

In cooperation with Onondaga Lake Cleanup Corporation

Hydrogeology of the Tully Lakes Area in Southern Onondaga and Northern Cortland Counties, New York

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Postcard (circa 1895) showing the Lake Park Hotel on the west shore of Tully Lake
(Courtesy of the Tully Area Historical Society)

Water levels in a series of kettlehole lakes and ponds known as the Tully Lakes respond to seasonal water-level changes in the surrounding aquifer but often differ from ground-water levels in the aquifer because the lakebed sediments are poorly permeable and inhibit the exchange of water. Three sets of ground-water-level measurements were made from the spring recharge period of 2000 through the fall of that year. Seasonal ground-water-level declines ranged from 1.5 to 8 feet. Average annual water-level fluctuations in the three western lakes ranged from 2.5 to 6 feet, whereas those in the two eastern lakes were only about 1.5 feet because these lakes have natural outlets. The ground-water divide between the St. Lawrence and Susquehanna River Basins did not coincide with the surface-water divide and the ground-water divide moved southerly in response to lower water levels in the aquifer during the summer and fall.

INTRODUCTION

The topography of central New York, and the associated hydrologic systems are the result of the advance and retreat of glaciers during the last (Wisconsinan) glaciation. A pause in the retreat of the glacial ice led to the formation of the Valley Heads Moraine near the village of Tully (fig. 1). This moraine, which consists mostly of sand and gravel with some till, trends east-west across the southern end of Tully Valley and forms the surface-water drainage divide between the St. Lawrence and Susquehanna River Basins.

The Tully Lakes area (fig. 1) encompasses a 3-square-mile area within the moraine and is characterized by gentle rolling hills, and kettlehole lakes and ponds. The coarse-grained moraine deposits and glacial outwash that extend south of the moraine form a large unconfined surficial aquifer, from the West Branch Tioughnioga River to the village of Tully. The area contains six kettlehole lakes (Green, Tully, Crooked, Song, Tracy, and Mud), several kettlehole ponds (Gatehouse, Round, and a few unnamed ponds), and several seasonally wet to permanently dry kettleholes. All of the western lakes and ponds (Song, Crooked, Mud, and Tracy Lakes, and Round and Gatehouse Ponds) were naturally landlocked, with no perennial inlet or outlet, until European settlement in the early 1800's. By the mid-1800's, outlet pipes or channels had been installed in Gatehouse Pond and Crooked, Mud, and Tracy Lakes to allow use of their water by several industries over the next 120 years. The two eastern lakes (Green and Tully), in contrast, have natural outlets at their southern ends. Green Lake drains through a short channel into the northern end of Tully Lake. The West Branch Tioughnioga River enters Tully Lake on its southeastern side (fig.1) and resumes its course at the southern end of Tully Lake. All of these lakes and ponds are connected to the surficial aquifer, but their water levels fluctuate individually, depending on the degree of hydraulic connection with the aquifer.

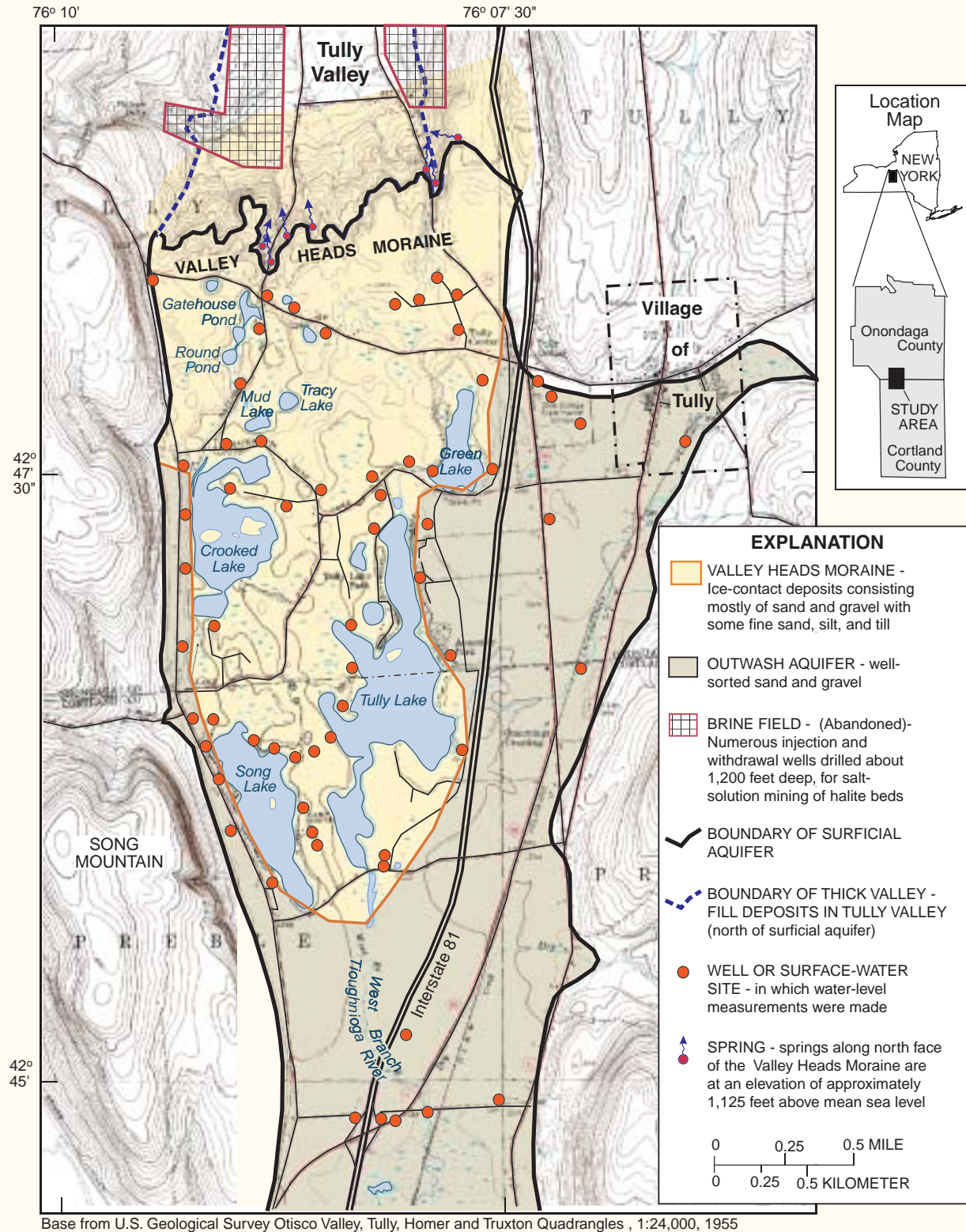


Figure 1. Principal geographic features of Tully Lakes area, including surficial aquifer, Valley Heads Moraine, Tully Valley brinefield, and locations of wells and water bodies used for water-level measurements.

PREVIOUS HYDROLOGIC STUDIES

The Tully Lakes area was first studied in the late 1800's, when J.J.R. Croes investigated the lakes' potential as a water supply for the city of Syracuse. Croes (1871) provided the first hydrologic data on the lakes, including their size, depth, and general water quality, and speculated on the water-quality differences among the lakes. Croes divided the lakes into two groups—the western lakes (Crooked, Van Housen [now named Song], and Mud Lakes) and the central-valley lakes (Green and Big [Tully] Lakes, referred to herein as the eastern lakes).

Croes (1871) mistakenly identified natural marl deposits in Green and Big [Tully] Lake as white limestone. The deposition of marl in a lake generally indicates high concentrations of calcium carbonate in the ground water and lakewater and is a visible indicator of the waters' hardness. Croes also noted that the banks of Crooked and Van Housen [Song] Lakes consisted of gravel but contained no "limestone" (marl deposits), presumably because the major source of the lake water is runoff from the shale hillsides to the west and, therefore, has little time in contact with the calcium-rich sand and gravel deposits along the western shores of these lakes. The absence of marl in Crooked and Van Housen [Song] Lakes indicates a softer ground water than that found in the eastern lakes area. Croes also noted that water from the four naturally landlocked northwestern lakes and ponds (Crooked, Mud, Tracy, and Gatehouse) had been diverted to the north 35 years earlier by constructed channels and that the annual water-level fluctuation in Crooked Lake was about 5 feet. Eventually, in the late 1880's, Skaneateles Lake, 6 miles to the northwest, was chosen as the water supply for Syracuse: thus, they were not altered for water-supply purposes.

Hollister (1905) compared the general water quality of several springs that discharge along the northern face of the Tully Moraine to water quality of the Tully Lakes. He noted, as Croes did, that... *"Song, Crooked, and Mud Lakes are comparatively soft due to surface and subsurface seepage of soft water off the western hillside. Green and Big [Tully] Lakes lie in the center of the valley surrounded by glacial material and have relatively high alkalinity and sodium chloride [salt] concentrations."*

Hollister also noted that... *"the marked difference in character of water in these two sets of lakes seems to point to the probability that subsurface water passes through the glacial gravels and, after becoming highly concentrated with calcium carbonate and sodium chloride by contact with the glacial material, this water appears in Green and Big Lakes greatly altered."*

Hollister's conclusion was that ground waters in this region ... *"take up, from whatever source, large quantities of salts found in the glacial debris and [this water] appears highly charged with them in the central lakes and in the springs which discharge off the north side of the moraine."*

Since Hollister's report (1905), several dissertations by students at Syracuse University and State University of New York at Syracuse - College of Environmental Science and Forestry (Mosley, 1983; Heath, 1974; and Durham, 1954; among others) have discussed the glacial sediments and water-quality characteristics of the Tully Lakes, the Valley Heads Moraine at Tully, and the two contrasting aquifer systems north (Tully Valley) and south (Tioughnioga Valley) of the moraine.

What is Marl?

Marl is formed through a long-term process. Glaciers eroded limestone and calcium-rich shale bedrock north of the Valley Heads Moraine and deposited calcium-rich gravel, sand, and fine sediment at the moraine and south of it. The calcium was subsequently leached by ground water into adjacent ponds and lakes, where it accumulated in the water column through chemical concentration or through biological actions of certain bacteria and plankton. During the summer, when surface-water temperatures and rates of organic decomposition would increase, the lakes' acidity would decrease and cause the calcium to precipitate as calcium carbonate from the water column to the lakebed. This process can cause what is called a "whiting event," whereby a lake's water becomes cloudy as calcium carbonate settles. Over time, the calcium carbonate mixes with organic detritus and fine lakebed sediment to form a cementlike deposit known as marl.

Hydrologic Study of the Tully Lakes, 1998-2000

In October 1998, the U.S. Geological Survey (USGS) began a study of the Tully Lakes area that included continuous water-level monitoring of Gatehouse Pond and Song, Crooked, Green, and Tully Lakes from October 1998 through November 2000. Synoptic ground-water-level measurements were made at about 50 wells (mostly domestic) on April 26, August 10, and October 26, 2000 to identify seasonal water-level differences, directions of ground-water flow, and degree of interaction between ground water and surface water.

Lake-Level Fluctuations

Water levels in all Tully Lakes are controlled by the amount of precipitation, recharge from upland sources, surface-water runoff, rates of evaporation from the lake surface and transpiration by wetland plants, rates of ground-water seepage into and out of the lakes, and elevation of outflow channels, if present. Average annual water-level fluctuations in the western lakes during the study ranged from as small as 2.5 feet in Gatehouse Pond to as large as 6 feet in Crooked Lake (fig. 2). Water-level fluctuations in the eastern lakes were much less—about 1.5 feet.)

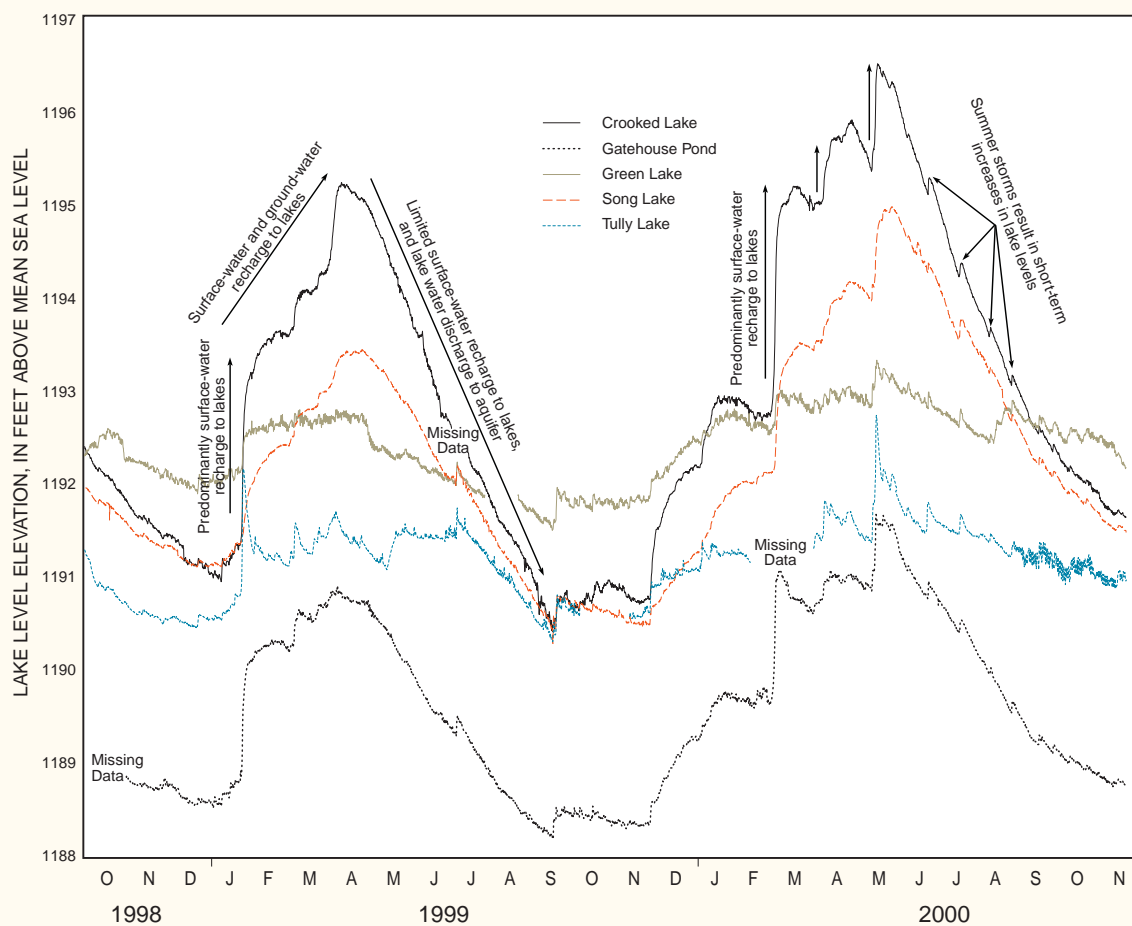


Figure 2. Water-surface fluctuations in five Tully Lakes, October 1998 through November 2000. (Locations are shown in fig. 1.)

Western Lakes and Ponds

Runoff from the hillsides along the west side of the Tioughnioga Valley can quickly recharge the three western lakes through surface-water flow (Gatehouse Pond and Crooked and Song Lakes) during winter snowmelt and early spring rain periods and cause lake levels to rise as much as 2 feet within 4 to 5 days (fig. 2). Before and after these sharp rises, the lake levels generally rise slowly when recharge consists only of ground-water seepage along the west sides of these lakes. Recharge to these lakes exceeds discharge from them during the late winter and early spring and results in rising lake levels; whereas recharge during the summer is greatly diminished by high rates of evapotranspiration by wetland plants, evapotranspiration from trees on the forested hillsides, and limited water storage in the thin hillside soils.

Discharge from the western lakes occurs through (1) seepage through the lakebeds, especially along the eastern side of these lakes, (2) outflow through the constructed channels, especially during high-flow periods, and (3) evapotranspiration during the warm season.

Eastern Lakes

Water levels in the two eastern lakes (Green and Tully Lakes) during the late winter and early spring of 2000 typically rose about 1.5 feet, mostly in response to ground-water seepage; those in Tully Lake resulted from inflow from the West Branch Tioughnioga River as well as ground-water seepage. Water levels in these lakes fluctuate less than those in the western lakes because the eastern lakes have outlets that allow rapid surface-water discharge. Outlet structures (dams or culverts) usually control the water level of the two eastern lakes, but beaver dams can affect lake levels periodically.

Water levels in the eastern lakes decline during the summer, when the rate of discharge exceeds the rate of recharge, mostly through lake-surface evaporation and by transpiration of wetland plants. Heavy rainstorms during the summer that produce short-term, storm-water runoff from the uplands can cause small rises in lake levels (fig. 2).

A Lake by Any Other Name

Several of the references cited in this report refer to some of the lakes by other names. A compendium of the lake names, and the references to these names from about 1850 to the present, is given below:

Current name	Former names	Source of information
Crooked Lake	Crooked Lake	Map of Onondaga County (French, 1859), the name has remained the same since that time.
Green Lake	Little Lake	Map of Onondaga County (French, 1859)
	Little Lake	Map of Onondaga County (Dawson, 1860)
	Green Lake	Map of Onondaga County (Clarke, 1889)
Tully Lake	Oserigooch	1745 citation by Spangenberg (Beauchamp, 1908)
	Susquehanna Lake	1766 citation by Zeisberger (Beauchamp, 1908)
	Big Lake	Croes (1871)
	Big Lake	Atlas of Cortland County - Town of Preble (Sweet, 1874)
	Tully Lake	Incorporation of the Tully Lake Association - 1888
	Big Lake	Hollister (1905)
	Tully Lake	Lake-level data of the Solvay Process Company 1924
Song Lake	Big Lake	USGS topographic map, 1947 - Note: Tully Lake Park is annotated on the west shore of the lake; the name apparently varied through and after this period.
	VanHousen Lake	Croes (1871)
	Preble Lake	Atlas of Cortland County - Preble Town(ship) (Sweet, 1874)
	Song Lake	Hollister (1905)

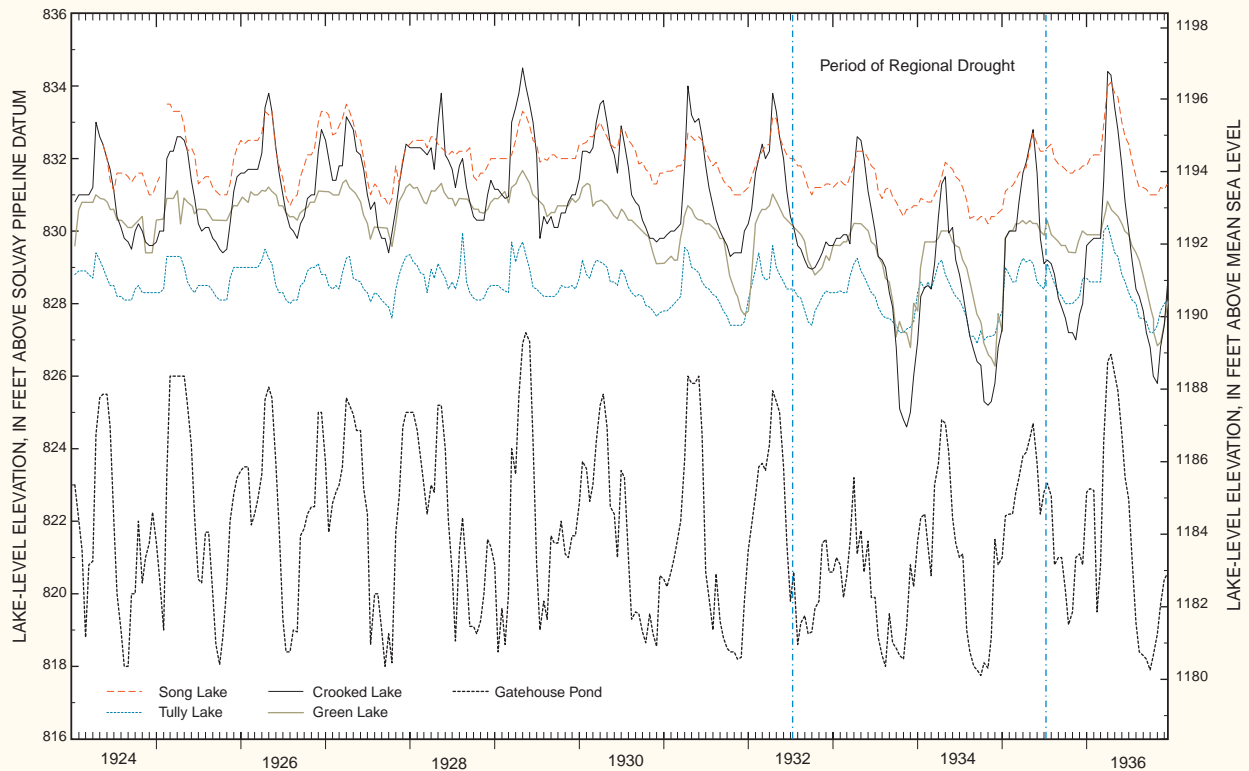


Figure 3. Lake-level fluctuations in five of the Tully Lakes, 1924-36. Water from Gatehouse Pond and Crooked Lake was diverted to the Tully brinefield during this period; the other three lakes had no diversions. (Data from the Solvay Process Company records, 1924-36.)

Historic Water-level Fluctuations

Water-level fluctuations in the Tully Lakes area were recorded by a mining company beginning in the late 1800's. The company used water from Crooked Lake, Gatehouse Pond, and intervening ponds for solution mining of halite (salt) beds in Tully Valley. Water levels in these lakes, as well as those in Song, Green, and Tully Lakes, which were not diverted, are plotted in figure 3. During the drought period of 1933-35, water levels in the lakes with diversions continued to follow trends seen in Green and Tully Lakes, which had no diversions. Therefore, the water levels in lakes probably were controlled by water levels in the surrounding aquifer, but the effects of diversion were most clearly seen in Gatehouse Pond, which supplied water to the Tully Valley. Gatehouse Pond is closest to the northern edge of the moraine, where aquifer levels were probably below the pond

bottom and, therefore, could not recharge the pond with ground water.

Lake-level fluctuations from October 1930 through November 1932 and from October 1998 through November 2000 are depicted in figure 4. Water levels in Gatehouse Pond were strongly affected by the diversion of water to the brinefield during the earlier period. The water-level fluctuations in Crooked, Green, and Tully Lakes were similar during both periods, even though some water from Crooked Lake was diverted for brine mining. The reason(s) for higher annual water levels in Song Lake during the 1930's than during the late 1990's is uncertain—it could be attributed to a less forested western hillside in the 1930's, which may have allowed greater recharge from the hillside to the lake through the summer, or, possibly, it could be due to an incorrect elevation datum for the 1930's lake level.

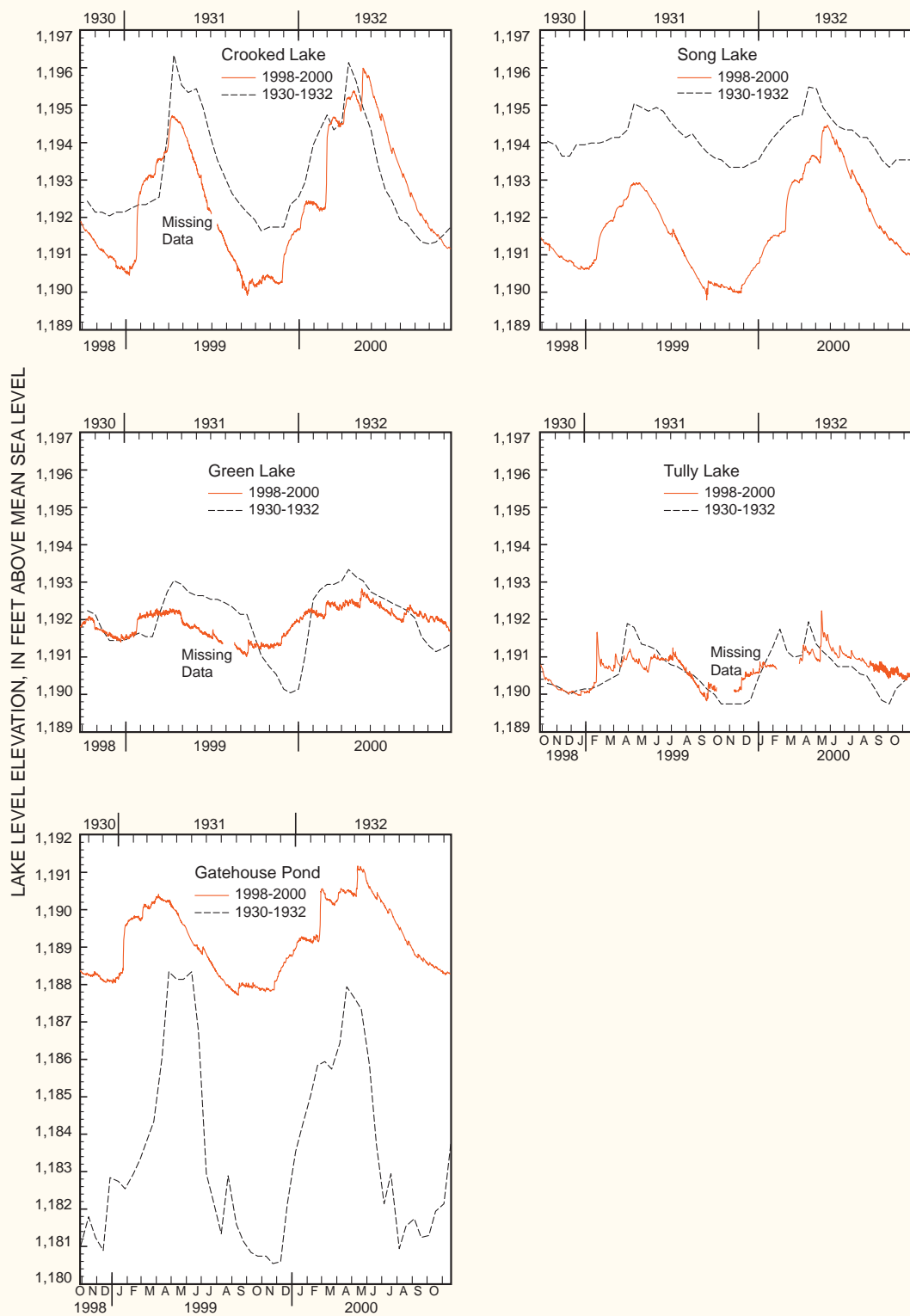


Figure 4. Lake-level fluctuations during 1930-32 during diversion of water from Gatehouse and Crooked Lakes to the Tully Valley, and during 1998-2000, when no diversions were occurring. (1930-32 data from Solvay Process Company.)

Water-Level Maps and Directions of Ground-Water Flow

The upper surface of the saturated zone in an aquifer is referred to as the water table. The depth to the water table in the Tully Lakes area is highly variable and can range from zero, where the water table is at land surface, to more than 50 feet. The depth to the water table is the depth to standing water in a well finished just below the water table. Water levels in wells finished at depths far below the water table, and in confined aquifers, are referred to as the potentiometric surface. Water-table and potentiometric-surface maps can be used to estimate an approximate depth for proposed wells, and lines drawn perpendicular to water-table and potentiometric-surface contours indicate the direction of ground-water flow. Water levels continuously fluctuate in response to changes in recharge and discharge patterns; therefore, any true representation of the water table or potentiometric surface refers only to a specific time and must be based on water levels measured at multiple locations at approximately the same time (a set of synoptic measurements).

Ground-water Levels in the Surficial Aquifer

In early 2000, a network of wells was established within the Tully Lakes area through the assistance of many homeowners and businesses who allowed access to their wells for this water-level survey. The water level in each well was measured three times (April 26, August 10, and October 26, 2000) to document (1) the location of the ground-water divide between the St. Lawrence and Susquehanna River Basins, (2) the seasonal decline in ground-water levels from high- to low-recharge conditions, (3) surface-water/ground-water interaction, and (4) the direction of ground-water flow.

Location of Ground-Water Divide and Seasonal Water-Level Decline

Potentiometric-surface (ground-water elevation) maps for April 26 (spring recharge period) and October 26 (fall dry period), 2000, were constructed (figs. 5A, 5B). The potentiometric-surface contours indicate that the major ground-water divide trends roughly west-east about 1 mile south of the crest of the moraine and migrates southward during the summer as ground-water levels decline. The water-level declines from April through October 2000 ranged from 1.5 to 8.0 feet.

Most ground water north of the divide flows northward and discharges to springs at an elevation of about 1,125 feet above sea level on the northern slope of the Valley Heads Moraine; the rest flows northward as underflow to deeper zones of valley-fill deposits in Tully Valley. The uniform elevation of the major springs is attributed to a layer of silt and clay and (or) a layer of cemented gravel near this elevation that forms the bottom of the sand and gravel aquifer and cuts across the face of the moraine. Ground water south of the divide flows southward through the West Branch Tioughnioga River Valley and enters the Tioughnioga River, which ultimately flows into the Susquehanna River.

Surface-Water/Ground-Water Interaction

The synoptic water-level measurements indicate that water levels in the western lakes are generally above those in the surrounding surficial aquifer; therefore, water seeps from the lakes to the aquifer most of the time. In contrast, the eastern lakes generally receive water from the aquifer. Green Lake commonly receives ground-water flow along its east side and discharges to the aquifer along its west side. Tully Lake receives ground-water flow from all sides during the spring recharge conditions; then, as water levels decline from summer through early winter, it discharges to the aquifer along its southern edge. The water-level measurements also indicate that the surficial aquifer may be only moderately connected to some of the lakes, inasmuch as lake levels in the western lakes are substantially higher than ground-water levels in the aquifer throughout the year, even long after surface-water runoff to the lakes has ceased. Lake-bottom sediments probably are poorly or semipermeable, in that they consist of fine-grained material such as clay, silt, organic muck, marl, or perhaps, in places, dense till, all of which impede the movement of water between the lakes and the surrounding aquifer.

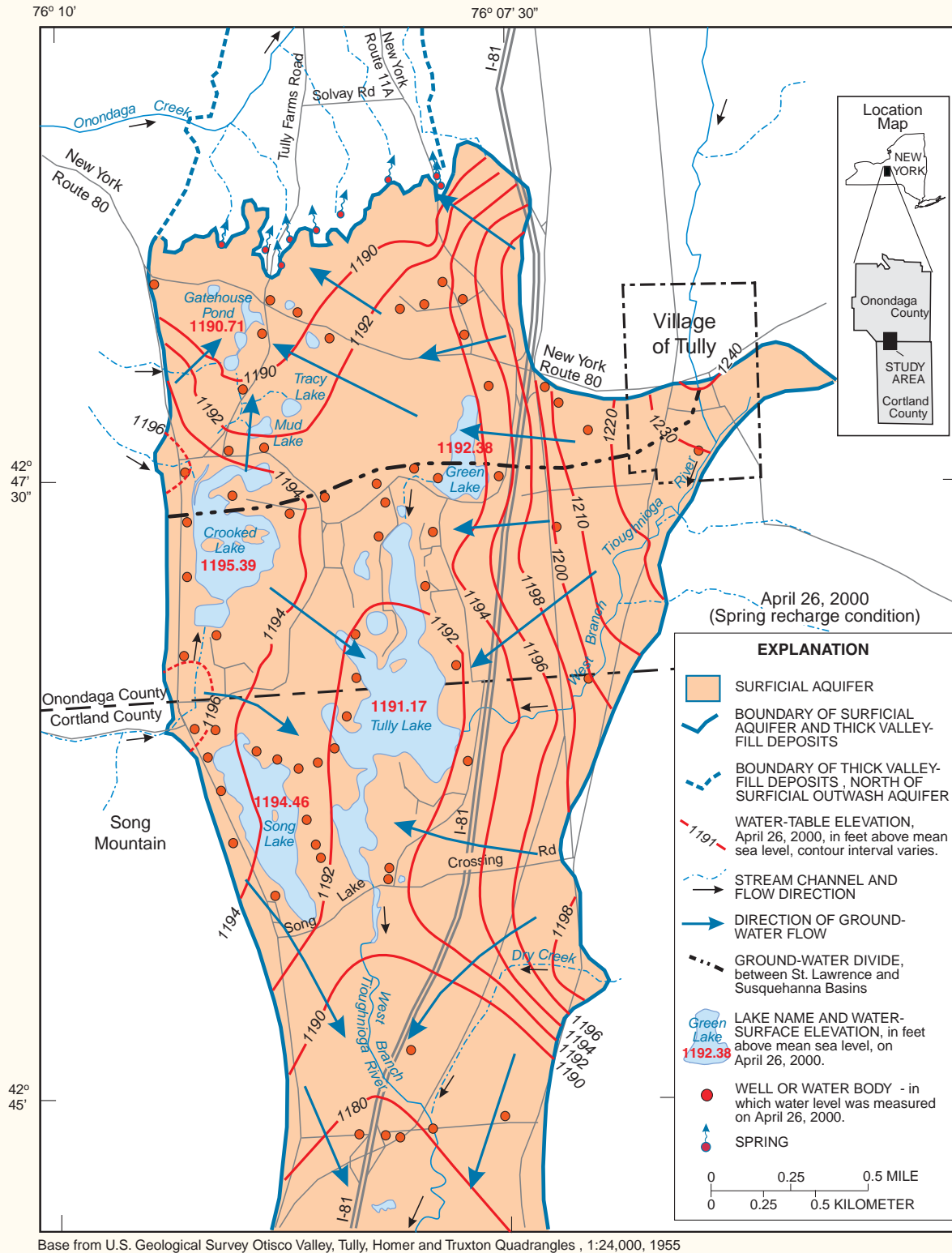


Figure 5A. Potentiometric-surface map of Tully Lakes area during spring recharge period (April 26, 2000) showing water-table elevations, directions of ground-water flow, and location of ground-water divide between the St. Lawrence and Susquehanna River Basins.

Direction of Ground-Water Flow

Ground water flows from areas of higher head to areas of lower head and, in the Tully Lakes area, is controlled by the distribution of recharge, locations of discharge areas, and the geometry of the aquifer. Ground water generally flows from the edges of the valley toward the center, where it discharges to lakes, ponds, wetlands, springs, and the West Branch Tioughnioga River (figs. 5A and 5B).

Green Lake —

Ground water in the tributary valley near the village of Tully flows west and either discharges into Green or Tully Lake along their eastern shores, or remains in the aquifer as underflow that moves to the south or north, depending on the location of the ground-water divide. Ground water that enters Green Lake from the east-shore area can (1) leave the lake as surface water through its southern outlet, (2) be lost through evapotranspiration, or (3) flow back into the aquifer along the west side and flow either northward toward the Valley Heads Moraine or southward toward Tully Lake.

Tully Lake —

Tully Lake receives surface-water inflow from Green Lake and the West Branch Tioughnioga River, and receives ground-water seepage from the east-, north-, and west-shore areas. Water discharges from Tully Lake through (1) evapotranspiration, (2) as surface water through the Tully Lake outlet at the southern end of the lake, and (3) as ground-water underflow that seeps into the aquifer from the southern part of the lake.

Song Lake, Crooked Lake, Gatehouse Pond —

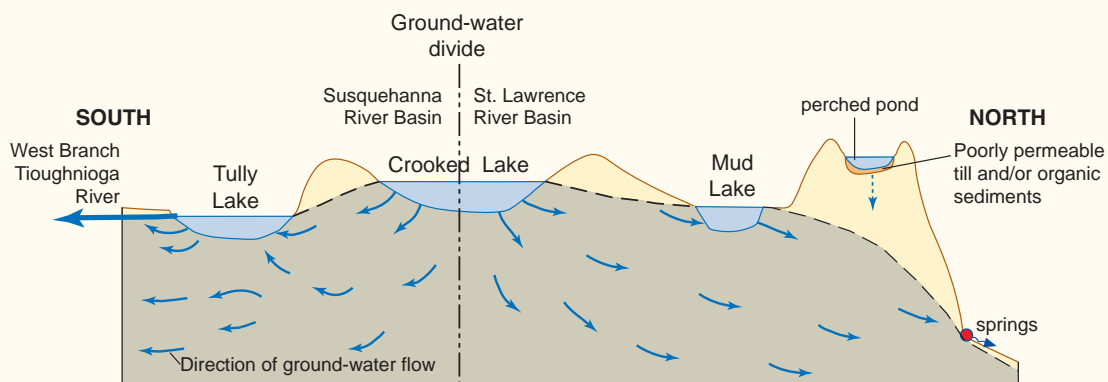
These water bodies receive recharge from upland sources to the west. This recharge is derived partly from (1) surface runoff from the hillside tributary channels that lose water to the aquifer, at and downstream from, the point where the bedrock hillside intersects the unconsolidated deposits of the valley floor, and (2) direct surface-water runoff from these tributaries to the lakes in the spring. The lakes lose water through evapotranspiration and through lateral seepage into the surficial aquifer at their northern, eastern, and southern ends. (Crooked Lake loses some water as surface outflow through its channel connection to Gatehouse Pond during periods of high flow). Seepage losses from Crooked Lake, like those from Green Lake, flow partly northward to the Tully Valley and partly southward toward Tully Lake and the West Branch Tioughnioga River. Seepage from Gatehouse Pond generally moves northward into the Tully Valley, whereas seepage from Song Lake moves eastward toward Tully Lake and southward, down the West Branch Tioughnioga River Valley.

GROUND-WATER-FLOW PATTERNS IN THE TULLY LAKES AREA

Kettlehole lakes and wetlands do not necessarily occupy the lowest areas; they can be found on slopes or even on drainage divides. They can receive seepage from ground water or can be a source of ground-water recharge, or they may receive inflow and provide outflow at different locations within the same depression.

The interaction between surface water and ground water is determined largely by position with respect to local and regional ground-water flow systems. A common belief is that lakes and wetlands in relatively high areas recharge ground water, and that those in low areas are recharged by ground water. However, lakes and wetlands that are underlain by poorly permeable deposits (see perched pond, below) can receive seepage from local ground-water system even if they are in a high area; conversely, they can lose water to local ground-water systems even if they are in a low area.

Kettlehole lakes and wetlands underlain by highly permeable deposits can receive ground-water seepage on one side and discharge ground water on the other side. The boundary between inflow to the lake or wetland and outflow from it, termed the hinge line, can move up and down along the shore (Winter and others, 1998) depending on the changing slope of the water table in response to fluctuations in ground-water recharge in the adjacent uplands.



Conceptual ground-water flow system for the Tully Lakes area, showing the interaction of kettle-hole lakes and the surficial aquifer.

DIVERSIONS AND DAMS - ALTERATIONS TO THE NATURAL SYSTEM

Diversion of water from several of the lakes and ponds in the northwestern part of the Tully Lakes study area (Crooked, Mud, and Tracy Lakes and Gatehouse and Round Ponds) began in the mid-1800's, when water from these lakes and ponds was diverted through constructed channels, some across their natural surface-water divides. Onondaga County maps and atlases dating from 1852-89 indicate that water was diverted into the Tully Valley for use by a sawmill, a carding mill, a rake factory, and possibly a tannery (Sidney and Neff, 1852; French, 1859; Dawson, 1860; Sweet, 1874; and Clarke, 1889).

Water-level Modifications at Gatehouse Pond

In the late 1880's, a brine-mining company rebuilt a small dam and constructed a gate structure on Gatehouse Pond to provide an adequate supply of water for salt-solution mining in the Tully Valley. In the early 1900's, the company increased the storage capacity by increasing the height of the dam 6 feet, which caused Gatehouse and Round Ponds and another small kettlehole pond (fig. 1) to merge into a single water body that is now called Gatehouse Pond. Outlying ponds and lakes to the south (Tracy, Mud, and Crooked Lakes) were also connected by constructed channels, pipes, and gate structures to further increase the water-storage capacity of the reservoir system. From the 1900's through the early 1960's, this series of lakes and ponds was the water supply for the solution-mining operations. After closure of the eastern brine field in the early 1960's, a small amount of water continued to flow through the pipeline into the Tully Valley until the early 1990's, when all pipes and gates were sealed.

After a flood during the spring of 1993, the overflow pipe in the old gatehouse structure was lowered 1 foot to mitigate future flooding along Gatehouse Road. Twice in 1996 similar flooding resulted; therefore, a culvert was installed at the outlet of Crooked Lake, and an additional 1-foot notch was cut into the overflow pipe at the old gatehouse structure to further reduce flood potential around Gatehouse Pond and Crooked Lake. Although these actions may have decreased flooding around these water bodies, the lowering of the overflow pipe caused the water level of Gatehouse Pond to rapidly fall to the outlet elevation of the overflow pipe much earlier in the year than would have occurred through natural leakage to the surrounding aquifer. In 2001, the notch was repaired to return the overflow point to its pre-1997 level, effectively raising the springtime water level of Gatehouse Pond by 1 foot.

Diversion of the Song Mountain Tributary

Currently (2001) the tributary that drains the north side of Song Mountain (fig. 1) enters the valley floor, then turns northward to enter the southern end of Crooked Lake. During high-flow periods, the stream has overflowed its banks with such force that it has caused the tributary waters to flow across an open field toward the northern end of Song Lake. Some time in the 1830's, water may have been diverted from the Song Mountain tributary to Crooked Lake, when water from Crooked Lake and other ponds was diverted northward into the Tully Valley. The earliest map of Onondaga County (Sidney and Neff, 1852) shows the tributary in its present position and draining to Crooked Lake, but the 1871 report by Croes indicates that the diversion of Crooked Lake and intervening lakes to Gatehouse Pond took place as early as 1836 (35 years earlier). If a map dating from before 1836 could be found, it might confirm the possible diversion of water from the Song Mountain tributary to Crooked Lake, although the reliability of hydrogeography on these early maps is uncertain. An 1838 atlas of the State of New York (Burr, 1838) shows the four major Tully Lakes (Crooked, Song, Tully and Green Lakes) as one V-shaped lake, whereas the 1840 atlas of Cortland County (Burr, 1840) indicates a stream draining from the northern end of Song Mountain into the upper third of Song Lake at a location where no former channel exists in the modern topography of the Song Mountain hillside. The question of a possible diversion of the Song Mountain tributary remains unresolved.

Green and Tully Lake Dams

Road culverts under Lake Road (fig. 1) and a private driveway control the level of Green Lake at its southwestern end, where the outlet channel enters a wetland that drains into Tully Lake. The bridge over the Tully Lake outlet on Song Lake Crossing Road controls the level of Tully Lake during high-flow conditions, and a concrete weir maintains the Tully Lake level during low-water periods. The weir was built in the mid-1960's during a regional drought and is maintained by the Tully Lake Association, which places stop-logs across the weir during the late spring to maintain the lake level, and removes them in the early fall to lower the lake level. Beaver dams upstream and (or) downstream from these roadway structures also can control the water levels of these two lakes. The beavers and their dams are usually removed by the State Department of Environmental Conservation when requested by the respective town or lake association.

SUMMARY

Glacial processes created the many kettlehole lakes, ponds, and depressions in the Tully Lakes area, as well as the Valley Heads Moraine, which forms the drainage divide between the St. Lawrence River drainage to the north and the Susquehanna River drainage to the south. The first hydrogeologic studies of the Tully Lakes area began in the 1870's, when the lakes were considered as a possible water supply for the city of Syracuse. Water was diverted from some of the northwestern lakes and ponds into the Tully Valley; these diversions occurred as early as the 1840's and ceased in the early 1960's, with the closure of the eastern Tully Valley brinefield.

In 1998, the USGS began a 2-year hydrogeologic study of the aquifer system underlying the Tully Lakes area that included monitoring water levels in five of the Tully Lakes and more than 50 wells. The average annual water-level fluctuations in the three western lakes ranged from about 2.5 feet to 6 feet. Water-level fluctuations in the eastern lakes, near the center of the valley, were much less—about 1.5 feet, because these lakes have natural outlets. Three sets of ground-water-level measurements were made from the spring recharge period through the fall dry period of 2000. The resulting potentiometric-surface maps indicate that the water-level declines from the spring to the fall ranged from 1.5 to 8 feet. The ground-water divide is about 1 mile south of the Valley Heads Moraine crest in the spring and migrates southward in response to declining water levels in the surficial aquifer during the fall. Water-surface altitudes in the kettlehole lakes and ponds respond slowly to seasonal water-level changes in the surrounding aquifer and often differ from water levels in the aquifer because the poorly permeable lakebed sediments impede the exchange of water.

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