GEOLOGY FOR ENVIRONMENTAL PLANNING IN THE JOHNSON-HARDWICK REGION, VERMONT

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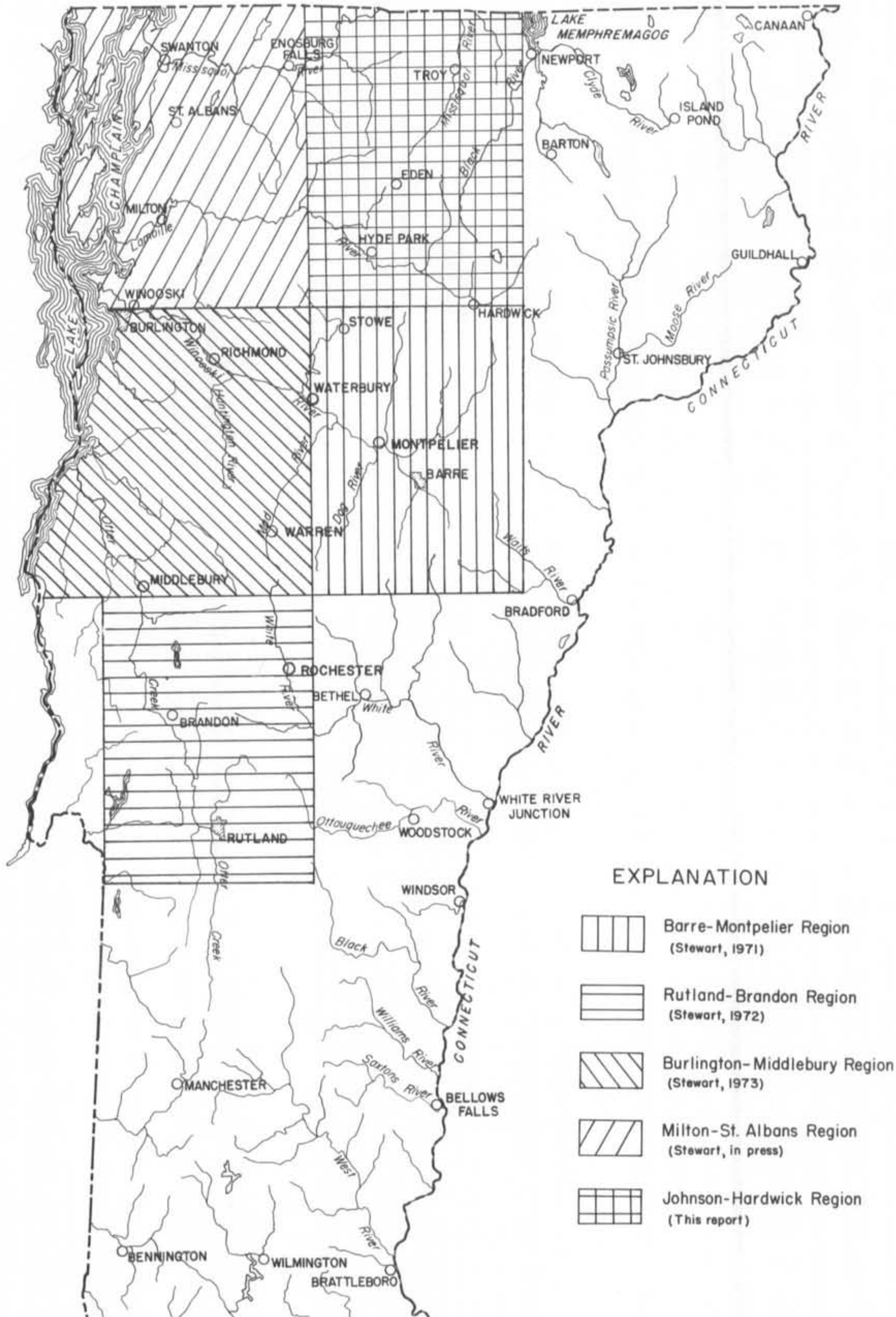

Figure 1. Index map showing where environmental geology studies have been completed.

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INTRODUCTION

This is the fourth report in a series of environmental studies sponsored by the Vermont Geological Survey. The first three of these studies were completed by Dr. David P. Stewart in the Barre-Montpelier (1971), Rutland-Brandon (1972), and Burlington-Middlebury (1973) regions. The field work for the present report was completed during the summer of 1973 by the writer, assisted by John S. Moore, graduate student in the Department of Geology, University of Vermont. This report, intended for publication in 1974, attempts to relate in a condensed and simplified form the geological conditions of the Johnson-Hardwick Region as they relate to existing environmental problems and to make this material available to planners and other interested parties (Figure 1). Much information, relating to the various categories treated, is included in a series of large-scale planning maps and seismic profiles.

Vermont's environmental assets are rich and diverse but increased demands upon state resources necessitates a re-evaluation of growth impact on the state. A geologic appraisal of the environment contributes much to such a re-evaluation. Geology is essential to many aspects of environmental planning in that the application of geologic knowledge to the appraisal of foundation conditions for building, highways, dams, airports, and other kinds of construction can lead to significant savings in building and maintenance costs. Furthermore, identification of natural hazards such as floodplains and potentially active land slides can help prevent terrible losses in life and property. Knowledge of the composition and physical properties of rocks at and beneath the surface can also provide the basis for determining the effects of subsurface disposal of liquid and solid wastes on ground water supplies, while knowledge of geologic processes can furnish the basis for both predicting and monitoring environmental effects of human activities (U.S. Dept. of Interior, Geological Survey News Release, October 6, 1972).

The regions that have been studied thus far were chosen because of their growth potential and the marked rise in urban-centered problems. Concern for the environment in the Johnson-Hardwick Region (Figure 2) is admittedly not the same as for the more heavily populated and industrialized parts of the state. Here, the growth potential of some communities may be regarded as moderate to high but their actual population growth has, at best, been slow and determined. Population increases of 50 (Hyde Park) to 800 persons (Morristown) between 1950 and 1970 are, in fact, atypical of this region as a whole. In reality, most central and northern communities are suffering from limited job opportunities and declining populations. Between 1950 and 1970, the populations of North Troy and Richford dropped approximately 400 persons each (Thomas, 1970, p. 6).

At present, the largest concentration of population in the Johnson-Hardwick Region occurs along the Lamoille River Valley in the communities of

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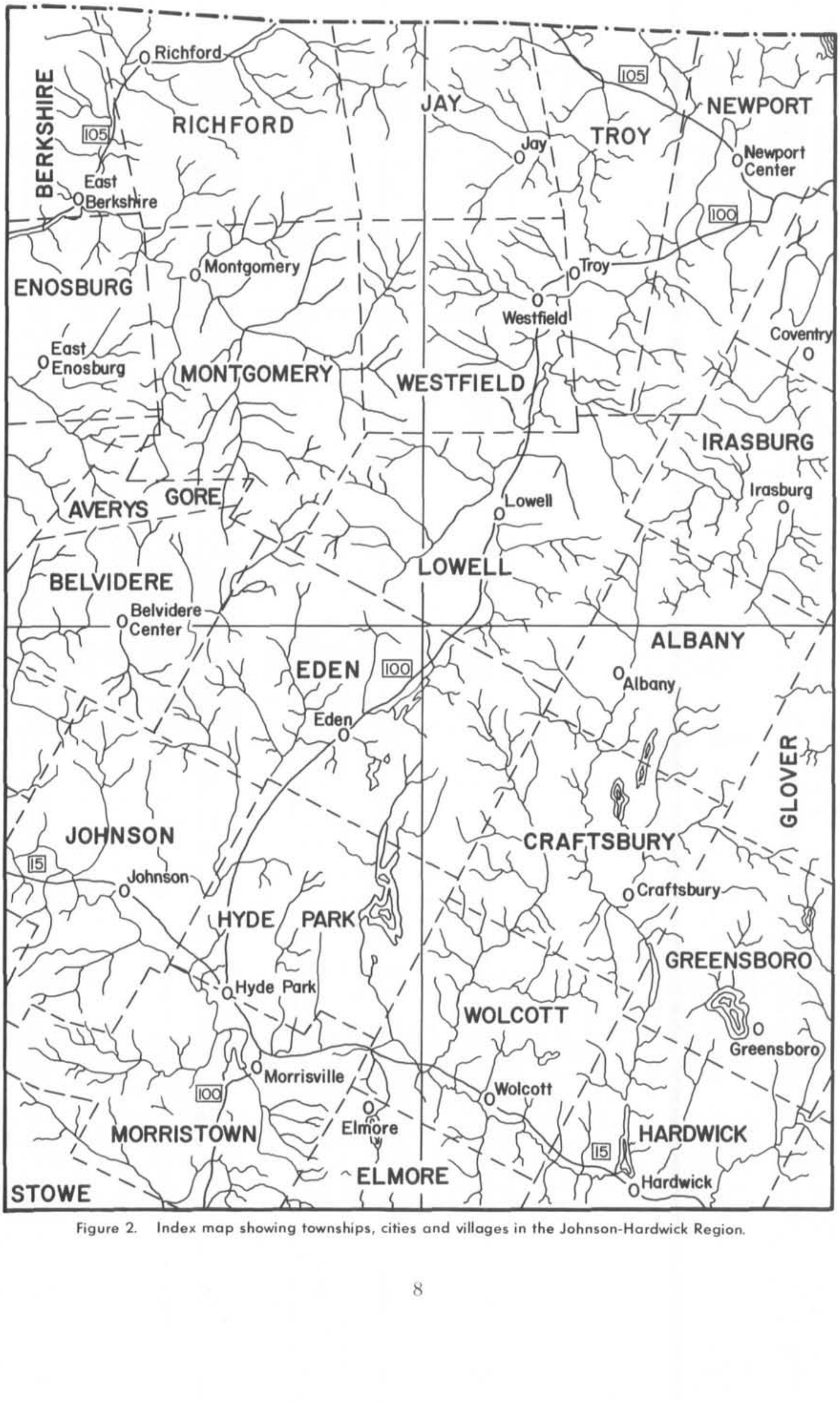

Figure 2. Index map showing townships, cities and villages in the Johnson-Hardwick Region.

Johnson (1,927 pop.), Hyde Park (1,347 pop.), Morristown (4,052 pop.), and Hardwick (2,466 pop.). Much of the growth within and adjacent to these communities may be attributed to tourism and the limited expansion of local industries. The continued growth of the Stowe-Mt. Mansfield and Madonna Peak ski developments has undoubtedly bolstered local economies as well. Similar limited growth is anticipated in the communities of Jay and Montgomery Center as the Jay Peak ski development begins to attract larger numbers of winter sports enthusiasts.

The most critical environmental problems in this region stem from the general inability of individual communities to meet the exceedingly high costs of construction and maintenance of adequate municipal water and sewage treatment systems, the transport and disposal of solid waste materials, and development of flood control systems. These problems are amplified further by the unpredecented construction of rural homesites and recreational dwellings. Between 1960 and 1970, the State of Vermont experienced a total population growth of 14 percent, which gave the state an average population density of 48 people per square mile of land. This growth of 14 percent does not indicate, however, that the total urban population of the state actually dropped by 7,000 people while the rural population climbed by 61,500 people for the same time period (Thomas, 1970, p. ii). Part of this rural population shift has occurred within the Johnson-Hardwick Region.

Sources of Material

The information used in the preparation of this report and its planning maps was collected from many different sources including the Vermont Geological Survey, Department of Water Resources, Board of Health, Environmental Protection Agency, and State Department, as well as the regional offices of the United States Soil Conservation Service. Too often, much of this material is difficult to interpret and adapt to specific planning uses or it is not well known. Specific questions regarding environmental planning problems should be directed to one or more of the above-mentioned agencies for assistance. This report, unlike the Interim Land Capability Plan (1972), attempts to explain some of the more pressing environmental problems of a specific region in such a fashion that the planner or citizen would have little trouble in understanding the information and applying it to his needs.

The surficial geology of the Johnson-Hardwick Region was mapped during the statewide program that resulted in the Surficial Geologic Map of Vermont (Stewart and MacClintock, 1970). The original mapping of the Jay Peak, Irasburg, Hardwick, and Hyde Park 15-minute quadrangles was completed by MacClintock (1964). During this investigation, the surficial maps were checked in the field and modified for environmental planning purposes. The explanations of these maps and their designated deposits were similarly modified for more utilitarian application to multi-purpose planning problems (Plate I).

Bedrock data used throughout this report were obtained primarily from the Centennial Geologic Map of Vermont (Doll, Cady, Thompson and Billings, 1961). The geologic reports of Enosburg, Irasburg, and Hardwick areas by Dennis (1964), Doll (1951), and Konig and Dennis (1964), respectively, were also used for more detailed geologic information. While these reports and the Centennial Geologic Map give formation names, stratigraphic and age relationships, and a description of each rock unit, the bedrock map for the Johnson-Hardwick Region (Plate II) and its discussion have been modified considerably in an attempt to make it more adaptable for use by planners.

Water-well records, on file with the Vermont Department of Water Resources, were examined in detail and used to determine, where possible, the

Figure 3. Field interpretation of seismic record by Weston Geophysical Engineer.

thickness of surficial materials, the vertical and lateral sequencing of the unconsolidated sediments, the depth to the water table in surficial materials and bedrock, and expected ground-water yields. This information was plotted on 15-minute quadrangle maps and compared with existing groundwater favorability maps (Hodges and Butterfield, 1967a, b, c) in an attempt to determine desirable sites for seismic analysis and to interpret regional groundwater potential (Plate III).

During the course of this investigation, six localities were selected for seismic analysis (Figure 3). Using the twelve point seismic refraction method and a twelve-channel seismograph, an indirect interpretation of the depth to and configuration of buried bedrock valleys, the vertical and lateral variations (caused by water saturation and textural change) of valley-fill sediments, and the general depth to the water table can be made in areas where well-log information is extremely limited or suggests significant subsurface conditions. The seismic work and profiles reproduced in this report were completed by Weston Geophysical Engineers, Inc., of Westboro, Massachusetts (1973).

Existing solid waste disposal sites were examined and evaluated in reference to the various surficial materials in which each site was developed, the type of "sanitary" cover material applied, if any, the local groundwater hydrology and contamination potential, and slope of the land. Based on these evaluations and recent studies of solid waste disposal problems, the Solid Waste Disposal Conditions Map (Plate IV) and its discussion, was prepared. While liquid waste disposal problems for municipalities and individual homesites pose serious environmental problems, sewage disposal practices for domestic installations (septic tanks, dry wells, lagoons, etc.) were examined more closely (Plate V) because of their strong dependence upon natural earth conditions for part of the treatment process.

Soils maps prepared by the United States Soil Conservation Service were compared with existing surficial maps in an attempt to better determine basic soil-geologic relationships and to delineate areas of low, moderate, and high foundation stability. The information obtained was later applied to general construction problems throughout the Johnson-Hardwick Region (Plate VI). Sand and gravel deposits were studied in some detail to identify possible sites for construction and those of possible economic potential (aggregate material). In each instance, identified sand and gravel deposits were evaluated as to their quality and the reserve available (Plate VII).

Explanation of the Planning Maps

Included in this report are a series of maps interpreted from and plotted on four 15-minute quadrangles (scale 1/62,500) which have been joined and reduced by one-fourth to illustrate basic geologic and environmental conditions in the Johnson-Hardwick Region. Plates I through VII, in the pocket at the end of this report, show the distribution of surficial and bedrock materials, groundwater potential, and the suitability of each area for various land uses. The maps of surficial deposits (Plate I) and bedrock (Plate II) show the broad distribution patterns and variations of these materials. The maps showing groundwater potential (Plate III), solid waste disposal conditions (Plate IV), septic tank conditions (Plate V), and general construction conditions (Plate VI) utilize color schemes adapted from the Illinois Geological Survey reports (Hackett and McComas, 1963; Jacobs, 1971) to depict general variations in site conditions. Areas shown in green on these maps are interpreted as offering only minor environmental problems and limitations. Areas shown in yellow have low to moderate limitations which can be controlled or corrected through various site modifications. Such localities require detailed investigations to ascertain site limitations and to determine the best possible methods of correction. Areas mapped in red are interpreted as having moderate to high limitations and many problems that are difficult to overcome. Where possible, these areas should be avoided in development planning. Where two symbols and shades of the same color (r-1 and r-2) are used, different site conditions are encountered within areas of similar degrees of limitation. All planning maps are, of necessity, quite generalized and do not eliminate the need for detailed site evaluations.

GEOLOGIC SETTING

The Johnson-Hardwick Region is located physiographically in the Green Mountain and Vermont Piedmont sections of the New England Province (Uplands) as described by Fenneman (1938, p. 346) and Thornbury (1965, p. 152) and tectonically in the crystalline Appalachians Province according to King (1959, p. 53). The rocks of this region are characteristically composed of various Paleozoic sedimentary and metasedimentary rocks. The latter comprise schists, phyllites, gneisses, slates, quartzites, and marbles which have been intensively folded and fractured. Small igneous intrusions of granite, diorite, and granodiorite are scattered throughout the region. Despite a strong structural influence, the present topography is largely erosional and has been suggested to be in the mature stage of landscape development according to the Davisian classification (Jacobs, 1950, p. 75).

Green Mountains

Although two physiographic subprovinces have been described in this area, the Green Mountains on the west and the Vermont Piedmont to the east, distinctions between them are often confusing due to their subtle variations in topographic form and lithologic composition. Extending from Canada to northern Massachusetts as a series of nearly continuous peaks and ridges, the Green Mountains form the backbone of Vermont's topography. In the Johnson-Hardwick Region, the Green Mountains are approximately 21 miles wide and consist of three moderately distinct north-south trending ridges and several subranges. The Cold Hollow Mountains, with summit elevations ranging from 1492 feet to 3360 feet, form the first and westernmost ridge of the Green Mountains. The somewhat distinct topographic change observed between these mountains and the Champlain Lowland to the west has been described as the Green Mountain Front (Jacobs, 1950) or the Fairfield Hill Escarpment (Dennis, 1964, p. 11). This physiographic boundary lies roughly parallel to the western margin of the Jay Peak Quadrangle. The second or main ridge of the Green Mountains is marked by such prominent summits as Jay Peak, Sugarloaf, Haystack, Belvidere, and White Face mountains which range in elevation from 2100 to 3861 feet. Readily identified subranges within this main ridge include Bean, Butternut, and Elmore mountains. The third or eastern ridge, dominated by the Lowell Mountains in the Johnson-Hardwick Region, extends southward to include the Worcester and Northfield mountains as well.

Structurally the three ridges of the Green Mountains are part of a large bedrock arch (anticlinorium), composed of a crystalline Precambrian core and mantled by various metamorphosed Paleozoic rocks, and a series of three lesser superimposed folds (anticlines) across its entire width. The axis of this anticlinorium trends generally north-south, roughly parallel to the middle ridge, but repeated episodes of compression and uplift have produced a series of smaller folds offset from the main axis. Due to the severe deformation and concomitant metamorphism of original rock materials during mountain building, individual structures and trends are not often readily apparent. These complexities are best described in lithologic studies prepared by Christman (1959) and Dennis (1964) and are graphically represented on the Centennial Geologic Map of Vermont (Doll, Cady, Thompson, and Billings, 1961).

Vermont Piedmont

Bordering the Green Mountains on the east, along a zone where highly metamorphosed and intruded rocks meet less severely altered bedrock forms, is a plateau-like upland (peneplain) that has been maturely dissected initially by streams and further subdued by glaciation. This undulating to rough-surfaced plateau, locally marked by mountain ranges and isolated peaks, has been described as the New England Upland (Fenneman, 1938, p. 346) or, more locally, as the Vermont Piedmont (Jacobs, 1950, p. 79). Approximately the eastern one fifth of the Johnson-Hardwick Region lies within the Vermont Piedmont. Unlike that portion of the region dominated by the major fold structures of the Green Mountains, this area has no continuous mountain ranges despite locally intense folding, faulting, and intrusion. Here, Allen, Ames, Barr, Beach, Chamberlain, Elmore, Miles, Sharps, and Scribner Hill, The Ledges, Mount Sarah, and Jeudevine Mountain comprise the more prominent topographic highs, ranging from 1280 to 2130 feet in elevation, in an otherwise more rolling landscape. Small hills and steeply incised streams lend further variation to the topographic expression of this area.

Drainage

The drainage patterns of the Johnson-Hardwick Region are complicated by a diversity of geologic structures, variations in bedrock lithology, and corresponding forms of topographic development. Somewhat irregular divides separate the area into three drainage basins: 1) the Black River; 2) the Lamoille River; and 3) the Missisquoi River basins (Figure 4). Waters of the Black River Basin flow roughly northward to Lake Memphremagog and ultimately to the St. Lawrence River. Waters of the Lamoille River and Missisquoi River basins flow westward through the Green Mountains into Lake Champlain.

The Black River Basin has a total area of approximately 160 square miles and is included within Orleans County. The basin extends 24 miles southwestward from the larger Lake Memphremagog Basin across portions of the Vermont Piedmont and eastern flank of the Green Mountains. The Black River heads in a low, structurally controlled divide between Alder Brook and Eligo Pond, approximately 5 miles north of Hardwick, and is fed by a number of small upland streams and ponds. As the river flows west, north, and northeast between Craftsbury and Irasburg, it meanders across broad floodplains and impinges against abrupt bedrock walls. Stream tribu-

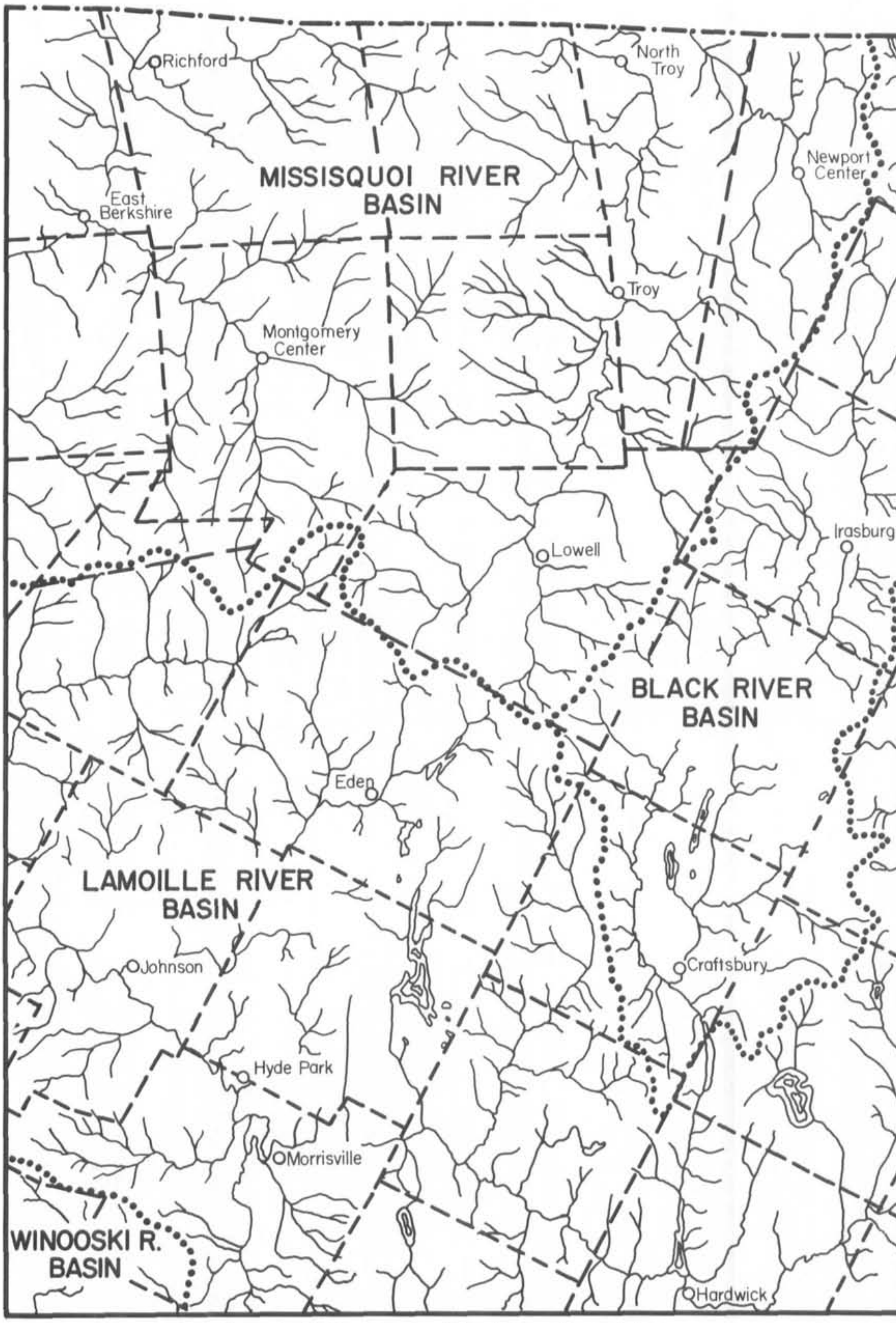

Figure 4. Drainage basins of the Johnson-Hardwick Region.

taries located along this reach include Seaver, Rogers and Shalney branches and McCleary and Lamphear brooks and all originate along the eastern slopes of the Lowell Mountains. Near Irasburg, the Black River flows into a much broader valley and is joined by Lords Creek and Brighton Brook before turning east into a narrow, rock-walled valley. Between Irasburg and Coventry, the river follows an irregular route to the north and northeast through thick kame deposits, outwash materials, and bedrock. Marked changes in drainage pattern and valley shape undoubtedly result from complex patterns of glacier movement and subsequent melt-water drainage.

The Lamoille River Basin has a total area of approximately 700 square miles and includes portions of Caledonia, Chittenden, Franklin, Lamoille and Orleans counties. The basin extends 53 miles eastward from Lake Champlain and has an average width of 15 miles, but where it crosses the Green Mountains, slightly west of the center of the basin, the watershed width is reduced to about 9 miles (Vermont Department of Water Resources, 1968, pp. 1-2). Respective to the Johnson-Hardwick Region, the Lamoille River Basin covers approximately three-sevenths of the area principally within the Hyde Park and Hardwick quadrangles. The Lamoille River heads from several small streams and ponds to the east of the Johnson-Hardwick Region, in the Town of Wheelock, and flows southwesterly to enter the area slightly northeast of the village of Greensboro Bend. From Greensboro Bend, the Lamoille River continues to flow southwesterly to the village of Hardwick, where it turns west and northwest, flowing into Hardwick Lake, and continuing on through the Town of Wolcott. Stream tributaries located along this reach of the river include Stannard, Greensboro, Bailey, Porter, Alder, Bunker, Millard, Kate, and Wolcott Pond brooks and Elmore Branch. Between the villages of Wolcott and Morrisville, the river resumes a westerly course, enters Lake Lamoille, and then flows northwest into the Town of Johnson. Along this reach Wild Branch, Rodman, Ryder, Centerville, Foot, and Waterman brooks, and the Gihon and Green rivers join the Lamoille River. From the village of Johnson, the river turns west and southwest and ultimately flows into Lake Champlain about 10 miles north of Burlington.

The Lamoille River is still in early maturity, meandering across broad floodplains in parts of its course, and flowing through narrow gorges and over rapids and falls in other stretches, notably near Johnson and Pottersville. As already demonstrated, the Lamoille River has a large number of tributary waters, most of which are moderately swift-flowing mountain streams. Major tributaries of the Lamoille River include North Branch, the Gihon River, and Wild Branch. North Branch has a length of approximately 14 miles and drains an area of 57 square miles. From its source at Belvidere Pond in the northwest corner of the Town of Eden, this stream flows out of the Cold Hollow and Green Mountains into the Town of Belvidere, where it turns westerly to pass through the settlements of Belvidere Center and Belvidere Junction. Here it turns to the south and southwest, flows through the village of Waterville and continues south into the Town of Cambridge, where it empties into the Lamoille River.

The Gihon River has a length of approximately 14 miles, a drainage area of 66 square miles, and originates at Lake Eden, in the Town of Eden. From its source, this river meanders to the west and south, passing through the villages of Eden Mills and Eden before entering the Town of Hyde Park. After flowing through the community of North Hyde Park, the river flows southwesterly through the villages of East Johnson and Johnson to join the Lamoille River. The Gihon River Basin, like many of the other drainage systems of this region, is filled with thick glacial and lacustrine deposits, on top of which the soil is of relatively shallow depth. These deposits combine to form impressive sand plains throughout much of the central and lower portions of the basin.

Wild Branch has an approximate length of 15 miles and a drainage area of 31 square miles. It originates on the easterly slopes of the Lowell Mountains in the Town of Eden and flows to the southeast into the Town of Craftsbury. It then alters its course to a southwesterly direction, passes through North Wolcott, and enters the Lamoille River.

The Missisquoi River Basin has a total area of approximately 620 square miles and includes portions of Franklin, Lamoille, and Orleans counties. This basin covers an additional three-sevenths of the Johnson-Hardwick Region and heads from several small streams located between the eastern flank of the central Green Mountains and the western slopes of the Lowell Mountains in the Irasburg Quadrangle. The Missisquoi River flows in a northerly direction from the confluence of Burgess and East branches in the Town of Lowell and is joined by LeClair, Snider, Mineral Spring, Taft, and Mill brooks as it flows through the Town of Westfield. Beetle and Coburn brooks and Jay Branch join the Missisquoi River in Troy. As the river meanders through the village of North Troy into Canada, it is joined by Mudd Creek before it re-enters the State of Vermont near the village of East Richford. Between East Richford and Richford, Lucas, Mountain, Stanhope and Loveland brooks enter the Missisquoi River while North Branch empties into the river at Richford. From Richford, the river turns south, is joined by the Trout River just east of the village of East Berkshire, and turns west toward the Champlain Lowland (Vermont Department of Water Resources, 1969a, p. 2).

While the headwaters of the Missisquoi River drain the eastern slopes of the central Green Mountains, the Trout River drains the western slopes of the range and the eastern flank of the Cold Hollow Mountains in the Jay Peak Quadrangle. This major tributary of the Missisquoi River has a main stream length of approximately 9 miles and drains an area of about 86 square miles. The river heads from various small streams and ponds along the western slopes of Jay and Sugarloaf mountains and as the river proceeds in a westerly direction from the confluence of Jay and Wade brooks it passes through Montgomery Center, is joined by the South Branch, and then turns northwesterly. Between Montgomery Center and its confluence with the Missisquoi River, the Trout River is joined by West Hill, Black Falls, and Alder brooks.

The Bedrock Complex

Bedrock exposed within the Johnson-Hardwick Region includes light- to dark-colored, moderate to highly metamorphosed phyllites, schists, and impure limestones, with varying amounts of interbedded greenstones, slates, dolomites, and quartzites which range in age from Cambrian to possibly Devonian. The stratigraphy of this area is greatly complicated by rapid facies changes and at least two mountain building episodes that have resulted in the folding, faulting, and metamorphism of the original sedimentary strata (Dennis, 1964, p. 10). The principal periods of deformation seem related to the development of the Green Mountain Anticlinorium and the Willoughby Arch to the east (Konig and Dennis, 1964, p. 7). Late Devonian intrusions of granites and granodiorites have further complicated problems of stratigraphic correlation.

The geologic map (Plate II) prepared for this report, has been modified from various geologic reports (Doll, 1951; Christman, 1959; Dennis, 1964; Konig and Dennis, 1964) and from the Centennial Geologic Map of Vermont (Doll, Cady, Thompson, and Billings, 1961). This map, unlike traditional geologic maps, does not give the formal names of individual rock units, their sequences, or stratigraphic (age) relationships, but rather, has been simplified to provide only a general description of the major lithologies and to show their basic regional patterns and variations. It is believed that such maps will prove to be of more practical use to planners than the more typical geologic map. For more detailed information on the bedrock geology of this region, consult the references listed above or the office of the State Geologist.

The rocks of the Green Mountains were originally deposited in a large trough-like depression (eugeosyncline) principally as graywackes, siltstones, and shales with minor amounts of volcanic, calcareous, and carbonaceous material, but they have been altered through regional diastrophism and concomitant metamorphism to metagraywackes, phyllites, schists, gneisses, greenstones, and amphibolites on the far west and to quartz-albite-muscovite schists along the axis of the Green Mountain Anticlinorium (Christman, 1959, p. 7). All of these deposits are described as belonging to the greenschist facies and therefore it implies that they have experienced moderate- to high-grade metamorphism, are foliated, and contain such common minerals as quartz, albite, muscovite, epidote, chlorite, and biotite (Dennis, 1964, p. 34). Most of these rocks are foliated because of recrystallization under stress, forming layers of platy and elongate minerals parallel to the bedding surfaces (foliation). Variations in the degree of local metamorphism are suggested in rock textures and the degree of perfection of foliation. Prominent formations within the Green Mountains include the schist- and phyllite-rich Camel's Hump Group (Cambrian) and the Ottauquechee (Cambrian), Stowe (Ordovician), and Missisquoi (Ordovician) formations.

The rocks of the Vermont Piedmont are somewhat distinct from those of the Green Mountains in that they are generally younger in age, were originally deposited in different sedimentary environments, and have also undergone intense deformation and corresponding metamorphism (Figure 5). While deposits of the Devonian age Shaw Mountain, Northfield, and Waits River formations consist of a series of schists, phyllites, slates, quartzites, impure limestones, and dolomites, the area to the east-southeast of the Alder Brook – Black River Valley is dominated by gray quartzose and micaceous crystalline limestones interbedded with phyllites, schists, quartzites, and volcanics. These rocks are locally cut by intrusives occurring as stocks, sills, and dikes which range in composition from acidic to ultrabasic. The larger of these intrusive masses are composed of granodiorite and closely related rocks, whereas the sills and dikes are usually granites (Konig and Dennis, 1964, p. 27). This rather marked lithologic change, from the Green Mountain schists (s) and interbedded phyllites and schists (ps) on the west to the interbedded limestones and phyllites (ls-p) of the Vermont Piedmont on the east, may serve to differentiate more accurately between the two physiographic provinces than does the associated topography.

For general description purposes, phyllites of the Johnson-Hardwick Region are commonly light- to medium-grey in color, finely textured and foliated, and occur interbedded with schists (ps) and/or slates (psl). Gneisses are generally coarser in texture and have thicker foliation (banding) than phyllites.

Figure 5. Highly fractured phyllite bedrock exposed along the Black River near Coventry.

Schists (s) are often intermediate to fine in texture and foliation, characteristically impart a lustrous sheen due to disseminated micas, and may be interbedded with local quartzites and phyllites. Greenstones (gr) include all basic and ultrabasic igneous rocks erupted during the geosynclinal phase of mountain building, but most notably those which owe their color to the presence of such minerals as chlorite, hornblende, and epidote. These rocks have, in general, suffered low-grade regional metamorphism and may be associated with local amphibolites and rocks possessing pillow structures. Amphibolites are composed predominantly of the minerals amphibole and plagioclase and are produced by medium- to high-grade regional metamorphism. In general, weathered and fresh surfaces of these rocks have similar appearances and may prove difficult to distinguish by visual inspection. For this reason, previous studies (Stewart, 1972, 1973) designated these rocks with a single color on the bedrock map and used letter symbols to indicate local lithologic variations. Due to the predominance of these rocks throughout the Johnson-Hardwick Region, however, major lithologic changes are denoted here through the use of colors and letter symbols. Problems of rock identification become less difficult to the east, in areas where limestones interbedded with quartzites, greenstones, schists, and phyllites predominate. Here, the limestones are impure and often greatly altered mineralogically and texturely through metamorphism. Quartzites are normally medium-grey to black in color, thin-bedded, fine to medium grained, and are frequently streaked with mineral zones parallel to the bedding (Doll, 1951, p. 15). Dolomites and marbles are of only spotty occurrence.

Surficial Materials

The surficial materials of the Johnson-Hardwick Region (Plate I) are composed of transported sediments deposited primarily during or shortly after the last glacial period (Wisconsinan) of the Great Ice Age. These materials were deposited directly from active and/or stagnating glacial ice, ice-marginal meltwater streams, and pro-glacial lakes associated with two different ice episodes, the Burlington and Shelburne stades (Stewart and MacClintock, 1969, p. 56).

Till (t) is composed of an unsorted, unstratified, heterogeneous mixture of sediments, ranging in particle size from clays to boulders, deposited directly from glacial ice. Throughout the Johnson-Hardwick Region, the summits of the mountains and higher hills are generally free of any glacial debris or are covered by only scattered deposits of till. On the lower slopes and across the upland flats, till deposits are much more continuous but remain generally less than 10 feet thick. Greater thicknesses of till (50-100 feet) are often found in the valleys and along valley walls. Due to the fact that glacial tills are unsorted and do have a wide range of textural components, they characteristically have low permeabilities and low water potential. Locally high concentrations of sand and gravel in the tills of this region may, however, provide for slightly higher water yields than normally anticipated, but even these remain too low for domestic water supplies.

Outwash (ow) materials are deposited by meltwater streams flowing from glacial ice and as a result commonly have a high concentration of stratified and well-sorted sands and gravels. Outwash, therefore, characteristically has a high porosity and permeability and serves as a fair to very good water-bearing material (aquifer). Kames and kame terraces (k) are ice-contact, valley deposits formed along the margins of the ice, between the ice and the valley wall or within wastage zones of the ice. These deposits are common in almost all of the region's drainage basins and in some areas they occur high on surrounding mountain slopes. They can usually be identified by marked changes in sediment texture and distribution as well as internal slumping or ice-

Figure 6. Gravel pit in kame terrace along Burgess Branch one mile west of Lowell.

contact structures formed when the ice supporting them melted (Figure 6). Significant kame deposits within the Johnson-Hardwick Region occur along the Black River valley between Albany and Coventry, along the Missisquoi River valley in the Westfield-Troy and Richford areas, and the Lamoille-Gihon River valley near Belvidere Center, Eden Mills, and Morrisville.

Lake sands and gravels (sg), including beach gravels and some deltas (Figure 7), are shallow water deposits that are usually well-sorted, have a medium to high permeability, and commonly exhibit moderate to high groundwater yields. The water-bearing characteristics of lacustrine sands and gravels are controlled by the thickness of the deposit, its texture and degree of sorting, the type of underlying material, the slope of the land surface, and the amount and type of vegetative cover (Stewart, 1973, p. 22). Although thicknesses of lake gravels are commonly much less than those of lake sands, such deposits may serve as important sources of aggregate material. Large lacustrine deposits occur along the Lamoille River Valley between Morrisville and Johnson, along the Missisquoi River Valley between Lowell and North Troy, and along the Trout River Valley near Montgomery. Lacustrine silts and clays (stc) are fine-grained bottom sediments which have relatively high porosities and are capable of holding large amounts of water. Unfortunately, despite local variations in composition, these deposits exhibit low permeabilities and correspondingly low groundwater yields. Furthermore, they commonly have medium to high plasticity ranges and as such are considered to be too plastic for favorable foundation material without site modifications. Lacustrine silts and clays in the Johnson-Hardwick Region are found along the Gihon River Valley in the vicinity of Eden, the Black River Valley west of Irasburg, the Missisquoi River Valley between Richford and Enosburg Falls, and Mud Creek between Newport Center and North Troy.

Recent alluvium (al) is post-glacial sediment which has been transported by streams with little or no modification of the original materials except through mechanical disintegration. Alluvium is a fair to moderately well drained deposit which forms a layer ranging from 5 to 20 feet in thickness across most modern-day valley floors. Due to its poor strength (bearing capacity), alluvium commonly makes a poor foundation material and as such, should be removed prior to heavy construction. The predominance of alluvium adjacent to most of the major river valleys throughout the region indicates areas

Figure 7. Gravel pit in deltaic deposit along White Branch two miles northwest of Eden.

that are most susceptible to seasonal flooding. Thick accumulations of alluvium may be found along the Black River Valley between Craftsbury and Irasburg, the Missisquoi River Valley between Richford and East Berkshire, and the Lamoille River Valley near Morrisville.

Peat, a fibrous material of vegetative origin, and muck, a highly decomposed organic soil material developed from peat, designate poorly drained lowlands or depressions and small swamps (p) within the region. Large areas of swampland developed on valley floors include portions of the Lords Creek valley north of Craftsbury, the Missisquoi River valley between Lowell and North Troy, and the Lamoille River valley near Belvidere Center. Large areas of swampland development adjacent to lakes and ponds include Bear Swamp, three miles northeast of Wolcott, Highland Swamp, two miles northeast of Newport Center, and the large swamp developed north of Eligo Pond near Craftsbury. Many smaller swamps may be found across the uplands and valley bottoms throughout the region. Few of these swamps, if any, are considered as good sources of peat.

CLEAN WATER – A NATURAL RESOURCE

Water is such an ever-present, pervasive substance in our lives that it enters into almost every environment-related decision we make. Any plan for land use eventually requires consideration of water acquisition, use, and disposal. While not everyone wants or needs to be an expert on water, the private citizen, the planner, the politician, the manager, and other decision makers need to know enough to listen and respond with intelligence and understanding as different solutions are offered for solving present and future water needs and problems. Unfortunately, almost everywhere throughout the United States habits of water usage are based on the assumption that water is free and virtually inexhaustible and as a result, most Americans use water without restriction or thought. In 1960, the average per capita use of water in American cities was about 150 gallons per day. As of 1970, the United States was withdrawing a total of 370 billion gallons of water a day from surface- and ground-water sources to meet the needs of public supplies, commerce, industry, irrigation, and rural users; an increase of 19 percent in off-channel use since 1965. This equals about 1,800 gallons of water per day per person (250 gpd in Vermont) on a pro-rata basis or an average per capita use of 180 gallons of water per day (U. S. Department of Interior New Release, August 30, 1972).

In recent years, many communities have experienced unprecedented water supply problems as growing populations and increased per capita water use have placed greater demands on municipal water supplies. Some communities have been able to increase their water supplies through a combination of new surface reservoirs and well fields. Others have not been as fortunate. For them the demand for fresh water has been increasing every year but their supply has not. To further complicate matters, water of good quality, both biologically and chemically, is harder to obtain each year. The development of modern treatment techniques has significantly reduced the occurrence of waterborne diseases to a very low level yet, nearly every year municipalities have problems with the taste and odor of their water and occasionally are beset with outbreaks of gastrointestinal problems that are most probably related to their water supply (Pettijohn, 1973, p. 1; Fagan, 1974, p. 69).

Surface Waters

Fresh, clear water. Sparkling streams running from the hillsides, cascading down from mountain heights. Wide rivers and gleaming lakes. These are as much a part of the special world of Vermont as are her Green Mountains (Figure 8). Each imparts excitement and recreation to native and tourist alike. The fundamental question is — will increasing burdens of untreated sewage, agricultural and industrial wastes, and silt ultimately turn the prospect of destruction into a reality? In thoughtless abuse, will man irreversibly befoul Vermont's lakes and rivers or will careful statewide planning and forceful legislative action avert this fate?

Interestingly enough, the Johnson-Hardwick Region constitutes one of the more sparsely populated areas of the state and, as such, still has a potentially good to moderate surface-water supply for agricultural, municipal, industrial, and scenic-recreational use. How long the surface waters of this region will remain relatively clear and uncontaminated is difficult to determine. In view of the irregular dis-

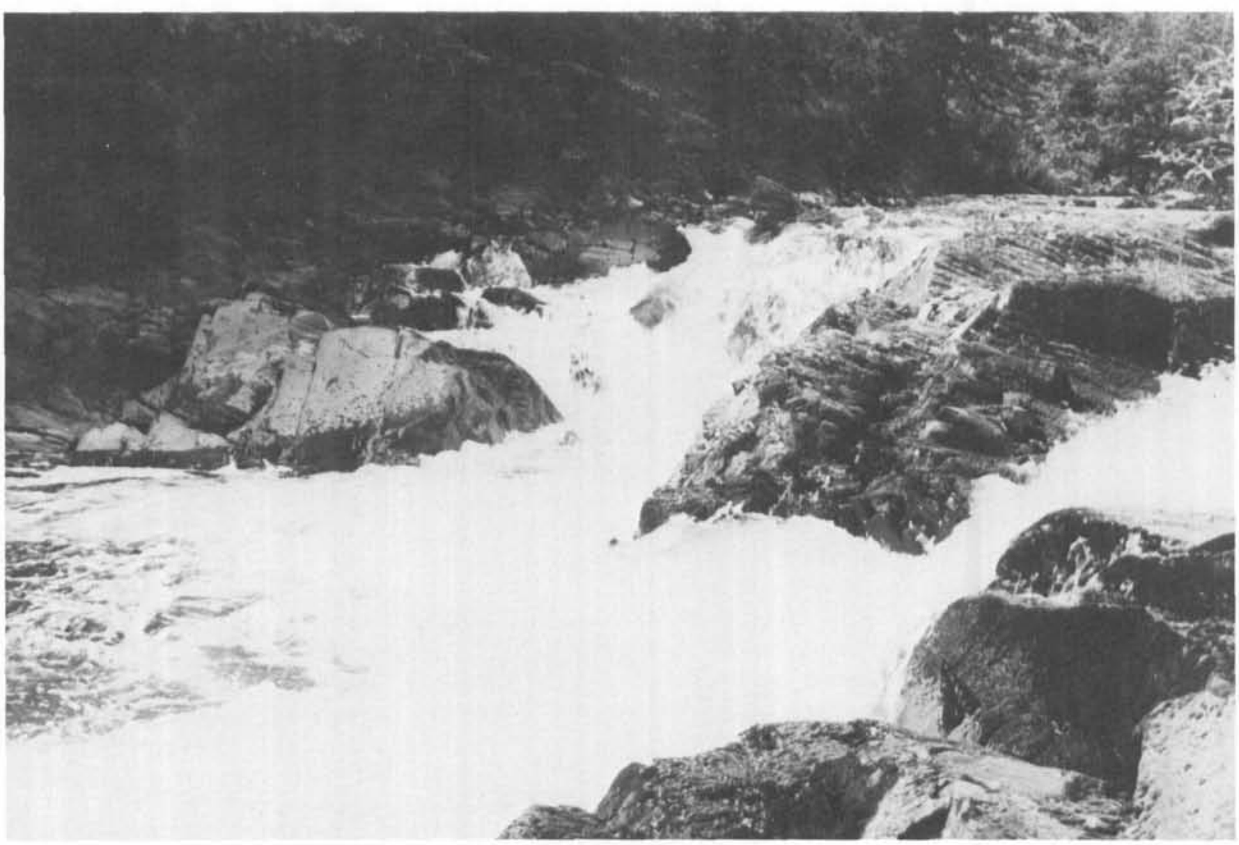

Figure 8. White water of the Black River near Coventry.

tribution of adequate groundwater supplies, increased pressures on existing water supplies in urban communities, and growing pollution problems, the surface water potential of this region should be considered a vital resource and undisturbed or sparsely settled upland areas and mountain slopes should be set aside for future surface-water development.

At the present time, rivers and streams of potential surface-water supply commonly head to the east and west of the central ridge of the Green Mountains. Lucas and Stanhope brooks, tributaries of the Missisquoi River in the Town of Richford, and the headwaters of Trout River in the Town of Montgomery are the most likely possibilities to the west. On the east side of the central Green Mountains, Mill, Taft, and Snider brooks, in the Town of Westfield, and the upper reaches of the Gihon River, in the towns of Eden and Johnson, may afford further surface water supplies. Other additional sources may be found along the eastern margin of the Lowell Mountains in the towns of Albany, Eden, Lowell, and Newport. Fortunately, many of these waterways are as yet somewhat removed from populated areas and remain relatively uncontaminated. Hopefully, Vermont's Land Use and Development Law as amended by the Capability and Development Plan and approved by the 1973 General Assembly, will assist in this measure. Clearly, watersheds already retained for municipal or private water systems are more apt to retain their value as a source of high quality water than watersheds without formal restrictions on use. Development commonly increases the probability of wastes entering surface waters and reduces a watershed's value as a source of potable water. Watersheds reserved for some private and municipal water systems are so large and the lands included within them are currently developed to such an extent that careful monitoring and effective treatment of water entering distribution systems is required (Vermont Interim Land Capability Plan, 1972, p. 18).

Lakes and ponds, although concentrated predominantly in the southeastern portion of the Johnson-Hardwick Region, should also serve as potentially good reserves of surface water. Caspian Lake and the Green River Reservoir are the two largest bodies of water in the region and are capable of supplying large volumes of surface water if needed. Additional sources of standing surface water include Belvidere, Daniels, Eligo, Little and Great Hosmer, and South ponds as well as Eden, Elmore, Hardwick, and Lamoille lakes. These water bodies are perhaps one of the most ephemeral of the physical features of the earth's surface and as such can be either an asset or a liability to nearby communities (Figure 9).

A clean, clear lake is a definite asset, whereas a weed-choked, foul-smelling mudhole is a distinct liability for all. Unfortunately, development along many of these lakes and ponds has proceeded to the point that potable water is no longer always available and contamination may ultimately render the water unfit for use. Greater efforts must be undertaken to control waste discharges into these natural surface reservoirs if they are to serve future generations.

Figure 9. Ritterbush Pond four miles northwest of Eden.

Increasing demands for water usage could be met through the construction of additional catchment and water storage facilities (reservoirs) similar to those already in existence. While costs incurred in such long-term development projects might seem excessive and certainly well beyond the costs of drilling multiple water wells, reservoirs could supply ample quantities of water to expanding municipalities situated in geologically low groundwater-yield areas. Secondary benefits of reservoir construction may be found in the production of hydro-electric power and better developed flood control systems.

Presently, more than 40 percent of all municipalities in the Johnson-Hardwick Region meet daily demands for water through a combination of reservoirs, springs, and water wells. Most of the larger communities have at least one reservoir. The village of North Troy relies on two reservoirs, with a combined capacity of 750,000 gallons, to provide 120,000 gallons of water per day to approximately 700 people — or about 170 gallons of water per person per day. The village of Irasburg, on the other hand, depends on a 5,000 gallon capacity reservoir and four artesian wells to supply 73 units with water. In contrast, communities such as Jay and Lowell rely almost exclusively upon individual wells for their daily water requirements while the village of Troy supplies 60 units with water drawn from nearby Coburn Brook.

While the availability of adequate surface-water supplies is of concern to the people of the Johnson-Hardwick Region, so too is the fundamental quality of their surface water. Throughout this region, surface water quality has been demonstrated to vary widely within the same stream and from one water body to another. Suitability of surface waters for a given use (irrigation, stock, industrial processing and domestic use) is determined by such chemical and physical properties as dissolved oxygen content, color and turbidity, temperature, pH factor, taste and odor, coliform bacteria level, and concentrations of sludge deposits, solid refuse, floating solids, oil, grease, and scum, to name a few. Variations in water quality may be related to the type of soil that the water contacts, length of contact time, past use of the water, amount and source of basic flow, amount of storm runoff, extent of man's use for irrigation, drainage control, and waste disposal, and many other factors.

In 1965, the United States Congress authorized the establishment of Water Quality Standards (the Water Quality Act) for interstate waters in an attempt to protect and enhance their productivity. Between June 15, 1967, and August 24, 1971, the Vermont Legislature adopted and revised various standards to protect the quality and usage of its interstate waters. The federally approved standards were intended to provide: 1) a designation of water usage; 2) written specifications and numerical criteria to protect and enhance water quality and associated aesthetic conditions; and 3) a plan of implementation and enforcement, which included treatment and control requirements for municipal, industrial and other waste products discharged into or affecting interstate waters (Water Quality Standards Summary, 1969, p. 2).

To the extent that it is possible, the Vermont water quality standards implemented were intended to tailor water quality criteria to existing quality or that anticipated to result from the installation of new water treatment facilities. At the time of its inception, the Vermont Water Pollution Control Act was considered unique in American legislation and probably one of the most effective antipollution measures yet introduced in the United States. The statute's uniqueness and strength was derived from the fact that it combined a discharge permit system and an effluent fee system (Moros, 1971, p. 631).

At present, the State of Vermont designates the following uses to be protected in various interstate waters:

Class A. Suitable for public water supply with disinfection when necessary; character uniformly excellent.

Class B. Suitable for bathing and recreation, irrigation and agricultural uses; good fish habitat; good aesthetic value; acceptable for public water supply with filtration and disinfection.

Class C. Suitable for recreational boating, irrigation of crops not used for consumption without cooking; habitat for wildlife and for common food and game fishes indigenous to the region; and such industrial uses as are consistent with other Class C uses.

Class D. Suitable for supporting aerobic aquatic life, for power, navigation and certain industrial process needs consistent with other Class D uses and for restricted zones of water to assimilate appropriately treated wastes. (Water Quality Standards Summary, 1969, p. 4).

In an attempt to clean up surface waters, the Vermont Water Resources Department and the former State Water Conservation Board made detailed studies of surface water conditions throughout the Johnson-Hardwick Region and throughout the state (1960, 1961) and established plans for periodic resampling of specific sites. Water quality tests were made to determine stream temperature, dissolved oxygen content, biochemical oxygen demand (BOD), pH, solids content, turbidity, coliform density (MPN), color, chloride, calcium and magnesium content, and general hardness of the water. Water classifications, based upon previously discussed standards, of various sections of the Lake Memphremagog-Black River, Lamoille River, and Missisquoi River basins clearly indicate polluted areas and the specific sources of their contamination. In every case those reaches of major rivers and their tributaries adjacent to such communities as Richford, North Troy, Montgomery, Johnson, Hyde Park, Morrisville, Lowell, and Hardwick are identified as substandard (Class C or D) while intermediate sections are of better quality (Class B or C) due to the natural dilution of liquidous discharges and the settling of many solid materials. Most headwaters of the major drainage systems throughout the region remain as good to high quality (Class A or B) sources of surface water. Surface water contamination throughout the Johnson-Hardwick Region has been clearly linked to improper disposal of solid wastes close to surface water drainage systems, direct discharge of partially or untreated municipal and industrial wastes into nearby rivers and streams, and improperly operating or closely packed septic tank systems.

When municipalities are obtaining daily water supplies directly from nearby rivers and streams, severe health hazards may obviously be incurred. Recently, the Vermont State Board of Health declared the village of Montgomery's municipal water supply "unsafe" due to its high level of biological contaminants. The 40 or 50 units in Montgomery which are presently supplied with water from a neighboring spring and brook will be linked with a municipal water well as soon as drilling is completed. Waters with excessively high coliform levels (Class C or D) may be drawn and used for domestic purposes when chlorination (1.0 mg/L) and detention practices are followed carefully. Such treatment can be costly but has been demonstrated to kill 99.9 percent of all coliform present in surface waters (Vermont Water Resources Department, 1968, p. 25). The most severe problems in surface water quality are experienced along the Lamoille River between Hardwick and Johnson (Class B, C, and D) where large volumes of contaminants enter the drainage system from domestic and municipal sewers, industrial facilities, refuse disposal sites in the valleys and along hillsides, and from natural surface runoff. Centerville, Elmore Pond, Kenfield, Ryder, and Wild brooks as well as the trunk sections of the Lamoille and Gihon rivers are all ranked as Class C or D waters. Class D conditions are consistently found adjacent to the municipalities of Hardwick, Morrisville, Hyde Park, and Johnson. Problems of municipal sewage treatment, the major source of surface-water contamination, are being steadily reduced by the careful planning and construction of modern sewage treatment plants supported by state and federal funding, i.e. Johnson Sewage Treatment Plant. Unfortunately, most municipalities within the Johnson-Hardwick Region are still awaiting assistance. In recent years, industrial waste contamination has been markedly reduced through strict enforcement of anti-dumping and effluent discharge legislation. Further effort is still required.

Groundwater

To sustain a human life in a physiological sense, about one gallon of water per day is needed. Today, however, the average American city dweller uses between 150 and 200 gallons of water a day. While such consumption rates will vary according to climate, degree of affluence, and regional custom, all reflect excessive water usage. In a time when the pollution of surface water supplies is increasing more rapidly than our solutions to the problem, many communities have turned to groundwater sources to meet growing demands for "pure water."

Only when moderate to large quantities of groundwater are retrievable, however, do they become useful to mankind. To be so, subsurface or underground water must be able to move with some degree of freedom. Groundwater sources of greatest importance are, therefore, those which occur in materials that are porous and permeable. Porosity is best defined as the volume, expressed as a percent, of unoccupied space present in sediments or bedrock. With rare exceptions, most materials at or near the earth's surface possess some degree of porosity. Hydrologically, porosity is important because it permits storage of water in the subsurface and, when determined quantitatively, it represents the approximate storage coefficient of a given material. Permeability, on the other hand, is a measure (Darcy) of the ease with which water may move through the openings of a given material.

Although it has been estimated that over 90 percent of Vermont's total available water supply consists of subsurface sources (Rural Sewage Management in Vermont, April 1971), groundwater within the Johnson-Hardwick Region is a limited resource due to its irregular geographic distribution in the region's fractured bedrock and unconsolidated valley sediments and its great variability in abundance (yield). In some localities, groundwater supplies are available in sufficient quantities for municipal, industrial, and commercial usage, while in other cases areas with severe limitations are restricted to minimal domestic use only. In this connection, it should be noted that areas with severe limitations will not tolerate unlimited residential development because the aggregate demand will ultimately be equivalent to that of a commercial or industrial user. Unfortunately, sufficient information is as yet unavailable to specify the density limits for residential development in specific areas. Preliminary information does suggest, however, that half-acre plots may be the maximum concentration possible for areas, with severe limitations, dependent on groundwater supplies. Greater densities may ultimately result in competition among users for the same groundwater supplies (Wagner, 1971, p. 5).

These and other observations make it readily apparent that groundwater management is one of the most important and critical aspects of environmental planning. Although many good quality surface water reserves are not being used to capacity and others remain untapped, attempts to prevent development on watersheds, restrict lake usage, and control pollution may not sufficiently protect this supply. Increasing contamination of surface waters and growing demands for readily available high volume, low cost sources of potable water will necessitate greater utilization of groundwater supplies in the years to come.

In an attempt to evaluate groundwater supplies in the Johnson-Hardwick Region, data was obtained from several different sources. Some 567 well completion reports, supplied by the Vermont Water Resources Department, served as a basic source of information and assisted greatly in the determination of such geologic conditions as the thickness and type of surficial materials, the depth of wells in each locality, and the amount of water produced (yield) by each well. These well records have been required of all licensed water-well drillers since 1966, and are available to all planning agencies through an open file system. The information obtained from these compiled reports can be readily applied to the solution of many environmental problems provided that they have been completed accurately. Unfortunately, such reports are often submitted in an incomplete, inaccurate, or sketchy fashion and therefore offer little assistance to any study.

Through the combined use of a twelve- or twenty-four trace seismic refraction method with a continuous profiling technique (Figure 10), Weston Geophysical Engineers, Inc. of Westboro, Massachusetts, completed 6 relatively quick and accurate seismic profiles at various locations throughout the region where well-log and geologic information indicated favorable groundwater conditions. The seismic refraction method is an indirect means of determining the depth, width, and general configuration of buried bedrock valleys, the depth to the local watertable, and a generalized profile of the overlying glacial and fluvial sediments. These interpretations are based on the measurement of the time required for elastic ("p") waves, generated at a point source, to travel to a series of vibration-sensitive devices (geophones or seismometers). These geophones are spaced at known intervals along a straight line on the ground surface and, with end shots, is called a seismic spread. The length of each spread is determined by the required depth of penetration. The deeper the penetration desired, the longer the spread must be. All spreads used in this study were 400 feet in length and corresponding geophone intervals of 20 feet (end-of-spread geophones) and 40 feet (center-spread geophones).

Using seismic data alone, earth materials are placed into broad classifications based on the velocity of the seismic wave transmitted through them. Each recorded velocity does not have a specific material correlation due to variations in bedrock lithology, degree of weathering or fracturing, sediment composition, compactability and wetness. Most bedrock as well as overburden materials do however fall within particular velocity ranges.

Since seismic velocities are determined by the moduli of elasticity and the density of each material, the magnitude of seismic velocities may, to some extent, be used as an indicator of the "behavior" of different materials for design and excavation purposes.

Bedrock characteristically has a high seismic velocity (10,000-14,000 feet/second) due to its density but variations in rock type and its degree of weathering and/or fracturing may produce velocities below 8,000 ft/sec. Seismic velocities above 11,000 ft/sec are indicative of sound bedrock which will require blasting for excavation. Bedrock with velocities ranging between 8,000 and 11,000 ft/sec may similarly require blasting but prediction of design characteristics for such material is uncertain. Weathered rock in the velocity range of 3,000-7,500 ft/sec will have the design characteristics of overburden but may require localized blasting for removal. Velocities in the 1,000-2,500 ft/sec range are characteristic of residual soils.

The seismic velocities of unconsolidated sediments are commonly much lower than those of bedrock. The velocity range of 500-800 ft/sec is usually indicative of very loose and unsaturated silts, humus, and loose, man-made fill materials. The velocities in the range of 800-2,000 ft/sec are characteristic of unconsolidated overburden materials, usually fluvial deposits which are unsaturated and relatively uniform. Velocities of 2,000-4,000 ft/sec are common to a number of materials, but in Vermont these usually indicate loose, thin, relatively dry tills (ground moraine). The most typical velocity range of the

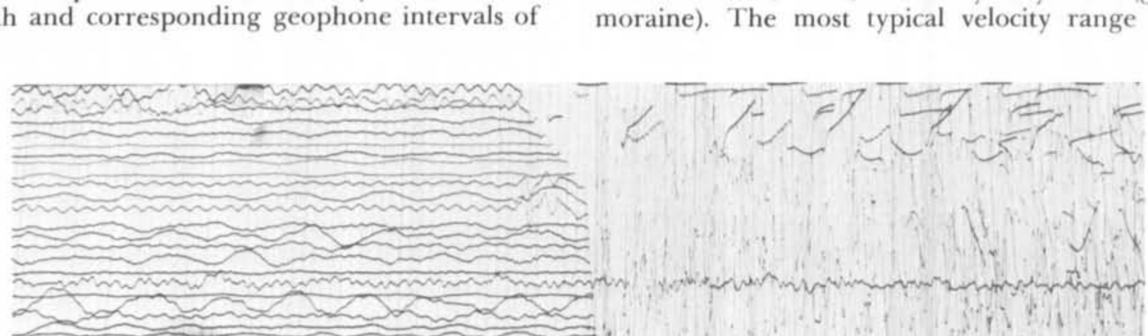

Figure 10. Twelve-point seismic refraction record.

ground moraine is 2,400-2,800 ft/sec. This range of seismic velocities is also indicative of some compacted and well-graded, unsaturated sands and gravels. Unsaturated tills commonly have velocities ranging from 3,500-4,000 ft/sec, while more compact glacial tills are suggested by velocities of 6,000-8,000 ft/sec. Seismic velocities between 6,000-6,300 ft/sec are associated with saturated tills located in river valleys throughout the state.

Unconsolidated sediments with seismic velocities ranging between 4,500 and 5,500 ft/sec are usually saturated with water. Groundwater in sufficient quantities for municipal water supplies have been found only in materials with velocities ranging between 4,800 and 5,300 ft/sec. Surficial materials having velocities below 4,800 ft/sec are usually not saturated while those above 5,300 ft/sec are too compact to be of sufficient porosity and permeability to yield large quantities of water (Stewart, 1972; Weston Geophysical Engineers, Inc., 1974). The seismic profiles reproduced in this report were prepared by Weston Geophysical Engineers, Inc. during the 1973 summer seismic study.

Ground Water Favorability maps (Hodges and Butterfield, 1967) of the Lake Memphremagog Basin and the Lamoille, Missisquoi, and Winooski River basins were examined and compared with all available information pertaining to groundwater conditions in the Johnson-Hardwick Region. These drainage basin maps were intended to serve as a guide for local groundwater exploration and as such, designate areas of potentially excellent, moderate, and low groundwater yields. In addition, they also locate several water wells of varying yields and indicate the type of water aquifer from which they are producing. Vermont Highway Department test borings are also located on these maps and their drill records are described. The Groundwater Potential Map (Plate III) prepared during this survey agrees closely with much of the information shown on the Ground Water Favorability maps of the Vermont Department of Water Resources. Due to the substantial volume of recent well-log, geologic, and seismic data utilized in the preparation of this map, however, a more precise interpretation of the groundwater conditions in this area has been achieved. Areas shown in green (g) indicate localities of good groundwater potential and/or medium to high yields (greater than 30 gpm) at depths to 200 feet in various sand and gravel deposits. Areas designated in yellow (y) characteristically have low to medium groundwater yields (10-30 gpm) from stream valley gravels or from bedrock below the valley fill at depths to 300 feet or are thought to have moderate groundwater potential. Areas shown in red (r) are considered to possess very low groundwater potential or have low yields (0-10 gpm) from fractured bedrock sources at depths to 300 feet.

To better evaluate the availability of groundwater supplies in the Johnson-Hardwick Region, it is important to examine closely the nature of the materials in which this resource occurs. Characteristically, the igneous and highly metamorphosed bedrock materials of this area, veneered with a thin mantle of till, possess extremely low to non-existent primary porosity (1 to 3 percent maximum) and virtually no permeability. Most of the groundwater produced from such bedrock sources comes, therefore, from secondary openings (2 to 10 percent maximum) created in fractures and weathered rock zones (Figure 11). Fractured zones tend to be more open at the surface and decrease in width downward. At depths below 300 to 400 feet, the fractures are usually so tight that they either contain little or no water or the water contained in them is held by capillary action (Stewart, 1972, p. 22). The fractures in the rock commonly trend in all directions and intersect at all depths, promoting highly irregular (anisotropic) groundwater flow and hydrostatic pressures sufficient for raised water levels (artesian conditions) in the well. Of all bedrock water wells drilled above the valley bottoms in Vermont, 5 to 20 percent should properly be classified as failures as they do not provide minimum yields of 2 gallons of water per minute (gpm) or more, which is a level considered adequate for low density residential supplies. Wells of low yields range between 1 and 10 gpm of water while moderate yields approach 10 to 25 gpm. High yield bedrock wells, such as would be required for commercial, industrial, high density residential and municipal supplies, are relatively scarce in the Johnson-Hardwick Region. Clustering of bedrock wells which produce in excess of 25 gpm is, however, more common near valley bottoms and in areas of intensely fractured bedrock.

Under natural conditions, the physical and chemical properties of water, derived from wells penetrating the water-bearing zones in bedrock, remains fairly uniform through time and commonly provides a supply of good to excellent quality water. In some instances, individual wells and small groups of wells may produce water which is high in silica and chlorides, hard, and generally poorly suited for domestic use. Where soil cover is thin or absent over fractured bedrock, biological contamination of groundwater may pose a serious problem even though the fractures may be less than 1 mm. wide. Pathogenic organisms may move more efficiently here than in normal alluvial aquifers where organic contaminants are removed through natural filtration over short distances of transport. Once contamination of groundwater held in rock fractures has begun, control and abatement of such problems is very difficult due to the erratic route traveled by the water.

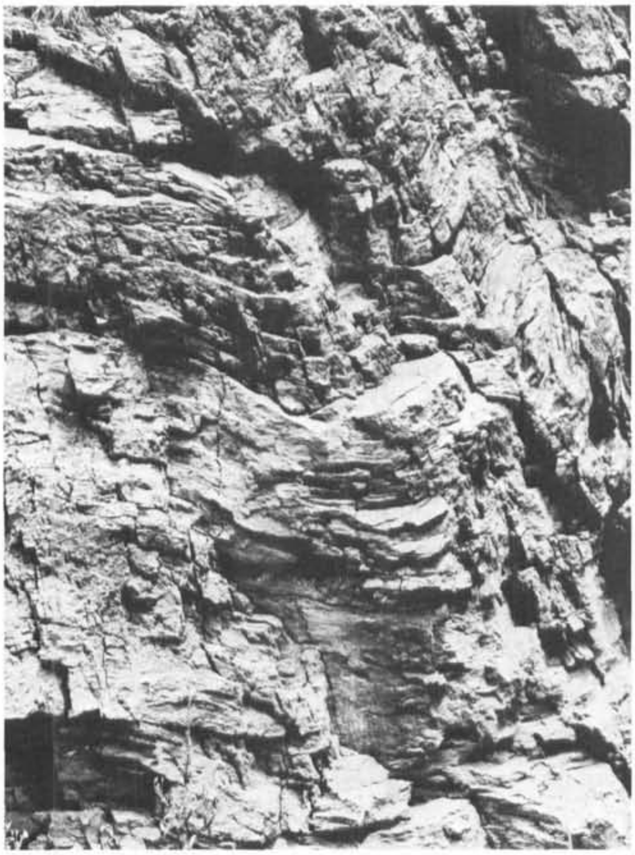

Figure 11. Folded and fractured schist bedrock exposed along the Trout River one and one-half miles west of Montgomery.

The uplands of the Johnson-Hardwick Region are covered by a discontinuous mantle of glacial till that generally varies from 0 to 20 feet in thickness and large areas of bedrock remain exposed. The till cover found on these upland areas is often too thin and too impermeable to yield reliable supplies of groundwater except from hand-dug wells producing from near-surface sources. Wells such as these are especially prone to contamination and should not be used. Due to problems of limited water supply and high contamination potential, most water wells developed in upland areas must draw water from the bedrock at depths as great as 855 feet (150-225 feet average). The measured groundwater yields of deep bedrock wells throughout the Johnson-Hardwick Region range from 1/8 to 70 gpm (3-6 gpm average). These generally very low yields are considered inadequate for most individual or commercial uses, but may be suitable for domestic or farm water supplies. The following two driller's logs (H. A. Manosh Corp., 1967, 1971) of bedrock wells near Morrisville and Irasburg, respectively, illustrate the low and moderate groundwater yields encountered while drilling in the Johnson-Hardwick Region.

Low groundwater yield in the Morrisville area:

STRATA	*THICKNESS*	*DEPTH*
Soil — dirt and clay	5	0-5
Sand, pack gravel and boulders	20	5-25
Dark gray-green, medium-hard bedrock	275 ft.	25-300 ft.

Yield = 1 gallon per minute

Moderate groundwater yield in the Irasburg area:

STRATA	*THICKNESS*	*DEPTH*
Clay and boulders	5	0-5
Soft shale	6	5-11
Blue, medium-hard bedrock	70 ft.	11-81 ft.

Yield = 54 gallons per minute (probably due to fracturing of local bedrock)

Throughout the Johnson-Hardwick Region, as in much of New England, glacial deposits form an important part of the framework for present water supply systems. These materials consist of varying proportions of sand, gravel, silt, and clay and may range up to 175 feet or more in thickness in many valley bottoms. Due to their differences in origin, composition, primary porosity and permeability, glacial materials will exhibit large variations in groundwater yields. Till aquifers, those composed principally of heterogeneous mixtures of glacial debris with interbedded sand and gravel deposits, are usually of low porosity and permeability and make poor groundwater sources due to their slow yield. Only when interbedded sand and gravel lenses are reasonably thick and extensive do till aquifers provide low to moderate groundwater supplies. The common irregularity of such deposits often results in distorted subsurface transmission of water and unreliable yields. Lacustrine and outwash aquifers, those composed of moderate- to well-sorted sands and gravels and confined to the region's stream valleys, commonly possess moderate to high porosities (5-25 percent) and permeabilities and make good groundwater sources. Here, thinner and less well-sorted sand and gravel deposits usually yield less than 20 g.p.m. of water while thicker and more well-sorted materials often yield 20-50 g.p.m. of water. In some instances, groundwater yields from such deposits may exceed 200 g.p.m. Where sand and/or gravel layers occur at depth in the valleys, they often serve as very good aquifers that yield water in much greater quantities than the surrounding bedrock with less chance of contamination. Valley aquifers presently afford the greatest reserve of water throughout the region and will undoubtedly be utilized more as demands for potable water increase. The following driller's log (B. and B. Artesian Well Co., Inc., 1966) of a water well developed in unconsolidated sediments near Richford illustrates the high yield potential of valley-fill sand and gravel deposits.

STRATA	*THICKNESS*	*DEPTH*
Sod cover and loam	2	0-2
Fine brown sand	8	2-10
Gray clay	90	10-100
Sand and gravel	195 ft.	100-265 ft.

Exceptionally high groundwater yields were encountered when completing a well in the Morrisville well field during the summer of 1973. Here, sand and gravel deposits along the south bank of the Lamoille River were drilled to a depth of 40 feet and a groundwater yield of 1500 g.p.m. was calculated. Much of this water may be coming directly from the nearby Lamoille River, through the sand and gravel deposits, to the well-head. If this is the case, little opportunity for natural filtration and purification is provided and this water should be chlorinated before use.

Lacustrine and outwash deposits commonly fill the major valleys of the Johnson-Hardwick Region and extend along adjacent hill slopes. These numerous and expansive recharge areas provide most of the groundwater that issues from wells, springs, and seeps within each drainage basin. When water flowing from upland areas enters these deposits and becomes confined to the more porous and permeable layers, artesian conditions may be produced. Such conditions provide a prime source of potable water.

As groundwater moves through the earth it picks up and dissolves various organic and mineral substances from many different sources. The nature and amount of material carried and/or dissolved through these contacts dictate to a large degree the water's quality. The physical and chemical properties of water derived from wells penetrating water-bearing unconsolidated sediments throughout the region remain fairly uniform with time and almost always provide a supply of good to excellent quality water, often significantly less contaminated and safer for human use than is surface water. In some instances, however, individual wells and small groups of wells may produce water which is high in various contaminants or dissolved mineral content and therefore poorly suited for domestic use.

The physical properties of groundwater that are of greatest concern are, like surface waters, color, taste, odor, temperature, and cloudiness or turbidity. Color, taste, and odor in groundwater usually originates from the presence of organic materials and dissolved substances while cloudiness or turbidity is caused by finely divided and suspended insoluble soils and silts and clays in the water. These properties are the most readily perceptible characteristics of groundwater. Everyone can tell whether or not water has an objectionable taste or odor, if it is hot or cold, or if it is clear or dirty. Although the general appearance, odor, or taste of drinking water may not threaten human health directly, they may lead people to drink more palatable but more dangerous water and thus such physical characteristics of water may be indirectly hazardous (Houston and Blackwell, 1972, p. 9; Wagner, 1971, p. 108).

Although groundwater percolation tends to remove by natural filtration, absorption, or biochemical degradation most of the contaminants potentially dangerous to man, various disease-producing bacteria, viruses, parasites, and chemically toxic substances may enter the groundwater system and be transmitted considerable distances before they are neutralized. Tests for water quality seek primarily to verify the presence or absence of such contaminants and their concentration levels so that precautionary or corrective measures may be taken for individual and grouped wells. One of the more sensitive and readily discernible forms of groundwater contamination stems from the presence of coliform bacteria. Coliform bacteria are normally present in exceedingly high numbers in the intestinal tract of man and animals and if intestinal discharges have contaminated water supplies, large numbers of coliform bacteria are certain to be present. While coliform bacteria rarely cause a disease in themselves, they are significant as an indicator of more serious sewage pollution problems. When well-water sample tests confirm the presence of coliform bacteria, domestic water should be boiled and the well chemically treated in accordance with Vermont State Health Department regulations (1971). Should such measures fail to reduce present contamination problems, some corrective construction on the well or well-site relocation may be necessary.

Unfortunately, regional problems stemming from high concentrations of mineral material and bacterial contamination are difficult to substantiate because few well drillers in Vermont adhere to requests by the Vermont Department of Water Resources for a water quality sample test at the time of well completion. Furthermore, the present systems used for filing well completion reports with the Department of Water Resources and water system sample collection data with the Vermont State Health Department do not coincide in such a fashion as to give a clear interpretation of regional groundwater quality patterns. Through interdepartmental cooperation and/or a better system of data collection within each agency, a significant contribution to understanding Vermont's groundwater problems could be achieved with little or no increased expense to the tax payer.

More important than problems of groundwater quality is the question of general groundwater availability and potential yield throughout the region. Theoretically, potential groundwater supplies are considerably greater than present demands for most portions of the study area. Continued population growth in some localities may, however, ultimately raise local demands for water to such an extent that practical sustained yields of groundwater reservoirs may be exceeded. Such heavy concentrations of water wells and corresponding withdrawal would undoubtedly result in eventual competition among users for the same groundwater supplies and general impairment of water quality. In the future, it may become necessary to complete detailed studies in local areas to determine quantitatively the limits to well densities and volume usage of such a resource. Sensible management of surface and groundwater supplies will undoubtedly continue to meet public demands for increased amounts of potable water in the years to come.

Inasmuch as the greatest population density for the Johnson-Hardwick Region is encountered along the Lamoille River Valley, it is appropriate that a discussion of groundwater availability in this area be considered first. While bedrock is widely exposed along many parts of the Lamoille River Valley, geologic investigations, available well records, and recent seismic profiles indicate that much of the main bedrock valley and its tributaries are filled with 50 to 130 feet or more of water-saturated sands and gravels with local concentrations of silt and clay (seismic velocity 5,000 ft/sec). The finer grained deposits are generally found close to the land's surface while variable thicknesses of coarser sediments are concentrated at the bottom of the valley in most areas. Well records show that these sand and gravel deposits, if properly drilled, should yield moderate to good quantities of groundwater.

Seismic profiles in the Lamoille River valley, completed approximately one mile west of Johnson (Figures 12 and 13) indicate a broad valley with depths to bedrock ranging from 80 feet near the river on the south to 130 feet at the deepest part of the valley, about 800 feet south of State Route 15. The bedrock surface becomes abruptly shallower near the highway, with a pronounced bedrock rise approximately 400 feet to the south. Nearby well-log data and seismic velocities indicate variable thicknesses of gravel, sand, and silt and clay overtopped with alluvium throughout this section. The water potential throughout this portion of the valley is ranked moderate to good and appears to be closely associated with basal sand and gravel deposits.

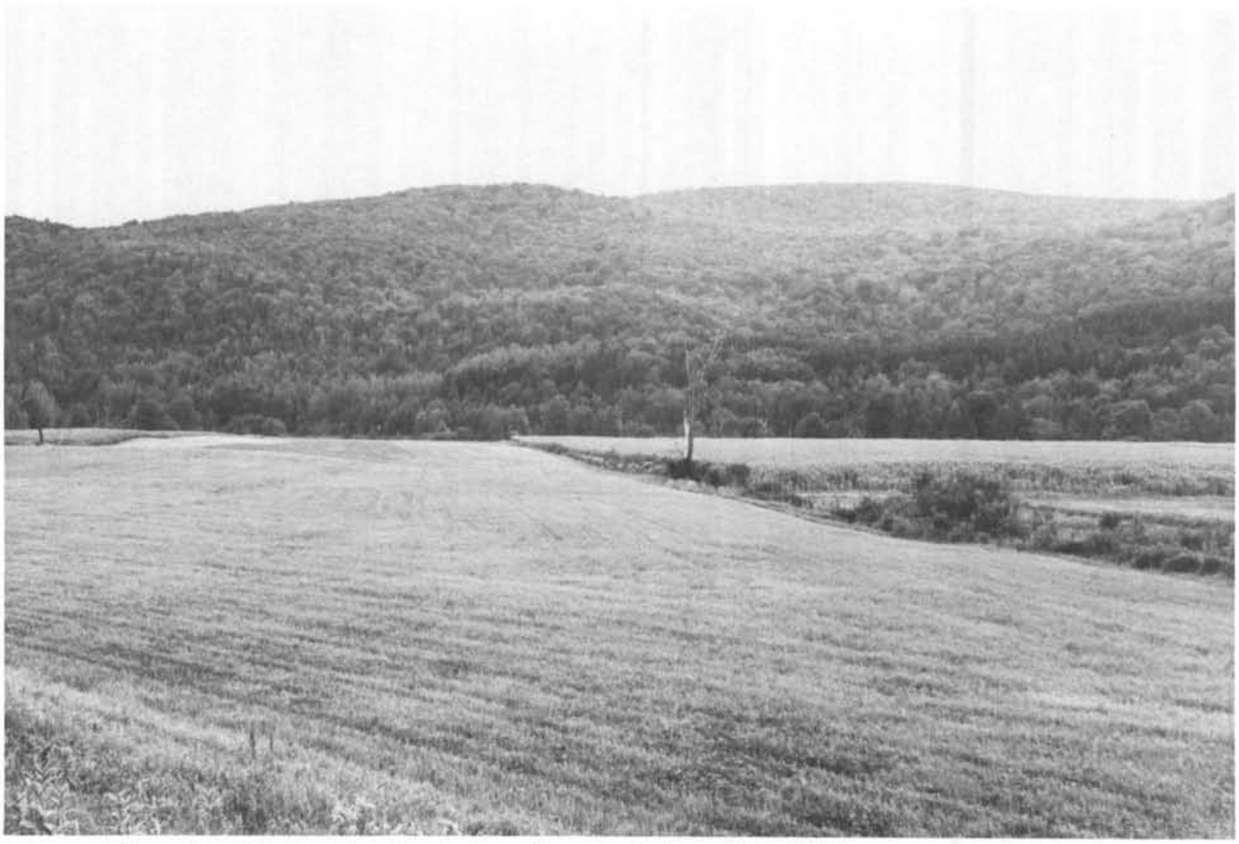

Figure 12. Site of north-south seismic profile across the Lamoille River Valley, one mile west of Johnson.

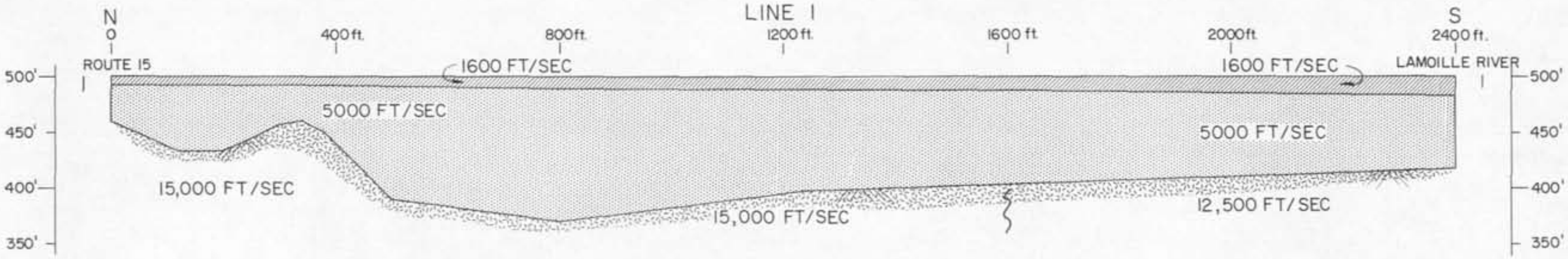

Figure 13. North-south seismic profile across the Lamoille River Valley one mile west of Johnson.

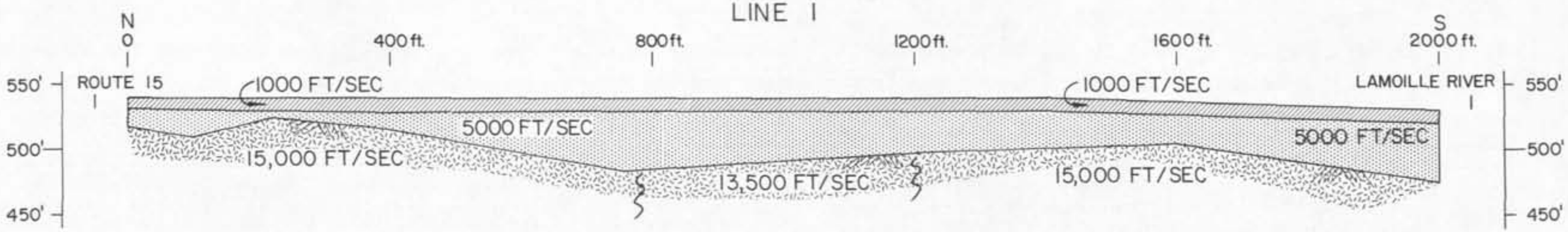

Figure 14. North-south seismic profile across the Lamoille River Valley about two miles northwest of Hyde Park.

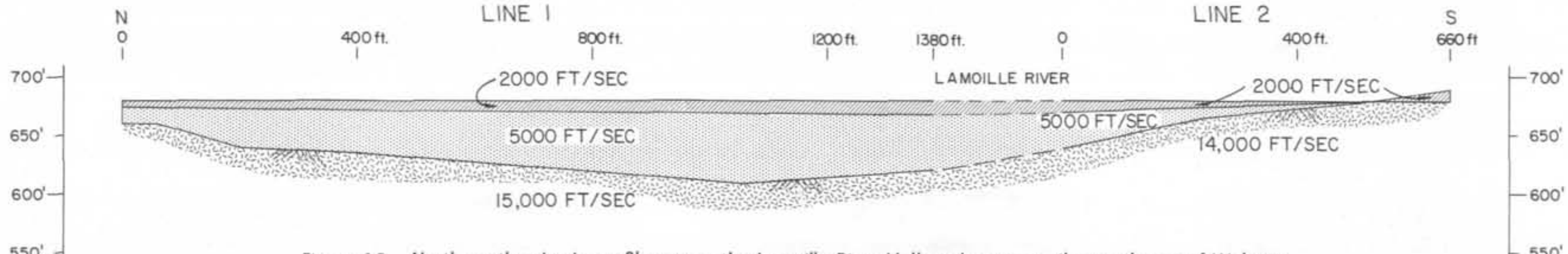

Figure 15. North-south seismic profile across the Lamoille River Valley about two miles northwest of Wolcott.

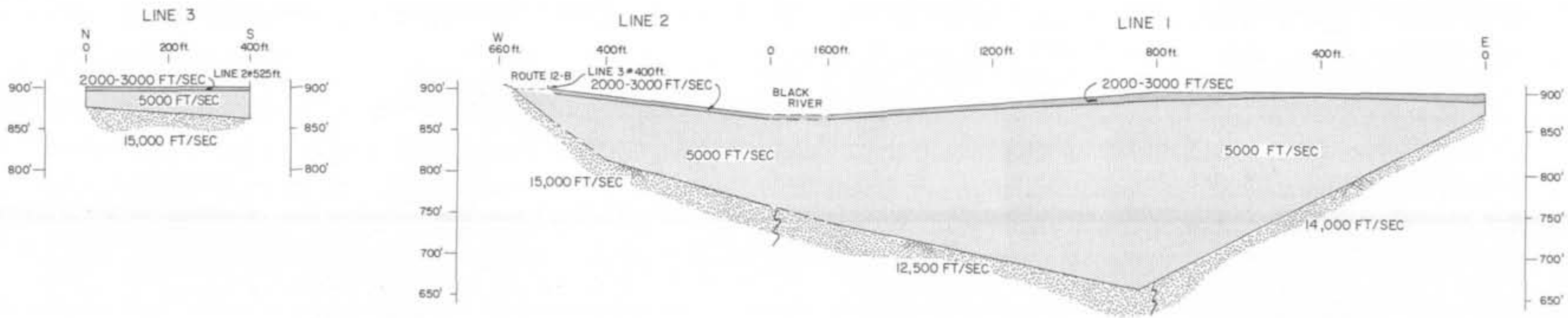

Figure 16. East-west seismic profile across the Black River Valley about two miles northwest of Mill Village.

Seismic profiles completed in the Lamoille River valley about two miles northwest of Hyde Park (Figure 14) suggest that bedrock is generally shallow throughout the section. The maximum thickness of 5,000 ft/sec overburden material, approximately 55 feet, was found close to the river and about 500 feet south of State Route 15. With limited cultural development, the saturated valley-fill sediments of this area may generally be expected to yield moderate to good supplies of groundwater. Similar studies (Figure 15) of the Lamoille River valley, just west of its juncture with Wild Branch (two miles northwest of Wolcott), indicate a maximum thickness of 70 feet of 5,000 ft/sec overburden material in the center of the valley and corresponding moderate to good groundwater yields are therefore anticipated. Where the bedrock valley of the ancestral Lamoille River is broad, deep, and extensively filled with medium- to coarse-grained sediments, groundwater potential is considered good. Limited valley development and sediment in-filling may restrict groundwater supplies considerably (low to moderate potential).

Seismic studies completed in the Black River valley, approximately two miles northwest of Mill Village (Figure 16) indicate a fairly well-developed "V"-shaped bedrock valley, with a maximum thickness of more than 230 feet of 5,000 ft/sec overburden material, located about 800 feet east of the Black River. Scattered water-wells already producing from the valley-fill sediments of this area show thick sequences of interbedded sands and gravels with some silts and clays. Wells penetrating to depths of approximately 100 feet commonly end in coarse gravels which yield between 15 and 100 g.p.m. of water. While this section of the Black River valley may have a moderate to good water potential, Highway Department test borings to the south indicate the presence of thicker sequences (approximately 81 feet) of silt and clay mixed with thin layers of sand and thereby suggest a much lower groundwater potential for that section of the valley. Similar studies conducted in the Black River valley between Round and Chamberlain hills, approximately 1.5 miles southwest of the village of Irasburg (Figures 17 and 18) indicate the greatest valley depth and corresponding thickness of overburden material measured during this study. A total thickness of 390 feet of 5,000 ft/sec material was measured in the center of the profile line near the Black River. Unlike the other seismic profiles developed for this study, an extensive deposit of dense glacial till was found along the western side of the valley. Although few water well completion reports were available for this portion of the Black River valley, a Highway Department

Figure 17. Site of northwest-southeast seismic profile across the Black River Valley, one and one-half miles southwest of Irasburg.

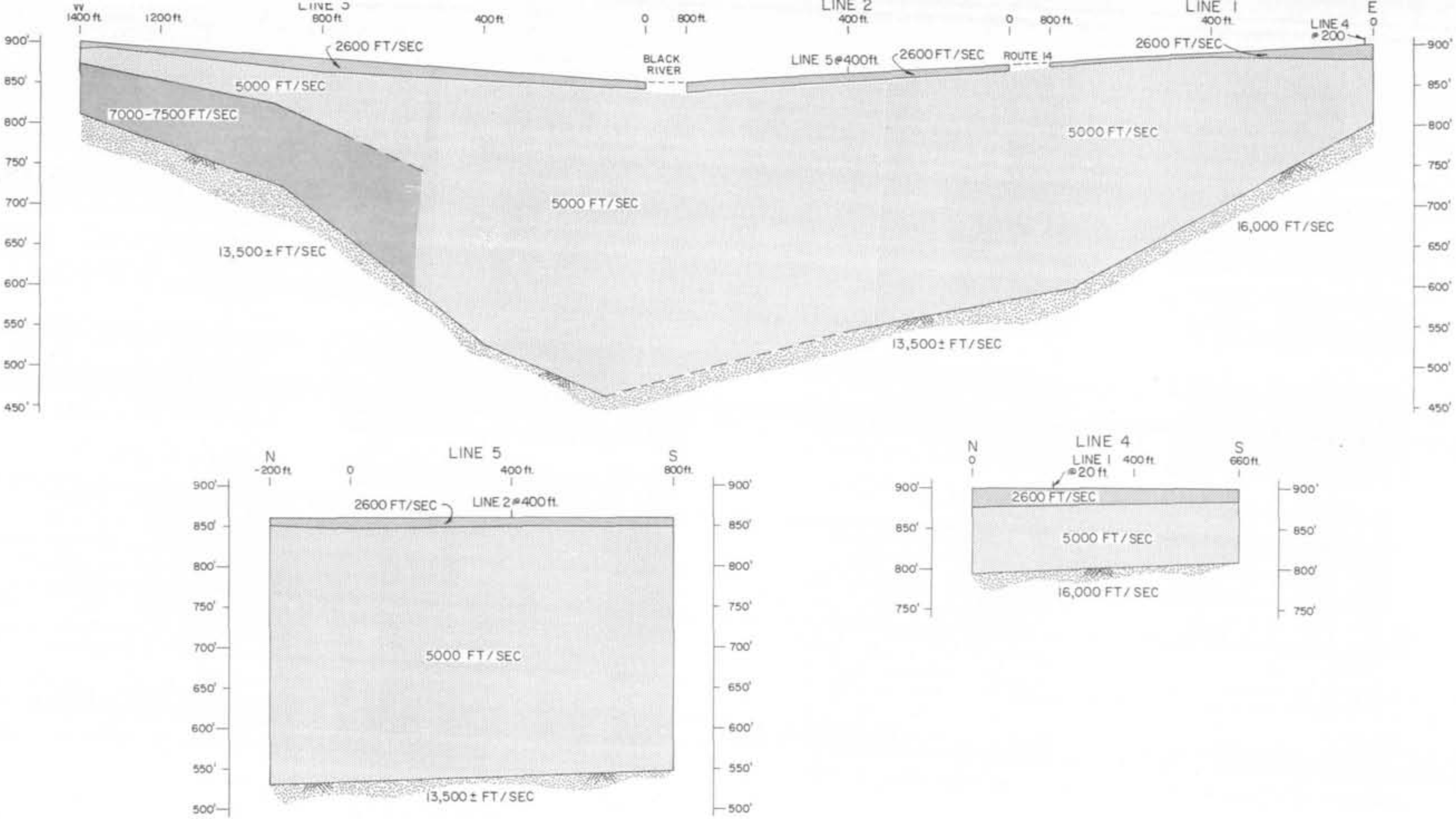

Figure 18. Northwest-southeast seismic profile across the Black River Valley, one and one-half miles southwest of Irasburg.

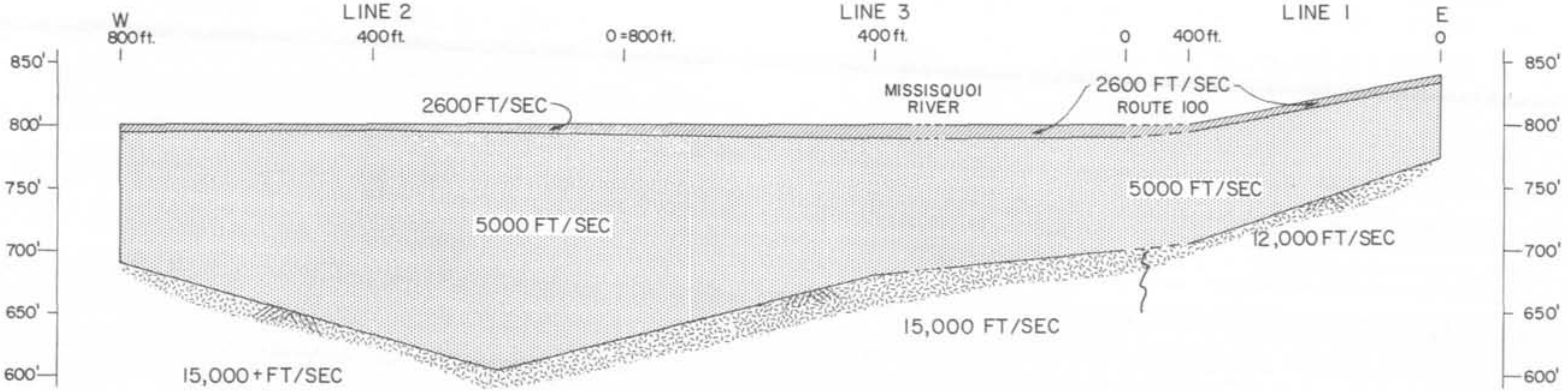

Figure 19. East-west seismic profile across the Missisquoi River Valley about two miles north of Lowell.

test boring in this area indicates that at least the upper 53 feet of the overburden material consists of fine-grained sands and gravels. Based largely on seismic information, it is suggested that this area has a moderate to good groundwater potential in those portions of the valley unaffected by the infilling of glacial till and a moderate to low potential for the western side of the valley.

Seismic studies in the Missisquoi River valley (Figure 19), approximately 2 miles north of the village of Lowell (east of Browns Ledges) indicate depths to bedrock ranging from 65 feet along the eastern end of the profile line to 195 feet at the deepest part of the valley, approximately 600 feet west of the river. Overburden velocities are consistently 5,000 ft/sec and thereby indicate saturated sediments. Scattered well logs for this area indicate variable thicknesses of sand and gravel in the valley bottom which yield from 5 to 30 g.p.m. of water. Groundwater potential for this section of the valley is considered moderate to good.

Despite the widespread occurrence of seemingly favorable groundwater source areas throughout the Johnson-Hardwick Region, little detailed information concerning groundwater favorability and quality is available except through scattered and often poorly documented well-log completion reports and water quality analyses. The six seismic profiles completed for this investigation have helped to better define specific site conditions throughout the region and provide additional support for regional interpretations, but because of the great variability in thickness and type of valley-fill sediments encountered in the Black, Lamoille, and Missisquoi River valleys, all evaluations as to groundwater potential are of a general nature. Due to the scanty availability of subsurface information concerning the areas selected for seismic investigation, Weston Geophysical Engineers, Inc. recommend test drilling for reliable water sources in all areas surveyed. This practice is similarly advised for all other municipal well-field development projects. For general evaluative purposes, however, the kame, outwash, and lake sediments which fill or lie adjacent to the Black, Lamoille, and Missisquoi rivers commonly exhibit moderate to good groundwater potential and often yield 5-20 g.p.m. of water. In many cases, those wells extended to considerable depth in bedrock might have produced equal or greater quantities of water if they had been completed in sands and gravels at shallower depths. For instance, a well near Newport Center was drilled to a depth of 31 feet, completed in gravel, and yielded 60 g.p.m. of water. Similarly, a well drilled near Montgomery was carried to a depth of 28 feet and produced approximately 100 g.p.m. of water from coarse sands and gravels.

Suffice it to say, that groundwater supplies are available in various quantities throughout the Johnson-Hardwick Region, but best reserves are characteristically found in the valley-fill sediments of the area's major drainage basins. While wells developed in upland areas will need to be carried to some depth in bedrock to guarantee sustained yields, wells developed in river valleys need not necessarily be completed in bedrock or be carried to such depths to provide adequate groundwater yields. In all cases, a reputable well driller should be consulted prior to drilling. Additional information may be obtained from the Vermont Department of Water Resources.

WASTES OF A SOCIETY

One of the most pressing social and environmental problems encountered today, is the disposal of waste. The geologic consequences of solid and liquid waste disposal include the general disruption of the earth's surface and the substantial chemical and biological changes brought about by the introduction of the two into the environment. While the problems of solid waste disposal are more obvious than those of contaminated liquids, both impose seri-

Figure 20. Dump located in lake sediments near Rodman Brook two miles northeast of Morrisville.

ous stresses on expanding urban and rural areas. As the volumes and varieties of wastes increase, the dilution and cleansing capabilities of many natural systems are easily overwhelmed and the deleterious effects become obvious even to the most casual observer. To avoid further disruption of surrounding environments, the traditional methods of waste disposal for residential areas, industries, and muncipalities must be re-evaluated.

Solid Waste Disposal

Solid waste is probably the most visible evidence of our environmental problems. The increasing volume and complexity of wastes plague communities across the nation (Figure 20). Private households are the largest contributors of solid waste (44 percent), industrial and construction operations rank second (30 percent), and commercial enterprises generate the remainder (26 percent) according to the U.S. Department of the Interior in 1971. The urban population of the United States is now producing an unprecedented 1,400 million pounds (estimate) of solid wastes each day. Based on a volume estimate of 5.7 cubic yards per ton of waste, this refuse is sufficient to cover more than 400 acres of land per day to a depth of approximately 10 feet (U.S. Department of Interior News Release, August 22, 1971).

With or without prior incineration, the so-called "sanitary landfill" is the principal means of solid waste disposal used today. Its popularity arises from the fact that it is often the cheapest form of disposal—costing as little as $0.65 to $1.10 per ton. What makes the landfill "sanitary" is the practice of covering each day's accumulation of waste with a compacted layer of earth so that gases and fluids, produced by chemical and biological action in the fill, are restrained from escaping into the surrounding atmosphere and surface- and/or ground-water system (Flawn, 1970, p. 148).

In 1968, the U.S. Public Health Service conducted a nationwide survey of solid waste disposal practices, examining 12,000 typical "land disposal sites" and found that only 6 percent could be classified as "sanitary landfills," while the remainder were little more than "open dumps." Of the 12,000 sites studied, less than 14 percent were covered daily, 41 percent got no cover at all, and 75 percent had an unacceptable appearance and some form of open burning (Figure 21). The survey did not reveal how many of these sites had fouled their environment because of penetration of pollutants into their local ground water system (Wagner, 1971, p. 418; Legget, 1973, p. 380). For too long the attitude toward solid waste has been to dump it, burn it, or bury it!

At the present time, those disposal sites which best classify as "sanitary landfills" can be described

Figure 21. Dump located in kame and outwash sediments one and one-half miles east of Eden, near Lake Eden.

according to their shape and the location of the space filled (Benarde, 1973, p. 183). These include such classifications as: 1) *area landfills* – refuse is deposited in horizontal layers on relatively flat ground compacted, and covered over, sides and top, with soil or another inert material, layer-cake fashion; 2) *trench landfills* – land excavated in the shape of a trench to a depth, length, and width determined by the particular characteristics of the tract. Depths of 10 to 15 feet and widths up to 20 feet are widely employed. Refuse is deposited in the trench, compacted and covered with earth to reduce fly and rodent attraction. Separation of the refuse by walls of soil keeps fires from spreading beyond a single cell. The soil cover, from 18 to 24 inches thick, virtually eliminates odors; and 3) *ramp landfills* – a method of filling land which employs existing ravines or quarries; refuse is deposited against side walls and, as with the area and trench methods, inert cover is placed on the sides and top at regular intervals.

The geologic problems associated with solid waste disposal, particularly the landfill type, are within all probability the second greatest environmental concern next to problems of water availability and quality. According to Flawn (1970, p. 149), the pollution potential of a landfill, regardless of its type, depends on five important factors. These include: 1) the reactivity of the waste itself as measured in the content of organic matter, soluble inorganic constituents, easily oxidized substances, etc.; 2) the physical stability of the refuse in terms of volume change (mostly shrinkage) as decomposition advances; 3) the geological and hydrological parameters of the site – the porosity and permeability of the formation in which the fill is located and whether or not the water table intersects the fill; 4) how efficiently the upper surface of the fill is protected from insects, animals (mainly rodents), and exposure to wind and rain; and 5) climate – chemical reactions are inhibited by low temperatures, and in areas where rainfall leaching of fill is slight. Where there is an original separation of food wastes (garbage) from nonfood wastes (trash or refuse) the resulting nonfood accumulation is more stable than a mixture of the two.

In a controlled, properly designed landfill, the energy released by the chemical changes taking place is so great that there is a precipitous rise in internal temperature. Recordings after 7 to 10 days have been as high as 150° to 160° F., well above the temperature needed to kill the heat-sensitive pathogens. This offers a fair degree of assurance that the fill is not a health hazard (Benarde, 1973, p. 183).

In many instances, however, site conditions and/or operating procedures associated with solid waste disposal do not meet optimum conditions. If garbage and refuse buried in a landfill come in contact with water, a liquid contaminant called leachate is produced. This obnoxious liquid is capable of moving as underground water and may serve as a transporting agent for biological and chemical pollutants at strengths of 100 times that of raw sewage (Bleur, 1970, p. 4; Benarde, 1973, p. 185). Leachate contains such toxic substances as lead, mercury, arsenic, and potentially dangerous viruses, such as the one which causes infectious hepatitis. In most landfills, reliance is placed on natural processes to reduce the dissolved solids content of the leachate to tolerable levels before it can reach a point of water use. Recent studies (Hughes, Landon, and Farvolden, 1969, 1971; Otton, 1972) concerning the hydrologic implications of solid waste disposal and evidence provided from a limited number of recorded cases of surface- and ground-water contamination, suggest that the overall pollution hazards from landfill sites may not be as difficult to control as had been formerly assumed. Hughes (1972, p. 1) is quick to point out, however, that most landfills have been located in out-of-the-way places, are not close to water wells, and have not been monitored. Undoubtedly, some landfills have no appreciable effect on the surrounding surface- and ground-waters. Others, however, may already be seriously degrading these waters, and the effect of this degradation may be difficult to overcome.

Throughout the Johnson-Hardwick Region, as mentioned before, significant quantities of subsurface water may be held in rock fractures, where natural filtering and purification proceed very slowly, or in the porous, unconsolidated sands and gravels of stream valleys. Increasing problems with crowding, multiple land use, and improper disposal of waste materials may seriously alter local environmental conditions throughout this region. It becomes imperative, therefore, that as part of a larger anti-pollution program, considerable care be taken in solid waste disposal techniques to limit or prohibit leachate contamination of present and potential groundwater sources. In areas where pollution seems to be inevitable, modification of the site so as to retard or contain leachate is generally possible at reasonable costs. Modifications may include the use of clay fill, spray seals, and plastic liners to reduce ground permeability to a satisfactory level, in addition to the development of proper slopes, terraces, surface drainage systems, and vegetative cover to limit infiltration of surface waters in the immediate vicinity of the landfill.

In the design and construction of solid waste disposal sites, several types of liners can be used but the selection of a particular liner will depend largely on the purpose for which it is intended and on the availability and current costs of different liner materials. Earthen liners are generally made of surficial materials containing a relatively high percentage of clay and consequently may have a permeability on the order of 10^{-6} centimeters per second or lower. An earthen liner can be compacted to approach maximum density and can be treated with additives such as bentonite, lime, asphalt, or cement to further reduce its permeability. Despite these efforts, most earthen liners will, however, allow minor amounts of leakage (Hughes, 1972, p. 6). Liners can also be constructed of plastic or other similar materials that are, for all practical purposes, impermeable. Plastics can, however, be punctured during installation and subsequent operation of the landfill. Rupturing of this type of liner would in some cases be equivalent to removing the plug from a full bathtub and could cause uncontrolled, and probably undetected, movement of contaminants into the subsurface. Here, a cover of soil is usually necessary to prevent punctures. It is important to point out at this time that the evaluations of solid waste disposal-site conditions included in this report (Plate IV) are based on the potential use of natural materials throughout the Johnson-Hardwick Region without any modifications.

As with all considerations of solid waste disposal, two important precautions must be taken in the use and development of present and future "sanitary landfills." These precautions include: 1) site location in surficial materials of low permeability and sufficient thickness to reduce the production of leachate and to limit its movement to restricted areas above the water table (Gross, 1970, p. 294). Throughout the Johnson-Hardwick Region, glacial till is perhaps the most suitable material for landfill use inasmuch as it has a low permeability, is more easily worked than lake silts and clays, and would require somewhat lower operating costs; and 2) the importance of topping all fill materials with a nonpermeable to semipermeable earthen layer (peat, muck, incinerator residue, or till) to prevent excessive infiltration of surface waters.

In most instances, a proper daily covering of 6 to 8 inches and a final layer of 2 to 3 feet thick (Wagner, 1971; Legget, 1973; Vermont Board of Health, 1970) for a landfill is important for at least three reasons: 1) to restrict the amount of water entering landfill refuse and garbage and thereby reduce rates of decomposition, leaching, and ultimately the amount of leachate formed. Large volumes of surface and/or groundwater produces less, but possibly more mineralized leachate (Hughes, 1972, p. 3); 2) to limit the formation of "water mounds." Water mounds form when infiltrating water is so restricted in its lateral flow that it builds up in and along the sides of the fill. When water mounds build high enough to intersect the ground surface, seeps or springs rich in leachate may form around the fill margin; 3) to prevent or lessen the repeated effects of freezing and thawing of collected water in the refuse during the winter months (Hughes, Landon, and Farvolden, 1971; Hughes, 1972, p. 3).

The Solid Waste Conditions Map (Plate IV) for the Johnson-Hardwick Region gives a generalized classification of the area's surficial materials as they relate to landfill suitability. The areas outlined on this map were identified primarily on the basis of the permeability and thickness of their surficial materials without any consideration for site modification. The planning map, prepared from existing geologic, hydrologic, and soils information as well as general field observations, is intended to serve only as a guide in the selection of landfill sites. In many instances, detailed studies of new locations will be necessary as site materials and hydrologic conditions are often difficult to predict from surface observations. Such site evaluations should include estimates of the permeability and wetness, shrinkage or swelling potential, compressibility, sequencing and lateral variation, topographic expression, water runoff yield, and erodability of all surficial deposits. Information pertaining to the position of the local water table, the nature and distribution of subsurface aquifers and nonwater-bearing formations, as well as general patterns of groundwater movement in each area should also be included in such studies.

Green (g) areas delimited on the solid waste conditions planning map, are underlain by relatively impermeable tills or silts and clays in excess of 25 to 30 feet thick. These thicknesses have been suggested by the Illinois Geological Survey (Cartwright and Sherman, 1969; Hughes, Landon, and Farvolden, 1969, 1971) as a minimum thickness of material between the base of the fill site and the local water table to assure the containment or retardation of leachate by-products. The Geological Survey of Alabama, however, urges the use of 50 feet or more basal material (Riccio and Hyde, 1971) due largely to the porosity and permeability of surficial materials. Inasmuch as many of the surficial materials in Vermont are texturally similar to those in Illinois, a minimum thickness of 30 feet for basal material seems adequate. Under these conditions landfills can be operated with maximum efficiency using glacial tills or silts and clays for cover. Throughout the Johnson-Hardwick Region, those areas designated as green are generally limited in size and geographic distribution. Too often these sites are found adjacent to populated areas or in relatively remote localities and as such do not provide immediate relief to present landfill problems. Potentially good sites for solid waste disposal may be located in the northeastern part of the Johnson-Hardwick Region near Newport Center. Although clays may offer the best sites in terms of their low permeabilities, effluents or leachates of various kinds can alter the physical properties of the clays. Studies conducted by the Illinois Geological Survey show that soaps, detergents, water softeners, starches, and fabric softeners changed plasticity and shrink-swell potential of the deposit and affect its overall stability (White and Kyriazis, 1968). This survey encourages greater utilization of thick till deposits remote from growing urban centers as sites for future sanitary waste disposal.

Yellow (y) areas delineated on the planning map represent broad upland regions draped with thin, highly variable, or unknown thicknesses of glacial till, silts, and/or clay over bedrock. Much of this area can be used for landfill purposes only if basal materials range from 25 to 30 feet or more in thickness. In locations where surficial materials range from 20 to 25 feet thick, a solid waste disposal site may be developed wi.h a minimum of modification. If surficial materials are of low porosity and permeability but are less than 20 feet in thickness, extreme caution must be exercised in landfill development. Here contamination of groundwater sources is highly probable unless modifications are made below the fill to minimize leachate discharges.

The dark red areas (r-1) identified on the planning map, commonly have moderate to highly permeable sands and gravels at the surface. In many

Figure 22. Solid waste in dump near North Hyde Park.

such localities, surface characteristics, well-log records, and scattered seismic data indicate that these kame, outwash, and lake deposits are of reasonably constant textures, medium to high groundwater potential, and considerable thicknesses. When sands and gravels are the only materials above the bedrock surface, such sites should be considered unsuitable for solid waste disposal due to their high potential for groundwater pollution and the lateral migration of landfill gases. Often such problems of degradation are too difficult to overcome through general site modification and dumping should be discontinued immediately (Figure 22). In other places, interbedded silts, clays, and glacial tills underlie these surface sand and gravel deposits and thereby partially reduce localized pollution problems. If these finer grained and less permeable materials are over 20 feet thick, the site may be used for waste disposal only if some type of liner or sealing material is introduced to limit the production and lateral migration of leachate. Development of a landfill under these conditions requires a detailed study of the site's hydrologic environment and professional consultation regarding the selection and installation of liners. Unfortunately, sand and gravel deposits constitute the most widely used surficial materials for solid waste disposal in the Johnson-Hardwick Region. These abandoned sand and gravel pits are used without modification chiefly because of the ease with which materials can be excavated and used for cover, and their low operational cost (Gross, 1970, p. 294; Stewart, 1973, p. 33; Bleur, 1970, p. 1). For these reasons, almost all of the existing solid waste disposal sites in the Johnson-Hardwick Region are located in unsatisfactory areas and it is logical to assume that some of them are, or soon will be, contaminating local surface and groundwater supplies. Although the refuse dumps for Belvidere Junction, Craftsbury, Eden, Johnson, Montgomery, and Morristown, to name a few, are located along stream valley walls in sand and gravel deposits, the most serious stress placed on the local environment occurs near Montgomery and Craftsbury. Here, solid waste disposal sites lie within close proximity to municipalities and surface waterways. Most landfills throughout the region are unsightly and poorly managed. Solid waste operations of this type should be brought closer to existing Vermont health regulations, discontinued, or relocated in more suitable areas following a complete site evaluation.

The light red areas (r-2) delineated on the planning map represent low strength, poorly drained materials of stream valleys and swamps. The more extensive of these areas are found along the Black and upper Missisquoi River valleys where high concentrations of silt and clay in valley-fill sediments prevent internal drainage and promote flooding. These areas are generally considered unsuitable for sanitary landfill inasmuch as it is virtually impossible to prevent saturation of rubbish and garbage and pollution of surface and groundwater supplies (Gross, 1970, p. 294; U.S. Dept. of Interior, 1971). Hughes (1972, p. 3) has, however, pointed out that solid waste disposal in some permeable deposits and bedrock landfills may cause more serious groundwater pollution than deposition of the same wastes in impervious materials below the water table.

It is readily apparent that the problems of solid waste disposal and possible recycling are exceedingly complex. In the opinion of the Citizens Advisory Committee on Environmental Quality (1971, p. 23), the solution will require an increase in the relatively small funds now devoted to technological innovation and will also require changes in tax policy, freight rates, market patterns, and consumer attitudes which presently favor the use of virgin rather than recycled materials. Furthermore, as long as the American tradition of individual freedom is taken as a license to dump waste wherever it is convenient, our problems will continue to build. At present, trash is not just discarded in landfills but it is thrown over cliffs, behind fences, off roadsides, into woods, rivers, and lakes or generally out of sight of the discarder. In severe cases, waste is merely allowed to accumulate around private dwellings. While unpleasant smells and sounds have already been judged as damaging by the courts on the grounds that they constitute a common law nuisance, this sort of dumping, as well as burning of waste, is considered increasingly more unacceptable or aesthetically obnoxious due to the general disfigurement of the landscape, the decline of open spaces, and associated pollution problems (Flawn, 1970, p. 91; Fagan, 1974, p. 223).

Throughout the Johnson-Hardwick Region, more than 30 sites were found where large volumes of waste material had been discarded out of expediency and with little regard for the ultimate corruption of the environment. Ugliness is a nuisance! Excessive accumulations of clutter and waste should not be permitted to continue or to develop. They are just as disgusting as improperly operated landfills and are often more readily apparent to public view.

Sewage Disposal

The term sewage usually represents the complex liquid and solid wastes generated in and transmitted by homes, schools, commercial buildings, hotels and motels, hospitals, and industrial plants. While sewage commonly has the appearance of used dishwater, its actual composition may vary greatly from day to day. On an average, however, domestic sewage usually consists of approximately 99.9 percent water and only 0.02 to 0.03 percent suspended solids and soluble substances. In a single family dwelling, the laundry and kitchen each contribute about 10 percent of the waste-water volume. The bathtub, shower, and basins contribute 40 percent of the load and toilets account for the remaining 40 percent (Goldstein, 1972, p. 36; Benarde, 1973, p. 132). The organic chemical content of domestic sewage comes primarily from paper, organic material derived from food preparation, feces, urine, soaps, detergents and cleaning compounds. These substances commonly generate or transmit various harmful bacteria, viruses, and other micro-organisms. Sewage may also contain industrial wastes such as those from meatpacking operations, milk and food processing plants, and chemical companies.

Of all the pollutants introduced into all present and potential water supplies, only two pose sufficient hazards to man. These include: 1) organic materials which make water generally unpalatable and 2) the few bacterial and viral diseases which can infect man as well as animals. The diseases most dangerous to man are those which infect him uniquely and are transmitted, usually by the fecal-oral route, via water contaminated with his personal wastes. The most important of these are hepatitis, poliomyelitis, amoebic and bacillary dysenteries, and a host of viral disorders. While deaths resulting from consumption of polluted water in the United States are uncommon, water-borne illness is prevalent. The sub-clinical effects of chronic intake of low level pollutants are poorly understood, but increasing evidence suggests that cadmium, mercury, lead, herbicides, and many other materials may directly cause blood or bone disease, brain damage, birth defects, cancer, and many emotional disorders (Houston and Blackwell, 1972).

In an attempt to avoid these problems, several approaches have been developed to treat liquid wastes. Sewage is generally treated and disposed of by two means: 1) individual septic tanks or their near equivalents and 2) municipal sewage treatment plants. Benarde (1973, p. 143) estimates that of the 200 million people living in the United States, approximately two-thirds (132 million people) are served by municipal sewers. The remainder use septic tanks, cesspools, or outdoor privies. Of all the people using municipal sewer lines, about 10 percent live in communities that discharge untreated sewage directly into rivers, streams, and lakes. Another 25 percent live in communities where raw sewage is discharged after only a short retention in primary settling basins.

Primary treatment facilities have the lowest removal efficiency of any treatment system and are also the least expensive to build and maintain. They include at best, screens to remove larger floating objects, a comminutor for shredding, a grit chamber, a sedimentation basin for collection of the heavier solids, and a system for chlorination. Such primary systems provide for little stabilization of effluent material. BOD and suspended solids removals of 30 to 60 percent can be expected and as such, primary treatment is no longer acceptable for any reason in most localities (Othmer and Pfafflin, 1972, p. 15). Despite these results, it has been estimated that the sewage discharges from communities throughout the United States providing primary treatment or none at all, corresponds to the wastes of almost 50 million people. Furthermore, statistics published in 1966, reveal that among the 11,420 communities that had sewer systems, 2,139 still discharged untreated wastes (Benarde, 1973, p. 143).

In 1972, there were only slightly more than 100 settled areas within Vermont that were serviced by approved waste water collection and treatment facilities, or by collection systems whose discharges required treatment (Vermont Interim Land Capability Plan, 1972). Of those systems that do exist, many are old, inefficient, and overloaded so that a substantial portion of the sewage is only partially stabilized before discharge. Other municipalities provide for no treatment and wastes are discharged directly into surface waters. It is easy to see, therefore, why surface waters of the major drainage basins throughout Vermont are of low quality adjacent to centers of habitation and industrial activity.

To better safeguard surface waters from eventual contamination and to improve conditions already existing, a secondary, or biological treatment facility can be incorporated with primary treatment systems. Secondary treatment accomplishes the removal of particles which pass unaffected through the primary treatment stage. Particles that are too small to settle under the effects of gravity (colloidal), or are in true solution, are removed by the transfer of the pollutant material to a mass of voraciously feeding organisms. The two basic secondary treatment processes are activated sludge and the trickling filter. In the trickling filter installation, the waste flows over coarse media to which the microbal mass has become fixed. The activated sludge, on the other hand, contains the mass of organisms in suspension in the flowing waste water. In each process there is an intimate contact between the waste water and the organisms. A typical secondary treatment plant will include a headworks of screening, metering, and commimution, followed by primary settling, biological treatment and aeration, secondary settling, and chlorination. BOD removals of 80-95 percent may be expected from a well operated secondary plant (Othmer and Pfafflin, 1972, p. 17).

Conventional sewage treatment plants such as those described above remove only gross contaminants. Purification of municipal water supplies, though moderately effective, often do not remove viruses such as those which cause the various forms of poliomyelitis or hepatitis, and no known treatment will feasibly remove most of the man-created chemicals (Houston and Blackwell, 1972, p. 2). In an attempt to further purify sewage, tertiary treatment facilities have taken on increased importance in recent years. Tertiary treatment is defined as any treatment step following conventional biological treatment by which additional removals are realized. BOD and suspended solids are the parameters to which this is usually applied, but phosphates and nitrates may also be included. Some tertiary processes that have found application are chemical precipitation, electrodialysis, activated carbon adsorption, lagooning, filtration, reverse osmosis, distillation, ion exchange, and foam separation. All of these processes are used in addition to conventional secondary treatment for the purpose of achieving a quality near to that of potable water (Othmer and Pfafflin, 1972, p. 18).

At the present time, there are 135 tertiary treatment plants in existence or under construction in the United States. With certain limited exceptions, tertiary treatment of all waste water should be adopted as the ultimate goal of any water quality program in urban areas. Currently, however, updating existing sewage treatment facilities to tertiary standards would almost double the cost of both construction and operation. The technology for processing sewage effluent to drinking water quality is available, but in Vermont it is more essential to initiate an immediate statewide program of secondary treatment plant construction.

Investigations made during this survey were not directly concerned with the problems associated with municipal and industrial liquid waste disposal except in areas where inadequate treatment might ultimately lead to contamination of existing and potential water supplies. At present, sewage treatment facilities and their discharges are controlled by the Federal Water Pollution Control Act Amendments of 1961, the Water Quality Act of 1965, the Clean Water Restoration Act of 1966, the Water Quality Improvement Act of 1970, and the Water Pollution Control Act of 1972. The Vermont Department of Water Resources and the former State Conservation Board have, for many years, monitored and maintained a continuous study of the surface waters of the state and staff reports are available on most drainage basins. These reports have classified the surface waters of the state, noted their sources of pollution, and suggested methods for upgrading water quality. Despite these measures, most of the municipalities in the Johnson-Hardwick Region still discharge their untreated effluent directly into nearby streams or use inadequate disposal systems. At present, the municipalities of Coventry, Irasburg, Hardwick, Hyde Park, Morrisville, North Troy, and Troy discharge their untreated sewage directly into nearby rivers and streams. Newport Center and Richford, however, utilize catchment ponds or lagoons, while the people of Craftsbury, Craftsbury Common, Jay, Lowell, Montgomery, Montgomery Center, and Wolcott depend largely on individual septic tanks to process their domestic liquid waste (Vermont Water Resources Department, 1968, 1969a). Although state law prohibits the dumping of raw sewage by any individual or village into streams and lakes, the Water Pollution Control Act of 1972 does provide for Discharge and Temporary Pollution permits to be issued for discharges that meet water quality standards assigned to the receiving waters and in cases of extreme hardship. Until individual municipalities vote additional taxes, bond issues, or levees or federal and/or state funds are granted for the construction of adequate sewage treatment facilities, few changes can be made in the quality of surface waters in the Johnson-Hardwick Region.

Another means of sewage disposal which is used widely throughout the United States is the septic tank. This is an individual system used where water is available to carry waste from a home not served by municipal sewer lines. With a rapid movement of Vermont's population into more rural areas and the development of various resorts and recreational facilities in similarly remote regions, considerable concern over the problems of domestic sewage disposal has been expressed by various state agencies. This study is very much concerned with the sewage disposal and groundwater contamination problems of the Johnson-Hardwick Region.

When properly installed, the septic tank and leach line disposal system is one of the most reliable methods available for sewage treatment and disposal in rural areas. In 1962, approximately 25 percent of the United States' population used septic tanks for domestic sewage disposal (Rickert and Spieker, 1972). This system is composed of three simple elements: 1) the septic tank; 2) a distribution box; and 3) a disposal field and, in general, it provides for the breakdown and decomposition of waste materials by the action of anaerobic bacteria. Contrary to public opinion, the septic tank and leach line sewage disposal system does not purify the water or remove infectious bacteria or viruses.

The core of this underground disposal system is the septic tank. Here, the discharge from the house is prepared for soil absorption. The septic tank must be water tight, should be constructed of reinforced concrete or not less than 16 gauge coated steel, and be large enough to accommodate the maximum discharge per family unit. Standard septic tanks range from 750, 1000, 1250, to 1500 liquid gallon capacity and will adequately service under 4, from 5 to 8, from 9 to 10, and 11 to 12 persons respectively. The maximum size of the tank needed may be estimated by multiplying the number of bedrooms per dwelling by 2. If a garbage disposal, dishwasher, or clothes washer is installed, the septic tank and leaching system should be 20 percent larger (Vermont Water Resources Department, 1971).

A properly constructed and installed tank promotes an anaerobic bacterial treatment of waste, removes the solids from the waste, and prevents, through the use of baffles, the heavier sludge and buoyant scum produced from passing off with the effluent to the distribution box and the disposal field. During the retention period in a properly operating system, between 50 and 70 percent of the suspended solids are removed by sedimentation (Benarde, 1973, p. 141). The Vermont Water Resources Department (1971, p. 8) encourages homeowners using septic tank systems to have them checked every 2 years and cleaned as necessary. Failure to remove the accumulated sludge and scum often results in discharge of solids into the absorption field, with resultant slogging and ponding. McGauhey and Winneberger (1963, p. 434) have found that as many as one-third of the septic tank systems in a single subdivision failed during the first 3 to 4 years of use due to excessive discharge, improper construction, and/or failure to remove accumulated sludge.

The distribution box of a septic tank and leach line sewage disposal system is considerably smaller than a septic tank and may be constructed of heavy-duty plastic, concrete, or corrosive-free steel. Its sole purpose is to transmit the odoriferous discharge and its constituent anaerobic bacteria, nutrients, salts, suspended solids, and pathogens from the septic tank to the leaching field. The leaching field, on the other hand, is essentially a network of perforated tiles laid in a flat-bottomed, gravel-filled trench. Minimum specifications for the leaching field require that trenches be 24 inches deep, 12 inches wide, and 25 feet long. Furthermore, it must be 3 feet or more above bedrock, surrounded with 12 inches of gravel, and overtopped by 12 inches of soil (Vermont Water Resources Department, 1971). The function of the leaching field or seepage pit is to dispose of the liquid waste discharged from the septic tank by allowing it to seep into a geologically suitable environment. As the effluent seeps from the leach lines and through the surrounding surficial materials, natural filtration, oxidation, and bacterial decomposition take place. The efficiency of the leaching field is, however, closely related to the texture, permeability, and thickness of the surficial materials and to the amount and strength of the septic tank effluent. The texture (effective grain size) of the soil or filtering medium is generally considered more important in the removal of bacteria than its permeability (Olson, 1964; Romero, 1970, p. 44; Franks, 1972, p. 195). In fine-grained materials or those exhibiting exceptionally low permeabilities, operating efficiency can be improved by lengthening the pipe line or by increasing the width of the trench. Highly permeable conditions in coarse-grained deposits can be modified through the addition of fine-grained silts and clays.

The most common test used to determine the degree of effluent purification in a leaching field is to measure coliform content. Coliforms are organisms that commonly inhabit the human intestine and in large numbers, they indicate the presence of additional harmful bacteria. Contrary to those standards suggested by the U.S. Public Health Service (1967) and the Vermont Agency of Environmental Conservation (1972), recent studies have demonstrated that seepage of septic tank effluent through only a few feet of unstratified, fine-grained sand will reduce coliform counts to nondetectable levels (McGauhey and Krone, 1954; Wayman, Page and Robertson, 1965) while similar passage of effluent through more than 232 feet of coarse sands and gravels may not reduce coliform counts to acceptable levels (Franks, 1972, p. 195). Furthermore, flow of contaminated wastes through unsaturated fine-grained sands may eliminate bacterial pollutants in less than 40 feet while more than 230 feet may be required in saturated deposits (Franks, 1972, p. 202).

Inasmuch as a large number of new homesites and recreational facilities are being developed on hillsides and mountain slopes throughout the Johnson-Hardwick Region, another factor to be considered in the development and proper operation of septic tanks is the effect of the sloping land surface and the flow route of the effluent on surrounding environments. The more difficult problems resulting from septic tank operation in sloping terrains include: 1) a high potential for surface and ground water contamination; 2) the tendency for effluent to surface downslope from the leaching field or seepage pit; and 3) the production of unstable slopes and resulting soil creep, mud flows, and landslides in saturated materials. Most rural homesites require both a waterwell and a sewage system. In areas where surficial deposits are thin, the contaminated liquid discharges from a leaching field can be readily transmitted to the underlying fractured bedrock and ultimately to nearby water wells without filtering bacterial and viral contaminants (Waltz, 1970, p. 42). On slopes of 20 percent or greater, effluent has been found to surface downhill from septic tank systems regardless of the type of surficial material or the depth to which the system is buried. Such discharges can readily contaminate surface waters (Frank, 1972, p. 201). In areas of thin soil cover and excessive wetting due to liquid waste discharge, satured surficial materials may be prone to downhill creep, slumping, landslides, and earthflow.

From these findings, it becomes readily apparent that in the selection of a site for a septic tank and leach line sewage disposal system, factors that should be considered in addition to porosity and permeability are the gross composition and texture of the unconsolidated sediments in contact with the leaching field, the distance of effluent travel in unsaturated materials, the direction of flow from the system, the nature of the surrounding slopes, and the proximity to surface and groundwater supplies and recharge areas. When septic tanks were widely scattered, distance and the opportunity for effluent dilution prevented contamination of water supplies from becoming a widespread or serious problem. Awareness of the pollution problem stemming from septic tank discharges has increased, however, as such systems have been used in crowded subdivisions and recreation-oriented developments (Nace, 1967, p. 6; Leopold, 1968, p. 2; Cain and Beatty, 1965, p. 438; Mazola, 1970, p. 21). This concern is well substantiated in a number of widely publicized hydrologic studies of which only two need be mentioned here. Investigations conducted by Woodward, Kilpatrick, and Johnson (1961) showed that of 63,000 wells surveyed in 39 Minnesota communities, 13,800 (21.8 percent) contained measurable quantities of synthetic detergents that could only have been introduced through subsurface effluent migration. Nicholas and Koepp (1961) similarly tested 2,167 water samples from private wells in Wisconsin and reported that 32.1 percent also contained measurable amounts of detergents while 20.3 percent were so influenced as to be considered unsafe for human use. More recent studies (Mazola, 1970, p. 21; Cain and Beatty, 1965, p. 438; McGauhey and Winneberger, 1963, p. 171) have similarly demonstrated that improper construction and/or use of septic tank systems under crowded conditions may seriously endanger groundwater supplies and have supported immediate curtailment to the construction of individual sewage systems for multiple-unit housing developments. At present, those municipalities and development tracts that rely exclusively on septic tanks for liquid waste treatment in the Johnson-Hardwick Region may be headed for a similar fate.

The Septic Tank Conditions Map (Plate V) of the Johnson-Hardwick Region delineates the general characteristics of the surficial materials as they relate to domestic sewage systems, particularly septic tanks. Area designations are based on current federal and state recommendations for septic tank and leach line sewage disposal systems. The wide distribution of yellow and red zones suggests that there are few localities in this region that do not have some geologic limitations for septic tank use. The green zones shown on this map designate areas where tills are high in sand content and thicknesses exceed 25 feet. These surficial deposits should have permeabilities high enough to transmit effluent from the leaching field and still protect groundwater sources from contamination. Seepage pits or dry wells are not recommended in till areas since they concentrate the effluent in a smaller area and must be placed at greater depth where tills are more compact and less permeable (Stewart, 1973, p. 35). The largest and most favorable sites for septic tank systems are found to the southwest of Newport Center, above Whitney Brook near East Craftsbury, and on the uplands near East Hardwick. Smaller and equally suitable sites are scattered throughout the region.

Most thin till areas are designated y-1 on the map. The safe use of septic tanks in these localities is dependent largely on the thickness of the till above bedrock and the slope of the land. Shallow deposits of 2 to 4 feet in thickness and slopes in excess of 20 degrees have been demonstrated to be unsuitable for filter fields and would probably result in contamination of surface and groundwater supplies (Franks, 1972, p. 195). For most efficient operation, there should be a minimum of 10 to 12 feet of till above the bedrock surface, the land slope should be less than 20 degrees, and at least 200 feet of leach line should be available to distribute the effluent (Stewart, 1973, p. 35).

Areas designated y-2 on the map commonly have well-drained sand and gravel deposits, with few apparent limitations for septic systems at the earth's surface. While some of these deposits may be too coarse-grained and permeable to be used for leaching fields, those which are over 15 feet thick and do not contact the water table may generally be considered suitable for scattered septic tank use. When sand and gravel deposits are interbedded with, or are underlain by, fine silts and clays the downward percolation of effluent may be significantly retarded and thereby provide higher density usage of septic tank systems. When planning sewage systems in areas such as these, it is extremely important to determine the thickness, texture, permeability, and sediment variation of each surficial deposit, because their discharge could contaminate underlying aquifers or significant groundwater recharge areas. Many of the large areas designated y-2 in the Johnson-Hardwick Region directly underlie or are closely adjacent to such municipalities as Coventry, Eden, Hyde Park, Irasburg, Johnson, Lowell, Montgomery, Morrisville, and Newport Center. Excessive use of these deposits for solid and liquid waste disposal may severely endanger individual and municipal water supplies.

The areas designated r-1 are low, poorly drained stream valleys and isolated swamps. Here, surface materials are commonly fine-textured and of low permeability and as a result are poorly drained, often wet, and frequently flooded. Under these conditions, septic tanks would only operate efficiently during dry periods. Such sites should, therefore, be considered unsuitable for septic tank and leach line waste disposal systems.

Areas of thick lacustrine silt and clay deposits are designated r-2 on the map. These deposits are most widely distributed along the upper Missisquoi River and Mud Creek valleys between North Troy and Newport Center, but are also found near East Berkshire and Irasburg. Septic tanks and leaching fields, as they are normally installed, will perform in an erratic and generally unsatisfactory fashion in these materials because of their inherent fine-grained texture, extremely low permeability, high soil-moisture content, and overall instability when excessively wet. With inevitable expansion into these areas, different specifications for the construction of sewage disposal systems in these materials must be formulated. In some instances, use of a so-called mechanical or aerobic tank with a 200-foot leach line might alleviate some of the problems of large volume liquid discharge in these localities. The mechanical tank uses an electric motor to inject air into the system or to activate a stirring mechanism and thereby, provide a more complete treatment of the sewage through the creation of aerobic conditions in the tank. Unfortunately, the mechanical tank has a higher initial cost than a regular septic tank, requires more frequent maintenance, and has never been proven to decrease coliform levels substantially over septic tank operations (Goldstein, 1972, p. 39). Under no conditions should dry wells, cesspools, or sewage lagoons be used in these areas due to the high risk of gross contamination of drinking water supplies (Benarde, 1973, p. 142).

LAND USE AND FUTURE DEVELOPMENT

Building, road construction, surface mining and other engineering works are fraught with many problems in land-use planning and development. Maintaining environmental quality and insuring wise and safe use of the land calls for sound knowledge about the physical and chemical characteristics, engineering properties, and the geologic and hydrologic settings of the surficial and bedrock materials at the proposed construction site and in surrounding areas. Plans for future development need not always involve the construction of additional homes or commercial facilities, but merely involve a reassignment of land use such as the cultivation of lands previously used for grazing. For purposes of discussion, land use within the Johnson-Hardwick Region might best be divided principally among agriculture, rangeland, industry, urban business, residential development, recreation, timber land, and small wetland tracts with abundant wildlife.

While it is probable that agriculture, lumbering, and recreation will continue to be important uses of the land throughout the Johnson-Hardwick Region in the years to come, continued urban growth in the vicinity of Johnson, Hyde Park, Morrisville, and Hardwick will place greater stresses on surrounding environs. The unpredecedented rate of rural and recreational facility development near Greensboro and Jay Peak may ultimately produce similar problems, unless measures are taken immediately to regulate the direction such growth is to take and the conditions under which it can occur. Despoiling of Vermont's landscape cannot be permitted to go unchecked indefinitely.

In an attempt to combat the current problems associated with rapid and complex changes in the use of land and water, the Vermont Legislature required (Act 250, 1969) that the State Environmental Board establish a statewide capability and development plan complete with the environmental goals and protective guidelines for land use. Consequently the Vermont Interim Land Capability Plan (1972) was prepared as a logical predecessor to the State Capability and Development Plan and the State Land Use Plan. While the Interim Land Capability Plan examines general land use, physical limitations for development, capabilities for agriculture, forestry, and mineral extraction, and unique or fragile areas in an attempt to provide a key to recognizing implications of changing land use patterns and individual land use decisions, it does not substitute for more precise data on local land use capability (Vermont Land Capability Plan, 1972). It is, therefore, in part the responsibility of individual communities and each citizen to utilize the land and its resources in the most efficient manner without imposing severe disturbances to the immediate environment.

General Construction Conditions

Among the physical requirements for successful site development are soil conditions adequate to support foundations of the types planned. While general construction conditions throughout the Johnson-Hardwick Region are not as critical as those environmental problems already discussed, mined out areas subject to subsidence, areas of steep, unstable slopes, and poorly drained lowland areas may impose severe structural limitations. Those surficial deposits which commonly exhibit a poor potential for supporting foundations include alluvial and lacustrine silts and clays, organic muck and peat, and excessively wet glacial tills. In some instances, site limitations can be overcome through careful design and construction, but for many the probability of structural failure due to unstable soil conditions is significantly high and development should not be undertaken.

The General Construction Conditions Map (Plate VI) for the Johnson-Hardwick Region attempts to classify surficial materials according to their general suitability for foundations and structural loads. The criteria used for evaluating individual sites include such geologic characteristics as the degree of land slope, the internal drainage characteristics of surficial deposits, the plasticity and bearing strength of the foundation materials, and the proximity of the site to flood-prone areas. The localities shown in green (g) are predominantly sand and gravel deposits with less than 10 feet of overburden material. Sands and gravels are generally favorable for construction inasmuch as they are commonly well drained, have adequate strength (high relative density), and good supplies of groundwater (moderate to high yields) are usually available. Due to the glacio-fluvial origin of many sand and gravel deposits, considerable caution must be exercised during individual site evaluations to detect abrupt lithologic variations within the surficial deposits. Such materials are among the most erratic with which an engineer has to deal (Terzaghi and Peck, 1968, p. 4-8). Where lacustrine sands and gravels are known to overlie silts and clays, detailed investigations should be made to ascertain both the thickness of each stratum, the shearing resistance and bearing capacity or compressibility of the silt and clay layers, and the potential for slope failure (slump, slide, or flow). Prior to construction on good quality sand and gravel deposits, some consideration should always be given to their short and long-range economic value. Many environmentalists, planners, and construction engineers favor the removal of good quality deposits prior to development. Once these materials have been removed, most locations still make good construction sites with only a minimum of filling or grading. The practice of abandoning gravel pits without reclamation or using them for waste disposal sites represents poor planning (Stewart, 1973, p. 35).

Those areas designated y-1 on the map are covered predominantly with silts and clays. Because these fine-grained lake deposits are often poorly drained, of high plasticity, and low bearing capacity, they are often subject to slumping or flow. Throughout the northeastern part of the Johnson-Hardwick Region, lacustrine silts and clays fill the valleys to depths in excess of 100 feet. Due to their poor capacity to support building foundations, plans for site development on such deposits should include evaluations to determine soil moisture content (porosity and permeability), plasticity, general shearing resistance, and bearing capacity, as well as provisions for internal drainage systems.

Areas covered predominantly by glacial till are designated y-2 on the map. Their suitability for construction purposes is dependent upon overall till thickness, soil moisture content, and general slope stability. Since till thicknesses vary greatly throughout the region, construction suitability will vary accordingly. In most upland areas the till cover is thin and where the bedrock is found at a depth of three feet or less, such areas will have limited potential for development. The presence of bedrock close to the surface makes foundation and subsurface utility excavations more difficult and expensive. In areas of less resistant, highly fractured and weathered schist and phyllite bedrock, excavation is not as difficult as in the eastern portion of the region where more resistant quartzite and granite bedrock is exposed. Regardless of local bedrock characteristics, areas of thin till cover are easily eroded and once erosion has begun, the likelihood of losing much of this limited cover is greatly increased.

Throughout the region, most floodplain sediments form continuous layers of silt and clay of fairly uniform thickness (5-20 feet) separated by equally persistent layers of coarser sediments. Medium- to fine-grained stream sediments are collectively called alluvium and are designated as r-2 on the map. Alluvium is a poor foundation material inasmuch as it is commonly of low strength, elastic, poorly drained, and subject to periodic flooding. Recognizing that floodplains are the natural extension of streams and rivers intended to store and carry excess runoff waters at times of exceptionally heavy rain or during rapid spring thaws, restriction of future construction in such areas should begin immediately. If the bottomlands are, however, to be used for industrial or other types of heavy construction, despite the risks of flood damage, the total thickness of alluvium should be removed, improved drainage systems provided, and special designs employed. Red areas marked r-1 on the map are poorly drained, swampy localities that cannot be used for any kind of development.

While the General Construction Conditions Map (Plate VI) does not directly indicate areas of steep slopes, their presence should be a very important consideration in land development. In recent years, the number of vacation homes and ski developments throughout Vermont have increased at an alarming rate. In an attempt to provide scenic panoramas and close proximity to outdoor recreational facilities, many sites have been developed on relatively steep hillsides without regard for various long-term environmental problems. During construction and prior to soil stabilization, erosion on steep slopes (10-15 percent) is significantly greater than on level lands. As the surface area available for absorption of rain water is reduced further by the construction of impervious surfaces (roofs, roadways, parking lots), surface runoff is increased and the potential for erosion is increased further. Discharges of liquid wastes from septic tanks and leaching fields amplify the problems of slope stability even more and may ultimately lead to their failure. In areas of thin or unstable surficial materials, slumping, sliding, and downhill creep may seriously endanger hillside development.

General county-wide soils maps for Orleans, Franklin, Lamoille and Caledonia counties, prepared by the U. S. Department of Agriculture, Soil Conservation Service (1972), may be used in conjunction with Plate VI as basic reference materials for the delineation of areas with varying construction limitations. Limitation ratings used for homesites, recreational buildings, commercial and industrial development, septic tank filter fields, sanitary landfills, highways and access roads, and agriculture, have considerable differences but are grouped into three classes: 1) slight – relatively free of limitations or easily overcome; 2) moderate – limitations need to be recognized but can be overcome with good management and careful design; and 3) severe – limitations sufficiently great to make use questionable. Prior to development, however, detailed studies of these and other engineering characteristics of each site's surficial materials is essential. Such investigations should include the distribution, type, sequence, thickness, and general physical character of the soil strata and their stability for foundation or construction purposes. These studies are performed to obtain solutions to the following groups of problems: 1) foundation problems or determinations of the stability and deformation of undisturbed subsurface materials under superimposed loads, on slopes and in cuts, or around foundation pits and tunnels; 2) construction problems or determinations of the extent and character of materials to be excavated or the location and investigation of soil and rock deposits for use as construction materials; 3) groundwater problems or determinations of the depth, hydrostatic pressure, flow, and composition of the groundwater, and thereby the danger of seepage, underground erosion, and frost action as well as the influence of water on the stability and settlement of structures, its action on various construction materials, and its

Figure 23. Aggregate processing plant and pit along Stony Brook three miles north of Coventry.

suitability as a water supply (Hvorslev, 1965, p. 5).

Geologic Resources

During the past several years, widespread concern for environmental quality and demands for immediate corrective action have greatly increased. This expression of environmental concern has taken many forms and, in some cases, the demands and regulations resulting from it are beyond industry's present technological and financial capability. In time, some of the more unreasonable or impossible of these demands will give way to more rational approaches as the general public recognizes that resource exploitation is not founded on a deliberate intent or disregard for the environment, but is aimed at many worthwhile goals. As is true of many activities, however, efforts to correct or avoid the detrimental effects of mineral production proceed slowly and at great expense.

Risser (1971, p. 2) gives three principal reasons why the mineral industry has received so much criticism lately from environmentalists. He suggests that: 1) by virtue of their manner of occurrence and their physical and chemical makeup, minerals are actually an integral part of the environment, and as such, their production, movement, or utilization will result in some modification of the environment; 2) the quantities involved in resource exploitation are so huge and production and consumption activities so widespread geographically that their effects are observable to everyone. As sources of energy, as metallic and nonmetallic materials, and as plant foods, minerals are directly related to, or involved in, almost every form of industrial, economic, and recreational activity. Between 3 and 4 billion tons of solid fuels and minerals, 5 billion barrels of liquid fuels, and 22 trillion cubic feet of natural gas are consumed nationally each year. Furthermore, the rate of use of some minerals has been doubling every 9 to 15 years; and 3) many minerals are so durable that they remain as scrap long after the product has served its useful purpose. Reclamation may not be economically attractive, but the production of new materials is criticized because old materials are so obviously available.

Thus, the problem that confronts the minerals industry today is that of finding ways to comply with the requirements for environmental quality protection (the atmosphere, water, land, and plant and animal wildlife) and still produce the minerals our nation requires at the lowest possible cost.

Nationally, growth in the use of nonmetallic resources, which consist primarily of construction and plant-food materials, has been considerably more rapid than that of metals. An especially significant aspect of this growth is the extremely large quantity of material involved. The combined output of the major construction minerals (crushed stone, sand and gravel) currently amounts to about 1.8 billion tons per annum and is projected to reach 5.6 to 8.0 billion tons per annum by the year 2000 (Risser, 1971, p. 3; Legget, 1973, p. 361). Because most construction activity normally occurs in or near large centers of population and industrial activity, most production of construction materials is highly visible to a large segment of the public and is therefore subjected to increasing objections and regulations (Figure 23).

In recent years, the production of nonmetallic minerals (asbestos, clay, granite, lime, marble, sand and gravel, slate, and talc) in Vermont has climbed to record proportions. In 1970, due largely to accelerated highway construction, the production of non-metallics reached a record 4.1 million tons; an increase of approximately 21 percent in tonnage and 36 percent in value over 1969 figures (Fulkerson, 1970). Further population growth, industrial expansion, and transportation development will undoubtedly spur increased nonmetallic mineral production in the years to come.

At the present time, greater demands for foundation and construction materials have greatly encouraged the growth of sand and gravel operations throughout the state and with it, have promoted a general degradation of Vermont's landscape. Within the Johnson-Hardwick Region, no fewer than 137 active and/or abandoned sand and gravel pits scar the land's surface. From an environmental standpoint, more planning should be given to the utilization of this region's sand and gravel resources and to the long-range usage of abandoned or exhausted workings. Hackett and McComos (1969) recognized these problems some time ago and suggested that additional sand and gravel reserves should be designated for open space use until they are needed. When exploitation of these materials becomes necessary, planned methods of excavation should be employed and, after the sand and/or gravel has been removed, the area should be returned to productive use, thereby avoiding the development of more flagrant scars in the landscape (Figure 24).

In an attempt to promote better usage of the land and to provide a key to recognizing the implications of changing land use patterns and individual land use decisions, the Vermont State Planning Office has developed the Vermont Interim Land Capability Plan (1972). The County Resource Opportunities maps (no. 3) for Caledonia, Franklin, Lamoille, and Orleans counties identify areas of potentially good to high quality agricultural and forest soils and locate significant mineral resources in each county.

Figure 24. Kame gravel exposed in a pit one-half mile south of Lowell.

The sand and gravel map (Plate VII), prepared during this survey, follows the procedures outlined in the previous Environmental Geology Reports (nos. 1, 2, and 3) and in part extends the concept of the County Resource Opportunities maps by attempting to classify deposits of aggregate material in the Johnson-Hardwick Region as to their quality and estimated reserves. The approximate location current and potential sources of sands and/or gravels shown here are, in many instances, comparable to the findings of the Materials Laboratory, Vermont Department of Highways. Evaluations of sand and gravel deposits indicated on this map, are likely to change as additional pits are opened and more subsurface information becomes available. Although this study provides a reasonable degree of accuracy in its evaluations it is only a general source of information and should be supported with additional in-depth site evaluations.

Within the Johnson-Hardwick Region, there are few sand and gravel deposits that meet standard specifications for cement, consequently the highest rank used in mapping is considered good in quality.

Evaluations of all sand and gravel deposits range from good to medium or low in quality while estimates of reserves range from large to moderate or low. Where sand and gravel deposits were located but their quality and reserve were difficult to determine, they were included (sgd) as sites for further investigation.

Esker, kame, deltaic and outwash gravel deposits are widely scattered throughout the region, but most are considered to be of medium to low quality due to their weak, nonresistent rock composition and high sand content. With only limited population growth rates and sporadic urbanization in northern Vermont, an adequate reserve of gravel will remain available for future use.

Sand and gravel deposits of large reserve are commonly found to the east of the central Green Mountains along the Black, Lamoille, and Missisquoi River valleys. In the Hyde Park Quadrangle, large reserves of sand and gravel have been identified between Johnson and Morrisville along the Lamoille and Gihon rivers, near Eden Mills, and south of the Green River Reservoir. Kame deposits along the mountain slopes, between Johnson and Morrisville, commonly grade laterally into deltaic and lake deposits and as a result are sandy near the surface but coarsen with increasing depth. Such sand and gravel deposits are often quite thick and would require subsurface investigation to more accurately determine their quality at depth. Deposits near Eden Mills are generally coarser in texture with localized irregular stratification. Use of these deposits would require screening and washing to remove incorporated silt and clay. The quality of the gravel produced, like much of the material throughout the region, would be of medium to low quality inasmuch as the stone in the gravel is weak and highly susceptible to wear. The section between the Green River Reservoir and the Lamoille River valley has not been excavated sufficiently enough to determine sand and gravel reserve and quality, but the type of the deposit suggests considerable reserves.

Significant reserves of sand and gravel occur throughout the Irasburg Quadrangle, between Irasburg and Newport Center and between Lowell and North Troy. Their quality varies from good to low, with the best deposits centered near Lowell and Coventry. Deposits between Troy and North Troy contain significant amounts of sand, silt and clay. Sand and gravel deposits in the Hardwick and Jay Peak quadrangles are widely scattered and highly variable in composition.

Figure 25. Lowell Area Quarry of the GAF Asbestos Mine (General Aniline and Film Company) located on the southeast slopes of Belvidere Mountain.

Figure 26. Waste material from the abandoned Asbestos Mine (Eden Quarry) high on the southern slopes of Belvidere Mountain.

Sand deposits are scattered all over the Johnson-Hardwick Region. These are mostly lake sands of highly variable thicknesses. The largest sand reserves are located along the Lamoille River between Johnson and Morrisville, the Westfield-North Troy area, the Newport Center area, the region around Richford and the kame terraces north and south of Irasburg.

When compared with the quarrying of sand and gravel, asbestos and talc mining operations constitute the second largest nonmetallic mineral production in the Johnson-Hardwick Region. At present, asbestos and talc mining operations are located throughout portions of the Hyde Park, Jay Peak, and Irasburg quadrangles in ultrabasic rocks (dunites and peridotites) which have been completely or partially altered to serpentinite. These rocks and their surrounding schists, gneisses, quartzites, and amphibolites comprise the Camels Hump Group of the central Green Mountains (Grant, 1968).

The GAF Asbestos Mine (part of the Building and Industrial Floor Products Division of the General Aniline and Film Corporation) is located on the northeast side of Belvidere Mountain in the towns of Eden, Lamoille County, and Lowell, Orleans County. Here, near the village of Eden Mills, there are three separate quarries; the Eden Quarry which is abandoned, the Lowell and "C" Area quarries which are being mined at present (Figure 25). Although thirty-two minerals are known to occur at the GAF Mine, chrysotile (asbestos) is the principal product. It is currently shipped to out-of-state company plants for the manufacture of asbestos-cement roofing and siding, industrial board, corrugated sheets, and asbestos papers. Even though asbestos production in Vermont declined by approximately 9 percent in 1970 (Fulkerson, 1970), moderate to large reserves still exist in the Johnson-Hardwick Region and production could no doubt continue for some time to come. From an environmental point of view, the large spoil piles of present and former asbestos quarries and their associated pits present an unsightly view. Land reclamation of these areas would be possible if the material in the spoil piles (Figure 26) was transferred to abandoned sections of the quarry and thin layers of topsoil were used to cover the spoil. At present, these large spoil piles exhibit highly unstable and infertile slopes to an otherwise thickly forested landscape.

The Eastern Magnesia Talc Company presently operates an underground mine (the Johnson Talc Mine) approximately 3 miles north-northeast of

Johnson (Figure 27) and a processing plant southwest of the village. Mining activities are centered in an ultramafic body of rock approximately 3,500 feet long and 200 feet wide, which has become completely altered through metamorphism to a talc-carbonate rock with localized concentrations of serpentinite (Grant, 1968). Production statistics for 1970 show that the Johnson Mine experienced an increase in tonnage and commercial value of about 11 percent over the previous year (Fulkerson, 1970). Processed talc is used in the manufacture of roofing paper, paint, insecticides, plastics, and rubber. While numerous old dumps and mine holes serve as a reminder of more than 70 years of talc mining throughout the Johnson-Hardwick Region, a more serious environmental problem is posed by the collapse of mine overburden near the Johnson Mine. Perhaps slag materials could be used to backfill these collapsed areas and thereby lessen the hazards imposed by shallow mining practices.

While nonmetallic mineral production continues to expand in the state, metallic mineral production has virtually ceased. To the writer's knowledge, there has been no metallic mining in Vermont since 1958, when the Elizabeth Copper Mine located in South Strafford, closed (Morrill and Chaffee, 1964). Over the years, however, mineral exploration has located various lead, copper, iron, manganese, and placer gold concentrations throughout the Johnson-Hardwick Region. These deposits characteristically occur in either various iron- and sulfide-rich igneous intrusives or immediately adjacent altered bedrock throughout the central portion of the state. A wide variety of secondary minerals (chromite, magnetite, graphite, garnet, magnesite, molybdenum, titanium and others) are also associated with these intrusives. Moderate to low grade iron concentrations have been found along the eastern flank of the central Green Mountains between Westfield and Jay. Highly variable concentrations of copper-bearing ore (pyrrhotite and chalcopyrite) have been located in the rocks of the Stowe Formation on Toothacher Hill near Wolcott and in the vicinity of Richford. Lead-zinc and manganese prospects have been identified west of Morristown and in the Tibbit Hill volcanics between Richford and Berkshire respectively. Placer gold deposits have been located along Wild Brook and the Lamoille River between Johnson and Cambridge, Jay Branch and Crook Brook north of Jay, the east branch of the Missisquoi River, Burgess Branch between Troy and Lowell, and Sterling Brook south of Morristown (Morrill and Chaffee, 1964; Grant, 1968).

Regardless of the type of product sought, it becomes apparent that the utilization of mineral resources in the Johnson-Hardwick Region carries with it a wide range of implications regarding land use

Figure 27. The Johnson Talc Mine three miles northeast of Johnson.

and the local economy. The extraction and processing of nonmetallic minerals will continue to provide employment opportunities for many local people in the years to come and as market values and demands for metallic minerals fluctuate, there will be periodic attempts to reactivate old mines or establish other operations in new localities. Opportunities for mineral extraction will not materialize or will be made considerably more difficult if mineral localities and adjoining areas have been committed to conflicting uses. Furthermore, when new mineral resources are developed, conflicting uses and values are certain to be established as greater demands are placed on the environment. Unless areas of significant mineral potential are located early and set aside for future exploitation, important opportunities for economic development may be lost.

In an attempt to identify mineral deposits and adjacent areas of possible economic significance, the Vermont State Planning Board, in cooperation with the Vermont Geological Survey and the Department of Geology at the University of Vermont, has already prepared county-wide capability maps (1972) showing sites worked in the past, those currently in production, and some sites which have been investigated but which remain undeveloped. Greater efforts must

Figure 28. Flood-swollen Lamoille River near Ithiel Falls.

be made to locate additional mineral sites for future use. Obviously, as individual mineral deposits are played-out and each site is abandoned, attempts must be made on state and local levels to reduce the deleterious effects of mineral production.

NATURAL HAZARDS

The term *natural hazard* refers to a variety of destructive phenomena that can result in death or endanger the works of man (Durrenberger, 1973, p. 159). Annually in the United States, the actual and potential losses from such natural hazards as earthquakes, volcanic disturbances, landslides and slope failures, severe storms, floods, droughts, frosts, and forest and grass fires are estimated to average from tens to hundreds of lives, and from several hundred million to more than a billion dollars in direct and indirect costs (Office of Emergency Preparedness, 1972, p. 1).

In 1973, the United States was struck by 46 major natural disasters which caused more than $1.2 billion worth of damage in 31 states. Of these presidentially declared disasters, 39 involved flooding while the others included tornadoes or other storms, dam failure, earthquake, mudslide, and urban fire (T. P. Dunne, Administrator of the Federal Disaster Assistance Administration).

While volcanic eruptions do not occur in Vermont, the land may, however, occasionally be shaken by minor earth tremors. Such disturbances have not yet had any effect on the land or man-made structures in Vermont. Severe storms, floods, landslides, and droughts pose more serious problems (Figure 28). In general, the Vermonter is incapable of controlling these phenomena and, indeed, in some instances his activities tend to increase their frequency of occurrence and the resulting damage. As an appreciation for an area's vulnerability to natural disasters is developed, greater allowances can be made for them. Sound geologic and soils information applied with adequate planning can substantially reduce the vulnerability of people and property to many natural hazards by encouraging the selective location of construction and development projects. Other potential problems may be ameliorated through such corrective measures as slope modification and stabilization, reforestation, and the construction of various drainage and flood control systems.

Landslides

It is perhaps a natural reaction to think that all landslides are something that cannot be avoided and must be accepted as part of the natural order of things. It is true that landslides do constitute an essential part of the geologic cycle and that many large landslides occur in nature without any assistance from man. At the same time, it may be emphasized that most landslides can be prevented, especially the smaller ones (Legget, 1973, p. 423).

Technically, landslides are part of a more general category of erosional processes called mass-wasting — the process of downslope movement of earth materials, primarily by gravity. Landslides take place in widely different rock types and are of almost every possible size and shape. Their causes can be traced to the inherent properties of underlying, low strength rock materials (presence of bedding planes, joints and fractures) and such external factors as the slope of the land, the amount, type, and duration of precipitation, and the dominant erosional processes for each area.

From a planning point of view, when potentially hazardous conditions (excessive groundwater erosion, artificially cut slopes, general slope instability, and intensive hillside development) are identified, preventative measures against landslides should be undertaken immediately. Such measures should include proper site preparation through drainage, removal of overburdened material, safe grading of slopes, and where possible, the limiting of construction, especially of homes and other habitable buildings. These control measures are becoming more common and when properly executed they are effective in reducing the incidence of all forms of landslides. At present, county-wide soils maps prepared by the U. S. Department of Agriculture, Soil Conservation Service (1972) for Orleans, Franklin, Lamoille, and Caledonia counties may prove helpful in site evaluation within the Johnson-Hardwick Region in that they provide information on natural soil stability for each identified soil type and land use limitations. More field and laboratory work is needed, however, on the causes and mechanics of landslides and on soil and rock slope stability before greater protective assurance is offered.

One of the larger slides in the Johnson-Hardwick Region occurred along Alder Brook between Little Eligo and Eligo ponds on Saturday, June 30, 1973. The slide (Figure 29) is located along the steep, eastern side of the river valley adjacent to State Route 14. As a result of prolonged rainfall, a thin layer of saturated glacial till and gravel dropped 35 to 40 feet down the steep slope and blocked the highway. Electrical power was briefly disrupted and various trees, shrubs, road signs, posts, guard rails, and sections of asphalt were carried with the slide. Irregular scars of similar form can readily be identified in many parts of the region.

During the same weekend, a large section of a parking area adjacent to the Village Restaurant in Hardwick collapsed into the Lamoille River (Figure 30). While structural damage to the restaurant itself was minor, release of a large mass of glacial sediment nearby carried portions of a log and granite block retaining wall, old foundation material, and fencing into the river. Judging from the nature of this slope failure and the pronounced rotation of another section of the retaining wall directly under the rear corner of the restaurant, another period of excessive rainfall could destroy the building and others nearby.

While these examples emphasize the ongoing nature of landslides, those slope failures that have occurred did not do significant amounts of damage to man-made features. As hill slopes continue to be modified by man's activities, landslides will probably become more common and cause more damage.

Flash Floods

Floods are natural and normal phenomena. They are catastrophic simply because man occupies

Figure 29. Landslide scar and debris one-half mile south of Eligo Pond.

Figure 30. Collapsed embankment along the south side of the Lamoille River in Hardwick.

the flood plain, the high water channel of a river. Man occupies these lowlands because it is convenient and profitable to do so, but, at the same time, he must purchase his occupancy at a price – either sustain flood damage or provide flood control facilities (Bue, 1967, p. 1). Where flood damages have been relatively minor or where flood protection costs greatly exceed anticipated reductions in flood damage, they are usually permitted to continue unchecked. Where flood damages become unbearably high, attempts are made to lessen their impact. The type of corrective or preventive measures taken depends on the nature of the development on the flood plain and the physical and economic feasibility of providing protection.

Flood problems, like problems of water supply, are without any clear-cut solutions. Various approaches to the flood problem have been made and found effective to a degree or another. No one measure is considered adequate except in minor floods, and if the flood is of considerable magnitude all measures fail as a complete solution to the problem. Measures most commonly taken to reduce losses from floods fall into two categories: 1) corrective flood control measures and 2) flood emergency measures.

Flood control measures are of a permanent nature, deliberately planned and executed over a period of time and based on the expectancy of floods of various magnitudes. These measures include land treatment (flood proofing) in the watersheds to abate water runoff; engineering works such as dams and detention reservoirs to regulate river flow, and flood walls (levees), channel improvements, and diversion or by-pass channels to keep flood waters out of specific areas; and regulations for land use to insure the most economical use of the flood plain. Detention reservoirs are the most prominent and familiar form of flood control. Their purpose is to hold and release slowly large volumes of water but they may also provide recreational and power generating facilities. Due to the considerable storage areas required for such projects and their restriction of free-flowing rivers, environmentalists consider the construction of dams as a last resort solution to the problem of flood control. Alternatives include flood plain zoning, public acquisition of some flood plain rights, scenic easements, and agricultural incentives. Channel improvements constitute another well accepted method of diminishing flood damage. Projects to clear, straighten, widen and deepen stream channels have been used extensively in restricted urban and industrial locations to increase the velocity and carrying capacity of a stream and thereby diminish the effects of high floodwater stages. Channel improvements, while not initially as expensive as dams and detention reservoirs, are relatively impermanent and necessitate repeated expenditures for maintenance. Furthermore, they tend to disrupt the natural stream regime, increase erosion, promote downstream flood damage beyond the termination of the dredging project, and generally impair landscape esthetics. Preventative measures (both incentive and regulatory) use the approach of keeping damage-prone development out of flood hazard areas. The regulatory method is most effective in areas that have not been widely developed and is implemented through subdivision regulations, building codes, encroachment limits, and other controls on the use and development of property on the flood plain (Bue, 1967, p. 2; Emerson, 1971, p. 62; Office of Emergency Preparedness, 1972, p. 15).

Flood emergency measures are of a temporary nature, taken on an emergency basis when flooding seems imminent. Included here are: 1) land treatment of watersheds suddenly denuded by fire or other natural causes; 2) engineering measures such as building temporary levees or improving permanent ones, clearing channels, and flood fighting activities; 3) evacuation of people and property from endangered areas; and 4) rescheduling production, transportation, and services to minimize interruptions and loss from the flood (Office of Emergency Preparedness, 1972, p. 15).

The State of Vermont has had a long history of flooding. In the past two hundred years Vermont has been subjected to twenty major floods and many more less intensive or localized ones, particularly in the Green Mountains. In many cases, these floods have been devastating. The flood of November 3-4, 1927, resulted in damages estimated at $35,000,000 and the death of 84 Vermonters (Wernecke and Mueller, 1972, p. vii). The flood of June 29-30, 1973, was estimated to have caused more than $47,000,000 damage and the loss of one life.

Throughout the Johnson-Hardwick Region, as in many other parts of Vermont's Green Mountains, rain storms occurring between May and September are commonly of high intensity and short duration. In areas of little bedrock cover and steep slopes, most precipitation runs off the land rather than returning to the atmosphere through evapotranspiration or soaking into the ground. Under these conditions, local areas commonly experience small flash floods. Flash flood frequencies and their magnitude will vary with differences in such tributary stream basin characteristics as altitude, slope, soil texture, and type and amount of vegetative cover. Consequently, tributaries which appear alike and have near equal drainage areas often have dissimilar flood-flow characteristics. Long duration, high intensity summer storms may initially saturate the soil and swell individual headwater streams within a particular basin, but as the volume of runoff increases, the trunk stream flow velocities, the flood peak amplitude, and the amount of overbank flow and sediment production may increase rapidly causing considerable damage and destruction to ill-placed works of man (Figures 31 and 32).

Such was the case during the month of June, 1973. Twelve significant thunderstorms delivered a record breaking 7.69 inches (average) of precipitation throughout Vermont; 4.20 inches above a normal of 3.49 inches (*The Burlington Free Press*, July 4, 1973, p. 4). The last of these rainstorms began as a fine drizzle on Thursday, June 28th and continued through Saturday, June 30th dumping half of the storm's total precipitation during a 6-hour period early on Saturday morning. With the ground already saturated from previous rains, most of this storm's precipitation ran off the land swelling nearby streams and rivers. In response to this excessive runoff,

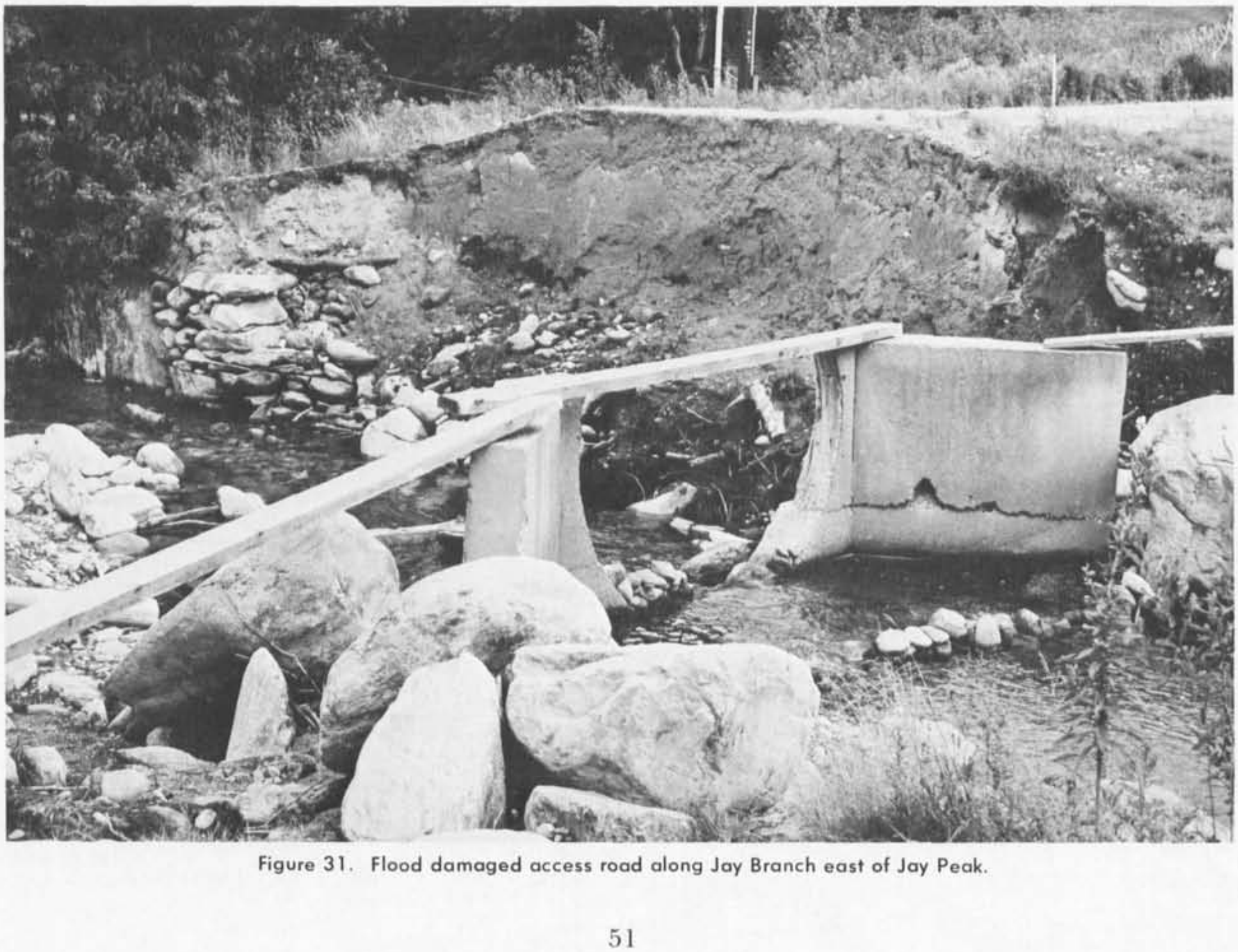

Figure 31. Flood damaged access road along Jay Branch east of Jay Peak.

Figure 32. Road damage due to excessive runoff on Jay Peak.

stream gauges near Johnson and Richford recorded the second and third highest discharges respectively for this century. Records for the Lamoille River (Johnson Station) indicate an average stream discharge of 514 cubic feet of water per second (cfs.) for a discharge area of approximately 310 square miles. A maximum flood discharge of 13,000 cfs. and a water height (stage) of 16.48 feet was, however, recorded for this station on March 18, 1936, while a minimum discharge of 16 cfs. was recorded on October 26, 1947. On July 1, 1973, the Lamoille River's stage was measured at 17.33 feet and a discharge of 14,400 cfs. was recorded. Normally, the Missisquoi River gauging station near Richford indicates stream discharges approaching the average of 900 cfs. for a discharge area of approximately 479 square miles. A maximum flood discharge of 17,200 cfs. and a stage of 15.15 feet was, however, recorded for this station on May 4, 1940, while a minimum discharge of 8 cfs. was recorded on July 14, 1911. Estimates of the November 1927 Flood indicate a discharge of 45,000 cfs. and a stage of 23.10 feet for the Missisquoi River at this station. On July 2, 1973, stream stage was measured at 11.28 feet and a discharge of 9,450 cfs. was recorded (U. S. Department of Interior, Geological Survey, Water Resources Division, August 31, 1973).

As a result of the late June flash flooding, many public and private buildings, roads, bridges, and railroad lines were damaged or destroyed (Figures 33 and 34). Similarly, water and sewer facilities inundated by flooding waters were damaged and thereby produced serious contamination problems in some localities. Crops in lowland areas were very seriously damaged or totally destroyed by raging currents, standing water, or subsequent sedimentation over sprouting crops.

While average flood damage estimates for the Lamoille River Basin are set at $139,000, flash flooding during this single storm resulted in excess of $542,000 in damages in Lamoille County alone. Here, damage estimates for municipal roads and culverts ranged from $200 in Belvidere to more than $20,000 in Wolcott and Morristown. Hardest hit in this region were Vermont farmers. After a previous summer of little hay, a year of record grain prices, and generally high operating costs, fear was expressed that the June 1973 Flood would spell the end for many a dairy man and farmer. The long term danger was that valley farms given up because of the flood, might pass into the hands of developers who would create housing tracts, resorts, and/or shopping cen-

Figure 33. Washed out road south of Lamoille River two miles west of Hardwick Lake.

Figure 34. Sand-choked cornfield resulting from flooding of the Lamoille River one mile west of Wolcott.

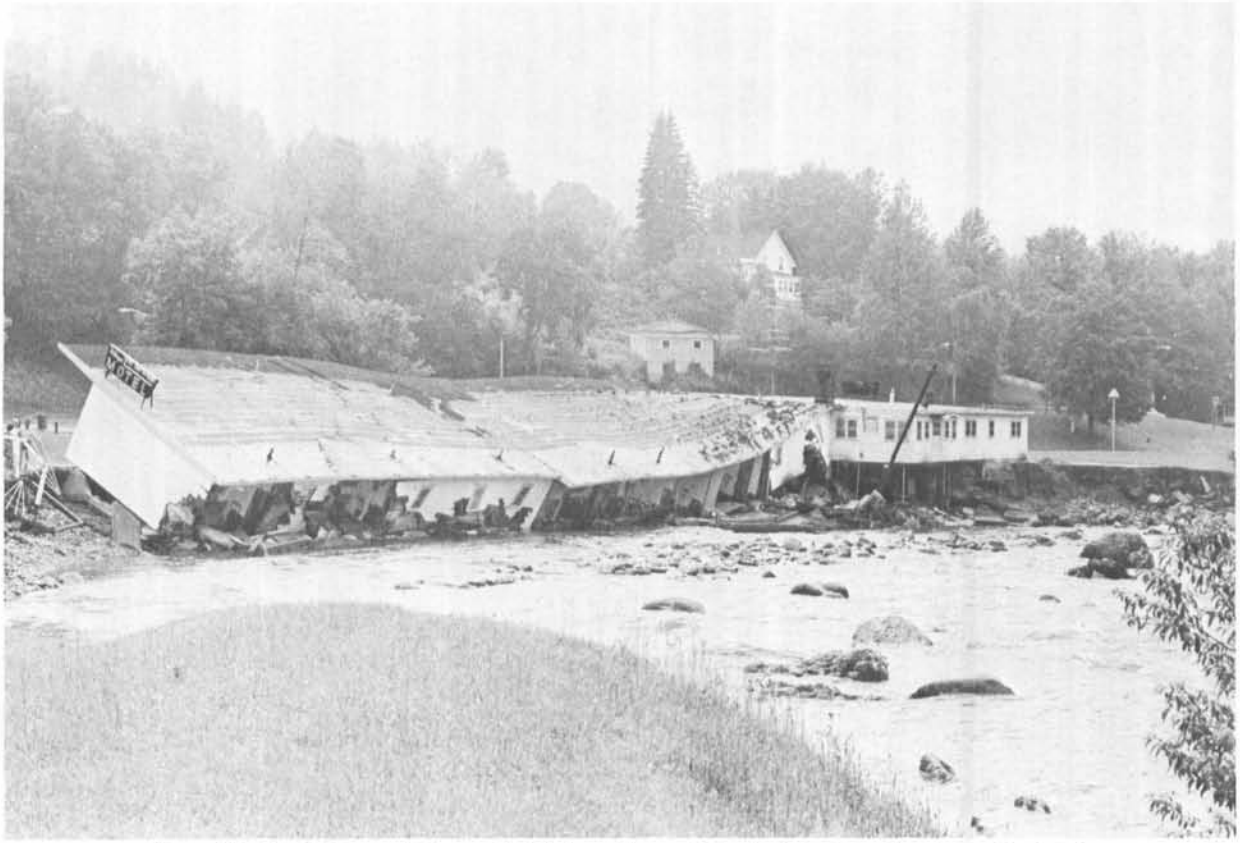

Figure 35 Flood damaged Village Motel along the south bank of the Lamoille River in Hardwick.

ters out of them (*The Caledonian Record*, July 2, 1973).

The June 1973 Flood demonstrated once again nature's terrible capacity for destruction. One of the more dramatic examples of flash flood damage within the Johnson-Hardwick Region occurred when raging waters of the Lamoille River breeched a ten-foot thick dike behind the Village Motel in Hardwick, undercut the motel's foundation, and caused it to topple halfway into the river (Figure 35). This disaster could have been avoided simply by not building on a flood plain, on the outer bend of a meandering river. These areas are highly subject to flooding and erosion. Fortunately, population pressures and urban development have not yet spurred construction on the flood plains in the Johnson-Hardwick Region to any marked degree. Only a few homes and businesses were directly affected by the flood and of those, fewer still sustained structural damage. If nothing else, the flood of June 1973 should strongly reinforce the fact that flood plains are those portions of river valleys which are covered with water when rivers overflow their banks and that man should avoid construction of dwellings and businesses in such areas. Tragically, public awareness and concern for flood problems usually declines in proportion to time since the last occurrence of disastrous flooding. The greater the time lapse since a major flood, the greater the tendency of people to forget the devastating effects, and the more apt they are to take greater risks by encroaching further into flood hazard areas (Wernecke and Mueller, 1972, p. 23).

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APPENDIX A
MAPS SHOWING FIELD LOCATIONS OF SEISMIC PROFILES


IRASBURG QUADRANGLE
Troy
Westfield
South Newport
Kidder Pond
Black Hill
Hitchcock School
Tamarack Brook
Farman Hill
Browns Ledges
Figure 19
W
E
Bel Air
Brighton
Brighton School
Lowell
Truland Brook
Figure 18
Round Hill
LINE 1
LINE 2
LINE 3
LINE 4
LINE 5
Potters Pond
Briggs Pond
CHAMBERLAIN HILL
Brown School
Beetle
Mill Brook
Lilly Br
CEM
GRAVEL PIT
SAND PIT
F I E L D
W E L L
L O W E L L
M O U N T A I N S
I R A S B U
A L B A N Y

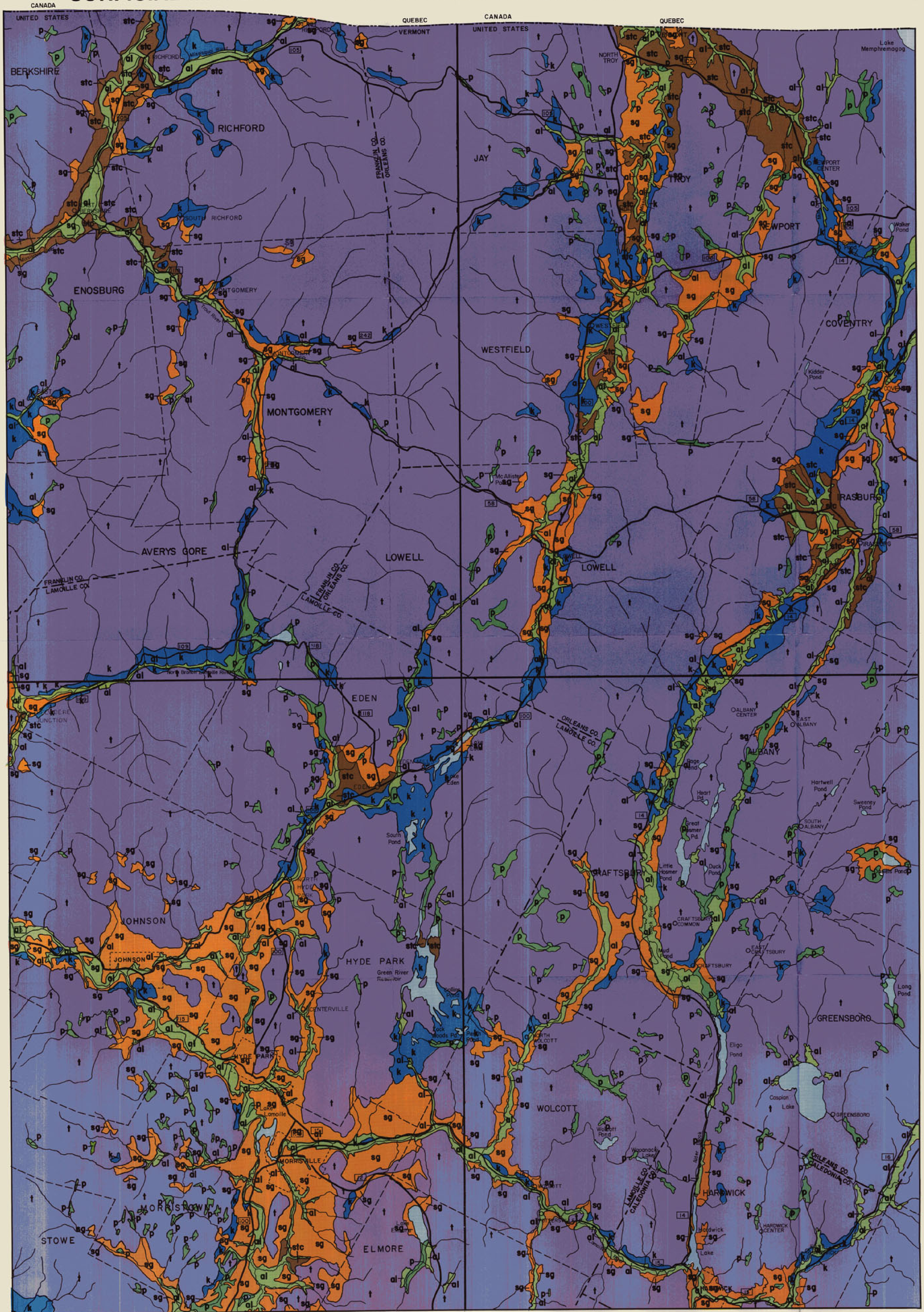
HYDE PARK QUADRANGLE


HARDWICK QUADRANGLE
Figure 16
LINE 3
LINE 2
LINE 1
N
W
S
E
Albany
Rogers Branch
Page Pond
Ames Hill
Merrill Corner
South Albany
Little Hosmer Pond
Duck Pond
Mill Village
Whitney
Brook
Craftsbury Common
C R A F T S B U R Y
East Craftsbury
Cate Hill
Mud Pond
Craftsbury
Branch Sch
Hazen Road Sch
Babcock Hill
Sharps Hill
Webber
West Hill
Mt Sarah
ORLEANS CO
LAMOILLE CO
G R E E N S B O
Baker Hill
Barr Hill
Reservoir
Bear Swamp
Beaver Meadow
Birch Point
Burlington Point
Caspian Lake
The Ledges

HYDE PARK QUADRANGLE
HARDWICK QUADRANGLE
Figure 15
LINE 1
LINE 2
N
S
Schofield Pd
McKinistry
Umbrella Hill
GREEN RIVER RESERVOIR
Collins Pd
Clear Pd
Zack Woods Pd
Perch Pond
North Wolcott
Davis Hill
Lower Diggings
Garfield
Mud Pd
Centerville
Cleveland Corners
Toothacher Hill
Town Hill
Town Hill Sch
Riverside Sch
Morrisville
COPLEY COUNTRY CLUB
LAMOILLE RIVER
ST JOHNSBURY AND LAMOILLE CHAMPLAIN
Wolcott
Pottersville
Lake Elmore
ELMORE STATE PARK
Elmore Mtn
Delano Sch
Elmore Hill
Brown Hill
Pleasant Valley Sch
H Y D E P A R K
E L M O R E
W O L C

SURFICIAL MATERIAL OF THE JOHNSON-HARDWICK REGION

Plate I



LEGEND

t

Glacial Till - generally thin over bedrock, much bedrock exposed, unsorted, poorly drained, bouldery surface. Low water potential.

k

Ice Contact Gravel, mostly kame terraces - well sorted, may have a high sand content, well drained above the water table. Good gravel source. High water potential below the water table.

sg

Lacustrine and Marine Sands and Gravels - Marine deposits only along Lake Champlain. Predominantly sand and pbebly sand, well drained above the water table. Good source for sand. Moderate to high water potential below the water table.

stc

Lacustrine and Marine Clays and Silts - Marine sediment only bordering Lake Champlain. Poorly drained. Medium to high plasticity.

p

Peat and Muck - Swampy, poorly drained areas, water table at or near the surface.

al

Recent Stream Aluvium - thin, covering valley floor, poor to moderately well drained, low strength. Poor foundation material.

Scale

1 1/2 0 1 2

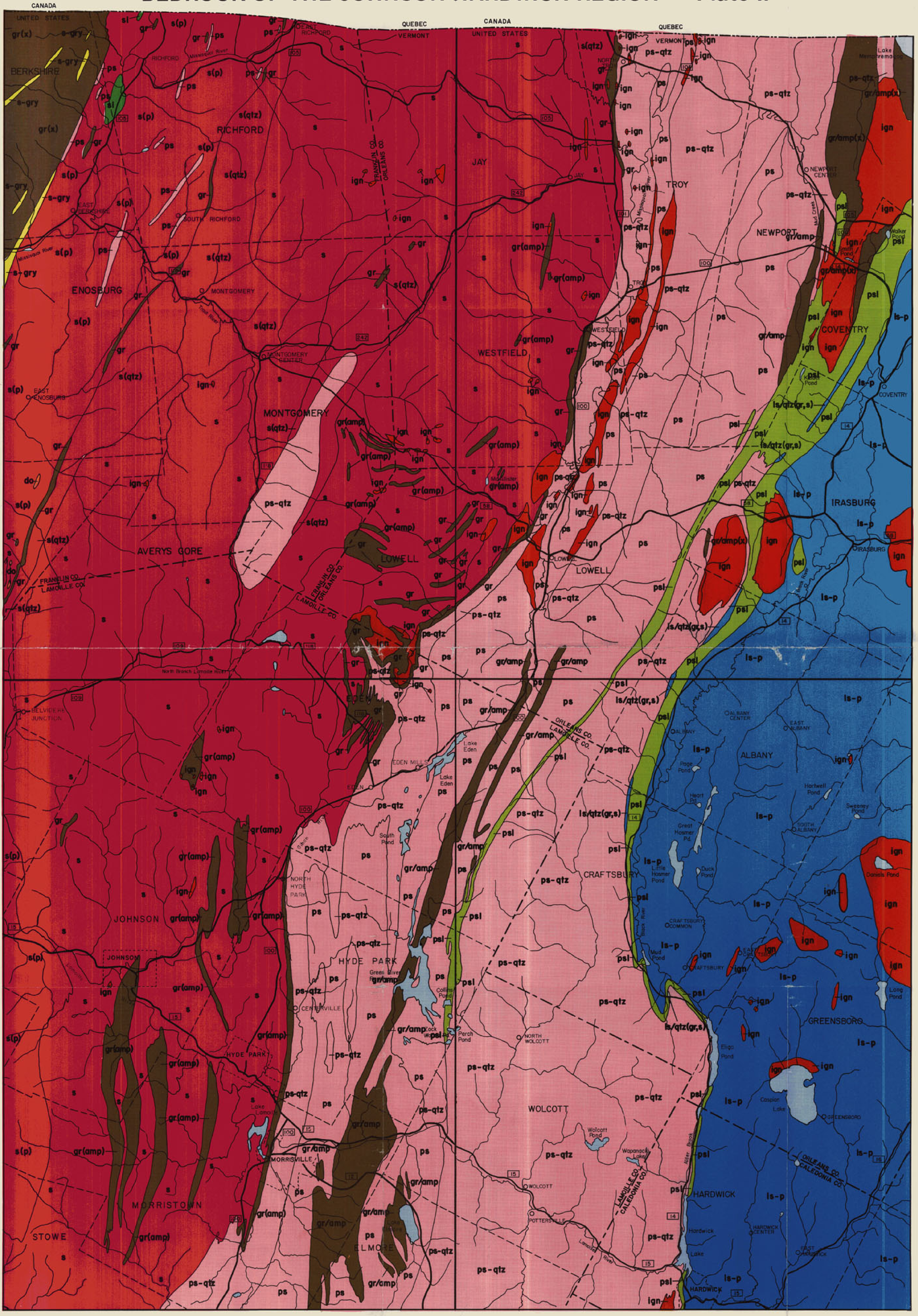
miles

true north

Geologic interpretation by F.M. Wright

Vermont Geological Survey
Charles G. Doll, State Geologist
Published 1974

BEDROCK OF THE JOHNSON-HARDWICK REGION Plate II



LEGEND
GREEN MOUNTAINS
AND
NEW ENGLAND UPLANDS

Complex, light to dark colored, highly metamorphosed rocks of the Green Mountains and New England Uplands consisting primarily of schists, phyllites, and impure limestones with varying amounts of greenstones, slates, dolomites, and quartzites. Locally highly folded, faulted, and intruded by granitic rocks. Wide variability in resistance to erosion due to compositional changes in rock materials.

s — Interbedded, pale silver-grey to green, carbonaceous and non-carbonaceous schists.
s(qtz) — schists with local quartzites.
s(p) — schists with local phyllites.

ps — Interbedded, grey to green, phyllites and schists.
ps-qtz — interbedded phyllites, schists, and quartzites.

psl — Pale greenish-grey to black phyllites which grade locally into grey to black slates.

sl — Grey to black slates.

s-gry — Light to dark green schistose graywacke with local interbedded phyllites.

gr — Massive, dark green, greenstones.
gr(amp) — greenstones with local amphibolites.
gr(x) — greenstones with local pillowed lavas or pillow structures.
gr/amp(x) — undifferentiated greenstones and amphibolites with local pillowed lavas or pillow structures.

do — White to pink dolomite (marble).

ls-p — Interbedded white to bluish-grey limestones and grey phyllites.
ls/qtz(gr,s) — undifferentiated limestones and quartzites with local greenstones and schists.

ign — Igneous plutonics, commonly granite.

Scale
1 1/2 0 1 2
miles

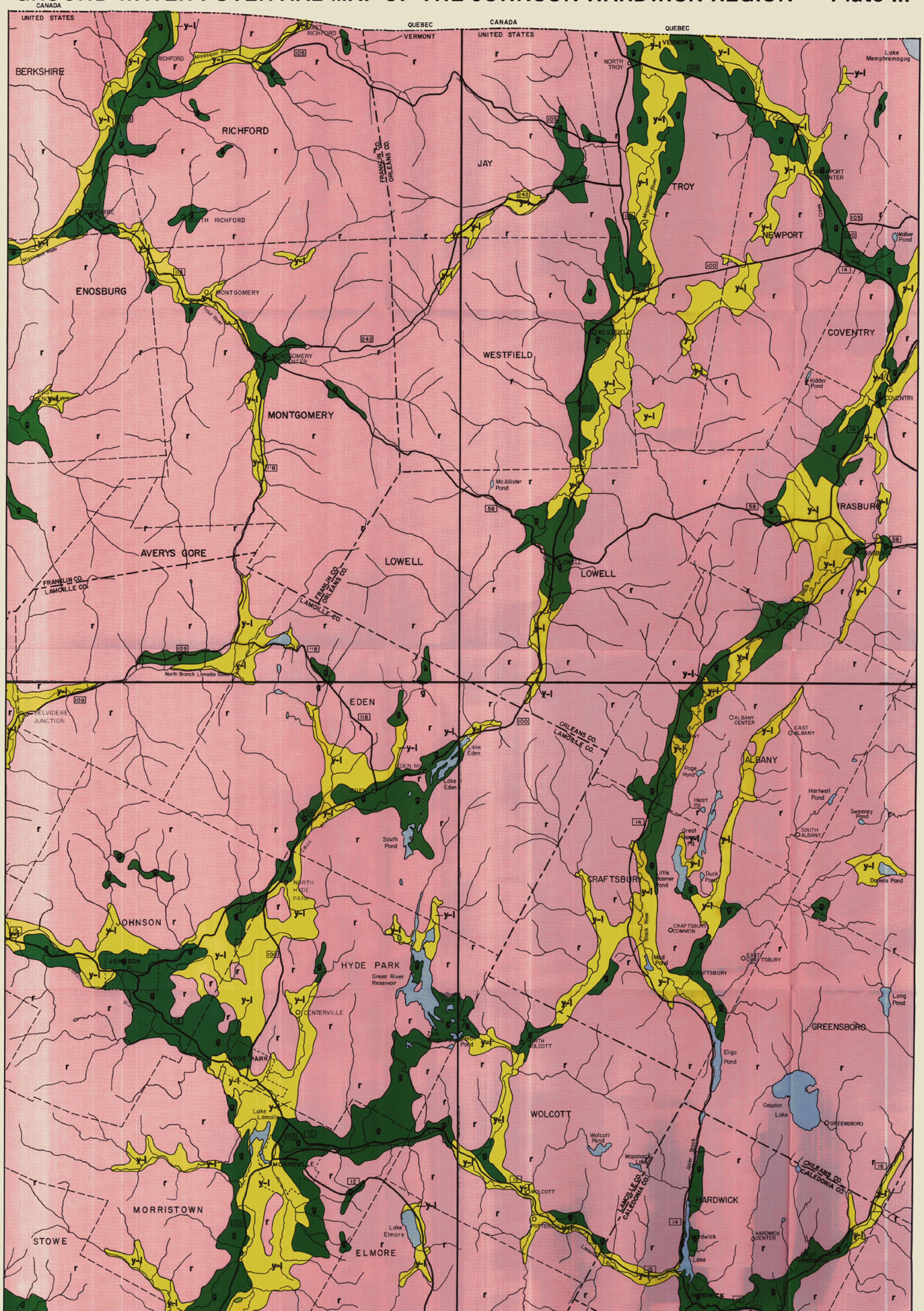
true north

Modified by F.M. Wright and Terry M. Kramer from the Centennial Geologic Map of Vermont (1961). Vermont Geological Survey Environmental Geology No. 4

Geologic interpretation by F.M. Wright

Vermont Geological Survey
Charles G. Doll, State Geologist
Published 1974

GROUND WATER POTENTIAL MAP OF THE JOHNSON-HARDWICK REGION Plate III



LEGEND

g

Areas of good ground water potential. Water available in sand and gravel deposits in stream valleys or buried valleys. Water yield medium to high from the unconsolidated sediments.

y-l

Areas of moderate ground water potential. Water available from sand and gravel in stream valleys or from bedrock below the valley fill. Water yield low to medium at depths to 300 feet.

r

Areas of very low ground water potential. Water available in these areas from low yield, bedrock sources to depths of 300 feet.

Buried Valley with Inferred Boundary.

Scale

1 1/2 0 1 2

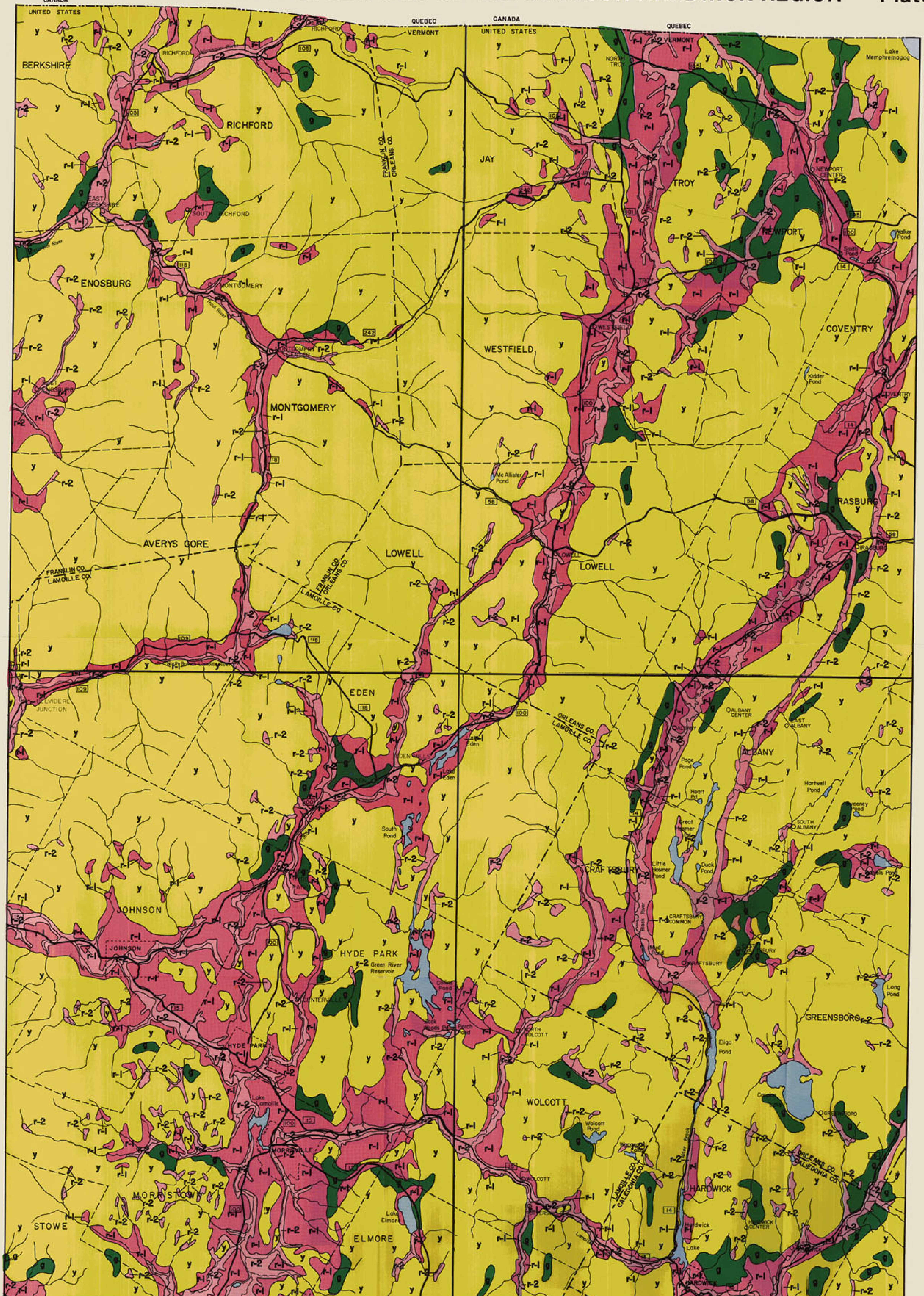
miles

true north

Geologic interpretation by F.M. Wright

Vermont Geological Survey
Charles G. Doll, State Geologist
Published 1974

SOLID WASTE DISPOSAL CONDITIONS OF THE JOHNSON-HARDWICK REGION   Plate IV



LEGEND

g

Areas of impermeable tills, silts and clays generally over 25 feet thick. Suitable for solid waste sanitary landfill with proper surface drainage precautions.

y

Areas of till over bedrock. Till cover usually thin with areas of bedrock exposed at the surface. Solid waste sanitary landfill only where till is over 30 feet thick and with proper surface drainage precautions. Contamination of ground water probable from barns, domestic sewage systems, landfills, etc., in areas of exposed bedrock or a till cover of less than 15 feet.

r-1

Areas of sand and gravel with medium to high permeability and medium to high water potential. Unsuitable for solid waste sanitary landfill.

r-2

Poorly drained, swampy areas. Mostly stream valley floodplains with low relief and periodic flooding. Unsuitable for solid waste sanitary landfill.

Scale

1 1/2 0 1 2

miles

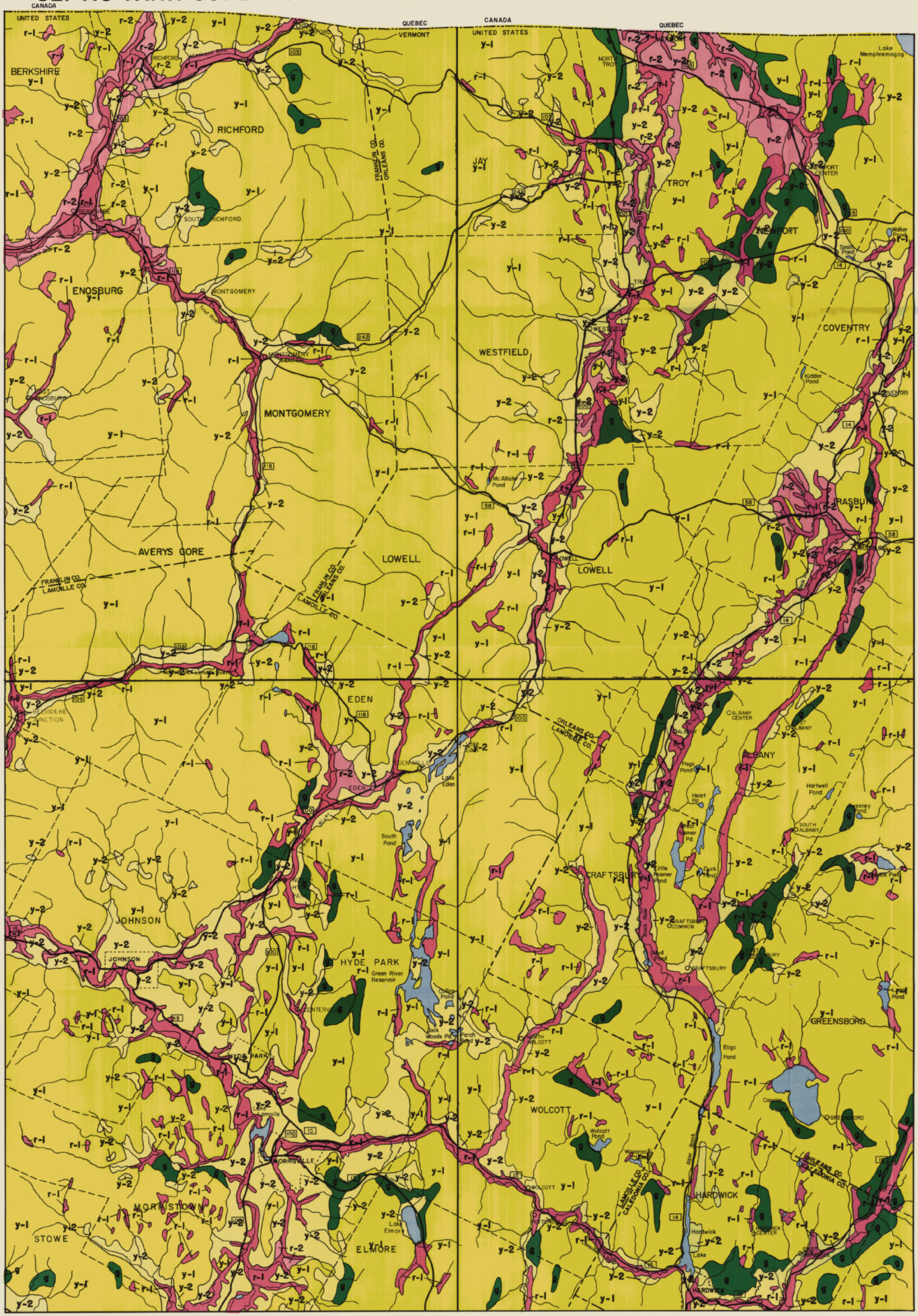
true north

Geologic interpretation by F.M. Wright

Vermont Geological Survey
Charles G. Doll, State Geologist
Published 1974

SEPTIC TANK CONDITIONS OF THE JOHNSON-HARDWICK REGION

Plate V



LEGEND

g

Areas of till over 25 feet thick. Low to medium permeability. Suitable for septic tanks with leaching fields at least 200 feet long.

y-1

Areas of thin till over bedrock. Bedrock commonly exposed at the surface. Septic tanks with at least a 200-foot leaching field only in areas where till is over 10 feet in thickness.

y-2

Areas of permeable sands and gravels. Suitable for septic tank use if deposit is over 15 feet thick and water table is over 25 feet below ground surface. Silt, clay or till below at least 6 feet of sand or gravel is desirable to prevent downward movement of affluent.

r-1

Low, poorly drained, frequently flooded stream floodplains covered with alluvium and/or swamps. Unsuitable for septic tanks.

r-2

Areas of silts and clays with very low permeability. Septic tanks will not function properly in these areas.

Scale

1 1/2 0 1 2

miles

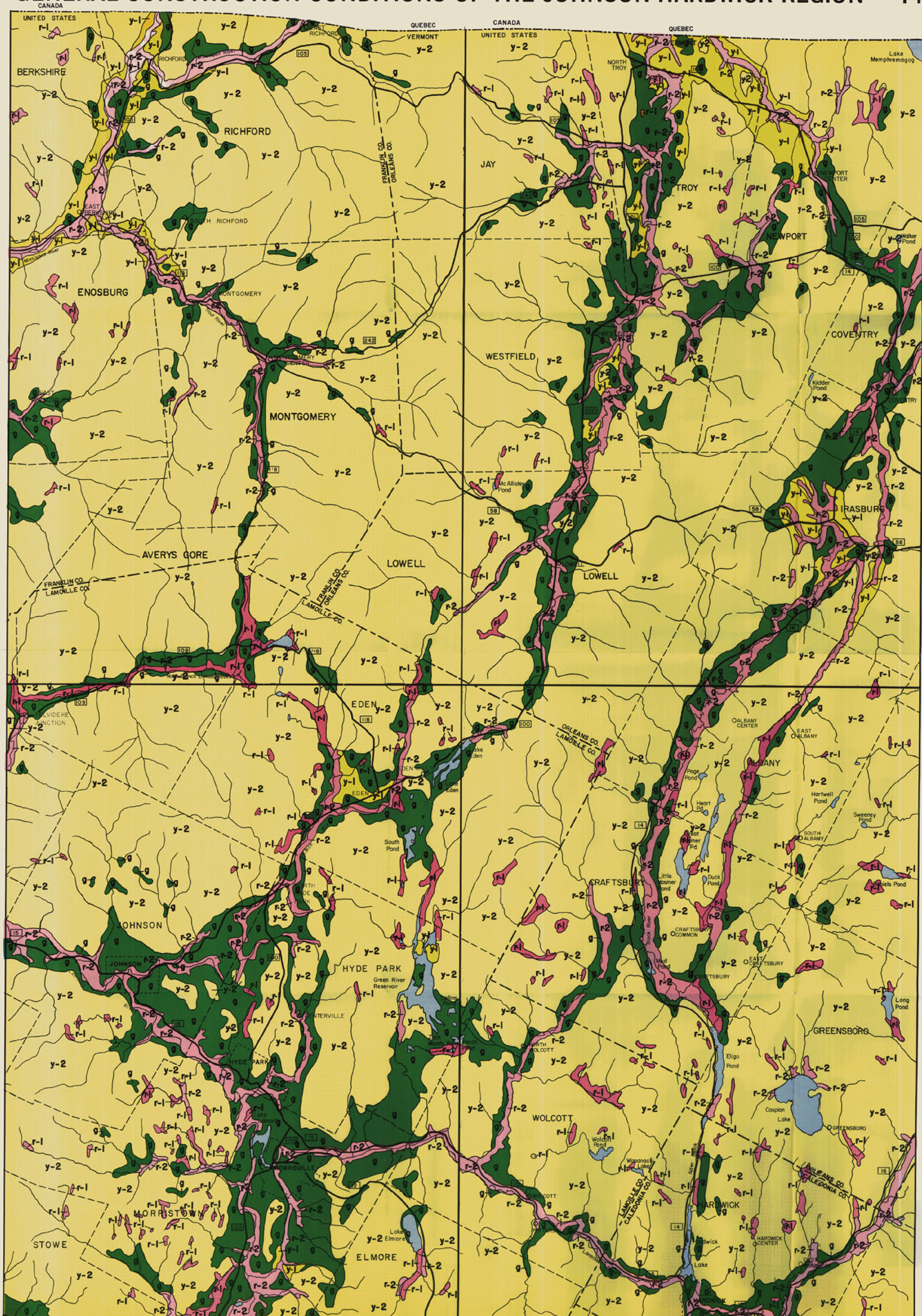
true north

Geologic interpretation by F.M. Wright

Vermont Geological Survey
Charles G. Doll, State Geologist
Published 1974

GENERAL CONSTRUCTION CONDITIONS OF THE JOHNSON-HARDWICK REGION

Plate VI



LEGEND

g — Areas of thick, well drained sand and gravel deposits with adequate bearing strength.

y-1 — Areas of lake sediment composed predominantly of silt and clay. May or may not be capped with sand and/or gravel. Steep slopes common on the outer margins of terraces.

y-2 — Areas of till and bedbock. Till cover generally less than 20 feet. Permeability of till very low. Wide areas have bedrock exposed at the surface or bedrock with less than 5 feet of till.

r-1 — Areas of poor drainage and swampy conditions. Ground water level near or at the surface. Contains wet, compressible sediment.

r-2 — Areas of stream bottom-land covered with 10 to 25 feet of alluvium. Subject of frequent flooding. Alluvium unsuitable for foundations of heavy structures.

Scale

1 1/2 0 1 2

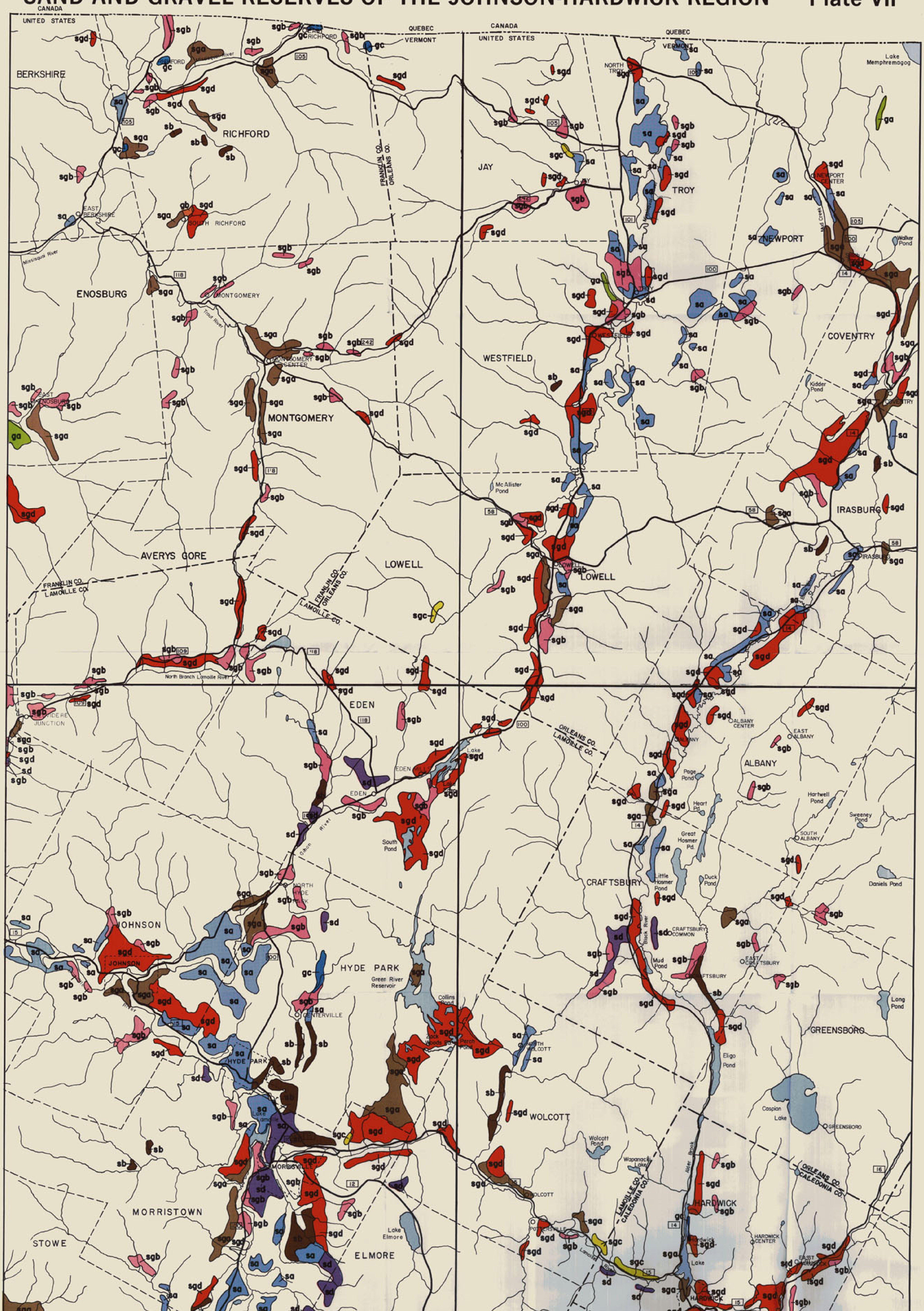
miles

true north

Geologic interpretation by F.M. Wright

Vermont Geological Survey
Charles G. Doll, State Geologist
Published 1974

SAND AND GRAVEL RESERVES OF THE JOHNSON-HARDWICK REGION Plate VII



LEGEND

ga — Gravel deposits containing less than 25% sand. Medium to good quality. Large reserve. Less than one-half the original reserve depleted.

gb — Gravel deposits containing less than 25% sand. Low to medium quality. Low to medium reserve. Less than one-half original reserve depleted.

gc — Gravel deposits. Medium to good quality. Low to medium reserve. Over one-half of the original reserve depleted.

sga — Sand and gravel deposits of medium to good quality and large reserve. Less than one-half original reserve depleted.

sgb — Sand and gravel deposits of low to medium quality and low to medium reserve. Less than one-half of the original reserve depleted.

sgc — Sand and gravel deposits. Medium to good quality. Over half of the original reserve depleted.

sgd — Sand and gravel deposits of unknown quality and reserve.

sa — Sand deposits containing less than 25% gravel. Medium to good quality. Large reserve. Less than one-half of the original reserve depleted.

sb — Sand deposits containing less than 25% gravel. Low to medium quality. Low to moderate reserve. Less than one-half of original reserve depleted.

sd — Sand deposits of unknown quality and reserve.

Scale

1 1/2 0 1 2
miles

true north

Geologic interpretation by F.M. Wright

Vermont Geological Survey
Charles G. Doll, State Geologist
Published 1974