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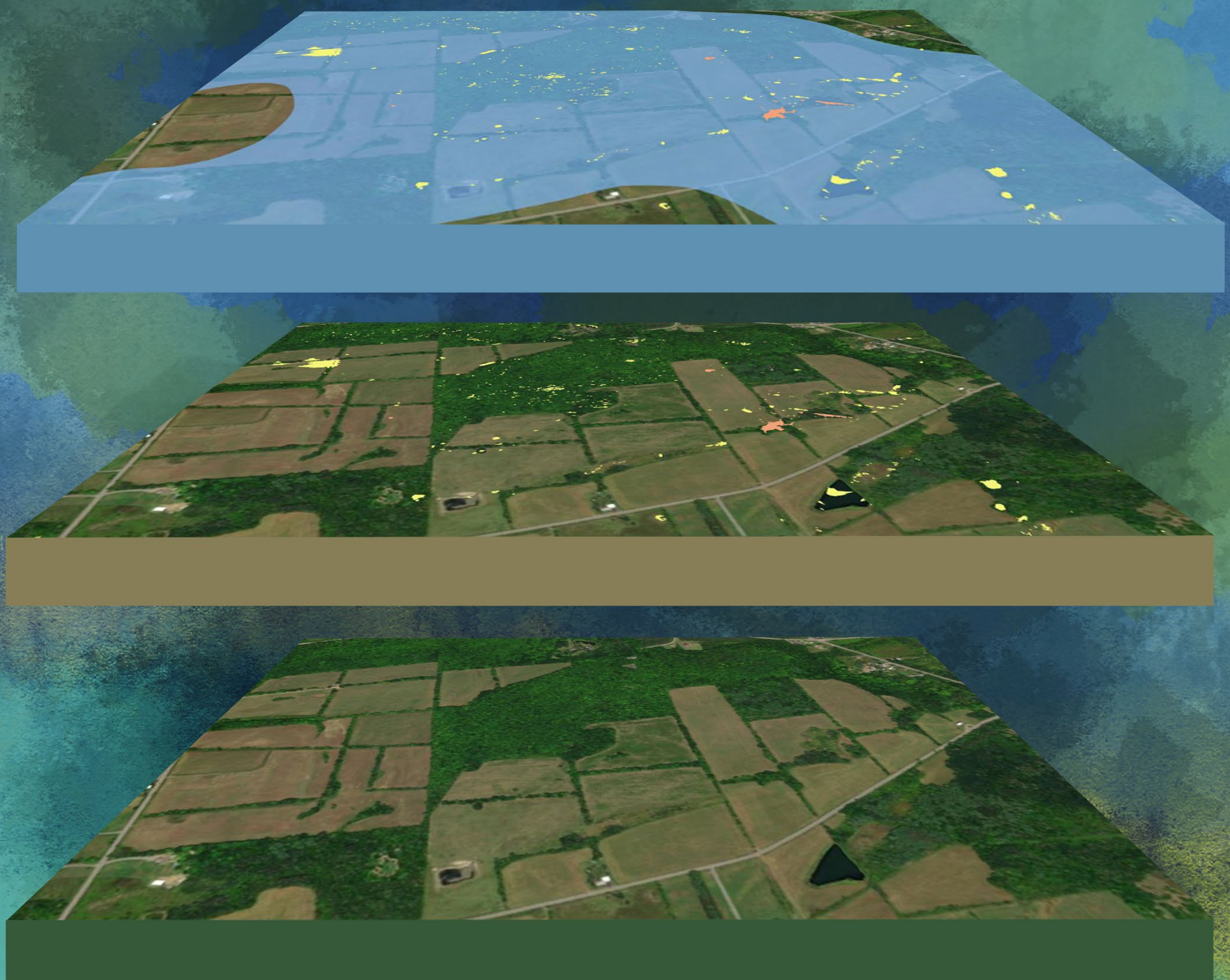
Methods of Data Collection and Analysis for an Assessment of Karst Aquifer Systems Between Albany and Buffalo, New York



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U.S. Department of the Interior
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Cover. Collage illustrating the creation of surficial karst geology maps. Satellite imagery (bottom) is overlaid by closed depression topography data (middle), and additionally overlaid by modified bedrock contacts (top). Satellite image by Esri.

Methods of Data Collection and Analysis for an Assessment of Karst Aquifer Systems Between Albany and Buffalo, New York

By Bradley A. Sporleder, Benjamin N. Fisher, Douglas S. Keto, William M. Kappel, James E. Reddy, and Laura M. DeMott

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Contents

Figure

Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
square meter (m^2)	10.76	square foot (ft^2)

Datums

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Elevation, as used in this report, refers to distance above the vertical datum.

Abbreviations

DEM	digital elevation model
GPS	Global Positioning System
gSSURGO	gridded Soil Survey Geographic (database)
NYSDEC	New York State Department of Environmental Conservation
USGS	U.S. Geological Survey

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Abstract

The U.S. Geological Survey, in cooperation with the New York State Department of Environmental Conservation, catalogued aquifers and closed depressions in a karst-prone area between Albany and Buffalo, New York to provide resource managers information to more efficiently manage and protect groundwater resources. The New York State Department of Environmental Conservation has been working with the agricultural industry to raise awareness of karst aquifer contamination susceptibility and how to reduce effects on surface water and groundwater resources, especially in karst areas. There is also a need to make industries, State and local regulators, planners, and the public aware of New York's karst resources to properly protect and manage these resources and the quality of surface water and groundwater that flows through the karst aquifer.

Publicly available geospatial data were identified, collated, and analyzed for a region of karst terrain extending from Albany to Buffalo. The region was divided into 10 subareas. A series of geospatial datasets were assembled to determine the location and extent of karstic rock; bedrock geology and depth to bedrock; average water-table configuration; surficial geology; soil type, thickness, and hydraulic conductivity; land cover; and closed depressions in the land surface.

Repeated glaciation and recession across New York have left the landscape pockmarked with closed depressions, which may or may not be related to the underlying bedrock. Closed depressions in areas where carbonate or evaporite karst are present are of primary concern to this study because of the increased potential of karst aquifer contamination from focused recharge. Closed depressions present in areas not associated with karst bedrock can also be evaluated to better understand their ability to transmit surface water to the groundwater system. Information on closed depressions can be used to develop land-management plans to protect local and regional water resources.

Introduction

The New York State Department of Environmental Conservation (NYSDEC) is studying groundwater contamination in the karst aquifers in New York State (fig. 1). Karst is a landscape formed from the dissolution of soluble rock which contains minerals that are easily dissolved. The landscape is characterized by sinkholes, caves, losing streams, springs, and underground rapidly-moving drainage systems. Groundwater contamination issues have been reported in a band of karst prone bedrock between Albany and Buffalo. The karst conditions can create areas of focused recharge of surface water and associated contamination to the underlying karst bedrock aquifer. Karst data across New York, compiled by Kappel and others (2020), were assembled to provide State and local agencies, industry, and the public with basic information on karst in New York. Karst aquifers are especially susceptible to the unintended introduction of industrial and agricultural contaminants (Reddy and Kappel, 2010). New York's karst bedrock aquifers are poorly characterized; large-scale (1:24,000) aquifer boundary maps are not available; and for most of these aquifers, the sources of recharge and direction of groundwater flow are unknown. The potential for focused recharge in karst prone areas is greatest where bedrock is found at the land surface or where closed depressions exist. To this end, the U.S. Geological Survey (USGS) has carried out a detailed study of karst prone bedrock units and the extent and type of surficial deposits overlying these units, and compiled an inventory of colocated closed depressions. There are many smaller communities, farmers, homeowners, and industries that rely on the carbonate-bedrock aquifers throughout New York as a water supply. Because there is little regional and local hydrogeologic knowledge of the karst bedrock units, State and local water-resource managers would benefit from knowledge of the location of these vulnerable karst regions to guide current and future water-resource assessments and planning activities.

This report provides detailed information on the methods used to collect and assess existing geospatial data to locate and describe the geologic and hydrologic characteristics of karst

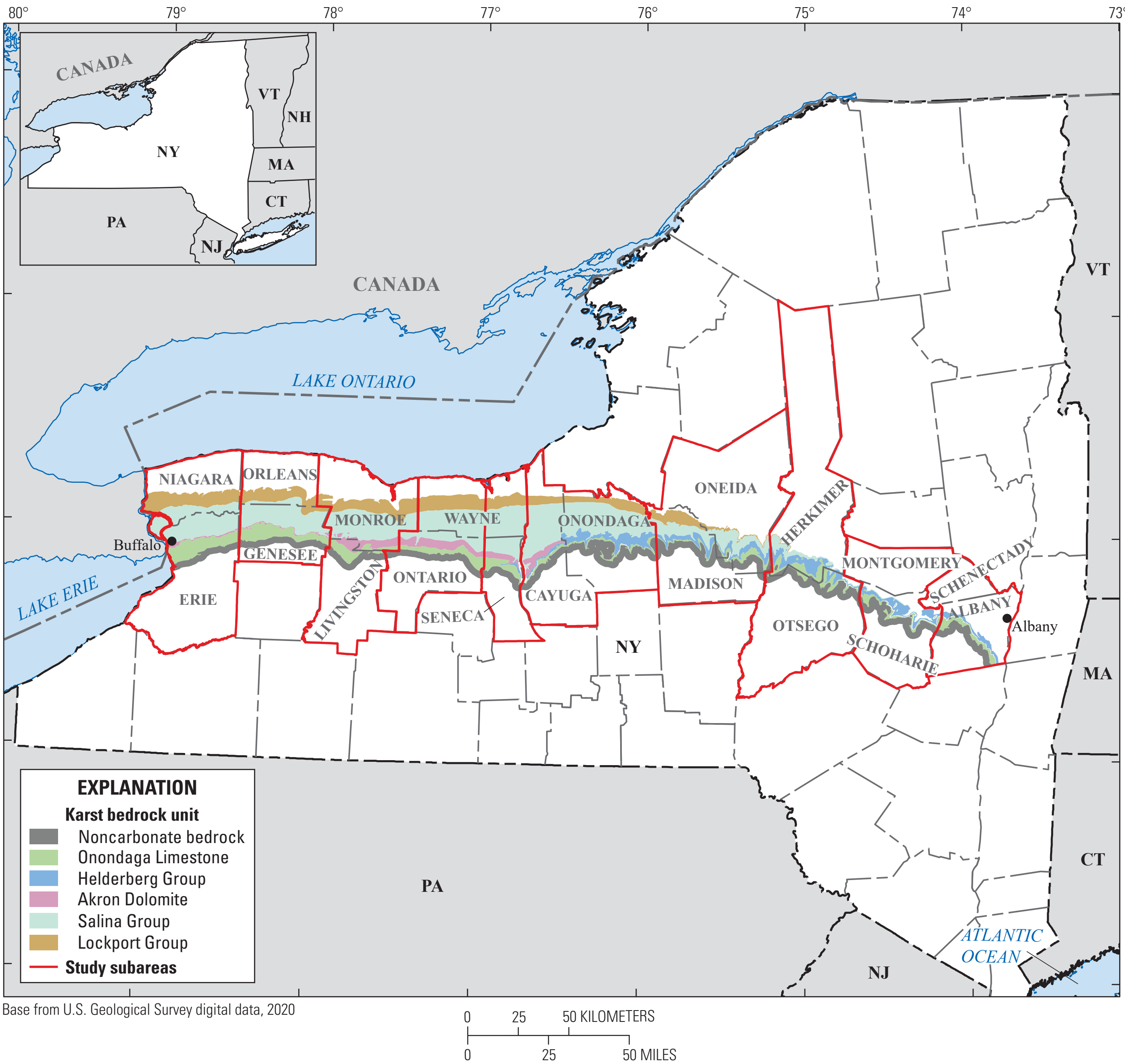

Figure 1. Map showing the bedrock units in which karst may have developed and the 10 study subareas between Albany and Buffalo, New York, where karst was assessed.

rock. Additionally, these methods can be used to evaluate how karst might be related to closed-depression features that direct surface water flow to groundwater aquifers (focused recharge). The region of karst bedrock extending between Albany and Buffalo was assessed in 10 study subareas (fig. 1) using these methods. The data produced from the karst terrain assessment are available in Sporleder and others (2021), and may be used by water-resource agencies to help manage and protect the groundwater resources within this karst bedrock region of New York. Sporleder and others (2021) at the time of publication of this report contains data for 3 of the 10 study areas.

Geology of Karst Between Albany and Buffalo, New York

In the region between Albany and Buffalo, karst is present in carbonate and evaporite bedrock lithologies of Silurian and Devonian age. In western and central New York, the Lockport Group is the oldest karst-prone unit of interest. The Lockport Group is mainly composed of dolostone (rocks composed predominantly of the mineral dolomite), with minor amounts of limestone and sandstone to the east. While dolostone is not prone to karst development, some karst-related features such as sinkholes and springs have been documented in the Lockport Group (Yager and Kappel, 1987). Numerous quarries are located within the Lockport Group, which provide locations for groundwater recharge. The Lockport Group is overlain by the shales of the Salina Group, which include evaporite deposits containing gypsum and halite. Whereas shales are typically resistant to the development of karst features, evaporite deposits are susceptible to dissolution and karst development. The upper part of the Salina Group is the Bertie Limestone, which is composed of dolostones, limestones, and shaly dolostones. In the central part of the state, the Bertie Limestone is overlain by the Akron Dolomite, composed of units similar to those of the Bertie Limestone. These four bedrock units (Lockport, Salina, Bertie, and Akron) thin eastward and terminate. In the eastern part of the study area near Albany, only the Helderberg Group and Onondaga Limestone are present. The Helderberg Group is a thick sequence of limestones and shaly limestones that are highly susceptible to karst development and contains some of the longest and largest caves in the northeastern United States (Cooper and Mylroie, 2015). The youngest and most widespread karst-prone unit in the state is the Onondaga Limestone. The Onondaga Limestone stretches across the entire study area and is composed of a thick sequence of limestone that readily develops karst features. The Helderberg Group and Onondaga Limestone contain the oldest and most well-developed karst in New York (more than 350 thousand years old; Lauritzen and Mylroie, 2000). These two units have varied karst conditions as well as surface water and groundwater flow complexity. The Onondaga Limestone is overlaid by noncarbonate bedrock of the Hamilton group, including part of the Marcellus Shale. These units are not susceptible to karst development, but may contribute surface water runoff to the underlaying karst prone units. The amount of supporting data available for this study varies across the State depending on the date of collection, resolution, distribution, and other characteristics that affect the assessment of karst aquifers.

Methods of Data Collection and Analysis

Various sources of geospatial data were acquired to identify and locate karst rock, characterize its geologic and hydrologic properties, and determine how closed-depression features might be associated with karst across upstate New York. Software used included Esri ArcGIS Desktop software ArcMap version 10.5.1 (Esri, 2017) and version 10.7.0 (Esri, 2019a), and ArcGIS Pro version 2.4.0 (Esri, 2019b) with Spatial Analyst and Geostatistical Analyst extensions. A 7.5-minute quadrangle map database was overlaid on the selected bedrock units, and an index of quadrangles containing karst bedrock was generated, forming the basis of the study area. The study area was further divided into 10 subareas that are coincident with county boundaries. Well logs from various State and Federal agencies were assembled, bedrock contact information from New York State Geological Survey and USGS studies was identified, and other geospatial data including land use, soil properties, stream networks, and locations of quarries and mines were compiled.

Well Log Location Verification and Compilation

There are three primary sources for the well data: (1) water-well completion reports from the NYSDEC (New York State Department of Environmental Conservation, 2019c), (2) construction boring logs from the New York State Department of Transportation and the New York State Thruway Authority (Douglas Hadjin, New York State Thruway Authority, written commun., March 25, 2019), and (3) oil- and gas-well drilling logs from the Empire State Organized Geologic Information System (New York State Museum, 2019a). The logs from these sources are of varying quality, ranging from basic lithologic logs from water-well completion reports to more precise construction boring logs. Water levels from these logs, which were collected over a period of more than 20 years and affected by differing climatic and seasonal conditions, produced a generalized static water-level surface. Geographic information system shapefiles containing verified well locations for construction boring logs were provided by the New York State Department of Transportation and the New York State Thruway Authority. Verified oil and gas well locations were obtained from the NYSDEC oil and gas database (New York State Department of Environmental Conservation, 2019b). Unverified water well locations contained within the water-well completion reports were compiled and verified prior to bedrock and groundwater mapping.

Three criteria were identified for use in well location verification: (1) Global Positioning System (GPS) coordinates, (2) street address of the well location (Google, 2019), and (3) county tax records (Systems Development Group, 2019). The county tax records and property transaction histories were used to verify locations of wells with limited GPS information. Well locations were considered verified and usable for bedrock and groundwater analysis when the correlation of two or more criteria indicated that their location was correct.

If correlation indicated that the original well location was correct, the well location was not moved in ArcMap or ArcGIS Pro. If correlation indicated that the original well location was incorrect but there was enough information to properly locate the well, the location of the well was placed at the correct location in ArcMap or ArcGIS Pro using orthoimagery and parcel information from country tax records. The distance and direction of the move to the proper well location were recorded in the “Notes” attribute field. If two well-location criteria could not be correlated, the well location was considered to be unverified, and the associated bedrock and water-level information were not used.

Information from water-well completion reports was used to populate attribute fields after location verification. The information used included static water level, well log, depth to bedrock, and depth to the lithologies of interest (carbonate or evaporite or both) below the bedrock surface, if this were not the uppermost bedrock unit. Well logs containing only unconsolidated sediments were only used for groundwater surface mapping if water level data were present because the sediments described in these logs often could not be correlated with surficial units used on the New York State Geological Survey 1:250,000-scale surficial geology maps (Fisher and others, 1971). Well logs in bedrock were checked with special attention paid to the position of carbonate- and evaporite-bearing units, the depth of bedrock below the surface, and water-level information. These well logs were used in the refinement of mapping of carbonate- and evaporite-bearing formations and the surface of bedrock.

Geologic Mapping of Karst Regions

Statewide bedrock maps are available from the New York State Geological Survey at 1:250,000-scale (Fisher and others, 1971). The contacts from these maps were revised to a smaller scale to provide a more practical resource for the evaluation of karst aquifer units. Procedures for revising the contacts of karst-prone bedrock units are described in this report.

Bedrock Geology and Formation Contacts

The initial bedrock unit determination for the study areas was based on the State Geologic Map Compilation geodatabase of the conterminous United States (Horton and others, 2017), based on the 1:250,000-scale state maps of Fisher and others (1971). Bedrock geologic units of interest were selected for detailed contact revision based on their documented association with karst development (Fisher and others, 1971; Horton and others, 2017). The bedrock units that were revised are the Lockport Group, the Salina Group, the Akron Dolomite, the Bertie Limestone of the Salina Group, the Helderberg Group, and the Onondaga Limestone. Additionally, a 3.2-kilometer wide area south of the Onondaga Limestone was delineated across the entire study area where the carbonate bedrock is overlain by shales of the Hamilton Group. This zone represents an area of potential recharge where surface water might flow from the shale buffer zone onto the adjacent carbonate bedrock and contribute to focused recharge. This zone was generated by creating a buffer on the revised Onondaga contact in ArcGIS Pro.

For each study area, vector unit contacts from the State Geologic Map Compilation geodatabase (Horton and others, 2017) were initially refined using extant maps. These maps were obtained from the USGS National Geologic Map Database (U.S. Geological Survey and Association of American State Geologists, 2019) and the New York State Museum open file geological collection (New York State Museum, 2019b). Maps at 1:24,000 scale were the preferred sources; however, maps up to 1:62,500 scale were considered acceptable. The maps were georeferenced using the USGS National Map topographic maps available in ArcMap and ArcGIS Pro to create spatially accurate base maps. Unit contacts were then adjusted for each study subarea based on the geology depicted on these extant maps.

Well and borehole logs were used to refine the bedrock geology of the study areas (New York State Department of Environmental Conservation, 2019c; Douglas Hadjin, New York State Thruway Authority, written commun., March 25, 2019; New York State Museum, 2019a). After verification, the well and borehole logs were analyzed to determine the general bedrock lithology (limestone, dolostone, sandstone, shale, or undifferentiated bedrock). After this initial revision of the bedrock contacts using the georeferenced maps, the bedrock unit contacts were further adjusted based on the well and borehole data.

Finally, the bedrock unit contacts were refined to reflect major topographic features. The stratigraphy of the karst-prone units and contiguous units exhibits an alternating sequence of resistant and less resistant units (such as carbonates alternating with shales). Weathering and erosion often produce distinct topographic features, such as cliffs or escarpments, or changes in slope, both of which are indicative of the unit contacts. The unit contacts were locally modified to reflect these features. When the extant maps, well log data, or topographic features did not allow for refinement of the unit contacts, the original contacts in the State Geologic Map Compilation geodatabase (Horton and others, 2017) were preserved.

Collection of Bedrock and Water-Table Surface Elevation Data

Raster geospatial datasets representing the generalized bedrock and water surfaces were created for this study using bedrock and the water-level depths reported from the well and borehole data (New York State Department of Environmental Conservation, 2019c; Douglas Hadjin, New York State Thruway Authority, written commun., March 25, 2019; New York State Museum, 2019a). Depth data points are distributed throughout the study area and extend into the adjacent geologic map quadrangles to minimize map inconsistencies between how units meet in adjacent subareas. Bedrock and water-table maps were extrapolated from these depths using surface interpolation techniques in ArcGIS Pro. The depth maps were then subtracted from the land surface elevation digital elevation model (DEM) from the USGS National Elevation Dataset (U.S. Geological Survey and Association of American State Geologists, 2019) to obtain the bedrock and water-table surface elevations (Raster Calculator, ArcGIS Pro).

A continuous digital surface can be created using multiple individual measured point locations through the use of interpolation or extrapolation techniques. Several different methods of surface interpolation were used to extrapolate bedrock and groundwater depths between data points. These methods include inverse distance weighting, kriging (simple, ordinary, and universal), and empirical Bayesian kriging. For each digital surface, multiple semivariograms and transformations were attempted to produce the lowest root mean square error among each method. The method that produced the lowest root mean square error was selected to generate the bedrock and groundwater surfaces for the entire dataset. The surface-prediction outputs from this assessment were stored as raster and vector (contour) datasets. The initial surfaces were smoothed using the Focal Statistics tool in ArcGIS Pro. Further iterations of smoothing were performed, producing surfaces that are faithful representations of the real surfaces (Yang and Hodler, 2000). These smoothed groundwater and bedrock surfaces were each then subtracted from the DEM of the land surface, which was resampled to match the cell size of the groundwater and bedrock surface rasters.

Compiling Soil Data

Soil unit types were derived from a gridded soil survey geographic (gSSURGO) database for New York (U.S. Department of Agriculture, 2014). Czymmek and others (2004) identified 182 soil units as having characteristics that potentially present an increased risk for groundwater contamination. For each study subarea, soil maps were produced for the following characteristics: (1) soils of interest, (2) soil thickness over bedrock, (3) saturated hydraulic conductivity, and (4) the presence of well-drained glacial deposits that might contribute to focused recharge to underlying aquifers.

A soils-of-interest dataset was derived from the gSSURGO database and included soils that have shallow depths to bedrock, are derived from carbonates or calcareous shales, and are well-drained glacial deposits. Based on these characteristics, these soils have a greater probability of being associated with focused recharge and possibly karst features.

Infiltration rate is an important soil characteristic to consider when assessing the probability that a closed depression contributes to focused recharge. The infiltration rate was evaluated using saturated hydraulic conductivity data from the gSSURGO database (U.S. Department of Agriculture, 2014).

Surficial Geology

Surficial geology plays a major role in controlling groundwater recharge. The surficial deposit types of the study subareas were derived from Cadwell (1986). The surficial deposit contacts from this map were first revised to conform with major topographic features visible in light detection and ranging (lidar) DEMs (New York State Geographic Information Systems (GIS) Clearinghouse, 2020). In areas lacking defined topographic features, such as western New York, geomorphic settings for soil units from gSSURGO (U.S. Department of Agriculture, 2014) were used to further modify the surficial contacts. Finally, surficial contacts were modified to close unmodified contacts with those that were revised. The original contacts were left intact if none of these techniques were justified.

Supplementary Information

In addition to the data sources listed in the previous sections, land use and land cover (Homer and others, 2015) information was included for each study subarea (Sporleder and others, 2021).

Closed-Depression Identification Methods

Data assembled for the identification of closed depressions include lidar-derived bare-earth DEMs used to identify, analyze, and classify closed depressions and ArcGIS Pro geometric layers to superimpose with the closed-depression inventory. The combined data can provide a means of determining where there could be a greater potential for focused recharge.

The collection of closed depression information compiled in each subarea (Sporleder and others, 2021) includes polygon features created from 1- and 2-meter horizontal resolution lidar-derived bare-earth DEMs (New York State Geographic Information Systems (GIS) Clearinghouse, 2020). The DEMs were created from lidar surveys from 2006 to 2020. The vertical accuracy of the lidar imagery ranged from

4.0 to 18.5 centimeters root mean square error. The horizontal accuracy for all lidar was less than 2 meters root mean square error. In the event lidar information was not available for a study subarea, or part of one, digital contour data for New York State (Tyler and Greenlee, 2012) were converted to DEMs for each 7.5-minute topographic quadrangle for closed depression identification. Contour characteristics and accuracy are described in Tyler and Greenlee (2012). The following process used to identify closed depressions was modified from methods described by Doctor and Young (2013).

Lidar-derived bare-earth DEMs for the statewide karst assessment (Kappel and others, 2020) were compiled for each 7.5-minute quadrangle where lidar data existed. Each DEM quadrangle was reconditioned in ArcGIS Pro by adding a stream network to it. This aids in the identification of artificial dams and manmade features (for example, streets and railroad embankments). To gain better coverage of flow paths throughout the entire study area, a synthetic stream network generated by USGS StreamStats (U.S. Geological Survey, 2019) was used. This DEM was reconditioned using a modified burn-in method with the Raster Calculator tool in ArcGIS Pro to raise the elevation of nonstream cells instead of burning the stream network into the DEM. The reconditioned DEM was then filled using the ArcGIS Pro Fill tool to remove small imperfections in the surface raster. This process determines locations of cells that are lower than their adjacent neighbors, and then increases the values of those cells to the lowest value of an adjacent cell. A fill-difference raster is created by subtracting the reconditioned DEM from the filled DEM. Values can then be extracted from the fill-difference raster that meet a desired depth threshold using the Raster Calculator, and then converted into polygons. From this, a final dataset can be created that meets a set criterion for depth and area.

For this study, thresholds of 10 and 30 centimeters for depth and 10 square meters for area were used to create the closed depression datasets. Geometric characteristics for eccentricity, circularity, thinness, and roundness were added to each feature using criteria set by Doctor and Young (2013). National Hydrography Dataset stream, waterbody, and area layers, NYSDEC mine, and Microsoft building layers (U.S. Geological Survey, 2017; New York State Department of Environmental Conservation, 2019a; Microsoft, 2018) were overlaid as well. These layers along with the geometric characteristics assist in eliminating false positives by filtering out features that do not meet the criteria for geometric characteristics or those that overlie existing waterbodies, streams, mines, and buildings. Closed-depression features that intersected with streams, waterbodies mines, or with buildings were filtered out to assist in eliminating false positives. A 25-meter buffer was placed around all roads and railways (active and abandoned) to eliminate false positives and remove any remaining artificial dams that are along roads and railways. Road and railway buffers were created in place of the manually-drawn culverts and bridges employed by Doctor and Young (2013) in order to eliminate false positives and remove those artificial dams. Buffers were considered a reasonable alternative given the amount of time required to manually draw these features for a study area of this size.

For verification of closed-depression features, a random subsampling of closed depressions in each quadrangle was performed on 1 percent of these features. This verification was performed using lidar-derived shaded topography and aerial imagery from Google Earth (Google, 2019) to determine if the chosen feature is in fact a closed depression regardless of origin (natural or artificial) or potential for contamination. Results from this verification are indicated in the polygon layers associated with each closed-depression layer in each subarea (Sporleder and others, 2021).

Limitations of the Assessment

The information contained within this report is meant to be used for planning purposes or preliminary site evaluation. It is not intended to be a substitute for site-specific evaluation of geologic or hydrogeologic conditions. The development of karst features depends on numerous factors, including bedrock type and geologic structures (fractures, joints, local faulting), surface and subsurface hydrology (preferential-flow pathways formed by the dissolution of the carbonate bedrock along with existing geologic structures), thickness and hydraulic conductivity of the soils overlying the carbonate bedrock, and land use (urban, farmed, undeveloped).

Summary

The U.S. Geological Survey, in cooperation with the New York State Department of Environmental Conservation, catalogued aquifers in karst in New York to provide resource managers information to more efficiently manage and protect groundwater resources. Karst is a landscape formed from the dissolution of soluble rock or rocks which contain minerals that are easily dissolved. The landscape is characterized by sinkholes, caves, losing streams, springs, and underground rapidly moving drainage systems. The two forms of karst in New York State are carbonate karst, in limestone and dolostone; and in evaporite karst, in rock that contains evaporite minerals (such as gypsum and halite). Closed depressions that are created at the land surface focus surface-water recharge into underlying bedrock and this water can be transported quickly with limited attenuation of any contamination within the recharge water.

Locations where karst rock is present in New York, its characteristics, and the location of closed depressions were identified using publicly available geospatial data. Carbonate and evaporite units between Albany and Buffalo were selected, a 7.5-minute quadrangle map database was overlaid on the selected bedrock units, and an index of quadrangles was generated, forming the basis of the study area. Using the index of quadrangles, a series of overlays were created at 1:24,000 scale to examine the bedrock geology, groundwater table, soils, and surficial geology. Bedrock geology was refined using extant bedrock maps, well and borehole data from water and gas wells, and lidar data. Groundwater data were collected from New York State Department of Environmental Conservation and U.S. Geological Survey water well databases to approximate the groundwater table. Soil data were used to examine soil thickness over bedrock and infiltration. Surficial geology was refined using lidar data and soil data.

An inventory of closed depressions was created using reconditioned lidar-derived bare-earth digital elevation models and a modeled stream network. Values were extracted from the processed digital elevation models with criteria of 10 and 30 centimeters for depth and 10 square meters for area. A combination of hydrologic, mining, and cultural features was used to eliminate false positives and filter out features that overlie existing waterbodies, streams, mines, and buildings; and to remove artificial dams along roadways and railways. Additional filtering was performed to remove geographic features that do not meet criteria for the geometric characteristics; eccentricity, circularity, thinness, and roundness. A random sample of 1 percent of the discovered closed depression features in each quadrangle was verified to ensure that features were in fact closed depressions regardless of origin (natural or artificial) or the potential for groundwater contamination. The extent of karst development is important in understanding the interaction between surface water and groundwater in karst terrains. The presence of karst, be it a short section of a solution fracture or an extensive cave system, requires careful consideration, forward-looking environmental planning, and consistent water-quality protection to preserve New York State's water resources.

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