

# Response to Comments by Vaughn, Young, and Michalski on my 7/13/17 Letter to you regarding Salt Mining under Lake Cayuga

The honorable Andrew M. Cuomo  
Governor of the State of New York  
The Capitol  
Albany, NY 12224

August 7, 2017

Dear Governor Cuomo:

A [July 21, 2017 letter to you](#) from Geologists Raymond C. Vaughn, Richard A. Young, and Andrew Michalski (hereafter referred to as VY&M) commented extensively on [my July 13<sup>th</sup> letter to you](#) (and the NYSDEC) regarding geological concerns raised by CLEAN (Cayuga Lake Environmental Action Now) about salt mining under Lake Cayuga. Here I briefly respond to their comments.

## The Context

The main issue under discussion is whether the negative declaration of the NYSDEC allowing the reaming of a ventilation and egress shaft in Lansing to proceed should be withdrawn. VY&M and CLEAN request the negative declaration be reversed because the shaft risks catastrophic mine flooding, mine collapse, and salinification of Lake Cayuga.

A second issue is whether permission for mining under Lake Cayuga should be withdrawn when modification or renewal of the mining permit is sought. VY&M request this be done because salt mining to the north may be riskier. They believe the shaft and continued mining decisions are linked.

## The Negative Declaration on Shaft #4

VY&M argue Shaft #4 poses a significant risk of mine flooding based on analogy with the Retsof mine. The analogy is not appropriate.

Flow into the Retsof mine accelerated uncontrollably as a portion of the mine collapsed and fractures that connected to an overlying confined aquifer dilated. Fracture permeability increases as the cube of fracture aperture and therefore increases dramatically with dilation. The Retsof analogy does not apply to the Shaft #4 area because the salt near shaft #4 has not been mined out and there is no open space into which collapse could occur. The volume of the narrow access tunnel from which the shaft will be reamed upward is simply insignificant in regards to the kind of collapse that could accelerate flooding.

The inflow of water into the shaft as it is reamed is likely to be similar to the ~30 gpm inflow in the Cayuga Shafts that have already been emplaced. Corehole #18 drilled in the Shaft #4 location indicates the inflow will be ~4 gpm. In the event that water did begin to enter the shaft at rates of concern, the upward reaming could be halted until the inflow was controlled. If the inflow could not be controlled,

the mine could be protected by sealing off the tunnel to the mine. Shaft #4 will be reamed in a stratigraphy dominated by low permeability shale with only one identified permeable zone- the Onondaga/Oriskany contact which Corehole #18 testing indicated could deliver ~4 gpm to the shaft. This inflow is barely enough to supply one household with water. The reaming of Shaft #4 simply does not pose a significant risk of mine flooding,

The significant environmental damage VY&M believe could result from mine flooding from Shaft #4 and justify rescinding the negative declaration is the salinification of Lake Cayuga that could occur as pillar creep causes the roof and floor of the flooded mined rooms to close together and squeeze the saline water in the flooded mine into the lake. I argued that, when quantified, this salinification risk “largely disappears”. VY&M challenged this, pointing out that for the 100-year exponential collapse time constant that I used to calculate one of my curves, I calculated a 175 ppm increase in lake salinity, which could be viewed as significant.

Fair enough. Prompted by their comment I have redone my calculations. A 100-year closure time constant is unrealistically small and an exponential collapse is not appropriate. Salt pillars collapse rapidly at first but the collapse decelerates far more strongly than exponentially. Underground mining at the [Wieliczka and Bochnia salt mines in Poland](#) started in the 13<sup>th</sup> century and workings hundreds of years old have remained open, allowing tourists to literally walk thorough salt mining history. Salt mines take more than 100 years to collapse. I have redone the calculation of mine collapse using a creep relationship based on laboratory data validated against measured pillar subsidence (see Appendix I).

The results of the new calculations are plotted as changes in Cayuga Lake chlorinity in Figure 1, and the changes are compared to those measured in Lake Cayuga from 1908 to 2014. In the figure the hypothetical mine flooding is assumed to have occurred in 2014. Figure 1 shows the chlorinity increase from mine collapse depends on the average pillar age at the time of flooding. If the pillars were brand new, the chlorinity increase could be 40 ppm, similar to the increase I calculated in my July 13<sup>th</sup> letter for a 200-year exponential mine closure constant. Since underground mining has been ongoing for 95 years, the average age of the pillars is very much older than zero years. If the average pillar age were 20 years, the calculated maximum chlorinity increase is 12 ppm; if the average pillar age is 50 years the calculated maximum increase is 9 ppm.

There are of course uncertainties in these calculations. As indicated by VY&M Salt dissolution could increase the volume of the mine by 18% if the flooding waters are fresh. I calculate this will increase the peak chlorinity by ~2 ppm (to 14 ppm for the 20-year average pillar age case). If the salt was dissolved from the pillars only, and not from the roof and floor of the mined areas, and the resulting pillar reduction together with the increased mine volume would increase peak chlorinity by ~12 ppm so the maximum chlorinity increase would be 24 ppm. The Salina salt might creep differently from the Permian salt used in the calculations, and water might increase the creep rates. My mine subsidence calculations could be refined using the subsidence models Cargill is already using, and it might be possible to take into account the effects of immersion in water on salt creep rates. Not all the water squeezed from the mine will go into the lake; most is likely to move into permeable strata below the lake. Hydrologic calculations could address the fraction of expelled brine that might enter the lake.

Despite these many kinds of uncertainties, I believe Figure 1 presents a reasonable, probably high, estimate of the likely lake salinification. The figure clearly shows that the quantified salinification risk has indeed “largely disappeared”. It is about the same magnitude as the changes in lake salinity

measured for Lake Source Cooling, for example. Thus, even if Shaft #4 did somehow flood the mine, it would be hard to argue that there would be significant environmental damage from lake salinification. Of course there could be other damages from shoreline subsidence and confined aquifer fluctuations, but these will be minimized by the mine being under the lake, and it could be hard to argue their significance in the regulatory context.

To summarize: Reaming of Shaft #4 should be routine and pose no flooding risk to the Cayuga Salt Mine. Even if it were flooded, it could be hard to argue that the ensuing environmental damage would be substantial in the regulatory sense. The negative ruling by the NYSDEC regarding the environmental risk of reaming Shaft #4 seems entirely appropriate. In fact, I do not see how a different ruling could have been responsibly made by the NYSDEC.

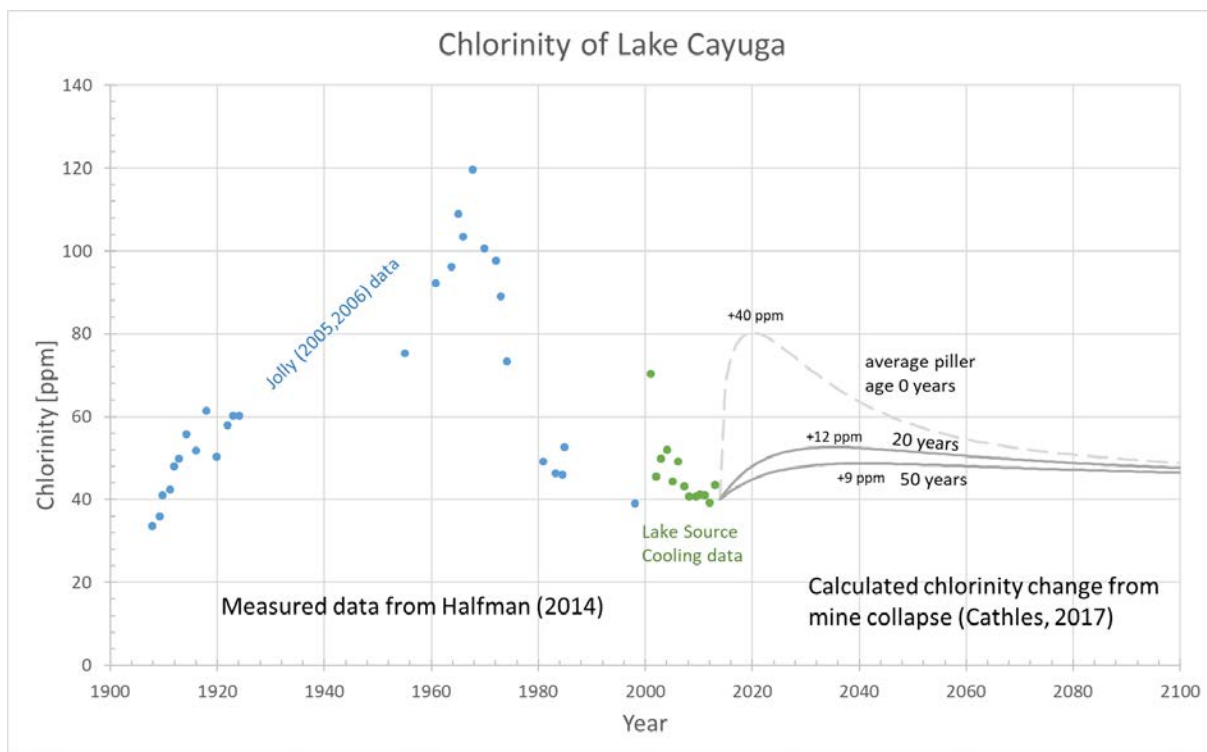


Figure 1. Measured Cayuga Lake chlorine concentrations from 1909 to 2014 followed by the calculated increases that could occur if the Cayuga salt mine flooded in 2014 and the subsequent closure of the mine openings squeezed salt-saturated water into Lake Cayuga. The increase depends strongly on the average pillar age at the time of flooding. Since the mine has been operating for 95 years, the average pillar age is probably at least 20 years. The calculation methods are presented in the Appendix. Chlorinity data were digitized from Figure 15 in [Halfman, J., 2014](#), "A 2014 update on the chloride hydrogeochemistry in Seneca Lake, New York, a report from the Finger Lakes Institute at Hobart and William Smith.

As a side note, since the rate of pillar creep depends strongly on vertical stress, mining under a deep lake such as Lake Cayuga greatly slows the rate of pillar creep and mine closure. If the low density of lake water were not taken into account, the peak chlorine concentration increase would be more than doubled to ~25 ppm. The chlorine concentration of Lake Cayuga would peak at 77 ppm rather than 52 ppm for the 20-year pillar age case. Reduced pillar creep and mine closure by more than a factor of 2 is a big advantage of mining under a deep lake such as Lake Cayuga.

## Should Salt Mining Under Lake Cayuga Continue?

VY&M worry that because the carbonate cap rock thins to the north, mining to the north (which will be facilitated and perhaps allowed by ventilation Shaft #4) will be risky. Cap rock arching is utilized by the thin pillar mining method to provide additional roof support and allow a greater fraction of salt to be safely extracted. My understanding is, however, that should the cap rock be too thin for arch support, the roof could still be safely supported with thicker pillars and a lower fraction of salt extraction. Of course, if the fraction of salt that could be safely extracted is too small, the mining might become uneconomic. The choice of mining methods, the economic calculations, and decisions on whether to continue mining are matters for Cargill and the NYSDEC. I see no reasons that these assessments and evaluations cannot be ably made, and that the present practice of NYSDEC supervision cannot assure that salt mining will continue as safely in the future as it has in the past.

Moreover, continued mining will reduce risks to Lake Cayuga because equipment and expertise will be available to manage pillar creep and fix or avoid leaks that might occur. An example is the ongoing maintenance on the present shafts to control water inflow. Permission for continued mining and mining plan modifications should be granted as long as the NYSDEC and their outside experts are confident mining can be safely done.

## Other Points Raised by VY&M

VY&M raise other points for discussion which it may be helpful to quickly discuss.

The standing water level of the Onondaga/Oriskany contact encountered in Corehole #18 is 100 ft below Cayuga Lake level. All agree that, if this is indeed an equilibrium water level, a connection with the mine workings 4 miles (6.5) away is suggested because this is the only known place where the hydraulic head is sufficiently below the Lake Cayuga surface. VY&M and CLEAN have argued that the connection is through moderately permeable but low storativity (e.g., low volume) fractures. I have pointed out that this conception also suggests there must be an aquiclude (barrier) between the Onondaga/Oriskany contact in Corehole #18 and the overlying aquifer hosting relatively shallow household water wells.

One can visualize the low volume fracture connection to the mine suggested VY&M as a single small bore garden hose running from the Onondaga/Oriskany contact in Corehole #18 to the mine workings 4 miles away. This 4-mile hose could lower the head at the contact while delivering a mine inflow between ~4 and 34 gpm (the observed inflow to the mine), provided there was not a similar garden hose connecting the Onondaga/Oriskany contact to the overlying shallow aquifer hosting the highly productive 60 gpm Koplinka-Lehrer and other household wells. If this second garden hose were present, the higher head near-surface aquifer would dominate, and the hydraulic head at the Onondaga/Oriskany contact would be above lake level rather than below it, as observed. In other words, the ~0.5 km interval between the Onondaga/Oriskany contact and the surface aquifers must be considerably less permeable than the interval between the contact and mine workings 6.5 km away (as I schematically indicated by the orange band in Figure 1 in my earlier letter). Only thus could such a small flow connection to the mine drop the head at the Onondaga/Oriskany contact by 100 ft.

As noted by VY&M other kinds of data are relevant. The water flowing into Corehole #18 at the Onondaga/Oriskany contact (the only significant point of inflow to the test well) was sampled after producing this interval for 9 hours and found to be saline (~130,000 ppm chloride) and tritium-rich. The

tritium content requires the brine to be contaminated by post-bomb (post-1960) meteoric water. The oxygen and hydrogen isotopic content of the produced samples fall on the local meteoric water line, indicating they came from relatively recent atmospheric precipitation. According to RESPEC, the consulting mining and hydrology company that prepared a report for Cargill, the brines could plausibly have come from the Helderberg Group carbonates (which VY&M refer to as the valley fill aquifers of Cayuga Lake) where the lake trough penetrates them about 4000 ft west-southwest of Corehole #18, or from waters injected for solution mining in Ludlowville about 3 miles to the south. RESPEC favors the latter possibility because the Helderberg Group brines are believed to have been driven into the Onondaga/Oriskany contact and Salina Group by high pressure waters in the mountainous glacier that existed to the north in glacial times, and these glacial waters would have a significantly lighter oxygen and hydrogen isotope signature than the brines samples collected at the Onondaga/Oriskany contact in Corehole #18. To the contrary, VY&M suggest that the Onondaga/Oriskany contact connects to both the valley fill aquifers under Lake Cayuga and to the Cayuga Mine, arguing that the isotopic signature of the valley fill brines could have been reset by recent ground water through-flow, which I regard as highly unlikely. Since the valley file aquifer water volume could be “huge” they consider its connection to the mine important.

On pages 11-15 of his report to CLEAN (posted on the CLEAN web site) entitled “Technical Requirements to approve construction of Shaft #4...” John Warren presents a clear and readable discussion of the long and short term hydrology of the Cayuga Lake area. He describes why it is believed that high pressure glacial waters forced their way into the outcrop of the Onondaga Escarpment and then south through the subsurface, dissolving the Salina salt and forming over-pressured brine pockets in ~10-mile-wide band south of the escarpment (and north of any proposed mining). Discharge from these brine pockets in artesian brine springs attracted attention to the potential for salt resources in the area in the 1700s.

Warren notes that “most Salina Group strata do not flow water”. The long-term expulsion of brine that was emplaced in glacial times ~12,000 years ago attests to the low permeability of the deeper subsurface stratigraphy in the Cayuga Lake area. The general idea is that glacial water was forced into the subsurface strata (including the valley fill aquifers under Lake Cayuga) and since has been decompressing and slowly moving out of these strata. If the formation permeability were not very low, the brine pockets would have decompressed quickly, and no historic brine seeps would have been observed. In this context, it is very unlikely that the valley fill aquifers under Lake Cayuga could have been flushed with post-1960 meteoric water, since this would require very active through-flow. In addition, the low flow, low total volume connection (single garden hose) to the mine could not have decompressed a voluminous confined aquifer by the equivalent of 100 ft of hydraulic head. An aquifer capable of filling the Cayuga mine could be decompressed by only a fraction of the 100 ft observed by the known leakage into the mine. The RESPEC explanation for the origin of post-1960 meteoric waters at the Onondaga/Oriskany contact in Corehole #18 is plausible; YV&M’s suggested connection between a voluminous valley fill aquifer that could provide an “unlimited supply of water” to the mine is contradicted by the observations in Corehole #18 and the limited inflow to the mine.

The picture that emerges from the above discussion is of a generally very low permeability environment with low hydraulic activity that poses low flooding risk to emplaced subsurface infrastructures such as tunnels, shafts, or mines. Yes, one should strive to “stay within salt”. Yes, one should watch out for over-pressured brine pockets and pockets of natural gas. Yes, stress concentration in valleys may produce more fractures, but the subsurface is so fractured that this hardly matters, and compressive

stress presses vertical fractures closed and greatly reduces vertical permeability. Yes, decompression of the valley fill aquifer would likely occur if the mine flooded, but the valley fill aquifer is deep and probably already saline and it is not clear what water wells would be affected by its decompression. Yes, the Cayuga mine could fill with water unless it were backfilled completely, but this will not change if mining is stopped. VY&M and CLEAN have compiled a large volume of interesting geologic and hydrologic material, and the material identifies many issues that would be scientifically interesting to pursue. But I do not see how any of the points raised significantly calls into question the viability of or identifies new risks to continued salt mining under Lake Cayuga.

## A Few Words on Process

CLEAN is an activist (action now) organization, and VY&M are the scientific foundation of CLEAN. They have presented the case against Salt mining under Lake Cayuga in a powerful fashion, but their presentation is the “case against” and not a balanced discussion of the pros and cons. Many may think that science can simply provide the answer to a question, but new scientific questions and most societal issues are complex enough that scientific insight can only be achieved through a process of discussion. My hope is that my two letters to you will encourage the kind of discussion that is needed, help experts in the NYSDEC see the geologic issues more clearly, and facilitate balanced political decisions. As is probably clear from the above discussion, I am convinced that the safety of Lake Cayuga and the interests of the local community will be best served by the NYSDEC standing by its negative declaration regarding Shaft #4 and continuing to monitor and regulate mine development in their past high quality fashion.

Sincerely yours,



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William Gracon, Senior Project Manager, Cargill  
Brian Eden, Chair, Tompkins County Environmental Management Council  
Ed LaVigne, Lansing Town Supervisor

Links to the full discussion:

[July 13 LMC Open Letter:](#)

[July 21 Response by VY&M](#)

[August 7 Response to VY&M](#)

[Brief summary on Cornell Blog](#)

## Appendix

This appendix updates the Lake Salinity section in the appendix of my July 13<sup>th</sup> letter.

If the Cayuga mine filled with water, the water dissolved salt until it was saturated at 260,000 ppm salt, and the mine closed completely, expelling all this water into the lake, the chlorine concentration of Lake Cayuga salinity would increase by  $\Delta[Cl]_{tot}$  :

$$\Delta[Cl]_{tot} = \frac{260,000 \left( \frac{M_{Cl}}{M_{Cl} + M_{Na}} \right) V_{mine}}{V_{lake}},$$

Where  $\Delta[Cl]_{tot}$  is the total possible increase in chloride concentration in ppm,  $V_{mine}$  is the volume of the Cayuga mine and  $V_{lake}$  is the volume of Lake Cayuga,  $M_{Cl}$  is the molecular weight of chlorine and  $M_{Na}$  is the molecular weight of sodium.

The fraction of mine closure as a function of time,  $F(n_{yr})$  can be expressed:

$$F(n_{yr}) = 1 - \exp \left( -5.85 \times 10^{-22} \left( H \bar{\rho} \frac{A}{A_{col}} \right)^{3.1} n_{yr}^{0.4} \right).$$

Here  $H$  is the thickness of sediments and water over the mine,  $\bar{\rho}$  is the average density of these sediments and water,  $A/A_{col}$  is the ratio of the total area mined to the area of the pillars that support the mine roof, and  $n_{yr}$  is the average pillar age. The mine closure formula is an integrated version of an empirical formula presented in [Bradshaw, Boegley and Empson](#), "Correlation of convergence measurements in salt mines with laboratory creep tests, an Atomic Energy report prepared by Oak Ridge National Laboratory. Their base pillar closure formula was determined from laboratory creep experiments and validated against observed mine closure.

For the mine closure in the above formula, the yearly step increase in lake chlorinity with no flow through the lake is:

$$\Delta[Cl]_{n_{yr}} = \Delta[Cl]_{tot} \left( F(n_{yr} + 1) - F(n_{yr}) \right).$$

Water flow through the lake will dilute these inputs of salinity. As a result, the lake salinity will change in the years,  $y$ , following mine flooding:

$$[Cl]_y = [Cl]_o + \sum_{j=0}^{y-1} \Delta[Cl]_{y-j} e^{-\frac{(y-j)}{\tau_{lake}}},$$

where  $\tau_{lake}$  is the residence time of water in the lake and  $[Cl]_o$  is the chlorinity of the lake when the mine is flooded. The parameter values used in the calculations in Figure 1 in this letter are:  $\tau_{lake} = 10$  y (water lifetime estimate from [NYSDEC](#); this is a better estimate than one I used previously from Wikipedia.),  $H = 579$  m,  $\bar{\rho} = 1626$  kg/m<sup>3</sup>,  $A/A_{col} = 2.5$ ,  $V_{mine} = 50$  million m<sup>3</sup>, and  $V_{lake} = 9379$  million m<sup>3</sup>.