GROUND-WATER AVAILABILITY IN THE BARRE-MONTPELIER AREA

BY

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1972

GROUND-WATER AVAILABILITY IN THE

BARRE-MONTPELIER AREA, VERMONT, 1972

ERRATA

Page 8	Line 13 - "wash borings" are EBX 1*, EBX 2
Page 8	Line 22 - "test-boring data" are EBW 47 to EBW 50
Page 11	Line 1 - "pumping-test data" is for EBW 46
Page 15	Chemical analysis is for well EBW 46. Sample collected for iron and manganese determination was on April 29, 1971.
Page 16	Line 4 - "wash boring" is MHX 1
	Line 13 - "wash boring" is MHX 3
Page 18	Line 8 - "wash boring" is BLX 1
Page 20	Line 17 - "8-inch test hole" is well NLW 13
	Line 18 - "wash-bore holes" are NLW 9 to NLW 12
Page 24	Line 7 - "wash borings" are NLX 1 to NLX 3
Page 26	Chemical analysis is for well NLW 13
Page 27	Insert "Lockwood, Kessler and Bartlett, Inc., 1970, Seismic refraction profiling Montpelier area, Vermont, 17p.

*Local well and boring numbers used by the U.S. Geological Survey

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GROUND WATER AVAILABILITY IN THE

BARRE - MONTPELIER AREA

By

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and
DAVID BUTTERFIELD, VERMONT DEPARTMENT OF WATER RESOURCES

INTRODUCTION

A study of the ground-water resources of the Barre - Montpelier area (fig. 1), Washington County, was begun in 1968 as part of a cooperative program between the Vermont Department of Water Resources and the U.S. Geological Survey. The purpose of the study is to provide technical appraisal of potential sources of water to meet the expanded needs of most towns in Washington County, as pointed out by the Rural Comprehensive Water and Sewer Plan (Vermont Department Water Resources, 1969). Funding was made available by the U.S. Department of Agriculture, Farmers Home Administration, for water-resources exploration, including the testing of the quantity and quality of the water in sand and gravel aquifers. The geology of the area was mapped, and private and municipal water supplies were inventoried in 1968.

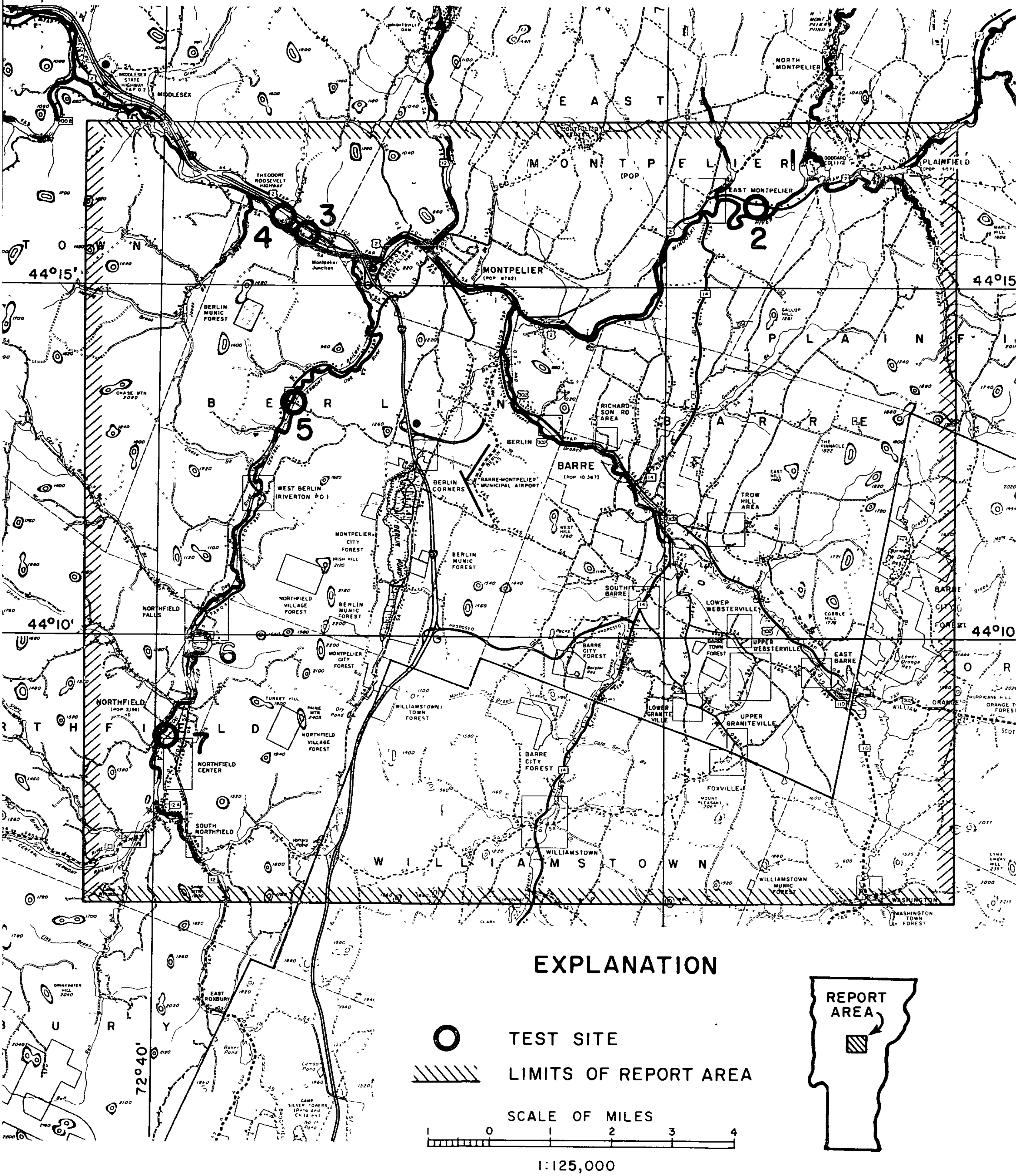

FIGURE 1 BARRE-MONTPELIER AREA

GEOLOGY

The Barre - Montpelier area lies wholly within the drainage basin of the Winooski River. In much of the area the valley is unsuitable for development of large supplies of ground water because it is underlain by silt and clay or bedrock at shallow depth. However, saturated sand and gravel in the valley is locally more than 80 feet thick and has potential for the development of high-capacity wells. Upland areas between the river valleys are underlain by bedrock that is covered by a variable thickness of glacial till. Most wells finished in bedrock and till yield small amounts of water, and the upland area, where this material is exposed, generally is unfavorable for the development of high-capacity wells. For this reason, exploration was limited to valleys in which thick deposits of water-bearing sand and gravel are known (Hodges, 1967).

EXPLORATION METHODS

Test work was carried out in three phases. The first was seismic refraction profiling at several locations in the Winooski and Dog River valleys to determine the shape, thickness, location, and type of materials below the valley floor. The second phase was driving wash borings, 2½ inches in diameter, to determine the permeability of the subsurface materials. Observation wells, 1¼ inches in diameter, were installed in the wash bore holes at two locations that were found to have potential for development as municipal water supplies. These small-diameter wells served as observation wells during the third phase of the program, during which an 8-inch well was constructed at each of the two locations and the aquifer tested. The two test wells, finished with 20 feet of wire-wrapped screen, were pumped until they were essentially sand-free, assuring good well efficiency during testing. After the wells were developed, each well was pumped for 48 hours, and measurements of drawdown and recovery were made in the pumping well and four observation wells.

TEST SITES AND AQUIFER TESTS

Test work was carried out at seven sites (fig. 1) within the Barre - Montpelier area.

Site 1 - East Montpelier - Plainfield town line on the properties of J. Tofani, J. E. Boudreau, and Caledonia Sand and Gravel Company (fig. 2). This site is in a broad valley at the junction of the Winooski River and Kingsbury Branch. East-west oriented seismic profiling across the former delta of the Kingsbury Branch, approximately half a mile south of the present mouth of the branch, indicated that bedrock is 45 to 120 feet below land surface, the deepest point being near the center of the valley. A short seismic profile perpendicular to this line showed that the bedrock surface slopes southward at about 10 degrees. Wash borings on the east-west seismic line showed that the east and central part of the valley are underlain by relatively impermeable lacustrine silt and clay. The west side of the valley, however, is occupied by an esker containing permeable gravel that extends far enough below the water table to constitute a good aquifer. Much of the sand and gravel above the water table has been removed from the core of the esker, and several water-filled pits have been produced by removing gravel from below the water table. Seismic and test-boring data indicate that the coarse sand

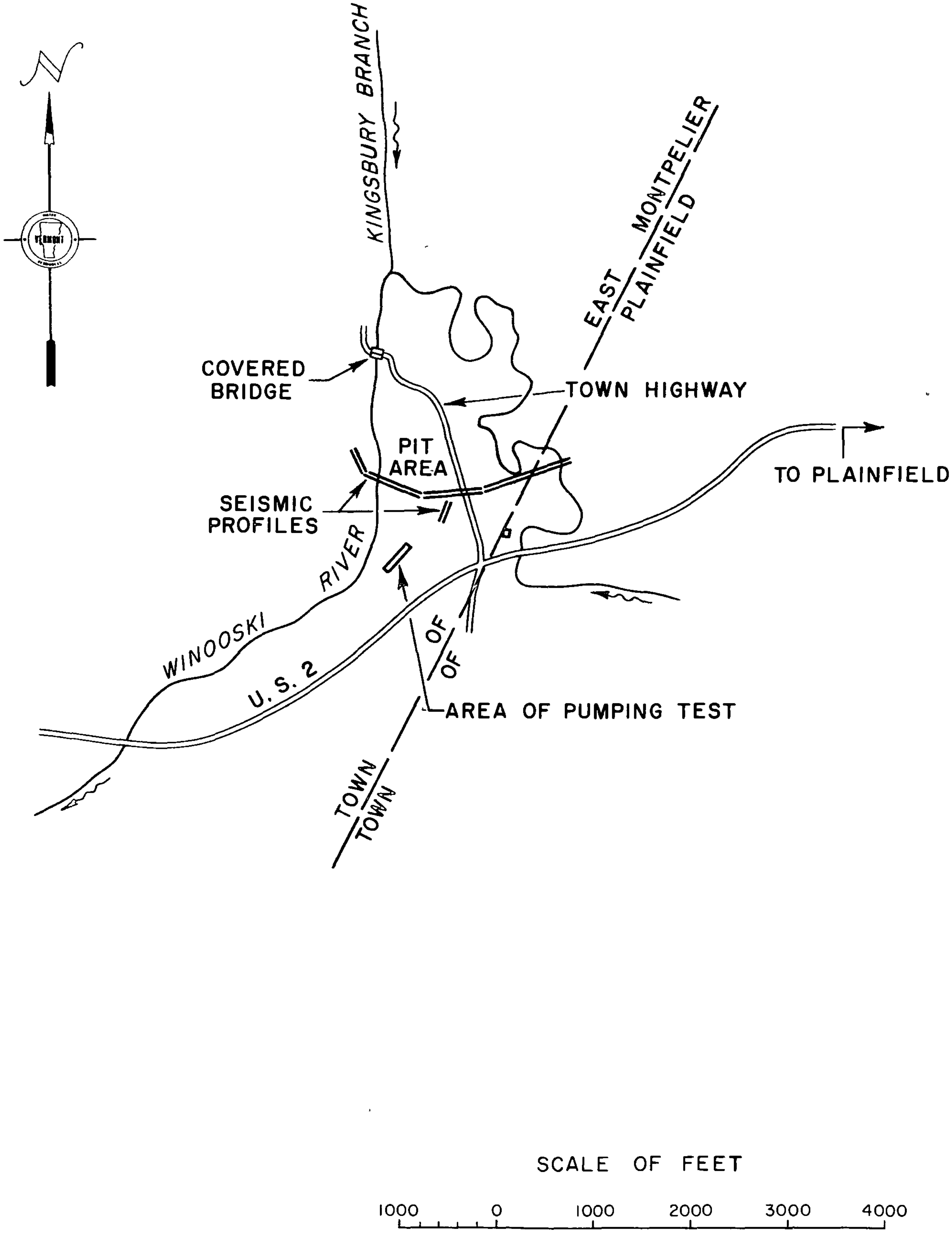

FIGURE 2 TEST SITE I

and gravel of the esker is probably less than 800 feet wide and 60 feet deep at the mouth of Kingsbury Branch. The thickness of this material increases to the southwest in the valley of the Winooski River. The width of the coarse material to the southeast of the test site is estimated to be at least 600 feet. Farther to the southwest, several privately owned gravel wells indicate that this aquifer extends toward the town of East Montpelier. A gravel pit on the south bank of the Winooski River upstream from East Montpelier may have been dug in a remnant of the esker. Fine sand, silt, and clay flank the esker to the south and east of the test site, and, to the north, the Winooski River marks the boundary between the esker and bedrock.

Pumping-test data analyzed by methods developed by Boulton (1963), Stallman (1965), and Hurr (1966) indicate that the transmissivity of the aquifer in this area is about 40,000 square feet per day. An aquifer having an average width of 700 feet is capable of transmitting about 2 mgd (million gallons per day) of water with a hydraulic gradient of about 50 feet per mile. This is considerably less than the lowest daily mean flow of the Winooski River, estimated to be 147 mgd. If most of the pumpage is derived from infiltration through the streambed, the low flow of the river would fall below the recommended limit of 0.2 cfs per sq mi during drought. The river flows along the northwest edge of the esker at the test site and would be the major source of recharge to the underlying aquifer if withdrawal from wells was large. The pumping rate in this area is limited by the 1) low flow of the Winooski River and 2) recommended limitation on flow depletion rather than aquifer transmissivity.

Estimates of Available Water at Site 1

Practically all pumpage at this site would be derived from infiltration from the Winooski River because of small aquifer storage and scant recharge from precipitation. Calculations of discharge in the Winooski River at the test site are based on records at the Montpelier gaging station, 12.3 miles downstream. Approximately 160 square miles, or 40 percent of the drainage basin above the gaging station at Montpelier, lies above the East Montpelier test site. For the purpose of calculation, 40 percent of the water is assumed to originate above the test site. Reservoirs within the basin above the gage regulate some of the flow past the test site.

The Vermont Department of Water Resources' recommendation that 0.2 cfs per sq mi of drainage area be maintained as a base flow at all points on a stream requires a minimum flow of 32 cfs, or 20.8 mgd at the test site. Calculations based on streamflow at Montpelier indicate that the daily mean discharge past the test site is below 32 cfs on an average of 12 days per year but has been below this value for as many as 60 days in a single year (1964).

Potential pumping from this aquifer is, in part, related to streamflow adjacent to the site. If 1 mgd is pumped from wells and not returned to the river, the daily mean discharge of 32 cfs or less will occur on an average of 15 days per year. If 10 mgd is pumped from the aquifer, a daily mean flow of 32 cfs or less will occur on an average of 44 days per year. Any practical plan to pump water from this aquifer continuously would consider adequate compensating storage to maintain the minimum recommended low flow during drought.

Analysis of the water sample taken during the pumping test at site 1 is given in table 1. The manganese content is well above the limit of 0.05 ppm (parts per million) recommended by the U.S. Public Health Service (1962) for drinking water. However, continued pumping from this aquifer may result in a decrease in manganese as river water is induced into the aquifer; however, treatment to remove manganese probably will be required to meet Public Health standards for a public water supply.

Site 2 - East Montpelier, south from U.S. Route 2, across the Winooski River, on property owned by Mrs. R. Taylor and Mrs. F. Delair (fig 3). Approximately 0.8 mile east of East Montpelier Village. A seismic profile extending from U.S. Route 2 southward across the Winooski River indicated as much as 140 feet of unconsolidated material overlying bedrock. The maximum depth to bedrock occurs approximately 100 feet south of U.S. 2, but seismic velocities suggest that the material in this area may be too fine grained and impermeable to yield water easily. Near the river, the depth to bedrock is shallower; however, seismic velocities in the unconsolidated material in this area suggest that the subsurface material may be coarse grained and, therefore, suitable for future ground-water exploration.

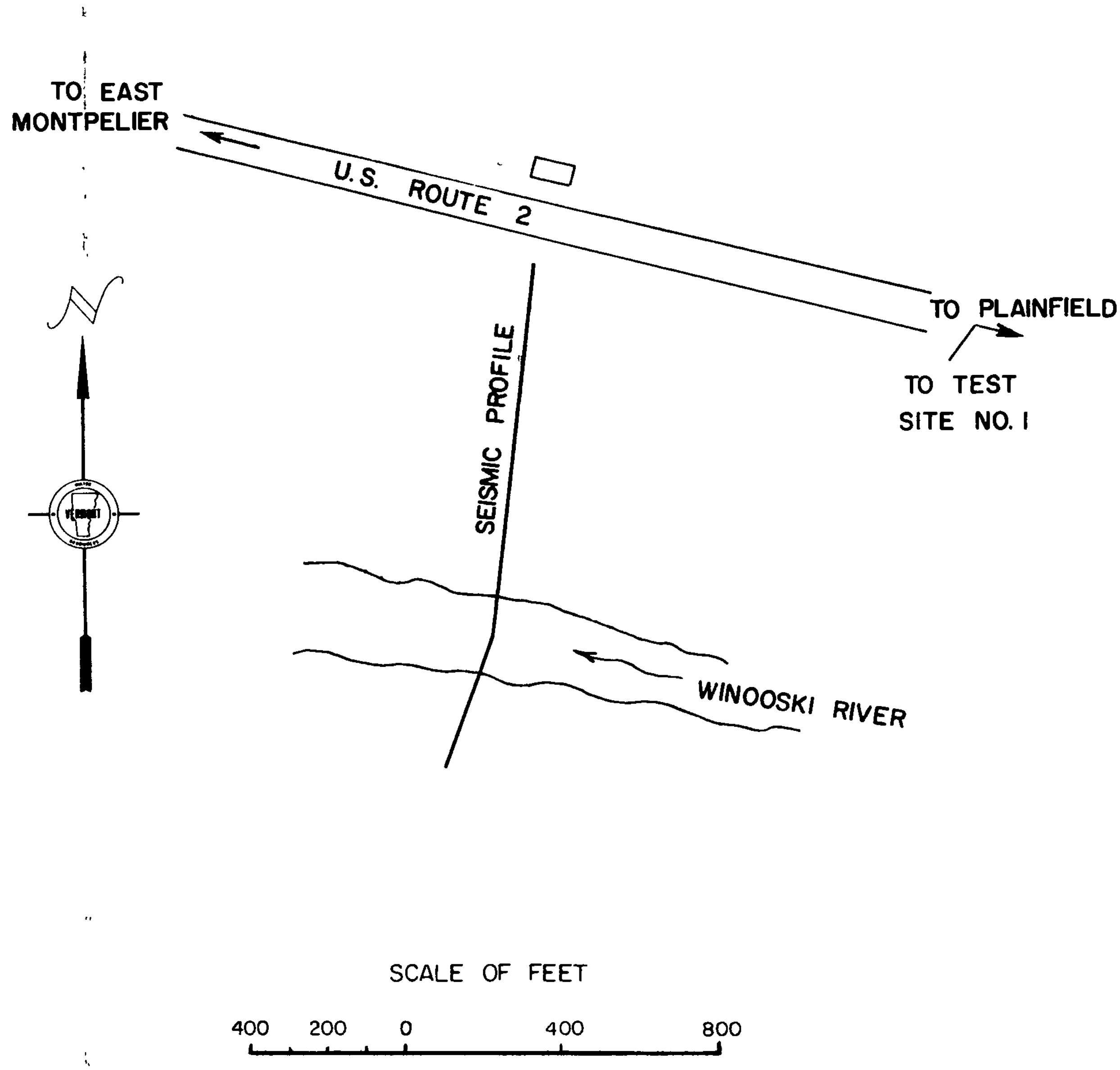

FIGURE 3 TEST SITE 2

Table 1.--Chemical analysis of ground water at site 1

Date: January 8, 1971 Previous pumpage: 2 days

(All values in milligrams per liter)

Calcium	64	Temperature, °F	46.0
Magnesium	6.4	Alkalinity as $CaCO_3$	179
Sodium	9.2	Color	6
Potassium	2.9	Dissolved solids at 180°C	232
Ammonia	.08	Dissolved solids, sum	229
Iron	.16	Hardness, Ca and Mg	186
Manganese	.43	Hardness, noncarbonate	7
Bicarbonate	218	Loss on ignition	26
Carbonate	0	Nitrate as N	.00
Sulfate	19	Nitrite as N	.01
Chloride	20	Nitrogen, NH_4 as N	.06
Fluoride	.0	pH	7.9
Nitrite	.05	Silica	.12
Nitrate	.00	Specific conductance	413

Site 3 - Middlesex, south from U.S. Route 2 to the Winooski River on property owned by DuBois Construction Company (fig. 4). Unconsolidated material overlying bedrock at this site is a maximum of 47 feet thick. A wash boring near the north bank of the Winooski River penetrated 28 feet of fine sand and clay overlying 12 feet of coarse sand and gravel. The lower material has sufficient permeability to produce water, but is too thin to be developed by high-capacity wells using standard well-construction methods. This area could be explored in the future for development as a well field.

Site 4 - Middlesex, near U.S. Route 2 underpass beneath Interstate 89 on property owned by the Town of Middlesex (see fig. 4). A single wash boring was driven in the delta of Sonny Brook. Thirty-one feet of sand and gravel were found underlying 56 feet of fine sand and clay. The sand and gravel yields little water.

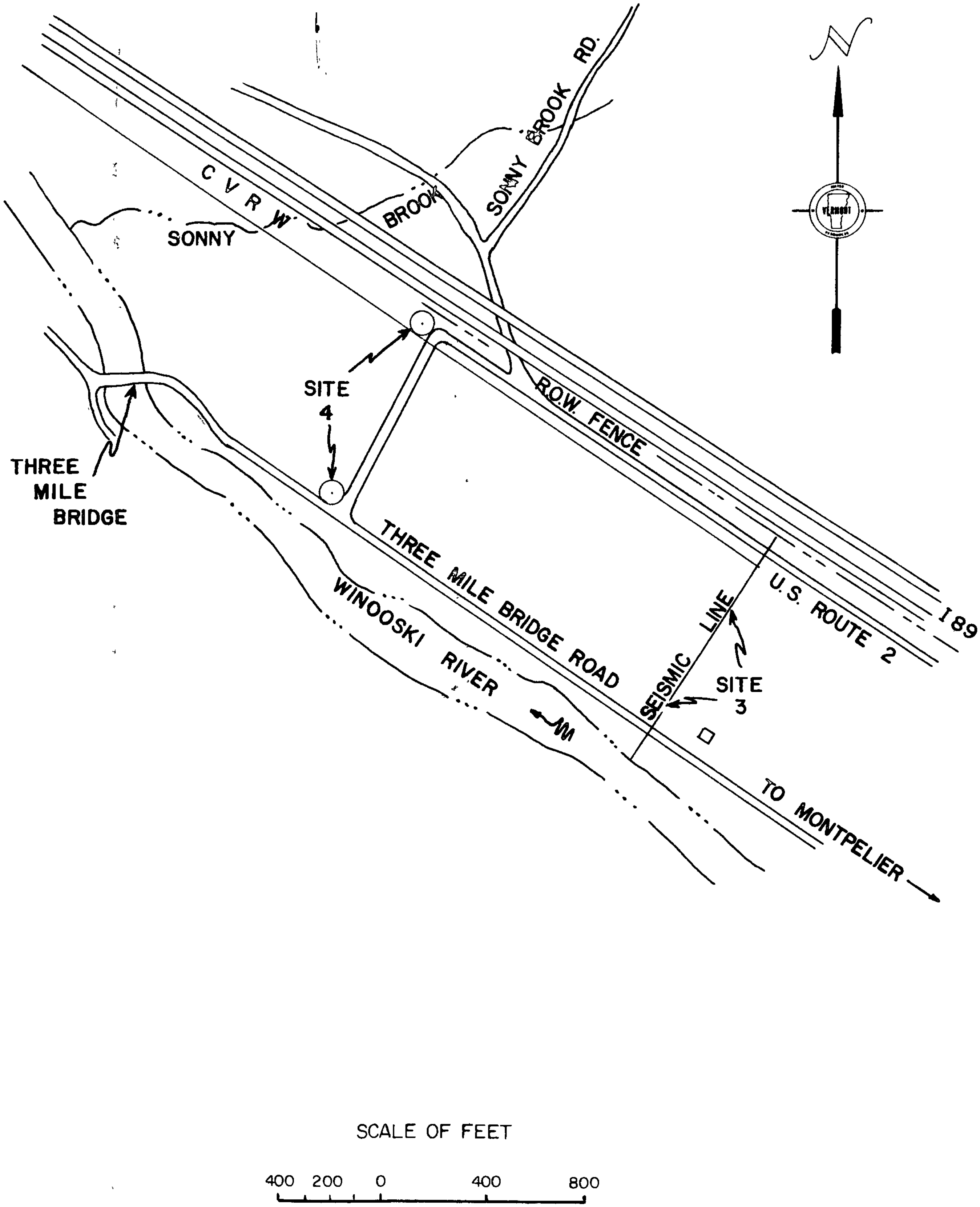

FIGURE 4 TEST SITES 3 and 4

Site 5 - Berlin, east from Vermont Route 12 across the Dog River and the Central Vermont Railroad on property owned by A.L. Granger (fig. 5). Rock walls confine the Dog River at this site to a narrow valley. Subsurface information from seismic profiling shows that, contrary to expectations, no deep buried channel exists below the present river level. The maximum depth to bedrock is 60 feet below the present channel of the river. A wash boring in the area of maximum depth penetrated only sand and silt that was too fine grained and impermeable to yield large supplies of water.

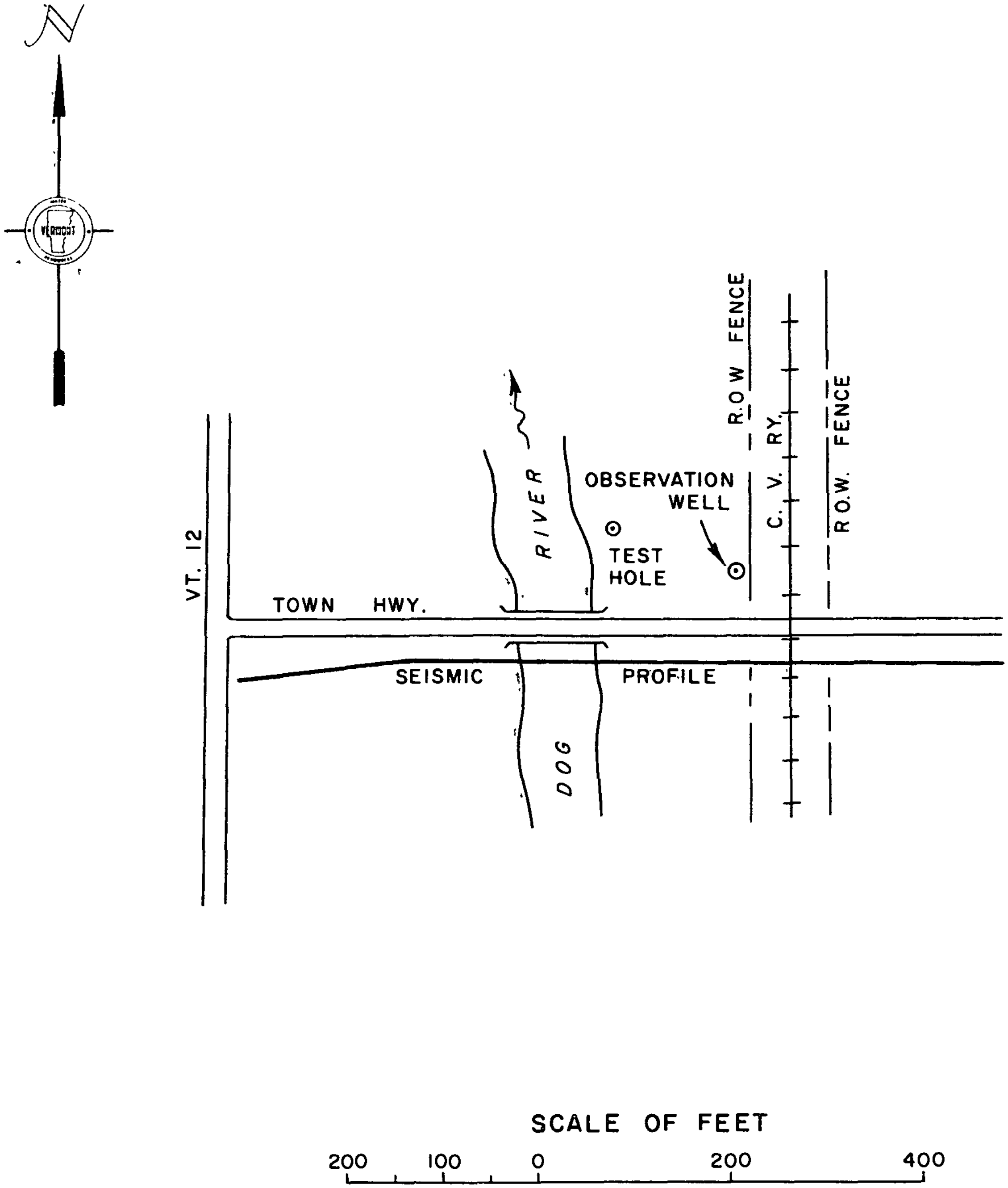

FIGURE 5 TEST SITE 5

Site 6 - Northfield, 0.4 mile south of Northfield Falls in a gravel pit owned by J. R. Covey, approximately 400 feet east of Vermont Route 12 (fig. 6). A rock ridge under and along the east edge of the highway separates the aquifer in a gravel-filled bedrock channel at the site from direct connection with the Dog River to the west. This ridge also would prevent movement of discharge from the Northfield Sewage Treatment Plant into the aquifer at the test site. Aquifer material beneath the site is recharged by precipitation and ground-water underflow from the east and south. Potential recharge may be available by induced infiltration from the Dog River 1,200 feet south of the test site. The actual cross-sectional area of the aquifer was not determined by seismic profiling because fuel-oil tanks are located within the pit, however, it is probably about 500 feet wide. Wash borings in the pit penetrated 49 feet of water-bearing sand and gravel having a static ground-water level 4 feet below land surface. An 8-inch test hole adjacent to the wash-bore holes penetrated 99 feet of sand and gravel. Casing was installed with screen between 75 and 95 feet below land surface, and, after 48 hours of pumping, the specific capacity was about 300 gallons per minute per foot of drawdown. Transmissivity of the aquifer estimated by extension of a method described by Hurr (1966) is approximately 65,000 square feet per day.

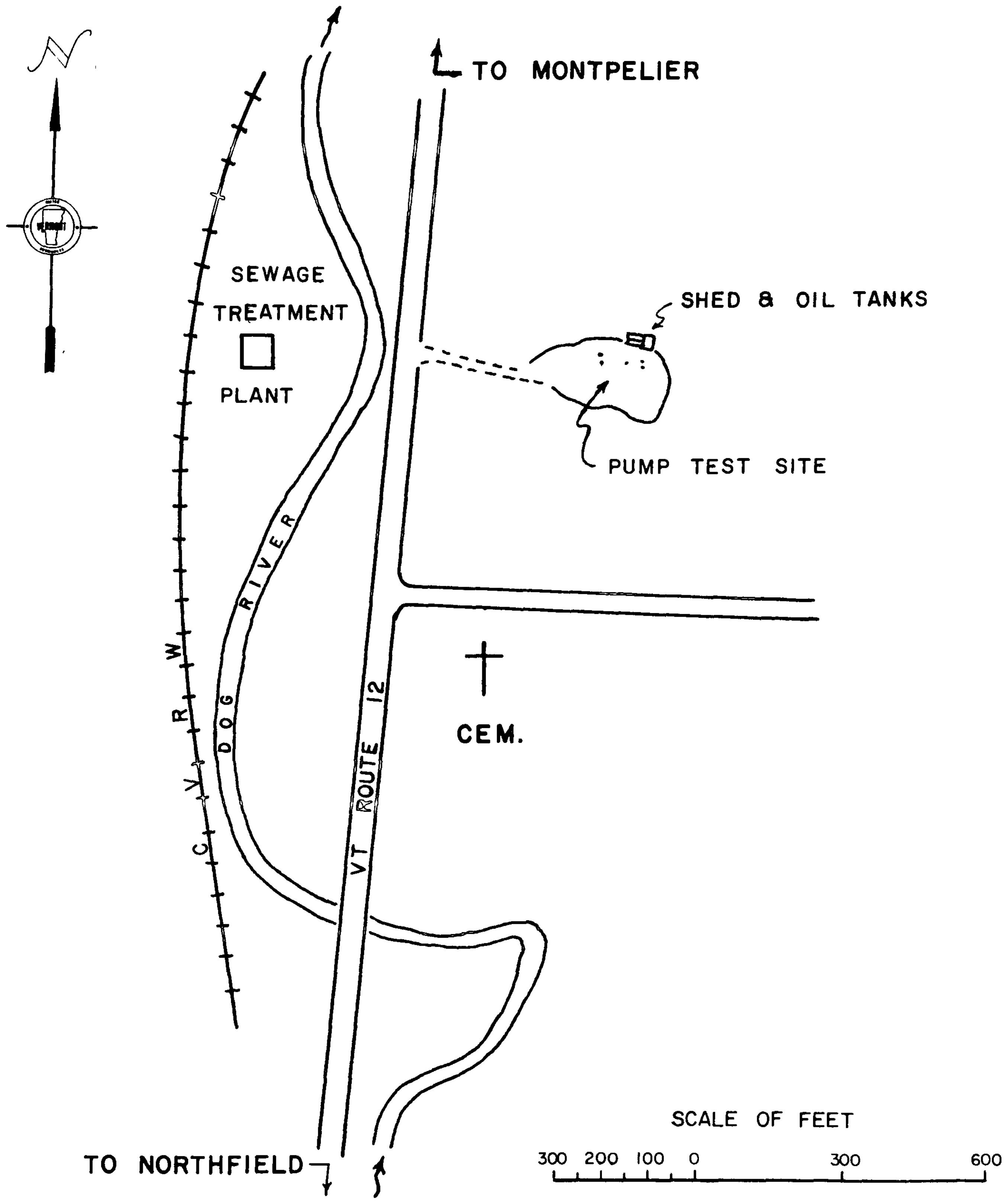

FIGURE 6 TEST SITE 6

Estimates of Available Water at Site 6

Calculations based on a transmissivity of 65,000 square feet per day indicate that the 500-foot cross section of aquifer is capable of transmitting about 2.5 mgd (million gallons per day) with a hydraulic gradient of about 50 feet per mile. Most of the recharge to the aquifer comes from precipitation on about 2 square miles of unconsolidated sediments east of the test site. It is estimated that half the yearly precipitation, or about 1 mgd, recharges the ground-water reservoir in sand and gravel.

The rate at which water would move from the Dog River into the underlying aquifer, once pumping lowers the water table beneath the river, depends on several factors: (1) the area of the streambed affected by well pumpage, (2) the vertical hydraulic gradient across the streambed, (3) the vertical permeability of the streambed, and (4) the temperature of the stream water. Estimates of average vertical streambed infiltration made by Rosenshein and others (1968) in Rhode Island, Randall and others (1966) in Connecticut, and Norris and Fidler (1969) in Ohio indicated that the average streambed infiltration rate ranged from about 17 gallons per day per square foot to 50 gallons per day per square foot with 1 foot of vertical head. No testing was done on the Dog River to determine streambed infiltration rates, but, based on the findings of the above studies, a value of 25 gallons per day per square foot seems to be reasonable.

Infiltration from the Dog River would probably occur south of the test site between the well and the river along a 500-foot reach of the stream that has an average width of 25 feet during low flow. The minimum area of infiltration, therefore, is about 12,500 square feet. At the estimated rate of infiltration of 25 gpd per sq ft, approximately 300,000 gpd, or 0.5 cfs, may be induced into the aquifer from the Dog River during low flow. This volume is less than 7 percent of the lowest daily flow of record at the Northfield gage.

Average annual discharge of the Dog River adjacent to test site 6 is about 92 cfs from a drainage area of 61 square miles. Low flow based on State recommendations should not be less than 12 cfs. Estimates of low flow based on data for the Northfield gaging station indicate that streamflow adjacent to the test site is 12 cfs or less on an average of 40 days per year. Infiltration of streamflow of 300,000 gpd caused by pumping would reduce streamflow at the site below the recommended limit for periods longer than 40 days per year.

In summary, a well or group of properly constructed wells favorably located to intercept most recharge, could dependably yield about 1 mgd with little streamflow depletion resulting from infiltration.

An analysis of water collected from the test well at site 6 is given in table 2. All chemical constituents were found to be well below limits recommended by the Public Health Service for a public water supply and, therefore, the water should be usable without treatment other than chlorination.

Site 7 - Northfield, east side of Dog River on property owned by Norwich University (fig. 7). Three wash borings were driven between the campus of Norwich University and the Dog River. Depth to bedrock ranged from 24 feet to 65 feet below land surface. Subsurface material ranged from fine sand and clay to coarse gravel mixed with silt. Gravel layers below a depth of 35 feet were tested by pumping, but they contained sufficient silt to make the permability low. Shallow gravel adjacent to the Dog River, however, may be a potential aquifer that can be developed by infiltration galleries, groups of well points, or collector wells.

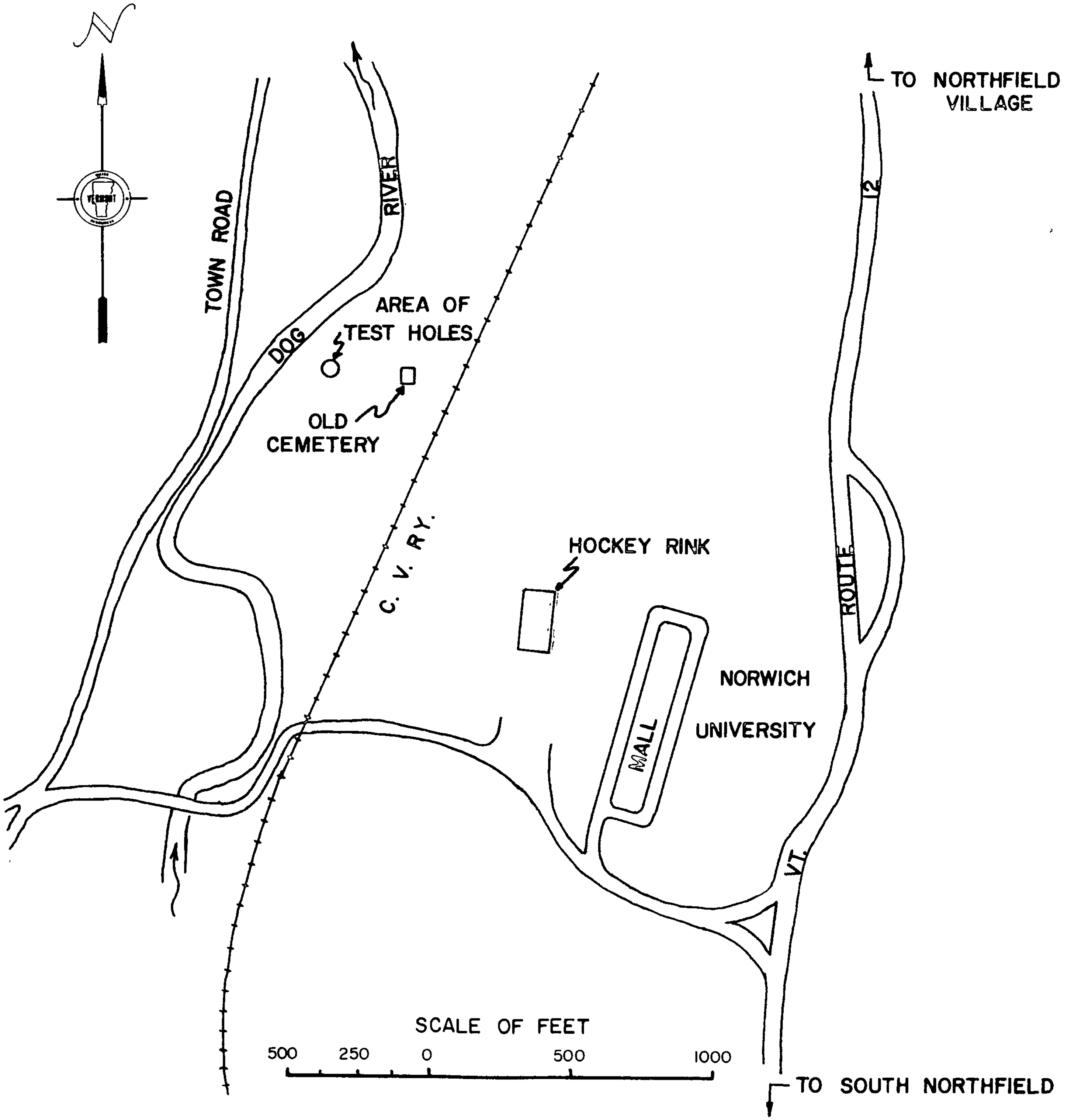

FIGURE 7 TEST SITE 7

Table 2.--Chemical analysis of ground water at site 6

Date: March 18, 1971 Previous pumpage: 2 days

(All values in milligrams per liter)

Calcium ------------	22	Temperature, ^{o}F ----------	45.5
Magnesium ----------	3.9	Alkalinity as $CaCO_3$ ------	43
Sodium -------------	7.8	Color --------------------	2
Potassium ----------	.9	Dissolved solids at $180^{o}C$-	140
Ammonia ------------	.02	Dissolved solids, sum ----	104
Iron ---------------	.10	Hardness, Ca and Mg ------	71
Manganese ----------	.00	Hardness, noncarbonate ---	28
Bicarbonate --------	53	Loss on ignition ---------	38
Carbonate ----------	0	Nitrate as N -------------	1.0
Sulfate ------------	14	Nitrite as N -------------	.11
Chloride -----------	18	Nitrogen, NH_4 as N -------	.02
Fluoride -----------	.0	pH -----------------------	6.8
Nitrite ------------	.37	Silica -------------------	6.4
Nitrate ------------	4.6	Specific conductance -----	191

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PLATE 1. OCCURRENCE OF WATER IN BEDROCK, BARRE-MONTPELIER AREA, VERMONT
BEDROCK GEOLOGY OF THE BARRE-MONTPELIER AREA
QUALITY OF WATER

GROUND WATER RESOURCES OF THE BARRE-MONTPELIER AREA, VERMONT

BY
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UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH STATE OF VERMONT
AGENCY OF ENVIRONMENTAL CONSERVATION, DEPARTMENT OF WATER RESOURCES

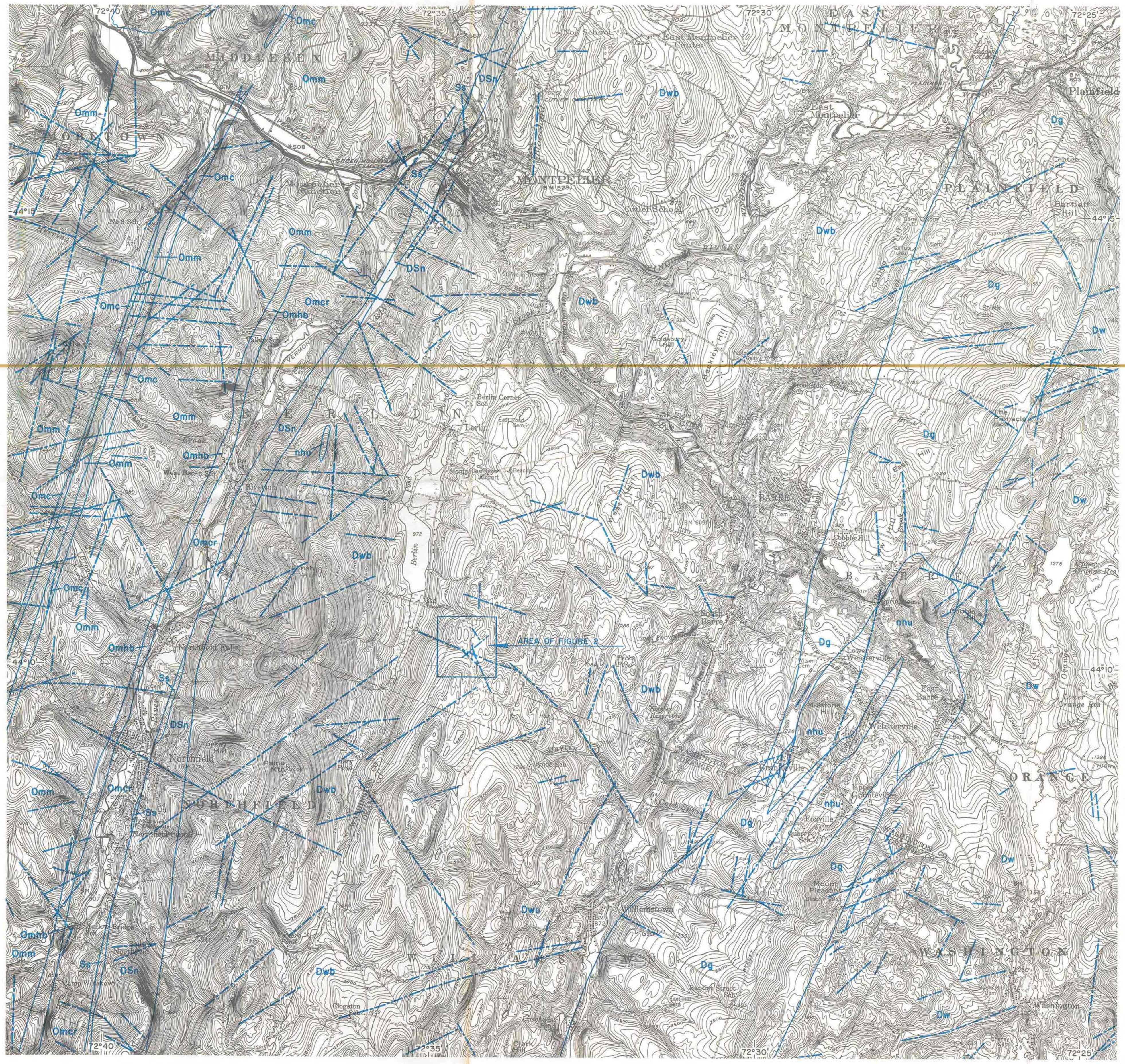


FIGURE 1. - - BEDROCK GEOLOGY OF THE BARRE-MONTPELIER AREA

EXPLANATION

ROCK UNITS

IGNEOUS

nhu	GRANITE, UNDIFFERENTIATED OF NEW HAMPSHIRE PLUTONIC SERIES	DEVONIAN

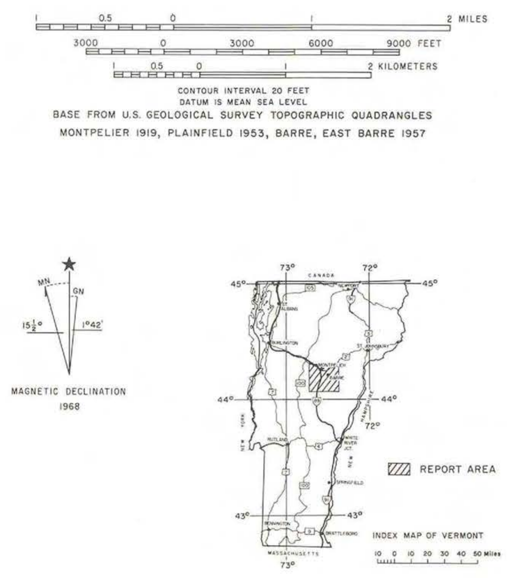
METAMORPHIC

Dg	GILE MOUNTAIN FORMATION QUARTZ MUSCOVITE PHYLLITE OR SCHIST	DEVONIAN
Dw	WAITS RIVER FORMATION QUARTZOSE AND MICACEOUS CRYSTALLINE LIMESTONE	DEVONIAN
Dwb	WAITS RIVER FORMATION - BARTON RIVER MEMBER SILICEOUS LIMESTONE AND PHYLLITE	DEVONIAN
DSn	NORTHFIELD FORMATION QUARTZ - SERICITE SLATE OR PHYLLITE	SILURIAN
Ss	SHAW MOUNTAIN FORMATION QUARTZOSE LIMESTONE AND CALCAREOUS QUARTZITE	SILURIAN
Omcr	MISSISQUOI FORMATION - CRAM HILL MEMBER PHYLLITE SLATE, MAFIC VOLCANICS	ORDOVICIAN
Omhb	MISSISQUOI FORMATION - HARLOW BRIDGE QUARTZITE MEMBER QUARTZITE WITH QUARTZITIC PHYLLITE	ORDOVICIAN
Omm	MISSISQUOI FORMATION - MORETOWN MEMBER QUARTZITE AND QUARTZ - PLAGIOCLASE GRANULITE	ORDOVICIAN
Omc	MISSISQUOI FORMATION CARBONACEOUS PHYLLITE AND SLATE	ORDOVICIAN

CONTACT BETWEEN FORMATIONS

FAULT - INFERRED

LINEAMENT



CONVERSION FACTORS

The following table may be used to convert English units to International System of Units (SI).

Multiply English units	By	To obtain SI units
inches (in)	25.4	millimetres (mm)
feet (ft)	.3048	metres (m)
gallons per minute (gal/min)	.06309	litres per second (1/s)
million gallons per day (Mgal/day)	3785	cubic metres per day (cm^3/day)

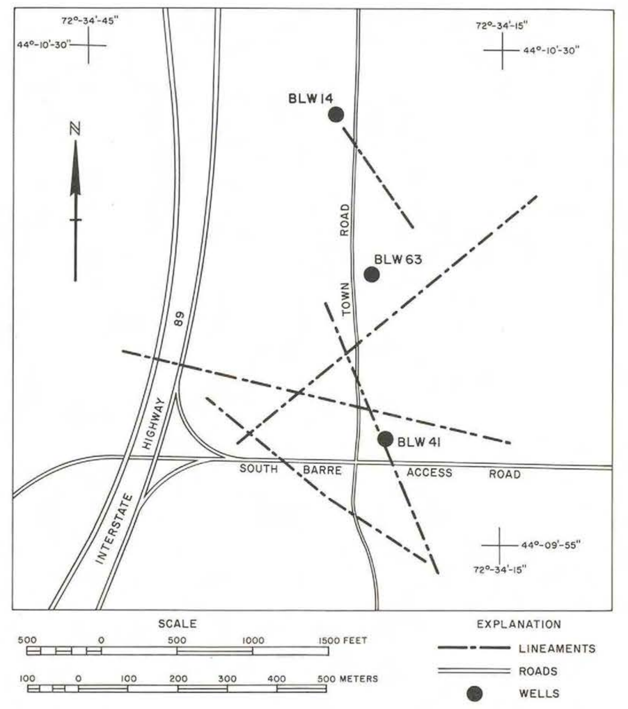


FIGURE 2. - - INVESTIGATION SITE OF BEDROCK WELL YIELDS

CHEMICAL QUALITY OF WATER

Ten analyses of ground water, and one analysis of water from the Winooski River were made by the Geological Survey during the study. In addition, data are available from numerous partial analyses of water from several streams in the area, which were made as part of a river classification study by the Vermont Department of Water Resources. These analyses are shown in tables 2 and 3, and the location of the sampling points are shown on Plate 3.

The effects of ground water movement through materials of different composition are evident in the analyses. The Winooski River above the East Montpelier test site (Plate 2, figure 2) drains an area underlain, in part, by the Waits River Formation, which is composed of silicious metamorphosed limestone. As a result, water moving through material derived from this formation is alkaline (pH more than 7.0) and calcium, bicarbonate, hardness, alkalinity, and dissolved solids concentrations are relatively high (wells EBW 46 and 100).

The Dog River drains an area predominantly underlain by the non-carbonaceous Northfield and Missisquoi Formations. Ground water in the Dog River drainage area is, therefore, slightly acidic (pH less than 7.0), and concentrations of calcium, bicarbonate, hardness, alkalinity, and dissolved solids (well NLW 13) are less than those found in the Winooski Drainage in East Montpelier.

Ground water at the Northfield test site (well NLW 13) is chemically suitable for public supply with respect to all components listed. Ground water from the East Montpelier test site (wells EBW 46 and 47), however, contains iron and manganese concentrations that approach or exceed Vermont Department of Health and U.S. Public Health Service (1962) recommended limits for public drinking water supplies. Reduction or removal of these constituents from such water used for public supply, therefore, would be necessary to meet State standards.

Surface water analyses show less contrast between the two areas (table 3) because samples of water from the streams represent a mixture of ground water and overland runoff. Analyses 11-14 were made on samples taken above the East Montpelier site, and analyses 20-26 were made on samples taken upstream from the Northfield test site. Calcium, hardness, dissolved solids, and pH are generally higher in water from the East Montpelier group than from the Northfield group, but the effects of differences in rock composition between the two groups are less obvious in the surface water analyses than in the ground water analyses.

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TABLE 2. - - CHEMICAL ANALYSES OF GROUND-WATER IN THE BARRE-MONTPELIER AREA

SOURCE OF DATA: A, U. S. GEOLOGICAL SURVEY; B, VERMONT DEPARTMENT OF HEALTH

LOCAL WELL NUMBER	DATE OF SAMPLE	TEMPERATURE (C)	SILICA (SIO2) (MG/L)	IRON (FE) (UG/L)	MANGANESE (MN) (UG/L)	CALCIUM (CA) (MG/L)	MAGNESIUM (MG) (MG/L)	SODIUM (NA) (MG/L)	POTASSIUM (K) (MG/L)	BICARBONATE (HCO3) (MG/L)	CARBONATE (CO3) (MG/L)	SULFATE (SO4) (MG/L)	CHLORIDE (CL) (MG/L)	FLUORIDE (F) (MG/L)	NITRATE (NO3) (MG/L)	DISSOLVED SOLIDS (CALC)	DISSOLVED SOLIDS (RESIDUE AT 180 C) (MG/L)	HARDNESS (CA, MG) (MG/L)	NONCARBONATE HARDNESS (MG/L)	ALKALINITY AS CACO3 (MG/L)	SPECIFIC CONDUCTANCE (MICROMHOS)	PH	COLOR	SOURCE OF DATA
BARRE TOWN (BF)																								
W 34	04-09-53	---	13	50	.00	40	9.8	16	1.7	162	0	24	14	0.4	0.3	--	202	140	7	--	336	7.6	2	A
EAST MONTPELIER (EB)																								
W 46	01-06-71	---	12	--	--	65	6.4	10	3.2	220	0	19	18	0.0	0.0	242	238	189	8	180	419	7.9	3	A
W 46	01-07-71	---	12	---	--	65	6.4	9.3	3.1	215	0	19	18	0.1	0.2	239	222	189	12	176	415	8.0	2	A
W 46	01-08-71	--	.1	--	--	64	6.4	9.2	2.9	218	0	19	20	0.0	0.0	229	232	186	7	179	413	7.9	6	A
W 47	04-28-71	--	--	160	430	--	--	---	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	A
W 100	11-07-72	--	--	83	16	--	--	4.0	--	--	--	--	5	0.0	0.1	--	209	182	--	158	--	7.2	10	B
MONTPELIER (MM)																								
W 2	04-19-67	--	8.9	20	40	94	13	83	6.5	179	0	52	176	.1	23	544	615	288	142	--	993	7.0	3	A
NORTHFIELD (NL)																								
W 2	05-09-66	5.0	12	0	0	14	2.2	5.6	.4	35	0	13	10	.0	.7	75	76	44	16	--	123	7.0	4	A
W 13	03-16-71	7.5	6.4	10	0	22	3.8	7.6	.9	53	0	14	18	.1	4.3	103	142	70	27	43	188	6.9	1	A
W 13	03-17-71	7.5	6.4	10	0	22	3.8	7.8	.9	54	0	14	18	.0	4.6	104	140	70	26	44	190	7.2	1	A
W 13	03-18-71	7.5	6.4	10	0	22	3.9	7.8	.9	53	0	14	18	.0	4.6	104	140	71	27	43	191	6.8	2	A

TABLE 3. - - CHEMICAL ANALYSES OF SURFACE-WATER IN THE BARRE-MONTPELIER AREA

SOURCE OF DATA: A, VERMONT DEPARTMENT OF WATER RESOURCES; B, U. S. GEOLOGICAL SURVEY

WATER	MAP NO.	SOURCE OF DATA	DATE OF SAMPLE	TEMPERATURE (C)	CALCIUM (CA) (MG/L)	MAGNESIUM (MG) (MG/L)	CHLORIDE (CL) (MG/L)	ALKALINITY $CACO_3$ (MG/L)	HARDNESS (CA,MG) (MG/L)	PH	TURBIDITY (STD. UNITS)	COLOR (STD. UNITS)	SUSPENDED SOLIDS (MG/L)	TOTAL SOLIDS (MG/L)	DISSOLVED OXYGEN (MG/L)	TOTAL COLIFORM BACTERIA PER 100 MILLILITERS
Winooski River	1	A	7/1/55	23.0	84	12	3.77	84	96	8.05	8	25	2	103	8.20	15,000
Winooski River	2	A	8/2/54	24.0	14	49	3.47	14	63	8.00	0	5	14	38	8.30	250
Winooski River	3	A	7/1/55	23.0	87	16	4.12	86	103	8.20	8	30	3	141	8.20	9,500
Winooski River	4	A	7/1/55	23.5	92	24	3.44	92	116	8.00	12	35	4	140	7.00	45,000
Winooski River	5	A	7/1/55	22.0	94	19	3.44	95	113	7.85	10	30	7	146	7.60	15,000
Winooski River	6	A	7/15/55	22.5	88	18	2.06	96	106	8.07	18	25	7	161	9.10	2,500
Winooski River	7	A	7/15/55	25.0	82	12	2.75	90	94	8.25	14	20	0	131	8.50	9,500
Winooski River	8	A	7/15/55	24.5	82	12	3.43	90	94	8.26	13	20	0	131	8.90	4,500
Winooski River	9	A	9/3/53	26.0	100	28	4.85	114	128	8.15	0	10	9	135	9.10	2,000
Winooski River	10	A	7/15/55	20.5	78	16	3.43	88	94	7.85	14	25	0	127	6.60	2,500
Winooski River	11	B*	9/10/71	18.5	35	3	7.40	--	100	7.30	--	--	--	118	--	---
Winooski River	12	A	7/15/55	21.5	64	8	0.69	68	72	8.54	9	20	0	109	9.80	9,500
Great Brook	13	A	9/3/53	19.0	104	20	4.24	112	124	8.22	0	0	1	125	9.00	450
Winooski River	14	A	7/15/55	21.0	68	10	3.43	72	78	7.86	14	30	3	111	10.90	45,000
Dog River	15	A	6/30/55	18.5	44	14	5.50	48	58	7.50	7	15	2	85	7.75	0
Dog River	16	A	6/30/55	18.0	44	12	5.50	46	56	7.70	8	15	1	84	9.30	4,500
Dog River	17	A	9/4/53	22.5	50	12	15.8	48	62	7.75	1	5	0	94	9.00	---
Dog River	18	A	6/30/55	20.5	44	10	5.50	48	54	8.60	15	15	2	88	12.55	20,000
Cox Brook	19	A	6/30/55	19.5	18	8	2.06	22	26	8.00	2	5	0	35	9.00	4,500
Dog River	20	A	6/30/55	18.5	48	10	3.44	54	58	7.85	40	15	9	96	8.55	250,000
Union Brook	21	A	6/30/55	22.5	22	4	3.75	28	26	7.45	16	25	7	55	8.10	150,000
Dog River	22	A	6/30/55	17.0	50	8	3.75	46	58	7.85	2	5	0	78	10.00	15,000
Sunny Brook	23	A	6/30/55	19.0	96	18	4.12	102	114	8.20	4	10	1	135	9.40	2,500
Bull Run	24	A	6/30/55	19.5	18	8	1.37	20	26	7.75	6	15	0	43	9.10	150
Stony Brook	25	A	6/30/55	23.0	18	6	1.37	22	24	7.75	2	10	0	34	9.05	150
Dog River	26	A	6/30/55	17.0	22	10	2.75	22	32	7.55	2	5	2	53	9.40	200
North Branch	28	A	7/11/55	24.5	30	6	0.0	23	36	6.81	19	30	10	81	4.00	450,000
North Branch	29	A	7/11/55	27.5	19	4	1.03	22	23	7.43	7	35	2	58	7.50	9,500
Berlin Pd. Br.	30	A	8/29/55	13.5	--	--	2.0	109	--	7.38	19	40	7	174	4.75	1,500
Stevens Branch	31	A	6/27/55	21.5	127	33	7.56	128	160	7.85	48	30	18	207	7.60	250,000
Stevens Branch	32	A	6/27/55	21.0	128	20	7.21	124	148	7.35	52	30	47	289	6.40	450,000
Stevens Branch	33	A	6/27/55	21.0	131	17	7.21	118	148	7.70	84	25	52	245	6.60	1,400,000+
Stevens Branch	34	A	6/27/55	18.5	131	21	4.47	132	152	8.30	8	10	4	180	10.80	95,000
Stevens Branch	35	A	6/27/55	18.0	127	19	3.78	124	146	8.55	9	10	3	172	10.00	25,000
Stevens Branch	36	A	6/27/55	16.0	129	17	4.12	126	146	8.40	6	10	9	172	10.85	45,000
Stevens Branch	37	A	6/27/55	15.5	121	21	4.12	120	142	8.40	4	10	3	158	10.30	4,500
Stevens Branch	38	A	6/27/55	15.5	114	35	2.40	117	149	8.55	5	10	2	145	9.60	150,000
Stevens Branch	39	A	6/27/55	18.0	100	28	2.75	103	128	8.25	8	20	0	137	9.35	2,500
Jail Branch	40	A	6/28/55	20.5	113	24	4.81	109	137	8.60	38	15	31	211	10.30	4,500
Jail Branch	41	A	6/28/55	21.0	110	17	3.44	113	127	8.40	7	15	6	161	9.20	4,500
Jail Branch	42	A	6/28/55	19.5	110	17	4.47	115	127	8.15	3	10	4	162	9.20	9,500
Jail Branch	43	A	6/28/55	18.5	95	19	2.06	106	114	7.95	7	10	5	143	8.90	2,500
Orange Branch	44	A	6/28/55	17.5	82	17	1.03	90	99	7.95	4	10	3	121	7.65	150
Jail Branch	45	A	6/28/55	16.0	107	16	1.03	112	123	8.50	24	15	12	172	9.40	45,000
Kingsbury Branch	46	A	9/3/53	22.5	92	34	7.27	116	126	7.85	1	15	4	124	6.80	9,500

* Additional parameters: Na 4.7, K 1.4, Fe 0.24, Mn 0.06, Si 3.5, $HCO_3$53., $CO_3$0.0, $SO_4$10.0, $NO_3$0.0, Specific conductance 216 micromhos per cm @ 25°C, F 0.0

BEDROCK AQUIFERS

Bedrock formations in the Barre-Montpelier area consist mainly of varying amounts of phyllite and schist. Differences in bedrock lithology are responsible for variations in resistance to weathering, structural competence, and yield to wells.

The Missisquoi Formation has four members. Those of most significance are the older Moretown Member, a quartzite and quartz-plagioclase granulite that forms the highest topographic features in the report area, and the younger Cram Hill Member, consisting of slate with some felsic and mafic volcanic rocks that have been deeply eroded and now form the valley of the Dog River.

The Northfield Formation is a predominantly slate unit that occupies the east side of the Dog River valley. It is not deeply weathered, and, because it is cleanly broken by fractures, it has been extensively quarried.

The Waits River and Gile Mountain Formations, lying east of the Northfield Formation, are composed of interbedded quartzose and micaceous crystalline limestone and quartz-muscovite phyllite and schist. The boundary between these two formations is arbitrary and is based on the relatively larger percentages of calcareous materials in the Waits River Formation, where impure limestone and quartzite constitute as much as 60 percent of the formation. Solution enlargement of joints and fractures in the limestone beds of the Waits River Formation has contributed to a higher average yield per foot of well depth in this formation than in the Gile Mountain Formation (table 1).

YIELD OF BEDROCK WELLS

A comparison of the average yield and depth of selected wells (table 1) shows that, although the average yield of all wells in bedrock is 18 gal/min (1 l/s), there are substantial variations between average yields of different formations. The Barton River Member of the Waits River Formation and the Northfield Formation have the highest average yields of all bedrock formations. The remaining bedrock units have relatively lower average yields.

A comparison of yield versus depth drilled (table 1) shows that the Northfield Formation not only has the highest average yield, but also has the highest average yield per foot drilled. The Gile Mountain Formation has the lowest average yield per foot. It is approximately half that of the Northfield Formation. Differences in average yields and yields per foot drilled are affected by differences in overburden thickness, rock competence, and size, number, orientation, and degree of interconnection of fractures.

Recent studies in Delaware (Woodruff and others, 1972) show that yields of rock wells are related to their position with respect to zones of rock fractures, termed "lineaments". In the Delaware study, lineaments were identified and subsequently drilled. Those wells drilled along the strike of the lineaments had yields substantially greater than the average yield of wells drilled in the same rock unit but offset from the lineaments.

Because identification of lineaments may provide information that could be used to locate sites for development of potentially high-yield rock wells, interpretations of topographic maps and aerial photos were used to map lineaments in the Barre-Montpelier area. Lineaments appear on maps and photos as straight lines or narrow zones of marked topographic or tonal change that in some places mark dryer or wetter conditions along the lineaments than on either side of the lineaments. These interpretations also suggest that major drainageways in the report area are in large-scale lineament zones.

A small area in the town of Berlin (figs. 1 and 2) was mapped in detail to estimate the relationship of lineaments to well yield. This area was selected for its shallow bedrock cover and because records had been obtained on several wells. All lineament zones mapped in the study area were of limited width (less than 100 ft or 30 m and appeared as straight lines on aerial photographs. Because of the relatively narrow width of the lineaments and rough terrain, field identification was generally only possible with the assistance of the photographs.

Of the three wells in the lineament study area, two (wells BLW 14 and 41) have yields of 60 and 90 gal/min (4 and 6 l/s), respectively, and were located on or adjacent to mapped lineaments. The third well (BLW 63) is about 300 ft (92 m) from the nearest lineament and has a yield of only 10 gal/min (0.6 l/s). The study area is underlain by the Barton River Member of the Waits River Formation, for which table 1 shows an average yield of 10 gal/min (0.6 l/s). The scant data suggest correlation of higher yields of bedrock wells to proximity of lineaments.

TABLE 1. - - AVERAGE YIELD AND DEPTH OF SELECTED WELLS

Type of Well	Number of Wells	Average Yield (gal/min)	Average Depth (feet)	Average Yield/Foot Drilled
Wells in Bedrock	421	18	185	0.097
Granite	3	*	*	*
Gile Mountain Formation	47	11	221	.050
Waits River Formation	21	12	165	.073
Waits River Formation Barton River Member	267	18	182	.099
Northfield Formation	10	19	147	.129
Shaw Mountain Formation	0	-	-	-
Missisquoi Formation, Cram Hill Member	18	11	177	.062
Missisquoi Formation, Harlow Bridge Quartzite Member	3	*	*	*
Missisquoi Formation, Phyllite and slate	2	*	*	*
Missisquoi Formation, Moretown Member	50	13	197	.066
Wells in unconsolidated material	61	87	53	1.642

* Numbers of wells insufficient to calculate meaningful average

PLATE 2. OCCURRENCE OF WATER IN UNCONSOLIDATED DEPOSITS IN THE BARRE-MONTPELIER AREA, VERMONT

THICKNESS OF UNCONSOLIDATED DEPOSITS

GROUND-WATER AVAILABILITY IN UNCONSOLIDATED DEPOSITS

GROUND-WATER LEVELS

GROUND WATER RESOURCES OF THE BARRE-MONTPELIER AREA, VERMONT

BY
A. L. HODGES, JR., D. BUTTERFIELD, J. W. ASHLEY

1976

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH STATE OF VERMONT
AGENCY OF ENVIRONMENTAL CONSERVATION, DEPARTMENT OF WATER RESOURCES

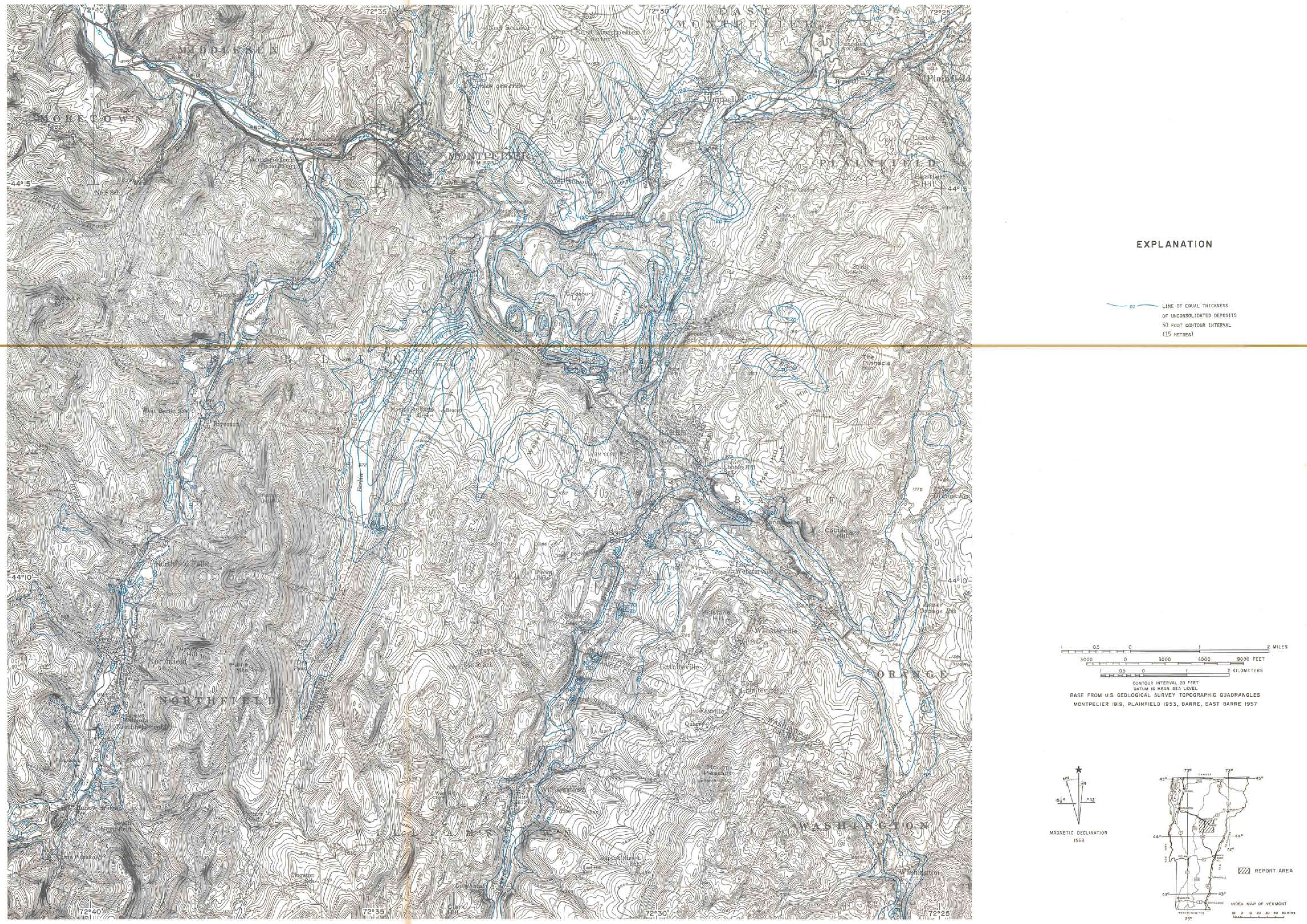

FIGURE 1. - - THICKNESS OF UNCONSOLIDATED DEPOSITS

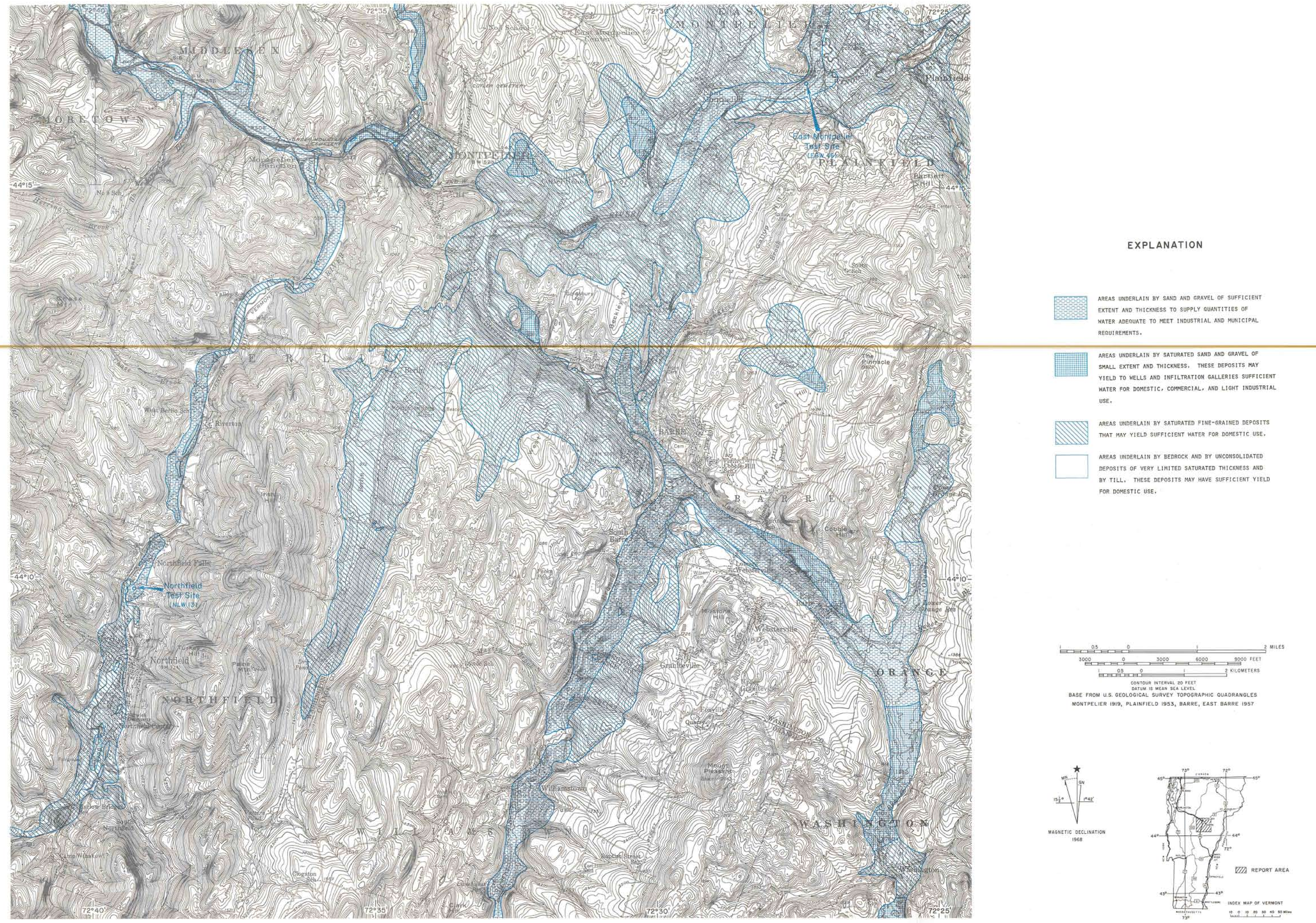

FIGURE 2. - - GROUND-WATER AVAILABILITY IN UNCONSOLIDATED DEPOSITS

THICKNESS OF THE UNCONSOLIDATED DEPOSITS

The thickness of the unconsolidated deposits overlying bedrock in the Barre-Montpelier area is illustrated in figure 1. Thickness ranges from zero on the many rock outcrops in the area to 303 ft (92 m) in Berlin (well BLW 17). Thickness and texture of these deposits is important because it affects their water-yielding properties and it may affect the yield and the cost of constructing bedrock wells. Thick deposits of clay or till may restrict the movement of recharge into bedrock fractures that are not part of a widespread fracture system, resulting in bedrock wells of low sustained yield. Conversely, thick deposits of sand and gravel may act as large storage reservoirs and, if connected with underlying bedrock fractures, could result in high sustained yields for bedrock wells. The cost of construction of a bedrock well is, in part, determined by the length of steel casing used to seal off overlying unconsolidated deposits. Knowledge of the length of casing required for a proposed well is useful in estimating the cost of the well.

SAND AND GRAVEL AQUIFERS

Deposits of sand and gravel have a higher permeability than any other subsurface materials in the Barre-Montpelier Area. At places where these deposits contain water, are sufficiently thick, and are connected to a source of recharge, they are capable of yielding large quantities of water to properly constructed wells (Hodges, 1969). Extensive beds of coarse gravel were deposited in the valley now drained by the Kingsbury Branch, the Winooski River, Gunners Brook, Stevens Branch, and the Second Branch of the White River. Locations of sand and gravel aquifers having sufficient water-saturated thickness to yield large quantities of water are shown on figure 2. In addition, deposits of sand and gravel with sufficient saturated thickness to yield the quantities of water necessary for domestic, commercial, or light industrial use are shown on the same figure.

Pumping tests of the aquifer in East Montpelier show that the transmissivity is about 45,000 ft^2/day (4,000 m^2/day). It is estimated that the potential sustained yield is about 1 Mgal/day (4,000 m^3/day). Additional information on aquifer testing is given in an earlier report, "Ground water availability in the Barre-Montpelier area, Vermont" (Hodges and Butterfield, 1972).

WATER IN FINE-GRAINED SEDIMENTS

Deposits of fine sand, silt, and clay cover much of the Barre-Montpelier area below an altitude of 1,300 ft (400 m). The most prominent areas include the valley of Berlin Pond, part of Stevens Branch, and much of the Winooski River valley between Montpelier and Plainfield. These deposits (fig. 2) have low potential for ground water development. Even where saturated, they yield water at a very low rate because of their low permeability. Occasional intercalated lenses of coarser-grained materials may increase the yield of wells in these deposits.

GROUND WATER IN TILL

Two types of till have been described in the Barre-Montpelier area by Stewart and MacClintock (1969). Basal till is a compact, gray mixture of material ranging in size from clay to boulders. It is often fissile, suggesting a subglacial origin. Ablation till is a loose mixture of brown sand, cobbles, and boulders containing minor amounts of silt and clay. Stewart and MacClintock ascribe the formation of this material to slow settling of supraglacial debris during ice-wasting. Water velocities were assumed to be only fast enough to remove clay and silt, while leaving the larger particles undisturbed. Thickness of the till ranges from less than 10 ft (3 m) in the uplands to many tens of feet (several tens of metres) in the valleys underlying the water-sorted sediments.

Most of the water taken from the till aquifer in the project area comes from large-diameter dug wells. Those wells penetrating basal till yield small quantities of water. Permeability of basal till is usually low because of the high percentage of the clay-silt component. If the well reaches the top of the underlying bedrock, however, a thin layer of permeable, water-bearing till is often found at the till-bedrock interface.

Dug wells finished in ablation till may yield adequate quantities of water for domestic use. Because ablation till has a low percentage of clay and silt, a loose matrix structure, and intercalated lenses of sand, its permeability is higher than that of basal till.

Almost all dug wells supplying water from till are located on hillsides or hilltops above the major stream valleys. Unless permeable zones in the till are directly connected to perennial streams, recharge is dependent upon local precipitation, and during drought, yield may become inadequate to meet domestic demand.

RECHARGE AND DISCHARGE

Water movement into and out of the project area can be expressed by the following equation:

$$P = R + ET + \triangle S$$

where P = precipitation

R = runoff

ET = evapotranspiration

$\triangle S$ = change in storage

Inflow as precipitation is equal to runoff and evapotranspiration adjusted for changes of water in storage, largely as ground water.

Precipitation measured at the Barre-Montpelier Airport averages 34 in (860 mm) per year, and is somewhat greater during summer than during winter. Average yearly snowfall is 94.4 in (2400 mm) per year, but accumulations are greater at higher altitudes.

Evapotranspiration returns 14 in (360 mm) to the atmosphere each year through direct evaporation of surface water and snow, and through transpiration of living organisms. Evapotranspiration is greatest during the spring and summer growing season. Ground water storage and levels decline during this period (fig. 3), as trees and plants remove water from the soil and release it to the atmosphere as water vapor. Killing frosts in September or October end the yearly growth cycle, and, as transpiration declines, ground water storage increases and water levels begin to rise.

Approximately 20 in (510 mm) leaves the area each year as runoff; runoff includes water that runs directly over the land surface and water that seeps into the ground, recharges ground water bodies, and moves to points of discharge in the streams. Ground water discharge to streams forms a significant proportion of total streamflow and sustains streamflow during drought and periods of below freezing temperature.

When water in a stream is at a higher level than the water table in adjacent permeable materials, stream water may move into the materials, raising the water table. Wells adjacent to a river commonly have high sustained yields because pumping lowers the water table and induces water to flow from the river into the ground.

Monthly measurements of water levels in seven wells in the Barre-Montpelier area (fig. 3) reflect the continuous change of storage in the ground water body. All the wells measured are in unconfined aquifers and, therefore, respond rapidly to local recharge. Normally, water levels are highest in March or April, coinciding with melting of the snow pack and breakup of ice in the rivers, and lowest in September and October, at the end of the growing season. This sequence, however, can be modified substantially by excessive rainfall or prolonged drought.

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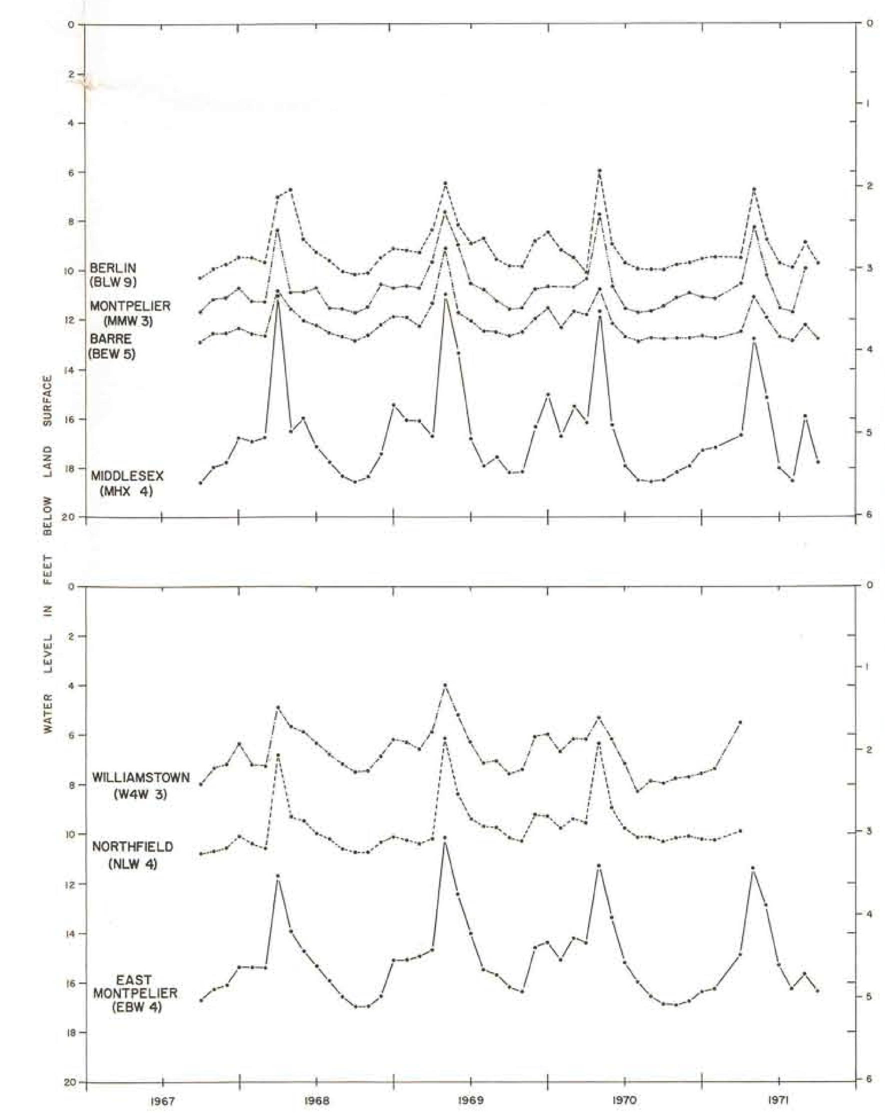

FIGURE 3. - - GROUND-WATER LEVELS IN THE BARRE-MONTPELIER AREA

PLATE 3. BASIC DATA FOR THE BARRE-MONTPELIER AREA, VERMONT

LOCATION OF DATA POINTS

TEST BORING INFORMATION

DESCRIPTION OF SELECTED WELLS

GROUND WATER RESOURCES OF THE BARRE-MONTPELIER AREA, VERMONT

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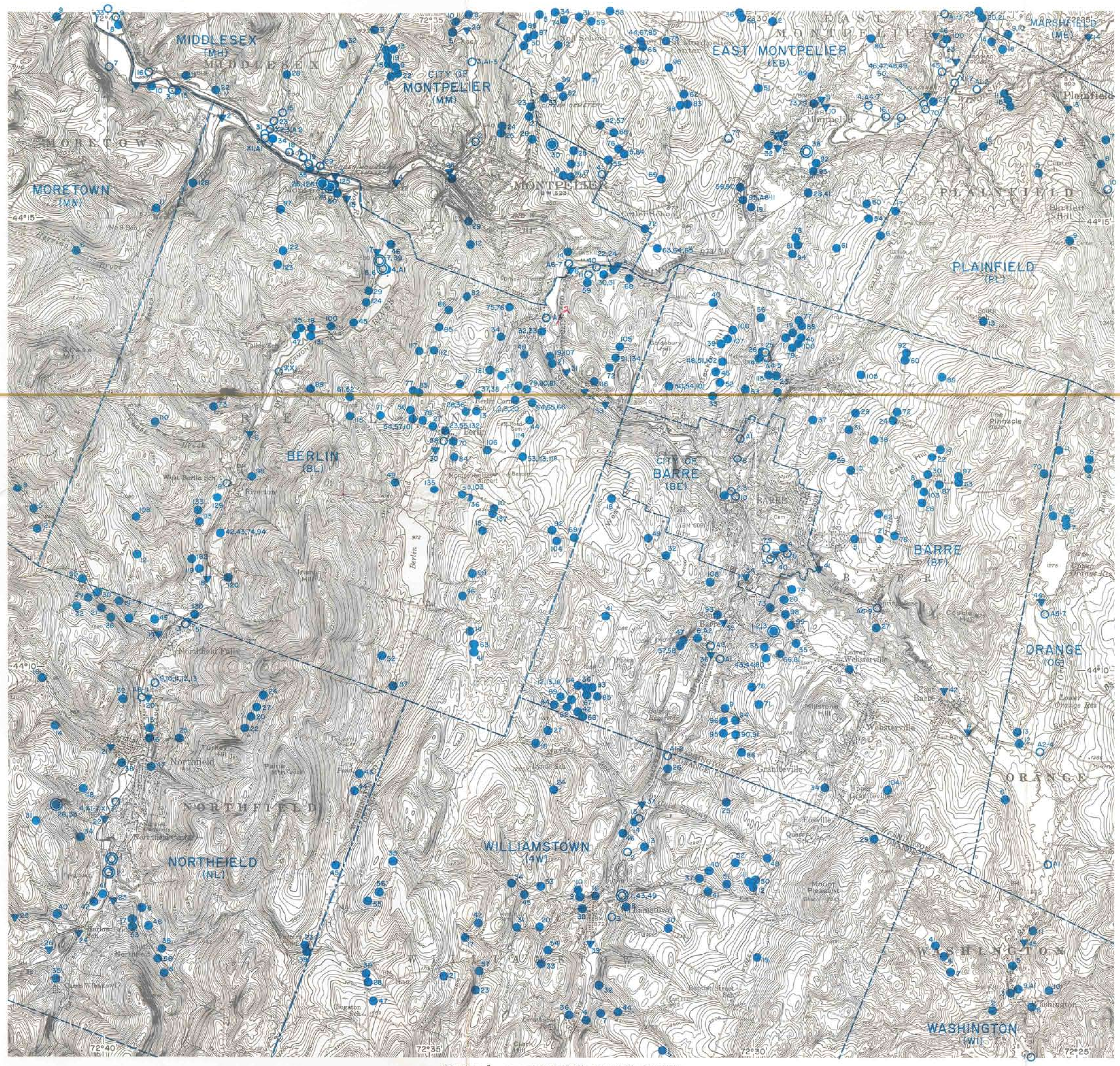

FIGURE 1. - - LOCATION OF DATA POINTS

EXPLANATION

- WELL FINISHED IN BEDROCK
- WELL FINISHED IN UNCONSOLIDATED DEPOSITS
- PUBLIC WATER SUPPLY WELL
- BORING: A - AUGER, X - MISCELLANEOUS
- OBSERVATION WELL
- SURFACE WATER QUALITY SAMPLING STATION

NUMBER INDICATES NUMBER OF WELL, BORING (PLATE 3, TABLES 1 AND 2) OR WATER QUALITY SAMPLING STATION (PLATE 1, TABLES 1 AND 2)

BASE FROM U.S. GEOLOGICAL SURVEY TOPOGRAPHIC QUADRANGLES MONTPELIER 1919, PLAINFIELD 1953, BARRE, EAST BARRE 1957

MAGNETIC DECLINATION 1968

REPORT AREA

INDEX MAP OF VERMONT

TABLE 1. - - DESCRIPTION OF SELECTED WELLS, TEST WELLS, AND BORINGS

[illegible]

TABLE 2. - - LOGS OF SELECTED WELLS, TEST WELLS, AND BORINGS

LOCAL WELL NUMBER: LETTER PREFIX INDICATES--A, U.S. GEOLOGICAL SURVEY AUGER BORING; B, BRIDGE BORING; R, ROADWAY BORING; W, WELL OR TEST WELL ; X, MISCELLANEOUS TEST BORING.

LATITUDE-LONGITUDE: NUMBER FOLLOWING DECIMAL POINT IS A SEQUENTIAL NUMBER FOR WELLS OR BORINGS IN A 1-SECOND GRID.

ALTITUDE OF LAND-SURFACE DATUM: ALTITUDES ARE EXPRESSED IN FEET ABOVE MEAN SEA LEVEL.

METHOD DRILLED: A, AIR-ROTARY; B, BORED OR AUGERED; C, CABLE TOOL; D, DUG; H, HYDRAULIC-ROTARY; J, JETTED; P, AIR-PERCUSSION; R, REVERSE-ROTARY; T, TRENCHED; V, DRIVEN; W, DRIVE-WASH.

WELL FINISH: C, POROUS CONCRETE; F, GRAVEL WALL WITH PERFORATED OR SLOTTED CASING; G, GRAVEL WALL WITH COMMERCIAL SCREEN; H, HORIZONTAL GALLERY OR COLLECTOR; O, OPEN END; P, PERFORATED OR SLOTTED CASING; S, SCREEN; T, SAND POINT; W, WALLED OR SHORED; X, OPEN HOLE IN AQUIFER (GENERALLY CASED TO AQUIFER).

WELL DEPTH: DEPTH OF FINISHED WELL, IN FEET BELOW LAND SURFACE.

WELL USE: A, ANODE; D, DRAINAGE; G, SEISMIC HOLE; H, HEAT RESERVOIR; O, OBSERVATION; P, OIL OR GAS; R, RECHARGE; T, TEST; U, UNUSED; W, WATER WITHDRAWAL; X, WASTE DISPOSAL; Z, DESTROYED.

WATER-BEARING MATERIAL: PRINCIPAL WATER-BEARING ZONE.

ADJECTIVE (FIRST CHARACTER)	LITHOLOGY (SECOND CHARACTER)
1 VERY FINE GRAINED	A ALLUVIUM
2 FINE GRAINED	B SEDIMENTARY ROCK, UNCLASSIFIED
3 MEDIUM GRAINED	C CONGLOMERATE
4 COARSE GRAINED	D DOLOMITE
5 VERY COARSE GRAINED	E GYPSUM OR ANHYDRITE
6 CLAYEY	F SHALE
7 SILTY	G GRAVEL
8 SANDY	H IGNEOUS, GRANULAR (GABBRO, GRANITE, ETC.)
9 GRAVELLY	I IGNEOUS, APHANITIC OR GLASSY (BASALT, ETC.)
0 CAVERNOUS	J IGNEOUS, UNCONSOLIDATED (TUFF, VOLCANIC ASH)
A ARGILLACEOUS	K SAPROLITE
B BOULDERY	L LIMESTONE
C CALCAREOUS	M MARL OR SHELL MARL
D DENSE	N METAMORPHIC, COARSE GRAINED (GNEISS, MARBLE, QUARTZITE)
E CONCRETIONARY	O METAMORPHIC, FINE GRAINED (SCHIST, SLATE)
F IRONSTAINED OR IRON CEMENTED	P CLAY
G GRANULAR	Q SILT OR LOESS
H HARD	R SAND AND GRAVEL
I INTERBEDDED	S SAND
J JOINTED OR FRACTURED	T TILL
K COLUMNAR	U UNCONSOLIDATED SEDIMENT
L LAMINATED OR BANDED	V SANDSTONE
M MASSIVE	W SILTSTONE
N NONCALCAREOUS	X SILTY SAND
O ORGANIC	Y CLAYEY GRAVEL
P POORLY SORTED	Z OTHER
Q CHERTY OR SILICEOUS	
R REDBED	
S SOFT	
T "SALT AND PEPPER"	
U UNCONSOLIDATED	
V SEMICONSOLIDATED	
W WELL SORTED	
X CROSS BEDDED	
Y SHALY OR SLATY	
Z WEATHERED	

WATER LEVEL: LEVELS ARE GIVEN IN FEET BELOW LAND SURFACE; "+" INDICATES WATER LEVEL ABOVE LAND SURFACE; "F" INDICATES FLOWING WELL.

WATER USE: A, AIR CONDITIONING; B, BOTTLING; C, COMMERCIAL; D, DEWATERING; E, POWER GENERATION; F, FIRE PROTECTION; H, DOMESTIC; I, IRRIGATION; M, MEDICINAL; N, INDUSTRIAL (INCLUDES MINING); P, PUBLIC SUPPLY; R, RECREATION; S, STOCK; T, INSTITUTIONAL; U, UNUSED; V, REPRESSURIZATION; W, RECHARGE; X, DESALINATION--PUBLIC SUPPLIES; Y, DESALINATION--OTHER SUPPLIES.

PUMPAGE/YIELD: IN GALLONS PER MINUTE (GAL/MIN).

PUMPAGE/DRAWDOWN: THE DIFFERENCE BETWEEN STATIC WATER LEVEL AND PUMPING LEVEL.

PUMPAGE/TIME: THE FOLLOWING CODES ARE USED FOR PUMPING PERIODS OF LESS THAN 1 HOUR: A, THROUGH 15 MINUTES; B, 16 TO 30 MINUTES; C, 31 TO 45 MINUTES; D, 46 TO 59 MINUTES.

LOG: D, DRILLER'S LOG; E, ELECTRIC LOG; G, GEOLOGIST'S LOG (*LOG AVAILABLE IN TABLE 2).

QW: TYPE OF CHEMICAL ANALYSIS AVAILABLE IN TABLE 2, PLATE 1. C, COMPLETE; J, CONDUCTANCE AND CHLORIDE; K, CONDUCTANCE; L, CHLORIDE; M, MULTIPLE (INCLUDES ONE COMPLETE AND ONE OR MORE PARTIAL); P, PARTIAL.

LOCAL WELL NUMBER	LATITUDE-LONGITUDE	ALTITUDE OF LSD (FT)	OWNER OR USER	YEAR/METHOD DRILLED		WELL DIAMETER (IN)	FINISH	DEPTH (FT)	USE	FEET TO BEDROCK	WATER-BEARING MATERIAL	WATER LEVEL (FT)	DATE MEASURED	USE	PUMPAGE YIELD (GPM)	DD (FT)	TIME (HR)	LOG	QW
BARRE CITY (BE)																			
A 1	441253N0723007.1	660	US GEOL SURVEY	1967	B	4	X	16	T	--	--	--	--	U	--	--	--	G	-
W 2	441200N0723020.1	590	GRANITE CITY CR	1943	J	8	S	45	W	50	R	11	-43	N	350	--	150	D	-
W 3	441200N0723020.2	590	GRANITE CITY CR	1956	J	10	O	45	W	50	R	11	-56	N	200	--	--	D	-
W 4	441123N0722935.1	625	JACKSON DAIRY	--	C	6	X	319	W	60	--	16	--	C	45	54	8	-	-
W 5	441113N0722948.1	630	US GEOL SURVEY	1967	B	1	T	51	O	65	3R	13	9-67	U	7	--	8	-	-

[illegible]