Identifying Sinkholes and Manure Management Setbacks in Albany County using LIDaR and Aerial Photography: Final Report

By

Paul L. Richards¹, Marine David¹, and Michael D. Rodgers²

1 Dept. of Earth Science, The College at Brockport
350 New Campus Drive, Brockport, NY.
prichard@brockport.edu
(585) 260-2988

2 Dept. of Biology and Environmental Science
350 New Campus Drive, Brockport, NY.

ABSTRACT

LIDaR Hillshades and 2013 aerial photography were used to map karst features in Albany County. This mapping was conducted because several previous well contamination events were caused by manure application near these features, and that new guidelines regarding the management of manure in karst areas may soon be implemented in New York State. Thinly-soiled karst areas, exposed bedrock, and sinkholes provide a direct route for surface pollutants like manure to travel into the groundwater table. As a consequence it is very easy to pollute nearby domestic water supply wells. The study found 416 such features of which 32 were individual sinkholes, 11 were swallets, and 373 were sinkhole complexes containing multiple open fractures and sinkholes. The latter are areas containing more than one sinkhole that are too small to map individually. The study also mapped 453 miles of escarpments which have been shown to be associated with karst areas. Soils identified as the Farmington series appear to be good guides to thinly-soiled karst features. Fieldwork undertaken during this study suggests the following 1) Sinkholes tend to be smaller than the 2 meter resolution of the existing LIDaR data. 2) Many of the sinkholes were linear in nature and constitute open fractures in the bedrock. 3) Larger oval and circular sinkholes, (the features observable from the LIDaR data) occur at the intersections fractures. 4) Sinkholes are located at regularly spaced intervals that are consistent with the spacing of significant fractures. These features are sometimes visible from the Hillshades as orthogonal textured patterns. They can be distinguished from plow patterns by not being parallel to the sides of fields. 5) Portions of the landscape were clear cut and farmed in karst areas. Sinkholes in these areas were filled up and leveled. These areas are not detectible from the surface relief (hillshades), but they can be observed in the field. A suite of high quality maps of these karst features overlain on 2013 aerial photography was created to assist farm planners and landowners to identify where these sensitive features are. The maps are available from our website: Karst.esc.brockport.edu. Land Use and Farm planners should make full use of this information in their decision making process, but we stress that all areas should be checked in the field for evidence of shallow bedrock before making any management decision.
INTRODUCTION

Manure application in the early spring is a major source of groundwater contamination in New York State. In the past 10 years there have been at least four well contamination events, the most recent of which occurred last year in Onondaga County. In each of these events, thinly-soiled karst, which provides an easy pathway for manure to travel into the groundwater, was implicated. For this reason the NYSDEC have implemented a new set of manure management guidelines that must be followed by all Confined Animal Feed Operators (CAFOs; Czimmek et al 2011). According to these guidelines, manure application is not allowed in the early spring on fields that contain specific soil series that are believed to only occur in thinly-soiled karst areas. These “targeted soils” (see Czimmek et al, 2004) have been chosen from the county soil surveys on the basis of their association with carbonate bedrock and their shallow depth to bedrock. The guidelines also state that manure application is not allowed within 100 feet of sinkholes and that catchment areas associated with sinkholes must also follow early spring management rules. These guidelines are an important step forward, but implementing them will be difficult in many counties of New York, because sinkhole and thinly-soiled karst areas have not been mapped. Furthermore, many of the targeted soils occur on non-carbonate bedrock (see Figure 1) or on thick glacial sediments where the depth to bedrock is much greater than what is stated in the soil survey. There is an urgent need to identify which of these targeted soils in Table 1 are accurate predictors of thinly-soiled karst in order to protect valuable groundwater supplies.

This study mapped sinkholes and exposed bedrock areas in order to identify which of the targeted soil types are actually associated with thinly-soiled karst. Fieldwork and existing well and borehole data were used to identify karst – targeted soil associations. Maps of this information were published as a series of PDF and rectified images that can be used by farmers and crop consultants to assist them in complying with the guidelines. These products were distributed to certified crop advisors (CCAs) that work in the region, NRCS-NY (Peter Wright, Conservation Engineer), Albany County Soil and Water Conservation District, and our funding agent, the New York State Water Resources Institute.

The study area, Albany County, contains two limestone bearing units where karst is known to occur: Onondaga FM and the Helderberg Group. The former consists of a suite of five limestone members: The latter consists of the Rondout FM, Manlius Limestone, the Coeyman’s Limestone, the Kalkberg FM and the New Scotland FM (Palmer et al, 2000)). Dating studies of stalactites suggest that most cave systems predate Wisconsin Glaciation, and some are even older than that (Weremeichik et al, 2013). Thus the surface expression of karst has been impacted by multiple glacial advances and retreats. Among the many impacts the ice sheets had (see Palmer et al, 2000 for details), are sinkholes were sometimes covered up by glacial till, uncovered by glacial meltwater, modified in shape through erosion, and occasionally plucked out completely by glacial movement. Also, lakes would form by ice dams left by the retreating ice sheet. This can inundate sinkholes, causing the deposition of lacustrine sediment within them (Weremeichik, 2013). Based on the work of Chimmek et al, 2004) our hypothesis is that the targeted soils that make up the best predictors of thinly-soiled karst will be located most frequently on or in closest proximity with sinkholes. Mapped karst areas will be rasterized with distance algorithms in GIS and overlaid with soils to statistically rank which of these targeted soil types are closest to targeted soils. Statistics will be assessed for both “false positives” and “false negatives”. The latter are important
because there may be soil types not on the list of targeted soils which are good predictors of thinly-soiled karst. To test this hypothesis and prepare the maps, we carried out the following objectives:

1) Identify all sinkholes and thinly soiled karst areas in the county using LIDaR, available water and gas well logs, aerial photography and available geological information.

2) Delineate setbacks associated with sinkholes, and produce a set of high quality geo-rectified maps that farmers and certified crop advisors can use to help agricultural producers comply with the new manure management guidelines.

Table 1  Targeted soil types found in Albany County (after Czymmek et al, 2004)

<table>
<thead>
<tr>
<th>Symbols</th>
<th>Soil Type</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>FwC, FrF, FrC, FrB, FaB</td>
<td>Farmington</td>
<td>Our field surveys determined that these are commonly associated with karst features</td>
</tr>
<tr>
<td>KeB</td>
<td>Kearsage</td>
<td>&lt; 20 in to non-calcareous bedrock</td>
</tr>
<tr>
<td>Ma</td>
<td>Madalin</td>
<td></td>
</tr>
<tr>
<td>NrD, NrC, NaC, NaB</td>
<td>Nassau</td>
<td>&lt; 20 in to non-calcareous bedrock</td>
</tr>
<tr>
<td>WnC, WcC, WcB, WcA</td>
<td>Wassaic</td>
<td></td>
</tr>
</tbody>
</table>
METHODOLOGY

Two meter digital elevation models for the study area, derived from LIDaR data, were converted to hillshades. Aerial photography (2013) was overlaid, along with available hydrography data, wetlands, targeted soils, surficial geology mapping, faults, DEC water wells, oil and gas wells, and USGS wells. Depressions, escarpments and glacial features such as ribbed moraines, end moraines, kettles, outwash channels, glacial mega flutes, and drumlins were identified and mapped using onscreen digitizing techniques. The mapping was conducted by zooming into individual tiles of the 2 meter LIDaR derived DEM and mapping features using ArcGIS software. Each tile was approximately 3000 feet wide. This tile grid forms the basis of the mapping index we use to prepare individual maps (Figure 2-6). Sinkholes were identified from the depressions by excluding glacial kettles (and other depressions located on thick glacial deposits) and anthropogenic depressions. Select features were verified in the field. Based on our field assessment, we classified karst features into three types, sinkholes, sinkhole complexes, and swallets.
Sinkholes are karst features that were large enough to be seen and digitized individually from two meter resolution hillshade. This tended to be features that were larger than 10 meters across. Sinkhole complexes are areas where more than one sinkhole or fracture were present (typically patterned ground sinkholes; Figure 7), and/or contained sinkholes too small to map. Swallets are individual sinkholes that are connected hydrologically to streams observable from aerial photography.

Once karst features were identified, a set of maps were created showing all karst features, escarpments, targeted soils, and well data indicative of depth to bedrock. One hundred foot setbacks from all sinkholes, sinkhole complexes and swallets were included. The maps also include 100’ setbacks for soil pedons classified as the Farmington series. These setbacks were created because our field work suggested that the Farmington series was almost always associated with patterned ground sinkholes. The maps were created with ArcGIS and converted to rectified JPGs, Google Earth files (KMZs), and printer friendly PDF files.

RESULTS

One hundred and seventy six karst features were mapped in the 523 square mile study area. These were classified into 32 individual sinkholes, 373 sinkhole complexes and 11 swallets. Four hundred and fifty three miles of escarpment were mapped, much of it associated with targeted soil and karst features. Karst-related features were observed on the carbonate units along the Helderberg escarpment. However there were some sinkholes and large areas of targeted soils present in the Helderberg Shale south west of the Helderberg escarpment. Sinkholes were best expressed near escarpments. Sinkholes and sinkhole complexes were also found in swales created by post glacial erosion processes. Sinkholes were located at the base of escarpments and at the edge of escarpments. We interpret these features to be bedrock ledges that are visible within thin soils. Large areas of targeted soils were mapped outside the carbonate zone, especially on the Mount Marion Formation Shale located south of the Helderberg escarpment. Terraced features in the hillshades were commonly associated with targeted soils, particularly those mapped as Farmington Soils. A cluster of targeted soils were observed in the northeastern part of the state. These were all Nassau Soils a depth to bedrock of < 20cm. They occur on Lacustrine Sands and Silts, Till and Alluvium according to mapping by Muller et al (1977), though in a few places they were mapped on Bedrock Areas. None occur on karst-forming bedrock. Odd sinuous bed forms were observed in the northern part of the county. These are interpreted to be the crests of large dune forms. They often occur in areas mapped as Dunes in the Surficial Geology Map by Muller et al (Muller, 1977).

Karst features were visible from the 2 meter LIDaR hillshades (see Figure 7a-f). They appear as small dimples often arranged in linear or orthogonal patterns. Some are irregularly-shaped and have small channels associated with them (Figure 7f). However when we conducted our field work, discussed hereafter, it was discovered that only a small fraction of the karst features appear to be visible from the hillshades. Only larger sinkholes (see Figure 7b) appear at the scale of this dataset.

Five field trips to the study area were conducted in the study area (9/11-13, 9/18-9/20, 9/25-27, 10/13-10-14, 11/3-11/5) to quality control the mapping. Sinkholes vary considerably in morphology ranging from exposed open fractures, to depressions with a variety of shapes (circles, troughs, ellipsoids); see Figure 8a-f. Larger sinkholes are commonly covered with shrub or forest (Figure 9a-f). Many have streams draining into them, suggesting that additional weathering from streamflow inputs may explain
why they are larger than surrounding sinkholes. Observations taken during these trips suggest the following. 1) Sinkholes tend to be smaller than the 2 meter resolution of the LIDaR data. 2) Many of the sinkholes were linear in nature and constitute open fractures in the bedrock (Figures 8b,d). 3) Larger oval and circular sinkholes, (the features observable from the LIDaR data) occur at the intersections fractures. 4) Sinkholes are located at regularly spaced intervals that are consistent with the spacing of significant fractures. These features are sometimes visible from the hillshades as orthogonal textured patterns (Figure 7a). They can be distinguished from plow patterns by not being parallel to the sides of fields. They are also parallel to the bedrock fracture directions. 5) Portions of the landscape were clearcut and farmed in karst areas. Sinkholes in these areas were filled up and leveled off (Figure 10). These areas are not detectible from the surface relief (hillshades). 6) Sinkholes are commonly filled up with rubble from farming activities (Figure 9b). In addition to sinkholes, there were also exposures of bedrock and limestone pavement (Figures 10b, 15a-b).

We classified the features into four types based on the field work and our experience in Genesee County (Richards et al, 2015). Large sinkholes, Patterned ground sinkholes (Figure 11), cleft sinkholes (Figure 12a-b), and Escarpment sinkholes (Figure 7e). Large sinkholes are features that were large enough to be mapped at the scale of the 2 meter hillshade. Many of these contain streams and were enlarged from surface drainage. Patterned ground sinkholes are the surface expression of numerous sinkholes that occur along and at the intersection of fractures. They are easily observed in the field as a regularly spaced set of depressions distributed in an orthogonal pattern. Sinkholes vary in size from 0.5 meters to 5 meters across. Shape is variable ranging from approximately circular to elongate ovals whose long axis is parallel to the fracture direction. Some sinkholes are simply open fractures that extend several meters. Larger sinkhole features occur at the intersections of fractures. Trees also appear to be associated with the larger openings (Figure 13a-d). Large blocks of limestone were sometimes enveloped by tree roots (Figure 13b). These observations imply that mechanical erosion associated with tree roots play a role in the development of patterned-ground sinkholes. Cleft sinkholes are open fractures near the edge of escarpments. Escarpment sinkholes are sinkholes located at the base of escarpments where it appeared that concentrated drainage from the top of the escarpment eroded bedrock at the base of the escarpment (see Figure 7e).

We talked to several property owners and learned that “new” (small < 0.8 m) sinkholes sometimes appear in the spring (Figure 14a-d). They commonly are arraigned in linear patterns. Inspection of one of these sinkholes revealed a thin soil layer covering bedrock that contain fractures (“Grikes”) see Figure 14d, Clint and Runnel features (see Vincent, 1995). Several of these small sinkholes occurred on an individual fracture. We hypothesize that extensive systems of fractured limestone pavement underlies the soil (Figure 15a-b). These small sinkholes thus form from soil piping processes that erode soil into fractures that already exist. The process appears to be triggered by large meteorological events and/or wet winters or springs. Two landowners believe that many sinkholes formed after the passing of Hurricane Irene. One land owner indicated that these features are hydrologically very active and provided some photos of two examples of karst-related flooding (Figure 16).
DISCUSSION

Statistics reinforce our notion that escarpments are a good guide for identifying karst areas. For example, of the over 450 miles of escarpment mapped in the study area, 99.9% occur in karst areas. In addition, 80% occur within targeted soils, most of which (60%) occur within Farmington Soils. Only 4.8% of the total length of escarpment were mapped within Wassaic targeted soils. Less than 1% of the total length of the escarpment are mapped within Madalin targeted soils. These are the other two types of targeted soils that form on carbonate bedrock. These statistics reinforce the impression we got from the field, that Farmington Soils are an excellent guide to thinly-soiled karst areas.

The karst features in Albany County are much different than features observed in Genesee County (see Richards et al, 2015). Sinkholes in Albany County are much more obvious in the field. The reason is local relief is much higher, glacial overburden is thinner, and the features are organized in spatial patterns that are clearly not parallel or perpendicular of the direction of glacial movement (as determined by mapped drumlins and glacial megaflutes). “Broad thin sinkholes”, and “Glacially modified sinkholes”, observed in Genesee County, were not observed in Albany County. Long meltwater channels, present in Genesee County were also not present in Albany County. However there were numerous large swales that we believe may be glacial in origin. Their size and orientation suggests they may be related to glacial or post glacial erosion processes. Like their longer cousins in Genesee County, they can contain exposed bedrock areas and patterned ground sinkholes. Interestingly, the opening for some of the caves frequented by spelunkers (Knox Cave, Ella Armstrong Cave) are quite small (Figure 17a-b) and not visible from the 2 meter hillshades.

We have made a set of detailed maps to guide farmers, farm planners, and home owners for locating these hydrologically sensitive features (Figure 18). These maps were created by mapping useful geological information that are indicative of thinly-soiled karst areas. These features were overlain on a basemap of 2013 Google Earth Imagery so that their location relative to features identifiable from the field can be determined. The maps included 100 foot setbacks from sinkhole features and all Farmington soil mapping units. This differs slightly from the Manure Guidelines drafted for Genesee County (Czimick, 2010) by including 100 ft setbacks for a specific Targeted Soil (Farmington Series). We did this because all Farmington soils we visited in the field contained sinkholes and other visual evidence for shallow bedrock. The following discusses what these features are and how they should be interpreted. Figure 18 is a sample map and key with which these features are represented on the mapping. Figures 2-6 are an index to the more than 700 maps we produced. How map features should be interpreted are presented in the paragraphs below.

Sinkholes, sinkhole complexes, and swallets are features that represent a direct conduit from the surface to the groundwater table. They are sensitive features that deserve the full protection of the manure guidelines including 100ft setbacks and 30ft vegetation setbacks. Watersheds associated with Swallets should have spring manure restrictions even if they do not contain thinly-soiled karst.

Farmington soil are all areas mapped as Farmington Soils (FwC, FrF, FrC, FrB, FaB). These are
thin soils that form over carbonate bedrock. Our field assessment and statistics suggest that they contain sinkholes or thinly-soiled karst areas, even if they are too small to see in the 2m hillshades. For this reason we have included 100 ft setbacks for this series. These areas should be considered thinly-soiled karst and are sensitive to groundwater contamination.

Targeted soils are all other targeted soils in Table 1, including Kearsage, Madalin, Nassau, and Wassaic. Although these soils are shallow, according to the profile descriptions, they may not always indicate shallow depth to bedrock. Some of these are located in areas that do not contain carbonate bedrock and or in glacial deposits mapped by the surficial geology layer. The thickness of these deposits can be considerable depending on the type of deposit. They should have early spring manure restrictions, especially when these areas contain other signs of shallow depth to bedrock including proximity to escarpments, shallow wells (all wells symbols marked in red), and bedrock zones in the Surficial Geology Map layer. Farm planners should walk through these areas carefully and look for evidence of shallow bedrock.

Escarpments are marked changes in relief that are visible in the hillshades. Some are visible in the field, while others are more subtle and represent breaks in the slope. They are included in the mapping because karst features are commonly associated with these features. In some cases they represent bedrock terraces (benches) that are draped by soils. They should be considered as a sign that the bedrock could be close to the surface.

Wells and boreholes were included in the mapping because they represent an independent measure of depth to bedrock. They are colored by the depth to bedrock indicated by the well log; red < 5ft, yellow, 5-10ft, green, 10-20ft, and blue, 20 or more feet.

Glacial features recognizable from the hillshades were also presented on the maps, including drumlins, bumpy moraine, and banded moraine deposits. Presence of these features usually indicate glacial sediments that are thicker than 4 feet. Thus, they may be contradictory to the shallow depth to bedrock suggested by targeted soils. Targeted soils within these features should always be field checked for shallow bedrock before excluding them from early spring restrictions. It may be most prudent to always institute early spring manure restrictions even if they are located within these features. Glacial Mega-Flutes were mapped because they provide an indication of the direction of glacial movement. Drumlins also indicate the direction of glacial movement.

Areas mapped as “bedrock” by the Surficial Geology map were also included on the maps. It should be cautioned that in some instances glacial features were mapped in these areas. Bedrock areas should be considered supporting evidence of shallow depth to bedrock where there are other lines of evidence of shallow bedrock, such as targeted soil, karst features, escarpments, and well log information. There appear to be issues with this data layer.

Maps have been prepared in three different formats, PdF files, rectified JPG images, and Google Earth (KMZ) files. PdF maps include a key to all features and are best for printing hard copies. The rectified JPG files include world files and should overlay properly on any kind of spatial data using any GIS software application. A key should be printed out, however, so that the features can be interpreted from the imagery. The KMZ files can be uploaded to Google Earth and are viewable from an IPOD, IPHONE and many other electronic devices. There are applications available for these devices that can
use the built in GPS capability of the device to plot a point on the map. The user can then walk around in the field and see exactly where he or she is relative to karst and other mapped features.

These maps provide as much geological information as we could find that might indicate the presence and extent of karst or thinly-soiled karst areas. Planners should make full use of this information in their decision making process, but we stress that all areas should be checked in the field for evidence of shallow bedrock before making any management decision.

CONCLUSIONS

LIDaR Hillshades and 2013 aerial photography were used to map karst features in Albany County. The study found 416 such features of which 32 were individual sinkholes, 11 were swallets, and 373 were sinkhole complexes. The latter are areas containing more than one sinkhole that are too small to map individually. Soils identified as the Farmington series appear to be the best guide to thinly-soiled karst features of all the targeted soils present in the county. The study mapped 453 miles of escarpments which have been shown to be associated with karst areas. Glacial features such as drumlins, glacial mega flutes, and bumpy moraine were also mapped as they represent areas where the depth to bedrock may be greater than 4 feet. Maps of these features were made to provide farm planners and land owners information on the location and extent of karst features where it is easy for runoff to move pollutants from the surface to the groundwater table. One hundred foot setbacks were determined for all karst features and soil mapping units classified as Farmington. The maps include targeted soils, wells and boreholes, and surficial geology information that may be indicative of shallow depth to bedrock. Maps are available from our website: Karst.esc.brockport.edu. Planners should make full use of this information in their decision making process, but we stress that all areas should be checked in the field for evidence of shallow bedrock before making any management decision.
REFERENCES CITED


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The lead author’s physics professor John K Elberfeld standing in a rubble-filled sinkhole.
Figure 3

Index to Tile Maps: Northeastern Quadrant
Figure 7  Relationship between karst features, Farmington soil, other targeted soil, and escarpments.
Figure 8  Hillshade (A) and field shot (B) of Patterned Ground Sinkholes. Note the dimples arranged in orthogonal patterns (arrows). Hillshade of Sinkhole Complex (C), Swallet (D), Escarpment Sinkholes (E). Note how linear sinkholes are arranged (F). Drainage gullies empty into the largest one (arrow).
Figure 9 Examples of smaller scale sinkholes. Roundish sinkholes with trees in them (A), open fractures (b), trough shaped sinkhole (C), sinkhole developing in open fracture (D), limestone float in sinkhole depression (E), rubble-filled sinkhole (F). Farmers commonly throw bedrock from fields into these features.
Figure 10  Examples of larger sinkholes. Trough in the field (between dotted lines, A) opens up into a large 5 m deep sinkholes (B). Large surface depression filled with trees and shrubs interpreted to be a sinkhole (C). Large linear sinkhole (D), Large irregularly shaped sinkhole that has been shaped by runoff draining into it (E). System of trough shaped depressions at the edge of a escarpment that are interpreted to be “Cleft” sinkholes (F).
Figure 11  Example of field that we believe was a patterned ground sinkhole that was filled in to enable it to be farmed (A). Across the road is a well-defined pattern ground sinkholes with bedrock exposures. This field also contains bedrock exposures (B) and areas that appear to be filled with a different type of soil. The field also contains rock piles where it appears limestone float was dragged to (C).
**Figure 12**  Example of Pattern Ground Sinkhole in the forest. These features consist of systems of trough-shaped sinkholes organized in orthogonal patterns.

**Figure 13**  Example of “Cleft” sinkholes (A-B). Note how the surface at the top of the escarpment is expressed.
Figure 14  Mechanical erosion by roots and tree falls appear to be important in the development of sinkholes. Sinkhole being widened by trees (A). Limestone bedrock uprooted by tree fall (B). Open fracture surrounded by trees (C). Tree roots growing into bedrock (D).
Figure 15  New sinkholes (A-C) that formed the spring before fieldwork (2014). These varied in size from 0.2 to 0.8 meters. They were arranged in linear patterns overlying fractures. Well developed Grike, Clint, and Runnel structures were within them (D). They appear to be formed by soil piping into pre-existing open fractures and voids underneath the soil profile.

Figure 16  Examples of limestone pavement. Orthogonal fractures in pavement (A). Pavement with multiple open fractures at the edge of a small escarpment (B).
Figure 17  Photos of karst related flooding and runoff taken during a storm.
Figure 18  Photo of entrance to Elle Fitzgerald Cave (A). The entrance is less than a meter wide. A stream flows into it (B).

Figure 18  Photo of entrance to Elle Armstrong Cave (A). The entrance is less than a meter wide. A stream flows into it (B).
Figure 19  
Sample map and key to all symbols.