Exhibit 3

Seneca Lake Hydrology Report
Tom Myers, Ph.D.

Technical Memorandum—Review of Finger Lakes LPG Storage, LLC, Proposed LPG Storage Facility

January 15, 2015, Corrected January 21, 2015

Tom Myers, Ph.D., Hydrologic Consultant

PUBLIC VERSION

FINAL: **Technical Memorandum—Review of Finger Lakes LPG Storage, LLC, Proposed LPG Storage Facility**

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Prepared by: Tom Myers, Ph.D., Hydrologic Consultant
Prepared for: Earthjustice, New York

EXECUTIVE SUMMARY

Finger Lakes LPG Storage, LLC, (FLLPG) proposes to store liquid petroleum gas (LPG) in two mined-out salt caverns in salt beds below ground on the west shore of Seneca Lake, near Watkins Glen, NY. Salt caverns in the formation that FLLPG proposes to use for LPG storage were previously used for LPG storage (starting in 1964). During that time, in the mid-1960s and continuing for several years while LPG storage was active in the salt caverns, there was a very large slug of highly-concentrated chloride (Cl) discharged into Seneca Lake. Because of Seneca Lake's very long "retention time", this spike drove Cl levels throughout Seneca Lake much higher, and this effect took several decades to subside somewhat (although the Cl levels in Seneca Lake are still relatively high).

In my opinion, the Cl discharges in the mid-1960s were caused by the LPG storage activities taking place at that time (in the same salt beds FLLPG now proposes to use for LPG storage). The scientific mechanism for the Cl discharges is explained in this paper. Simply put, the changes in pressure inherent in LPG storage—where higher pressure brine displaces LPG when you want to remove LPG from the caverns, and where lower pressure LPG displaces brine when you want to add LPG into the caverns—exert pressure on the salt formation. The salt formation slopes upward as you travel north up Seneca Lake, until the salt beds intersect with sediments directly under Seneca Lake. The pressure from the LPG activities is transmitted along the salt formation until it essentially squeezes out high-Cl groundwater into the bottom of Seneca Lake. The Cl discharges in the mid-1960s were extremely high, and greatly increased the overall CL concentration in the lake. The currently-proposed LPG storage in the salt beds would, in my opinion, do the same thing. Since there is no real way to monitor or prevent these discharges, as explained below, FLLPG's proposed LPG storage should not be permitted in the salt beds.

SUMMARY

The salt formations that FLLPG proposes to use for LPG storage are about 1000 feet below the bottom of Seneca Lake at this location, but these salt beds slope upwards to intersect with sediments beneath the lake bottom north of the site (and, from there, continue to intersect with sediments immediately beneath the lake bottom all the way to the northern end of the lake).

This proposed project is similar to an LPG storage project that occurred at the site from 1964 to 1984. This earlier project coincided with and caused a massive spike of chloride (155,000,000 kg Cl/year for at least five years) to enter Seneca Lake, starting around 1965. It caused the chloride (Cl) concentration in Seneca Lake to increase by about 70 mg/l in a short time period. Other potential sources of chloride, such as road salt, discharges from salt mines, diffusion from groundwater, and leakage of brine from salt caverns, have affected Seneca Lake salinity over time but are insufficient to explain the large spike in concentration starting in the mid-1960s.

In my opinion, the pressure changes caused by LPG storage—LPG is pumped into the salt caverns, displacing brine that is already there and causing pressure changes, with the process reversed to remove LPG from storage (brine is pumped into the caverns and displaces the LPG stored there)—drive pressure changes that change groundwater flow rates into the lake from the high-salt (or saliniferous) sediments beneath the lake. The literature on Cl concentrations in Seneca Lake agrees that the most significant source of chloride entering the lake is deep groundwater that intersects with the salt beds below the lake floor. My research indicates that LPG storage in the salt mines—as is proposed here—can cause significant discharges of additional salt into Seneca Lake. The mechanics of this "advection" process are that pressure causes strain to propagate which increases fluid pressure under the salt-containing sediments. The increased fluid pressure increases the pressure drop, or gradient, across the sediments, which increases the flow rate through the sediments. My calculations indicate that even relatively small changes in pressure from LPG storage at the site will cause salt discharges into the lake. This salt release would occur primarily in the northern two-thirds of Seneca Lake where the salt beds intersect the sediments beneath the lake. My calculations do not depend on any assumptions of cavern integrity.

The advection process is extremely complex and representative data is very difficult to collect, so it would be very difficult for FLLPG or others to complete analyses that would suggest that LPG storage over the next 50 years could be done safely and without causing massive salt influxes to Seneca. For the same reasons, I also do not believe that FLLPG can adequately monitor or prevent serious adverse water quality changes from additional chloride discharges into Seneca Lake through its LPG storage operations. The risk of a saline influx to the lake from LPG storage is very high and should be avoided, especially since (i) Seneca Lake already has much higher overall chloride concentrations than the other Finger Lakes and (ii) Seneca Lake has a very slow discharge rate (by my calculations it would take 33 years for the lake to empty out from its discharge; Wing et al. (1995) estimate the retention time to be 18 years)[1] meaning that a load of salt in Seneca Lake will require a long time to flush out.

INTRODUCTION

I was asked to prepare this technical memorandum analyzing the potential effect that developing the liquid petroleum gas (LPG) site near Watkins Glen will have on salinity in Seneca Lake. I have a Ph.D. and M.S. in Hydrology/Hydrogeology[2] from the University of Nevada, Reno, and a B.S. in Civil Engineering from the University of Colorado. I have approximately 20 years of experience consulting and researching hydrogeology, including unconventional natural gas development including fracking and coal-bed methane development, contaminant transport, mine dewatering, and groundwater modeling. My curriculum vitae is attached as Appendix I to this memorandum.

Proposed Action

FLLPG proposes to store LPG (liquid butane and propane) in salt caverns created by salt mining on the west side of Seneca Lake north of Watkins Glen, NY. FLLPG would inject LPG to displace the existing brine, which consists of water containing as high as 400,000 mg/l of total dissolved solids (NYSDEC 2011).[3] Recovering the LPG occurs by injecting brine back into the cavern to remove the LPG. The primary question addressed in this report is whether this LPG storage could cause large quantities of salt to discharge into Seneca Lake, thereby degrading the water quality of the lake.

The memorandum provides a detailed summary of the findings with details provided in seven appendices, as follows:

APPENDIX A: ANALYSIS OF OBSERVED SURFACE AND GROUNDWATER FLOW AND WATER QUALITY
APPENDIX B: SALINITY AND SALT LOADING TO SENECA LAKE
APPENDIX C: ANTHROPOGENIC SOURCES OF SALT TO SENECA LAKE
APPENDIX D: GROUNDWATER FLOW AND ADVECTION INTO THE LAKE
APPENDIX E: DETAILS OF HYDROGEOLOGY OF THE SENECA LAKE AREA
APPENDIX F: DETAILS OF VISCOELASTIC FLOW OF SALT NEAR SALT CAVERNS

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[1] See Appendices A and B.
[2] Hydrology is the science that encompasses the occurrence, distribution, movement and properties, including physical and chemical, of the waters of the earth and their relationship with the environment within each phase of the hydrologic cycle. Hydrogeology is an emphasis on water beneath the ground surface. http://water.usgs.gov/edu/hydrology.html.
[3] See SEQR Documents (Final DSEIS Text at 6, 7, 32).

APPENDIX G: DETAILED DESCRIPTION OF FINGER LAKES' PROPOSED PROJECT AND APPLICATION
APPENDIX H: REFERENCES
APPENDIX I: CURRICULUM VITAE OF TOM MYERS

Previous Storage of LPG in Salt Caverns near Seneca Lake

Salt mining in salt formations in the Finger Lakes region began in the late 1800s (NYSDEC 2011).[4] The mining essentially involved freshwater being injected into the salt beds to dissolve the salt, with the resulting very salty water, or brine, being pumped back to the surface to recover the salt. This salt mining process resulted in caverns being created as salt dissolved into brine. It is a process that has created thousands of caverns around the world (Berest et al. 1996).

Beginning in 1964, the International Salt Company began to store liquid petroleum gas in previously-mined salt caverns at Seneca Lake (Jacoby 1973, 1970), in a process similar to that currently being proposed; [redacted][5] This LPG storage process would have caused significant pressure changes in the salt beds and adjacent stratigraphic layers (Berest et al. 1996).

Salinity in Seneca Lake

Seneca Lake has higher salinity levels, expressed as sodium (Na), chloride (Cl), or total dissolved solids (TDS) than the other Finger Lakes (Wing et al. 1995). This comparison is shown in Figure 1, below, which indicates that Seneca Lake had much higher Cl levels than the other Finger Lakes in 1963, 1978, and 1994 (Figure 1). The salinity trend is up for all of the Finger Lakes over time, as shown in Figure 1—except for Seneca and Cayuga, the lakes with the highest concentrations. Seneca and Cayuga Lakes obviously receive salt load from sources not common to the other Finger Lakes. This memorandum focuses on Seneca Lake, although some of the same processes affecting Seneca Lake may cause the higher salinity in Cayuga Lake (Wing et al. 1995). The rising Cl levels in Seneca Lake are discussed below.

[4] Id. p 67.
[5] See [redacted]

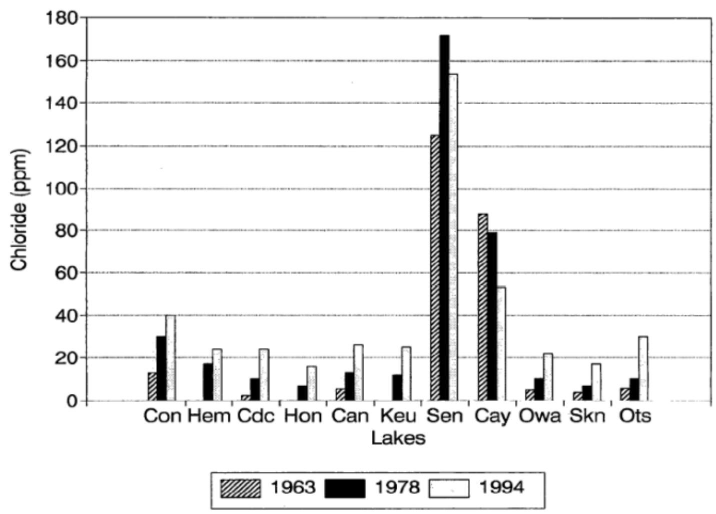

Fig. 1. Chloride concentrations (ppm) in 11 Finger Lakes spanning three decades: 1963 data from Berg (1963); 1978 data from Schaffner and Oglesby (1978); 1994 data from this study. Abbreviations: Con—Conesus Lake; Hem—Hemlock Lake; Cdc—Canadice Lake; Hon—Honeoye Lake; Can—Canandaigua Lake; Keu—Keuka Lake; Sen—Seneca Lake; Cay—Cayuga Lake; Owa—Owasco Lake; Skn—Skaneateles Lake; Ots—Otisco Lake.

Figure 1: Snapshot of Fig. 1 from Wing et al. (1995) comparing chloride among the various Finger Lakes with time. Wing et al. indicate that 1963 data is from Berg (1963), 1978 data is from Schaffner and Ogelsby (1978) and 1994 data is their own. Same as Figure B3 in Appendix B.

The salinity of Seneca Lake, as represented by Cl concentrations, one of the dominant anions (Hobart and William Smith Colleges et al. 2012), has varied substantially over the past 110 years, but primarily has trended higher (Figure 2). Appendix B provides a detailed description of the Cl changes in Seneca Lake over the years, some of which can be summarized as follows:

> The Cl concentrations rose from about 50 mg/l to 110 mg/l, from 1905 to about 1964. Between 1965 and the early 1970s, the concentration jumped to about 180 mg/l. Since that time to about 2004, the concentration dropped from 180 to about 145 mg/l. Between 2004 and 2008, the concentration dropped to about 120 mg/l (see description in Hobart and William Smith Colleges et al. 2012, p 89). Chloride concentration during a sampling event in October 2014 was about 132 mg/l.

As shown in Figure 2 below, Cl concentration in Seneca Lake started trending higher after 1905 or so. In 1965 there was a very large jump in Cl concentration in the lake caused by a significant inflow Cl load of 155,000,000 kg/y for several years. As is discussed below, this load coincides with the beginning of the time that LPG storage was taking place in salt caverns located in the same formation currently proposed for LPG storage by FLLPG. As explained below, in my opinion the former LPG storage activities that started at the site in 1964 caused this dramatic increase in Cl discharges, and overall Cl concentration, in Seneca Lake.

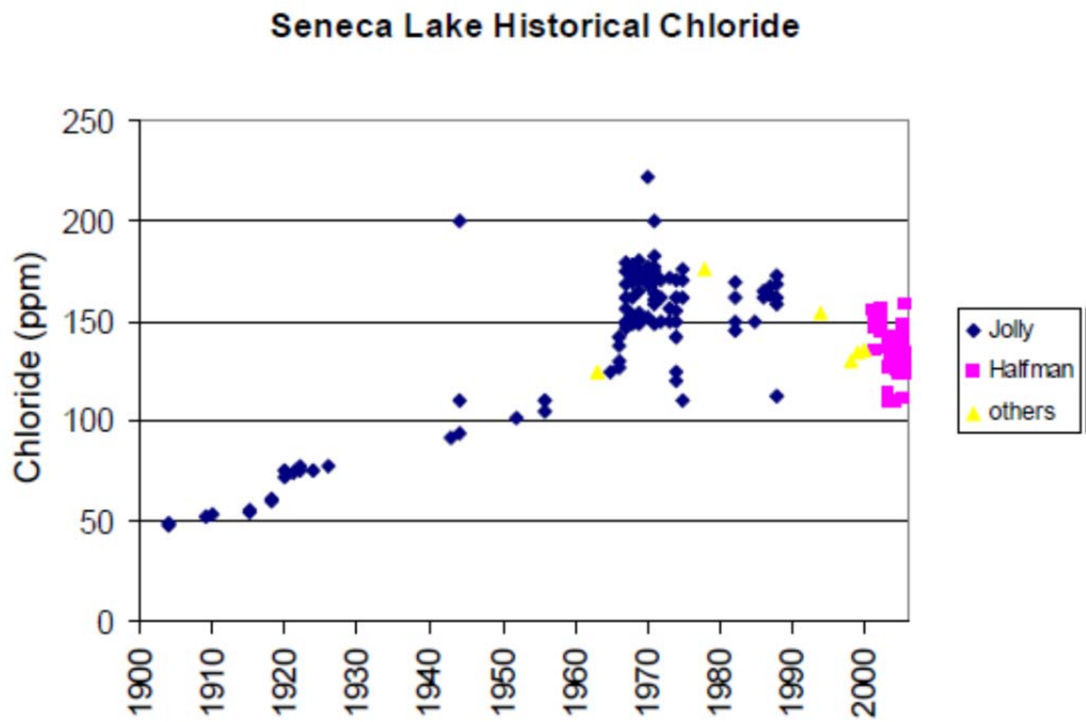

Figure 2: Trend of observed and model chloride data for Seneca Lake, snapshot from Hobart and William Smith Colleges et al. (2012). The figure shows an upward trend in concentration from less than 50 mg/l in 1905 to about 110 mg/l in 1960. After that the concentration spiked to more than 180 mg/l after which it slow decreased to less than 150 mg/l.[6]

The average flow from Seneca Lake equals approximately 590 cfs (Appendix A) based on gages on the Seneca River, the outlet from Seneca Lake. Seneca Lake volume equals 12,500,000 acre-feet (af) which is almost 33 years of 590 cfs outflow.[7] Such a large volume to outflow ratio indicates that significant water quality changes on a short-term basis require a substantial slug (contaminant load) of materials, and that changes to Seneca Lake's water quality can take decades to subside.

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[6] Cayuga Lake also saw Cl concentration reach a peak in the mid-1960s at the same time as the Seneca Lake Cl spike, although the Cl concentration in Cayuga Lake decreased much faster than did Cl concentration in Seneca Lake. It cannot be ruled out that the Cl increases in Cayuga Lake have been affected by the LPG Storage in the Salt Caverns in the 1960s (because the same Syracuse salt formation under Seneca Lake also underlies Cayuga Lake). However, Halfman (2014) indicates that Cl concentrations in Cayuga Lake decreased significantly from the mid 1960s through the 1970s because the Cargill Rock Salt plant in the Cayuga watershed changed its disposal methods for salt tailings so that they no longer reach the lake. Discharges from the Cargill plant were limited to the Cayuga watershed and therefore could not have affected Seneca Lake.

[7] Wing et al. (1995) estimate the retention time to be 18 years, which is still an extremely long retention time, but do not actually estimate a flow rate. See Appendix B.

Seneca Lake's volume fluctuates within a small range. Appendix B shows that the range is just 2.2% of the total lake volume. Overall changes in Seneca Lake volume are such a small proportion of the total volume that they are not a significant factor controlling or contributing to the lake's overall salinity.

Method of Analysis

This technical memorandum assembles available data from all known sources, including the US Geological Survey (USGS) and academic literature, to analyze the water and mass balance of Seneca Lake. Ultimately, although the available data are too sparse to assign detailed mass fluxes on either steady state or transient bases, the net loading was determined by examining the difference in total load in the lake determined from concentration and lake volume. The changes in load were assessed with a literature review of sources that document various discharges into the lake that could have affected the overall load in the lake. Finally, significant literature was reviewed to assess the mechanical process that would result from LPG storage beneath the lakeshore that will cause salt spikes into the lake.

Regional Hydrogeology

Seneca Lake is located in a humid region with short warm summers and cold winters. Precipitation exceeds evaporation by approximately one foot per year, which causes a gain in water to Seneca Lake of about 43,500 af/y, or 60 cubic feet per second (cfs) (Appendix A).

The bottom of the lake is glacially carved into bedrock formations of the Silurian Group,[8] including the salt-filled (saliniferous) Syracuse formation (Figure 3 and Appendix E, Figure E1). The bottom of the lake is filled with up to several hundred meters of sediment. The northern 2/3rds of the lake, or tens of miles of the lake bottom sediments, intersect with the salt-filled Syracuse formation that underlies the lake because the formation slopes upward heading north from the project area. This salt-filled Syracuse formation is the same formation that has been previously developed as salt mines in the Finger Lakes area and is proposed for LPG storage by FLLPG (2010).

As shown in Figure 3 below, reproduced from Appendix E, the Syracuse formation is the salt formation proposed for LPG storage. Towards the left of the drawing are, at approximately 42° 25' N (at the south end of the lake), the location of the proposed LPG storage caverns. At that location, the Syracuse formation does not directly intersect with the lake bottom. However,

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[8] Different references describe the stratigraphy differently. For this report, I have adopted the nomenclature of NYSDEC (2011) (SEQR Documents (Final DSEIS Text)) and refer to the Syracuse formation as one of the formations within the Silurian group.

the Syracuse formation slopes upward as you head north until it intersects with the porous glacial sediments on the lake bottom.

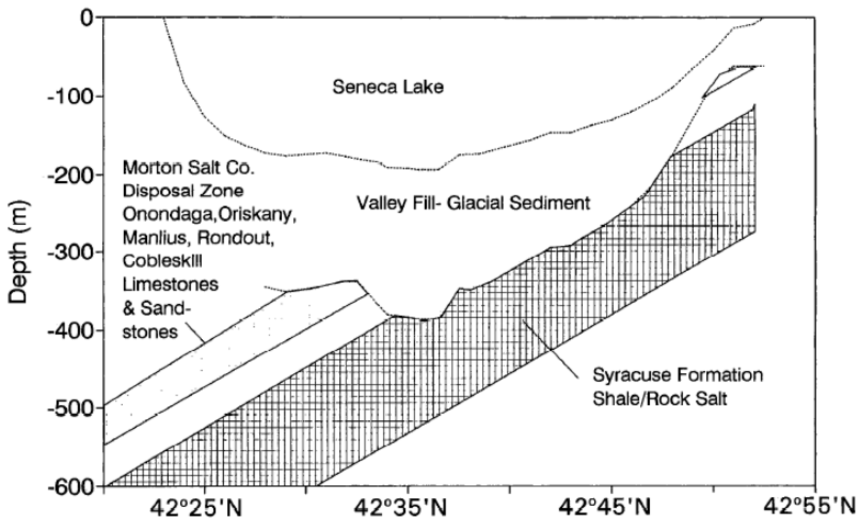

Fig. 6. Schematic longitudinal bedrock profile of Seneca Lake at maximum depth.

Figure 3: Snapshot of Figure 6 in Wing et al. (1995) showing general stratigraphy from south to north. Same as Figure E2 in Appendix E.

Both Halfman et al. (2006) and Wing et al. (1995) determined that groundwater inflow to the lake through the sediments was a significant source of salt in Seneca Lake. "Deep saline seepage from these rock units through the sediments and into the water column is thus likely" (Wing et al. 1995, p 797).

Salt Loading to Seneca Lake

The total Cl load in the lake may be determined as the product of the lake volume and concentration. The net change in total load is the difference in inflow and outflow loads (Thomann and Meuller 1987). Inflow or outflow load is the product of the flow rate and concentration for any inflow or outflow. Appendix B contains the details of the estimates of total and net loads in Seneca Lake. The total load in the lake increased from about 745 million kg in 1905 to about 2.72 *billion* kg in 1970 (Figure 4). The average net inflow load ranged from 3.1 million kg/y around 1930 to 18.6 million kg/y through the 1940s. During the late 1960s, the inflow load spiked to about 155 million kg/y (Figure 4). After 1970, the total began to decrease as the net load became negative—ranging from negative 15,000,000 to negative 40,000,000 kg/y—until 2010 because the outflow load exceeded the inflow load.

Surface water has a low Cl concentration, and provides only a small inflow of Cl. Shallow groundwater may have localized high concentrations of Cl but the flux of Cl from any of these sources would barely be measureable in Seneca Lake. Appendix A outlines the measured natural sources of salt to Seneca Lake. Other sources, both anthropogenic (caused by humans) and natural, must explain the larger fluctuations of groundwater into the lake.

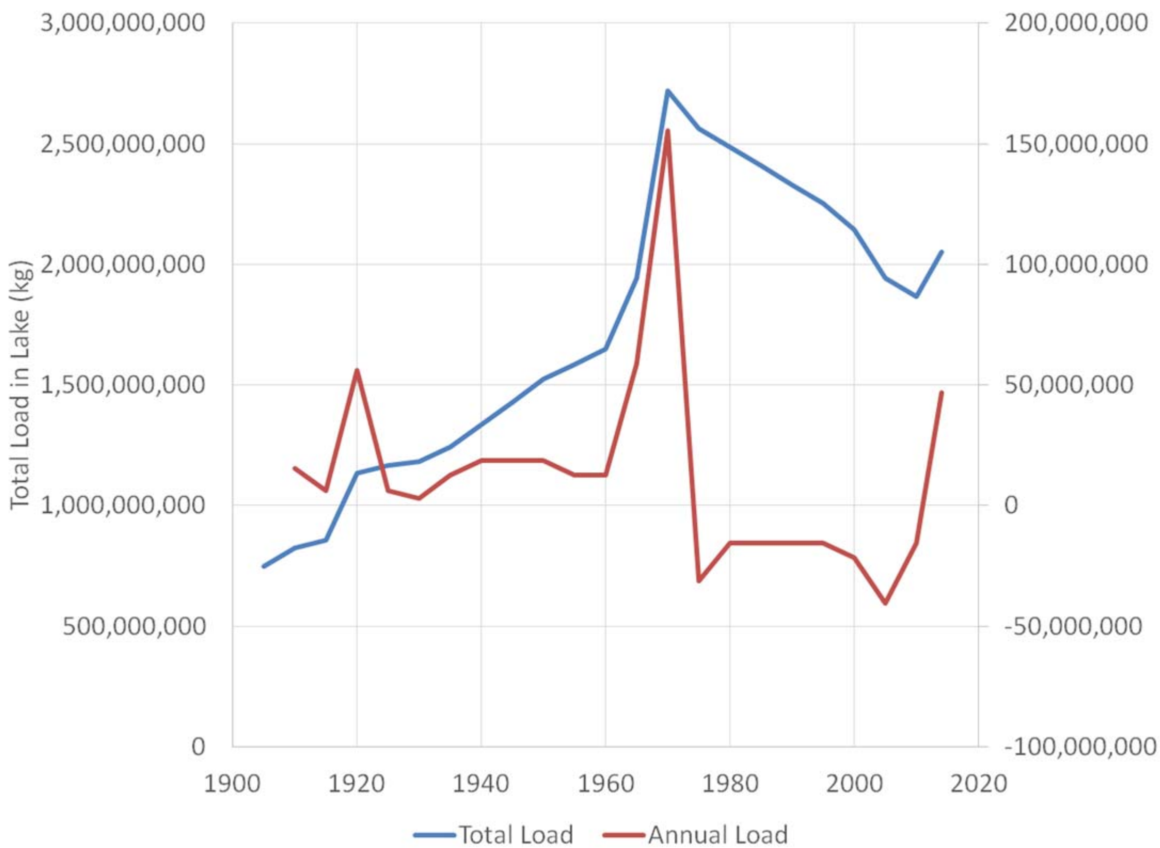

Figure 4: Total Cl load (kg) in Seneca Lake and net annual load necessary to reach that level (kg/y). Total load is the product of concentration from Figure 2 and lake volume. Annual load is the difference in total load over five-year time steps. The largest spikes in concentration in the 1960s caused the spikes in total load on the graph. Same as Figure B2 below.

Anthropogenic (Human) Sources of Salt to Seneca Lake

There are numerous potential sources of salt loading to Seneca Lake: natural, anthropogenic, and a combination of both. Appendices A and C discuss the sources in detail.

Salt mines near Seneca Lake are permitted to discharge salt into the lake, and the average annual discharge may be as much as 12,000,000 kg, which could explain much of the increase in load prior to the 1960s. But the loads from salt mines are far too low to explain the large spike observed in the late 1960s. Total salt production from the lake area also correlates weakly and negatively (Halfman 2014) with the net load of salt reaching Seneca Lake, which means that more discharge of salty waste occurred when production of salt was lower than when it was higher, but the correlation was low. The negative correlation further confirms that salt mining does not cause a substantial amount of salt load in Seneca Lake.

Halfman (2014) documented a leak of 1.1 million tons of salt into the lake during the late 1960s through early 1970s. This leak could have added 10 mg/l in a year and certainly contributed to maintaining high concentrations through the 1970s, but it was not large enough and occurred too late to have caused the earlier inflow of salt and the spike in the mid-1960s.

Road salting has been increasing over the previous century and explains much of the increases in Cl in other Finger Lakes, but not in Seneca Lake. Cl concentration correlates weakly with road density in other Finger Lake watersheds, which supports the hypothesis that road salting explains much of the level of and variation of Cl in the Finger Lakes, other than Seneca and Cayuga (Halfman 2014, Hobart and William Smith Colleges 2012).

Wing et al. (1995) documented that a salt company had pumped approximately 1,000,000,000 kg salt into a deep disposal well in the 1970s. This disposal does not coincide with a significant increase in Cl in Seneca Lake, and the disposal well was located in sandstone far below the lake bottom about ten miles south of where the salt formations intersect the lake bottom. Figure 3 shows the location of the disposal well. Use of the disposal well in the 1970s also postdates the period during which the Cl increased significantly in the lake.

Deep Groundwater Sources of Salt to Seneca Lake

Two types of groundwater discharge to Seneca Lake can be responsible for additional load in the lake, as described in detail in Appendix D. These are diffusion and advection.

Halfman et al. (2006) estimated that 6,000,000 kg/y entered the lake by diffusion, based on data from Wing et al. (1995). Diffusion is the movement of salt from high concentration to low concentrations, without regard to movement of the water. The rate depends on the concentration gradient but diffusion would remain a source of salt as long as the concentration in the sediment remained higher than the concentration of the lake. It would occur regardless of the anthropogenic sources. However, this amount of diffusion is much too small to have caused the spike in the mid 1960s.

The second groundwater source of salt inflow is advection, which is simply the movement of salt along with the flow of the groundwater. Groundwater flow into the lake from the sediments beneath the lake would carry groundwater at the concentration observed in the sediments. This flow is also known as Darcian flow and is driven by a pressure, or head, gradient across the sediments.[9] This salt flow is in addition to the flow caused by diffusion and, being natural, would be in addition to the anthropogenic sources listed in the previous section. Both Halfman et al. (2006) and Wing et al. (1995) concluded this source was the mostly likely to provide sufficient Cl to match concentrations observed in the 1990s. Evidence for such flow is the presence of mudboils and brine springs observed in the north of the lake and the driving force, or gradient, could be explained by the unloading[10] of glaciers from the area (Goodman et al. 2011) (Appendix D).

My analysis indicates that on a long-term basis at 16,000 mg/l, the necessary flow to deliver 10,000,000 kg/y Cl to the lake is about 1700 m^3/d (0.7 cfs). If flow across the sediments occurs over just half of the lake bottom area, and a conductivity of 0.1 m/d is assumed for the sediments, the necessary gradient would be 0.0002 m/m, meaning that the pressure head drop across 50-m of sediment would be less than 0.01 m. In order to deliver 150,000,000 kg/y to the lake, the groundwater inflow would be about 25,700 m^3/d (10.5 cfs) and the necessary head drop 0.14 m. Anything that could cause a relatively small head change could cause significant spikes of salt to enter the lake. In my opinion, the proposed LPG storage in the salt caverns can easily cause the necessary pressure changes to result in significant Cl discharges to Seneca Lake.

Cause of the 1960s Concentration Spike

Salt concentration spiked in the late 1960s, due to the Cl load equaling about 155,000,000 kg/y for at least five years, but the cause of this spike has not been identified from review of the available literature. My analysis indicates that the most likely source is advection through the sediments beneath the lake, because the necessary major increases or spikes from the other identified sources are very unlikely to occur. An increase in the gradient driving groundwater through the lakebed sediments would be necessary to cause the spike from these sources. The cause of such a change in gradient has not been identified in the literature. Glacial unloading[11] is a long-term, and steady process (Goodman et al. 2011), so short-term fluctuations due to the primary cause of the gradient are not likely.

The LPG storage that commenced in 1964 is the most likely source of such a pressure change, because of the temporal coincidence, the lack of any alternative explanation, and because

[9] Head is pressure expressed as the height of a water column, commonly expressed as feet or meters of head.
[10] Unloading of glaciers, or glacial unloading, occurs as a glacier melts or recedes from an area. The weight of the glacier causes pressure throughout the stratigraphic profile that is not immediately relieved when the weight is removed because the pressure is due to strain in the geologic formations that only slowly rebounds. As it rebounds, the pressure reduces but it may requires thousands of years to fully rebound during which time a pressure remains.
[11] Id.

changing the fluids from brine to LPG in the cavern results in very high pressure changes that can propagate through the salt beds. The pressure changes were not measured in 1964, but analysis of the proposed changes due to FLLPG's proposed LPG storage project indicates that [redacted] (Appendix G describes the process and discusses the expected pressures in detail). This pressure level is more than enough to cause the small changes needed to increase the pressure gradient across the sediments, with the pressure being propagated as described in the following paragraphs.

The changing pressure in the galleries would have caused strain on the granules in the formations that intersect the caverns, including both salt and shale, and increased the pressure in the brines in pore spaces. The pressure changes essentially squeeze the formations, causing elastic strain to propagate along the plane of the formations; the pressure also propagates through brine in the connected pores. Because the salt has low permeability, the strain relation is most important. Calculations of pressure changes through the formation include coupled relations between standard hydraulics and strains. The strain propagates essentially instantaneously, and it manifests by increasing pressure which squeezes fluid from the pores. This viscoelastic strain increases the pressure in the formations under the sediments that intersect the lake and thereby increases the head drop across the sediments. This increased pressure likely increased the gradient across the sediments to drive much additional salt into the lake. Appendix F presents the details of this process, including the full set of mathematical equations based on the coupled hydraulic and strain relations necessary to describe the process.

There are examples in the literature of these equations and the stress/strain relations they describe. Examples of short-term natural viscoelastic flow include earth tides, seismic activity, or earthquakes at a distance causing pressure fluctuations, strain exerted by pumping confined aquifers on the confining layers, and barometric pressure changes affecting groundwater levels (see the expanded description of these processes in Appendix F).

The pressure changes would have been much higher closer to the caverns, but relatively intact shale layers could prevent advection to the lake in this area except through fault/fracture zones. Geologic studies, including those conducted in the 1950s and 1960s by the salt company, have shown that faults do occur beneath and near the lake and that they occur both above and below the salt beds (Jacobi 2002; Jacoby 1970). This is an additional potential pathway for salt to enter the lake due to pressure changes.

Potential alternative explanations for the spike in salt concentrations in the 1960s are extremely unlikely. One alternative is that the high-concentration samples were drawn from beneath the thermocline, where the water is saltier.[12] Some of these observations may have been from the intake of a local water company. Vertical water quality data indicate this explanation is unlikely as suggested by profiles presented by Halfman (2014) and Ahrnsbrak (1975) and data by Dietrich (2014) which show that hypolimnion water is saltier, but by only about ten percent, not the 40 percent increase in Cl loading in Seneca Lake observed in the 1960s (Appendix B).[13] These analyses indicate that the Cl in Seneca Lake is pretty well mixed throughout the lake.

Second, there is scatter around the high concentration data, which suggests that there are some errors in the data. However, the scatter is less than 10 to 20 percent, which is not unusual for water quality data. Additionally, the data in Figure 2 is not controlled for depth or location, which could cause some scatter. Despite the scatter, the spike in Cl concentration in the mid-1960s is clear, and the overall Cl levels in Seneca Lake have consistently been much higher than the other Finger Lakes.

Third, the LPG storage cycling lasted longer than the spike of salt inflow. There are several explanations for this. The salt concentration remained high for several years before beginning a slow decline (Figure 2). The advection likely slowed as a result of the salt being flushed from the sediments, so that the concentration was reduced temporarily. However, the Syracuse formation that abuts the sediments should provide a ready refill source of salt.

An alternative source of the salt spike to the lake could be the release of brine from an underground cavern to the lake through natural faults or through the lake bottom. Berest el al. (2001) noted that brine-filled caverns can fail as the pressure within the caverns increases and the cavern walls break down. If this failure occurs, it could affect salinity in the lake, but there is no evidence of any brine-filled cavern failures in the 1960s nor that any cavern could have released enough salt to cause the large spike in the mid-1960s. Moreover, such an event occurring during LPG storage operations would be linked to that storage and could recur, so it would be another risk that will be created by FLLPG's proposed storage.

The low flows during the mid 1960s also cannot account for the spike in chloride concentrations. Seneca Lake's volume fluctuates within a small range. See Appendix B. The range is just 2.2% of the total lake volume. Overall changes in Seneca Lake volume are such a small proportion of the total volume that they are not a significant factor controlling or contributing to the lake's overall salinity.

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[12] The thermocline is the transition layer between the mixed layer at the surface and the deep water layer.

[13] The hypolimnion is the dense, bottom layer of water in a thermally-stratified lake. It is the layer that lies below the thermocline. Typically the hypolimnion is the coldest layer of a lake in summer, and the warmest layer during winter.

The early to mid-1960s hydraulic fracturing that was done in connection with the LPG storage activities in the salt beds (Jacoby 1970) could not have caused the Cl spike in the mid-1960s because the hydraulic fracturing was a short-term activity, in this case designed to create a pathway to connect two wells. The process would not have occurred for a period as long as the Cl spike. Also, the high pressure used for the fracturing would have occurred in a concentrated area and not have increased pressures over the canyon wall as would have LPG storage. Hydraulic fracturing to connect caverns is not similar to the day-to-day operation of the LPG storage which increases and decreases pressure along most of the thickness of the formation where it intersects with the cavern.

Seismic activity also could not have caused the mid-1960s Cl spike because there is no record of significant activity in the Finger Lakes region during the relevant time frames (Arlington 2013).[14] Additionally, the area is currently considered to be of low seismic hazard (see map at http://earthquake.usgs.gov/earthquakes/states/new_york/hazards.php). The USGS does not list any significant earthquakes ever occuring in this area (http://earthquake.usgs.gov/earthquakes/states/historical_state.php#new_york).

Finally, Halfman (2014) documents a leak of 1.1 million tons of salt into the lake during the late 1960s through early 1970s. The amount of the leak could certainly have contributed to maintaining high concentrations through the 1970s, but it occurred too late and was not of sufficient load to have been the primary cause of the earlier spike of salt.

In my opinion, the LPG operations at the site, starting in 1964, caused the spike in Cl in Seneca Lake.

Conclusion and Recommendations

The salt levels in Seneca Lake are much higher than any of the other Finger Lakes, and additional significant salt discharges into Seneca Lake (above and beyond those currently permitted for existing salt mining operations), should be avoided. Prior operation of LPG storage at the site caused a significant spike in Cl concentration in Seneca Lake in the mid-1960s, and it took many years to recede. My analysis indicates that LPG storage at the site today would do the same thing—cause significant elevated Cl discharges to the lake—as the pressure changes inherent in LPG storage in the salt caverns increases saline groundwater flow to sediments below the lake and from there into the lake. Due to the higher overall levels of salt in Seneca Lake as compared with the other Finger Lakes, and as compared with Seneca

[14] The citation Arlington (2013) lists the earthquakes that have occurred within 150 km of the site since the 1850s. The list in Appendix 6-G shows that during the second half of the 1960s there were no earthquakes within 100 kilometers of the site.

Lake in the early 1960s, and the very long retention time of up to 33 years, the LPG operation should not be permitted unless these types of salt discharges can be prevented. The future plans to develop salt caverns into LPG storage sites create a high risk that massive quantities of salt will once again discharge from the salt formations and sediment underlying Seneca Lake into the lake and degrade the lake's water quality. Although I do not believe that FLLPG can do so, FLLPG should not be given a permit for this project unless it can collect sufficient data and conduct sufficient peer-reviewed modeling to show that pressure changes or other LPG-related activities will not drive salt into the lake.

APPENDIX A

Analysis of Observed Surface and Groundwater Flow and Water Quality

APPENDIX A: Analysis of Observed Surface and Groundwater Flow and Water Quality

Concentration of salt (or other elements) increases when the entering load exceeds the leaving load, and the concentration decreases when the loads are reversed. Seneca Lake is a flow-through system meaning that inflow equals outflow, with outflow including evaporation. This appendix discusses the volume, flows, and chemistry of water in and entering Seneca Lake.

The outflow from Seneca Lake is to the Seneca River which also drains most of the Finger Lakes until it joins the Oswego River downstream from Oneida Lake. Ultimately, the Finger Lakes flow into Lake Ontario. Seneca Lake has a drainage area of about 1180.6 km^2 (Callinan 2001). The inflow to Seneca Lake comes from a number of tributaries (Catherine Creek being one of the largest) and the outflow from Keuka Lake (which sits at a higher elevation).

The US Geological Survey (USGS) has maintained gaging stations for flow *into* Seneca Lake periodically since the 1950s, but the data is meager. One of the largest tributaries, Catharine Creek, which enters at the south end of the lake, has just a three-year period of record, from 1975 to 1977, at gage #042322000. The average flow over that short period was 44.9 cubic feet per second (cfs). Three other gages operated for just a few years in the 1960s on very small tributaries. Catharine Creek provides just 9% of the flow, as represented by outflow during the earlier period. The precise amounts of inflow to Seneca Lake from other sources has not been adequately documented throughout the years, but it includes the flow from Catherine Creek and other tributaries that flow to the lake, shallow and deep groundwater, precipitation, and the outflow from Keuka Lake.

Average stream flows from 1999 to 2011 on nine tributaries varied from 0.1 to 3.2 m^3/s (3.5 to 113 cfs), with the highest being the Keuka Outlet and Catharine Creek (Hobart and William Smith Colleges et al. 2012). Average flow at the other sites (Castle, Wilson, Kashong, Plum Pt., Big Stream, Reeder, and Kendig Creeks) was less than 27% of the flow at Catharine Creek (Id.), confirming that Catharine Creek is the largest tributary draining freely from a watershed. Keuka Outlet has higher flow but it is mostly supplied by Keuka Lake. Differences in the size of the drainage areas feeding the surface water sources to Seneca Lake explained 99% of the variation in the average tributary flow (Id.).

The USGS maintains no long-term water quality measurement sites on tributaries to the lake. The USGS database included many one-time measurements that did not include flow rate, so neither a load nor time trend could be determined. The date of the measurements was also variable so the measurements do not provide a snapshot of load at any specific time.

The Catharine Creek gage had five water quality readings in 1975, but three of them occurred before the short-term flow gage station had been established. The average specific conductivity, chloride, and TDS was 500 uS/cm, 33.6, and 297 mg/l, respectively. The Cl value was very similar to the value used for surface inflow by Halfman et al. (2006). Flow measurements on 9/5/75 and 10/8/75 were 11 and 28 cfs, much below the average, suggesting the water quality readings are representative of baseflow conditions. Salinity parameters tend to be higher during baseflow because groundwater discharge tends to dominate unless the runoff is through a contaminated site (and there is no evidence of runoff passing through a contaminated site). Data presented by Hobart and William Smith Colleges et al. (2012) shows that only Castle Creek has salinity higher than the overall Seneca Lake average, and its discharge averages 0.4 m^3/s (14.1 cfs) so its load is a small fraction of the average load to the lake. As discussed above and herein, the Cl concentrations in the tributaries to Seneca Lake are not significant and certainly could not have caused the Cl spike in the mid-1960s.

The best record of flows into or out of Seneca Lake is on the outlet from Seneca Lake, the Seneca River, on which the USGS has operated two gages (with very little intervening drainage area). Gage #4232650, Seneca River near Lock 4, which operated from 1930 to 1979, had an average, standard deviation, skewness, maximum, and minimum flows equal to 547, 683, 1.97, 14,500, and 15 cfs, respectively. Gage #4232730, Seneca River near Seneca Falls, which operated from 2006 to 2014, had an average, standard deviation, skewness, maximum, and minimum flows equal to 636, 649, 1.39, 3290, and 0 cfs, respectively. The differences between periods are minimal and the average for the two gages is about 590 cfs.

Annual average flows considering the two gages varied from 60.6 to 1078 cfs, with the low and high years being 1965 and 1978, respectively, at the Seneca River near Lock 4 gage (Figure A1). Several low flow years occurred in the mid 1960s (Figure A1). These years also are the only years in the record that have individual daytime flows as low as 15 cfs.

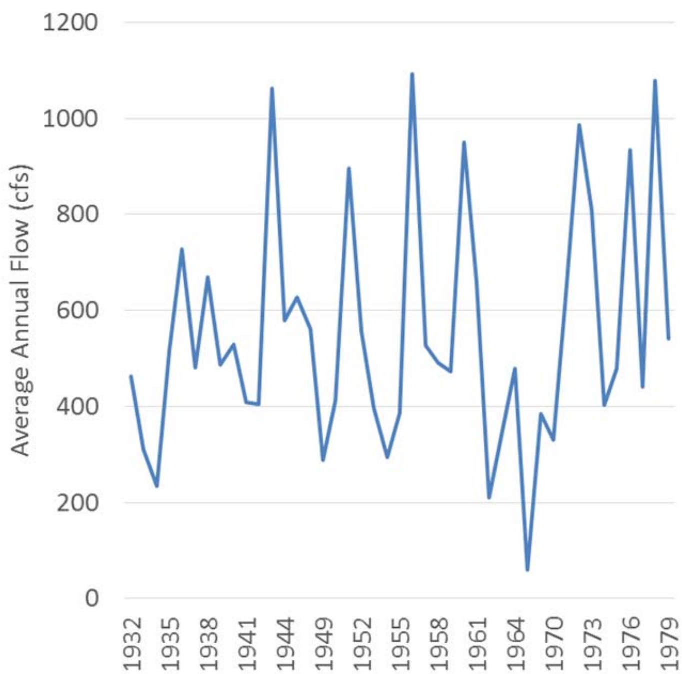

Figure A1: Average annual flow at the Seneca River nr Lock 4 gage.

Precipitation and evaporation are major components of water balance. The pan evaporation rate for Geneva was 32.75 in/y, the second highest value reported for New York (Farnsworth and Thompson 1982). The pan coefficient is commonly considered to be 0.7, so the evaporation rate from the lake could be considered to be 22.9 in/y. Precipitation at the site in Geneva has averaged 37.5 in/y, although the average precipitation for the Seneca Lake watershed ranges from 32.5 to 37.5 in/y (Hobart and William Smith Colleges et al. 2012). The high end of the range occurs over a small area on the southeast side. For these purposes, the midrange value of 35 in/y will be used. Precipitation and evaporation results in a net gain of 43,500 af/y, or approximately a foot of water over the 43,244 acre lake, or 60 cfs.

Seneca Lake's volume fluctuates within a small range. See Appendix B. The range is just 2.2% of the total lake volume. Overall changes in Seneca Lake volume are such a small proportion of the total volume that they are not a significant factor controlling or contributing to the lake's overall salinity, and thus the low flows noted in the graph in Figure A1 above during the mid 1960s cannot account for the spike in chloride concentrations seen at that time.

Since the lake stays at generally the same volume, and the discharge from the lake averages 590 cfs, the total inflow to the lake from all sources is about 530 cfs, with the other 60 cfs coming from precipitation (taking into account losses from evaporation).

Groundwater Inflow

Salt enters Seneca Lake from groundwater inflow, both deep (Halfman et al. 2006; Wing et al. 1995) and shallow. There is only one long-term data set regarding groundwater quality, a time series of samples collected on wells shallower than 250 feet along from the mid-1970s to the mid-1980s, about midway north-south along the west side of Seneca Lake, about 12 miles north of the proposed project. Interestingly, Cl concentration varies over about four orders of magnitude and about five of ten wells experienced a general upward trend over the time period (Figure A2). Two of the sites began the period with Cl much higher than others but they did not continue to increase. Two wells (MW4 and MW6) increased by at least an order of magnitude (ten times the previous measurement). Overall, the trends are not consistent among wells, but the data shows that salinity reaching the lake increased in the early 80s. The large variability also suggests there could be significant preferential pathways for salinity. Surface sources however have relatively low concentrations which are insufficient to have significant effects on the concentrations in the lake.

The draft environmental monitoring plan for the FLLPG project shows baseline TDS concentrations for wells near the brine ponds (Male 2014).[1] The five baseline wells at the West Brine Pond had low TDS concentration, all below standard. The five baseline wells with the highest TDS are nearest the road upgradient of the proposed East Brine Pond. Downgradient of the proposed East Brine Pond, TDS remains elevated but is only half as high as that upgradient of the pond. This indicates that road salt usage, which would be seasonal in nature as salt is generally only used in the winter, is affecting the shallow groundwater that reaches the lake. Measurements by Dietrich (2014) from stream sources near the lake show also that streamflow salt concentrations increase along the streams as they enter Seneca Lake. For measurements that occur during periods when there is no runoff, they reflect shallow groundwater draining to the streams. Groundwater quality in shallow groundwater would affect the lake both by discharging into the streams and by discharging directly to the lake.

[1] 2014-11-14, Draft Environmental Monitoring Plan.

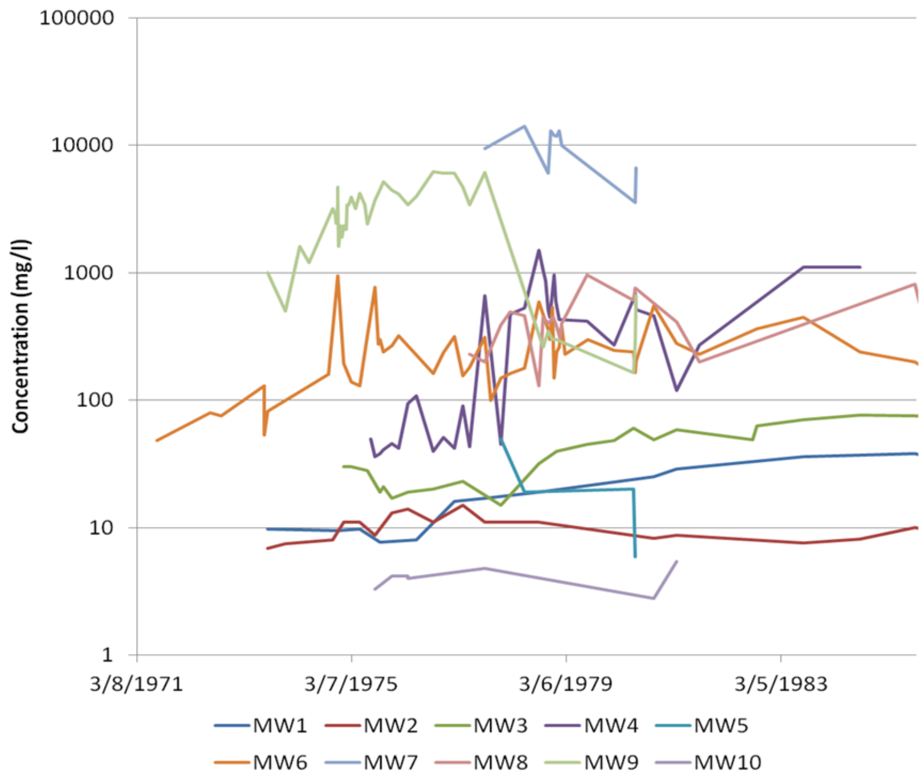

Figure A 2: Trend of chloride concentration in groundwater wells on the west side of Seneca Lake (Table A 1).

Table A 1: USGS wells used to show groundwater trend. The USGS id is latitude and longitude in degrees, minutes and seconds. The first six digits are latitude in degrees, minutes, second; the next seven digits are longitude in degrees (3 digits), minutes, seconds. The 01 means there is one well at the site.

USGS Id	Label
423539076552501	MW1
423528076560001	MW2
423524076561701	MW3
423524076562201	MW4
423527076562601	MW5
423526076563001	MW6
423524076563101	MW7
423506076561501	MW8
423541076563601	MW9
423535076564501	MW19

Shallow groundwater flow would be a small fraction of the surface water flows, and its salt concentration is not generally high, so shallow groundwater sources would be a relatively small percentage of the load in Seneca Lake. However, deep groundwater moving through the salt formations has been recognized in the literature as a potentially significant source of Cl into Seneca Lake (Halfman et al. 2006, Wing et al. 1995).

In summary, the volume of Seneca Lake is about 33 years of the outflow from the lake. Natural sources of salt, both surface and shallow groundwater, contributed relatively minor portions of the lake's salt load. Deep groundwater is the probable source of much of the salt in Seneca Lake.

APPENDIX B

SALINITY AND SALT LOADING TO SENECA LAKE

APPENDIX B: SALINITY AND SALT LOADING TO SENECA LAKE

Salinity in Seneca Lake

The salinity of Seneca Lake, as represented by chloride (Cl) concentrations, one of the dominant anions (Hobart and William Smith Colleges et al. 2012), has varied substantially over the past 110 years (see Figures 1-2 in the main body of this report). The data in Figure 2, as noted on the graph, was from Glen Jolly of the US Geological Survey (USGS) in Reston VA, and cited as Jolly (2005, 2006). The pre-1960s data was primarily from water company intake measurements.

The Cl concentrations rose from about 50 mg/l to 110 mg/l, from 1905 to about 1964. Between 1965 and the early 1970s, the concentration jumped to about 180 mg/l. Since that time to about 2004, the concentration dropped from 180 to about 145 mg/l. Between 2004 and 2008, the concentration dropped to about 120 mg/l (see description in Hobart and William Smith Colleges et al. 2012, p 89). Chloride concentration during a sampling event in October 2014 was about 132 mg/l with a standard deviation of 4.5 for 18 sites along a north-south transect with surface and bottom measurements (Dietrich 2014).

The volume of the lake is 15.54×10^9 m^3 (12,500,000 acre-feet (af)) (Halfman et al. 2006). Based on outflow estimates developed in Appendix A of 530 cfs, the lake volume equals almost 33 years of outflow. Wing et al. (1995) estimated the volume to be equal 18 years of the average inflow[1] (Wing et al. 1995), based on various estimates using tritium, stable isotopes and USGS runoff data (reference). Either volume to flow ratio is large enough to conclude that significant water quality changes—such as the salt spike in the mid 1960s—require a substantial inflow load, and that significant water quality changes can take decades to dissipate.

Over the years, the lake volume fluctuates within a small range. At the USGS stage gage near Watkins Glen (gage # 042324000) the maximum and minimum stages were 448.95 and 442.62 ft above mean sea level (amsl) from October 1956 to October 2013, respectively (Figure B1). The maximum stage in 1972 coincides with Hurricane Agnes. The volume at maximum area (43,244 acres) over this stage range is 273,736 af, or 2.2% of the total lake volume. This small range in volume indicates that changes in volume are not a significant factor contributing to or controlling the salinity concentration. The small volume range of the lake, and the large volume to flow ratio, also indicate that large loads and water quality changes will not flush from the lake quickly. There are no Cl sinks within the lake (Halfman et al. 2006) so the only Cl losses from the lake occur due to outflow.

[1] At 12.5 million af and 18 year turnover time, the average outflow is 970 cfs or 700,000 af/y.

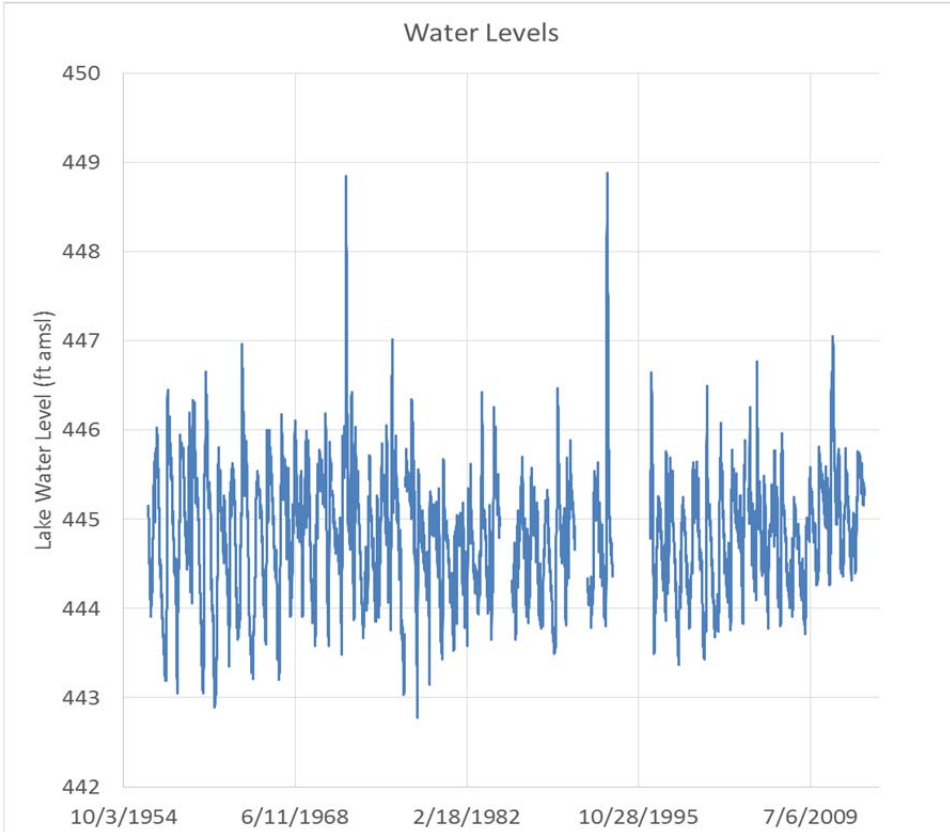

Figure B 1: Water levels at Seneca Lake, USGS gage # 04232400

Based on observed Cl concentration trends (Figures 1-2, main body of report), inflow Cl load exceeded outflow load from 1905 to 1965. In the late 1960s, when concentration spiked, there must have been a distinct short-term load into the lake. After the early 1970s, the downward concentration trend indicates that load leaving the lake exceeds the incoming load; the large load causing the later 1960s spike either stopped or was significantly reduced. The significant reduction from 2004 onward indicates the inflow load of CL has decreased substantially.

The total Cl load in the lake may be determined as the product of average concentration and total volume in the lake. The net change in load in the lake equals the change in total load and also equals the difference in inflow and outflow loads (Thomann and Meuller 1987). Figure B2 shows a graph of the total load and annual load in five-year increments. Concentrations were selected from Figure 2 (in the main body of the report) on five-year increments and annual net values were chosen as five year averages. Figure B2 shows that the total load in the lake increased from about 745,000,000 kg to about 2,720,000,000 kg in 1970. Interestingly, the Cl concentration in Seneca Lake in 1905 was 48 mg/l, a value that exceeds today's average influent streamflow Cl concentration of 33 mg/l (Appendix A). The present streamflow concentration also is probably higher than in 1905 because surface inflow Cl must have increased due to the use of road salt. With an average Cl concentration of 33 mg/l, surface water flows into Seneca Lake are a relatively minor source of salinity in Seneca Lake.

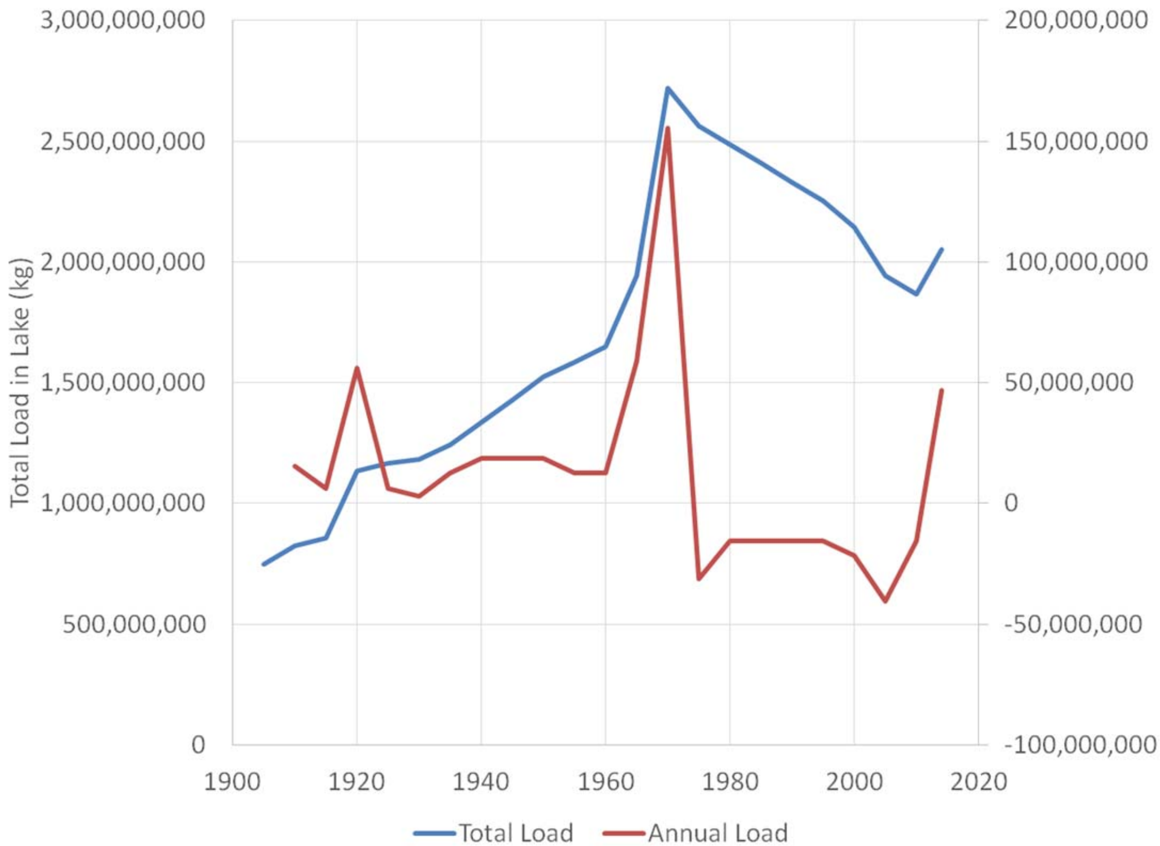

Figure B 2: Total Cl load (kg) in Seneca Lake and net annual load necessary to reach that level (kg/y). Total load is the product of lack Cl concentration and volume and annual load is the net load that resulted in the total load. In other words, net load entering the lake is the difference in total load between two points in time presented as an annual value. Same as Figure 4 above.

The average net inflow load ranged from 3,100,000 kg/y around 1930 to 18,600,000 kg/y through the 1940s. During the late 1960s, the inflow load spiked to about 155,000,000 kg/y (Figure B2, also reproduced as Figure 4 above). After 1970, the net load decreased to negative 15,000,000 to 40,000,000 kg/y until 2010, after which it has started to increase again.

In summary, Figure B2 shows that the load of Cl in Seneca Lake more than doubled from the early 1900s to 1965, and after that it almost doubled again by the early 1970s due to a very large spike of salt into the lake. After the mid 1970s, the net load to the lake became negative, which means that the outflow load, which depends on the very high concentration of the outflow, exceeds the load coming into the lake.

Seneca Lake has higher salinity levels, expressed as Cl, than the other Finger Lakes (Wing et al. 1995) during 1963, 1978, and 1994 (Figure B3, also reproduced above as Figure 1). Interestingly, the salinity trend is up with time for all of the lakes except Seneca and Cayuga, the lakes with the highest concentrations. The 1978 concentration in Seneca Lake is a result of an inflow spike that occurred in the late 1960s whereas the 1994 concentration occurs after the concentration has decreased due to decreased salt inflow. The fact that two lakes have substantially higher Cl concentrations in general indicates that these lakes may be subject to different sources or have different characteristics than the other Finger Lakes. These lakes are the two largest and deepest of the Finger Lakes. The spike that occurred in Seneca Lake indicates that that lake was individually affected by an event that caused its Cl level to spike.

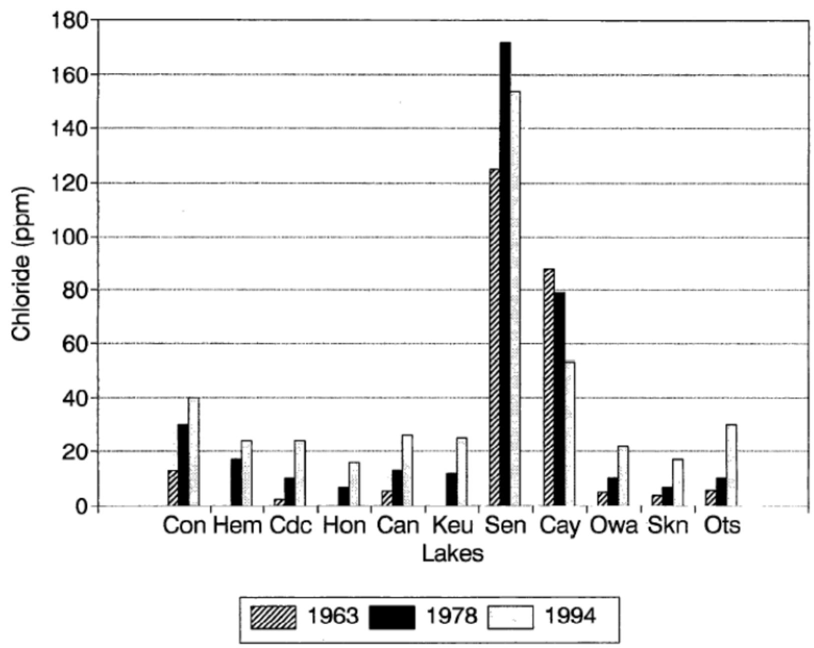

Fig. 1. Chloride concentrations (ppm) in 11 Finger Lakes spanning three decades: 1963 data from Berg (1963); 1978 data from Schaffner and Oglesby (1978); 1994 data from this study. Abbreviations: Con—Conesus Lake; Hem—Hemlock Lake; Cdc—Canadice Lake; Hon—Honeoye Lake; Can—Canandaigua Lake; Keu—Keuka Lake; Sen—Seneca Lake; Cay—Cayuga Lake; Owa—Owasco Lake; Skn—Skaneateles Lake; Ots—Otisco Lake.

Figure B 3: Snapshot of Fig. 1 from Wing et al. (1995) comparing chloride among the various Finger Lakes with time. Wing et al. indicate that 1963 data is from Berg (1963), 1978 data is from Schaffner and Ogelsby (1978) and 1994 data is their own. It is not known if the data used to develop the Seneca Lake portion of this graph is from Figure 2 in the main body of the report. Same as Figure 1 above.

Concentration varies through the lake volume due to stratification and the location of point sources, however the variation with depth is less than 10 or 20 percent. For example, the highest specific conductance[2] observed in the Finger Lakes is 730 uS/cm in the hypolimnion[3] of Seneca Lake (Halfman and O'Neil 2009). Dietrich (2014) found the highest specific conductance values, 728 and 720 uS/cm, were at the lake bottom in the hypolimnion at sites 7 and 8, which are in the middle of the south portion of the lake, but also found a low standard deviation which indicates that Cl was well mixed through the lake. That the slightly higher values are on the bottom is expected as this reflects the fact that high TDS water (of which Cl is a portion) is denser and tends to settle, and also the volume of inflow to the epilimnion contains quite dilute concentrations of salt.[4]

Herein, for this study, the low variation in salinity throughout the vertical profile allows the lake to be assumed fully mixed as shown by previous authors (Halfman 2014; Halfman et al. 2006, Wing et al. 1995) and data (Dietrich 2014, Ahrnsbrak 1975), which means the concentration equals the total mass in the lake divided by the volume.

Concentrations of Cl, sodium, and sulfate and measures of specific conductance in Seneca Lake are much higher than in streams entering the lake (Halfman et al. 2006). The concentration in surface water reflects the added loads from road salting and other discharges but cannot account for the rise in Cl seen in the lake over the years. Halfman et al. (2006) estimated that to attain the Cl concentrations observed in 2006, the average annual total flux of Cl would have to equal 106,000,000 kg/y, based on steady state conditions. They estimate—based on their 33 mg/l average Cl from streams feeding into Seneca Lake—that the streams provide 26,000,000 kg/y, which means 80,000,000 kg/y enters from other sources. If the stream and other water sources inflow is actually 530 cfs (as estimated in Appendix A based on measured flow data), and average concentration is 33 mg/l, the inflow load from streams is 15,600,000 kg/y. Other sources would have to contribute up to 90,000,000 kg/y.

Halfman et al. (2006) suggest the other chloride source would be "extra, non-fluvial source of chloride, sodium and to a lesser degree sulfate . . . from a groundwater source interacting with the Silurian evaporates beneath the lake" (Id. p 328). I agree. My analysis indicates that the source of much of this chloride is deep groundwater. Appendices D, E, and F discuss the mechanics of how this occurs, including a discussion of advective flow of salt and groundwater, the stratigraphy of the area showing that salt beds intersect with the lake, and explain the

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[2] Specific conductance is a measure of the ability of water to conduct an electrical current, which is highly dependent on the amount of dissolved solids, such as salt, in the water. A common measurement of SC is microsiemens per centimeter (uS/cm) with the standard measure taken at 25 degrees Celsius. http://water.usgs.gov/edu/characteristics.html#Conductance.

[3] In a dense, thermally stratified lake, the hypolimnion is the dense, lower level of the lake. Cold water is denser than warm, so it sinks to the bottom of the lake.

[4] Epilimnion is the less dense, upper layer of a lake. See also SEQR Documents (Final DSEIS Text).

mechanics of how changing pressure due to LPG storage can cause additional advective flow of salt into the lake.

APPENDIX C

ANTHROPOGENIC SOURCES OF SALT TO SENECA LAKE

APPENDIX C: ANTHROPOGENIC SOURCES OF SALT TO SENECA LAKE

Seneca Lake has received salt from numerous natural and anthropogenic (human-caused) sources since the late 1800s, and possibly earlier. Appendix A documented the flow rate and water quality of some natural sources, although it must be noted that surface water inflow discussed there could include anthropogenic sources such as road salt increases. This appendix discusses additional anthropogenic sources and shows they may explain early 1900s trends but cannot explain the spike in the 1960s.

Salt mines near Seneca Lake are permitted to discharge salt into the lake, but the amount is not sufficient to explain the 1960s Cl concentration spike discussed in Appendix B. Wing et al. (1995) noted there was permitted discharge into the lake of 3600 kg/d, or 1,300,000 kg/y. Halfman (2014) documents discharges of 34,000 kg/d (12,400,000 kg/y) in 1999, decreasing to 17,000 kg/d (6,200,000 kg/y) in 2006 and increasing to 30,000 kg/d (10,900,000 kg/y) by 2014 (Figure C1). Records of permitted salt discharges to the lake prior to 1999 are not available but it is reasonable to expect that similar discharges occurred prior to that time and possibly commenced in the late 1800s with the advent of salt mining. Legal controls on such discharges would have been minimal for much of the period, but it is also unlikely that the salt mines would have been discharging extreme amounts of the product they are mining and producing. Assuming that salt mines discharged 12,000,000 kg/y through the 1900s is reasonable and could explain a portion of the necessary annual load that caused the Cl concentration to increase from 1905 through 1965 (Appendix B).

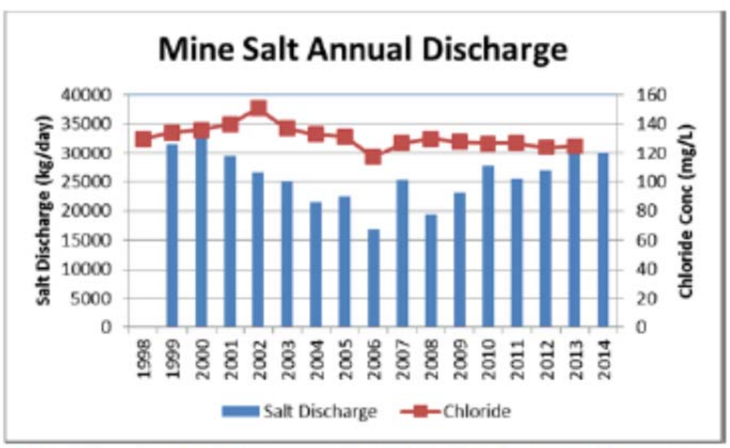

Fig. 12. Annual mean salt-mine discharge of waste chloride and sodium to the lake from the two salt mines near Watkins Glen.

Figure C 1: Snapshot of Figure 12 from Halfman (2014) showing the salt mine discharge to Seneca Lake from 1999 to 2014.

Total salt production from the lake area correlates weakly and negatively with the net load of salt reaching Seneca Lake (Halfman 2014). This negative correlation suggests that salt mining does not add a consistent and substantial salt load to Seneca Lake beyond that documented due to measured discharges in the previous paragraph.

Halfman (2014) documents a leak of 1.1 million tons of salt into the lake during the late 1960s through early 1970s. The documentation of this event is from newspaper reports, so the quantities cited and the circumstances surrounding the leak may not be accurate. The inflow pathway was apparently through surface water, meaning a leak or discharge flowed down a stream or streams to the lake. If the reported amount is all NaCl and it entered the lake at one time and completely mixed, it would have increased the Cl by over 40 mg/l. Halfman's description is that the leakage occurred through the early 1970s, for up to five years, so the leak could have increased the Cl concentration by up to 10 mg/l [1] if it had added to other sources and could certainly have contributed to maintaining high concentrations through the 1970s. However, it occurred too late and was not of sufficient load to have been the primary cause of the earlier spike of salt.

Road salting has been increasing over the previous century, but does not explain the increases in Cl concentration in Seneca Lake. Halfman (2014) estimated that present day fluvial fluxes[2] of Cl and sodium would support concentrations of 44 and 27 mg/l, respectively. These concentrations are relatively close to the salt concentrations in the other Finger Lakes, but much less than in Seneca and Cayuga Lakes. Halfman (2014) also found a weak correlation of ion concentration with road density in the watersheds, which provides additional evidence that road salting explains much of the level of and variation in salt concentrations in the Finger Lakes, other than Seneca and Keuka. Additionally, even if there was a higher salting rate in the Seneca Lake watershed, the much higher water volume in Seneca Lake would have absorbed extra load, as previously noted. Road salt usage increases over the years are much too low to have caused the high overall level of salt in Seneca Lake, or the chloride spike in the mid-1960s.

Wing et al. also documented that the salt company had pumped approximately 1×10^9 kg salt into a deep disposal well in the 1970s, although that also postdates the period during which the Cl increased so significantly and the disposal well location was in sandstone much below the lake bottom and about ten miles south of where the salt formations intersect the lake bottom. The data does not suggest that this deep well disposal caused a significant increase in salt in the lake.

[1] This is based on the 1.1 million tons being spread evenly over five years.
[2] A flux is a flow and fluvial refers to being from a stream source.

In summary, salt mine discharges and road salt probably have caused more than 12,000,000 kg/y of Cl to enter Seneca Lake through much of the 1900s and probably to the present. This may explain most of the salt increases prior to the 1960s. After the spike in the 1960s, this may again be the primary source which had allowed the Cl concentration to decrease since the 1970s, but it does not explain the large spike that caused a decade of very high Cl concentrations.

APPENDIX D

GROUNDWATER FLOW AND ADVECTION INTO THE LAKE

APPENDIX D: GROUNDWATER FLOW AND ADVECTION INTO THE LAKE

The bulk of the spike of approximately 155,000,000 kg/y Cl to the lake for several years in the 1960s had to result from groundwater inflow, simply because all other potential sources have been ruled out, as shown in Appendix C. As shown in Appendix B, Halfman et al. (2006) determined a non-fluvial source must contribute between 80,000,000 and 90,000,000 kg/y of Cl to Seneca Lake for the concentration to reach values seen in the 2000s.

Two types of groundwater discharge to Seneca Lake can add load to the lake—diffusion and advection—as explained in this appendix. The source of salt is the existing sediments beneath the lake. As salt is discharged from those sediments, it will be replenished by salt from the Silurian salt beds which intersect the lake sediments (Appendix E).

Sufficient salt is present in the sediment beneath the lake to provide the source for both diffusion and advection of salt into the lake. Assuming that the 175 km^2 lake bed is covered with 50 m of sediment[1] with porosity equal to 0.25 and 16,000 mg/l Cl (Wing et al. 1995), the sediments would contain 35,000,000,000 kg Cl. One year's worth of load from groundwater, 155,000,000 kg, is just 0.4 percent of the total in storage so Cl availability is not a limiting factor. Also, Cl concentration may continue to increase with depth deeper than 2.5 m into the sediment so the total salt load may be even higher.

The first groundwater source is diffusion. Diffusion is the movement of salt from high concentration to low concentrations, without regard to movement of the water. Halfman et al. (2006) estimated 6,000,000 kg/y enter the lake by diffusion, based on data from Wing et al. (1995). Wing et al. (1995) reported the concentration of Cl in the sediments was several times that of seawater, reaching 16,000 mg/l at 2.5 m beneath the surface of the sediments. The gradient that this establishes from depth in the sediments to the surface drives the diffusion. This amount of salt that could come from diffusion is far less than the load in the lake, and much too low to have caused the chloride spike in the mid 1960s.

The second groundwater source is advection, which is simply the movement of salt along with the flow of the groundwater. Groundwater flow into the lake from the sediments beneath the lake would carry groundwater at the concentration observed in the sediments. This flow is also known as Darcian flow and is driven by a pressure, or head,[2] gradient across the sediments. This salt flow is in addition to the flow caused by diffusion. *Both Halfman et al. (2006) and*

[1] At the deepest point of the valley, the thickness may be several hundred meters (Wing et al. 1995), so 50 meters is a conservative value to use in this estimate. It is conservative because a thicker sediment thickness could provide for more salt availability.
[2] Head is pressure expressed as the height of a water column, commonly expressed as feet or meters of head.

Wing et al. (1995) concluded that advection is the most likely source of additional salt to match concentrations observed in the 1990s.

Evidence of advective flow into the lake includes mudboils at the north end of the lake which discharge 0.003 m^3/s at 50,000 mg/l, a flux of 500,000 kg/y (Halfman 2014; Goodman et al. 2011; Halfman et al. 2006). These are small enough to be missed by routine sampling and seismic surveys and the flow is too small to be noticeable in the lake water balance. Also, nearby deep wells drilled during the 1800s have found brine with TDS exceeding 100,000 mg/l at depths which would be along the pathway for advective flow to the lake (Goodman et al. 2011).

Advective flow carrying salt into the lake must have an upward gradient to drive the flow. Goodman et al. (2011) identified a potential source of that gradient, as discussed in Appendix E. The advective flux necessary to deliver to the lake 10,000,000 kg/y Cl at 16,000 mg/l is 1712 m^3/d (0.7 cfs), a rate that would scarcely be noticed in the water balance of the lake. If half of the lake bottom intersects the salt beds (Appendix E, Figure E2), it can be assumed that the salt inflow occurs over half of the lake bottom, or half of 175 km^2. This would require a Darcy velocity of 1.96×10^{-5} m/d. Darcy velocity is gradient (i) times conductivity (K) for average flow through a cross-section; total flow is Darcy velocity times cross-sectional area. Gradient is change in head divided by flow distance (first occurrence of gradient). Neither i nor K is known for the sediments beneath Seneca Lake. Assuming a range of K, i can be determined as $i = v/K$. Table D1 shows that for a low conductivity, K=0.001 m/d, the necessary i would be less than 0.02 m/m or over 50 m the head drop would be less than a meter. A midrange K would require a head drop over the sediment of less than 0.01 m.

If the entire 150,000,000 kg/y were delivered by advective flow through the sediments and the concentration of Cl in the sediments remains the same, the flow would have to be 25,685 m^3/d (10.5 cfs). Table D1 shows the additional head that would be required to drive the additional flux across the sediments into the lake. For K ranging from 0.1 to 10 m/d, the required change in head is much less than a meter. Darcy flow calculations support the conclusion that advection could easily drive the needed salt into Seneca Lake if the gradient changes to increase the flow.

Table D 1: Comparison of required gradient and head drop over 50 m of lake bed sediments for a range in sediment conductivity (K). At a concentration of 16,000 mg/l, 1723 m^3/d would deliver 10,000,000 kg/y and 25,684 m^3/d would deliver 150,000,000 kg/y to Seneca Lake across 85 km^2 of lake bottom sediments.

	Flux = 1712 m^3/d		Flux = 25,684 m^3/d		
K (m/d)	i	over 50 m	i	over 50 m	added head
0.001	0.019	0.98	0.29	14.7	13.7
0.01	0.0019	0.098	0.029	1.47	1.37
0.1	0.00019	0.0098	0.0029	0.147	0.14
1	1.96E-05	0.000978	0.00029	0.0147	0.014
10	1.96E-06	9.78E-05	2.94E-05	0.00147	0.0014

In summary, this appendix shows that salt can flow with natural groundwater inflow to the lake in amounts sufficient to account for the high Cl concentrations observed in the lake. While groundwater inflow is a very small proportion of the lake water balance, the high concentration of salt makes for a very high load. Small changes in pressure beneath the sediments can account for large changes in flow and salt load to the lake.

APPENDIX E

DETAILS OF HYDROGEOLOGY OF THE SENECA LAKE AREA

APPENDIX E: DETAILS OF HYDROGEOLOGY OF THE SENECA LAKE AREA

Figures E1 and E2 present a regional view of stratigraphy in the Seneca Lake region. Figure E1 is a cross-section north by about ten minutes of latitude from the proposed LPG storage project. Figure E2 is a longitudinal north-south profile through Seneca Lake. FLLPG's application also discussed stratigraphy in a few locations. Section A-A' (Figure E3) shows the details near the project site.[1] The salt formations are hundreds of feet below the lake bottom at the application site, but rise in profile to the north (Figure E2). Ten minutes is about 11 miles or 58,000 feet at latitude 42°, and a 500-foot rise requires a slope of just one percent. Considering that formations observed a couple thousand feet below ground surface at the application site outcrop just north of the lake (Halfman et al. 2006), the one percent slope required for the salt formations to intersect with the lake for most of the profile beginning a few miles north of the project is reasonable. As implied on Figure E1, a substantial portion of the Syracuse Formation has been eroded and replaced by the valley fill—glacial sediment. Tens of miles of the longitudinal profile of the Seneca Lake valley intersect with the Syracuse Formation, including the salt beds (Figure E2).

There are brine springs along the Onondaga escarpment north of the Finger Lakes. These springs discharge from various Silurian formations (Goodman et al. 2011) including the Syracuse, and are very salty. Their presence demonstrates the presence of an upward gradient, or artesian pressure, in the Syracuse formation (Goodman et al. 2011). The current groundwater discharge zone, as represented by the brine springs, would have been a recharge zone during the glacial periods which ended near 10,000 years ago (Ellis et al. 2004). The formations which received the recharge dip downward to the south and pinch out, so there was no place for the groundwater to go. Once the glaciers retreated, the pressure which had built up in the pinched-out aquifers, or pocket aquifers as termed by Goodman et al. (2011), was higher than the ground surface. Springs formed at the location where the glaciers had been recharging the groundwater. The springs are salty because the flow is along the Silurian formations including many layers of salt. The higher pressure in the Silurian group would also manifest in the areas where the group intersects the sediment in the lake bottom and cause an upward pressure into the sediments or any faults intersecting the formations between the salt and the lake sediments (Halfman et al. 2006, Wing et al. 1995).

The combination of stratigraphy with salt formations intersecting the sediments under the lakebed and the presence of an upward gradient due to glacial unloading indicates that groundwater flows into the lake as described by Halfman et al. (2006) and Wing et al. (1995).

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[1] August 2014 Gallery Map and Section (2000-00-01-16-R9 SECTION 8-28-14 INERGY SECT A-A' FINGERLAKES).

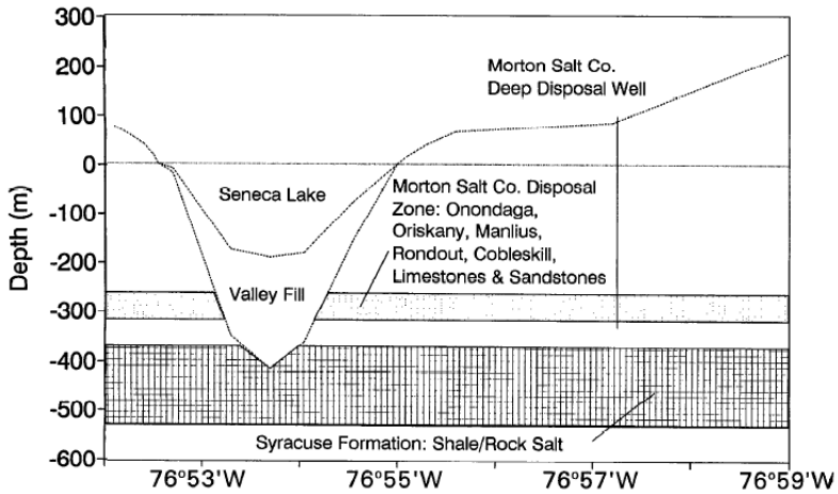

Fig. 5. Schematic latitudinal bedrock profile of Seneca Lake at 42°35′N.

Figure E1: Snapshot of Figure 5 in Wing et al. (1995) showing general stratigraphy from west to east at latitude 42° 35'.

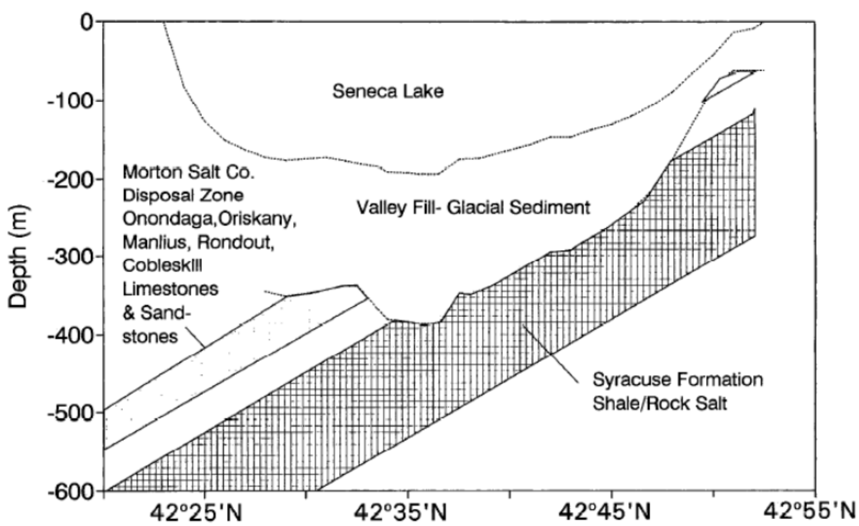

Fig. 6. Schematic longitudinal bedrock profile of Seneca Lake at maximum depth.

Figure E2: Snapshot of Figure 6 in Wing et al. (1995) showing general stratigraphy from south to north. Same as Figure 3 above.

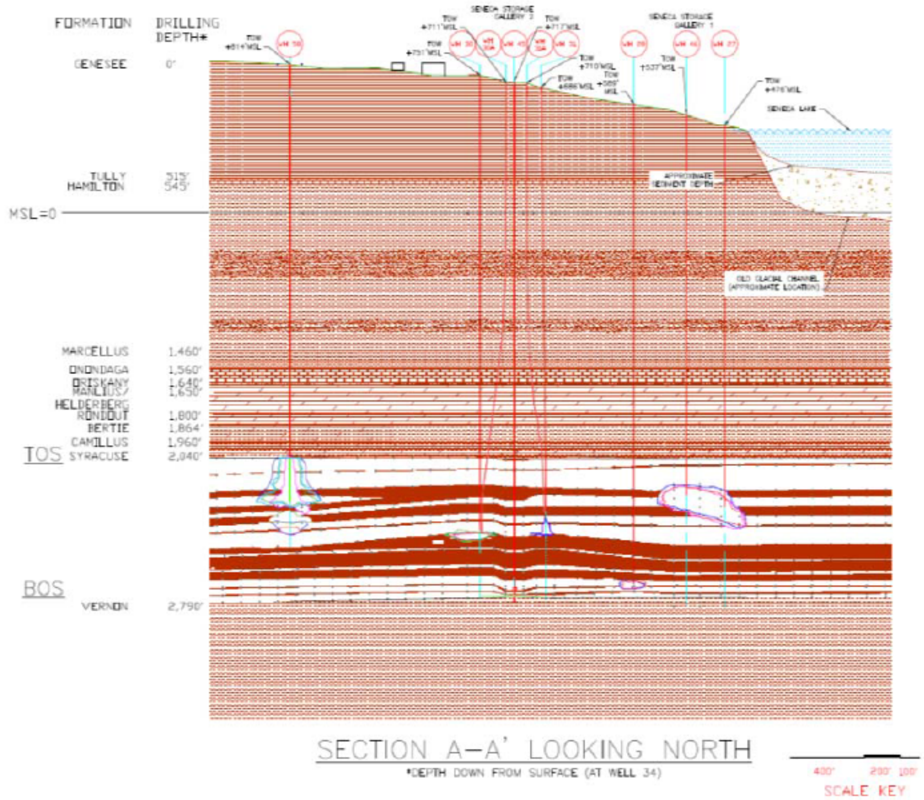

Figure E3: Snapshot of section A-A' from FLLPG's application.[2]

[redacted][4][5]

In the south near the project site, the salt layers would be connected with the sediments directly overhead through faults/fractures through the overlying shale layers. Early industry studies also provide evidence of faults through these formations (Jacoby 1970, 1966; Jacoby and Dellwig 1973). More recent mapping found faults throughout the area (Jacobi 2002).

[2] August 2014 Gallery Map and Section (2000-00-01-16-R9 SECTION 8-28-14 INERGY SECT A-A' FINGERLAKES).

[3] [redacted]

[4] This report does not attempt to address the structural stability, or instability, of the proposed salt caverns.

[5] See [redacted]

Jacoby (1966) noted that faulting in the salt and/or flow along interbedded shale caused significant problems with estimating where injected fluid for hydraulic fracturing operation would go. He wrote that the company found injected fluid discharging from wells roughly perpendicular to the intended well, a finding that indicated substantial heterogeneity, or high variability, in parameters that describe the properties of the fracture system around their wells. Also, during fracturing to connect wells, Jacoby (1970) found that pressure must be maintained in a fracture that has connected two wells or the fracture will heal (Jacoby 1970). This "creep" is an example of the viscoelastic flow that may be established due to highly differential pressures caused intermittently storing brine and LPG gas in caverns.[6] Faults provide pathways connecting the salt beds with the fill underlying Seneca Lake.

[redacted] Vertical cores are very unlikely to actually intersect vertical fractures at a rate even similar to the actual proportion of the rock containing such fractures (Schulze-Mackuck et al. 1999). [redacted]

Further north along the lake profile, the salt layers proposed to be used for this LPG project directly contact the sediments (Figure E2), so there is a direct pathway from the salt into the sediments which would probably be saturated (Bredehoeft 1988). There is already an upward gradient of unknown magnitude that drives advective flow into the lake; changing the pressure in the salt beds would increase that gradient and therefore the advective flow. This is likely the area with the largest proportion of salt flow into the lake.

The formations near the project are faulted. Faults may not always extend through the salt as much as through the overlying shale because salt tends to heal itself over time (Davidson 2009). Faults do form through salt, and under certain conditions fluid can flow along them (Davidson

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[6] Note that Dionisio and Istvan (2012), for the company, reports the faults do not cause problems for the galleries. He also suggested that he found no evidence of faults extending through the salt bed, in response to a request from NY DEC to examine the papers of Jacoby. His opinion was not supported by any data or references. See 2014-01-03 & 06, BSK, Istvan & Dionisio to DEC – Valley Stress Conditions Response.

[redacted]

2009), but even with healing in the salt they are unlikely to prevent strain or pressure from being transmitted. Faults thus do not constrain the strain and some near the project site could transmit brine to shallow groundwater due to changing pressures caused by the proposed project. In sum, faults around the caverns can transmit pressure even if the salt has healed on one end of the fault. And faults can directly release Cl or LPG to shallow groundwater, surface waters, and Seneca Lake. Finally, the more that a cavern is intact or free from faults, the more that cavern can increase in pressure and transmit pressure through the salt beds to release salt/Cl into Seneca Lake.

APPENDIX F

DETAILS OF VISCOELASTIC FLOW OF SALT NEAR SALT CAVERNS

APPENDIX F: DETAILS OF VISCOELASTIC FLOW OF SALT NEAR SALT CAVERNS

The galleries would have been alternately filled with brine and with LPG gas in the 1960s, just as the proposed project would do, albeit at different galleries within the same formation. Each change would have sent a pressure surge horizontally along the various salt and stringer layers that intersect the galley, based on principles of viscoelastic flow discussed in Ingebritsen et al. (2006). The gallery, if it does not leak, would transmit pressure to the surrounding media similar to that of a balloon perfectly fitting into the gallery pushing on the formations. Increasing pressure would push, or add a compressive stress, to the various layers which would begin to compress, or strain. This volumetric strain is also called dilation (Ingebritsen et al. 2006). Pressure changes and fluid movement could occur along these layers, even without leakage from the gallery. Where plastic deformation compacts the sediments, there can be "important effects on fluid pressure" (Id. p 69). Depending on the magnitude of the stress and the time over which it is applied, the strain is consecutively elastic and then inelastic.

The complex behavior of the flow of salt was best summarized by Berest et al. (2001) (emphasis added):

(a) Salt behavior is elastic-ductile, when short-term compression tests are considered, and elastic-fragile when tensile tests are considered; but in the long term, salt behaves as a fluid in the sense that it **flows even under very small deviatoric stresses**.[1]
(b) Creep rate is a **highly non-linear function of applied deviatoric stress** and test temperature.
Furthermore, experts generally distinguish between . . .
(i) Steady-state (or secondary) creep, which is reached after some time (**several weeks**) when a constant mechanical loading is applied to a rock sample; steady state is characterized by a constant creep rate, which is a function of the (constant) temperature and stress applied during a test; and
(ii) Transient (or primary) creep, which is triggered when the stress applied to a sample is suddenly changed. Transient creep is characterized by high initial rates (following a load increase) that slowly reduce to reach steady-state creep or by slow, sometimes reverse, initial rates (following a load decrease) that slow increase to reach steady-state creep.

The flow is usually considered to be salt creep and contributes to the claim that salt formations are somewhat impermeable (Berest et al. 2001). Over geologic time periods, the movement of

[1] A deviatoric stress is the difference between actual stress and hydrostatic pressure, or that which causes a deviation in the strain.

salt leads to various formations such as salt diapirs (vertical stringers of salt) (Poliakov et al. 1996; Schultz-Ela et al. 1993). Over the short term, salt creep can cause seals around the wells entering salt mines (Berest et al. 2001). All of these processes reflect the short-term transfer of pressure, at time frames as emphasized above, which can lead to significant groundwater flows, such as into Seneca Lake due to salt beds transferring pressure so that the driving force for flow into Seneca Lake changes (Appendix D).

The complete set of poroelastic equations that describe the interactions of pressure, strain, and stress in three dimensions along a formation is highly complex and derived in detail in Ingebritson et al. (2006). In standard groundwater analysis, pressures and flows are a function of standard hydraulic and conservation of mass equations. When stress/strain becomes important, as with the viscous properties of salt, the derivation of the equations couples the standard groundwater equations with stress/strain relations. It assumes the system is at rest, meaning the sum of forces equals zero, and the sum of stresses in all directions equals zero. The equation converts strain, or the compression or pulling of a volume, to stress. Summed, stress equals the total pressure at a location. The set of equations follows:

$$\nabla^2\hat{\sigma}_{xx} + \frac{1}{1+\vartheta}\frac{\partial^2\hat{\sigma}_{kk}}{\partial x^2} = \frac{1-2\vartheta}{1-\vartheta}\,\alpha\left[\frac{1-\vartheta}{1+\vartheta}\frac{\partial^2\hat{P}}{\partial x^2} + \nabla^2\hat{P}\right] + 2G\sigma_T[\frac{\partial^2\hat{T}}{\partial x^2} + \frac{1+\vartheta}{1-\vartheta}\nabla^2\hat{T}$$

$$\nabla^2\hat{\sigma}_{yy} + \frac{1}{1+\vartheta}\frac{\partial^2\hat{\sigma}_{kk}}{\partial y^2} = \frac{1-2\vartheta}{1-\vartheta}\,\alpha\left[\frac{1-\vartheta}{1+\vartheta}\frac{\partial^2\hat{P}}{\partial y^2} + \nabla^2\hat{P}\right] + 2G\sigma_T[\frac{\partial^2\hat{T}}{\partial y^2} + \frac{1+\vartheta}{1-\vartheta}\nabla^2\hat{T}$$

$$\nabla^2\hat{\sigma}_{zz} + \frac{1}{1+\vartheta}\frac{\partial^2\hat{\sigma}_{kk}}{\partial z^2} = \frac{1-2\vartheta}{1-\vartheta}\,\alpha\left[\frac{1-\vartheta}{1+\vartheta}\frac{\partial^2\hat{P}}{\partial z^2} + \nabla^2\hat{P}\right] + 2G\sigma_T[\frac{\partial^2\hat{T}}{\partial z^2} + \frac{1+\vartheta}{1-\vartheta}\nabla^2\hat{T}$$

$$\nabla^2\hat{\sigma}_{xy} + \frac{1}{1+\vartheta}\frac{\partial^2\hat{\sigma}_{kk}}{\partial x\partial y} = \frac{1-2\vartheta}{1-\vartheta}\,\alpha\left[\frac{\partial^2\hat{P}}{\partial x\partial y}\right] + 2G\sigma_T[\frac{\partial^2\hat{T}}{\partial x\partial y}]$$

$$\nabla^2\hat{\sigma}_{yz} + \frac{1}{1+\vartheta}\frac{\partial^2\hat{\sigma}_{kk}}{\partial y\partial z} = \frac{1-2\vartheta}{1-\vartheta}\,\alpha\left[\frac{\partial^2\hat{P}}{\partial y\partial z}\right] + 2G\sigma_T[\frac{\partial^2\hat{T}}{\partial y\partial z}]$$

$$\nabla^2\hat{\sigma}_{xz} + \frac{1}{1+\vartheta}\frac{\partial^2\hat{\sigma}_{kk}}{\partial x\partial z} = \frac{1-2\vartheta}{1-\vartheta}\,\alpha\left[\frac{\partial^2\hat{P}}{\partial x\partial z}\right] + 2G\sigma_T[\frac{\partial^2\hat{T}}{\partial x\partial z}]$$

These equations are written along the x, y, z axis although i, j, and k are the principal axes. This means that a property such as stress may not be maximum or minimum along the chosen reference coordinate system, the arbitrary x, y, and z system, but rather along a i, j, and k system. The x, y, z system may be manipulated to coincide with the i, j, and k system but the equations do not assume that to be the case. In the salt formations underlying Seneca Lake it may be that reference coordinates in the horizontal and vertical planes do not align with principal coordinates as defined by the direction of maximum stress or a formation property such as conductivity, K. The gradient operator is defined as follows:

$$\mathbf{\nabla} = {}^{i\partial}/_{\partial x} + {}^{j\partial}/_{\partial y} + {}^{k\partial}/_{\partial z}$$

This essentially means that the gradient of a property, such as σ for stress in the equation above, multiplied by the unit vector gives a vector value of the stress in its primary direction. It essentially defines the property along its direction of highest or principal value. The equations translate stress from its primary magnitude and direction to the chosen x, y, z directions. The left side of all six equations essentially defines the stress in six directions along the reference and principal access, including its value at a point and the rate that it changes in all six directions.

Values of density and viscosity vary in space and time as a function of temperature, pressure, and solute concentration. Temperature has a significant effect on the density of brine and can cause pressures in brine-filled caverns to be high enough to fracture the cavern walls (Berest et al. 2001). Density and viscosity combine with the basic properties of the medium such as permeability to determine the conductivity of a formation. Permeability is a property of the medium defined by porosity and connectivity of pores, but the medium is also changing and shifting due to both elastic and inelastic strain caused by geologic processes and also due to changes in pressure caused by the storage of LPG gas; pressure will cause the formations to strain, thereby changing their intrinsic properties. Thus, both the properties of the fluid and porous medium, the formation, are changing both spatially and temporally.

G is the shear modulus, in force per area or the same as pressure, and is a function of Young's modulus and Poisson's ratio (E and υ). E is a measure of stiffness and literally is the ratio of stress to strain for a substance and υ is a ratio of the strain normal to the applied stress to the strain parallel to the applied stress. In other words, υ defines how a material deforms due to an applied stress (Ingebritson et al. 2006, p 44).

Together the equations convert strain to stress and pressure, and allow it to be affected by temperature effects. Pressure affects the flow of fluids through the system. Although the properties depend on pressure and actual strain, it may be appropriate to assume that temperature is constant which will make part of the right side of the equation simpler. The partial differential equations are written in gradients along axes, or with distance, not with time, which indicates the changes propagate essentially immediately rather than over time.

A strain applied at a point, such as the gas reservoirs, would be felt instantaneously throughout the domain. Pressure changes caused by LPG gas and brine cycling through the caverns would be felt under the sediments under Seneca Lake instantaneously. Because the strain propagates laterally, the pressure change miles away will be a smaller proportion of that felt at the cavern; however, because the propagation of strain changes the size and shape of the pores within the medium which causes an instantaneous change in the fluid pressure, the pressure change will still be noticeable. The salt beds are probably saturated with brine having a salt concentration equal to saturation (otherwise the fluid would dissolve the salt) (Bredehoeft 1988). Goodman et al. (2011) discuss that early wells drilled to and through the salt beds encountered significant brine which indicates the salt was not dry. A change in stress on one end of the salt bed, at the cavern, could increase pressure and squeeze brine from the salt as it undergoes compressive strain. This increased stress would cause the head increase that increases the gradient driving flow through the sediments to the lake. As discussed in Appendix D, effective pressure head changes of much less than a meter are sufficient to cause significant changes in the gradient across the sediments under the lake and change the groundwater flow through the sediments by an order of magnitude or more.

The changing properties of the system however make it almost impossible to model the precise pressure shifts without making assumptions, such as isothermal conditions or no change with pressure, that could render the modeling inaccurate. *The parameter selection and modeling assumptions are too complex for the applicant to be able to conduct modeling to show that storage of LPG gas is safe.*

[redacted]

The equations presented above describe a stress/strain relationship as long as it remains elastic, which means that the strain has not gone so far as to not be irreversible—the nonlinearity mentioned in the quote above by Berest et al. (2001). Irreversible strain occurs

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[redacted]

when slip or failure occurs along a plane of weakness. It could be as major as an earthquake or as minor as slow motion diapir formation; a diapir is an intrusion in which a mobile or ductily deformable material is forced into more brittle, or stiffer, overlying bedrock. Salt is one of the most deformable geologic materials in the natural world. Salt flows like a very viscous liquid when pressure is applied to it. This viscoelastic flow is described by the equations above. Salt diapirs are vertical stringers of salt that form in overlying bedrock formations (Poliakov et al. 1996; Schultz-Ela et al. 1993).

In geologic time scales, a salt bed may come under increasing stress due to the accumulation of sediments above it. This increasing stress squeezes the salt until it flows viscoelastically. If constrained in one direction, the flow will find a path of less resistance, such as through vertical fractures, and cause vertical stringers of salt (Poliakov et al. 1996). Existing diapirs could be a source of salt to the sediments under Seneca Lake south of the point where the valley intersects the Syracuse formation (Appendix D). Strains caused by LPG storage, as described above, will cause pressures in any existing diapirs and cause salt to discharge into the lake or sediments above. This process is not expected to be as significant a process as the large-scale advection across the sediments (Appendix C), but it could still cause salt to reach the lake at a time simultaneous to the additional salt advection from the groundwater.

Viscoelastic relations between groundwater and the media it flows through also help to explain many observations of groundwater flow and pressure observed on a much shorter term. The time frame and spatial scale of these observations supports the conclusion that viscoelastic relations between the salt caverns and sediments beneath Seneca Lake can cause significant fluxes of groundwater and salt to reach the lake.

Examples of short-term natural viscoelastic flow are earth tides, seismic activity, or earthquakes at a distance causing pressure fluctuations, strain exerted by pumping confined aquifers on the confining layers, and barometric pressure changes. Earth tides are strains induced on the earth's crust that cause significant changes in pore pressures, and well water levels, by gravitational pull of the moon and sun (Hsieh et al. 1988, Bredehoeft 1967). Earth tides also affect the discharge from springs. At a hot spring in Japan, Kitagawa and Koizumi (2000) found that discharge varied cyclically by about seven percent once they controlled for atmospheric pressure and seismic changes.

Pumping wells cause strain that can have unusual effects on water levels in piezometers of the confining layers. As the hydrostatic pressure in a confined aquifer decreased due to pumping, water levels in the clay confining layers increased, contrary to expectation of standard well hydraulics (Wolff 1970a and b). Pumping the aquifer essentially pulled the clay toward the well, thereby squeezing it which increased the pore pressure and causing the pressure in the clay to increase (Wolff 1970a). Within six and ninety seconds of the commencement of pumping, water levels half a meter within the clay had increased by 10 and 25 centimeters, respectively (Wolff 1970a). After 18 days, the changes began to approximate that expected from standard groundwater relations (Wolff 1970b). Gambolati et al. (2000) also found that pumping from a confined aquifer pulled the confining layers causing strain and temporarily increasing pressures, contrary to that expect from standard well hydraulics.

Jha and Juane (2014) manipulated the equations of poroelastic flow to simulate pressures in a simplified horizontal formation similar to what exists beneath Seneca Lake. They derived a numerical and analytical solution to the equations. Their simulation shows that initially pressure transmits along the entire length. During the short-term, the pressure at the bottom of the section exceeds that applied at the boundary while the applied pressure dissipates at an upper steady boundary condition; at Seneca Lake, pressure would be applied at the boundary that intersects the cavern and the upper boundary would be the base of the sediments where the pressure is hydrostatic based on the lake level above it. Initially, the upper gradient is higher and with time it dissipates. Jha and Juane (2014) did not simulate flow, but the pressure simulations are similar to those expected at Seneca Lake to potentially drive upward flow across the sediments. They also ran simulations of the effects that groundwater pumping have on faults, showing that pumping can change pressures and strain which could activate historic faults (Jha and Juane 2014); if the pressure changes caused by storing LPG gas encounter faults, which are prevalent in the area (Jacobi 2002), the faults could be activated which could cause earthquakes or allow fluid transport.

Beavan et al. (1991) used barometric and tidal fluctuations in well water levels to estimate aquifer parameters, assuming there is no flow occurring in the formation of interest. Evans et al. (1991) used water level data driven by earth tides and barometric pressure to estimate regional-scale permeability and elasticity parameters; the scale of their work was similar to the scale at Seneca Lake, indicating that the forcing at the proposed salt cavern storage will propagate pressure changes into Seneca Lake. Also, this suggests it is possible to use field data to estimate parameters at Seneca Lake, if one assumes no flow enters the salt at the caverns, or to ignore it if there is leakage (Beavan et al. 1991). However, there are no wells measuring water levels in the salt formations at Seneca Lake, so the data is not readily available.

Lin et al (2004) found that viscoelastic equations best explained the dissipation of the fluctuation in water levels in an alluvial fan resulting from earthquakes. The initial water level changes were as high as 10 meters while the observed strains were less than 0.5 meters due to the earthquake. The modeling simulated pulses among the bedrock, sand and gravel formations, including the transmission of pressure across a bedrock/sediments boundary, as at

Seneca Lake. The simulation was possible because the alluvial aquifer had an extensive alluvial monitoring system which does not exist at Seneca Lake or anywhere else in salt bed formations.

Conversely, Gambolati et al. (2000) found that, except for initially in the confining layers, simulating the strain/pressure effects of pumping in alluvial partially confined aquifers was just as accurate with uncoupled equations; uncoupled means that standard hydraulic calculations were used to simulate pressures and changing aquifer shapes were simulated based on those pressures rather than including each in the same set of equations as is done by the viscoelastic approach. The primary reason is that the aquifer is highly heterogeneous which leads to significant dampening of pressure waves among the different lithologies (among gravel, sand, silt and clay). The salt formations beneath Seneca Lake are relatively homogeneous, at least from a lithologic perspective, so the coupling of processes as represented by the viscoelastic equations is necessary to estimate the change in pressures beneath the sediments under Seneca Lake.

In summary, this appendix describes some of the mathematics that would be necessary to model the potential for pressure-related strain to cause pressure changes under Seneca Lake. The transfer of pressure from the proposed LPG storage to sediments beneath Seneca Lake has the potential to cause massive inflows of salt to the lake, as it did during the late 1960s. The mechanics of this are extremely complex, and the data needed to analyze the expected quantities of salt that can be discharged by these changes in pressure is not available. Even if additional data is collected it would likely be at a small scale and only valid at a single time and a single location for a given pressure and temperature. The assumptions necessary to model the salt discharge potential would render the results highly inaccurate at predicting salt discharges at other locations, pressures and temperatures. Data collection and modeling cannot be used to obtain assurances that such discharges are not possible.

APPENDIX G

DESCRIPTION OF FINGER LAKES' PROPOSED PROJECT AND APPLICATION

APPENDIX G: DESCRIPTION OF FINGER LAKES' PROPOSED PROJECT AND APPLICATION

FLLPG proposes to convert Gallery 1 and Gallery 2 to LPG storage, similar to what was done in the 1960s. A cross-section of Gallery 2 is shown in Figure E3 in Appendix E (along with a number of caverns not proposed for LPG storage).[1] LPG will be added to the top of the galleries while brine is removed from the bottom. Because of the density differences, there will be a line of separation (interface) between the brine and LPG in the galleries that moves up and down. There is uncertainty in the rate that the interface moves up and down depending on the exact cross-section of the gallery (it varies with time) and the amount of rubble on the gallery floor. The TDS concentration in the brine ranges from 31,100 to 417,000 mg/l (NYSDEC 2011).[2] Brine that is pumped to the surface will be stored in two large brine ponds. LPG is recovered by pumping brine to the bottom of the cavern while LPG is withdrawn from the top.

[redacted]

[redacted]

The draft permit states that Galleries 1 and 2 will store a maximum of 1,500,000 and 600,000 barrels.[7] [redacted]

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[1] August 2014 Gallery Map and Section (2000-00-01-16-R9 SECTION 8-28-14 INERGY SECT A-A' FINGERLAKES).
[2] SEQR Documents (Final DSEIS Text).
[redacted]
[7] Draft permit conditions at Attachment 1 ¶ 1.d.
[redacted]

[redacted]

For consideration of pressure transfer along the formations, [redacted] is accurate as a description of the pressure change that occurs at the point the formations intersect with the caverns.

[redacted]

[redacted]

APPENDIX H

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APPENDIX H: References

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APPENDIX I

CURRICULUM VITAE OF TOM MYERS

Tom Myers, Ph.D.
Consultant, Hydrology and Water Resources
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Curriculum Vitae

Objective: To provide diverse research and consulting services to nonprofit, government, legal and industry clients focusing on hydrogeology specializing in mine dewatering, contaminant transport, natural gas development, groundwater modeling, NEPA analysis, federal and state regulatory review, and fluvial morphology.

Education

Years	Degree	University
1992-96	Ph.D. Hydrology/Hydrogeology	University of Nevada, Reno Dissertation: Stochastic Structure of Rangeland Streams
1990-92		University of Arizona, Tucson AZ Classes in pursuit of Ph.D. in Hydrology.
1988-90	M.S. Hydrology/Hydrogeology	University of Nevada, Reno Thesis: Stream Morphology, Stability and Habitat in Northern Nevada
1981-83		University of Colorado, Denver, CO Graduate level water resources engineering classes.
1977-81	B.S., Civil Engineering	University of Colorado, Boulder, CO

Professional Experience

Years	Position	Duties
1993- Pr.	Hydrologic Consultant	Completion of hydrogeology studies and testimony focusing on mine dewatering, groundwater modeling, natural gas development, contaminant transport, NEPA review, and water rights for nonprofit groups and government agencies.
1999- 2004	Great Basin Mine Watch, Exec Director	Responsible for reviewing and commenting on mining projects with a focus on groundwater and surface water resources, preparing appeals and litigation, organizational development and personnel management.
1992- 1997	Univ of NV, Reno, Res. Assoc.	Research on riparian area and watershed management including stream morphology, aquatic habitat, cattle grazing and low-flow and flood hydrology.
1990- 1992	U of AZ, Res. and Teach. Assistant	Research on rainfall/runoff processes and climate models. Taught lab sections for sophomore level "Principles of Hydrology". Received 1992 Outstanding Graduate Teaching Assistant Award in the College of Engineering
1988- 1990	U of NV, Reno Res. Asst	Research on aquatic habitat, stream morphology and livestock management.
1983- 1988	US Bureau of Reclamation Hydraulic Eng.	Performed hydrology planning studies on topics including floodplains, water supply, flood control, salt balance, irrigation efficiencies, sediment transport, rainfall-runoff modeling and groundwater balances.

Peer-Reviewed Publications

Myers, T., 2013. Remediation scenarios for selenium contamination, Blackfoot Watershed, southeast Idaho, USA. *Hydrogeology*. DOI 10.1007/s10040-013-0953-8.

Myers, T., 2013. Reservoir loss rates from Lake Powell and their impact on management of the Colorado River. *Journal of the American Water Resources Association*. DOI: 10.1111/jawr.12081.

Myers, T., 2012. Potential contaminant pathways from hydraulically fractured shale to aquifers. *Ground Water* 50(6): 872-882. doi: 10.1111/j.1745-6584.2012.00933.x.

Myers, T., 2009. Groundwater management and coal-bed methane development in the Powder River Basin of Montana. *J Hydrology* 368:178-193.

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Myers, T.J. and S. Swanson, 1995. Impact of deferred rotation grazing on stream characteristics in Central Nevada: A case study. *North American Journal of Fisheries Management* 15:428-439.

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Myers, T.J. and S. Swanson, 1992. Aquatic habitat condition index, stream type, and livestock bank damage in northern Nevada. *Water Resources Bulletin* 27:667-677.

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Representative Reports and Projects

Myers, T., 2014. Expert Report: In the Matter of California Department of Parks and Recreation v. Newmont Mining Corporation, et al. Prepared for the California Department of Justice, February 2014.

Myers, T., 2014. Groundwater Flow and Transport Modeling, NorthMet Mine and Plant Site. Prepared for the Minnesota Center for Environmental Advocacy.

Myers, T., 2014. Review of the Water Quality Modeling, NorthMet Mine and Plant Site, Minnesota. Prepared for Minnesota Center for Environmental Advocacy.

Myers, T., 2014. Technical Memorandum: Review of the Hydrogeologic Aspects of the Draft Environmental Impact Statement, Haile Gold Mine, Lancaster County, South Carolina. Prepared for Southern Environmental Law Center, May 8, 2014.

Myers, T., 2014. Technical Memorandum: Review of the Supplemental Draft Environmental Impact Statement, NorthMet Mining Project and Land Exchange. Prepared for Minnesota Center for Environmental Advocacy. March 10, 2014.

Myers, T., 2014. Technical Memorandum: Twin Metals and the Boundary Waters Canoe Area Wilderness, Risk Assessment for Underground Metals Mining. Prepared for Northeastern Minnesotans for Wilderness. August 8, 2014.

Myers, T., 2012-3. Participation in EPA Potential Impacts of Hydraulic Fracturing on Drinking Water Resources Study. US Environmental Protection Agency, Washington DC.

Myers, T., 2013. DRAFT: Chapter 5.1: Water Quality. Initiative for Responsible Mining.

Myers, T., 2013. DRAFT: Chapter 5.2: Water Quantity. Initiative for Responsible Mining.

Myers, T., 2013. Technical Memorandum: Comments on Encana Oil and Gas Inc.'s Application for the Madison Aquifer to be Exempt Wyoming Oil and Gas Conservation Commission Docket No. 3-2013. Prepared for Natural Resources Defense Council, Powder River Basin Council. June 12, 2013.

Myers, T., 2013. Technical Memorandum: Impact Analysis: Wishbone Hill Water Right Application. Prepared for Trustees for Alaska.

Myers, T., 2013. Technical Memorandum: Review of Montanore Mine Dewatering Instream Flow Methodology. Prepared for Save our Cabinets, Earthworks. March 26, 2013.

Myers, T., 2012. Technical Memorandum: Chuitna Coal Mine Project, Review of Arcadis DRAFT Hydrogeologic Conceptual Site Model Update and Associated Documents. Prepared for Cook Inletkeeper. May 11, 2012.

Myers, T., 2012. Technical Memorandum, Review of DRAFT: Investigation of Ground Water Contamination near Pavillion Wyoming Prepared by the Environmental Protection Agency, Ada OK. April 19, 2012.

Myers, T., 2012. Participation in: Keystone Center Independent Science Panel, Pebble Mine. Anchorage AK, October 1–5, 2012.

Myers, T., 2012. Technical Memorandum, Review and Analysis, Revised Draft, Supplemental Generic Environmental Impact Statement on the Oil, Gas and Solution Mining Regulatory Program, Well Permit Issuance for Horizontal Drilling and High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and Other Low-Permeability Gas Reservoirs. Prepared for Natural Resources Defense Council.

Myers, T., 2012. Technical Memorandum, Review of the Special Use Permit PP2011-035-Camilletti 21-10, Groundwater Monitoring Requirements. Prepared for Routt County Board of Commissioners and the Routt County Planning Department. June 19, 2012.

Myers, T., 2012. Testimony at Aquifer Protection Permit Appeal Hearing, Rosemont Mine. Phoenix AZ, August and September, 2012.

Myers, T., 2012. Drawdown at U.S. Forest Service Selected Monitoring Points, Myers Rosemont Groundwater Model Report. Prepared for Pima County, AZ. March 22, 2012.

Myers, T., 2011. Baseflow Conditions in the Chuitna River and Watersheds 2002, 2003, and 2004 and the Suitability of the Area for Surface Coal Mining. January 14, 2011.

Myers, T., 2011. Hydrogeology of Cave, Dry Lake and Delamar Valleys, Impacts of pumping underground water right applications #53987 through 53092. Presented to the Office of the Nevada State Engineer On behalf of Great Basin Water Network.

Myers, T., 2011. Hydrogeology of Spring Valley and Surrounding Areas, Part A: Conceptual Flow Model. Presented to the Nevada State Engineer on behalf of Great Basin Water Network and the Confederated Tribes of the Goshute Reservation.

Myers, T., 2011. Hydrogeology of Spring Valley and Surrounding Areas, Part B: Groundwater Model of Snake Valley and Surrounding Area. Presented to the Nevada State Engineer on behalf of Great Basin Water Network and the Confederated Tribes of the Goshute Reservation.

Myers, T., 2011. Hydrogeology of Spring Valley and Surrounding Areas, PART C: IMPACTS OF PUMPING UNDERGROUND WATER RIGHT APPLICATIONS #54003 THROUGH 54021. Presented to the Nevada State Engineer on behalf of Great Basin Water Network and the Confederated Tribes of the Goshute Reservation.

Myers, T., 2011. Rebuttal Report: Part 2, Review of Groundwater Model Submitted by Southern Nevada Authority and Comparison with the Myers Model. Presented to the Nevada State Engineer on behalf of Great Basin Water Network and the Confederated Tribes of the Goshute Reservation.

Myers, T., 2011. Rebuttal Report: Part 3, Prediction of Impacts Caused by Southern Nevada Water Authority Pumping Groundwater From Distributed Pumping Options for Spring Valley, Cave Valley, Dry Lake Valley, and Delamar Valley. Presented to the Nevada State Engineer on behalf of Great Basin Water Network and the Confederated Tribes of the Goshute Reservation.

Myers, T., 2011. Baseflow Selenium Transport from Phosphate Mines in the Blackfoot River Watershed Through the Wells Formation to the Blackfoot River, Prepared for the Greater Yellowstone Coalition.

Myers, T., 2011. Blackfoot River Watershed, Groundwater Selenium Loading and Remediation. Prepared for the Greater Yellowstone Coalition.

Myers, T., 2011. Technical Memorandum Review of the Proposed Montanore Mine Supplemental Draft Environmental Impact Statement and Supporting Groundwater Models.

Myers, T., 2010. Planning the Colorado River in a Changing Climate, Colorado River Simulation System (CRSS) Reservoir Loss Rates in Lakes Powell and Mead and their Use in CRSS. Prepared for Glen Canyon Institute.

Myers, T., 2010. Technical Memorandum, Updated Groundwater Modeling Report, Proposed Rosemont Open Pit Mining Project. Prepared for Pima County and Pima County Regional Flood Control District.

Myers, T., 2009. Monitoring Groundwater Quality Near Unconventional Methane Gas Development Projects, A Primer for Residents Concerned about Their Water. Prepared for Natural Resources Defense Council. New York, New York.

Myers, T., 2009. Technical Memorandum, Review and Analysis of the Hydrology and Groundwater and Contaminant Transport Modeling of the Draft Environmental Impact Statement Blackfoot Bridge Mine, July 2009. Prepared for Greater Yellowstone Coalition, Idaho Falls, Idaho.

Myers, T., 2008. Hydrogeology of the Carbonate Aquifer System, Nevada and Utah With Emphasize on Regional Springs and Impacts of Water Rights Development. Prepared for: Defenders of Wildlife, Washington, D.C.. June 1, 2008.

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Myers, T., 2008. Hydrogeology of the Santa Rita Rosemont Project Site, Numerical Groundwater Modeling of the Conceptual Flow Model and Effects of the Construction of the Proposed Open Pit, April 2008. Prepared for: Pima County Regional Flood Control District, Tucson AZ.

Myers, T., 2008. Technical Memorandum, Review, Record of Decision, Environmental Impact Statement Smoky Canyon Mine, Panels F&G, U.S. Department of the Interior, Bureau of Land Management. Prepared for Natural Resources Defense Council, San Francisco, CA and Greater Yellowstone Coalition, Idaho Falls, ID. Reno NV.

Myers, T., 2007. Groundwater Flow and Contaminant Transport at the Smoky Canyon Mine, Proposed Panels F and G. Prepared for Natural Resources Defense Council, San Francisco, CA and Greater Yellowstone Coalition, Idaho Falls, ID. Reno NV. December 11, 2007.

Myers, T., 2007. Hydrogeology, Groundwater Flow and Contaminant Transport at the Smoky Canyon Mine, Documentation of a Groundwater Flow and Contaminant Transport Model. Prepared for Natural Resources Defense Council, San Francisco, CA and Greater Yellowstone Coalition, Idaho Falls, ID. Reno NV, December 7, 2007.

Myers, T., 2007. Review of Hydrogeology and Water Resources for the Final Environmental Impact Statement, Smoky Canyon Mine, Panels F and G and Supporting Documents. Prepared for Natural Resources Defense Council, San Francisco, CA and Greater Yellowstone Coalition, Idaho Falls, ID. Reno, NV. December 12, 2007.

Myers, T., 2007. Hydrogeology of the Powder River Basin of Southeast Montana Development of a Three-Dimensional Groundwater Flow Model. Prepared for Northern Plains Resource Council. February 12, 2007.

Myers, T., 2007. Hydrogeology of the Santa Rita Rosemont Project Site, Conceptual Flow Model and Water Balance, Prepared for: Pima County Flood Control District, Tucson AZ.

Myers, T., 2006. Review of Mine Dewatering on the Carlin Trend, Predictions and Reality. Prepared for Great Basin Mine Watch, Reno, NV.

Myers, T., 2006. Hydrogeology of Spring Valley and Effects of Groundwater Development Proposed by the Southern Nevada Water Authority, White Pine and Lincoln County, Nevada. Prepared for Western Environmental Law Center for Water Rights Protest Hearing.

Myers, T., 2006. Potential Effects of Coal Bed Methane Development on Water Levels, Wells and Springs of the Pinnacle Gas Resource, Dietz Project In the Powder River Basin of Southeast Montana. Affidavit prepared for Northern Plains Resource Council, April 4, 2006.

Myers, T., 2006. Review of Hydrogeology and Water Resources for the Draft Environmental Impact Statement, Smoky Canyon Mine, Panels F and G, Technical Report 2006-01-Smoky Canyon. Prepared for Natural Resources Defense Council.

Myers, T., 2006. Review of Nestle Waters North America Inc. Water Bottling Project Draft Environmental Impact Report / Environmental Assessment. Prepared for McCloud Watershed Council, McCloud CA.

Myers, T., 2005. Hydrology Report Regarding Potential Effects of Southern Nevada Water Authority's Proposed Change in the Point of Diversion of Water Rights from Tikapoo Valley South and Three Lakes Valley North to Three Lakes Valley South. Prepared for Western Environmental Law Center for Water Rights Protest Hearing.

Myers, T., 2005. Review of Draft Supplemental Environmental Impact Statement, Ruby Hill Mine Expansion: East Archimedes Project NV063-EIS04-34, Technical Report 2005-05-GBMW. Prepared for Great Basin Mine Watch.

Myers, T., 2005. Hydrogeology of the Powder River Basin of Southeast Montana, Development of a Three-Dimensional Groundwater Flow Model. Prepared for Northern Plains Resource Council, Billings, MT in support of pending litigation.

Myers, T., 2005. Nevada State Environmental Commission Appeal Hearing, Water Pollution Control Permit Renewal NEV0087001, Big Springs Mine. Prepared for Great Basin Mine Watch, Reno NV.

Myers, T., 2005. Potential Effects of Coal Bed Methane Development on Water Levels, Wells and Springs In the Powder River Basin of Southeast Montana. Prepared for Northern Plains Resource Council, Billings, MT.

Myers, T., 2004. An Assessment of Contaminant Transport, Sunset Hills Subdivision and the Anaconda Yerington Copper Mine, Technical Report 2004-01-GBMW. Prepared for Great Basin Mine Watch.

Myers, T., 2004. Technical Memorandum: Pipeline Infiltration Project Groundwater Contamination. Prepared for Great Basin Mine Watch.

Myers, T., 2004. Technical Report Seepage From Waste Rock Dump to Surface Water The Jerritt Canyon Mine, Technical Report 2004-03-GBMW. Prepared for Great Basin Mine Watch.

Myers, T., 2001. An Assessment of Diversions and Water Rights: Smith and Mason Valleys, NV. Prepared for the Bureau of Land Management, Carson City, NV.

Myers, T., 2001. Hydrogeology of the Basin Fill Aquifer in Mason Valley, Nevada: Effects of Water Rights Transfers. Prepared for the Bureau of Land Management, Carson City, NV.

Myers, T., 2001. Hydrology and Water Balance, Smith Valley, NV: Impacts of Water Rights Transfers. Prepared for the Bureau of Land Management, Carson City, NV.

Myers, T., 2000. Alternative Modeling of the Gold Quarry Mine, Documentation of the Model, Comparison of Mitigation Scenarios, and Analysis of Assumptions. Prepared for Great Basin Mine Watch. Center for Science in Public Participation, Bozeman MT.

Myers, T., 2000. Environmental and Economic Impacts of Mining in Eureka County. Prepared for the Dept. Of Applied Statistics and Economics, University of Nevada, Reno.

Myers, T., 1999. Water Balance of Lake Powell, An Assessment of Groundwater Seepage and Evaporation. Prepared for the Glen Canyon Institute, Salt Lake City, UT.

Myers, T., 1998. Hydrogeology of the Humboldt River: Impacts of Open-pit Mine Dewatering and Pit Lake Formation. Prepared for Great Basin Mine Watch, Reno, NV.

Selected Abstracts, Magazine and Proceedings Articles

Myers, T., 2014. Reservoir Loss Rates, Lakes Mead and Powell and Fill Mead First. INVITED PRESENTATION at 2014 Future of the Colorado Plateau Forum – Drought and the Colorado River. http://musnaz.org/educational-programs/public-programs/future-of-the-colorado-plateau-forums/.

Myers, T., 2013. Three-dimensional Groundwater and Contaminant Flow around Marcellus Gas Development. INVITED PRESENTATION at 2013 Associated Engineering Geologists Conference, Seattle WA.

Myers, T., 2012. Mine Dewatering: Humboldt River Update. INVITED PRESENTATION at 2012 Nevada Water Resources Association Annual Conference.

Myers, T., 2012. Reservoir loss rates from Lake Powell, and long-term management of the Colorado River system. 2012 Nevada Water Resources Association Annual Conference.

Myers, T., 2011. Reservoir loss rates from Lake Powell, and long-term management of the Colorado River system. 2011 Fall Conference, American Geophysical Union.

Myers, T., 2006. Modeling Coal Bed Methane Well Pumpage with a MODFLOW DRAIN Boundary. In MODFLOW and More 2006 Managing Ground Water Systems, Proceedings. International Groundwater Modeling Center, Golden CO. May 21-24, 2006.

Myers, T., 2006. Proceed Carefully: Much Remains Unknown, *Southwest Hydrology 5(3)*, May/June 2006, pages 14-16.

Myers, T., 2004. Monitoring Well Screening and the Determination of Groundwater Degradation, Annual Meeting of the Nevada Water Resources Association, Mesquite, NV. February 27-28, 2004.

Myers, T., 2001. Impacts of the conceptual model of mine dewatering pumpage on predicted fluxes and drawdown. In MODFLOW 2001 and Other Modeling Odysseys, Proceedings, Volume 1. September 11-14, 2001. International Ground Water Modeling Center, Golden, Colorado.

Myers, T., 1997. Groundwater management implications of open-pit mine dewatering in northern Nevada. In Kendall, D.R. (ed.), Conjunctive Use of Water Resources: Aquifer Storage and Recovery. AWRA Symposium, Long Beach California. October 19-23, 1997.

Myers, T., 1997. Groundwater management implications of open-pit mine dewatering in northern Nevada. In Life in a Closed Basin, Nevada Water Resources Association, October 8-10, 1997, Elko, NV.

Myers, T., 1997. Uncertainties in the hydrologic modeling of pit lake refill. American Chemical Society Annual Meeting, Las Vegas, NV, Sept. 8-12, 1997.

Myers, T., 1997. Use of groundwater modeling and geographic information systems in water marketing. In Warwick, J.J. (ed.), Water Resources Education, Training, and Practice: Opportunities for the Next Century. AWRA Symposium, Keystone, Colo. June 29-July 3, 1997.

Myers, T., 1995. Decreased surface water flows due to alluvial pumping in the Walker River valley. Annual Meeting of the Nevada Water Resources Association, Reno, NV, March 14-15, 1995.

Special Coursework

Years	Course	Sponsor
2011	Hydraulic Fracturing of the Marcellus Shale	National Groundwater Association
2008	Fractured Rock Analysis	MidWest Geoscience
2005	Groundwater Sampling Field Course	Nielson Environmental Field School
2004	Environmental Forensics	National Groundwater Association
2004 and -5	Groundwater and Environmental Law	National Groundwater Association