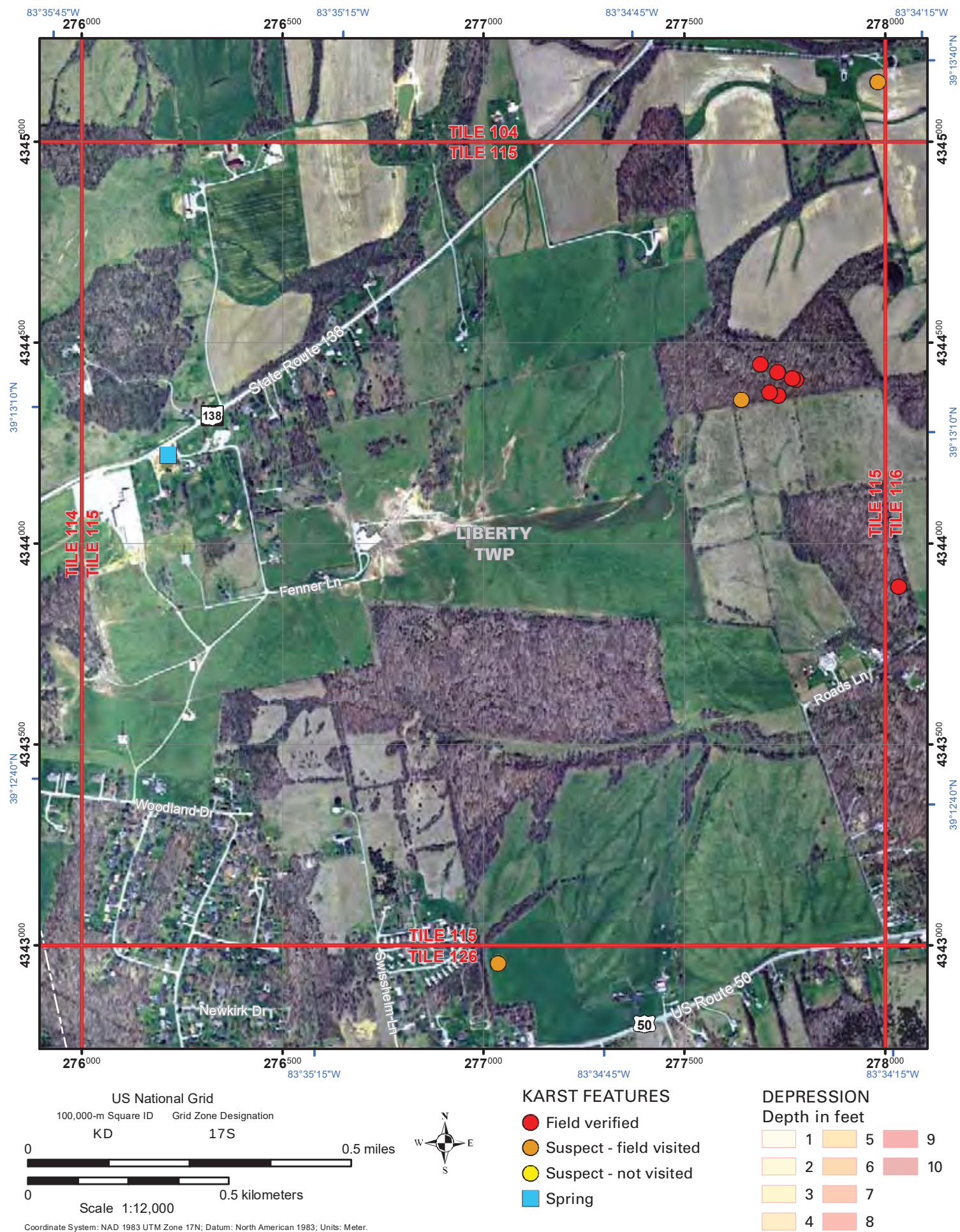
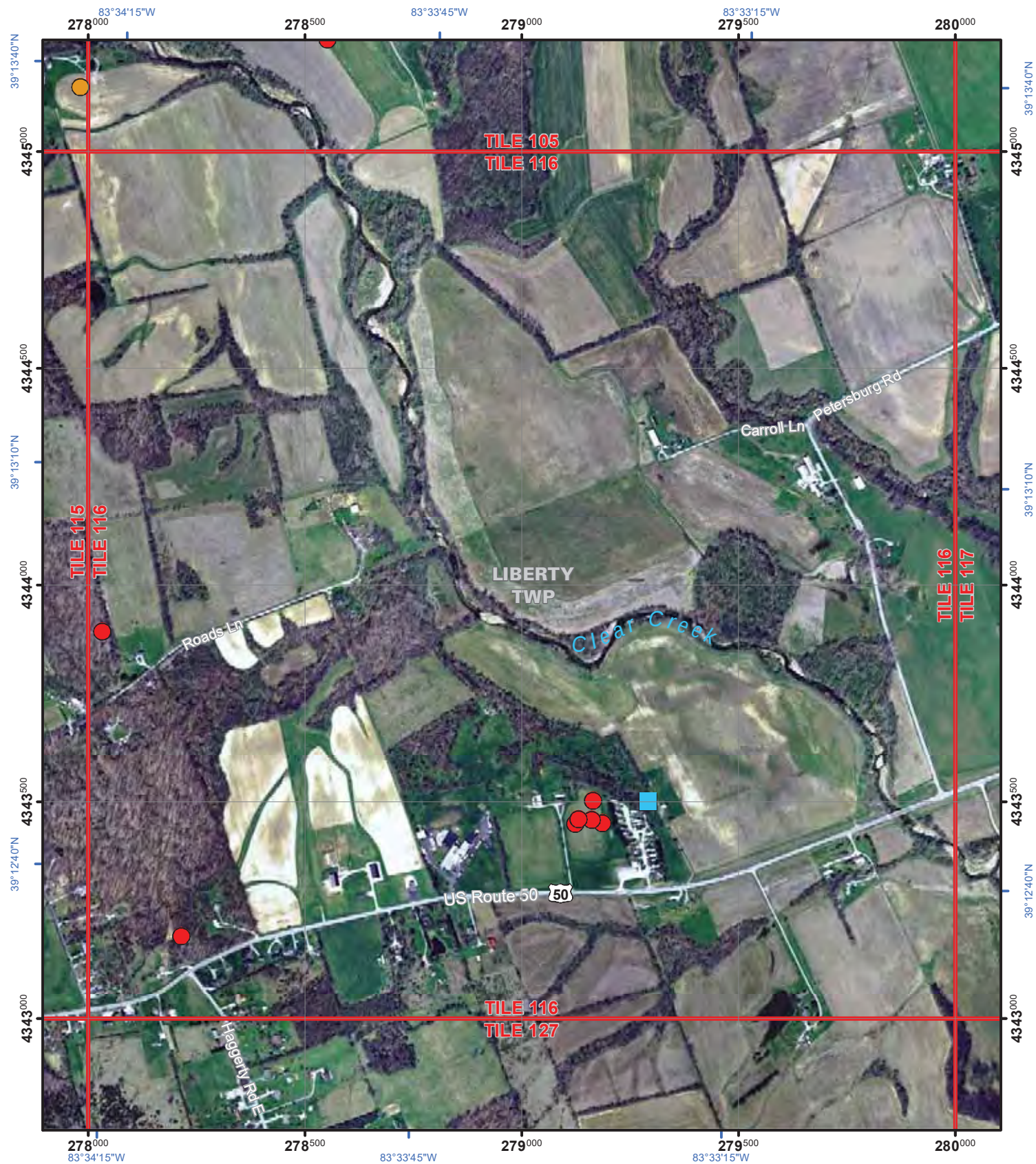


Tile Number: 115





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

DEPRESSION

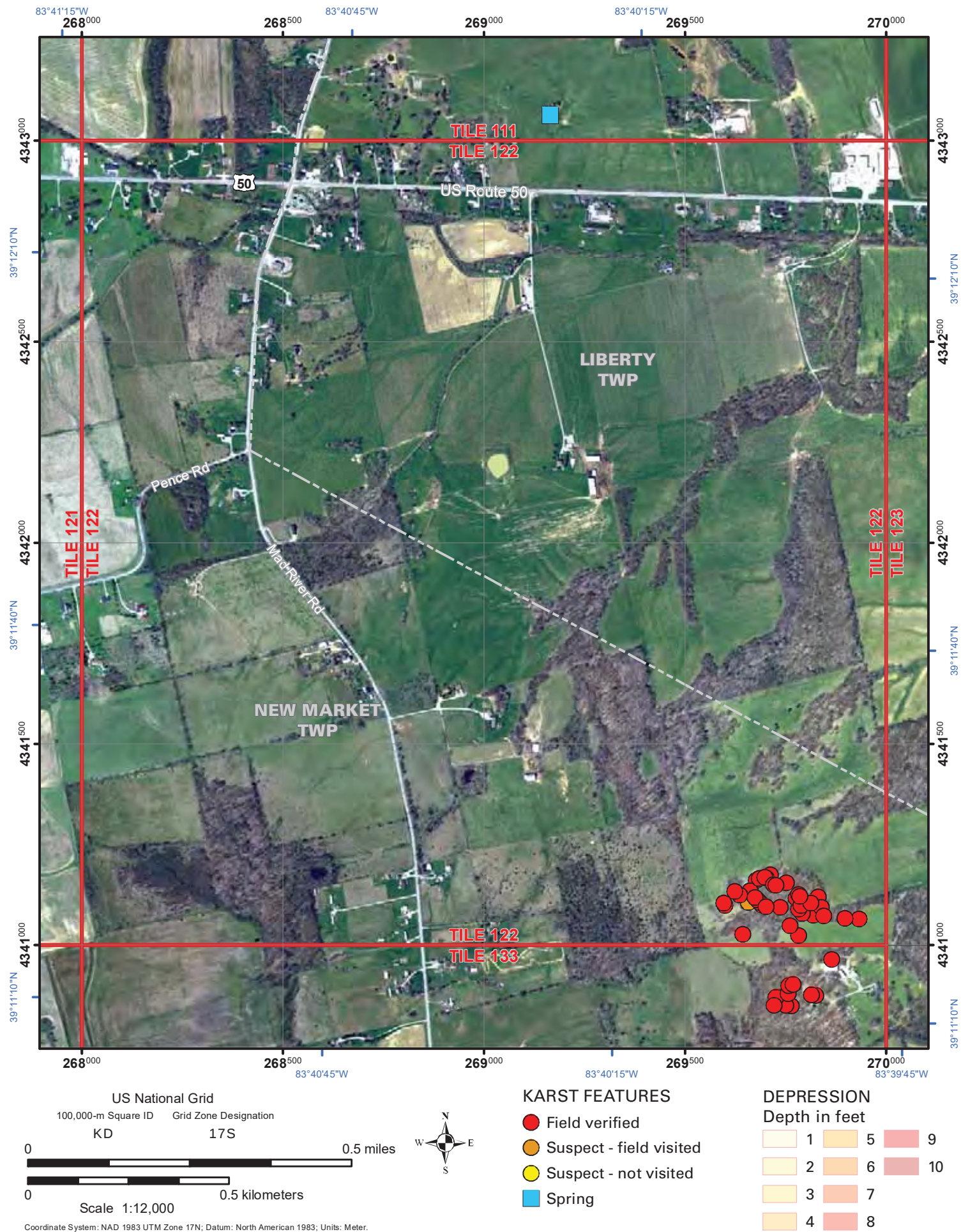
Depth in feet

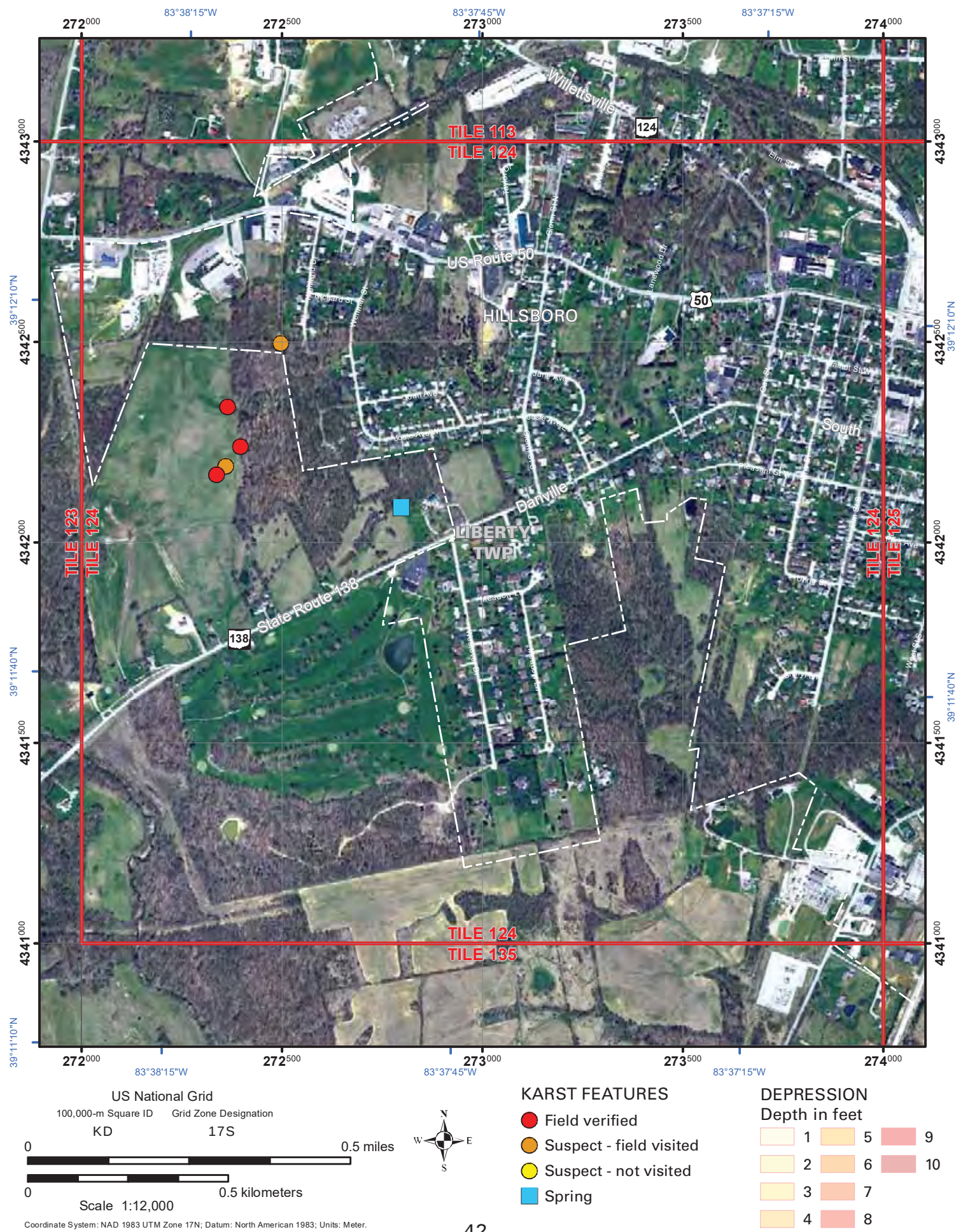
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2	6	10
3	7	
4	8	

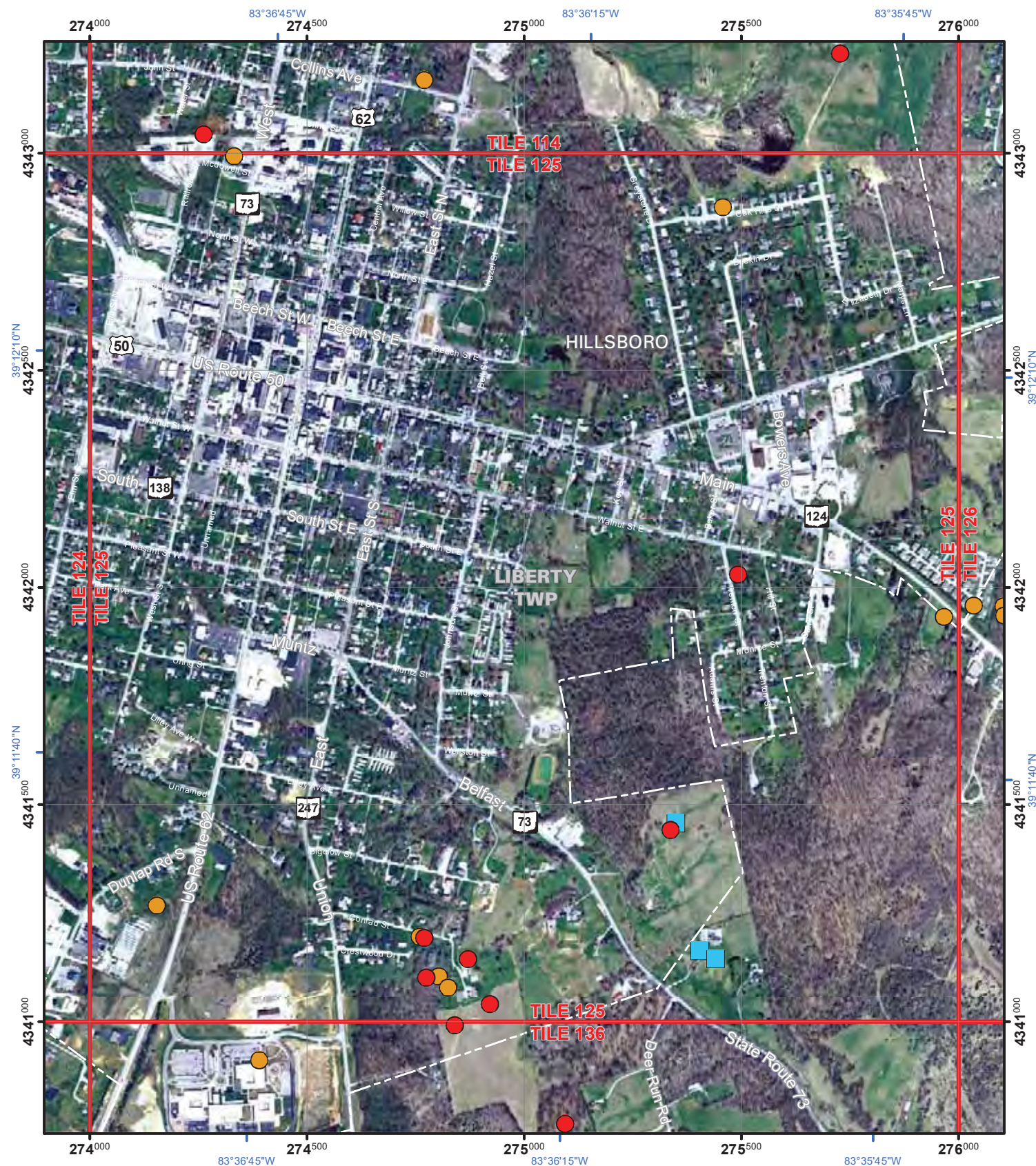




Tile Number: 122







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

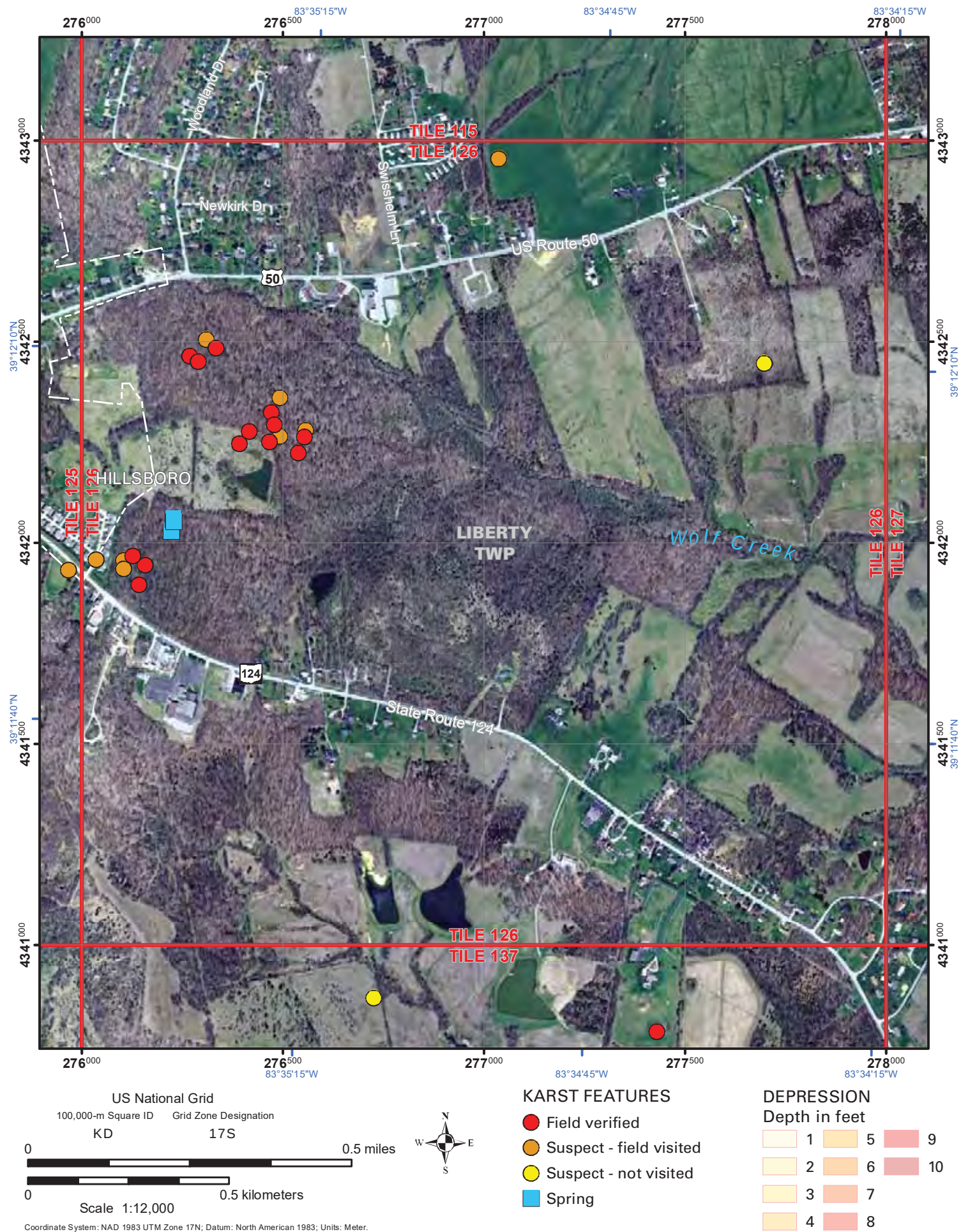
Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

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

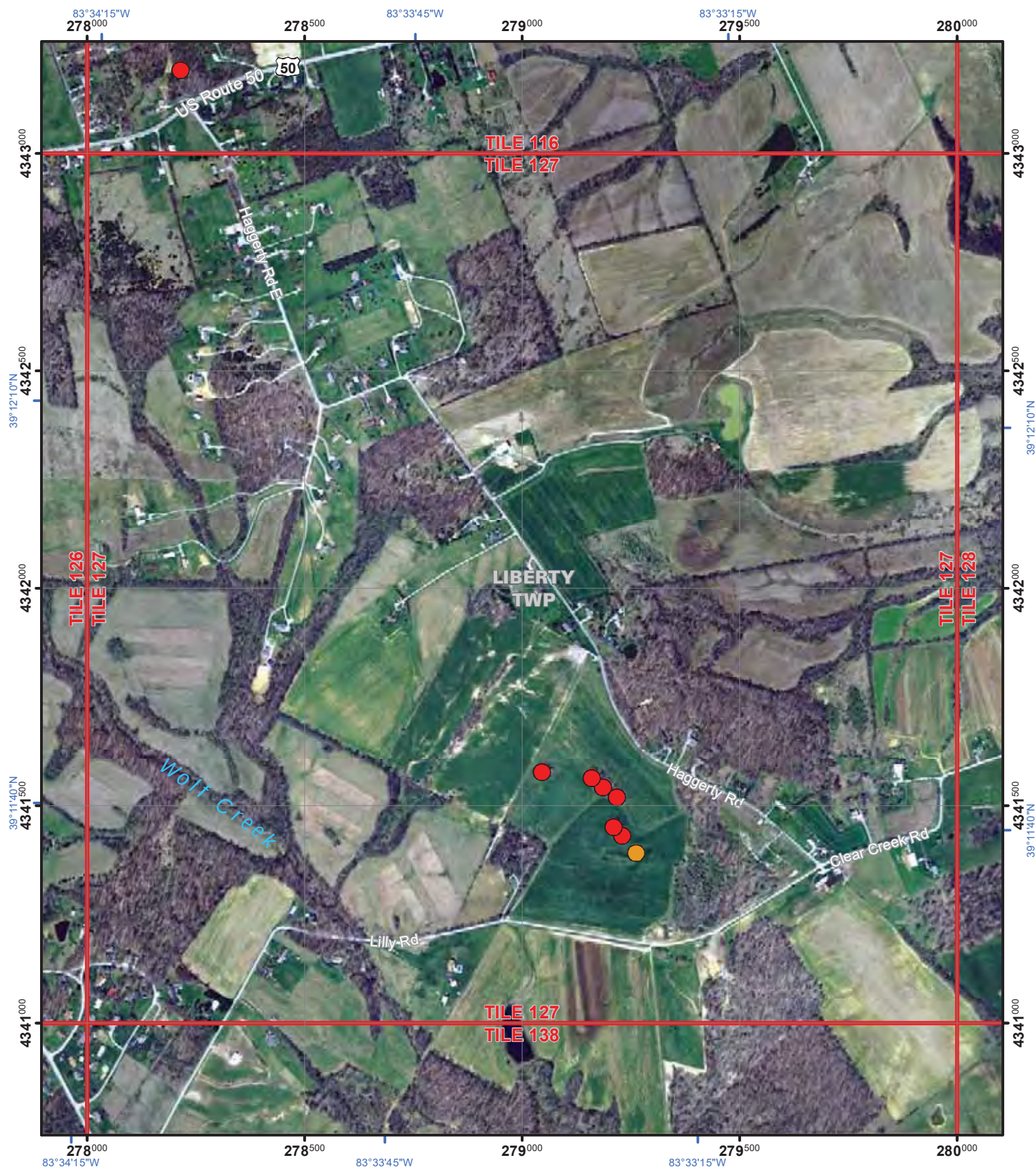
DEPRESSION

Depth in feet

1	5	9
2	6	10
3	7	
4	8	



Tile Number: 127



US National Grid

[illegible]

KD

17S

A horizontal scale bar with a black background and white markings. It is labeled '0' at the left end and '0.5 miles' at the right end. The bar is divided into four equal segments by three white vertical lines.

0 0.5 kilometers
Scale 1:12,000

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

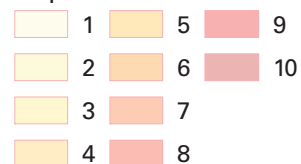


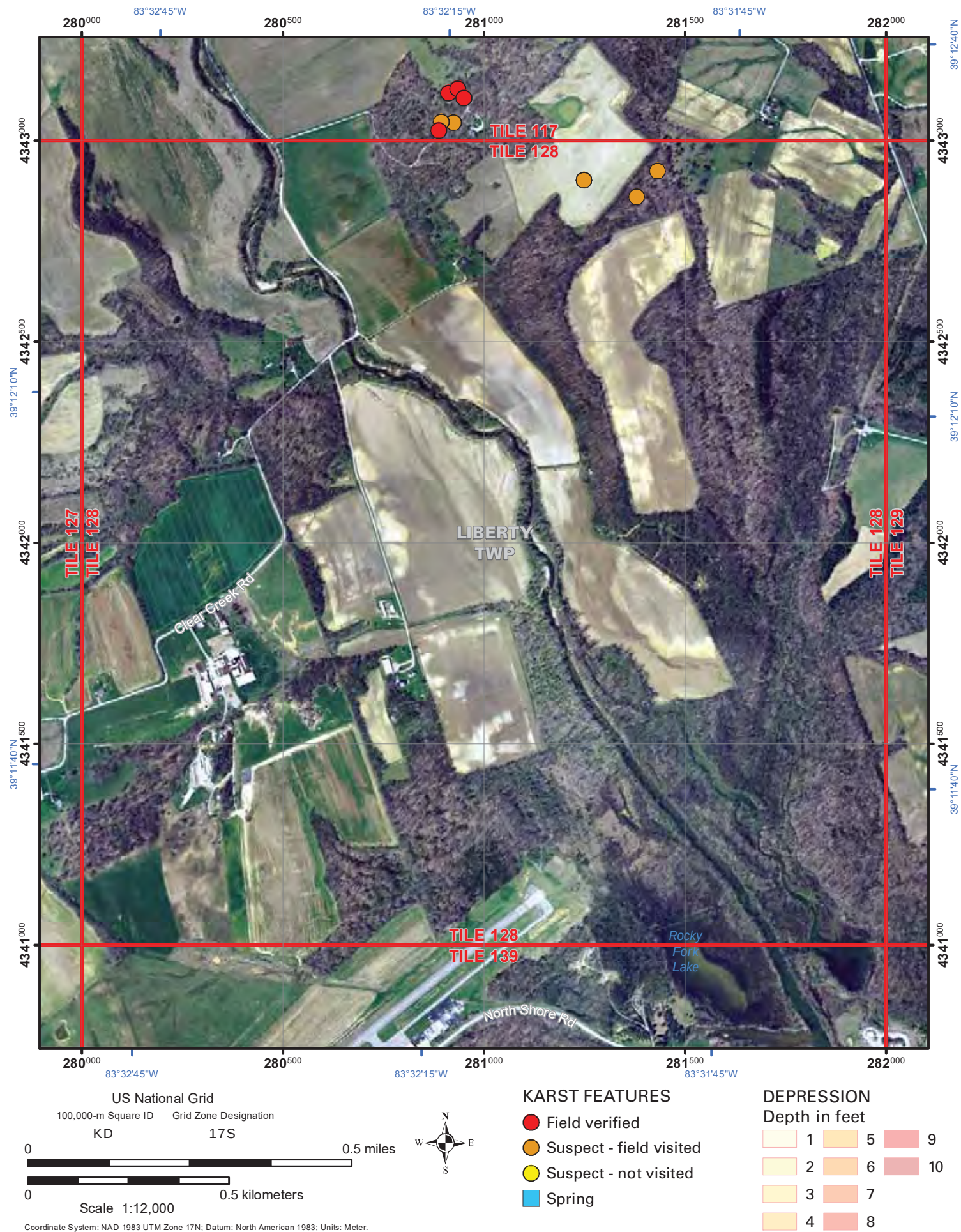
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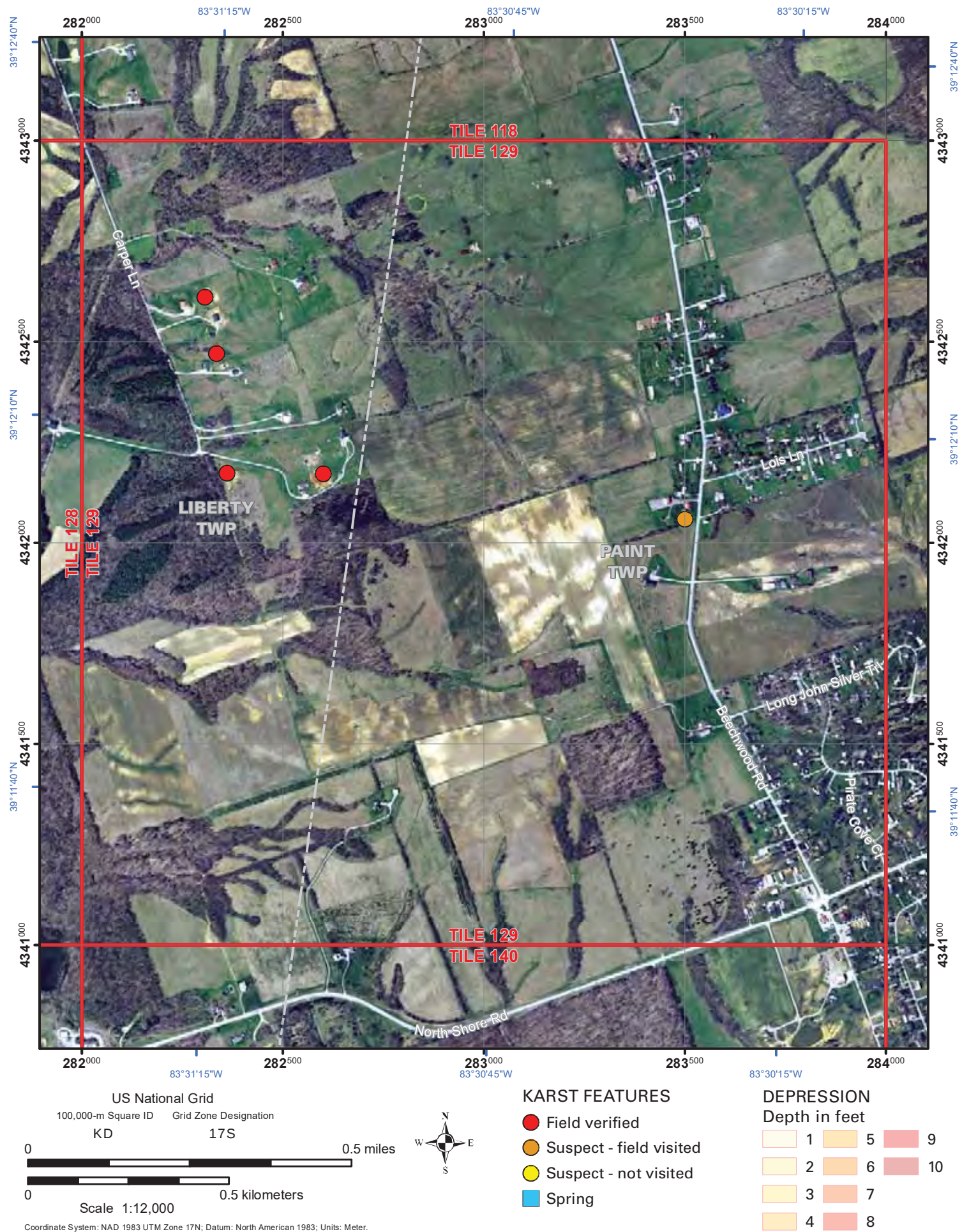
-  Field verified
 Suspect - field visited
 Suspect - not visited
 Spring

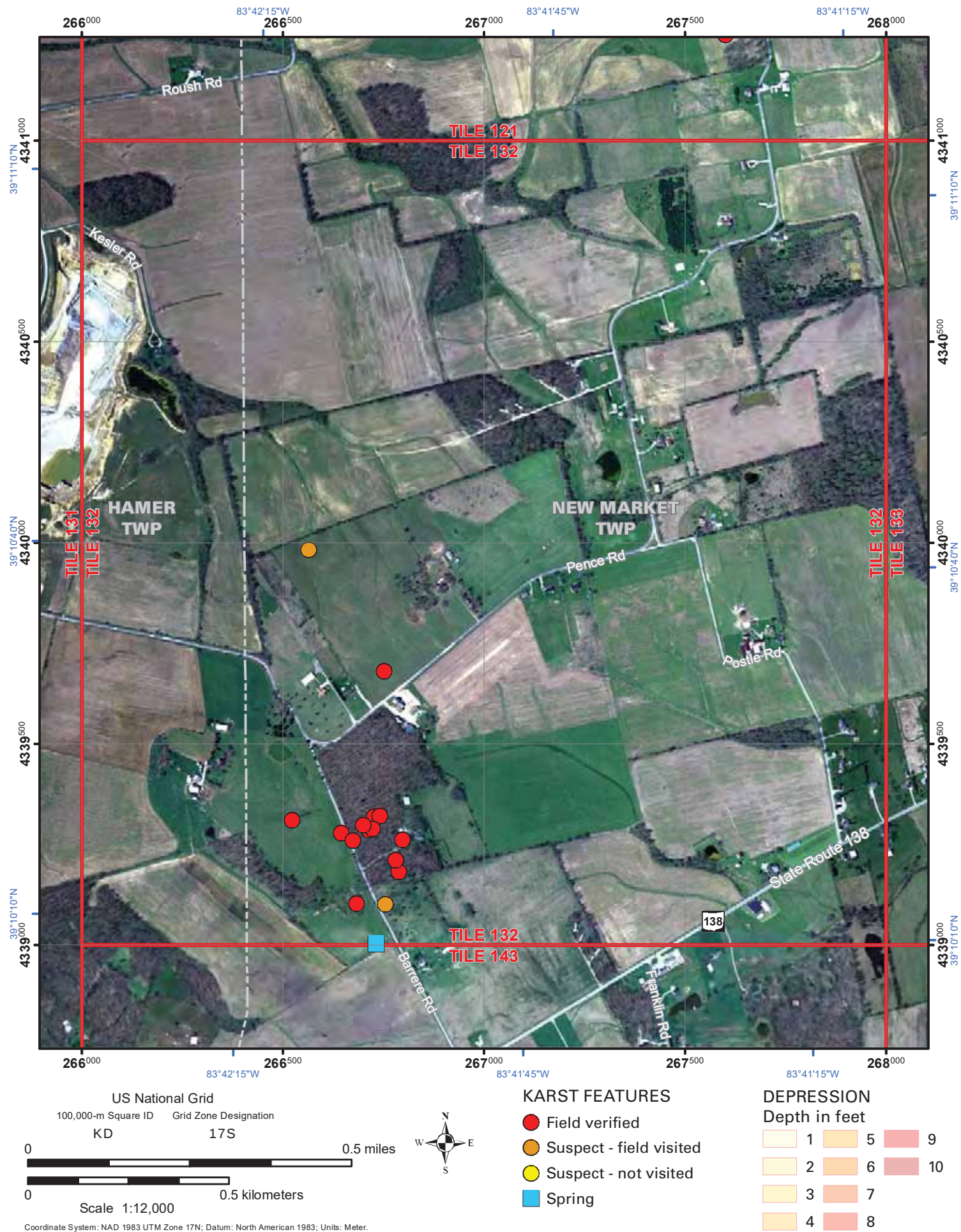
DEPRESSION

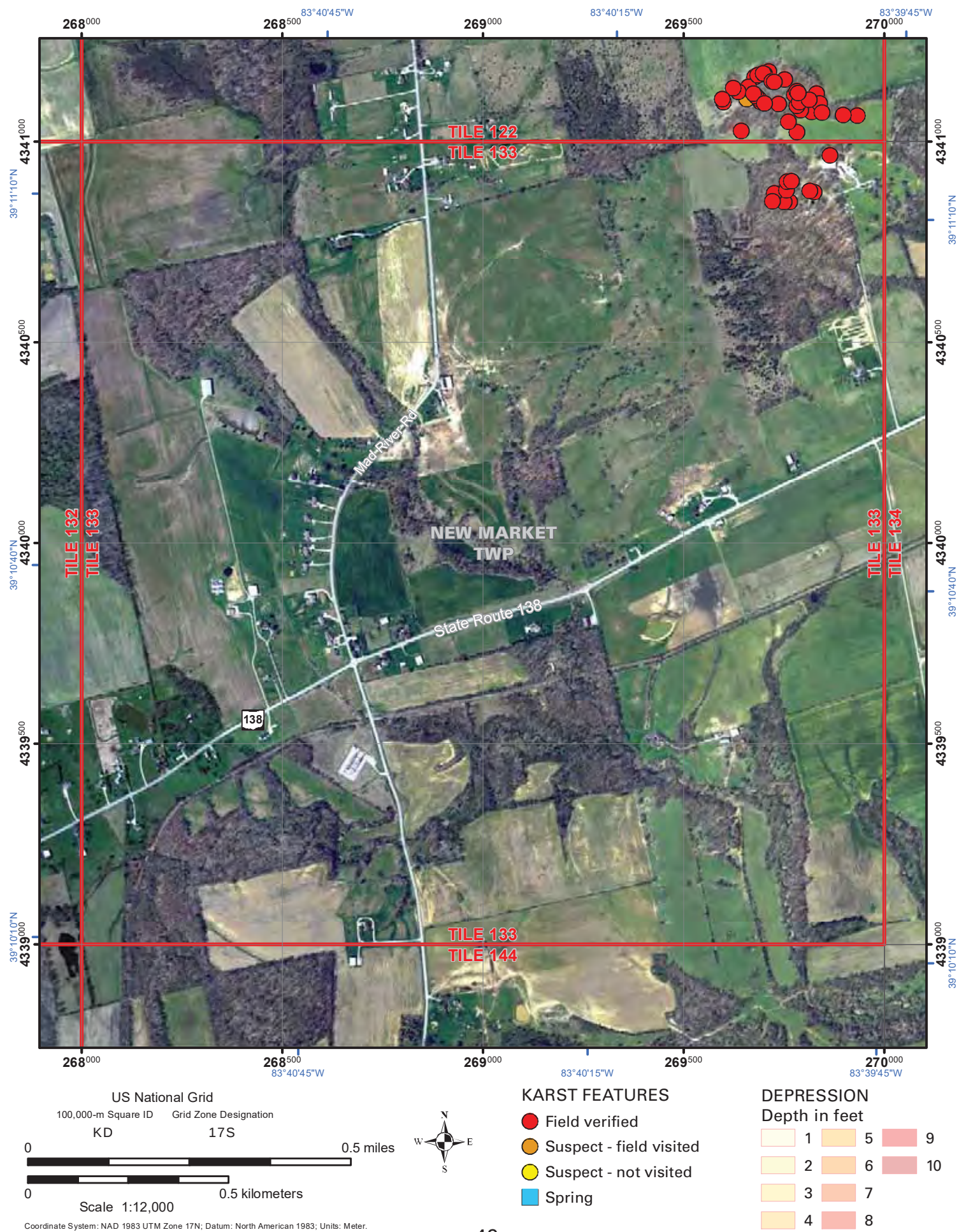
Depth in feet



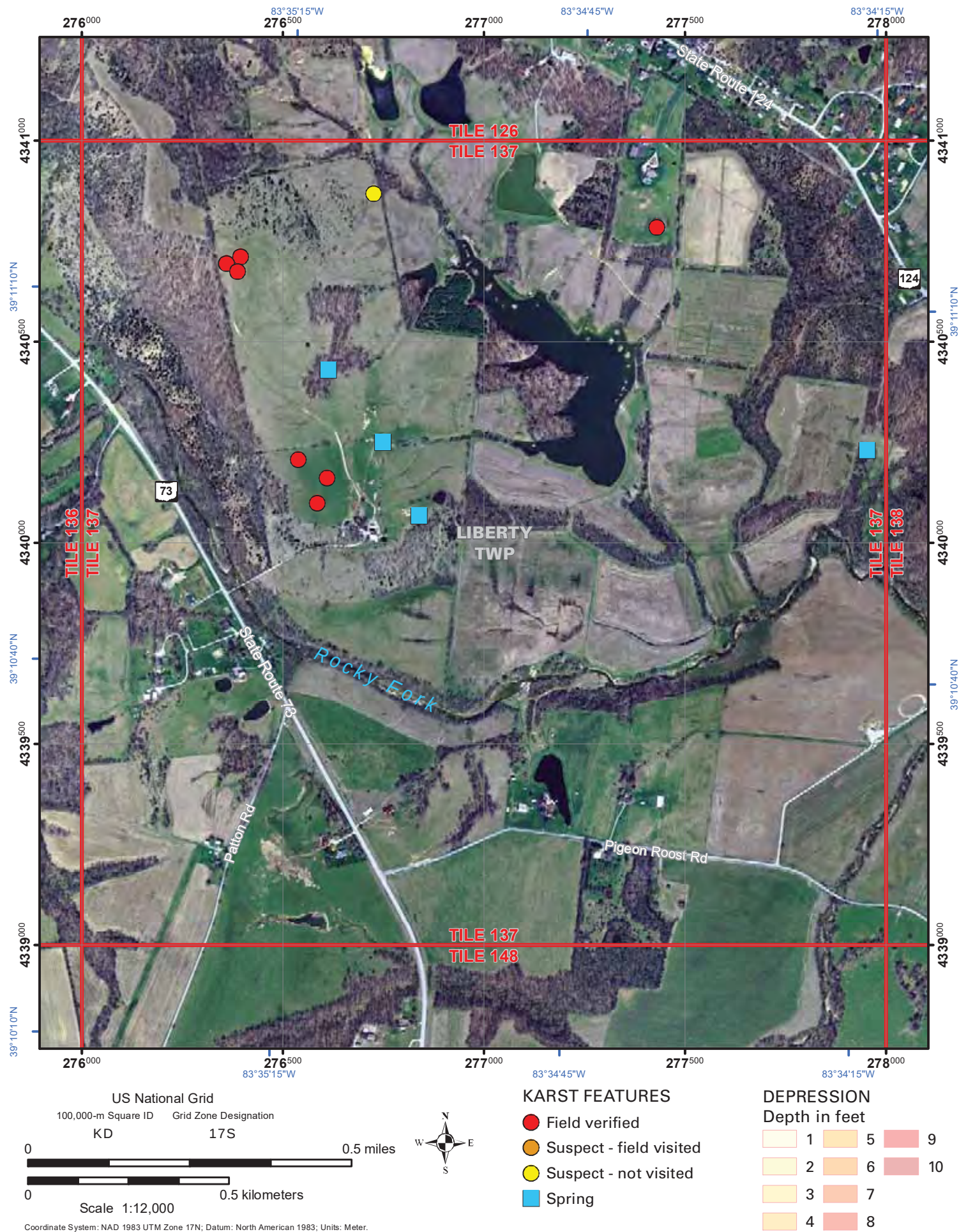






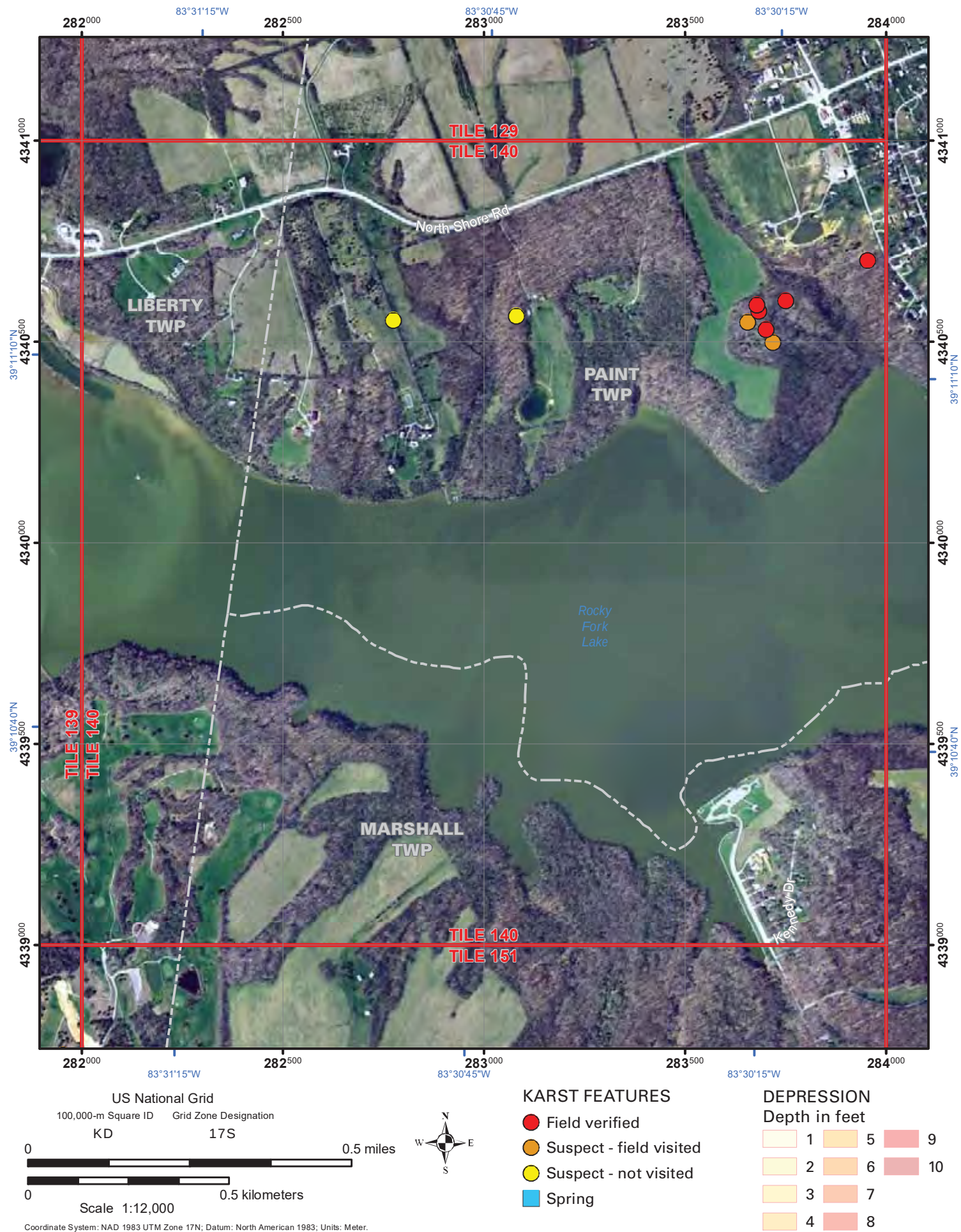


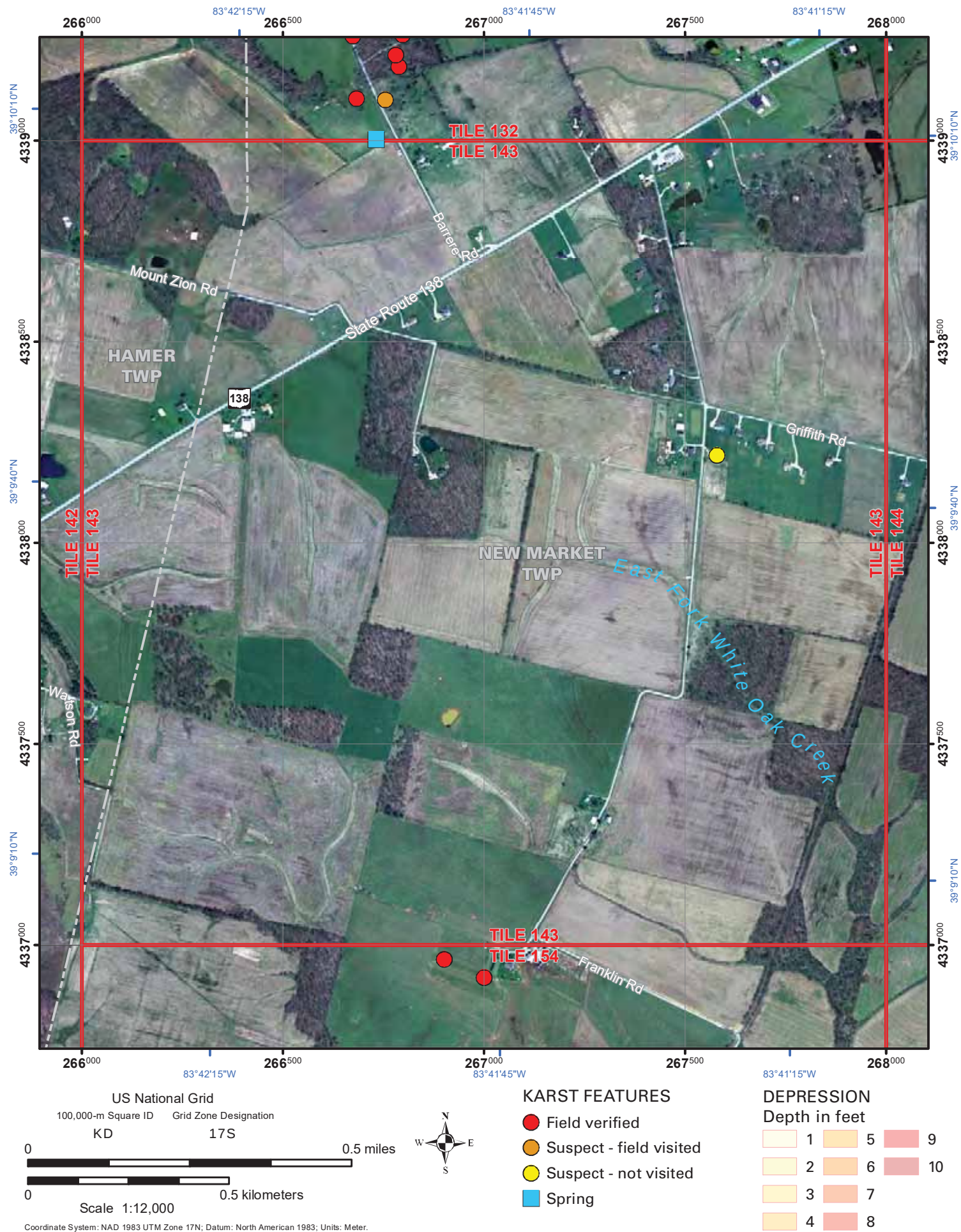


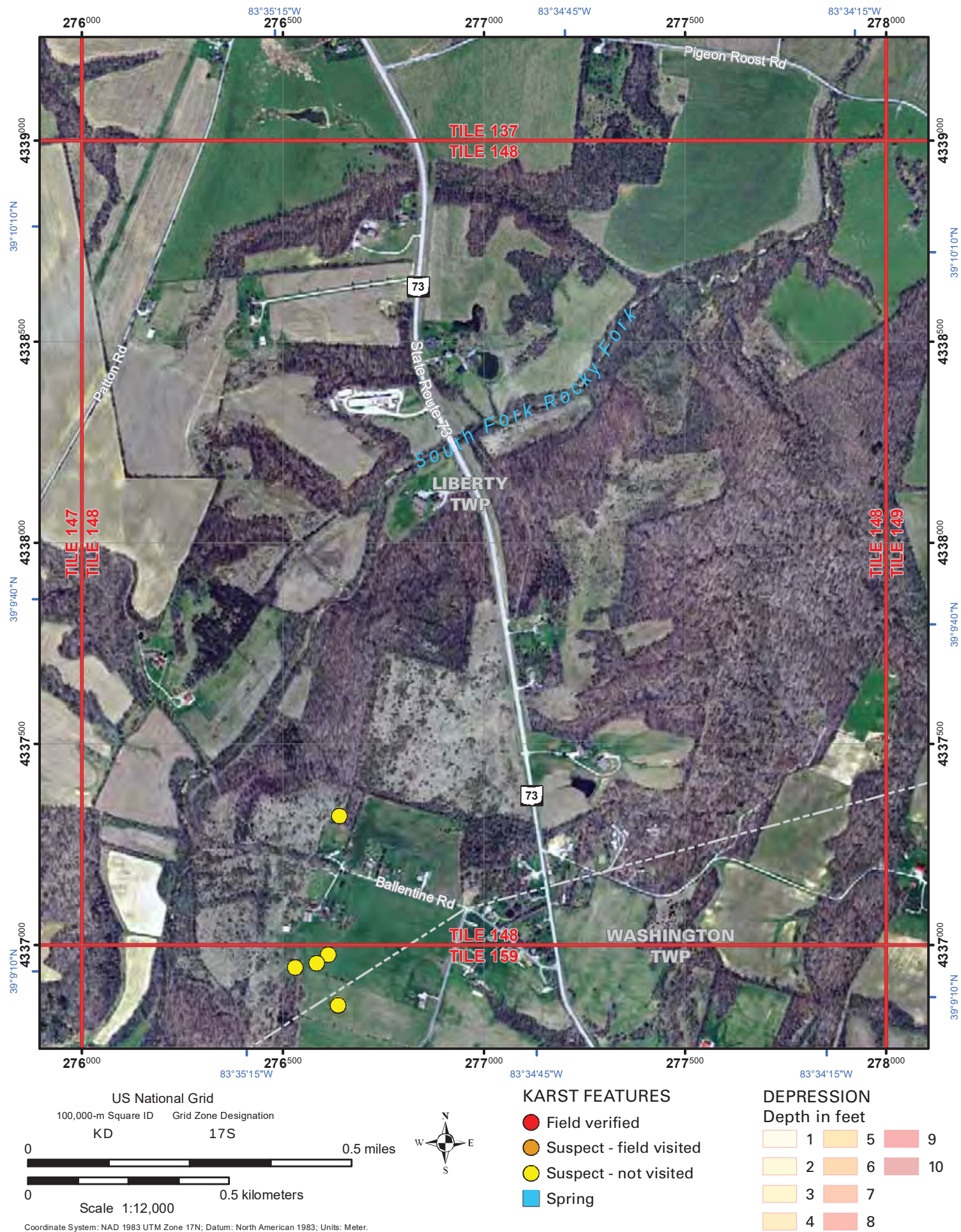


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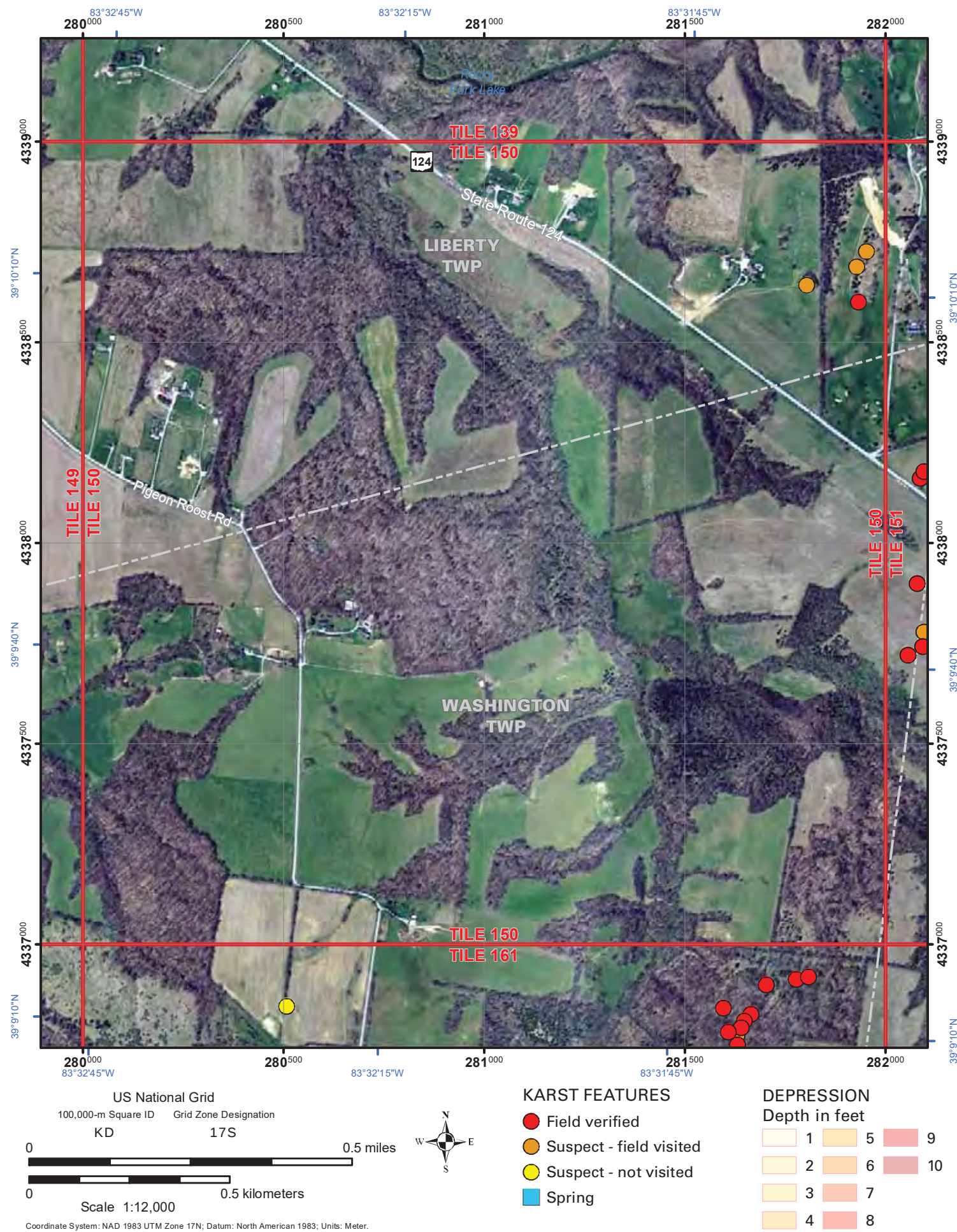


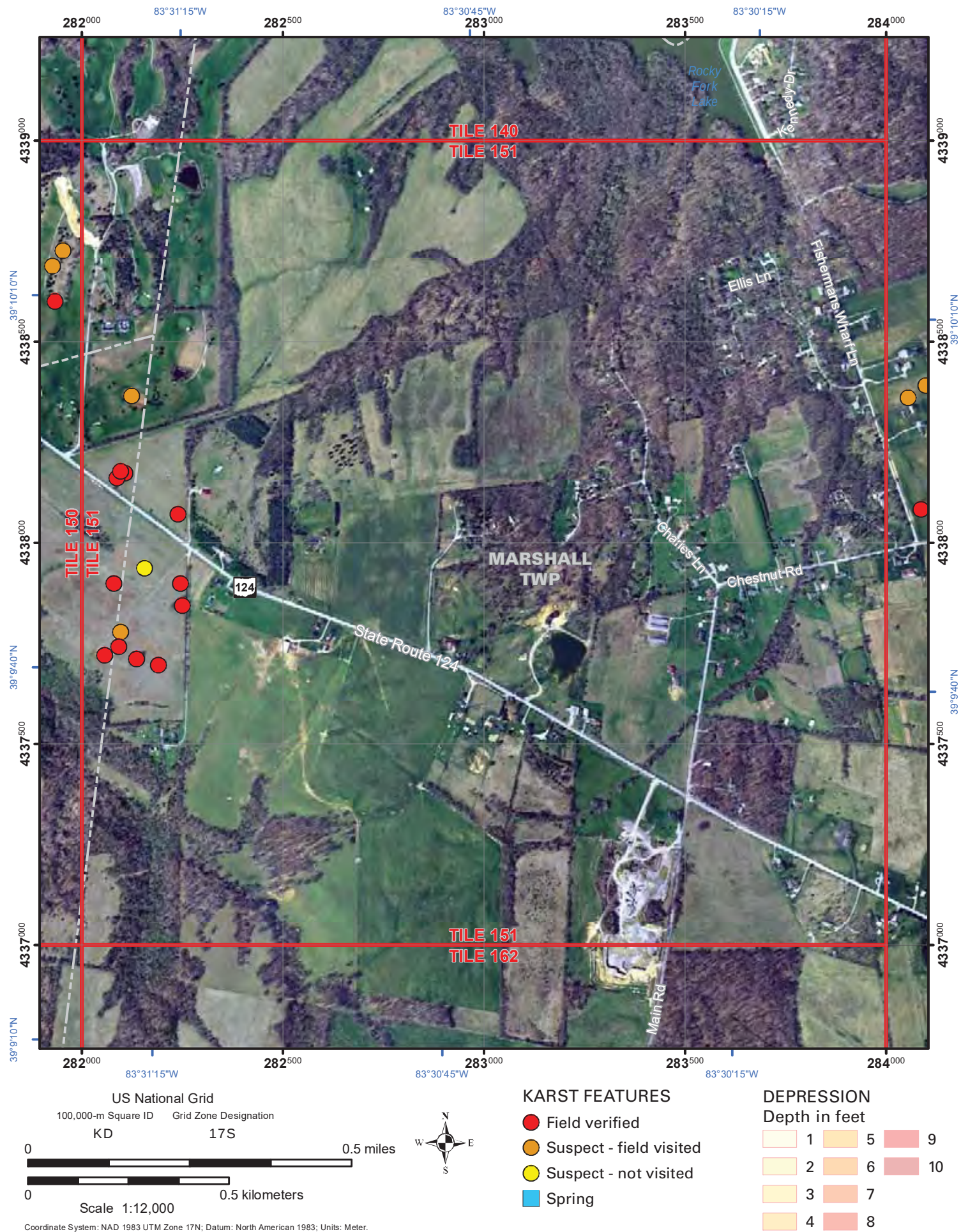






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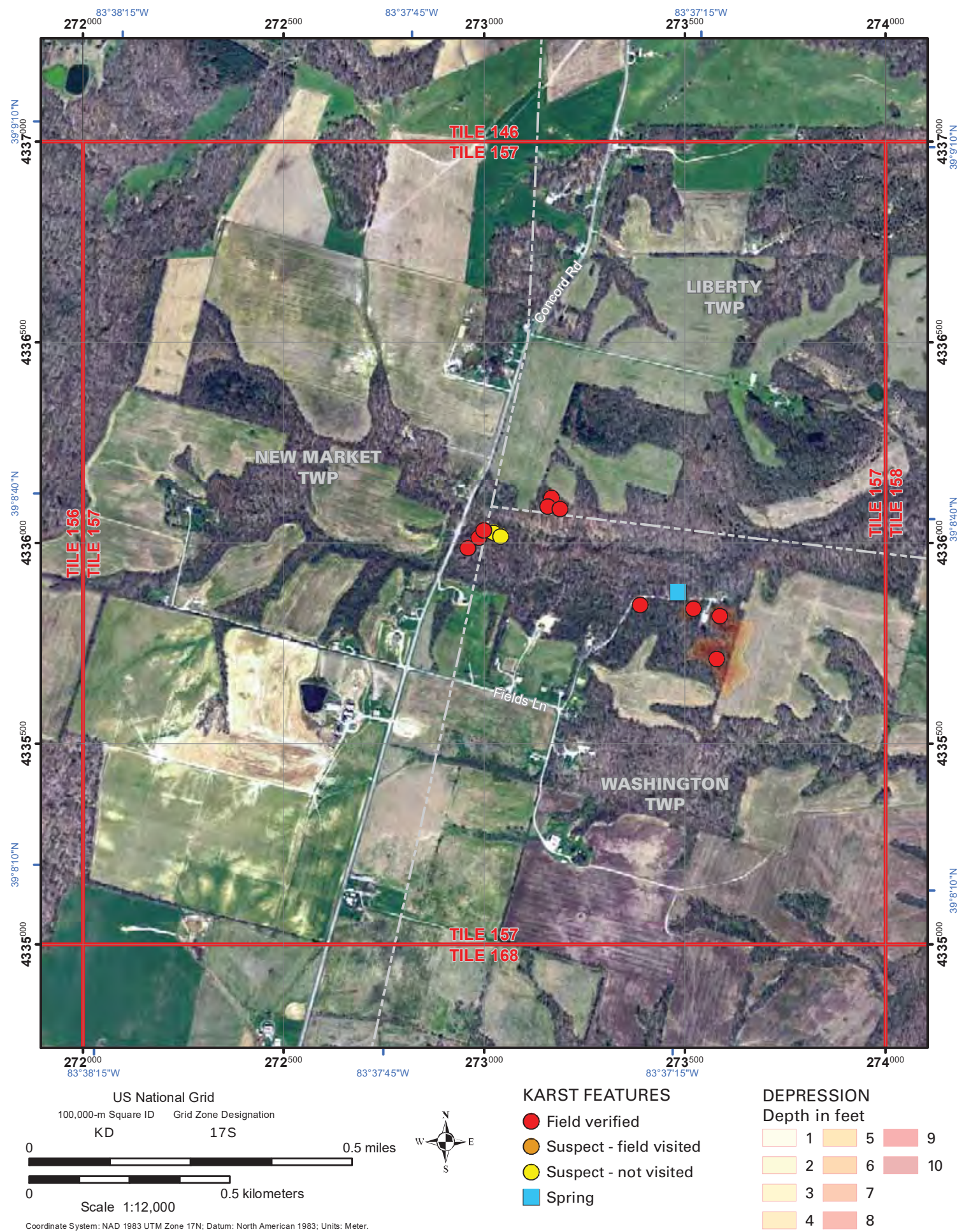


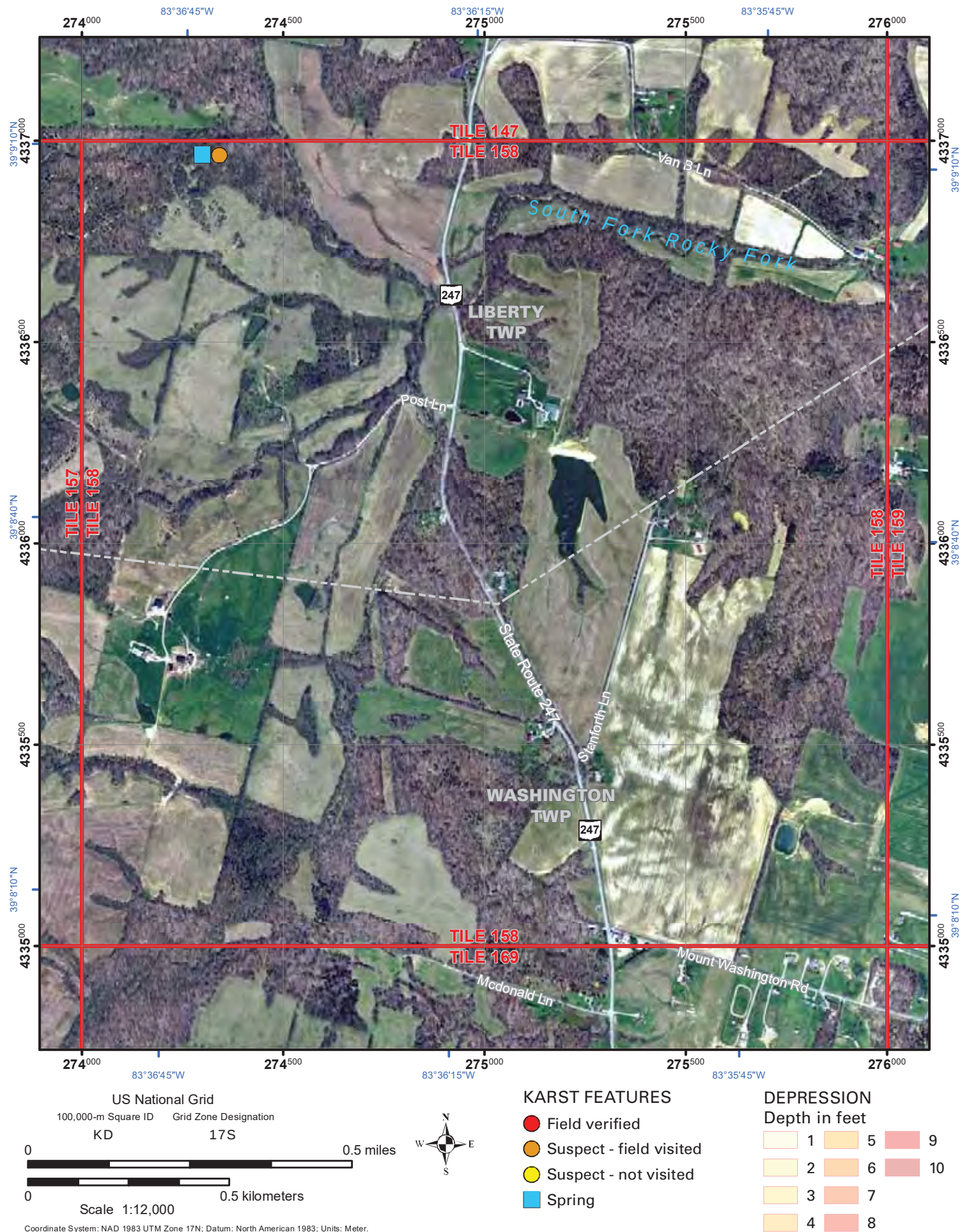


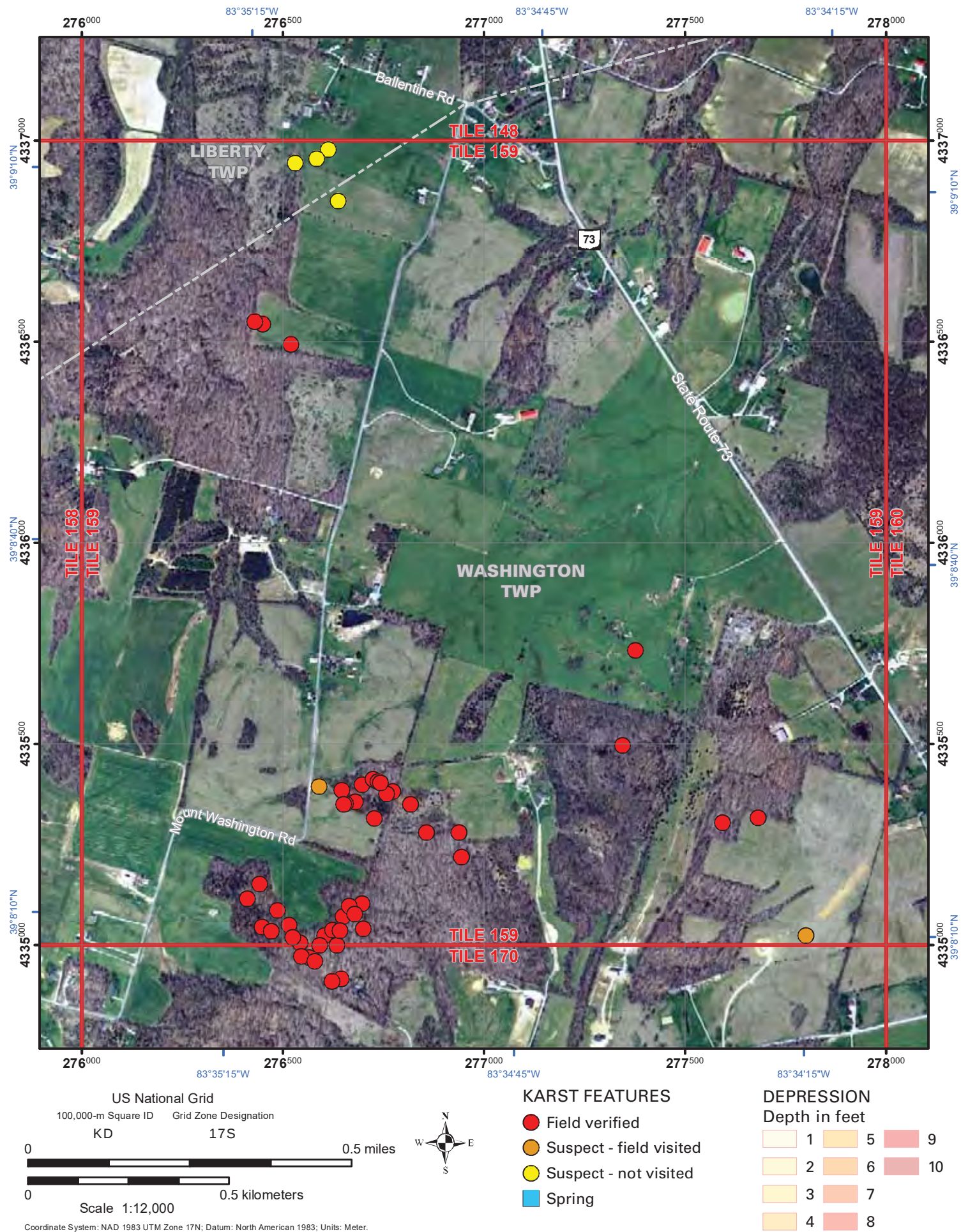


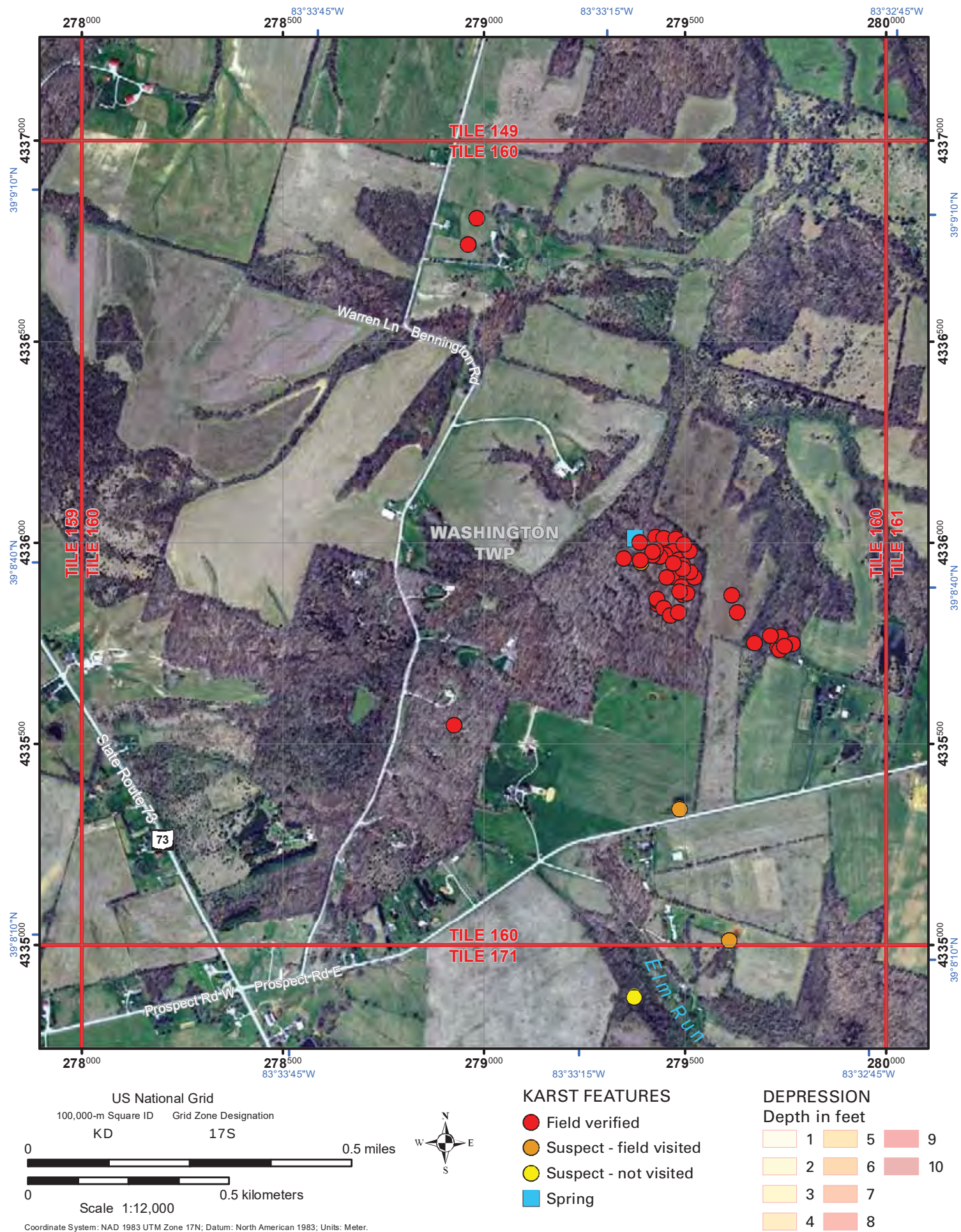
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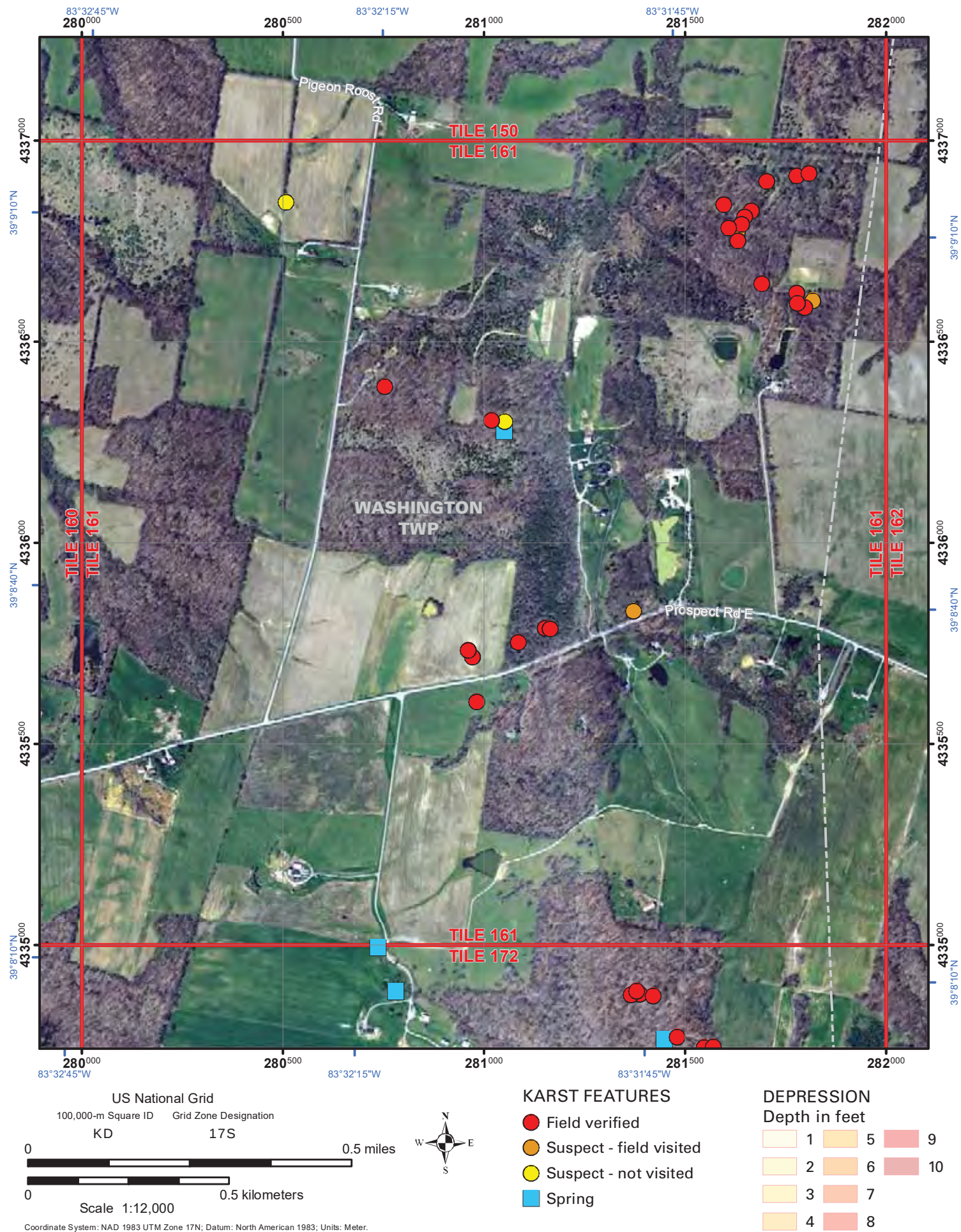


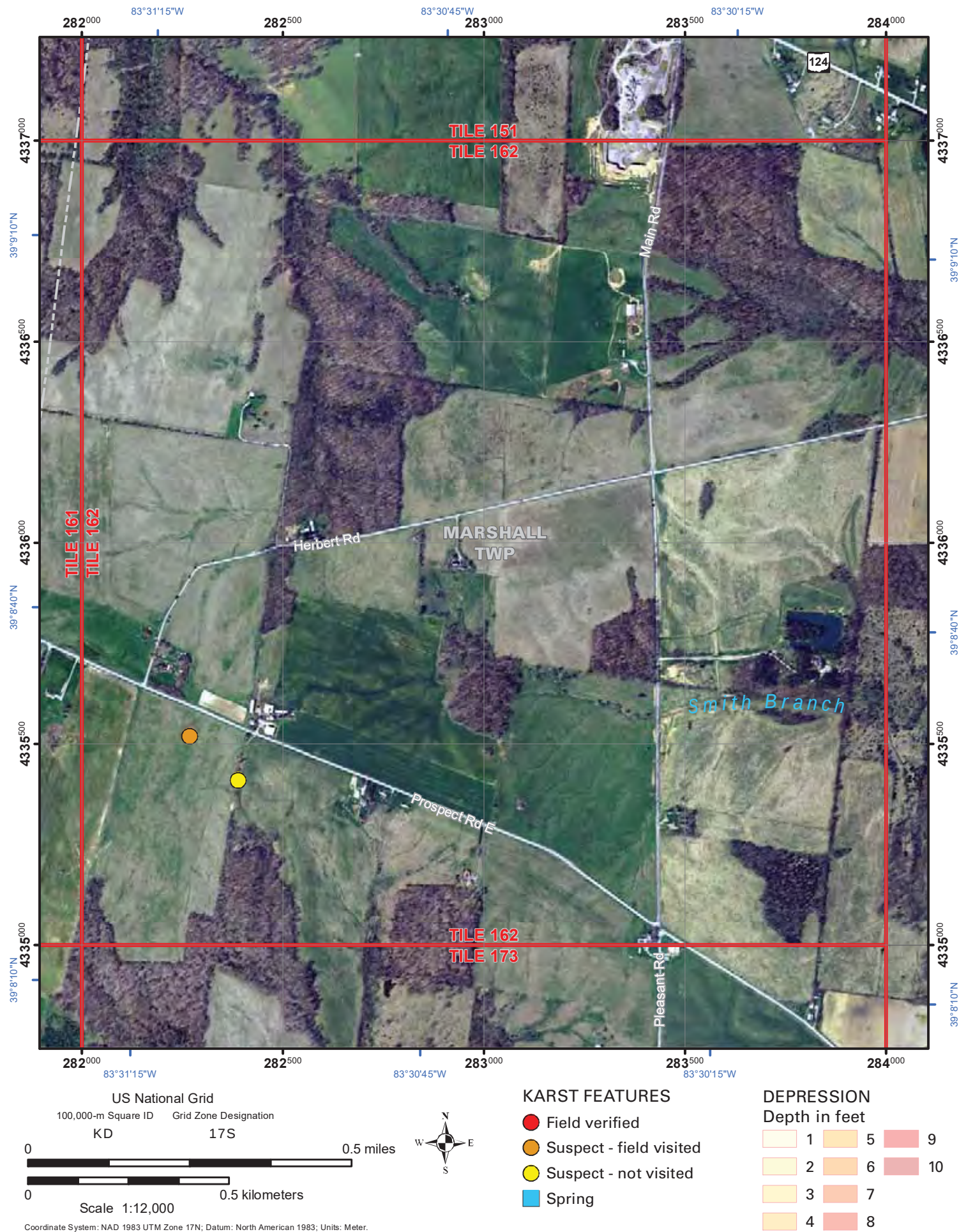






Tile Number: 161







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.

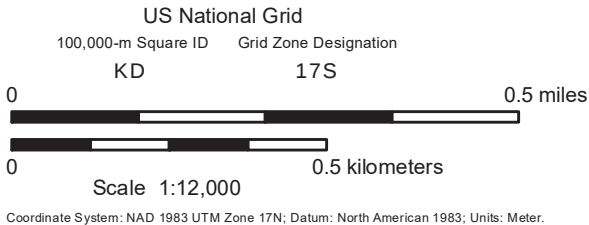
KARST FEATURES

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

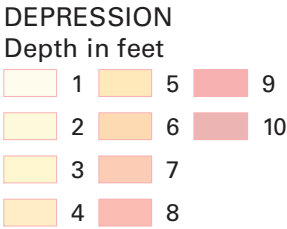
DEPRESSION

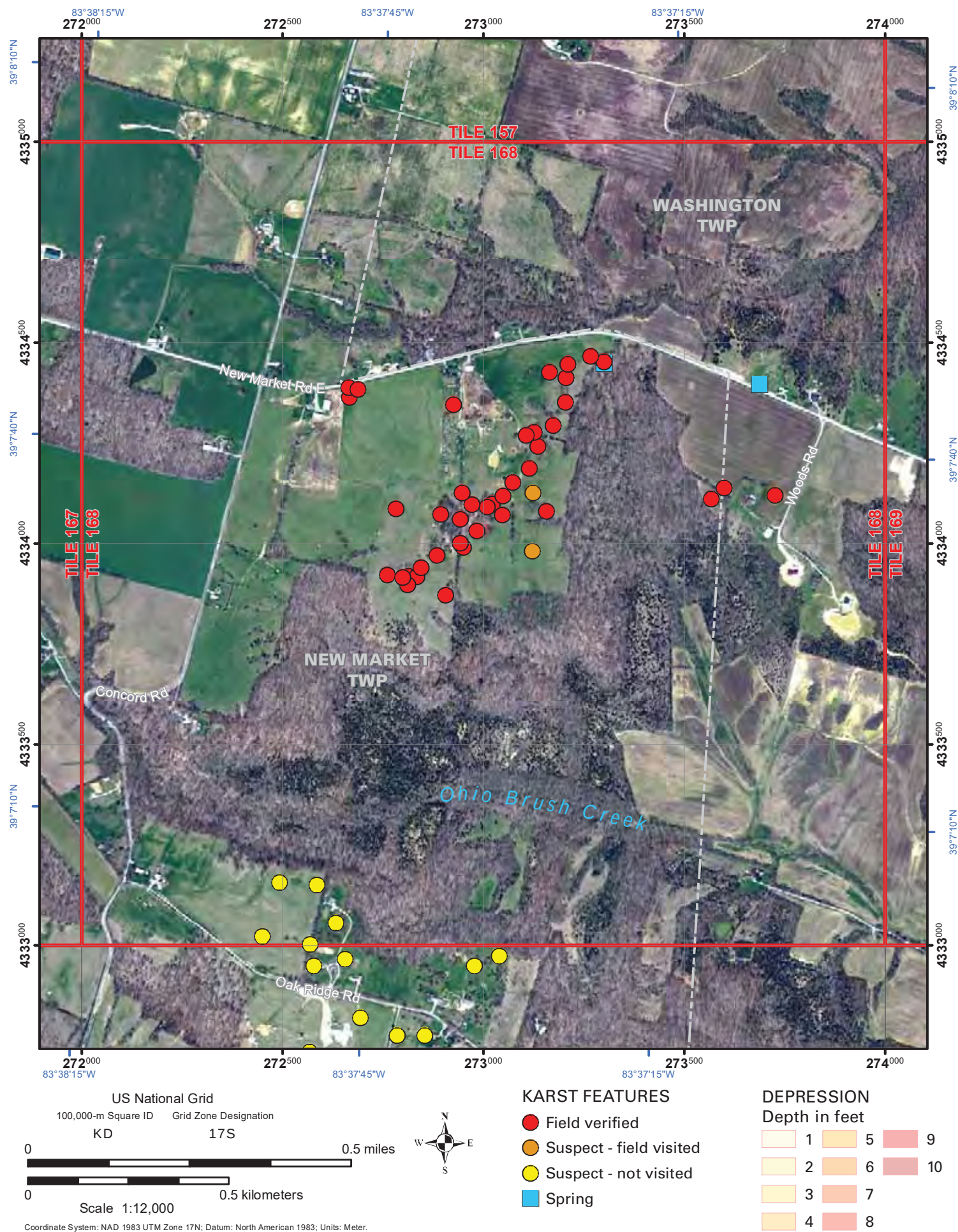
Depth in feet

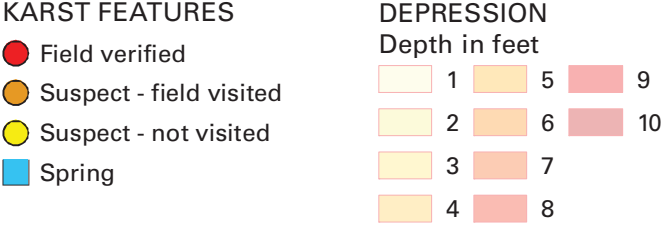
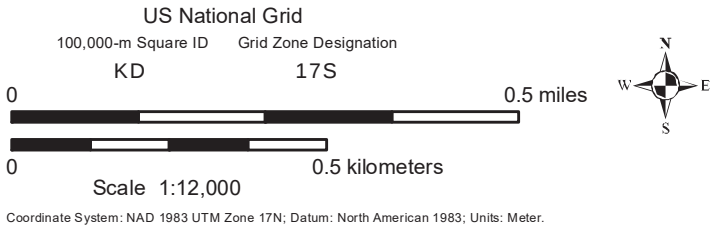
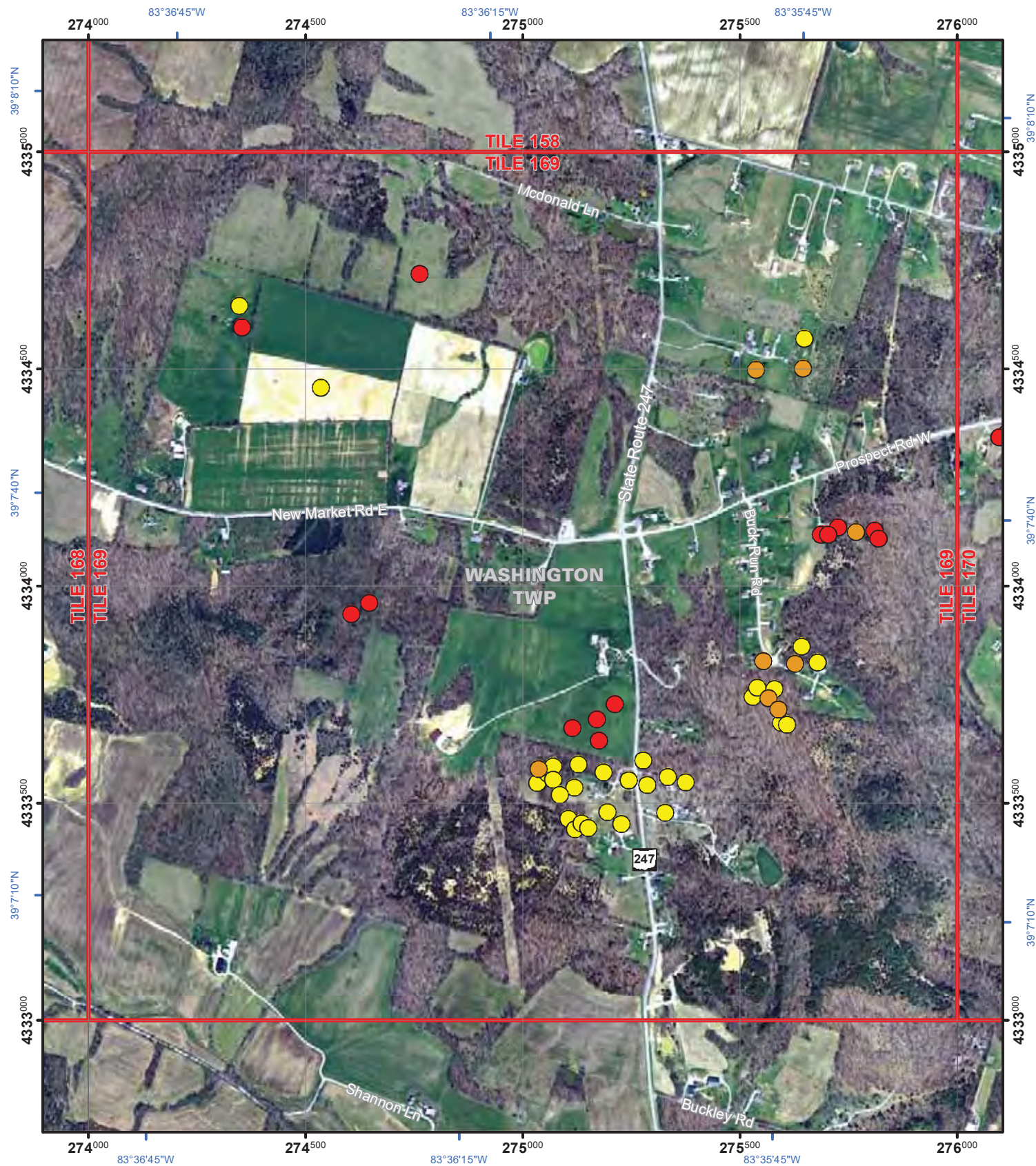
1	5	9
2	6	10
3	7	
4	8	

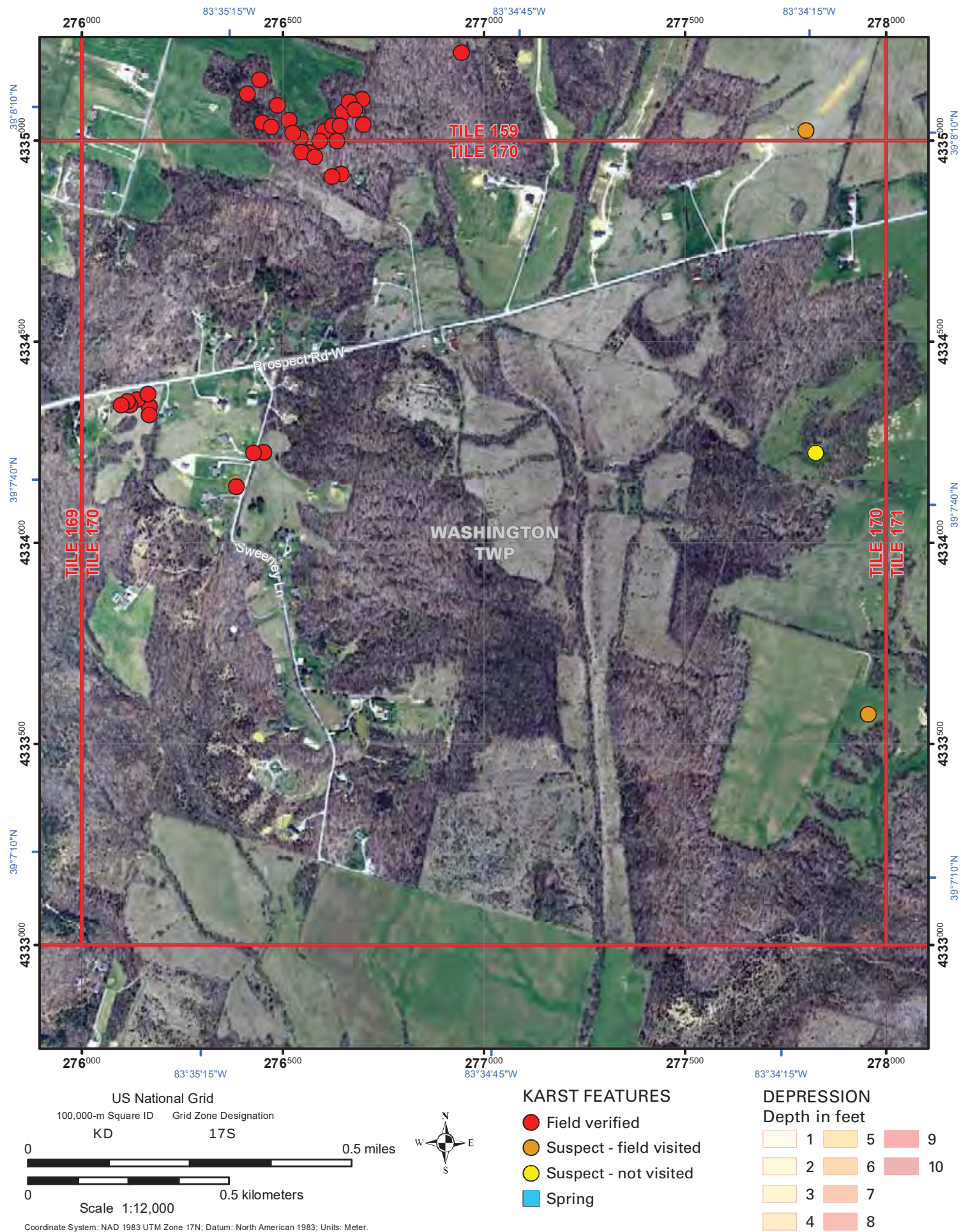


- KARST FEATURES
- Field verified
 - Suspect - field visited
 - Suspect - not visited
 - Spring











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

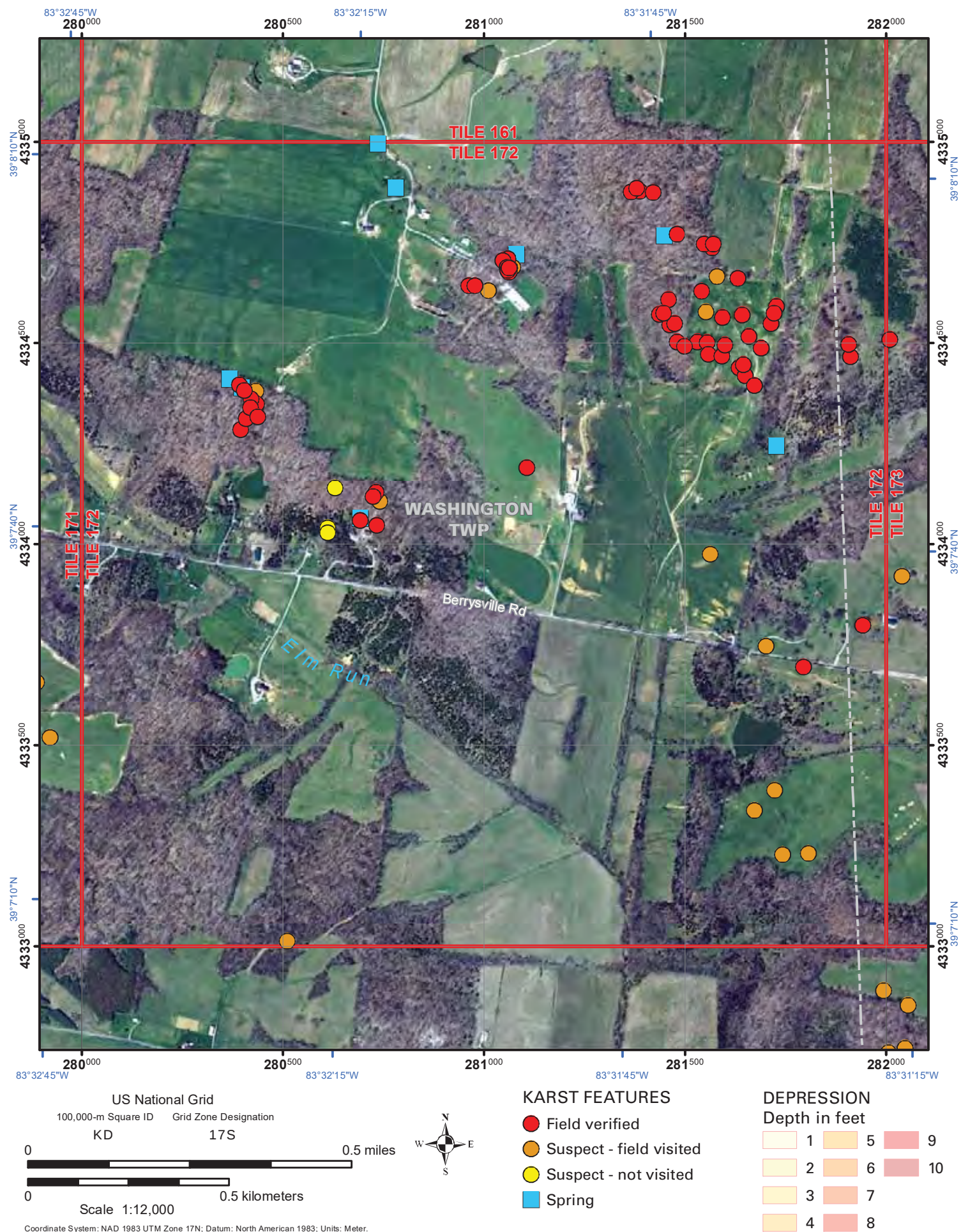
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- Suspect - field visited
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- Spring

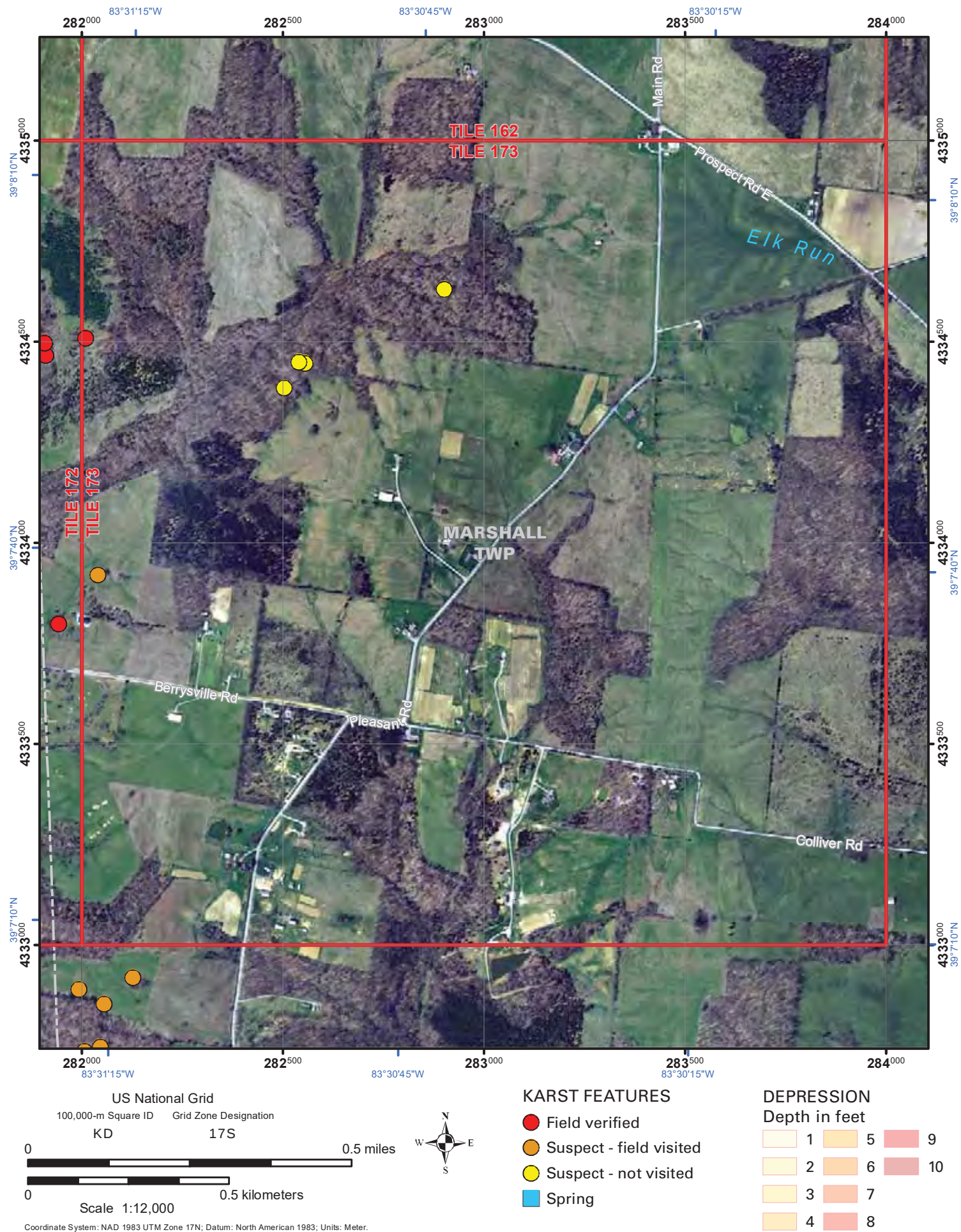
DEPRESSION

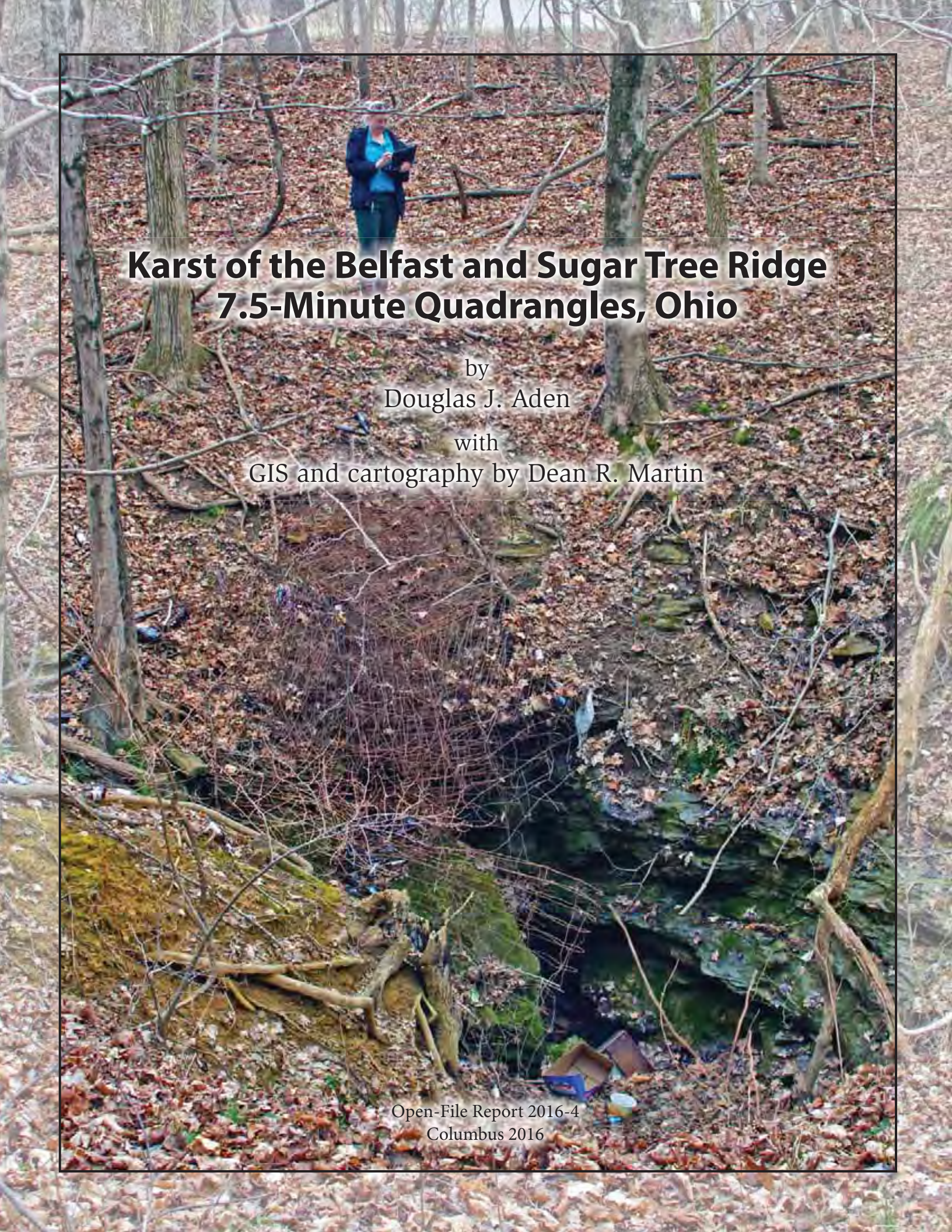
Depth in feet

1	5	9
2	6	10
3	7	
4	8	

Tile Number: 172





A photograph of a forest floor covered in fallen leaves and branches. In the background, a person wearing a blue shirt and dark pants is standing and looking at a device. The foreground shows a rocky outcrop with some debris and a small stream or ditch.

Karst of the Belfast and Sugar Tree Ridge 7.5-Minute Quadrangles, Ohio

by
Douglas J. Aden

with
GIS and cartography by Dean R. Martin

Open-File Report 2016-4
Columbus 2016



DISCLAIMER

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Cover image: An active, 19-feet deep sinkhole in Adams County, Ohio. The bedrock is Silurian-age Peebles Dolomite, Lilley Formation, and Bisher Formation undivided and has been exposed by slow subsidence. Metal fencing and some trash is present, likely because of the proximity of a small road along the top edge of the sink. The depression extends just across the road and may cause road problems as sinking continues. Left and outside of the photo frame, a culvert drains from across the road into this sink, likely increasing erosion and sinking.

Recommended bibliographic citation: Aden, D.J., 2016 Karst of the Belfast and Sugar Tree Ridge 7.5 Minute Quadrangles, Ohio: Columbus, Ohio Department of Natural Resources, Division of Geological Survey Open-File Report 2016-4, 7 p., 68 maps.

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

Karst of the Belfast and Sugar Tree Ridge 7.5-Minute 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 dolostone, 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 and often have a “throat” or opening at the bottom that drains to the subsurface. A stream that flows into a sinkhole is known as a *disappearing stream* or *losing stream*. Water flowing into the ground can cause solution enlargement of natural fractures in the rock; these fractures 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). When water exits these solutional features, a spring is formed.

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 can filter contaminants. Consequently, when compounds such as fertilizers,

pesticides, and waste enter sinkholes, they are rapidly transported to the water table and can quickly pollute water wells, streams, springs, and rivers.

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 Belfast, Ohio (fig. 1). This effort is among several other karst mapping projects (fig. 1) undertaken by the Ohio Geological Survey in recent years to document karst terrain throughout Ohio.

PREVIOUS WORK

Karst areas have been studied in Ohio for many years. During the 1980s and 1990s, karst was re-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 updated with new data in 2003, 2005, and 2007.

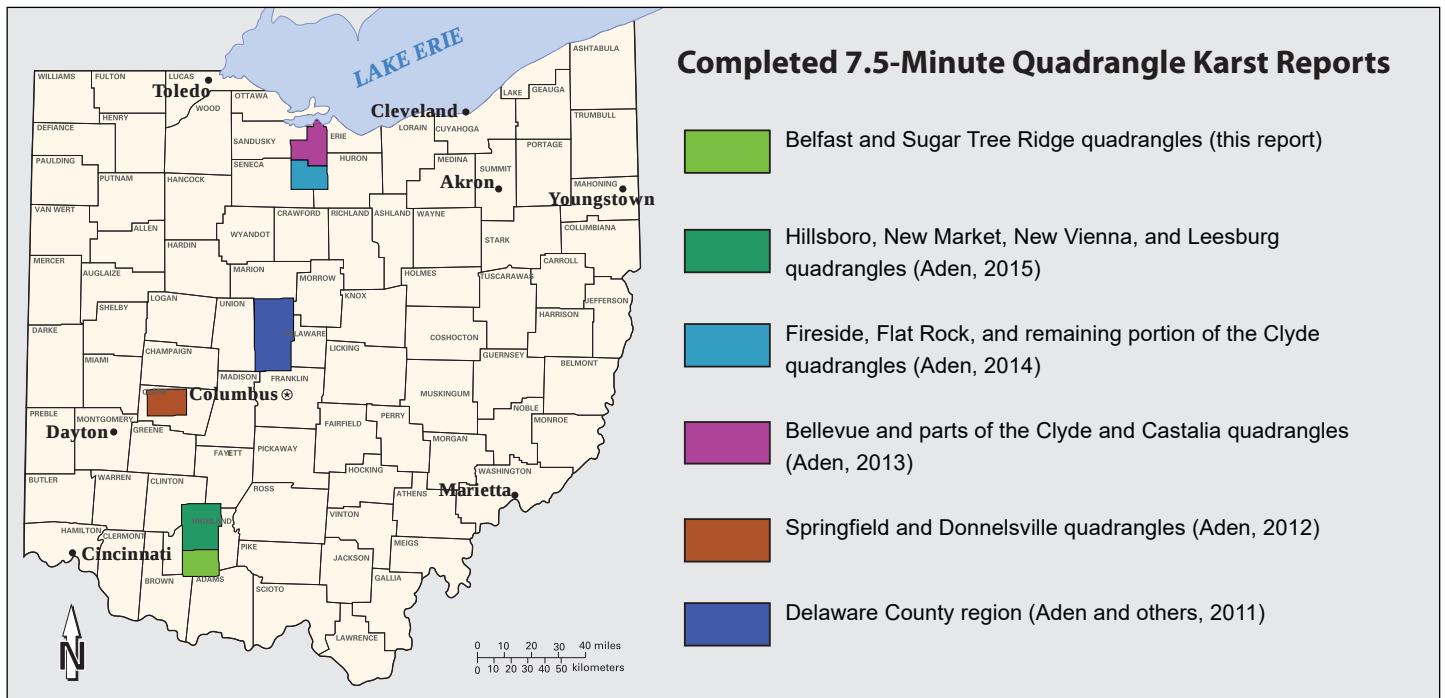


FIGURE 1. Locations of completed quadrangle-based karst reports in Ohio since 2010. The Delaware County regional study included six full quadrangles and parts of 14 other quadrangles in the region.

During the spring of 2008, severe karst-related flooding occurred in Bellevue and led to concerns among area residents regarding Ohio's geologic hazards related to karst features (Raab and others, 2009; Pavey and others, 2012) and initiated detailed karst mapping of the state, which began in 2010. This report represents the sixth completed karst mapping project since that time (fig. 1). All six completed areas have a map book and a DVD containing the Geographic Information System (GIS) data, metadata, Light Detection and Ranging (LiDAR) depressions, and photographs of many of the features. The GIS data contains details such as the location of each point and a brief description of what was found. 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.

METHODOLOGY

A digital elevation model (DEM), generated from LiDAR 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 from previous studies, bedrock geology, aerial photography of multiple sources and ages, soil maps, glacial drift thickness maps, and water well logs. Many depressions were determined not to be karst by examining aerial photography and from previous experience conducting field verification.

Suspected karst features 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. 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 spring-houses.

Field visits are important for confirming sinkhole sizes and depths as well. Digital elevation models based on LiDAR data often do not depict maximum sinkhole depths because the laser pulses fail to hit the lowest point within a depression. This year a plumb bob was used to measure the depths, lengths, and widths of many sinkholes, especially if they were deeper than the LiDAR indicated or not present on the LiDAR. Some small sinkholes have formed since this LiDAR dataset was collected (2006–2010), and every effort was made to measure these in the field. Field mapping this year also was facilitated by using an electronic tablet with ArcGIS Collector software. For previous projects, paper maps were used with aerial photographs for locating sinkholes in the field. Field

digitizing on an electronic tablet with an integrated Global Positioning System (GPS) was helpful for precisely locating new or small sinkholes and springs that were not detected on LiDAR or imagery.

RESULTS

The resulting karst feature data set was overlain on a reference map and four geologic maps showing the Land Surface, Bedrock Geology, Bedrock Topography, and Drift Thickness. The Land Surface map (fig. 2) shows the 88 two-km² tiles and the 7.5-minute quadrangles that form the project area overlain on a DEM of the land surface. The Land Surface map of the Belfast region shows a concentration of sinks, near the break in slope at the tops of hills, that often occur in clusters. A strong directional trend was not observed in this project area.

On all maps, tiles outlined in red contain the karst features identified during this project. No karst features were identified in tiles outlined in black. In total, the study area has 2,020 karst features (table 1), including 121 springs. These karst features occur in 67 of the 88 mapped tiles. Note that the project area is defined by the tiles and not the 7.5-minute quadrangle boundaries. Also, there is minor overlap with the previous project, along the northern border where some points were updated. At the top left of each aerial imagery page (p. 8–74), a Tile Number references the corresponding numbered tile on the four overlay maps and the reference map (figs. 2–6).

There are four types of karst features identified on the maps:

- 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 subtle LiDAR depressions—in a location where access to the property could not be gained, or where the field point was not verified.
- Blue squares represent springs where water was found or reported to be flowing from the subsurface.

The Bedrock Geology map (fig. 3) shows that the karst features are forming primarily by dissolution of Silurian-age Peebles, Lilley, and Bisher Dolomites (table 1). Most well-developed karst is expressed as steep-walled, cone-shaped depressions with active sinking and a sink throat where water drains.

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. Springs also are located on shale; this is to be expected since water percolating down through vuggy (holes formed by dissolution) limestone is impeded by shale and moves horizontally until it reaches the land surface.

is called *bedrock topography* and is shown on fig. 4. The elevations of the bedrock surface were subtracted from the DEM (fig. 2) to create the Drift Thickness map (fig. 5). Knowing the drift thickness is useful because sinkholes generally develop where the drift is shallow (about 25 feet or less). Other sinkholes may exist in areas that have more than 25 feet of drift, but they were either buried beneath the glacial drift or

prevented from forming because of thick drift. The Belfast Drift Thickness map clearly shows the sinkholes are concentrated along areas of thin glacial drift (fig. 5).

A reference map also is provided to orient the user to the point and tile locations relevant to the roads, streams, counties, and townships (fig. 6).

TABLE 1. Number of karst points and the bedrock units in which they occur in the study area

Bedrock Unit ¹	No. of Karst Points
Peebles Dol, Lilley Fm, and Bisher Fm undiv. (Splb)	874
Tymochtee, Greenfield, and Peebles Dol, Lilley Fm, and Bisher Fm undiv. (St-b)	433
Estill Sh (Se)	340
Silurian Dayton Ls, Noland Fm, and Brassfield Fm undiv. (Sdnb)	311
Ordovician Drakes Fm and Waynesville Fm undiv. (Odw)	62
TOTAL	2,020

¹Dol = Dolomite; Fm = Formation; Ls = Limestone; Sh = Shale; undiv. = undivided.

Formations on the Bedrock Geology map are buried in many places by surficial glacial materials. The elevation of the bedrock below the surficial materials

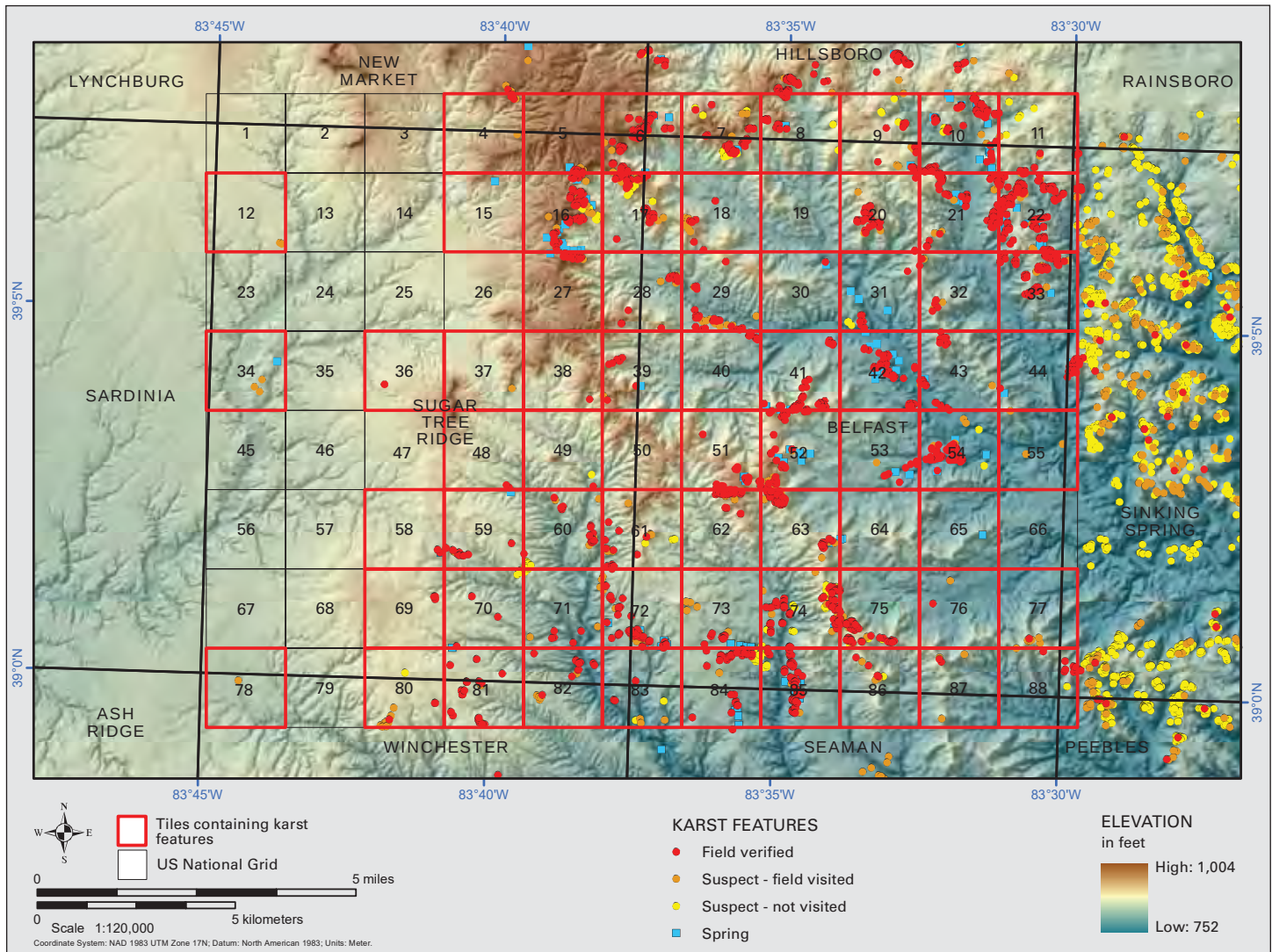


FIGURE 2. Digital elevation model (Land Surface map) showing topographic relief in the study area.

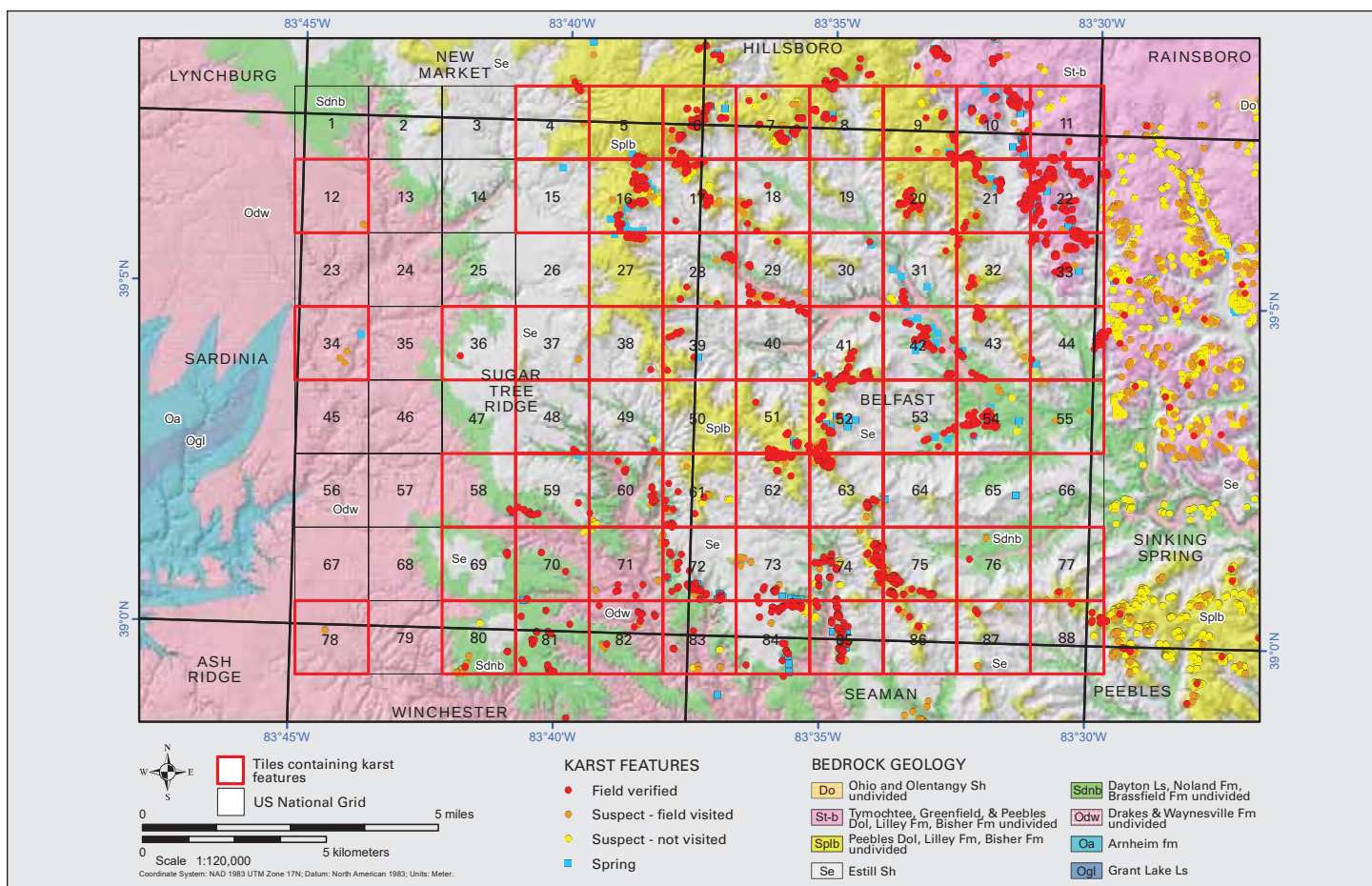


FIGURE 3. Lithified rock (bedrock geology) at the surface or beneath glacial material in the study area.

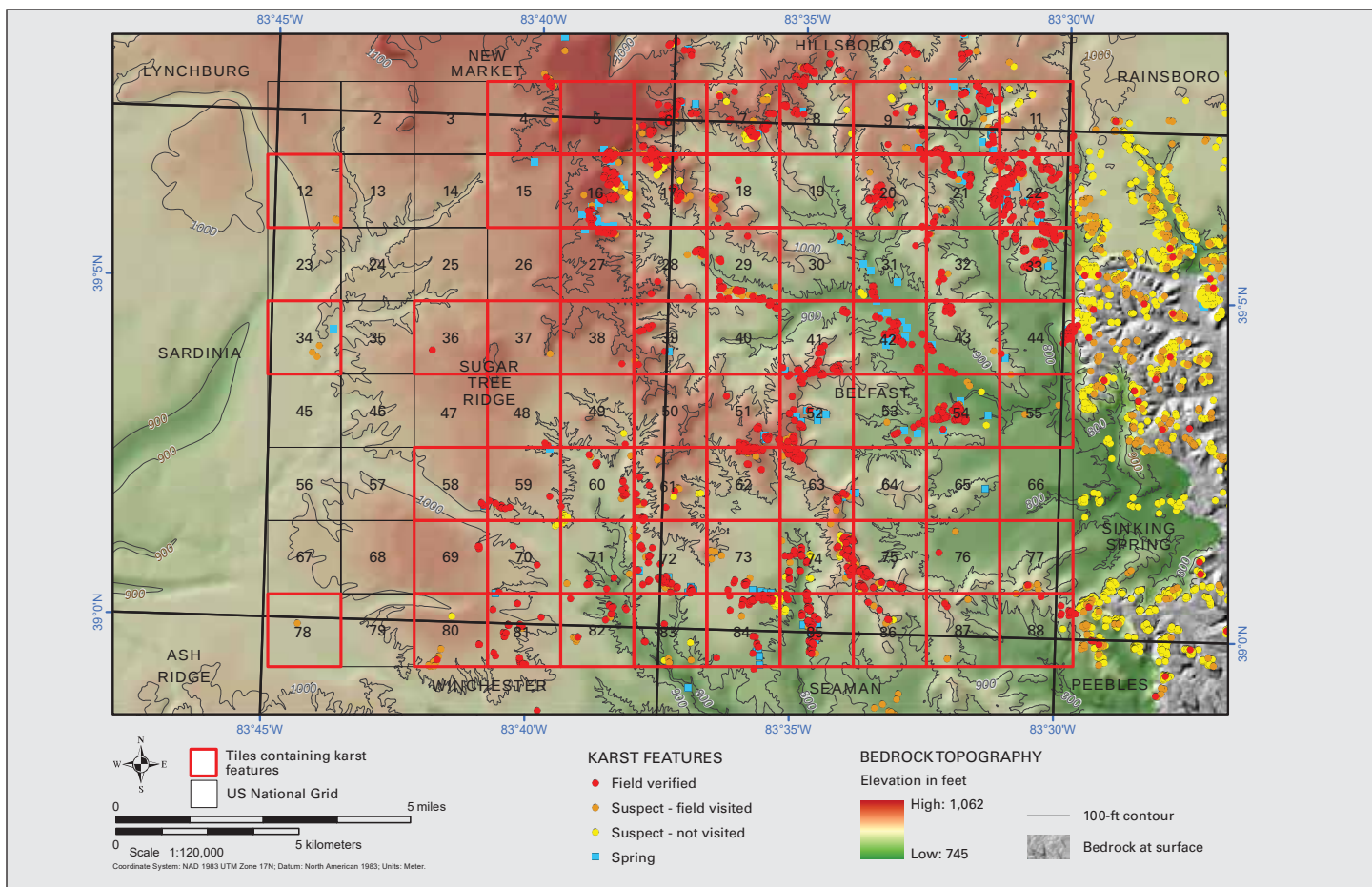


FIGURE 4. Bedrock topography in the study area.

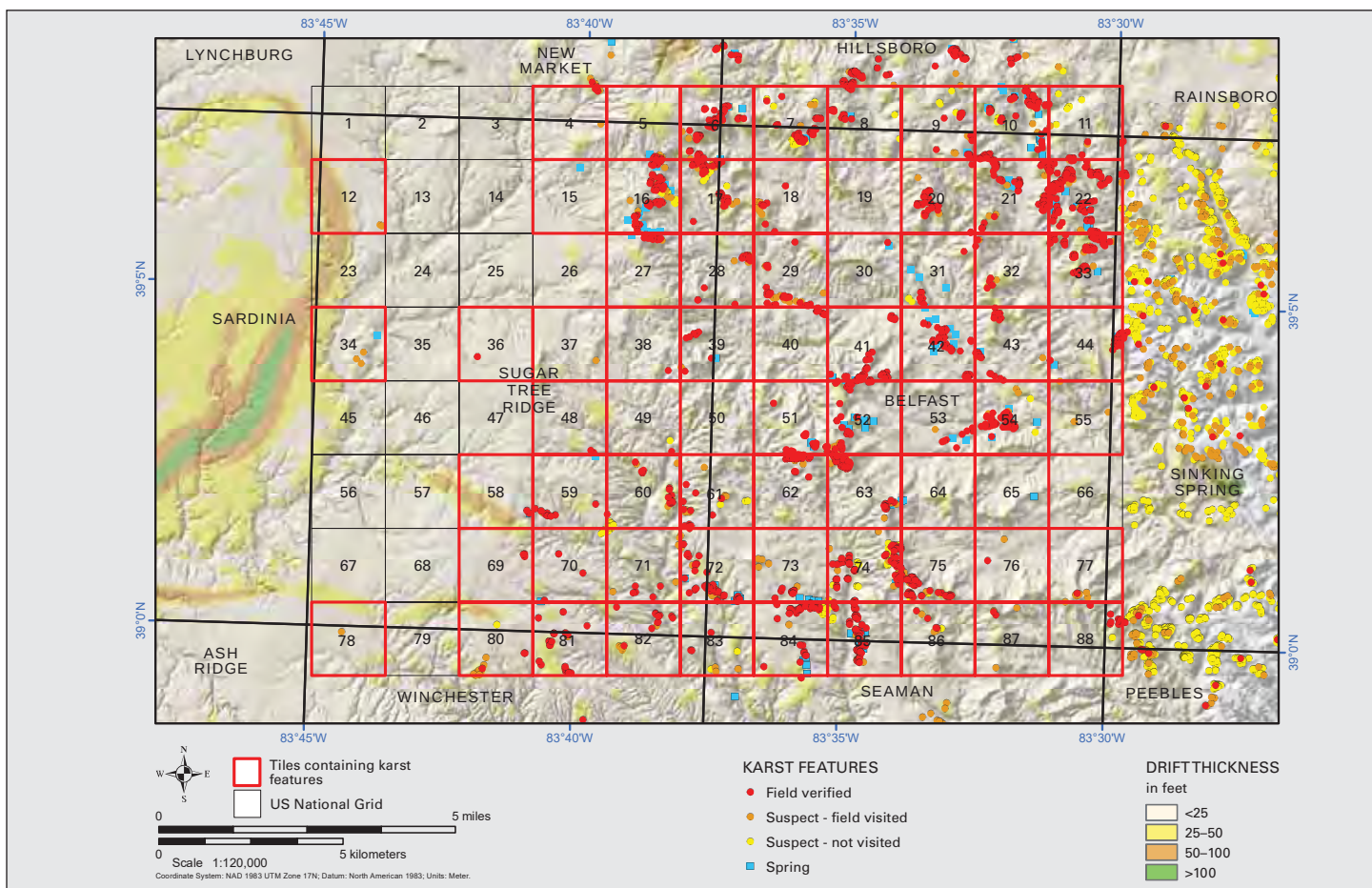


FIGURE 5. Thickness of glacial material (DEM minus Bedrock Topography) in the study area.

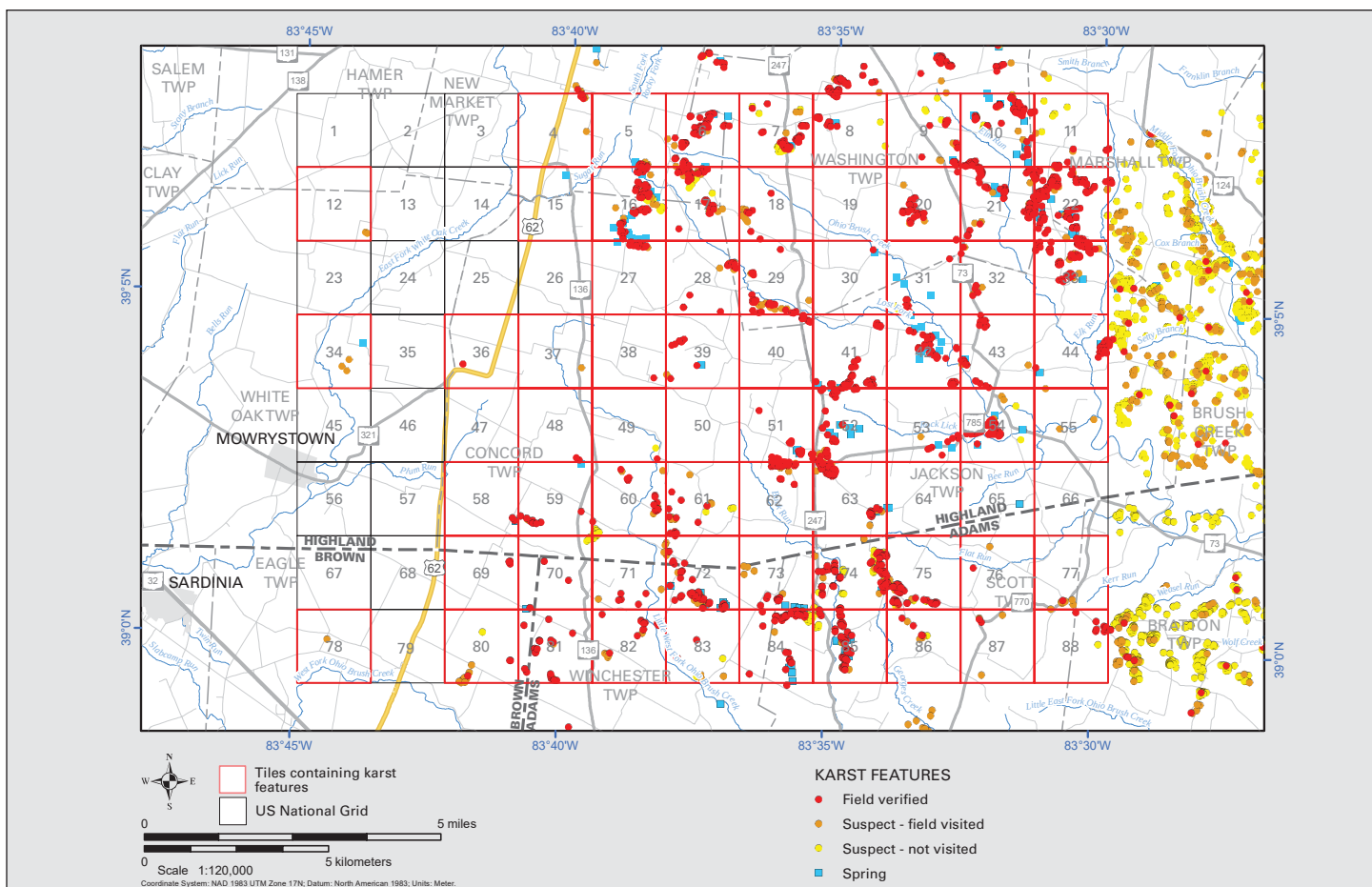


FIGURE 6. Reference map of the study area showing counties, townships, roads, towns, and streams.

Detailed two-km² map tiles (p. 8–74) contain specific karst point locations. Also included on these maps are karst depressions represented by yellow to red topographic lines. Each concentric ring represents a drop of one foot in elevation toward the low point of an internally drained area. Many of the depressions are covered by the points because the depressions are so small at the scale of the tiles.

CONCLUSIONS

Of the 2,020 mapped karst features, 1,436 have photos (from multiple angles for interesting features), and 1,143 were found using the LiDAR-derived depressions. In the study area, 121 springs were located and generally are found associated with clusters of sinkholes. The large number of sinks found without LiDAR (877) attests to the need for field verification near known karst areas. For example, about half of the features in tile 22 (p. 23) were located without the processed LiDAR, including 7 of 9 in an east-to-west trend in the center of tile 23. 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 works, and even sinkholes that have been periodically or historically filled in. In the study area, 439 depressions were reviewed and recorded as not being sinkholes.

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 ground water pollution, and subsidence can damage structures and alter land use. The maps and available GIS data of this report allow for, informed land use and development planning near karst features, and their impacts on natural resources and infrastructure to be mitigated.

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- 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

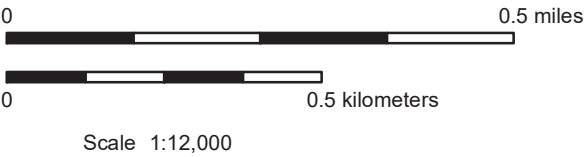
Lowlands—Ohio, *in* Palmer, A.N., and Palmer, M.V., eds., *Caves and Karst of the USA*: National Speleological Society, p. 136–140.

U.S. Geological Survey

USGS Groundwater Information, Karst and the USGS,

accessible at < <http://water.usgs.gov/ogw/karst/> > .

Tile Number: 4

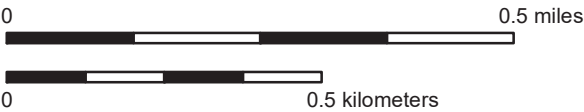


- KARST FEATURES**
- Field verified
 - Suspect - field visited
 - Suspect - not visited
 - Spring

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

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

Tile Number: 5



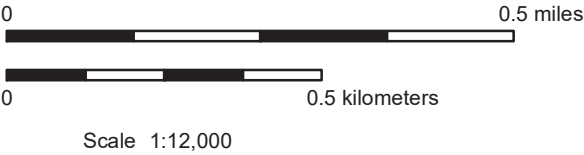
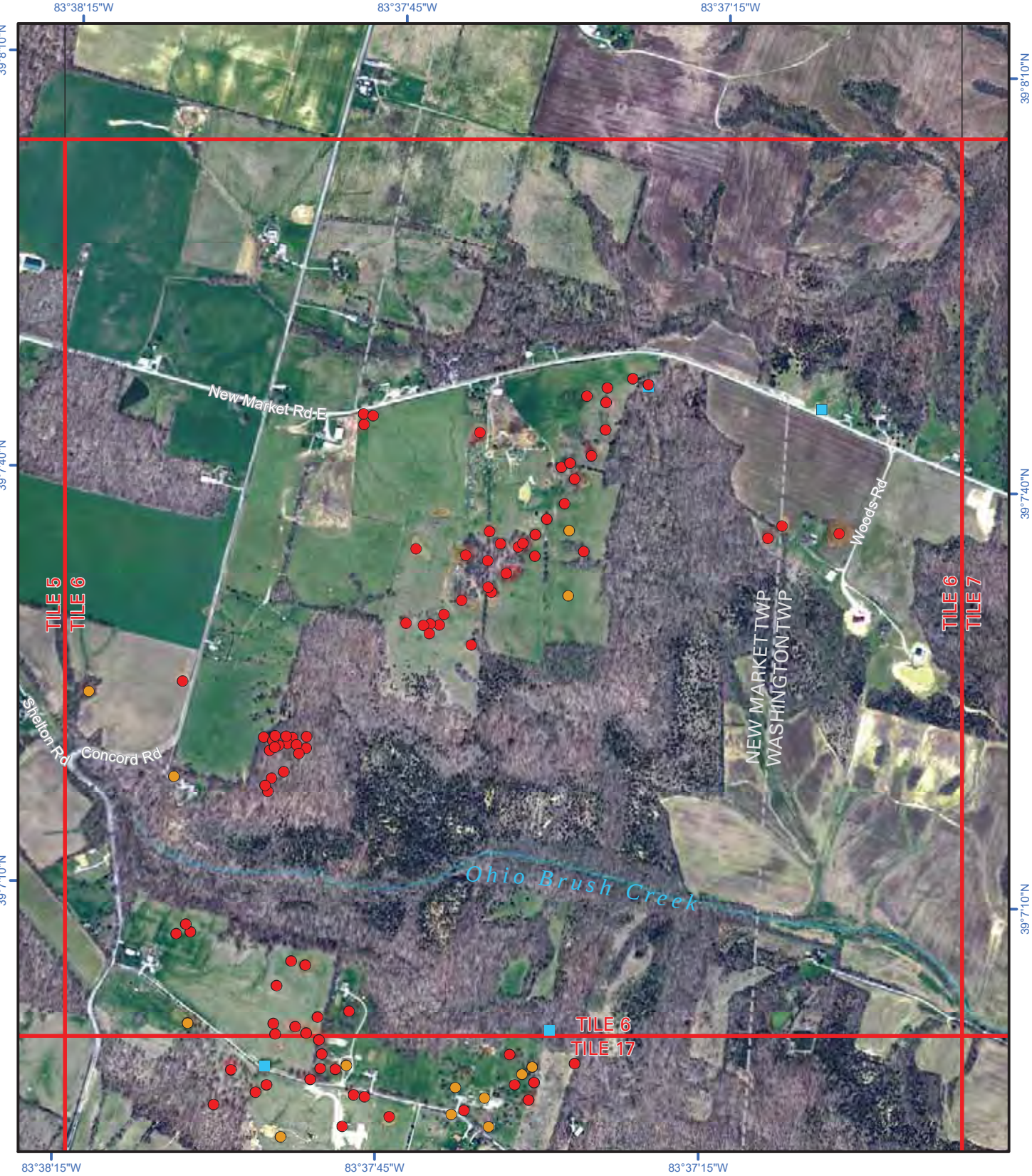
- KARST FEATURES**
- Field verified
 - Suspect - field visited
 - Suspect - not visited
 - Spring

DEPRESSION
Depth in feet

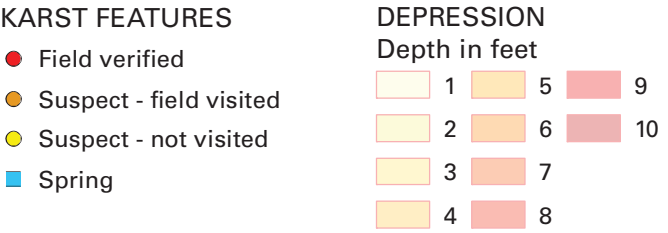
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3	7	
4	8	

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

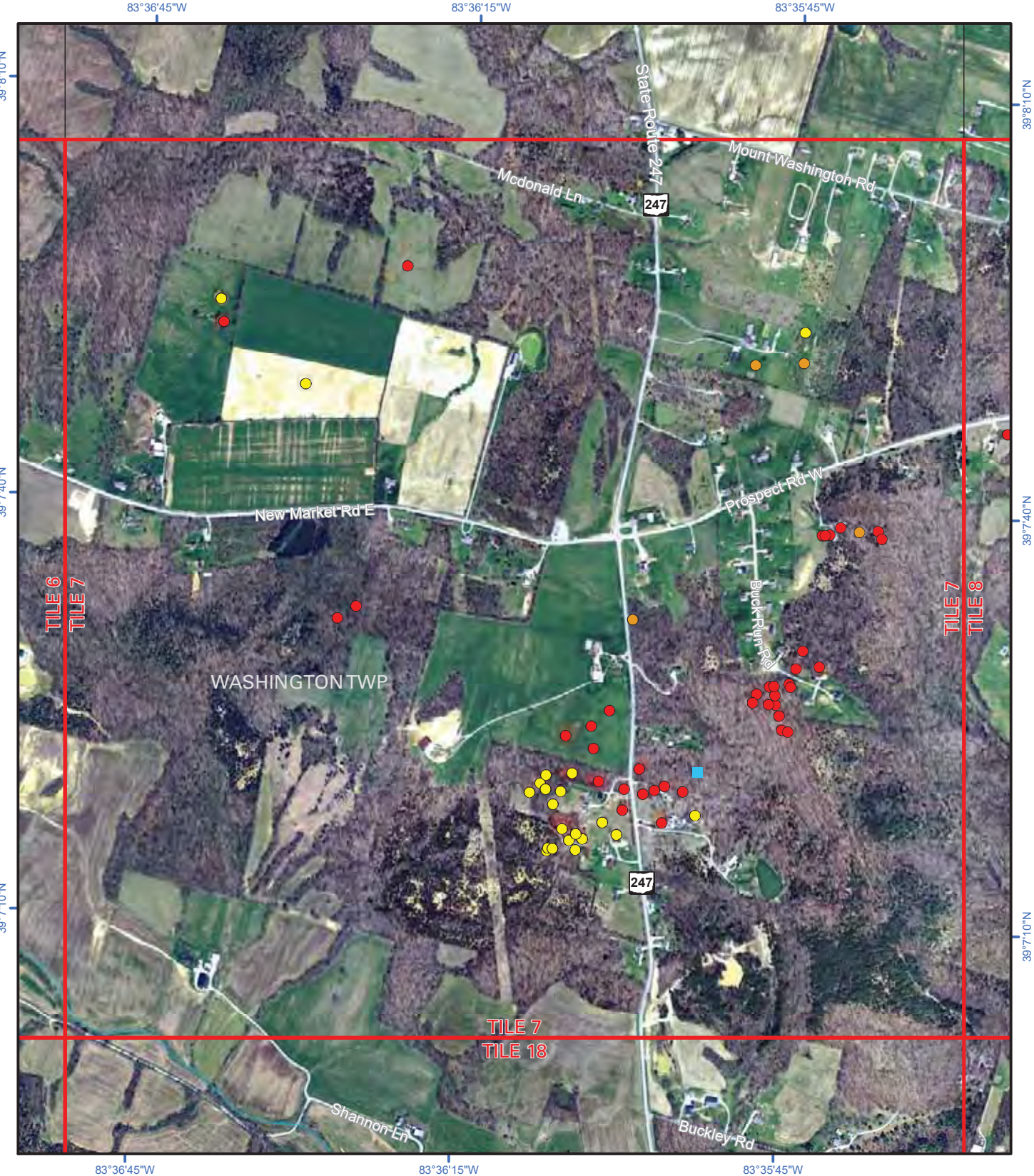
Tile Number: 6



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



Tile Number: 7



0 0.5 miles

0 0.5 kilometers

Scale 1:12,000



KARST FEATURES

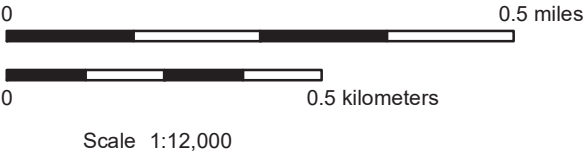
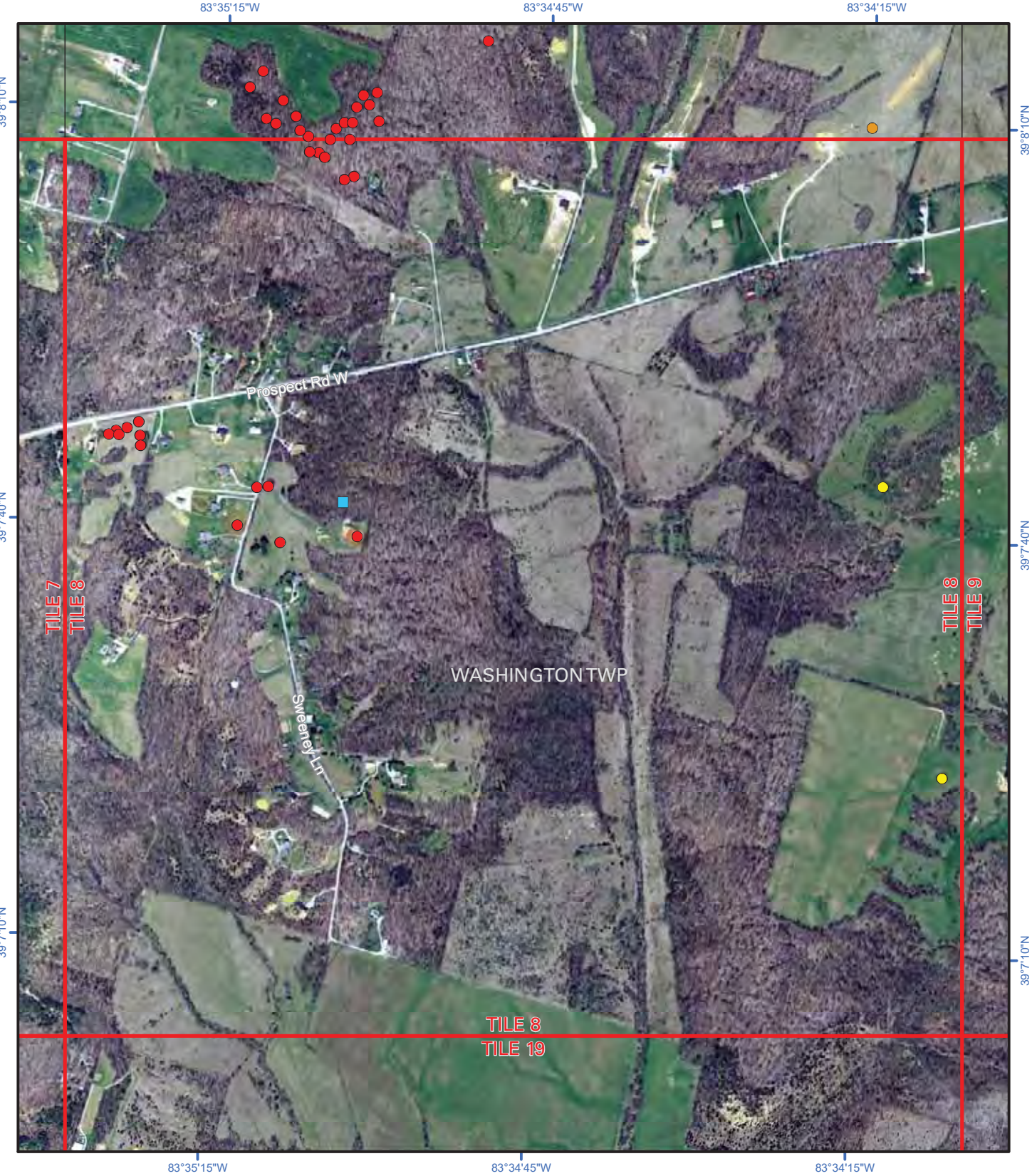
- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

DEPRESSION
Depth in feet

1	5	9
2	6	10
3	7	
4	8	

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

Tile Number: 8



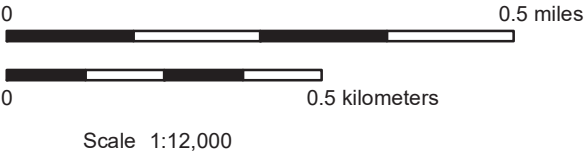
- KARST FEATURES**
- Field verified
 - Suspect - field visited
 - Suspect - not visited
 - Spring

DEPRESSION
Depth in feet

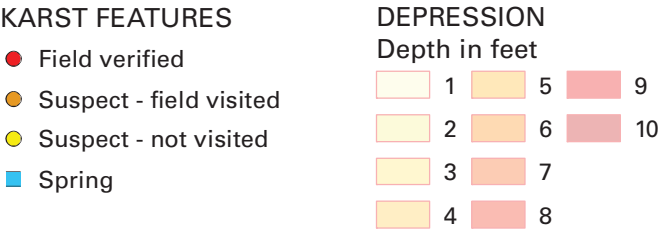
1	5	9
2	6	10
3	7	
4	8	

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

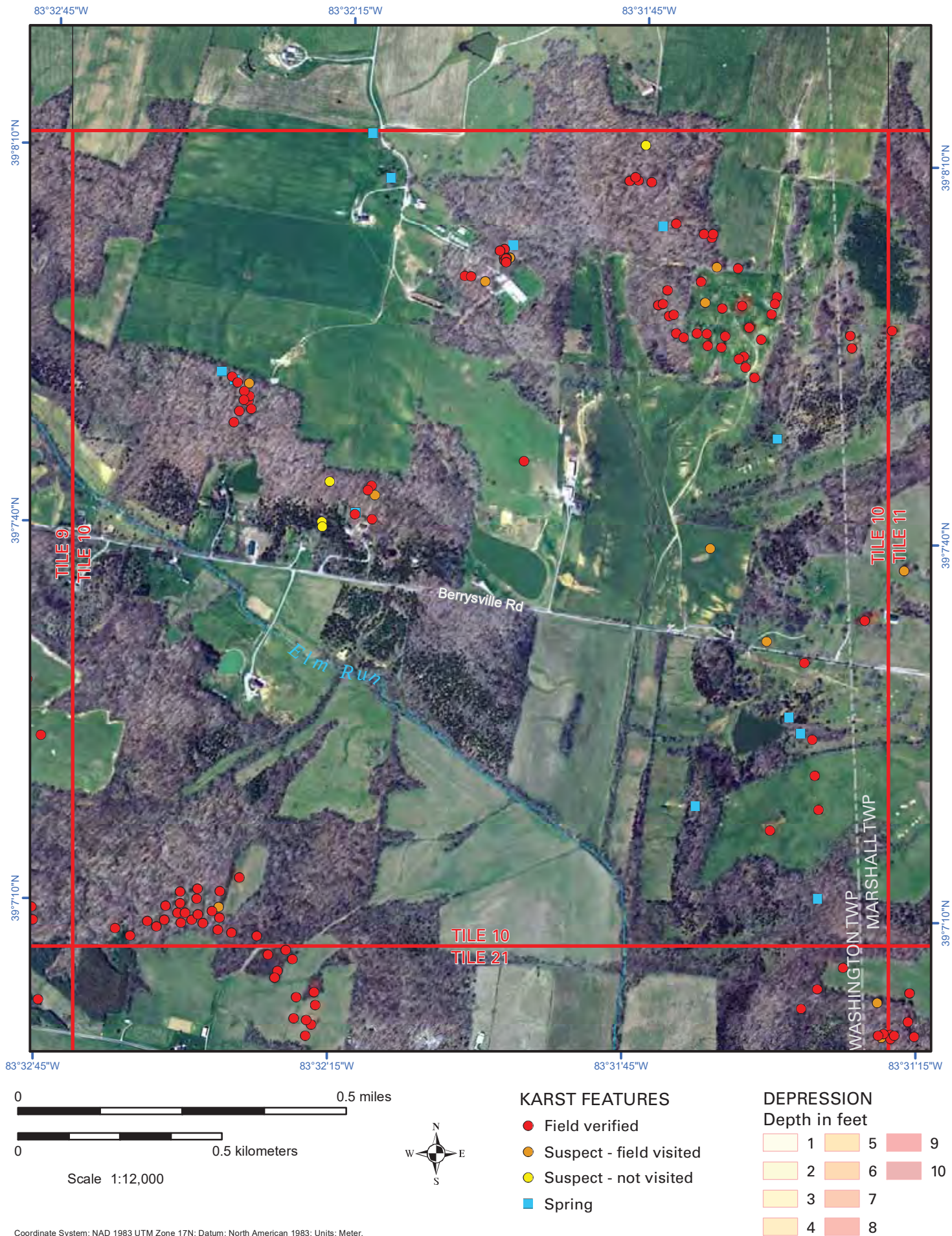
Tile Number: 9



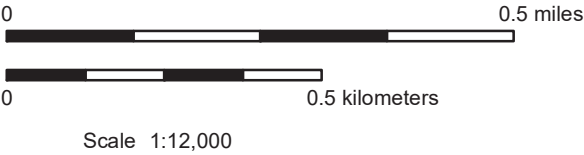
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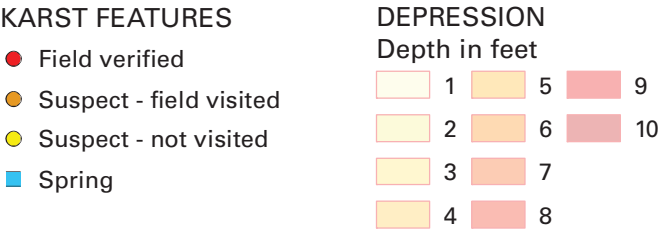
Tile Number: 10



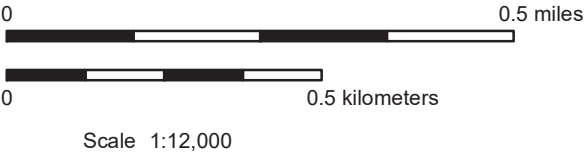
Tile Number: 11



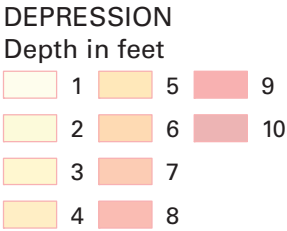
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Tile Number: 12

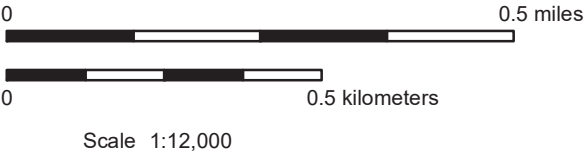


- KARST FEATURES**
- Field verified
 - Suspect - field visited
 - Suspect - not visited
 - Spring



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

Tile Number: 15



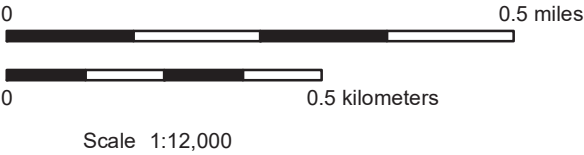
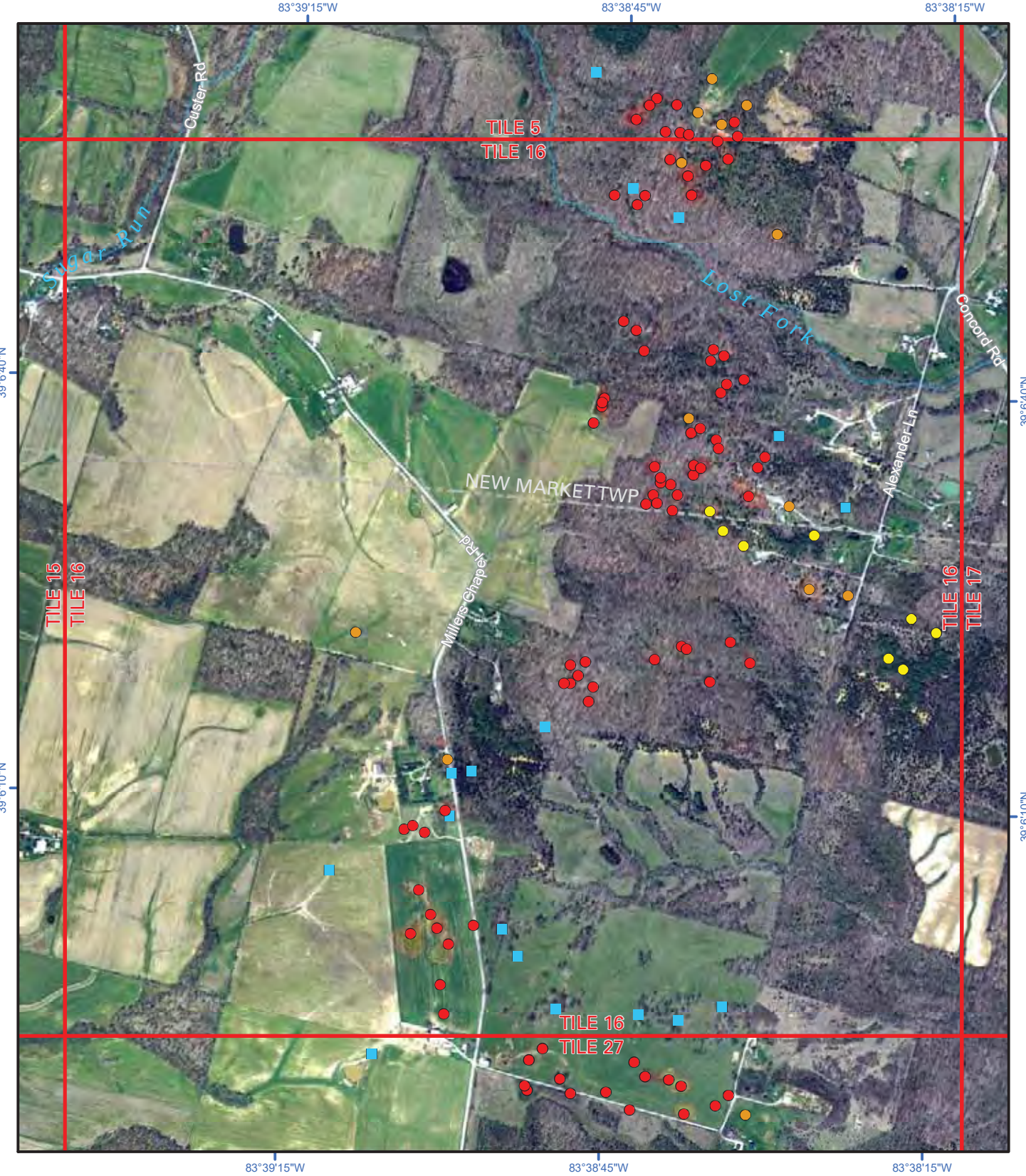
- KARST FEATURES**
- Field verified
 - Suspect - field visited
 - Suspect - not visited
 - Spring

DEPRESSION
Depth in feet

1	5	9
2	6	10
3	7	
4	8	

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

Tile Number: 16



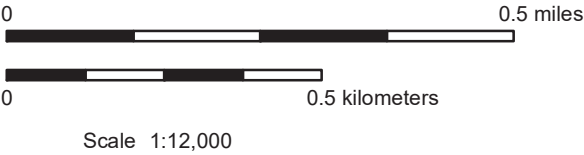
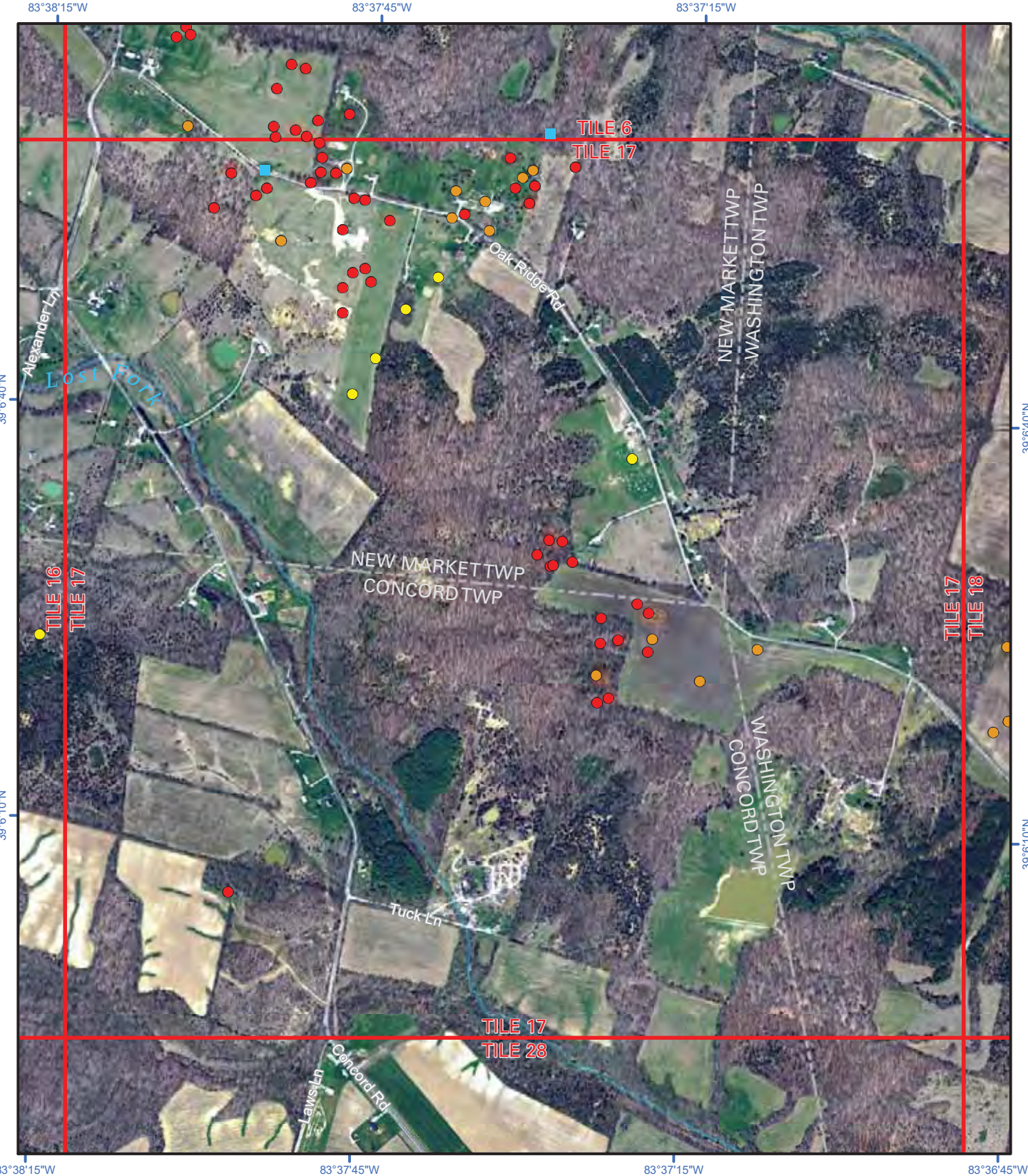
Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

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

DEPRESSION
Depth in feet

1	5	9
2	6	10
3	7	
4	8	

Tile Number: 17



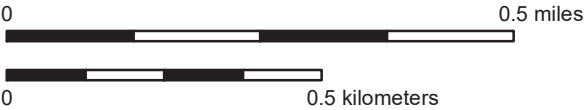
- KARST FEATURES**
- Field verified
 - Suspect - field visited
 - Suspect - not visited
 - Spring

DEPRESSION
Depth in feet

1	5	9
2	6	10
3	7	
4	8	

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

Tile Number: 18



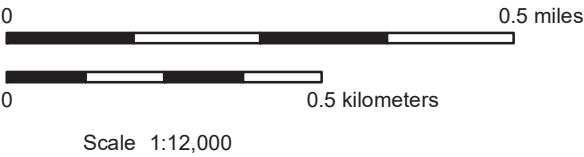
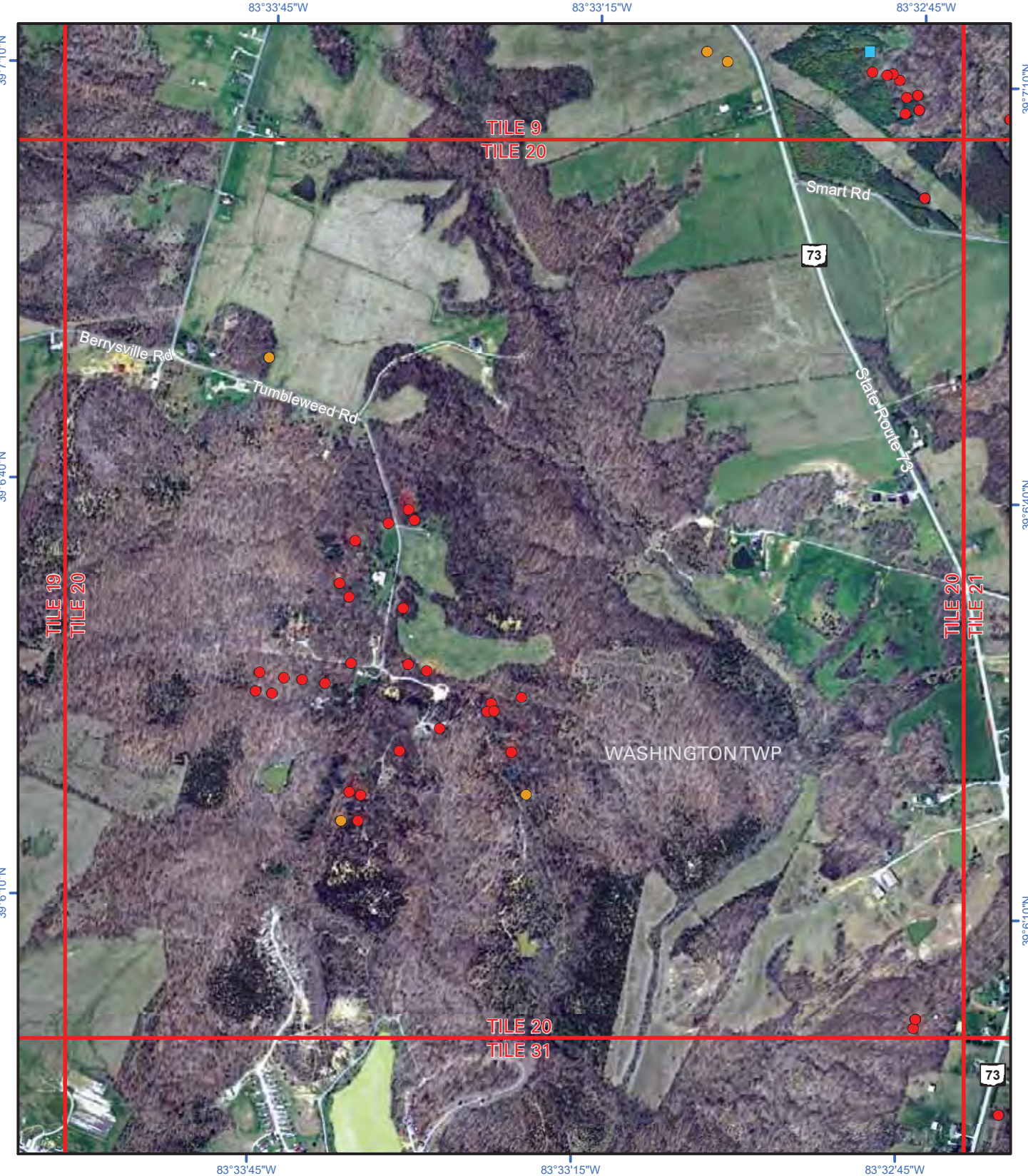
- KARST FEATURES**
- Field verified
 - Suspect - field visited
 - Suspect - not visited
 - Spring

DEPRESSION
Depth in feet

1	5	9
2	6	10
3	7	
4	8	

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

Tile Number: 20



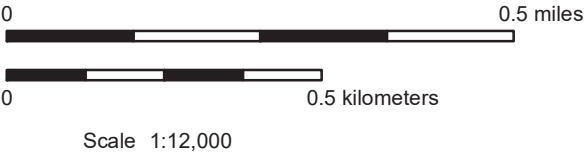
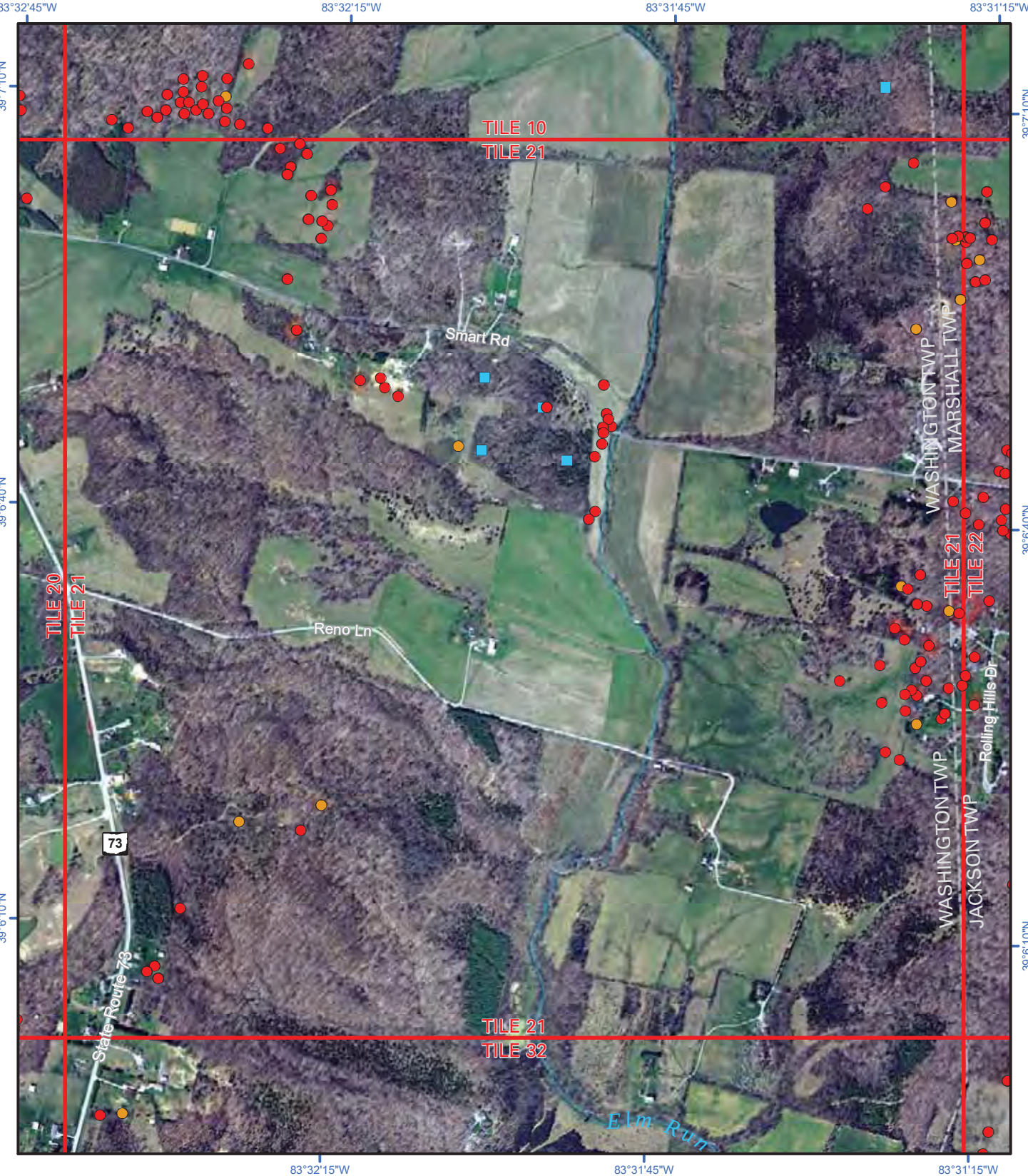
- KARST FEATURES**
- Field verified
 - Suspect - field visited
 - Suspect - not visited
 - Spring

DEPRESSION
Depth in feet

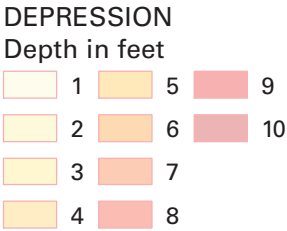
1	5	9
2	6	10
3	7	
4	8	

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

Tile Number: 21

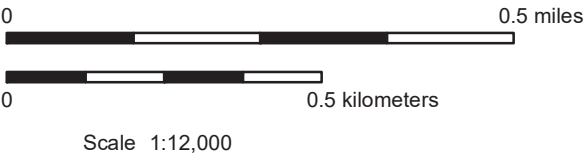
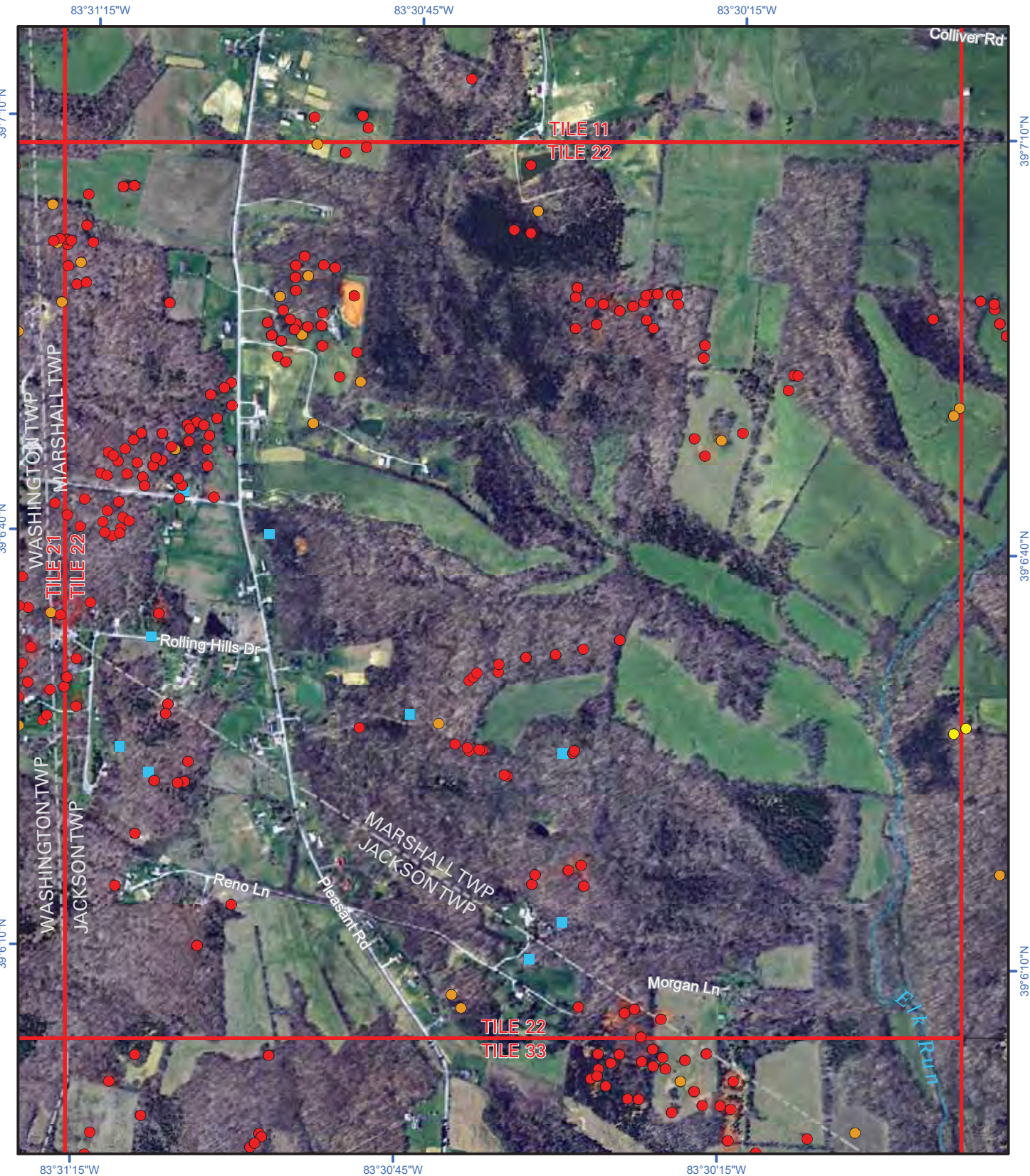


- KARST FEATURES**
- Field verified
 - Suspect - field visited
 - Suspect - not visited
 - Spring

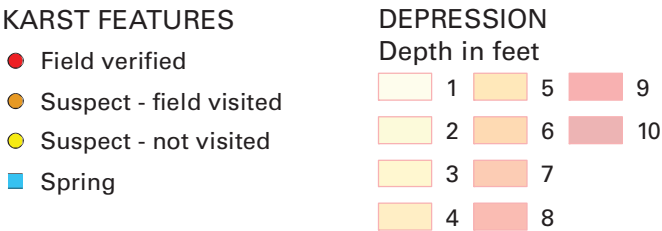


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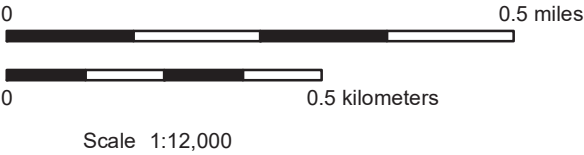
Tile Number: 22



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



Tile Number: 27



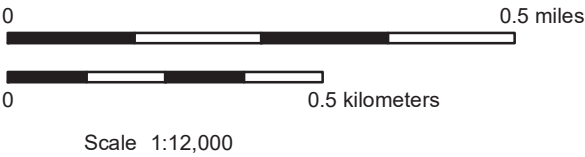
- KARST FEATURES**
- Field verified
 - Suspect - field visited
 - Suspect - not visited
 - Spring

DEPRESSION
Depth in feet

1	5	9
2	6	10
3	7	
4	8	

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

Tile Number: 28



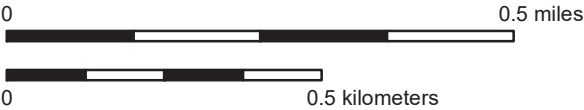
- KARST FEATURES**
- Field verified
 - Suspect - field visited
 - Suspect - not visited
 - Spring

DEPRESSION
Depth in feet

1	5	9
2	6	10
3	7	
4	8	

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

Tile Number: 29



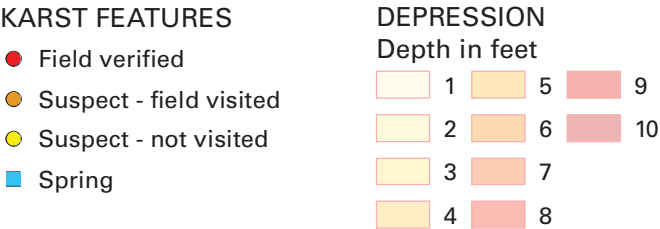
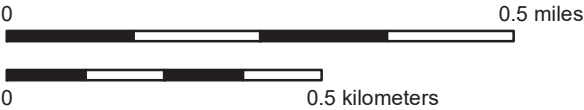
- KARST FEATURES**
- Field verified
 - Suspect - field visited
 - Suspect - not visited
 - Spring

DEPRESSION
Depth in feet

1	5	9
2	6	10
3	7	
4	8	

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

Tile Number: 30

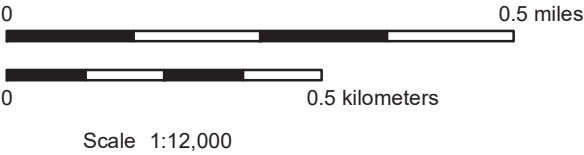


Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

Tile Number: 31



Tile Number: 32



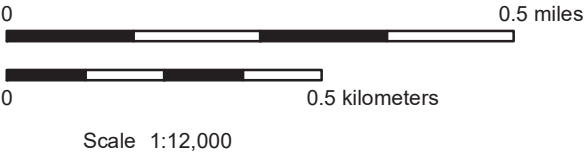
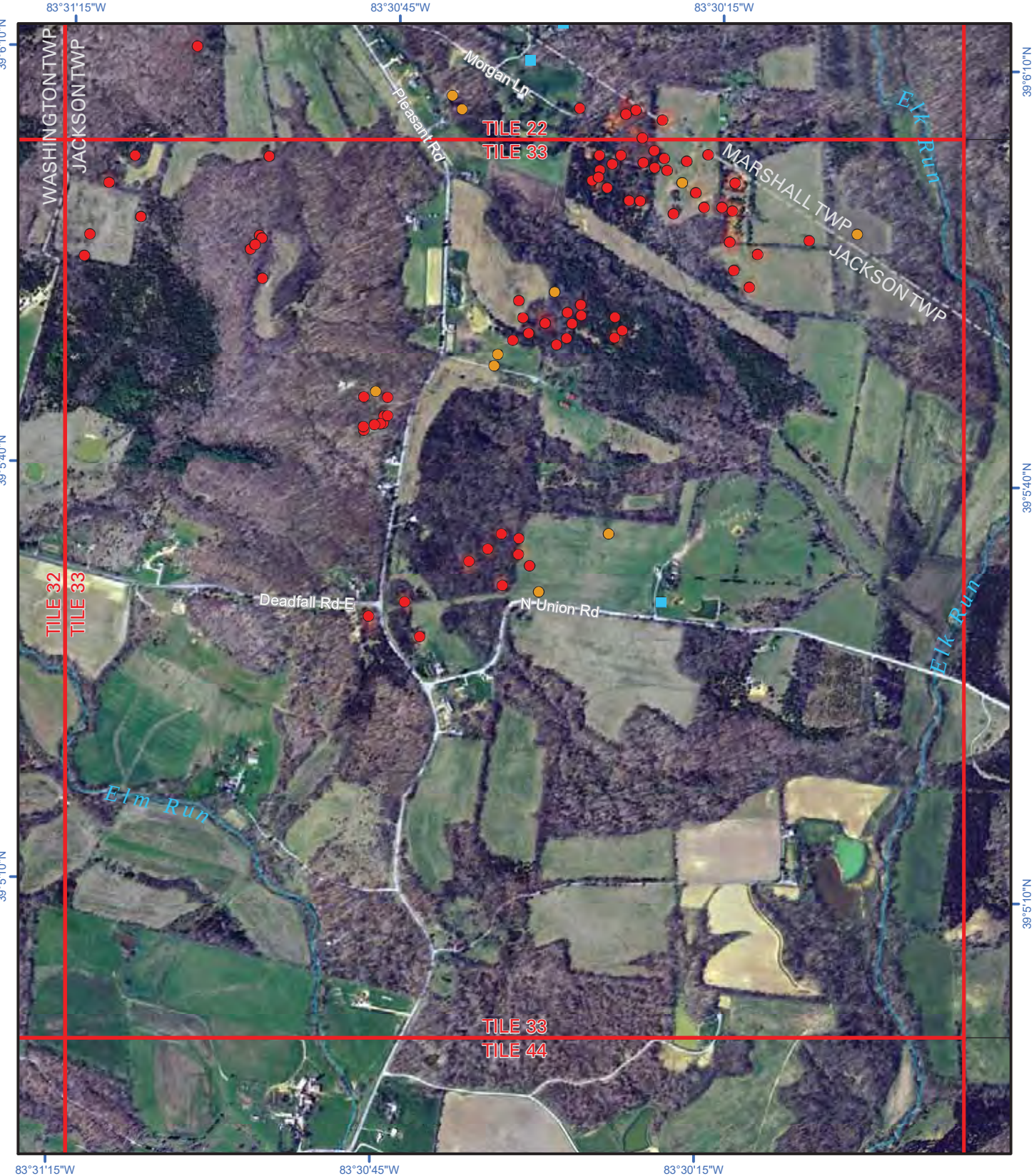
- KARST FEATURES**
- Field verified
 - Suspect - field visited
 - Suspect - not visited
 - Spring

DEPRESSION
Depth in feet

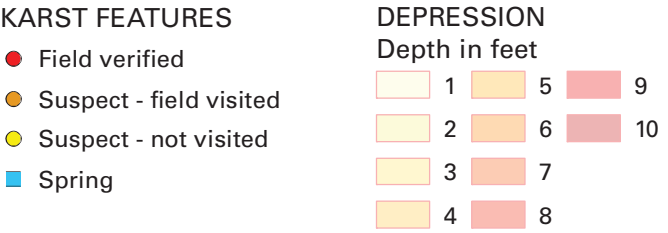
1	5	9
2	6	10
3	7	
4	8	

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

Tile Number: 33



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



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Commission of Ohio Docketing Information System on

9/17/2018 3:47:09 PM

in

Case No(s). 18-1024-EL-BGN

Summary: Application Exhibit F, Part 2 of 3 electronically filed by Mr. MacDonald W Taylor on behalf of Willowbrook Solar I, LLC