GROUND WATER IN DALE VALLEY, NEW YORK

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 78-120

Prepared in cooperation with the County of Wyoming and the Town of Middlebury, New York

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by Allan D. Randall

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Albany, New York

1979

UNITED STATES DEPARTMENT OF THE INTERIOR

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GEOLOGICAL SURVEY

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CONVERSION FACTORS AND ABBREVIATIONS

The following factors may be used to convert the U.S. customary units of measurement in this report to the International System of Units.

Multiply	by	To obtain
cubic feet	28.32	liters
	0.02832	cubic meters
cubic feet per second	28.32	liters per second
	0.02832	cubic meters per second
degrees Fahrenheit, minus 32 degrees	5/9	degrees Celsius
feet	0.3048	meters
feet per day	0.3048	meters per day
feet squared per day	0.0929	meters squared per day
gallons	3.785	liters
gallons per minute	0.0631	liters per second
inches	25.4	millimeters
miles	1.609	kilometers
million gallons per day	43.8	liters per second
million gallons per day per square mile	1,460	cubic meters per day per square kilometer
square miles	2.590	square kilometers

Abbreviations used in the text of this report include:

mg/L, milligrams per liter
°C, degrees Celsius (temperature)
°F, degrees Fahrenheit (temperature)

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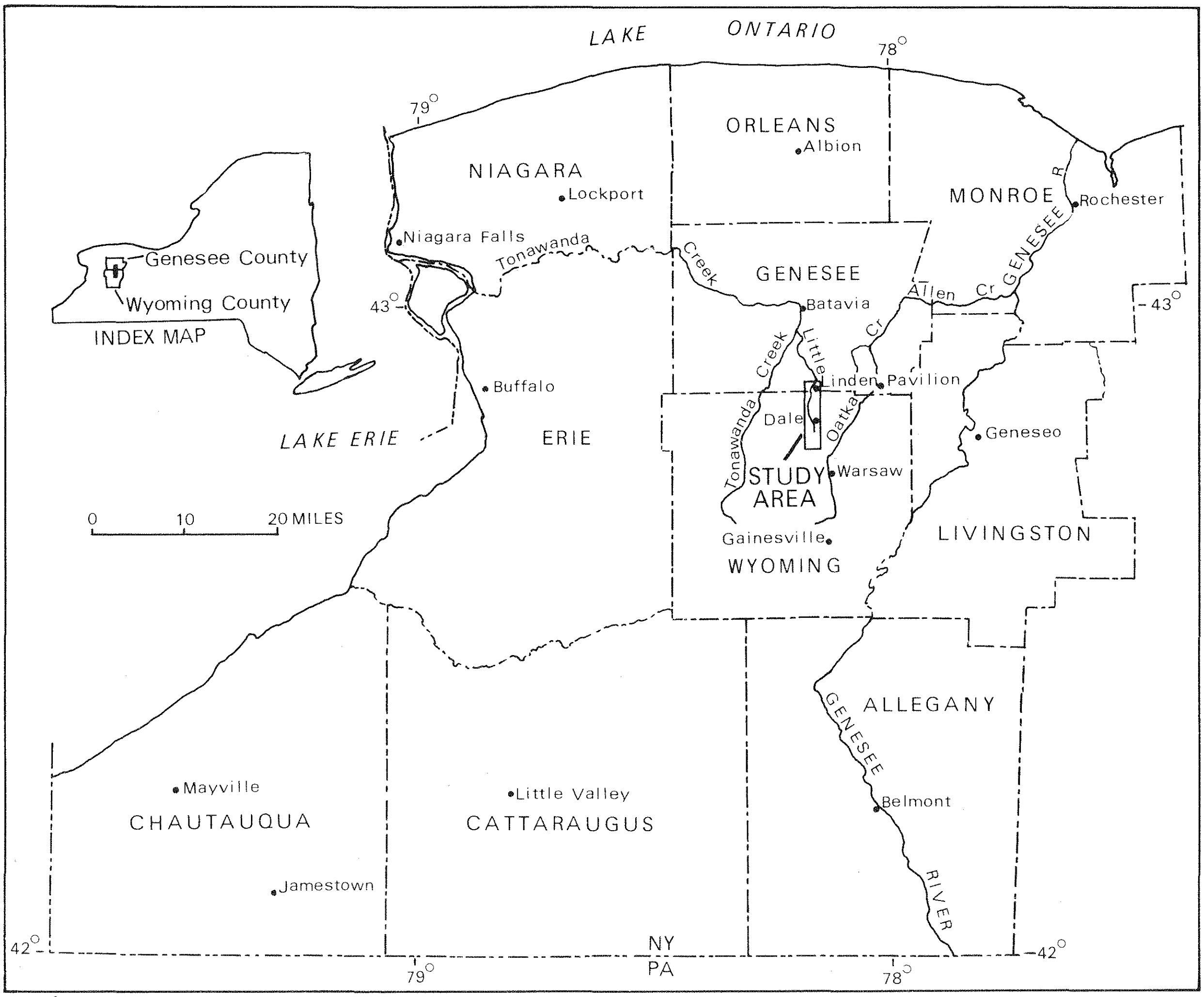
By

Allan D. Randall

ABSTRACT

Dale Valley, which lies north of Warsaw, New York, is a distinctive segment of the headwaters of Little Tonawanda Creek in that it was enlarged by glacial erosion. The valley contains two principal aquifers composed of sand and gravel--a thin, shallow alluvial aquifer, which immediately underlies most of the valley floor and is little used, and the Dale Valley aquifer, which is buried beneath many feet of lake deposits and is tapped by several industrial wells. A digital-computer model of the Dale Valley aquifer predicted that in a moderately wet year, such as the period when the model was calibrated, an industrial demand of 750 gallons per minute could be met by a combination of withdrawal from Little Tonawanda Creek and from the Dale Valley aquifer without excessive drawdowns at the industrial wells or at domestic wells in the valley. Creek flow would be ample to meet the demand for much of the year, but ground-water withdrawals would be required for about 100 days. After some reasonable but unverified adjustments were made to simulate an unusually dry year, the model predicted that a demand of 600 gallons per minute is the largest that could be sustained in such a year from the creek plus the Dale Valley aquifer.

Water high in chloride has migrated from the bedrock into parts of the Dale Valley aquifer and has resulted in chloride concentrations about 50 times greater than those found elsewhere in the aquifer. The chloride concentrations seem to be increasing. Industrial development, faults in the bedrock, and the natural ground-water flow system may have helped create the anomaly.



Base from U.S. Geological Survey
State base map, 1:500,000, 1974

Figure 1.--Location of Dale Valley, New York.

INTRODUCTION

Location of Dale Valley and History of Water Use

Dale Valley is the name used by local residents for a relatively wide and level segment of the valley of Little Tonawanda Creek in western New York. It lies in the western part of the town of Middlebury, in north-central Wyoming County. The hamlet of Dale, near the south end of the valley, is 6 miles north of Warsaw and 12 miles south of Batavia (fig. 1). The valley is bordered by steep slopes that rise 350 feet to the surrounding upland. Its floor is 0.4 mile wide over a distance of 4 miles from Dale north to the Genesee County line, where the wide valley ends and Little Tonawanda Creek continues northward through a narrow gorge several miles long.

Nearly all of Dale Valley was cleared for agriculture years ago, and most of the valley was still farmed in 1974. The main line of the Erie-Lackawanna Railroad has followed the west wall of the valley since about 1855, and remnants of an earlier rail line may be seen on the valley floor. During the days of steam locomotives, water was piped across the valley to the railroad from a former pond behind a dam on a tiny spring-fed tributary of Little Tonawanda Creek just south of Dale Gulf. The ground water in Dale Valley was used only for domestic supplies until 1970, when salt mining began. Since then, several hundred thousand gallons of water per day from wells and from Little Tonawanda Creek have been used to dissolve rock salt deep below the valley floor. The resulting brine is piped to Niagara Falls, N.Y., for use by industry.

The gorge of Little Tonawanda Creek near Linden, immediately north of Dale Valley (figs. 1, 17), has long been recognized as a potential site for a major dam. Two water-resources-planning studies (New York Conservation Commission, 1912; Erie-Niagara Regional Water Resources Planning Board, 1969) recommended construction of a reservoir at Linden for regional public water supply and other uses. Such a reservoir would inundate much of Dale Valley north of Dale. The potential for aquifer development in Dale Valley was recognized by LaSala (1968), who estimated that annual recharge to the aquifers in Dale Valley averages 2 to 4 million gallons per day per square mile. An evaluation of the need and potential for public water supplies in Wyoming County (Teetor-Dobbins, 1970) made no mention of aquifers in Dale Valley nor of any need for a public water system at Dale; it tentatively recommended ground-water development, where needed, rather than the proposed Linden reservoir because such development would be less costly.

Reasons For This Study

Nearly all the homes and farms in Dale Valley have been occupied for many years, and all obtain water from private wells near the homesites or from springs on nearby hillsides. However, several wells and springs yield less water than the occupants would like, at least during the dry part of the year. At a few homes, several wells were drilled but did not obtain a usable supply of water.

In 1970 and 1971, four large-yield wells were drilled along the center of Dale Valley for industry; each tapped gravel at depths of about 150 feet below land surface. The water withdrawn was pumped down other wells to dissolve salt beds about 1,300 feet below the valley floor, and the resulting brine was conveyed out of the valley by pipeline. Testing and subsequent operation of the wells lowered water levels in several private wells by as much as 40 feet, and a few of these wells had to be deepened or replaced as a result. Residents of Dale Valley became concerned as to whether other wells might become affected, and, as residents and local government officials turned their attention to the ground-water resources of Dale Valley, other questions were raised. Would those resources be adequate to permanently sustain the present demand? What would result if industry were to expand, or if other new developments were built? Should a municipal water supply be considered for Dale? After the salt mining has been completed, what description of local ground-water resources could the community present to potential developers or water users?

To help answer these questions, the U.S. Geological Survey began an investigation of the ground-water resources of Dale Valley early in 1974 in cooperation with Wyoming County and the Town of Middlebury.

Acknowledgments

This investigation could not have been successful without the help of the Texas Brine Corp. staff, who adjusted their pumping schedules for several months to provide a sufficiently consistent stress on the aquifer, nor without the cooperation of the residents of Dale Valley, who permitted frequent access to their wells for measurement. Information on well construction was provided by Texas Brine Corp., local residents, and several well drillers. The Wyoming County Soil and Water Conservation District played a major role in organizing public interest in an investigation of water in Dale Valley.

Identification and Location of Wells

A record of every well in Dale Valley for which useful information could be obtained in 1974 is given in table 7, at the end of this report; the location of every well is plotted in figure 17, which accompanies table 7. Well records are tabulated and identified according to the latitude and longitude of the well site, as explained in table 7. For the convenience of local readers, wells mentioned in the text are identified by the owner's name (and owner's well number, if any); readers unfamiliar with these names and numbers may locate the wells from figure 3.

GEOLOGIC UNITS IN DALE VALLEY

Origin and Distribution

More than 300 million years ago, thousands of feet of mud accumulated on an ocean floor in what is now western New York. Compressed by the weight of subsequently deposited sediment, the mud hardened into siltstone and shale bedrock. Amid the older, more deeply buried layers of shale are layers of limestone, dolostone, salt, and gypsum that had precipitated from the ocean waters. Over the years, stresses in the earth produced a myriad of cracks in the bedrock. Nearly all the cracks are pressed tightly together, but some, especially near land surface, are open enough to transmit a little water. The bedrock has shifted in different directions along a few cracks, notably along the Clarendon-Linden fault, which lies beneath Dale Valley. This fault probably intersects land surface in the upland a few thousand feet west of Dale Valley, although its exact surface location is not obvious (A. Van Tyne, oral commun., 1975). The fault dips downward to the east, beneath Dale Valley, where its presence is demonstrated by the offset of distinctive beds penetrated by deep wells drilled for oil, gas, or salt. Branch or splinter faults are associated with it near Linden and perhaps elsewhere.

About a million years ago, the first of several vast glaciers flowed into New York and covered both hills and valleys. Moving ice scrubbed off many feet of soil and rock, particularly in the larger valleys, where the ice was thickest and flowed most rapidly. Erosion by successive glaciers gave Dale Valley its smooth, straight walls and carved its bedrock floor far deeper than those of its tributaries. The bedrock floor includes a basin-shaped depression (fig. 2) that could not have been created by streams. Eroded material that accumulated in the ice was gradually released by melting at the base and the front of the glacier and was thereby spread over the bedrock as a blanket of unsorted, clay-rich sediment known as till. Meltwater carved temporary channels within and under the ice and occasionally deposited gravel, some of which has been preserved as lenses within the blanket of till.

The retreat, or dissipation, of the latest glacier was a gradual process that had a marked effect on Dale Valley. A tongue of ice remained in Dale Valley for some time after ice had largely disappeared from the surrounding upland. The gravel visible along the east side of the valley south of Dale (fig. 4) was deposited on or beside the ice tongue by southward-flowing meltwater streams that must have risen several miles to the north within the glacier. Gravel that lies many feet below land surface north of Dale, termed the Dale Valley aquifer in this report, may be a remnant of the same stream system. Its depth may be explained by deposition beneath the ice in tunnels or by deposition atop the ice and collapse when the ice melted. As the ice tongue melted and retreated northward, meltwater formed a lake in Dale Valley that at first spilled southward across the divide near Beehive Crossing and later spilled across a lower divide northeast of West Middlebury (fig. 2). Clay, silt, and very fine sand that accumulated in this lake now form the confining layer atop the Dale Valley aquifer. Apparently the ice

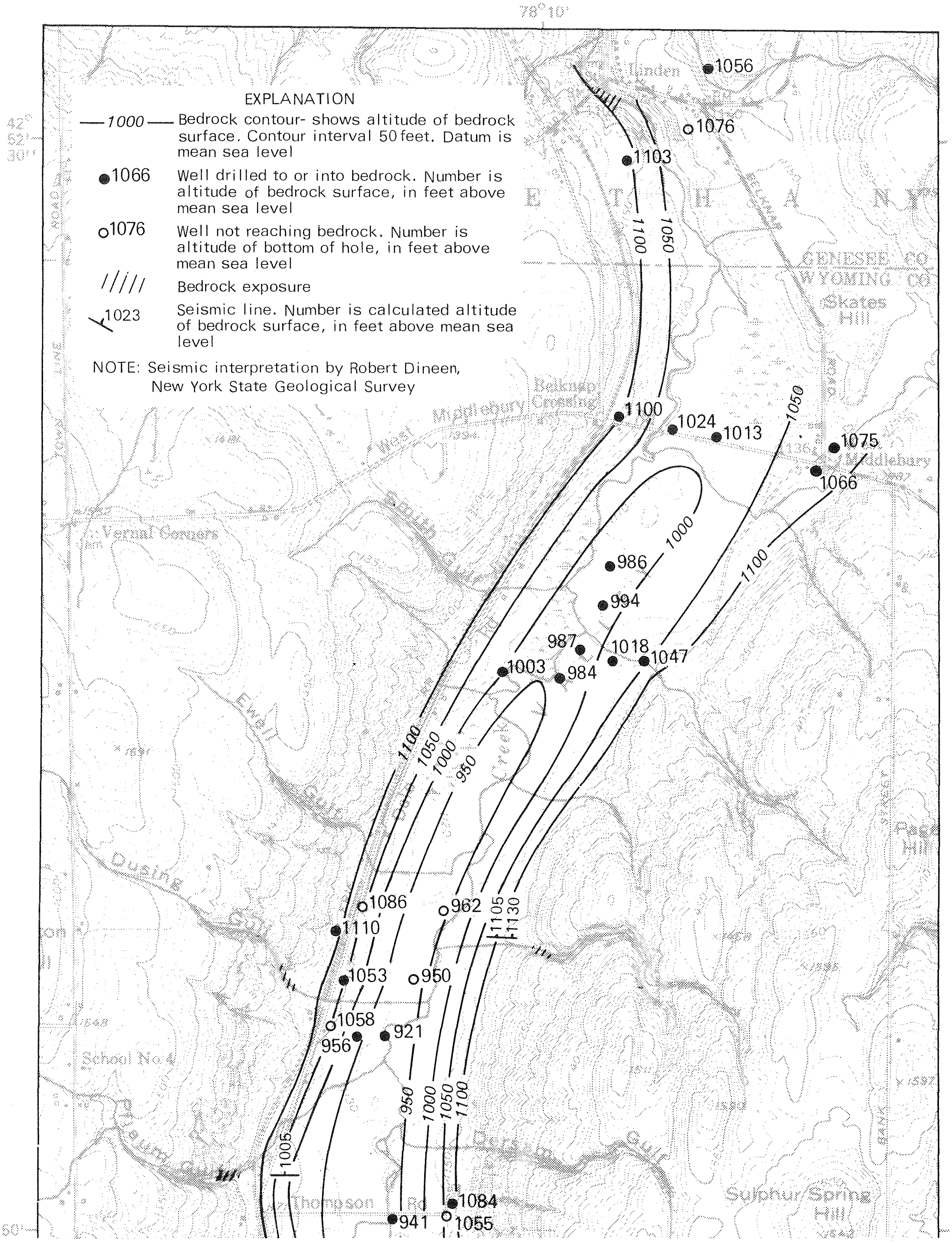
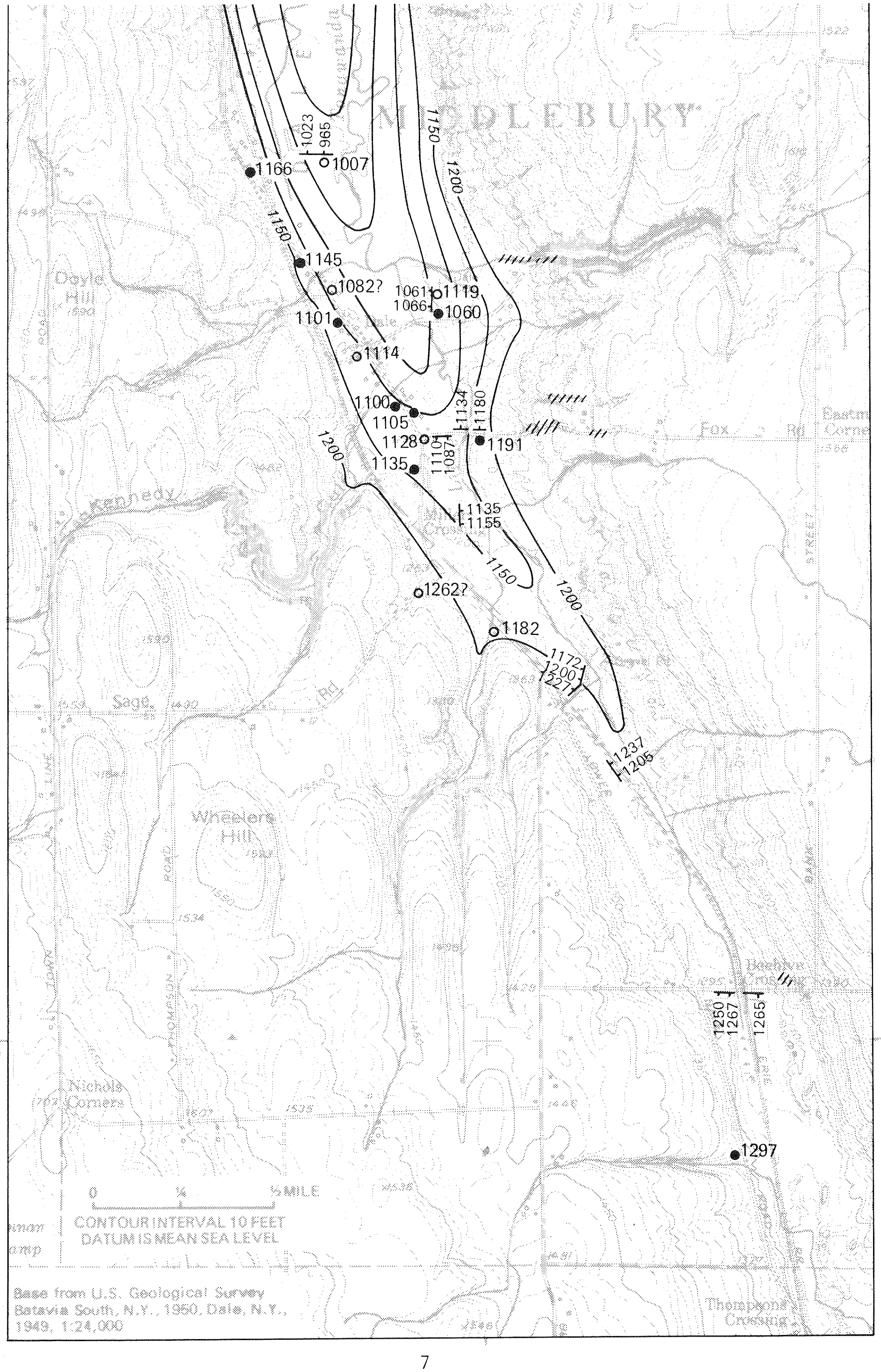


Figure 2.--Bedrock topography in Dale Valley. (South half of this and subsequent maps is on facing page).


MIDDLEBURY
1023
965
1007
1166
1150
1200
1145
1082?
1061
1119
1066
1060
1101
1114
1134
1180
1100
1105
1128
1191
1110
1087
1135
1155
1262?
1182
1172
1200
1221
1237
1205
1250
1267
1265
1297
Doyle Hill
Kennedy
Sage
Rd
Fox Rd
Wheelers Hill
Nichols Corners
Beehive Crossing
Thompsons Crossing
42°
47'
30"
0 ¼ ½ MILE
CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL
Base from U.S. Geological Survey
Batavia South, N.Y., 1950, Dale, N.Y.,
1949, 1:24,000

tongue readvanced into the lake periodically, for some layers of silt and clay contain scattered pebbles (which probably dropped to the lake bottom from a floating ice tongue), and some till on the valley sides contains masses of clay and silt (which were picked up by ice advancing across lake deposits).

Eventually the ice retreated north from Linden, which allowed the lake remaining in Dale Valley to spill northward across till that plugged the valley near Linden. As the overflow eroded a gorge through the till, the lake gradually drained. Tributary streams deposited small deltas of sand and gravel wherever they entered the lake; the largest of these deltas form the terraces at West Middlebury. As lake level declined and during the several thousand years since it disappeared, tributary streams deposited alluvial fans of silty gravel across parts of the former lake bottom. Meanwhile, Little Tonawanda Creek spread gravelly alluvium along its meandering channel and deposited silt across the floor of Dale Valley during floods. These shallow gravel deposits of the present streams, along with some gravel deposited as deltas in the former lake, constitute the alluvial aquifer described in this report.

Water-yielding capacity

Bedrock

The bedrock that underlies Wyoming County to depths of several hundred feet is predominantly shale, but includes some siltstone and occasional thin beds of limestone and dolostone. It is arranged in nearly horizontal layers and is generally capable of yielding only small amounts of water. The bedrock is described more fully by Sutton (1950) and La Sala (1968). At most locations, shale bedrock will provide at least the few gallons per minute needed for a home, but dry holes or wells with yields inadequate for a home are not uncommon (La Sala, 1968, p. 26; Kammerer and Hobba, 1967, p. 34). The 25 water wells inventoried during this study that penetrate bedrock (table 7) may be divided into two categories--those that yield a few gallons per minute and are adequate for the homes they serve, and those that yield much less than a gallon per minute and are inadequate or have been abandoned. The low-yield wells lie along the west side of Dale Valley (table 7, fig. 3); wells drilled into bedrock beneath the valley floor or beneath terraces have adequate yields. Most wells reaching bedrock penetrate only a few feet or a few tens of feet into bedrock.

At least three hypotheses may be offered to explain why wells that penetrate bedrock differ significantly in yield and generally penetrate only a small distance into bedrock.

1. La Sala (1968, p. 25) reports that at the top of the shale bedrock in this region there is commonly a layer of intensely fractured or broken rock from 1 to 10 feet thick that yields more water than the underlying bedrock. This layer might be especially thick or extensive beneath the floor of Dale Valley, or fractures associated with the Clarendon-Linden fault might be numerous there.

2. In valleys, bedrock is commonly overlain by sand or gravel. Where this is true, water draining into wells through fractures in the bedrock is replenished by seepage from above more readily than in upland areas where bedrock is overlain by till. Records of most wells in or near Dale Valley (table 7) do not show whether gravel and (or) intense fracturing are present at the top of bedrock. However, water levels in wells penetrating bedrock near Dale correspond to levels in wells ending in deeply buried gravel and also respond to pumping from the gravel, which indicates interconnection.

3. Throughout western New York, the concentration of dissolved solids in ground water increases with depth (La Sala, 1968, p. 61; Johnston, 1964, p. 39), and all water below some depth is too salty for most uses. Several wells near Dale penetrated 10 to 30 feet into bedrock without obtaining salty water (see section "Quality of Ground Water"), but three wells penetrating more than 100 feet into bedrock obtained water from the deeper beds that was too salty or too highly mineralized for household use. The risk of obtaining salty water may be one reason why wells of very small yield were not drilled deeper.

In summary, although the wells penetrating bedrock are too few and too unevenly distributed to allow firm conclusions, wells drilled on the valley floor or terraces could probably obtain a few gallons per minute from the top 10 to 40 feet of bedrock (although many wells in these areas would obtain an adequate yield from sand or gravel before reaching bedrock). At sites low on the sloping sides of the valley, and perhaps also in the upland, the chances of obtaining more than a gallon per minute from a well in bedrock seem no better than 50 percent.

Till

Till is an unsorted mixture of clay, silt, sand, and stones. In areas of shale bedrock such as the Town of Middlebury, till contains a large proportion of clay and silt; consequently, water penetrates it very slowly. Except where eroded away by modern streams, till is present all along the sides of Dale Valley and over the surrounding upland. In these areas, it is generally the only geologic unit above bedrock. Till was recognized beneath many feet of younger sediment, perhaps immediately above bedrock, in a U.S. Geological Survey test well (fig. 3, table 7); its distribution beneath the floor of Dale Valley is otherwise unknown.

Because till is nearly impermeable, the only practical way to obtain water from it is by means of wells several feet in diameter. The water stored within such wells may be pumped out as rapidly as needed and is eventually replenished by seepage from the till. However, the rate of replenishment is likely to be much less than 1 gallon per minute and may often be too small to meet the modest demands of a single home--especially in late summer, when seasonal decline of the water table reduces the saturated sidewall area through which seepage into the well can occur. Occasionally, a large-diameter shallow well will intersect a lens of sand or gravel within the till, which greatly increases its yield.

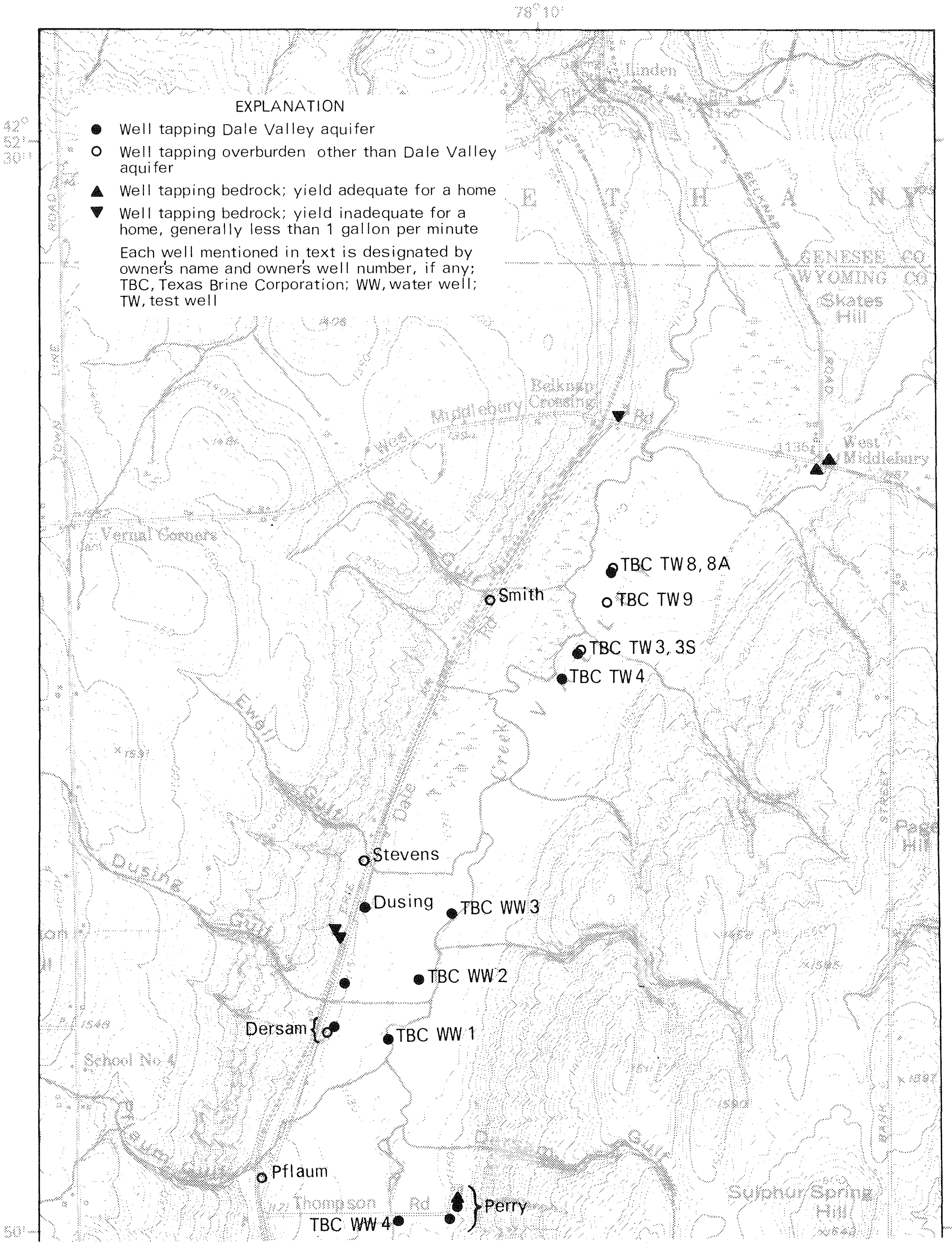
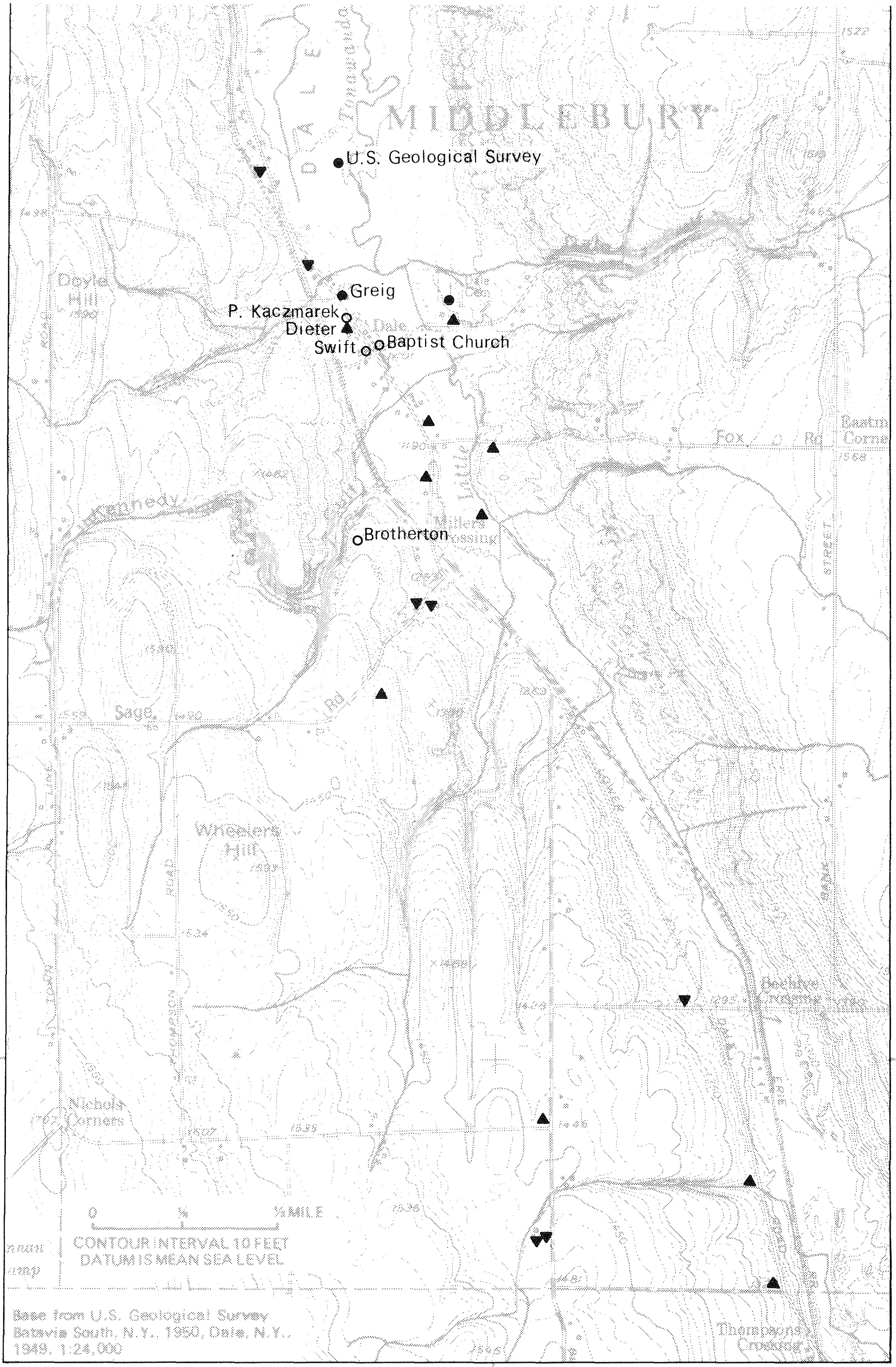


Figure 3.--Location of wells mentioned in text, and other deep wells.


MIDDLEBURY
DALE
Tonawanda
U.S. Geological Survey
Greig
P. Kaczmarek
Dieter
Swift
Baptist Church
Doyle Hill
Brotherton
Kennedy
Millers Crossing
Fox Rd
Little
Sage
Wheelers Hill
Beehive Crossing
Nichols Corners
Thompsons Crossing
ROAD
STREET
0
½ MILE
CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL
42°
47'
30"
Base from U.S. Geological Survey
Batavia South, N.Y., 1950, Dale, N.Y.,
1949, 1:24,000

Several large-diameter dug wells that apparently penetrate till were inventoried during this study (table 7). Most are reported to be inadequate, at least seasonally, for the homes they supply. One owned by R. Brotherton is known to penetrate at least 1 foot of gravel within the till and has provided an ample supply for two homes for several years. A few dug wells in areas of lake deposits near Dale also have very small yields; they probably penetrate chiefly clay or silt, and perhaps till in part. Locations of these wells, and the extent of till and of lake deposits, are shown in figure 5.

Some large-diameter wells with very small yields have been used as storage reservoirs for potable water pumped in periodically from a tank truck (table 7). Storage may be practical in wells penetrating till or lake deposits, but only if the water-level rise after periods of use is less than 100 gallons per day, because water will not seep away faster than it seeps in. In fact, it may not seep away at all because the water level in such wells is likely to remain many feet below the water table as long as the well is in regular use (fig. 4A). Storage of imported water is not practical in wells tapping the alluvial aquifer because water pumped into such wells would seep away within 24 hours (fig. 4B).

The Alluvial Aquifer

Soils on the floor of Dale Valley are silt loams that grade to shaly silt loams near the sides of the valley along tributary streams (Wulforst and others, 1974). Underlying these soils, beginning 4 to 10 feet below land surface, are at least 5 feet of silty or loamy gravel or sandy gravel. Locally, the gravel may reach 20 feet in thickness. This shallow gravel is referred to in this report as the alluvial aquifer. Logs of some test wells in the northern part of the valley report only brown clay and gravel at shallow depth, which presumably did not yield water; however, these wells were drilled in search of large water supplies by mud-rotary drilling equipment, and a layer of silty gravel that would yield several gallons per minute to a large-diameter shallow well could have been overlooked or ignored.

The inferred extent of the alluvial aquifer is shown in figure 5. A few areas where soils were derived from alluvial gravel (Wulforst and others, 1974) are not included with the aquifer because the gravel is suspected to be very thin or largely above the water table (for example, along Little Tonawanda Creek south of Fox Road and on steep alluvial fans near very small tributary streams). Also excluded is a large area where older gravel deposited by glacial meltwater lies above the valley floor on the east wall of Dale Valley south of Miller's Crossing (fig. 5). This deposit is largely dry but may extend below the water table near the valley axis; if so, it would constitute a shallow source of small water supplies and would be comparable to the alluvial aquifer.

Considerable interchange of water takes place between the alluvial aquifer and the streams in Dale Valley. Tributary streams consistently

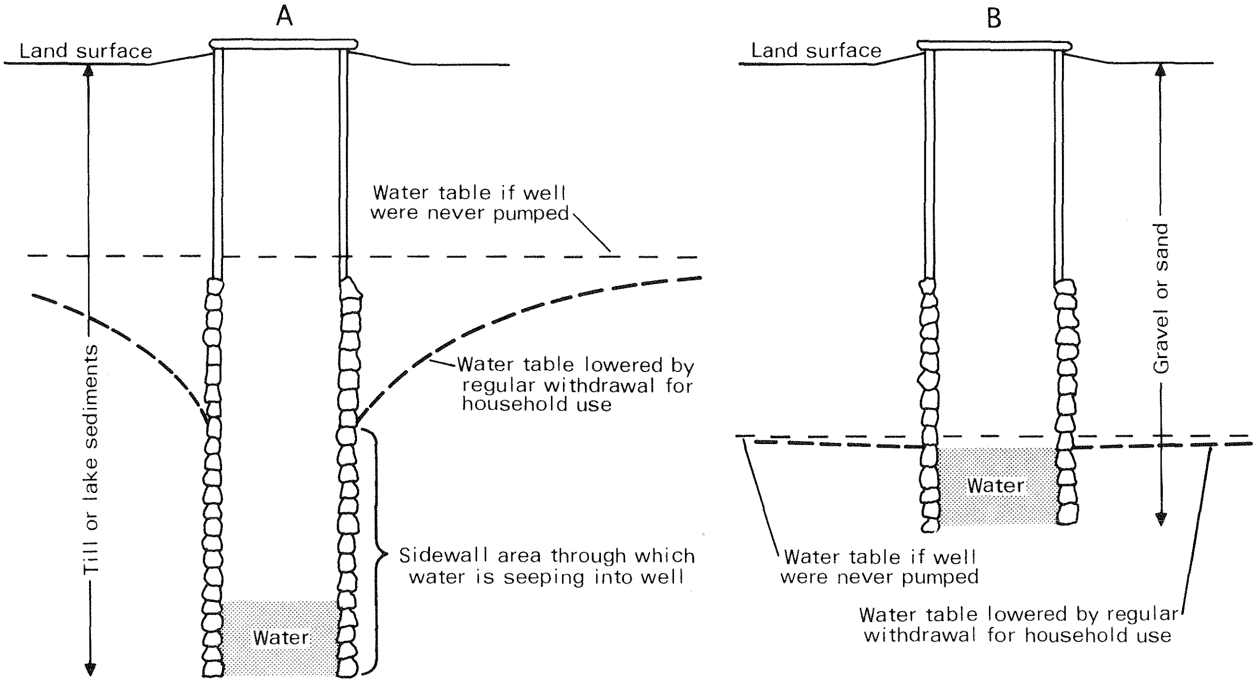


Figure 4.--Water table near typical dug wells penetrating different earth materials and pumped regularly for a home. The sketches represent conditions a few hours after each well was last pumped. Although the amount of water in each well is the same, conditions nearby are different.

A. Well dug in till or in lake deposits (silt and clay). The water level in the well is many feet below the dashed line that represents the "natural" water table and is rising very slowly as water seeps into the well from the poorly permeable sediment surrounding the well. If water were poured into this well, much of it would occupy the part of the well below the natural water table and could flow only a short distance outward before being trapped by the present water table that slopes toward the well. This water would be available for later use.

B. Well dug in gravel or sand. If water were poured into this well, it would at first stand as a column above the water table, but would quickly flow out into the surrounding gravel and away from the well.

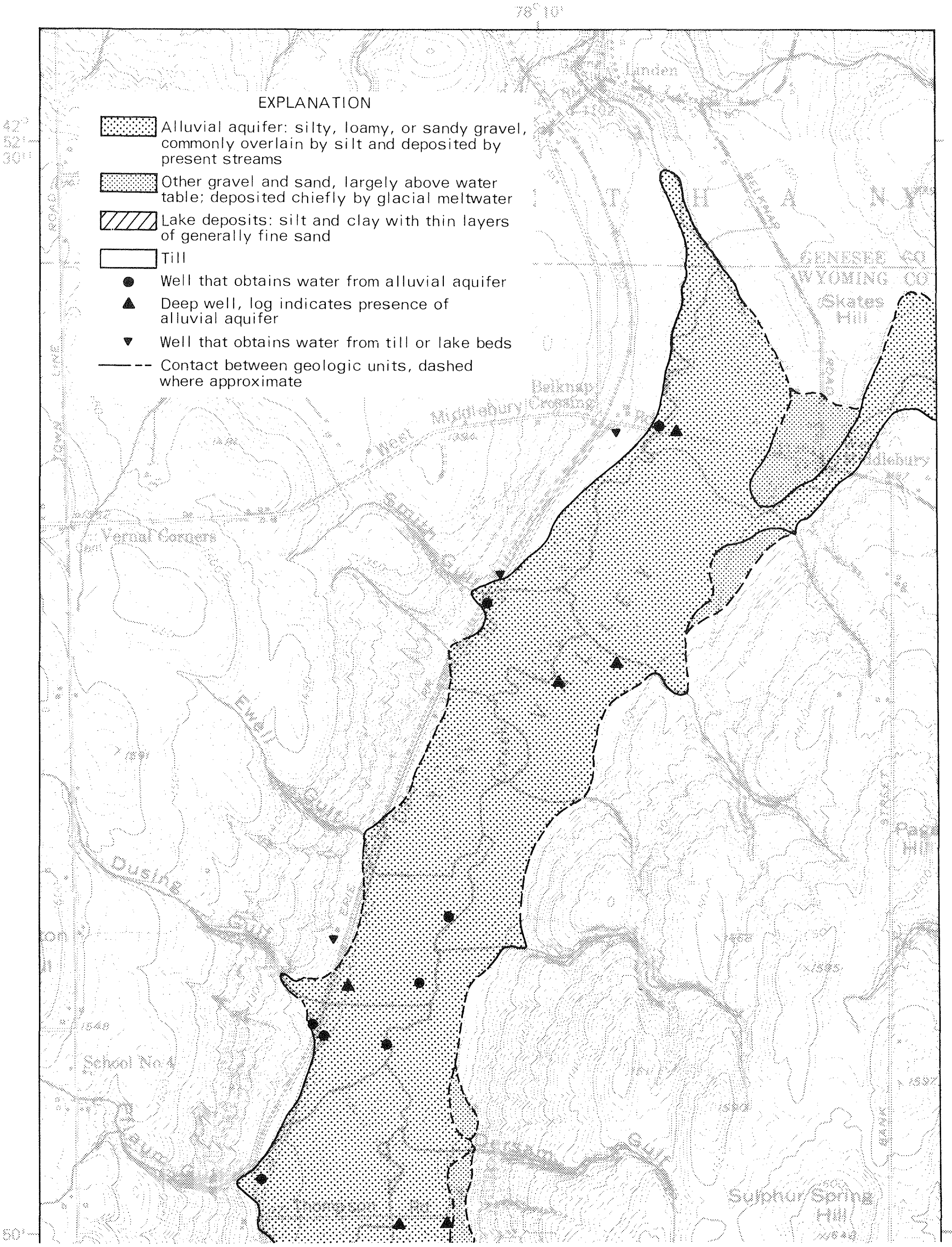
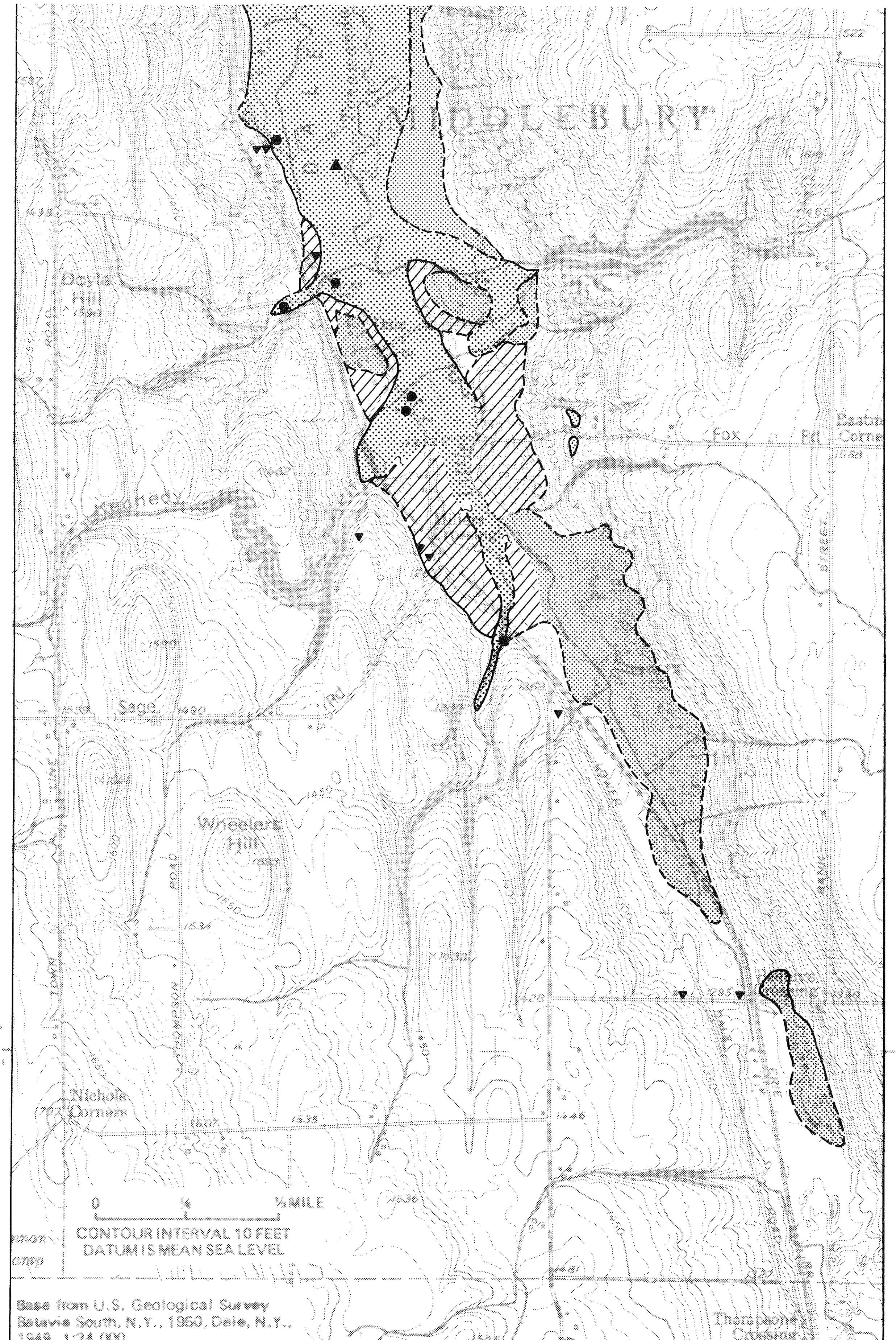


Figure 5.--Extent of alluvial aquifer and other unconsolidated earth materials.


MIDDLEBURY
Doyle Hill
Fox Rd
Kennedy
Sage
Wheelers Hill
Nichols Corners
Thompsons Crossing
0 ¼ ½ MILE
CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL
Base from U.S. Geological Survey
Batavia South, N.Y., 1950, Dale, N.Y.,
1949, 1:24,000
42° 47' 30"

lose water to the aquifer where they emerge from their own valleys and cross alluvial fans near the sides of Dale Valley. In late summer, most of these streams go dry within a few hundred feet downstream from the last bedrock exposure in their channels. This pattern of water loss is typical of tributary streams throughout southwestern New York (Ku and others, 1975). Water is also lost to the aquifer from a reach of Little Tonawanda Creek north of Dale Gulf, where a few thousand feet of the channel commonly go dry in late summer. Near and north of Thompson Road, water that has entered the aquifer from losing stream reaches and from precipitation reappears in Little Tonawanda Creek. For example, measurements in a reach about 2,500 feet long beginning near the mouth of the tributary from Pflaum Gulf on August 2 and 22, 1974, showed that the creek gained 150 and 200 gallons per minute, respectively, after correction for pumpage from that reach.

As of 1974, several large-diameter dug wells obtained water from the alluvial aquifer in Dale Valley (table 7). Three of these were pumped intermittently, reportedly at about 40 gallons per minute; several others have adequately supplied individual homes for many years. Yields from 5 to 25 gallons per minute could probably be obtained from shallow wells almost anywhere within the area of the alluvial aquifer (fig. 4). Shallow wells commonly decline in yield as the water table declines, particularly during severe droughts; the most dependable yields from the alluvial aquifer would be near Little Tonawanda Creek, near tributaries close to the valley sides (where streamflow normally continues through the summer), and on broad, level parts of the valley floor.

The alluvial aquifer could be more widely used to supply small amounts of water for scattered homes and farms. With modern standards of construction (New York State Department of Health, 1966), including watertight casing to a depth of several feet below land surface and careful placement with respect to septic tanks and barnyards, dug wells and other shallow wells should be quite safe as sources of domestic water supply. Along the west side of Dale Valley are several homes at which one or more drilled wells obtained little or no water, where salt water deep in the bedrock precludes drilling deeper, and where dug wells are unproductive because they penetrate only till or lake beds. (See next section.) One way to obtain an ample water supply for these homes would be to dig wells some distance away--either in a wet, springy area on the hillside upslope or in the alluvial aquifer on the valley floor. Perennial springs on upland hillsides commonly offer the advantage of gravity flow to the point of use; however, they are not easily found, and their use may require digging a pipeline through difficult materials on steep wooded slopes. Sites in the alluvial aquifer are usually easier to find and excavate.

The Dale Valley Aquifer

From West Middlebury Road south nearly to Dale, almost all deep drilled wells east of Dale Road penetrate 10 to 25 feet of water-yielding gravel and sand that is near bedrock and is buried beneath many feet of fine-grained sediment. Water levels in these wells are normally near or above land surface and respond promptly to large changes in pumping rate at Texas Brine Corp. water wells (fig. 3). This water-level behavior indicates that all the buried sand and gravel is part of an interconnected, confined system, referred to in this report as the Dale Valley aquifer. Near and south of Dale (table 7), well records indicate little or no gravel near bedrock, and south of Dale the effect of industrial pumpage is slight, which suggests that the Dale Valley aquifer either does not extend as far south as Dale or becomes very thin and poorly permeable there. Logs of two test wells along West Middlebury Road, at the north end of the valley (table 7, fig. 17), did not mention deep water-yielding gravel, which suggests that the aquifer may not extend this far north.

Although the Dale Valley aquifer functions as a hydraulic unit, it is probably not one continuous sand and gravel layer deposited all at the same time. Logs of test wells near Texas Brine Corp. water wells 1 and 2 indicate several sand and gravel layers below a depth of 120 feet. Furthermore, steep water-level gradients were observed between some wells during periods of industrial pumping in 1974, which could mean that those wells tap different gravel layers separated by a few feet of fine-grained sediment through which water cannot flow readily.

The six largest yields obtained from wells in the Dale Valley aquifer are fairly consistent and thus provide some indication of potential well yield. The four Texas Brine Corp. water wells were each tested by pumping at rates of 210 to 250 gallons per minute; drawdowns after 8 hours to 8 days of pumping ranged from 60 to 85 feet. A well at the site of test well 3, in the northern part of the valley (fig. 3), was pumped at more than 100 gallons per minute. The U.S. Geological Survey test well south of Thompson Road was finished open-ended (no screen) and overflowed briefly at about 225 gallons per minute before completion.

A record of water-level changes in wells over several hours as a result of pumping may be used to calculate hydraulic properties of the aquifer such as storage coefficient[1/] and transmissivity[2/]. Measurements suitable for analysis were obtained (a) during two 24-hour tests supervised by the U.S. Geological Survey, (b) during routine operation of the Texas Brine Corp. well field when pumping started or stopped at only one well, and (c) from records of tests performed by the driller upon completion of several wells and test wells. Equations developed for nonleaky, confined conditions were applied to logarithmic and semilogarithmic data

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1/ Storage coefficient is a measure of how much water must be removed from the aquifer (disregarding recharge) to lower the water level by a specified amount.

2/ Transmissivity is a measure of how rapidly an aquifer transmits water laterally under a specified water-level gradient.

plots and to specific-capacity data, as described in standard manuals (for example, Lohman, 1972 and Walton, 1962). The principal results were:

1. Transmissivity values generally fell between 0.4×10^3 and 4×10^3 feet squared per day.

2. Storage coefficient values generally fell between 0.001 and 0.0001.

3. Nearly all tests were influenced by one or more impermeable lateral boundaries.

4. The aquifer does not fully meet the assumptions on which calculations were based--it is probably nonhomogeneous and may receive leakage from adjacent materials. This conclusion is inferred from the inconsistent results obtained when calculations were based on data from observation wells near the sides of the valley and (or) distant from pumped wells. Transmissivity values calculated from these data were too large to explain the water-level distribution under natural or long-term pumping conditions, and distances to lateral boundaries of the aquifer calculated from these data were too large when compared with known distances to the sides of the valley defined from geologic evidence.

Differences in geologic materials and in water levels from place to place also provide clues as to aquifer properties. For example, between the U.S. Geological Survey test well and Dale, water-level gradients are more gentle than in surrounding areas (figs. 7, 8), and two wells that penetrate gravel once overflowed freely (table 7). Therefore, that area is inferred to have higher transmissivity than surrounding areas.

The properties of the Dale Valley aquifer were also evaluated by fitting a digital computer model to records of water level and pumpage. A map of transmissivity, as derived from the model and from the analyses described above, is presented later in this report as figure 14.

The pattern of ground-water flow in Dale Valley is illustrated in simplified fashion in figure 6, which represents a vertical east-west slice through the valley. The fine-grained sediment, many feet thick, that overlies the Dale Valley aquifer acts as a seal that confines water in the aquifer. All wells known to tap the Dale Valley aquifer have water levels far above the aquifer, and, except near the sides of the valley, water levels are above land surface under natural conditions. This shows that the water has enough head, or pressure, to seep upward through the confining layer into the alluvial aquifer, although the rate of seepage must be very slow in areas where clay is abundant in the confining layer. Water enters the Dale Valley aquifer by slow upward seepage from the bedrock below and by downward seepage in small areas near the sides of the valley where the aquifer is closer to land surface and higher in altitude than in midvalley. (See fig. 6A.) When a well penetrating the Dale Valley aquifer is pumped heavily, head in nearby parts of the aquifer may fall below the water table in the alluvial aquifer. If this happens, the natural upward leakage through the confining layer is reversed (fig. 6B), and water begins to flow slowly into the Dale Valley aquifer from the overlying fine-grained sediment. At the same time, the rate of upward flow from the underlying bedrock increases.

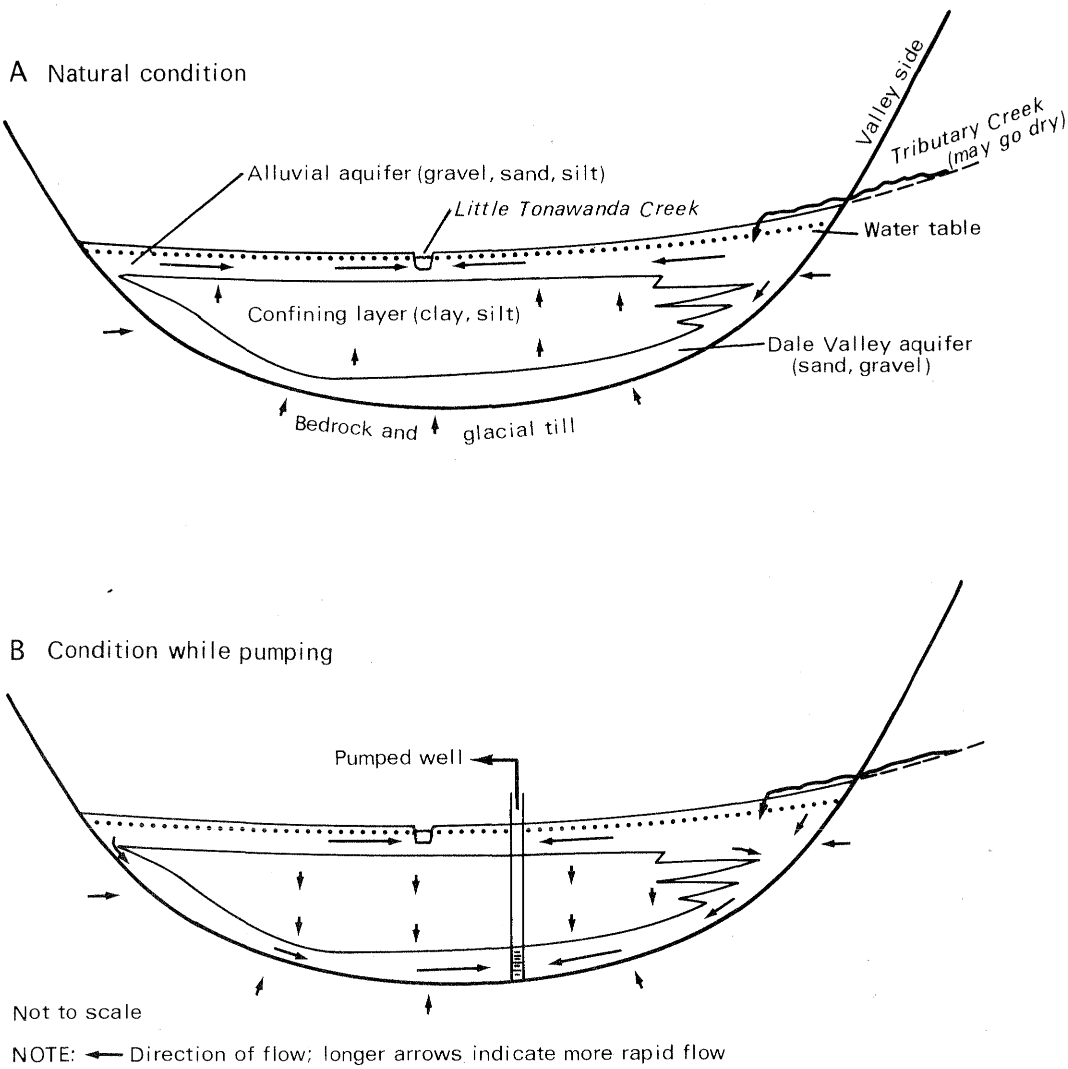

Figure 6.--Idealized sketch of aquifer system in Dale Valley.

A, direction of ground-water flow under natural conditions; B, direction of ground-water flow during long-term pumping of Dale Valley aquifer.

Pumping stress on the Dale Valley aquifer during the 12 months ending in November 1971, before the turbine creek pumps were usable, was probably greater than during any other year through 1974. Records show that pumpage averaged at least 360 gallons per minute for 11 months. However, the records are not complete, nor do they indicate how much of the water pumped, if any, may have been derived from the creek or from the alluvial aquifer. Furthermore, records of the effect of this pumpage on water levels are scanty. Therefore, the 1971 experience does not provide an adequate basis for evaluating aquifer yield.

A more complete record of the Dale Valley aquifer's response to stress was obtained in 1974. From mid-June to mid-September, Texas Brine Corp. water wells were pumped at rates as large and steady as could be achieved while meeting the requirements of industrial operations. Water levels were measured periodically in all suitable wells. Daily average pumpage rates for each production well from June 19 through September 17, 1974, are given in figures 12 and 13. The rates equal withdrawals from the Dale Valley aquifer because the centrifugal "helper" pumps and shallow wells were not used. Pumpage from wells 1 and 3 was measured by orifice-type recording flow meters, as was pumpage from the turbine creek pumps and brine flow at many points in the system. Daily average pumpage from well 4 was calculated as the difference between measured pumpage of freshwater from all other sources and measured recovery of brine from the system, allowing for water to fill the space vacated by dissolved salt.

Maps show the level to which water would rise in wells that penetrated the Dale Valley aquifer or the uppermost few feet of bedrock on June 19, when the 1974 test began, and on September 17, when it ended (figs. 7, 8). Water levels on June 19 were several feet below natural static levels because Texas Brine Corp. had pumped well 1 occasionally and well 3 fairly regularly since mid-March; withdrawals from the aquifer before June 19 are unknown because recorded pumpage includes unmeasured, variable contributions from centrifugal "helper" pumps and dug wells. Most of the net decline in water level as of September 17 (fig. 9) was due to pumping. However, the effect of pumping could not be recognized as far north as West Middlebury nor south of Fox Road near Dale. Deep wells in these areas had water-level declines of only 1 to 2 feet, as did shallow wells on the valley floor and observation wells several miles away (fig. 15). These small declines are attributed to natural seasonal factors (Johnston, 1964, p. 56-57; Crain, 1966, p. 28-29), which must also have affected deep wells throughout the Valley.

Because pumpage and water-level response in 1974 were reasonably well documented over so much of Dale Valley, this experience provided the principal basis for reevaluation of potential aquifer yield.

The Digital Model

The principal technique used in this study to evaluate the Dale Valley aquifer was to develop a digital model of the aquifer. A digital model is merely a set of numbers representing aquifer properties and a code or set of detailed instructions that will cause a digital computer to apply those numbers in solving equations of ground-water flow by repeated calculations. An explanation of how ground-water flow may be simulated by finite-difference calculations with a computer is given by Pinder and Bredehoeft (1968) and by Remsen and others (1971). The code used was originally documented by Pinder (1970) and later modified by Trescott (1973). In the following paragraphs, the basic structure of the model and its response to simulated pumping are compared with observed data from Dale Valley. Further detail is provided in the section "Technical Aspects of Model Calibration."

General Features of the Model

The digital model developed for this study simulates many elements of the real system, as shown in figure 10. It incorporates a deep aquifer, a confining layer, and a shallow aquifer. The computer code allows for horizontal flow in any direction within the deep aquifer and vertical flow up or down through the confining layer. The shallow aquifer is treated as a reservoir that supplies the water needed for downward flow through the confining layer and receives any upward flow, but the code does not provide any way to simulate horizontal flow or pumping in the shallow aquifer. The bottom and sides of the deep aquifer are treated as being totally impermeable; therefore, simulated flow through the confining layer must represent inflow to the aquifer from bedrock in addition to inflow or outflow through the confining layer. This is a fairly reasonable simplification, as explained in the section "Technical Aspects of Model Calibration," but as a result the numerical values developed for the confining layer are presumably somewhat larger than the true values.

Calibration of the Model

The code chosen for this study could be applied to aquifers of many different shapes, sizes, and properties. To adapt the code to conditions in Dale Valley, it was necessary to first lay out a grid over a map of the area studied (fig. 11) and then to specify numerical values for several properties of the aquifer system for each cell in the grid. These properties include water level in the shallow aquifer, water level in the deep aquifer at the start of a test period, rate of withdrawal from each well in the deep aquifer, transmissivity and coefficient of storage of the deep aquifer, and the hydraulic conductivity[1/] and thickness of the confining layer. The computer then calculated for each cell the changes in water level in the deep aquifer that would result from specified periods of pumping or of natural flow, based on interaction of all the aquifer properties mentioned. Results were compared with water levels

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1/ Hydraulic conductivity, like transmissivity, is a measure of water-transmitting capacity but is expressed per unit area.

actually observed, and estimated values for aquifer characteristics within some cells were modified to achieve a better match. This process is known as calibration and is essential to produce a reliable model. The basis for the initial estimates and the modifications are explained under "Technical Aspects of Model Calibration."

Two types of simulation--steady-state and transient--were used to calibrate the model. In both types, water levels in the deep aquifer of the model were initially set equal to those observed in the Dale Valley aquifer on June 19, 1974. Neither pumpage nor seasonal water-level changes were incorporated in the steady-state simulation; therefore, the simulated water levels (table 1) represent an average natural equilibrium. In general, the simulated steady-state water levels were higher than those observed on June 19, particularly in the central part of the aquifer. This was expected because intermittent industrial pumping from March through mid-June had lowered water levels over much of the aquifer and, even though pumping essentially ceased early on June 16, water levels were still rising on June 19. Static water levels under natural conditions were also estimated for several wells in table 1, generally from measurements recorded before industrial wells were pumped regularly or from measurements made early in March 1974 after several months in which the only stress on the aquifer caused by industrial development was overflow of a few gallons per minute at several uncapped wells. These estimates are only an approximation of the average natural equilibrium that would have prevailed in 1974 in the absence of pumping but are close enough to the simulated steady-state water levels to justify confidence in the model calibration.

The first transient simulation was designed to reproduce pumpage and changes in water level from June 19 through September 17, 1974. Simulation of all day-to-day changes in pumping rate would have been cumbersome and costly, so average rates during periods of 7 to 35 days were used (figs. 12, 13). Results are summarized in table 2 (p. 33). Simulated water levels were generally within 2 feet of those observed throughout the summer. Except at four wells near the ends of the valley, simulated drawdowns on September 17 were within 10 percent of those observed. Another indication of how closely the model was able to duplicate aquifer behavior is provided by figures 12 and 13, in which water levels measured daily in two wells tapping the Dale Valley aquifer are compared with simulated water levels. The large difference between simulated and observed water levels at Texas Brine Corp. wells 1 and 3 (table 2) may be due more to well inefficiency than to a defect in the model. If the screens in these wells had become partly plugged during the previous 4 years of regular use, water levels would have been lower within the wells than in the aquifer nearby whenever the wells were being pumped, and it is conditions in the aquifer, not in the wells, that the model simulates. Measured and simulated water levels at well 4 were in close agreement. The water levels were apparently measured in the annular space outside the screen (above the gravel pack), and the well had received little use after it was drilled and tested; therefore, well inefficiency should have contributed little to drawdown measured in this well.

Table 1.--Calibration of model under steady-state conditions

Well owner's name and well number[1]	Model cell in which well is located[2]	Water level, in feet above mean sea level: Measured June 19, 1974	Simulated by model	Estimated for conditions before industrial development
Parsonage, W. Middlebury	3, 21	1115	1117.0	3/ 1116
TBC TW 8D	6, 10	1111.6	1112.9	4/ 1113
TBC TW 4	9, 10	1117.9	1119.2	4/ 1119
TBC WW 3	16, 10	1124.4	1131.2	-
R. Dusing	17, 4	1129.2	1136.1	3/,4/ 1140
TBC WW2	18, 10	1127.0	1134.2	-
TBC Office	19, 6	1131.4	1139.0	-
G. Dersam	20, 6	1136.5	1142.5	4/ 1143
TBC WW1	20, 10	1127.6	1136.3	3/ 1134
H. Perry	24, 21	1142.9	1147.0	3/ 1152
TBC WW4	25, 17	1141	1146.4	-
USGS	30, 22	1170.2	1168.5	4/ 1173
Dale Cemetery	32, 30	1186.9	1185.6	3/,4/ 1189
P. Dieter	34, 27	1177.0	1175.6	4/ 1178
R. van Dusen	35, 31	1186.0	1185.8	4/ 1186.5

1/ TBC, Texas Brine Corp.; TW, test well; WW, water well; USGS, U.S. Geological Survey.

2/ Row number is given first, column number second. See model grid, figure 11.

3/ Based on record of water level when well was drilled or water level in older well at same location.

4/ Based on measurements in March and (or) May 1974.

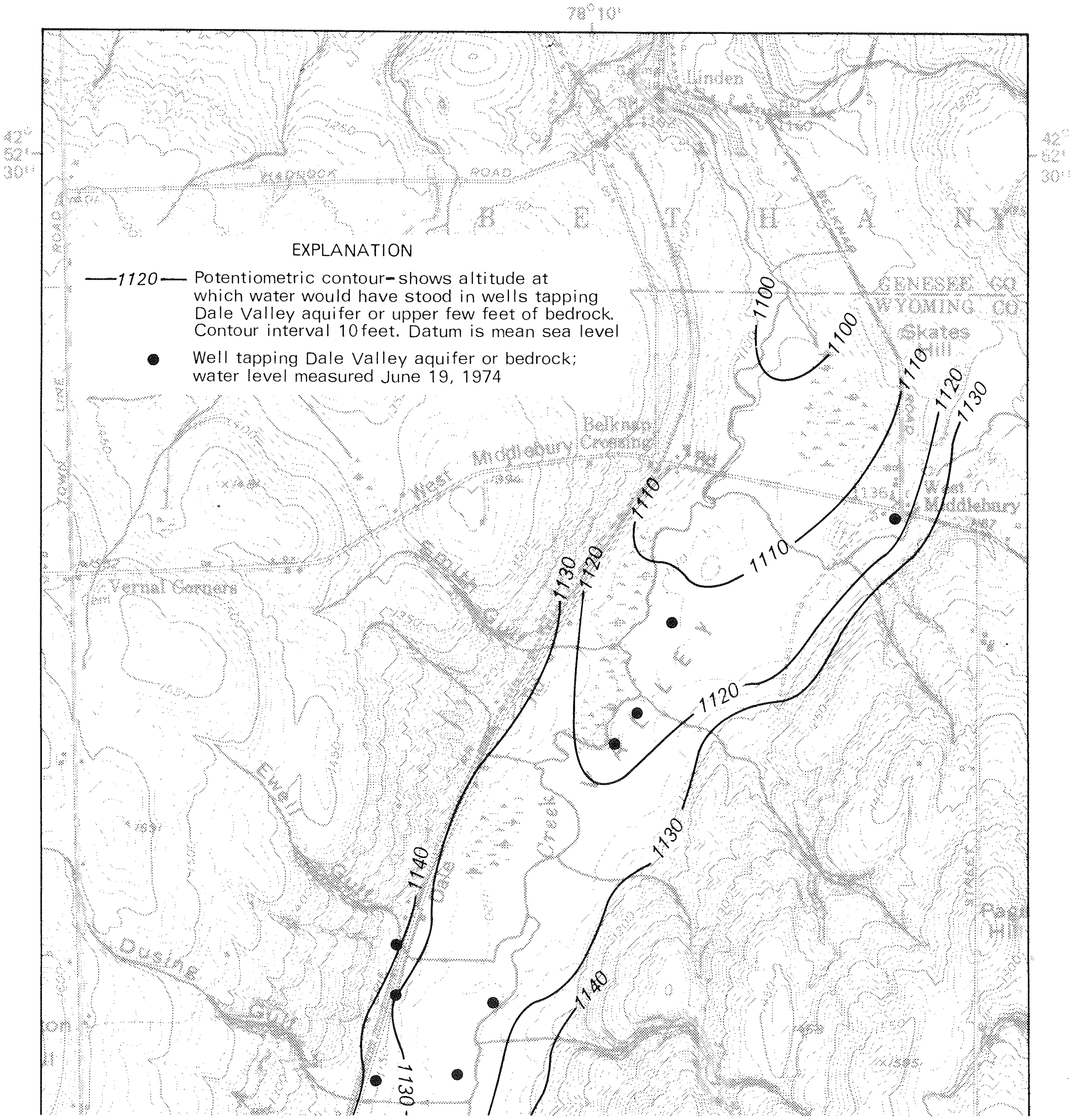
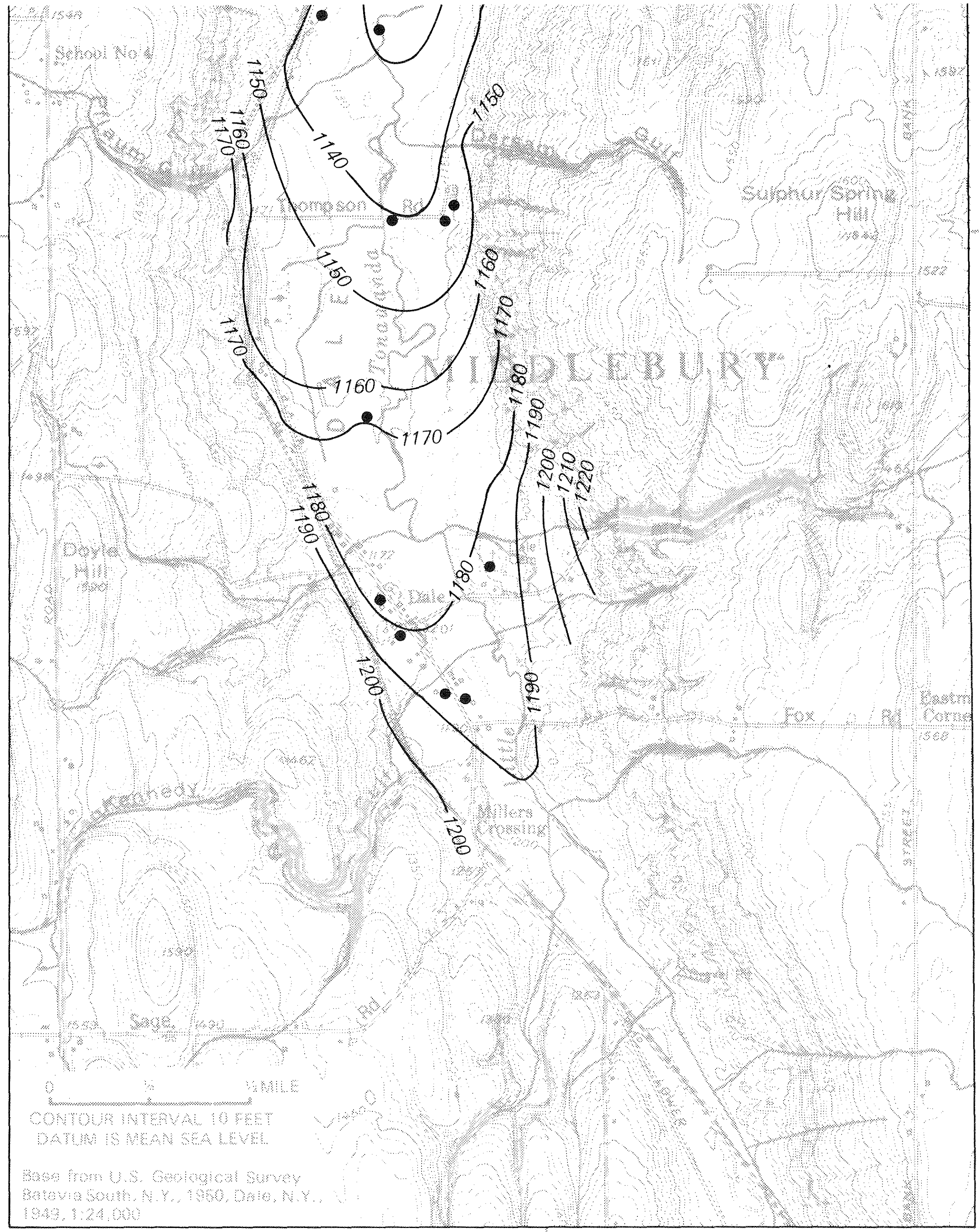


Figure 7.--Potentiometric surface on June 19, 1974, Dale Valley aquifer.


School No 4
Thompson Rd
Sulphur Spring Hill
MIDDLEBURY
Doyle Hill
Dale
Fox Rd
Millers Crossing
Kennedy
Sage
42°
50'
78°10'
1140
1150
1160
1170
1180
1190
1200
1210
1220
0 ½ 1 MILE
CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL
Base from U.S. Geological Survey
Batavia South, N.Y., 1950, Dale, N.Y.,
1949, 1:24,000

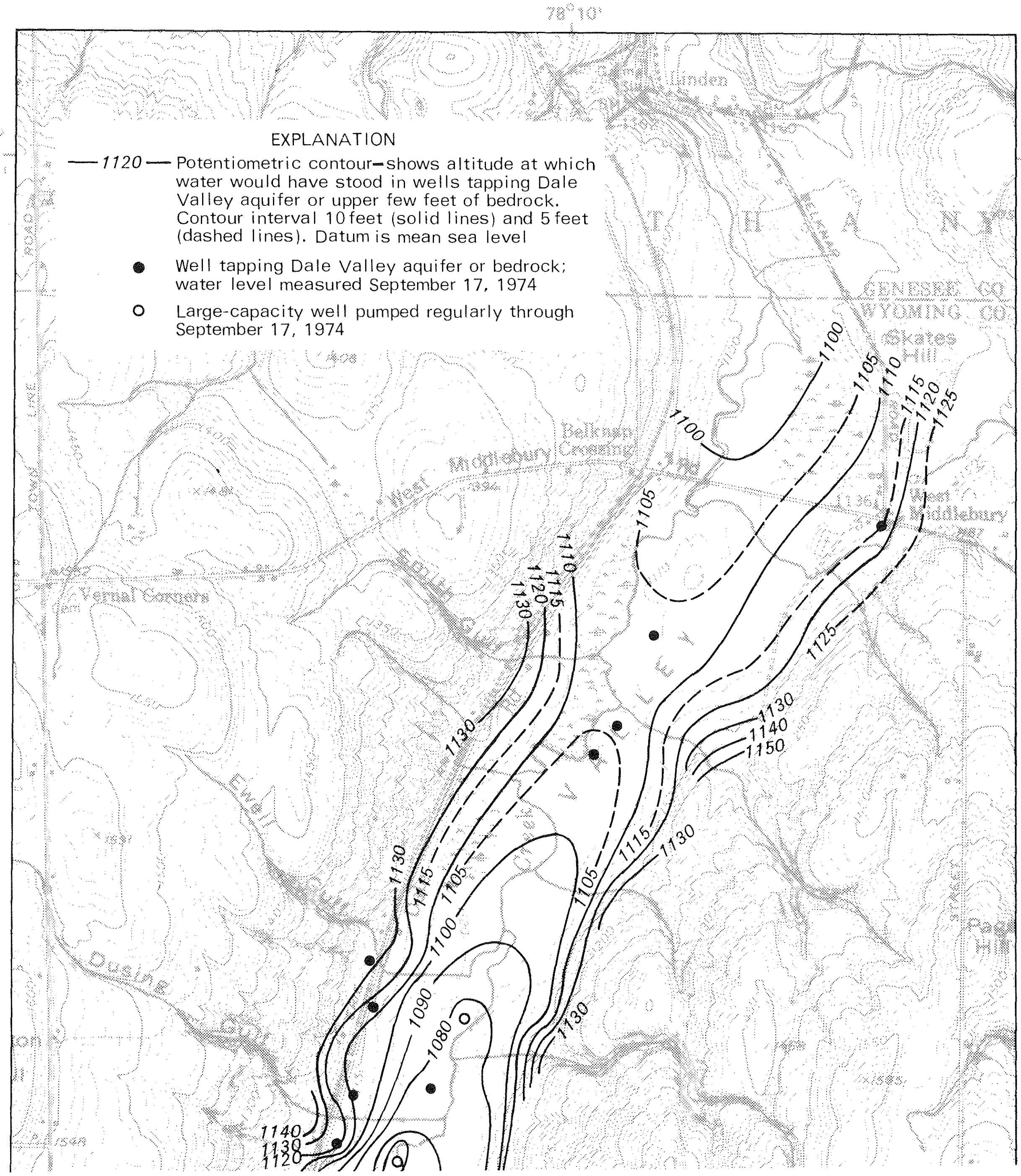
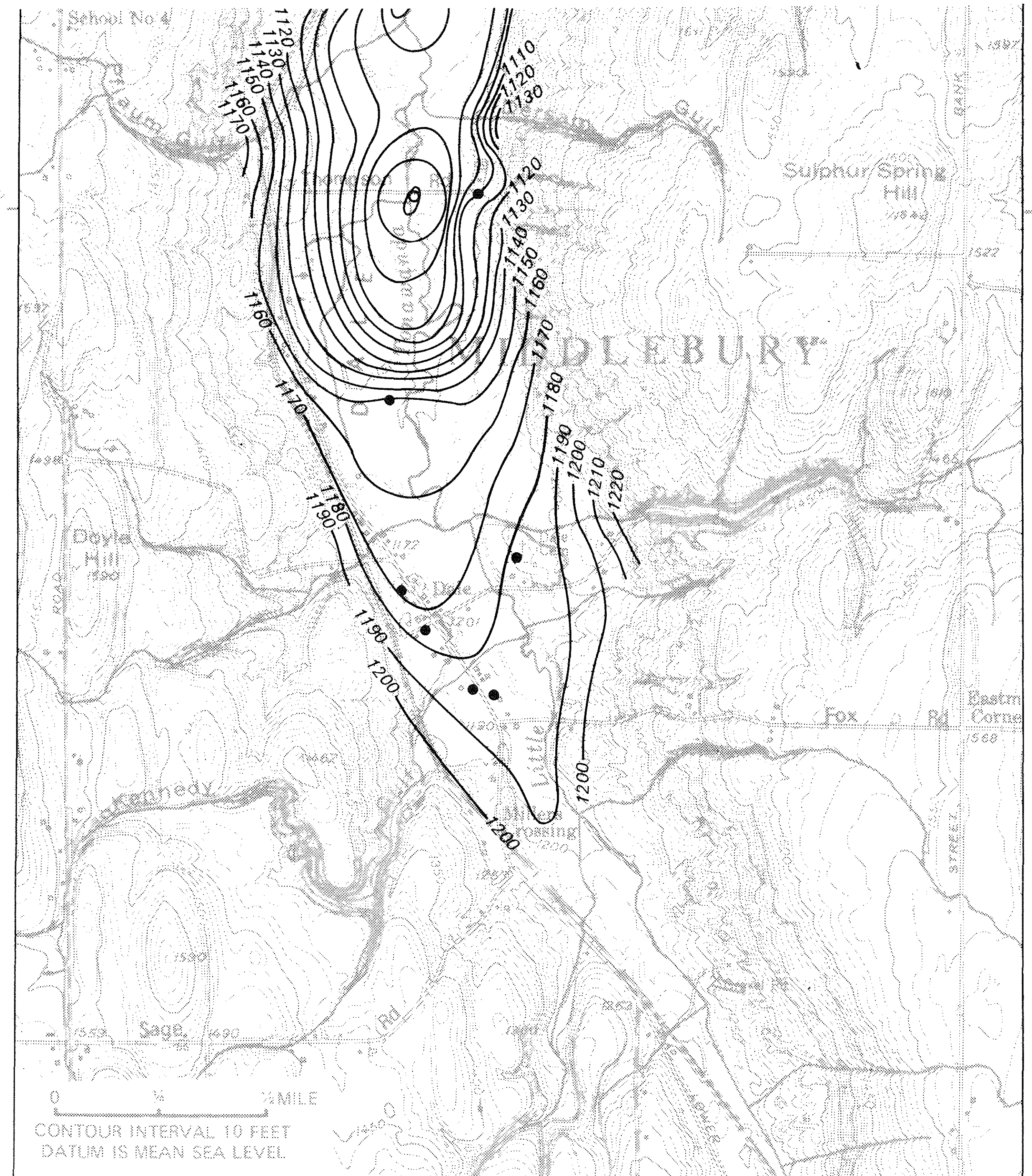


Figure 8.--Potentiometric surface on September 17, 1974, Dale Valley aquifer.


0 ¼ ½ MILE
CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL
Base from U.S. Geological Survey
Batavia South, N.Y., 1950, Dale, N.Y.,
1949, 1:24,000
42° 50'
78° 10'
Sulphur Spring Hill
Doyle Hill
Dale
Fox Rd
Kennedy
Sage
School No 4
Little
Millers Crossing

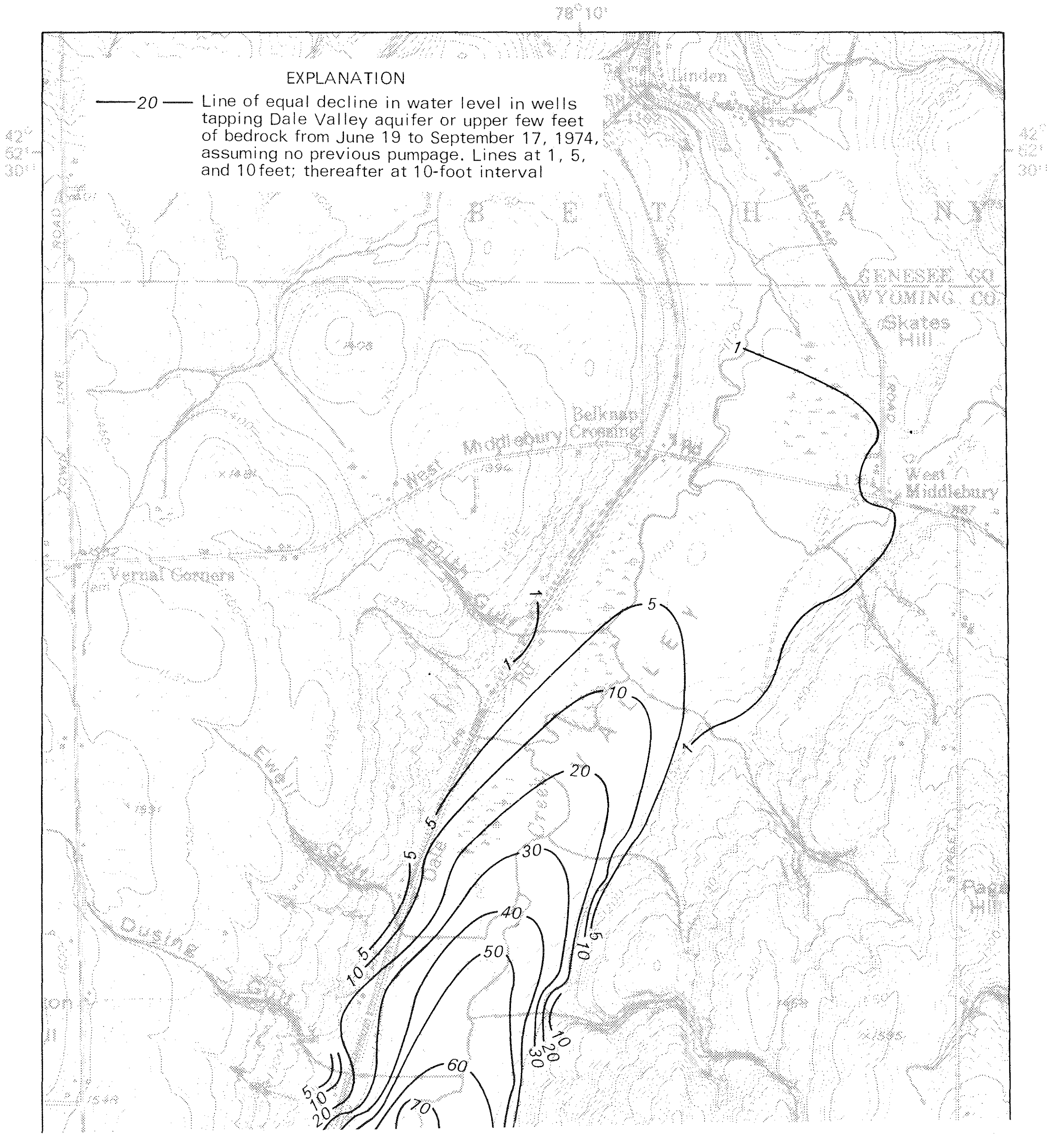
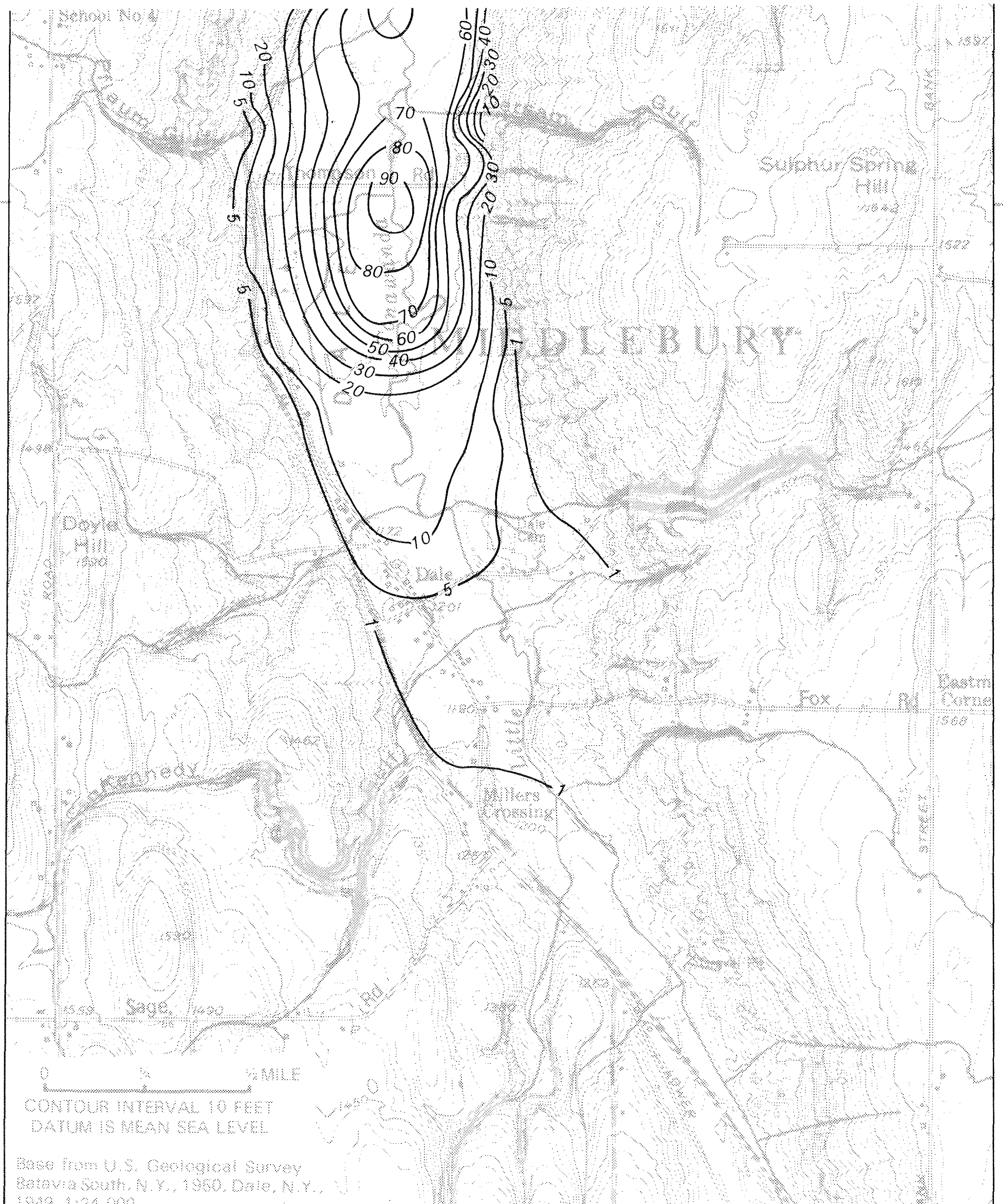


Figure 9.--Net decline in water level in 1974, Dale Valley aquifer. Lines represent the difference between water-level altitudes observed on September 17 (fig. 8) and water-level altitudes that would have been observed on June 19 had the aquifer not been pumped previously. (The latter are generally higher than those actually observed June 19, fig. 7). This difference is the result of all industrial pumping from the aquifer in 1974 through September 17 plus the natural seasonal decline in water level from mid-June to mid-September, which is generally about 1 foot.


School No 4
Gulf
Sulphur Spring
Hill
Thompson Rd
MIDDLEBURY
Doyle
Hill
Dale
Fox Rd
Eastman
Corners
Little
Millers
Crossing
Kennedy
Sage
Rd
42°
50'
0
¼
½ MILE
CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL
Base from U.S. Geological Survey
Batavia South, N.Y., 1950, Dale, N.Y.,
1949, 1:24,000
78°10'

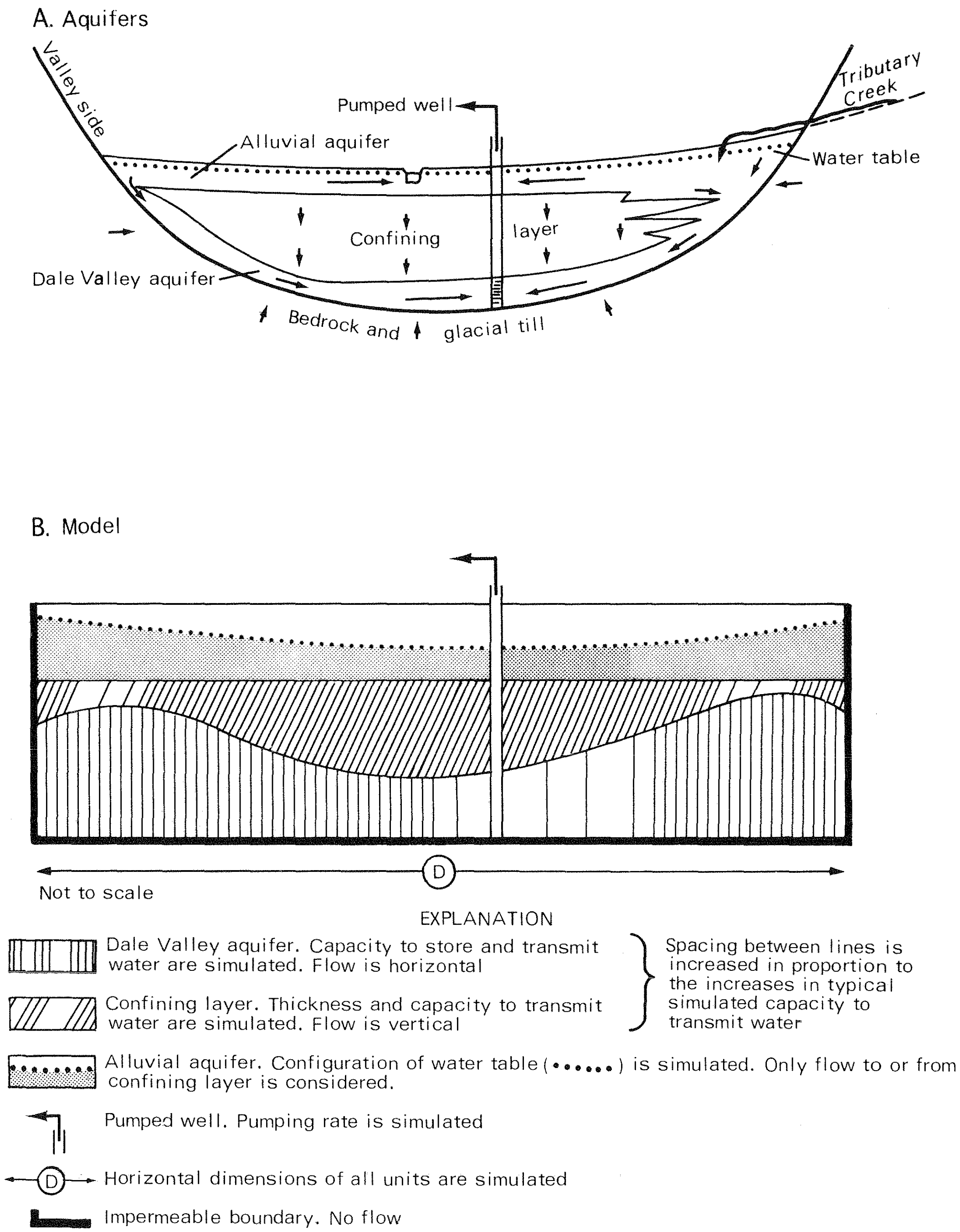


Figure 10.--Aquifer system in Dale Valley compared with digital-model representation.

A. Idealized cross section of real system.
B. Same cross section as represented by digital model.

Table 2.--Calibration of model under transient conditions, June 19-September 17, 1974

Well owner and well number 1/	Location (model cell) 2/	Water levels, in feet above mean sea level						Net decline in water level, June 19-September 17, in feet	
		August 1			September 17				
		Measured	Simulated	Difference	Measured	Simulated	Difference	Measured	Simulated
Parsonage, W. Middlebury	3, 21	1115	1117	+2	1114	1116	+2	1	+1(rise)
TBC TW8D	6, 10	1108.7	1109.5	+0.8	1105.5	1107.4	+1.9	6.1	4.2
TBC TW4	9, 10	1110.9	1109.7	-1.2	1104.7	1105.9	+1.2	13.2	12.0
TBC WW3	16, 10	3/1060	1080	4/+20	3/	1070	--	--	54.
R. Dusing	17, 4	1116.9	1115.7	-1.2	1105.6	1106.6	+1.0	23.6	22.6
TBC WW2	18, 10	1091.5	1092.0	+0.5	1075.5	1076.1	+0.6	51.5	50.9
TBC Office	19, 6	--	1118.6	--	1108.1	1108.7	+0.6	23.3	22.7
G. Dersam	20, 6	1128.9	1128.3	-0.6	1120.5	1119.8	-0.7	16.0	16.7
TBC WW1	20, 10	3/1056	1067	4/+11	3/	1045	--	--	83.
H. Perry	24, 21	1130.4	1133.9	+3.5	1105.6	1105.0	-0.6	37.3	37.9
TBC WW4	25, 17	1126.9	1126.0	-0.9	3/1034	1035	+1	107.	106.
USGS	30, 22	1164.5	1163.9	-0.6	1150.5	1150.9	+0.4	19.7	19.3
Dale Cemetery	32, 30	--	1184.7	--	1181.0	1182.0	+1.0	5.9	4.9
P. Dieter	34, 27	1174.4	1173.4	-1.0	1168.0	1168.2	+0.2	9.0	8.8
R. Van Dusen	35, 31	1184.5	1185.6	+1.1	1183.4	1184.2	+0.8	2.6	1.8

1/ TBC, Texas Brine Corp.;
TW, test well;
WW, water well;
USGS, U.S. Geological Survey

2/ Row number is given first, column number second. See model grid, figure 11.

3/ Pump operating on this date.

4/ Difference is probably due chiefly to well inefficiency and partly to short-term fluctuation in pumping rate.

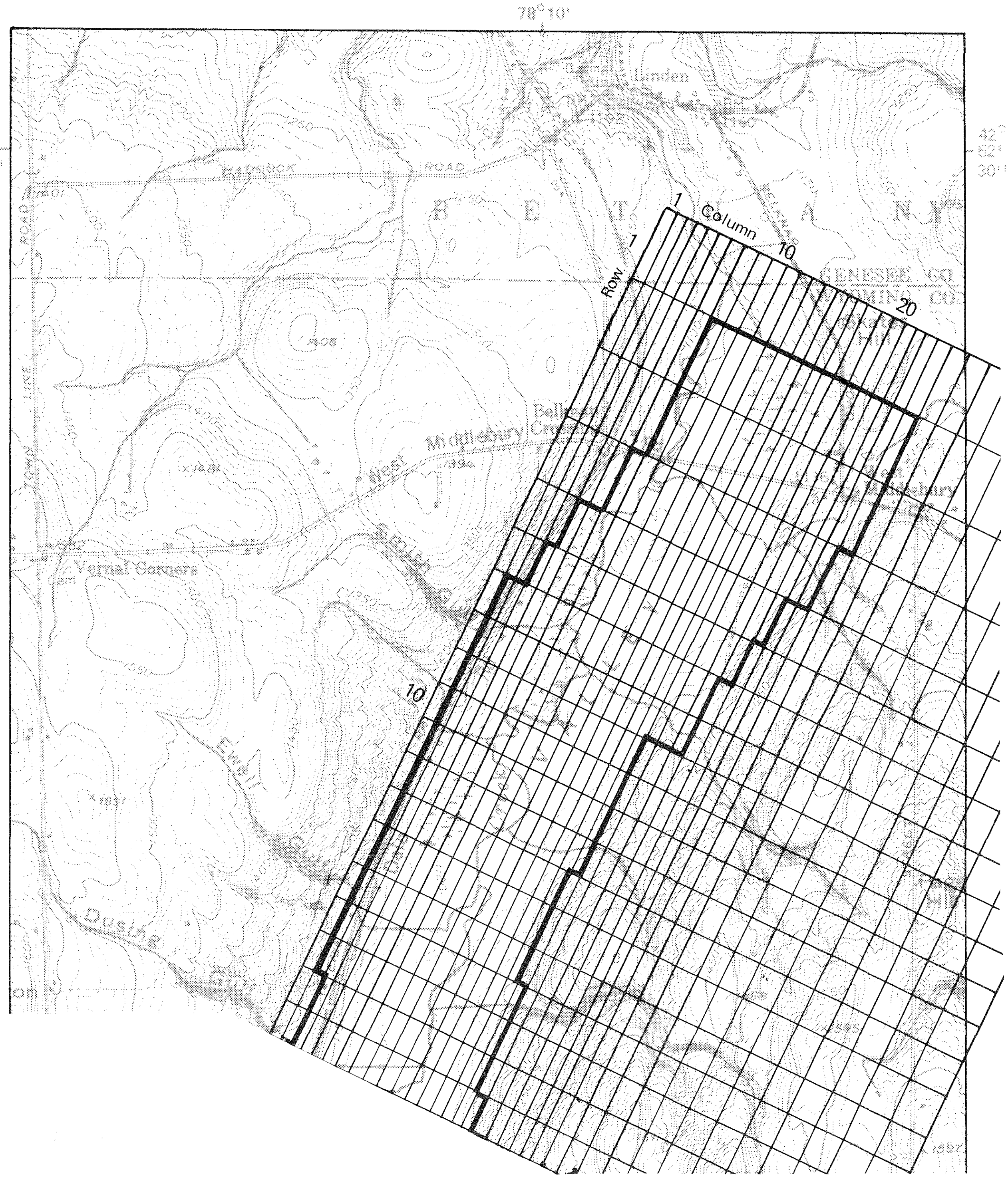
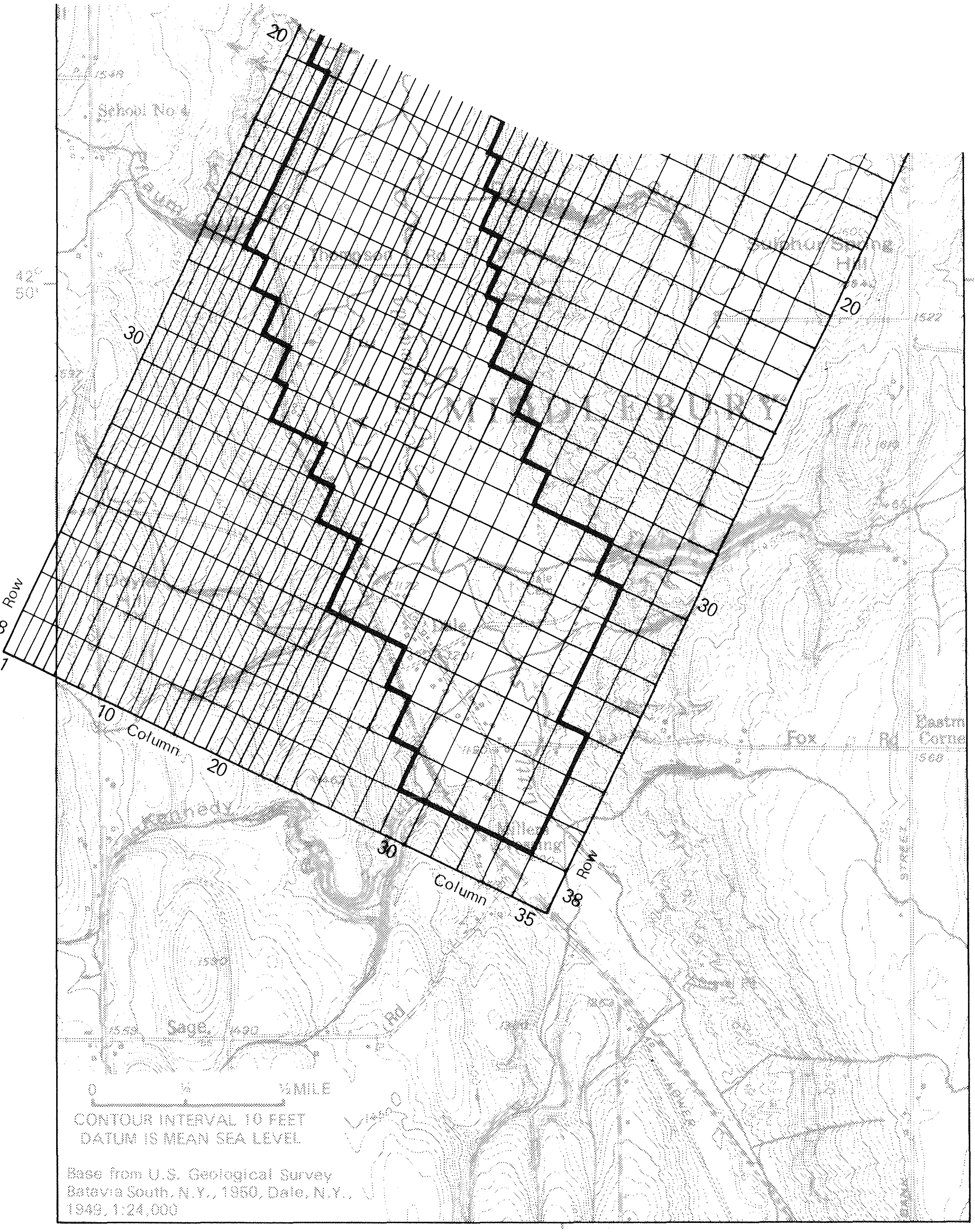


Figure 11.--Digital-model grid for Dale Valley aquifer. Every cell must be assigned a representative numerical value of every aquifer-system characteristic that is incorporated in the model.



Row
38
1
10
Column
20
30
Column
35
Row
38
20
30
20
30
School No 4
Thompson Rd
Sulphur Spring Hill
MIDDLEBURY
Fox Rd
Eastman Corners
Kennedy
Sage
Rd
42°50'
42°50'
78°10'
0 ¼ ½ MILE
CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL
Base from U.S. Geological Survey
Batavia South, N.Y., 1950, Dale, N.Y.,
1949, 1:24,000

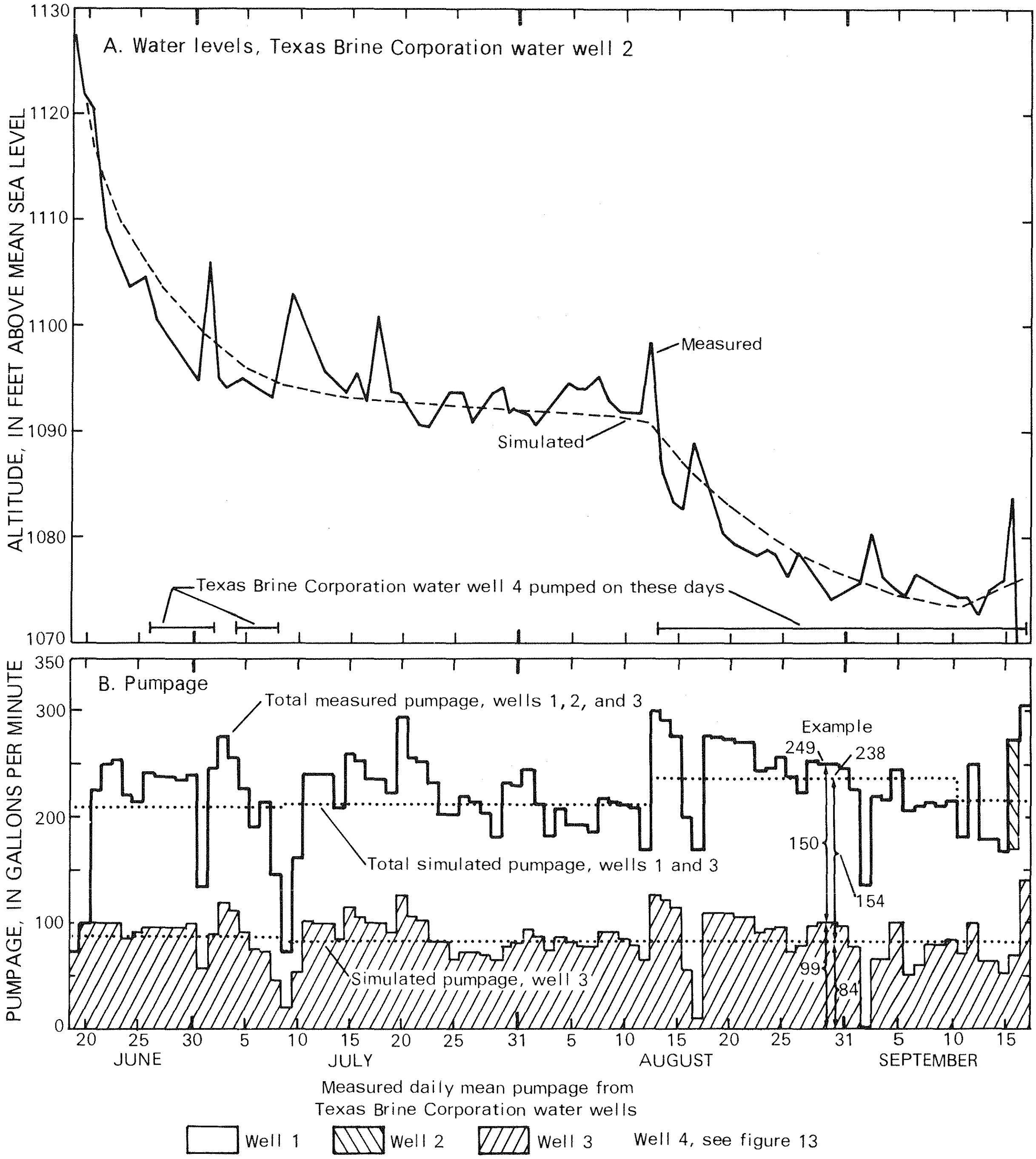


Figure 12.--A. Measured and simulated water levels at Texas Brine Corp. water well 2 in 1974;
B, measured and simulated pumpage from Texas Brine Corp. water wells 1-3. Measured water levels reflect day-to-day variations in rate of pumping from these nearby wells. Both measured and simulated water levels are affected by prolonged pumping of water well 4 (fig. 13). Pumpage from wells 1 and 3 is simulated at average rates that incorporate measured pumpage from well 2 on September 16.

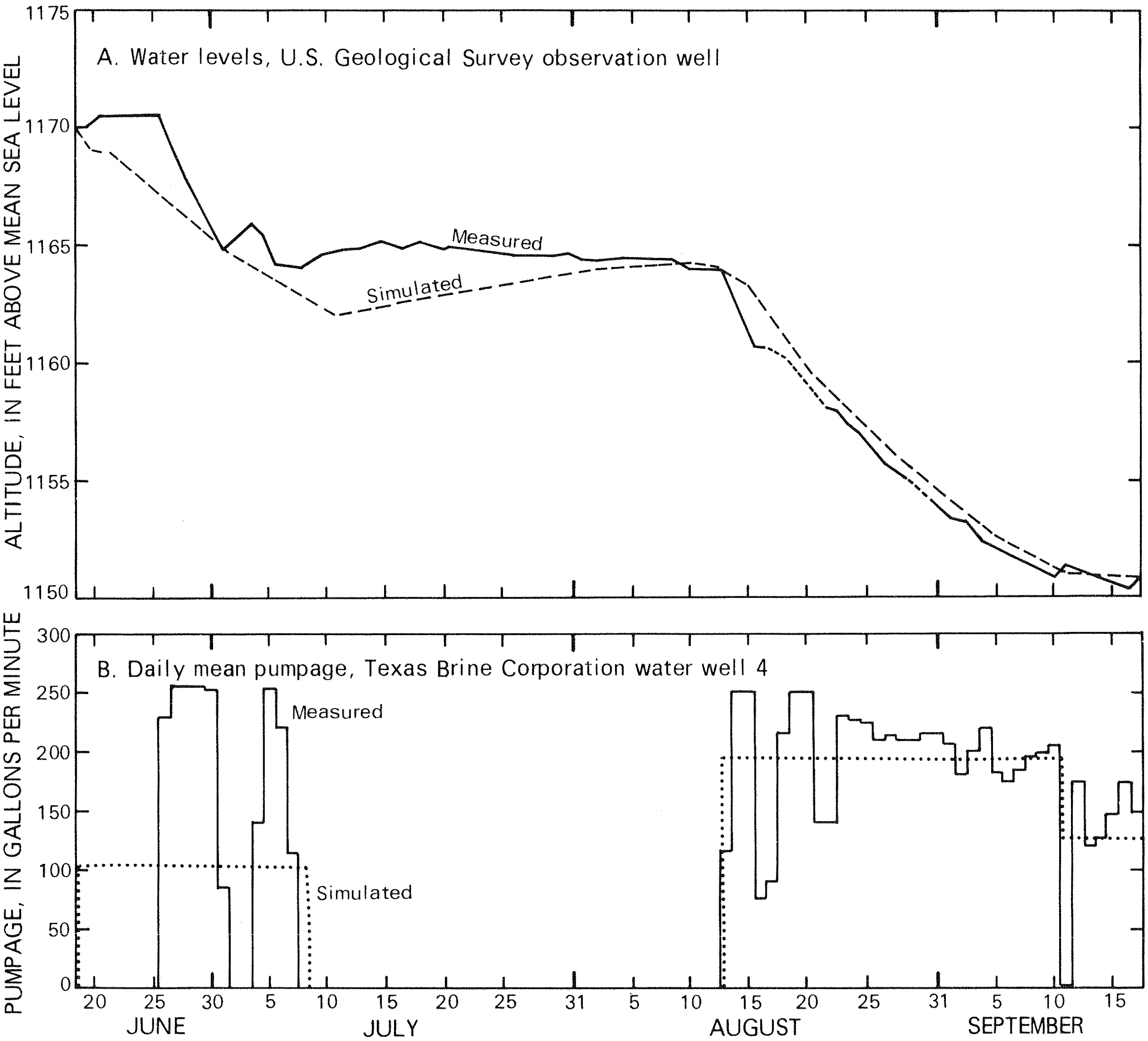


Figure 13.--A. Measured and simulated water levels at U.S. Geological Survey observation well in 1974; B, measured and simulated daily mean pumpage at Texas Brine Corp. water well 4, nearby.

Another transient simulation used in calibrating the model was designed to reproduce pumpage and water-level changes that were recorded in May 1970 during an aquifer test. Simulated water levels at various times (table 3) were reasonable but did not match observed water levels as closely as in the 1974 simulation--the model responded to stress more slowly at first, later more rapidly, than the real aquifer.

One result of the calibration process was a map showing calculated transmissivity values throughout the Dale Valley aquifer (fig. 14). Where transmissivity is high, wells are more productive than elsewhere, at least during short periods of pumping. Although the interpretation shown in figure 14 resulted in more accurate calibration than other versions tested, it could undoubtedly be altered somewhat and still conform equally well to all available data. Therefore, test drilling would be necessary to determine yields actually available in areas interpreted to be favorable for productive wells.

Relation of the Model to Fluctuations in Climate

It is important to consider what part of the range of possible hydrologic conditions is represented by the model. Unfortunately, there is little evidence to indicate whether recharge to the Dale Valley aquifer or volume of water stored in the aquifer differ much from year to year as a result of differences in precipitation or other climatic factors. In any case, the model should represent conditions similar to those in 1974 because calibration was based chiefly on data from that year, and the position of that year in the long-term range of climatic fluctuation can be evaluated.

A brief but remarkable hydrologic event on June 21, 1974, just after the start of the observation period used for model calibration, may have led to above-normal recharge. Heavy thundershowers passed through Wyoming County, left 1.15 inches of rain at a gage on Sage Road, just south of Dale, and probably left much more near Pflaum Gulf and Dusing Gulf. Tributary streams became torrents, spilled over the railroad and over Dale Road in several places, washed out the bridge below Pflaum Gulf, and spread several feet of water over low areas on the valley floor. Erosion and redeposition of gravel were spectacular on alluvial fans immediately below Pflaum and Dusing Gulf and were noticeable along other streams. One result was probably an increase in streambed permeability near the heads of the alluvial fans, hence greater aquifer recharge there during the summer. Shallow wells owned by C. Pflaum and R. Smith near the heads of two alluvial fans (fig. 3) showed little or none of the usual decline in water level that summer (table 7), and Mr. Pflaum reported in August that the water level in his well had never been higher at that time of year.

Other observations, described on page 42, also suggest that the amount of water stored underground in Dale Valley was above average during the summer of 1974.

Table 3.--Calibration of model under transient conditions, May 4-30, 1970

Well owner and well number[1]	Location (model cell)[2]	Water level, in feet above mean sea level[3]: May 4 (Start) Meas-ured	May 4 (Start) Simu-lated	May 11-12 (after 7.5 days) Meas-ured	May 11-12 (after 7.5 days) Simu-lated	May 22 (Shutdown) Meas-ured	May 22 (Shutdown) Simu-lated	May 30 Meas-ured	May 30 Simu-lated
TBC TW4	9, 10	1111+	1118.0	1111+	1110.4	1105	1102.6	1111+	1105.6
TBC WW3[4]	16, 10	1123+	1124.4	1025	1028	1021.5	1013	1113	1102.7
TBC WW2	18, 10	1126+	1127.0	1080	1071.0	1073	1054.9	1115	1104.2
TBC WW1[4]	20, 10	1127+	1127.6	1026	1026	1020	1010	1118	1106.2
H. Perry[5]	24, 21	[6]1138.5+	1143.0	1132	1142.7	[7]1125	1137.2	--	1136.8
TBC TW11[8]	25, 17	1133.5+	1141.5	1132.5	1133.4	1126.5	1122.8	1133.5+	1127.2

1/ TBC, Texas Brine Corp.; TW, test well; WW, water well
2/ Row number is given first, column number second; see model grid, figure 11
3/ Where followed by +, well was overflowing at that altitude
4/ Pumped at 250 gallons per minute, May 4-22 (18 days)
5/ Well finished in bedrock
6/ Measured May 7
7/ Estimated
8/ Test well at site of Texas Brine Corp. water well 4

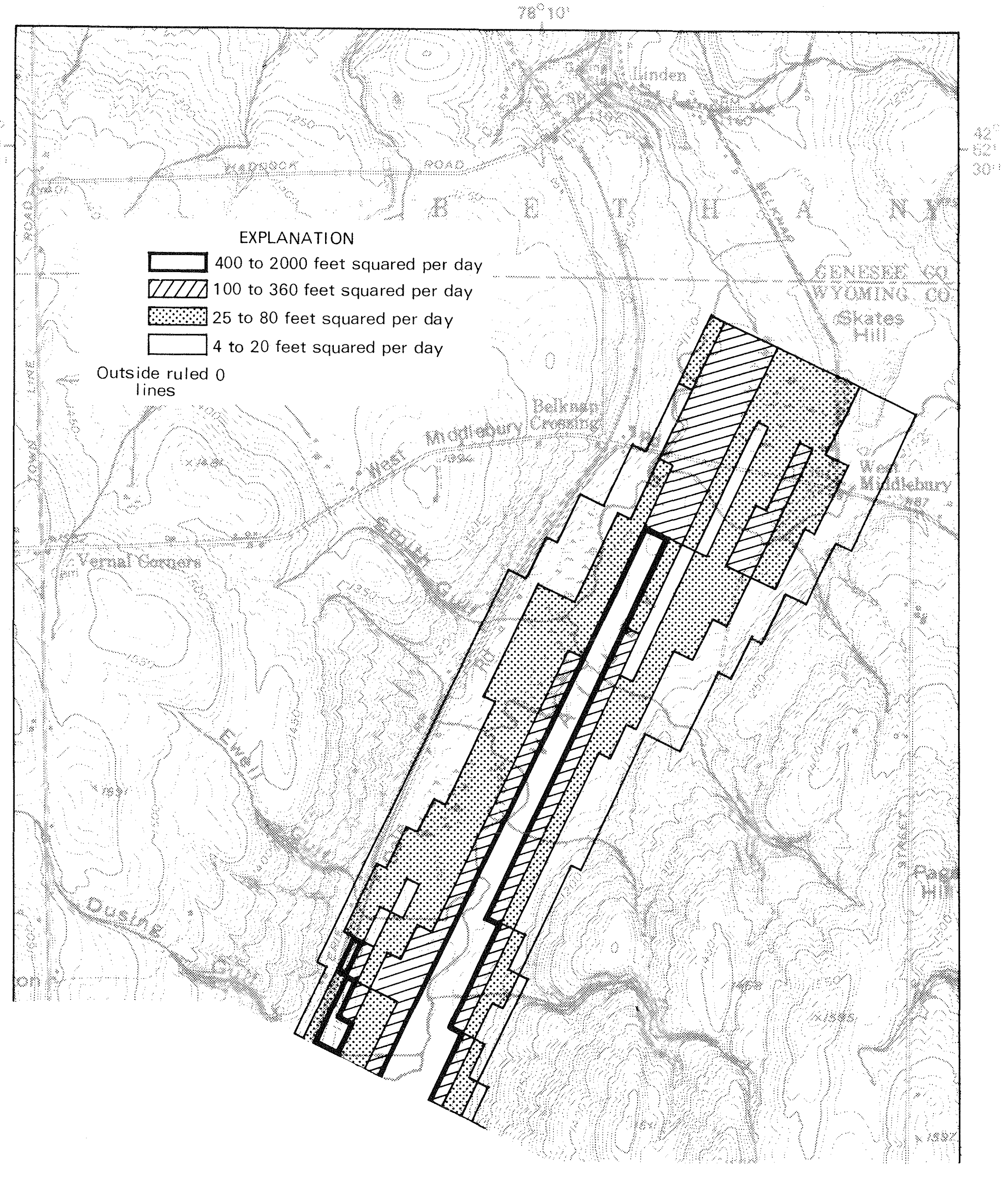
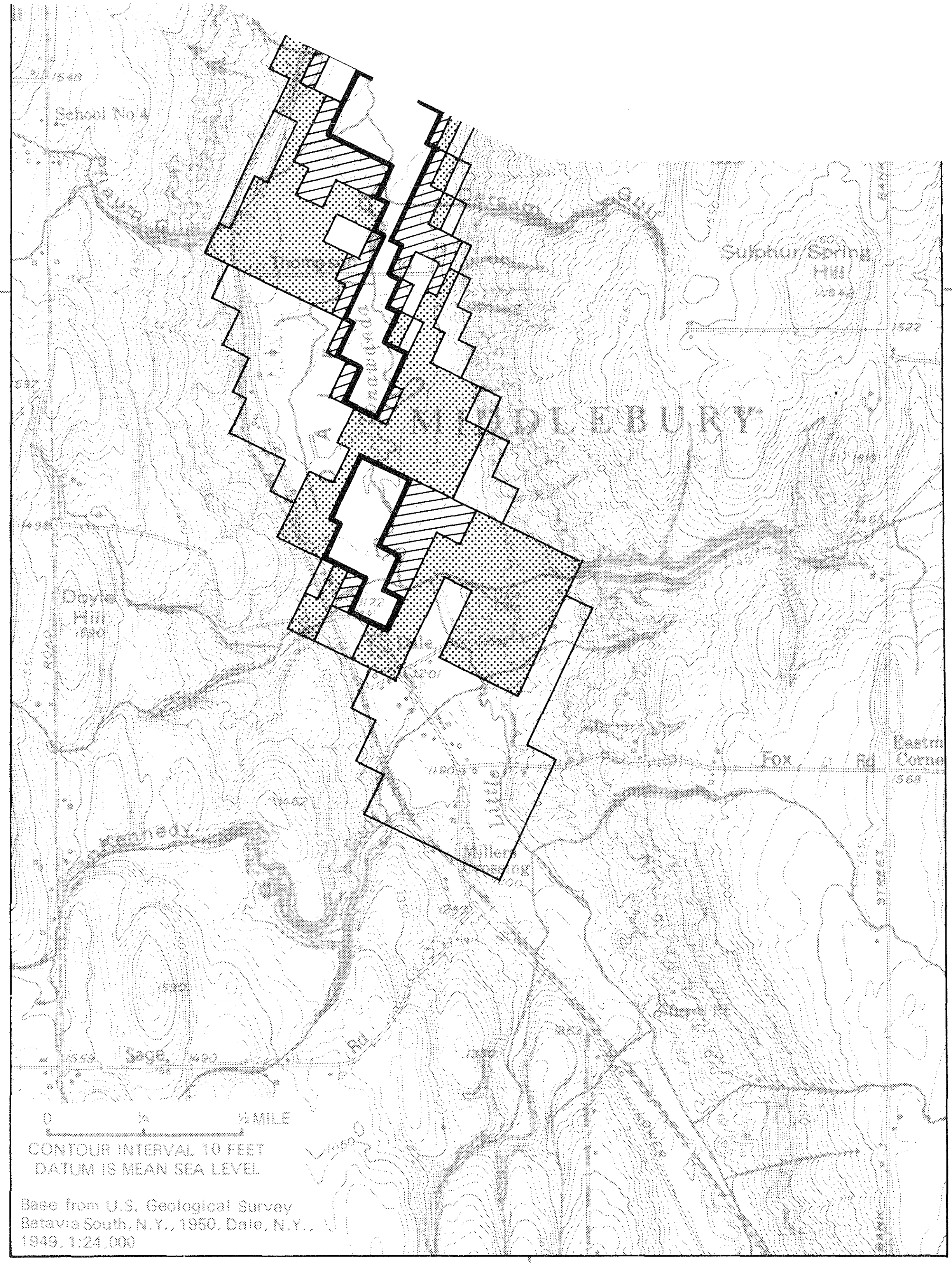


Figure 14.--Transmissivity of the Dale Valley aquifer as used in the digital model.


School No 4
Sulphur Spring Hill
42°
50'
MIDDLEBURY
Doyle Hill
Fox Rd
Eastm
Corne
Kennedy
Little
Millers Crossing
Sage
Rd
0
½ MILE
CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL
Base from U.S. Geological Survey
Batavia South, N.Y., 1950, Dale, N.Y.,
1949, 1:24,000
78°10'

1. Total flow of Tonawanda Creek at Batavia from June through September was larger in 1974 than in 23 of the previous 30 years. More than one-third of the 1974 summer total consisted of surface runoff from the unusual storm of June 21, but even if runoff from this storm were disregarded, flow during these 4 months would have been larger in 1974 than in 18 of the previous 30 years.

2. In a shallow well near Gainesville, Wyoming County (fig. 1), water levels from June through September were higher in 1974 than in 8 of the previous 10 years (1964-65 levels being estimated). However, the margins were slight for some years, and the 1974 hydrograph was close to the 1966-73 median (fig. 15B).

3. In a shallow well near Pavilion, Genesee County (fig. 1), water levels from June through September were higher in 1974 than in 19 of the previous 20 years (fig. 15A).

All the above observations reflect principally near-surface conditions and may not be an accurate measure of recharge to or storage in the deeply buried Dale Valley aquifer in 1974 as compared with other years, but they suggest that summer recharge was probably in the upper third of its natural range in 1974. Therefore, the model, as calibrated, would probably not underestimate yields obtainable in wet years but might overestimate for dry years.

Potential Aquifer Yield

About 42 million gallons of water was withdrawn from the Dale Valley aquifer by Texas Brine Corp. over 3 months in the summer of 1974 without seriously affecting well yields. However, persons concerned with the future of Dale Valley have questioned whether increased stress on the aquifer would cause critical problems. For example, what if demand for water by Texas Brine Corp. were to increase substantially? Or, what if the 1974 demand were maintained in a very dry year such as 1964? If a new industry were considering a site in Dale Valley and needed a substantial water supply, or if a major recreational development or a public water supply for Dale were proposed, how much water could be obtained, and where? Reasonable answers to questions such as these may be obtained by simulating any proposed withdrawal with the digital model. If the proposed hydrologic conditions differ from those under which the model was calibrated, adjustments to the model may be necessary.

How Much of the Future Demand must be Supplied from the Dale Valley Aquifer?

As previously explained, the water required by Texas Brine Corp. can generally be obtained from Little Tonawanda Creek, but when creek flow is inadequate or one of the creek pumps is broken down, water must be obtained from wells tapping the Dale Valley aquifer. Accordingly, to determine how much water must be withdrawn from the aquifer to meet any proposed demand by Texas Brine Corp., the first step is to estimate how much of that demand could be met from Little Tonawanda Creek and for how long. Such an estimate requires knowledge of the variation in creek flow.

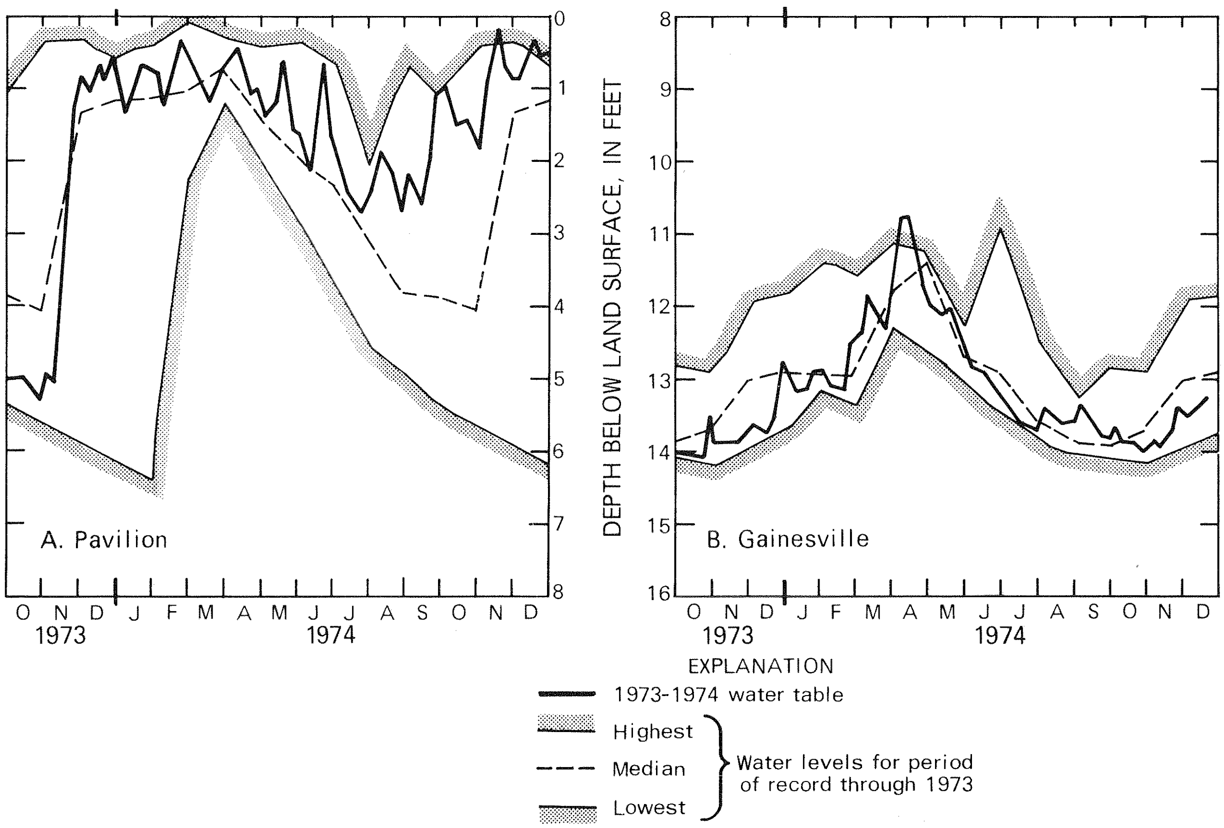


Figure 15.--Comparison of water levels in 1973-74 with those of previous years in two observation wells near Dale Valley. (Locations of Pavilion and Gainesville are shown in figure 1).

A. Dug well in till, lined with fieldstone, depth 21 feet. Near Pavilion, Genesee County; records began in 1954.

B. Drilled well in gravel and sand, cased to 18 feet, depth 21 feet. Near Gainesville, Wyoming County; records began in 1966.

Variation in flow of Little Tonawanda Creek from day to day was recorded at Linden, immediately downstream from Dale Valley, at a Geological Survey gaging station maintained from 1912 through 1968. The data have been published (U.S. Geological Survey, 1976, and earlier reports listed therein) and have been evaluated as part of a regional analysis of streamflow (Harding and Gilbert, 1968). In this basin, storm runoff should vary from one place to another nearly in proportion to drainage area. Excluding storm runoff, streamflow is derived largely from ground water seeping out of sand and gravel along the valleys and varies from place to place in proportion to the area of sand and gravel (Ku and others, 1975). The area drained by Little Tonawanda Creek upstream from Texas Brine Corp. water well 3 is 71 percent of the area drained at Linden, and the area of sand and gravel upstream from water well 3 is about 55 percent of that at Linden. Flow of Little Tonawanda Creek at the Texas Brine Corp. well field could be estimated by classifying measured flows at Linden as storm runoff or ground-water discharge, then applying the percentages noted above to the respective fractions. In this report, however, a simplified approximation was used in which flow at the well field was considered to be 65 percent of flow greater than 2 cubic feet per second at Linden and 60 percent of flow less than 2 cubic feet per second at Linden.

During periods of low flow, Texas Brine Corp. has limited its rate of withdrawal from Little Tonawanda Creek to allow at least a small flow to pass downstream. In August 1974, flow measurements in Little Tonawanda Creek (U.S. Geological Survey, 1975) were made on two dates when withdrawals were limited for this reason. On both dates, the flow immediately downstream from the well field was about 0.5 cubic foot per second. Accordingly, calculations in this report assume that 0.5 cubic foot per second will be allowed to pass at all times and that any excess flow will be available to meet Texas Brine Corp. demand.

In this report, the yield of the Dale Valley aquifer is predicted for a moderately wet year and for an unusually dry year. Average streamflow during various numbers of consecutive days of lowest flow have been compiled for each complete year of record at the gaging station at Linden. If the 183-day low flow is used as an index of sustained low flow, the driest year in 53 complete years of record was 1960 (183-day average flow of 0.67 cubic foot per second at Linden) and the second lowest was 1941 (183-day average flow of 0.77 cubic foot per second at Linden). Records for 1941 were selected to represent a dry year; therefore, the flows analyzed should have an average recurrence interval of 27 years (which means that one year in 27, on the average, would have sustained low flows at least this low). The daily flows at Linden during 1941 were (1) grouped into classes on the basis of magnitude, (2) multiplied by 0.6 or 0.65 to estimate flows at the Texas Brine Corp. well field, (3) reduced by the 0.5 cubic foot per second allowed to pass downstream, and (4) averaged to obtain average usable creek flow for the number of days in each class. The average usable flows were then subtracted from postulated Texas Brine Corp. demand to determine the additional amount of water that would have to be pumped from the aquifer during the number of days in each class to meet the demand. Results are given in table 4.

Table 4.--Duration and magnitude of withdrawals from Dale Valley aquifer needed as a supplement to creek flow to meet various postulated demands during a moderately wet year and a dry year

[Creek flows and withdrawals from aquifer are in cubic feet per second]

Little Tonawanda Creek		Moderately wet year (1968)			Dry year (1941)		
			Withdrawal from aquifer needed for number of days listed			Withdrawal from aquifer needed for number of days listed	
Selected classes of daily mean flow at Linden	Average estimated flow available for use at well field	Number of days that creek flow was within range in left column	For demand of 1,000 gallons per minute[1/]	For demand of 750 gallons per minute[2/]	Number of days that creek flow was within range in left column	For demand of 1,000 gallons per minute[1/]	For demand of 500 gallons per minute[3/]
Less than 0.8	0	11	2.23	1.67	111	2.23	1.11
0.8-1.0	0.05	30	2.18	1.62	36	2.18	1.07
1.1-1.5	0.3	49	1.93	1.37	30	1.93	0.83
1.6-2.0	0.6	17	1.63	1.07	11	1.63	0.53
2.1-2.5	1.0	6	1.23	0.67	12	1.23	0.13
2.6-3.0	1.3	7	0.93	0.37	8	0.93	None
3.1-4.1	1.8	9	0.43	None	9	0.43	None
More than 4.1	2.23 or more	237	None	None	148	None	None

1/ 2.23 cubic feet per second
2/ 1.67 cubic feet per second
3/ 1.11 cubic feet per second

Most aquifer data were collected in 1974, which was a moderately wet year (as explained in the section "Relation of the model to fluctuations in climate"). Average usable flow of Little Tonawanda Creek in 1974 could not be estimated from current records at Linden because the gage there had been discontinued. However, a Geological Survey gage several miles downstream on Tonawanda Creek at Batavia had functioned from 1944 through 1974. Calculation of mean flow at Batavia for June through September of each year, as well as comparison of individual monthly flows, showed that 1974 was more nearly similar to 1968 than to any year since 1944, at least during the summer. Therefore, daily flows at Linden during 1968 were used in the same manner as those during 1941 to estimate the amount of water that would have to be pumped from the Dale Valley aquifer to meet postulated total demand by Texas Brine Corp. in a moderately wet year (table 4).

Use of the Digital Model for Prediction

The procedure for using the digital model to predict whether a proposed demand for water can be met by pumping the Dale Valley aquifer is easily explained:

1. Distribute the proposed demand among present and proposed wells.

2. Set the computer to simulate the number of days during which withdrawal is expected.

3. Examine the water-level distribution predicted by the model. If some water levels are unacceptably low, change the proposed rates of withdrawal or the locations of proposed wells and repeat the procedure.

To understand or interpret model predictions, however, answers to two questions must be provided: (1) What are the minimum acceptable water levels? and (2) how can the model represent aquifer response to pumping in both wet and dry years?

Criteria for acceptable water levels.--In this report, the lowest acceptable water level is defined as the top of the screen at industrial wells, the top of the aquifer at proposed industrial or other large-capacity wells, and 10 feet above the bottom of domestic wells. Conventional practice in designing and operating large-capacity wells is to keep the water level above the well screen; greater drawdown may accelerate plugging of the screen or the gravel envelope. New large-capacity wells would probably be designed with the top of the screen just below the top of the aquifer, as in present wells. Most domestic wells tapping the Dale Valley aquifer or bedrock beneath the valley floor are productive enough that normal intermittent operation of the owner's pump does not lower the water level by as much as 10 feet. However, if static water levels were only about 10 feet above the bottoms of these wells, the owner might have to spread out periods of heavy water use (such as for laundry or watering stock) over longer time intervals to avoid "sucking air."

Some readers may wish to reevaluate model predictions using different criteria. If it were acceptable to let wells at a few homes go completely dry and to supply these homes by a public water system or in some other way, a greater predicted yield could be obtained from the Dale Valley aquifer as a whole. Alternatively, it could be argued that minimum water levels should be higher than those defined in this report to minimize any risk of problems. For example, the model does not simulate head loss due to turbulence and restricted flow near the well screen; such loss, which varies according to the square of the pumping rate, the efficiency of well design, and any plugging of the screen, could be estimated and allowed for by requiring slightly higher minimum water levels at large-capacity wells. A minimum of 10 feet of water in a domestic well might seem acceptable if it were reached only near the end of infrequent droughts, but not if it became a regular condition.

Modifying the model to simulate drought: Streamflow analysis has shown that, to meet a constant demand by Texas Brine Corp., withdrawals from the Dale Valley aquifer would have to be greater in a dry year than in a moderately wet year. This difference in rate of withdrawal is easily simulated. However, it is not known whether aquifer response to any particular rate of withdrawal might be significantly different in a dry year than in the moderately wet period to which the digital model was calibrated, because aquifer response has not been measured over a range of climatic conditions. The deeply buried Dale Valley aquifer should be much less sensitive than the shallow alluvial aquifer to variations in precipitation from one year to the next; accordingly, the Dale Valley aquifer model does not incorporate any way to directly simulate variation in recharge. Nevertheless, for this report it seemed prudent to make two changes in the model when simulating withdrawals in an unusually dry year such as 1941:

1. The simulated water table was lowered by an average of 2 feet below its position in September 1974. Near Little Tonawanda Creek north of Thompson Road, a decline of only 1 foot was simulated, but at some cells along the sides of the valley and on alluvial fans, declines of 3 to 5 feet were simulated. The declines were estimated from records of wells tapping shallow sand and gravel. This change in the model is a reasonably accurate representation of what would actually happen during a drought, and its effect is to gradually lower water levels by 2 to 3 feet throughout the simulated Dale Valley aquifer.

2. The hydraulic conductivity of the confining layer was reduced to 0.004 foot per day at all valley-side cells that had been assigned higher values in the 1974 data array. The capacity of earth materials to transmit water would not actually decline during a drought; however, small tributary streams that ordinarily provide recharge near the valley sides would dry up, and the easiest way to simulate the cessation of streambed recharge is to reduce the average simulated water-transmitting capacity of the intervening sediment in the appropriate cells. The effect of this change in the model is to gradually lower

simulated water levels in the deep aquifer by about 14 feet near the south end of the valley, but by only about 0.5 foot near the north end, where hydraulic conductivities were not as high in the 1974 data array. This change in the model is of questionable validity, but the resulting large change in water level is probably conservative and provides a margin of safety in prediction.

Predicted Yield of the Aquifer

Several postulated or hypothetical demands upon the Dale Valley aquifer were simulated by means of the digital model to answer questions raised during this study and to illustrate the potential yield of the aquifer. Each simulation is described briefly below.

The average demand for water by Texas Brine Corp. in late 1974 was 500 gallons per minute. If this were doubled in a moderately wet year, such as 1968, increased ground-water withdrawals would be required, as estimated in table 4. Measurements in 1974 suggested that such large sustained withdrawals could not be met from the four production wells in use at that time. Accordingly, two additional wells were postulated in the area of high transmissivity north of the four wells. Resulting drawdowns (table 5, simulation 1) exceeded acceptable limits at most wells.

A usual remedy for excessive drawdown at production wells is to pump the wells at smaller rates and to drill more wells some distance away to make up for the reduction in total withdrawal. Accordingly, a second simulation was designed that incorporated the same demand but postulated five rather than two new production wells north of the 1974 well field. The simulated wells were about 1,000 feet apart and were pumped at modest rates. Resulting water levels (table 5, simulation 2) were generally higher than in the previous simulation but were still unacceptably low at most wells. In summary, the model predicts that even in a moderately wet summer such as 1968, a demand of 1,000 gallons per minute by Texas Brine Corp. could not be sustained by any reasonable number and arrangement of production wells tapping the Dale Valley aquifer between Thompson Road and West Middlebury Road without causing excessive drawdowns at most production wells and failure of some domestic wells.

Because results of the first two simulations were not acceptable, conditions in 1968 were simulated again, this time assuming a demand of only 750 gallons per minute by Texas Brine Corp. and postulating two new production wells, one south and one north of the 1974 well field. The model predicted that only at one domestic well would drawdown slightly exceed acceptable limits for a brief period (table 5, simulation 3).

Finally, the model was modified to represent conditions during a dry year, in the manner previously described. This time, a year-round withdrawal of 100 gallons per minute was simulated about 2,000 feet north of Dale (model cell 31, 24). Because that withdrawal was represented as continuous, simulated water levels in the well stabilized at an altitude of 1,081 feet before the simulated Texas Brine Corp. withdrawals began in early summer. Demand by Texas Brine Corp. was postulated to be only 500 gallons per minute, about the same as in 1974, because it was expected that drought conditions and competing withdrawals would not allow a larger demand to be met. The duration and rates of ground-water withdrawal required to meet that demand under 1941 drought conditions are estimated in table 4. The model predicted that the water level in the postulated year-round well north of Dale would reach a minimum altitude 3 feet below the estimated top of the aquifer and that the water level in one domestic well would fall a similar distance below acceptable limits (table 5, simulation 4). However, these two excesses are small enough to be corrected by slight, temporary cutbacks in pumping and would be experienced only one year out of 27, on the average. In summary, the demand postulated in column 4 of table 5 could generally be met even during a severe drought, although temporary problems would be likely at a few wells.

The four simulations described above and in table 5 give a fairly complete picture of the potential yield of the Dale Valley aquifer. However, other proposed development schemes could also be tested on the model. The digital computer program and data arrays that make up the Dale Valley aquifer model will be kept on file at the U.S. Geological Survey office in Albany, N.Y., for several years and can be made available to those who wish to use the model or to modify it in accordance with new data.

YIELD OF THE ALLUVIAL AQUIFER

As long as the alluvial aquifer is used only to supply scattered domestic wells, the question of potential aquifer yield is academic because withdrawals would be insignificant. However, the aquifer could be used to provide an industrial, agricultural, or community water supply if several shallow, large-diameter wells were pumped as a unit. To obtain maximum yield from the alluvial aquifer, a line of dug wells (or infiltration galleries) would be needed along Little Tonawanda Creek in the northern reaches of Dale Valley near West Middlebury Road, although similar wells upstream along the creek could be used to extract part of the yield if that were more convenient. Pumping from such wells would soon reduce creek flow by the amount pumped, either by causing water in the creek to infiltrate the channel bottom or by capturing water that would have seeped into the creek. The chief advantage of pumping wells rather than pumping directly from the creek is that the water would be clear, filtered, and more uniform in temperature. If zero flow in Little Tonawanda Creek were acceptable, aquifer yield during critical low-flow periods would be slightly greater than minimum creek flow, which has averaged as low as 160 gallons per minute over periods of 60 days in 4 of the 54 years of record at Linden. A more refined estimate, which

Table 5.--Predicted minimum water levels resulting from different simulated pumping rates during dry and moderately wet years

[Demands and pumping rates are in gallons per minute; water levels are in feet above mean sea level]

	Well present in 1974 (if any) 1/	Model cell 2/	Lowest acceptable water level: Altitude	Lowest acceptable water level: Criterion 3/	Moderately wet year (1968), Simulation 1 (TBC demand 1,000): Pumping rate 4/	Moderately wet year (1968), Simulation 1 (TBC demand 1,000): Minimum water level 5/
1	Parsonage, W. Middlebury	3, 21	1067	BW	--	1115.4
2	TBC TW8D	6, 10	1015	TA	--	1068.2
3	-	6, 11	1015	ETA	--	1068.3
4	-	8, 11	1023	ETA	--	1028.2
5	TBC TW4	9, 10	1023	TA	--	*1001.7*
6	-	9, 11	1023	ETA	157	*959.3*
7	-	10, 11	1019	ETA	--	*1003.2*
8	-	12, 11	1010	ETA	--	*990.6*
9	-	13, 11	1005	ETA	180	*952.2*
10	-	14, 11	1000	ETA	--	*985.9*
11	TBC WW3	16, 10	987	TS	157	*966.2*
12	R. Dusing	17, 4	1097	BW	--	*1062.1*
13	TBC WW2	18, 10	1003	TS	112	*979.0*
14	TBC office	19, 6	1080	BW	--	*1070.0*
15	G. Dersam	20, 6	1101	BW	--	*1093.9*
16	TBC WW1	20, 10	1008	TS	157	*972.4*
17	H. Perry	24, 21	1080	BW	--	*1071.1*
18	TBC WW4	25, 17	980	TS	224	*953.2*
19	USGS	30, 22	1040	TA	--	1138.3
20	-	31, 24	1055	ETA	--	1145.9
21	Dale Cemetery	32, 30	1130	BW	--	1178.3
22	P. Dieter	34, 27	1103	BW	--	1161.5
23	R. Van Dusen & C. Austin	35, 31	1113	BW	--	1182.9

1/ TBC, Texas Brine Corp.; TW, test well; WW, water well; USGS, U.S. Geological Survey.
2/ Row number followed by column number (see model grid, fig. 11).
3/ BW, 10 feet above bottom of well; TA, top of aquifer; ETA, estimated top of aquifer; TS, top of screen.

Table 5.--Predicted minimum water levels resulting from different simulated pumping rates during dry and moderately wet years (Continued)

	Moderately wet year (1968)				Dry year (1941)	
	Simulation 2 (TBC demand 1,000)		Simulation 3 (TBC demand 750)		Simulation 4 (TBC demand 500; other demand [6] 100)	
	Pumping rate[4]	Minimum water level[5]	Pumping rate[4]	Minimum water level[5]	Pumping rate[4]	Minimum water level[5]
1	--	1114.8	--	1115.7	--	1113.2
2	--	1031.3	--	1087.4	--	1086.7
3	67	*1007.5*	--	1087.5	--	1086.8
4	90	*986.8*	--	1067.2	--	1070.3
5	--	*1010.2*	81	1024.0	--	1054.6
6	--	*1009.7*	--	1048.4	112	1024.3
7	67	*983.0*	--	1052.6	--	1063.7
8	90	*979.9*	--	1052.6	--	1072.0
9	--	*995.6*	130	1016.2	--	1072.1
10	90	*982.1*	--	1042.3	--	1070.2
11	112	*984.2*	90	1035.6	81	1052.2
12	--	*1067.8*	--	*1094.0*	--	*1094.1*
13	135	*986.5*	--	1054.5	--	1059.3
14	--	*1075.5*	--	1098.8	--	1095.2
15	--	*1097.9*	--	1113.3	--	1104.5
16	112	*993.1*	126	1028.7	153	1024.0
17	--	*1074.9*	--	1086.2	--	1088.0
18	224	*958.7*	202	980.7	148	1007.0
19	--	1139.5	--	1086.4	--	1079.8
20	--	1146.9	108	1057.4	100	*1051.9*
21	--	1178.6	--	1163.6	--	1156.9
22	--	1162.2	--	1127.9	--	1119.1
23	--	1183.0	--	1178.4	--	1175.0

4/ Rates are the maximum required (during part of year simulated) to supply whatever part of postulated Texas Brine Corp. demand cannot be obtained from Little Tonawanda Creek, as shown in table 4, and to supply the other demand postulated in simulation 4; pumpage at individual homes is too small to simulate.

5/ Well loss in pumped wells not included; numbers in italics are below lowest acceptable water level.

6/ Continuous withdrawal year-round, simulated at model cell 31, 24.

would take into account seasonal changes in streamflow and the modest storage capacity of the aquifer, does not seem warranted until there is serious interest in constructing a system of dug wells to obtain maximum yield from the alluvial aquifer and until a few such wells are tested to evaluate aquifer properties.

If leakage from the alluvial aquifer is the principal source of recharge to the deeper Dale Valley aquifer, large-scale withdrawal from the Dale Valley aquifer should lower water levels and yield in the alluvial aquifer. Crain (1966) showed that water levels in alluvial fans along the sides of Cassadaga Valley near Jamestown, N.Y., were affected by pumping from the Jamestown aquifer, an extensive sand-and-gravel layer buried beneath silt and clay. During the summer, water levels near the head of a large alluvial fan near Jamestown declined to a lower altitude than water levels near the periphery of the fan, which indicated that ground water flowed toward some point near the valley wall where it could drain readily downward through sand and gravel to recharge the deeper, pumped aquifer. A similar flow pattern may prevail in Dale Valley inasmuch as the geologic setting of the Dale Valley aquifer resembles that of the Jamestown aquifer.

Water levels were measured regularly on one alluvial fan near the center of pumping in Dale Valley; the measurements (fig. 16) show that water in the alluvial aquifer near the Dersam wells drained eastward toward Little Tonawanda Creek throughout the spring and summer and, after late July, also drained downward to the Dale Valley aquifer. The Dersam drilled well taps gravel at depths between 47 and 56 feet and was affected by pumping in the Dale Valley aquifer, as shown by the steep water-level decline after late June. The nearby Dersam dug well is 29 feet deep; its rate of decline was no steeper after continuous pumping from the Dale Valley aquifer began than before. However, its net seasonal decline in 1974 was greater than measured in any other dug well in Dale Valley and apparently was also greater than would have occurred under natural conditions because the well rarely if ever went dry prior to local industrial pumping.

From figure 16 and from measurements summarized in table 7, it seems that dug wells penetrating the alluvial aquifer near the center of Dale Valley have seasonal water-table fluctuations ranging from 2 to 4 feet that are not greatly affected by withdrawals from the Dale Valley aquifer. If the Dale Valley aquifer is pumped chiefly in the summer, the water table near the sides of the valley may fluctuate 5 to 15 feet seasonally, with the largest fluctuations on alluvial fans near the center of pumping. Where fluctuations are large, shallow wells would decline greatly in yield in late summer.

The alluvial aquifer as a whole may be considered as a source of moderately large water supplies. It is generally independent of the Dale Valley aquifer but is interconnected with the stream system. Withdrawals from the Dale Valley aquifer would have little effect on yield of the alluvial aquifer during periods of excess streamflow but might cause periods of low streamflow and minimum yield from the alluvial aquifer to be longer and more severe than normal. Thus, the alluvial aquifer could be used to supplement yields from the Dale Valley aquifer, but only in the same way streamflow has been used by Texas Brine Corp.--by withdrawing water from the alluvial aquifer (or from the stream) during periods of excess streamflow and relying on the Dale Valley aquifer when streamflow is minimal.

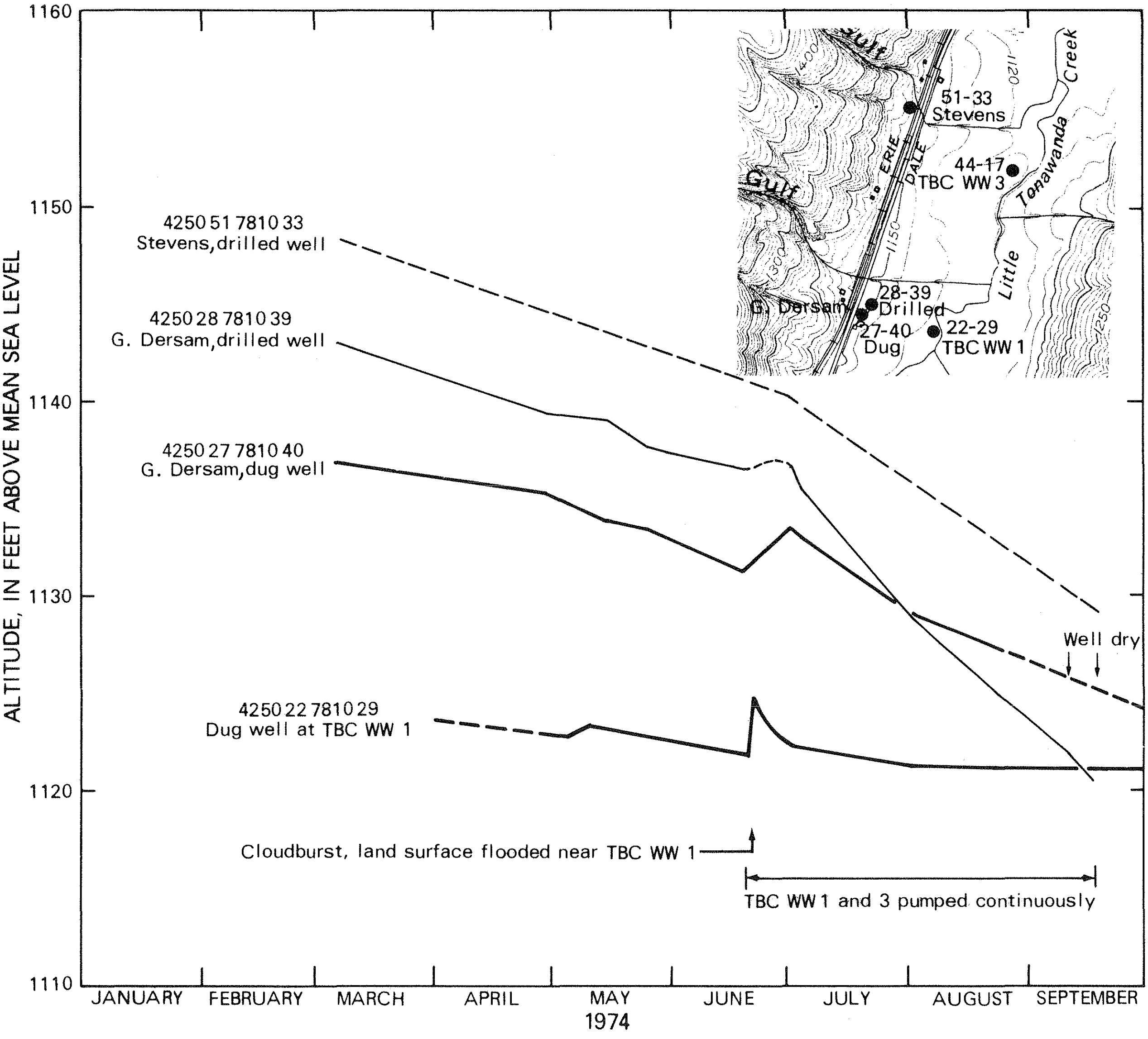


Figure 16.--Water levels in wells on an alluvial fan below Dusing Gulf in 1974. TBC, Texas Brine Corp.; WW, water well.

QUALITY OF GROUND WATER

General Quality

The information available on chemical quality of ground water in Dale Valley (table 6) is chiefly from the deeper wells. Specific conductance is generally at least 320 micromhos per centimeter, which suggests that dissolved-solids concentrations generally exceed 180 mg/L (La Sala, 1968, table 8). Most of the water sampled would be classified as hard to very hard by the U.S. Geological Survey (Durfor and Becker, 1964). Such terms are to some extent relative, but water with a hardness greater than 120 mg/L is commonly softened for home use to increase the efficiency of soap and to reduce development of mineral scale in pipes or containers in which water is heated. Many analyses did not include all individual constituents in table 6, but those constituents that were determined were generally below the limits recommended by the U.S. Public Health Service (1962) and by the National Academy of Science and National Academy of Engineering (1973) for drinking water, except for iron. Water containing more than about 0.3 mg/L of dissolved iron, although not a hazard to health, has a metallic taste and, when exposed to, air develops an orange-brown iron precipitate that stains laundered clothes and plumbing fixtures. Chloride exceeded recommended limits in a few wells and is discussed subsequently. Water from most shallow wells and springs in Dale Valley probably contains lower concentrations of dissolved constituents than water from the wells listed in table 6.

Many of the deep wells in Dale Valley, particularly those penetrating bedrock near Dale, exhibit a characteristic water-quality pattern--abundant natural gas, iron concentrations much greater than 0.3 mg/L, and sulfate concentrations below the range of 5 to 20 mg/L typically measured in precipitation (Archer and others, 1968, p. 12). This pattern is common in deep wells in this part of New York (La Sala, 1968, p. 60) and indicates the absence of oxygen in the water. Under such conditions, sulfate is reduced on contact with methane to hydrogen sulfide or insoluble metal sulfides, and iron is moderately soluble, as explained by Hem (1970, p. 120, 170; 1960).

Chloride

Chloride concentrations between 5 and 25 mg/L are typical of water from most wells in Dale Valley (table 6). There are several exceptions, however.

Three wells drilled into bedrock at widely separated points low on the sides of Dale Valley, all more than 165 feet deep, yielded salty or highly mineralized water and were plugged back or abandoned (table 7). One of these yielded water containing 8,700 mg/L chloride (table 6). Salty water is present below some depth in bedrock throughout western New York, and records elsewhere (Crain, 1974; Randall, 1972) show that the depth to salty water is greater in uplands than in valleys.

Two wells finished at the top of bedrock near Dale yield water containing 50 and 310 mg/L of chloride (table 6), which is somewhat above the typical values but satisfactory to the owners. The exact cause of this anomaly is not known, but apparently migration of water upward from deep in the bedrock is more rapid near these wells than at other places nearby.

In two wells tapping the Dale Valley aquifer, chloride concentration and specific conductance were slightly above typical values and showed pronounced changes during the summer of 1974. In Texas Brine Corp. water well 4, chloride concentration increased from 5 to 36 mg/L. Meanwhile, chloride decreased from 45 to 15 mg/L in a well 700 feet to the east that supplied the Howard Perry residence. Changes in specific conductance paralleled the changes in chloride. The changes at each well could be explained in terms of chloride concentration increasing with depth. At water well 4, which was pumped at 150 to 250 gallons per minute for 44 days between June 26 and September 17, 1974, water originally below the bottom of the well may have migrated upward in response to a drawdown that occasionally exceeded 100 feet. Pumpage from Perry's well was only a few hundred gallons per day, but the water level declined 38 feet during the summer as a result of pumping elsewhere; consequently, water with 45 mg/L chloride that was at the lower part of the well in March may have subsided to deeper levels in the aquifer. If this hypothesis is correct, comparison of well depths and relative altitudes (table 7) indicates that water of 45 mg/L chloride must have been at least 105 feet higher in altitude in the spring of 1974 at Perry's well, near the side of the valley, than at water well 4--which is not what would be expected from the regional-flow model proposed by La Sala (1968, p. 61). Because water was moving through the aquifer past Perry's well toward water well 4, other hypothetical distributions of mineralized water could be invoked to explain the observed changes. One possible source of chloride is the unused well at Perry's house (table 7), which is cased only a few feet into bedrock and may provide an avenue for rapid flow of high-chloride water from deep in the bedrock into the overlying sand and gravel.

Texas Brine Corp. water wells 2 and 3 have produced water with chloride concentrations as high as 260 and 1,100 mg/L, respectively, or about 50 times those found in water from other wells tapping the Dale Valley aquifer. Most other chemical constituents were also somewhat higher than at other wells (table 6), and the temperature of water discharged from well 3 was from 3° to 4°C higher than that in several other wells of comparable depth (table 7). These contrasts suggest a localized source of rather mineralized water rising from greater depth somewhere between wells 2 and 3. The two wells are finished more than 25 feet above the bedrock surface and are within a depression, or basin, on that surface (fig. 2). They are also within the Texas Brine Corp. well field, which includes 14 "brine wells" through which fresh water is pumped to salt beds at depths of about 1,300 feet and through which brine is forced back to land surface under pressure. The anomalous water quality in water wells 2 and 3 could not have resulted from leaks

Table 6.--Chemical analyses of ground water

[Concentrations in milligrams per liter; all samples were collected before water treatment]

Well symbol	Location[1/] Lat ° ' "	Location[1/] Long ° ' "	Owner	Well depth (ft)[2/]	Aquifer[3/]	Date of collection	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)
A	4248 47	7810 03	Robt. Brotherton	64	Bedrock (?)	6/21/74	1.9	0.07	53	12	72	1.8
B	4248 52	7810 13	John Harvey	92	Bedrock	6/21/74	2.4	.22	65	14	47	--
C	4249 00	7810 14	Richard vanDusen	89	Bedrock	6/21/74	--	--	--	--	--	--
D	4249 01	7810 17	Charles Austin	84	Gravel (?)	6/19/74	1.1	.12	29	7.2	150	--
E	4249 08	7810 25	Donald Swift	87	Gravel (?)	6/21/74	--	--	--	--	--	--
F	4249 10	7810 25	Donald Swift	29	Sand	12/08/71	.12	--	--	--	--	--
G	4249 13	7810 29	Paul Dieter	101	Bedrock	3/05/74	--	--	--	--	--	--
						6/22/74	--	--	--	--	--	--
H	4249 14	7810 09	Richard Colton	161	Bedrock	3/07/74	--	--	--	--	--	--
I	4249 22	7810 36	R. Houseknecht	49	Bedrock	12/08/71	.32	--	--	--	--	--
J	4249 36	7810 31	U.S. Geol Survey	108	Gravel(DV)	6/21/74	.55	.02	48	13	6	.8
K	4250 01	7810 17	Howard Perry	72	Gravel(DV)	3/06/74	--	--	--	--	--	--
						8/03/74	--	--	--	--	--	--
						9/16/74	--	--	--	--	--	--
L	4250 01	7810 27	Texas Brine WW4	165	Gravel(DV)	6/19/74	--	--	43	12	4.8	--
						9/16/74	--	--	--	--	--	--
M	4250 03	7810 16	Howard Perry	179	Bedrock	8/02/74	--	--	--	--	--	--
N	4250 26	7810 29	Texas Brine WW1	149	Gravel(DV)	6/21/74	--	--	--	--	--	--
O	4250 34	7810 37	Texas Brine	78	Gravel(DV)	6/22/74	--	--	--	--	--	--
P	4250 35	7810 23	Texas Brine WW2	137	Gravel(DV)	9/16/74	.82	.09	120	58	77	2.5
Q	4250 40	7810 38	K. W. Birge	84	Bedrock	11/24/71	.16	--	--	--	--	--
R	4250 41	7810 39	K. W. Birge	59	Bedrock	6/09/64	--	--	--	--	--	--
S	4250 44	7810 17	Texas Brine WW3	152	Gravel(DV)	6/21/74	2.9	.07	170	52	510	3.8
						8/01/74	--	--	--	--	960	--
						9/16/74	4.0	--	210	71	600	--
T	4250 44	7810 33	Reginald Dusing	61	Gravel(DV)	12/08/71	.48	--	--	--	--	--
U	4251 16	7809 57	Texas Brine TW4	105	Gravel(DV)	11/20/68	.03	.01	34	9.7	--	--
						6/20/74	--	--	39	12	--	--
V	4251 20	7809 53	Texas Brine TW3	92	Gravel(DV)	11/14/68	.49	0	34	9.7	--	--
						6/20/74	--	--	39	14	23	--
W	4251 26	7809 48	Texas Brine TW9	46	Gravel	12/04/68	.03	0	36	11.7	--	--
X	4251 31	7809 47	Texas Brine TW8	104	Gravel(DV)	6/20/74	.84	.03	39	13	24	1.4
Y	4251 31	7809 47	Texas Brine TW8A	61	Gravel	12/02/68	.03	0	37	11.2	--	--
Z	4251 45	7809 07	Herman C. Ewell	65	Bedrock	11/20/64	--	--	--	--	--	--

1/ Wells listed from south to north in order of increasing latitude.
2/ Depth is in feet below land surface. For other well dimensions, see table 7.
3/ (DV) indicates gravel is judged to be part of the Dale Valley aquifer.

Table 6.--Chemical analyses of ground water (Continued)

Well symbol	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Alkalinity	Ca,Mg hardness (as $CaCO_3$)	Specific conductance (µmhos at 25°C)	pH	Source of analysis[4]	Remarks[5]
A	351	3.2	31	288	180	632	--	a	Gas bubbles rise in well.
B	--	2.0	11	--	220	579	--	a	Gas reported by owner.
C	595	--	16	488	--	442	--	a	Gas bubbles rise in well.
D	394	.2	59	323	100	783	--	a	Do.
E	--	--	24	--	--	266	--	a	Yield very small; sample of water standing in capped casing.
F	--	--	7.1	197	239	--	7.8	b	NH_4, 0.02; NO_2, 0.007; NO_3, 5.5 (all as N).
G	586	--	320	481	--	1,620	7.0	a	Gas, iron, H_2S reported by owner.
	--	--	300	--	--	1,841	--	a	Do.
H	--	--	11	--	--	443	--	a	Gas bubbles rise in well.
I	--	--	18	205	261	--	7.3	b	NH_4, 0.45; NO_2, 0.21; NO_3, 3.7 (all as N).
J	180	27	5.1	148	170	343	7.9	a	Silica (SiO_2), 12.
K	--	--	45	--	--	601	--	a	--
	--	--	26	--	--	551	--	a	--
	--	--	15	--	--	422	--	a	--
L	164	26	4.7	135	160	317	--	a	Well flowed in 1974 through June 19.
	--	2.1	36	--	--	356	--	a	Well pumped Aug. 13 - Sept. 17.
M	--	--	8,700	--	--	23,076	--	a	Suction line to 97 ft, pumped 10 min.
N	--	--	16	--	--	336	--	a	Well rarely pumped in 1974 until June 21.
O	--	40	14	--	--	506	--	a	--
P	227	190	260	186	540	1,121	--	a	Well pumped 4 hours before sampling, otherwise unused since May 1974.
Q	--	--	7.3	184	207	--	7.5	b	NH_4, 0.02; NO_2, 0.02; NO_3, 1.7 (all as N); well also perforated above bedrock.
R	--	.4	46	--	200	849	--	a	Cloudy occasionally.
S	209	14	980	171	640	3,400	--	a	Pumped often, net 30 g/m est., Mar.-June.
	--	--	1,100	--	--	3,913	--	a	Pumped 86 g/m avg., June 19- Aug. 1.
	--	--	750	--	817	4,111	--	a	Pumped 84 g/m avg., Aug. 2- Sept. 17.
T	--	--	4.8	215	263	--	7.9	b	NH_4, 0.13; NO_2, 0.001; NO_3, <0.3 (all as N).
U	--	--	15.7	152	124	--	7.5	c	Total solids 186.
	188	--	10	150	150	317	--	a	Gas bubbles rise in well.
V	--	--	12.8	152	124	--	7.7	c	Total solids 176.
	205	.0	23	168	160	391	--	a	Gas bubbles rise in well.
W	--	--	13.7	164	138	--	7.6	c	Total solids 196.
X	211	.8	20	173	150	387	--	a	--
Y	--	--	16.6	174	138	--	7.6	c	Total solids 212.
Z	--	7.8	22	--	135	569	7.5	a	Filter to remove sediment.

4/ a. U.S. Geological Survey, Albany, N.Y.; b. New York State Department of Health; c. Commercial laboratory.
5/ avg., average; est., estimated; g/m, gallons per minute.

in the shallow buried pipelines that crisscross the well field, for two reasons: first, the specific conductance of water in shallow wells near wells 2 and 3 was low, and second, the many feet of clay and silt below the pipelines, and the upward ground-water gradient when the water wells are not in use, would cause shallow leakage (if there were any) to seep into Little Tonawanda Creek rather than to the Dale Valley aquifer. However, three other possible explanations for the localized anomaly cannot at present be ruled out:

1. The casing of one of the brine wells might be leaking opposite either the Dale Valley aquifer or the upper part of the bedrock. This seems unlikely, however, because the wells are reported to have three casings, generally set to depths of at least 180 feet (into bedrock), 1,000 feet, and 1,300 feet, with cement grout between the middle casing and bedrock.

2. The mineralized water may be entirely natural and may have been in this part of the Dale Valley aquifer for centuries. La Sala (1968, p. 61) argues that the theoretical pattern of ground-water flow toward points of discharge along a major stream can explain the presence of highly mineralized water at shallow depth near the central part of a valley.

3. The water naturally present near water wells 2 and 3 may have been similar to that elsewhere in the Dale Valley aquifer, but industrial development may have caused high-chloride water to migrate from the bedrock into the aquifer more rapidly since 1971. The rate of flow of water from the bedrock into the Dale Valley aquifer must have increased somewhat when head in that aquifer was lowered by pumping, and the increase in pressure deep in the bedrock caused by the brine-well system may also have favored an increase in upward flow. The rate of flow through 1,100 feet of shale between the salt beds and the aquifer should be minute unless faults or abandoned boreholes provide an avenue for rapid flow, and flow from great depth is not necessary to explain high chloride concentrations in water in the Dale Valley aquifer inasmuch as salty water was obtained at depths less than 200 feet by wells described earlier in this section. However, it is worth noting that when new brine wells in Dale Valley are first put into use, injection at extremely high pressures for several hours or days is required to initiate flow from one well to another through the salt beds. Subsequently, as salt is dissolved and avenues of flow become enlarged, pressure is reduced to that required to lift the brine to land surface and into an elevated storage tank. During development of new wells in 1971, some 7 million gallons of water was injected under extreme pressure before interconnection between the new wells was achieved. Interpretation of seismic data collected at the time suggests that some of this water may have moved to and along the Clarendon-Linden fault to points unknown (Paul Pomeroy, oral commun., 1974). Such migration may have contributed to the observed anomaly.

There is no record of chemical analyses having been made when water wells 2 and 3 were drilled, so water quality before development cannot be documented. However, about 1,000 feet south of well 2 is an abandoned well that overflowed at a small rate for many years. It was originally drilled deep into the bedrock in search of natural gas and was later plugged by the driller, but the casing was not pulled. The water, which presumably entered from the upper part of the bedrock, was described by local residents as "not bad; mineralized, but not salty." If the source of water is correctly inferred, water at the top of the bedrock beneath the center of Dale Valley before 1971 was similar to that pumped from wells 2 and 3 in 1974. However, the water pumped from wells 2 and 3 should be a blend, the largest component of which would be relatively unmineralized water moving downward and laterally through the Dale Valley aquifer, whereas the smaller component would be mineralized water moving upward through the poorly permeable bedrock. If so, the smaller, mineralized component may have been more mineralized in 1974 than in 1971.

Specific conductance and concentrations of several constituents increased as water well 3 was pumped continuously during the summer of 1974; the third analysis for this well in table 6 is internally inconsistent and may include an analytical error. This increasing trend could be due to a recent increase in inflow of highly mineralized water to the aquifer, or to progressive upward migration beneath the pumped well of mineralized water that had always been present at somewhat greater depth--a process known as "brine coning" (Bennett and others, 1968). Brine coning, however, does not explain the apparent temperature anomaly at water well 3, nor the moderately mineralized water at water well 2, which was pumped for only a few hours in 1974. Another argument for recent change is provided by Texas Brine Corp. test wells 4 and 3, north of water well 3. Water-level contours for the Dale Valley aquifer under natural conditions resemble those for June 19, 1974 (fig. 7) in showing northward flow; if a substantial amount of highly mineralized water had long been entering the Dale Valley aquifer near water wells 2 and 3, then test wells 3 and 4 should contain substantially higher chloride concentrations than wells to the south, which is not the case (table 6).

In conclusion, although chloride and dissolved solids in water in the Dale Valley aquifer near water wells 2 and 3 seem to have increased during the period of industrial development from 1971 through 1974, data are not adequate to eliminate any of the three hypotheses offered above to explain the presence of the mineralized water. If the increase were to continue, the water would still be suitable for industrial use in producing brine but might become unsuitable for most other purposes. Periodic analysis of samples from water wells 2 and 3 in future years, correlated with pumpage records, should permit better understanding of trends. If the anomalous mineral content in the Dale Valley aquifer is due to migration of water from the bedrock, its extent could probably be reduced by drilling a new well open to the deepest affected part of the aquifer and pumping at a few tens of gallons per minute during wet periods when no other wells need to be pumped. Under such circumstances, much of the mineralized water pumped out would be replaced by freshwater from elsewhere in the aquifer.

SUMMARY

Dale Valley contains two gravel aquifers that are potential sources of small industrial or community water supplies. The alluvial aquifer lies immediately below the valley floor; it has been little used nor studied but could probably supply a few hundred gallons per minute to a system of shallow wells or infiltration galleries near Little Tonawanda Creek, with a corresponding reduction in creek flow.

The Dale Valley aquifer lies buried beneath many feet of fine-grained lake deposits; several wells finished in it have yielded 100 to 250 gallons per minute. However, long-term total withdrawals from this aquifer are limited by slow recharge through surrounding fine-grained materials. In a moderately wet year such as 1974, the largest demand that could be met by withdrawals from the Dale Valley aquifer and Little Tonawanda Creek without causing excessive drawdown at some wells would be approximately 750 gallons per minute, as estimated from streamflow records and a digital model of the aquifer. Creek flow would be more than adequate to meet this demand during much of the year, but for about 100 days ground water would be needed to meet part or all the demand. In a dry year, withdrawals from the Dale Valley aquifer would have to be less than in a moderately wet year because recharge would probably be smaller and the period of deficient creekflow would certainly be longer. After some reasonable but unverified adjustments in the model were made to simulate a dry year, the largest demand that could be met in such a year was estimated to be 600 gallons per minute. If it were acceptable to let a few existing wells fail, slightly larger withdrawals would be possible.

Water high in chloride has migrated into parts of the Dale Valley aquifer. Chloride concentrations in one area were as much as 50 times greater than those found elsewhere in the aquifer in 1974 and seem to be increasing. Continued increase would render the water unsuitable for many purposes. The increase in chloride may have resulted from large-scale withdrawals from the aquifer; it probably could be controlled by pumping from the center of the affected area during periods of minimal pumping elsewhere.

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TECHNICAL ASPECTS OF MODEL CALIBRATION

TECHNICAL ASPECTS OF MODEL CALIBRATION

Input to the Model

Model parameters.--Operation of the digital model is affected by values specified by the user for several features of the model itself (Trescott, 1973). Values used were: number of iteration parameters, 5; criteria for closure or steady-state condition, 0.04 feet; multiplication factor for successive time steps, 1.5; and length of initial time step, 0.2 to 24 hours.

Size of model.--The model grid is 38 cells long by 35 cells wide; cells falling outside Dale Valley were assigned zero values, leaving 560 functional cells (fig. 11) representing 2.2 square miles. Grid spacing is variable to provide more detail near pumping centers and to place the center of a cell at most observation wells.

Data arrays.--The model incorporates several arrays of data that represent the aquifer, confining layer, and water table at each functional cell. Selection and adjustment of these data are discussed in general terms in this section; the complete data arrays will be kept on file for several years by the U.S. Geological Survey office in Albany, N.Y.

Characteristics of the aquifer.--The Dale Valley aquifer was modeled as a two-dimensional, confined aquifer. Well records and pumping tests show that it is confined and very thin relative to its extent. Although not strictly horizontal, it rises toward the sides of the valley at a slope of only 1:10. Near the heads of alluvial fans, the aquifer may have a steeper slope and is probably unconfined, but accurate simulation of heads in these small areas was not of primary concern. Water levels in several wells penetrating the upper few feet of bedrock respond to pumping in the aquifer and were used to calibrate the model, usually assuming low transmissivity near such wells.

Aquifer transmissivity was initially estimated from pumping tests, well records, and other data as explained in the section "The Dale Valley Aquifer." Initial estimates of transmissivity were changed repeatedly at many cells during calibration. The final product (fig. 14) retains values similar to those suggested by pumping-test analysis in the area of highest transmissivity near the valley axis. Low values were inserted as barriers at a few cells to separate nearby wells having widely different water-level response.

The storage coefficient was assigned values ranging from 0.0003 to 0.0006 near the axis of Dale Valley, which is consistent with interpretation of pumping tests. Values ranging from 0.0018 to 0.012 were assigned near the sides of the valley to allow for locally greater thickness of silty gravel and to provide additional storage needed to calibrate the model. Values of 0.06 were assigned near the heads of alluvial fans on the assumption that water-table conditions prevail there.

Boundaries of the aquifer.--Impermeable (zero-flow) boundaries surround the model. Boundaries along the sides of the valley represent nearly impermeable bedrock and were drawn just outside the gently sloping alluvial or glacial deposits on the valley floor. At the south end of the valley, the boundary was drawn several hundred feet south of the southernmost well that clearly was affected by 1974 pumpage in an area where nearly all deep wells tap bedrock. At the north end, the boundary was drawn several thousand feet beyond the last well clearly affected by 1974 pumpage. Logs of two test holes near the north boundary report no deep aquifer, but potentiometric contours (figs. 7, 8) suggest some northward flow, so a thin or discontinuous gravel layer may cross the boundary. Such a layer was simulated by increasing vertical hydraulic conductivity of the confining layer in several cells along the north boundary to 8 times the values assigned in nearby cells. Manual calculations based on simulated 1974 water levels indicate that a continuous discharge of about 2.5 gallons per minute was thereby simulated. This discharge is equivalent to the horizontal flow across the boundary that would have occurred through a sand or gravel layer 1 foot thick and 1,000 feet wide having a hydraulic conductivity of 150 feet per day and a hydraulic gradient parallel to Little Tonawanda Creek.

Seepage from the bedrock.--The model treats the bottom of the aquifer as totally impermeable (fig. 10); hence any inflow from the underlying bedrock must be incorporated in simulated vertical flow through the confining layer. Some inflow from bedrock has taken place, as shown by salt water present locally within the Dale Valley aquifer and by the way water levels in some wells penetrating a short distance into bedrock decline in response to pumping in the Dale Valley aquifer. Vertical flow in the model is controlled by simulated areal variations in thickness and hydraulic conductivity of the confining layer and in altitude of the water table in the shallow aquifer, which were designed to resemble actual variations in those units and are probably not closely representative of the bedrock. However, this approximation of the real system appears reasonable because (1) the hydraulic conductivity of the bedrock is probably much smaller than that of the confining layer--perhaps not much smaller along the axis of the valley where the confining layer is thick and rich in clay, but likely very much smaller near the sides of the valley where the confining layer is thin and sandy. The generally small chloride content of water in the aquifer, despite the presence of salty water a short distance into bedrock along the valley sides, suggests that the rate of inflow from the bedrock was small under natural steady-state conditions. (2) Heads deep in the bedrock are not known but probably exceed those in the Dale Valley aquifer (if corrected for salinity), so may be many feet higher than heads in the shallow aquifer near the valley axis. However, along much of the valley axis drawdown reached several tens of feet in 1974 (fig. 9). Hence, even if seepage from bedrock were an appreciable component of total vertical flow in this area, rates of seepage from below as well as from above should vary roughly in proportion to drawdown in the Dale Valley aquifer except at small drawdowns.

Characteristics of the confining layer.--Thickness of the confining layer was initially estimated from well records, test-well logs, and seismic profiles. Only minor changes were made during calibration of the model.

Vertical hydraulic conductivity of the confining layer was estimated from published values for similar materials but was modified considerably during calibration. Originally, a uniform low value (0.001 foot per day) was postulated for most of the valley, with somewhat higher values where alluvial fans are developed along the valley sides. Much higher values (0.02 to 0.04 foot per day) were postulated near the heads of alluvial fans on the assumption that the confining layer pinches out there as demonstrated by Crain (1966) in a similar valley in southwestern New York. The model chosen to represent Dale Valley cannot simulate local absence of a confining layer, but high values of vertical hydraulic conductivity should adequately represent the gravelly sediments and the seepage from tributary streams near fan heads. The first attempts to calibrate the model resulted in excessively low water levels in the southern part of the valley and excessively high water levels in the northern part. To achieve a reasonably good fit, it was necessary to:

1. Greatly reduce the postulated high values of vertical hydraulic conductivity near fan heads in the northern two-thirds of the valley, thereby reducing recharge to that part of the valley. High values were retained near the heads of fans at and south of Pflaum Gulf.

2. Increase the low values of vertical hydraulic conductivity near the axis of the valley north of Thompson Road, thereby increasing discharge under nonpumping conditions in that part of the valley. In the final data array, vertical hydraulic conductivity near the valley axis increases gradually from about 0.001 foot per day south of Thompson Road to 0.004 foot per day north of Smith Gulf.

Neither of these changes is confirmed by specific field data. Possibly an equally satisfactory calibration could have been achieved by further manipulation of transmissivity. There was not enough time to explore all possible alternatives, nor enough data to be sure the alternative chosen was the one that most resembled the real system.

Altitude of the water table.--Depth to water below land surface was measured in late May or June 1974 in several shallow wells. For each cell containing one of those wells, altitude of the water table was estimated by subtracting that measurement from average land-surface altitude for that cell estimated from the topographic map. The water table in many cells was assumed to be coincident with Little Tonawanda Creek or with swamps shown on the map. Elsewhere, the water-table gradient was assumed to be uniform in the direction of the valley axis but to steepen toward alluvial fans. The resulting data array, modified somewhat during calibration, was used in simulations for the period June 19 through August 1, 1974.

The Pinder-Trescott code does not provide for changes in altitude of the water table during a simulation of water levels in a confined aquifer. However, a decline in the water table during the summer would normally be expected anywhere in New York, and measurements in shallow wells in and near Dale Valley generally showed a decline of about a foot from mid-June through mid-September 1974. Therefore, a second data array was prepared to represent the water table from August 2 through September 17, 1974. The second array was one foot lower than the first at nearly all cells, but two feet lower on the lower slopes of alluvial fans and near a reach of Little Tonawanda Creek that went dry in August. It was unchanged at the heads of large alluvial fans, where streamflow continued throughout the summer and where measurements in wells showed no decline in water level.

To use both data arrays, the summer of 1974 was simulated by two successive computer runs. The effect of the change was to gradually lower heads in the deep aquifer by about one foot at all cells.

Evaluation of the Model

Several tables and graphs comparing observed and simulated water levels have been presented. The steady-state simulation (table 1) is reasonable; the 1974 transient simulation (table 2, figs. 12, 13) is generally very close to observed water levels; the May 1970 transient simulation (table 3) is fair, and errors are conservative in that the later drawdowns are somewhat larger than observed. The program calculates volumes of leakage into and out of the aquifer; in each simulation, net leakage plus storage very closely approximate pumpage. Dividing cumulative leakage into the aquifer as of September 17, 1974 by the area in which simulated heads in the deep aquifer were lower than the water table on September 17 gave an average loss from the shallow aquifer of 0.15 foot of water, which (allowing for effective porosity) would require an average water-table decline of about 1 foot. This result cannot be verified but seems reasonable. The actual effect on the alluvial aquifer would be smaller than calculated because leakage into the Dale Valley aquifer comes in part from the bedrock and in part from storage in the confining layer. Also, the actual effect would be concentrated near the sides of the valley rather than uniformly distributed.

The model simulation may be questioned in some respects. For example, drawdown at an observation well may be simulated by postulating a uniform transmissivity for all cells between the well and the center of pumping, or by postulating much smaller transmissivity at one or more of those cells and larger transmissivity at the other cells. The cells with transmissivity much less than the others may be thought of as barriers. In the Dale Valley model, barriers were simulated in several cells (row 20, columns 7-8; row 24-25, column 20; row 29, columns 21-23), and less distinctly in a few other places, where they seemed necessary to reproduce observed drawdown although other information suggested generally larger transmissivity. They may represent thin or silty parts of the real aquifer; alternatively, they may be necessary because the real wells tap different permeable lenses at nearly the same stratigraphic position that are imperfectly separated by fine-grained beds. If an observation well had been available for each cell in the Dale Valley model, the resulting water-level data would quite possibly have forced the simulation of more barriers in areas now represented by rather uniform transmissivity values. In other words, the true transmissivity may be more heterogeneous than currently modeled.

South of row 29, simulated steady-state water levels are slightly lower than water levels observed on June 19 and considerably lower than estimated predevelopment levels. Neither transmissivity nor properties of the confining layer in the model could be adjusted to raise the steady-state simulation here without also increasing the departure from observed drawdown on September 17. Adjustments in the two water-table arrays to simulate a greater seasonal decline of the water table would have forced water levels in the Dale Valley aquifer to compare more favorably with observed data on June 19 and September 17, but such adjustments were not made because they seemed inconsistent with the scattered field data. The natural pattern of seasonal change in water level in deep wells is not known; perhaps the observed levels on June 19 and some of the estimated natural levels reflect recharge in the spring and would have declined naturally in July to levels close to the steady-state simulation.

Simulated drawdowns after 18 days of pumping in May 1970, at rates much larger than in 1974, were from 10 to 20 percent greater than observed drawdowns in most wells. If well losses in the pumped wells were considered, the error would be somewhat greater. Simulation of an aquifer test in July 1970 also yielded drawdowns that were about 20 percent too great in some wells after about 16 days of pumping. Several possible explanations for this discrepancy were considered:

1. At some wells, the altitude of the point at land surface from which water-level measurements were made in 1970 is not exactly known; therefore, observed water-level altitudes could be in error by 1 to 3 feet.

2. Ground-water levels and streamflow were slightly higher in May 1970 than in July 1974; perhaps recharge was also slightly greater. However, allowance for a higher water table would reduce the difference between simulated and observed water levels on May 28 only about a foot, and no allowance could be justified for July 1970.

3. Reported pumping rates might be in error--too large in 1970 and (or) too small in 1974. However, it seems unlikely that a large drilling firm would overestimate pumping rates by as much as 20 percent during two 18-day tests, or that a firm paid according to the volume and concentration of brine produced would underestimate its output by 10 to 20 percent. As was previously explained, pumpage from water

well 4 in 1974 was calculated daily from other measured water inputs and brine output; although errors from day to day are quite possible owing to storage in the system, they should average out.

4. In all transient simulations, model response for the first few days of pumping or recovery generally lagged behind changes in the real aquifer; later the simulated water levels changed more rapidly. Apparently the storage properties of the real aquifer system are more complex than those of the model. The model assumes that all storage is in the aquifer and that release of water from storage and leakage through the confining layer are simultaneous with decline in head. Probably release of water from storage in the confining layer is a factor in the real aquifer that slows the rate of drawdown for many days. Possibly storage capacity has decreased in some places since 1970 owing to compaction of fine sediments during several cycles of drawdown. An attempt to improve model fit with an option in the computer program to simulate storage in the confining layer was unsuccessful. Nevertheless, a good fit for September 17, 1974, may be more important than for other dates because any effect of transient storage would be more nearly dissipated after the longer period of pumping and because the model is most likely to be used for simulating long periods of pumping.

For this report, 1974 data were emphasized in calibrating the model because the water-level measurements in 1974 were more widely distributed and the test period longer than in 1970 and because the resulting model is more conservative than would be obtained by emphasizing the 1970 tests.

As a further check on reliability of the model, the cumulative volume of leakage into the deep aquifer was calculated by the computer to be 19.6×10^6 cubic feet after 200 days of pumping under drought conditions such as prevailed in 1941. Dividing this volume by the area in which simulated heads in the deep aquifer were lower than the water table at the end of the 200 days gave an average leakage of 0.35 feet of water. If all leakage came from storage in the shallow aquifer and gravity yield were 0.15, the water table would decline an average of 2.3 feet. A decline of about 6 feet near the sides of the valley and about 0.5 feet over the central part of the valley would be equivalent in magnitude and more realistic. Actual water-table declines would be smaller than thus calculated because part of the leakage into the Dale Valley aquifer comes from the bedrock and part from storage in the confining layer. The calculated declines are reasonably consistent with those allowed for in the model. However, the latter were based on interpretation of water-level behavior due to lateral flow and evapotranspiration under natural drought conditions; downward leakage caused by pumpage would slow these other processes, but the combined effect might lower the water table more than allowed for in the model, particularly near the sides of the valley. If so, water levels in the Dale Valley aquifer might be a foot or two deeper than predicted. Also, flow of Little Tonawanda Creek would be slightly reduced, thereby increasing by several days the period when the entire postulated demand must come from the aquifer. These two ways in which pumping in the Dale Valley aquifer would affect conditions used to define model simulations are throught to be small and were not allowed for.

The present model is an approximate and partial representation of the aquifer system in Dale Valley. It should be possible to simulate that system more completely and more accurately with a 3-dimensional multilayer model, which could incorporate the properties and stresses within the shallow aquifer (including recharge from precipitation and stream seepage, lateral flow, storage, and discharge through wells, streambeds, and evapotranspiration), and which could account for vertical flow through the confining layer separately from vertical flow through the underlying bedrock. However, such models were not readily available in 1974, much of the additional data needed for calibration would have to be estimated, and computer costs would be substantially greater for calibration and prediction. Initial judgement, confirmed by results in this report, was that a two-dimensional model could represent the principal aquifer in Dale Valley reasonably well and provide satisfactory answers to questions raised in 1974.

TABLE 7

Records of wells, with explanation of terms.

Locations of wells are shown in figure 17 (p. 76-77).

Table 7.--Records of wells

EXPLANATION OF TERMS

Location: Coordinates of latitude and longitude are shown for each well. Wells are listed from south to north, in order of increasing latitude. Latitude and longitude were measured from a 7 1/2-minute topographic map, scale 1:24,000; each well was plotted on the map after a visit to the site unless otherwise noted under "Remarks." Locations of all wells listed are shown in figure 17 (p. 76-77).

Owner: Owner's name is listed with any number the owner has assigned to the well. Some names are abbreviated or run together because of space limitations. The following abbreviations are used:
TW, test well WW, water well BW, brine well

Use:

- B Brine Production
- C Commercial
- H Domestic
- N Industrial
- O Observation
- S Stock
- T Test hole, drilled to obtain geologic or hydrologic information. Such holes were destroyed or abandoned soon after completion. Some test holes were converted to observation wells and are so listed.
- U Unused
- Z Destroyed (filled and casing pulled) or deepened. Formerly used other than as a test hole.

Method: Method of well construction

- B Bored or augered
- C Cable-tool
- D Dug
- V Driven
- H Hydraulic rotary

Yield: gpm = gallons per minute. The letters to the right of the gpm column show the source of the information, as follows:

C Calculated, assuming the drawdown listed in the next column, from specific capacity determined by the U.S. Geological Survey during recovery from operation of owner's pump. Where calculated yield exceeds 1 gallon per minute, actual drawdown during recovery test was generally 1 to 2 feet. Where calculated yields are smaller, recovery was measured over many hours, and true static water level on date of test was estimated.

Table 7.--Records of wells (Continued)

Yield (cont.):

- D From driller's bill, log, or written records
- E Estimated
- M From memory of owner, driller, or some other person
- S Measured by U.S. Geological Survey
- W From owner's written records

Drawdown: The difference, in feet, between static water level and water level when pumped (or flowing) at the yield indicated.

Well Diam: Diameter of casing (inner casing if more than one) or of hole (if no casing), in inches.

Well Depth: The numbers show the depth of the well to the nearest foot below land surface. The letters to the right of the depth column show the source of the information, as follows:

- D From driller's bill, log, or written records
- M From memory of owner, driller, or some other person
- S Measured by U.S. Geological Survey
- W From owner's written records.

Casing Depth: The numbers show the depth in feet of solid casing to the shallowest point at which water can or might enter the well. The letters to the right side of the depth column show the source of the information, as explained under "well depth." Casing-depth measurements by the U.S. Geological Survey were made using a weighted magnet (except for very shallow measurements in dug wells); + after the number indicates that the full casing length could not be measured because the weight had reached the bottom of the well.

Finish: Refers to the character of the openings that permit water to enter the well, as follows:

- F Gravel wall or gravel pack, perforated or slotted casing
- G Gravel wall or gravel pack, commercial well screen
- O Open end; cased to bottom of hole, all water enters through bottom

Table 7.--Records of wells (Continued)

Finish (cont.):

P Perforated or slotted casing

S Sand point or drive point

W Walled with open-jointed fieldstone, concrete blocks, tiles, or similar materials

X Open hole; no casing or other support opposite aquifer

Aquifer: (DV) indicates that the gravel and sand tapped by the well is judged to be part of the Dale Valley aquifer, as described in text.

Altitude: Altitude of most wells was estimated from a topographic map (fig. 17). Altitude was determined by spirit leveling by U.S. Geological Survey (from Texas Brine Corp. benchmarks) for wells where altitude of measuring point is given under "Remarks." Spirit leveling was reported by Texas Brine Corp. for a few other wells. All numbers are feet above mean sea level.

Water level: Numbers show water level to the nearest foot below land surface (or above if preceded by +), under nonpumping (static) conditions except as noted under "Remarks"; F means well flowing. The letters to the right of the water-level column show the source of the information, as explained under "Well depth."

Remarks: Several symbols or expressions are used to abbreviate data:

C Chemical analysis in table 6.

L Log of materials penetrated compiled by U.S. Geological Survey.1/

W Series of water-level measurements compiled by U.S. Geological Survey.2/

1/ Log of U.S. Geological Survey test well (4249 36 7810 31) is given at the end of this table; other logs will be kept on file at the Albany, N.Y. USGS office for several years.

2/ Data compiled will be kept on file at Albany, N.Y. for several years.

Table 7.--Records of wells (Continued)

Remarks (cont.): DD for 8 hr. Drawdown shown in table was measured at the end of 8 hours pumping. Records of pumping tests at some of these wells were compiled by U.S. Geological Survey.2/

MP Measuring point; number that follows is altitude as determined by U.S. Geological Survey spirit leveling, in feet, of the point described next.

WL Water level below land surface.

T9.2°C 8-2-74 Temperature 9.2° Celsius on Aug. 2, 1974, measured in pail fed by overflow or pump discharge.

#251-809-2, ENB-3 Number used in report ENB-3 (La Sala, 1968) to identify a record of this well.

Other words abbreviated include the following:

diam	diameter	hr	hour
engr	engineer	5-in	5-inch
est	estimated	SE	southeast
ft	foot or feet	TBC	Texas Brine Corp.
gpm	gallons per minute	TW	test well
		WW	water well

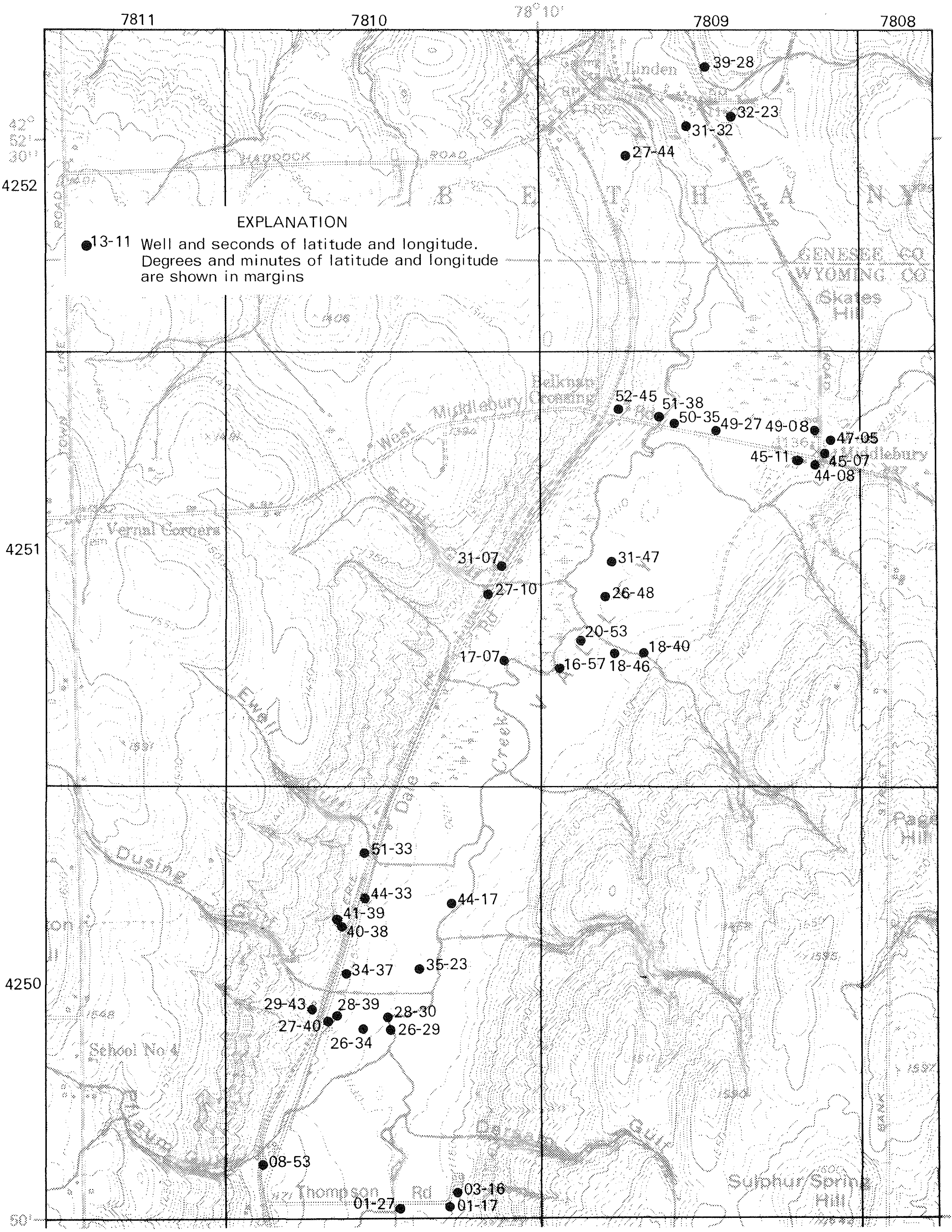
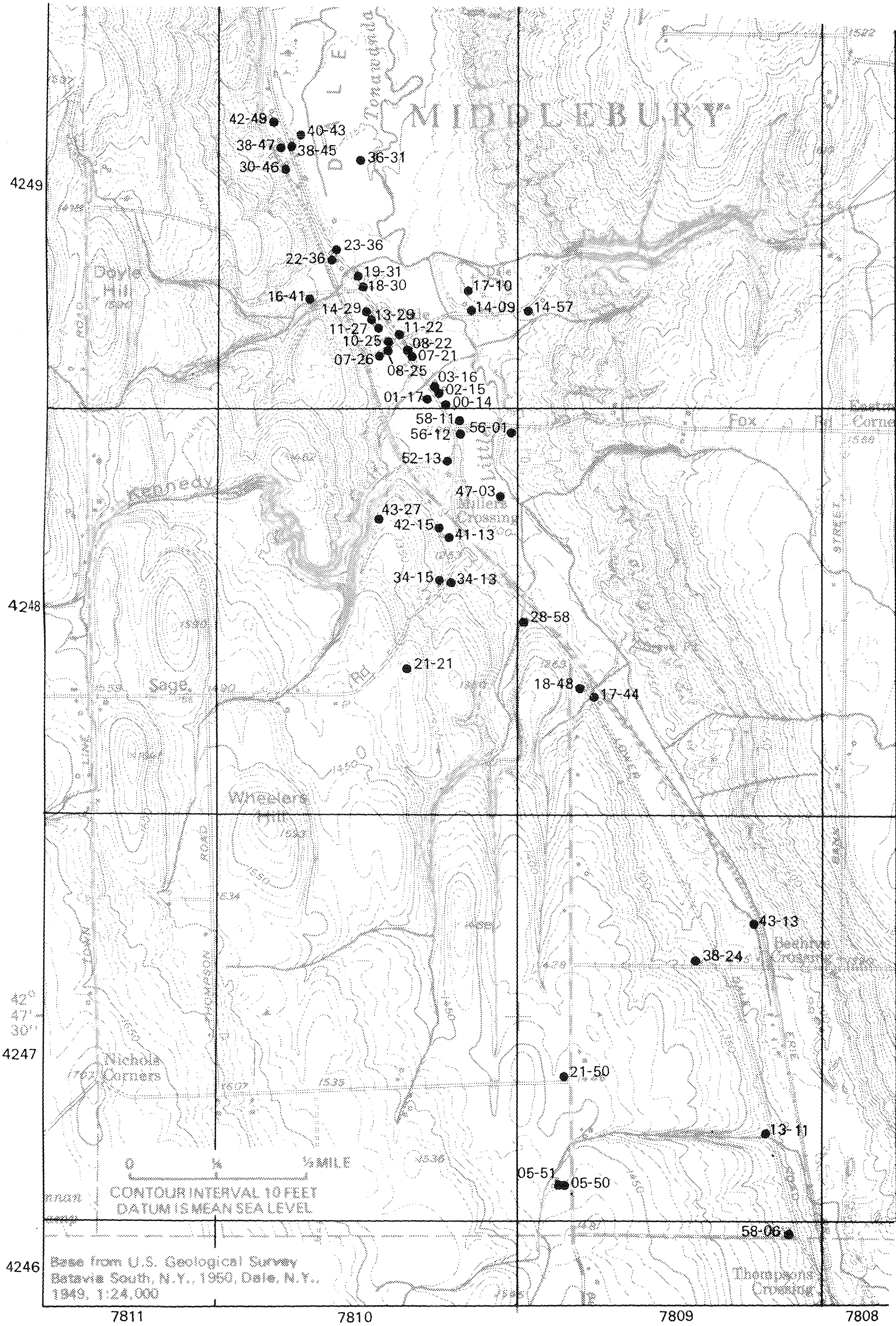


Figure 17.--Location of wells in and near Dale Valley.



MIDDLEBURY
Tonawanda
42-49
40-43
38-47
38-45
30-46
36-31
23-36
22-36
19-31
18-30
17-10
16-41
14-29
13-29
14-09
14-57
11-27
11-22
10-25
08-22
07-26
07-21
08-25
03-16
02-15
01-17
00-14
58-11
56-12
56-01
52-13
47-03
43-27
42-15
41-13
34-15
34-13
28-58
21-21
18-48
17-44
43-13
38-24
21-50
13-11
05-51
05-50
58-06
Doyle Hill
Kennedy
Millers Crossing
Fox
Sage
Rd
Wheelers Hill
Nichols Corners
Thompsons Crossing
0
¼
½ MILE
CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL
Base from U.S. Geological Survey
Batavia South, N.Y., 1950, Dale, N.Y.,
1949, 1:24,000
4249
4248
4247
4246
42°
47'
30"
7811
7810
7809
7808

Table 7.--Records of wells (Continued)

Location	Owner	Use	Date drill-ed	Method	Well diam (in)	Well depth (ft)	Cas-ing depth (ft)	Depth to bed-rock	Finish	Aquifer	Alti-tude	Line
4246 58 7809 06	Keith Buttles	H	1925	C		89 M			X	Bedrock ?	1340	A
4247 05 7809 50	Norman Smith	Z		C		25 M	18 M	18	X	Bedrock	1462	B
		U		C		225 M	18 M	18	X	Bedrock	1462	C
4247 05 7809 51	Norman Smith	C	1963	C		65 M		12	X	Bedrock	1460	D
4247 13 7809 11	Edwin Squires	H	1968	C	6	21 S	22 D	22	0	Bedrock ?	1318	E
4247 21 7809 50	Norman Smith	H				35 M			X	Bedrock ?	1445	F
4247 38 7809 24	Henry Golas	H		D	24	12 S	3 S		W	Till	1320	G
4247 38 7809 24	Henry Golas	H	1971	C	6	95 M	85?M	60?	X	Bedrock ?	1320	H
4247 43 7809 13	Frank L Kessler	H		D	20	7 S	1 S		W	Gravel ?	1260	I
4248 17 7809 44	M. Muscarella	H				54 M					1252	J
4248 18 7809 48	Mortimer	H		D		14 M			W	Till ?	1265	K
4248 21 7810 21	Lavern Bauer	H	1971	C	6	120 S		45?	X	Bedrock	1440	L
4248 28 7809 58	Don Richardson	H	1964		6	50 S	47+S		0	Gravel ?	1232	M
4248 28 7809 58	Don Richardson	U		D	20	5 S	1 S		W	Gravel	1223	N
4248 34 7810 13	Robt Brotherton	Z	1962	C		135 M	90 M	13?	X	Bedrock	1275	O
4248 34 7810 15	Norman Smith	Z	1968	C	6	130 M	0 M	90	X	Bedrock	1272	P
4248 41 7810 13	Gary Weidman	U		D	28	18 S	0 S		W	Lake Beds ?	1238	Q
4248 42 7810 15	Gary Weidman	H		D	22	20 S	0 S		W	Till ?	1238	R
4248 43 7810 27	Robt Brotherton	H		D		8 M	1 S		W	Gravel	1325	S
4248 47 7810 03	Robt Brotherton	H	1925	C	12	64 S	55+S			Bedrock ?	1190	T
												U
4248 52 7810 13	John Harvey	H	1964	C	6	92 S	74 S		X	Bedrock	1209	V
4248 56 7810 01	Steven Bandy	H	1967	C	6	50 S		17	X	Bedrock	1208	W
4248 56 7810 12	Ron Kaczmarek	H			6	66 S	62+S			Gravel ?	1190	X
4248 58 7810 11	Lawrnce Carmody	Z	1930	V	1	16 S	14 S		T	Gravel	1186	Y
4249 00 7810 14	R Van Dusen	H	1965	C	6	89 S	80 M		X	Bedrock	1185	Z
4249 00 7810 14	R Van Dusen	U		D	24	7 S	3 S		T		1185	A
4249 01 7810 17	Charles Austin	H	1965	C	6	86 D	86 D			Gravel ?	1186	B
						84 S						C
4249 01 7810 17	Charles Austin	U		D	42	9 S	0 S		W	Gravel ?	1186	D
4249 02 7810 15	Charles Koch	H		D	60	9 S	0 S		W	Lake Beds?	1183	E
4249 02 7810 15	Charles Koch	H	1965	C	6	25 D	21 M		P	Gravel	1182	F
						20½S						G
4249 03 7810 16	L Greil	H		D	22	8 S	0 S		W	Gravel ?	1183	H
4249 07 7810 21	Jim Rutherford	U		V	1	21 S			T		1200	I
4249 07 7810 26	W Winchester	H			6	23 M	25 M			Gravel ?	1205	J
4249 08 7810 22	Albert Davis	H		V	1	21 M			T	Sand ?	1202	K
4249 08 7810 25	Donald Swift	U	1968	C	6	87 S	85+S		0	Gravel ?	1201	L
4249 10 7810 25	Donald Swift	U			6	29 S			0	Sand	1201	M
												N
4249 10 7810 25	Donald Swift	H	1973	C	6	33 S	33 M		0	Sand	1201	O

Table 7.--Records of wells (Continued)

Line	Water level (ft)	Date	Yield (gpm)	Draw-down (ft)	Remarks
A	19 M	1956	3 M		Supplies farm 1000 ft SE; 3 wells drilled there, bad taste or no water.
B					Yield inadequate for farm; deepened, see next record.
C					Yield still small; water now corrosive, salty, very hard. Well buried.
D					Yield small, water quality good.
E	10 S	7-2-74	3 D		Finished at top of shale (driller's records).
F					Supplies farm 1600 ft south, not enough for cattle; former schoolhouse.
G	8 S	8-3-74			Occasionally inadequate.
H	16 M	1971	.5 M		Gas, gray fine sediment in water; standby use only.
I	2 S	9-19-74	6 E	2	Supplies house 500 ft south; has not failed in 60 yrs; iron in water.
J					Drilled before 1944.
K					Well fails each year, is usually filled twice from tank truck Oct-Nov.
L	71 S	8-1-74			Yield ample, once ran garden hose for 2 days.
M	23 S	6-22-74	.06C	33	WL rising, last pumped 6-21, est static 13 ft. Well often out of water.
N	3 S	6-21-74			Water dark in color. Well 40 ft from creek.
O			0		L. Dynamite set off at 94 ft, no water obtained.
P			0		Clay 0-90 ft, casing not needed. 4 wells drilled here earlier, no water
Q	3 S	9-17-74			WL 2.2 ft 6-18-74, 3.1 ft 9-17-74.
R	15 S	6-18-74			WL below static, used 6-18-74. Supplies 2 sinks, often fails in summer.
S	0 S	5-6-74			Hardpan 0-4, pea gravel 4-5, blue clay 5-8 ft (owner). Supplies 2 homes.
T	+1 S	5-6-74	11.5 C	50	C. Drilled 2200 ft for gas, plugged; flowed for years; redrilled 1962.
U			50 M	7	Casing leak at pump pipe 1974 (usually out). Obstructions below 58 ft.
V	23 S	6-22-74	4.3 C	50	C. WL 23.2 ft 6-22-74, 25.4 ft 9-17-74. Has supplied home + 70 horses.
W	4 S	6-20-74	3 M		
X	F S	5-23-74	3 E		Flows through pipe 3 ft below grade. Hard water. Reported depth 95 ft.
Y					Failed 1974, pulled; point showed gravel 14-15, sandy clay 15-16 ft.
Z	+1 S	6-21-74	13.5 C	50	C.W. MP1185.60, top casing. Flowed 1964-74.
A					Sand point put in dug well, depth ?, gravel backfill. Used 1954-64.
B	+2 S	6-20-74	2.5 D		C. Ends in thin gravel atop rock (driller). Soft sediment 84-85 ft 1974
C	0 S	9-16-74	6.5 C	50	Casing leak at pump pipe 1974. Flowed 1965-74. MP1187.62 top casing.
D	6 S	6-18-74			WL 6.0 ft 6-18-74, 7.5 ft 9-17-74. Water very clear.
E	4 S	5-23-74			Inadequate in summer; pump dry in 1 hr to clean, recovers slowly.
F	•3 S	5-23-74	5 D		Slots reported 20.5-22 ft; well inadequate since bottom filled in, used
G					mostly in summer. Casing leak at pump pipe 1974.
H	4 S	5-21-74			Well failed once, about 1957, for 2 days, not again through 1974.
I	20 S	3-7-74			Well plugged. Similar well, reported 24 ft deep, east side house, used.
J	16 M	7- -73			Dug well helps supply house. Fine sand, silt, clay 0-8 ft nearby.
K	18 M	5- -73			Similar wells at next 2 buildings to north.
L	20 S	6-21-74	0 S		C.L. Lowered WL 10 ft 6-21-74, recovery 0.003 gpm. MP1202.67 top casing
M	19 S	3-5-74	6.5 M		C. Supplied house pre-1948 to 1973; depth 34 ft, 1948; replaced suction
N					pump by jet, 1970; tried to drill out sand in casing, failed, 1973.
O	21 S	7-30-74	20 M		L.W. MP1200.94, top of hole in concrete slab. Old well is 2 ft away.

Table 7.--Records of wells (Continued)

Location	Owner	Use	Date drilled	Method	Well diam (in)	Well depth (ft)	Casing depth (ft)	Depth to bedrock	Finish	Aquifer	Altitude
4249 11 7810 22	Baptist Church	H	1968	C	6	39 S	39 D		0	Gravel	1196
4249 11 7810 27	Don Strathearn	H			5	78 S					1195
4249 13 7810 29	Paul Dieter	H			6	101 S	91 S		X	Bedrock	1192
4249 14 7809 57	George Wombwell	H		D	24	14 S	0 S		W		1205
4249 14 7810 09	Richard Colton	H	1973	C	6	161 D	129 W	129	X	Bedrock	1189
4249 14 7810 29	Paul Kaczmarek	H	1963	C	6	54 S	54 D		0	Gravel	1185
4249 16 7810 41	Fred Ott	H		D	8	7 S	5 S		W	Gravel	1153
4249 17 7810 10	Dale Cemetary		1965	C	6	79 S 80 W			0	Gravel (DV)	1199
4249 18 7810 30	Kenneth Greig	H	1962	C	6	90 M	90 M		0	Gravel (DV)	1172
4249 19 7810 31	Douglas Wolcott	H		D		13 S			W	Gravel	1172
4249 22 7810 36	R Houseknecht	H	1970	C	6	49 S	39 D	38	X	Bedrock	1183
4249 23 7810 36	R Houseknecht	H		D	24	12 S	4 S		W	Lake beds?	1179
4249 30 7810 46	Donald Dutton	H	1953	C	6	89 S	29 S		X	Bedrock	1195
4249 36 7810 31	U S Geol Survey	0	1974	C	6	108 S	115 D	145+	0	Gravel (DV)	1152
4249 38 7810 45	Joseph Bodekor	S		D	24	8 S	0 S		W	Till ?	1170
4249 38 7810 47	Wayne Dersam	Z		D	36	11 S	0 S		W	Till ?	1177
4249 40 7810 43	Joseph Bodekor	S	1973	D	36	12 S	0 S		W	Gravel	1148
4249 42 7810 49	Sam Holmes	U		D		11 S			W		1166
4250 01 7810 17	Howard Perry	H	1970	H	6	72 D	62 D		F	Gravel (DV)	1140
4250 01 7810 27	TexasBrine TW11	0	1968	H	2	167 D	157 D	192	G	Gravel (DV)	1133
4250 01 7810 27	Texas Brine WW4	N	1971	C	12	165 D	156 D		G	Gravel (DV)	1135
4250 03 7810 16	Howard Perry	Z			6	34 S	40 M		0	Gravel (DV)	1152
4250 03 7810 16	Howard Perry	U	1970	C	6	179 S	68 S	68	X	Bedrock	1152
4250 08 7810 53	Carl Pflaum	H		D	26	15 S	0 S		W	Gravel	1170
4250 26 7810 29	TexasBrine TW10	T	1968	H	2	135 D	125 D	205	G	Gravel (DV)	1126
4250 26 7810 29	Texas Brine	T	1969		12					Gravel (DV)	1126
4250 26 7810 29	Texas Brine WW1	N	1970	C	12	149 D	119 D		G	Gravel (DV)	1126
4250 26 7810 29	Texas Brine	N	1971	D	48	9 S	2 S		W	Gravel	1125
4250 26 7810 34	TexasBrine BW11	B	1971	C	11		178 D	175		Bedrock	1131
4250 27 7810 40	George Dersam	U		D	36	29 S	10 M		W	Gravel ?	1155
4250 28 7810 30	Texas Brine	U	1912	C	12					Bedrock ?	1130

Table 7.--Records of wells (Continued)

Line	Water level (ft)		Date	Yield (gpm)	Drawdown (ft)	Remarks
A	20	S	3-5-74	7	D	L.W. MP1197.43, top of casing. Supplies church + parsonage. About 10
B	21	S	7-30-74			wells drilled here in past years, no water.
C	23	S	5-26-74			WL rising 5-26-74. Well often out of water. Water has excessive iron.
D	15	S	6-20-74	32	C 50	C.W. Fine sand in house foundation. MP1189.47, top of casing, in pit.
E	8	S	5-24-74			WL 9 ft 6-9-64. #249-809-1 in ENB-3.
F	5	S	8-23-74			C. Flowing, T9.2°C, 3-7-74. Clay 0-129, water enters at 161 ft (owner).
G	22	S	6-10-64	10	D	WL rising 5-26-74, up 1.1 ft in 24 hr; yield based on recovery at 28 ft
H	25	S	5-26-74	0.1	C 30	5-23-74. Well is adequate; water has excessive iron. #249-810-1, ENB-3
I	6	S	8-22-74			Adequate 1952-74 except for 1 or 2 weeks in 2 severe droughts.
J	11	S	5-25-74	20	W	MP1201.21, top of casing. WL 12 ft 12-65 (records). Hand pump, used to
K	18	S	9-17-74	0.2	C 50	water plants. Slow recovery; soft sediment 79.3-80.3 ft, 1974.
L	F	S	6- -64			Sand at 70 ft; ends in gravel (driller) or rock (owner). No flow? 1974.
M	12	S	9-17-74			WL 8.5 ft 5-26-74; well adequate 1955-74; yield occasionally limited.
N	3	S	3-5-74	2.5	D	C. Inadequate in summer 1971-73; recovery slow. Water sometimes cloudy.
O	4	S	3-5-74			Inadequate in summer 1963-69; dry in summer 1970-73. Used winter-spring
P	26	S	6-21-74	0.4	C 50	WL rising 6-21-74, up 4.3 ft in 48 hr since last pumped.
Q	+19	S	5-15-74	0.8	S 18	C.L.W. Flowed 225 gpm, silt + sand in water, during construction; then
R	4	S	9-17-74			casing driven 1 ft deeper to cut yield; 7-ft plug of gravel in casing.
S	4	S	3-5-74			Used for 50 cows 1960-65; used for 20-30 horses 1969-73, inadequate.
T	5	S	6-10-64			Yield small; well sometimes filled from truck, 1000 g. lasted 1 week.
U						#249-810-2, ENB-3.
V	2	S	5-24-74			MP1148.52, top concrete block as of 1974. Surface runoff from barnyard
W	7	S	9-19-74			enters well 3-6-74. Silty gravel 0-12 ft.
X	6	S	3-6-74			Well in cellar; water dark, cloudy. House supplied by spring, to west.
Y	+3	S	6-22-74	20	D	C.L.W. T9°C 3-6-74. MP1142.12,top casing. Silt in water 9-74, see text.
Z	F	D	12-17-68	5	D	L. Flowing 5-24-74, depth 156 ft (1974 surface 1135 ft); nearly plugged
A	+6	S	6-22-74	210	D 84	C.L. DD for 8 hr. Leak (0.5 gpm?) lowered WL 6-22-74. T10.5°C 6-19-74.
B	2	S	6-9-74	2±	C 30	Supplied house, 60 cows pre-1947 to 1970; suction pump, flowed when not
C						in use. Cleaned 1962±, pea gravel added. Replaced after test of Texas
D						Brine WW 1-3 caused 20-ft drawdown. #250-810-2, ENB-3.
E	6	S	3-6-74	5	D	C. WL 48 ft 9-17-74. MP1153.02, top of casing. Well never used due to
F	9	S	6-19-74	7	C 50	poor quality.
G	12	S	6-10-64			Unfailing 1909-74. WL 10.7 ft 5-25-74, 8.8 ft 8-2-74, 9.0 ft 9-17-74.
H						#250-810-3, ENB-3.
I	+8	D	12-16-68	45	D 8	L. 45 gpm is flow. Pumped 75gpm 4 hr, drawdown 3.8 ft in well 5 ft away.
J	+8	D	2-4-69	100	D	Pumped 100 gpm 66 hr, drawdown 7.5 ft in well (TW10?) 24 ft away.
K	F+4	D	1-6-70	250	D 67	C.L. DD for 8 hr. MP1129.45, nipple in cover. Screen 116-126, 139-149ft
L	3	S	9-18-74	35	M	W. Sump pump, runs intermittently when used, discharges into WW1.
M						Depth 1445 ft, 7-in casing to bottom; top of rock from geophysical log.
N	19	S	3-7-74			W. Platform at 10 ft; earth fill above, around 5-in casing. MP1156.19,
O						top casing. Supplied house, barn; failed while testing TBC WW1-3, 1970
P	F	M	1970			Drilled for gas, plugged; flowed 1912-70, water mineralized, not salty.
Q						Drilled out and cemented to 400 ft by Texas Brine Corp.

Table 7.--Records of wells (Continued)

Location	Owner	Use	Date drilled	Method	Well diam (in)	Well depth (ft)	Casing depth (ft)	Depth to bedrock	Finish	Aquifer	Altitude	Line
4250 28 7810 39	George Dersam	H	1970	H	6	56 S	47 D	88+	F	Gravel (DV)	1146	A
4250 29 7810 43	Earl Busch	H		D	30	11 S	10 S		O	Gravel	1165	B
4250 34 7810 37	Texas Brine	H	1970	H	6	78 S	65 D	94	F	Gravel (DV)	1147	C
4250 35 7810 23	Texas Brine	O	1969	H	2	137 D	127 D	175+	G	Gravel (DV)	1125	D
4250 35 7810 23	Texas Brine WW2	N	1970	C	12	137 W	122 W		G	Gravel (DV)	1124	E
												F
												G
4250 35 7810 23	Texas Brine	N	1971	D	48	10 S	2 S		W	Gravel	1124	H
												I
4250 40 7810 38	K W Birge	U		D	30	19 S	0 S		W	Till ?	1160	J
												K
4250 40 7810 38	K W Birge	H	1970	H	6	84 S	26 D	49	P	Till ?	1160	L
									X	Bedrock		M
4250 41 7810 39	K W Birge	H	1958	H	6	59 S	30 M		X	Bedrock	1165	N
												O
4250 44 7810 17	Texas Brine	O	1969	H	2	147 D	127 D	160+	G	Gravel (DV)	1122	P
4250 44 7810 17	Texas Brine WW3	N	1970	C	12	152 D	132 D		G	Gravel (DV)	1122	Q
												R
4250 44 7810 17	Texas Brine	N	1971	D	48	10 S	2 S		W	Gravel	1121	S
4250 44 7810 33	Reginald Dusing	H	1959	C	6	61 S	62 M		O	Gravel (DV)	1148	T
												U
4250 51 7810 33	James T Stevens	H			6	35 S				Sand ?	1160	V
												W
4251 16 7809 57	Texas Brine TW4	O	1968	H	2	105 S	90 D	127	G	Gravel (DV)	1111	X
4251 17 7810 07	Texas Brine TW5	T	1968	H	7	117 D	0 D	115		Gravel ?	1118	Y
4251 18 7809 40	Texas Brine TW1	T	1968	H	7	101 D	0 D	96			1143	Z
4251 18 7809 46	Texas Brine TW2	T	1968	H	7	112 D	0 D	109		Gravel	1127	A
4251 20 7809 53	Texas Brine TW3	O	1968	H	2	92 S	88?D	124	F	Gravel (DV)	1111	B
4251 20 7809 53	TexasBrine TW3S	O	1968	H	2	43 S	32?D			Gravel	1111	C
4251 26 7809 48	Texas Brine TW9	O	1968	H	2	46 S	40 D	115	G	Gravel	1109	D
4251 27 7810 10	Ross Smith	H		D	45	15 S	0 S		W	Gravel	1160	E
4251 31 7809 47	Texas Brine TW8	O	1968	H	2	104 S	100 D	124	G	Gravel (DV)	1110	F
4251 31 7809 47	TexasBrine TW8A	O	1968	H	2	61 S	56 D		G	Gravel	1110	G
4251 31 7810 07	Norman Caryl	H		D	36	13 S	0 S		W	Till	1170	H
4251 44 7809 08	W.M. Baptist Ch	H	1961	C	6	79 S	70 S		X	Bedrock	1136	I
												J
4251 45 7809 07	Herman C Ewell	H	1961	C	6	65 S			X	Bedrock	1134	K
4251 45 7809 11	Frank Koppe	U	1920	C		40 S				Gravel ?	1139	L
4251 47 7809 05	Herman C Ewell	S	1972	C	6	87 S	68 S		X	Bedrock	1140	M
4251 49 7809 08	Frank Koppe	H	1927	V	1	29 M	26 M		T	Sand	1138	N
4251 49 7809 27	Texas Brine TW7	T	1968	H	7	100 D	0 D	97			1110	O
4251 50 7809 35	Texas Brine TW6	T	1968	H	7	86 D	0 D	81			1105	P
4251 51 7809 38	Wesley Spring	S	1971	D		12 M			P	Gravel	1100	Q

Table 7.--Records of wells (Continued)

Line	Water level (ft)		Date	Yield (gpm)	Drawdown (ft)		Remarks
A	3	S	3-7-74				L.W. Slotted casing 47-67 ft. MP1147.73, top of casing.
B	4	S	3-7-74	2	M	3	Sump pump 4 ft away, ran often 3-7-74. Adequate for many years.
C	15	S	5-14-74	10	D		C.L. WL 16.1 ft 6-19-74, 40.2 ft 9-18-74. MP1148.76, top of casing.
D	F	S	6-19-74				L. Depth 83 ft 1974 (same well?), slow response to pumping of TBC WW 2.
E	F+2	W	7-9-70	250	W	59	C.L. T10.8°C 10-17-74. DD for 7 days, from est. static; DD 50ft for 2
F							days. DD 125 ft 5-74 (1 day, 215 gpm). Original depth 142 ft, screen
G							raised after test 3-70. MP1128.1, nipple in concrete cover.
H	1	S	4-29-74	35	M		Sump pump, runs intermittently when used, empties into WW2. MP1124.71,
I	4	S	9-18-74				top of tile, east side. WL 2.8 ft 6-19-74.
J	9	S	3-7-74				Formerly supplied house, inadequate, dry each summer. WL 13.4ft 6-19-74
K	12	S	5-13-74				16.5 ft 8-22-74, 16.3 ft 9-18-74.
L	14	S	3-7-74	1.5	D		C.L. WL rising slowly when measured. Drilled to 208 ft, salt water, so
M	18	S	5-13-74				backfilled to 100 ft; slotted pipe 26-52 ft; cloudy when pumped a lot.
N	14	S	6-10-64				C. Small yield 1974, supplies toilets. Drilled to 83ft, redrilled after
O	35	W	1-19-72				cave-in (owner); depth 62 ft 6-9-64. #250-810-1,ENB-3. WL 29ft 5-14-74
P	F	D	12-8-69	40	D		L. 40 gpm is flow.
Q	F	D	1-19-70	250	D	69	C.L. DD for 8hr. MP1125.63 nipple in cover. WL73ft 7-3-74(120gpm), 62ft
R							8-1-74(81 gpm), 81 ft 8-21-74(105gpm). T14.5°C 8-23-74, 13.7°C 10-17-74
S	3	S	9-18-74	35	M		T16.5°C 8-23-74. Sump pump, pumps intermittently (when used) into WW3.
T	8	M	6-2-59				C.W. Centrifugal pump 1959-70, broke suction while testing Texas Brine
U							WW3. MP1147.51, top of 1-in pipe from sanitary seal in pit.
V	12	S	3-7-74				Hand pump, 2 pails/day. Water had strong brown color, much medium sand
W	31	S	9-17-74				3/74; raised pump 1 ft, water clear but unsafe (bacterial test).
X	+8	D	11-20-68	38	D	8	C.L.W. Temp. profile 10-21-74, 9.6°C at 100 ft. 38 gpm is flow, 11-68.
Y							L. Location as plotted by consulting engineer.
Z							L. Location as plotted by consulting engr., verified by local resident.
A							L. Location as plotted by consulting engineer.
B	+5	S	5-4-74				C.L.W. Later test well here, larger diam, pumped at more than 100 gpm.
C	0	S	5-4-74	75	D		W. Drawdown 5.8 ft after 1 hour 40 minutes, in well 5 ft away.
D	+2	S	5-4-74	75	D		C.W. Drawdown 11.7 ft after 2.5 hr in well 5 ft away.
E	9	S	5-24-74				WL 9.8 ft 8-22-74, 9.4 ft 9-17-74. Unfailing 1956-74; also use cistern.
F	+3	S	5-4-74	60	D		C.L.W. Temperature profile 10-21-74, 9.7°C at 100 ft.
G	1	S	5-4-74	42	D		C.W. DD 8.2 ft in 2 hr at same depth 5ft away; no effect on TW8, 5ft away
H	3	S	3-7-74				Often fails in summer; no water for 5 months in 1973.
I	21	S	5-4-74	18	C	50	Supplies parsonage; sand filter to remove silt. WL 21.4 ft 8-1-74, 21.9
J							ft 8-21-74, 22.0 ft 9-17-74.
K	15	S	6-11-74	40	M		C. WL 14.7ft 5-4-74, 15.3ft 8-1-74, 15.9ft 9-17-74. #251-809-2, ENB-3.
L	30	S	5-4-74				Supplied former dairy barn. WL 31.3 ft 9-17-74. Depth 48 ft(owner).
M	18	S	8-1-74				WL 18.0 ft 9-17-74. Former nearby well 40 ft deep, in sand, inadequate
N							4 more driven wells nearby, similar depth; no water when driven deeper
O							L.
P							L.
Q				4	M	10	L. Well is 8 ft from creek; plotted location + yield are approximate.

Table 7.--Records of wells (Continued)

Location	Owner	Use	Date drill-ed	Method	Well diam (in)	Well depth (ft)	Cas-ing depth (ft)	Depth to bed-rock	Finish	Aquifer	Alti-tude	Line
4251 52 7809 45	Wesley Spring	H				165 M			X	Bedrock	1160	A B
4251 52 7809 45	Wesley Spring	U	1961	C	6	123 S	60 M		X	Bedrock	1160	C D
4252 27 7809 44		T	1967	B		60 D	0 D	60			1163	E
4252 31 7809 32		T	1967	B		84 D	0 D				1160	F
4252 32 7809 23		T	1967	B		67 D	0 D				1155	G
4252 39 7809 28		T	1967	B		62 D	0 D	62			1118	H

Log of well at location 4249 36 7810 31, drilled for U.S. Geol. Survey; log based on field examination of drill cuttings by A. D. Randall. SWL, static water level. Depths are below land surface.

Depth Interval	Materials Penetrated
0 - 10 ft	Silty clay.
10 - 18 ft	Gravel, sandy, mostly silty, some layers clean and water-yielding, SWL 5.5 ft; many flat shale chips in gravel; brown
18 - 38 ft	Sand, fine to very fine, silty; medium to very fine and loose at 25 ft; scattered clay layers generally less than 1/2 inch thick; gray.
38 - 40 ft	Clay, silty, rare small pebbles.
40 - 47 ft	Silt and fine to very fine sand, a few thin clay layers in lower part, gray.
47 - 48 ft	Clay, with embedded sand and small pebbles; most pebbles poorly rounded.
48 - 73 ft	Clay, in part silty, gray.

Table 7.--Records of wells (Continued)

Line	Water level (ft)	Date	Yield (gpm)	Draw-down (ft)	Remarks
A					About 1961, water became salty (or other bad taste). Cement poured
B					into well, yield reduced, taste now good.
C	29 S	6-11-64	1	M	Drilled to replace original well but yield inadequate. WL affected by
D					pumping in original well. #251-809-1, ENB-3.
E					L. Test boring for proposed Linden dam.
F					L. Test boring for proposed Linden dam.
G					L. Test boring for proposed Linden dam.
H					L. Test boring for proposed Linden dam.

Log of well. (continued)

Depth Interval	Materials Penetrated
73 - 80 ft	Clay, with about 10 percent embedded sand and small pebbles.
80 - 84 ft	Sand, chiefly medium to very fine, pebbly at top; may contain thin layers of silty clay with embedded coarse sand; water-yielding, SWL >3.6 ft above land surface.
84 - 90 ft	Sand, very fine, silty.
90 - 112 ft	Silt and clayey silt, a few layers of very fine sand.
112 - 120 ft	Sand, fine to very coarse, pebbly, clean, water-yielding.
120 - 122 ft	Gravel, pebble sizes, subordinate medium to coarse sand, water-yielding.
122 - 140 ft	Clay, silty; gray; some embedded angular pebbles and perhaps sandy layers below 135 feet.
140 - 145 ft	Till, stony, sandy, clayey, blue-gray, tough.

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