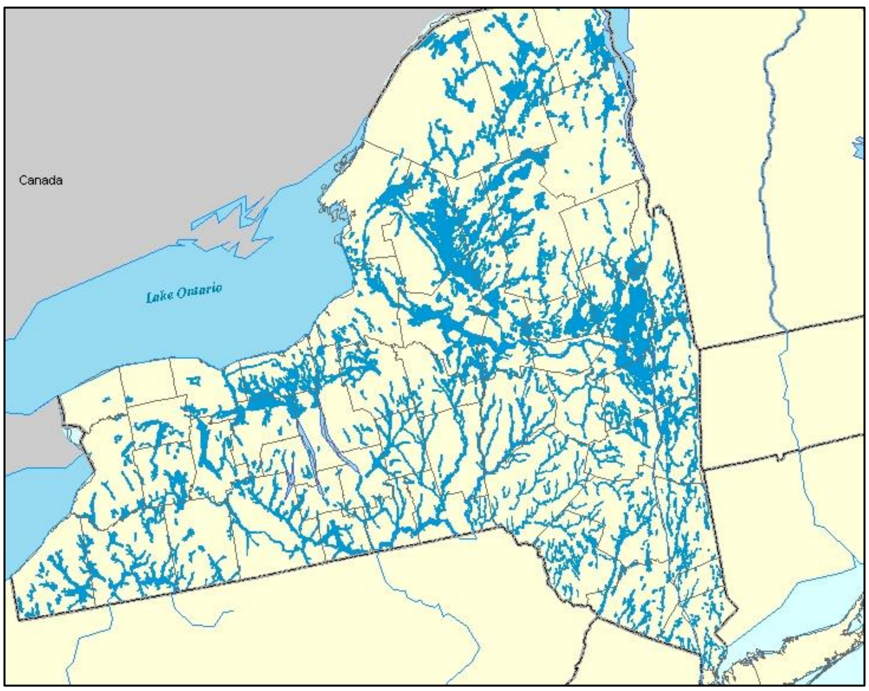
Groundwater Protection Guidelines for Agriculture

10-28-2021

Quirine M. Ketterings[1], Greg Albrecht[2], Dale Gates[3], Ron Bush[2], Brendan Jordan[2], Mary Kerstetter[3], and Sara Latessa[4]

[1]Nutrient Management Spear Program (NMSP), Department of Animal Science, Cornell University, [2]New York State Department of Agriculture and Markets (NYSAGM), [3]United States Department of Agriculture Natural Resources Conservation Service (USDA-NRCS), [4]New York State Department of Environmental Conservation (NYSDEC)



In conjunction with the Cornell NMSP Advisory Committees

Correct Citation: Ketterings, Q.M., Albrecht G., Gates, D., Bush, R., Jordan, B., Kerstetter, M., and Latessa, S. (2021). Groundwater Protection Guidelines for Agriculture. Accessible at: http://nmsp.cals.cornell.edu/publications/files/GroundwaterGuidelines2021.pdf.

Cornell University, Ithaca, NY 14853

Executive Summary

- Groundwater is the primary source of potable water for much of New York. Protection of that resource is a high priority for both the private and public sectors who rely on that resource. Agricultural activities, specifically manure application, can provide inherent risks to groundwater but with thoughtful assessment and understanding of those risks, they can be greatly reduced through implementation of beneficial management practices.

- This guidance document combines previous groundwater protection guidelines into an updated, more concise reference for planners and farm managers. The document provides an overview of the areas associated with increased risks related to manure spreading; offers a step-by-step assessment method to help determine where risks exist; and outlines specific manure management practices to help mitigate the high-risk conditions identified.

- Areas of higher risk of groundwater contamination include glacial outwash soil and areas with rapid infiltration; soils less than 20 inches deep over non-carbonate bedrock; and soils less than 40 inches deep overlying carbonate bedrock and karst topography.

- Guidance in this document focuses on the bedrock-controlled areas. Glacial outwash soils are described herein as well, but for manure management guidelines, we refer directly to CPS 590 and the Nitrate Leaching Index Guidelines.

- This document is intended to support planner and farmer efforts to plan and implement site-specific recommendations in comprehensive nutrient management plans (CNMPs) or stand-alone nutrient management plans (NMPs) for manure application rates, timings, methods, and setbacks to reduce groundwater risks. Guidelines are intended to supplement the baseline manure application criteria found in the NRCS-NY Nutrient Management Conservation Practice Standard (CPS) 590.

- The guidelines in this document are based on available knowledge of processes contributing to groundwater contamination. Following the guidance, while a good start toward *reducing* farm business risk associated with the potential for contaminating a drinking water well and groundwater resource, cannot be expected to *eliminate* all risk of groundwater contamination, because there are conditions and combinations of circumstances that are difficult or impossible to predict or evaluate.

- It should be recognized that while this guidance is solely focused on agriculture, other activities and conditions, including those related to residential, commercial, industrial, and wildlife, can pose an elevated risk for groundwater contamination as well. Furthermore, protecting groundwater may demand improved manure management and additional farm resources in the coming years.

Acknowledgments

This document includes groundwater protection guidelines for use with comprehensive nutrient management plans and nutrient management plans that involve manure management. It replaces two earlier documents: (1) Manure and groundwater: the case for protective measures and supporting guidelines (2004); and (2) Manure Management Guidelines for Limestone Bedrock/Karst Areas of Genesee County, New York: Practices for Risk Reduction (2011). Authors and advisory team members involved in development of the 2004 and 2011 documents included: Karl Czymmek, formerly Senior Extension Associate with PRO-DAIRY at Cornell University, Larry Geohring, Senior Extension Associate, Department of Biological and Environmental Engineering at Cornell University (retired), William Kappel, Dave Eckhardt (both retired), and James Reddy of USGS, Jacqueline Lendrum, Ron Entringer and Dan Kendall of NYSDEC, Peter Wright (retired), Steve Indrick (retired), Steve Page (retired), Jerry Smith, and Tibor Horvath of NRCS, Jeff Ten Eyck and Bob Brower of NYSAGM (both retired), Harold van Es, School of Integrative Plant Science at Cornell University, and Paul Kaczmarczyk of NY-Department of Health (NY-DOH).

Contents

1. Introduction 1
2. Areas of Increased Risk 2
    2.1 Glacial Outwash Soils and Areas of Rapid Infiltration 2
    2.2 Soils Less Than 20 Inches to Non-Carbonate Bedrock 3
    2.3 Soils less than 40 Inches to Carbonate Bedrock and Karst Topography 3
3. Soil and Landscape Feature Assessment 4
4. Manure Management Guidelines 5
    4.1 Guidelines for Glacial Outwash Soils and Areas of Rapid Infiltration 5
    4.2 Guidelines for Bedrock-Controlled Soils 6
    4.3 Additional Guidelines for Fields with Karst Features 6
References 7
Appendix A: Karst 8
Appendix B: Soils Less Than 20 Inches to Non-Carbonate Bedrock 10
Appendix C: Soils Less Than 40 Inches to Carbonate Bedrock 11

1. Introduction

Groundwater is the primary source of potable water for rural residents, providing drinking water for about one-third of New York's population. Preventing groundwater contamination is a high priority involving many areas of management across multiple sectors in our communities, including public, private, residential, and commercial. Groundwater protection is also critical for agriculture to maintain local drinking water supplies for farms, homes, and rural communities while applying manure and other agricultural inputs essential for crop production, soil health, and agricultural environmental management.

Neighboring homeowners are often unaware of where their water comes from, and little information is provided during real estate transactions. There are several types of wells that are used now or have been constructed in the past for residential supplies. Dug wells and well points are relatively shallow and can be more easily contaminated by surface activities or contaminants, especially when wells are poorly located. Drilled wells can also be shallow and may have been improperly installed or maintained. Shallow wells in general are more prone to contamination from activities around the wellhead, including, but not limited to, nearby on-site septic systems, road salt, commercial activities, wildlife, and manure spreading. It should be recognized that in addition to farming activities, water wells can be vulnerable to nitrate and bacteria associated with on-site septic systems. Some residential water supplies do not meet current health standards in terms of the well's original construction and its current physical and chemical condition. Wells are often tested for bacterial contamination prior to purchase, but shock chlorination of the well may disguise lingering and potential sources of contamination.

Contamination concerns related to manure spreading are typically fecal coliform bacteria (*E. coli*) and nitrate. Much is already known about the characteristics of these contaminants. Nitrate is highly water-soluble and thus moves readily through soil as water drains. However, manure, which consists primarily of ammoniacal and organic sources of nitrogen, must first undergo biochemical transformation before it becomes nitrate. *E. coli* bacteria are not water-soluble, but because of their small size, can move through coarse soils and preferential flow paths such as cracks or wormholes. The high water-content and organic nature of liquid manure serves to enhance the movement of these contaminants.

Areas of higher risk of groundwater contamination include glacial outwash and some well drained alluvial soils with rapid infiltration; soils less than 20 inches deep to non-carbonate bedrock; and soils less than 40 inches to carbonate bedrock and karst topography.

In this document, we focus on bedrock-controlled areas (less than 40 inches to bedrock) and provide guidelines identifying and protecting sensitive groundwater resources to reduce the risk of groundwater contamination posed by manure applications. These guidelines are intended to supplement the baseline manure application criteria found in the NRCS-NY Nutrient Management Conservation Practice Standard (CPS) 590. Glacial outwash soils are described herein as well, but for manure management guidelines, we refer directly to CPS 590 and the Nitrate Leaching Index Guidelines.

This document is intended to support planner and farmer efforts to plan and implement site-specific recommendations in comprehensive nutrient management plans (CNMPs) or stand-alone nutrient management plans (NMPs) for manure application rates, timings, methods, and setbacks to reduce groundwater risks. Hereafter, guidance that refers to CNMPs are assumed applicable to NMPs utilizing manure. These guidelines are based on available knowledge of processes contributing to groundwater contamination. They are a good start toward reducing farm business risk associated with the potential for contaminating a drinking water well and groundwater resources in general. Manure handlers must understand that there are inherent risks associated with any manure application. Independent of soil and landscape features, manure application should always be conducted with care and follow the provisions of the CNMP when one exists. Carefully managing the level of manure in storages and field applications throughout the year as well as choosing low risk fields for any applications that are necessary in late winter/early spring will further reduce risk. Additional information is available in the 2015 guidance document "Revised winter and wet weather manure spreading guidelines to reduce water contamination risk".

The groundwater protection guidelines in this document cannot be expected to eliminate all risk of groundwater contamination, because there are conditions and combinations of circumstances that are difficult or impossible to predict or evaluate. It should be recognized that while this guidance is solely focused on agriculture, other activities and conditions, including those related to residential, commercial, industrial, and wildlife, can pose an elevated risk for groundwater contamination as well. Furthermore, protecting groundwater may demand improved manure management and additional farm resources in the coming years. While researchers develop improved risk indicator tools, the guidelines below are suggested for planners and farmers to enhance their efforts to evaluate the landscape more carefully for potential contamination risks and manage accordingly.

2. Areas of Increased Risk

There are three general conditions that can present an increased risk for the contamination of groundwater resources: (1) glacial outwash and some well drained alluvial soils with rapid infiltration; (2) soils less than 20 inches deep over any bedrock types; and (3) soils less than 40 inches deep overlying carbonate bedrock and karst topography. Because features and processes involved in each situation are somewhat different, guidelines are presented separately, below. To get a general idea of the geology of New York and to estimate the bedrock type that lies beneath a farm, see: https://mrdata.usgs.gov/geology/state/state.php?state=NY. Regional scale surficial and bedrock geology maps can be obtained as GIS files at: http://www.nysm.nysed.gov/research-collections/geology/gis. Aquifer maps can be found at: https://ny.water.usgs.gov/maps/aquifer/ and https://www.dec.ny.gov/lands/36118.html.

2.1 Glacial Outwash Soils and Areas of Rapid Infiltration

Glacial outwash and areas of rapid infiltration are often found on valley floors across the state but are also found in other upland locations around New York. These soils are deep, typically made up of relatively coarse sand, gravel, and cobble, and are characterized as well to excessively well-drained. In these settings, water at the surface must first drain through a deep soil matrix to reach groundwater; this is in contrast to some karst and shallow bedrock scenarios where surface runoff may reach bedrock features and groundwater directly. Because these soils have high specific water yield or "drainable porosity", water and soluble materials, such as nitrate, rapidly move out of the root zone. Many public water supply wells are in these types of soils. Consequently, these soils may present a moderate to high water quality risk.

2.2 Soils Less Than 20 Inches to Non-Carbonate Bedrock

These soils can be found anywhere in New York and are often situated on fractured bedrock including shale, sandstone, or older metamorphic "basement" bedrock. When the soil is less than 20 inches deep over fractured bedrock, there is a high potential for local groundwater impact. It is often difficult to know if critical fractures are present, where surface contaminants can easily contaminate groundwater and move great distances in a short time. Therefore, shallow soils should be treated as though fractures are present.

2.3 Soils less than 40 Inches to Carbonate Bedrock and Karst Topography

A considerable portion of New York's prime agricultural land overlies carbonate bedrock. The presence of soils less than 40 inches deep to carbonate bedrock and/or karst features indicates another area of elevated risk for groundwater contamination by surface activities. "Carbonate" includes limestone, dolomite, calcareous shale, and other carbonate-containing sedimentary bedrock that can develop enhanced fracture pathways due to dissolution from groundwater. Bands of carbonate bedrock can be found (1) roughly parallel to the New York Thruway from Albany to Buffalo, (2) along the western side of the Hudson River south of Albany, and (3) in some portions of northern New York. The United States Geological Survey (USGS) published a statewide study of carbonate bedrock and corresponding geographic information system (GIS) layers, as part of an ongoing effort to better understand karst in New York (Kappel, W.M., Reddy, J.E., and Root, J.C., 2020. Statewide assessment of karst aquifers in New York with an inventory of closed-depression and focused-recharge features. U.S. Geological Survey Scientific Investigations Report 2020–5030, 74 p, https://doi.org/10.3133/sir20205030). The report and GIS layers provide a 1:250,000 scale map of the carbonate bedrock areas in the state, including a two-mile buffer area of shale overlying Onondaga-Helderberg limestone units (Figure 1). The report also provides a preliminary, statewide assessment of closed depressions within the carbonate bedrock areas and serves as a precursor to county-level studies underway to further aid karst feature identification. The information, combined with soil survey information, in-field observation, and other landscape features, can further help farmers and planners identify if their fields are within carbonate bedrock areas and have karst features needing additional management to reduce risk.

Some of the bedrock in these areas has developed what is known as "karst topography" where sinkholes, closed drainage depressions, dissolved caverns and solution enlarged fractures (zones of rapid flow) are often exhibited. These karst areas are at high risk for groundwater contamination and special care must be taken when considering manure spreading. Localized areas of carbonate bedrock within all these broader units can be highly fractured, providing rapid drainage pathways for surface runoff to reach groundwater. The fractures are important pathways between the surface and the ground water flow system providing rapid groundwater recharge, even when filtered by a few feet of soil. As water seeps into the cracks, the carbonate material is slowly dissolved causing further widening of fractures and increasing the capacity of such areas to accept shallow groundwater recharge. These characteristics make carbonate areas very vulnerable to rapid recharge from the surface and to equally rapid changes in water quality (i.e., groundwater under the direct influence of surface water), especially when large quantities of manure may be moved offsite during periods of heavy rainfall or snow melt. Either type of event can cause rapid surface water runoff and subsequent infiltration into the bedrock aquifer system. For a more detailed description of karst, a glossary of terms, and additional resources, see Appendix A.

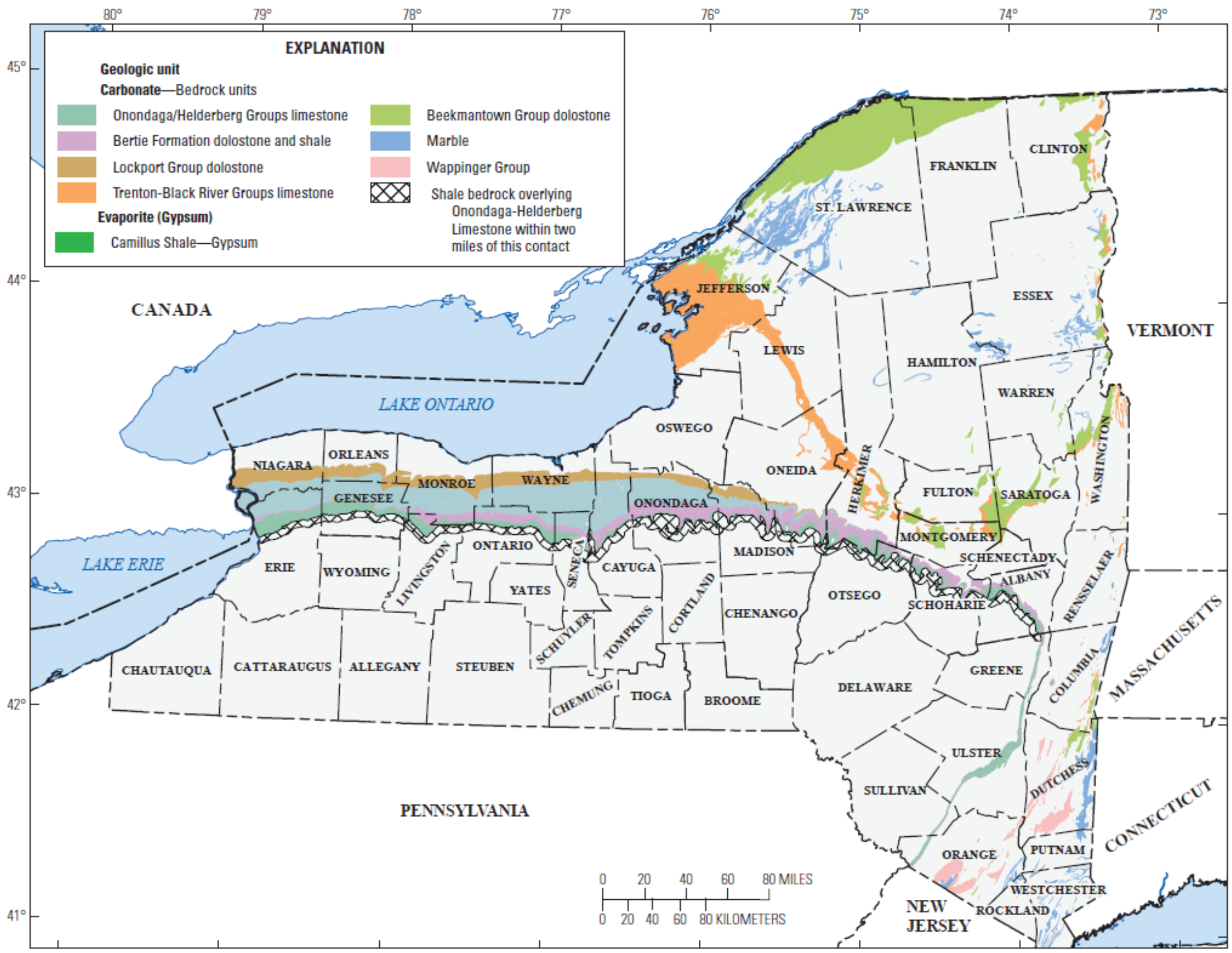


Figure 1. 1:250,000 scale carbonate bedrock unit map of New York State (Source: Kappel et al., 2020; reprinted with permission).

3. Soil and Landscape Feature Assessment

Management of areas with increased risk for groundwater contamination begins with an assessment of soil and landscape features through the process, below.

- Review the soil survey maps and map unit descriptions to determine the likely extent and component makeup of soils on the farm.
    - Glacial outwash soils and alluvial soils should be identified in the plan through the CPS 590 and the Nitrate Leaching Index assessment processes.
    - Check for soils less than 20 inches deep to non-carbonate bedrock (Appendix B) and soils less than 40 inches to carbonate bedrock (Appendix C) and, if present, identify in the plan. Soil Map Units with a major component (i.e., a

named map unit within a soil series listed in Appendix B or C) are of higher concern. Stoney or highly permeable soil classifications for some deeper soil map units in association with the soil series listed in Appendix B or C, or map units that contain minor components of soils series listed in Appendix B or C may also warrant further evaluation. Proceed to a higher level of evaluation and verification of site-specific concerns associated with shallow bedrock features if Appendix B or C soils are present.

- When soils less than 20 inches deep to non-carbonate bedrock (Appendix B) are indicated by the soil survey, planners should perform the following, additional assessments.
    - Identify additional risk features through discussions with farmers and use of topographic maps, in-field visual assessments, and other available resources. Note that these features may extend well beyond a farm's immediate boundary. Additional risk features may include:
        - Neighboring wells (abandoned or in-use), springs, areas of historical local groundwater problems, closed depressions, and areas where runoff water or tile flow disappears into the ground.
- When soils less than 40 inches to carbonate bedrock (Appendix C) are indicated by the soil survey, planners should perform the following, additional assessments to identify karst features.
    - Identify additional risk features through discussions with farmers and use of topographic maps, in-field visual assessments, and other available resources. Additional risk features may include:
        - Neighboring wells (abandoned or in-use), areas of historical local groundwater problems, and karst features including sinkholes, swallets, caves, disappearing streams, closed depressions, rock outcrops, shallow bedrock (e.g., restricts tillage, tile line depth, or plant growth), areas where runoff water or tile flow disappears into the ground, and areas contributing runoff to karst features.
- Update maps (1:24,000 scale or better) and supporting documentation in the plan for fields with soils and landscape features identified through this process, including additional manure application recommendations based on the guidelines, below. If no areas are identified, document consideration of these factors in the Conservation Assistance Notes portion of the plan. Update the plan if, over time, additional information becomes available.

4. Manure Management Guidelines

4.1 Guidelines for Glacial Outwash Soils and Areas of Rapid Infiltration

Per CPS 590, see the New York Nitrate Leaching Index for manure management guidelines for glacial outwash soils and other areas of rapid infiltration (Czymmek, K.J., Q.M. Ketterings, H.M. van Es, and S.D. DeGloria (2003). The New York Nitrate Leaching Index. Cornell University, Dept. Crop and Soil Sciences Extension Publication E03-2. 34 pages).

4.2 Guidelines for Bedrock-Controlled Soils

The following manure management guidelines apply for fields with bedrock-controlled soils (i.e., all soils in Appendix B or C):

- All activities should be consistent with other CNMP requirements when a farm is operating with a CNMP, such as those found in CPS 590 and relating to managing manure storages. Planners should be mindful of the tillage aspects of manure incorporation and how tillage and/or manure application may impact other CNMP compliance issues relating to the amount of residue needed for erosion control, nutrient balances, and risk indices. The CNMP should be updated accordingly.
- Manure should not be applied to saturated or frozen saturated soils (“concrete frost”), per CPS 590.
- When feasible, avoid manure applications on these fields during winter and wet weather conditions by storing manure or applying to lower risk fields without soils shallow to bedrock.
    - Winter conditions are defined as when the soil is frozen (4 inches or more), snow covered (4 inches or more), or encumbered by significant surface icing.
    - Wet weather conditions are defined as times when significant precipitation (e.g., greater than 0.25 inches of rain within a 24-hour period when soils are approaching saturation or greater than 1 inch of rain independent of soil moisture content) and/or snowmelt events (e.g., greater than 40°F for 6 hours or more) are forecast within the next 48 hours.
- When applications on these fields are necessary during winter and/or wet weather conditions as defined above, manure should be incorporated or injected the same calendar day as it is applied.
- Manure should not be applied within 100 feet of any water well or spring, per CPS 590. Wells with a history of water quality problems, or where wells are known to be of sub-standard construction or placement, implementation of greater setback distances may be required. For properties where well location is uncertain, the application setback should be initiated from the adjacent property boundary or apparent lot boundary associated with a residence. The establishment of long-term perennial vegetation in well setback areas is encouraged.
- Single application rates may need to be reduced and/or timing adjusted to account for fields determined to be higher risk for manure transport.

4.3 Additional Guidelines for Fields with Karst Features

The following additional manure management guidelines apply for fields with karst features:

- Direct entry points to groundwater such as sinkholes, swallets, and exposed bedrock should be protected using a vegetated buffer with a minimum width of 35 feet and a manure application setback of 100 feet at all times, consistent with the NRCS-NY Karst Sinkhole Treatment CPS 527 and CPS 590, respectively. Setbacks may need to be extended to include significant concentrated flows draining to karst features.

- Field areas with the potential to drain to any identified karst feature should be protected through the options, below.
    - When feasible, avoid manure applications in these areas during winter and wet weather conditions as defined, above, by storing manure or applying to lower risk fields not draining to karst features.
    - When applications in these areas are necessary during winter and/or wet weather conditions, manure should be incorporated or injected the same calendar day as it is applied.

References

- Czymmek, K.J., L. Geohring, Q.M. Ketterings, P. Wright, T. Walter, G. Albrecht, J. Lendrum, and A. Eaton (2015). Revised winter and wet weather manure spreading guidelines to reduce water contamination risk. Cornell University, Department of Animal Science Extension Publication #245. 9 pages.
- Czymmek, K.J., Q.M. Ketterings, H.M. van Es, and S.D. DeGloria (2003). The New York Nitrate Leaching Index. Cornell University, Department of Crop & Soil Sciences Extension Publication E03-2. 34 pages.
- Kappel, W.M., J.E. Reddy, and J.C. Root (2020). Statewide assessment of karst aquifers in New York with an inventory of closed-depression and focused-recharge features: U.S. Geological Survey Scientific Investigations Report 2020–5030, 74 pages.
- Natural Resources Conservation Service (2020). Nutrient management Code 590 Conservation Practice Standard. USDA-NRCS.

Appendix A: Karst

"Karst" is the term used for areas associated with carbonate bedrock (limestone or dolomite), where cracks, fractures, and other solution channel irregularities are present. Karst conditions enhance these bedrock features over time through the action of flowing water to create sinkholes, caves, depressions in the land surface, disappearing streams, etc., which provide a direct connection between surface water and ground water – these enhanced connections are known as "focused recharge". While cracks and karst channels in bedrock provide for high yielding wells, this type of landscape and geology, especially where the topsoil is thin, allows water to rapidly flow into (or out of) bedrock with little or no filtration. In such areas where ground water is under the influence of surface water, recharge waters influenced by residential, commercial, industrial, wildlife, or agricultural activities may also generate a contaminant risk to surface and ground water supplies. Human activities in karst areas, including manure application, have a higher potential to contaminate groundwater as compared to most other hydrogeologic conditions found in New York.

Glossary of Karst Terms

This glossary is adapted from: Field, M.S. 2002. A Lexicon of Cave and Karst Terminology with Special Reference to Environmental Karst Hydrology | Science Inventory | US EPA.

- **Aquifer**: A formation (bedrock or soil), or part of a formation that contains sufficient saturated, permeable material to yield significant quantities of water to wells and springs.
- **Bedrock Controlled Soil**: Any soil with less than 40 inches to bedrock.
- **Contributing drainage area**: The portion of land-surface area from which measurable accumulated runoff water flows to a receiving surface or ground waterbody of interest.
- **Joint**: A break or paper-thin fracture in the bedrock occurring either singly, or more frequently in a set or system, but not attended by a visible movement parallel to the surface of the joint. A joint is where water may initially seep and slowly dissolve carbonate rock to begin to create solution channels and initiate karst.
- **Karst**: A terrain, generally underlain by limestone or dolomite, in which the topography is formed chiefly by the dissolving of rock, and which may be characterized by sinkholes, losing (sinking) streams, closed depressions, subterranean drainage, and caves (Monroe, W.H., 1970. A glossary of karst terminology. US Geological Survey, Water-Supply Paper 1899).
- **Karst aquifer**: A body of soluble rock that conducts water principally via a connected network of tributary conduits, formed by the dissolution (slow dissolving) of the rock, which drain a groundwater basin and may discharge to a spring. The conduits may be partly or completely water filled and the volume and nature of flow in karst varies throughout the year.
- **Karst topography:** A landscape characterized by the presence of sinkholes, caves, springs, and losing streams created by groundwater solution of sedimentary rock such as limestone.
- **Sinkhole**: Any closed depression in soil or bedrock formed by the erosion and transport of earth material from below the land surface, which is illustrated by a closed topographic contour on a map and drains to the subsurface. Types of sinkholes formed in soluble rock include dissolution sinkhole or doline (gently sloping depression that is wider than it is deep), karst window (sinkhole exposing an underground stream), vertical shaft (depressions in bedrock much deeper than it is wide and roughly circular in plan), grike (depression in bedrock much deeper than wide and crudely shaped like a lens (lenticular in plan).

- **Sinking (losing) stream**: Any stream that disappears underground, typically over a longitudinal section of a stream channel or directly into a swallet.
- **Spring:** Any natural discharge of water from rock or soil onto the surface of the land or into a body of surface water.
- **Surface depression:** A closed, bowl-shaped feature in the land surface that does not drain to a stream or to any other surface feature.
- **Swallet (swallow hole):** A place where water disappears or sinks underground. A swallet generally implies nearly instantaneous water loss into an opening of a sinkhole or karst valley.
- **Topography**: The general configuration of the land surface or any part of the earth's surface, including its relief and the position of its natural and man-made features. Maps of the topography commonly represent the shape of the surface with contour lines of constant elevation. Sinkholes and surface depressions are represented by contours that form a closed loop and may be marked with a series of tick marks on the interior or downslope side.

GIS Map Resources to Assist in Identifying Karst Landscapes and Features
(note, GIS resources may be updated or added based on availability at time of publication)

Bedrock-Controlled Soils:
- Web Soil Survey: http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm
- USDA Soil Data Access: https://sdmdataaccess.nrcs.usda.gov

Depressions:
- USGS 7.5 Minute Topographic Maps – 1:24,000 scale Digital Raster Graphics: http://cugir.mannlib.cornell.edu/datatheme.jsp?id=92
- Other Elevation Data: http://gis.ny.gov/elevation/
- Orthoimagery from NYS GIS Clearinghouse: http://gis.ny.gov/gateway/mg/

Sinkholes and Swallets:
- USGS 7.5 Minute Topographic Maps – 1:24,000 Digital Raster Graphics: http://cugir.mannlib.cornell.edu/datatheme.jsp?id=92
- Other Elevation Data: http://gis.ny.gov/elevation/
- Web Soil Survey: http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm
- USDA Soil Data Access: https://sdmdataaccess.nrcs.usda.gov/

Lower Resolution Bedrock Geology for all of New York:
- New York State Museum Bedrock Geology Data – 1:250,000 scale: http://www.nysm.nysed.gov/research-collections/geology/gis

Assessments of karst aquifers and features in New York:
- Kappel, W.M., Reddy, J.E., and Root, J.C., 2020, Statewide assessment of karst aquifers in New York with an inventory of closed-depression and focused-recharge features: U.S. Geological Survey Scientific Investigations Report 2020–5030, 74 p., https://doi.org/10.3133/sir20205030.
- Sporleder, B.A., Fisher, B.N., Keto, D.S, Kappel, W.M. and Reddy, J.E., 2021. Methods of data collection and analysis for an assessment of karst aquifer systems between Albany and Buffalo, NY. U.S. Geological Survey Scientific Investigations Report 2021-5094, 8 p., https://www.sciencebase.gov/catalog/item/5e614312e4b01d509255bfbc

Appendix B: Soils Less Than 20 Inches to Non-Carbonate Bedrock

New York soil series, variants, and miscellaneous units that are less than 20 inches to non-carbonate bedrock:

- Abram
- Arnot
- Canaan
- Couchsachraga
- Glover
- Halcott
- Hannawa
- Hawksnest
- Hogback
- Hollis
- Holyoke
- Insula
- Irona
- Kearsarge
- Knob Lock
- Lyman
- Nassau
- Quetico
- Ricker
- Rock Land
- Rock Outcrop
- Skylight
- Taconic
- Topknot
- Tor
- Torull
- Tuller
- Woodstock
- Wotalf

In all cases, refer to the soil map unit description for soil series composition of the mapped unit for the area being evaluated. Soils map units with the above-named series as major components are of higher concern. However, map units with significant minor components or associations from the above list may also be a concern.

Appendix C: Soils Less Than 40 Inches to Carbonate Bedrock

New York soil series, variants, and miscellaneous units that are less than 40 inches deep to carbonate bedrock (e.g., limestone, dolomite):

- Benson
- Chaumont
- Chippeny
- Farmington
- Galoo
- Galway
- Gouverneur
- Groton Variant (Jefferson Co.)
- Guff*
- Guffin*
- Joliet
- Kings Falls
- Madalin Variant (Montgomery, and Schenectady Co.)
- Matoon*
- Neckrock
- Nehasne
- Newstead
- Ogdensburg
- Rockland, limestone
- Ruse
- Summerville
- Sun Variant (Monroe Co.)
- Wassaic
- Wilpoint

* In some areas these glaciolacustrine soils are over non-calcareous rock. These areas are indicated at a small scale on the bedrock geology map (Adirondack sheet) from the New York State Geological Survey.

The following soils are typically over calcareous shale but may be over limestone in areas where shale and limestone bedrock formations are in close proximity. In addition, the calcareous shale may be porous enough in places to allow rapid infiltration, creating an increased risk of groundwater contamination.

- Aurora
- Varick
- Brockport
- Camillus
- Lairdsville
- Lockport
- Palatine
- Riga

In all cases, refer to the soil map unit description for soil series composition of the mapped unit for the area being evaluated. Soils map units with the above-named series as major components are of higher concern. However, map units with significant minor components or associations from the above lists may also be a concern.