New Jersey Geological Survey
Open File Report No. 83-3

Results of the 1980-81 Drought Emergency Ground Water Investigation in Morris and Passaic Counties, New Jersey

New Jersey Department of Environmental Protection • Division of Water Resources

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Robert E. Hughey, *Commissioner*

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ABSTRACT

The drought emergency ground water investigation of 1980-1981 in Morris and Passaic Counties, New Jersey, was undertaken to evaluate the potential of using unconsolidated sand and gravel valley fill aquifers to augment streamflow of the Rockaway and Pequannock Rivers to reservoirs of the Newark and Jersey City water systems. These unconsolidated valley fill aquifers consist of late Wisconsinan glacial deposits within an integrated pre-glacial drainage system developed by the Ancestral Rockaway River. The deposits lie between ridges of Precambrian and middle Paleozoic consolidated bedrock and are generally less than one-half mile (0.8 km) wide and 200 feet (61 m) thick. Water-bearing sands and gravels are interstratified with less permeable tills, silts, fine sands and colluvium.

Existing geologic and geohydrologic data, drilling, surface and borehole geophysics, aquifer pumping tests, and analytical models were used in the investigation of six areas of valley fill. Highly productive water-bearing zones were found to be of limited extent and best found by drilling in the deepest portions of filled valleys. The chemical quality of the ground water at the sites investigated is generally good, but iron and manganese concentrations exceed drinking water standards at some sites.

The total volume of ground water available for flow augmentation to the Pequannock River above Charlotteburg Reservoir is estimated to be between 3.0 and 4.5 mgd (11,370 and 17,100 m^3/day). This represents an increase of the safe yield of the watershed of 5 to 8 percent. Ground water available for flow augmentation of the Rockaway River upstream from Beaver Brook, Rockaway Township, is estimated to be between 4.5 and 5.0 mgd (17,100 and 19,000 m^3/day). No permanent adverse impacts are to be expected from 120 days of continuous pumping during a drought.

INTRODUCTION

Water supply reservoirs of northern New Jersey were affected in 1980 by a severe precipitation deficit. The Bureau of Water Supply Planning and Management recorded the average rainfall at twelve reservoirs from May to August, 1980, as 7.3 inches (18.6 cm) below the normal of 16.0 inches (40.0 cm) (fig. 1). As a result, reservoir levels had dropped to critically low levels.

In response, Governor Brendan Byrne issued Executive Order No. 94 on September 9, 1980, declaring a state of emergency in northeastern New Jersey. Subsequently, Executive Order No. 104 was issued, in which a Drought Coordinator was appointed and empowered to coordinate drought-related activities. The Coordinator solicited recommendations from the Bureau of Ground Water Management, Division of Water Resources. (In February, 1983, the Bureau of Ground Water Management was merged with the New Jersey Geological Survey.) This Bureau recommended that the State examine the potential of unconsolidated sand and gravel aquifers in Morris and Passaic Counties to augment streamflow to the reservoirs that serve Newark and Jersey City. Sand and gravel aquifers supply large quantities of water in eastern Morris County, but had not been evaluated within the reservoir watershed areas. Evaluation of the flow augmentation potential of these aquifers was assigned to the Bureau of Ground Water Management.

The following approach to this evaluation was adopted:

1) choose, on the basis of readily available geologic and geohydrologic data, areas having a high probability for suitable ground water yield;

2) inventory existing geologic and geohydrologic data, such as aerial photographs, well records and geohydrologic reports;

3) perform geophysical field surveys to estimate the extent and composition of the unconsolidated valley fill sediments;

4) drill test wells to confirm the geophysical interpretations and assess the aquifer potential of the valley fill sediments; and

5) perform aquifer pumping tests to evaluate long term aquifer yield, using standard hydrologic parameters and aquifer simulation models.

The investigation covered portions of the watersheds of the Pequannock River and the Rockaway River upstream from Denville (fig. 2). Drainage to the Pequannock River in the study area flows to the Charlotteburg Reservoir, from which water is pumped into the Newark Water Department's distribution system. Downstream from Denville the Rockaway River flows to the Jersey City Reservoir at Boonton. Six areas were chosen for evaluation:

Area 1: Newfoundland/Green Pond in Rockaway and Jefferson Townships, Pequannock Watershed.

Area 2: Newfoundland/Macopin in West Milford Township, Pequannock Watershed.

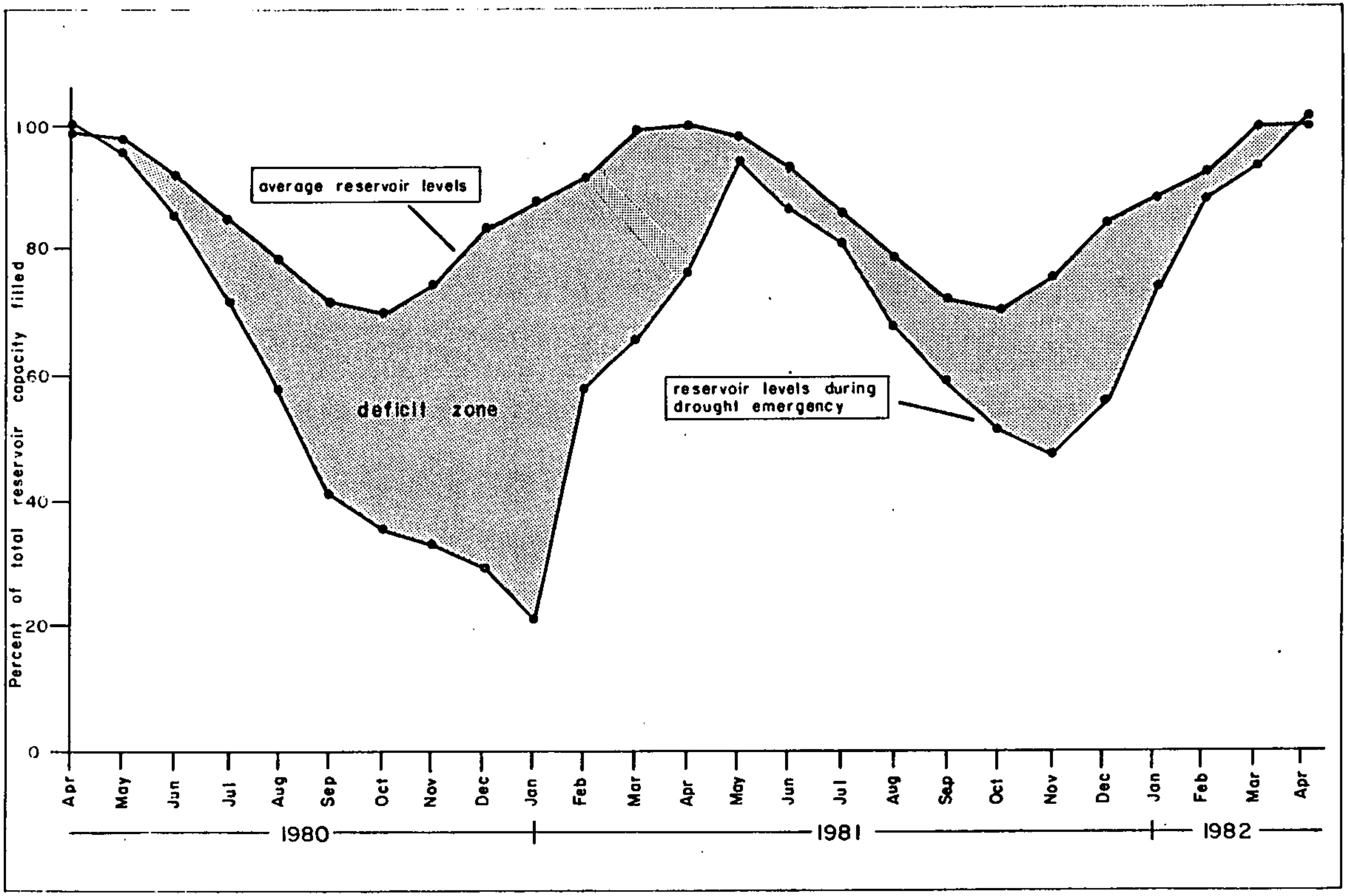

Figure 1. Graph comparing reservoir capacity filled, 1980-82 to long-term average filled capacity. Includes Boonton, Canistear, Charlottesburg, Clinton, Oak Ridge, Oradell, Split Rock and Wanaque Reservoirs, Echo and Woodcliff Lakes, Lake DeForest and Lake Tappan.

Area 3: Oak Ridge/Milton/Longwood Valley in Jefferson and West Milford Townships, Pequannock and Rockaway Watersheds.

Area 4: Berkshire Valley in Jefferson Township, Rockaway Watershed.

Area 5: Northern Roxbury Township, Rockaway Watershed.

Area 6: Beaver Brook Valley in Rockaway Township, Rockaway Watershed.

Personnel of the Bureau of Ground Water Management supervised the project, conducted geophysical investigations to locate optimum sites for test well installation, interpreted the geophysical and aquifer test data, assessed ground water potential and compiled this report.

A portion of the geophysical investigation was contracted to Woodward-Clyde Consultants of Wayne, New Jersey. The consultant subcontracted the drilling of test wells to New Jersey Drilling of Netcong, New Jersey.

The responsibility of the consultant was to:

1) determine the depth to bedrock within several study areas;

2) supervise the drilling of the test wells, including the collection and classification of well samples; and

3) perform bore-hole geophysics on all test wells.

In addition to evaluating the feasibility of augmenting surface water supplies with water from valley fill aquifers, this study may serve as a source of geologic and ground water information for local agencies and individuals. Knowledge of the location, depth and composition of the buried valley glacial deposits will increase the ability to assess the potential of aquifers within these valleys as underground sources of drinking water.

Acknowledgements

Many people contributed to the completion of this study. Frank J. Markewicz, Acting State Geologist, provided guidance in formulating the project. His knowledge of New Jersey geology and geohydrology was invaluable. Mr. Markewicz also acted as liaison with local government officials. Haig Kasabach, Chief, Bureau of Ground Water Management, was responsible for administration of the project. Richard Dalton, Supervising Geologist, provided interpretation of the geology of the region and supervised operation of the Bureau's drill rig. From the Bureau of Ground Water Management, Drew Gould, Paul Albrecht, Ted Hayes, Walt Samsel, Katherine McBride, Scott Sherman, Leo Lynch, and Jon Rocker contributed. Daniel Dombroski of the Geological Survey assisted in geophysical surveys. Jim Walters of the Bureau of Potable Water performed the water quality sampling.

GEOD Aerial Surveys, Inc., provided information on benchmark and survey monuments.

Mary Hill of Princeton University reviewed aquifer test analyses and provided information based on her study in Roxbury Township. Newark Watershed Authority

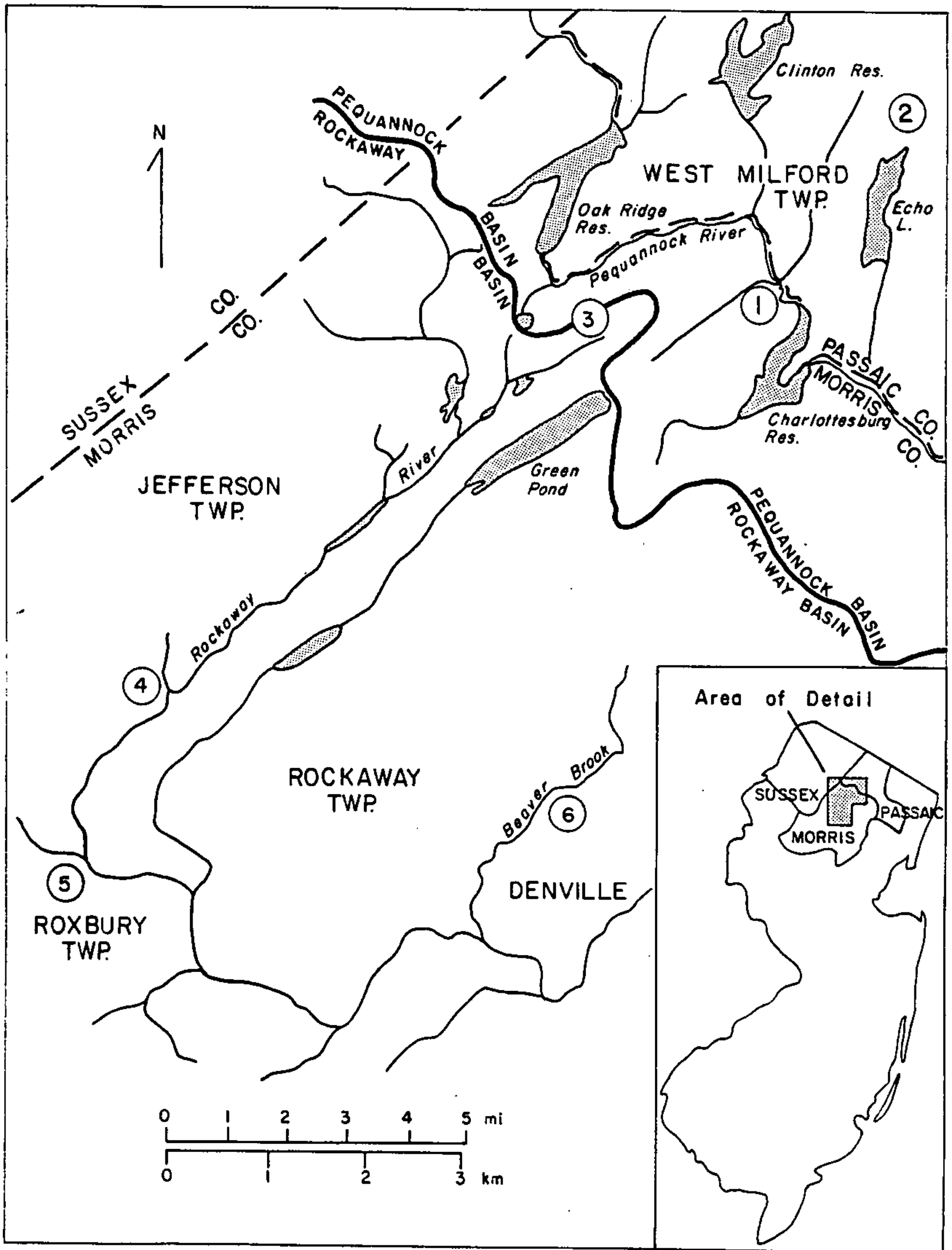

Figure 2. Map of area of investigation.

employees at the Charlotteburg Reservoir arranged for access and provided a secure parking area for our vehicles and drill rig. Ian Walker, David Harper, Hugh Houghton and William Graff of the Geological Survey edited the final manuscript.

Finally, we wish to acknowledge Brenda Ford, Beverly Dash, Francesca Marrazzo, Cindy Britton, Lisa Lugo, Barbara Smith, Jean Starkey and Lillian Allar who typed the text and tables and Allen Bell and Linda Spildener who drafted the figures.

CONCLUSIONS

Geohydrology

1) Description of Valley Fills

Valley fills in the study area are, in general, less than one-half mile (0.8 km) in width. Maximum thickness of the unconsolidated valley fill is more than 180 feet (55 m) beneath Green Pond village, 130 feet (40 m) beneath Newfoundland, over 150 feet (46 m) in Berkshire Valley, and more than 275 feet (92 m) beneath Kenvil.

The general stratigraphic sequence within the valley fill north of Roxbury Township consists of:

a) a surficial layer of colluvium, glacial till, poorly stratified drift; b) fine-grained sediments consisting of clay, silt and fine sand, with occasional lenses of gravel; c) stratified, water-bearing sand and gravel; d) a basal layer of till up to 50 feet (15 m) thick; and e) the bedrock floor of the valley. Greater vertical variation occurs in buried valleys to the south in Roxbury Township.

2) Ground Water Potential

Sands and gravels within valley fill deposits constitute major aquifers. Estimates of ground water availability for flow augmentation are summarized in table 1.

The total volume of ground water available for flow augmentation to the Pequannock River above Charlotteburg Reservoir is estimated to be between 3.0 mgd and 4.5 mgd (11,370 to 17,100 m^3/day).

An analysis of the Pequannock system in the New Jersey Water Supply Master Plan (N.J. Department of Environmental Protection, 1980) indicates that the system can supply 48 mgd (181,920 m^3/day) at a 90% level of reliability. Ground water diversion, then, could increase the safe yield of the Pequannock system by 5 to 8 percent.

Ground water available for flow augmentation to the Rockaway River above the confluence with Beaver Brook, Rockaway Township, is estimated to be between 4.5 and 5.0 mgd (17,100 to 19,000 m^3/day). This estimate does not include water in aquifers in Area 6.

3) Well Yields

Wells drilled and tested in this study exhibited a wide range of yields, from less than 10 gpm (55 m^3/day or .014 mgd) to 400 gpm (2,180 m^3/day or .57 mgd). Transmissivities also exhibited a wide range. The transmissivity of aquifers at two wells which each yielded over 400 gpm were 17,000 gpd/ft (211 m^2/day) at TW-8 and 108,000 gpd/ft (1,341 m^2/day) at TW-9.

A summary of specific capacities for the test wells drilled as part of this investigation is shown on table 2. The average specific capacity for the test wells in the study is 13.3 gpm/ft (238.3 m^3/day/m). The

Area	Watershed	Estimated Yield mgd (m^3/day)
1	Pequannock	1.5-3.0 (5685-11370)
2	Pequannock	1.0 (3790)
3	Pequannock	0.5 (1895)
	Rockaway	1.0 (3790)
	Total	1.5 (5685)
4	Rockaway	2.5-4.5 (9475-17055)
5	Rockaway	not estimated
6	Rockaway	1.0 (3790)

Table 1. Estimated availability of ground water for flow augmentation.

Well	Specific Capacity* $= \frac{Q}{S} = \frac{\text{Yield gpm } (m^3/\text{day})}{\text{Drawdown ft } (m)}$ gpm/ft (m^3/day/m)
TW-1	18.01 (322.56)
TW-2	0.36 (6.45)
TW-3	0.27 (4.84)
TW-4	Abandoned
TW-5	17.16 (307.34)
TW-6	0.45 (8.06)
TW-7	Abandoned
TW-8	17.17 (307.51)
TW-9	45.07 (807.20)
TW-10	1.17 (20.95)
TW-11	Abandoned
TW-12	not tested
Average	13.31 (238.38)

*Values are based on drawdown after eight hours of pumping.

Table 2. Specific capacities of test wells.

range is from 0.27 to 45.1 gpm/ft (4.84 to 807.2 m^3/day/m). The average specific capacity for 110 large diameter water wells reported by Gill and Vecchioli (1965) as producing from sand and gravel in Morris County is 30.86 gpm/ft (552.56 m^3/day/m). The range is from 0.24 to 500 gpm/ft (4.3 to 8,953 m^3/day/m). Most of the test wells drilled for this study have a specific capacity lower than the mean for wells drilled in unconsolidated deposits within Morris County as a whole. Test wells TW-1, TW-5, TW-8 and TW-9 each had a specific capacity greater than 10 gpm/ft (179 m^3/day/m).

4) <u>Extent of Aquifers</u>

Glacial valley fill aquifers were found to occur in the Pequannock and Rockaway River Valleys over the entire extent of the study area. These deposits extend beyond the study area in a downstream direction. Highly productive water-bearing zones were found to be of limited extent and best encountered by drilling in the deepest portions of filled valleys. These are commonly close to or directly beneath streams, lakes, wetlands or flood plains. This proximity facilitates the logistics of flow augmentation, but places slight limitations on ground water exploration.

Changes in the sorting characteristics of glacial sediments are known to occur along the long axis of the buried valleys. These changes are related to the sequence of events which occurred during the Pleistocene Epoch. The result of these glacial related events is that highly productive water-bearing zones will not occur everywhere in the deep portion of the buried valleys. In places, for example, fine-grained sediments related to deposition in glacial lakes may replace stratified outwash deposits found elsewhere in the buried channel. An analysis of the glacial history of the Pequannock and Rockaway River Valleys and additional subsurface investigations are required to better define the precise sequence of sediments which occupy the buried valley channels.

5) <u>Ground Water Quality</u>

The chemical quality of ground water in the test areas is good to excellent. All test wells conform to potable water standards for all parameters except, in some cases, total iron and manganese. Ground water in valley fill aquifers occurs under unconfined or semi-confined conditions. The presence of permeable sediments overlying the aquifers therefore makes them highly susceptible to contamination from the surface. The present low density of development in the watershed areas probably accounts for the good chemical quality of the ground water.

<u>Limitations to Flow Augmentation</u>

Factors which limit withdrawals from buried valley aquifers include:

1) <u>Width of valleys</u>: The water-bearing valley fill deposits delineated during this investigation are generally less than one-half mile (0.8 km) in width. Because the most productive glacial deposits appear to be within the deepest parts of the valleys, the areal extent of the productive sand and gravel aquifers is limited and a preferred direction of high transmissivity probably exists. Boundary effects caused by bedrock valley walls in the subsurface further limit long-term yields.

2) Thickness of water-bearing zones: Highly productive water-bearing gravels encountered in the subsurface investigations were usually less than 30 feet (9 m) thick. Aquifer yields are a function of permeability, and saturated thickness. Therefore, the thin nature of these sand and gravel aquifers presents a potential limitation to yields.

3) Fine-grained sediment: Fine sand, silt and clay overlie the water-bearing sand and gravel zones in many areas, thereby reducing the overall hydraulic conductivity of the valley fill. In places, the entire valley fill sequence consists of fine-grained sediment. In other places, medium to coarse water-bearing sand (0.25 to 1.0 mm) and gravel are found which have a fine-grained matrix. The fine matrix reduces hydraulic conductivity, limiting yields to wells.

4) Induced Recharge: In most cases incised bedrock valleys containing highly permeable sand and gravel are located beneath a river channel. In a water table situation, there can be a direct interconnection between surface water and the aquifer. Where a semi-confining layer exists, indirect interconnections can occur. Where direct interconnections exist, the cone of depression caused by the pumping well can intersect the waterbody and bring about an influx of surface water. This reduces the net gain for flow augmentation, because some of the flow from the well will consist of water loss via seepage from a stream or other surface water body. Where a confining layer exists between the river and the aquifer, seepage from the river to the aquifer will be less. The potential for water loss by seepage must be established in order to evaluate the potential net contribution of the aquifer to surface water flow.

5) Long-term effects: Ground water diversion for flow augmentation is a consumptive use of ground water. Ground water in storage is transferred out of the watershed. The impact of temporary diversions for flow augmentation may be a reduction of ground water in storage or a reduction in stream flow. The effects of infrequent, short-term pumpage, as during a 120 day drought, would be temporary.

6) Proximity to private wells: Test wells were drilled in remote locations, on land owned by municipal or state agencies. The test drilling and aquifer test pumping program demonstrated that high-yield wells could be located to ensure that no interference would occur with existing private supplies over the 24 hour period of the aquifer tests. The effects of longer durations of pumping are not known, but have been simulated. It appears that interference with private wells over a period of 120 days would be minimal. In some promising areas, residential and commercial development exists in close proximity to prospective high yield well sites, and impacts could be more significant. The impact on private wells should be assessed prior to undertaking a flow augmentation program.

Program Costs

1) The approximate cost of installing a single production well for flow augmentation, in 1982, was $180,000. This cost includes the construction of the well and a well house structure. The estimate does not include the costs of a pipe system to deliver ground water to surface waters. This cost will vary, depending upon the distance to the stream. In

comparison to the cost of drilling and constructing the well, the cost of the delivery pipe system would be minor, probably between $1,500 and $7,500 per well.

2) The approximate cost of operating a production well would be $10,000 per year. This cost covers the twenty-four hour operation of a fifty horse-power (37,300 watts) electrical motor for a period of 120 days, plus a minimum charge for a forty kilowatt demand for the remaining eight months of the year. (If the initial cost for electrical power extension exceeds $25,000, the estimated extension cost must be paid in advance). Personnel and capital costs for maintenance are not included.

3) The estimated cost in 1982 for construction and operation of approximately 5 wells to deliver between 2.0 mgd and 3.5 mgd (7,580 and 13,300 m^3/day) to the Pequannock River was between $708,000 and $914,000 for the first year. Operational costs would be between $60,000 and $80,000 per year in subsequent years for electrical power.

   Estimated cost, in 1982, to construct and operate production wells to deliver between 4.25 mgd and 5.0 mgd (16,100 and 19,000 m^3/day) to the Rockaway River was between $944,000 and $1,512,000 for the first year.

   Operational costs would be between $80,000 and $100,000 per year in subsequent years for electrical power. This estimate does not include sites in Area 6.

PREVIOUS INVESTIGATIONS

Studies of the valley fill deposits in Morris County have been conducted by the United States Geological Survey, [Nichols (1967), (1968), Vecchioli and Nichols (1966), and Gill and Vecchioli (1965) and Thompson (1932)], and by private consultants [Geonics (1979a, b), Geraghty and Miller (1978) and Woodward-Clyde Consultants (1981)]. Valley fill deposits in Passaic County have been delineated by Carswell and Rooney (1976).

Gill and Vecchioli (1965), "Availability of Ground Water Resources in Morris County," summarizes ground water usage throughout the county and from the various aquifers. Most of the large diameter wells finished in sand and gravel aquifers listed in this report produce in excess of 200 gallons per minute (0.28 mgd or 1,100 m^3/day).

Nichols and Vecchioli (1966, 1967) undertook a test drilling program near Morristown during the drought of 1963-1966. This report concentrated on the valley fill south of the Boonton Reservoir and underlying the Black, Great Piece and Troy Meadows.

Nichols (1968), "Bedrock Topography of Eastern Morris and Western Essex Counties, New Jersey," delineates buried bedrock surfaces on the basis of seismic data and water well logs. The report includes maps of the buried valleys in the vicinity of Chatham, East Hanover and Millburn.

Geraghty and Miller (1978) evaluated the ground water resources of the Rockaway Valley from Denville to Mountain Lakes. Eleven areas with potential for additional ground water development were identified. The report characterized the naturally-occurring chemical quality of the ground water in the glacial drift as generally good, but with localized elevated concentrations of iron and manganese.

Geonics (1979a) studied the water resources of the Rockaway Valley in the area between Boonton and Mountain Lakes and delineated the Towaco Valley aquifer (Geonics, 1979b) in Montville Township. Thick zones of saturated sand and gravel capable of supplying Montville Township were found to fill narrow buried valleys underlying existing river valleys. According to the report however, the aquifer is highly susceptible to changes in water quality from land or surface water contamination. Prime aquifer zones are delineated by Geonics (1979a) and a minimum yield of 11 mgd (41,700 m^3/day) is estimated as being available from the aquifer.

Woodward-Clyde Consultants (1981) studied the geohydrology of the glacial valley fill deposits of the Alamatong Well Field in the Randolph area. Their study discusses the stratigraphy of the valley fill, the relationship between the buried channel and the overlying Lamington River, and aquifer characteristics of the water-bearing sand and gravel.

GEOLOGIC SETTING

Bedrock Geology

The area covered by this report lies within the New Jersey Highlands, a physiographic belt of rugged topography approximately 15 miles (24 km) wide crossing north central New Jersey in a northeast-southwest direction. The Highlands consists of ridges, composed primarily of Precambrian gneiss, separated by narrow valleys underlain primarily by sedimentary rocks of Paleozoic age.

The valley fill deposits in northwestern Morris County lie within the Green Pond Outlier, a one to four mile (1.6 to 6.4 km) wide belt of lower and middle Paleozoic shales, carbonates, sandstones, and conglomerates infolded and downfaulted into the Highlands. Studies of the Precambrian bedrock geology of this area include Baker and Buddington (1970), Young (1969), and Smith (1969). The geology of the Green Pond Outlier has been studied by Kummel (1902) and by Barnett (1970, 1976).

The ground water potential of the Precambrian gneisses and the Paleozoic sedimentary rocks is generally low. Investigation of ground water for flow augmentation was therefore concentrated on glacially-derived unconsolidated sediments which fill deep valleys incised into the more easily eroded Paleozoic formations prior to the Wisconsin glaciation.

Glacial Deposits

Glacial deposits in the study area include tills, stratified sand and gravel, silts, and clays deposited during the Wisconsin glaciation, between 21,000 and 6,000 years ago. Tills are deposited directly from moving glacial ice and consist of compact, heterogeneous mixtures of particles ranging in size from boulders to clay. The hydraulic conductivity of tills is generally low, but where little silt or clay is present, tills may yield sufficient water for domestic use.

Stratified sands and gravels are deposited by glacial melt water. In the immediate vicinity of a glacier, sediments deposited from melt water are commonly interlayered with till and are highly variable both vertically and horizontally. Farther from the glacier, sediments are more uniform. Boulders are smaller and usually less common. The hydraulic conductivity of the sands and gravels is highly variable. Well-sorted sands and gravels can yield several hundred gallons of water per minute to a well. Poorly sorted sands and gravels, which have fine particles filling spaces between larger grains, may yield only small quantities of ground water. Fine-grained sand, silt and clay were deposited in lakes and ponds by slowly-flowing water during melting of the glaciers. These deposits range from thin stringers within sand and gravel to continuous layers up to several tens of feet thick. The thicker, more continous deposits act to restrict ground water flow and may constitute confining layers separating more permeable water-bearing zones from other water-bearing zones or surface water.

Glacial deposits are thin or absent in upland areas within the study area. Where upland deposits exist, these are usually poorly sorted. Valley fills are sediments that occupy previously incised river valleys. The thicknesses of valley fills in the study area reach 285 feet (87 m) in Area 5, and are generally less than 200 feet (61 m) thick in the northern areas.

Buried Channels

During this study it became apparent that a major buried valley and its tributaries could be traced through the entire area of investigation (plate 1). At its uppermost reaches the buried valley appears to be structurally controlled by a plunging syncline mapped by Barnett (1976). A major fault, coincident with portions of the valley in Area 1, may provide additional structural control. In Berkshire Valley, Jefferson Township and in Union Valley, West Milford Township, the location of the buried valley appears to coincide with more reasily eroded carbonate bedrock. The valley presumably marks the course of a pre-glacial river, an "Ancestral Rockaway River", which drained the areas now within the basins of the Pequannock River above Charlotteburg Reservoir and the Upper Rockaway River west of Green Pond Mountain.

Near its head in the area immediately northeast of Green Pond, the Ancestral Rockaway channel is beneath approximately 170 feet (52 m) of sediment. The bedrock elevation is approximately 850 feet (259 m) above sea level. From here the channel can be traced northeastward beneath Green Pond Road (Morris County Route 513) and toward the Pequannock River. South of the Pequannock River the channel passes beneath an elevated glacial landform. In the vicinity of the Pequannock it is joined by a southward-deepening channel which runs beneath the Kanouse Brook Valley (Union Valley).

The Ancestral Rockaway River may have exited the Newfoundland area: (1) eastward, as does the present Pequannock River, (2) northeastward, through Union Valley, or (3) westward, into Jefferson Township, opposite the flow of the present Pequannock drainage.

To identify which of these paths the Ancestral Rockaway followed, a seismic survey was conducted in the Copperas Mountain/Kanouse Mountain gap, where the Pequannock River flows into Charlotteburg Reservoir. A seismic survey showed a minimum bedrock elevation at this gap of approximately 675 feet (206 m) above mean sea level. Test borings performed during the construction of Charlotteburg Reservoir were combined with the seismic survey to develop a bedrock profile at the gap (fig. 3, A-A').

On the basis of this profile, bedrock elevations appear too high to have allowed eastward drainage of the Ancestral Rockaway River. Bedrock elevations north of the Pequannock River between Bearfort Mountain and Kanouse Mountain preclude the possibility that the Ancestral Rockaway River drained to the northeast through Union Valley.

The Ancestral Rockaway River, therefore, appears to have flowed westward around the nose of Green Pond Mountain near the present New Jersey Route 23. The present easterly drainage of the Pequannock River is reversed from the pre-glacial flow direction. Such reversals of pre-glacial drainage were common during the Ice Age. For example, the present course of the Passaic River in eastern Morris County is altered from its pre-glacial course (Salisbury, 1902).

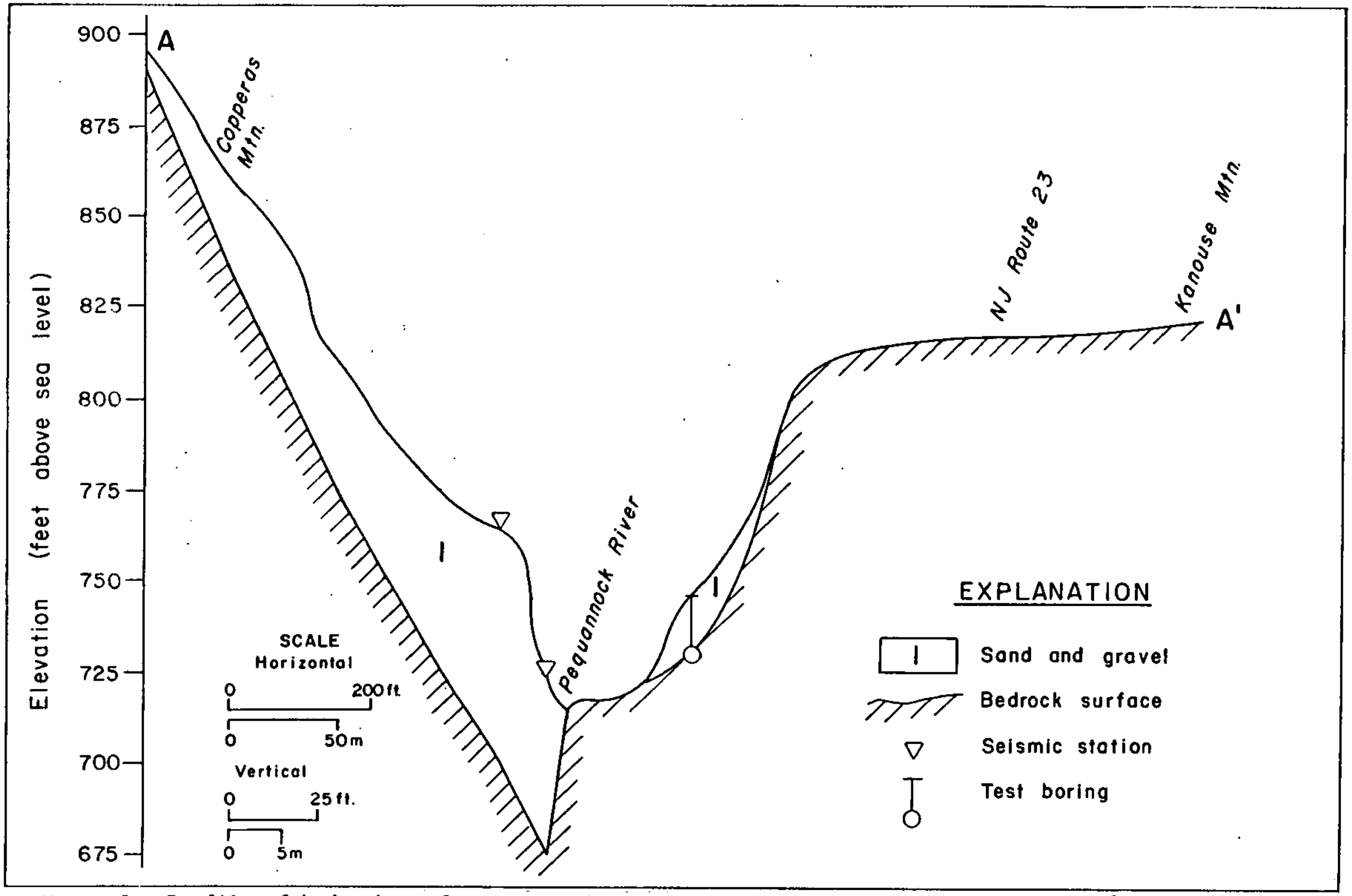

Figure 3. Profile of bedrock surface at gap between Copperas and Kanouse Mountains from reflection and refraction seismology and test boring.

From the northern end of Green Pond Mountain the buried channel follows a southwestward course, opposite that of the existing Pequannock River. The channel, buried under nearly 150 feet (46 m) of glacial sediments in Oak Ridge, appears to parallel the course of the Pequannock River to the vicinity of Chamberlain Road. From here the channel continues in a southwesterly direction, toward the eastern part of Moosepac Pond in Longwood Valley (plate 1).

From Moosepac Pond, well records indicate that the channel crosses beneath Berkshire Valley Road, swings southeastward beneath the eastern part of Lake Swannanoa, and then approaches the eastern shore of Oak Ridge Lake. A driller's well log to the north of the latter lake reports a thickness of 196 feet (47 m) of unconsolidated sediments (Appendix 4, Well No. 3). No bedrock was encountered, indicating the bedrock elevation is at approximately 600 feet (188 m) above sea level.

At the east shore of Longwood Lake, a water-bearing gravel was reported in a drillers log 134 feet (41 m) below the surface. No bedrock was encountered. Bedrock outcrops occur on the southwestern edge of the lake, indicating that the deepest portion of the valley lies to the east of the Rockaway River below Longwood Lake.

In Berkshire Valley, south of Longwood Lake, the channel of the Ancestral Rockaway lies roughly beneath or to the east of the channel of the present Rockaway River. Detailed subsurface exploration in Berkshire Valley (Gerard Engineering, 1968) produced evidence that the main channel of the buried valley coincides with a fault zone separating brecciated Precambrian gneiss from folded Devonian sandstone and shale (fig. 9). The mechanical weakness of the faulted rock appears to control the position of the incised channel. The lowest bedrock elevation encountered was 607 feet (185 m) above sea level in decomposed gneiss in the fault zone. This elevation may have been low enough to have allowed southward drainage of the ancestral Rockaway River through Berkshire Valley.

In Lower Berkshire Valley south of NJ Route 15, it appears that the buried channel may lie slightly to the west of the Rockaway River, based upon evidence from seismic surveys, test wells and residential well logs. Seismic surveys conducted parallel to Interstate Route 80 and east of the Rockaway River (Appendix 3, SP73-SP16) indicate that the main buried channel follows the river to the south, passing beneath Route 80 at the Roxbury/Jefferson Township boundary.

To the south of Route 80 drainage appears to have been northward towards the present Rockaway River. The southward flowing Lamington River occupies a valley in which pre-glacial drainage was to the north. This pre-glacial drainage joined the Ancestral Rockaway in the vicinity of Dell Avenue and Berkshire Valley Road. A smaller pre-glacial valley in the area between Duck Pond and Ledgewood, appears to have drained southward toward Kenvil, then eastward, parallel to U.S. Route 46, to the pre-glacial stream draining the Lamington River Valley.

HYDROGEOLOGIC ASSESSMENTS

Area 1: Newfoundland/Green Pond, Rockaway and Jefferson Townships

Location

Study Area 1 covers the valley between Green Pond Mountain and Copperas Mountain (plate 1). The southern boundary is Green Pond. The northern boundary is the Pequannock River. Most of the area falls within Rockaway Township. A small part lies in Jefferson Township.

Hydrogeologic Setting

Valley fill extends along the valley bottom between Green Pond and Copperas Mountains and covers a low-lying triangular area of approximately one-half square mile (1.3 sq. km), bounded by the Pequannock River, Copperas Mountain and the northern end of Green Pond Mountain.

Data on sediments within the valley between Green Pond and Copperas Mountains in the immediate vicinity of Green Pond came from records of residential wells. The sediment reaches a thickness of 170 feet (52 m) and includes appreciable amounts of sand and gravel. The maximum yield reported from unconsolidated deposits was 100 gpm (546 m^3/day). A high percentage of the wells pump from bedrock aquifers, rather than sand and gravel aquifers.

Data on sediments in the triangular area between the Pequannock River, Copperas Mountain, and the northern end of Green Pond Mountain were gathered from lithologic and borehole geophysical logs of eight test wells, a test boring and an array of surface geophysical surveys (plate 1).

A sand and gravel aquifer is present beneath the center of the valley. Lithologic and borehole geophysical logs indicate that between TW-1 and TW-3 a 10 to 20 foot (3 to 6 m) surficial layer of sand, gravel, and fine-grained sediments is underlain by 20 to 60 feet (6 to 18 m) of fine-grained sediments, consisting of fine sand, silty sand and clayey silt (fig. 4, B-B'). The upper fine-grained interval appears to thicken to the east and south, but was not encountered in the southern part of the valley at TW-5. The aquifer consists of water-bearing sand and gravel beneath this fine-grained layer and atop discontinuous basal till in the center of the valley. Bedrock underlies the till. An examination of the borehole geophysical log for TW-8 reveals that lenses of coarse sand and gravel, less than 10 feet (3 m) thick, occur within the fine-grained interval. These thin gravel lenses were noted in the mud rotary test boring (DEP-1) and are indicated in natural gamma borehole geophysical logs (Appendix 2). The lenses are of insufficient thickness and lateral extent to yield adequate quantities of water for flow augmentation, but may be useful for domestic water supply.

The high yield sand and gravel aquifer encountered in wells TW-5 and TW-8 in the center of the valley appears to grade laterally into a low yield (50 gpm or 273 m^3/day) clayey sand and gravel unit in the eastern portion of the buried valley. Wells TW-2 and TW-3 encountered coarse, but low yield, glacial sediments atop till and bedrock.

Wells TW-2 and TW-3 were drilled through the valley fill and into the underlying sedimentary bedrock in an attempt to intercept weathered carbonate bedrock

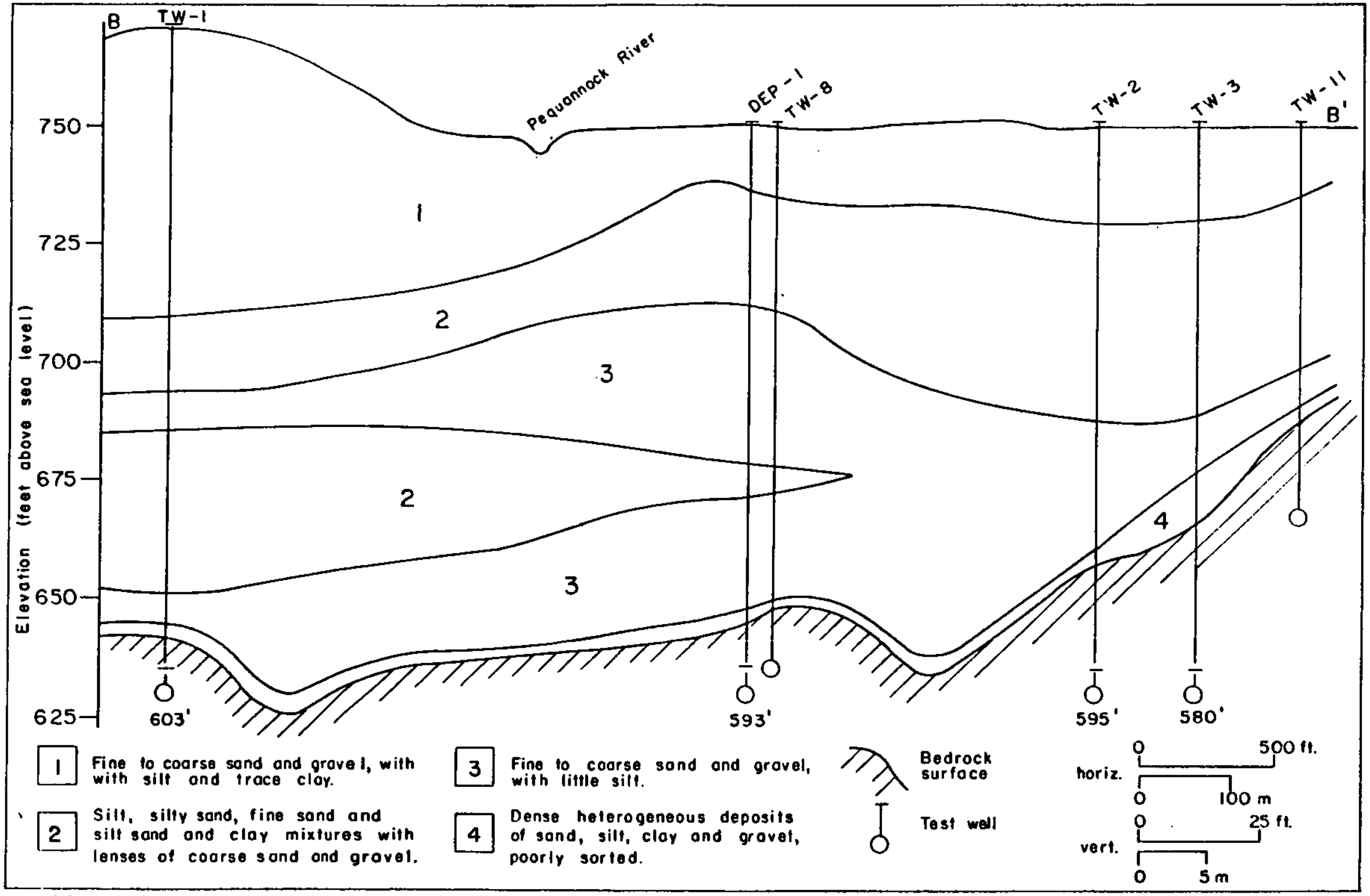

Figure 4. Cross section of valley fill deposits along the Pequannock River in Area 1, Jefferson and Rockaway Townships.

units. At TW-3 casing and a well screen were installed extending from sand and gravel into deeply weathered bedrock. Well TW-2 was finished with a screen in sand and gravel and an open hole in the underlying bedrock. The piezometric surface in well TW-3 was above the top of the casing (750.48 ft or 228.75 m) causing the well to flow at the surface. The piezometric surface in TW-2 is 1.5 feet (0.4 m) below ground surface, but nearly 6 feet (1.8 m) above the elevation of adjacent marshland. The relationship between the piezometric surface in the sand and gravel and the combined bedrock/sand and gravel suggest that ground water flow is from the bedrock to the valley fill. Ground water yields from the bedrock aquifer were not good.

The stratigraphic sequence encountered at well TW-1, starting at the ground surface, consists of: a) a 50 foot (15 m) inverval of coarse, water-bearing sand and gravel extending to the ground surface; b) a complex sequence of fine-grained stratified sediments interbedded with a thin layer of coarse sand and gravel; c) densely packed, heterogeneous deposits, probably till; d) a thin layer of coarse sand and gravel; and e) bedrock. The sand and gravel deposits at the surface act as a water table aquifer. The water table at TW-1 was slightly above the elevation of the adjacent Pequannock River. The underlying fine-grained sediment, approximately 20 feet (6 m) thick, and the heterogeneous till and fine-grained deposits directly overlying bedrock yielded little water to the test well.

Aquifer Test: TW-5

An aquifer pumping test of 24 hours duration was conducted on test well TW-5 (plate 1). Six observation wells of PVC casing with a diameter of 1.5 inches (0.04 m) were installed in an array around the test well (fig. 5). Water pumped from the well was discharged through a 6-inch (0.15 m) diameter pipe to a swampy area about 300 feet (91 m) east of TW-5. Water level changes were measured in each well.

The test well was pumped at a rate of 375 gpm (0.54 mgd or 2,050 m^3/day) for 24 hours. After 24 hours, the pump was stopped and the water level recovery rate in all wells was measured for a period of 12 hours. After this time only 60 percent of the total drawdown had recovered. This slow rate of water level recovery probably indicates a dewatering of the aquifer. This is to be expected in an aquifer of limited areal extent.

Drawdown vs. time and recovery vs. time relationships from the aquifer test were analyzed by methods developed by Theis (1935) and Cooper and Jacob (1946) for confined aquifers and by the method of Prickett (1965) for water table aquifers.

The latter method was applied to compensate for inaccuracies in the calculated value for transmissivity attributable to gravity drainage in the aquifer during the aquifer pumping test. Analytical results from the various methods were similar. Transmissivity of the aquifer at well TW-5 was estimated to be in the range of 30,000 to 34,000 gpd/ft (370 to 420 m^2/day). A storativity (storage coefficient) of 1.72 x 10^{-3} was calculated for the aquifer. This value is intermediate between typical values for water table aquifers and those for confined aquifers.

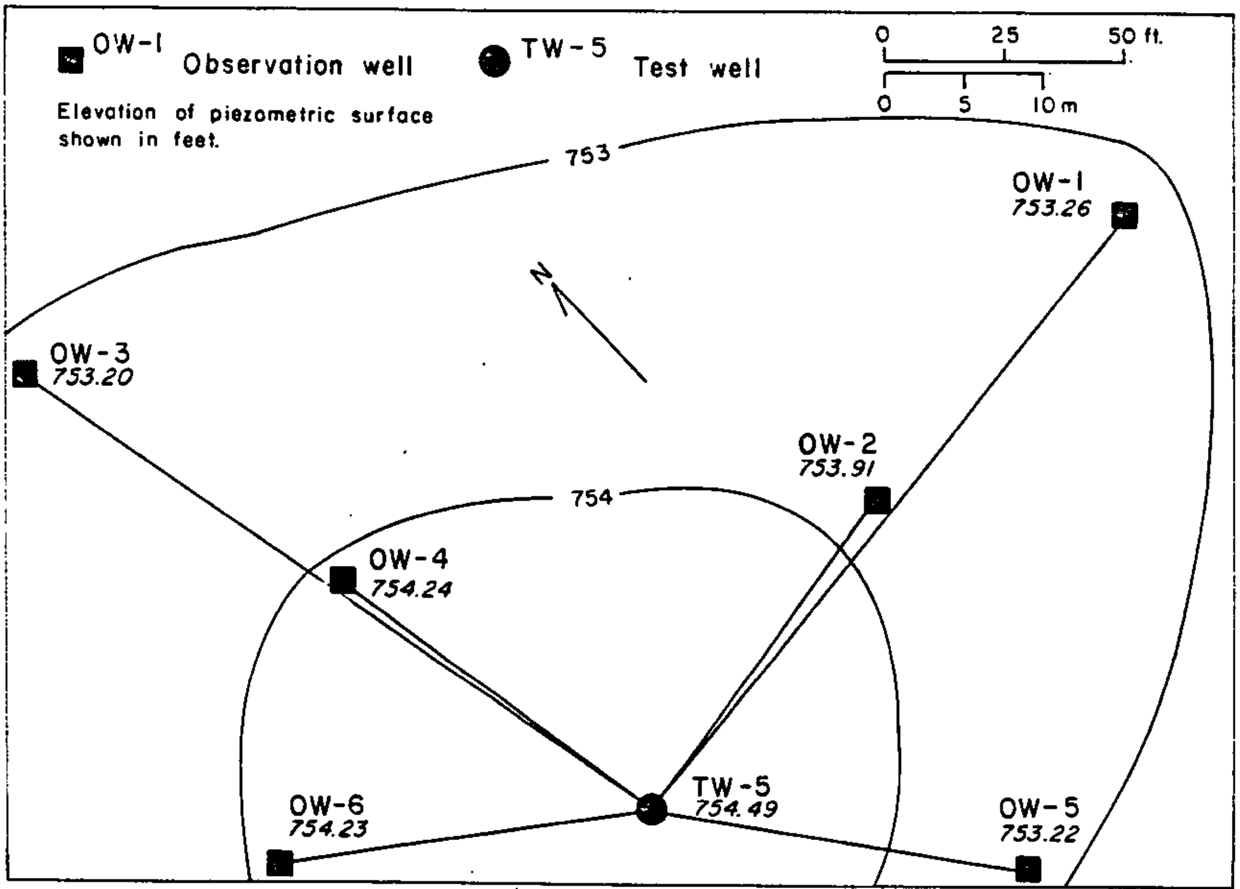

Figure 5. Array of observation wells for TW-5 aquifer test in Area 1, and piezometric surface before pumping.

The Computer Analysis of Pump Test Data (CAPTD) program (Hoffman, in press) was used to estimate transmissivity and storativity based on data from observation well OW-1. The program yielded values for transmissivity of 35,400 gpd/ft (590 m^2/day) and storativity of 1.4 x 10^{-3}. The latter value indicates that the aquifer is neither a true water table aquifer nor a confined aquifer, but some intermediate type. The driller's sample log and the natural gamma log both lack evidence of a significant impervious confining stratum at TW-5.

Aquifer Test: TW-8

An aquifer test was conducted on May 18, 1981 at test well TW-8, adjacent to the Pequannock River (plate 1). The well was constructed of steel casing with a diameter of six inches (0.15 m), finished in sand and gravel, and screened from 50 to 70 feet (15 to 21 m) below the surface. An observation well (DEP-1) was located 92 feet (28 m) west-northwest of TW-8. It was screened in sand and gravel from 40 to 60 feet (12 to 18 m) below the ground surface.

Discharge was measured at an orifice of four inches (0.1 m) diameter on the discharge pipe. Water level measurements in TW-8 were taken with a pressure line. Drawdown in DEP-1 was measured using an electronic water level indicator. All measurements used the top of the well casing as a reference point. The recovery of water levels was measured in both the pumping and observation wells for a period of three hours after the cessation of pumping.

Well TW-8 was pumped for eight hours at an initial rate of 415 gpm (2,265 m^3/day). This rate was gradually diminished to 411 gpm (2,243 m^3/day) during the test. After eight hours, the drawdown in TW-8 was 24 feet (7.3 m). At an average pumping rate of 412 gpm (2,249 m^3/day), this represents a specific capacity of 17.2 gpm/foot (308 m^3/day/m) for the pumping well.

The values obtained for the transmissivity of the aquifer depend upon whether data from the pumping stage or the recovery stage are used. Values of transmissivity were 16,900 gpd/ft (210 m^2/day) for the pumping stage and 34,900 gpd/ft (433 m^2/day) for the recovery stage. Storativity was computed from water level recovery data (Johnson, 1975). The value obtained, 2.66 x 10^{-3}, is intermediate between storativity values for unconfined and confined aquifers, and most likely represents a semi-confined or "leaky artesian" situation.

Aquifer Test: TW-1

TW-1 (plate 1) yielded 100 gpm (546 m^3/day) during an aquifer test of eight hours duration. The well is adjacent to the Pequannock River and is finished in a water table aquifer, which is in hydraulic connection with the river. Therefore, a large proportion of the water pumped from the well was most likely derived from water loss from the river. More deeply buried gravels at TW-1 failed to yield significant quantities of ground water. Geophysical results indicate the main buried channel may lie directly below the Pequannock River or below its northern bank, across the river to the north of TW-1. It appears possible to intercept a deep, semi-confined sand and gravel aquifer north of the river between Green Pond Road and Cross Road.

TIP Aquifer Drawdown Simulation

To gain an understanding of the potential impact of withdrawing ground water at the rates estimated above, the Theis Interactive Program (TIP, Hoffman, unpublished), a predictive computer model, was applied to hypothetical pumping and observation wells.

In the simulation, three production wells were placed approximately in the center of the valley in Area 1 (fig. 6). The model called for the pumping wells to be spaced over a distance of 3500 feet (1,067 m). Each well was simulated to pump at 500 and at 400 gpm (2,730 and 2,180 m^3/day or 0.72 and 0.58 mgd) for a period of 120 days with no recharge to the aquifer. The simulation represented a four month summer drought in which no precipitation was available as recharge to the aquifer.

Six observation wells were placed in this simulation at distances of 1750; 1,500; 2,500; 3,500; and 4,000 feet (0.3; 230; 460; 760; 1,070; and 1,220 m) northeast of pumping well TW-5. Values for transmissivity were derived from aquifer tests using wells TW-5 (34,000 gpd/ft or 420 m^2/day) and TW-8 (16,000 gpd/ft or 200 m^2/day). An average value of 25,000 gpd/ft (310 m^2/day) was applied to all three pumping wells. Storativity was set at 2 x 10^{-3}, as calculated from the aquifer test data.

The TIP program was applied under the following assumptions:

a) the aquifer is confined;
b) the aquifer has a seemingly infinite extent;
c) the aquifer is homogeneous and isotropic and of uniform thickness;
d) the aquifer receives no recharge, and;
e) discharge from the well is constant.

The drawdowns in the simulated observation wells are shown in table 3. The greatest drawdown was at observation wells adjacent to the pumping wells. The maximum expected drawdown after 120 days of pumping at 500 gpm (2,730 m^3/day) is on the order of 80 feet (24 m) at the pumping wells, and represents approximately 86 percent of the available drawdown (92 feet or 28 m) in the aquifer. At 400 gpm (2,180 m^3/day) the maximum drawdown at the pumping wells reaches 64 feet (20 m), or 69 percent of the available drawdown in the aquifer. Drawdowns in the simulated observation wells ranged from 48 to 76 feet (15 to 23 m) at 500 gpm (2,730 m^3/day) and from 38 to 61 feet (12 to 19 m) at 400 gpm (2,180 m^3/day). All drawdowns account for the mutual interference of the individual cones of depression caused by the three pumping wells. The predicted drawdowns would most likely exceed actual drawdowns under real pumping conditions, because the simulation does not provide for recharge. Under actual pumping conditions, recharge would be drawn into the aquifer from the river, streams and overlying wetlands. The TIP simulation gives a good approximation of the response of the aquifer at the pumping well, where drawdown limits the rate of withdrawal from the aquifer.

The TIP analysis provides an evaluation of the feasibility of locating production wells within the valley. From the simulation it appears that 400 gpm (2,180 m^3/day or 0.58 mgd) may represent the maximum feasible pumping rate for each sand and gravel production well for a 120 day flow-augmentation period in the Newfoundland area.

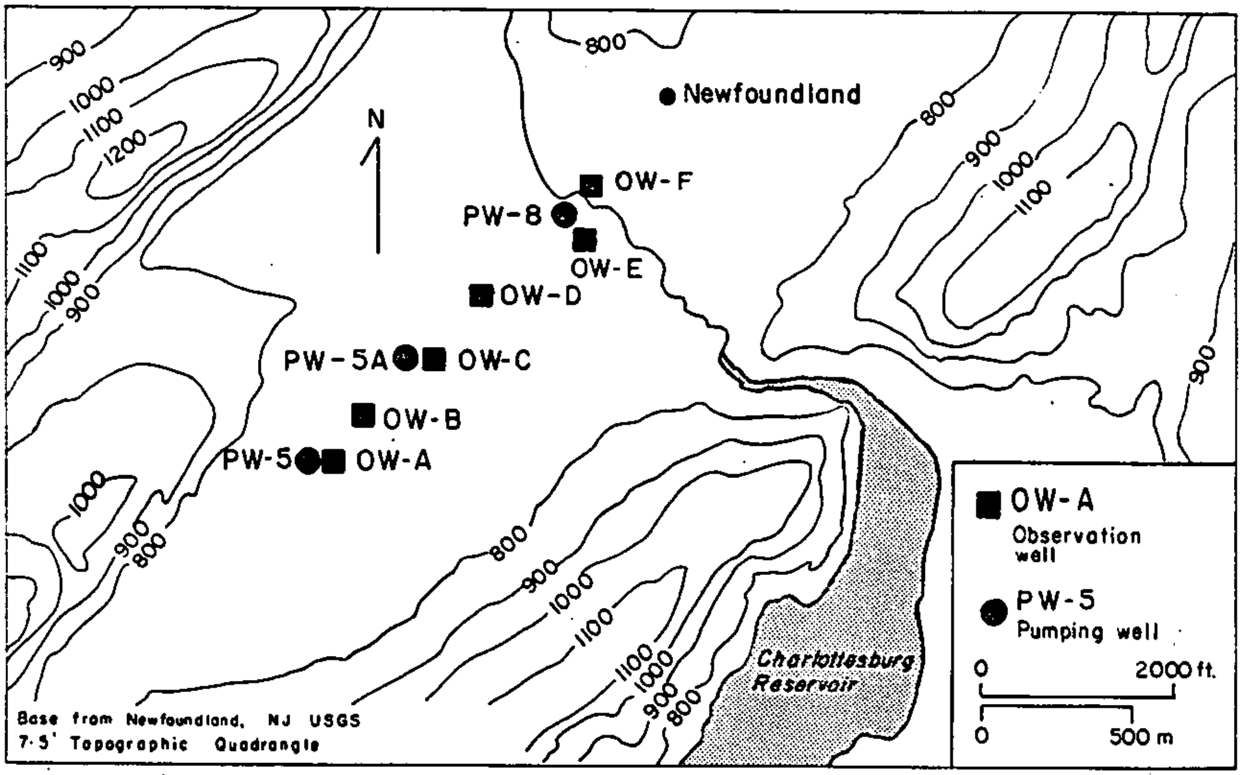

Figure 6. Map of pumping wells and observation wells in TIP Simulation at Area 1.

TIP Well	Distance NE of PW-5 ft (m)	Averaged Transmissivity gpd/ft (m^2/day)	Averaged Storativity	Simulated Drawdown 400 gpm (.58 mgd) ft (m)	Simulated Drawdown 500 gpm (.72 mgd) ft (m)
PW-5		25,000 (310.5)	$2x10^{-3}$		
OW-A	1 (.3)			61 (18.6)	77 (23.5)
OW-B	750 (229)			45 (13.7)	56 (17.1)
PW-5A	1500 (458)	25,000 (310.5)	$2x10^{-3}$		
OW-C	1501 (458)			64 (19.5)	80 (24.4)
OW-D	2500 (762)			45 (13.7)	56 (17.1)
PW-8	3500 (1070)	25,000 (310.5)	$2x10^{-3}$		
OW-E	3501 (1070)			61 (18.6)	77 (23.5)
OW-F	4000 (1220)			39 (11.9)	49 (14.9)

Table 3. Results of TIP Simulation in Area 1. Transmissivity and storativity were averaged from aquifer tests at the pumping wells. Simulated drawdown is after 120 days of pumping with no recharge.

Ground Water Potential

The aquifer identified in test wells TW-5 and TW-8 was traced to the area between TW-5 and TW-4 using terrain conductivity surveying. Low conductivities for sediments at depth within the bedrock channel, approximately 1,000 feet (305 m) northeast of TW-5, indicate similarity to the coarse sediments responsible for high ground water yields at TW-5. It appears possible, therefore, to locate a well approximately 1,000 feet (305 m) north of TW-5 that will yield at least 250 gpm (0.36 mgd or 1,360 m^3/day) on a sustained basis through a 120 day drought. Together, that well and TW-5 may be able to sustain 500 gpm (2,730 m^3/day). In order to assess water availability for flow augmentation near TW-8, this well was pumped at approximately 400 gpm (0.6 mgd or 2,180 m^3/day) for a period of eight hours. The volume of flow augmentation after correction for water loss from the adjacent Pequannock River by induced recharge is uncertain. To resolve this uncertainty would require additional tests involving river gauging and installation of an observation well on the opposite side of the river and aquifer pumping tests. It is reasonable to assume that the aquifer near TW-8 could sustain a yield of 250 gpm (0.36 mgd or 1,360 m^3/day) without exceeding the available drawdown and probably without causing infiltration to the aquifer from the Pequannock River.

It is reasonable to assume that one, or possibly two production wells, yielding a total of 500 gpm (0.72 mgd or 2,730 m^3/day), can be located in West Milford Township, immediately north of the Pequannock River and west of the intersection of Route 23 with Route 513 (Green Pond Road).

In summary, it appears reasonable that four wells producing a total of 1,100 to 1,300 gpm (1.6 to 1.9 mgd or 6,000 to 7,100 m^3/day) could be successfully located in Area 1. In view of the fact that wells TW-5 and TW-8 together have already been pumped at a combined rate of 775 gpm (1.1 mgd or 4,230 m^3/day), the projected yield of 1.6 to 1.9 mgd appears easily obtainable. Preliminary findings indicate the "safe yield" of Area 1 may exceed 2.5 mgd (9,600 m^3/day).

Area 2: Newfoundland/Macopin, West Milford Township

Location

Study Area 2 consists of three buried valleys in West Milford Township (plate 1). The first, Clinton Brook buried valley, is located northwest of Newfoundland along Clinton Brook. The second is Union Valley, following Kanouse Brook south of the town of West Milford. The third buried valley is in the Macopin area, through Echo Lake, between Kanouse Mountain and the town of Upper Macopin.

Hydrogeologic Setting

Clinton Brook Valley

Within Clinton Brook Valley unconsolidated valley fill covers an area of approximately one half square mile (1.3 sq. km) and extends northward from the Pequannock River for a distance of one mile (1.6 km). Investigations were carried out in the thicker portions of the deposit between LaRue Road and the Pequannock River. The unconsolidated valley fill is thickest along the Pequannock River where a depth of 110 feet (36 m) to bedrock was recorded in a domestic well record at Cross Road and NJ Route 23. The valley fill thins northward to LaRue Road (fig. 7, C-C'), where a seismic survey showed a maximum depth to bedrock of 70 feet (21 m).

Union Valley

Investigations in Union Valley were performed along Gould Road in the northern portion of the valley and on Kanouse Road in Newfoundland in the southern portion of the valley. Near Newfoundland, test boring DEP-2 encountered bedrock at 47 feet (14 m) below the surface in Union Valley.

The boring was made near the crossing of Kanouse Brook and Kanouse Road on the south side of the brook. This is along the western margin of the Union Valley buried channel. Unconsolidated materials encountered in boring DEP-2 included fine sand and silty sand with thin layers of coarse sand. No aquifer test was performed, but observations during drilling allowed a yield estimate of 50 gpm (270 m^3/day) for a well in these deposits.

Macopin Area

Valley fill sediments in the Macopin area occupy a pre-glacial valley beneath Echo Lake and the peat bog to its north (fig. 7, E-E'). The western wall of the valley is formed by Paleozoic sedimentary rock. The eastern wall of the valley and islands within the peat bog are composed of Precambrian gneisses. Data were from reflection seismic traverses, domestic well records, and examinations of a sand pit north of Wooley Road. The valley consists of two narrow channels, each less than one-quarter mile (0.4 km) wide and less than 100 feet (30 m) deep (fig. 7, F-F'). Wells drilled in a housing development along Gould Road to the north of Echo Lake demonstrate the existence of two narrow buried channels. All wells in the development are finished in bedrock at depths less than 80 feet (24 m) (fig. 7, D-D'). The finishing of wells in bedrock suggests that significant quantities of ground water have not been encountered in the overlying sand and gravel. It is likely that the valley fill beneath the peat bog was deposited in a small glacial lake and consists primarily of fine sand,

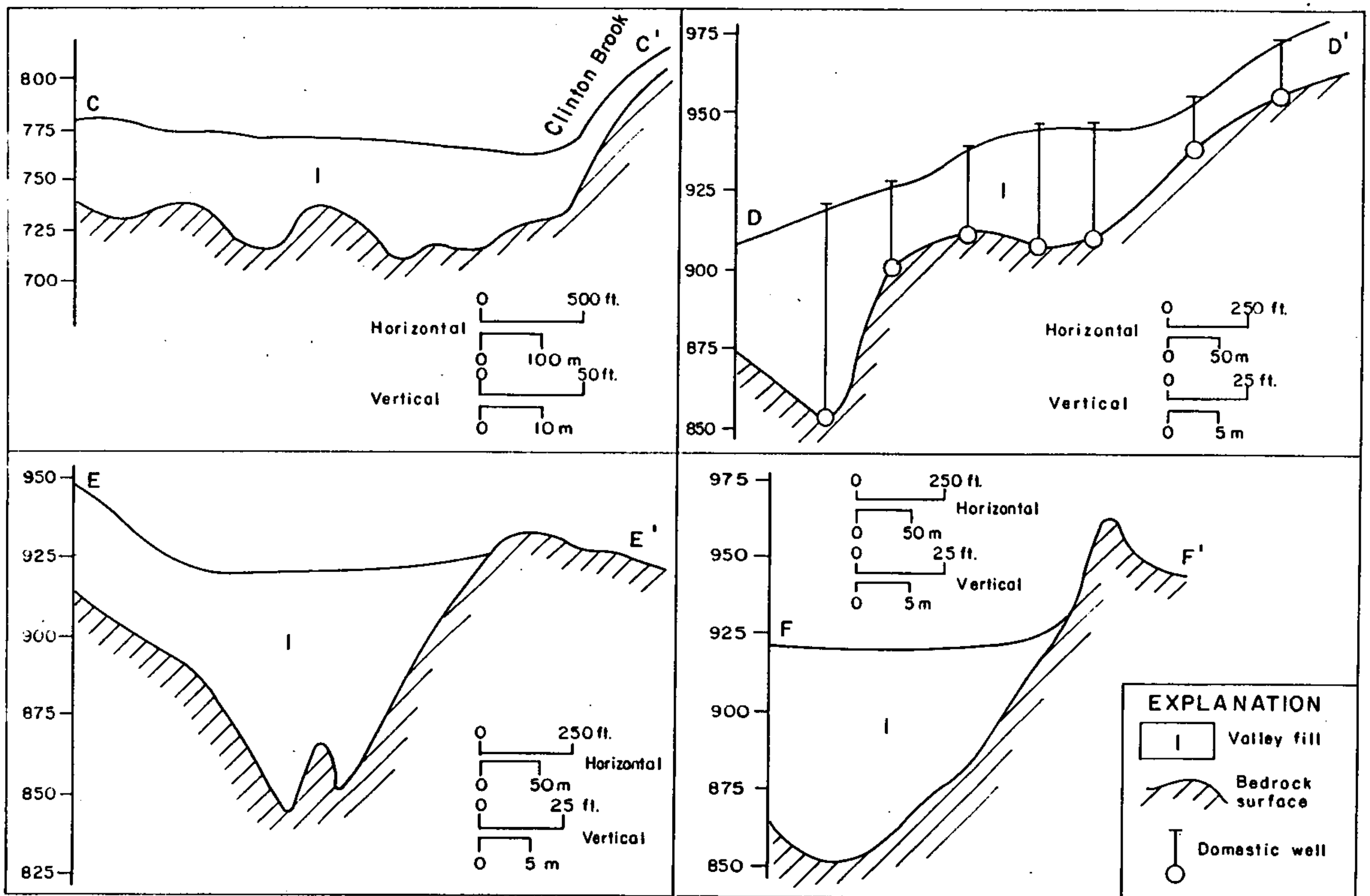

Figure 7. Profiles of bedrock surface in Area 2, West Milford Township. Elevations are in feet above sea level. C-C': Along LaRue Road as interpreted from reflection seismology. D-D': Along Gould Road as interpreted from domestic water well logs. E-E': Across bog North of Echo Lake as interpreted from reflection seismology. F-F': Along Wooley Road as interpreted from reflection seismology.

silt and clay. The pit north of Wooley Road, for instance, exposes predominantly fine sand.

Ground Water Potential

A thickness of 110 feet (34 m) of unconsolidated material near the confluence of Clinton Brook and the Pequannock River may include permeable sands and gravels, but no test wells were drilled in this area. A production well may be feasible in the vicinity of Kanouse Brook. Deposits of glacial sediment over 100 feet (30 m) in thickness occur near the intersection of Kanouse Brook and Route 23. A test boring (DEP-2) installed by Bureau of Ground Water Management personnel encountered water-bearing sand on the flank of this buried channel. Although no aquifer test was performed for confirmation, it may be possible that a well yielding 100 to 200 gpm (546 to 1,100 m^3/day) can be located in the main channel of the buried valley beneath Kanouse Brook, in the vicinity of Route 23. It may be possible to gain additional flow from a second well located upstream along the brook. The relationship between ground water pumpage and induced recharge from the brook must be established to properly evaluate the net ground water gain available for flow augmentation. In the Macopin area the narrowness of the valley, the fine texture of the glacial sediments seen in exposure and the inaccessibility of potential drilling sites in the valley fill limits the potential for developing high yield production wells.

Area 3: Oak Ridge/Milton/Longwood Valley, Jefferson and West Milford Townships

Location

Study Area 3 consists of the broad valley south and east of Oak Ridge Reservoir including upper Longwood Valley, the Milton area of Jefferson Township, and the Oak Ridge area of West Milford Township (plate 1).

Hydrogeologic Setting

Within the valley, the most significant deposits of unconsolidated sand and gravel are found within the Longwood Valley west of Green Pond Mountain. Bedrock is near the surface in the Milton area and no thick, saturated sand and gravel deposits are known to exist.

Data on the sand and gravel deposits in the Oak Ridge and Longwood Valley regions were gathered from domestic well records. Many residents of the lake communities overlying the principal bedrock channel rely on the sand and gravel valley fill for water supply, but those wells pumping from the stratified drift represent only a small percentage of all residential wells. Wells drilled on the periphery of the deep channel, or where bedrock is less than about 90 feet (27 m) from the surface, draw ground water from the underlying bedrock. Where the glacial overburden is thicker than 90 feet (27 m), some residential wells are finished in sand and gravel while others are finished in bedrock.

Information from well logs in the area is insufficient to conclude whether the practice of drilling through deep overburden to bedrock is a practice of the individual driller, or a reflection of the water-bearing characteristics of the valley fill. There is evidence from well records that thick deposits of fine-grained, poorly sorted glacial sediments occur in the Rockaway River valley in eastern Jefferson Township. The fine-grained silty deposits do not constitute zones of high ground water yield.

Aquifer Test: TW-6

Test Well TW-6 was drilled on Newark watershed property north of the intersection of Schoolhouse and Ridge Roads in Jefferson Township (plate 1). Geophysical work indicated that sand and gravel deposits in the area were insufficiently thick to provide for flow augmentation. Work performed by Barnett (1976) indicated the presence of a bedrock fault. TW-6 was drilled into this fault to determine whether fracturing along the fault zone could allow sufficient ground water yield for flow augmentation.

TW-6 was drilled to a depth of 210 feet (69 m). Overburden was 25 feet (8 m) thick. The remainder of the well was drilled in highly weathered sandy shale. Casing and screen were required to keep the weathered rock from caving into the open well. Faulting was indicated by slickensides on rock fragments, the high clay content of the cuttings, and the broken nature of the bedrock.

A four hour pump test was performed on TW-6. Water was muddy initially, but cleared to slightly cloudy by the end of the test. Pumping was begun at 50 gpm (273 m^3/day), then increased to 70 gpm (382 m^3/day). At 70 gpm the water level dropped to the pump elevation, and so pumping was reduced to 50 gpm (273 m^3/day). At the 50 gpm pumping rate drawdown was 110 feet (34 m), giving a specific capacity of 0.45 gpm/ft (8.1 m^3/day/m). This indicates that the fault would not be a significant source of water for flow augmentation.

Ground Water Potential

Well drillers' logs indicate that coarse deposits of sand and gravel occur near the Pequannock River in the Oak Ridge area. Coarse sediments are also indicated in logs from the incised Ancestral Rockaway River channel in Longwood Valley. Many of the records from this area indicate yields exceeding 20 gpm (109 m^3/day), the usual capacity of pumps employed for tests of residential wells.

The residential wells were not drilled or tested to determine whether the large quantities of water needed for flow augmentation are obtainable. In the area between Cozy Lake, Moosepac Pond and Lake Swannanoa the density of development is low and it is possible that production wells could be emplaced to intercept high yield water-bearing sand and gravel at depth.

One test well (TW-6) was drilled to evaluate the ground water potential of a fault in the bedrock in the Milton section south of the Oak Ridge Reservoir. The results of an aquifer pumping test on this fault well are not encouraging, as the well could barely sustain a yield of 50 gpm (273 m^3/day). The available data makes it difficult to assess the quantity of ground water available for flow augmentation in Area 3. Pumping rates which might reasonably be attained are: (a) 0.5 to 1.0 mgd (1,900 to 3,790 m^3/day) for augmentation to the Pequannock River from the Oak Ridge area, and; (b) 1.0 mgd (3,790 m^3/day) to the Rockaway River from the Longwood Valley area.

Area 4: Berkshire Valley, Jefferson Township

Location

Study Area 4 is located in the Berkshire Valley of the Rockaway River about three miles (4.8 km) northwest of the town of Dover (plate 1). The south end of Green Pond Mountain forms the east wall of the valley. Mase Mountain and Mount Arlington make up the western slopes. The northern limit of the study area is placed at Longwood Lake. Berkshire Valley is the southern extension of Longwood Valley.

Hydrogeologic Setting

Data on the thickness and composition of the valley fill are from two test wells (TW-7 and TW-9, plate 1) drilled in Lower Berkshire Valley and from domestic well logs.

An aquifer test was performed at well TW-9 to determine the hydraulic characteristics of the aquifer. Sand and gravel deposits in Berkshire Valley supply water to residential wells north of NJ Route 15 along Berkshire Valley Road. Drillers' well logs indicate a thick sequence of fine-grained sediments lying atop water-bearing sand and gravel. The stratigraphy is similar to that found in well records from Longwood Valley to the north, where fine-grained sediments or till overlie relatively thin, well-sorted water-bearing gravel layers. A similar sequence is found in domestic wells in Lower Berkshire Valley and in test well TW-9 located south of NJ Route 15. TW-9 was drilled near a marshy area of Lower Berkshire Valley, west of the Rockaway River. The well penetrated 100 feet (30 m) of sand and gravel deposits before encountering bedrock (fig. 8, G-G'). The lower 20 feet (6 m) of unconsolidated material was mostly rounded, fine to medium gravel and coarse sand. The well screen was set in this water-bearing interval between 80 and 100 feet (26 to 30 m) below the surface. The material above the screened interval consisted mostly of fine-grained sand and silty sand which appeared to serve as a leaky confining layer. Well records in Lower Berkshire Valley south of well TW-9 report sand and gravel deposits 120 to 200 feet (37 to 61 m) thick. A well located 1100 feet (335 m) south of TW-9 and 1000 feet (305 m) east of Berkshire Valley Road (Appendix 4, Well No. 63) penetrated 140 feet (43 m) of predominantly fine sand before encountering crystalline bedrock. The finished well yielded approximately 20 gallons per minute (109 m^3/day). A second well (Appendix 4, Well No. 65) located 100 feet (301 m) east of Berkshire Valley Road and approximately 800 feet (244 m) south of the aforementioned well (No. 63) reports 199 feet (61 m) of overburden; bedrock was not encountered. This well record reports over 100 feet (30 m) of fine-grained sediments overlying 9 feet (3 m) of waterbearing sand and gravel. Records of residential wells in the Mill Road area report relatively thin water-bearing deposits of sand and gravel atop bedrock, overlain by a thick interval of fine-grained glacial deposits.

Detailed subsurface exploration of Berkshire Valley was performed by Gerard Engineering of Jersey City in conjunction with the proposed Longwood Valley Reservoir project (Gerard Engineering, Inc., 1968). The Gerard Engineering report includes a series of rotary borings spaced at intervals of 200 feet (61 m) along the main dam axis (Dam 6) of the proposed Lower Longwood Valley Reservoir. The information generated in the boring program was used to construct a geologic cross section of Berkshire Valley (fig. 9, H-H'). It is evident

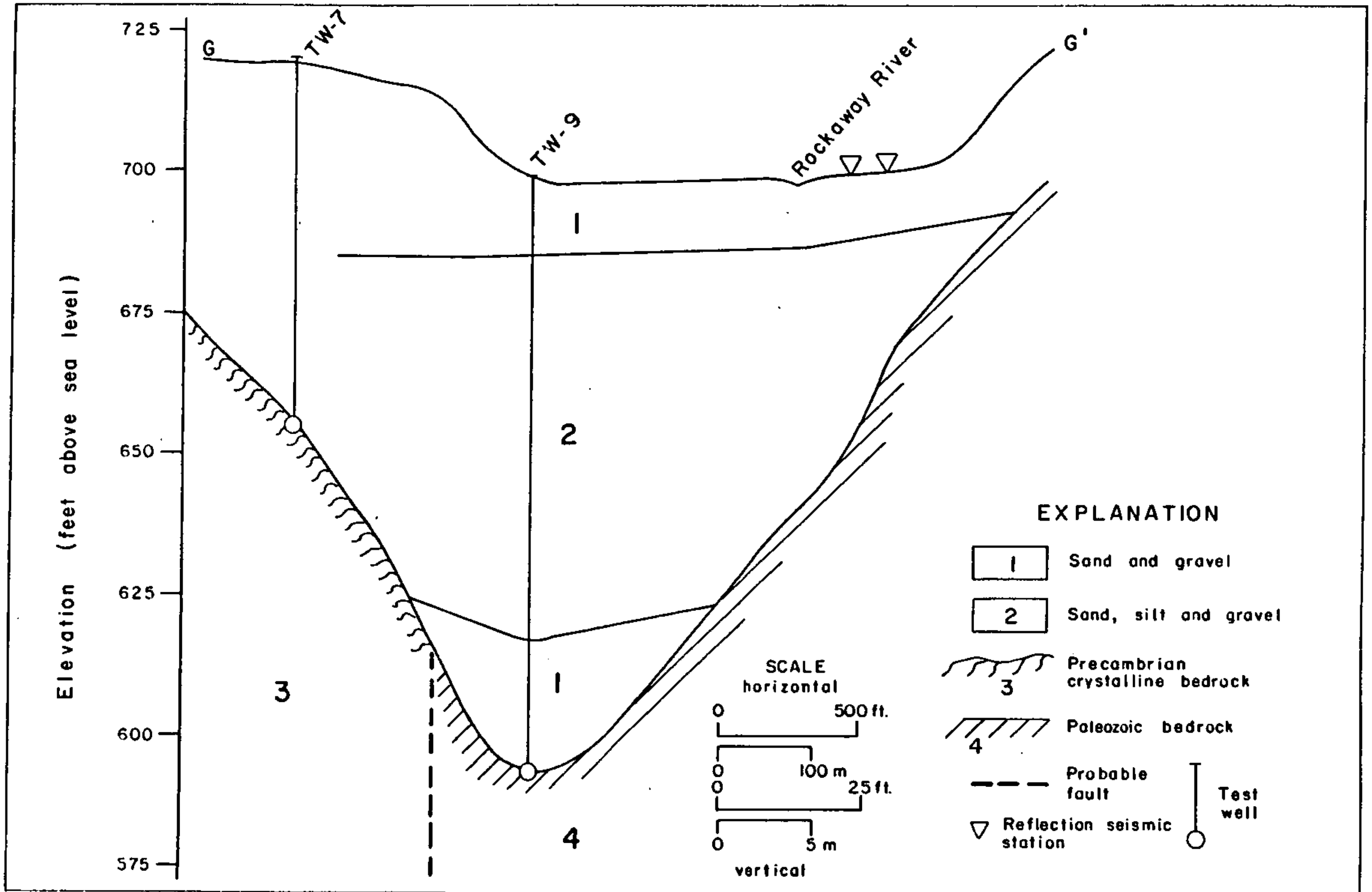

Figure 8. Cross section of valley fill deposits in Lower Berkshire Valley, Area 4, Jefferson Township.

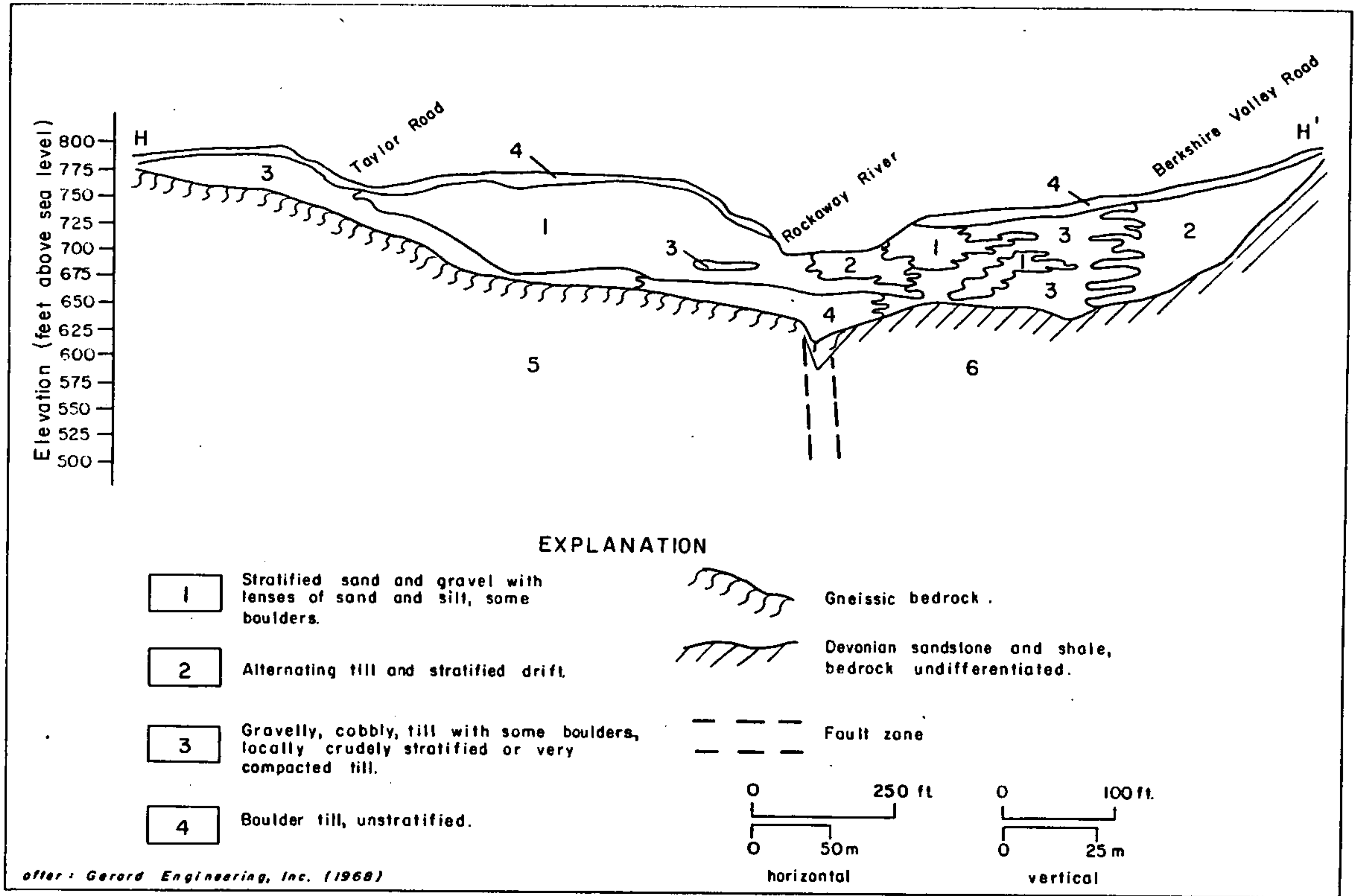

Figure 9. Cross section of bedrock surface and valley fill deposits in Berkshire Valley, Area 4.

from the borings that the main channel of the buried valley coincides with a fault zone separating brecciated Precambrian gneiss from the Devonian Bellvale Sandstone and Pequanac Shale.

As in upper Rockaway Township, the buried valley of the Ancestral Rockaway River is a narrow trough. In the vicinity of test well TW-9, the portion of the channel in which sediment thickness exceeds 50 feet (15 m) is approximately 2000 feet (730 m) wide. The glacial sediments in the Lower Berkshire Valley in the vicinity of Route 15 are part of the Wisconsin terminal moraine. High yield well fields have been successfully located elsewhere in New Jersey in the vicinity of the terminal moraine.

Additional test wells, geophysical studies and aquifer pumping tests would be required to define the hydrology and ground water potential of the stratified drift deposits underlying Berkshire Valley. In addition, the interaction of the Rockaway River and surrounding wetlands with the aquifer(s) requires assessment before the potential ground water yield could be accurately evaluated.

Aquifer Test: TW-9

In order to monitor the response of the proposed high rates of pumpage per well (200 to 500 gpm or 1,100 to 2,700 m^3/day), seven PVC-cased observation wells, each 1.5 inches (0.04 m) in diameter, were installed in an array around test well TW-9 (fig. 10). Two pairs of observation wells (OW-1, OW-2 and OW-6, OW-7) were aligned with TW-9 to allow for assessment of distance/drawdown relationships and to test for directional variations in transmissivity within the aquifer. The most distant monitor wells were installed 150 feet (46 m) from the pumping well. TW-9 was pumped with a two-stage turbine pump set 70 feet (21 m) below the top of the casing. Water was discharged through a six inch (0.15 m) diameter steel pipe into a marshy area north of the well. It was assumed the sediments underlying the marsh would not readily allow the discharged ground water to re-infiltrate the aquifer. Discharge measurements were made with a four-inch (0.1 m) diameter restricting orifice on the discharge pipe coupled to a riser tube. Discharge volumes were estimated with standard tables (Anderson, 1963). During pumping, water levels in TW-9 were measured with an air line.

Water level measurements were taken at each monitor well during the 24 hour pumping period and during the 12 hour recovery period following 24 hours of pumping. Changes in water levels in the observation wells were measured to the nearest 0.01 ft. (0.3 cm) with electronic water level indicators. The test well was pumped at a rate of approximately 375 gpm (2,050 m^3/day) for a period of 24 hours. A total of about 540,000 gallons (2,050 m^3) were pumped during the test. Water levels in the six observation wells responded immediately at the onset of pumping. The reaction of the piezometric surface was slight, with drawdowns ranging from 0.02 to 0.54 feet (0.01 to 0.16 m) in the first minute of the aquifer pumping test. At the end of 24 hours, drawdown was still increasing in five of the observation wells. Drawdown in the pumping well stablilized after 180 minutes and no appreciable change in water level was recorded after this time. Recovery rates of water levels in the first minute were similar to drawdown rates recorded during the first minute of the pumping phase. Full recovery to initial static water levels for all the observation wells occurred within 24 hours at the TW-9 site. It appears that little or no dewatering of the aquifer took place during the aquifer test and that the aquifer may be of the confined type.

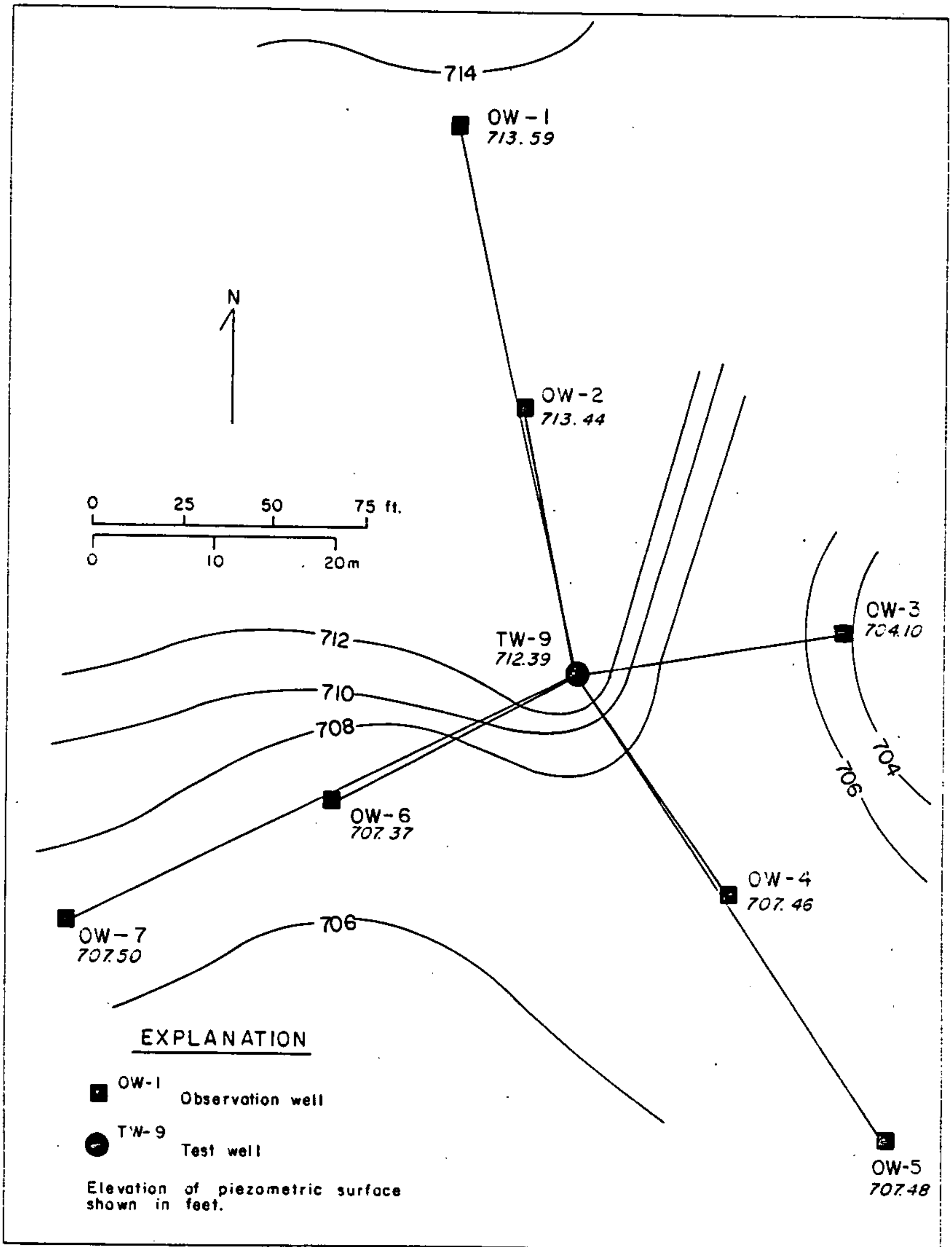

Figure 10. Array of observation wells for TW-9 aquifer test in Area 4, and piezometric surface before pumping.

Pumping at the rate of 375 gpm produced a drawdown of 8.32 feet (2.5 m) in the test well. This performance represents a specific capacity of 45 gpm/ft (807 m^3/day/m). Drawdown solutions (Theis, 1935; Cooper and Jacob, 1946) and recovery solutions (Johnson, 1975) were applied to the aquifer test data for each observation well to calculate values of transmissivity (T) and storativity (S) for the aquifer from the measurements taken in the observation wells.

The calculated values of transmissivity range from 108,000 to 146,000 gpd/ft (1,340 to 1,800 m^2/day). The storativity of the aquifer averages 4.9 x 10^{-3} (dimensionless), indicating that the fine-grained sediments which overlie the coarse aquifer gravel create leaky confining conditions. The majority of ground water is stored and transmitted by the gravelly deposits, yet the fine-grained deposits provide some recharge to the gravel. The CAPTD computer program (Hoffman, in press) was used to analyze the test results. The value for (T) from the computer analysis, 124,000 gpd/ft (1,500 m^2/day), agrees with values derived by the other analytical methods.

TIP Aquifer Drawdown Simulation

In order to gain an understanding of the potential impact on the aquifer of pumping water for flow augmentation, a TIP simulation (Hoffman, unpub.), similar to that performed for Area 1, was applied to Area 4. The six production wells in the simulation were spaced within 12,000 feet (3,600 m) of one another along Berkshire Valley west of the Rockaway River, starting from well TW-9, north to the Longwood Lake area. Each well was simulated to continuously pump 300 gpm (1,640 m^3/day) for 120 days. Eight observation wells were simulated to measure the drawdown resulting after 120 days of pumping with no recharge to the aquifer. Observation wells were placed adjacent to the pumping wells and at distances of up to 100 feet (30 m) to measure drawdown. A transmissivity of 100,000 gpd/ft (1,242 m^2/day) was applied throughout the aquifer, based upon results of the aquifer test at TW-9. Maximum drawdowns at the pumping wells in the TIP simulation were 15 feet (4.6 m). This value compares with an actual drawdown of 8.32 feet (2.5 m) after pumping TW-9 for one day at 375 gpm (2,050 m^3/day). Drawdowns predicted by TIP at the other pumping wells were similar.

TIP assumes an aquifer is homogeneous and of infinite areal extent. Since boundary conditions exist, in the form of bedrock valley walls and lateral gradations of well-sorted sediments into poorly sorted till layers, greater physical limitations exist in the aquifer than can be accounted for by TIP. TIP also assumes no recharge will take place to the aquifer, which may not reflect the bedrock storage as a possible long-term contribution to yields from the sand and gravel. In any event, the TIP simulation allows for an approximation of drawdowns near pumping wells after 120 days of continuous pumping under drought conditions. It appears that pumping at a rate of approximately 2.6 mgd (9,854 m^3/day) can be sustained in Berkshire Valley. The possibility of inducing recharge to the aquifer from the Rockaway River by pumping at this rate could not be investigated at this time. Since ground water occurs under unconfined conditions in places in the valley, induced recharge is a possibility. Additional aquifer testing would be required to evaluate this possibility.

Ground Water Potential

The results of an aquifer test on well TW-9 indicate that high ground water yields can be obtained from a sand and gravel aquifer beneath the Rockaway River Valley in the area known as Berkshire Valley. In places, the gravel aquifer interfingers with till or fine grained glacial lake bed sediments at the same elevation in the subsurface. The till and fine sediments limit overall ground water yields from the valley fill.

Additional geophysical work and test borings are thus necessary to accurately locate high yield wells. Most domestic well records and test borings show a gravelly water-bearing layer a few tens of feet thick above bedrock, overlain by 50 to 100 feet (15 to 30 m) or more of finer-grained, poorly sorted glacial sediment. Aquifer pumping test results indicate that the fine-grained interval acts as a partial or leaky confining layer. The confining layer, which becomes thicker to the south of TW-9 toward the terminal moraine, does not yield significant quantities of ground water directly to wells, but serves to store ground water which is released to the underlying confined sand and gravel aquifer during pumping. The sand and gravel aquifer probably receives some recharge from direct percolation of rain water through the overlying fine-grained sediments. Additional recharge probably occurs through unconfined strata elsewhere in the valley, most likely to the west and north. Areas underlain by bedrock along the valley flanks probably also contribute minor amounts of recharge.

Test pumping at TW-9 indicated a specific capacity of 45 gpm/ft (806 m^3/day/m) for the aquifer in this area. This value is greater than the average of 30.9 gpm/ft (553 m^3/day/m) for 110 large diameter sand and gravel wells in the county (Gill & Vecchioli, 1965). The transmissivity values computed at TW-9 indicate extremely high hydraulic conductivity for the well-sorted sediments. It is likely that TW-9 could sustain a yield in excess of 500 gpm (0.72 mgd or 2,700 m^3/day), and perhaps as much as 750 gpm (1.1 mgd or 4,100 m^3/day). Data gathered on the regional subsurface geology indicate that at least one production well could be located between TW-9 and Route 15 to intercept the high yield sand and gravel deposits.

North of Route 15, in the vicinity of the proposed Longwood Valley Reservoir, water-bearing strata of sand and gravel occur in association with glacial till. Despite a thin surficial veneer of colluvium or till, the saturated zone within the stratified drift appears to be under water table conditions. Preliminary indications are that three to four high yield wells could be located in Berkshire Valley north of Route 15 to intercept the water-bearing stratified drift deposits. The net water gain for flow augmentation from glacial sediments in this region cannot be accurately predicted without further investigation. A conservative estimate of the ground water available for flow augmentation in Area 5 is in the range of 2.1 mgd to 3.0 mgd (7,960 to 11,370 m^3/day). This is on the basis of six production wells, each capable of producing 250 to 350 gpm (0.36 to 0.50 mgd or 1,360 to 1,910 m^3/day) on a continuous basis for 120 days.

Much of the land in Berkshire Valley is owned by Jersey City. This ownership would facilitate access for additional test drilling. Extensive wetlands associated with the flood plain of the Rockaway River would limit the access in some parts of the valley. South of test well TW-9 there is little land in public ownership in the valley. In addition, it appears from well records that the percentage of low-yield, fine-grained sediments in the stratigraphic section increases to the south in areas readily accessible to drilling.

Area 5: Northern Roxbury Township

Location

Area 5 is entirely within Roxbury Township and extends from Mill Road southward to U.S. Route 46 and from Mine Hill westward to Arlington Boulevard (plate 1).

Hydrogeologic Setting

Valley fill deposits underlie low lying areas to the east and west of an elongate bedrock knoll extending northeastward from Hercules Road. Data on the valley fill sediments are from domestic, public, and industrial water well records, seismic reflection and refraction surveys and resistivity surveys. One test well, TW-10 (plate 1), was drilled. Information gathered for the preparation of a finite-element ground water model for Roxbury Township (Hill and Pinder, 1981) was made available for this study, but the model itself had not been completed. To the west of the bedrock knoll, valley fill sediments occupy a southward-deepening valley. Thickness of sediment in this buried valley reaches a maximum of 200 feet (61 m), determined by seismic methods at the intersection of Lake and Main Streets in Kenvil. To the east of the knoll is a northward-deepening valley. The greatest reported sediment thickness in this buried valley is 285 feet (87 m), which was encountered in a well at the intersection of Dell Avenue and Mine Road (Appendix 4, Well No. 66).

Stratigraphic sequences within the buried valleys are complex and not well known. At some places, as the intersection of Dell Avenue and U.S. Route 46, and along Berkshire Valley Road, the entire thickness consists of poorly sorted sands and gravels with lenses of well-sorted, permeable sediments. At other sites, as for example at TW-10, the column of sediments as a whole is less well sorted and less permeable.

In still other areas, as at the Hercules Powder Company property near Berkshire Valley Road, permeable outwash up to 60 feet (18 m) thick overlies finer-grained, less permeable sediments and constitutes a water table aquifer. Furthermore, coarse-grained deposits commonly underlie such fine-grained sediments, and constitute a deep, confined aquifer. A thorough evaluation of ground water resources in this area would require further investigation of the distribution and interfingering of the different types of sedimentary units.

Ground Water Potential

Ground water in Area 5 is primarily derived from outwash within 60 feet (18 m) of the surface and from lenses of sand and gravel within finer-grained sediments at greater depths. Sand and gravel outwash within 60 feet (18 m) of the surface yields large quantities of water at the Hercules Powder Company property. Wells drilled in 1940 and 1941 (Appendix 4, Well Nos. 67 and 69) produce 1500 and 1,100 gpm (8,200 and 6,000 m^3/day), respectively, from shallow outwash and sand and gravel lenses at depths of 60 to 100 feet (18 to 30 m). A cluster of nine 50 feet (15 m) deep wells collectively yield 3,000 gpm (7.2 mgd or 16,400 m^3/day). Permeable sand and gravel occurs as lenses throughout the valley fill sediments near the intersection of Dell Avenue and U.S. Highway 46 and also along the western margin of this same buried valley to the north along Berkshire Valley Road. Conditions for ground water production appear promising.

Ground water potential of other areas is less well known. Test well TW-10 was drilled approximately 1000 feet (305 m) west of Berkshire Valley Road along the western margin of the buried valley extending northward from Dell Avenue. The well encountered poorly sorted sands and gravels through the entire thickness of valley fill and yielded 50 gpm (273 m^3/day). The low yield is attributed to poor sorting of the deposits. A resistivity survey performed between Duck Pond and Howard Boulevard immediately south of Interstate Route 80 indicated that sediments are probably poorly sorted and of low hydraulic conductivity. No well records or borings were available for confirmation. Thin sand and gravel aquifers, well known elsewhere in the township, would not have been detected by this method.

Area 6: Beaver Brook Valley, Rockaway Township

Location

Study Area 6 was in the portion of the Beaver Brook Valley in Rockaway Township extending from one-half mile (0.8 km) north of the Rockaway Township well field to the Meriden area (plate 1).

Hydrogeologic Setting

Data on valley fill sediments were obtained from domestic, industrial, and public water supply well records, and three seismic traverses performed by Woodward-Clyde Consultants. The width of the buried valley is between 0.3 and 0.5 miles (0.5 to 0.8 km). Seismic refraction surveys indicate that depths to bedrock beneath Beaver Brook are approximately 100 feet (30.5 m). The existence of unconsolidated water-bearing valley fill is confirmed by well records.

Coarse, water-bearing sand and gravel deposits have been used for ground water supply by the Rockaway Township wells near Meadow Brook, 0.6 miles (1 km) south of the area of investigation. Well yields for Rockaway Township wells #4 and #6 exceed 500 gpm (2,700 m^3/day). Well #7 has been tested at 1,000 gpm (5,500 m^3/day). Wells drilled for the Boonton Radio Corporation at Beach Glen near the intersection of Green Pond and Meriden Roads (Appendix 4, Well Nos. 54, 55, 56) encountered coarse sand and gravel at depths greater than 80 feet (24 m). The sand and gravel aquifer at this site is overlain by 70 to 90 feet (21 to 27 m) of fine sand with silt and clay. This material acts as a confining layer. The ground water in the gravel aquifer was under artesian pressure at the time the wells were drilled. One well yielded 108 gpm (590 m^3/day) during a pumping test, exhibiting a specific capacity of 1.16 gpm/foot (21 m^3/day/m). A second well drilled at the Boonton Radio site in 1960 was able to pump 548 gpm (2,990 m^3/day) from an interval of coarse sand and gravel 30 feet (9 m) thick lying atop the bedrock. The specific capacity of this well was 6.1 gpm/ft (110 m^3/day/m).

Ground Water Potential

It is reasonable to estimate that 0.75 to 1.0 mgd (2,840 to 3,790 m^3/day) of ground water could be pumped from sand and gravel deposits in the Beaver Brook area of Rockaway Township above Beach Glen. The thick confining layer of fine-grained sediments encountered in the Beach Glen wells may pose a significant limitation to the development of ground water supplies.

Surface geophysical techniques would aid in the differentiation between low yield, fine-grained sediments and coarse-grained potentially water-bearing sediments in the Beaver Brook Valley.

GROUND WATER QUALITY

The chemical quality of the ground water in the test areas is good to excellent. Water was sampled at five test wells with the assistance of the Department's Bureau of Potable Water. Analyses are summarized in table 4, where they are compared to New Jersey water quality standards and to analyses of water from two nearby community water supply wells finished in Pleistocene sand and gravel nearby in Morris County.

Initially, an attempt was made to sample seven test wells (TW-1, 2, 3, 5, 8, 9 and 14). Samples were not collected from wells TW-2 and TW-3. Well TW-2 pumped fine sand during pre-sampling evacuation. Water from TW-3, which is screened in the bedrock and overburden, was discolored by iron during evacuation. Based upon the clarity of samples from the remaining test wells, it was concluded that the iron visible in water from TW-3 probably originates in the bedrock.

Elevated levels of iron were detected in all test wells, but this would not present a major problem for flow augmentation. All test wells conform to New Jersey Primary and Secondary Drinking Water Regulations for all parameters other than total iron and manganese. Treatment for iron and, in Area 1, manganese would be required if wells drilled at the test well sites were to be used for individual or community water supply.

It should be noted that the sand and gravel water-table aquifers throughout northern New Jersey are especially susceptible to contamination because of the shallow depth to ground water and high infiltration rates of large areas of the surficial deposits.

Parameter	TW-1	TW-5	TW-8	TW-9	TW-14	Dover Well No. 3***	Boonton Twp. Boonton No. 1***	NJ DEP Regulations (mg/1)
Nitrate (NO_3-N) (mg/1)	0.84	0.05	0.05	0.35	0.05	3.9	11	10*
Cadmium (mg/1)	0.001	0.001	0.001	0.001	0.001	-	-	0.01*
Chloride (mg/1)	37	6	1	5	1	8.6	5.8	250**
Total Iron (mg/1)	5.67	2.55	1.78	0.37	12.05	0.07	0.08	0.3 *
Manganese (mg/1)	0.06	0.24	0.41	0.005	0.144	0.19	0.00	0.05**
ABS/LAS (mg/1)	0.1	0.1	0.1	0.1	0.1	-	-	0.5 **
Hardness ($CaCO_3$) (mg/1)	80	128	126	100	86	174	123	250**
Sodium (mg/1)	17.9	2.9	3.4	4.0	2.3	8.4	4.5	50**
Sulfate (mg/1)	20	23	12	14	21	26	26	250**
Total Dissolved Solids (mg/1)	154	144	128	160	128	204	134	500**
pH	6.8	8.3	8.0	8.3	6.9	6.9	6.8	-
Color	5	50	5	5	5	2	3	-
Odor	1	1	1	1	1		-	-
Alkalinity to pH_4 (mg/1)	55	115	120	75	78	-	-	-
Ammonia (mg/1)	0.20	0.20	0.15	0.10	0.15	-	-	-
Total Phosphate (mg/1)	0.06	0.15	0.40	0.40	0.06	-	-	-
COD (mg/1)	5	5	5	5	5	-	-	-
Specific Conductance (micromho/cm)	-	200	160	186	-	322	216	-

*Primary Drinking Water Regulation
**Secondary Drinking Water Regulation
***Gill and Vecchioli, 1965

Table 4. Chemical analyses of water from selected test wells and public supply wells finished in Pleistocene sand and gravel.

COST OF WELLS

The potential costs for developing a system to augment stream flow to the reservoirs that serve Newark and Jersey City include:

1) acquisitions of land, where needed;

2) drilling and construction of production wells and associated equipment, and;

3) the maintenance and operation of the wells.

Additional site-specific geophysical investigations would be needed to choose the best locations for the production wells. It appears from the initial evaluation that potential production well sites are available on publicly owned land and that sufficient buffer areas exist around the well sites. If the services of a geotechnical consultant are required to obtain geophysical information, these costs may be estimated from table 5. The table presents costs for geotechnical services provided to the Bureau of Ground Water Management during the drought emergency in 1981.

Installation Costs

An estimate for the current cost of providing a complete sand and gravel production well in the study area is $180,000. For this cost the production wells would be constructed according to the following specifications:

1) The well (Approximate cost: $75,000)

    a) drill a hole 16 inches (0.4 m) in diameter to a maximum depth of 200 feet (61 m) using the mud rotary method;

    b) install approximately 30 feet (9 m) of stainless steel well screen and 170 feet (52 m) of steel casing (both with diameters of about 12 inches or 0.3 m);

    c) install gravel pack around the well screen and fully grout the casing in place, and;

    d) develop and test the well.

2) The pump (Approximate cost: $30,000)

    a) install a two stage vertical turbine pump, about 12 inches (0.3 m) in diameter (provided with a 50 horsepower, 1800 rpm, vertical hollow shaft non-reversing motor);

    b) the pump would be set about 100 feet (30 m) below the static water level and be capable of producing up to 1,000 gpm (1.4 mgd) or 5458 m^3/day) at a total dynamic head of 80 feet (24 m), and;

    c) the pump is to include discharge piping with a blowoff system, valves, flow meter and other necessary appurtenances.

3) Pump house (Approximate cost: $50,000)

   a) construct a concrete block pump house to protect pumping equipment;

   b) house would have a removable roof hatch to allow installation and removal of well pump;

   c) approximately 25 feet (8 m) of external piping would be installed below grade for connection to a distribution system to deliver to surface water bodies, and;

   d) the house would be surrounded by a chain link fence, painted, and equipped with a gravel driveway.

4) Electrical equipment (Approximate cost: $20,000)

   a) installation of pump starter, lights, ventilating system, thermostatically-controlled heating system, electrical outlets and miscellaneous items, as required, and;

   b) electrical meter (see Operating Costs below).

The above costs were derived by consulting two private companies. Drilling and construction costs would, of course, vary among contractors, and will most likely increase in the future.

Operating Costs

The principal operating cost associated with the production wells would be electrical power costs. This cost is estimated to be approximately $10,000 per well per year. This service would be purchased from Jersey Central Power and Light Company (JCP&L), as they are the utility servicing the study area. Operating costs were estimated on the basis of 120 days of continuous, round-the-clock pumping of a 50 horsepower motor. The costs reflect the proximity of the proposed production well locations to an existing JCP&L Company power transmission line. The $10,000 cost estimate also includes a minimum charge for a power demand of 40 kilowatts during the eight months of the year when the wells theoretically would not be in operation.

Operation costs for electrical power would differ should the wells not be put into operation yearly. The power company compares projected revenue from a project for a five year period to construction costs required to supply the facility. If construction costs exceed projected revenue a separate deposit would be required for each well.

Other maintenance costs may, in the long term, be associated with the operation of the production wells. Pump repair, re-development of the wells in the event of decreasing yield, motor repairs, physical plant repairs, road repairs and vandalism can present unforeseen maintenance costs. Costs of this variety are difficult to anticipate or quantify.

Service	Cost
Geophysics	
seismic refraction surveys	$1.15 line foot
drill hole logging	
mobilization of equipment	250.00 well
natural gamma/neutron log	2.50 foot
density log	2.50 foot
Drilling	
200 foot well (6 inch casing with 50 feet of 10 inch casing and well screen)	12000.00
well development	187.50 hr.
test pumping	187.50 hr.
Personnel	12.50 hr. - 25.00 hr.
Miscellaneous	
standby time	143.50 hr.
heavy equipment	variable
fill material	± 5.00 yd.^{3}

Table 5. Costs for geotechnical services during study.

METHODOLOGIES

Geophysical Investigations

Geophysical methods used in this study were seismic reflection and refraction, electrical resistivity, and electromagnetic conductivity. These methods provide a great deal of data on the subsurface with a minimum of test borings or monitor wells required to confirm the geophysical interpretations. The conjunctive use of two or more geophysical methods provides independently obtained results which can be used to make better interpretations of the subsurface stratigraphy.

Seismic Reflection and Refraction

Seismic reflection and refraction yield stratigraphic data based on the movement of seismic waves travelling through sediments or rocks of varying velocity characteristics.

In seismic reflection, energy from a sledgehammer blow, drop weight, or explosive charge is reflected from interfaces between materials with contrasting seismic velocities and detected at the surface using a vibration-sensitive geophone. The time between the blow and the return of reflected energy can be used to estimate depth to the interface. Reflection soundings using a sledgehammer or drop weight can be used in investigations to depths in excess of 300 feet (91 m).

In order to use reflection seismology, the seismic velocity of the material(s) must be known or estimated. This can be accomplished by performing a short refraction seismic traverse or "back-calculating" the velocity of the subsurface materials from reflection seismic data adjacent to a well or boring where depth to bedrock is known.

In refraction seismic, wave energy is refracted along stratigraphic interfaces between earth materials of different velocities if the velocity of each layer increases with depth. Refraction can be used to estimate both depth to contrasting strata and seismic velocities of the strata. Refraction traverses utilizing a sledgehammer or drop weight are usually restricted to depths of 100 feet (30 m) below the surface. Explosives were used by the Woodward-Clyde Consultants for deeper investigations in this study. Additional information and explanation of the refraction and reflection seismic methods may be found in Mooney (1977), Dobrin (1976), Zohdy et al. (1974), and Griffiths and King (1965).

Electrical Resistivity and Electromagnetic Conductivity

Electrical resistivity and electromagnetic conductivity provide data based upon the ability of different lithologies to transmit an electrical current. Conductivity is the reciprocal of resistivity. Conductivity and resistivity of surface materials are determined primarily by the amount, quality and distribution of water contained in the materials. Saturated materials exhibit lower resistivity and, conversely, higher conductivity values than unsaturated or dry material. Lower resistivities are also associated with increasing saturated porosity, mineralization of water, and the presence of clay or conductive minerals.

Resistivity can be used to investigate changes in lithology or ground water quality with depth using sounding techniques or to map lateral changes using profiling techniques.

Resistivity sounding is based on a proportional relationship between the electrode spacing and depth at which resistivity is measured. In general, closely spaced electrodes measure resistivity at a shallow depth. More widely spaced electrodes measure resistivity at greater depths. In resistivity sounding, a fixed location is maintained as the center of the electrode spread. Electrodes are placed at increasingly greater distances on opposite sides of this point and measure electrical properties at increasing depths below the point.

In resistivity profiling, the distance between electrodes, and therefore the approximate depth of investigation, is kept constant. The center of the electrode spread is moved so as to measure lateral variability. Profiling is particularly effective in investigating the lateral changes characteristic of glacial valley fill sediments.

Additional information on surficial electrical geophysical methods may be found in Mooney (1980), Zohdy, et al. (1974), Keller and Frischknect (1966), and Griffiths and King (1965).

Electromagnetic conductivity profiling is similar to resistivity profiling except that instead of directly applying an electrical current to the ground through electrodes, a magnetic field, H_p, is used to generate a weak current in the subsurface. This current generates a secondary magnetic field, H_s, which is detected by a receiver coil. H_s varies with H_p, coil spacing (s), the operating frequency (f) and the ground conductivity (c). By maintaining H_p, f, and s at constant values, variations in the ground conductivity (c) over a wide area may be mapped.

Additional information on electromagnetic conductivity may be found in Keller and Frischknecht (1966) or McNeill (1980a, 1980b, 1980c, and 1980d).

Well Construction and Development

Test wells were drilled during the investigation to determine:

1) the depth to bedrock;

2) the composition of unconsolidated sediments overlying the bedrock, and;

3) the stratigraphic sequence of the sediments through the use of geophysical well logging, measurements and the subsurface stratigraphy.

Test wells were drilled by the air rotary method, as selected by the consultant. Air rotary drilling involves the use of a percussion tool called a down-hole hammer. This tool combines abrasive rotary cutting action with percussive force generated by air pressure. Cuttings are evacuated from the bore hole to the surface by means of the same air pressure. In unconsolidated formations, such as glacial sand and gravel, the bore hole is kept open by advancing the well casing behind the drill bit as it proceeds downward.

The air rotary method has advantages in cost and speed, but is not the ideal method for stratigraphic interpretation or for optimization of ground water yields (Johnson, 1950). Samples collected from air rotary drilling can be used to characterize the gross nature of deposits and to identify principle water-bearing zones, but sorting characteristics important to aquifer properties are difficult to judge. Under some circumstances, wells drilled using the air rotary methods may have lower yields than those drilled in the same formation by other methods.

The Bureau established specifications for the construction of the test wells. These well specifications are depicted in figure 11. The test wells were finished with either one or two sections of galvanized steel well screen. Each well screen section is 10 feet (3 m) in length, with an outside diameter of 5-3/8 inches (13.6 cm) and a slot opening size of 0.30 inches (30 slot or 0.8 cm). The screen was set within a steel casing with an inside diameter of 6 inches (15 cm). A packer was used to seal the screen inside the end of the casing. Wells were started with 10 inch (25 cm) inside diameter steel casing where boulders were a potential problem. A bentonite-cement seal was emplaced in the annuluar space between the bore hole and the casing by the tremie-pipe grouting method.

Test well specifications called for eight hours of development time for each well. Well development consists of different methods of surging the water in the well in an attempt to remove fine sediments from the formation which restrict flow to the well screen. Proper well development can improve the well yield dramatically.

In the air pressure, or blowing method of well development, compressed air is forced into the formation in an attempt to flush fine-grained sediments from the sand and gravel aquifer. These are brought to the surface by rising water pushed by air pressure being applied at depth. In unconsolidated formations it is possible to achieve the opposite of the desired result when using the air pressure method. Fine-grained sediments can be forced into the spaces between coarser sand and gravel, thereby packing the grains tightly together. This reduces the overall hydraulic conductivity of the formation around the well screen, because void space formerly available for water passage becomes blocked by fine sediments.

The surge-block development method employs a plunger-type device which is worked steadily up and down the well, causing a flow of water into the formation on the downstroke through compression of the water column, then reversing this flow through suction caused by the pulling action of the plunger as it is raised in the well. The intent of the surge-block method is to pull fine-grained sediments from the formation. The surge-block method for developing wells is a preferred method for enhancing the yield from wells in unconsolidated sand and gravel.

Aquifer Pumping Tests: Interpretation

Aquifers can be evaluated by test pumping to allow quantitative estimates of expected yield from wells, to determine the optimum density and positioning of wells in a well field, to determine the capacity of the aquifer to transmit and store ground water and to predict the environmental effects of pumping. Aquifer tests performed during the course of the study were analyzed by the

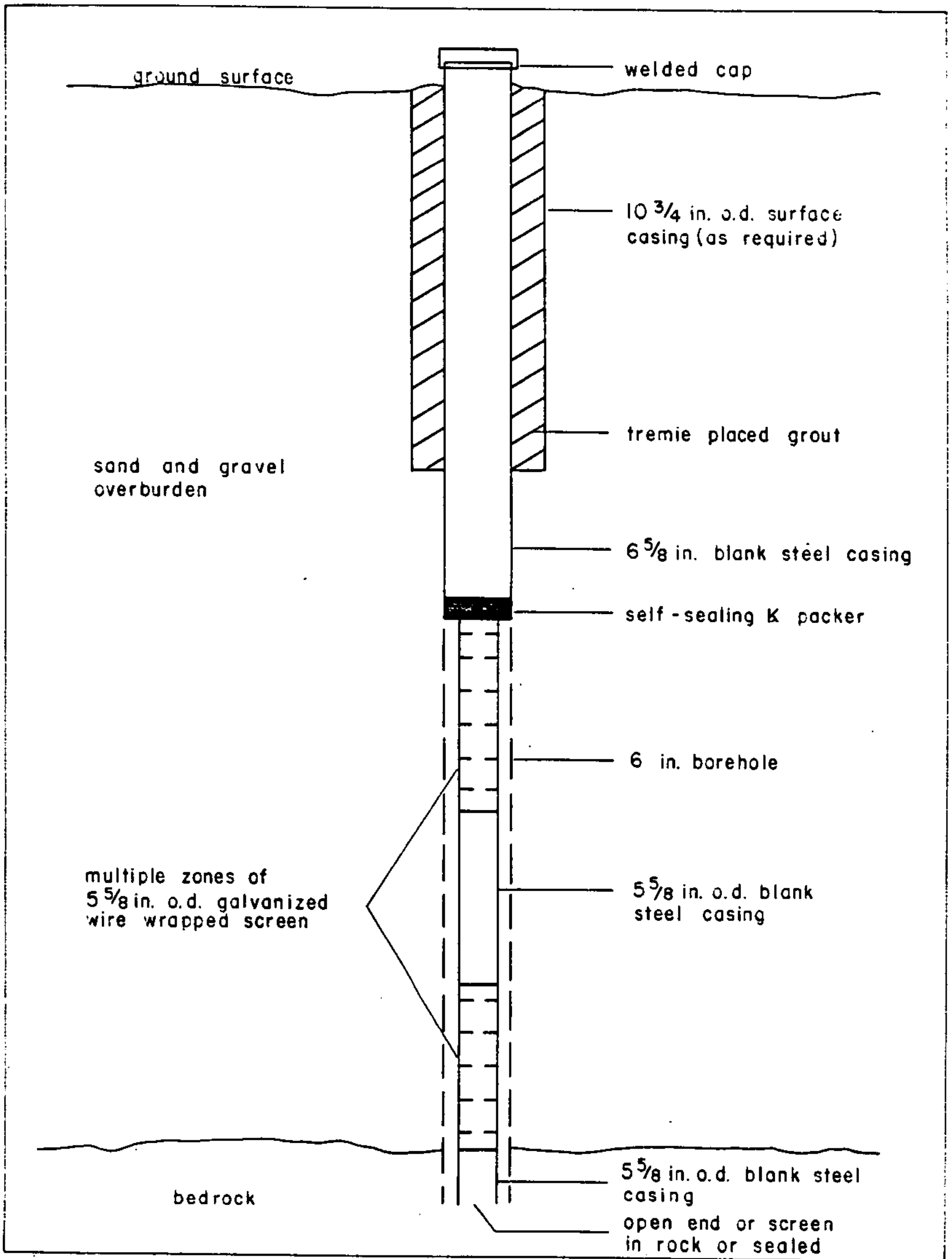

Figure 11. Construction of test wells used in the study.

methods described by Theim (1906), Theis (1935), Cooper and Jacob (1946), Jacob (1963), Prickett (1965) and Johnson (1975). These methods for analyzing aquifer pump tests apply only under the constraints of certain assumptions. The methods developed by Theim (1906), Theis (1935) and Jacob (1963) apply under the following assumptions (Kruseman and de Ridder, 1979):

1) The aquifer is confined;

2) The aquifer has an apparently infinite areal extent;

3) The aquifer is homogeneous, isotropic and of uniform thickness over the area influenced by the pumping test;

4) Prior to pumping, the piezometric surface is nearly horizontal over the area influenced by the pumping tests;

5) The aquifer is pumped at a constant discharge rate, and;

6) The pumped well penetrates the entire aquifer and thus receives water from the entire thickness of the aquifer by horizontal flow.

In addition to the above, the methods of Cooper and Jacob (1946) and Johnson (1975) assume the following:

7) The storage in the well can be neglected, i.e., the well diameter is very small, and;

8) Water removed from storage is discharged instantaneously with decline in head.

Prickett's method (1965) applies to aquifers where condition #8 above is not met. Specifically, when groundwater continues to seep from sediments overlying the zone of influence, the rate of decline in the head during the aquifer test is reduced due to the delayed yield.

The valley fill aquifers investigated in this study do not strictly meet all of the above assumptions. The aquifers are not confined, but rather, semi-confined or under water table conditions. They are limited in areal extent, so that boundary conditions may have affected aquifer tests. Glacial valley fill deposits are not homogeneous or isotropic, as an inspection of the well logs and cross-sections in this report demonstrate. The remaining assumptions were essentially satisfied during the tests.

Deviation from ideal assumptions does not preclude the use of analytical methods for determining aquifer characteristics. As noted by Kruseman and de Ridder (1979), "slight deviations are not prohibitive to the application of the methods." It is common practice to apply analytical methods to aquifer test data to arrive at an approximation of the values for transmissivity and storativity of an aquifer. One must anticipate, though, that during the course of a long term pumping program, such as for flow augmentation, effects that are not evident during the course of a 24 hour aquifer pumping test will affect long term yields. For instance, it is not possible at this time to assess the influence of the geometry of the valley fill deposits or boundary conditions, such those as created by valley walls or surface waters, upon long term sustained aquifer yields. Neither was it possible to assess the impact of a pumping program on streamflow or on existing wells.

Additional aquifer tests, streamflow studies, geophysical investigations and analytical ground water modeling would be required to refine the estimates proposed in this report.

Items which can be observed or calculated from aquifer pumping test data include:

1) aquifer transmissivity and hydraulic conductivity;
2) aquifer storativity (storage coefficient);
3) specific capacity and efficiency of test wells;
4) isotropy (or anisotropy) of the aquifer, and;
5) interference with other wells due to pumping.

Evaluation of these parameters allows the results of the aquifer test to be taken into account in decision-making processes. These decisions include the appropriate depth, spacing, areal distribution and discharge rates of production wells.

Transmissivity

Transmissivity is a physical characteristic which can be estimated for all aquifers. The transmissivity of an aquifer is a function of the hydraulic conductivity (k) of the materials composing the aquifer and the thickness of the aquifer (b). Transmissivity is usually expressed in units of gallons per day per foot (gpd/ft), but may be expressed as square feet per day (ft^2/day) or square meters per day (m^2/day) in the metric system. The higher the absolute value of transmissivity, the greater the potential instantaneous yield of the aquifer from a pumping well and the less the impact of the pumping well on surrounding wells.

Transmissivity can be calculated through the use of graphical or analytical methods. For the analyses of aquifer pumping tests performed in the buried valley aquifers, values for transmissivity were derived by the methods developed by Prickett (1965), Jacob (1963), Cooper and Jacob (1946), Theis (1935) and Theim (1906). The water supply potential of an aquifer is determined not only by its transmissivity, but also by the storage characteristics, or storativity, of the aquifer.

Storage coefficient

Storage coefficient, or storativity, is a dimensionless quantity defined as the volume of water released from or taken into storage in an aquifer per unit surface area of the aquifer per unit change in head normal to the surface. Extremely low values of storage coefficient (10^{-5} to 10^{-3}; Johnson, 1975) indicate that the ground water in the aquifer is under pressure beneath a confining or semi-confining layer. Water entering a recharge zone increases pressure on water beneath the confining sediments. That portion of the aquifer beneath the confining sediments is said to be under artesian or confined conditions. A well penetrating an artesian aquifer will allow the ground water to rise above the level of the confining layer, and in some cases above the ground surface, resulting in a flowing well.

Test well TW-3, near the Pequannock River, is a flowing well in which the static water level (or piezometric surface) of the aquifer is above ground surface. The drawdown effects of a pumping well in an artesian aquifer are rapidly distributed over a large area. Recovery of the artesian aquifer after cessation of the stress of pumping is usually rapid, since water in the aquifer is under pressure and moves rapidly to the area of diminished pressure corresponding to the pumping area.

The storativity for water table aquifers is essentially equivalent to its specific yield (S_y). Typical values are 0.01 to 0.30 (Johnson, 1975). Under water table conditions, the top of the ground water surface is open to the atmosphere through the unsaturated soil, and water is recharged directly to the aquifer from percolating precipitation. There is no extensive confining layer between the ground surface and a water table aquifer. The drawdown effects of a pumping well in a water table aquifer spread slowly from the pumping well over a relatively small area.

GLOSSARY

Aquifer: A permeable, water-bearing geologic formation capable of yielding economically significant quantities of water to wells or springs.

Aquifer pumping test: A test made by pumping a well or group of wells for a specified period of time and observing changes in hydraulic head in aquifers, confining layers, or surface water bodies.

Boundary condition: In ground water, a condition created by a lateral feature which reduces or increases recharge to an aquifer. Boundary conditions created by clay or rock tend to reduce water availability, while surface water bodies may provide additional recharge to an aquifer through induced infiltration.

Breccia: Rock composed of angular, broken fragments cemented in a fine-grained matrix.

Buried valley (channel): A former valley (channel) that has been filled with alluvial or glacial deposits.

Colluvium: Heterogeneous, unconsolidated sediment deposited primarily by mass wasting.

Confining layer: A stratum of relatively impermeable material that restricts flow of ground water to or from an adjacent aquifer. It does not yield significant amounts of water to a well or spring, but may serve as a storage unit for ground water.

Discharge area: An area in which ground water flows to the surface through springs, seeps or as baseflow to streams.

Drawdown: The change in the elevation of the piezometric surface in a well caused by withdrawal of water from that well or from another well some distance away.

Fault: A fracture or fracture zone along which there has been displacement.

Geophysical method: An indirect method to determine subsurface geologic conditions based on sound wave propagation, electrical currents, magnetic fields, gravitational attraction or radioactive characteristics.

Glacier: A mass of ice formed from the compaction and recrystallization of snow and moving due to the stress of its own weight.

Ground water: Subsurface water occupying the zone of saturation. In a strict sense the term applies only to water below the water table. Wells and springs are fed from ground water.

Head: The height of the free surface of fluid above a point in a hydraulic system. In physical terms, this corresponds to the elevation to which the water of a flowing artesian well rises in a pipe extended high enough to stop the flow.

Hydraulic conductivity: The rate of flow of water through a unit cross section of aquifer under a unit hydraulic gradient at the prevailing temperature or adjusted to a temperature of 60°F. Typical units are gallons per day per square foot (gpd/ft^2), feet per day (ft/day) or meters per day (m/day). [See, for example, Freeze and Cherry (1979, p. 26) for an explanation of the differences between hydraulic conductivity and permeability].

Hydrogeology: The branch of geology that deals with ground water occurrence, movement, replenishment, depletion and quality, as well as the properties of the rocks that control ground water movement, and the methods of groundwater investigation.

Isotropic: In hydrogeology, a condition in which the hydraulic properties of an aquifer are equal in all directions.

Observation well: A non-pumping well used to observe elevation or change in elevation of the water table or potentiometric surface.

Outwash: Stratified drift deposited by melt water streams beyond the terminus of the active glacier.

Piezometric surface: A surface representing the static head of ground water; also called potentiometric surface. Physically, this is the level to which water will rise in a well. The water table is a potentiometric surface.

Pleistocene: The earlier of the two epochs comprising the Quaternary Period, also called the glacial epoch. Pleistocene also refers to the series of sediments deposited during that epoch. The Pleistocene Epoch began about 1.5 million years ago and ended about 10,000 years ago.

Quaternary: The later of the two geologic periods of the Cenozoic ("recent life or time") Era. The Quaternary Period is subdivided into the Pleistocene and Recent (or Holocene) Epochs. It comprises geologic time from the end of the Tertiary Period, 1.5 million years ago, to the present.

Recharge area: An area in which there is infiltration of water which reaches the zone of saturation of an aquifer.

Recovery: The rise of the water levels in a pumped well or observation wells after ground water pumping has ceased.

Sedimentary: Formed by the deposition of sediments such as clay, silt, sand and gravel. Pertaining to the process of sedimentation where clay, silt, sand gravel and/or chemical precipitates are deposited by air, water or ice in a loose, unconsolidated form.

Seismograph: An instrument that records vibrations or motions of the ground surface.

Silt: A sediment composed of grains finer than sand and coarser than clay size. The size range of silt is from 1/256 to 1/16 mm in diameter.

Specific capacity: The rate of discharge of a well per unit length of drawdown. Typical units are gallons per minute per foot of drawdown (gpm/ft) or cubic meters per day per meter of drawdown (m^3/day/m).

Static level: The elevation of the water table or piezometeric surface when not influenced by pumping. Also known as static head.

Storage coefficient (Storativity): The volume of water an aquifer releases from or takes into storage per unit area for a unit change in head. It is a dimensionless quantity.

Stratified drift: Unconsolidated, sorted and layered sediment which was deposited from glacial melt waters in streams or lakes.

Till: Non-sorted, non-stratified sediments deposited directly by a glacier.

Transmissivity: The rate at which water can be transmitted through a unit width of an aquifer under a unit hydraulic gradient. It is equal to the product of the hydraulic conductivity (k) of the aquifer materials and their saturated thickness (b). Typical units are gallons per day per foot (gpd/ft) or square meters per day (m^2/day).

Unconfined aquifer: An aquifer in which the water table is the upper boundary.

Unconsolidated sediment: Sedimentary material in which grains have not become cemented together to become rock.

Watershed: The area contained within a drainage divide. The area drained by, or contributing water to, a stream.

Water table: The water level surface in an unconfined aquifer or in a confining bed in which the pore water pressure is equal to the atmospheric pressure. Roughly equivalent to the top of the zone of saturation.

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APPENDIX 1. LOCATION, FORMATION, DEPTH, PIEZOMETRIC SURFACE AND ELEVATION OF TEST WELLS

Well	Location			Formation	Total Depth (feet)	Piezometric Surface (feet)	
	Area	Latitude	Longitude			Depth from top of casing	Elevation
TW-1	1	41°03'00"	74°26'38"	Qsd	175	19.14	749.84
TW-2	1	41°02'19"	74°26'18"	Qsd/ Bedrock	155	3.63	747.05
TW-3	1	41°02'21"	74°26'16"	Qsd/ Bedrock	180	flows	
TW-4	1	41°02'27"	74°26'28"	Abandoned			
TW-5	1	41°02'08"	74°26'59"	Qsd	154	5.00	754.49
TW-6	3	41°02'52"	74°31'01"	Bedrock	280		
TW-7	4	40°55'38"	74°36'24"	Abandoned			
TW-8	1	41°02'34"	74°26'25"	Qsd	120	2.92	749.13
TW-9	4	40°55'29"	74°36'17"	Qsd	115	13.00**	714.49
TW-10	5	40°54'17"	74°36'45"	Qsd	125	7.83***	689.79
TW-11	1	41°02'18"	74°26'11"	Abandoned			
TW-12	1	41°02'26"	74°26'24"	Bedrock	300	4.60	747.93
DEP-1	1	41°02'35"	74°26'26"	Qsd	157	2.63	748.23
DEP-2	2	41°02'49"	74°25'49"	Abandoned			

* 12/82
**5/16/81
***5/29/81

Qsd - stratified drift

Location, formation, depth and piezometric surface of test wells.

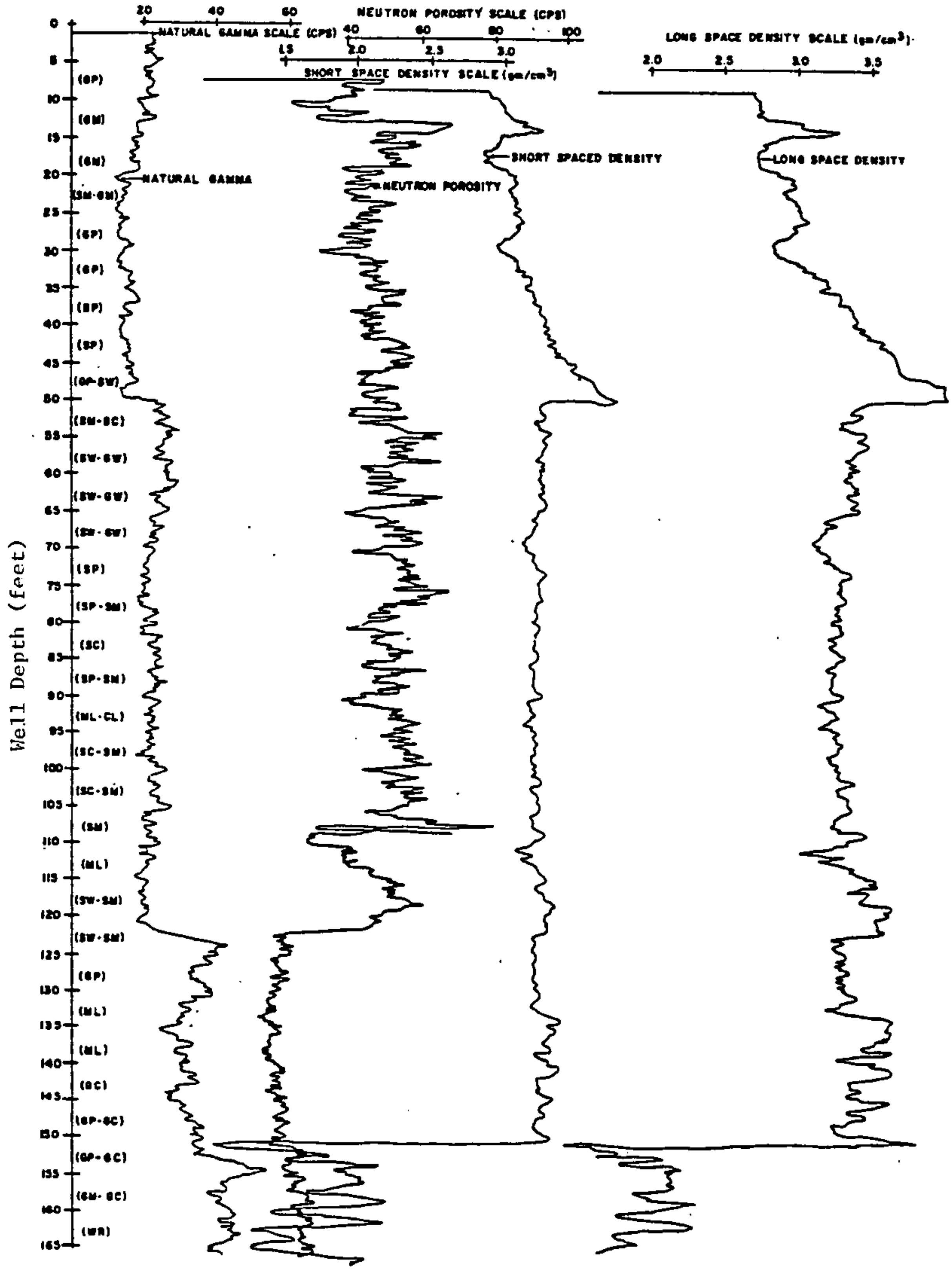
Well	Well Elevations (feet)				Bedrock Elevation (feet)
	Ground	Top of Casing	Screen(s) (top-bottom)	Bottom	
TW-1	767.19	768.98	742.8-676.8	594	641
TW-2	748.95	750.68	670.7-660.7	596	641
TW-3	749.73	750.48	690.5-640.5 620.5-580.5	570	647
TW-4	Abandoned				
TW-5	757.29	759.49	679.5-639.5	605	640
TW-6	880±	881.7±	681.7-601.7	601	861
TW-7	Abandoned				
TW-8	750.43	752.05	702.0-682.0	632	672
TW-9	725.64	727.49	649.5-629.5	595	625
TW-10	695.51	697.63	627.6-607.6	573	595
TW-11	Abandoned				
TW-12	749.50	752.53	none	450	628
DEP-1	750.33	750.86	691.4-671.4	596	640
DEP-2	Abandoned				

Test well elevations.

APPENDIX 2. GEOPHYSICAL AND GEOLOGIC LOGS OF TEST WELLS

Symbol	Description
(GW)	Well-graded gravels and gravel-sand mixtures, little or no fines
(GP)	Poorly graded gravels and gravel-sand mixtures, little or no fines
(GM)	Silty gravels, gravel-sand-silt mixtures
(GC)	Clayey gravels, gravel-sand-clay mixtures
(SW)	Well-graded sands and gravelly sands, little or no fines
(SP)	Poorly graded sands and gravelly sands, little or no fines
(SM)	Silty sands, sand-silt mixtures
(SC)	Clayey sands, sand-clay mixtures
(ML)	Inorganic silts, very fine sands, rock flour, silty or clayey fine sands
(CL)	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, lean clays
(OL)	Organic silts and organic silty clays of low plasticity
(MH)	Inorganic silts, micaceous or diatomaceous fine sands or silts, elastic silts
(CH)	Inorganic clays of high plasticity, fat clays
(OH)	Organic clays of medium to high plasticity
(PT)	Peat, muck, and other highly organic soils

Explanation of well sample abbreviations shown with geologic and geophysical logs.
(from: ASTM Soil Classification)



Geophysical logs of Test Well TW-1.

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LOG OF BORING TW-1 SHEET 1 OF 6

PROJECT AND LOCATION: Buried Valley Study - Morris County	ELEVATION AND DATUM: 768.98'	PROJECT NO.
DRILLING AGENCY: NJDEP -	DATE STARTED: March 16, 1981	DATE FINISHED: -
DRILLING EQUIPMENT: Air Rotary	COMPLETION DEPTH: 175'	ROCK DEPTH: 127'
CASING 12"(50') to 6"	WATER LEVEL: 19.3'	
CASING HAMMER / WEIGHT / DROP		
SAMPLER		
SAMPLER HAMMER / WEIGHT / DROP		

LOG OF BORING

DEPTH IN FEET	DESCRIPTION	REMARKS
5	Brown, moist, f-m sand, with some coarse sand, trace to some gravel and trace of silt and organic frags. (GP)	
10	Tannish-brown, wet, f-c sandy f-m gravel, with a trace to some silt. (GM)	
15	Brownish-gray, wet, f-c sandy f-m gravel, with a trace to some silt. (GM)	
20	Brown, wet, f-c sandy f-c gravel, with some silt. (SM-GM)	
25	Brown, moist, f-c sandy f gravel, with a trace of silt. (GP)	
30	Brown, moist, f-c sandy f-m gravel, with a trace of silt. (GP)	

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LOG OF BORING TW-1 SHEET 2 OF 5

LOG OF BORING

	DESCRIPTION	REMARKS
35	Brown, wet, f-m sand with some c. sand and f-m gravel, trace silt and clay. (SP)	
40	Brown, wet, f-m sand, with some c. sand and occ f-m gravel, trace silt and clay. (SP)	
45	Brown, wet, f-m gravely f-c sand, trace silt and clay. (GP-BW)	
50	Brown, wet, f-c sand, with some f-m gravel and a trace to some silt and clay. (SM-SC)	
55	Brown, wet, f-c sandy, f-c gravel, with a trace of silt. (SW-GW)	
60	Brown, wet f-c sandy, f-c gravel, with a trace of silt. (SW-GW)	
65	Brown, wet, f-c, sandy, f-c gravel with a trace of silt. (SW-GW)	
70	Brown, wet f-m sand, with occ c. sand and f gravel, with a trace of silt and clay. (SP)	
75	Brown, wet f sand, with a trace to some silt and clay. (SP-SM)	

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LOG OF BORING TW-1 SHEET 3 OF 5

Depth, ft	Log of Boring — Description	Remarks
80	Brown, wet, clayey f. sand, with a trace to some silt and occ. m-c sand of gravel. (SC)	
85	Brown, wet, f-m. sand and a trace to some silt and clay. (SP-SM)	
90	Brown, wet, f. sandy silt and clay. (ML-CL)	
95	Brown, wet, f-m. sand, some silt and clay. (SC-SM)	
100	Brown, wet, f-m. sand, some silt and clay. (SC-SM)	
105	Brown, wet, silty, vf. sand (SM)	
110	Brown, wet vf. sandy silt with occ f. gravel and m-c. sand. (ML)	
115	Brown, wet, f-c. sand, with some f-c gravel and a trace to some silt and clay. (SW-SM)	
120	Brown, wet, f-m. gravely f-c. sand with a trace to some silt and clay.	

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LOG OF BORING TW-1 SHEET 4 OF 5

LOG OF BORING

Depth, ft	DESCRIPTION	REMARKS
125	Brown, wet, f-c. sandy, f-m gravel, with occ. c. gravel and trace silt. (GP)	Distinct color change at 127' along with dryness - possible decomposed rock.
130	Tannish-yellow, dry, silt with occ. clay balls. (ML)	
135	Orangey-yellow, dry, silt with occ. clay balls. (ML)	
140	Brown, moist, f-c. sandy f. gravel with some clay. (GC)	
145	Brown, moist, f-c. sandy f. gravel with a trace to some clay. (GP-GC)	
150	Brown, moist, f-c. sandy f. gravel with a trace of some clay. (GP-GC)	
155	Tannish Brown, wet, f-c. sandy f. gravel, some silt and clay, occ. m gravel. (GM-GC)	Changed from highly weathered to partially weathered after 160' - as seen by drilling rate.
160	Tannish Brown, wet, f-c. sandy f. gravel, some silt and clay, occ. m gravel.	
165	Rock chips of c. sand to m. gravel size, weathered.	

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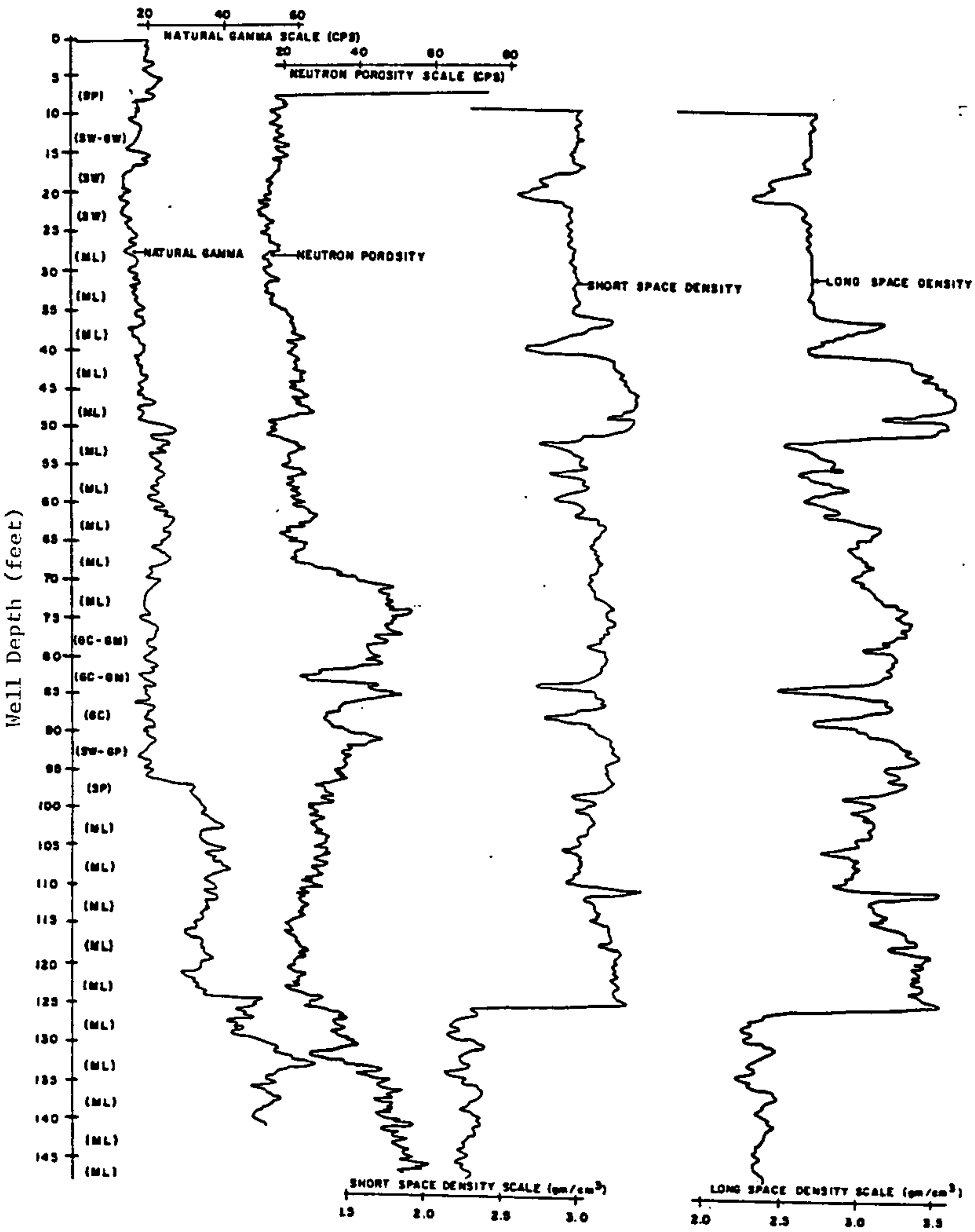
LOG OF BORING TW-1 SHEET 5 OF 5

Depth, ft	LOG OF BORING: Description	Remarks
170	Rock chips, partially weathered.	
175	Rock chips, partially weathered. Bottom of hole.	Hole ended in partially weathered rock.
180		



Geophysical logs of Test Well TW-2.

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LOG OF BORING TW-2 SHEET 1 OF 3

Buried Valley Study - Morris County			750.68'	
NJDEP			March 16, 1981	March 19, 1981
Air Rotary			155'	97'
CASING 12"(50') to 6"			3.5'	
CASING HAMMER	WEIGHT	DROP		
SAMPLER				
SAMPLER HAMMER	WEIGHT	DROP		

LOG OF BORING

DEPTH FT	DESCRIPTION	REMARKS
5	Gray, moist, f-m.gravely f-c. sand with a trace of silt and clay (SP)	
10	Gray, wet f-c. sandy f-c.gravel with a trace of silt and clay (SW - GW)	
15	Gray, wet, f-m. gravely f-c. sand with a trace of silt (SW)	
20	Gray, wet, f-m. gravely f-c. sand with a trace of silt (SW)	
25	Gray, wet silt, trace to some, f-c. sand (ML)	
30	Gray, wet, silt, trace to some f-c. sand (ML)	
35	Gray, wet, silt, trace to some f-c. sand (ML)	
40	Gray, wet, silt, trace to some f-c. sand (ML)	
45	Gray, wet, silt, tract to some f-c. sand (ML)	
50	Gray, wet, vf. sand silt (ML)	
55	Gray, wet, vf. sand silt (ML)	

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LOG OF BORING TW-2 SHEET 2 OF 3

Depth, ft	Description	Remarks
60	Gray, wet, silt, some vf. sand (ML)	probably wet due to flushing 10" casing.
65	Gray, wet, silt, some f-c. sand (ML)	
70	Gray, wet, silt, some f-c. sand (ML)	
75	Gray, wet, f-m. gravel, some clay & silt with a trace of f-c. sand (GC-GM)	
80	Gray, wet, f-c, sandy f-m. gravel, with some clay and silt (GC-GM)	
85	Gray, wet, clayey f-m. gravel, with some f-c. sand (GC)	
90	Gray, moist, f-m. gravely f-c. sand with a trace of silt and clay (SW-GP)	
95	Gray, moist to wet, g-m. sand, some coarse sand and trace f-m gravel & silt. (SP)	New water Zone at ± 95.0"
100	Tan-white, dry, silt, with a trace to some f-c. sand & f gravel (ML)	Dry from ± 97' probably badly decomposed rock
105	Tan-Gray, dry, silt with a trace to some f-c. sand & f. gravel (ML)	
110	Gray, dry, silt with some clay balls and a trace of f-m. sand (ML)	Sand occurs in layers in silt
115	Gray, dry, silt, with a trace of vf. sand (ML)	
120	Gray, dry, silt, with a layer of tan, dry clay with trace of f. sand (ML)	
125	Gray, tan, reddish-brown and brown silt, with a trace of f-c. sand (ML)	Layered
130	Tan and brown, dry, silt, with a trace of clay balls (ML)	Clay balls
135	Gray, tan, red, brown, dry, silt, with a trace of clay and a trace of f. gravel (ML)	Pebbles-rounded

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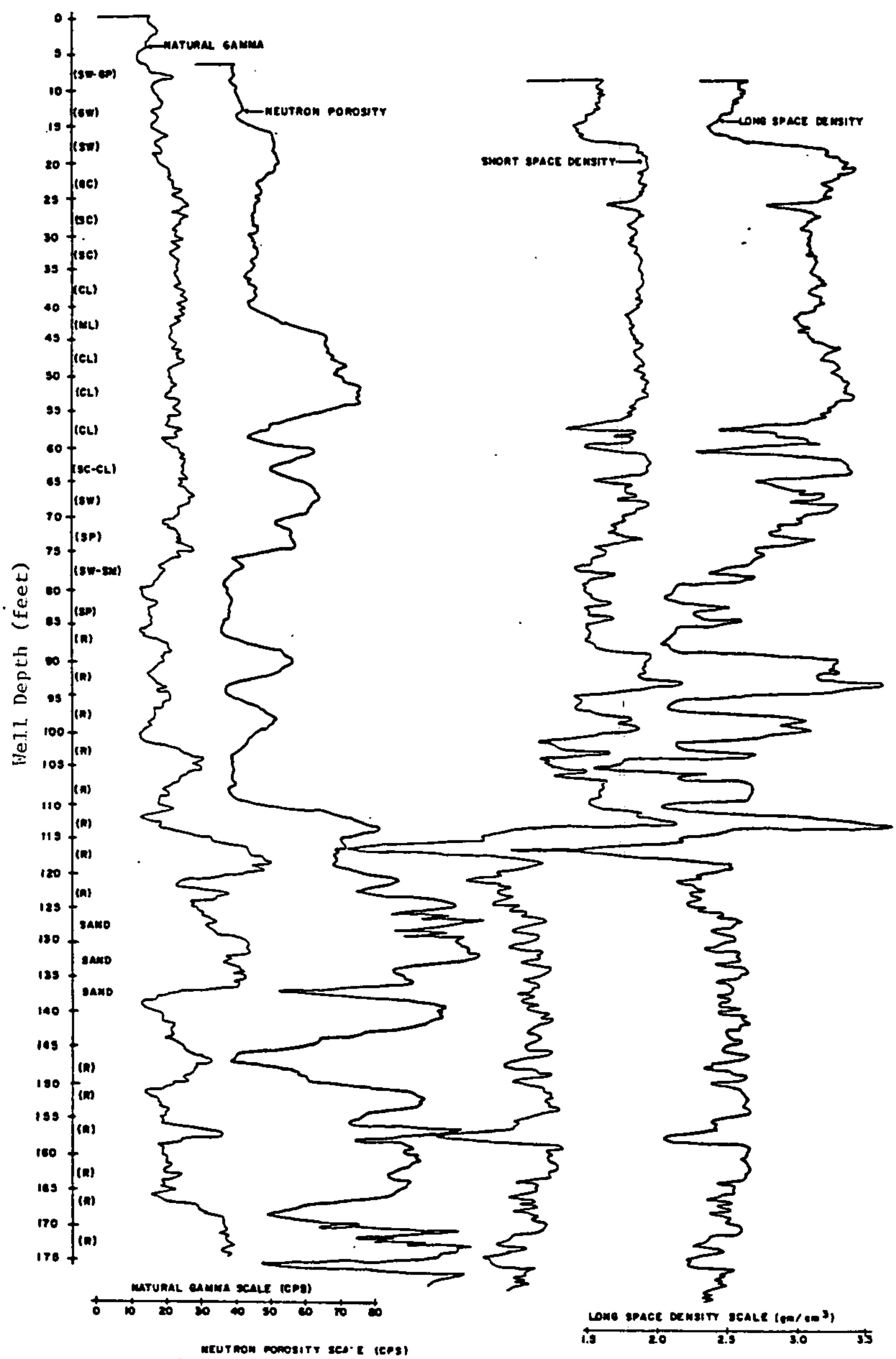
LOG OF BORING TW-2 SHEET 1 OF 3

LOG OF BORING

DEPTH, FT	DESCRIPTION	REMARKS
140	Gray, dry, silt	
145	Gray, dry, silt, with occ. rock of fragments	Rock decomposition decreasing
150	Gray, dry, silt, with occ. rock fragments (ML)	
155	Bottom of hole	
160		



Geophysical logs of Test Well TW-3.

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LOG OF BORING TW-3 SHEET 1 OF 5

Buried Valley Study - Morris Co.	750.48'	TW-3
N.J.D.E.P.	3/20/80	
Air Rotary	180	85'
CASING 12"(50') to 6"		
CASING HAMMER / WEIGHT / DROP	1.6'	
SAMPLER		
SAMPLER HAMMER / WEIGHT / DROP		

LOG OF BORING

DEPTH FT.	DESCRIPTION	REMARKS
5	Brown, moist, f:c. sandy f:m. gravel, occ. c. gravel and a trace of silt (SW-GP)	
10	Brown & gray, moist, f.c. gravel, some f-c. sand, a tract silt (GW)	
15	Gray, moist, f-m. rounded gravely f-c. sand, with a trace of silt (sw)	
20	Gray, wet, f-c. sandy f-c. gravel, some clay (GC)	
25	Gray, wet, clayey f-c. sand, occ f-m rounded gravel (SC)	
30	Gray, wet, clayey f-c. sand, occ f-m rounded gravel (SC)	

LOG OF BORING TW-3 SHEET 2 OF 5

LOG OF BORING TW 3

DEPTH, FT	DESCRIPTION	REMARKS
35	Gray, wet, clay, with some f.-c. sand and occ. f.-m. rounded gravel (CL)	
40	Gray, wet, silt, with a trace to some f.-c. sand and occ f.-m. rounded gravel (ML)	
45	Gray, wet, clay, with some silt, and a trace to some f.-c. sand, occ f.-m. rounded gravel (CL)	
50	Gray, wet, clay, with a trace of f.-c. sand & f. gravel (CL)	
55	Gray, wet, clay, with some f. gravel and a trace to some f.-c. sand (CL)	
60	Gray, moist to wet, f.-c. sandy clay, with some f. gravel and occ. rounded m. gravel (SC-CL)	Drilling hard at 62' (top of sand and gravel)
65	Grayish-brown, dry to moist f. gravely f.-c. sand, with occ. m. gravel & trace silt (SW)	
70	Reddish-brown, moist to dry f. sand & f.-m. gravel with occ. c. gravel & trace silt (SP)	73.5' started getting wet
75	Brown, wet, f.-c. sand, with some f.-m. gravel and trace to some silt (SW-SM)	

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LOG OF BORING TW-3 SHEET 3 OF 5

LOG OF BORING TW-3

Casing Blows	Blows/ft	Depth, ft	No. & Loc.	Type	Recov. ft	Penetra. Resist. Blows/6 in	Description	Remarks
		80					Grayish-Brown, wet, f-m. gravel, with some f-c. sand and a tract of silt & clay (SP)	
		85					Top of rock, weathered, hammered to yellow, m Brown, wet, silty, f-c. sand, trace to some subangular f-m. gravel of qtz. & s.s. frag.	return changed to yellow-brown at 85' probably top of weathered rock.
		90					Rock-weathered, hammered to yellow, wet f-c. sand, some angular f. gravel, occ. m. angular gravel of Qtz. & s.s. fragments	
		95					Rock-weathered, hammered to yellow, wet f-c sand, some angular f. gravel, occ. m angular gravel of Qtz. & s.s fragments	
		100					Rock-weathered, hammered to yellow, wet f-c. sand, some angular f. gravel, occ. angular m. gravel of Qtz. & s.s fragments	
		105					Rock-weathered, hammered to yellow, wet angular f. gravely f-c. sand, with occ. angular m gravel of s.s. & Qtz fragments	
		110					Rock-weathered, hammered to yellow, wet angular f. gravely f-c. sand, with occ. angular m gravel of s.s. & Qtz. fragments	Drillings hard at 113' slight color change probably change to partially weathered rock or a new formation
		115					Rock, partially weathered, hammered to yellow-brown, wet, f.c sand some angular f. gravel & occ. angular m. gravel of s.s.	
		120					same as above	

LOG OF BORING TW-3 SHEET 4 OF 5

LOG OF BORING TW 3

Depth	Description	Remarks
125	Brown, wet, f-c sand, with some angular f gravel & occ. angular c gravel of s.s. and shale	Drilling very hard at 125.5' probably on weathered rock
130	Brown, wet, f. angular gravel f-c sand, with occ. angular M gravel	
135	Brown, wet, f-c sand, with some angular f. Gravel frags. & occ. c gravel frags.	
140	Broken s.s. & Qtz.	
145	Rock-broken to Brown, wet f-c sand, with some angular f. gravel of Qtz., s.s., and shale (dolomite?)	
150	Rock-hammered to light brown, wet, f-m sand with some c sand, and angular f. gravel consisting of Qtz., s.s. and shale fragments.	
155	Rock-hammered to light Brown wet, f-c sand with some f angular c gravel of Qtz., s.s., and l.s./dol fragments.	
160	Rock-hammered to light brown, wet, f-m sand, with some c sand & occ. f. gravel of qtz and dolo frags.	
165	Rock-hammered to light brown, wet, f-m sand, with some c sand & occ. f. gravel of qtz and dolo frags.	soft zone at 165' for 2"-4" Wash turned darker at 166'

All move up 5'

Note: s.s. is probably washing off the sides from higher up the hole

LOG OF BORING TW-3 SHEET 5 OF 5

DEPTH, FT	LOG OF BORING — DESCRIPTION	REMARKS
170	Rock-hammered to brown, wet, f-m sand, with some c sand & occ f. gravel of Qtz. s.s. & dolo frags	
175	Rock-hammered to gray, wet f-c. sand with some f. gravel & occ. m-c. gravel of Qtz., dol., & s.s. - possible chert nodules	
180	Rock-hammered to gray- brownwet, f-c. sand with some angular f. gravel and occ. angular m-c gravel with Qtz., dol., s.s.	
	Bottom of hole - 180'	

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LOG OF BORING TW-4 SHEET 1 OF 3

Buried Valley Study-Morris Co.		± 750'	TW 4
N.J.D.E.P.		4/7/81	4/14/81
Air Rotary		130'	110'
CASING 12"(50') to 6"		3'	12' / 12'
CASING HAMMER	WEIGHT	DROP	
SAMPLER			
SAMPLER HAMMER	WEIGHT	DROP	

LOG OF BORING

Depth ft	Description	Remarks
0		No samples taken in the upper 15' due to problems with the hole caving
20	Gray, wet, f.-c. gravel, with a trace to some f.-c. sand and clay (G-C)	All 10" and 6" casing was pulled out on this hole, & no screen installed
25	Gray, wet, silty f. sand, with a trace of m-c sand & occ. f.-m. gravel (SM)	
30	Gray, wet, silty & clayey f. sand, with a trace of m.-c. sand and occ. f.-m. gravel (SM-SC)	
35	Gray, wet, silt & clay, with some f.-c. sand, occ. f. gravel (ML-CL)	
40	Gray, wet, clayey silt, with some f.-c. sand, & occ. f. gravel (CL-ML)	
45	Gray, wet, silty clay, with some f.-c. sand, and occ f. gravel (ML-CL)	

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LOG OF BORING TW-4 SHEET 2 OF 3

LOG OF BORING TW 4

Depth, ft	Description	Remarks
50	Gray, wet, clay, with a trace of f. sand (CL)	
55	Gray, wet clay (CL)	
60	Gray, wet clay, with a trace to some f.-c. sand, and occ. f. gravel (CL)	
65	Gray, wet, clayey f. sand with a trace to some m-c sand & occ. f. gravel (SC)	
70	Gray, wet, f.-m. sand, with trace to some c. sand (SP)	Casing going down very hard from 70' - tight
75	Gray, wet f.-m. gravely f.-c. sand, with occ. c. gravel (GP-SW)	
80	Gray, wet f.-m. gravely f.-c. sand, with occ. gravel (GP-SW)	silt coming up in wash from 70' down
85	Gray, wet f.-c. sand, some f.-m. gravel (SW)	
90	Gray, wet f.-m. gravel, some f.-c. sand & trace silt (GP)	

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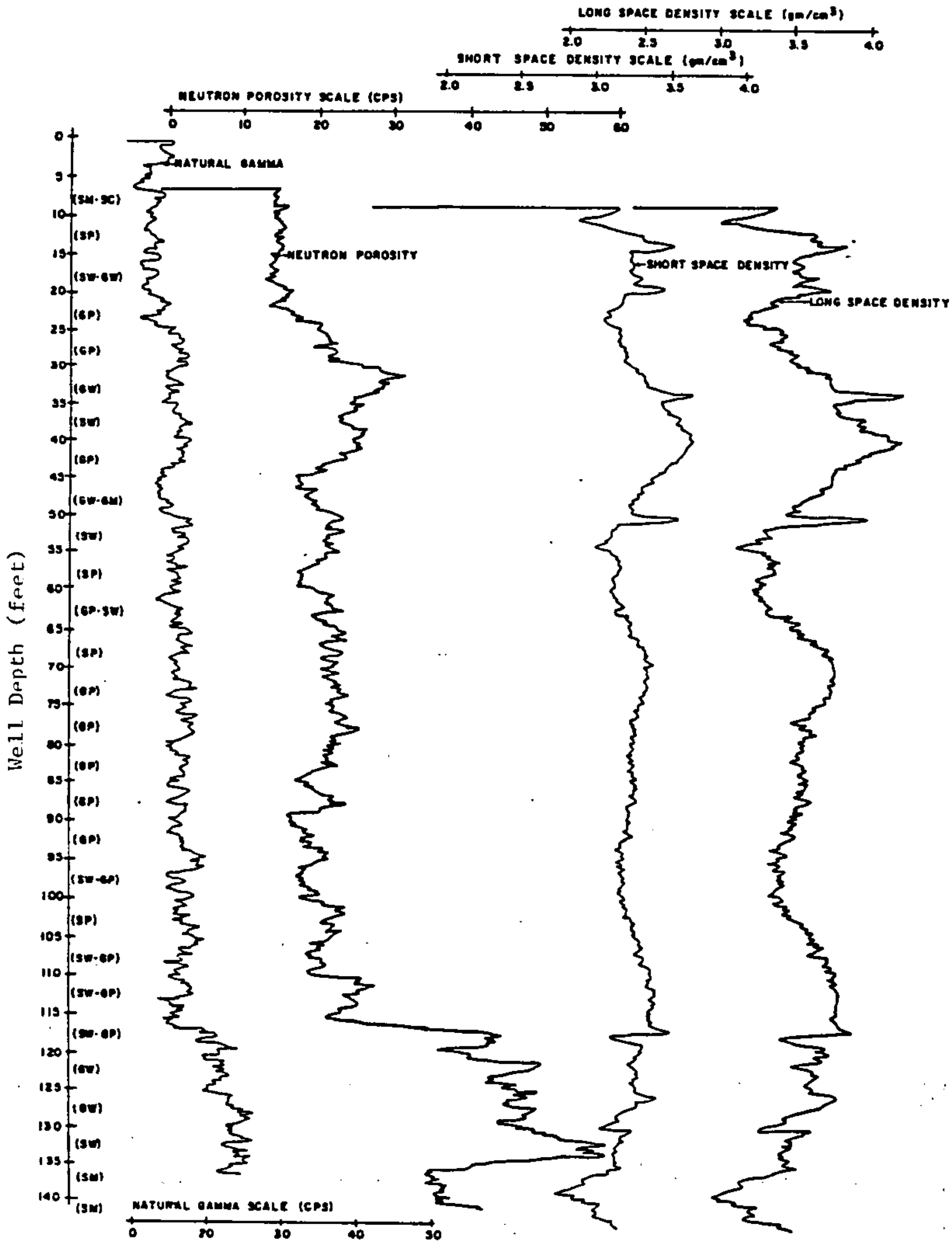
LOG OF BORING TW-4 SHEET 3 OF 3

LOG OF BORING TW 4

Depth (ft)	Description	Remarks
95	Gray, wet f.-m. Gravel, some f.-c. sand & trace silt (GP)	
100	Gray, wet f.-c. sand, some f.-m. gravel & trace silt (SW)	
105	Gray, wet f.-c. sandy f.-m. rounded Gravel, with occ. c. gravel & trace silt (GP)	
110	Rock, dry, charcoal gray powder	Top of rock 110' water changed color below 110'
115	Mixture of rock & glacial	
120	Mixture of rock & glacial	Casing to 100' ± for 115' & 120' samples
125		
130	Well terminated and abandoned at 130 ft.	



Geophysical logs of Test Well TW-5.

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LOG OF BORING TW-5 SHEET 1 OF 3

Buried Valley Study - Morris Co.		759.49'	
N.J. DEP		4/7/81	4/24/81
Air Rotary		154'	120
CASING 12" (50') to 6"			+ 12'
CASING HAMMER	WEIGHT	DROP	
SAMPLER			
SAMPLER HAMMER	WEIGHT	DROP	

LOG OF BORING

DEPTH	DESCRIPTION	REMARKS
		10" - 8'10", 19' 3" 8" - 20'1", 20'1", 20'1", 20'1"
5	light brown, dry to moist, f-c. sand, some f-m. gravel and with root fragments. (SM-SC)	screen-set from 80' - 120'
10	light brown, moist, f. sand trace to some m. sand (SP)	
15	brown, wet, f-c. rounded graveley f-c. sand, with occ. f. cobbles (SW-GW)	
20	Gray, wet f. rounded gravel with some f-c. sand and occ. m. gravel (GP)	
25	Gray, wet, f-m. rounded gravel, some f-c. sand, lenses of trace silt and clay. (GP)	
30	Gray, wet, f-c. rounded gravel, with some f-c. sand (GW)	
35	Gray, wet f. gravely f-c. sand with occ. m. gravel trace silt (SW)	
40	Gray, wet, f-c sandy f-m. gravel with occ. c gravel, trace silt. (GP)	
45	Gray, moist to wet, f-c. sandy f-c gravel, with a trace to some silt. (GW-GM)	
50	Gray, wet, f-m. gravely f-c sand, trace silt. (SW)	
55	Gray, wet f. sand, some m-c. sand & f. gravel, occ. m gravel, trace silt. (SP)	

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LOG OF BORING TW-5 SHEET 2 OF 3

Depth, ft	Description	Remarks
60	Gray, wet f-m. gravely f-c. sand, trace silt. (GP-SW)	
65	Gray, wet f-m. sand, some c. sand, occ. f. gravel (SP)	6" casing drove hard from 65'-80'
70	Gray, wet f-c. sandy f-m. rounded gravel, trace silt (GP)	
75	Gray, moist to wet, f-m. gravel, some f-c. sand & trace silt (GP)	Probably moist due to driving casing
80	Gray, wet f-c. sandy rounded f-m. gravel with trace silt. (GP)	Making 10-15 gpm f-m gravel at 80'
85	Gray, wet f-m. gravel, some f-c. sand and trace silt (GP).	
90	Gray wet, f-m. gravel, some f-c. sand and trace silt (GP).	
95	Gray, wet f-c. sandy f.m. rounded gravel with trace silt (SW-GP).	
100	Gray, wet f-m. sand, trace to some c. sand, occ. f. gravel & trace silt. (SP)	
105	Gray, wet f-c. sandy f-m gravel, trace silt. (SW-GP)	
110	Gray, wet f-c. sandy f-m. rounded gravel, trace silt (GW-GP)	
115	Gray, wet f-c. sandy f-m. rounded gravel, trace silt. (SW-GP)	Boulder 118'-121'
120	Gray, wet f-c. gravel, some f-c. sand, trace silt. (GW)	
125	Gray moist f-c. sandy f-c. gravel, trace silt.	Dense material from 125' to bottom of hole- moist, not wet due to 6" casing
130	Gray, wet f-m. gravely f-c. sand, occ. c. gravel, trace silt. (SW)	Blowing 50 gpm with hole to 132' Casing to 127' and blowing from 121'.
135	Gray, wet f-c. sand, some f. gravel occ. m gravel, trace to some silt & clay (SP)	Not making water with hole to 135' and casing to ± 130'

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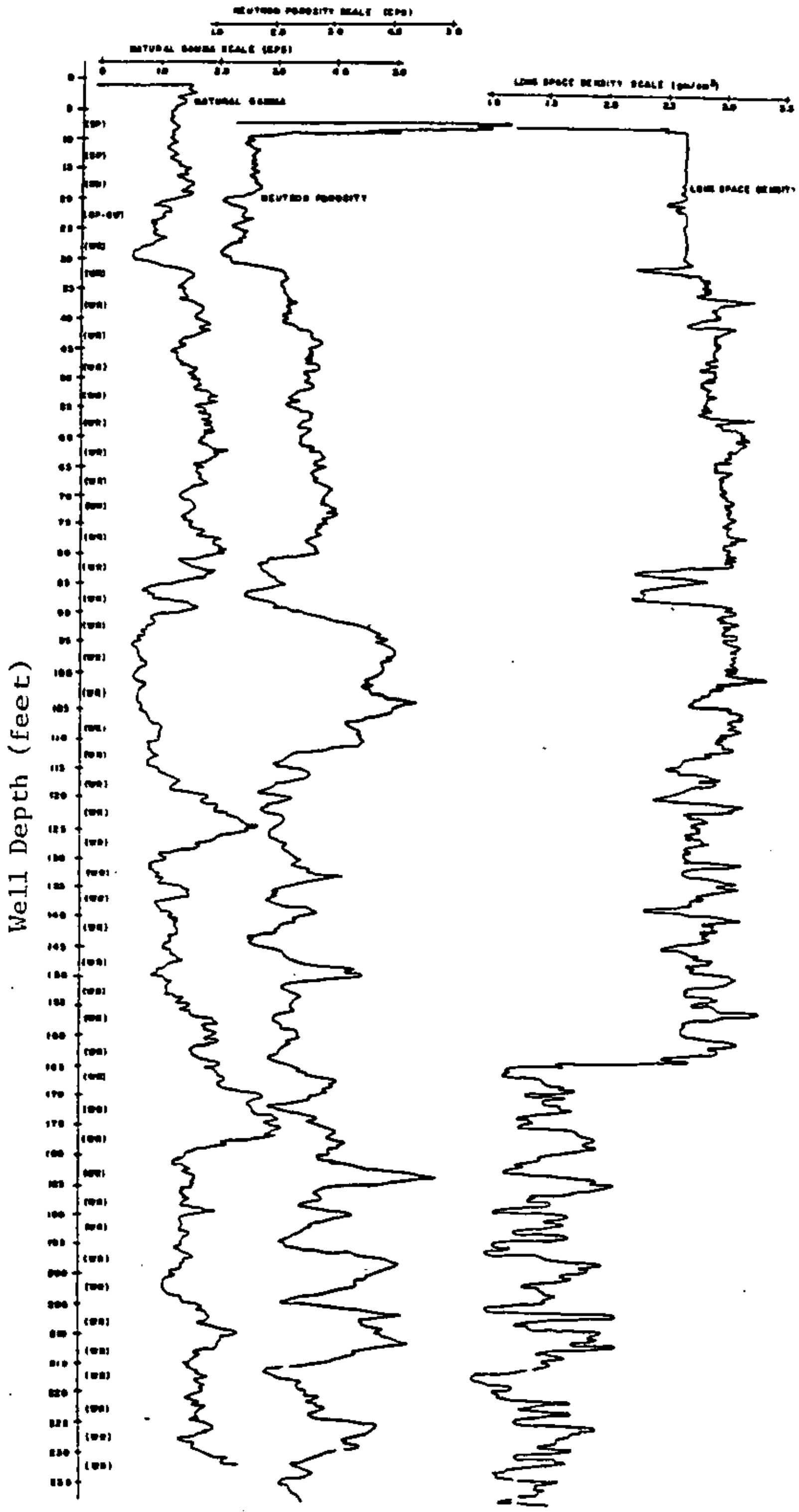
LOG OF BORING TW-5 SHEET 3 OF 3

Depth, ft	LOG OF BORING — DESCRIPTION	REMARKS
140	Gray moist f-m. sand, some c. sand, occ. f. gravel, some silt. (SM)	
145	Gray, wet f-m. sand, some c sand occ. f. gravel, trace to some silt. (SM)	
150	Gray, moist, f-c. sand, some f-m. gravel, trace silt. (SW)	
	Top of rock at 153'-hole completed to 154'.	color change to tannish-yellow powder at 153', water at 154'



Geophysical logs of Test Well TW-6.

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LOG OF BORING TW-6 SHEET 1 OF 4

Project and location: Buried Valley Study - Morris County	Elevation and datum: 860'
Drilling agency: N.J. D.E.P.	Date started: 4/9/81
Drilling equipment: Air Rotary	Completion depth: 280' — 20'
CASING 12" (50') to 6"	Water level: 7.8'
CASING HAMMER / WEIGHT / DROP	
SAMPLER	
SAMPLER HAMMER / WEIGHT / DROP	

Depth ft.	DESCRIPTION	REMARKS
5	Brownish orange, wet f-m. sand, with a trace to some c. sand & occ. f. gravel (SP)	
10	Brownish orange, wet f-m sand, trace to some c. sand, occ. rounded f. gravel (SP)	
15	Brownish orange, wet f-c. sand with occ. rounded f. gravel (SW)	
20	Brownish orange, wet f-m. rounded gravely f-c. sand, trace to some clay and root frags. (GP-SW)	Sample return changed to decomposed rock just below 20'
25	Rock, orange, wet, highly weathered consisting of clay, sand, and angular gravel sized material.	
30	Rock, orange, wet, highly weathered (BDR)* consisting of clay, sand and angular gravel sized material	*Badly decomposed rock
35	Rock orange, wet, high weathered (BDR) consisting of clay, sand and angular gravel-sized material.	
40	Rock, orange, wet (BDR)* consisting of clay, sand and angular gravel sized material.	*Badly decomposed rock
45	Rock, orange, wet, BDR consisting of clay, sand and angular gravel-sized material.	
50	Rock, orange, wet BDR consisting of clay, sand and angular gravel-sized material	Started drilling harder at 51'
55	Rock, orange, dry to slightly moist, consisting of clay, silt and f-c. sand sized material.	Started drilling hard at 56'
60	Rock weathered and hammered to tan, wet, clayey f. sand.	Slight color change at 63'
65	Rock, weathered and hammered, tan, wet, clayey f-m. sand.	Color changed at 68'

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LOG OF BORING TW-6 SHEET 2 OF 4

LOG OF BORING

Casing Blows	Depth, Ft	No. Loc.	Type	Recov. Ft	Penetra. Resist. Bl/6in	Description	Remarks
	70					Rock, weathered and hammered to reddish and yellow-brown, dry, powder	Some chips at 70'
	75					Rock, weathered and hammered, to tan, dry, powder and a trace to some f-m. sand.	water at 77', dry again at 78'
	80					Rock, tan, dry, powder	very dry at 82'
	85					Rock,weathered and hammered to reddish-yellow brown, dry, powder	changed to mostly rock chips and moist to wet at 86'
	90					Rock, weathered and hammered to yellowish-brown, wet angular f. gravely f-c. sand and occ. angular m. gravel.	
	95					Rock weathered and hammered to yellowish-brown, wet angular f-m. gravely f-c. sand, some clay.	
	100					Rock, weathered & hammered to yellowish-brown, wet f-c. sandy angular f-c. gravel	
	105					Rock, weathered and hammered to yellowish-brown, wet f-c. sandy angular f-c. gravel.	
	110					Rock, weathered & hammered to tan wet f-c. sand with some f-m. angular gravel.	
	115					Rock, weathered & hammered to grayish/yellow-brown f-m. angular, gravely f-c. sand, some clay.	
	120					Rock, weathered & hammered to reddish-brown, f. sand, some m-c. sand and occ. f-angular gravel.	Hole & Bit at 120' with casing to 105.5' glowing 15-20 gpm
	125					Rock, weathered & hammered to yellowish-brown f. sand, some m-c. sand, occ. c gravel - of qtz.	
	130					Rock, weathered & hammered, to yeallowish-brown f-m sand some c. sand, occ. c. gravel & qtz.	Blowing ± 208 gpm
	135					Rock, weathered & hammered, to yellowish-brown f-c. sandy f. gravel, occ. m. gravel, trace to some clay.	
	140					Rock, weathered & hammered, to yellowish-brown f-c. sand, f. gravel, occ. m gravel, trace to some clay	

LOG OF BORING TW-6 SHEET 3 OF 4

DEPTH, FT	DESCRIPTION	REMARKS
145	Rock, weathered & hammered to yellowish-brown, f.-c. sandy f.-m. gravel.	washed clear
150	Rock, weathered & hammered to yellowish-brown f.-c. sandy f.-m. gravel	blowing ± 205 gpm
155	Rock, weathered & hammered to yellowish-brown, f.-c. sandy f.-m. gravel, trace to some clay	All samples below 160' were washed up out of an open hole & are probably a mixture
160	Rock, weathered & hammered to yellowish-brown f.-c. sand, occ. f.-m. gravel, some clay.	
165	Rock, weathered & hammered to yellowish-brown, f.-c. sand, occ. f.-m. gravel, some clay.	Highly weathered
170	Rock, weathered & hammered to tannish-brown, f.-m. gravely f.-c. sand, some clay.	
175	Rock, weathered & hammered to yellowish-brown, f.-m. gravely f.-c. sand trace to some clay, qtz. frags.	Highly weathered
180	Rock, weathered & hammered to grayish yellow-brown, m.-c. sand and occ. from gravel, trace to some clay with Qtz. frags.	
185	Rock, weathered to yellowish brown f.-c. sand, f.-m. gravel, occ. clay, with angular frags. of sugary Qtz.	
190	Rock, weathered to yellowish-brown f.-c. sand, f.-m. gravel, occ. clay with angular frags. of sugary Qtz.	
195	Rock, weathered & hammered to yellowish-brown, f.-c. sandy f.-m. angular gravel, gravel - Qtz - Opaques	
200	Rock, weathered & hammered to yellowish-brown, f.-c. sandy f.-m. angular gravel - qtz. - Opaques.	Moderately weathered
205	Rock, weathered & hammered to yellowish-brown, f.-c. sandy angular f. gravel, occ. m. gravel	
210	Rock, weathered & hammered to yellowish-brown, f.-c. sandy angular f. gravel occ. m. gravel.	

LOG OF BORING TW-6 SHEET 4 OF 4

Depth, ft	Description	Remarks
215	Rock, weathered & hammered to yellowish-brown, f-c. sandy angular f. gravel, occ. m. gravel	
220	Rock, weathered & hammered to yellowish-brown f-c.sand angular f. gravel, occ. m-gravel	
225	Rock, weathered & hammered to yellowish-brown, f-c. sandy angular f. gravel, occ. m gravel	
230	Rock, weathered & hammered to yellowish-brown, f-c. sandy angular f. gravel	
235	Rock, weathered & hammered to yellowish-brown, f-c. sandy angular f-m. gravel, consisting of qtz., Opaques, and feldspar.	
240	Rock, weathered & hammered to yellowish-brown f-c. sandy, angular f-m. gravel consisting of qtz., opaque, feldspar?	
245	Rock, weathered & hammered to yellowish-brown, f-c, sandy angular f-m gravel, of qtz., opaques, feldspar	
250	Rock, weathered & hammered to yellowish-brown, f-c. sandy angular f. gravel, occ. m-gravel, consisting of qtz. occ. opaques, and feldspar.	
255	Rock, hammered to orange-brown, with angular f. gravely f-c. sand	silt and clay in wash water blowing at gpm with hole at 257
260	Samples from 260' to 280' taken	
280	Bottom of Hole - 280'	

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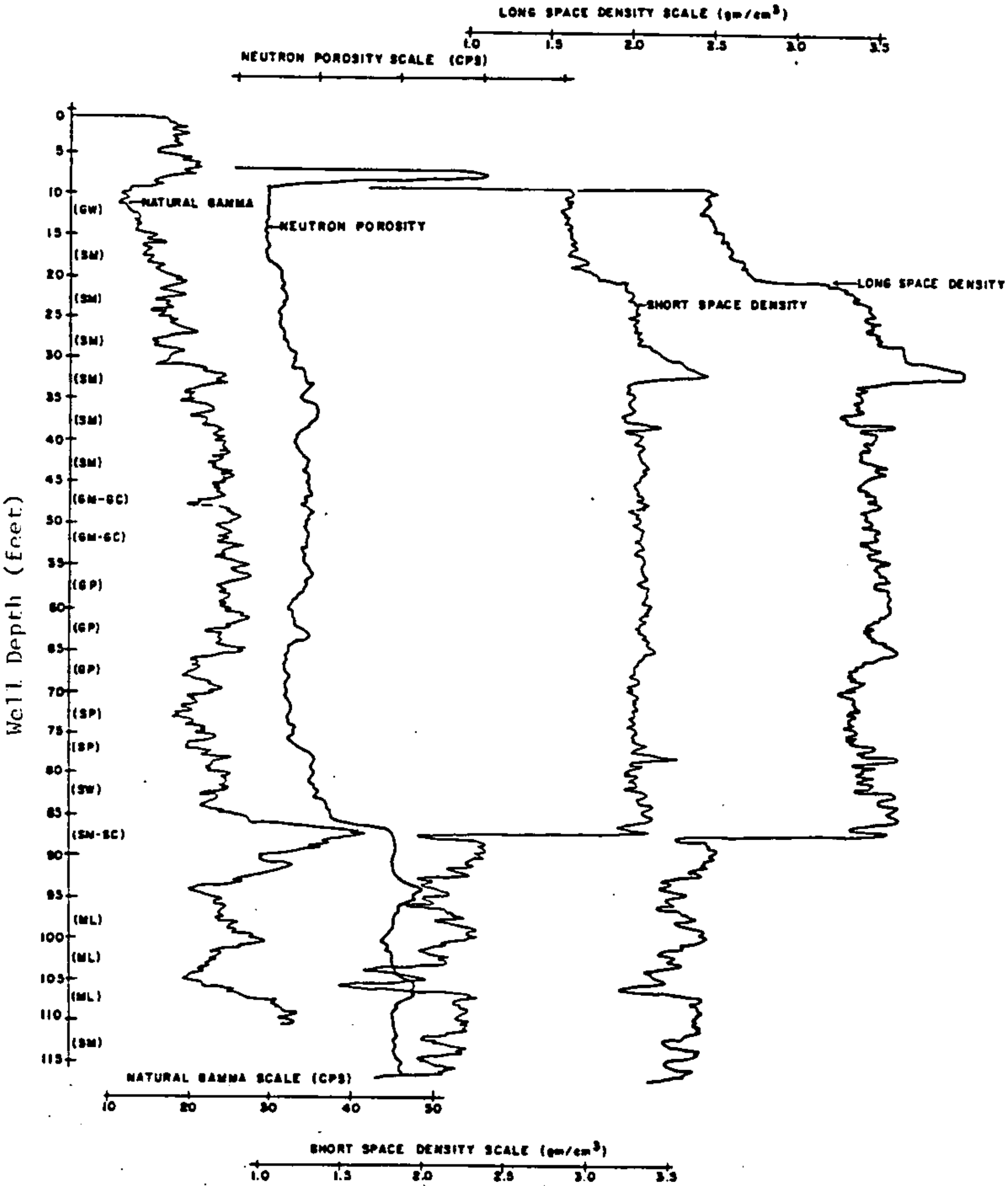
LOG OF BORING TW-7 SHEET 1 OF

Project and location: Buried Valley Study - Morris County		Elevation and datum:	Project no.:
Drilling agency: NJ DEP	Foreman:	Date started: 4/15/81	Date finished: 8/1/81
Drilling equipment: Air Rotary		Completion depth:	Rock depth:
Size and type of bit: CASING 12" (50) to 6"	Size and type core barrel:	No. samples:	
CASING HAMMER	WEIGHT	DROP	Water level:
SAMPLER			
SAMPLER HAMMER	WEIGHT	DROP	Inspector:

LOG OF BORING

DESCRIPTION	REMARKS
Hole Abandoned by Driller due to casing problems.	



Geophysical logs of Test Well TW-8.

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LOG OF BORING TW-8 SHEET 1 OF 3

Buried Valley Study - Morris Co.		752.05'	TW 8
N.J. D.E.P.		4/24/81	5/5/81
Air Rotary			90'
CASING 12" (50') to 6"			2'
CASING HAMMER	WEIGHT	DROP	
SAMPLER			
SAMPLER HAMMER	WEIGHT	DROP	

LOG OF BORING

Depth	DESCRIPTION	REMARKS
		32'8" of 10" casing in the ground with 4" of stick up
5	Light Brown, wet, f-c.gravel with some f-c. sand, and trace silt. (GW)	89'4" of 6" casing in the ground to ± 87.
10	Light Brown, wet, f-c.gravel, with some f-c. sand and trace silt. (GW)	51'8" of 6" casing last in ground with 1'6" stick up
15	Grayish-brown, wet f. sand some m-c. sand and some m-f. gravel, with some silt and clay. (SM)	Screen set from 50-70' - 18'2" of 5" casing attached to bottom of screen
20	Gray, wet, silt vf. sand. (SM)	
25	Gray, wet, sitly vf. sand. (SM)	
30	Gray, wet, silty, vf. sand. (SM)	

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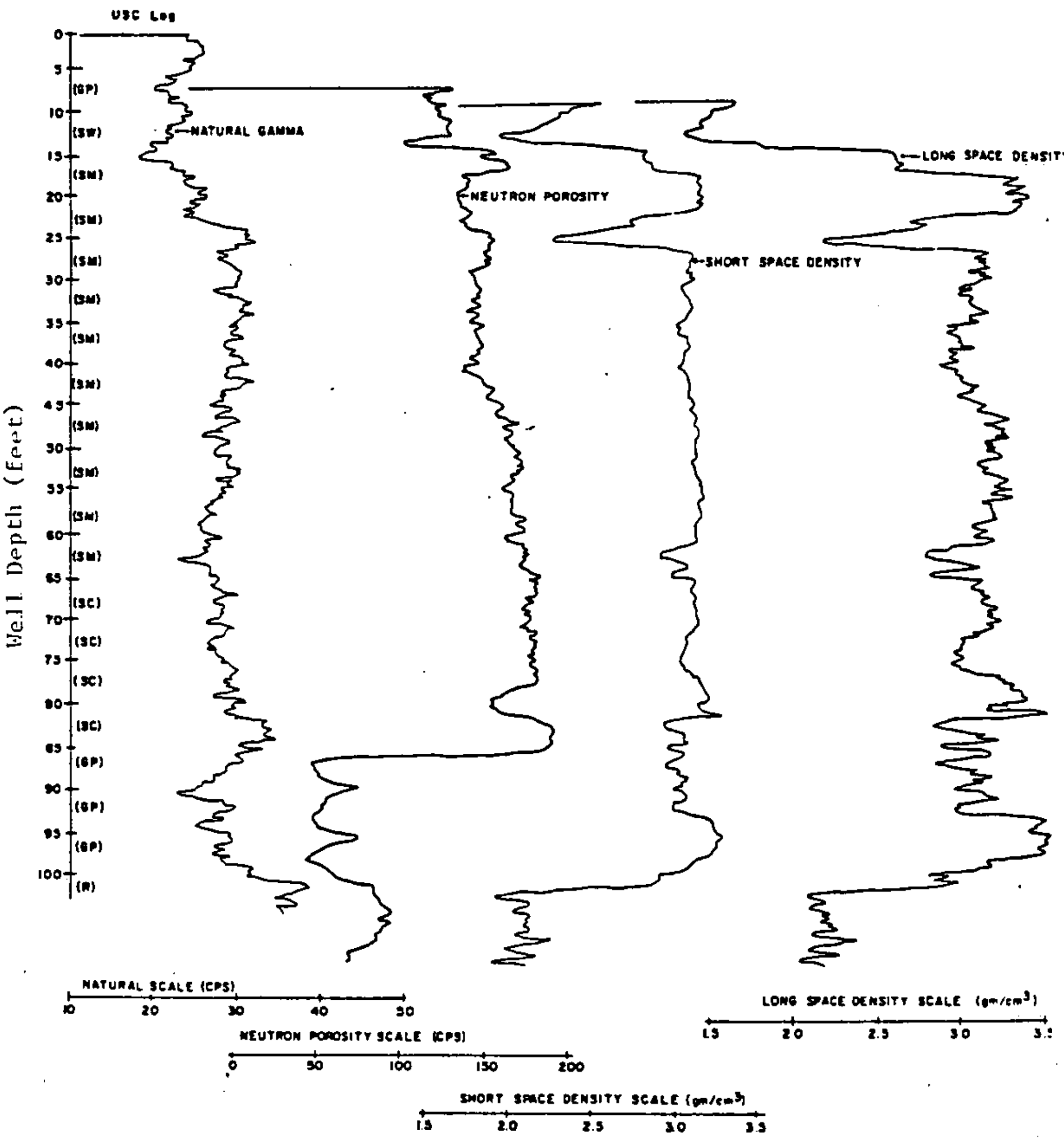
LOG OF BORING TW-8 SHEET 2 OF 3

Depth, ft	Description	Remarks
35	Gray, wet, silty vf sand, occ m-c. sand and f. Gravel (SM)	
40	Gray, wet, silt f. sand, Trace to some m-c. sand and occ. f. Gravel (SM)	
45	Gray, wet, f-c. sandy f-c. gravel, with a trace to some silt and clay. (GM-GC)	
50	Gray, wet, f-c. sandy f-m. gravel, with some site (GM)*	75 gpm * Most of the silt was washed out of the sample
55	Gray, wet, f-m. gravel, some f-c. sand, trace silt. (GP)	
60	Gray, wet, f-m. gravel, some f-c. sand, trace silt. (GP)	
65	Gray, wet f-m. gravel, some f-c. sand, trace silt. (GP)	
70	Gray, wet, f-m. sand, with some c. sand and occ f. gravel, trace silt. (SP)	
75	Gray, wet, vf-f sand, with occ. f-c. sand and trace f. Gravel and silt (SP)	

LOG OF BORING TW 8 SHEET 3 OF 3

Depth, ft	Description	Remarks
80	Gray, wet, f-c. sand, with occ f-m. Gravel and trace silt (SW)	
85	Gray, wet, f-c. sand, with occ f-m. Gravel and trace to some silt and clay. (SM-SC)	
90	Rock-decomposed and hammered to light-brown moist f-c. sand, occ. f. gravel and trace silt	
95	Rock-decomposed and hammered to light Gray, dry, silt, with a trace of m-c. angular sand and f angular gravel-qtz./dol. (ML)	
100	Rock-dark to light gray, dry, silt, trace of m-c. angular sand and f. angular gravel-qtz./dol. (ML)	
105	Rock-dark to light gray, dry, silt, with trace m-c. angular and gravel-qtz./dol. (ML)	samples show slight change (weathering?) 105'-110'
110	Rock-dark to light tannish gray, dry, f-c. sand, with occ. angular f. Gravel and trace to some silt-qz.·dol. (SM)	less weathered 110'-115'
115	Rock-chips, light tannish Gray, wet Qtz./dol.	
120	Rock-dark to light tannish gray, moist f-c. sand with occ. ang. f. gravel and trace to some silt, Qtz./dol.	115'-120' weathered



Geophysical logs of Test Well TW-9.

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LOG OF BORING TW-9 SHEET 1 OF

Buried Valley Study - Morris County	695.68	
NJDEP		
Air Rotary		102.5
CASING 12" (50') to 6"		
CASING HAMMER / WEIGHT / DROP		
SAMPLER		
SAMPLER HAMMER / WEIGHT / DROP		

LOG OF BORING

Depth	DESCRIPTION	REMARKS
5	Tannish-brown, f-c sandy f-m gravel, with occ. c gravel, and a trace of silt & root fragments. Dry (GP)	26'7" of 10" casing with 2' of stickup 105' of 6" casing with 2.5' stickup screen - from 78-98' casing 80' of 6" left in ground
10	Light brown, moist, f-m gravely f-c sand with a trace of silt (SW)	(2' stickup)
15	Light brown, moist f sand, with some m-c sand and f-m Gravel, a trace to some silt (SM)	
20	Light brown, wet, silty, v.f. sand, with a trace to some m-c sand, and occ. f. gravel. (SM)	
25	Greensih-gray, wet, silty v.f. sand, with a trace m-c sand (SH)	
30	Greensih-gray, wet, silty vf sand, with a trace m-c sand. (SH)	

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LOG OF BORING TW9 SHEET ___ OF ___

Depth, ft	Description	Remarks
35	Greenish-gray, wet, silty vf sand, with a trace of m *sand, and a trace of clay (SM)	* medium
40	Greenish-gray, wet vf *sand, some silt, and a trace of m sand (SM)	* very fine
45	Greenish-gray wet, vf sand, some silt, a trace of m sand, and trace clay. (SM)	
50	Greenish-gray, wet, cf sand, some silt (SM)	
55	Greenish-gray, wet, vf sand, some silt, a trace m sand (SM)	
60	Greenish-gray, wet, vf sand, some silt (SM)	
65	Greenish-gray, wet, clayey vf sand, with a trace to some f-c sand, and occ. f Gravel (SC)	
70	Greenish-gray, wet, clayey f-c sand, with occ f-m Gravel (SC)	
75	Greenish-gray wet, clayey f sand, some m-c sand, and occ. f-m gravel (SC)	

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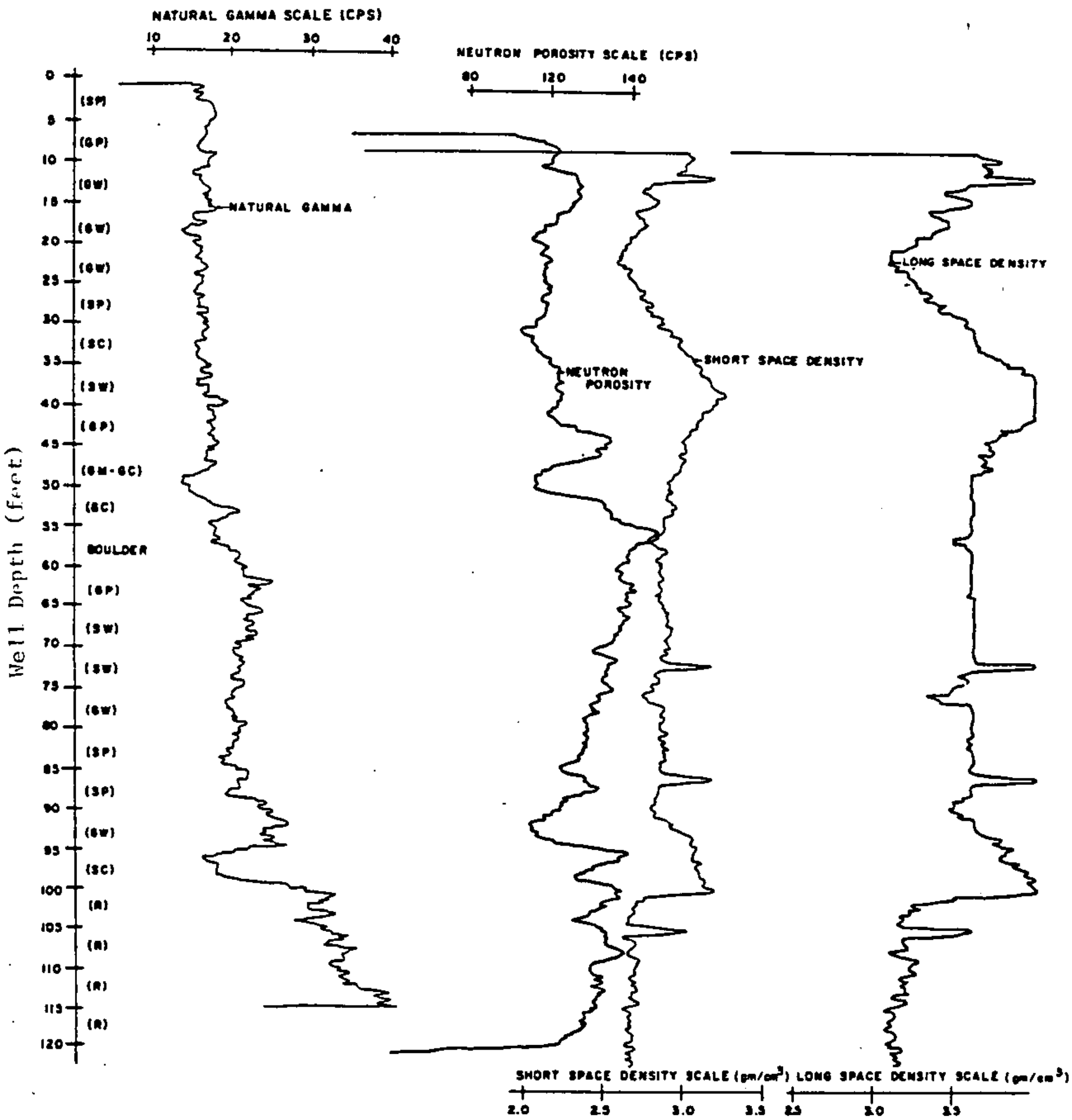
LOG OF BORING TK9 SHEET ___ OF ___

Depth	Description	Remarks
80	Greenish-gray, wet, f-m gravely f-c sand, with a trace to some silty clay (SC)	Blowing 25-100 gpm with hole to 80' +6" to 79' (static =12')
85	Greenish-gray, wet-f-, gravel, some f-c sand and occ. c gravel, trace silt (GP)	
90	Greenish-gray, wet f-c sandy f-c gravel with a trace silt (GW)	casing driving hand at ± 90' Blowing 25+ gpm with casing and hole to 90' lots of sand and Gravel coming up
95	Gray, wet f-c sandy f-m gravel, with a trace silt* (GP)	* Most of silt washed out
100	Grayish, wet f-m gravely f-c sand[XX] Tannish, moist f-m gravely f-c sand, Trace silt-Rock-weathered and hammered to Tan moist f-c sand, some f gravel	XX Clean, due to washing - Top of rock 102.5'
105	Rock-weathered and hammered to tan, moist f-m sand some c sand and silt	
110		Started drilling a little harder at 113'
115	Rock-weathered and hammered to tan, moist, f-m sandy silt, trace to some clay.	
120	Bottom of hole 115'	



Geophysical logs of Test Well TW-10.

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LOG OF BORING TW-10 **SHEET** 1 **OF** 2

Buried Valley Study - Morris County		697.63'	
N.J. D.E.P.		5/5/81	
Air Rotary		125'	102.5'
CASING 12" (50') to 6"		± 3'	7'10" / 7'1C"
CASING HAMMER	WEIGHT	DROP	
SAMPLER			
SAMPLER HAMMER	WEIGHT	DROP	

LOG OF BORING

DEPTH	DESCRIPTION	REMARKS
	Grayish-brown, moist to wet f-m sand with occ. c. sand, and trace to some silt and clay (SP)	6" 8" 10" Total 128'2" 106'1" 57'10" Stick-Up 2'6" 2' 1' Depth 125'9" 104'1" 56'10"
5	Reddish-brown, wet f-c. sandy f-m. rounded gravel, with occ. c. gravel and a trace to some silt & clay. (GP)	
10	Greenish-brown, wet f-c. rounded gravel, with some f-c. sand, and trace of silt. (GW)	
15	Brown, wet f-c. sub angular to rounded f-c. gravel, with some f-c. sand, and a trace of silt. (GW)	
20	Grayish-brown, wet f-c. sandy rounded f-c. gravel, trace of silt. (GW)	
25	Gray, wet f-m. sand, with a trace to some c. sand and occ. f-c. rounded gravel. (SP)	
30	Gray, wet, clayey f. sand with a trace to some f-c. sand and occ. f-m. pieces of gravel (SC)	
35	Gray, wet f-c. sand, with some f-m. gravel, a piece of c. gravel, and trace silt. (SW)	
40	Gray, wet, f-c. sandy, sub angular to rounded c. gravel, with some f-m. gravel, trace silt (GP)	
45	Gray, wet, f-m. subangular to rounded gravel with some f-c. sand and trace to some sandy clay. (GM-GC)	10" casing started to drive hard at ± 48'.
50	Gray, wet f-m. subangular to round Gravel with some f-c. sand and some clay. (GC)	
55	Boulder	Boulder 56'-58', material above 50-55' sample.

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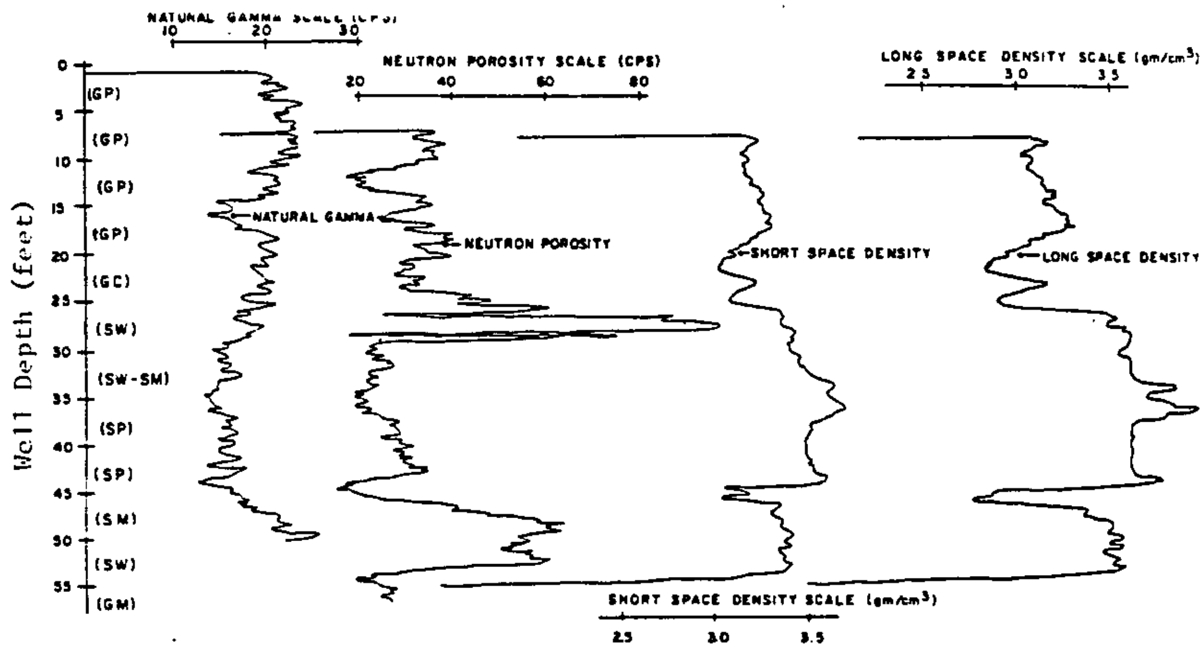
LOG OF BORING TW10 SHEET 2 OF 2

LOG OF BORING

Depth (ft)	Description	Remarks
60	Grayish-brown, wet f-c. sandy f-m. rounded gravel. (GP)	Blowing ± 20 gpm
65	Gray-brown, wet, f-m. rounded gravel; f-c. sand with a trace silt.	
70	Gray-brown, wet f-c. sand, occ. rounded c. gravel, and trace silt. (SW)	Blowing ± 30 gpm
75	Gray-brown, well rounded f-c. gravel some f-c. sand, and trace silt (GW)	Blowing ± 50 gpm
80	Gray-brown, wet f-m. sand, some c. sand, and occ. rounded f gravel (SP)	The 80-85' sample has the appearance of being washed.
85	Gray-brown, wet f-m. sand some c. sand, and occ. rounded f. gravel (SP)	Blowing ± 50 gpm
90	Gray-brown, wet, f-c. sandy rounded f-c. gravel (GW)	
95	Light-brown, wet, rounded f-m. gravelly f-c. sand, some clay (SC)	
100	Top of rock 102.5'	Color of material changing to reddish-grown
105	Rock-hammered and weathered to red-brown, moist, f-m. sand, some c. sand and clay, occ. angular f. gravel	
110	Rock-hammered and weathered to red-brown, wet, clayey f-c. sand & occ. angular f. gravel	113' drilling is getting harder (less weathered) *casing not sealed in rock-leaking
115	Rock-hammered and weathered to red-brown, wet clay with some f-c. sand and occ. f. angular gravel	



Geophysical logs of Test Well TW-11.

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LOG OF BORING TW-11 SHEET 1 OF 3

Buried Valley Study - Morris County		749	
NJDEP		5/19/81	
		85'	64'
CASING 12" (50') to 6"			
CASING HAMMER	WEIGHT	DROP	
SAMPLER			
SAMPLER HAMMER	WEIGHT	DROP	

Water level: +7'

LOG OF BORING

Depth	Description	Remarks
	Tan moist, f.-c. gravel, with some f.-c. sand and trace silt. (GP)	46' 9" of 10" casing with 1' 6" stickup 58' 6" casing with 2.0' stickup
5	Tan, wet, f.-m. rounded gravel, with some f.-c. sand, occ. c. Gravel and trace silt]. (GP)	
10	Tannish-Brown, wet, f.-m. gravel, with a trace to some f.-c. sand. (GP)	
15	Brown, wet f.-m. Gravel, with some f.-c. sand and occ. c Gravel, trace silt. (GP)	
20	Gray, moist to wet, f.-c. sandy f.-m. gravel, with some clay. (GC)	
25	Gray, wet, f.-m. rounded gravelly f.-c. sand, with trace silt and clay. (SW)	
30	Gray, wet, f.-m. rounded gravelly f.-c. sand with trace to some silt (SW-SM)	

LOG OF BORING TW-11 SHEET 2 OF 3

Depth	Description	Remarks
35	Gray, wet f.-m. rounded and angular Gravel with some f.-c. sand, occ. c. Gravel and trace silt. (SP)	
40	Gray, wet, vf. sand, with some f.-m. Gravel and trace to some m.-c. sand, trace silt and clay. (SP)	Casing drove hard from 42'
45	Gray, moist, f. sand with some m.-c. sand and f.-m. rounded Gravel, with some silt. (SM)	
50	Gray, moist, f.-c. sand, with some f. Gravel and trace silt. (SW)	
55	Gray moist f.-m. rounded gravel, with some f.-c. sand and silt.	Drilling very hard and dense from 55' down-over compacted till
60	Grayish-brown moist f.-m. rounded Gravel with some f.-c. sand and silt (GM)	
65	Rock-hammered and weathered to white, gray, dry powder f-c. sand with occ. f. gravel size frags. of qtz, & s.s.	Drilling hard and steady with occ. softer zones at +64'
70	Rock-hammered and weathered to white and yellow-brown, dry powder and angular f. gravel with some f.-c. sand size material of qtz./dol (gray)	

LOG OF BORING TW-11 SHEET 3 OF 3

DEPTH, FT	DESCRIPTION	REMARKS
75	Rock-hammered and weathered to gray and brown, dry to slightly moist, powder, and frags of f.-c. sand and f. gravel size qtz./dol.	Slicker slides on face of gravel size fragments.
80	Rock-hammered and weathered to gray and gray-green, dry to slightly moist, powder and frags of f.-c. sand and f. gravel size qtz/dol (gray).	
85	(Bottom of hole)	

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LOG OF BORING TW-12 SHEET 1 OF 4

Buried Valley Study - Morris County			8104036
NJDEP	Mike Korbulick	Sept. 3, 1981	Sept. 8, 1981
Chicago Pneumatic 650 WS		300'	
5 7/8" Tricane/Pneumatic Hammer			
CASING 10"-50'/6"-140'		26	
CASING HAMMER	WEIGHT	DROP	Vertical
SAMPLER			
SAMPLER HAMMER	WEIGHT	DROP	S. Halbig

LOG OF BORING

DEPTH	DESCRIPTION	REMARKS
	Brown, Dry Silt, Some angular to rounded gravel, minor to Tr. Sand. (ML)	
	Brown, wet silty f-sand, minor gravel, tr. Clay (SM)	Moist at 7'
10	" "	
15	Gray, wet clay, tr. Silt (CL)	Drove 10" casing to 50' and cleaned out with Pneumatic Hammer.
20	" "	
25	" "	Water level 26' after cleaning out 10" casing.
30	" "	Flowing sand + silt filled in 10" casing.
35	" "	pulling rods, drove 6" casing through sand.
40	Gray, wet, clay, ~~tr~~-No silt. (CL)	
45	Gray, wet, f. to m. sand, ~~tr~~. silt, gravel, Tr. to no clay (SP)	
50	gray, wet, c-sand gravel, tr. silt (GW)	
55	Gray, wet, f. sandy gravel, Minor silt, tr. clay. (GM)	
60	" "	End Sept. 3, 1981 Start Sept. 4, 1981

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LOG OF BORING TW-12 SHEET 2 OF 4

LOG OF BORING

Depth	Description	Remarks
65	Gray-Brown, Wet, sand tr. (SP) Silt.	using Hammer Hawk
70	Gray-Brown, Wet, f-m sand, Minor - tr. Silt, occ. gravel. (SP)	
75	Gray - Brown, Wet, f-m sand. tr. gravel, silt. (SP)	
80	Gray, wet alternating layers of: clay f. sand; plastic clay f. sandy gravel; f. sandy clay, all with tr. to Minor Silt (SC) (CH) (GF) SC-CL)	
85	" "	
90	Gray, wet, laternating c.sand and gravel, tr. silt (GP-SP)	5 gpm
100	97' silt lens	
105	gray, wet, sandy silt, minor Gravel, tr. Clay. (ML)	5-10 gpm
	Gray, wet, c. sand and gravel, Tr. silt	(GP-SP)
	Gray wet, sandy silt, tr. gravel	(ML)
110	Gray, wet, clayey silt, tr. sand, gravel.	(MH)
115	Dark gray, sand and gravel, tr. silt.	(GP-SP)
120	occ. stiff black clay balls. Dark Gray, sand and gravel, tr. silt, clay	(GP-SP)
125	gravel, tr. silt, clay (All frag. of black shale) (GP)	5 gpm Rock
130	Black, moist = Wet, stiff clay Balls, sand, gravel(black shale fragments). (GP-SP) (CH)	
135	" "	Rapid Penetration End Sept. 4, 1981 140'
140	" "	Start Sept. 8, 1981 - switched to Downhole Hammer
145	Black, Dry, clay (Powder) tr. c. sand, (CH)	

LOG OF BORING TW-12 SHEET 3 OF 4

LOG OF BORING

Depth, ft	Description	Remarks
150	Black, Dry to Sl. Moist, clay (Powder) tr. sand fragments of black shale. (CH)	
155	" "	
160	" "	
165	" "	
170	" "	
175	Black, Sl. Moist, Sl. plastic clay tr. sand Fragments of black shale	(CH)
180	Black moist-wet clay and brown c. sand fragments, Minor Silt.	(CH)
	Greenish-Gray Wet clay tr. sand	(CH)
185	" "	
190	" "	
195	Gray, Wet clay and buff + red wet c. sand, tr. gravel	(CH)
200	Gray-brown, wet c. sandy clay tr. red + buff gravel	(SP)
205	Light Brown, very wet clay with, some sand, minor gravel, tr. silt	(CH) Making Mud 1 gpm
210	" "	
215	" "	210'-240' several 1' thick soft zones (Rods penetrated without triping Hammer)
220	" "	
225	" "	
230	" "	Making very muddy water 1-2 gpm

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LOG OF BORING TW-12 SHEET 4 OF 4

LOG OF BORING

Depth	Description	Remarks
235	Brown, very wet sand clay., minor gravel, tr. black Shale Fragments	(SC-CH)
240	Brown wet sand, minor gravel (fragments of buff - red sandstone	Making v. muddy Water 20 gpm
245	" " *(SP)	
250	" "	Making 40 gpm muddy water
255	" "	
260	Brown, wet, c. sand, tr. gravel, clay. (fragments of Buff and Red Sandstone with some Fe oxide stained veins) *(SP)	Hammer bit broke-switched to Roller Bit.
265	" "	
270	Brown Wet c. sand, minor gravel tr. silt, clay (Fragments of: red and buff sandstone, gray sandstone, black shale). *(SP)	
275	" "	
280	" "	
285	" "	
290	occ. Qtz fragments	
295	" "	
300	" "	
305	Wet, c. sand, minor gravel, tr. silt, clay (fragments of: buff and red sandstone, gray sandstone, Fe Oxide Vein, black Shale) *(SP)	Making 50 gpm muddy water
310		Boring terminated 300 Sept. 8 1981
315	*Clay and Silt Fractions Probably washed out.	

Log of Boring DEP-1

Depth (ft)	Description	Remarks
2	peat	
8	sand and gravel with silt	
14	gravel	
42	silty very fine sand	
47	sandy gravel	
75	fine to coarse sand with some gravel layers	taking ± 30 gpm of water at 75 feet
82	very fine to fine sand	
90	fine to coarse sand with gravel layers - gray	
121	coarse gravel and hard packed sand yellow brown	
125	very fine sand with some gravel	
147	gravel with thin layers of reddish brown silt and clay	
157	heavy gravel layer	
		Set 61' well with 20' of 20 slot 2" screen - PVC Top of Rock ± 112 feet

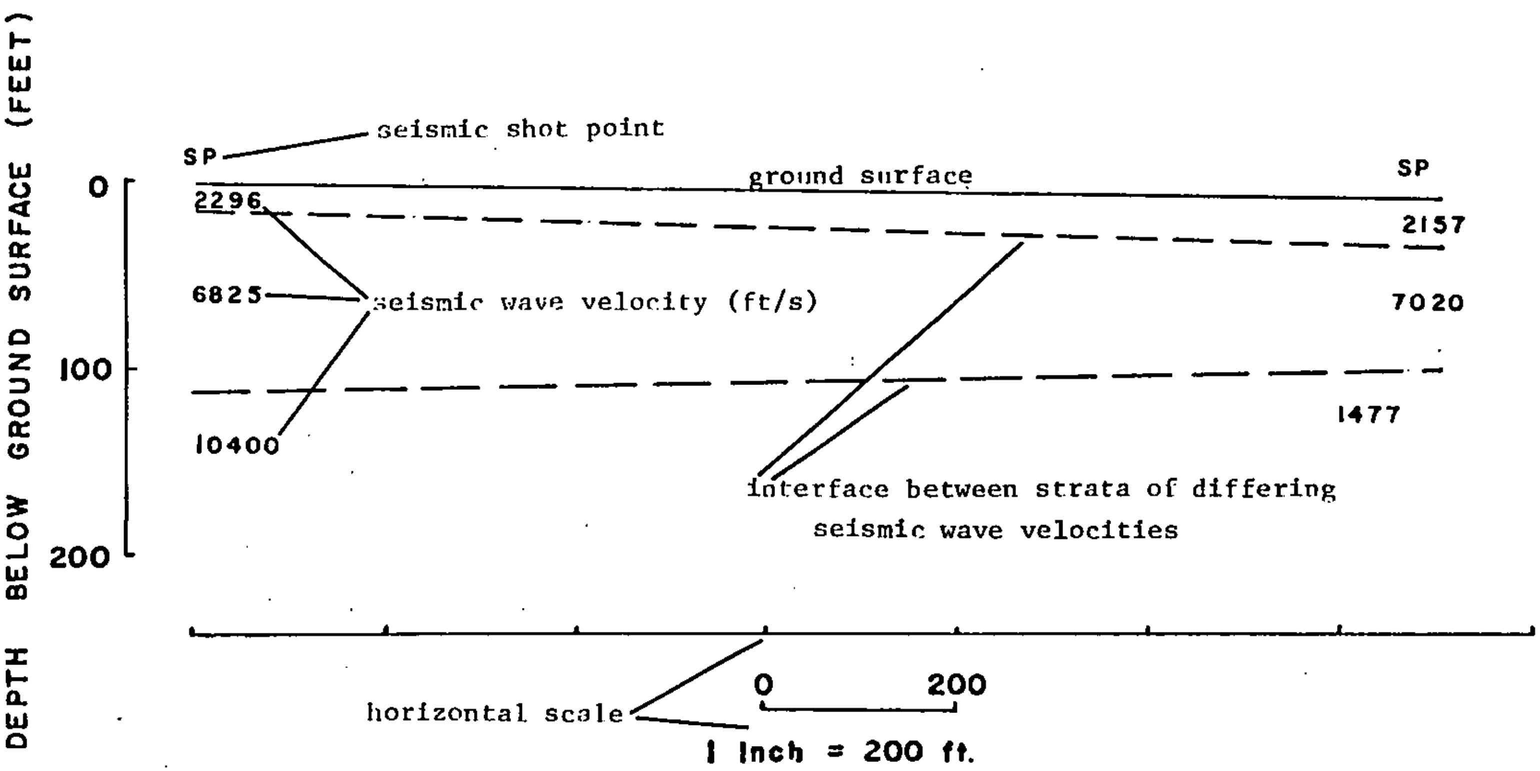
Drilled by: R. Dalton, DEP
Logged by : R. Dalton, DEP

Log of Boring DEP-2

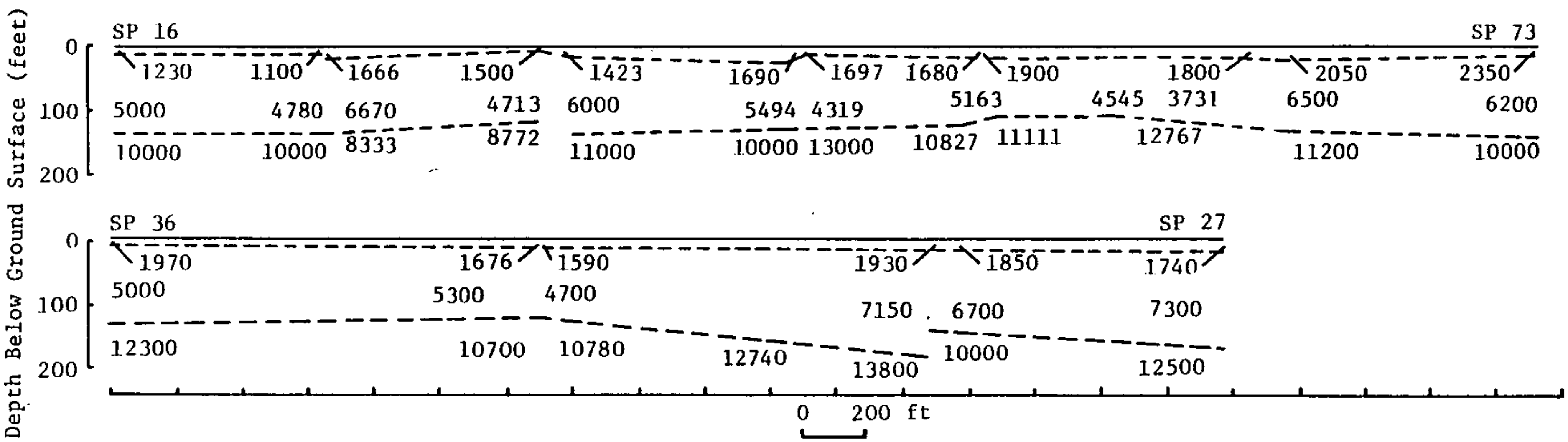
Depth (ft)	Description	Remarks
5	Sand, brown medium to coarse with silt and gravel	
	- angular to rounded quartz, quartzite and gneiss, grains and pebbles - rounded shales, grains and pebbles	
10	Sand, brown very fine to coarse, silty	
	material same	
15	Sand, brown very coarse to fine gravel rounded quartz, shale, quartzite, gneiss	
20	Sand, brown very fine to coarse, silty trace of gravel material same as 10'	
25	Sand, charcoal gray, very fine to fine, trace silt and fine gravel	
	rounded quartz, quartzite and shale	color due to a black sugary textured shale-like material
30	Sand, gray, fine to coarse, trace of silt material similar to 25' feet less black shale	
35	Sand, gray brown fine to coarse, less silt than last sample similar to 35'	
40	SAME	
45	Sand - same as 30'	
50	Sand - gray fine to coarse, trace of silt material same as last - Note top of rock at 47'	rock is the Marcellus Shale Formation, the sand is from 22 - 47 foot interval
55	Sand - gray - very fine to fine - material same - more angular black shale present	
60	SAME	
70	SAME	
75	SAME	
80	SAME	

Drilled by: R. Dalton, DEP
Logged by : R. Dalton, DEP

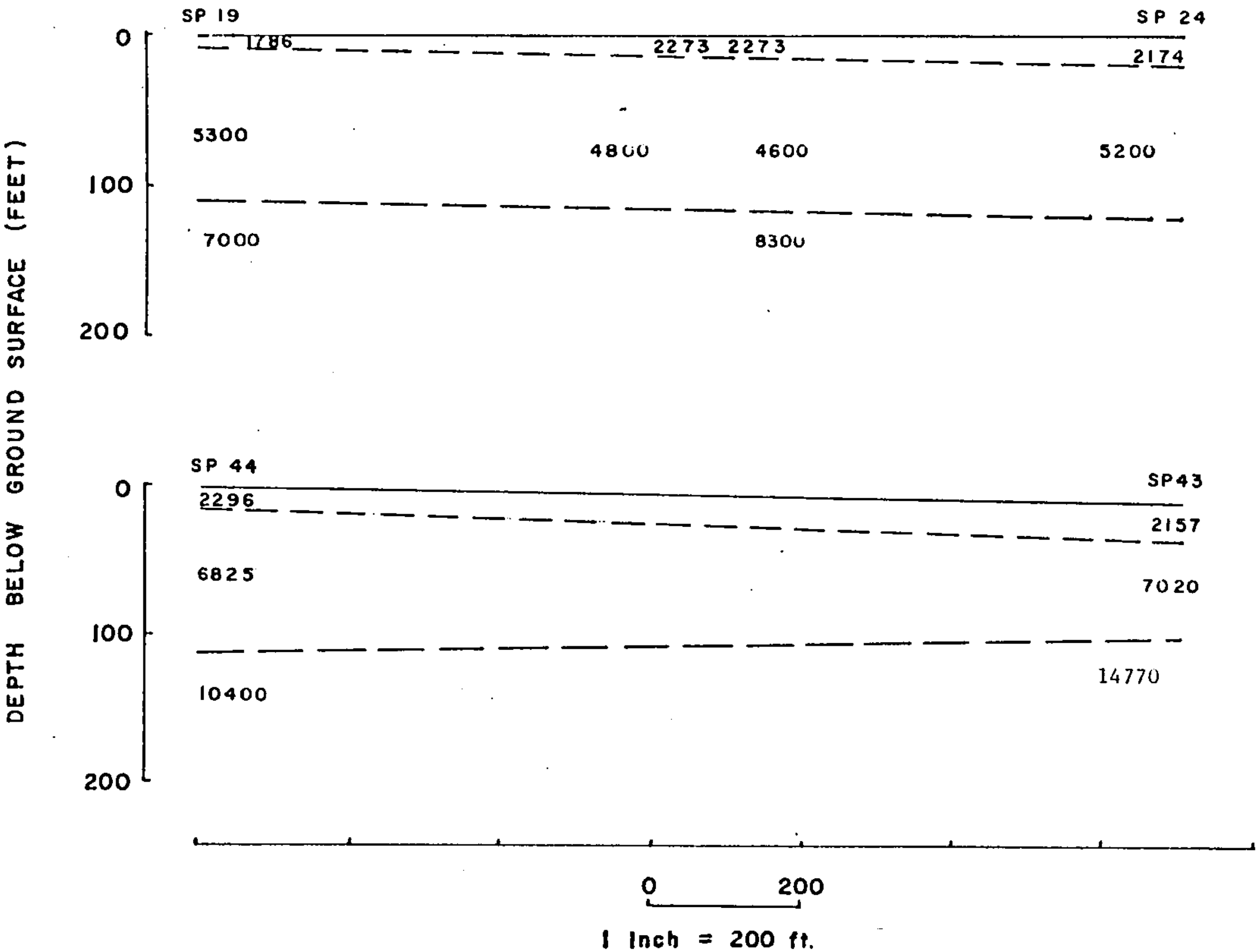
APPENDIX 3. CROSS SECTIONS FROM SEISMIC TRAVERSES



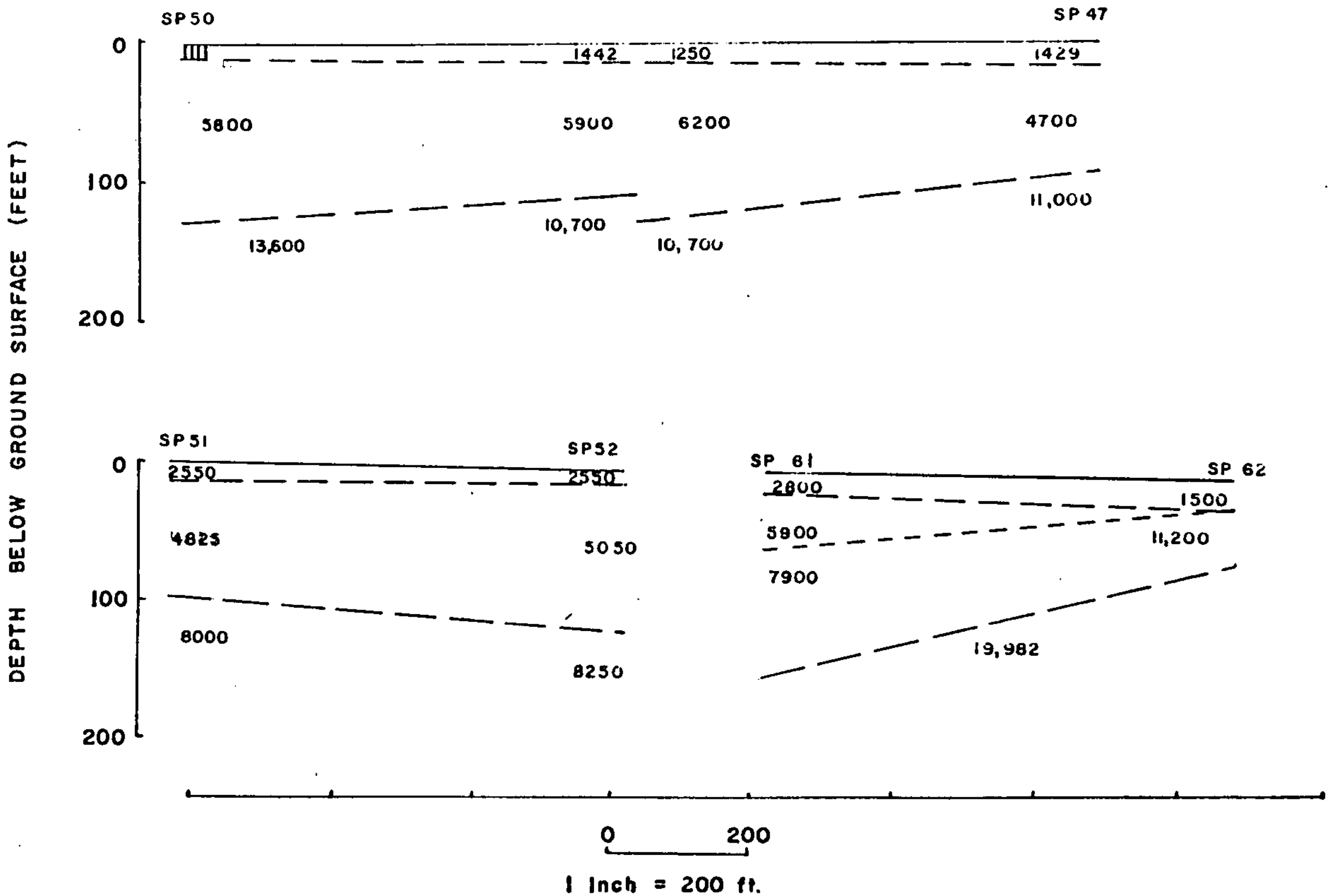
Explanation of cross sections from seismic traverses. Locations shown on Plate 2.

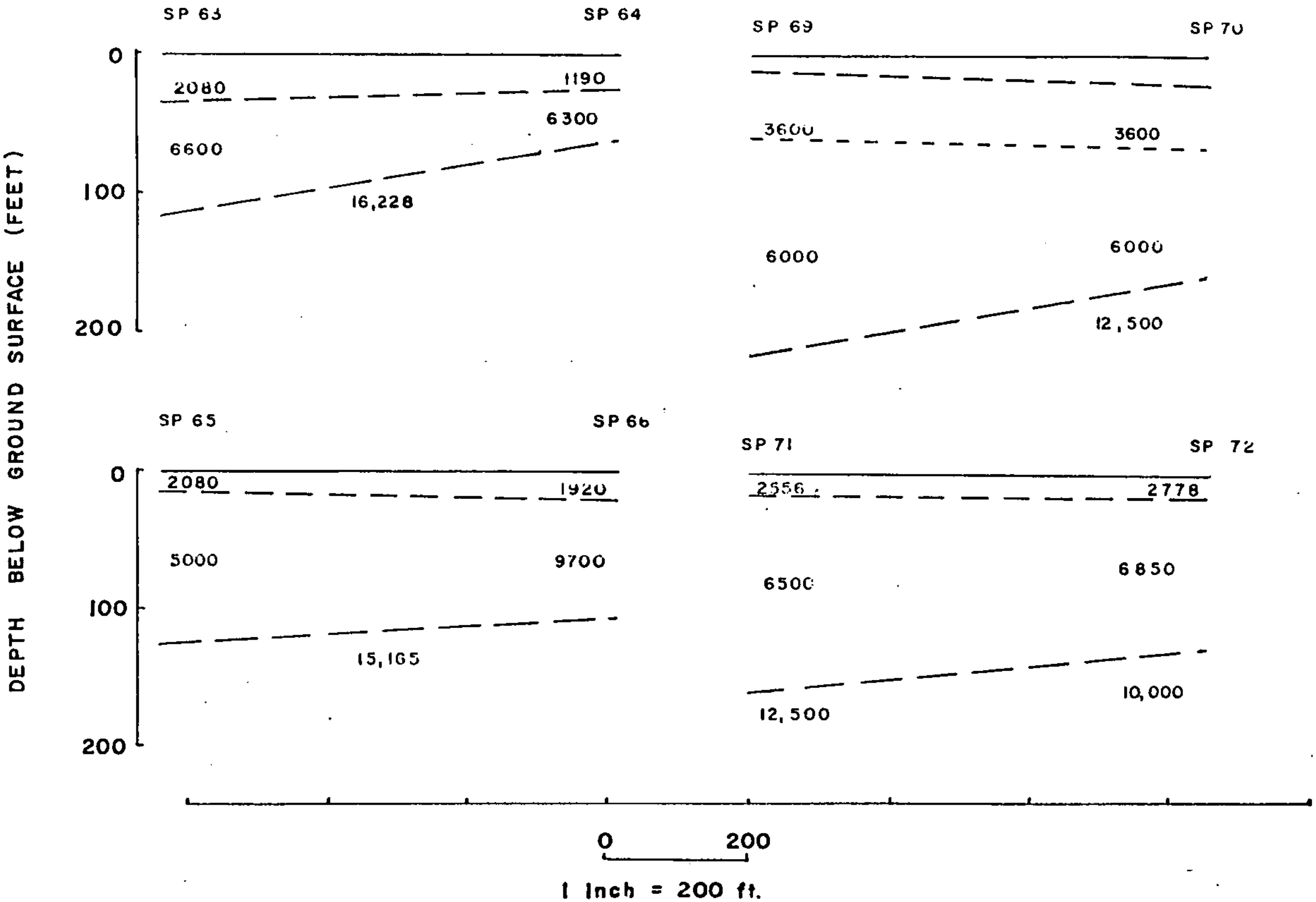


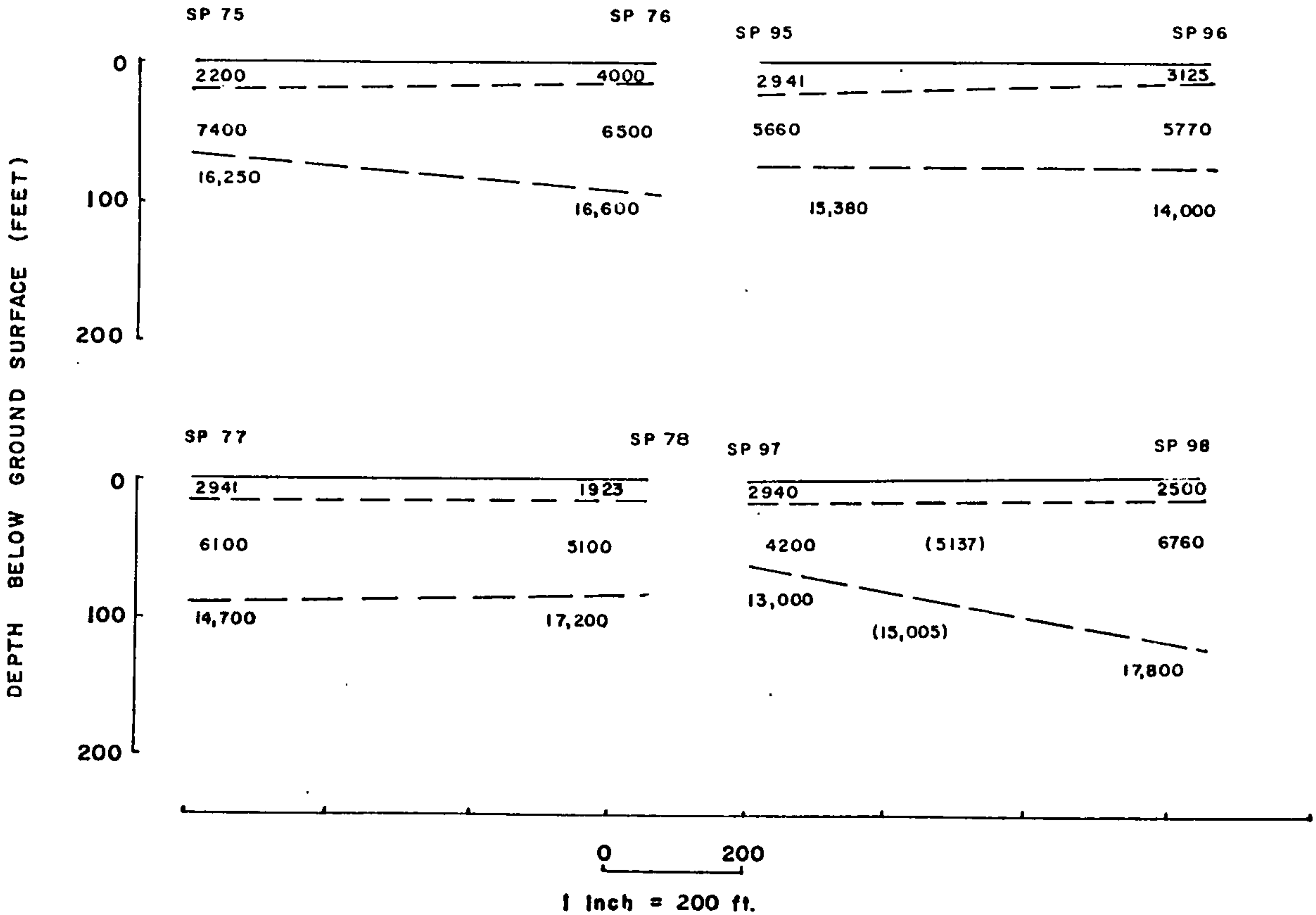
Depth Below Ground Surface (feet)
0
100
200
SP 16
SP 73
1230
1100
1666
1500
1423
1690
1697
1680
1900
1800
2050
2350
5000
4780
6670
4713
6000
5494
4319
5163
4545
3731
6500
6200
10000
10000
8333
8772
11000
10000
13000
10827
11111
12767
11200
10000
SP 36
SP 27
1970
1676
1590
1930
1850
1740
5000
5300
4700
7150
6700
7300
12300
10700
10780
12740
13800
10000
12500
0 200 ft



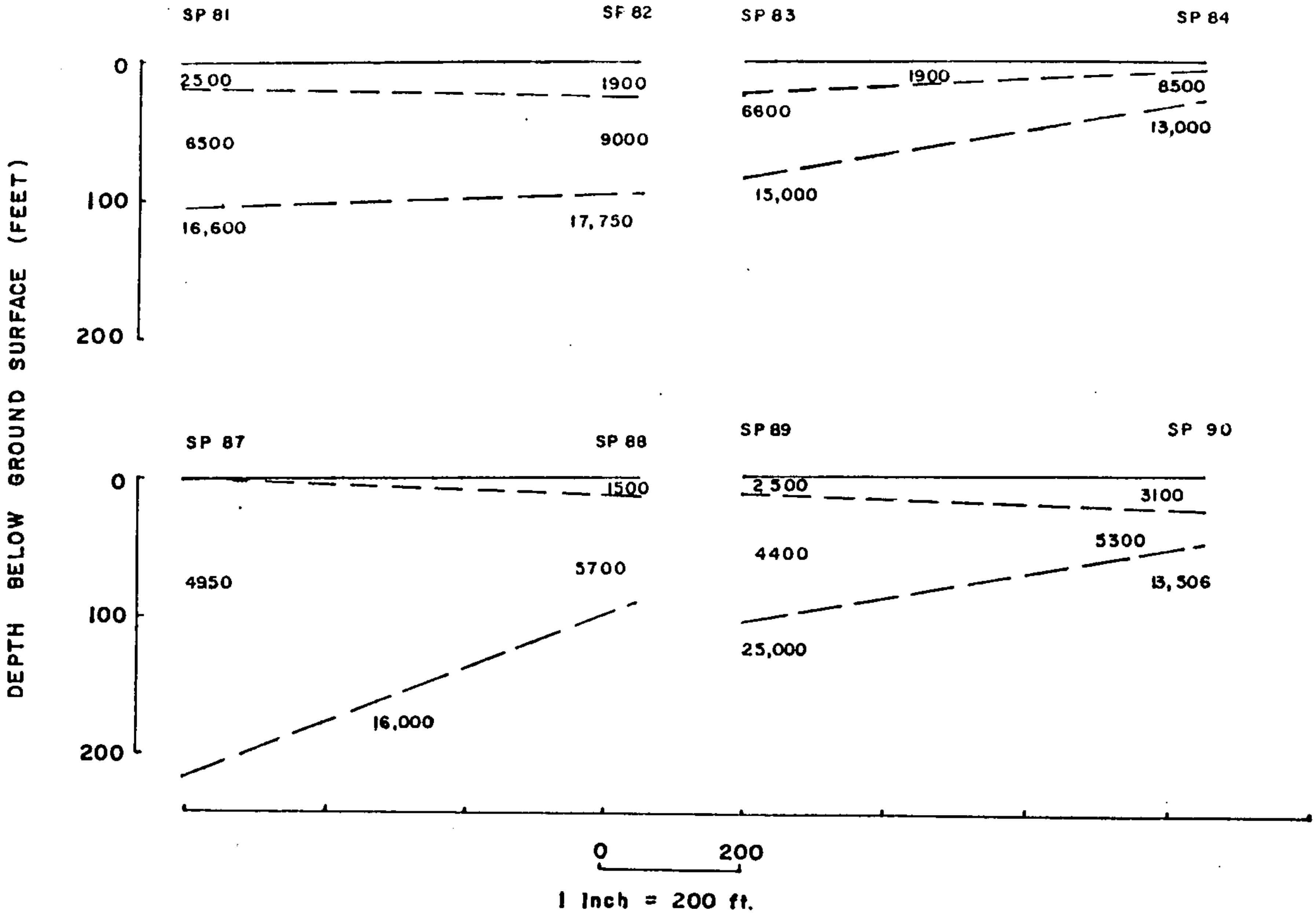
SP 19
SP 24
1786
2273
2273
2174
5300
4800
4600
5200
7000
8300
SP 44
SP43
2296
2157
6825
7020
10400
14770
0
100
200
DEPTH BELOW GROUND SURFACE (FEET)
0
200
1 Inch = 200 ft.


DEPTH BELOW GROUND SURFACE (FEET)
SP50
SP 47
0
100
200
1111
1442
1250
1429
5800
5900
6200
4700
11,000
10,700
10, 700
13,600
SP51
SP52
SP 61
SP 62
2550
2550
2800
1500
4825
5050
5900
11,200
7900
8000
8250
19,982
0
200
1 Inch = 200 ft.

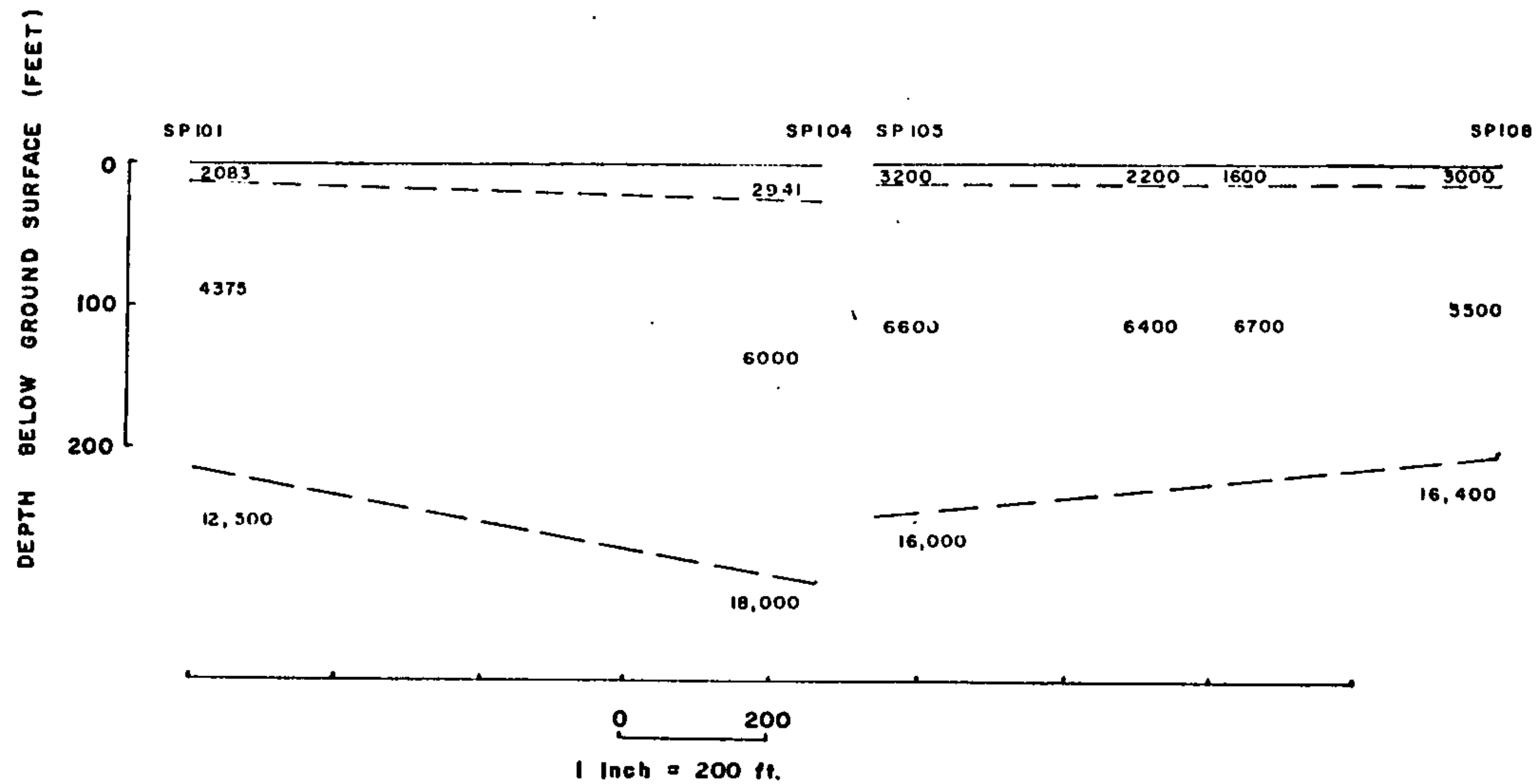

DEPTH BELOW GROUND SURFACE (FEET)
SP 63
SP 64
0
100
200
2080
1190
6300
6600
16,228
SP 69
SP 70
3600
3600
6000
6000
12,500
SP 65
SP 66
0
100
200
2080
1920
5000
9700
15,165
SP 71
SP 72
2556
2778
6500
6850
10,000
12,500
0
200
1 Inch = 200 ft.

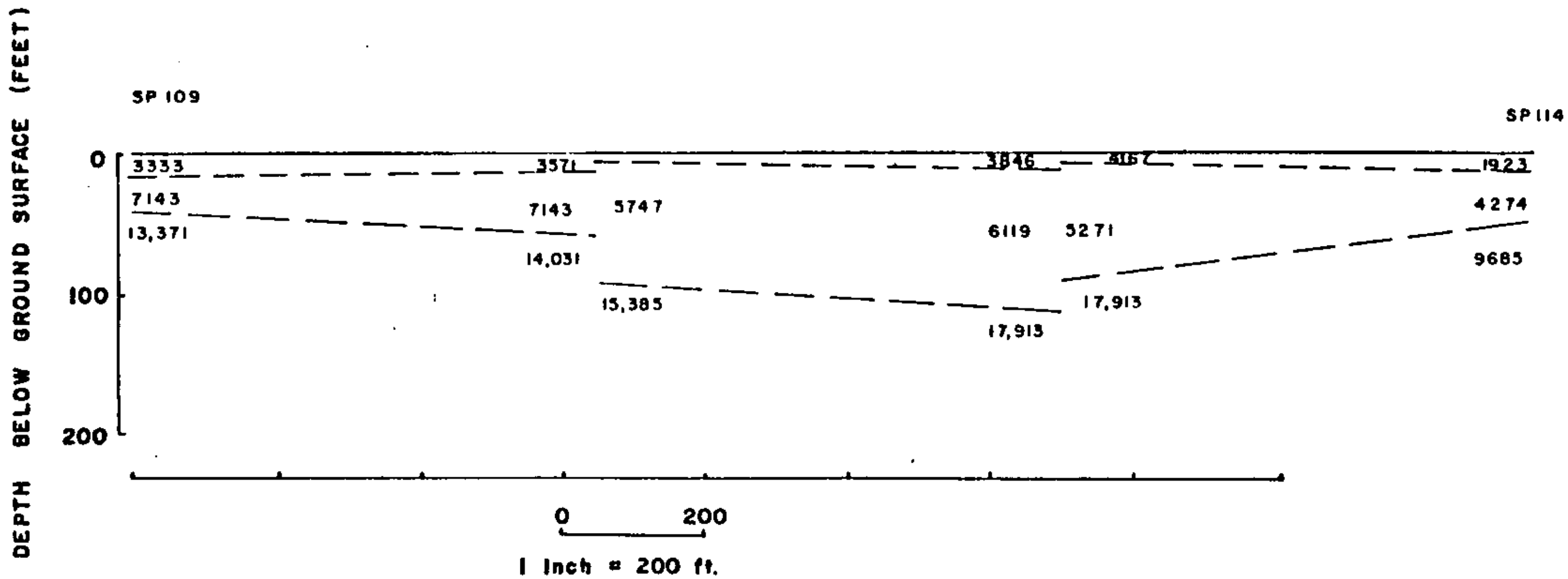


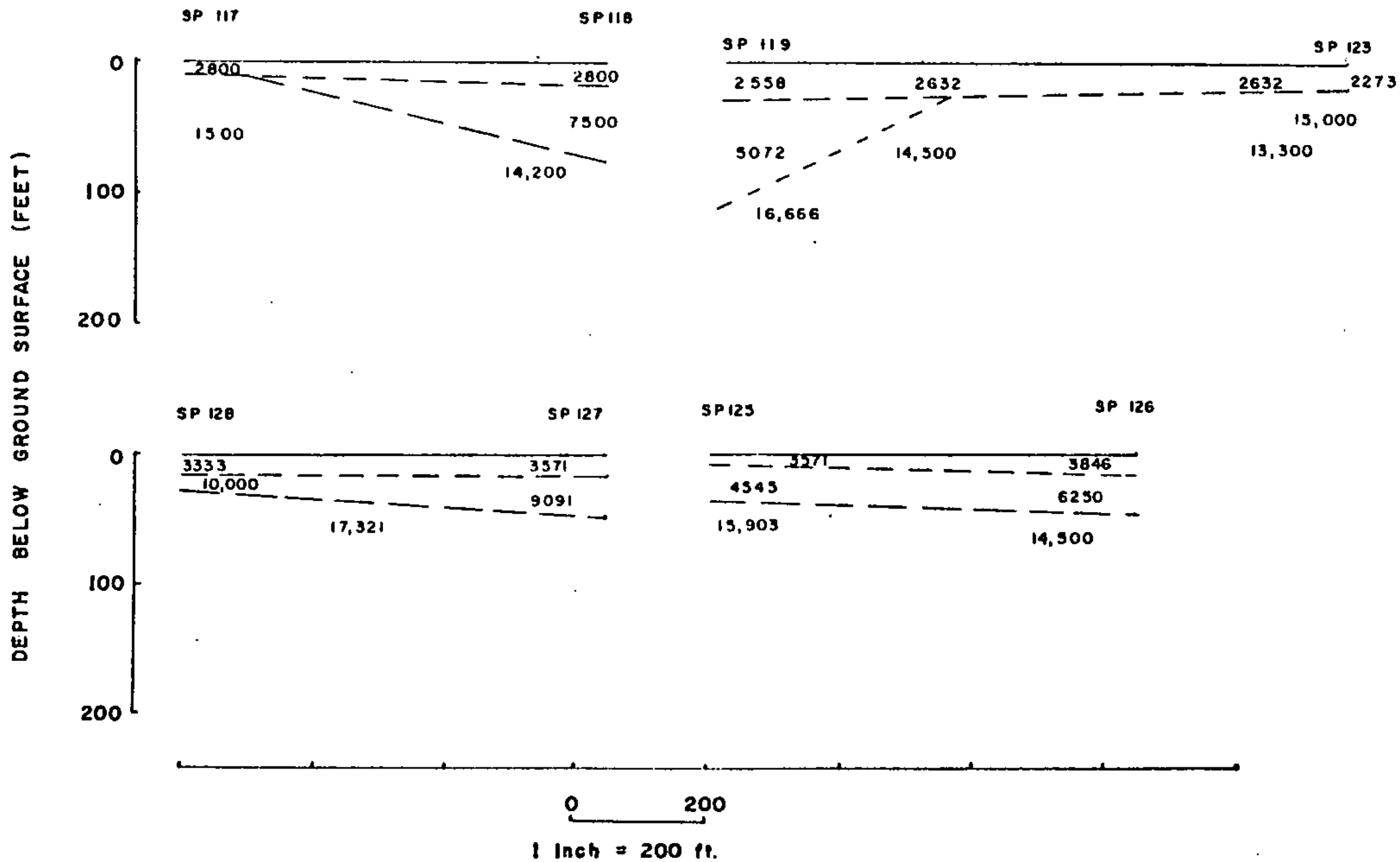
DEPTH BELOW GROUND SURFACE (FEET)
SP 75
SP 76
SP 95
SP 96
0
100
200
2200
4000
2941
3125
7400
6500
5660
5770
16,250
16,600
15,380
14,000
SP 77
SP 78
SP 97
SP 98
0
100
200
2941
1923
2940
2500
6100
5100
4200
(5137)
6760
14,700
17,200
13,000
(15,005)
17,800
0
200
1 inch = 200 ft.



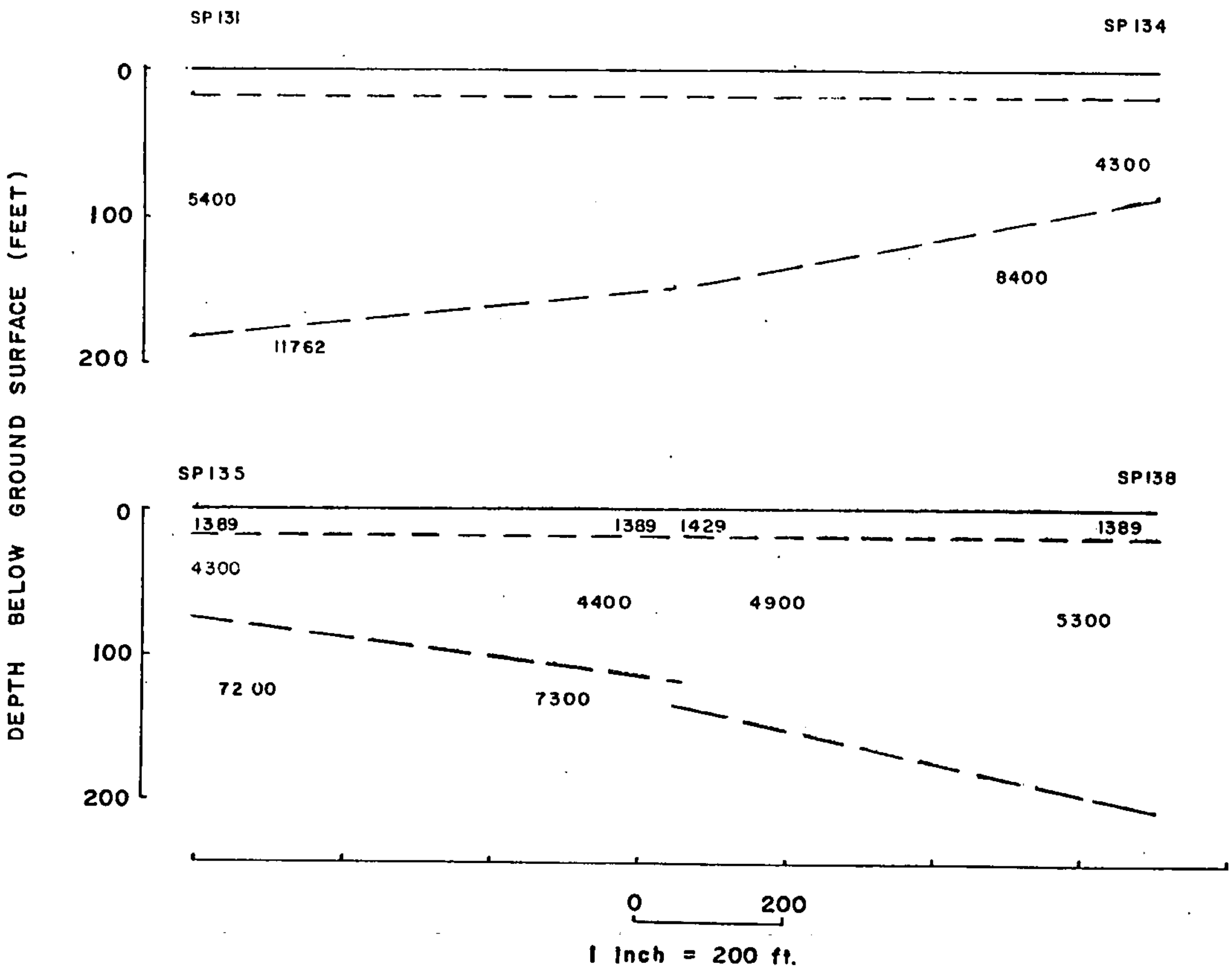
SP 81
SP 82
SP 83
SP 84
SP 87
SP 88
SP 89
SP 90
DEPTH BELOW GROUND SURFACE (FEET)
0
100
200
2500
1900
6500
9000
16,600
17,750
1900
8500
6600
13,000
15,000
1500
4950
5700
16,000
2500
3100
4400
5300
13,506
25,000
0
200
1 Inch = 200 ft.


DEPTH BELOW GROUND SURFACE (FEET)
0
100
200
SP101
SP104
SP105
SP108
2083
2941
3200
2200
1600
3000
4375
6000
6600
6400
6700
5500
12,500
18,000
16,000
16,400
0
200
1 Inch = 200 ft.


DEPTH BELOW GROUND SURFACE (FEET)
0
100
200
SP 109
SP 114
3333
7143
13,371
3571
7143
5747
14,031
15,385
3846
4167
6119
5271
17,913
17,913
1923
4274
9685
0
200
1 Inch = 200 ft.



DEPTH BELOW GROUND SURFACE (FEET)
SP 117
SP 118
0
100
200
2800
2800
1500
7500
14,200
SP 119
SP 123
2558
2632
2632
2273
15,000
5072
14,500
13,300
16,666
SP 128
SP 127
3333
3571
10,000
9091
17,321
SP 125
SP 126
3571
3846
4545
6250
15,903
14,500
0
200
1 Inch = 200 ft.



SP 131
SP 134
0
100
200
5400
4300
8400
11762
DEPTH BELOW GROUND SURFACE (FEET)
SP 135
SP 138
1389
1389
1429
1389
4300
4400
4900
5300
7200
7300
0
200
1 inch = 200 ft.

APPENDIX 4. THICKNESS OF UNCONSOLIDATED OVERBURDEN OF SELECTED WELLS

Well No. (See Plate 2)	Thickness of Overburden (feet)	New Jersey State Permit No.	Owner Name
1	135	22-16315	Andradi
2	122+	22-10042	Bell
3	133	22-11472	Berry
4	100	22-17273	Brandell
5	218+	22-14819	Denigris
6	144	22-7163	Faber
7	94	22-73364	Fenwick Machinery
8	93	22-7019	F.G.R. Holding Co.
9	98+	22-10136	Joseph Ganter
10	97+	22-10896	Hill
11	153+	22-16469	Hornsman
12	103+	22-12853	Jaffree
13	196+	22-11380	Koeppe
14	108+	22-7068	McLachlan
15	104	22-10154	Montagnino
16	100+	22-9324	Moritz
17	147+	22-11634	Phed Enterprises, inc.
18	109+	22-10495	White Birch Homes, Inc.
19	175	22-16866	Proctor
20	85+	22-8332	Remesi
21	113	22-8340	Smykla
22	134+	22-16589	Snyder
23	200	22-16763	Wilk
24	79+	22-15079	Churn
25	66+	25-13584	Goldblatt
26	80+	25-13784	Jayne
27	75+	25-15191	Knipper
28	135+	25-19330	Loftus
29	50	22-6900	Bobby's Acre, Inc.
30	22	22-16761	Dock's Bar & Grill
31	225*	22-8994	Emerson
32	86+*	---	Hillman
33	120+	---	Little
34	92	22-6938	Jezek
35	48	22-4662	Lakeland (Assoc.)

*No driller's log available; depth determined from well record or personal communication.

Thickness of unconsolidated overburden of selected wells.

Well No. (See Plate 2)	Thickness of Overburden (feet)	New Jersey State Permit No.	Owner Name
36	92+	22-9486	Linden Estates, (Inc.)
37	73	22-7260	Spann
38	59	22-9320	Newfoundland Methodist Church
39	93	---	Dairy Queen
40	140+	22-18344	Carpenter
41	180	22-9218	Clark
42	147+	22-5394	Condit
43	130+	22-9219	Constant
44	146+	22-9826	DeJonge
45	115+	22-10404	Graveman
46	157+	22-6906	Hollenback
47	200	22-9108	Johnson
48	168+	22-9108	Kutter
49	123+	---	Reinhardt
50	141+	22-5856	Schneider
51	102+	22-7924	Smith
52	135+	22-7924	Steiger
53	154+	22-8417	Weaver
54	105+	25-9396	Boonton Radio Corp.
55	70	25-9626	" "
56	119	25-9587	" "
57	74+	25-13968	Flynn
58	135+	25-14341	Le Jay Construction
59	122+	25-14343	Co.
60	132+	25-15004	" "
61	140+	25-15005	" "
62	123+	25-15021	" "
63	135+	25-15028	" "
64	185+	25-20692	Welen, Inc.
65	199+	25-12385	Vandehoof
66	290	25-11371	Concrete Industries, Inc.
67	120+	---	Hercules Powder Co. (Harrison Well)
68	45+	---	Hercules Power Co. (Wells No. 2, 3, 4, 8, 9)
69	116	---	Hercules Power Co. (Well No. 1)
70	100+	25-16961	Central R.R. Co.

Thickness of unconsolidated overburden of selected wells.

Well No. (See Plate 2)	Thickness of Overburden (feet)	New Jersey State Permit No.	Owner Name
71	196+	25-14187	Nazarene Church
72	182+	25-17336	Denwood Homes Inc.
73	118+	25-17918	Anthony Donofrio
74	173+	25-15241	Kenvil Newcrete Products
75	140+	25-15648	Lakeland Animal Hospital
76	220+	25-17468	Elfrieda Monroe
77	200+	25-16845	George Billy
78	180+	25-17613	Osman & Angela Naim
79	236+	25-20819	Jose Rivera

Thickness of unconsolidated overburden of selected wells.

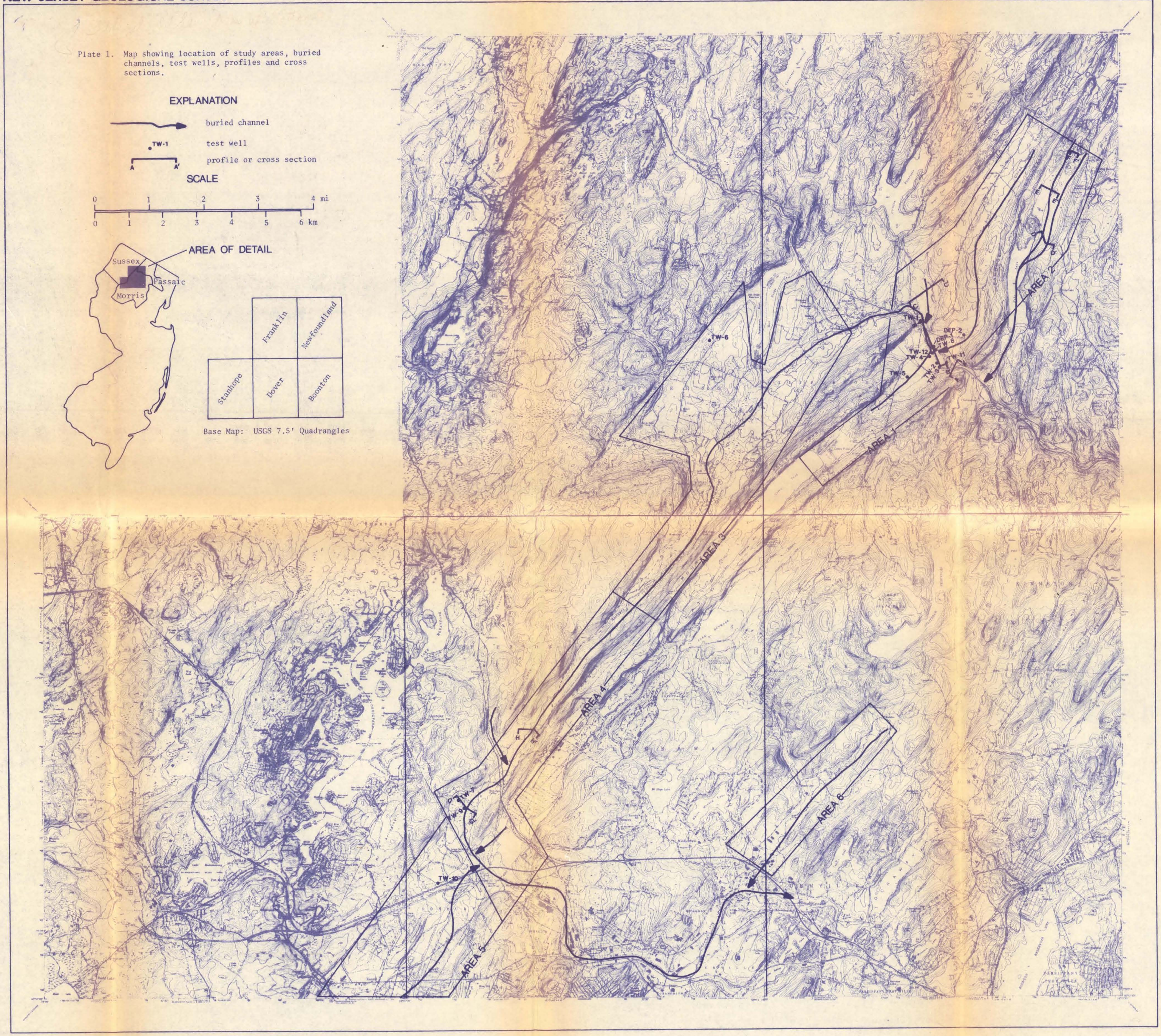


Plate 1. Map showing location of study areas, buried channels, test wells, profiles and cross sections.
EXPLANATION
buried channel
TW-1
test well
A
A'
profile or cross section
SCALE
0 1 2 3 4 mi
0 1 2 3 4 5 6 km
AREA OF DETAIL
Sussex
Passaic
Morris
Franklin
Newfoundland
Stanhope
Dover
Boonton
Base Map: USGS 7.5' Quadrangles
AREA 1
AREA 2
AREA 3
AREA 4
AREA 5
AREA 6
TW-6
TW-5
TW-12
TW-7
TW-10
TW-11
DEP-2

Plate 2. Map showing location of study areas, seismic traverses and selected domestic and industrial wells.

EXPLANATION

SP 70 — SP 69 seismic traverse (refers to Appendix 3)

• 76 domestic or industrial well (refers to Appendix 4)

SCALE

0 1 2 3 4 mi

0 1 2 3 4 5 6 km

Base Map: USGS 7.5' Quadrangles