QUATERNARY GEOLOGY AND WATER SUPPLY ISSUES

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INTRODUCTION

Scope

While specialists in water resources have always been aware of the connection between recent geologic sediments and water supply issues, concerns have heightened during the past 15 years. Across the nation, Source Water Assessment Programs (SWAP),Wellhead Protection Programs (WHPP), new turbidity standards for drinking water, etc., are responses to outbreaks of giardiasis, cryptosporiodosis, and other concerns such as viruses as hitch-hikers on colloidal particles and the inability of traditional chlorination to treat these parasites. SWAP and WHPP also counter concerns for landfills, outfalls, agricultural runoff, and other point or non-point source contamination.

During stops 1, 2, and 3 (Figure 1) on this trip, we will pay particular attention to SWAP and WHPP issues at the recently renovated Village of Forestville Hall Springs and the long occupied Village of Sinclairville wellfield. This guidebook article particularly zeros-in on aquifer characterization and relationships to source areas, natural filtration of microparticulates and associated phenomena such as dilution.

Stops 1 through 5 (Figure 1) aid in understanding water well drilling successes and failures. Public and private water wells north of the St. Lawrence-Mississippi drainage divide in Chautauqua County have had low productivity. While gravel deposits and sometimes the fractured top of bedrock have moderate to high hydraulic conductivities, these zones north of the drainage divide are typically poorly recharged due to extensive confinement. Confinement relates not only to shifts in ice marginal environments but also to melt-out of underlying ice which yielded structural failure of the sediment masses and consequent abrupt changes in sediment hydraulic conductivities. The sediments exposed in cross-section in gully walls and landslide blocks, and indicated by cores, help to visualize the situation (Stop 5). Also, for those interested, the Sunday trip (this guidebook) visits a buried valley exposure with abrupt changes in hydraulic conductivities.

Turbidity sources, effects and human responses regarding drinking water from reservoirs and stream diversions are especially covered in Stops 5 to 7 (Figure 1). One of the nastier problems locally is the loss of reservoir capacity, in addition to upgrading filter plants. Which reservoir receives high sediment loads depends partly on reservoir design and partly on subtle glacial features such as end moraine control of watershed boundaries or stratigraphic control of erosive seepage or landslides.

Setting

Figure 2 is an index map for Chautauqua County municipal water supplies. Chautauqua Institute uses a surface water source, Chautauqua Lake. Otherwise, supplies north of the St. Lawrence-Mississippi drainage divide are surface waters and sources to the south are goundwaters. While the Forestville spring collectors (Stop 1) are north of the Mississippi River divide, the spring source waters (Stop 2) are south, as are Forestville's wells. With the exception of Cherry Creek's springs (fractured top of bedrock), all the groundwater sources are sandy

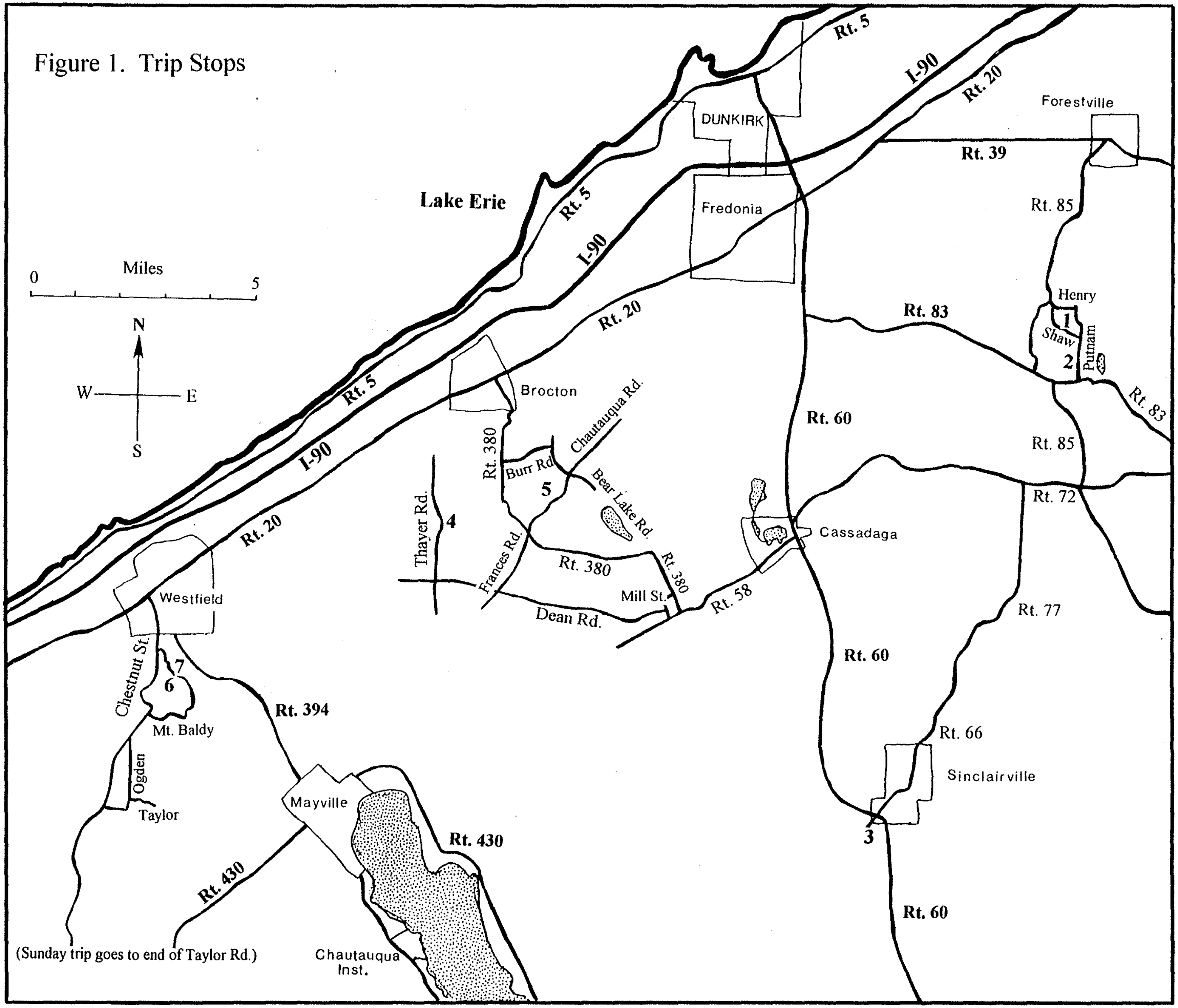


Figure 1. Trip Stops

gravels. Surface sources (north of the divide) are small reservoirs, with Westfield's Minton Reservoir supplemented by partial diversion of Chautauqua Creek. The City of Dunkirk draws from Lake Erie, and beginning in the 1990s, the Village of Silver Creek abandoned its reservoirs and connected to the Erie County, New York, Water Authority (Lake Erie). Most of the reservoirs have been plagued with high turbidities and excessive sedimentation.

WHP areas for municipal supplies are shown in Figure 2. The extensive primary protection areas that lie between Sinclairville (Stop 3) and Jamestown are the fan-delta deposits on the margins of Cassadaga Creek valley. These alluvial fan and delta gravels and sands interfinger with a continuous 20-foot thick gravel under an extensive 100 foot thick silt. This confined gravel aquifer is known as the Jamestown Aquifer (Crain 1966). Streams flowing off the uplands lose water into their beds as they cross the fan-delta gravel deposits which then recharge the aquifer. The City of Jamestown is supplied by this aquifer and the Village of Sinclairville wellfield (Stop 3) lies in one of the fan-delta deposits.

Other municipal well supplies occur in valley-bottom settings generally similar to Sinclairville or Jamestown. Most of these large valleys have bottoms that are a mile or two wide and underlain by sediments several hundred feet thick. Composition of sediments at depths greater than about one-hundred feet are poorly understood. The Appalachian or Alleghany Plateau that occupies about three-fourths of the county is roughly segmented by about a half dozen of these large valleys oriented in mostly northwest-southeast directions. The uplands between the valleys commonly create 500 feet of relief. The upland surfaces form a gently rolling plateau covered with drumlins oriented northwest (Muller, 1963). The underlying bedrock is composed of 1,000 or more feet of Devonian-age shale with 10% siltstone and sandstone in the north and much larger amounts of sandstone to the south (Tesmer, 1963). The bedrock dips 20 to 40 feet per mile southward and contains very modest structures such as 10 foot amplitude, 100 foot wavelength folds at quarter or half mile intervals.

The northern portion of Chautauqua County borders Lake Erie and contains the Lake Erie Plain. The lake plain has very low relief and is about 2 miles wide to the southwest and 5 miles wide to the northeast, typically extending a mile south of Rt. 20 (Figure 1). The lake plain and plateau are separated by the Portage Escarpment (also called the Allegheny Escarpment). The name Portage comes from attempts by the French army in the 1750s to establish a portage over the escarpment in order to link a canoe route between the eastern Great Lakes and their fortifications at Pittsburgh. Today, reservoir watersheds occupy the steep escarpment ravines (Stops 5 to 7). The drainage divide between the escarpment ravine headwaters and the southerly draining Mississippi headwaters is known as the Lake Escarpment Moraines (Muller, 1963). These glacial end moraines are thought equivalent to the Valley Heads Moraines to the east (Muller, 1963; Muller and Calkin, 1993). The Forestville Springs form by water percolating through outwash south of the Lake Escarpment Moraines and draining northward back under the moraines and out the escarpment face.

Figure 2.

SW New York Water Utilities

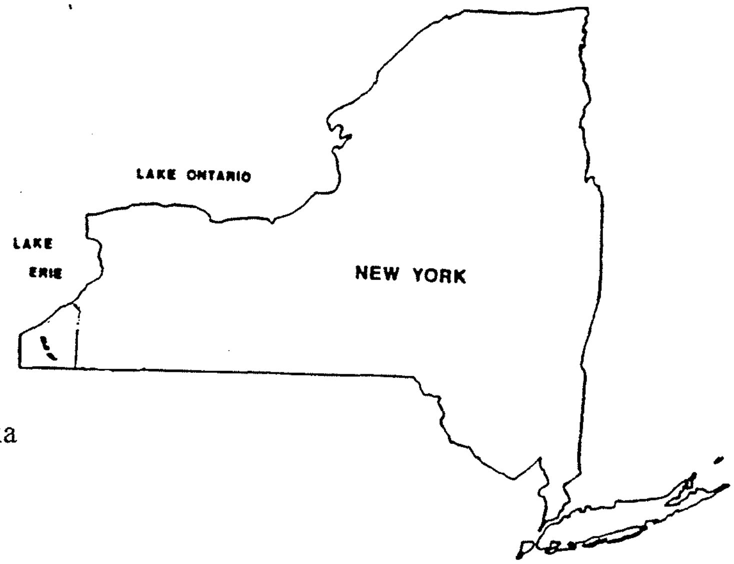
Lake Erie: Dunkirk, Silver Creek

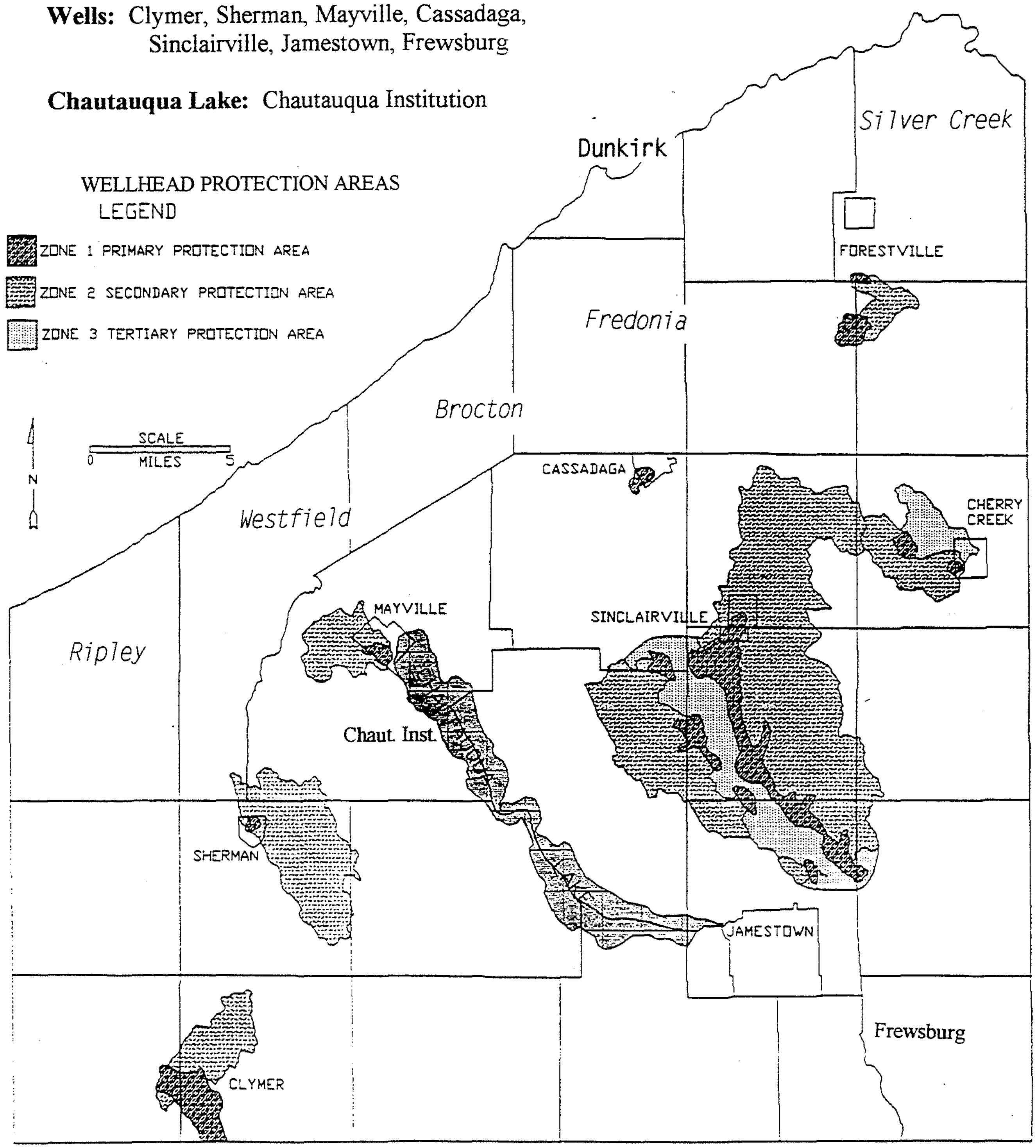
Reservoirs: Ripley, Westfield, Brocton, Fredonia

Springs (and wells)**:** Forestville, Cherry Creek

Wells: Clymer, Sherman, Mayville, Cassadaga,
Sinclairville, Jamestown, Frewsburg

Chautauqua Lake: Chautauqua Institution





FORESTVILLE HALL SPRING SYSTEM AND PRODUCTION WELLS 6 and 7

Hydrogeologic Setting

The Village of Forestville utilizes three spring systems and two drilled wells to meet their potable water demands. These ground-water collection devices are located 1.5 to 3.5 miles south of the village. Figure 3 shows locations for the two principal springs, two production wells, and one non-producing well (#5). This guidebook reviews Hall Spring and the wells (Henry Spring is similar and the third spring has inconsequential production).

Unconsolidated surficial deposits across northern Chautauqua County consist of glacial till (matrix of silt with clay and sand; clasts dominated by Canadian granitics, Medina sandstones, Lockport dolostone, Onondaga limestone, and local shale and sandstone) and sand and gravel outwash. Near-surface bedrock at this site consists of Upper Devonian, Northeast Shale (Tesmer, 1963). Various other shales (with about 10% sandstone) extend a thousand feet below the site.

The study site contains several unique physiographic features. The Lake Erie-Allegheny River divide transects the area bordering the drainage basins for Hall spring and Henry spring (Figure 4). A buried bedrock valley was described by Wilson and others (1983; using well logs, geophysics and surface mapping) as obliquely undercutting the divide. This through valley was filled by glacial drift and lies below the spring areas. This buried valley occurs (Figure 5) beneath the West Branch of Conewango Creek south of the study area and beneath Walnut Creek and its tributaries to the north. Near the study area, the buried valley is confirmed to be at least 334 feet deep by drilling records, and estimated to be 450 feet deep using geophysical methods (Wilson and others, 1983).

Water Use

The Village's public water supply serves about 725 people and several businesses. Water yields from the springs decreased into the early 1990s and although new wells were drilled, they provide minimal quantities of water. These wells (6 and 7) were drilled in response to declining spring production. Because of poor well production, and our evaluation of aquifer geometry and evidence that the spring source waters were **not** likely to be classified as "ground water under the direct influence of surface water," the spring collectors were rebuilt in 1995 and 1996.

In 1991 the average daily water use in Forestville was 156,700 gpd, and in 1992 was 143,400 gpd. The Village was able to reduce daily use at the end of 1992 by performing repairs to water mains and services. However, when ground-water production was near the minimum (100,800 gpd) the Village could not meet its average daily water demand in late 1992 (126,600 gpd) even though the system was operating conservatively (i.e. no major water leaks). Consequently, Henry and Hall springs were reconstructed in 1995 and 1996, respectively.

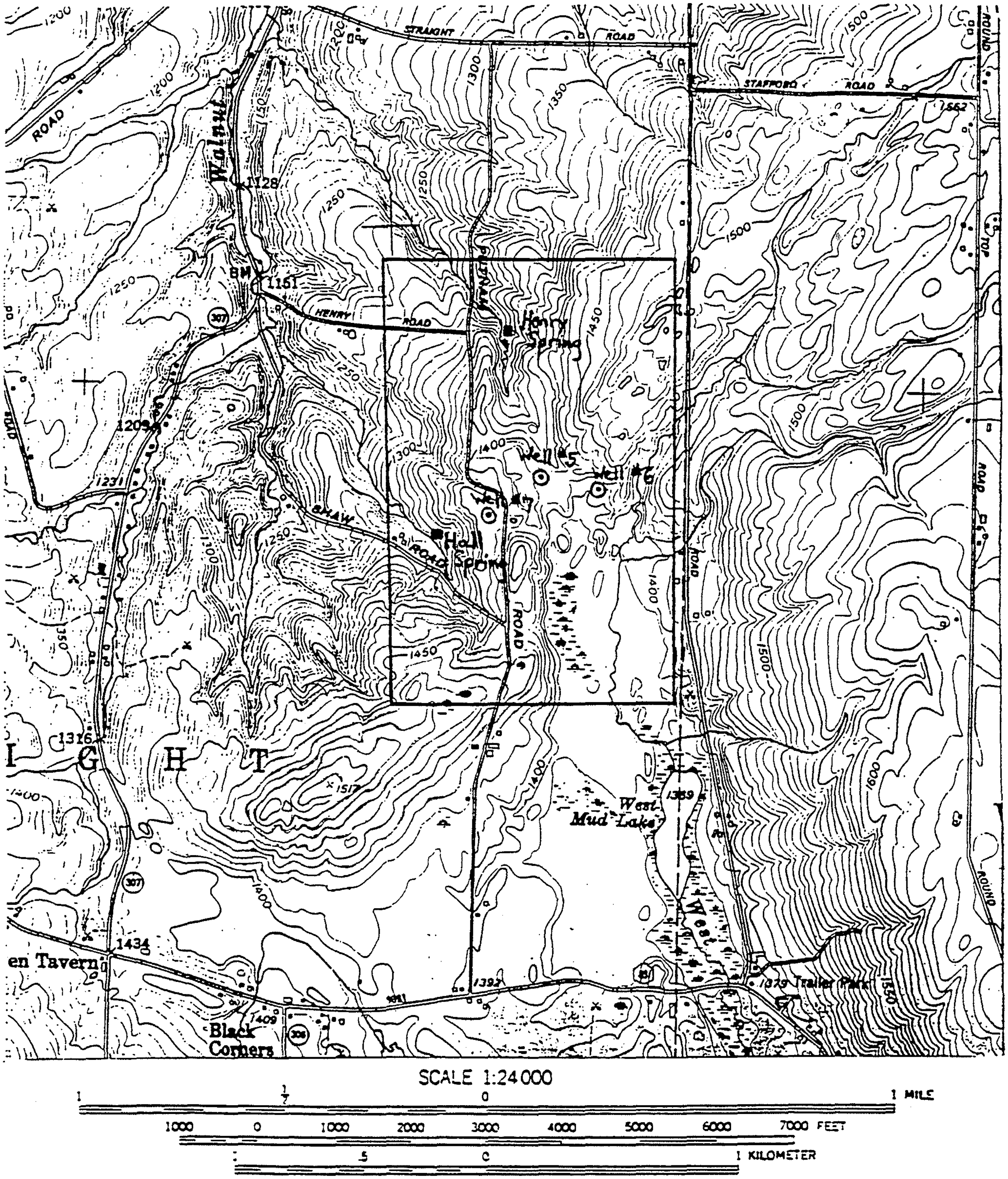


Figure 3. Location of Forestville's springs and wells in the Town of Arkwright, NY (Source: USGS 7.5' topographic map - Forestville quad, scale: 1"=2,000 ft). Note: Bradigan Spring (not shown) is located approximately 1.5 miles north-northeast of Henry Spring.

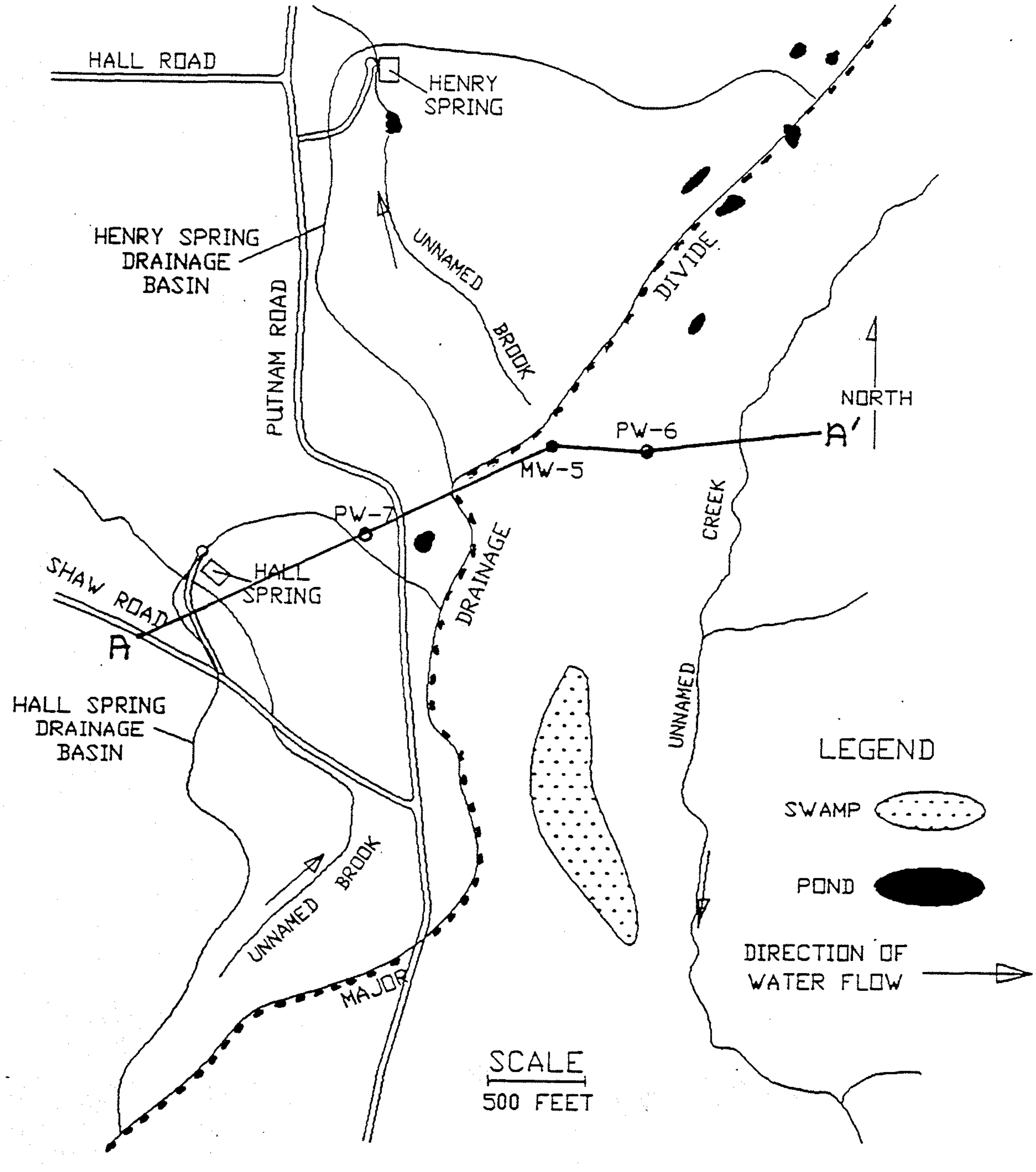


Figure 4. Drainage basins in the vicinity of Hall and Henry springs, the major drainage divide separates the Lake Erie and Alleghany River drainage systems. The locations of the two production wells (6 and 7) and observation well 5 are also shown along with the location of cross section A-A' provided in Figure 7.

The longitudinal section in figure 5 lies about one-half mile west of AA' and perpendicular to AA', encompassing several times the NS dimension of either figure 3 or 4.

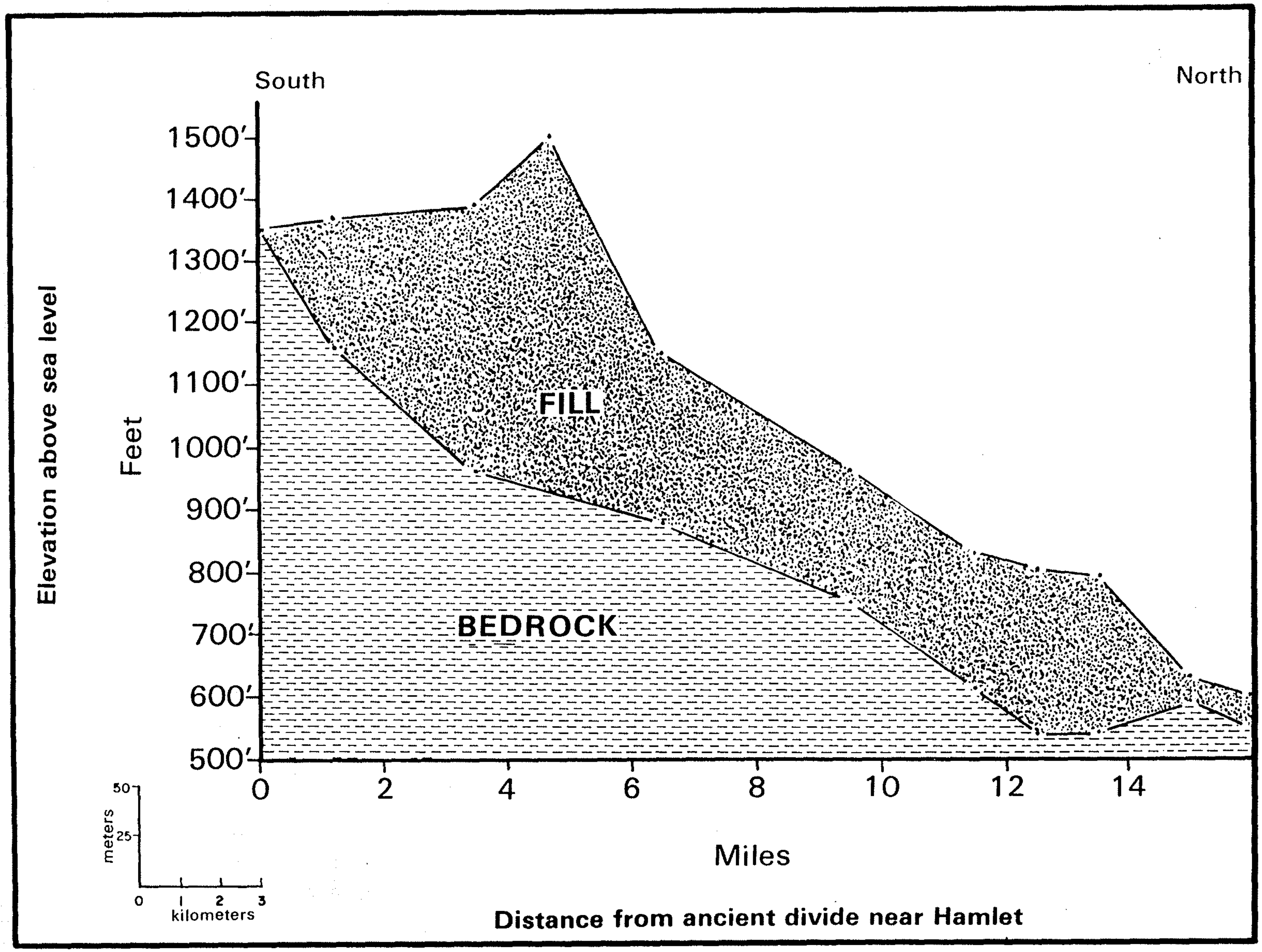


Figure 5. Buried Valley Longitudinal Section. Oriented approximately NS; from Lake Erie, through Forestville, then parallel to Walnut Creek (Fig. 3), and continuing southeast of Black Corners (Fig. 3).

Hall Spring Prior to 1996

Hall spring, contained three separate lateral systems, laterals 1, 2, and 3 (Figure 6). Lateral 1 was constructed in 1985 and disconnected in 1993 (for reasons discussed later in this article). Lateral 2 was originally constructed in 1898 and reconstructed in the 1940s. Laterals 1 and 2 consisted of perforated or open-joint 4 in. tiles laid in pebble gravel 2.5 to 4.5 feet below ground surface and back-filled with native materials. These extended radially from a series of manhole collectors, which were connected together by solid pipe. Lateral 1 had one collector and lateral 2 had eight. The ground water entered the system through the pebble gravel and open joint pipe, then flowed by gravity to a manhole collector and then down a transmission line to the spring house. Lateral 3 was recently constructed (1976) and consisted of two round, 8 ft long precast concrete manholes with open bottoms buried 6 to 7 ft deep. These were 4 ft in diameter and were set on a bed of pebble gravel. Ground water infiltrated through the bottom of the manhole where it was sustained at a constant head by a 4 in. overflow pipe, which transmitted the water to the spring house.

The Hall spring house is a 30 x 39 ft covered concrete reservoir, similar in design to a pole barn with steel sides and roof. The water level in the spring house is held constant, at about a 3 ft depth, by means of a spillway, which overflows into the adjacent brook. The water in the spring house ultimately seeps through a pebble filter approximately 1 ft thick, then through a 4 in. water main to the village.

Since 1990 the Hall spring water supply has been supplemented by ground water from well #7 (Figure 3 and 4). Ground water from the well is pumped into the Hall spring house pool via a 1.5 in. flexible plastic pipe buried a few feet below ground. In 1989, well 6 was added to the system. This was connected to the system with 4 in. cast iron pipe running from the well to the 4 in. main, which carries water from the Henry spring house to the village.

Principal Aquifers

Bedrock in this area consists of about 1000 ft of Upper Devonian shales with interbedded siltstone (Tesmer 1963). An escarpment-face (i.e., north flowing) valley cut into the bedrock by pre-glacial or interglacial drainage, was altered (scoured and filled with glacial, lacustrine and fluvial sediments). This buried valley runs through the area trending in a northerly direction. Wilson and others (1983) suggested that two components of ground-water flow exist in the buried valley fill, one flowing toward the center of the valley, the other flowing northward along the valley axis. All the spring systems are located between or very close to multiple glacial end moraines (Muller, 1963). These end moraines include those formed during both the most recent Lake Escarpment (approx. 14,000 BP; Muller and Calkin, 1993) and the somewhat older Lavery (approx. 16,000 BP) glaciations. Muller (1963) also found evidence of glacial meltwater channels near Henry and Hall springs and demonstrated that multiple episodes of glacier overriding took place in Wisconsinan and earlier times.

Wilson and others (1983) postulated that a portion of precipitation south of the divide (Figure 5) infiltrates and flows in the valley fill, under the divide, and into the Lake Erie basin. Figure 7 is a cross-section oriented roughly east-west (Figure 4), or obliquely transverse to the Figure 5 section. The major watershed divide (the Lake Escarpment moraine) trends northeast-

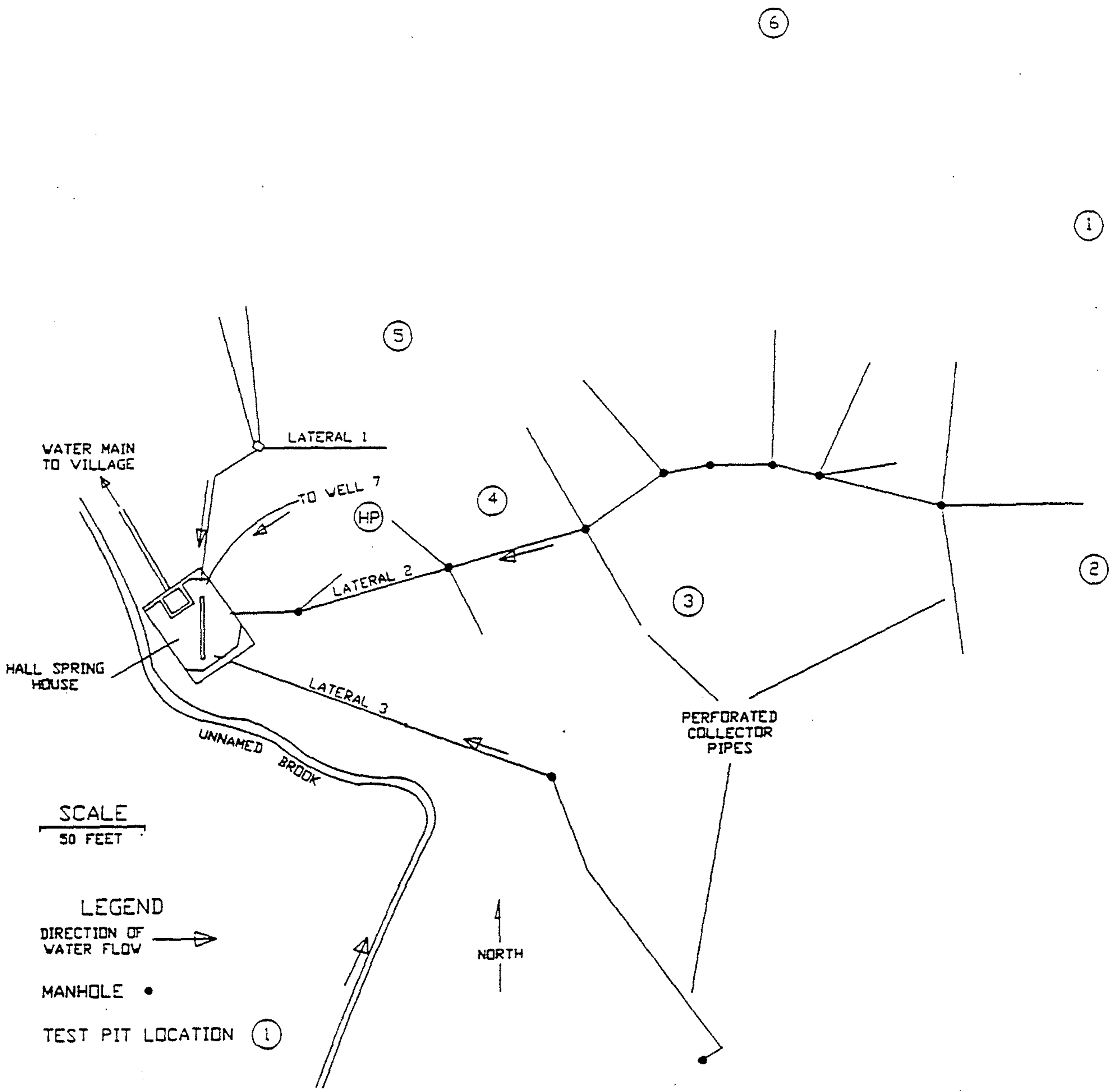


Figure 6. Schematic drawing of the Hall spring lateral system (Before 1996).

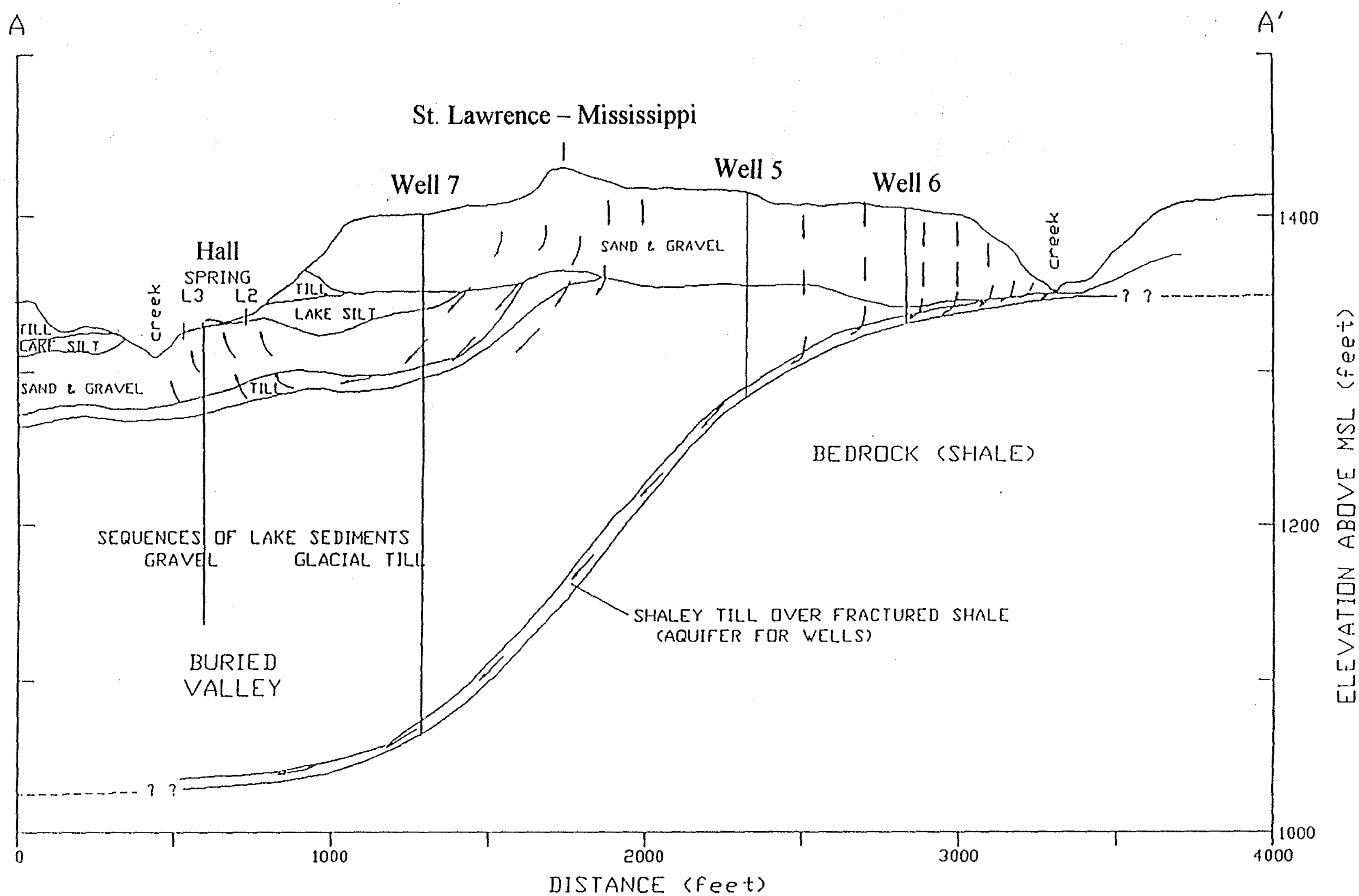


Figure 7. Cross-section A-A'

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southwest obliquely across the two sections. Thus, there is a natural interbasin transfer of water. The **springs** flow from porous media, in this case a gravelly sand, partially confined by lake silts and glacial till. The **wells** are screened across fractured rock (firm, Devonian-age shale and fine sandstone) and overlying shaley glacial till with some interbedded sands and gravels.

An extensive near-surface investigation was conducted at Hall spring in the area around lateral 2. Toward the lower end of the lateral, a shallow monitoring well was installed . The aquifer was encountered from about 5 ft to 22 ft at which point drilling was terminated. This aquifer is likely deeper than 22 ft. An 8 ft deep, 2 in. PVC piezometer was installed having a gravel pack at the bottom and a well annulus sealed with bentonite clay. The static water level in the piezometer was several feet above ground surface. A second piezometer was installed at the far end of lateral 2. This piezometer is 7 ft deep and back-filled with native material; the water level was at land surface. Seven, 8 to 10 ft deep test pits were dug around lateral 2 to determine the areal extent of the aquifer at shallow depths. As indicted by the pit logs and particle size analysis, the shallow aquifer consists of medium to coarse sand with fine gravel. This is overlain by a confining layer of fine sandy silt, 3 to 5 ft thick, and 1 ft of organic topsoil. The confining unit is leaky in some spots; this is what originally created ground-water seeps at the surface. The aquifer in the vicinity of lateral 2 appears topographically to be bounded between local highs, but in the subsurface must be more laterally extensive (Figure 7). This can be substantiated by performing some simple calculations. The drainage basin for the small valley that confines lateral 2 is 600,000 ft^2. Maximum precipitation available as recharge falling on this area averages 7.1 million gallons per year (precipitation-evapotranspiration) while average yearly production of lateral 2 was approximately 13 million gallons. This indicated that recharge to the shallow aquifer was captured from more than just the immediate area. Recharge in the form of precipitation falling near and south of the divide contributes water to a regional ground-water flow system. Ground-water flow not tapped by collectors follows the long axis of the buried valley toward Lake Erie, or recharges Walnut Creek.

The buried bedrock valley which transects the study area plays an important role in ground water available to production wells 6 and 7. It is apparent from water level observations made in wells 5, 6, and 7 along with two abandoned deep wells (one near the Hall spring house, and the other near the Henry spring house), that pumping of the production wells affects water levels in other wells. These wells must therefore be hydraulically connected (Figures 3, 4, and 7).

Well 6 was drilled to a depth of 73 ft. The well penetrates 10 ft of "overburden" (glacial till?) and 56 ft of numerous gravel layers, becoming clayey at the base. Under static conditions, the water level in well 6 is above the land surface. Under pumping conditions, the water level is stable at 50 to 55 ft below ground surface. Well 6 is near the margin of the buried bedrock valley; well 5 is 500 ft west of well 6. Well 5 was drilled 128 ft to bedrock. Well 6 produces about 12 gpm and is pumped as needed; well 5 is not used.

Well 7 was drilled to a depth of 334 ft into the buried valley. The well penetrates 10 ft of "overburden" (glacial till?), 324 ft of various gravels with some sand and clay layers, and bottoms in bedrock (Figures 3, 4, and 7). This well produces about 20 gpm and is pumped when needed.

The static water level in the well is 41 ft below land surface. The pumping water level in well 7 has gradually decreased from 90 ft to about 160 ft since first drilled.

Logs for wells 5, 6, and 7 demonstrate that multiple glacial advances yielded complex sediments, possibly containing several sequences of fine-grained, low permeability lake sediments, gravel, and glacial till. The direction of ground-water flow in the deep aquifer is controlled by the orientation of the bedrock surface in the area. Recharge to this aquifer occurs east and southeast of wells 5, 6, and 7. Previous work by Muller (1963) shows extensive outwash deposits of sand and gravel where primary recharge most likely occurs. Additional work by the U.S. Dept. of Agriculture Soil Conservation Service (1994) confirms Muller's work in greater detail. Stream loss on shallow gravel deposits over the bedrock likely occurs along a tributary to the West Branch of Conewango Creek 500 ft east of well 6, providing recharge to the aquifer (Figures 3 and 4). Additional recharge to the aquifer is from precipitation and other surface water infiltration across these coarse grained deposits. Because well 6 is closer to the recharge area, its pumping water levels are more stable than well 7's. Well 7 appears to be drawing water from storage faster than it is replenished, hence there is a decreasing water level trend in the well. Bedrock in this area has a general downward slope towards the buried valley. We conclude that water from the recharge area, southeast of the major watershed divide, enters the system and migrates into and along the buried valley.

Time of Travel

Because of concerns for water borne diseases such as giardiasis or cryptosporiodosis, knowing the time of travel between surface source waters and ground-water collection devices is helpful. When time of travel (TOT) is months or longer, parasites loose infectivity and ultimately die in the subsurface, regardless of other issues such as natural filtration.

Daily temperature data for well 6 (Figure 8), collected in 1991 at the wellhead, exhibits a range of 3.2^{0}C while a plot of conductivity data is extremely stable, almost a straight line. These data suggest that ground-water velocities from the recharge areas to well 6 are relatively slow with fairly long (months to years) times-of-travel within the aquifer. Temperature data for well 7 show seasonal summer warming and winter cooling trends (Figure 9). This is due to the exposure of the water line to near surface temperatures between the wellhead and sampling point at the Hall spring house 1,000 ft away. A plot of conductivity data for well 7 is similar to that for well 6, a straight line (Figures 8 and 9). Times-of-travel from the area of recharge to well 7 are probably years to decades, considering aquifer geometry.

Using the seepage velocity equation, (i.e., velocity equals gradient times hydraulic conductivity divided by porosity), times-of-travel from recharge areas to the wells were estimated. Static water levels in the wells decline toward the buried valley axis defining a hydraulic gradient of 0.025 ft. The water levels and gradients are in keeping with a regional recharge zone physically above and to the south of the wells, with flow northward toward the Lake Erie Plain. Hydraulic conductivity of the interval across the top of fractured rock and base of glacial sediment is between 0.023 and 5.7 ft/day with a porosity of 20%, estimated from extensive tests at

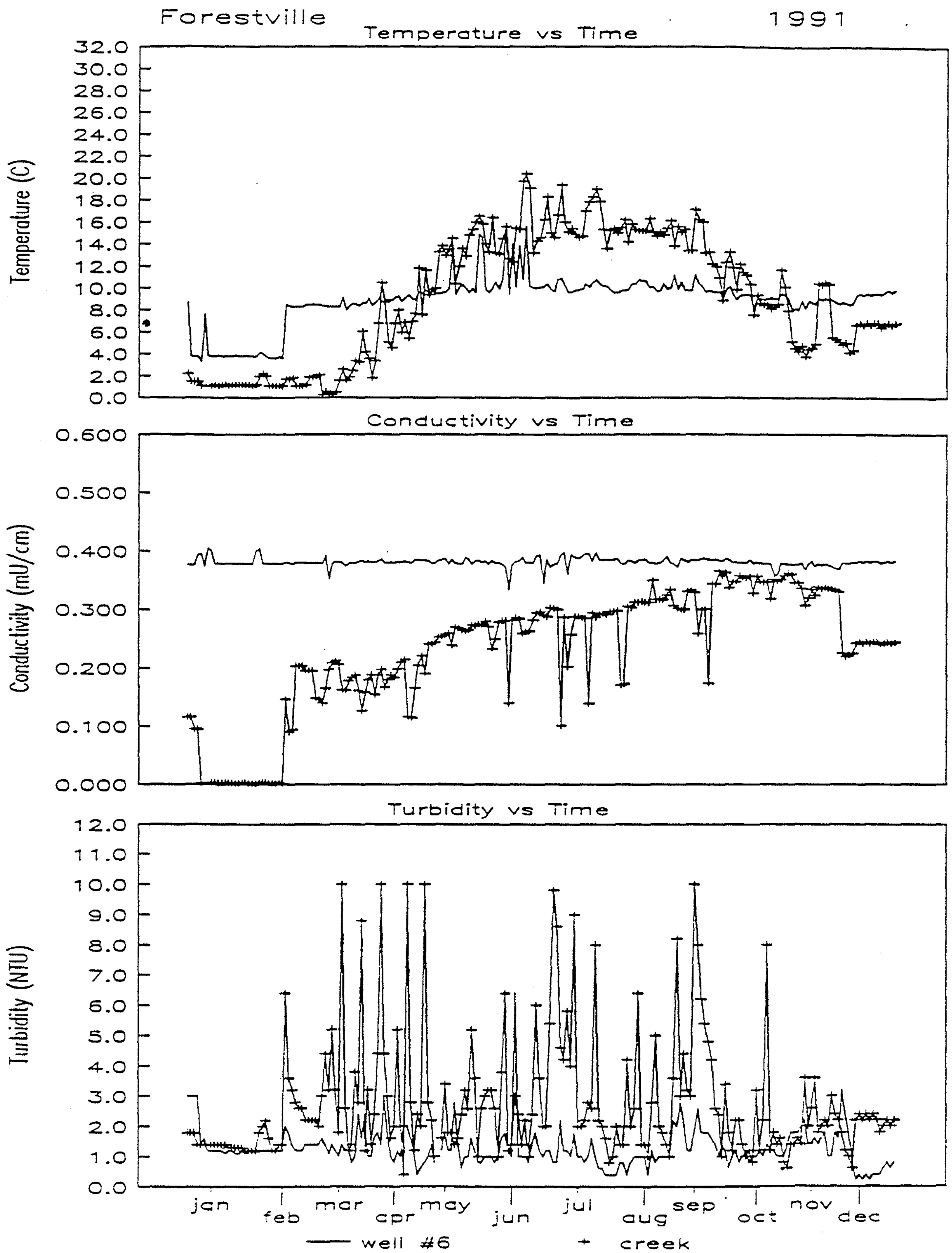


Figure 8. Water quality graphs for well 6 and the creek near Henry spring.

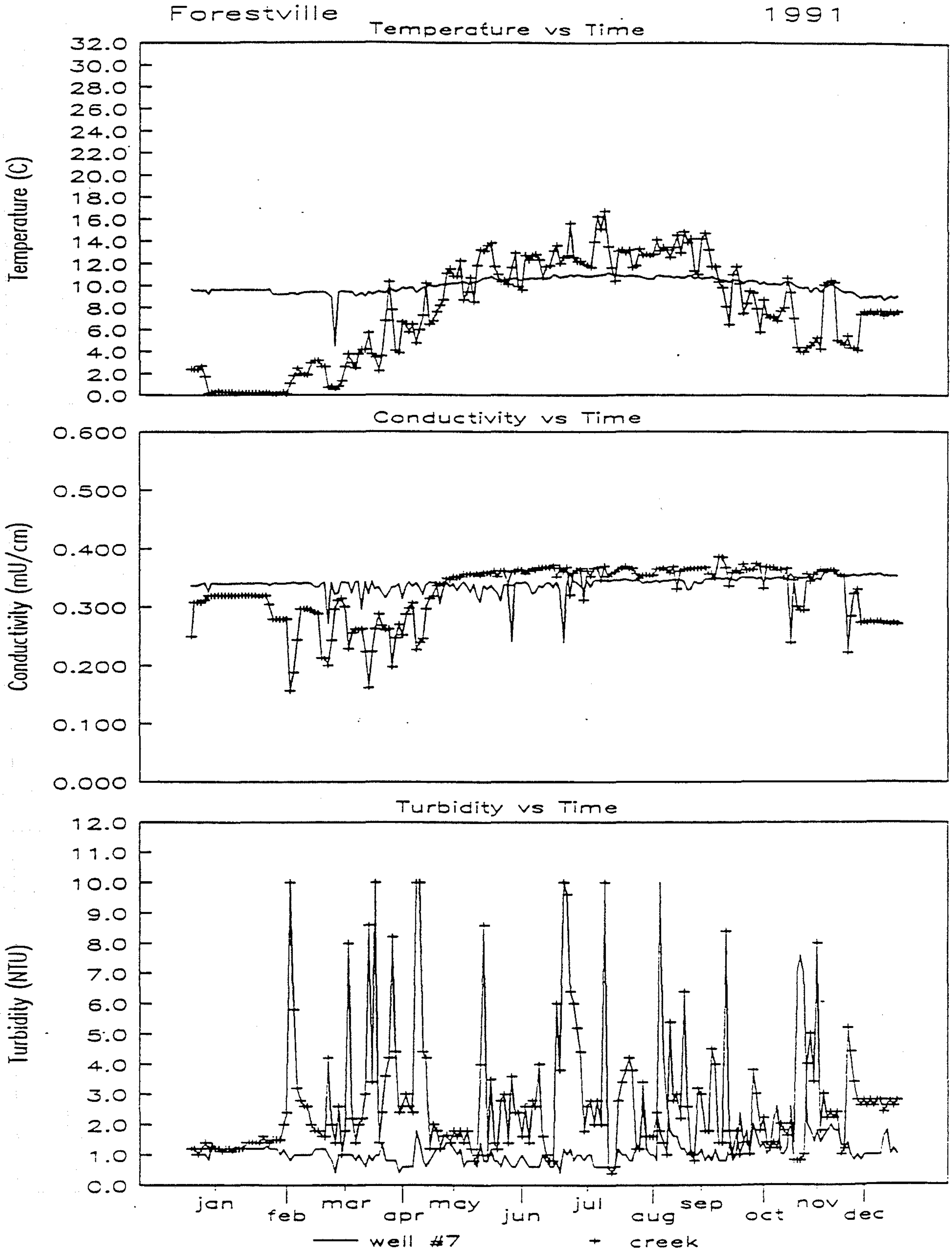


Figure 9. Water quality graphs for well 7 and the creek near Henry spring.

Chautauqua County landfills (Wilson and others, 1993). Solving the equation gives a time-of-travel of greater than 2 years for well 6 and greater than 8 years for well 7.

After using seepage velocity estimates and conductivity and temperature graphs as three indicators of TOTs of years for the wells, we can obtain additional information by comparing among the three spring laterals. Comparing temperature graphs for the Hall spring laterals is very revealing, each plot is different (Figures 10, 11 and 12). The temperature for lateral 1 varies 7.5^0, from 5.2^0 to 12.7^0C, and generally tracks surface water temperature trends. The ground-water temperature from lateral 2 varies 5^0 from 6.0^0 to 11.0^0C and also exhibits a correlation to surface water temperature trends but not as pronounced as lateral 1. Lateral 3 temperature varies 2.6^0 from 7.0^0 to 9.6^0C and shows very little correlation to surface water temperatures other than a general warming trend occurring during summer months. Because the laterals are so shallow, the ground-water temperature would be expected to track the air temperature, but why is the temperature plot of each lateral different? At the Hall spring, the differences in lateral construction may be responsible. Lateral 1 intercepts ground water closest to the surface (approximately 1 to 2 ft deep), lateral 2 intercepts ground water 3 to 4 ft below the surface, and lateral 3 receives ground water from about 6 ft below the surface. Because ground water closer to the surface will reflect surface temperatures to a greater extent than deeper ground water, these temperature plots do partly make sense. However, the profiles were excessively flattened with depth if the sole cause was thermal dampening from the insulating effects of overlying sediment. Significant portions of lateral 3 water must be from a distant source.

Scrutinizing daily conductivity and turbidity data (Figures 10, 11 and 12) and comparing them to the temperature data may provide further insight as to the cause of the variations between the temperature plots. Conductivity data for lateral 1 at Hall spring closely tracks that of the surface water between January and May, then levels off as a straight line on the graph. Conductivity data for lateral 2 shows a very minor correlation to the surface water during the same period and then also levels off. Lateral 3 conductivities show no significant correlation to surface water conductivities. It should be pointed out that due to the lack of precipitation from May to October 1991, the conductivities measured in the streams were elevated. This is because the streams were primarily receiving base flow (ground water) derived at least partly from mineral-rich bedrock-contact ground-water.

These data suggest that the temperature trends for lateral 1 at the Hall spring are due to surface runoff entering the lateral system. Additional data cited in following sections supported this conclusion. Review of the data in 1992, along with presentation of findings to municipal officials, led to disconnection of lateral 1 in 1993. These temperature and conductivity data are also interpreted to suggest that a small amount of early season surface water (such as snowmelt) entered lateral 2 and almost none entered lateral 3. In addition to depth of burial of laterals, the poor external manhole seals (annular space), and sometimes low tops, were thought to be sources of surface water entry to the system.

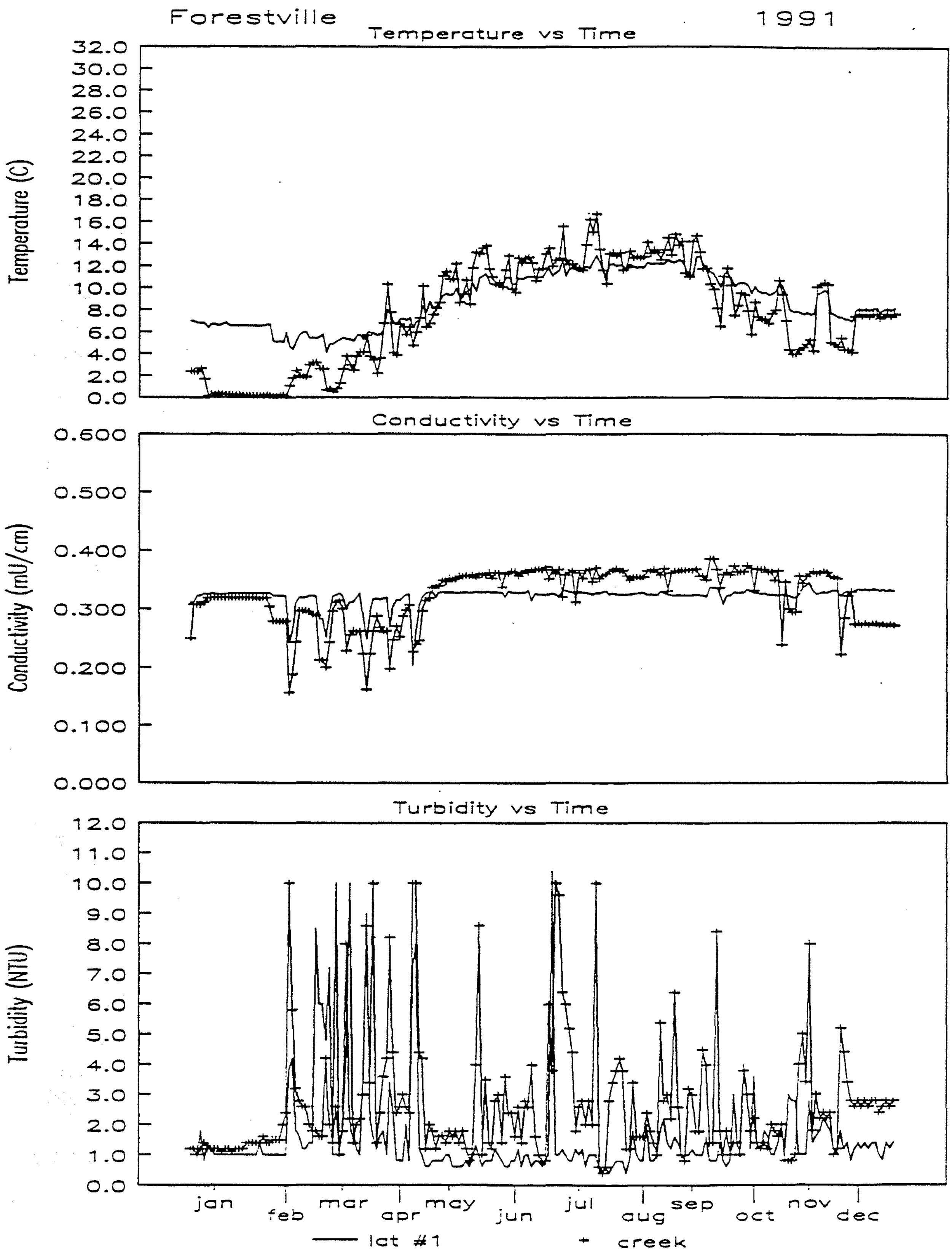


Figure 10. Water quality graphs for Hall spring lateral 1 and the nearby creek.

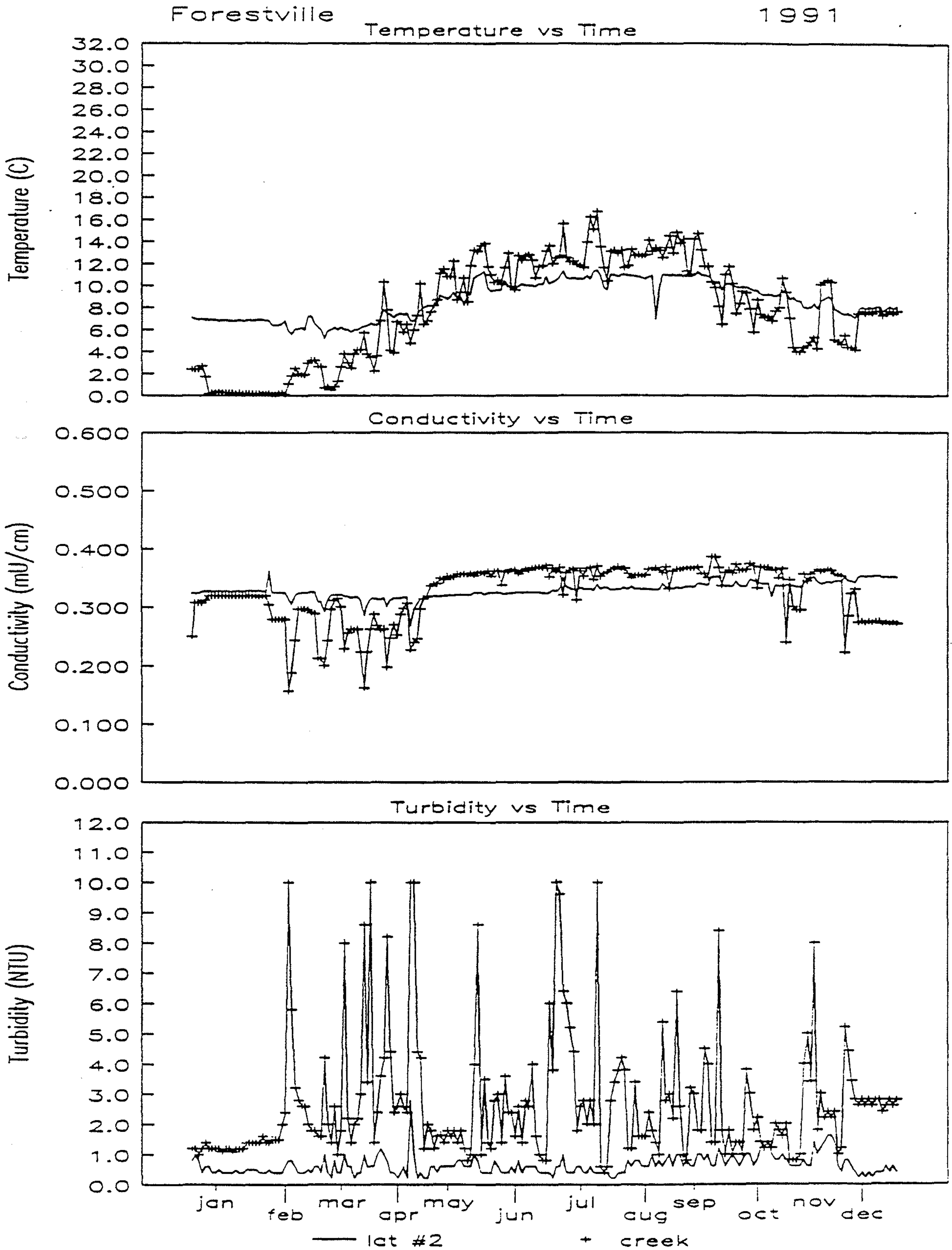


Figure 11. Water quality graphs for Hall spring lateral 2 and the nearby creek.

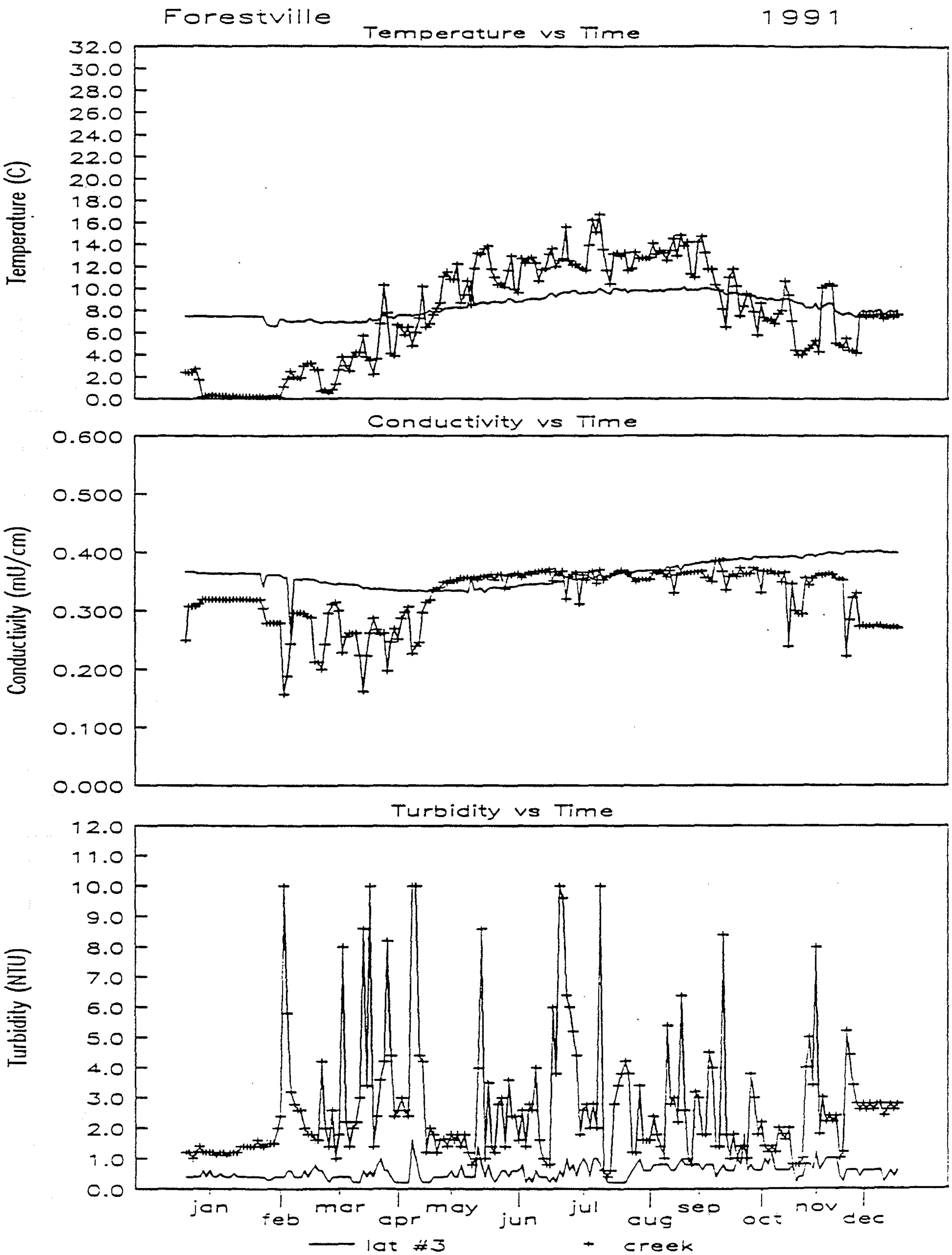


Figure 12. Water quality graphs for Hall spring lateral 3 and the nearby creek.

Microscopic Particulate Recharge

Historically, the water quality in Forestville has been acceptable. There have been instances, during water shortages, where the village has had to divert unfiltered surface water from either the creek near Hall spring or the old reservoir near Henry spring into the water supply to meet their demand. During these emergencies, a "boil water order" was enacted.

Turbidity data (Figures 8-12) were collected daily (5 days per week) for one year from the laterals in both Hall and Henry springs, wells 6 and 7, and nearby surface waters. Turbidity for Hall spring lateral 1 tracks closely with surface water turbidities and averaged 1.6 NTU for 1991. Turbidities for laterals 2 and 3 averaged 0.6 NTU, supporting the contention that lateral 1 was under the direct influence of surface water. Bacteria levels (sampled weekly) varied according to lateral with coliform present in 38% (lateral 1), 32% (lateral 2) and 20% (lateral 3), of the samples. Heterotrophic bacteria levels were 500 CFU/ml or greater in: 17% (lateral 1), 8% (lateral 2) and 0% (lateral 3), of the samples.

Water quality data for wells 6 and 7 also vary. Turbidity graphs (Figures 8 and 9) exhibit a random fluctuation for both wells ranging from 0.5 to about 3 NTU. Average daily turbidity during 1991 was 1.3 NTU for well 6 and 1.2 NTU for well 7. There is no correlation between ground-water and surface water turbidity trends or ground-water turbidities and precipitation. The turbidity is probably due to the presence of fine sediment (clay and silt) within the aquifer. When wells 6 and 7 were being developed after drilling, they were pumped for several weeks before the water cleared of sediment (prior to this the well water was visually turbid). Conductivity graphs show plots typical of deep ground waters, fairly high and stable curves. Bacteria levels in well 7 were low, with coliform present in 4% of the samples and heterotrophic bacteria levels 500 CFU/ml or higher in 16% of the samples. Bacterial levels in well 6 were higher with coliform present in 43% of the samples, and heterotrophic bacteria levels 500 CFU/ml or higher in 77% of the samples.

The bacteriological data for well 6 is puzzling. It is unlikely that the bacteria was traveling through the aquifer from its point of recharge. The wellhead was below grade and sample collection was difficult; some samples may have been compromised. A recent follow-up bacteria sample from well 6 was negative for coliform (<1/100 ml) and contained very low heterotrophic bacteria (2 CFU/ml).

MPA (microscopic particulate analysis) samples were taken in 1991 at well 7 and Hall spring laterals 1, 2 and 3 (Table 1). An MPA sample taken from well 7 in July showed no biological material whatsoever. We do not know if surface recharge to well 7 is steady state and therefore it is difficult to draw a conclusion from this one MPA sample. However, the low Consensus Method (Vasconcelos and Harris, 1992) relative risk value is what was expected.

MPA samples were collected at Hall spring (Table 1) in March and July 1991 from laterals 1 and 2, and in July from lateral 3. The results indicate that increased biological activity occurred in the summer as compared to winter. The March samples for lateral 1 contained primarily plant debris; lateral 2 contained only one nematode and one crustacean per 100 gallons of water

Table 1. Forestville - MPA DATA

Device	Source Type	Filter ID#	Date	Giardia	Coccidia	Diatoms	Other Algae	Insects/ larvae	Rotifers	Plant Debris
*	Surface Water	1434	07/02/91	0	0	30,000	0	0	0	0
L 1	Spring	1320	03/18/91	0	0	1	1	0	0	320,000
L 1	Spring	1433	07/03/91	0	0	2,000	0	0	800	0
L 2	Spring	1307	03/12-13/91	0	0	0	0	0	0	0
L 2	Spring	1436	07/03/91	0	0	0	0	0	16	0
L 3	Spring	1437	07/03/91	0	0	0	0	1	0	0
W 7	Drilled Well	1435	07/03/91	0	0	0	0	0	0	0

- MPA DATA (cont'd.)

Device	Source Type	Nematodes	Crustaceans	Amoeba	Non-Photo. flagellates & ciliates	Photo-synthetic flagellates	Other: iron bacteria	EPA TOTAL RISK	EPA RELATIVE RISK
*	Surface Water	9,000	0	0	0	0	0	16	Moderate
L 1	Spring	1	0	0	0	0	100	13	Moderate
L 1	Spring	0	0	0	0	0	500	20	High
L 2	Spring	1	1	0	0	0	0	0	Low
L 2	Spring	80	0	0	0	0	1	1	Low
L 3	Spring	100	0	0	0	0	0	3	Low
W 7	Drilled Well	0	0	0	0	0	0	0	Low

sampled. Results from the July sampling showed that lateral 1 contained 2,000 diatoms and 800 rotifers per 100 gallons sampled, lateral 2 had 16 rotifers and 80 nematodes present per 100 gallons, and lateral 3 had 100 nematodes per 100 gallons of water sampled. These results show that the biological quality of the spring water (excluding bacteria levels) is good.

Conclusion: spring water quality was good but was degraded by surface water infiltration to the laterals. Lateral 1 was unacceptable. Laterals 2 and 3 were much better than lateral 1. Considering MPA evidence along with TOT findings and aquifer geometry led us to advise reconstruction of the springs to increase the quantity of a water source with good quality. Consultants and regulators should be cautious not to be over-influenced by construction deficiencies, which would lead to premature abandonment of spring aquifers in addition to spring collection devices. Apparently, collection devices at this location were faulty, not the ground-water.

Renovation of Springs

In April of 1995 the Village of Forestville, New York was awarded a grant from the New York State (NYS) Department of Environmental Conservation to partially fund a non-point source (NPS) pollution abatement project. The purpose of the project was to improve the Village's public water supply by reducing NPS pollution impacts to their source water, i.e. reconstruction of Hall and Henry Springs.

Over the years, both water quality and production declined, spurring the village to search for a suitable well source to replace the springs. However, the discontinuous and confined nature of the aquifers near Forestville led to poor well performance due to poor ground-water recharge. While the Village was able to obtain an additional 32 gpm from the two wells drilled in 1989 and 1990 (wells 6 and 7) it required almost 100 gpm to meet daily water demands.

In an effort to address source water problems, the Village formed partnerships with the Chautauqua County Health Department (CCDOH) and SUNY College at Fredonia (SUNY-Fredonia), both members of the Chautauqua County Water Quality Task Force (Task Force). In the 1991 County Water Quality Strategy, the Task Force had identified the Village of Forestville water supply as an important aquifer lacking sufficient water quality data. Therefore, once exploration for more wells was considered unlikely, CCDOH and SUNY-Fredonia performed a source water and water quality evaluation in 1991 and 1992 (Wilson and others, 1996), the results of which were presented above. The investigators determined (as previously discussed) that the ground water itself was of high quality but that surface water carrying NPS pollutants such as parasites, bacteria, sediment and organic matter could seep into the lateral collectors of the Hall and Henry Springs. In addition, tree roots had clogged the lateral pipes, reducing the yield of the spring systems and providing another avenue for NPS pollutants to enter the spring collectors. Reconstruction of the existing spring systems was identified as the best, most cost effective solution to the village's water quality problems.

At this point, it seemed natural to involve the Task Force to obtain funding and engineering services to proceed with restoring and protecting the springs. Task Force members helped village personnel write a successful proposal seeking NPS funds to renovate Hall and Henry springs.

The primary goal of the project was to eliminate NPS pollution impacts to the village public water supply. Secondary goals were to improve system efficiency and increase water production. The project was divided into three major parts. Part one was to reconstruct the two ground-water collection systems by replacing most of the lateral systems and developing deeper zones that are sealed from surface runoff. Part two was to conduct a project evaluation by measuring and comparing pre-construction to post construction conditions. Finally, part three was to implement a watershed maintenance plan in order to preserve the integrity of the new systems and protect them from contamination.

A collaborative approach went far to contain costs and guarantee success. In order to reduce engineering costs, Task Force members contributed technical suggestions to the design of a spring water collection system that would be adequately sealed from surface contamination (Figures 13 and 14). The current and previous village water operators, the Mayor, the Chairman of the Village Water Supply Committee and the Village's engineer contributed other design suggestions. With water supplies limited during spring renovations, volunteer water conservation measures and mandated use restrictions were implemented. To minimize project costs, the village did as much site preparation as possible with help from NYS correctional facility prisoners.

Once topsoil was stripped and stockpiled, the old manholes and related laterals were removed to assure that surface water could not migrate into the new collection system through the old pipes. Ten manholes with related piping were installed at Hall Spring to replace lateral 2 (Figures 13 and 14). Lateral 3 was not altered. New lateral-2 pipes were buried at least 5 ft below ground. Other features to inhibit surface water infiltration to the collection systems included several rock lined and grassed diversion ditches to intercept overland flow prior to the lateral areas and divert it to a nearby stream. Disturbed areas were then fine graded, seeded, and mulched.

In order to assess the effectiveness of this NPS implementation project, the Village water operator and the CCDOH monitored water quality (Figures 15-18) and spring flow rates before and after construction. Temperature (Figure 15), conductivity (Figure 16), and turbidity (Figure 17), were measured daily, five times a week, and bacteria samples (Figure 18) and flow measurements were collected once a week. The water quality tests in 1995 through 1997 used the same equipment and methods as during 1991. In addition, spring water was examined several times during the project for the presence of Giardia, Crytosporidium and other biological particulate matter using MPA as during 1991.

Both the pre-construction temperature and conductivity data showed greater short-term variability than post-construction measurements. Once construction was complete, these fluctuations diminished, indicating that surface water seepage into the collectors was greatly reduced or eliminated altogether. Immediately following construction turbidities increased, then gradually declined to about 1 NTU and remained stable. Bacteria levels (Figure 18) before construction varied sporadically in response to runoff events. Immediately after construction was

Figure 13. Design construction, Hall Spring Lateral 2.
(Lateral 1 removed and Lateral 3 not altered)

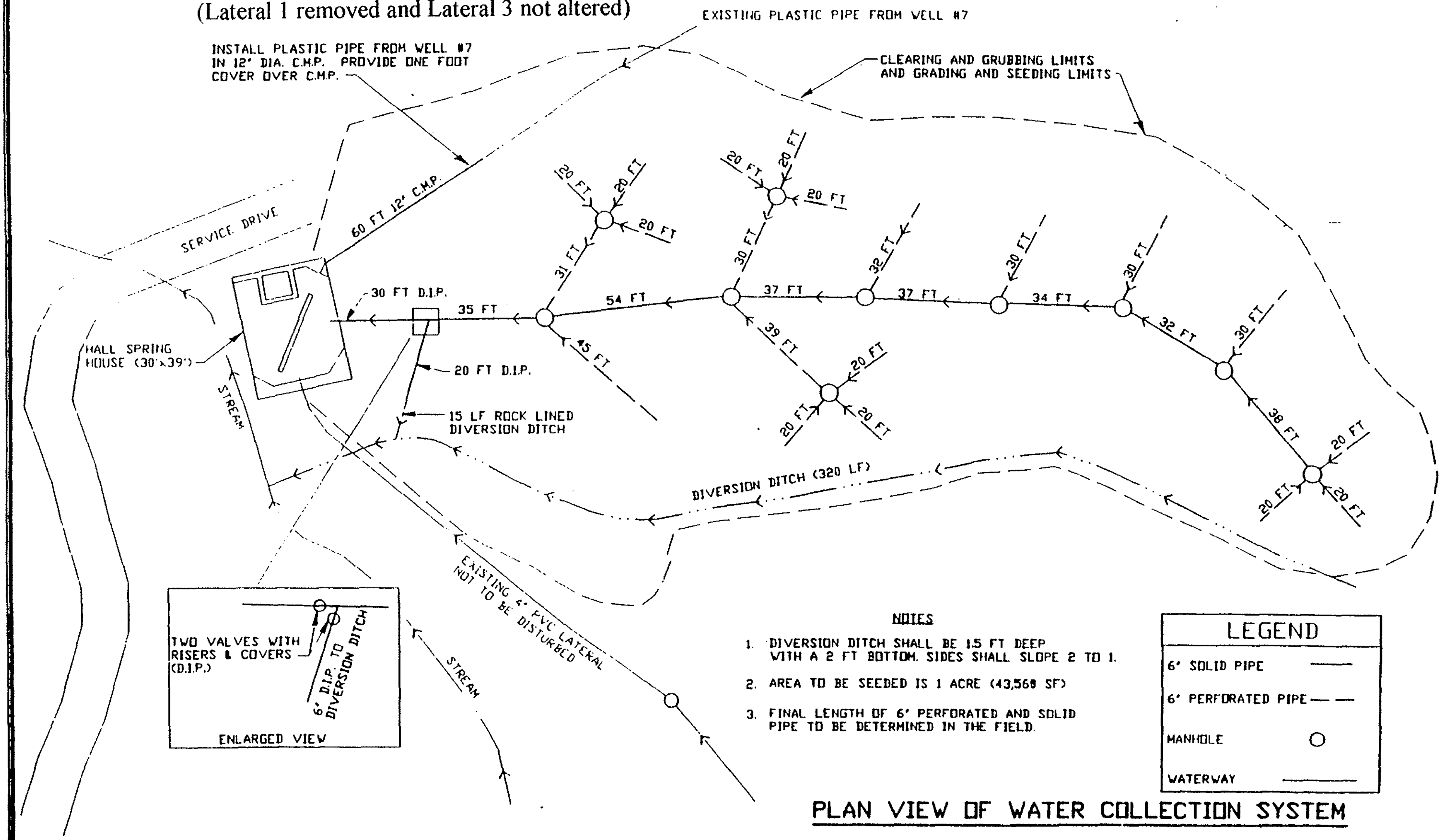


Figure 14. Design diagrams for Hall Spring Lateral 2.

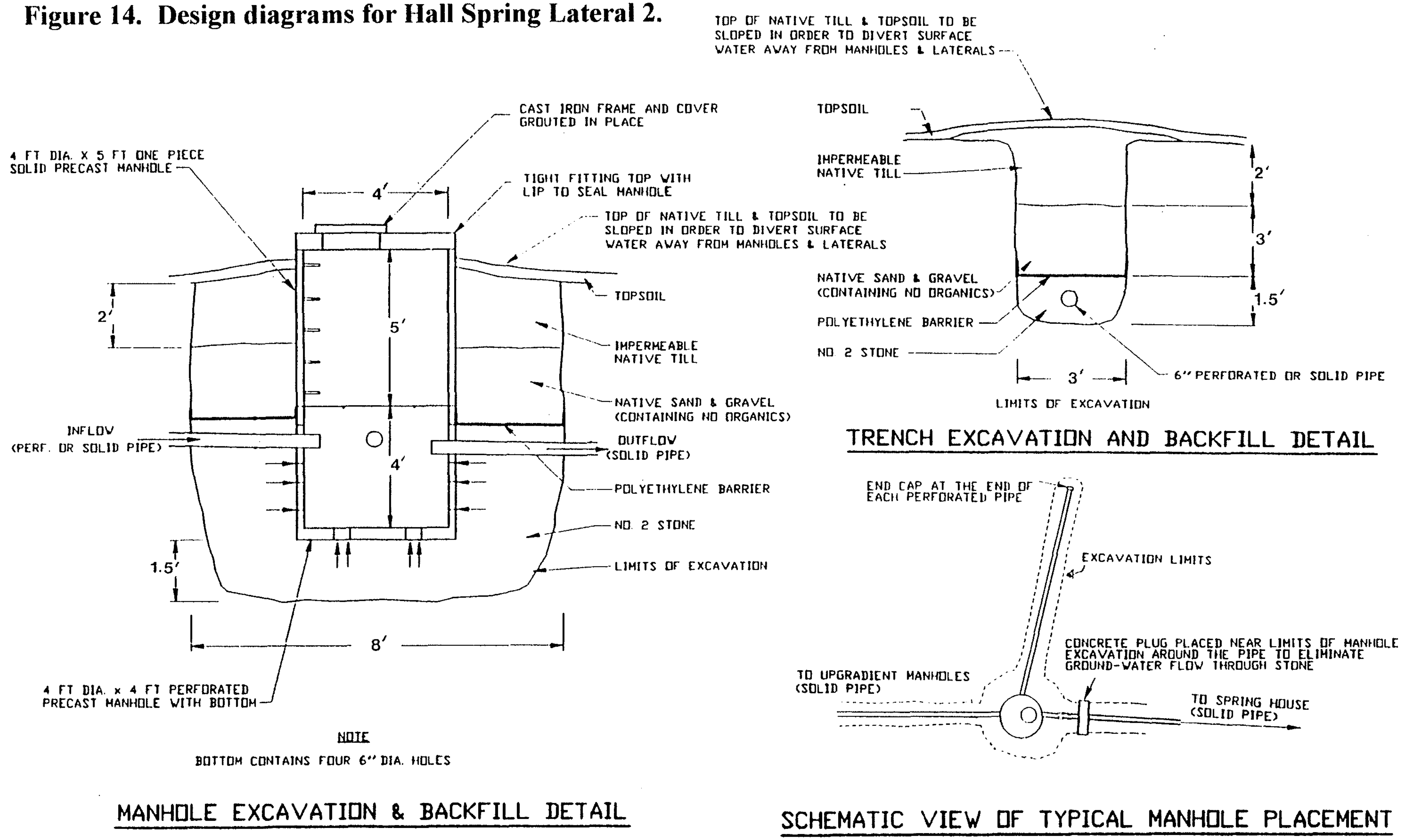
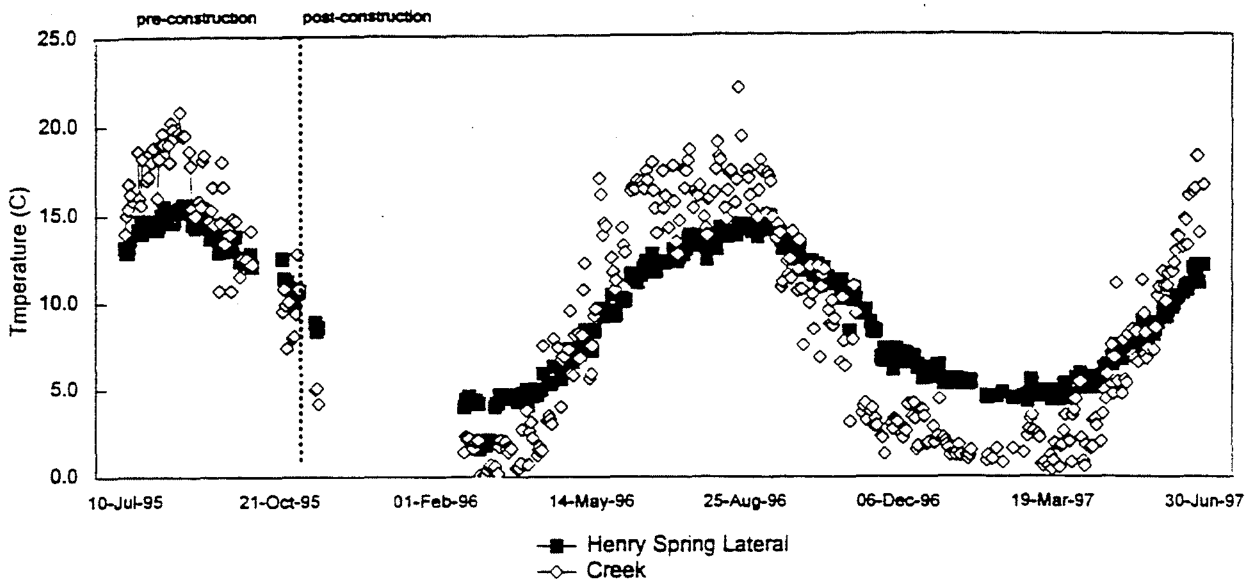
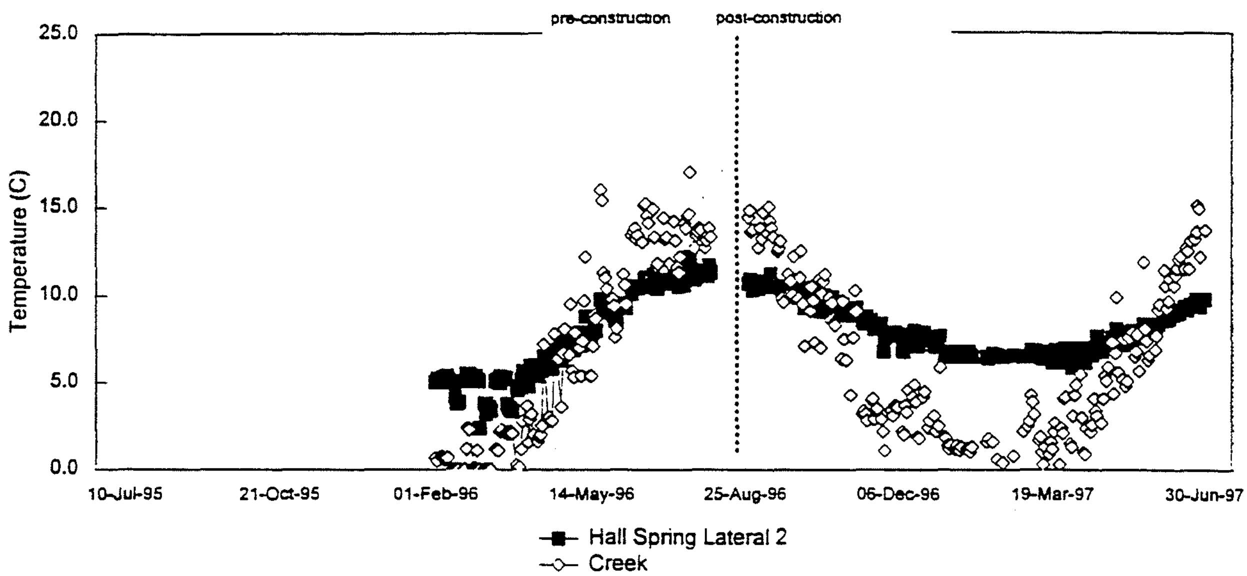


Figure 15. Ground Water and Surface Water Temperature





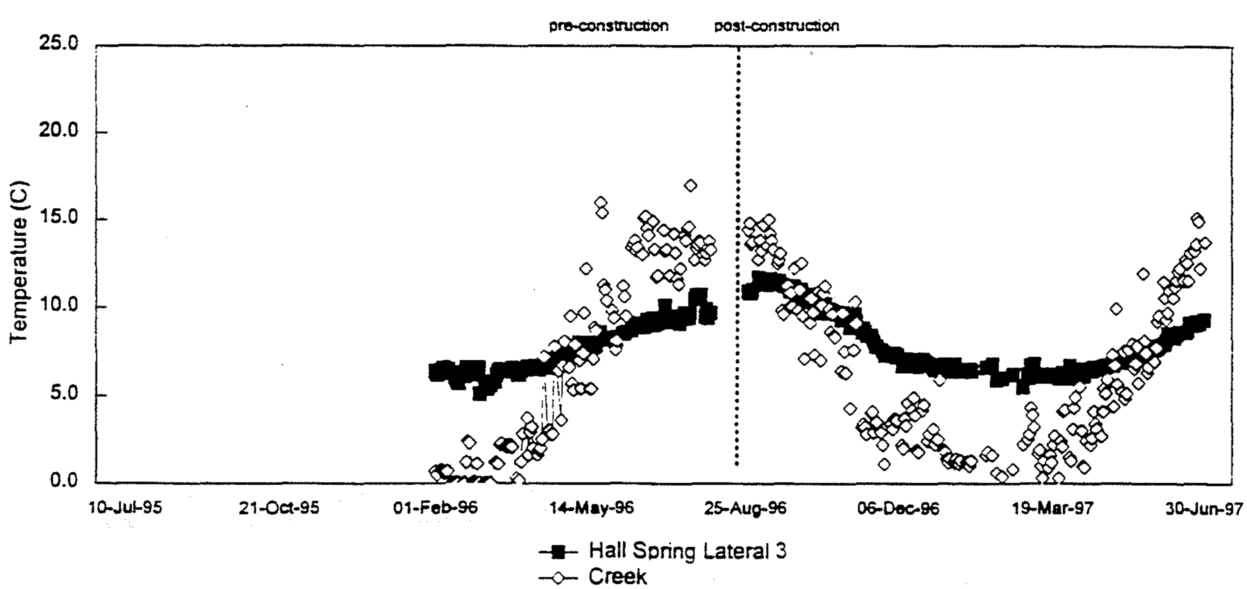
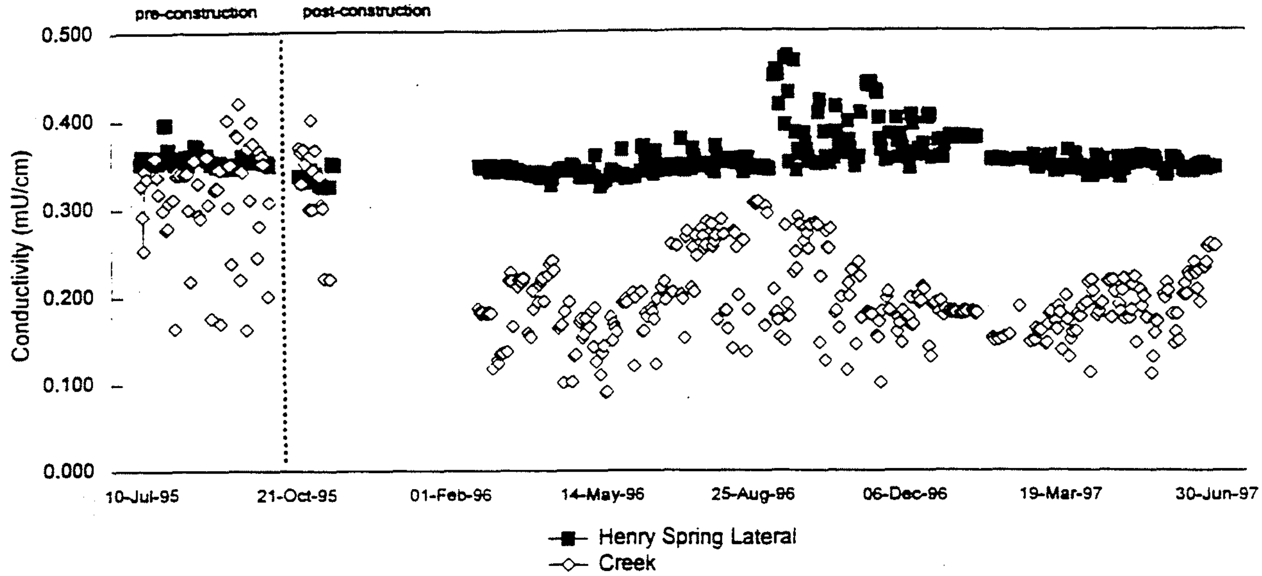
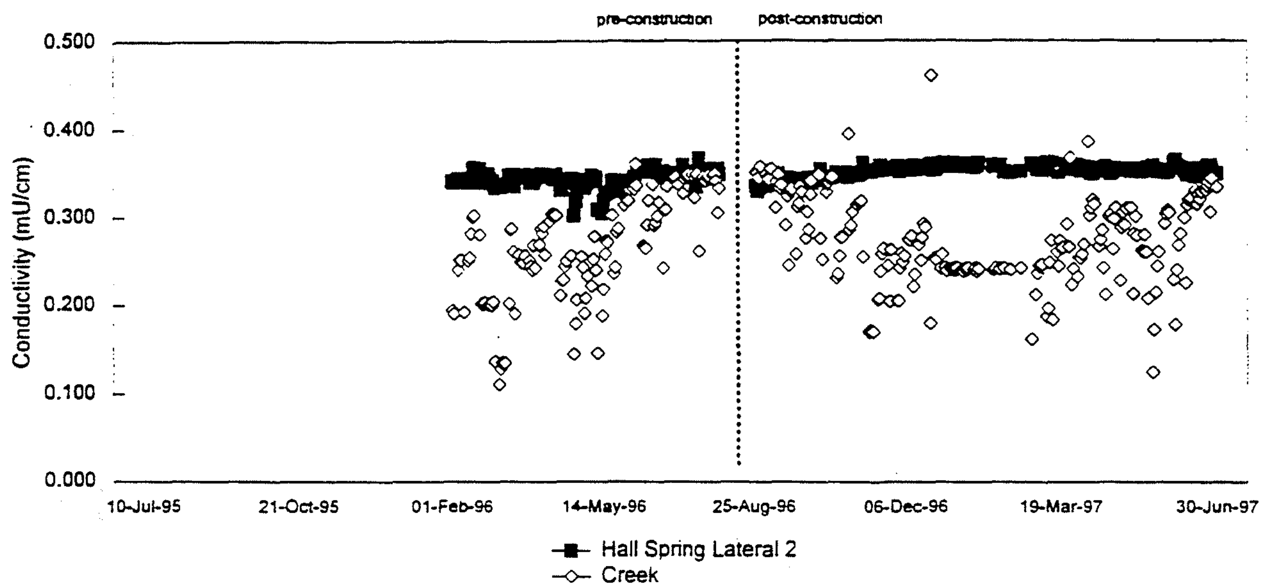


Figure 16. Ground Water and Surface Water Conductivity





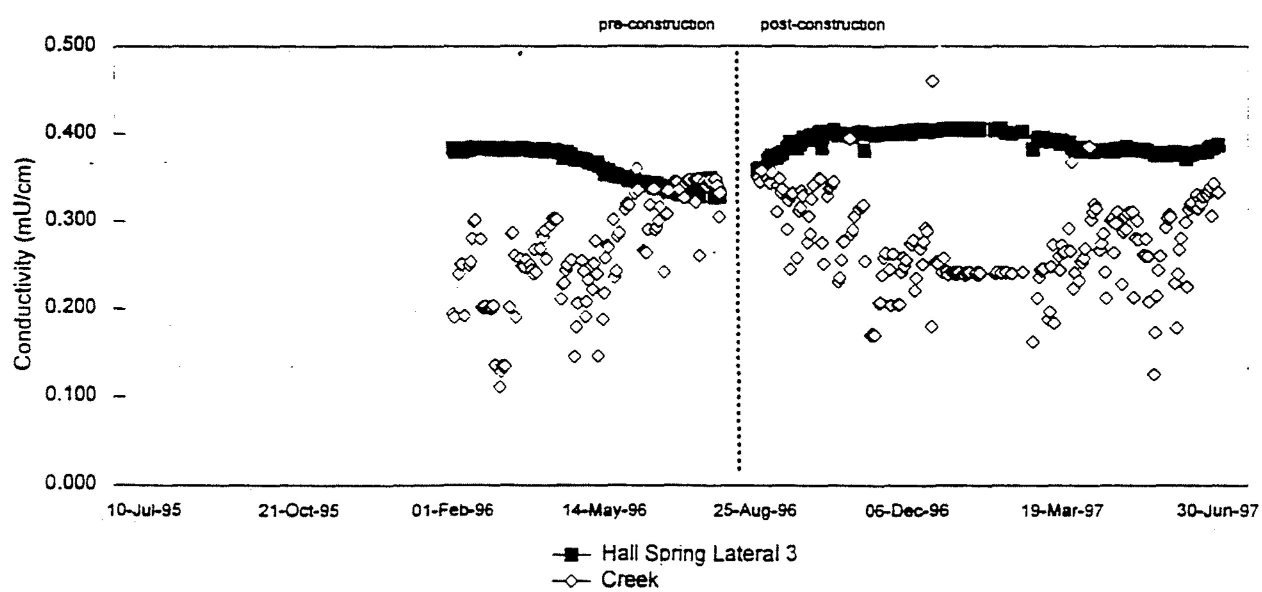
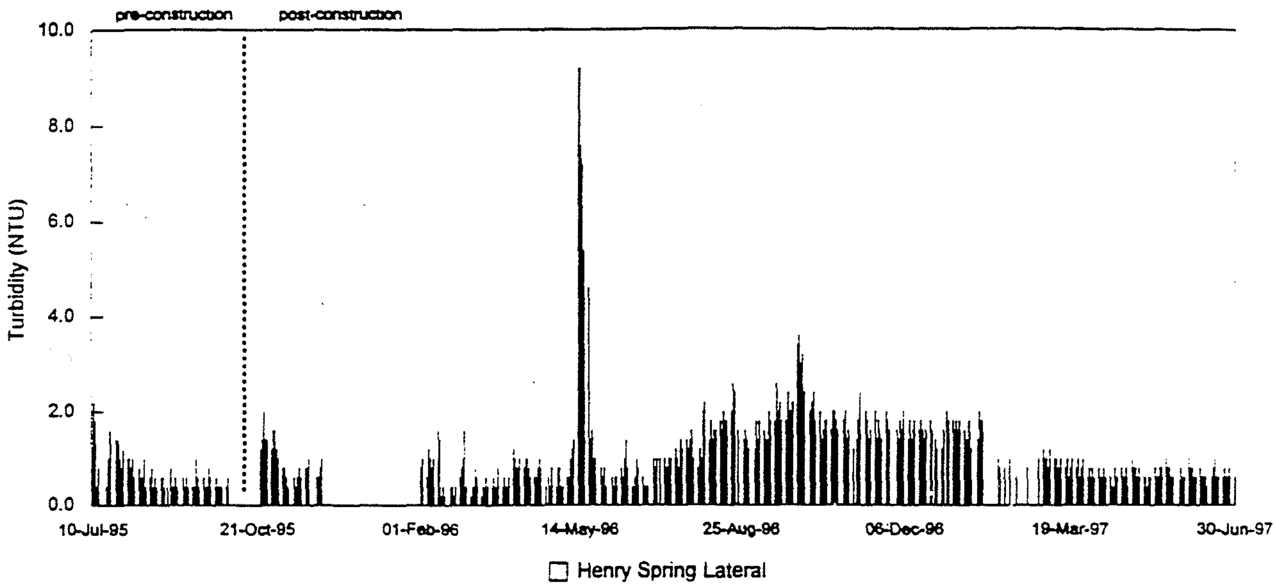
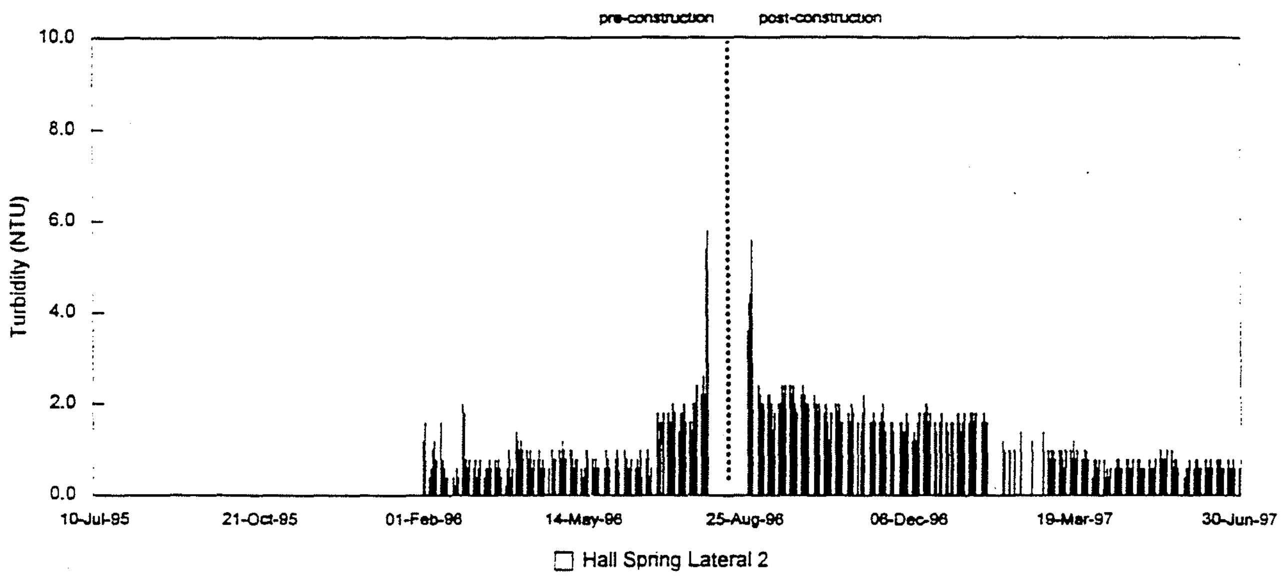


Figure 17. Ground Water Turbidity





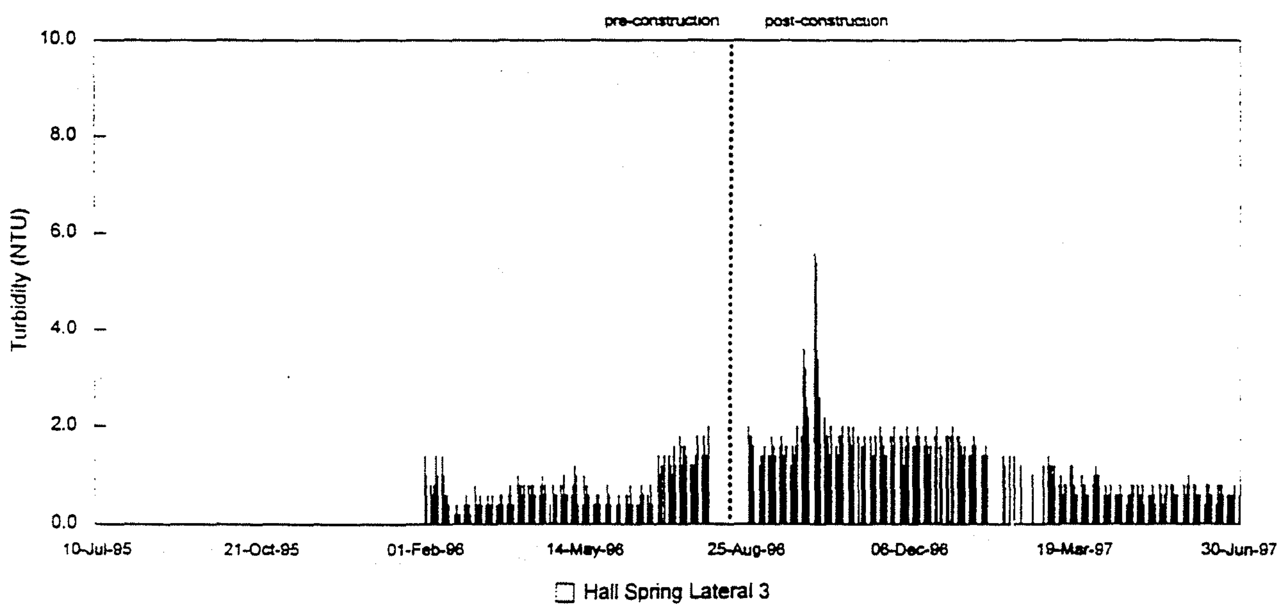
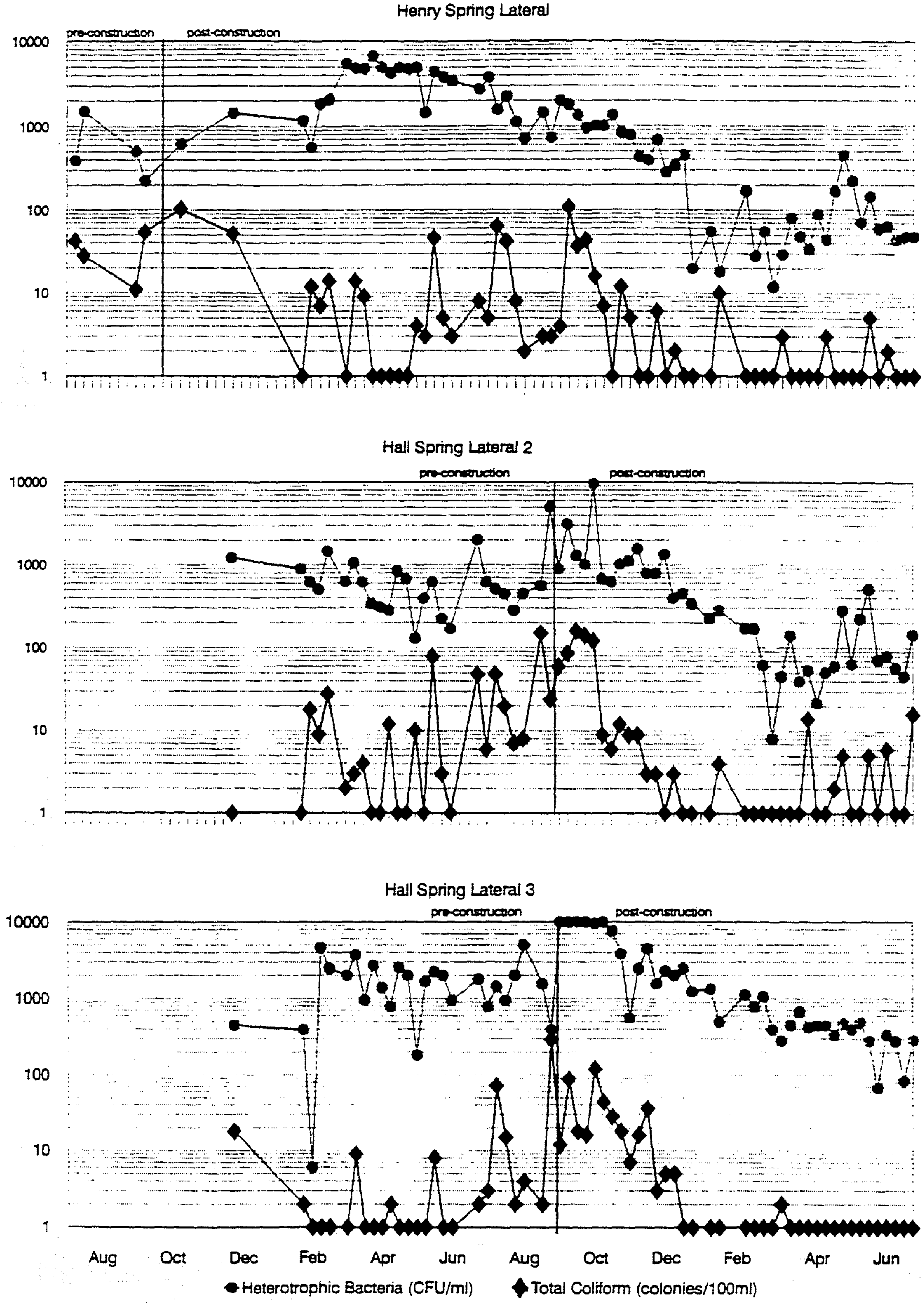


Figure 18. Ground Water Bacteria Levels 1995 - 1997



complete, bacteria levels rose, indicating abundant bacteria from topsoil was introduced into the aquifer during spring renovations. Following construction, bacteria gradually died in the aquifer. Post-construction MPA samples indicated good biological quality at both springs with diatoms at zero. Average production increased from 13 gpm before construction to 24 gpm after construction at Henry Spring and from 24 gpm to 60 gpm at Hall Spring.

In order to preserve both ground-water quality and spring system integrity, a watershed maintenance program was developed. Village officials met with CCDOH and SUNY-Fredonia representatives (Boria and Wilson) to review existing groundwater protection programs, develop a routine watershed inspection and spring maintenance plan, and identify other mechanisms that would protect the village water supply.

Thanks to the cooperation between local, county, state and federal agencies, the Village was able to procure the funding needed to upgrade its spring systems. A total of $124,405 in cash was spent to perform the construction improvements, $53,600 of which came directly from NPS grant monies. As well as dramatically improving water quality and production, the Village has also realized some long-term financial benefits by decreasing chlorine use by half to attain the same level of disinfection as before reconstruction. Finally, increased spring production has allowed the Village to rest their two low yielding wells, saving on electricity. Probably the most noteworthy measure of improvements is the experience of Village water customers, who no longer have annual water restrictions or roily water coming from their drinking water taps during heavy rain storms.

Delineated Wellhead Protection Areas

Due to the complex nature of the aquifer systems that supply water to both the springs and the wells, traditional ZOC delineation methods could not be used. Instead, wellhead protection areas (Figure 19) are based on geologic mapping and drainage basin limits. From what is known of ground-water flow in the Henry and Hall spring areas, recharge to both the springs and wells occurs south of the Mississippi – Great Lakes divide in areas containing highly permeable soils from outwash.

The primary protection zones for the springs are based on the extent of the small drainage basin of each spring system. The basins were delineated using topographic maps beginning at a point immediately down-gradient from each spring house.

The primary protection zones for the wells extended to the area east of Hall and Henry springs where permeable soils are present. This area was chosen by reviewing geologic maps (Muller 1966) and soils information (Puglia 1994). It also encompasses the land area around each well.

The small drainage basins for Hall and Henry springs form the western boundary of the primary protection zone for the two springs and wells. The eastern boundary extends to the permeable deposits along the West Branch of Conewango Creek. Since all of these areas border one another, they were combined to form one primary protection zone. A 500 ft buffer was then

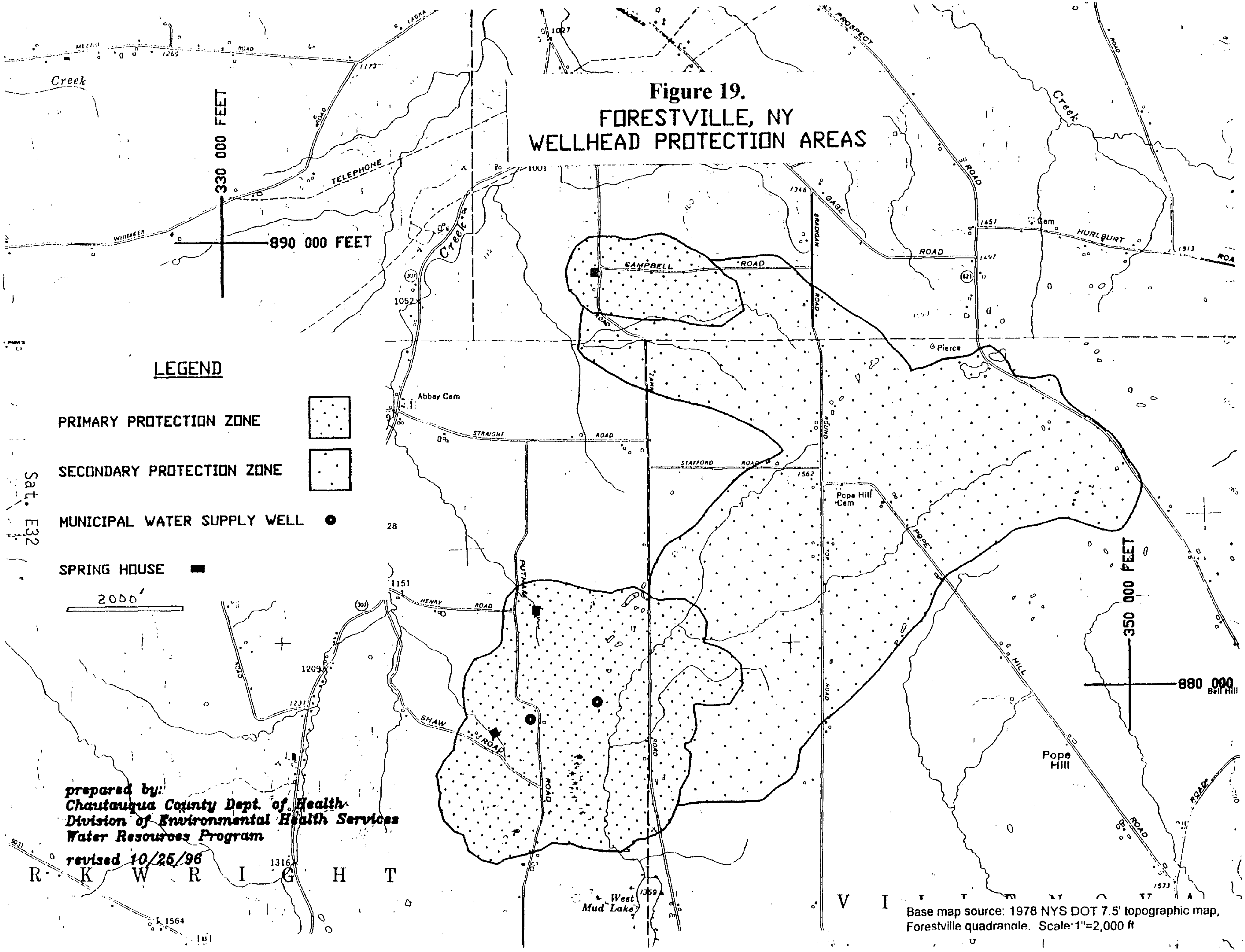


Figure 19.
FORESTVILLE, NY
WELLHEAD PROTECTION AREAS

added to the outer perimeter of this area to create the final zone. This is shown in Figure 19 along with the primary protection zone for Bradigan spring, delineated in a similar fashion.

The secondary protection zone for the spring and well system is included for the protection of surface water that recharges the aquifers. The delineation is based on watershed limits beginning at a point on the West Branch of Conewango Creek, down stream of the primary protection zone, and encompassing the entire drainage basin up-gradient from that point.

SINCLAIRVILLE WELLFIELD

Hydrogeologic Setting

The Sinclairville wellfield is located on a fan-shaped gravel deposit flanking a ridge along one side of a glaciated valley (Figures 20 and 21). The deposit consists of coarse-grained fluvial sediment (sand and gravel) originating in the uplands and deposited in a late Wisconsin-age glacial lake. This lake has subsequently filled with sediment to form the present-day Cassadaga Valley. The sand and gravel overlies and is interbedded with, valley-filling sediments (Muller, 1963; Crain, 1966). A portion of the underlying stratified drift is a regional aquifer (Lower Cassadaga Valley Aquifer, also known as the Jamestown Aquifer) extending down-valley.

The aquifer, identified in both production well logs, consists of alluvial fan sand and gravel grading downward into delta sand and gravel. The wells were drilled through approximately 60 ft of various sand and gravel layers overlying a layer of sandy clay. The depth to bedrock at the well field is unknown. The aquifer is unconfined with static water levels varying seasonally from about 9 to 22 ft below ground (saturated thickness ranges from 38 to 51 ft). The fan-delta is 1 mi^2 in area, bounded to the north and east by till covered bedrock, and to the south and west by lake sediments. Based on other well logs in the Sinclairville area, the fan-delta deposit thins or pinches-out approaching the bedrock hills. The delta gravel also dips westward as it becomes interlayered with the Jamestown Aquifer. The Jamestown Aquifer is thought to be outwash, 20 ft thick underneath about 100 ft of lake silt.

Municipal Wells

Sinclairville currently uses two vertical wells drilled adjacent to Mill Creek (Figure 20). The water system serves about 772 people and provides water to commercial and light industrial users. Their average and maximum daily water demands are 130,000 and 180,000 gpd respectively.

Well 1 was drilled in 1956 to a depth of 59 ft and screened from 54 to 59 ft. Well 2 was drilled in 1974 and is located closer to Mill Creek. It is 60 ft deep and is screened between 50 and 60 ft. The annuli of the wells are properly sealed with concrete and both wells are enclosed in separate buildings with concrete floors. The wells are both pumped at an average rate of 130 gpm with maximum pumping rates of 150 gpm for well 1 and 187 gpm for well 2. The wells are pumped one at a time, 17 to 23 hours per day depending upon demand. It is common practice to

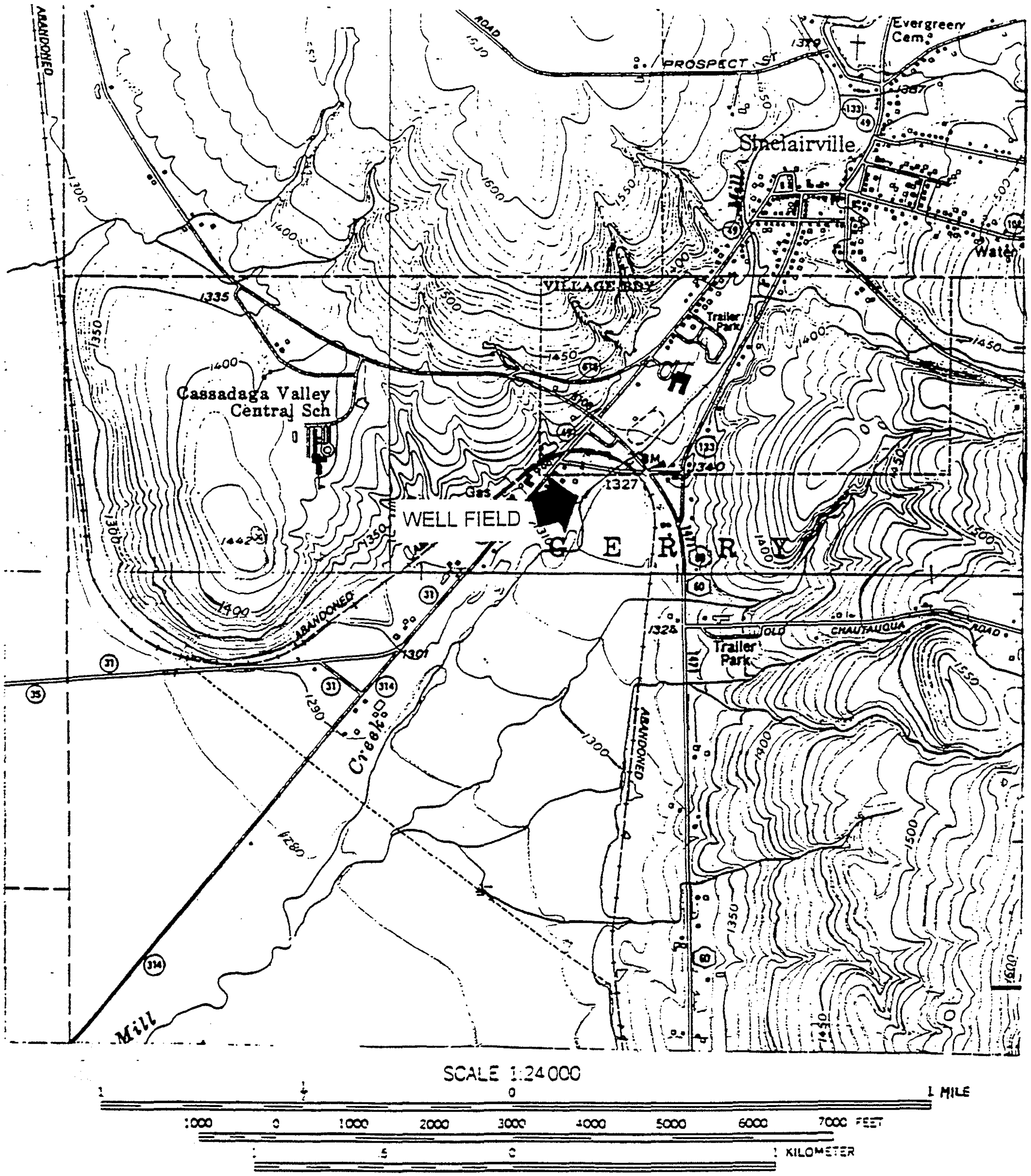
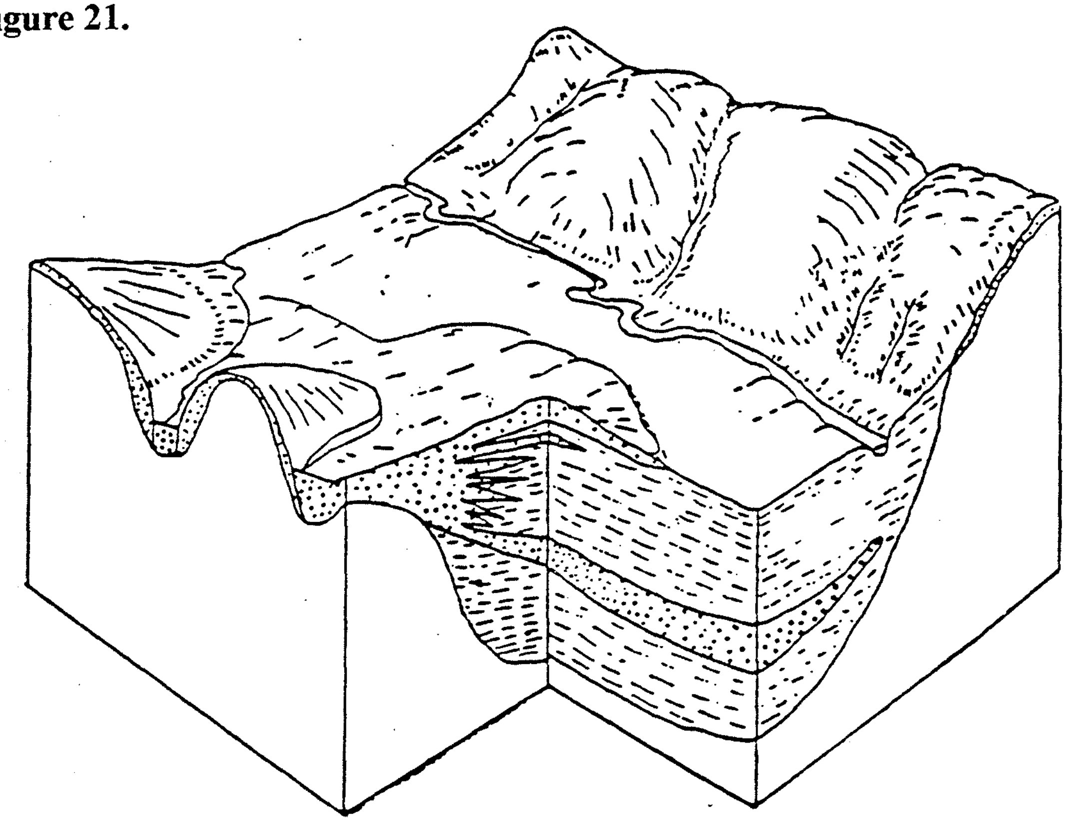
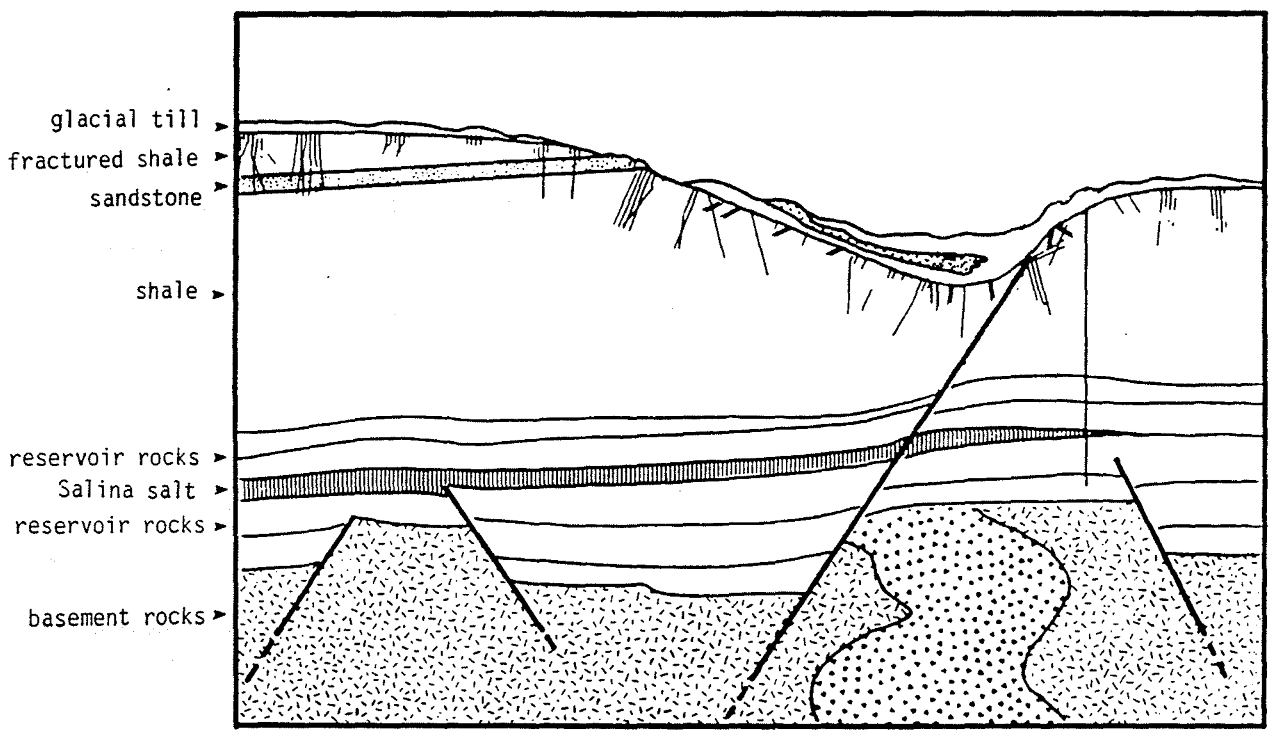


Figure 20. Location of the Sinclairville well field (Source USGS 7.5' topographic map - Cassadaga and Ellery quads, scale: 1"=2,000 ft).

Figure 21.



21a Block Diagram of Mill Creek Fan and Cassadaga Valley
(modified from Crain, 1966)



21b Deep Section **(not to scale; Wilson 1985)**

alternate the wells every two to three days in order to distribute wear, although it is not uncommon for each well to be run for a week at a time.

Original pump test data for either well is not available. Documentation by the well driller indicates that well 1 was continuously pumped for 5 days at 150 gpm with only 1.6 ft of drawdown. No information is available for well 2. A pump and recovery test was performed on well 1 on 8/13/91 as part of an American Water Works Association Research Foundation (AWWARF) project to characterize microparticulate recharge and associated phenomena (Wilson and others, 1996). Water level data was collected from well 2 and a monitoring well 75 ft away from well 1. The monitoring well is a 2 in. steel pipe, the top of which is buried about 2 ft below grade. Water level data collected from the monitoring well was analyzed using the AQTESOLV computer program (Geraghty & Miller, 1989) by both the Theis and the Cooper-Jacob method for evaluating unconfined aquifers. Transmissivity and storativity of the aquifer are approximately 5,000 ft^2/day and 0.65 respectively; hydraulic conductivity is about 151 ft/day.

Ground-Water Flow

Water table elevation data is limited, preventing the determination of actual flow directions and gradients. But since the aquifer is unconfined, surface topography can be used to approximate them. Based on local topographic maps, regional flow is from approximately north 35 degrees east. Water drains off the till covered hills, entering the aquifer through the porous sediments of the delta, and flows toward the center of Cassadaga Valley. The gradient of ambient ground-water flow, based on both topographic maps and streambed surveys, is between 0.005 and 0.010. The majority of the upland watershed drains into Mill Creek which flows across the delta. Towards the center of the valley, the delta deposit merges with the fine grained lake sediments (silts and clays) thereby restricting horizontal flow as the ground-water moves downward into the Jamestown Aquifer. This being the case, it is likely that hydraulic gradients in the delta aquifer are steeper than predicted by surface topography.

Water available to the wells is from water stored in the saturated sediments of the aquifer, as well as from recharging precipitation, Mill Creek infiltration, and hillslope runoff to the delta margin. The total land area of the delta aquifer up-gradient of the wells is approximately 0.32 mi^2. Using an average saturated thickness of 20 feet and a porosity of 20%, a conservative estimate of water available to the wells in storage is 267 million gallons. Additional storage may occur in the upland till areas. Mill Creek, which flows directly across the delta and into Cassadaga Creek, is a major source of recharge to the aquifer. The delta watershed is approximately 20 mi^2. The maximum amount of water available for recharge from runoff (precipitation: 42in. – evapotranspiration: 23in.) on an annual basis, averages 6.6 billion gallons. Only a portion of this would actually recharge ground water; the majority would contribute to stream flow. Although no actual streamflow data is available for Mill Creek, it has been observed that flow routinely diminishes during middle to late summer with all or a majority of streamflow disappearing as it flows across the delta (Wilson and others, 1996). This is typical of valley-fill aquifer systems in western New York State (Crain, 1966; Randall and Johnson 1987).

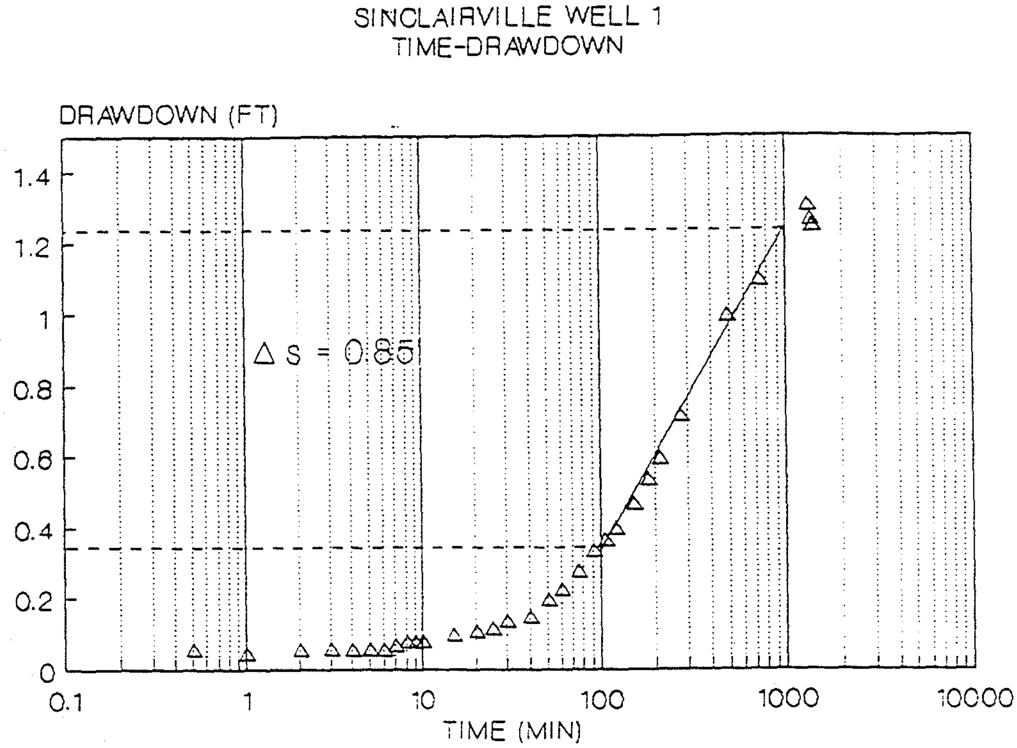
A distance-drawdown graph for the well field (Figure 22) shows that the cone of depression extends approximately 400 feet. The water level in the well never stabilized during the pump test, therefore the cone was still growing when the test was terminated. When this pump test was conducted, Mill Creek was dry immediately adjacent to the wells. Upstream, creek flow was observed to be very low with flow completely disappearing about 1,000 feet up-gradient of the well field. Drawdown in the well was greater than usual due to the depletion of water from storage. The cone of depression was, therefore, extending up-gradient towards the flowing portion of the stream and inducing recharge. It should also be pointed out that the water table elevation in the delta aquifer may be reduced by ground-water withdrawals from the Jamestown aquifer.

Time of Travel

Periods of induced surface water recharge to the aquifer were estimated utilizing surface water and ground-water temperature and conductivity data (Figure 23). During the early part of the year, there was sufficient precipitation to maintain water in storage in the aquifer. The ground-water temperatures did not vary significantly above or below the ambient air temperature (9.5^0C for this area), signifying that most of the water was in the aquifer for several months or longer. In May, ground-water temperatures began to increase to above the ambient air temperature after a one-month dry period. This condition continued through the summer and into the fall, most notably in well 2 which is closer to the stream. The warmer ground-water temperatures are due to stream water recharging the aquifer up-gradient of the well field. The onset of ground-water warming began in mid-May, two months after the onset of surface water warming. This difference in times for the onset of warming suggests a time-of-travel from the creek to the well of about 60 days. The temperature peaks for stream water and ground water nearly coincide and indicate travel times of 20 days or less during mid-summer. That the amplitudes on the ground water temperature graph are so small indicates that induced stream water is a small portion of flow to the wells. The amplitude of the ground-water graph is about 10 or 20% of the surface water graph. Conductivity data (Figure 23) also provide recharge and travel time information. Ground-water conductivity is relatively stable until mid-April, then declines (receives amounts of creek recharge). Between mid-June and mid-July, the well water conductivity rises as does Mill Creek conductivity. Base flow dominates the upper basin of Mill Creek, making Mill Creek more conductive; then lower Mill Creek infiltrates the aquifer, raising the conductivity of ground water at the wells.

Computer Modeling

Several WHPA computer modeling runs were conducted for the Sinclairville well field using various hydraulic parameters. The well field was modeled using a single well pumping at 130,000 gpd (average demand) since both wells are similar and do not run concurrent. ZOCs (zones of contribution) were computed for wet periods (late fall-winter-spring when storage in the aquifer is at or near maximum capacity) and also for dry periods (summer-early fall when storage is at a minimum). For wet period simulations, the maximum saturated thickness (51 ft), minimum estimated hydraulic gradient (0.005), and ambient flow direction (58^0 above an east-west line) were used. For dry period simulations, the minimum saturated thickness (38 ft) and maximum



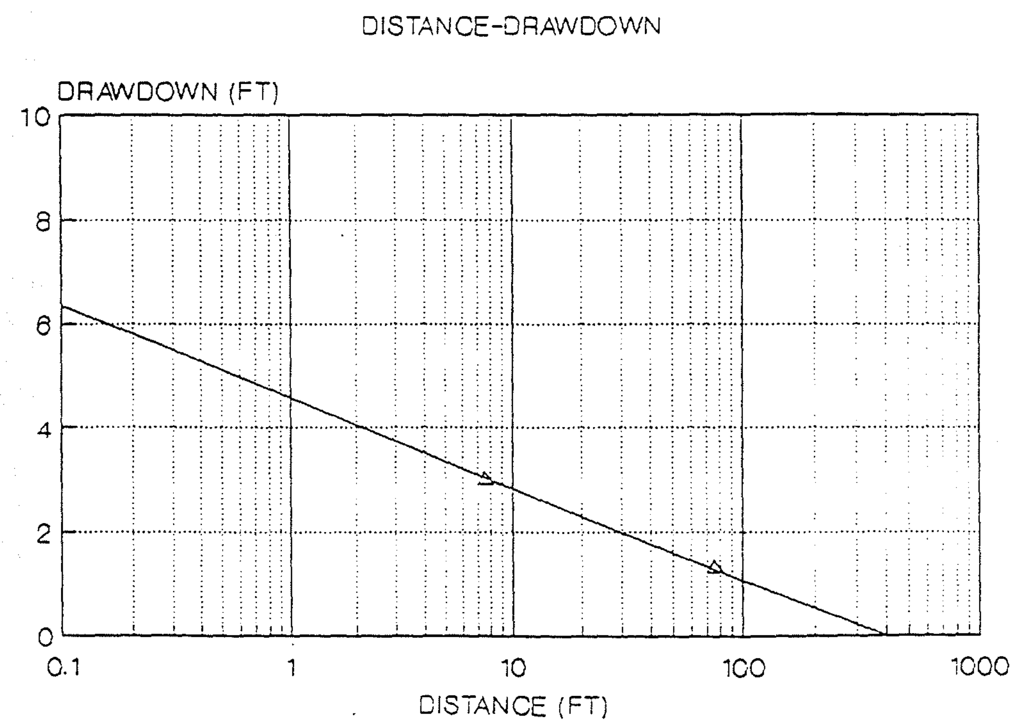


Figure 22. Distance-Drawdown graph for well 1 (bottom) at time = 1310 minutes into the 8/13/91 pump test. One point is the drawdown measured in a monitoring well 75 ft from well 1, the second point was calculated using the equation from Driscoll (1986): drawdown = 2 X Δs (over 1 log cycle), where Δs is computed from the Time-Drawdown graph (top). This identifies the cone of depression extends approximately 400 ft from well 1, but since the well did not stabilize during the pump test, the cone of depression was still growing.

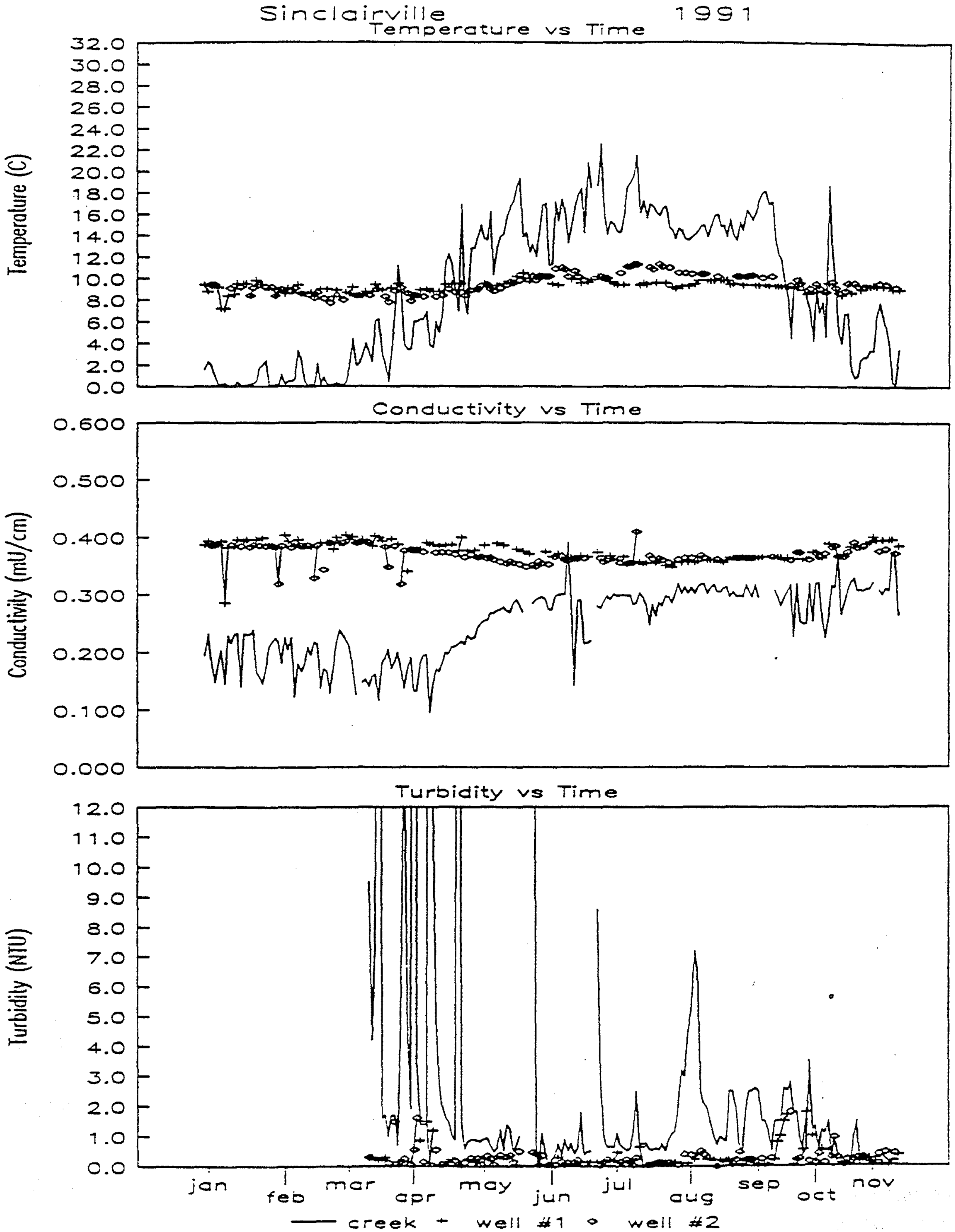


Figure 23. Water quality graphs for wells 1, 2, and nearby Mill Creek.

estimated hydraulic gradient (0.010) were used. During dry periods, the direction or ambient ground-water flow would be skewed towards the stream, therefore, a flow direction of 46^0 above an east-west line was used. The other parameters and results of the modeling are shown in Figures 24 and 25. Note that during the dry period simulation, the ZOC is much longer and thinner, intersecting a portion of the stream bed. It is speculated that as aquifer water is depleted, the ZOC makes a gradual transition from that shown in Figure 24b to that shown in Figure 24a and begins to induce surface water recharge through pumping. Otherwise, natural stream loss and precipitation are the primary sources of recharge.

Times-of-travel were also estimated using the WHPA computer model. The shortest possible travel time between the stream and well 2 (the well closest to the stream) was estimated to be from 10 to 20 days (Figure 25). This computer model run is based upon a relatively steep gradient being created between the high stream stage and increased drawdown in the well due to a lack of stored water. This situation would occur at or near the end of a dry period during a storm event. The model simulates ground-water flow to be from a point in the stream closest to the well, in an east to west direction, using a gradient of 0.22. The MWCAP module was used to perform this run which allowed the simulation of induced recharge from a stream, the other runs were performed using the RESSQC module.

Microscopic Particulate Recharge

Because of concerns for giardiasis, cryptosporiodosis, and other surface water diseases that may move as particulate matter from surface waters into ground waters, we evaluated microparticulate recharge using utility in-kind support and resources from grants. Lines of evidence included temperature dilution, conductivity dilution, turbidity data, bacteria data, and microscopic particulate analysis (MPA) test results. In prior sections above, we already established that aquifer geometry, pump tests, and water observations indicated hydraulic connection and a time of travel less than the viability period of giardia cysts (90 days) for example.

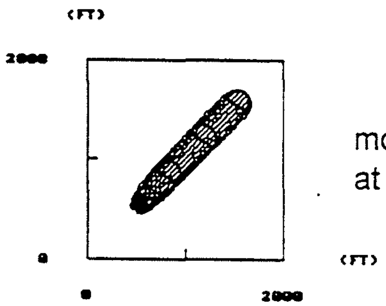
As previously stated, relative magnitudes of the ground-and-surface-water temperature amplitudes suggest a significant dilution of creek water by ground water. In these sand and gravel deposits, hydraulic conductivities are high but not so high as to be like cavernous limestones. Therefore, dilution is essentially dispersion; turbulent or diffusive mixing is negligible. During the summer, 9.5^0C ambient ground water is raised to 10 or 11^0C by 16^0C-average surface water. While this comparative approach is highly simplified, a mix of 20% surface water (that is, 7^0C above ambient ground water) with ambient ground water yields 10.8^0C ground water. In winter, ground water is 0.39 mU/cm; in summer it's 0.36 to 0.37 and surface water is 0.30 to 0.32. If the well water is composed of 30% of 0.31 conductivity and 70% of 0.39, then the late summer mix is the observed 0.366 conductivity.

Figure 24.

```
RESSQC PROBLEM SUMMARY

       Simulation Option:   capture zones
  Number of Pumping Wells:        1
 Number of Recharge Wells:        0
          Transmissivity:     5000. ft**2/d
      Hydraulic Gradient:  0.010000 ft/ft
   Angle of Ambient Flow:    226.00 degrees
        Aquifer Porosity:      0.25 dimensionless
       Aquifer Thickness:       38. ft
         Simulation Time:      270. days
No. of Capture Zone Times:        4

Would you like to see well parameters? (Y/N)
```



WHPA computer modeling results for a 9 month "dry period" simulation with a single well pumping at 130,00 gpd. Scale of ZOC plot is 1" = 2,000 ft.

```
RESSQC PROBLEM SUMMARY

       Simulation Option:   capture zones
  Number of Pumping Wells:        1
 Number of Recharge Wells:        0
          Transmissivity:     5000. ft**2/d
      Hydraulic Gradient:  0.005000 ft/ft
   Angle of Ambient Flow:    238.00 degrees
        Aquifer Porosity:      0.25 dimensionless
       Aquifer Thickness:       51. ft
         Simulation Time:      270. days
No. of Capture Zone Times:        4

Would you like to see well parameters? (Y/N)
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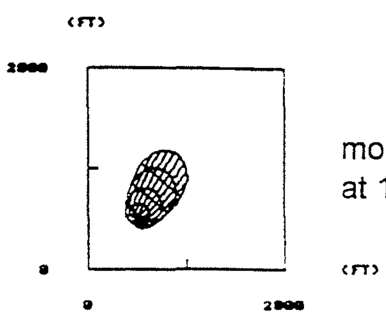

WHPA computer modeling results for a 9 month "wet period" simulation with a single well pumping at 130,00 gpd. Scale of ZOC plot is 1" = 2,000 ft.

```
                SUMMARY OF INPUT DATA FOR WELL # 1

                           X Coordinate:         500. ft
                           Y Coordinate:         500. ft
                    Well Discharge Rate:       17380. ft**3/d
                         Transmissivity:        5000. ft**2/d
                     Hydraulic Gradient:    0.022000 ft/ft
                  Angle of Ambient Flow:      180.00 degrees
                       Aquifer Porosity:        0.25 dimensionless
                      Aquifer Thickness:         38. ft
                          Boundary Type:   stream boundary
         Distance from Well to Boundary:        185. ft
           Orientation of Local System:      180.00 degrees
                      Capture Zone Type:   time-related
                            Travel Time:         14. days
                     Number of Pathlines:          5

                  <Press Any Key to Continue>
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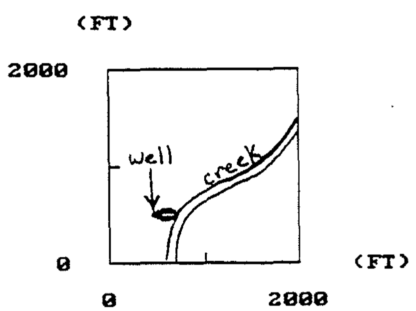


Figure 25. WHPA computer modeling results using the MWCAP module of the program. This run simulates the shortest possible time-of-travel within the aquifer assuming all ground water pumped from the well is from induced surface-water recharge from nearby Mill Creek. This situation could occur during a storm event (when Mill Creek is at high stage) at the end of an extended dry period (late-summer or early fall) when the aquifer is depleted. Travel times from the creek to the wells would be between 10 and 20 days under these conditions.

Turbidity data collected in 1991 indicates 90% of the values for the wells were below 0.3 NTU and all were below 2.0 NTU (Figure 23). Surface waters varied widely from 0.5 to over 12 NTU. Ground-water turbidity variations were minimal and not correlative with other parameters or events. Weekly coliform and heterotrophic bacteria levels were zero for the twelve months of 1991 in the two wells, while nearly always present in Mill Creek.

MPA was performed during the summer months on creek water and ground water from both wells (Table 2). Also, we determined natural reduction (filtration plus dilution) efficiency by comparing the number of surface water particulates and ground-water particulates. An apparent near-total removal of particulates in March and July suggested an extremely high natural reduction efficiency through the aquifer.

A second MPA was performed on creek water and ground water from well 1 in December. The well was pumping during an identified major recharge period. A number of surface water indicators (Table 2) were identified in the ground water at this time. The resulting high EPA relative risk score indicated direct surface water influence. Natural filtration efficiencies for diatoms and "other algae" were calculated at 5-log and –2-log removals respectively. These results represent a period of cold wet conditions following drought. The negative log reduction of the "other algae" likely reflects the effect of TOT on the measurement, i.e., TOT was not fully accounted for in the choice of measurement dates for the surface samples vs. the well sample.

Conclusion: although Sinclairville wells experience periods of short TOT, these periods are infrequent and particulates from the stream water face reduction by dilution and natural filtration in the ground as well as some inactivation during their 10 or 20 day subsurface transport. There is further dilution in the holding tank and distribution pipes. There is also extended contact time with chlorine in the distribution system.

Delineated Wellhead Protection Areas

Primary recharge to the aquifer is from precipitation falling on permeable aquifer (delta) sediments along with stream loss occurring along segments of Mill Creek. Additionally, during dry periods, well pumpage induces surface water recharge from the creek.

Due to the nature of this aquifer, ground-water protection is best accomplished using the geologic extent of the delta formation. The primary protection zone for wells 1 and 2 was delineated using the areal extent of the aquifer up-gradient of the well field. The 500 ft buffer was then added to the outer perimeter of this area to create the final primary protection zone shown in Figure 26.

A secondary protection zone is included for the protection of surface water that recharges the aquifer through both overland flow and stream loss. The delineation is based on watershed limits beginning at a point down stream from well 2 and encompassing the entire drainage basin up-gradient from that point. A portion of the secondary protection zone is shown in Figure 26.

Table 2. Sinclairville - MPA DATA

Device	Source Type	Filter ID#	Date	Giardia	Coccidia	Diatoms	Other Algae	Insects/ larvae	Rotifers	Plant Debris
*	Surface Water	1640	12/09/91	0	0	4,000,000	1	0	0	0
*	Surface Water	1438	07/09/91	0	0	90,000,000	3,000,001	0	0	0
*	Surface Water	1334	03/28/91	0	0	2,000,000	4,000,000	1	0	0
Well 1	Drilled Well	1337	03/28/91	0	0	0	1	0	0	5
Well 1	Drilled Well	1440	07/11/91	0	0	0	0	0	0	0
Well 1	Drilled Well	1641	12/10/91	0	0	20	60	0	0	0
Well 2	Drilled Well	1439	07/10/91	0	0	0	0	0	0	0

* Sample results relate spatially to both wells

- MPA DATA (cont'd.)

Device	Source Type	Nematodes	Crustaceans	Amoeba	Non-Photo. flagellates & ciliates	Photo-synthetic flagellates	Other: iron bacteria	EPA TOTAL RISK	EPA RELATIVE RISK
*	Surface Water	0	0	0	0	0	0	20	High
*	Surface Water	0	0	0	0	0	0	30	High
*	Surface Water	1	0	0	0	0	0	33	High
Well 1	Drilled Well	0	0	0	0	0	0	4	Low
Well 1	Drilled Well	0	0	0	0	0	0.3	0	Low
Well 1	Drilled Well	0	1	0	0	0	0	20	High
Well 2	Drilled Well	0	0	0	0	0	0	0	Low

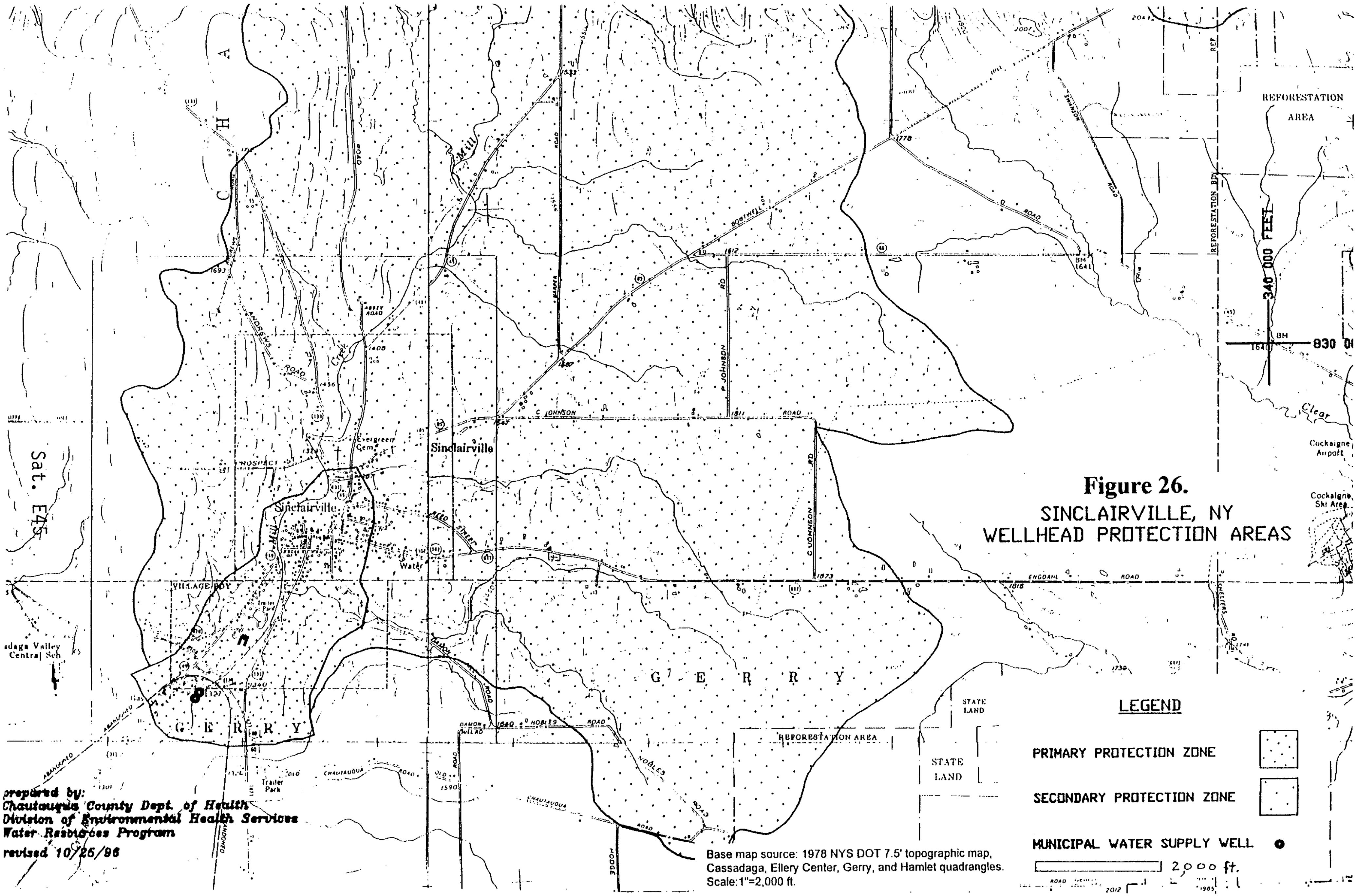


Figure 26.
SINCLAIRVILLE, NY
WELLHEAD PROTECTION AREAS
LEGEND
PRIMARY PROTECTION ZONE
SECONDARY PROTECTION ZONE
MUNICIPAL WATER SUPPLY WELL
2,000 ft.
Base map source: 1978 NYS DOT 7.5' topographic map, Cassadaga, Ellery Center, Gerry, and Hamlet quadrangles.
Scale:1"=2,000 ft.
prepared by:
Chautauqua County Dept. of Health
Division of Environmental Health Services
Water Resources Program
revised 10/25/96
Sinclairville
GERRY
REFORESTATION AREA
STATE LAND
Cockaigne Airport
Cockaigne Ski Area
340 000 FEET
Evergreen Cem
VILLAGE BDY
Water
Trailer Park

DRINKING WATER TURBIDITY AND RESERVOIR SEDIMENTATION, BROCTON, NY

System Description

The Village of Brocton is located in north central Chautquaua County, southwestern New York (Figure 27). The village is served by a system of three reservoirs and a filter plant. Water is distributed to about 1,500 residential customers, area businesses, and the Lakeview Correctional Facility. The reservoirs are fed by Slippery Rock Creek, a north flowing stream that drains from the north edge of the Allegheny Plateau. West Branch Slippery Rock Creek drains into Burr Reservoir (built 1897), East Branch drains into Risley Reservoir (1918), and the outlets for each of these reservoirs drain north into Brocton Reservoir (1953). Burr Reservoir currently has a capacity of 6,000,000 gallons (6MG); Brocton Reservoir is 70 MG and Risley is less than 1 MG. Risley and Brocton Reservoirs function by direct stream through-flow while Burr Reservoir receives water from occasional stream diversion through an artificial inlet channel roughly 50 ft in length. The Village owns 625 of the 2000 acre watershed.

Background and Purpose

Village water plant operators prefer to utilize water from Burr Reservoir because of its low turbidity. However, West Branch stream replenishment of Burr Reservoir is insufficient to replenish the level of this reservoir during summer and early fall. Consequently, Burr Reservoir water supply must be augmented by the Brocton Reservoir during summer and early fall. The high turbidity of the Risley and Brocton Reservoirs is often visually obvious from poor clarity when compared to the Burr Reservoir. And, Risley Reservoir is filled with sediment such that its surface is mostly exposed sediment, and there is essentially no water capacity. Fine suspended sediments that reach the Brocton Reservoir overload filter beds at the treatment plant compromising the treatment process, creating turbid finished water, and posing a potential health threat to the public.

The problems of the Brocton reservoirs came to the attention of several members of the Chautauqua County Water Quality Task Force in 1996. Several initial site reviews were conducted by USDA (Larry Brown), County Soil and Water Conservationist (Dave Wilson), SUNY-Fredonia (Mike Wilson), and County Health Department personnel (Steve Johnson and Bill Boria). The importance of the landslide area as a sediment source was determined during initial visits by this group.

The purposes of this guidebook article are to summarize investigations of: (1) the disparity in water clarity between West Branch (less turbid) and East Branch (more turbid); and (2) the sedimentation of Risley Reservoir. The importance of the landslide area as a source of turbidity is confirmed and quantified.

The purpose of our investigation was to further evaluate turbidity causes prior to constructing site renovations. The previously planned site renovations were: First and foremost the landslides and creek channel were to be stabilized by dewatering the slope, removing debris

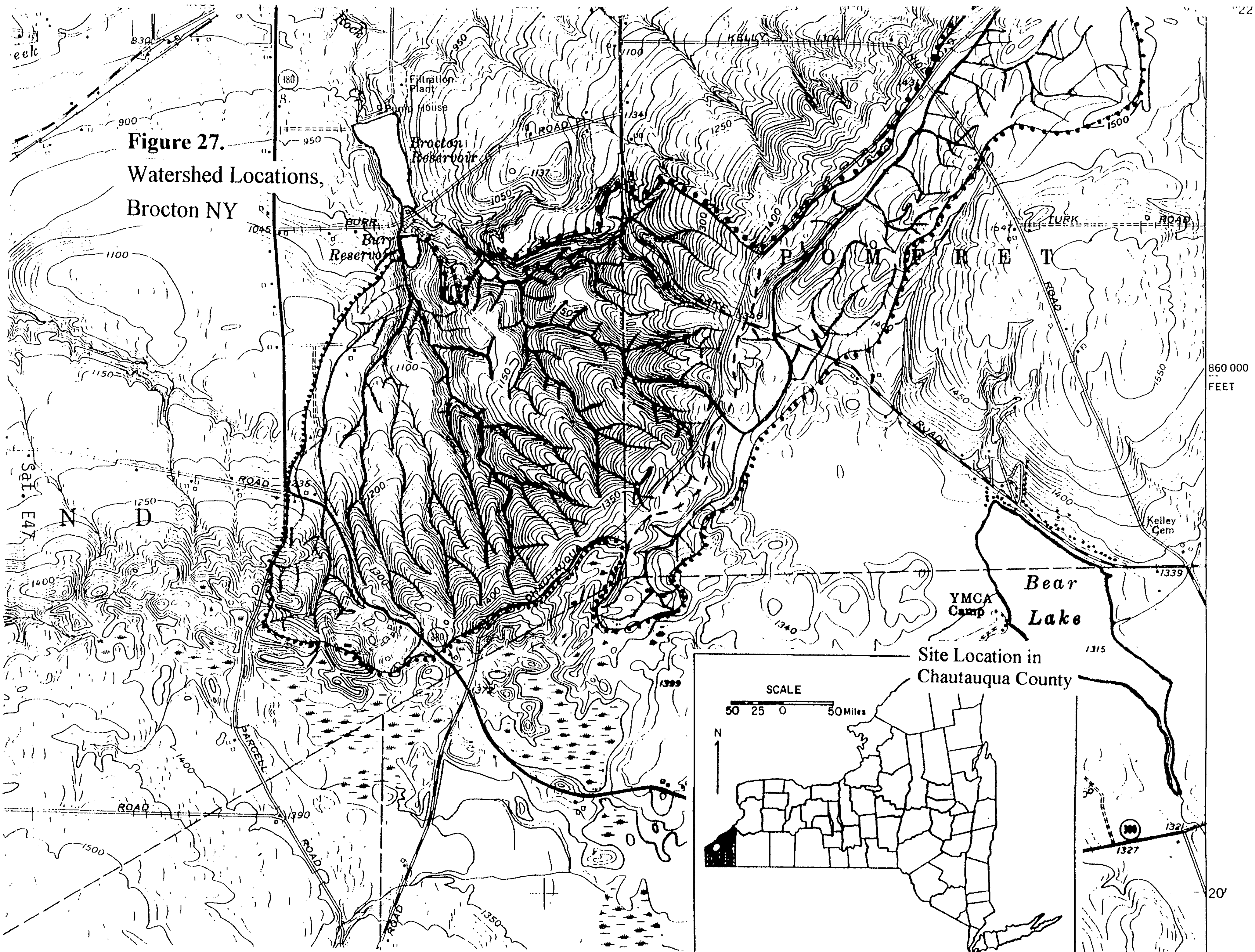


Figure 27.
Watershed Locations, Brocton NY

dams, and placing gabions along both sides of approximately 200 ft of creek bed. Secondly, both sides (a total of 200 ft) of Chautauqua Road at the culvert were to be stabilized with gabions and rip-rap. Finally, an access road was to be built leading to the Risley Reservoir which would be dredged and used again as a water supply.

However, partly because of the findings reported herein, practicality and costs of the above three-phase plan were reconsidered. Landslide and channel stabilization is being given further thought and not being implemented immediately. A massive Chautauqua Road culvert stabilization was completed. And, Risley Reservoir will be dredged and is being referred to as a "sedimentation basin". With good access, this sedimentation basin can be maintained yearly by the Village, removing creek bed-load material that would otherwise settle in the Brocton Reservoir.

Participants

The Geomorphology class (GS 330) from SUNY-Fredonia consisted of 26 students from sophomore to senior level. These students conducted much of the work reported herein. Wilson and Boria organized the investigation. Brian Mentley and Marty Terrell were Teaching Assistants. Much of the field data collection was accomplished by dividing the class into 4 teams of about 6 students each. Wilson, Boria, Mentley and Terrell each worked with one team in a different portion of the watershed. Also, lab and computational work was routinely divided among teams and re-checked by teams. Student reports ranged from about 50 to 150 pages.

Boria was liaison to the Village and made arrangements for test drilling, records review, historic information on treatment plant operation, and finance for items such as water sample analysis.

Sub contractors on the project were Earth Dimensions, Inc. (Buffalo, NY) and Microbac Labs (Erie, PA). Earth Dimensions provided drilling and soil sampling services. Microbac analyzed water samples for total suspended solids (TSS). Additionally, Wanda Gustafson of Chautauqua County Emergency Management supplied sandbags used by us to temporarily dam very small streams when we were measuring flow and sampling.

Summary of Methods

We investigated the history of the site concerning reservoirs construction, operations and maintenance. Muller's Pleistocene geology map of Chautauqua County (1963) was reviewed. Likewise, we converted the USDA Soil Survey maps to parent materials maps (i.e., surficial geology maps) throughout and adjacent to the drainage basins. A generalized cross-section of bedrock and sediment was constructed from the Lake Erie plain through the reservoir area and into the Allegheny Plateau near Bear Lake. The 7.5 minute Brocton quad topographic map was enlarged and copies highlighted for: drainage patterns, gully patterns, flat-topped inter-fluves, morphologic features (such as eskers or moraines), watershed boundaries, etc. We computed morphometric properties such as stream orders, drainage densities, stream lengths, watershed areas, stream profiles, relief and relief ratios. We began outdoor work by driving and walking through the watershed with the above materials at hand.

We took field notes of watershed and reservoir conditions including description of exposed sediment and rock materials, general locations of landslides, and appearance of eroded areas and other landscape features. This fieldwork and all succeeding fieldwork was supplemented and documented with photography.

Test borings were completed at four locations in the vicinity of the landslide area near Chautauqua Road. These four borings were sited above the landslides and drilled to below the ravine bottom so that cross-sections could be drawn through the slides, hills, valleys, and surface and subsurface materials. The cross-sections could be drawn utilizing drilling observations, standard penetration test results, water levels, topography, notes and photographs of surface conditions, and soil parent materials maps. To improve the drawings, the continuous split spoon samples were taken to the College at Fredonia and sub-sampled. The sub-samples were sorted for observation in custom-cut wood trays placed side by side relative to sampled elevations. Elevations of tops of borings and points along the nearby streambed were surveyed by transit. These data and drawings allowed for documentation and interpretation of subsurface material types, aquifer geometries, and general pore pressure conditions.

Below Chautauqua Road we sketched, photographed, sampled and measured the slide masses. Measurements were made with high quality tape measures and the clinometers on Brunton compasses (slope angles). Fluvial conditions including erosion scars, deposits, knick points (upstream migrating water falls), and vegetative debris jams were reviewed. Landslide failure planes were investigated and then scarps, fractures and exposed-toe slip-planes noted. For the largest landslide we calculated the approximate maximum average-soil shear-strength by solving the Factor-of-Safety equation for the Ordinary Method of Slices for shear strength when the slip circle is known and the soil weight is estimated.

Erosion and sediment transport were investigated in moderate detail at about a dozen locations (Figure 28). With tape measures, wading rods, and flow meters, we measured stream cross-sections and subsection velocities and discharges. At several locations, water depth or velocity were too low to measure accurately with a flow meter. At these locations, the stream was sandbagged to create a temporary weir and discharge was measured by stop watch and bucket. Water samples were taken from high velocity subsections at each location. Chain of custody records were kept and Microbac, Inc. analyzed the samples for Total Suspended Solids (TSS). A blind duplicate sample was included; it yielded good reproducibility of results. The TSS concentrations were multiplied by stream discharge to obtain sediment loading. These results were a measure of baseflow sediment transport above and below the landslides, into each reservoir, and from several tributaries.

Additionally, high flow conditions were estimated by collecting TSS samples during high flows of Spring 1998 (all other measures described above were from Fall 1997). These TSS values were multiplied by bank-full discharge estimates in order to approximate flood sediment transport (Table 3). The bank-full discharges were estimated using the Manning equation to estimate velocity. Variables in the Manning equation were measured by tape measure and rod (slope, hydraulic radius from cross-section). Manning's n was determined from channel

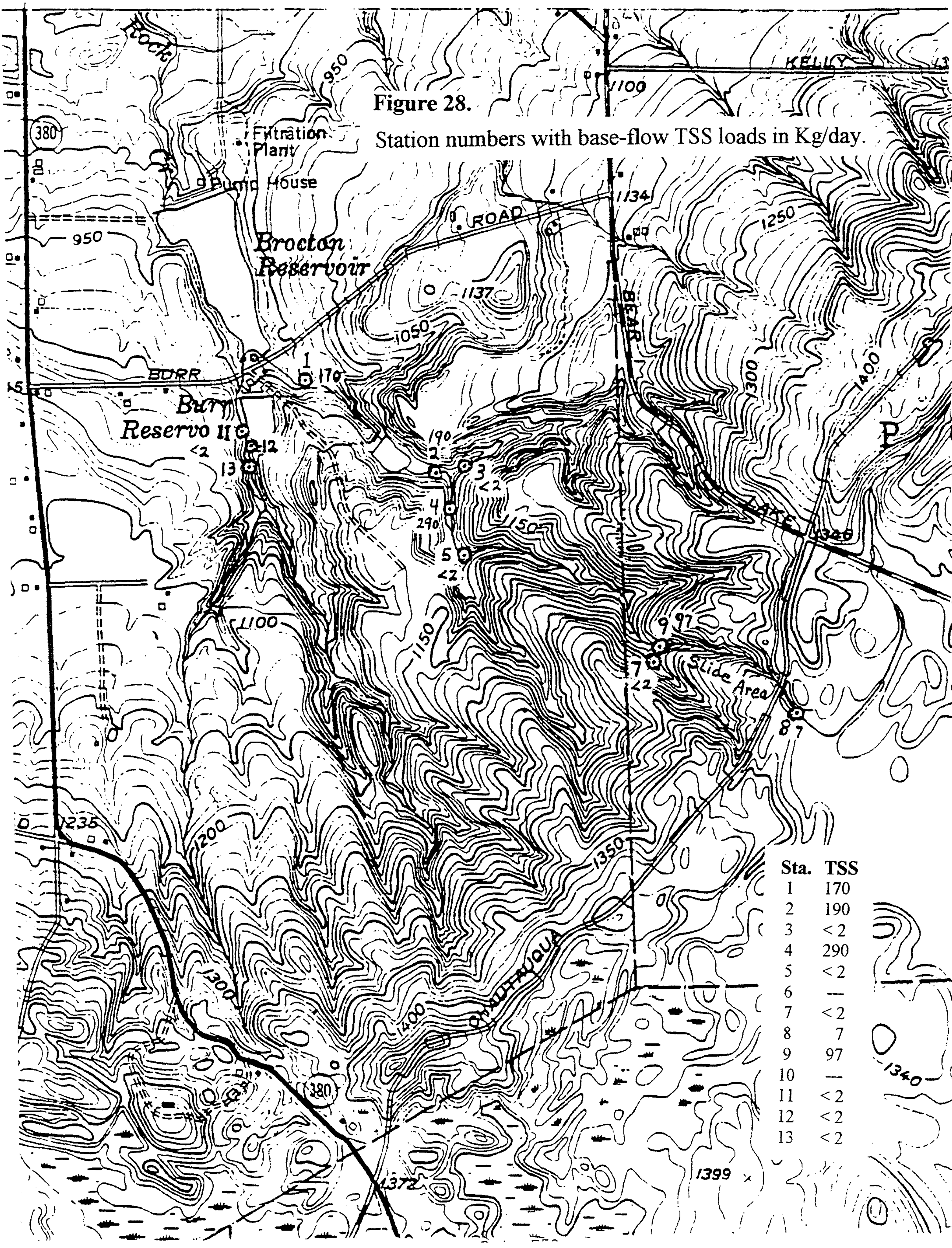


Figure 28.

Station numbers with base-flow TSS loads in Kg/day.

Sta.	TSS
1	170
2	190
3	< 2
4	290
5	< 2
6	—
7	< 2
8	7
9	97
10	—
11	< 2
12	< 2
13	< 2

comparison to US Geological Survey Water Supply Paper No. 1849 (Barnes, 1967). Bank-full water levels were estimated from bank shape and high water marks.

Results

This section of the report presents a summary of the main results. Details of results and methods were given to the Mayor of Brocton in an Appendix of approximately 150 pages. Most of the appendix was a copy of one of several outstanding student participant reports. This report by Cynthia Pettit included all of the project generated data (mostly group generated).

Figure 29 gives the change in reservoir volumes through time. The sedimentation rates (reservoir capacity losses) are: Burr 2,900 ft^3/yr, Risley 27,100 ft^3/yr, and Brocton 40,800 ft^3/yr. These data suggest that the rate for sedimentation in Risley Reservoir was fairly consistent throughout its existence. Either or both of two factors may account for the low sedimentation rate in Burr Reservoir: (1) lower sediment transport rate along West Branch Slippery Rock Creek; or (2) operation of Burr Reservoir in a way that allows sediment to bypass the reservoir.

Baseflow TSS loading measurements (Figure 28) into Burr Reservoir and in the bypass channel around the reservoir were less than 2 kg/da on 11/6/97, while Risley Reservoir received between 190 and 290 kg/da and Brocton Reservoir received 170 kg/da. Thus, the baseflow sediment loads to Brocton Reservoir were diminished by Risley Reservoir. Baseflow particle sizes were clay-silt dominated as indicated by qualitative settling observations in our labs. These East Branch loads were about 100 times the West Branch baseflow loads.

Numerous casual observations of stream colors and clarity agree. East Branch is commonly grayish. Also, pH measurements collected in 1938 were 7.5-7.8 in Risley and 7.0-7.2 in Burr. High clay concentrations in Risley would cause these pH differences.

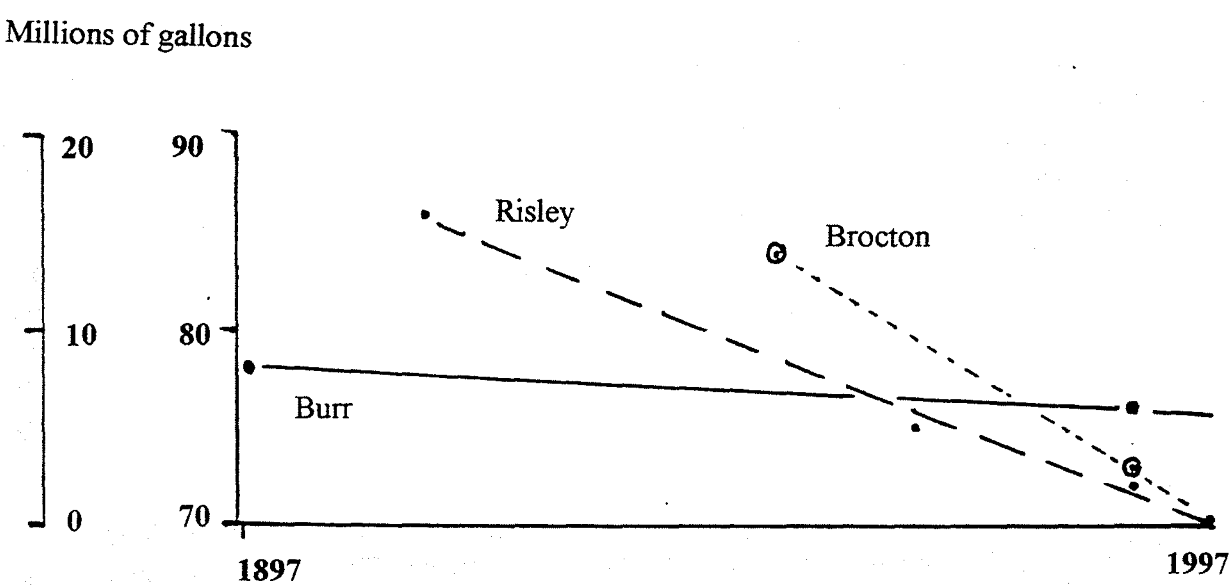
Another set of TSS samples was collected at 3 locations on 4/21/98 during high flow storm water conditions. Table 3 gives the TSS concentrations at locations (Figure 28): #13 (above Burr), #8 (Chautauqua Rd.), and #2 (below the landslides and above Risley Reservoir). The discharges are those estimated by use of the Manning equation for bank full conditions. Consequent hypothetical bank full storm water loads for West Branch are 9,000 kg/da (200 ft^3/da); 22,000 kg/da for East Branch at Chautauqua Rd.; and 226,000 kg/da (5,000 ft^3/da) into (or through) Risley. Thus, it appears that the disparity in sediment load between East Branch and West Branch is about 2 orders of magnitude for **either** baseflow **or** storm conditions. Therefore, the operation of Burr reservoir with a bypass channel may aid water clarity in Burr Reservoir, but does not account for disparity of sediment transport between East and West Branches of Slippery Rock Creek.

East and West Branches of Slippery Rock Creek carry very different sediment loads. Why? What is similar and what is different about the two systems? There are several similarities. Both became fourth order streams a short distance before entering Burr or Risley reservoirs and have drainage densities about 9 mi/mi^2. Both have dendritic patterns below Chautauqua Road. Each has a similar trunk stream profile below Chautauqua Road, which is concave-up with

Table 3. **Storm Water TSS**

Location #	Site	TSS (mg/L)	Discharge (L/s)	Load (kg/da)
13	Burr	20	5.000	9.000
8	Chaut. Rd.	52	5.000	22.000
2	Risley	262	10.000	226.000

Figure 29. Reservoirs Capacities Through Time.



possible knickpoints (water falls). Below Chautauqua Road, they have similar shaped watersheds, share a common drainage divide, and have the same climate and similar vegetation.

But there are also striking differences between the two watersheds. The East Branch (Risley) has a large additional watershed above Chautauqua Road (Figure 27). The portion of the East Branch sediment load from above Chautauqua Road is by itself greater than the West Branch load. The stream profile for East Branch (Figure 30) indicates extreme disequilibrium because the profile is not fully smooth or concave-up. The East Branch is composed of two separate drainage systems. The system above Chautauqua Road is separate, developed parallel to the glacial end moraines, and could have once flowed into Bear Lake (Figure 27). This upper drainage system literally falls into the head of the main gully of East Branch at Chautauqua Road. Considering our measured erosion rates and the scale, we expect one to several thousand years of intense erosion in the Chautauqua Road area.

Steep side slopes of gullies are apparent in Figures 27 and 28. The east portion of the West Branch watershed is highly gullied, and the whole of East Branch watershed is highly gullied. These areas coincide with surficial mapping of extensive sands, silts and clays, while surrounding areas are dominantly glacial till and minor amounts of exposed bedrock. Thus, the extensive gullying in East Branch is in response to easily eroded sediments.

On the main East Branch channel just below Chautauqua Road (Figure 28, between stations 8 and 9) is an area of extensive landslides. In addition to landslides, we observed several instances of erosive seepage (sapping creating a new tributary gully head and several locations of piping in the main stream bank wall). As already noted, the landslide area is responsible for about half of the baseflow sediment load and also is an important contributor during storms. However, the landslides themselves are not the sole contributor. Without the landslides, this reach would still be an important contributor of sediment due to gully head advance aggravated by the water and sediment contribution from drainage above Chautauqua Road, and due to sapping and piping (erosive ground-water seepage).

The hillside materials in the landslide area are composed of glacial till, gravel, sand, silt and clay deposited originally by streams flowing on, in or under glacial ice. These deposits generally coarsen northward, toward the former ice position. As the ice melted away, the deposits partly collapsed. Consequently, the geometry of the depositional layers is complex: water level observations in the test borings indicate one instance of ground-water confinement. Occasional aquifer confinement could result from obstructions of coarse layers caused when the glacier melted or from movements of modern landslide blocks.

Landslide blocks are of two types at this location: (1) fairly large (10's meters across), up to two or three slices, rotational failures with well defined slip circles, top scarps, back rotated vegetation, slide faults and scarps, and toe slip planes exposed in banks of the streambed (with no apparent uplift of the opposite bank); and (b) small (meters across), vegetated, translation failures, where the failure surface is the base of the root zone (a meter or less thick). In both cases, recent failure surfaces are very smooth. Sediments along the recent surfaces are very wet. Sediment along the recent translation slip surfaces appears liquid-like. Using the Ordinary Method of slices

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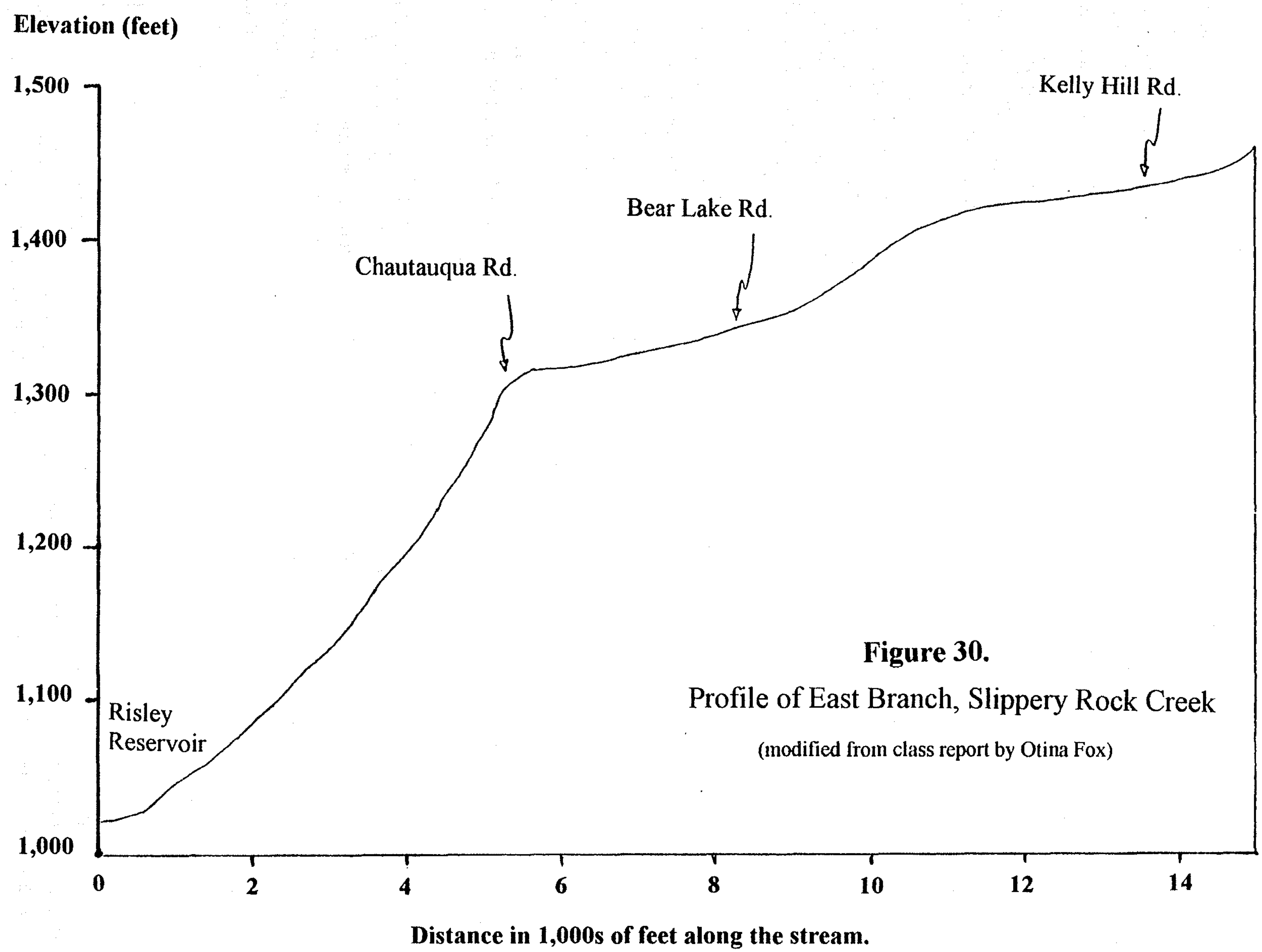


Figure 30.

Profile of East Branch, Slippery Rock Creek

(modified from class report by Otina Fox) approach for rotational landslides, and estimating a soil density of slightly less than 2 g/cc and measuring the approximate top and toe of the exposed slip circle, we calculated the consequent average maximum shear strength of the hillside soils as 5 lb/in^2. (i.e., 700 lb/ft^2) for the time of failure.

There is a very dynamic balance here between the stream and its hillslope process. As fast as the stream down cuts, the landslides will occur due to low strength and steep slopes. However, the stream can only downcut to the extent that it is not overfilled with landslide debris. These processes are aggravated and complicated by sapping and piping and the large water flow off the watershed area south of Chautauqua Road.

The sub-grade fill of Chautauqua Road played no apparent role in any of the stream or slope processes except that floods built up behind the embankment and washed away the road and its fill approximately once per decade. We estimated that the road embankment routinely lost about 6,000 ft^3 per year to the stream and lost its full volume (37,500 ft^3) once per decade. This combined to give an average roadway sediment yield of about 10,000 ft^3/year. This is approximately 15% of the annual combined loss of volume of Risley and Brocton Reservoirs. The road embankment erosion is therefore an important source of reservoir loss, although not the primary cause.

Conclusions

The Brocton and Risley Reservoirs suffer from excessive turbidity and sediment infilling (loss of capacity). About 15% of the volumetric (capacity) loss was due to repeated erosion of the Chautauqua Road embankments. Most of the problem, however, is due to natural erosion at the head of the gully below Chautauqua Road. This area is subject to erosive ground-water seepage and landslides and excess stream flow from above Chautauqua Road that falls into the top of the gully.

Reservoir capacity can be re-established by dredging and the costs figured into long-term maintenance. **Turbidity, however, is a dilemma**. Unless the stream flow above Chautauqua Road is diverted to Bear Lake (likely politically difficult but inexpensive), turbidity will continue. Even if flow is diverted, erosive seepage in the gully head may yield turbidity. Attempts to stabilize landslides in the gully head will be hampered by low strength soils, erosive seepage, and stream down cutting. Stabilization may last only 1 to 5 years.

If the watershed is maintained for drinking water, future activities should include improved timber management practices, especially reduction of logging road erosion. Only one dairy farm (potential source of cryptosporidium) is present.

TURBIDITY REMEDIATION AT SOURCE AREA AND TREATMENT PLANT, WESTFIELD, NY

Water Use

The Village of Westfield water supply (Figure 31) serves about 4,000 people, a number of commercial businesses, three fruit processing plants, the Westfield Central School and the Westfield Memorial Hospital. The village is situated along the Lake Erie plain on and between glacial Lake Warren and Lake Whittlesey beach ridge deposits. Micro-climates created by the proximity of Lake Erie, along with the presence of the sand and gravel beach ridge deposits, make this part of the Lake Erie plain an excellent grape growing location. Drinking water for the village is obtained from the Chautauqua Creek watershed, tributary to Lake Erie. Average daily production at the water treatment plant ranges from 0.5 to 0.8 MGD but, in the fall during grape packing season, production increases to approximately 1.3 MGD.

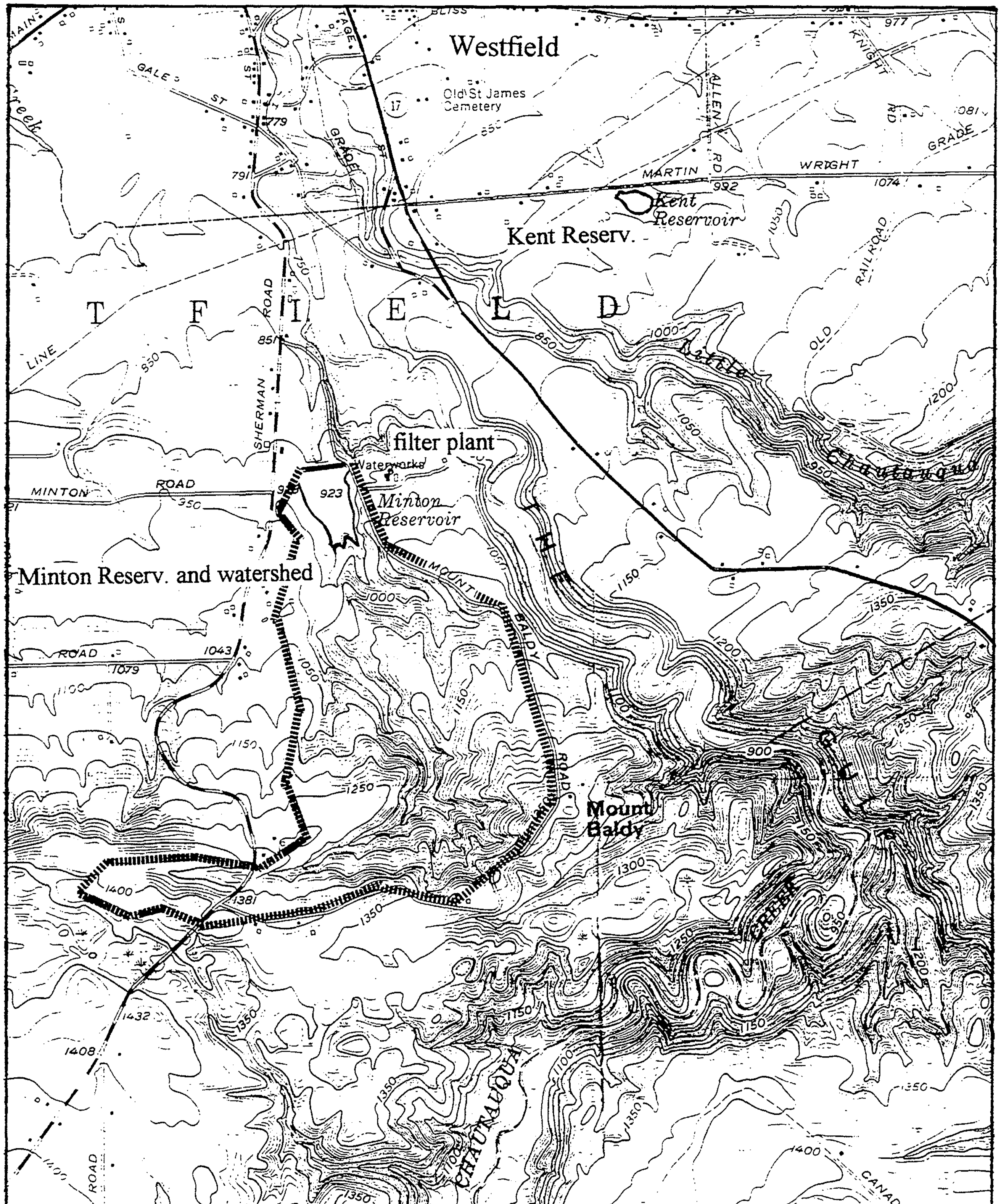
Water Supply History

The first public water supply and distribution system to serve the Village of Westfield was constructed in the early 1890s. The original system conveyed water from Chautauqua Creek to the village through a gravity pipeline whose intake was located several miles upstream from the present-day water treatment plant. Much of the pipeline was laid along the creek bank and was subject to breaks caused by stream erosion, making it a high maintenance system. Water flowed from the source, into a sedimentation basin, and then through the village distribution system. The old 7 MG Kent Reservoir stored water for emergency use. The drinking water received no disinfection until 1915, when a water-borne typhoid fever outbreak occurred in the village creating a serious need for chlorination.

This system was unable to meet the Village's water needs so, in 1939, the Minton Reservoir was built on a tributary to Chautauqua Creek (Figure 31). While a complete and detailed history of the Westfield water supply is not available at this time, information suggests that an original reservoir capacity of 45 MG was augmented in 1962 to 50 MG by raising the spillway, and in 1992 to 55 MG by partial dredging (Wayne Cardy, 1999, personal communication). The watershed area of this reservoir is only 0.7 square miles; Minton Reservoir was designed to provide only a portion of demand. Since before Minton Reservoir was built, a low-flow diversion dam in Chautauqua Creek was fitted with a pump and used to supplement the supply. Up until 1977, all of the above mentioned sources were used by the Village. The method of operation in recent decades was to rely primarily on Chautauqua Creek, especially when creek turbidity was below 20 NTU and when creek discharge was above a permitted base flow.

In 1951, a conventional 2.0 MGD filtration plant was constructed which used ferric sulfate coagulation with lime softening, sedimentation and rapid sand filtration using anthracite as the filter media. These down-flow filter beds consisted of a layer of anthracite coal on top of a porous Carborundum plate, which kept the coal in place. Backwash water, used to clean the filters, was discharged to the creek. After filtration, the water was disinfected with chlorine gas and fluoridated prior to distribution.

Figure 31. Westfield Water Works



Increasingly stricter drinking water turbidity standards have occurred (prior to 1962 10.0 NTU; 1962 to 1976 5.0 NTU; 1977 to 1988 1.0 NTU; and from 1988 onward the current standard of 0.5 NTU 95% of the time). These increasingly stringent standards along with sporadic high turbidity in the raw water caused the village drinking water to be frequently out of compliance with the turbidity regulation.

We estimated from CCDOH records that by the mid-1980s the Minton Reservoir had lost about 15% of its original capacity to sedimentation. Thus, capacity loss was a problem, in addition to high raw water turbidities in both Chautauqua Creek and Minton Reservoir. Two approaches were taken to address these issues. The first was improved watershed management; the second was construction of a new filtration plant.

Reducing Turbidity Sources

Several approaches to improved watershed management were taken. Activities within the Minton Reservoir and Chautauqua Creek watersheds that contributed to the problem (i.e., logging, oil and gas exploration, etc.) are now carefully managed, especially on the extensive areas of land in the source watersheds owned by the Village. The Village has upgraded its Watershed Rules and Regulations, Part 105 of the New York State Health Law, to address changes in land uses and modern issues unforeseen when the original regulations were enacted in the early 1900s. These regulations give the Village legal authority to address violations discovered during watershed inspections. Causes (i.e. landslides and stream down-cutting) in the creek feeding the Minton Reservoir were also treated with direct structural responses (channelization with check dams).

In 1993, the Village initiated a stream bank stabilization project in the main tributary to Minton Reservoir. With assistance from the Chautauqua County Soil and Water Conservation District, the USDA-NRCS and FORECON, Inc. (the Village's forestry consultant), plans were developed to reduce stream bank erosion and control stream down-cutting.

Active landslides and extensive gullying along the Minton Reservoir tributary compounded erosion and sediment transport problems. These areas coincided with surficial mapping of sands, silts and clays, while surrounding areas are dominantly glacial till. The Minton tributary is quite different from much of Chautauqua Creek, whose banks and bed are primarily Devonian shale and siltstone. The hillside materials in the landslide area were a complex mix of glacial till, gravel, sand, silt and clay deposited originally from streams flowing on, in or under glacial ice. Landslides here were triggered mainly by stream down-cutting. Fresh slides transported easily eroded sediment to the active creek channel, where it was subsequently transported down stream.

Access to the stream was the first problem to overcome. A 500 ft access road was constructed from Mount Baldy Road to the stream at a cost of approximately $10,000. Stream bank stabilization consisted of placing gabion baskets longitudinally along both sides of the stream at problem areas. Care was taken to anchor starting and ending gabions securely into the stream bank so water could not flow between gabions and the bank. In addition, the first tier of gabions was buried at least one foot below the existing stream bed and geotextile placed under and behind all gabions. Several check dams or sills were constructed across the stream channel to control stream down-cutting and decrease stream velocity. These too were securely anchored into both banks and geotextile used as above. Splash pads made of gabion baskets were placed on the down stream side of each check dam to prevent bed erosion (Figure 32).

Each gabion basket was placed in position then filled with local rock by hand. Close inspection reveals very tight packing of rock and nice straight sides on exposed gabion faces. This is critical to achieving the desired stability and long lasting results.

With the aide of a backhoe and operator, a prison crew from the Lakeshore Correctional Facility in Brocton spent approximately 10 months on the project. Prison inmates worked 25 to 30 hours each week placing each gabion basket by hand, then packing them tightly with rock in layers. Correctly installing gabion baskets is very labor intensive. Key to a quality job was having a conscientious prison guard, who was trained for this specific project. The project was successful and within budget because of the opportunity to have the same guard throughout the entire project. The project cost approximately $15,000 to complete, plus labor.

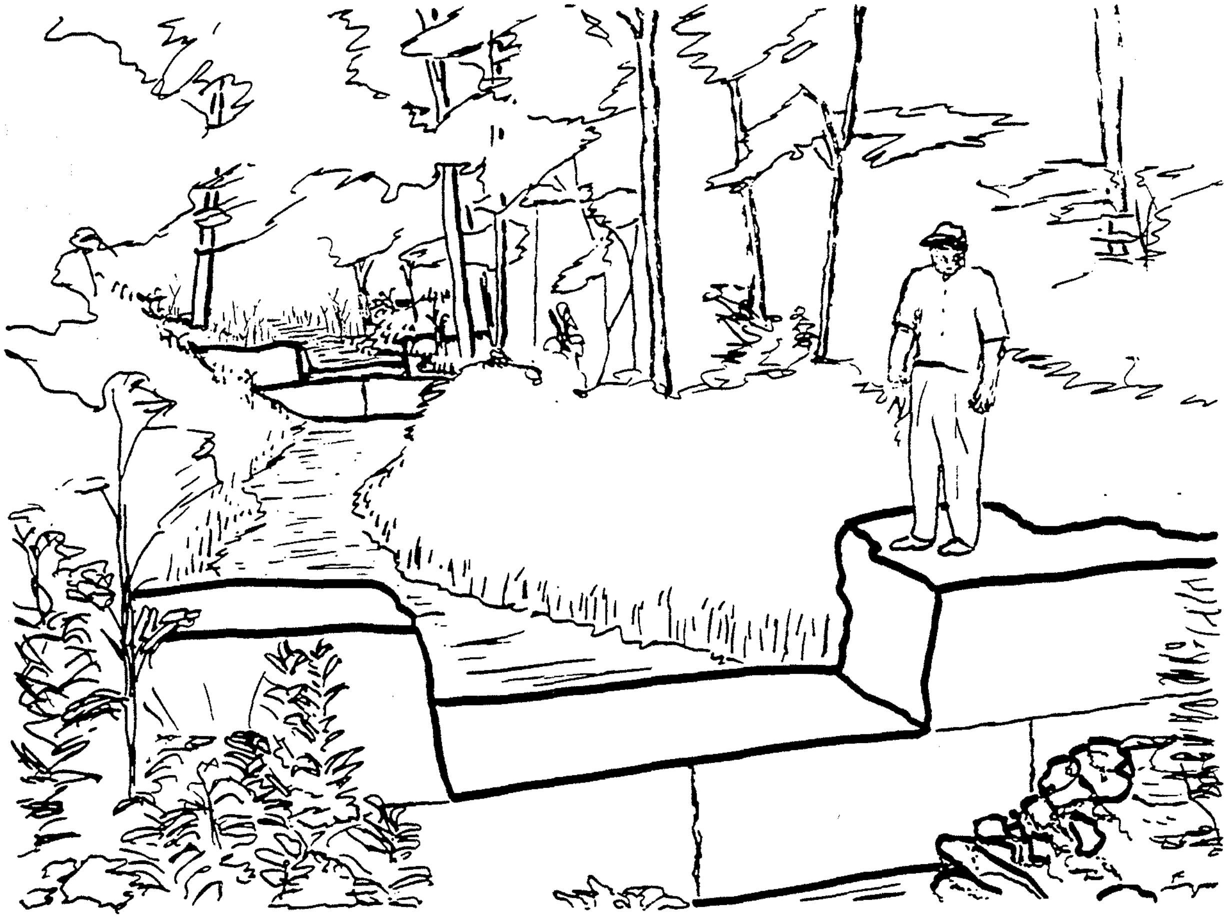
Improved Turbidity Filtration

In 1995 major upgrades and additions were made to the water filtration plant and the Minton Reservoir intake. Three modular Microfloc Trident package treatment units each containing an upflow clarifer and multi-media filter were installed next to the existing treatment plant building, inside a new steel building. The plant, rated at 3 MGD, is capable of fully automatic operation. One of the three clarifer-filter units is rested while the other two are being used. As raw water enters the plant, ferric chloride is added as a coagulant in a mixing chamber followed by the addition of activated carbon in a second mixing chamber. Pre-treated water then flows through an upflow absorbent clarifier containing buoyant plastic media, then down through a multi-media filter containing anthracite coal and several layers of various sized graded gravel. Chlorine gas is added for disinfection after the filters, followed by fluoridation in the clearwell. Finished water is stored in an underground storage tank adjacent to the water plant.

Conclusions

Reduction of stream erosion, improved watershed management and major upgrades to the Westfield Water Treatment Plant have dramatically reduced raw and finished water turbidity. Prior to 1995, finished water turbidities often violated the NYS Health Department MCL. This situation increased the risk of exposing water customers to microbiological contaminants, requiring the Village to initiate intense public notification of the violations to its water customers as required under New York State law.

Since watershed and filter plant improvements have been made, the Village has been in complete compliance with turbidity standards. Finished water turbidity is now consistently below 0.1 NTU, which may soon be the new MCL for turbidity nationwide. The old plant finished-water ranged from 1.0 to 4.0 NTU while the new plant values range from 0.03 to 0.08 NTU.



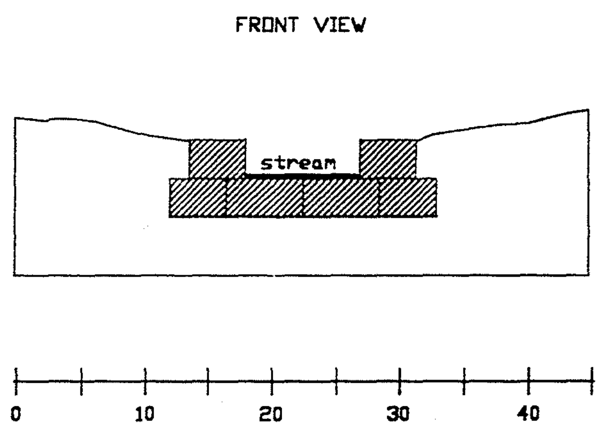
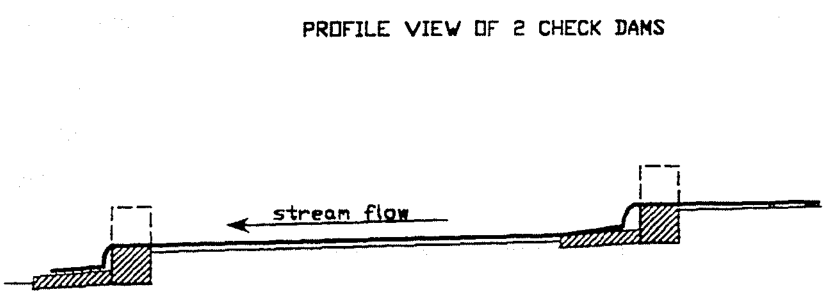
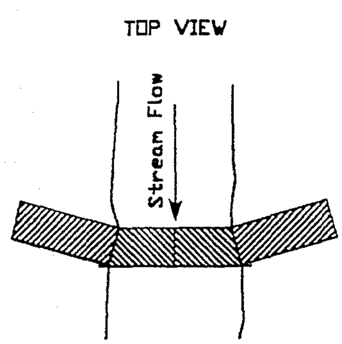


Figure 32.
Gabion-basket
Check Dams





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Illustrations for our guidebook article were modified from:

CCDOH, 1998, Village of Forestville Non-Point Source Pollution Abatement Program, 47p.

CCDOH, 1996, Chautauqua County Wellhead Protection Program, Phase II: Delineation of Wellhead Protection Areas, 158p.

CCDOH and SUNY-Fredonia, 1998, Investigation of Drinking Water Turbidity and Reservoir Sedimentation, Brocton, NY, 171p.

ACKNOWLEDGEMENTS

In addition to participants already described in the article and the references cited above, we wish to thank several other contributors. Water supply operators provided invaluable support. Wayne Cardy (Westfield Water Works) helped reconstruct the history of the Westfield water supply and operating methods of their filter plants. He generously agreed to provide a tour of their new "package" filter plant. Harold Richter collected water quality data on a daily basis for nearly three years (1991 and 1995-97), for the Forestville springs and wells. Richard Smith collected similar data at the Sinclairville wellfield for one year (1991).

David Wilson (District Conservationist, County Soil and Water Conservation District) and Lawrence Brown (USDA Natural Resources Conservation Service) provided erosion control planning for Hall Spring (Forestville), Chautauqua Road stabilization (Brocton), and the Minton Reservoir inlet-stream gabions. Brian Bullard of FORECON, Inc. reviewed with us the history of renovations to the Minton Reservoir inlet stream (FORECON is a forestry management company that consults on the watersheds owned by the Village of Westfield). Steven Johnson (CCDOH Public Health Engineer) reviewed the designs for the Hall Spring renovation and Robert Brown (independent consulting engineer) prepared specifications and bid packages for the Hall Spring renovation.

Road Log

Quaternary Geology and Water Supply Issues

Total miles	Miles from Last Point	Route Description
0.0	0.0	Leave the SUNY Fredonia campus at the Temple Street exit. Turn Left (south) onto Temple Street
0.7	0.7	Turn Left (north east) onto State Route 20. The village of Fredonia lies mostly on Glacial Lake Warren shoreline and Canadaway Creek delta and terrace sand and gravel.
4.2	3.5	Turn Right (east) onto State Route 39.
		Cross Glacial Lake Whittlesey shoreline. We will drive slowly in this area**, possibly stopping but not exiting vehicles,** in order to regroup vehicles. At mile 5.1 see "beach ridge" through the front and right vehicle windows approx. 1500 feet away. Cross the "beach ridge" at 5.4 miles. At 7.5 miles, view left is Lake Erie and the Canadian shoreline (40 to 50 miles weather permitting).
9.1	4.9	Turn Right (south) onto Water Street (County Rt. 85), as you enter the Village of Forestville.
12.9	3.8	Turn Left (south east) onto Henry Road.
12.9	0.0	Turn Immediate Right onto Shaw Road.
13.9	1.0	**STOP 1.** Hall Springs, Village of Forestville. Park on side of Shaw Road. We will walk eastward on the gravel entry road for about 100 meters. After returning to vehicles from Stop 1, continue southeast on Shaw Road.
14.1	0.2	Turn Right (south) on Putnam Road.
14.3	0.2	**STOP 2.** Brief look at Hall Spring source water area. Park on side of Putnam Road.
14.3	0.0	Continue south on Putnam Road. A water well drilled near the intersection of Putnam Rd. and Route 83 penetrated 324 feet of sediments without encountering bedrock. Depth to

		bedrock near this road intersection was estimated at 450 ft using a high-precision gravity survey.
15.1	0.8	Turn Right (west) onto State Rt. 83.
15.6	0.5	Turn Left (south) onto County Rt. 85.
18.0	2.4	Turn Right (west) onto County Rt. 72.
19.3	1.3	Turn Left (south) onto County Rt. 77.
26.7	7.4	Continue...Leave County Rt. 77 by continuing straight ahead onto County Rt. 66. Enter Village of Sinclairville driving southwest on County Rt. 66 and leave the Village by continuing driving southwest on County Rt. 66.
27.9	1.2	Continue driving on County Rt. 66 under State Rt. 60.
28.0	0.1	Turn Left (east) onto Bloomer Street.
28.1	0.1	Turn Right (south) into water supply property. Park left (north) of the first well-house, on the lawn.
28.1	0.0	**STOP 3**. Village of Sinclairville wellfield.
28.2	0.1	Turn Left onto Bloomer Street, when leaving the Sinclairville wellfield.
28.2	0.0	Turn Right onto County Rt. 66, heading in the reverse direction (northeast), approximately 0.1 mile.
28.3	0.1	Turn Right (east) onto the access road for State Rt. 60.
28.4	0.1	Turn Left (north) onto State Rt. 60.
35.6	7.2	Turn Left (west) onto County Rt. 58 at the Cassadaga Village stop light. Due to the sometimes heavier traffic on Rt. 60, the vehicle group may become disaggregated between Sinclairville and Cassadaga. Consequently, we will drive slowly through the Cassadaga Village portion of County Rt. 58, possibly stopping but not exiting vehicles, near or at the:
36.4	0.8	Cassadaga Water Works (wells) and maintenance buildings. Cassadaga Lakes are on the right (north) side of the road. The lakes are kettle lakes between the Lake Escarpment Moraines to the north and the Lavery Moraine

		to the south. Rt. 58 that we are traveling is on outwash between the moraines. If the Lavery Moraine dates at 16,000 BP and the Lake Escarpment dates at 14,000 BP, were the kettles formed from Lavery ice buried by Lake Escarpment outwash?
38.8	2.4	Continue westward on County Rt. 58 through Village of Stockton stop light.
39.0	0.2	Turn Right (north) onto Mill Street.
39.1	0.1	Turn Left (west) onto Dean Road. Dean Road passes through a small Amish community. A large Amish community is found about 30 miles to the east in the Conewango Valley.
44.4	5.3	Turn Right (north) onto Thayer Road.
45.6	1.2	**STOP 4.** Turn Right (east) into Luensman Overview Park. Lunch and rest stop at the park. The park is located on the Mississippi River-Great Lakes drainage divide. A brochure is available in the pavilion. There is a short nature trail. Weather permitting, features of the Canadian shoreline 40 miles and more distant may be observed. A faint pale yellow or tan haze is often in the lower atmosphere. This haze is the drifting air pollution from the mid-western U.S. In spite of our somewhat pristine surroundings, the nearby National Atmospheric Deposition Program station sometimes registers the highest acidity and deposition. The acid portion of deposition is buffered by the calcareous glacial till.
45.9	0.3	Turn Left (south) onto Thayer Road (backtrack), when leaving Luensman Park.
47.0	1.1	Turn Left (east) onto Dean Road (backtrack).
48.4	1.4	Turn Left (northeast) onto Frances Road. Note the kame and kettle topography of the Lake Escarpment Moraines.
50.1	1.7	Continue northeast on Chautauqua Road (road name changes from Frances to Chautauqua as road crosses County Rt. 380). Note kame and kettle topography. Chautauqua Road is often perched on one of the moraine ridge crests. For about 0.6 mile the moraine ridge under the road is the St. Lawrence – Mississippi watershed divide

50.9	0.8	Note the lack of gully erosion in the ravines to the left as we drive along Chautauqua Road.
51.4	0.5	**STOP 5.** In the Brocton Reservoirs drainage basin. Parking on roadside.
51.4	0.0	Continue northeast on Chautauqua Road.
51.7	0.3	Turn Left (north) onto Bear Lake Road.
52.5	0.8	Turn Left (west) onto Burr Road.
53.3	0.8	Drive slowly. The largest of the three reservoirs supplying the Village of Brocton (Brocton Reservoir) is north, on the right side of Burr Road. The sloped bank on the left (south side of the road) is the earthen dam of Burr Reservoir. A third small reservoir (Risley Reservoir) is out of view on the left (south).
53.3	0.0	Continue on Burr Road.
53.7	0.4	Turn Right (north) onto County Rt. 380.
55.7	2.0	Turn Left (west) onto State Rt. 20. Rt. 20, again, as at the beginning of the trip, follows mostly on top of the Glacial Lake Warren shoreline (gravelly sand).
55.9	0.2	Continue (west) through the Village of Brocton; then about 8 miles, through the Village of Westfield and over the long bridge over Chautauqua Creek on the immediate west side of the center of the Village of Westfield.
64.8	8.9	Turn Left (south) onto Chestnut Street.
66.0	1.2	Turn Left (east) onto Mt. Baldy Road.
66.4	0.4	Drive slowly past Minton Reservoir on left.
66.7	0.3	**STOP 6**. Renovated gully draining into Minton Reservoir. Park on roadside. We will enter the forest at the gated dirt road to the right. This road was cut to give access to the gully so gabions could be placed for erosion prevention.

		CAREFULLY: Please turn vehicles around and drive back into the Village of Westfield Water Works on right.
66.9	0.2	**STOP** 7. Westfield Water Works.
84.9	18.0	Return: drive back down the hill to Westfield, then right (east) onto Rt. 20 to Fredonia; at the intersection of Temple Street and Rt. 20 (at Barker Common), turn left onto Temple Street, then right onto campus.

Total Trip Approximately 84.9 Miles