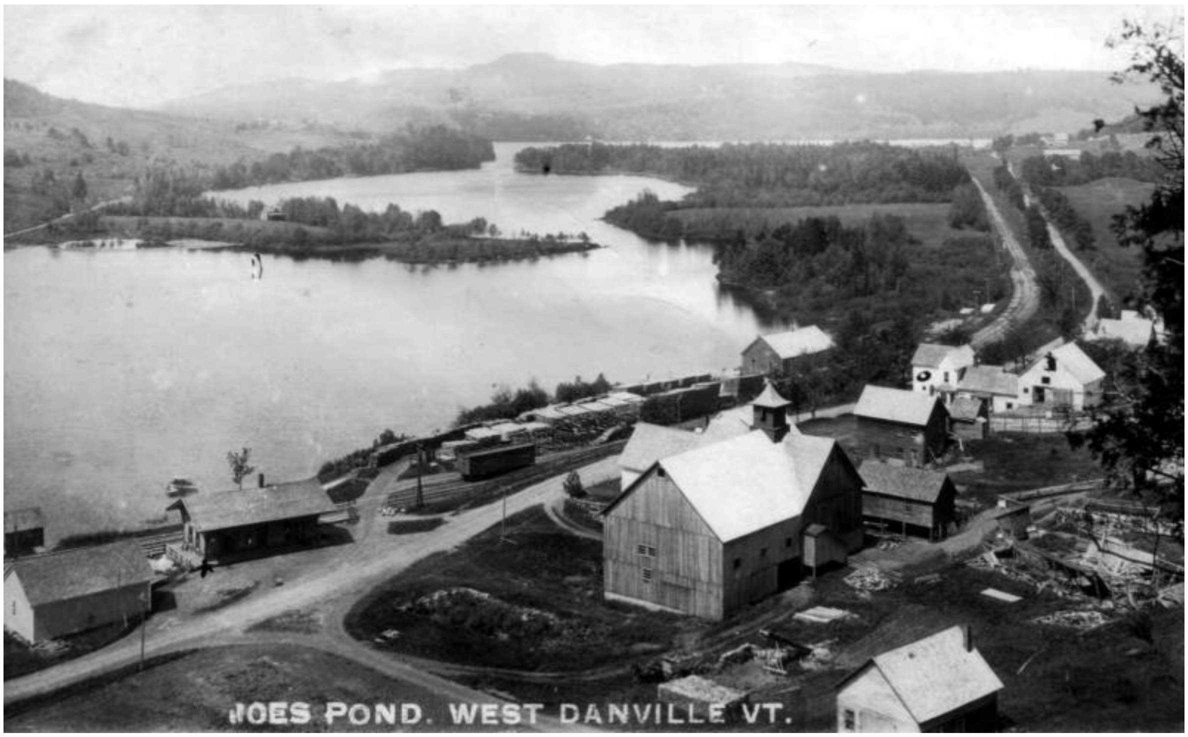
Vermont Geological Survey Open File Report VG2018-3: Surficial Geology and Hydrogeology of the Joes Pond 7.5 Minute Quadrangle, Vermont



George Springston
Norwich University Department of Earth and Environmental Sciences
Northfield, VT 05663
gsprings@norwich.edu

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1 National Life Dr., Davis 2, Montpelier, VT 05620-3902

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On the cover: View looking west from West Danville across Joes Pond in 1913. Note the two sets of peninsulas that cut across the pond. These are interpreted as being moraine crests. Photo LS03800_000 from Vermont Landscape Change Program. Original from collection of Fairbanks Museum, St. Johnsbury.

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Executive Summary

The purpose of this project was to conduct 1:24,000 scale mapping of the surficial geology and groundwater resources of the Joes Pond 7.5 minute quadrangle.

Glacial till is the most widespread surficial material in the study area. It is generally dense to very dense, unsorted to very poorly sorted, fine-sandy-silt to silt matrix till. Exposures of fine-sand- to medium-fine-sand matrix till were encountered, mostly in the south-central portion of the quadrangle to the southeast of Joes Pond, in the vicinity of Keiser Pond and Harvey Hollow.

Anomalously thick till (> 30 meters or 100 feet) was encountered in two areas. These are in the northeastern portion of the quadrangle on the east flank of the Kittredge Hills and in the southwestern portion of the quadrangle to the southwest of Mollys Pond.

Striations and grooves in bedrock indicated that ice motion directions ranged from 155 to 181°. As in the Cabot quadrangle immediately to the west, striations and grooves were uncommon, especially when compared to the Woodbury quadrangle further west.

No evidence in support of the Danville Moraine of Stewart and MacClintock (1969) was found during this mapping. Where examined, the areas that had been mapped as moraine were generally thin till. Bedrock outcrops were common in these areas.

Although no evidence was found of the Danville Moraine, there is evidence of small ridges of till that appear to be moraines within and near Joe’s Pond. The two most prominent examples are the two pairs of peninsulas that extend most of the way across Joe’s Pond.

Ice-contact deposits are relatively sparse in the study area. Where seen, they consist of unsorted to poorly-sorted sand, gravel, and silt deposited in contact with glacial ice. Deformation features are common. A large but poorly-exposed area of ice-contact sand and gravel is located to the southeast of Joe’s Pond. Although an earlier interpretation suggests a kame terrace, the origin of this deposit is uncertain.

A better-exposed set of ice-contact deposits is seen in the northeast of the study area at Pierce’s Pit. Materials include deformed, bedded, pebble gravel, pebbly sand, medium to fine sand, and silt. The topographic form suggests a pair of kames.

Mean yields (in gallons per minute) of bedrock water wells are somewhat above the statewide average (20.2 gpm versus 14.0 gpm statewide) and depths of bedrock water wells are similar to the statewide average (285.0 feet versus 290.0 feet statewide).

Yields from wells in the Waits River Formation are higher than those in the Gile Mountain Formation (median yields of 10 gpm in the former versus 5 gpm in the latter).

No areas with high potential to serve as surficial aquifers have been identified in the study area.

Introduction

The study area is located in Washington and Caledonia Counties in northeastern Vermont on the Joes Pond 7.5 minute quadrangle (Figure 1). The area is ~53 square miles and includes parts of the towns of Cabot, Danville, Peacham, and Walden. The study area includes the southwestern portion of the USGS Sleepers River Research Watershed (SRRW).

The bedrock consists mostly by the Silurian to Devonian Waits River Formation and the Devonian Gile Mountain Formation, with the exception of an area in the southwest that is underlain by Devonian biotite granite (Figure 2, after Ratcliffe and others, 2011).

The Joes Pond quadrangle is located in the Vermont Piedmont physiographic province (Stewart and MacClintock, 1969). The terrain is generally rolling (Figures 3 and 4), with the steep east faces of the Kittredge Hills standing as exceptions. The stream network is shown in Figure 5. Most of the quadrangle (including the SRRW) is within the Passumpsic River watershed. A small portion in the south-central part of the study area is within the Stevens River watershed. The Passumpsic and the Stevens drain into the Connecticut River watershed. The southwestern corner of the study area is within the Winooski River watershed and the northwestern portion is within the Lamoille River watershed. The Winooski and Lamoille drain into Lake Champlain. Typical views of the landscape are shown in Figures 4 and 5.

General Surficial Geology

The surficial materials in the region are dominantly of glacial origin and were deposited in the late Pleistocene while the area was covered by the Laurentide ice sheet and during and shortly after the retreat of that ice. Typical of most of New England, the upland areas are covered by till that varies considerably in thickness, composition, and texture. Local glacial erratics are common. Large areas of the uplands consist of thin till and bedrock and many of the first-order streams have cut down to bedrock. Till in the stream valleys may be overlain by a variety of ice-contact sediments deposited during ice retreat. In much of the region, these in turn are overlain by sediments deposited in proglacial lakes. The present study area, however, is outside of the extents of the large regional proglacial lakes (glacial Lake Winooski to the west and glacial Lake Hitchcock to the east). The modern valley bottoms are also the sites of Holocene stream terrace and modern alluvial deposits. Small talus accumulations are seen at the bases of cliffs and colluvial (slope-wash) deposits are common on the lower portion of steep slopes.

Prior Work

Early reconnaissance surficial mapping within the Saint Johnsbury 15-minute quadrangle by David P. Stewart as reported by Stewart and MacClintock (1969) and shown on Doll (1970). This mapping delineated an extensive moraine complex (Danville Moraine) that extends across the quadrangle from southeast to northwest (Figure 5). Moore and Hunt (1970) studied the modern bottom sediment patterns of Joe’s Pond. Mapping by Springston and Haselton (1999a and b) to the east of the study area casts doubt on the existence of this moraine. The investigation of the Danville Moraine will be a major focus of the mapping. A wide-ranging study of the surficial geology of the Passumpsic River watershed, which makes up the northeastern quarter of the quadrangle, was undertaken by Newell (1970). The surficial geology of the St. Johnsbury 7.5 minute quadrangle, located to the east of the Joes Pond quadrangle, was mapped by Springston and Haselton (1999a and b). The USGS has undertaken a number of soil borings to determine depth to rock in the SRRW (Jamie Shanley, USGS, personal communication, Oct., 2012).

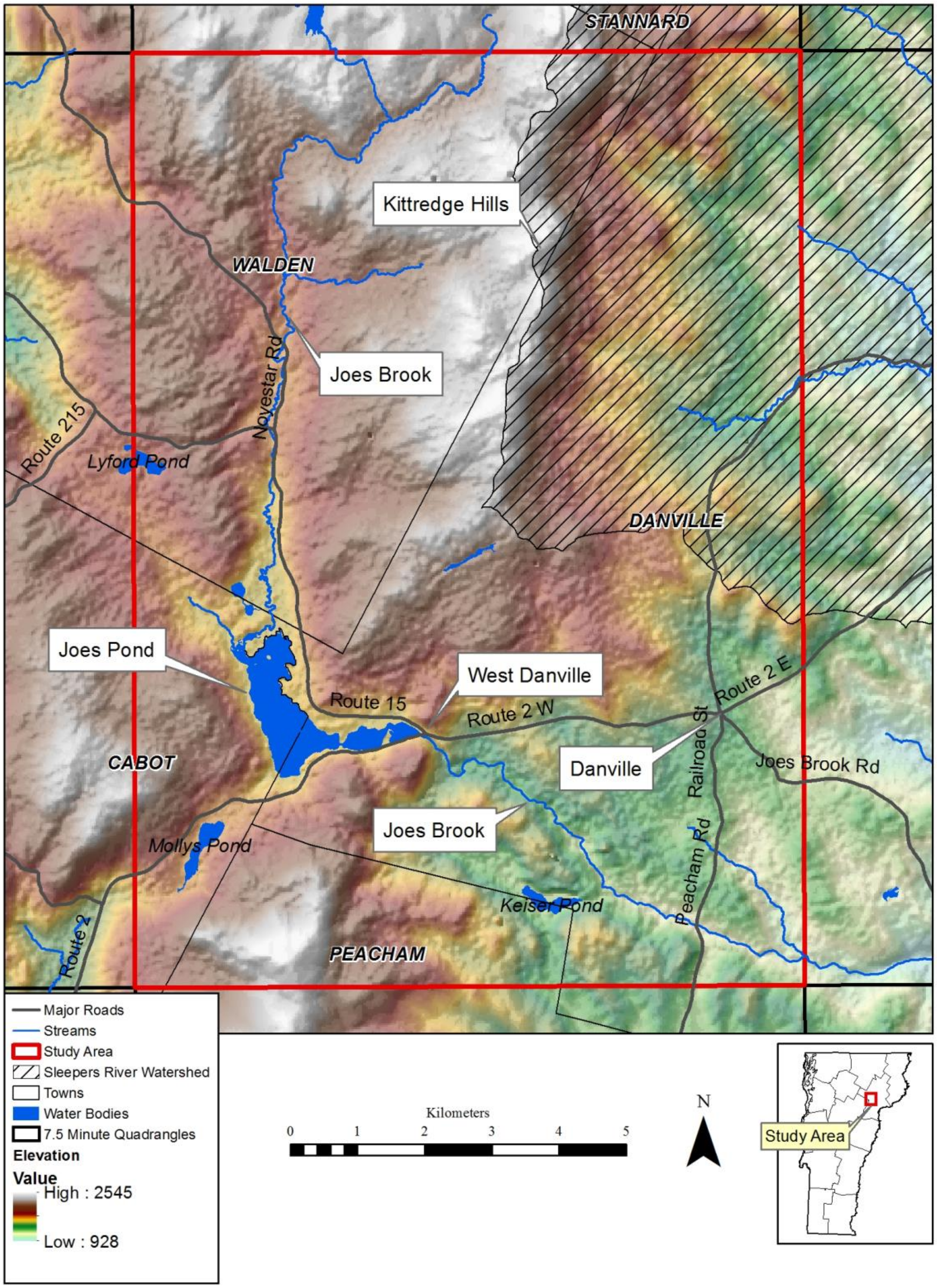

Figure 1. Location map.

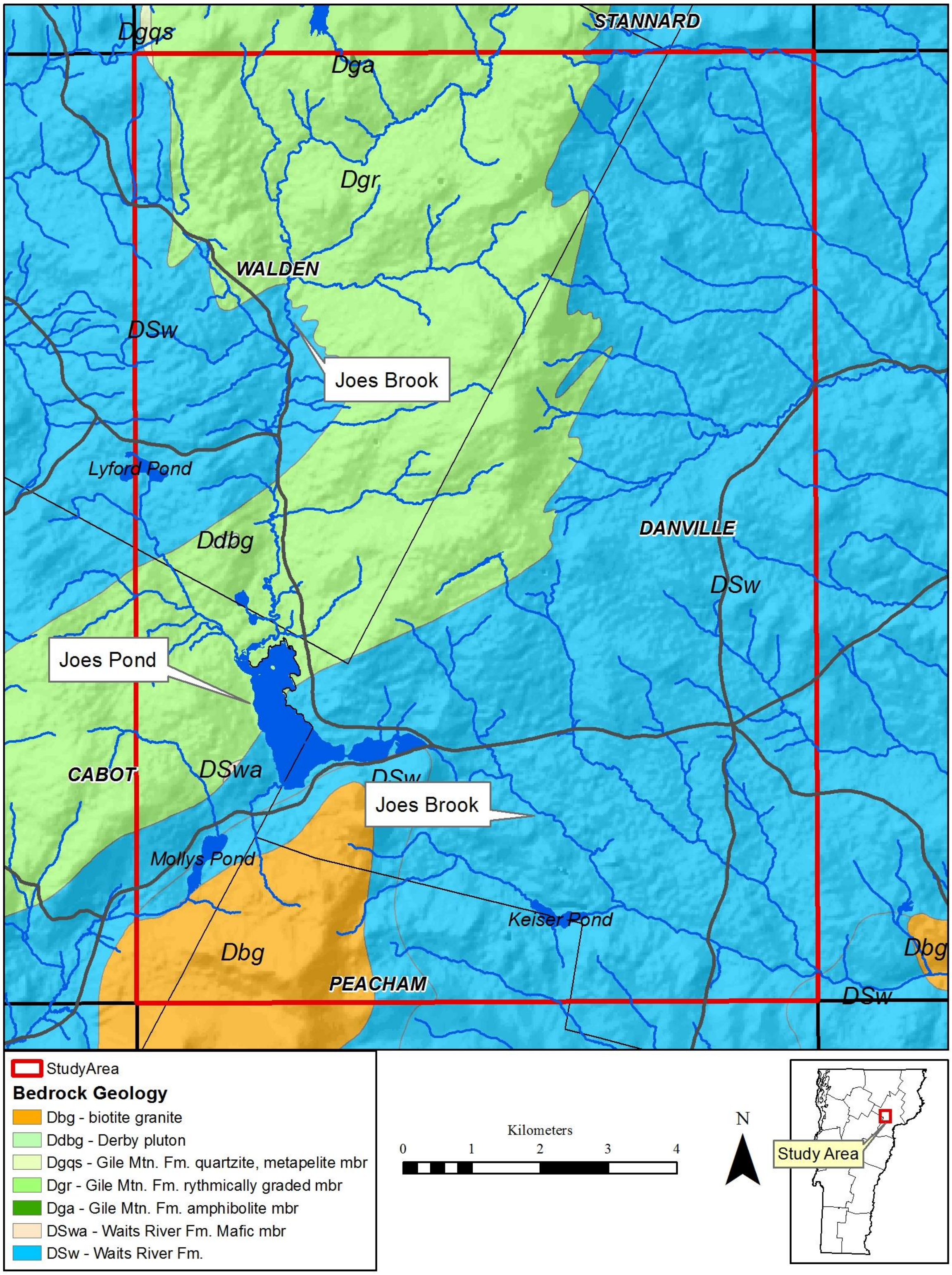

Figure 2. Bedrock geology (after Ratcliffe and others, 2011).

Figure 3. View looking northeast over the Sleepers River watershed from Coles Pond Road in the northeastern portion of the study area.

Figure 4. View of rolling hills of the Sawyer Brook valley in south-central part of study area. Taken from Barber Farm on Deweysburg Road looking northeast.

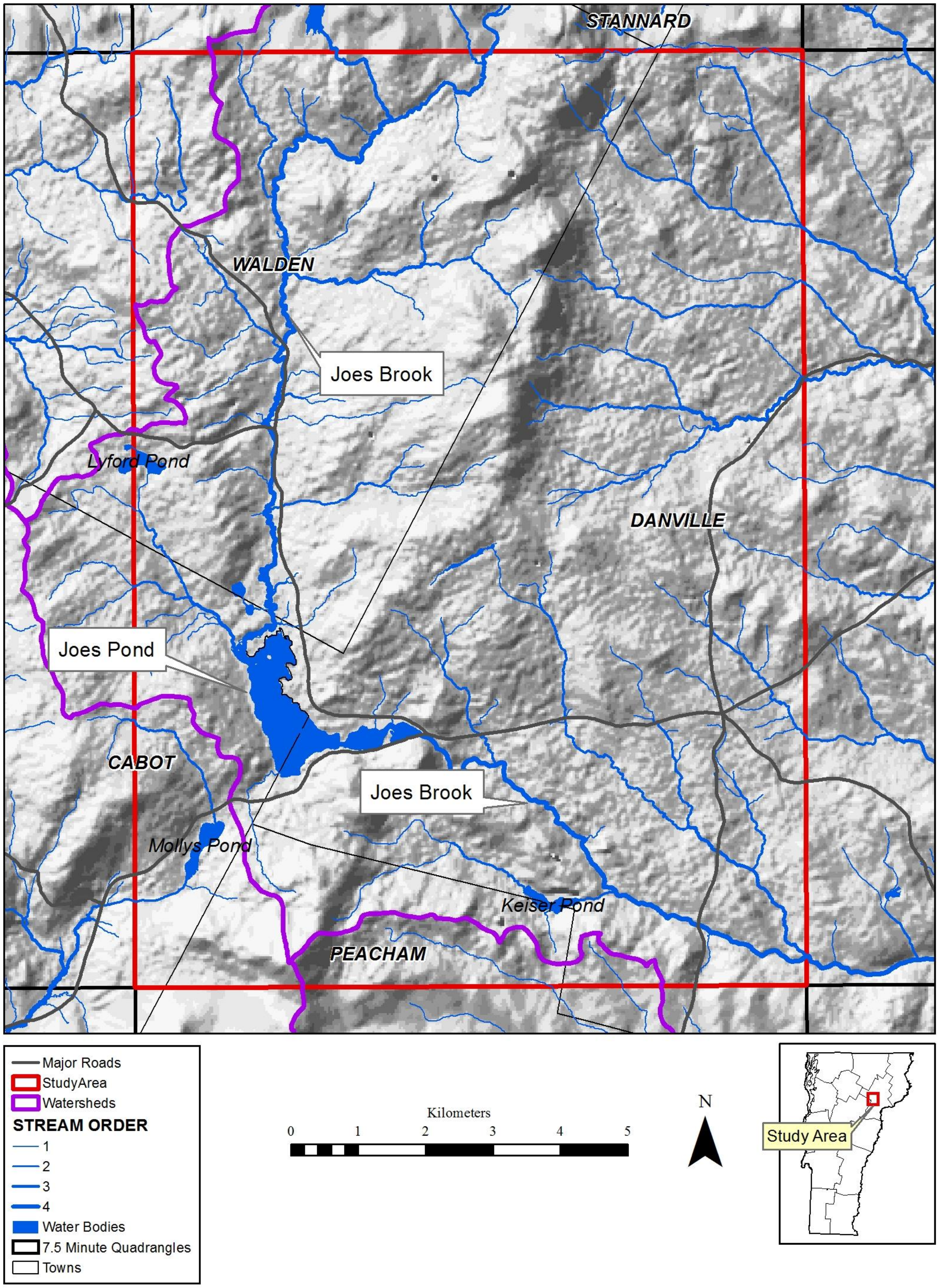

Figure 5. Watersheds and stream network.

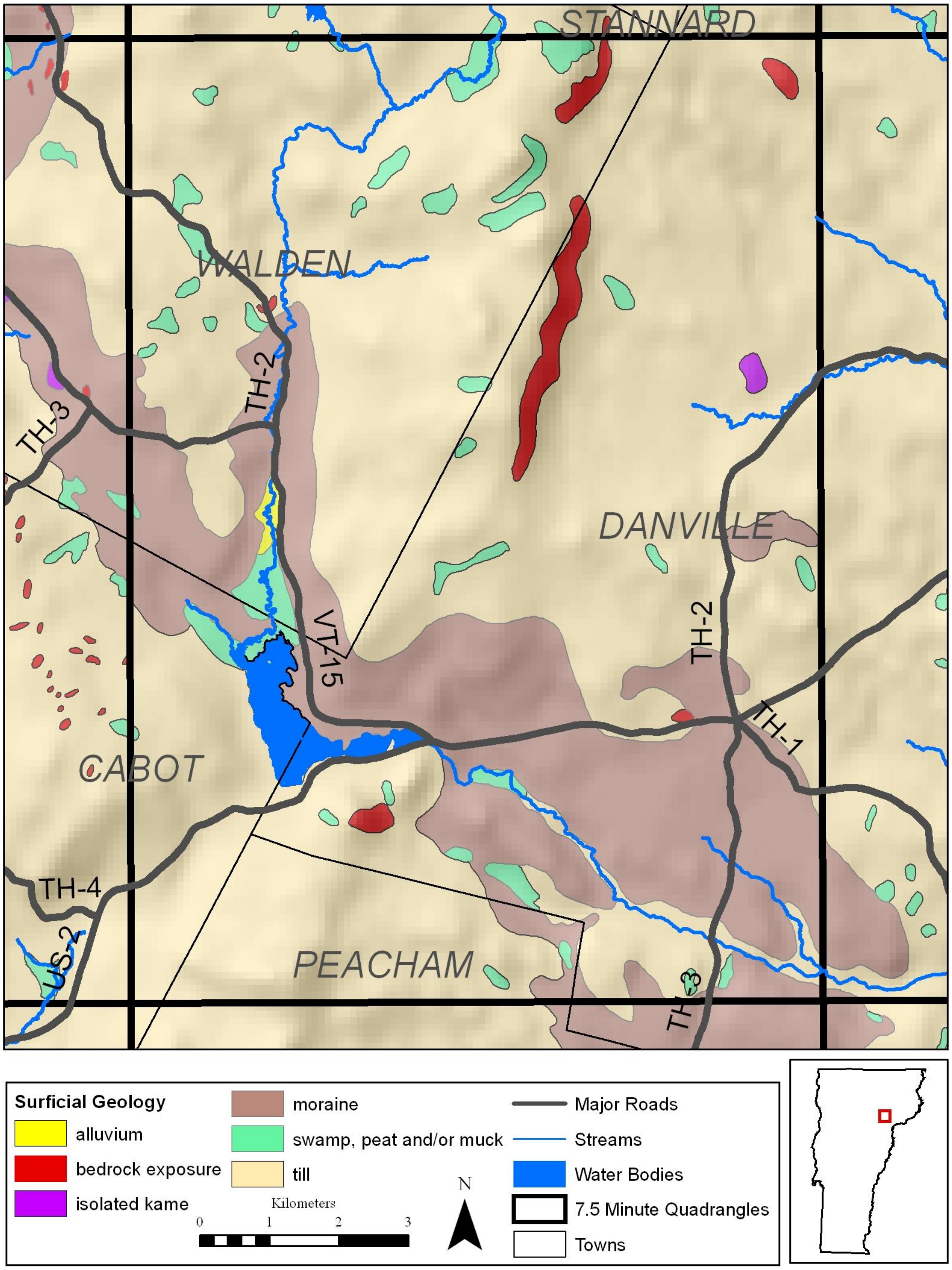

Figure 6. Reconnaisance surficial geology of the Joes Pond quadrangle, after Doll (1970). Based on 1:62,500 mapping by David P. Stewart. See discussion in text of the area shown as moraine.

Methods

Field work involved visits to 301 exposures of surficial deposits and 141 bedrock outcrops. The locations of approximately 300 bedrock outcrops were obtained from Hall (1959). Additional surficial geologic information was obtained by analysis of 102 water well logs. The logs were derived from databases managed by the Drinking Water and Groundwater Protection Division of the Vermont Department of Environmental Conservation. The water well locations are shown on Plate 1. As many of the older wells have uncertain locations, only wells with verified locations are used in this analysis. Newer wells with driller-reported GPS locations or E911 addresses are assumed to be close to the correct locations. Additional boring logs were obtained from the Vermont Agency of Transportation and from State records of hazardous waste sites. Descriptions of sand and gravel resources from 22 sites were obtained from Highway Materials Studies undertaken by the Vermont Agency of Transportation. All of the above are also shown on Plate 1.

Surficial Geology

Ice-movement Indicators

Striations and grooves in bedrock indicated that ice motion directions ranged from 155 to 181°. A typical example is shown in Figure 7. As in the Cabot quadrangle immediately to the west, striations and grooves were uncommon, especially when compared to the Woodbury quadrangle further west. No cross-cutting relationships were observed in this study area, but in the Woodbury quadrangle at station WO872 the 194° striations cross-cut the 164° striations and are thus younger. In the St. Johnsbury quadrangle at station SJ-60, Springston and Haselton (1999a) found excellent striae, which indicate that striae with a maximum of 185° cross-cut striae with a maximum of 135°. This relationship has been seen at many other sites in the region and Wright (2015) has interpreted this to suggest an earlier regional ice flow trending roughly 160° with a later more southerly re-orientation of flow.

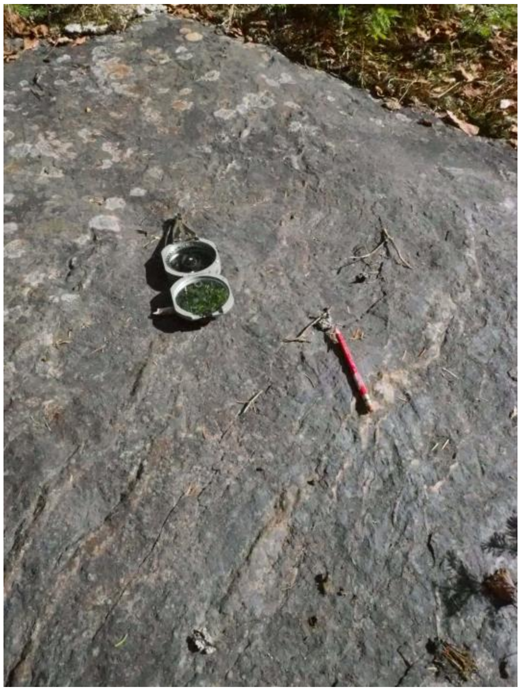

Figure 7. Glacial striations on phyllite outcrop. Compass and pencil parallel to striations oriented 159°. In northwest of study area on Old Duke Road, Station JP866.

Stratigraphy

Pleistocene Deposits

The Pleistocene deposits are greater than about 12,000 years old. Although the Pleistocene epoch extends back to between 1.8 million and 2.58 million years, all of the glacial deposits in the study area are believed to belong to the last stage of the Pleistocene, the Wisconsinan Glacial Stage, which extends from about 71,000 to 12,000 years before present.

Till in the study area is generally dense to very dense, unsorted to very poorly sorted, fine-sandy-silt to silt matrix till. Munsell color of relatively unweathered samples is commonly 5Y3/1 to 5Y3/2, but deep, unweathered samples range from N3/0 to N4/0. Surface boulders are common. Thickness of the till is highly variable, from less than 3 meters to greater than 30 meters. The areas mapped as till include small areas of talus (fans or aprons of fallen rock at the bases of cliffs) and colluvium (slope-wash deposits on the lower portions of slopes). Exposures of fine-sand- to medium-fine-sand matrix till were encountered, mostly in the south-central portion of the quadrangle to the southeast of Joes Pond, in the vicinity of Keiser Pond and Harvey Hollow. There, the sandy till is moderately loose and reddish brown (10YR3/2). Individual exposures of the sandy till are shown by symbols.

Anomalously thick till was encountered in two areas. These are in the northeastern portion of the quadrangle on the east flank of the Kittredge Hills and in the southwestern portion of the quadrangle to the southwest of Mollys Pond. Figures 8 and 9 show a thick exposure of the dense, unweathered silt till at site JP602. Figures 10 and 11 show a much more weathered till at site JP1, also with a silt matrix. Although the clast compositions appear superficially similar, it is unclear whether or not the till at site JP1 is simply a weathered version of the till at site JP602.

Figure 8. Exposure of dense silt till in landslide on Morrill Brook, Station JP602.

Figure 9. Closeup of freshly eroded dense silt till at Station JP602.

Figure 10. Excavation in weathered silt till at Site JP1, southwest of Keiser Pond. The material is weathered to a depth in excess of 2 meters.

Figure 11. Closeup of weathered silt till at Site JP1, southwest of Keiser Pond. Weathered clasts of phyllite and sandy marble are easily scraped with a trowel.

Ice-contact deposits are relatively sparse in the study area. Where seen, they consist of unsorted to poorly-sorted sand, gravel, and silt deposited in contact with glacial ice. Deformation features are common. A poorly-exposed area of ice-contact sand and gravel is located to the southeast of Joe’s Pond. The Highway Material Survey interpreted these materials as being part of a kame terrace. Due to lack of exposure, the origin remains obscure.

A better-exposed set of ice-contact deposits is seen in the northeast of the study area at Pierce’s Pit. Materials currently exposed include deformed, bedded, pebbly sand, medium to fine sand, and silt. The Highway Materials Survey reports pebble gravel as well. Figure 12 shows soft-sediment deformation in the deposit. The topographic form suggests a pair of kames.

Figure 12. Ice-contact sediments from kame deposit. Medium sand overlying find sand and silt showing soft-sediment deformation. From Pierce's Pit, located south of Morrill Road at Station SJ95.

Moraines

As discussed in Larsen and others (2003), there is substantial evidence in central Vermont for a late Wisconsinan readvance, which appears to correlate with the Bethlehem-Littleton readvance in New Hampshire (Thompson and other, 2017). More recent discoveries of thick dense till over lacustrine sediments at several locations in Washington County support this interpretation (Dunn and others, 2011; Dunn and others, 2015). Thick deposits in some of the valleys are reminiscent of till-over-lacustrine sequences seen in nearby areas, but no clear evidence of a readvance was found during this study.

Early reconnaissance surficial mapping within the St. Johnsbury 15-minute quadrangle by Paul MacClintock is reported by Stewart and MacClintock (1969) and shown on Doll (1970). This mapping delineated an extensive moraine complex (Danville Moraine) that extends across the quadrangle. Mapping by Springston and Haselton in the St. Johnsbury 7.5 minute quadrangle (1999a and b) to the east of the study area casts doubt on the existence of this moraine. No evidence in support of the moraine was found during this mapping. On the contrary, where examined, the areas that had been mapped as moraine were generally thin, dense, silt-matrix till. Bedrock outcrops were common in these areas. In the village of Danville itself, which lies within Stewart and MacClintock's Danville Moraine, waterline excavations in 1998 and a variety of subsequent borings reveal that the village is underlain by till that is generally less than 10 feet thick. The depth to bedrock along part of the water line laid parallel to Rt. 2 in front of the High School was so shallow that blasting was required.

Although we have not found evidence of the extensive Danville Moraine, there is evidence of smaller ridges of till within and near Joe's Pond. Features that may be similar have been seen in the Knox Mountain area to the southwest (Springston and Kim, 2008). The two most prominent examples are the pairs of peninsulas that extend most of the way across Joe's Pond. These are indicated on Plate 1 and shown in the photo from 1913 below. Water well logs and limited field observations indicate that these ridges are underlain by thick till. Several less definite examples can be seen in the vicinity.

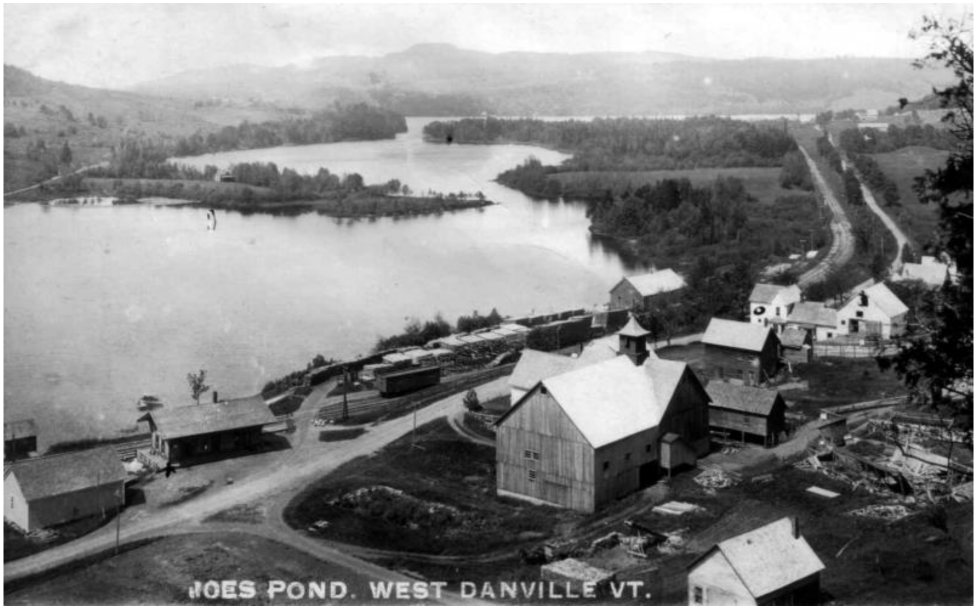

Figure 13. View looking west from West Danville across Joes Pond in 1913. Note the two sets of peninsulas that cut across the pond. These are interpreted as being moraine crests. Photo LS03800_000 from Vermont Landscape Change Program. Original from collection of Fairbanks Museum, St. Johnsbury.

Meltwater Channels

Meltwater channels cut into till are seen in two areas. The first is in the east-central part of the study area to the east of Webster Hill Road. These were first encountered and described by Springston and Haselton (1999a and b). The second set is seen on the surface of the area of thick till in the southwest of the study area to the southwest of Mollys Pond.

Holocene Deposits

The Holocene deposits are described briefly below. These are less than about 12,000 years old.

Artificial Fill. Artificially-emplaced earth along road beds, embankments and in low-lying areas.

Alluvium. Silt, sand, and gravel deposited by modern streams. Deposits include stream channel and bar deposits and finer-grained floodplain deposits. Wetland deposits are common within these areas and are not distinguished. Thickness in the tributaries is typically less than 3 meters, although the depth may be much greater in the Joes Brook valley.

Wetland Deposits. Accumulations of clastic sediment and/or organic matter. Commonly includes areas of alluvium and commonly overlaying till. Only a few of the larger deposits are shown. The areas shown as wetland deposits at the north end of Joes Pond are a complex mosaic of alluvium and wetland peat or muck deposits. Thickness in the smaller wetlands is generally less than one meter, but the deposits at the north end of Joes Pond are probably considerably greater.

Wetland Deposits, Peat or Muck. Thick accumulation of organic matter with minor clastic sediment. Commonly overlaying other sediments such as alluvium, lacustrine deposits, or till. Thickness of organic horizon ranges from 0.3 meter to greater than one meter.

Stream Terrace Deposits. Silt, sand, pebble, cobble, and boulder gravel deposited on terraces above the modern floodplains of streams. They represent former floodplains that have been dissected by younger streams.

Hydrogeology

The distribution and quantity of groundwater have been studied by analysis of the surficial geologic data collected for this project and by analysis of water well data derived from databases managed by the Drinking Water and Groundwater Protection Division of the Vermont Department of Environmental Conservation. The water well locations are shown on Plate 2. As many of the older wells have uncertain locations, only wells with verified locations are used in this analysis. Newer wells with driller-reported GPS locations or E911 addresses are assumed to be close to the correct locations. Other well locations have been verified by use of State records of hazardous waste sites and septic systems, searches of town records, local knowledge, or online searches to verify that the listed owner has a residence at the location shown.

Bedrock well statistics are shown in Table 1 and will be discussed in the paragraphs below. Note that the percentile values and histograms for depth to bedrock, yield, and well depth are all skewed to the left. For each of these the median value serves as a better measure of central tendency than the mean.

Table 1. Descriptive statistics for all located bedrock wells in the Joes Pond quadrangle (N = 103). Well depth and depth to bedrock in feet, yield is in gallons per minute.

Variable	N	Mean	StDev	Minimum	25^{th} Percentile	Median	75^{th} Percentile	Maximum
Well Depth (ft)	103	285.0	134.4	0.0	180.0	265.0	360.0	722.0
Yield (gpm)	103	15.95	20.16	0.00	3.00	10.00	20.00	100.00
Static Water Level (ft)	103	17.50	47.23	0.00	0.00	4.00	20.00	454.00
Overburden (ft)	103	39.10	37.75	0.00	14.00	27.00	56.00	210.00

Depth to Bedrock

Depth to bedrock or overburden depth is shown on Plate 3. Depth is indicated by the size of the green symbols at each well location. Bedrock outcrops are shown as black dots. The red lines are approximate contours at depths of 20, 40, 60, 80, and 100 feet. A histogram of the data is shown in Figure 14 below. As shown in Table 1, the median depth to bedrock in the wells is 27.0 feet. Note that only limited areas have a depth to bedrock that is greater than 20 feet. The depth is more certain in areas with abundant water well logs and/or bedrock outcrops and less certain in areas where this information is sparse.

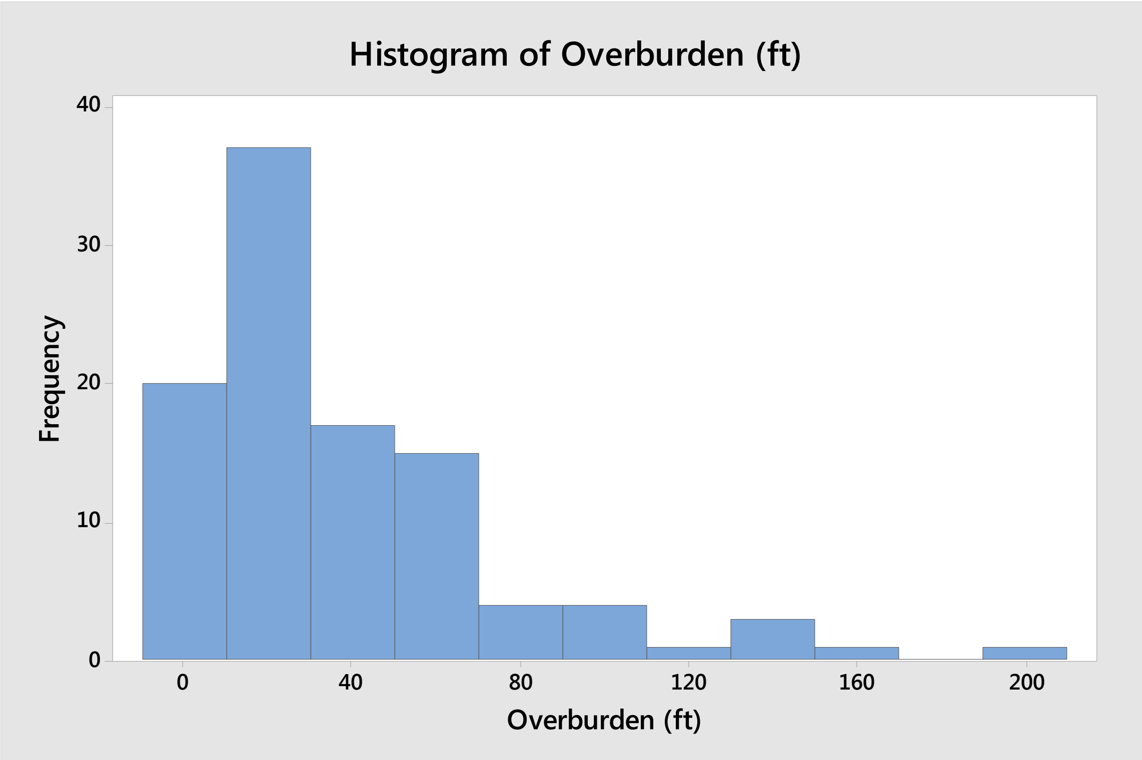

Figure 14. Histogram of depth to bedrock in feet for all bedrock wells within the quadrangle. Median depth to bedrock is 27.0 feet.

Well Depths

Bedrock well depths are shown on Plate 4. Depths (in feet) are indicated by the labels, as well as the size of the green symbols. A histogram of well depths is shown in Figure 15 below. The mean well depth is 285.0 feet and the median value is 265.0 feet. Statewide, the mean depth of bedrock wells is 290 feet (Gale and others, 2014). Thus, the wells in the quadrangle are being completed at depths that are similar to the statewide average.

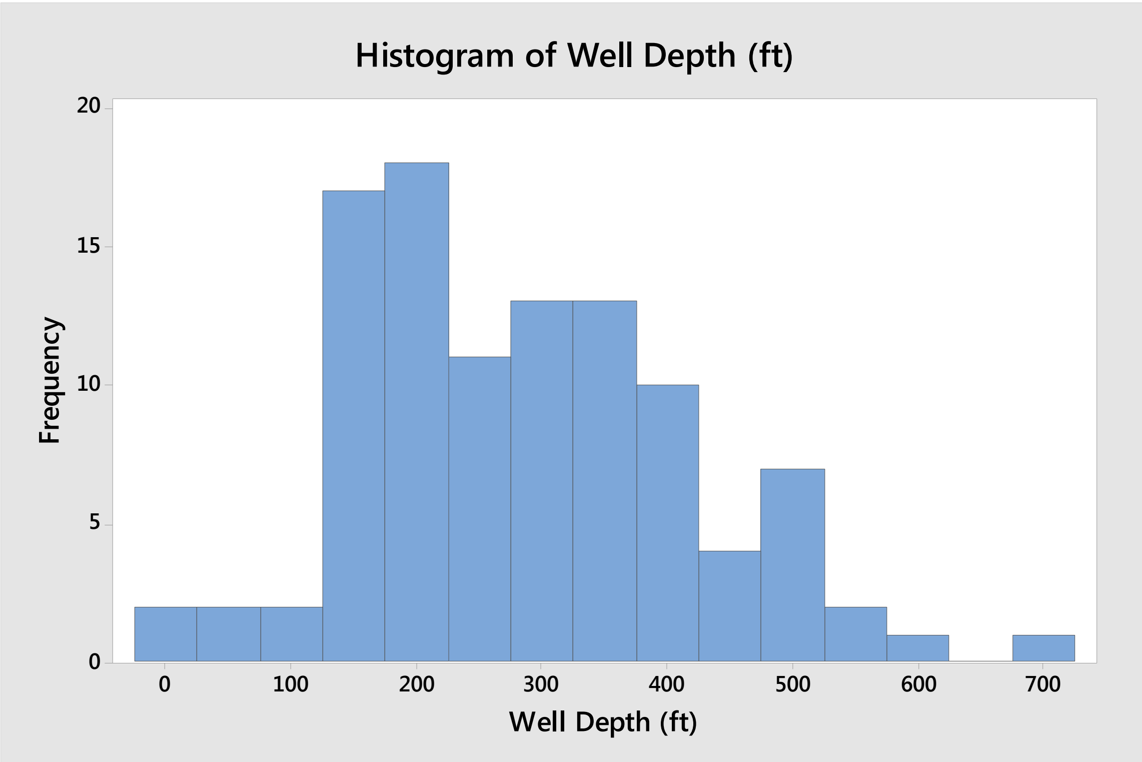

Figure 15. Histogram of well depth for all bedrock wells within the quadrangle. The median well depth is 265.0 feet.

Yields

Driller's estimates of yields of bedrock wells are shown on Plate 5. Yields (in gallons per minute) are indicated by the labels, as well as by the size of the green symbols. Bedrock geologic units are also shown. The mean well yield is 20.2 gallons per minute and the median value is 10.0 gallons per minute. A histogram of the data is shown in Figure 16. Statewide, the mean yield of bedrock wells is 14 gallons per minute (Gale and others, 2014). Thus, the wells in the quadrangle have yields that are somewhat higher than average.

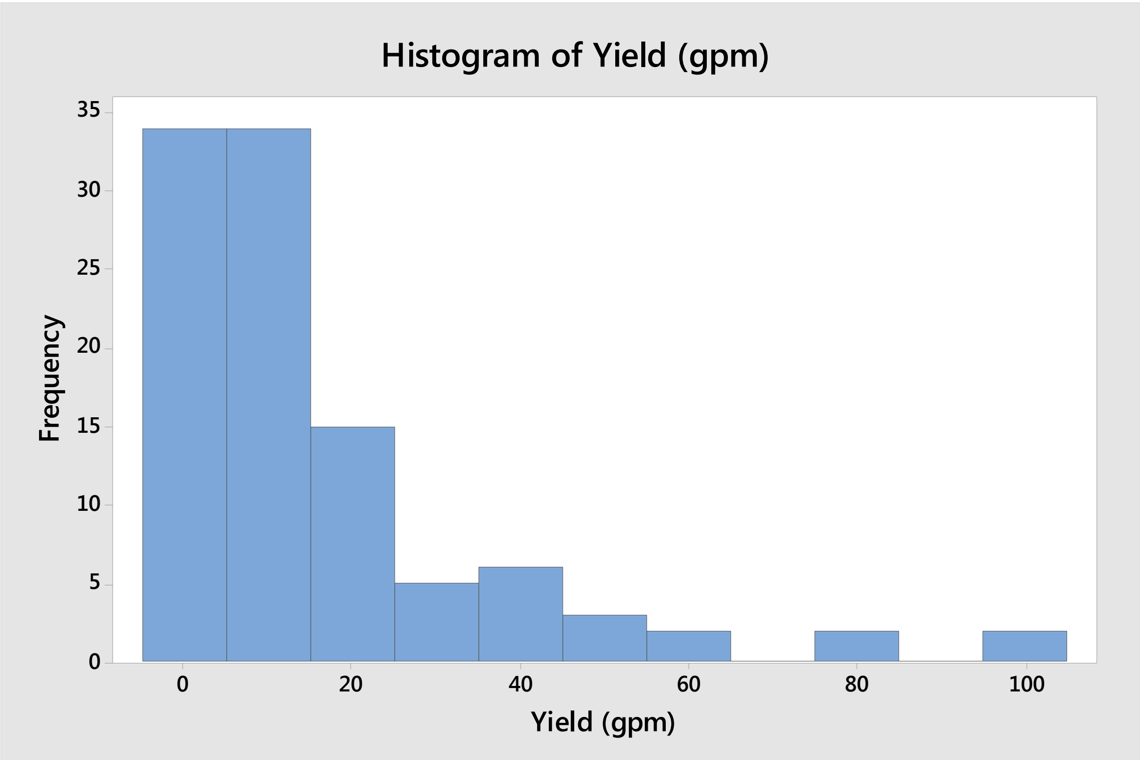

Figure 16. Histogram of driller's estimates of well yield in gallons per minute for all bedrock wells within the quadrangle. The median yield is 10 gallons per minute.

Yields in the Waits River and Gile Mountain Formations are compared below. Only two wells are located in the areas mapped as granitic intrusives.

Bedrock wells in the quadrangle that are in the Waits River Formation have a mean yield of 17.2 gallons per minute and a median yield of 10.0 gallons per minute while those in the Gile Mountain Formation have a mean yield of 8.7 gallons per minute and a median yield of 5.0 gallons per minute. The median yield values were compared using a Wilcoxon-Mann-Whitney test. With a 95% confidence limit the yield from the Waits River Formation is found to be statistically higher than that from the Gile Mountain Formation.

Table 2. Comparison of driller's estimates of yields of bedrock wells drilled in the Waits River and Gile Mountain Formations. Values are in gallons per minute.

	Number of Wells	Minimum	Maximum	Mean	Standard Deviation	Median
Waits River Formation	77	0	100	17.2	20.1	10.0
Gile Mountain Formation	22	0	35	8.7	8.7	5.0

Static Water Levels and Groundwater Flow Directions

Plate 6 contains information on the height of water levels in existing wells (static water levels) and groundwater flow directions. Static water levels are collected during well installation and are subject to considerable seasonal variation. Labels indicate the depth to the water surface in feet. If the groundwater flowing through the bedrock and surficial deposits is unconfined, then the groundwater will tend to move from higher areas to lower areas and converge towards the streams, ponds, and wetlands. In that case, contours of equal elevation on the groundwater surface would be roughly parallel to the topographic contours shown on the map. However, any confining layers in the surficial deposits or within the bedrock units would result in wells that have water levels higher than the topography would indicate.

Although there is abundant opportunity for groundwater recharge over much of the quadrangle due to the relatively thin surficial deposits (see Plates 3 and 9), the recharge areas for many wells may be relatively small and thus the wells may not be able to sustain heavy withdrawal without excessive lowering of the water levels.

Hydrogeologic Interpretation of Water Well Logs

The purpose of the hydrogeologic classification shown on Plate 7 is to rank how easily ground water can move through the surficial materials. The classification is made using water well logs and is based almost entirely on the coarseness of the surficial materials, with the assumption that ground water will be able to flow easier through coarser materials than through finer ones (Table 3). Interpretations based on this data will be shown on other plates in this report. As the driller’s logs are not very detailed and vary widely in accuracy and completeness, these interpretations are of limited accuracy. They are perhaps most useful in areas where several nearby well logs all show similar stratigraphy.

Relatively thin, coarse-grained surface horizons that are less than about 20 feet thick are ignored in this classification as they are likely to be of little importance either as significant aquifers or as barriers to prevent or slow infiltration of ground water. In the classification below a "thick" surface horizon measures 20 feet or more.

Surficial deposits that are less than about 40 feet in **total** thickness are not considered to be good candidates for surficial aquifers. Even if such deposits can supply sufficient yields during dry seasons, they are quite likely to be at risk from contamination from surface waters.

Table 3. Hydrogeologic classification of water well logs.

0	Thick, coarse-grained, stratified deposits over till over coarse-grained stratified deposits.
1	Fine-grained stratified deposits over coarse-grained stratified deposits.
2	Fine-grained stratified deposits over coarse-grained stratified deposits over fine-grained stratified deposits or till.
3	Thick, coarse-grained, stratified deposits over fine-grained stratified deposits over coarse-grained stratified deposits.
4	Sand-matrix till over coarse-grained stratified deposits.
5	Silt-to-clay-matrix till over coarse-grained stratified deposits.
6	Thick, coarse-grained, stratified deposits.
7	Thick, coarse-grained, stratified deposits over fine-grained stratified deposits and/or till.
8	Thick section of sand-matrix till.
9	Thick section of silt-to-clay matrix till over fine-grained stratified deposits.
10	Thick section of fine-grained stratified deposits over silt-to-clay-matrix till or directly over bedrock.
11	Thick section of silt-to-clay-matrix till.
12	Thin surficial deposits or no surficial deposits overlying bedrock. Includes the very common case of thin till over bedrock. Generally less than 40 feet thick.
13	Other. Commonly, this is a thick section of surficial deposits with either no details of stratigraphy or highly variable stratigraphy.
-999	Problem record. Usually due to location being suspect.

Surficial Aquifer Potential

Plate 8 uses the hydrogeologic classification of private water well logs shown on Plate 7 to estimate the surficial aquifer potential of the surficial deposits in the quadrangle. Hydrogeologic Classes 0 through 5 are interpreted as having a high surficial aquifer potential due to the presence of thick coarse-grained deposits overlain by finer grained deposits. These are shown as large green dots. Classes 6 and 7 are interpreted to have a moderate surficial aquifer potential as they have thick coarse-grained deposits but these are not overlain by a fine-grained deposit that could serve to prevent direct infiltration of surface water. These are shown as orange dots. Classes 8 through 12 do not have a thick coarse-grained deposit and therefore have a low potential to serve as a surficial aquifer. These are shown as small red dots. Class 13 has insufficient detail for classification.

Out of the 103 well logs examined, none were classified as having high potential and only 7 as having moderate potential. As these are scattered throughout the study area, there do not appear to be any areas in the quadrangle with high potential as surficial aquifers. However, as only a few accurately located well logs were available for this study, further research may identify areas in the valley bottoms with greater surficial aquifer potential.

This study area is unusual in that there is only a single located well that ends in the surficial deposits without reaching bedrock (these are often called “gravel wells” but as they do not necessarily contain significant gravel, the term should therefore be avoided).

Bedrock Aquifer Recharge Potential

Plate 9 contains information on the favorability of recharge to bedrock aquifers. It is based on an interpretation of the hydrogeologic classification of water well logs shown on Plate 7. Hydrogeologic Classes 0, 1, 3 through 5, and 12 are interpreted as having a high bedrock aquifer recharge potential due to the presence of either thick coarse-grained deposits at the base or else the presence of thin surficial deposits. These are shown as green dots. Classes 6 and 8 are interpreted to have a moderate potential. These are shown as orange dots. Classes 2, 7, and 9 through 11 are interpreted to have a low potential for bedrock aquifer recharge as there is thick fine-grained material at the base of the surficial deposits. These are shown as small red dots.

High recharge potential is suggested for 57 of the wells in the study area due to the presence of a thin cover of till over bedrock. Eight wells rank as moderate, and 26 rank as having low recharge potential.

Areas of thick till are shown in the southwestern and northeastern portions of the study area. The areas of thick till shown on the map may be areas of low bedrock aquifer recharge potential, but these areas contain few wells. There are none within the southwestern polygon and of the 9 wells shown in the northeastern thick till polygon, only 5 rank as having low recharge potential.

Actual groundwater recharge will depend heavily on the detailed stratigraphy of the surficial deposits, as well as the bedrock units present and the distribution, length, orientation, spacing, and openness of fractures in the bedrock. The bedrock characteristics are not considered here.

Future Work

New lidar topographic data will soon be available for the study area. Experience with lidar data in adjacent areas demonstrates that this will reveal many features that are currently unknown or poorly defined, such as numerous bedrock outcrops, glacial meltwater channels, areas of thick versus thin deposits, etc. The Vermont Geological Survey is currently undertaking water well location studies in many parts of the state. Such a study here would supply additional located wells, which would add greatly to the hydrogeologic interpretations.

Summary

Glacial till is the most widespread surficial material in the study area. It is generally dense to very dense, unsorted to very poorly sorted, fine-sandy-silt to silt matrix till. Exposures of fine-sand- to medium-fine-sand matrix till were encountered, mostly in the south-central portion of the quadrangle to the southeast of Joes Pond, in the vicinity of Keiser Pond and Harvey Hollow.

Anomalously thick till (> 30 meters or 100 feet) was encountered in two areas. These are in the northeastern portion of the quadrangle on the east flank of the Kittredge Hills and in the southwestern portion of the quadrangle to the southwest of Mollys Pond.

Striations and grooves in bedrock indicated that ice motion directions ranged from 155 to 181°. As in the Cabot quadrangle immediately to the west, striations and grooves were uncommon, especially when compared to the Woodbury quadrangle further west.

No evidence in support of the Danville Moraine of Stewart and MacClintock (1969) was found during this mapping. Where examined, the areas that had been mapped as moraine were generally thin till. Bedrock outcrops were common in these areas.

Although no evidence was found of the Danville Moraine, there is evidence of small ridges of till that appear to be moraines within and near Joe's Pond. The two most prominent examples are the two pairs of peninsulas that extend most of the way across Joe's Pond.

Ice-contact deposits are relatively sparse in the study area. Where seen, they consist of unsorted to poorly-sorted sand, gravel, and silt deposited in contact with glacial ice. Deformation features are common. A large but poorly-exposed area of ice-contact sand and gravel is located to the southeast of Joe's Pond. Although an earlier interpretation suggests a kame terrace, the origin of this deposit is uncertain.

A better-exposed set of ice-contact deposits is seen in the northeast of the study area at Pierce's Pit. Materials include deformed, bedded, pebble gravel, pebbly sand, medium to fine sand, and silt. The topographic form suggests a pair of kames.

Mean yields of bedrock water wells are somewhat above the statewide average (20.2 gpm versus 14.0 gpm statewide) and depths of bedrock water wells are similar to the statewide average (285.0 feet versus 290.0 feet statewide).

Yields from wells in the Waits River Formation are higher than those in the Gile Mountain Formation. Wells in the Waits River Formation have a mean yield of 17.2 gallons per minute and a median yield of 10.0 gallons per minute while those in the Gile Mountain Formation have a mean yield of 8.7 gallons per minute and a median yield of 5.0 gallons per minute. The median yield values were compared using a Wilcoxon-Mann-Whitney test. With a 95% confidence limit the yield from the Waits River Formation is found to be statistically higher than that from the Gile Mountain Formation. There was insufficient data to analyze yields in the granitic intrusions (only two wells).

The water level measurements from bedrock wells suggest that groundwater flow directions generally mimic the topography, with groundwater moving from recharge zones in the uplands towards discharge zones in the lowlands.

No areas with high potential to serve as surficial aquifers have been identified in the study area.

Most of the bedrock in the quadrangle is covered by relatively thin surficial deposits, suggesting that the potential for recharge of bedrock aquifers is generally good. Although there is abundant opportunity for groundwater recharge over much of the quadrangle due to the relatively thin surficial deposits (see Plates 3 and 9), the recharge areas for many wells may be relatively small and thus the wells may not be able to sustain heavy withdrawal without excessive lowering of the water levels. The areas delineated as thick till may possibly be areas of limited recharge to the bedrock, but well data in these areas is sparse.

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