Prepared in Cooperation with the Onondaga Lake Partnership and the Onondaga Environmental Institute

Ground-Water-Flow Modeling of a Freshwater and Brine-Filled Aquifer in the Onondaga Trough, Onondaga County, New York—A Summary of Findings

By William M. Kappel and Richard M. Yager

In 2007, the U.S. Geological Survey (USGS) completed a hydrogeologic study that included the development of a ground-water-flow model of the glacial-drift aquifer in the Onondaga Trough near Syracuse, N.Y., which extends from the Valley Heads Moraine near Tully, N.Y., to Onondaga Lake (fig. 1). Glacial sediments within the Onondaga Trough contain freshwater, saline water, and brine, which has historically supported several chemical industries in Syracuse. The ground-water-flow model was developed as a means to assist the members of the Onondaga Lake Partnership (local, State, and Federal governmental agencies) to assess remediation plans for Onondaga Lake and the Onondaga Creek watershed. Prior to this study, in the late 1990s, very little information was known about the physical nature of the valley-fill aquifer or the quality of water within it. Acquisition of this information would help local agencies understand the interactions of fresh and saline water within the aquifer and Onondaga Lake, and would facilitate the design of proposed and ongoing remediation work in and near the lake.

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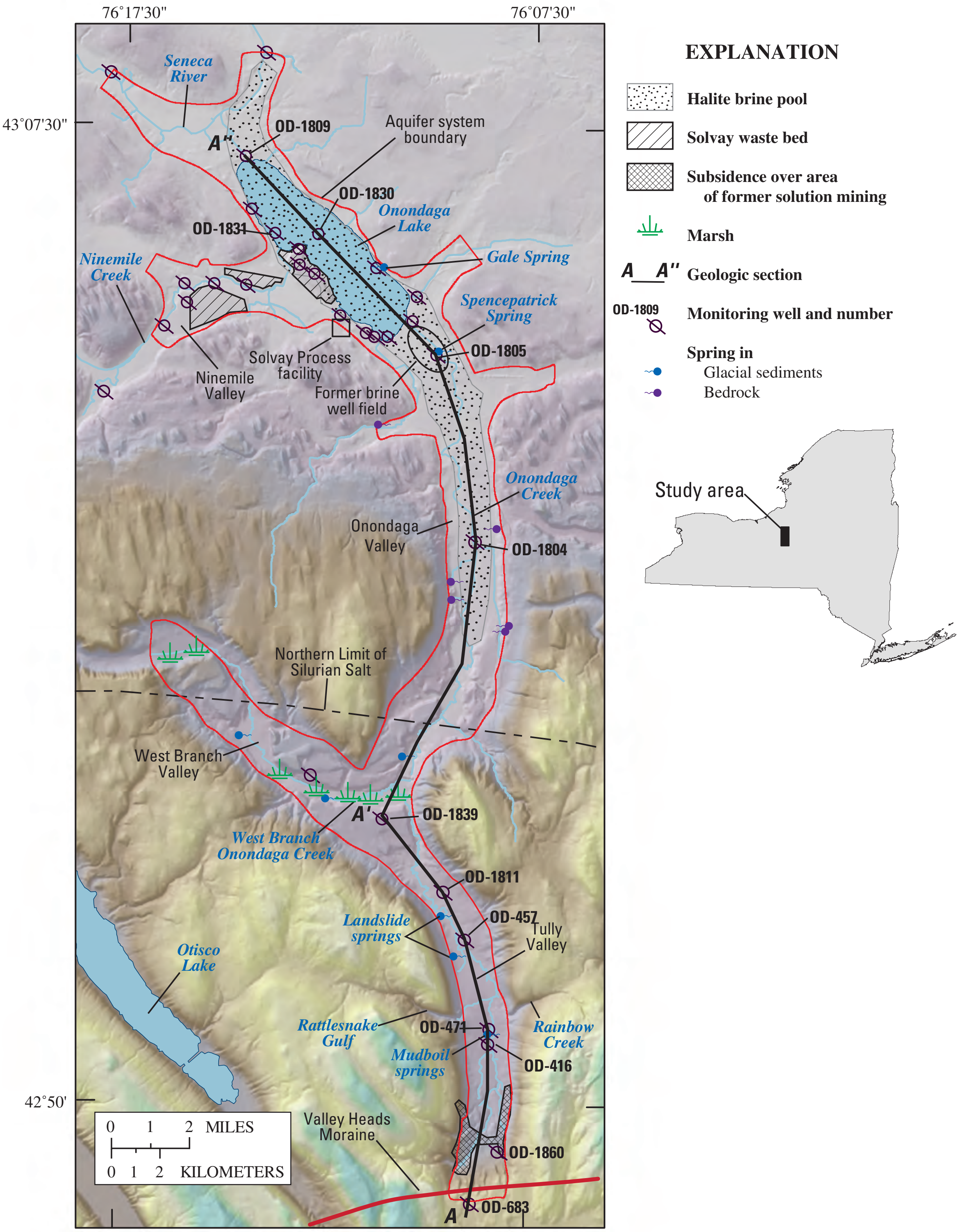

Base from USGS 10-meter digital elevation model;
North American Datum of 1983, Universal Transverse
Mercator projection, Zone 18N

Figure 1. Geographic features of the Onondaga Trough, Onondaga County, New York, including physical and manmade features, location of test wells and borings, springs, the Solvay Process facility and associated waste beds, and location of the brine pool in the valley-fill aquifer.

The USGS study characterized the geology and geochemistry of the aquifer system, estimated the rate and direction of ground-water movement, and estimated mass loadings of chloride to Onondaga Lake and its tributaries from natural and anthropogenic sources. The study required analysis of existing hydrogeologic data and drilling of new test wells to collect additional hydrogeologic data to supplement this database. A three-dimensional geologic model of the unconsolidated deposits that fill the Onondaga Trough was developed from this information. Water-quality samples were collected, and hydraulic head (water-level) measurements were made in the test wells. The water samples were analyzed for a variety of chemical constituents to determine the composition and age of saline waters within the aquifer. The geologic model, together with the water-quality and hydraulic-head data, supported the development of several variable-density flow models of the aquifer system. The complete results of this study are summarized in Yager and others (2007a), which discusses the present location of the brine pool, potential sources of the brine, and the effects of the brine pool on ground-water flow near Onondaga Lake.

History of the Salt City and Onondaga Lake

The history of Syracuse as "The Salt City" began with the discovery of brine springs along the lakeshore in the late 1600s, followed by development of extensive salt-manufacturing works in the early 1800s. The manufacturing process utilized saline water pumped from glacial sediments near the southern shore of Onondaga Lake (Kappel, 2000). This salt industry persisted from the early 1800s to the early 1900s and produced millions of pounds of salt from the brine pool in the aquifer, primarily by evaporating the brine to produce granular salt. In the late 1800s, local investors purchased the manufacturing rights to the Solvay Process, which mixed limestone, saturated brine, and ammonia in a chemical process to make soda ash (sodium carbonate), used in the production of glass, paint, detergent and many other industrial products.

Brine concentrations in the aquifer near Onondaga Lake had diminished by 1885 due to extraction of brine from the deepest part of the aquifer (Kappel, 2000). As a result, the Solvay Process Company had to search elsewhere for a new source of bedded halite (salt) or concentrated brine. Geologists eventually found bedded halite at a depth of 1,200 feet below land surface at the southern end of the Onondaga Trough near Tully. During the next 96 years (1890–1986), millions of tons of halite were converted to saturated brine and piped northward to the Solvay Process facility along the shore of Onondaga Lake (fig. 1). The production of soda ash resulted in about 1.5 pounds of waste material containing calcium carbonate (limestone) and sodium- and calcium-chloride for each pound of soda ash produced. A slurry of residual waste was discharged to waste-disposal beds that occupy the southwestern shore of Onondaga Lake and the Ninemile Creek valley (fig. 1). Later, the Solvay Process Company became part of the Allied Chemical Corporation, and other chemical processes at this facility produced different residual chemicals that were also discharged to the waste beds. Various chemicals leaked slowly into both ground water and surface water that flowed to Onondaga Lake, and by the middle of the 20th century the lake waters had become hypersaline.

The cessation of soda-ash production and other chemical processes at the facility in the late 1980s was an important milestone in the water-quality history of Onondaga Lake. The discharge of chlorides from the waste beds to Ninemile Creek and Onondaga Lake was greatly diminished by the late 1990s, signaling one of the initial phases of water-quality improvement in the lake.The former salt springs that initially supported the salt industry at Syracuse can no longer be found along the shoreline, but the hydrology of the glacial aquifer has not changed. Saline water is still discharged from the aquifer to Onondaga Creek and Onondaga Lake. The results of ground-water-flow modeling indicate, however, that chloride discharges from the waste beds were much greater than saline discharges from the aquifer.

Hydrogeology and Geochemistry

A geologic section along the thalweg (deepest part) of the Onondaga Trough (fig. 2) depicts the general southern dip of the bedrock (40 to 50 feet per mile), the approximate location of halite beds, and the composition of glacial sediments. The thickness of glacial sediments increases from north to south, ranging from 245 feet thick beneath Onondaga Lake, to about 400 feet thick in the Onondaga and Tully Valleys and over 800 feet thick beneath the Valley Heads Moraine. The glacial sediments in the Onondaga Trough are primarily composed of fine-grained lacustrine sediments, although relatively thin layers of coarse-grained sediments containing sand and gravel occur at the base of the unconsolidated deposits and at land surface. These coarse-grained deposits form aquifers through which most of the ground water flows. The thickness of the basal aquifer increases near Onondaga Lake, but the lake is underlain by a thick layer of fine-grained glacial and postglacial sediment that impedes the upward flow of ground water into the lake.

A brine pool covers an area of about 10 square miles within glacial sediments at the northern end of the Onondaga Trough and extends southward (up valley) about 10 miles. The principal constituents of the brine are sodium and chloride, but elevated concentrations of potassium, calcium, magnesium, iron, boron, and sulfate are also present. A complete listing of the chemical and isotopic composition of ground water in the Onondaga Trough is given in Yager and others (2007a). The chemical composition of the halite brine differs from saline water in the bedrock of the Onondaga Trough, which has greater concentrations of most cations (except sodium) and bromide, and lesser concentrations of chloride and sulfate. The carbon-14 (^{14}C) isotopic content of the brine contains only 4 to 15 percent modern carbon. The radiocarbon age of these waters was computed from these values to be 22,000 to 16,700 years old, indicating that (1) the halite brine was created as glacial ice began to recede from the Onondaga Trough, and (2) the halite brine was derived from dissolution of halite beds by glacial melt water. The present position of the brine pool north (down valley) of where the halite beds intersect the bedrock floor of the Onondaga Trough (fig. 2) indicates the brine has since migrated northward to its current location.

Ground-Water Modeling

Three-dimensional (3-D) and two-dimensional (2-D) numerical models were constructed to simulate flow through the aquifer system in the Onondaga Trough. The models were developed using SEAWAT (Langevin and others, 2003), which accounts for the effects of variable density (freshwater and brine) on ground-water flow. The objectives of the flow modeling were: (1) to simulate the current chloride and density distributions in the aquifer system and (2) to investigate alternative hypotheses that could explain the origin of the brine pool.

The 3-D model represented a 46 square mile area including the Onondaga Trough and two tributary valleys (West Branch of Onondaga Creek and Ninemile Creek), and was calibrated to changing aquifer conditions over a 215-year period from 1790 to 2005. The design of the 3-D model was selected to limit computational time and allow calibration of model parameters (hydraulic characteristics of the aquifer), but was not sufficiently detailed to accurately represent the flow dynamics in the vicinity of the brine pool over extended periods of time. A higher resolution, two-dimensional (2-D) cross-sectional model aligned along the longitudinal axis of the Onondaga Trough was later developed to simulate the origin and fate of the brine over a 17,000-year period, using the hydraulic parameter estimates obtained with the 3-D model.

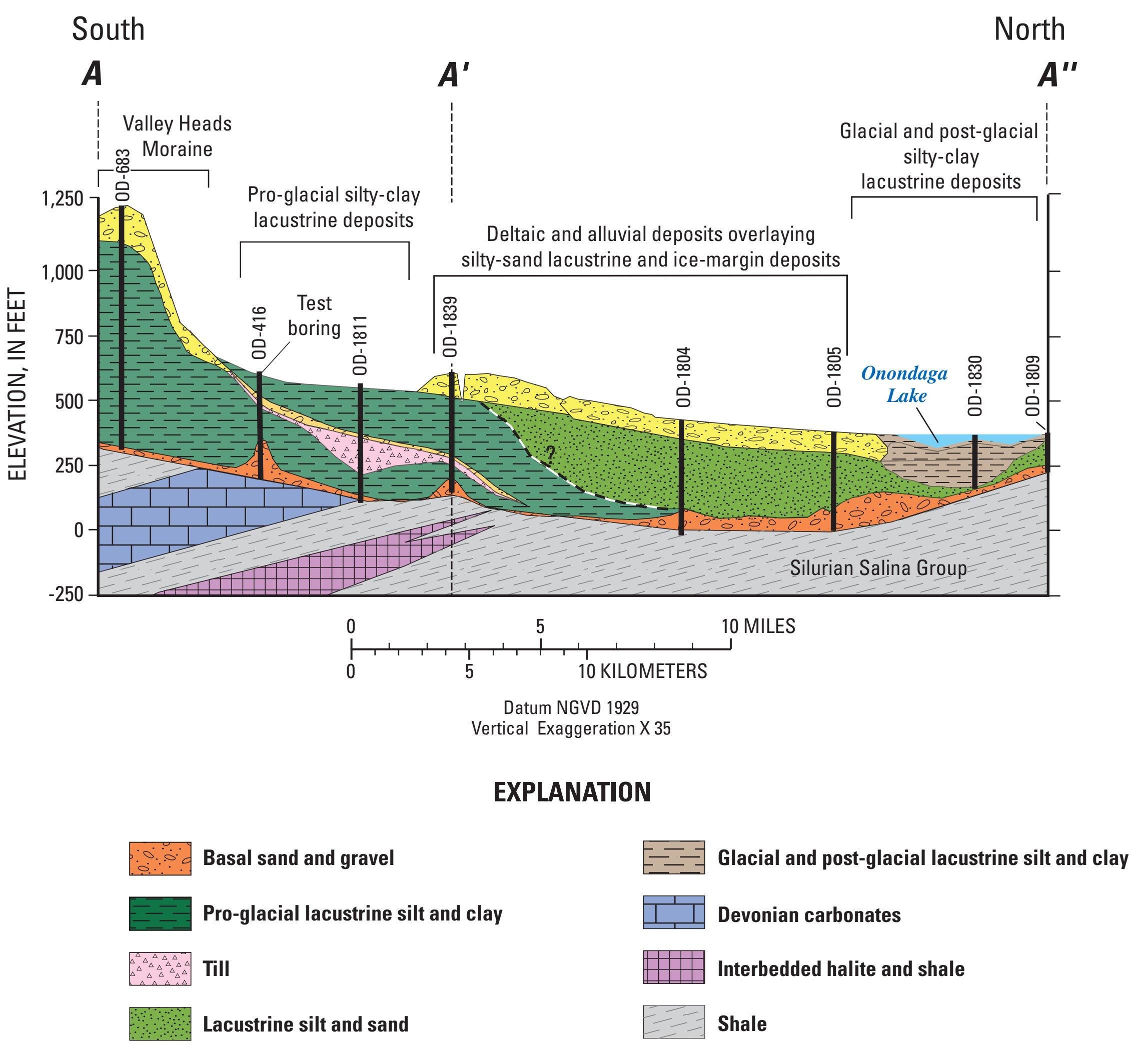

Figure 2. Geologic section along the Onondaga Trough from the Tully Moraine to the Onondaga Lake outlet showing unconsolidated sediment in the Onondaga Trough, location of the halite beds, and bedrock geology. (Location of section shown in Figure 1.)

Model Designs

Construction of ground-water-flow models requires that boundary conditions (mathematical edges of the model) be specified to help in defining the numerical problem to be solved by application of the model. Boundary conditions are representations of source or discharge areas through which water can enter or leave the aquifer system. In the 3-D model, changing hydrologic conditions required the specification of different boundary conditions during the 215-year simulation to represent (1) pumping of brine from the aquifer near Onondaga Lake in the 19th century, (2) changing water levels in Onondaga Lake caused by dredging the lake outlet in 1822 and raising the lake level during the reconstruction of the Erie Barge Canal in the early 1910s, and (3) disposal of saline waste from the soda-ash facility to the various waste beds during the 20th century. In addition to boundary conditions, values of 15 hydraulic properties (such as hydraulic conductivity and recharge) were specified in the 3-D model, 8 of which were estimated automatically through nonlinear regression using UCODE (Poeter and Hill, 1998), a computer program that minimizes the difference between observed and simulated data. The calibration data included observations of water levels and chloride concentrations in wells, and measured water and chloride mass discharges from the aquifer system.

The 2-D model simulated ground-water flow through the Onondaga Trough from the Valley Heads Moraine to Onondaga Lake (fig. 3). The purpose of the model was to assess two alternative hypotheses for the formation of the brine pool over a 17,000-year period following the deglaciation of the area. Under the first hypothesis (scenario A), halite beds that were eroded by glacial ice remained within the trough, perhaps embedded in the glacial till, which is largely derived from local bedrock. The halite brine formed following the glacial recession when meltwater dissolved the exposed halite and was later modified through mixing with saline bedrock water as it migrated northward through the aquifer. The brine pool was trapped at the northern end of the trough by lacustrine sediments beneath Onondaga Lake, which limited discharge of the brine to the lake. The alternative hypothesis for the origin of the brine pool (scenario B) assumes a source of halite brine in the shale bedrock that underlies the Onondaga Trough. Under this second hypothesis, subglacial recharge during the advance or retreat of the ice sheet dissolved halite in place, and later this brine mixed with saline bedrock water, forming a brine pool within the bedrock. The brine pool in the glacial sediments then formed later through upward transport of brine from the bedrock as ground water flowed northward through the aquifer from the Tully Valley toward Onondaga Lake.

Boundary conditions in the 2-D models were specified to represent recharge at the Valley Heads Moraine and discharge to Onondaga Creek, Onondaga Lake, and mudboil and landslide springs in the Tully Valley. Additional boundary conditions were specified to represent the source of salt water to the freshwater aquifer under the alternative scenarios: (scenario A) a short-lived salt source was specified for an arbitrary 2,000-year period in the aquifer, followed by a 15,000-year period without the salt source, and (scenario B) a continuing salt source was specified in the bedrock underlying the aquifer for the entire 17,000-year period. A complete discussion of the development, calibration, and application of the 3-D and 2-D models is contained in Yager and others (2007a and b).

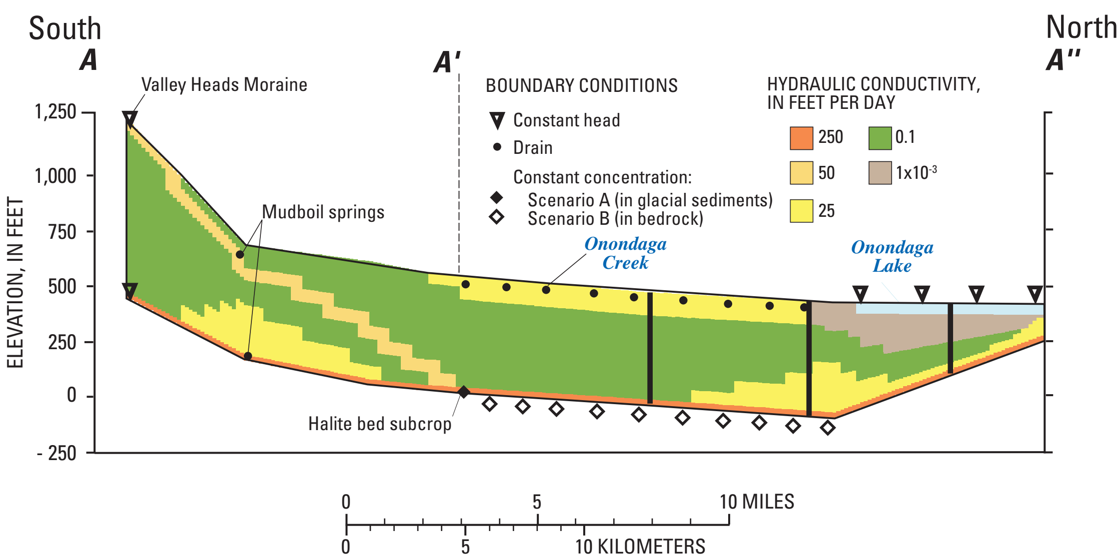

Figure 3. Representation of the unconsolidated sediments in the Onondaga Trough in the two-dimensional ground-water-flow model.

Photographs showing (1) the drilling of the 361-foot deep Spencer Street test hole (OD-1805 on figure 1) in the Onondaga Trough using Rota-sonic drill-rig equipment, (2) the recovery of a continuous sample of glacial material, (3) the installation of a monitoring well in the completed test hole, and (4) the opening of a recovered sample to describe and subsample the core for further analyses.

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Conclusions from 2-D Model Simulations

- Both model scenarios for brine formation predict brine pools similar to that observed at the north end of the Onondaga Trough, but the brine pools are created through different mechanisms. In scenario A (brine source in glacial sediments), a large brine pool fills the north end of the trough and is then diluted by freshwater recharge to form a stable pool (figs. 4, 5A). In contrast, the brine pool predicted in scenario B (brine source in bedrock) results from the steady accumulation of brine in the aquifer system (fig. 4) with additional freshwater recharge. The brine pool forms from south to north following the regional hydraulic gradient, which forces the concentrated brine to the northern end of the trough.
- The ground-water age-distributions simulated by the two model scenarios are significantly different. The age of the brine is nearly 17,000 years throughout the pool simulated in scenario A (fig. 5B), while only small areas of brine older than 13,000 years are simulated in scenario B. In scenario A, most of the freshwater from upgradient areas south of the brine pool is deflected upward by denser brine water toward discharge areas along Onondaga Creek, and the rate of flow within the brine pool is very small. In scenario B, fresher water in the aquifer flows northward to the end of the trough, and the rate of flow is higher than in scenario A, resulting in a greater discharge of saline water to the north end of Onondaga Creek.
- Variable-density-flow simulations support the first hypothesis (scenario A) that the halite brine was derived from dissolution of halite by glacial meltwater. The simulations indicate that there has been sufficient time for the brine pool to migrate from the halite subcrop area to the northern end of the Onondaga Trough and that the brine pool could have persisted for over 16,000 years. The simulated age throughout the brine pool was about 17,000 years (fig. 5B), which is consistent with the radiocarbon age of sampled brine.
- The concentration and velocity distributions simulated by the model indicate that brine is slowly depleted through a mixing zone formed by upward flow of fresher water over the southern end of the brine pool (fig. 5A). These results suggest that the brine pool is a finite resource that could be largely depleted within 1,000 years at the current rate of saline discharge to Onondaga Creek, which has probably been accelerated within the past 150 years by leakage through abandoned well casings—possibly the source of the Spencepatrick Spring in Onondaga Creek. The depletion of the brine pool is also supported by the observation of declining salt saturations following removal of brine through pumping in the 19th century (Kappel, 2000). Salt saturation in the aquifer has never recovered to its original levels in the nearly 100 years since the production of salt from the brine ceased in this part of the aquifer as would be expected, according to the second hypothesis (scenario B), if the brine pool was sustained by a continuing salt/brine source in the bedrock beneath the Onondaga Trough.

Conclusions from 3-D Model Simulations

- The 3-D model provides a reasonable representation of concentration and density distribution within glacial sediments over a 215-year period (from 1790 to 2005), and simulated hydraulic heads are in good agreement with measured water levels in wells. Model results indicate that freshwater flows northward from the Tully and West Branch Valleys and eastward through the Ninemile Valley into the Onondaga Trough. Freshwater is diverted upward and over the brine pool, forming mixing zones where some brine is entrained in the upward, fresher water flow and eventually lost from the aquifer system as it discharges to surface water.
- Brine withdrawals near Onondaga Lake between 1820 and 1920 accounted for about one-third of the chloride lost from the brine pool, while the most substantial natural discharges were to Onondaga Creek and the Spencepatrick Spring (fig. 6). Ninemile Creek became the largest chloride discharge area in 1945 following the application of Solvay waste, and remains so today. Natural chloride discharges from the aquifer to Onondaga Lake and the Seneca River averaged about 5 percent of the total during the 215-year period. Removal of brine through pumping of the lower aquifer near Onondaga Lake substantially reduced chloride concentrations in the brine pool, as indicated by the simulated shrinkage of the 130 grams per liter chloride isosurface (a 3-D representation of chloride concentration) between 1820 and 1920 (fig. 7).
- Simulated chloride concentrations in the Ninemile Valley aquifer increased substantially from 1945 to 1985 following the discharge of Solvay wastewater. Simulations suggest that saline water from the Solvay waste beds moved downward and spread laterally beneath Onondaga Lake (fig. 8). These results are consistent with the chemical content of water sampled from well OD-1831 along the west shore of Onondaga Lake (figs. 1 and 8), which indicated that about 40 percent of the ground water at this location originated from the Solvay waste beds.
- Simulated hydraulic heads are as much as 60 feet above land surface in the Tully Valley, where a combination of (1) a thick confining layer at land surface, (2) a steep topographic gradient of the Tully Moraine and valley walls, and (3) the reduction in the thickness of permeable material in the valley near OD-1811 (fig. 2) creates natural, flowing-artesian conditions on the floor of the Tully Valley. Simulated heads increased even more (to 200 feet above land surface) in a separate model run that simulated no ground-water discharge through mudboil and landslide springs in the Tully Valley (fig. 9), suggesting that these ground-water discharges on the valley floor substantially release the artesian pressure generated in the underlying aquifers.

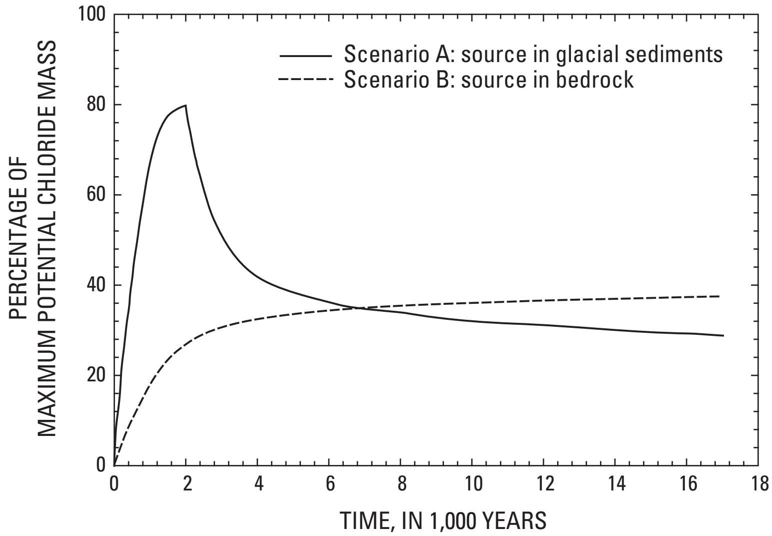

Figure 4. Chloride mass simulated by two-dimensional ground-water flow models under scenario A (brine source in glacial sediments) and scenario B (brine source in bedrock), expressed as percentage of the total possible mass in storage.

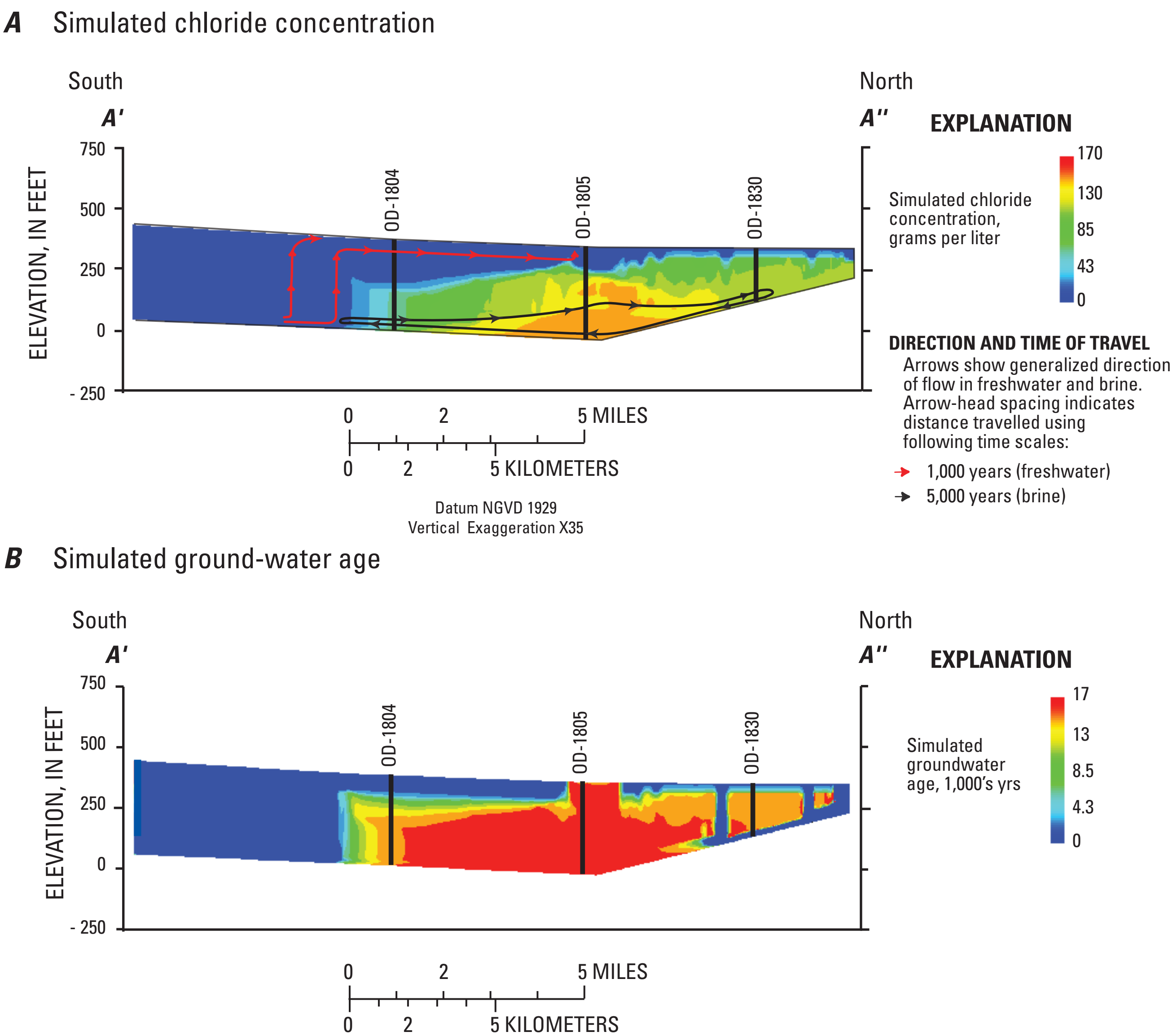

Figure 5. Characteristics of brine pool simulated by two-dimensional ground-water flow models at the end of 17,000-year period under scenario A (brine source in glacial sediments): *(A)* simulated chloride concentration and *(B)* ground-water age distribution.

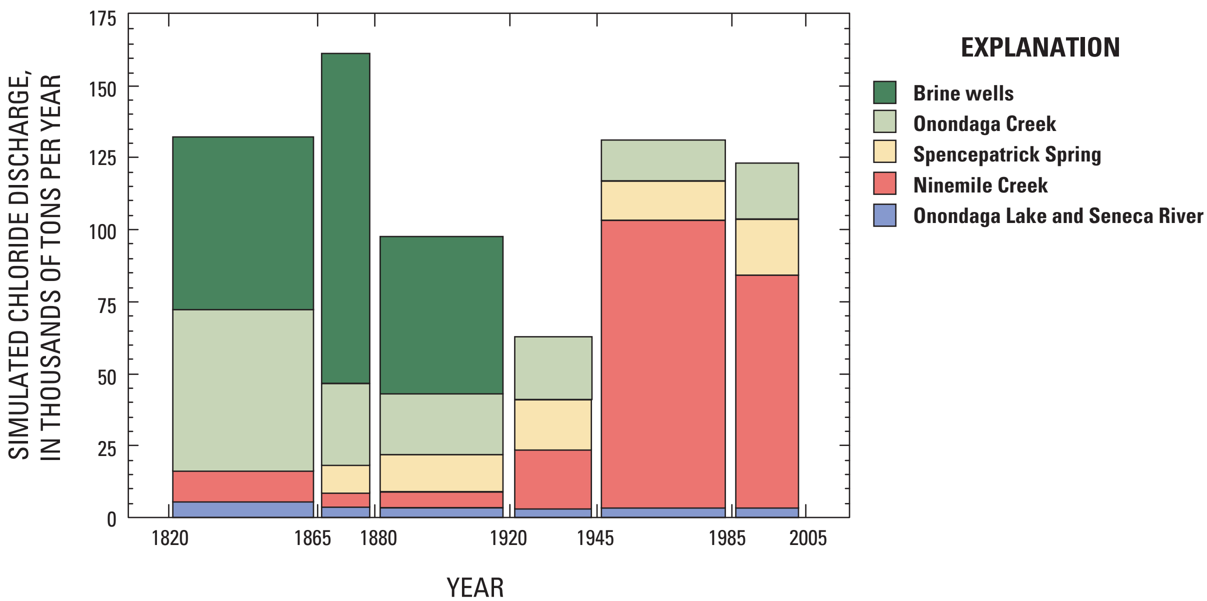

Figure 6. Mass of chloride discharged from specific locations in the Onondaga Trough from 1790 through 2005 as simulated by three-dimensional ground-water-flow model.

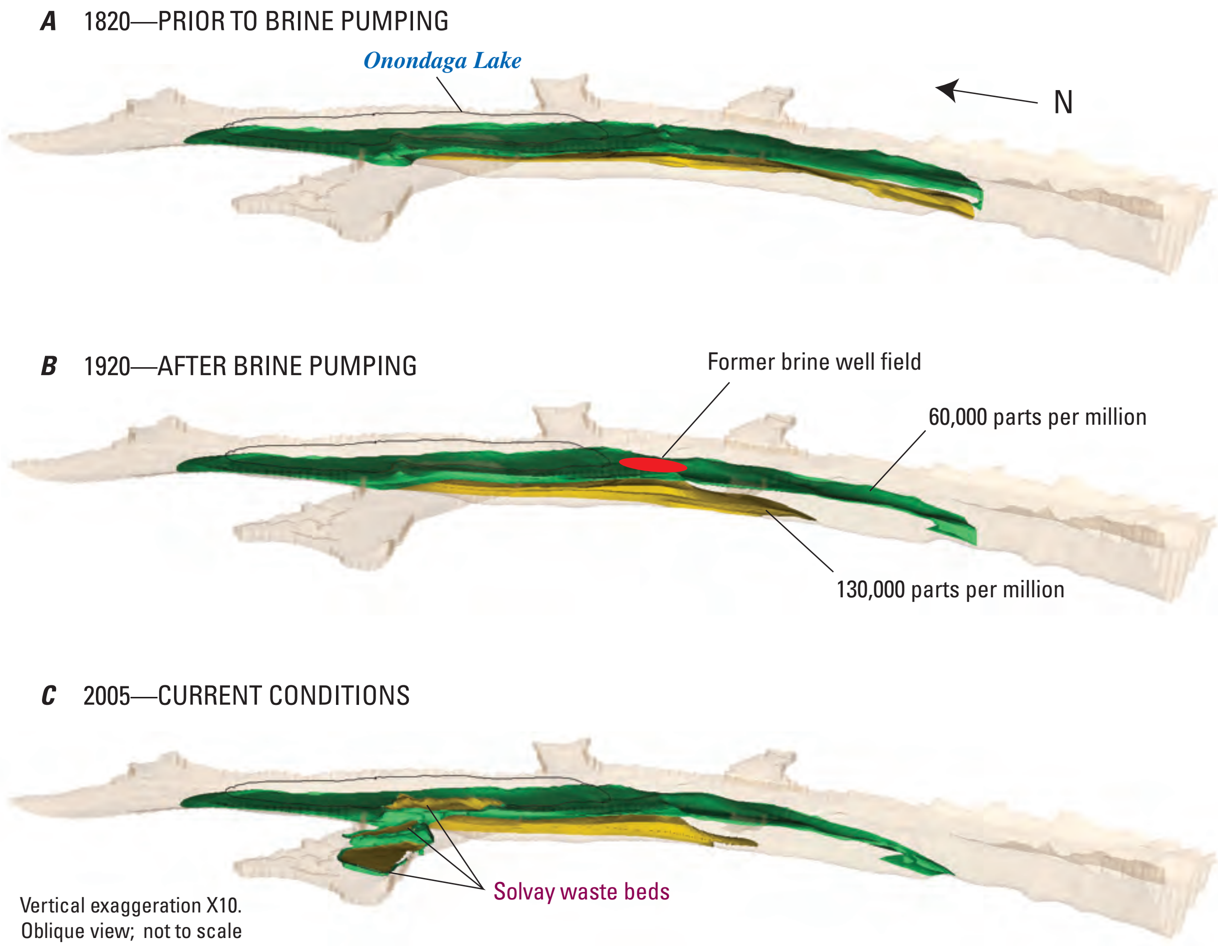

Figure 7. Isosurfaces (layers) of equal chloride concentration during 215-year simulation with the three-dimensional ground-water-flow model in *(A)* 1820, prior to brine pumping, *(B)* 1920, after brine pumping, and *(C)* 2005, current conditions, including additional chlorides from the Solvay waste beds.

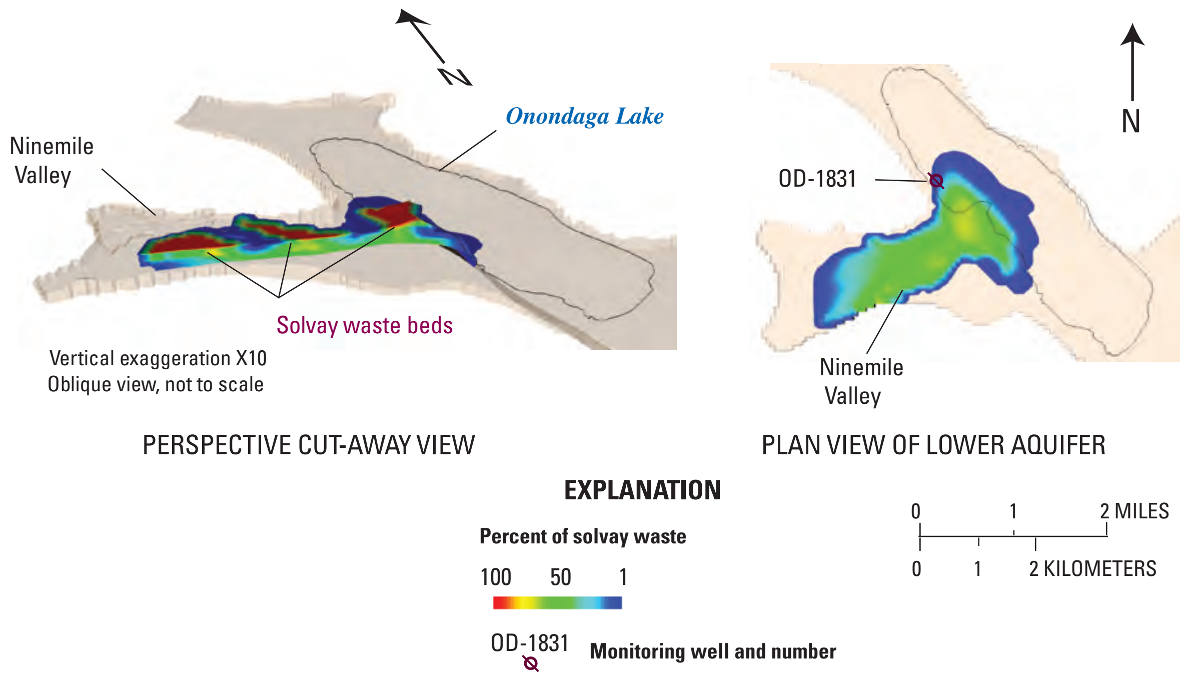

Figure 8. Perspective view showing extent of saline water migration from Solvay waste beds in 2005 simulated by three-dimensional ground-water-flow model.

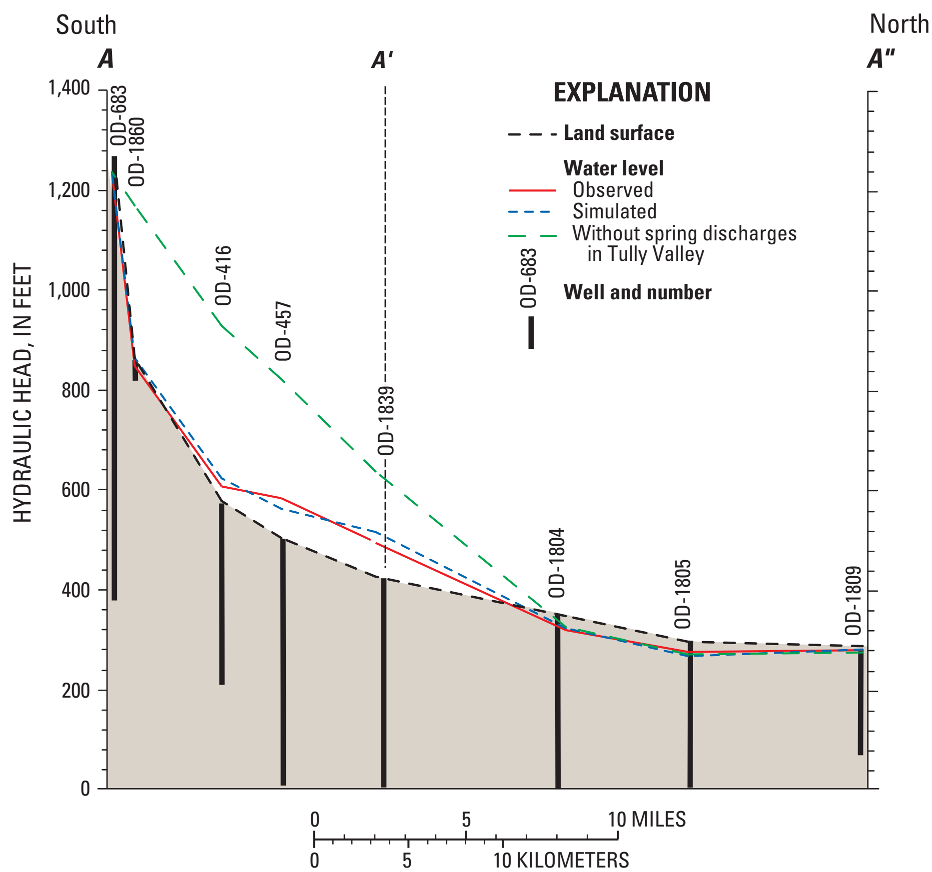

Figure 9. Observed and simulated potentiometric surface through the Onondaga Trough showing the influence of the mudboil/landslide spring discharges on the water levels in the Tully Valley. (Location of the section shown in figure 1.)

Summary

Results of USGS field work and subsequent numerical modeling of ground-water flow through the valley-fill aquifer in the Onondaga Trough indicate that a pool of halite brine (saturation ranging from 45 to 80 percent) resides in the northern part of the trough. The source of the brine was dissolution of halite beds exposed by glacial erosion in the Onondaga Trough by meltwater during deglaciation of the area about 17,000 years ago. The brine pool has moved northward (downgradient) to its present position in the deepest part of the bedrock trough under Syracuse and Onondaga Lake. The brine pool is currently being depleted as fresher water flows over the southern end of the pool and discharges saline water to Onondaga Creek through natural and manmade pathways. Discharge of brine also occurs in Onondaga Lake through slow diffusion of the brine through a thick layer of fine-grained lacustrine sediments beneath the lake, but the rate of brine discharge is much smaller than the rate of discharge to Onondaga Creek. Historical discharges of saline water from waste beds associated with the former Solvay Process facility on the west shore of Onondaga Lake were much greater than natural discharges, however, and created the hypersaline conditions observed in the lake by the mid-20th century. Continued depletion of brine from the glacial-drift aquifer to surface waters will slowly diminish the size of the brine pool in the Onondaga Trough.

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View of a typical Tully Valley mudboil or mud volcano.

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