Groundwater Resources of Woodstock, Vermont

by Laurence Becker[1], David DeSimone[1], Peter Thompson[2], and Marjorie Gale[1]

1 Vermont Geological Survey, 103 South Main St., Logue Cottage, Waterbury, VT 05671-2420
2 University of New Hampshire, Dept. of Geology, Durham, NH 03824

Abstract

The Town of Woodstock requested surficial and aquifer mapping from the Vermont Geological Survey to aid in groundwater protection and planning, which are priorities in the Woodstock Municipal Plan and the Two Rivers-Ottauquechee Regional Plan. Bedrock mapping was included since many residential wells penetrate bedrock.

The Waits River Formation consists of interbedded garnet schist and punky-weathering sandy marble and underlies much of the town. This bedrock was easily abraded by glacier ice and hills were rounded and veneered with till. Marble layers are more permeable than schists. Where the layers are nearly horizontal, bedrock wells penetrate alternating schist and marble and thus are likely to yield more water. Where the layers are more vertical, wells may show exceptionally high or low yields. A few high-yield wells in the SW corner of town tap well jointed, dense Barnard Volcanics. Two dominant joint sets, oriented roughly east-west and northeast, may explain the course of the Ottauquechee River and may also control the location of glacially scoured pockets in bedrock. Lineaments that are coincident with joint sets measured in the field may help locate future productive wells

As part of the surficial mapping project, data from well logs were consulted to evaluate yield, recharge potential to aquifers, delineate the extent of overburden aquifers, and to determine the 3-D distribution of glacial deposits. Thin till predominates in the upland region. Ice contact deposits, chiefly sand and gravel, occur primarily as isolated kamic deposits including minor kame terraces along the major valleys. Valleys contain thick overburden, primarily till, with glacially over deepened valley pockets. Beneath this till is a gravel unit yielding water to wells from a confined aquifer. The stratigraphy of these gravel wells is commonly capped by a fluvial terrace or flood plain unit of sand and gravel representing an unconfined aquifer.

Maps that combine information from the bedrock and surficial studies help to identify areas where till with relatively high recharge potential coincide with areas underlain by more permeable, moderately inclined marble layers. Derivative groundwater resource maps and recharge area maps are the result of these studies.

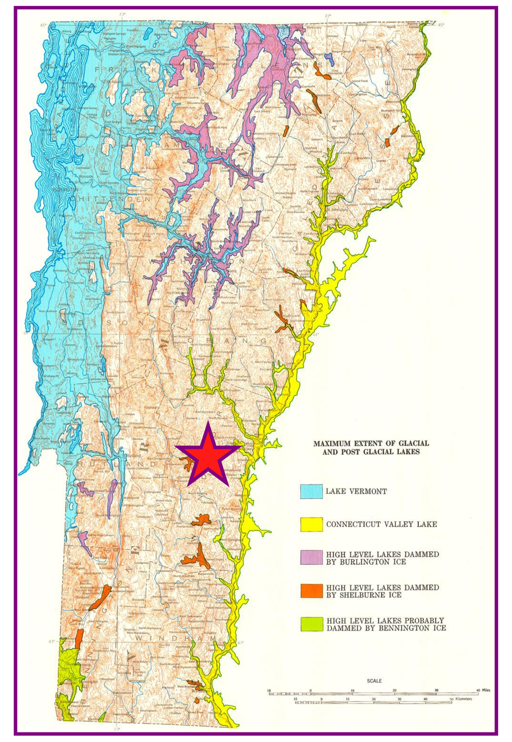
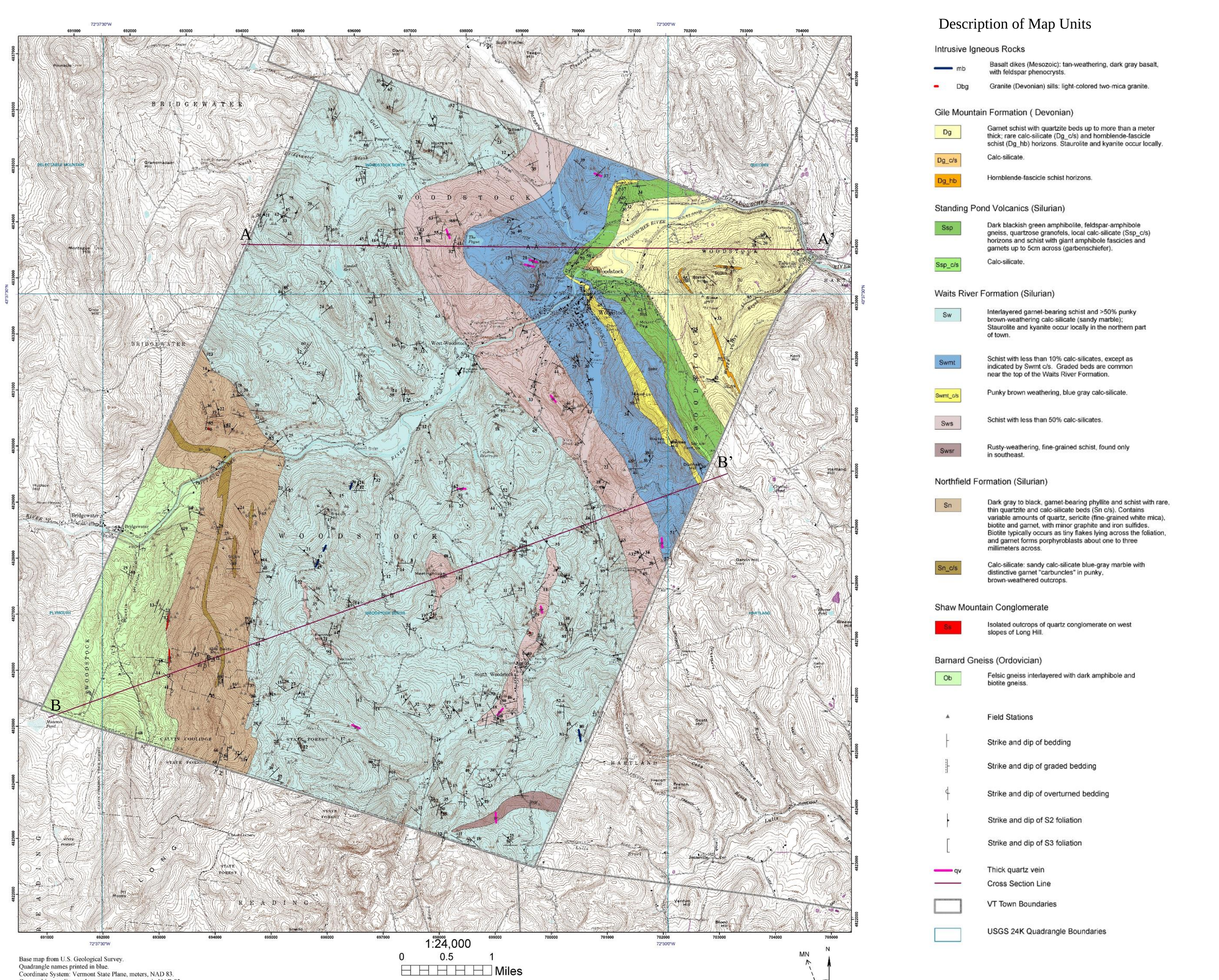
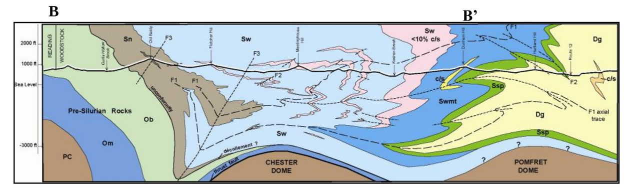


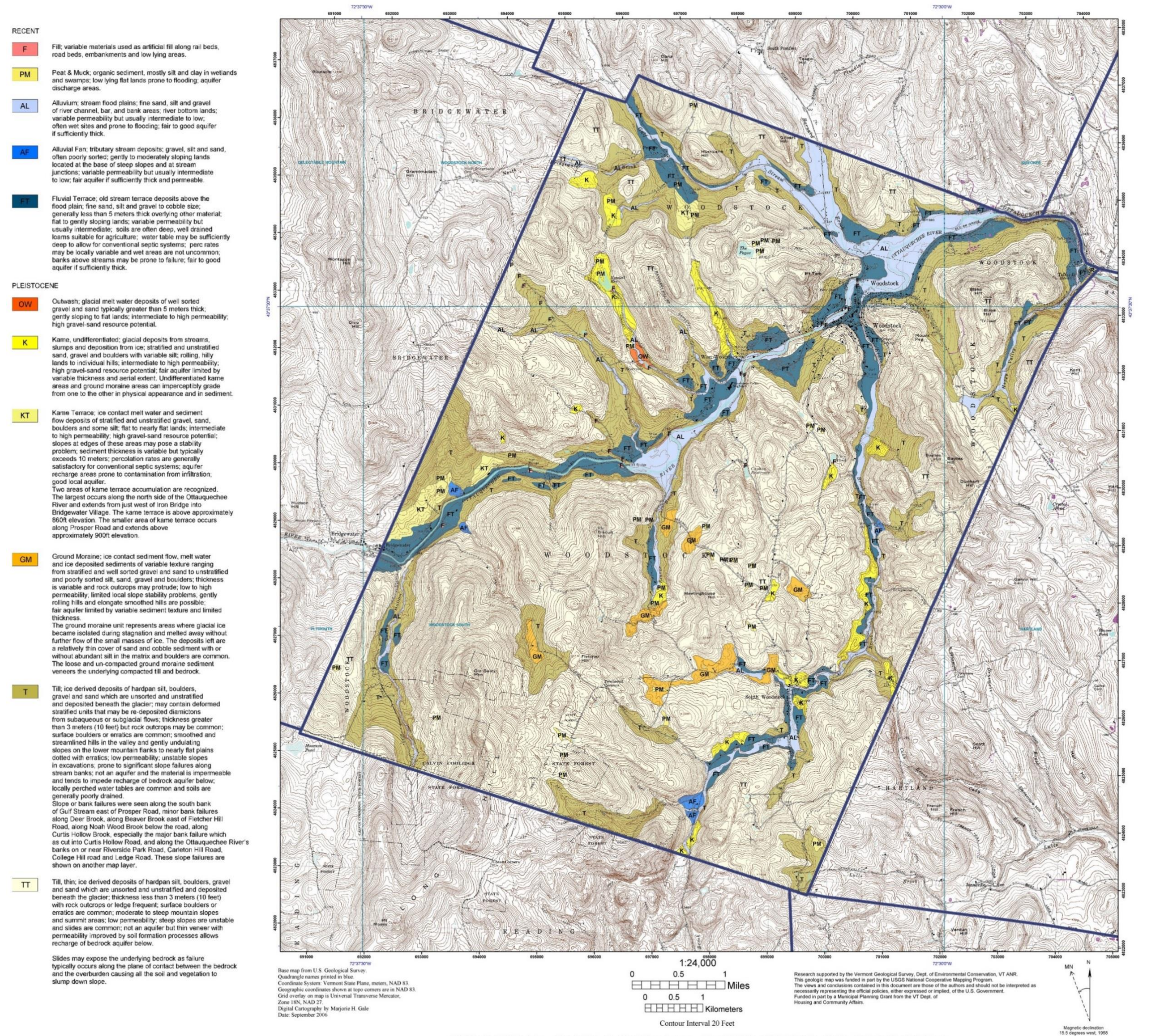
Figure 2. Location of Field Area



BEDROCK GEOLOGIC MAP OF WOODSTOCK, VERMONT
by
Peter J. Thompson
2006

Figure 3. Bedrock cross-section B – B' shows three fold generations (F1, F2, and F3). Woodstock is situated geologically on the east flank of the Green Mountain anticlinorium, in a structural saddle between the north-plunging end of the Chester dome (Thompson, 1950; Ratcliffe, 2000) and the south-plunging end of the Pomfret dome (Lyons, 1955). The domes (D3) deform an older set of folds that are overturned toward the east. A major anticline in this system passes through the town.





SURFICIAL GEOLOGIC MAP OF WOODSTOCK, VERMONT
David DeSimone
2006

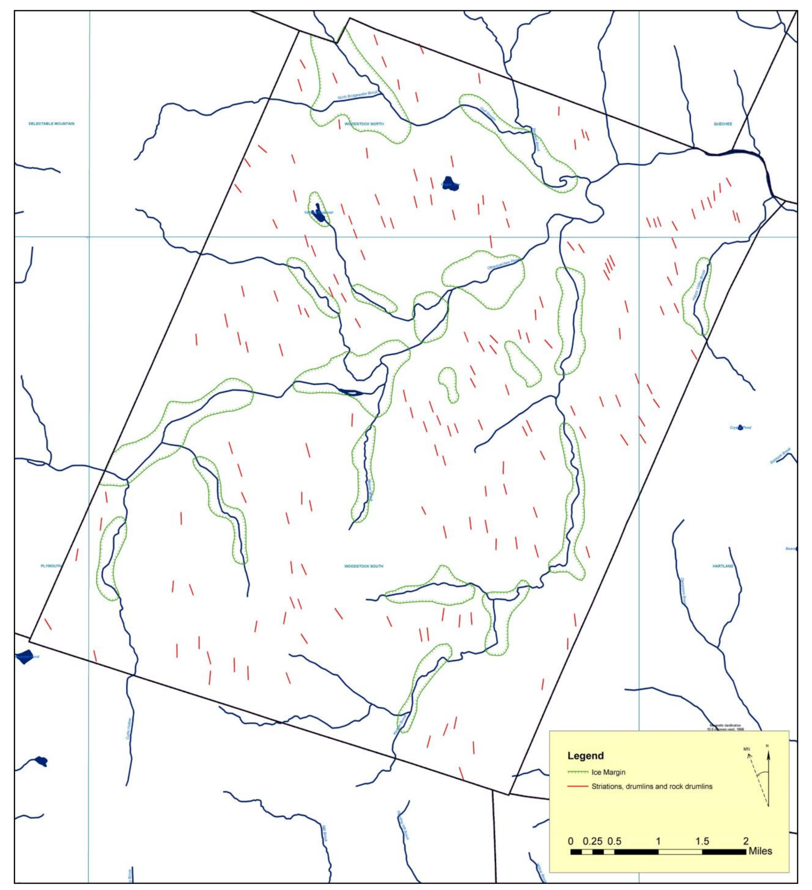
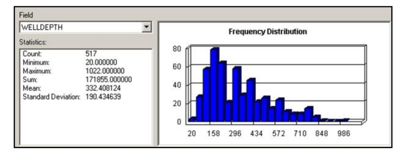
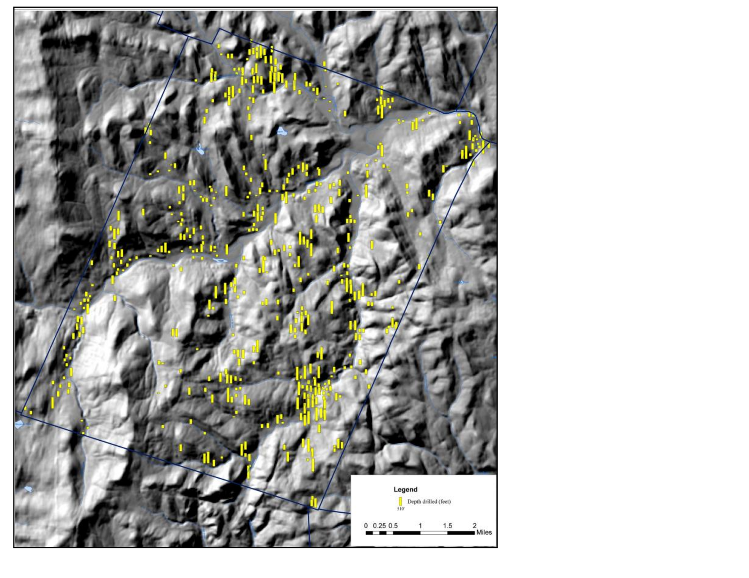
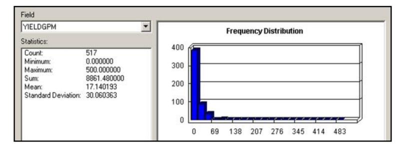


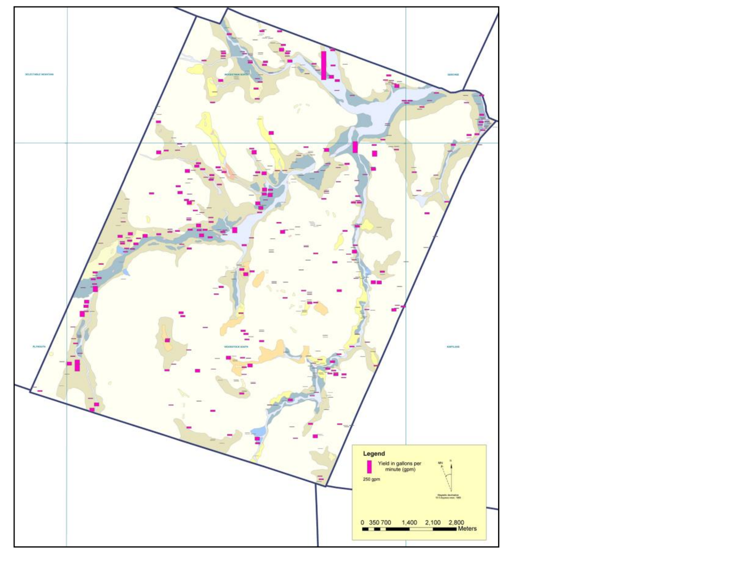
Figure 12. Ice Flow Data and Deglaciation. Axes of streamline molded forms such as drumlins, rock drumlins and striations reveal that glacier ice advanced from the N-NW. Glacial geomorphology and field data indicate no organized sequencial retreat of active ice margins. The steep terrain with narrow tributary valleys and the orientation of the Ottauquechee Valley approximately normal to ice flow direction both precluded the establishment of discrete valley glaciers during ice retreat. The patchy distribution of ice contact kame and ground moraine sediment and the occurrence of only one significant kame terrace suggest that glacier ice down-wasted via stagnation and melted into numerous isolated ice blocks occupying the low elevations in town. Furthermore, there is no firm evidence of the existence of an extensive ice marginal lake during deglaciation. Isolated ponds probably existed adjacent to the residual ice blocks patchily distributed throughout the valleys.





Figures 13 and 13A. Depths of all (517) located wells are shown on shaded relief. Total well depth ranges from 20-1022' with a mean depth of 332'. Statewide the mean well depth is 275'.





Figures 14and 14A. Well yields from 517 wells range from 0-500 gpm with a mean value of 17 gpm. Statewide the mean yield is 14 gpm. Most wells in Woodstock are in the Waits River Fm.

Specific yield is 0.051 gpm/foot. The statewide the specific yield, based on 91,469 wells is also 0.051 gpm/foot.

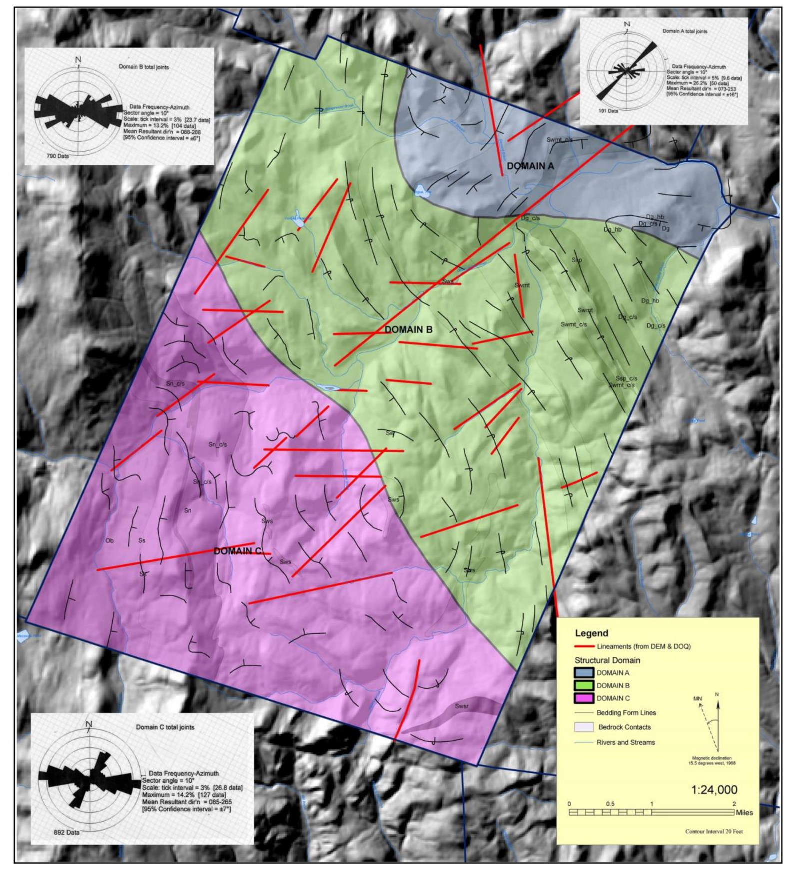
Fig. 1. Potential Flow Paths in Bedrock. This figure shows bedding form lines, photolinears from DEM and DOQ maps, rose diagrams of joints measured in outcrop, and structure domains.

Structural domains: Domain A -short limb of F2 fold, in which strikes are mostly toward the NE and dips are moderate SE (F2 inverts the overturned F1 limb such that bedding is upright). Folds and lineations plunge S. Domain B - long limb of F2 fold, overturned F1 limb. Strikes are mostly NW and dips are variable, but Domain B includes the zone of steep dips (Fig. 4) in the overturned F1 anticlinal axial region. Folds and lineations plunge S. Domain C - mostly upright F1 limb. Strikes are variable, dips to NW, N and NE. Folds and lineations plunge N. Also includes a portion of the zone of steep dips (Fig. 4).

Bedding form lines: Joints and parting often develops parallel to bedding, which can be visualized as layers parallel to the form lines on the map.

Photolinears: These are linear features which may or may not represent zones of closely-spaced joints. Those that are likely due to glacial flow have been omitted.

Rose diagrams: Geologists refer to cracks in bedrock, many of which may be potential conduits for groundwater, as "joints". The most interesting ones for water transmission are the long through-going joints and the shorter joints that cross or abut bedding-plane joints. The strikes of total joints measured in outcrops are plotted on three rose diagrams corresponding to the structural domains. There is some correspondence between the photolinears and the preferred orientations of joints.



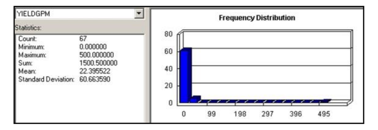


Figure 1A. Well yields in Domain A range from 0-500 gpm with a mean value of 22 gpm.

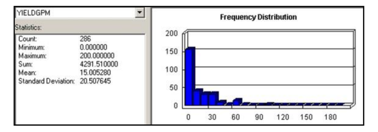


Figure 1B. Well yields in Domain B range from 0-200 gpm with a mean value of 15 gpm.

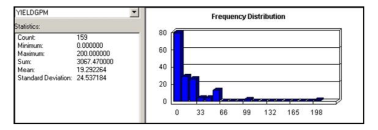


Figure 1C. Well yields in Domain C range From 0-200 gpm with a mean value of 19 gpm.

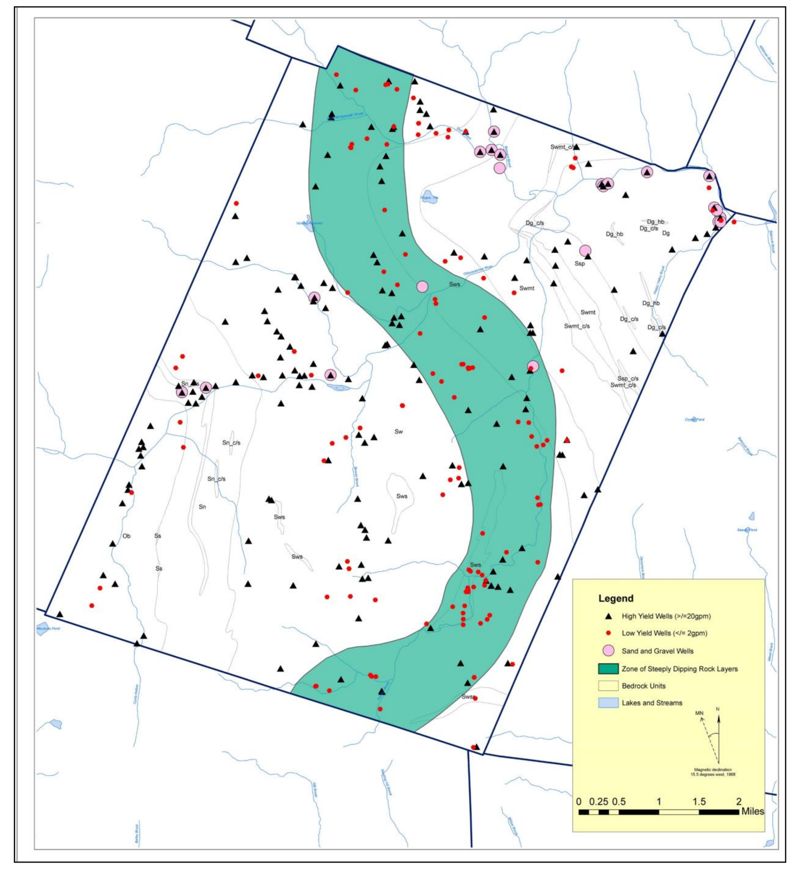


Figure 4. This map shows high yield wells (>/= 20 gpm), low yields wells (</= 2 gpm), wells in sand and gravel, and a zone of steeply dipping rock layers. Where the stratigraphy is nearly vertical (highlighted in green), wells drilled into bedrock may provide either exceptionally high or low yields depending on whether the wells are in sandy marble or schist. Where the stratigraphy is more nearly horizontal or inclined at moderate angles, bedrock wells will penetrate alternating layers of schist and calc-silicate and thus be less likely to have low yields.

Many joints strike perpendicular to bedding and S1 foliation, as seen in the rose diagrams from the different domains. The joints are younger than the bedding and foliation. They may have formed during arching of the domes or more likely during Mesozoic extension. The orientation of bedding and the dominant foliation may have controlled, in part, the orientation of joints. The implication for water flow is that many joints strike parallel to the dip direction of bedding planes. The flow direction (see Fig. 8), however, would be toward lower hydraulic head, which might be either in the down-dip or up-dip directions (generally west or east).

Intersecting joint sets in the Barnard Gneiss result in rectangular blocks that break away from the outcrop. The joints seem to be widely spaced but through-going. Some of the highest yielding bedrock wells in Woodstock are found in areas underlain by the gneiss (SW area of Town).

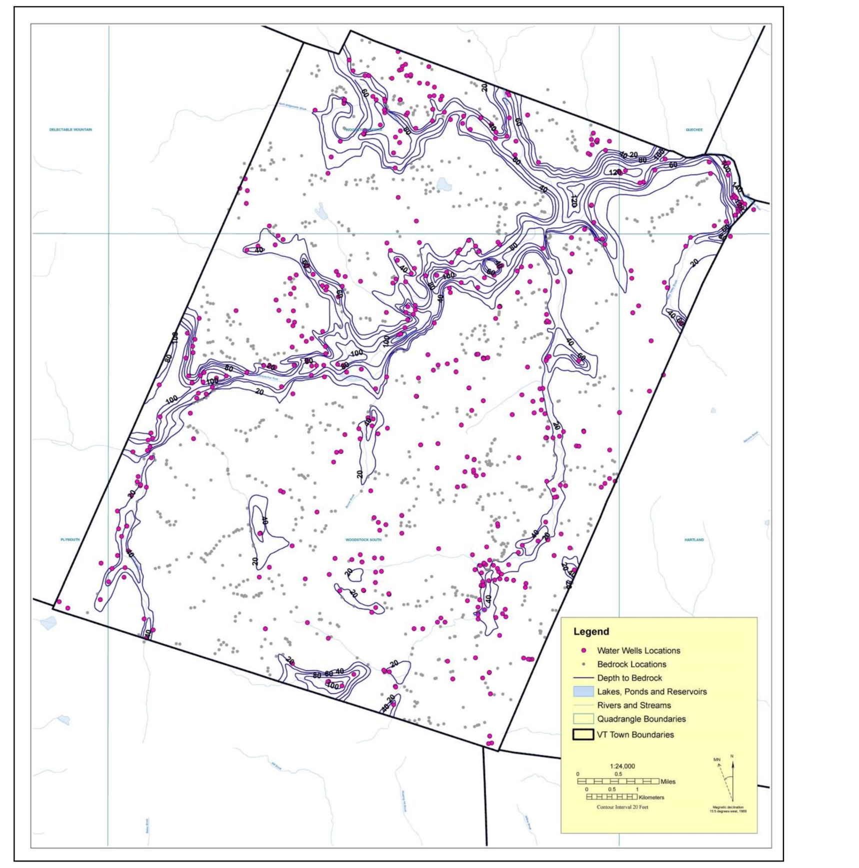


Figure 5. Depth to Bedrock Map - Data contained in well driller's logs (pink dots) were contoured to generate a depth to bedrock map for the Town. These data are plotted and contoured at a 20 ft contour interval. Zero contours are not shown but are reflected by the bedrock outcrops.

Most of the town is covered by less than 20 feet of overburden. This interpretation is based on available well log data which report depth to rock and/or length of casing. A thin blanket of till atop bedrock predominates in the uplands and many of the tributary valleys.

Major valleys and some tributaries contain greater than 20 feet of overburden. Thick overburden interpreted to be till from drillers' logs and field exposures underlies the flood plains and terraces. Well data reveal glacially scoured pockets filled with the thickest overburden along the Ottauquechee River, Gulf Stream, Barnard Brook and Happy Valley Brook troughs.

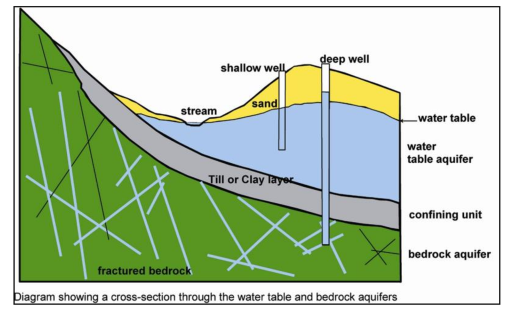


Figure 6. Schematic cross-section through the water table and fractured bedrock aquifers. From *Report on the Status of Groundwater and Aquifer Mapping in the State of Vermont*, January 2003

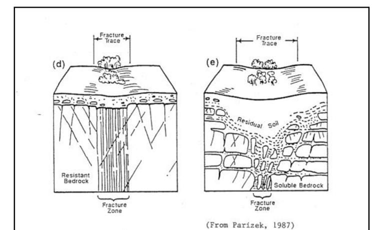


Figure 7. The diagrams show possible groundwater pathways due to primary and secondary porosity in surficial materials and bedrock. Calc-silicates in the Waits River Fm. are more susceptible to chemical weathering and many joints have been widened through solution, especially at and above the water table. Miniature karst features can be seen in some outcrops. Topographic sinkhole-like depressions also occur.

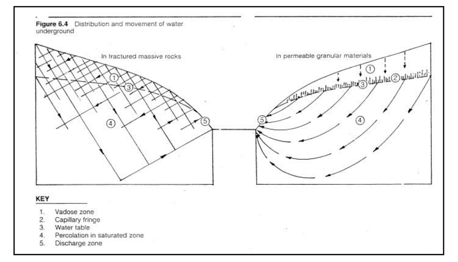


Figure 8. Comparison of 2D flow-lines in fractured rock versus unconsolidated homogeneous material.
(From Dennen, W. H., and B. R. Moore, 1986, *Geology and Engineering.* Dubuque, IA: Wm. C. Brown Publishers)

Figures 9, 10, 11. RECHARGE TO BEDROCK, SHALLOW OVERBURDEN & BURIED OVERBURDEN AQUIFERS: Recharge potential to the 3 different aquifer types involves several factors. The pathway that surface water takes to the subsurface and how overburden affects the downward movement of groundwater toward the bedrock is important. Recharge to bedrock and shallow overburden aquifers is by direct downward flow of groundwater from the surface. Impermeable sediments, especially thick till, greatly retard the downward movement of water. Thin, weathered till, however, has opened up pathways from the surface to the subsurface. Soil formation may result in the upper few feet of sediment becoming more permeable than the parent material. Alternatively, permeable parent materials do not impede downward movement of water. Sediments such as sand and gravel allow water to penetrate and flow downward readily. Recharge to buried aquifers must consider several pathways.

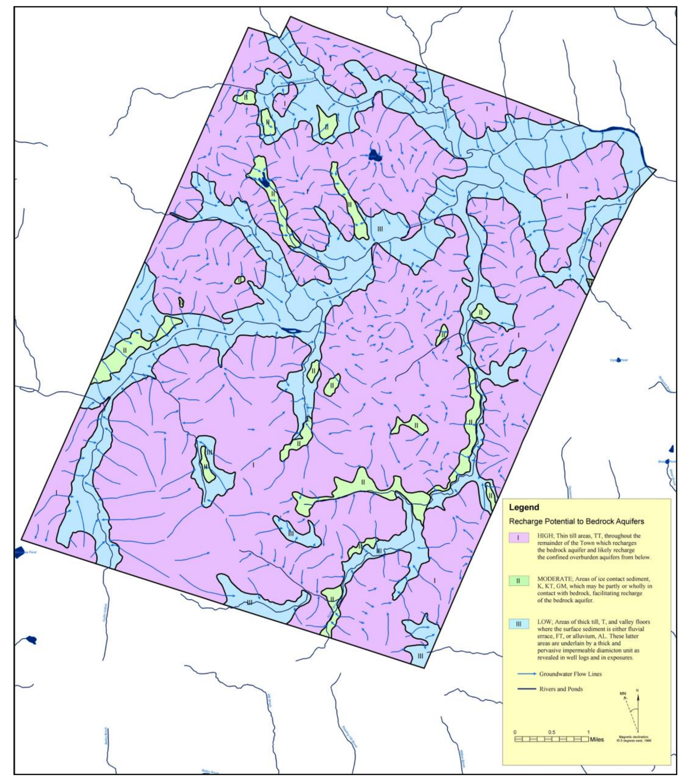


Figure 9. Recharge potential to bedrock aquifers is ranked as high, moderate, and low. HIGH - Thin till areas throughout the Town recharge the bedrock aquifer; MODERATE - Areas of ice contact sediment which may be partly or wholly in contact with bedrock, facilitating recharge of the bedrock aquifer; LOW - Areas of thick till, and valley floors where the surface sediment is either fluvial terrace, or alluvium. These latter areas are underlain by a thick and pervasive impermeable till unit as revealed in well logs and in exposures.

Flow lines indicate general flow paths from recharge to discharge areas. Flow lines were generated from the piezometric surface map based on static water levels from well logs. Refer to Fig. 8 for flow paths in bedrock.

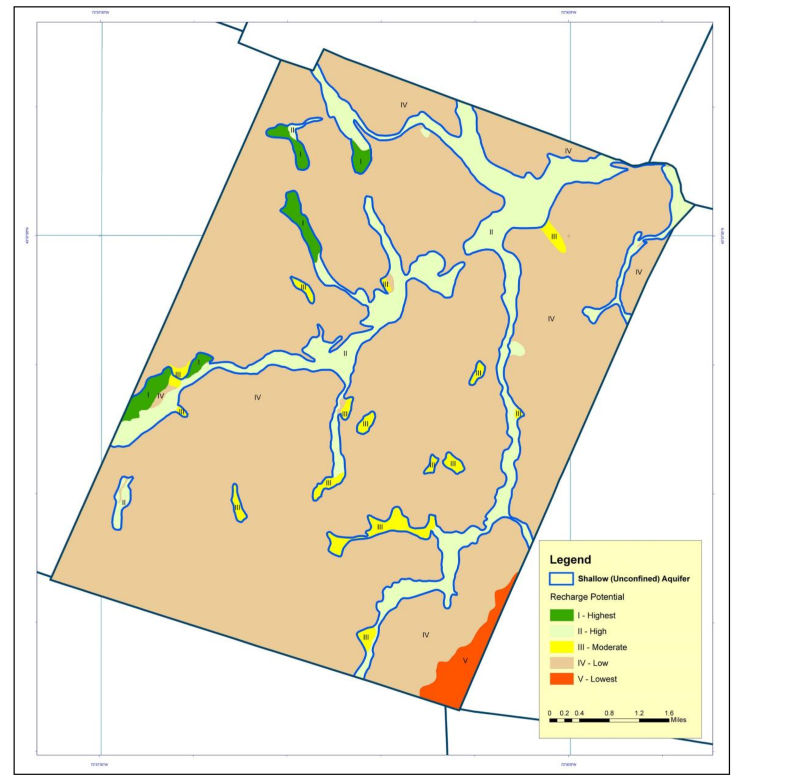
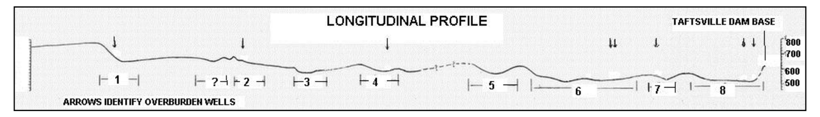


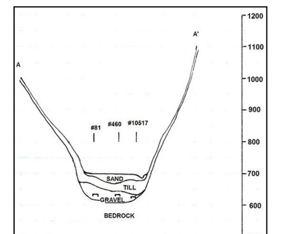
Figure 10. A <u>shallow aquifer</u> is defined here as a volume of porous and permeable sediment, either sand or gravel or a mixture of sand and gravel, which is exposed at the ground surface. Hydrologists refer to this as an <u>unconfined aquifer</u> because the aquifer is not sealed, capped or confined by an impermeable layer. Shallow aquifers are recharged by direct downward infiltration of surface water from precipitation,snow melt and possibly through the bottoms of stream channels.

Recharge potential is ranked from I being the highest to V being the lowest. Rankings are based on surficial geology, overburden thickness and the stratigraphy of the overburden. The recharge potentials are qualitative only, especially because of the heterogeneous nature of most surficial materials deposited in glacial environments. Areas of the thickest and most permeable sediments are assigned the highest recharge potential. Lowest potential recharge areas are where the sediment is relatively impermeable (ex. till or lacustrine clay) to areas down the hydraulic gradient from the extent of the overburden aquifer, and to presumed aquifer discharge areas represented by wetlands.

Recharge Potential to Shallow Aquifers: HIGHEST - Thick areas of ice contact sediment; HIGH - Thinner areas of ice contact sediment, fluvial terrace sands and gravels, and valley floor alluvium; MODERATE - Areas of ground moraine, isolated areas of ice contact sediment away from the valley floors, alluvial fan sediment, and higher fluvial terrace surfaces; LOW - Thin till areas within aquifer catchment, thick till areas, and areas of muck, presumed to be aquifer discharge zones; LOWEST - Areas where shallow ground water flow is directed away from any possible contribution to shallow aquifers in the town.

Figure 11A: The preglacial bedrock channel of the Ottauquechee is interpreted as containing 8 overburden pockets where thick overburden generally in excess of 100' fills in scour holes along the length of the paleochannel thalweg.





<u>Cross section A-A'</u>: A cross valley profile illustrating overburden valley bottom stratigraphy. Three overburden gravel wells tap a water-bearing basal gravel (buried aquifer #7 in Fig.10). A surface sandy unit comprises the valley's shallow aquifer. The till layer separates the 2 aquifer units and forms a cap or seal over the buried aquifer. The bedrock surface is from drillers' logs along or near the line of the cross section. The bedrock surface below the 3 gravel wells is inferred because the wells did not penetrate to bedrock.

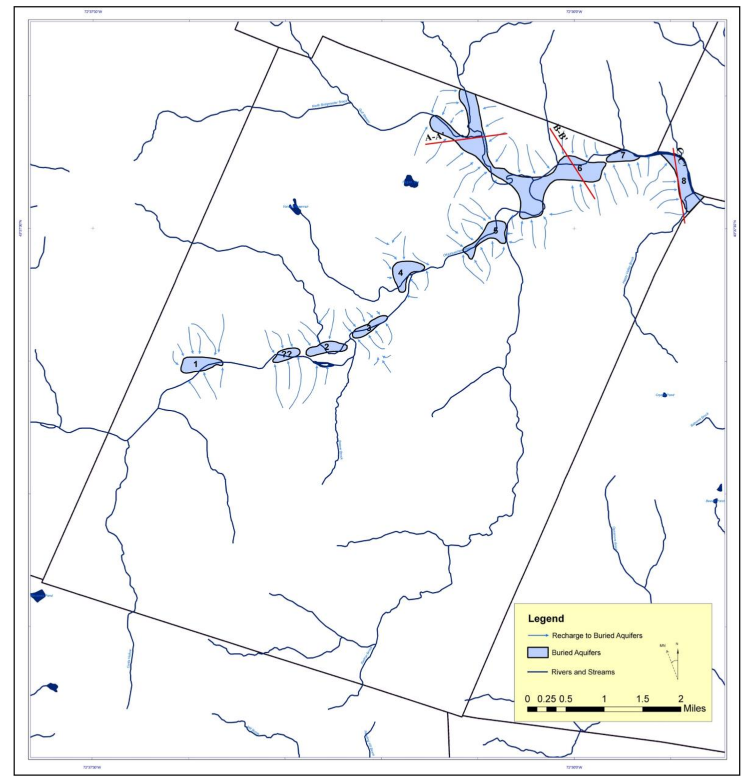


Figure 11. <u>Buried aquifers</u> are <u>confined aquifers</u>, volumes of porous and permeable sediment, either sand or gravel or a mixture of sand and gravel buried beneath the ground surface. This permeable valley bottom sediment is isolated from the surface sediment which comprises the shallow aquifers by a variably thick layer of impermeable till.

Recharge pathways: 1-Groundwater flowing in bedrock may flow upward under pressure and recharge the buried aquifer sediment when there is no barrier between the bedrock and the permeable sediment. 2-Buried aquifers may have a physical and hydraulic connection to permeable sediment exposed at the surface along valley flanks. #2 has not been demonstrated by logs or mapping evidence. It is likely that recharge to the buried aquifers comes from the underlying bedrock.

The inference that the buried aquifers are recharged from the underlying bedrock suggests that recharge to the buried aquifers follows the same pathways as recharge to the bedrock aquifer. However, the bedrock aquifer is widespread while the buried overburden aquifers are extremely limited in extent (#1-8). Accordingly, only those groundwater flow lines directed toward the buried aquifer are shown to illustrate that only infiltration into the bedrock from areas largely adjacent to the buried aquifers should be important for buried aquifer recharge.

The relationship of the surface streams to bedrock recharge is not known. The presence of the thick till layer beneath much of the valley indicates that major streams such as the Ottauquechee River may not recharge the buried aquifers. Groundwater flow lines may cross under these streams.

Conclusions:

The preglacial bedrock channel of the Ottauquechee is interpreted as containing 8 overburden pockets where thick overburden generally in excess of 100' fills in scour holes along the length of the paleochannel thalweg. The overburden stratigraphy persistently demonstrates the presence of basal gravel beneath thick till. This gravel represents buried aquifers. One public water supply well taps this buried gravel and the opportunity exists to further develop buried aquifers for water supply wells. The buried aquifers may represent the most valuable groundwater resource currently identified in town.

The thickness and lateral extent of the buried aquifers is not well known due to a lack of sufficient subsurface data. Recharge to the buried aquifers is also not well known and should be better understood in order to better evaluate these aquifers as a future water resource.

The town's surficial geology is dominated by till which blankets the uplands and fills the preglacial valleys. Permeable sediments are comparatively thin and form a surface mantle covering patchy areas of the valley floors. There is a general lack of widespread and thick sand and gravel deposits of glacial origin except for the kame terrace extending into town from Bridgewater along the north side of the Ottauquechee Valley.

Numerous fluvial and flood plain terraces along the major water ways represent shallow aquifers that may be suitable for limited use as a water resource. The shallow aquifers are limited by their relatively thin accumulation of permeable sediment, but, more importantly, by their tendency to be easily contaminated and to suffer from fluctuations in the water table due to seasonal and longer term changes in recharge.

Almost every outcrop contains at least one joint oriented roughly east-west (between N70E and S70E) and this is reflected as a strong preferred orientation in the rose diagrams of joints measured in Woodstock. Through-going, planar joints in schist are most likely to be in that position; joints in calc-silicates and curved joints show much more variation in orientation. A second set of joints trending northeast is apparent in many outcrops, approximately parallel to the trend of the Ottauquechee River.

Woodstock is situated on the east flank of the Green Mountain anticlinorium, in a structural saddle between the N-plunging end of the Chester dome (Thompson, 1950; Ratcliffe, 2000) and the S-plunging end of the Pomfret dome (Lyons, 1955). The domes (D3) deform an older set of folds (D2) that are overturned to the east. A major anticline passes through the town, and where the stratigraphy is nearly vertical, wells drilled into bedrock may provide either exceptionally high or low yields.