GEOLOGY FOR ENVIRONMENTAL PLANNING IN THE BARRE-MONTPELIER REGION, VERMONT

By

DAVID P. STEWART

VERMONT GEOLOGICAL SURVEY

Charles G. Doll, *State Geologist*

WATER RESOURCES DEPARTMENT

MONTPELIER, VERMONT

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(In Pocket)

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INTRODUCTION

Environmental quality is a matter of choice. We cannot have industrial development, and the employment that it provides, and still have country-fresh air in our cities. We cannot have clean streams and lakes without the cost of efficient, well-operated sewage disposal systems. We cannot have an adequate potable water supply without much study and planning to assure that it is not contaminated or misused. In another vein, we cannot condemn industry, technology and science and at the same time refuse to pay the price for state, municipal and local facilities for a clean environment. Charles A. Dambach (1970), a noted Ohio conservationist, says that "our position on environmental quality is ambivalent." That is, we are simultaneously attracted to and repulsed by the environmental problems. We are attracted to the need to clean up, but we are repelled by the cost, the personal inconvenience, and the restrictions it entails.

The Vermont state government has recently become concerned about the environment and is committed to a program to improve its quality. Agencies, both state and regional, have been established for the purpose of studying the problems, determining their causes, and suggesting solutions on a state-wide basis. Most state agencies are involved in this cooperative, coordinated program. The success or failure of the program, however, will be the choice of the people of the state.

This report is the result of the first field study sponsored by the Vermont Geological Survey that pertains specifically to environmental planning. The survey was made by the writer, assisted by Frank M. Wright, III, during the summer of 1970 under the direct supervision of Dr. Charles G. Doll, the State Geologist. The report and the accompanying planning maps are based solely on the geological conditions without regard to cost, limitation or political implications.

The Barre-Montpelier region was selected for the initial study since it includes the capital district and is composed of both urban and rural environments. It seems logical to assume that this region will have a steadily increasing population over the next several years and that environmental planning is a prime prerequisite to successfully meet the increased demands of a growing region. Four quadrangles—the Barre, Montpelier, Plainfield and East Barre—were selected as a representative region that could be completed in a single field season.

GEOLOGIC SETTING

The Barre-Montpelier region is located physiographically in the New England Uplands Province as it was described by Fenneman (1938) and tectonically in the Crystalline Appalachians Province as classified by King (1959). The rocks are highly metamorphosed and they have been folded, faulted, jointed and fractured (Figures 1 and 2). Small igneous intrusions, both acidic and mafic, are scattered over the region. The topography is erosional forming a dissected plateau that is probably in the stage of early maturity according to the Davis classification.

The major portion of the region is drained by the Winooski River and its tributaries. The major tributaries include the Dog and Waterbury rivers, North, Stevens and Kingsbury branches, and

*Department of Geology
Miami University
Oxford, Ohio

Figure 1. Jointing (fractures) in the bedrock one and one-fourth miles north of Brookfield.

Thatcher and Jail brooks. The First, Second and Third branches of the White River drain the southern margin of the area studied. The stream valleys have steep walls and relatively wide valley floors.

Woodbury, Worcester and Northfield mountains are the dominant topographic highs in the western and central sections. The east central section is highest and most rugged due to the presence of the Knox Mountain granite intrusion and the so-called granite mountains. The mountains that are most conspicuous, rising above the 3000-foot contour, are Knox, Signal, Burnt, Spruce, and Butterfield, (Murthy, 1957; Konig, 1961).

The surface material of the region is all of glacial and post-glacial origin. The uplands are covered mostly by unstratified glacial debris called till. Some of the valley deposits were made by glacial meltwater streams, some were deposited in lakes that existed during the waning stages of the last glaciation, and some have been deposited by streams since the glacial epoch (Stewart and MacClintock, 1969).

EXPLANATION OF THE PLANNING MAPS

The color schemes used on the planning maps (Plates II, III and IV), green (go), yellow (caution) and red (stop), were copied from the Illinois State Geological Survey (Hackett and McComas, 1969, Plate II). Those areas shown in green are interpreted as offering only minor problems and only slight limitations. The areas in yellow have moderate to severe limitations, but the problems are controllable. These areas require study to ascertain the limitations and to determine the necessary controls. The areas mapped in red have severe limitations and many problems that are impractical to overcome. These areas should be avoided in most cases. Where two different symbols are used for the same color, for example y-1 and y-2, it is to show different conditions that have different, but not necessarily more (or less) severe, limitations.

SOURCES OF MATERIAL

The data that were used in the preparation of this report were collected and assimilated from many different sources.

The surficial geology of the four quadrangles had been mapped during the program that produced the *Surficial Geologic Map of Vermont* (Stewart and MacClintock, 1970). The writer mapped the Barre and Montpelier quadrangles and MacClintock the Plainfield and East Barre. The surface maps of the quadrangles were checked in the field and adapted for use for environmental planning. The legends on the maps were somewhat simplified and the description of each material was changed to be more applicable to environmental problems (Plate I).

Percolation tests were made to determine the water properties of the top three feet of surface material. A six-inch auger mounted on the back of a jeep was used to auger holes to a depth of three feet.

Figure 2. Fractured bedrock one and one-half miles north of Brookfield.

Figure 3. Jeep equipped with auger used to make holes for percolation tests.

The holes were filled with water and the drop in the water level in a given time interval was recorded (Figure 3).

Soil maps prepared by the United States Soil Conservation Service were obtained for comparison with the surficial maps and to determine the soil-geology relationships.

Water-well records, on file at the Water Resources Department, were studied to ascertain water potentials. The data were compared with and used for modification of the existing ground water favorability map (Hodges and Butterfield, 1967). The logs were also used to determine, where possible, the depth of the water table, the depth to bedrock, the sequence of unconsolidated sediment in the valley and to help determine desirable locations for seismic study.

Sand and gravel deposits were evaluated as to quality and the percent of original reserve still available.

Vermont regulations pertaining to water, sewage, and solid waste disposal were collected for analysis in relation to the associated geological problems.

Existing solid waste disposal sites were evaluated in reference to the geology of the locality in which they were located.

Twelve locations were selected for seismic study. The seismic work and the interpretation of the data was done by Weston Geophysical Engineers, Inc., of Weston, Massachusetts.

SURFICIAL MATERIALS

Till is unsorted glacial debris deposited directly from melting ice. The material contains all particle sizes ranging from clay through large boulders. The tills in the Barre-Montpelier region, according to Cannon (1964), vary in composition from 25% to 75% sand, 15% to 50% silt and 4% to 30% clay. In general, the tills have a higher sand composition and a lower clay content than do average tills. Tills are low in permeability chiefly because they are unsorted. In the Barre-Montpelier region, the tills veneer the uplands with thicknesses generally ranging from 0 to 20 feet. When found in the valleys, the till is usually much thicker. The tills in the western part of the area studied are younger (Burlington) than the tills of the eastern part (Shelburne) (Stewart and MacClintock, 1969). Although the older till is loose and sandy in a large exposure, it is more deeply weathered than the younger till and therefore the physical characteristics of the two tills are not significantly different.

Outwash is stratified glacial drift that was deposited by streams from a melting glacier. Outwash is usually well sorted and it has a high permeability. It is a very good water-bearing material (aquifer), and a good source of gravel. Kame terraces are outwash deposits formed along the valley wall. The deposits were made in contact with ice and can usually be identified by the slumping structures contained in them (Figure 4). Kame terraces are the most common

type of outwash deposit in the Barre-Montpelier region. Kames are rounded hills of outwash that were also deposited in contact with ice. They are also good gravel sources.

Lacustrine clays and silts are fine-grained lake bottom sediment. This designation includes clay, silty clay and silt. These deposits are of low permeability and are therefore not water yielding. Lake clay is ordinarily too plastic to be favorable foundation material, but in this region the silt content is, in many places, high enough to reduce the plasticity below critical limits.

Lacustrine sands and gravels, including beach gravel and deltas, are shallow water lake deposits that are well sorted. They are high in permeability and make good aquifers. Except for the deltas, the lake sands and gravels are usually horizontally bedded. The deltas, however, have long, gently dipping (foreset) beds. The gravel is usually much thinner than the sand and both commonly occur above the silts and clays (Figure 5).

Peat and muck in the Barre-Montpelier region designate a shallow, marshy, poorly drained area containing little or no peat. The one exception is along the margins of Berlin Pond and upstream for about three miles beyond it. Peat may occur in the depressions containing the pond.

Recent alluvium is stream deposited sediment that covers the valley floor. The alluvium varies in thickness from 5 to 25 feet. The alluvium is a poor foundation material and must be removed for heavy construction.

SEISMIC INVESTIGATIONS

Eleven localities were selected for seismic study in the region of this survey. The seismic work was done by the Weston Geophysical Engineers, Inc., of Weston, Massachusetts. The twelve-point seismic refraction method was employed using a portable twelve-channel seismograph (Figure 6). The refraction method is an indirect means of determining the depth to bedrock and the depth to seismic discontinuities caused by saturation and textural changes of the unconsolidated sediment above bedrock. The profiles reproduced in this report are those made by the Weston Geophysical Engineers during the seismic study (Weston Geophysical Engineers, 1970).

Using seismic data alone, materials may be placed into broad classifications based on the velocities of the seismic wave transmitted through them. Each velocity does not, however, have a unique material correlation, but most bedrock and sediment has a particular velocity range.

Bedrock, of course, has a high seismic velocity because of its density. The velocities of seismic waves through bedrock are generally above 12,000 feet/second, but velocities as low as 10,000 feet/second are possible. Weathered bedrock can have velocities as low as 4000 feet/second.

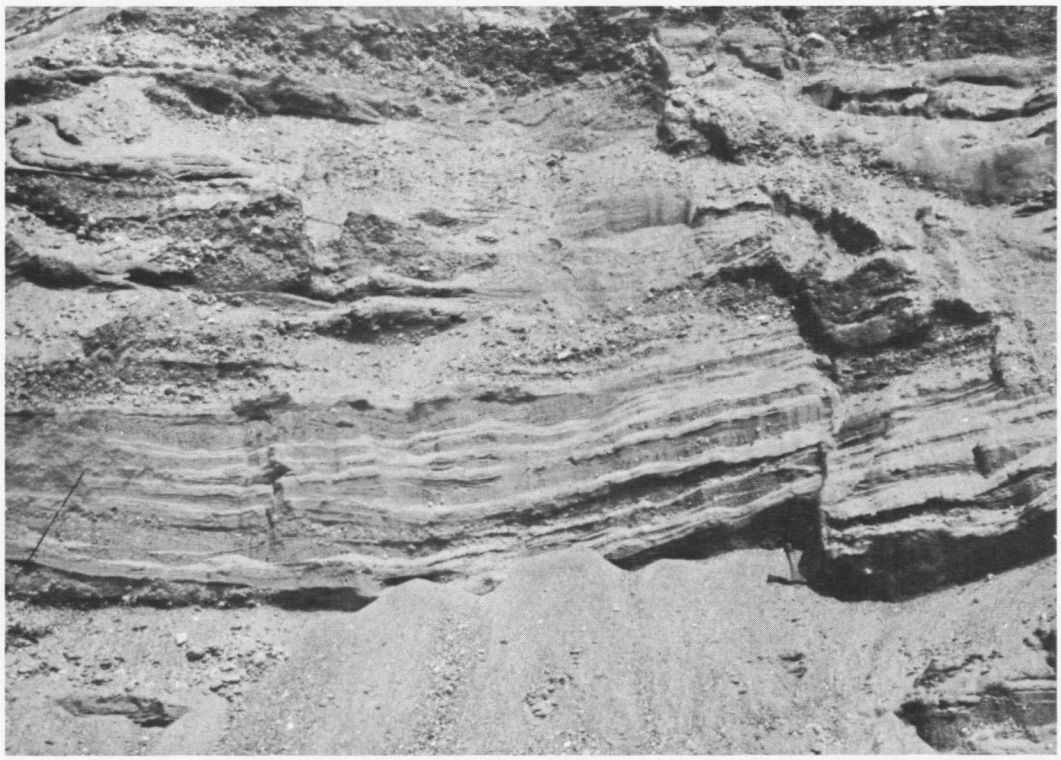


Figure 4. Kame terrace gravel exposed in a pit one and one-half miles north-northeast of Waterbury Center.

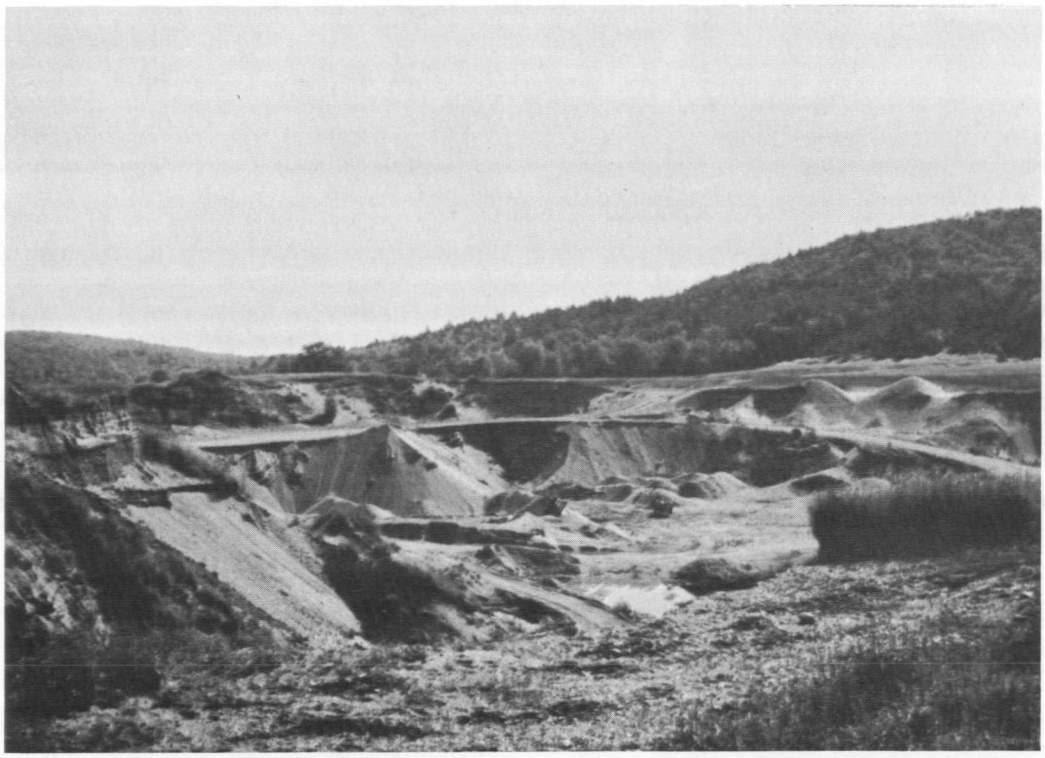


Figure 5. Lake sand in the Dog River valley one mile north of Roxbury.

Figure 6. Field unit used for seismic studies by Weston Geophysical Engineers.

The seismic velocities of unconsolidated sediment are much lower than bedrock. Velocity ranges between 800 feet/second and 2,000 feet/second usually indicate alluvium on the flood plain of a stream valley. Velocities of 2,000 to 4,000 feet/second are common to a number of materials, but in Vermont these usually indicate loose, thin till of a ground moraine. Dense unsaturated till commonly has a velocity range of 3,500 to 4,000, but some compact tills that possess high densities range between 6,000 and 8,000 feet/second.

Materials in the velocity range of 4,500 to 5,500 feet/second are usually saturated with water. Ground water in sufficient quantity for municipal water supply has been found only in materials with seismic velocities ranging between 4,800 and 5,300 feet/second. Materials having seismic velocities below 4,800 feet/second are usually not saturated, and those with velocities above 5,300 feet/second are compact and dense, indicating low porosity and permeability (Weston Geophysical Engineers, 1970).

BOLTON FALLS SEISMIC PROFILE

One seismic profile was made during this study at Bolton Falls three miles west-northwest of Waterbury (Figure 7). Although this location is in the Camels Hump Quadrangle, and three miles west of the area studied, it is a significant location and should be noted here. The profile was made due south of the falls in a north-south direction and shows a channel to the south of the present river that is 75 feet deep. It is apparent that this was the former channel of the Winooski River. Diversion of the river to its present channel was probably due to the filling of the older, deeper channel with sediment during the glacial stage. The channel seems to have a very good water potential and more study is needed to determine the length of the channel and the kind of material filling it.

GROUND WATER

Ground water is a limited resource in the Barre-Montpelier region and its management poses one of the most important and most critical aspects of environmental planning. The surface sources of potable water are being used almost to capacity inasmuch as other surface water sources that might be available are, as a general rule, contaminated. Since it is certain that the demand for water will increase, the most readily available reserve is ground water (Plate II).

Ground water in this region occurs in two quite different environments: in the fractures in the bedrock and in the unconsolidated sediment in stream valleys.

Most of the water produced from the bedrock comes from the fractures in the rock. Since, as has already been stated, all of the rocks are highly metamorphosed, the bedrock contains little or no pore space between the grains to hold water and through which the water can readily move. The fractures are open at the surface and their widths decrease downward. At depths greater than 300 to 400 feet below the surface, the fractures are usually so tight that they either contain little or no water or the water contained in them is held by capillary attraction. The fractures in the rock trend in all directions and they intersect at all depths. For this reason, the water is usually under hydrostatic pressure and commonly rises in the well.

The water that occurs in rock fractures is most susceptible to contamination (Hughes, 1967, p. 12). According to Hodges (1969, p. 6) organic contaminants may travel for miles through rock fractures whereas they would be removed in as little as 10 feet of filtration through sand. Once contamination occurs in this environment, control and abatement are very difficult because of the erratic route traveled by the water.

The uplands of the Barre-Montpelier region are covered by a discontinuous mantle of till that generally varies from 0 to 15 feet in thickness. Large areas of bedrock are exposed. The till on these uplands is too thin and too impermeable to yield water except for hand-dug wells that produce from near the surface sources. Wells in these areas, therefore, must produce water from the bedrock at depths as great as 400 feet. The yield of the wells in the uplands usually ranges from 2 to 15 gallons per minute. This is a very low yield, inadequate for most industrial or commercial uses, but suitable for a domestic or farm supply.

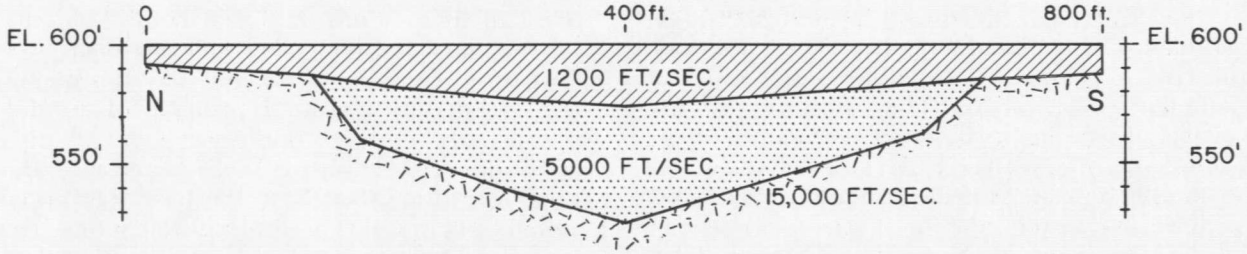


Figure 7. North-south seismic profile across the Winooski River valley immediately south of Bolton Falls, two and three-fourths miles west-northwest of Waterbury.

The stream valleys and two buried valleys in this region are filled with unconsolidated sediment. The depth of the fill varies from 0 to 200 feet. The most common type of valley fill is the lake sediment that accumulated in lakes that occupied the valleys during the waning stage of the last glacial episode. Much of the lake sediment is silt and clay with sand and gravel in the upper levels. Some of the valleys contain outwash gravel and some have fluvial gravel at the bottom.

Where sand and/or gravel occur at depth in the valleys, they are very good aquifers that yield water in much greater quantities than the bedrock. The valley aquifers afford the greatest reserve of water for use in the area and will no doubt be needed as the demand for water increases.

Water-well drillers in Vermont seem better equipped to drill in bedrock than in unconsolidated sediment. When drilling in the valley fill, they do not take the time, or they do not know how, to establish the aquifer characteristics and the rate of inflow of water. As a result, many wells in the valley penetrate 100 or more feet of unconsolidated sediment and then through bedrock to depths of 300 feet or more. These wells have low yield. A well with higher yield and better water probably could have been established at a shallower depth in the unconsolidated sediment.

Wells that are already producing in the valleys attest to the quantity of water available in the valley fill. The town of Northfield has two wells located immediately south of the village in the Dog River Valley. The two wells are at depths of 40 and 50 feet and produce 400 and 600 gallons of water per minute. The town of Waterbury has a well in the Winooski Valley at Waterbury that is 140 feet deep that yields 300 gallons per minute. One well 52 feet deep located in the Dog River Valley, one mile south of the Winooski River, produces 500 gallons per minute. A well 45 feet deep in the city of Barre, owned by the Granite City Co-operative Creamery, yields 350 gallons per minute (Hodges and Butterfield, 1967). The city of Barre recently drilled two test wells in the valley of Stevens Brook and the lower section of Jail Brook. The yield potential of the two wells is approximately a million gallons per day.

The upper Winooski Valley, between East Montpelier and Plainfield, is filled with from 50 to 225 feet of sediment. The available well records and one seismic cross-section (Figure 8) indicate that much of the sediment is silt and clay. There is, however, sand and gravel of variable thickness at the bottom of the valley in most areas. Well records show that the gravel at the bottom, if properly drilled, should yield moderate quantities of water. The lower part of Kingsbury Valley, in the vicinity of North Montpelier, is filled with lake sediment to depths of as much as 135 feet. Sand and gravel are found in the lower part of the sequence. The water potential in this section appears to be quite good. There are no well records available in the upper reaches of Kingsbury Branch, but the sand deposits in that section indicate good water potential.

The Winooski Valley between Montpelier and East Montpelier is cut in bedrock and there is little fill and, therefore, a low water potential. Well records and seismic data (Figure 9), however, prove the existence of a buried valley between East Montpelier and Barre (Figure 10). It is probable that this is a former course of the Winooski River. Two miles north of Barre the valley is 175 feet below the present land surface, and one mile south of East Montpelier it is over 200 feet. The valley is blocked with kame gravel (outwash) north of the city of Barre for a distance of about two miles (Figure 11). Beyond this point, the valley seems to be filled with lake sediment grading from sand and gravel to the south to sand and clay to the north. It is the opinion of the writer that this valley has a high water potential, and that it is a source of water for the aquifers in the Stevens Branch Valley at Barre.

Stevens Branch, between Barre and Williamstown and into the city of Barre, contains sediment 50 to 100 feet deep. The kind of material filling the valley south of Barre is not definitely known. Seismic studies one mile south of South Barre (Figure 12), however, indicate favorable material and a need for test wells to determine the water potential. Wells in Barre, already noted, indicate a high water potential in that part of the valley and the lower reaches of Jail Brook.

Stevens Brook west of Barre seems to be filled with fine-grained, low permeability lake silts and clays (Figure 13). No well records are available on this part of the valley and whether or not sands and/or gravel occur in the bottom of the valley is, as yet, unknown. It seems logical to assume at this time that the water potential is lower than other sections of the valley.

Berlin Pond is located in a valley that was formed either by a former tributary of Stevens Brook or the headwaters of a stream that antedates Stevens Brook. The stream that formed the valley headed at least three miles south of Berlin Pond and flowed north to the north end of the pond and then east to the present valley of Stevens Brook. Well records indicate that the buried valley is 50 feet deep two and one-half miles south of Berlin Pond, 200 feet deep just north of the pond and 300 feet deep two miles northeast of the pond. Seismic velocities suggest that the valley is filled with till, probably of two different ice episodes (Figure 14) and water probability is low in this kind of sediment. Wells penetrating the bedrock below the valley, however, have yields up to 200 gallons per minute, indicating that water from the buried valley is entering the fractures in the bedrock. The valley warrants further study to ascertain the type of sediment, the source of the natural recharge and the maximum amount of water available.

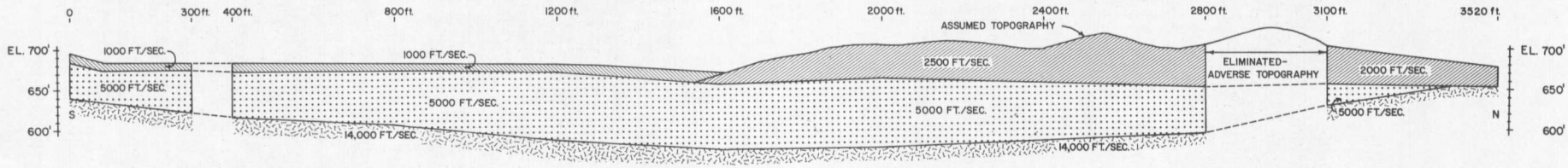


Figure 8. North-south seismic profile across the Winooski River valley, one and one-fourth miles east of East Montpelier.

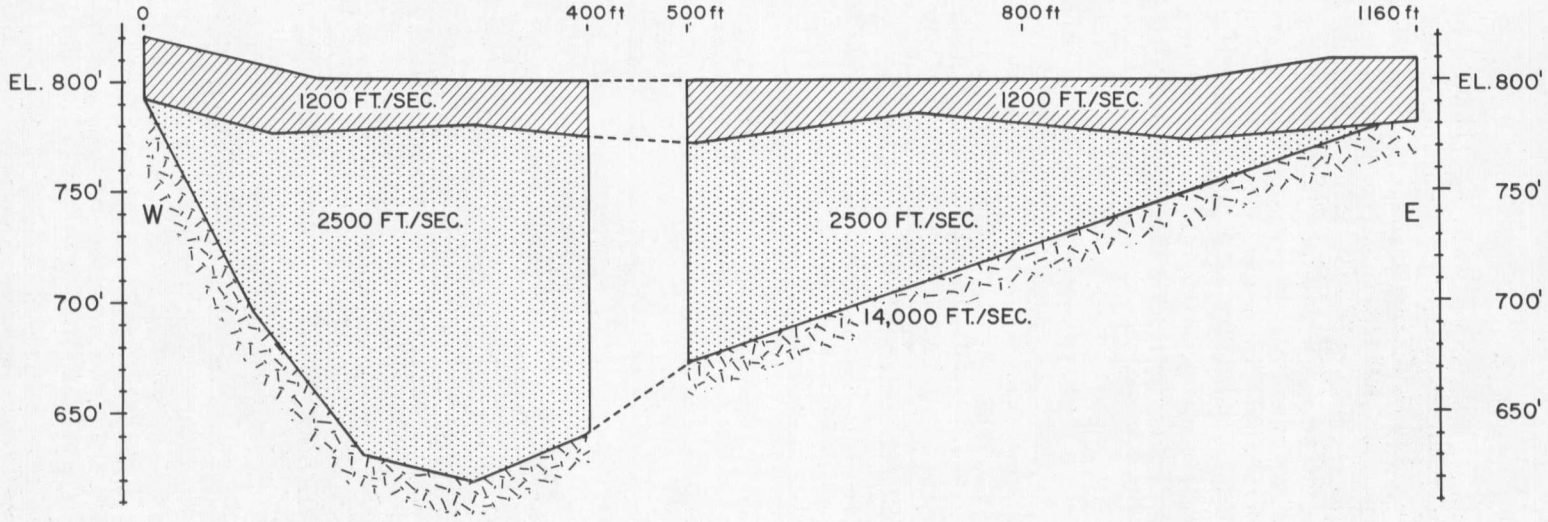


Figure 9. East-west seismic profile across a buried valley between Barre and East Montpelier. One mile north of Barre.

Figure 10. Looking north through the East Montpelier-Barre valley from the Maplewood Cemetery one mile north of Barre. Seismic profile (Figure 9) made opposite white house in left foreground.

Figure 11. Kame gravel in the East Montpelier-Barre buried valley. One-half mile north of Barre.

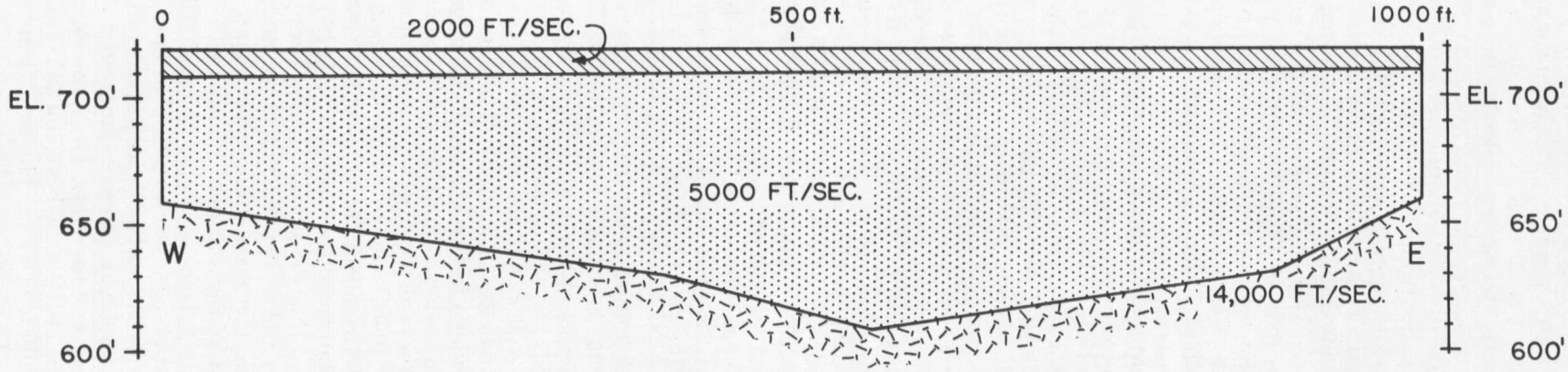


Figure 12. East-west seismic profile across Stevens Brook valley, one mile south of South Barre.

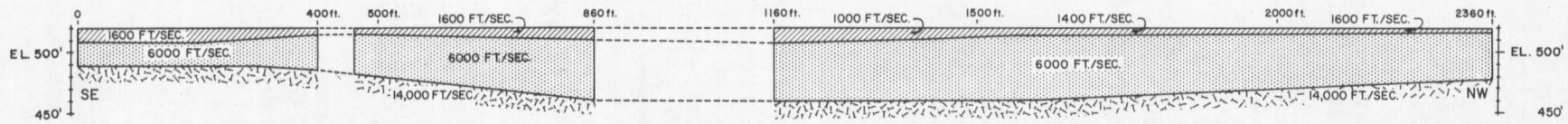


Figure 13. Southeast-northwest seismic profile across Stevens Brook valley at the confluence with the Winooski River valley. Vermont Highway Department test boring one-half mile to the northeast suggests that the material with velocity 6,000ft./sec. is clay.

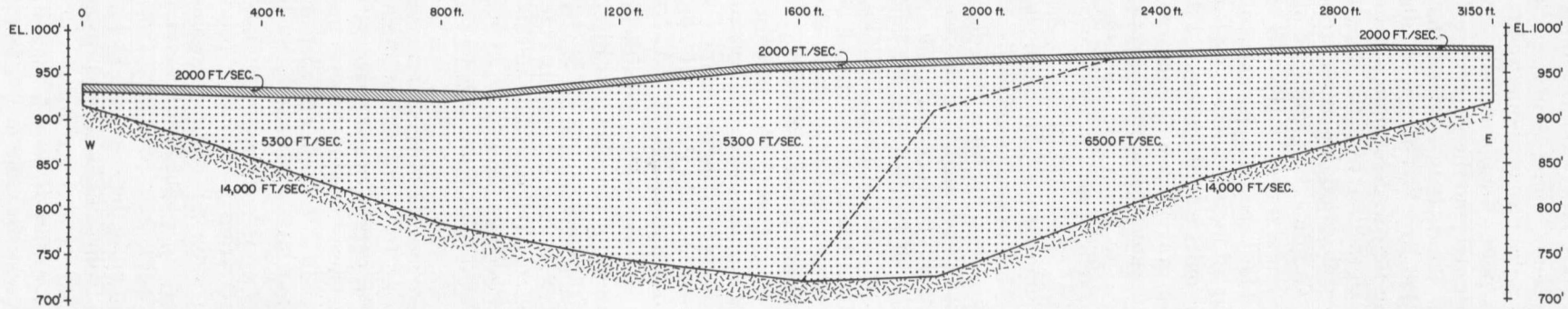


Figure 14. East-west seismic profile across buried valley north of Berlin Pond. One mile north of Berlin. Seismic interpretations, field study, and well logs, suggest that the materials with velocities of 5300 and 6,500 ft./sec. are tills.

Jail Brook flows over the surface of unconsolidated sediment filling a deep valley east of East Barre for a distance of about two and one-half miles. From this point, the buried valley swings northeastward to Orange and thence eastward in the direction of Riddle Pond. It is assumed that this is the old valley of Jail Brook. There is insufficient data available at this time to determine whether or not a valley is buried to the south in the direction of Washington. The valley, judging from well records, is 208 feet deep two miles east-southeast of East Barre, 200 feet at Orange and over 165 feet two miles east of Orange. The valley is apparently filled with a bouldery till at all localities where well records are available. Two miles east of Orange a well that penetrates five feet of gravel below 160 feet of till produces five gallons of water per minute. No other well records show gravel at any level. Additional information is needed to determine the water available in this section.

The amount of sediment in the North Branch, north of Montpelier, is generally less than 50 feet. The thickness of the fill is irregular and a few wells reportedly penetrated approximately a hundred feet above the bedrock. Lake silts and clays fill the valley south of Putnamville, but sand and gravel are the surface material north of Putnamville. Little is known about the depth of the fill between Putnamville and Worcester. It seems doubtful that a large reserve of water exists in this valley.

The Dog River Valley in most sections is filled with sediment only 50 to 60 feet deep. The fill in the valley, however, is predominantly sand and gravel with a very good water yield. The available well records and seismic data (Figure 15) show that the valley in the vicinity of Northfield and the lower sections south of the Winooski River have wells producing 400 to 600 gallons of water per minute. This valley seems to have one of the best water potentials in the region. Contamination in this valley is a possibility inasmuch as the surface material is permeable and the water table is only five to ten feet below river level.

The Winooski River Valley from Montpelier down stream for a distance of about four miles contains fills to depths ranging from 40 to 90 feet. The records in this section of the river are sketchy and incomplete, but it is apparent that much of the fill is fine-grained lake sediment capped with alluvium. Sand and gravel layers are irregularly spaced and wells penetrating these layers produce two to five gallons of water per minute. Additional information is necessary to establish the water potential in that locality.

Sediment in the Winooski Valley, from two miles upstream from Middlesex downstream to Waterbury, seems to have a large reserve of water. The fill in this section, according to seismic data and available well records, varies from 60 to 180 feet and is composed mostly of sand with gravel at the bottom of the valley (Figure 16). Wells that produce water from the sediment in this segment of the valley yield from 5 to 300 gallons per minute. About two miles northwest of Middlesex, the valley narrows and the river flows through a restricted bedrock channel for a mile and one-half. Downstream from this restriction, however, the valley widens and rapidly deepens to 165 feet. At the eastern edge of the village of Waterbury, a seismic profile made during this study shows that the deeper part of the valley is south of U. S. Route 2 (Figure 17). The valley is about 35 feet deep under the river and the highway. Bedrock comes to the surface just south of U. S. Route 2 and then steepens rapidly to a depth of 75 feet approximately 500 feet south of the highway.

Water should be available in large quantities in the valleys in the vicinity of Stowe. It is a fact, however, that most existing wells produce water from the bedrock below the valley fill. One well at the Stowe Flake Motel, one and one-half miles northwest of Stowe, yields 100 gallons of water per minute from sand and gravel at a depth of 140 feet (Hodges and Butterfield, 1967). To the writer's knowledge, this is the only well of recent date that produces water from the valley sediment. The fill in this area is contained in the Waterbury River, West Branch and a buried valley in the locality now drained by Barrows Brook (Figures 18, 19 and 20). It is the opinion of the writer that the Waterbury River formerly flowed west from a point one mile north of Stowe through the valley now occupied by West Branch for two miles and then south to join the present reservoir a mile west of Moscow. The fill in the valley ranges between 60 and 175 feet. The problem of water production here is that much of the sediment is lake clay, silt and fine sand. A well was drilled in the valley three miles northeast of Stowe in 1959, for example, to a depth of 265 feet in fine lake sand. Water was available in the well, but it was abandoned because the sand could not be controlled. The Waterbury River flows through a bedrock gorge between Stowe and Lower Village where the valley widens again to one-half mile. Immediately south of the mouth of Gold Brook (two miles south-southwest of Stowe) the valley is three-tenths mile wide, has a flat bottom and is filled with sediment to a depth of 60 feet (Figure 19). It is believed that the unconsolidated sediment contains a reserve of water, but that more study of the area and more precise drilling techniques will need to be employed to ascertain the potential.

Vermont Laws Relating to Water Resources (1969) contain very little about ground water. The law commissions the Water Resources Department to maintain a continuing study of ground water, but it does not specify the scope of the study. The subchapter on water pollution control does not even include ground water in the definition of water. The law requires the Water Resources Department to license drillers, but

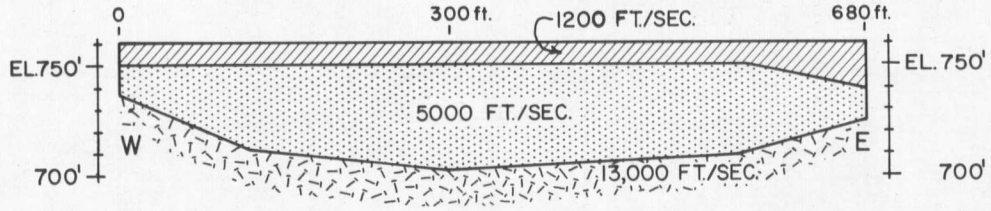


Figure 15. East-west seismic profile across the Dog River valley, one mile south of Northfield. Wells, one-fourth mile north of this profile, indicate that material with velocity 5,000ft./sec. is sand and gravel.

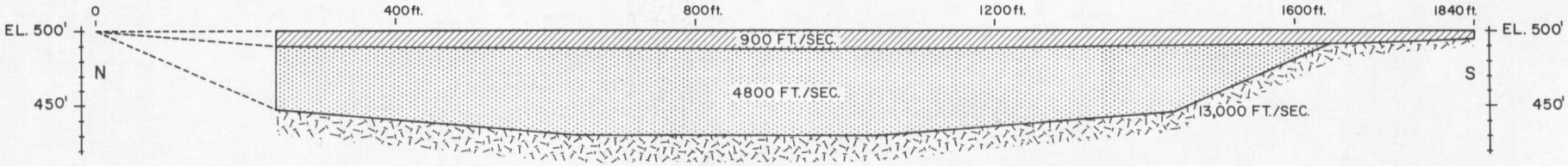


Figure 16. North-south seismic profile across the Winooski River valley, one and one-fourth miles southeast of Middlesex. One water-well log indicates that material with velocity 4,800ft./sec. is gravel and sand.

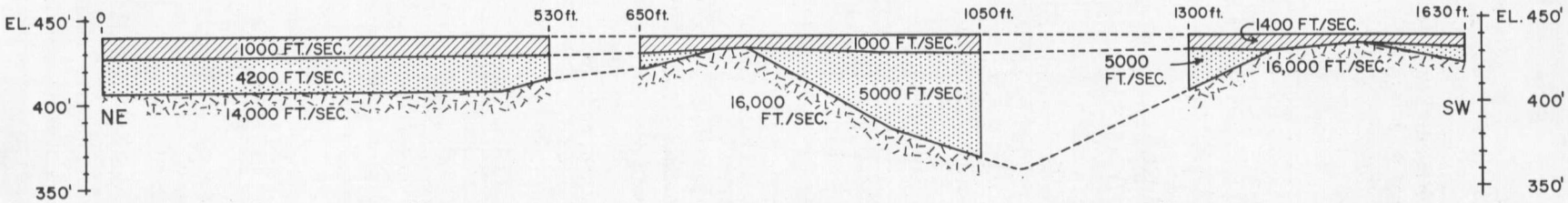


Figure 17. Northeast-southwest seismic profile across the Winooski River valley, one-fourth mile east of Waterbury.

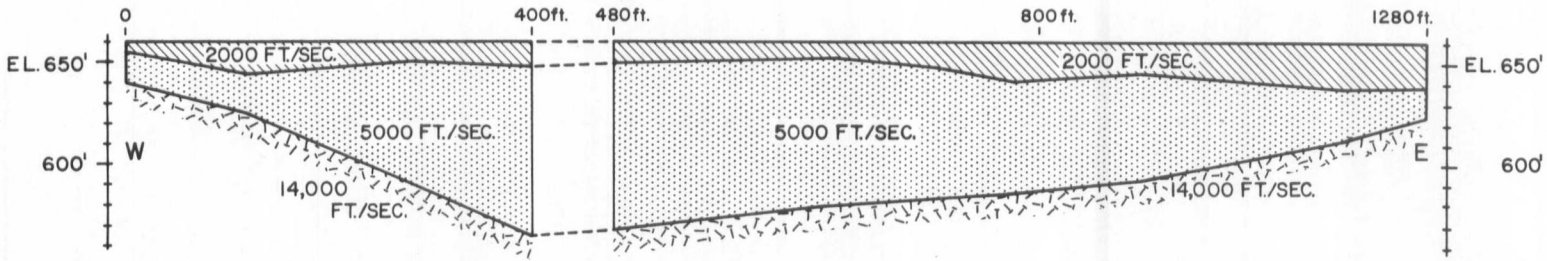


Figure 18. East-west seismic profile across a buried valley one and one-fourth miles northwest of Moscow. The valley is believed to be a former course of the Waterbury River.

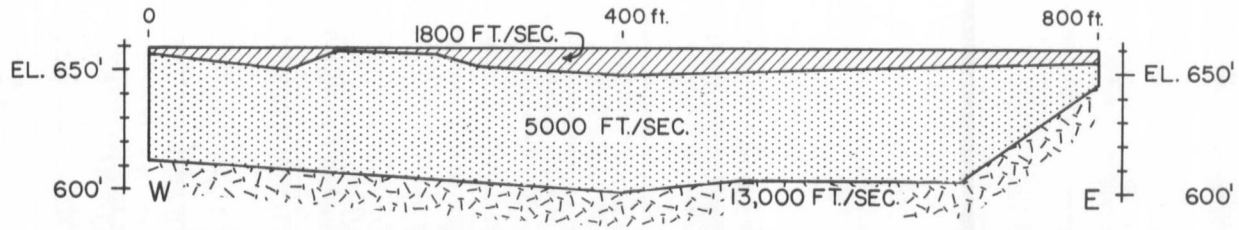


Figure 19. East-west seismic profile across the Waterbury River valley, two miles south-southwest of Stowe.

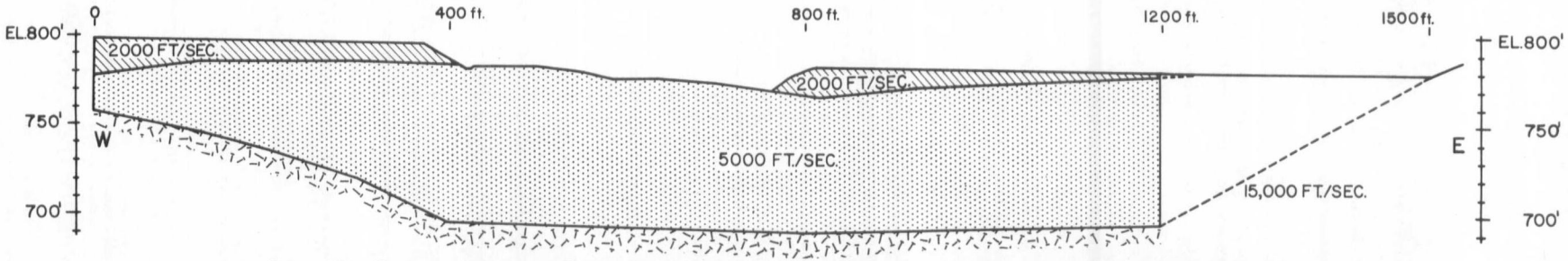


Figure 20. East-west seismic profile across West Branch valley, two and one-fourth miles west-northwest of Stowe.

the law does not define the qualifications of the driller. Neither the Water Resources Department nor any other state agency is given the authority to regulate drilling procedures and practices.

There is definitely a need for more complete and explicit set of laws relating to ground water. Probably the greatest need, insofar as ground water is concerned, is the need for laws defining the qualifications of drillers and drilling practices. The Water Resources Department should have the authority to define and administer these regulations.

Well records are most useful in many types of studies and particularly so in environmental investigations. A majority of the well records now on file, however, are not as complete as they should be. Most drillers logs give the depth to bedrock, water yield of the well and the depth to water. Most drillers, however, do not note the various layers of unconsolidated sediment above bedrock. This information is very important and should be included in the log. The probability of water in the stream valleys is closely related to the type of sediment in the valley.

It is not intended that the Ground Water Potential Map of this report (Plate II) will supersede or replace the Ground Water Favorability Map of Hodges and Butterfield (1967). Their work has been most useful during this study and their map should be most useful in water planning. The map included in this report is somewhat more simplified and it includes the more recent well records, seismic data, and unpublished research material generously supplied by Hodges and Butterfield.

SURFACE WATER

The surface water of the Barre-Montpelier region is not a major concern of this study inasmuch as the Water Resources Department and the former State Water Conservation Board have made detailed studies of the surface water situation and have excellent staff reports on the subject (1960, 1961). The water classification of the various reaches of the Winooski River and its tributaries is known, the sections that are polluted are delineated, and the sources of contamination are on record. The writer of this report supports the conclusions and recommendations of the Water Resources Department and suggests that even more specific regulations may be necessary to control the water quality of the Winooski River system.

It is common knowledge that the water of the Winooski River and its tributaries is substandard in many sections. Contaminants enter the streams from domestic and municipal sewage systems, from industrial facilities along the stream courses, and from refuse disposal sites located in the valley and along the valley walls. The municipal sewage problems are slowly being reduced by careful planning and with state and federal assistance. Solid waste and domestic sewage problems are discussed in following sections of this report. The industrial waste situation in this area, however, is a matter of legislation and regulation inasmuch as the sources are known. The necessary installations to control these wastes are available and it is important that such measures be taken to assure the desired water quality.

WATER MANAGEMENT

This report suggests that a regional agency should be established to initiate a surface and ground water management plan and to pursue a continuing water management program in the Barre-Montpelier region. It should no longer be assumed that the water supply is unlimited or inexhaustible or that the water resources belong to individuals, groups of individuals or political units. Water must be considered a public resource and therefore subject to regulation for the common good.

The function of a water management agency should be: 1) to educate the public on the need and principles of water management; 2) to correlate the work of all other agencies pertaining to surface and ground water; 3) to initiate and continue a study of the water resources and their utilization; and 4) to recommend legislation for water control.

Inasmuch as water planning and management is a most important prerequisite to all other planning and because water studies require specialized personnel, the agency should be separated from other planning units. The water problems involve geology, engineering, public health, government and law. There is a definite need for a water inventory to ascertain the available water, an assessment of the need and future need, studies to determine the advisability of artificial ground water recharge, and plans for allocation for use if and when the allotment of water becomes necessary (Sheaffer and Zeizel, 1966).

In the event a regional agency is not feasible or acceptable, a state agency for water planning would be advisable, probably under the jurisdiction of the Water Resources Department.

SOLID WASTE DISPOSAL

Because of the large amount of solid waste generated, the types of surface material, and the occurrence of water under the conditions already described, solid waste disposal is possibly the second most important environmental concern in the Barre-Montpelier region. Many of the problems associated with solid waste are not geological, but the location of disposal sites and the relation to ground and surface water is definitely a geological consideration (Plate III).

The geological problems relating to solid waste result from the fact that when refuse is saturated, even intermittently, it produces a liquid contaminant

Figure 21. Marshfield dump located on the east valley wall of the Winooski River. One mile southwest of Marshfield.

Figure 22. Barre dump located in gravel of the East Montpelier-Barre buried valley. One-half mile north of Barre.

called leachate that usually has a high content of dissolved mineral material. The leachate can carry biological contaminants and therefore acts as a transporting agent (Cartwright and Sherman, 1969). It is important that these solutions do not seep downward to the water table or flow into surface streams. As stated above, disposal sites are one of the sources of pollution that lowers the quality of water in the Winooski River system.

Stream valley walls are a favorable location for refuse dumps in Vermont (Figure 21). Examples of these are the disposal sites at Marshfield, Northfield, Graniteville and Orange. Some of these are not land-fill types and there is no protection from precipitation. The leachate from these sites drains down the slopes of the valley walls onto the valley floor and into the streams. The surface material in the valley floor is often permeable sand and/or gravel and the leachate may seep through to the water table. These are definitely not favorable locations for refuse dumps.

Abandoned gravel pits are also a choice location for disposal sites in the Barre-Montpelier region. Such a location is a "cheap" solution of a pressing problem for the present, but its long-time effects are quite expensive. Gravel is the most permeable of unconsolidated surface materials and water flows through it with ease. The water table is commonly near the surface, or at least near the bottom of the pit, and contamination of the ground water is almost a foregone conclusion. When landfill techniques are employed in these disposal areas, gravel and/or sand are the common types of cover and these materials do not prohibit water from entering the refuse. Saturation therefore occurs unabated.

As heretofore stated, there are several different kinds of gravel in the region. The outwash gravel is most permeable and is usually thickest, especially in kames and kame terraces. The water table is usually high in these deposits. Lake gravel is usually thin and covers sand, which in turn covers lake silts and clays. The lake sand is well sorted and has a high permeability. If the gravel and sand are thin and a considerable thickness of lake silt and/or clay lies above the water table, these deposits may be used, with caution, for refuse sites.

The city of Barre has a landfill type disposal site located in the kame gravel deposit blocking the Barre-East Montpelier (buried) valley already described (Figure 22). As has been explained, it is believed that this valley supplies much water to the sediment in Stevens Brook valley at Barre. The city may, in the near future, have to use ground water to supply an ever increasing demand for water. The dump is also located along the course of Gunners Brook and pollution of the stream is probable. It is therefore important that the dump be moved from its present site.

Waterbury also has a disposal site located in sand and gravel deposits of the Winooski Valley just east of the village. Leachate formed in this dump is in close proximity to the river and the water table.

Sand deposits are quite permeable and the same problems occur as with gravel. The use of these as disposal sites requires investigations to determine the thickness of the sand, the underlying material and the depth to the water table.

Sand and gravel excavations can be utilized for refuse if they are properly sealed to prevent the discharge of leachate. There are various methods for sealing, the most common being the use of a clay liner. Recently plastic sprays have been used to waterproof the liner. The sealing of sand and gravel is expensive, however, and the selection of a more desirable site is probably a better solution.

Lake silts and clays have a low permeability and, if they are of sufficient thickness and above the water table, they are suitable materials for solid waste disposal sites. Most of the silt and clay deposits of the Barre-Montpelier region, however, occur in and along the stream valleys and safeguards are necessary to prevent surface water contamination. Many of the deposits have terrace form and, if the area of the top is large enough, problems can be overcome by a carefully planned drainage away from the stream.

The city of Montpelier has a landfill disposal site on silt and clay lake sediment located south of the Winooski River three miles east-southeast of the city. Some problems have been encountered because of the low permeability and freezing in winter, but contamination is not likely either to the river or to ground waters.

Probably the best suited material for waste disposal is the till that covers the uplands and some valleys. The chief problem with upland till is that it is often too thin to prevent the leachate from entering the fractures in the bedrock. According to Cartwright and Sherman (1969), a minimum thickness of 30 feet of relatively impermeable material is required in Illinois to prevent the escape of leachates. This seems like a reasonable thickness, and is recommended for use in the Barre-Montpelier area. Since water can pass through the fractures in the rock with little or no purification, it is the thickness of the unconsolidated material above bedrock that is critical.

SEWAGE DISPOSAL

As already stated, this report is not particularly concerned with municipal sewage treatment plants. State and federal regulations concerning these systems are quite rigorous and specific. There are probably municipalities, particularly small villages, in the region that do not have disposal systems and these should be encouraged to install acceptable plants in the near future. State law should prohibit, without exception, the dumping of raw sewage by any individual or village into the streams or lakes (Plate III).

During the summer of 1970, when the field work for this study was in progress, a new sewage disposal system was being constructed at Williamstown. The operation consisted of forming walls of gravel to make two square pits about 12 feet deep. The location was in outwash at the site of an old gravel pit. The gravel walls and the floor of the pits were covered with paper-thin polyethelene plastic which was covered by one to two feet of gravel. It is the opinion of the writer that the approval of this installation by a state agency was poor judgment. It is very doubtful that the polyethelene liner will remain intact and that the facility will give satisfactory service. The gravel under the pits extends to the water table and contamination of the ground water is probable.

Domestic sewage disposal is a serious problem that has not, as yet, been fully realized in the State of Vermont. In spite of the inadequacies of the septic tank as a domestic sewage system, it is still the most desirable for rural use. New housing subdivisions that use septic tanks, however, are a different situation inasmuch as multiple dwellings compound the problem. The desirability of the septic tank with a leaching field is that it distributes the affluent over a large area. Cesspools, lagoons, and similar methods, by contrast, concentrate the affluent in a small area.

State specifications regarding septic tanks require percolation tests to determine the size of the leaching field. That is, the tests indicate the length of seepage tile to be used. These regulations do not, however, specify the thickness of unconsolidated material that must occur below the leaching field and above bedrock. The assumption is, of course, that the bedrock is impermeable, which it is not. To ascertain that the affluent from a leaching field does not reach bedrock, some requirements for thickness of the surface material should be contained in the regulation. The minimum thickness of surficial material above bedrock should vary with the permeability of the sediment as indicated by the results of percolation tests. Minimum till thickness, for example, could be much less than gravel thickness.

Regulations concerned with the development of new subdivisions also assume an impermeable bedrock as well as a consistently low permeability of the overlying sediment. These specifications require that the thickness of the mantle material be at least 8 feet over 20% of the area of the development and at least 3 feet over the remaining 80%. Because of the differences in permeability of different materials, if the above requirements are sufficient for an area of till or lake silt, they are surely not adequate for an area of lake sand or gravel. Seepage tests should be required in this case to determine the desired thickness of overlying material.

Housing developments should have a single, well designed sewage system, constructed by the developer, where municipal sewage is not available. The present regulation, as stated above, may be sufficient for silt and till surfaces. In areas of sand and gravel, however, and particularly in the stream valleys, more rigid regulations are required. In the Dog River valley, for example, the surface material is mostly sand and gravel and the water table is within 5 to 10 feet of the surface. It is impossible to prevent contamination by a subdivision with a number of individual septic tanks.

FOUNDATION MATERIAL

Foundation conditions in the Barre-Montpelier region are not so critical as the already discussed environmental considerations. The criteria for construction involve such factors as slope, drainage, plasticity, strength, flooding and the availability of water and building materials. In this area, special planning and certain limitations are necessary because of the poor drainage of the till, lake silt and lake clay, the plasticity of the clay, the flooding of the river and stream bottomland, the steep slopes, and the strength of stream deposits on the valley floor (Plate IV).

Most of the stream bottomlands are veneered with 5 to 25 feet of stream-deposited detritus called alluvium. The material is not desirable for foundations, particularly heavy industry, inasmuch as it is usually poorly drained, flooding is a seasonal problem and the strength is quite variable. If the valley floors containing alluvium are used for industrial and other types of heavy construction, the total thickness should be removed. The water table may be above the bottom of the material to be removed.

Sand and gravel deposits are good foundation materials since they are well drained, have good strength, and usually yield water in large quantities. The sand and gravel, however, may be of economic value and this factor should be considered when locations are selected. Many abandoned sand and gravel pits would be suitable for construction with a minimum of grading and filling. Lake sands and gravels overlying silt and/or clay might be a problem if the sand and/or gravel are thin and the plasticity of the underlying silt and/or clay is high. In these cases, the thickness of the sand and gravel should be determined as well as the physical characteristics of the sediment that it overlies.

Lake clay has, as a general rule, a high plasticity and is therefore subject to flow. In the Barre-Montpelier region, however, much of the lake sediment seems to contain enough silt to reduce the plasticity to an acceptable range. Plasticity and bearing strength tests are recommended at each site. The lake bottom deposits (silt and clay) have low permeability, therefore poor drainage, and compensation for this characteristic should be included in the building plans.

Steep slopes are common along the valley walls in all sections of the region. Slumping, sliding and

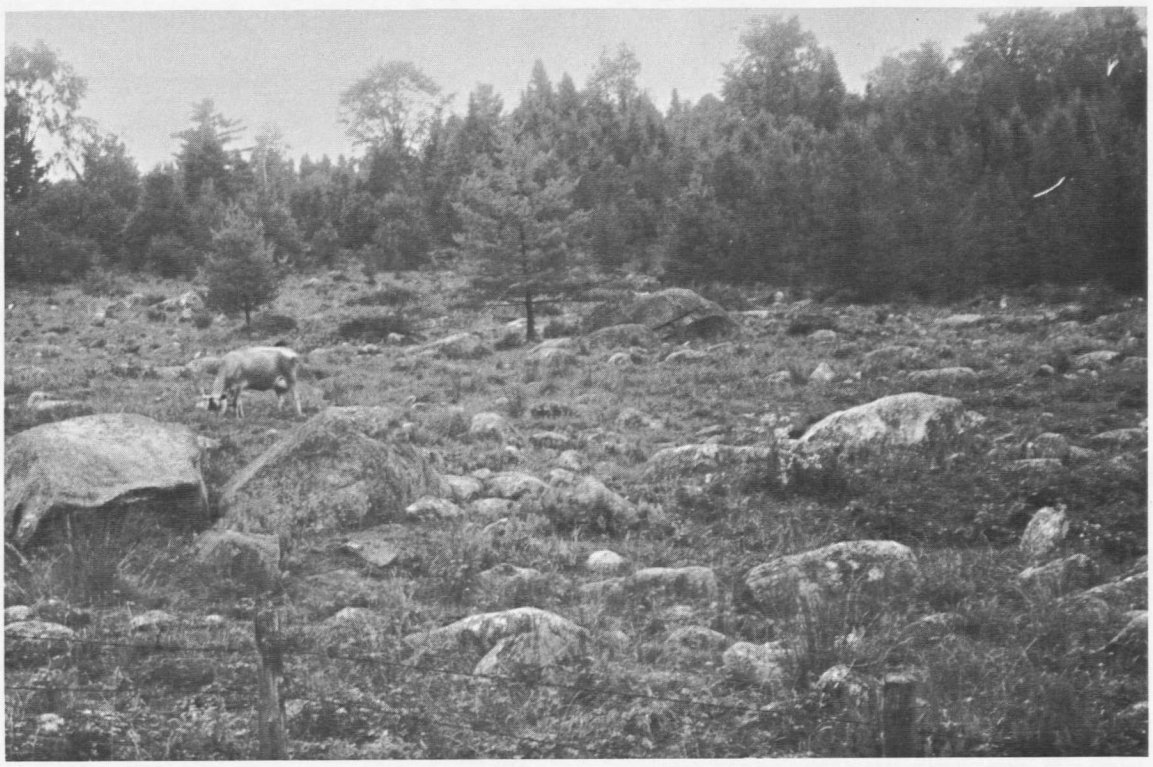


Figure 23. Bouldery surface of the Knox Mountain granite region. One and one-half miles northwest of Marshfield.

creeping are common along these slopes, particularly those slopes that are cut in lake sediment. Buildings should not be located on these slopes, on top near the break of the slope, or in the valley near the base.

Building conditions vary from place to place in the till areas due mostly to the variable till thickness. The till, like the lake clay and silts, has a low permeability and therefore requires planned drainage. In most areas, the till is so thin that excavation of the underlying bedrock is necessary. Except in granite areas, however, excavation of the bedrock is generally not difficult. In the east-central part of the area studied, the bedrock is granite and the surface material is so bouldery that excavation would be a problem (Figure 23). Steep bedrock slopes covered with a thin veneer of till should be avoided.

SAND AND GRAVEL

The sand and gravel map prepared during this survey (Plate V) classifies the deposits as to quality and reserve. There is no sand and gravel in the region that meets standard specifications for cement and, therefore, the best gravel is classified as good. The gravel reserves have been greatly reduced by construction in the region, particularly the new interstate highway. An adequate reserve for the near future, however, still remains (Plate V).

From an environmental standpoint, more planning should be given to the sand and gravel areas. Hackett and McComos (1969) suggest that these areas should be designated for open space use until they are needed. When the sand and/or gravel is needed, planned methods of excavation should be employed and, after the gravel has been removed, the area should be returned to productive use.

LAND USE AND FUTURE DEVELOPMENT

It is probable that agriculture and recreation will continue to be the most important uses of the land in the Barre-Montpelier region. The centers of population will expand into their environs, but this expansion will be quite limited except in the vicinities of Barre, Montpelier, Stowe, and possibly Waterbury, Northfield, Middlesex and Plainfield. Planning should start immediately to regulate and control the direction of the expansion and the conditions under which it can occur.

Expansion into the stream valley areas should be particularly controlled so as to minimize the possibilities of damage to the water, both surface and subsurface, in those sections. The Dog River valley should have special regulation because of the reserve of water, the type of sediment and the nearness of the water table to the surface. Other areas, probably as important as the Dog River valley, in the Barre environs, for example, should be delineated.

Commercial expansion should and will continue in the Stevens Branch and Winooski River valleys between Barre and Montpelier. Because the valleys

are filled mostly with lake bottom sediment, this area offers few problems insofar as ground water contamination and foundation material are concerned. Expansion of Barre southward in Stevens Branch should occur only after suitable sewage disposal regulations have been initiated. The Winooski valley west of Montpelier requires special study because of the flooding and because of the alluvium at the surface. The other population centers located in the valleys should have similar restrictions.

Agricultural pollution, which is increasingly becoming an environmental problem in other parts of the country (Edwards and Harrold, 1970), is not discussed in this report inasmuch as it is not a geological problem. The effects of agricultural practices and the use of insecticides and pesticides on surface and subsurface water supply should be studied in Vermont.

There is a need for more recreational areas in the region for use by local residents. Except for state parks, there is a minimum of land set aside for recreational purposes. The state parks are not near the centers of population, and the cost of using the parks for picnicking and recreation is becoming a factor in their use. The south side of the Waterbury Reservoir, near Waterbury Center, is used for recreation, but no agency is responsible for its use and the users of the facilities are negligent. Some agency should be responsible for its use and keeping it clean. There are many localities in the region studied that are too rugged or too bouldery for use other than forests or recreation. The largest of these are found along the slopes of Worcester Mountain and in the east-central section where the bedrock is the Knox Mountain granite. There are, however, in all sections, small plots of land that are either abandoned or unfit for cultivation that are suitable for recreational activities. Some of these should be purchased by local governments for parks.

ACKNOWLEDGMENTS

Inasmuch as a rather large amount of data, necessary for interpreting the geology for environmental planning, is already on file at various agencies, many persons were contacted and asked to furnish information. The writer is indebted to all of those who so willingly gave of their time and shared the results of their work. Special thanks are expressed for the assistance and cooperation of Mr. David Butterfield, geologist, Vermont Water Resources Department, Mr. Arthur L. Hodges, geologist, United States Geological Survey, Mr. George Allen, soil scientist, United States Soil Conservation Service, Mr. Frank Lanza, geologist, Vermont Highway Department, and Mr. Thomas F. Sexton, Weston Geophysical Engineers, Inc. Dr. Charles G. Doll, the State Geologist, was most helpful and it was his interest and work that set up the program and secured funds for its completion. He also supplied a voluminous amount of data already on file at the Geological Survey. Frank Wright, III, graduate student at Syracuse University and field assistant, contributed much to the summer's work and did much of the drafting of the planning maps. Walter Coppinger, graduate student at Miami University, did the drafting for the report. Dr. A. Dwight Baldwin, Geology Department, Miami University, read the report and made many helpful suggestions. Gratitude is expressed to the landowners for their cooperation in granting access to their properties for the seismic profiling studies and the geologic mapping.

APPENDIX ... MAPS SHOWING FIELD LOCATIONS OF SEISMIC PROFILES

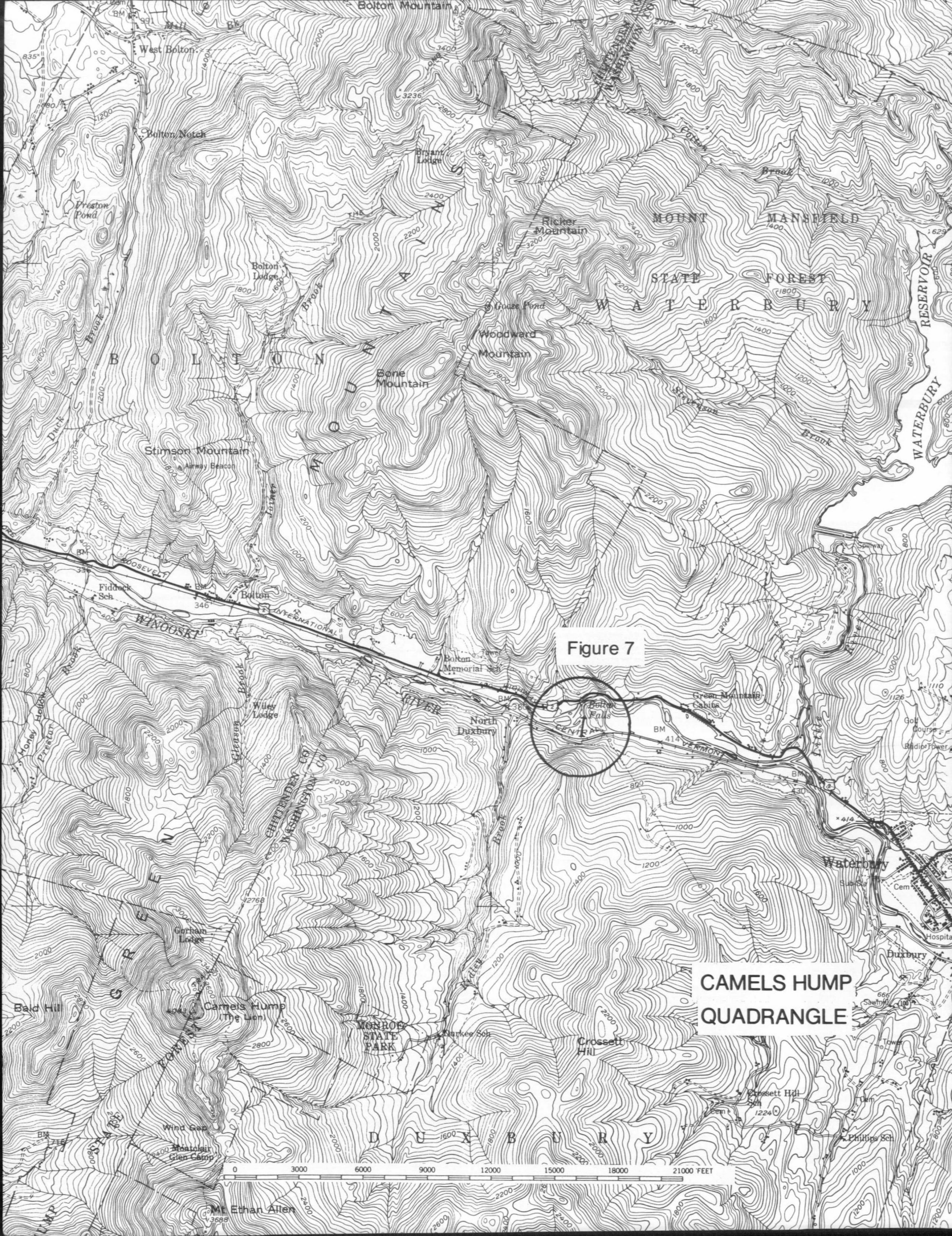


Figure 7
CAMELS HUMP
QUADRANGLE
Bolton Mountain
West Bolton
Bolton Notch
Preston Pond
Bryant Lodge
Ricker Mountain
MOUNT
MANSFIELD
STATE
FOREST
WATERBURY
RESERVOIR
Bolton Lodge
Gouge Pond
Woodward Mountain
Bone Mountain
BOLTON
MOUNTAINS
Stimson Mountain
Airway Beacon
Fiddlock Sch
Bolton
WINOOSKI
RIVER
Bolton Memorial Sch
Wiley Lodge
North Duxbury
Bolton Falls
Green Mountain Cabins
Golf Course
Radio Tower
Waterbury
Hospital
Duxbury
Gorham Lodge
Bald Hill
Camels Hump
(The Lion)
MONROE
STATE
PARK
Darkee Sch
Crossett Hill
Crossett Hill Sch
Phillips Sch
Wind Gap
Montclair Glen Camp
Mt Ethan Allen
DUXBURY
0 3000 6000 9000 12000 15000 18000 21000 FEET

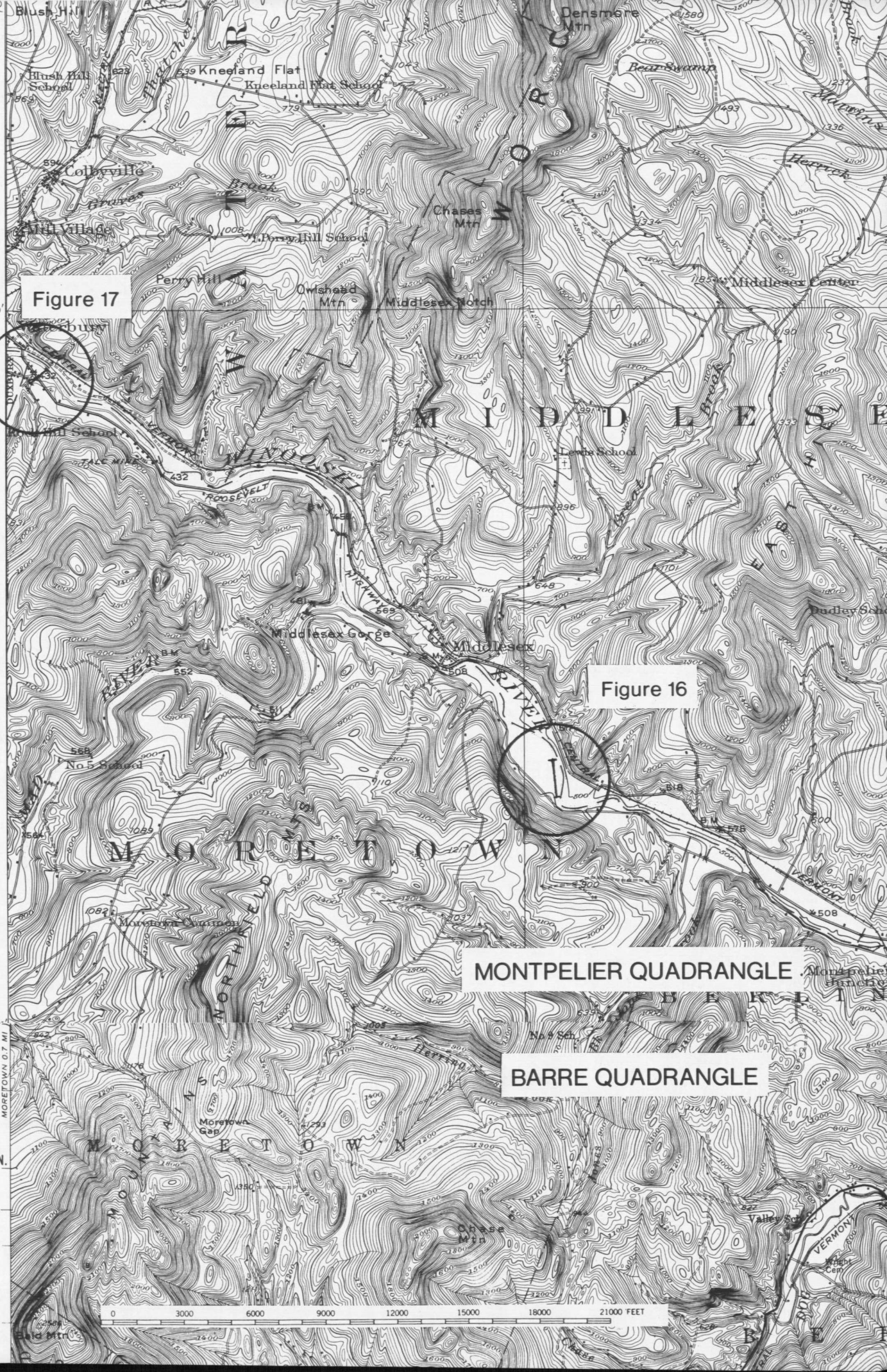


Figure 17
Figure 16
MONTPELIER QUADRANGLE
BARRE QUADRANGLE
Blush Hill
Blush Hill School
Kneeland Flat
Kneeland Flat School
Densmore Mtn
Bear Swamp
Colbyville
Mill Village
Perry Hill School
Perry Hill
Owlshead Mtn
Middlesex Notch
Chases Mtn
Middlesex Center
Waterbury
Rock Hill School
Lamb School
Middlesex Gorge
Middlesex
No 5 School
Moretown Gap
Chase Mtn
Bald Mtn
Valley Sch
0 3000 6000 9000 12000 15000 18000 21000 FEET

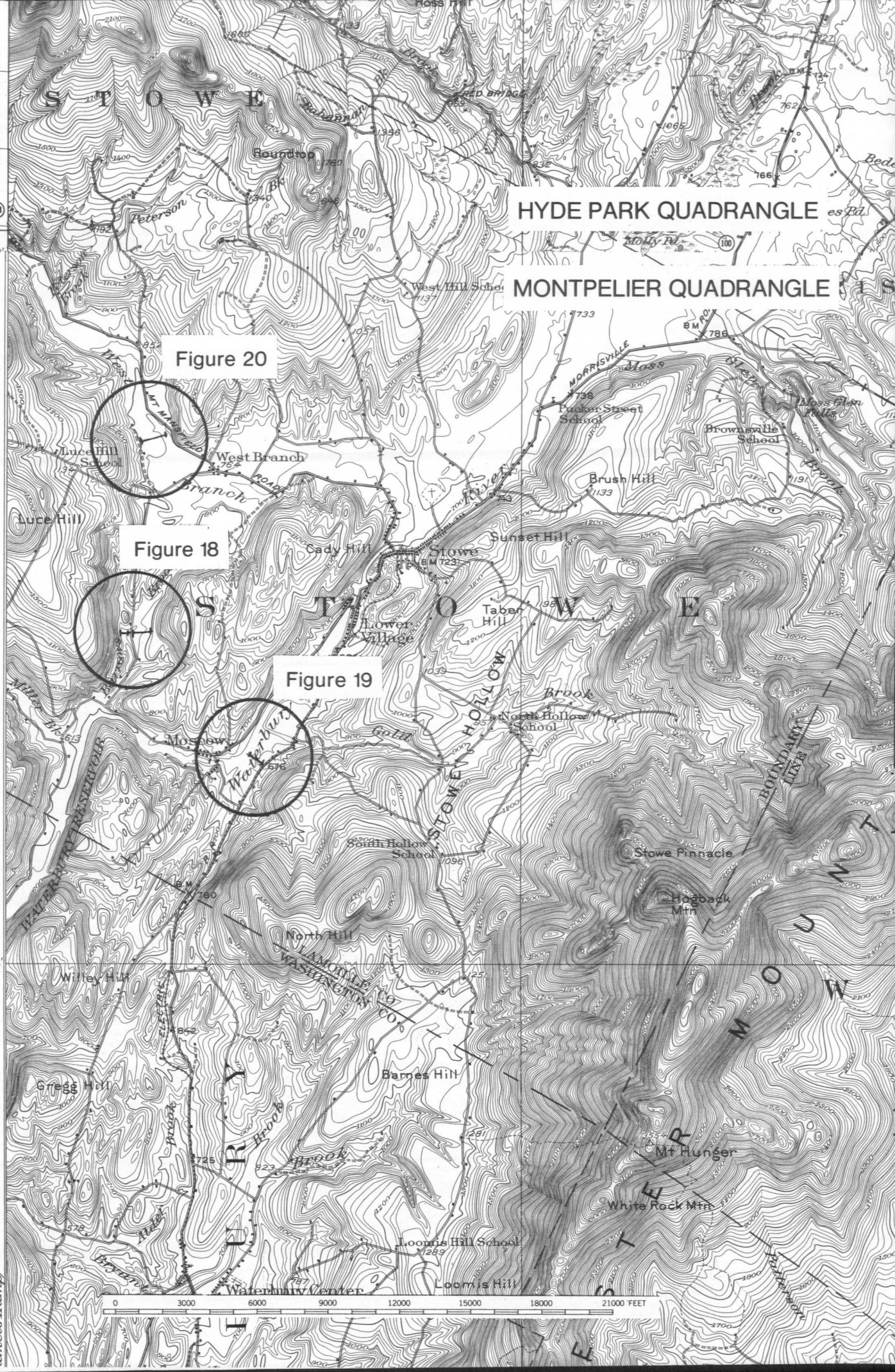

HYDE PARK QUADRANGLE
MONTPELIER QUADRANGLE
Figure 20
Figure 18
Figure 19
JEFFERSONVILLE 13 MI.
SMUGGLERS NOTCH 4.9 MI.
730000 FEET
STOWE
Roundtop
Peterson
Luce Hill School
West Branch
Luce Hill
Cady Hill
Stowe
Lower Village
Taber Hill
Sunset Hill
Brush Hill
Tucker Street School
Brownsville School
Moss Glen Falls
Moscow
Waterbury
North Hollow School
South Hollow School
Stowe Pinnacle
Hogback Mtn
North Hill
Willey Hill
Barnes Hill
Gregg Hill
Mt Hunger
White Rock Mtn
Loomis Hill School
Loomis Hill
Waterbury Center
WATERBURY RESERVOIR
STOWE HOLLOW
LAMOILLE CO
WASHINGTON CO
0 3000 6000 9000 12000 15000 18000 21000 FEET


Figure 15
BARRE QUADRANGLE
NORTHFIELD
ROXBURY
Northfield Falls
Northfield
South Northfield
East Roxbury
Roxbury
Camp Wihakowi
Teela-Wooket Camp
Drinkwater Hill
Baker Pond
Warner Pond
Fairgrounds
Harlow Bridge Sch
Dog River
Stony Brook
Fletcher Brook
Union Brook
Shaw Brook
Turkey Hill
Paine Mtn
Cram Hill
Roxbury Flat
ROXBURY STATE FOREST
(LINCOLN MOUNTAIN)
WARREN 6.4 MI.
10'
5'
0 3000 6000 9000 12000 15000 18000 21000 FEET

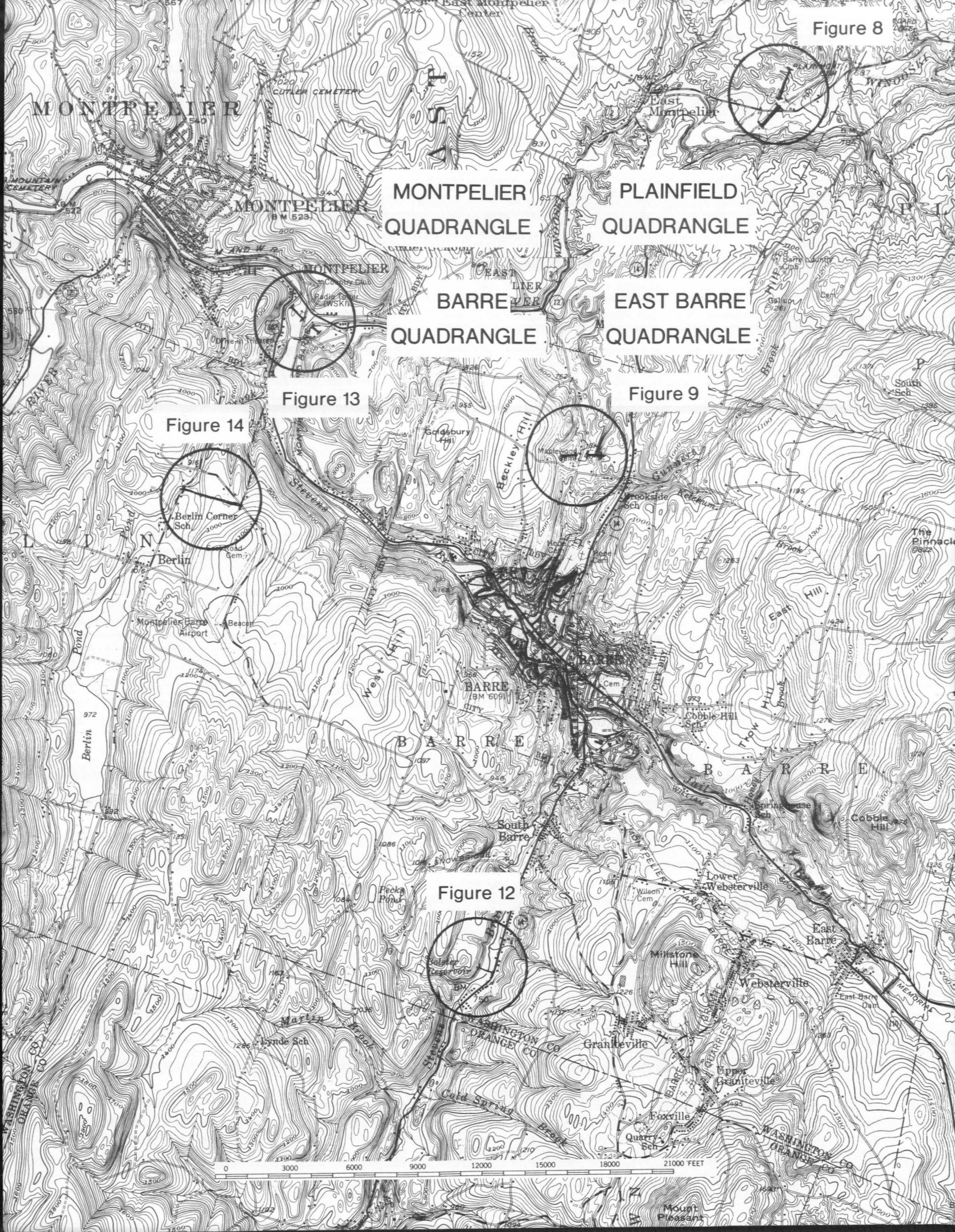


Figure 8
MONTPELIER QUADRANGLE
PLAINFIELD QUADRANGLE
BARRE QUADRANGLE
EAST BARRE QUADRANGLE
Figure 13
Figure 9
Figure 14
Figure 12
MONTPELIER
East Montpelier
Berlin
BARRE
South Barre
Graniteville
Upper Graniteville
Foxville
Lower Websterville
Websterville
East Barre
Cobble Hill
Berlin Corner Sch
Montpelier-Barre Airport
Beacon
Lynde Sch
Cobble Hill Sch
Brookside Sch
Goldsbury Hill
Beckley Hill
Milestone Hill
Wilson Cem
Quarry Sch
Mount Pleasant
WASHINGTON CO
ORANGE CO
0 3000 6000 9000 12000 15000 18000 21000 FEET

REFERENCES CITED

Cady, W.M., 1956, Bedrock geology of the Montpelier quadrangle, Vermont: U. S. Geol. Survey Geol. Quad. Map GQ 79.

Cannon, W. F., 1964, The petrology of tills in northern Vermont: Unpublished M. S. Thesis, Miami University, Oxford, Ohio.

Cartwright, K., and Sherman, F. B., 1969, Evaluating sanitary landfill sites in Illinois: Illinois Geol. Survey, Environmental Geology Notes No. 27, 15 pp.

Damboch, C. A., 1970, The search for environmental quality: Ohio Jour. Science, V. 70, pp. 199-201.

Fenneman, N. M., 1938, Physiography of the Eastern United States, McGraw Hill, New York, pp. 343-392.

Hackett, J. E., and McComas, M. R., 1969, Geology for planning in McHenry County: Illinois Geol. Survey, Circular 438, 29 pp.

Hodges, A. L., 1969, Drilling for water in New England: U. S. Geol. Survey (Reprint from Jour. New England Waterworks Assn.), 31 pp.

Hodges, A. L., and Butterfield, D., 1967, Ground water favorability map of the Winooski River Basin: Vermont Department of Water Resources.

Hughes, G. M., 1967, Selection of refuse disposal sites in northeastern Illinois: Illinois Geol. Survey, Environmental Geology Notes, No. 17, 18 pp.

King, P. B., 1959, The evolution of North America: Princeton Univ. Press, Princeton, N. J., pp. 41-75.

Konig, R. H., 1961, Geology of the Plainfield Quadrangle, Vermont: Vermont Geol. Survey, Bul. 16, 86 pp.

Murthy, V. R., 1957, Bedrock geology of the East Barre Quadrangle, Vermont: Vermont Geol. Survey, Bul. 12, 121 pp.

Sheaffer, J. R., and Zeizel, A. J., 1966, The water resources in northeastern Illinois: Planning its use: Northeastern Illinois Planning Commission, Chicago, Technical Report No. 4, 182 pp.

Stewart, D. P., and MacClintock, P., 1969, The surficial geology and Pleistocene history of Vermont: Vermont Geol. Survey, Bul. 31, 251 pp.

_____, 1970 Surficial Geologic Map of Vermont: C. G. Doll, Editor, Vermont Geol. Survey.

Vermont Department of Water Resources, Undated, Classification of the Upper Winooski River: Unpublished Staff Report.

_____, 1960, Stevens Branch drainage basin, Winooski watershed: Unpublished Staff Report.

_____, 1961, Middle Winooski River drainage basin: Unpublished Staff Report.

_____, 1969, Vermont laws relating to water resources, 115 pp.

REFERENCES FOR PLANNERS

Baldwin, H. L., and McGinness, C. L., 1963, A primer on ground water: U. S. Geol. Survey, Washington, D. C., 26 pp.

Bauer, A. M., 1965, Simultaneous excavation and rehabilitation of sand and gravel sites: National Sand and Gravel Assn., Silver Spring, Md., 60 pp.

Bleuer, N. K., 1970, Geologic considerations in planning solid-waste disposal sites in Indiana: Indiana Dept. Natural Resources, Geological Survey Special Report 5, 7 pp.

Cartwright, K., and Sherman, F. B., 1969, Evaluation of sanitary landfill sites in Illinois: Illinois Geol. Survey, Environmental Geology Notes No. 27, 15 pp.

Edwards, M. M., and Harrold, L. L., 1970, Agricultural pollution of water bodies: Ohio Jour. Science, V. 70, pp. 50-56.

Gambach, C. A., 1970, The search for environmental quality: Ohio Jour. Science, V. 70, pp. 199-201.

Gardner, W. I., et al. (editors), 1969, Colorado governor's conference on environmental geology: Colorado Geol. Survey, Special Publication No. 1, 78 pp.

Gross, D. L., 1970, Geology for planning in DeKalb County, Illinois: Illinois Geol. Survey, Environmental Geology Notes No. 33, 26 pp.

Hackett, J. E., and McComas, M. R., 1969, Geology for planning in McHenry County: Illinois Geol. Survey, Circular 438, 29 pp.

Hayes, W. C., and Vineyard, J. D., 1969, Environmental geology in town and country: Missouri Geol. Survey and Water Resources, Educational Series No. 9, 42 pp.

Hodges, A. L., Jr., 1969, Drilling for water in New England: U. S. Geol. Survey, Washington, D. C. (Reprint from Jour. New England Water Works Assn.), 31 pp.

Hodges, A. L., and Butterfield, D., 1967, Ground water favorability map of the Winooski River Basin, Vermont: Vermont Department of Water Resources.

Hughes, G. M., 1967, Selection of refuse disposal sites in northeastern Illinois: Illinois Geol. Survey, Environmental Geology Notes No. 17, 18 pp.

Johnson, C., 1966, Practical operating procedures for progressive rehabilitation of sand and gravel sites: National Sand and Gravel Assn., Silver Spring, Md., 75 pp.

Leopold, L. B., and Langbein, W. B., 1960, A primer on water: U. S. Geol. Survey, Washington, D. C., 50 pp.

Logan, J. A., Oppermann, P., and Tucker, N. E., 1962, Proceedings of the first conference on environmental engineering and metropolitan planning: Northwestern Univ. Press, Evanston, Ill., 265 pp.

McComas, M. R., 1968, Geology related to land use in the Hennepin Region: Illinois Geol. Survey, Circular 422, 22 pp.

Mazola, A. J., 1970, Geology for environmental planning in Monroe County, Michigan: Michigan Dept. Natural Resources, Geol. Survey Div., Report of Investigation No. 13, 34 pp.

Sheaffer, J. R., 1970, Reviving the Great Lakes: Saturday Review, Nov. 1970, pp. 62-65.

Sheaffer, J. R., von Boehm, B., and Hackett, J. E., 1963, Refuse disposal needs and practices in northeastern Illinois: Northeastern Illinois Planning Commission, Chicago, Technical Report No. 3, 72 pp.

Sheaffer, J. R., and Zeizel, A. J., 1966, The water resources of northeastern Illinois: planning its use: Northeastern Illinois Planning Commission, Chicago, Technical Report No. 4, 182 pp.

Swenson, H. A., and Baldwin, H. L., 1965, A primer of water quality: U. S. Geological Survey, Washington, D. C., 27 pp.

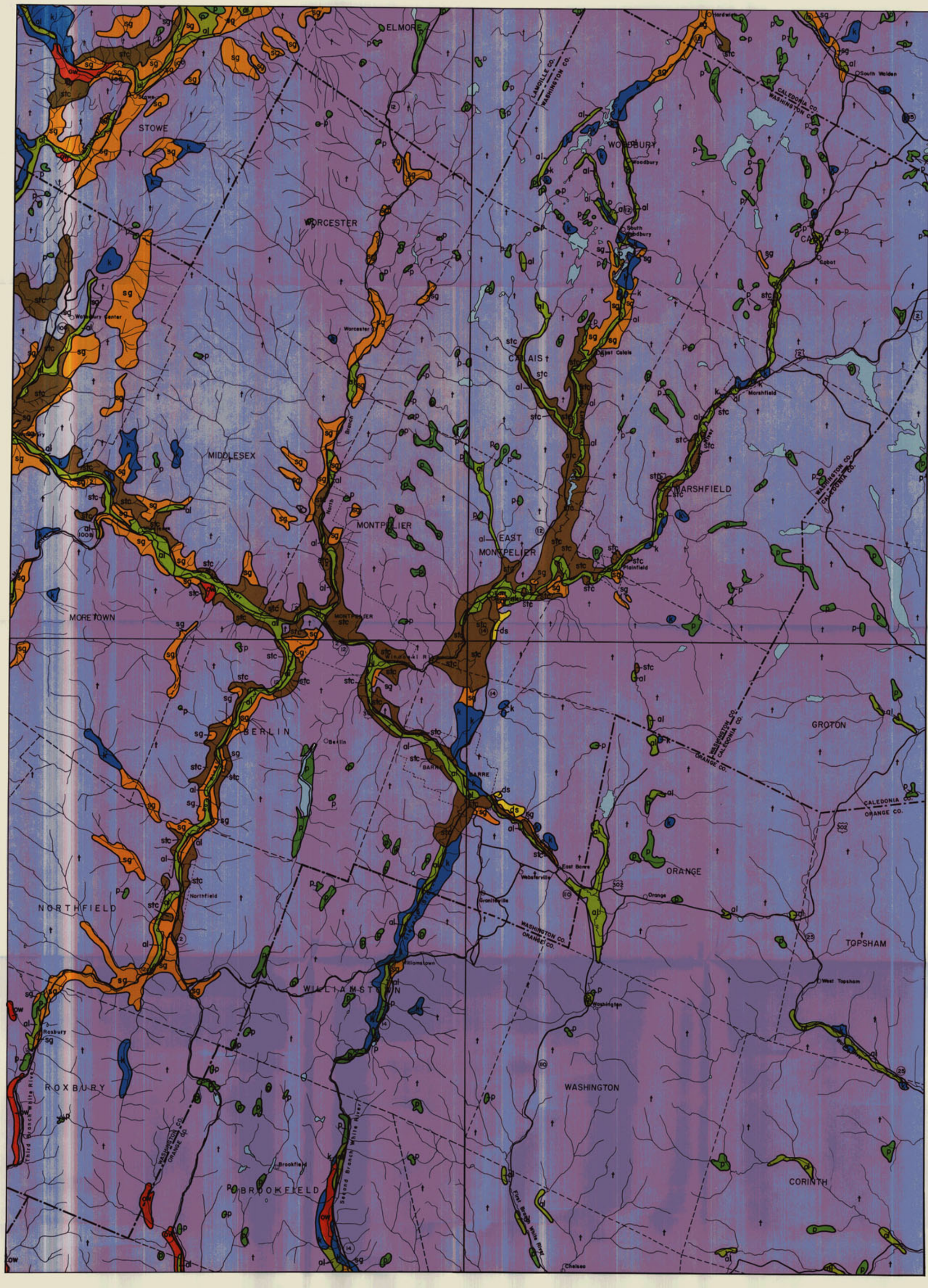
Taft Sanitary Engineering Center, 1961, Ground water contamination: Symposium proceedings, Technical Report W61-5, U. S. Department of Health, Education and Welfare, Cincinnati, 218 pp.

U. S. Public Health Service, 1967, Manual of septic-tank practices: U. S. Department of Health, Education and Welfare, Public Health Service Publication No. 526, Washington, D. C.

Verduim, J., 1969, Man's influence on Lake Erie: Ohio Jour. Science, V. 70, pp. 65-70.

Wilson, G. V., Joiner, T. J., and Warmon, J. C., 1970, Evaluation, by test drilling, of geophysical methods used for ground water development in the Piedmont area, Alabama: Geol. Survey of Alabama, Circular 65, 15 pp.

SURFICIAL MATERIALS IN THE BARRE-MONTPELIER REGION



LEGEND

t

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

k

Ice Contact Gravel, mostly kame terraces - good gravel source, well drained above water table. High water potential below water table.

ow

Outwash and Fluvial Gravel - in stream valleys, well drained. Fair to good water potential.

sg

Lacustrine Sands and Gravels - predominantly sands and pebbly sand, good source for sand, good drainage above water table. Moderate to high water potential below water table.

stc

Lacustrine Clays and Silts - poorly drained, medium to high plasticity. Low water potential.

p

Peat and Muck - swampy, poorly drained areas.

al

Recent Stream Alluvium - thin covering valley floor, poor foundation material. Fair to moderately well drained.

ds

Dune Sand

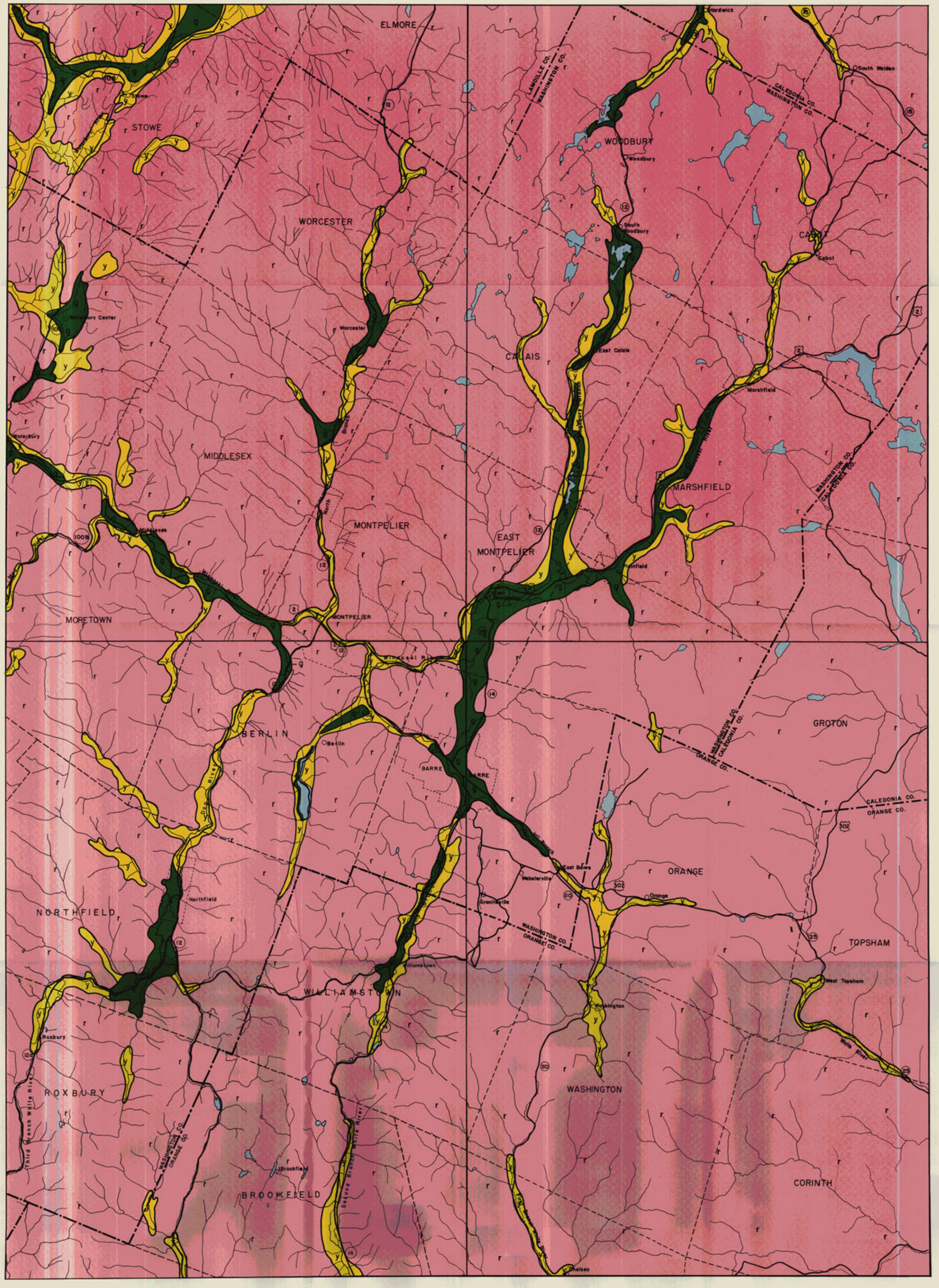
scale 1/62500

1 1/2 0 1 2

miles

true north

GROUND WATER POTENTIAL IN THE BARRE-MONTPELIER REGION



LEGEND

g

Areas of good ground water potential. Water probably available in gravel and sand. Yield medium to high at depths to 200 feet.

y

Areas of moderate ground water potential. Water available from gravels in stream valley or from bedrock below the valley fill. Yield low to medium at depths to 300 feet.

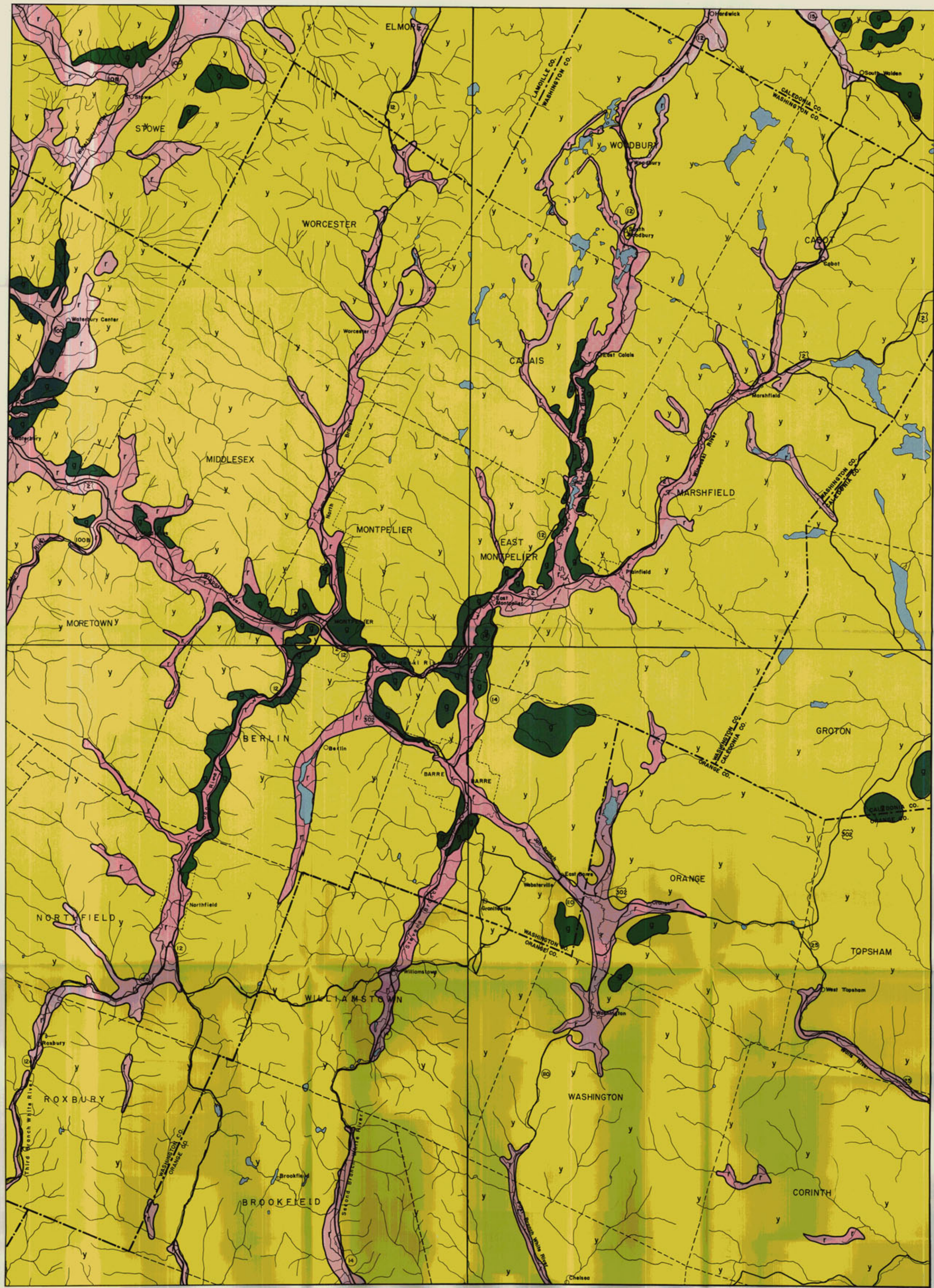
r

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

1 1/2 0 1 2
miles

true north

SOLID WASTE AND SEWAGE DISPOSAL CONDITION IN THE BARRE-MONTPELIER REGION



LEGEND

g

Areas of impermeable tills, silts, and clays generally over 25 feet thick. Suitable for solid waste, land fill, septic tanks with caution, and sewage disposal sites.

y

Areas of thin till over bedrock. Solid waste land fill only where till is over 30 feet thick. Septic tanks with at least 200 foot leaching field where till is over 10 feet thick. Contamination of ground water from barns, sewage systems, land fill, etc. in areas of bedrock and thin cover.

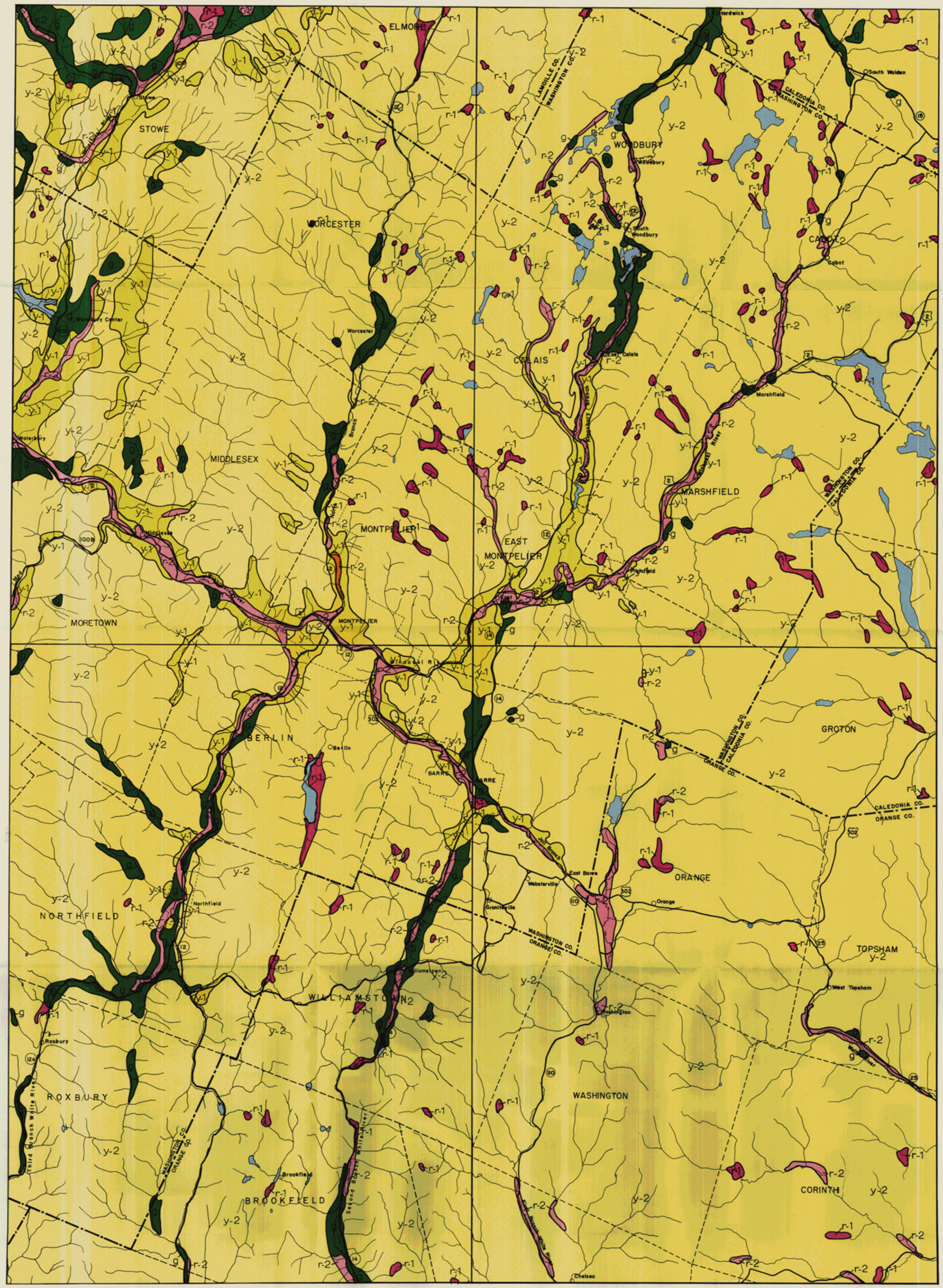
r

Areas of sand and gravel, medium to high permeability and medium to high ground water potential. Unsuitable for solid waste and sewage disposal.

1 1/2 0 1 2
miles

true north

GENERAL CONSTRUCTION CONDITIONS IN THE BARRE-MONTPELIER REGION



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 bedrock. 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.

1 1/2 0 1 2
miles

true north

SAND AND GRAVEL IN THE BARRE-MONTPELIER REGION

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.

sc

Sand deposits. Medium to high quality. Over one-half of original reserve depleted.

sd

Sand deposits of unknown quality and reserve.

1 1/2 0 1 2
miles

true north