In cooperation with the Vermont Army National Guard

Hydrogeologic Framework and Water Quality of the Vermont Army National Guard Ethan Allen Firing Range, Northern Vermont, October 2002 through December 2003

Scientific Investigations Report 2005-5159

U.S. Department of the Interior
U.S. Geological Survey

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U.S. Department of the Interior
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U.S. Geological Survey, Reston, Virginia: 2005

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Suggested citation:
Clark, S.F., Jr., Chalmers, Ann, Mack, T.J., and Denner, J.C., 2005, Hydrogeologic framework and water quality of the Vermont Army National Guard Ethan Allen Firing Range, northern Vermont, October 2002 through December 2003: U.S. Geological Survey Scientific Investigations Report 2005-5159, 48 p.

Acknowledgments

The authors would like to thank the personnel of the Vermont Army National Guard for their assistance with this study. Special thanks go to Lieutenant Colonel Raymond P. Bouchard and Lieutenant Colonel George Bergeron for guidance and input on study design, Michael O'Hara and Sergeant Neal Sargent for logistical support in field operations, and Edward Rounds for technical assistance. The authors also wish to thank the following U.S. Geological Survey personnel for their involvement: Martin Risch, of the Indiana Water Science Center, for general project guidance; and from the New Hampshire-Vermont Water Science Center, James Degnan and Craig Johnston for GIS assistance, Jeffrey Deacon for surface-water and fish-tissue sampling, Anita Cotton for graphic assistance, and Glenn Berwick and Jeffery Grey for drilling.

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Conversion Factors and Datum

Multiply	By	To obtain
	Length	
millimeter (mm)	0.03937	inch (in.)
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square meter (m^2)	0.0002471	acre
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
liter (L)	0.2642	gallon (gal)
cubic meter (m^3)	264.2	gallon (gal)
	Flow rate	
liter per minute (L/min)	0.2642	gallons per minute (gal/min)
meter per day (m/d)	3.281	foot per day (ft/d)
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32$$

Vertical coordinate information is referenced to the “North American Vertical Datum of 1988 (NAVD 88)”

Horizontal coordinate information is referenced to the “North American Datum of 1983 (NAD 83) unless otherwise noted.

Altitude, as used in this report, refers to distance above the vertical datum.

Abbreviations used in the report: centimeter per year (cm/yr), inch per year (in/yr)

Water quality units used in this report: Specific conductance are measured in microsiemens per centimeter at 25 degrees Celsius; turbidity in nephelometric turbidity units (NTU); concentrations in milligrams per liter (mg/L); milligram per kilogram (mg/kg)

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Abstract

The Ethan Allen Firing Range of the Vermont Army National Guard is a weapons-testing and training facility in a mountainous region of Vermont that has been in operation for about 80 years. The hydrologic framework and water quality of the facility were assessed between October 2002 and December 2003. As part of the study, streamflow was continuously measured in the Lee River and 24 observation wells were installed at 19 locations in the stratified drift and bedrock aquifers to examine the hydrogeology. Chemical analyses of surface water, ground water, streambed sediment, and fish tissue were collected to assess major ions, trace elements, nutrients, and volatile and semivolatile compounds. Sampling included 5 surface-water sites sampled during moderate and low-flow conditions; streambed-sediment samples collected at the 5 surface-water sites; fish-tissue samples collected at 3 of the 5 surface-water sites; macroinvertebrates collected at 4 of the 5 surface-water sites; and ground-water samples collected from 10 observation wells, and *Escherichia coli* samples collected at all surface- and ground-water sites.

The hydrogeologic framework at the Ethan Allen Firing Range is dominated by the upland mountain and valley setting of the site. Bedrock wells yield low to moderate amounts of water (0 to 23 liters per minute). In the narrow river valleys, layered stratified-drift deposits of sand and gravel of up to 18 meters thick fill the Lee River and Mill Brook Valleys. In these deposits, the water table is generally within 3 meters below the land surface and overall ground-water flow is from east to west.

Streamflow in the Lee River averaged 0.72 cubic meters per second (25.4 cubic feet per second) between December 2002 and December 2003. Streams are highly responsive to precipitation events in this mountainous environment and a comparison with other nearby watersheds shows that Lee River maintains relatively high streamflow during dry periods.

Concentrations of trace elements and nutrients in surface-water samples are well below freshwater-quality guidelines for the protection of aquatic life. Brook-trout samples collected in 1992 and 2003 show trace-metal concentrations have decreased over the past 11 years. *Escherichia coli* concentrations in water samples are well below levels that restrict swimming at all five stream sites at moderate and low-flow conditions and in all observation wells. Comparisons among surface-water, streambed-sediment, and biological samples collected in 2003 to earlier studies at the Ethan Allen Firing Range indicate water-quality conditions are similar or have improved over the past 15 years.

Ground water in the stratified-drift aquifers at the facility is well buffered with relatively high alkalinities and pH greater than 6. Concentrations of arsenic, cadmium, chromium, lead, nickel, uranium, and zinc were below detection levels in ground-water samples. Barium, cobalt, copper, iron, manganese, molybdenum, and strontium were the only trace elements detected in ground-water samples. Cobalt and iron were detected at low levels in two wells near Mill Brook, and copper was detected at the detection limit in one of these wells. These same two wells had concentrations of barium and manganese 2 to 10 times greater than other ground-water samples. Concentrations of nutrients are at or below detection levels in most ground-water samples. Volatile organic compounds and semivolatile organic compounds were not detected in any water samples from the Ethan Allen Firing Range.

Introduction

The Vermont Army National Guard (VTANG) Ethan Allen Firing Range (EAFR) is composed of 45.4 km^2 (11,220 acres) of mountainous land and is about 19 km east of Burlington, in northern Vermont (fig. 1). Originally, the area was used for farming and pasture. Established by the War department in 1926 for use as an artillery range, the area has been used during the 1930s for Reserve Officer Training corps (ROTC) and two Civilian Conservation Corp (CCC) camps. In 1941, the EAFR was expanded and used as a bombing range by the Army Air Corps. From 1952 to present (2003), developmental and proof testing of newly manufactured weapons systems on 3.1 km^2 within EAFR (U.S. Army, 1980) has been done by the Armament Systems Department of General

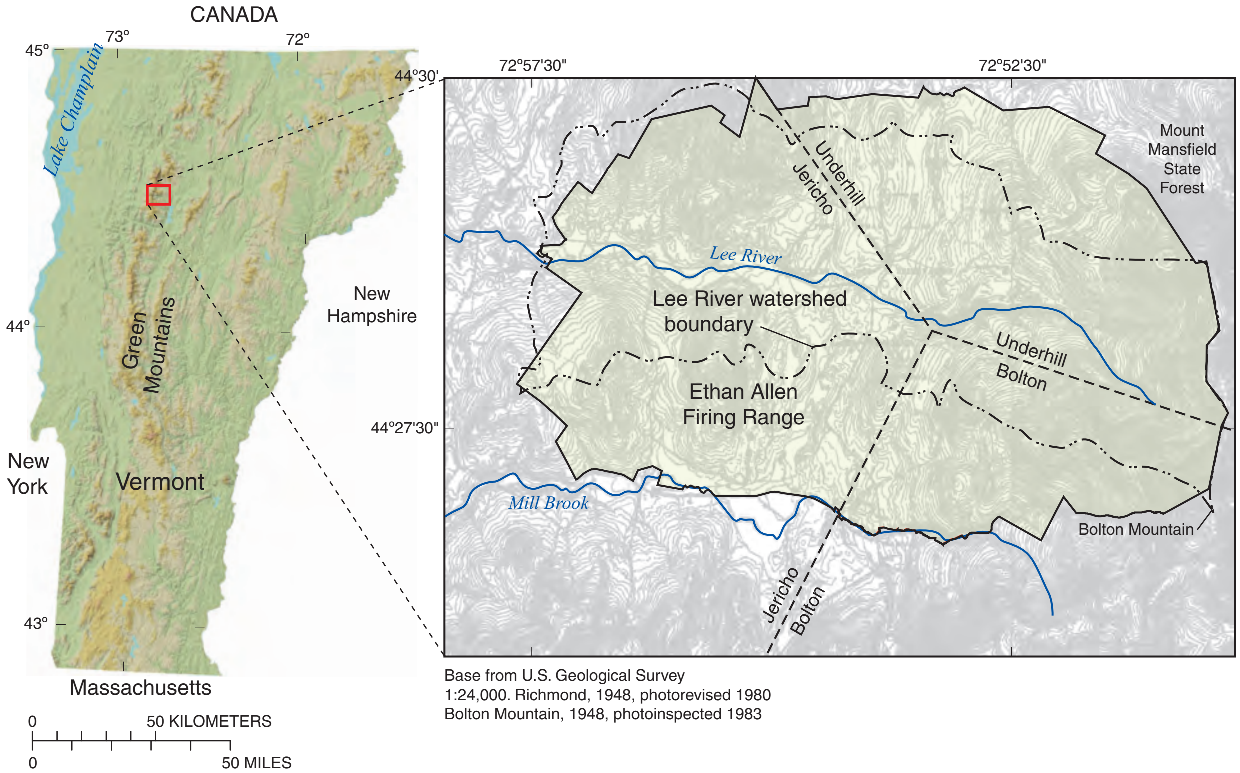


Figure 1. Location of the Ethan Allen Firing Range in northern Vermont.

Electric. The EAFR includes 18 active gunnery ranges also used by National Guard units for armor, artillery, combat engineer, and helicopter training.

The U.S. Geological Survey (USGS), in cooperation with the VTANG, did an assessment of the physical hydrogeologic framework of the site and the chemical and biologic quality of the ground water and surface water from October 2002 through December 2003. A thorough understanding of the hydrogeologic framework and water quality of EAFR is needed to quantify current (2003) water resources and provide a baseline for future activities. This study is the first base-wide geologic and hydrologic assessment of the site.

Background and Physical Setting

The EAFR is in the Green Mountains of Vermont, in the New England Physiographic Province. Altitudes range from about 213 m (699 ft) along the Lee River, to 1,122 m (3,681 ft) above NAVD 88 at Bolton Mountain on the eastern boundary of the range. Mount Mansfield, the highest point in Vermont, is about 11 km (6.8 mi) northeast of the site and lies on the central ridge of the north-south trending Green Mountains. The facility is rural and supports a wide variety of wildlife. Most of the EAFR is contained within a watershed drained by the Lee River in the center of EAFR (fig. 1) and is bounded by the surrounding peaks and hillsides. Mill Brook drains southern areas of the EAFR, and makes up much of the southern boundary, whereas a small area (Steinhour Brook) drains to the north to Browns River (outside the study area). The physiography is characterized by narrow east-west trending valleys that bisect the regional north-south trending mountain range. Precipitation averages about 86.4 cm/yr (36 in/yr).

The EAFR facility is sparsely populated (fig. 2), consisting of a few offices, barracks, and equipment maintenance buildings in the Lee River Valley. Onsite barracks occasionally are used to house a few hundred individuals during training exercises. Weapons-training activities are held throughout the year and historically have occurred at more than 10 firing ranges in the EAFR (U.S. Army, 1980, table 4). Weapons training involves the firing of various caliber weapons at specific targets in the ranges. The use of explosive ammunition is limited to an area termed the Impact Area (fig. 2). Historically, the EAFR was used by the Vermont Militia to fire large-caliber artillery into small areas in, and adjacent to, an area called the Impact Area (the old Impact Area). This area may contain shrapnel and duds (U.S. Army, 1980, p. 26). Current (2003) policy requires an accounting of all rounds fired and tracking and exploding duds in place. A government-owned, contractor-operated (GOCO) facility in the EAFR conducts weapons test-firing operations in the Lee River Valley. Between 1969 and 1982, depleted uranium ammunition was tested at the GOCO facility. Soils were removed after the munitions testing ceased and residual radiation above background levels was not

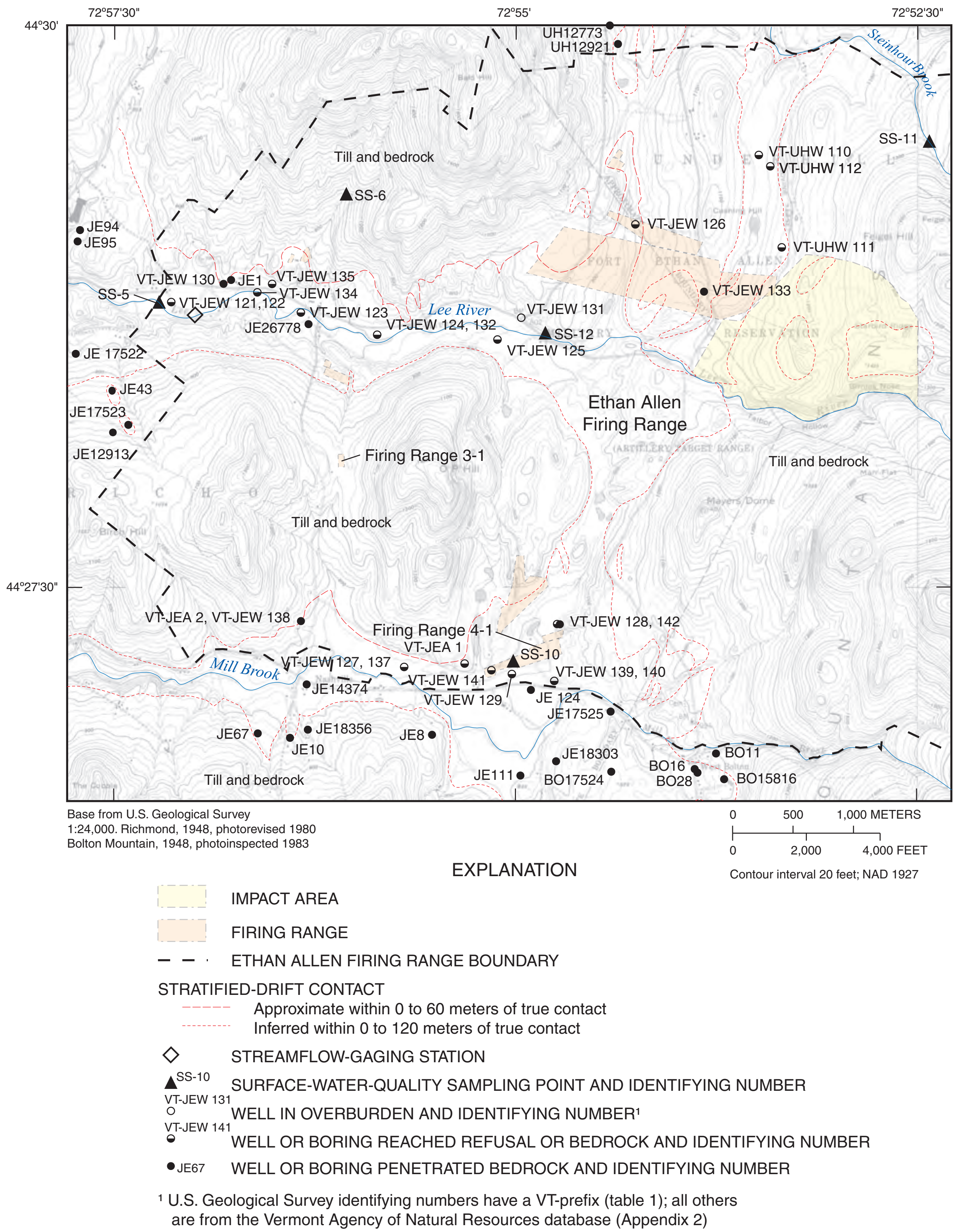


Figure 2. Hydrologic observation points in the Ethan Allen Firing Range in northern Vermont. (Location of site shown in figure 1.)

detected at the affected sites (Bonds and others, 1987). Waste materials generated from the testing activities were contained and shipped off-site to licensed disposal facilities.

Since 1999, the primary drinking-water source for the EAFR has been the Champlain Water District system. Previously, EAFR facilities were served by three onsite bedrock wells. Two, approximately 91-m-deep bedrock wells at the Mountain School Complex formerly supplied water to that facility and a 43-m-deep bedrock well formerly provided water to the Cantonment facility. The well formerly used for the Cantonment facility is now occasionally used to fill portable drinking-water-supply tanks. The GOCO facility is still supplied by onsite water from a bedrock well. Firing Range 3-1 also is supplied water onsite by an infrequently used 69-m-deep bedrock well. The West Bolton Public Water Source Protection area includes land areas in the EAFR; however, the water system is upgradient of the EAFR watershed and not likely to be affected by activities at the firing range.

Purpose and Scope

The purpose of this report is to present (1) the hydrogeologic framework including a description of surficial and bedrock geology, areal extent of stratified-drift aquifers, water-table altitudes, general directions of ground-water flow, and saturated thickness; (2) the surface-water discharge of the Lee River watershed in order to understand the watershed hydrology and stream-aquifer interactions at the EAFR; and (3) the general quality of surface water, streambed sediment, fish tissue, biota, and ground water. The area of study is delineated by the EAFR site boundary. The study was performed at the watershed scale.

Previous Studies

Bedrock geology of the region including the EAFR has been described and mapped by Christman and Secor (1961), Mallard (2000), and Thompson and Thompson (1997). Surficial geology and hydrology have been studied by Stewart and MacClintock (1969), Stewart (1973), Ladue (1982), and Clapp and Bierman (1994).

Surface-water and streambed-sediment samples were collected and analyzed in 1992 at 10 sites on the Lee River and Mill Brook (Bouwkamp, 1992) and again in 1999 at the same locations (Goetz, 1999). Ten locations sampled in 1999 did not indicate an adverse effect on water quality or streambed sediment from munitions training (Goetz, 1999). Fish-tissue samples were collected and analyzed at two sites on the Lee River in 1992; the 1999 survey did not include chemical analysis of fish tissue. Macroinvertebrate samples were collected from five sites on the Lee River in 1992 and six sites in 1999. Three of the six sites sampled in 1999 corresponded to sites sampled in 1992. Results from 1999 were inconclusive, taxa richness was higher (an indication of improving water quality) in 1992 than in 1999, but macroinvertebrate abundance was lower than in 1999. Although ground-water sampling in the stratified-drift aquifer was done to test for potential contamination at two locations (a former waste-disposal site and a logistical-operations building) at the EAFR (Butoryak, 1995 and 1996), previous studies have not included a comprehensive investigation of ground-water resources and background water quality.

Methods of Study

The following section describes the methods used to accomplish the objectives of the study. These methods include streamflow gaging; geohydrologic data collection including lineament analysis, observation-well drilling, and mapping; and water-quality, streambed sediment, and biologic sampling. Databases and geographic information system (GIS) coverages used to complete analysis of the geohydrologic framework are referenced or described.

Streamflow

Streamflow was gaged at the Lee River between December 16, 2002, and December 22, 2003, to assess the magnitude and range of streamflow in the Lee River watershed. The streamflow-gaging station (fig. 2) was located near where the river leaves the EAFR. Streamflow measured at the Lee River station was indexed to nearby stations to provide a context for understanding flow in the Lee River during water year 2003, in relation to long-term regional trends. Specific study methods included

1. Installation of a continuously recording streamflow-gaging station at the Lee River to allow streamflow in the watershed to be indexed to nearby long-term USGS network stations. Streamflow data were collected using standard USGS techniques (Rantz and others, 1982; Buchannan and Somers, 1969). The station at Lee River was equipped with a datalogger that recorded stage data at 10-minute intervals. A stage-discharge relation was developed from numerous current-meter discharge measurements.

2. Additional streamflow measurements were made at two sites on Lee River (above and below the station), and on tributaries to Lee River and at Steinhour Brook (fig. 2, SS-11), to assess flow conditions during the sampling period at macroinvertebrate-sampling sites.

Geologic Mapping

Bedrock geologic maps at a scale of 1:24,000, which include areas of the EAFR, were made by Mallard (2000) and Thompson and Thompson (1997). A 1:100,000-scale compilation by the Vermont Geological Survey (Stanley and others, 2002) forms the basis for the bedrock geologic map. Bedrock outcrops were located and examined during the course of this study; however, no revision of Mallard's (2000) or Thompson and Thompson's (1997) work was warranted.

A map of generalized surficial geologic materials was prepared based on observations of materials exposed in eroding unconsolidated cliffs, gravel pits, road cuts, stream banks, pits dug in unconsolidated materials, well borings, split-spoon samples from observation wells, and the distribution of boulders on the land surface. A 1:62,500-scale surficial-geologic map including the EAFR, accompanies Christman and Secor's (1961) report on the geology of the Camels Hump Quadrangle. Christman and Secor's (1961) surficial-materials map and maps by Stewart (1973) and Ladue (1982) and interpretations by Ladue (1982) are consistent with those of this study.

Geohydrologic Data Collection

Observation wells were located to assess the geohydrologic framework and local and regional ground-water-flow systems. Wells were installed along the central axis of the Lee River and Mill Brook Valleys to determine the thickness of valley-fill deposits and the general gradient of the water table. Wells were located at the valley perimeter along the main stem of each river and in headwater stream reaches to determine general ground-water-flow directions and provide points for assessment of ground-water quality. Rock core retrieved from observation wells drilled in bedrock provided a measure of the extent of fracturing within the bedrock aquifer (Deere and Deere, 1988). Additional existing domestic bedrock wells, beyond the boundary of the EAFR, were identified to provide data relevant to aquifers underlying the study area.

Characteristics of the bedrock aquifer are described by well depths and yields. Domestic-well data were obtained from the Vermont Agency of Natural Resources (Ken Yelsey, Vermont Agency of Natural Resources, written commun., 2004). Domestic wells were reviewed and assessed for use in estimating stratified-drift aquifer thicknesses.

A photolineament analysis of the study area identified potential high-transmissivity bedrock zones. Moore and others (2002) found that increased bedrock-well yields were associated with lineaments that correlated with the direction of primary bedrock fracturing in New Hampshire. Two observers independently identified linear patterns on 1:58,000-scale color-infrared aerial photographs following the methods of Clark and others (1996). Coincident photolineaments identified by two observers are provided in the GIS lineaments coverage. Comparison of photolineament position and orientation with field-measured fractures at outcrop-scale was beyond the scope of this study; therefore, the relation between photolineaments and bedrock structure at the study area is uncertain.

Observation wells were installed at 16 locations (fig. 2, table 1) in glacial sediments to improve the understanding of the thickness and nature of stratified-drift aquifers. Pairs of wells with screens set relatively shallow and deep were installed at four locations to assess ground-water quality and head difference from different depths within the aquifers. Split-spoon samples were collected at approximately 3-m intervals to determine the composition of the sediments with increasing depth. Lithologic logs of wells drilled at the EAFR are presented in appendix 1. Information from well reports from the surrounding area collected by the VTANR is provided in appendix 2. Stratified-drift wells consisted of a 5-cm (2-in.) inside-diameter polyvinyl chloride (PVC) well and 1.5-m long, 0.01-mm slotted screen. Four bedrock wells were installed in selected locations to improve the understanding of the bedrock aquifer. Bedrock wells consisted of a 10-cm-diameter open borehole drilled in rock. Boreholes were cased with 11-cm outer-diameter steel casing, set into a 15-cm-diameter hole, grouted with cement approximately 1.5 m into the bedrock surface. Well characteristics and construction information are provided in table 1. The wells were used to provide ground-water-sampling points and are shown on figure 2. Numbers assigned to wells consist of a code that corresponds to the town the site is in and a sequential number. Well codes used are BO, Bolton; JE, Jericho; and UH, Underhill.

Depth to the water table in the stratified-drift (layered sands and gravel) aquifers was used to determine the altitude of the water table. Measurements of the depth to the water table were obtained from measurements made for this study, well-completion-report records maintained by the VTANR, and from approximated altitudes of the surface of ponds and streams as shown on USGS 1:24,000-scale topographic maps. The altitude of the water-table surface generally fluctuates by less than 2 m during the year at observation wells in northern Vermont (Keirstead and others, 2004); therefore, measurements from various times of the year are sufficient for use in creating a regional water-table map and in determining general directions of ground-water flow. The saturated thickness of the stratified-drift aquifers was determined using the data mentioned above in addition to the thickness of stratified glacial sediments as reported in drillers' well-completion reports (appendix 2).

Water-Quality, Streambed Sediment, and Biologic Sampling

Surface-water sampling sites (fig. 2, table 2) were selected to assess surface-water, streambed-sediment and biologic quality at EAFR. Sites were selected that were at, or near, 4 of the 10 previous sampling sites (Goetz, 1999) to provide continuity and correlation with the previous studies. Sites SS-5, SS-6, and SS-10 (fig. 2) were coincident with previous sample sites (Lieutenant Colonel Bouchard, Vermont Army National Guard, oral commun., 2003). Site SS-5 provides a surface-water sampling site that captures most of EAFR drainage and provides a measure of the overall quality of water leaving the base. In contrast, site SS-6 provides an analysis of a relatively undisturbed upland tributary drainage. Site SS-12 (fig. 2), about 305 m downstream from site SS-3 (Goetz, 1999), is downstream of all tributaries draining the Impact Area. This site provides an indicator of the effect of the Impact Area, and other active firing ranges to the north,

Table 1. Well-depth and screened-interval data for the wells in the study area, Ethan Allen Firing Range, northern Vermont.

[Site locations are shown in figure 2. Latitude and longitude are in degrees, minuntes, seconds, ° ′ ″. All depths in meters from land-surface datum. Measurement point (MP) is top of casing. Altitude is in meters (m) above NAVD 88; L/min, liter per minute; --, not applicable or unknown]

Site identifier	Latitude °	′	″	Longitude °	′	″	Measurement point (m)	MP above land-surface[1] (m)	Depth to water September 1, 2003 (m)	Depth to screened or open interval (m)	Depth to end of boring well, or casing (m)	Well yield (L/min)	Aquifer type
VT-JEA 1	44	27	9	72	55	17	244	--	--	--	11.8	--	--
VT-JEA 2	44	27	19	72	56	20	242	--	--	--	3.6	--	--
[2]VT-JEW 121	44	28	47	72	57	8	195	0.8	1.53	14.8	19.5	23	Unconfined stratified drift
VT-JEW 122	44	28	47	72	57	8	195	.7	1.53	4.8	9.4	4	Unconfined stratified drift
[2]VT-JEW 123	44	28	43	72	56	20	203	.9	.80	9.4	11.9	6	Unconfined stratified drift
VT-JEW 124	44	28	37	72	55	51	215	.9	1.89	20.1	23.2	1	Confined stratified drift
[2]VT-JEW 125	44	28	36	72	55	5	232	.6	.88	11.6	14.9	1	Confined stratified drift
[2]VT-JEW 126	44	29	6	72	54	16	180	.9	3.15	7.6	9.1	5	Unconfined stratified drift
[2]VT-JEW 127	44	27	9	72	55	41	236	.9	1.12	2.4	7.6	45	Unconfined stratified drift
[2]VT-JEW 128	44	27	18	72	54	41	250	.8	2.28	5.2	7.0	6	Unconfined stratified drift
[2]VT-JEW 129	44	27	6	72	54	58	241	.9	1.08	7.9	22.2	6	Confined stratified drift
VT-JEW 130	44	28	50	72	56	48	204	.3	1.73	4.0	21.3	0	Bedrock
VT-JEW 131	44	28	42	72	54	57	241	.4	3.91	16.7	16.7	--	Unconfined stratified drift
[2]VT-JEW 132	44	28	37	72	55	51	215	.7	1.52	2.3	4.6	30	Unconfined stratified drift
VT-JEW 133	44	28	47	72	53	47	299	.4	2.99	2.1	9.1	2	Bedrock
VT-JEW 134	44	28	47	72	56	33	200	.8	1.91	11.9	13.4	5	Confined stratified drift
VT-JEW 135	44	28	51	72	56	35	207	.9	2.23	9.4	11.6	1	Unconfined stratified drift
VT-JEW 137	44	27	9	72	55	41	236	.9	1.08	6.7	8.2	1	Confined stratified drift
VT-JEW 138	44	27	19	72	56	20	242	.6	1.70	5.9	14.8	4	Bedrock
VT-JEW 139	44	27	5	72	54	48	250	1.2	.53	16.2	18.9	1	Unconfined stratified drift
VT-JEW 140	44	27	5	72	54	48	250	1.0	.62	7.2	9.1	47	Unconfined stratified drift
VT-JEW 141	44	27	6	72	55	7	244	.9	2.15	9.1	14.0	4	Unconfined stratified drift
VT-JEW 142	44	27	18	72	54	41	250	.6	2.38	8.4	16.6	0	Bedrock
VT-UHW 110	44	29	25	72	53	30	308	.9	1.83	4.0	5.7	1	Unconfined stratified drift
[2]VT-UHW 111	44	29	1	72	53	19	331	.9	3.05	5.2	10.1	1	Unconfined stratified drift
[2]VT-UHW 112	44	29	22	72	53	23	314	.9	3.76	4.0	8.5	1	Unconfined stratified drift

[1] Land-surface altitude determined from map altitude, vertical accuracy is approximately 3 meters.

[2] Wells sampled.

Table 2. Summary of physical properties and water-quality characteristics of surface water at the Ethan Allen Firing Range in northern Vermont.

[Sites are located on figure 2. Date samples are in months, days, year mm/dd/yy. EC, Specific conductance in microsiemens per centimeter, µS/cm; °C, degrees Celsius; NTU, nephelometric turbity units; DO, dissolved oxygen; mg/L, milligrams per liter; <, less than; --, no standard]

				Physical properties						Water-quality characteristics		
Site identi-fier	Name of river	Flow conditions	Date site sampled mm/dd/yy	EC (µS/cm)	pH (stan-dard units)	Water tempera-ture (° C)	Turbidity (NTU)	DO (mg/L)	Alkalinity (mg/L)	Dissolved solids (mg/L)	Suspended solids (mg/L)	Total solids (mg/L)
SS-5	Lee River (near outlet from Ethan Allen Firing Range)	Moderate flow	06/05/03	78	7.4	13.7	0.24	9.7	36.6	68	0.6	48
		Low flow	07/30/03	110	7.5	20.5	.16	8.7	17.9	91	1.9	43
SS-6	Unnamed tributary to Lee River	Moderate flow	06/04/03	25	6.8	9.8	.31	10.4	7.6	18	<.5	24
		Low flow	07/30/03	46	6.8	15.5	.18	7.5	48.0	133	<.5	75
SS-10	Unnamed tributary to Mill Brook	Moderate flow	06/05/03	56	7.1	19.3	.69	6.3	36.4	53	.9	52
		Low flow	07/30/03	90	7.0	21.0	1.4	5.3	51.9	136	1.9	77
SS-11	Steinhour Brook	Moderate flow	06/04/03	29	7.0	11.5	.21	10.0	23.8	20	.6	25
		Low flow	07/30/03	57	7.3	16.0	.09	9.2	34.3	135	1.0	54
SS-12	Lee River (upstream)	Moderate flow	06/05/03	51	7.4	11.4	.36	10.1	33.3	63	.8	40
		Low flow	07/31/03	73	6.9	15.0	.24	9.4	37.4	99	.6	373
			Summary statistics									
			Moderate flow									
			Minimum	25	6.8	9.8	0.21	6.3	7.6	18	0.6	24
			Maximum	78	7.4	19.3	.69	10.4	36.6	68	.9	52
			Median	51	7.1	11.5	.31	10	33.3	53	.7	40
			Low flow									
			Minimum	46	6.8	15.0	0.09	5.3	17.9	91	.6	43
			Maximum	110	7.5	21.0	1.4	9.4	51.9	136	1.9	373
			Median	73	7.0	16.0	.18	8.7	37.4	133	1.4	75
			Overall									
			Minimum	25	6.8	9.8	0.09	5.3	7.6	18	.6	24
			Maximum	110	7.5	21.0	1.4	10.4	51.9	136	1.9	373
			Median	56	7.0	15.3	.24	9	35.4	79	.8	50
			Guidelines or standards									
			MCL[1]	--	--	--	5	--	--	--	--	--
			SMCL[2]	--	6.5–8.5	--	--	--	--	--	--	500
			CCREM[3]	--	6.5–9.0	--	--	5.5–9.5	--	--	--	--

[1] Maximum Contaminant Level (MCL) established by the U.S. Environmental Protection Agency (2002a).

[2] Secondary Maximum Contaminant Level (SMCL) established by the U.S. Environmental Protection Agency (2002b).

[3] Canadian water-quality guidelines for the protection of freshwater-aquatic life (Canadian Council of Resources and Environmental Ministers, 2003).

on the water quality of the Lee River. Site SS-11, on Steinhour Brook, was used to assess water quality from the one watershed that drains to the north, towards Underhill (fig. 1), from the study area. Site SS-10, a tributary to Mill Brook, was selected to provide an indicator of the effect of Guard activities along the southern side of the EAFR in the Mill Brook watershed. Because most of Mill Brook watershed is outside the EAFR area, no other sites in this watershed were assessed.

Surface- and ground-water chemistry, streambed sediment, benthic macroinvertebrates, and fish samples were collected in the Lee River watershed during June and July 2003. Water-quality and biological data collection focused on background sampling (sampling from relatively pristine areas within the EAFR) in addition to assessing the overall water quality of the study area. Field data collection included (a) surface- and ground-water samples, (b) streambed-sediment samples, (c) fish-tissue samples, and (d) an aquatic macroinvertebrate inventory. Water, streambed-sediment, and fish-tissue samples were analyzed for major ions and trace elements listed in appendix 3. Water samples were also analyzed for alkalinity, turbidity, dissolved solids, total suspended solids, *Escherichia coli* (*E-coli*) bacteria, nutrients, volatile organic compounds (VOCs) identified in U.S. Environmental Protection Agency (USEPA) schedule 8260, and semivolatile organic compounds (SVOC) in USEPA schedule 8270 (appendix 3). All analyses except *E-coli* were performed at Severn-Trent Laboratory (a contract laboratory for USGS Department of Defense work) using USEPA analytical methods. *E-coli* counts were analyzed by Aquatec Biological Sciences in Williston, Vt., in accordance with U.S. Environmental Protection Agency (1983) protocol.

Ten observation well sites (fig. 2, table 1) were selected to provide comprehensive geographic coverage for ground-water sampling and geohydrologic characteristics within selected aquifers. Observation-well-site selection and construction methods are described in the "Geohydrologic Data Collection" section.

Surface Water

Surface-water-quality sampling was completed at five sites (fig. 2) during moderate-flow conditions (0.45 m^3/s at Lee River streamflow-gaging station, June 4–5, 2001), and again during a low-flow (base flow) condition (0.15 m^3/s at the Lee River station, July 30–31, 2003). Water samples and field water-quality parameters (pH, specific conductance, water temperature, and dissolved oxygen) were collected and measured consistent with guidelines for the USGS Field Manual for the Collection of Water-Quality Data (Wilde and others, 1998). Grab samples were collected because all streams were well mixed. *E-coli*, VOC, and SVOC samples were collected directly into sample containers from a single vertical mid-stream dip sample. Samples for major ions, trace elements and nutrients were dip-collected with a Teflon bottle and composited using a Teflon churn.

Streambed Sediment

Fine-grained streambed sediment consisting primarily of very fine sand, silt, clay and organic material were collected from depositional areas at five stream sites during base-flow conditions on July 4, 2003. Composite samples were collected from the top 2–3 cm of continuously submerged streambed sediment from 10 to 15 depositional areas in a manner consistent with guidelines for the USGS National Water-Quality Assessment Program (Shelton and Capel, 1994). Samples were not sieved, however, to permit for comparison with unsieved samples collected in 1992 and 1999. Samples were analyzed for major ions and trace elements (appendix 3).

Biologic

Fish were collected at three sites by electrofishing during moderate-flow conditions (June 10–11, 2003). Brook trout (*Salvelinus fontinalis)* were collected at sites SS-11 and SS-12 (fig. 2). Brook and brown trout (*Salmo trutta*) were collected at site SS-5. Fish-tissue samples were a composite of five whole individuals. Samples were analyzed for major ions and trace elements (appendix 3). Benthic macroinvertebrates were collected at four stream sites (SS-5, SS-6, SS-11, and SS-12) in the Lee River and Steinhour Brook watersheds on June 18, 2003. A Surber sampler was used to collect a semi-qualitative sample to provide a measure of relative abundance of invertebrate taxa living in the richest habitat (riffles) at each stream site. Organisms were dislodged in a 0.09-m^2 area to a depth of about 10 cm immediately upstream of the sampler and collected in a 500 µm mesh net. A series of five representative discrete collections were combined and processed at each site. Samples were preserved in 95-percent alcohol. Three-hundred organism counts were done by Aquatec Biological Sciences in Williston, Vt. Taxa were identified to the level of genus and species. The diversity and taxa richness of samples was compared against historical samples to test for changes in biodiversity and population numbers.

Ground Water

Ground-water samples were collected from 10 wells during July 21–25, 2003. The wells were developed from 2 to 4 weeks prior to sampling by pumping until a drop in temperature indicated that water stored in the casing was removed and that the aquifer was being pumped. A low-discharge submersible pump was used to purge and sample the wells. Purging involved setting the pump at the well screen and pumping greater than 3 times the casing volume until the pH, specific conductance, dissolved oxygen, and water temperature stabilized. Field water-quality parameters (pH, specific conductance, water temperature, and dissolved oxygen) were collected according to USGS guidelines (Wilde and others, 1998). Samples were collected for major ions, trace elements, nutrients, *E-coli*, VOCs, and SVOCs (appendix 3).

Quality Assurance

Water-quality assurance included equipment blanks, field blanks, and replicates collected following USGS guidelines (Wild and others, 1998). Equipment blanks were taken before any samples were collected. Approximately10 percent of samples were collected for water-quality assurance (field blanks and replicates). Equipment and field blanks verified that decontamination procedures are adequate, and field and(or) laboratory procedures did not contaminate samples. Trip blanks were kept with the samples and analyzed for VOCs with every batch of samples brought to the lab. VOC trip blanks verified that shipping, handling, and storage of sample vials did not result in the contamination of the samples.

Hydrogeologic Framework

The EAFR is on the west flank of the central ridge of the Green Mountains (fig. 1) and is underlain by fine- to medium-grained micaeous metamorphic rocks with a granofels or phyllite texture. Unsorted sediment deposited by glacial ice discontinuously covers bedrock. Streambed sediment associated with outwash from melting glacial ice formed stratified deposits in glacial lakes in the Lee River and Mill Brook Valleys. The hydrogeologic framework consisting of streamflow, bedrock geology, glacial sediments, and the hydrology of the bedrock and stratified-drift aquifers is described in the following sections.

Streamflow

The headwaters of the Lee River and Mill Brook drain the west flank of the central ridge of the Green Mountains (fig. 1). The Lee River represents the primary hydrologic feature in the EAFR site and its watershed encompasses most of the study area site. The drainage area for the Lee River watershed upstream of SS-5 (figs. 1 and 2) is about 26.5 km^2. The drainage area for Mill Brook (fig. 2) upstream of its downstream EAFR boundary is about 15.5 km^2. The only other drainage leaving the area is Steinhour Brook (fig. 2), a small tributary to Browns River (outside the study area) in Underhill. Steinhour Brook has a drainage area of about 3.4 km^2 within the EAFR.

The period of record for the Lee River streamflow-gaging station is from December 16, 2002, to December 22, 2003. The period from December 17, 2002, to December 16, 2003, was used for statistical reporting. A hydrograph of daily mean flow for the Lee River is shown in figure 3. Flows ranged from a daily maximum flow of 10 m^3/s (360 ft^3/s) on November 20, 2003, to a low flow of 0.13 m^3/s (4.7 ft^3/s) on July 19 and 20, 2003, and September 15 and 19, 2003. The mean streamflow for the year of record was 0.72 m^3/s (25.4 ft^3/s) and the runoff for the year was 85.8 cm (33.8 in). The streamflow record during the winter of 2003 (fig. 3) illustrates a period of recession from January through March. Although precipitation was low during this period (fig. 3), January and February were some of the coldest months observed in the past 25 years in the region and precipitation remained in the snowpack.

The Dog River streamflow-gaging station (station no. 04287000, Keirstead and others, 2004), at Northfield Falls, Vt. (43 km to the southeast of the study area), is used as a reference site to describe long-term hydrologic conditions in north-central Vermont during the period of record at the EAFR. Streamflow at Dog River was 107 percent of normal, and total precipitation on Mt. Mansfield was 116 percent of normal. The above normal conditions at reference stations nearby indicate that Lee River streamflow during the study was probably about 10 percent above normal.

West Branch Little River (15 km to the east of the study area), a highly developed watershed, and Ranch Brook (15 km to the east), an undeveloped watershed, are nearby watersheds on the east slope of Mt. Mansfield, and have physiographic settings similar to the Lee River. Monthly total discharge in the Lee River (fig. 4) was compared to discharge in Ranch Brook (station no. 04288230) and the Dog River (station no. 04287000) (Keirstead and others, 2004). The Dog River, a large watershed (197 km^2) in the region, with a low mean basin altitude, provided a long-term discharge record for comparison with closely paired Ranch Brook and Lee River. Total annual runoff (normalized) for the period of the Lee River record, at the three watersheds, was Dog River 65.5 cm (25.8 in), Ranch Brook 106.2 cm (41.8 in) and Lee River 85.8 cm (33.8 in). This comparison shows that the Dog River has the least runoff and runoff from Ranch Brook is greater than the runoff from Lee River. Peak snowmelt occurred in March at Lee River, the result of a more southerly exposure than at Ranch Brook, where peak snowmelt occurred in April (fig. 4).

The Lee River watershed on the western slopes of the Green Mountains has less (normalized) runoff than Ranch Brook on the eastern slope of the Green Mountains and may receive less precipitation. The western slope (upwind) of the Green Mountains is assumed to receive more precipitation than the eastern slope (downwind). However, the National Weather Service (NWS) indicates that the western slope may have received less precipitation in 2003 than the east slope, and evapotranspiration (ET) is likely higher on the western slopes (Gregory Hansen, National Weather Service, oral commun., 2004).

Analysis of flows per unit area in the three watersheds discussed previously shows that the Lee River maintains a relatively high discharge (greater than 0.01 m^3/s) during dry periods (fig. 5), notably July and September 2003. This comparison indicates that there is likely a large ground-water contribution to streamflow during periods of low rainfall. The Lee River watershed contains a large area of relatively permeable stratified-drift deposits (discussed in the “Glacial Sediments” section) that likely acts as a storage reservoir for ground water.

Analysis of a short-term hydrograph (fig. 6) shows that the Lee River is similar to other nearby mountain watersheds

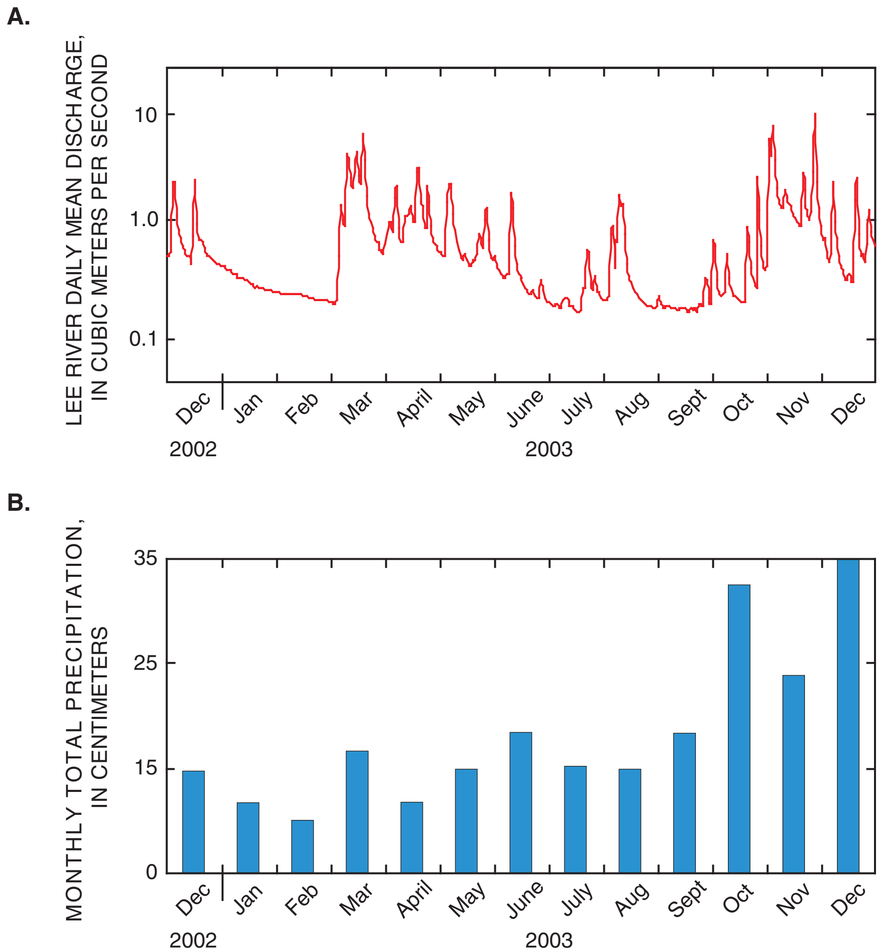


Figure 3. (A) Daily mean streamflow at U.S. Geological Survey streamflow-gaging station on the Lee River at the Ethan Allen Firing Range near Jericho, Vermont, December 17, 2002, through December 22, 2003 (location shown on figure 2) and (B) monthly total precipitation at Mount Mansfield, Vermont.

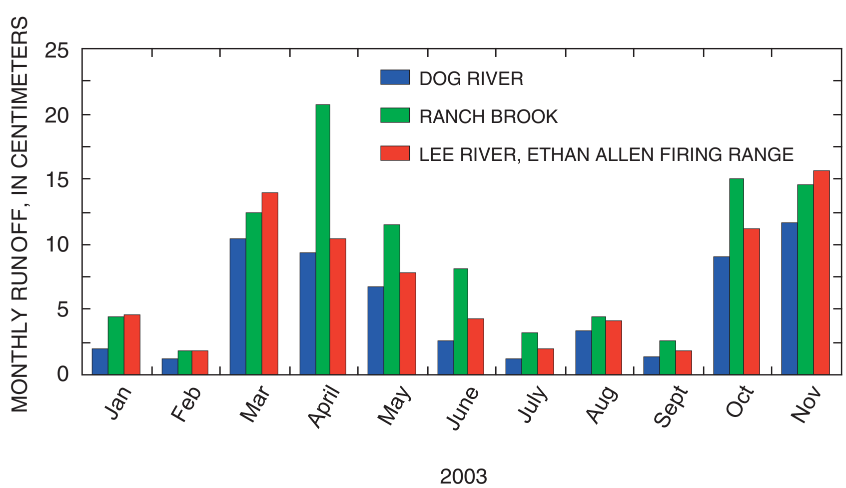


Figure 4. Monthly total runoff at the Dog River, Ranch Brook, and Lee River streamflow-gaging stations in northern Vermont, January 1, 2003, through November 30, 2003. (Location of Lee River shown in figure 1.) Dog River and Ranch Brook are outside of study area.

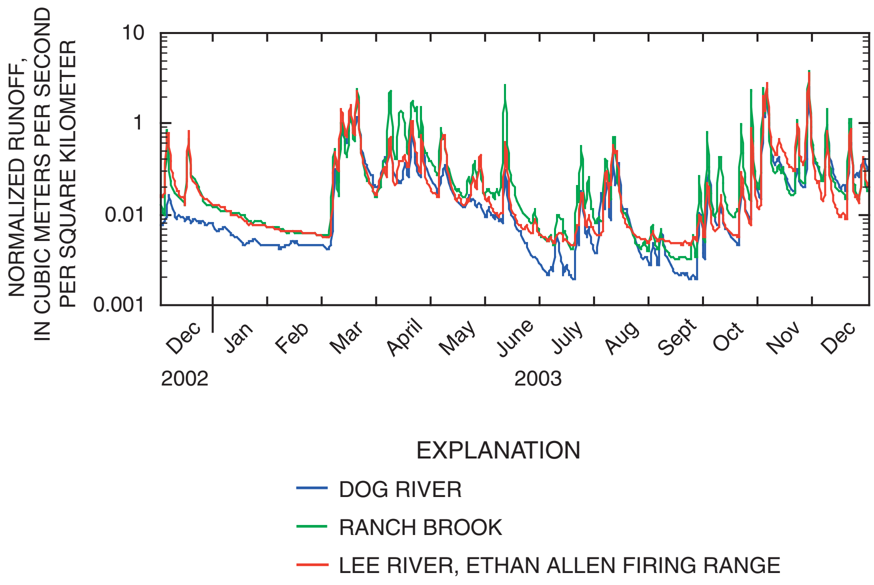


Figure 5. Normalized runoff hydrographs of the Dog River, Ranch Brook, and Lee River streamflow-gaging stations in northern Vermont, December 16, 2002, through December 22, 2003. (Location of Lee River shown in figure 1.) Dog River and Ranch Brook are outside of study area.

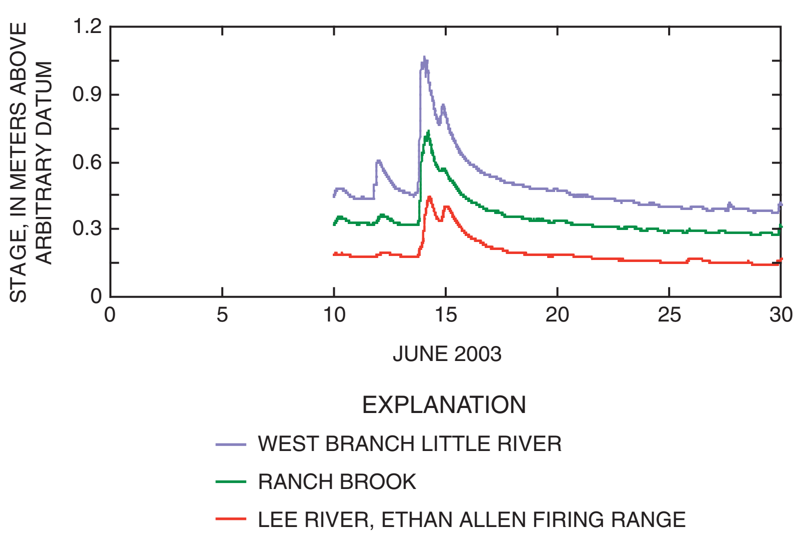


Figure 6. Hydrograph showing stream stage at the West Branch Little River, Ranch Brook, and Lee River in northern Vermont, June 10–30, 2003. (Location of Lee River shown in figure 1.) West Branch Little River and Ranch Brook are outside of study area.

in that it is highly responsive to storm events. A typical response of mountain streams to intense rainfall is a rapid rise at the onset of precipitation followed by a fairly steep recession after the rainfall ends. The rainfall runoff response at the Lee River is slightly subdued, when compared to the West Branch Little River (fig. 6), because of the undeveloped nature of the Lee River watershed and the extensive stratified glacial sediments.

Bedrock

The texture and composition of rocks and the nature and orientation of structural elements in rocks affect the magnitude and anisotropy (orientation) of the hydraulic conductivity in the bedrock aquifer. Minerals more susceptible to weathering (such as pyrite and calcite), which may be aligned with the schistosity, can produce porosity in rocks that allows ground-water movement such as the weathered, water-producing zone identified in bedrock well VT-JEW 133. Aligned mica minerals form planar features, such as schistosity and cleavage, that control patterns of jointing in rocks and provide pathways for ground-water flow.

The EAFR, on the western flank of the Green Mountain anticlinorium, is underlain by fine- to medium-grained sandy-textured micaeous metamorphic rocks consisting of low-grade granofels and phyllites. The original pre-metamorphic rocks were coarse- to fine-grained graywacke, siltstone, and shale which locally contain minor amounts of volcanic material (Christman and Secor, 1961). These rocks have been grouped into the Pinnacle, Underhill, Hazens Notch and Sweetsburg Formations in previous studies (Christman and Secor, 1961; Thompson and Thompson 1992, 1997; Mallard, 2000). Robinson and Kapo (2003) classify the general lithogeochemistry of this region as primarily noncalcareous pelitic rocks with a moderate to high sensitivity to acid deposition.

The geologic map of the EAFR (fig. 7) is based on work in the 7.5-min USGS Richmond Quadrangle (Mallard, 2000)

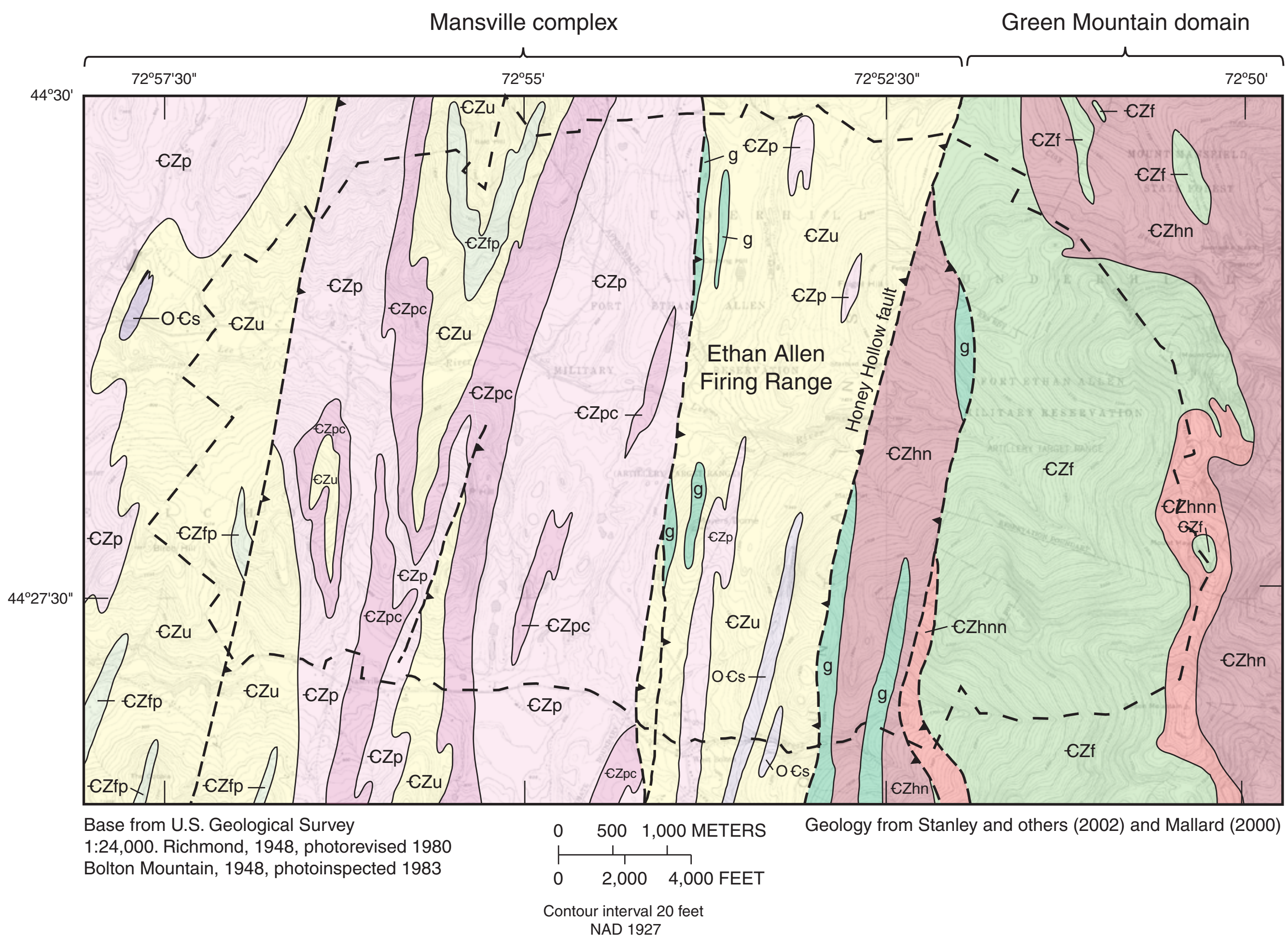


Figure 7. Bedrock geology at the Ethan Allen Firing Range in northern Vermont.

EXPLANATION

Bedrock geology from Stanley and others (2002) and Mallard (2000)

Greenstone and amphobolite (age unknown)

g — Thinly bedded, albite-epidote-carbonate greenstone and massive albite-amphibole-biotite-magnetite amphibolite; fine- to medium-grained, light- to dark-green amphibole-albite-chlorite-epidote schist; coarse-grained, dark-green, weakly foliated amphibole-albite-biotite-epidote amphibolite

Sweetsburg Formation (Ordovician and Cambrian)

OꞒs — Graphitic phyllite; graphitic, quartzitic phyllite and schist with tan-weathering layers and pods of gray dolostone and black quartzite

Hazens Notch Formation (Cambrian and Late Proterozoic)

ꞒZhn — Undifferentiated dark, rusty, graphitic quartz-chlorite-muscovite-biotite±garnet schist and gneiss; dark albite porphy roblasts, large euhedral pyrite, and beds of dark-gray foliated quartzite are common; includes dark, rusty schist without graphite

ꞒZhnn — Nongraphitic schist; rusty-weathering, nongraphitic, sulfidic, chlorite schist

Fayston Formation (Cambrian and Late Proterozoic)

ꞒZf — White albitic schist; silvery-green, medium-grained, muscovite-quartz-chlorite-garnet-magnetite schist with thin, light-gray quartzite; medium- to coarse-grained, salt-and-pepper colored, quartz-albite-biotite-magnetite-pyrite schist and gneiss; silvery, dark-gray to rusty, medium-grained quartz-muscovite-albite-tourmaline-chlorite schist

Fairfield Pond Formation (Cambrian and Late Proterozoic)

ꞒZfp — Light-gray to light-green quartz-sericite-chlorite phyllite±magnetite±biotite

Underhill Formation (Cambrian and Late Proterozoic)

ꞒZu — Silver-gray to silver-green, nongraphitic-chlorite-muscovite-quartz schist and phyllite, commonly with albite and magnetite±dolomite. Local lenses of white to pale-gray quartzite, quartz-albite granulite, and quartz-chlorite±biotite metawacke. Schist and phyllite dominate

Pinnacle Formation (Cambrian and Late Proterozoic)

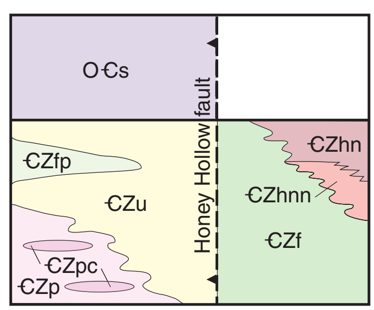
ꞒZp, ꞒZpc — **ꞒZp**—Silver-green to brown to olive-green pinstripe granofels (metawacke) and phyllite interlayered with small, visible clasts of quartz and feldspar; magnetic; granofels (metawacke) dominates. Locally contains greenstone, which is not mapped separately, and feldspathic, calcareous, amphibolitic mafic metavolcanic rock

ꞒZpc, quartz-pebble conglomerate member; rounded, sorted, blue, white, and clear quartz pebbles ranging in size from 0.25 to 3 centimeters; occurs as lenses within massive metawacke or, locally, as bands of coarse-grained rock paralleling bands in the massive metawacke; grades across strike into the massive metawacke

Contact between bedrock units(from Stanley and others, 2002, and Mallard, 2000)

Thrust fault—Approximately located; teeth on upper plate

Ethan Allen Firing Range boundary



Correlation chart (after Mallard, 2000)

Figure 7. Continued.

and on unpublished work in the 7.5-min USGS Bolton Quadrangle (Peter J. Thompson, University of New Hampshire, oral commun., 2004). Their maps have been compiled into a 1:100,000-scale map by the Vermont Geological Survey (Stanley and others, 2002). The geology for this report presented in figure 7 is reproduced from Stanley and others (2002) and Mallard (2000). Mallard (2000) has divided the Pinnacle and Underhill Formations into mapable units and identifies three stratigraphic sequences (Oak Hill group and Mansville complex (Mallard, 2000) and the Green Mountain domain) separated by two major fault complexes (West Fletcher fault and the Honey Hollow fault) that parallel the trend of regional schistosity. Two of the three fault-bounded stratigraphic packages, the Mansville complex, and Green Mountain domain, underlie EAFR and the Honey Hollow fault separates these stratigraphic packages. Minor faults are mapped where stratigraphic units are truncated. The Honey Hollow fault (fig. 7) was mapped as a west dipping, thrust fault (rocks of the Hazens Notch Formation thrust westward over rocks of the Pinnacle, Underhill, and Sweetsburg Formations, then folded to west-dipping) (Thompson and Thompson, 1992; Mallard, 2000).

Two structural domains defined by the fabric (schistosity) of the rock underlie the EAFR. The “central domain” (Mallard, 2000) underlies the western third of the study area. Here, schistosity trends north-south and is nearly vertical or dipping moderately to the east. “Large-scale antiforms and synforms control the map pattern (folding discontinuous lenses) within the western third of the EAFR” (Mallard, 2000). In the “eastern domain”, schistosity trends north-northeast and dips moderately to steeply west and also dips moderately to the east (Mallard, 2000).

At the EAFR, the textural and compositional differences in the mapped bedrock units (Pinnacle and Underhill Formations) are enough to define mapable rock units, but are not great enough to create regional variations in ground-water flow in the bedrock aquifer among mapped units. Thick-bedded to massive granofels (wackes) of the Pinnacle Formation may be more likely to fracture (Peter J. Thompson, University of New Hampshire, oral commun., 2004); however, there were few fractures in cores from wells drilled into bedrock (fig. 2). Rock-quality designation (RQD) values (Deere and Deere, 1988) range from good (1 well) to excellent (2 wells) indicating little fracture. Outcrops of exposed bedrock also were not highly fractured. Structural features common to these rocks are described in the following paragraph. In some locations, structural features may control fracture formation, which can affect the permeability of the bedrock aquifer.

Three structural geologic deformations have affected the rocks that underlie EAFR. The first-deformation produced structures seldom seen within rocks at the EAFR. The second deformation produced the dominate schistosity in axial-plane orientation to isoclinal folds plunging either north or south. The second-deformation folds are generally sheared parallel to third-deformation cleavage. The second-deformation schistosity passes from east-dipping, through the vertical, to west-dipping across the area. The third deformation produced open upright folds, which plunge north or south at shallow amounts, and a spaced cleavage (Mallard, 2000).

Glacial Sediments

Glacial ice covered the region during the Wisconsinan glaciation between 90,000 and 12,000 years ago (Larsen, 1999). Sediments deposited in processes related to glaciation can be broadly grouped into till and stratified drift (fig. 8). Till is an unsorted mixture of rock fragments ranging in size from boulders 2–3 m in diameter to clay-size rock flour deposited beneath, or at, the margin of moving glacial ice. Stratified drift is composed of sediment moved by water (melting glacial ice) and deposited in water adjacent to glacial ice or at some distance from the ice. Because stratified drift is moved by water, the sediment is sorted and the deposits are layered. In general, well-sorted, coarse-textured (sand sized and greater) stratified drift has greater hydraulic conductivity and transmissivity than the generally poorly sorted, more compacted, till. The contact between till (unsorted to poorly sorted material) and stratified drift, consisting of sorted to well sorted, layered gravels, sands, silt and clay, ranges from approximately located (within about 60 m) to inferred (within about 120 m) (fig. 8). Various areas, originally covered by thin stratified sand and gravel and disturbed by the construction of firing ranges, are mapped on the basis of materials currently at land surface.

Till was deposited in a discontinuous fashion at the EAFR by southeastward advancing glaciers. Glaciers scoured calcareous rock material from the Lake Champlain Valley and incorporated some into till and outwash deposits at EAFR. Tills generally have a high silt or clay content and, therefore, have a low hydraulic conductivity. Hydraulic conductivities of about 0.3 m/d are common for tills in New England (Mack, 1995; Melvin and others, 1992) (table 3). Where till contains more sand-sized sediment, its hydraulic conductivity and, therefore, transmissivity, can be greater. Tills in the EAFR area are usually less than 6 m thick and discontinuously cover the bedrock surface. Examination of well-completion reports (appendix 2) from areas surrounding the EAFR indicated that the thickness of till deposits are generally from 3 to 6 m. Thick till (greater than 6 m thick) is found on north to west-facing slopes and thin till is found on bedrock ridges.

Stratified-drift deposits with varying characteristics can be broadly grouped into the following three settings in the study area: (1) high altitude coarse- and fine-grained ice-margin deposits, (2) intermediate altitude coarse-grained stream-valley deposits leading to fine-grained lake-margin deposits, and (3) low altitude valley-fill coarse- and fine-grained glacial-lake deposits (fig. 8). The horizontal hydraulic conductivities of stratified-drift deposits were estimated for similar deposits in Bristol, Vt. (Mack, 1995) and are listed in table 3. The hydraulic conductivity of clay is very low and

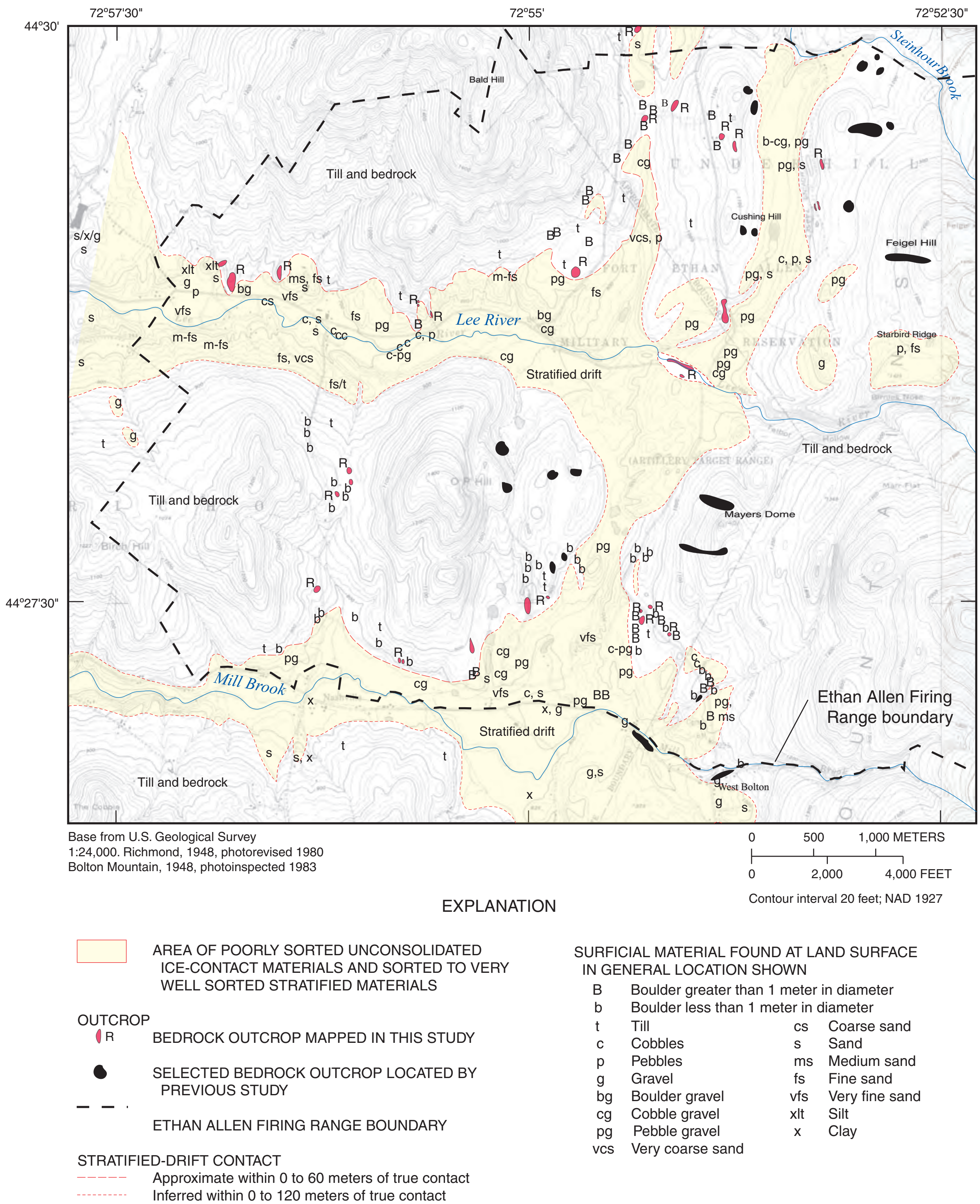


Figure 8. Surficial materials at the Ethan Allen Firing Range in northern Vermont. (Location of site shown in figure 1.)

Table 3. Estimated horizontal hydraulic conductivity of aquifer materials in the region in northern Vermont from Mack (1995).

[mm, millimeters; m/d, meters per day; <, less than; >, greater than]

Material type	Mean grain size (mm)	Estimated horizontal hydraulic conductivity (m/d)	
		Median	Range
Till	<0.01–0.5	0.3	<0.3–1.2
Sand, fine	.1	3	0.3–9.1
Sand, medium	.3	9	3–18
Sand, coarse	.7	36	18–61
Gravel	2.0–4.0	76	46->76

ranges from approximately 0.44 to 7.2 × 10^{-5} m/d (Freeze and Cherry, 1979).

Ice-marginal deposits, composed of discontinuous thin (less than 6 m thick) sheets of interbedded cobble gravel, pebble gravel, and sand overlie till and bedrock above altitudes of 361 m (1,185 ft). These deposits likely collected in glacial ice-marginal meltwater pools and channels on Feigle Hill, Starbird Ridge, and Mayers Dome. Meltwater drained southward through Bolton Notch as retreating ice blocked drainage to the west down the Lee River and Mill Brook Valleys.

Ice-marginal coarse-grained deposits grade into thicker, finer-grained deposits found at the head of the Mill Brook Valley and occur as thin sheets of sandy cobble-gravel and pebble-gravel near West Bolton. These form roughly flat-topped terraces from altitudes of 326 m (1,070 ft) to 282 m (925 ft). This material grades westward to interfinger with 6–21 m thick, stratified, fine- to medium-grained sand on west-facing slopes from 296 m (970 ft) to 282 m (925 ft) altitude. Locally, very fine sand and silt occur below 282 m (925 ft) altitude. Stratified drift was deposited between 274 m (900 ft) and 305 m (1,000 ft) altitude along the southern side of the eastern end of the Lee River Valley. Fluvial ice-marginal cobble and pebble gravels deposited in thin sheets along the stream valleys east and west of Cushing Hill. Thick deposits of very fine sand at the east end of firing range 4-1 (fig. 2) formed as moving water from melting glacial ice entered a glacial lake in the Mill Brook Valley. Deposits of pebble gravel and sand southeast of Bald Hill along the north side of the Lee River Valley, ranging in altitudes from 274 m (900 ft) to 286 m (940 ft), likely formed during this period.

Drilling logs from wells VT-JEW 127, VT-JEW 129, and VT-JEW 139 (appendix 1) show a pattern of very-fine sediment (clay) over coarse sands and gravel indicating various glacial lake levels in Mill Brook Valley. The fine sediment over coarse sediment is consistent with ice-margin deposits of coarse-grained glacial drift, deposited near westward retreating ice in the Mill Brook Valley, with clay deposited in the quiet water of the lake that formed as the ice withdrew. These stratified-drift sediments form a confined aquifer in places overlain by an unconfined aquifer that make up the stratified-drift aquifers.

Glacial ice blocked the Lee River Valley at a point about 244 m (800 ft) east of well VT-JEW 124 (fig. 2). East of that point, terrace deposits rise to 274-m (900-ft) altitude, and to 238 m (780 ft) to the west. West of that point, terraces are at 232-m (760-ft) altitude and valley-fill deposits are from 207-m (680-ft) to 213-m (700-ft) altitude. A diagrammatic hydrogeologic section representing the Lee River Valley deposits is presented in figure 9. Typical deposits, from land surface to till or bedrock, consist of 2–7 m of cobbles, pebbles, and coarse sand overlying 3–6 m of interfingering medium sand, very fine sand, silt, and 0–1 m of clay overlying boulders, cobbles, and very coarse sand (well logs VT-JEW 121, VT-JEW 134, VT-JEW 135, VT-JEW 123, VT-JEW 124, VT-JEW 125). This pattern of coarse over fine over coarse-grained deposits (fig. 9), indicates a glacial history similar to the Mill Brook Valley. As the glacier receded, coarse materials were deposited along the ice margins and a lake was formed. In the quiet lake environment, fine-grained materials settled to the lake bottom. A fluvial environment followed that quickly deposited coarse material over the fine-grained materials without eroding or removing the underlying lake deposits. This sequence of deposits formed a confined aquifer overlain by an unconfined aquifer.

Aquifer Characteristics

Wells are commonly drilled into bedrock for domestic supply in areas beyond the boundary of EAFR. Drillers' well-completion reports (Ken Yelsey, Vermont Agency of Natural Resources, written commun., 2004) for the towns of Jericho, Bottom, and Underhill (appendix 2) indicate that bedrock-aquifer characteristics vary widely over short distances. However, median well depths are about 90 m (300 ft) deep and median short-term yields are about 23 L/min (6 gal/min). Characteristics of bedrock wells near the EAFR are most likely similar to those found in a statewide analysis of New Hampshire (Moore and others, 2002). The bedrock-aquifer characteristics inside the EAFR boundary are most likely similar to the general characteristics in Jericho and will include a wide range of hydraulic properties. For example, the supply well at the COGO facility has a reported yield of 11 L/min and a depth of 98 m. Bedrock borings drilled by this study were used to determine shallow bedrock properties, not to provide a water supply. The yield of the four bedrock-observation wells drilled for this investigation were generally low, less than 8 L/min to near zero, and do not reflect regional bedrock-aquifer characteristics. Bedrock hydraulic properties are likely similar to those found in New Hampshire (Mack, 2003; Tiedeman and others, 1998). The bulk (regional) bedrock hydraulic conductivity at the EAFR is likely to be about 0.3 m/d or less.

Based on drillers' well-completion reports from Bolton, Jericho, and Underhill (Ken Yelsey, Vermont Agency of

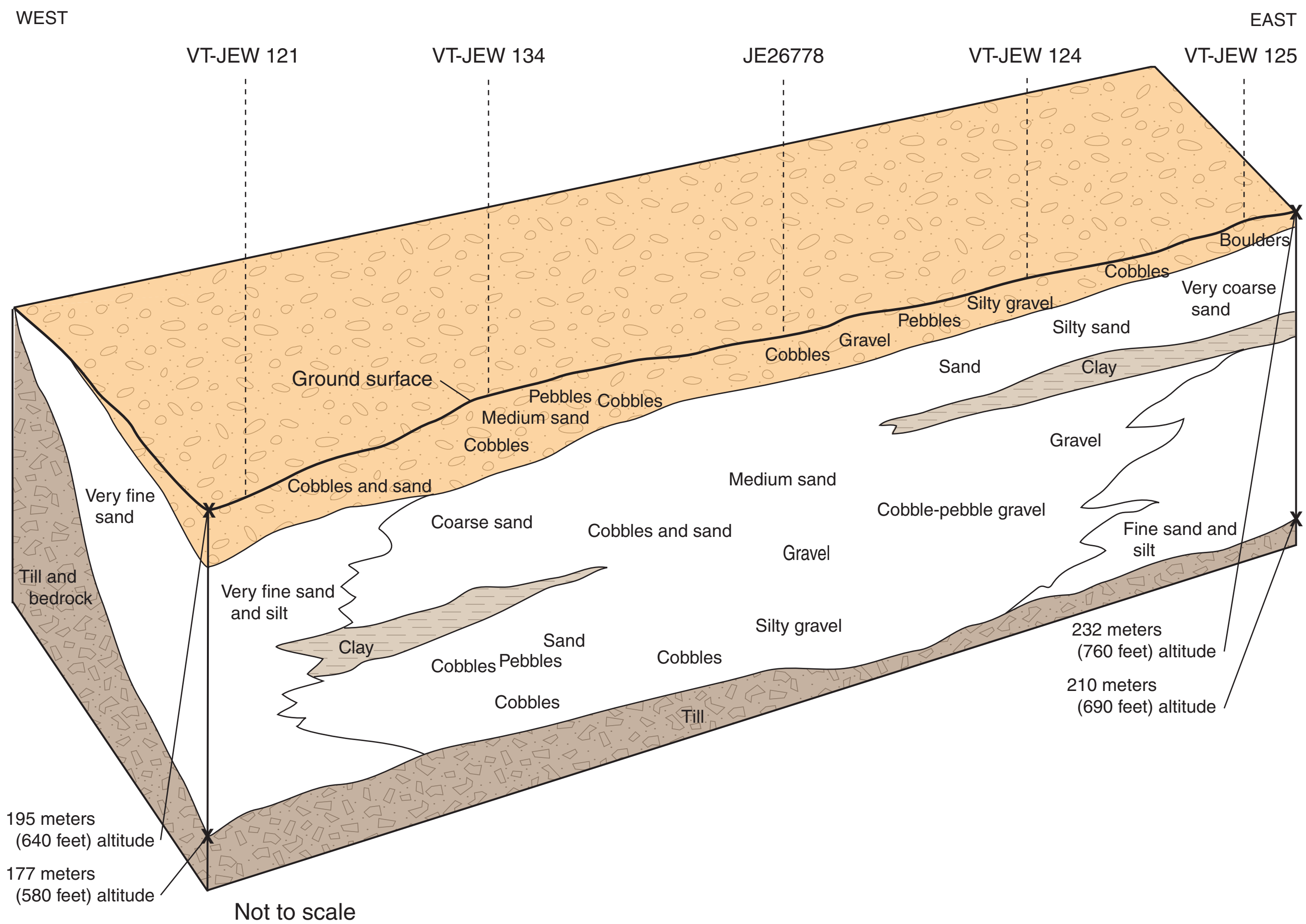


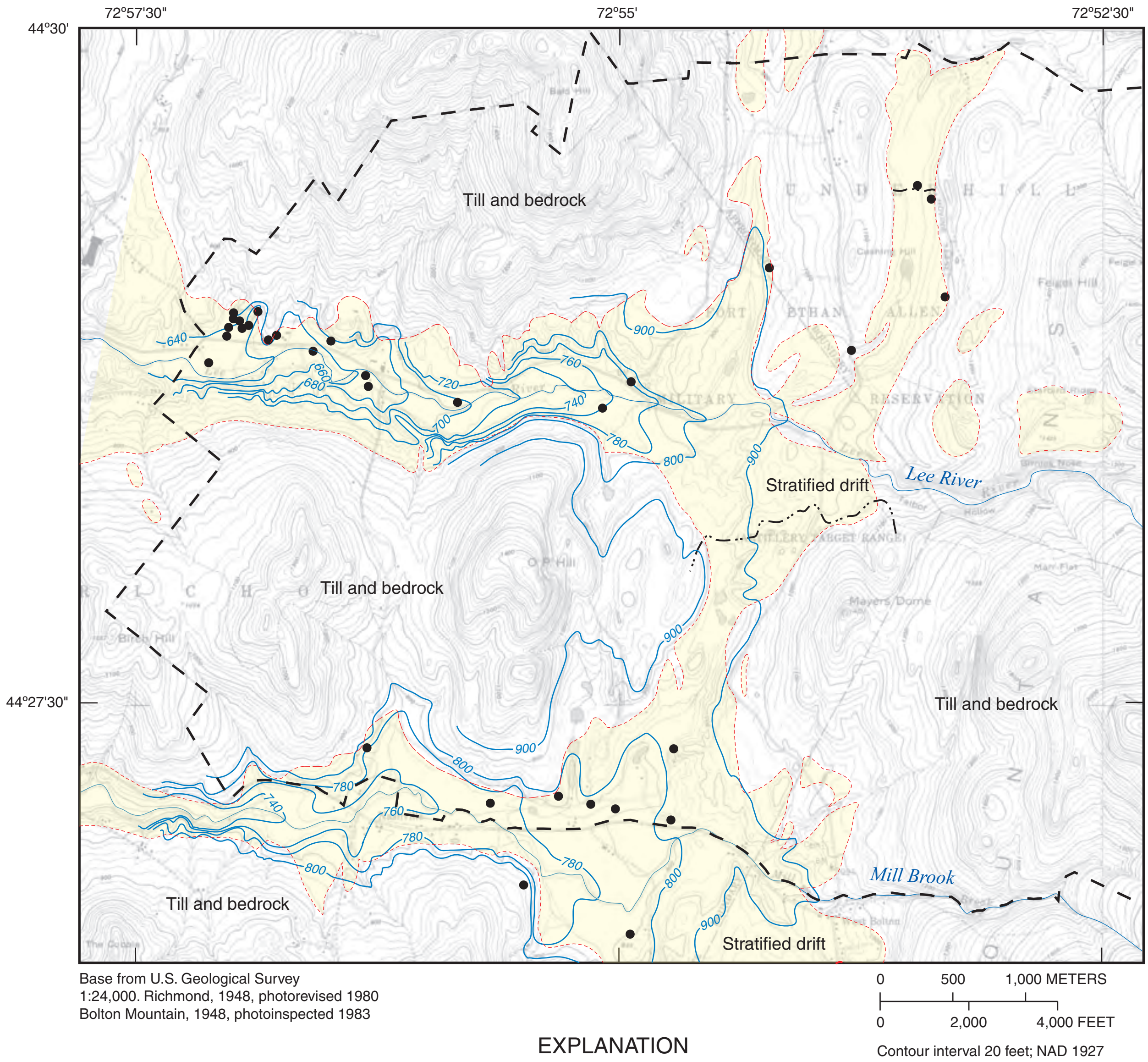
Figure 9. Hydrogeologic section of the Lee River Valley, Ethan Allen Firing Range in northern Vermont. (Location of wells shown in figure 2.)

Natural Resources, written commun., 2004), the static depth to water in the bedrock aquifer is commonly 3–6 m below land surface. Deeper depths to water (greater than 6 m) are usually found at higher altitudes and ridges, whereas shallower depths to water are usually found in topographic depressions or near surface-water bodies. The ground-water potentiometric surface in the bedrock aquifer generally follows the land surface (Mack, 2003), and the direction of ground-water flow is from topographic highs to low areas. As a result of the generally low permeability of the bedrock aquifer, relative to glacial deposits, most of the ground water moving through the region will occur in the overlying glacial deposits.

The altitude of the water table (fig. 10) and the saturated thickness describe basic characteristics of the stratified-drift aquifers in the EAFR. In similar valley-fill stratified-drift aquifers in Vermont, water-level fluctuations (Keirstead and others, 2004) in stratified-drift aquifers are generally less than 2 m during the course of a year. The water table generally is 3 m below land surface (fig. 10). The 6-m (20-ft) contour interval provides an approximation of the regional water-table position. Water-table contours generally follow the land surface and indicate areas of recharge and discharge. For example, streams in the center of the valley in stratified-drift deposits generally drain the aquifer, and water-table contours bend, or “V”, upstream. Where streams cross from till uplands into stratified-drift deposits, they generally lose water to the stratified-drift aquifer.

The overall direction of ground-water flow in the Lee River and Mill Brook Valleys (fig. 10) is east to west, while the localized flow is from the valley walls to the Lee River or Mill Brook in a north or south direction. A generalized representation of ground-water flow in a typical valley setting is shown in figure 11.

The water-table altitude in the stratified-drift aquifer in the Lee River watershed ranges from just less than 195 m to more than 274 m. In the Lee River watershed, the water-table gradient (a dimensionless unit measured as water-table change per length of land surface), down the center of the watershed, is moderate at about 0.0175. The gradient at the valley walls and at the east end of the valley is much steeper. At the east



EXPLANATION

AREA OF POORLY SORTED UNCONSOLIDATED ICE-CONTACT MATERIALS AND SORTED TO VERY WELL SORTED STRATIFIED MATERIALS

BOUNDARIES

ETHAN ALLEN FIRING RANGE BOUNDARY

LEE RIVER WATERSHED AND GROUND-WATER DIVIDE IN STRATIFIED DRIFT

STRATIFIED-DRIFT CONTACT

Approximate within 0 to 60 meters of true contact

Inferred within 0 to 120 meters of true contact

740 WATER-TABLE CONTOUR SHOWING ALTITUDE OF WATER LEVEL— Contour interval 20 feet in valley below 800-feet altitude; contour interval 100 feet above 800-feet altitude. Contours drawn to the extent of available data. Datum is NAVD 88

WELL OR BORING

Figure 10. Generalized altitude of the water table in the Lee River and Mill Brook watersheds, Ethan Allen Firing Range in northern Vermont. (Location of site shown in figure 1.)

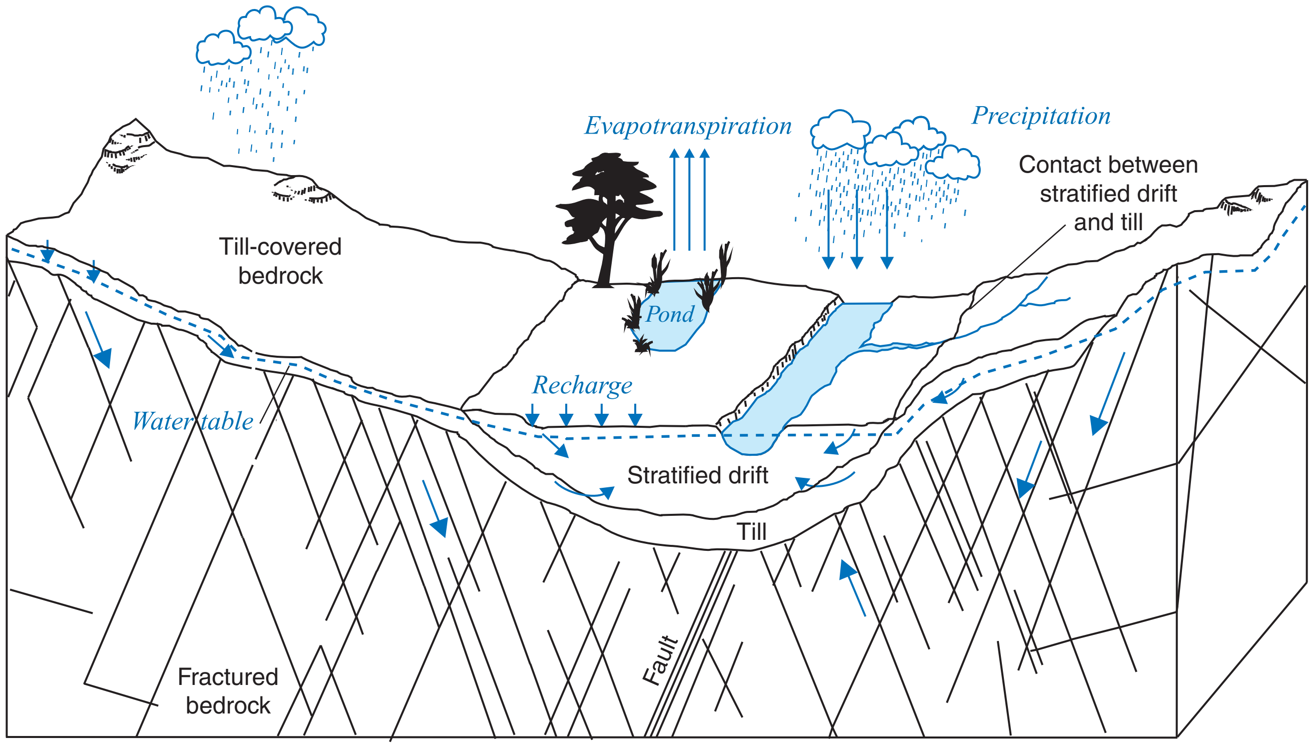


Figure 11. Generalized hydrogeologic section.

end of the Lee River and Mill Brook Valleys, the gradient is too steep to accurately contour the water table between the 243 and 274-m (800 and 900-ft) land-surface contours. In contrast, the water-table altitude in the Mill Brook watershed ranges from about 226 to more than 274 m and the overall gradient is relatively flat at 0.006. The velocity of ground-water flow in the center of the Lee River Valley is estimated to be 0.2 to 0.6 m/d, which is caused by the steep gradient in the Lee River Valley and relatively coarse stratified drift (compared to other sediments). Because of the shallow gradient and generally fine-grained streambed sediments, the velocity of ground-water flow in the Mill Brook Valley is estimated to be 0.2 m/d or less.

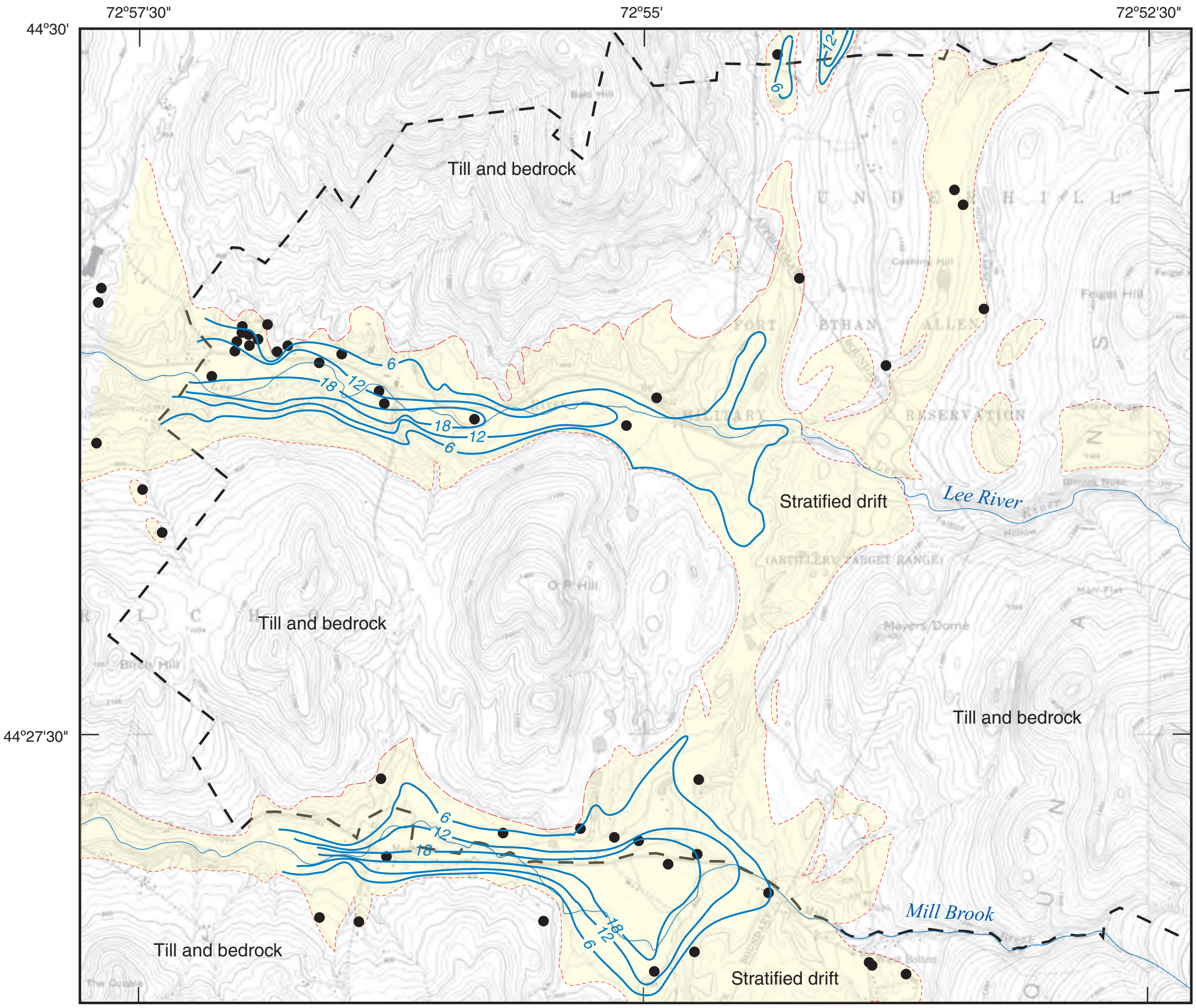
The saturated thickness of stratified drift in the Lee River and Mill Brook Valleys is shown in figure 12. Saturated thicknesses of about 18 m or more are found in the center of the Lee River and Mill Brook Valleys. Thick (more than 12 m) saturated stratified-drift deposits are confined to a narrow area along the Lee River. Broad areas of thinly saturated (about 6 m or less) stratified drift are present towards the east end of the Lee River Valley (fig. 12). Thin stratified-drift deposits extend up the Lee River Valley into Underhill, between Cushing and Feigel Hills (fig. 12), and saturated thicknesses are likely to be less than 6 m. Areas of thinly saturated (less than 6 m), or unsaturated, stratified-drift deposits are present in the headwaters of the Lee River watershed (fig. 12). Most of the Impact Area (fig. 2) is expected to be thinly saturated to unsaturated stratified drift. At the northern EAFR boundary in Underhill, east of Range Road (fig. 12), are small areas of thinly saturated stratified drift. At the southern EAFR boundary along Mill Brook, drillers' well-completion reports indicate that stratified-drift deposits may be much greater than 18 m thick and, toward the east end of the valley, thick deposits may be more extensive.

Water Quality

Surface- and ground-water chemistry, streambed sediment, benthic macroinvertebrates, and fish-tissue samples were collected at the EAFR in June and July 2003. Results are compared to state and national water-quality guidelines and previous studies of the firing range (Goetz, 1999; Ward, 1999; Bouwkamp, 1992; Vermont Department of Environmental Conservation, 1988).

Surface Water

Stream-water samples were collected from sites SS-5, SS-6, SS-10, SS-11, and SS-12 (fig. 2, table 2) during moderate-flow conditions on June 4–5, 2003, and during low-flow conditions on July 30–31, 2003. Water-quality and physical characteristics of surface water are summarized in table 2.



Base from U.S. Geological Survey
1:24,000. Richmond, 1948, photorevised 1980
Bolton Mountain, 1948, photoinspected 1983

0 500 1,000 METERS

0 2,000 4,000 FEET

Contour interval 20 feet; NAD 1927

EXPLANATION

AREA OF POORLY SORTED UNCONSOLIDATED ICE-CONTACT MATERIALS AND SORTED TO VERY WELL SORTED STRATIFIED MATERIALS

BOUNDARIES

ETHAN ALLEN FIRING RANGE BOUNDARY

STRATIFIED-DRIFT CONTACT

Approximate within 0 to 60 meters of true contact

Inferred within 0 to 120 meters of true contact

12 SATURATED STRATIFIED THICKNESS CONTOUR— Contour interval 6 meters. Contours drawn to extent of available data

WELL LOCATION

Figure 12. Generalized saturated thickness of stratified-drift deposits in the Ethan Allen Firing Range in northern Vermont. (Location of site shown in figure 1.)

Surface-water samples had a median pH of 7.0 (neutral) and ranged from pH 6.8 to pH 7.5. Alkalinity ranged from 7.6 to 52 mg/L with a median value of 35 mg/L. Dissolved oxygen concentrations were high (7.5–10 mg/L) at all sites except at site SS-10 (fig. 2), a low-gradient environment just below a beaver dam on a tributary to Mill Brook. Median specific conductance (56 µS/cm), turbidity (0.2 NTU), and suspended solids (0.8 mg/L) were low (table 2). Values for specific conductance, dissolved and suspended solids increased slightly from moderate- to low-flow conditions (table 2). VOCs and SVOCs (appendix 3) were not detected in any samples. Concentrations of major ions, trace elements, and nutrients in stream-water samples were well below USEPA drinking-water regulations and Canadian freshwater-quality guidelines for the protection of aquatic life (Canadian Council of Ministers of the Environment, 2003; U.S. Environmental Protection Agency, 2002a,b).

Concentrations of major ions, and trace elements, and nutrients in surface water are summarized in table 4. Concentrations of arsenic, cadmium, chromium, cobalt, copper, lead, nickel, uranium, and zinc were below detection levels for all samples. Barium, iron, manganese, and strontium were the only metals above reporting levels. Concentrations of iron and manganese were higher at the tributary to Mill Brook (SS-10, fig. 2) than other sampling sites. Nitrogen was present predominately as dissolved inorganic nitrogen, except at SS-10 (fig. 2), which is a tributary to the Mill River where wetlands around a beaver dam probably contributed higher dissolved ammonia plus organic nitrogen. Substantial differences in concentrations of major ions, trace elements, or nutrients were not observed between moderate (June) and low-flow (July) sampling conditions (table 4).

Surface water at the Mill Brook tributary (SS-10), Lee River tributary (SS-6), and Lee River outlet (SS-5) were compared with similar samples collected in 1992 and 1999 (table 5). Concentrations of major ions, trace elements, and nutrients at these 3 sites are relatively similar over the past 11 years. Most metal concentrations were below reporting levels. Concentrations of metals with detectable levels were lower in 1999 and 2003 than in 1992.

Streambed Sediment

Of the 23 major ions and trace elements analyzed in streambed sediment, 18 were detected in all 5 sediment samples (table 6). Molybdenum and sodium were not detected in any samples; antimony was detected in one sample, beryllium was detected in two samples, and selenium was detected in four samples. Concentrations of arsenic, cadmium, chromium, copper, lead, nickel, and zinc were well below streambed-sediment-quality guidelines for the probable adverse effects to aquatic life (MacDonald and others, 2000; Canadian Council of Ministers of the Environment, 2003). Streambed-sediment guidelines were not available for the other elements. Streambed-sediment samples collected at the Mill Brook tributary, Lee River tributary, and Lee River outlet from the firing range were compared with similar samples collected in 1992 and 1999 (table 7). Substantial changes in concentrations were not noted over the 11 years. Generally higher concentrations in 2003 appear to be because of differences in particle-size distribution and organic content as indicated by percent moisture. Median moisture in streambed sediment was 71 percent in 2003, 36 percent in 1999, and 46 percent in 1992. Streambed sediments with high percent moisture generally have fine particle sizes and(or) high organic contents where trace elements tend to be concentrated (Brady, 1974).

Biologic

Biologic sampling was done to assess the overall surface-water quality of the EAFR. Biological data included benthic macroinvertebrate samples, fish-tissue samples, and bacteria counts from surface and ground water. The results of these analyses are compared to investigations from 1988, 1992, and 1999. (Vermont Department of Environmental Conservation, 1988; Bouwkamp, 1992; Goetz, 1999; and Ward, 1999).

Macroinvertebrates

Benthic macroinvertebrates were collected on June 18, 2003, at four stream sites to assess the biologic health of the streams (appendix 4). Three sites were in the Lee River watershed (SS-5, SS-6, and SS-12) and one site was on Steinhour Brook (SS-11). Total abundance for the 4 sites sampled was 4,240 or 212 specimens per 0.09 m^2 (1 ft^2). The greatest abundance of specimens was found at the Lee River outlet from the firing range (SS-5, fig. 2). A total of 84 taxa were identified from the 4 sites. The greatest taxa richness was found at Steinhour Brook (SS-11, fig. 2) located in a relatively remote area in the northeastern corner of EAFR (fig. 2).

In addition to abundance and taxa richness, two numeric indexes were calculated to evaluate water quality. The EPT richness index is the total number of taxa in the pollution-intolerant members of Ephemeroptera, Plecoptera, and Trichoptera (EPT). The highest EPT richness index was found at Steinhour Brook (SS-11) indicating that this stream had the best aquatic habitats and highest biological health. A tributary to the Lee River (SS-6) had the lowest EPT richness index, possibly relating to the intermittent nature of this stream. The Hilsenhoff Biotic Index (HBI) was used to rate water quality based on abundance of pollution-tolerant and intolerant macroinvertebrate species (Hilsenhoff, 1987). All site samples collected in 2003 had HBI values between 2 and 2.5. On a scale from 0 to 10, values from 0 to 3.5 are ranked as excellent water quality with no apparent organic pollution.

A comparison with historical data was done for the Lee River outlet (SS-5, fig. 2). The Vermont Department of Environmental Conservation (VTDEC) collected timed kick-net samples from about 0.5 mi west of the EAFR boundary in

Table 4a. Concentrations of dissolved major ions, trace elements, and nutrients in surface water during moderate and low-flow conditions at the Ethan Allen Firing Range in northern Vermont.

[Site locations shown on figure 2. Sample dates are in month, day and year (mm/dd/yy); All concentration units are in micrograms per liter (µg/L). The following compounds were below detection: aluminum, antimony, arsenic, beryllium, cadmium, chromium, cobalt, copper, lead, lithium, molybdenum, nickel, potassium, selenium, sodium, uranium, zinc; J = associated laboratory blank sample contains compound concentrations above method detection level but below reporting level, laboratory blank calcium concentrations are less than 3 percent of associated sample concentrations; E = estimated concentration, result less than reporting level; <, less than; --, no standard]

Site identifier	Flow conditions	Date site sampled (mm/dd/yy)	Major ions				Trace elements				
			Calcium	Chloride	Magnesium	Sulfate	Barium	Iron	Manganese	Silica	Strontium
SS-5	Moderate	06/05/03	J 11,000	570	2,100	4,900	5.6	< 100	7.2	5,500	42
	Low	07/30/03	15,000	< 200	2,900	5,400	6.2	E 23	5.4	6,400	57
SS-6	Moderate	06/04/03	J 3,600	2600	540	5,500	10	< 100	2.6	4,000	15
	Low	07/30/03	6,600	< 200	1,000	1,700	15	< 100	1.1	5,500	30
SS-10	Moderate	06/05/03	J 11,000	480	2,000	4,700	4.8	< 100	12	1,400	41
	Low	07/30/03	14,000	390	2,500	6,700	6.3	160	12	3,700	53
SS-11	Moderate	06/04/03	J 3,700	700	800	6,200	8.3	< 100	2.8	4,900	18
	Low	07/30/03	8,400	2,900	1,900	5,600	12	< 100	6.1	8,100	38
SS-12	Moderate	06/05/03	J 7,500	370	1,500	3,000	5.8	< 100	3.2	4,800	27
	Low	07/31/03	12,000	260	2,500	5,100	6.6	E 42	1.9	6,400	43
Summary statistics											
		Minimum	3,600	< 200	540	1,700	4.8	< 100	1.1	1,400	15
		Maximum	11,000	2,900	2,900	6,700	15	160	12	8,100	57
		Median	9,700	435	1,950	5,250	6.4	< 100	4.3	5,200	39
Guidelines or standards											
		MCL[1]	--	--	--	--	2,000	--	--	--	--
		SMCL[2]	--	250,000	--	250,000	2,000	300	50	--	--
		CCREM[3]	--	--	--	--	--	300	--	--	--

[1] Maximum Contaminant Level (MCL) established by the U.S. Environmental Protection Agency (2002a).

[2] Secondary Maximum Contaminant Level (SMCL) established by the U.S. Environmental Protection Agency (2002b).

[3] Canadian water-quality guidelines (CCREM) for the protection of freshwater aquatic life (Canadian Council of Resources and Environmental Ministers, 2003).

September 1988 (Vermont Department of Environmental Conservation, 1988). These data was compared to Surber samples collected east of the EAFR boundary in 1992 (Bouwkamp, 1992); 1999 (Ward, 1999), and July 2003. Because of differences in sampling methods (Surber and timed kick, and three replicates collected per sample in 1992 and 1999 compared to five replicates in 2003), the data are not directly comparable; however, data comparison still may indicate general changes in water quality. Taxa richness and EPT richness index were 38 and 21, respectively, in 2003 samples; 45 and 24.5, respectively, in 1988; 30 and 11, respectively, in 1992; and 20 and 13, respectively, in 1999 (fig. 13). These results probably indicate little change in the biological condition of the Lee River at the EAFR between 1988 and 2003. Any differences in taxa richness and EPT index are most likely the result of a combination of natural variability and sampling methods.

Fish Tissue

Whole-body-composite tissue samples of brook trout were collected at three stream sites; Steinhour Brook (SS-11, fig. 2), and two sites on the Lee River (SS-5 and SS-12, fig. 2). Of the 4 major ions and 19 trace elements analyzed for in fish tissue, 13 were detected in all 3 samples (table 8). Antimony, arsenic, beryllium, lithium, molybdenum, and uranium were not detected in any samples. Little difference in concentrations of trace elements was noted between samples below the Impact Area on Lee River (SS-12), at the outlet of Lee River from EAFR (SS-5), or from Steinhour Brook (SS-11). Concentrations of arsenic, cadmium, lead, nickel, and selenium in fish-tissue samples were well below USEPA screening criteria for protection of human health (U.S. Environmental Protection Agency, 1995) and(or) U.S. Food and Drug Administration (1993) “levels of concern” in shellfish. A comparison of

Table 4b. Concentrations of nutrients in surface water during moderate and low-flow conditions at the Ethan Allen Firing Range in northern Vermont.

[Site locations shown on figure 2. The sample date is in month, day, year (mm/dd/yy). All concentration units are in mg/L, milligrams per liter. NO_3, Nitrate; NO_2, Nitrite; The following compounds were below detection: aluminum, antimony, arsenic, beryllium, cadmium, chromium, cobalt, copper, lead, lithium, molybdenum, nickel, potassium, selenium, sodium, uranium, zinc; <, less than]

Site identifier	Flow conditions	Date site sampled (mm/dd/yy)	Nutrients									
			Total ammonia	Dissolved ammonia	Total ammonia plus organic nitrogen	Dissolved ammonia plus organic nitrogen	Total NO_3+NO_2	Dissolved NO_3+NO_2	Total nitrogen)	Dissolved nitrogen	Total phosphorus	Dissolved orthophosphate
SS-5	Moderate	06/05/03	0.043	0.027	< 0.24	< 0.24	0.086	0.086	0.129	0.113	< 0.010	0.012
	Low	07/30/03	< .024	< .024	< .24	< .24	.09	.093	.102	.105	< .010	< .010
SS-6	Moderate	06/04/03	.050	.054	< .24	.24	.013	.011	.063	.251	< .010	.052
	Low	07/30/03	< .024	< .024	< .24	< .24	.098	.095	.098	.095	< .010	< .010
SS-10	Moderate	06/05/03	.06	.047	.41	.37	< .010	< .010	.410	.375	.011	< .010
	Low	07/30/03	.033	.038	.38	.32	< .010	< .010	.380	.325	.013	< .010
SS-11	Moderate	06/04/03	.037	.049	< .24	< .24	.035	.034	.072	.083	< .010	.014
	Low	07/30/03	< .024	< .024	< .24	< .24	.140	.140	.140	.140	< .010	< .010
SS-12	Moderate	06/05/03	.034	.032	< .24	< .24	.037	.031	.071	.063	< .010	< .010
	Low	07/31/03	< .024	< .024	< .24	< .24	.091	.059	.091	.059	< .010	< .010
Summary statistics												
		Minimum	< 0.024	< 0.024	< 0.24	< 0.24	< 0.010	< 0.010	0.063	0.063	< 0.010	< 0.010
		Maximum	.06	.054	.41	.37	.140	.140	.410	.375	.013	.052
		Median	.033	.029	< .24	< .24	.061	.046	.106	.110	< .010	< .010

brook-trout samples, collected at the outlet of the firing range in 1992 (Bouwkamp, 1992) and 2003, indicates metal concentrations may have decreased over the past 11 years (table 9). Concentrations of cadmium, chromium, copper, and lead were all about an order-of-magnitude lower in 2003 than in 1999. Concentrations of aluminum, selenium, and zinc were similar in 2003 to 1992 samples, only iron was 3 times higher in 2003 sample. Because some of the brook trout caught in 2003 may have been stocked, a sample of brown trout (a species of fish not commonly stocked) collected in 2003 is included in the comparison. Similar concentrations of trace elements in fish tissues of brown and brook trout collected in 2003 most likely indicate that the lower trace-metal concentrations in the brook-trout samples are not an artifact of fish stocking. Native, reproducing (non-stocked) trout found at the site generally indicates high-quality water.

Bacteria

Fecal indicator bacteria, *Escherichia coli* (*E-coli*), in water indicates the possible presence of pathogens. *E-coli* concentrations in water samples were well below the State of Vermont (77 counts/100 mL) swimming guidelines at all five stream sites at moderate- and low-flow conditions, and all 10 ground-water observation wells (Vermont Water Resource Board, 2004). *E-coli* counts were higher in stream samples during low-flow conditions (median 20/100 mL) than during moderate-flow conditions (median <10/100 mL). *E-coli* counts were above detection levels (10/100 ml) at four surface-water sites (SS-5, SS-6, SS-10, SS-11) during low-flow conditions, and above detection levels at moderate-flow conditions at one site directly below a beaver dam (SS-10). Any detection of *E-coli* warrants concern for potable waters (Wilde and others, 1998). *E-coli* were not detected in ground-water samples.

Table 5. Comparison of surface-water chemistry at three stream sites, Ethan Allen Firing Range in northern Vermont, 1992, 1999, and 2003.

[Site locations shown on figure 2. *1992 and 1999 data does not indicate if analysis is for total or dissolved nutrients; mg/L, milligrams per liter; µg/L, micrograms per liter; NO_3, Nitrate; NO_2, Nitrite; E = estimated concentrations; <, less than; --, no data]

		Major ions			Trace elements		Nutrients									
Site identifier	Year data collected	Calcium (µg/L)	Magnesium (µg/L)	Sulfate (µg/L)	Barium (µg/L)	Iron (µg/L)	Total ammonia (mg/L)	Dissolved ammonia (mg/L)	Total ammonia plus organic nitrogen (mg/L)	Dissolved ammonia plus organic nitrogen (mg/L)	Total $NO_3 + NO_2$ (mg/L)	Dissolved $NO_3 + NO_2$ (mg/L)	Total nitrogen (mg/L)	Dissolved nitrogen (mg/L)	Total phosphorus (mg/L)	Dissolved orthophosphate (mg/L)
[2]SS-5	*1992	17,000	3,000	7,200	30	< 50	<.05	--	<.05	--	.12	--	.12	--	.02	--
[1]SS-5	*1999	13,400	2,690	7,600	< 14.1	62.8	.02	--	< .24	--	.14	--	.16	--	< .01	--
SS-5	2003	15,000	2,900	5,400	6.2	E 23	< 0.024	< 0.024	< 0.24	< 0.24	0.09	0.093	0.09	0.093	< 0.01	< 0.01
[2]SS-6	*1992	12,000	1,800	11,000	40	130	.06	--	.08	--	.49	--	.57	--	.02	--
[1]SS-6	*1999	4,380	669	7,300	< 14.1	< 44	.04	--	< .24	--	.02	--	.06	--	< .01	--
SS-6	2003	6,600	1,000	1,700	15.0	< 100	< .024	< .024	< .24	< .24	.098	.095	.098	.095	< .01	< .01
[2]SS-10	*1992	10,000	1,800	2,700	50	270	.05	--	.34	--	.07	--	.41	--	< .02	--
[1]SS-10	*1999	9,070	1,790	7,000	< 14.1	180	.05	--	.45	--	< .01	--	.45	--	.02	--
SS-10	2003	14,000	2,500	6,700	6.3	160	.033	.038	.38	.32	< .01	< .01	.38	.32	.013	< .01

[1]Goetz, 1999.

[2]Buowkamp, 1992.

Table 6. Concentrations of major ions and trace elements in streambed sediment at the Ethan Allen Firing Range in northern Vermont.

[Site locations are shown on figure 2. The sample date is in month, day, year (mm/dd/yy). Concentration units are in mg/kg, milligrams per kilogram dry weight. E = estimated result, result is less than reporting level; J = associated laboratory blank sample contains compound concentrations above method detection level but below reporting level, laboratory blank concentrations are less than 0.1 percent of associated sample concentrations; ND = not detected at method detection level; Molybdenum, and sodium were below method detection levels in all samples; --, no standard]

Site identifier	Date site sampled (mm/dd/yy)	Moisture (percent)	Major ions			Trace elements						
			Calcium	Magnesium	Potassium	Aluminum	Antimony	Arsenic	Barium	Beryllium	Cadmium	Chromium
SS-5	07/04/03	60	J 4,000	3,600	1,300	J 9,900	ND	E 2.3	J 45	ND	E 0.34	J 10
SS-6	07/04/03	71	J 3,500	3,700	1,500	J 15,000	E 0.36	E 2.2	J 84	E 0.87	E .76	J 13
SS-10	07/04/03	73	J 4,700	2,400	E 800	J 6,800	ND	E 1.0	J 38	ND	E .29	J 7.6
SS-11	07/04/03	69	J 4,000	2,700	1,200	J 11,000	ND	E 1.9	J 73	E .70	E .94	J 11
SS-12	07/04/03	84	J 7,500	3,600	E 1,500	J 12,000	ND	E 3.4	J 110	ND	E 1.20	J 14
Summary statistics												
Minimum	--	60	3,500	2,400	800	6,800	ND	1.0	38	ND	0.29	7.6
Maximum	--	84	7,500	3,700	1,500	15,000	0.36	3.4	110	0.87	1.20	14
Median	--	71	4,000	3,600	1,300	11,000	ND	2.2	73	ND	.76	11
Guidelines or standards												
		CCREM[1]	--	--	--	--	--	17	--	--	3.5	90

Table 6. Concentrations of major ions, and trace elements in streambed sediment at the Ethan Allen Firing Range in northern Vermont.—Continued

[Site locations are shown on figure 2. The sample date is in month, day, year (mm/dd/yy). Concentration units are in mg/kg, milligrams per kilogram dry weight. E = estimated result, result is less than reporting level; J = associated laboratory blank sample contains compound concentrations above method detection level but below reporting level, laboratory blank concentrations are less than 0.1 percent of associated sample concentrations; ND = not detected at method detection level; Molybdenum, and sodium were below method detection levels in all samples; --, no standard]

Site identifier	Date site sampled (mm/dd/yy)	Trace elements										
		Cobalt	Copper	Iron	Lead	Lithium	Manganese	Nickel	Selenium	Strontium	Uranium	Zinc
SS-5	07/04/03	J 9.9	J 13	J 22,000	J 9.5	15	J 680	J 12	E 0.75	J 18	E 0.95	70
SS-6	07/04/03	J 24	J 16	J 21,000	J 12	19	J 1,000	J 20	E 1.1	J 20	E 1.4	150
SS-10	07/04/03	J 4.9	J 9.4	J 12,000	J 12	E 9.6	J 210	J 7.6	ND	J 20	E .72	50
SS-11	07/04/03	J 14	J 11	J 16,000	J 10	E 14	J 1,300	J 15	E 1.0	J 22	E 1.3	150
SS-12	07/04/03	J 17	J 19	J 26,000	J 17	E 16	J 2,800	J 19	E 1.9	J 34	E 2.0	140
Summary statistics												
	Minimum	4.9	9.4	12,000	9.5	9.6	210	7.6	ND	18	0.72	50
	Maximum	24	19	26,000	17	19	2,800	20	1.9	34	2.0	150
	Median	14	13	21,000	12	15	1,150	17	1.0	21	1.35	145
Guidelines or standards												
	CCREM[1]	--	197	--	91.3	--	--	35.9	--	--	--	315

[1] Canadian water-quality guidelines (CCREM) for the protection of freshwater aquatic life (Canadian Council of Resources and Environmental Ministers, 2003).

Table 7. Comparison of trace-element concentrations in streambed sediment collected at the Ethan Allen Firing Range in northern Vermont, 1992, 1999, and 2003.

[All concentration units are in mg/kg, milligrams per kilogram dry weight. E = estimated result, result is less than reporting level; J = associated laboratory blank sample contains compound concentrations above method detection level but below reporting level; <, less than; location of sites shown on figure 2; --, no standard]

Site identifier	Year sampled	Trace elements													Moisture (percent)
		Aluminum	Antimony	Arsenic	Barium	Beryllium	Cadmium	Chromium	Copper	Iron	Lead	Nickel	Selenium	Zinc	
[2]SS-5	1992	4,600	< 1.0	.95	18	< .50	< 0.25	5.6	7.1	11,000	4.8	8.6	< .50	34	22
[1]SS-5	1999	3,400	< 4	< 4	< 20	< 1	1	50	< 3	11,000	< 10	14	< 4	23	10.8
SS-5	2003	J 9,900	< 0.037	E 2.3	J 45	< 0.24	E 0.34	J 10	J 13	J 22,000	J 9.5	J 12	E 0.75	70	60
[2]SS-6	1992	8,780	< 1.0	.99	49	< .50	< .25	8.7	10	16,036	11	11	< .50	63	46
[1]SS-6	1999	7,400	< 4	< 4	< 20	< 1	1	66	11	15,000	10	18	< 4	67	35.8
SS-6	2003	J 15,000	E .36	E 2.2	J 84	E .87	E 0.76	J 13	J 16	J 21,000	J 12	J 20	E 1.1	150	71
[2]SS-10	1992	6,800	< 1.0	3.2	55	< .50	.37	8.5	8.9	13,000	16	9.4	.7	70	76
[1]SS-10	1999	6,200	< 4	< 4	< 20	< 1	1	50	6.0	12,000	< 10	11	< 4	30	36.9
SS-10	2003	J 6,800	< .054	E 1	J 38	< .35	E 0.29	J 7.6	J 9.4	J 12,000	J 12	J 7.6	< .92	50	73
Guideline or standard															
	CCREM[3]	--	--	17	--	--	3.5	90	197	--	91.3	--	--	315	--

[1]Goetz, 1999.

[2]Bouwkamp, 1992.

[3]Canadian water-quality guidelines (CCREM) for the probable effect level (PEL) for the protection of freshwater aquatic life (Canadian Council of Resources and Environmental Ministers, 2003).

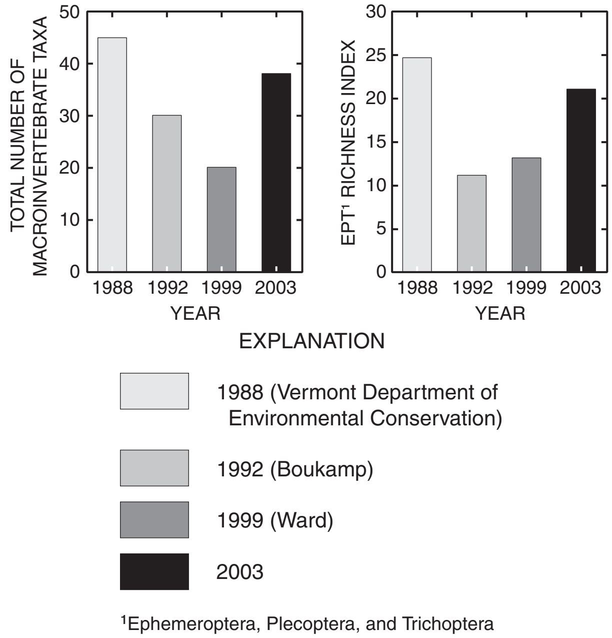


Figure 13. Comparison of macroinvertebrate taxa and Ephemeroptera, Plecoptera, and Trichoptera (EPT) richness index collected over a 15-year span from the Lee River at the outlet of the Ethan Allen Firing Range (SS-5) in northern Vermont.

Table 8. Concentrations of major ions and trace elements in fish tissue at the Ethan Allen Firing Range in northern Vermont.

[Site locations are shown on figure 2. The sample date is in month, day, year (mm/dd/yy). Units are in mg/kg wet weight, milligrams per kilogram. Samples are five fish composites of 5 to 7.5 inch long brook trout (*Salvenlinus fontinalis*). E = estimated result, result is less than reporting level; J = associated laboratory blank sample contains compound concentrations above method detection level but below reporting level, laboratory blank strontium and calcium concentrations are less than 3 percent of associated sample concentrations, laboratory blank chromium concentrations are less than 18 percent of associated sample concentrations; antimony, arsenic, beryllium, lithium, molybdenum, and uranium concentrations were below method detection levels in all samples.]

Site identifier	Date site sampled (mm/dd/yy)	Major ions				Trace elements			
		Calcium	Magnesium	Potassium	Sodium	Aluminum	Barium	Cadmium	Chromium
SS-5	06/10/03	J 11,000	390	3,400	720	E 9.6	E 0.59	E 0.039	J 0.32
SS-11	06/10/03	J 7,000	370	3,600	700	32	1.10	E .068	J .4
SS-12	06/11/03	J 2,000	240	2,800	650	29	E .45	E .046	J .38

Site identifier	Date site sampled (mm/dd/yy)	Trace elements								
		Cobalt	Copper	Iron	Lead	Manganese	Nickel	Selenium	Strontium	Zinc
SS-5	06/10/03	E 0.06	1.3	42	E 0.021	5.8	E 0.08	0.53	J 9.9	25
SS-11	06/10/03	.17	1.1	87	E .08	8.8	.23	E .46	J 9.3	39
SS-12	06/11/03	.11	1.3	79	E .034	4.1	.12	.52	J 2.8	18

Table 9. Comparison of trace-element concentrations in fish tissue from the Lee River at the Ethan Allen Firing Range in northern Vermont.

[Site locations are shown in figure 2. All concentration units are in milligrams per kilogram (mg/kg) wet weight. Site SS-5 2003 sample is a 5-fish composite of 6 to 7 inch long brook trout (*Salvenlinus fontinalis*); Site SS-5 2003 Duplicate is a 5-fish composite of 5-10 inch long brown trout (*Salmo tratta*); Site SS-5 1992 sample is a composite of 3-6 inch long brook trout (*Salvenlinus fontinalis)*; E = estimated result, result is less than reporting level; J = associated laboratory blank sample contains compound concentrations above method detection level but below reporting level; ND = not detected at method detection level; <, less than]

Site identifier	Year sampled	Species	Trace elements						
			Aluminum	Antimony	Arsenic	Barium	Beryllium	Cadmium	Chromium
[1]SS-5	1992	Brook trout	21.5	< 2	< 100	< 1.97	0.197	.182	7.03
SS-5	2003	Brook trout	E 9.6	ND	ND	E 0.59	ND	E 0.039	J 0.32
DUPLICATE	2003	Brown trout	100	ND	ND	E .91	ND	E .038	J .78

Site identifier	Year sampled	Species	Trace elements					
			Copper	Iron	Lead	Nickel	Selenium	Zinc
[1]SS-5	1992	Brook trout	14.3	14.3	3.78	< 9.85	.53	37
SS-5	2003	Brook trout	1.3	42	E 0.021	0.08	0.53	25
DUPLICATE	2003	Brown trout	1.3	310	E .061	.99	E .47	16

[1] Buowkemp, 1992.

Ground Water

Ten ground-water samples were collected in July 2003 from wells in stratified-drift aquifers (fig. 2) in the Lee River and Mill Brook watersheds. The bedrock wells installed for this study were low yielding (generally less than 0.06 L/s) and may not have provided water-quality samples representative of bedrock water-supply wells in the region. Water-quality and physical characteristics of ground water are summarized in table 10. Ground water in most wells was slightly alkaline, pH ranged from 6.1 to 8.3 with a median of 7.5. Alkalinities in ground water (median 75 mg/L) were higher than in surface water (median 35 mg/L, table 2). The high alkalinities reflect the carbonate nature of some glacially derived source rock materials from the Lake Champlain Valley to the northwest. Dissolved oxygen concentrations were variable for ground water, ranging from 0.4 to 7.8 with a median value of 3.3 mg/L. Specific conductance, suspended solids, and turbidity (median 161 µS/cm, 49 mg/L, and 22 NTU, respectively) were slightly higher in ground water than in surface water. Values of dissolved solids (median 97 Mg/L, table 10) were similar to values measured in surface water (median 79 mg/L, table 2).

Concentrations of half of the 14 trace elements analyzed (arsenic, cadmium, chromium, lead, nickel, uranium, and zinc) were below detection levels. Barium, cobalt, copper, iron, manganese, molybdenum, and strontium were the only metals detected in ground-water samples (table 11). Cobalt (3.1 and 2.5 µg/L) and iron (230 and 27,000 µg/L), and were detected only at 2 wells (VT-JEW 127 and VT-JEW 129) near Mill Brook, and copper (2 µg/L) was detected at one of these wells (VT-JEW 127). These same two wells also had higher concentrations of barium and manganese (from 2 to 10 times greater) than other ground-water samples. The higher concentrations of these trace elements are believed to be natural occurrences. The low occurrence of metals in ground water is probably due, in part, to the buffered nature (high alkalinity) and high pH of ground water in the EAFR stratified-drift aquifers.

Concentrations of nutrients in ground water were at or below detection levels in most samples (table 12). Ammonia and ammonia plus organic nitrogen were only found in ground-water samples in the Mill Brook watershed. Wetlands and beaver ponds in this low-gradient watershed may explain the presences of organic nitrogen in both surface and ground water in this area. Total inorganic nitrogen was essentially all dissolved, ranging from below detection (0.010) to 0.26 mg/L. Phosphorus was associated with suspended sediments, and concentrations ranged from below detection (0.010) to 0.43 mg/L.

Ground-water chemistry in the Mill Brook watershed, a low-gradient environment, generally had higher concentrations of dissolved trace elements and organic nitrogen than the Lee River watershed, a high-gradient environment. Concentrations of trace elements and nutrients were below USEPA drinking-water standards for all except one constituent in one well. The concentration of iron in a well sample (VT-JEW 129) from the Mill Brook watershed was 27,000 µg/L (table 11), well above the 300 µg/L USEPA safe drinking-water guideline. VOCs and SVOCs (appendix 2) were not detected in any samples.

Table 10. Summary of physical properties and water-quality characteristics of ground water at the Ethan Allen Firing Range in northern Vermont.

[Site locations shown on figure 2. The sample date is in month, day, year (mm/dd/yy). EC, specific conductance, in µS/cm, microsiemens per centimeter; °C, degrees Celsius; NTU, nephelometric turbity units; DO, dissolved oxygen; mg/L, milligrams per liter; --, no standard]

Site identifier	Date site sampled (mm/dd/yy)	Physical properties						Water-quality characteristics		
		EC (µS/cm)	pH (standard units)	Water temperature (°C)	Turbidity (NTU)	DO (mg/L)	Alkalinity (mg/L)	Dissolved solids (mg/L)	Suspended solids (mg/L)	Total solids (mg/L)
VT-JEW 121	07/24/03	103	6.55	9.4	3.8	6.70	38	78	45.5	67
VT-JEW 123	07/25/03	323	7.57	10.0	3.0	.55	138	173	5.1	160
VT-JEW 132	07/24/03	113	7.16	13.6	26.5	5.07	54	76	62.7	82
VT-JEW 125	07/25/03	173	8.10	9.3	16.3	.45	82	104	39.8	109
VT-UHW 110	07/21/03	231	8.31	11.0	76.6	2.29	114	143	229	405
VT-UHW 111	07/22/03	149	7.50	14.4	63.9	4.40	74	99	397	198
VT-JEW 126	07/22/03	197	8.34	11.8	16.6	4.32	100	121	34.0	147
VT-JEW 127	07/24/03	125	6.15	12.3	48.7	1.86	58	88	52.0	111
VT-JEW 128	07/23/03	143	7.80	--	2.8	7.83	68	95	4.9	81
VT-JEW 129	07/23/03	211	6.38	9.8	128	1.03	76	85	138	239
Summary statistics										
	Minimum	103	6.15	9.3	2.8	0.45	38	76	4.9	67
	Maximum	323	8.34	14.4	128	7.83	138	173	397	405
	Median	161	7.54	11	22	3.3	75	97	49	129
Guidelines or standards										
	MCL[1]	--	--	--	--	--	--	--	--	--
	SMCL[2]	--	6.5–8.5	--	--	--	--	500	--	--

[1] Maximum Contaminant Level (MCL) established by the U.S. Environmental Protection Agency (2002a).

[2] Secondary Maximum Contaminant Level (SMCL) established by the U.S. Environmental Protection Agency (2002b).

Table 11. Concentrations of dissolved major ions and trace elements in ground water at the Ethan Allen Firing Range in northern Vermont.

[Site locations are shown in figure 2. The sample date is in month, day, year (mm/dd/yy). All units are in µg/L, micrograms per liter. The following trace elements were below detection: aluminum, antimony, arsenic, beryllium, cadmium, chromium, lead, lithium, nickel, selenium, uranium, zinc; E = estimated value, result less than reporting limit; <, less than; --, no standard]

Site identifier	Date site sampled (mm/dd/yy)	Major ions								Trace elements						
		Calcium	Magnesium	Sodium	Potassium	Sulfate	Chloride	Fluoride	Silica	Barium	Cobalt	Copper	Iron	Manganese	Molybdenum	Strontium
VT-JEW 121	07/24/03	12,000	2,400	E 3,800	E 920	7,000	1,000	< 200	6,800	2.5	E 0.04	E 0.24	< 100	10	E 0.09	49
VT-JEW 123	07/25/03	41,000	8,700	E 3,200	E 1,600	370	410	< 200	9,700	3.9	E .53	< 2.0	< 100	190	E .66	170
VT-JEW 132	07/24/03	16,000	2,900	< 5,000	E 500	5,100	300	< 200	7,300	2.2	E .06	E 0.55	E 70	5.9	E .16	58
VT-JEW 125	07/25/03	24,000	5,100	E 2,700	E 2,700	6,800	400	< 200	6,900	3.2	E .19	< 2.0	E 30	92	2.5	82
VT-UHW 110	07/21/03	33,000	3,700	7,500	3,000	6,500	7,000	< 200	8,400	8.7	E .15	E 1.5	< 100	41	2.7	83
VT-UHW 111	07/22/03	23,000	3,300	E 1,400	E 2,200	6,200	450	< 200	8,300	4.2	E .16	E .41	< 100	50	E .71	67
VT-JEW 126	07/22/03	27,000	6,700	E 2,400	4,000	12,300	3,100	< 200	8,700	5.7	E .36	E .25	< 100	190	4.8	80
VT-JEW 127	07/24/03	17,000	3,800	E 1,300	E 780	7,500	310	< 200	10,000	14	3.1	2.0	230	1,000	E .08	67
VT-JEW 128	07/23/03	21,000	3,400	E 1,900	E 1,800	11,500	650	< 200	9,100	3.1	E .06	E .17	< 100	3.1	E .26	76
VT-JEW 129	07/23/03	20,000	2,700	< 5,000	E 1,700	9,400	500	200	8,300	24	2.5	< 2.0	27,000	460	E .37	80
Summary statistics																
	Minimum	12,000	2,400	< 5,000	500	6,200	310	< 200	6,800	2.2	0.04	< 2	< 100	3.1	0.08	49
	Maximum	41,000	8,700	7,500	4,000	12,300	7,000	200	10,000	24	3.1	2.0	27,000	1,000	4.8	170
	Median	22,000	3,550	2,150	1,750	8,450	575	< 200	8,350	4.0	.17	.24	< 100	71	.51	78
Guidelines or standards																
	MCL[1]	--	--	--	--	--	--	4,000	--	2,000	--	1,300	--	--	--	--
	SMCL[2]	--	--	--	--	250,000	250,000	2,000	--	--	--	1,000	300	50	--	--

[1] Maximum Contaminant Level (MCL) established by the U.S. Environmental Protection Agency (2002a).

[2] Secondary Maximum Contaminant Level (SMCL) established by the U.S. Environmental Protection Agency (2002b).

Table 12. Concentrations of nutrients in ground water at the Ethan Allen Firing Range in northern Vermont.

[Site locations are shown on figure 2. The sample date is in month, day, year (mm/dd/yy). All concentration units are in mg/L, milligrams per liter; <, less than; NO_3, nitrate; NO_2, nitrite]

Site identifier	Date site sampled (mm/dd/yy)	Nutrients										
		Total ammonia	Dissolved ammonia	Total ammonia plus organic nitrogen	Dissolved ammonia plus organic nitrogen	Total NO_3+ NO_2	Dissolved NO_3 + NO_2	Total nitrogen	Dissolved nitrogen	Total phosphorus	Dissolved phosphorus	Dissolved orthophos-phate
VT-JEW 121	07/24/03	< 0.024	< 0.024	< 0.24	< 0.24	0.260	0.260	0.260	0.260	0.093	< 0.010	< 0.010
VT-JEW 123	07/25/03	< .024	< .024	< .24	< .24	.078	.081	.078	.081	.013	< .010	< .010
VT-JEW 132	07/24/03	< .024	< .024	< .24	< .24	.110	.100	.110	.100	.110	< .010	< .010
VT-JEW 125	07/25/03	< .024	< .024	< .24	< .24	.037	.037	.037	.037	.068	< .010	< .010
VT-UHW 110	07/21/03	< .024	< .024	< .24	< .24	< .010	.110	< .010	.110	< .010	.012	< .010
VT-UHW 111	07/22/03	< .024	< .024	< .24	< .24	.032	.033	.032	.033	.430	< .010	.011
VT-JEW 126	07/22/03	< .024	< .024	< .24	< .24	.170	.190	.170	.190	.069	< .010	< .010
VT-JEW 127	07/24/03	.046	.051	< .24	< .24	.100	.110	.146	.161	.077	< .010	< .010
VT-JEW 128	07/23/03	< .024	< .024	< .24	< .24	.160	.150	.160	.150	< .010	< .010	< .010
VT-JEW 129	07/23/03	.420	.380	.57	.58	.057	< .010	.627	.580	.240	< .010	< .010
Summary statistics												
	Minimum	< 0.024	< 0.024	< 0.24	< 0.24	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
	Maximum	.420	.380	.57	.58	.260	.260	.627	.580	.430	.012	.011
	Median	< .024	< .024	< .24	< .24	.089	.105	.128	.130	.073	< .010	< .010

Summary

The Ethan Allan Firing Range (EAFR) in the Green Mountains of northern Vermont has been used for weapons training since 1926. The U.S. Geological Survey, in cooperation with the Vermont Army National Guard, designed and implemented a base-wide study of the hydrogeologic framework and the overall effects of military-training activities on water quality. Field activities for this study were conducted from October 2002 through December 2003.

Altitudes at the site range from about 213 to 1,122 m (700 to 3,680 ft) above NAVD 88, and the physiography is characterized by narrow east-west trending valleys that bisect the regional north-south trend of the Green Mountains. Most of the facility is contained within, and bounded by, the drainage that makes up the Lee River watershed. The 45.4-km^2 (17.5 mi^2) facility is sparsely populated, consisting of only a few offices and barracks, and supports a wide variety of wildlife. Weapons-training activities are conducted throughout the year at the facility, and historically at more than 10 firing ranges onsite. The use of explosive ammunition is limited to an Impact Area in the center of the Lee River Valley.

The headwaters of the Lee River and Mill Brook drain the west flank of the central ridge of the Green Mountains. From December 17, 2002, through December 16, 2003, streamflow in the Lee River ranged from a daily maximum flow of 10 m^3/s (353 ft^3/s) on November 20, 2003, to a low flow of 0.13 m^3/s (4.6 ft^3/s) on July 19 and 20, 2003, and September 15 and 19, 2003. The mean streamflow was 0.72 m^3/s (25 ft^3/s) and the runoff for the year was 85.8 cm (34 in). Comparison with streamflow in a nearby watershed with a long-term record indicates that the Lee River streamflow during the study was probably about 10 percent above normal. The Lee River watershed, on the western slopes of the Green Mountains, received less precipitation and had less annual runoff than Ranch Brook on the eastern slope of the Green Mountains for the study period.

The Lee River maintained a relatively high streamflow during dry periods (as compared to other nearby similar-sized watersheds), notably July and September 2003. This comparison indicates that there is likely a large ground-water contribution to streamflow during periods of low recharge. The Lee River Valley contains a large area of relatively permeable stratified-drift deposits that act as storage for ground-water resources.

The EAFR is underlain by fine- to medium-grained micaeous metamorphic rocks consisting of low-grade granofels and phyllites. The bedrock-well yields in these rocks are generally low, typically 23 L/min (6 gal/min) or less, but may be greater in fracture zones or where minerals more susceptible to weathering produce more porous rock. The textural and compositional differences in the mapped bedrock units (Pinnacle and Underhill Formations) are enough to define mapable rock units, but generally do not create regional variations in hydraulic properties of the bedrock aquifer underlying the EAFR.

The Lee River Valley floor is capped by a thin layer of stratified drift, consisting of well-sorted sand and gravel. Beneath this coarse cap, sand grades to poorly sorted cobble, gravel, and pebble gravel with sand. In some areas, a meter of clay locally divides the coarse cobble gravels and sands. Thick deposits, up to about 18 m (60 ft) thick of fine sand and silt, lie beneath this clay at the eastern extent of the valley floor. At the western boundary of the EAFR, the unconsolidated aquifer consists of very fine sand and silt beneath a coarse-streambed-sediment cap. The overall direction of ground-water flow in the Lee River and Mill Brook Valleys is east to west as indicated by water-table contours.

The stratified-drift deposits in the Mill Brook Valley grade from coarse pebble gravel, cobble gravel, and coarse sand on the east to clay towards the west side of the valley. The coarse deposits at ground surface in the Lee River Valley are not present in the Mill Brook Valley. Maximum thickness of stratified-drift deposits in the Mill Brook Valley is generally about 18 m (60 ft) but locally may be greater. Ground-water gradients and hydraulic conductivities in the Lee River Valley are greater than those in the Mill River Valley. As a result, ground-water flow in the Lee River Valley is estimated to be approximately 0.2 to 0.6 m/d (0.6 to 2 ft/d), and in the Mill River Valley is estimated to be 0.2 m/d (0.6 ft/d) or less.

Ground-water samples were collected during July 2003, while surface-water samples were collected during moderate-flow conditions in June 2003 and during low-flow conditions in July 2003. The regional surface- and ground-water quality of the base reflects the rural nature of the site and the buffering effect of the glacial deposits of the region. A high abundance and diversity of aquatic macroinvertebrates, particularly pollution-intolerant species, indicate that steams had excellent biological health. Of particular interest is the presence of native-trout populations, which are intolerant of degraded water quality.

Comparisons between surface water, streambed sediment, and biological samples collected in 2003 to earlier studies of the EAFR indicate that water-quality conditions are similar or have improved over the past 15 years. The alkalinities and pH of surface and ground water are moderate to relatively high compared to other areas of New England. Sampling results indicate that overall water-quality conditions at the facility meet State and Federal guidelines. Concentrations of trace elements (except for iron in ground water from one well) and nutrients in surface water were below freshwater-quality guidelines for the protection of aquatic or human life at all sites. Concentrations of trace elements in streambed sediments and fish tissue were also well below guidelines for the probable adverse effects to aquatic or human health. Concentrations of *Escherichia-coli* in surface water were below swimming guidelines at all sites, but above detection levels at most surface sites during low-flow conditions, indicating surface water at the facility should not be used for drinking unless it is first treated. The buffered effect of the glacial sediments at

the EAFR likely contributes to the low occurrence of trace elements in surface and ground water. Volatile organic compounds and semivolatile organic compounds were not detected in any water samples.

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Appendixes 1–4

Appendix 1. Lithologic logs of wells and boring drilled at the Ethan Allen Firing Range in northern Vermont.

Well name	Depth below land surface (meters)	Lithologic description of material
VT-JEA 1	0–0.9	disturbed gravels
	0.9–3.0	very fine to coarse sand, pebbles
	3.0–3.3	well sorted clay and silt
	3.3–6.1	coarse sand with few cobbles
	6.1–9.1	very fine sand
	9.1–10.6	cobble gravel
	10.6	till, end of hole 11.8 meters
VT-JEA 2	0–0.6	disturbed till
	0.6	till, end of hole 3.6 meters
VT-JEW 121	0–0.9	brown loam
	0.9–2.4	cobbles, sand
	2.4–18.2	silt, very fine sand
	18.2–19.5	small boulders, till
	19.5	bedrock, end of hole 19.5 meters
VT-JEW 122	0–0.9	brown loam
	0.9–2.4	cobbles, sand
	2.4	silt, very fine sand, end of hole 9.4 meters
VT-JEW 123	0–0.6	soil
	0.6–2.7	boulders, cobbles, pebbles
	2.7–7.6	medium sand
	7.6–9.1	cobbles
	9.1–10.6	small boulders
	10.6	till, end of hole 11.9 meters
VT-JEW 124	0–1.5	pebble gravel, medium sand
	1.5–2.1	cobbles, pebbles, silty gravel
	2.1–4.5	silty sand
	4.5–7.6	blue gray clay,
	7.6	cobble to pebble gravel, end of hole 23.2 meters
VT-JEW 125	0–1.2	Boulders, cobbles, pebbles
	1.2–2.1	Silty gravel
	2.1–2.4	cobbles
	2.4–2.7	very coarse sand
	2.7–3.4	clay
	3.4–12.5	fine sand and silt layers
	12.5	till, end of hole 14.9 meters
VT-JEW 126	0–2.7	cobbles and sand
	2.7–4.2	silty sand
	4.2–7.9	very coarse sand and granules
	7.9	till, end of hole 9.1 meters
VT-JEW 127	0–0.6	loam
	0.6–3.0	clay and pebbles (not till)
	3.0–4.5	fine sand
	4.5–6.1	blue clay
	6.1	cobble gravel, pebble gravel, boulders, end of hole 7.6 meters
VT-JEW 128	0–2.1	fine sand
	2.1–3.3	fine sand and cobbles
	3.3–5.1	fine sand
	5.1–7.0	pebbles and sand
	7.0	bedrock (no till), end of hole 7.0 meters
VT-JEW 129	0–3.6	unsorted pebbles, clay, sand
	3.6–12.8	very coarse sand
	12.8–15.8	cobbles and tight sand
	15.8	refusal in sand at 22.2 meters
VT-JEW130	0–2.2	unconsolidated sediment
	2.2	very fine-grained granofels in 2 to 15 millimeter layers with partings of chlorite phyllite, unfractured, end of hole 21.3 meters
VT-JEW 131	0–8.2	cobble and boulder gravel
	8.2	till with large boulders end of hole 16.7 meters
VT-JEW 132	0–1.5	pebble gravel, medium sand
	1.5–2.1	cobbles, pebbles, silty gravel
	2.1–3.9	silty sand
	3.9	blue gray clay, end of hole 4.6 meters

Appendix 1. Lithologic logs of wells and boring drilled at the Ethan Allen Firing Range in northern Vermont.—Continued

Well name	Depth below land surface (meters)	Lithologic description of material
VT-JEW 133	0	Quartz-chlorite-calcite-pyrite-garnet granofels and quartz-muscovite-chlorite medium-grained schist; calcite-pyrite layers parallel foliation; 2 liters per minute from high permeability zone where calcite and pyrite are weathered or removed to leave sponge-like rock, end of hole 9.1 meters
VT-JEW 134	0–0.9	medium sand
	0.9–6.7	cobbles, pebbles, medium sand
	6.7–9.1	very coarse sand
	9.1–9.4	clay
	9.4–11.2	cobbles, pebbles, sand
	11.2	cobbles, end of hole 13.4 meters
VT-JEW 135	0–2.1	medium sand and pebbles
	2.1–3.7	cobbles
	3.7–8.8	tightly wedged very fine sand
	8.8	boulders, till, end of hole 11.6 meters
VT-JEW 137	0–0.6	loam
	0.6–3.0	clay and pebbles (not till)
	3.0–4.5	fine sand
	4.5–6.1	blue clay
	6.1	cobble gravel
		end of hole 8.2 meters
VT-JEW 138	0–5.9	boulders and till
	5.9	rusty micaeous schist; rotton rock, saprolite, clay-filled fracture; water in porous green-gray calcareous granofels, end of hole 14.8 meters
VT-JEW 139	0–3.6	cobbles, pebbles, sand
	3.6–14.0	very coarse to coarse sand and pebbles
	14.0	medium sand with silt and pebbles, end of hole 18.9 meters
VT-JEW 140	0–3.6	cobbles, pebbles, sand
	3.6	very coarse to coarse sand and pebbles, end of hole 9.1 meters
VT-JEW 141	0–1.0	cobbles and sand
	1.0–11.2	very fine sand
	11.2–13.1	cobbles and small boulders
	13.1	till, refusal on bedrock at 14.0 meters
VT-UHW 110	0–1.8	cobble to pebble gravel
	1.8–4.2	silty pebble gravel
	4.2–5.7	medium to fine sand, coarse sand
	5.7	boulders, end of hole 5.7 meters
VT-UHW 111	0–1.8	cobbles, small boulders, sand
	1.8–3.6	pebbles and sand
	3.6	cobbles
	3.6–4.8	tightly wedged sand and pebbles
	4.8–8.8	sand and pebbles
	8.8	till, end of hole 10.1 meters
VT-UHW 112	0–3.6	cobbles, pebbles, sand
	3.6–4.2	1-centimeter pebbles and clay
	4.2–7.9	silty tightly wedged medium sand
	7.9	cobbles, till, end of hole 8.5 meters

Appendix 2. Well data in and near the Ethan Allen Firing Range in northern Vermont. Data from the Vermont Agency of Natural Resources.

[Well locations shown in figure 2. m, meters; L/min, liter/minute; --, no data]

Well number (m)	Well depth (m)	Yield (L/min)	Depth to water (m)	Overburden thickness (m)	Casing length (m)	Latitude			Longitude		
						Degrees	Minutes	Seconds	Degrees	Minutes	Seconds
BO11	72.3	170	--	--	19.2	44	26	45	72	53	43
BO16	60.4	30	--	--	21.0	44	26	41	72	53	51
BO28	53.0	23	--	--	24.4	44	26	40	72	53	50
BO15816	42.7	114	--	18.9	20.9	44	26	38	72	53	40
BO17524	83.8	95	--	12.8	17.1	44	26	40	72	54	22
JE1	47.9	227	1.5	18.3	18.3	44	28	51	72	56	46
JE8	91.5	114	--	--	11.0	44	26	50	72	55	29
JE10	60.4	19	--	--	8.2	44	26	49	72	56	22
JE43	44.2	19	--	--	20.4	44	28	22	72	57	29
JE67	38.1	114	--	--	9.1	44	26	50	72	56	34
JE94	121.3	19	--	--	14.0	44	29	5	72	57	41
JE95	121.0	30	--	--	9.8	44	29	2	72	57	42
JE111	74.1	57	--	--	32.3	44	26	39	72	54	56
JE124	68.0	4	--	--	26.2	44	27	2	72	54	52
JE12913	182.9	9	--	19.2	25.0	44	28	11	72	57	29
JE14374	92.4	19	--	31.4	32.3	44	27	3	72	56	16
JE17522	106.7	38	--	10.7	30.5	44	28	32	72	57	42
JE17523	236.3	19	--	49.4	54.9	44	28	13	72	57	23
JE17525	129.6	227	--	11.9	15.2	44	26	56	72	54	23
JE18303	76.2	34	--	5.2	24.4	44	26	43	72	54	43
JE18356	77.7	76	--	13.7	30.5	44	26	51	72	56	15
JE26778	97.9	11	1.5	22.3	--	44	28	42	72	56	16
UH12773	99.1	17	.0	1.5	18.3	44	30	0	72	54	23
UH12921	68.6	57	.0	4.0	18.3	44	29	55	72	54	20

Appendix 3. Constituents analyzed and reporting limits for analysis of water, streambed sediment, and fish tissue at the Ethan Allen Firing Range in northern Vermont.

[Constituent reporting levels for analysis of water (surface and ground) and solids (streambed sediment and fish tissue) collected at the Ethan Allen Firing Range. All constituents were analyzed in surface- and ground-water samples. Major ions and trace elements were analyzed in streambed sediment and fish-tissue samples. Units are in mg/L, milligrams per liter; NTU, nephelometric turbitiy units; µg/L, micrograms per liter; mg/kg, milligrams per kilogram]

Constituent	Media	Reporting limit	Units
Characteristics, nutrients, major ions			
Total dissolved solids	Water	5	mg/L
Total suspended solids	Water	.5	mg/L
Total solids	Water	5	mg/L
Turbidity (NTU)	Water	.05	NTU
Chloride dissolved	Water	.2	mg/L
Fluoride dissolved	Water	.2	mg/L
Sulfate dissolved	Water	.2	mg/L
Calcium	Solids	20	mg/kg
Calcium	Water	200	µg/L
Magnesium	Solids	20	mg/kg
Magnesium	Water	200	µg/L
Potassium	Solids	300	mg/kg
Potassium	Water	3,000	µg/L
Silica	Water	1,100	µg/L
Sodium	Solids	500	mg/kg
Sodium	Water	5,000	µg/L
Hydroxide alkalinity	Water	1	mg/L
Carbonate alkalinity	Water	1	mg/L
Bicarbonate alkalinity	Water	1	mg/L
Total alkalinity	Water	1	mg/L
Ammonia-Nitrogen dissolved	Water	.024	mg/L
Ammonia-Nitrogen total	Water	.024	mg/L
Ammonia plus organic nitrogen, dissolved	Water	.24	mg/L
Ammonia plus organic nitrogen, total	Water	.24	mg/L
$NO_3 + NO_2$ Nitrogen dissolved	Water	.01	mg/L
$NO_3 + NO_2$ Nitrogen total	Water	.01	mg/L
Orthophosphate as P dissolved	Water	.01	mg/L
Phosphorus as P dissolved	Water	.01	mg/L
Phosphorus as P total	Water	.01	mg/L
Trace elements			
Aluminum	Solids	10	mg/kg
Aluminum	Water	100	µg/L
Antimony	Solids	200	µg/kg
Antimony	Water	2	µg/L
Arsenic	Solids	500	µg/kg
Arsenic	Water	5	µg/L
Barium	Solids	1	mg/kg
Barium	Water	1	µg/L
Beryllium	Solids	0.5	mg/kg
Beryllium	Water	5	µg/L
Cadmium	Solids	100	µg/kg

Appendix 3. Constituents analyzed and reporting limits for analysis of water, streambed sediment, and fish tissue at the Ethan Allen Firing Range in northern Vermont.—Continued

[Constituent reporting levels for analysis of water (surface and ground) and solids (streambed sediment and fish tissue) collected at Ethan Allen Firing Range. All constituents were analyzed in surface- and ground-water samples. Major ions and trace elements were analyzed in streambed sediment and fish-tissue samples. Units are in mg/L, milligrams per liter; NTU, nephelometric turbitiy units; µg/L, micrograms per liter; mg/kg, milligrams per kilogram]

Constituent	Media	Reporting limit	Units
	Trace elements--Continued		
Cadmium	Water	1	µg/L
Chromium	Solids	200	ug/kg
Chromium	Water	2	µg/L
Cobalt	Solids	100	ug/kg
Cobalt	Water	1	µg/L
Copper	Solids	200	ug/kg
Copper	Water	2	µg/L
Iron	Solids	10	mg/kg
Iron	Water	100	µg/L
Lead	Solids	100	ug/kg
Lead	Water	1	µg/L
Lithium	Solids	5	mg/kg
Lithium	Water	10	µg/L
Manganese	Solids	1	mg/kg
Manganese	Water	1	µg/L
Molybdenum	Solids	2	mg/kg
Molybdenum	Water	2	µg/L
Nickel	Solids	100	ug/kg
Nickel	Water	2	µg/L
Selenium	Solids	500	ug/kg
Selenium	Water	5	µg/L
Strontium	Solids	1	mg/kg
Strontium	Water	10	µg/L
Uranium	Solids	100	ug/kg
Uranium	Water	1	µg/L
Zinc	Solids	1,000	ug/kg
Zinc	Water	10	µg/L
	Volatile organic compounds		
Ethylbenzene	Water	1	µg/L
Styrene	Water	1	µg/L
cis-1,3-Dichloropropene	Water	1	µg/L
trans-1,3-Dichloropropene	Water	1	µg/L
n-Propylbenzene	Water	1	µg/L
n-Butylbenzene	Water	1	µg/L
4-Chlorotoluene	Water	1	µg/L
1,4-Dichlorobenzene	Water	1	µg/L
1,2-Dibromoethane	Water	1	µg/L
Acrolein	Water	5	µg/L
Allyl Chloride	Water	1	µg/L
1,2-Dichloroethane	Water	1	µg/L
Propionitrile	Water	4	µg/L
Acrylonitrile	Water	1	µg/L
Vinyl Acetate	Water	1	µg/L
4-Methyl-2-pentanone	Water	5	µg/L
1,3,5-Trimethylbenzene	Water	1	µg/L

Appendix 3. Constituents analyzed and reporting limits for analysis of water, streambed sediment, and fish tissue at the Ethan Allen Firing Range in northern Vermont.—Continued

[Constituent reporting levels for analysis of water (surface and ground) and solids (streambed sediment and fish tissue) collected at Ethan Allen Firing Range. All constituents were analyzed in surface- and ground-water samples. Major ions and trace elements were analyzed in streambed sediment and fish-tissue samples. Units are in mg/L, milligrams per liter; NTU, nephelometric turbitiy units; μg/L, micrograms per liter; mg/kg, milligrams per kilogram]

Constituent	Media	Reporting limit	Units
Volatile organic compounds--Continued			
Bromobenzene	Water	1	μg/L
Toluene	Water	1	μg/L
Chlorobenzene	Water	1	μg/L
Tetrahydrofuran	Water	14	μg/L
trans-1,4-Dichloro-2-butene	Water	1	μg/L
2-Chloroethyl Vinyl Ether	Water	1	μg/L
1,2,4-Trichlorobenzene	Water	1	μg/L
1,4-Dioxane	Water	50	μg/L
Dibromochloromethane	Water	1	μg/L
Methacrylonitrile	Water	1	μg/L
Chloroprene	Water	1	μg/L
Tetrachloroethene	Water	1	μg/L
Xylene (m,p)	Water	1	μg/L
Xylene (total)	Water	1	μg/L
sec-Butylbenzene	Water	1	μg/L
1,3-Dichloropropane	Water	1	μg/L
cis-1,4-Dichloro-2-butene	Water	1	μg/L
cis-1,2-Dichloroethene	Water	1	μg/L
trans-1,2-Dichloroethene	Water	1	μg/L
Methyl-t-Butyl Ether	Water	1	μg/L
1,2-Dichloroethene (total)	Water	1	μg/L
1,3-Dichlorobenzene	Water	1	μg/L
Carbon Tetrachloride	Water	1	μg/L
1,1-Dichloropropene	Water	1	μg/L
2-Hexanone	Water	5	μg/L
2,2-Dichloropropane	Water	1	μg/L
1,1,1,2-Tetrachloroethane	Water	1	μg/L
Acetone	Water	5	μg/L
Chloroform	Water	1	μg/L
Benzene	Water	1	μg/L
1,1,1-Trichloroethane	Water	1	μg/L
Bromomethane	Water	1	μg/L
Chloromethane	Water	1	μg/L
Methyl Iodide	Water	1	μg/L
Dibromomethane	Water	1	μg/L
Bromochloromethane	Water	1	μg/L
Chloroethane	Water	1	μg/L
Vinyl Chloride	Water	1	μg/L
Methylene Chloride	Water	1	μg/L
Carbon Disulfide	Water	1	μg/L
Bromoform	Water	1	μg/L
Bromodichloromethane	Water	1	μg/L
1,1-Dichloroethane	Water	1	μg/L
1,1-Dichloroethene	Water	1	μg/L

Appendix 3. Constituents analyzed and reporting limits for analysis of water, streambed sediment, and fish tissue at the Ethan Allen Firing Range in northern Vermont.—Continued

[Constituent reporting levels for analysis of water (surface and ground) and solids (streambed sediment and fish tissue) collected at Ethan Allen Firing Range. All constituents were analyzed in surface- and ground-water samples. Major ions and trace elements were analyzed in streambed sediment and fish-tissue samples. Units are in mg/L, milligrams per liter; NTU, nephelometric turbitiy units; µg/L, micrograms per liter; mg/kg, milligrams per kilogram]

Constituent	Media	Reporting limit	Units
Volatile organic compounds--Continued			
Trichlorofluoromethane	Water	1	µg/L
Dichlorodifluoromethane	Water	1	µg/L
Freon TF	Water	1	µg/L
Isobutyl Alcohol	Water	50	µg/L
1,2-Dichloropropane	Water	1	µg/L
2-Butanone	Water	5	µg/L
1,1,2-Trichloroethane	Water	1	µg/L
Trichloroethene	Water	1	µg/L
1,1,2,2-Tetrachloroethane	Water	1	µg/L
Methyl Methacrylate	Water	1	µg/L
1,2,3-Trichlorobenzene	Water	1	µg/L
Xylene (o)	Water	1	µg/L
2-Chlorotoluene	Water	1	µg/L
1,2-Dichlorobenzene	Water	1	µg/L
1,2,4-Trimethylbenzene	Water	1	µg/L
1,2-Dibromo-3-Chloropropane	Water	1	µg/L
1,2,3-Trichloropropane	Water	1	µg/L
Ethyl Methacrylate	Water	1	µg/L
tert-Butylbenzene	Water	1	µg/L
Isopropylbenzene	Water	1	µg/L
4-Isopropyltoluene	Water	1	µg/L
Semivolatile organic compounds			
4-Nitroaniline	Water	26	µg/L
4-Nitrophenol	Water	26	µg/L
Benzyl Alcohol	Water	10	µg/L
Benzaldehyde	Water	10	µg/L
4-Bromophenyl-phenylether	Water	10	µg/L
Azobenzene	Water	10	µg/L
Caprolactam	Water	10	µg/L
2,4-Dimethylphenol	Water	10	µg/L
4-Methylphenol	Water	10	µg/L
4-Chloroaniline	Water	10	µg/L
2,2’-oxybis(1-Chloropropane)	Water	10	µg/L
Phenol	Water	10	µg/L
Pyridine	Water	10	µg/L
bis(2-Chloroethyl)Ether	Water	10	µg/L
bis(2-Chloroethoxy)methane	Water	10	µg/L
bis(2-Ethylhexyl)phthalate	Water	10	µg/L
Di-n-octylphthalate	Water	10	µg/L
Hexachlorobenzene	Water	10	µg/L
Anthracene	Water	10	µg/L
2,4-Dichlorophenol	Water	10	µg/L
2,4-Dinitrotoluene	Water	10	µg/L
Pyrene	Water	10	µg/L
Dimethylphthalate	Water	10	µg/L
Dibenzofuran	Water	10	µg/L
Atrazine	Water	10	µg/L

Appendix 3. Constituents analyzed and reporting limits for analysis of water, streambed sediment, and fish tissue at the Ethan Allen Firing Range in northern Vermont.—Continued

[Constituent reporting levels for analysis of water (surface and ground) and solids (streambed sediment and fish tissue) collected at Ethan Allen Firing Range. All constituents were analyzed in surface- and ground-water samples. Major ions and trace elements were analyzed in streambed sediment and fish-tissue samples. Units are in mg/L, milligrams per liter; NTU, nephelometric turbitiy units; µg/L, micrograms per liter; mg/kg, milligrams per kilogram]

Constituent	Media	Reporting limit	Units
Semivolatile organic compounds--Continued			
Benzo(g,h,i)perylene	Water	10	µg/L
Indeno(1,2,3-cd)pyrene	Water	10	µg/L
Benzo(b)fluoranthene	Water	10	µg/L
Fluoranthene	Water	10	µg/L
Benzo(k)fluoranthene	Water	10	µg/L
Acenaphthylene	Water	10	µg/L
Chrysene	Water	10	µg/L
Benzo(a)pyrene	Water	10	µg/L
2,4-Dinitrophenol	Water	25	µg/L
4,6-Dinitro-2-methylphenol	Water	26	µg/L
Dibenz(a,h)anthracene	Water	10	µg/L
Benzo(a)anthracene	Water	10	µg/L
4-Chloro-3-methylphenol	Water	10	µg/L
2,6-Dinitrotoluene	Water	10	µg/L
N-Nitroso-di-n-propylamine	Water	10	µg/L
Aniline	Water	26	µg/L
N-Nitrosodimethylamine	Water	10	µg/L
Benzoic Acid	Water	26	µg/L
Hexachloroethane	Water	10	µg/L
4-Chlorophenyl-phenylether	Water	10	µg/L
Hexachlorocyclopentadiene	Water	10	µg/L
Isophorone	Water	10	µg/L
Acenaphthene	Water	10	µg/L
Diethylphthalate	Water	10	µg/L
Di-n-butylphthalate	Water	10	µg/L
Phenanthrene	Water	10	µg/L
Butylbenzylphthalate	Water	10	µg/L
N-nitrosodiphenylamine	Water	10	µg/L
Fluorene	Water	10	µg/L
Carbazole	Water	10	µg/L
Hexachlorobutadiene	Water	10	µg/L
Pentachlorophenol	Water	26	µg/L
2,4,6-Trichlorophenol	Water	10	µg/L
2-Nitroaniline	Water	26	µg/L
2-Nitrophenol	Water	10	µg/L
Naphthalene	Water	10	µg/L
2-Methylnaphthalene	Water	10	µg/L
2-Chloronaphthalene	Water	10	µg/L
3,3’-Dichlorobenzidine	Water	10	µg/L
1,1’-Biphenyl	Water	10	µg/L
Benzidine	Water	26	µg/L
2-Methylphenol	Water	10	µg/L
2-Chlorophenol	Water	10	µg/L
2,4,5-Trichlorophenol	Water	25	µg/L
Acetophenone	Water	10	µg/L
Nitrobenzene	Water	10	µg/L
3-Nitroaniline	Water	26	µg/L

Appendix 4. Macroinvertebrate abundance and average flow velocity in five streams at the Ethan Allen Firing Range in northern Vermont, June 18, 2003.

[m/s, meters per second; --, not present]

Macroinvertebrate name					Abundance				
Phylum	Class	Order	Family	Genus/Species	SS-5	SS-5 Duplicate	SS-6	SS-11	SS-12
		Average streamflow velocity (m/s)			0.56	0.71	0.49	0.49	0.66
Mollusca	Gastropoda	Basommatophora	Ancylidae	*Ferrissia rivularis*	--	--	--	--	2
Platyhelminthes	Turbellaria	Tricladida	Planariidae	*Hymanella retenuova*	--	--	1	--	--
Annelida	Oligochaeta	Lumbriculida	Lumbriculidae	*Lumbriculus variegatus*	--	2	--	--	--
		Tubificida	Enchytraeidae	*Enchytraeus* species	--	--	--	1	--
				Lumbricillus species	--	--	1	--	--
			Naididae	*Nais variabilis*	--	--	--	1	--
Arthropoda	Arachnoidae	Acariformes	Lebertiidae	*Lebertia* species	--	2	--	--	--
			Hygrobatidae	*Atractides* species	--	--	1	--	--
			Torrenticolidae	*Torrenticola* species	--	--	1	--	--
	Crustacea	Decapoda	Cambaridae	*Cambarus bartoni*	--	--	1	--	--
	Insecta	Coleoptera	Elmidae	*Optioservus*	3	--	3	--	5
				Oulimnius	1	--	--	39	1
				Promoresia species	--	--	--	1	--
		Diptera	Blephariceridae	*Blephariceera*	2	2	1	2	15
			Ceratopogonidae	*Bezzia* species	--	--	1	--	--
			Chironomidae	*Microtendipes* species	--	--	--	--	14
				Polypedilum aviceps	19	11	2	4	14
				Polypedilum fallax	--	--	--	--	1
				Polypedilum scalaenum	1	1	--	--	--
				Polypedilum tritum	--	--	--	--	2
				Constempellina species	--	--	--	1	--
				Micropsectra species	4	4	--	39	15
				Rheotanytarsus exiguus	2	3	--	1	--
				Stempellinella species	--	1	--	1	1
				Sublettea coffmani	--	--	--	--	1
				Tanytarsus species	28	12	2	11	19
				Corynoneurua taris	--	2	--	--	--
				Eukiefferiella brehmi	--	--	--	--	1
				Eukiefferiella gracei	1	1	--	--	--
				Eukiefferiella claripennis	--	--	1	3	--
				Eukiefferiella devonica	--	--	--	2	--
				Orthocladius obumbratus	1	--	2		--
				Parametriocnemus lundbecki	1	--	--	3	--
				Tvetenia bavarica	5	3	1	4	--
				Thienemannimyia species	1	--	--	--	1

Appendix 4. Macroinvertebrate abundance and average flow velocity in five streams at the Ethan Allen Firing Range in northern Vermont, June 18, 2003.—Continued

[m/s, meters per second; --, not present]

Macroinvertebrate name					Abundance				
Phylum	Class	Order	Family	Genus/Species	SS-5	SS-5 Duplicate	SS-6	SS-11	SS-12
Arthropoda--Continued			Empididae	*Chelifera* species	--	--	--	1	--
			Phoridae		1	--	11	1	1
			Simuliidae	*Prosimulium* species	16	--	24	1	31
				Simulium species	--	10	--	23	--
			Tipulidae	*Antocha* species	--	1	9	2	1
				Cryptolabis species	1	1	--	--	--
				Dicranota species	--	--	--	2	2
				Hexatoma species	1	3	--	1	1
		Ephemeroptera	Baetidae	*Acentrella* species	32	33	--	13	92
				Baetis species	6	6	--	1	13
			Ephemerelllidae	*Drunella* species	33	26	--	8	22
				Ephemerella species	78	43	--	20	6
				Serratella species	42	18	--	--	6
			Heptageniidae	*Epeorus* species	54	60	124	197	82
				Leucrocuta species	--	--	9	1	--
				Rhithrogena species	5	14	--	--	--
				Stenacron species	--	--	17	1	--
			Leptophlebiidae	*Habrophlebiodes* species	--	18	10	3	--
				Paraleptophlebia species	10	--	--	1	10
		Odonata	Gomphidae	*Lanthus* species	--	--	2	--	--
		Plecoptera	Chloroperlidae	*Haploperla* species	7	7	6	4	3
			Leuctridae	*Leuctra* species	--	--	11	2	1
			Nemouridae	*Amphinemura* species	--	--	32	14	2
			Perlidae	*Acroneuria* species	--	--	--	2	1
				Agnetina capitata	2	--	--	3	2
				Paragnetina species	1	--	--	---	--
			Perlodidae		--	1	--	2	--
				Isoperla species	--	--	2	--	--
			Pteronarcyidae	*Pteronarcys* species	1	--	--	6	1
		Tricoptera	Brachycentridae	*Brachycentrus americanus*	1	3	--	--	--
				Micrasema species	2	--	--	--	--
			Glossosomatidae	*Glossosoma* species	3	--	--	--	71
				Agapetus species	17	1	2	--	--
			Hydropsychidae	*Cheumatopsyche* species	2	1	--	--	--
				Diplectrona species	--	--	--	7	2
				Parapsyche species	--	--	--	1	--
				Symphitopsyche bronta	--	1	--	--	--
				Symphitopsyche sparna	--	--	--	2	--

Appendix 4. Macroinvertebrate abundance and average flow velocity in five streams at the Ethan Allen Firing Range in northern Vermont, June 18, 2003.—Continued

[m/s, meters per second; --, not present]

Macroinvertebrate name					Abundance				
Phylum	Class	Order	Family	Genus/Species	SS-5	SS-5 Duplicate	SS-6	SS-11	SS-12
Arthropoda--Continued			Hydroptilidae	*Stactobiella* species	--	2	--	--	2
			Lepidostomatidae	*Lepidostoma liba*	5	--	1	4	5
			Leptoceridae	*Ceraclea* species	--	--	--	--	1
			Limnephilidae	*Neophylax* species	1	1	13	4	26
			Odontoceridae	*Psilotreta* species	--	--	--	1	--
					--	--	--	--	--
			Philopotamidae	*Dolophilodes* species	34	12	--	5	7
				Wormaldia species	--	--	23	--	--
			Polycentropodidae	*Polycentropus* species	--	--	1	1	1
			Rhyacophilidae	*Rhyacophila acutiloba*	--	--	--	--	1
				Rhyacophila carolina	--	--	--	1	--
				Rhyacophila fuscula	--	--	--	2	--
					--	--	--	--	--
Total specimens counted					434	316	317	450	485
Specimens per site					1,736	1,264	634	900	970
Specimens per 0.09 square meter					347.2	252.8	126.8	180	194

Prepared by the New Hampshire-Vermont Water Science Center
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