GROUND-WATER RESOURCES OF THE MATTAPOISETT RIVER AQUIFER, PLYMOUTH COUNTY, MASSACHUSETTS: SUMMARY FOR WATER-RESOURCE MANAGERS

By Virginia de Lima and Julio C. Olimpio

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FACTORS FOR CONVERTING INCH-POUND UNITS TO INTERNATIONAL SYSTEM OF UNITS (SI)

For readers who prefer to use SI Units, conversion factors for terms used in this report follow:

Multiply inch-pound units	By	To obtain SI Units
inch (in)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
inch per year (in/yr)	25.40	millimeter per year (mm/yr)
foot per day (ft/d)	0.3048	meter per day (m/d)
foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2/d)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.0630	liter per second (L/s)
million gallons per day (Mgal/d)	0.0438	cubic meter per second (m^3/s)

NGVD of 1929 (National Geodetic Vertical Datum of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, called NGVD of 1929, is referred to as sea level in this report.

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ABSTRACT

Proposed increases in municipal pumpage in the Mattapoisett River valley will triple ground-water withdrawals in the next two decades. Because of growing State and local concern about the long-term effects of these withdrawals on ground-water levels and streamflow, a computer ground-water-flow model was developed to assist in water-resource management. An executive summary of the modeling work, as well as the mathematical and hydrologic principles used in the hydrogeologic study and the development of the ground-water-flow model are presented in nontechnical terms accompanied by a detailed glossary.

Monthly ground-water-level measurements, continuous streamflow data, and measurements of low flow on Mattapoisett River were used to develop the steady-state ground-water-flow model. The model simulates a high-yielding sand and gravel aquifer which fills a bedrock channel as much as 110 feet deep. Recharge to the aquifer is from precipitation and from water entering the aquifer from the less permeable material adjacent to it. Ground water flows horizontally and discharges to the river through the streambed. Water in the aquifer and in the river is soft and slightly acidic. Water levels calculated by the model were within 4 feet of observed levels over 90 percent of the model area, calculated ground-water flow to the river closely matched measured flow, and inflows to the system balanced outflows to within 0.02 percent.

Ten scenarios to represent the current and proposed pumping demands in the valley were simulated using drought conditions. Under conditions simulating the driest year of record, predicted water levels in the aquifer were as much as 9 feet lower than average. Under severely dry conditions simulating only enough recharge to keep the river flowing with no pumping, predicted water levels were as much as 19 feet lower than average. During the greatest pumping demands, predicted water level in five wells was low enough to cause the wells to fail. Simulated pumping demands in 6 out of 10 scenarios used all the available ground-water discharge to the river. Under severely dry conditions, if there were no additional streamflow entering the river from ponds in the valley, the results indicated that the southern half of the river would dry up under most pumping plans.

EXECUTIVE SUMMARY

Introduction

The Mattapoisett River and the Mattapoisett River aquifer form a single hydrologic system which provides fresh water for water supply, recreation, and agriculture to four communities in Plymouth County, Massachusetts. Ground water has been the source of municipal water supply in the Mattapoisett River valley since the early part of this century, and in 1982 supplied an average of 1 million gallons per day to domestic and commercial users in the towns of Mattapoisett, Fairhaven, and Marion. In addition, Rochester depends on the aquifer for private supply. Herring use the Mattapoisett River as a run from the ocean to their spawning area in Snipatuit Pond, and cranberry growers use the river as a source of water for bog irrigation and flooding during harvest. Withdrawal of ground water for municipal supply is expected to triple in the next two decades, and because of the many diverse users, there is a need for careful water-resource planning based on thorough knowledge of the basin hydrology.

This study is the first under Chapter 800 Massachusetts legislation that provides funds to quantitatively assess regional ground-water resources in the State. The U.S. Geological Survey, in cooperation with the Massachusetts Water Resources Commission, selected the sand and gravel aquifer in the Mattapoisett River valley for detailed study of the ground-water resources and the interdependence between pumping wells and streamflow.

The purpose of the Mattapoisett River aquifer study is to describe the flow, quantity, and quality of the water in the stream-aquifer system. A computer simulation model of the system was developed to aid in the hydrologic description of the system and to provide a management tool for predicting changes in ground-water levels and variations in streamflow resulting from alternative water-supply development scenarios.

The Mattapoisett River flows southward from Snipatuit Pond to Buzzards Bay through the western sections of the towns of Rochester and Mattapoisett (fig. 1). The study area includes the 23.6 square mile drainage basin which contributes water to Snipatuit Pond or to Mattapoisett River. The focus of the study and the computer model is on an 8 square mile portion of the basin south of Snipatuit Pond including the river, several tributaries, and the sand and gravel aquifer.

This report summarizes the results of the hydrogeologic study and the computer model. Included is background material for those who want to increase their understanding of hydrology and hydrologic computer modeling. A second report by Olimpio and de Lima, 1984, gives a thorough, technical discussion of the work including the (1) hydrogeologic characteristics of the area, (2) development and refinement of the computer model, (3) testing of the alternative pumping scenarios, and (4) results of those scenarios.

Water Issues in the Mattapoisett River Basin

The Mattapoisett River aquifer supplies 80 percent of the domestic and commercial water needs in the town of Mattapoisett. The municipal supply system includes three separate pumping centers. One is an infrequently used well field consisting of many small-diameter wells. The other two are single, large-capacity, gravel-packed wells.

The aquifer also supplies a significant and increasing portion of the water supply for the towns of Fairhaven and Marion. These towns are located outside the drainage basin, but under legislation passed in 1889, Fairhaven was granted water rights in the town of Mattapoisett, and under legislation passed in 1970, Marion was granted water rights in the town of Rochester. Currently, Fairhaven has a field of small-diameter wells near the mouth of the Mattapoisett River and a system of three gravel-packed wells near the Mattapoisett-Rochester town line. Marion has one gravel-packed well on the Rochester side of the town line. The town of Rochester has no municipal supply, and no wells are planned. Exploration for additional municipal wells continues in the valley. Marion has a test-well site in Rochester, and Mattapoisett has one in Mattapoisett which, when developed, will replace its well field. Both test sites have been approved for development by the DEQE (Massachusetts Department of Environmental Quality Engineering). Fairhaven is planning further tests in Mattapoisett. Current and proposed public-supply wells for Fairhaven, Marion, and Mattapoisett are shown in figure 2. If all the proposed wells are developed, total withdrawal is estimated to average 4.5 million gallons per day by the year 2000. Three quarters of this withdrawal will be removed from the basin either as water supply for other towns or by sewering.

The location of the municipal supply wells in the Mattapoisett River valley presents a further concern because most of the current, planned, and proposed wells are close to one another in the southern part of the basin (fig. 2). If two wells are close together, the lowered water level resulting from pumping one will reduce the water available to the other and decrease the total amount of water that can be pumped.

The current and proposed municipal wells are close to the stream and, therefore, can have an effect on the quantity of water in that section of the stream. Because the stream and the aquifer are interconnected, increased pumpage will diminish streamflow. The resulting volume and velocity of the water in the stream might be insufficient to dilute pollutants and keep the water aerated. Therefore, water-quality problems might result. Insufficient water for herring to ascend the river to spawn in Snipatuit Pond is another possible effect. The amount of water in the stream can also affect the wells. Regulation at Snipatuit Pond and at the State-owned fish hatchery off Hartley Road sometimes reduces the flow in the river. During the summer and fall, when water is pumped from the river for cranberry irrigation and harvesting, the flow is aqain reduced. Substantial reduction in streamflow lessens the amount of surface water which could be drawn into the ground, and thus into the wells. Without this source of water, the wells probably would be unable to maintain the current pumpage.

Because of the complexly interrelated stresses affecting the aquifer and the stream in the Mattapoisett River basin, a ground-water-flow model was developed whose response to applied stresses, such as pumpage, is similar to the response of the actual aquifer. Such a model not only helps in understanding the hydrologic system, but also can be used as a management tool to efficiently predict the response of the aquifer to proposed development.

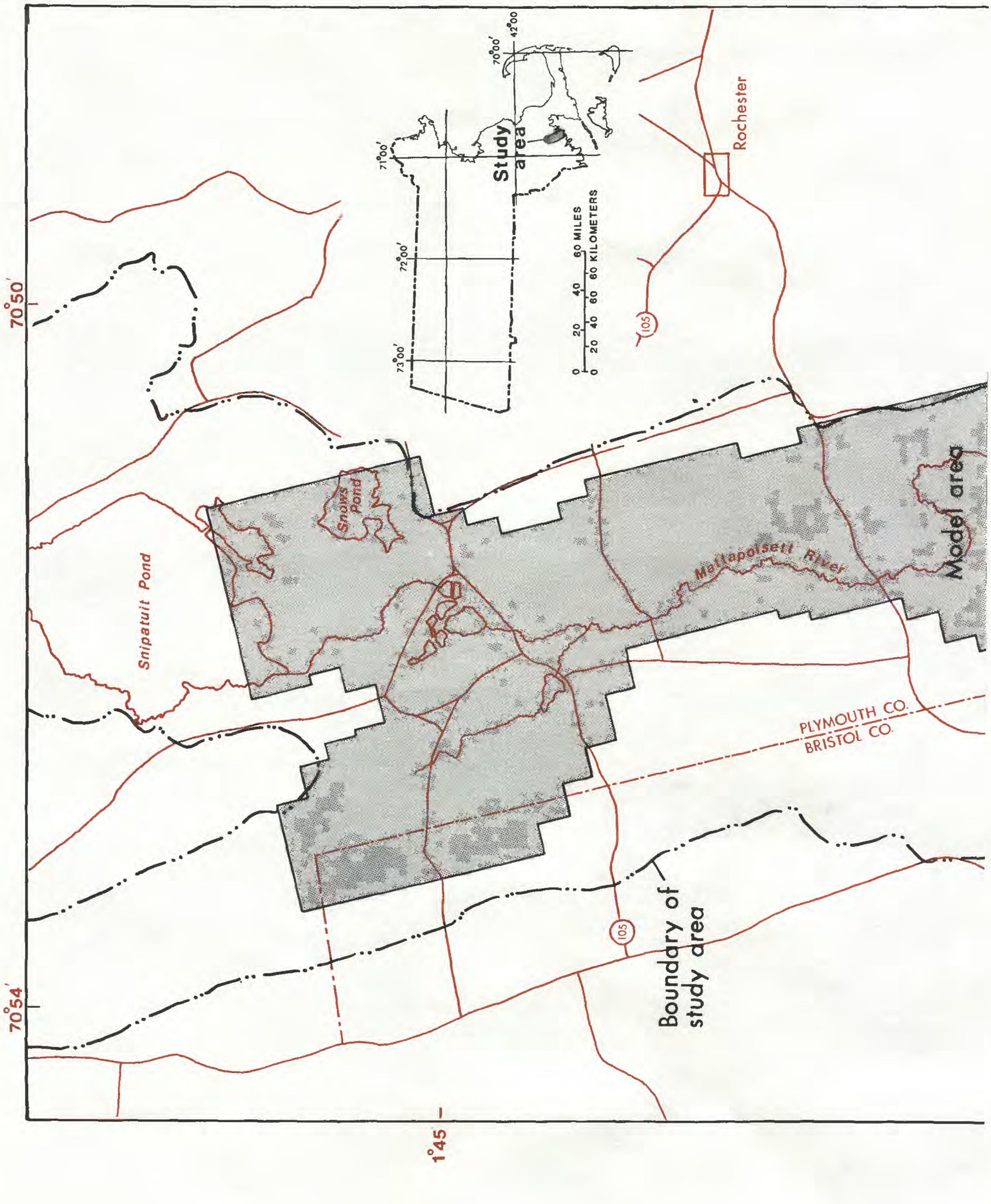
Simulation of Ground-Water Flow Using a Computer Model

Comparisons of monthly precipitation, water-level, and streamflow data gathered during this study and long-term mean annual data, indicated that average conditions were most closely approximated in May 1982. As a result, the ground-water-flow model was based on May 1982 water-level and streamflow data. The response of the aquifer to the pumping stresses simulated by the model closely matched the observed response of the aquifer. This indicates that the model can be used to predict how the aquifer will respond to proposed development. To demonstrate the predictive use of the model, 10 scenarios were developed which represent current and planned pumpage under drought conditions. These scenarios provide illustrative examples of the cause-and-effect relation of pumping, water level, and streamflow. An indepth description of the scenarios and the results of the scenarios are given in the section "The Mattapoisett Aquifer Model as a Management Tool;" in tables 4 and 5; and in figures 15 and 16. Planners and decisionmakers can use these tables and maps to determine (1) if wells will be able to maintain the pumping rates proposed, (2) how much the water table will be lowered by the proposed withdrawals, and (3) how these withdrawals will affect the amount of water in the stream. The results of these and future scenarios developed by the State and the communities involved can be used to devise a comprehensive water-resources management plan for the region.

In the 10 illustrative scenarios, three levels of pumping stress were analyzed: (1) the average pumping rate for the summer (June, July, and August), (2) the average pumping rate for the highest month (July), and (3) the maximum daily pumping rate of each well (the well capacity). The 10 scenarios were run under both dry and severely dry conditions. The dry condition was based on the total precipitation at Rochester, Massachusetts, during the driest year of record, 1965. The severely dry condition was based on an estimate of how much precipitation would be needed to keep the river flowing when no wells were pumping.

Each of the 10 scenarios represented an increase in pumpage above average (1982) conditions. Therefore, water levels would drop throughout the aquifer because more water would be withdrawn from the system. Under dry conditions, with all the current and proposed wells pumping, the water table in some areas would be more than 9 feet lower than average levels, and the model predicted that four wells could fail. Under severely dry conditions, the water table would be as much as 19 feet lower than average and five wells could fail if pumped at capacity. Also, because the amount of water in a stream-aquifer system is finite and the amount of ground water withdrawn from wells is no longer available for discharge to the river, the flow of the Mattapoisett River decreases as total pumpage increases. In the six scenarios representing the greatest pumpage under severely dry conditions, the wells intercepted all the ground water that would have entered the stream in that area and would have drawn water from the stream into the ground if it had been available. Hypothetically, streamflow could be augmented to meet this need if water stored in ponds in the valley were released to the stream.

Scenario 10 pumping under severely dry conditions may be considered a "worst case" situation in that it simulated pumping from all current and proposed wells in the valley with no streamflow augmentation or artificial recharge from surface-water impoundments. In this scenario, the model indicated that the river would be dry from the confluence of Branch Brook south of Wolf Island Road to the ocean. An additional 2.61 cubic feet per second of surface water would have been drawn into the ground under these conditions if it had been available. Without this additional surface water, the given pumping rates would result in increased drawdowns and probably well failure.



70°50'
70°54'
1°45'
Snipatuit Pond
Snows Pond
Mattapoisett River
Model area
PLYMOUTH CO.
BRISTOL CO.
105
Boundary of study area
Rochester
Study area
71°00'
72°00'
73°00'
70°00'
42°00'
0 20 40 60 MILES
0 20 40 60 KILOMETERS

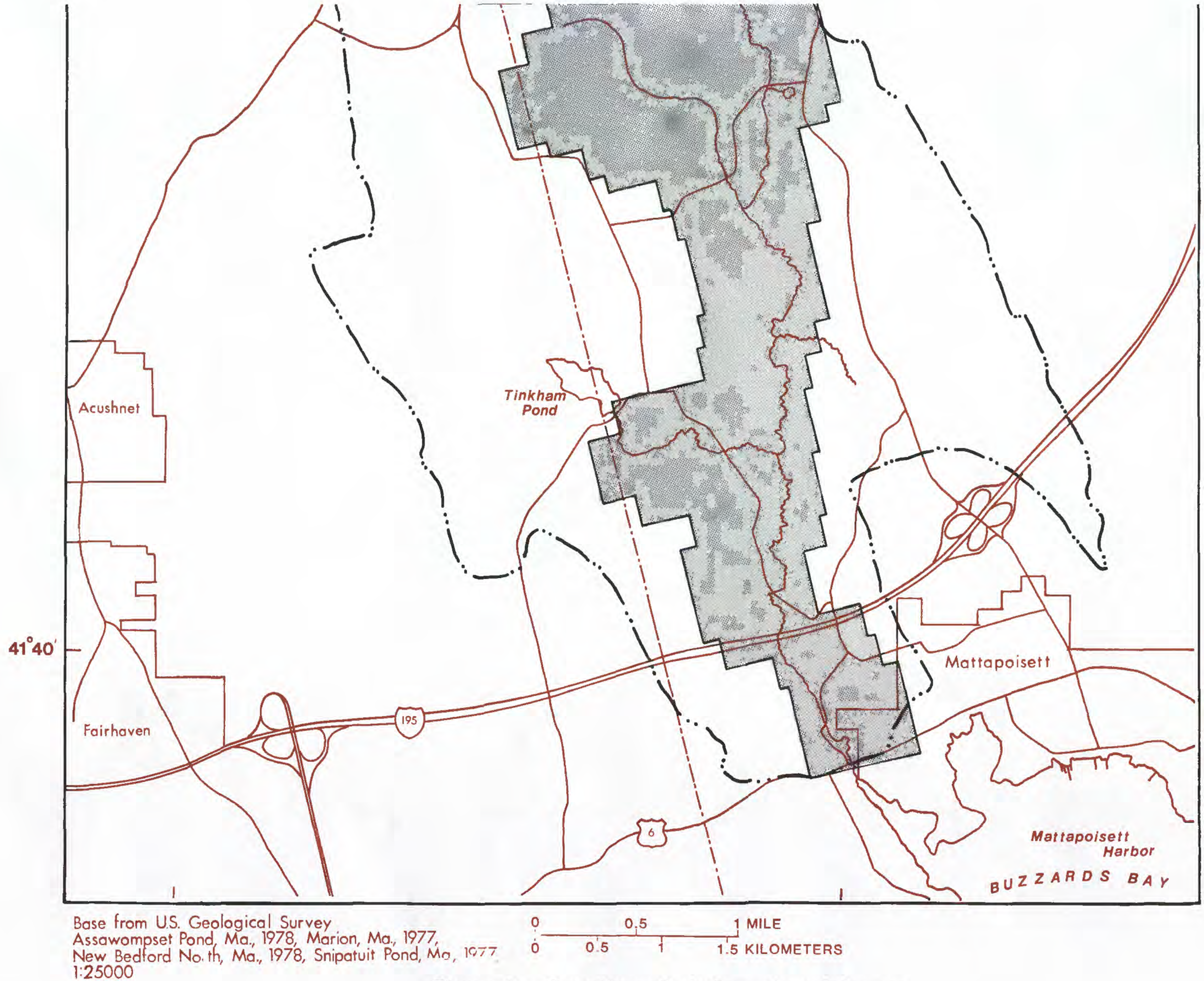


Figure 1.--Location of study and model area.

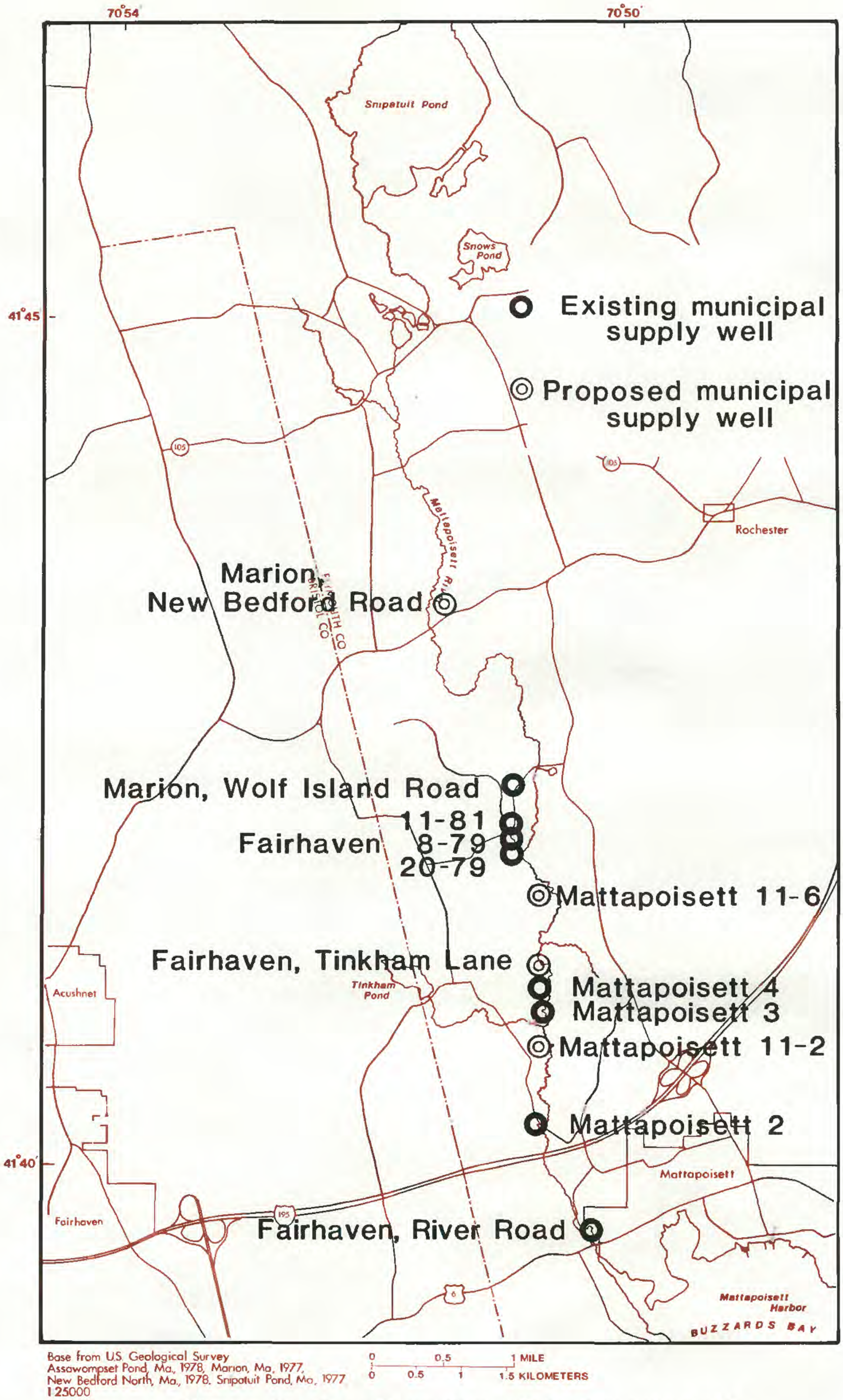


Figure 2.--Location of municipal supply wells.

BACKGROUND HYDROLOGY

To understand the discussion of the Mattapoisett River aquifer, it may be helpful to review several fundamental concepts of hydrology. The hydrologic cycle (fig. 3) describes the movement of water:

> It evaporates from the oceans and lands of the earth, condenses to form clouds, falls back to the earth as precipitation, and returns to the oceans via streams or subsurface flow to evaporate again.

In humid areas, such as the Mattapoisett River basin, about half of the water which falls as precipitation returns to the atmosphere through the process of evapotranspiration. This process is a combination of: (1) evaporation from the land and water surfaces and (2) transpiration, which is the release of water vapor from plants. Of the remaining water that falls on the earth, some, called surface runoff, flows directly over the land to surface-water bodies, such as rivers and lakes. The rest infiltrates the ground. The amount of infiltration depends on the nature of the materials, the vegetation cover, and the topography of the area. For example, on Cape Cod the fairly coarse sands, sparse vegetation, and gentle slopes allow most of the water to enter the ground, consequently there are very few streams. In areas of solid rock or pavement, however, very little water infiltrates; most runs off to drains and streams.

There are two distinct hydrologic zones below the land surface. In the upper, unsaturated zone, the openings in the rock or sediment are filled with air and some water adhering to the solid portion. In the lower, saturated zone, the openings are completely filled with water. The boundary between these two zones is the water table. Wells and natural depressions, such as lakes and stream channels which extend below the water table into the saturated zone, fill with water to the level of the water table.

In sediments, water in the saturated zone must flow in tortuous paths around the grains of rock material. It can flow more freely in coarse-grained sediment, such as gravel, than in fine-grained sediment, such as silt and clay. Hydraulic conductivity is the measure of the capacity of a porous material to transmit water—the volume of water that passes through a given cross section of aquifer material in a day. Values of hydraulic conductivity typically range from less than 1 cubic foot per square foot per day (1 foot per day) in silt and clay to several hundred feet per day in coarse gravel. Although the rate of ground-water flow varies with the type of sediment through which the water passes, it is always much slower than the rate of surface-water flow. It is a misconception that ground water flows in underground rivers. Only when flowing through fractures in bedrock or through caverns can water move unimpeded. However, bedrock fractures are rarely well interconnected, so the overall flow of the water through the rock is slow.

Under natural conditions, the direction of ground-water flow is controlled by the altitude of the water table. In sand and gravel where the water table is free to rise and fall with changes in precipitation and evapotranspiration, ground water moves from areas of high water-table altitude to areas of low water-table altitude. Eventually, the water discharges to a stream, the ocean, a spring, a swamp, or a pumping well.

An aquifer (from the Latin words aqua meaning "water" and fer "bearer") is a rock or sediment which yields water in significant quantity to a well or spring. The material must be able both to store and to transmit water which means there must be many interconnected pores or cracks.

A stream flowing over a sand and gravel aquifer is hydraulically connected to the ground water in the aquifer. In humid regions, ground water typically flows toward and discharges to the stream which causes the stream to flow even during dry weather. Seasonal, and longer term climatic, fluctuations in the level of the water table affect the streamflow. When the water table is low, less ground water discharges to the stream and, therefore, streamflow is less.

A typical sand and gravel aquifer hydraulically connected to a stream is shown in figure 4. Under natural conditions (4a), the ground water discharges to the stream. If a fully screened well were constructed but not pumped, the water level in the well would be at the level of the water table. The ground water would continue to discharge to the stream (4b). Pumping the well would lower the water level in a cone-shaped area centered at the well. Such an area of

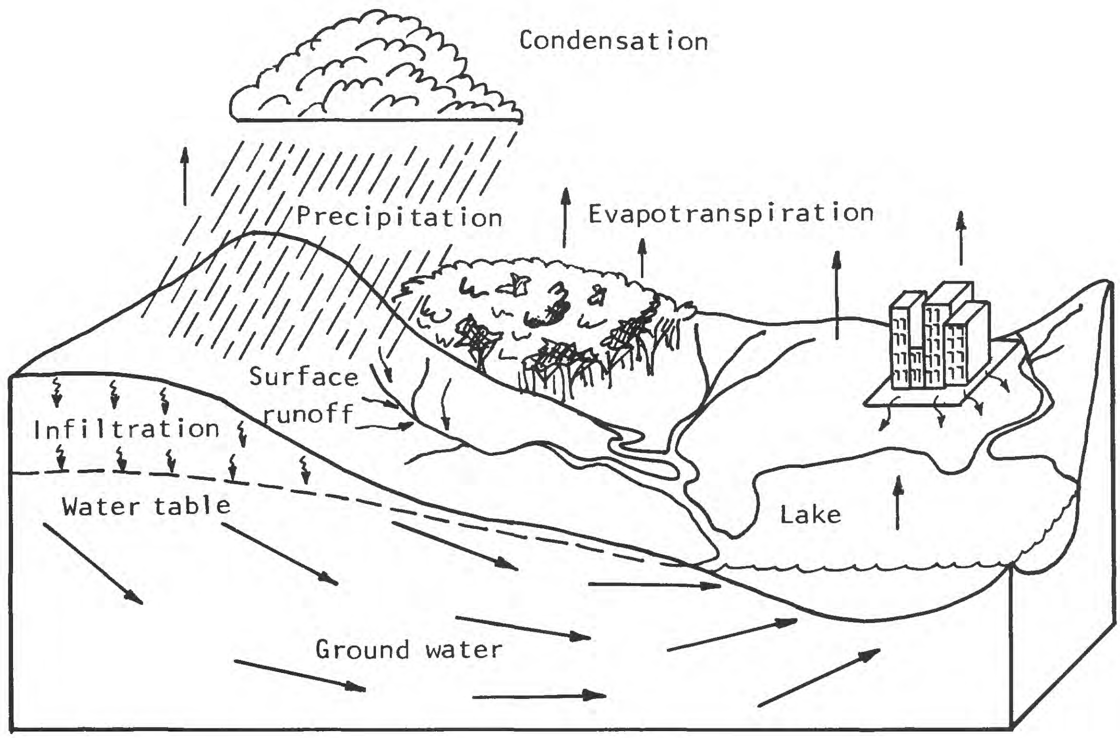
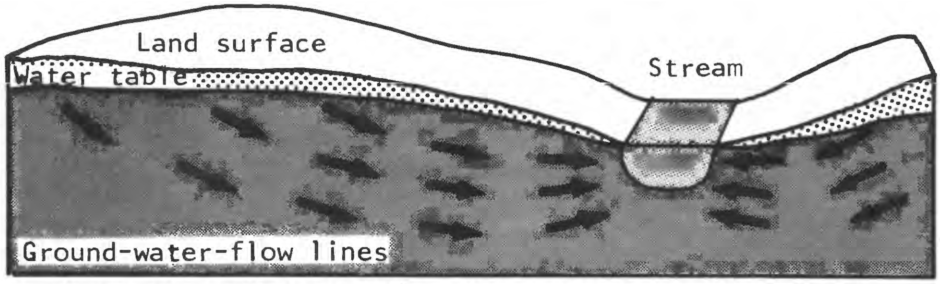
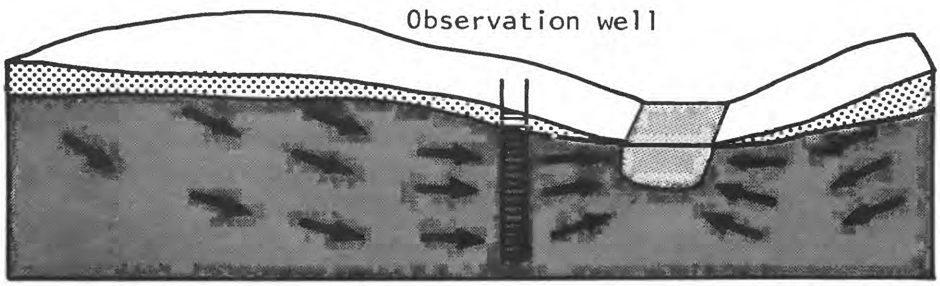


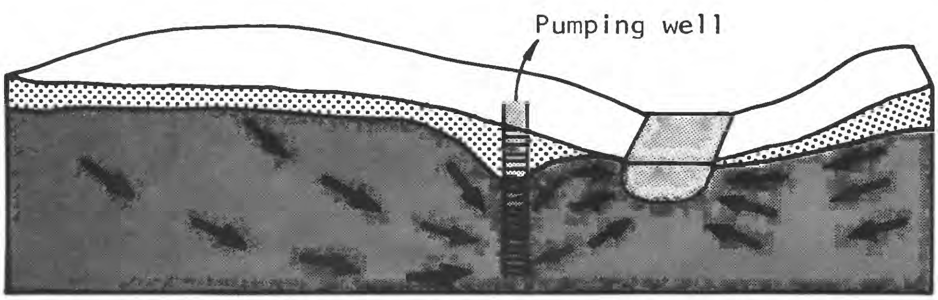
Figure 3.-- Hydrologic cycle.



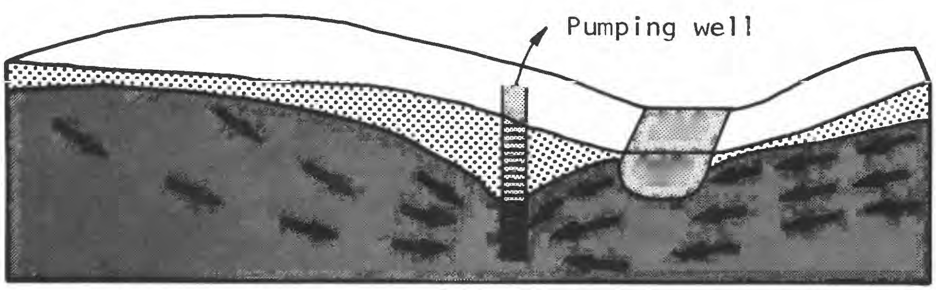
a. Natural conditions; ground water discharging to stream



b. Non-pumping conditions; ground water discharging to stream



c. Pumping conditions (small volume); intercepted ground-water discharge



d. Pumping conditions (large volume); intercepted discharge and induced infiltration

Figure 4.-- Effect of well development on the stream-aquifer system.

lowered water level is called a cone of depression. Some ground water that would otherwise discharge to the stream is intercepted and withdrawn by the pumping well (4c). Increasing the pumpage would cause more of the ground-water discharge to be intercepted, and might cause some of the water in the stream to be drawn into the ground and eventually into the well (4d). With increased pumpage, water levels are lowered over a larger area and the level of the stream is lowered. This happens because the water level in the well is at a lower altitude than the water level in the stream. The process of drawing water from the stream into the aquifer is called induced infiltration and is common in areas where wells are near streams.

GEOHYDROLOGIC SETTING

The storage and movement of ground water in the Mattapoisett River basin is controlled by three geologic materials whose origin and water-yielding characteristics differ significantly (fig. 5). Folded and fractured crystalline bedrock, commonly called "ledge," underlies the entire basin. In the uplands on the east and west sides of the basin, small exposures of the bedrock are at the surface. In the valley, bedrock is covered by as much as 100 feet of sediment.

During glaciation, which lasted from 2,000,000 to 10,000 years ago, continental glaciers advanced from the north and covered the Mattapoisett area. Existing bedrock channels were scoured and deepened by the ice, and rock material picked up and carried by the glaciers was redeposited.

An unlayered mixture of rock material deposited directly by glacial ice is called till, or commonly "hardpan." This material has not been sorted or layered by flowing water and therefore can be a mixture of all sizes of rock fragments ranging from clay to boulders. In the Mattapoisett River basin, till is found in thick deposits on the uplands and in a thin layer covering the bedrock beneath the valley sediments.

Glacial rock debris that was transported, sorted, and deposited by flowing water is called stratified drift. It may include separate layers of sand, gravel, silt, and clay. Glacial meltwater flowed through the Mattapoisett Valley and deposited as much as 100 feet of stratified drift in a bedrock channel in the center of the valley (fig. 6).

Each of these geologic materials could be considered an aquifer. However, the potential yields of wells vary depending on the material in which each is located. Deep wells drilled in bedrock supply water to many residences. Yields of these wells depend on the number, size, and interconnection of the fractures that the well intercepts and is typically less than 10 gallons per minute.

Dug wells in till have long been used for domestic and agricultural supply. The yield of these wells is limited because of the mixture of sizes of rock material in the till. Small grains fill the spaces between large grains reducing the amount of pore space, which in turn reduces the amount and rate of water flowing through the material. Some of these wells are still used in the Mattapoisett River basin, but many have been abandoned or converted to septic pits.

Wells in the stratified drift can provide large quantities of water for municipal supplies. The material in each layer of the drift is relatively homogeneous, so the pore spaces are open and transmit water readily. In areas where there is a thick layer of saturated drift, wells can yield between 300 and 1000 gallons per minute.

The average altitude of the bedrock surface underlying the Mattapoisett River aquifer is about 60 feet below land surface (fig. 7) with isolated parts of the central valley as much as 110 feet below land surface (Caswell, Eichler and Hill Inc, 1983). The altitude of the bedrock surface was determined from drillers' records of test holes and wells, from outcrops, and from seismic refraction surveys. Figure 8 shows cross sections of the valley along the three seismic lines located in figure 7.

A network of 58 observation wells (fig. 6) was used to monitor water levels throughout the valley and to construct a water-table map of the basin. All wells in the town of Mattapoisett are identified by the three-letter code MJW followed by a number. All wells in Rochester are identified by the code RFW. For clarity, the letter codes are omitted from figure 6.

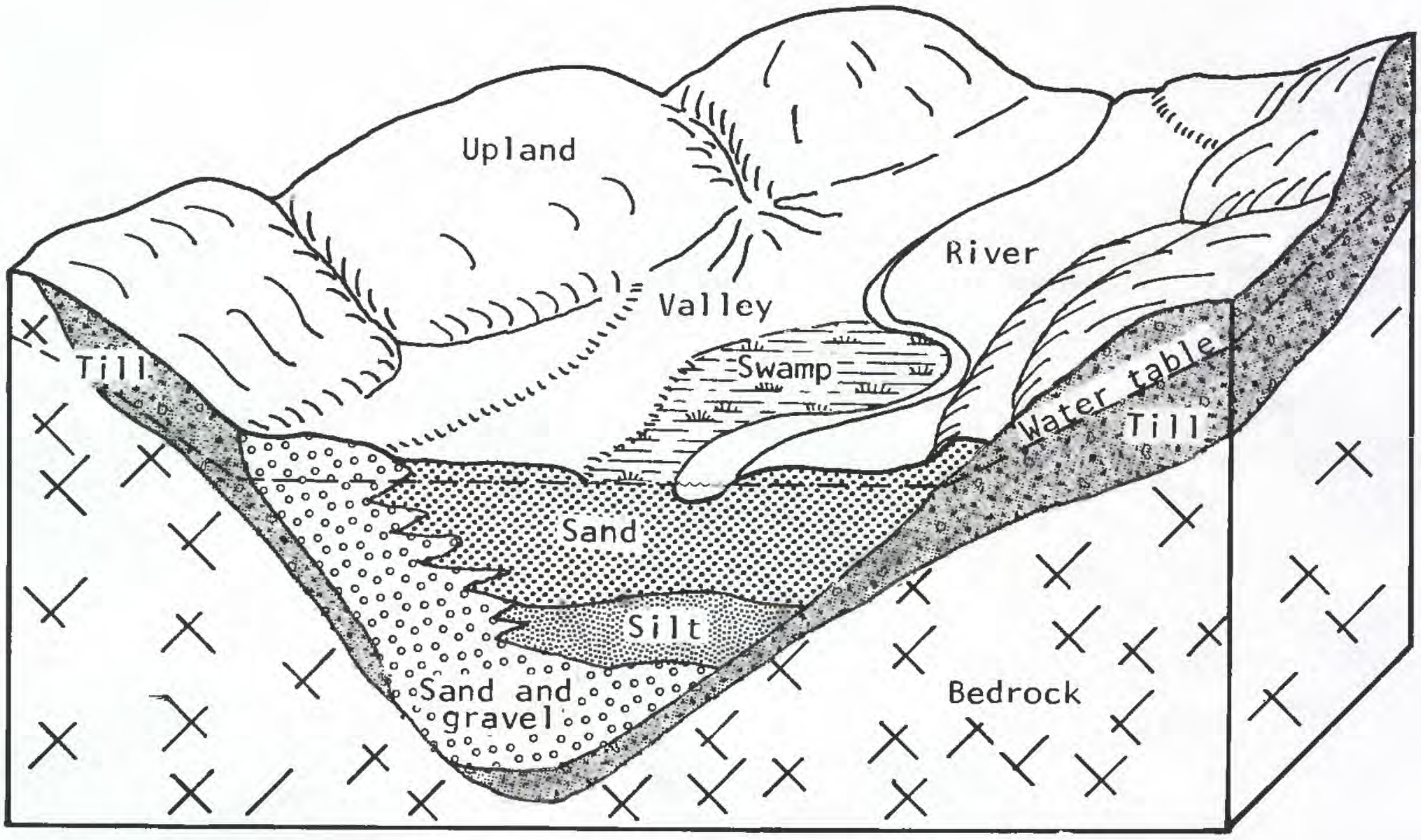
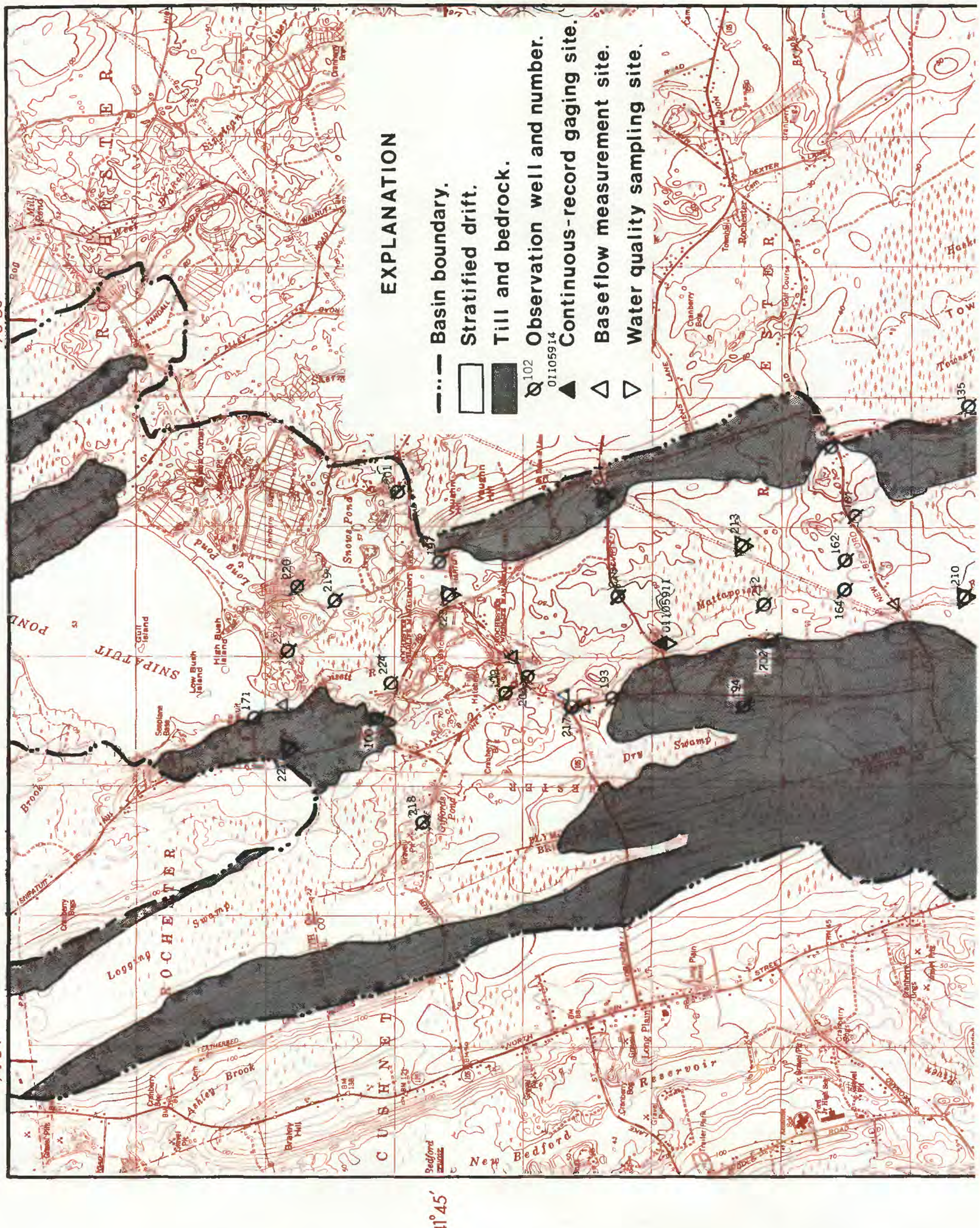


Figure 5.--Idealized diagram showing relationship of stratified-drift, till, and bedrock.


EXPLANATION
Basin boundary.
Stratified drift.
Till and bedrock.
102 Observation well and number.
01105914 Continuous-record gaging site.
Baseflow measurement site.
Water quality sampling site.
70°50'
70°54'
41°45'

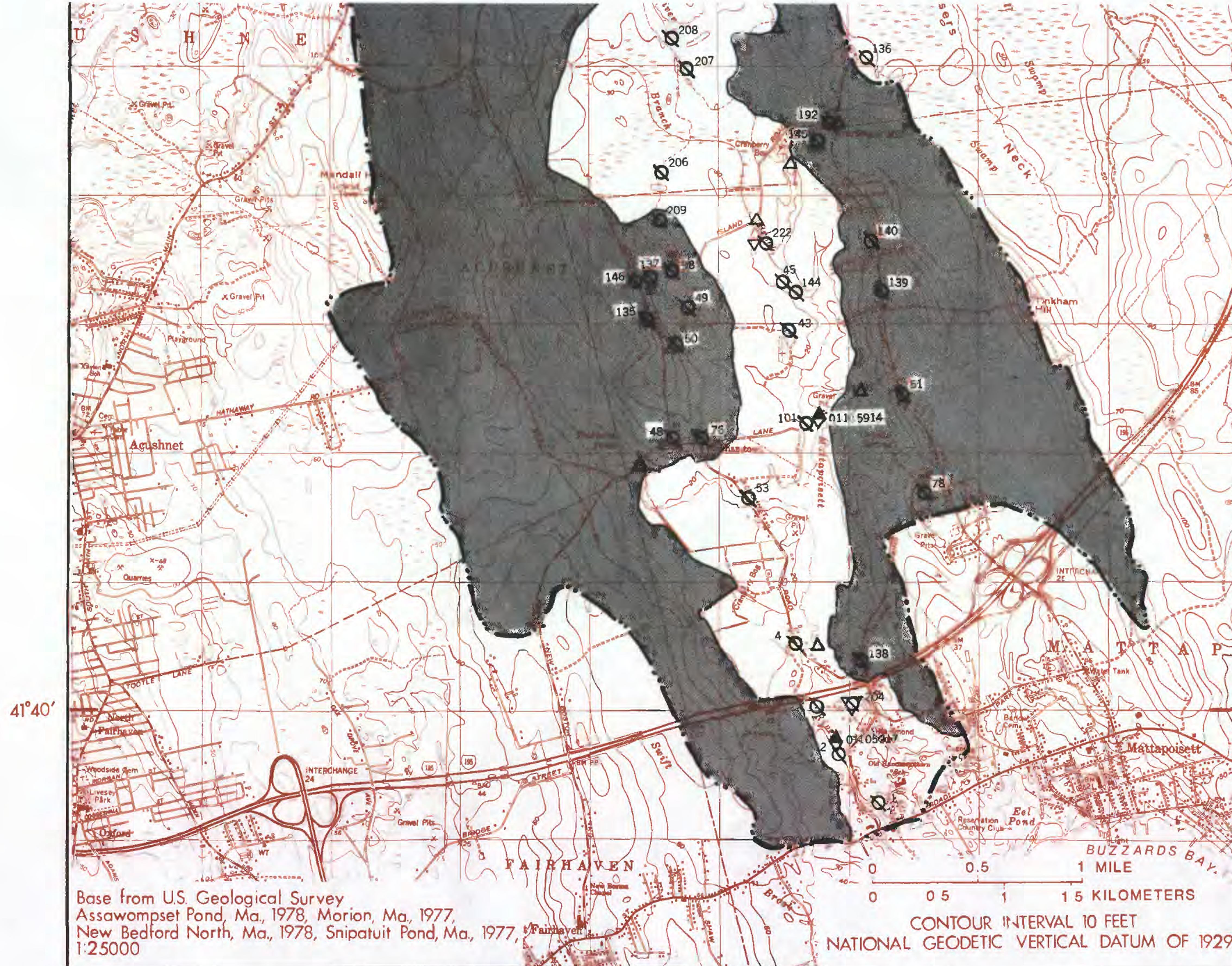
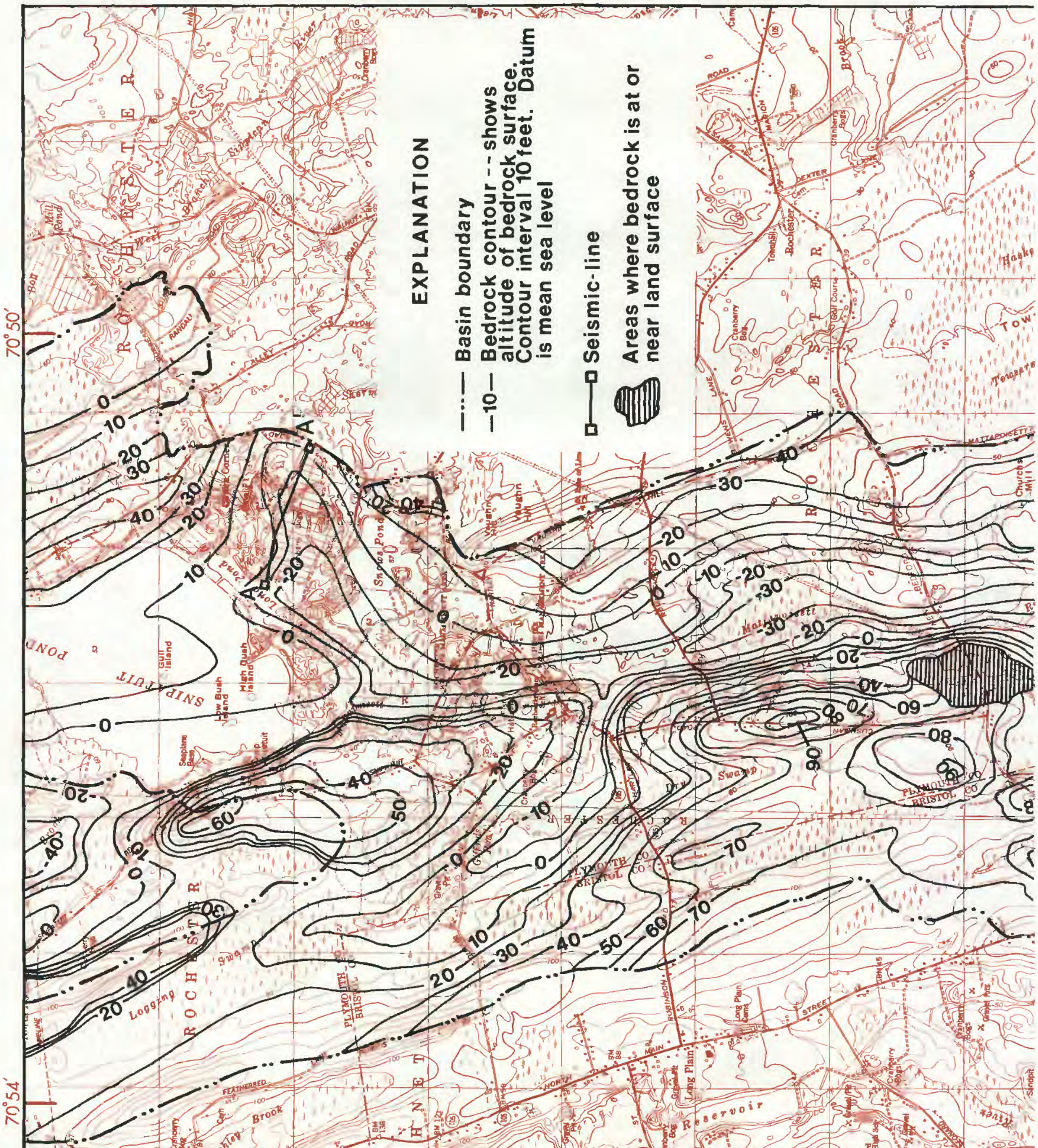


Figure 6.--Ground-water and surface-water monitoring sites and surficial sediments of the Mattapoisett River drainage basin.


EXPLANATION
Basin boundary
—10— Bedrock contour -- shows altitude of bedrock surface. Contour interval 10 feet. Datum is mean sea level
Seismic-line
Areas where bedrock is at or near land surface
70°50′
70°54′
41°45′

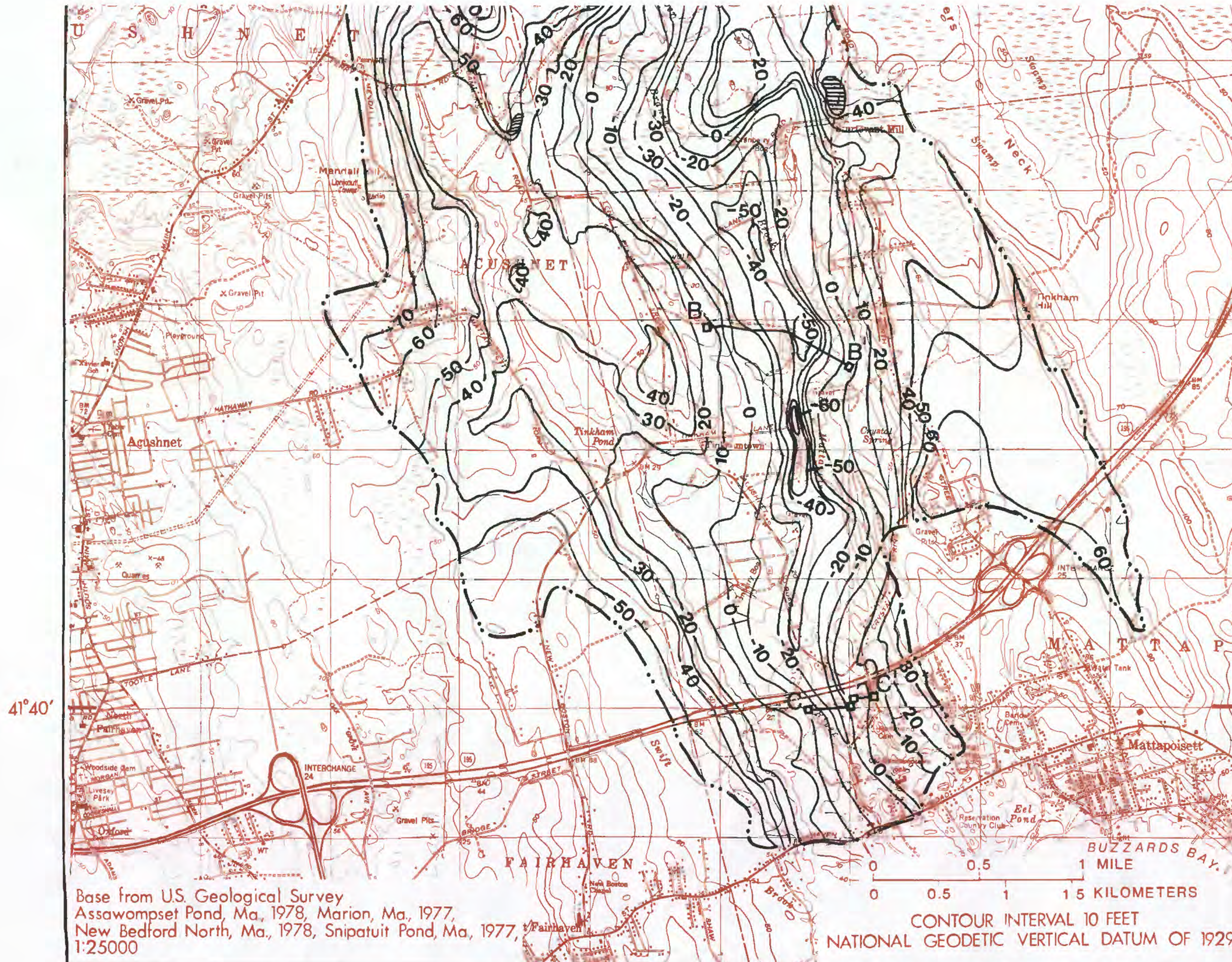


Figure 7.--Bedrock topography.

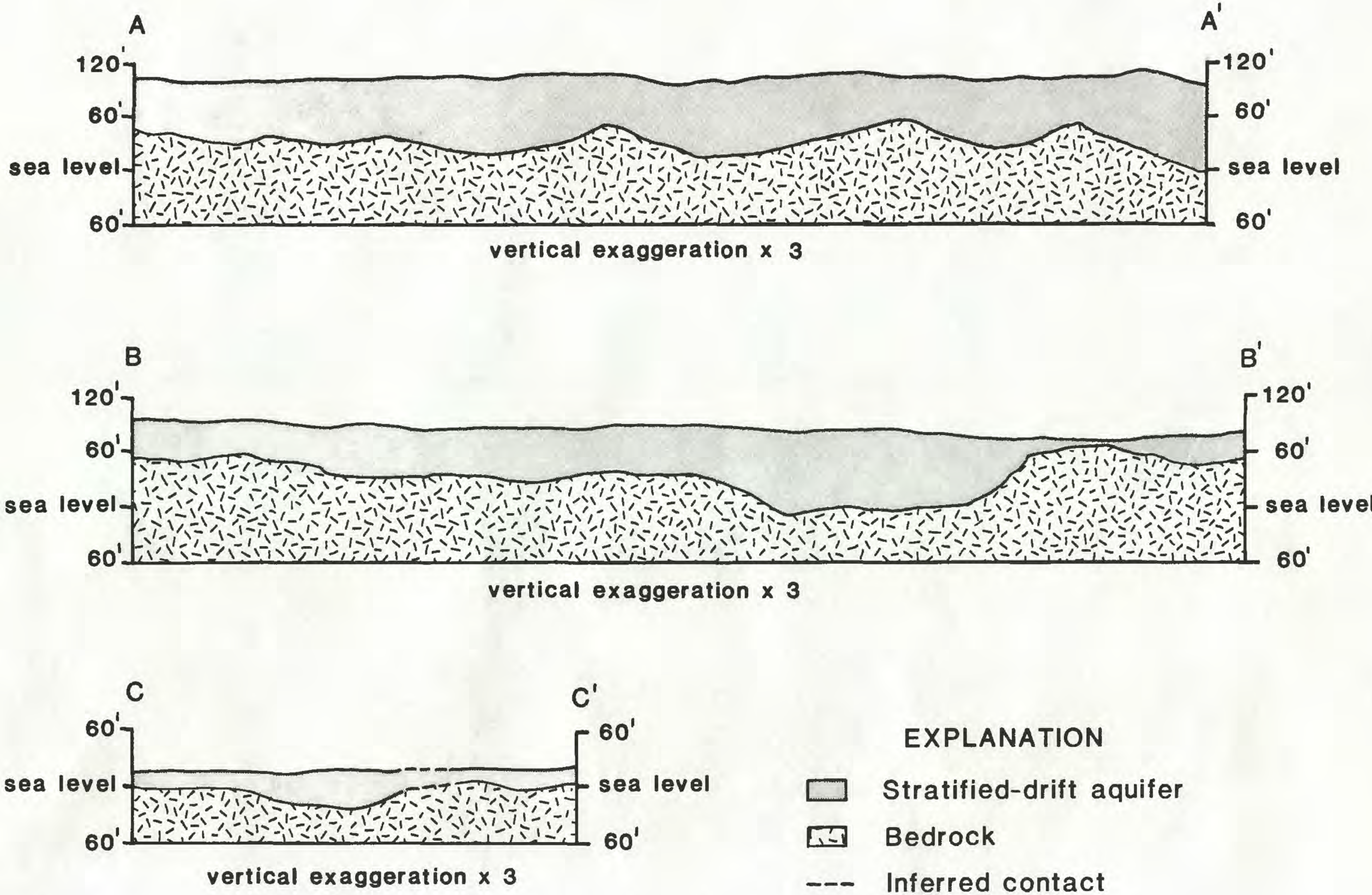


Figure 8.--Seismic cross sections.

Interpretation of a water-table map shows the directions of ground-water flow and shows drawdown of the water table caused by pumping wells. The altitude of the water table at every location varies throughout the year, usually from a low in the early fall to a high in the spring. The altitude of the water table in May 1982 approximates the average level and is shown in figure 9. Ground water flows primarily from the sides of the valley toward the river. The water table slopes gently toward the river in the coarse-grained materials of the aquifer and more steeply in the till.

The saturated thickness of the Mattapoisett River aquifer is shown in figure 10. The thickness contours indicate that saturated thickness exceeds 50 feet in the center of the bedrock valley. Saturated drift exceeds 75 feet in the northern part of the aquifer where the land surface is higher and the bedrock valley is wider.

Hydraulic conductivity of the sand and gravel was estimated by two methods: (1) grain-size analysis of samples collected during installation of the U.S. Geological Survey observation wells and (2) analysis of the rate and amount of water-level drawdown in observation wells surrounding a pumping test well. Hydraulic conductivity varies throughout the aquifer but, in general, values greater than 100 feet per day are common in the central part of the valley, and values less than 50 feet per day are common along the sides of the valley (fig. 11).

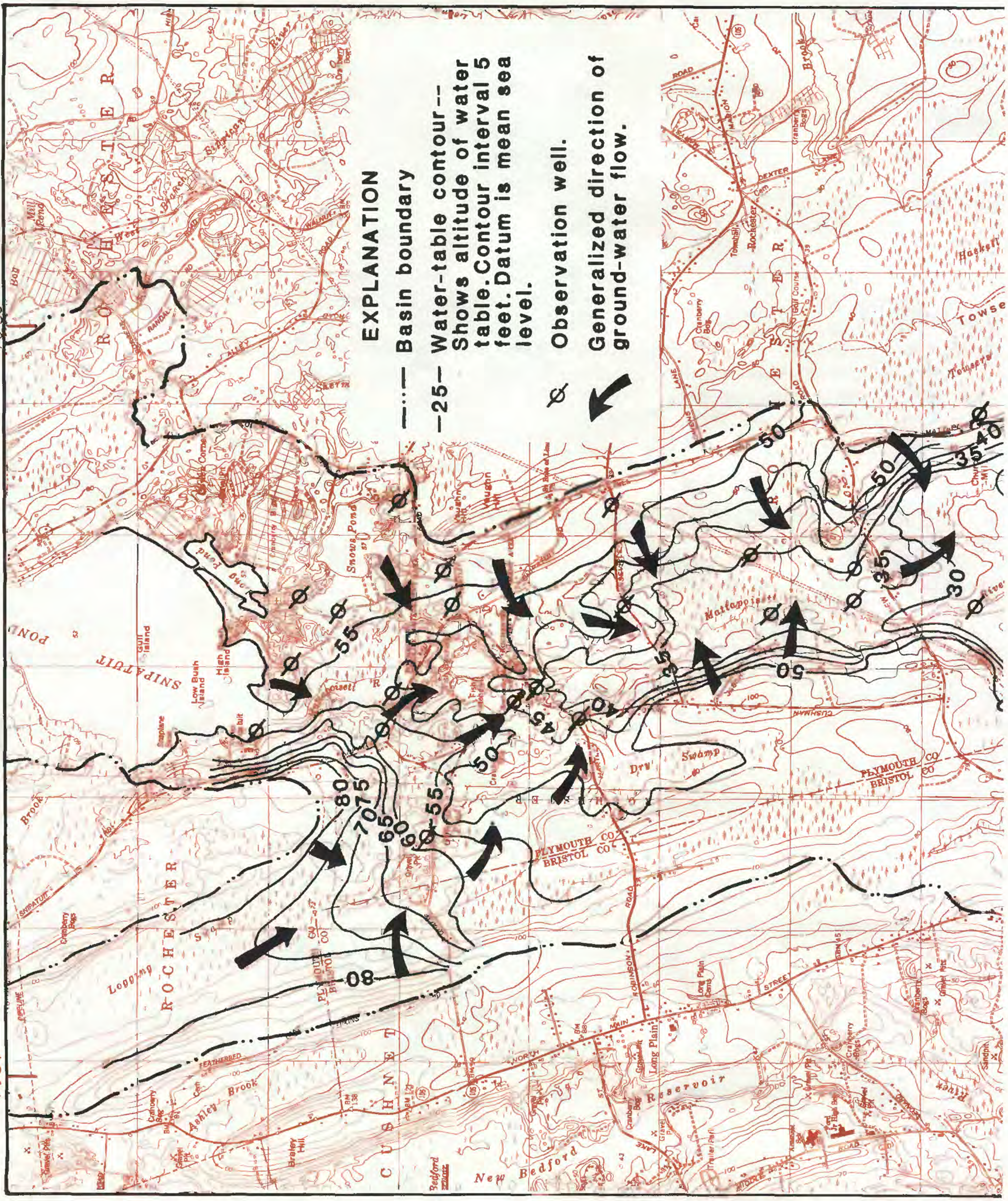
The Mattapoisett River and its two major tributaries, the unnamed brooks through Hartley Pond and Tinkham Pond, are perennial streams. Other tributaries, including Branch Brook, flow intermittently during the year. Three continuously-recording stream gages were set up on the Mattapoisett River to record stream stage, which is the height of the water surface. Streamflow measurements were made monthly at these locations (see fig. 6 for gage locations). In the 1982 water year (October 1, 1981, to September 30, 1982), the flow in the Mattapoisett River at the gage above River Road, Mattapoisett, ranged from 2.6 to 246 cubic feet per second.

In addition to the monthly data on streamflow, measurements were made to determine the amount of ground water discharged to the stream. When there has been no precipitation for many days, one can assume that all the flow in an unregulated river is from ground-water discharge. After each of five different periods without precipitation during 1982, a series of flow measurements was made along the river and its tributaries. The measured total ground-water flow at the River Road gaging station varied from 8.3 to 52.9 cubic feet per second. In general, these measurements--called seepage runs--showed that the flow of the Mattapoisett River increases downstream. However, a few measurements indicated that occasionally streamflow decreases near pumping wells due to induced infiltration, and in swampy terrain due to high evapotranspiration.

QUALITY OF WATER

Water-quality samples were collected in the Mattapoisett River basin at five wells in stratified drift, two wells in till, and at the three gaging stations. The objective of the sampling program was to assess the current water quality of both the aquifer and the river. Samples collected in August 1981 and July 1982 were analyzed for major constituents, insecticides, pesticides, and volatile organic compounds (mainly solvents). Locations of the ground-water and surface-water sampling sites are shown in figure 6.

In general, both the river and the ground water can be classified as soft and slightly acidic. Dissolved iron and manganese concentration levels are relatively high as is typical in stratified drift aquifers in New England. Above normal concentrations of sodium and chloride were detected in one well and several organic compounds were detected in a few samples (Olimpio and de Lima, 1984).


EXPLANATION
Basin boundary
—25— Water-table contour--Shows altitude of water table. Contour interval 5 feet. Datum is mean sea level.
Observation well.
Generalized direction of ground-water flow.
70°50'
70°54'
41°45'
ROCHESTER
ROCHESTER
ACUSHNET
Snows Pond
SNIPATUIT POND
Mattapoisett
Dry Swamp
PLYMOUTH CO
BRISTOL CO
New Bedford Reservoir
Long Plain
Ashley Brook
Towse

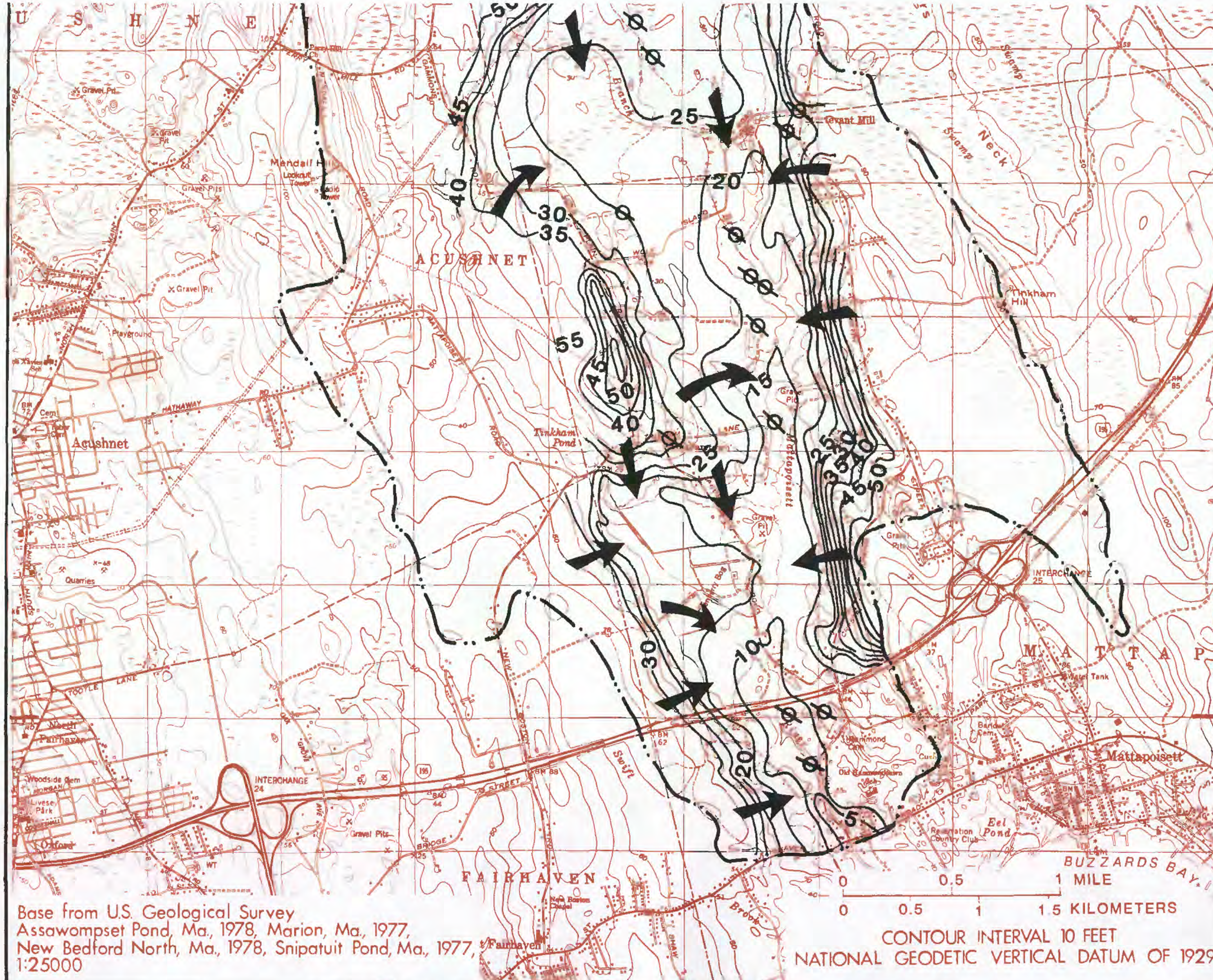
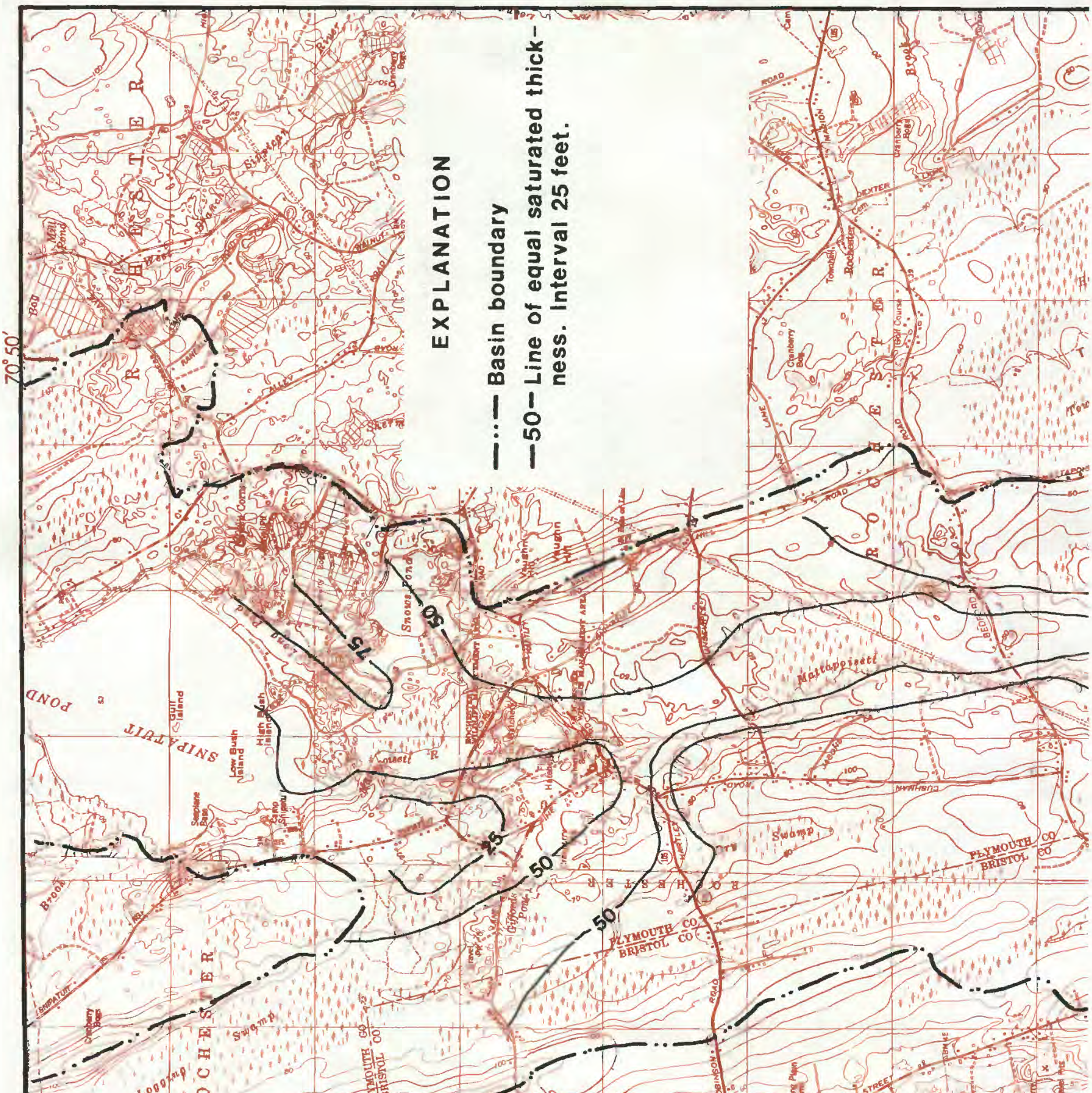


Figure 9.--Altitude of water table, May 1982.


EXPLANATION
Basin boundary
—50— Line of equal saturated thickness. Interval 25 feet.
70°50′
70°54′
41°45′
75
50
25
PLYMOUTH CO
BRISTOL CO
ROCHESTER
Mattapoisett
Swamp
SNIPATUIT POND

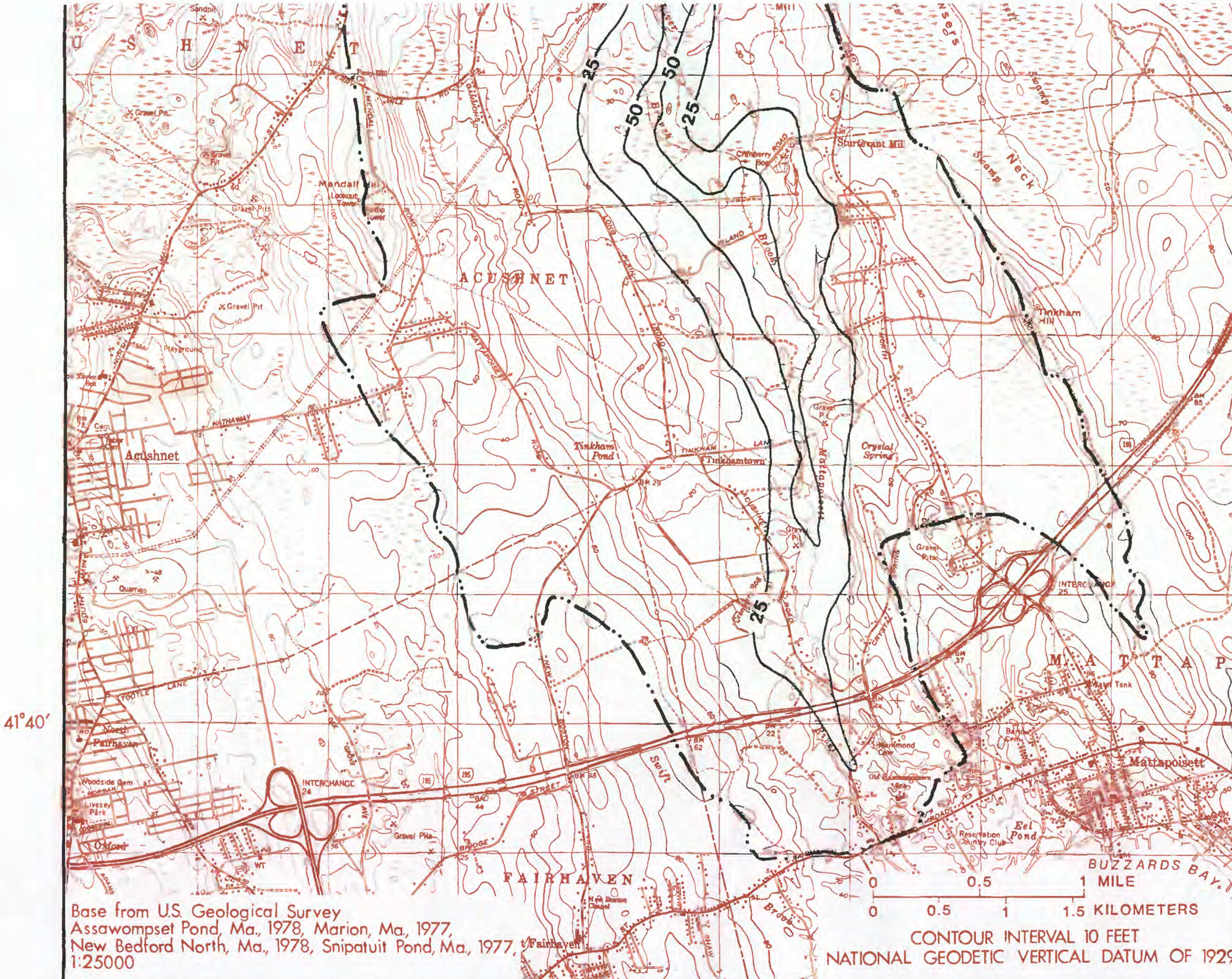
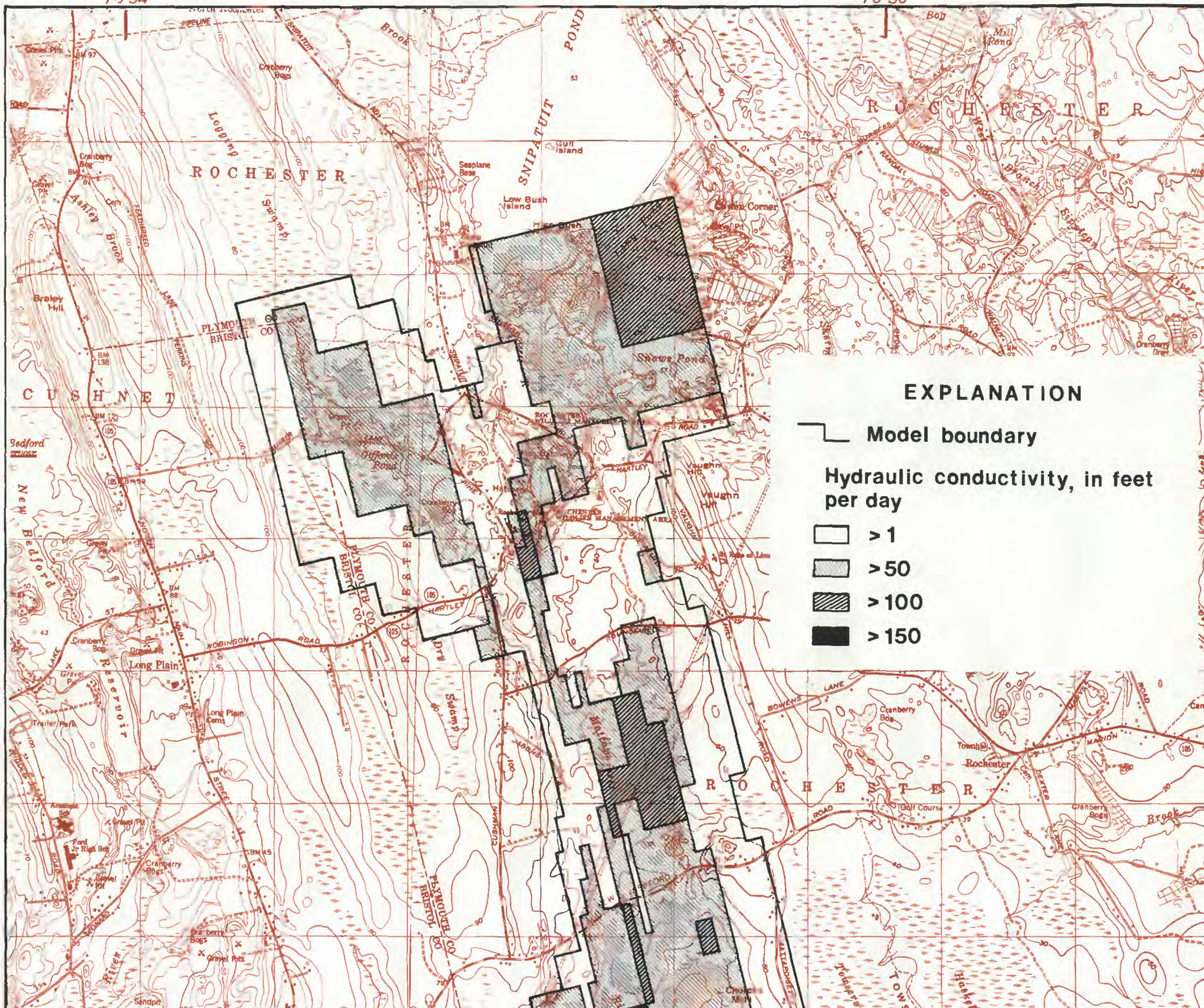


Figure 10.-- Saturated thickness of the stratified-drift aquifer.



70°54′
70°50′
41°45′
EXPLANATION
Model boundary
Hydraulic conductivity, in feet per day
> 1
> 50
> 100
> 150
ROCHESTER
CUSHNET
SNIPATUIT POND
Snows Pond
Mattapoisett
Long Plain
Reservoir
Dry Swamp
Logging Swamp
PLYMOUTH CO
BRISTOL CO
New Bedford

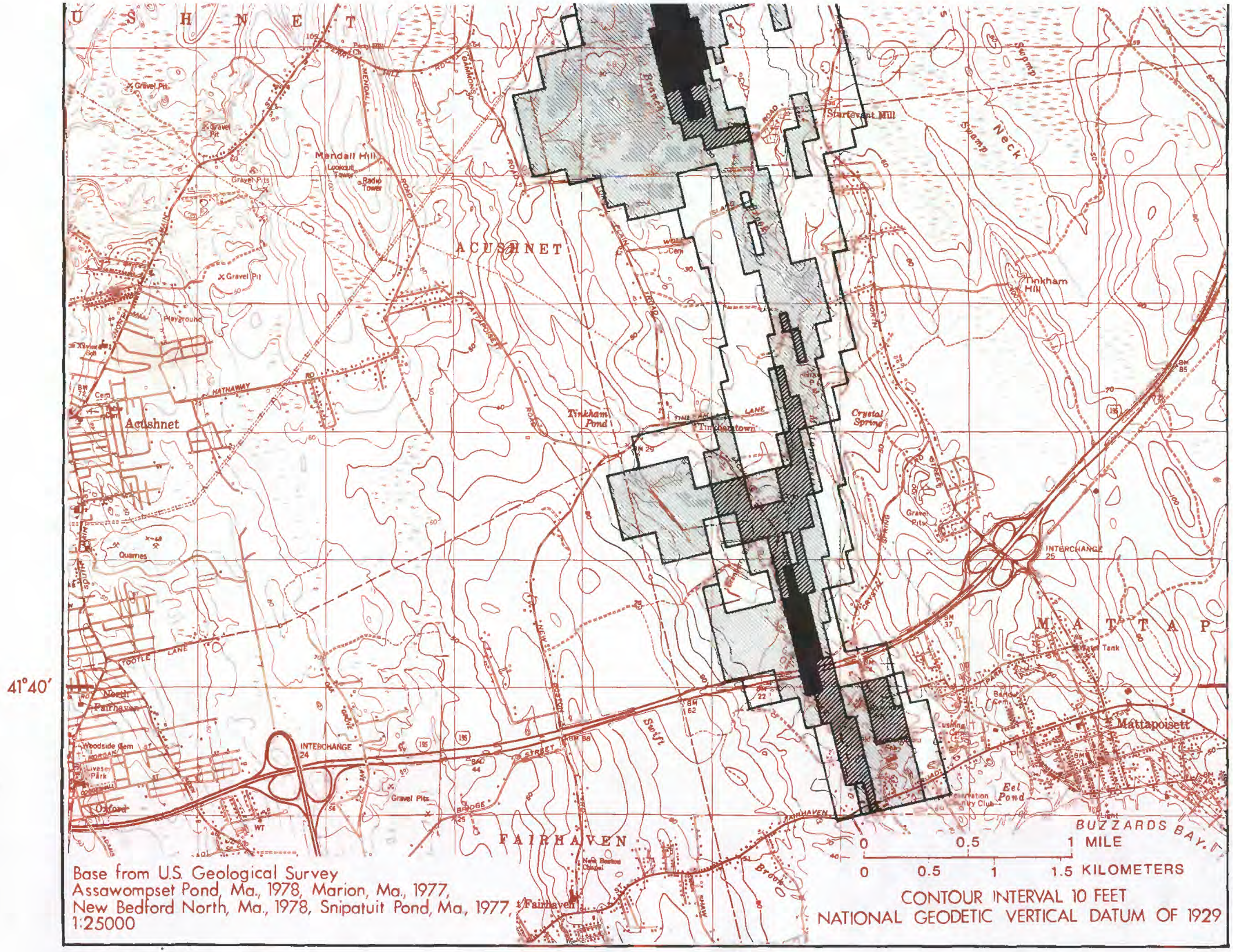


Figure 11.--Hydraulic conductivity of the aquifer as used in the computer model.

DESCRIPTION OF COMPUTER MODEL

The mathematical model used in the analysis of the Mattapoisett River aquifer is a computer simulation model, a set of mathematical equations which describe ground-water flow and the key physical properties of the aquifer. A computer was used to solve the complex equations and to calculate ground-water levels and ground-water discharge resulting from multiple natural and manmade stresses on the aquifer.

A mathematical model is based on the hydrologist's understanding of the dynamics of the real ground-water system. A simplifying description is devised which consists of general ideas on how the ground-water system works. Figure 12 depicts this simplified description. The Mattapoisett River aquifer can be described as follows:

1. The aquifer is long, narrow, and thin; the ground-water flow is horizontal.
2. The bottom boundary of the aquifer is impermeable; there is no flow either to or from the underlying bedrock.
3. The side boundary of the aquifer is the contact between stratified drift and till. This is a leaky boundary because some ground water flows from the adjacent till to the aquifer.
4. The altitude of the surface water in streams and ponds remains constant with time.

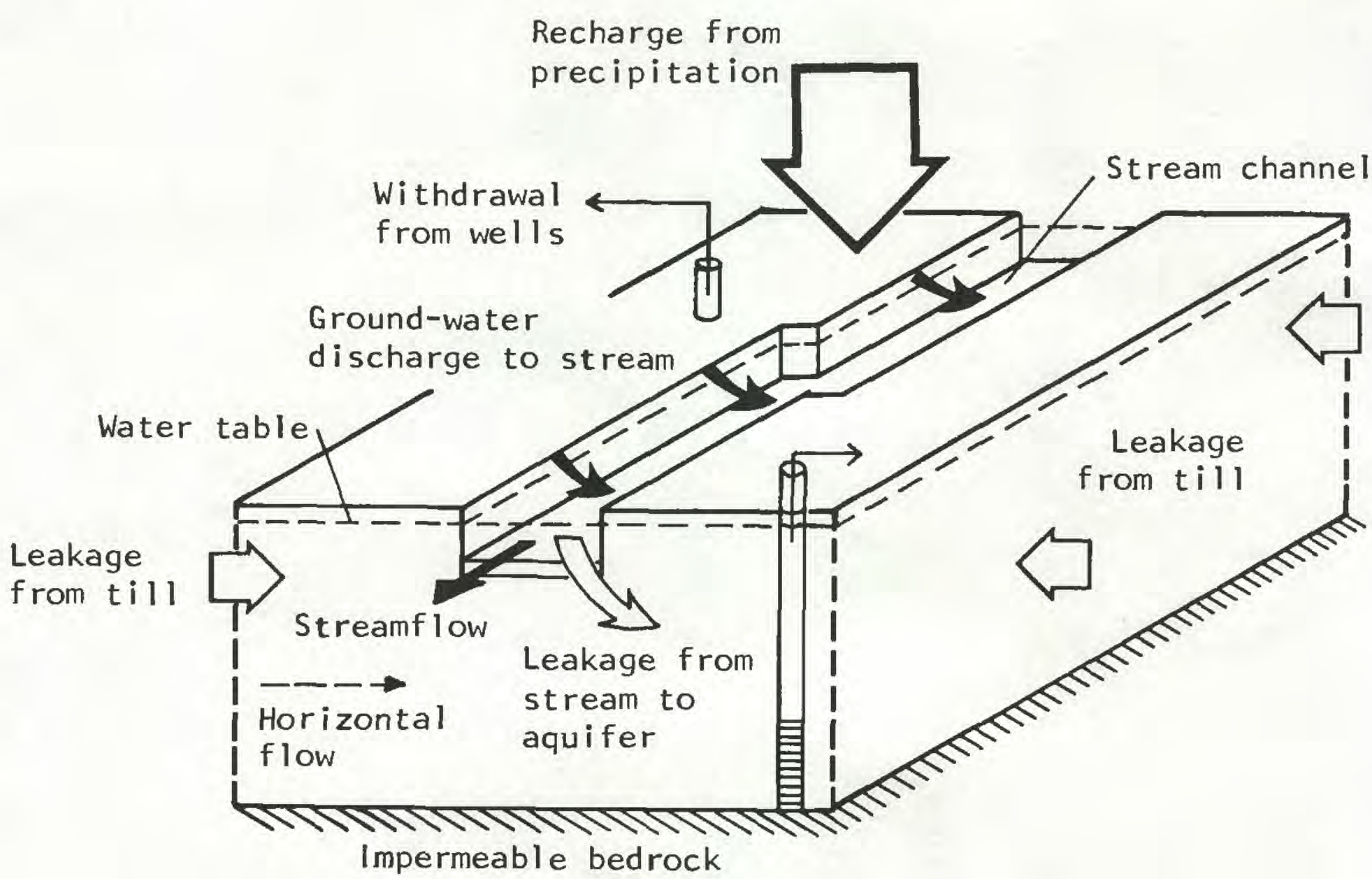


Figure 12.--Idealized diagram of steady-state ground-water flow.

A ground-water-flow model is based on the principle of conservation of mass: the inflow of water (recharge) minus the outflow of water (discharge) must equal the change in water storage. In the Mattapoisett River aquifer model, recharge to the ground-water system is from precipitation and from ground water flowing from the adjacent till. Discharge is to streams and pumping wells.

To simplify the initial modeling process, average values are used and fluctuations in the hydrologic system with time are ignored. This type of system is in "steady state" and the recharge to the system equals the discharge from the system. Recharge from precipitation was estimated to be 15.9 inches per year. This figure was calculated from the 1982 water year precipitation at Rochester, Massachusetts, minus the estimated evapotranspiration.

The hydrologic properties of the Mattapoisett River aquifer are not uniform, so one equation cannot define the entire area. To account for the variation in the aquifer, the model area is divided into many smaller areas called nodes. For each node, aquifer properties, such as saturated thickness and hydraulic conductivity are assumed to be uniform. The ground-water-flow equation is then solved for each node.

A rectangular grid was superimposed on a map of the study area (fig. 13). Sections of the grid ranged from 208 X 208 to 832 X 832 feet. Nodes of different sizes were used in order to analyze in greater detail the areas of special interest along the stream, near pumping wells, and in areas of steeply sloping water table. Within the grid area, model boundaries were selected to match either geologic or hydrologic boundaries (fig. 13). Ground-water flow into and out of each node is simulated for the 1068 nodes within the active model area delineated by the model boundaries.

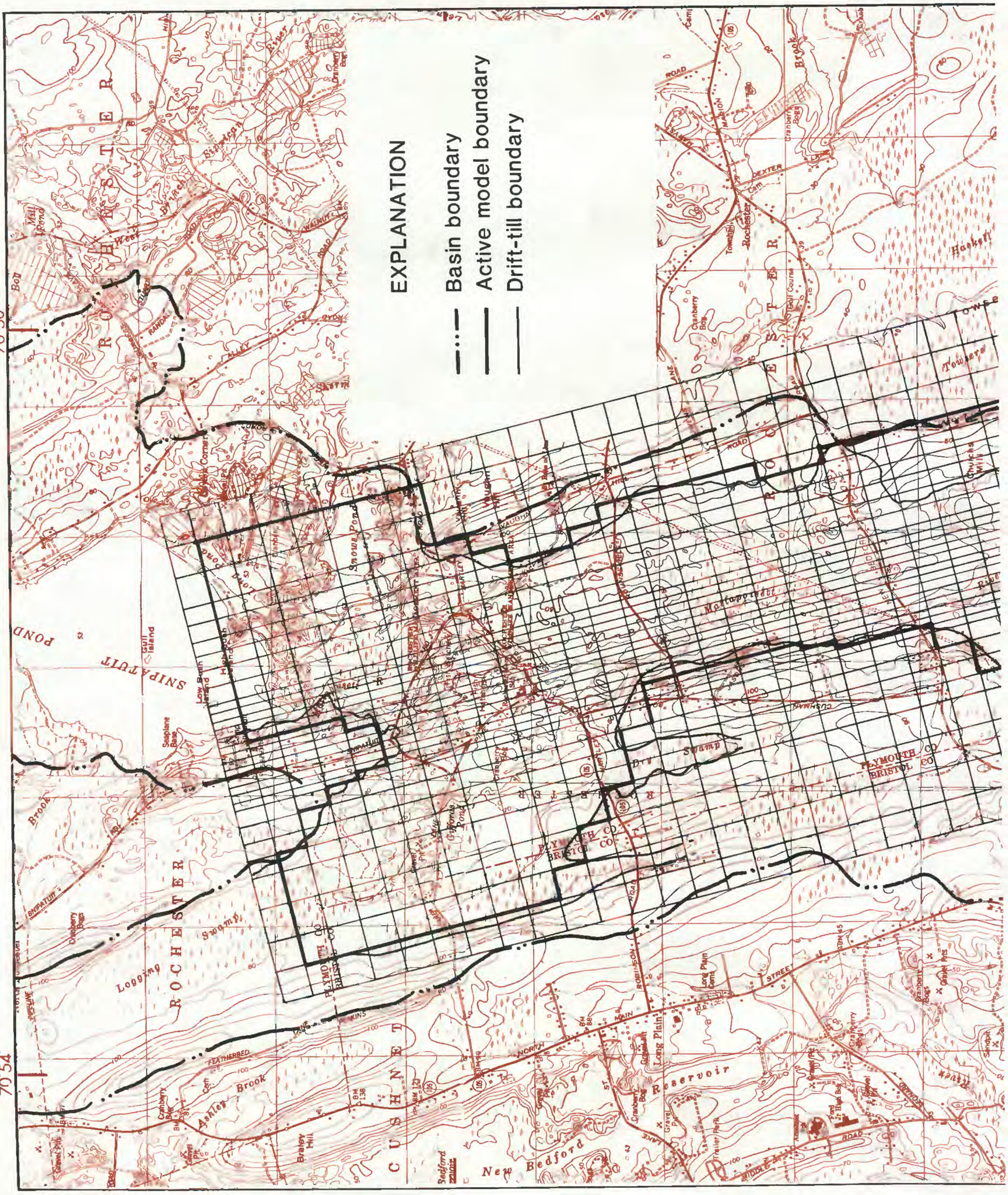
Accurate data do not exist for every node in the active model area. Therefore, it was necessary to interpolate between known data points. The initial estimates were further refined during the process of model testing and development. This testing was a repetitive process of adjustment and readjustment of input data within reasonable limits until the computed water table and ground-water discharge matched the field observations.

CALIBRATION OF THE MATTAPOISETT RIVER AQUIFER MODEL

The steady-state model of the Mattapoisett River aquifer predicted ground-water levels throughout the model area. The difference between computed and measured water-level values was less than 1 foot at 80 percent of the observation wells and less than 4 feet over 90 percent of the model area (fig. 14). Most differences greater than 4 feet were near the aquifer boundaries on the east and west sides of the valley where there is vertical flow due to the steeply sloping water table. In these areas, the simplified description of all ground-water flow as horizontal is inaccurate. To correct this problem, a three-dimensional model would be needed. Because the apparent errors are small and located in parts of the aquifer which are unlikely to be developed, the simpler two-dimensional model is considered adequate to meet the study objectives.

An equally important check on the accuracy of the steady-state model was the comparison of the computed ground-water discharge to streams with the ground-water discharges measured during the May 18, 1982, seepage run. Measured and calculated flow were compared along the seven stream segments shown in table 1. The streamflow measurements match the calculated discharges fairly closely, considering the errors inherent in streamflow measurements and the relatively coarse node spacing in the northern part of the model area. The discrepancy in the upstream section is probably the result of flow regulation at the Snipatuit dam.

The accuracy of the model was also assessed by analysis of the volume and rate of inflows and outflows to the ground-water system (table 2). The total ground-water inflow rate for the active model area was 13.37 cubic feet per second. The outflow rate, primarily ground-water discharge to the river, matched the inflow rate to 0.02 percent indicating that inflows balanced outflows and that mass was conserved.


EXPLANATION
Basin boundary
Active model boundary
Drift-till boundary
70°50'
70°54'
41°45'

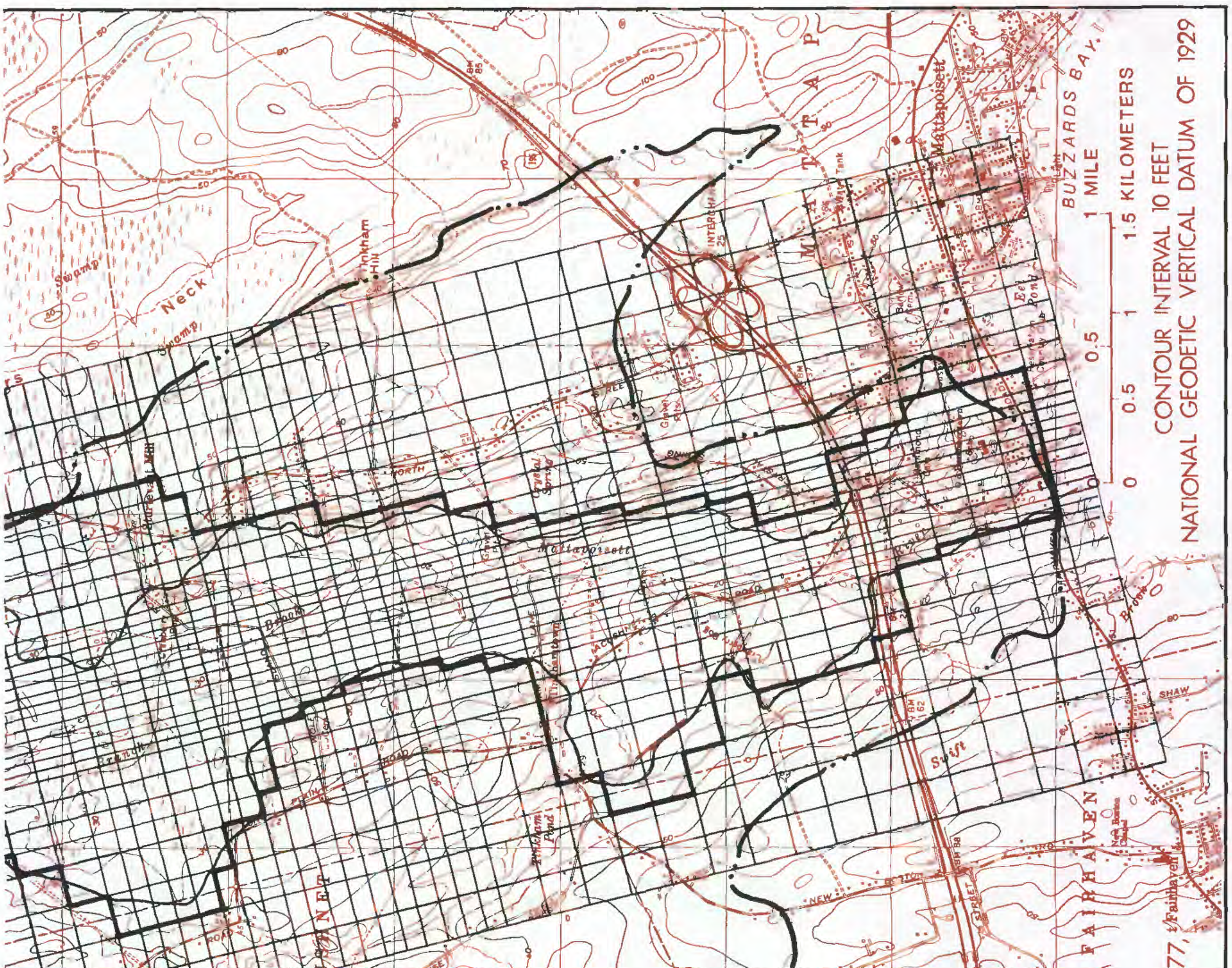
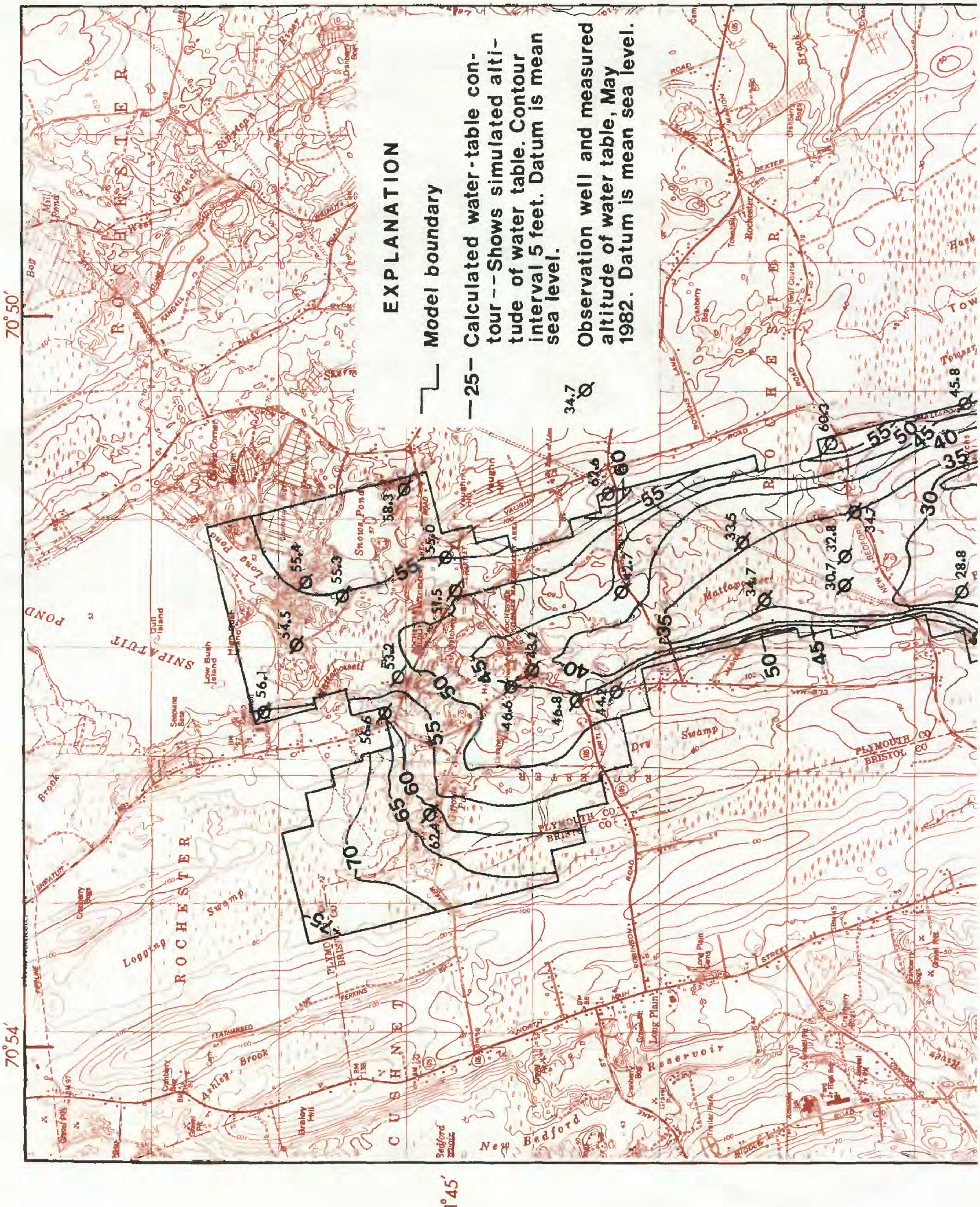


Figure 13.--Model grid.



EXPLANATION
Model boundary
—25— Calculated water-table contour--Shows simulated altitude of water table. Contour interval 5 feet. Datum is mean sea level.
34.7 Observation well and measured altitude of water table, May 1982. Datum is mean sea level.
70°50′
70°54′
41°45′

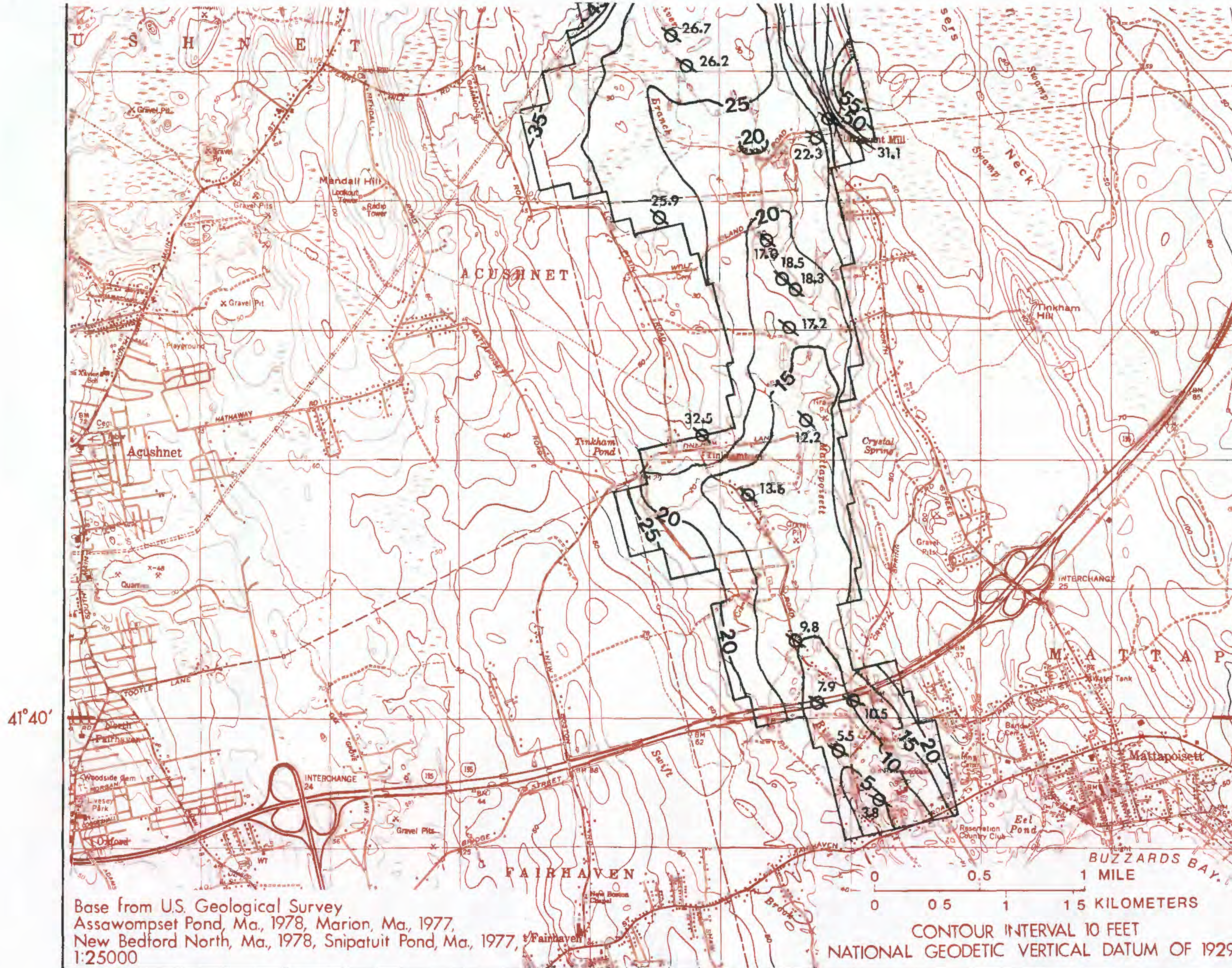


Figure 14.--Altitude of simulated steady-state water table, May 1982.

Table 1.—Observed and computed ground-water discharge from the aquifer, May 1982
(Discharge, in cubic feet per second)

Stream segment	Measured discharge in the segment May 18, 1982	Computed discharge in the segment
Upstream		
Snipatuit Pond-Rounseville Road	3.60	2.45
Tributaries: Hartley Pond and Cushman Road	1.52	1.88
Rounseville Road-Tinkham Lane	3.24	4.28
Tributary: Branch Brook	.42	.67
Tributary: Sturtevant Mill	.22	.06
Tributary: Crystal Spring	.13	.07
Tinkham Lane-River Road (including Tinkham Brook)	1.92	1.72
Downstream		
Total ground-water discharge at River Road	11.05	11.13

Table 2.—Balance of inflows and outflows to the aquifer, May 18, 1982
(Rates, in cubic feet per second)

Inflow rate		Outflow rate	
Recharge from precipitation	9.74	Ground-water discharge to streams[1]	11.28
Leakage from till	3.15	Pumpage	1.80
Leakage from ponds	.48	Leakage to ponds	.29
Total inflow	13.37	Total outflow	13.37

[1] Includes 0.15 cubic foot per second of water from a thick layer of clay in the Wolf Island Road area.

THE MATTAPOISETT RIVER AQUIFER MODEL AS A MANAGEMENT TOOL

Testing indicated that the ground-water-flow model of the Mattapoisett River aquifer can be used to predict how the aquifer will respond to proposed development. Ten scenarios were developed to demonstrate the use of the model and how pumping affects streamflow. The pumping rates used in the scenarios are given in table 3. The three levels of pumping stress analyzed were: (1) the average pumping rate for the summer (June, July, and August), (2) the average pumping rate for the highest month (July), and (3) the maximum daily pumping rate of each well (the well capacity). The projected pumping rates in table 3 were obtained from the towns; the Massachusetts Department of Environmental Management, Division of Water Resources; and consultants' reports on proposed well sites for the towns.

Scenarios 1-3 represented the pumping demands of wells existing prior to 1983. Scenarios 4-6 included the Fairhaven three-well system which began operation in the summer of 1983. Scenarios 7-10 simulated the demands of existing wells plus the progressive start-up of the proposed wells after the year 1990.

Table 3.—Ten steady-state pumping scenarios

(Pumping rates, in cubic feet per second)

	Current pumpage 1982			Current and proposed pumpage[1] 1983-90			Current and proposed pumpage 1990+			
	Summer aver-age	High month	Maxi-mum daily	Summer aver-age	High month	Maxi-mum daily	High month	High month	High month	High month
Scenario number: Well	1	2	3	4	5	6	7	8	9	10
Fairhaven, River Road	0.50	0.56	1.11	0.50	0.56	1.11	0.56	0.56	0.56	0.56
Mattapoisett 2	.00	.00	.23	.00	.00	.23	.00	.00	.00	.00
Mattapoisett 3	.23	.23	1.24	.23	.23	1.24	.23	.23	.23	.23
Mattapoisett 4	.54	.68	1.55	.54	.68	1.55	.68	.68	.68	.68
Marion, Wolf Island Road	.62	.81	1.24	.62	.81	1.24	.81	.81	.81	.81
Fairhaven 20-79	—	—	—	[2].33	[3].41	[4].57	.41	.41	.41	.41
Fairhaven 8-79	—	—	—	.37	.46	.64	.46	.46	.46	.46
Fairhaven 11-81	—	—	—	.24	.31	.43	.31	.31	.31	.31
Mattapoisett 11-6	—	—	—	—	—	—	[3].77	.77	.77	.77
Marion, New Bedford Road	—	—	—	—	—	—	—	[5].60	.60	.60
Fairhaven, Tinkham Lane	—	—	—	—	—	—	—	—	[5].77	.77
Mattapoisett 11-2	—	—	—	—	—	—	—	—	—	[5].77
TOTAL	1.89	2.28	5.37	2.83	3.46	7.01	4.23	4.83	5.60	6.37

[1] Assume 1982 demands at current wells.
[2] 80 percent of 1982 approved pumping limit (Massachusetts Department of Environmental Quality Engineering, written commun., 1982).
[3] 1982 approved pumping limit (Massachusetts Department of Environmental Quality Engineering, written commun., 1982).
[4] 90 day safe discharge (Wright-Pierce, 1982, p. 15).
[5] Approximately 50 percent of the proposed pumping capacity.

The ten scenarios were run for both dry and severely dry conditions. For the dry condition, an average annual recharge rate of 9.2 inches was used in model simulations. This rate was estimated from the 1965 precipitation at Rochester, Massachusetts. (Average annual recharge under steady-state, "average" conditions was 15.9 inches.) For the severely dry condition, a recharge rate of 5.6 inches was used. The results of the scenarios are given in tables 4 (dry conditions) and 5 (severely dry conditions). Also provided are contour maps (figs. 15 and 16) showing the decline in water level from the average annual (May 1982) levels. The contour lines connect points of equal change in water level. Thus, the water level declined 10 feet everywhere along the 10-foot contour line. Areas where the water level declined the most are indicated with the highest values on the contour lines.

Effects of Pumping on Wells

The effects of current and proposed pumpage under dry conditions are shown in table 4. For each well, the predicted drawdown of the water level caused by a given pumping rate (table 3) should be compared to the available drawdown for that well. The available drawdown was defined as the depth from the average level of the water table to 5 feet above the well screen. It indicates how much the water level can be lowered before risking the well going dry. In the proposed wells, the available drawdown was estimated from aquifer thickness and probable well design. As might be expected, drawdown in each well increased when the pumpage increased.

Scenarios 3 and 6 simulated extremely high pumping demands and in each case the predicted drawdowns at a number of wells (shown in parentheses on table 4) exceeded the available drawdown. In scenario 3, simulating pumping at capacity in the current wells, the drawdown in well Mattapoisett 4 exceeded the available drawdown which means that the well could fail. (See fig. 2 for location of municipal supply wells.) Under dry conditions, Mattapoisett 4 could not be pumped at capacity. In scenario 6 (also pumping at capacity in current and proposed wells), Mattapoisett 4 and the three Fairhaven wells on Wolf Island Road exceeded the available drawdown, and the Marion Wolf Island well nearly reached the available limit. It must be pointed out that these results assume prolonged pumping (many weeks) at well capacity. Several days of pumping at capacity might not cause these extreme drawdowns. More realistic long-term pumping rates were represented by scenarios 2, 5, and 10 which simulated the average pumpage during July. Under these conditions, available drawdown was not exceeded in any of the wells indicating that these pumpages could be maintained without well failure.

The amount of water pumped from wells is no longer available for discharge to the river because much of the water withdrawn from the aquifer is piped to towns outside the basin. Therefore, ground-water discharge to the Mattapoisett River would decrease as total pumpage increased (table 4). In every scenario under dry conditions, some ground water was discharged to the river because pumpage does not intercept all the potential ground-water discharge. The effects of pumping on different segments of the river are discussed in the section "Effects of Pumping on Streamflow."

In each of the ten scenarios, water levels would drop throughout the aquifer because more than the average amount of water would be withdrawn from the system. The lowering of the water table caused by pumping all the current and proposed wells under dry conditions (scenario 10) would be greatest along the eastern and western boundaries and in the northern part of the model area where simulated water levels would be more than 9 feet lower than average levels (fig. 15). The increased drawdowns around each pumping well are clearly shown on the map by the many circular contour lines which represent deepening cones of depression.

Under severely dry conditions, the drawdowns would be greater and the streamflows would be less than those predicted under dry conditions (table 5). In the central part of the aquifer area, the predicted decline of water levels in severely dry conditions was approximately 1 foot more than in dry conditions. In scenario 3, the available drawdown would be exceeded in Mattapoisett 4; and in scenario 6, available drawdown also would be exceeded in all the wells along Wolf Island Road. The model results further showed that the pumping demands of scenarios 3, 6, 7, 8, 9, and 10 would result in negative amounts of ground-water discharge to the Mattapoisett River. This means that the wells would intercept all the ground-water discharge in that area and would induce infiltration of more water if it were available in the stream. Streamflow could be augmented if water stored in ponds in the valley were released to the stream. From 0.47 to 3.25 cubic feet per second of surface water (depending on the scenario) would be induced under the the severely dry conditions simulated. If no extra surface water entered the stream, it would be dry in the southern half of the valley. Without surface water for induced infiltration, the given pumping rates would result in increased drawdowns and probably well failure.

Under severely dry conditions, with recharge 10 inches less than average, the water table would decline as much as 19 feet along the eastern and western boundaries and in the northern part of the model area (fig. 16). The cones of depression around the pumping wells would be broader and deeper than those predicted under dry conditions.

Table 4.--Steady-state model results--dry conditions: Computed well drawdown and total ground-water discharge

(Drawdown, in feet; pumpage rates and ground-water discharge, in cubic feet per second. Values enclosed in parentheses indicates that the predicted drawdown exceeds the estimated available drawdown.)

Well	Available drawdown[1]	Drawdown from current pumpage, 1982			Drawdown from current and proposed pumpage, 1982-90			Drawdown from current and proposed pumpage, 1990+			
		Summer average	High month	Maximum daily	Summer average	High month	Maximum daily	High month	High month	High month	High month
Scenario number		1	2	3	4	5	6	7	8	9	10
Fairhaven: River Road[2]	[3]30.0	4.70	5.40	7.70	4.70	5.40	7.70	5.40	5.40	5.40	5.40
Mattapoisett 2[2]	[3]21.5	.00	.00	3.70	.00	.00	3.70	.00	.00	.00	.00
Mattapoisett 3	43.0	3.94	4.04	23.61	3.94	4.04	23.61	4.04	4.04	4.25	4.46
Mattapoisett 4	[4]30.0	8.68	10.49	(38.79)	8.68	10.49	(38.79)	10.49	10.49	11.80	11.94
Marion: Wolf Island Road	40.0	14.96	20.59	38.70	15.05	20.72	39.05	20.72	20.72	20.72	20.72
Fairhaven 20-79	43.2	--	--	--	27.91	35.06	(49.35)	35.27	35.27	35.27	35.27
Fairhaven 8-79	41.7	--	--	--	29.26	36.75	(51.68)	36.82	36.82	36.82	36.82
Fairhaven 11-81	33.0	--	--	--	23.57	31.02	(43.92)	31.04	31.04	31.04	31.04
Mattapoisett 11-6	44.0	--	--	--	--	--	--	18.85	18.85	18.89	18.89
Marion: New Bedford Road	52.0	--	--	--	--	--	--	--	30.62	30.62	30.62
Fairhaven: Tinkham Lane	95.0	--	--	--	--	--	--	--	--	11.44	11.48
Mattapoisett 11-2	[5]33.0	--	--	--	--	--	--	--	--	--	20.89
Total pumpage from aquifer[6]		1.89	2.28	5.37	2.83	3.46	7.01	4.23	4.83	5.60	6.37
Total ground-water discharge of the Mattapoisett River[6]		5.86	5.48	2.37	4.92	4.29	0.74	3.53	2.92	2.15	1.38

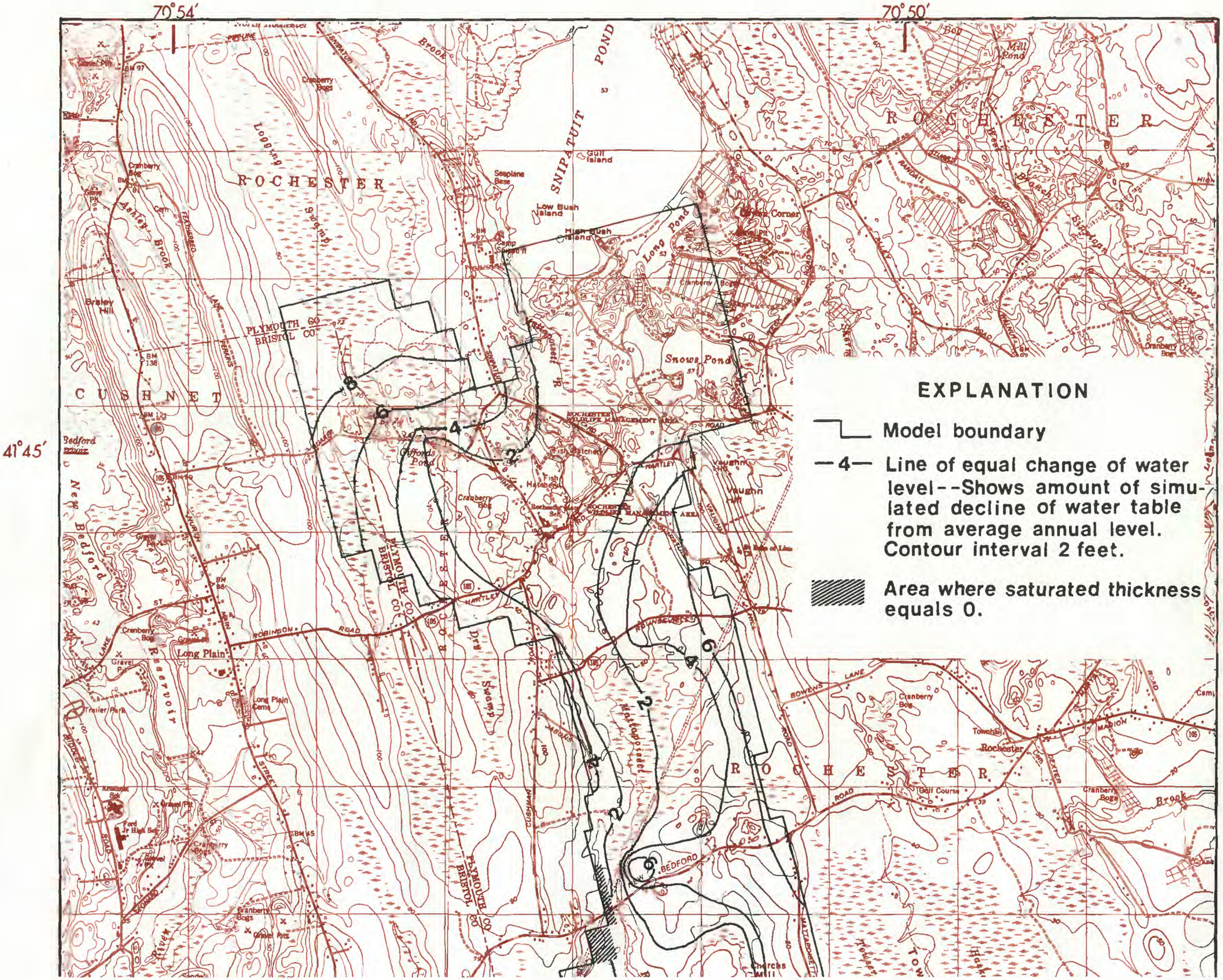
[1]Depth from average level of water table to 5 feet above the top of the current/proposed well screen; interference effects of Marion, Fairhaven, and Mattapoisett wells located in the Wolf Island Road area included. The estimated available drawdown values are obtained from reports of aquifer tests conducted by town consultants.
[2]Drawdown in the node representing a well field composed of numerous 2-inch diameter wells.
[3]Estimated average available drawdown of well field.
[4]Upper screen estimate; drawdown does not include interference from Fairhaven Tinkham Lane well.
[5]Estimated; no field data.
[6]Under "no pumping" conditions, total ground-water discharge of Mattapoisett River is 7.75 cubic feet per second.

Table 5.--Steady-state model results--severely dry conditions: Computed well drawdown and total ground-water discharge

(Drawdown, in feet; pumpage rates and ground-water discharge, in cubic feet per second. Values enclosed in parentheses indicates that the predicted drawdown exceeds the estimated available drawdown.)

Well	Available drawdown[1]	Drawdown from current pumpage, 1982			Drawdown from current and proposed pumpage, 1982-90			Drawdown from current and proposed pumpage, 1990+			
		Summer average	High month	Maximum daily	Summer average	High month	Maximum daily	High month	High month	High month	High month
Scenario number		1	2	3	4	5	6	7	8	9	10
Fairhaven: River Road[2]	[3]30.0	5.80	6.70	7.70	5.80	6.70	7.20	6.70	6.70	6.70	6.70
Mattapoisett 2[2]	[3]21.5	.00	.00	3.80	.00	.00	3.80	.00	.00	.00	.00
Mattapoisett 3	43.0	4.13	4.22	25.40	4.13	4.22	23.40	4.22	4.22	4.51	4.73
Mattapoisett 4	[4]30.0	8.95	10.80	(42.67)	8.95	10.80	(42.67)	10.80	10.80	12.63	12.77
Marion: Wolf Island Road	40.0	15.47	21.19	39.93	15.56	21.32	(40.33)	21.32	21.32	21.32	21.32
Fairhaven 20-79	43.2	--	--	--	28.10	35.26	(49.55)	35.47	35.47	35.47	35.47
Fairhaven 8-79	41.7	--	--	--	29.44	36.94	(51.87)	37.01	37.01	37.01	37.01
Fairhaven 11-81	33.0	--	--	--	23.74	31.19	(44.09)	31.21	31.21	31.21	31.21
Mattapoisett 11-6	44.0	--	--	--	--	--	--	19.51	19.51	19.51	19.51
Marion: New Bedford Road	52.0	--	--	--	--	--	--	--	31.74	31.74	31.74
Fairhaven: Tinkham Lane	95.0	--	--	--	--	--	--	--	--	11.84	11.87
Mattapoisett 11-2	[5]33.0	--	--	--	--	--	--	--	--	--	21.35
Total withdrawal from aquifer[6]		1.89	2.28	5.37	2.83	3.46	7.01	4.23	4.83	5.60	6.37
Total ground-water discharge of the Mattapoisett River[6]		1.88	1.48	-1.61	0.93	0.30	-3.25	-0.47	-1.07	-1.84	-2.61

[1]Depth from average level of water table to 5 feet above the top of the current/proposed well screen; interference effects of Marion, Fairhaven, and Mattapoisett wells located in the Wolf Island Road area included. The estimated available drawdown values are obtained from reports of aquifer tests conducted by town consultants.
[2]Drawdown in the node representing a well field composed of numerous 2-inch diameter wells.
[3]Estimated average available drawdown of well field.
[4]Upper screen estimate; drawdown does not include interference from Fairhaven Tinkham Lane well.
[5]Estimated; no field data.
[6]Under "no pumping" conditions, total ground-water discharge of Mattapoisett River is 3.76 cubic feet per second.


70°54′
70°50′
41°45′
EXPLANATION
Model boundary
—4— Line of equal change of water level--Shows amount of simulated decline of water table from average annual level. Contour interval 2 feet.
Area where saturated thickness equals 0.
ROCHESTER
CUSHNET
SNIPATUIT POND
Snows Pond
Long Pond
Mattapoisett
Long Plain
New Bedford Reservoir
PLYMOUTH CO
BRISTOL CO
Dry Swamp
Logging Swamp

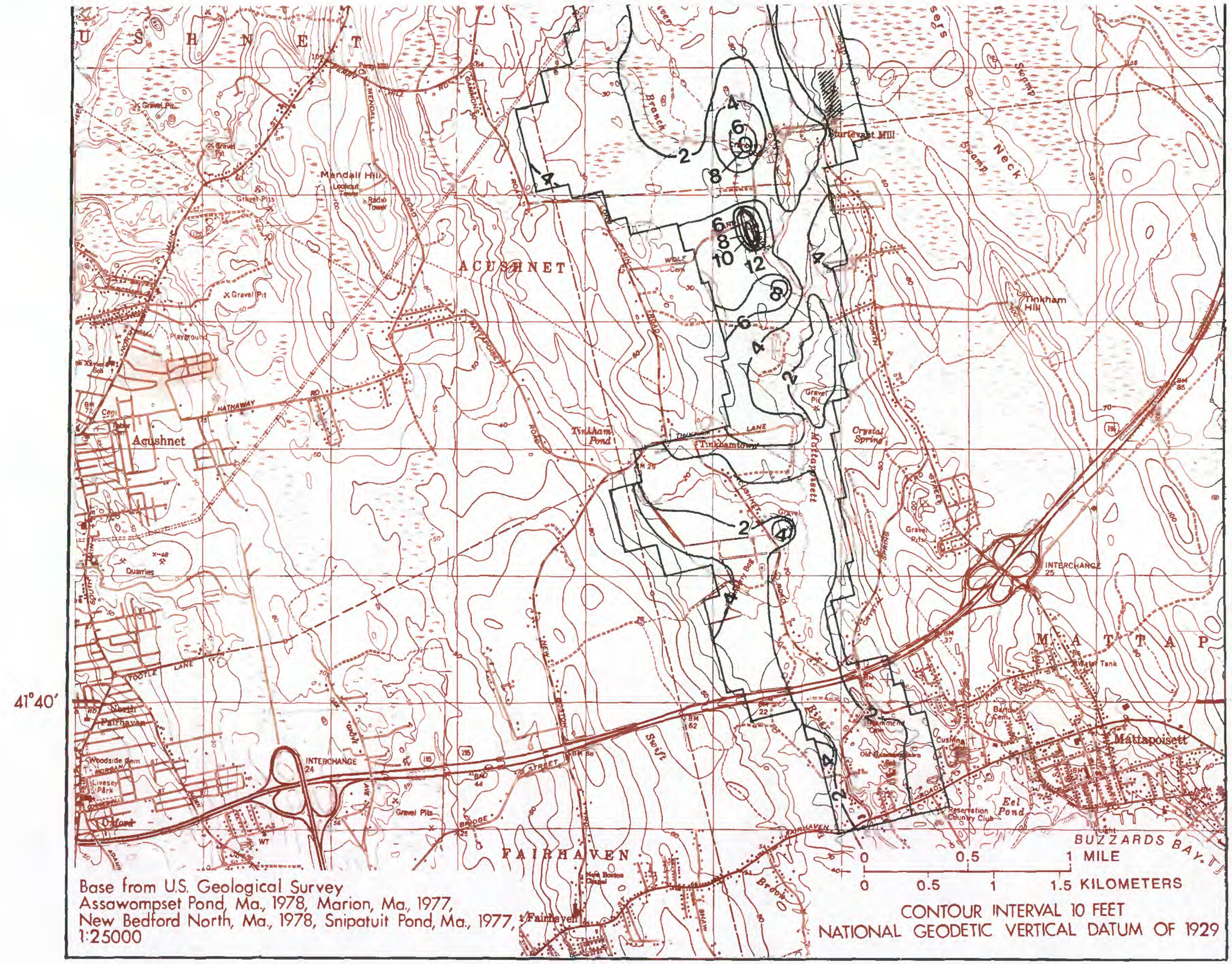
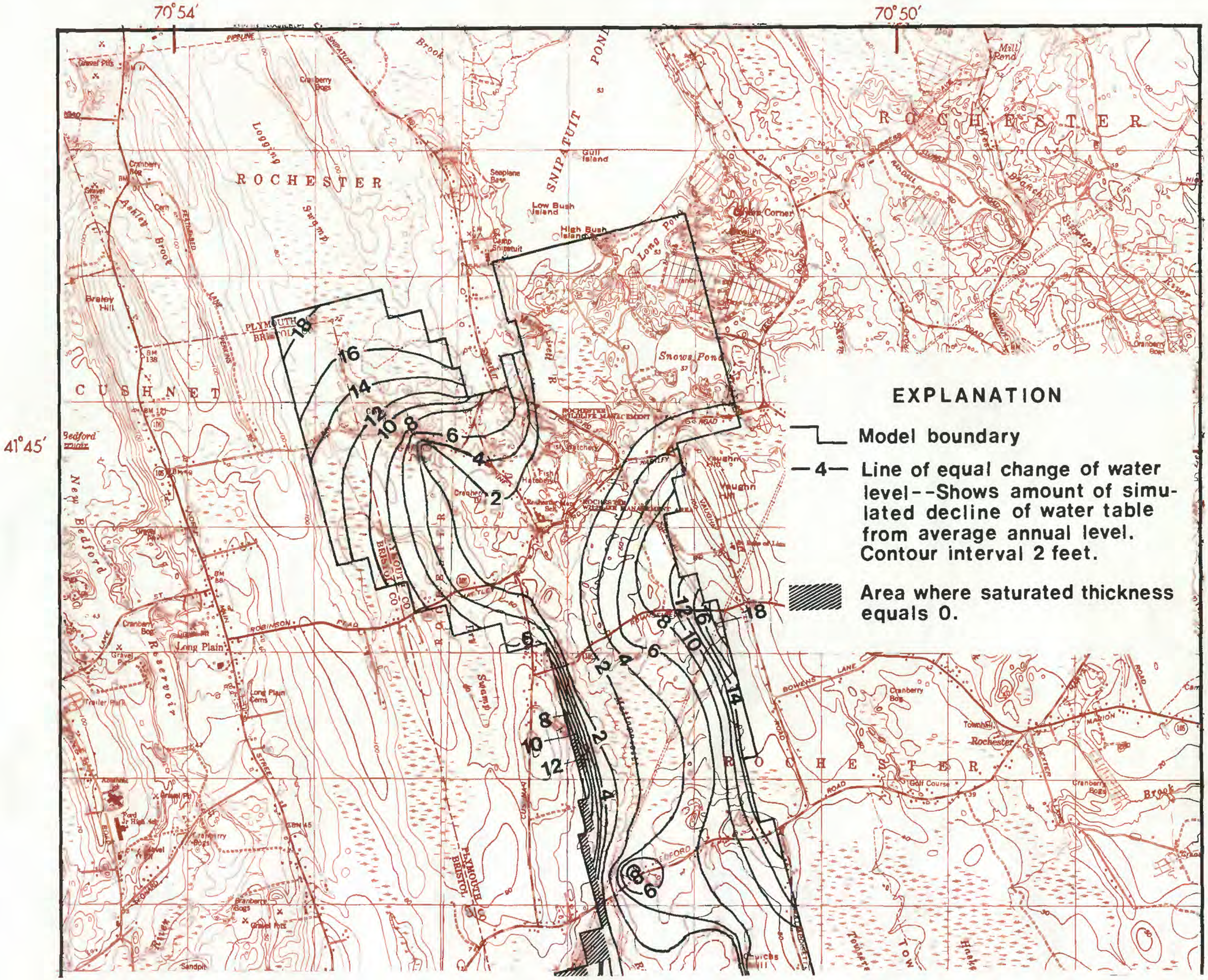
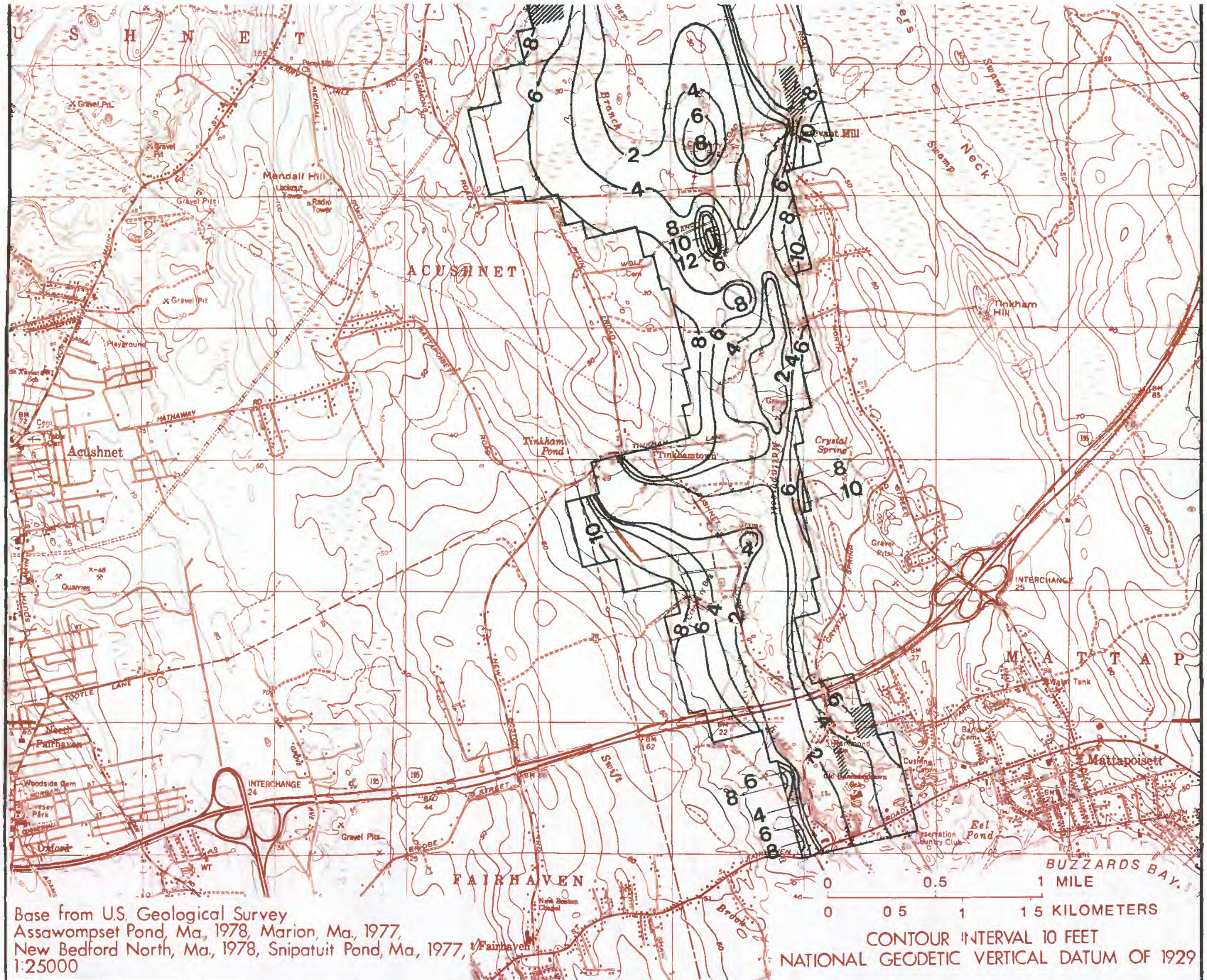


Figure 15.-- Simulated decline in the altitude of the water table: Scenario 10, dry conditions.


70°54′
70°50′
41°45′
EXPLANATION
Model boundary
—4— Line of equal change of water level--Shows amount of simulated decline of water table from average annual level. Contour interval 2 feet.
Area where saturated thickness equals 0.
ROCHESTER
CUSHNET
SNIPATUIT POND
Long Pond
Snows Pond
Logging Swamp
New Bedford
Long Plain
PLYMOUTH CO
BRISTOL CO
ROCHESTER



1°40′

Figure 16.--Simulated decline in the altitude of the water table: Scenario 10, severely dry conditions.

Effects of Pumping on Streamflow

Ground-water discharge to the Mattapoisett River is affected by the volume of pumpage from the municipal supply wells. The predicted effects on streamflow of the pumpage simulated in scenarios 2, 5 and 10 in both dry and severely dry conditions were used as examples and are illustrated in figure 17.

When no wells were pumping, the total amount of ground-water discharge available from the Mattapoisett River aquifer entered the stream. Under this "no impact" alternative in both dry and severely dry conditions, streamflow increased downstream. As wells began pumping, streamflow was reduced downstream from each operating well because of induced infiltration caused by pumping the well. In scenario 10, under dry conditions, and in scenarios 2, 5, and 10, under severely dry conditions, the effect would be large enough to cause the stream to lose water as it flowed downstream. In scenario 10, severely dry conditions, the river would be dry from Wolf Island Road to the ocean (fig. 17). Scenario 10 pumping conditions may be considered a "worst case" situation in that it simulates pumping from all current and proposed wells in the valley with no streamflow augmentation or artificial recharge from surface-water impoundments. Other pumping plans should cause impacts that fall between the extremes of the "no pumping" and the "worst case" scenarios.

The information given in these tables and illustrations are examples of the cause and effect relations between pumping, water levels, and streamflow. The results of the model runs show the range of drawdowns and the magnitude of impact on the stream for different pumping alternatives. This information can be used to manage the ground-water resource. The graphs shown in figure 17 can be used by water-resource managers in several ways. For example, assume the owner of the cranberry bog located at 7.8 river miles were authorized to withdraw water from the river at the rate of 1 cubic foot per second. If the bog owner withdrew this amount, the discharge curve on each of the graphs would have to be adjusted downward 1 cubic foot per second downstream of his location to represent the reduced streamflow. The adjusted graphs would show how much water would remain in the river. Scenario 10, under severely dry conditions, would reduce river flow to the point where the bog owner's water rights could not be exercised. Decisions concerning water allocation among the diverse users in the Mattapoisett River valley can thus be facilitated by the computer simulation model.

SUMMARY

The hydrology of the 25 square mile Mattapoisett River drainage basin, Plymouth County, Massachusetts, was studied to determine the flow, quantity and quality of the water in the stream-aquifer system. In most of the area, the ground water flows toward and discharges to the stream. In areas near large pumping centers, water is drawn from the river into the aquifer thus reducing the flow in the river. In swampy areas, streamflow losses occur due to high evapotranspiration rates. Water in the basin is soft and slightly acidic.

The hydology of the 8 square mile aquifer was simulated using a computer ground-water-flow model to predict changes in water levels and streamflow owing to proposed increases in municipal pumpage. The model of the high-yielding, sand and gravel aquifer is designed to provide information to town officials, regional planners, and State regulatory agencies to aid in managing and allocating the water resource.

Results of 10 scenarios that describe current and proposed pumpage under dry and severely dry conditions demonstrate the use of the model and show the probable range of impacts of different pumping alternatives on water levels and streamflow. In the most extreme case of pumping all the current and proposed wells at capacity in severely dry conditions, five of the wells would probably fail, water levels would be as much as 19 feet below average levels, and the Mattapoisett River would be dry in the downstream half of the valley.

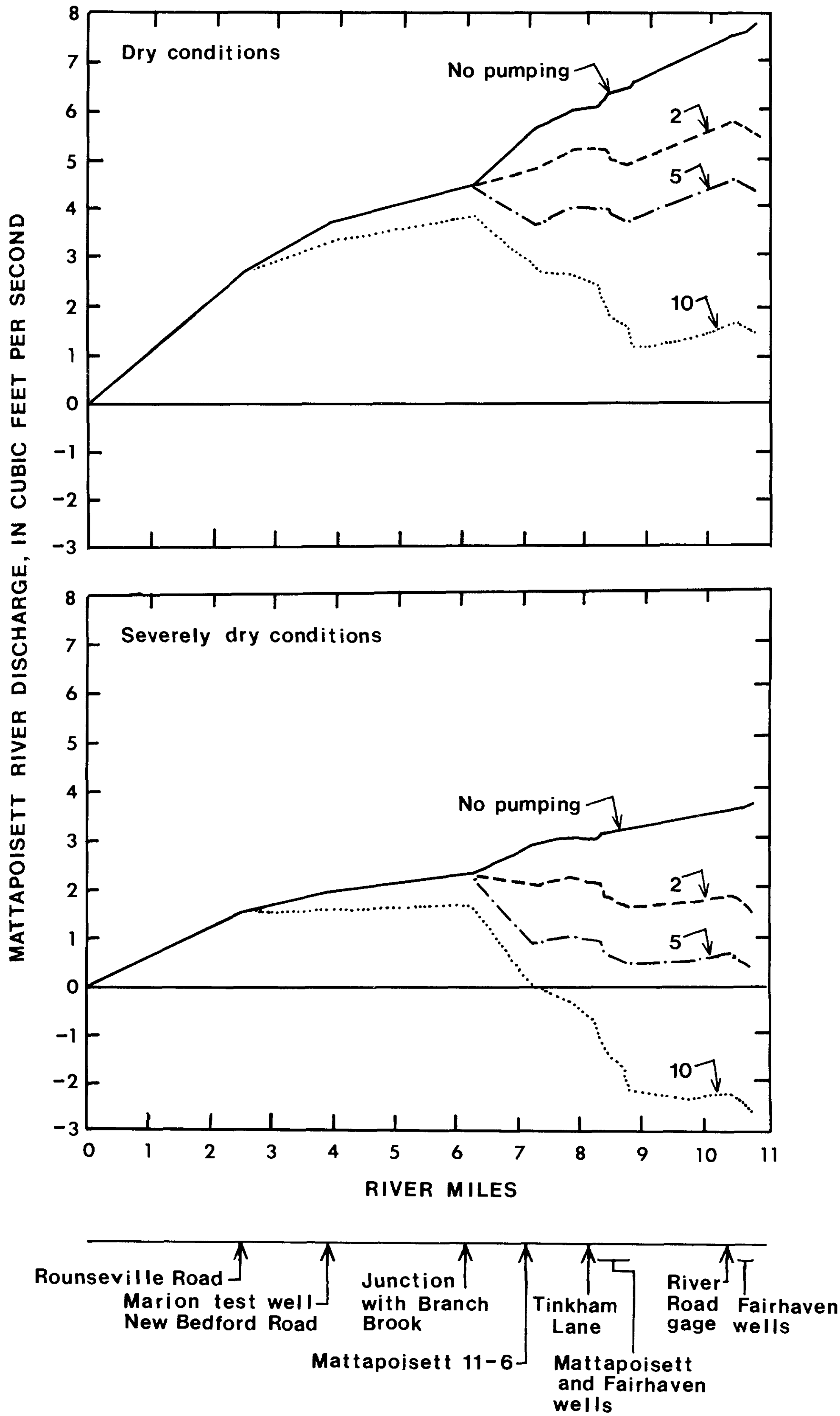


Figure 17.-- Predicted streamflow profiles of the Mattapoisett River: dry and severely dry conditions.

GLOSSARY

Active model area: That portion of the area simulated by a computer model for which equations describing ground-water flow are solved. In this report, it is the area representing the aquifer.

Aquifer: A porous geologic material (for example, sand or sandstone) that will yield water in significant quantity to a well or spring.

Aquifer test: A test to determine the water-yielding capacity of an aquifer. The test involves withdrawing a measured quantity of water from a well and measuring the resulting changes in water level in observation wells surrounding the pumping well. Potential yield of the well is estimated by analysis of the distance, time, and drawdown data.

Bedrock: Solid rock, locally called "ledge," that forms the earth's crust. It is locally exposed at the surface as an "outcrop" but more commonly is buried beneath unconsolidated deposits which range in thickness from a few inches to hundreds of feet.

Computer simulation model: A computer program to solve a set of equations which simulate a given system. In this study, the equations simulate the ground-water-flow system.

Cone of depression: The area of lowered water level around a pumping well caused by withdrawal of water from the well.

Conservation of mass: A law of physics stating that matter can neither be created nor destroyed except by conversion to energy. In hydrology, the volume of water entering a system must equal the volume of water leaving the system plus (or minus) the change in storage.

Contour line: A line on a map connecting points of equal value. A water-table contour line connects points of equal water-table altitude.

Cubic feet per second (ft^3/s): A unit of flow or discharge. For example, 1 ft^3/s is equal to the flow of a stream 1 foot wide and 1 foot deep flowing at an average velocity of 1 foot per second.

Data: Factual information used as a basis for analysis.

Discharge: The rate of flow of water at a given moment in time. In this report, discharge is expressed in cubic feet per second. See also ground-water discharge and stream discharge.

Drainage basin: The area that gathers water originating as precipitation and contributes it ultimately to a particular stream channel or lake.

Drawdown: The amount the water level is lowered either in a well or in the aquifer because of withdrawal of water from the well.

Drift: Loose rock material transported by a glacier and deposited either directly by ice or by running water emanating from the ice.

Dug well: A shallow, large-diameter well dug in the surficial sediments.

Evapotranspiration: Loss of water to the atmosphere by evaporation from water surfaces and moist soil, and by transpiration from plants.

Gage or gaging station: A site on a stream instrumented to measure the changing height of the water surface.

Gage height: The water-surface elevation of a stream referenced to some arbitrary level. Also referred to as "stage."

Glacier: A large perennial mass of ice formed by the compaction and recrystallization of snow. A glacier moves slowly due to its own weight. A continental glacier can be as much as 1 mile thick.

Gravel-packed well: A large-diameter (1-2 foot) well with gravel surrounding the well screen. The gravel increases the effective diameter of the well screen and allows water to flow into the well more easily.

Ground water: Water when it is beneath the land surface. If the water moves to the land surface, it is then called surface water.

Ground-water discharge: Water that is released from the saturated zone of the ground. It includes leakage of water into stream channels, lakes, and oceans; evapotranspiration; and withdrawal from wells.

Ground-water-flow model: A computer program to solve a set of equations which simulate ground-water flow.

Homogeneous: Uniform in composition.

Hydraulic conductivity: Capacity of a cube of porous material to transmit water; expressed in a volume per area per day ($ft^3/ft^2/d$ or ft/d). A material has a hydraulic conductivity of 1 ft/d if, in 1 day, it transmits 1 cubic foot of water through a 1-square foot cross section measured at right angles to the direction of flow, where there is a 1-foot change in water level over a 1-foot flow path.

Hydraulic connection: A stream and aquifer are hydraulically connected if fluctuations in flow or water level in one can affect the flow or water level in the other.

Hydrologic boundary: A physical feature that controls the flow of water through the ground. A hydraulic boundary limits or defines an aquifer.

Induced infiltration: Recharge to ground water from a surface-water body due to pumping of a nearby well and the resultant lowering of ground-water level below surface-water level.

Intermittent stream: A stream that is dry during part of the year.

Leaky boundary: Edge of a hydrologic system or model which allows water to either enter or leave the system.

Meltwater: Water derived from the melting of a glacier.

Model: Physical, analytical, or mathematical representation of a natural system.

Model boundary: Boundary of the active model area in which ground-water flow is computed. Model boundaries generally coincide with hydrologic boundaries.

Node: In this report, the center point of a rectangular block of a computer-simulation model. Often used to refer to the entire block.

Observation well: A nonpumping well that is used to measure the depth to the water table.

Outcrop: Exposure of bedrock at the land surface.

Perennial stream: A stream that flows continuously throughout the year.

Permeable: Material is permeable if it has pores or openings that permit liquid to pass through.

Pore space: Open spaces between the grains in a sediment.

Pumpage: Volume of water pumped from a well.

Recharge: Water that is added to the ground water in the saturated zone.

Saturated thickness: Thickness of the saturated portion of an aquifer. In the Mattapoisett River valley, the difference in altitude between the water table and the bedrock surface.

Saturated zone: A subsurface zone in which all open spaces are filled with water. The water table is the upper limit of this zone.

Seepage run: A series of streamflow measurements along the length of a stream after a period of no precipitation when all the streamflow is assumed to be ground-water discharge. Gains and losses in flow along individual stream reaches are determined from comparison of the measurements.

Seismic refraction: A geophysical method of determining the depth to the water table or to bedrock. A seismograph is used to determine the time it takes sound energy created by a small explosion to reach a series of sensors. Because sound travels at different velocities in different rock materials and is refracted (bent) at the boundary between these materials, it is possible to determine depths to different types of material.

Spawning area: Area where fish deposit eggs.

Stage: See "Gage height".

Steady state: Average, natural, unchanging conditions.

Stratified drift: A sorted and layered sediment deposited by meltwater from a glacier; may include separate layers of sand, gravel, silt, and clay.

Stream-aquifer system: An aquifer and a stream that are hydraulically connected.

Streamflow measurement: Measurement of streamflow. Units of flow are cubic feet per second. Also referred to as discharge measurement.

Surface runoff: Water that moves over the land surface directly to streams or lakes. Surface runoff usually occurs shortly after rainfall or snowmelt.

Surface water: Water when it is on the surface of the land in lakes and rivers. If it seeps into the ground, it is called ground water.

Surficial sediments (deposits): Unconsolidated deposits lying on top of bedrock.

Till: An unsorted, unstratified sediment deposited directly by a glacier. Till may be composed of boulders, gravel, sand, silt, and clay.

Transpiration: The release of water vapor to the atmosphere by plants.

Unconsolidated: Loose, not firmly cemented or interlocked; for example, sand in contrast to sandstone.

Volatile organic compound: Chemical which vaporizes when exposed to air. Many highly toxic solvents are volatile organic compounds.

Water table: The upper surface of the saturated zone. The altitude of the water table is indicated by the altitude of the water level in an observation well which penetrates to the bottom of the aquifer and allows water to enter the well at any level.

Water year: A continuous 12-month period October 1 through September 30, during which streamflow fluctuates from low to high and back to low. It is designated by the calendar year in which it ends.

Well capacity: Highest rate at which water can be withdrawn from a particular well.

Well field: a group of small-diameter (usually 2.5 inch) wells connected to a single pump.

Well screen: Slotted section of a well, usually at the bottom, through which water can enter the well.

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GROUND-WATER RESOURCES OF THE MATTAPOISETT RIVER AQUIFER,

PLYMOUTH COUNTY, MASSACHUSETTS

EXECUTIVE SUMMARY

By Virginia de Lima and Julio C. Olimpio

Excerpted from

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 84-4023

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COMMONWEALTH OF MASSACHUSETTS

WATER RESOURCES COMMISSION

Boston, Massachusetts

1984

UNITED STATES DEPARTMENT OF THE INTERIOR

WILLIAM P. CLARK, Secretary

GEOLOGICAL SURVEY

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FACTORS FOR CONVERTING INCH-POUND UNITS TO

INTERNATIONAL SYSTEM OF UNITS (SI)

For readers who prefer to use SI Units, conversion factors for terms used in this summary follow:

Multiply inch-pound units	By	To obtain SI Units
inch (in)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2/d)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
million gallons per day (Mgal/d)	0.0438	cubic meter per second (m^3/s)

GROUND-WATER RESOURCES OF THE MATTAPOISETT RIVER AQUIFER, PLYMOUTH COUNTY, MASSACHUSETTS

EXECUTIVE SUMMARY

By Virginia de Lima and J. C. Olimpio

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Water-Resources Investigations Report 84-4023.

INTRODUCTION

The Mattapoisett River and the Mattapoisett River aquifer form a single hydrologic system which provides fresh water for water supply, recreation, and agriculture to four communities in Plymouth County, Massachusetts. Ground water has been the source of municipal water supply in the Mattapoisett River valley since the early part of this century, and in 1982 supplied an average of 1 million gallons per day to domestic and commercial users in the towns of Mattapoisett, Fairhaven, and Marion. In addition, Rochester depends on the aquifer for private supply. Herring use the Mattapoisett River as a run from the ocean to their spawning area in Snipatuit Pond, and cranberry growers use the river as a source of water for bog irrigation and flooding during harvest. Withdrawal of ground water for municipal supply is expected to triple in the next two decades, and because of the many diverse users, there is a need for careful water-resource planning based on thorough knowledge of the basin hydrology.

This study is the first under Chapter 800 Massachusetts legislation that provides funds to quantitatively assess regional ground-water resources in the State. The U.S. Geological Survey, in cooperation with the Massachusetts Water Resources Commission, selected the sand and gravel aquifer in the Mattapoisett River valley for detailed study of the ground-water resources and the interdependence between pumping wells and streamflow.

The purpose of the Mattapoisett River aquifer study is to describe the flow, quantity, and quality of the water in the stream-aquifer system. A computer simulation model of the system was developed to aid in the hydrologic description of the system and to provide a management tool for predicting changes in ground-water levels and variations in streamflow resulting from alternative water-supply development scenarios.

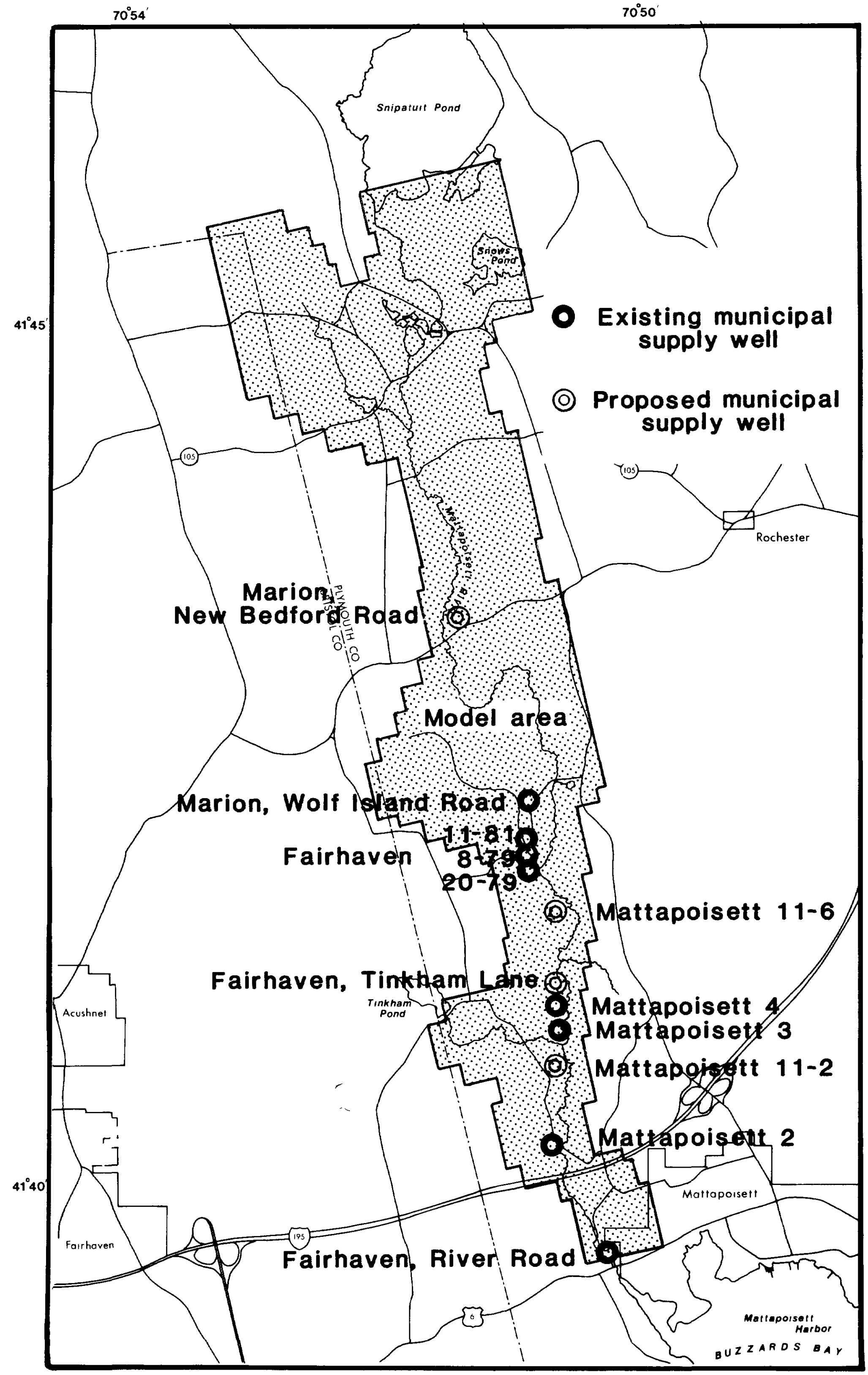
Mattapoisett River flows southward from Snipatuit Pond to Buzzards Bay through the western sections of the towns of Rochester and Mattapoisett. The study area includes the 23.6 square mile drainage basin which contributes water to Snipatuit Pond or to Mattapoisett River. The focus of the study and the computer model is on an 8 square mile portion of the basin south of Snipatuit Pond including the river, several tributaries, and the sand and gravel aquifer (fig. 1).

Two reports summarize the results of the hydrogeologic study and the computer model. "Ground-Water Resources of the Mattapoisett River Valley, Plymouth County, Massachusetts" by Olimpio and de Lima (1984) gives a thorough, technical discussion of the work including the (1) hydrogeologic characteristics of the area, (2) development and refinement of the computer model, (3) testing of the alternative pumping scenarios, and (4) results of those scenarios. The second report, "Ground-Water Resources of the Mattapoisett River Aquifer, Plymouth County, Massachusetts: Summary for Water-Resource Managers" by de Lima and Olimpio (1984) is a non-technical summary of the study. Included is background material for those who want to increase their understanding of hydrology and hydrologic computer modeling.

WATER ISSUES IN THE MATTAPOISETT RIVER BASIN

The Mattapoisett River aquifer supplies 80 percent of the domestic and commercial water needs in the town of Mattapoisett. The municipal supply system includes three separate pumping centers. One is an infrequently used well field consisting of many small-diameter wells. The other two are single, large-capacity, gravel-packed wells.

The aquifer also supplies a significant and increasing portion of the water supply for the towns of Fairhaven and Marion. These towns are located outside the drainage basin, but under legislation passed in 1889, Fairhaven was granted water rights in the town of Mattapoisett, and under legislation passed in 1970, Marion was granted water rights in the town of Rochester. Currently, Fairhaven has a field of small-diameter wells near the mouth of the Mattapoisett River and a system of three gravel-packed wells near the Mattapoisett-Rochester town line. Marion has one gravel-packed well on the Rochester side of the town line. The town of Rochester has no municipal supply, and no wells are planned. Exploration for additional municipal wells continues in the valley. Marion has a test-well site in Rochester, and Mattapoisett has one in Mattapoisett which, when developed, will replace its well field. Both test sites have been approved for development by the Massachusetts Department of Environmental Quality Engineering. Fairhaven is



Base from US Geological Survey
Assawompset Pond, Ma, 1978, Marion, Ma, 1977,
New Bedford North, Ma, 1978, Snipatuit Pond, Ma 1977
1:25000

0 0.5 1 MILE
0 0.5 1 1.5 KILOMETERS

Figure 1.--Location of model area and municipal supply wells.

planning further tests in Mattapoisett. Current and proposed public-supply wells for Fairhaven, Marion, and Mattapoisett are shown in figure 1. If all the proposed wells are developed, total withdrawal is estimated to average 4.5 million gallons per day by the year 2000. Three quarters of this withdrawal will be removed from the basin either as water supply for other towns or by sewering.

The location of the municipal supply wells in the Mattapoisett River valley presents a further concern because most of the current, planned, and proposed wells are close to one another in the southern part of the basin (fig. 1). If two wells are close together, the lowered water level resulting from pumping one will reduce the water available to the other and decrease the total amount of water that can be pumped.

The current and proposed municipal wells are close to the stream and, therefore, can have an effect on the quantity of water in that section of the stream. Because the stream and the aquifer are interconnected, increased pumpage will diminish streamflow. The resulting volume and velocity of the water in the stream might be insufficient to dilute pollutants and keep the water aerated. Therefore, water-quality problems might result. Insufficient water for herring to ascend the river to spawn in Snipatuit Pond is another possible effect. The amount of water in the stream can also affect the wells. Regulation at Snipatuit Pond and at the State-owned fish hatchery off Hartley Road sometimes reduces the flow in the river. During the summer and fall, when water is pumped from the river for cranberry irrigation and harvesting, the flow is aqain reduced. Substantial reduction in streamflow lessens the amount of surface water which could be drawn into the ground, and thus into the wells. Without this source of water, the wells probably would be unable to maintain the current pumpage.

Because of the complexly interrelated stresses affecting the aquifer and the stream in the Mattapoisett River basin, a ground-water-flow model was developed whose response to applied stresses, such as pumpage, is similar to the response of the actual aquifer. Such a model not only helps in understanding the hydrologic system, but also can be used as a management tool to efficiently predict the response of the aquifer to proposed development.

SIMULATION OF GROUND-WATER FLOW USING A COMPUTER MODEL

Comparisons of monthly precipitation, water-level, and streamflow data gathered during this study and long-term mean annual data, indicated that average conditions were most closely approximated in May 1982. As a result, the ground-water-flow model was based on May 1982 water-level and streamflow data. The response of the aquifer to the pumping stresses simulated by the model closely matched the observed response of the aquifer. This indicates that the model can be used to predict how the aquifer will respond to proposed development. To demonstrate the predictive use of the model, 10 scenarios were developed which represent current and planned pumpage under drought conditions. These scenarios provide illustrative examples of the cause-and-effect relation of pumping, water level, and streamflow. An indepth description of the scenarios and the results of the scenarios are given in each of the two reports. Planners and decisionmakers can use the tables and maps to determine (1) if wells will be able to maintain the pumping rates proposed, (2) how much the water table will be lowered by the proposed withdrawals, and (3) how these withdrawals will affect the amount of water in the stream. The results of these and future scenarios developed by the State and the communities involved can be used to devise a comprehensive water-resources management plan for the region.

In the 10 illustrative scenarios, three levels of pumping stress were analyzed: (1) the average pumping rate for the summer (June, July, and August), (2) the average pumping rate for the highest month (July), and (3) the maximum daily pumping rate of each well (the well capacity). The 10 scenarios were run under both dry and severely dry conditions. The dry condition was based on the total precipitation at Rochester, Massachusetts, during the driest year of record, 1965. The severely dry condition was based on an estimate of how much precipitation would be needed to keep the river flowing when no wells were pumping.

Each of the 10 scenarios represented an increase in pumpage above average (1982) conditions. Therefore, water levels would drop throughout the aquifer because more water would be withdrawn from the system. Under dry conditions, with all the current and proposed wells pumping, the water table in some areas would be more than 9 feet lower than average levels, and the model predicted that four wells could fail. Under severely dry conditions, the water table would be as much as 19 feet lower than average and five wells could fail if pumped at capacity. Also, because the amount of water in a stream-aquifer system is finite and the amount of ground water withdrawn from wells is no longer available for discharge to the river, the flow of the Mattapoisett River decreases as total pumpage increases. In the six scenarios representing the greatest pumpage under severely dry conditions, the wells intercepted all the ground water that would have entered the stream in that area and would have drawn water from the stream into the ground if it had been available. Hypothetically, streamflow could be augmented to meet this need if water stored in ponds in the valley were released to the stream.

Scenario 10 pumping under severely dry conditions may be considered a "worst case" situation in that it simulated pumping from all current and proposed wells in the valley with no streamflow augmentation or artificial recharge from surface-water impoundments. In this scenario, the model indicated that the river would be dry from the confluence of Branch Brook south of Wolf Island Road to the ocean. An additional 2.61 cubic feet per second of surface water would have been drawn into the ground under these conditions if it had been available. Without this additional surface water, the given pumping rates would result in increased drawdowns and probably well failure.

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