Geohydrologic Impacts of Coal Development in the Narragansett Basin, Massachusetts and Rhode Island

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2062

Prepared in cooperation with the Massachusetts Science and Technology Foundation

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CONVERSION FACTORS

Multiply	*By*	*To obtain SI Units*
	Length	
miles (mi)	1.609	kilometers (km)
feet (ft)	3.048×10^{-1}	meters (m)
inches (in)	2.540×10^{1}	millimeters (mm)
	Area	
square miles (mi^2)	2.590	square kilometers (km^2)
	Volume	
gallons (gal)	3.785	liters (L)
million gallons per day (Mgal/day)	43.81	liters per second (L/s)
	Flow	
gallons per minute (gal/min)	6.309×10^{-2}	liters per second (L/s)
gallons per minute per foot [(gal/min)/ft]	2.07×10^{-1}	liters per second per meter [(L/s)/m]

GEOHYDROLOGIC IMPACTS OF COAL DEVELOPMENT IN THE NARRAGANSETT BASIN, MASSACHUSETTS AND RHODE ISLAND

By MICHAEL H. FRIMPTER and ANTHONY MAEVSKY

ABSTRACT

The hydrologic impacts of possible coal mining in the 900-square-mile Carboniferous Narragansett Basin in southeastern New England are described. Geophysical tests and hydrologic observations were made in thirteen 3-inch-diameter test holes which were 330 to 1,500 feet deep. Fractures and lithology, including graphite and coal, were identified and located from interpretation of geophysical logs. Ground-water levels measured in 1976–77 were less than 15 feet below land surface at all test sites. Specific capacities of the test holes to yield water ranged from 0.01 to 5.7 gallons per minute per foot of drawdown after short (2–5-hour) pumping periods. In a test hole in Halifax, Massachusetts, water levels showing drawdown caused by pumping nearby domestic-supply wells indicate that mine dewatering would reduce yields of private wells tapping bedrock. In test holes near Narragansett Bay, ground water was brackish, and water levels fluctuated with about one-fifth the magnitude of the tide in the bay. These conditions suggest that there is potential for a high rate of mine seepage from the bay.

As a result of mining, the iron disulfide minerals, pyrite and marcasite, react with air and water to produce acid water containing iron. However, acid mine water is not expected to be as serious a problem in the Narragansett Basin as it is in the Appalachian coal fields. No marcasite and only small amounts of coarsely crystalline pyrite have been observed in the metamorphosed sediments of the basin.

INTRODUCTION

In 1976, the first phase of an investigation began under the overall direction of Weston Observatory to evaluate the economic potential of coal deposits in the 900-mi^2 Narragansett Basin of Carboniferous age (fig. 1) in eastern Rhode Island and southeastern Massachusetts. As part of this evaluation, the U.S. Geological Survey, in cooperation with the Massachusetts Science and Technology Foundation, began a study of ground-water occurrence in the coal and enclosing rocks of the Rhode Island Formation to estimate potential impacts of mine dewatering on the water table and well yields, mine-water seepage rates, and impacts of mining activity on water quality.

During 1976 and 1977, deep test holes were drilled by Weston Observatory at 7 sites in Rhode Island and 10 sites in Massachusetts (fig.

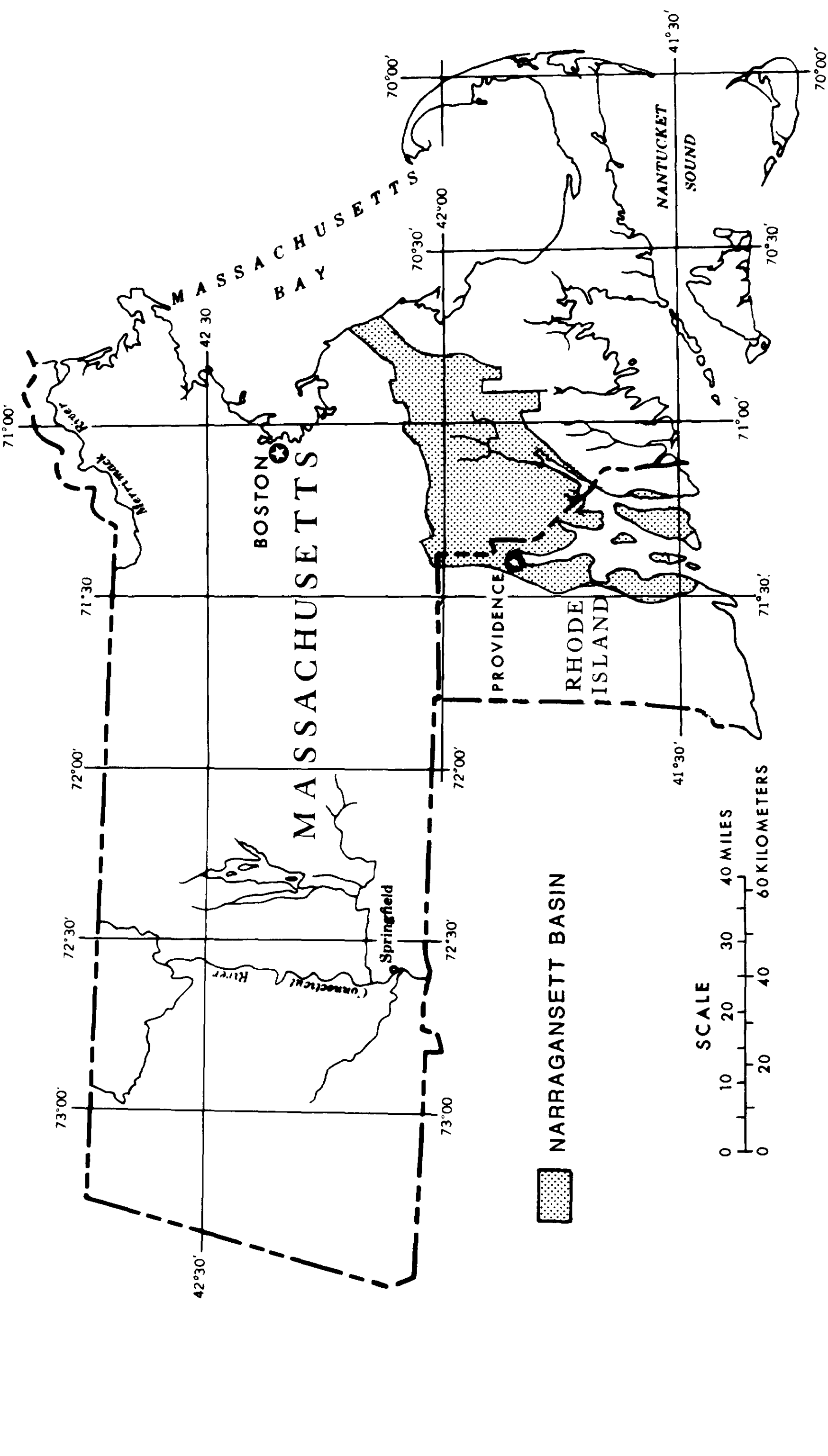

FIGURE 1.—Location map of Narragansett Basin, Massachusetts and Rhode Island.

2) to collect geologic, hydrologic, and water-quality data necessary to describe ground-water conditions. Of the 13 test holes cased, 3 were partly obstructed by objects put into the holes by vandals, and 1 casing was broken by construction equipment. During the drilling, records were kept by the driller, noting water loss, water level, and artesian flow. The Geological Survey measured water levels monthly for about 1 year in all of the cased test holes and obtained continuous records of water-level fluctuations with recording gages on six test holes for periods ranging from about a week to 2 months. Twelve of the cased test holes were pumped with a suction pump for short

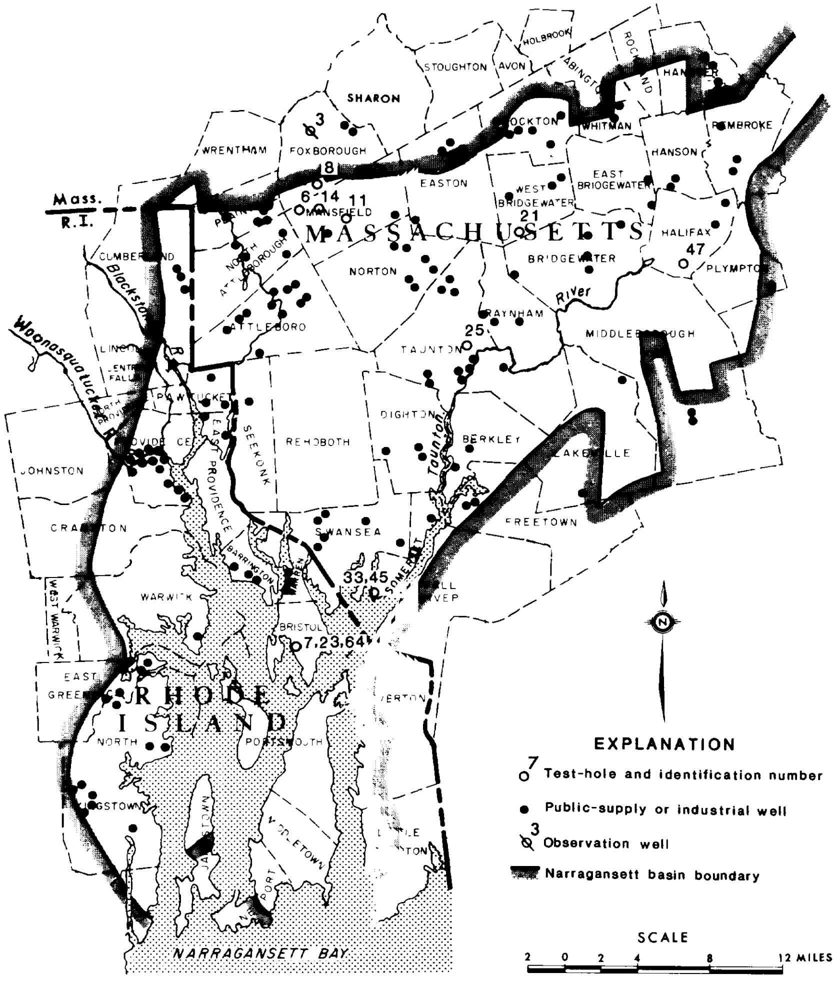

FIGURE 2.—Map of industrial- and public-supply wells and coal test holes.

periods to determine yield and specific capacity and to collect water samples for chemical analyses. Geophysical logs, including gamma, self potential, single point resistivity, caliper, temperature, and fluid conductivity, were obtained from eight of the test holes (table 1).

Some test holes contained brackish water or were contaminated with lubricants and bentonite, and only three yielded samples representative of formation water for chemical analysis. Results of analyses of these samples are included and discussed in the section titled "Water Quality."

The authors acknowledge the cooperation of James W. Skehan, S.J., and the staff of Weston Observatory conducting the coal exploration program and the landowners and tenants who allowed access to the test sites for this study.

BASIN GEOLOGY AND OCCURRENCE OF GROUND WATER

Sedimentary rocks of the Narragansett Basin are predominantly Carboniferous conglomerate and sandstone (arkose and feldspathic graywacke), and siltstone and shale, with some coal (Lyons and Chase, 1976). The rocks of the basin have been divided, from youngest to oldest, into the following units of Pennsylvanian age: Dighton Conglomerate, Rhode Island Formation, Purgatory Conglomerate, Wamsutta Formation, and Pondville Conglomerate (Shaler and others, 1899; Mutch, 1968; Skehan and others, 1976; Weston Observatory, Boston College, 1976). Metamorphic grade increases toward the south. The more pelitic sediments have been metamorphosed to slate and phyllite and have reached staurolite grade schist in parts of southern Rhode Island. The Rhode Island Formation contains coal and carbonaceous shale, which are commonly graphitic. The predominant depositional environment was one of rapid fluvial sedimentation, with lacustrine and swamp environments, where organic matter could accumulate and ultimately form coal. Therefore, the location, trend, and extent of coal deposits in this basin are difficult to predict, unlike those in the regular cyclothem deposits in the Appalachian coal fields.

Folding and faulting throughout the Narragansett Basin also make the structure complex and difficult to analyze. The sedimentary rocks are highly indurated, and although primary porosity remains relatively high (M.M. Lidback, oral commun., 1977), the openings are poorly interconnected and the permeability of the rock is relatively low. The conglomerate and sandstone have been metamorphosed to felsic quartzite and the shale to slate or phyllite. In many of the core samples from the test borings, healed and unhealed fractures and slickenside surfaces were common, indicating that these rocks have

TABLE 1.—*Test-hole information*

Weston Observatory identification number	U.S. Geological Survey local number	Latitude and longitude	Owner	City or town and state	Depth (ft)	Depth to bedrock (ft)	Length of casing (ft)	Topographic setting	Hydrologic setting (D, discharge; R, recharge; U, undetermined)	Influenced by tidal water bodies	Geophysical logs*	Remarks
7	BRW-145	41°40′24″ 71°16′48″	Town of Bristol, R.I.	Bristol, R.I.	332	46	53	Valley flat.	D	Yes	SP,R,G,T,FC,C	Saltwater.
23	BRW-146	41°40′26″ 71°15′47″	do.	do.	524	30	30	do.	D	Yes	do.	Do.
64	BRW-152	41°40′21″ 71°16′48″	do.	do.	800	26	54	do.	D	Yes	do.	Do.
8	FXW-91	41°02′20″ 71°14′43″	Taunton Cooperative Bank.	Foxborough, Mass.	600	16	16	Hilltop	R	No	SP,R,G	
47	HBW-97	41°58′20″ 70°52′28″	Richard R. Green	Halifax, Mass.	945	90	90	Flat	U	No		Partially plugged at 18 feet.
6	MDW-226	42°01′07″ 71°14′43″	Myles Fremey	Mansfield, Mass.	805	17	42	Hillside	D	No		Partially plugged at 26 feet.
11	MDW-228	42°01′07″ 71°12′33″	Town of Mansfield, Mass.	do.	1,261	50	55	Flat	U	No		Casing broken.
14	MDW-227	42°01′27″ 71°14′57″	do.	do.	545	46	47	Hillside	U	No		Partially plugged at 60 feet.
33	SPW-160	41°42′47″ 71°11′34″	New England Power Company.	Somerset, Mass.	1,500	51	51	do.	D	Yes		
42	SPW-161	41°44′20″ 71°08′44″	Montaup Electric	do.	1,500	26	26	do.	D	No	SP,R,G,C	
45	SPW-162	41°42′43″ 71°11′35″	New England Power Company.	do.	1,000	15	15	do.	U	Yes	do	
25	TAW-258	41°54′54″ 71°06′18″	Joseph Mozzone	Taunton, Mass	1,006	10	10	Terrace	R	No	SP,R,G,T,C,BT	
21	WTW-115	41°59′56″ 71°01′42″	James Haseotes	West Bridgewater, Mass.	720	38	38	Flat	D	No	SP,R,G,T,FC,C,BT	

*SP, self potential; R, resistivity; G, natural gamma; T, temperature; FC, fluid conductivity; C, caliper; BT, brine trace.

been subjected to brittle deformation. Ground water occurs in these fractures (secondary porosity) where they remain open. Water in the fractures is under pressure and rises in the well bore above the level of intersection with the water-bearing fracture; accordingly, wells in bedrock are described as artesian. Most homes not served by a public water supply rely on wells drilled 100 to 300 feet deep in this bedrock aquifer. Generally, 4 gal/min or more can be obtained from 6-inch-diameter wells and is adequate for single-family supplies.

Unconsolidated deposits of glacial origin mantle bedrock nearly everywhere in the basin, and bedrock exposures are few. A nearly continuous layer of till up to several tens of feet thick overlies bedrock. Stratified deposits of clay, silt, sand, and gravel overlie till and bedrock and may exceed 100 feet in thickness. Wells in silt and clay or till will not yield large quantities of water. Silt and clay deposits may have high primary porosity but have low specific yield and permeability. The principal aquifers in unconsolidated deposits are composed of thick saturated sand and gravel beds along water courses. These aquifers sustain public and industrial water-supply wells. Water in wells tapping these deposits stands at the level where encountered in drilling and, therefore, is considered to be under water-table conditions. Artesian conditions can occur locally in a few areas where silt or clay layers overlie and confine water in sand and gravel. Materials forming these aquifers typically have a specific yield of about 0.25 (25 percent). Wells screened in sand and gravel deposits, however, are commonly designed to yield 1 Mgal/day (about 700 gal/min). Sixteen towns and cities in the basin depend wholly on ground water, and nine more depend partly on ground water from unconsolidated deposits for public supply (fig. 2).

INTERPRETATION OF GEOPHYSICAL LOGS

Geophysical logs aid in precise identification of depths of lithologic boundaries, identification of lithologic character, and identification of hydrologic properties. They may also be used to assist lithologic correlation for structural analysis. Examples of these applications of the geophysical logs collected as part of this project follow.

BEDROCK LITHOLOGY

Lithologic descriptions of bedrock were prepared by Weston Observatory from inspection of continuous rock core obtained during drilling. This information is supplemented by descriptions from geophysical logs obtained by the U.S. Geological Survey. Interpretation of the spontaneous potential (SP) and resistivity logs allows identification of the major lithologic types, conglomerate and sandstone, shale, and coal. Spontaneous potential is a measure of the spontaneously generated voltage developed between the borehole fluid and the formation and formation fluids by an electrode moved through the borehole. Single-point resistivity is the resistance to the flow of an electric current through earth material between an electrode at land surface and an electrode moved through the borehole.

Coarse-grained clastic sedimentary rock (conglomerate and sandstone) cause a negative shift in self potential (left deflection of the SP curve) and an increase of resistivity (right deflection of the resistivity curve) as shown in figures 3 and 4. Changes between coarse-grained (sandstone) and fine-grained (shale) clastic sedimentary rocks cause changes in the self-potential curves from holes containing brackish water, but not from those containing freshwater. Therefore, SP logs were useful for lithologic identification only from those holes containing brackish water. Coal and graphite layers are indicated by rapid fluctuations of both SP and resistivity curves, a pattern typical of that produced by electrical "noise." This is attributed to the presence of graphite, a good conductor, which occurs in the coal and to a lesser extent in some layers of carbonaceous shale. SP and resistivity logs for Bristol 7 (fig. 3) show three graded sandstone beds interlayered with shale between 50 and 199 feet, coal with graphite from 199 to 229 feet, shale from 229 to 240 feet, sandstone from 240 to 250 feet, shale from 250 to 265 feet, and alternating beds of sandstone and shale from 265 to 318 feet; at 318 feet a thin layer of graphitic coal or shale may overlie a sandstone bed.

Natural gamma ray logging measures the gamma radiation produced by different rocks. Sedimentary rocks can be differentiated on a basis of differing amounts of potassium-40 (a radioactive isotope of potassium) contained in them. Normally, sandstone and shale can be differentiated on a basis of the amount of gamma radiation they emit because quartz sand contains little potassium, whereas clay minerals in shale contain relatively large amounts of potassium. However, the conglomerate and sandstone of the Narragansett Basin are arkose and feldspathic graywacke and therefore contain potassium minerals. Accordingly, the potassium-40 radiation is about the same in the sandstone as in shale, and the gamma log is not a very useful tool for separating these lithologies. Coal, however, has a characteristically low potassium concentration and is therefore readily identifiable in the Bristol 7 gamma log between 199 and 228 feet (fig. 3). Where coal is known to be present but does not show this low natural gamma radiation, it is inferred to contain clay impurities. For example, although 15 feet of coal was described in the lithologic log, as cored from 452 to 472 feet in Bristol 23, the gamma log indicates low radiation

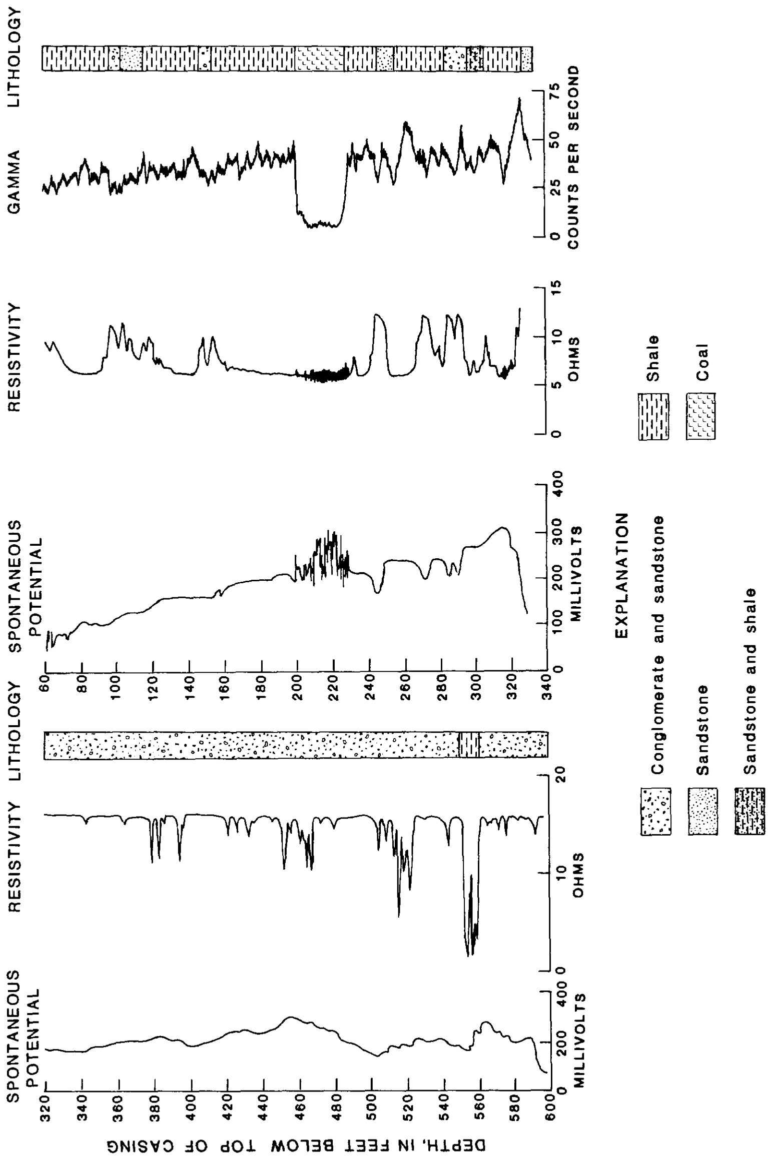

FIGURE 3.—Geophysical logs of test holes containing freshwater (Taunton 25) and brackish water (Bristol 7).

between only 463 and 468 feet (fig. 4). This suggests that 10 of the 15 feet of coal reported here contains clay or may be carbonaceous shale. Higher than normal shale background gamma counts were observed at 304 and 577 feet in Somerset 42 and at several depths between 105 and 135 feet and 256 to 292 feet in West Bridgewater 21. Close inspection of core samples from these zones may indicate increased concentration of potassium-bearing minerals.

Of the geophysical logs obtained for this study, the electric (SP and resistivity) are the most useful for correlating lithologic units from hole to hole. Correlation of lithologic units from geophysical logs is

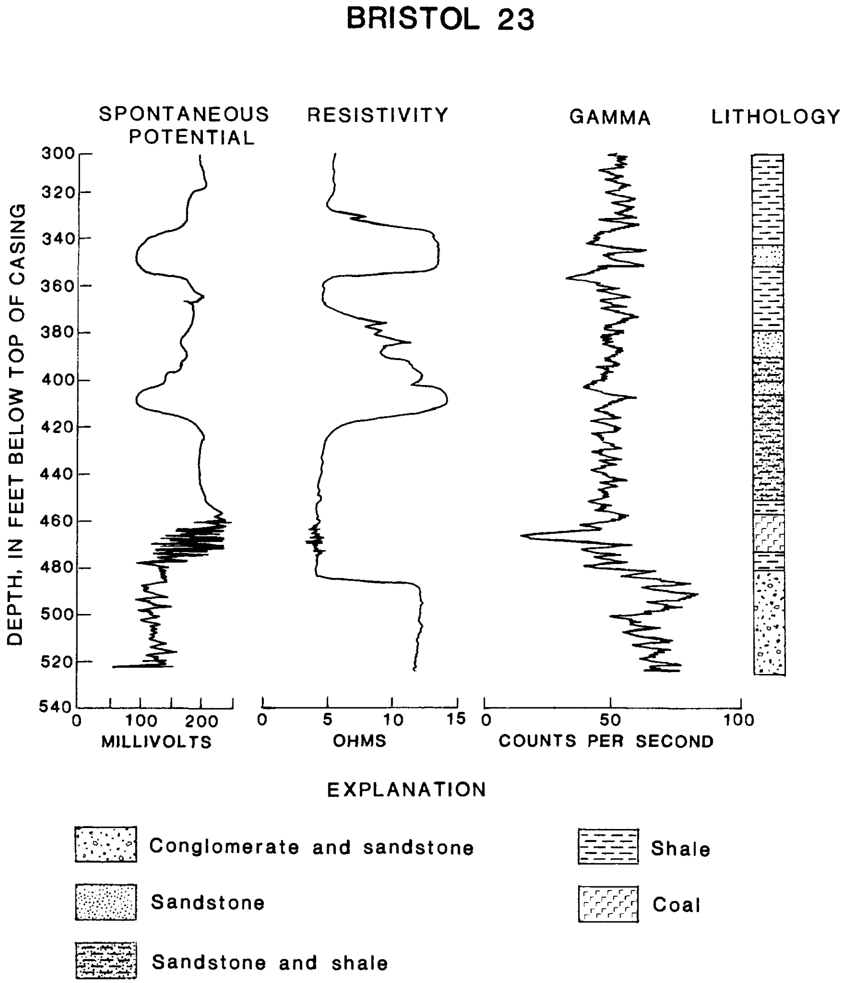

FIGURE 4.—Self-potential, resistivity, and natural gamma logs (Bristol 23).

illustrated in logs of test holes in Rhode Island, Bristol 23, Bristol 7 (235 feet south of Bristol 23), and Bristol 64 (360 feet south of Bristol 7) in figures 3–5. Similarities of the shapes of the curves are interpreted to represent similar changes in lithology, and similar shapes of the electric log curves are, therefore, interpreted to be a basis for correlation (fig. 5). The electric log from 50 to 325 feet in Bristol 7 forms a pattern very similar to that from 170 to 440 feet in Bristol 23, and the section from 20 to 270 feet in Bristol 23 is similar to the section from 355 to 550 feet in Bristol 64. A 66–68-foot-thick bed of coarse-grained clastic rock from 124 to 192 feet in Bristol 64 and from 425 to 490 feet in Bristol 23 projected to the Bristol 7 site would be above bedrock surface and would have been removed by erosion. This bed seems unique in that it is about three times thicker than any other coarse-grained beds indicated by the logs. Stratigraphically, below this thick sandstone or conglomerate at all three test-hole sites is a sequence of shale-sandstone-shale-sandstone-shale where the contacts of the sandstone beds with shale are sharp at the top and graded at the bottom. Below this graded sandstone and shale sequence, 30 feet of coal was cored between 119 and 228 feet in Bristol 7. A 5-foot-thick coal bed was cored between 620 and 625 feet in Bristol 64, but no coal was found at the expected depth (325 feet) in Bristol 23. The coal may be faulted out in Bristol 23, because the caliper log shows enlargement of the borehole diameter, as might be produced by a fault at 323 feet. Also, the coal in cores from Bristol 7 contained slickensided fractures and quartz veinlets, indicating faulting.

Records of coal mining and test drilling suggest that the coal beds at Portsmouth and Bristol, Rhode Island, may be thickened and thinned by flowage and faulting into large pods or boudins. Coal beds are commonly zones of structural weakness where faulting is more common. Black mud interpreted to be fault gouge was found in one test hole (Bristol 64). Fault gouge is commonly claylike and can form an effective low-permeability barrier to ground-water flow.

The caliper log provides a record of the average diameter of the hole and thus may be used to locate and measure the size of openings such as fractures in the borehole. The caliper logs indicated openings at 126 and 147 feet in Bristol 64; 23, 74, and 323 feet in Bristol 23; an enlargement of the hole from 3 to 3¾ inches between 16 and 40 feet and narrow openings at 58, 72, 89, and 98 feet in Somerset 45 (fig. 6); openings at 25 and 47 feet in Somerset 42 (fig. 6); and small openings at 111 and 555 feet in Taunton 25. Other test holes showed only small or no openings; however, because of the relatively long length of the arms on the caliper used and small diameter of the borehole, small fractures were not detected. The ends of casing detected in Somerset 42 (fig. 6) and in Bristol 23 were apparently 23 feet and 19 feet,

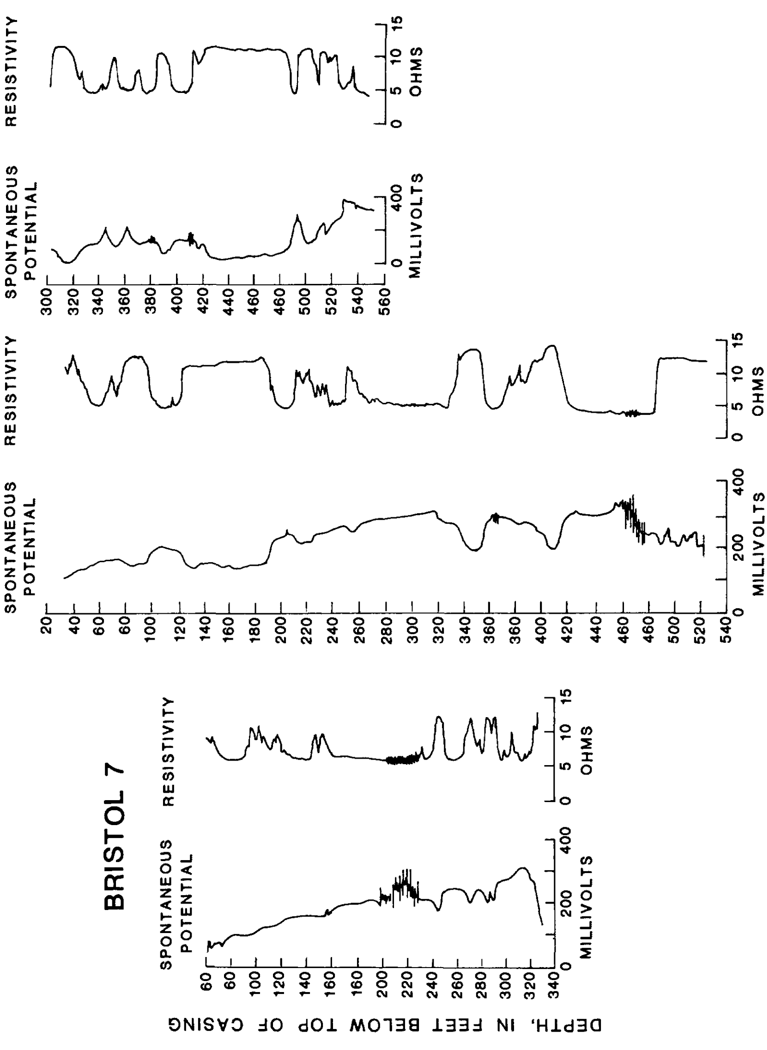

FIGURE 5.—Correlation of geophysical logs from test holes in Bristol, Rhode Island.

respectively, although the drillers reported 26 and 30 feet, respectively, for these holes.

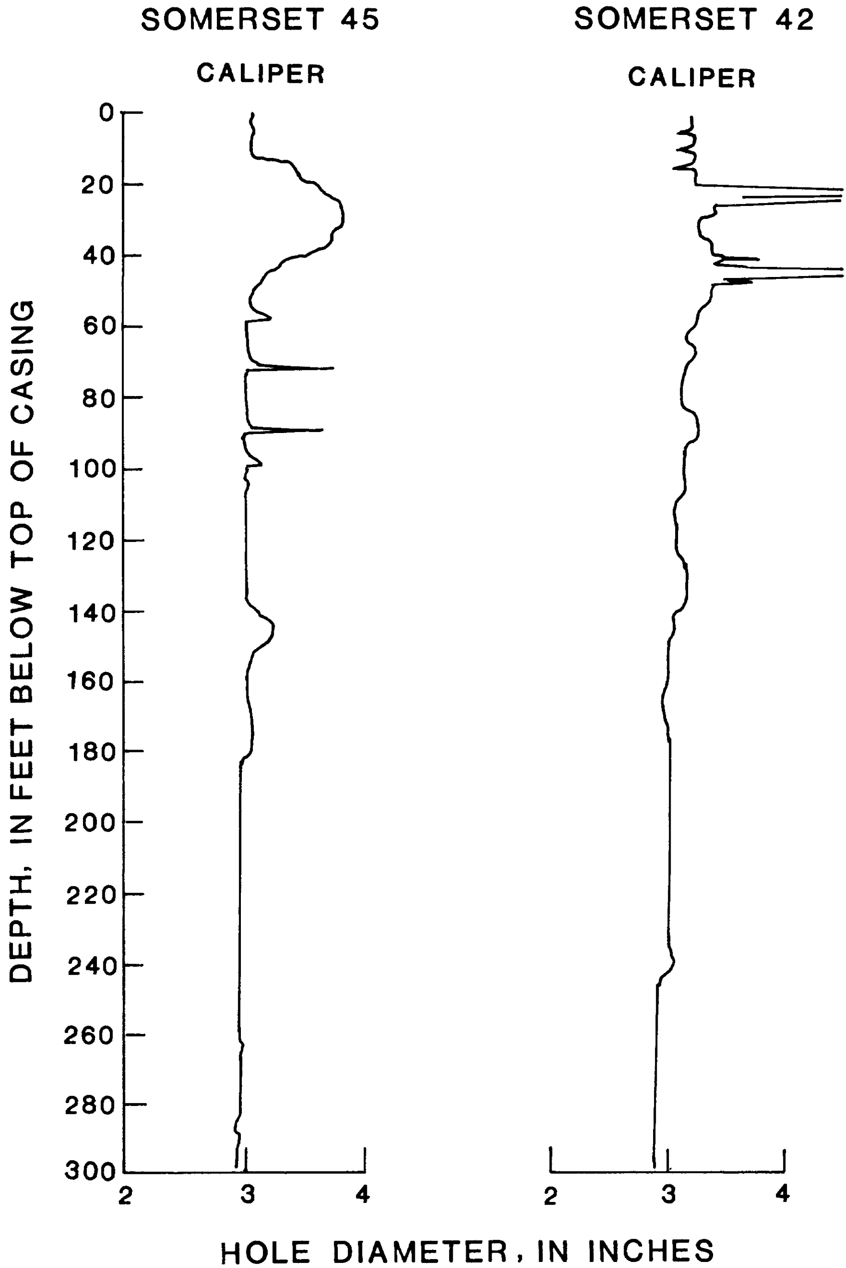

FIGURE 6.—Caliper logs for Somerset 42 and Somerset 45.

Fluid conductivity and temperature logs were made in several holes to detect permeable zones. A deflection of the temperature log toward warmer water between 106 and 112 feet in Bristol 64 was the only indication of permeability change shown in any of the temperature logs. Brine was injected and traced in Taunton 25 and West Bridgewater 21. In Taunton 25, brine injections were made and traced at two depths. They indicated downward flows of 1.7 feet per minute, or about 0.6 gal/min, at 100 feet deep and 3 feet per minute, about 1 gal/min, at 180 feet deep. No movement of the brine injections at 60, 110, or 220 feet was detected in West Bridgewater 21.

WATER YIELDS OF TEST HOLES

Twelve test holes were pumped for periods ranging from 2 to 5 hours to determine yield, specific capacity, and water quality (table 2). Clear freshwater samples were obtained from three of the test holes, Mansfield 6, Foxborough 8, and Taunton 25. Although some holes yielded "black" water as pumping began, the water began to clear and become gray and turbid or clear as pumping continued. Several of the holes yielded "white" water (table 2), apparently as a result of lubricants used during drilling. Specific capacity ranged from 0.01 to 5.7 (gal/min)/ft of drawdown. Pumping rates for Taunton 25 and Halifax 47 were limited to 30 and 25 gal/min, respectively, by the pump capacity. The pumping rates for the other 10 test holes were limited to rates that would not produce drawdown below the level of suction lift of the pump, about 27 feet.

Drawdown and recovery curves for selected holes are shown in figures 7–10. The continued increasing drawdown during pumping and the lack of recovery to original static water level after pumping stopped in test hole Taunton 25 (fig. 7) indicates that water pumped

TABLE 2.—*Results of pumping tests, 1977*

Location and test-hole number	Static water level (ft below land surface)	Date of measurement	Pumping rate (gal per min)	Pumping period (min)	Drawdown (ft)	Specific capacity (gal per min per ft)	Specific conductance (micromhos per cm at 25°C)	Temperature (°C)	Appearance
Bristol 7	6.6	July 12	5.8	240	22.8	0.25	Saltwater	15	Clear.
Bristol 23	5.4	July 13	8	300	20.5	.39	do.	15	Gray.
Foxborough 8	9.6	June 21	2	300	18.0	.11	195	13	Clear.
Halifax 47	3.6	June 23	25	210	6.7	3.7	250	12	White.
Mansfield 6	+ .5	June 24	9	150	23.3	.39	240	11	Clear.
Mansfield 11	4.3	June 17	11	270	21.7	.51	210	11	Gray.
Mansfield 14	9.4	June 20	4	190	17.3	.23	170	12	Black.
Somerset 33	7.3	July 8	1.3	180	19.0	.07		17	White.
Somerset 42	14.8	July 6	6	180	10.0	.60	530	12	White.
Somerset 45	2.0	July 7	.36	180	25.4	.01	330	19	White.
Taunton 25	11.6	June 16	30	120	5.3	5.7	100	10	Clear.
West Bridgewater 21	1.0	June 22	10	300	25.0	.40	295	12	Black-gray.

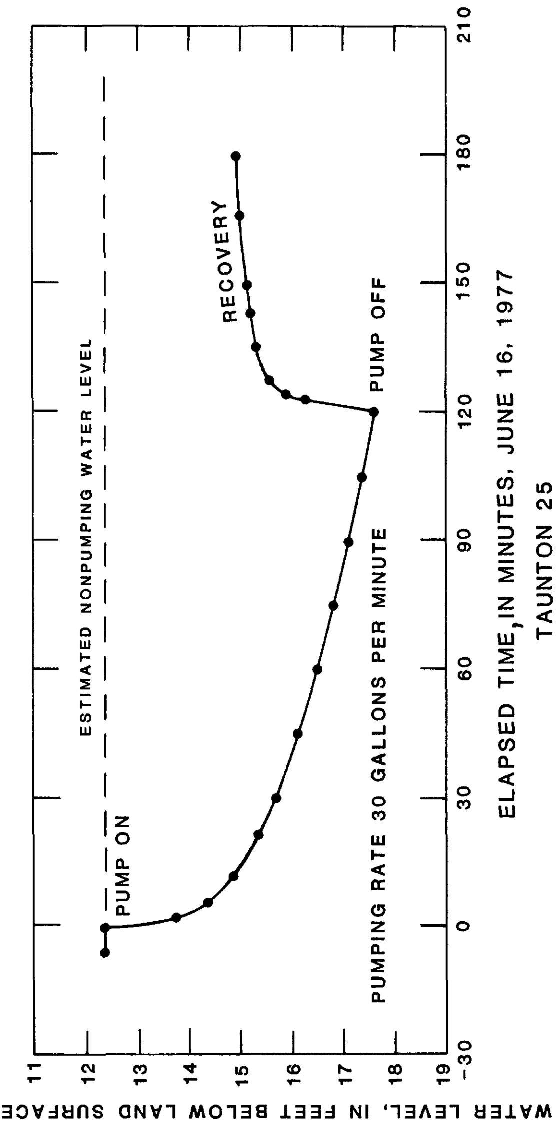

FIGURE 7.—Drawdown from pumping tests of Taunton 25 and Mansfield 6.

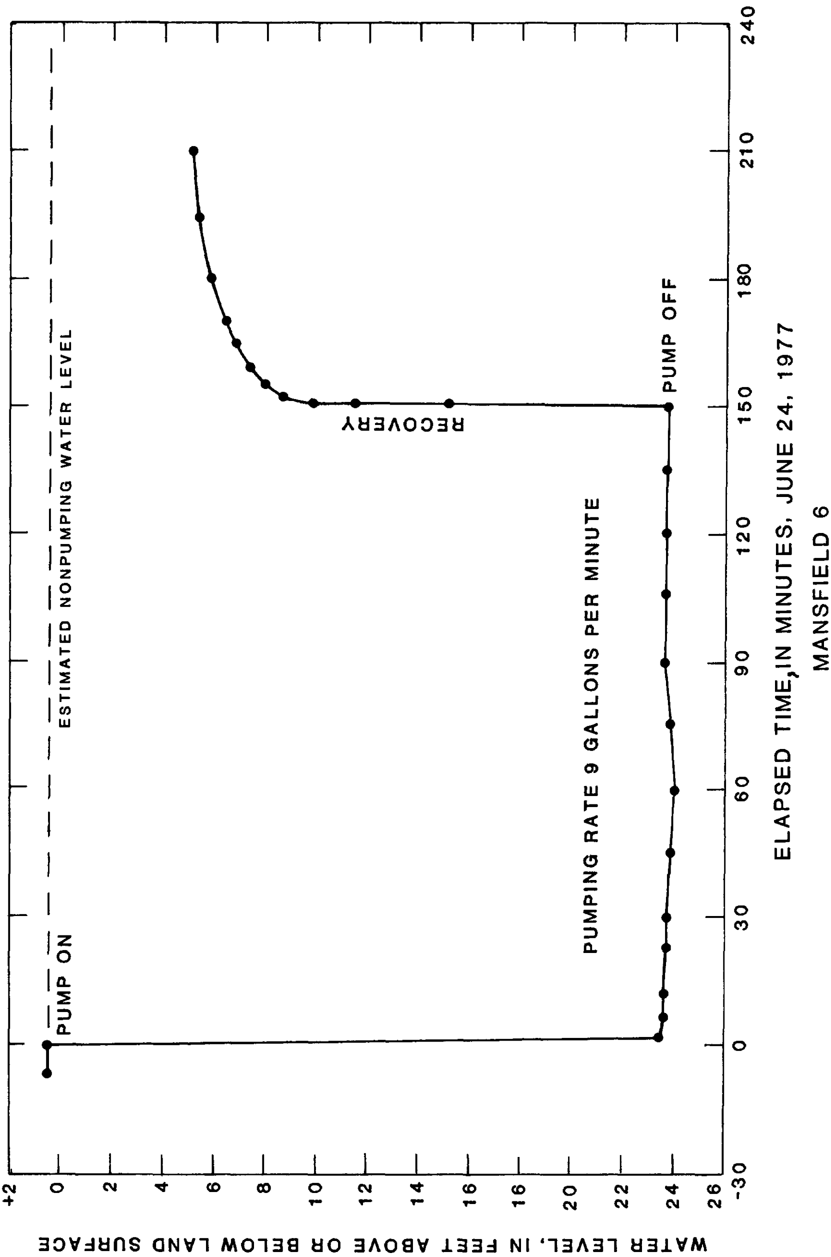

FIGURE 7.—CONTINUED.

from the well was being taken from storage near the well, water that is replaced very slowly. The slow rate of recovery and lack of full recovery in test holes Mansfield 6 (fig. 7) and Somerset 33 (fig. 8) are indicative of similar conditions. Long-term sustained yields from these holes would, therefore, be less than initial pumping tests indicate. Conversely, the steady drawdown and nearly complete and rapid recovery of water levels in test hole West Bridgewater 21 (fig. 9) indicate that the 10 gal/min pumping rate could be sustained for a longer period.

During the pumping of Bristol 23 (fig. 10), water color gradually changed from black to gray. At about 180 minutes, it turned black again and yield increased as a result of the unplugging of a water-bearing fracture in coal or carbonaceous shale. Water from Bristol 7 and 23 remained salty throughout pumping and remained at 15°C—warmer than the 11°–12°C common for shallow ground water in southeastern New England. The rapid and nearly complete recovery of water levels in Bristol 7 and 23 suggest little depletion of water in storage. The water level in Bristol 7 declined 0.8 foot during pumping of Bristol 23, owing to low tide in Narragansett Bay 220 feet to the west. These data and the water-level information, to be described in a later section, strongly suggest that these test holes are in hydrologic contact with Narragansett Bay and that mining would facilitate saltwater seepage.

Water temperatures of 17° and 19°C from test holes Somerset 33 and 45 are higher than the normal 12°C for ground water in southeastern New England and probably are affected by warm water discharged from the nearby Brayton Point New England Powerplant. Somerset 33 is less than 100 feet from a saltwater body, and specific conductance of the pumped water gradually rose from 510 to 880 during the 3-hour pumping test because pumping induced saltwater to flow to the well. During the pumping of Mansfield 14, drawdown remained relatively constant as limited by suction lift, but the pumping rate dropped irregularly from 10 to 4 gal/min the first hour and remained constant at 4 gal/min for the remaining 2 hours and 10 minutes of pumping.

WATER LEVELS AND MINE-WATER PROBLEMS

Ground water in the Narragansett Basin is derived from precipitation. Some of the precipitation may run overland directly to the ocean, some may return to the atmosphere by evaporation or transpiration, or some may flow through the ground eventually to be returned to the atmosphere or discharged to surface-water bodies. Water entering the ground is temporarily retained as soil moisture or percolates downward, through the zone of aeration, to the water ta-

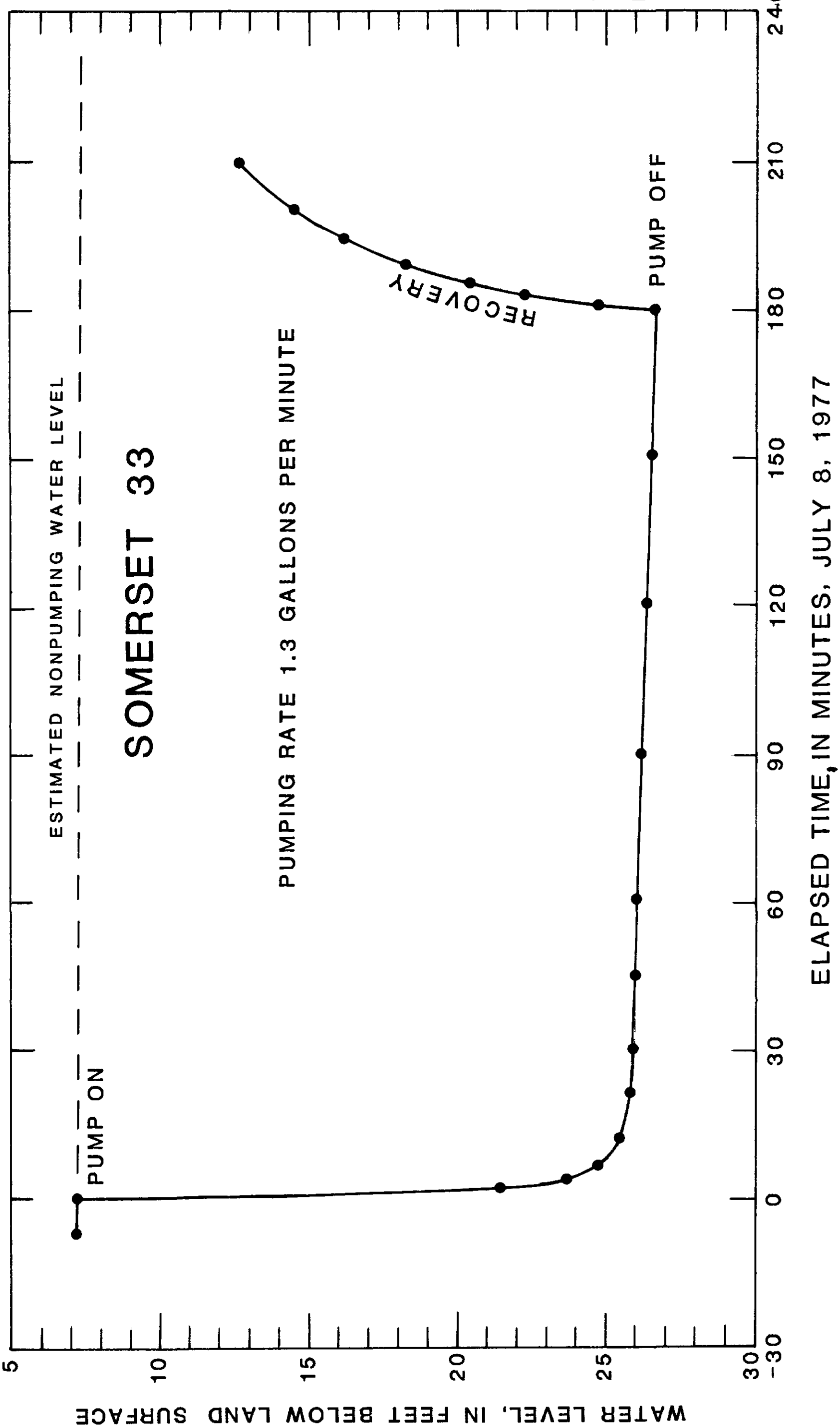

FIGURE 8.—Drawdown from pumping test of Somerset 33.

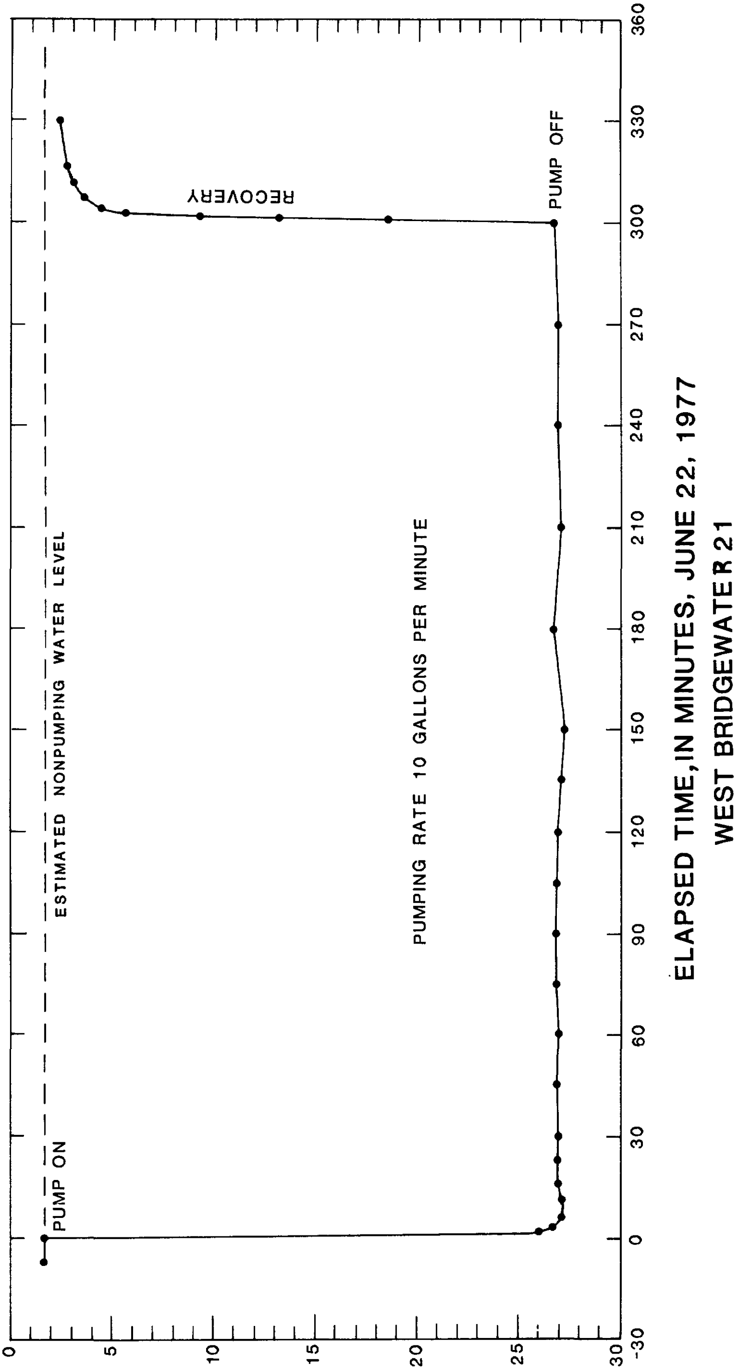

FIGURE 9.—Drawdown from pumping test of West Bridgewater 21.

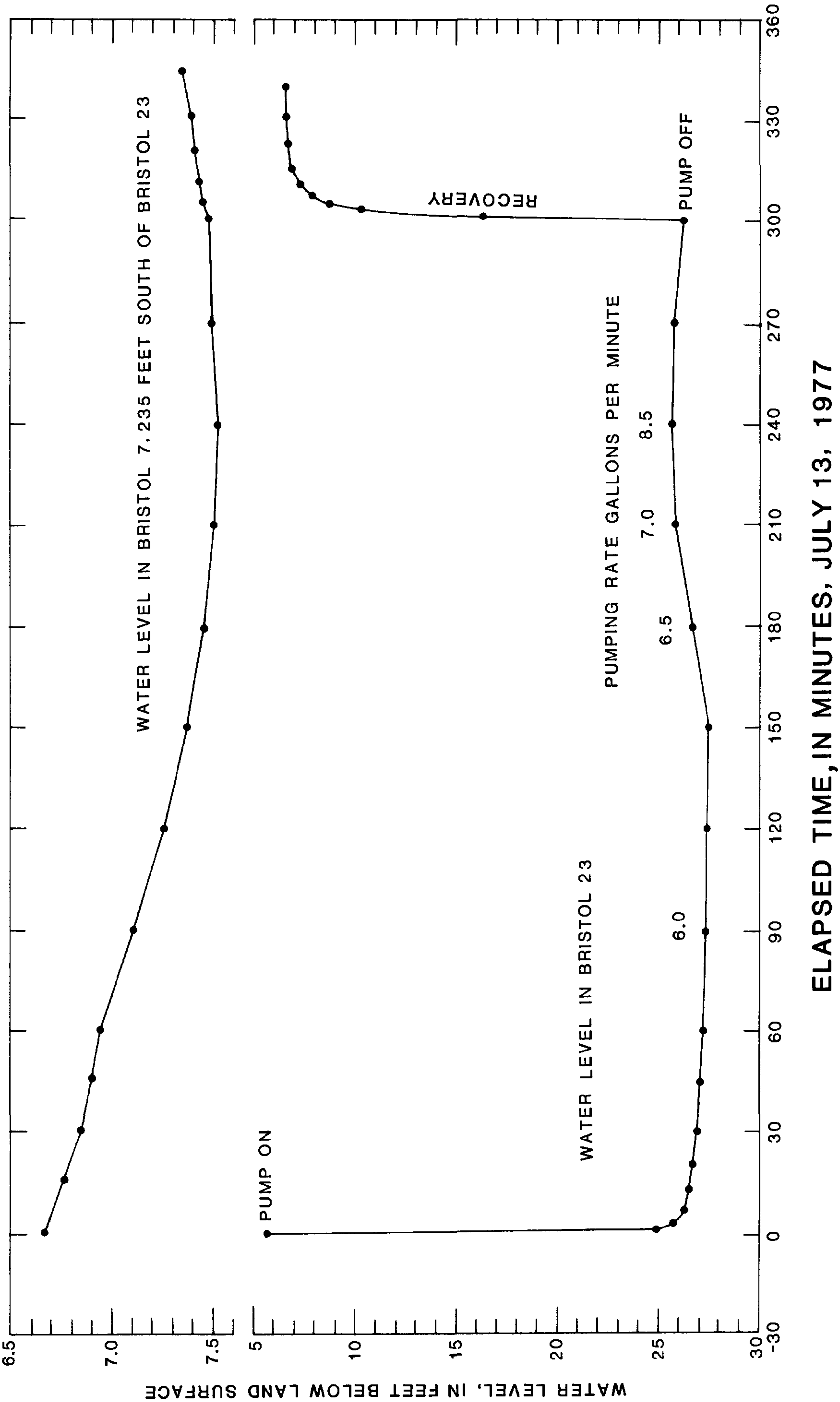

FIGURE 10.—Drawdown from pumping test of Bristol 23.

ble, which is, except for capillary water, the upper limit of the zone of saturation. Ground water moves from areas of recharge to streams, swamps, and the ocean, where it discharges (fig. 11). Generally, in recharge areas there is a downward component to ground-water movement, and in discharge areas there is an upward component. During drilling in a recharge area, the static water level in a well (or test hole) declines as the well is drilled deeper, and in a discharge area it rises as the well is drilled deeper because ground water moves from zones of higher head to zones of lower head.

Static drilling fluid levels reported by the driller for Somerset 42 indicated a rise from about 30 feet below land surface, when the test hole was shallow, to 15 feet below land surface at the completion of drilling at a depth of 1,500 feet. At Somerset 33, the drilling fluid level was about 7 feet below land surface through most of the drilling, but a slight artesian flow was obtained 2 days before completion of the hole at 1,500 feet deep. During drilling of Mansfield 6, the static drilling fluid level rose from 1.1 feet below land surface, when the hole was 36 feet deep, to 2 feet above land surface, when the hole was 80 feet deep, and to artesian flow from the casing, which was 2 feet above land surface, when the hole was 105 feet deep. The hole continued to flow on completion at a depth of 805 feet. During drilling of Taunton 25, the drilling fluid level was about 7 feet below land surface until the well reached 119 feet, where the driller noted a loss of circulation. At 195 feet, the level was 13.6 feet below land-surface datum, and the water level ranged from 10.5 to 15 feet below this datum between November 1976 and September 1977 in the completed 1,006-foot-deep hole. Mansfield 6 (adjacent to the Wading River) and Somerset 33 and 42 (near the shores of Narragansett Bay) are located in ground-water discharge areas as indicated by increase of head as the holes were drilled deeper. Taunton 25 is in a recharge area as indicated by decrease of head as the hole was drilled deeper.

The ground-water level fluctuates in a seasonal pattern; highest ground-water levels normally occur each spring, and lowest in late summer or early fall. The long-term record of an observation well, USGS number FXW 3, is shown for comparison with the short records available from the test holes (fig. 12). During the growing season, from May to September, little, if any, net ground-water recharge occurs because nearly all precipitation is returned to the atmosphere by evaporation and transpiration. During the October through April period, net recharge occurs at varying rates, depending on precipitation and temperature. Melting snow and ice release large quantities of water to recharge ground-water reservoirs. In 1977, the highest water levels in the test holes occurred in March (figs. 12 and 13; table 3).

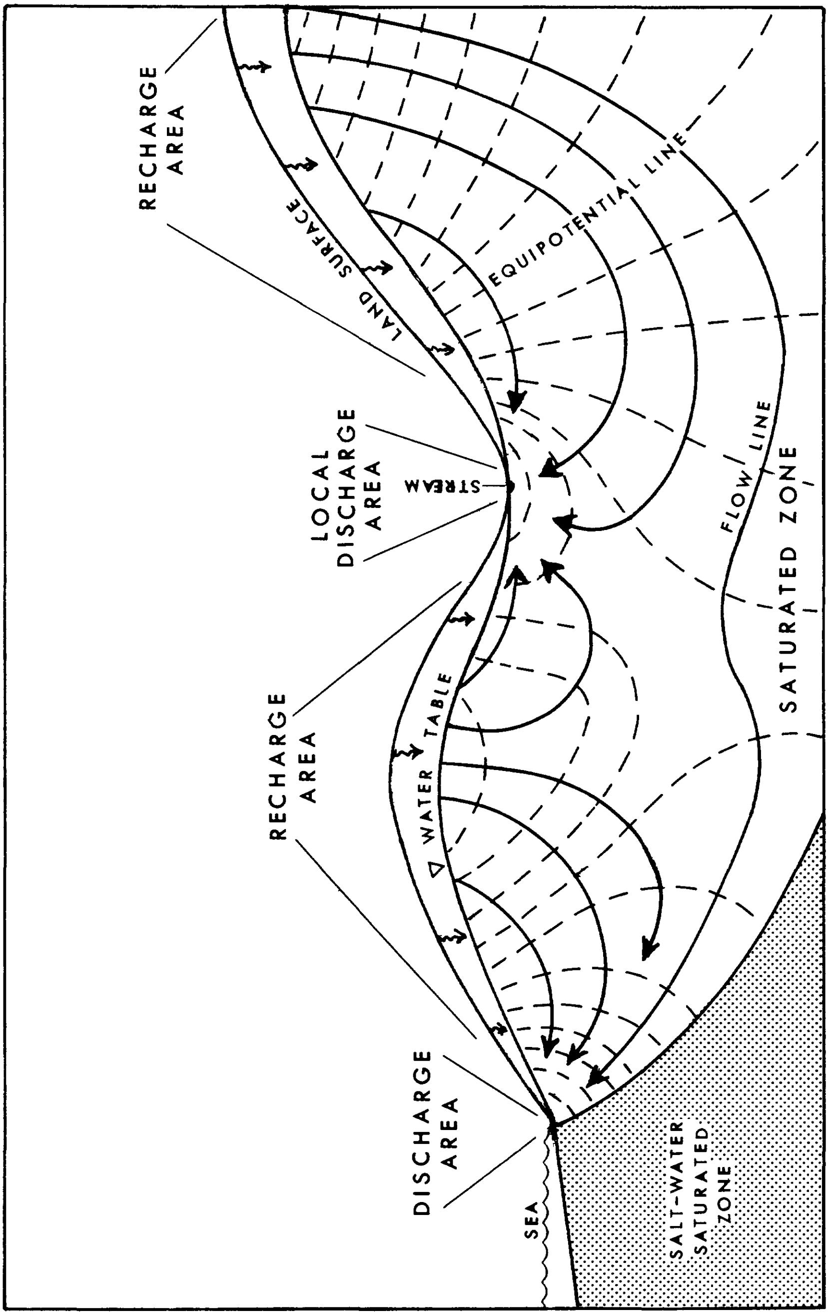

FIGURE 11.—Diagram of ground-water circulation.

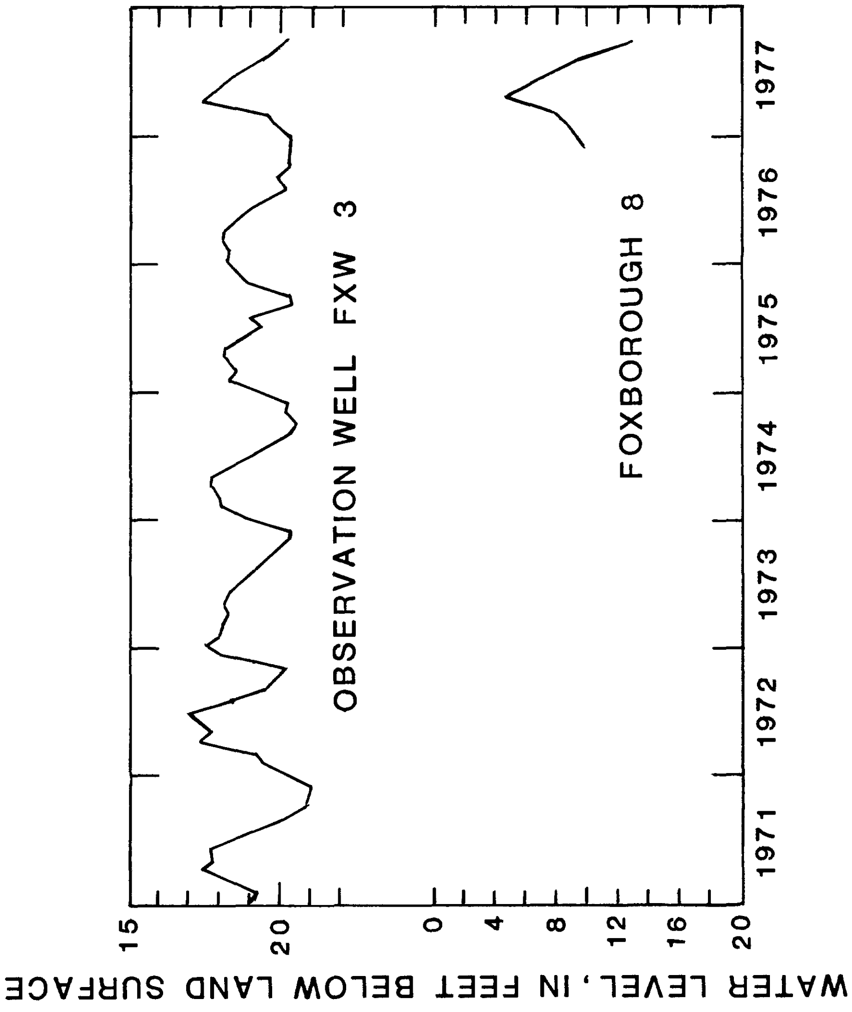

FIGURE 12.—Short- and long-term water-level observations.

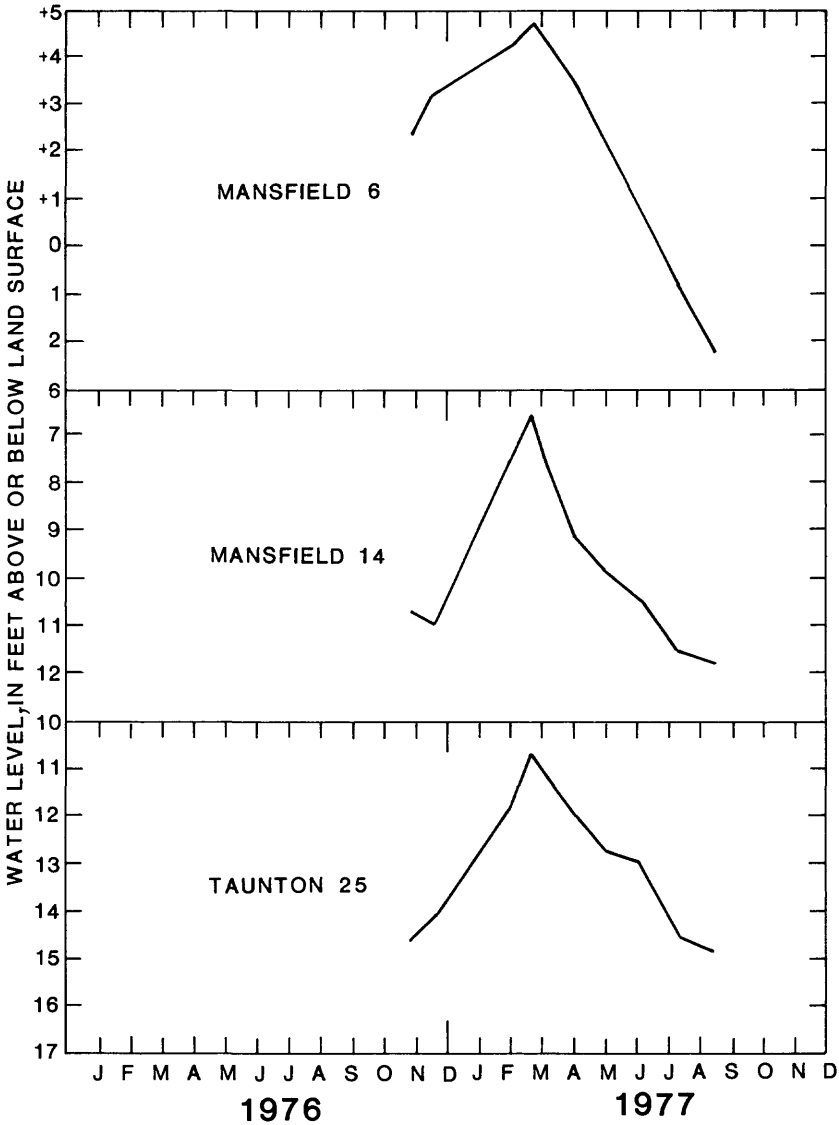

FIGURE 13.—Seasonal water-level fluctuations in Taunton 25, Mansfield 6, and Mansfield 14.

Water-level recorders placed on Bristol 23 and 64 showed (fig. 14) that water levels in these holes fluctuated diurnally in response to tides in Narragansett Bay, as did water levels in a mine pit in Bristol (Conrad Beauregard, Bristol resident, oral commun., 1977). Bristol 23 had a range of about 1 foot, whereas Bristol 64 had a range of 1.5 feet.

TABLE 3.—*Water levels*

[Water levels are expressed in feet below land surface except when preceded by a + indicating that water levels are expressed in feet above land surface]

Bristol 7

NOV. 9, 1976	6.41
MAR. 2, 1977	6.35
MAR. 23	5.97
APR. 1, 1977	6.69
MAY 3	6.42
JUNE 1	6.20
JULY 5, 1977	5.69
AUG. 10	6.66
SEPT. 1, 1977	5.40
SEPT. 15	5.85

Bristol 23

NOV. 9, 1976	5.74
MAR. 2,1977	5.51
MAR. 23	4.72
APR. 1,1977	4.77
MAY 3	5.22
JUNE 1	5.34
JULY 5,1977	4.80
AUG. 10	5.62
AUG. 24	5.56
SEPT. 1, 1977	5.06
SEPT. 15	5.61

Bristol 64

AUG 10, 1977	5.28
AUG. 24, 1977	5.92
SEPT. 1, 1977	4.07
SEPT. 15, 1977	4.68

Foxborough 8

OCT. 15, 1976	11.43
OCT. 18	11.50
NOV. 5	9.93
NOV. 19	9.98
NOV. 23, 1976	9.60
DEC. 14	9.65
MAR. 2, 1977	4.92
MAR. 23	5.17
APR. 1, 1977	6.85
MAY 3	8.50
JUNE 1	9.27
JULY 5,1977	10.38
AUG. 10	11.83
SEPT. 15	12.85

Halifax 47

APR. 1, 1977	3.30
APR. 5	2.94
MAY 3	3.56
JUNE 1, 1977	3.81
JULY 5	3.82
AUG. 10	4.44
AUG. 24, 1977	4.38
SEPT. 1	4.45
SEPT. 30	3.92
OCT. 28, 1977	3.77
NOV. 25	3.54

Mansfield 6

NOV. 19, 1976	+1.06
NOV. 23	+2.30
DEC. 14	+3.15
MAR. 2, 1977	+4.28
MAR. 23	+4.71
APR. 1, 1977	+4.19
MAY 3	+3.39
AUG. 10, 1977	0.87
SEPT. 15	2.25

Mansfield 11

OCT. 15, 1976	10.79
OCT. 18	10.85
NOV. 5	10.48
NOV. 19	11.03
NOV. 23, 1976	10.61
DEC. 14	10.98
MAR. 2, 1977	7.85
MAR. 23	6.56
APR. 1, 1977	7.54
MAY 3	9.41
JUNE 1	9.89
JULY 5, 1977	10.46
AUG. 10	11.46
SEPT. 15	11.74

Mansfield 14

NOV. 23, 1976	5.02
DEC. 14	4.79
MAR. 2,1977	2.92
MAR. 23,1977	2.10
APR. 1	3.19
MAY 3	4.19
JUNE 1, 1977	4.88
JULY 5	5.09
AUG. 10, 1977	5.90
SEPT. 15	6.15

Somerset 33

JAN. 25, 1977	5.36
MAR. 2	4.45
MAR. 23	6.37
APR. 1, 1977	6.80
MAY 3	7.09
JUNE 1	7.33
JULY 5, 1977	6.56
AUG. 10	5.39
AUG. 12	8.13
AUG. 15, 1977	7.54
AUG. 24	6.28
SEPT. 15	7.98

Somerset 42

MAR. 2,1977	13.42
MAR. 23	8.98
APR. 1	9.64
MAY 3, 1977	13.09
JUNE 1	13.82
JUNE 30	14.19
JULY 31, 1977	16.59
AUG. 12	17.21
SEPT. 15, 1977	17.68
NOV. 25	13.45

Somerset 45

MAY 3,1977	1.15
JUNE 1	1.51
JULY 5, 1977	1.62
AUG. 10	3.63
AUG. 12, 1977	4.03
AUG. 15	3.97
AUG. 24, 1977	3.75
SEPT. 15	4.45

Taunton 25

NOV. 23, 1976	14.60
DEC. 14	14.07
MAR. 2,1977	11.88
MAR. 23, 1977	10.63
APR. 1	11.09
MAY 3	12.30
JUNE 1, 1977	12.77
JUNE 30	12.95
JULY 31	14.23
AUG. 10, 1977	14.57
SEPT. 15	14.95
NOV. 25	12.03

West Bridgewater 21

MAR. 2, 1977	0.42
APR. 1, 1977	+0.26
MAY 3	1.07
JUNE 1, 1977	1.62
JULY 5	1.61
AUG. 10,1977	2.95
SEPT. 15	3.10

Because the tidal range in Narragansett Bay at Bristol during this period was 5.4 feet, the tidal efficiency of these test holes is 18 and 28 percent, respectively. Fluid-conductance logs of these test holes indicate they contained saltwater. Pumping for 5 hours did not yield freshwater. These data and a specific capacity of 0.25 to 0.39 gallons per minute per foot of drawdown for test holes 7 and 23 strongly suggest that mine shafts, tunnels, or pits would encounter high inflow or seepage rates at this location.

Fractured and faulted coal beds may become conduits for groundwater movement and storage. Wells may yield more water from coal than the roof or floor rock, and mine seepage may be greater from the coal also.

Water problems were encountered in the early prospecting and mining efforts in the last century in the Mansfield, Massachusetts, area. During dewatering of the 84-foot Skinner mine shaft west of Tremont Street in Mansfield, home wells went dry. On August 24, 1923, the Mansfield News reported: "The first attempt to pump out the water was successful although continuous pumping is necessary to keep the shaft dry***." On August 31, the News reported: "Following a lengthy hearing at the Selectmen's meeting last night, given to several residents of Tremont St., West Mansfield, whose supply of water has dwindled to nothing on account of the continuous pumping at the coal mine, the Board voted to call a town meeting on September 17 to take action on the matter." And, on September 31, "A debate of an hour at the special town meeting Monday evening resulted in the Selectmen and town manager being empowered to furnish relief for any resident who has no supply of water***. Albert H. Bagloe said that the wells were only dry when the mine was being pumped."

Harry B. Chase (oral commun., 1976) reported that an early attempt to develop the Hardon mine north of School Street in Mansfield ended in 1838 because of water, difficulty of mining steeply inclined seams, and national depression. Mr. Chase also reported that in 1917–18 mining operations at the Hardon mine failed because of inability to pump out the shaft; that in 1920 two to five pumps ran continuously to drain the mine; and that in 1922–23 a 25-horsepower electric pump failed to pump the shaft dry.

A continuous record of water-level fluctuations in test hole Halifax 47 (945 ft deep) shows the effects of pumping nearby domestic-supply wells (fig. 15). The nearest well, about 180 feet away, is 85 feet deep, and five additional wells are within about 400 feet of the test hole. The water-level record from Halifax 47 shows drawdown caused by pumping of, perhaps, several domestic-supply wells. Pumping one well causes 0.1 foot of drawdown, and simultaneous pumping of two causes 0.2 foot of drawdown in Halifax 47. Several smaller draw-

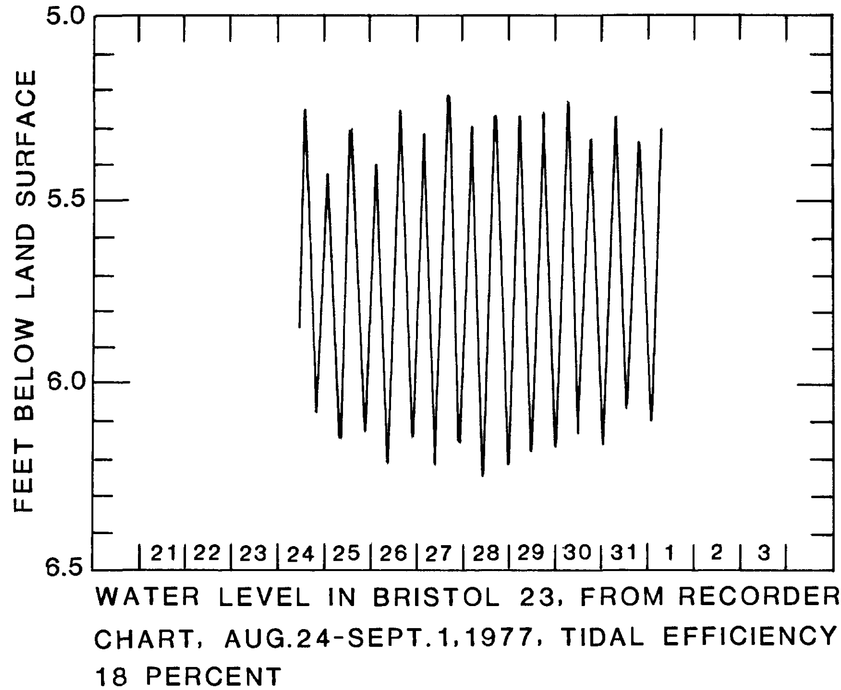

FIGURE 14—Tidal water-level fluctuations of ground water at Bristol, Rhode Island.

downs may be caused by pumping more distant wells or pumping close wells for a short duration. Domestic wells are commonly pumped at 5 to 30 gal/min. The record of drawdown in this test hole and historical accounts from Mansfield indicate that dewatering of bedrock would rapidly affect water levels in domestic wells over distances of hundreds and perhaps thousands of feet.

Dewatering of bedrock for mining requires only the removal of water from storage in secondary porosity (joints and fractures) in the bedrock and removal of water from storage in primary porosity in overlying unconsolidated deposits hydraulically connected with the bedrock. The specific yield of a rock is the ratio of the volume of water that will drain by gravity from water-saturated rock to the volume of the rock. Because primary pores of the conglomerate and sandstone of the Rhode Island Formation in the Narragansett Basin are very poorly interconnected and because secondary pores (joints and fractures) make up only a small percentage of total rock volume, specific yield of the upper 300 feet of bedrock is estimated to be less than 0.5 percent. The degree of rock fracture and therefore specific yield is greatest near the top of the bedrock and decreases rapidly to a negligible amount between 300 and 400 feet.

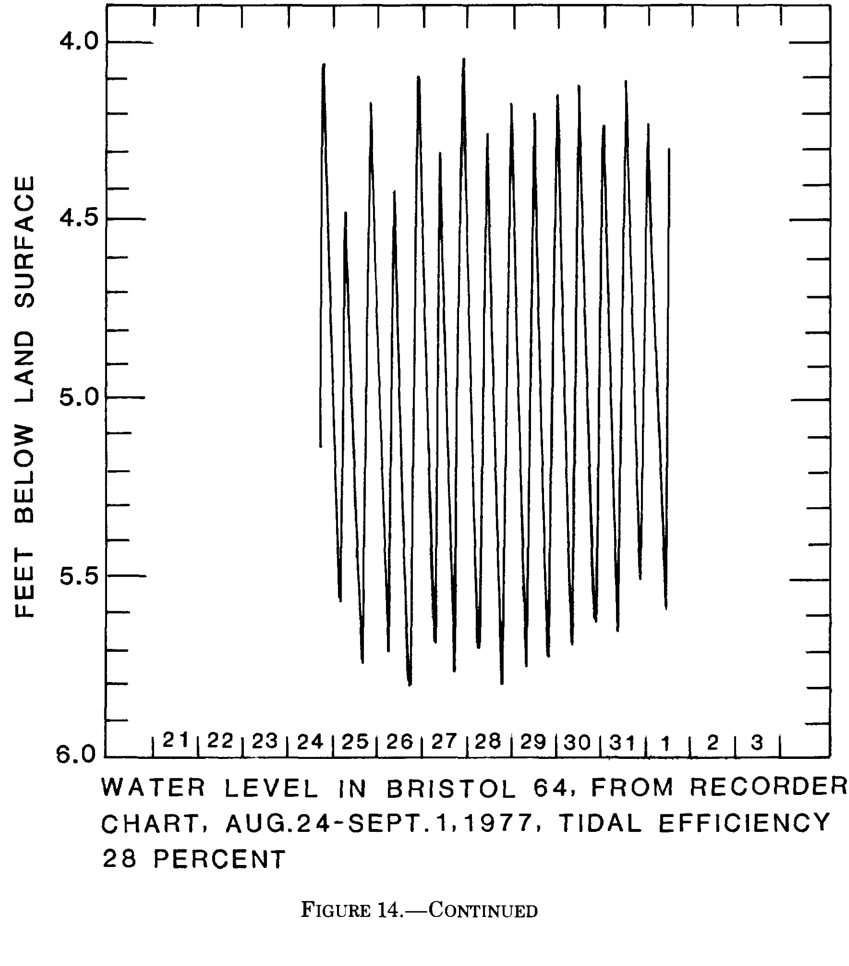

FIGURE 14.—CONTINUED

Unconsolidated sand and gravel deposits of glacial origin in New England commonly have specific yields of about 20 percent and therefore may store large quantities of water. For example, a 1-mile-long section of a 1-mile-wide valley filled to an average depth of 30 feet with water-saturated sand and gravel constitutes a ground-water reservoir that contains 1.1 billion gallons of water. The aquifer mapped by Williams (1968) between Lake Mirimichi and Greenwood (Bungay) Lake in Mansfield and Foxborough is about this size but is also in contact with the lakes and additional water-saturated sand and gravel both to the north and to the south. Mansfield withdraws an average of 1 Mgal/day from wells in this ground-water reservoir, and Attleboro has a pumping capacity of 2.75 Mgal/day at its diversion station on the Wading River in Mansfield (Williams and Willey, 1967). Base flow in the Wading River at this station is partly dependent on

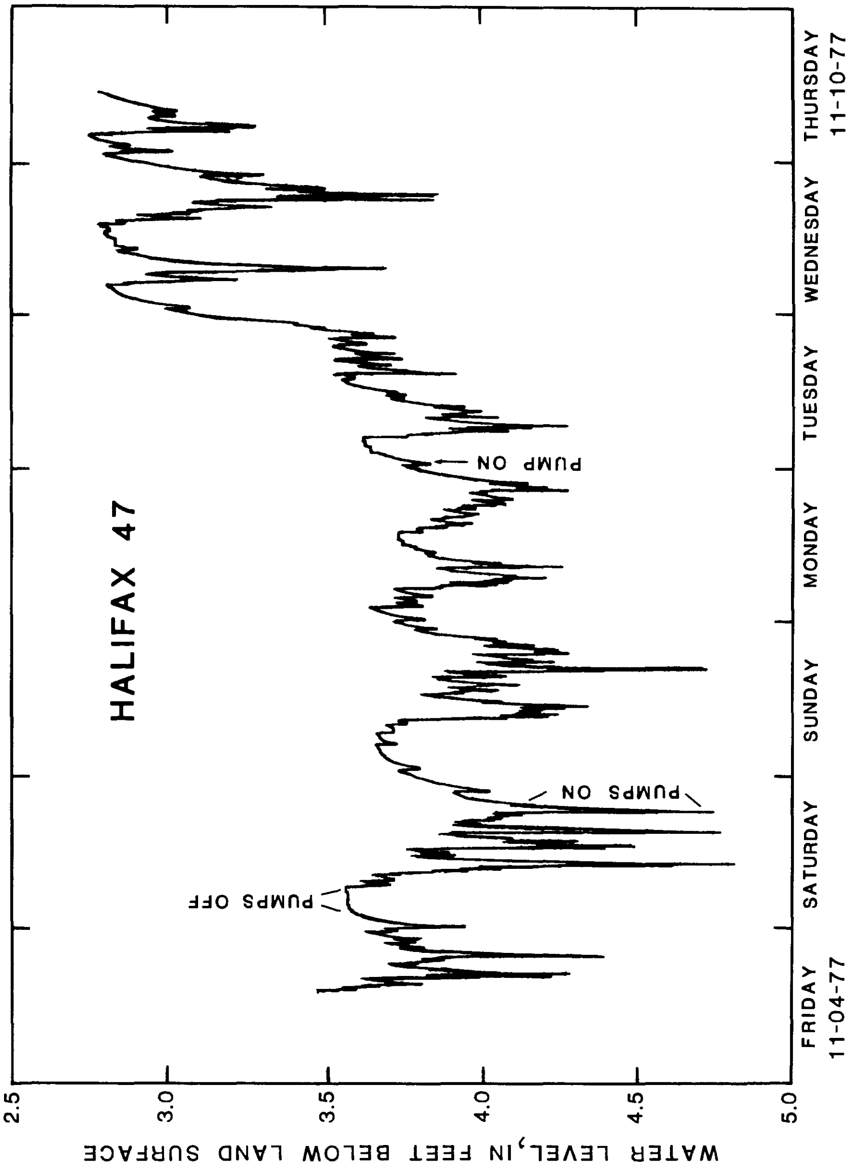

FIGURE 15.—Water-level fluctuations in Halifax 47 due to pumping domestic wells.

ground-water discharge from the 1.1 billion gallon ground-water reservoir and releases from Lake Mirimichi. Mines close to ground-water reservoirs such as this would have a large potential for ground-water inflow. However, there commonly is a layer of till separating rock from sand and gravel, so inflow to rock would depend on the thickness and permeability of the till and the hydraulic gradient induced by dewatering.

Measures to prevent mine flooding from sand and gravel aquifers and to prevent interference with municipal water supplies would be an important part of coal mining in many parts of the Narragansett Basin. Maps showing the location and water-yielding potential of sand and gravel aquifers in the basin in Massachusetts have been prepared by Williams (1968); Williams and others (1973); and Willey and others (1976). Maps of sand and gravel deposits and reports of water-bearing characteristics for areas in Rhode Island have been prepared by Allen (1953); Allen and Gorman (1959); Allen and Ryan (1960); Bierschenk (1954); Lang (1961); Rosenshein and others (1968); and Schiner and Gonthier (1965a and 1965b). Descriptions and locations of municipal-supply wells are given in these reports and are located in figure 2.

Because stream base flow is sustained by ground-water discharge and because surface water can be induced to recharge aquifers in which the water table is depressed, mine dewatering could cause local streamflow depletion and lowering of pond levels. Low permeability barriers such as clay-filled trenches or grouted bedrock might be used to restrict infiltration. Water pumped from mines could be returned to the depleted surface-water bodies to reduce undesirable impacts, provided that the quality of the return flow water is not seriously impaired.

WATER QUALITY

In the Narragansett Basin, surface water and ground water are typically low in dissolved-solids concentration (Williams and others, 1973). Similar to rainwater, the waters are mildly acidic with median pH's of 6.7 and 6.3, respectively. The median concentrations of common constituents and properties of ground water are shown in table 4. Chemical analyses of water samples pumped from the three coal test holes (table 5) were consistent with this general description of ground-water quality in the basin. Water from only 3 of the 12 test holes that could be pumped was analyzed because representative samples could not be obtained within the time and resources available for sampling or because the ground water was saline. With longer pumping periods to exhaust the mud and lubricants intro-

TABLE 4.—*Chemical quality of ground water in the Taunton River Basin*

[Constituents are given in milligrams per liter except pH, color, conductance, and turbidity. Table taken from Williams and others, 1973]

Constituent	Maximum	Minimum	Median
Silica (SiO_2)	23	6.9	12
Iron (Fe)	.70	.00	.07
Manganese (Mn)	2.2	.00	.06
Calcium (Ca)	29	4	12
Magnesium (Mg)	14	1.0	5.8
Sodium (Na)	42	4.2	14
Potassium (K)	4.8	.2	1.8
Carbonate (CO_3)	3.6	.0	.0
Bicarbonate (HCO_3)	83	4	15
Sulfate (SO_4)	61	5.3	23
Chloride (Cl)	130	4.0	13
Fluoride (F)	.3	.0	.1
Nitrate (NO_3)	122	.0	4.4
Dissolved solids	268	39	107
Hardness ($CaCO_3$)	116	13	48
Noncarbonate hardness	96	0	32
pH	8.6	5.6	6.3
Color	27	0	2
Specific conductance (μmho per cm at 25°C)	369	43	135
Turbidity	7	0	0

TABLE 5.—*Chemical analyses of water from test holes*

[Constituents are given in milligrams per liter except as indicated]

	Foxborough 6	Mansfield 6	Taunton 25
Date of sample	6–21–77	6–24–77	6–21–77
Specific conductance (μmho per cm at 25°C)	195	240	100
Temperature (°C)	13.0	10.0	10.0
Hardness (Ca, Mg)	73	94	0
Dissolved calcium (Ca)	25	29	14
Dissolved magnesium (Mg)	2.5	5.2	1.3
Dissolved sodium (Na)(μg/L)	8.3	13	4.6
Dissolved potassium (K)	.8	.4	1.0
Bicarbonate (HCO_3)	86	140	32
Alkalinity as $CaCO_3$	71	110	26
Dissolved sulfate (SO_4)	13	3.5	3.3
Dissolved chloride (Cl)	4.3	3.3	4.4
Dissolved fluoride (F)	.1	.1	.1
Dissolved silica (SiO_2)	21	14	9.0
Total nitrite plus nitrate (N)	.01	.00	.00
Total phosphorus (P)	.00	.00	.00
Total barium (Ba) (μg/L)	0	0	0
Total copper (Cu) (μg/L)	15	480	19
Dissolved iron (Fe) (μg/L)	960	210	20
Total lithium (Li) (μg/L)	0	10	0
Total manganese (Mn) (μg/L)	520	300	140
Total strontium (Sr) (μg/L)	190	680	250
Dissolved vanadium (V)(μg/L)	1.0	.0	.0
Total zinc (Zn) (μg/L)	0	180	30

duced by drilling, representative samples might be obtained from the other nine test holes.

The samples were analyzed for common chemical constituents and for constituents that might originate from the coal beds. U.S. Geological Survey chemical analyses of coal samples from the test holes (J.H. Medlin, Branch of Coal Resources, written commun., 1976) suggest the ground water in contact with the coal might be expected to contain abnormal concentrations of barium, strontium, or vanadium.

Analyses of four coal samples showed 650–810 ppm (parts per million) barium, 170–300 ppm strontium, and 140–170 ppm vanadium. Lithium, copper, and zinc were also sought in the three water samples, but none of these elements were found in abnormal concentrations (table 5).

The heavy metals, iron and manganese, are common natural constituents of ground water in the region. These commonly occur in concentrations in excess of the 300 and 50 μ/L (micrograms per liter) maximum limits recommended for public drinking water supplies (U.S. Environmental Protection Agency, 1975) for iron and manganese, respectively. All the samples taken for this study had manganese concentrations in excess of the recommended limit, and one had iron in excess of the recommended limit.

In many coal regions, as the result of strip mining or underground mining, marcasite and pyrite (iron disulfides) in the rock adjacent to the coal are exposed to air and water. Once so exposed, the sulfide rapidly oxidizes to ferrous and ferric sulfates which are soluble in water and forms sulfuric acid. Ahmad (1974) estimated that 6,000 tons of sulfuric acid is produced daily by oxidation of pyrite in the Appalachian region. The iron further reacts with air and water to form orange-brown precipitates of iron oxides and hydroxides. These iron deposits are commonly seen where ground water containing dissolved iron comes in contact with air, as in springs, seeps, and mine-drainage streams. The iron chemically combines with available oxygen thereby keeping the water depleted in dissolved oxygen until all of the iron is precipitated. The sulfuric acid causes the water to be highly corrosive. These chemical qualities make the water unsuitable for drinking and for almost any other use. They form a hostile environment for normal stream life, especially fish, and commonly cause the formation of an orange slime of iron hydroxides and iron-metabolizing bacteria.

Pyrite is reported to occur in minor quantities disseminated throughout the rocks of the Narragansett Basin, but visual inspection and chemical analyses of coal samples show low sulfur-bearing mineral contents. Caruccio and Ferm (1974) found that in the Appalachian coal fields the severity of acid mine drainage is, in part, a direct function of the amount of framboidal pyrite in the rock strata disturbed by mining. Framboidal pyrite occurs as clusters of spheres of iron disulfide about 0.25 microns in diameter. Euhedral crystals and coarse-grained crystals of the type reported in the Narragansett Basin, however, do not decompose rapidly enough to produce severe acid mine drainage. The occurrence of framboidal pyrite has been correlated with paleodepositional environments and shown to be high in marine-influenced back-barrier and lower delta-plain deposits and poor in upper delta-plain and alluvial-plain deposits (Caruccio and Ferm, 1974). Because the Naragansett Basin sediments are alluvial-plain deposits and have been metamorphosed (the coal is anthracite), little if any framboidal pyrite is expected to be present, and severe acid mine drainage problems would not be likely.

Both iron and sulfate concentrations are chacteristically high in mine drainage water. Water in the Naragansett Basin region has somewhat elevated iron concentrations, but sulfate concentrations are characteristically low. The recommended limit (U.S. Environmental Protection Agency, 1975) for maximum sulfate concentration in drinking-water supplies is 250 mg/L (milligrams per liter), much greater than the 17 mg/L maximum found in the samples from the test holes or the median concentration reported for ground water in the Taunton River Basin (Williams and others, 1973).

Suspended sediment can be a problem in streams of coal mining areas. Coal processing with water to remove fine material from the coal produces large quantities of silt, which must be removed from the process water to avoid sediment problems in streams and harbors. Settling basins are used to separate the sediment from wastewater from mines.

Saline water was pumped from two test holes at Bristol, and measurements of specific conductance during pumping indicated increasing salinity in Somerset 33, as described previously. Mine dewatering below sea level and near surface saltwater bodies could induce saltwater intrusion into rock between the mine and source. Such conditions could result in saltwater contamination of wells in the area of intrusion; however, most municipal-supply wells seem to be so far from saltwater that this is not a threat, except possibly in Barrington, North Kingston, and East Greenwich, in Rhode Island, and Somerset and Dighton, in Massachusetts. Most areas adjacent to saltwater bodies are served by public supplies, and therefore not many domestic wells would be affected by saltwater intrusion. A public-supply well in Barrington and an industrial-supply well in Providence have been affected by saltwater intrusion caused by pumping the wells themselves.

CONCLUSIONS

Hydrologic concerns related to potential coal mining in the Narragansett sedimentary basin of Massachusetts and Rhode Island are not unique. Sustained high rates of ground-water seepage to mines are not expected unless the mines are in proximity to large bodies of surface water or water-saturated glaciofluvial deposits. Avoidance of infiltration from water-saturated glaciofluvial deposits to minimize mine seepage and pumping costs would also lessen chances of interference with public-supply wells tapping glaciofluvial deposits. However, interference with domestic water-supply wells tapping bedrock should be expected near underground or deep-pit operations. Historical and hydrologic evidence indicate that mining operations could cause local dewatering of the bedrock aquifer and resultant failure of domestic water-supply wells. Public water-supply service might be extended into areas where mining might have this effect.

Ground-water quality in the basin is generally satisfactory for private and public supplies. It is commonly slightly acid (pH less than 7) and commonly contains iron and manganese in excess of the recommended limits for drinking water (U.S. Environmental Protection Agency, 1975). Relatively inexpensive treatment is available to upgrade water quality through pH control and iron and manganese removal to meet these recommended quality criteria. Coal-mine drainage commonly contains ions of heavy metals, especially iron, and is acidic, owing to the oxidation and solution of iron sulfide exposed to air and water as a result of mining. Iron sulfide as pyrite is reported to be widely disseminated in the rocks of the basin and was found thus in many of the core samples of shale, sandstone, and conglomerate but not in the coal recovered from the exploration program. The low sulfate content of ground water suggests that pyrite is not the source of iron or acidity in ground water under present conditions. Mining of coal in the Narragansett Basin would probably not expose large quantities of pyrite, and therefore neither acid mine drainage nor iron would be the major water-quality problems that they are in other coal mine areas.

Geophysical logs were demonstrated to be useful for determining lithology, including coal, for stratigraphic correlation, and for locating fractures. Brine injection and geophysical logging were also shown to be useful in determing permeable zones and might be utilized more extensively in investigations to determine water sources such as fracture zones.

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