HYDROGEOLOGY OF THE BENNINGTON AND SHAFTSBURY AREA, VERMONT

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HYDROGEOLOGY OF THE BENNINGTON AND SHAFTSBURY AREA, VERMONT

by
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This thesis is dedicated to

the memory of Mr. Joseph DeSimone,

father of Mr. David DeSimone, my thesis

advisor and friend.

Going for Water

The well was dry beside the door,
And so we went with pail and can
Across the field behind the house
To seek the brook if it still ran;

Not loth to have excuse to go,
Because the autumn eve was fair
(Though chill), because the fields were ours
And by the brrok our woods were there.

We ran as if to meet the moon
That slowly dawned behind the trees,
The barren boughs without the leaves,
Without the birds, without the breeze.

But once within the wood, we paused
Like gnomes that hid us from the moon,
Ready to run to hiding new
With laughter when she found us soon.

Each laid on other a staying hand
To listen ere we dared to look,
And in the hush we joined to make
We heard, we knew we heard the brook.

A note as from a single place,
A slender tinkling fall that made
Now drops that floated on the pool
Like pearls, and now a silver blade.

Robert Frost
1913

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ABSTRACT

A hydrogeologic study was completed for the Towns of Bennington and Shaftsbury, Vermont. Surficial mapping information, aerial photographic interpretation and 317 well-logs were analyzed in order to identify and delineate aquifer systems and potential aquifer recharge areas. The stratigraphic relationships and thickness of overburden consisting of Pleistocene glacial sediments and Holocene alluvium were examined and features of the buried bedrock paleosurface were identified. The piezometric surface and a groundwater flow net were mapped so that groundwater flow paths might be understood. A graded aquifer recharge potential map was produced based on consideration of the compiled information.

Three distinct aquifer systems exist in the study area, unconfined sand and gravel aquifers, confined sand and gravel aquifers, and bedrock aquifers. Approximately 73 percent of the wells in the study area tap water resources in bedrock fracture systems. Due to carbonate dissolution, the aquifer system is best developed in carbonate rock, and less developed in quartzite, granite/gneiss, and phylllite/ schist lithologies. Bedrock wells providing adequate yields range in depth from 100 to 300 feet, but they may be deeper in carbonate units. Recharge enters this system at elevations above 1,200 feet where till deposits are thin and scattered and bedrock fracture systems are exposed precipitation.

A second aquifer system exists in sand and gravel confined beneath a

thick layer of till. These deposits are continuous in the deepest portions of the bedrock paleo-valleys, but may be locally discontinuous. Well yield from these deposits ranges from 5 to 100 gallons per minute. Well-log data suggest that these deposits are recharged by the bedrock fracture systems. The recharge zones for the confined sand and gravel aquifer are the same zones designated for the bedrock aquifer system.

About 3.5 percent of the study wells produce water from unconfined sand and gravel deposits of Pleistocene and Holocene age. Yield in these wells ranges from 5 to 60 gallons per minute. Recharge enters this aquifer system in the form of direct precipitation. The unconfined nature of this aquifer system renders it particularly susceptible to contamination.

Recommendations for the protection of groundwater resources in Bennington and Shaftsbury are presented: (1) protect aquifer recharge areas; (2) require rigorous design of leaching fields; (3) restrict underground storage of hazardous materials; (4) discourage use of fertilizers, herbicides and pesticides; (5) decrease the use of potentially hazardous roadway deicers; (6) monitor and test water-quality for contaminants; (7) educate and inform.

ACKNOWLEDGEMENTS

This project originated in the fall of 1989 with the cooperation of the Vermont State Agency of Environmental Conservation (Memorandum of Agreement #NR-0030). Beginning in September of 1989, I was sub-contracted to work as a field assistant on the project for David DeSimone of Williams College.

This project would not have been possible without the help and resources of the Vermont Agency of Environmental Conservation. In particular, a special thanks goes out to Charles Ratte, Jim Ashley and Tammy Leno.

Here at Williams, my first thanks must go to David DeSimone. More than just a thesis advisor, David was a friend, knowing just when to back off a little, and knowing when to push, especially when it came to getting those cross-sections done. I thank him for all his suggestions, guidance, editing, but most of all for all the laughs in that window-less dungeon of an office in Bronfman.

A special must also go to Professor David Dethier for all his help and suggestions. The thought-provoking, and sometimes unanswerable, questions that he frequently threw in my direction have helped to develop and refine the ideas presented here. I also thank him for his editing prowess and help in locating references.

I would be amiss in not thanking Professors Wobus, Fox, Johnson and Karabinos who also helped with finding references, providing insight, and just generally being there to answer one of my eighty-thousand questions.

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INTRODUCTION

The purpose of this project is to study the hydrogeology of the Bennington and Shaftsbury, Vermont area. Hydrogeologic data were analyzed with the intent of identifying and delineating aquifers, aquifer recharge areas, and the piezometric surface. In the course of the project, I have also examined the buried bedrock topography and the thickness and stratigraphy of unconsolidated overburden. It is my hope that the findings presented here will be useful for locating adequate and accessible groundwater resources, and for protecting these resources. Many municipalities in Vermont, including Bennington and Shaftsbury, are experiencing residential expansion in the second home/vacation home sector. As development proceeds, it is crucial that these communities have access to clean water resources. At the same time, identification of these groundwater resources could attract future commercial development to the region.

Information for the project was obtained from well-logs provided by the Vermont State Geological Survey (Agency of Environmental Conservation, open files). Of the 625 well-logs from the towns of Bennington and Shaftsbury, 317 could be located in the study area with some degree of accuracy. Many of the remaining wells were located outside the study area, but nonetheless within town boundaries. The logs contain information about the unconsolidated surficial sediment deposits, the thickness of the various deposits, the total depth to bedrock, water level, and yield test information. Of the 317 located wells, 290 reached to a buried bedrock surface; for 45 of the wells reaching bedrock, subsurface lithologies were not specified.

Table 1
Summary of well-log interpretations

Interpretation	Well-log entry
Till	hardpan; hardpack; hardpan with sand, gravel, packed gravel, clay and/or boulders; clay with sand, gravel, boulders and/or hardpan; conglomerate with hardpan, sand, clay, and/or boulders
Weathered Carbonate	decomposed lime; red clay over limestone or marble; red ochre; yellow ochre; ochre; rotten marble; bad lime rock; lime-"had to be cased"; broken lime stone with red, rotten seams; deteriorated marble; red-orange clay

The primary difficulties encountered over the course of the project related to the well-log data. Most serious is the low density of wells in several regions of the study area. In these low-density areas, the contouring of data was difficult and therefore less accurate. Housing developments of the last ten to twenty years have provided some additional coverage. Low well-density is still a problem in the following areas: Bennington proper and the adjacent area to the east; the southern end of the Furnace Brook valley; the North Bennington/ Lake Paran area, from the Walloomsac River north to South Shaftsbury; and the Trumbull Mountain area in the northeast corner of the study area.

Interpretation of the well-logs was an additional difficulty. Not only are many well-logs incomplete, but the well drillers are often insufficiently trained in geology (Appendix A, well-log: S201). To the geologist, the language of the well driller can be foreign, disconcerting, or down-right frustrating. I would like to review my interpretations of well-log entries for the purpose of clarification. Table 1 presents various terms used by the well drillers which I have interpreted as till and terms which I have inferred to mean weathered carbonate bedrock.

All data appear in the Appendex and plates included at the back of this volume. Appendix A is a listing of characteristic and/or interesting well-logs. Where well-log data may be important for demonstrating notable features of the subsurface geology, these logs are cited in the text. The seven folded plates at the back of the volume are drawn at a scale of 1:24,000 and have been reproduced on vellum paper to enable the interested reader to view overlayed combinations of desired data on a light table. These maps are the primary products generated for the study and, it is hoped, will provide a useful data set for the Bennington and Shaftsbury area.

Figure 1 Study area base map

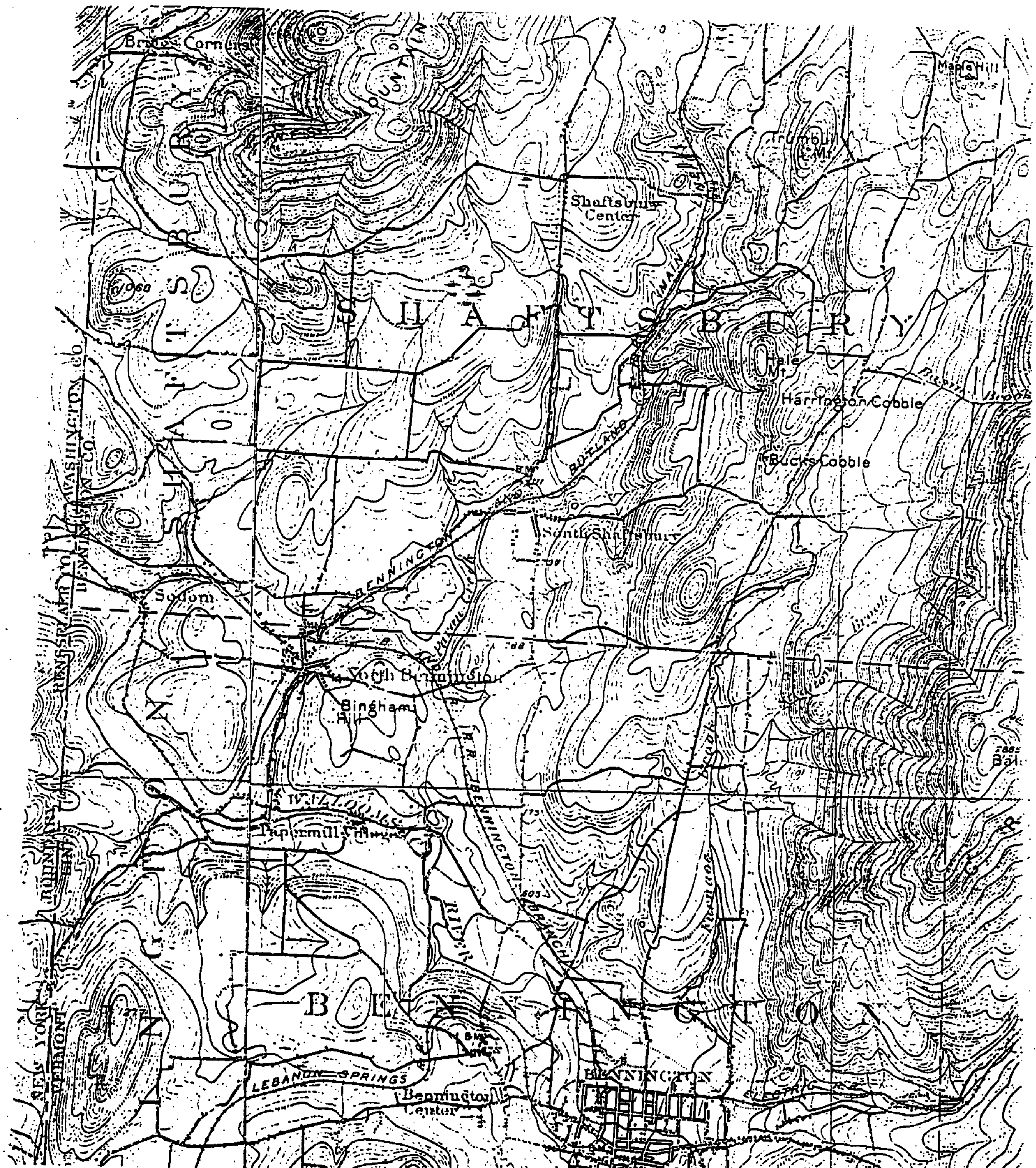
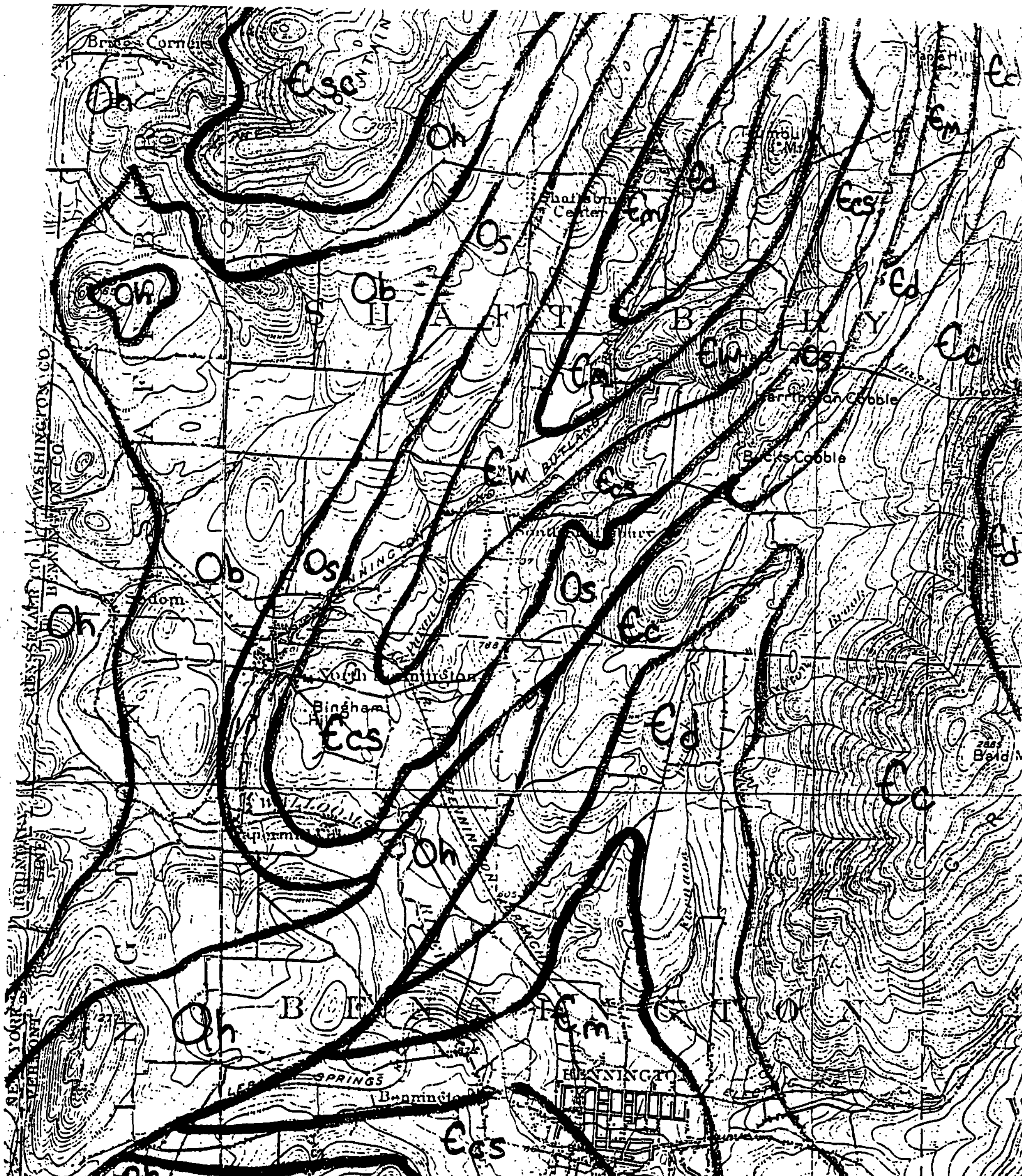


Figure 2 Bedrock geology of Bennington and Shaftsbury (after MacFadyen, 1956; Doll et al., 1961)



Oh Hortonville Slate and Phyllite
Ob Bascom Limestone
Os Shelburne Limestone
Ɛcs Clarendon Springs Dolomite
Ɛw Winooski Dolomite
Ɛm Monkton Quartzite
Ɛd Dunham Dolomite
Ɛc Cheshire Quartzite
Ɛsc Saint Catherine Slate and Phyllite
Ɛdt Dalton Quartzite

GEOLOGIC AND PHYSIOGRAPHIC SETTING

The study area includes portions of the towns of Bennington and Shaftsbury, Vermont. It includes all of the area covered by the Bennington Quadrangle (USGS, 1:24,000 series, 1954), as well as the eastern third of the Hoosick Falls, New York-Vermont Quadrangle (USGS, 1:24,000 series, 1943, photorevised 1980) to the Vermont-New York border (Figure 1).

The area can be divided into three physiographic regions, the Taconic Highlands to the west, the uplands of the Green Mountains to the east, and the central Vermont Valley. Figure 2 displays the extent of the various bedrock lithologies in the study area. The Taconic Highlands are underlain by metamorphosed Cambrian and Ordovician sedimentary rocks: the Lower Cambrian Saint Catherine Formation slate and phyllite and Middle Ordovician Hortonville Formation slate and phyllite. The resistant rocks of the Green Mountains are Precambrian and Lower Cambrian in age: the Precambrian Mount Holly Complex gneiss, the Cambrian Dalton Formation quartzite, and the Cambrian Cheshire Quartzite. The low-elevation Vermont Valley is underlain by comparatively weaker Cambrian and Ordovician meta-sedimentary rocks: the Lower Cambrian Dunham Dolomite, the Lower Cambrian Monkton Quartzite, the Lower to Middle Cambrian Winooski Dolomite, the Upper Cambrian Clarendon Springs Dolomite, the Lower Ordovician Shelburne Formation marble and limestone, the Lower Ordovician Bascom Formation limestone and the Middle Ordovician Hortonville Formation slate and phyllite. The more resistant Lower Cambrian Cheshire Quartzite and Lower Cambrian Monkton Quartzite form the topographic highpoints of Maple Hill, Trumbull Mountain, Hale Mountain, and other unnamed hills to the south. Bucks Cobble and Harrrington Cobble are underlain by the Lower Ordovician Shelburne Formation marble and limestone. (MacFadyen, 1956, Plate I; Doll et al., 1961). These rocks were extensively deformed during the late-Ordovician Taconian Orogeny (peak, 460 Ma) and the mid-Devonian Acadian Orogeny (peak, 380 Ma) (Ratcliffe et al., 1988). Metamorphosed Taconic lithologies were thrust-emplaced over the unmetamorphosed Vermont Valley carbonates during the Taconian Orogeny.

During the Pleistocene Epoch, the region was buried many times by advances of an ice sheet of continental proportions. The most recent glaciation commenced during the late Wisconsinan when the Hudson-Champlain Lobe of the Laurentide Ice Sheet advanced over the region. The ice cover was at a maximum by 21,000 years ago (21 Ka)(Cotter et al, 1986; Sirkin, 1986). Sometime before 18Ka, the ice began to thin and the margin began to retreat (Cotter et al., 1986; Sirkin, 1986). By 14.5 Ka, the study area was probably free of glacial ice (DeSimone and LaFleur, 1986). These dates may need correction as a result of recent developments with the C14 dating method (Bard et al., 1990).

Latest Pleistocene and Holocene rivers and streams have reworked the glaciated topography, eroding and depositing sediment, to create the modern landscape.

Approximately 40 square miles of the valley are covered by glacial sediments. Till deposits on the mountain slopes are scattered and thin. The valley proper is filled by a thick till blanket, large recessional valley moraines and outwash. The thickness of these deposits may reach up to 300 feet (Appendix A. well-log: S118).

The Walloomsac River provides the major drainage as it flows from east to west across the southern end of the study area. The Roaring Branch emerges from a deep gorge cut across the structure of the Green Mountains east of Bennington proper (Figure 1). North of the center of the city of Bennington, the Roaring Branch joins the Walloomsac River and continues westward through the Taconic Mountains to join with the Hoosic River near Hoosick Junction, New York. Two tributary streams flow southward, draining the Vermont Valley and merge with the Walloomsac. Furnace Brook flows from the uplands east of Shaftsbury Center near Maple Hill and follows the Green Mountain front until it meets the Wallomsac northwest of Bennington. Paran Creek drains a marshy area north of Shaftsbury Center and has incised a deeper valley than Furnace Brook. It flows into Lake Paran, whose level is artificially controlled, before joining with the Walloomsac near Bennington College. Third-order streams generally trend northeast-southwest before merging with the Walloomsac River, Furnace Brook or Paran Creek.

The local relief of the study area is 2,350 feet. The highest elevations are to the east in the Green Mountain National Forest; Bald Mountain, northeast of Bennington, is the highest point in the study area at 2,857 feet above sea level. The lowest elevations are in the southern portion of the study area along the Walloomsac River; the lowest elevation of the Walloomsac River floodplain is near White Creek Station at less than 510 feet above sea level.

Mean annual precipitation data for the study area were available (Tompkins et al., 1964); estimates of evapotranspiration and runoff were derived from nearby areas with comparable precipitation values (Table 2).

Table 2
Estimated hydrologic budget for two elevations in the Southern Vermont area

	Elevation	Precipitation *1	Evapotranspiration *2	Water for runoff or aquifer recharge
Valley	800 feet	40 inches	20 inches	20 inches
Mountain	2000 feet	50 inches	15 inches	35 inches

*1 From Tompkins et al. (1964)

*2 Estimated by difference using precipitation data of Tompkins et al. (1964) and gauging records of the United States Geological Survey for the Green River in Williamstown (Wandle, 1984) (In Dethier et al., 1989)

Note: Precipitation data for the Bennington/Shaftsbury area were available. Evapotranspiration data are for Williamstown, Massachusetts.

HISTORICAL REVIEW

The earliest reference to glaciation of the Bennington area dates from 1861. Edward Hitchcock et al. (1861) noted that glacial drift in the Green Mountains had apparently moved in a southeasterly direction. This conclusion was based on displacements of erratics derived from Cheshire Quartzite and Stamford Gneiss southeasterly from outcrops.

Studies by Frank Taylor (1903, 1916) described the moraines that occupy the southern terminus of the Vermont Valley, attempted to correlate moraines from valley to valley, and established a deglaciation history for the region. His later work described the deposits of glacial Lake Bascom in the Hoosic River valley and correlated these deposits to a deglaciation history.

The findings of Frederick Burt (1928) suggested that glacial erosion in the Vermont Valley was minimal. Burt examined thirteen kaolin deposits in the Bennington/Pownal area which were found at scattered sites along the Green Mountain Front over a north-south distance of 95 miles from Monkton, Vermont, to below the Vermont-Massachusetts border. Burt showed that these kaolins formed by the weathering of Precambrian gneisses and feldspathic or argillaceous quartzites. After reviewing paleobotanical evidence, Burt concluded that the kaolin deposits are of Miocene age, and that their preservation is due to burial by glacial drift as a consequence of ice stagnation in the valley.

John A. MacFadyen (1956) studied the bedrock geology of the Bennington area. He summarized the important rock units which underlie the Green Mountains, the Taconics, and the Vermont Valley but argued against the notion of Taconic thrust faults which are now generally accepted. For surficial lithologies, however, his mapping is consistent with information obtained from well-logs and surficial exposures.

William Shilts (1966, open file report and map) mapped and interpreted the Pleistocene geology of the Bennington 15-minute quadrangle at the reconnaissance level. Shilts identified two recessional valley moraines which he named the Harwood Hill Moraine and the Hale Mountain Moraine. He mapped extensive ice-contact sediments as well as a valley outwash train which extends south from Shaftsbury Center to Lake Paran. He proposed the existence of an ice-marginal lake, Lake Shaftsbury, at an elevation of 900 feet. Detailed surficial mapping presently in progress contradicts this conclusion and indicates that this 900 foot lake was an arm of Lake Bascom (DeSimone, 1991). Shilts recognized the great thickness of glacial drift in the study area and ascribed these materials primarily to glaciofluvial or glaciolacustrine origins.

Stewart (1961) and Stewart and MacClintock (1969) incorporated Shilts' data in their statewide syntheses of the Pleistocene history of Vermont. More recently, ice margins in the study area have been incorporated into a revised regional synthesis of deglaciation history (DeSimone and LaFleur, 1985, 1986).

Detailed surficial and hydrologic mapping projects have been completed for much of the adjacent region. These include studies of the Town of Williamstown, Massachusetts (Dethier, DeSimone, Oelkers, 1989), the Pownal and North Pownal, Vermont area (DeSimone and Dethier, 1991, in press), the Town of New Lebanon, New York (LaFleur and DeSimone, 1990), and the Town of Stephentown, New York (DeSimone, 1989).

AN INTRODUCTION TO GROUNDWATER HYDROLOGY

Water beneath the land surface is referred to as underground water and occurs in two different zones. The unsaturated zone occurs immediately below the surface and contains both water and air. Below the unsaturated zone is the saturated zone in which all interconnected openings are filled with water.

Water in the saturated zone is the only water to which the term groundwater can properly be applied. This water is available to supply wells and springs. Recharge of the saturated zone occurs by the downward percolation of water from the unsaturated zone. The upper limit of the saturated zone is called the water table. The water table is located where downward barometric pressure counterbalances upward hydraulic pressure. The position of the water table is not stationary but fluctuates up and down periodically and seasonally. The water table rises when the downward percolation of water from the unsaturated zone increases. It may fall during periods of drought.

An aquifer is any geologic unit that will yield water in usable quantities to a well or spring. Such units may be composed of unconsolidated sediments or may be consolidated bedrock.

Consolidated rocks, commonly referred to as bedrock, are composed of mineral grains of varying size and shape that have been welded together by heat, pressure or chemical reactions. There are different types of voids within these rocks. Voids that were formed at the same time as the rock are called primary openings. If voids were created after the rocks were formed, they are referred to as secondary openings. Solutional cavities in carbonate rocks and fractures in granite or quartzite are important water-bearing secondary fractures.

Unconsolidated sediments consist of material derived from the disintegration of rocks. Unconsolidated material is often comprised of particles of rocks or minerals of many sizes. In order of increasing grain size, the important unconsolidated deposits are clay, silt, sand, and gravel.

The capability of a geologic unit to store and transmit water is a function of the porosity and permeablilty of the material. The porosity of a water-bearing unit is the percentage of volume that consists of pores or openings. Porosity is an index of how much water the unit can hold, but not necessarily how much water the material will yield. When water drains from an initially saturated material, only a portion of the stored water is released. The amount that is released by gravity is called the specific yield. The remaining water is held against the force of gravity by molecular attractions and capillary action. The quantity of water that is retained in the pore spaces is called the specific retention. Surprisingly, size of the individual particles has little effect on porosity; silt and clay may be just as porous as sand and gravel. More important to porosity are the shape and arrangement of particles, the degree of compaction of the sediment, the degree of sorting, the extent of interstitial cementation of grains, and the amount of material that has been removed by percolating water.

Permeability is the water-transmitting potential a geologic unit. In general, sediment composed of fine material will have lower permeability than coarse sediment. However, the sorting of a material will also have a significant effect on permeability. A well-sorted sediment has a high degree of uniformity in grain size; a poorly-sorted sediment displays a range of grain sizes. In a well-sorted sediment, there is generally a significant amount of connected pore space, so permeability is high; in a poorly-sorted sediment, the pore spaces between the larger grains are filled with smaller grains, so that porosity and permeability are reduced. In most cases, porosity and permeability are best measured directly in a laboratory.

Movement of water through the material will occur whenever there is a difference in hydraulic head between two points. The velocity at which this movement will occur is found by Darcy's Law,

$$V=K(h1-h2)/l$$

where V is velocity, (h1-h2) is the difference is hydraulic head, l is the distance along the flow path, and K is hydraulic conductivity. Hydraulic conductivity is expressed in the same units as velocity, distance per time unit, such as feet per day or meters per day. However, the factors involved in hydraulic conductivity include the volume of water that will move in a unit of time under a specific hydraulic gradient through a unit area. Hydraulic conductivity values range through 12 orders of magnitude. Coarse sediments have higher hydraulic conductivity values than fine sediments; in addition, hydraulic conductivty is higher in well-sorted materials.

In some aquifers groundwater occurs under water table conditions. The upper level of the aquifer is then defined by the water table. This type of aquifer is referred to as an unconfined aquifer. In a well drilled into an unconfined aquifer, the static water level in the well will stand at the same elevation as the water table. Gravity is the dominant force driving groundwater flow in unconfined aquifers. Groundwater will generally move downward under natural conditions. In the shallowest portions of the saturated zone, water will move from high, interstream elevations towards lower-lying streams, springs, lakes or coastlines. The shape of the water table, then, relates to the shape of the land surface but is not as severe.

The saturated zone may include both permeable and impermeable layers of unconsolidated or consolidated materials. The permeable layers will function as aquifers. Where an aquifer is positioned between impermeable layers, the aquifer and the water it contains are said to be confined. This water is not exposed to atmospheric pressure.

Groundwater in a confined aquifer is said to exist under artesian conditions. When a well is drilled into a confined aquifer, the static water level will rise to a point above the top of the aquifer. This water level represents the artesian pressure of the system and is referred to as hydraulic head. An imaginary surface representing the hydraulic head throughout the confined aquifer is called the equipotential or piezometric surface. A line connecting points of equal pressure is called an equipotential line.

In a confined aquifer, groundwater will flow from areas of high equipotential to areas of low equipotential. The direction of groundwater flow in the subsurface will be perpendicular to the equipotential lines, that is in the direction of maximum potential gradient. Similar to the water table, the piezometric surface slopes from areas of recharge to areas of discharge. A flow net depicts the direction of groundwater flow in relation to the equipotential lines.

WELL LOCATIONS AND CROSS-SECTION TRANSECTS

At the outset of the project, the first task was to locate as many wells as possible in the study area. The Well Locations and Cross-Section Transects Map is the product of these initial efforts (Plate I). Relying upon base maps provided by Vermont State Geological Survey, well locations were plotted on an overlay of the USGS 7.5-Minute Series Quadrangle Maps of Bennington, Vermont and Hoosick Falls, New York-Vermont. The locations of these wells were verified in the field wherever possible. Time constraints and the nature of the data prevented verification for all well locations. Incomplete, confusing and sometimes incorrect location maps furnished by the Vermont Agency of Natural Resources complicated the procedure. Where uncertainty exists as to the location of a well, it is indicated on the map by a triangular symbol. Field verified wells are indicated by a circle.

The key for of Plate I contains a list of all wells and corresponding data. Well numbers preceeded by a "B" are located within the town of Bennington; those preceeded by an "S" are within the town of Shaftsbury. Elevations of the bedrock surface, piezometric surface and top of well are in feet above sea-level. Well yield from drilling reports is in gallons per minute. Under the piezometric surface column, the designation "^" indicates that water is flowing at the surface. On the map, a well completed in bedrock is indicated by a solid symbol, whereas wells ending in unconsolidated sediments are designated by an open, rimmed symbol.

The locations of cross-section transects also appear on Plate I. These locations were chosen for several reasons. To depict the stratigraphic relationships of the various glacial facies, well-log data must be available across the entire section. It is also important that the transects represent various parts of the valley. In this way, it is possible to examine changes in valley shape from north to south as well as east to west. Finally, the transects must cover all regions of the study area to obtain a complete understanding of glacial stratigraphy. The cross-sections appear on Plate III.

BEDROCK SURFACE ELEVATION MAP

Underlying the Bennington and Shaftsbury area is a bedrock paleo-surface buried beneath Pleistocene glacial sediments and Holocene alluvial sediments. Bedrock is at or near the surface in the topographic highlands. Till on these slopes is scattered and generally less than 10 feet thick. At elevations below 1200 feet, the bedrock surface is covered by a thick till blanket, large valley moraines and outwash sediments.

Plate II, the Bedrock Surface Elevation Map, shows the bedrock paleo-surface. This map was created from well-log data and surficial exposures of bedrock. Elevation of the bedrock surface at a given well was computed by subtracting the depth to bedrock listed in the well-logs from the estimated elevation at the top of the well obtained from USGS 7.5 Minute Series Quadrangles. Field reconaissance and aerial photographic interpretation confirmed surficial exposures of bedrock.

The most prominent features of the buried bedrock paleo-surface are two deeply incised river/stream valleys (Plate II; and Figure 1). Modern Paran Creek and Furnace Brook occupy the regions which overlie these paleo-valleys, which in places lie up to 290 feet below the modern streams. Another deeply buried paleo-valley drains the area west of the center of Bennington, in the vicinity of the airport. This valley is buried by the Whipstock Hill Moraine which is up to 160 feet thick (DeSimone, 1991).

Comparison of the pre-glacial topography (Plate II) to the bedrock geology (Figure 2) suggests that the locations of the deeply incised river valleys are dependent upon lithology and structural features.

Post-orogenic erosion eventually carved the Vermont Valley with its two sub-valleys, detailed above, into carbonate rock. These carbonates are flanked by the comparatively resistant igneous crystalline and metamorphic rocks which compose the Green Mountains and the Taconic Highlands. The Furnace Brook drainage developed in the Dunham Dolomite, wheras the Paran Creek valley was developed in the Winooski Dolomite and Clarendon Springs Dolomite. Both the Furnace Brook and the Paran Creek valleys trend north-south, parallel to the regional strike of the metamorphosed sedimentary units. It is also possible that the locations of thrust faults exercise control over the formation of the valleys. Rock at and near fault zones is shattered as a result of shearing forces and heat, rendering it particularly susceptible to erosive downcutting. As groundwater moves through these faults zones, it will further degrade the bedrock. MacFadyen (1956, Plate I) has mapped the locations of these faults.

The relief of the bedrock paleo-surface in these ancient valleys is up to 300 feet greater than that of the modern valley. The nine cross-sections created for the study area reveal the steepness of the the buried topography (Plates I and IV). The paleo-rivers were deeply incised into the bedrock surface. In addition, these paleo-rivers had cut back well into the valley walls. In profile, these paleo-valleys display the typical V-shape produced by fluvial erosion.

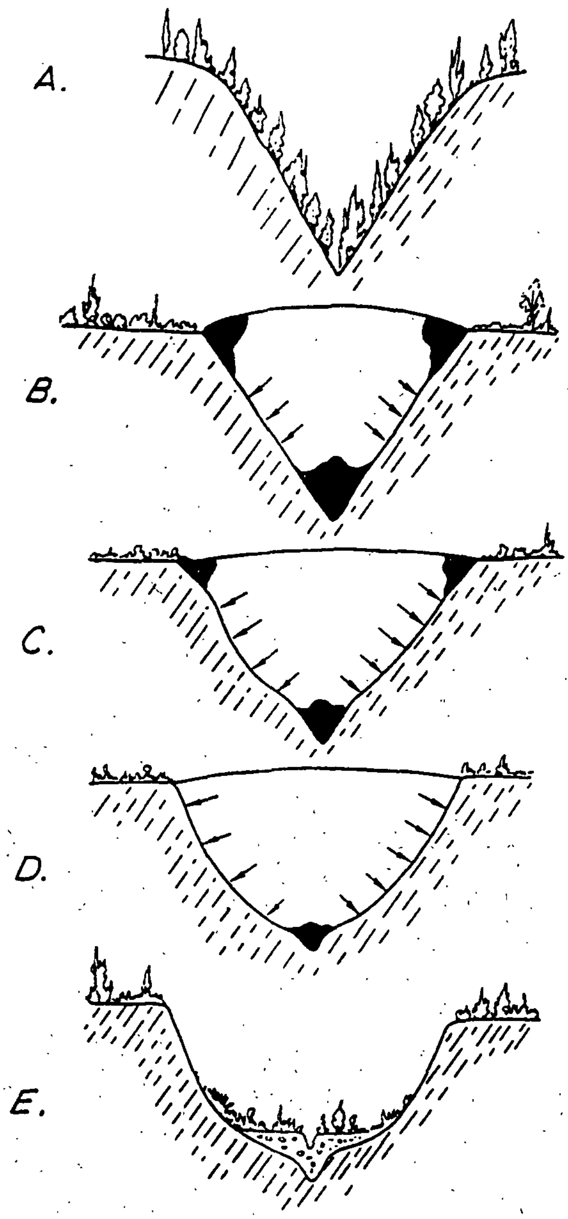
In contrast to the ancient valleys, modern valley profiles are severe; stream valleys are not deeply incised. Typical slopes in the modern topography are comparatively gentler. The profiles of modern topographic features are more rounded. In appearance, the valley is well-characterized as a U-shaped glacial valley. The superimposition of a U-shaped glacial valley onto the V-shaped paleo-river valley is best depicted in cross-sections taken through the northern end of the Paran Creek valley and through the Furnace Brook drainage (Plate IV A,E).

Well-logs provide some indication of how this transformation occured as the buried valleys are filled with sand, gravel and till (Appendix A, well-logs: S120, S118). Most interesting in the deep paleo-valleys is the presence of sand and gravel buried beneath the till (Plate IV, B,C,D,F). There would seem to be two potential sources for this material: preserved proglacial outwash sediments deposited during glacial advance, or preserved pre-Woodfordian alluvium. Hypotheses regarding the exact source would be purely speculative without coring and subsequent analysis.

More important than their source, however, is the simple fact that the gravels were preserved. Theories of valley transformation based on erosional processes propose that a glacier widens and deepens the valley (Flint, 1947; Nye, 1965; Johnson, 1970; Reynaud, 1973)(Figure 3). In such a case, it might be expected that subglacial processes would strip away the pre-existing unconsolidated surface materials, as well as sediments deposited ahead of the advancing glacier. In this case, we would expect to find till or meltwater sediments directly overlying the bedrock. It is clear, however, that this is not the case. Net deposition, not erosion, was responsible for the transformation which occurred in the deepest portions of the valley, complemented by erosion of the valleys walls to produce the U-shaped profile.

A further examination of well-logs suggests extensive deposition on

Figure 3 Transformation of a river valley by a glacier (after Johnson, 1970)

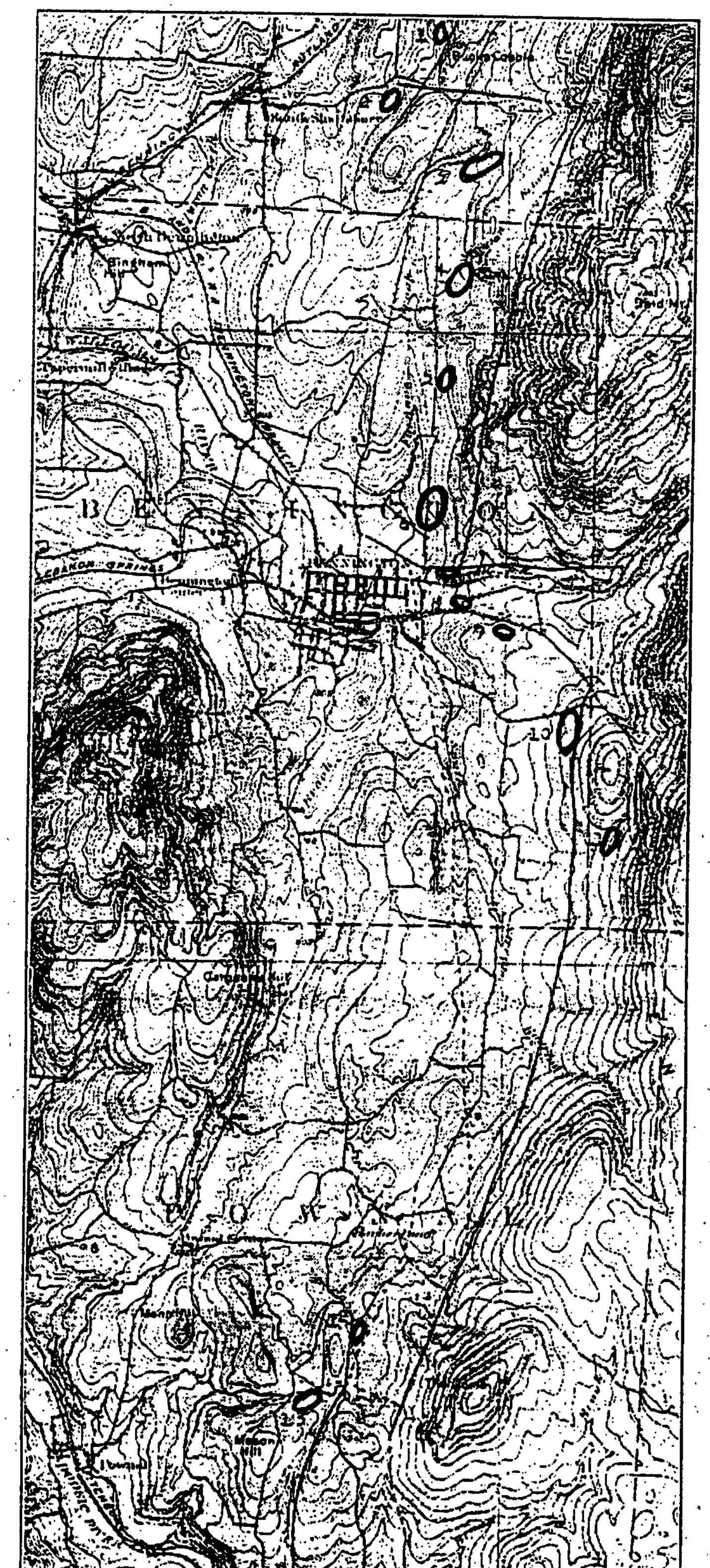


A. V-shaped river valley profile
B. Glacial ice flows into river valley
C. and D. Glacial erosion widens and deepens valley
E. Glacier retreats leaving modified valley profile

the hillslopes adjacent to the deep valleys. These higher regions are covered by a wedge of till, up to 150 feet thick on the south or leeward slopes of West Mountain (Appendix A, well-logs: S063, S279). Many borings penetrate to a yellow-orange, unconsolidated layer of ochre, rotten limestone. While this ochre layer is variable in extent and thickness, it is locally up to 230 feet thick. Above this ochre is a thick till blanket, again, most prominent on the southern slopes of West Mountain (Appendix A, well-log: S08). This extensive till is essentially a large till "shadow", deposited on the downflow or leeward side of the topographic obstruction presented by West Mountain. It is probable that some of the ochre was stripped away by the ice. There are well-logs where till rests directly on relatively fresh limestone or marble (Appendix A, well-log: S03). However, the presence of a substantial ochre layer suggests that depositional, not erosional, forces had largely influenced the valley profile.

A recent study of the Brandon Lignite suggests that the age of this bedrock surface may be much older than Mid-Wisconsinan (Stockwell, 1990). As described by Burt (1928), a band of kaolin deposits stretches for 95 miles along the Green Mountain Front. He identified 11 kaolin deposits in the Bennington Area (Figure 4). In Brandon, similar kaolin deposits have been found interlayered with the Brandon Lignite, a well-studied, small, organic swamp deposit (Stockwell, 1990). This deposit has recently been estimated to be Early to Middle Cretaceous in age (130 to 90 Ma)(Stockwell, 1990). If the Bennington kaolins can be correlated with the Brandon deposits, this suggests that the buried bedrock surface could be at least of Middle Cretaceous age.

Figure 4 Kaolin deposits in the Bennington and Shaftsbury area (after Burt, 1928)

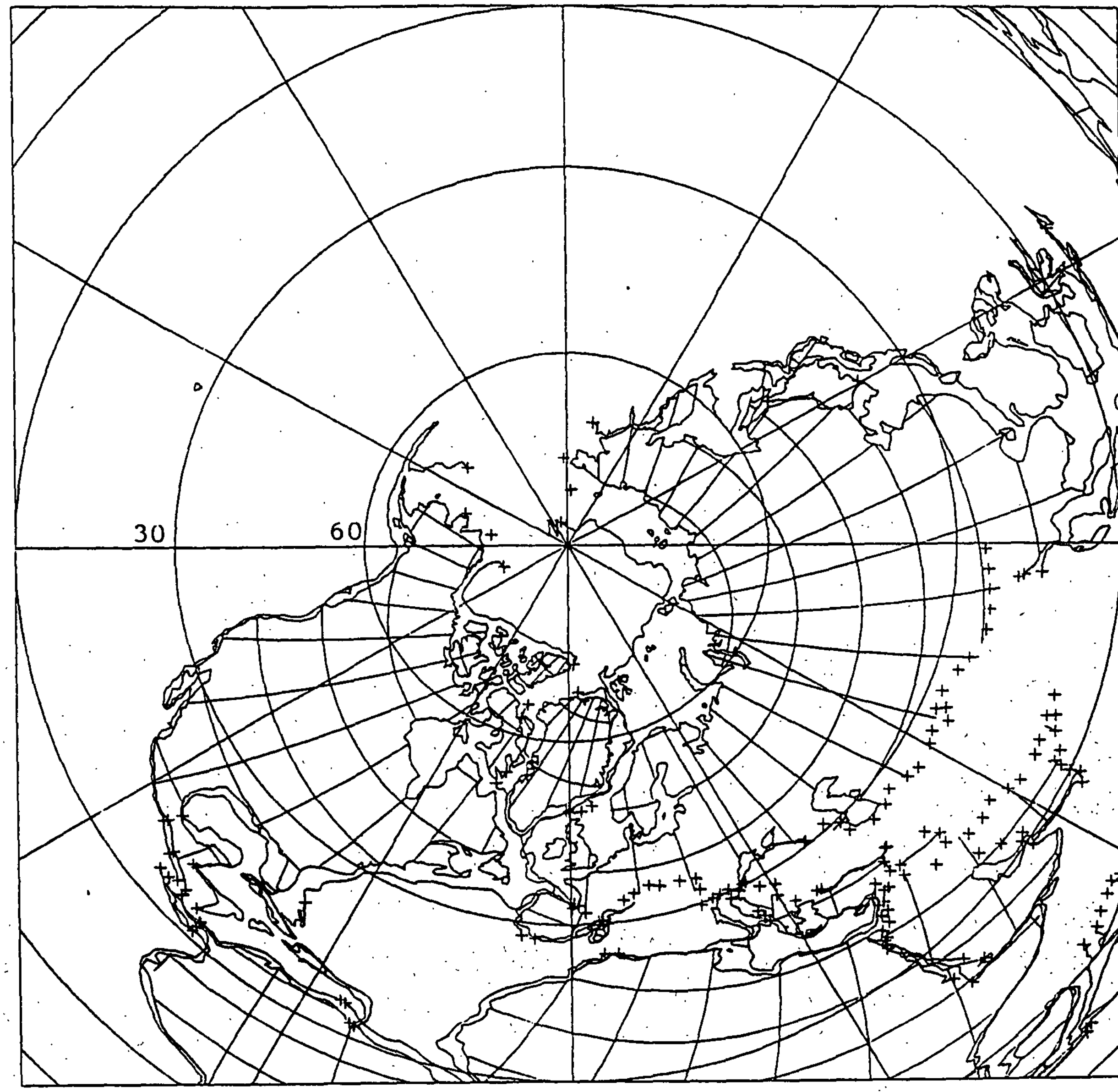


This correlation, however, is problematic. It is clear that the kaolin is not continuous along the mountain front from Bennington to Brandon, but rather exists in distinct, isolated deposits. Fortunately, studies have shown that kaolin formation is governed by strict climatic conditions. Kaolin frequently forms from the weathering and erosion of distant source material and subsequent deposition in topographic basins (Tourtelot, 1983). Kaolin can also form in place from hydrothermal alteration along faults (Kerr, 1955) or as a weathering residuum (Hunt, 1972) The association of deeply weathered bedrock profiles with isolated depressions filled with deposits of kaolin and bauxite, or carbonaceous silt and clay is common in the Appalachians (Hunt, 1972). Kaolin-rich deposits form in climates ranging from warm-temperate to tropical (Tourtelot, 1983). High temperature (>25 degrees C for most of the year) and high rainfall (rainfall exceeding evaporation for 11 months of the year), in combination with good drainage, are necessary for the formation of such deposits (Millot, 1970; Parrish and Barron, 1986). Given the climatic limitations and comparatively rare occurence of kaolin deposits, it is probable that the series of deposits stretching along the Green Mountain Front are contemporaneous.

The preservation of pre-Woodfordian sand and gravel and possible Early to Middle Cretaceous kaolin deposits beneath the till indicates that the buried bedrock surface is not the product of the most recent glaciation and may not have been too severely affected by any of the Pleistocene glaciations. The buried surface must then be a reflection of some pre-Wisconsinan or at least pre-Woodfordian erosional regime. The deeply incised paleo-river valleys extend back to the mountain fronts whereas the modern streams do not. It is not clear why the modern streams have not cut down to the paleo-surface but this further suggests that paleoclimatic conditions differed from the modern conditions.

The buried topography suggests that the paleoclimate was much warmer and wetter than the modern climate. Well S08 penetrates a 235 foot thick layer of extensively weathered marble. Such deep weathering profiles are similar to those found in warm, humid regions of the United States, particularly in the Southeast (Buol et al., 1973). If a correlation between the kaolin/lignite deposits of Brandon and the Bennington kaolins can be accepted, the bedrock surface could reflect a Early to Middle Cretaceous climate. Recent information suggests that the Middle Cretaceous was the time of maximum climatic warmth for the Cenozoic and Mesozoic (Kerr, 1991). The apparent paleolatitude of Southern Vermont during the Early to Middle Cretaceous would place the Bennington/ Shaftsbury area at 30 to 35 degrees North., roughly the latitude of the Southeastern United States (Irving and Irving, 1982 from Stockwell, 1990) (Figure 5). Tropical to subtropical climate conditions existed at least to 45 degrees North during Cretaceous time (Frakes, 1979).

Figure 5 Middle Cretaceous (Cenomanian) paleogeographic map (from Smith et al., 1981)



OVERBURDEN THICKNESS MAP

The Overburden Thickness Map depicts the thicknesses of pre-glacial, glacial and post-glacial sediments in the Bennington-Shaftsbury area (Plate III). Data for sediment thickness was obtained directly from the well-logs. In addition, interpretations of aerial photographs and surficial mapping information were used to delineate the contact between thick till and thin till contact line (DeSimone, 1991).

Approximately 40 square miles of the valley are covered by Pleistocene and Holocene sediments. The thickness of these deposits varies, but may reach up to 300 feet in some areas of the valley. The thickest packages of sediment are those which fill the bedrock paleo-valleys. Thinner overburden packages are found at higher elevations along the valley slopes, overlying prominent bedrock ridges, and along the major surface drainage features such as Furnace Brook, Paran Creek, and the Walloomsac River. Extensive deposition in the valleys has diminished the steep character and greater relief of the pre-Woodfordian bedrock surface.

In order to compute the total volume of sediment underlying the modern surface, the valley was divided into trapezoidal sections. The area of sediment fro a given cross-section was then integrated over the length of the trapezoidal section to obtain a volume. The total volume of sediment deposited in the valley was previously calculated to be 1,960,000,000 cubic yards (Table 3).

The Vermont Valley is crossed by three large recessional moraines composed of variable thicknesses of till, gravel, and sand as determined from well-logs. The Whipstock Hill Moraine blocks the southern end of the valley, lying south of the Walloomsac River in the vicinity of the

Table 3
Total volume of unconsolidated sediment in the Bennington and Shaftsbury area

Region	Boundaries of Region	Average Area of Boundaries (square feet)	Length of Region (feet)	Volume for Region (cubic feet)
A	A-A, border	656,000	4,260	2,800,000,000
B	A-A, B-B	1,076,000	12,000	13,000,000,000
C	B-B, C-C	1,292,000	7,000	9,000,000,000
D	C-C, D-D	964,000	8,240	7,900,000,000
E	apex, E-E	76,000	17,000	1,300,000,000
F	E-E, F-F	480,000	8,880	4,300,000,000
G	border, G-G	264,000	4,880	1,300,000,000
H	G-G, H-H	264.000	10,250	2,700,000,000
I	H-H, I-I	352,000	8,000	2,800,000,000
J	I-I, border	440,000	4,750	2,100,000,000
K	D-D, G-H line	840,000	1,500	1,300,000,000
L	F-F, H-I line	808,000	4,000	3,200,000,000
SUB-TOTAL				51,700,000,000

Areas covered by thin till:
735,295,000 square feet
x 3 feet average thickness= 2,205,885,000

TOTAL 53,905,885,000 cubic feet

or

1,996,000,000 cubic yards

airport. This moraine is essentially a continuation of the Mount Anthony moraine which lies south of Bennington proper (DeSimone and Dethier, 1991, in press). The Harwood Hill Moraine lies just north of the Walloomsac, crossing the valley from Harwood Hill, continuing below Bennington College and extending west to the Sodom area. The Hale Mountain Moraine is largely kamic in nature. This moraine abuts West Mountain and extends under Shaftsbury Center to Trumbull Mountain.

Elsewhere, a thick till blanket occupies much of the valley below elevations of 1,200 feet. Well-logs on the southern slope of West Mountain show that this till blanket locally exceeds a thickness of 150 feet (Appendix A, well-logs: S43, S63, S279). This till sheet is a classic example of a till shadow. Nobles and Weertman (1974) demonstrated that the rate of till deposition at the base of an ice sheet is dependent upon the temperature gradient at the bottom of the ice sheet. The larger the gradient, the smaller the rates of basal melting and till deposition. As the thermal gradient is higher over a hill than over a hollow, "till shadows" will form on the lee side of topographic obstructions. The till overlies unconsolidated sand and gravel or ochre in many locations in the valley. It will be shown that the thickness of the till in the lowest portions of the valley has a significant impact on the nature of the aquifer systems.

The thickness of till on the mountain slopes is more variable. Above elevations of 1,200 feet, these till deposits are scattered and thin (thin till < 10 feet). Thin till deposits, however, have been mapped as low as 700 feet (DeSimone, 1991). Low-lying thin deposits are generally found in the vicinity of bedrock nobs and ridges. These thinly covered uplands will prove to be important as aquifer recharge regions.

Underlying the till deposits in sections of the valley are sand and gravel deposits of uncertain age or origin. These deposits have been identified solely on the basis of well-log information (Appendix A, well-logs: B06, B154, S95, S96, S118). These sand and gravel deposits are found in the deepest portions of the pre-Woodfordian bedrock paleo-valleys. Due to the sparse coverage of well data in many areas, it is not clear how extensive these deposits might be. Well-log data from the Furnace Creek valley indicate that these sands and gravels are not continuous along the entire length of this paleo-valley. However, it is likely that these deposits are continuous in the Paran Creek valley.

Holocene deposits are concentrated around the drainage features of the valley. The city of Bennington is underlain by the most prominent Holocene feature, a large alluvial fan created by the Roaring Branch of the Walloomsac River. This fan has been built up to a thickness of at least 80 feet (Appendix A, well-log: B40; Plate IV, Section I). Over the length of this fan, the Roaring Branch is incised at least 10 feet into the Holocene gravel and sand. Locally, the fan sediments may overly a thin layer of till (Appendix A, well-log: B50). A smaller fan developed at the base of Furnace Brook coalesces with the larger Roaring Brook fan. Other smaller Holocene fans may be found at higher elevations, particularly along the Green Mountain Front. Surficial mapping has identified small fans along Basin Brook and Stratton Brook (DeSimone, 1991).

Holocene sand and gravel can be found along most major drainage features. These sand and gravel deposits rarely exceed 10 feet in thickness. Although most of these deposits overly glacial till, well-log data suggests that locally these Holocene sediments may directly overly bedrock (Appendix A, well-logs: S67, S242, S250). In these places, it is possible that glacial till was extant at some time, but has been removed by high discharge events, perhaps of glacial origin. Elsewhere, the alluvial materials may overly proglacial outwash sediments. In such areas, sand and gravel deposits may be upwards of 150 feet thick (Appendix A, well-logs: S74, S183, S256). Extensive stream-terraces of this Holocene alluvium have been mapped along the length of the Walloomsac River (DeSimone, 1991).

VALLEY CROSS-SECTIONS

Cross-sections were constructed for 9 transects across the valley. These cross-sections appear on Plate IV and the transect locations can be found on Plate I. Cross-sections were constructed from well-log data, the Bedrock Surface Elevation Map (Plate II), the Overburden Thickness Map (Plate III), a USGS topographic map and preliminary surficial mapping information (DeSimone, 1991). Well-log data were of primary importance. Well locations have been indicated across the top of the section. Where well density is low, proximal wells have been projected at constant elevation onto the transect; these wells are indicated with a "p" following the well number. Most wells were projected 1,000 to 2,000 feet; in extreme cases, wells have been projected as much as 5,000 feet.

For discussion purposes, the cross-sections are organized into three groups: the Paran Creek Valley (A-D), the Furnace Creek Valley (E-F), and the Walloomsac River Valley (G-I).

The Paran Creek Valley Sections

Four sections have been constructed across the Paran Creek valley to depict three-dimensional changes in glacial sedimentary facies, as well as changes in the topography and paleo-topography along the length of the valley. Paran Creek drains the major north-south valley through the study area.

Section A is the northernmost section. Two glacial features are characteristic of this section. On the western side of the valley, this section intersects the northernmost moraine in the valley, the Hale

Mountain Moraine named by Shilts (1966). The moraine is characterized in well-logs as sand and gravel, with minor amounts of silt. In the center of the valley, two prominent eskers with sediment thicknesses locally exceeding 80 feet parallel Paran Creek. A massive sand and gravel quarry has been developed into the eastern esker. Ice-contact deposits are extensive in the northern end of the valley. Underlying the moraine and eskers is a thick till deposit which overlies bedrock in this area.

Ice-contact sediments are not recognized in Section B which is largely composed of till. Modern alluvial sand deposits along Paran Creek are thicker than in Section A. To the east, a small sand and gravel alluvial fan formed on the southwest slopes of Hale Mountain. This fan is evidence of a paleo-stream which must have drained the slopes of Hale Mountain, Harrington Cobble and Bucks Cobble. It is possible that this stream channeled meltwater from a retreating ice tongue in the Furnace Creek drainage. The paleo-valley here is much deeper and sand and gravel deposits are preserved in the valley bottom beneath the till. These deposits are confined by a thick till layer, which serves as an excellent aquaclude. The age of these sand and gravel deposits is problematic as only a minimum age of early Late Wisconsinan can be inferred from stratigraphic considerations.

Till is the major component of Sections C and D. Modern alluvial deposits are substantial along Paran Creek and other smaller drainages. In Section C, a thin layer of kamic material overlies the till in regions adjacent to Paran Creek, while in Section D till is continuous at the surface. The buried paleo-valleys again preserve sand and gravel deposits which seem to be continuous along the length of these paleo-valley segments.

The buried sand and gravel deposits present an excellent aquifer resource. Unfortunately, well-log data are not continuous along the length of the valley, so it is not possible to determine the continuity of the buried sand and gravel deposits. It would appear that these buried deposits are discontinuous in the area between Sections A and B. From Section B south to Section D, it is probable that the deposits are continuous. These deposits are not continuous from Section D to the confluence of Paran Creek with the Walloomsac.

The Furnace Brook Valley Sections

Furnace Brook drains the smaller north-south trending valley below the Green Mountain Front. This valley is confined to the west by a moderate topographic ridge. During glacial retreat, this valley may have been occupied by a small ice tongue, and served to channel meltwater and sediment from this ice and from the Green Mountain Front (DeSimone, 1991). Unlike Paran Creek valley, the two sections across the Furnace Brook valley display stratigraphic relationships which are discontinuous from north to south.

Section E was constructed across a narrow portion of the valley. All well-logs in this area record the presence of sand and gravel, but no till was encountered by any of the drillers. It would appear that meltwater discharge coming off the ice was sufficiently large to strip away any deposits of till. In addition, a paleo-drainage channel enters the valley from the Green Mountain Front just north of the section.

Thus, the possible combination of glacial meltwater and intense meteoric run-off from higher elevations must certainly have removed any older deposits. It is probable that the valley was then filled with outwash sand and gravel and later Holocene alluvial gravel and sand.

Further south in the Furnace Brook valley, Section F records the thick till that may have existed at one time further north. Above the till are modern alluvial sand and gravel deposits. Beneath the till are confined sand and gravel deposits similar to those encountered in the Paran Creek cross-sections. As well-density is low, it is not possible to determine the extent of these deposits. They may be continuous along the valley, or, alternatively, may exist as small lenses. The age of these sand and gravel deposits is not clear.

The Walloomsac River Valley Sections

The sections constructed across the Walloomsac River valley depict the most extensive Holocene deposits found in the study area. The Walloomsac River is the major surface drainage of the study area. Trending east to west, the valley cuts across the structural grain of the Green Mountain and Vermont Valley geomorphic provinces, as the major streams flowing from the north and the south empty into it. The valley originates to the east, where the Roaring Branch crosses the Green Mountain Front in a steep, narrow gorge. North of the center of Bennington, the Roaring joins the Walloomsac River and flows west into New York.

Section I is the easternmost, and its most prominent feature is the large fan which the Roaring Branch has constructed since latest

Pleistocene time. This fan is upwards of 80 feet thick. Well-logs indicate that it is composed primarily of sand and gravel with minor silt. A look at the automobile-sized boulders along the riverbanks will bear witness to the power of this river as it flows down from the Green Mountain Front. At present, the Roaring is elevated along the northern edge of the fan. This fan rests, apparently unconformably, over a thin layer of till. This till layer may originally have been thicker, but was eroded perhaps during the latest Pleistocene- earliest Holocene when base level as fixed by global sea level was lower. Till deposits continue up the sides of the valley.

Section H is further downstream. Here the fan deposits are thinner, and the sediment is generally finer gravel with more silt and clay, more typical of distal fan facies. Again, a thin till layer lies below the Holocene river deposits and extends up the valley side. A small esker is preserved along the northern edge of the valley.

Section G is constructed far enough to the west to be beyond the extent of the fan. A slightly thicker till layer is overlain by Holocene silt, sand and gravel typical of floodplain alluvium.

THE BEDROCK AQUIFER

Approximately 73 percent of the wells in the Bennington and Shaftsbury area tap water resources in bedrock (Figure 6). Depending upon the location of the well, this bedrock may be schist, phyllite, limestone, marble, quartzite or granite (Figure 2 and MacFadyen, 1956, Plate I). The relative extent of water-bearing units in each lithology varies with the characteristics of the different lithologies. Most importantly, a lithologic unit's capacity to function as an aquifer resource is dependent upon the network of fractures that exists within the rock. A unit with a well-developed and integrated fracture system can supply wells with high yields; a unit in which fractures are small or disconnected will supply low quantities of water (Figure 7).

Wells reaching to granite or gneissic rock are most common on the eastern side of the valley along the base of the Green Mountains. Roughly 6 percent of the study wells penetrate into granite or gneiss. These wells give a consistently high yield. A graph of yield versus well depth suggests that extensive fracture systems exist from 80 feet to 225 feet below the ground surface (Figure 8). The highest yields were reported at average depths of 150 feet below the ground surface. At depths greater than 400 feet yields are low and insufficient for residential use. It is recommended that wells penetrating granite or gneiss should not be drilled to depths greater than 400 feet.

Similar yield results were reported for wells penetrating quartzite bedrock. Comprising roughly 4 percent of the study wells (Figure 6), wells finished in quartzite are typically found in the Furnace Brook valley, on the slopes of the Green Mountains to the east and the slopes

Figure 6
Well Type Distribution Graph

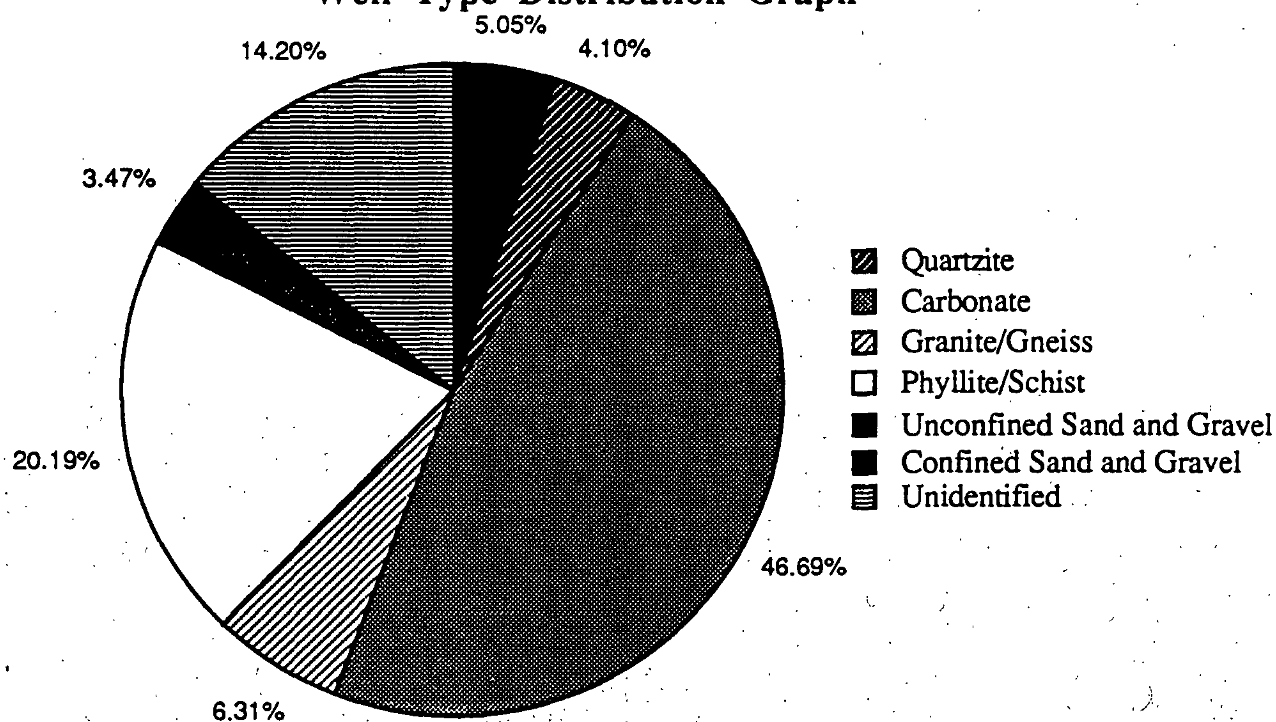
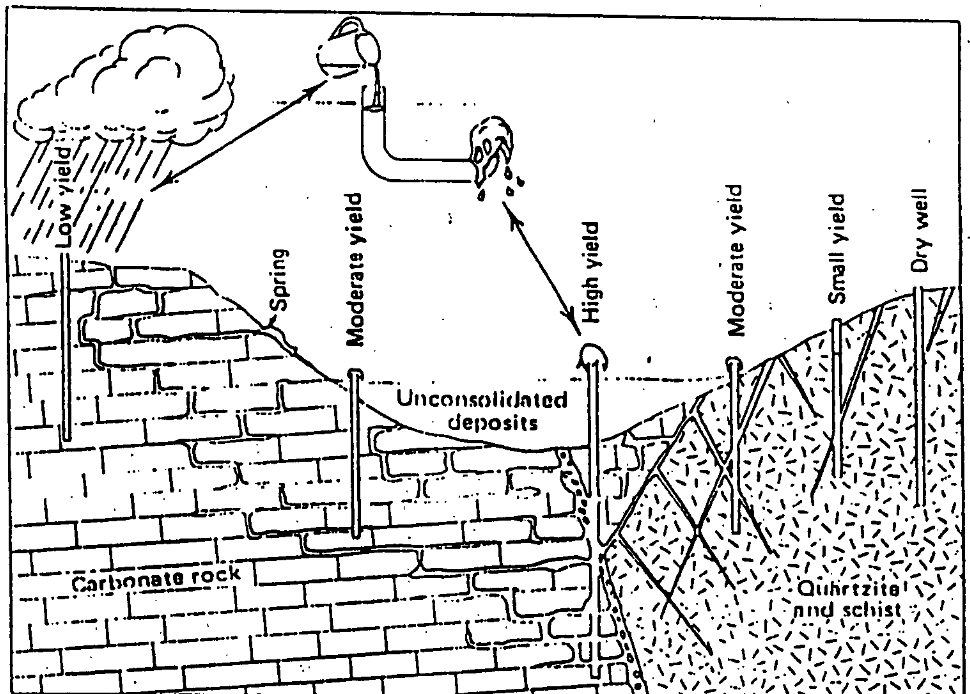
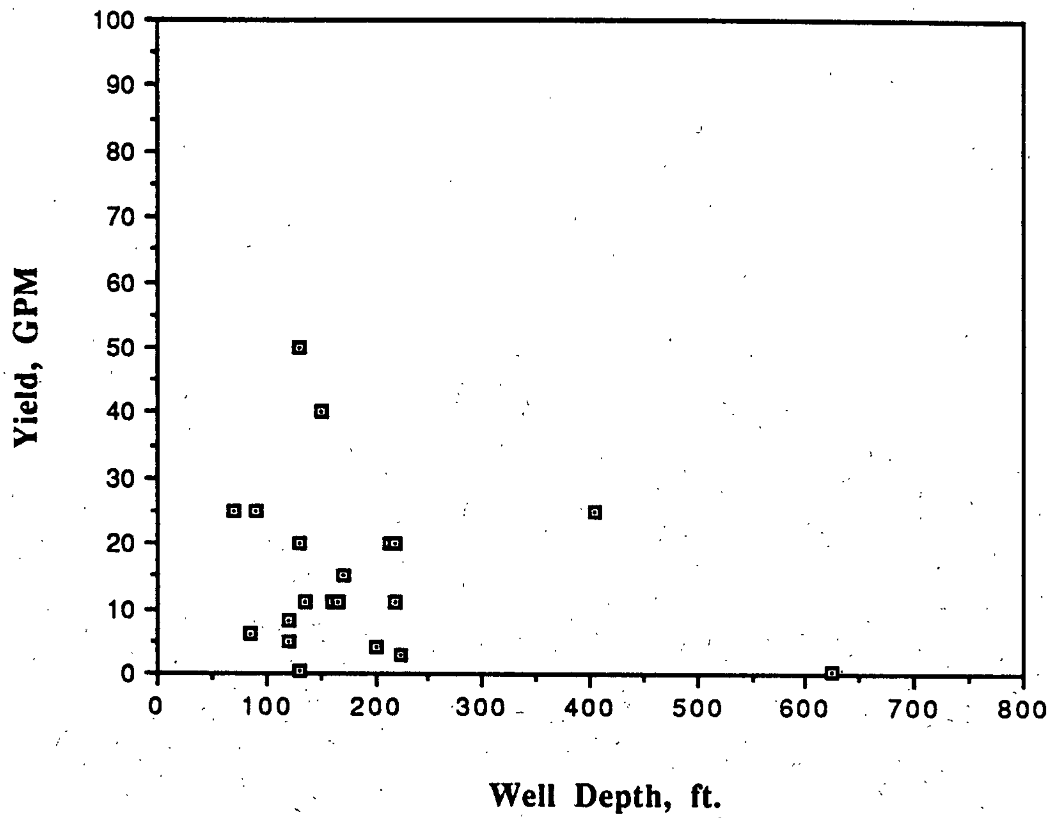


Figure 7 Relationship of water yield to bedrock fractures and cavities for a bedrock penetrating well (from Hansen et al., 1973)



Water is obtained from secondary openings, such as fractures and joints in schist and quartzite and, in addition, from solution cavities in limestone. Increased fracturing along fault zones may provide higher yield to wells. The high-yielding solution cavities in carbonate rocks are usually larger and more numerous near faults and along geologic contacts. Artesian conditions occur when a well taps an aquifer in which water is confined under hydrostatic pressure.

Figure 8
Granite and Gneiss Well Data



of the topographic ridge to the west. Yield reports suggest that an integrated fracture system exists at depths ranging from 75 to 275 feet (Figure 9). Similar to the granite and gneiss wells, water yields at depths greater than 400 feet are typically inadequate for residential use.

An overlapping plot of granite/gneiss well data and quartzite well data suggests that the bedrock fracture systems are connected between these lithologies (Figure 10). These aquifer systems may be hydraulically connected. This would be consistent with their stratigraphic reltionship.

Wells penetrating phyllite or schist are comparatively common, comprising 20 percent of the study wells (Figure 6). These wells are concentrated in the western half of the study area. Yield in phyllite- or schist-penetrating wells is highly variable, ranging from .25 to 88 gallons per minute (Figure 11). The anomolously high yields at depths of 100 to 300 feet suggest that the well has reached a fault zone were the bedrock has been shattered by shearing forces. Wells producing adequate yield commonly extend to depths ranging from 50 to 350 feet below the ground surface. Due to lithostatic pressure at depths greater than 400 feet, the fracture system would appear to be discontinuous, as yields are commonly less than 3 gallons per minute. It is recommended that wells in phyllite or schist not extend below 400 feet.

Wells drilled into carbonate rocks comprise almost 47 percent of the study wells and are the most common well type (Figure 6). Carbonate wells are located throughout the study area, but are particularly concentrated in the lower elevations of the valleys. Yields in carbonate wells range from .5 to 100 gallons per minute. Most wells range from 100 to 350 feet in depth, but sufficient yield is found at depths up to 780 feet below the

Figure 9
Quartzite Well Data

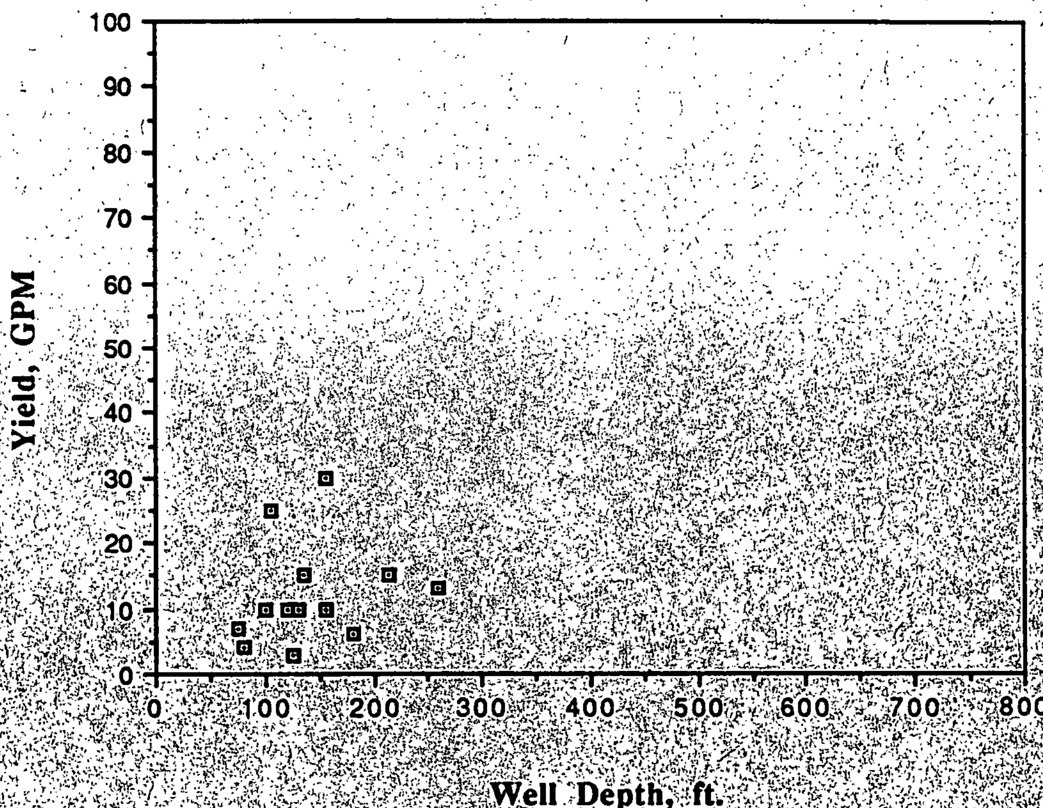


Figure 10
Overlay of Granite/Gneiss and Quartzite Well Data Showing Hydraulic Connection

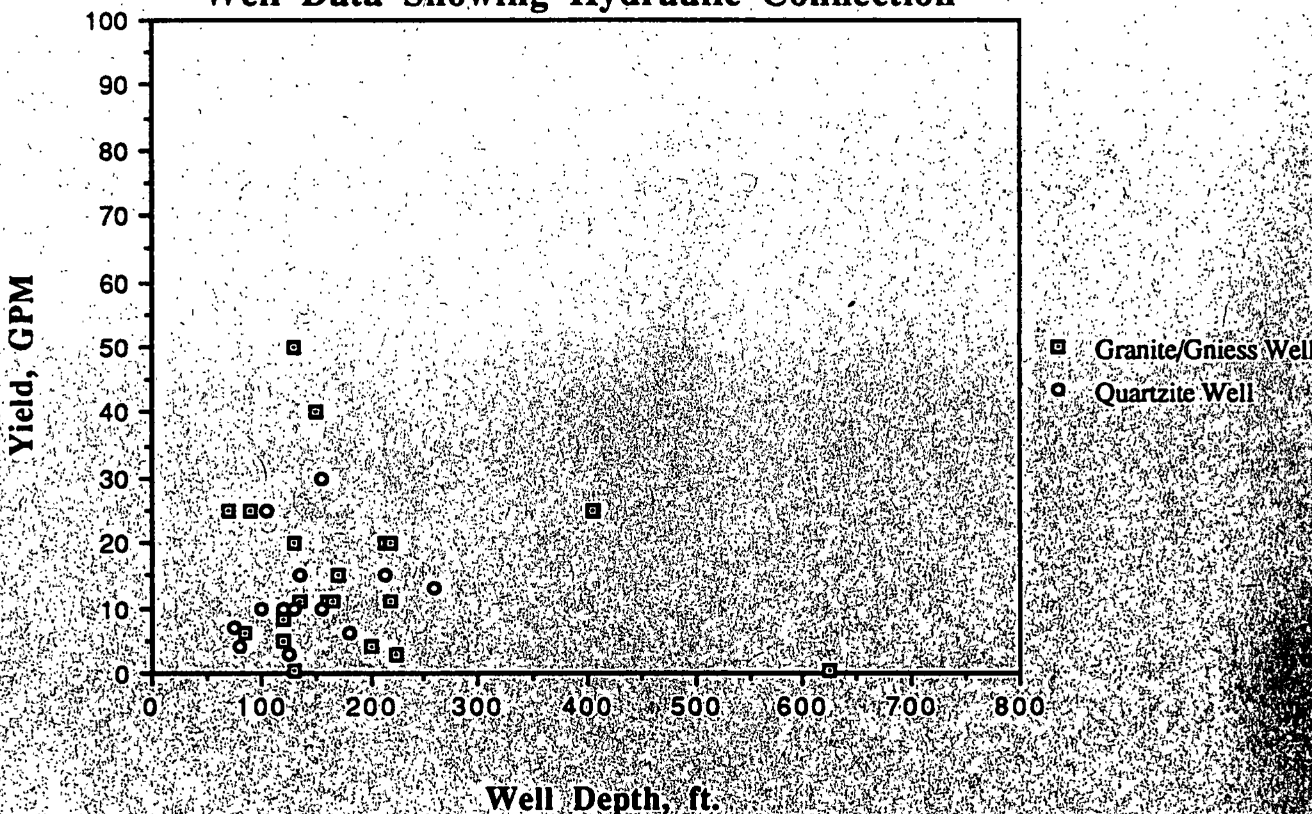
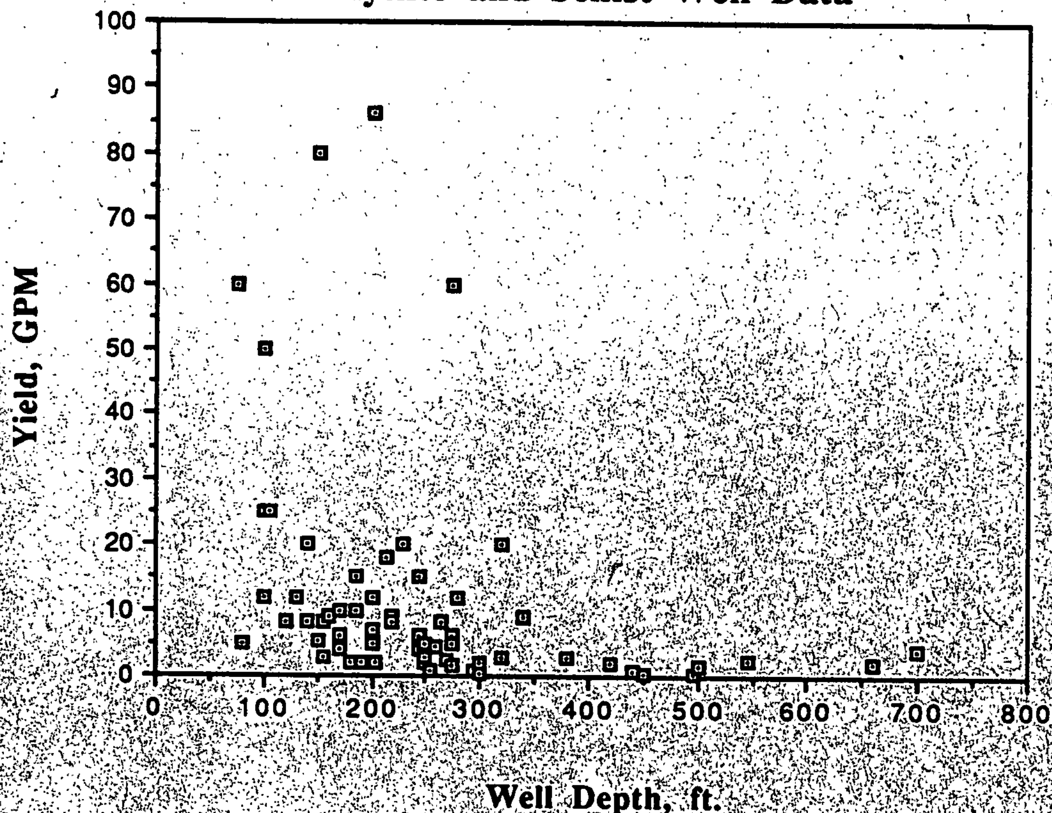


Figure 11
Phyllite and Schist Well Data



ground surface (Figure 12). The abundance of wells with yield ranging from 10 to 30 gallons per minute reflects the enhancement of the bedrock fracture system in the carbonate rocks by dissolutional processes.

In the study area, carbonate and meta-sedimentary lithologies are commonly interbedded (MacFadyen, 1956). An overlay of phyllite/schist well data and carbonate well data suggests these lithologies are hydraulically connected via their secondary fracture networks (Figure 13). As expected, however, the dissolution-enhanced fractures in the carbonate provide higher yields.

Figure 12
Carbonate Well Data

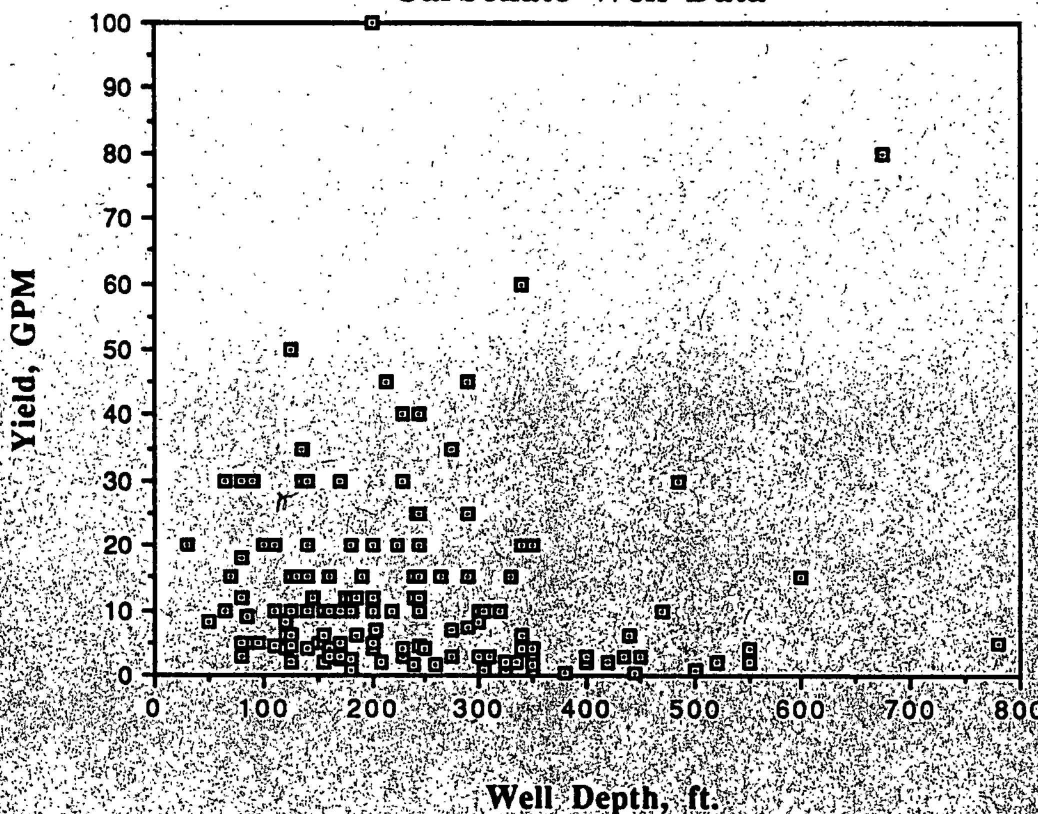
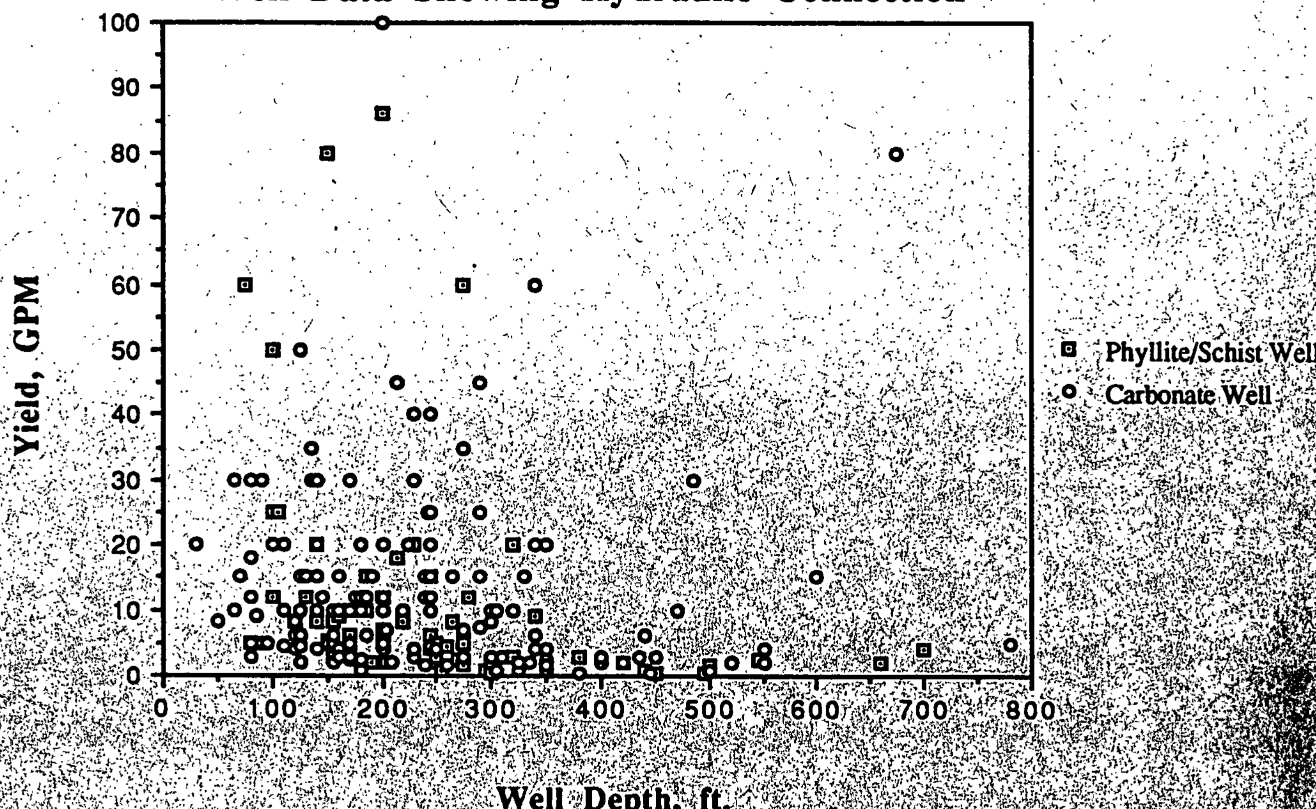


Figure 13
Overlay of Phyllite/Schist and Carbonate Well Data Showing Hydraulic Connection



THE CONFINED SAND AND GRAVEL AQUIFER

The sand and gravel buried deeply in the bedrock paleo-valleys is an important water resource for the towns of Bennington and Shaftsbury. These sand and gravel aquifers lie directly over bedrock and are overlain by thick till deposits (Plate IV). Wells encounter these buried deposits in the Paran Creek valley, particularly in three areas: west of U.S. Route 7A, east of the Rutland Railroad, and south of North Road; south of Bucks Cobble near Snow School; and in Shaftsbury Hollow near the New York-Vermont border. Other wells in the Furnace Brook valley tap similar buried deposits; these deposits are south and west of White Chapel along Chapel Street and Park Street.

Yield from wells drilled into these confined aquifers is high, ranging from 5 to 100 gallons per minute (Figure 14). Due to the nature of these deposits, well depths commonly range from 75 to 220 feet below the ground surface, and rarely exceed 290 feet. It cannot be ascertained whether or not the sand and gravel is continuous along the length of the valleys. Therefore, it is not certain that these sand and gravel aquifers are hydraulically connected to one another. What seems clear, however, is that this aquifer system is hydraulically connected with the bedrock aquifer system. An overlay of bedrock well data with the sand and gravel well data reveals that yield values are similar at depth for both systems (Figure 15). This would suggest that the sand and gravel is recharged directly by the fracture systems in the surrounding bedrock. Recharge of this aquifer from above is minimal, given the relative impermeability and thickness of the overlying till deposits.

Figure 14
Confined Sand and Gravel Aquifer Well Data

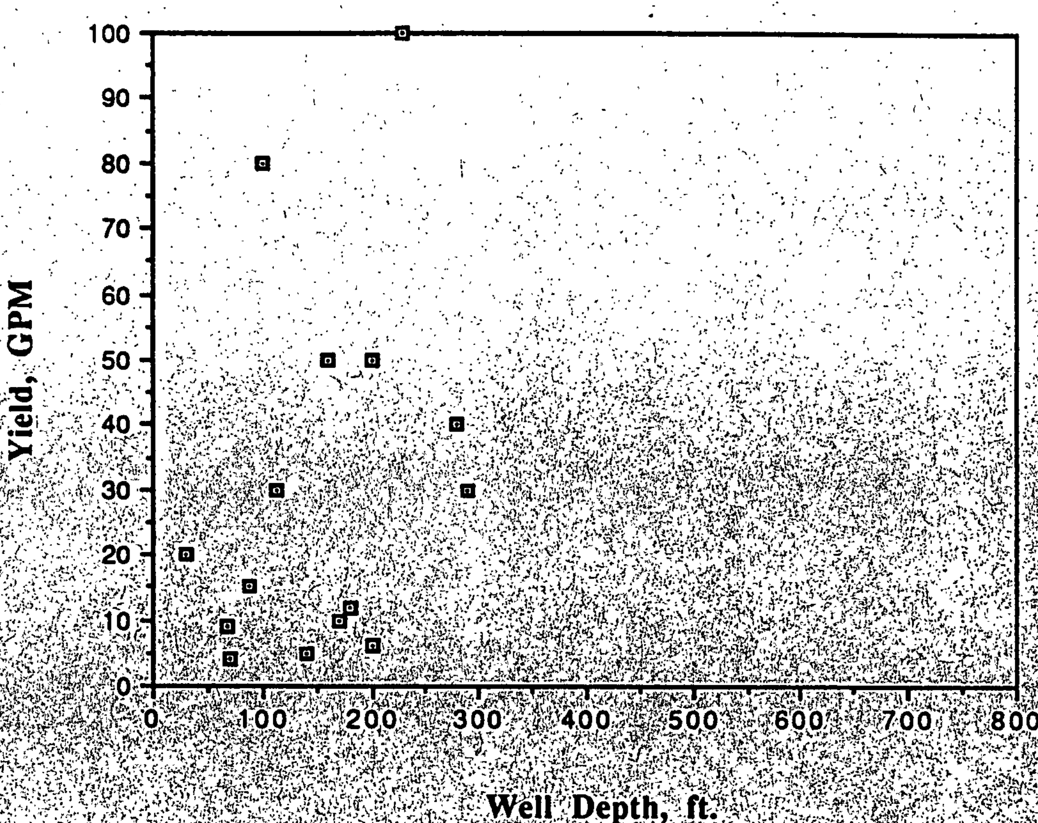
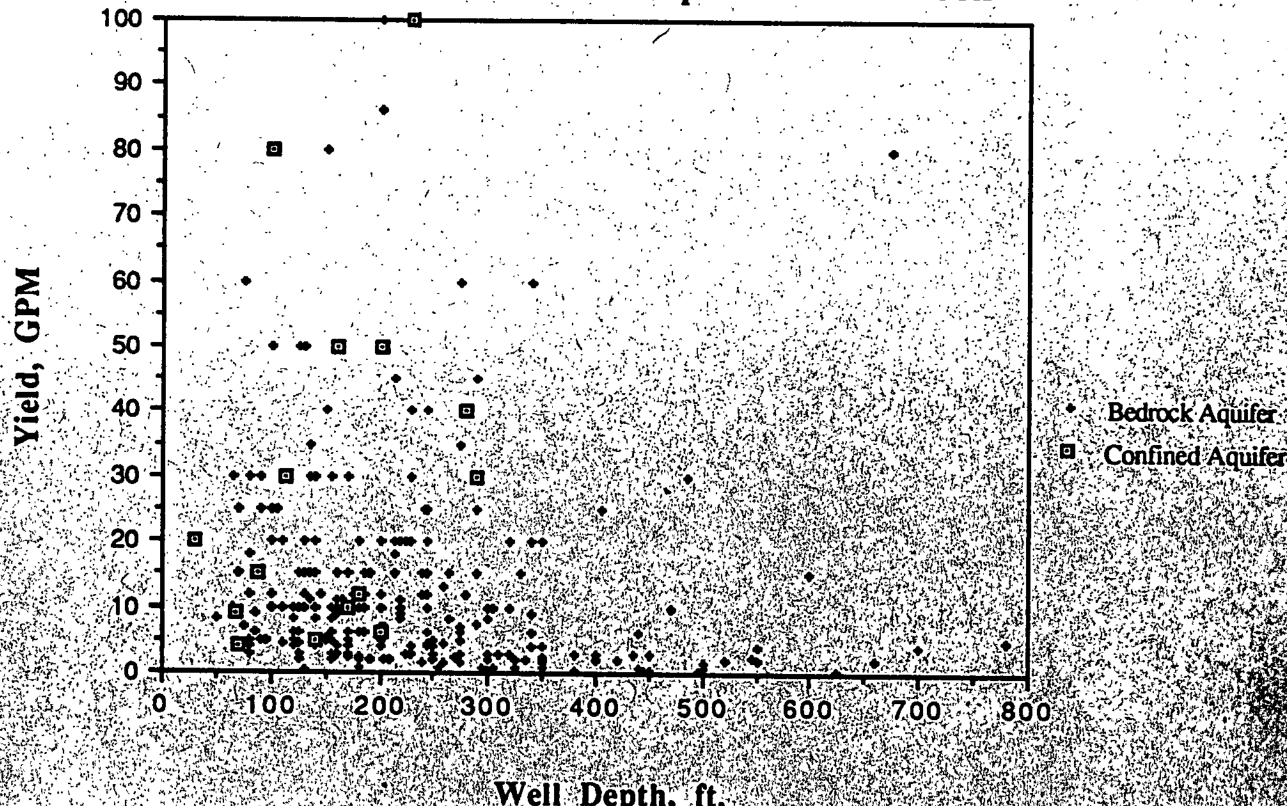


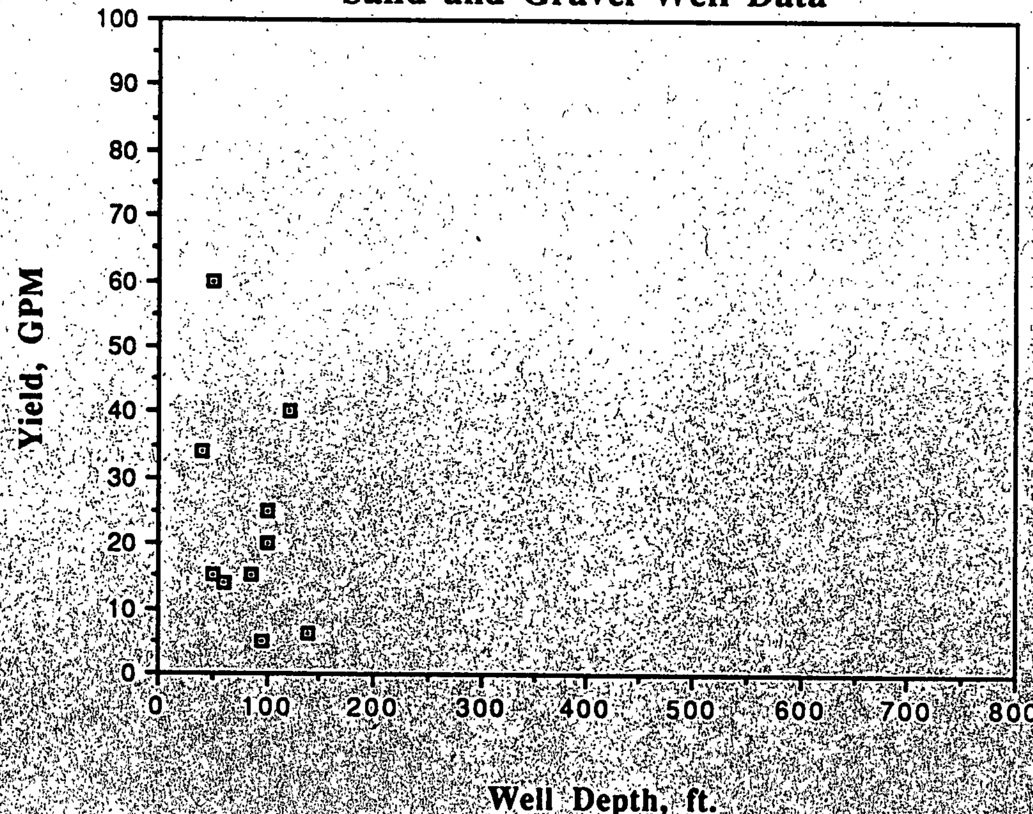
Figure 15
Overlay of Well Data Showing Hydraulic Connection of Confined Aquifer to Bedrock



THE UNCONFINED SAND AND GRAVEL SURFACE AQUIFER

A third aquifer system exists in surface deposits of sand and gravel. Few wells draw water from this system as these Pleistocene and Holocene sediments are quite vulnerable to contamination from surface pollutants carried in runoff. There is also a danger that these wells may dry up during summer and fall drought periods. The depths of these wells consistently range from 40 to 130 feet below the ground surface. Drillers report generally high yield, ranging from 5 to 40 gallons per minute (Figure 16). This system receives direct recharge from precipitation and surface drainage. In most of the study area, these sand and gravel deposits are perched above till deposits. In sections of the Paran Creek valley east and northeast of Shaftsbury Center, these deposits may directly overly bedrock and function as a potential source of recharge to the bedrock fracture systems.

Figure 16
Unconfined Near Surface
Sand and Gravel Well Data



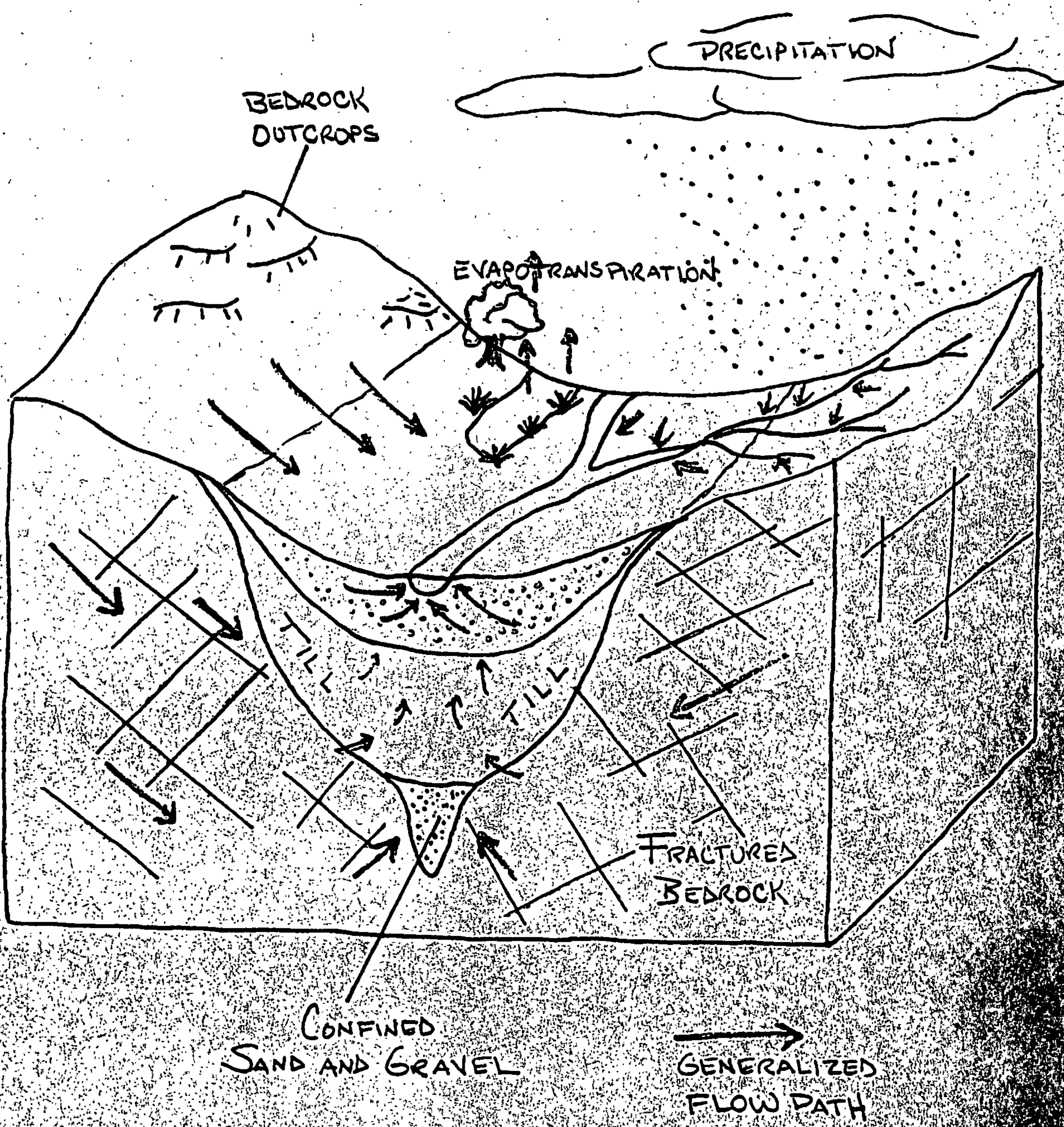
PIEZOMETRIC SURFACE MAP
AND
GROUNDWATER FLOW NET

After drilling a well, it is the responsibility of the well driller to conduct a yield test on the well. The depth to which the water level in the well recovered after the pumping test was taken as the static water level and represents the elevation of the piezometric surface. The elevation of the piezometric surface for a given well was computed by subtracting the static water level from the approximate surface elevation of the well as indicated on a standard topographic map. Where well density was sufficient, it was possible to construct the piezometric surface with a fair degree of certainty. The Piezometric Surface Map, Plate V, depicts the piezometric surface. Interpreted contours of the piezometric surface in areas where well data were sparse were indicated by dashed contour lines.

The piezometric surface in the Bennington-Shaftsbury area varies widely in its depth below the surface. In topographic uplands, the piezometric surface is near the ground surface. Water is found in extensive quantities less than 10 feet below the ground. At several wells along the Green Mountain Front, the piezometric surface is at or above the ground surface level and water flows freely from these wells. In lower portions of the valley, static water levels average 100 feet below the ground surface.

Wells encounter groundwater in bedrock aquifers and in unconsolidated sediment aquifers (Figure 17). Where the water in the bedrock or buried sediments is under sufficient artesian pressure, static water levels may rise upwards of 300 feet in the well through overlying materials. Such

Figure 17 Groundwater flow in valley aquifer systems



overlying materials are commonly till; till may function as an aquitard, significantly decreasing the rate of infiltration of pore waters, or as an aquiclude, completely impeding downward infiltration.

Due to variation in hydraulic head through the confined aquifers, many features observed either in the bedrock surface or at the modern ground surface do not appear in the piezometric surface. That is, the piezometric surface is not restricted by subsurface features or the modern topography. For example, the bedrock paleo-surface is marked by deep paleo-valleys. These features do not show up in the piezometric surface map. Where bedrock may lie upwards of 300 feet below the ground surface at a given well, static water level may be a mere 50 feet below the ground surface. Water confined in the buried sand and gravel of the paleo-valleys may be under similar hydrostatic pressure. This suggests that the bedrock fractures and the buried sands and gravels are hydraulically connected.

The Groundwater Flow Net, Plate VI, depicts directions of groundwater flow in the subsurface. Longer lines depict flow paths through the bedrock fracture systems and the confined aquifer systems; flow through these systems is perpendicular to the equipotential lines of the piezometric surface. Shorter arrows indicate flow paths through unconfined materials into the surficial drainage network of streams and brooks; these flow paths are directed by the features of the surface topography. The flow net provides insight into regions of influence and recharge for the major aquifers (O'Donnell, 1984). In future planning for the protection of groundwater supplies, it is important to identify any regions which supply recharge to the various aquifer systems.

AQUIFER RECHARGE POTENTIAL MAP

The Aquifer Recharge Potential Map is a grading of regions based on the potential for recharge (Plate VII). These areas are graded on a scale of 1 to 5, where 1 represents the highest recharge potential. Because there are esentially two aquifer systems in the study area, recharge potential zones are graded independently for each. Bedrock aquifer recharge zones are indicated by a single digit. Recharge zones for near-surface aquifers in unconsolidated sediment are indicated by a digit followed by an "s". The aquifer systems will be discussed independently but the reader should note that some regions may function as recharge areas for both the bedrock and the surficial aquifers, and are so indicated on Plate VII.

Delineation of aquifer recharge zones was based upon a combination of factors. Data from well-logs, a map of bedrock geology (MacFadyen, 1956, Plate I; Doll et al., 1961), surficial mapping information (DeSimone, 1991), and estimates for material permeability and hydraulic conductivity (Figure 18) were analyzed to contruct the map. A summary of recharge potential zones appears in Table 4.

Figure 18 Hydraulic conductivity of selected geologic units (from Heath, 1982)

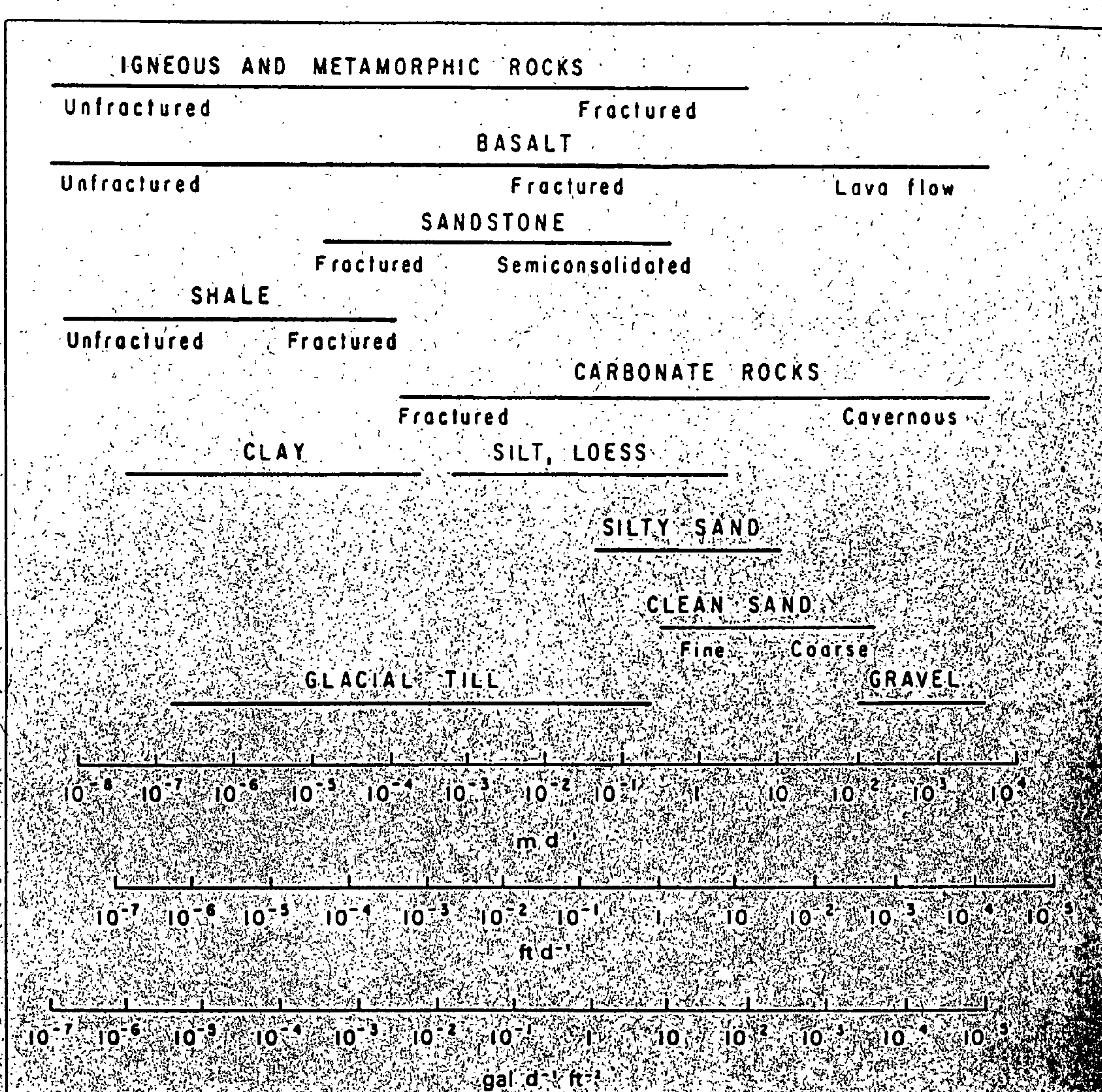


Table 4
Aquifer Recharge Potential
for Bedrock and Surficial Aquifers

Map Designation		Explanation
Bedrock:	1 highest	Carbonate, granite or quartzite bedrock in surface outcrops or beneath a thin veneer of till (<10 feet); also bedrock covered by permeable and porous ice-contact sand and gravel deposits
	2	Phyllite, schist or slate bedrock in surface outcrops or beneath a thin veneer of till (<10 feet); same lithologies covered by permeable and porous sand and gravel deposits; carbonate, granite or quartzite covered by low-silt content moraine materials
	3	Bedrock covered by moraine deposits or alluvial fan deposits with high-silt content
	4	Bedrock covered by moderate, but variable, thicknesses of till (10 ft.<till<25 ft.)
	5 lowest	Bedrock covered by thick till (25 ft.<till)
Surface:	1s highest	Ice-contact sand and gravel, clean, well-sorted, with no silt content
	2s	Ice-contact sand and gravel with some silt, sandy moraine deposits; also extensive stream alluvium sand and gravel deposits
	3s	Alluvial fan deposits; zones of contribution to ice-contact materials; less extensive stream alluvium deposits
	4s	High-silt content floodplain alluvium and lacustrine deposits
	5s lowest	Thick till (>25 feet)

Bedrock and Confined Sand and Gravel Aquifers

The presence of an aquifer system in bedrock is a direct result of the fracture systems which exist in the various lithologies. To facilitate water entry, these fractures must be exposed subaerially or be in contact with permeable sediments. The quantity of recharge into a bedrock unit will then be dependent upon the thickness, aerial extent and permeability of the overburden. In the previous section it was inferred that the buried sand and gravel aquifers receive recharge from the bedrock fracture systems. Therefore, the recharge areas for the bedrock aquifers also serve the buried sand and gravel aquifer.

"1" and "2"

The most certainty exists for recharge areas which have been graded as "1" or "2". This designation has been applied where bedrock is exposed at the surface, or where till cover is sufficiently thin to allow for infiltration (thin till<10 feet; see Plate III). Based upon an examination of outcrops, as well as analyses of depth versus yield in the various lithologies (Figures 9-14), fracture systems are best developed in carbonates, and well-developed in quartzite or granite/gneiss. These bedrock lithologies and thin till-veneered areas overlying these lithologies are designated as "1". Fracture systems in phyllite/ schist/ slate are less well-developed. Recharge rates into these units will be lower and, hence, these lithologies and thin till-veneered areas overlying these lithologies have been graded as "2" (Table 5).

High recharge potentials have also been assigned to areas in the north which are underlain by permeable ice-contact materials. These ice-contact

Table 5
Bedrock geologic units of the
Bennington /Shaftsbury area

Rock Type	Formation Name	Permeability and Water Yield
Gneiss or granite gneiss	Mount Holly Complex	moderate permeability and yield, fracture system is apparently interconnected
Marble and dolomitic marble with beds of quartzite or phyllite	Bascom Formation; Clarendon Springs Dolomite; Winooski Dolomite; Dunham Dolomite; Shelburne Formation	High permeability, especially along fracture zones and solutional cavities; moderate yield where fractures or cavities are not interconnected.
Phyllite or schist	Saint Catherine Formation	low to moderate permeability and low to moderate yield
Phyllite with interbedded marble	Hortonville Formation	low to moderate permeability and yield; moderate yield from carbonate layers
Quartzite with interbeds of phyllite, dolomite or conglomerate	Monkton Quartzite; Cheshire Quartzite; Dalton Formation	moderate to high permeability and yield; higher yields where fractures are extensive.

deposits are largely sand and gravel, and may reach upwards of 100 feet in thickness. As these sediments are extremely permeable, they are saturated at some depth and function as a surface or unconfined aquifer. Yields as high as 100 gallons per minute were reported in wells drilled into these sediments. It is also highly plausible that water from these sediments may seep into the fracture systems of the underlying bedrock. In this case, these sediments will serve as excellent sources of recharge for the bedrock aquifer. Where the material seems to be strictly ice-contact sand and gravel (kame deposits, esker deposits, and proglacial outwash), these areas have been graded as "1". A grade of "2" has been assigned to the areas underlain by the northernmost moraine, the Hale Mountain Moraine, since this sediment contains some fine silt and an unknown amount of till, perhaps as lenses, interlayered with sand and gravel. The silt and till will impede downward infiltation of water to the bedrock aquifer.

<u>"3"</u>

The Whipstock Hill moraine resting against the slopes of Mount Anthony has been assigned the only "3" grade for bedrock recharge. The sediment in this moraine consists of sand, gravel, and fine sediment perhaps locally derived from the Mount Anthony phyllite/schist. The amount of silt in this sediment impedes its ability to function as a high-recharge area.

<u>"4"</u>

Where till thickness is intermediate (>10 feet but <25 feet) infiltration of rainwater will be variable, but generally low. These areas have been designated as "4".

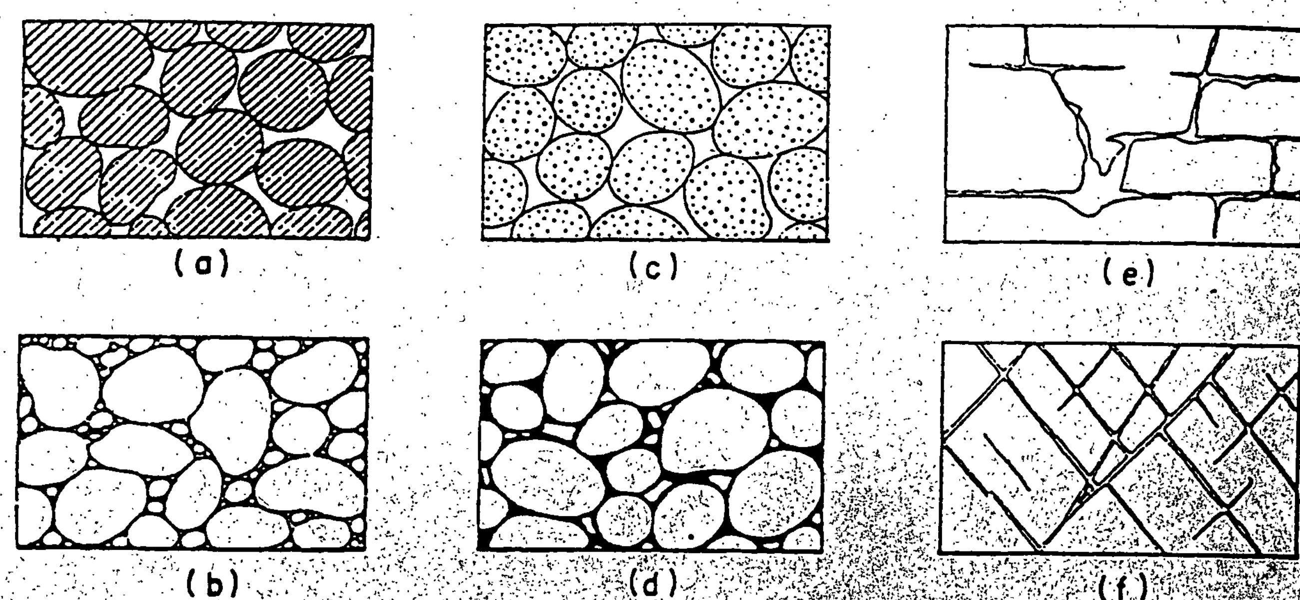
"5"

Where till is thick, infiltration rates and recharge potential will be low to negligible. Due to the compaction of the sediment from its subglacial origins, the hydraulic conductivity of till is extremly low (Figure 18 and Table 6). Rather than infiltrating down towards the buried bedrock surface, water will flow laterally into surface drainages. Hence, areas where till deposits are thicker than 25 feet have been assigned the lowest grade of "5".

Unconfined Surface Aquifers

Isolated, unconfined aquifers are developed in sand and gravel deposits exposed at the surface. Recharge into these aquifer systems will be largely dependent upon the particle size and sorting of the sediment, as both factors contribute to a determination of hydraulic conductivity (Figure 19). In general, a well-sorted gravel or sand will have higher porosity and permeability than a poorly-sorted deposit. Additionally, a sediment consisting of large grains will have higher porosity and permeability than a sediment consisting of small grains. No sieve analyses of materials were done; estimates of porosity, permeability, and hydraulic conductivity were made from surficial exposures (DeSimone, 1991). Recharge potential will also be dependent upon the areal extent of the aquifer unit. Recharge is supplied foremost by direct rainfall. Throughout the year, streambeds may receive discharge from an unconfined

Figure 19 Porosity and texture in unconsolidated sediments and bedrock (from Meinzer, 1923)



a. well-sorted sediment having high porosity
b. poorly sorted sediment having low porosity
c. well-sorted sediment consisting of porous lithic fragments with very high porosity
d. well-sorted sediment with porosity diminished by interstitial cementation
e. bedrock rendered porous by solution
f. bedrock rendered porous by fracturing

aquifer; during high discharge events, however, the streambed may also supply recharge to the aquifer.

A summary of surficial geologic deposits and their hydraulic properties appears in Table 6.

"1s"

The best sediment for developing a surface aquifer will consist of well-sorted sand and gravel. Porosity and permeability and, hence, hydrauilic conductivity are highest in these materials. The northernmost section of the valley is underlain by ice-contact sediments, largely kamic in form, with sediment thicknesses upwards of 100 feet. Several eskers are also preserved in this region. These sediments are saturated at depth and typical well yields range from 10 to 50 gallons per minute. This area has been assigned the highest grade of "1s".

"2s"

Elsewhere, ice-contact materials contain a higher percentage of finer sediment, especially in moraine-type deposits. The silt content in the sediment lowers the hydraulic conductivity, and so these regions have been designated "2s". Sand and minor gravel are characteristic of alluvial deposits. At the southern end of Furnace Brook, alluvial deposits of sand and gravel are laterally extensive. These sediments have also been assigned grades of "2s".

"3s"

Regions that have been graded "3s" can be divided into several

Table 6
Geologic description and hydraulic properties
of surficial deposits
(adapted from Bierman et al., 1988)

Geologic Unit	Depositional Process	Description	Thickness	Hyrdraulic Conductivity K = m/day
ALLUVIUM	1. fluvial	stratified sand, gravel and silt	thickest near tributaries	.001 to 1
	2. alluvial fan	stratified sand, gravel and silt	thickest near trunk stream	.001 to 10
GLACIO FLUVIAL	1. ice marginal and englacial	stratified sand and gravel	thickest near outwash heads and valley walls	1 to 100
	2. debris flows	unsorted debris	variable but genarally thin	1 to 100
TILL	emplaced at base of ice	unstratified poorly sorted sand, silt, clay and gravel	dependent upon original thickness and subsequent erosion	.0001 to 1 but variable

categories: alluvial fans, floodplain alluvium, and zones of contribution to ice-contact sediments. The largest such region underlies the city of Bennington and consists of an alluvial fan deposited by the Roaring Branch of the Walloomsac River. This fan is roughly 9.5 miles long and 3.5 miles wide. Its thickness may reach 80 feet (Plate IV, section I; Appendix A, well-log: B40). The sediment is largely sand and gravel with lesser quantities of silt. A second and smaller fan with similar sediment texture is located southwest of Hale Mountain. Alluvial floodplain sand with minor gravel deposits are thinner and smaller in areal extent then the "2s" alluvium deposits. The northern end of the Furnace Brook valley north of Snow School on East Road is one example. The "3s" classification has also been assigned to areas which are zones of contribution to the ice-contact sediments of the "2s" regions. Groundwater flow paths suggest that any rainwater falling in the "zone of contribution" will infiltrate the laterally-adjacent ice-contact zones (O'Donnell, 1984). The boundaries of these up-gradient recharge areas are defined by the topography.

<u>"4s"</u>

Variable but generally low recharge is characteristic of the areas which have been graded "4s". The sediment in these areas contains a high percentage of silt and clay. Such deposits are typical of floodplains, where high-discharge events deposit these fine sediments as overwash. Similar silt-rich sediments are characteristic of lacustrine deposits; the area around Lake Paran has been designated "4s".

"5s"

The regions which have been designated "5" for the bedrock aquifers also function as "5s" for the surface aquifers. No distinction between recharge for bedrock and surface aquifers is necessary in grading these areas.

An estimation of potential annual recharge into the various geologic units in the study area appears in Table 7.

Table 7
Estimated annual recharge into geologic units from precipitation

Surface Deposit	Recharge inches/yr
Sand and gravel	20
Sandy till	5 to 10
Silt-rich till	5
Silt and fine sand	<<5

Note: Based on average basin precipitation of 45 inches per year and average evapotranspiration of about 20 inches per year. Recharge amounts were estimated from data in Handman (1986)(After Dethier et al., 1989).

RECOMMENDATIONS FOR THE PROTECTION OF AQUIFERS AND RECHARGE AREAS

Protection of recharge areas will be crucial in the forthcoming years as the southern Vermont region continues to be pressured by residential and industrial expansion and development. These recommendations are based on information that has been gathered and analyzed over the course of this study. Implementation of these suggestions in some form should help to ensure that the residents of Bennington and Shaftsbury will be provided with potable water resources in the future. A summary of these recommendations appears in Table 8.

The unconfined sand and gravel aquifers are the least protected groundwater resource in the Bennington and Shaftsbury area. These deposits cannot be properly protected from surface pollutants. Shallow wells drilled into these sediments in areas of residential development, particularly in the vicinity of industry or within urban city limits, are especially vulnerable and should be eliminated. If such wells cannot be eliminated, regular monitoring and testing of well-water quality is encouraged. Possible contamination should be immediately confirmed and reported. Future shallow wells should be discouraged by town ordinances as they are too easily contaminated.

In the coming years, the bedrock aquifer systems and the confined sand and gravel aquifer systems should be utilized as the primary water resources in the area. These aquifer systems will be able to provide the highest yield wells. The recent propensity for clustered community developments has necessitated a need for such high yield wells. Given the nature of Pleistocene and Holocene deposits, these aquifer systems are best protected against possible contamination from surface pollutants.

Table 8
Summary of recommendations for the protection of water resources

1. Protection of recharge areas (1,1s,2,2s) for bedrock and confined sand and gravel aquifers:
   - limit quarrying activity and residential development
   - housing density in same zones should not exceed 1 house per acre
   - require hydrogeologic investigations for any non-sewered subdivision to assure that no polluted waste leaves the site
   - prohibit landfills and auto-salvage industries

2. Require more rigorous design of leaching fields to avoid nitrate pollution, particularly in high recharge potential areas for unconfined aquifers; no leaching fields where percolation rates exceed 2 inches per minute

3. Restrict use of underground tanks containing petroleum products, herbicides, or other potentially hazardous materials

4. Discourage the use of "backyard" fertilizers, pesticides and herbicides; promote chemical-free farming practices

5. Decrease the amount of salt put on roadways, particularly in high recharge potential areas; adopt safer deicers if economically feasible

6. Carefully monitor and test water-quality of poorly protected unconfined sand and gravel aquifers; wells into such deposits should be discouraged

7. Educate and inform residents about potential hazards; public awareness and cooperation are crucial

The low permeability and hydraulic conductivity of overlying thick till deposits will help to protect the buried sand and gravel aquifer and the bedrock fracture systems from surface contaminants. Inferred upward groundwater flow vectors in the deepest portions of the valley should further inhibit the infiltration of contaminants (Morrissey, 1987).

Protection of the bedrock aquifer and buried sand and gravel aquifer systems most focus on the protection of recharge areas. Most recharge enters the bedrock aquifer system in the uplands of the Green Mountains and in the vicinity of West Mountain where till deposits are thin and scattered. Fortunately, the Green Mountain National Forest will serve to protect much of the high potential recharge area. Steep slopes in the vicinity of West Mountain should help to limit development in other high recharge areas.

The least protected area with high recharge potential is the extensive ice-contact deposit to the east and northeast of Shaftsbury Center. This low-lying, generally flat area has not yet been heavily developed. However, an extensive sand and gravel quarrying operation in the esker east of the Rutland Railroad may threaten the safety of this recharge zone. Expansion of quarrying activity and future residential development should be carefully monitored in this area. Persky (1986) suggested that housing density, where septic systems are used, should not exceed one house per acre in areas underlain by ice-contact sand and gravel. He demonstrated that housing density shows a direct relationship to nitrate contamination. Clearly, no landfills of any kind should be allowed in this area.

Although certain areas have been identified as having high potential for aquifer recharge (1,1s,2,2s), any area of potential recharge should be carefully protected (also 3,3s,4,4s) while development in these latter areas can be more easily accomodated. Landfills should not be considered for these areas. State and county regulations should prohibit the disposal of particularly harmful substances; such items include paint, gasoline, pesticides, automobiles, and batteries.

Other land use activities present potential problems in aquifer recharge zones. The widespread use of pesticides and fertilizers could lead to the contamination of groundwater supplies (Hallberg, 1988; Thorp, 1989). Non-essential use of these items should be reduced or eliminated. As these items may be necessitated by farming activities, the use of such products cannot be prohibited. Nitrate contamination is also a threat in agricultural areas (Plumb and Morrisette, 1988). It is therefore recommended that regular monitoring and testing of wells near large farms be undertaken. The agricultural landowners must take responsibility for the protection of groundwater supplies beneath their lands. Town and county regulations should require the landowners to submit water quality reports annually. Any contamination should be immediately reported. Educational programs at the town or county level could encourage the use of safer farm chemicals and gradually promote chemical-free farming practices.

Another potential hazard to groundwater resources is the use of highway deicers. Many wells in the Northeast have been seriously contaminated by sodium chloride, NaCl, the most widely used deicer (Frimpter, 1987; White, 1987). Excessive sodium in human diets is a health hazard, having been linked to cardiovascular, kidney, and liver diseases; there is also a proven relationship between hypertension and sodium chloride intake (White, 1987). Excessive chloride concentrations may interfere with the normal stratification and mixing patterns of standing bodies of water (Bubeck and Burton, 1989). Low-cost, less harmful substitutes for NaCl are presently unavailable; the use of sand with less salt or no salt is the only economic alternative. It is recommended that the use of salt in high recharge potential areas be decreased or eliminated on secondary roads with application to primary roads done in a more timely and economical fashion. Personal observtions suggest that pre-storm salting in not effective, but that salt should only be applied after the roads have been plowed. Should a reliable substitute become available, it should be adopted for use in these areas. Although the costs are presently prohibitive, studies have shown that calcium magnesium acetate (CMA) is one such safer substitute (Amrhein and Strong, 1990).

As final preventative measures, the towns of Bennington and Shaftsbury would be wise to utilize regulatory to encourage development in areas with low aquifer recharge potential. The institution of a well-organized well-water testing and monitoring program could prove invaluable for identifying and hopefully averting potential groundwater problems. Homeowners are encouraged to have water quality tests conducted periodically.

The responsibility for the protection of the water resources will ultimately rest upon the residents and industries in the Bennington and Shaftsbury area. Public awareness, cooperation and education is crucial.

CONCLUSIONS

The towns of Bennington and Shaftsbury, Vermont receive groundwater from three major aquifer systems: a bedrock aquifer, a confined sand and gravel aquifer, and an unconfined, near-surface sand and gravel aquifer. The nature of these aquifers is a product of bedrock lithology, Pleistocene glacial deposits, and Holocene alluvial deposits.

The bedrock aquifer system is developed in all the major lithologic units previously identified in the study area. This aquifer is encountered by wells drilled into carbonate, phyllite/schist, quartzite and granite/gneiss units. Wells encounter water flowing in bedrock fracture systems. Wells which provide the highest yield are in carbonate rock, where dissolution processes have enlarged the fracture systems. Wells with adequate yield range in depth from 100 to 300 feet in all lithologies; wells deeper than 400 feet typically have low yields. High quantities of recharge enter the bedrock aquifers in uplands, where till is scattered and thin or where permeable unconsolidated sediments directly overly bedrock. These aquifers are well-protected from surface pollutants but care should be taken to preserve recharge areas.

The confined sand and gravel aquifer system exists in deep paleo-valleys cut into a bedrock surface that may be of Cretaceous age. These sand and gravel deposits could consist of pre-Woodfordian alluvium and/or Late Wisconsinan proglacial sediments. The continuity and extent of these deposits is uncertain. Yields from wells drilled into these deposits are comparatively high; well depths range from 40 to 290 feet. These aquifers are hydraulically connected to the bedrock fracture systems from which they receive recharge. This water resource is well-protected from surface pollutants by the confining layer of overlying impermeable till.

The unconfined near-surface aquifer is developed in Late Pleistocene ice-contact sediment and Holocene stream alluvium. In wells tapping this aquifer, reported yields range from 5 to 40 gallons per minute and wells rarely exceed 150 feet in depth. These aquifers receive recharge directly from meteoric precipitation and are not protected from surface pollutants.

Protection of these water resources depends ultimately upon the protection of recharge areas. Guidelines regulating the locations of landfills, industry, and residential development and the use of pesticides, fertilizer, and roadway deicers should be formulated by the towns of Bennington and Shaftsbury. It is strongly recommended that a comprehensive well-water testing and monitoring program be established.

Appendix A

Selected Well-logs

Bennington Wells

B06

0-10 ft.	clayey gravel
10-25	clay
25-60	hardpan
60-70	sand and gravel

B40

0-90 ft.	clay (floodplain)
90-125	limestone

B50

0-1 ft.	topsoil
1-4	brown sand, some clay
4-24	light-brown, fine and coarse sand
24-34	coarse sand and gravel
34-41	fine and medium sand with fine gravel
41-43+	gray till

B154

0-6 ft.	sandy loam
6-11	stony
11-40	sand
40-50	hardpan and gravel
50-60	white clay hardpan
60-68	coarse sand and gravel

Shaftsbury Wells

S03

0-30 ft.	till
30-230	limestone or marble

S08

0-25 ft.	boulders and gravel
25-100	hardpan
100-335	rotten marble
335-350	blue marble

S43

0-50 ft.	hardpan
50-190	clay (till)
190-335	limestone

S48

0-10 ft.	packed gravel
10-155	marble

S63

0-165 ft.	hardpan, gravel and boulders
165-200	very soft brown rock

S74

0-150 ft.	sand and gravel
150-275	marble

S76

0-11 ft.	packed gravel
11-200	limestone

S95

0-50 ft.	boulders and hardpan
50-150	packed gravel and hardpan
150-185	clay
185-200	gravel

S96

0-50 ft.	boulders and hardpan
50-130	packed gravel and hardpan
130-150	sand
150-160	clean gravel

S118

0-120 ft.	sand and packed gravel
120-280	clay and hardpan
280-290	coarse gravel

S120

0-95 ft.	gravel and sand
95-270	hardpan
270-283	coarse gravel

S183

0-90 ft.	gravel
90-210	sand
210-240	marble

S201

0-40 ft.	clay
40-50	volcanic ash and ochre
50-60	stony gravel

S242

0-20 ft.	gravel
20-70	fractured bedrock
70-90	ochre

S256

0-40 ft.	fine loamy sand and boulders
40-184	fine fine sand
184-200	fractured limestone and ochre

S279

0-12 ft.	medium gravel
12-190	hardpan and boulders
190-242	grey limestone

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Well Locations and Cross-Section Transects
Bennington and Shaftsbury, Vermont

Randon M. Jerris
Department of Geology
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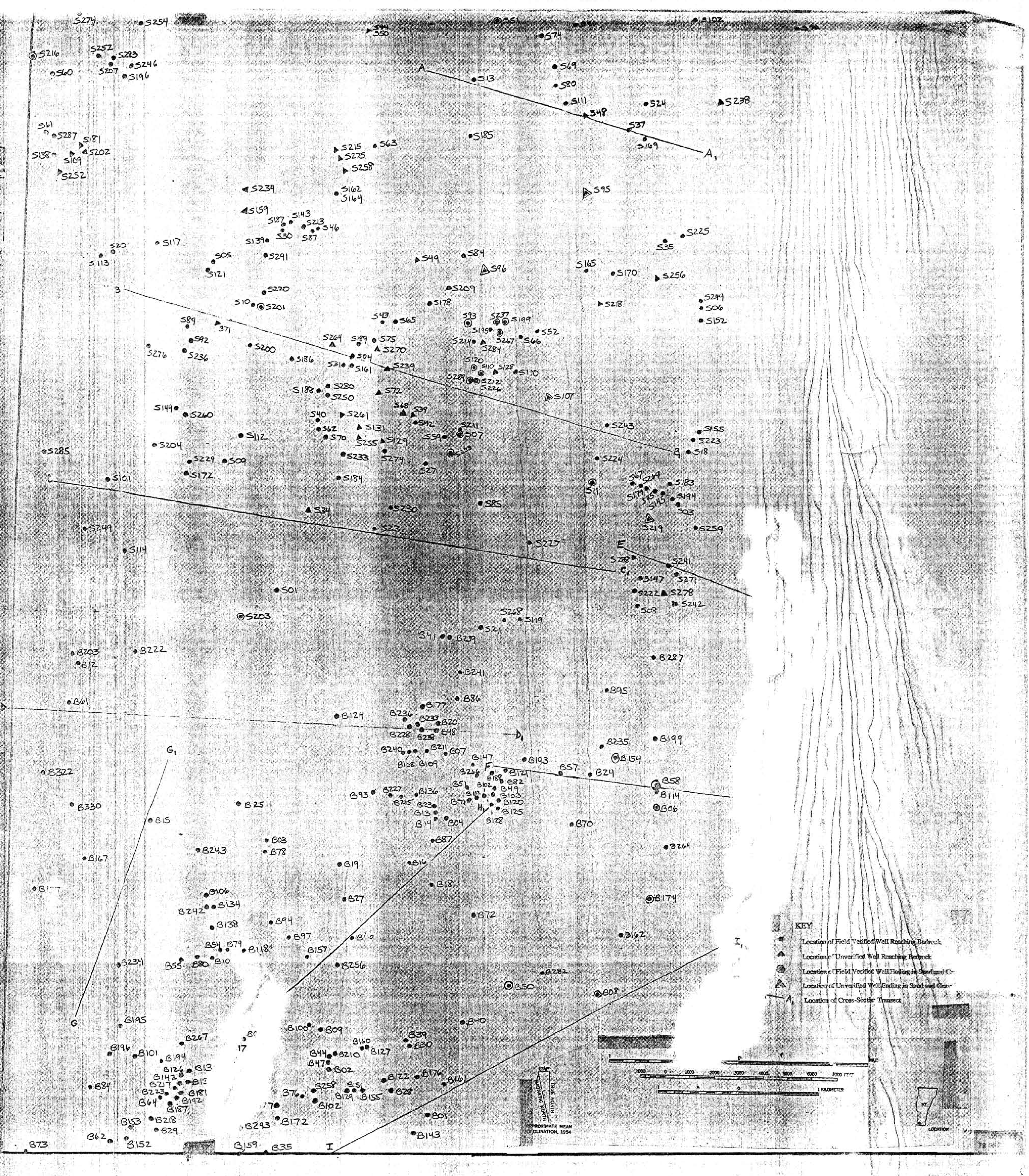
1991

WELL NUMBER	ELEVATION AT TOP OF WELL	BEDROCK SURFACE ELEVATION	PIEZOMETRIC SURFACE ELEVATION	YIELD (GPM)
B01	820	790	?	20
B02	830	800	820	12
B03	590	570	565	5.5
B04	750	740	730	4
B05	790	620	760	7.5
B06	900	<830	870	4
B07	815	810	795	6
B08	670	<640	660	20
B09	850	835	?	8
B10	760	740	735	1.5
B12	560	535	?	1
B13	740	670	710	7
B14	720	670	705	10
B15	540	530	525	10
B16	620	600	?	5
B17	800	740	^	5
B18	610	580	660	6
B19	585	570	545	15
B20	800	620	780	4
B23	750	720	735	30
B24	860	860	810	3
B25	560	540	?	20
B27	573	550	535	50
B28	800	780	785	8
B29	845	840	815	15
B30	825	745	805	6
B35	1045	1030	885	50
B39	840	825	820	4.5
B40	690	590	640	4.5
B41	780	650	740	15
B44	830	825	820	10
B47	825	820	805	30
B48	805	800	785	10
B49	880	800	800	4
B50	620	<590	615	34
B51	815	780	780	15
B54	760	<640	?	5
B55	775	760	770	2
B57	900	800	805	10
B58	930	<730	880	6
B61	635	620	?	3
B62	850	800	830	30
B64	835	839	825	6
B70	820	690	740	3
B71	830	820	810	3
B72	580	550	^	18
B73	810	750	805	5
B76	875	860	855	4
B77	890	875	?	3
B78	620	570	600	8
B79	770	760	755	2
B80	760	680	720	3
B82	910	740	^	10
B84	940	830	920	8
B86	820	640	810	3
B87	670	640	650	20
[illegible]	620	[illegible]	420	86
[illegible]	825	[illegible]	775	2
B93	1000	[illegible]	975	3

WELL NUMBER	ELEVATION AT TOP OF WELL	BEDROCK SURFACE ELEVATION	PIEZOMETRIC SURFACE ELEVATION	YIELD (GPM)
B97	855	800	835	20+
B100	815	790	810	5
B101	800	790	785	5
B102	900	890	870	.5
B103	870	760	865	5
B106	730	710	700	45+
B108	730	610	715	15
B109	730	650	735	10
B112	840	810	820	10
B114	920	?	900	4
B118	810	700	770	6
B119	610	570	605	1
B120	890	880	790	4.5
B121	950	840	930	15
B122	800	790	785	30+
B124	700	670	670	.5
B125	855	840	825	4
B126	830	830	810	1
B127	820	785	800	5
B128	840	830	810	10
B129	830	820	810	1+
B130	850	820	835	10
B134	760	740	730	2
B136	705	650	690	80
B137	660	660	650	12
B138	750	720	730	2
B139	850	800	830	6
B142	840	790	820	5
B143	850	830	830	3
B147	865	860	835	20
B151	830	800	815	11
B152	870	740	850	40
B153	880	710	850	11
B154	900	<830	885	9
B155	825	810	810	11
B157	825	740	810	15
B159	1040	940	960	20
B160	820	810	805	10
B161	740	730	660	25
B162	840	800	800	25
B167	585	560	550	5
B172	920	850	910	5
B174	840	<750	810	5
B176	800	780	540	15
B177	750	700	730	12
B181	850	730	830	10
B187	850	820	830	3
B188	720	840	?	7
B192	860	700	?	7
B193	950	950	940	4
B194	780	730	760	4
B195	860	860	845	2
B196	860	830	?	10
B199	980	920	?	7
B203	560	540	?	20
B210	840	830	825	7
B211	765	760	745	8
B215	670	655	^	12

WELL NUMBER	ELEVATION AT TOP OF WELL	BEDROCK SURFACE ELEVATION	PIEZOMETRIC SURFACE ELEVATION	YIELD (GPM)
B217	830	800	815	5
B218	850	840	835	8
B222	670	640	?	.5
B223	835	800	825	5
B227	630	610	625	25
B228	750	720	?	10
B233	750	740	720	10
B234	765	640	730	15
B235	940	920	885	8
B236	750	740	730	15
B238	765	740	740	25
B239	775	710	715	15
B240	715	710	615	9
B241	790	670	?	20
B242	740	-720	710	30
B243	590	570	570	50
B256	640	620	620	1
B258	880	870	860	3
B264	900	830	870	15
B266	880	873	840	7.5
B267	820	785	780	1
B282	630	550	590	7.5
B287	1035	1000	1020	5
B293	960	860	930	6
B322	580	560	565	1
B330	530	530	510	1.5




Valley Cross-Sections
Bennington and Shaftsbury, Vermont
Randon M. Jerris
KEY
Alluvium; sand with minor gravel
Alluvium; gravel with minor sand
Alluvial fan; silt, sand and gravel
Esker; sand and gravel
Kame; sand and gravel
Glacial moraine; silt, sand and gravel with interbedded till
Glacial till
For location of cross-section transects see Plate 1.
Well locations are indicated across the top of each section.
A well number followed by a "P" indicates a well location that has been projected onto the section.
1 MILE
7000 FEET
1 KILOMETER
Vertical Scale 1 inch = 100 feet
Vertical Exaggeration 20 : 1
Elevation in feet above sea level.

Piezometric Surface Map
Bennington and Shaftsbury, Vermont

Randon M. Jerris
Department of Geology
Williams College
1991

KEY

Contour Line
(contour interval: 50 feet)

Projected Contour Line

1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 KILOMETER

TRUE NORTH

MAGNETIC NORTH

APPROXIMATE MEAN DECLINATION, 1954

VT.

LOCATION

Overburden Thickness Map
Bennington and Shaftsbury, Vermont

Randon M. Jerris
Department of Geology
Williams College
1991

KEY

Contour Line
(contour interval: 50 feet)

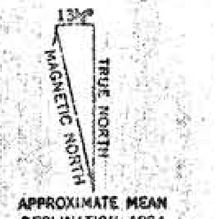
Thick Till - Thin Till Contact
(thin till < 10 feet)

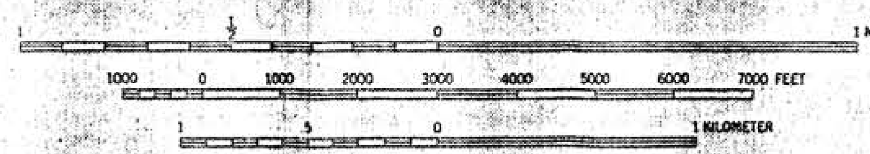
Bedrock Surface Elevation Map
Bennington and Shaftsbury, Vermont

Kandon M. Jerris
Department of Geology
Williams College
1991

KEY

Contour Line
(contour interval: 100 feet)





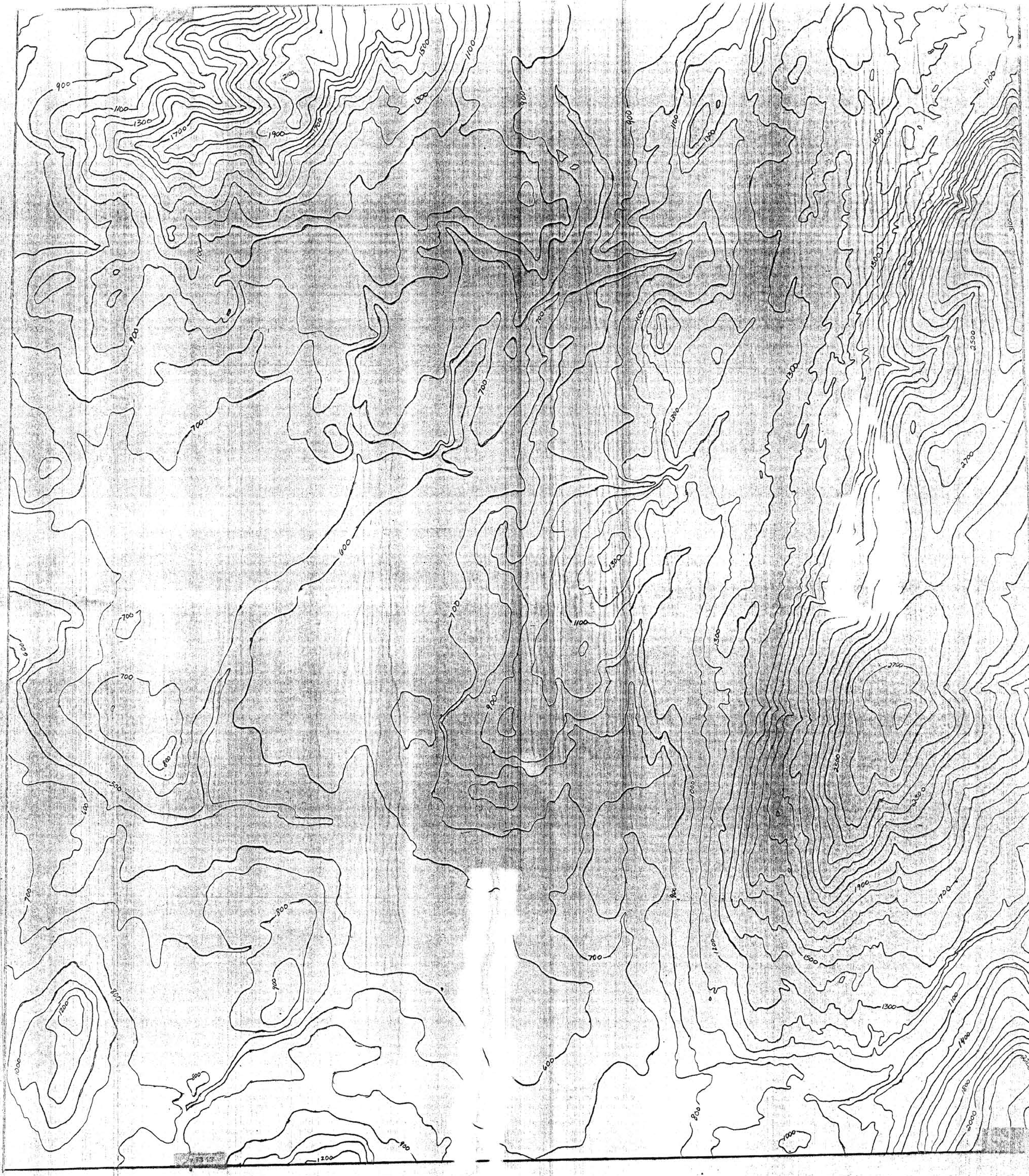
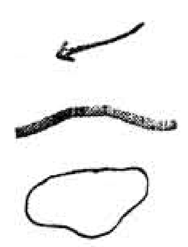


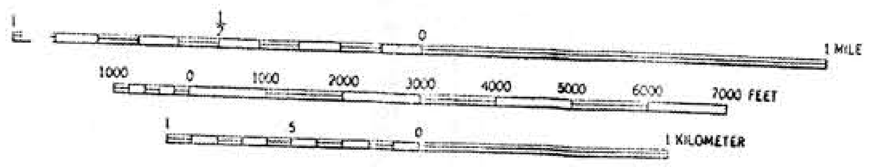
PLATE VI

Groundwater Flow Net
Bennington and Shaftsbury, Vermont

Randon M. Jerris
Department of Geology
Williams College
1991

KEY





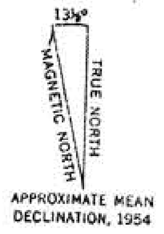
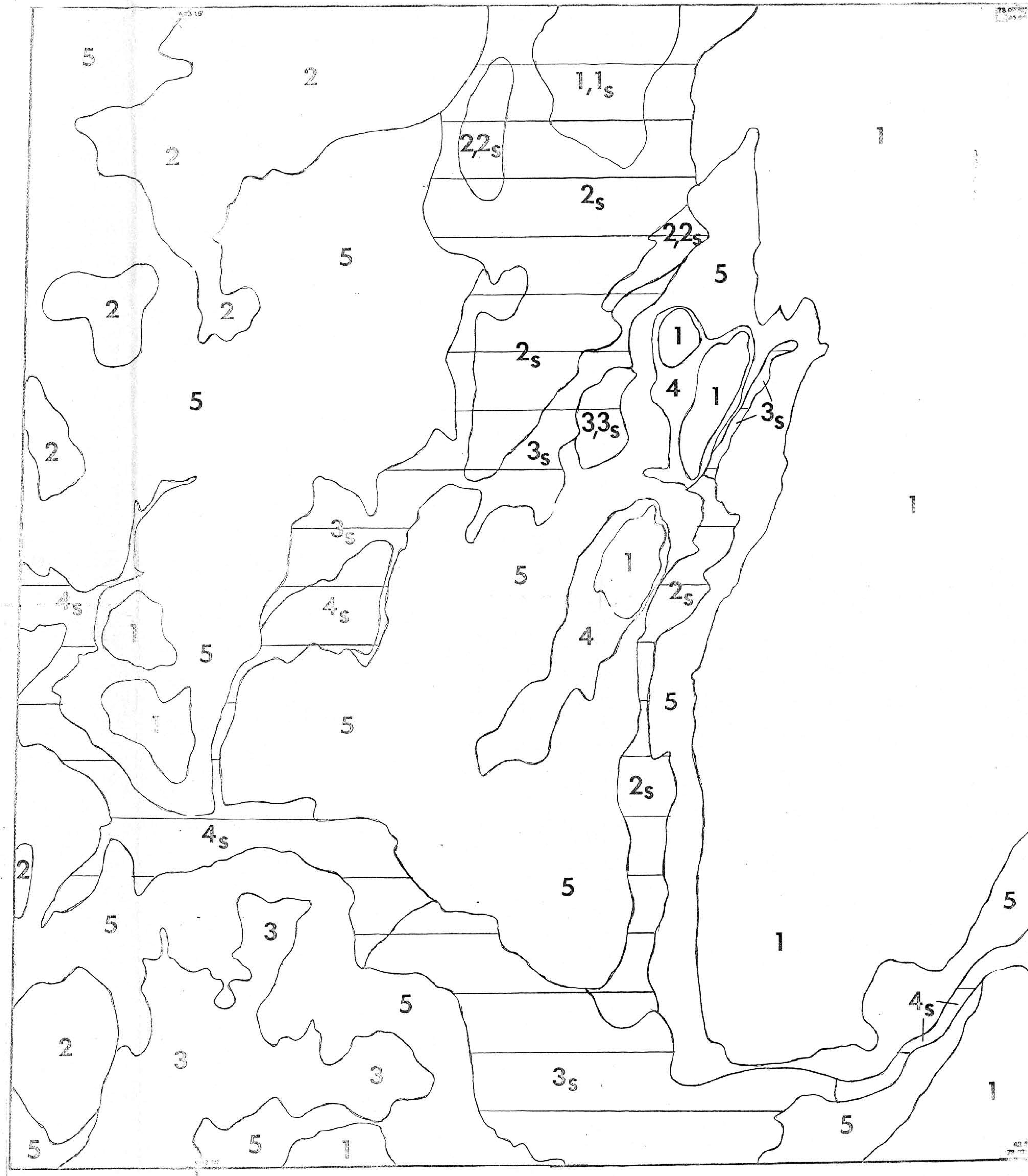


PLATE VII

Aquifer Recharge Potential Map
Bennington and Shaftsbury, Vermont

Randon M. Jerris
Department of Geology
Williams College
1991



KEY

Bedrock Aquifers (Unruled Areas)	Surface Aquifers (Ruled Areas)
1 Highest	1s Highest
2 High	2s High
3 Moderate	3s Moderate
4 Variable/Low	4s Variable/Low
5 Low	5s Low

NOTE: Recharge areas may function for both bedrock and surface aquifers. These areas are indicated by two grading symbols in the form #,#s.

1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 KILOMETER

TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 1954

VT.
LOCATION