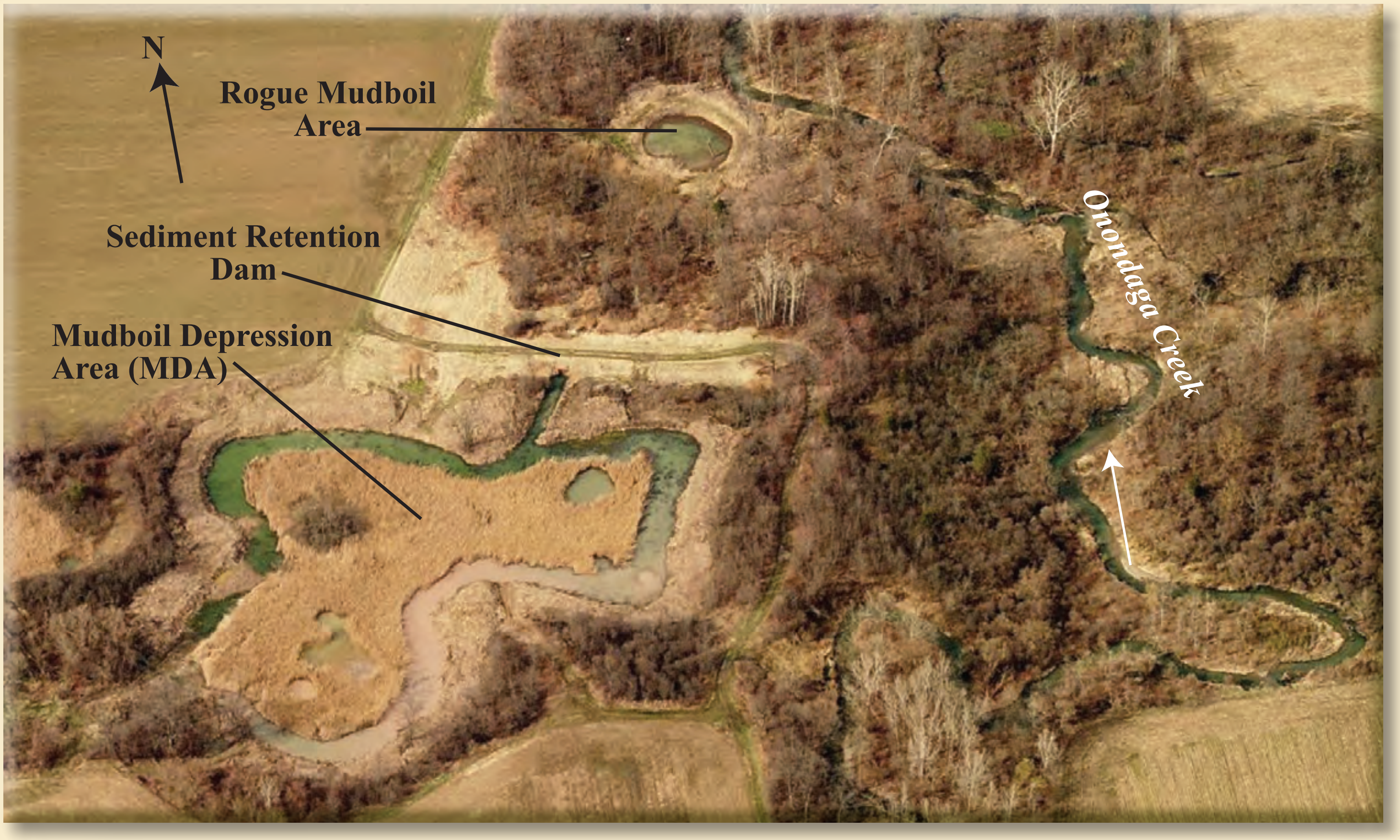
Remediation of Mudboil Discharges in the Tully Valley of Central New York



Mudboils have been documented in the Tully Valley in Onondaga County, in central New York State, since the late 1890s and have continuously discharged sediment-laden (turbid) water into nearby Onondaga Creek since the 1950s. The discharge of sediment causes gradual land-surface subsidence that, in the past, necessitated rerouting a major petroleum pipeline and a buried telephone cable, and caused two road bridges to collapse. The turbid water discharged from mudboils can be either fresh or brackish (salty).

Mudboil activity was first reported in the Syracuse, NY, Post Standard in a short article dated October 19, 1899:

"Tully Valley—A Miniature Volcano

Few people are aware of the existence of a volcano in this town. It is a small one, to be sure, but very interesting. In the 20-rod gorge where the crossroad leads by the Tully Valley grist mill the hard highway bed has been rising foot after foot till the apex of a cone which has been booming has broken open and quicksand and water flow down the miniature mountain sides. It is an ever increasing cone obliterating wagon tracks as soon as crossed. The nearby bluff is slowly sinking. Probably the highway must sometime be changed on account of the sand and water volcano, unless it ceases its eruption."

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What is a Mudboil?

The Tully Valley mudboils are volcanolike cones of fine sand and silt that range from several inches to several feet high and from several inches to more than 30 feet in diameter. Where active, mudboils are dynamic ebb-and-flow features that can erupt and form a large cone in several days, then cease flowing, whereas others may discharge continuously for several years. In the early 1990s the Onondaga Lake Management Conference was charged with improving the water quality of Onondaga Creek and Lake, and the Tully Valley mudboils were identified as a chronic water-quality problem within the Onondaga watershed. This report presents results of ongoing U.S. Geological Survey studies of mudboil activity and remediation efforts in the Tully Valley.

This newspaper article accurately describes mudboil activity and presages the collapse of the Otisco Road bridge, 92 years later in 1991. The article indicates that land subsidence occurred nearby, but gives no indication that Onondaga Creek was turbid; this was either an oversight by the reporter or was not a concern at that time.

In 1991, the Onondaga Lake Management Conference (OLMC) identified the Tully Valley mudboils as the major source of turbidity being discharged into Onondaga Lake. The OLMC created the Mudboil Working Group (representing local, State, and Federal agencies) in the fall of 1991 to develop a plan of study to identify the cause of mudboil activity and formulate ways to reduce or eliminate mudboil discharges, thereby decreasing associated turbidity in Onondaga Creek and nearby land subsidence. The U.S. Geological Survey, in cooperation with researchers from the New York State Department of Environmental Conservation and Syracuse University, began the first comprehensive, long-term study of mudboil activity in the Tully Valley. The initial hydrogeologic study was to (1) define the mechanism and extent of mudboil development; (2) drill test wells to define the glacial stratigraphy (layering of glacial materials) and thereby delineate ground-water flowpaths within the valley, including drilling a deep test well to penetrate the salt beds below the mudboil area; (3) monitor the flow and sediment concentrations of mudboils to calculate the amount of water and sediment discharged to Onondaga Creek; and (4) identify and implement remedial actions to reduce mudboil discharge and monitor the results of those actions.

The results of the hydrogeologic study indicated that flow from a mudboil is driven by artesian pressure that forces water and sediment upward from two sand and gravel aquifers through a 60-foot-thick layer of dense silt and clay which covers the floor of the Tully Valley. The artesian pressure within the aquifer can lift water 20 feet or more above land surface on the valley floor and 30 feet above the bed of Onondaga Creek. The source of the artesian pressure is related to the infiltration of surface water to the confined ground-water system along the valley walls—primarily at the southern end of the valley at the Tully Moraine and from valley-wall alluvial fans at the mouth of both Rattlesnake Gulf and Rainbow Creek (fig. 1). Water may also enter the mudboil aquifer system at the former brine field areas along the east and west valley walls in the southern part of the Onondaga (Tully) valley (fig. 1).

The flow of water from the mudboils changes seasonally in response to changes in artesian pressure in the two aquifers. In the spring, when ground-water recharge is greatest, mudboils in the main mudboil depression area (MDA) (fig. 1, inset map) can discharge 400 gallons per minute (gal/min) or more. As recharge to aquifers declines during the summer, artesian pressure in the aquifers also declines, and flow from mudboils typically decreases to about 200 gal/min or less. The rate of mudboil discharge does not change in response to individual rainstorms but does respond to seasonal variations in precipitation.

Suspended-sediment discharge from the MDA to Onondaga Creek had been measured between October 1991 and September 2008. The yearly average daily suspended-sediment load for water years[1] 1992–2008 is shown in figure 2. Most of the suspended sediment is very fine clay and silt with a small fraction of very fine sand.

Chemical analyses of mudboil discharge in the MDA indicate that the source of the discharged water is both the upper, confined freshwater aquifer and the underlying brackish-water (salty) aquifer (fig. 3). Chloride concentrations in the upper, freshwater aquifer range from 37 to 430 milligrams per liter (mg/L) and from 2,000 to 7,100 mg/L in the lower, brackish-water aquifer. The difference in chloride concentrations between these two aquifers is due partly to the source of salt, deep within the bedrock, as well as the greater density of the saltwater, which causes the brackish water to concentrate in the lower aquifer.

[1] Water year—This is the 12-month period from October 1 through September 30. The water year ending on September 30, 2008, is the 2008 water year.

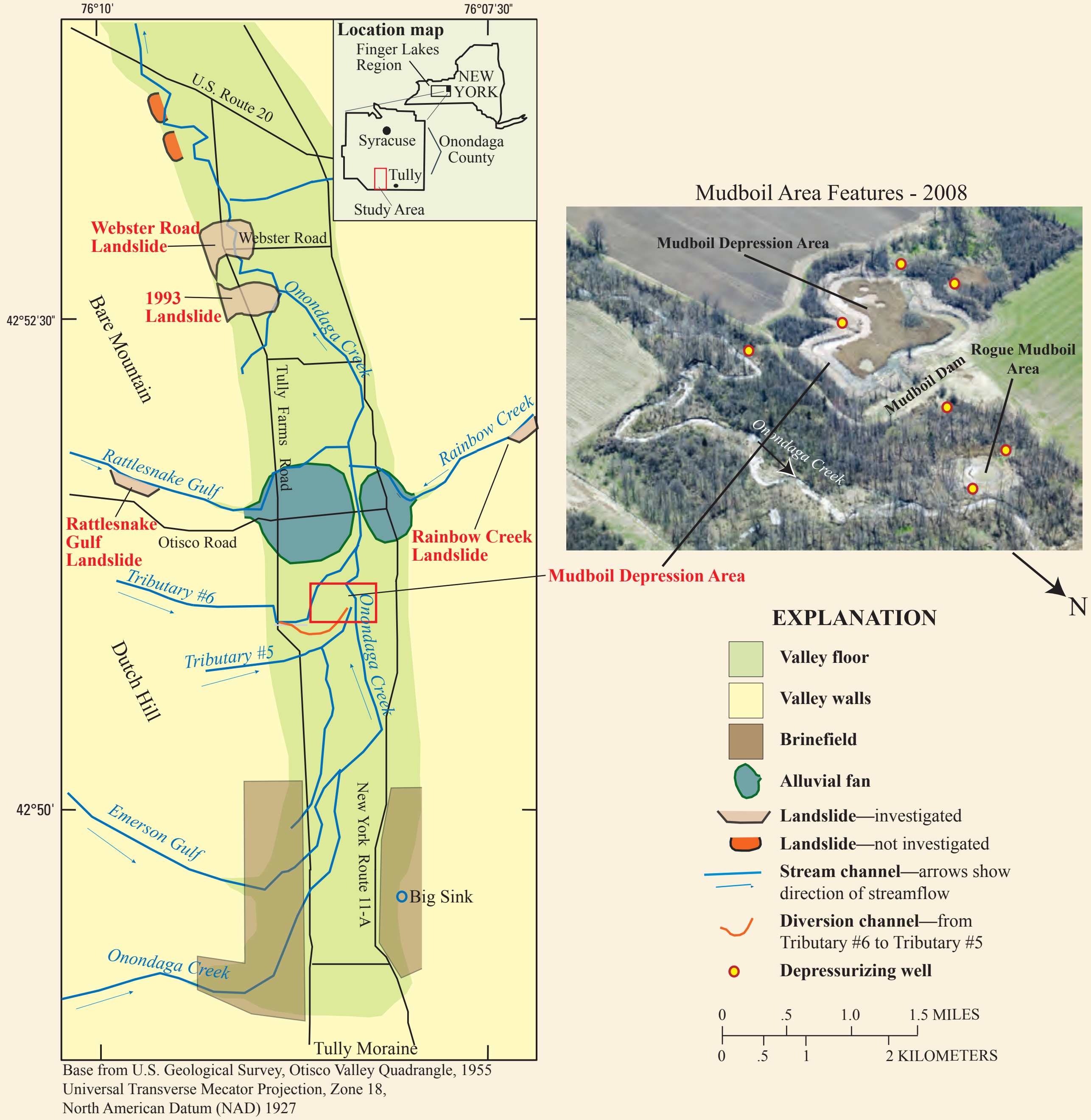


Figure 1. Physiographic features in the Tully Valley, Onondaga County, New York, and location of brine field, diversion channel, and mudboil areas. Insert picture shows detail of the Mudboil Depression Area (MDA), Rogue mudboil area, and location of several depressurizing wells and MDA dam.

Purpose of the Onondaga Lake Management Conference:
"*To prepare and implement a comprehensive Management Plan to define a cleanup strategy for Onondaga Lake, rehabilitate the Lake ecosystem, and restore beneficial uses of the Lake to the citizens of Onondaga County.*"
—Statement from: Citizens Advisory Committee, General Goals and Objectives, April 1991

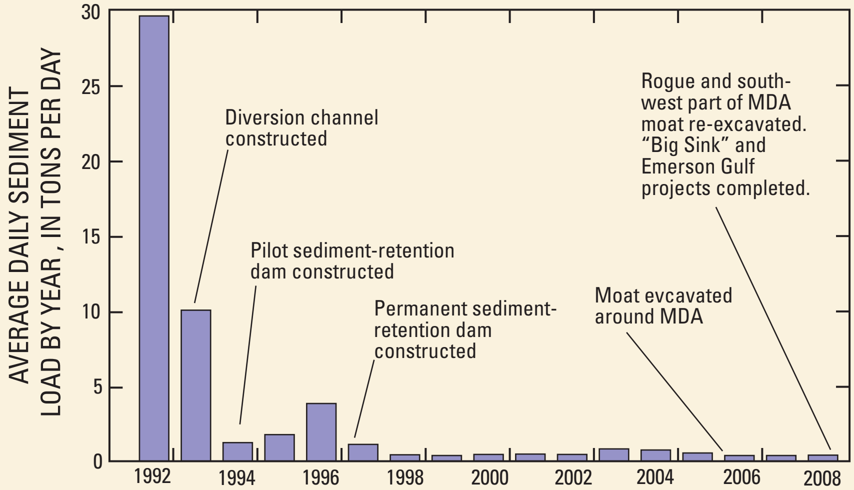


Figure 2. Annual average daily sediment load discharged to Onondaga Creek from the mudboil depression area (MDA) for water-years 1992–2008, and annotation of construction projects during that period.

Remedial efforts near the Tully Valley mudboils include (1) diverting flow from the tributary that feeds the MDA to an adjacent tributary, (2) installing depressurizing wells at several locations around the MDA and along Onondaga Creek to decrease the artesian pressure, (3) constructing a dam and sediment-retention impoundments to detain mudboil sediment that would normally discharge to Onondaga Creek, and (4) modifying several geologic features that allow surface water to recharge the ground-water system in the southern Tully Valley (alluvial fans, losing-stream reaches, and sinkholes).

Surface-Water Diversion

Flow from the upper 0.7 square miles of the Tributary #6 drainage area was diverted south to Tributary #5 (fig. 1) in June 1992. This diversion reduced total annual surface-water inflow to the MDA by about two-thirds, which in turn, reduced sediment loading to Onondaga Creek—from 30 tons per day (the equivalent of about 3 large dump-truck loads per day) before the diversion to about 10 tons per day (T/d) (about 1 dump-truck load per day) thereafter (fig. 2). Although effective, the diversion channel has required some maintenance to reduce sedimentation and erosion in the upper and lower reaches of the channel, respectively.

Aquifer Depressurizing Wells

Depressurizing wells were installed near the collapsed Otisco Road bridge during the winter of 1992–93 to test the concept of “locally” reducing artesian pressures in the upper aquifer, thereby slowing nearby mudboil activity. The wells were drilled to the base of the freshwater aquifer, and 10-foot-long well screens were installed to allow artesian-pressured water to flow out of the well while holding the fine-grained sand and silt in place. These two wells initially had a combined discharge of about 25 gal/min of sediment-free water and have modestly reduced artesian pressure in the freshwater aquifer by about 1 pound per square inch, or about 2.5 feet of hydraulic head within a 100-foot radius of each well. In 2008, the combined flow of these wells was about 10 gal/min as the aquifer matrix has been slowly clogged by fine-grained sediment drawn to the well screens with the flow of artesian-pressured water—well-screen redevelopment in 2007 did not substantially improve the flow rate at either well. While mudboil activity has not redeveloped near the former bridge site since the wells were installed 16 years ago, there is no guarantee that future mudboil activity will not return.

Eight additional wells were installed in the aquifer underlying the MDA and Onondaga Creek in 1996–1997 to further reduce artesian pressure and slow mudboil activity. Ground-water flow from all wells initially was about 350 gal/min, but in 2009 that total flow was about 150 gal/min. Aquifer-matrix clogging at each well screen has occurred, even after well redevelopment. The chemical quality of water discharged from these wells varies seasonally and with position around the MDA; most of the flows around and downgradient from (north of) the MDA are slightly brackish to saline, while one well south of the MDA has remained fairly fresh. A very slow and slight increase in chloride content has been seen in discharge from all the wells and is presently not a problem for aquatic life in Onondaga Creek (McKenna and others, 1999).

Sediment-Retention Dam

A temporary sediment-retention dam was constructed at the outlet of the MDA (fig. 1, inset map) in July 1993 to reduce the average daily load of sediment discharging to Onondaga Creek. The impounded water covered several mudboils and allowed most of the silt and sand to settle out before flowing to Onondaga Creek. Also, the weight of water over active mudboils, and the additional weight of sediment settling on the mudboils likely reduced mudboil discharge. The dam reduced the average daily load of sediment discharged from the MDA to

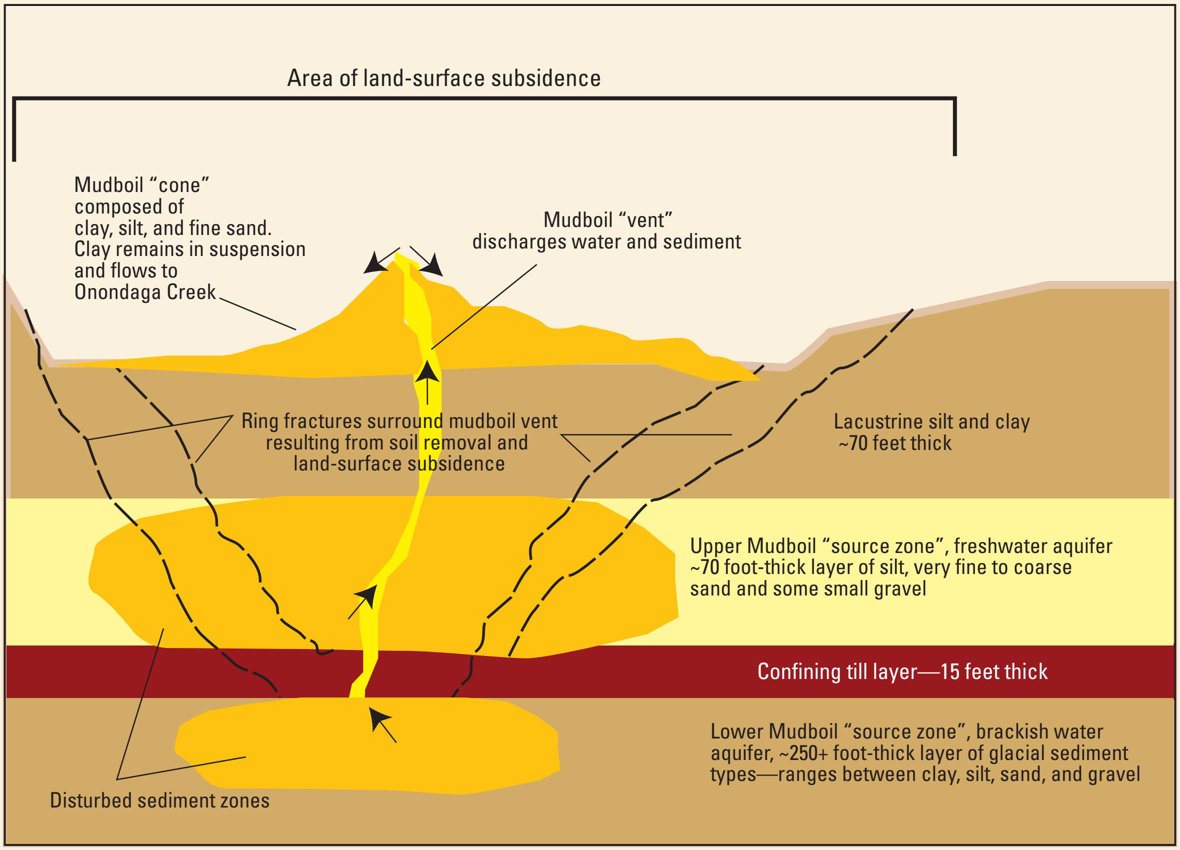


Figure 3. General sediment stratigraphy of glacial deposits beneath the mudboil area on the floor of the Tully Valley showing the upper (freshwater) and lower (brackish water) mudboil aquifer zones that discharge water and fine-grained sediment through mudboil vents. These discharged sediments create the mudboil cone and, in turn, cause land-suface subsidence. Water and finer-grained sediment flow to Onondaga Creek.

Onondaga Creek from 10 T/d in 1992 to about 1.5 T/d during water years 1993–94 (fig. 2). By 1995, however, the impounded area was filled with sediment, and sediment discharge to Onondaga Creek began to increase. The dam was reconstructed in the summer of 1996, and since that time the average-daily sediment discharge has remained at or below 1 T/d. The impoundment area did fill completely with sediment by 2004 and subsequently a "moat" was dug around the perimeter of the MDA to maintain its sediment-retention capability. However, as with most remedial activities, sections of the moat need to be periodically cleaned near active mudboils. A new mudboil area developed downstream from the MDA in 1998 ("Rogue" mudboil area shown on fig. 1, inset map) which requires similar remedial actions to keep the sediment loading to Onondaga Creek as low as possible.

Other Mudboil Aquifer Projects

In the western brine field area, Emerson Gulf (fig. 1) has long been known to lose surface water to the ground-water system at the rate of about 1 cubic foot per second or about 450 gal/min where the stream leaves its bedrock-lined channel and flows into a subsidence area. In the fall of 2008, a 450-foot section of the channel was lined with clay to prevent the loss of surface water to ground water and route the streamflow to the natural clay layer on the valley floor. In the eastern brine field, the water level in one of the larger sinkholes (fig.1, "Big Sink") fluctuates about 15 feet on an annual basis—while other sinkhole water levels in either brine field only change by about 1.5 feet annually. The bedrock exposure in the southeastern side of the sinkhole allows a direct hydraulic connection between the surface- and ground-water systems. The outlet of this sinkhole was lowered to prevent the 15-foot fluctuation, reduce surface-water infiltration, and eliminate the former 15-foot hydraulic head in the sinkhole from influencing the mudboil aquifer system. These two projects will be evaluated in 2009 and 2010 to determine if they are effective in reducing mudboil activity on the valley floor.

In a similar fashion, the alluvial fans at Rattlesnake Gulf and Rainbow Creek, where they enter the valley floor area on either side of the Tully Valley (fig. 1), also contribute surface water to the ground-water system at rates over 500 gal/min. A pilot project using "Green Technology"—windmill or solar-powered pumps—will be implemented in 2009 to determine if this technology can be used to reduce the amount of surface-water infiltration to the mudboil aquifer system and thereby further reduce mudboil activity.

Other Sources of Turbidity in the Onondaga Valley

The Tully Valley mudboils are not the only source of turbidity in Onondaga Creek. The 1993 landslide at the base of Bare Mountain (fig. 1), about 2.5 miles northwest of the mudboils, is but one in a series of landslides that contribute turbid, saline water to Onondaga Creek. Ongoing landslide activity is also occurring in middle sections of the Rainbow Creek and Rattlesnake Gulf tributary valleys (fig. 1), just north of the mudboils area. Remedial efforts to stabilize these landslides in the two side valleys are not possible due to difficult access, and the steep and unstable nature of the slopes that are currently failing. These landslide areas can contribute as much, if not more turbidity to Onondaga Creek than do the mudboils under the current mudboil-remediation program. Also, stream- and road-banks within the Onondaga Creek watershed can contribute sediment to the Creek during heavy runoff periods. Ongoing stream- and road-bank stabilization work by the Onondaga County Soil and Water Conservation District has reduced the amount of sediment being eroded from these potential sources.

Conclusions

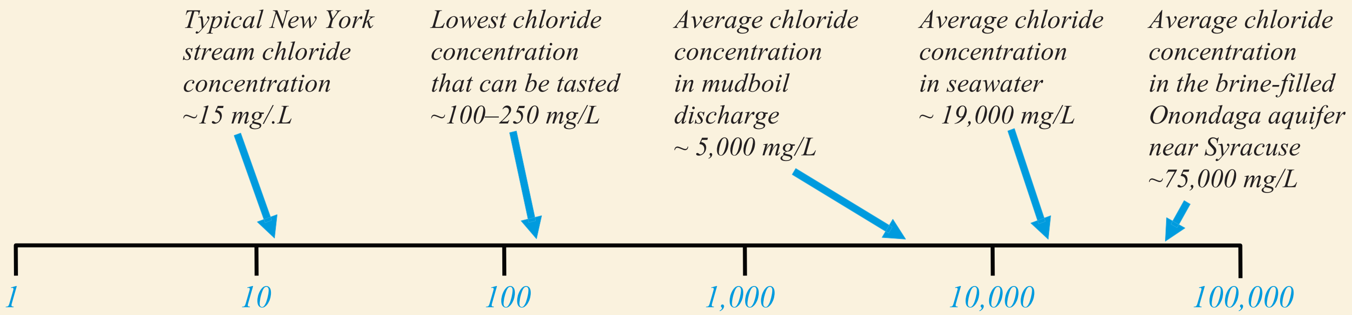
The Onondaga Lake Partnership's (OLP) primary goal is to restore Onondaga Creek and Onondaga Lake's ecological integrity. As one of seven major environmental issues identified by the Partnership that affect the quality of Onondaga Lake, the Tully Valley mudboils "must be controlled to improve the water quality of the Creek and Lake, and improve their ecologic habitats." The OLP has continued to fund the study and remediation of the mudboils begun by the Onondaga Lake Management Conference (OLMC) in the early 1990s but, Federal funds have declined; therefore, the OLP is hoping that the mudboil remediation projects will slow mudboil activity and make long-term management less costly. The OLP is also actively seeking other sources of funding to maintain this project, which is vital in keeping mudboil turbidity in Onondaga Creek and Lake as low as possible.

Over all, the past 15 years of mudboil study and remediation work has greatly improved the quality of Onondaga Creek and Lake. Even though other sources of erosion exist, the loading from all these other sources is much less than the original 30 T/d of sediment that was originally being discharged from the mudboils and carried by Onondaga Creek to Onondaga Lake.

By William M. Kappel

How Salty Is That?

Chloride Concentration, in milligrams per liter (mg/L) or parts per million (ppm)



Onondaga Creek – Average Chloride Concentrations (2004-2008)

Onondaga Creek at Tully Farms Road upstream of mudboils
~ 17 mg/ L

Onondaga Creek at Otisco Road downstream of mudboils
~ 170 mg/ L

Onondaga Creek at US Route 20 downstream of mudboils and Tully Valley landslides
~212 mg/ L

Onondaga Creek at Dorwin Avenue downstream of West Branch
~143 mg/ L

Recent History of Mudboils and Remediation Efforts

May 1991—Slow collapse of the Otisco Road bridge over Onondaga Creek begins.

July 1991—Mudboil appears upstream of Otisco Road bridge; bridge deck is removed soon thereafter.

October 1991—USGS Mudboil project begins.

Factors affecting flow and sediment loading to Onondaga Creek by Water Year (WY) [October 1–September 30].

WY 1992—Mudboil Depression Area (MDA) discharges, on average, ~29.7 tons/day of sediment to Onondaga Creek.
June 12, 1992—Diversion Channel construction completed—watershed area at MDA reduced from 1.02 mi^2 to 0.32 mi^2
Effect of Diversion Channel on sediment loading does not appear until later in 1992.

WY 1993—MDA discharges, on average, ~9.8 tons/day of sediment to Onondaga Creek from October 1992 through July 1993. July 1993—Bladder dam installed. Mudboil area discharges 0.4 tons/day August–September 1993.

WY 1994—MDA discharges, on average, ~1.4 tons/day of sediment to Onondaga Creek.
November 1993—Bladder dam replaced by temporary earth-fill dam.

WY 1995—MDA discharges, on average, ~1.8 tons/day of sediment to Onondaga Creek.
1995–96 Pilot depressurizing wells installed either side of the Otisco Road Bridge.
West side well (December 1995) East side well (January 1996).

WY 1996—MDA discharges, on average, ~4.7 tons/day of sediment to Onondaga Creek.
1996–Present earth-fill dam reconstructed—completed October 1996. Depressurizing wells installed, fall 1996.

WY 1997—MDA discharges, on average, ~0.8 tons/day of sediment to Onondaga Creek.
Rogue mudboil area develops late 1996, depressurizing well 97-1 installed January 1997.

WY 1998—MDA discharges, on average, ~0.6 tons/day of sediment to Onondaga Creek.

WY 1999—MDA discharges, on average, ~0.4 tons/day of sediment to Onondaga Creek (October 1998 through June 1999—9 months of record).

WY 2000—MDA discharges, on average, ~0.6 tons/day of sediment to Onondaga Creek (full year).

WY 2001—MDA discharges, on average, ~0.5 tons/day of sediment to Onondaga Creek.

WY 2002—MDA discharges, on average, ~0.8 tons/day of sediment to Onondaga Creek.

WY 2003—MDA discharges, on average, ~1.4 tons/day of sediment to Onondaga Creek.

WY 2004—MDA discharges, on average, ~1.2 tons/day of sediment to Onondaga Creek.

WY 2005—MDA discharges, on average, ~0.7 tons/day of sediment to Onondaga Creek.
During a fairly dry summer, extensive maintenance work occurs at the MDA and Rogue areas—digging of a '"moat" around the MDA, excavation of the entire Rouge impoundment area, and redevelopment of five depressurizing wells. Well redevelopment efforts gain little increase in flows, but sediment concentrations leaving the MDA and Rogue areas do fall in relation to the successful dredging activities.

WY 2006—MDA and Rogue area discharges, on average, ~0.6 tons/day of sediment to Onondaga Creek.
Due to an above-normal amount of precipitation during 2006, a mudboil in the southwest corner of the MDA discharges large amounts of sediment and fills ~400 feet of the moat. These sediments were removed in the summer of 2006. Land-surface subsidence is noted along the southwest rim of MDA.
Increased mudboil activity also is noted in the Rogue mudboil area with associated land-surface subsidence. The wells on either side of the Rogue area shift, and soon thereafter sediment and turbid water discharge between well and surface casings, followed by the development of mudboils adjacent to the failing wells.

WY 2007—MDA and Rogue area discharges, on average, ~0.5 tons/day of sediment to Onondaga Creek.
As stated above (WY 2006) increased mudboil activity is continuing at the Rogue mudboil area with associated land-surface subsidence. The 97-1 well is lost to mudboil activity (casing slips into sinkhole created by the mudboil) and there is a large mudboil at 96-3 (close to the tributary stream and Onondaga Creek), and in the summer of 2007 two mudboils developed along the tributary channel. This area has also subsided by several feet—Onondaga Creek might become involved if a mudboil develops in the channel.

WY 2008—MDA and Rogue area discharges, on average, ~0.6 tons/day of sediment to Onondaga Creek.
Increased mudboil activity is continuing at the Rogue mudboil area, and the area adjacent to well 96-3 continues to subside. Dredging of the southwest quadrant of the MDA and Rogue areas took place in the summer of 2008. In the brine fields south of the MDA a 500-ft section of Emerson Gulf Creek (west brine field) was lined with clay to reduce surface-water infiltration to the mudboil aquifer. In the east side brine field, the outlet of "Big Sink" was lowered by 15 feet to keep the sinkhole water level at its usual summertime low level and to reduce surface-water infiltration to the mudboil aquifer.

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