HYDROGEOLOGY OF THE CANAL CREEK AREA,

ABERDEEN PROVING GROUND, MARYLAND

By James P. Oliveros and Don A. Vroblesky

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ILLUSTRATIONS

CONVERSION FACTORS AND ABBREVIATIONS

For the convenience of readers who may prefer to use International System (SI) units rather than the inch-pound units used in this report, values may be converted by using the following factors:

Multiply inch-pound units	by	To obtain SI units
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
foot per day (ft/d)	0.3048	meter per day (m/d)
foot per year (ft/yr)	0.3048	meter per year (m/yr)
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)
cubic foot per day (ft^3/d)	0.02832	cubic meter per day (m^3/d)
cubic foot per year (ft^3/yr)	0.02832	cubic meter per year (m^3/yr)
mile (mi)	1.609	kilometer (km)
gallon (gal)	3.785	liter (L)
	0.003785	cubic meter (m^3)
gallon per minute (gal/min)	0.06308	liter per second (L/s)
	0.003785	cubic meter per minute (m^3/min)
pound per square inch (psi)	6895	Pascal (Newton/square meter) (N/m^2)

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

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ABSTRACT

Geologic logs and geophysical logs of boreholes made at 77 sites show that the hydrogeologic framework of the Canal Creek study area, Edgewood area of Aberdeen Proving Ground, Maryland, consists of a sequence of unconsolidated clay, silt, sand, and gravel deposits typical of the Coastal Plain of Maryland. Three aquifers and two confining units were delineated in the study area: (1) the surficial aquifer, (2) the upper confining unit, (3) the Canal Creek aquifer, (4) the lower confining unit, and (5) the lower confined aquifer. The surficial aquifer and the Canal Creek aquifer are hydraulically connected because of the cropping out of the upper confining unit within the study area, and the presence of a sand-filled paleochannel where the upper confining unit was eroded. The potential for vertical ground-water flow between aquifers is high and may increase under pumping stress.

Currently, no pumping stresses are known to affect the aquifers within the study area. Under current conditions, downward vertical hydraulic gradients prevail at topographic highs, and upward gradients typically prevail near surface-water bodies. Regionally, the direction of ground-water flow in the confined aquifers is to the east and southeast. Significant water-level fluctuations correspond with seasonal variations in rainfall, and minor daily fluctuations reflect tidal cycles.

INTRODUCTION

Background

The Edgewood area of Aberdeen Proving Ground (APG), Maryland (fig. 1), has been used to develop and manufacture military-related chemicals since World War I. Ground water has been contaminated as a result of the various manufacturing activities and the disposal of wastes that have occurred over the last 70 years. In 1984, the Maryland Department of Health discovered ground-water contamination by volatile organic compounds in several water-supply wells; however, the extent of the contamination was unknown.

The U.S. Geological Survey is conducting a 5-year study of the Canal Creek area for the Environmental Management Office of APG, U.S. Department of Defense. The study includes evaluation of the hydrogeology of the area, the type and degree of ground-water contamination from past activities in the area, and the possible hydrologic effects of various remedial actions.

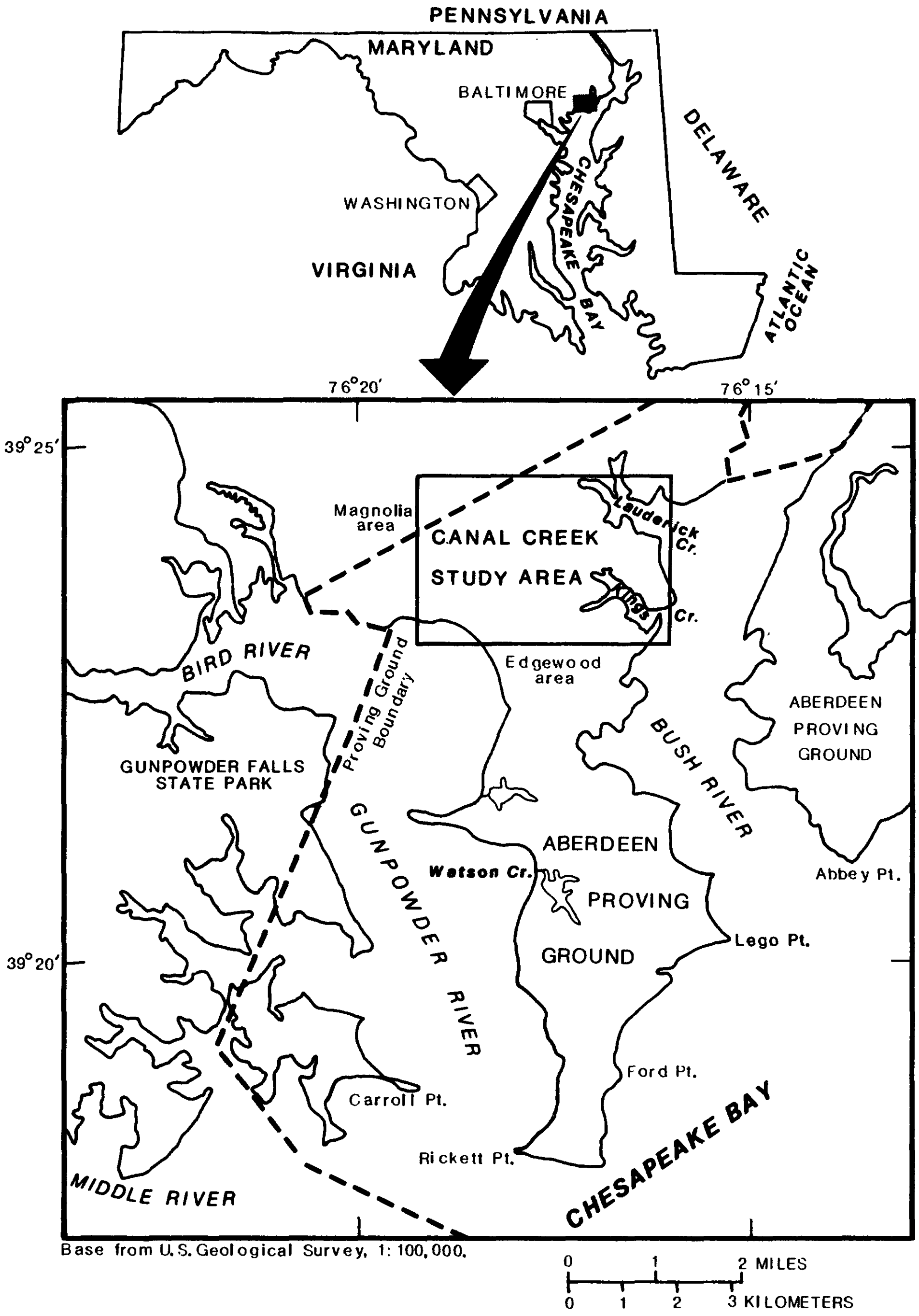


Figure 1.--Location of the Canal Creek study area.

Heavy pumping stresses were placed on the ground-water system during 1950-68 by several manufacturing plants located in the Edgewood area. Data from a ground-water-level recorder located near several of the pumped wells show that the previous flow system was dominated by a cone of depression around the pumped wells. According to facility records, most of the waste disposal occurred during the time of heavy pumpage (1950-68).

The movement of ground water was probably different under pumping stress than under the present unstressed conditions. Flow velocities were probably much higher and flow directions may have been reversed in some parts of the aquifer because of the cone of depression that formed around the pumped wells. The water levels rose substantially after 1968 when heavy pumping ceased and the wells were used only occasionally to supplement water supplies.

Purpose and Scope

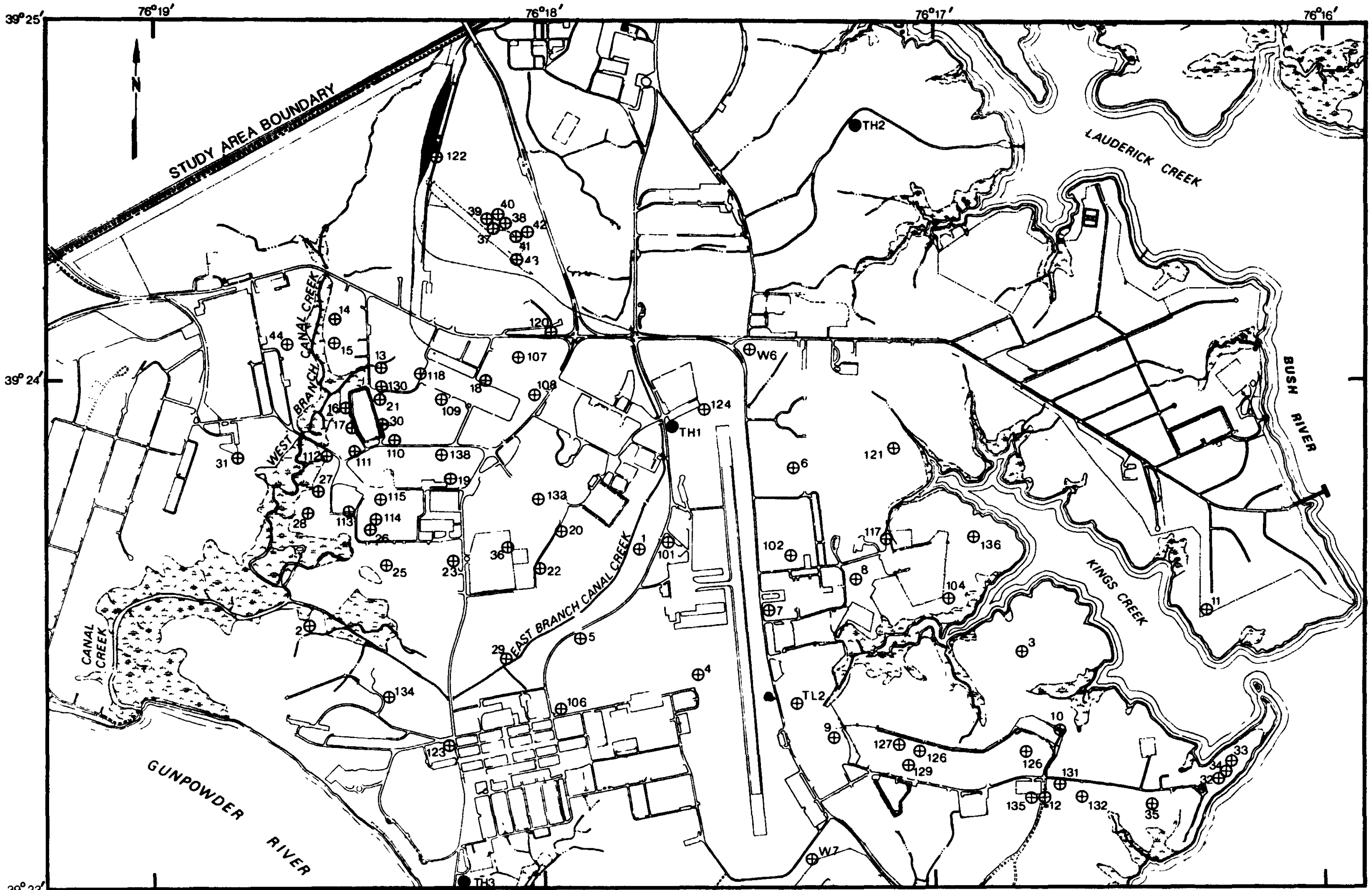
This is one of three reports presenting the findings from drilling operations and the first phase of data collection. This report describes the hydrogeology of the Canal Creek study area (fig. 1). Specifically, the report:

1. Delineates the aquifers and confining units in the Canal Creek study area.
2. Describes the lithologies of the sediments comprising the aquifers and confining units.
3. Evaluates the ground-water flow system, including the description of the hydraulic head distribution, flow direction, and hydraulic properties of each aquifer.

The study area includes those areas drained by the East and West Branches of Canal Creek as well as part of the area drained by Kings Creek (figs. 1 and 2).

Each drill site was assigned a number and any well installed at the site was given the same site number. If more than one well was installed at a site (well cluster), each well was assigned a site number followed by a letter, with the letter corresponding to the relative depth of each well. For example, site 5 contains wells 5A, 5B, and 5C, where 5A is the shallowest well and 5C is the deepest. A total of 149 wells were installed at 75 drill sites in two phases of drilling. In the event that a drill site was only used for test boring, the site was assigned a number preceded with a "T", such as drill sites T1, T2, and T3 (fig. 2).

In the first phase, test borings were made at 17 sites, geophysical logs were made of 42 boreholes, geologic logs were documented at 42 sites, and 87 wells were installed at 42 sites. In the second phase, 23 test holes were drilled, geophysical logs were made of 29 boreholes, geologic logs were documented at 31 sites, and 62 additional wells were installed at 33 sites. Numbered sites showing the locations of test borings and wells are shown in figure 2.



Base modified from Edgewood map, Engineering Plans and Services Division, Aberdeen Proving Ground, 1984

0 500 1000 2000 FEET
0 300 600 METERS

EXPLANATION

TH2 ● Test boring location and number

133 ⊕ Test boring location and number where well was later installed.

Figure 2.--Location of test borings and wells.

Water levels were monitored at the study area to collect data for hydrographs and hydraulic head contour maps. Continuous water-level recorders were installed on wells 1A, 1B, 1C, 1D, 7A, 8C, 16A, and 18B. Four synoptic water-level measurements were made; the last two synoptic measurements included all of the second-phase wells. Contour maps were constructed for three hydrogeologic contacts and unit-thickness maps were constructed for the surficial aquifer and the confining units. Five hydrogeologic sections were drawn from the lithologic and geophysical data. Slug tests were performed in 25 wells. Data used in this report were collected between January 1986 and April 1988.

Previous Investigations

The U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) conducted a surface- and ground-water investigation of several sites at the Edgewood area, including the area covered by the Canal Creek study area (Nemeth and others, 1983). Fourteen shallow wells were installed and sampled for several constituents including heavy metals, toxic-agent breakdown products, base-neutral organic compounds, and volatile organic compounds. Twelve surface-water and bottom-sediment sites also were selected and sampled for the same constituents. Sampling revealed the presence of "white phosphorus" (WP) in the water and sediment in the upper reaches of Canal Creek; however, no WP was detected in the lower reaches. Although no other contamination was mentioned as significant, Nemeth and others (1983, p. 4-3) concluded, "due to the limited number of wells utilized to monitor the Canal Creek area, the possiblity of localized pockets of contamination cannot be eliminated."

The U.S. Army Environmental Hygiene Agency (USAEHA) sampled several streams within the study area and detected volatile organic compounds at several locations (U.S. Army Environmental Hygiene Agency, 1985). In 1985, the USAEHA began a detailed assessment of past activities in the Edgewood area to identify potential sources of contamination (Gary Nemeth, U.S. Army Environmental Hygiene Agency, written commun., 1988). Historical records were examined and interviews of past employees were conducted to assess the environmental effects of known chemical discharges and spills. Much of this information was used to assist in locating observation-well clusters for this study.

Acknowledgments

Many people outside the U.S. Geological Survey made contributions to this investigation. Thanks are given to Cynthia L. Couch and David Parks of the Office of Environmental Management, APG, for their support of the study. Thanks are also given to personnel of the U.S. Army Technical Escort Unit, APG, for providing support during well-drilling operations, and to the U.S. Army Corps of Engineers for installing observation wells.

METHODS OF INVESTIGATION

Well Drilling and Collection of Lithologic Data

The methods used for drilling wells and test borings were designed to (1) install observation wells with minimal disturbance of the aquifer system, (2) collect lithologic and geophysical data from each site, and (3) limit the use of drilling fluids. Two drilling techniques--mud rotary and hollow-stem augering--were used for well installation in the Canal Creek study area. Both techniques were used at some sites to maximize core recovery. In most cases, more than one well was drilled at each site, and the depths of the wells differed with location. More than one observation well was placed within an aquifer if it contained a clay lens or if the sand was thicker than 15 ft. An exploratory boring was drilled at each site so that geophysical and lithologic data could be used to define the hydrogeologic framework and to optimize observation-well screen placement.

Exploratory borings and most wells deeper than 120 ft were drilled by the mud-rotary technique. An organic-free bentonite mud was used to minimize organic contamination of the ground water by the drilling fluid. After the geophysical data were collected, all exploratory borings were grouted from the bottom upward using Type V Portland Cement[1]. The grouting process evacuated the drilling mud and sealed the borehole.

Hollow-stem augers require no drilling fluids, eliminating contamination of the aquifer from drilling fluid constituents. During the first phase of drilling, 10-in.-outside-diameter hollow-stem augers were used to install observation wells less than 120 ft deep--the approximate depth limit of the augering. During the second phase, a more powerful augering rig, using 10-in.-outside-diameter hollow-stem augers, was used to install the deeper wells.

Using the hollow-stem auger technique, samples of the formation were taken with a core-barrel sampler that was inserted into the bottom of the auger column and advanced with the augers. This technique yielded excellent core recovery in clay, silt, and tightly packed sand. The resulting samples were approximately 5 ft long and 4 in. in diameter. Detailed lithologic descriptions of the core samples were made at the site by U.S. Geological Survey personnel using a hand lens with a magnification of 10 times and a grain-size comparison chart. Samples were collected and placed in glass jars for subsequent examination. Several samples of the clay were submitted for pollen analysis to determine the geologic age of the sediments.

Frequently, zones of coarse, wet sand, or "running sand," were encountered. It was difficult to retain the samples in the core barrel and the core recovery was commonly poor. Moreover, in areas of particularly fluid sand, the sand would rise into the augers when the sampling tube was removed, making it difficult to replace the core barrel properly. Generally, once running sand was encountered, drilling proceeded without sampling until a more cohesive sediment was reached.

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[1] The use of trade names is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

Using the mud-rotary drilling technique, samples of the formation were collected using a 2-ft-long, 2-in.-diameter split-spoon sampler. Although the technique is slower and yields relatively small samples, zones of "running sand" can be sampled more easily than with the core-barrel sampler used in augering. In some cases where running sand inhibited sample collection during augering, a mud boring was later drilled and samples were collected with the split-spoon sampler. Samples from the formation below 120 ft could only be collected with the mud-rotary drilling technique using the split-spoon sampler during the first phase of drilling.

The construction of a typical well is shown in figure 3. Polyvinyl chloride (PVC) 4-in.-outside-diameter casing and screens were used for all the wells. Five-ft-long screens with a slot size of 0.01 in. were used in all but two of the wells. Three 2-ft-long screens were used in wells 4A and 5C. The screened intervals in well 4A were located at depths of 88 to 90 ft and 95 to 99 ft, and the screened intervals in well 5C were located at depths of 73.5 to 75.5 ft, 80.5 to 82.5 ft, and 83 to 85 ft. The odd-screened intervals were placed to experiment with various well-purging techniques. Quartz sand-pack material was placed from the bottom of the screen up to 12 in. above the top of the screen, and 12 to 24 in. of bentonite pellets were placed on top of the sand pack to prevent the grout from reaching the screen.

A grout seal was placed around the outside of the casing from the top of the bentonite plug up to land surface to prevent the vertical movement of water along the casing and cross-contamination between the aquifers. The casing was grouted with a mixture of 96-percent Type V Portland Cement and 4-percent bentonite that was injected just above the bentonite plug. By injecting the grout from the bottom upwards, the water around the outside of the casing was evacuated as the grout was injected, resulting in a more uniform grout seal.

Borehole Geophysics

Borehole geophysical techniques were used at each site to aid in observation-well screen placement and to supplement the lithologic data collected during drilling. Single-point electric logs and natural-gamma logs were run in each boring drilled with mud, but only natural-gamma logs were run in augered borings. In most cases, single-point electric logs correlated well with natural-gamma logs. Because single-point electric logs were limited to mud-drilled borings and natural-gamma logs correlated well with lithologic logs, the single-point electric logs were not used in geologic interpretation other than to verify deflections in the natural-gamma logs which were considered suspect. Natural-gamma logs made through hollow-stem augers were useful, although some interference was encountered when clay adhered to the outside of the augers and was displaced into sand zones.

Lithologic data were collected at most sites and natural-gamma logs were made of all borings. After comparing the natural-gamma logs with lithology from several sites, it was discovered that there was a good correlation between the two. Sand and clay were precisely plotted on the gamma log and a vertical line, or "sand line", was drawn through the gamma log, separating the sand deflections on the left from the clay deflections on the right (fig.4).

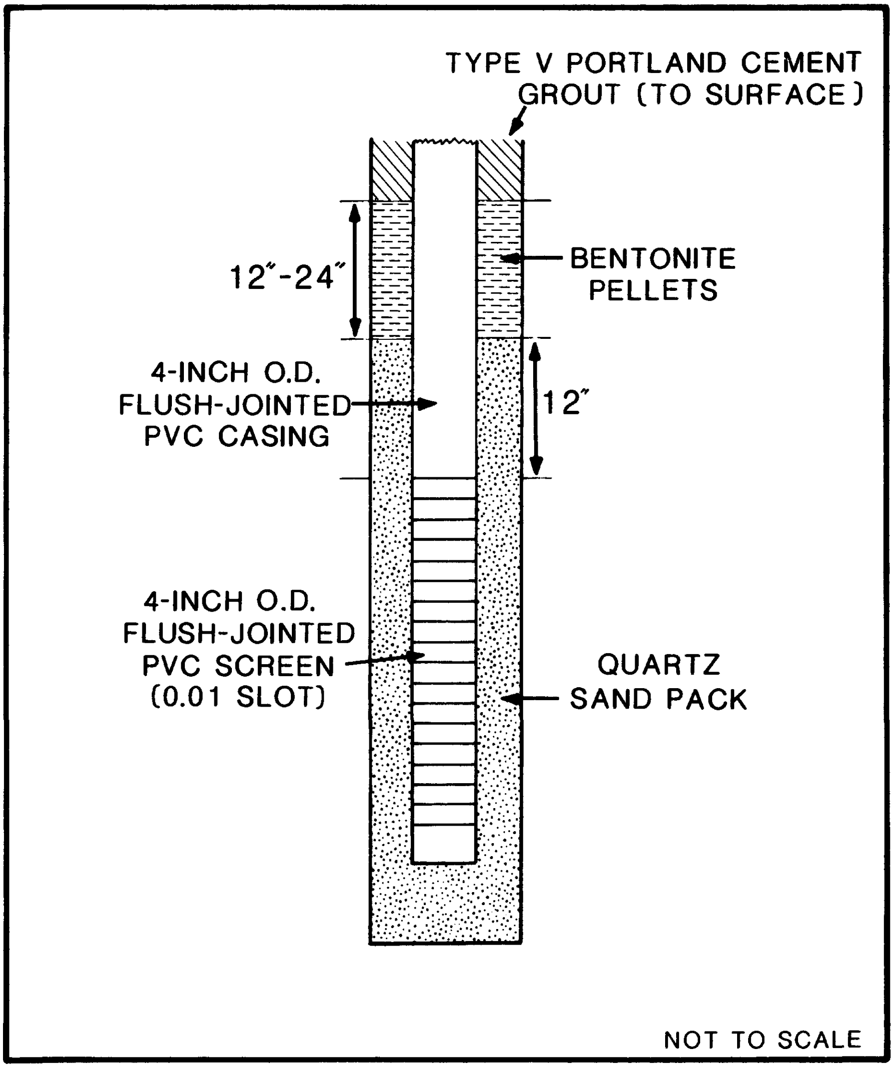


Figure 3.--Typical well construction.

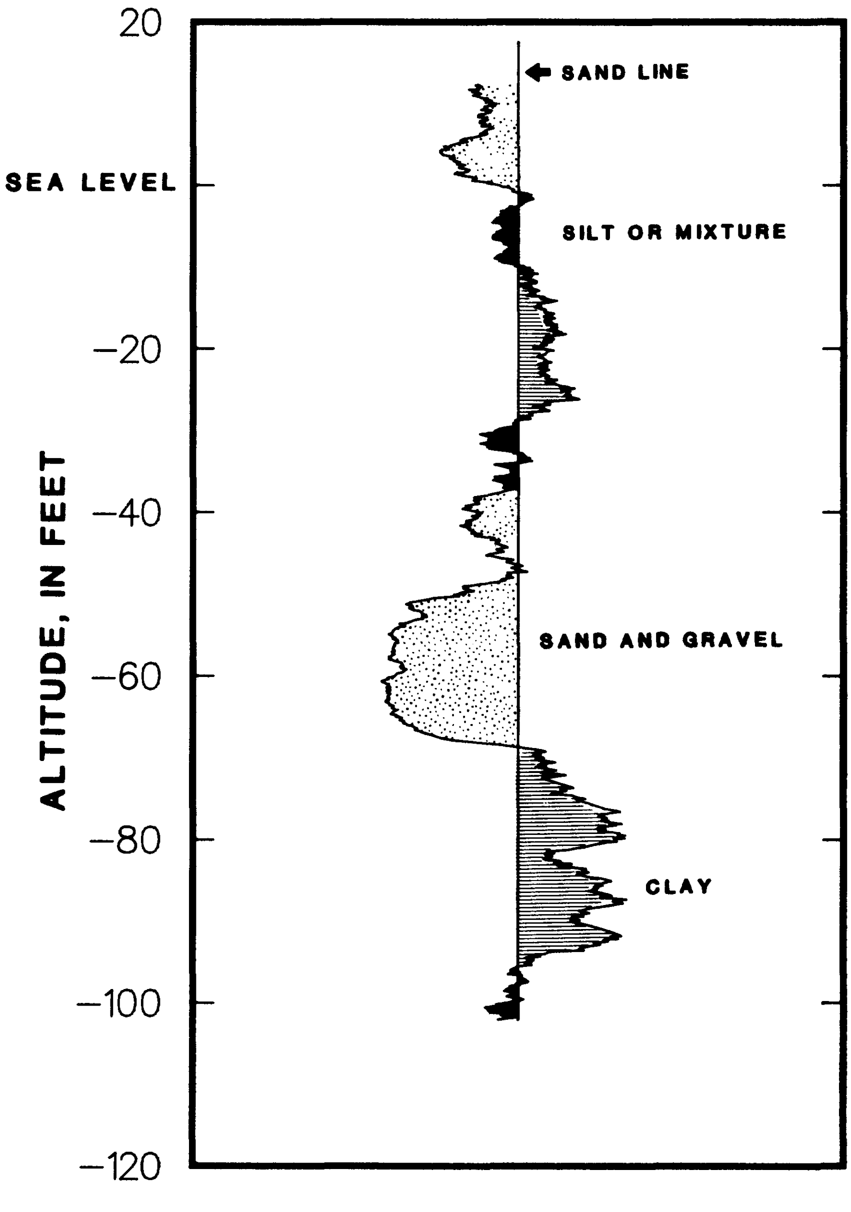


Figure 4.--Relation between the gamma-log and lithologic-log data from site 5.

Sand and clay characteristically caused strong deflections and silt or mixtures of sand and clay caused weak deflections. Intervals where lithologic samples were not collected were inferred using the natural-gamma logs.

Water-Level Measurements

Water-level measurements of all existing wells were made in November 1986, February 1987, August 1987, and March 1988. Data from August 1987 and March 1988 (representing the seasonal extremes in water levels) are used in this report. The data were used to produce seasonal water-level maps for each aquifer and to establish vertical hydraulic-head gradients within well clusters.

Digital water-level recorders, accurate to 0.01 ft, were installed at sites 1, 7, 8, 16, and 18 to record water levels at 15-minute intervals. The water-level recorders made it possible to monitor the tidal and seasonal head fluctuations in each aquifer, as well as the tidal and seasonal effects on vertical head gradients within well clusters. Tidal data were collected at a station installed in Gunpowder Falls State Park (fig. 1) using the same type of digital recorder with the same data-collection interval.

Aquifer Testing

Hydraulic conductivity was calculated for 15 wells in the study area by performing slug tests. A solid Teflon slug with a displacement volume of approximately 1.5 gallons was used for all tests. The slug was added to each well tested and the resulting water-level decline was recorded on a logarithmic schedule with a portable, digital data logger using a 5-pounds-per-square-inch pressure transducer. The data-collection schedule was tailored to each slug test, depending on the recovery time for the given well.

Hydraulic conductivity (K) was determined from the slug-test data by use of the Hvorslev (1951) analysis. The Hvorslev analysis operates on the basic principle that hydraulic conductivity is dependent upon the geometry of the well and a lag time (T_o), determined graphically from a semi-logarithmic plot of the slug-test recovery curve. Hydraulic conductivity is determined from the relation

$$K = \frac{r^2 \ln(L/R)}{2LT_o}$$

where

- K is the horizontal hydraulic conductivity (ft/d),
- T_o is the lag time (d),
- r is the radius of the well casing (ft),
- R is the radius of the well screen (ft), and
- L is the length of the well screen (ft).

Transmissivity (T) was then determined by multiplying horizontal hydraulic conductivity (K) by the aquifer thickness (b).

Although horizontal hydraulic conductivities were obtained from slug tests in 15 wells, slug tests in 10 wells produced anomalously low horizontal hydraulic conductivities. According to the drilling logs, the wells were screened in coarse sand and gravel, but the calculated hydraulic conductivities were less than 0.1 ft/d, much less than the expected 10 to 100 ft/d. Because of the anomalously low hydraulic conductivity values calculated from the suspect wells, it was suspected that the screens were obstructed with grout, drilling mud, or clay that had been deposited during well construction. Upon examination of several suspect wells with a down-hole camera, several screens were found to be obstructed with grout. Because it was uncertain to what extent the suspect wells were obstructed, the test results for the suspect wells were disregarded.

Aquifer Delineation

Aquifers and confining units were delineated on the basis of both hydrologic characteristics of the units and the stratigraphic relations between the units. The lower confined aquifer and lower confining unit were easily delineated because they are relatively continuous over the study area. The remaining units were more difficult to separate because (1) the upper confining unit crops out within the study area, and (2) the upper confining unit is missing within a paleochannel (fig. 5). The Canal Creek aquifer and the surficial aquifer are in direct hydraulic connection within the paleochannel and near the West Branch of Canal Creek; however, the distinction was made from hydrologic data indicating a divergence in flow, rather than by lithologic characteristics.

The lateral continuity of the surficial and Canal Creek aquifers was maintained in defining the lower boundary of the surficial aquifer and the upper boundary of the Canal Creek aquifer. For the purpose of contouring the thicknesses and boundary elevations of the unit, the boundary between the two aquifers was extrapolated in areas where the upper confining unit is missing.

HYDROGEOLOGY

Regional Setting

Harford County, Maryland, encompasses two physiographic provinces--the Piedmont and the Coastal Plain. The Piedmont consists of crystalline, igneous and metamorphic rocks that crop out along a line called the Fall Line. East of the Fall Line, the unconsolidated Coastal Plain sediments overlie the much older Piedmont basement rocks. The Coastal Plain sediments thicken rapidly southeastward from the Fall Line with a stratigraphic dip of approximately 40 ft/mi (Dingman and others, 1956 p. 12).

The Coastal Plain sediments in Harford County were deposited during the Cretaceous Period and the Pleistocene Epoch. Most of the unconsolidated sediments in Harford County comprise the Potomac Group, deposited during the Cretaceous Period. South of Harford County near Baltimore City, the Potomac

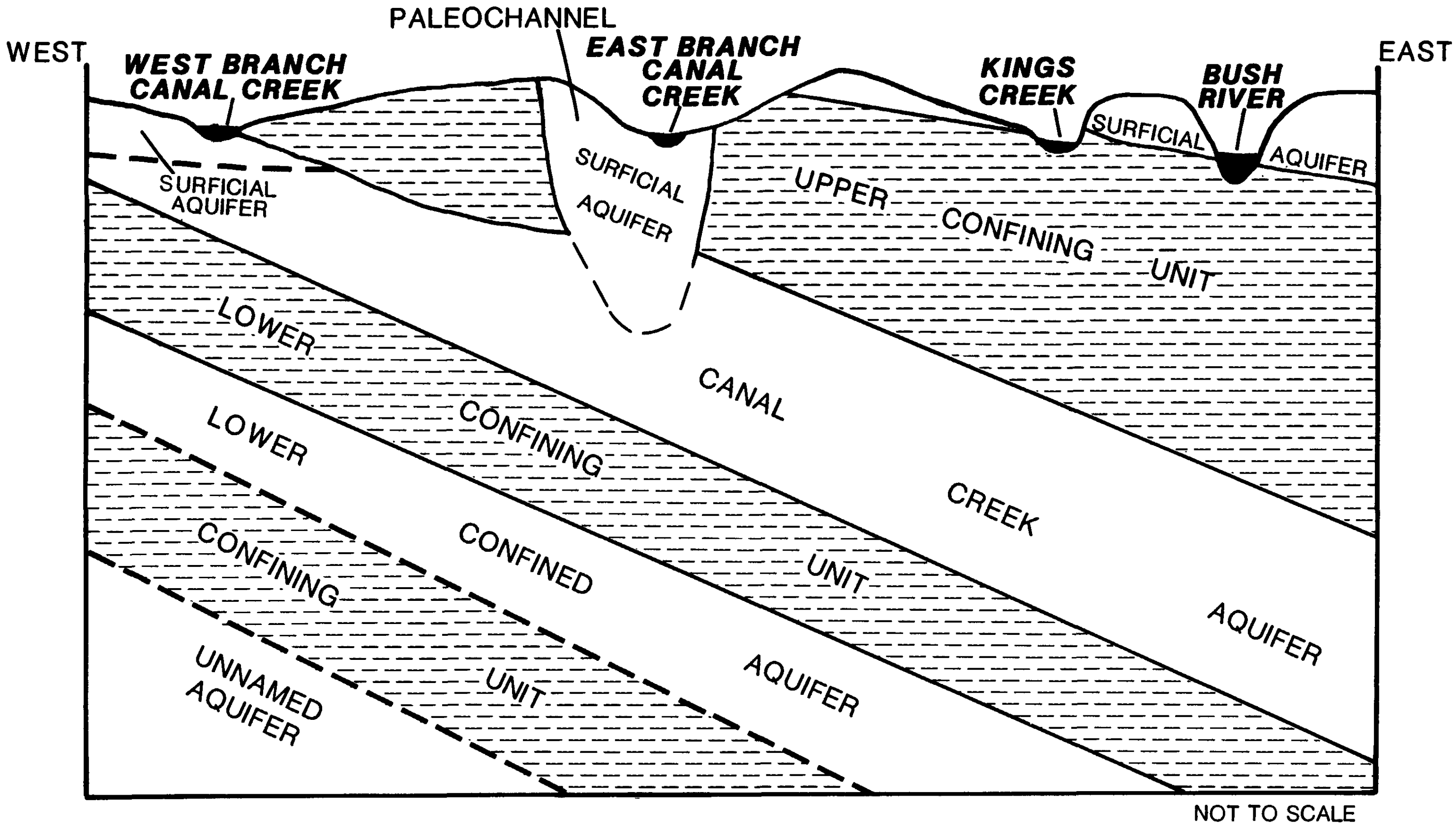


Figure 5.--Generalized hydrogeologic section of the Canal Creek study area.

Group is subdivided into the following three formations, listed from youngest to oldest: (1) the Patapsco Formation, (2) the Arundel Clay, and (3) the Patuxent Formation (Dingman and others, 1956, p. 12). The Arundel Clay serves as a confining unit between the water-bearing Patapsco and Patuxent Formations. In Harford County, the three formations are not easily distinguished and are referred to collectively as the Potomac Group.

The sediments that overlie the Potomac Group in Harford County consist primarily of the Talbot Formation of Pleistocene age with minor amounts of Quaternary alluvium. The Talbot Formation is relatively thin and horizontally discontinuous in its westernmost extent. The formation thickens and becomes more continuous eastward, reaching a thickness of approximately 60 ft north of the Edgewood area at the Aberdeen area of Aberdeen Proving Ground (Southwick and others, 1969, p. 96). The formation has been eroded by streams and rivers, exposing the underlying Potomac Group.

Local Geology

In Harford County, the Potomac Group is characterized by alternating sand and clay layers that can be identified as discrete aquifers and confining units. According to Southwick and others (1969), the Potomac Group crops out over much of the Canal Creek study area, especially near surface-water bodies. The aquifers are used as a source of water for various municipal and agricultural applications throughout the Coastal Plain of Harford County. The more productive wells yield as much as 500 gal/min (Dingman and others, 1956, p. 13).

The Talbot Formation covers most of the study area where the Potomac Group is not present at the surface, but some modern alluvium is present in the creek beds. Pollen analysis indicates that Cretaceous clay exists at a depth of approximately 25 ft at site 27 (Grace Brush, University of Maryland, written commun., 1987); therefore, 25 ft is the maximum thickness of the Talbot Formation near the West Branch of Canal Creek. South of the Canal Creek study area at an Army range area referred to as "O-Field," pollen analyses performed during a previous study indicate that the Talbot Formation is present at a minimum depth of 50 ft, suggesting that the Talbot Formation thickens to the south of the Canal Creek study area (Don Vroblesky, U.S. Geological Survey, written commun., 1988).

The Talbot Formation is thickest within the study area where it occurs as fill in a paleochannel that is cut to a depth of at least 50 ft into the Potomac Group sediments. The paleochannel resulted from the erosional activity of a Pleistocene stream. The abrupt change in lithology caused by the paleochannel creates complex hydrologic relations among the various aquifers. The location of the paleochannel deposits approximates the present course of the East Branch of Canal Creek (fig. 5). The uppermost confining unit is absent where the paleochannel deposits are present.

The Talbot Formation and the Potomac Group have similar mineralogies within the study area but differ in grain size and relative abundance of various minerals. The Talbot Formation generally is finer grained within the study area. The sand and gravel grains in both formations consist primarily of quartz; the fine-grained sand and silt fractions contain a large percentage of muscovite mica. Organic matter, present as lignite, also is abundant in the fine-grained sand and silt layers of both formations, and iron mineralization is found in sand and clay layers, commonly near the contacts between the sand and clay.

Dense, plastic clay is common in thin lenses in both formations. Clay from the Talbot Formation generally is gray; clay from the Potomac Group is a mixture of white, red, and multicolored clay. The multicoloring of the clay suggests that oxidized metals, especially iron, are present.

The total thickness of the Coastal Plain sediments in the eastern part of the Canal Creek study area is approximately 400 ft. An exploratory boring drilled near site 1 in 1942 encountered granite at a depth of 402 ft (Gary Nemeth, U.S. Army Environmental Hygiene Agency, written commun., 1985), and a recent boring at site TL2 encountered basement rock at approximately the same depth. At a location near the western border of the study area, basement rock was encountered at approximately 300 ft (Gary Nemeth, U.S. Army Environmental Hygiene Agency, written commun., 1988).

Local Aquifers and Confining Units

This report primarily discusses the Coastal Plain sediments that are shallower than 200 ft. The sediments have been divided into five hydrogeologic units that from the surface downward, are called the (1) surficial aquifer, (2) upper confining unit, (3) Canal Creek aquifer, (4) lower confining unit, and (5) lower confined aquifer (figs. 6-11).

Surficial Aquifer

The surficial aquifer is unconfined and is defined as the saturated part of the uppermost sand unit. The upper surface of the aquifer is taken as the average-annual altitude of the water table as measured over the last 2 years. Within the study area, the aquifer is composed of a relatively thin veneer (0 to 35 ft) of discontinuous sand and gravel. In some areas, the surficial aquifer is composed of sediments of both the Talbot Formation and the Potomac Group; however, over most of the study area, the surficial aquifer consists of the Talbot Formation.

Excavation and landfilling activities have altered the surficial sediments in some localities within the study area. The disturbed sediments are horizontally discontinuous, poorly sorted, clayey sands mixed with assorted fill material and organic matter. The undisturbed surficial sediments are discrete layers of horizontally continuous sand and clay.

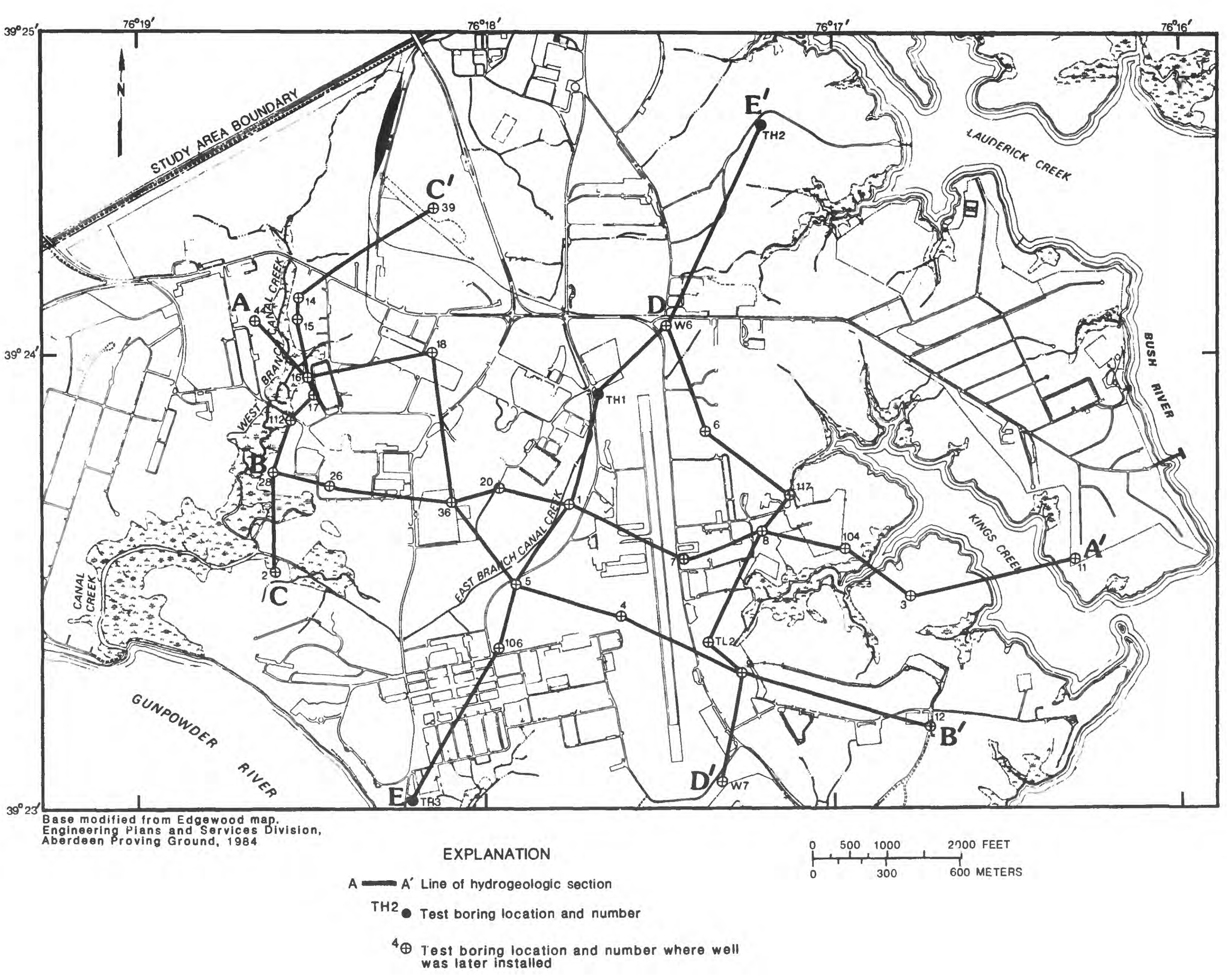


Figure 6.--Location of hydrogeologic sections.

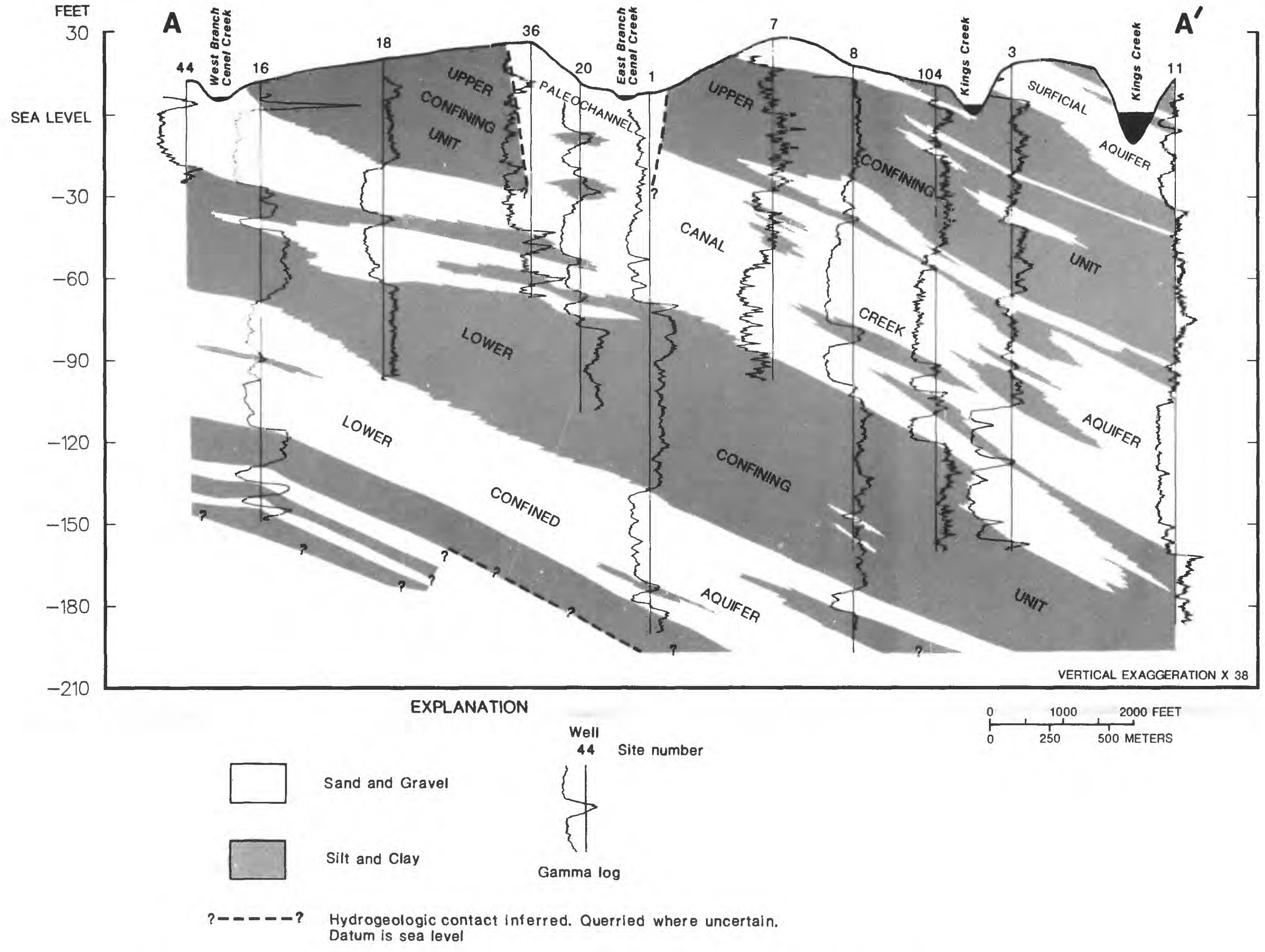


Figure 7.--Hydrogeologic section A-A′, line of section shown in figure 6.

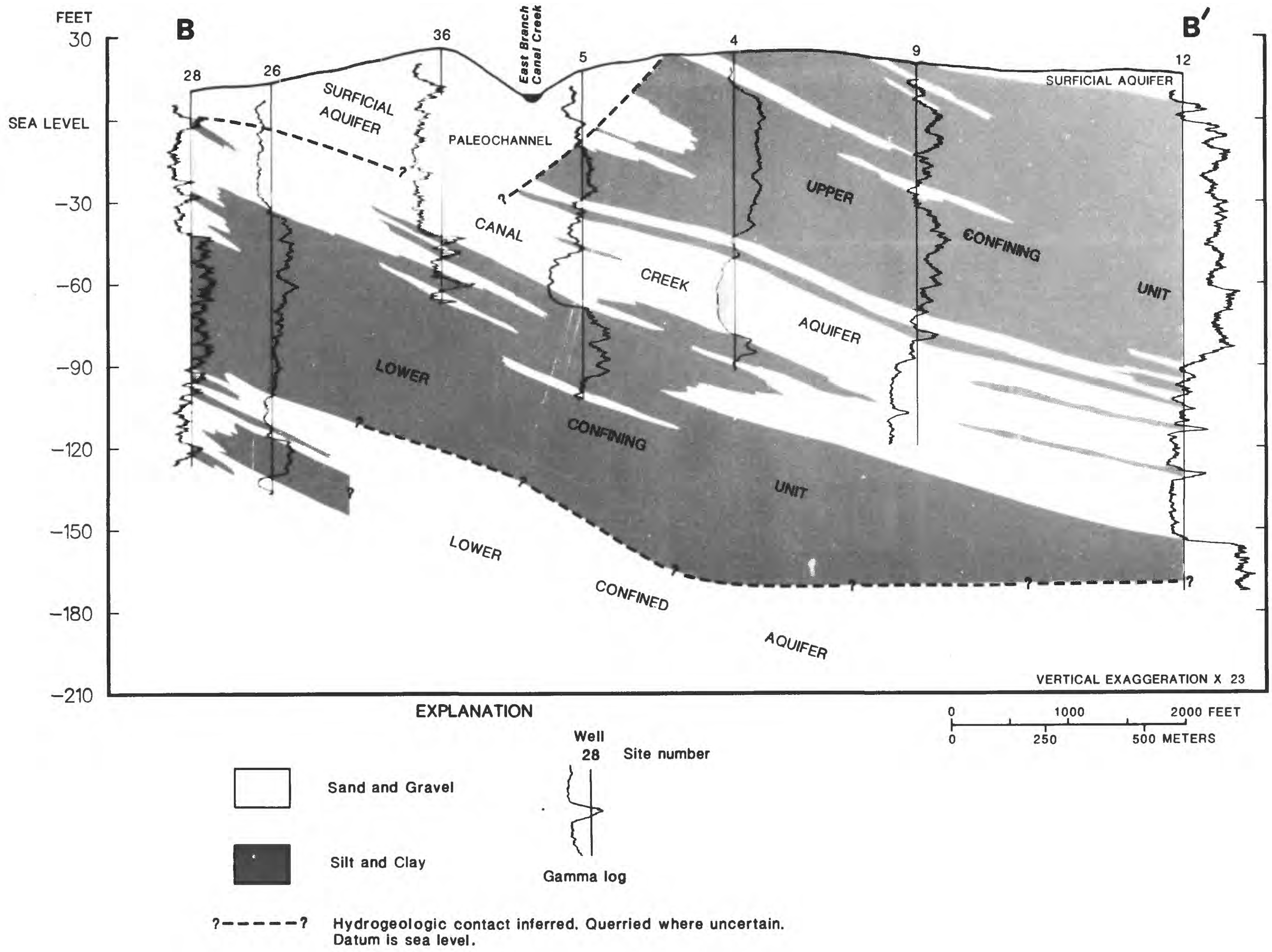


Figure 8.--Hydrogeologic section B-B′, line of section shown in figure 6.

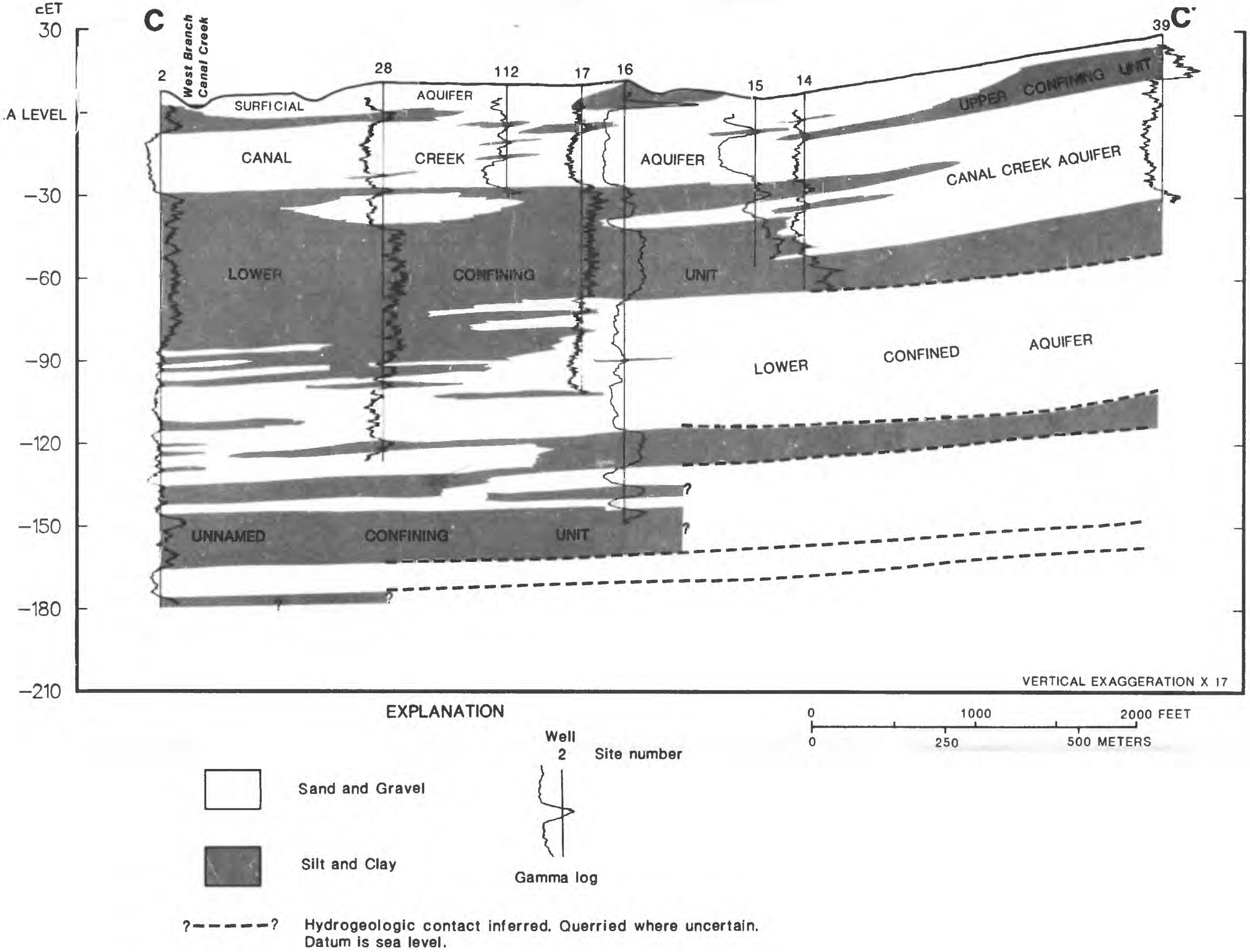


Figure 9.--Hydrogeologic section C-C′, line of section shown in figure 6.

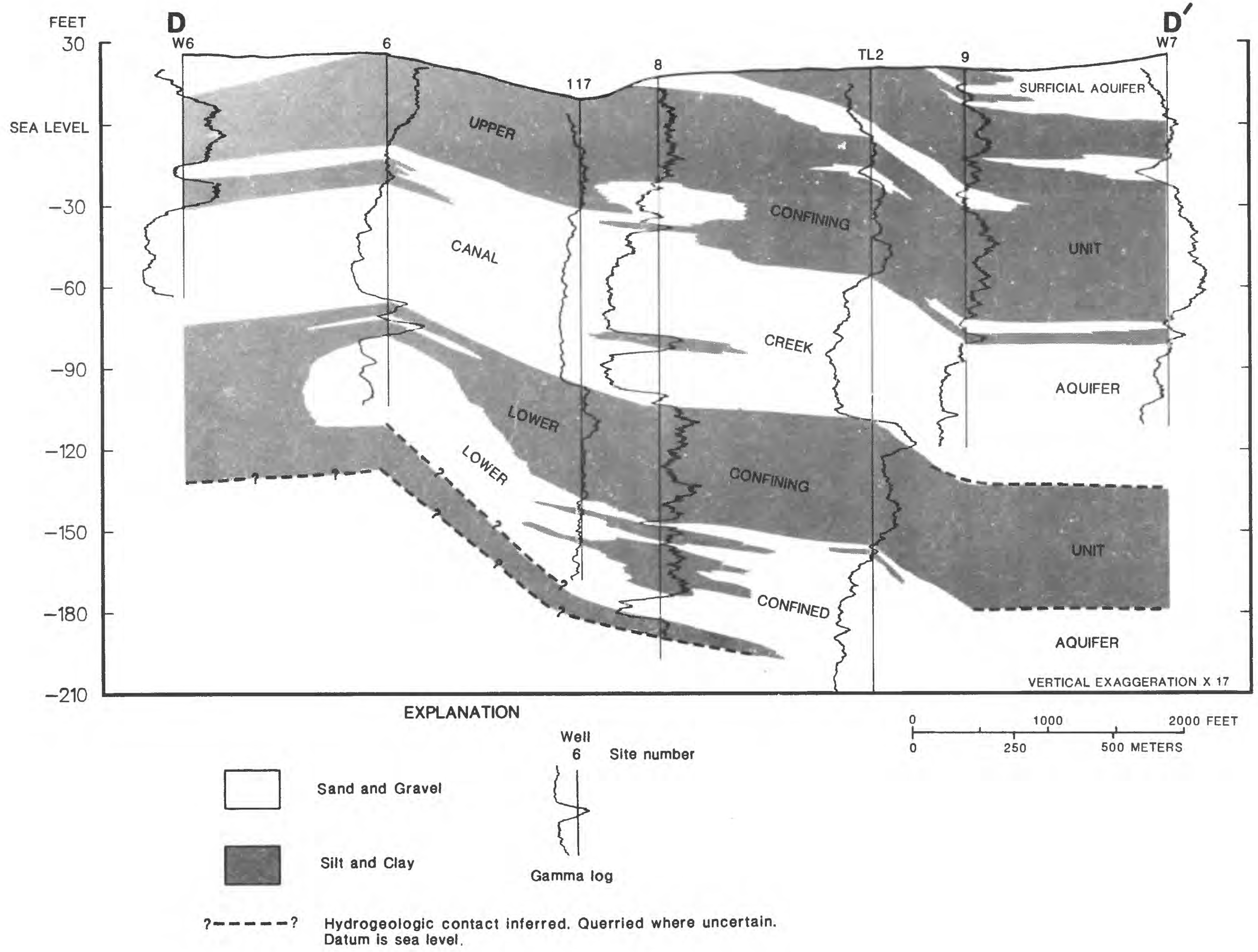


Figure 10.--Hydrogeologic section D-D′, line of section shown in figure 6.

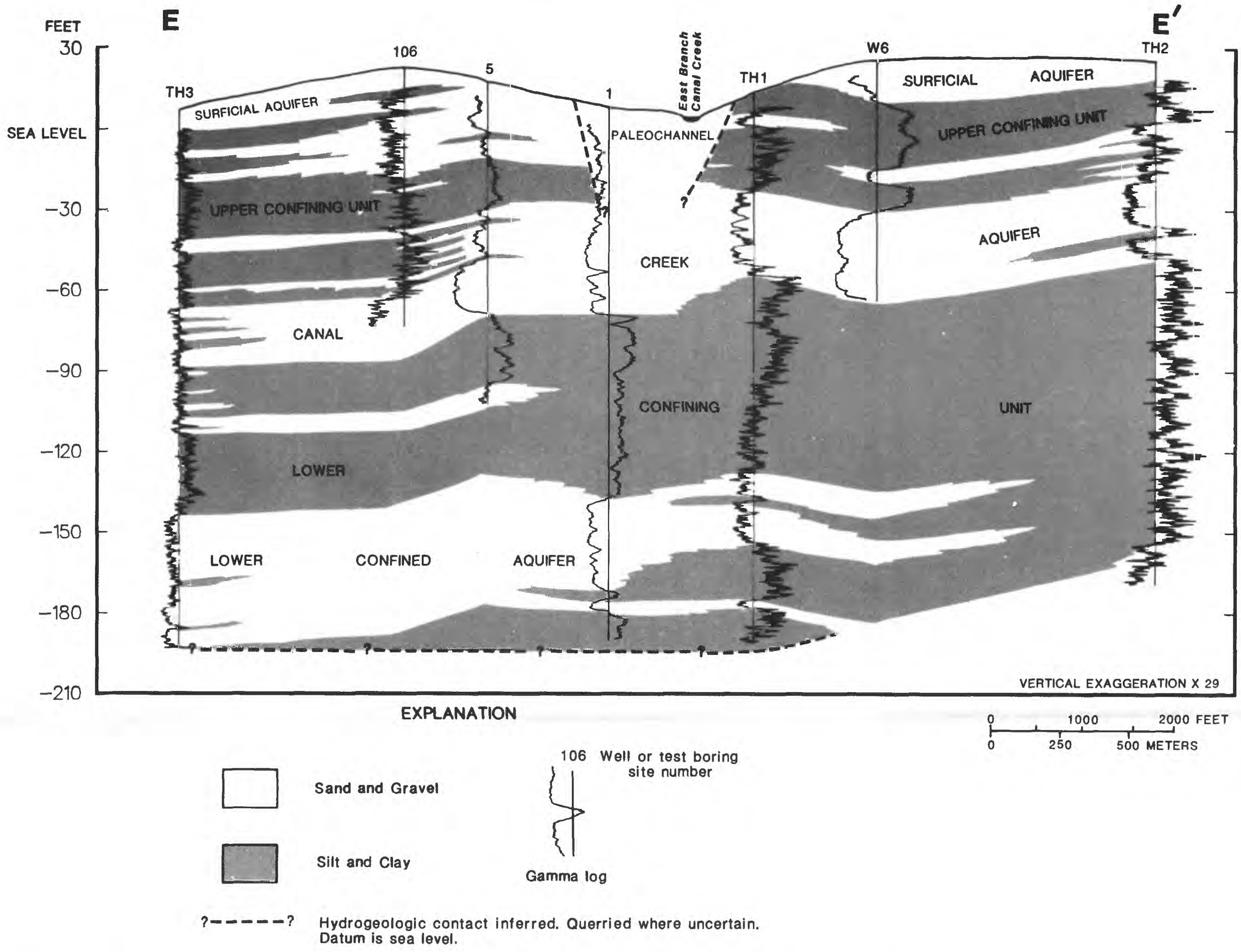


Figure 11.--Hydrogeologic section E-E′, line of section shown in figure 6.

The disruption of the materials comprising the surficial aquifer has had a major effect on the nature of ground-water flow. A lowering of aquifer transmissivity by the disruption and mixing of sand and clay layers may have occurred over much of the study area. Channelizing of ground water into storm drains, sewer lines, and channels created by buried debris may increase the overall aquifer transmissivity in some areas. Channels below the water-table may act as drains to the ground water, lowering the water table.

Lithology and extent

The lithology of the surficial aquifer is somewhat variable because the aquifer is composed of sediments from both the Talbot Formation and the Potomac Group. The aquifer generally is more coarse-grained along the West Branch of Canal Creek where the aquifer materials are dominated by the Potomac Group. In the eastern half of the study area, the surficial aquifer is comprised of sediments primarily of the Talbot Formation and is, therefore, finer grained.

The extent and thickness of the surficial aquifer is shown in figure 12. The surficial aquifer is continuous over the western half of the study area but is discontinuous and pinches out eastward. The aquifer is absent in a large northeast- to southwest-trending band where the upper confining unit crops out at the surface. The surficial aquifer is thickest near the West Branch of Canal Creek and in the paleochannel. An isolated part of the aquifer is present in the southeast quadrant, south of Kings Creek, but little aquifer material was found in the extreme eastern and northeastern parts of the study area.

Near the West Branch of Canal Creek, the surficial aquifer consists of fine-grained, orange to brown, poorly sorted, silty sand and gravel that ranges in grain size from silt to large cobbles (up to 3 in. in diameter). Thin lenses (up to 6 in. thick) of gray and orange, silty clay commonly are interfingered with the sand. A direct hydraulic connection exists between the surficial aquifer and the Canal Creek aquifer near the West Branch of Canal Creek because of the absence of the upper confining unit. The boundary between the two aquifers is not obvious and was identified at individual well sites on the basis of the presence of clay lenses and the hydrologic behavior of wells screened in the sand. The boundary does not necessarily correspond with the contact between the Talbot Formation and the Potomac Group.

An abrupt truncation of the upper confining unit was discovered near the East Branch of Canal Creek (fig. 6). Fairly well-sorted, fine- to coarse-grained sand is present at a depth of 85 ft at site 1. The sand is cleaner, shows better sorting, and is considerably thicker than sand elsewhere in the surficial or Canal Creek aquifers. The sand contains a few thin clay stringers and some lenses of gravel, but, otherwise, varies little in lithology.

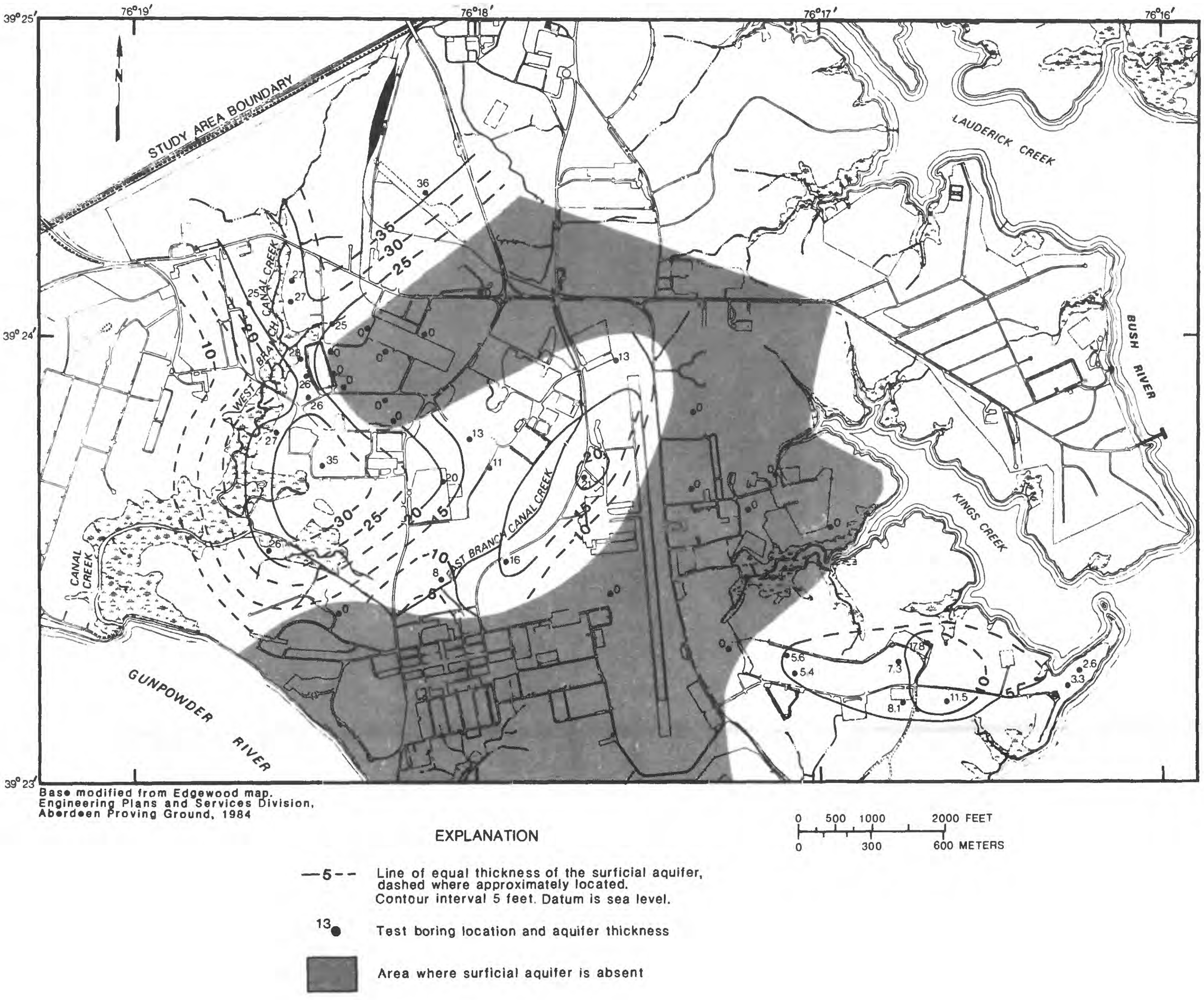


Figure 12.--Extent and thickness of the surficial aquifer.

An isolated part of the surficial aquifer is present in the southeastern quadrant of the study area (fig. 12). The upper confining unit is continuous and greater than 75 ft thick in the area. The aquifer consists of fine- to medium-grained, poorly sorted sand, interfingered with thin lenses of clay and silty sand.

Elsewhere in the study area, the surficial aquifer is less than 10 ft thick and consists mainly of poorly sorted, fine- to medium-grained sand that is commonly clayey or silty. The sand is interfingered with thin lenses of silt and clay that are horizontally discontinuous. The aquifer is essentially a thin, saturated soil zone with little horizontal continuity.

Hydrology

As a result of the interaction between the surficial aquifer and the Canal Creek aquifer, the hydrology of the surficial aquifer is complex. In parts of the Canal Creek study area, the upper confining unit is absent, resulting in a direct hydraulic connection between the unconfined local flow system of the surficial aquifer and the confined regional flow system of the Canal Creek aquifer (fig. 13). Recharge entering the surficial aquifer has the potential to enter either flow system in areas where the upper confining unit is missing.

Head distribution and direction of ground-water flow.--The head distribution in the surficial aquifer is typical of an unconfined, unstressed system. Ground-water flow generally is from topographic highs to topographic lows. Ground-water flow in the surficial aquifer is dominated by a local flow system in which recharge occurs at topographic highs and discharge occurs at topographic lows.

The surficial aquifer receives recharge from three sources: (1) infiltration from precipitation or surface water, (2) infiltration from leaky storm drains during high tides, and (3) vertically upward leakage from the Canal Creek aquifer. Surface infiltration from precipitation occurs in areas where there is a downward head gradient within the aquifer, most significantly at topographic highs. Recharge to the surficial aquifer through the many leaky storm drains that are below the high-tide mark occurs when the water table is also below the high-tide mark. Recharge from Canal Creek during high tide may be important during drought periods when the water table is lowest. Recharge to the surficial aquifer from the Canal Creek aquifer occurs where an upward head gradient exists between the two aquifers, generally near surface-water bodies.

The surficial aquifer discharges to (1) surface-water bodies, (2) the surface water through leaky storm drains, and (3) the Canal Creek aquifer in areas of vertically downward head gradients. Discharge to surface-water bodies occurs through streambanks, the bottom sediments, and low-lying marshes where the head gradient within the aquifer is upward. Discharge into leaky sewers and storm drains occurs when the altitude of the water table is higher than that of the bottom of a given sewer or storm drain. In most areas, the

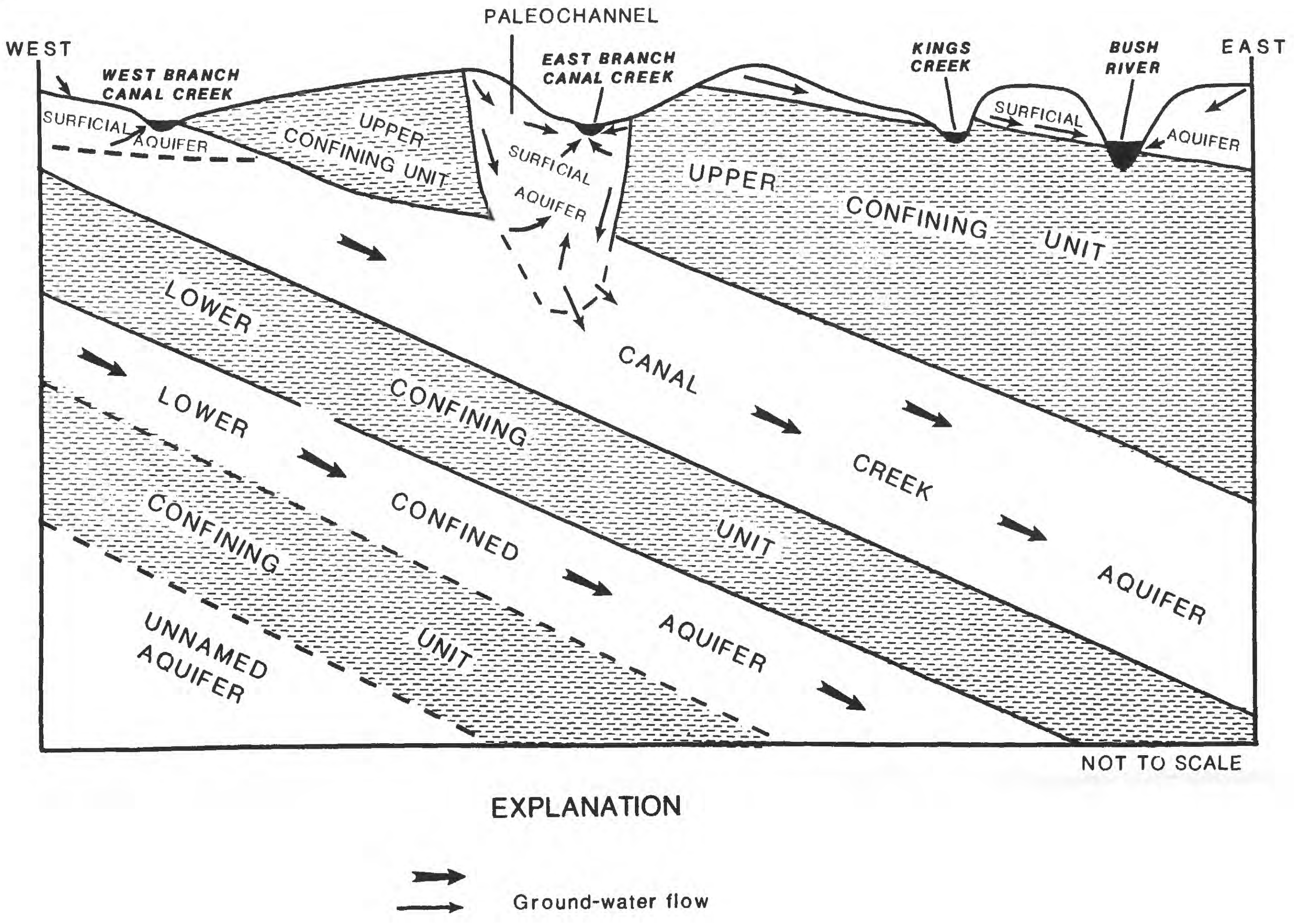


Figure 13--Conceptualization of ground-water flow in generalized hydrogeologic section.

water levels are not significantly affected by discharge into storm drains and sewers, but, at sites 16 and 17, the water-table contours bend upgradient (figs. 14 and 15), indicating convergent ground-water flow. The convergent ground-water flow suggests that discharge to storm drains and sewers is occurring.

Discharge to the Canal Creek aquifer from the surficial aquifer is limited to areas where there is a downward head gradient between the aquifers, generally at higher altitudes away from surface-water bodies. The amount of vertical flow of any kind is dependent upon the vertical hydraulic conductivity of the aquifer materials and the presence or absence of a confining unit between the aquifers. In the southeastern quadrant, for instance, it is unlikely that a significant amount of vertical flow occurs between the two aquifers despite the 5-ft downward head gradient, because the upper confining unit is greater than 100 ft thick. In areas where the upper confining unit is absent, a significant amount of vertical flow might occur.

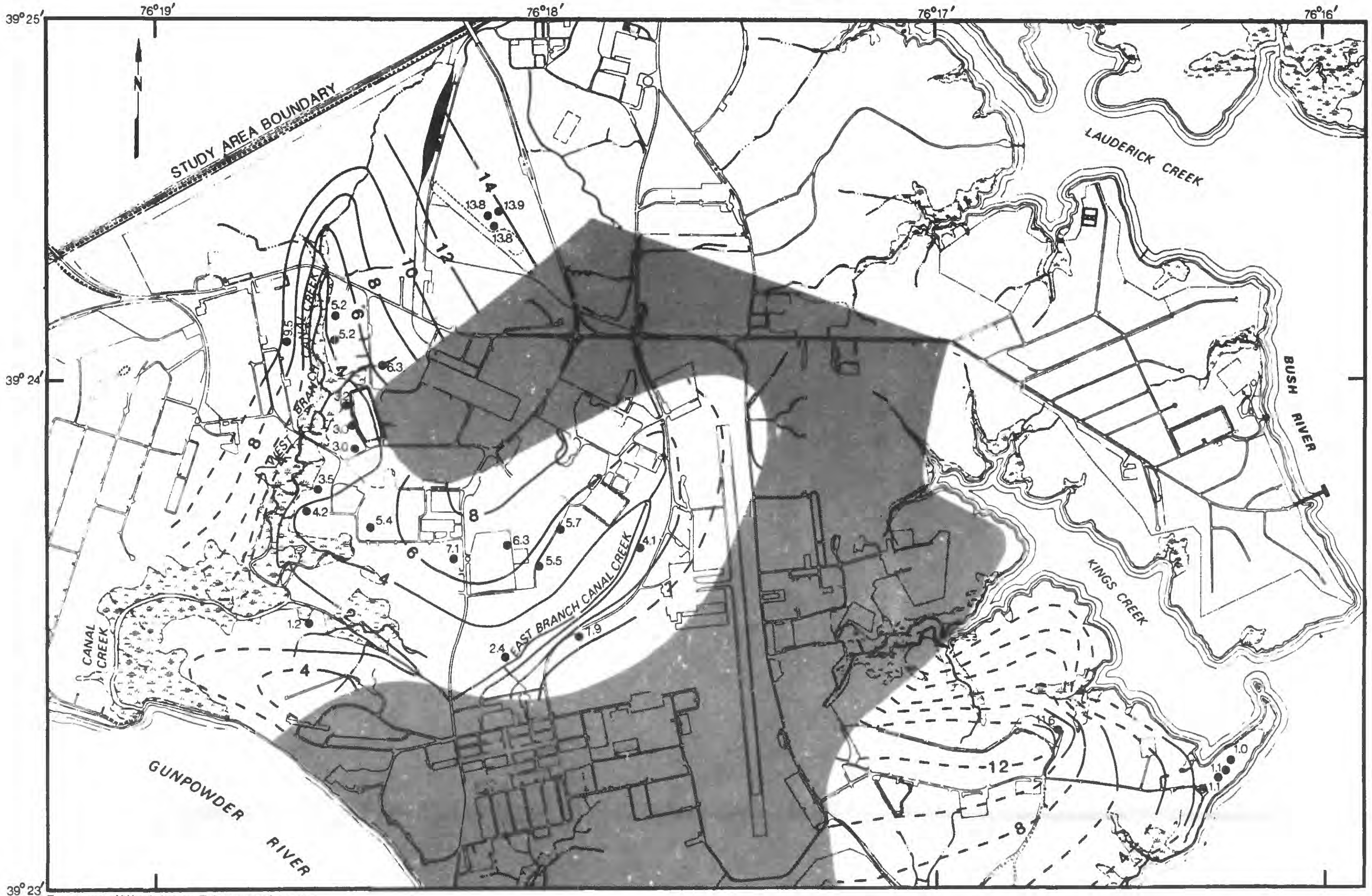
Seasonal head fluctuations.--The amount of head fluctuation in the surficial aquifer differs over the study area. Relatively shallow, hydrologically isolated parts of the aquifer showed seasonal differences in head as high 5.5 ft, but areas near the West Branch of Canal Creek showed seasonal differences of less than 0.5 ft. Without pumping stress, precipitation is the primary contributing factor to seasonal head fluctuations, and at site 1, the head fluctuations correlate well with precipitation (fig. 16).

Hydraulic properties.--Slug tests were performed in four wells in the surficial aquifer (sites 1, 14, 20, and 39). All four sites are located either in the paleochannel or near the West Branch of Canal Creek. The calculated horizontal hydraulic conductivity values are 11 ft/d (site 1), 13 ft/d (site 39), 23 ft/d (site 14), and 44 ft/d (site 20). The wells tested are screened in fine- to medium-grained sand that ranges from silty and poorly sorted to clean and well sorted. The hydraulic conductivities determined from slug tests fall in the range that is commonly measured in such aquifer materials.

Upper Confining Unit

The upper confining unit underlies the surficial aquifer and is present over most of the study area (fig. 17). The unit crops out at the surface in many localities where the surficial aquifer is absent. Most of the clay in the upper confining unit is in the Potomac Group; however, in some areas a thin veneer of clay from the Talbot Formation overlies the clay in the Potomac Group.

During the Pleistocene Epoch, the confining unit was eroded over a large area near the East Branch of Canal Creek by a stream which laid down the paleochannel deposits. The paleochannel was infilled with sequences of sand with thin clay stringers. The hydrologic relation between the surficial aquifer and the Canal Creek aquifer has been greatly altered by the removal of the confining unit (see fig. 7).



Base modified from Edgewood map.
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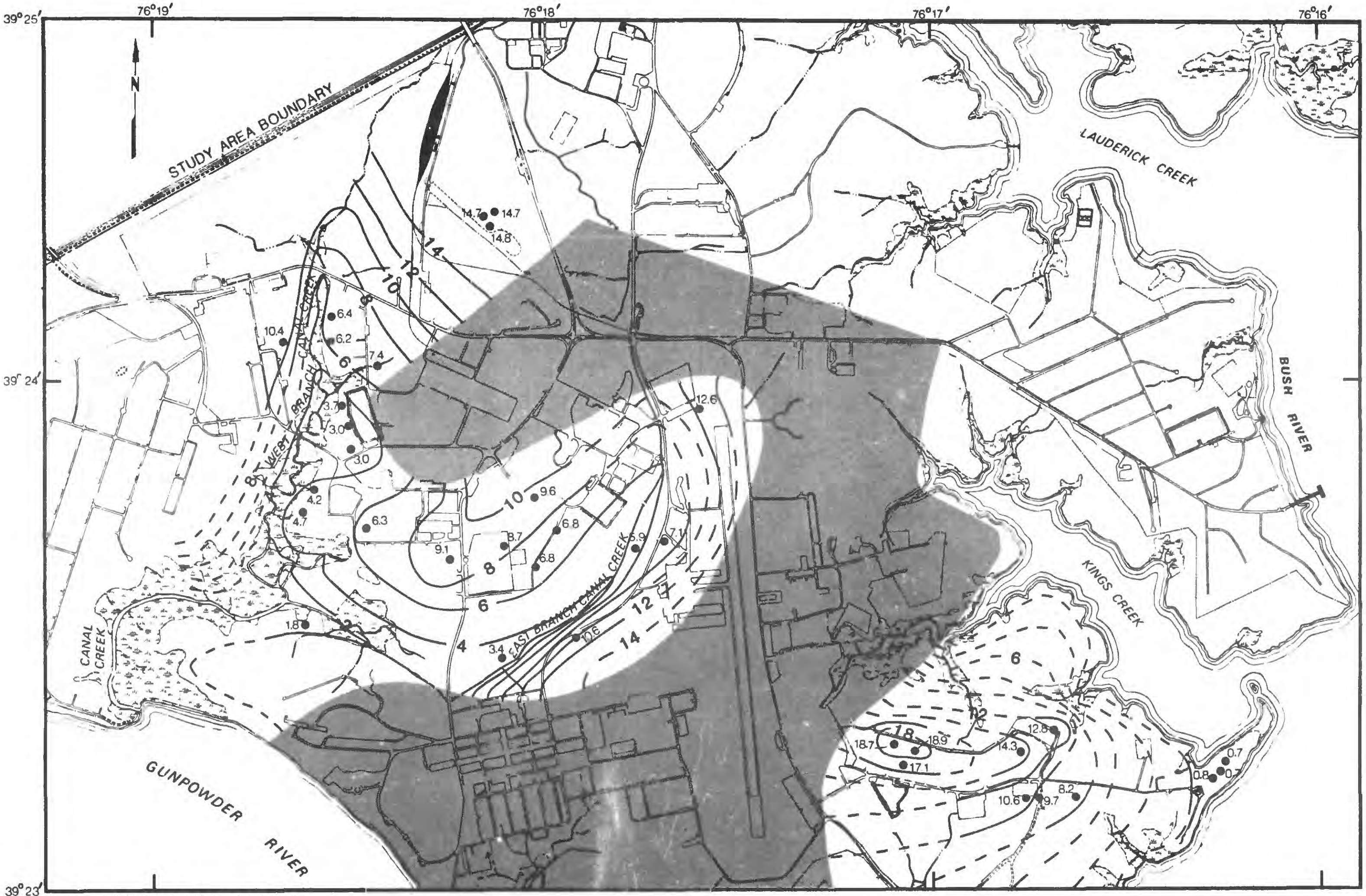
EXPLANATION

— 6 - - Line of equal head in the surficial aquifer, dashed where approximately located. Contour interval 2 feet. Datum is sea level

5.5● Well location and hydraulic head

Area where surficial aquifer is absent



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0 500 1000 2000 FEET
0 300 600 METERS

EXPLANATION

— 2 - - Line of equal head in the surficial aquifer, dashed where approximately located. Contour interval 2 feet. Datum is sea level.

6.3 ● Well location and hydraulic head

Area where surficial aquifer is absent

Figure 15.--Heads in the surficial aquifer, March 1988.

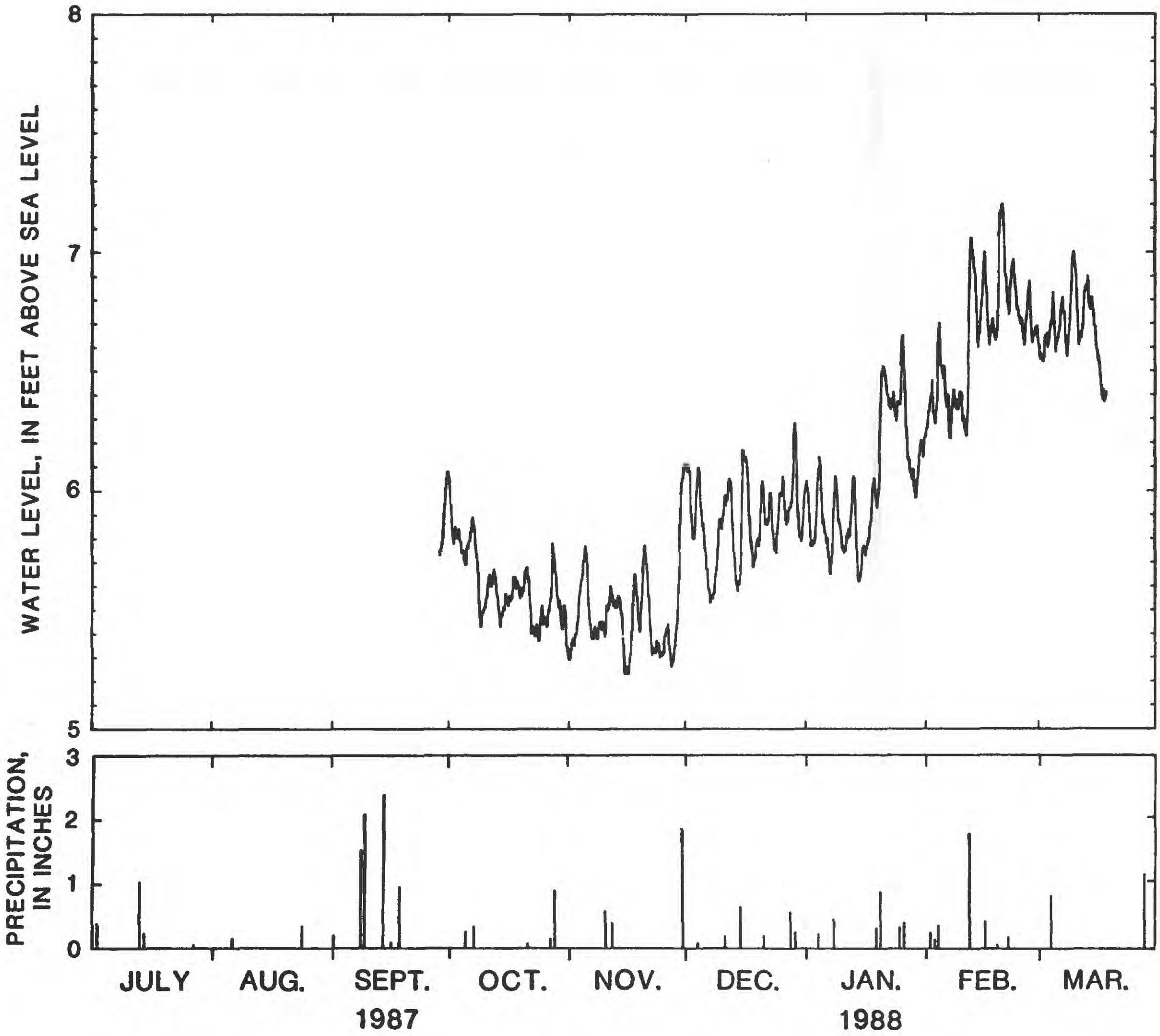
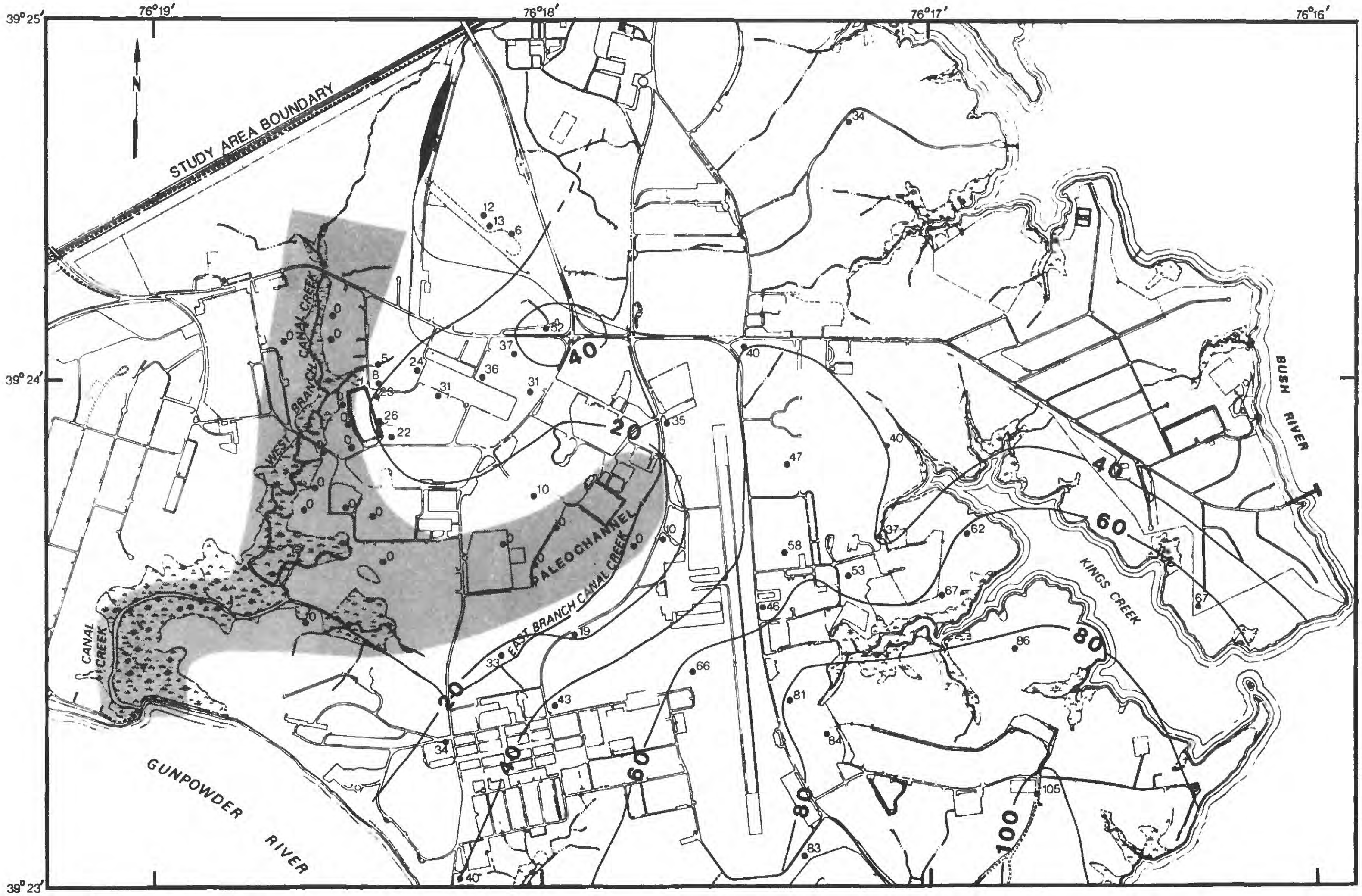


Figure 16.--Changes in water level in the surficial aquifer at site 1, and precipitation from the Edgewood area, July 1987 through March 1988.



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0 500 1000 2000 FEET
0 300 600 METERS

EXPLANATION

—40- - Line of equal thickness of the upper confining unit, dashed where approximately located Contour interval 20 feet. Datum is sea level.

47● Test boring location and unit thickness

Area where upper confining unit is absent

Figure 17.--Thickness of the upper confining unit.

The upper confining unit crops out east of, and parallel to, the West Branch of Canal Creek. Downdip, east of the paleochannel, the unit thickens significantly and has a dense, plastic texture. Except for the area adjacent to the paleochannel, the upper confining unit is continuous eastward to the eastern extent of the study area (fig. 7).

Canal Creek Aquifer

The Canal Creek aquifer is designated the "uppermost confined aquifer," although the aquifer is both confined and unconfined within the Canal Creek study area. It is part of the Potomac Group and is lithologically typical of Potomac Group aquifers found elsewhere in Harford County as described by Southwick and others (1969).

The Canal Creek aquifer is unconfined in parts of the paleochannel and near the West Branch of Canal Creek where the confining unit is absent. The Canal Creek aquifer is more confined south and east of the paleochannel where the upper confining unit thickens and is composed predominantly of dense, plastic clay.

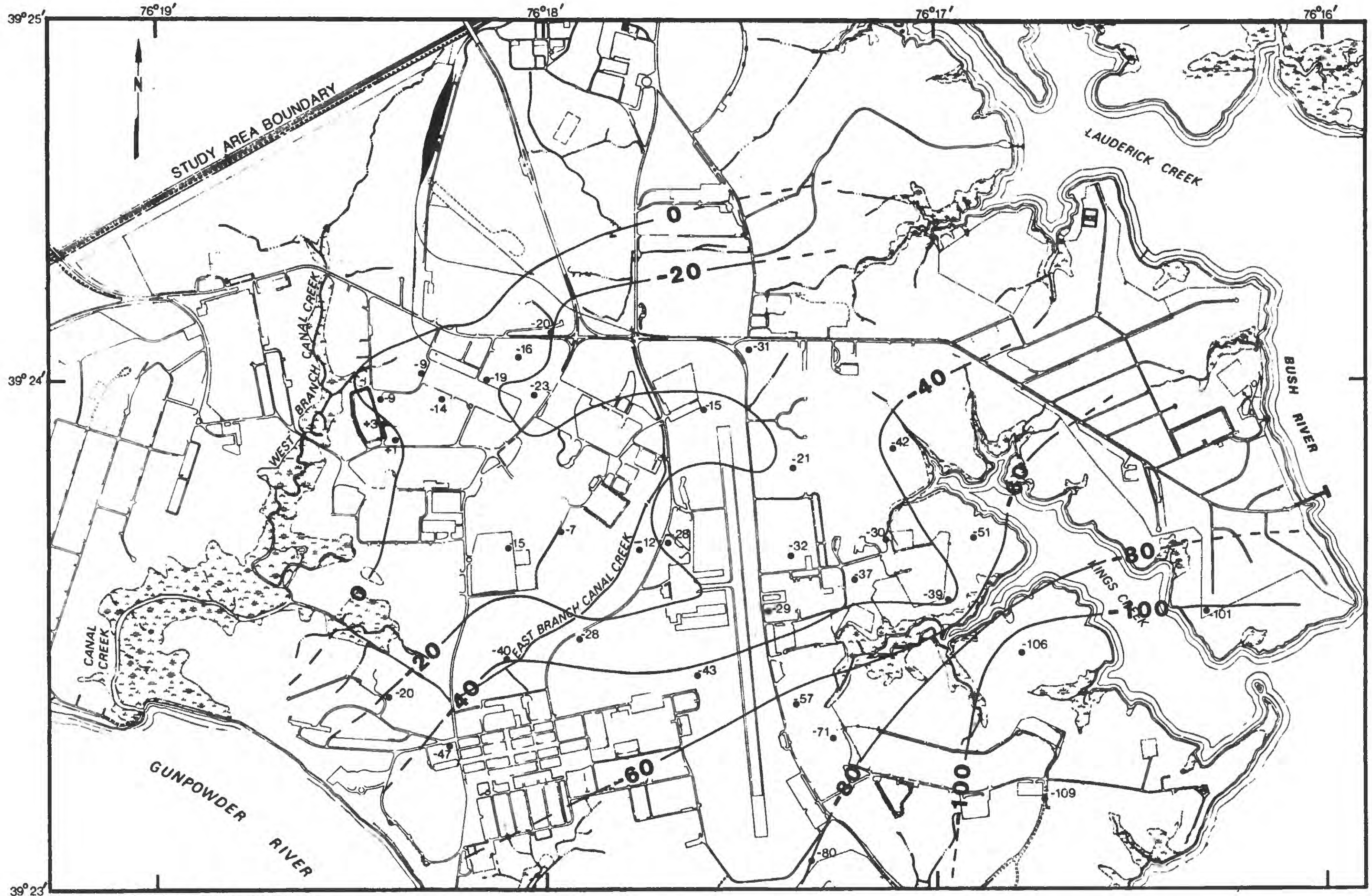
Lithology and extent

The Canal Creek aquifer primarily consists of coarse-grained, quartz sand and gravel, with a small percentage of dark heavy-mineral grains. The coarse-grained sequences contain lenses of gravel and cobbles. Cobbles are as large as 5 in. in diameter.

Sequences of fine-grained sand and silt also are present in the aquifer and contain an abundance of muscovite and organic matter, present as lignite. Some layers up to 5 ft thick, composed entirely of lignite, were found during core sampling. A seed cone and parts of branches and limbs from a gymnosperm were found in the thicker lignite layers.

Clay lenses within the aquifer generally are composed of white to gray, dense, plastic clay commonly bounded by iron mineralization occurring in small nodules and by zones of cemented sand and gravel. The small nodules also are common within clay layers. Multicolored bands of lavender, purple, red, orange, and yellow sand commonly occur in otherwise white sand, and are usually found near contacts between sand and clay. Orange to yellow iron staining also is common in the sand and gravel throughout the aquifer.

The Canal Creek aquifer is present over most of the study area and has a thickness of 30 to 70 ft. Individual sand lenses are discontinuous and pinch out in some areas (see fig. 7). Thin clay lenses are common and can be persistent over large distances (see fig. 8). The aquifer thins westward and is directly beneath the surficial aquifer near the West Branch of Canal Creek. Eastward, the aquifer has an average dip of approximately 50 ft/mi (fig. 18), which is consistent with the regional dip of the Coastal Plain sediments.



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0 500 1000 2000 FEET
0 300 600 METERS

EXPLANATION

--40-- Line of equal altitude of the top of the Canal Creek aquifer, dashed where approximately located. Contour interval 20 feet. Datum is sea level.

-42● Test boring location and aquifer altitude

Figure 18.--Altitude of the top of the Canal Creek aquifer.

The apparent variations in the slope of the upper surface of the Canal Creek aquifer in figure 18 are the result of the pinching out of individual sand lenses at the top of the aquifer. In hydrogeologic sections A-A′ and C-C′ (figs. 7 and 9), the nature of the pinchouts and their effect on the contours of the upper surface of the Canal Creek aquifer become apparent. The contours converge between sites 104 and 3 (fig. 18), an area of complex interfingering of sand and clay lenses. The apparent change in slope of the sediments, indicated by the contours, is caused by a thinning of the sands in the upper part of the aquifer. As a result, the uppermost sand member is much deeper at site 3 than would be expected from its depth at site 104 and the general dip of the sediments. The occurrence of pinchouts, interfingering, and the discontinuity of clay units made extrapolations of contacts necessary at sites where obvious contacts did not exist, such as sites 1, 20, and 36.

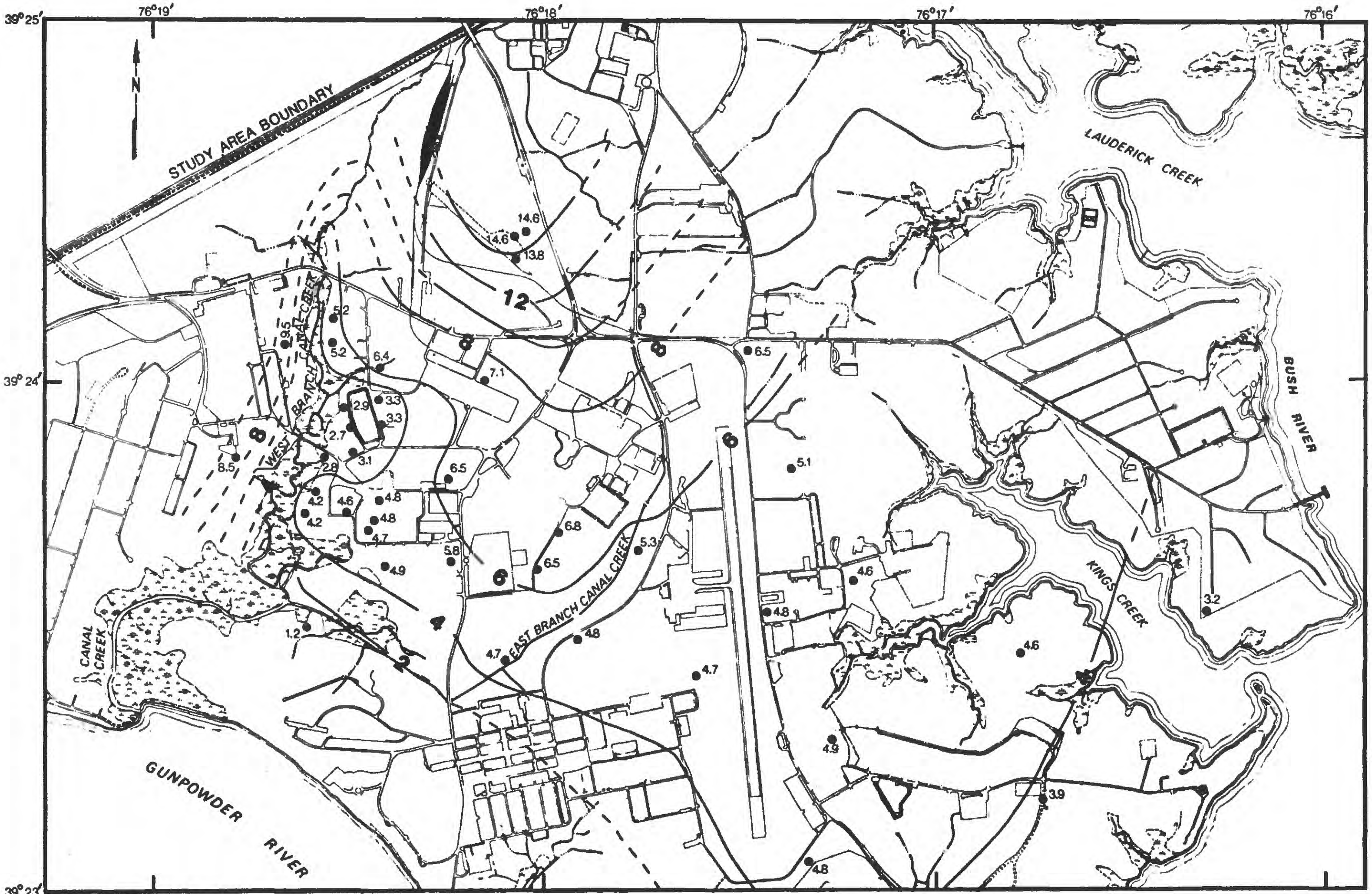
Hydrology

Ground-water flow in the Canal Creek aquifer is complex, primarily for two reasons: (1) some individual sand lenses are discontinuous and interfinger with clay lenses, making distinct flow paths within the aquifer difficult to define; and (2) the Canal Creek aquifer is confined in most areas but unconfined near the West Branch of Canal Creek and within the paleochannel. The result of the variability in the degree of confinement of the Canal Creek aquifer is the existence of two different flow systems within the aquifer.

Head distribution and direction of ground-water flow.--Heads in the Canal Creek aquifer are typical of regional flow conditions over the eastern part of the study area, but show characteristics of local flow conditions near both branches of Canal Creek. Near the West Branch of Canal Creek, the heads are controlled by surface-water levels. In the area of the paleochannel, the heads are only slightly affected by surface-water levels, and in the eastern half of the study area the contours are unaffected by surface-water levels (figs. 19 and 20).

The Canal Creek aquifer is directly beneath the surficial aquifer near the West Branch of Canal Creek, and heads in both aquifers respond similarly to recharge events. This part of the Canal Creek aquifer has been designated "unconfined." As was explained in the methods section, the two aquifers are treated separately to maintain lateral continuity, even though both are unconfined.

In the area of the paleochannel, the heads in the Canal Creek aquifer are not as strongly influenced by the East Branch of Canal Creek as are the heads in the surficial aquifer. The difference in response of the heads in the two aquifers indicates that the Canal Creek aquifer is experiencing some degree of hydrologic isolation from the surface water. The thick sequence of sand overlying the Canal Creek aquifer contains some thin clay stringers, but the thickness of the clay is not likely to be sufficient to explain the apparent hydrologic isolation of the aquifer from the surface water. It is likely that the vertical hydraulic conductivity within the paleochannel is somewhat lower than the horizontal hydraulic conductivity, and, with the presence of clay



Base modified from Edgewood map.
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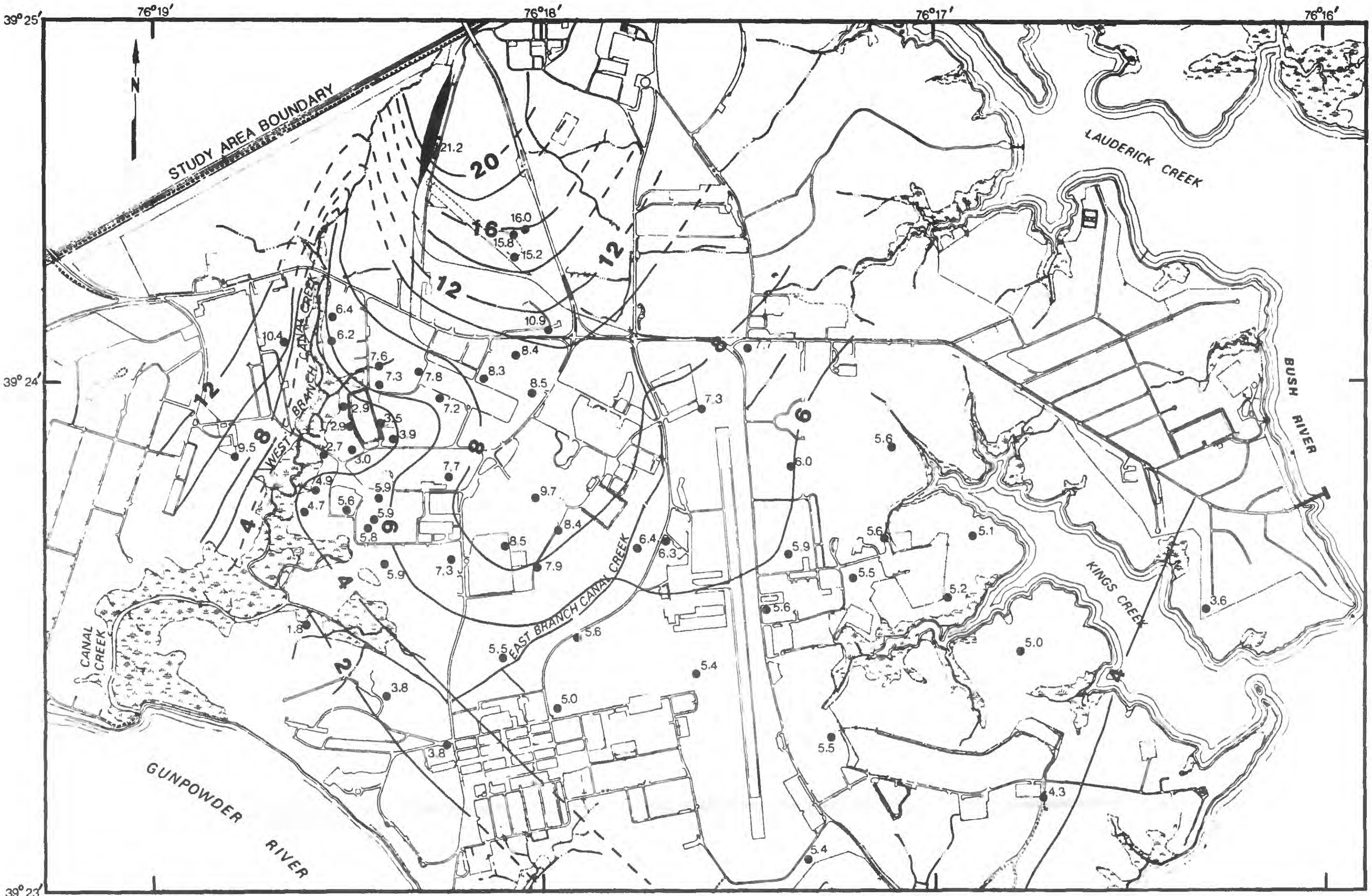
0 500 1000 2000 FEET
0 300 600 METERS

EXPLANATION

—6- - Line of equal head in the Canal Creek aquifer, dashed where approximately located. Contour interval 2 feet. Datum is sea level.

5.1● Well location and hydraulic head

Figure 19.--Heads in the Canal Creek aquifer, August 1987.



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EXPLANATION

—4-- Line of equal head in the Canal Creek aquifer, dashed where approximately located. Contour interval 2 feet. Datum is sea level.

5.1● Well location and hydraulic head

Figure 20.--Heads in the Canal Creek aquifer, March 1988.

stringers, the result is a condition of hydraulic isolation from the surface water. An upward component of flow discharges to the surficial aquifer and produces a slight bend in the contours near the East Branch of Canal Creek and a horizontal component of flow into the confined system that serves to subdue the response of the Canal Creek aquifer to the presence of the East Branch of Canal Creek. The subdued response is evident when comparing the heads near the West Branch of Canal Creek to those near the East Branch of Canal Creek.

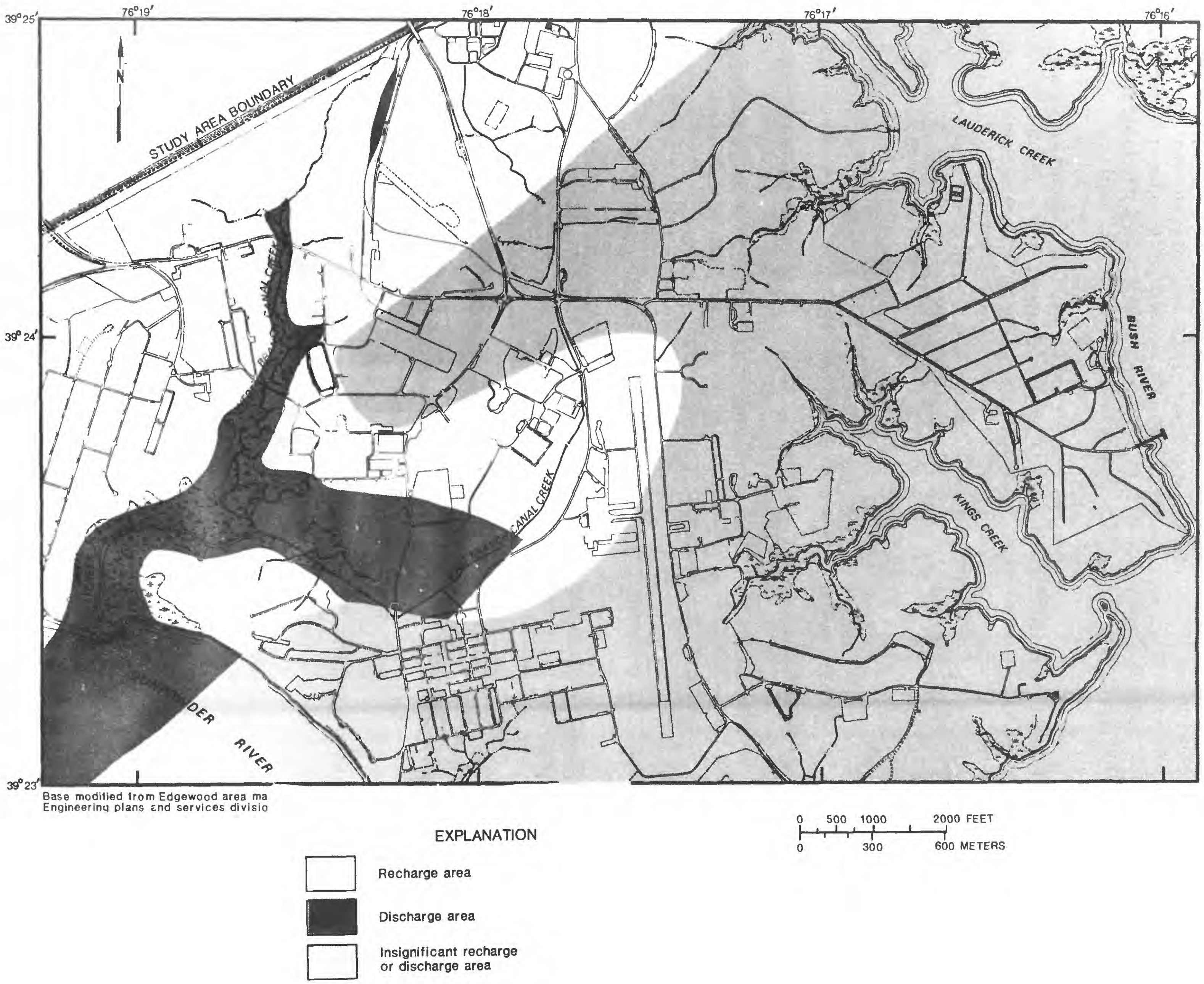
The two components of flow in the Canal Creek aquifer near the East Branch of Canal Creek are indicative of the two separate flow systems within the aquifer--one which is part of the local flow system, and the other which is part of the regional flow system (fig. 13). A transition zone between the two flow systems causes the ground-water flow to diverge. Divergence is vertical in the area of the paleochannel and horizontal in a zone that approximately parallels the West Branch of Canal Creek. Ground water in the local flow system of the Canal Creek aquifer discharges vertically upward to the surficial aquifer, and ground water in the regional flow system moves southeastward into the deeper regional flow system.

The Canal Creek aquifer receives recharge from three sources: (1) the surficial aquifer, (2) the lower confined aquifer, and (3) the movement of ground water from upgradient. Recharge from the surficial aquifer occurs over a limited part of the study area where the vertical head gradient is downward (shown in fig. 21 as the unshaded zone). The zone of insignificant recharge and discharge in figure 21 is where clay is at or near the surface and is thick enough to prevent vertical ground-water flow.

An upward head gradient was observed between the Canal Creek aquifer and the lower confined aquifer at all sites where measurements were made. Although the lower confining unit separating the two aquifers is 35 to 65 ft thick, a persistent upward head gradient across the confining unit over large areas might result in a significant amount of ground-water flow upward across the confining unit. It was not determined how much flow occurs, but tightly compacted clay with a vertical hydraulic conductivity of less than 10^{-4} ft/d (from Darcy's law) would yield a vertical flow rate of 0.0075 cubic feet of water per square foot of confining unit per year with a 2-ft upward head gradient.

It is likely that the Canal Creek aquifer receives recharge from precipitation west of the study area; however, the recharge would not reach the aquifer within the study area because it would discharge locally to the West Branch of Canal Creek. Recharge to the aquifer north of the study area has a much greater potential to reach the aquifer within the study area than recharge from the west because of the ground-water flow direction (figs. 19 and 20). Subsurface movement of water from the north, outside the study area, is probably an important source of recharge for the Canal Creek aquifer within the study area.

The Canal Creek aquifer discharges to the surficial aquifer where the head gradient between the two aquifers is upward. The primary discharge area for the Canal Creek aquifer is near the West Branch of Canal Creek. The remaining flow moves into the regional flow system and discharges through the regional discharge areas off-site.


39°25′
76°19′
76°18′
76°17′
76°16′
39° 24′
39° 23′
N
STUDY AREA BOUNDARY
LAUDERICK CREEK
BUSH RIVER
KINGS CREEK
CANAL CREEK
RIVER
Base modified from Edgewood area ma
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0 500 1000 2000 FEET
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EXPLANATION
Recharge area
Discharge area
Insignificant recharge
or discharge area

Seasonal head fluctuations.--The Canal Creek aquifer is unstressed within the study area, and seasonal fluctuations in head are primarily a function of recharge. The highest water levels were observed during the spring when rainfall was greatest, and the lowest water levels were observed in the late summer when rainfall was least (fig. 22). At any given site, the maximum seasonal fluctuation observed was 2 to 3 ft. The effects of seasonal fluctuations were most pronounced in the unconfined parts of the aquifer. At sites 3, 11, and 12 in the southeastern corner of the study area, the fluctuations in head were approximately 1 ft. Overall, flow direction was not altered significantly over the entire study area from seasonal fluctuations.

Hydraulic properties.--Slug tests were performed in 11 wells in the Canal Creek aquifer. The 11 values for horizontal hydraulic conductivity listed in the following table vary by more than an order of magnitude, from a low of 6 ft/d to a high of 176 ft/d. The mean of the following values is 50 ft/d.

Hydraulic conductivity values determined from slug tests

Well No.	Horizontal hydraulic conductivity (feet per day)
1C	21
2A	152
4B	24
5C	23
7A	34
7B	6
8C	68
8D	18
18A	176
18B	11
26B	15

Based on the variable lithology of the Canal Creek aquifer, the horizontal hydraulic conductivity is expected to differ spatially. Wells associated with the highest listed hydraulic conductivity values were screened in coarse-grained sand and gravel, and most wells associated with the lowest listed values were screened in fine- to medium-grained sand.

Lower Confining Unit

The lower confining unit underlies the Canal Creek aquifer and is lithologically similar to the upper confining unit. At most sites, the upper contact of the lower confining unit is bounded by iron-mineralized nodules and iron-mineral cemented layers up to several inches thick. The contact was also identified from geophysical logs, as can be observed at sites 18, 1, 104, and 3, in figure 7.

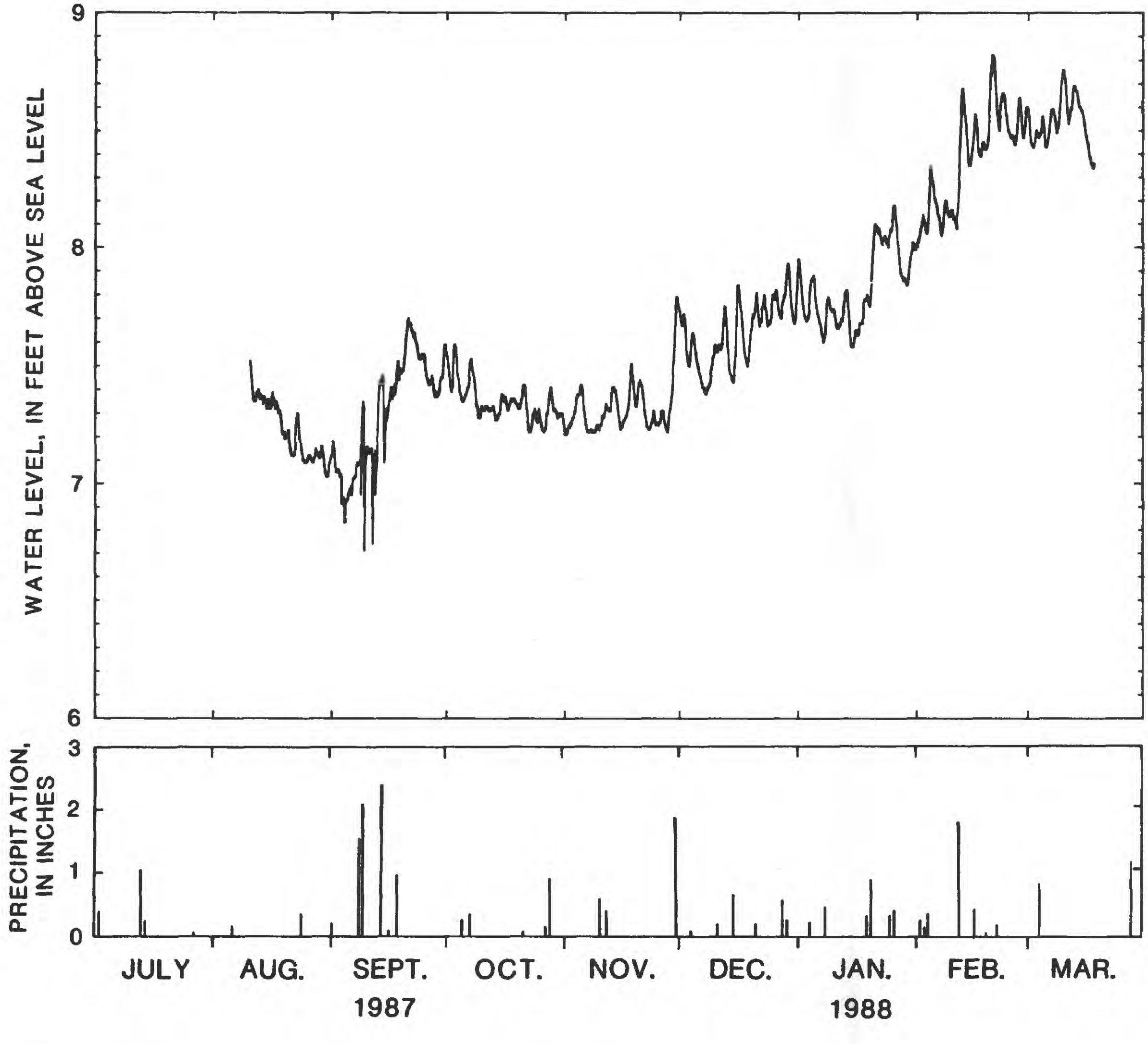


Figure 22.--Changes in water level in the Canal Creek aquifer at site 18, and precipitation from the Edgewood area, July 1987 through March 1988.

The lower confining unit clay is commonly dark gray, olive green, dark brown, red, and yellow. Mottling also was common. Some parts of the unit (generally the upper part) consisted of a dense, plastic clay similar to the clay in the upper confining unit. The lower part of the unit consists of sandy, friable clay with a large percentage of muscovite and lignite fragments.

The unit is approximately 35 to 65 ft thick (fig. 23) and is present throughout the study area. The unit contains thin lenses of fine-grained sand and silt near the bottom where the lower contact is gradational. The exact location of the lower contact was subjective at several sites.

Lower Confined Aquifer

The lower confined aquifer is highly variable in lithology and thickness. Geophysical and lithologic data collected from the lower confined aquifer were limited and it was assumed that the upper boundary of the aquifer was approximately parallel to the lower boundary of the Canal Creek aquifer in areas where data were unavailable. The lower boundary of the lower confined aquifer was more distinctive than the upper boundary and was established at six sites by use of geophysical logs.

Lithology and extent

The lower confined aquifer consists of interfingered fine-grained sand and clay in laterally discontinous discrete layers that range in thickness from less than 1 in. to several feet. The sand is fine grained, gray, and muscovite-rich with some silt and clay. Lignite is abundant in the sand and clay layers, occurring as small fragments in the sand layers and thin laminae of sand- to silt-sized lignite fragments within the clay layers. The dark gray, silty, muscovite-rich clay layers tend to separate along horizontal planes parallel to the alignment of the the mica grains.

Geophysical data from test borings in the lower confined aquifer suggest that the aquifer is continuous east to west, but pinches out toward the northeast (see fig. 11). Figure 24 shows the configuration of the upper surface of the aquifer. The presence of discontinuous sand lenses in the upper part of the aquifer makes the upper surface of the aquifer irregular compared to the actual orientation of the sediments. The general orientation of the lower surface is consistent with that of the overlying Canal Creek aquifer (fig. 25), conforming to the regional orientation of the Coastal Plain sediments.

Hydrology

The lower confined aquifer is hydrologically complex because of the numerous clay lenses that interfinger with the sand. Because clay interfingering is so extensive, flow paths are difficult to define. Figure 9 illustrates the complexities involved in defining the ground-water flow paths. For example, several clay lenses are present between sites 2 and 16 that appear to isolate individual sand lenses, and it is difficult to determine if the ground-water flow is continuous along a path from site 2 to site 16 at a given horizon. Similar complexities are also prevalent elsewhere in the aquifer.

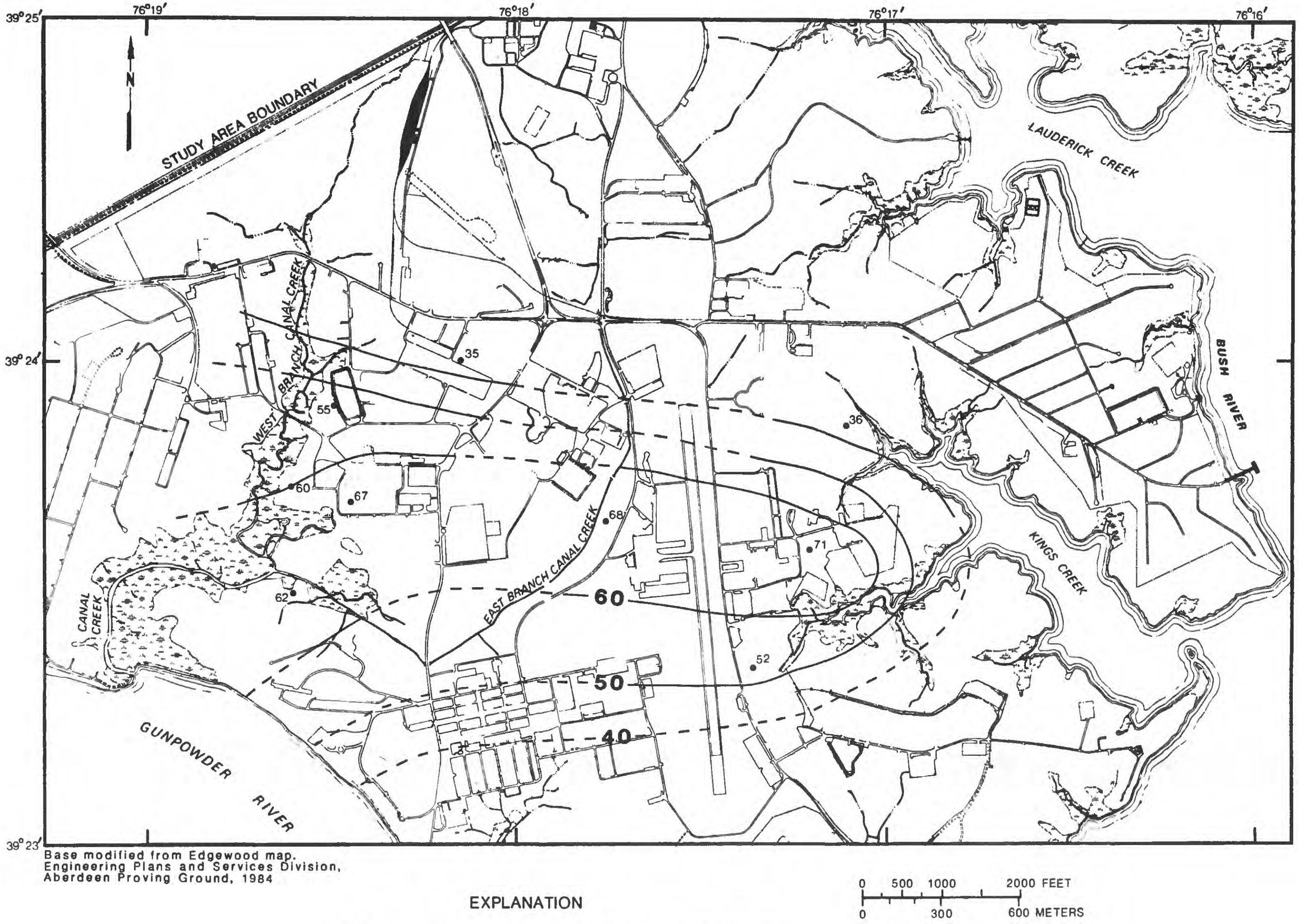
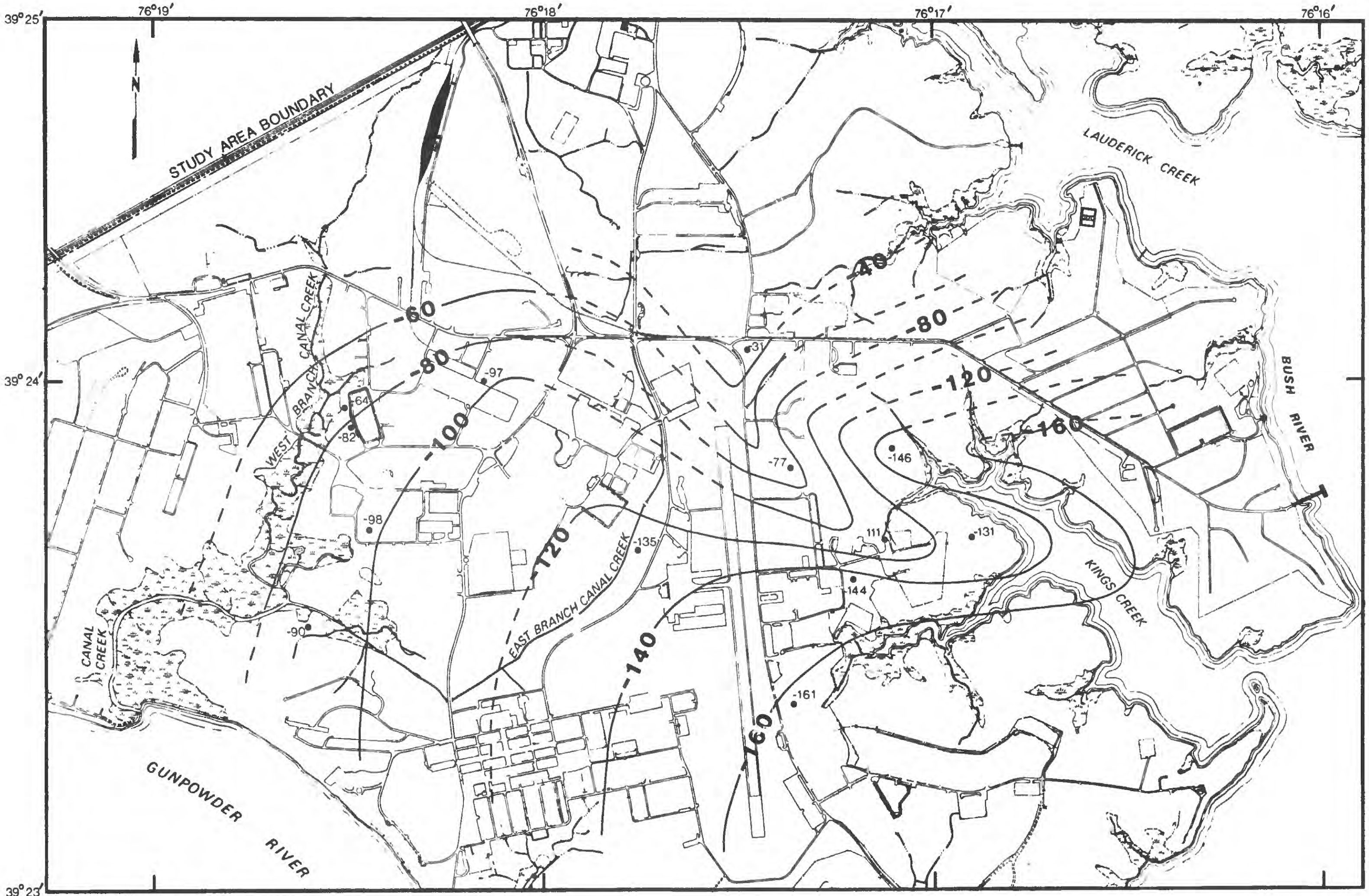


Figure 23.--Thickness of the lower confining unit.



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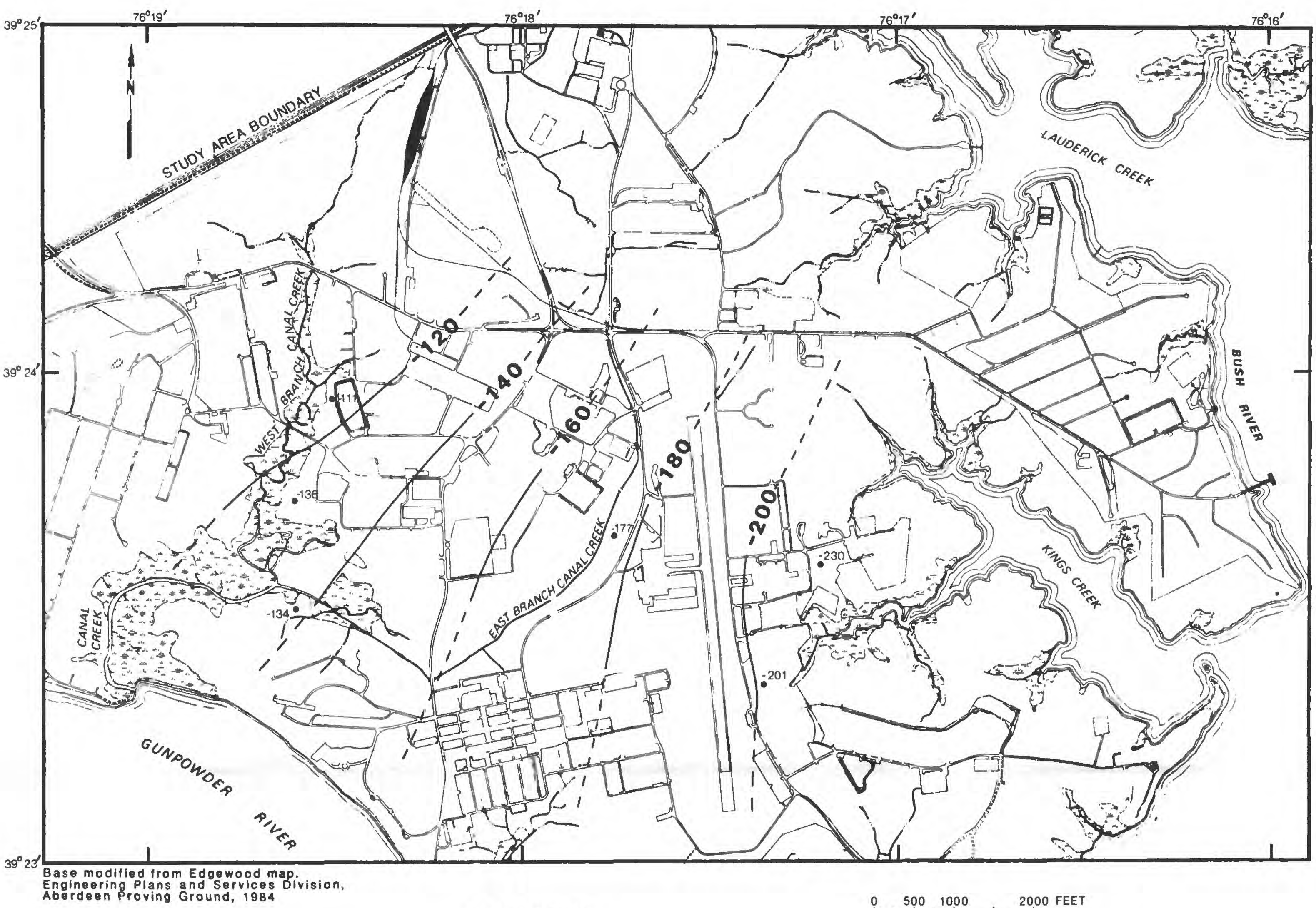
0 500 1000 2000 FEET
0 300 600 METERS

EXPLANATION

--80-- Line of equal altitude of the top of the lower confined aquifer, dashed where approximately located. Contour interval 20 feet. Datum is sea level.

-135● Test boring location and aquifer altitude

Figure 24.--Altitude of the top of the lower confined aquifer.



EXPLANATION

— -140 - - Line of equal altitude of the bottom of the lower confined aquifer, dashed where approximately located. Contour interval 20 feet. Datum is sea level.

-177● Test boring location and aquifer altitude

Figure 25.--Altitude of the bottom of the lower confined aquifer.

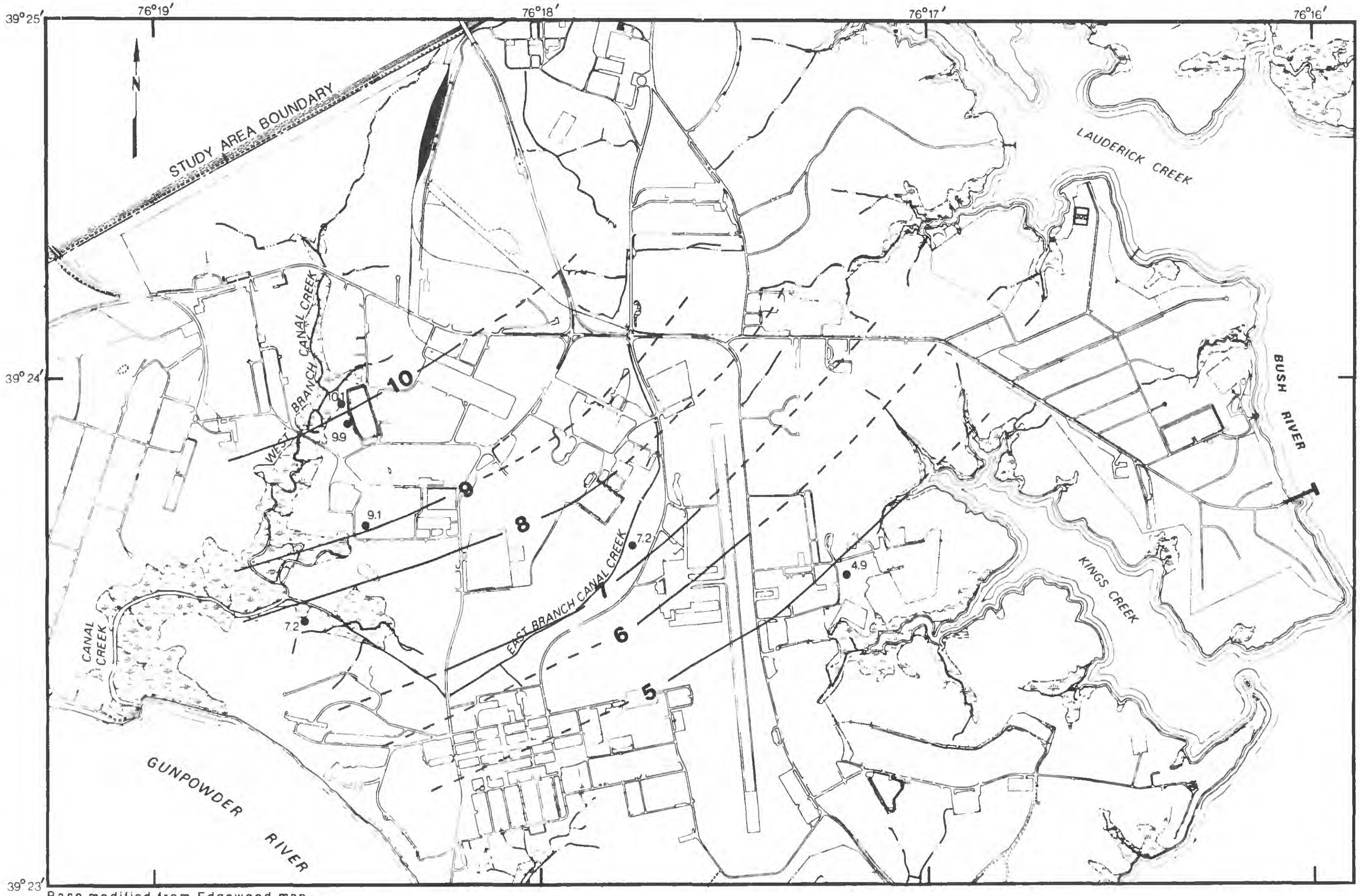
Head distribution and direction of ground-water flow.--Horizontal ground-water flow is approximately northwest to southeast; heads in the lower confined aquifer are highest in the northwestern quadrant of the study area and lowest in the southeastern quadrant (figs. 26 and 27). During March 1988, the maximum head measured was 10.93 ft above sea level at site 16, and the minimum head measured was 5.60 ft above sea level at site 8.

An upward hydraulic gradient exists between the lower confined aquifer and the overlying Canal Creek aquifer. The head difference between the two aquifers was highest at site 16 (8 ft). Heads in the lower confined aquifer rose above land surface at several sites during the spring rainy season.

Ground-water recharge and discharge is vertical in the lower confined aquifer within the study area. No data were gathered below the lower confined aquifer, and it was not determined whether ground-water flow occurs between the lower confined aquifer and deeper aquifers. Additional recharge to the aquifer might occur upgradient where the aquifer is closer to the surface. The head contours indicate that water also moves downdip along the regional flow path.

Seasonal head fluctuations.--Fluctuations in head of as much as 1 ft were recorded in the lower confined aquifer seasonally (fig. 28). The highest heads were measured in the spring when rainfall was greatest, and the lowest heads were measured during the late summer dry period.

Hydraulic properties.--Slug tests performed at several wells screened in the lower confined aquifer resulted in calculated hydraulic conductivity values of several orders of magnitude lower than expected from the lithologic data. Observations made using a down-hole camera indicated that several of the well screens were obstructed with grout. Therefore, the unreasonably low hydraulic conductivities were rejected on the basis of the camera observations and the lithologic data. In addition, the wells positioned in the lower confined aquifer were drilled using the mud-rotary technique, which is often unsuitable for slug tests because of the displacement of clay down-hole during the drilling process. On the basis of the lithologic data, the hydraulic conductivity is expected to differ laterally and vertically because of the interfingering of silt and clay lenses with sand deposits and the variability in grain size of the sand deposits. Similar sediments from the Canal Creek aquifer were found, from slug tests, to have horizontal hydraulic conductivities ranging from approximately 5 ft/d to greater than 100 ft/d. Because of the higher clay content and finer sands in the lower confined aquifer, the horizontal hydraulic conductivities are expected to be lower, possibly ranging from 0.1 to 10 ft/d.



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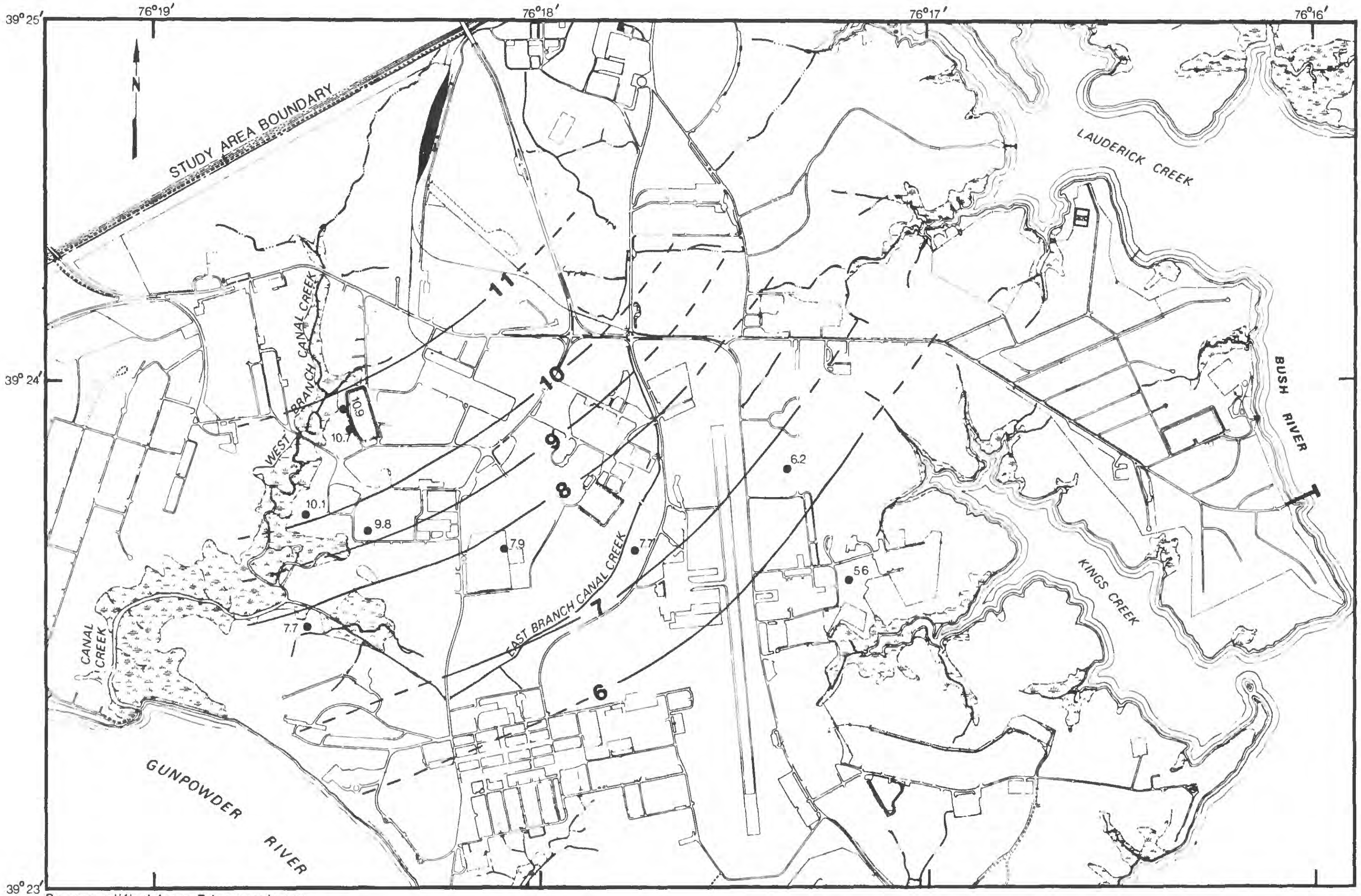
Aberdeen Proving Ground, 1984

EXPLANATION

—8-- Line of equal head in the lower confined aquifer, dashed where approximately located. Contour interval 1 foot Datum is sea level.

7.2● Well location and hydraulic head



Base modified from Edgewood map,
Engineering Plans and Services Division,
Aberdeen Proving Ground, 1984

0 500 1000 2000 FEET
0 300 600 METERS

EXPLANATION

—8— — Line of equal head in the lower confined aquifer, dashed where approximately located. Contour interval 1 foot. Datum is sea level

7.7 ● Well location and hydraulic head

Figure 27.--Heads in the lower confined aquifer, March 1988.

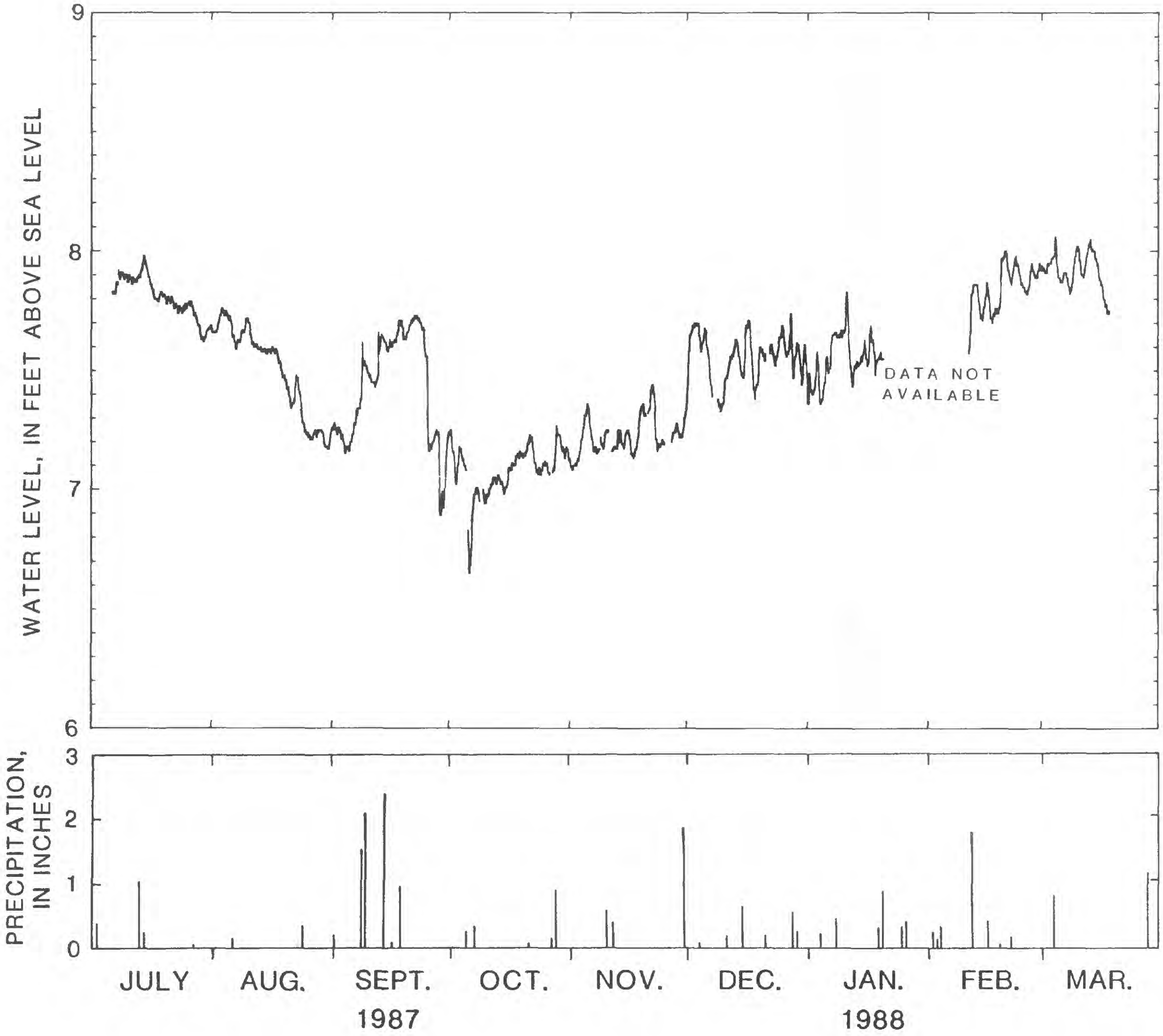


Figure 28.--Changes in water level in the lower confined aquifer at site 1, and precipitation from the Edgewood area, July 1987 through March 1988.

SUMMARY AND CONCLUSIONS

The hydrogeologic framework of the Canal Creek study area consists of a sequence of unconsolidated clay, silt, sand, and gravel deposits that are typical of the Coastal Plain of Maryland. Discrete aquifers and confining units can be delineated, but the units are commonly discontinuous and have complex spatial relations.

The Coastal Plain sediments were deposited during the Cretaceous Period and the Pleistocene Epoch. Most of the sediments in the study area are part of the Potomac Group, which was deposited during the Cretaceous Period. The Pleistocene sediments that overlie the Potomac Group are the Talbot Formation. The Talbot Formation is relatively thin and discontinuous within the study area, except near the East Branch of Canal Creek where a Pleistocene paleochannel is filled with sediment. The Talbot Formation and the Potomac Group both thicken southeastwardly. The regional dip to the deposits is approximately 40 ft/mi.

The sediments within the study area generally consist of alternating layers of sand and clay that can be identified as discrete aquifers and confining units. Five hydrogeologic units were delineated. From the surface down, they are (1) the surficial aquifer, (2) the upper confining unit, (3) the Canal Creek aquifer, (4) the lower confining unit, and (5) the lower confined aquifer. The boundaries between the units do not necessarily correspond to geologic-formation boundaries.

The unconfined surficial aquifer consists primarily of fine- to medium-grained sand approximately 0 to 35 ft thick. The aquifer is absent in large areas where clay is present at the surface. The surficial aquifer is underlain in much of the study area by the upper confining unit. The upper confining unit is greater than 100 ft thick in the southeastern part of the study area and thins to the north and west until the bottom of the unit crops out approximately parallel to and east of the West Branch of Canal Creek. The unit is also absent in the paleochannel where it has been eroded.

The Canal Creek aquifer underlies the upper confining unit and consists primarily of medium- to coarse-grained sand and gravel. It subcrops beneath the surficial aquifer in the paleochannel and near the West Branch of Canal Creek, producing a direct hydraulic connection between the two aquifers.

The lower confining unit underlies the Canal Creek aquifer and is horizontally continuous over the entire study area. The upper boundary is distinct, whereas the lower boundary is gradational and variable. Silty clay and sand characterize the sediments near the bottom of the unit, and the upper part consists of dense, plastic clay. The unit ranges in thickness from 35 to 65 ft; the variability in thickness is attributed to the presence of sand lenses that interfinger and pinch out near the bottom of the unit.

The lower confined aquifer consists primarily of poorly sorted, silty, fine-grained sand, intermixed with lenses of well-sorted medium-grained sand. Numerous lenses of fine-grained materials also interfinger with the sand. The thickness of the lower confined aquifer is highly variable. The lower contact of the aquifer is relatively uniform and follows the regional dip of the sediments.

Ground-water flow in the Canal Creek study area is complex. Three important factors that dominate the flow system are (1) the direct hydraulic connection between the surficial aquifer and the Canal Creek aquifer in parts of the study area, (2) the presence of leaky storm drains and sewers below the water table, and (3) the upward head gradient between the Canal Creek aquifer and the lower confined aquifer. Other factors certainly affect ground-water flow, but the three listed are primarily responsible for the present head distribution and flow characteristics of the system.

The surficial aquifer and the Canal Creek aquifer are in direct hydraulic connection near the West Branch of Canal Creek and in the paleochannel, creating two separate flow systems in the Canal Creek aquifer--one local and one regional. Vertical flow from the Canal Creek aquifer to the local flow system of the surficial aquifer occurs where the upper confining unit is absent and there is an upward head gradient.

Leaky storm drains and sewers can have an effect on ground-water flow in the local flow system by lowering the water table in areas where the drains or sewers lie below the water table. A uniform lowering of the water table might not be obvious from head data, but a localized drop in the water table, such as that which occurs near sites 16 and 17, can dramatically alter the shape of the contours to the point of creating convergent ground-water flow. Convergent flow indicates that a significant amount of water is leaving the aquifer.

The head gradient between the Canal Creek aquifer and the lower confined aquifer was upward during the period of head-data collection. The gradient was as high as 8 ft at site 16. Although the lower confining unit between the two aquifers is relatively thick, the persistent upward gradient across the confining unit over a large area results in an upward flow of water.

The surficial aquifer receives recharge from two sources within the study area: (1) direct infiltration of rainfall or surface water, and (2) discharge from the Canal Creek aquifer. Direct infiltration can occur over most of the aquifer surface area. Recharge from the Canal Creek aquifer is limited to those areas where an upward gradient exists between the two aquifers, primarily in the low-lying areas near surface-water bodies.

The surficial aquifer discharges to (1) surface water, (2) the Canal Creek aquifer, and (3) leaky storm drains and sewers. Discharge to surface water generally occurs adjacent to or through the bottom sediments of the creeks and in low-lying marshes. Discharge to the Canal Creek aquifer may occur if the vertical head gradient between the aquifers is downward, generally at topographic highs away from surface-water bodies. Leaky storm drains and sewers receive discharge where they lie below the water table.

Overall, flow in the surficial aquifer is characterized by local recharge and discharge with short flow paths. The unconfined part of the Canal Creek aquifer is an integral part of the local flow system, acting as an extension of the surficial aquifer near the West Branch of Canal Creek. Although most of the discharge from the surficial aquifer to the Canal Creek aquifer probably returns as recharge to the surficial aquifer at topographic lows, some may enter the regional flow system of the Canal Creek aquifer, providing recharge to the regional flow system.

The Canal Creek aquifer receives recharge within the study area from the surficial aquifer and the lower confined aquifer. A substantial amount of recharge might enter the Canal Creek aquifer through the lower confining unit due to the strong upward gradient from the lower confined aquifer. Much of this recharge probably moves into the regional flow system of the Canal Creek aquifer. Recharge also reaches the aquifer from upgradient, off site, where the Canal Creek aquifer crops out at the surface. Recharge from the west probably enters the local flow system and discharges to the West Branch of Canal Creek, but recharge from the north might comprise a significant part of the recharge to the regional flow system.

The Canal Creek aquifer is of primary hydrologic concern within the study area because it is the major water-bearing unit. It receives recharge from both the surficial aquifer and the lower confined aquifer and has the greatest capacity for ground-water flow of the three aquifers. The Canal Creek aquifer is also vulnerable to contamination from the surficial aquifer in the areas designated as "recharge areas" in figure 21. The percentage of recharge to the regional flow system that comes from the surficial aquifer is uncertain, but the presence of relatively strong head gradients in the direction of the regional flow indicates that a substantial amount of flow from the surficial aquifer into the regional flow system might occur.

Recharge entering the Canal Creek aquifer can enter one of two flow systems. It might enter the local flow system and discharge back into the surficial aquifer, or it might enter the deeper regional flow system by following the horizontal head gradient downdip. The flow divergence occurs along a zone that approximately follows the line of outcrop of the upper confining unit. West of the divergent zone, much of the flow is part of the local flow system, and east of the zone the flow is regional.

The lower confined aquifer discharges upward throughout the study area. The aquifer probably receives most of its recharge from the updip westerly direction, outside the study area where the aquifer is closer to the surface. Under present unstressed conditions, it is unlikely that any flow from the overlying Canal Creek aquifer could reach the lower confined aquifer. Pumping might lower the hydraulic head in the lower confined aquifer sufficiently to reverse the vertical head gradient, resulting in the downward movement of ground water through the lower confining unit.

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[1] The name of this agency was changed to the Maryland Geological Survey in June 1964.