DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, Secretary

U.S. GEOLOGICAL SURVEY

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CONVERSION FACTORS AND ABBREVIATIONS

The following factors may be used to convert the inch-pound units used in this report to metric (International System) units:

Multiply inch-pound unit	By	To obtain metric units
inch (in)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
million gallons per day (Mgal/d)	0.003786	cubic meter per day (m^3/d)
million gallons per day per square mile [(Mgal/d)/mi^2]	1,461.4	cubic meter per day per square kilometer [(m^3/d/)km^2]
feet per mile (ft/mi)	0.1894	meter per kilometer (m/km)
gallons per day (gal/d)	3.785	liter per day (L/d)
feet per day (ft/d)	0.3048	meter per day (m/d)
feet squared per day (ft^2/d)	0.0929	meter squared per day (m^2/d)

Chemical concentrations and water temperature are given in metric units. Chemical concentration is given in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight of solute per unit volume of water, and 1,000 micrograms per liter is equivalent to 1 milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is the same as for concentrations in parts per million.

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Sea Level Datum of 1929.")

HYDROGEOLOGY AND WATER QUALITY OF THE TUG HILL GLACIAL AQUIFER IN NORTHERN NEW YORK

By Todd S. Miller, Donald A. Sherwood, and Martha M. Krebs

Abstract

The Tug Hill aquifer, in northern New York, is a 47-mile-long, 0.25- to 3.5-mile-wide, crescent-shaped sand and(or) gravel deposit that formed during deglaciation of the region during the Pleistocene Epoch, between 12,800 and 11,400 years ago. It consists of sequences of glacial, glaciofluvial, and glaciolacustrine sediments that flank the western slope of the Tug Hill Plateau in the northern and central part of the aquifer and partly fill a bedrock valley in the southern part.

The northern and central parts of the aquifer are under water-table conditions; the southern part has both water-table and discontinuous confined conditions. Ground water and streams in the northern and central parts flow westward; those in the southern part flow from the edges of the valley to West Branch Fish Creek, which flows southeastward along the center of the valley.

Principal sources of aquifer recharge are (1) infiltration of precipitation on the aquifer, estimated to be 137 million gallons per day, (2) infiltration from small streams that cross the north half of the aquifer, estimated to be 4.9 million gallons per day, and (3) seepage of runoff from adjacent till and bedrock, estimated to be 11.4 million gallons per day. Ground water discharges from the aquifer (1) by evapotranspiration, (2) through pumping, (3) as subsurface flow from the southern end of aquifer at McConnellsville, (4) as seepage to springs, wetlands, and streams along the western margin of the central and northern parts of the aquifer, and (5) as seepage to tributary streams and West Branch Fish Creek on the valley flat.

Good-quality water that is suitable for drinking and most other uses is found in most parts of the aquifer. The pH of the ground water in the study area ranges from 5.9 to 8.0 (slightly acidic to slightly basic), with a median pH of 7.5. Water in the northern part, which is underlain by limestone, has higher specific conductance and higher concentrations of hardness, alkalinity, calcium, and sulfate than water in other parts of the aquifer, which are underlain by shale, siltstone, and sandstone. Median concentrations of hardness, dissolved solids, chloride, and sulfate in the Tug Hill aquifer were less than those in six other upstate New York aquifers.

INTRODUCTION

The U.S. Geological Survey, in 1980 and 1981, investigated the hydrogeologic character of the part of the Tug Hill aquifer that lies in Oswego County (Miller, 1981). The Oswego County Health Department and the Planning Departments of Jefferson, Oswego, and Oneida Counties needed further delineation of the aquifer boundaries and an appraisal of the ground-water potential of the aquifer, which lies within all three counties, and asked The Temporary State Commission on Tug Hill to coordinate a ground-water study. In 1983, the Oswego County Health Department, Northern Oneida County Council of Governments, the Tug Hill Commission, and the Towns of Adams, Ellisburg, and Lorraine provided funds for a preliminary ground-water project by the U.S. Geological Survey, which collected data and drew preliminary maps to show the aquifer boundaries, potentiometric-surface altitude, and bedrock-surface altitude. Completion of the project was funded jointly during 1984-86 by the U.S. Geological Survey, New York State Department of Environmental Conservation, Temporary State Commission on Tug Hill, Oswego County Health Department, the St. Lawrence Eastern Ontario Commission, and Black River Regional Planning Board (Jefferson and Lewis Counties).

Purpose and Scope

This report provides a general source of hydrogeologic and water-quality information on the Tug Hill aquifer and thus serves as a foundation for more detailed studies and appraisals of local water-supply potential as development of this largely rural area proceeds. Discussed in the report are the origin and extent of the aquifer, ground-water use and availability, sources and amounts of recharge, ground-water flow and discharge, water-level fluctuations, and ground-water quality, including comparisons with other aquifers. It includes maps showing (1) aquifer boundaries and well locations, (2) surficial geology, (3) potentiometric-surface altitude and direction of ground-water flow, (4) bedrock-surface altitude, (5) potential well yields, and (6) land use. Tables of water-quality analyses and well data also are presented.

Description of Study Area

Physiographic Setting

The Tug Hill aquifer is a 47-mile-long, crescent-shaped deposit of permeable sand and gravel that flanks the western and southwestern side of the Tug Hill Plateau in northern New York (see inset map, fig. 1). The Tug Hill Plateau is an elevated, comparatively flat area that was separated from the Allegheny Plateau to the south by erosion. (See inset map, fig. 1). It is surrounded by lowlands--the Black River lowlands to the north and east, the Ontario lowlands to the west, and the Oneida-Mohawk lowlands to the south. The Tug Hill Plateau ranges from about 500 feet (ft) above sea level at the edges to 2,000 ft on top. It consists of slightly southwestward dipping sedimentary rocks that are overlain in most places by 5 to 40 ft of glacial deposits, but some valleys contain as much as 187 ft of unconsolidated deposits. Most of the plateau is covered by relatively impermeable till. Valleys contain sand and gravel and lacustrine fine sand and silt. Large precipitation rates of 45 to 55 in/yr (inches per year), low relief, and poor drainage make the plateau swampy in many places.

In the study area, the Tug Hill aquifer consists of kames and outwash of glaciofluvial deposits, deltaic and beach sand and gravel of glaciolacustrine deposits, and some recent alluvial deposits. The central and northern parts of the aquifer overlie till or bedrock, whereas the southern part overlies either

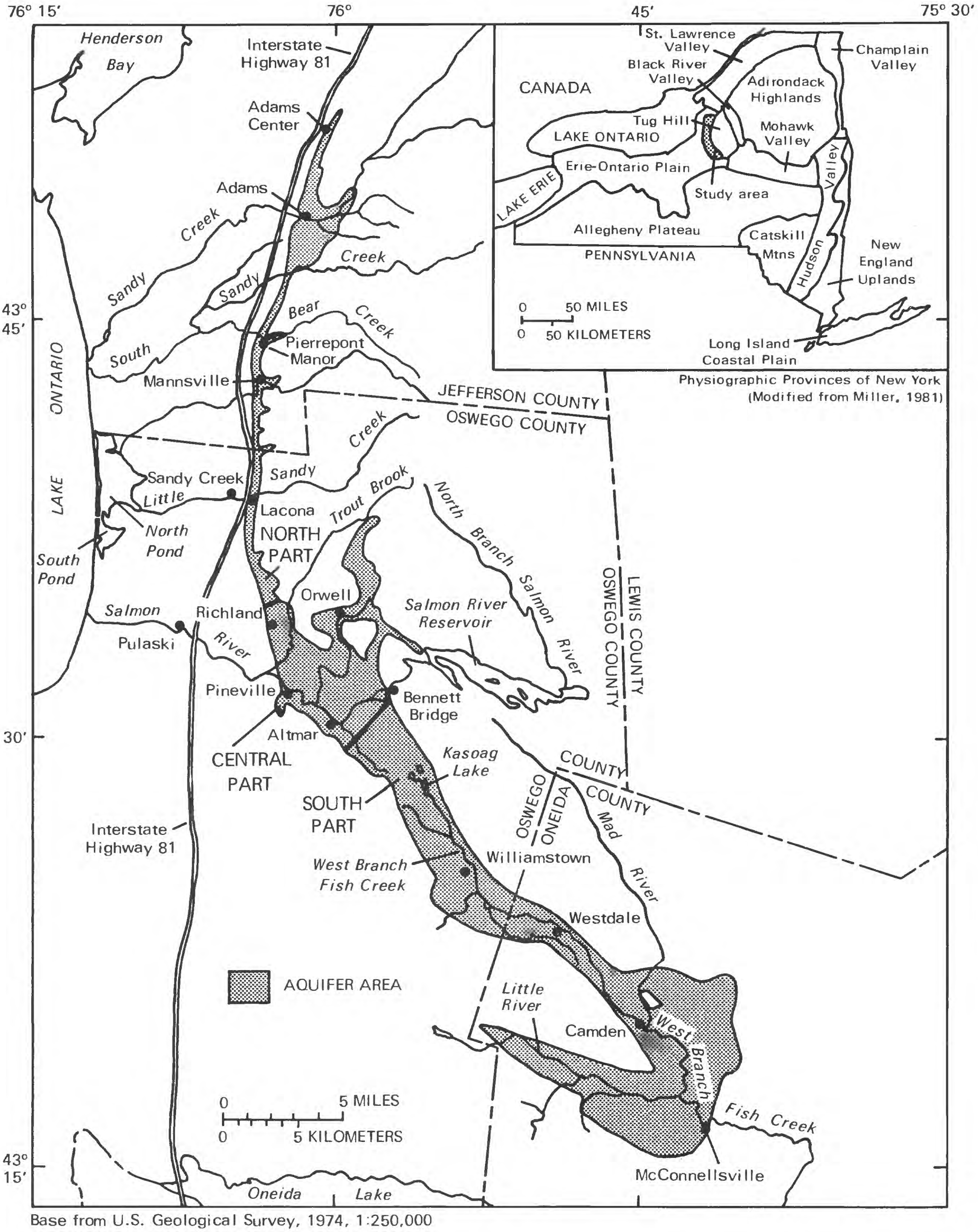


Figure 1.--Location and major geographic features of the Tug Hill aquifer area.

lacustrine fine sand, silt and clay, till, or bedrock. (These units are discussed later.) The northern and central parts of the aquifer flank the west slope of the plateau and drain into Lake Ontario. The southern part occupies a partly drift-filled preglacial valley now drained by West Branch Fish Creek, which flows into Oneida Lake (fig. 1). The aquifer ranges from 0.25 to 3.5 mi (miles) wide and extends 47 mi from Adams Center in Jefferson County in the north to McConnellsville in Oneida County in the south.

Land Use

The Tug Hill Plateau is one of the most sparsely populated and least developed areas in New York. Only some areas in the Adirondack Mountains of New York (inset maps, fig. 1) are as remote. The cool climate, poor drainage, thin, acidic soil, and abundant precipitation limit the development of this area. Most farming has been abandoned, and secondary-growth vegetation has taken the place of crops.

Most development is on the aquifer along the western and southern edges of the Tug Hill Plateau. The predominant land uses in the area are woodlands, which occupy 41 percent of the total area, and crop and dairy farming, which occupies 31 percent of the total area (pls. 1F-4F). Another 6 percent of the area contains industries, sand- and gravel-mining operations, commercial enterprises, residential areas, and some transportation routes. The remaining 22 percent is predominantly wetlands (17 percent), inactive land (4.4 percent), and open public land (0.6 percent) such as parks and State forests.

Methods of Data Collection

Hydrogeologic information was collected through fieldwork and compilation of reports and records provided by Federal, State, and local government agencies, consulting firms, private businesses, and industries.

Well Inventory and Test Drilling

A major part of the hydrogeologic investigation consisted of a well inventory. Well sites were visited and the owners interviewed to obtain information about each well. The depth to water was measured in accessible wells, and selected wells were sampled for water quality.

Test drilling was done from April through June 1985 in areas for which little or no data were available. A total of 26 holes were drilled with auger rigs, 6 by the U.S. Geological Survey, and 20 by the New York State Department of Environmental Conservation. Test holes were drilled to the top of bedrock or until boulders or upheaving sand prohibited further drilling. Fifteen 1.5- or 2.0-inch-diameter wells with screens at the bottom were installed in the significant water-bearing zones. Test holes at sites with no significant water-bearing zones were backfilled, and the sites were abandoned. The test holes provided information on the character of geologic units, depth to bedrock (where encountered), depth to water, and saturated thickness. Well records are given in table 7 (at end of report).

Seismic Surveys

Seismic-refraction surveys were done at 20 sites to supplement test-drilling data and to provide information on the saturated thickness and depth to bedrock.

Streamflow Seepage Measurements

Streamflow was measured at two or three sites along selected reaches of 15 streams that cross or flow on the Tug Hill aquifer. These measurements identified areas where streams lose water to the aquifer (recharge areas) and where they gain water from the aquifer (discharge areas).

Ground-water Sampling

Ground-water samples were collected from 40 wells that tap the Tug Hill aquifer--13 from test wells drilled during this study and 27 from selected private and municipal wells. The samples document background water quality and indicate areas that might be affected by contamination. The U.S. Geological Survey test wells were sampled by pumping with a peristaltic pump equipped with plastic tubing or bailed with a stainless steel bailer. A minimum of three volumes of water was removed from the well so that fresh water from the aquifer would enter the well before the sample was collected. Private, domestic, and municipal wells were sampled at convenient taps after water had been allowed to run several minutes.

Samples were analyzed for specific conductance, pH, and concentrations of common cations and anions, nutrients, alkalinity, and hardness. In addition samples from five wells were analyzed for trace elements. These constituents were selected because they are good indicators of general ground-water quality. Results are given in table 4 (further on) and in table 9 (at end of report).

Identification and Location of Wells and Streamflow Measurement Sites

Records of selected wells are given in table 7 (at end of report). The locations of wells and seepage-measurement sites are plotted on plates 1A, 2A, 3A, and 4A. Well records are tabulated and identified according to the latitude and longitude of the well site, as explained on the plates. Streamflow-measurement sites have an 8-digit number. The first two digits, "04," identify streams tributary to the Great Lakes, followed by a 6-digit downstream-order number. An example is 04240930.

Acknowledgments

The Temporary State Commission on Tug Hill, Oswego County Health Department, New York State Department of Environmental Conservation, Salmon River Cooperative Planning Board/Conservation Advisory Council, and the Oneida, Oswego, and Jefferson County Departments of Planning assisted in providing land-use and well data and in organizing public interest in this investigation.

GEOLOGY OF THE TUG AQUIFER

Within the study area, the Tug Hill aquifer consists of glaciofluvial deposits, deltaic and beach sand and gravel of glaciolacustrine deposits, and some recent alluvial deposits that overlie till or bedrock (pls. 1B, 2B, 3B, and 4B). Glacial sediments are unsorted and poorly stratified deposits left by the ice alone, such as till; glaciofluvial deposits are stratified and relatively well-sorted sediments deposited by streams that flowed from, on, within, or at the bottom of the glacier, such as outwash, eskers, and kames; and glaciolacustrine deposits are well-sorted and stratified fine sand, silt, and clay, such as deltas and bottom sediments, that accumulated in impounded water caused by temporary closure of a basin by the ice front or by sand and gravel deposited as beaches along the shore.

The southern, central, and northern parts of the aquifer differ geologically. The southern part consists mostly of unconfined glaciofluvial deposits (kames, kame terraces, eskers, outwash, and outwash deltas) that are underlain by thick deposits (as much as 160 ft thick) of lacustrine fine sand, silt, and clay that, in some areas, confine discontinuous buried sand and gravel deposits (kames) that lie at the bottom of the partly sediment-filled West Branch Fish Creek valley. Water in the southern part of the aquifer is contained by the relatively impermeable till and bedrock that form the walls and floor of the West Branch Fish Creek valley.

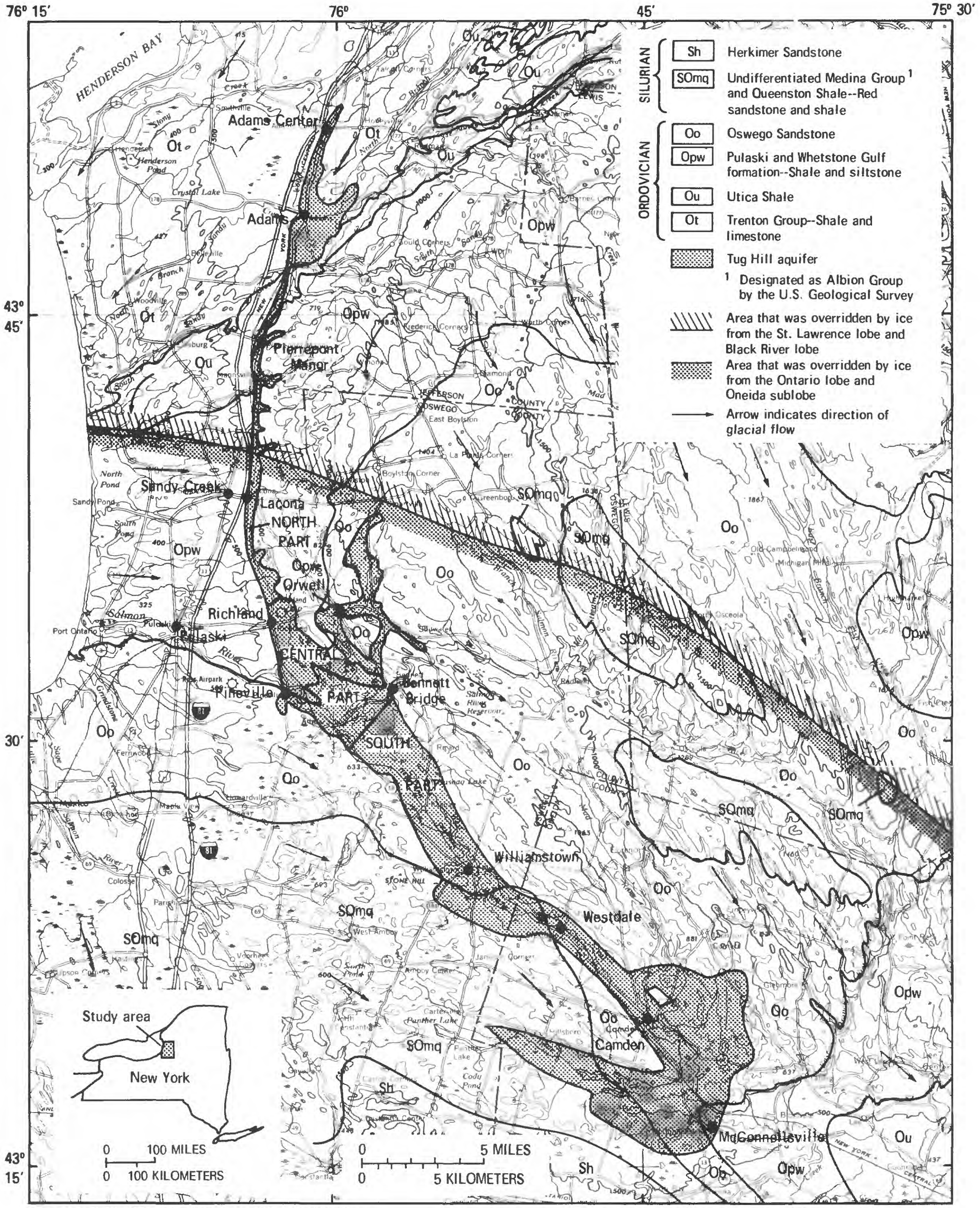
The central part of the aquifer consists mostly of glaciofluvial and glaciolacustrine deposits (beaches and deltas) over till and(or) bedrock. The top of the bedrock surface slopes westward and contains a narrow, buried valley. Lake-bottom sediments are rare in this part of the aquifer.

The northern part of the aquifer consists mostly of 10- to 50-ft-thick and 0.25- to 0.75-mi-wide belts of unconfined shoreline deposits (beaches, offshore bars, and deltas) that formed along proglacial Lake Iroquois, with minor outwash and alluvial deposits along its east side. The northern part has no bedrock valley to contain the ground water; rather, the bedrock floor slopes westward, and water is contained by 10 to 25 ft of lacustrine silt and clay that flank the west side of the beach deposits.

Stratigraphy

Bedrock

During Middle Ordovician to early Middle Silurian age, between 460 and 420 million years ago, hundreds of feet of calcareous ooze, mud, silt, and sand were deposited on an ocean floor that covered western, central, and northwest-central New York. Compressed by the weight of subsequently deposited sediments, the underlying deposits consolidated into limestone, shale, siltstone, and sandstone bedrock. Uplift and subsequent erosion of the younger, overlying sediment over the next several million years exposed the older sedimentary rocks of Middle Ordovician and early Middle Silurian age (fig. 2). The northern part of the aquifer is underlain by limestones of the Trenton Group, the central and western part by shales and siltstones of the Utica Shale, Whetstone Gulf Formation (Isachsen and Fisher, 1970), and Pulaski



Base from U.S. Geological Survey, 1974, 1:250,000

Bedrock geology by Rickard and Fisher, 1970 and Isachsen and Fisher, 1970. Glacial geology by Wright, 1983

Figure 2.--Bedrock geology and glacial lobes and sublobes of the Wisconsin ice sheet that covered the Tug Hill area.

Shale, and the southern part by sandstones and siltstones of the Oswego Sandstone, Queenston Formation and Medina Group. The relatively resistant Oswego Sandstone forms the caprock on top of the plateau.

Lodgment Till

During advance of the glacier, some of the eroded material that had accumulated at the base of the ice was deposited, typically on bedrock, as lodgment till, which is an unsorted mixture of clay, silt, sand, and stones. The till was deposited either as a 3- to 15-ft-thick blanket or as 20- to 150-ft-thick ellipical hills known as drumlins. The till contains a large proportion of fine-grained sediments that were compressed beneath the weight of the ice and is therefore characterized by compactness, fissile structure, and low permeability. Till and(or) bedrock forms the bottom and sides of many parts of the Tug Hill aquifer.

Glaciofluvial Deposits

Glaciofluvial deposits form the major part of the central and southern parts of the Tug Hill aquifer. The sequences of glaciofluvial and glaciolacustrine deposition in the West Branch Fish Creek valley are depicted in figures 3A through 3D.

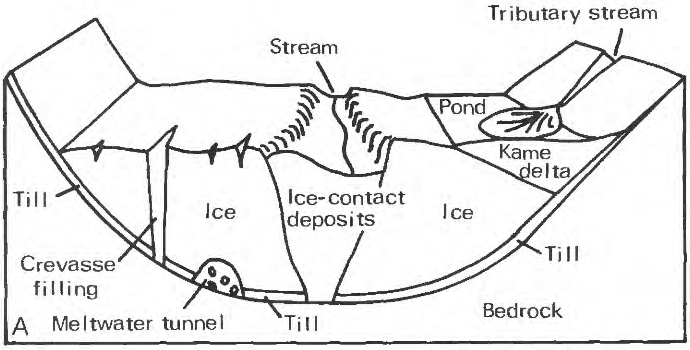
Kames.--Where the retreating ice front paused (for periods that may have lasted from tens to several hundreds of years), streams that drained uplands and meltwaters that flowed on, within, or beside the ice deposited large amounts of sediment at the ice front and along the sides of the ice (fig. 3A) to form interbedded layers of poorly to moderately sorted silt, silty sand and gravel, and cobbles. As the underlying ice melted, these sediments settled and formed deposits known as kames. The composition of kame deposits is variable and is related to the conditions at the stagnating ice front. Fine-grained sediments were deposited where streams flowed slowly during periods of gradual melting and in small ponds or lakes that formed in depressions in the ice (fig. 3B). Coarse-grained material that was carried by fast-flowing streams during periods of rapid melting was deposited wherever flow diminished.

The melting of ice beneath these deposits resulted in the slumping, faulting, and collapse of the deposits and the disruption of their stratified structures. The sediments settled in place--on top of till, bedrock, or lake deposits in the valleys and also on hillsides (fig. 3C). Sediments at the ice margins formed kame moraines, which form a belt of irregular knolls (small, conical hills) and flat-topped and irregular kame terraces and kame deltas along the sides of the ice and adjacent to valley sides (fig. 3C).

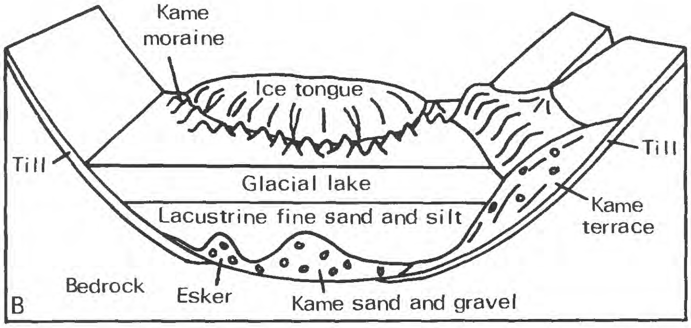
Kame moraines form part of the Tug Hill aquifer southeast of Camden, at Williamstown, and near Orwell, Bennett Bridge, and Altmar, where the ice front stagnated for several tens of years (fig. 4). Kame moraines generally extend down to till or bedrock at the bottom of the valley floor (geologic section D-D', pl. 3B).

Kame terraces and kame deltas form part of the aquifer where meltwaters that flowed through Mad River, Emmons Brook, and Cobb Brook valleys deposited some of their coarse sediment in the West Branch Fish Creek valley between the

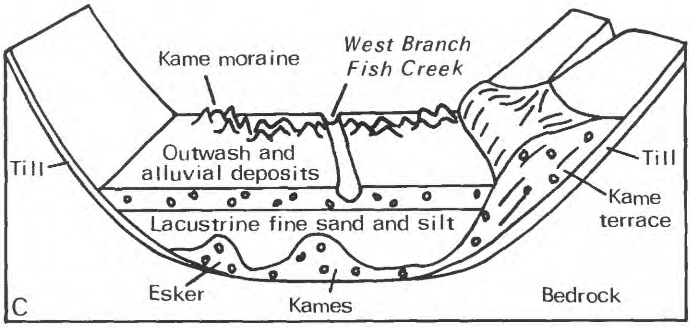
A. Tongues of ice extend southeastward down valley several miles ahead of main ice sheet. Meltwater deposits are laid down on, within, and atop the ice. (Modified from Randall, 1986.)



B. As the ice tongue continues to recede, the previously deposited sediments lose their support and partly collapse. A lake may form between the receding ice and older deposits downvalley, allowing lacustrine silt and clay deposits to accumulate. (Modified from Reynolds, 1984)



C. As remaining ice recedes and lake drains, outwash covers lacustrine fine sand and silt. (Modified from Lyford, 1986.)



D. Geomorphology and stratigraphy along West Branch Fish Creek valley.

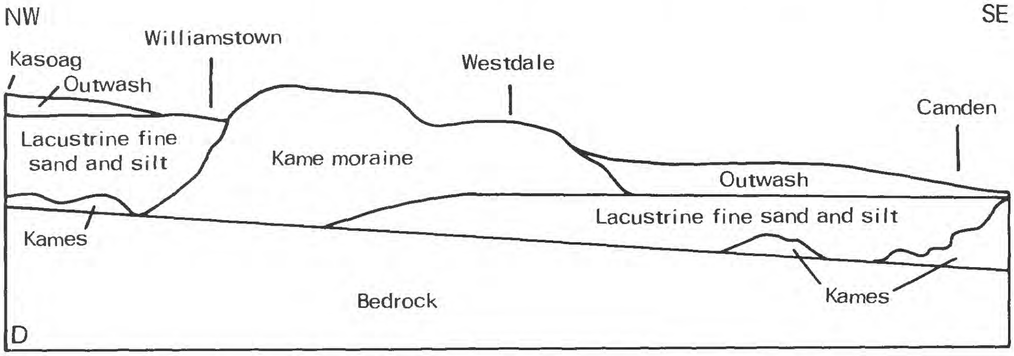


Figure 3.--Origin of typical glacial features in the West Branch Fish Creek valley. Idealized diagrams A through C do not necessarily represent average conditions nor any particular locality. Diagram D shows generalized conditions in the southern part of the aquifer.

northern side of the ice lobe and the north valley wall (fig. 4). In some areas, kame deposits extend from the valley sides to the valley floor and, in some areas, became buried to form confined aquifers or partly buried by glaciolacustrine and outwash deposits (fig. 3C and geologic section B-B', pl. 1B).

Outwash.--Outwash consists of stratified sand and gravel left by meltwater beyond the ice front (figs. 3C and 3D). Outwash forms large parts of the southern part of the Tug Hill aquifer in the West Branch Fish Creek valley and small parts of the central and northern parts. Outwash typically extends several miles from the ice-stagnation zones, where kame moraines were deposited (fig. 4). The coarsest outwash was deposited near the ice front, where the velocity of meltwater was highest and could transport large clasts. Farther from the ice, where the meltwater velocity decreased, the outwash graded into finer gravel and pebbly sand. Outwash has more continuous horizontal bedding, better sorting, and rounder particles than kame deposits as a result of the greater fluvial action.

Outwash forms parts of the southern part of the Tug Hill aquifer in two areas in the west Branch Fish Creek valley and in several tributary valleys in the central and southern parts (fig. 4). In the West Branch Fish Creek valley, one of the outwash deposits extends from Westdale to Camden. It is 10 to 55 ft thick and typically is underlain by lacustrine fine sand and silt in the center of the valley, and by kame or till and bedrock along the northeastern side of the valley (geologic section B-B', pl. 1B). The other outwash deposit in the West Branch Fish Creek valley extends from south of the Bennett Bridge to 1.5 mi south of Kasoag Lake (pl. 2B). The outwash ranges from 20 to 30 ft thick near Bennett Bridge and 18 to 53 ft thick in the vicinity of Kasoag Lake. The outwash grades southward from coarse cobble gravel near Bennett Bridge, which was near the ice front, to finer sand and gravel near Kasoag Lake and to even finer pebbly sand south of Kasoag Lake where meltwater was depositing an outwash delta in a small glacial lake in the Williamstown area. Farther south, where the lake was deeper, the surficial deposits grade into fine sand (section C-C', pl. 2B).

Near Bennett Bridge, the outwash overlies till and bedrock. Near Kasoag Lake, the outwash is underlain by 50 to 160 ft of lake-bottom sediments that consist of silt and very fine sand. In some places the lake deposits overlie buried sand and gravel that, in turn, overlies till or bedrock.

Some outwash surfaces are pitted with "kettles," which are circular to irregular depressions that range from a few feet to several miles across and typically are 5 to 100 ft deep. Kettles formed where ice blocks broke away from the retreating glacier and became incorporated in the outwash. When these ice blocks melted, they left depressions. Kettles that are filled or partly filled with water are called kettle lakes. Kasoag Lake (pl. 2B) is an example of a kettle lake.

Some of the low areas in the higher elevations of the Tug Hill Plateau contain thin (5 to 20 ft thick) outwash and kame sand and gravel deposits. Meltwater from ice in the Mad River valley flowed into and deposited outwash in the Emmons Brook and Cobb Brook valleys 1 to 2 mi northeast of Camden (fig. 4). Other thin outwash deposits are found on the uplands east of the central part of the aquifer (fig. 4). In these areas, outwash overlies till and(or) bedrock.

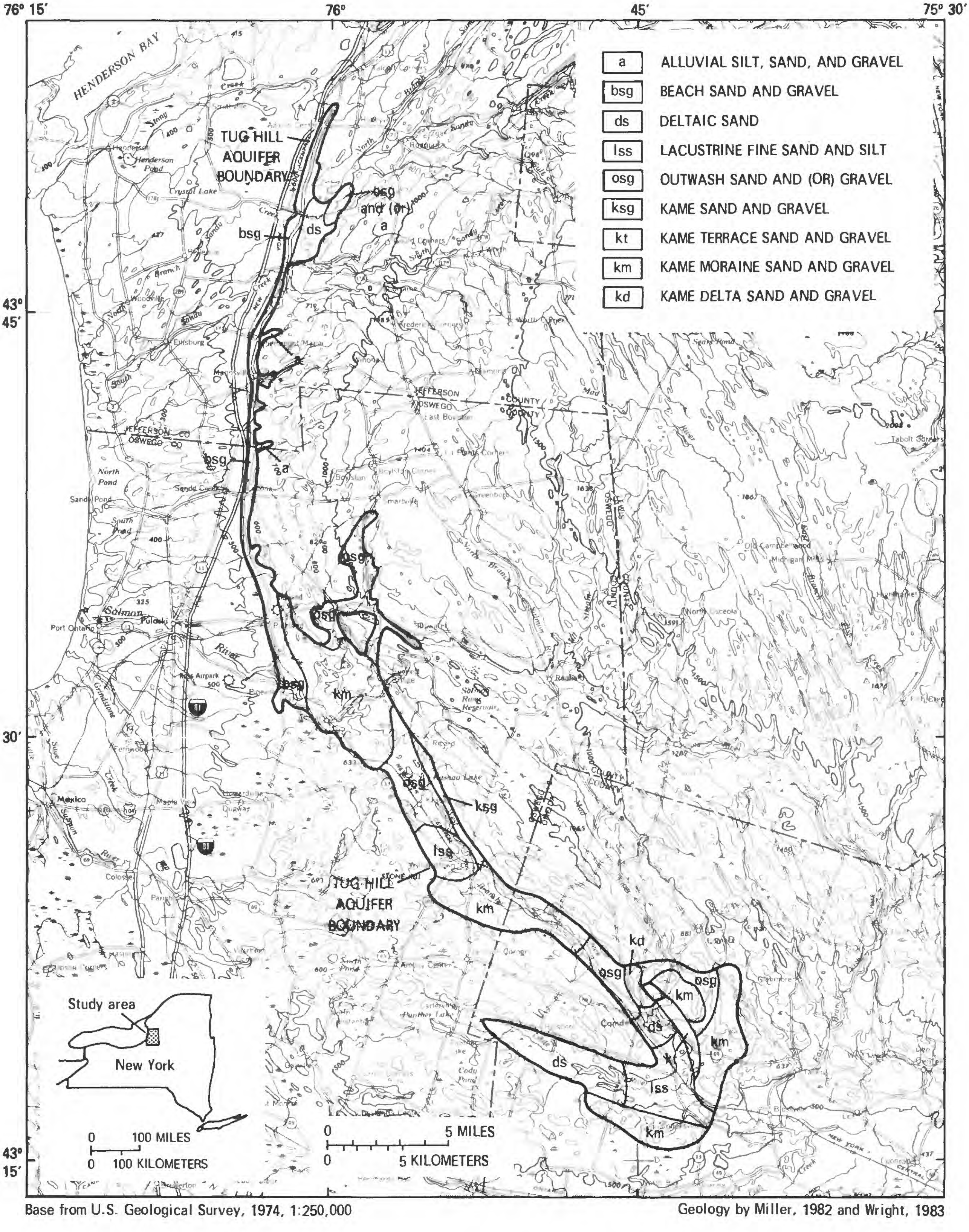


Figure 4.--Surficial geology of the Tug Hill aquifer.

Glaciolacustrine Deposits

During retreat of the ice, the ice margin dammed northward-flowing drainage in the Lake Ontario basin, which resulted in the formation of temporary glacial lakes. The largest lake to affect the study area was Lake Iroquois. Some of the coarse sediments that were deposited along the margin of the lake formed most of the northern part and part of the southern part of the Tug Hill aquifer. Further west, in deeper water, some of the finer particles settled to form the bottom sediments that now form part of the western boundary of the aquifer.

Beaches and deltas.--Wave action along the shore of the lake eroded, reworked, and winnowed the fine sediments from the coarse ones and redeposited them as well-sorted sand and gravel in a series of essentially continuous linear beaches. Beach deposits that form part of the Tug Hill aquifer are identified in figure 4. Section A-A' (fig. 5) shows the stratigraphy of a typical offshore beach deposit near Adams, in the northern part of the aquifer. The beach deposit is thickest (20 to 50 ft) in a 10-mi reach that extends from 2 mi south of Richland north to Mannsville. Here many upland streams that drained the plateau to the east flowed into and deposited large quantities of fluvial sediment in Lake Iroquois.

The beach deposits are thinner where no nearby streams were present to deliver sediment to the shore, and they may be saturated only during wet

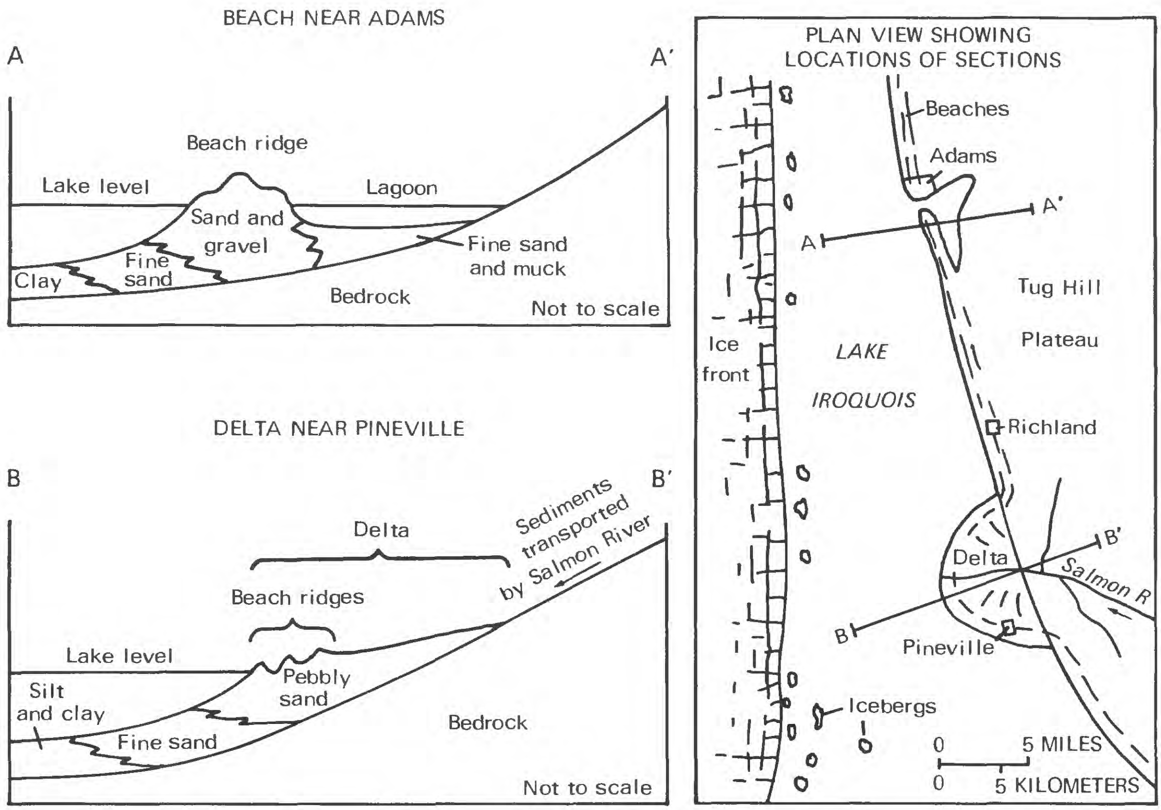


Figure 5.--Typical glaciolacustrine deposits in the northern and central parts of the aquifer.

periods. This condition is found from Pierrepont Manor to South Sandy Creek (pls. 3D and 4D) and in some places in the 5-mi reach from Sandy Creek at Adams to Adams Center (geologic sections G-G' and H-H', pl. 4B). The northern boundary of the Tug Hill aquifer is 1 mi north of Adams Center, where the Trenton Limestone rises to land surface and forms an escarpment.

Deltas are fan-shaped, nearshore deposits of stratified sand that accumulated at the mouths of streams that emptied into a lake (fig. 5B). Deltas also formed where meltwater that flowed on top of, or in tunnels within or at the base of the ice (subaqueous outwash) emptied into a lake. Delta deposits that form part of the aquifer are identified in figure 4.

A large deltaic plain forms part of the northern part of the aquifer at a reentrant of the plateau near Adams. Sediments grade from sand and gravel along the edges to sand and silt in the central part. The western and northeastern edges of the plain have 40 to 50 ft of sand and gravel that overlies 1 to 5 ft of till, which, in turn, overlies bedrock. A well in the middle of the plain penetrated 3 ft of gravel that overlies 15 ft of till that overlies 32 ft of fine to coarse sand that, in turn, overlies bedrock. A buried bedrock valley in the southwestern part of the plain contains at least 117 ft and possibly as much as 170 ft of mostly sand.

Lake-bottom sediments.--Fine sand, silt, and clay that settled out of suspension in temporary glacial lakes form the side or bottom of the surficial aquifer and the confining or semiconfining layer above buried sand and gravel deposits (figs. 3B, 5A, and 5B). Sediments grade from fine sand near the shores of lakes to silt and clay in the deeper and quieter water offshore. Bottom sediments are relatively impermeable.

Lake-bottom sediments form the western boundary of most of the northern and central parts of the aquifer (figs. 5A, 5B). Thick (as much as 160 ft) lake-bottom deposits underlie most of the southern part of the surficial aquifer in the West Branch Fish Creek valley and, in some places, they confine a discontinuous buried sand and gravel unit in the bottom of the valley (section B-B', pl. 1B).

Recent Deposits

Alluvium.--In some places, postglacial streams that drained the uplands deposited 5 to 30 ft of silty sand and gravel on top of the glacial deposits. Streams that drained the uplands deposited small alluvial fans on the southern part of the aquifer and built up parts of the valley floor. Some of the eastern part of the northern part of the Tug Hill aquifer consists of alluvial deposits in the small tributary valleys. One of these alluvial valleys--the Bear Creek valley near Pierrepont Manor--has been indicated by U.S. Geological Survey test well 16-55 and a seismic survey to contain 30 ft of silty, sandy gravel (geologic section F-F', pl. 4B).

Swamp deposits.--Swamp deposits consist of organic material, marl, peat, muck, silt, and clay that accumulated in shallow, stagnant water. Wetlands have formed on the aquifer in some of the depressions and poorly drained low areas, such as kettles, former meltwater channels, and former lagoons of glacial Lake Iroquois.

Chronology of Glaciation

An understanding of the glacial history of the study area is fundamental to interpreting the stratigraphy, geometry, and boundaries of the Tug Hill aquifer, and these in turn determine the distribution of ground water. This section describes, from south to north, the formation of the aquifer.

About 1 million years ago, the first of several glaciers flowed into New York and covered hills and valleys. Moving ice eroded many feet of soil and rock, especially in valleys such as West Branch Fish Creek (fig. 1), where the ice was thickest and flowed rapidly because the valley was aligned in the direction of glacier flow. During the last glacial episode to affect the area, ice from the Ontario lobe and Oneida sublobe (fig. 2) covered the central and southern parts of the aquifer, and ice from the St. Lawrence lobe and Black River sublobe covered the northern part.

As the first glacier melted, it released the eroded material that had accumulated within and upon it and deposited this material on bedrock. Each succeeding glacial advance scrubbed off most of the material left by the previous ice retreat, so that most of the unconsolidated sediments remaining in the study area today were those deposited during the last retreat of the ice during late Wisconsin age.

Final deglaciation of the Tug Hill aquifer area began about 12,000 years ago (Terasme, 1978) when the last readvance (Stanwix glaciation) that covered the area began to retreat as the climate grew warmer. The deglaciation process lasted until about 11,400 years ago, when Lake Iroquois drained; no significant subsequent glacial erosion or deposition has affected the study area since then (Chambers, 1978). The ice melted first where it was thinnest in the uplands in the south-central part of the Tug Hill Plateau (Street, 1966).

Camden Moraine Complex

As deglaciation progressed, the ice front stagnated several miles east of Camden, where it deposited the Camden moraine complex (fig. 6) from Pond Hill through McConnellsville and to Thompson Corners (Wright, 1972). Although the uplands north and south of Camden were becoming ice free, the valleys retained tongues of ice that extended short distances ahead of the main ice mass. The major Ontario lobe began to divide into two sublobes at the Camden moraine complex (fig. 6); the Oneida lowlands sublobe retreated westward, while the Ontario sublobe, with its tongues of ice that extended into the West Branch Fish Creek and Mad River valleys, retreated northwestward. The moraine complex is a mixture of kames, kame terraces and deltas, outwash, and till. The moraine formed a "valley plug" of mostly stratified silt and sand with some sand and gravel, and some till, in the West Branch Fish Creek valley at McConnellsville (geologic section A-A', pl. 1B).

Williamstown Moraine

Ice in the West Branch Fish Creek valley retreated rapidly 7 mi to the northwest from the Camden moraine complex and paused just south of Williamstown (fig. 6), where a constriction in the valley caused it to stagnate and deposit

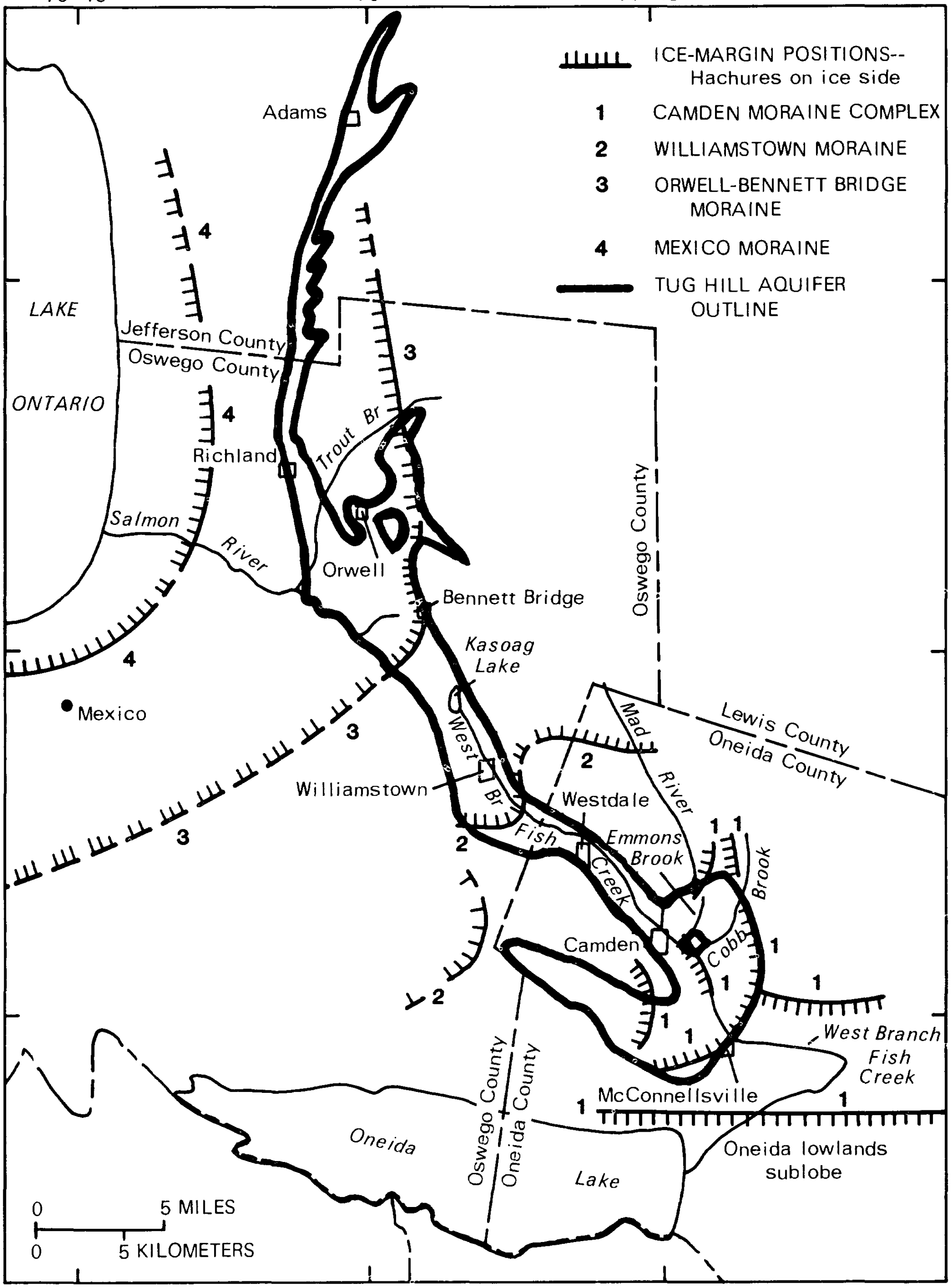


Figure 6.--Ice-margin positions of the Tug Hill aquifer area. (Modified from Chambers, 1978)

the Williamstown moraine (Street, 1966). A temporary lake formed in the West Branch Fish Creek valley between the "valley plug" near McConnellsville and the stagnant ice front just south of Williamstown. Deltas consisting of interbedded silt, sand, and sand and gravel formed where meltwater from the retreating ice and streams that drained uplands emptied into the lake. Mad River deposited a large kame delta where it emptied into the West Branch Fish Creek valley about 1.5 mi northwest of Camden (pl. 1B). The finer sediments, which consisted of very fine sand, silt, and clay, were carried by lake currents to deeper and quieter parts of the lake, where they settled to form a lake-bottom deposit that is as much as 160 ft thick in the central and deepest part of the valley.

Lake sediments accumulated fastest in the northern part of the lake, which was closer to the main source of sediment from the ice front, and eventually filled the lake from Westdale to 2 mi south of Camden. Subsequent meltwaters from the receding ice front deposited 5 to 30 ft of outwash or deltaic outwash consisting of well-sorted, stratified, fine to coarse sand and pebbly sand over the lake-bottom sediments (fig. 3C and geologic section B-B', pl. 1B).

Orwell-Bennett Bridge Moraine

As ice retreated northwestward from Williamstown, kame sand and gravel was deposited on the northeastern side of the West Branch Fish Creek valley between Williamstown and Bennett Bridge and extended at depth below lake deposits in some places in the valley (geologic section C-C', pl. 2B). The sand and gravel is buried by fine sand and silt that were deposited in a small lake that formed between the Williamstown moraine and Kasaog Lake area.

Ice again paused near Bennett Bridge and Orwell (fig. 6), where it deposited another large kame moraine, the Orwell-Bennett Bridge moraine (Chambers, 1978), which forms the divide between drainage into Lake Ontario and drainage into Oneida Lake. The moraine is 2.5 mi wide and 6 mi long and occupies the area bounded roughly by Altmar, Richland, Orwell, and Bennett Bridge. The moraine has many stagnant-ice and lake-deposit features, such as kettles, eskers, kames, kame terraces, and kame deltas (geologic section D-D', pl. 3B). The west side of the Orwell-Bennett Bridge moraine from Pineville to Richland was reworked by wave action of Lake Iroquois to form a large beach deposit (pl. 3B). Foreset bedding (a series of successively bedded sediments, typically of deltaic origin, that slope at an angle to the principal surface of accumulation) of sand and silty sand interbedded with poorly bedded kame sand and gravel attest to a deltaic and an ice-stagnation environment. Several drumlins, such as Lighthouse Hill along the south shore of Lower Reservoir (pl. 2B), are interspersed throughout the eastern part of the aquifer. Most of the moraine is irregular and hummucky with interspersed flat, low areas that are mostly wetlands.

Lake Iroquois

As ice retreated from the Orwell-Bennett Bridge area, the main influence on deposition of the northern part of the aquifer was glacial Lake Iroquois, which inundated lowlands parallel to the present-day Lake Ontario. The lake outlet was either southeast of Rome or northeast of Watertown (fig. 7). Lake Iroquois, which remained for about 200 years, was one of the longer lasting glacial lakes (Fullerton, 1980), and some of its shoreline deposits are the largest in upstate New York. The east-west beach profiles in figure 8 show a series of bars at differing elevations, which indicates that the lake drained in several stages. Total relief from the crest of the highest beach to the foot of the lowest bar is about 50 ft. The crest of the beach rises northward from an elevation of 565 ft at Richland to 660 ft at Adams Center (fig. 7) as a result of an increased rate of isostatic rebound of land to the north as the weight of the ice was removed.

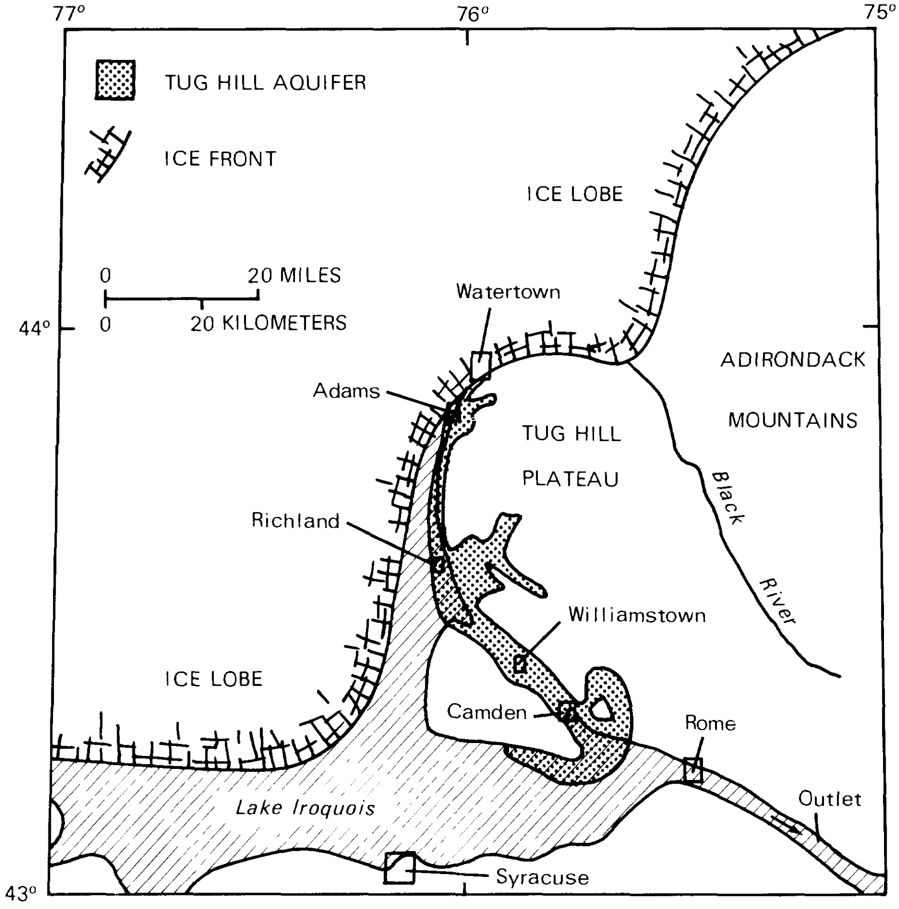


Figure 7.--Extent of glacial Lake Iroquois. (Modified from Fairchild, 1908)

Recent Deposits

As ice retreated northwest from the study area and glacial Lake Iroquois drained, about 11,400 years ago, streams that drained the Tug Hill Plateau deposited minor amounts of alluvial sand and gravel that form parts of the eastern side of the northern part of the aquifer.

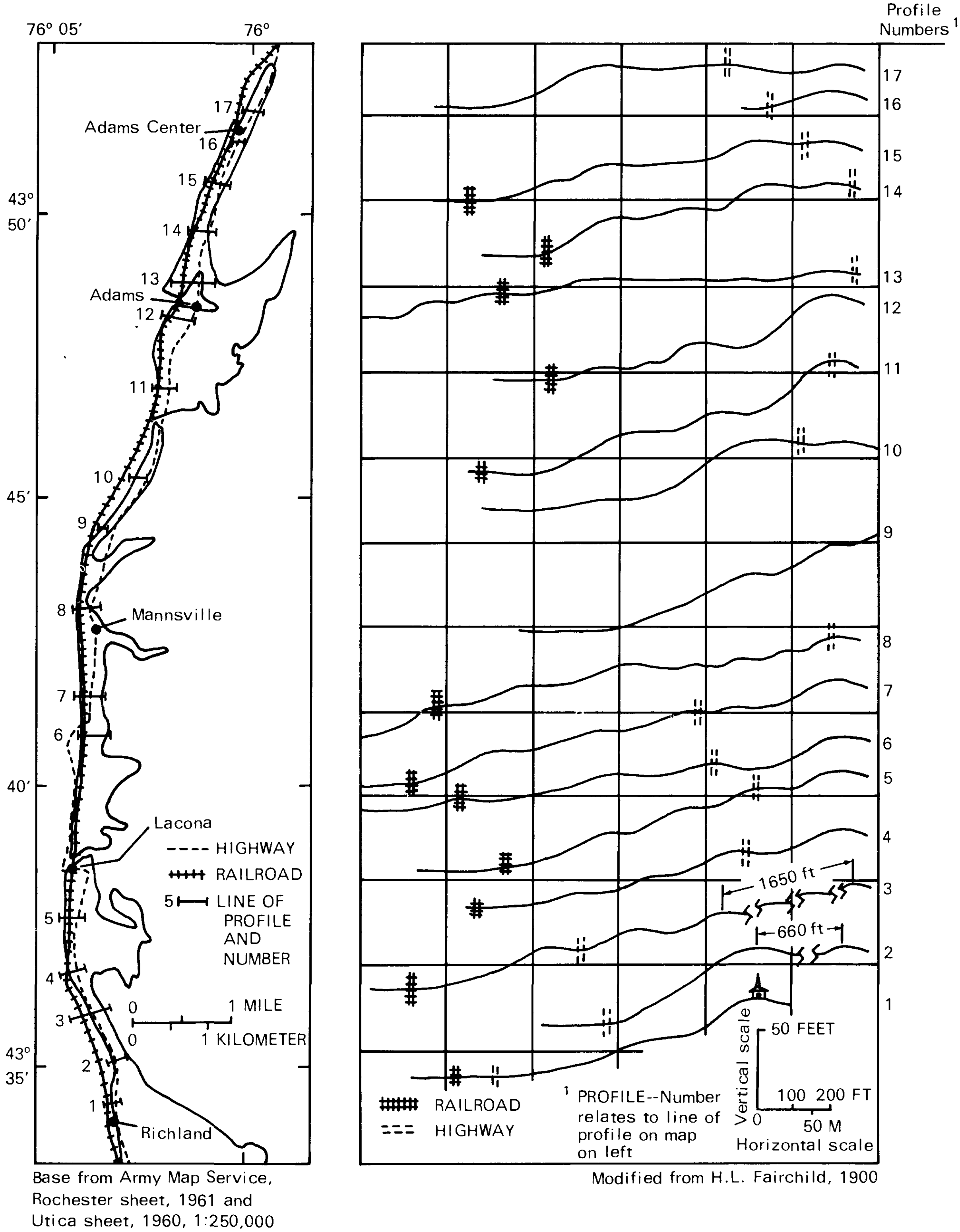


Figure 8.--Location of profiles (left) and profiles of Lake Iroquois beach deposits (right).

HYDROLOGY OF THE TUG HILL AQUIFER

All ground water in the study area is derived from precipitation as rain, snow, and hail. Some of the precipitation that falls on land evaporates, some is transpired by plants, some runs overland into streams and lakes, some is retained by molecular attraction to soil particles in the unsaturated zone, and some percolates to the water table and zone of saturation (fig. 9).

Most of the precipitation that falls on the Tug Hill area originates from storms that develop in the southwestern and western United States, or from clouds that form by evaporation from Lake Ontario and become cooled as they ascend eastward over the Tug Hill Plateau, which results in an increase in precipitation. This is locally known as lake effect. Storms from both sources cause the Tug Hill study area to have nearly the largest quantity of precipitation in New York. Monthly precipitation at the three weather stations in the Tug Hill area during 1983-86 is plotted in figure 10. Precipitation in the study area ranged between 45 and 50 in/yr (fig. 10).

All water-bearing deposits can be classified either as aquifers or as confining units. An aquifer is defined as a permeable deposit that can yield water in a usable quantity to a well or spring. A confining unit has very low permeability (hydraulic conductivity) and restricts the movement of ground water into or out of adjacent units.

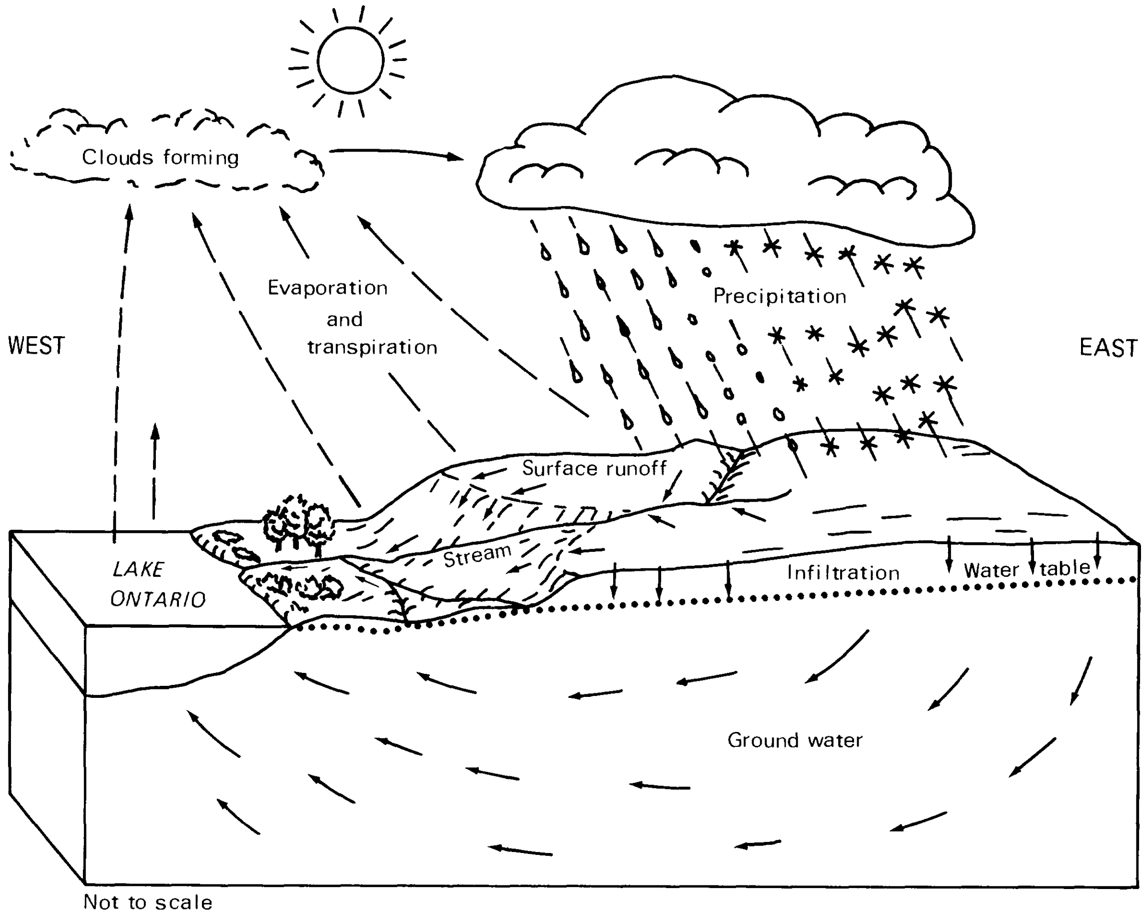


Figure 9.--Hydrologic cycle in the Tug Hill area.

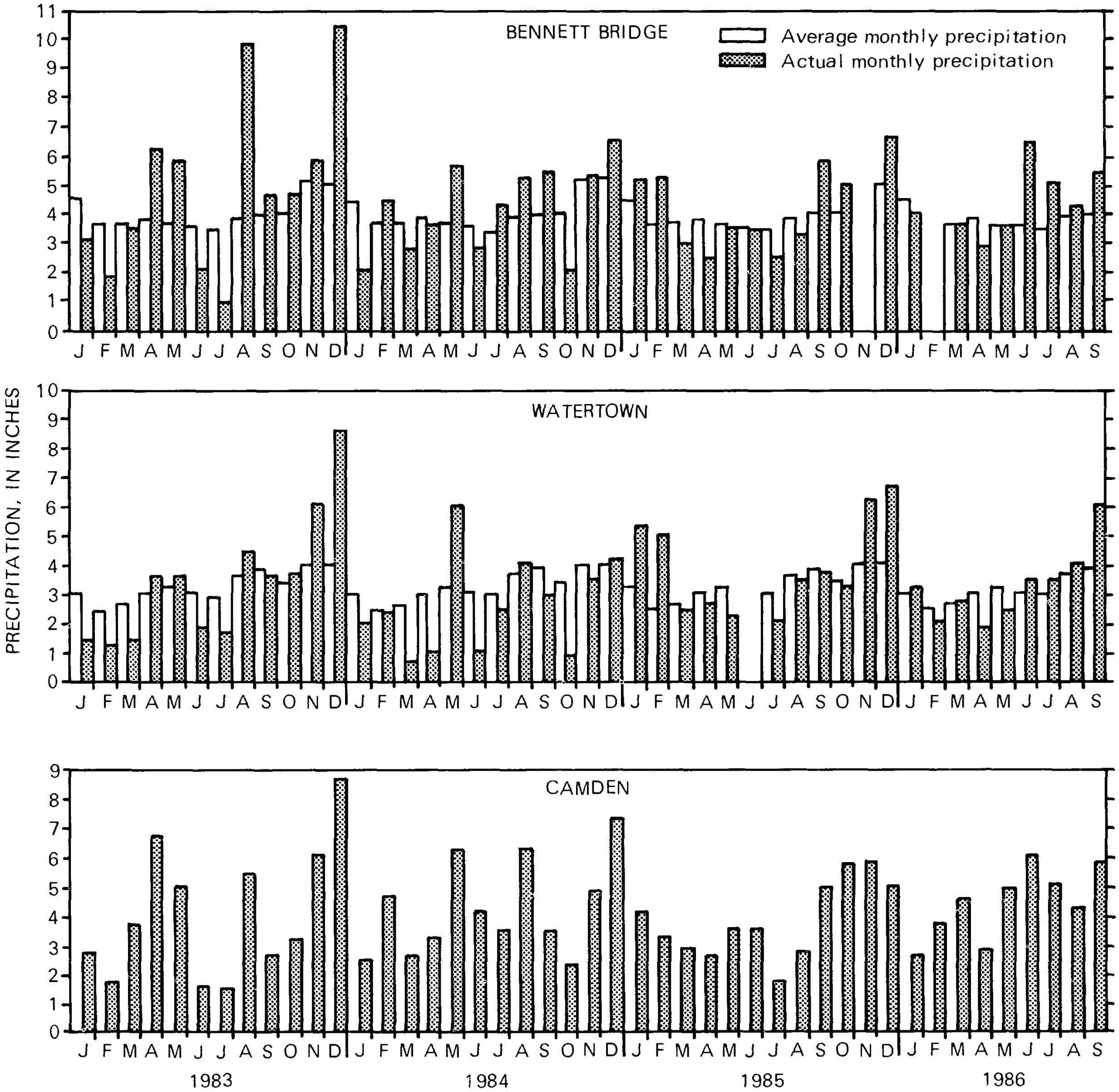


Figure 10.--Monthly precipitation at three stations in the study area, January 1983 through September 1986. (Station locations are shown in fig. 11)

The Tug Hill aquifer consists of glaciofluvial deposits and deltaic and beach sand and(or) gravel of glaciolacustrine deposits. The aquifer contains water in both unconfined (water table) and confined conditions. The water-table part of the aquifer consists of surficial sand and(or) gravel, and the water level in wells that tap the unconfined part represents the height of the water table. A sand and gravel deposit that is overlain by a bed of silt and clay (confining bed) is called a confined aquifer, and the water level in tightly cased wells that tap a confined aquifer rise according to the pressure within the aquifer. The height to which the water rises is known as the potentiometric surface (fig. 12). Wells drilled into confined aquifers are known as artesian wells, and wells in which the water level rises above land surface are called flowing artesian wells.

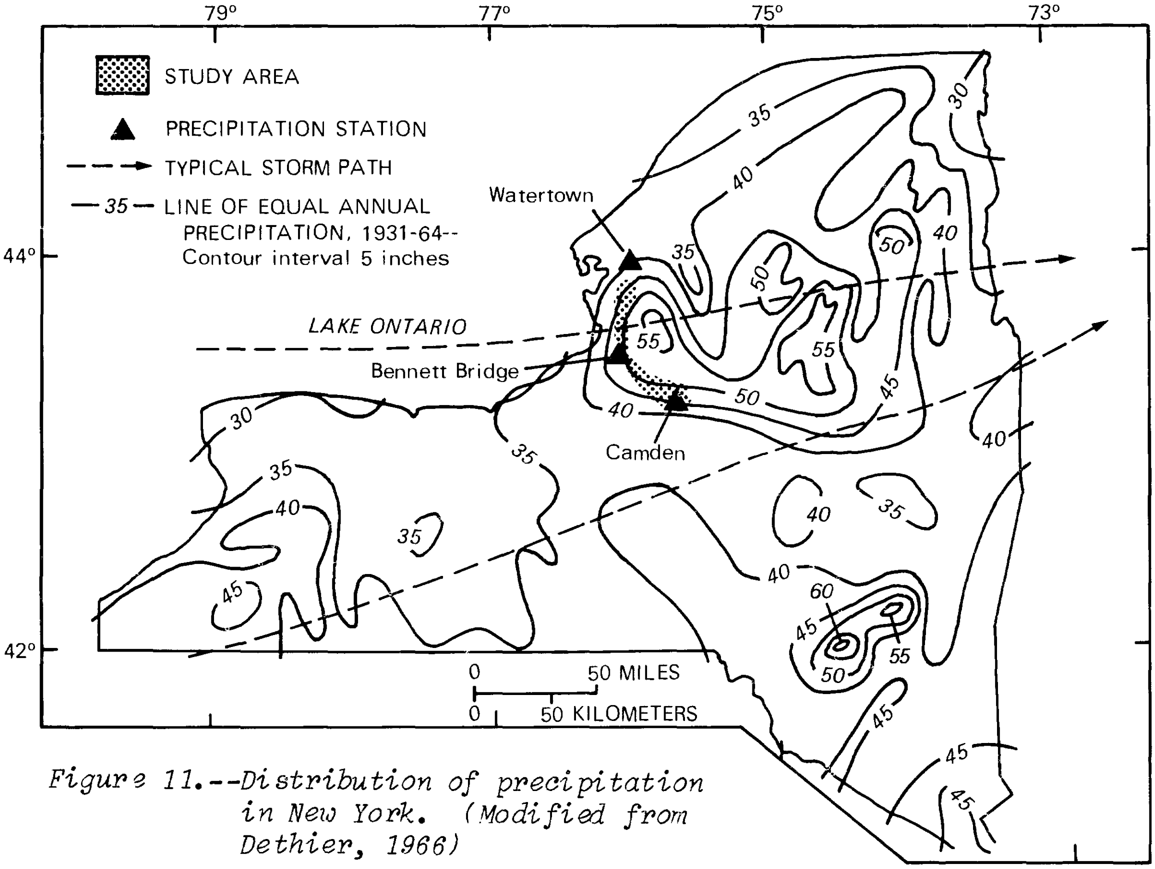


Figure 11.--Distribution of precipitation in New York. (Modified from Dethier, 1966)

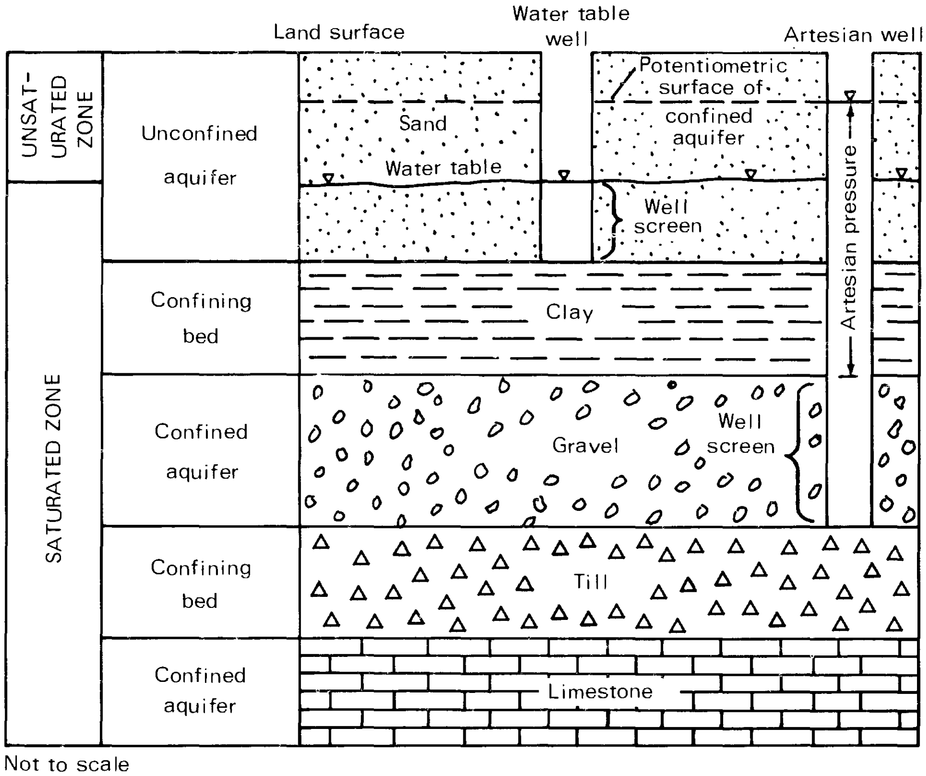


Figure 12.--Water table in an unconfined aquifer and potentiometric surface in a confined aquifer. (Modified from Heath, 1983)

Recharge

Most recharge occurs during and shortly after periods of precipitation and snowmelt and thus is intermittent except in areas where streams continuously lose water to the aquifer. (Discharge, in contrast, is continuous as long as ground-water levels are above the level at which discharge occurs.) Ground-water levels decline continuously during the growing season from April or May to October. Most recharge of ground-water systems occurs from late fall to early spring, when plants are dormant and evaporation rates are less than in summer (fig. 13). Ground-water levels rise when the rate of precipitation or snowmelt is greater than the rate of evapotranspiration and discharge.

Recharge results from precipitation in most upland areas except along streams and their adjoining flood plains, both of which typically are ground-water-discharge areas. Recharge also may come from streams, though, wherever they lose water by infiltration through the channel bottom to the water table.

Sources of recharge to the Tug Hill aquifer under natural conditions include (1) infiltration of precipitation that falls on the aquifer, (2) infiltration from streams that drain till-covered bedrock uplands and then cross the aquifer, and (3) unchanneled runoff from adjacent till and bedrock hillsides that seeps into the ground at the edges of the aquifer. Each of these is discussed in detail in the next section.

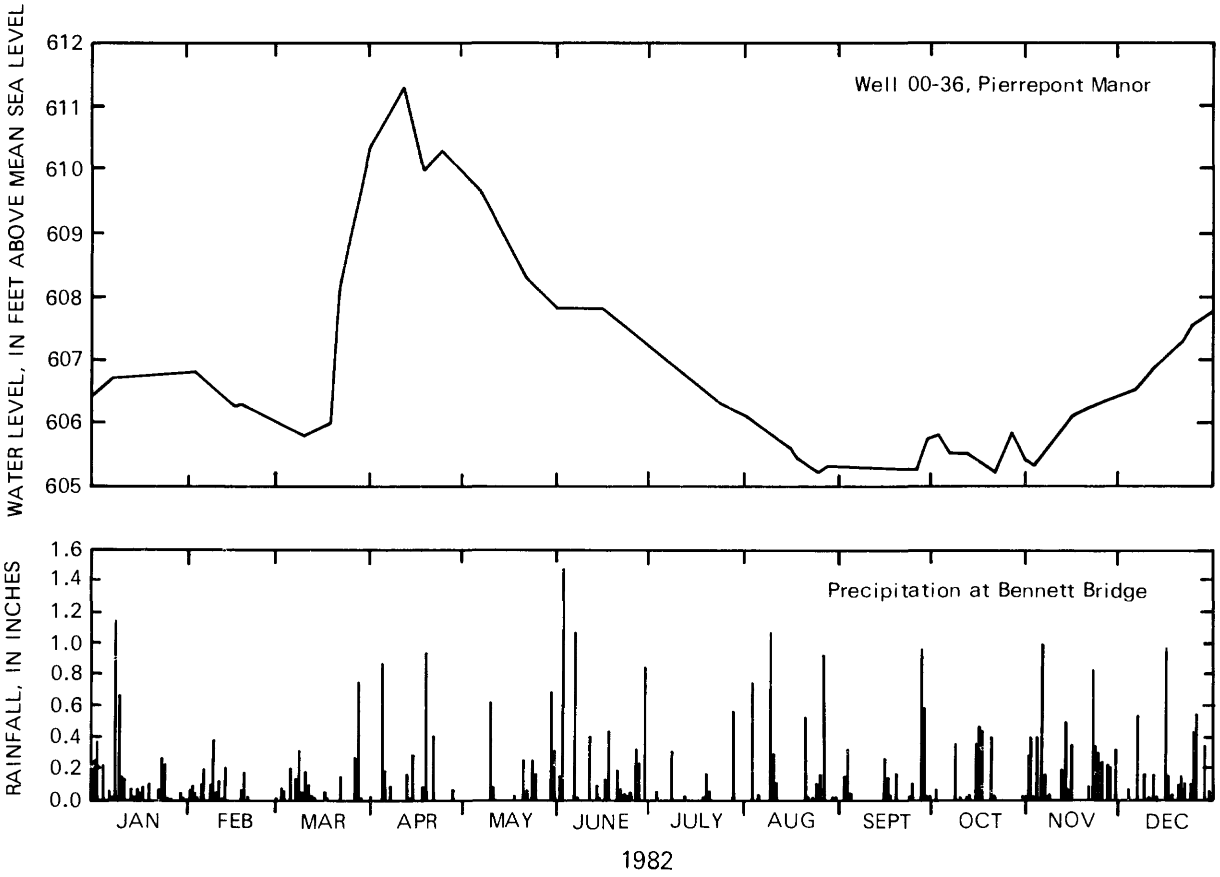


Figure 13.--Annual (1982) fluctuation of ground-water levels in the Tug Hill aquifer and precipitation. (Precipitation data from National Oceanic and Atmospheric Administration, 1982. Well location is shown on pl. 1D)

Infiltration of Precipitation on the Aquifer

Wherever sand and gravel are at land surface, surface runoff is minimal because nearly all rain and melting snow that is not lost through evapotranspiration infiltrates to the subsurface. About half the total precipitation reaches the water table as recharge, some is retained as soil moisture in the unsaturated zone, and the rest is returned to the atmosphere by transpiration and evaporation. Thus, recharge from precipitation over the aquifer is approximately the amount of precipitation minus the amount of evapotranspiration. Average precipitation is 45 in/yr (inches per year) in the northern and southern parts and 49 in/yr in the central part; evapotranspiration in the study area is estimated to be 18 in/yr (Weist and Giese, 1969). Thus, it is estimated that annual recharge equals about 27 in/yr or 1.46 million gallons per day per square mile [(Mgal/d)/mi^2] in the northern and southern parts of the aquifer and 31 in/yr or (1.65 Mgal/d)/mi^2 in the central part. The amounts of recharge to the aquifer from the major sources are given in table 1.

Runoff from Adjacent Hillsides

The quantity of recharge derived from runoff on hillsides is primarily a function of annual precipitation, slope, permeability of hillside materials, and the size of the areas that slope directly toward the aquifer. The south part of the aquifer (West Branch Fish Creek valley) is bordered on both sides by till-covered bedrock hillsides, whereas the north part is bordered by till-covered bedrock hillside only on the east. Only a small quantity of rainfall can seep into till before runoff begins because the till is relatively impermeable. Where upland hillsides slope directly toward the aquifer, unchanneled runoff infiltrates directly to the water table at the edges of the aquifer.

Randall (1978, 1982), in a study of aquifer recharge in the Susquehanna River basin in south-central New York, reported that the contributing upland area was nearly constant along the length of aquifer along the valley. For each linear mile of aquifer, Randall reported about 0.3 mi^2 of till-covered hillside from which storm runoff (about 25 percent of the precipitation) flowed overland to infiltrate into the adjacent aquifer. From an average annual rate of precipitation of about 47 in/yr over the study area, the recharge would be 0.17 Mgal/d per mile of aquifer border. Where till-covered hillsides abut both sides of the aquifer, such as in the West Branch Fish Creek valley, the recharge would be twice as great. Table 1 includes average annual recharge from these adjacent hillsides.

Infiltration from Streams

Streams that flow from till-covered uplands onto the permeable sediments that form the aquifer can contribute significant amounts of recharge. Where the water level in the aquifer is lower than the stream-water level, stream water can infiltrate into the aquifer. The rate of infiltration to the aquifer depends more on the permeability of the aquifer than of the streambed itself (Randall, 1978).

Visual examination of many streams and 37 streamflow measurements from 14 selected streams throughout the aquifer during base-flow conditions on July 18 and September 23, 1985, indicated that (1) most tributary streams in the West Branch Fish Creek valley usually gain water from the aquifer and thus are discharge areas, and (2) upland tributary streams that flow onto the northern part of the aquifer lose water at the east side of the aquifer and regain water at the west edge of the aquifer. The recharge provided to the aquifer by these streams was measured to range from 10 to 260 gal/d per foot of stream reach.

Estimates of average annual recharge from tributary streams (table 1) in the northern part of the aquifer and at some locations in the southern part are calculated by multiplying the length of the stream reach by the measured infiltration rate. Results of seepage measurements on selected streams over the aquifer are given in table 8 (at end of report). For streams not measured, an infiltration rate of 10 (gal/d)/ft was used for areas of sand and 100 (gal/d)/ft for areas of sand and gravel.

In some parts of the aquifer, those where sand and gravel deposits are in hydraulic connection with a stream and where large quantities of water are pumped from nearby wells, some of the pumped water is derived from streamflow that enters the aquifer by induced infiltration. (Induced infiltration occurs when the drawdown of the water table, called the cone of depression, caused by pumping reaches the stream and creates a water-table gradient sloping from the stream to the well.) Induced infiltration occurs at the village of Mannsville public water-supply well, at the paper company's well field near Richland, and at the fish hatchery well field near Altmar.

Table 1.--Summary of average annual recharge to the north, central, and south parts of the Tug Hill aquifer.

[All recharge values are in million gallons per day.]

Part of aquifer	Area (mi^2)	Length (mi)	Recharge Source: Direct precipitation	Recharge Source: Runoff from adjacent hillsides	Recharge Source: Infiltration from streams	Total
North	11.5	18.3	16.8	2.6	2.2	21.6
Central	29.4	7.5	48.5	2.0	1.7	52.2
South	49.1	21.2	71.7	6.8	1.0	79.5
Total	90.0	47.0	137.0	11.4	4.9	153.3

Ground-water Movement and Discharge

Ground water moves from recharge areas to discharge areas by gravity, and the rate is controlled by the hydraulic gradient and hydraulic conductivity. Under nonpumping conditions, ground water moves to lower altitudes until it discharges at land surface as a spring or seep along the side or bottom of a stream channel or to a surface-water body such as a lake or wetland.

The altitude of the water table and the direction of ground-water movement are determined by measurement of the water level in wells. The water table roughly parallels land surface in most places (fig. 14).

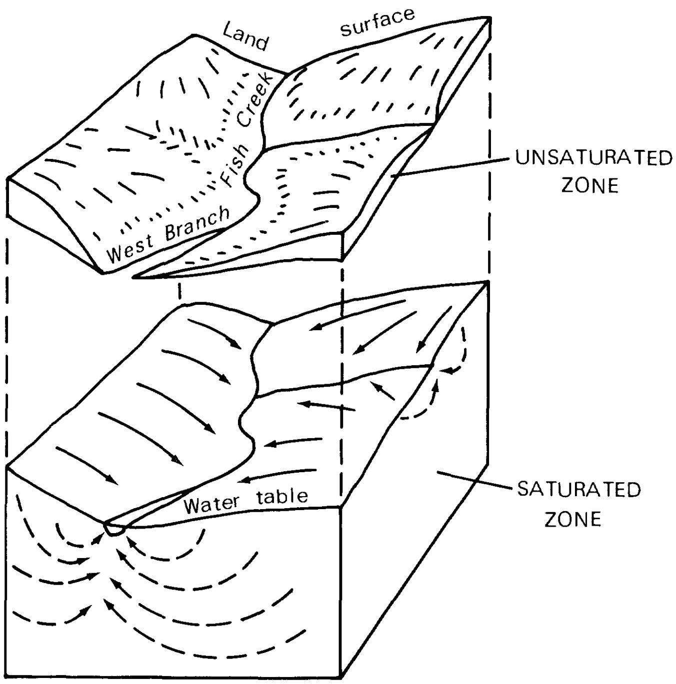


Figure 14.

Relation between topography and direction of ground-water movement. Solid arrows indicate direction of flow at water table; dashed arrows indicate direction of flow beneath water table.

The potentiometric surface of confined aquifers, like the water table, slopes from recharge areas toward discharge areas. Shallow confined aquifers, which are relatively common in the glaciated northeastern United States, discharge and are recharged in approximately the same areas as the overlying unconfined aquifers. The deeper confined aquifers, in contrast, are recharged mainly along the buried bedrock valley walls and their outcrop areas along the edges of the valley. The directions of ground-water movement in an idealized cross section of the West Branch Fish Creek valley are indicated in figure 15.

The Tug Hill aquifer contains two types of ground-water-flow systems--one in the southern part of the aquifer (West Branch Fish Creek valley and Little River valley), the other in the northern and central parts, from Bennett Bridge to Adams Center (fig. 1). Ground water in the southern part flows from the valley walls toward the central valley axis and discharges (1) to tributaries to West Branch Fish Creek on the valley flat, (2) to West Branch Fish Creek, (3) as subsurface flow at McConnellsville, (4) through evapotranspiration, and (5) to wells. The ground-water flow system in the Little River valley is similar. Ground water in the northern part of the aquifer flows westward, and streams that cross the aquifer lose water along its east side and gain water along the west side. Water discharges from the aquifer (1) by seepage to streams, springs, and wetlands along the west side of the aquifer, (2) through evapotranspiration, (3) as subsurface flow to adjacent deposits along the west margin of the aquifer, and (4) to wells.

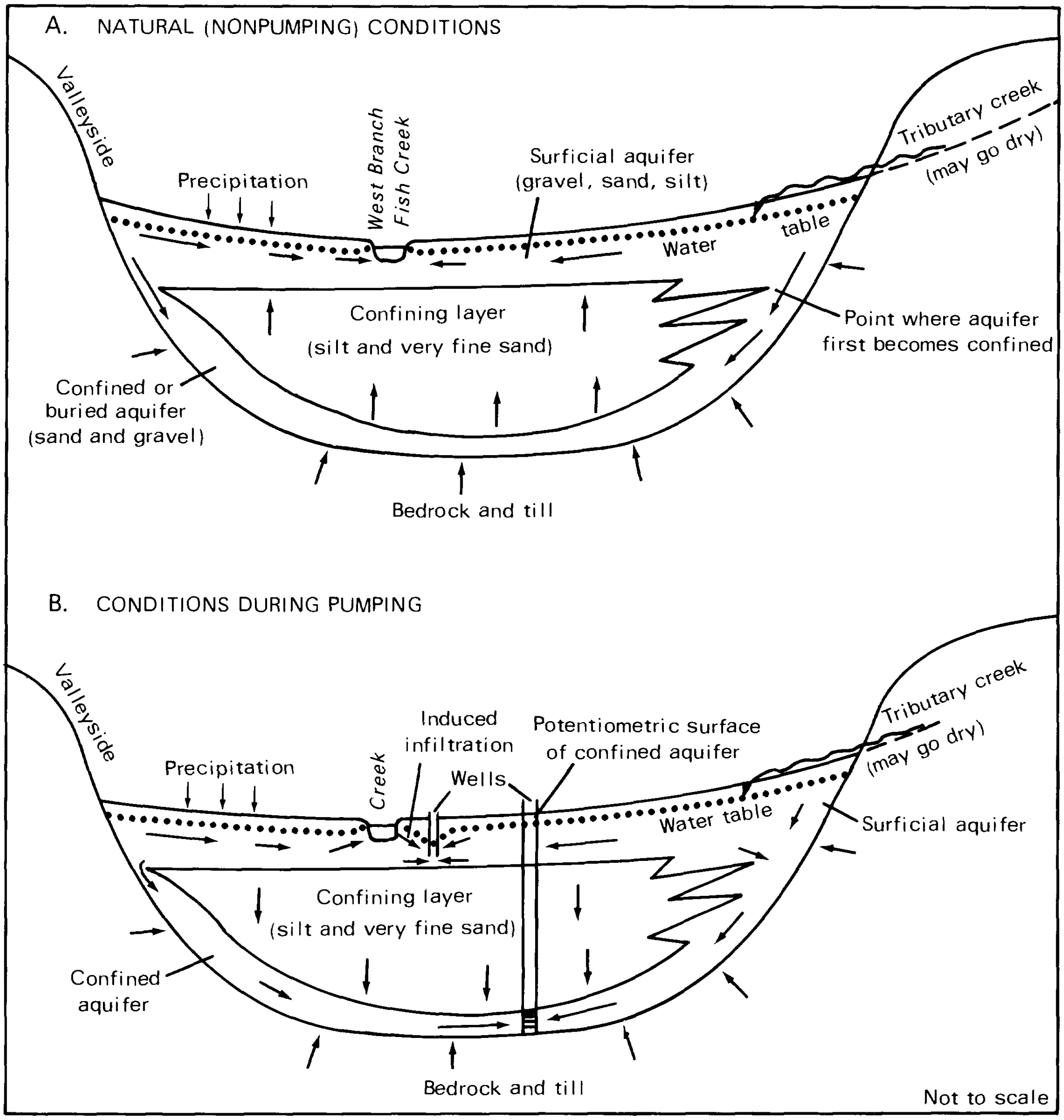


Figure 15.--Generalized directions of ground-water movement in the West Branch Fish Creek valley during (A) nonpumping conditions, and (B) pumping conditions.

Water-level Fluctuations

The annual fluctuation of ground-water levels in the water-table aquifer ranges from 2 to 15 ft but usually ranges between 5 and 10 ft (pls. 1D, 2D, 3D, 4D). Ground-water levels rise when the rate of recharge exceeds the rate of discharge, which usually occurs in late fall, winter, and early spring (fig. 13), when plants are dormant and the evaporation rate is low. Ground-water levels decline during late spring, summer, and early fall, when the rate of discharge exceeds the rate of recharge. Large storms during this period may cause ground-water levels to rise for short periods, however.

Ground-water Availability

Water Use

Ground water is the major source of water for residents living on or, in some places, adjacent to the Tug Hill aquifer. Before 1960, ground-water use was small because development was sparse. Most ground-water withdrawals were from springs, dug wells, and some drilled wells that supplied homes, farms, and small communities. After 1960, people began to realize that some parts of the aquifer could yield large quantities of water. Since 1960, a paper company and a fish hatchery have developed well fields that yield as much as 1.5 and 2.3 Mgal/d, respectively. The villages of Mannsville and Sandy Creek-Lacona (fig. 1) have installed new wells to increase their water supplies, and several hundred homeowners have had wells drilled. Also, two irrigation wells have been installed near Williamstown. By 1986, several villages and industries were planning to use ground-water sources to enlarge their water supplies. The population and ground-water pumpage of communities overlying the Tug Hill aquifer are summarized in table 2.

Table 2.--Population served and ground-water pumpage from the Tug Hill aquifer.

[Locations of communities are shown in fig. 1.]

Source		Population served[1]	Average pumpage (Mgal/d)
Municipal Community Water Systems:			
Village of Camden		2,940	0.60*
McConnellsville Water Company[2]		230	.06
Hamlet of Orwell[3]		250	.02
Village of Pulaski[3]		2,500	.25
Villages of Sandy Creek-Lacona[3]		1,450	.33
Village of Mannsville[4]		580	.04
Village of Adams and Adams Center[4]		2,900	.75
	Subtotal	10,820	2.05
Other Community Water Systems:			
Trailer parks (two)	Subtotal	70	.01
Private Water Systems			
Hamlet of Westdale		200*	.02*
Hamlet of Williamstown		400*	.04*
Village of Altmar[3]		350	.03
Hamlet of Pierrepont Manor		200*	.02*
Hamlet of Richland		400*	.04*
Other individual supplies		2,100*	.21*
	Subtotal	3,650	.36
Industry:[4]			
Fish hatchery		--	2.3
Paper company		--	1.5
	Subtotal	--	3.8
	Total	14,540	6.12

[1] New York State Department of Health, 1982
[2] Parratt-Wolff, Inc., 1984
[3] McFarland-Johnson, 1982
[4] O'Brien and Gere, 1968
* Estimated

Potential Well Yields

Porosity indicates the maximum amount of water that a rock can contain when saturated. The porosity of unconsolidated deposits depends on the degree of sorting and the shape of the sediment particles but not on their size. Fine-grained materials tend to be better sorted than coarser deposits and thus generally have higher porosity.

Only a part of the water in the pore spaces is available to supply a well or spring. If the aquifer is unconfined, the percentage of water that would drain out under the influence of gravity is called specific yield. The remaining water is retained by molecular attraction as a film on the surfaces of sediment grains and in very small openings; this is called specific retention. The smaller the grain size, the more surface area is available for molecular attraction between water and sediment; thus, fine-grained sediments such as clay and silt have a higher specific retention and lower specific yield than coarse-grained sediments such as sand and gravel (table 3). Specific yield indicates how much water is available for withdrawal, and specific retention indicates how much water remains in the deposit after it is drained by gravity. Saturated clay, for example, has a high porosity (50 percent), yet most of the water is retained by molecular attraction to clay particles so that specific yield is only 2 percent. In contrast, gravel has a lower porosity (20 percent) but also a low specific retention (1 percent or less) and high specific yield (19 percent); thus, more water is available from gravel than from clay.

Table 3.--Representative porosity, specific yield, and specific-retention values for selected aquifer materials.

[From Heath, 1983. Values in percent by volume]

Material	Porosity	Specific yield	Specific retention
Clay	50	2	48
Sand	25	22	3
Gravel	20	19	1
Limestone	20	18	2
Sandstone	11	6	5
Granite	.1	.09	0.01

The rate of ground-water movement is determined by the slope of the water table (hydraulic gradient) and permeability (hydraulic conductivity) of the deposit. Ranges of horizontal hydraulic conductivity for fractured bedrock and unconsolidated deposits are given in figure 16. For a given hydraulic conductivity, the steeper the hydraulic gradient, the faster ground water will flow. Thus, under a given hydraulic gradient, the greater the hydraulic conductivity, the faster the ground water will flow. For example, ground water under a given hydraulic gradient would move faster horizontally through gravel (generally several hundred feet per day) than through fine sand (generally several tens of feet per day) or clay (generally fractions of a foot per day).

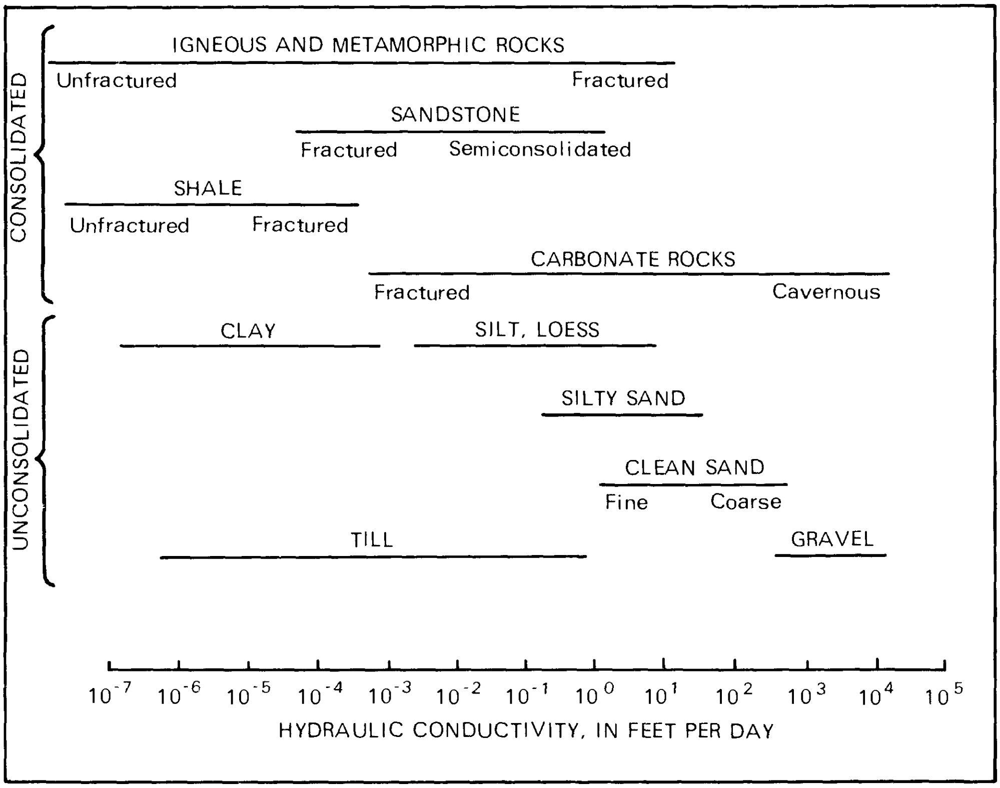


Figure 16.--Ranges of hydraulic conductivity for selected types of consolidated and unconsolidated deposits. (Modified from Heath, 1983)

When a surficial (unconfined) aquifer is pumped, the water table declines in proportion to the amount of water removed from storage. Ground-water levels reach equilibrium when the rate of pumping equals the reduction in the rate of natural discharge and(or) by an increase in the rate of recharge.

Bedrock.--The limestone that underlies the northern part of the aquifer (fig. 2) is likely to yield 50 to 150 gal/min to a properly constructed well for at least several hours (Kantrowitz and Snavely, 1982), although both smaller and larger yields have been reported (Waller, 1975). Most wells that yield more than 50 gal/min penetrate major solution-widened joints and bedding planes.

Shale that underlies the north-central part of the aquifer (fig. 2) has the lowest yields of the bedrock units, less than 10 gal/min in most places. The part of the shale that is most likely to yield large amounts of water to wells is in the upper 10 ft, where it is most weathered and fractured.

The part of the Oswego Sandstone that underlies the south part of the aquifer generally yields from 10 to 100 gal/min (Ontario Water Resources Commission, 1970). As in the shale, the upper, weathered part of the sandstone generally produces the highest yields.

Bedrock wells with the highest yields are in areas where water in the overlying sand and gravel drains directly into the bedrock. The downward flow of water from overlying deposits in areas where till or clay overlie the rock is restricted, though.

Till.--Till, which covers most of the uplands and forms the bottom of most of the Tug Hill aquifer, yields useful amounts of water only to dug wells that are typically several feet in diameter and can store more than 100 gallons of water. The rate of replenishment by seepage is slow--generally less than 1 gal/min. Drilled wells are generally not installed in till because the rate of replenishment is slower than in a dug well.

Alluvium.--Several streams that drain the Tug Hill uplands have deposited moderately permeable silty and sandy gravel alluvium along the east side of the northern part of the aquifer. Although these deposits are generally less than 30 ft thick, they can yield significant amounts of water to wells because they are replenished by infiltration from streams. Infiltration of streamflow is common in the northern part of the aquifer.

A drilled well (36-23) and a 12-ft-deep dug well (39-22) that taps an alluvial deposit just east of the village of Mannsville supplies the village with water (pl. 4A). The drilled well is 29 ft deep, has a 5-ft-long, 6-inch-diameter screen, and is pumped at rates as high as 60 gal/min. Although the stream adjacent to the two wells usually dries up in summer, a reservoir 1,000 ft west of the wells has kept ground-water levels from declining seriously during dry periods and thus prevents the dug well from drying up.

In another small alluvial deposit in Bear Creek valley near Pierrepont Manor (pl. 4A), the fire department pumped more than 30 gal/min with little drawdown from a 13-ft-deep private dug well (19-45). This area could produce much more water because the well has shown little drawdown and does not penetrate the full thickness of the deposit. A test well (16-55) drilled near the dug well indicated 30 ft of sand and gravel. These alluvial deposits probably would yield 10 to 100 gal/min of water to screened wells and 10 to 250 gal/min where induced infiltration from streams supplements ground water pumped by a well.

Beach sand and gravel.--Some beach deposits in the northern part of the aquifer have the potential to yield large quantities of water to wells. Well yield depends on (1) the saturated thickness (in general, the greater the thickness, the greater the well yield), (2) the presence of a stream to provide induced infiltration, and (3) the hydraulic conductivity of the aquifer material. In general, the western part of the aquifer is thicker (20 to 50 ft thick) than the eastern part (10 to 30 ft thick). Where the saturated thickness exceeds 20 ft, the aquifer probably could yield from 10 to 250 gal/min and more than 250 gal/min near streams. Public-supply wells for the villages of Sandy Creek and Lacona are in 20- to 30-ft-thick beach deposits at Lacona and can pump from 180 to 400 gal/min. Abandoned test wells that tapped beach deposits 1.5 mi north of Lacona have been reported to yield from 200 to 400 gal/min.

The beach deposits in some areas are thin and may be above the water table in the dry season. During wet periods, however, these deposits may have a saturated thickness of 5 to 10 ft and probably could yield 10 to 100 gal/min.

Wells in areas where the aquifer may go dry during dry periods need to be drilled into the underlying bedrock to reach a reliable water supply. Several dug wells in beach deposits in and north of Pierrepont Manor have gone dry during late summer and early fall, and some residents have had water hauled in or had their wells deepened. The residents of Pierrepont Manor are evaluating the feasibility of installing a public water-supply system, possibly in the Bear Creek valley, where well records indicate there may be sufficient ground water to supply a small municipality.

Sand and gravel-filled valley near Richland.--The area with the highest well yields from the Tug Hill aquifer is a bedrock valley filled with 60 to 85 ft of beach and kame sand and gravel. The high-yielding area extends from Richland to about 3 mi southeast of Richland (pl. 3E). The high yields (greater than 250 gal/min) are due to the relatively large saturated thickness of permeable sediments and to substantial recharge by infiltration in the eastern part of the aquifer from Trout Brook and other small tributary streams (Apfel, 1963). Trout Brook receives ground water most of the year in the central and western parts of this area.

This part of the aquifer supplies water to (1) the village of Pulaski through springs at Richland, (2) individual home and farm wells in the Richland area, and (3) a well field for a paper company just southeast of Richland. Individually screened wells at the paper company well field pump between 400 and 1,000 gal/min, and the daily average pumpage is 1.5 Mgal/d.

Kame deposits.--Kame deposits are moderately permeable but generally less sorted than outwash or beach deposits. Extensive test drilling and pumping tests by the New York State Department of Environmental Conservation in the Orwell-Bennett Bridge moraine near Altmar during 1973-74 revealed that (1) the aquifer thickness ranges between 20 and 110 ft, (2) the deposits contain a high percentage of sand, and (3) most well yields are between 10 and 250 gal/min, but some are as high as 400 gal/min. Most of the larger yields are in areas where wells induce infiltration from Beaverdam Brook and a tributary to Beaverdam Brook.

Other significant kame deposits are in the vicinity of Kasoag Lake, along the northeast valley wall of West Branch Fish Creek valley, the Williamstown kame moraine just south of Williamstown, and the Camden kame moraine north and south of McConnellsville (fig. 6). Homes along New York State Route 69, southeast of Camden, tap ground water from the lower parts of kame terraces along the east valley wall of West Branch Fish Creek valley. Test holes in the Camden moraine penetrated mostly sand with some gravel. Well yields from the Camden moraine would probably be several tens of gallons per minute. Test wells in the Camden kame moraine complex at Powell Road, 3,000 ft south of McConnellsville (pl. 1A), had relatively low well yields (10 to 20 gal/min), probably because the material has a relatively small saturated thickness and moderate to low permeability (Parratt Wolff, Inc., 1983).

Outwash.--The south part of the Tug Hill aquifer contains several outwash deposits. One outwash deposit in the West Branch Fish Creek valley extends 5 mi from south of the Bennett Bridge-Orwell moraine to 1.5 mi south of Kasoag Lake (pl. 2B), and another deposit extends 3 mi from south of the Williamstown moraine to Camden (pls. 1B and 2B). The coarse outwash adjacent to the moraine is thinly saturated, generally 10 ft or less, and well yields may range from 10 to 250 gal/min. Well yields may exceed 250 gal/min near surface-water bodies such as Kasoag Lake and other nearby ponds and streams because water from these surface-water bodies can be sources of induced infiltration. Well yields south of Kasoag Lake probably would be in the range of 1 to 50 gal/min as a result of the high sand content and the gradation of the outwash from pebbly sand at land surface to fine sand with depth.

The outwash deposit southeast of the Williamstown moraine contains 10 to 55 ft of sand and gravel overlying lacustrine fine sand. The hamlet of Westdale and many other rural residents obtain water from this upper outwash deposit. Where the outwash is thin, however, most drilled wells penetrate through the upper aquifer and the thick underlying lake-bottom sediments and end in buried sand and gravel (if present) or in bedrock. Shallow wells probably could yield 10 to 100 gal/min. Well yields may range from 10 to 250 gal/min along the northeast side of the valley, where sand and gravel are thicker and where outwash overlies kame deposits.

Upland sand and gravel deposits.--Some of the low areas in the higher elevations of the Tug Hill Plateau contain thin (5 to 20 ft thick) outwash and kame sand and gravel deposits. Little information is available from which to evaluate well yield or saturated thickness because these areas are the least developed part of the aquifer. If these deposits are saturated, they probably could yield 10 to 100 gal/min and more near streams. Because these deposits are thin, dug wells or infiltration galleries such as those used to supply water for the hamlet of Orwell are more likely to obtain a reliable water supply than a drilled well. Emmons Brook and Cobb Brook valleys, northwest of Camden, also contain outwash deposits. The village of Camden obtains ground water from dug wells in the outwash deposits in the Emmons Brook valley.

Buried aquifer in the West Branch Fish Creek valley.--The West Branch Fish Creek valley contains a discontinuous buried sand and gravel layer between the thick lake-bottom deposits (fine sand and silt) and till or bedrock. Large yields have been reported in some areas and small yields in others; in some areas the water is too turbid for drinking, or the aquifer is absent. Exploratory gas wells 1 mi north and 1 mi south of Kasoag Lake (pl. 2A) pumped 800 and 500 gal/min, respectively, from the buried aquifer. Test holes drilled in the northwest part of Williamstown for a wire company did not encounter any significant buried aquifer, although it is tapped by many domestic wells in and south of the village.

Most drilled wells in the northeast part of the West Branch Fish Creek valley near and south of Camden penetrate the buried aquifer, but some in the middle and southwest parts of the valley did not, which indicates that the buried aquifer is discontinuous. The northeast part of the valley is more likely to yield large quantities of water, possibly 10 to 250 gal/min.

Extensive test drilling for the village of McConnellsville and a sand company in McConnellsville failed to locate a significant buried aquifer in that area. The southern boundary of the Tug Hill aquifer was drawn at McConnellsville because (1) no significant buried aquifer is evident, and (2) well logs show the surficial aquifer to grade from coarse outwash sand and gravel in front of the Williamstown moraine to deltaic pebbly sands at Camden, then to deltaic fine to medium sand just west of McConnellsville, then to mostly lacustrine silt east of McConnellsville (Parratt Wolff, Inc., 1983).

WATER QUALITY OF THE TUG HILL AQUIFER

Water samples were collected from 40 selected wells in the Tug Hill aquifer during August 1985; 32 of the wells tap the unconfined surficial aquifer; the other 8 tap the buried or confined part of the aquifer. Wells that tap the unconfined aquifer range in depth from 11 to 60 ft; those that tap the confined aquifer range in depth from 75 to 195 ft.

Chemical and Physical Characteristics

Chemical analyses of ground-water samples (table 9, at end of report) indicate that the quality of water in the Tug Hill aquifer generally meets State drinking-water standards.

pH

The pH of water is a measure of hydrogen-ion activity. The pH scale ranges from 0 to 14, and each unit increase on the scale represents a tenfold decrease in hydrogen-ion activity. The major influence on pH in most ground water is the interaction of the soil and rock molecules with gaseous and dissolved carbon dioxide, bicarbonate, and carbonate ions. The pH of ground water in the study area ranges from 5.9 to 8.0 (slightly acidic to slightly basic) with a median pH of 7.5 (table 4).

Specific Conductance and Dissolved Solids Concentration

Specific conductance is a measure of the capacity of water to conduct an electric current. It is related to the type and concentration of ions in solution and can be used for approximating the dissolved-solids concentration of water. Commonly the concentration of dissolved solids, in milligrams per liter (mg/L) is about 65 percent of the conductance value, in microsiemens per centimeter at 25° Celsius (μS/cm)[1]. This relation is not constant, though, and may range from about 55 percent to about 80 percent. Conductance values for water in the Tug Hill aquifer ranged from 56 to 2,230 μS/cm, with an average value of 327 μS/cm. Dissolved-solids values ranged from 32 mg/L to 360 mg/L with an average of 147 mg/L.

Hardness

Hardness values in ground water in the Tug Hill aquifer ranged from 23 to 300 mg/L as $CaCO_3$ (soft to very hard), with a mean value of 115 mg/L (moderately hard) (table 4). Classification of hardness is as follows (Hem, 1970):

Hardness range (mg/L of $CaCO_3$)	Description
0 - 60	Soft
61 - 120	Moderately hard
121 - 180	Hard
More than 180	Very hard

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[1] Formerly micromhos per centimeter (μmho/cm) at 25° Celsius.

Hardness in water used for ordinary domestic purposes does not become particularly objectionable until it exceeds a concentration of 100 mg/L. Elevated concentrations of hardness generally occur in areas where ground water is in contact with limestone or unconsolidated sediments derived from limestone.

Table 4.--Minimum, maximum, mean, and median concentration or value and standard deviation for selected constituents and properties of ground water from Tug Hill aquifer.

[Values are in milligrams per liter, unless otherwise indicated, µg/L = micrograms per liter; or µS/cm = microsiemens per centimeter. A dash indicates no applicable standard. Analyses by U.S. Geological Survey]

Constituent or property	Number of samples	Value or concentration				Standard deviation	New York State drinking-water standard[a]
		minimum	maximum	mean	median		
Depth (ft)	40	11	195	46	33	42	--
Total alkalinity dissolved (as $CaCO_3$)	40	9	293	100	90	61.6	--
Calcium, dissolved	40	6.2	110	34	26	26.1	--
Chloride, dissolved	40	.80	660	31	5.4	105	250
Fluoride, dissolved	40	<.1	.5	.14	.10	<.1	1.5
Hardness (as $CaCO_3$)	40	23	300	115	98	75	--
Magnesium, dissolved	40	.94	24	7.3	6.5	5.0	--
Nitrate, dissolved	40	<.10	22	2.1	.78	4.0	10[c]
Dissolved solids	40	32	360	147	120	86	--
pH (standard units)	40	5.9	8.0	--	7.5	.44	--
Orthophosphate, dissolved (as P)	40	<.01	.48	.03	.01	.08	--
Potassium, dissolved	40	.3	9.9	1.8	1.1	2.0	--
Silica, dissolved	40	2.3	12	5.9	5.6	2.1	--
Sodium, dissolved	40	.8	340	19	3.3	56	20
Specific conductance (µS/cm)	40	56	2,230	327	232	350	--
Iron, dissolved (µg/L)	40	<3	1,700	103	18	287	300[b]
Sulfate	40	<.2	36	13	9.6	7.9	250
Manganese, dissolved (µg/L)	40	<1	3,500	249	15	627	300[b]
Arsenic, dissolved (µg/L)	5	<1	<1	<1	<1	0	50
Barium (µg/L)	5	14	200	70	49	76	1,000
Boron, dissolved (µg/L)	5	<20	70	38	30	22	--
Cadmium, dissolved (µg/L)	5	<1	<1	<1	<1	0	50
Copper, dissolved (µg/L)	5	1	16	8	5	7.4	1,000
Lead, dissolved (µg/L)	5	<1	1	<1	1	0	50
Lithium, dissolved (µg/L)	5	<4	66	17	4	27	--
Mercury, dissolved (µg/L)	5	<.1	<.1	<.1	<.1	0	--
Selenium, dissolved (µg/L)	5	<1	<1	<1	<1	0	10
Strontium, dissolved (µg/L)	5	29	820	218	67	338	--
Zinc, dissolved (µg/L)	5	<3	500	132	5	215	5,000

[a] Drinking-water standards from New York State Department of Health, 1964 and 1977.
[b] If iron and manganese are both present, the total concentration of both substances should not exceed 300 µg/L.
[c] Nitrate as nitrogen.

Concentrations greater than 100 mg/L may decrease the effectiveness of soap because the cations react with the soap to form insoluble compounds, and the water may leave a residue when heated (Hem, 1970).

Alkalinity

Alkalinity is a measure of the capacity of a solution to neutralize acid. The alkalinity is a measure of the concentrations of carbonate ($CO_3^{=}$), bicarbonate (HCO_3^-), and hydroxide (OH^-). In water within the pH range of the ground water in the study area, the bicarbonate ion is the dominant anion. Alkalinity is reported in tables 4 and 9 (at end of report) in terms of equivalent concentrations as calcium carbonate ($CaCO_3$). The mean alkalinity of ground water in the study area is 100 mg/L, which indicates that, in general, the soils have a moderate capacity to neutralize acid precipitation. Precipitation in the study area is moderately acidic, with a pH range of 4.2 to 4.4 (Peters and Bonelli, 1982).

Nitrate

Nitrate does not occur naturally in any of the rocks of this area but is a common degradation product of organic wastes. Nitrate sources include the decomposition of organic nitrogen that is introduced to the soil by nitrogen-fixing plants and bacteria, human and animal wastes, and organic and inorganic fertilizers. Thus, nitrate enters ground water from activities on the land surface or from waste-disposal systems. Nitrate levels were higher in water from the shallow wells in the unconfined parts of the aquifer than from the deeper wells in the confined aquifer. Nitrate (as N) concentrations ranged from <0.10 mg/L (below detection limit) to 22 mg/L and averaged 2.1 mg/L.

The New York State drinking-water standard for nitrate is 10 mg/L as N. Nitrate contamination of ground water may be localized, such as at well 22-00 near Altmar (pl. 3A). The water sample collected from that well had a concentration of 22 mg/L as N. Another water sample collected from this well by the Cornell Center for Environmental Research had a concentration of 23 mg/L of nitrate as N (Hughes, 1985). The recharge area for this well includes a large dairy operation and corn fields. The major source of nitrate probably is manure in the barnyard and fertilizer and manure that are spread on the surrounding corn fields. Water from four other wells in Jefferson County had nitrate concentrations greater than 5 mg/L, and seven others had concentrations above 2 mg/L. These wells are all less than 40 ft deep and installed in the unconfined aquifer, which is susceptible to direct surficial contamination from agricultural sources and leakage from failing septic systems.

Chloride and Sodium

Sources of chloride and sodium are road salt, dissolution of sodium-bearing minerals in unconsolidated deposits, and mineralized ground water in bedrock that may discharge into sand and gravel aquifers (especially the buried aquifer on bedrock in the West Branch Fish Creek valley). The larger concentrations of chloride are found in water near major roads on which salting is heaviest and in water from some deep wells that extend close to bedrock in the West Branch Fish Creek valley. Only one sample (from well 09-05, near

Williamstown, pl. 2A) exceeded the New York State drinking-water standard for chloride (250 mg/L). That sample had a chloride concentration of 660 mg/L and also had the highest concentrations of potassium (9.9 mg/L) and sodium (340 mg/L) and the highest specific conductance (2,230 μS/cm) of all samples tested. That sample was also high in iron (260 μg/L) and very hard (230 mg/L). Although no standard has been established for sodium, the U.S. Environmental Protection Agency (1976) recommends less than 20 mg/L in drinking water for people on sodium-restricted diets. Although the well log was not available to determine the aquifer type, the highly mineralized water suggests that the well, 111 ft deep, may be finished in or near the top of the sandstone where highly mineralized water is typically found (Kantrowitz, 1970).

Trace Elements

Mean concentrations of iron and manganese in water from the Tug Hill aquifer were 103 micrograms per liter (μg/L) and 249 μg/L, respectively (table 4). Dissolved iron and manganese concentrations exceeded the New York State drinking-water standards in 10 of the wells sampled; maximum concentrations were 1,700 μg/L for iron and 3,500 μg/L for manganese. New York State drinking-water standards specify a maximum concentration of 300 μg/L for either iron or manganese or a total of 300 μg/L if both are present. Even though the large concentrations of iron and manganese do not constitute a health hazard, they affect taste, odor, and color of the water and also interfere with laundering operations, cause staining of plumbing fixtures, and support the growth of iron bacteria in distribution systems. When exposed to air, water that contains large iron and manganese concentrations becomes turbid as the iron and manganese ions become oxidized to form colloidal precipitates. Filtration units can be installed by individual well owners to help remove objectionable concentrations of iron and manganese.

Concentrations of other trace elements did not exceed New York State drinking-water standards. Concentrations of arsenic, cadmium, mercury, and selenium were below the laboratory detection limits in many samples. Minimum, maximum, mean, and median values for all measured constituents are presented in table 4 along with New York State drinking-water standards.

Environmental Influences

The primary influences on water quality in the Tug Hill aquifer are (1) the rock type and mineral composition of the sand and gravel deposits, and (2) effects of man's activities. A statistical comparison of ground-water quality by well depth and by location was done to identify patterns or significant differences in chemical concentrations within the aquifer. A statistical test that compares significant differences between medians of distributions uses "box plot" diagrams with "notches" (McGill and others, 1978). The notches represent an approximate 95-percent confidence interval around the median. If the notches of one distribution do not overlap those of another distribution, the differences between the two distributions are considered significant at the 95-percent confidence interval.

Statistical comparison of water quality by location revealed a correlation between the water chemistry and source terrain of sediments that form the aquifer. During the last glaciation of the Tug Hill area, ice that overrode limestones in the northern part of Jefferson County transported and deposited carbonate-rich sediments that form the northern part of the aquifer. The carbonate content of glacial drift decreases southeastward with distance from the limestone source. Glacial ice in the central and southern parts of the aquifer (southern Jefferson County and most of Oswego and Oneida Counties) overrode shales and sandstones; therefore, the aquifer in this area consists mostly of sediments derived from shale and sandstone. Water in the northern part of the aquifer had significantly higher (95-percent confidence level) specific conductance and concentrations of alkalinity, calcium, hardness, and sulfate, which are associated with the dissolution of limestone, than water in the southern and central parts of the aquifer, which is underlain by shale and sandstone.

The effects of human activities on water quality in the Tug Hill aquifer are reflected primarily in the surficial (unconfined) part of the aquifer. The top of the surficial aquifer is at land surface; therefore precipitation infiltrates readily and transports contaminants from the land surface to the aquifer, whereas confined or buried aquifers are protected from surface contamination to varying degrees by filtration and layers of smaller permeability.

The primary activity of man in the Tug Hill area is agriculture. Most agricultural land is heavily fertilized, either with commercial fertilizer or manure, and in some areas excess nitrogen from the fertilizer is carried to the aquifer by infiltrating water as indicated by the high concentrations of nitrate in water from several wells in agricultural areas. Other sources of nitrogen contamination are septic systems and barnyard runoff.

Wells were divided into two groups, deep and shallow, for comparison by depth. Deep wells (75 ft or deeper) tap the buried or confined part of the aquifer, whereas shallow wells (less than 75 ft) tap the surficial aquifer. Deep wells had slightly higher median concentrations of iron, magnesium, potassium, sodium, and specific conductance values, whereas shallow wells had slightly higher median concentrations of alkalinity, hardness, calcium, and nitrate. The median concentrations of water from the deep wells were not significantly different (95-percent confidence level) from those of water from the shallow wells.

Temporal Changes

To document changes in water quality with time, data collected in this study (1985) were compared with data for samples collected in 1971 and 1973 from public water-supply samples from the Tug Hill aquifer (table 5). Results of the comparison show no significant changes in water quality during the intervening 12 to 15 years.

Comparison with Water Quality in other Upstate Aquifers

Water quality of the Tug Hill aquifer was compared with that of six other upstate aquifers in terms of the five constituents commonly used to evaluate ground-water quality (table 6 and fig. 17); the Tug Hill aquifer has lower mean concentrations of all constituents except nitrate. The mean concentration of nitrate, on the other hand, was higher and reflects the greater agricultural land use in the Tug Hill aquifer area. Tug Hill also had the lowest mean concentrations of dissolved solids and sulfate and the second lowest concentration of hardness. Only the glacial-drift aquifer near Elmira (fig. 17) had a higher mean concentration of nitrate (table 6).

A box-plot comparison of the median values of the five constituents among the seven aquifers showed that water in the Tug Hill aquifer had significantly lower median concentrations of hardness, sulfate, and dissolved solids than the Endicott, Schenectady, and Elmira aquifers.

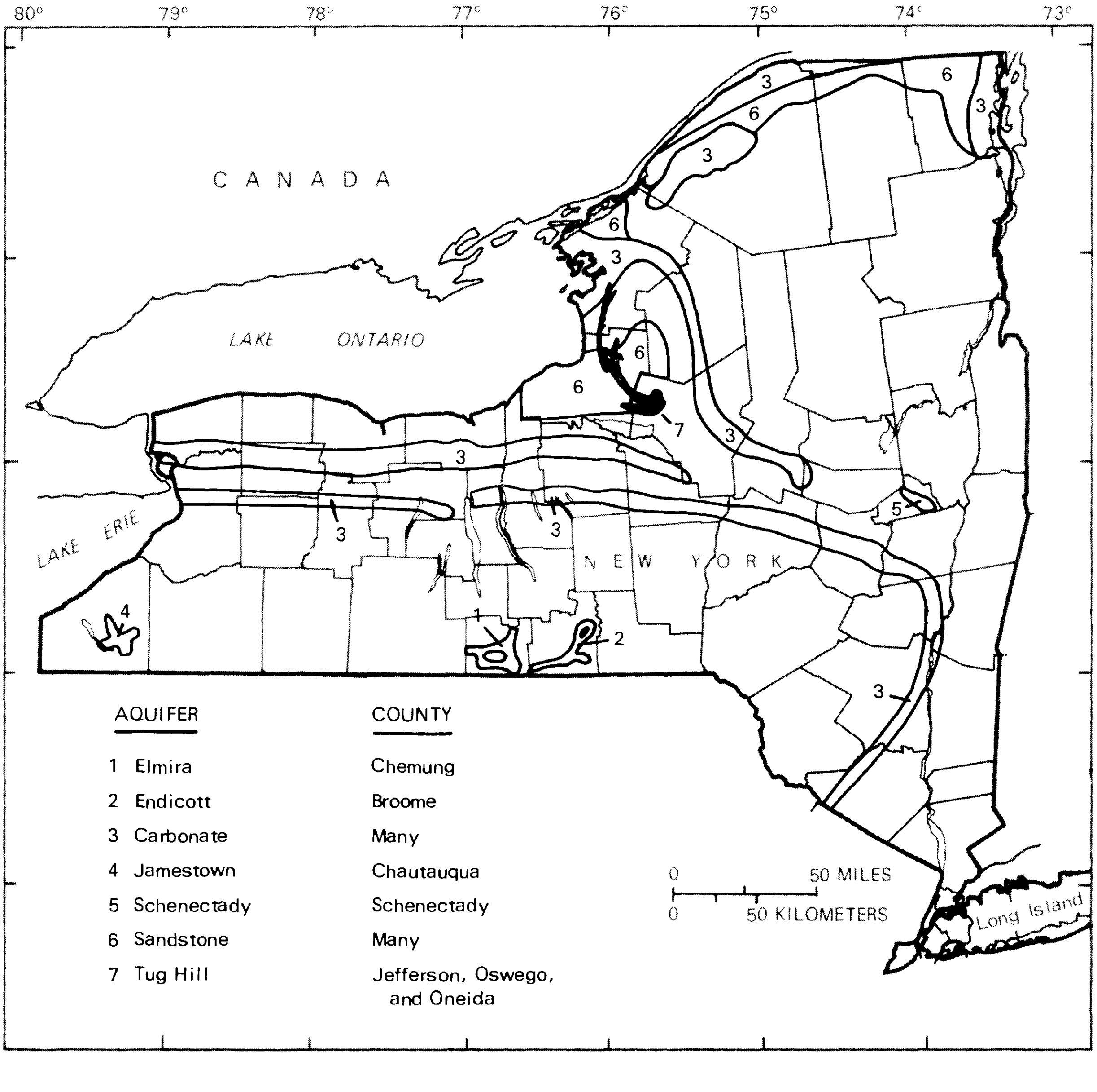

Figure 17.--Locations of the seven glacial-drift aquifers used in water-quality comparison. (Modified from Kantrowitz and Snavely, 1982)

Table 5.--Chemical analyses of water from public water supplies.

[Values are in milligrams per liter unless otherwise indicated, µg/L = micrograms per liter; or µS/cm = microsiemens per centimeter]

Constituent or characteristic	Town and date of sampling Adams 9/27/71	Camden 8/19/71	Lacona 8/11/71	Orwell 7/25/73	Pulaski 8/11/71	Number of samples	Concentration or value Minimum	Maximum	Mean
Calcium	94	16	37	16	30	5	16	94	38.6
Chloride	10	1.3	3.1	2.4	3.5	5	1.3	10	4.06
Fluoride	10	10	.10	.30	.10	5	.10	.30	.14
Hardness (as $CaCO_3$)	257	70	115	60	99	5	60	257	120
Iron	21	20	26	88	82	5	20	88	47.4
Magnesium	5.3	7.3	5.4	4.8	5.9	5	4.8	7.3	5.7
Manganese (µg/L)	<3.0	13	11	6.0	1.0	5	1.0	13	6.8
Nitrate	2.2	.30	.30	3.0	.90	5	.30	3.0	1.34
pH (standard units)	7.8	7.9	8.0	7.0	8.0	5	7.0	8.0	7.7
Potassium	1.1	.70	.90	.30	.80	5	.30	1.1	.76
Dissolved solids	277	81	128	66	113	5	66	277	133
Silica	4.9	5.7	3.8	5.6	5.1	5	3.8	5.7	5.0
Sodium	5.3	1.8	3.1	1.3	2.8	5	1.3	5.3	2.9
Specific conductance (µS/cm)	487	148	237	129	206	5	129	487	241
Sulfate	21	7.3	11	8.2	11	5	7.3	21	11.7

Table 6.--Comparison of major constituent concentrations in the Tug Hill aquifer with those in eight other upstate aquifers.

[Values are in milligrams per liter, unless otherwise indicated; micrograms per liter, (µg/L); or microsiemens per centimeter (µS/cm). A dash indicates no applicable standard. Based on analyses by U.S. Geological Survey, 1945-85. Locations are shown in fig. 18]

Aquifer	Number of samples	Concentration (mg/L) Minimum	Maximum	Mean	Median	Standard deviation
			Hardness			
All aquifers	367	2.8	1,500	234	190	209
Elmira[1]	13	81	400	230	200	97
Endicott[1]	17	96	470	247	235	110
Limestone	79	9	8,200	728	390	1,030
Jamestown[1]	6	76	200	113	92	49
Schenectady[1]	6	140	290	190	180	53
Sandstone	20	47	1,900	489	240	560
Tug Hill[1]	40	23	300	115	98	75
			Dissolved solids			
All aquifers	226	16	13,000	359	214	894
Elmira	10	140	530	302	244	125
Endicott	11	118	940	296	240	227
Limestone	67	120	14,300	1,240	620	1,870
Jamestown	30	90	1,000	249	174	186
Schenectady	6	180	420	243	218	89
Sandstone	17	72	8,700	1,170	300	2,210
Tug Hill	40	32	360	147	120	86
			Chloride			
All aquifers	475	0	41,500	145	11	1,930
Elmira	13	1.9	66	24.6	17	23
Endicott	17	10	480	63	30	110
Limestone	100	.2	7,100	202	41	747
Jamestown	30	2	240	24	5.5	49
Schenectady	39	2	76	18	10	18
Sandstone	20	.7	3,200	505	105	853
Tug Hill	40	.8	660	31	5.4	105
			Sulfate			
All aquifers	360	0	8,300	83	24	254
Elmira	11	8.3	130	48	38	48
Endicott	10	13	99	29	23	25
Limestone	89	0	1,900	392	140	534
Jamestown	6	1.5	51	21	18	17
Schenectady	11	26	71	36	30	13
Sandstone	20	11	3,600	416	42	872
Tug Hill	40	.2	36	13	9.6	7.9
			Nitrate as N			
All aquifers	216	.1	21	1.7	.31	2.7
Elmira	6	.2	5	2.2	2.2	1.6
Endicott	13	.1	.85	.2	.1	.2
Limestone	24	.1	4.3	.7	.2	1.0
Jamestown	--	--	--	--	--	--
Schenectady	5	.1	2.7	.8	.3	1.1
Sandstone	2	.1	.1	.1	.1	.1
Tug Hill	40	.1	22	2.1	.8	3.9

[1] Glacial aquifer.

SUMMARY AND CONCLUSIONS

The Tug Hill aquifer is a 47-mi-long, 0.25- to 3.5-mi-wide, crescent-shaped deposit of sand and gravel along the west and southwest flanks of the Tug Hill Plateau in northern New York. The aquifer was formed during deglaciation of the region during the Pleistocene Epoch, between 12,800 and 11,400 years ago. The aquifer consists primarily of glaciofluvial material and beaches and deltas of glaciolacustrine deposits.

The southern, central, and northern parts of the aquifer differ geologically. The southern part consists mostly of unconfined glaciofluvial deposits (kames, kame terraces, eskers, outwash, and outwash deltas) that are underlain by thick deposits (as much as 160 ft) of lacustrine fine sand, silt, and clay that in some areas confines discontinuous buried sand and gravel kames that lie at the bottom of the partly sediment-filled West Branch Fish Creek valley. Water in the southern part of the aquifer is contained within the relatively impermeable till and bedrock walls and floor, which form a bathtub-shaped reservoir.

The central part of the aquifer consists mostly of glaciofluvial and glaciolacustrine deposits (beaches and deltas) over till and(or) bedrock. The top of the bedrock surface slopes westward and contains a narrow buried bedrock valley. Lake-bottom sediments are rare in this part of the aquifer.

The northern part of the aquifer consists mostly of 10- to 50-ft-thick and 0.25- to 0.75-mi-wide belts of unconfined shoreline deposits (beaches, offshore bars, and deltas) that formed along preglacial Lake Iroquois, with minor outwash and alluvial deposits along the lake's east side. The northern part has no bedrock valley to contain the ground water; rather, the bedrock floor slopes westward, and water is contained by 10- to 25-ft-thick lacustrine silt and clay that flanks the west side of the beach deposits.

A large deltic plain forms part of the northern part of the aquifer at a reentrant of the plateau near Adams; its sediments grade from sand and gravel along the edges to sand and silt in the central part. Areas near the western and northeastern edges of the plain have 40 to 50 ft of sand and gravel that overlies 1 to 5 ft of till that in turn overlies bedrock. A well in the middle of the plain penetrated 3 ft of gravel overlying 15 ft of till that in turn overlies 32 ft of fine to coarse sand that overlies bedrock. A buried bedrock valley in the southwestern part of the plain contains at least 117 ft and possibly as much as 170 ft of mostly sand.

All ground water in the aquifer is derived from precipitation. Recharge to the aquifer includes (1) direct infiltration of precipitation, estimated to be 137 Mgal/d, (2) infiltration from streams that drain till-covered bedrock uplands and cross the aquifer, estimated to be 4.9 Mgal/d, and (3) unchanneled runoff from adjacent till and bedrock hillsides that infiltrates the aquifer at its edges, estimated to be 11.4 Mgal/d.

Ground water discharges from the aquifer (1) by evapotranspiration, (2) through pumping, (3) as subsurface flow at the southern end of the aquifer at McConnellsville, (4) as seepage to springs, wetlands, and streams along the western margin of the northern part of the aquifer, and (5) as seepage to tributary streams in the valley flat that flow into West Branch Fish Creek.

Ground water in the southern part of the aquifer flows from the edges of the West Branch Fish Creek valley to the center of the valley. Ground water in the northern part flows from east to west across the aquifer. Annual water-table fluctuations range from 2 to 15 ft.

Alluvial deposits in the northern part of the aquifer may yield from 10 to 100 gal/min but can yield as much as 250 gal/min where stream infiltration replenishes ground water withdrawn from the aquifer.

Beach deposits in the northern part of the aquifer may yield 10 to 100 gal/min in areas where saturated thickness is between 5 and 20 ft. Where saturated thickness is greater than 20 ft, yields ranging from 10 to more than 250 gal/min may be expected. Beach deposits from Pierrepont Manor south to Sandy Creek are thin and have gone dry during late summer.

The largest well yields, more than 250 gal/min, are from a 60- to 85-ft-thick sand and gravel deposit that fills a bedrock valley from Richland to 3 mi south of Richland. An industrial well field pumps about 1.5 Mgal/d from this part of the aquifer.

Aquifer tests at a fish hatchery near Altmar and capacity tests of wells installed in a nearby kame moraine indicate that most yields range from 10 to 250 gal/min, but some are as large as 400 gal/min. The larger yields generally are in areas where stream infiltration replenishes ground water.

Yields from outwash in front of the Williamstown and Orwell-Bennett Bridge Moraine would be expected to decrease progressively from a range of 10 to 250 gal/min where the deposits grade from coarse sand and gravel just in front of the moraine, to a range of 1 to 50 gal/min where the deposits grade to pebbly fine-to-medium sand where meltwater flowed into a lake. Some areas along the northeastern side of the West Branch Fish Creek valley contain thick sand and gravel where outwash overlies kames. Yields in these areas may range from 10 to 250 gal/min. Some parts of the buried aquifer yield as much as 800 gal/min; other parts yield less or produce water too turbid for drinking, and some areas contain no buried aquifer.

Water quality in most places generally is suitable for drinking. Water in the northern part of the aquifer, which is underlain by limestone, has higher specific conductance values and higher concentrations of hardness, alkalinity, calcium, and sulfate than water in the central and southern parts, which are underlain by shale and sandstone. Nitrate concentrations in water in the surficial unconfined aquifer were higher than in the deeper confined aquifer in most areas. Comparison of mean concentrations of constituents in samples collected from public water supplies in 1971 and 1973 with those samples collected during this study indicates no significant temporal trends. Median concentrations of hardness, dissolved solids, chloride, and sulfate in water from the Tug Hill aquifer were lower than those in water from six other upstate New York aquifers but did not differ from them significantly.

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Table 7.--Records of wells in the study area.
[A dash indicates no data.]

Location Latitude ° ' "	Location Longitude ° ' "	Owner	Year drilled	Type of well[1]	Casing diameter (inch)	Test boring and well depth (feet)	Depth to bedrock (feet)	Aquifer type[2]	Altitude of land surface (feet)	Water level feet below land surface	Water level date	Yield (gallons per minute)	Remarks[3] (* = chemical analysis available)
4315 48	7541 47	McConnellsville Water Co.	1983	Drl	--	76	--	--	525	6.0	9-83	10-20	Test boring. M sand 0-22.5, f-m sand 22.5-33, silt 33-35, sand with silt 35-76 ft.
4315 48	7541 52	McConnellsville Water Co.	1983	Drl	--	41	--	--	530	6.5	9-83	10-20	Test boring. Sandy loam 0-2, f-m sand 2-26, S&G 26-41 ft.
4315 49	7541 47	McConnellsville Water Co.	1983	Drl	--	41	--	--	525	6.5	9-83	10-20	Test boring. Sand & silt 0-3.5, m sand 3.5-19, f sand 19-30, silt 30-34.5, sand with silt and clay 34.5-41 ft.
4316 10	7541 52	G.W. Bryant Core Sands Inc.	1979	Drl	--	62	--	--	505	dry	5-21-79	--	Test boring. F-c sand with some f-c gravel 0-15, f-c sand with some f gravel 15-45, f-c sand 45-62 ft.
4316 12	7542 10	G.W. Bryant Core Sands Inc.	1979	Drl	--	21	--	--	540	dry	5-22-79	--	Test boring. F sand & silt with some gravel (till?) 0-21 ft.
4316 16	7541 55	G.W. Bryant Core Sands Inc.	1979	Drl	--	62	--	--	510	20.5	5-18-79	--	Test boring. F-m sand 0-10, f-c sand trace f gravel 10-40, no recovery 40-55, f-c sand & f-c gravel 55-58, silt 58-62 ft.
4316 33	7541 11	McConnellsville Water Co.	1983	Drl	--	64	--	--	458	--	--	--	Test boring. Silt 0-50, f sand 50-53, sandstone 53-64 ft.
4316 43	7541 59	McConnellsville Water Co.	1983	Drl	--	86	--	--	467	11	11-11-84	--	Test boring. M sand 0-5, silt 5-6, f-m sand 6-15, silt 15-18, f-m sand 18-78, silt with f sand 78-85.5 ft.
4316 44	7546 16	Cain	1940	Drl	6	118	90	SmOq	620	86	7-18-60	--	
4316 45	7541 49	G.W. Bryant Core Sands Inc.	1979	Drl	--	61	--	--	490	27.5	5-16-79	--	Test boring. F-c sand some f gravel 0-10, f-c sand 10-25, silt 25-30, f-m sand 30-35, m-c sand with little gravel 35-38, silt 38-50, f sand 50-61 ft. Water level 15 ft while drilling.
4316 49	7541 48	G.W. Bryant Core Sands Inc.	1979	Drl	--	37	--	--	490	15	5-15-79	--	Test boring. F-m sand 0-15, f-m sand some f-m gravel 15-25, f-m sand 25-30, f-m gravel 30-37 ft.
4317 02	7543 34	G.W. Bryant Core Sands Inc.	1978	Drl	--	47	--	--	490	39.3	4-27-78	--	Test boring. silt some f-m sand 0-10, f-m sand 10-47 ft.
4317 05	7542 28	G.W. Bryant Core Sands Inc.	1978	Drl	--	47	--	--	490	37.6	4-26-78	--	Test boring. F-c sand 0-38, f-m sand 38-46, f-c gravel 46-47 ft.
4317 06	7542 38	G.W. Bryant Core Sands Inc.	1978	Drl	--	47	--	--	490	35	4-27-78	--	Test boring. Silt 0-16, f-c sand 16-47 ft.
4317 07	7541 54	G.W. Bryant Core Sands Inc.	1979	Drl	--	62	--	--	500	dry	5-9-79	--	Test boring. F-m sand 0-62 ft.

1 Drl = drilled; Spr = Spring; Drv = driven.
2 Oo-ss = Oswego Sandstone; SmOq = Sandstone of Medina Group and Queenston Shale; S&G = Sand and gravel; Br = Bedrock (undifferentiated).
3 F = fine; m = medium; c = coarse; f-m = fine to medium; m-c = medium to coarse; f-c = fine to coarse.

Table 7.--Records of wells in the study area (continued).
[A dash indicates no data.]

Location Latitude ° ' "	Longitude ° ' "	Owner	Year drilled	Type of well[1]	Casing diameter (inch)	Test boring and well depth (feet)	Depth to bedrock (feet)	Aquifer type[2]	Altitude of land surface (feet)	Water level: feet below land surface	Water level: date	Yield (gallons per minute)	Remarks[3] (* = chemical analysis available)
4317 13	7541 51	G.W. Bryant Core Sands Inc.	1979	Drl	--	62	--	--	540	dry	5-11-79	--	Test boring. F-m sand 0-62 ft.
4317 15	7543 00	E. Graham	1950	Drl	6	161	--	S&G	480	20	1950	8	F. sand 0-160, S&G 160-161 ft.
4317 17	7541 59	G.W. Bryant Core Sands Inc.	1979	Drl	--	62	--	--	540	dry	5-10-79	--	Test boring. F-m sand 0-62 ft.
4317 17	7542 11	G.W. Bryant Core Sands Inc.	1979	Drl	--	62	--	--	505	dry	5-7-79	--	Test boring. F-m sand 0-62 ft.
4317 17	7543 01	E. Graham	--	Drl	6	195	--	S&G	490	--	--	--	*Turbid. Not used.
4317 18	7546 03	W. Evans	1940	Drv	1.5	22	--	Sand	500	--	--	5	Sand 0-22 ft.
4317 21	7541 47	G.W. Bryant Core Sands Inc.	1979	Drl	--	62	--	--	590	dry	5-14-79	--	Test boring. F-m sand 0-62 ft.
4317 25	7543 26	G.W. Bryant Core Sands Inc.	1979	Drl	--	62	--	--	505	53	5-8-79	--	Test boring. F-m sand 0-62 ft.
4317 27	7542 16	G.W. Bryant Core Sands Inc.	1979	Drl	--	52	--	--	525	50	5-9-79	--	Test boring. F-m sand 0-52 ft.
4317 29	7546 53	R. Clark	1952	Drl	6	105	--	S&G	545	18	1952	10	Sand 0-60, clay 60-104, S&G 104-105 ft.
4317 35	7542 40	Irving Manley	1945	Drl	--	155	--	--	485	--	--	--	F sand 0-100, clay 100-155 ft.
4317 47	7546 49	U.S. Geological Survey	1985	Drl	2	37	--	S&G	529	30	7-6-85	--	*S&G 0-47 ft.
4318 01	7548 40	U.S. Air Force	1956	Drl	6	120	50	SmOq	510	--	--	4	Sand 0-50, Br 50 ft.
4318 15	7538 29	H. Coons	--	Drl	6	125	--	S&G	700	60	9-6-60	2	Sand 0-40, clay 40-124, gravel 124-125 ft.
4318 31	7540 52	Rielly	1951	Drl	6	78	--	S&G	560	36	8-12-54	10	S&G 0-78 ft.
4318 38	7543 23	--	--	Dug	--	16	--	Sand	502	10	6-9-83	--	--
4318 39	7541 41	Kelly	--	Drl	6	79	--	S&G	562	28.8	8-29-60	10	Sand 0-38, gravel and till 38-75, S&G 75-79 ft.
4318 42	7543 28	Stanford	1964	Drl	6	116	90	Oo-ss	502	35	6-9-83	6	F sand & silt 0-85, dirty gravel 85-90, Br 90 ft. Water from S&G wouldn't clear up. Sulfur odor.
4318 53	7542 41	Yerdon	--	Drl	6	110	--	S&G	490	--	--	--	--
4318 57	7542 18	--	1975	Drl	6	78	--	S&G	525	--	--	>7	--
4318 59	7542 17	Sampson	1952	Drl	6	74	--	S&G	525	--	--	--	--
4319 02	7543 18	Phillips	--	Dug	24	15.3	--	S&G	506	3	6-9-83	>10	*S&G 0-15 ft.
4319 12	7544 11	Myers & Sons	--	Dug	--	12	--	S&G	505	3	6-9-83	--	--
4319 24	7543 13	Monroe	--	Drl	--	120	--	S&G	502	47.8	9-6-60	15	--
4319 24	7543 16	Stevens	--	Drl	--	131	--	S&G	505	57	6-10-83	13	Sand 0-10, silt & clay 10-129, S&G 130-131 ft.
4319 31	7543 13	Harris	--	Drl	--	100	--	S&G	475	--	--	--	*Sand and silt 0-95, S&G 95-100 ft.
4319 42	7544 48	Laribee Wire	1982	Drl	--	108	13	Oo-ss	506	--	--	70	S&G 0-20, sandstone at 20 ft.
4319 43	7543 27	Loevengoth	1960	Drl	6	86	--	S&G	510	30	8-29-60	25	S&G 0-12, sand 12-86, S&G 86 ft.
4319-44	7543 28	Loevengoth	--	Drl	6	51	--	S&G	510	--	--	25	--
4320 13	7543 35	Kelly	--	Drl	6	80	--	S&G	560	35	6-10-83	15	Till 0-75, clean gravel 75-80 ft.

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Table 7.--Records of wells in the study area (continued).

[A dash indicates no data.]

Location Latitude ° ' "	Location Longitude ° ' "	Owner	Year drilled	Type of well[1]	Casing diameter (inch)	Test boring and well depth (feet)	Depth to bedrock (feet)	Aquifer type[2]	Altitude of land surface (feet)	Water level: feet below land surface	Water level: date	Yield (gallons per minute)	Remarks[3] (* = chemical analysis available)
4320 38	7544 49	Village of Camden	1981	Drl	--	36	55	S&G	510	5.5	6-10-81	--	Testhole; S&G 0-5, silt and sand 5-15, S&G 15-30, f-m sand 30-36, S&G 36-38, f-m sand 38-46, S&G 46-55, boulder or bedrock at 55 ft.
4320 47	7543 47	Konawicz	--	Dug	--	36	--	Sand	600	8	--	--	Sand 0-36 ft.
4321 09	7543 18	Village of Camden	1987	Drl	2	21	--	Sand	650.6	11	12-10-87	--	Sand and silt 0-19, till 19-21 ft.
4321 09	7546 56	Piersal	--	Drl	6	127	102	Oo-ss	555	--	--	--	S&G 0-35, 35-102 till, 102-127 sandstone.
4321 10	7544 56	Gage	1964	Drl	6	172	74	Oo-ss	560	--	--	0.5	--
4321 11	7543 15	Village of Camden	1987	Drl	2	20	--	S&G & till	648.4	4	12-10-87	--	S&G 0-5, till 5-20 ft.
4321 15	7543 15	Village of Camden	1987	Drl	--	46	--	--	695.2	20	12-11-87	--	Test boring. Sand, silt, and trace gravel 0-30, gravel 30-36, till 36-46 ft.
4321 15	7544 51	Babis	1951	Drl	6	51	46	Oo-ss	620	15	8-12-51	5	--
4321 16	7546 04	Chambers	--	Drl	6	120	--	S&G	555	--	--	90	*Drilled mostly through sand, S&G at bottom of well.
4321 17	7543 15	Village of Camden	1987	Drl	10	84	58	S&G & Oo-ss	697	23	10-87	75	Sand, clay, and little gravel 0-38, S&G 38-46, till 46-50, cemented gravel (till?) 50-58, sandstone 58-84 ft.
4321 20	7545 25	Armstrong	--	Drv	--	86	--	Oo-ss	560	12.2	6-9-83	--	--
4321 20	7546 32	--	--	Drv	2	24	--	S&G	521	--	--	15	--
4321 21	7546 29	--	--	Drv	--	22	--	Sand	515	14	--	--	--
4321 32	7545 30	Castor	--	Drl	6	70	--	Oo-ss	580	18	6-9-83	--	Owner has another well, dug 25 ft, water level 20 ft.
4321 36	7546 53	--	--	Drl	--	142	115	--	525	15	10-25-54	50	Sand 0-115, sandstone 115-142 ft.
4321 38	7542 32	Village of Camden	1935	Dug	--	--	--	S&G	710	--	--	--	Three other dug wells nearby.
4321 39	7542 50	Village of Camden	1965	Dug	48	15	--	S&G	720	--	--	--	One other dug wells nearby.
4321 39	7546 27	U.S. Geological Survey	1985	Drl	2	33	--	S&G	550	7.4	6-20-85	--	S&G 0-49 ft.
4321 47	7546 35	Brown	1958	Dug	36	16	--	S&G	536	14.8	7-28-64	.	
										15	6-9-83	40	S&G 0-16 ft.
4321 56	7546 44	Brown	1967	Drl	6	60	--	S&G	531	6	6-9-83	--	Sand 0-55, S&G 55-60 ft.
4322 00	7546 50	Balcom	1949	Drl	6	80	--	Oo-ss	530	26	9-15-54	30	--
4322 01	7547 19	Souva	--	Dug	--	12.5	--	Sand	533	11.8	6-2-83	--	*
4322 12	7543 05	Village of Camden	1930? 1957	Dug	96	15	--	S&G	790	--	--	--	Three other dug wells nearby.
4322 30	7547 56	Roberts	1950	Drl	6	40	--	S&G	560	19	9-3-54	8	--
4322 42	7547 03	Nickol	--	Dug	36	14	--	S&G	550	7.0	9-3-54	--	--

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4322 54	7548 21	Ubb	--	Dug	--	16	--	S&G	555	10.5	6-2-83	--	--
4323 14	7549 01	Westdale School	1946	Drl	6	36	--	S&G	550	10	10-25-54	15	S&G 0-36, till at 36 ft.
4323 14	7548 54	Whaley	--	Drl	6	34	--	S&G	552	12	9-15-54	20	S&G 0-34, till 34 ft.
4323 17	7548 52	Kenny	1965	Drl	6	47	--	S&G	545	9	6-2-83	>10	*. S&G 0-47 ft.
4323 18	7549 01	Asario	1948	Drl	6	78	51	SmOq	550	20	10-25-54	20	Sand 0-51, sandstone 51-78 ft.
4323 19	7551 17	--	--	Drl	6	30	--	SmOq	590	16.6	6-2-83	--	--
4323 21	7551 08	Kennedy	--	Drl	6	35	--	S&G	565	18.0	10-21-54	--	--
4323 22	7549 20	Norris	1981	Drl	6	38	37	S&G	552	8.5	6-2-83	--	S&G 0-37, bedrock 37 ft.
4323 23	7549 56	--	--	Drl	6	72	--	SmOq	665	3	6-20-83	--	Sulfur odor.
4323 25	7551 26	LaSalle	1973	Drl	6	55	--	S&G	595	--	6-2-83	10	--
4323 28	7551 34	LaSalle	1950	Drl	6	36	--	S&G	594	12.2	6-2-83	--	*
4323 30	7548 45	Bross	1925	Drv	1.25	40	--	Sand	560	25	7-28-64	--	--
4323 36	7548 39	--	--	Dug	--	14	--	S&G	558	11.3	6-2-83	--	--
4323 40	7548 54	U.S. Geological Survey	1985	Drl	1.25	24	--	Sand	530	14.3	6-4-85	--	*S&G 0-20, sand with some pebbles 20-25, f sand 25-57 ft.
4323 40	7552 01	Livengoth	--	Dug	--	17.5	--	S&G	611	11.9	6-9-83	--	--
4323 41	7551 55	Hart	1977	Drl	6	44	35	SmOq	605	33.7	6-9-83	3	--
4323 43	7550 54	Hart	--	Drl	6	65	--	SmOq	590	4.8	6-20-85	--	
4324 01	7550 13	U.S. Geological Survey	1985	Drl	2	39	54	S&G	540	4.8	6-20-85	--	*Sand 0-25, sand with some gravel 25-32, S&G 32-45, till 45-54, bedrock at 54 ft.
4324 05	7553 18	J. Baker	1983	Drl	1.5	15	23	S&G	642	13	6-29-83	--	S&G 0-23, bedrock 23 ft.
4324 18	7550 34	--	--	Drl	6	90	--	Oo-ss	605	--	--	--	--
4324 19	7550 33	Grant	--	Dug	36	20	--	S&G	610	17	10-18-54	--	--
4324 28	7552 58	Sams	1977	Drl	6	25	25	S&G	565	13	6-29-85	--	S&G 0-25, bedrock 25 ft.
4324 35	7551 49	U.S. Geological Survey	1985	Drl	2	14.5	--	S&G	561	5.4	6-18-85	--	*Cobble gravel 0-15 ft.
4324 53	7551 36	Burmingham	1977	Drl	6	62	12	Oo-ss	625	55	1979	4	S&G 0-12, bedrock 12 ft.
4324 57	7553 03	Thurman	1976	Drl	6	95	--	S&G	555	3.3	6-29-83	--	F sand 0-94, S&G 94-95 ft.
4325 09	7553 05	McConnell	--	Drl	6	111	--	S&G & Oo-ss	555	--	--	--	*
4325 09	7553 55	Schuh	--	Drl	6	130	--	S&G	600	--	--	--	F sand and silt 0-130, S&G 130 ft.
4325 14	7554 22	DeMassey	1943	Drl	6	100	--	S&G	612	10	7-6-83	10	F sand 0-98, gravel 98-100 ft.
4325 18	7553 03	--	--	Drl	6	83	--	S&G	595	--	--	--	--
4325 21	7553 15	Castle	1979	Drl	8	126	--	Gravel	602	22	1979	7	F sand and silt 0-28, silt and clay 28-52, silt and f sand 52-105, silt and S&G 105-115, silt, clay, gravel 115-126, gravel at 126 ft.

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Table 7.--Records of wells in the study area (continued).

[A dash indicates no data.]

Location Latitude ° ' "	Location Longitude ° ' "	Owner	Year drilled	Type of well [1]	Casing diameter (inch)	Test boring and well depth (feet)	Depth to bedrock (feet)	Aquifer type [2]	Altitude of land surface (feet)	Water level: feet below land surface	Water level: date	Yield (gallons per minute)	Remarks [3] (* = chemical analysis available)
4325 30	7553 14	Cowan	1982	Drl	6	83	--	S&G	600	15	1982	>50	F sand and silt 0-76, S&G 76-83 ft.
4325 36	7553 12	Dairymans League	1916	Drl	6	80	75	Oo-ss	595	50	10-14-59	--	--
4325 38	7553 12	Roberts	1978	Drl	6	62	--	S&G	605	21	4-18-78	3	F sand & silt 0-58, S&G 58-62 ft. Water first encountered at 8 ft.
4325 38	7553 13	Joyner	--	Drl	6	75	--	S&G	605	--	--	--	*
4325 47	7553 07	--	--	Dug	--	8	--	Sand	585	2.5	6-19-83	--	--
4325 59	7554 13	Hopkinson Farms	1981	Drl	5	155	--	S&G	612	--	--	30	*F sand 0-154, gravel 154-155 ft.
4326 04	7554 40	--	--	Dug	--	10	--	Sand	620	7.5	6-18-83	--	--
4326 36	7555 22	Irrigation Co.	--	Drl	--	~187	187	S&G	625	--	--	--	Water from thin gravel zone on top of bedrock.
4326 48	7554 46	--	--	Dug	--	11.2	--	S&G	620	8.6	7-6-85	--	--
4326 56	7555 54	Russell	1970	Drl	6	48	--	S&G	633	4	6-29-83	--	--
4327 46	7556 36	McCullagh	1967	Drl	6	40	10	Oo-ss	655	17	8-14-68	--	--
4327 25	7555 56	Ripka	--	Dug	--	17.6	--	S&G	635	15	7-6-83	--	*
4327 28	7555 10	Dave Jones (Irrigation Co.)	1983	Drl	6	103	--	Gravel	625	10	6-16-83	15	F S&G 0-18, f-m sand 18-50, silt & f sand 50-101, gravel 101-103 ft.
4327 52	7555 33	U.S. Geological Survey	1985	--	--	95	--	Sand	640	16	5-23-85	--	S&G 0-18, f sand 18-95 ft.
4328 28	7555 35	Cox	1963	Drl	6	53	--	S&G	640	19	7-28-64	--	S&G 0-53 ft.
4328 46	7557 42	Trumble	1962	Drl	6	96	88	Oo-ss	685	--	--	--	--
4328 51	7558 26	--	--	Dug	--	36.5	--	S&G	665	31.4	7-6-83	--	--
4328 58	7555 20	Roser	1953	Drl	--	80	--	Oo-ss	685	37	8-14-68	--	--
4329 01	7555 29	--	1948	Drl	--	55	--	Oo-ss	670	--	--	--	Well log indicates lots of fine sands, well drilled into Br.
4329 06	7557 24	--	1985	Drl	2	38	54	S&G	626	9	7-6-83	10	S&G 0-16, m-c sand 16-21, gravel with silt, clay 21-32, gravel, sand, silt, clay (till) 32-38, Br 38 ft.
4329 11	7555 16	Trumble	1978	Drl	--	38	35	Oo-ss	695	21	8-10-80	9	--
4329 16	7556 01	--	--	Drl	6	103	--	S&G	680	28	7-6-83	--	*Site also known as Bartlett Rd.
4329 19	7556 08	--	--	Drl	--	--	127	S&G	680	--	--	800	Gas exploration well. Water pumped from S&G zone on top of bedrock.
4329 25	7555 42	Rodgers	4-28-83	Drl	6	41	38	Oo-ss	680	13	7-6-83	5	S&G 0-22, till 22-38, Br 38 ft.
4329 39	7555 55	--	--	Dug	--	31	--	S&G	690	17	7-6-83	--	--

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Table 7.--Records of wells in the study area (continued).

[A dash indicates no data.]

Location Latitude ° ' "	Longitude ° ' "	Owner	Year drilled	Type of well [1]	Casing diameter (inch)	Test boring and well depth (feet)	Depth to bedrock (feet)	Aquifer type [2]	Altitude of land surface (feet)	Water level feet below land surface	Water level date	Yield (gallons per minute)	Remarks [3] (* = chemical analysis available)
4329 44	7555 10	--	--	Drl	6	42	--	Oo-ss	725	--	--	--	--
4330 12	7559 02	NYSDEC	1974	Drl	8	75	50	S&G & Oo-ss	586	4.7	11-8-74	150	S&G 0-50, sandstone 50-70 ft. Sulfur.
4330 14	7559 00	NYSDEC	1974	Drl	6	74	--	S&G	608	21.6	11-21-74	--	Sand & silt 0-72, S&G 72-76, sand, silt and tr. gravel 76-94 ft.
4330 14	7559 12	NYSDEC	1974	Drl	--	--	48	Sand Oo-ss	576	--	--	--	S&G 0-20, silt and f sand with some S&G 20-44, silt 44-48 ft.
4330 14	7559 14	NYSDEC	1974	Drl	--	59	44	S&G	580	0	11-11-74	--	Sand 0-12, S&G 12-29, sand 29-40, S&G 40-44, sandstone at 44 ft.
4330 14	7559 17	NYSDEC	1975	Drl	6	24	--	S&G	576	5.2	1-6-75	--	S&G 0-24 ft.
4330 17	7557 50	NYSDEC	1974	Drl	2.5	105	--	Silt & sand	670	37	4-11-74	--	S&G 0-37, silt, clay, f sand 38-105, till 105-115 ft.
4330 17	7559 01	NYSDEC	1974	Drl	8	84	--	S&G	610	26.6	12-74	367	Sand, silt, trace gravel 0-37, m-c gravel some sand 37-42, sand and trace silt 42-62, c-f sand 62-71, c sand, f-m gravel 71-84 ft.
4330 19	7559 02	NYSDEC	1974	Drl	8	83	84	S&G	618	--	--	--	Sand 0-50, sand and some gravel 50-72,
4330 19	7559 16	NYSDEC	1975	Drl	8	33	33	S&G	574	5.6	1-5-75	300	S&G 0-33, Br at 33 ft.
4330 19	7558 25	NYSDEC	1973	Drl	--	20	31	Gravel	620	13	9-12-73	--	Silty S&G 0-31, sandstone 31-37 ft.
4330 20	7559 01	NYSDEC	1974	Drl	8	75	--	Gravel	619	--	--	--	S&G 0-39, c sand 39-56, f sand 56-73, coarse gravel 73-76 ft. Abandoned.
4330 20	7559 08	NYSDEC	1974	Drl	2.5	47	47	--	572	6	4-10-74	--	S&G 0-14, sand, silt and gravel 14-28, silty S&G 28-42, till 42-47, Br at 47 ft? Well abandoned.
4330 20	7559 18	NYSDEC	1975	Drl	8	24	32	S&G	574	5.62	1-75	303	M sand, f-m gravel 0.12, m-c gravel & m sand 12-33, gray sandstone 33 ft.
4330 23	7559 20	NYSDEC	1974	Drl	8	75	55	S&G & Oo-ss	568	2.65	11-14-74	280	S&G with clay 0-10, f sand 10-38, 38-55 S&G, sandstone 55-75 ft. Gravel over bedrock supplying water to bedrock.
4330 26	7559 17	NYSDEC	1974	Drl	12	53	--	S&G	572	8.17	11-74	460	Sand, trace gravel 0-5, m sand - m-f gravel 5-36 sand, silt, gravel 36-42, gravel some c sand 42-53 ft.
4330 28	7559 06	NYSDEC	1974	Drl	8	47	40	Oo-ss	625	--	--	--	Sand with some gravel 0-40, sandstone 40-47 ft. No appreciable water.
4330 28	7559 12	NYSDEC	1974	Drl	6	68	--	S&G	581	16.3	10-31-74	100±	f sand 0-29, S&G 29-67, f sand 67-68 ft. Yield is from open end casing--could probably yield much more with a screen.
4330 28	7559 16	NYSDEC	1974	Drl	6	53	--	S&G	571	7.4	10-29-74	150±	Sand 0-6, m. sand & f-m gravel 6-36, S&G 36-53 ft. Yield from open end casing. Could probably yield much more water with a screen.

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Table 7.--Records of wells in the study area (continued).
[A dash indicates no data.]

Location Latitude ° ' "	Location Longitude ° ' "	Owner	Year drilled	Type of well[1]	Casing diameter (inch)	Test boring and well depth (feet)	Depth to bedrock (feet)	Aquifer type[2]	Altitude of land surface (feet)	Water level feet below land surface	Water level date	Yield (gallons per minute)	Remarks[3] (* = chemical analysis available)
4330 30	7559 37	NYSDEC	1973	Drl	--	27	25	--	550	4.0	8-6-73	--	Test boring. S&G 0-25, sandstone 25-27 ft.
4330 32	7559 33	NYSDEC	1974	Drl	6	55	40	S&G & Oo-ss	555	1	11-6-74	--	S&G 0-37, till 37-40, sandstone and shale 40-55 ft.
4330 32	7600 10	Village of Altmar	--	Drl	6	40	--	S&G	565	--	--	--	*
4330 33	7559 53	NYSDEC	1974	Drl	6	44	29	--	540	--	--	--	S&G 0-29, sandstone 29-44 ft. No significant water, well abandoned.
4330 35	7559 22	NYSDEC	1974	Drl	6	42	--	S&G	572	8.6	12-19-74	--	S&G 0-42 ft.
4330 36	7557 40	NYSDEC	1974	Drl	2.5	85	94	Sand & silt	575	17	4-15-74	--	S&G 0-7, sand & silt 7-9, silt 9-36, silt & f. sand 36-94, Br 94 ft.
4330 38	7559 45	NYSDEC	1974	Drl	6	41	40	Oo-ss	543	1	11-15-74	--	S&G 0-17, sand 17-40, sanstone 40 ft. No appreciable ground water, well abandoned.
4330 39	7600 03	NYSDEC	1974	Drl	2.5	20	20	S&G & clay	540	6	5-28-74	1	S&G with some clay 0-20, Br 20 ft; screen 15-20 ft.
4330 41	7558 45	NYSDEC	1974	Drl	8	23	28	S&G	620	--	--	--	Sand, silt, some gravel 0-28, sandstone 28 ft. No appreciable ground water. Abandoned.
4330 45	7558 22	NYSDEC	1974	Drl	8	24	29	Oo-ss	585	7	12-9-74	50	S&G 0-29, sandstone 29-42 ft. Yield from open-end casing.
4331 01	7559 00	NYSDEC	1974	Drl	6	35	23	--	591	--	--	--	Test boring. S&G 0-23, sandstone 23-35 ft. Casing pulled out and site abandoned.
4331 04	7558 53	NYSDEC	1973	Drl	--	48	42	--	597	11	8-9-73	--	Test boring. S&G with trace silt 0-42 sandstone 42-48 ft. pulled to 36 ft and yielded 50 gal/min from open end. Casing removed and site abandoned.
4331 25	7557 27	Four Season Trout Hatchery	1973	Drl	6	49	49	S&G	658	8	2-27-73	67	S&G 0-20, sand and silt 20-25, silty sand and gravel 25-32, S&G 32-49, bedrock at 49 ft.
4331 44	7557 52	NYSDEC	1974	Drl	2.5	25	25	Oo-ss	658	8	4-16-74	--	S&G 0-20, gravel, silt, clay, sand (till) 20-25, Br 25 ft.
4331 45	7600 41	Kronk	--	Dug	--	25	--	S&G	555	--	--	--	*
4331 47	7601 02	NYSDEC	1973	Drl	--	55	41	--	555	9	7-11-73	--	Test boring. F. sand with some silt 0-41, shale 41-55 ft.
4331 48	7559 53	NYSDEC	1973	Drl	--	63	63	S&G	610	33	7-30-73	--	Test boring. Sand 0-63, sandstone at 63 ft.
4332 02	7600 28	NYSDEC	1973	Drl	--	26	21	--	562	5	7-31-73	--	Test boring. S&G 0-11, till 11-21, sandstone 21-26 ft.
4332 03	7601 19	Ackley	1860	Dug	--	17	--	S&G	565	14	8-27-68	--	--
4332 22	7601 00	Mattison	--	Dug	--	--	--	S&G	575	--	--	--	*

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[A dash indicates no data.]

Location Lati-tude ° ′ ″	Longi-tude ° ′ ″	Owner	Year drilled	Type of well[1]	Casing diam-eter (inch)	Test boring and well depth (feet)	Depth to bed-rock (feet)	Aqui-fer type[2]	Alti-tude of land sur-face (feet)	Water level feet below land surface	Water level date	Yield (gallons per minute)	Remarks[3] (* = chemical analysis available)
4332 38	7602 16	NYSDEC	1973	Drl	--	62	56	--	550	12	7-20-73	--	Test boring. S&G 0-51, till 51-56, sandstone 56-62 ft.
4332 42	7602 31	Freckies	--	Drl	6	40	40	S&G	548	25.6	8-3-83	--	--
4333 38	7602 17	Schoeller Paper Co.	--	Drl	12	58	63	S&G	559	11.63	10-5-62	50	S&G 0-58, till 58-63, Br. 63 ft.
4333 39	7601 57	Schoeller Paper Co.	1961	Drl	6	62	75	S&G	554	2	10-5-62	--	S&G 0-62, till 62-75, Br. 75 ft.
4333 40	7602 11	Schoeller Paper Co.	1961	Drl	6	51	52	S&G	558	9	10-5-62	--	*.S&G 0-51, till 51-52, Br. 52 ft.
4333 49	7602 26	Schoeller Paper Co.	1961	Drl	6	36	84	S&G	553	12	10-5-62	--	S&G 0-57, till 57-84, Br. 84 ft.
4333 51	7601 54	Schoeller Paper Co.	1961	Drl	12	49	51	S&G	559	6	10-5-62	--	S&G 0-49, till 49-51, Br. 51 ft.
4333 57	7602 09	Schoeller Paper Co.	1961	Drl	6	55	80	S&G	560	18	10-5-62	--	S&G 0-62, till 62-80, Br. 80 ft.
4333 59	7602 18	Schoeller Paper Co.	1961	Drl	6	51	86	S&G	567	29	10-5-62	--	S&G 0-69, till 69-86, Br. 86 ft.
4334 01	7602 12	Schoeller Paper Co.	1961	Drl	6	60	64	S&G	575	34	10-5-62	--	--
4334 06	7603 54	Cornwell	1961	Drl	6	50	--	S&G	495	13	8-26-68	--	--
4334 08	7601 56	Lee Schoeller Paper Co.	1961	Drl.	6	38	50	S&G	570	31	10-5-62	--	S&G 0-38, till 38-50, Br 50 ft.
4334 09	7602 07	Lee Schoeller Paper Co.	1961	Drl.	6	35	51	S&G	564	18	10-5-62	--	--
4334 09	7602 48	Minot	--	Drl.	6	35	--	S&G	560	--	--	--	*.
4334 10	7602 09	Lee Schoeller Paper Co.	1961	Drl.	6	43	77	S&G	575	29	10-5-62	--	--
4334 11	7602 02	Lee Schoeller Paper Co.	1961	Drl.	6	36	53	S&G	573	24	10-5-62	--	S&G 0-50, till 50-53, Br 53 ft.
4334 19	7602 20	Lee Schoeller Paper Co.	1961	Drl.	6	47	52	S&G	568	30	10-5-62	--	S&G 0-47, till 47-52, Br 52 ft.
4334 25	7603 03	Broduer	--	Drl.	6	58	--	S&G	540	20	8-3-85	--	--
4334 32	7603 03	Watson	--	Drl.	6	50	--	S&G	550	25	8-3-85	100	--
4334 41	7602 57	Colvin	1975	Drl.	6	65	--	S&G	560	--	--	--	S&G 0-65 ft.
4334 48	7558 11	Stafford	--	Dug	--	15	--	S&G	1,010	--	--	--	*.
4334 50	7602 59	Minnett	1983	Drl	6	53	20	Shale	550	25	8-3-85	--	--
4335 27	7603 09	Stevens	--	Drl	6	83	50	Shale	555	8.4	8-3-85	--	Br 83 ft. Owner also has dug well 9.6 ft deep.
4335 58	7603 32	Krakau	--	Dug	--	15	--	S&G	580	--	--	--	*.
4337 02	7604 01	--	--	Dug	--	18	--	S&G	583	15	8-3-85	--	--
4337 06	7603 54	U.S. Geological Survey	1985	Drl	--	11	11	S&G	585	9	5-23-85	--	S&G 0-10, till 10-11, Br 11 ft.
4337 14	7604 04	--	--	Dug	--	15	--	S&G	580	11.6	8-3-85	--	--
4337 22	7604 09	—	--	Dug	--	12	--	S&G	580	8	8-3-85	--	--
4337 45	7604 03	U.S. Geological Survey	1985	Drl	1.5	46	49	S&G	594	41.6	5-2-85	--	*.S&G 0-27, sand with some silt 27-28, S&G 28-49, Br 49 ft.
4339 02	7604 10	Villages of Sandy Creek and Lacona	--	Dug	24	22.5	--	S&G	548	--	--	225	--
4339_04	7604 10	Villages of Sandy Creek and Lacona	--	Dug	24	21	--	S&G	548	--	--	325	--
4339 06	7604 10	Villages of Sandy Creek and Lacona	1985	Dug	48	12	--	S&G	548	2.4	4-12-85	130	--
4339 09	7605 44	--	--	Drl	6	30	30	S&G	603	25	8-17-83	--	--

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4339 24	7603 42	--	--	Dug	--	30	30	S&G	602	22	8-17-83	--	--
4339 58	7604 03	Villages of Sandy Creek and Lacona	1965	Drl	--	42	39	S&G	555	3	8-65	--	Test well. F-m sand 0-8, S&G 8-38,
4340 06	7604 02	Villages of Sandy Creek and Lacona	1965	Drl	--	31	27	S&G	552	3	8-65	400	M-c sand 0-9, S&G 10-27, Br 27 ft.
4340 08	7603 47	--	--	Dug	--	43	--	S&G	595	38.6	8-17-85	--	--
4340 10	7604 03	Villages of Sandy Creek and Lacona	1965	Drl	--	30	28	S&G	555	2	8-65	--	Test well. S&G 0-28, Br 28 ft.
4340 13	7604 02	Villages of Sandy Creek and Lacona	1965	Drl	--	35	32	S&G	555	2	8-65	200	F-m sand 0-10, S&G 10-32, Br 32 ft.
4340 16	7603 44	--	--	Dug	--	9	--	S&G	581	6.5	8-17-83	--	--
4340 33	7603 47	--	--	Dug	--	13	--	S&G	575	12.1	8-17-83	--	--
4341 18	7603 50	U.S. Geological Survey	1985	Drl	2	34	45	S&G	597	13.2	6-18-85	--	*.S&G 0-35, till 35-45, Br 45 ft.
4341 41	7603 50	--	--	Dug	--	20	--	S&G	595	14	8-17-83	--	--
4341 42	7603 54	Lakeview Golf Course	--	Dug	--	25	--	S&G	600	22	9-7-83	--	F sand 0-10, gravel 10-25 ft.
4341 53	7603 20	Spencer	--	Dug	--	16	--	S&G	634	9	8-17-83	--	--
4342 36	7603 23	Village of Mannsville	1962	Drl	6	29	--	S&G	600	4.5	8-17-83	60	--
4342 39	7603 22	Village of Mannsville	1930	Dug	--	12	--	S&G	600	5.5	8-16-83	--	*.
4343 44	7603 33	--	--	Dug	--	15	--	S&G	625	10	8-17-83	--	--
4343 59	7603 30	--	--	Dug	--	21	--	S&G	625	16.1	9-7-83	--	Owner has a 2nd well drilled 78 ft in till, water level = 53 ft.
4344 00	7603 36	Osgood	--	Dug	--	25	77	S&G	625	21.5	6-24-85	--	--
4344 04	7603 30	Blisses	--	Drl	6	15	--	S&G	627	13	9-7-83	--	--
4344 07	7604 10	Houghton Farm Supply	--	Dug	--	8	--	Sand	585	4	9-7-83	--	--
4344 08	7603 34	U.S. Post Office	--	Dug	--	6.5	--	S&G	610	3.0	9-7-83	--	--
4344 12	7603 10	--	--	Dug	--	12	--	S&G	624	9.0	9-7-83	--	--
4344 16	7602 55	U.S. Geological Survey	1985	Drl	2	30	33	S&G	630	4.4	6-20-86	--	S&G 0-30, till 30-33, Br 33 ft.
4344 19	7602 45	Larmon	--	Dug	24	13	--	S&G	638	11	9-7-83	>30	*.
4344 21	7602 27	Porter	--	Dug	--	14	--	Till	665	8	8-28-68	.--	--
4345 07	7602 50	Overton	--	Dug	6	40	40	Till	618	15	4-15-83	--	Thin gravel over till 0-40 ft.
4346 36	7602 47	Harmer	--	Dug	18	17	--	Sand	540	13.2	8-28-68	--	--
4346 43	7602 12	U.S. Geological Survey	1985	Drl	--	66	--	Sand	555	34	5-15-85	--	Test boring. F-m sand 0-30, silty sand 30-68 ft.
4346 53	7601 48	Spinner	--	Drl	6	170	170	S&G	635	--	--	--	--
4346 53	7601 54	--	1986	Drl	6	117	--	Sand	635	--	--	--	--

1 Drl = drilled; Spr = Spring; Drv = driven.

2 Oo-ss = Oswego Sandstone; SmOq = Sandstone of Medina Group and Queenston Shale; S&G = Sand and gravel; Br = Bedrock (undifferentiated).

3 F = fine; m = medium; c = coarse; f-m = fine to medium; m-c = medium to coarse; f-c = fine to coarse.

Table 7.--Records of wells in the study area (continued).
[A dash indicates no data.]

Location Latitude ° ' "	Location Longitude ° ' "	Owner	Year drilled	Type of well[1]	Casing diameter (inch)	Test boring and well depth (feet)	Depth to bedrock (feet)	Aquifer type[2]	Altitude of land surface (feet)	Water level feet below land surface	Water level date	Yield (gallons per minute)	Remarks[3] (* = chemical analysis available)
4346 53	7602 01	Brown	--	Drv	--	25	--	Sand	635	--	--	--	*.
4346 54	7601 51	Laemmermann	1979	Drl	6	170	--	S&G	635	--	--	--	--
4347 02	7601 05	--	--	Dug	--	24.6	--	S&G	652	22.5	8-28-85	--	--
4347 17	7601 11	U.S. Geological Survey	1985	Drl	2	25	54	Sand	640	18.0	5-16-85	--	*. S&G 0-3, till 3-18, S&G 18-21, sand 21-50, S&G 50-54, Br 54 ft.
4347 21	7602 14	--	1986	Drl	6	60	--	S&G	639	--	--	--	--
4347 39	7602 07	U.S. Geological Survey	1985	Drl	2	40	48	S&G	639	22	4-16-85	--	*. Pebbly sand 0-40, silty sand 40-46
4347 53	7601 34	Ford	1975	Drl	6	45	--	S&G	628	9.8	9-8-83	--	S&G 0-45 ft.
4347 58	7601 43	Barry Lumber	--	Dug	--	14	--	S&G	629	12	9-8-83	--	--
4348 05	7601 27	Fairman	1983	Drl	6	58	40	Limestone	633	--	--	--	One foot of gravel on top of rock.
4348 12	7601 51	Village of Adams	1970	Drl	--	10.5	--	--	633	5	2-5-70	--	Test boring. S&G 0-8, till 8-10 ft.
4348 16	7600 05	U.S. Geological Survey	1985	Drl	2	37	43	S&G	635	12	4-17-85	--	*. S&G 0-40, till 40-45, Br 43 ft.
4348 17	7601 17	Village of Adams	1969	Drl	--	8	8	--	630	--	--	--	Test boring. F-c sand 0-5, S&G 5-8, Br 8 ft.
4348 36	7601 51	Village of Adams	1969	Drl	--	5	5	--	582	--	--	--	Test boring. F sand and silt 0-5, Br 5 ft.
4348 39	7600 31	Village of Adams	1969	Drl	--	9	9	--	635	--	--	--	Test boring. F-m sand and silt 0-5, S&G 5-9, Br 9 ft.
4348 40	7601 26	Village of Adams	1969	Drl	--	7	7	--	650	--	--	--	Test boring. S&G 0-7, Br or till 7 ft.
4348 43	7602 16	Overtown	--	Drl	6	56	--	Limestone	585	37.8	8-28-68	--	Br near surface, Sulfur odor.
4348 46	7600 41	Village of Adams	1969	Drl	--	8	8	--	640	--	--	--	Test boring. F sand and silt 0-5, S&G 5-8, Br 8 ft.
4348 59	7601 25	Village of Adams	1970	Drl	--	10.5	--	--	645	5.7	2-5-70	--	Test boring. S&G 0-7.5, till 7.5-10.5 ft.
4349 55	7559 36	--	--	Drv	--	21	--	Sand	635	--	--	--	All S&G 0-14, till 14-16, sand with some gravel 16-21 ft.
4349 17	7559 30	Neuppert	--	Drl	6	31	--	S&G	655	25	--	--	S&G 0-31 ft.
4349 34	7601 34	U.S. Geological Survey	1985	Drl	2	21	36	Sand	620	7.3	4-16-85	--	*. S&G 0-18, sand 18-22, silt 22-32, till 32-36, Br 36 ft.
4349 35	7601 36	Village of Adams	--	Spr	--	--	--	S&G	615	--	--	--	Spring supplies villages of Adams and Adams Center.
4350 07	7600 50	U.S. Geological Survey	1985	Drl	2	12	15	S&G	642	7.0	4-17-85	--	S&G 0-13, till 13-15, Br 15 ft. Well destroyed.
4350 21	7601 02	U.S. Geological Survey	1985	Drl	2	23	36	S&G	634	7	4-17-85	--	*. Sand with some gravel 0-23, sand 23-31, sand with pebbles 31-34, till 34-35, Br 35 ft.
4350 21	7601 13	U.S. Geological Survey	1985	Drl	2	11	25	S&G	623	9.0	6-18-85	--	*. S&G 0-12, m-c sand 12-17, m-f sand 17-20, f sand 20-24, till 24-25, Br 25 ft.

1 Drl = drilled; Spr = Spring; Drv = driven.
2 Oo-ss = Oswego Sandstone; SmOq = Sandstone of Medina Group and Queenston Shale; S&G = Sand and gravel; Br = Bedrock (undifferentiated).
3 F = fine; m = medium; c = coarse; f-m = fine to medium; m-c = medium to coarse; f-c = fine to coarse.

Table 7.--Records of wells in the study area (continued).

[A dash indicates no data.]

Location Latitude ° ' "	Location Longitude ° ' "	Owner	Year drilled	Type of well[1]	Casing diameter (inch)	Test boring and well depth (feet)	Depth to bedrock (feet)	Aquifer type[2]	Altitude of land surface (feet)	Water level: feet below land surface	Water level: date	Yield (gallons per minute)	Remarks[3] (* = chemical analysis available)
4350 34	7558 13	U.S. Geological Survey	1985	Drl	--	25	25	--	670	--	--	--	Test boring. Fill 0-5, till 5-25, Br 25 ft.
4351 06	7600 42	Cean	1955	Drl	6	33	--	Limestone	640	16	8-28-68	--	--
4351 36	7600 25	Knapp Hardware	--	Dug	--	10	--	S&G	630	14	9-8-83	--	--
4351 46	7600 14	Knapp	1900	Dug	--	17.3	--	S&G	645	15.1	9-8-83	--	*.

[1] Drl = drilled; Spr = Spring; Drv = driven.
[2] Oo-ss = Oswego Sandstone; SmOq = Sandstone of Medina Group and Queenston Shale; S&G = Sand and gravel; Br = Bedrock (undifferentiated).
[3] F = fine; m = medium; c = coarse; f-m = fine to medium; m-c = medium to coarse; f-c = fine to coarse.

Table 8.--Streamflow gains and losses in streams crossing the Tug Hill aquifer, July 19 and September 23, 1985.

[Base-flow measurements were made in the West Branch Fish Creek basin, Salmon River basin, and Sandy Creek basin to determine loss of flow to, or ground-water discharge from, the underlying aquifer. Indicated gains or losses may be substantially affected by small inaccuracies in discharge measurements. All values are in cubic feet per second.]

Site number	Stream name	Plate showing location	Measuring site	Discharge (July 18, 1985)	Gain(+) or loss(-) (July 18, 1985)	Discharge (Sept 23, 1985)	Gain(+) or loss(-) (Sept 23, 1985)
0424085350	Rowell Brook	2A	State Highway 183 near Williamstown	0.105		0.039	
0424085400	Rowell Brook	2A	Nichols Road near Williamstown	.139	+0.034	.055	+0.016
0424085500	Rowell Brook	2A	County Highway 17 near Williamstown town	.578	+0.439	.432	+.377
04240866	West Branch Fish Cr. Trib.	2A	State Highway 13 near Williamstown	.428		.242	
04240867	West Branch Fish Cr. Trib.	2A	Southwest of railroad underpass near Williamstown	.552	+0.124	.186	-.056
04240898	West Branch Fish Creek Trib. No. 2	1A	Howard Road near Camden	.216		.077	
04240899	West Branch Fish Creek Trib. No. 2	1A	VanBuren Road near Camden	.196	- .02	dry	-.077
0424092910	Mad River	1A	Quarry Road near Camden	15.7		9.56	
0424092980	Mad River	1A	River Road near Camden	15.1	- .6	9.83	+.27
04240930	Mad River	1A	State Highway 69 at Camden	17.1	+2.0	10.5	+.67
04240973	Fields Brook	1A	Elpis Road west of Thompson's Corners near Camden	1.02		.254	
042409735	Fields Brook	1A	Howd Road near Thompson's Corners near Camden	1.32	+ .30	.459	+.205
04240974	Fields Brook	1A	Preston Hill Road at Thompson's Corners near Camden	2.42	+1.10	.828	+.369
04249804	Pine Meadows Cr.	3A	McChesney Road near Bennett Bridge	0.666		.188	
04249808	Pine Meadows Cr.	3A	County Highway 30 near Bennett Bridge	.639	- .027	.175	-.013
04249822	Beaverdam Brook Tributary	3A	Wright Road near Bennett Bridge	.027		.004	
04249826	Beaverdam Brook Tributary	3A	County Highway 30 near Bennett Bridge	dry	- .027	dry	-.004

Table 8.--Streamflow gains and losses in streams crossing the Tug Hill aquifer (continued).

Site number	Stream name	Plate showing location	Measuring site	Discharge July 18, 1985	Gain(+) or loss(-) July 18, 1985	Discharge Sept 23, 1985	Gain(+) or loss(-) Sept 23, 1985
04249970	Pekin Brook	3A	County Highway 22 near Bennett Bridge	1.81		1.64	
04249980	Pekin Brook	3A	North of Hogback Road near Bennett Bridge	3.40	+1.59	2.04	+0.40
0425051110	Little Deer Creek	3A	Gravel Pit near Richland	0.129		no flow	
0425051120	Little Deer Creek	3A	Richland Road near Richland	.030	-0.099	dry	
0425051130	Little Deer Creek	3A	Penn Central Railroad near Richland	.158	+0.128	0.050	+0.050
0425053120	Lindsey Creek	4A	Hagen (North Boylston) Road near Lacona	2.06		.456	
0425053125	Lindsey Creek	4A	County Highway 22 near Lacona	1.73	-0.33	.453	-0.003
0425053130	Lindsey Creek	4A	U.S. Highway 11 near Mannsville	1.23	-.50		
04250619	Bear Creek	4A	Opposite Cobb Place Road near Pierre-pont Manor	2.42		1.18	
04250620	Bear Creek	4A	U.S. Highway 11 at Pierrepont Manor	2.21	-.21	1.23	+.05
04250621	Bear Creek	4A	Milk Plant Road at Pierrepont Manor	3.14	+.93	1.28	+.05
04250738	Sandy Creek Trib. No. 3	4A	Lawrence (Borden) Road, 900 ft south of Spring Street, near Adams	.021		dry	
04250740	Sandy Creek Trib. No. 3	4A	Spring Street near Adams	dry	-.021	dry	
04250741	Sandy Creek Trib. No. 4	4A	Lawrence (Borden) Road near Adams	.126		.005	
04250743	Sandy Creek Trib. No. 4	4A	Spring Street at Adams	dry	-.126	dry	-.005
04250742	Sandy Creek Trib. to Trib No. 4	4A	State Highway 178 near Adams	dry		dry	
0425074250	Sandy Creek Trib. to Trib No. 4	4A	State Highway 178 near intersection of U.S. Highway 11 at Adams	dry		dry	
04250745	Sandy Creek Trib. No. 5	4A	U.S. Highway 11, near Spook Hill Road, near Adams	1.01		dry	
04250746	Sandy Creek Trib. No. 5	4A	Adams Reservoir Road near Adams	dry	-1.01	dry	
04250747	Sandy Creek Trib. No. 5	4A	Interstate Highway 81 at Adams	.233	+.233	.135	+.135

Table 9.--Chemical analyses of water samples collected August 27, 28, 1985 from selected wells in the Tug Hill aquifer.

[µg/L, micrograms per liter; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25°C]

Site number Latitude	Site number Longitude	Owner	County	Type[1] of well	Depth (ft)	Total alkalinity (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L)	Chloride, dissolved (mg/L)	Fluoride, dissolved (mg/L)	Hardness (mg/L as $CaCO_3$)	Iron, dissolved (µg/L)	Magnesium, dissolved (mg/L)	Manganese, dissolved (µg/L)	Nitrate (mg/L as N)	pH	Ortho phosphate, dissolved (mg/L as P)
431716	0754301	Graham	Oneida	Dug	15	120	10	130	0.5	42	25	4.1	59	0.16	7.9	<0.01
431717	0754301	Graham	Oneida	Drl	195	9	7.4	8.0	.1	23	40	1.1	380	.80	5.9	<.01
431747	0754649	USGS	Oneida	Drl	37	176	35	1.5	.2	122	1,700	11	340	.20	7.5	.01
431853	0754241	Yeardon	Oneida	Drl	110	109	29	47	.4	100	650	6.7	3,500	<.10	6.8	<.01
431902	0754318	Phillips	Oneida	Dug	15	26	9.8	3.5	<.1	35	10	2.6	3	.77	7.5	.01
431931	0754313	Harris	Oneida	Drl	100	103	11	38	.2	46	130	4.5	20	<.10	7.8	<.01
432106	0754604	Chamberlain	Oneida	Drl	119	80	21	2.6	<.1	109	5	14.00	6	.31	7.6	<.01
432139	0754627	USGS	Oneida	Drl	33	106	27	1.7	<.1	113	10	11.00	700	1.10	7.6	<.01
432201	0754719	Souva	Oneida	Dug	15	39	8.6	51	<.1	27	32	1.30	15	2.00	6.9	.04
432317	0754852	Kenny	Oneida	Drl	47	124	29	8.3	<.1	130	42	14	150	.19	7.7	<.01
432322	0754920	Norris	Oneida	Drl	42	33	9	1.4	<.1	39	10	3.9	11	.17	7.2	<.01
432328	0755134	LaSalle	Oswego	Drl	36	82	22	2.7	<.1	96	17	10	62	2.30	7.0	<.01
432340	0754954	USGS	Oneida	Drl	24	94	22	3.2	<.1	113	46	14	44	.28	7.9	<.01
432401	0755013	USGS	Oneida	Drl	39	49	16	1.2	<.1	62	15	5.4	7	1.20	7.0	.01
432435	0755149	USGS	Oswego	Drl	14	75	18	3.1	<.1	72	16	6.50	1,600	<.10	7.1	<.01
432509	0755305	McConnell	Oswego	Drl	111	87	67	660	<.1	229	260	15	70	<.10	7.4	<.01
432538	0755313	Joyner	Oswego	Drl	75	95	21	29	.3	82	87	7.0	16	<.10	7.9	<.01
432559	0755413	Hopkinson	Oswego	Drl	155	13	8.8	4.7	<.1	26	430	.94	28	.33	6.3	<.01
432725	0755556	Ripka	Oswego	Dug	22	45	11	.9	<.1	50	14	5.4	4	.11	8.0	.01
432916	0755601	Bartlett	Oswego	Drl	103	75	22	2.5	<.1	89	6	8.2	2	1.50	7.6	<.01
432917	0755601	Bartlett	Oswego	Dug	20	91	29	5.0	.1	111	3	9.7	1	3.60	7.4	<.01
433032	0760010	Altmar-village	Oswego	Drl	40	215	68	56	<.1	252	8	20	3	3.90	7.5	<.01
433145	0760041	Kronk	Oswego	Drl	25	57	23	14	<.1	89	15	7.6	19	<.10	7.7	<.01
433222	0760100	Mattison	Oswego	Dug	15	169	71	26	<.1	276	14	24	12	22.00	7.6	.02
433340	0760211	Schoeller Paper	Oswego	Drl	60	98	31	4.4	<.1	106	4	7.0	1	.35	7.5	<.01
433409	0760248	Minot	Oswego	Drl	35	81	27	3.8	<.1	92	3	5.9	3	.85	7.7	<.01
433448	0755811	Stafford	Oswego	Dug	15	18	6.2	.8	<.1	23	35	1.9	4	<.10	6.9	<.01
433558	0760332	Krakau	Oswego	Dug	15	44	23	4.9	<.1	78	140	5.1	16	2.90	6.8	<.01
433745	0760403	USGS	Oswego	Drl	46	64	22	7.0	<.1	78	50	5.6	14	.91	7.6	.10
434118	0760350	USGS	Jefferson	Drl	34	100	34	11	.2	109	17	6.0	500	.83	7.7	.02
434239	0760322	Mansville-Vill.	Jefferson	Drl	29	71	24	4.6	<.1	75	33	3.7	2	.38	6.9	<.01
434419	0760245	Larmon	Jefferson	Dug	13	74	28	6.7	<.1	84	37	3.3	3	2.00	7.1	<.01
434653	0760201	Brown	Jefferson	Drl	25	144	70	11	.2	197	15	5.4	3	9.00	7.5	<.01
434717	0760111	USGS	Jefferson	Drl	25	162	61	5.9	.2	183	23	7.5	1,200	<.10	7.5	<.01
434739	0760207	USGS	Jefferson	Drl	40	176	69	13	.2	199	59	6.5	620	.11	7.3	.02
434816	0760005	USGS	Jefferson	Drl	37	89	39	2.8	.1	108	18	2.5	4	1.30	7.8	<.01
434934	0760134	USGS	Jefferson	Drl	21	228	90	7.7	.1	254	45	7.0	370	2.30	7.4	<.01
435021	0760102	USGS	Jefferson	Drl	23	121	50	5.0	.2	138	18	3.1	9	7.90	7.3	<.01
435021	0760113	USGS	Jefferson	Drl	11	171	88	34	<.1	250	10	7.3	160	5.20	7.5	<.01
435146	0760014	Knapp	Jefferson	Dug	17	293	110	14	<.1	303	16	6.9	3	8.10	7.3	.48

[1] Drl = drilled.

Table 9.--Chemical analyses of water samples collected August 27, 28, 1985 from selected wells in the Tug Hill aquifer (continued).

[µg/L, micrograms per liter; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25°C]

Site number Lati-tude	Site number Longi-tude	Residue, dis-solved (mg/L)	Silica, dis-solved (mg/L)	Sodium, dis-solved (mg/L)	Con-duct-ance (µS/cm)	Sul-fate (mg/L)	Arsenic (µg/L)	Barium (µg/L)	Boron, dis-solved (µg/L)	Cad-mium (µg/L)	Copper (µg/L)	Lead (µg/L)	Lith-ium (µg/L)	Mercury (µg/L)	Sele-nium (µg/L)	Stron-tium (µg/L)	Zinc (µg/L)
431716	0754301	340	2.3	120	674	2.0	--	--	--	--	--	--	--	--	--	--	--
431717	0754301	44	7.0	3.3	82	9.5	--	--	--	--	--	--	--	--	--	--	--
431747	0754649	170	8.4	1.8	257	8.6	--	--	--	--	--	--	--	--	--	--	--
431853	0754241	190	3.6	14	380	15	--	--	--	--	--	--	--	--	--	--	--
431902	0754318	49	2.7	1.5	91	9.3	--	--	--	--	--	--	--	--	--	--	--
431931	0754313	180	7.8	52	336	4.4	--	--	--	--	--	--	--	--	--	--	--
432106	0754604	120	4.6	2.2	223	28	--	--	--	--	--	--	--	--	--	--	--
432139	0754627	120	5.0	1.8	228	10	<1	14	<20	<1	2	<1	4	<0.1	<1	29	<3
432201	0754719	140	2.8	43	286	9.3	--	--	--	--	--	--	--	--	--	--	--
432317	0754852	150	6.7	4.6	275	9.0	--	--	--	--	--	--	--	--	--	--	--
432322	0754920	51	4.9	1.6	91	9.7	--	--	--	--	--	--	--	--	--	--	--
432328	0755134	100	7.2	4.7	199	8.5	--	--	--	--	--	--	--	--	--	--	--
432340	0754954	130	5.9	2.1	233	21	--	--	--	--	--	--	--	--	--	--	--
432401	0755013	69	5.8	1.6	127	8.8	--	--	--	--	--	--	--	--	--	--	--
432435	0755149	90	5.4	3.0	168	5.9	--	--	--	--	--	--	--	--	--	--	--
432509	0755305	—	7.8	340	2,230	<.2	--	--	--	--	--	--	--	--	--	--	--
432538	0755313	180	8.1	31	329	27.0	<1	200	70	<1	1	1	66	<.1	<1	820	5
432559	0755413	39	3.6	1.7	74	9.6	--	--	--	--	--	--	--	--	--	--	--
432725	0755556	60	6.0	1.6	103	7.3	--	--	--	--	--	--	--	--	--	--	--
432916	0755601	92	5.6	1.7	177	7.0	--	--	--	--	--	--	--	--	--	--	--
432917	0755601	109	5.9	1.5	231	7.4	--	--	--	--	--	--	--	--	--	--	--
433032	0760010	330	8.7	28	625	14	<1	49	50	<1	16	1	8	<.1	<1	109	500
433145	0760041	109	6.0	3.3	198	18	--	--	--	--	--	--	--	--	--	--	--
433222	0760100	270	12.0	6.8	599	23	--	--	--	--	--	--	--	--	--	--	--
433340	0760211	120	5.1	2.3	215	8.2	--	--	--	--	--	--	--	--	--	--	--
433409	0760248	100	5.6	2.7	190	8.4	--	--	--	--	--	--	--	--	--	--	--
433448	0755811	32	4.0	.8	56	7.2	--	--	--	--	--	--	--	--	--	--	--
433558	0760332	83	4.9	1.2	167	17	--	--	--	--	--	--	--	--	--	--	--
433745	0760403	92	4.5	2.7	178	9.3	--	--	--	--	--	--	--	--	--	--	--
434118	0760350	150	5.2	7.9	262	19	--	--	--	--	--	--	--	--	--	--	--
434239	0760322	94	5.2	3.4	169	8.9	--	--	--	--	--	--	--	--	--	--	--
434419	0760245	100	3.6	4.4	194	8.6	<1	69	30	<1	16	1	4	<.1	<1	67	150
434653	0760201	200	9.8	3.7	399	17	--	--	--	--	--	--	--	--	--	--	--
434717	0760111	219	3.7	4.4	394	36	--	--	--	--	--	--	--	--	--	--	--
434739	0760207	240	10.0	9.2	421	24	--	--	--	--	--	--	--	--	--	--	--
434816	0760005	120	4.0	2.4	234	19	<1	18	<20	<1	5	1	4	<.1	<1	66	4
434934	0760134	270	6.5	4.7	491	15	--	--	--	--	--	--	--	--	--	--	--
435021	0760102	160	5.2	2.0	280	25	--	--	--	--	--	--	--	--	--	--	--
435021	0760113	280	6.2	13	559	25	--	--	--	--	--	--	--	--	--	--	--
435146	0760014	360	8.1	18	669	18	--	--	--	--	--	--	--	--	--	--	--

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