HYDROLOGY IN RELATION TO GLACIAL GEOLOGY ALONG THE SUSQUEHANNA RIVER VALLEY, BINGHAMTON TO OWEGO, NEW YORK

by

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INTRODUCTION

Over the past 20 years, several regional and localized studies have increased our knowledge of aquifers in the Susquehanna River basin of New York. This article extracts and summarizes some results of these studies that pertain to sites visited on this field trip along the Susquehanna valley from Binghamton downstream to Owego.

DISTRIBUTION OF AQUIFERS WITHIN THE GLACIAL DRIFT

About 85 percent of the Susquehanna River basin of New York is an upland in which shale, siltstone, and fine sandstone of Devonian age is dissected by narrow valleys and mantled by till. Stratified drift is confined largely to broad valleys, 1,000 to 8,000 feet wide, which occupy the remaining 15 percent of the basin.

During the waning stages of glaciation, tongues of ice extended southward along the broad valleys beyond the main ice sheet. Lakes formed near the ends of the shrinking ice tongues, temporarily filling any space vacated by melting of the ice that lay below the level of stratified drift previously deposited downstream. Many of these lakes were extensive, particularly in the deeper valleys, and trapped much clay, silt, and very fine sand. Elsewhere, particularly in relatively shallow valleys such as the Susquehanna River valley from Binghamton to Owego, smaller lakes and stream channels formed atop and against ice tongues that became too thin to flow. As each small lake filled with sediment, others formed nearby, and water velocities were often great enough to keep fine-grained sediment in suspension. The resulting stratified drift is heterogeneous but predominantly coarse grained, like the idealized sketch in Figure 1 and the actual cross sections in Figures 2 and 3.

Only the coarser sands and gravels within the stratified drift yield enough water to be considered aquifers. Several generalizations may be made as to their distribution within the broad valleys of the Susquehanna River basin:

1. As a rule, the greater the depth to bedrock, the greater the thickness of non-water-yielding clay, silt, and very fine sand. In broad valleys northeast of Binghamton, depth to bedrock generally ranges from 250 to 500 feet. Near and west of Binghamton, depths of 70 to 200 feet are typical, although bedrock is deeper than 250 feet locally. Total thickness of gravel and coarse sand rarely exceeds 150 feet in any of these valleys and can be as little as 10 feet.

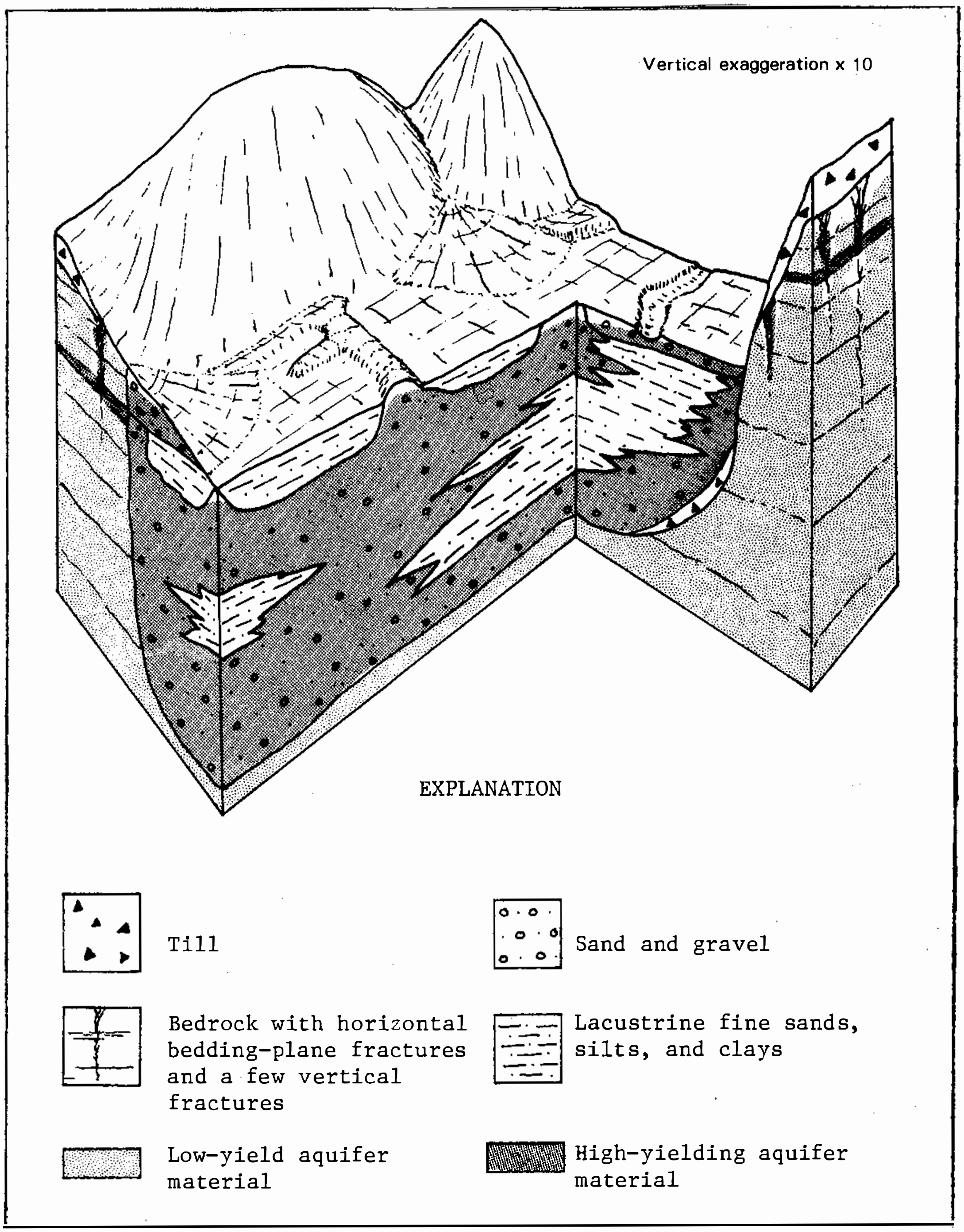

Figure 1. Geology and hydrology typical of broad valleys where ice tongues stagnated. Depth to bedrock is commonly less than 100 feet below stream grade. (From R. D. MacNish, written commun., 1969).

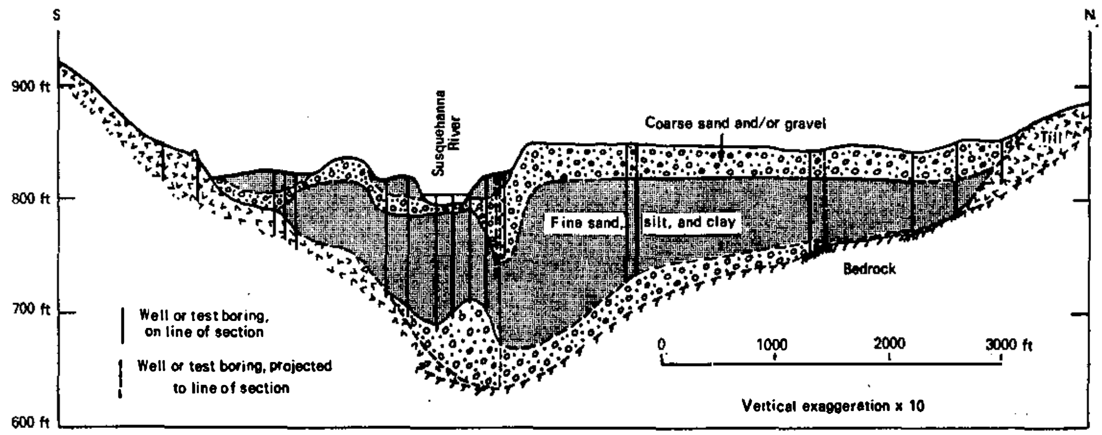

Figure 2. Geologic cross section beneath Route 26 in Vestal and McKinley Avenue in Endicott (Modified from Randall, 1970). Approximate location is shown in figure 7.

2. Sands and gravels are present at or near land surface in all broad valleys. In some places, the near-surface sands and gravels are thin or largely above the water table, but elsewhere they form the most productive aquifers in the basin because they are moderately to highly permeable and generally in hydraulic contact with streams from which water can infiltrate to sustain well yields.

3. Some of the broad valleys also contain basal sand-and-gravel aquifers beneath extensive silts and clays. The basal aquifers tend to be thin or less permeable than the near-surface aquifers and generally yield only moderate quantities of water. The water is commonly of inferior chemical quality, widely characterized by high iron and, in a few places, by high chloride.

4. Locally, the entire thickness of stratified drift is sand and gravel. In the deeper valleys, the condition is generally limited to the sides of the valleys.

LITHOLOGY AS A CLUE TO DEGLACIAL HISTORY AND AQUIFER DISTRIBUTION

MacClintock and Apfel (1944) were the first to call attention to a marked contrast in drift lithology within the Appalachian Plateau of south-central New York. They recognized a "Binghamton" drift whose bright, colorful appearance is caused by numerous pebbles of limestone, chert, quartzite, and other rock types foreign to the plateau, and a contrasting drab "Olean" drift in which limestones generally constitute less than 3 percent of the pebbles, and sandstone or shale of local origin constitute more than 85 percent. They inferred that the two drifts represent successive ice advances from different directions. Later writers

(Merritt and Muller, 1959; Denny and Lyford, 1963; Moss and Ritter, 1962) reinterpreted the drab and bright drifts as facies of a single drift sheet in which the bright facies was largely restricted to some of the major valleys.

In the Susquehanna River valley from Binghamton downstream to the Pennsylvania border, bright outwash forms prominent terraces but is commonly underlain by relatively drab sand and gravel and locally bordered by drab kames or kame terraces at slightly higher elevation (Randall, 1978a). Stratified drift in which 85 to nearly 100 percent of the pebbles are local shale and less than 6 percent are limestone is abundant and may constitute the bulk of the valley fill, even where shallow exposures are much brighter. The bright outwash entered the Susquehanna valley from the broad north-side valleys—Chenango River, Owego Creek, Cayuta Creek—but even these valleys contributed drab sediment, or none at all, when deposition of stratified drift was beginning in the Susquehanna valley.

The stratigraphy described in Table 1 and illustrated in Figure 3 is based on exposures and drilling samples from Binghamton and Johnson City, immediately west of the confluence of the Chenango and Susquehanna Rivers. The bright gravel and sand are part of a valley train extending down the Chenango River valley. Terrace altitudes[1/] descend from 940 feet east of Kattellville, 6 miles north of Binghamton, to 880 feet in Binghamton and to 840 feet near the Broome-Tioga County line, 9 miles west of Binghamton. The terraces do not fall on a single profile, but instead seem to form a set of imbricate profiles dipping downvalley, each steeper than the present stream gradient. This suggests that they may represent successive kame deltas built into a lake or lakes. The bright gravel capping these terraces is highly calcareous and is commonly lime-cemented. In most places, 30 to 50 percent of the pebbles are exotic (that is, unlike the local bedrock). The bright gravel is continuous beneath silt and organic deposits in iceblock depressions and varies widely in thickness, which indicates that it was deposited when stagnant ice was still present in the Susquehanna valley. Drab gravel is exposed locally along the sides of the Susquehanna valley at altitudes that descend from 910 feet in Binghamton to 850 feet near the Broome-Tioga County line. Where penetrated by wells and test holes, the drab gravel ranges in thickness from zero to 75 feet over short distances; much of it is very silty, but clean layers are also common and in places have yielded 250 to 2,500 gallons per minute to wells. These features suggest that the drab gravel originated as ice-contact deposits early in deglaciation. Several holes penetrated sharply contrasting bright and drab gravel separated by many feet of silt, but in holes penetrating only sand and gravel, the content of exotic materials seemed to change gradationally. Till penetrated beneath stratified drift was universally drab (Randall, 1978a).

Distribution of bright and drab sand and gravel near Owego, where Owego Creek joins the Susquehanna River, is similar to that near

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1/ Altitudes here, and in figures 2, 3, and 6, are above the National Geodetic Vertical Datum of 1929, formerly called mean sea level.

Binghamton (Randall, 1978a). Gravel pits in a prominent terrace in the center of the Susquehanna valley reveal at least 40 feet of bright outwash. Near the north end of the terrace, however, a well penetrated sand with drab pebbles beneath the bright gravel. Another well, drilled on the flood plain within the valley of Owego Creek, abruptly entered drab noncalcareous gravel beneath bright gravel (Randall, 1972); although the bright gravel in this well is appreciably lower in altitude than that capping the terrace, it may be a collapsed equivalent. A succession of slightly younger terrace remnants upstream from the village of Owego along Owego Creek are also capped by bright gravel. Drab gravel was not observed along the valley side near Owego, but 4 miles downstream, at Tioga Center and Lounsberry, kames near the sides of the valley are much less bright than younger outwash terraces. Thus, the earliest melt-water streams along both the Susquehanna River and Owego Creek valleys apparently carried very drab sediment (Randall, 1978a).

The evidence summarized above, and additional data described by Randall (1978a), suggest that the last ice sheet to invade this region removed whatever older drift may have been present in the major valleys and that the increase in exotic content of the stratified drift with time is best ascribed to changes in sediment transport during the latest deglaciation rather than to a succession of ice advances. Most exotic materials reached the Susquehanna River valley by transport along broad valleys, probably by one or a combination of the following mechanisms:

1. Preferential flow of ice along the valleys when the continental ice sheet covered the region (Muller, 1965).

2. Tongues of ice continuing to flow south in the valleys beyond active ice in the uplands. Moss and Ritter (1962, p. 104) summarize evidence that such valley tongues were at most a few miles long, however.

3. Englacial or subglacial melt-water streams extending many miles along the valleys, perhaps in active as well as stagnant ice (Randall, 1978a). There is some local evidence that melt-water drainage systems were extensive in or under the retreating glacier. (a) Large volumes of stratified drift were deposited in the broad valleys in proglacial lakes that formed when ice melted below the level of older outwash downstream. By contrast, kames or kame terraces are rare in the uplands, which implies that lakes rarely formed in upland valleys during deglaciation. Some of these valleys drain north for more than 10 miles and descend several hundred feet below the lowest saddles on the divides. The lack of lakes in such valleys seems to require that extensive channels existed in or under the decaying ice sheet to drain melt water into the nearest broad valley. (b) Drab stratified drift between Owego and Waverly, a distance of 14 miles (or 6 miles north-south), is not necessarily all precisely the same age, but all must have been deposited against stagnant ice by south-flowing melt water before the valley of Owego Creek began to carry bright sediment. Thus, at an early stage in deglaciation of the master valley, melt-water drainage on, in, or under stagnant ice must have extended more than 14 miles.

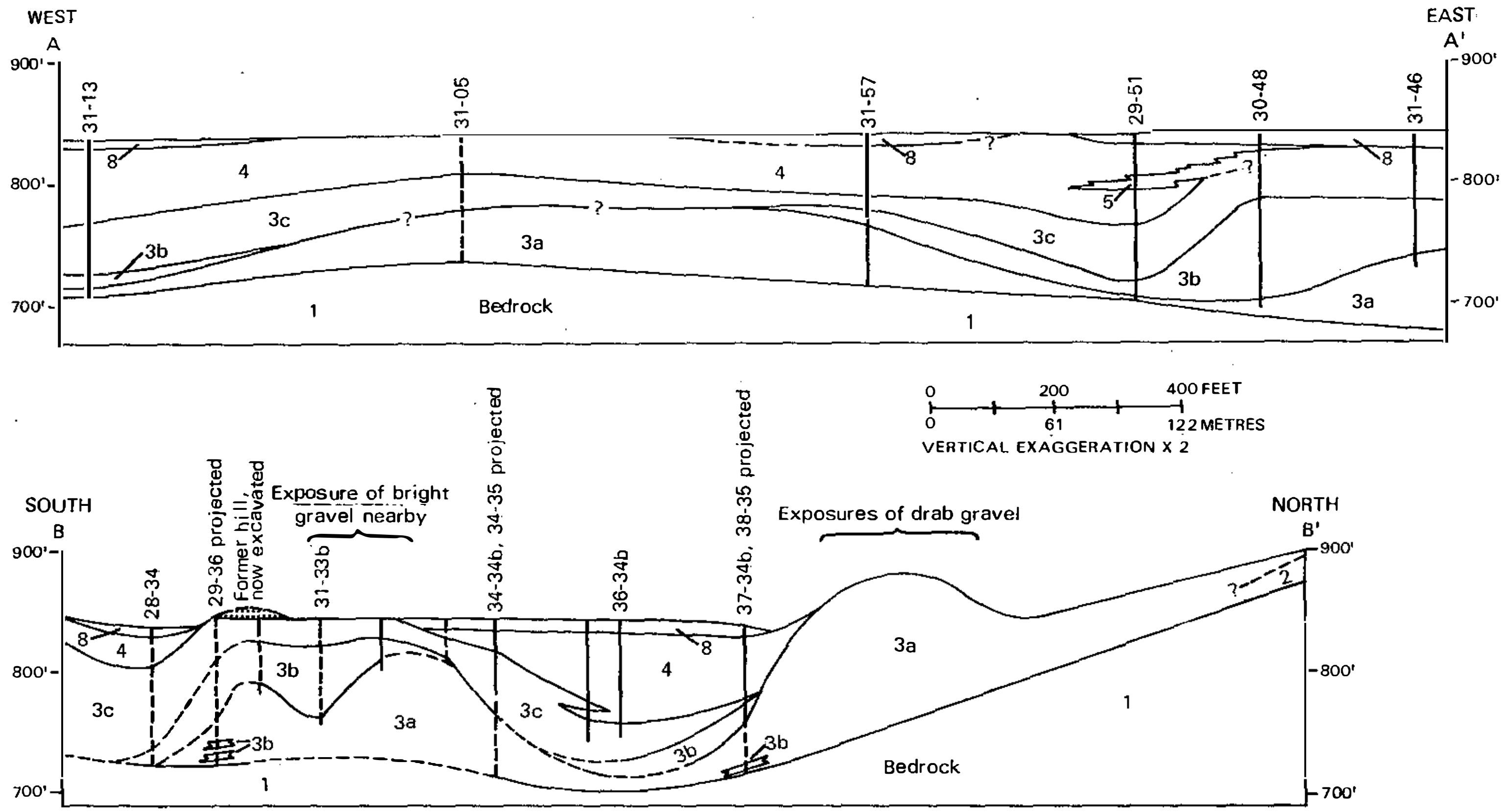


Figure 3. Geologic cross sections in Binghamton (from Randall, 1978a). Numbers in section refer to stratigraphic units in table 1. Wells and test borings are represented by vertical lines, solid where samples were studied, otherwise dashed. Other borings near section B (not shown) were also studied. Vertical numbers are seconds of latitude and longitude ("b" indicates engineering test boring) and indicate that log is published (Randall, 1972). All sites are lat 42°06' N, long 75°55' W (or 75°54' W near east end of section A). Approximate locations of sections are shown in Figure 7.

Table 1. Pleistocene and Holocene stratigraphic units in Binghamton and Johnson City, New York
[From Randall, 1978a]

Stratigraphic unit	Number in figure 3	Lithology, thickness, distribution
Fill	8	Chiefly trash and ashes; some sand, gravel, and other materials. Placed in most natural depressions, 5 to 20 feet thick.
Flood-plain silt	-	Brown silt and very fine sand with roots and little organic matter; typically 5 to 15 feet thick.
Alluvial fan deposits	-	Gravel, moderately sandy and commonly moderately silty; most stones are flat local shale or siltstone. Deposited by small streams entering the Susquehanna River valley.
Older river alluvium	5	Sand and gravel, bright but leached mostly free of limestone; as much as 35 feet thick; interfingers with and overlies unit 4 near Chenango River, where thin silt or silty sand interbeds (unit 4) contain abundant wood and fine organic matter.[a/]
Postglacial or late-glacial lake beds	4	Silt and very fine sand with some clay and scattered fine organic fragments, commonly grading up into peat and highly organic silt; as much as 80 feet thick. Fills ice-block depressions in a narrow east-west zone near the deepest part of the bedrock valley.
Stratified drift:		
Bright gravel	3c	Sandy gravel and pebbly sand with variable amounts of silt; highly calcareous. Upper part very bright (35 to 75 percent exotic pebbles), lower part moderately bright (15 to 30 percent exotic pebbles); ranges in thickness from near zero to at least 100 feet.
Lake beds	3b	Silt to fine sand, some clay, no organic matter; lenses may occur anywhere within unit 3, but seem most common between bright and drab gravels.
Drab gravel	3a	Sandy gravel and pebbly sand with variable amounts of silt; slightly calcareous; 10 percent or less exotic pebbles; thickness varies widely.
Glacial till	2	Typically a stony silt; only a foot or so thick in places, but forms low hills in southern part of valley.
Bedrock	1	Shale and siltstone.

a/ Wood from a well at lat 46°06'25" N, long 75°54'50" W (Randall, 1972) at depths of 24 and 45 feet had radiocarbon ages of 2649 ±79 and 3801 ±60 years, respectively (Randall and Coates, 1973).

Knowledge of the drift lithology is helpful in subsurface correlation and in understanding ground-water quality. For example, the downwarp of the upper gravel layer near the east side of Figure 3A was first recognized from pebble lithology; the downwarp was later verified by water-level and water-temperature data (Randall, 1977). Hardness of ground water, which is caused by dissolved calcium and magnesium, is commonly much higher in the bright stratified drift than in the drab (Ku and others, 1975; Randall, 1977).

SOURCES OF RECHARGE TO AQUIFERS

Ground-water-resource appraisals must not only determine the extent and lithology of aquifers but also evaluate the yield obtainable from each aquifer. Many recent appraisals of the water resources of large drainage basins in New York and New England have evaluated potential aquifer yield by determining representative regional rates of ground-water recharge and applying those rates to the dimensions of each aquifer or area of stratified glacial drift (Cohen and others, 1968, p. 24-46; Crain, 1974, p. 45, pl. 3; Kantrowitz, 1970, p. 67; La Sala, 1968, p. 54; Randall and others, 1966, p. 66; Cervione and others, 1972, p. 46-47). Different sources or components of recharge were treated separately in most of these studies. The principal sources of recharge to stratified-drift aquifers in the Susquehanna River basin are described in the following paragraphs.

Precipitation on land surface above the aquifer

Where sand or gravel are present at land surface, nearly all rain and melting snow will infiltrate, and about half will eventually reach the water table as recharge. (The rest is returned to the atmosphere by plants or evaporation.) Thus, the annual volume of recharge from precipitation to a surficial aquifer depends principally on the extent of surficial sand and gravel and on the annual precipitation rate. Randall (1977) calculated recharge from precipitation to a surficial aquifer in Binghamton and Johnson City.

Precipitation on upland hillsides adjacent to the aquifer

Most stratified-drift aquifers in upstate New York are in valleys bordered by till-covered hillsides. Where the till contains a large percentage of silt and clay, as in the Susquehanna River basin, only a small part of the water from rain or snowmelt infiltrates deeper than the top foot or two; the excess moves downslope in rivulets or through shallow openings in the soil. Where upland hillsides slope toward a stratified-drift aquifer (rather than toward an upland stream), runoff that reaches the permeable sand or gravel in the valley infiltrates there. Annual recharge to an aquifer from upland hillsides depends principally on annual precipitation and on the size of upland areas that slope toward that aquifer. Permeability of soils overlying the aquifer is rarely a limitation.

Natural infiltration from streams

Where the water level in a surficial stratified-drift aquifer is lower than the water surface in a stream crossing the aquifer, water will infiltrate from the stream into the aquifer. In the Susquehanna River basin, this occurs naturally wherever a tributary stream leaves its own valley to flow over the sand and gravel fill of a larger valley (Ku and others, 1975). This is true on all scales. For example, as suggested in figure 4, a tiny ephemeral stream descending a steep hillside loses water where it reaches the narrow flood plain of a creek draining perhaps a square mile, and that creek loses water where it crosses the alluvial gravel that borders a large upland stream draining 10 or 20 square miles. Similarly, the upland stream loses water where it enters the valley of a major river and crosses a thick stratified-drift aquifer or its own alluvial fan.

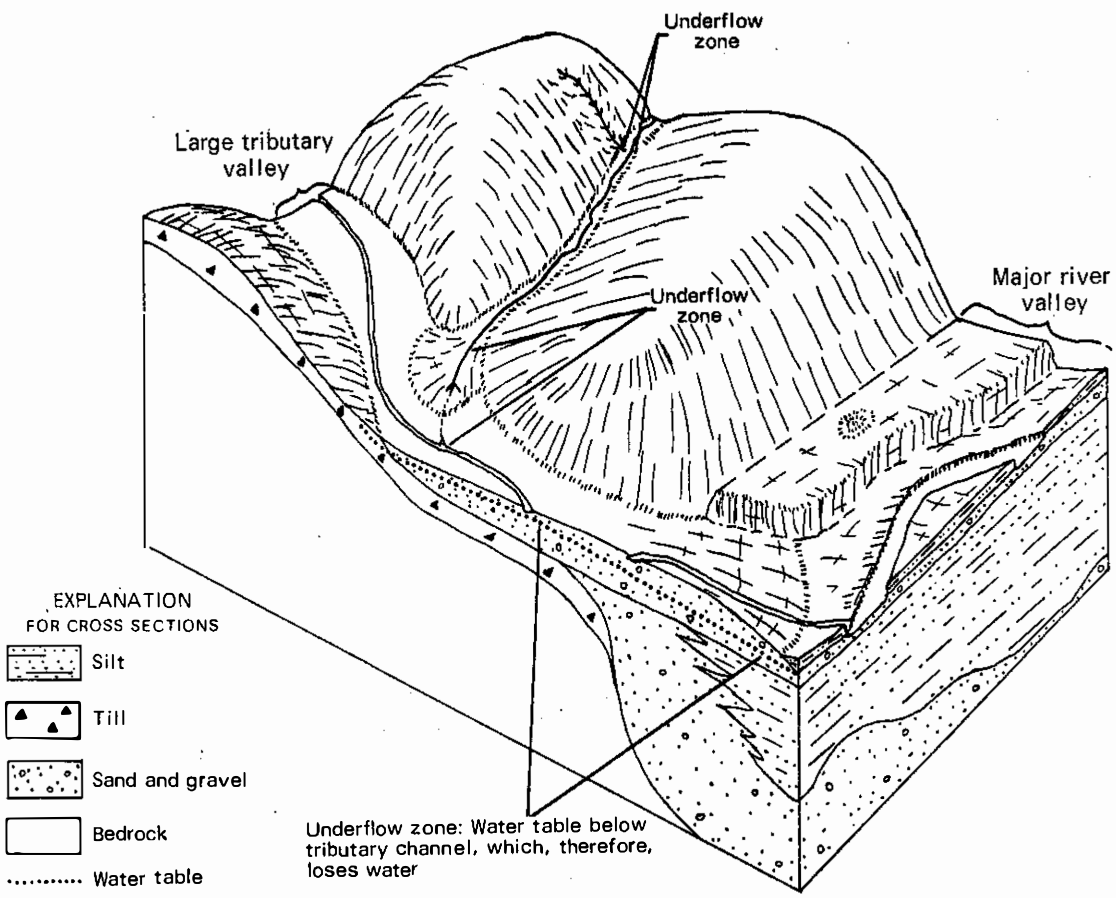


Figure 4. Typical distribution of losing stream reaches. (From Ku and others, 1975).

Infiltration losses from seven tributary streams where they cross stratified-drift aquifers in major valleys were measured and analyzed by Randall (1978b). Flow was measured at the most downstream point at which the channel was known to be cut in till or bedrock, or at least was still clearly within its own upland valley, and at one or more points farther downstream within a major valley, where streamflow losses were expected. Each set of flow measurements was completed within 2 hours. Near the stream reaches studied, the upper 15 to 30 feet of sediment is chiefly compact silty and sandy gravel deposited in alluvial fans by postglacial streams. Upstream from the edges of broad valleys, this alluvium overlies till or bedrock; downstream, it commonly overlies sandy glaciofluvial gravel, and farther downstream a wedge of silt and very fine sand may overlie or replace the glaciofluvial gravel. The glaciofluvial gravel generally has a more varied lithologic composition and a lower silt content than the alluvium and has much greater water-yielding potential. The actual streambed contains loose sandy gravel, generally slightly silty or free of silt.

Each stream studied began to lose water rapidly several hundred feet downstream from where it entered the major valley, or from the lowermost known exposure of till or bedrock in its channel. Measured losses in this zone of rapid loss varied directly with stream length between measurement sites; that is, infiltration per unit length of channel was approximately constant (Fig. 5). By contrast, stream width and depth had little effect on infiltration. Plots of infiltration per unit length against width, and against the product of width and depth, showed no correlation. Along most streams, the uniform maximum rate of infiltration loss per unit length of channel prevails for 300 feet or more when sufficient flow is available. The loss rate for typical streams would be at least 10 liters per second per 100 meters (1 cubic foot per second per 1,000 feet), and average hydraulic conductivity of the alluvium was estimated to be at least 13 meters per day (50×10^{-5} feet per second, or 320 gallons per day per square foot).

Several papers dealing with infiltration from streams state or imply that the rate of infiltration is normally controlled by a thin streambed layer that is less permeable than the underlying sediment (Walton, 1963; Walton and others, 1967; Norris, 1970; Moore and Jenkins, 1966). Nevertheless, evidence cited by Randall (1978b) suggests that infiltration from most tributary streams in the Susquehanna River basin is controlled by permeability distribution within the alluvium or stratified drift rather than at the streambed. Along some tributary streams, rapid infiltration loss begins near where the depth to till and bedrock increases, but along other streams till and bedrock seem to lie far below the channel more than 300 ft upstream from where infiltration increases (fig. 6). Furthermore, the point at which rapid infiltration begins shifts somewhat from one date to another. These changes may be caused by changing water-table configuration within the alluvium—a function of prior infiltration and rainfall as well as of permeability distribution.

EXPLANATION

▲ Point at which stream went dry (infiltration equaled inflow)

● Point of flow measurement downstream from inflow measurement

●——▲ Measurements made on same date

—— Trend line, estimated average infiltration rate

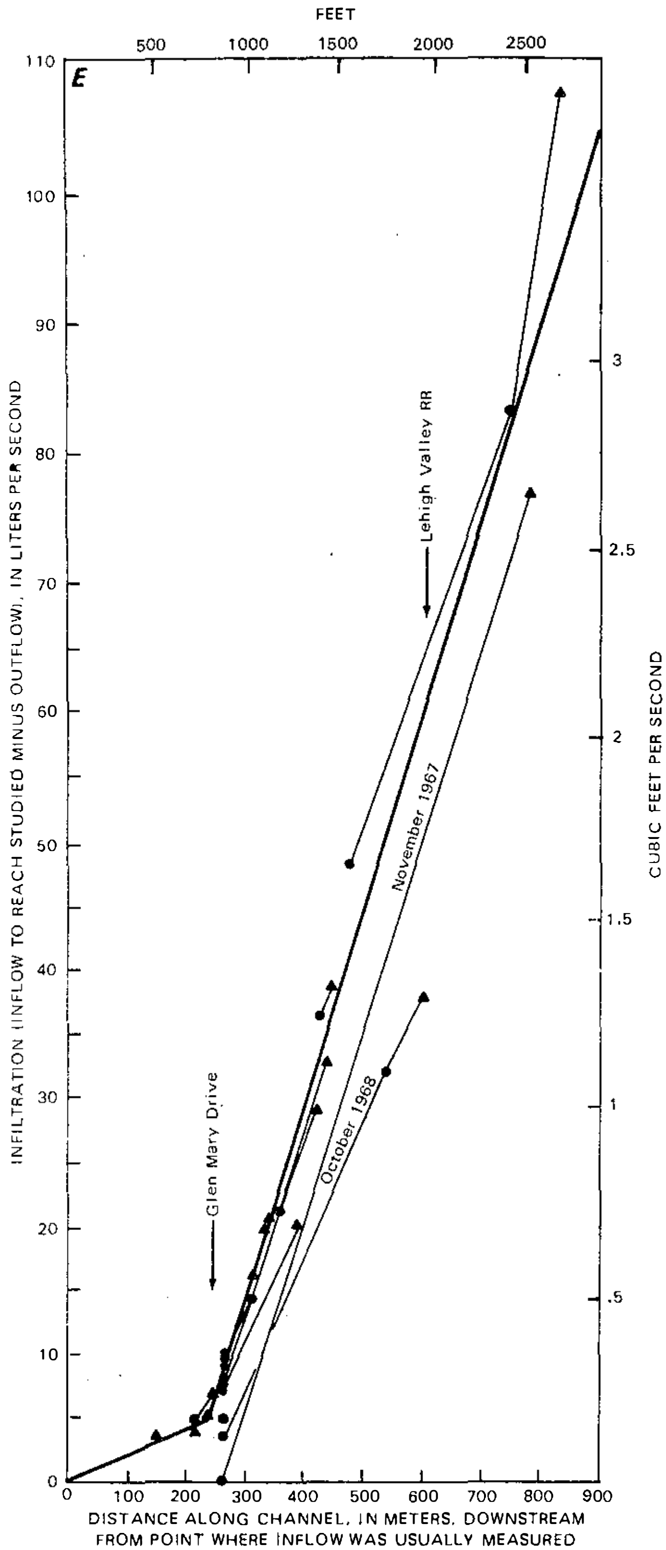


Figure 5. Loss of water from Thorn Hollow Creek in relation to stream length. (From Randall, 1978b.)

EXPLANATION
SYMBOLS IN CROSS SECTIONS
Line of section is along creek

Top of bedrock

Well or test boring, projected perpendicular to stream except as noted. Solid line represents casing, dashed where casing has been removed (test borings) or not used (bedrock). Log available (Randall, 1972) unless otherwise indicated

Streambed cut in dense silt
Stream and point of dryness
Water level in well
} Only on date indicated

Water table

Contact between lithologic units

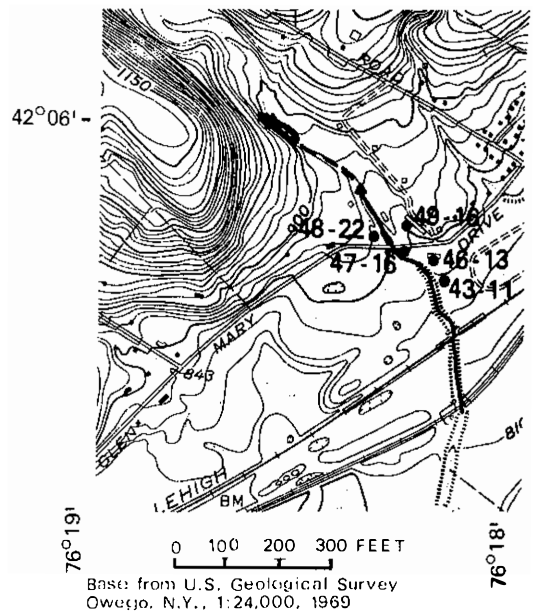
Silty sandy gravel, yields little water to drilled wells; tributary creek alluvium

Sandy gravel or sand, variably silty, in part water yielding; glaciofluvial valley-train deposits

Silt to fine sand; lake-bottom deposits

Glacial till

Uncertain



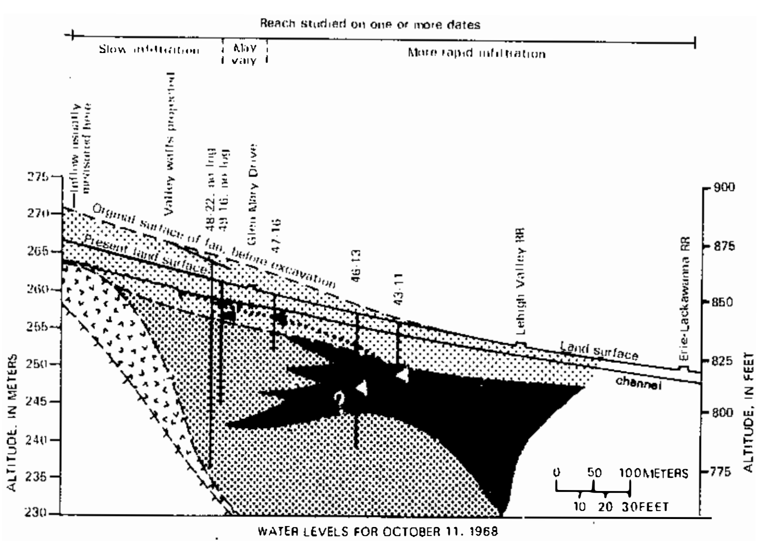


Figure 6. Geohydrologic features along Thorn Hollow Creek. (Modified from Randall, 1978b).

Induced infiltration from large streams

Whenever water levels in surficial aquifers are drawn below stream stage by pumping, infiltration is induced from stream reaches that do not lose water ordinarily. The rate of induced infiltration depends on many factors, including the distribution of wells, pumping rates, hydraulic conductivity of the streambed and nearby parts of the aquifer (which together may be termed "effective streambed permeability"), and changes in stage, bottom area, and water temperature of the stream. Potential induced infiltration from the Chenango River to the Clinton Street-Ballpark aquifer in Binghamton was estimated by Randall (1977, Appendix F), and induced infiltration from the Susquehanna River to the South Street well field in Endicott was estimated by Ground Water Associates (1978). In 1981, water-level distribution around several municipal well fields on the banks of the Susquehanna River will be measured under steady-state pumping conditions and under the transient conditions caused by starting or stopping of pumping. Results are expected to be useful in calibrating a digital model of the stratified-drift aquifers, which should lead to a better understanding of potential induced infiltration and aquifer yield.

GROUND-WATER PROBLEMS AND TRADEOFFS

In most urban areas, numerous competing demands are placed on the local earth resources and landscape. The use or modification of the land to meet human needs generally has some impact, negative or positive, on the quantity or quality of ground water. Several examples from the Susquehanna River valley are mentioned briefly below.

Excavation of river channels

A village of Endicott municipal well 180 feet from the north bank of the Susquehanna River continuously delivered more than 1 million gallons per day of bacteria-free water for 19 years until December 1964, when coliform bacteria were detected in routine weekly water samples. Since then, coliforms have never been absent for more than a few weeks, despite greatly reduced pumping. Randall (1970) demonstrated that the bacteria came from the river and argued that the most likely explanation was repeated excavation of the river bed within 200 feet upstream and downstream of the well for pipeline and bridge construction in the early 1960's. The backfill that replaced the naturally stratified streambed sediments may have been more permeable, permitting greater induced infiltration but also greater movement of bacteria.

Riverbeds have been excavated for many reasons. The Chenango River between the Erie Railroad and DeForest Street in Binghamton has been relocated and deepened at least twice to accomodate dike and highway construction (Randall, 1977). According to a local contractor and dealer in earth materials (R. Murphy, oral commun., 1981) large volumes of gravel were removed before 1970 from four reaches of the Susquehanna River channel between Johnson City and Endicott by draglines that may have dug as deep as 40 feet locally. Each reach was at least 1,000 feet long.

Presumably silt settled in the resulting abnormally deep pools, but its thickness and the net effect of excavation and siltation on infiltration have not been studied.

Lining of stream channels

Several reaches of tributary streams crossing the Susquehanna River valley within the Triple Cities (Endicott, Johnson City, and Binghamton) have been encased in culvert pipe or routed in open channels having a concrete floor and sides. This was done to eliminate the meandering and bank erosion that are characteristic of natural channels but costly in areas of urban development. Randall (1977, p. 31) noted that continuation of this process would eliminate recharge from such streams and suggested that recharge could be increased if needed by digging multiple parallel channels or by replacing the oily and silty streambed sediment in other reaches by clean gravel.

Paving of recharge areas

Pavement and buildings covered a substantial part of the Clinton Street-Ballpark Aquifer in 1967, and Randall (1977, appendix E) estimated that, as a result, about 2 inches of recharge that would have occurred annually under natural conditions was lost as storm runoff. However, he also estimated that evapotranspiration had been reduced by at least 4 inches because of lowered water tables due to intensive ground-water development and through the replacement of soil and plants by buildings and paved surfaces. If so, the amount of water available for pumping under the degree of development prevailing in 1967 exceeded that which would have discharged naturally to streams had the city not been there.

Landfills

Innumerable studies have shown that leaching of municipal refuse by infiltrating precipitation or rising ground water produces a strong chemical solution characterized by a large oxygen demand, an offensive odor, and several thousand milligrams per liter of dissolved solids (Zanoni, 1971). Traces of leachate have been recognized at distances of several thousand feet from landfills in permeable glacial outwash (Kimmel and Braids, 1974).

In the 1950's and earlier, some industrial wastes reportedly were dumped east of Charles Street in Binghamton, above part of the Clinton Street-Ballpark aquifer. In 1958, traces of chemicals ascribed to the wastes reportedly were detected in nearby GAF wells 2 and 4 and led to the abandonment of these wells, although no problems were reported at other nearby wells (Randall, 1972; A. Schmidt and others, GAF Corp., oral commun. 1965).

In the late 1960's, the Broome County Board of Supervisors considered establishing a regional municipal landfill in a large gravel pit on Prentice Road in Vestal, which offered advantages in location and capacity.

However, the edge of the pit was only a few hundred feet east of Vestal municipal wells 4-2, 4-3, and 4-4, and the likelihood of adverse impact on ground-water quality was a major factor leading to a decision to look for a site elsewhere (R. J. Martin, consulting engineer, written commun. 1969).

In the 1970's the Village of Endicott operated a large landfill immediately west of their sewage-treatment plant near the north bank of the Susquehanna River. No problems due to ground-water contamination have been reported (R. Austin, Broome County Health Dept, oral commun. 1981). Note, however, that during construction of the Endicott sewage-treatment plant, dewatering pumps withdrew about 5,000 gallons per minute to lower the water table 25 feet (Randall, 1972), which demonstrates presence of a highly productive aquifer; the dedication of this area for a sewage-treatment plant and landfill may have precluded for the time being any use of that aquifer.

Organic fluids

In urban areas such as the Triple Cities, hydrocarbon fuels (including gasoline, kerosene, and fuel oil) and liquid organic chemicals (including solvents and cleaning fluids) are widely used, transported, and stored. Although most of these liquids have slight solubility in water, the minute quantities that can dissolve cause objectionable tastes and odors in drinking water and (or) have been shown to be toxic. Some are volatile to the extent that vapors evolved from films floating on the water table can be explosive or toxic in basements. Over the years, several instances of leaks, spills, or disposal of these liquids have been reported, and the geologic setting of each has influenced the outcome.

In 1965, a petroleum pipeline crossing the State University of New York campus in Vestal was ruptured by a backhoe excavating for new buildings; 29,000 gallons of gasoline erupted and flowed downslope toward the Susquehanna River. About half of it was recovered within hours by pumping from the initial excavation and from ditches and sumps dug downslope (Binghamton Press, Sept. 1965; C. J. Yablonski, Sun Pipeline Co., oral commun., 1981). No ground-water contamination was reported, probably because the rupture and runoff of gasoline was confined to an area underlain by impermeable till in which most buildings were served by public water systems.

In 1979, a leak was discovered in a large tank used to store solvents at a factory in Endicott. Investigation disclosed more than 12,000 gallons of chlorinated hydrocarbons (chiefly methyl chloroform and trichloroethylene) in the subsurface (Dames & Moore, 1980). More than 100 observation wells were drilled to define the extent of the contamination and help devise a method of recovery (Dames & Moore, 1980). Efforts to recover the solvents have been simplified by the stratigraphy in the immediate locality, which consisted of a surficial gravel generally 15 to 35 feet thick having a saturated thickness of 3 to 15 feet, resting upon a few tens of feet of silt and clay (Dames & Moore, 1980; Randall, 1970, fig. 5). The silt and clay must have greatly retarded downward migration of the solvents, which are heavier than water and sank to the bottom of the surficial aquifer (Dames & Moore, 1980). The surficial aquifer is not tapped as a source of water locally but seems to be continuous laterally with thicker aquifers elsewhere along the valley.

In 1980, water samples collected from public-supply wells and numerous points in the water-distribution systems of the Triple Cities were analyzed for several organic chemicals (New York State Department of Health, written commun. 1981). Samples from Vestal municipal well 4-2 on Prentice Road consistently contained 1,1,1-trichloroethane, trichloroethylene, and tetrachloroethylene, in concentrations as high as 217, 92, and 14.8 micrograms per liter, respectively (New York State Department of Health, written commun, 1981). The New York State Department of Environmental Conservation has set a limit of 10 micrograms per liter for discharges of trichloroethylene to potable ground water; no standards have been set for the others (New York State Department of Environmental Conservation, 1980). The New York State Department of Environmental Conservation (1980) and Parratt-Wolff, Inc. (1980) have investigated the contamination, and both report that one possible source is a chemical plant 200 feet west of well 4-2 that repackages chemicals including 1,1,1-trichloroethane, trichloroethylene, and other chlorinated solvents, and has discharged water from rinsing empty containers to a leach pit. In this locality, the glacial drift consists almost entirely of sand and gravel of variable silt content (Parratt-Wolff, 1980; Randall, 1972), which may have favored migration of the organic solvents to the depth of the well screen.

A LIMITED ALTERNATIVE: THE BEDROCK AQUIFER

Most studies of ground water in the Susquehanna River basin in New York have emphasized the stratified-drift aquifers because of their potential for high-yield wells, even though these aquifers underlie no more than 15 percent of the basin. Bedrock, chiefly siltstone and shale of Devonian age, underlies 100 percent of the basin and has been tapped by many wells to meet domestic and other small yields. A well drilled at any point in the basin stands a very good chance of obtaining enough water for a single-family home, although "dry holes" yielding almost no water are occasionally reported (Wetterhall, 1959; Soren, 1963; Randall, 1972). Wetterhall (1959) reports the average yield of wells tapping bedrock in Chemung County to be 8 gallons per minute. This average may be somewhat misleading, however, for two reasons: First, it is based on mostly domestic wells in which drilling was stopped as soon as the owner's needs were met, without attempting to determine the maximum yield of fresh water obtainable from the bedrock. Second, no one has studied the yield of the bedrock aquifer to clusters of wells, as distinguished from the yields of individual wells. One might ask: if 200 homes were built on contiguous half-acre lots and were supplied by individual wells, would the yield of all these wells average close to 8 gallons per minute? It seems reasonable to expect the cone of depression to be deep enough that wells near the center would have smaller yields than wells near the perimeter, but how much smaller cannot be easily predicted at present.

Near the Triple Cities, residents of some planned or unplanned concentrations of homes that were initially supplied by private wells later voted to form water districts and import public water, in part because of fear of water shortages. Study of several such clusters should lead to at least a semiquantitative relationship between maximum drawdown and cluster density, total demand, and topographic setting. In principle, it should be possible to specify limits of size and location within which a cluster of individual wells could be expected to function indefinitely, thus avoiding the cost of providing duplicate water systems and making maximum use of local resources before importing water.

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ROAD LOG
HYDROLOGY IN RELATION TO GLACIAL GEOLOGY, SUSQUEHANNA VALLEY, BINGHAMTON TO OWEGO

[Route and location of stops are shown in Figure 7]

CUMULATIVE MILEAGE	MILES FROM LAST POINT	ROUTE DESCRIPTION
0.0	0.0	Intersection of Route 434 (Vestal Parkway) and main entrance of State University of New York campus in town of Vestal, New York. Proceed west on Route 434 to Owego.
11.7	11.7	Marshland Road on right; continue on Route 434; note level terrace surface on right.
12.7	1.0	Pause on road shoulder.

HESITATION STOP. Pit on left, in the highest (oldest) stratified drift in this part of the valley: cobble-boulder gravel to coarse sand, variably silty (piles of coarse gravel rejected by operator are visible); pebbles are relatively drab (few limestones); topography is irregular, maximum altitude 880 feet; wet areas on pit floor suggest till at shallow depth. Barn on right marked "Tioga Manor"; trip will return past this barn.

17.7	5.0	Turn right (north) on Route 96, cross steel bridge over Susquehanna River, enter Village of Owego.
18.0	0.3	Turn left (west) on Route 17C (Main Street).
18.8	0.8	Cross bridge over Owego Creek.
19.3	0.5	Deep Well Motel is on right; Route 17C is on nearly level surface of valley train.
19.5	0.2	Entrance (on left) to pit owned by Concrete Materials, Inc.
19.6	0.1	Entrance (on left) to pit owned by C & C Ready Mix Corp.

STOP 1. KAME DELTA, BRIGHT GRAVEL. Stop 1 will be in whichever of these two pits offers the better exposures on the date of the trip. Topset and foreset beds of bright gravel have been observed beneath the valley-train surface; lower terraces are capped by bright fluvial gravel overlying fine-grained lake-bottom sediments.

--	-?-	Leave pit, turn left (west) on Route 17C.
23.8	4.2	Tioga Center; school on right at intersection.
24.0	0.2	Bear slightly right on dirt road.
24.1	0.1	Turn right at second driveway; proceed to gate at entrance to pasture and gravel pit owned by Kenneth Pipher. Be sure to close gate after entering.

STOP 2. KAMES AND ICE-CHANNEL FILLING, DRAB GRAVEL. Several pits in the kamic features in this locality revealed drab gravel and sand with very few limestone or other exotic rock types; west-dipping foresets have been observed. Maximum altitude is 860 feet, well above the bright valley-train surface to the east.

--	-?-	Return to Route 17C, turn left (north).

26.9	2.8	Turn left on Glen Mary Drive, just before Route 17C rises to cross RR.
28.1	1.2	Cross Thorn Hollow Creek, park along road.

STOP 3. GROUND-WATER RECHARGE FROM THORN HOLLOW CREEK. In 1967-68, streamflow measurements on 15 dates showed a loss of about 0.02 ft^3/s (10 gal/min) per 100 feet of channel upstream from Glen Mary Drive and 0.16 ft^3/s per 100 feet downstream. During most of the year, this stream goes dry somewhere on its alluvial fan.

		Continue northeast on Glen Mary Drive.
29.1	1.0	Intersection; turn right and immediately cross RR.
29.6	0.5	Intersection; turn left.
29.7	0.1	Intersection with Route 17C; continue east (straight ahead).
30.1	0.4	Cross bridge over Owego Creek.
30.9	0.8	Turn right, follow Route 17C past county courthouse.
31.0	0.1	Drive straight ahead across bridge (Route 17C turns left).
31.3	0.3	Turn left (east) on Route 434.
34.9	3.6	Turn left on Marshland Road, go under expressway.
35.7	0.8	Note road bordered and arched over by large maples.
36.2	0.5	Tioga Manor barn on right. Behind barn is a hummoky surface 820-830 feet in altitude; a small pit revealed 1.5 feet of highly calcareous,bright, fine-pebble gravel with abundant limestone atop several feet of drab gravel.
36.5	0.3	Pause beside road.

HESITATION STOP. View to right of oval hill in midvalley, composed of (or perhaps heavily mantled with) till. Terraces at about 830 feet altitude between the road and the hill, now largely excavated, were capped by bright fine-pebble gravel and coarse sand.

38.1	1.6	End Marshland Road; turn left (east) on Route 434.

42.2	4.1	Tracy Creek; pause on road shoulder near bridge.

HESITATION STOP. The reach of Tracy Creek beneath the bridge visible to the right was dry on all eight occasions when visited by the U.S Geological Survey in the summers of 1962-65 as part of a study of low streamflow in the Susquehanna River basin. Like most tributary streams, Tracy Creek suffers severe seepage loss when crossing the stratified drift in the Susquehanna River Valley. Upstream 2,000 feet, where the creek has cut a gorge through till and bedrock, a small flow continued throughout the 1962-65 drought.

44.6	2.4	Cross Choconut Creek.
45.1	0.5	Turn left at traffic light on Bridge Street.
45.3	0.2	Pass under expressway, turn left on narrow road.
45.4	0.1	Turn left on dirt road; Vestal municipal well is in well house on right.
45.6	0.2	Cross dike, bear right; park.

STOP 4. VESTAL WATER DISTRICT 1 WELL FIELD. Three municipal wells tap sand and gravel between 70 and 150 feet in depth. Induced river infiltration is potentially an important source of recharge; temperature profiles in April 1981 indicate river water infiltrated past well 1-3 at a time when only well 1-2 was in use. The sand and gravel seems to be relatively drab, perhaps totally drab near the base.

46.1	0.5	Return to Bridge Street, turn left.
46.2	0.1	Turn right (east) at traffic light on Old Vestal Road.
49.2	3.0	Turn left on Prentice Road.
49.5	0.3	Park beside road.

STOP 5. VESTAL WATER DISTRICT 4 WELL FIELD. To the west is municipal well 4-2, water from which was found to contain organic solvents in 1980 (see text). To the north are two more municipal wells. To the south are numerous oil tank farms. To the east, the land was once level with Prentice Road, but has been excavated for gravel; the owner plans to mine gravel below the water table by dragline both east and west of the road. The pit to the east was once considered as a site for a municipal landfill

--	-?-	Turn around, return to Old Vestal Road.
49.8	0.3	Turn left (east) on Old Vestal Road.

51.5	1.7	Turn left on ramp up to Route 201, toward Johnson City.
52.2	0.7	Traffic circle on north side of bridge, continue on 201 (2/3 of the way around the circle).
52.9	0.7	Bear right on ramp, join Route 17 east.
53.9	1.0	Take exit for Stella-Ireland Road.
54.1	0.2	Turn left (north) on Stella-Ireland Road.
55.0	0.9	Flood-control reservoir is on right, on Little Choconut Creek.
55.5	0.5	Turn left at traffic light (Lewis Road); then immediately turn right on Rhodes Road.
56.0	0.5	Top of steep grade, stop beside road.

STOP 6. VIEW OF HOUSING CLUSTER. All homes in this area have public sewers and on-lot wells tapping bedrock. In 1981, water levels were as deep as 100 to 130 feet seasonally in some wells on Rhodes Road, and yields of a few wells were not as large as desired by occupants. Further building has been proposed downslope.

--	(?)	Turn around; retrace route following Stella-Ireland Road, Route 17 west, Route 201 south; cross Susquehanna River on Route 201, go past Old Vestal Road.
60.7	4.7	Bear right on ramp to Route 434 east.
61.0	0.3	Entrance to State University of New York campus.

END OF TRIP

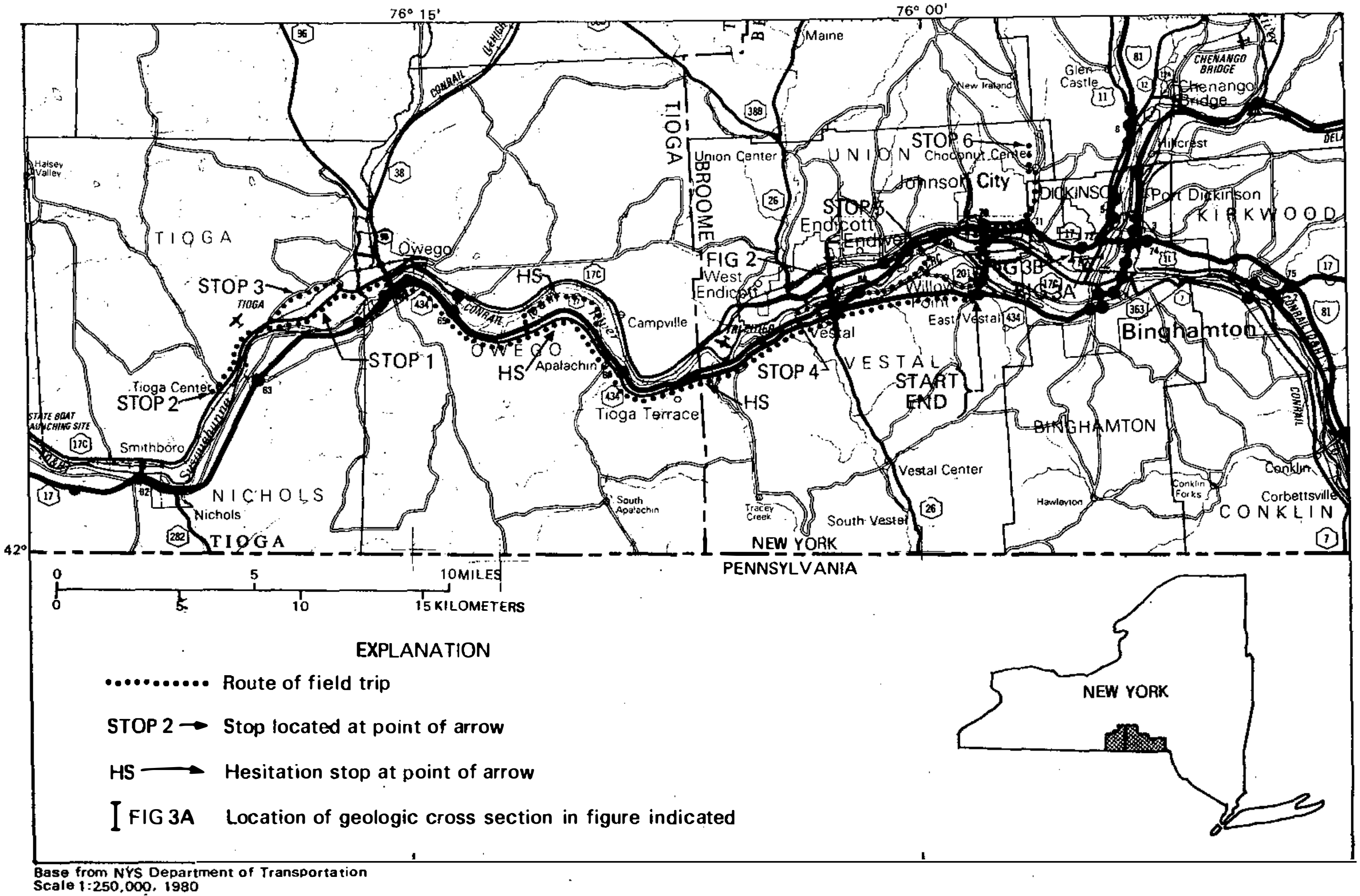

Figure 7. Location of field-trip stops and geologic cross sections.