A: Very low likelihood (or has rarely occurred in industry)—for example, twice in sixty years among an average of 30 UGS facilities = 2/60/30 < 0.1% /year or < 2.5% /25 years.

B: Low likelihood (or happens several times per year in industry)—for example, four times a year among current 40 UGS facilities = 4/40 = 0.1-1% /year or 2.5-25% /25 years.

C: Medium likelihood (or has occurred in operating company)—for example, once or twice in ten to 20 years = 5-20%/year or many times in 25 years.

No hazard events were scored higher than medium likelihood over 25 years.

C. EXPOSURE INTERVAL
While cumulative risk is a function of time, choice of a particular exposure interval for reporting is somewhat discretionary. In this report, an exposure interval of twenty-five years was chosen because (a) it is expected that the community likely will be subject to the various risks described for at least twenty-five years, (b) use of the caverns in question has changed and may continue to change over time, (c) the expected life of the LPG storage facility may be longer than 25 years but I wanted to use a relatively conservative time estimate for this analysis; and (d) risks may be more likely to change over longer intervals.

D. ACCEPTANCE CRITERIA
Standard community health acceptance criteria as shown in the figures were used:

<table>
<thead>
<tr>
<th>Likelihood</th>
<th>Extremely Serious</th>
<th>Serious</th>
<th>Moderate</th>
<th>Minor</th>
<th>Very Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colour</td>
<td>Red</td>
<td>Yellow</td>
<td>Green</td>
<td>White</td>
<td>Red</td>
</tr>
<tr>
<td>Description</td>
<td>Unacceptable risk, measures must be taken to reduce the risk.</td>
<td>Assessment range, measures must be considered.</td>
<td>Acceptable risk, measures can be considered based on other considerations.</td>
<td>Probability of occurrence is low.</td>
<td></td>
</tr>
</tbody>
</table>

For example, using such criteria Schuyler County would accept the risk of an extremely serious event, (such as happened in Hutchinson, Kansas, with deaths, injuries, and long-term evacuations) if the 25-year risk is less than 2.5%, but not if it were as much as 25%.
ATTACHMENT 3
On January 17, 2001, a gas explosion and fire destroyed two businesses in downtown Hutchinson in central Kansas. The next day in the Big Chief mobile home park 3 miles away another explosion occurred and 2 residents died of injuries received. The explosions were tied to geysers spewing gas and water, and their appearance caused the excavation of hundreds of Hutchinson residents.

The January 17–18, 2001 eruptions of gas and brine, driving 30-ft geysers in the town, resulted from the loss of 3.5 Mcf of gas from the Yaggy natural gas storage facility located 7 miles down the road from the town community of 40,000 people.

The Yaggy field of salt caverns was originally developed in the early 1980s to hold propane. Because the company had difficulty making a financial success of the operation, the storage wells were filled with brine and then plugged by partially filling them with concrete. However, a second company acquired the facility in the early 1990s, converted it to natural gas storage, and the plugged wells were drilled out to return the caverns to use.

It is thought that cavern over-pressurization cause rupture through a previously undocumented area of damage to a well casing. The route followed to the surface by the escaping gas is
thought to be a fractured shale layer that facilitated drainage to the crest of the anticlinal culmination that underlies the town of Hutchinson, where gas escape to the surface via old unplugged brine wells:

Like Seneca Lake, the Hutchinson region had been an area of solution mining since the late 1800s with numerous unplugged brine wells, long ago drilled and abandoned without appropriate documentation. Likewise, it has a mix of bedded salt and permeable rock formations with natural dissolution irregularities similar to those in Seneca County, which facilitated the escape of gas to the surface and the subsequent fires, explosions, deaths, injuries, and evacuation.

(from Evans, 2008 and Warren, 2006)
ATTACHMENT #2
Exhibit 1

Cavern Integrity Report
H. C. Clark, Ph.D.
Cavern Integrity Analysis
Finger Lakes LPG Storage, LLC

January 15, 2015

H.C. Clark, Ph.D.
I. Introduction

Finger Lakes LPG Storage, LLC (FLLPG) has applied for a permit to store liquid petroleum gas (LPG) in two underground galleries—known as Gallery 1 and Gallery 2—in the Watkins Glen Brine Field along the west side of Seneca Lake.\(^1\) I was asked to prepare this technical report analyzing whether there are any risks to the integrity of the caverns proposed for LPG storage that are not addressed by FLLPG’s application materials or the draft permit conditions published by the New York State Department of Environmental Protection (DEC) in connection with this project. In my opinion, there are serious questions remaining about the solution-mined salt caverns in this area and their future integrity, and the data gaps are serious enough to warrant denial of the permit. Moreover, even if sufficient new studies are performed to supply the missing information, and the application materials are revised to provide a comprehensive and accurate picture of the caverns and their geological context, it will be impossible to respond in a timely and effective way to any problems that may develop, unless significant additional conditions are included in the permit.

My report examines the geology of the area and its solution-mined caverns, with special focus on Galleries 1 and 2, the caverns bordering Galleries 1 and 2 on the south and north, and the high-angle strike-slip (tear) fault along the eastern boundary of the project. A thorough understanding of the surrounding geology is critical because that geology will be the container for LPG, and the caverns were not simply hollowed from a homogeneous and isotropic mass (that is, a uniform material with the same properties in all directions). The geology where these caverns have been dissolved has been folded, thrust faulted, and cut by vertical faults, leaving a complex geology that has controlled the development of the Watkins Glen Brine Field. The development, shape, and behavior of the caverns are, in large part, a product of that geology, acting over the history of each cavern, and for most of them, it’s a very long history.

Questions about how this geology is involved with the caverns of the Watkins Glen Brine Field are important because problems involving salt storage caverns, wells, and mines have been documented over many years.\(^2\) Examples of such problems in both bedded salt formations and domal salt include:

- Mid-1990s collapse of the Retsof, NY, bedded salt room and pillar mine, where a 500-foot-by-500-foot block of ceiling fell, leading to the flooding and closure of the mine.
- Yaggy bedded salt storage cavern leak and 2001 fire at Hutchinson, KS.
- Salt mine collapse in 1974 forming the 300-foot-diameter Cargill Sink at the Hutchinson, KS, bedded salt mine.

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1 “The Watkins Glen brine field, located in Schuyler County, is in the south central part of New York State, along the west shore of Lake Seneca . . . . It is approximately four miles north of the Village of Watkins Glen.” (Jacoby, 1962: 506) As used in this report, the “Watkins Glen Brine Field” or “Watkins Glen” refers to that area, including the wells and galleries in the Town of Reading that FLLPG proposes to use for LPG storage.

2 Reports of these and other problems follow the list of references at the end of this report.
- Explosion at Mt. Belvieu, TX, when stored LPG leaked from salt dome through corroded well casing, then to town sewer system.

- Ongoing collapse of Oxy3 Cavern at Bayou Corne, Louisiana, where a solution mined cavern in the Napoleonville Salt Dome has breached the salt wall, and subsequent collapse has chimneyed to the surface, creating a sinkhole that continues to expand.

Although the caverns listed above do not represent precise analogues of the FLLPG Galleries, the history should remind us that accidents do happen, and when they do, they can be very serious. No two caverns are exactly alike, if only because the local geology is different, and each requires careful study, controlled solutioning, and meaningful and frequent monitoring—to avoid the problems of these examples.

The basic question presented by FLLPG's application is whether or not there is adequate evidence of long-term cavern integrity—so DEC and the public can have confidence that problems encountered elsewhere will not happen at Seneca Lake—and the answer is no. The evidence is inadequate because much of the information that a geologist would ordinarily expect to find about the surrounding geology and features of the caverns is missing, incomplete, or incorrect. Moreover, the information that is available indicates that Galleries 1 and 2 and surrounding caverns—some more than half a century old—show effects of age and anomalies suggesting that long-term integrity may not be possible.

Documents supporting FLLPG's application for the underground storage permit were heavily redacted before public release, so public information about the site area is available largely from published articles and an application released by the New York State Electric Gas Corporation (NYSEG) for compressed air energy storage (CAES) nearby. That information was enough to raise a number of preliminary questions about the project, but it was not enough to answer them.

To summarize the critical issues I identify:

- A professional geologist assessing the integrity of solution-mined salt caverns proposed for hydrocarbon storage will begin with the applicant's maps and cross-sections, which are supposed to depict the geology of the area, including stratigraphy and faults, as well as the extent, contours, and developmental history of the caverns. Comprehensive and accurate maps and cross-sections serve three crucial functions: (1) they allow analysts to flag issues that may become serious problems; (2) they help to identify where additional study or monitoring is needed; and (3) they expedite response when something goes wrong, by enabling analysts to understand quickly what happened and what corrective action is needed. FLLPG's application lacks the comprehensive and detailed maps and cross-sections that provide the framework for an adequate assessment of cavern integrity.
Some readily available and relevant data (for example, from publications by Charles Jacoby, the geologist who developed these caverns) is missing and some of the visually displayed information is incorrect. When the omissions are cured, and the mistakes are corrected, the need for further study is immediately apparent. The map and cross-sections should be supplemented with the results of additional studies I identify below as well as known sources of information, both published and from company files evidently available to FLLPG. Cavern integrity analysts should not have to comb through thousands of pages of application materials—as I have had to do—to piece together a comprehensive picture of the geology and storage cavities. It is dangerous and irresponsible not to have the resource readily available, if a problem develops in the future.

For example, there are zones or planes of weakness in the walls and roofs of these caverns—such as thrust faults, fractures, and high-angle strike-slip faults—that are not shown on the maps and cross-sections. Some of these faults served as pathways for communication between wells in the past or for accidental transmission of fluids to the surface, and some have been linked to roof collapse. FLLPG insinuates that the documented Jacoby-Dellwig Fault does not exist or is sealed. Full studies of faults and fractures should be required, all such zones of weakness should be evaluated as potential pathways for communication, and the complete results of that analysis should be described and portrayed graphically in revised application materials, including in a monitoring plan.

The caverns of the Watkins Glen Brine Field have grown outward and upward, and this growth will continue. Outward cavern growth may lead to communication with nearby caverns or fault zones. Upward growth may lead to partial roof failure or complete collapse—as is evident from the rubble piles in the caverns of the Watkins Glen Brine Field. Sonars from 2009 and 2011 show that the roof of FLLPG Gallery 2 (Cavern 58)—which previously was abandoned because of a prior collapse—has reached the Camillus shale, appears to be sinking at the center, and may be unstable. This uncontrolled growth is partially depicted in the limited sonar slices shown on the cross-sections and

3 The 2010 Reservoir Suitability Report submitted by FLLPG refers to “US Salt company files” (2010-5-14, BSK to DEC – NOIA Response Reservoir Suitability Report (redacted) at 1). Companies routinely maintain records of project development and performance over the lifetime of a project and after it has ended, so FLLPG may have access to additional historical documentation from company files. Such detailed records are important in understanding what has happened if there is a failure of some sort—such as a cavern roof fall—and in deciding how to address the problem.
but a full complement of sonar comparisons, typical of cavern evaluations in the cavern development industry, is needed.

- The project borders are suspect. On the southern border of the FLLPG galleries (the site of the Arlington Storage Company, LLC ("Arlington") gas storage expansion project), the roof of Cavern 30 failed, and Bordering caverns should be thoroughly evaluated. These caverns should be fully characterized, and their ongoing measurement should be included in the monitoring program. The Federal Energy Regulatory Commission ("FERC") has required more extensive monitoring of Cavern 30 than previously was required for gas storage at the Arlington facility, as a condition of the approval issued for expansion. Enhanced monitoring should be required for both of the FLLPG Galleries and all neighboring caverns and galleries.

- The monitoring program planned is minimal, and much of it—including the subsidence leveling program that seems to monitor the weather, rather than the intended cavern roof subsidence—is inadequate. If the informational gaps and errors are addressed in revised documentation, and FLLPG’s application is granted, DEC should require enhanced monitoring, providing real-time, continuous measurements, as additional conditions of the permit.

As a professional geologist, critically reviewing the FLLPG project, I would expect to see, at the beginning of an analysis, geologic maps and cross-sections fully describing the brine cavern field; the geology involved: operations, such as hydraulic fracturing, that created the passages between the caverns; and faults, folds, and fractures that have been involved the cavern development process. Then, I would expect to examine detailed studies, measurements, and discussions of specific issues introduced by a review of the basic data. FLLPG has provided enough information to raise safety questions and to create conflicts with published articles about the caverns to be used in this project and anomalous features of the surrounding geology. Ordinarily, I would expect a storage permit applicant to provide responses to those questions and resolution of those conflicts. Only after all the questions about cavern integrity are answered, would I expect to see development of a monitoring plan, using currently available technology, to serve as an early warning of impending cavern failure. The FLLPG application and draft permit conditions defeated all of my expectations and failed to conform to standard industry practices I have observed over decades as a professional geologist. In my opinion, FLLPG understates cavern integrity risks, and the incomplete and inaccurate information in its application leads me to conclude that the Galleries cannot be used safely to store LPG, even with the monitoring required in the current draft permit conditions.

5 I have been an academic and consulting geologist and geophysicist for nearly 50 years. My curriculum vitae is attached to this report as Exhibit F.
II. Overview of Relevant Geology

To place my analysis in context, it is important to understand the salt cavern solutioning process in its geological context. Making caverns like those in the Watkins Glen Brine Field is a matter injecting fresh water into a well, dissolving the bedded salt, and withdrawing the resulting brine. The geologic cross-section in Figure 1 below shows an injection well and a withdrawal well typical of the multi-well caverns at the Watkins Glen Brine Field. (Jacoby, 1973). In fact, this is a cross-section of two of the wells involved in Gallery 1 of the FLLPG project—Wells 33 and 43—now part of a mega-cavern joining Wells 33, 43, 34, and 44.

Figure 1: Wells 33 and 43
Source: Jacoby, 1973
Both wells were first drilled, then fresh water was pumped into one under pressure—creating a hydraulically fractured connection along a fault plane connecting the two wells, and solution of the cavity followed. The wells still exist and can be opened for logging and to lower sonar devices or other equipment used to monitor cavern pressure, salinity, and seismic events with periodic or continuous measurements.

The stratigraphy (rock layers) shown in Figure 1, like that of the Watkins Glen Brine Field generally, involves salt beds (shown with the letters and subscripts) and interbedded layers of shale, limestone and dolomite (shown by the patterns). The cross-section illustrates the folded rocks and salt layers, along with thrust faults—one is just below elevation -1700 with the notation “dislocation.” The original hydraulic fracture in this example was near the bottom of the cavern, and as solutioning of the cavity progressed, rock layers—which did not dissolve—were undermined and fell into the cavern, creating the “rubble pile.” The tubing through which the fresh water was injected and the brine was removed was cut off as the process moved upward (and cut off pipe pieces are depicted in the rubble pile).

The caverns of the brine field are solutioned in bedded salt of the Silurian Syracuse Formation, sandwiched between Vernon shales below and Camillus shale (shale, dolomite and gypsum) above. The stratigraphic column in Figure 2, below, from the proposed NYSEG CAES plan, describes the nearby rock section (PB Energy Storage Services, 2011:5). Here, the interbedded salt and rock layers are designated by letters, then numbers and numbers within (like F1/1 and F1/2). The nomenclature has changed through the years and the lettering in Figures 1 and 2 may not match exactly.
Figure 2: Column of Rock Layers
Source: PB Energy Storage Services, 2011

SOUTH CENTRAL NEW YORK

Axion Formation

Berkshire Formations

Cambridge Formations

F3

F2

F1

E

D

C

B

A

Lockport Group

Feet

0

100

200

300

400

500

SALT

SHALE

DOLOMITE

ANHYDRITE
Within the Syracuse formation, salt layers are interbedded with shales and dolomites that resist solutioning but not gravity, and fall from the walls and roofs of these caverns, leaving all the caverns here at least partially filled with rock rubble. The alternating salt and rock beds were originally laid down in a shallow interior sea that was oftentimes limited in its connection to ocean exchange—thus the salt. Devonian rocks complete the section to the surface as gently folded east-northeast trending anticlines (areas bowing up like the arch) and synclines (areas bowing down like a trough) (here the Corbett Point Syncline), the signature of Appalachian tectonism left behind. These structures in the vicinity of Seneca Lake have long been well known, and Figure 3 below illustrates their relationship to Appalachian geology to the south of Watkins Glen.

Figure 3: Map of Geology
Source: Kindle, 1904

The Syracuse Formation beneath these folds was not treated so gently. The Appalachian push from the south used the salt layers, being quite malleable, and the shale, still holding a lot of water, like a skateboard’s rollers, floating the Devonian rocks over folded, thrust faulted and tear faulted Silurian beds, leaving often thickened salts and shales pushed up and over one
another in stacks of repeated sections, cut again by high-angle strike-slip faults (Jacoby and Dellwig, 1973). The FLLPG site-specific, thrust fault thickened, salt, and the effect of the high-angle strike-slip fault, are shown on Figure 4 below, a salt isopach (thickness) map of the vicinity from the NYSEG CAES application (PB Energy Storage Services, 2011). This is the complex that makes up the walls, floors, and roofs of the caverns in the Watkins Glen Brine Field, most of which are about a half-century old. Those walls, floors, and roofs reflect both the area's long-term geologic history and events that occurred during individual cavern development.

**Figure 4: Salt Isopach Map**
*Source: PB Energy Storage Services,*

| Figure 4: Salt Isopach Map  
Source: PB Energy Storage Services, |

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**III. Assessment of Cavern Integrity**

My assessment of cavern integrity is organized around a map showing Watkins Glen Brine Field wells and gallery outlines and three cross-sections created by FLLPG to outline its
plan. I begin with an overview of the caverns in the area, move to an examination of the cross-sections provided in the application, and then consider faulting and other geological features affecting the caverns and concerns about cavern growth. I offer observations at each stage in the context of additional information that I have obtained from public sources. My report concludes with a set of recommendations for studies, tests, and monitoring.

A. Gallery Map

How are these caverns related or could they become related; that is, what happens to the rest if there is a problem at one? To answer that question, it is essential to understand a lot more information—some of which I add in this report.

There needs to be a comprehensive study of all the caverns in the brine field and development of a “state of the brine field” map that includes geology as well as information about each cavern and how it is related to others.

Much of this added information was developed by International Salt geologist Charles Jacoby. He was able to use geologic mapping of structural grain and associated planes of weakness to plan pairs of wells, where fractures would develop along preferred pathways between the pressured and the interceptor well. Most of the caverns in the Watkins Glen Brine Field were formed by this hydraulic fracturing from one well to another, and the coalescent history has resulted in some complex, large elongate cavern shapes.
There is a lot more about hydraulic fracturing pathways that would be good to know, and a lot more hydraulic fracturing was done or attempted at the Watkins Glen Brine Field. This missing information would illuminate weaknesses in the rocks that created the pathways for hydraulic fracture flow and may explain present cavern growth behavior.

Charles Jacoby wrote a number of papers about geology and cavern research and development, including articles with a number of examples of well behavior in the Watkins Glen Brine Field and descriptions of the geology that influenced this behavior. Table 1 below is a partial list of well pairs subject to hydraulic fracturing that were documented by Jacoby.

<table>
<thead>
<tr>
<th>Year</th>
<th>Well Pumped for Fracture</th>
<th>Target Well</th>
<th>Connected?</th>
<th>Well Unintentionally Connected</th>
<th>Note</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1955</td>
<td>25</td>
<td>23</td>
<td>No</td>
<td>Fluid pumped through Well 25 went to &quot;vacuum&quot;</td>
<td></td>
<td>Jacoby, 1962</td>
</tr>
<tr>
<td></td>
<td>41</td>
<td>42</td>
<td>No</td>
<td>37</td>
<td></td>
<td>Jacoby, Dellwig, 1973</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>39</td>
<td>No</td>
<td>42</td>
<td></td>
<td>Jacoby, Dellwig, 1973</td>
</tr>
<tr>
<td></td>
<td>29</td>
<td>34</td>
<td>No</td>
<td>32</td>
<td>Fluid traveled south along Jacoby-Dellwig Fault</td>
<td>Jacoby, Dellwig, 1973</td>
</tr>
<tr>
<td>1962</td>
<td>29</td>
<td>34</td>
<td>No</td>
<td>surface</td>
<td>Fluid reached surface 1/2-mile north, along Jacoby-Dellwig Fault.</td>
<td>Jacoby, Dellwig, 1973</td>
</tr>
<tr>
<td>1962</td>
<td>33</td>
<td>34</td>
<td>Yes</td>
<td>Thrust fault caused fluid to reach well at unintended location.</td>
<td></td>
<td>Jacoby, 1965</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>31</td>
<td>Yes</td>
<td>Thrust fault caused fluid to reach well at unintended location.</td>
<td></td>
<td>Jacoby, 1969</td>
</tr>
<tr>
<td></td>
<td>33</td>
<td>43</td>
<td>Yes</td>
<td></td>
<td></td>
<td>Jacoby, 1973</td>
</tr>
<tr>
<td>1963</td>
<td>35</td>
<td>36</td>
<td>Yes</td>
<td></td>
<td></td>
<td>Jacoby, 1969</td>
</tr>
<tr>
<td>1963</td>
<td>37</td>
<td>38</td>
<td>Yes</td>
<td></td>
<td></td>
<td>Jacoby, 1969</td>
</tr>
</tbody>
</table>

Jacoby's knowledge about the regional structural grain (the near east-west Corbett Point Syncline) allowed him to plan locations of connections where there had been only apparently
random connection before. He was able to take advantage of the east-west weaknesses of folding and thrusting as long as there was not an easier path for hydraulic fracturing fluid flow. An unexplained change in the behavior of attempted fracturing, as fracture operations moved north and approached Seneca Lake, led him to recognize the role of north-south tear faulting. Several wells failed to fracture to an east-west target well and instead connected with a well to the south or north.

Comparison of geophysical logs from wells near this change in fracture path described a vertical fault plane with about 1200 feet of horizontal displacement (and related smaller faults), as well as thrusts (Jacoby and Dellwig, 1973). This tear fault, or high angle strike-slip fault, is the Jacoby-Dellwig Fault, shown in Figure 4, above). East of the Jacoby-Dellwig fault, thrust development of the salt section is reduced. The significance of this tear fault is in part that, when fracturing Well 29, fluid travelled along this fault and flowed out at the surface a half-mile north of the initial fracture.

B. Cross-Sections of the Caverns

The FLLPG Reservoir Suitability Report includes three cross-sections. The first, cross-section AA', shows caverns along the southern border of the FLLPG property and includes Cavern 58, or FLLPG Gallery 2. The second, cross-section BB’, is through the caverns of
For example, the salt isopach map in Figure 4 shows the detail of the section in the area of this cavern project, and that cumulative salt thickness, built by thrust faulting, should be shown... The significance of the thrust faults in this region is that, as nearly horizontal bedding plane features, they represent horizontal planes of weakness that have functioned as pathways for hydraulic fracture fluid flow. The faults, related hydraulic fracture connections, and the differences in salt, shale, and dolomite layer properties influenced the creation of all of the caverns of the Watkins Glen Brine Field, including the caverns that FLLPG storage proposes to use for storage. The salt caverns here are not solutioned out of a homogeneous and isotropic mass, and the caverns reflect this geology. The differences in the salt and rock remain, along with the folds, fractures, and faults that are part of the walls and roofs of these caverns.

Showing rock and salt layers as solid, intact materials, where a cavern in fact is filled with broken rock, is inaccurate and misleading. It is important to know what these cavern systems look like, how and where these caverns are connected, and how the geology may affect the system including these caverns.

Each of the three cross-sections is examined below, with reference to mark-ups attached to this report as Exhibits B–D.

1. Cross-Section AA' (revised 8-28-14)

This west-to-east cross-section begins at the left edge of the diagram with Cavern 58, or FLLPG Gallery 2, and then depicts the subsurface along the southern border of FLLPG property, incorporating the Arlington natural gas Caverns 30, 31, 28, and 27. The inset on the lower left shows the stratigraphic context of the interbedded salt and rock in the detailed cross-section at the top. The letters with subscripts on the left edge and near the right edge name the interpreted
layers of salt (shown as white), and the interbedded rock layers (shown as a red pattern).
Typically, rock core description data and/or geophysical logs are superposed or referenced on a
cross-section to support the interpretations and allow independent verification, but that is not the
case here. The addition to cross-section AA' of the log data developed by Jacoby (in his
published papers) and the logs for Well 58 (included in the application, e.g., 2010 Reservoir
Suitability Report, Exs. 5 and 6) would be helpful.

Cavern 58 will be discussed in more detail later, but some basic information requires
immediate correction. Two rock layers are depicted abutting Cavern 58 in unlikely locations.
One layer is shown a third of the way up in the new cavern being solutioned above the collapsed
original and passing through the 2011 and 2013 sonar outlines (likely a drafting error). The
other rock layer, shown beneath and apparently supporting the new Cavern 58, conflicts with the
underlying information in the application. The implied structural support beneath the new
Cavern 58 raises an important question: Is the layer real, making its future over the previous
Cavern 58 rubble pile somewhat precarious? Or, is the new Cavern 58 floored on the rubble of
the lower Cavern 58 roof collapse, and the continuous bed pictured an error? According to the
well status report in the Reservoir Suitability Report, the base of the new Cavern 58 is "top of
rubble,"8 making the depiction as solid rock an error. The phrase "top of rubble" here and at
several places on the cross-section indicates that there is rubble between the old and new cavern
floors and that, as Cavern 58 has been solutioned, the relatively insoluble interbedded rock has
fallen and filled the base of the cavern. A complete cross-section should show the volumes now
filled by this rock. The rubble-filled historic cavern outline for Cavern 58 is shown on
Exhibit B.

a. Caverns 27, 28, 30, 31, and 46

Moving to the east on cross-section AA’, the galleries of Caverns 30 and 31 and Caverns
28 and 27 are part of the Arlington natural gas storage expansion project recently approved by
the Federal Energy Regulatory Commission. This proposal was the subject of detailed
comments, and most of the comments and FERC’s responses are available for review. FERC
has asked for "a new sonar survey of Gallery 2, through all three cavern wells, to obtain the
current size of the gallery, the size and shape of the rubble pile, and the shape of the roof around
each well."9 That is, for the gallery involved with the 400,000-ton roof fall described by Jacoby,
Arlington not only must develop measurements of the currently open cavern, but also must
obtain measurements that fully characterize the size and shape of the rubble pile at the bottom of
the complete gallery. The latter measurement likely will require seismic testing, because sonar
cannot penetrate the rubble.

Information missing from cross-section AA’ is available from Jacoby studies of these
specific caverns. The 1967 cross-section of these caverns (Jacoby, 1969), shown below in

8 2010-5-14, BSK to DEC – NOIA Response Reservoir Suitability Report (redacted) (Ex. 9 at 2).
9 FERC, Order Issuing Certificate and Reaffirming Market-Based Rates, 147 FERC ¶ 61,120, at ¶ 31 & Engineering
Condition 3 (May 15, 2014).
Figure 5, below, was developed after their initial hydraulic fracture connection. It provides a clearer picture of the actual situation here, in contrast with the current open space measured by recent sonars above beds depicted as continuous on FLLPG cross-section AA'. The information on this Jacoby cross-section should be disclosed on cross-section AA', but it is not.

Figure 5 shows the outlines of the caverns, the hydraulic fracturing connections between caverns, thrust faulting and tear faulting, in addition to the more detailed stratigraphy here that Jacoby developed from core samples and geophysical logs. The notation in the middle of the rectangular shape at the base of Cavern 30, “Fallen Rock Mass,” describes a 400,000-ton block that fell from the roof (outlined by sonar). I have sketched the cavern outlines developed from the 1967 sonars on cross-section AA' and have attached the marked cross-section as Exhibit B to this report, to allow comparison.

Figure 5: Wells 27, 28, 30, and 31
Source: Jacoby 1969

Also, on FLLPG cross-section AA', note the “Top of Rubble” arrows between Caverns 30 and 31 and the “Estimated Location of Pressure Connection” arrow between the two caverns—two features that help to reconcile the Jacoby cross-section with cross-section AA'(in addition to the depths shown on the Jacoby cross-section). Corresponding locations of “Top of Rubble” and “Estimated Location of Pressure Connection” appear on cross-section AA' for
Caverns 28 and 27, enabling the match with the Jacoby cross-section there, as well. Additional published sonar measurements (Jacoby, 1973) of Cavern 27 provide information about the upward path of the cavern roof.

There is a cautionary tale about Cavern 27, the basis for the Jacoby research paper related to this additional sonar. Cavern 27 sonar was used to guide the drilling of Well 46 to recover LPG that had migrated upward, as roof fall developed out and away from the original Well 27. He noted that additional LPG might be trapped above weakened rock leaves of the then-present cavern roof. This rock is now part of the rubble pile noted on AA'.

![Figure 6: Wells 46 and 27](source: Jacoby, 1973)

Figure 6 (Jacoby 1973) shows Wells 46 and 27. Well 46 was drilled to recover trapped LPG and likely did not extend to the depth shown on cross-section AA'. Cross-section AA', with the addition of information from these sonar studies, would provide a picture of the cavern advancing from Jacoby's initial work, through the Well 46 experiment, and on to the present roof outline.

My mark-up of cross-section AA' in Exhibit B shows cavern outlines and the Jacoby-Dellwig Tear Fault, shown in Figure 3 above between Caverns 31 and 28 and in Figure 4 parallel to the shore of Seneca Lake. Thrust faulting shown on the Jacoby cross-section and discussed in his 1973 article with respect to the thickened salt in Well 27 also should be added to cross-section AA'. The locations of the thrust faults were developed from the repeated signatures shown on gamma logs from Wells 27, 28, 30, and 31 and discussed in several Jacoby papers. Jacoby discussed subsidiary faulting related to both of the major faults shown on his cross-section, and that faulting should be recognized and plotted on cross-section AA'. The original sonar information and the geophysical logs that were the basis for Jacoby's cross-sections and
interpretations—and that are necessary to provide a complete account of the geology in the area covered by cross-section AA—are likely in salt company files available to FLLPG. Once completed, the revised cross-section AA' should show the thrust faults and tear faults that explain the variations in salt and rock layers shown on the 8/28/14 cross-section AA' now in the application.

In response to a Notice of Incomplete Application with questions from DEC about faults, FLLPG discussed only the Camillus shale above the interbedded salt and rock layers and repeated the conclusion that thrust faults do not involve the Camillus. But the thrust faults and tear faults that are part of the overall geology, the appropriate time to present interpretations of beds above and below the deformed salt is after all the geological information is presented visually in the cross-sections.

b. Cavern 58

Figure 7 below is my mark-up of the portion of cross-section AA' depicting Cavern 58, which is FLLPG Gallery 2. This cavern has been a focus of concern for a long time. It could be described as the combination of two caverns: (1) the new one with its roof at the Camillus shale, the upper bound of the interbedded salt and rock layers, and with its base outlined by the 2009 sonar, with a "morning glory" shape, and (2) the original attempt at cavern development, below the new one, as outlined by the 1997–1999 sonars, which now is filled with rubble, the result of a roof collapse and consequent abandonment. FLLPG shows them as isolated on cross-section AA', but in fact they are connected, as I show on Exhibit B.

10 2010-05-14, BSK to DEC – NOLA Response (redacted) at 8.
The 1997 sonar survey (lowermost outline on Figure 7) captures the status of the cavern's solutioning at that time. The open cavern sequence continued as shown on successive sonars from 1998 and 1999. The base of the 1999 sonared cavity was flat, illustrating the accumulated rubble from the collapsed rock layers (red pattern) and that cavern development was progressing upward from that rubble base as solutioning continued. The next routine sonar logging attempt found a catastrophic change—outlined in a series of documents describing the situation and summarized in a letter dated May 24, 2001, from US Salt to DEC:
Reports and conversations with Larry Sevenker prior to the last loggings appeared that the cavern at Well 58 was progressing normally. The latest logging indicated that the roof of the cavern had collapsed and filled with rubble. Mr. Sevenker further reported that it appeared that the upper formations may have been in a fractured and faulted zone and that a small magnitude earthquake could have damaged the cavity.

Other (partially redacted) documents disclosed by DEC pursuant to a Freedom of Information Law Request (but not included in the documents released to the public for this proceeding) make it clear that the Cavern 58 project ended because of concerns that questionable geology ("fractured and faulted zone") in the immediate vicinity made it unwise to place a cavern there.12 The cavern had collapsed, and continued to collapse each time they pulled up tubing and tried to work again, so the well was plugged and sealed.

FLLPG attempts to discredit Mr. Sevenker

This explanation fails for several reasons. First, the cavern developers were "unable to sonar survey due to cavity conditions" (Jan. 8, 2001 report); Second, the presence of open hole from the top of the abandoned area to the top of the salt was known at the time and disclosed on the plugging report. Cross-section AA' shows the "original" cavern at its original position; what is there now has been solutioned above the original cavern. Exhibit B demonstrates that neither alternative is correct; rather, the new cavern was solutioned above the old. The serious questions remaining about the integrity of Cavern 58, given its earlier catastrophic collapse, cannot be explained away by impugning the reputation of a geologist with first-hand knowledge of the event.

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12 These documents include the letter quoted above; page 3 of a report dated January 8, 2001, on the inability to use sonar in Well 58 (apparently from the files of DEC petroleum geologist William Glynn), and the 2003 plugging report and cover letter from the consultant, Mr. Sevenker. These documents are collected and attached to this report as Exhibit E.
Moreover, there is evidence not only of past cavern failure but also of current roof instability. The sonars in cross-section AA' show that the roof in 2009 is higher than in 2011 and that, by 2013, the roof is visibly sagging.

The sagging occurs even as the extent of the roof grows, adding to the risk of collapse. Finally, Cavern 58 extends to the Camillus shale: there is no salt layer to provide support for the roof.

c. Summary of Cross-Section AA' Issues

Summarizing the review of FLLPG cross-section AA': the depiction of rock and salt layers beneath sonar outlines of Caverns 58, 30 and 31, and 28 and 27 as continuous is incorrect and misleading: there are rubble-filled caverns here that have been solutioned upward through time, and this area should be shown not as a continuous red pattern and white area meant to characterize intact rock layers, but rather with a rubble symbol.
The fact that there is no such attempt with respect to Caverns 30 and 31 and 28 and 27, increases concerns about FLLPG’s misrepresentation of conditions in the caverns.

My concerns about a broader analysis of the caverns bordering proposed FLLPG Gallery 2 mirror my concerns and are reflected in FERC’s insistence upon further study of the rubble piles and conduits as a condition of approving Arlington’s gas storage expansion. Complete and accurate information about caverns bordering the FLLPG project is crucial because the Arlington caverns holding and cycling compressed natural gas could fail—in turn jeopardizing the integrity of the adjacent FLLPG caverns. Exhibit B shows the southern border of the proposed LPG storage caverns to be far more complicated and potentially compromised than shown in cross-section AA'. DEC should analyze the new information that FERC has required from Arlington before determining whether to grant FLLPG a permit for LPG storage.

Finally, more study is needed not only of Cavern 58’s rubble-filled base but also of its unsupported rock roof. FLLPG has gone to some length to demonstrate the healing power of salt, but it now has at least two caverns with flat or sagging rock roofs. FLLPG’s claim that thrust faulting does not appear to affect the Camillus shale—two things not expected in a uniform shale. Thus, FLLPG’s own records about the rock roof raise serious and unanswered questions about Cavern 58’s suitability for LPG storage. DEC’s permit determination should be deferred until after it has a full and correct understanding of Gallery 2 and the bordering caverns, and until that additional study is complete, the application lacks sufficient data to show that the reservoir is adaptable for storage purposes.

C. Cross-section BB'
1. FLLPG Gallery 1

Specifically, the Jacoby (1973) cross-section, reproduced above as Figure 1, illustrates the early history of the cavern originally created when Well 33 was hydraulically fractured to Well 43.

First, the Jacoby cross-section in Figure 1 shows a thrust fault cutting (at depth 2449) just above the cavern that existed at the time, which was formed by the connection of Wells 33 and 43. That fault forced the rock and salt beds up and over one another within the Silurian section.

The thickened salt mass found in Well 34 was noted by Jacoby (1969) in discussing the northern involvement of thrust faulting.

While the fault and folds shown in Figure 1 are largely now part of the rubble pile, they are also part of the walls of the cavern. These faults are planes of weakness that could serve as fluid pathways or influence future cavern deformation.

The Jacoby cross-section clarifies that, as salt was dissolved, the rock layers above the former salt were no longer supported and fell to the bottom, forming the rubble shown. That process began at the base and moved up, with accumulated rubble below.
Figure 1 also shows an apparently well cemented casing at Well 43, but void space around the casing at Well 33 from the cavity as it existed then up to about 2010 depth.

Beginning with the area beneath Cavern 44, the Well Status and Condition Report lists “Top of rubble, bottom of existing cavern” as 2423 feet for Well 44. For Cavern 34, the Well Status and Condition Report lists the “Top of rubble, bottom of existing cavern” as 2383 feet.\(^\text{15}\)

\(^{15}\) 2010-5-14, BSK to DEC – NOLIA Response Reservoir Suitability Report (redacted) (Ex. 9 at 2).

\(^{16}\) Id. at Ex. 9 at 1.
The discussion in the previous paragraphs raises a question about the connections of the mega-cavern in the upper open cavern space. Where and how did they all become connected in the first place? The answer is: at the level of the rubble pile "tunnel" and not intentionally. The Jacoby (1973) cross-section discussed earlier shows the base of the cavern connecting Wells 33
and 43, near the base of the Syracuse, and then subsequent solution up from there. The hydraulic fracture that connected Well 33 to Well 43 was apparently a second event. Here, Jacoby (1965) described an unintended fracture connection where Well 33 fractured to Well 34, rather than the intended target, Well 32.

Well #33 was an injection well with an intended target of Well #32 across a distance of 735 feet. Unexpectedly, it connected with Well #34, or almost due north, a distance of 745 feet. Within 24 hours after the fracture had been initiated, brine was being produced by the target well. The volume of brine produced quickly reached a point where it was proportional to the volume of water injected. The quality of brine with respect to calcium and magnesium chlorides was extremely high, thus being relatively poor for the production of evaporated salt. Pump pressures remained extremely high despite the fact that large quantities of salt were extracted. No second plateau ever developed.

It was surmised that fracturing fluid had passed horizontally along a faulted zone with at least a portion of the travel route being in shale layers.

Jacoby's articles demonstrate that there was a hydraulic fracturing operation that connected Wells 33 and 43 (illustrated in Jacoby, 1973) and an operation that connected Well 33 to Well 34 (described in Jacoby, 1965). Both of these fracture pathways were near the base of the Syracuse, but they had to have taken independent routes in order to develop pressure for each connection. These routes were involved with the zones of weakness related to faulting.

Jacoby wrote more about the role of faulting between Wells 33 and 34, describing the pressure variation experience:

In fracturing Well 33 to 34, alternate buildup and recession of pumping pressures indicated that the solution channel was being closed by rock movement from time to time. In the light of subsequent geologic information, the occurrence of intermittent collapse should have been unexpected, inasmuch as in this area of the brine field the major thrust has broken up, into and through the No. 3 salt. Faulting above the cavity created by solution between Wells 33 and 34 may have resulted in a weakness which led to the observed periodic collapse and pressure buildup. It is over this area that the major thrust bifurcates at several points, creating a series of planes of weakness in the section overlying the solution zone.

(Jacoby, 1973) (emphasis added).
Observations such as these, made by the US Salt geologist involved with the creation of these caverns, make it clear that a time sequence describing the role of geology in the history of each cavern is necessary in order to give an accurate portrayal of the current situation. Information like the presence and position of the major thrust fault and bifurcated thrust faults, along with the rubble-filled caverns developed in a time sequence and other information,
similar modeling of other features of Gallery 1 should be done as well. Without more study, the data on Gallery 1 is insufficient to demonstrate that the reservoir is suitable for LPG storage.

2. Gallery 10

DEC Comment 9b. Page 9 of the May 14, 2010 Reservoir Suitability Report states "there was no pressure encountered on well 52 . . ." In other parts of the application (i.e., Gallery 1 & Gallery 2), Finger Lakes says that encountered pressure during well re-entry is an indication of tightness for the proposed storage galleries. Conversely, is "no pressure encountered" an indicator of Gallery 10 not being tight?

Finger Lakes Response: It is assumed that the cavern does leak and will be monitored as explained in response to DEC Comment 9d below. 32

Well 52 presents additional challenges. In response to DEC's question about the cavern at Well 52, FLLPG replied:
A professional geologist examining a project expects to see accurate, clearly identified, and consistent data on cross-sections that can be traced to underlying information;
more data is needed to show that the Gallery 1 reservoir is safe for LPG storage.

D. Cross-section CC'