Hydrologically Active Karst and Disappearing Lake Phenomenon in the Onondaga Escarpment, Western New York

Paul L Richards

SUNY Brockport, Brockport, NY, New York State Professional Geologist No 83

ABSTRACT

Karst-related flooding and disappearing lake phenomenon are occurring between Leroy and Caledonia in an area where water tables exhibit dynamic seasonal variation. This peculiar groundwater environment resulted from the history of deglaciation which has eroded much of the unconsolidated glacial sediments, leaving behind thin, immature soils overlying fractured, karsitic, carbonate bedrock. Stream incisions and highlands to the south (**Figure 1**) have resulted in high potentiometric gradients and water table events that sometimes respond to individual meteorologic events. This peculiar hydrogeologic regime poses a challenge to current watershed management because of the dynamic nature of subsurface flowpaths and their potential to carry pollution. At least seven well contamination events have occurred because of manure and other pollutants entering karst features. This field trip seeks to understand this groundwater system in the Onondaga Escarpment and evaluate the cause of this flooding, much of which occurs along Route 5, the Village of Leroy, Quinlan and Britt roads.

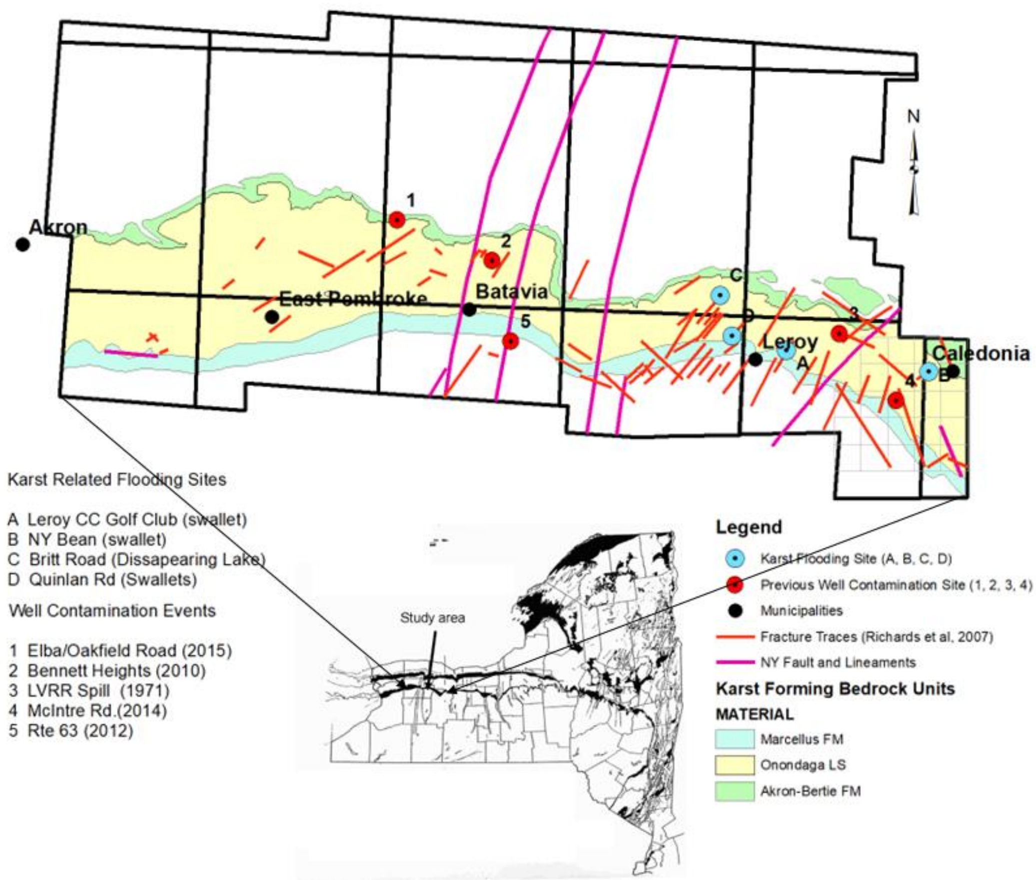

Figure 1. Karst-forming bedrock, fracture traces, and faults, and karst flooding sites in Genesee County, NY. The map also shows locations of well-contamination events that have been attributed to surface contamination through karst features. The field trip is focused on karst features in the green rectangle.

BACKGROUND

Exposed at the base and northern part of the study area are the Camillus shale, Falkirk FM and the Bertie Limestone. Overlying these units is the Onondaga Formation, which consists of the following members: Edgecliff, Clarence, Nedrow and Moorehouse. Beds dip slightly towards the south with the result that the farther south you go the thicker the Onondaga formation and the deeper it is to the base of the unit. Overlying these rocks are the Oatka Creek shale, Stafford Limestone and Levanna shale. Much of the area south of Rte 5 exposes these shales which have been demonstrated by the DEC to be not very permeable. There is some local structure (minor folds or "popup ridges"; broken anticlines, see Sutton, 1951). Boreholes drilled along Spring Creek indicate that the fracture trace Spring Creek is located in is actually a fault with significant displacement along its length (Unicorn Management Consultants, UMC (2014)). The Onondaga limestone and Bertie Formation in this area are extensively fractured with two major joint directions that trend North East and East South East (determined by mapping fractures in the abandoned quarries along Golf Road). Fracture mapping by Fronk (1991) indicates these joint sets change with height and can be variable. Pump tests conducted by Unicorn Management (UMC, 2014) and NYSDEC (Rust Environment and Infrastructure, 1996) suggest the permeability in the Onondaga is low and dominated by fracture flow. A thesis by Libby (2009) included observations at Buttermilk Falls (in Oatka Creek) and quarry exposures of flooding that show strong evidence of fracture flow. Rhinehart (2005) demonstrated through hydrologic calculations that the flooding at one of these sites (Quinlan road sinkhole), was increased by fracture flow coming from outside the watershed. Fracture traces are numerous and well logs in the Village of Leroy indicate bedrock is between 0 and 12 feet of the ground surface. Aerial photographs and inspection in the field suggest that many sinkholes are present (see Richards et al., 2010; Rodgers, 2016; and Kita, 2018), however no "caves" have been found. These features are usually subtle depressions and conform to sinkholes at the early stages of development (see Palmer, 1991). All the tributaries east of the town of Leroy end near Rte 5 with the exception of Mud Creek. These streams probably terminate in sinkholes or thinly soiled epikarst and contribute surface water directly into the Onondaga FM. Mud Creek flows into a sinkhole just south of the LVRR grade (Mud Creek Sinkhole). The study area contains broken craggy relief with numerous depressions and hummocky ridges. Information on subsurface flow paths is scant, but a TCE plume mapped by the NYS DEC (Dunn Geos. Eng., 1992, Fronk (1991), and Unicorn Management Consultants (UMC, 2014) suggest groundwater flows East South East and is discharged at the springs of Caledonia. This is also supported by water table maps. A GPR survey by Dunn Geos. Eng. (1992) suggests that there are large rubble filled depression features at the top of the bedrock below the soil zone. These are NOT expressed in the surface topography and could be zones of enhanced permeability.

INTERPRETATION

Our interpretation (see arrows in **Figure 2**) is that groundwater flows into the area through a series of northeast fracture traces (**A**). This flow is believed to be shallow and flows on top of the Oatka Creek and Levanna shales, which acts as an aquitard. When the flow reaches the Onondaga FM, the major groundwater flowpath is eastward through East-West fractures toward the Caledonia Springs (**B**) and Spring Creek. Some of this water probably seeps northward into Oatka creek at the base of the Onondaga (**C**); where springs have been mapped along its length. During karst related flood events, a pulse of groundwater causes water tables in the area betweenRte 5 and the eastward segment of Oatka Creek to rise. This fills up the abandoned quarries in the region and contributes to the extensive flooding observed at Mud Creek. As this groundwater progresses towards Caledonia it causes water tables to rise in the vicinity of the sinkholes that capture streams flowing from the south sinkholes and other tributaries that terminate inexplicably at Rte 5 (**D**). When surface flows exceed the ability of these sites to accept allogenic recharge, these sites flood. Flooding at New York Bean (in Caledonia), are caused by a combination of groundwater rise and drainage from surface tributaries. The latter features are also probably impacted by urban runoff from Caledonia. Flooding at Britt Rd is probably caused by the low permeability underlying Onondaga bedrock that cannot accommodate runoff and snowmelt.

TCE isoconcentration maps from a Railroad spill site at Golf Road, suggest the groundwater within the Onondaga Escarpment in this area is moving East Southeast (Rust Environment & Infrastructure, 1996; UMC, 2014). An important question is why does the plume (and groundwater) not flow northeast along the downslope direction of topography. Hydraulic conductivity tests conducted by Dunn Geos. Eng. (1992) indicate that the Onondaga is much less permeable than the rock below it and that much of this permeability is through fractures. This was confirmed by a soak test study by Payne, 2009 who found very little primary porosity in the bedrock. Our hypothesis is that these Northeast-oriented secondary fractures have much less permeability in that direction. Flow instead is along Eastward oriented open fractures. This anisotropic hydrologic conductivity effectively dams the groundwater in the Onondaga Formation from flowing along the prevailing topographic slope, forcing it to move eastward along open fractures to the Caledonia springs that make up the piezometric low of the area (Spring Creek). Karst flooding is enhanced in this area because soils are thin and bedrock storativity from open fractures is low. These two characteristics mean that there is little opportunity to store water. The low storativity of the bedrock from fractures also helps to explain some of the dynamic water table fluctuations seen in monitoring wells in the LVRR plume, which may increase 40 feet or more in a single 24-hour period. We interpret the flooding (and disappearing lake phenomenon) to be caused by the presence of high-elevation recharge areas south of the Onondaga Escarpment and a piezometric surface that is close enough to the ground elevation to enable the groundwater table to rise above the surface of the ground during high groundwater discharge events.

Figure 2. Showing hypothesis for how karst-related flooding may be occurring.

Site 1. Quinlan Road Swallet Site Watershed area 2.44 km

https://goo.gl/maps/VX9ATy5HsYfwXSecA 42.989858, -78.008144

Most karst features on the Onondaga FM in this region are subtle areas of highly fractured bedrock covered by thin soils. The Quinlan Road Sinkhole site is the rare exception of a deep sinkhole that may be a collapse feature (**Figures 3,4**). The feature receives runoff from a drainage ditch along a nearby cropfield. During Karst-related flooding events, flow into the swallet reverses and groundwater spills out of the feature, flooding the land outside (see figures below). Floods can sometimes flood over Quinlan Road itself. The feature and its flooding were first studied by Rhinehart (2005), and then by Daniluk (2009), who monitored the water level in it for three years and compared it to local precipitation and snowpack data. Daniluk found that this feature did not respond to local meteorological events, but rather followed regional groundwater fluctuations as measured from a transducer in a groundwater monitoring well located at the LVRR plume superfund site. This well is located 4 miles East of the site and is also within a feature that is believed to be a sinkhole.

Figure 3. The Quinlan Road Sinkhole.

Figure 4. Quinlan Road Sinkhole during Flood Stage.

Site 2. Britt Road Flooding site Watershed area 0.97 sq km

https://goo.gl/maps/A4UUjKDSvxnZH1P7A 43.0110416, -78.015354

This site does not contain any visible karst features or sinkholes. It floods, however, whenever The Quinlan Road Swallet and the Leroy Golf Course Sinkhole floods (**Figure 5**). A Master's Thesis by Simons and Voortman (2009) developed watershed models for this site and the Quinlan Road sinkhole site. Uncalibrated model simulations indicate that flood water from Britt Road is dominantly surface runoff. In contrast, simulations on Quinlan Road revealed that a high percentage of floodwater was groundwater. Due to the lack of any surface karst features at Britt Road, the site is believed to be underlain by fractured bedrock that has low vertical conductivity. Our interpretation is that under normal circumstances, this conductivity is sufficient to keep the area drained. During karst-related flooding events, runoff and snowmelt exceed the site's ability to accept allogenic recharge in the bedrock. When this happens, the area floods. The Keeney Road berm is believed to exasperate the flooding by keeping water from flowing East towards Oatka Creek, where, according to local residents, it re-infiltrates back into the ground.

Figure 5. Britt Road site during Flood Stage.

Site 3. LVRR Spill Site (Movie-overview of the hydrology)

https://goo.gl/maps/mtdsUKAbeY1cDwHj7 43.2439296, -77.643776

This stop is located at the site of a train derailment that spilled 30,000 gallons of TCE into the Onondaga Escarpment on December 6, 1970. The spill created a four-mile-long plume that terminates at Spring Creek in the Village of Caledonia. The dynamics and shape of the plume appear to be greatly impacted by recharge coming from overlying karst features. Much of the knowledge of the hydrology in this area has been collected through well observations and hydrologic modeling needed to understand this plume. This movie (https://youtu.be/5ZrMXOJkB6M) synthesizes much of the scientific work carried out by the New York DEC, Unicorn Management Consultants, and students and faculty from SUNY Brockport. We will be visiting six sites along its length, starting from where Mud Creek enters the Escarpment to where this water is believed to reappear at Spring Creek.

Sites 4 and 5. Mud Creek Fracture Zone

In this region**,** Mud Creek is the only stream that crosses completely over the Onondaga escarpment, except for Oatka Creek. The stream flows along a major fracture trace. This narrow bedrock stream is heavily fractured and contains many small sinkholes along its length. The flow here is non-existent during most of the year, despite that it receives flow from the Dolomite Products SPDES outfall, which releases an average of 4.5 cfs continuously into it (**Figure 6**). It is subject to karst-related flooding in the segment overlying the Onondaga Escarpment (**Figure 7**). Flow from the SPDES outfall typically disappears within a hundred meters of its outfall. During events and spring runoff, the stream will flow all the way into the Mud Creek Sinkhole. We will be visiting two sites in this feature: the Mud Creek Sinkhole, which is the swallet that captures most of the flow in this system and the canyon north of Golf Road, where the character of the streambed, fractures, and smaller sinkholes can be seen.

Figure 6. Dolomite Products SPDES outfall into Mud Creek (left). Discharge disappearing into the Mud Creek streambed a few hundred meters downstream of the outfall (Right).

Figure 7. Karst related flooding along Mud Creek (Left) and at the Mud Creek Sinkhole (Right).

Site 4. Mud Creek Sinkhole

https://goo.gl/maps/tn8Q1ZmtpTrmyBs46 42.9912921, -77.9308537

This large circular feature is located just north of the tunnel underlying the LVRR tracks (**Figure 8**). The regional water table is exposed in it. The feature receives all of the runoff from Mud Creek Watershed, which is a 30 sq km watershed. The feature was instrumented with a water level recorder in 2008 and discharge measurements before and after indicate that almost all of the water from Mud Creek watershed disappears in this feature and flows East towards Spring Creek. Only when the water table rises above it during karst flooding events, does water pass this feature and flow along Mud Creek Canyon to its outlet in Oatka Creek.

Figure 8. Water Table within the Mud Creek Swallet. Mud Creek flows into this feature through the railroad culvert.

Site 5. Mud Creek Canyon

https://goo.gl/maps/gZPn7WWu6qihQtEP9 43.2439296, -77.643776

At this site, we will walk along the exposed bedrock to see one of the many smaller “sinkholes” caused by enhanced weathering at the intersection of fractures (**Figure 9**). Because most of the water disappears in the Mud Creek Sinkhole, the creek bed here receives very little flow. It runs only during the most extreme snowmelt or karst-related flooding events. A study by Richards 2010 measured the flow at the outlet of Mud Creek over a two-year period and determined that virtually no flow makes it to Oatka Creek. The flow was only observed once (out of 18 measurements) during a January flooding event.

Figure 9. Sinkholes developing in the Mud Creek streambed.

Site 6. Church Hill Road Sinkhole

https://goo.gl/maps/Q1f28DwGX85fMFCn8 43.2439296, -77.643776

This large, deep, sinkhole is overlain by thin carbonate soils. It does not flood when karst-related flooding events take place in these other sites. A LiDAR hillshade indicates the sinkhole may have been modified through erosion by glacial meltwater moving towards the Genesee River Valley at the end of the last Glacial Retreat. NYS-DEC drilled two wells in this sinkhole in the 1990's. When the first well (DC-7) was drilled, the driller hit a void and the borehole collapsed. As a consequence, a second well was drilled (DC-7R). Well-level measurements indicate that the vertical hydraulic gradient is generally downward. The lack of flooding in this feature suggests the sinkhole is underlain by a heavily fractured zone with enough vertical permeability to recharge any precipitation or snowmelt event. It is interesting to note that in some TCE isoconcentration maps, the plume thins in the region of this sinkhole.

Site 7. Rte 5 Sinkhole / "popup ridge"

https://goo.gl/maps/MEnA5H5soqAT8LND8 43.2439296, -77.643776

A small unnamed tributary with a watershed area of 9.2 sq km flows into this feature which consists of a waterfalls made up of in situ bedrock (**Figure 10**). After the waterfalls, the flow is lost in the wetland. The feature sometimes floods the southern shoulder of Route 5. All channelized flow terminates in this feature. A broken anticline or "pop up ridge" is located just East of this feature.

Figure 10. Photos of the Rte 5 Sinkhole during flood stage.

Site 8. Mackay Spring

https://goo.gl/maps/RK6PeEGxfFc6t5oQ7 42.9748128, -77.8593758

Mackey Spring is one of the many large springs in Caledonia that supply water to Spring Creek. Spring Creek has a very small surficial watershed area. It is much too small to account for its high rate of discharge. It is believed that Springs such as this site and others contribute to its steady flow. Unicorn Management Consultants Geologists Richard Bush and Mike O' Connor discovered through fieldwork and well drilling that Spring Creek is a fault. This fault creates a low piezometric zone in the escarpment where groundwater can drain to. Meteoric water recharges into swallets and thinly-soiled karst at the top of the escarpment, ultimately draining out of springs along the Spring Creek Fault. An analogous situation is the headwaters of Bigelow Creek along Seven Springs Road near Batavia. This stream and its springs occur on the Clarendon Linden Fault system. Those springs are probably fed by sinkholes and thinly soiled karst zones at the top of the escarpment (Richards et al, 2010, Reddy and Kappel, 2010).

Mackay Spring rarely dries up. It is shallow and underlain by open fractures in Akron Bertie bedrock that are as wide as 10 centimeters (**Figure 11**). Water flows out of these fractures. White speckles of what is presumably calcium carbonate can sometimes be seen in the water if sediment is kicked up within it.

Figure 11. Photo of one of the many large open fractures that underly Mackay Spring.

Site 9. Spring Creek

https://goo.gl/maps/ByL5iBWyXBMJkPPV6 42.9871394, -77.8614285

In our last site, we will visit Spring Creek where it flows through a railroad tunnel. Water from the many springs along Spring Creek in Caledonia ultimately come together to form this stream segment, which is located just downstream of the NYS DEC Caledonia Fish Hatchery. The stream then flows North to its confluence with Oatka Creek in Mumford, NY.

The stream was gaged by the author for an approximately 18-month period. This data was used to calibrate the SWAT model that was used to evaluate recharge into the LVRR plume (Richards, 2016). Streamflow records indicate Spring Creek is not very responsive to precipitation events. The shape of its discharge curve strongly resembles the water level record at well cluster DC-5, which is located four miles west of Spring Creek. This well is located far outside of its surficial watershed divide (south of the LVRR spill site and just west of Mud Creek sites). Spring Creek has a mean annual discharge to the drainage area that is many times higher than streams in the area (if the surficial watershed area is used in this calculation). If this ratio is recalculated by including the watershed area of the LVRR plume and all the tributaries that enter sinkholes that overly the plume (**Figure 12**), the resulting annual discharge to drainage area ratio in Spring Creek is much more consistent with other streams in the area.

A geochemical study of the groundwater by Richards (2017), made possible by water quality sampling conducted by NYS-DEC, and Unicorn Management Consultants (UMC, 2014), SUNY Brockport Undergraduate Theses (Libby, 2009 and Simmons, 2011), and Cornell University (Pacenka et al, 2017) suggests that Spring creek contains very little meteoric water. Its chemistry, which contains more sulfate than carbonate, is dominated by a blending of groundwater from the Camillus and Akron-Bertie Formation. A chemical mixing model suggests that Camillus groundwater may provide anywhere from 41 to 83% of its water. This chemistry data would also be consistent with a groundwater origin for the Creek.

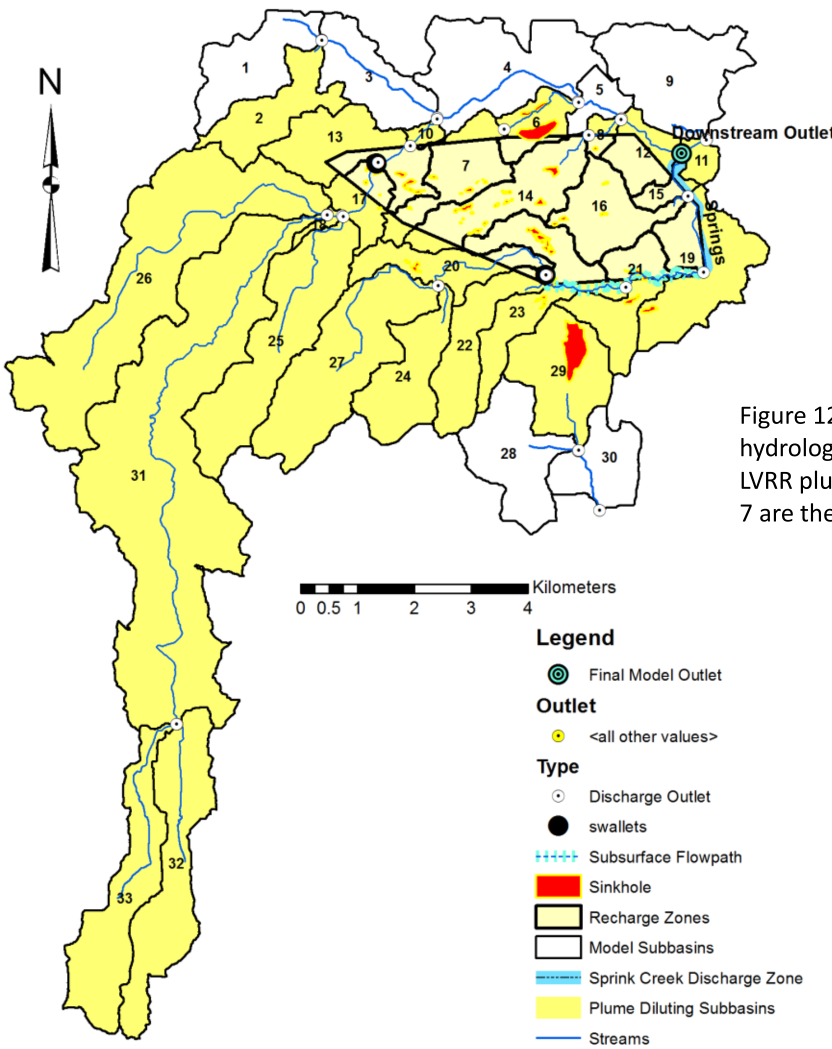

Figure 12. Watershed divides associated with the SWAT hydrologic model used to compute recharge into the LVRR plume (after Richards, 2016). Fieldtrip Sites 4 and 7 are the swallets in the map above.

REFERENCES

Daniluk, T.L. (2009) *Source of Flood Water at the Quinlan Road Sinkhole Leroy, New York*, Undergraduate Thesis, Dept. of Earth Sciences, The College at Brockport., Brockport, NY, USA.

Dunn Geo. Eng. (1992) Task 2, Phase A Report State Superfund Standby Program Lehigh Valley Railroad Derailment Site RI/FS, Town of Leroy County of Genesee, New York, pub. by Dunn Geoscience Engineering Co., P.C. Albany, NY 12205 80pp.

Fronk, A.M. (1991) *Lehigh Valley Railroad Spill: A Study of a Contaminated Carbonate Aquifer*, Undergraduate Thesis, Hobart William Smith Colleges, Geneva, NY 44pp

Fairchild, H.L. (1909) *Glacial Waters in Central New York*, Bulletin 127 of the New York State Museum, Albany NY

Libby, J. (2009) *Determining the Source of Water from Conduit Flow at Buttermilk Falls, LeRoy NY*, Undergraduate Thesis, Dept. of Earth Sciences, The College at Brockport., Brockport, NY, USA.

Kita, A. (2018) *Identifying sinkholes using a Geographical Information Systems (GIS)*, Undergraduate Thesis, Department of Earth Sciences, The College at Brockport 30pp.

Pacenka, S., Richards, P.L., and Richards, B. K. (2017). *Should karst settings receive special attention in New York pesticide registration?* Technical Report, Department of Biological and Environmental Engineering, Cornell University, Ithaca, NY, 55pp.

Palmer, A.N. (1991) Origin and Morphology of Limestone Caves, *Geological Society of America Bulletin*, **103** 1-21.

Payne, C. (2009) *Stratigraphic Analysis of the Onondaga Formation and Relationships with Groundwater Flow, Case Study in Leroy, New York, Undergraduate Thesis*, Dept. of Earth Sciences, The College at Brockport., Brockport, NY, USA.

Reddy, J.E. and Kappell, W.M. (2010) Hydrogeologic and Geospatial data for the Assessment of Focused Recharge to the Carbonate-Rock Aquifer in Genesee County, New York., *USGS Scientific Investigations Map* **3132**.

Rhinehart, S. (2005) *Origin of Anomalous Flooding in the Quinlan Rd Sinkhole, Leroy New York.* Undergraduate Thesis, SUNY College at Brockport.

Richards, P. L., J. Libby, A. Kuhl, T. Daniluk, and M. Lyzwa. (2010) *Prediction of Areas Sensitive to Fertilizer Application in Thinly-Soiled Karst, FINAL REPORT*. New York State Water Resources Institute http://wri.eas.cornell.edu/grants.html 29pp.

Richards, P.L. (2016) *Recharge into the LVRR plume estimated by the Soil Water Assessment Tool, (SWAT)*, Technical Report prepared for Unicorn Management Consultants LLC., 60pp.

Richards, P.L. (2017) *Geochemical Assessment of Groundwater at the LVRR Plume Site*, Report prepared for Unicorn Management Consultants, LLC.,28pp.

Rodgers, M. (2016) *Sinkhole Analysis and Classification Using Pictometry in Genesee County, NY and Surrounding Areas,* Masters Thesis, Department of Ecology and Environmental Science, The College at Brockport, 87pp.

Rust Environment & Infrastructure. (1996) *Remedial Investigation Report, Lehigh Valley Railroad Derailment Site,* Volumes 1-3, On file at the Leroy Public Library, Leroy, NY.

Simmons, A. (2011) *Source of water for Spring Creek, Caledonia, New York.* Undergraduate Thesis, Dept. of Earth Sciences, The College at Brockport, Brockport, NY

Simons, GWH and Voortman. B.R. (2009) Quantifying the contribution of surface runoff to Karst Related Flooding between Leroy and Caledonia. NY, Masters Thesis, Department of Geography, The University of Utrecht, 79pp.

Sutton, R.G. (1951) *Stratigraphy and Structure of the Batavia Quadrangle: Rochester, New Yor*k Rochester Academy of Science, 348-408.

UMC (2014) *Remedial Investigation Report, US EPA Operable Unit 2 Groundwater Plume* Lehigh Railroad Derailment Superfund Site, Leroy NY.