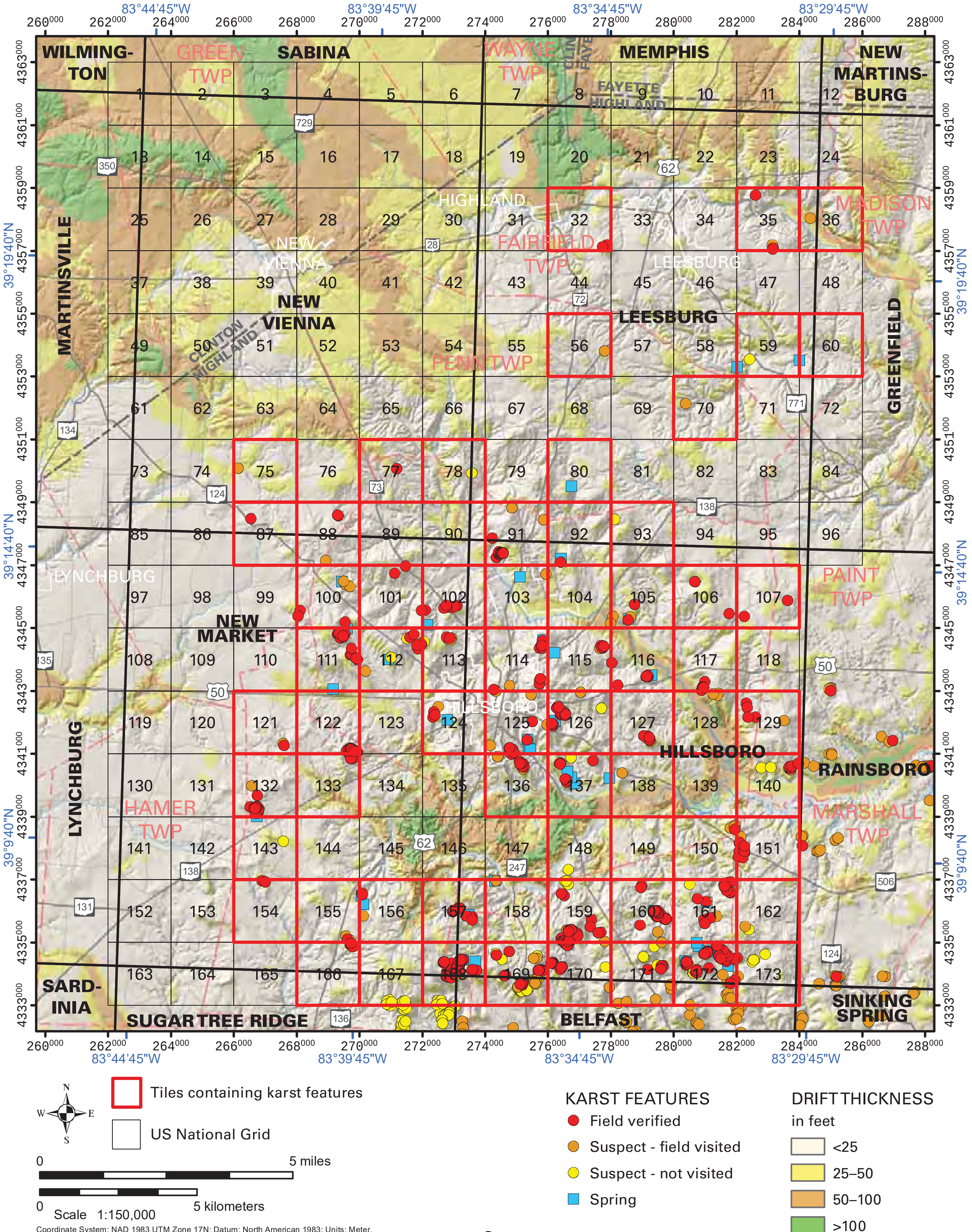


WILMINGTON
GREEN TWP
SABINA
MEMPHIS
FAYETTE HIGHLAND
NEW MARTINSBURG
HIGHLAND
NEW VIENNA
LEESBURG
MARTINSVILLE
CLINTON HIGHLAND
PENN TWP
GREENFIELD
LYNCHBURG
NEW MARKET
PAINT TWP
HILLSBORO
RAINSBORO
HAMER TWP
MARSHALL TWP
SARDINIA
SUGARTREE RIDGE
BELFAST
SINKING SPRING
83°44'45"W
83°39'45"W
83°34'45"W
83°29'45"W
39°19'40"N
39°14'40"N
39°9'40"N
Tiles containing karst features
US National Grid
0
5 miles
0
5 kilometers
Scale 1:150,000
Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.
KARST FEATURES
Field verified
Suspect - field visited
Suspect - not visited
Spring
BEDROCK GEOLOGY
Do Ohio and Olentangy Sh undivided
St Tymochtee Dol
Sg Greenfield Dol
Splb Peebles Dol, Lilley Fm, Bisher Fm undivided
St-b Tymochtee, Greenfield, & Peebles Dol, Lilley Fm, Bisher Fm undivided
Se Estill Sh
Sdnb Dayton Ls, Noland Fm, Brassfield Fm undivided
Odwl Drakes, Whitewater, & Liberty Fm undivided
Odw Drakes Fm & Waynesville Fm undivided
Ow Waynesville Fm


83°44'45"W
83°39'45"W
83°34'45"W
83°29'45"W
39°19'40"N
39°14'40"N
39°9'40"N
WILMINGTON
GREEN TWP
SABINA
WAYNE TWP
MEMPHIS
NEW MARTINSBURG
FAYETTE HIGHLAND
HIGHLAND
NEW VIENNA
FAIRFIELD TWP
LEESBURG
MADISON TWP
MARTINSVILLE
GREENFIELD
CLARK TWP
UNION TWP
PENN TWP
CLINTON HIGHLAND
LYNCHBURG
PAINT TWP
NEW MARKET
HILLSBORO
RAINSBORO
HAMER TWP
MARSHALL TWP
SARDINIA
SUGAR TREE RIDGE
BELFAST
SINKING SPRING
Tiles containing karst features
US National Grid
0
5 miles
0
5 kilometers
Scale 1:150,000
Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.
KARST FEATURES
Field verified
Suspect - field visited
Suspect - not visited
Spring
BEDROCK TOPOGRAPHY
Elevation in feet
High: 1,202
Low: 744


83°44'45"W
83°39'45"W
83°34'45"W
83°29'45"W
39°19'40"N
39°14'40"N
39°9'40"N
WILMINGTON
GREEN TWP
SABINA
WAYNE TWP
MEMPHIS
FAYETTE
HIGHLAND
NEW MARTINSBURG
HIGHLAND
FAIRFIELD TWP
MADISON TWP
NEW VIENNA
LEESBURG
MARTINSVILLE
CLINTON
HIGHLAND
PENN TWP
GREENFIELD
LYNCHBURG
PAINT TWP
NEW MARKET
HILLSBORO
RAINSBORO
HAMER TWP
MARSHALL TWP
SARDINIA
SUGARTREE RIDGE
BELFAST
SINKING SPRING
Tiles containing karst features
US National Grid
0
5 miles
0
5 kilometers
Scale 1:150,000
Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.
KARST FEATURES
Field verified
Suspect - field visited
Suspect - not visited
Spring
DRIFT THICKNESS
in feet
<25
25–50
50–100
>100

Tile Number: 32

US National Grid

100,000-m Square ID KD

Grid Zone Designation 17S

0 0.5 miles

0 0.5 kilometers

Scale 1:12,000

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

N W E S

KARST FEATURES
- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

DEPRESSION
Depth in feet
1 2 3 4 5 6 7 8 9 10

Tile Number: 35

US National Grid

100,000-m Square ID	Grid Zone Designation
KD	17S

0 — 0.5 miles

0 — 0.5 kilometers

Scale 1:12,000

N W E S

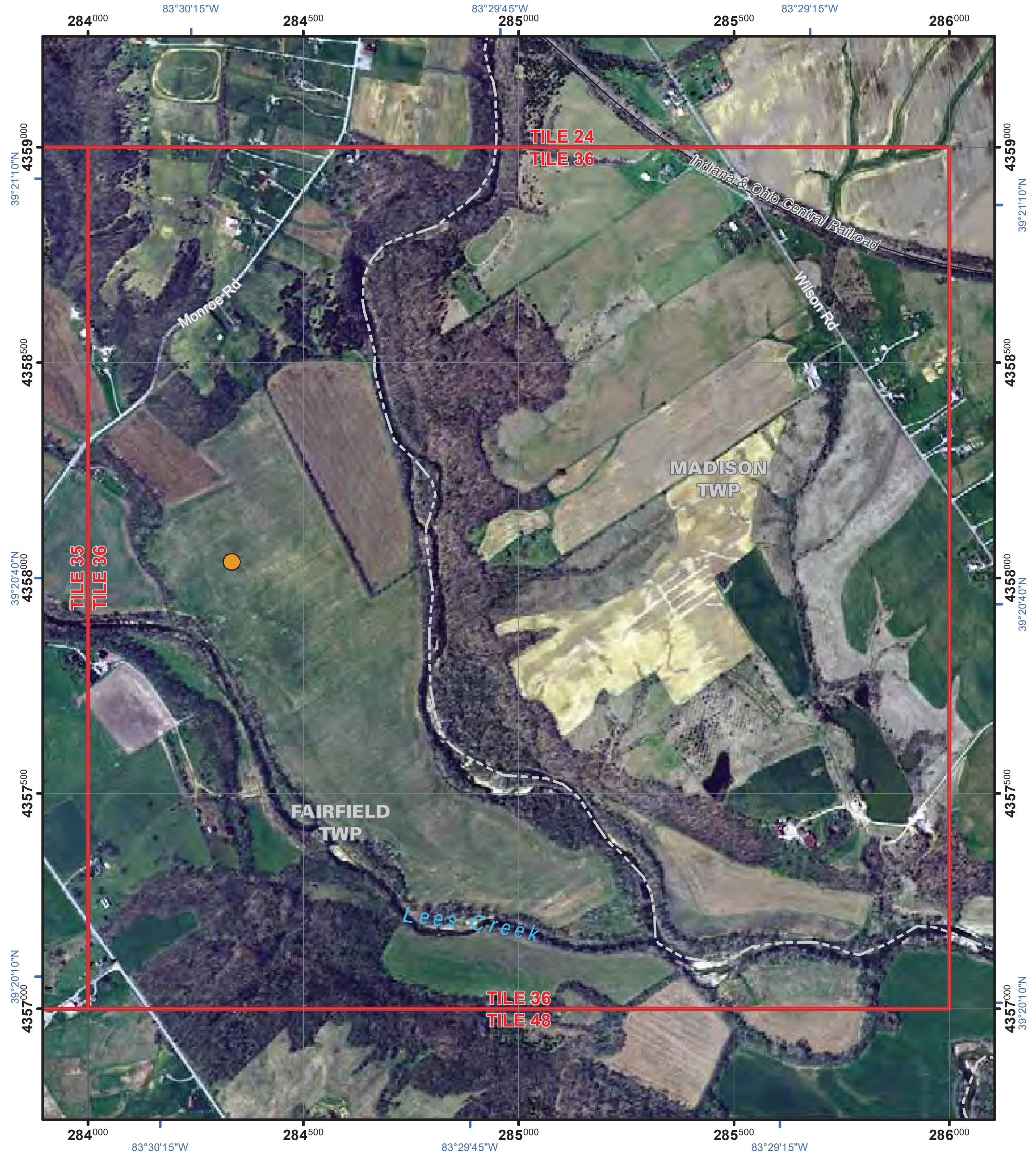
Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

KARST FEATURES
- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

DEPRESSION
Depth in feet

1, 2, 3, 4, 5, 6, 7, 8, 9, 10

Tile Number: 36



US National Grid

100,000-m Square ID: KD

Grid Zone Designation: 17S

0 — 0.5 miles

0 — 0.5 kilometers

Scale 1:12,000

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

N E S W

KARST FEATURES

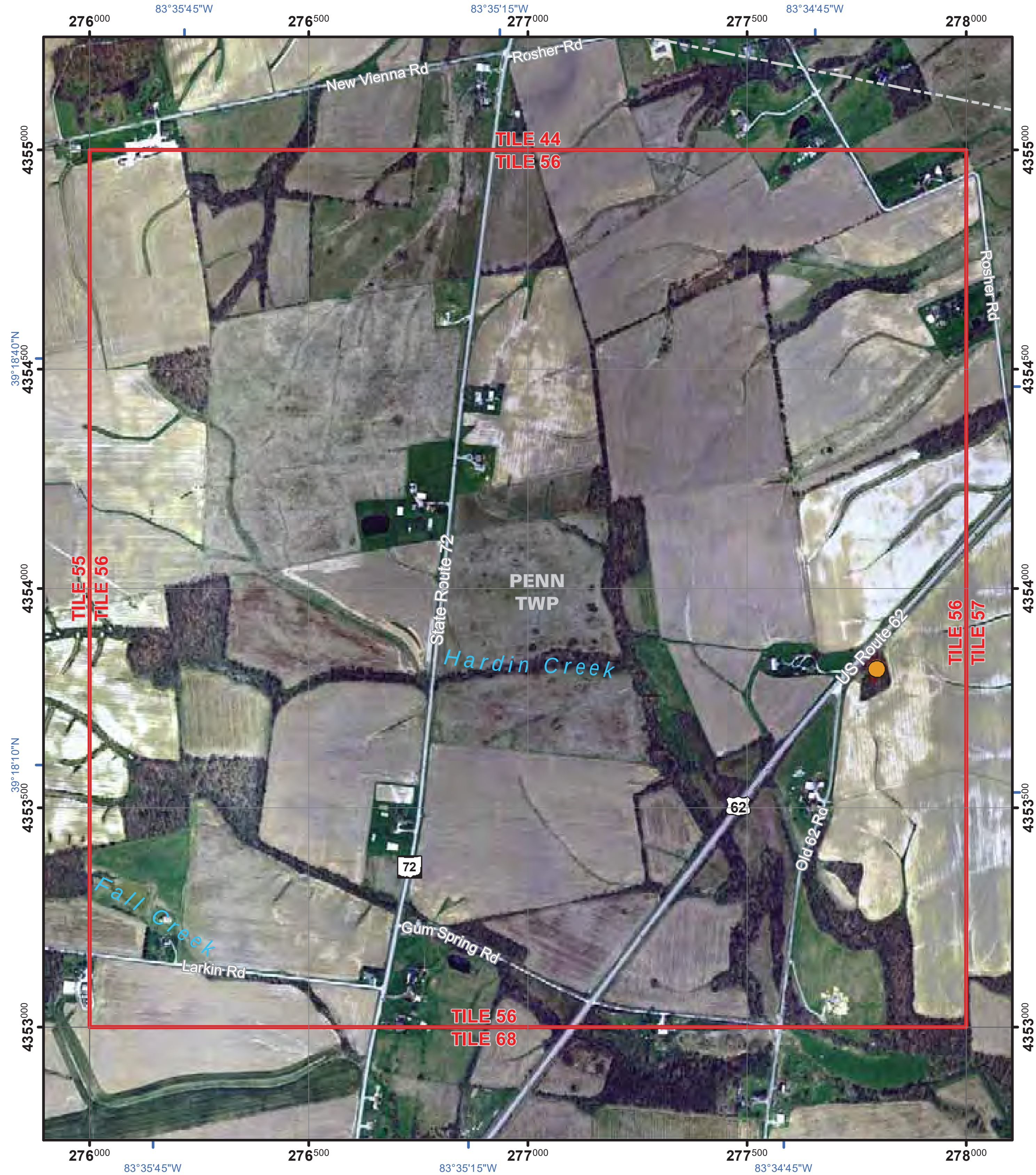
- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

DEPRESSION

Depth in feet

1 2 3 4 5 6 7 8 9 10

Tile Number: 56



US National Grid

100,000-m Square ID: KD

Grid Zone Designation: 17S

0 — 0.5 miles

0 — 0.5 kilometers

Scale 1:12,000

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

KARST FEATURES

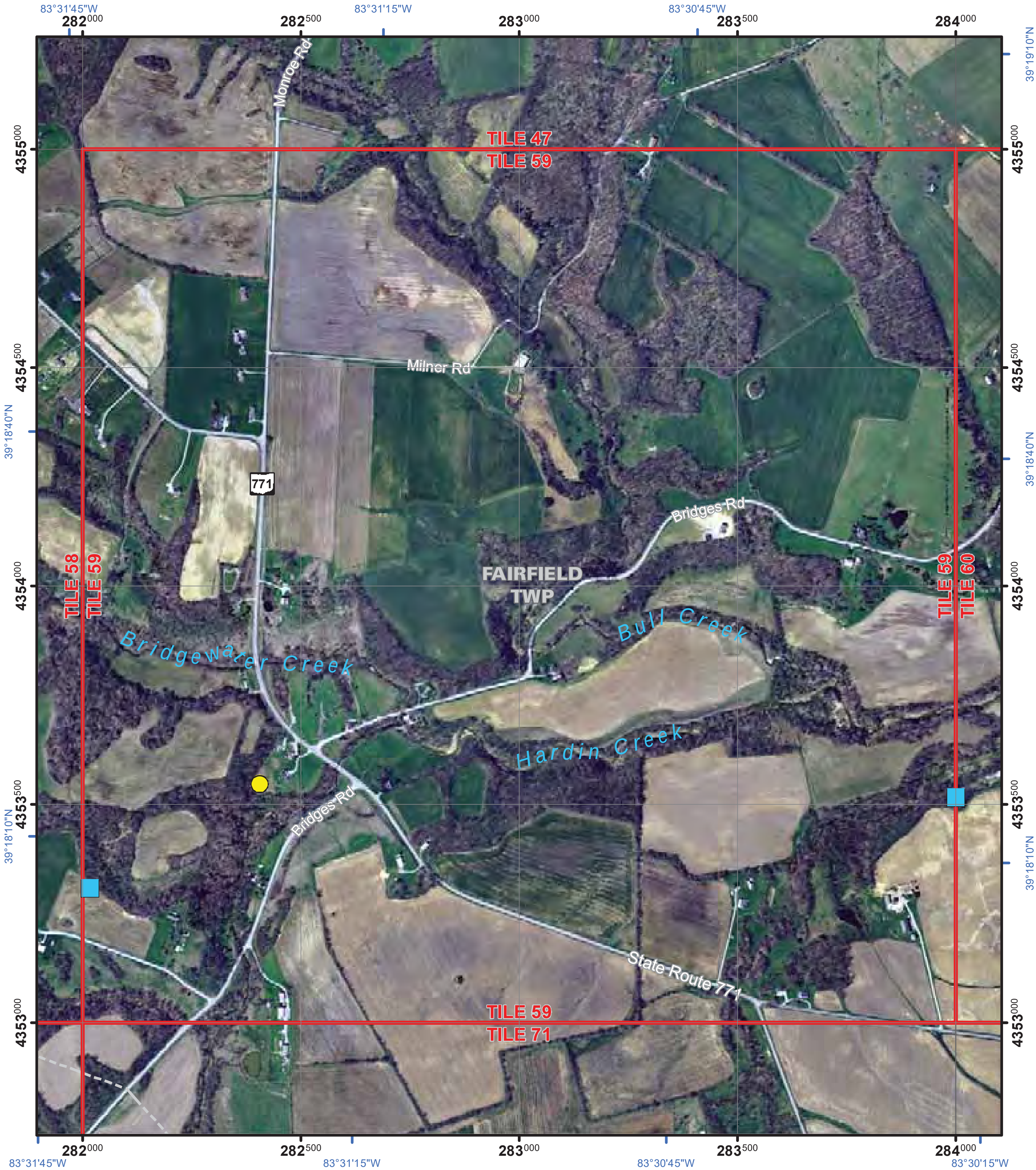
- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

DEPRESSION

Depth in feet

1, 2, 3, 4, 5, 6, 7, 8, 9, 10

Tile Number: 59



US National Grid

100,000-m Square ID: KD

Grid Zone Designation: 17S

0 — 0.5 miles

0 — 0.5 kilometers

Scale 1:12,000

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

KARST FEATURES

- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

DEPRESSION

Depth in feet

1, 2, 3, 4, 5, 6, 7, 8, 9, 10

Tile Number: 60

US National Grid

100,000-m Square ID: KD

Grid Zone Designation: 17S

0 — 0.5 miles

0 — 0.5 kilometers

Scale 1:12,000

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

N E S W

KARST FEATURES

- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

DEPRESSION

Depth in feet

1, 2, 3, 4, 5, 6, 7, 8, 9, 10

Tile Number: 70

US National Grid

100,000-m Square ID	Grid Zone Designation
KD	17S

0 0.5 miles

0 0.5 kilometers

Scale 1:12,000

N W E S

KARST FEATURES

- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

DEPRESSION
Depth in feet

1 2 3 4 5 6 7 8 9 10

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

Tile Number: 75

US National Grid

100,000-m Square ID: KD

Grid Zone Designation: 17S

0 — 0.5 miles

0 — 0.5 kilometers

Scale 1:12,000

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

N / W / E / S

KARST FEATURES

- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

DEPRESSION

Depth in feet

1, 2, 3, 4, 5, 6, 7, 8, 9, 10

Tile Number: 77

US National Grid

100,000-m Square ID: KD

Grid Zone Designation: 17S

0 — 0.5 miles

0 — 0.5 kilometers

Scale 1:12,000

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

KARST FEATURES

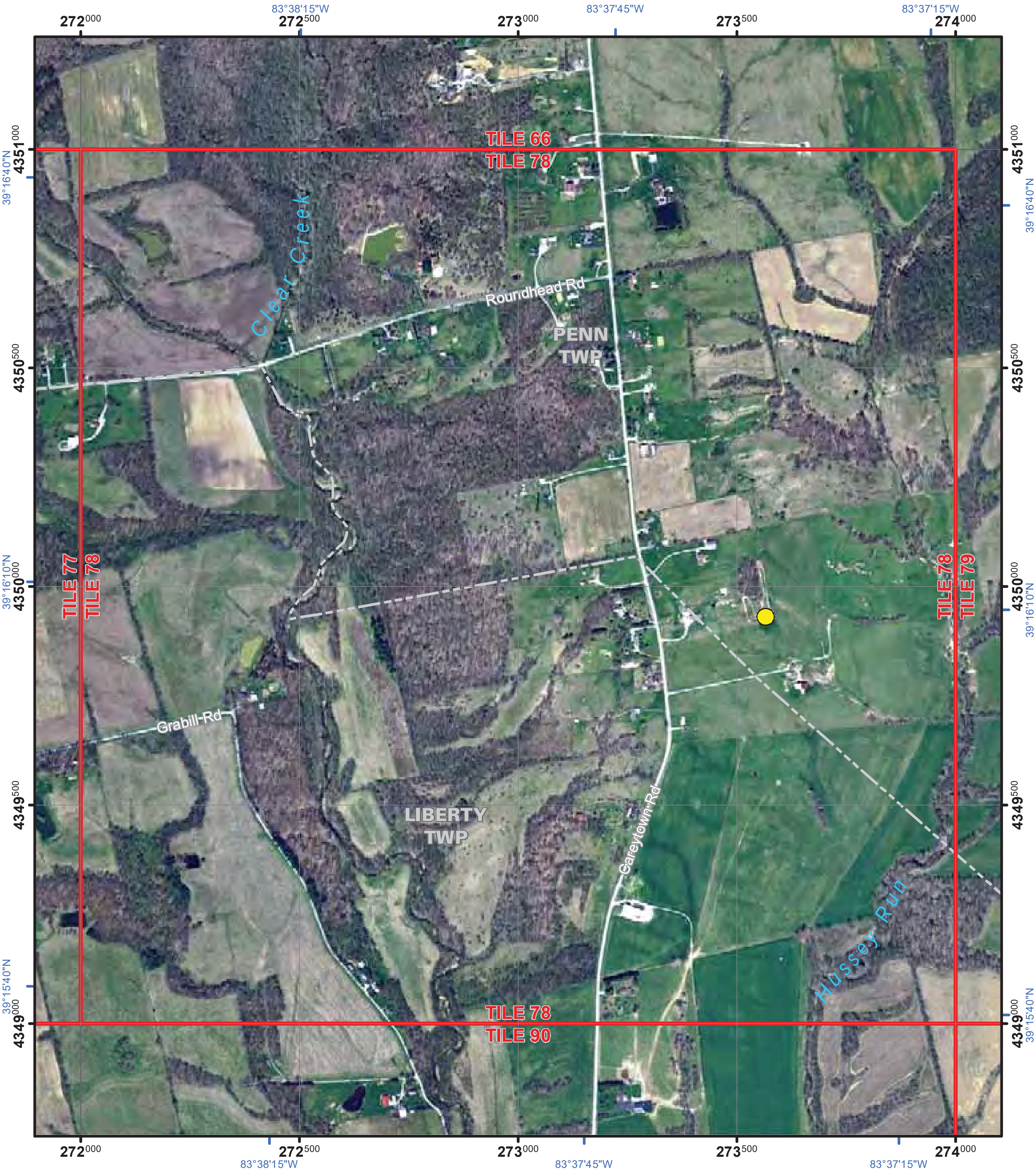
- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

DEPRESSION

Depth in feet

1, 2, 3, 4, 5, 6, 7, 8, 9, 10

Tile Number: 78



US National Grid

100,000-m Square ID KD

Grid Zone Designation 17S

0 0.5 miles

0 0.5 kilometers

Scale 1:12,000

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

N W E S

KARST FEATURES

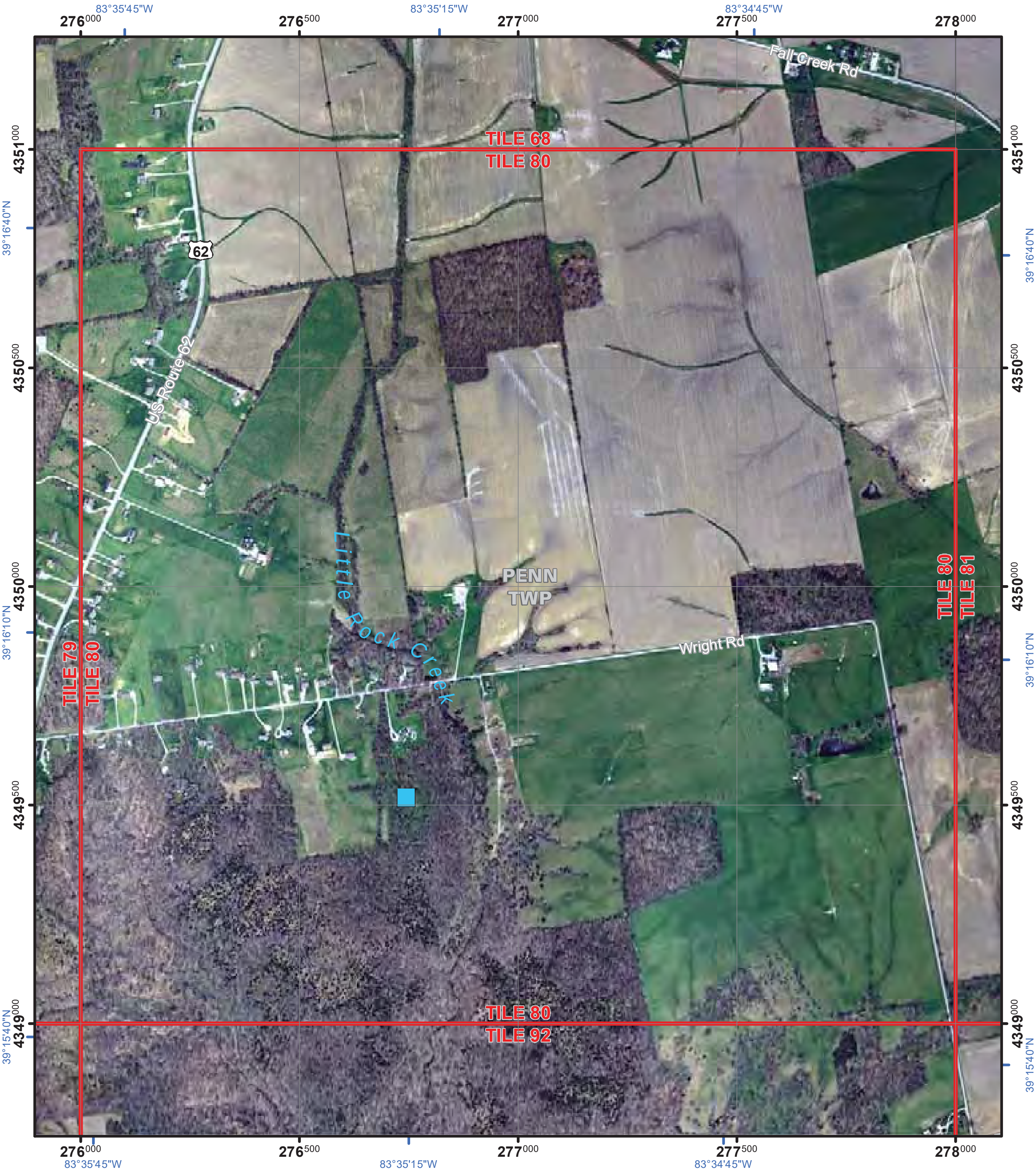
- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

DEPRESSION

Depth in feet

1 2 3 4 5 6 7 8 9 10

Tile Number: 80



US National Grid

100,000-m Square ID KD

Grid Zone Designation 17S

0 0.5 miles

0 0.5 kilometers

Scale 1:12,000

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

KARST FEATURES

- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

DEPRESSION

Depth in feet

1 2 3 4 5 6 7 8 9 10

Tile Number: 87

US National Grid

100,000-m Square ID	Grid Zone Designation
KD	17S

0 0.5 miles

0 0.5 kilometers

Scale 1:12,000

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

N W E S

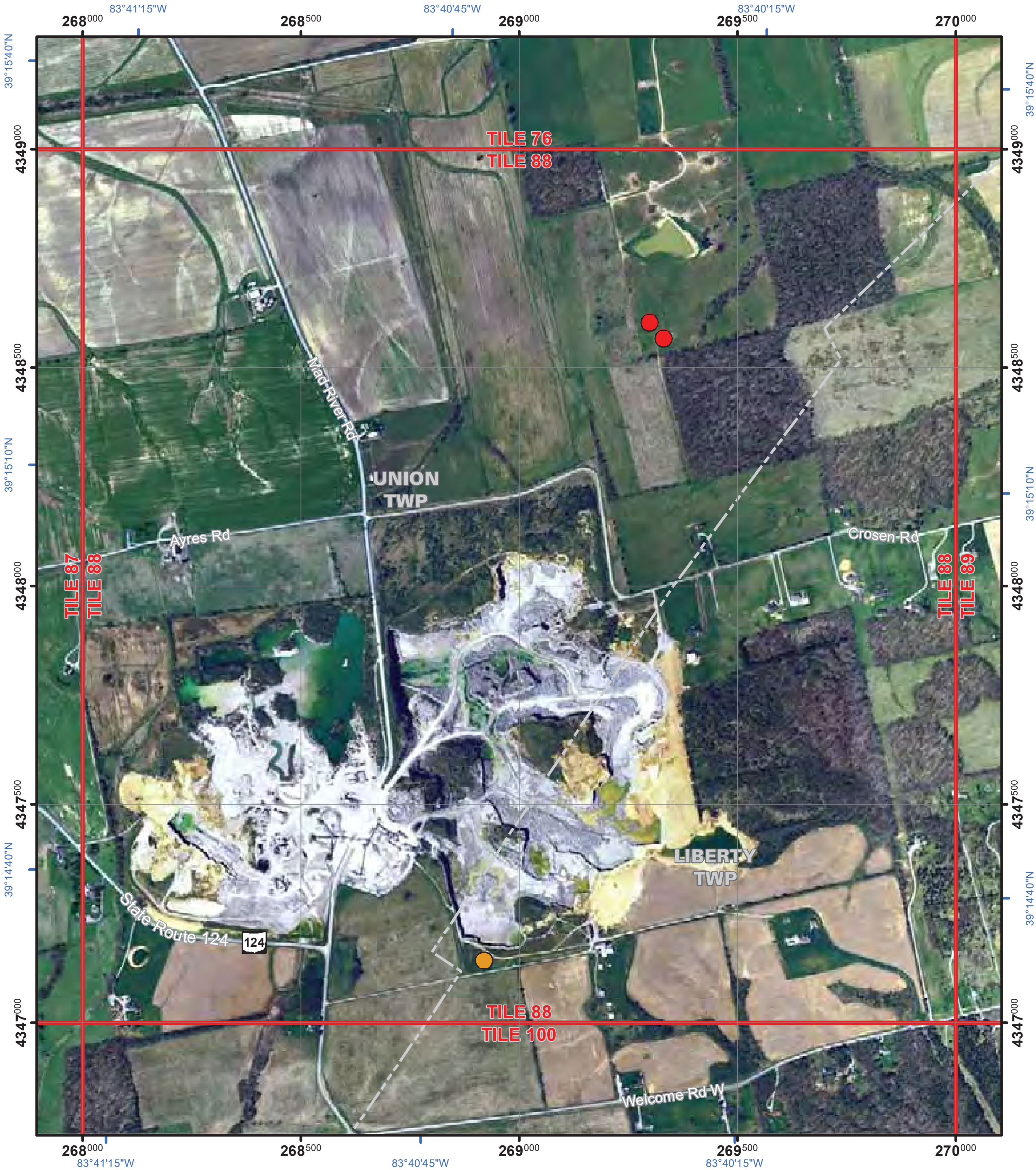
KARST FEATURES

- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

DEPRESSION
Depth in feet

1 5 9
2 6 10
3 7
4 8

Tile Number: 88



US National Grid

100,000-m Square ID: KD

Grid Zone Designation: 17S

0 — 0.5 miles

0 — 0.5 kilometers

Scale 1:12,000

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

N / E / S / W

KARST FEATURES

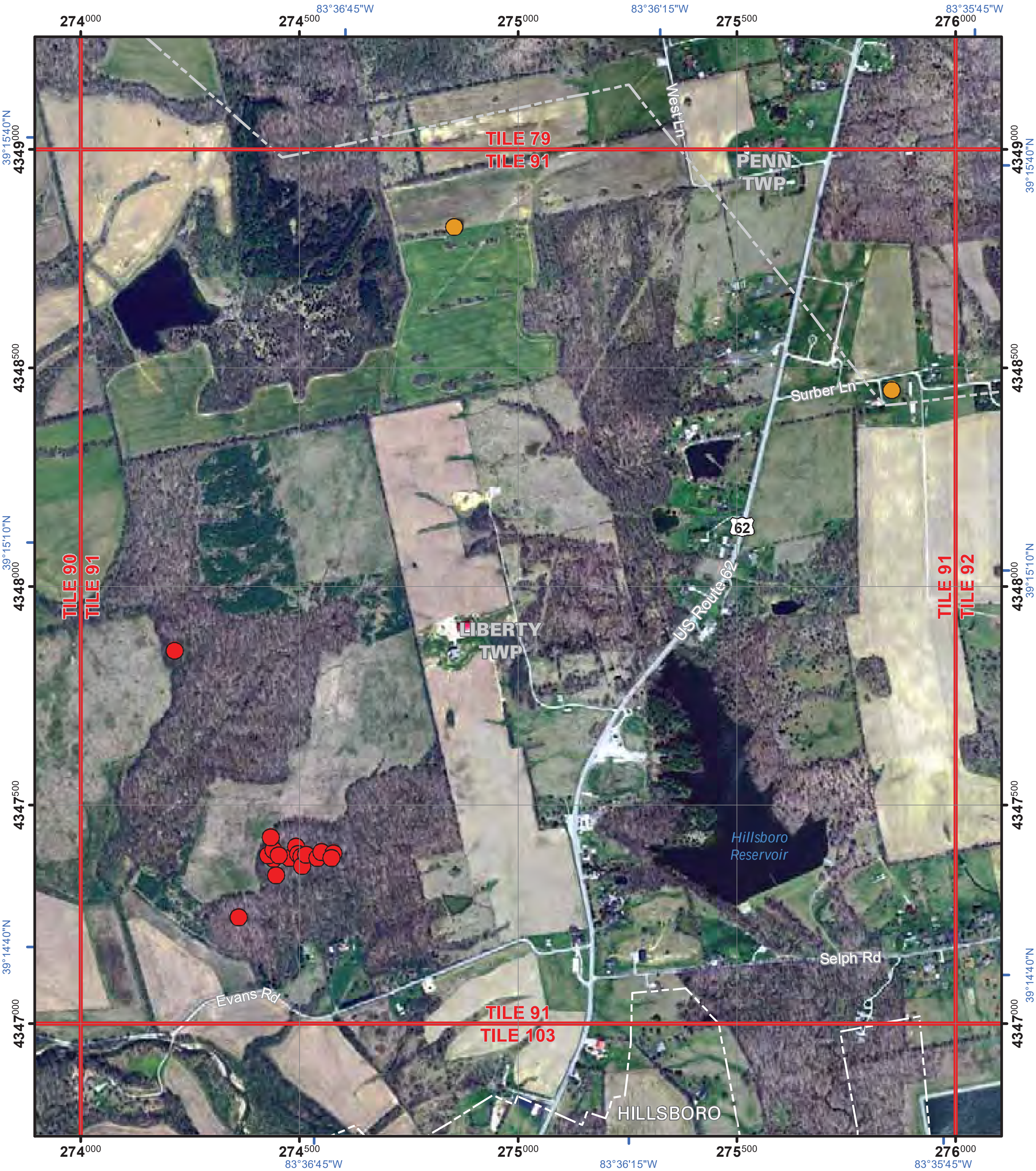
- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

DEPRESSION

Depth in feet

1, 2, 3, 4, 5, 6, 7, 8, 9, 10

Tile Number: 91



US National Grid

100,000-m Square ID: KD

Grid Zone Designation: 17S

0 — 0.5 miles

0 — 0.5 kilometers

Scale 1:12,000

N / E / S / W

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

KARST FEATURES

- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

DEPRESSION

Depth in feet

1, 2, 3, 4, 5, 6, 7, 8, 9, 10

Tile Number: 92

US National Grid

100,000-m Square ID	Grid Zone Designation
KD	17S

0 0.5 miles

0 0.5 kilometers

Scale 1:12,000

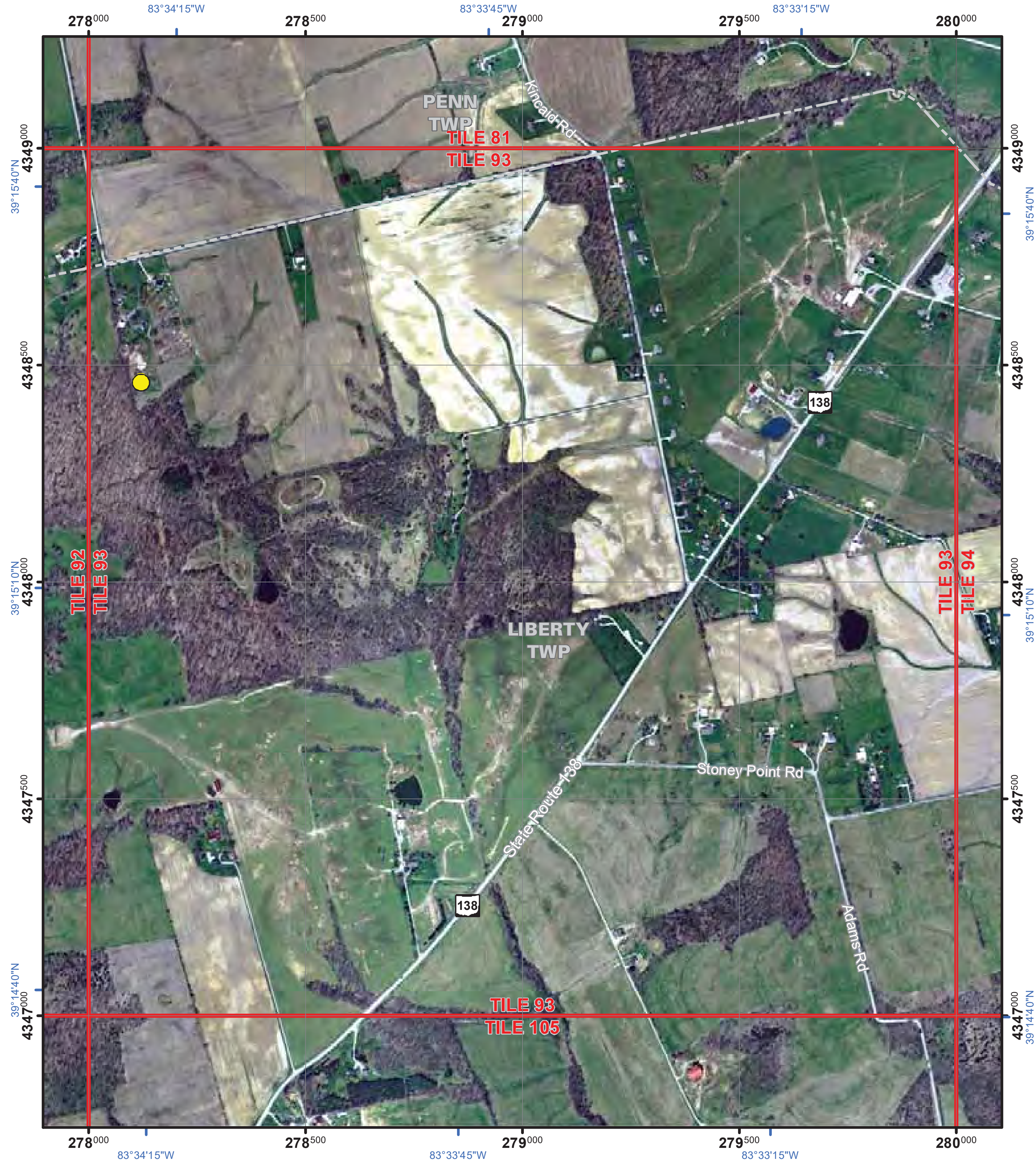
Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

N E S W

KARST FEATURES
- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

DEPRESSION
Depth in feet
1, 2, 3, 4, 5, 6, 7, 8, 9, 10

Tile Number: 93



US National Grid

100,000-m Square ID	Grid Zone Designation
KD	17S

0 — 0.5 miles

0 — 0.5 kilometers

Scale 1:12,000

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

N W E S

KARST FEATURES

- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

DEPRESSION
Depth in feet

1, 2, 3, 4, 5, 6, 7, 8, 9, 10

Tile Number: 100

US National Grid

100,000-m Square ID KD

Grid Zone Designation 17S

0 — 0.5 miles

0 — 0.5 kilometers

Scale 1:12,000

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

N W E S

KARST FEATURES

- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

DEPRESSION

Depth in feet

1 2 3 4 5 6 7 8 9 10

Tile Number: 101

US National Grid

100,000-m Square ID: KD

Grid Zone Designation: 17S

0 — 0.5 miles

0 — 0.5 kilometers

Scale 1:12,000

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

N / W / E / S

KARST FEATURES

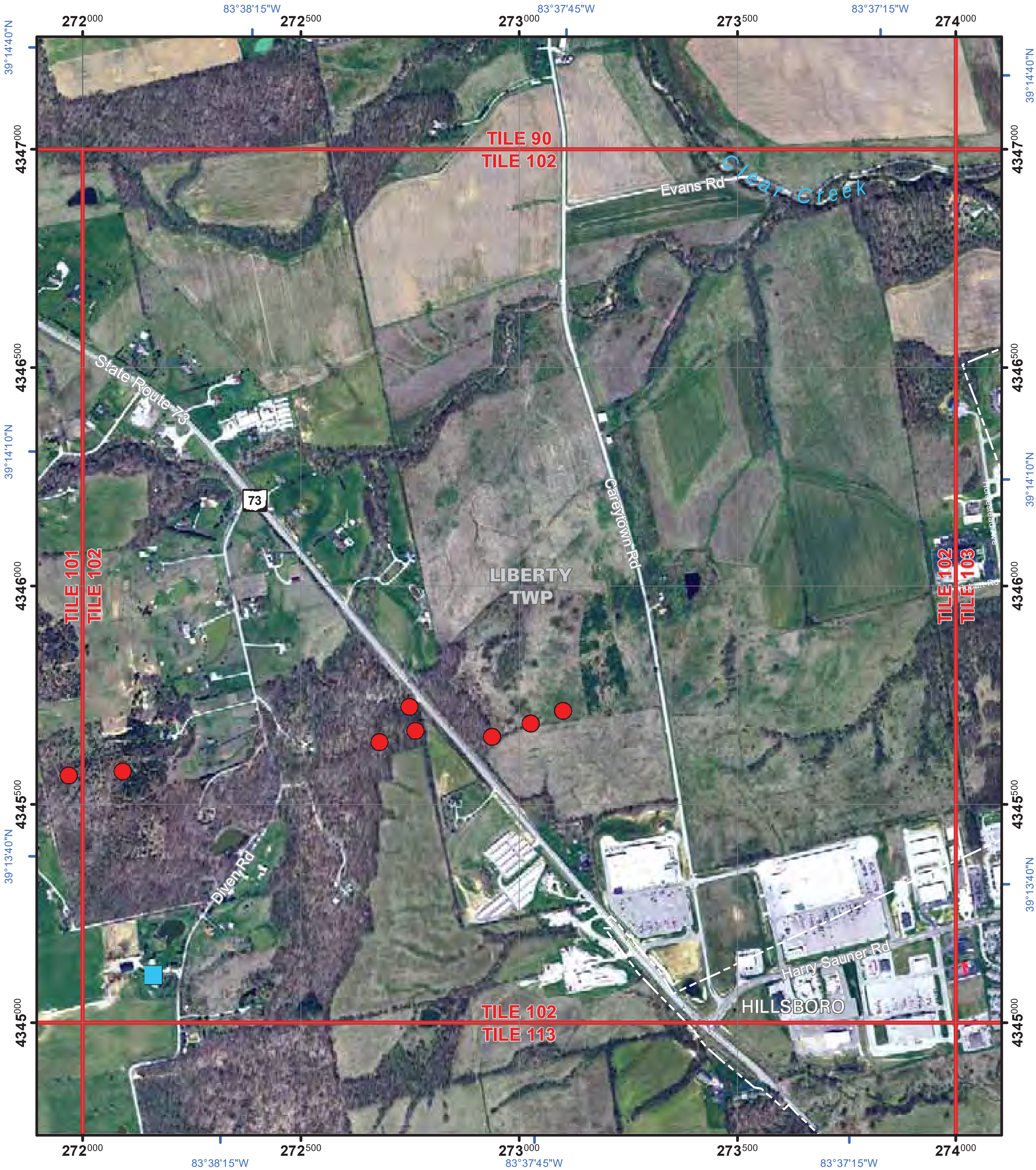
- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

DEPRESSION

Depth in feet

1, 2, 3, 4, 5, 6, 7, 8, 9, 10

Tile Number: 102



US National Grid

100,000-m Square ID: KD

Grid Zone Designation: 17S

0 — 0.5 miles

0 — 0.5 kilometers

Scale 1:12,000

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

N / E / S / W

KARST FEATURES

- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

DEPRESSION

Depth in feet

1, 2, 3, 4, 5, 6, 7, 8, 9, 10

Tile Number: 103

US National Grid

100,000-m Square ID	Grid Zone Designation
KD	17S

0 0.5 miles

0 0.5 kilometers

Scale 1:12,000

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

N W E S

KARST FEATURES
- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

DEPRESSION
Depth in feet

1, 2, 3, 4, 5, 6, 7, 8, 9, 10

Tile Number: 104

US National Grid

100,000-m Square ID	Grid Zone Designation
KD	17S

0 0.5 miles

0 0.5 kilometers

Scale 1:12,000

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

N W E S

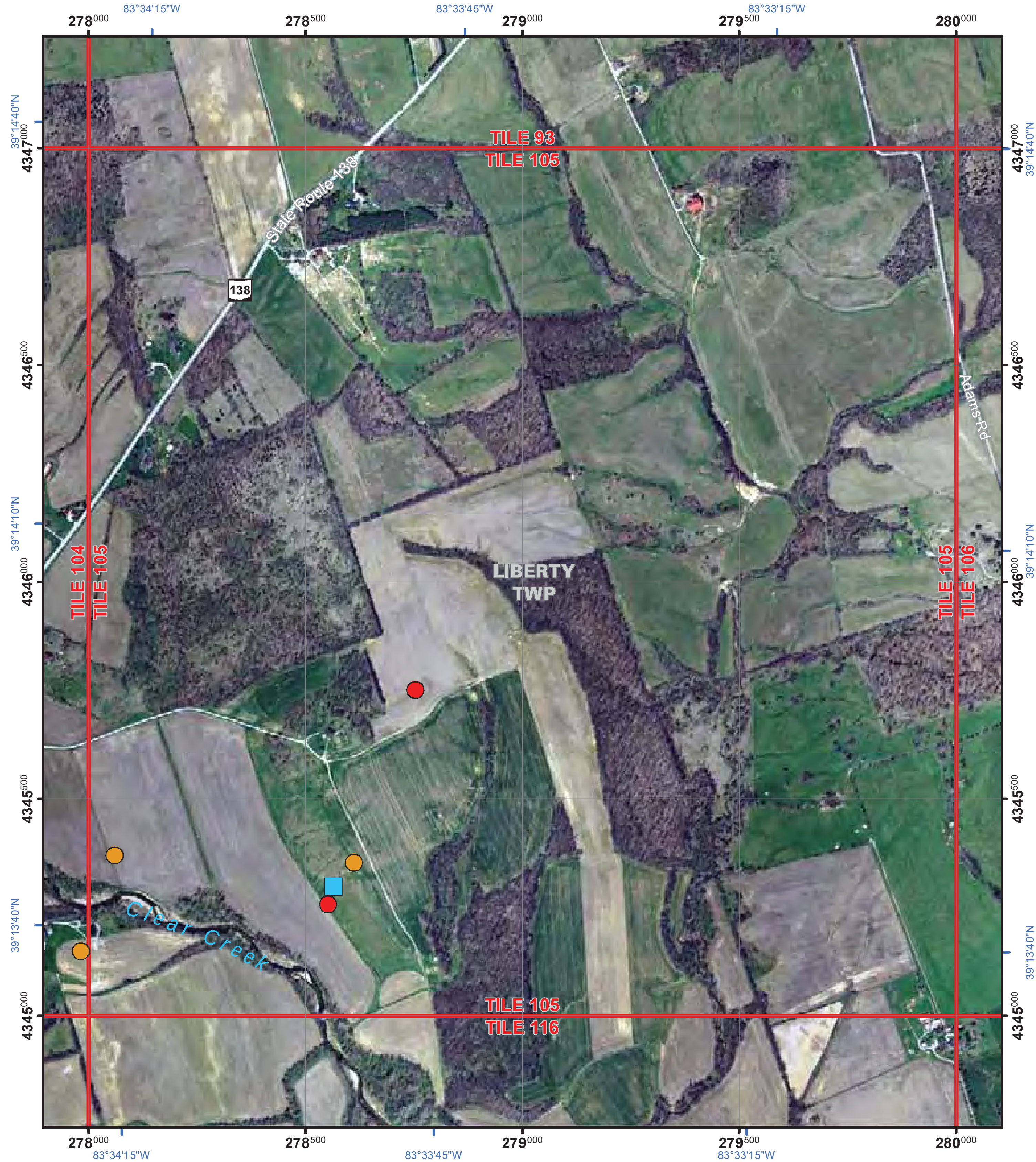
KARST FEATURES

- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

DEPRESSION
Depth in feet

1, 2, 3, 4, 5, 6, 7, 8, 9, 10

Tile Number: 105



US National Grid

100,000-m Square ID KD

Grid Zone Designation 17S

0 — 0.5 miles

0 — 0.5 kilometers

Scale 1:12,000

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

N W E S

KARST FEATURES

- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

DEPRESSION

Depth in feet

1, 2, 3, 4, 5, 6, 7, 8, 9, 10

Tile Number: 106

US National Grid
100,000-m Square ID KD
Grid Zone Designation 17S

0 0.5 miles
0 0.5 kilometers
Scale 1:12,000

KARST FEATURES
- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

DEPRESSION
Depth in feet
1 2 3 4 5 6 7 8 9 10

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

Tile Number: 107

US National Grid

100,000-m Square ID	Grid Zone Designation
KD	17S

0 — 0.5 miles

0 — 0.5 kilometers

Scale 1:12,000

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

KARST FEATURES

- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

DEPRESSION
Depth in feet

1, 2, 3, 4, 5, 6, 7, 8, 9, 10

Tile Number: 111

US National Grid

100,000-m Square ID: KD

Grid Zone Designation: 17S

0 — 0.5 miles

0 — 0.5 kilometers

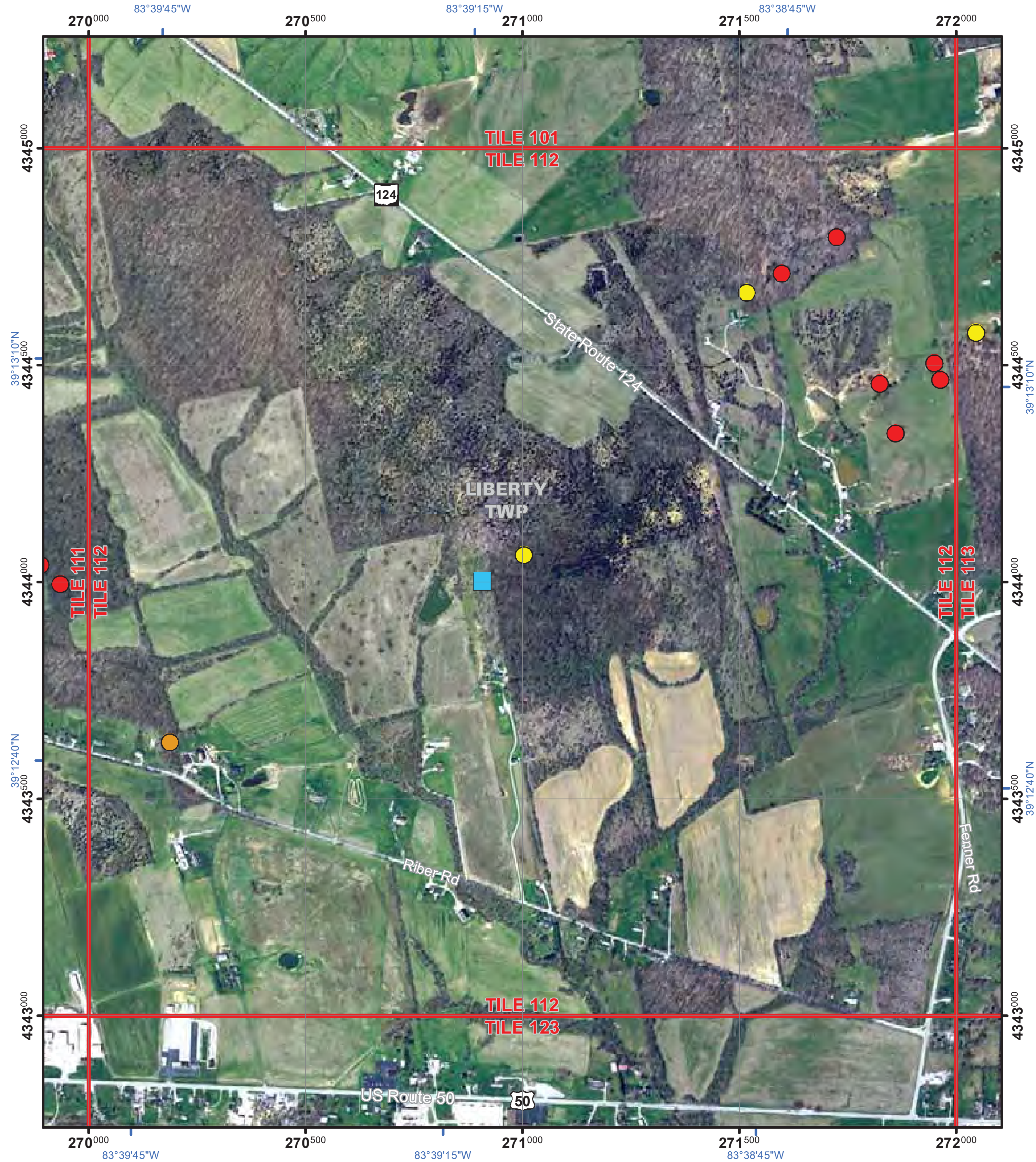
Scale 1:12,000

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

KARST FEATURES
- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

DEPRESSION
Depth in feet
1, 2, 3, 4, 5, 6, 7, 8, 9, 10

Tile Number: 112



US National Grid

100,000-m Square ID KD

Grid Zone Designation 17S

0 0.5 miles

0 0.5 kilometers

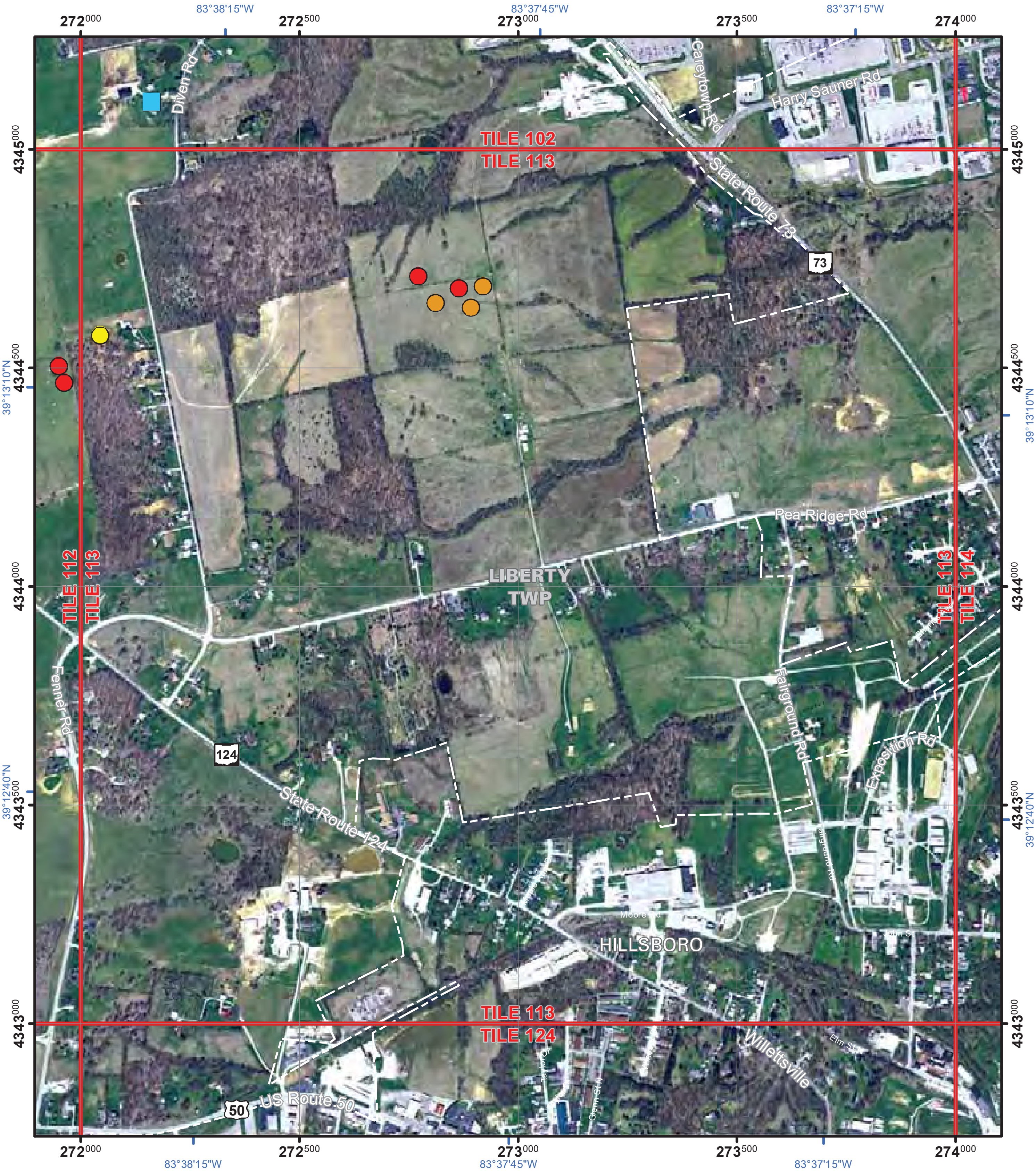
Scale 1:12,000

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

KARST FEATURES
- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

DEPRESSION
Depth in feet
1 2 3 4 5 6 7 8 9 10

Tile Number: 113



US National Grid

100,000-m Square ID: KD

Grid Zone Designation: 17S

0 — 0.5 miles

0 — 0.5 kilometers

Scale 1:12,000

N W E S

KARST FEATURES
- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

DEPRESSION
Depth in feet
1, 2, 3, 4, 5, 6, 7, 8, 9, 10

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

Tile Number: 114

US National Grid

100,000-m Square ID KD

Grid Zone Designation 17S

0 0.5 miles

0 0.5 kilometers

Scale 1:12,000

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

KARST FEATURES
- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

DEPRESSION
Depth in feet
1, 2, 3, 4, 5, 6, 7, 8, 9, 10