

Open Letter to Governor Andrew Cuomo and the NYSDEC on the Safety of Continued Salt Mining under Lake Cayuga

On June 13, 2017, I attended a public information session organized by CLEAN (Cayuga Lake Environmental Action Now), and on June 14, 2017 a small (7 person) geological discussion session that included the geologists who presented at that public session. Subsequently I have read the two reports by John K. Warren (an Australian salt consultant) and some of the other material posted on the [CLEAN web site](http://www.cayugalake.org/content/view/CLEAN) (<http://www.cayugalake.org/content/view/CLEAN>). The June 13th geological presentations, the reports by Warren, and the June 14th discussion were/are of high quality and points are raised which could be useful to mine development. However, the CLEAN arguments that reaming a new shaft and continuing mining under Lake Cayuga is unduly risky to the lake water quality are not compelling because the CLEAN analysis is too one sided and does not address the risk context broadly enough. Looked at more equitably and broadly it can be seen that salt mining under Lake Cayuga can safely continue under the current yearly monitoring system, and that there are no grounds for reversing the negative declaration that allows emplacement of Shaft #4 in Lansing.

Technical Material Assembled by CLEAN

The June 13th technical presentations by Young (Emeritus Professor SUNY Geneseo) and Vaughn (Geologist, Buffalo) were excellent, and the two reports by Australian salt expert and consultant Warren^{1,2} provide a readable and fascinating history of salt mining in New York, as well as a good geological summary with many details and good advice. Briefly, Young discussed how horizontal stress is concentrated in valleys, particularly perhaps valleys notched by glaciers such the Lake Cayuga valley. He described how this stress concentration can lead to deformation, faulting, and stress pop-up structures, all of which could affect fluid flow. He discussed how arching is engineered by small pillar methods to support the salt mine roof, and how thinning of the competent rock layers in the arch (as may occur to the north of the present Cayuga mine) could increase the risk of mine collapse. Vaughn commented on the lack of a closure plan, the need for collapse prevention measures, the risk of thin bedrock to the north, gamma ray evidence in Corehole #18 (the pilot test hole drilled at the Shaft #4 location) for replication of the stratigraphic section by a thrust fault that could produce additional fractures and increase risk, and suggested the shaft be reamed down from the surface rather than up from the mine tunnel to reduce the risk of mine flooding. The Warren reports suggest (1) the hydrology in the gap between the bottom of Corehole #18 and the tunnel to which the shaft will connect should be tested by drilling, (2) salt textures should be examined to assess the commercial value of the salt resource in the areas where the mine will be extended, (3) seismic data should be collected and examined to be sure that mining will “stay within salt” and that (4) the caprock thickness is sufficient for roof support, and (5) water storage in the mine should be avoided because humidity accelerates column creep.

The Regulatory Issue

CLEAN is taking action in response to the New York State Department of Environmental Conservation (NYSDEC) ruling that allows the construction of a ventilation and access shaft (Shaft #4) in Lansing to go forward. The mine is now 7 miles long and, as the mine advances northward, surface access at the north end of the mine is needed for ventilation and safety. On June 30, 2016 the NYSDEC issued a negative declaration, indicating that it had determined that there would be no adverse impact to the environment from the drilling the shaft. The negative declaration means that no environmental impact statement needs to be prepared before construction of the shaft can proceed. CLEAN seeks to reverse this negative finding.

The Main Technical Arguments for Reversal

The arguments for reversal are articulated in a May 1, 2017 letter to the NYDEC from Brian Eden, Chair of the Tompkins County Environmental Management Council. This letter is posted on the CLEAN web site. The letter lists many reasons, but the substantial ones are that drilling of Shaft #4 risks flooding the mine (from the shaft and the mine extension), and this could lead to the salinification of Lake Cayuga.

Flaws in the Technical Arguments for Reversal

Catastrophic flooding from the shaft

The shaft is considered a flood risk by CLEAN because: (1) it will penetrate a permeable unconformity (the Onodoga/Oriskany aquifer), (2) the gamma log of Corehole #18 suggests a thrust fault could be intersected (which could be permeable), and (3) the standing water level in Corehole #18 is 100 ft below lake level which suggests a flow connection to the mine workings 20,000 ft (~4 miles) away. It is acknowledged that testing of Corehole #18 showed low permeability, but it is feared that nearby faults with much greater permeability that were not encountered by the test drill hole could be encountered by the wider 14 ft diameter shaft.

These concerns are not compelling. First, both the unconformity and the possible thrust fault are nearly horizontal planar features so Corehole #18 passed through them. The permeability might vary laterally within these features, but the low permeability measured by the Corehole shows that at least parts of these surfaces are not especially permeable. A RESPEC survey tested the permeability of the Onodoga/Oriskany contact finding that the stabilized inflow would be 3 gallons per minute (gpm). Consulting geologists Michalski (Michalski Associates, NJ) believes that the actual input from Shaft #4 “would be on the order of 30+ gpm” (1-31-2017 memo on CLEAN web site). This higher estimate is plausible. Water presently enters the Cayuga mine from Shaft #1 at 20 gpm (down from 30 gpm due to recent grouting of the shaft), and at 10 gpm from Shaft #2. The total inflow to the mine is 34 gpm. (2015 Cargill Annual Report posted on CLEAN web site.) An inflow as high as 30+ gpm into Shaft #4 is thus possible. However, even this high estimate of possible inflow could be easily handled by the mine (it is handling such shaft inflows now), and it is well below the level of flooding which would threaten the mine. The uncontrollable inflow that flooded the Retsof mine was 5,500 gpm after the first roof collapse and 18,000 gpm after the second roof collapse, for example (Warren, Implications report, CLEAN web site). Since no salt will have been mined from around the tunnel from which the shaft will be drilled, there is no possibility roof collapse in the Cargill Shaft #4 case. The analogy between the shaft #4 and

the Retsof collapse is simply not a good one, and the leakages into the shaft that have been suggested might be encountered are nowhere near large enough to threaten the mine with flooding.

The observation that the standing water level in Corehole 18 may be 100 ft (31 m) below lake level is an interesting observation, but it suggests lower rather than higher inflow to Shaft #4, and confirms the hydrologic isolation of the Cayuga mine. The relevant relationships, gleaned from the material compiled by CLEAN, are displayed in the sketch in Figure 1. Corehole #18 was drilled from an elevation of 784 ft (239 m) above mean sea level to a depth of at least 1490 ft (456 m). The well was cased to 500 ft (152 m) depth or down to 86 m msl. The Onondoga/Oriskany contact was pump tested. This indicated that the steady inflow at this level was ~3 gpm, and the standing water level was 86 m msl (501 ft below grade), which coincidentally is the same depth as the bottom of casing, and 31 m below the elevation of the Cayuga Lake surface which stands at 116 m (382 ft) msl. The 200 ft (60 m) deep Koplinka-Loehr water well was drilled from a surface elevation of 152 m msl at a position 1725 ft (526 m) down gradient of Corehole # 18. It can produce water at a remarkably high 60 gpm. Cargill has a domestic water well 690 ft (210 m) upgradient, but its depth and flow rate are not known. Also shown on the diagram are the approximate depth of the top and bottom of the Salina Salt beds, the depth and sediment fill of Lake Cayuga, and the position of the #6 Salt layer, which I assume will be approximately the elevation of the tunnel that connects to Shaft #4. Although the vertical scale in Figure 1 is fairly accurate, the horizontal scale positioning of features is schematic and intended only to facilitate understanding the hydrologic relationships.

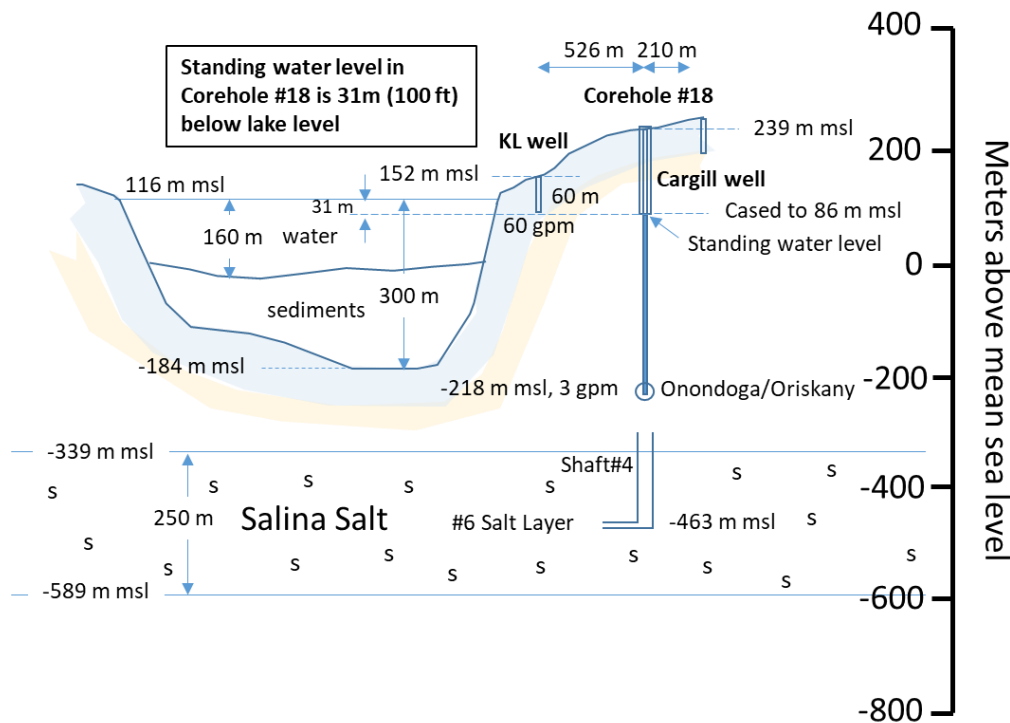


Figure 1. Schematic cross section of Lake Cayuga at roughly Meyers Point and the wells and features discussed in the text.

CLEAN points out that the hydrologic head in Corehole #18 can lie below lake level (the local water table low) only if head is lost to a lower potential sink, and the only sink available is the Cayuga Salt mine 4

miles away. Of course it is not certain that the standing level in Corehole #18 is that asserted, but assuming it is, and assuming this means a connection to the mine (I cannot think of another explanation), the implication is that there is an aquiclude separating the shallow near-surface permeable zone penetrated by the local water wells, the very productive Koplinka-Loehr well in particular, and the deeper levels of Corehole #18. The blue band in the figure depicts the near-surface relatively permeable zone penetrated by water wells. The upper part of the aquiclude that isolates this from the underlying sediments is indicated by the orange band. For the tested Onondoga/Oriskany contact to have a better hydrologic connection to the mine 4 miles away than to the permeable blue zones hosting the Koplinka-Loehr well ~370 m above, there must be a major aquiclude (permeability barrier) between the tested interval (circle in Figure 1) and the near surface. Since the flow into the mine, excepting the flow into Shafts #1 and #2, is only 4 gpm, another implication is that permeability of the formations surrounding the mine is very low. The suggested fractures of moderate permeability but very low storage volume that make the 4-mile connection (Michalski 5/24/2017 memo to CLEAN) clearly are incased in very low permeability sediments from which they can draw very little water. Otherwise flow into the mine would be very much larger than it is. It is, of course, not a surprise that the Cayuga mine is hydrologically isolated. It is encased in fine-grained (and therefore low permeability) sediments, which are further reduced in permeability by interbedded salt which acts as an additional sealant. The standing level 100 ft below lake level and the low inflow to the mine confirm the low permeability suggested by this geology.

With this perspective, data from the Cargill domestic water well is not of particular interest to inflow to the deeper portions of Shaft #4 and the Onondoga/Oriskany contact. If the Cargill domestic water well were as productive as the Koplinka-Loehr well, it would simply emphasize the integrity of the aquiclude (orange band). The very productive Koplinka-Loehr well does, however, indicate caution should be exercised when emplacing the shaft within 100m of so of the surface, and this caution would be emphasized if the Cargill water well were also unusually productive.

Despite these interesting observations, nothing has been suggested that indicates that drilling the shaft poses a special risk of mine flooding. On the evidence presented by CLEAN, I see no basis for reversing the NYSDEC negative declaration regarding the shaft.

[Flooding from mine extension](#)

CLEAN raises concern about mine collapse. The caprock between the salt and valley fill that supports the roof over mined areas thins to the north. In addition, the caprock may be cut into by glacial scouring along the lake axis. For both reasons the caprock may be too thin in some places to prevent mine collapse if the mine is extended to the north.

Cargill is surely concerned about exactly these questions, and presumably this is part or all of the reason Cargill carried out a seismic survey in the area. Certainly Cargill has no interest in losing their mine to flooding. It is difficult to second guess mining decisions with limited information and not being a mining engineer, and probably impossible for anyone to second guess them to the level of certainly that could justify rescinding Cargill's license to operate. The CLEAN logic, expressed explicitly at the information session, is that denial of permission to drill Shaft #4 would preclude (for ventilation and safety reasons) extension of the mine to the north, and this would be a good thing because mining to the north may be riskier, and, in any case, mining under a lake is undesirable per se, and less desirable than under land (which is not true).

Lake Salinification

The CLEAN information session depicted mine flooding, such as occurred at Retsof, as an unalloyed disaster, which of course it is. But it is important to understand why. The mine flooding was a disaster to Retsof and its employees, who lost their income, and to the local economy which lost jobs and tax income. There were other substantial damages because human infrastructure was impacted. Surface collapse was severe (up to 10 meters of subsidence) in two 180 m diameter locations, 4 homes were abandoned and others damaged because of subsidence, a bridge over U.S. Route 20A was lost because of subsidence, water wells temporarily dried out, and, when the water table rebounded the well water was saline in some locations because the fresh water had drained into the mine and been replaced by salty formation water.

The CLEAN information session asserted that mining under lakes is riskier than under land, but this is not the case. Other than the loss of the mine, none of the other substantial Retsof surface damages mentioned would have accrued if that mine had been under a lake. If the Cayuga mine flooded, subsidence related to breccia pipes daylighting at the lake bottom would have no societal impact, water well levels would not drop because the local water table is pinned to lake level, and the water table could not recover with salty water because it did not drop in the first place. Flooding of the mine would be a disaster to Cargill and its employees (180 local workers receiving \$10 million in salaries, according to the information session), but would not have the other negative consequences experienced at Retsof because the Cayuga salt mine is overlain by a lake, not human infrastructure.

Filling of the Cayuga mine with water would not in itself be damaging. Filling the mine could (if it filled instantly) drop the lake level 0.27 m or about a foot (the drop equals the volume of the mine divided by the area of the lake). This drop in lake level would not occur if the mine flooded slowly (over the course of many months for example, as did Retsof). The lake outflow would just be reduced by the flow into the mine.

The information session presented the prime societal consequence and risk of mine flooding to be salinification of Lake Cayuga. The concern is that water filling the mine would dissolve salt and the salty water would then be squeezed out into the lake as the mine collapsed. This risk was not quantified. When quantified, it largely disappears.

The salinification of Lake Cayuga due to mine collapse can be quantified by assuming that the Cayuga mine fills with water instantly and then starts to exponentially collapse (e.g., rapid closure at first and progressively slower closure as the collapse progresses). My calculations assume that each year a volume of halite-saturated (26 wt% NaCl) brine equal to the volume of mine closure in that year is expelled into Lake Cayuga. The yearly inputs of salty water mix into the lake, but the increase in lake salinity is reduced by fresh water flow into and through the lake. Because of this flow through the lake, each yearly increase in lake salinity due to input from the collapsing mine declines exponentially with a time constant equal to the residence time of water in the lake. Despite the flushing of the lake, the yearly pulses of salt into it accumulate and the lake salinity rises. Eventually, as the mine collapse slows, the lake salinity begins to decrease. (See appendix for mathematical details.)

Figure 2 shows how the salinity of Lake Cayuga would change as the result of expulsion of brine from a flooded and collapsing salt mine. The residence time of water in Cayuga is assumed to be 18.2 years, and the lake volume $9460 \times 10^6 \text{ m}^3$ (data from Wikipedia). The $\sim 50 \times 10^6 \text{ m}^3$ volume of the Cayuga mine is

estimated from its salt production history (see appendix). The time constant for mine collapse is indicated for each curve on the diagram. The calculation depends only on these parameters. The figure shows that if the mine collapses with a decay constant of 200 years (probably a fast collapse rate), the increase in lake salinity will peak at ~100 ppm 50 years after the flooding that initiates collapse. For reference the salinity of the lake was about 100 ppm before Cargill took over mine operation and reduced the release of fine salt. The lake salinity is presently ~40 ppm. If the retention time of water in Lake Cayuga is ~10 years, as estimated by the US Geological Survey, the salinity increase would be about half that shown in Figure 1 for a collapse with an exponential time constant of 200 years, and the salinity increase would be ~110 ppm 30 years after flooding for a 100-year collapse time. The salinity increases shown in Figure 1 are maximum estimates because not all the water in the mine will be expelled into the lake; some will be expelled into salty aquifers below the lake. Furthermore, expulsion could be reduced if the closure of mined areas were accelerated while they are air filled, and prevented entirely if the mined areas were back-filled with waste as new mining proceeded. My conclusion is that, even if the mine flooded and collapsed in the worst fashion conceivable, the salinity risk to Lake Cayuga would be small, and this small salinity increase could be reduced or eliminated if that were deemed desirable.

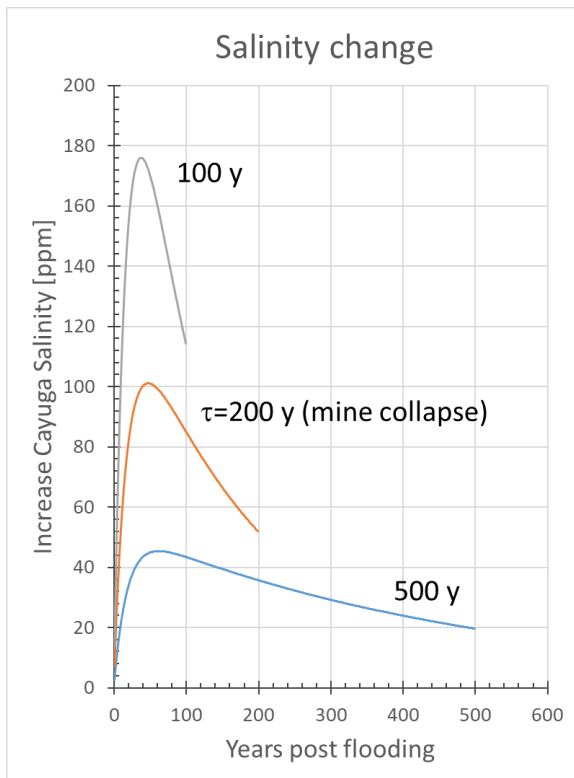


Figure 2. Change in salinity of Lake Cayuga if the Cayuga salt mine was flooded with halite saturated brine and expelled this brine into the lake as the lake collapsed with the exponential time constant shown. The lake volume assumed is 9.46 km³ and the lake residence time 18.2 years (Wikipedia values).

Conclusions and Recommendations

We live in a complex world in which almost every activity requires deep human expertise. Nether CLEAN nor the NYSDEC have expertise to second guess salt mining. Both utilize outside experts, and properly so; the needed expertise is not quickly acquired. NYSDEC utilizes John T. Boyd Company

(mining and geological consultants) to review the yearly mine plans of Cargill, and consultants like RESPEC to evaluate drilling results like Corehole #18. CLEAN contracts or solicits reports from salt experts like John Warren (Australia) and hydrology consultants like Andrew Michalski (New Jersey).

Under the present regulatory system as I understand it, the NYSDEC oversees licensed mining operations such as the Cayuga Salt Mine by reviewing yearly reports, posing questions, and requiring actions where needed. If something is required that will have a significant adverse environmental impact, preparation of an environmental impact statement is required. With its negative declaration the NYSDEC ruled that Shaft #4 did not pose the risk of significant environmental impact, and I think this is transparently the correct decision. The issues raised by CLEAN are simply not anywhere near substantial enough to warrant reversal of this ruling. The NYSDEC should keep in place the Negative Declaration and continue overseeing the mine as it is currently doing.

Sincerely yours,

A handwritten signature in blue ink that reads "Lawrence M. Cathles III". The signature is written in a cursive style and is placed on a light blue rectangular background.

Lawrence M. Cathles III
Professor
Department of Earth and Atmospheric Sciences
Cornell University

This open letter is posted on <http://blogs.cornell.edu/cayugalakesaltmining/sample-page-1/>.

Appendix

Lake Salinity

If the Cayuga mine filled with water, the water dissolved salt until it was saturated at 260,000 ppm salt, and the mine suddenly and fully collapsed expelling all this water into the lake, the Cayuga salinity would increase by ΔC_{tot} :

$$\Delta C_{tot} [ppm] = \frac{260,000 V_{mine}}{V_{lake}},$$

where V_{mine} is the volume of the Cayuga mine and V_{lake} is the volume of Lake Cayuga.

If the mine collapsed exponentially with a time constant of τ_{mine} , the amount the lake salinity would increase each year is:

$$\Delta C[n_{yr}] = \Delta C_{tot} \left(e^{-n_{yr}/\tau_{mine}} - e^{-(n_{yr}+1)/\tau_{mine}} \right).$$

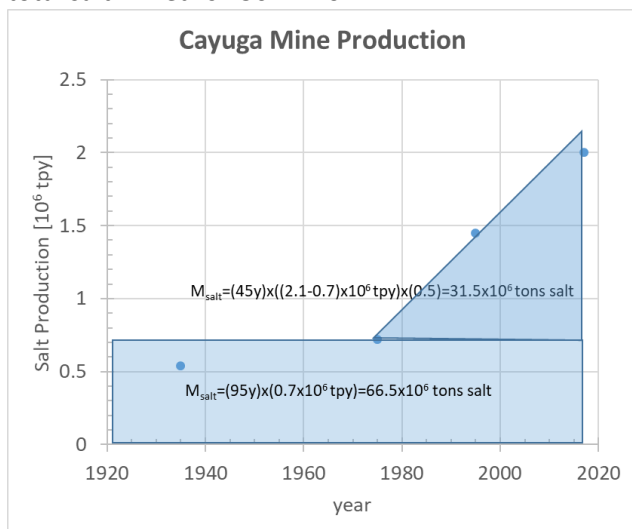
Water flow through the lake will dilute these inputs of salinity. As a result, the lake salinity will change with time:

$$C(n_{yr}) = \sum_{j=0}^{n_{yr}-1} \Delta C(j) e^{-\frac{(n_{yr}-(1+j))}{\tau_{lake}}}.$$

τ_{lake} is the residence time of water in the lake. The calculation is carried out to $n_{yr} = \tau_{mine}$, and plotted in Figure 2 in the text.

Cayuga Salt Mine Volume

The production history is indicated in the table and plot below. Assuming mining started in 1922, the total salt mined is ~ 50 million m^3 .



year	Salt production in million tons/year (from Warren, Implications of a comparison...)
1930s	0.54
1975	0.72
1995	1.45
2017	2.00

From the area of the rectangle and triangle, the salt mass mined = 66.5 + 31.5 million tons. At a salt density of 2t/ m^3 , the mine volume is ~ 50 million m^3 .