Aquifer and Aquifer Recharge Mapping of the Town of Bristol

Authors:

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The Anticline, Jonathan Blake

During the field seasons of 2012-2014, the Vermont Geological Survey and partner from Norwich University conducted bedrock and surficial geological mapping in the Bristol and South Mountain quadrangles in Addison County that was funded by the U.S. Geological Survey STATEMAP program. The purpose of this study was to develop an understanding of groundwater resources in the Town of Bristol. The Town of Bristol straddles the boundary between these two quadrangles and the first goal of this study was to assemble separate bedrock and surficial geologic maps for the town. In order to complete the surficial geologic map, a database of accurately-located domestic and public water wells in the area was constructed by integrating land parcel information at the Bristol Town Clerk's Office with well data from the digital database of well information at the Vermont Department of Environmental Conservation. This accurately-located well database was also used in concert with the bedrock and surficial maps to produce "derivative" maps, which bear on the hydrogeology of Bristol.

The list of maps that are associated with this report is below. Detailed descriptions of these maps follow this Table of Contents.

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Plate 7- Well (Bedrock) Yield Map for the Town of Bristol

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Plate 8- Map that Constrains Recharge, Discharge, and Generalized Groundwater Flow Directions in the Town of Bristol

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Plate 1- Bedrock Geologic Map of the Town of Bristol

The Town of Bristol straddles a major ancient fault boundary that separates the Green Mountains from the Champlain Valley. This tectonic boundary, which is called the Hinesburg Thrust Fault, runs ~north-south from Franklin County to the Green Mountain National Forest in Bristol, a distance of ~75 kilometers. This fault formed during the Taconian Orogeny (mountain-building event) in the Ordovician Period, ~450-460 million years ago, when an island complex collided with ancient eastern North America (Laurentia).

Bristol can basically be divided into two groups of formations: 1) those that run from the northeastern-most to the southeastern-most parts of town and 2) those that comprise the rest of town. The rock formations that comprise the hanging wall (see legend on Plate 1) are from oldest to youngest the Mount Holly Complex, Pinnacle, Forestdale, Fairfield Pond formations, and a small part of the Cheshire Formation. The foot wall rocks (see legend on Plate 1) consist of the Cheshire and Dunham formations. Hanging wall rocks make up the upper part/ plate of the Hinesburg Thrust Fault whereas foot wall rocks make up the lower part/plate of this fault. In very general terms, the Hinesburg Thrust is located east and uphill of Route 116, except in the Bristol town center. See the cross-section, which is a hypothesized cut through the earth based on surface information, to see what the Hinesburg Thrust looks like in three-dimensions.

During orogenies, the faulting and folding increases the temperature and pressure of the rocks involved and new minerals may grow and align themselves in planes called foliations; this general process is called metamorphism. The hanging wall rocks are truly metamorphic rocks whereas the footwall rocks are termed weakly-metamorphosed sedimentary rocks. The thrust faulting, where the hanging wall rocks were pushed westward over foot wall rocks, was succeeded by two episodes of folding that likely occurred during the Devonian Acadian Orogeny (~390-375) millions years ago.

The Dunham Formation, which is found in the foot wall, is a dolostone composed primarily of dolomite. Dolostones were once limestones that were altered by the introduction of magnesium after they were deposited. In Bristol, the valleys are primarily dolostone because it is relatively easy to erode. Because dolostones also contain considerable calcium, the soils that developed on them are very rich and suitable for farming.

The ridges on the easternmost side of town are held up by metamorphic rocks of the Pinnacle, Fairfield Pond, and Mount Holly Complex, whereas the ridges to the west of this are composed of Cheshire Formation quartzites. The rocks in these ridges are very resistant to erosion and therefore stand high compared to the easily-eroded dolostones of the valleys. The Cheshire Formation ridges are anticlines (up folds with the oldest rocks in the center) and the Dunham Formation dolostones are complementary synclines (down folds with the youngest rocks in the center) in the valleys. The huge anticlines and synclines can be seen the cross-section on Plate 1. Local overlooks like "Bristol Cliffs" and "Deer Leap" are in the Cheshire Formation quartzite.

Plate 2- Surficial Geologic Map of Bristol

The surficial geologic map shows the unconsolidated sediments that lie above the bedrock. This map was developed by combining information on bedrock and surficial material exposures with water well logs and geotechnical boring logs. See the Description of Map Units on the plate for a complete discussion of these materials. Newly available topographic data derived from airborne lidar (**li**ght **d**istance **a**nd **r**anging) has been of great utility for mapping and interpretation of the surficial deposits and landforms in the study area and has enabled us to produce improved glacial lake shoreline projections.

Glacial striations and other ice-motion indicators are abundant in the uplands of the town. Striations generally indicate ice motions ranging from 120 to 195°, with those from 135 to 165° being the most common. The massive quartzites of the Cheshire Formation appear to be so hard that although they commonly show glacial polish, striations are somewhat rare. Chattermarks were seen at several sites and stoss-and-lee bedrock landforms (including roche moutonées) are common. Crag and tail landforms southeast of the town have an average orientation of 154°, which is consistent with the dominant striations. At several sites short, fine striations trending roughly east-west are seen. Although these clearly crosscut the dominant striations, the movement direction is uncertain. It seems most likely that these were formed by late ice moving in a westerly direction off of the crest of the Green Mountains (Ackerley and Larsen, 1987).

Glacial till is widespread throughout the study area, ranging from very thin and scattered till in the midst of the abundant bedrock outcrops on the higher parts of the mountains to thick till deposits with very few bedrock outcrops in the Green Mountain National Forest in the vicinity of Upper Notch Road. Several benches composed of till are visible on the mountain slopes. These are far above the regional glacial lake levels and may represent ice-marginal positions. This idea is supported by the numerous meltwater channels seen on the lidar terrain data and in the field.

The combination of scattered ice-contact sand and gravel deposits and areas of thick till in the Upper Notch Road area in the southern part of town suggests stagnation of residual ice in this part of the study area.

The prominent terrace at Bristol Village has a composite origin, with much of the deeper sand and gravel deposits appearing to be of kame terrace origin. The early kame terrace deposits may well have played a role in impounding the waters of glacial Lake Bristol. In Coveville time, and later in Upper Fort Ann time, this was the location of a large delta formed by the entry of the waters of the New Haven River into the lakes. The river subsequently cut down through the delta and kame terrace deposits.

A complex bench of sand and gravel deposits extends from Bristol Village south along the western flank of South Mountain down to East Middlebury (Axelson, 1981). Environments of deposition on this bench include kame terrace, ice-contact (kame) delta, lacustrine delta and shoreline, and alluvial fan. An ice-contact delta deposit formed in the narrow gap between South Mountain on the east and The Cobble on the west as meltwater entered the Coveville stage of Lake Vermont. For this site to have functioned as a spillway, the ice margin must have extended west from The Cobble. As the ice margin continued to retreat north during the Coveville, stage, meltwater would no longer be impounded by the Cobble and the delta would have been abandoned.

Glacial lake deposits are common on many of the prominent terraces and in the lowlands of the town. These range from coarse-grained delta and shoreline deposits composed of sand and gravel to fine-grained lake bottom deposits composed of silt and clay. The earliest lake deposits are to be found in the New Haven River valley in the northeastern portion of the study area. Mapping by Franzi (1988) and as part of this study showed an extensive series of glacial lake deposits and associated fluvial deposits in the valley of Baldwin Brook to the north. Delta deposits in the New Haven River valley to the northwest of West Lincoln appear to correlate with the youngest of the Lake Bristol deposits, which may have been graded to the kame terrace deposits at Bristol Village.

Projections of the isostatically tilted shorelines of the Coveville and the Upper and Lower Fort Ann Stages of glacial Lake Vermont using the shoreline data of Rayburn (2004) indicate that all three lakes inundated the lowlands west of South Mountain. This area is dominated by fine-grained lake deposits in the low areas interspersed with knobs and ridges of thin till and bedrock.

Areas of wave-washed till are seen on some of the slopes in the western half of the study area below the Coveville level.

Extensive aprons and fans of colluvium and talus are found at the bases of the high, steep slopes in the quadrangle. The largest talus aprons are found on the west flank of South Mountain. These features indicate that rockfall has been an important geomorphic process in shaping the mountain flanks since the retreat of the glaciers. Freshly fallen boulders were observed in several locations and residents report that rockfalls are common in some locations.

A large alluvial fan has developed at the mouth of Notch Brook where it exits the mountains south of Bristol. Several smaller alluvial fans, some of which are clearly still occasionally active, are found at the mouths of steep tributaries.

Extensive areas of Holocene stream terrace deposits and Holocene alluvium are found in the valley bottoms. The stream terrace deposits are old stream deposits that are now many feet above the modern floodplains. They formed after the glacial lakes drained and streams began to cut down through the lake deposits and ice-contact deposits. Modern stream deposits are mapped as alluvium.

Cross-sections through the surficial materials are shown in Figure 1. These show schematic views of the thickness and distribution of surficial deposits below the land surface. The cross section locations are shown on Plate 2.

***Plate 3*- Wells and Borings**

This map shows the locations of wells and borings used in the construction of the surficial geologic map (Plate 2) and several of the plates that follow.

The private water well data was obtained from the Vermont Agency of Natural Resources Natural Resource Locator (http://www.anr.state.vt.us/dec/maps.htm , last accessed on June 23, 2015). Due to problems with the accuracy of locations for many of the older wells, the analysis was limited to newer wells that included either GPS coordinates or E911 addresses and older wells that had their locations verified by checks of town records or by knowledgeable residents.

Information on borings was obtained from the Materials and Research Division of the Vermont Agency of Transportation, Hodges (1967), and Mack (1995). Locations of Public Water Supplies are also shown.

***Plate 4*- Depth to Bedrock**

This map shows depth to bedrock (also known as depth of overburden) by means of approximate contour lines and by scaled map symbols. See Plate 6 for a discussion of how the thickness of the surficial materials influences their potential as aquifers.

The contour lines were drawn using the wells and borings shown in Plate 3 and the bedrock locations and locations of surficial materials exposures that were used in construction of the bedrock and surficial maps in Plates 1 and 2. The lines are at depths of 20, 40, 60, 80, 100, and 200 feet. The depth to bedrock at individual wells is shown by the green dots, which increase in size as the depth increases. Depth to bedrock is also shown for the borings, although many of these did not penetrate all the way to bedrock and thus give only a minimum value (indicated by “>” ahead of the depth figure).

Contouring is limited to those areas with sufficient wells and borings. Thus, only the 20-foot contour is shown in much of the northwestern part of town and contours are not shown in the southeastern part of the town (which is largely within the Green Mountain National Forest). Although individual wells exceed 200 feet to bedrock in the vicinity of the village center, the density of data only allows the 200-foot contour to be drawn in the southwestern portion of the town.

***Plate 5*- Hydrogeologic Classification of Well Logs**

The purpose of the hydrogeologic classification 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 1). Interpretations based on this data will be shown on other plates in this report.

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 1. 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.

***Plate 6*- Surficial Aquifer Potential**

This map uses the hydrogeologic classification of private water well logs shown on Plate 5 to estimate the surficial aquifer potential of the surficial deposits in the town. Wells in Hydrogeologic Classes 0, 1, 2, 3, and 5 were assigned a high potential, those in Classes 6 and 7 were assigned a moderate potential, and those in Classes 8 through 12 were assigned a low potential. There were no wells assigned to Class 4, which would have a high potential.

The wells that end in the surficial deposits (often called "gravel wells") are shown on the plate and their yields (in gallons per minute) provide a means of checking the accuracy of the class assignments. Although the yields are estimates by the drillers and are of limited accuracy, they are indeed generally high where the classes are ranked as moderate or high.

Refer to the explanation of Plate 5 for details of the classification. Note that these estimates are based solely on water well logs and that subsurface conditions vary markedly from well to well.

***Plate 7*- Well (Bedrock) Yield Map for the Town of Bristol**

Bristol can basically be divided into two groups of formations: 1) those that run from the northeastern-most to the southeastern-most parts of town and 2) those that comprise the rest of town. The rock formations that comprise the hanging wall (see legend on Plate 7) are from oldest to youngest the Mount Holly Complex, Pinnacle, Forestdale, Fairfield Pond formations, and a small part of the Cheshire Formation. The foot wall rocks (see legend on Plate 7) consist of the Cheshire and Dunham formations. Hanging wall rocks make up the upper part/ plate of a fault called the Hinesburg Thrust Fault whereas foot wall rocks make up the lower part/plate of this fault.

There are considerable differences in average wells yield, overburden thickness, and well depth between hanging wall and foot wall rocks. The map in Plate 7 shows individual well locations with their yields scaled by the size of the dots, with larger dots representing higher yields and vice versa.

For example, A) The average overburden for a foot wall well (62') is ~2.3 times that of a hanging wall well (27')(see the column graph on Plate 7); B) The average yield of a hanging wall well (7 gpm) is only ~25% that of a foot wall well (29 gpm)(see the column graph on Plate 7); and C) The average depth for a hanging wall well is 416' whereas that of a foot wall well is only 245' (see column graph on Plate 7).

In summary, on average, wells that are completed in foot wall wall rocks have higher yields, shallower depths, and deeper overburden than those completed in the hanging wall rocks.

<u>Plate 8</u>- Map that Constrains Recharge, Discharge, and Generalized Groundwater Flow Directions in the Town of Bristol

This map shows the general factors that may influence the recharge of groundwater to the bedrock aquifer such as bedrock outcrops (ledges) exposed at the surface, glacial till thickness, and topography. Wherever bedrock is exposed at the ground surface, it is possible for rainwater or water running on the ground surface to flow downward (recharge) to the bedrock aquifer, if open cracks or "beds" are present in the rock.

Glacial till is composed of pebbles, sand, silt, and clay that were left behind on the ground surface by the glacier as it melted thousands of years ago. Glacial till was generally deposited in areas of higher elevation. Whenever glacial till is thin (<10' thick with interspersed outcrops of bedrock), rainwater or water flowing along the ground surface may percolate downward through the till to the bedrock below and enter (recharge) the bedrock aquifer through open cracks or "beds". If glacial till is thick (>10' thick with no interspersed bedrock), downward flow of water can still occur, but this percolation takes longer because of the thicker till.

Groundwater flows from higher elevations toward lower elevations under the influence of gravity and also flows from higher pressure to lower pressure. On the map, green arrows show the direction groundwater will travel from higher elevations to lower elevations under the influence of gravity alone. Generally, recharge areas are at higher elevations whereas discharge areas are valley bottoms.

The static water level (SWL) is the level that groundwater will rise to in a well based on the upward pressure from the aquifer. It is usually measured in feet below the ground surface. Well drillers measure the SWL after they have finished drilling a well. The SWL was not measured in many wells in Bristol so it is not possible to construct a “water table” (piezometric surface) contour map. This map shows the location of all accurately-located wells in the Town of Bristol that have an SWL. The SWL is the distance in feet below the ground surface to the “water table”.

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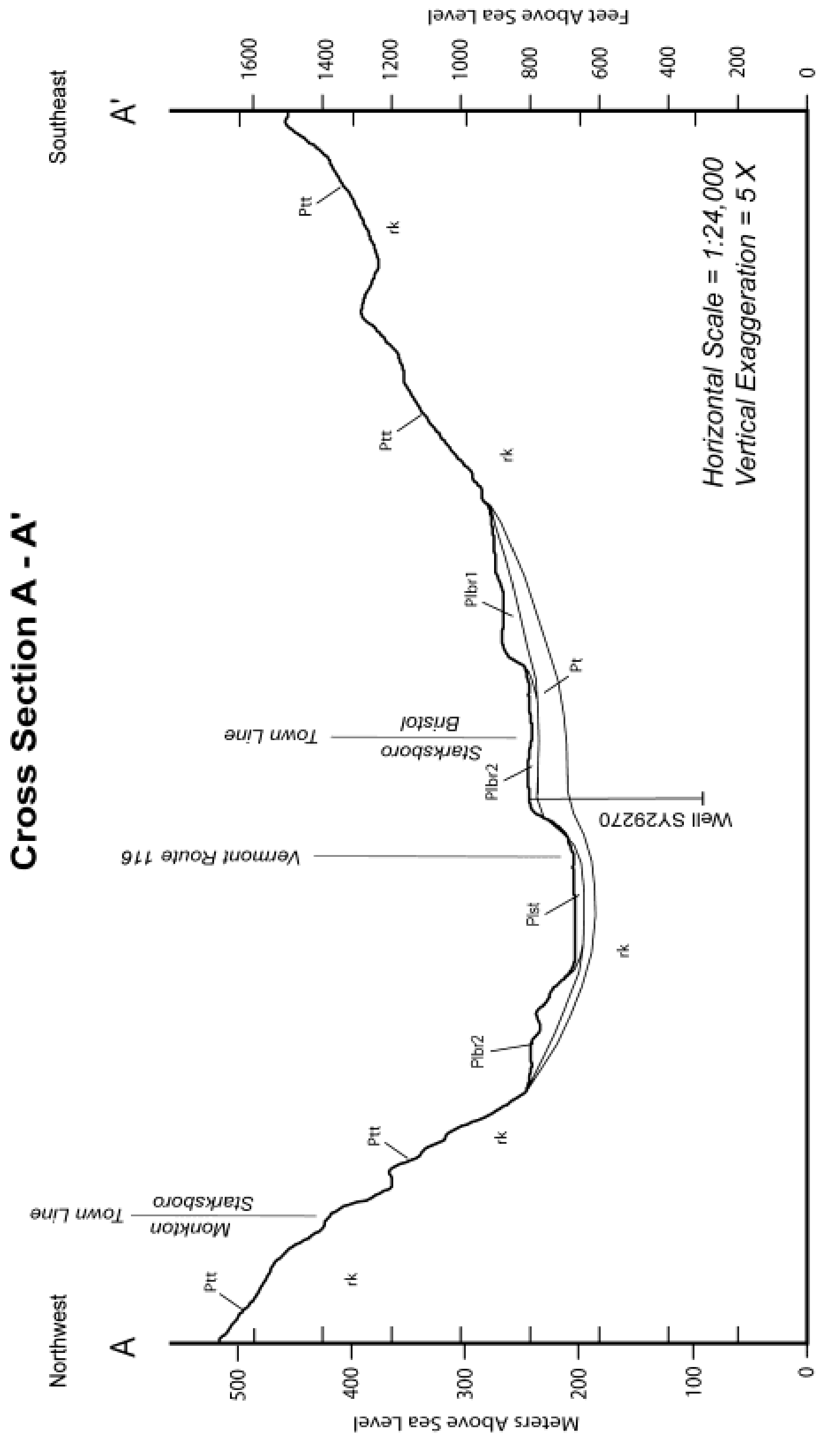


Figure 1a. Cross-section A-A’. See Plate 2 for location.

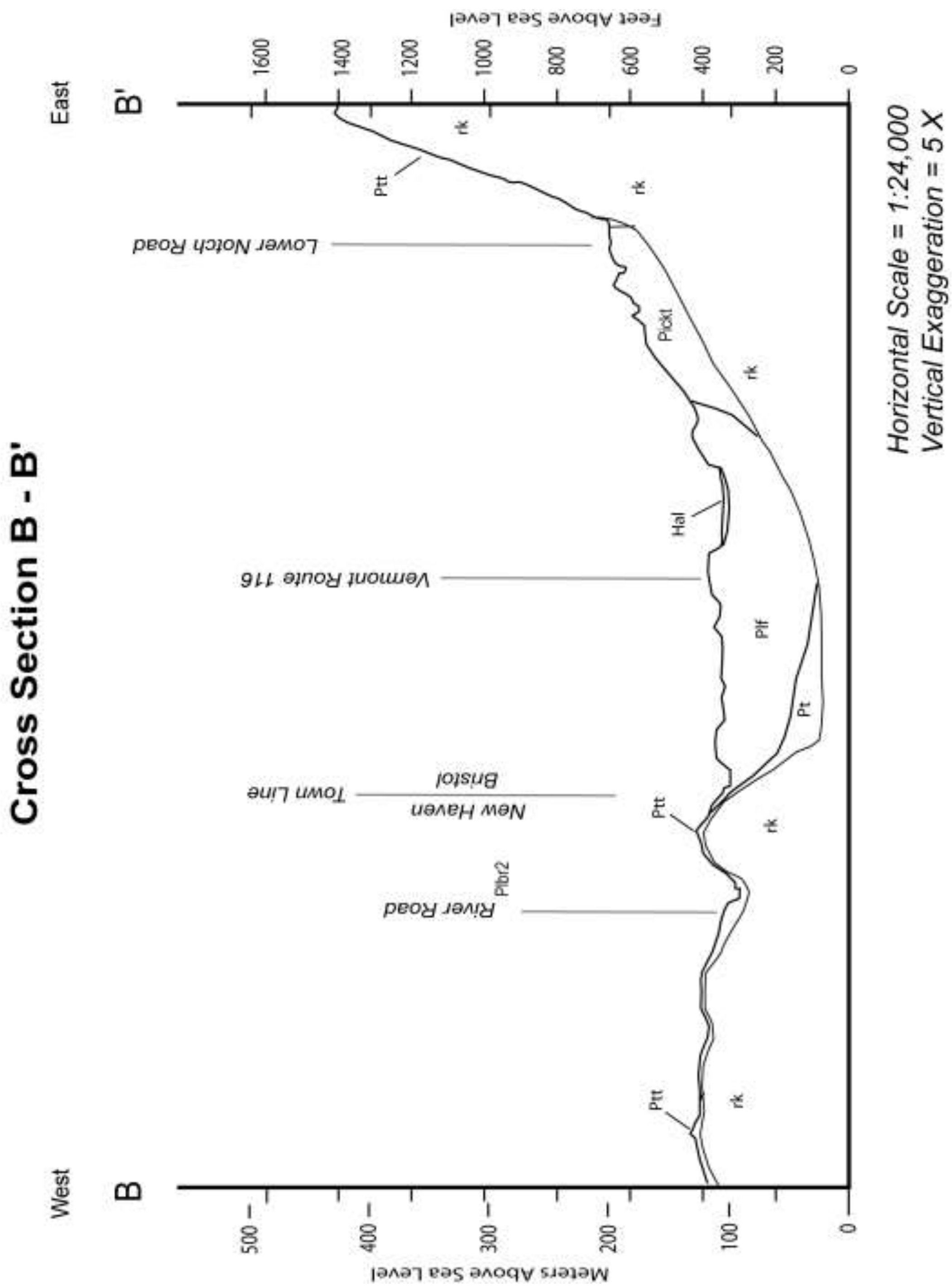
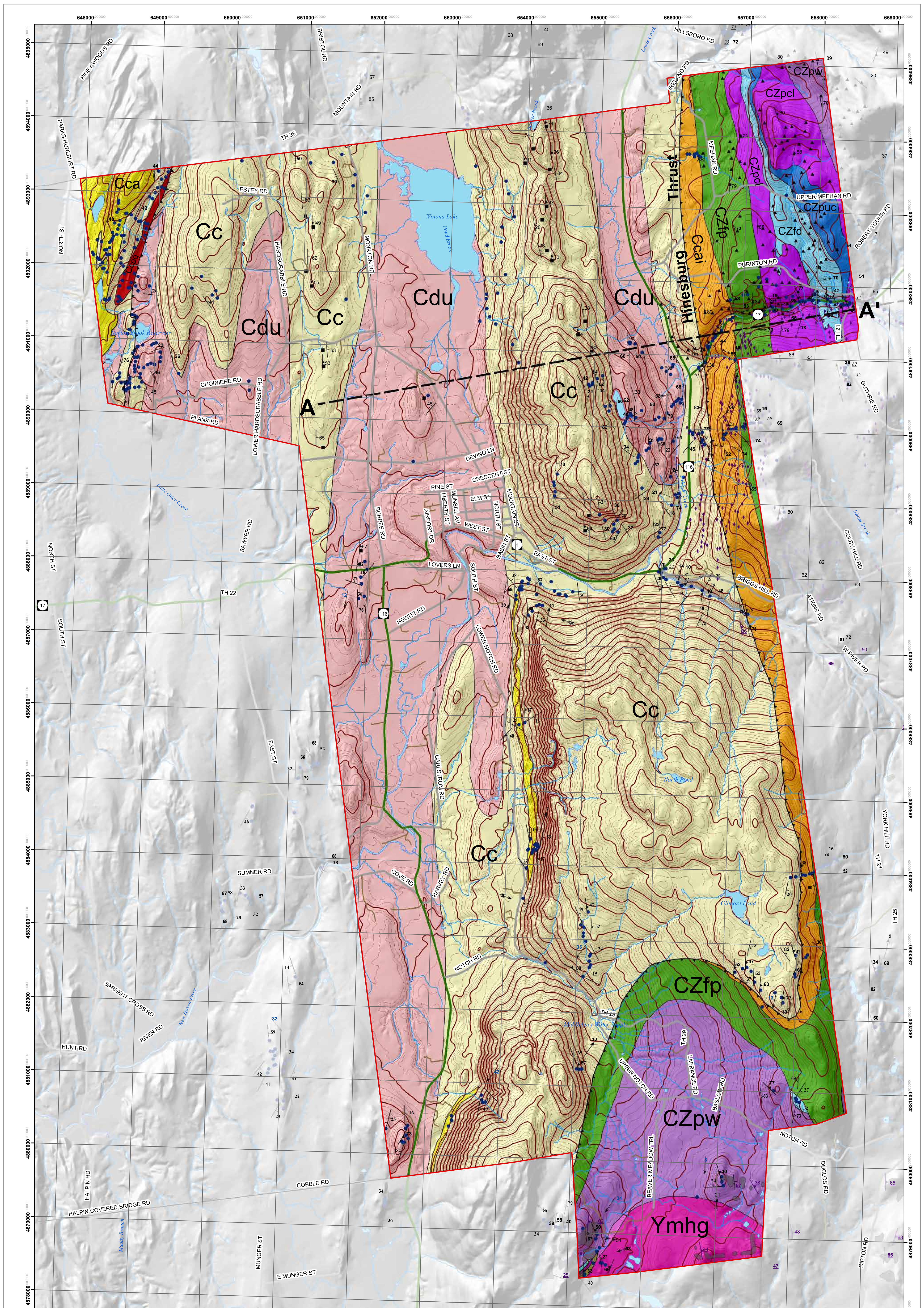


Figure 1b. Cross-section B-B’. See Plate 2 for location.



Bedrock Geologic Map of theTown of Bristol, Addison County, Vermont

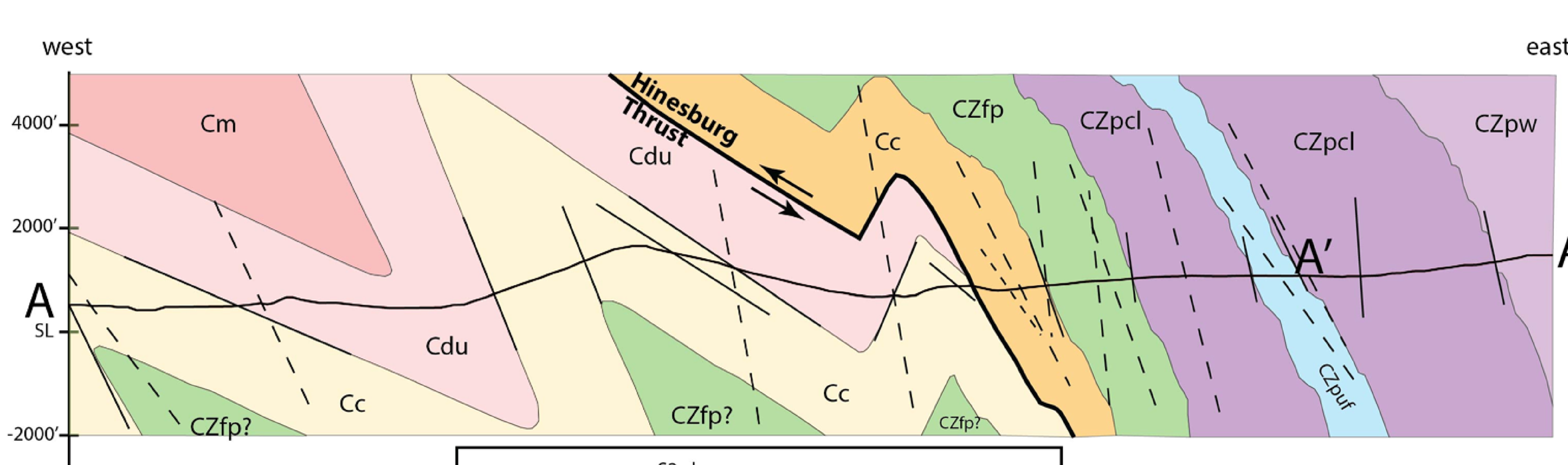
Authors: Jonathan Kim, Marjorie Gale, Kevin Chu, Malayika Cincotta, and Laura Cuccio

Kilometers 0 0.5 1 2 3 4

Miles 0 0.5 1 2

scale = 1: 24,000
contour interval = 20'

MN 15 degrees



S2 cleavage
S1 foliation- hanging wall of Hinesburg Thrust
Bedding- footwall of Hinesburg Thrust

VERMONT
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Description of Map Units

Lower Cambrian

Cdu	**Dunham Formation** Brown-weathering, massive, irregularly-bedded buff to gray to white dolostone. Contact with underlying Cheshire and overlying Monkton Formations is gradational and interbedded.
Ccpq	**Cheshire Formation** Light pink to light gray, fine grained, vitreous, well-bedded quartzite.
Cc	Light to dark gray, fine to medium grained, quartzite and argillaceous quartzite with minor phyllite. Beds of dolostone occur near contact with Dunham Fm. and quartzite has a pinkish hue. Discontinuous, white, mottled, rippled quartzite beds from 2.5 to 20 cm occur locally.
Cca	Fine to medium grained, gray and rusty weathered, dark gray argillaceous quartzite with thin light gray quartzite layers and abundant quartz veins.
Ccai	Fine grained, dark gray and rusty weathered, dark gray argillaceous quartzite that is interlayered with light gray phyllitic quartzite layers. Found interlayered with CZfp in the hanging wall of the Hinesburg Thrust.

Cambrian and Neoproterozoic

CZfp	**Fairfield Pond Formation** Gray to gray green, light gray to light brown weathered, fine grained quartz, sericite, chlorite phyllite. Fine, light gray laminations are common. Magnetite is common near the base of the unit. Contact with overlying Cheshire Fm. is gradational.
CZfd	**Forestdale Formation** Light brown, brown to black weathered, sandy dolarenite. Typically thickly bedded with thin interbedded chlorite schist.
CZpw	**Pinnacle Formation** Light to dark gray, medium to coarse grained, massive to thick bedded, quartz, feldspar, muscovite, chlorite, biotite metawacke with minor carbonate. Locally contains conglomeratic beds less than 1 m thick with well-rounded quartz (commonly blue-gray) and gneiss pebbles less than 5 cm long. Characteristic "Pinnacle" lithology.
CZps	Light gray to gray green, rusty weathered, fine grained, massive quartz, felspar, muscovite, metawacke and schist with minor chlorite, epidote, magnetite and tourmaline. Biotite is rare and rock fragments are absent. Laminations are locally well developed.
CZpcl	Light green, locally rusty, silver gray weathered, fine grained quartz, plagioclase, muscovite, magnetite, chlorite schist. Abundant magnetite porphyroblasts (<7mm) are diagnostic. Locally interbedded with chlorite rich metawacke and dolomite.
CZpcg	Poorly sorted, matrix supported, quartz and gneiss cobble conglomerate. Cobbles up to 55 cm in diameter and rare quartzite boulders up to 3 m in diameter have been observed. Matrix is gray weathered quartz, feldspar, biotite, muscovite, chlorite schist with minor calcite and magnetite.
CZpuc	Lustrous green chloritic phyllite and fine-grained metagraywacke.

Mesoproterozoic

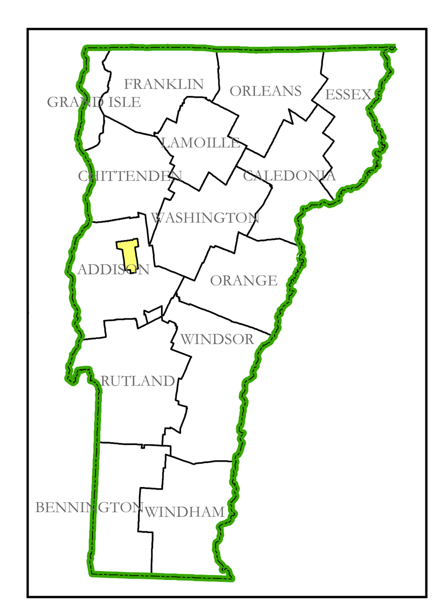
Ymhg	**Mount Holly Complex** Pink gray, light gray, and greenish white, fine to coarse grained quartz, plagioclase gneiss with varying amounts of sericite, chlorite, microcline and biotite. Other minor minerals include epidote, apatite, calcite, garnet, tourmaline, rutile, zircon, magnetite and sphene. (Y1,2bg of Ratcliffe and others, 2011)
Ymhq	Massive, light blue to gray weathered quartzite with minor amounts of sericite, biotite, chlorite, plagioclase, rutile and opagues. Interbedded with tourmaline chloritoid schist (Ymht). (Middle to Early Mesoproterozoic Y2q of Ratcliffe and others, 2011)

Explanation of Structural Symbols

12	Trend and plunge of L2 crenulation lineation (Acadian); proxy for F2 fold axis.
18	Trend and plunge of L1 stretching/ intersection lineation (Taconian); proxy for F1 fold axis.
60	Strike and dip of S2 crenulation cleavage (Acadian); axial planar to open-tight, asymmetric, west-verging folds.
45	Strike and dip of S1 spaced cleavage (Taconian); axial planar to reclined isoclinal folds that may be rootless/intrafolial.
25	Strike and dip of bedding.

Explanation of Map Symbols

- Outcrop locations from Kim et al. (2013; 2014)
- Outcrop locations modified fromTauvers (1982)
- Outcrop locations modified from Dipietro (1983)
- Outcrop locations modified from Smith, J.(unpublished)
- Outcrop locations modified from DelloRusso and Stanley (2006)
- Thrust fault (teeth on hanging wall)



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Base maps of the South Mountain and Bristol quadrangles from U.S. Geological Survey.
Coordinate System: Vermont State Plane, meters, NAD 83.
Grid overlay on map is Universal Transverse Mercator, Zone 18N, NAD 83.
Digital Cartography by Jonathan Kim
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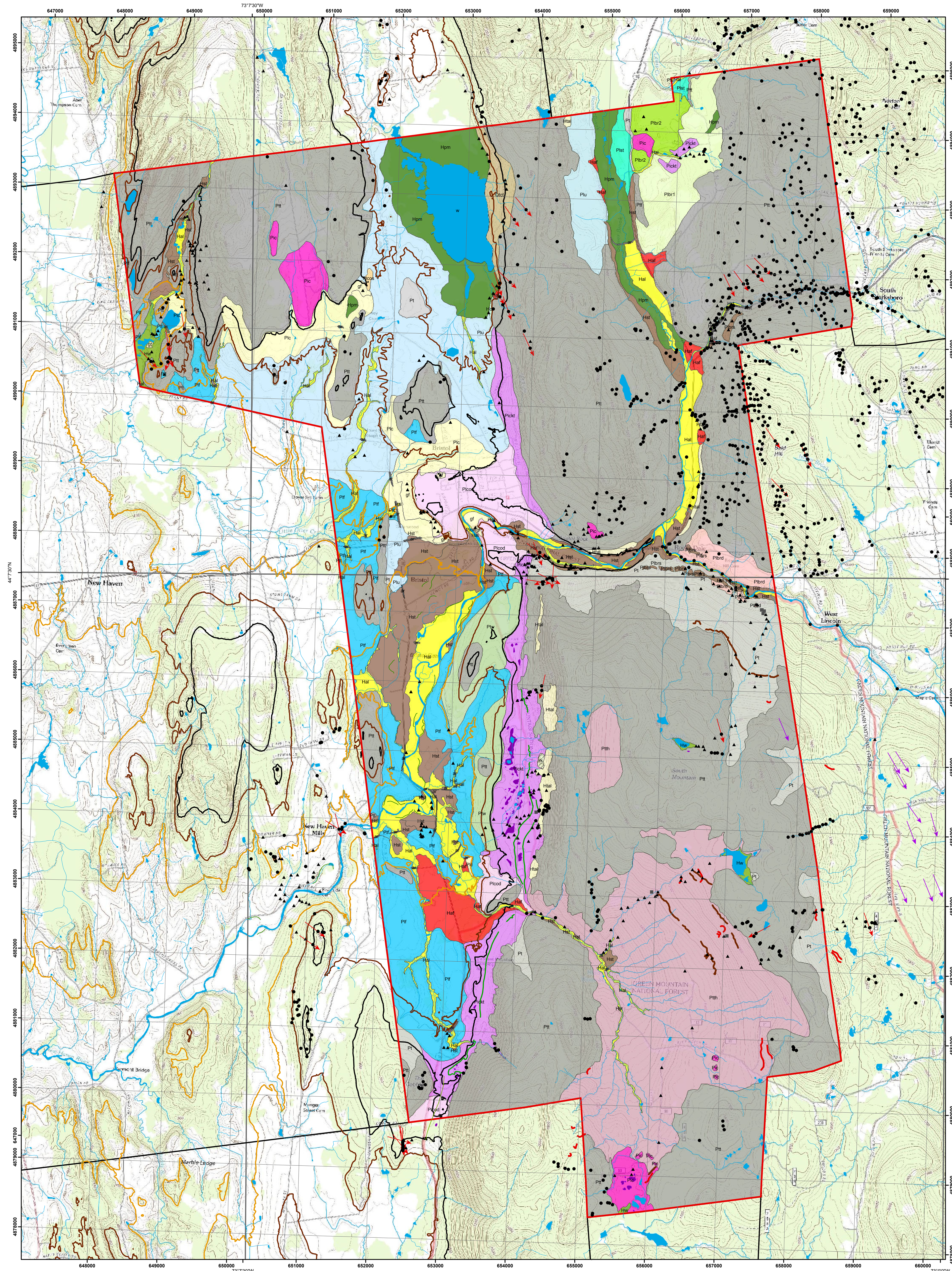


DESCRIPTION OF MAP UNITS

Holocene Deposits

- **gf** — Graded or Filled. Area of extensive artificial excavation or filling.
- **ar** — Artificial Fill. Artificially emplaced earth along road beds, embankments and low-lying areas.
- **w** — water
- **Hal** — Alluvium. Silt, sand, and gravel deposited by modern streams. Deposits include stream channel and bar deposits and finer-grained floodplain deposits. Minor 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 valleys of the larger streams.
- **Hpm** — Wetland Deposits, Peat or Muck. Thick accumulation of organic matter with minor clastic sediment. Commonly overlaying lacustrine sediments or till. Thickness of organic horizon ranges from 0.3 meter to greater than one meter.
- **Hw** — Wetland Deposits. Accumulations of organic matter and/or clastic sediment. Commonly overlaying lacustrine sediments or till. Thickness of organic horizons (where present) ranges from 0.3 meter to greater than one meter.
- **Haf** — Alluvial Fan Deposits. Boulder, pebble, and cobble gravel and pebbly sand deposited at the mouths of tributaries. Commonly less than 5 meters thick.
- **Hst** — Stream Terrace Deposits. Silt, sand, pebble, cobble, and boulder gravel deposited on terraces above the modern floodplains of streams. Commonly overlaying lacustrine sediments. They represent former floodplains that have been dissected by younger streams. Generally less than 5 meters thick.
- **Htal** — Talus. Fans or aprons of fallen rock at the base of steep slope segments. May contain colluvial (slope-wash) deposits as well. Of variable thickness.
- **Hco** — Colluvium and/or Talus. Fans or aprons of sediment at the base of steep slope segments. Slope-wash and/or talus deposits of variable thickness.

Holocene or Pleistocene Deposits

- **Qtct** — Mix of Till, Colluvium, and Talus. Heterogeneous deposits at the base of steep slope segments on the Hogback Mountains. See Hco and Pt descriptions.

Pleistocene Deposits

- **Plcod** — Delta Deposits, Coveville Stage of glacial Lake Vermont. Coarse gravels and gravelly sand deposits, generally well-sorted, deposited at the mouth of the ancestral New Haven River. These deposits make up the upper horizons on most of the main terrace at the Village of Bristol, mantling thick kame terrace deposits that are exposed on the eastern edge of the terrace.
- **Plcos** — Shoreline Deposits, Coveville Stage of glacial Lake Vermont. Shallow-water deposits consisting of well-sorted sand and/or gravel deposits.
- **Plbrd** — Delta Deposits, glacial Lake Bristol. Sand and gravel deposited as a (meteoric?) delta into glacial Lake Bristol east of Bristol Village and southeast of Rocky Dale in the south-central part of the quadrangle. Lake level at this time was probably controlled by an outlet in the defile between the Hogback Mountains and South Mountain at Bristol Village.
- **Plbrs** — Shoreline Deposits, glacial Lake Bristol. Shallow-water deposits consisting of well-sorted sand and/or gravel. In the Baldwin Creek valley at elevations of about 890 to 950 feet. Lake level at this time was probably controlled by an outlet in the defile between the Hogback Mountains and South Mountain at Bristol Village.
- **Plbr2**, **Plbr1** — Lake Deposits, glacial Lake Bristol. Sand and gravel deposited as ice-contact and meteoric deltas and associated fluvial sediments deposited in glacial Lake Bristol. Lake levels were probably controlled by outlets in the southern reaches of Baldwin Creek or in the defile between the Hogback Mountains and South Mountain at Bristol Village. Numbers denote relative ages of the deposits (1 = oldest, 3 = youngest).
- **Plst** — Lake Deposits, glacial Lake Starksboro. Coarse gravel and sand deposited as ice-contact deltas and associated alluvial sediments into glacial Lake Starksboro. The level may have been graded to a spillway near the junction of Beaver Brook and Baldwin Creek.
- **Plf** — Lake Deposits, Fine-grained. Clay, silt, and very fine to fine sand deposited in deeper waters. Commonly varved. Dropstones are locally common. Deposited in Coveville or Upper Fort Ann Stages of glacial Lake Vermont.
- **Plc** — Lake Deposits, Coarse-grained. Well-sorted sand and/or gravel deposited in shallow waters or as proximal subaqueous outwash from delta at Bristol Village. Deposited in Coveville or Upper Fort Ann Stages of glacial Lake Vermont.
- **Plu** — Lake Deposits, undifferentiated. Coarse- to fine-grained lake deposits. Deposits in the Lewis Creek valley north of Starksboro are probably mostly from Coveville Stage. Deposits west of Hogback Mountains and west of Bristol Village are from Coveville or Upper Fort Anne Stage.
- **Pickt** — Kame Terrace Deposits. Poorly- to moderately-sorted, generally weakly bedded, sand, gravel, and silt deposits. These lie beneath the delta deposits on the main terrace at Bristol Village.
- **Pic** — Ice-contact Deposits. Unsorted to poorly-sorted sand, gravel, and silt deposited in contact with glacial ice. Includes esker and possible kame or kame terrace deposits in the western part of the quadrangle.
- **Ptw** — Wave-washed Till. Similar to Pt and Ptt, but with low-relief wave-cut shorelines. Found on slopes below the Coveville level of glacial Lake Vermont.
- **Ptth** — Thick Till. Dense to very dense, unsorted to very poorly sorted, sand- to silt-matrix till. Surface boulders are common. Thickness is highly variable, but general from 5 meters to greater than 30 meters. Bedrock outcrops are uncommon.
- **Pt** — Till. Dense to very dense, unsorted to very poorly sorted, sand- to silt-matrix till. Surface boulders are common. Thickness is highly variable, from less than 1 meter to greater than 30 meters.
- **Ptt** — Till, Thin. Descriptions as in preceding unit. Thickness highly variable but generally less than 3 meters and bedrock outcrops are very common. The till is particularly thin on the Hogback Mountains in the center of the quadrangle.
- **rk** — Bedrock exposures.

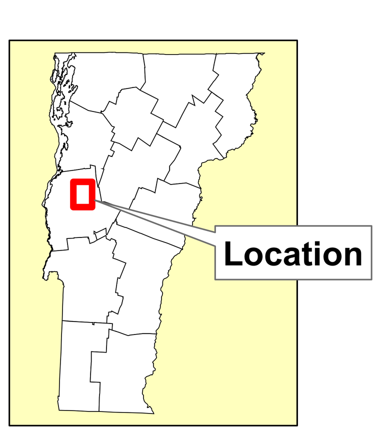
- Field Sites
- Bedrock Outcrops
- Crag and Tail Landforms
- Glacial Striations
- Kettle Holes
- Water Bodies
- Streams
- Meltwater Channels
- Pre-CovevilleShorelines
- Spillway
- Terrace Edges
- Till Bench Edges
- Bristol Town Boundary
- Upper Fort Ann Shoreline of Glacial Lake Vermont
- Lower Fort Ann Shoreline of Glacial Lake Vermont
- Coveville Shoreline of Glacial Lake Vermont
- Town Boundaries
- Quadrangle Boundaries

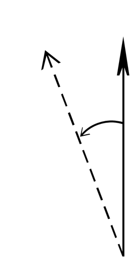
Scale 1:24,000

Miles 0 1 2 3

Kilometers 0 1 2 3 4 5

Contour Interval 20 feet





Magnetic declination
14.7 degrees west, 2012

Base map from U.S. Geological Survey.
Coordinate System: Vermont State Plane, meters, NAD 83.
Geographic coordinates shown at topo corners are in NAD 83.
Grid overlay on map is UTM, Zone 18N, NAD83.

Digital cartography by George Springston, February 24, 2015.
Research supported by the Vermont Geological Survey,
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The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the State of Vermont.

Surficial Geologic Map of Bristol, Vermont (Draft)

by
George E. Springston, Ethan J. Thomas,
and Jonathan J. Kim
2015

Published by:
Vermont Geological Survey, Marjorie Gale, State Geologist
Department of Environmental Conservation
Agency of Natural Resources
1 National Life Drive, Davis 2
Montpelier, VT 05620-3902
http://www.anr.state.vt.us/dec/geo/vgs.htm

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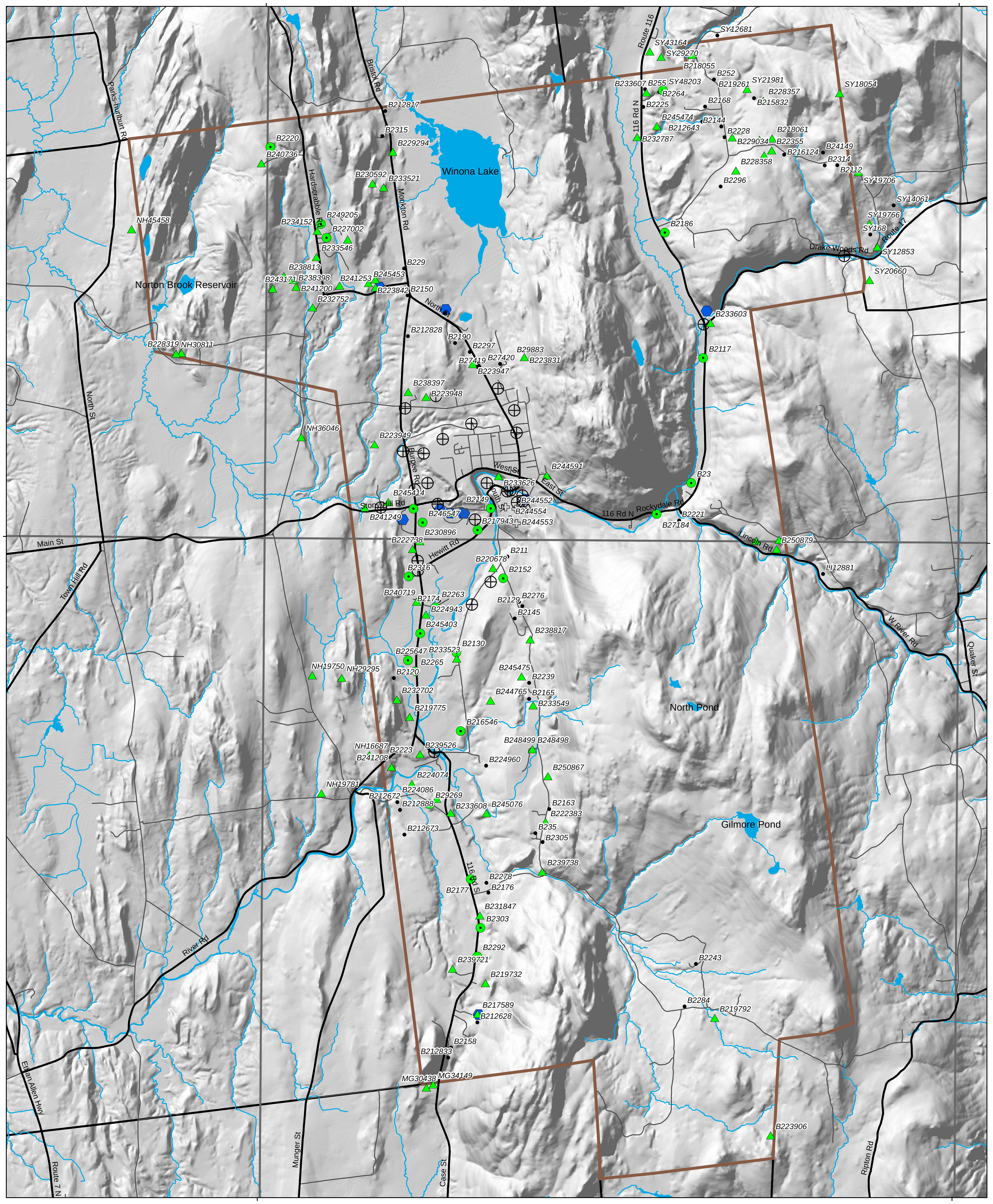


Scale 1:24,000

Miles: 0, 1, 2

Kilometers: 0, 1, 2, 3, 4

Wells

WELLTYPE

- Unknown
- Bedrock
- Bedrock
- Gravel
- Gravel
- Monitoring
- Borings
- Public Water Supplies
- Major Roads
- Minor Roads
- Quadrangle Boundaries
- Bristol Town Boundary
- Town Boundaries
- Streams
- Water Bodies

Explanation

This map shows the locations of wells and borings used in the construction of the surficial geologic map (Plate 2) and several of the plates that follow.

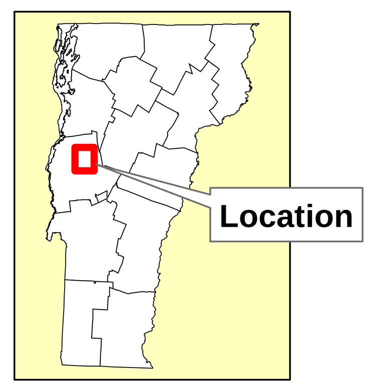
The private water well data was obtained from the Vermont Agency of Natural Resources Natural Resource Locator (http://www.anr.state.vt.us/dec/maps.htm , last accessed on June 23, 2015). Due to problems with the accuracy of locations for many of the older wells, the analysis was limited to newer wells that included either GPS coordinates or E911 addresses and older wells that had their locations verified by checks of town records or by knowledgeable residents.

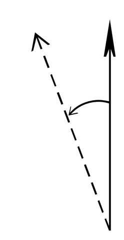
Information on borings was obtained from the Materials and Research Division of the Vermont Agency of Transportation, Hodges (1967), and Mack (1995). Locations of Public Water Supplies are also shown.

References:

Hodges, A.L., Jr., 1967, Ground-water favorability map of the Otter Creek basin, Vermont: Vermont Department of Water Resources, Montpelier, 1 plate.

Mack, T.J. Hydrogeology, simulated ground-water flow, and ground-water quality at two landfills in Bristol, Vermont: U.S. Geological Survey Water-Resources Investigations Report 94-108, 65 p. plus appendices.





Magnetic declination
14.7 degrees west, 2012

Base map from U.S. Geological Survey.
Coordinate System: Vermont State Plane, meters, NAD 83.
Geographic coordinates shown at topo corners are in NAD 83.
Grid overlay on map is UTM, Zone 18N, NAD83.

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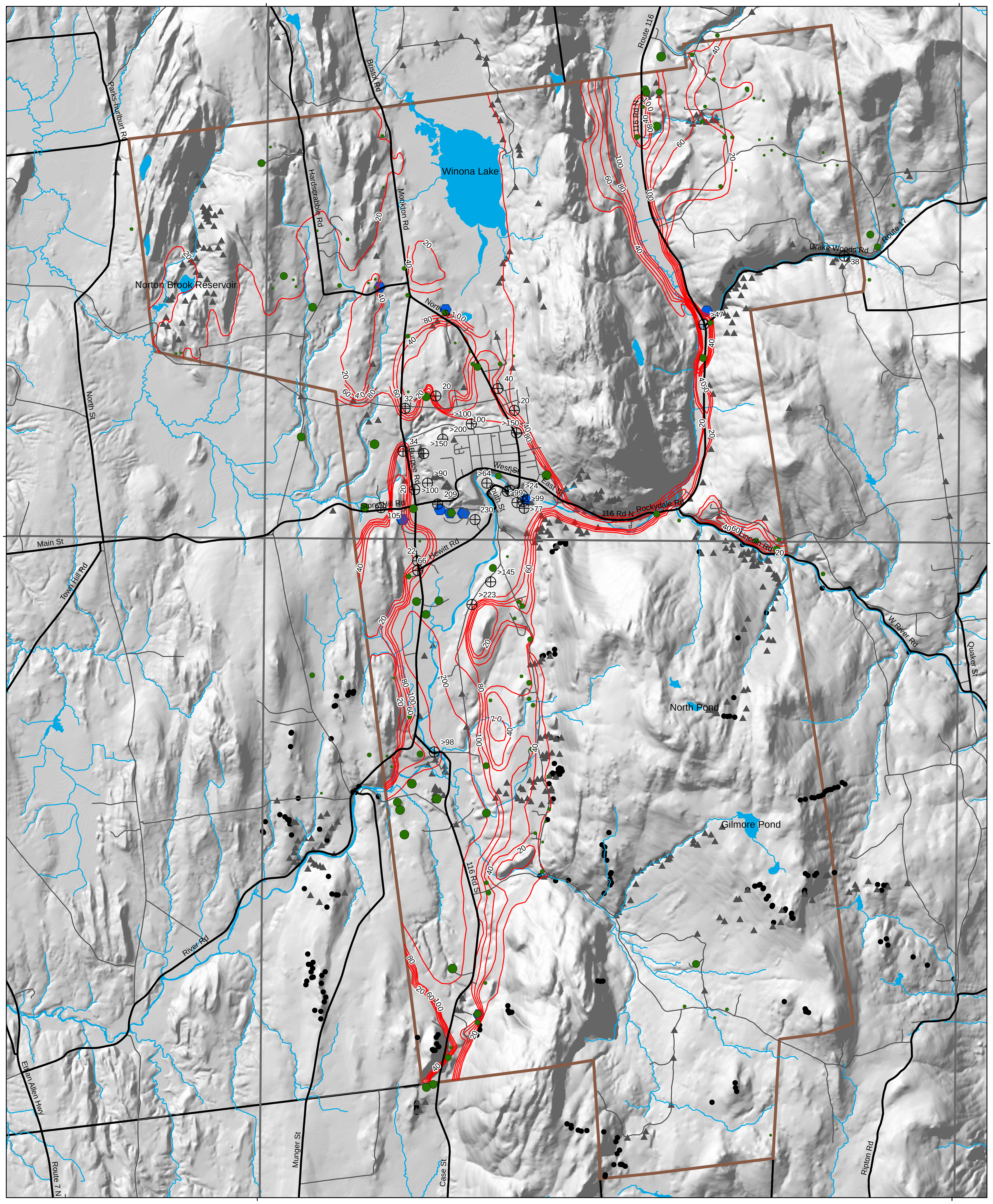
Wells and Borings, Bristol, Vermont
by
George E. Springston
2015



Scale 1:24,000

Miles: 0, 1, 2

Kilometers: 0, 1, 2, 3, 4

Well with Depth to Bedrock (feet)

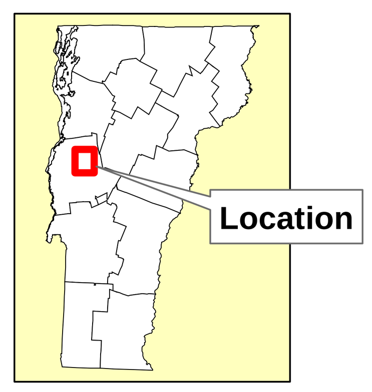
- 0 - 20
- 21 - 40
- 41 - 60
- 61 - 80
- 81 - 100
- 101 - 150
- 151 - 200
- 201 - 409
- Boring with Depth to Bedrock (feet)
- Bedrock Outcrops
- Field Sites in Surficial Deposits
- Major Roads
- Minor Roads
- Public Water Supplies
- Quadrangle Boundaries
- Streams
- Bristol Town Boundary
- Town Boundaries
- Water Bodies

Explanation

This map shows depth to bedrock (also known as depth of overburden) by means of approximate contour lines and by scaled map symbols. See Plate 6 for a discussion of how the thickness of the surficial materials influences their potential as aquifers.

The contour lines were drawn using the wells and borings shown in Plate 3 and the bedrock locations and locations of surficial materials exposures that were used in construction of the bedrock and surficial maps in Plates 1 and 2. The lines are at depths of 20, 40, 60, 80, 100, and 200 feet. The depth to bedrock at individual wells is shown by the green dots, which increase in size as the depth increases. Depth to bedrock is also shown for the borings, although many of these did not penetrate all the way to bedrock and thus give only a minimum value (indicated by ">" ahead of the depth figure).

Contouring is limited to those areas with sufficient wells and borings. Thus, only the 20-foot contour is shown in much of the northwestern part of town and contours are not shown in the southeastern part of the town (which is largely within the Green Mountain National Forest). Although individual wells exceed 200 feet to bedrock in the vicinity of the village center, the density of data only allows the 200-foot contour to be drawn in the southwestern portion of the town.



Magnetic declination
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Base map from U.S. Geological Survey.
Coordinate System: Vermont State Plane, meters, NAD 83.
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Grid overlay on map is UTM, Zone 18N, NAD83.

Digital cartography by George Springston, June 25, 2015.
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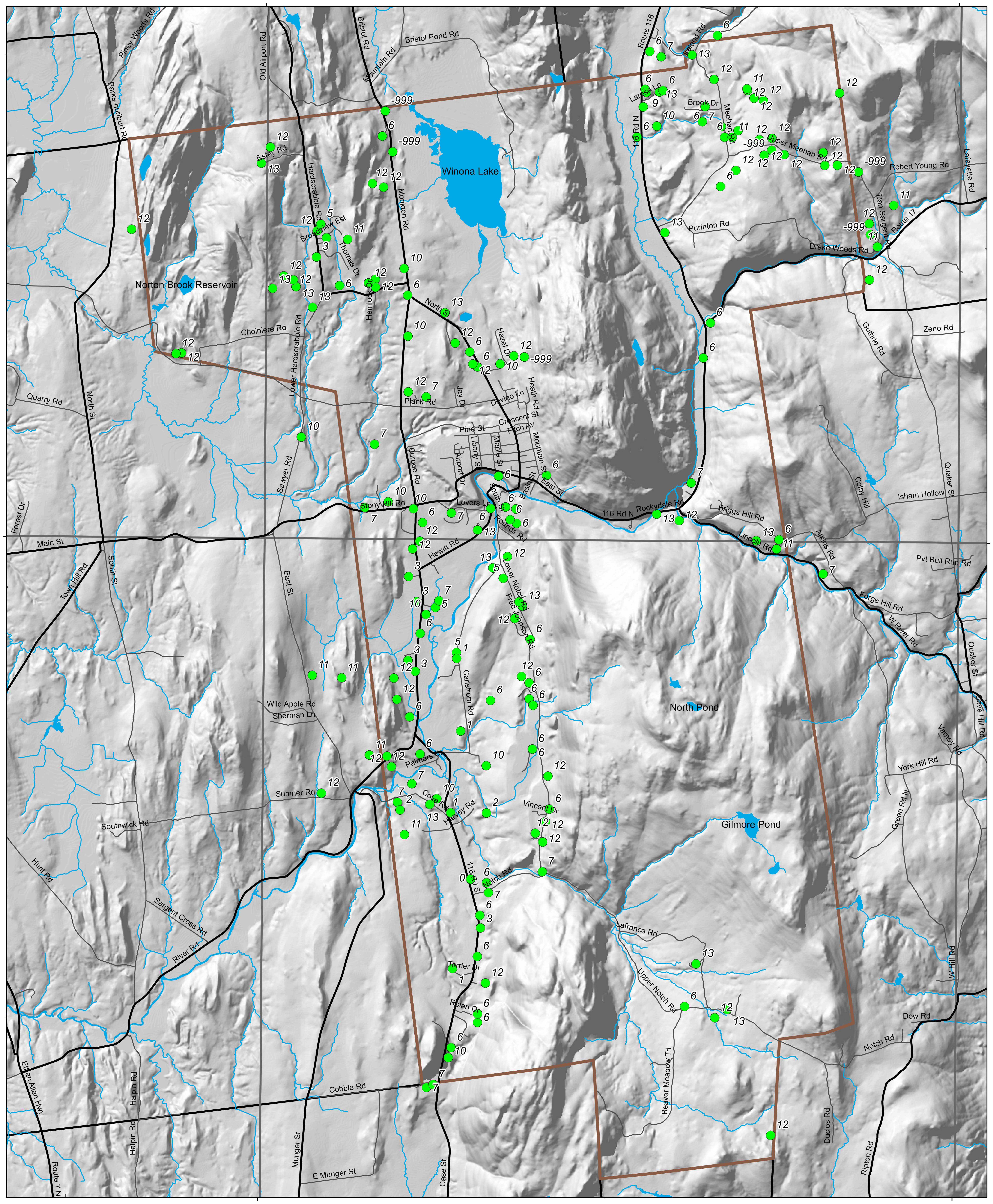
Depth to Bedrock, Bristol, Vermont

by
George E. Springston
2015

Vermont Geological Survey Open File Report VG15-1, Plate 4



- Hydrogeologic Classification of Well Logs
- Major Roads
- Minor Roads
- Streams
- Water Bodies
- Bristol Town Boundary
- Quadrangle Boundaries
- Town Boundaries

Explanation

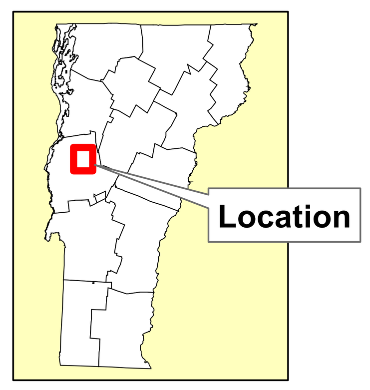
The purpose of the hydrogeologic classification is to rank how easily ground water can move through the surficial materials. The classification is made using water well logs and is based almost entirely on the coarseness of the surficial materials, with the assumption that ground water will be able to flow easier through coarser materials than through finer ones. Interpretations based on this data will be shown on other plates in this report.

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.

Hydrogeologic Classification

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.



Magnetic declination
14.7 degrees west, 2012

Scale 1:24,000

Miles
0 1 2

Kilometers
0 1 2 3 4

Base map from U.S. Geological Survey.
Coordinate System: Vermont State Plane, meters, NAD 83.
Geographic coordinates shown at topo corners are in NAD 83.
Grid overlay on map is UTM, Zone 18N, NAD83.

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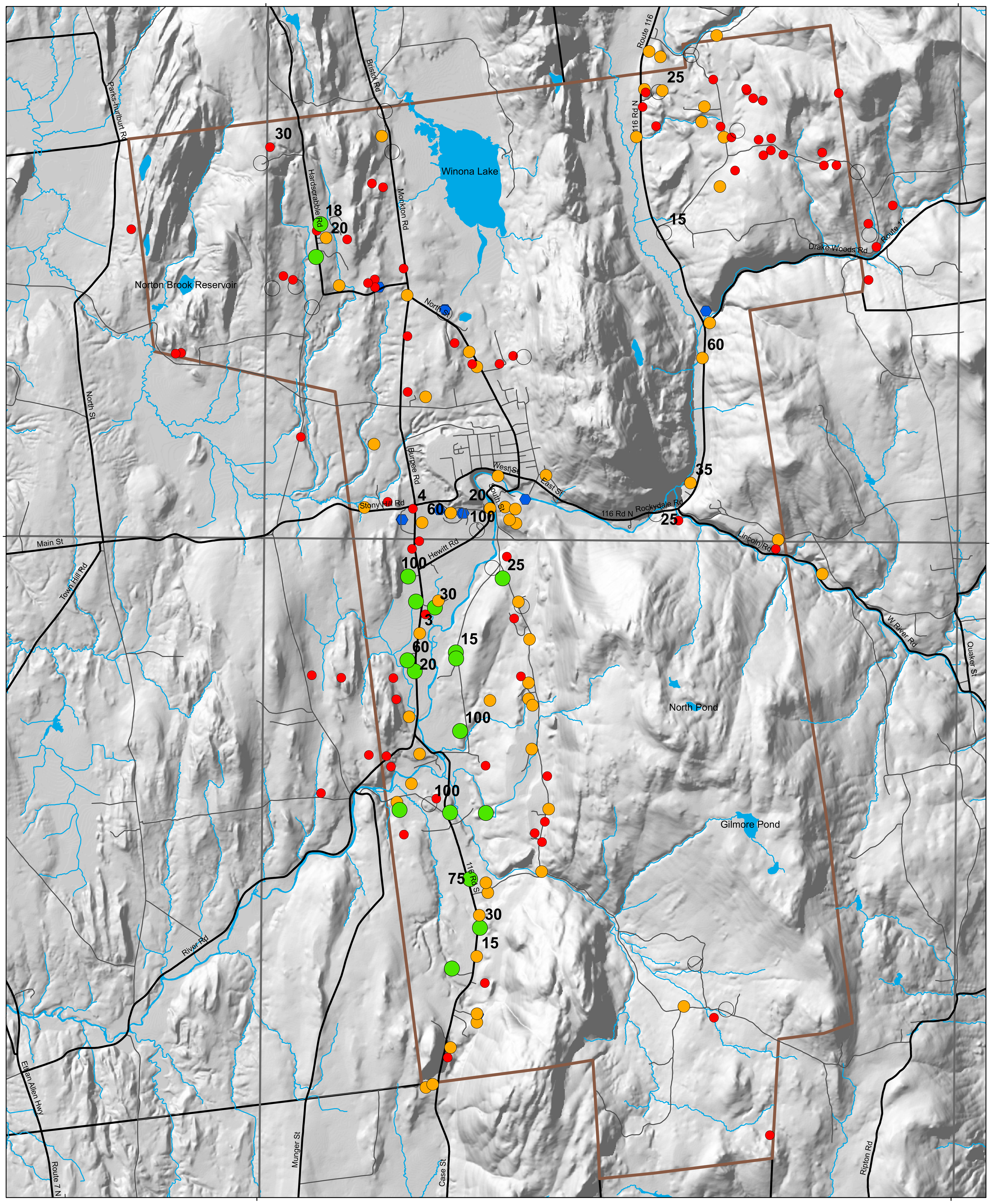
Hydrogeologic Classification of Well Logs, Bristol, Vermont

by

George E. Springston

2015

Vermont Geological Survey Open File Report VG15-1, Plate 5



Bristol Surficial Aquifer Potential

Hydrogeo

- High
- High
- High
- High
- High
- Moderate to High
- Moderate to High
- Low
- Low
- Low
- Low
- Low
- Unknown
- Unknown
- Public Water Supplies
- Major Roads
- Minor Roads
- Quadrangle Boundaries
- Bristol Town Boundary
- Town Boundaries
- Streams
- Water Bodies

Scale 1:24,000

Miles
0 1 2

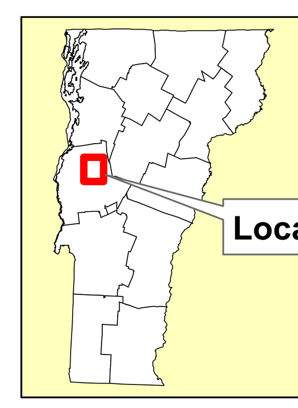
Kilometers
0 1 2 3 4

Explanation

This map uses the hydrogeologic classification of private water well logs shown on Plate 5 to estimate the surficial aquifer potential of the surficial deposits in the town. Wells in Hydrogeologic Classes 0, 1, 2, 3, and 5 were assigned a high potential, those in Classes 6 and 7 were assigned a moderate potential, and those in Classes 8 through 12 were assigned a low potential. There were no wells assigned to Class 4, which would have a high potential.

The wells that end in the surficial deposits (often called "gravel wells") are shown on the plate and their yields (in gallons per minute) provide a means of checking the accuracy of the class assignments. Although the yields are estimates by the drillers and are of limited accuracy, they are indeed generally high where the classes are ranked as moderate or high.

Refer to the explanation of Plate 5 for details of the classification. Note that these estimates are based solely on water well logs and that subsurface conditions vary markedly from well to well.



Magnetic declination
14.7 degrees west, 2012

Base map from U.S. Geological Survey.
Coordinate System: Vermont State Plane, meters, NAD 83.
Geographic coordinates shown at topo corners are in NAD 83.
Grid overlay on map is UTM, Zone 18N, NAD83.

Digital cartography by George Springston, June 25, 2015.
Research supported by the Vermont Geological Survey, Dept. of Environmental Conservation, VT ANR.

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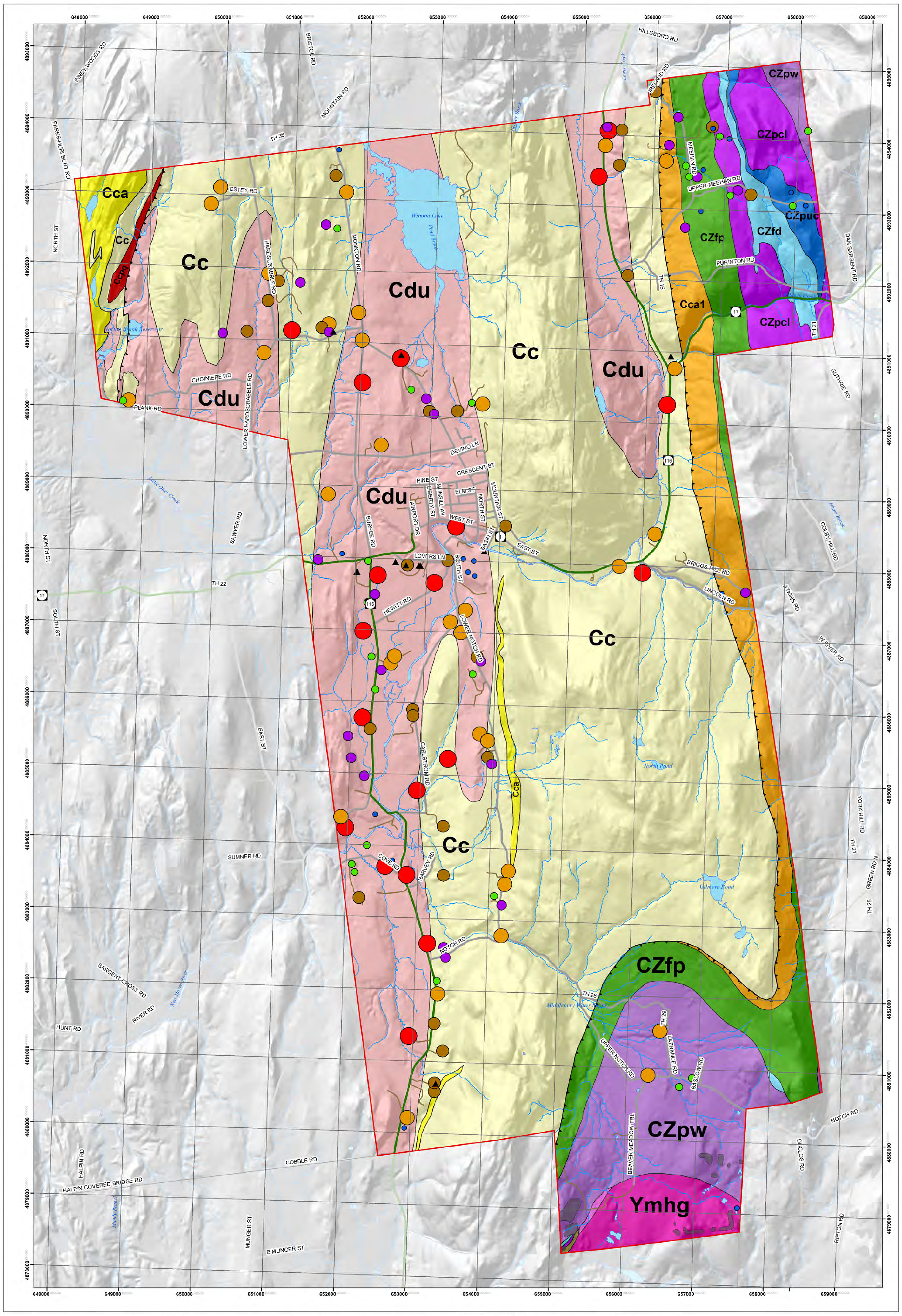
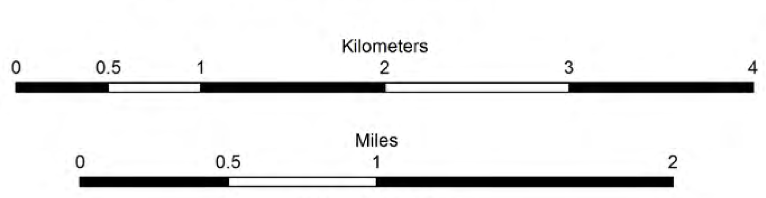
Surficial Aquifer Potential, Bristol, Vermont

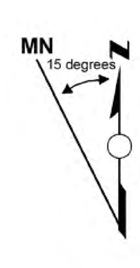
by
George E. Springston
2015



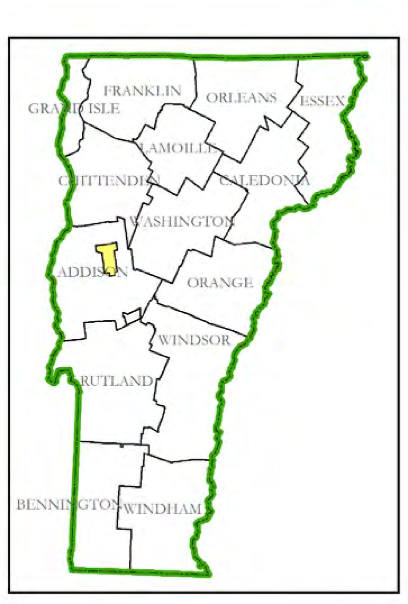
Well Yield Map of theTown of Bristol, Addison County, Vermont

Author: Jonathan Kim





scale = 1: 24,000
contour interval = 20'



Driller's Well Yield (gpm)

- 0 - 1
- 2 - 5
- 6 - 10
- 11 - 20
- 21 - 50
- 51 - 180

Published by:
Vermont Geological Survey
Marjorie H. Gale, State Geologist
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Montpelier, VT 05620-3902
http://www.anr.state.vt.us/dec/geo/vgs.htm

Base maps of the South Mountain and Bristol quadrangles from U.S. Geological Survey.
Coordinate System: Vermont State Plane, meters, NAD 83.
Grid overlay on map is Universal Transverse Mercator, Zone 18N, NAD 83.
Digital Cartography by Jonathan Kim
Date: February 2015

Research supported by the Vermont Geological Survey, Dept. of Environmental Conservation, VT ANR. This geologic map was funded in part by the USGS National Cooperative Mapping Program. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

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Vermont Geological Survey

Description of Map Units

Foot Wall of Hinesburg Thrust

Lower Cambrian

Cdu — **Dunham Formation**
Brown-weathering, massive, irregularly-bedded buff to gray to white dolostone. Contact with underlying Cheshire and overlying Monkton Formations is gradational and interbedded.

Ccpq — **Cheshire Formation**
Light pink to light gray, fine grained, vitreous, well-bedded quartzite.

Cc — Light to dark gray, fine to medium grained, quartzite and argillaceous quartzite with minor phyllite. Beds of dolostone occur near contact with Dunham Fm. and quartzite has a pinkish hue. Discontinuous, white, mottled, rippled quartzite beds from 2.5 to 20 cm occur locally.

Cca — Fine to medium grained, gray and rusty weathered, dark gray argillaceous quartzite with thin light gray quartzite layers and abundant quartz veins.

Hanging Wall of Hinesburg Thrust

Ccai — Fine grained, dark gray and rusty weathered, dark gray argillaceous quartzite that is interlayered with light gray phyllitic quartzite layers. Found interlayered with CZfp in the hanging wall of the Hinesburg Thrust.

Cambrian and Neoproterozoic

CZfp — **Fairfield Pond Formation**
Gray to gray green, light gray to light brown weathered, fine grained quartz, sericite, chlorite phyllite. Fine, light gray laminations are common. Magnetite is common near the base of the unit. Contact with overlying Cheshire Fm. is gradational.

CZfd — **Forestdale Formation**
Light brown, brown to black weathered, sandy dolarenite. Typically thickly bedded with thin interbedded chlorite schist.

CZpw — **Pinnacle Formation**
Light to dark gray, medium to coarse grained, massive to thick bedded, quartz, feldspar, muscovite, chlorite, biotite metawacke with minor carbonate. Locally contains conglomeratic beds less than 1 m thick with well-rounded quartz (commonly blue-gray) and gneiss pebbles less than 5 cm long. Characteristic "Pinnacle" lithology.

CZps — Light gray to gray green, rusty weathered, fine grained, massive quartz, felspar, muscovite, metawacke and schist with minor chlorite, epidote, magnetite and tourmaline. Biotite is rare and rock fragments are absent. Laminations are locally well developed.

CZpcl — Light green, locally rusty, silver gray weathered, fine grained quartz, plagioclase, muscovite, magnetite, chlorite schist. Abundant magnetite porphyroblasts (<7mm) are diagnostic. Locally interbedded with chlorite rich metawacke and dolomite.

CZpcg — Poorly sorted, matrix supported, quartz and gneiss cobble conglomerate. Cobbles up to 55 cm in diameter and rare quartzite boulders up to 3 m in diameter have been observed. Matrix is gray weathered quartz, feldspar, biotite, muscovite, chlorite schist with minor calcite and magnetite.

CZpuc — Lustrous green chloritic phyllite and fine-grained metagraywacke.

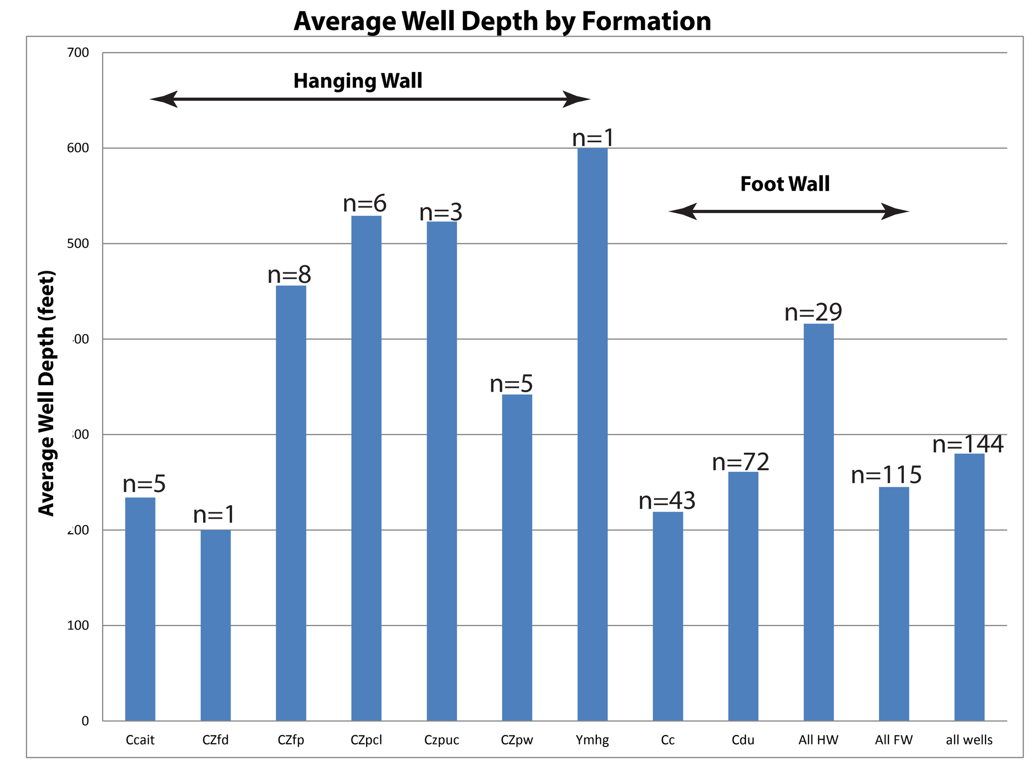
Mesoproterozoic

Ymhg — **Mount Holly Complex**
Pink gray, light gray, and greenish white, fine to coarse grained quartz, plagioclase gneiss with varying amounts of sericite, chlorite, microcline and biotite. Other minor minerals include epidote, apatite, calcite, garnet, tourmaline, rutile, zircon, magnetite and sphene. (Y1,2bg of Ratcliffe and others, 2011)

Ymhq — Massive, light blue to gray weathered quartzite with minor amounts of sericite, biotite, chlorite, plagioclase, rutile and opagues. Interbedded with tourmaline chloritoid schist (Ymht). (Middle to Early Mesoproterozoic Y2q of Ratcliffe and others, 2011)

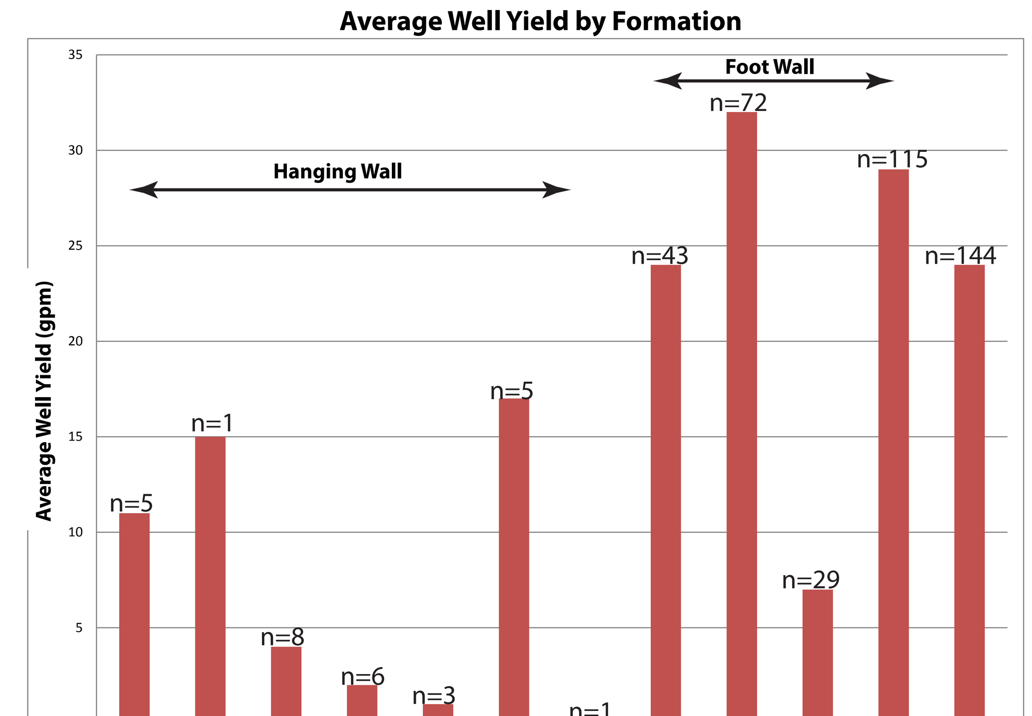
Well Statistics By Formation

Average Well Depth by Formation



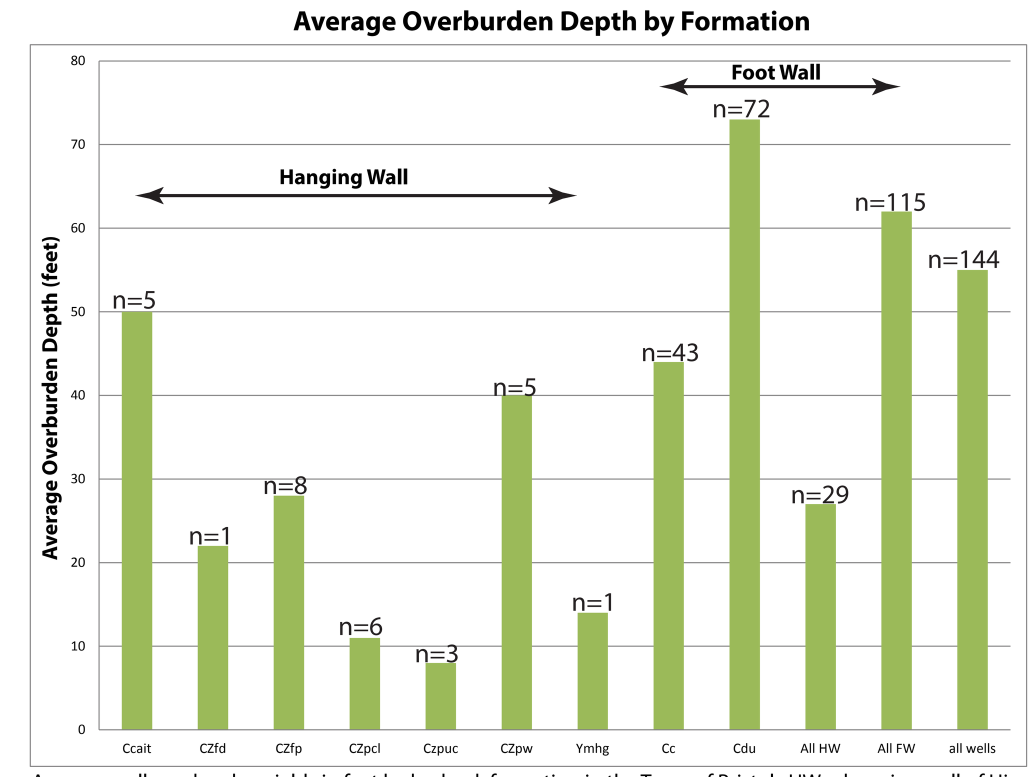
Average well depths in feet by bedrock formation in the Town of Bristol. HW = hanging wall of Hinesburg Thrust; FW= foot wall of Hineburg Thrust; n= # of wells in each grouping. The average depth for a hanging wall well (416') is 1.7 X that of a foot wall well (245').

Average Well Yield by Formation

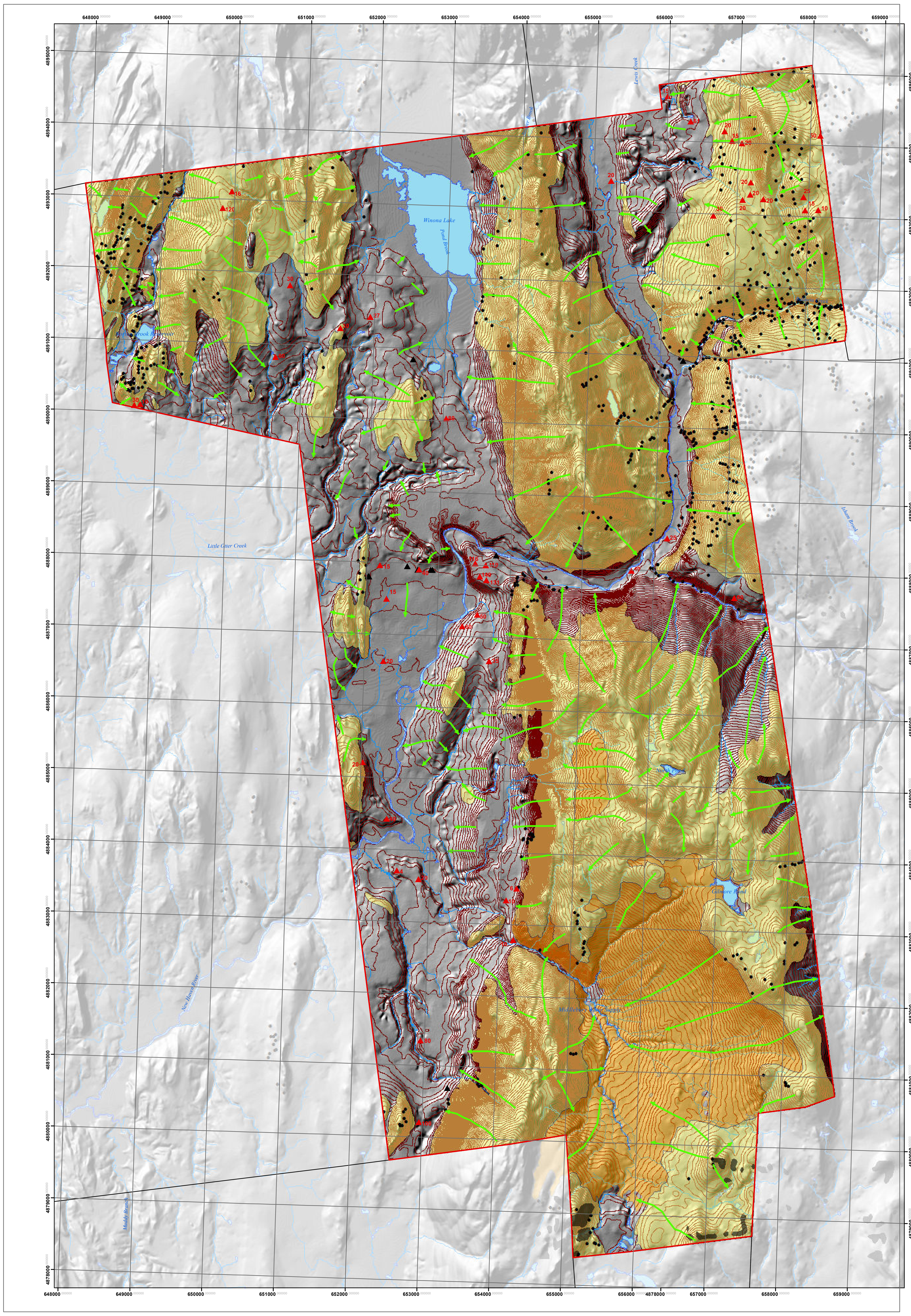


Average well yields in gallons/ minute by bedrock formation in the Town of Bristol. HW = hanging wall of Hinesburg Thrust; FW= foot wall of Hineburg Thrust; n= # of wells in each grouping. The average yield for a hanging wall well (7 gpm) is ~25% of that of a foot wall well (29 gpm).

Average Overburden Depth by Formation



Average well overburden yields in feet by bedrock formation in the Town of Bristol. HW = hanging wall of Hinesburg Thrust; FW= foot wall of Hineburg Thrust; n= # of wells in each grouping. The average overburden for a hanging wall well (27') is ~2.3 X of that of a foot wall well (62').



- Bedrock Outcrop Exposed at the Surface
- Thick Glacial Till (>10' thick with little exposed bedrock)
- Thin Glacial Till (<10' thick with abundant exposed bedrock)
- Well with Reported Static Water Level (in feet)
- Public Water Supply LOcation
- Generalized Groundwater Flow Directions, if constrained by topography alone

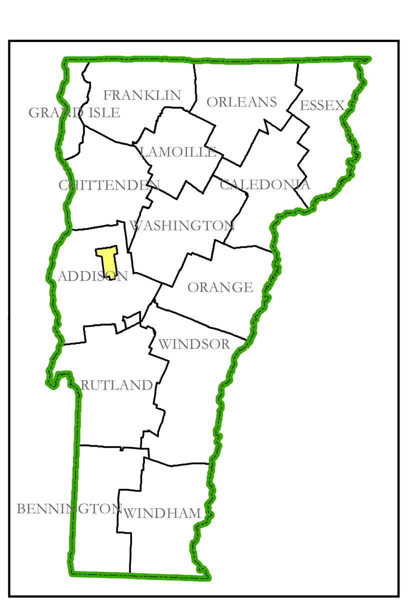
This map shows the general factors that may influence the recharge of groundwater to the bedrock aquifer such as bedrock outcrops (ledges) exposed at the surface, glacial till thickness, and topography. Wherever bedrock is exposed at the ground surface, it is possible for rainwater or water running on the ground surface to flow downward to the bedrock aquifer, if open cracks or “beds” are present in the rock.

Glacial till is composed of pebbles, sand, silt, and clay that were left behind on the ground surface by the glacier as it melted thousands of years ago. Glacial till was generally deposited in areas of higher elevation. Whenever glacial till is thin (<10’ thick with interspersed outcrops of bedrock), rainwater or water flowing along the ground surface may percolate downward through the till to the bedrock below and enter the bedrock aquifer through open cracks or “beds”. If glacial till is thick (>10’ thick with no interspersed bedrock), downward flow of water can still occur, but flow takes longer because of the thicker till.

Groundwater flows from higher elevations toward lower elevations under the influence of gravity and also flows from higher pressure to lower pressure. On the map, green arrows show the direction groundwater will travel from higher elevations to lower elevations under the influence of gravity alone.

The static water level (SWL) is the level that groundwater will rise to in a well based on the upward pressure from the aquifer. It is usually measured in feet below the ground surface. Well drillers measure the SWL after they have finished drilling a well. The SWL was not measured in many wells in Bristol so it is not possible to construct a “water table” (piezometric surface) contour map. This map shows the location of all accurately-located wells in the Town of Bristol that have an SWL.

Map That Constrains Recharge, Discharge, and Generalized Groundwater Flow Directions in the Town of Bristol



Authors: Jonathan Kim and George E. Springston

Kilometers: 0 0.5 1 2 3 4

Miles: 0 0.5 1 2

MN 15 degrees

scale = 1: 24,000
contour interval = 20'

VERMONT
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Vermont Geological Survey

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Base maps of the South Mountain and Bristol quadrangles from U.S. Geological Survey.
Coordinate System: Vermont State Plane, meters, NAD 83.
Grid overlay on map is Universal Transverse Mercator, Zone 18N, NAD 83.
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