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

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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. - - 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
- Dw — WAITS RIVER FORMATION QUARTZOSE AND MICACEOUS CRYSTALLINE LIMESTONE
- Dwb — WAITS RIVER FORMATION - BARTON RIVER MEMBER SILICEOUS LIMESTONE AND PHYLLITE
- DSn — NORTHFIELD FORMATION QUARTZ - SERICITE SLATE OR PHYLLITE
- Ss — SHAW MOUNTAIN FORMATION QUARTZOSE LIMESTONE AND CALCAREOUS QUARTZITE

DEVONIAN / SILURIAN

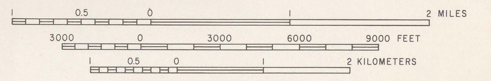
- Omcr — MISSISQUOI FORMATION - CRAM HILL MEMBER PHYLLITE SLATE, MAFIC VOLCANICS
- Omhb — MISSISQUOI FORMATION - HARLOW BRIDGE QUARTZITE MEMBER QUARTZITE WITH QUARTZITIC PHYLLITE
- Omm — MISSISQUOI FORMATION - MORETOWN MEMBER QUARTZITE AND QUARTZ - PLAGIOCLASE GRANULITE
- Omc — MISSISQUOI FORMATION CARBONACEOUS PHYLLITE AND SLATE

ORDOVICIAN

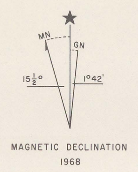
CONTACT BETWEEN FORMATIONS

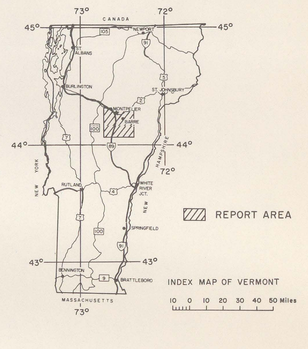
FAULT - INFERRED

LINEAMENT



CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL
BASE FROM U.S. GEOLOGICAL SURVEY TOPOGRAPHIC QUADRANGLES
MONTPELIER 1919, PLAINFIELD 1953, BARRE, EAST BARRE 1957





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 (l/s)
million gallons per day (Mgal/day)	3785	cubic metres per day (cm^3/day)

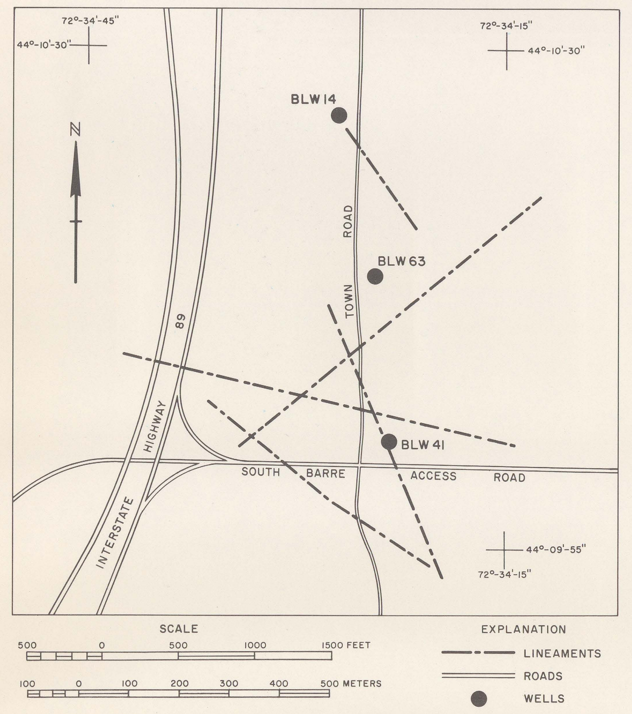


FIGURE 2. - - INVESTIGATION SITE OF BEDROCK WELL YIELDS

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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U.S. Public Health Service, 1962 (revision), Public Health Service drinking water standards: U.S. Dept. Health, Education and Welfare, Public Health Service, pub. no. 956, 61p.

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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)	HARDNESS (CA, MG) (MG/L)	NON-CARBONATE 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