Vermont Geological Survey Open File Report VG11-1b (Text and Maps):

Surficial Geology and Hydrogeology of Dover, Vermont

by

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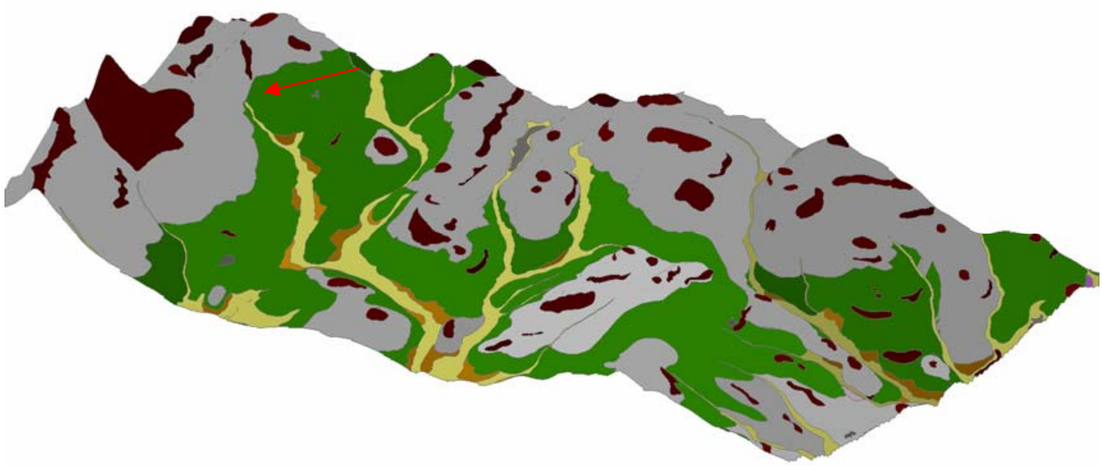
Final Report Summarizing the Surficial Geology and Hydrogeology of Dover, Vermont

A view taken standing on thick glacial till looking southwest towards Mt Snow, covered by thin glacial till and the summit and thicker till towards the base of the mountain.



A two-dimensional view of the surficial geology draped over topography illustrating the spatial distribution of surficial deposits. The red arrow illustrates the viewing angle in the above photo.

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1.0 – Executive Summary

During the summer of 2010, I mapped the surficial geology and spatially rectified 405 private and municipal wells within the Town of Dover, Vermont. I identified and mapped seven distinct surficial units using traditional field and digital mapping techniques and information gathered from rectified wells. I also collected GPS coordinates for 246 bedrock outcrops, 197 surficial sites and one site with well-preserved striations. Bedrock outcrop locations were collected and used with well logs to help refine bedrock topography and facilitate the production of an overburden isopach map and three cross-sections.

Bedrock topography generally mimics surface topography and the well logs and isopach map suggest that valleys containing the North Branch of the Deerfield and Rock Rivers are filled with thick deposits of alluvium overlain by fluvial terraces. Unfortunately only one gravel well exists in the rectified well database, therefore the subsurface characteristics of unconsolidated aquifers in Dover are poorly understood. Well yields are highest in bedrock associated with rocks of the Green Mountain Sequence Type I, however there is only one well that terminates in carbonates of the Green Mountain Type Ib sequence, so caution should be when interpreting these data for planning purposes. Static water levels from well log data were used to interpolate a potentiometric surface, which indicates groundwater generally flows from high potentiometric potential along the western edge and northern half of town to the east and southern half of the town. In general, water flows from north to south, mimicking surface topography and drainage valleys.

Field mapping identified extensive deposits of a thick Wisconsinan age dense, clay-rich till mantling valley walls and creating gently sloping topography and a thinner, often sandy and strongly oxidized till occurring as a surface veneer mimicking the underlying topography. Glacial till is variable in thickness ranging from a thin veneer to thicknesses exceeding 25 meters. One small and isolated kame deposits occurs near the intersection of Yeaw and Dover Hill Roads. This singular landform suggests that either few supraglacial lakes formed and/or accumulated sediment or other kame deposits were eroded following deglaciation. The latter is more likely given the high-relief and steep slopes found throughout the study area. Similarly, a relatively small deposit of outwash gravels was mapped in the northeastern corner of the town. These gravels are limited in extent and thickness, suggesting they mark the highest elevation where outwash gravels were deposited. The Dover area contains few ice flow indicators, which is not surprising given the foliated and friable nature of the dominant bedrock. However striations were identified that indicate a northwest to southeast flow direction.

2.0 – Background

This report summarizes the results of surficial mapping and digital mapping efforts within the town of Dover, Vermont. The mapping occurred over approximately 5 months during the spring and summer of 2010 and interpretation took place during the subsequent 4 months. This effort was contracted by the Vermont Geological Survey and supported by the United States Geological Survey, National Cooperative Mapping Program.

The purpose of this project was to develop a 1:24,000 map of the surficial geology and integrate this information with subsurface data derived from private well logs. This mapping project also produced 8 derivative maps that provide additional information regarding bedrock and unconsolidated aquifers, which can be used to address land-use questions and water issues concerns within the town of Dover (Table 1).

Table 1: Summary of map layers produced for this report.

1. Bedrock Locations	7. Possible Overburden Aquifer
2. Field Station Locations	8. Recharge Potential to Shallow Aquifers
3. Surficial Geologic Map	9. Recharge Potential to Bedrock Aquifer
4. Isopach Map	10. Potentiometric Surface + Flow Lines
5. Bedrock Topography	
6. Hydrogeologic Units	

The population of Dover, Vermont grew by 41.9% between 1990 and 2000 (660 to 1410 residents respectively) (Vermont Indicators Online). This dramatic growth rate is linked with an expansion of vacation homes and commercial lodging that support tourism associated with the Mt Snow Ski Resort. Dover officials are concerned that continued development will adversely affect residential water supplies because all potable water for the town is drawn from groundwater. Ancillary concerns include: (1) fire protection capacity, (2) groundwater interference between existing wells, (3) impact on surface waters, and (4) development on soils and slopes that are inadequate for traditional septic technologies. During the summer of 2009, the Vermont Rural Water Association identified interference in 55 out of 151 public community water system (PCWS) wells in Dover (Hanson, 2009) (Figure 1). Similarly, Medalie and Horn (2010) report both high groundwater and surface water withdrawal rates within the town of Dover (Figure 2) in 2005 and projected for 2020. It is important to note that Dover has high surface water withdrawal and return rates associated with snowmaking efforts at Mt Snow.

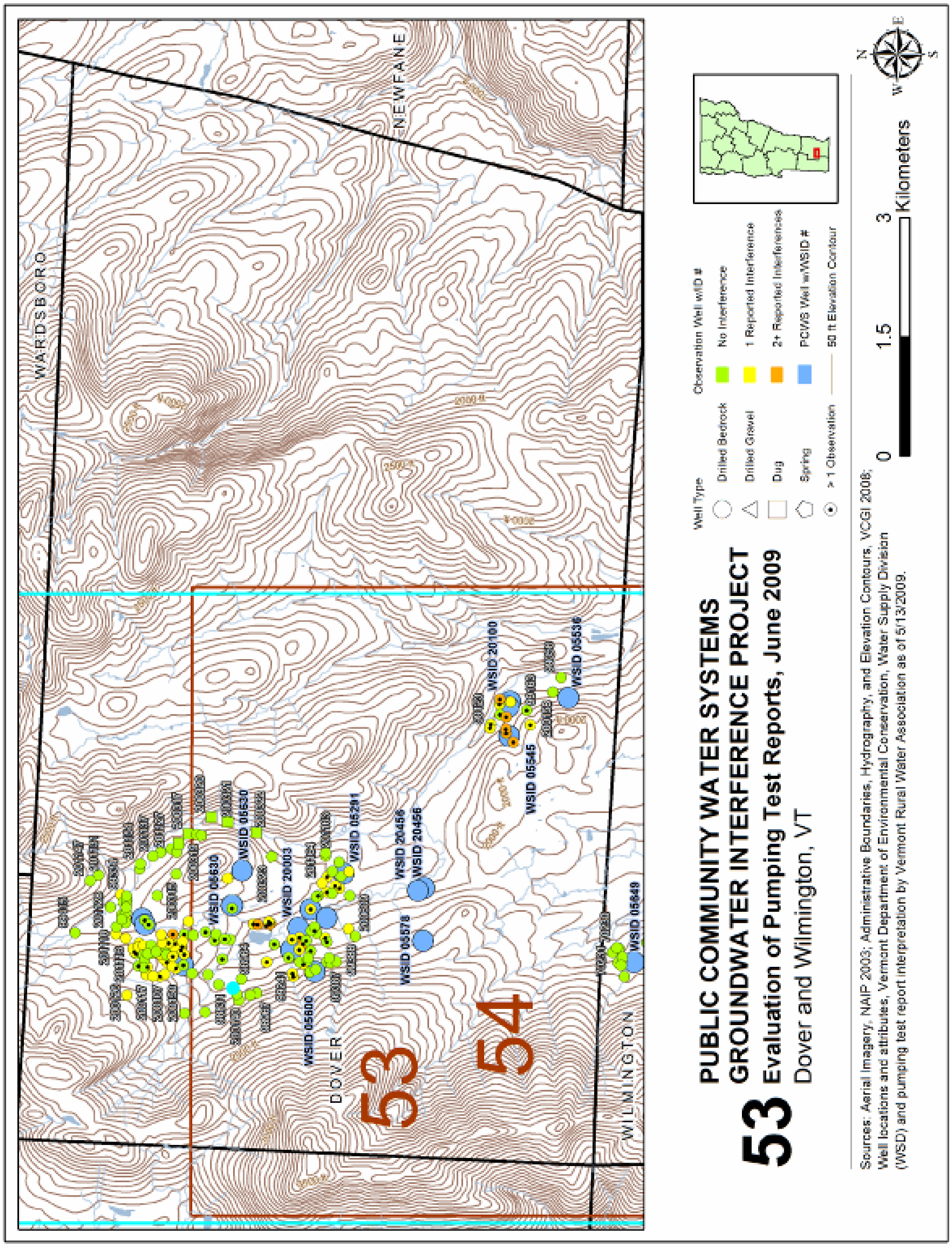


Figure 1: Map illustrating the distribution of wells reporting interference in Dover, VT (modified from Hanson, 2009).

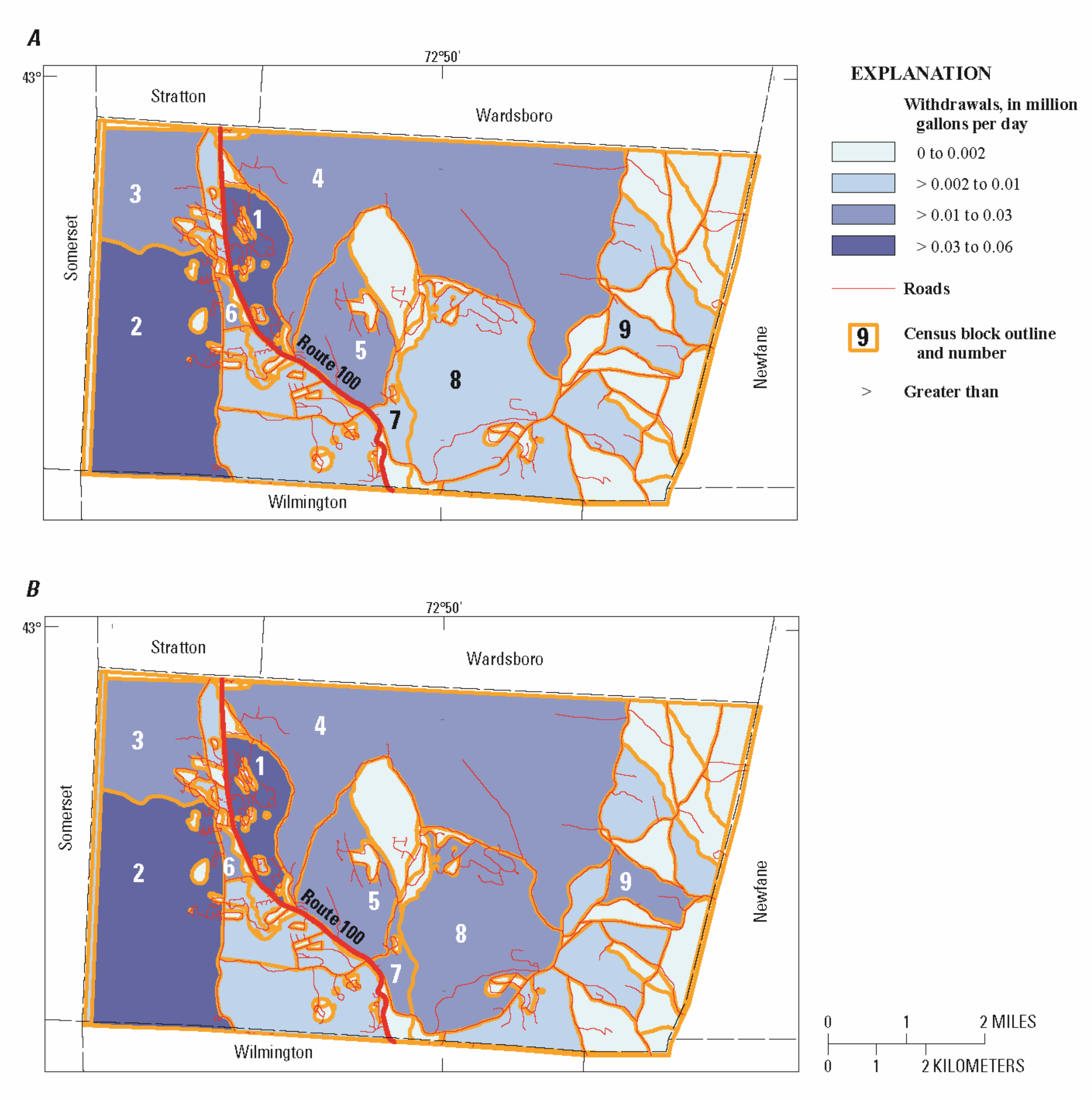


Figure 2: USGS map illustrating groundwater withdrawal in 2005 and projected withdrawals in 2020, suggesting an increase in high withdrawal rates (>0.01-0.03 Mgal/d) within three additional census blocks. Areas of highest withdrawal occur in the western half associated with development around the Mt Snow Ski Area.

3.0 – Location and Geologic Setting

3.1 – Physiographic Characteristics

The Town of Dover is located in Windham County in south-central Vermont and has a total area of approximately 92km^2. The town is bordered by Somerset to the west, Wardsboro to the north, Newfane to the east and Wilmington to the south, straddling both the Mt Snow and West Dover U.S.G.S quadrangles. Elevations range from approximately 322 to 1,088 meters (1,056 to 3,569 feet) with the greatest topographic relief on the western edge of town (Figure 3). This area of town is both heavily wooded and largely developed depending on the specific location. The area is characterized by north-south oriented valleys exhibiting high relief drained to the southeast by numerous fluvial systems. The region is drained by the North Branch of the Deerfield River, Rock River, and numerous smaller creeks and tributaries; Table 2 summarizes the length and gradient of these features. The North Branch of the Deerfield River is the largest and most important in terms of surficial deposits since it meanders through Holocene alluvium over its entire course and is underlain by approximately 6-25 meters (20-80 feet) of courser sand and gravels.

Table 2: Summary of the length and gradient of fluvial features draining Dover, VT.

Feature	***~ Length (km)***	***~ Gradient (m/km)***
Adams Brook	4.5	31.6
Bemis Brook	5.1	7.0
Blue Brook	6.9	20.8
Cheney Brook	5.2	23.9
Cold Brook	4.7	85.8
Ellis Brook	8.8	21.0
Hunter Brook	3.6	73.2
Negus Brook	3.9	52.9
North Branch Deerfield River	12.4	26.7
Rock River	9.2	51.1
Taft Brook	4.4	72.3

This region is part of the Western Highlands and Lowlands and Central Lowlands of the New England physiographic province (Denny, 1982) and the Grenville Belt geologic province (Robinson and Kapo, 2003). The Mt Snow quadrangle contains the complex Sadawga domal structure composed of folded imbricate thrust sheets of mid-Proterozoic age while the West Dover quadrangle contains Middle Proterozic lithologies of the Rayponda dome and Sadawga lake antiform that extend through thick faulted sequences of Cambrian and Ordivican rocks to the east and Silurian and Devonian rocks to the southeast (Ratcliff and Anderson, 1999 and Ratcliff, 1993) (Figure 4).

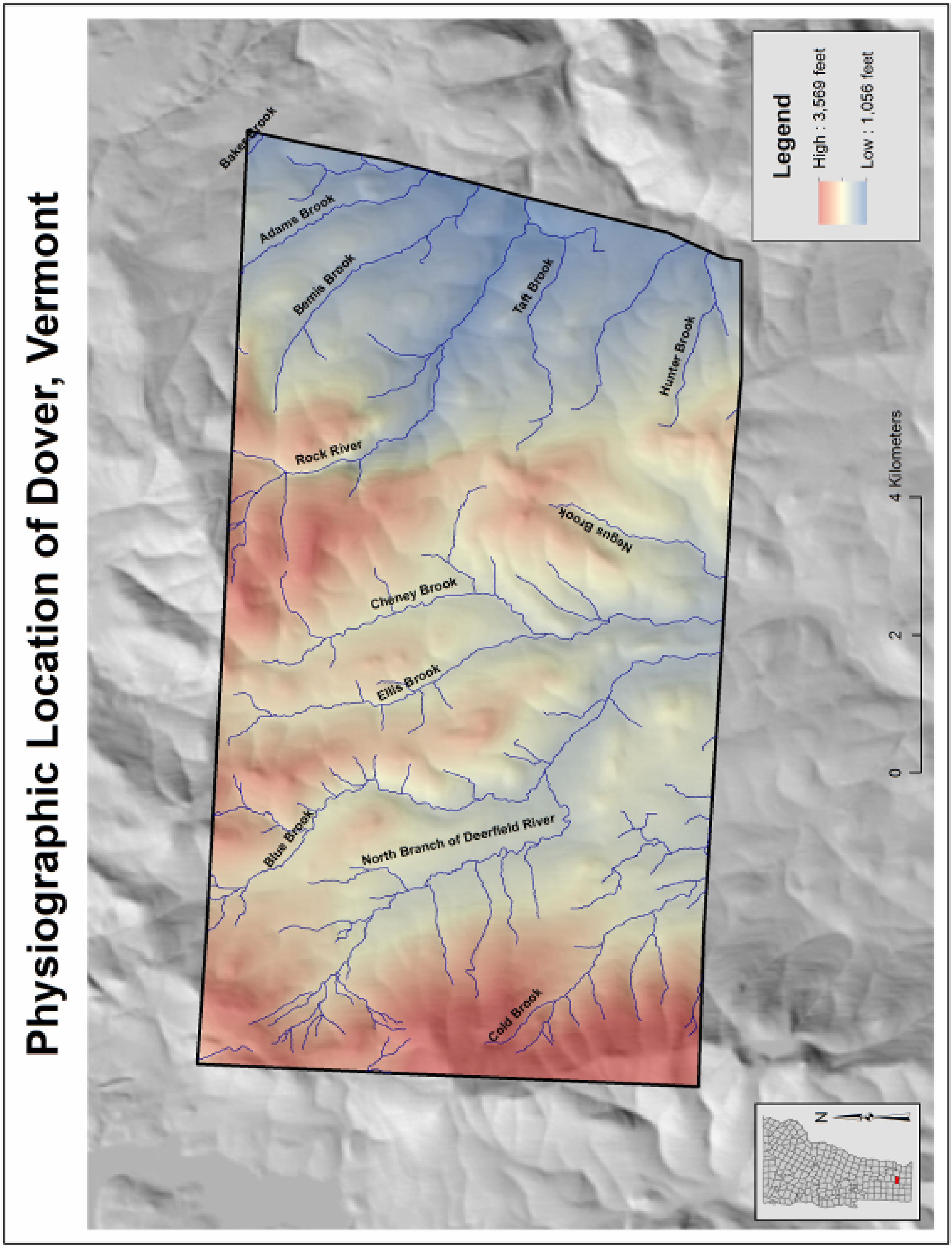


Figure 3: Map depicting the physiographic location of Dover, Vermont draped over a shaded relief map.

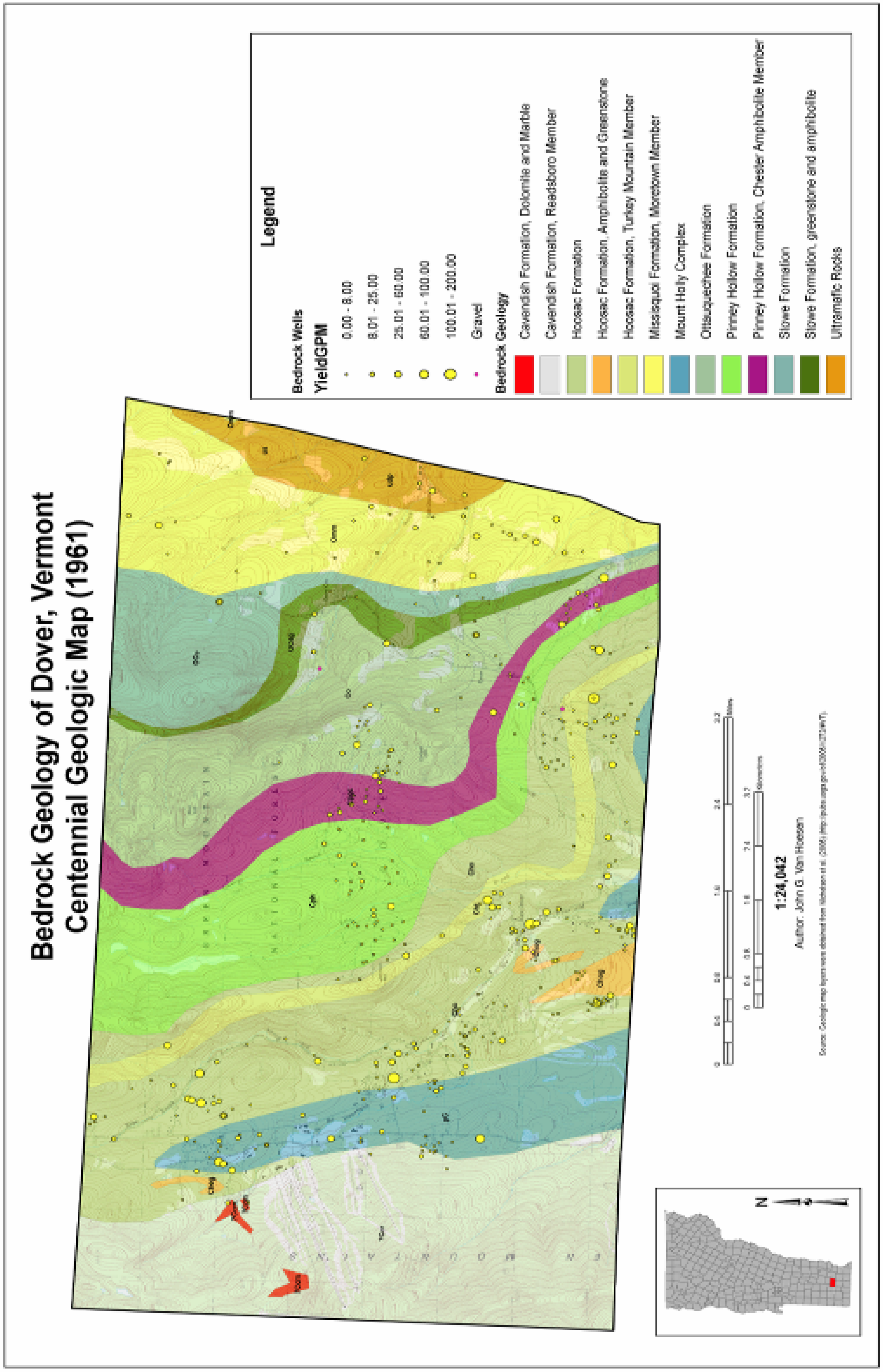


Figure 4: Generalized bedrock geology of the Town of Dover based on the Centennial Geologic Map of Vermont produced by Doll et al. (1961) and data digitized by Nicholson et al. (2006).

3.2 – Previous Work

The Wilmington quadrangle was first mapped by Shilts (1966), discussed by Stewart and MacClintock (1969), and integrated into the State Surficial Geologic Map (Doll, Ed., 1970), which indicates the northern half of the Mt Snow and West Dover quadrangles recorded a northeasterly derived “Shelburne till” and the southern half of the quadrangles recorded a northwesterly derived “Bennington till.” Carlson (2002) and White (1979) found no evidence in the region for northeasterly transport based on striations, trace-element geochemistry, fabric analysis, and XRD analysis of bulk soil samples nor did they find evidence for two areally distinct till sheets and rejected Stewart and MacLintock’s hypothesis regarding glaciation in the state of Vermont. Both White and Carlson worked in the region mapped as Bennington till, so although both studies do not find evidence for a northeasterly transport direction, other regions within the northern half of the quadrangles may record evidence for northeasterly transport.

4.0 – Methodology

4.1 – Field Techniques

Traditional field techniques were employed to differentiate between deposits depicted on the final surficial geologic map. Soil augers and hand-dug soil pits were used to sample below weathered soil horizons. An HP iPAQ running ArcPad 8.0 were used to collect GPS coordinates in Vermont State Plane – the accuracy of these units varied from 1-5 meters depending on atmospheric conditions and canopy interference. Almost all streams were walked, all gravel pits and exposures were visited and mapping was conducted both in the highlands and valleys. I collected frequent GPS coordinates of exposed bedrock and inspected each outcrop for glacial striations – with limited success.

4.2 – GIS-Derived Map Products

Using rectified well location logs and field site and bedrock outcrop locations, I used a geographic information system (GIS) to produce the surficial geologic map and all the ancillary derivative maps. All interpolation and extrapolation techniques in this report relied on a 30-meter digital elevation model (DEM) and reflect the inherent limitations of a base layer with this resolution.

4.2.1 – Isopach Map

An isopach map was constructed using (1) the overburden attribute provided in the well logs, (2) bedrock outcrops mapped by previous workers, and (3) bedrock outcrops mapped during this project. To facilitate the process of isopach map production and provide a surface covering the entire map area and not just those areas with wells, I chose to extrapolate an overburden layer using an ordinary kriging function and contour the data using automated functions within a GIS. To help determine which kriging function was best suited for these data, I used ESRI's Geostatistical Analyst extension to evaluate whether the data exhibited a normal distribution or spatially dependent trends.

The data is not normally distributed but rather strongly weighted towards thin overburden and bedrock exposures (Figures 5 and 6) and there isn't a strong trend in one direction or another (Figure 7), so ordinary kriging was used following Gao et al. (2006) and Locke et al. (2007). Training and testing subsets were split 80/20 for cross validation and validation prediction results, which are summarized in Table 3.

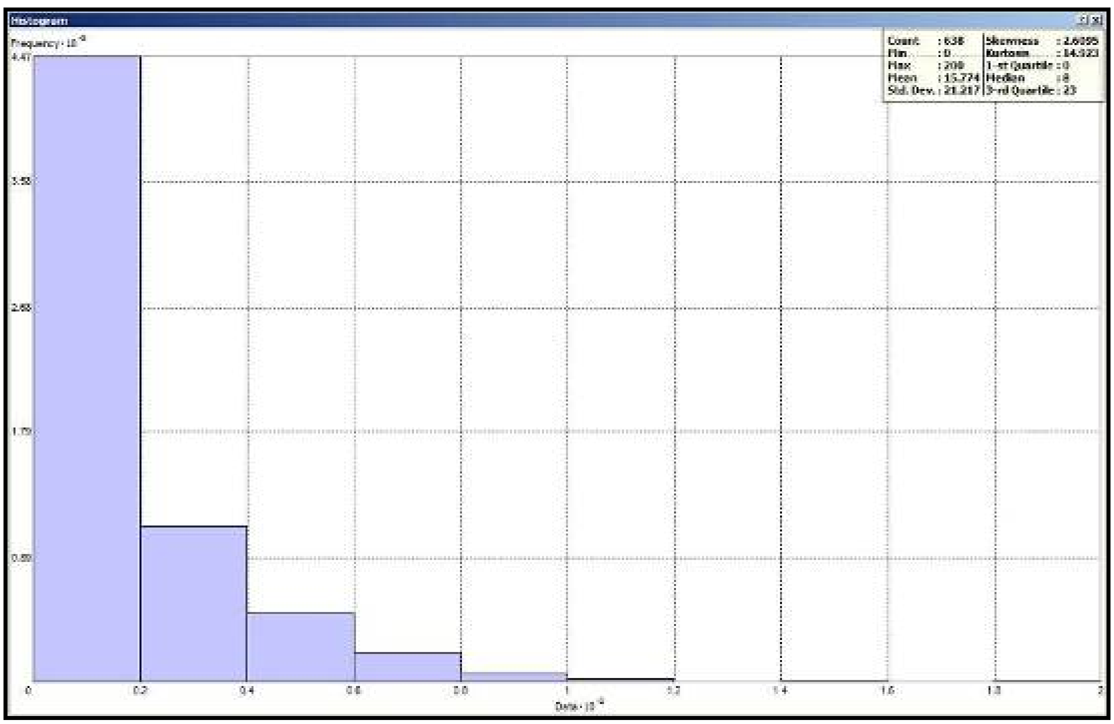


Figure 5: Histogram of well data and bedrock outcrop locations illustrating a non-normal distribution influenced by abundant thin till cover coupled with over-sampling of bedrock outcrops to increase control on overburden. However, histogram is still strongly influenced by lower values when only using well data overburden (no outcrop values).

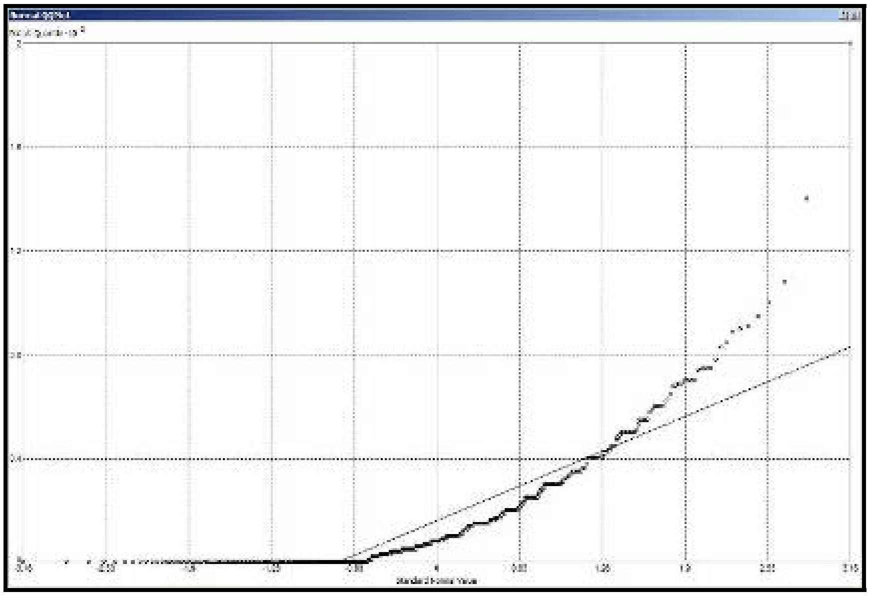


Figure 6: A general QQ plot is a graph on which the quantiles from two distributions are plotted versus each other. For two identical distributions, the QQ plot will be a straight line. This analysis also suggests the overburden values do not exhibit a normal distribution.

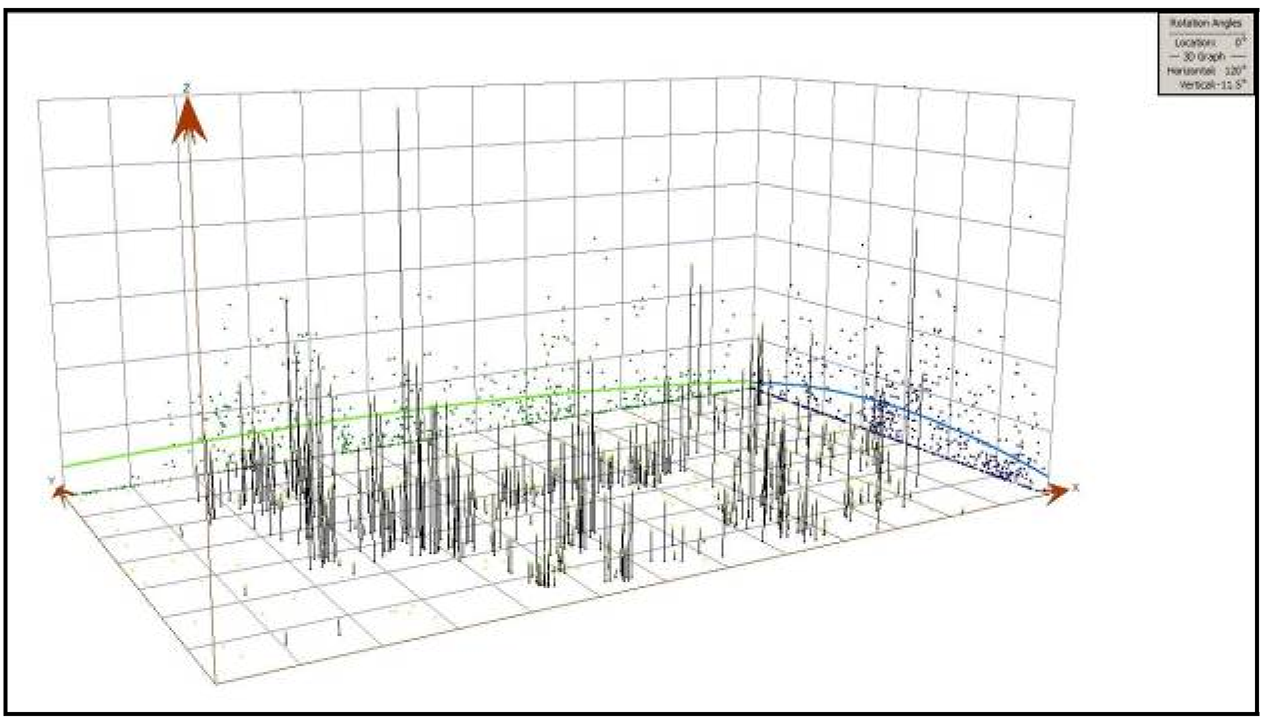


Figure 7: Trend analysis suggests the data exhibits a minor trend across the x and y axes with higher values towards the center of the field area. This suggests that overburden is generally homogeneous across the Town of Dover with thinning in the extreme western and eastern areas.

Cross Validation Prediction Error Results				
Variogram Model Type	**Mean Prediction Error**	**RMS Error**	**Average Standard Error**	**RMS Standardized**
Circular	0.11	17.56	17.58	1.01
Spherical	0.11	17.54	17.33	1.03
Tetrapsherical	0.10	17.54	17.32	1.03
Pentaspherical	0.09	17.51	17.41	1.02
Exponential	0.03	17.59	17.27	1.03
Gaussian	0.10	17.57	17.06	1.05
Rational Quadratic	0.03	17.45	16.93	1.05
Hole Effect	0.20	17.66	18.41	0.97
K-Bessel	0.08	17.54	17.08	1.05
J-Bessel	0.11	17.56	17.17	1.04
Stable	0.09	17.54	17.19	1.04

Table 3: Summary of prediction error values reported using cross-validation in Geostatistical Analyst for each Variogram model type using the training dataset. "For a model that provides accurate predictions, the mean prediction error should be close to 0 if the predictions are unbiased (centered on the measured values), the root-mean-square standardized prediction error should be close to 1 if the standard errors are accurate, and the root-mean-square prediction error should be small if the predictions are close to the measured values. If the average standard errors are greater than the root-mean square prediction errors, then the model overestimates the variance in the predicted values. If the average standard errors are less than the root-mean square prediction errors, then the model underestimates the variance in the predicted values." (Johnston et al. 2001).

I used the rational quadratic variogram model because it provided the best fit based on predicted error results (Johnston et al. 2001). Using the smoothing function available within the Advanced Editing toolbar in ArcGIS, I manually smoothed the 20-foot contour lines to produce the final isopach contours (Figure 8). This minor smoothing is helpful in creating a better cartographic representation of reality, following the argument of Xang and Hodler (2002) that certain techniques may be more "visually faithful to reality" even though their statistical behavior is not always the best.

4.2.2 – Potentiometric Surface Map

A potentiometric surface was interpolated using (1) the static water level attribute provided in both the public community water system (PCWS) database and private well logs and (2) a 30-meter DEM. The depth to the static water in each well was subtracted from the grid cell within the DEM directly beneath the well location and added to the attribute table to identify the elevation of water within each well. Similar to the isopach map, to facilitate the process of potentiometric surface production and provide a surface covering the entire map area and not just those areas with wells, I chose to interpolate this surface using an inverse distance weighting function (IDW) and contour the data in

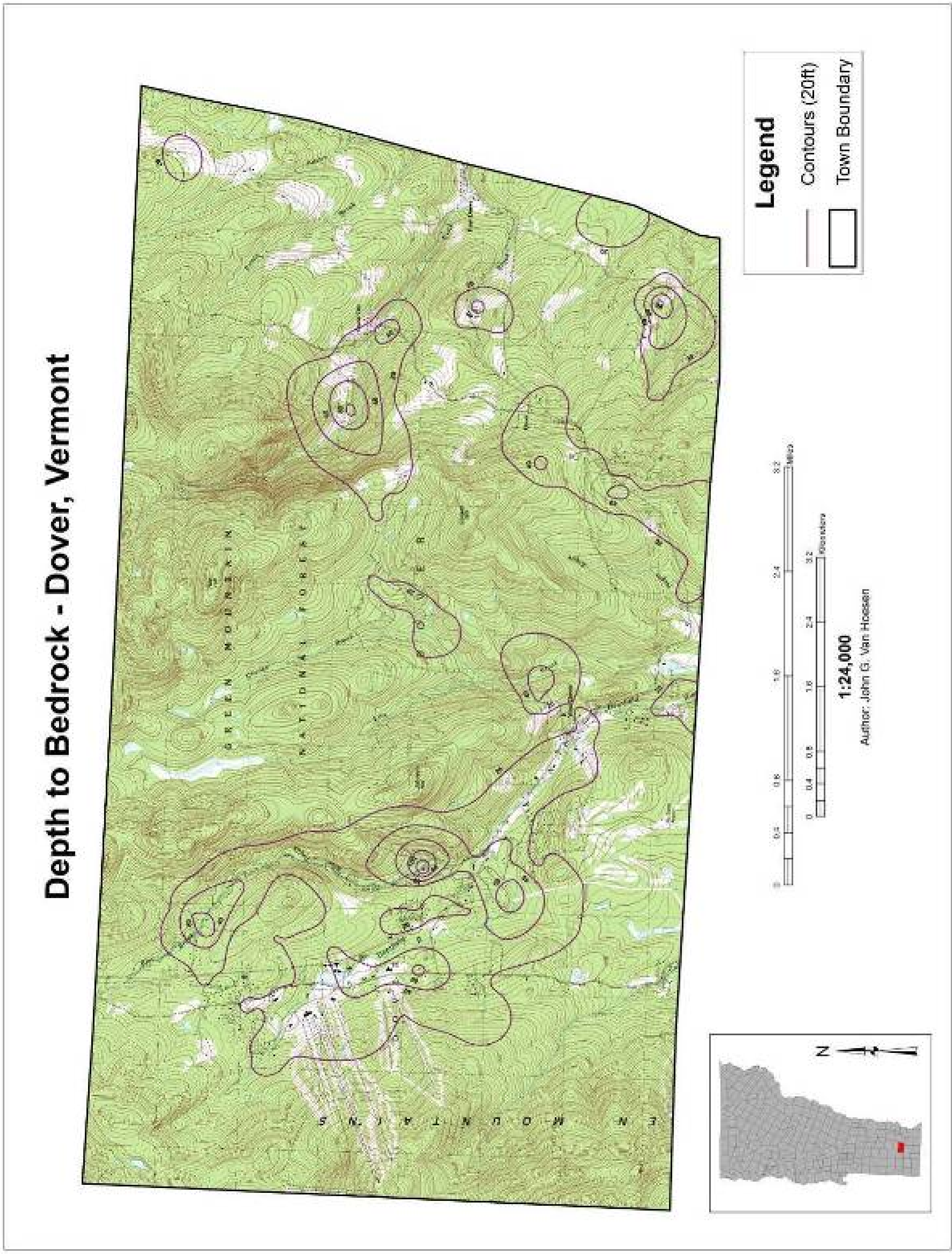


Figure 8: Isopach map of Dover, Vermont extrapolated from well log data and bedrock exposures.

200 foot increments using automated functions within a GIS following Hamad (2008), Spahr et al. (2007), Bajjali (2005), and Desbarats et al. (2002).

Using the Geostatistical Analyst to explore data, the data is not normally distributed and I identified two distinct trends in the piezometric surface; the surface drops sharply as you move west to east and north to south (Figure 9). The piezometric surface produced through IDW interpolation was contoured using 200 foot increments to illustrate the generalized hydraulic gradient (Figure 10).

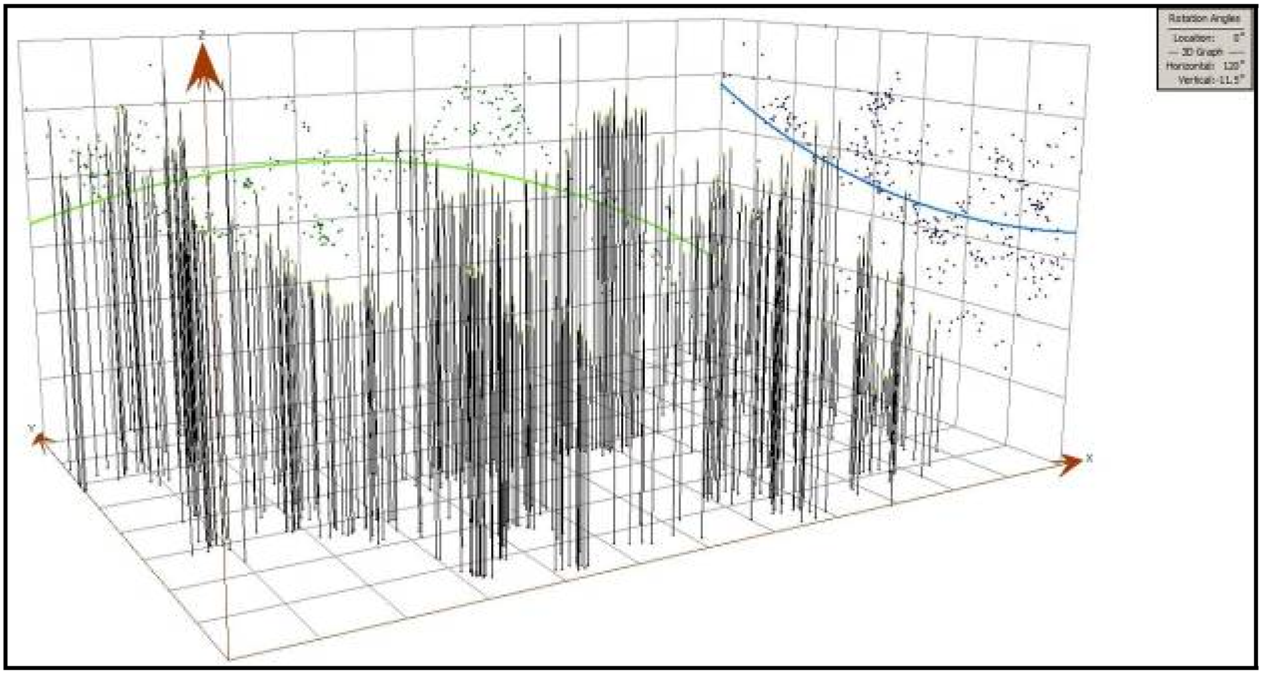


Figure 9: Trend analysis suggests the data exhibits sharply decreasing trends from west to east and north to south. This suggests the hydraulic gradient in this area should result in water flowing in a similar fashion (i.e. – west to east and north to south).

4.2.3 – Bedrock Topography

A visualization of bedrock topography was created using (1) the previously described overburden layer and (2) a 30-meter DEM. The raster overburden layer (representing the thickness of overburden throughout the town) was subtracted from the DEM to produce a “corrected” DEM of the bedrock topography. For the most part, bedrock topography mimics the overlying surface topography. 100 foot contours were then produced using the bedrock DEM (Figure 11).

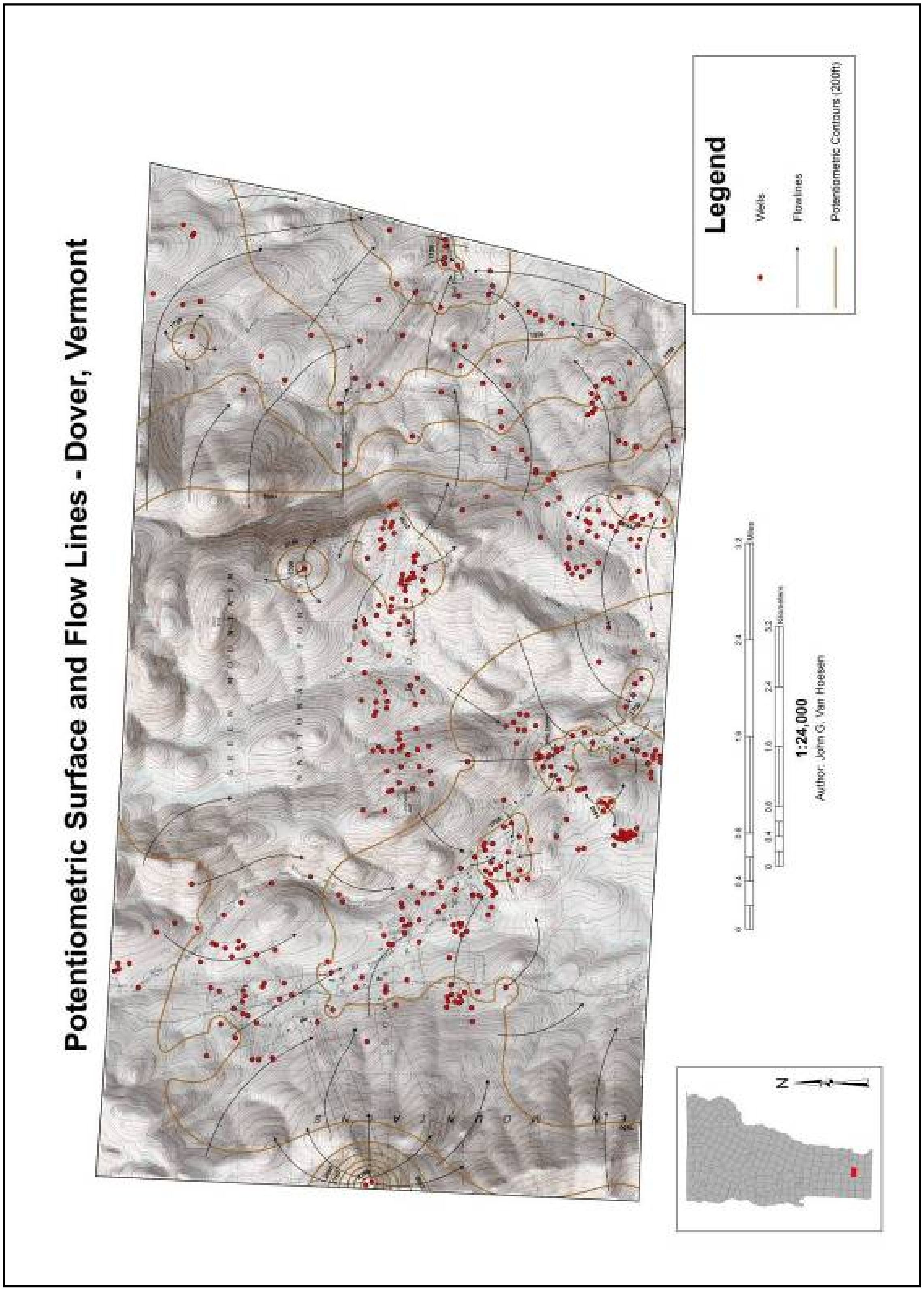


Figure 10: Potentiometric surface of Dover, Vermont created using PCWS and private well log data.

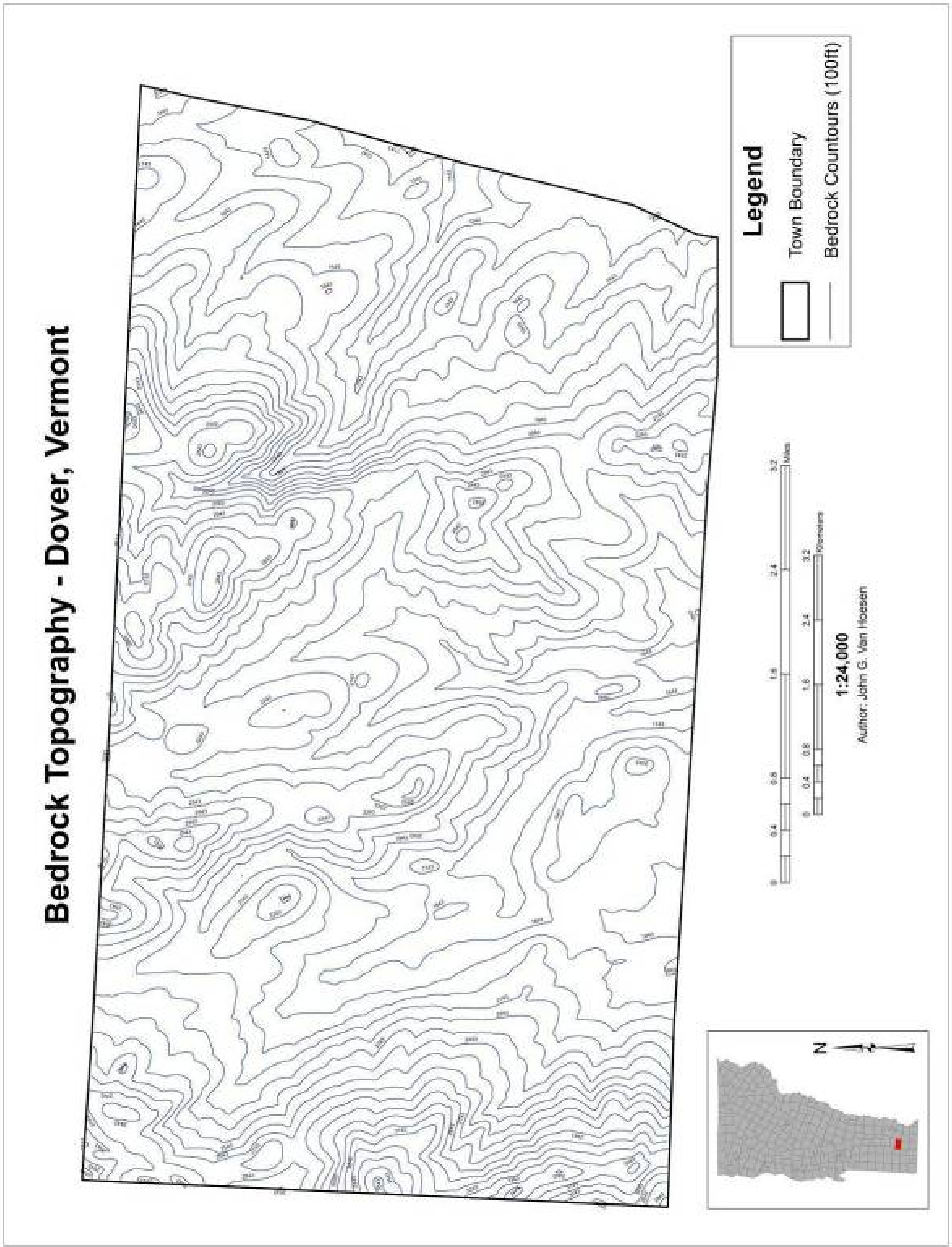


Figure 11: Bedrock topography of Dover, Vermont creating by subtracting overburden from modern DEM.

5.0 – Results

5.1 – Surficial Units

Alluvium: deposits of well-sorted, well-stratified, fluvial deposits adjacent to or in stream channels composed of sand, silt, pebbles, and cobbles. It has variable thickness depending on location in the field area, ranging from a thin veneer covering small floodplains to thick (> 25 meters) deposits filling locally extensive lowlands (Figures 12 and 13).

Figure 12: View looking southwest at a dissected alluvial floodplain along Taft Creek.

Figure 13: Well-developed spodosol in sandy/pebbly alluvium in southwestern Dover.

Fluvial Terraces: deposits of well-sorted, well-stratified sand, silt, pebbles, cobbles that represent historical floodplain sediments above the modern floodplain and often dissected by modern streams (Figures 14). These deposits are relatively common along rivers and larger brooks.

Figure 14: Sand, pebble, cobble deposit with strongly oxidized sands.

Kame: deposit of moderately-sorted, well-stratified sand and silt with few pebbles that exhibits irregular topography (Figure 15). There is only one kame deposit exposed in the study area; it is limited in extent and exhibits weak evidence for topographic reversal.

Figure 15: Exposed face of hummocky kame deposit exposed near the intersection of Yeaw and Dover Hill Roads and a close-up of less oxidized sand sampled from the lower horizon.

Outwash: well-sorted, well-stratified coarse sand/gravel deposit containing rounded to sub-rounded clasts of varying size (~4cm – 0.5m) and lithology. There is only one small exposure of outwash gravels in the extreme northeastern corner of the field area, limited in thickness and extent. Clasts exhibit evidence of strong imbrication and dip down valley approximately 18º to the southeast (Figure 16).

Figure 16: Small exposure of outwash gravels dipping downvalley exhibiting imbrication.

Thin Till: thin (< 3m), unsorted, unstratified sandy/clay till, characterized by frequent bedrock exposures, cobbles/boulders of varying lithology, with fewer rock walls and piles and a veneer that mimics topography (Figures 17). Thin till exposures are frequently sandy and strongly oxidized while thicker till cover is more commonly clay-rich and exhibits a gleyed color. Thin till cover also provided access to bedrock exposures exhibiting striations (Figures 18). However, it is surprising how few striations were preserved within the field area.

Figure 17: Typical thin till topography with bedrock exposures (arrows) and smaller rock walls and an example of an oxidized sandy till exposure.

Figure 18: Bedrock exposure and glacially scoured pond exhibiting striations oriented 177-189º north/south. Red arrow indicates orientation of striations at the outcrop scale.

Till: unsorted, unstratified, dense clay-rich/silty till containing common pebbles, cobbles, and boulders of varying lithology (Figure 19), predominantly found on gently sloping, often streamlined hills with very common rock walls and piles (Figure 20).

Figure 19: Exposure of dense till in Mt Snow Village development project illustrating less oxidation, higher clay content and larger clasts.

Figure 20: Typical surface morphology of thick till (minor oxidation and high clay content) exhibiting abundant surface boulders and extensive rock walls.

Wetland/Peat: well-sorted, well-stratified silt/clay deposits associated with concave topography lacking drainage (Figure 21). Primarily found in low-lying valley; however some deposits occur in higher elevation uplands.

Figure 21: Wetland area located near the headwaters of Ellis Brook exhibiting the typical landscape associated with wetland areas.

5.2 – Cross Section Interpretations

Five cross sections were created using well log data, surficial geology and the spatial extent of glacial and post-glacial landforms. The location of each cross section is noted on the Surficial Geologic Map of Dover (Figure 22) and each section was chosen to illustrate the subsurface relationships of surficial deposits within the study area.

Note: many wells were not close enough to be included on the actual cross section, but are readily identified on the geologic map.

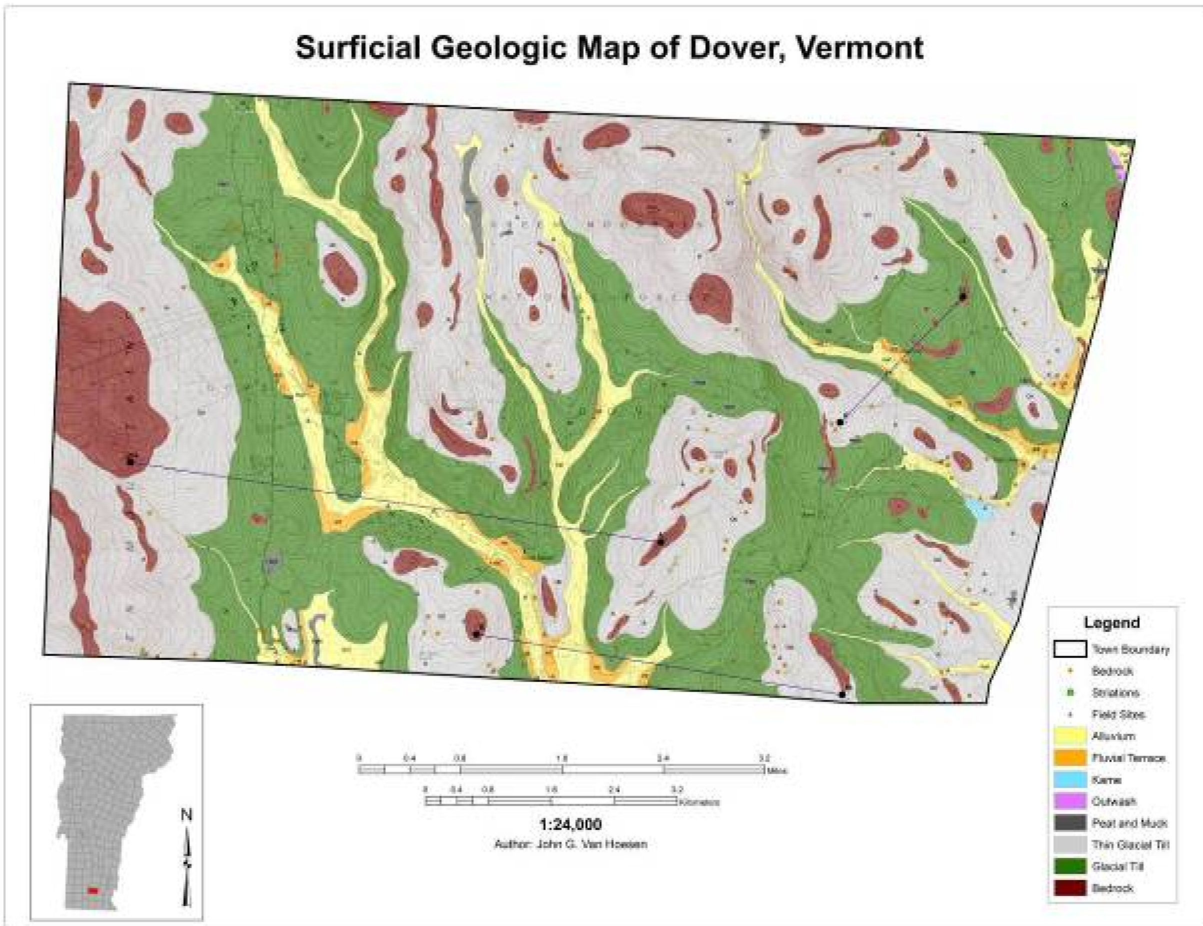
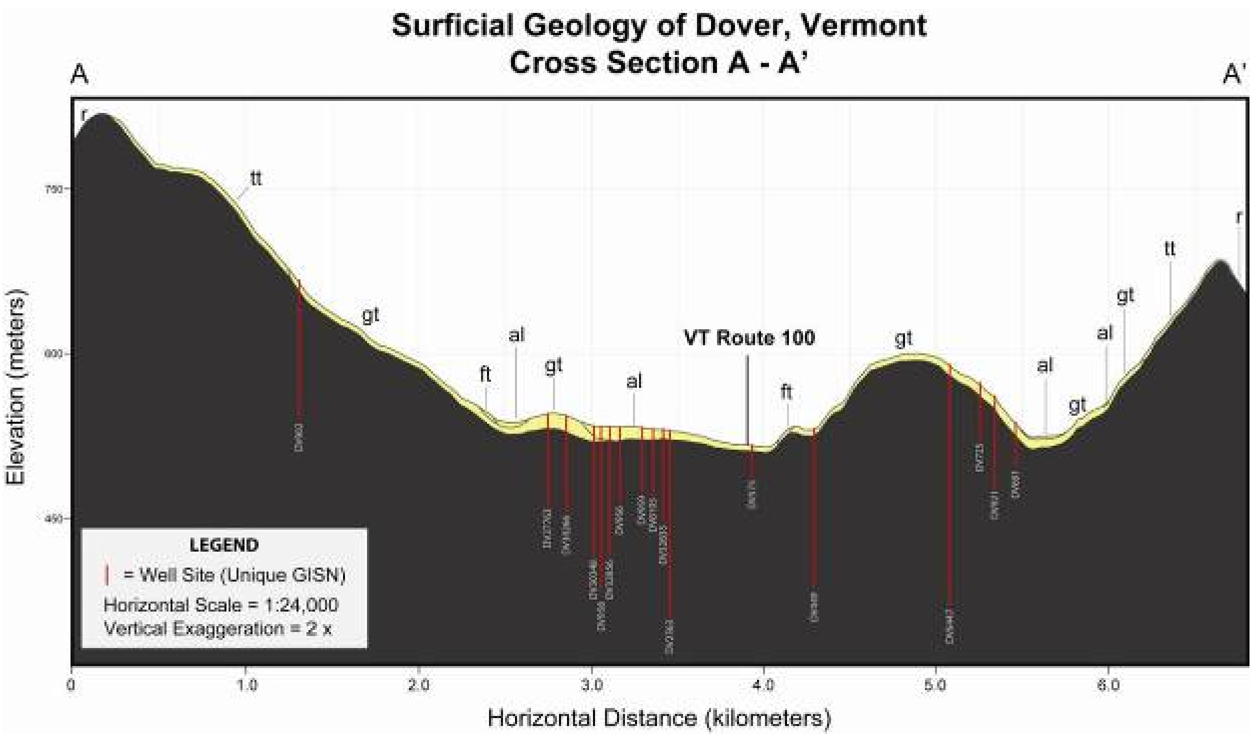


Figure 22: Surficial geologic map of Dover, Vermont.

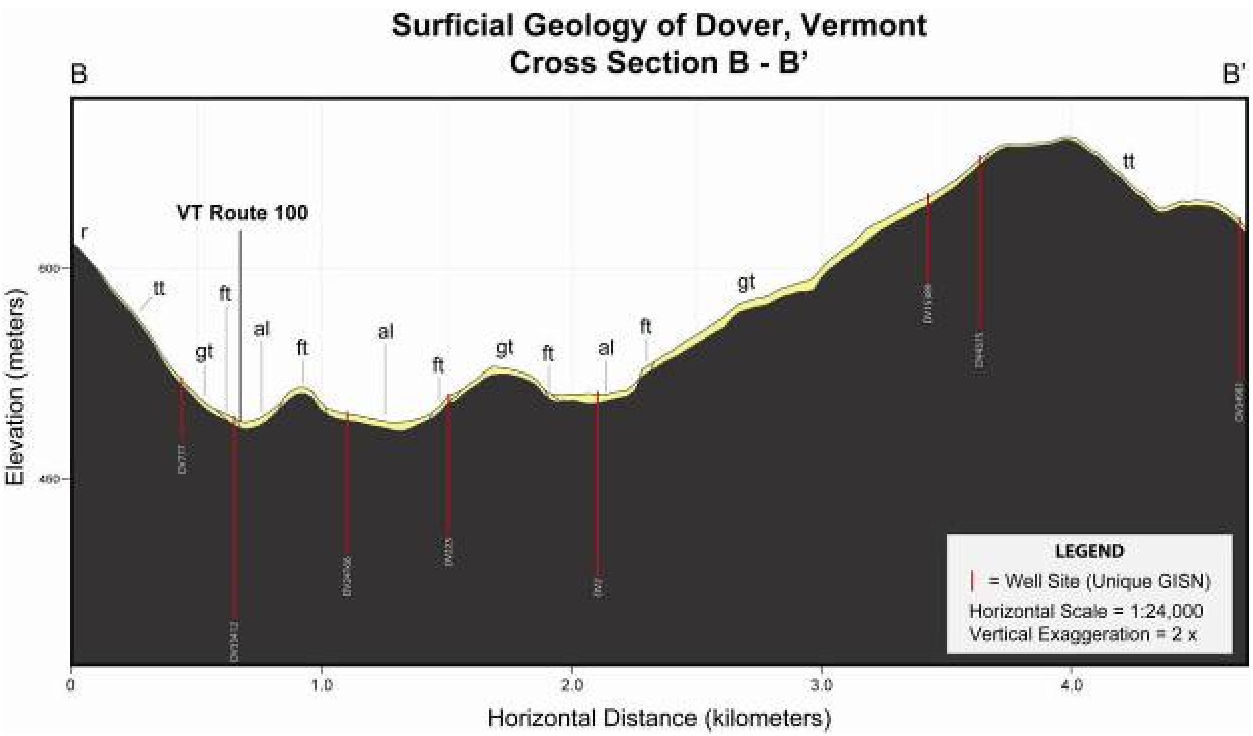
5.2.1 – West Dover Cross Section (A - A')

This cross section extends approximately 7 kilometers across higher elevation highlands in the west, the North Branch of the Deerfield River, Ellis Brook and terminates in thin till mantling a bedrock knob. Surficial deposits in the western portion of the section are dominated by thin till at higher elevations and thicker till (6-15 meters) closer to the valley walls. Fluvial terrace and alluvium fill the river and stream valleys with deposits ranging from 6 to 25 meters thick. All 17 wells along this cross section pass through variable thickness overburden and terminate in bedrock.



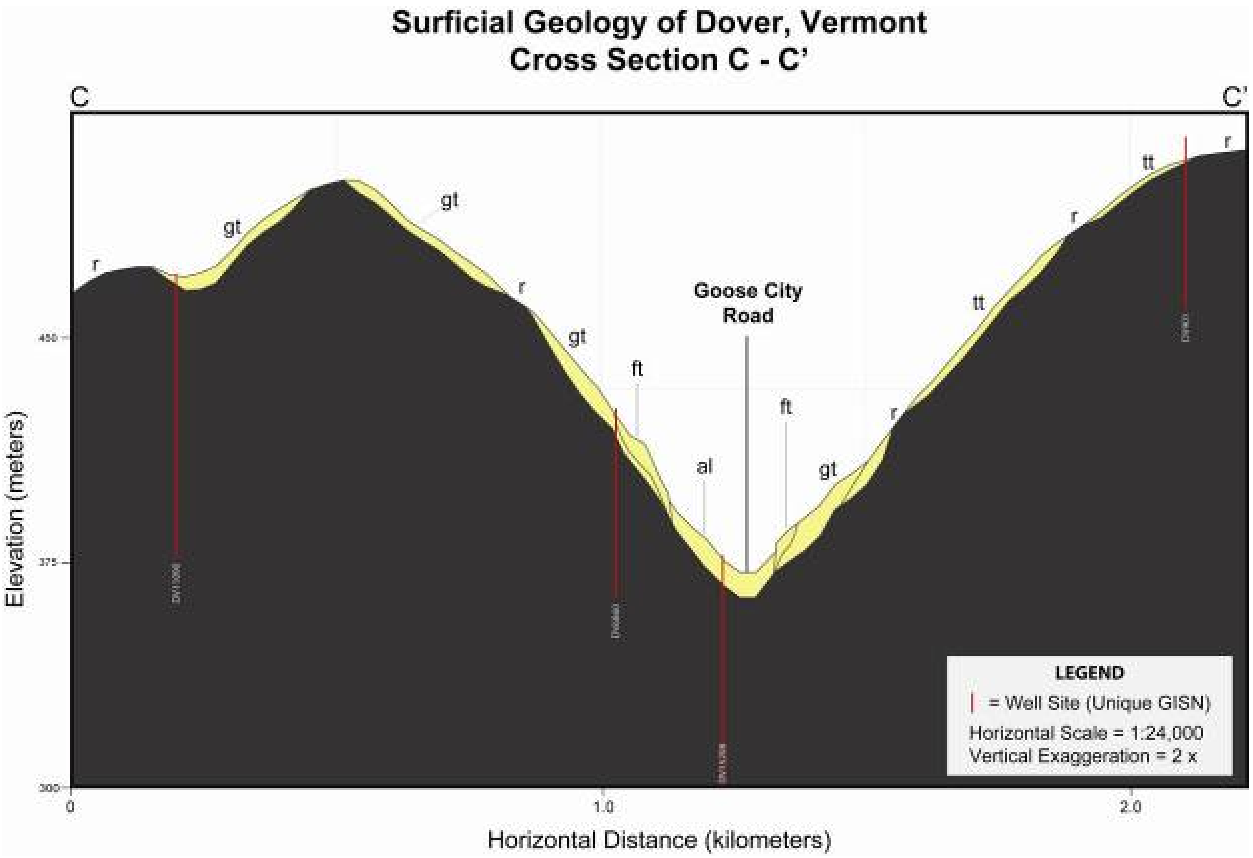
5.2.2 – South Dover Cross Section (B - B')

This cross section extends approximately 5 kilometers between two bedrock knobs across the North Branch of the Deerfield River and Negus Brook. The surficial geology of the western portion of the section is dominated by thin till and bedrock exposures. Fluvial terrace deposits and alluvium fill the widest section of the North Branch of the Deerfield River with overburden ranging from 5-10 meters. Thick till (4-7 meters) also mantles the valley wall in this locality grading into thin till and bedrock exposures moving up in elevation. All seven wells along this cross section pass through variable thickness overburden and terminate in bedrock.



5.2.2 – Northeast Dover Cross Section (C - C')

This cross section extends approximately 2.3 kilometers across the widest section of Rock River. Surficial deposits in the western portion of the section are dominated by thin till at higher elevations and thicker till (4-8 meters) closer to the valley walls. Fluvial terrace deposits and alluvium fill the river valley with deposits ranging from 6 to 15 meters thick. All four wells along this cross section pass through variable thickness overburden and terminate in bedrock.



5.3 – Isopach Map

The isopach map is consistent with the well data, surficial deposits and bedrock outcrops (Figure 8). Areas of thin or no overburden occur on the western edge and in the north central portion of town. The lack of overburden predicted by the extrapolation in the central and northwestern corner of town is supported in the field by a thin veneer of till riddled with abundant bedrock outcrops – these outcrops indicate zero overburden and clearly influenced the final distribution of overburden in this area of the map and ultimately bedrock topography. Areas of thick till mantles the valley walls and alluvium and fluvial terrace deposits fill the valley floors. Figure 23 highlights two areas dominated by extensive bedrock outcrops and thin till on the western edge of town (A) and the northern quarter of town near the headwaters of Ellis and Cheney Brook (C) and two areas of thickest overburden are associated with thick till mantling the eastern slopes of Mt Snow and alluvium filling the West Branch of the Deerfield River valley (B) and thick till and alluvium along the Rock River drainage (D).

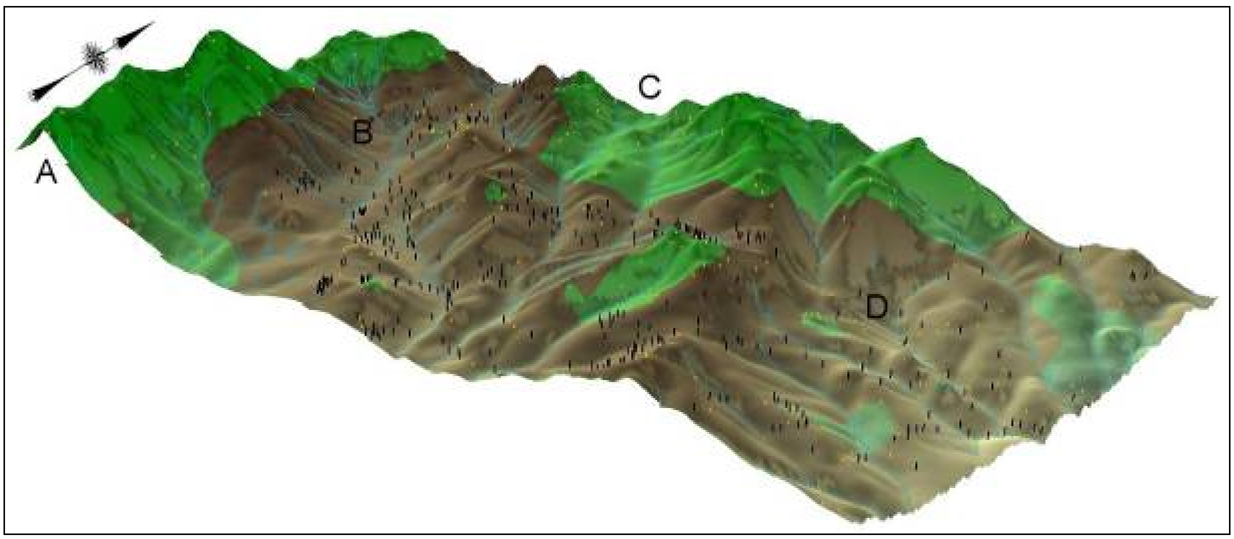


Figure 23: Two dimensional representation of bedrock topography relative to surface topography. Brown hues represent areas of greatest overburden and green hues represent inferred bedrock topography. Vertical black bars represent wells and orange bars indicate the location of bedrock outcrops.

5.4 – Summary of Hydrogeologic Characteristics

Of the 405 rectified wells in the Town of Dover, 404 of them terminate in bedrock and 1 terminates in unconsolidated sediment. The bedrock wells were differentiated by their lithologic suitability for groundwater flow – (e.g. - carbonates, slates/phyllites, quartzites, and crystalline rocks) (Figure 24). The primary hydrogeologic unit in the study area is classified as the Type I Green Mountain Sequence (357 wells), 46 wells occur in the Green Mountain Sequence Type Ic, and only one well occurs in the Type Ib Green Mountain Sequence. A summary of wells within each hydrogeologic unit and their associated geologic formations, yield and depth are summarized in Table 4.

Well yields are apparently highest in Type I rocks (mean = 22gpm), however there are very few exposures of carbonates within the study area for proper comparison. Wells in Type Ic rocks have much lower yields even thought their mean depths are very similar.

Table 4: Summary of well yield and depth for wells within specific hydrogeologic units.

Hydrogeologic Unit	**Well Yield (gpm)**		**Well Depth (ft)**	
	Mean	Median	Mean	Median
Type I -Green Mountain Seuqence (n = 357) Exposures of schist, amphibolite, greenstone, phyllite, and rare quartzite within the Cavendish Hoosac, Pinney Hollow, Ottauquechee, and Stowe Formations, the Readsboro Member of the Cavendish Formation, the Turkey Mountain Member of the Hoosac Formation and the Moretown Member of the Missisquoi Formation	21	12	340’	320’
Type Ib -Green Mountain Sequene (n = 1) Exposures of dolomite and marble within the Cavendish Formation.	7	7	225’	225’
Type Ic -Green Mountain Sequence (n = 46) Exposures of bioite gneiss, amphibolite and minor beds of quartzite and granulate within the Mt Holly Complex	13	4	339’	327’

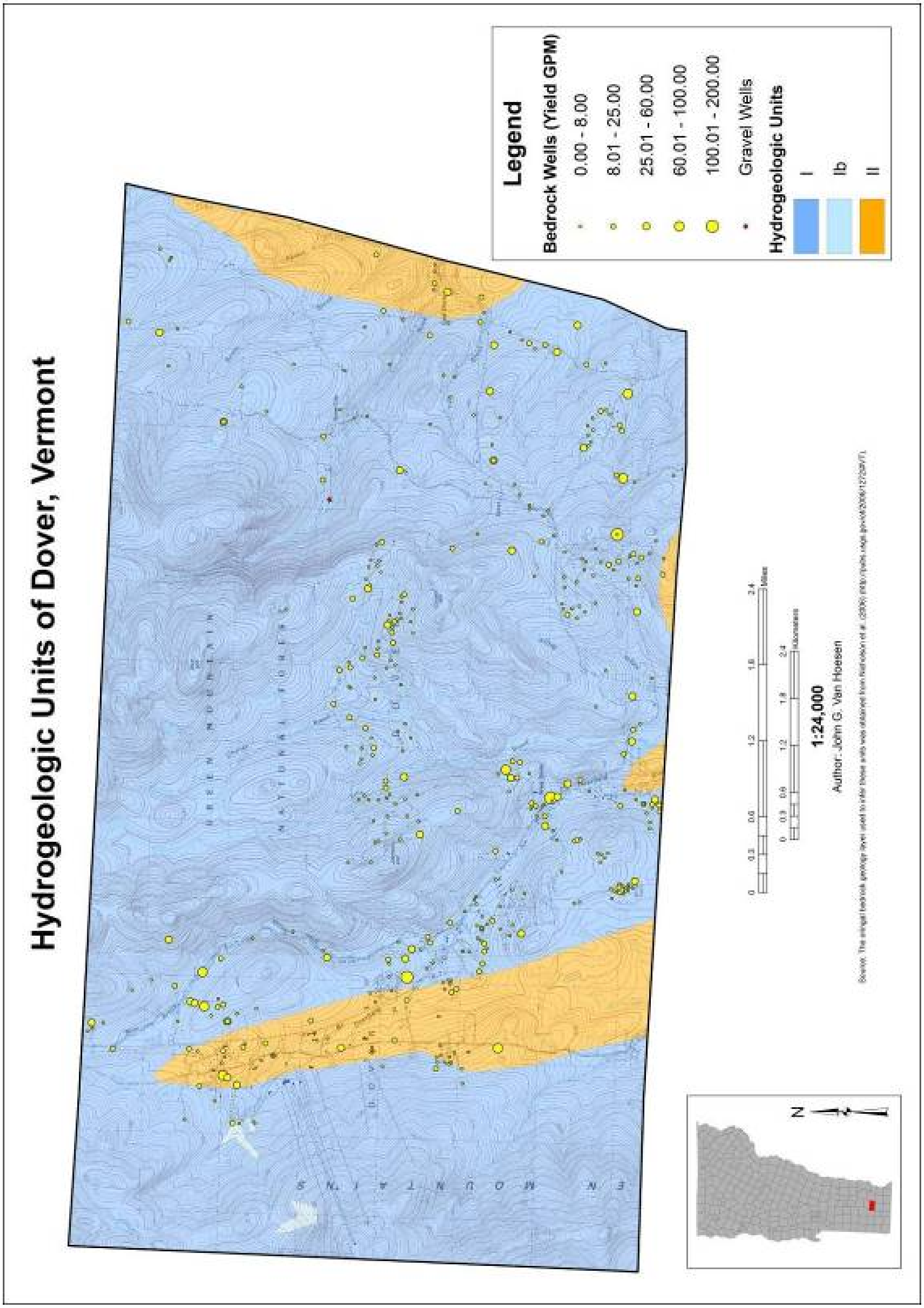


Figure 24: Classification of hydrogeologic units within the Town of Dover.

5.5 – Potentiometric Surface + Flow Lines

The interpolated potentiometric surface is consistent with well data, surficial geology, and surface topography. A potentiometric surface does not typically characterize the physical top of the water table but is a proxy for the potential energy available to move groundwater within an aquifer. The map depicts 200 foot contours extracted from the underlying potentiometric surface (Figure 10). Both of these data layers rely on the static level of water within wells drilled throughout the Town of Dover.

Because private and municipal wells are not evenly distributed through the town uncertainty exists in the inferred flow direction in some areas of the map. However, the general trend of flowing west to east and north to south is readily apparent in both the trend analysis and the resulting interpolated surface.

5.6 – Bedrock Recharge

The Town of Dover exhibits a bimodal distribution of recharge between high and lowest recharge potential (Figure 25). Areas of highest bedrock recharge occur in the highlands, which are primarily covered by thin till and frequent rock outcrops. This facilitates infiltration into the underlying fractures and foliation of the bedrock. However, bedrock type and weathering of the exposed till and bedrock influences infiltration rates. Areas with low recharge potential are characterized by impermeable thick, compacted glacial till, wetland areas and modern and fluvial deposits – specifically alluvium and fluvial terrace deposits. Areas of thick, dense till typically inhibit infiltration because of low permeability associated with compaction and clay content. Although alluvium and fluvial terraces typically have higher porosity and permeability than dense till, it is more likely that groundwater flows through these deposits and discharges into adjacent streams rather than recharging the bedrock aquifer. However, it is important to recognize that the hydraulic conductivity of these deposits were not field-tested in this study area.

5.7 – Shallow Aquifer Recharge

Areas with the highest potential for shallow aquifer recharge are limited to areas filled with unconsolidated sediment characterized by high porosity and permeability associated with alluvium and fluvial terrace deposits. Because only one gravel well is available in the rectified well database, the extent to which shallow aquifers can be identified and characterized is limited. However, based on well log data and the isopach map, it is possible to infer the location of potential aquifer locations (Figure 26). I identified five possible locations that could support a localized shallow aquifer, but these are inferences and should be field verified.

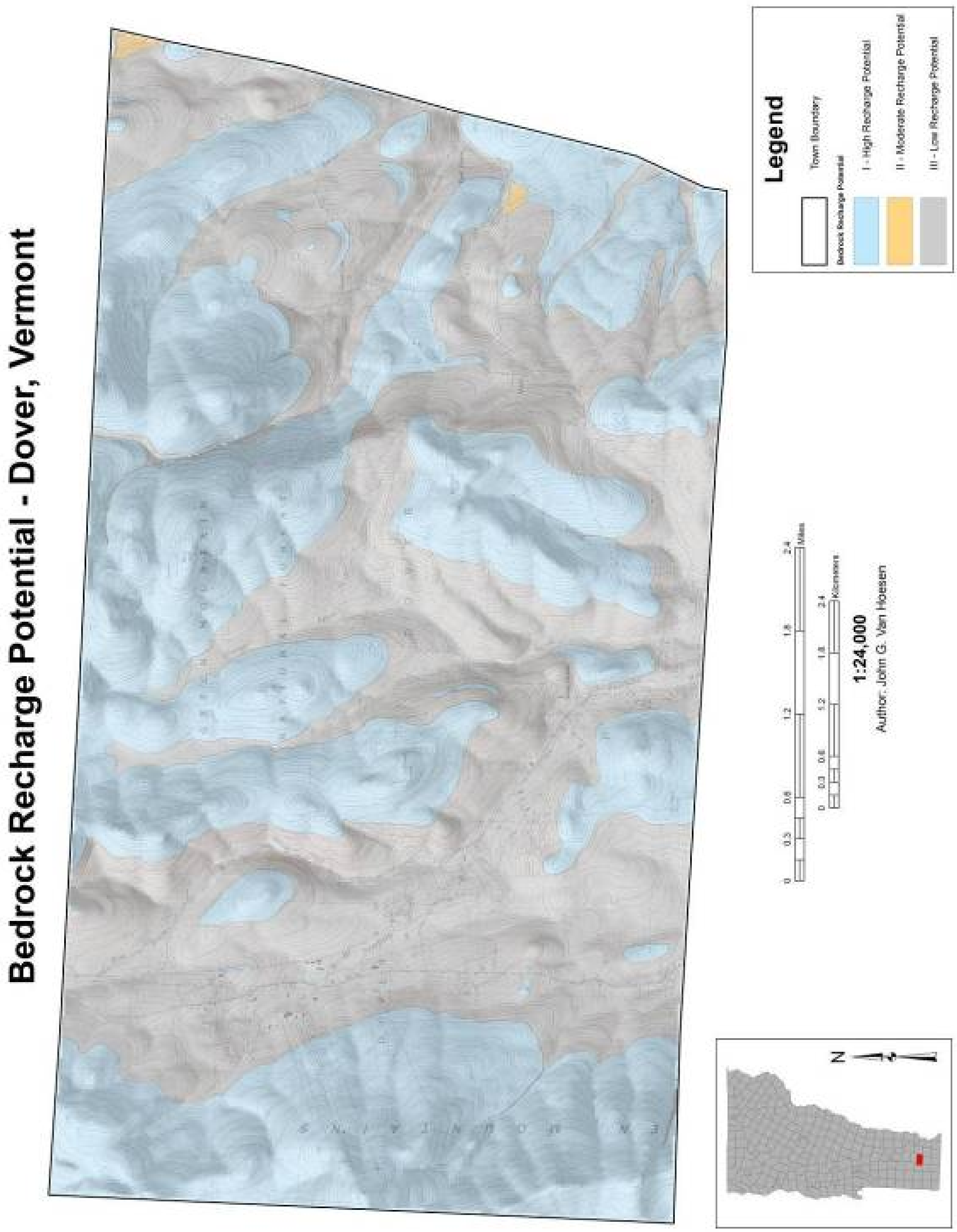


Figure 25: Map illustrating the bimodal distribution of bedrock recharge in Dover.

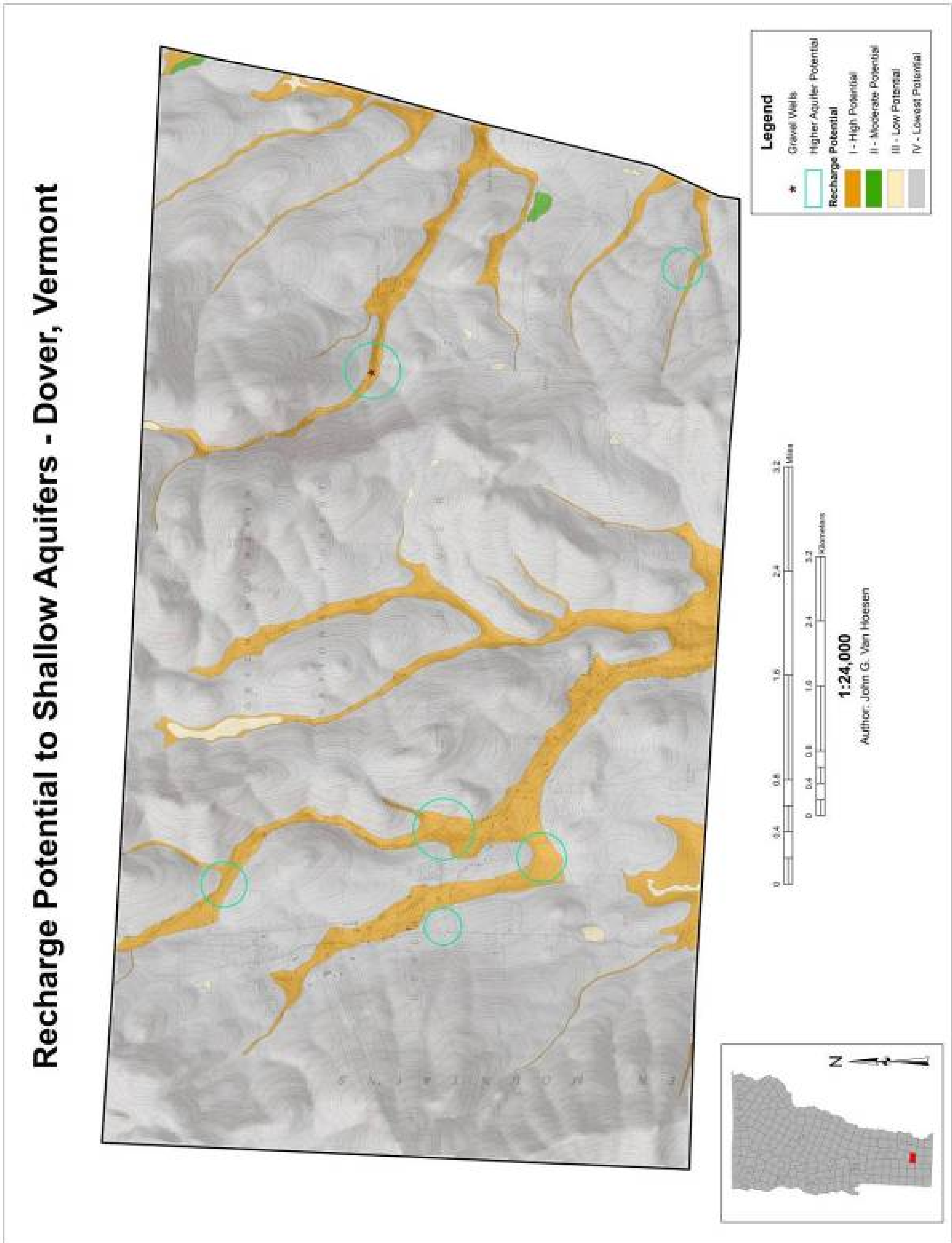


Figure 26: Map of shallow aquifer recharge potential, primarily limited to alluvial filled valleys and drainages.

6.0 – Future Work

Given the limited time for pursuing activities beyond the scope of creating a detailed surficial geologic map and associated derivative maps, the following suggestions are of potential interest:

1. Characterizing the stability of thick, clay-rich till deposits along the headwaters of Rock River.

2. Developing a better understanding of the relationship between thin sandy till and thicker clay-rich till sequences.

3. Linking the small outwash gravels in the northwestern corner of town with gravels and deltas observed during brief reconnaissance visits to valleys draining into the town of Newfane.

4. Developing a better understanding between the behavior of deglaciation within the Town of Dover and evidence for lacustrine deposits found along Rock River just outside the town boundary.

7.0 – References

Bajjali, W., 2005, Model the effect of four artificial recharge dams on the quality of groundwater using geostatistical methods in GIS environment, Oman. Journal of Spatial Hydrology, Vol. 5, No.2.

Carlson, H.A., 2002, Quantitative x-ray diffraction analysis as a means of determining Last Glacial maximum ice flow directions in Vermont. B.S. Thesis, Middlebury College, Vermont, 76p.

Denny, C.S., 1982, Geomorphology of New England: U.S. Geological Survey Professional Paper 1208, 18 p.

Desbarats, A.J., Logan, C.E., Hinton, M.J., and Sharpe, D.R., 2002, On the kriging of water table elevations using collateral information from a digital elevation model. Journal of Hydrology, 255: 25□38.

Gao, C., Shirota, J., Kelly, R.I., Brunton, F.R., and van Haaften, S., 2006, Bedrock topography and overburden thickness mapping, southern Ontario. Ontario Geological Survey, Miscellaneous Release – Data 207.

Hamad, S., 2008, Spatial analysis of groundwater level and hydrochemsitry in the south Al Jabal Al Akhdar area using GIS. MS Thesis, Salzburg University, 122p.

Johnson, K., ver Hoef, J.M., Krivoruchko, K., and Lucas, N., 2004, Using ArcGIS Geostatistical Analyst. ESRI Press, 300p.

Locke, R.A., and Meyers, S.C., 2007, Kane County Water Resources Investigations: Final Report on Shallow Aquifer Potentiometric Surface Mapping. Contract Report 2007□6, Illinois State Water Survey.

Nicholson, S.W., Dicken, C.L., Horton, J.D., Foose, M.P., Mueller, J.A.L., and Hon, R., 2006, Preliminary integrated geologic map databse for the United States: Connecticut, Maine, Massachussettes, New Hampshire, New Jersey, Rhode island, and Vermont. U.S. Geological Survey, Open□File Report 2006□1272. (http://pubs.usgs.gov/of/2006/1272).

Ratcliffe, N.M., 1993, Bedrock geologic map of the Mount Snow and Readsboro quadrangles, Bennington and Windham counties, Vermont: U.S. Geological Survey Miscellaneous Investigations Series Map I-2307.

Ratcliffe, N. M., and Armstrong, T. R., 1999, Bedrock geologic map of the West Dover and Jacksonville quadrangles, Windham County, Vermont: U.S. Geological Survey Miscellaneous Investigations Map I-2552, scale 1:24,000.

Robinson, G.R. and Kapo, K.E., 2003, Generalized Lithology and Lithogeochemical Character of Near-Surface Bedrock in the New England Region. Open-File Report 03-225, U.S. Geological Survey, 60p.

Robinson, G.R., Peper, J.D., Stevens, P.A., and DeSimone, L.A., 1999, Lithogeochemical character of near-surface bedrock in the Connecticut, Housatonic, and Thames River Basins. Water-Resources Investigations Report 99-4000, U.S. Geological Survey.

Shilts, W.W., 1966, The Plestocene geology of the Wilmington area, Vermont: A report to the State Geologist on open file report at the Vermont Geological Survey.

Spahr, P.N., Jones, A.W.J., Barret, K.A., Agnle, M.P., and Raab, J.M., 2007, Using GIS to Create and Analyze Potentiometric□Surface Maps, in, Digital Mapping Techniques '06—Workshop Proceedings, U.S. Geological Survey Open□File Report 2007–1285.

Stewart, D.P. and MacClintock, P., 1969, The surficial geology and Pleistocene history of Vermont. Vermont Geological Survey Bulletin 31, Montpelier, Vermont, 251p.

Stewart, D.P. and MacClintock, P., 1970, Surficial geologic map of Vermont: Montpelier, Vermont, Vermont Geological Survey, one sheet.

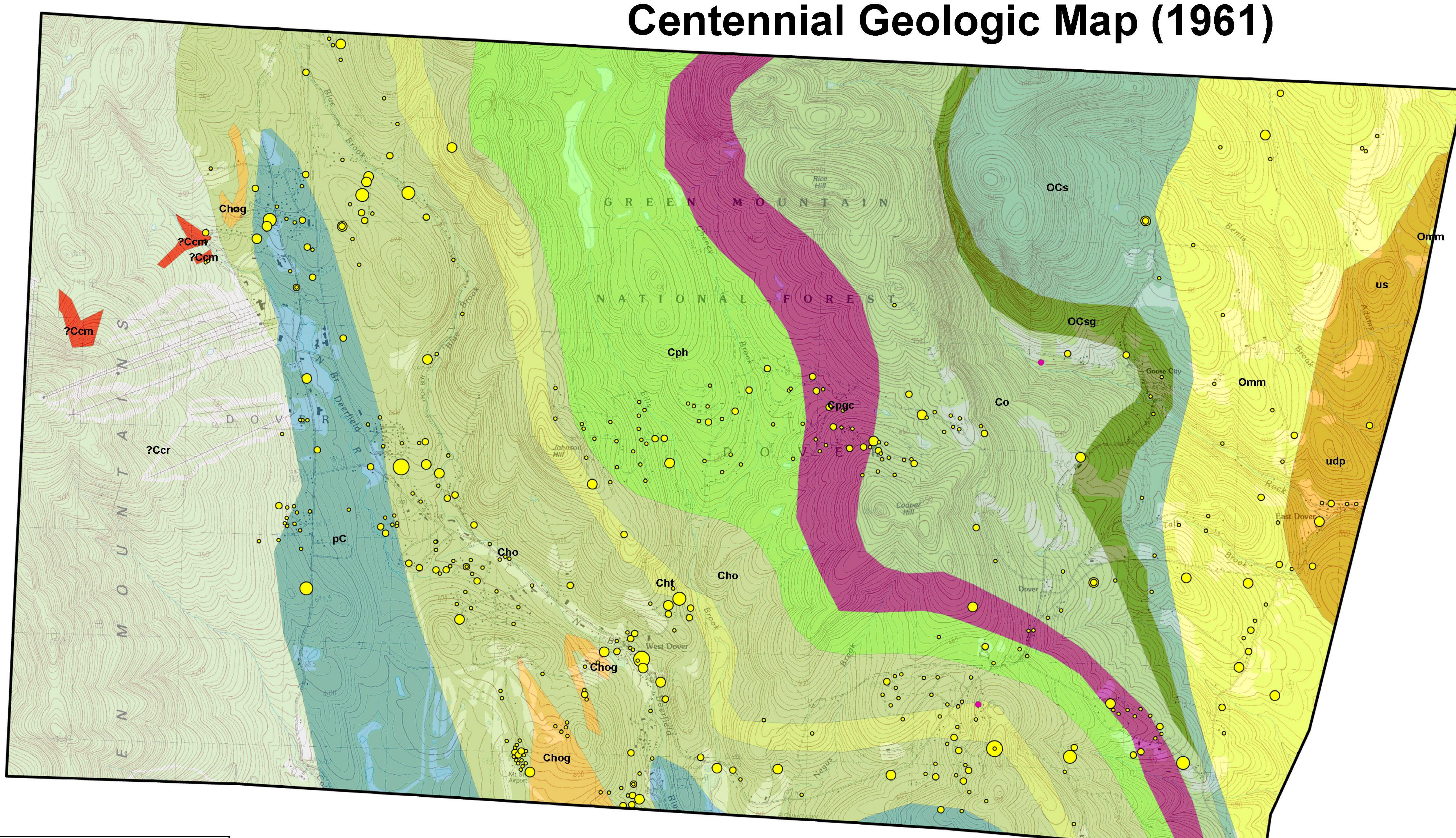
Hanson, E.R., 2009, Public Community Water Systems Groundwater Interference Project. Vermont Rural Water Association Final Report.

Vermont Indicators Online: http://www.vcgi.org/indicators/

White, C., 1979, Surficial geology and mode of deglaciation in the Wilmington Quadrangle, Vermont. M.S. Thesis, University of Massachusetts at Amherst, Amherst, MA. 212p.

Yang, X. and Hodler, T., 2000, Visual and statistical comparisons of surface modeling techniques for point□based environmental data. Cartography and Geographic Information Systems, 27(2): 165□175.

Bedrock Geology of Dover, Vermont
Centennial Geologic Map (1961)



Legend

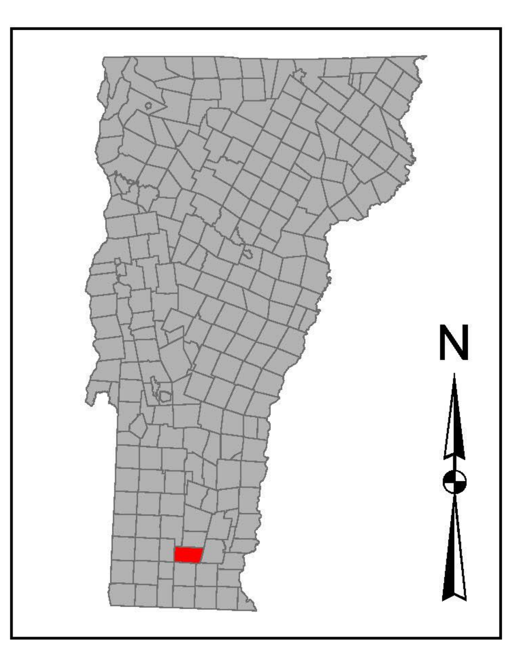
Bedrock Wells

YieldGPM

- 0.00 - 8.00
- 8.01 - 25.00
- 25.01 - 60.00
- 60.01 - 100.00
- 100.01 - 200.00
- Gravel

Bedrock Geology

- Cavendish Formation, Dolomite and Marble
- Cavendish Formation, Readsboro Member
- Hoosac Formation
- Hoosac Formation, Amphibolite and Greenstone
- Hoosac Formation, Turkey Mountain Member
- Missisquoi Formation, Moretown Member
- Mount Holly Complex
- Ottauquechee Formation
- Pinney Hollow Formation
- Pinney Hollow Formation, Chester Amphibolite Member
- Stowe Formation
- Stowe Formation, greenstone and amphibolite
- Ultramafic Rocks



0 0.4 0.8 1.6 2.4 3.2 Miles

0 0.4 0.8 1.6 2.4 3.2 Kilometers

1:24,042

Author: John G. Van Hoesen

Source: Geologic map layers were obtained from Nicholson et al. (2006) (http://pubs.usgs.gov/of/2006/1272/#VT).

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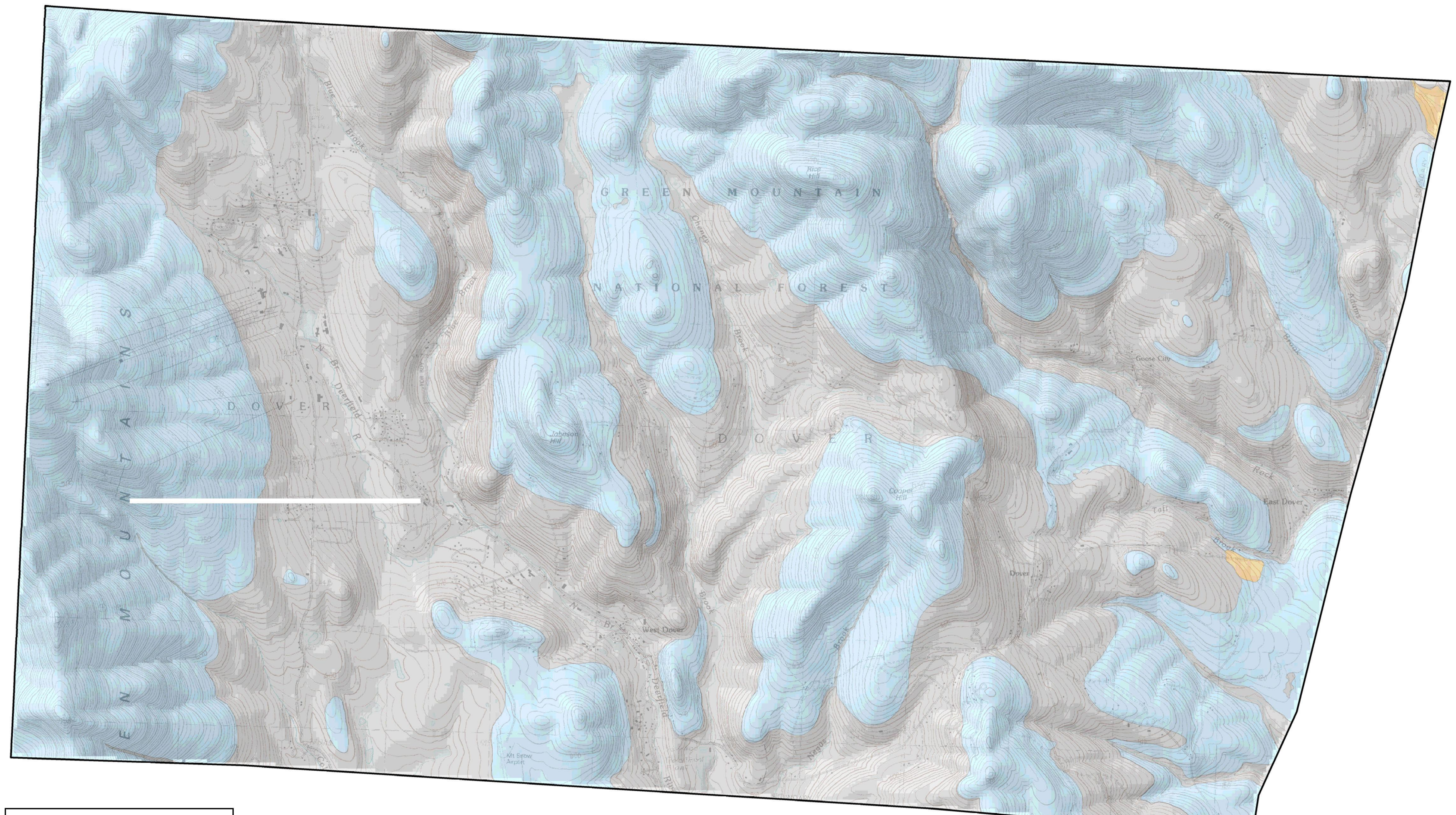
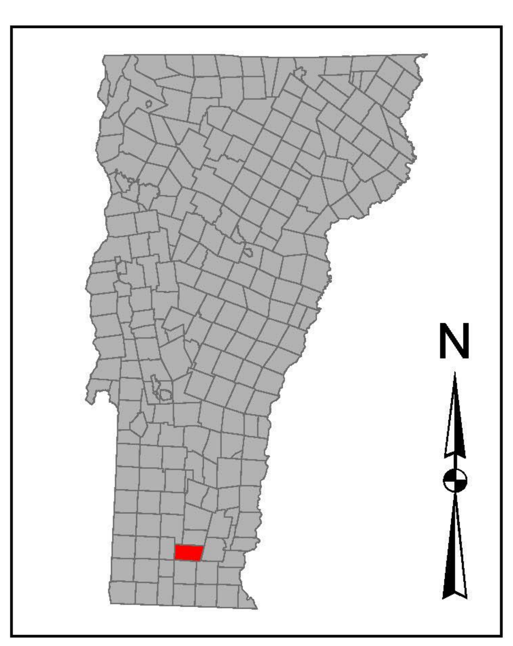
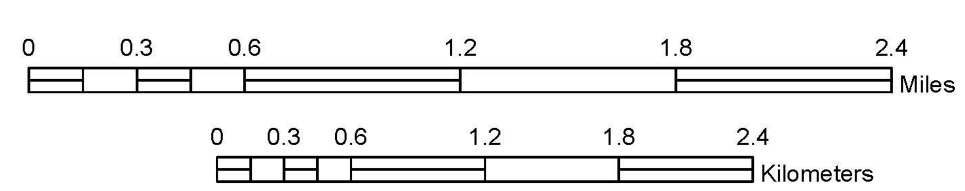
Bedrock Recharge Potential - Dover, Vermont







1:24,000

Author: John G. Van Hoesen

Legend

Town Boundary

Bedrock Recharge Potential

I - High Recharge Potential

II - Moderate Recharge Potential

III - Low Recharge Potential

I – High Recharge Potential: Primarily located in highlands covered by thin till and frequent rock outcrops where water can easily infiltrate into the underlying fractures and foliation of the bedrock. Weathering of this exposed till and bedrock facilitates infiltration and higher recharge rates in higher elevation areas.

II – Moderate Recharge Potential: Characterized by unconsolidated sediment derived from fluvial and glaciofluvial processes. Specifically areas covered by kame deposits (Qk), and outwash gravel (Qow) – however both of these are limited in extent and thickness. These unconsolidated deposits are primarily found filling valley bottoms and along valley walls and facilitate recharge because they typically exhibit high porosity and permeability.

III – Low Recharge Potential: Characterized by impermeable thick, compacted glacial till, wetland areas and modern and fluvial deposits – specifically alluvium (Hal) and fluvial terraces (Hft). Areas of thick, dense till typically inhibit infiltration because of low permeability associated with compaction and clay content. Although alluvium and fluvial terraces typically have higher porosity and permeability than dense till, it is more likely that groundwater flows through these deposits and discharges into adjacent streams rather than recharging the bedrock aquifer. Wetlands represent areas of groundwater discharge rather and therefore also fail to recharge the bedrock aquifer.

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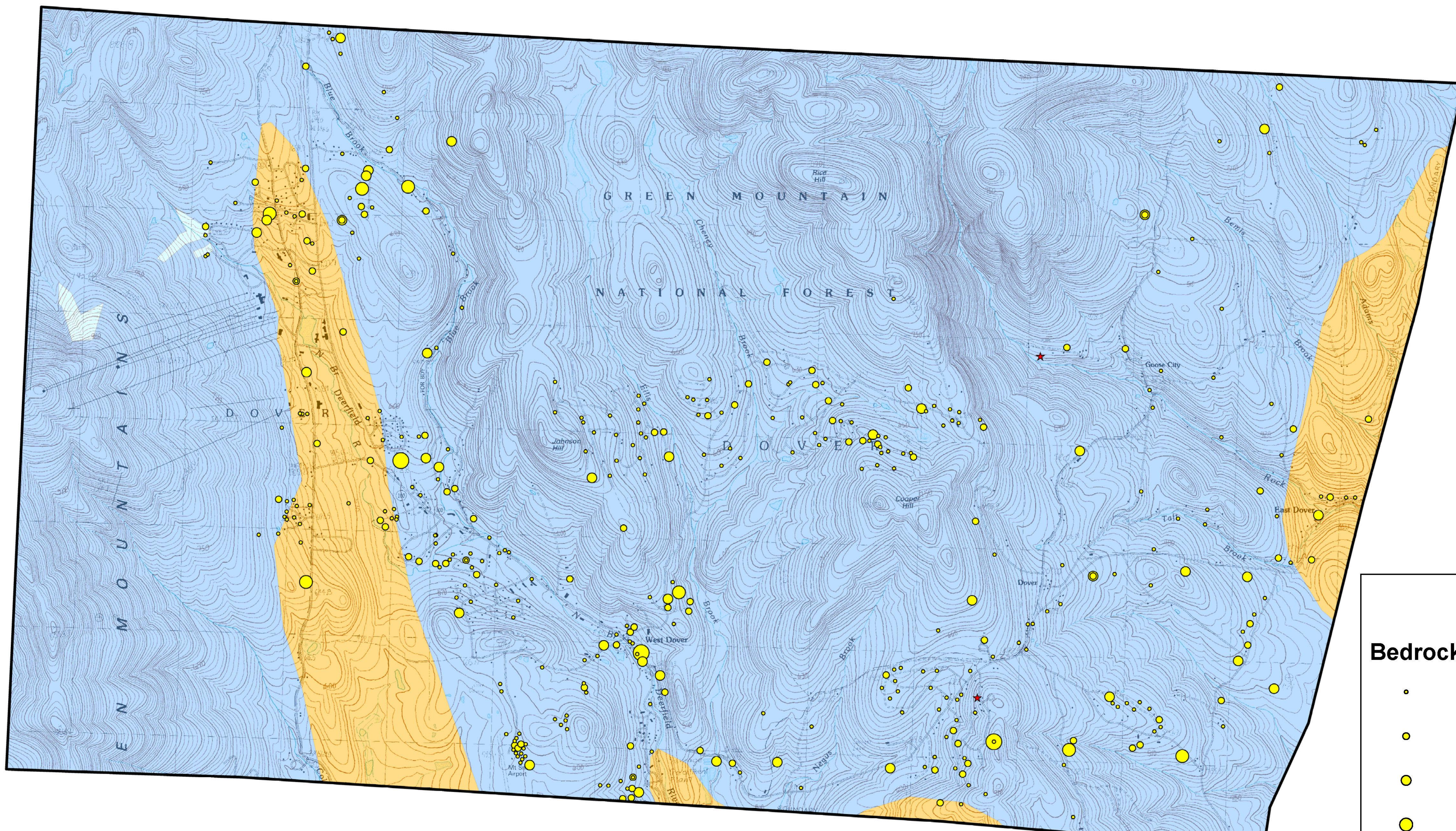
Hydrogeologic Units of Dover, Vermont



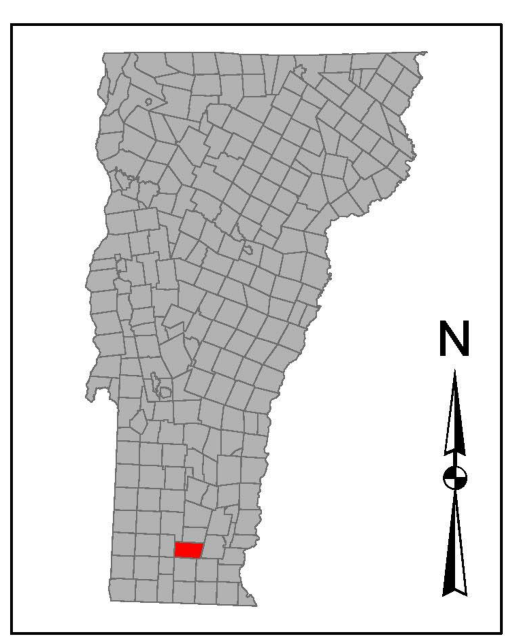
Legend

Bedrock Wells (Yield GPM)

- 0.00 - 8.00
- 8.01 - 25.00
- 25.01 - 60.00
- 60.01 - 100.00
- 100.01 - 200.00
- Gravel Wells

Hydrogeologic Units

- I
- Ib
- II



0 0.3 0.6 1.2 1.8 2.4 Miles

0 0.3 0.6 1.2 1.8 2.4 Kilometers

1:24,000

Author: John G. Van Hoesen

Source: The oringal bedrock geology layer used to infer these units was obtained from Nicholson et al. (2006) (http://pubs.usgs.gov/of/2006/1272/#VT).

All Bedrock Wells (n=404)
Mean Yield: 11.82 gpm
Mean Depth: 339.02 ft
Median Yield: 4.0 gpm
Median Depth: 320 ft

All Gravel Wells (n=1)
Yield: 2.65 gpm
Depth: 517.5 ft

HYDROGEOLOGIC UNIT

Unit I – Green Mountain Sequence (n = 357): includes exposures of schist, amphibolite, greenstone, phyllite, and rare quartzite within the Cavendish, Hoosac, Pinney Hollow, Ottauquechee, and Stowe Formations, the Readsboro Member of the Cavendish Formation, the Turkey Mountain Member of the Hoosac Formation and the Moretown Member of the Missisquoi Formation.
These rocks have fair to poor aquifer potential depending on the ability of water to flow through fractures and along foliation.
Mean Yield: 21 gpm
Mean Depth: 340 ft
Median Yield: 12 gpm
Median Depth: 320 ft

Unit Ib - Green Mountain Sequence (n=1): includes exposures of dolomite and marble within the Cavendish Fm.
These rocks have limited exposure but have moderate aquifer potential depending upon the ability of water to flow through fractures.
Yield: 7 gpm
Depth: 225 ft

Unit Ic – Green Mountain Sequence (n=46): includes exposures of biotite gneiss, amphibolite and minor beds of quartzite and granulite within the Mt. Holly Complex.
These rocks have fair to poor aquifer potential depending on the ability of water to flow through fractures and along foliation.
Mean Yield: 13 gpm
Mean Depth: 339 ft
Median Yield: 4 gpm
Median Depth: 327 ft

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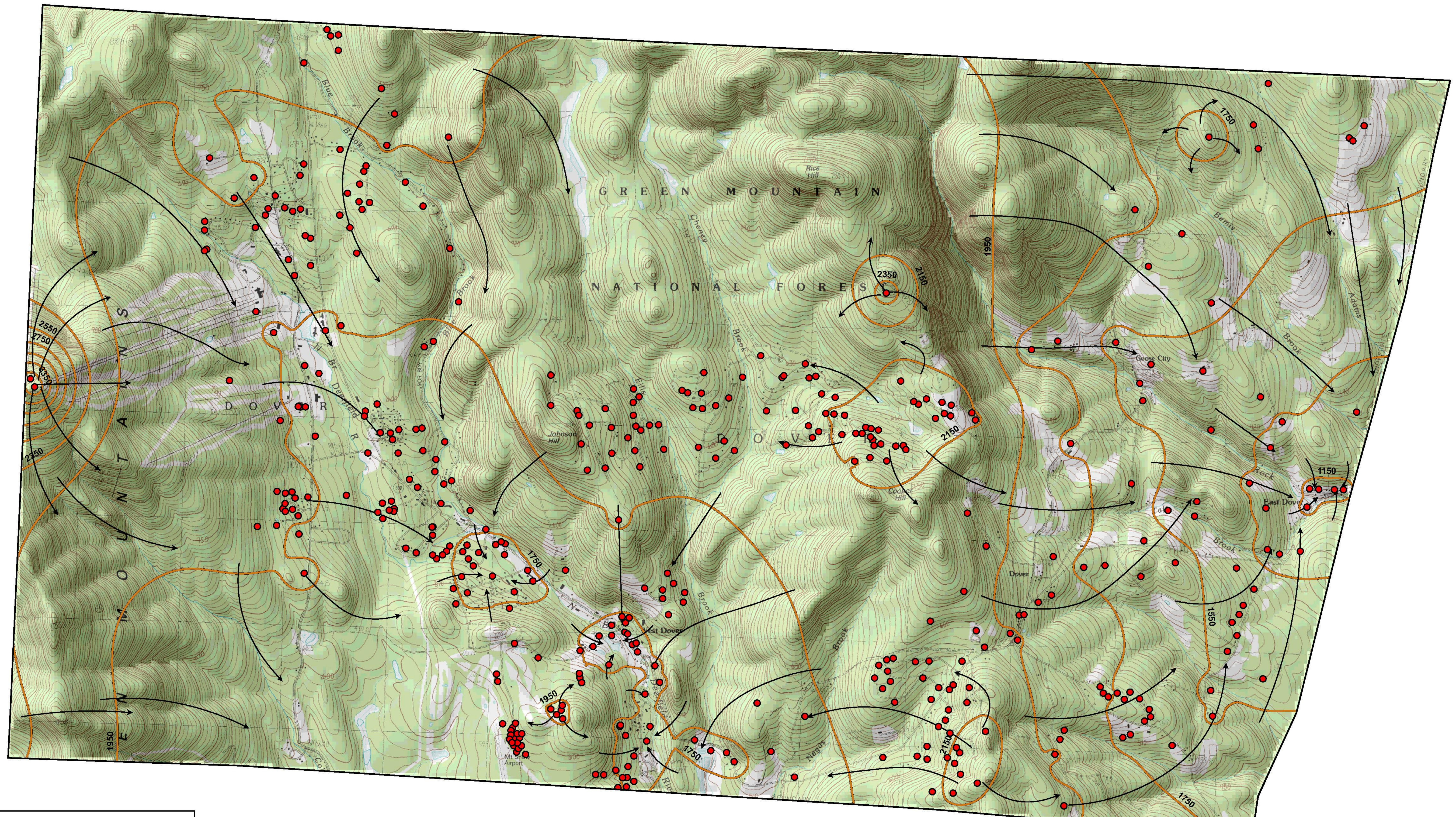
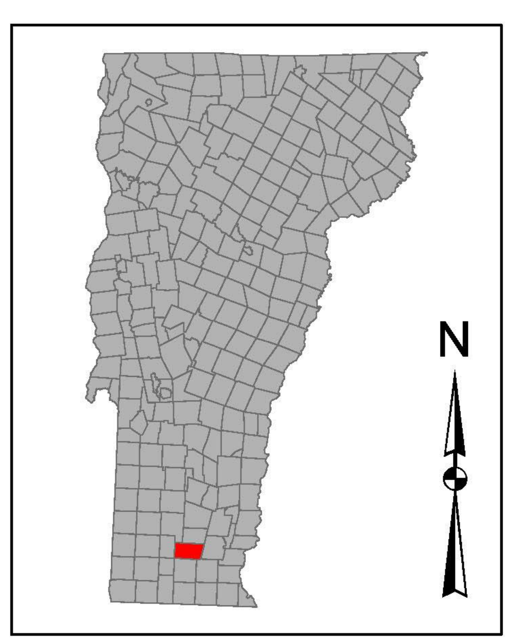
Potentiometric Surface and Flow Lines - Dover, Vermont



This map depicts 200 foot contours extracted from the inferred potentiometric surface for the town of Dover. Both the potentiometric surface and resulting contours rely on the accuracy of static water levels recorded within wells drilled throughout the town. This technique provides a mechanism to infer a potentiometric surface but is limited by the fact that many wells were drilled during different decades and different times of the year. While the contours are widely spaced and some level of uncertainty exists in the inferred flow direction in portions of the map area, the general trends of flow from west to east and north to south is apparent.

Groundwater flow lines are indicators of potential flow down hydraulic gradient within an aquifer. The flow lines indicate the inferred direction of recharge from higher regions of an aquifer to lower regions of discharge. However, it is important to note that water levels do not represent the actual height of the water table.



0 0.4 0.8 1.6 2.4 3.2 Miles

0 0.4 0.8 1.6 2.4 3.2 Kilometers

1:24,000

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Legend

- Wells
- Flowlines
- Potentiometric Contours (200ft)

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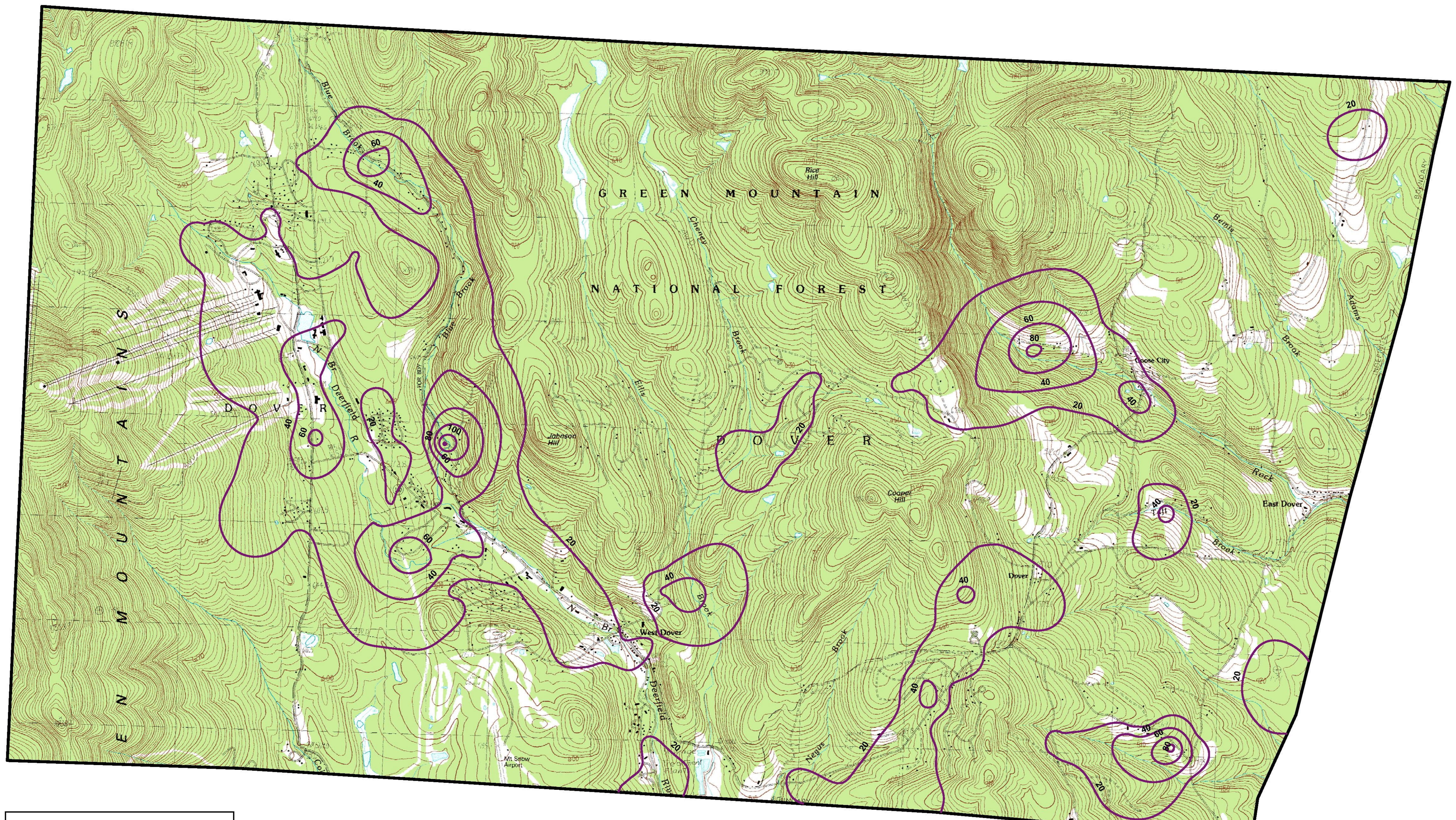
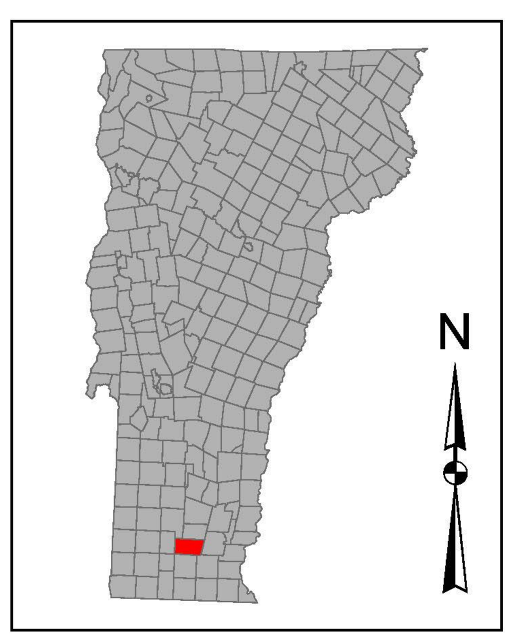
Depth to Bedrock - Dover, Vermont





0 0.4 0.8 1.6 2.4 3.2 Miles

0 0.4 0.8 1.6 2.4 3.2 Kilometers

1:24,000

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Legend

Contours (20ft)

Town Boundary

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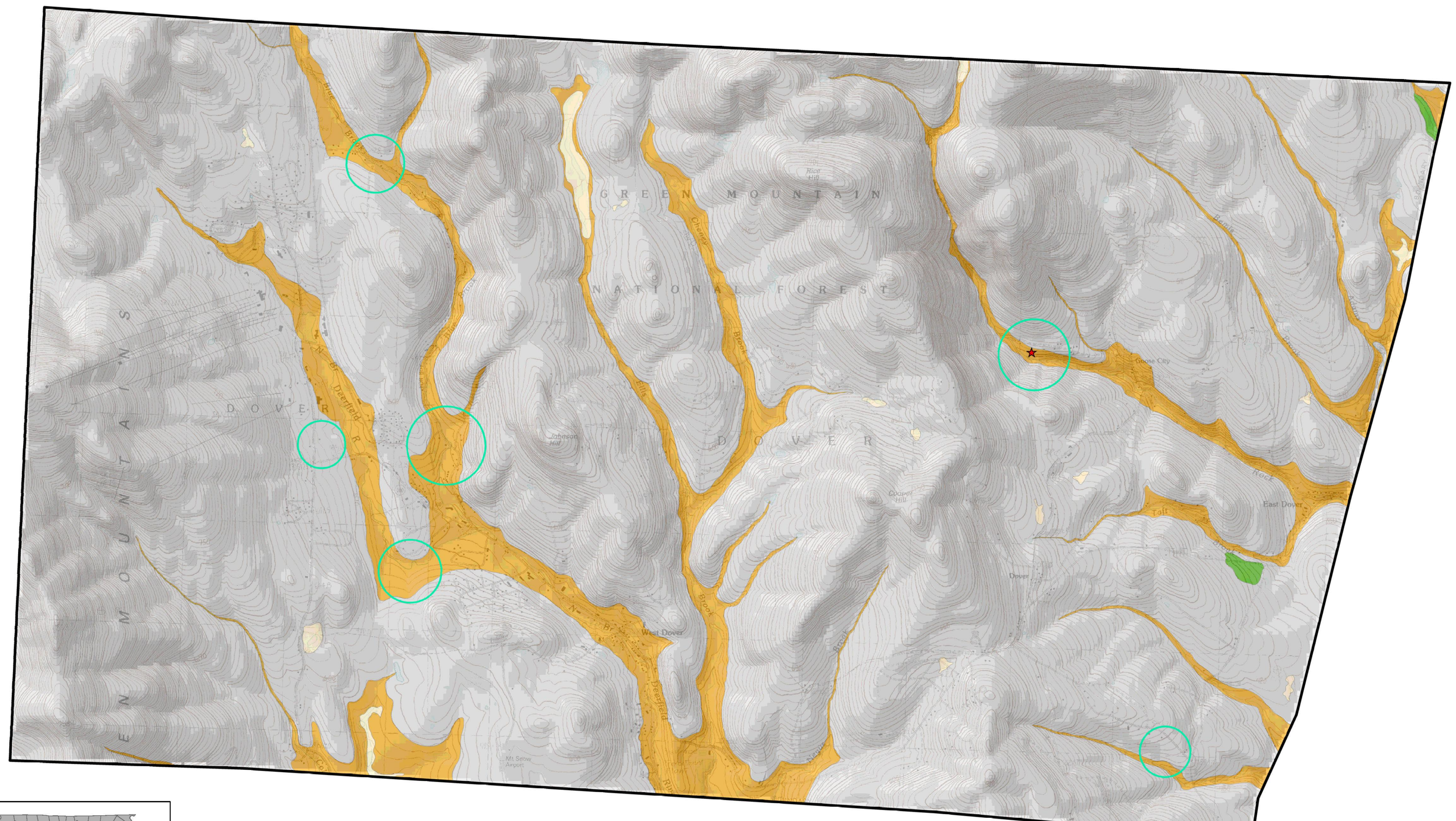
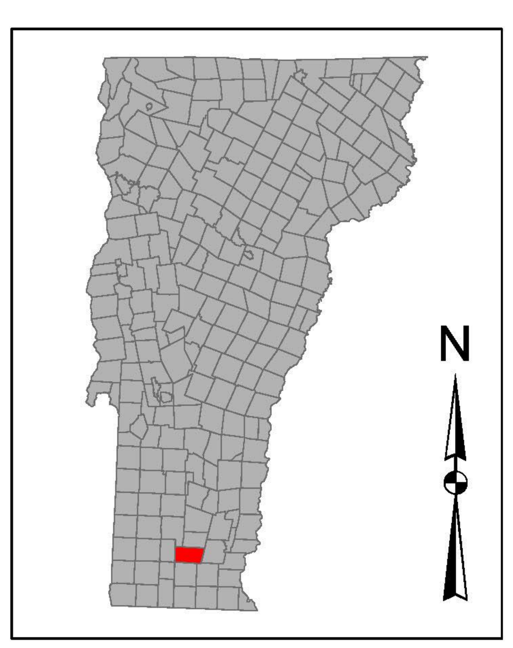
Recharge Potential to Shallow Aquifers - Dover, Vermont





0 0.4 0.8 1.6 2.4 3.2 Miles

0 0.4 0.8 1.6 2.4 3.2 Kilometers

1:24,000

Author: John G. Van Hoesen

Legend

- ★ Gravel Wells
- Higher Aquifer Potential

Recharge Potential

- I - High Potential
- II - Moderate Potential
- III - Low Potential
- IV - Lowest Potential

EXPLANATION

Regions of unconsolidated sediment with high porosity and permeability, typically some mixture of sands and gravels, were identified as areas capable of supporting an unconfined shallow aquifer.

These aquifers experience recharge through infiltration following precipitation events, melting snow and losing stream reaches.

These areas were ranked based on their potential for infiltration based on well log data, surficial geology and geomorphic position.

Those areas with the thickest (>60ft) and most permeable deposits were given the highest ranking (i.e – thick alluvium) and those areas covered by thinner (<60ft) and/or less permeable deposits were given a lower ranking (i.e. – till).

Higher elevation areas dominated by thin till and bedrock exposures increase surface stream runoff. When these streams cross more permeable sediments in the valley floors it is possible they also contribute to potential recharge of the aquifer.

Higher Aquifer Potential Layer: Generalized areas where slightly higher potential for presence of a shallow aquifer based upon well data interpretations. Aquifer may be limited in extent.

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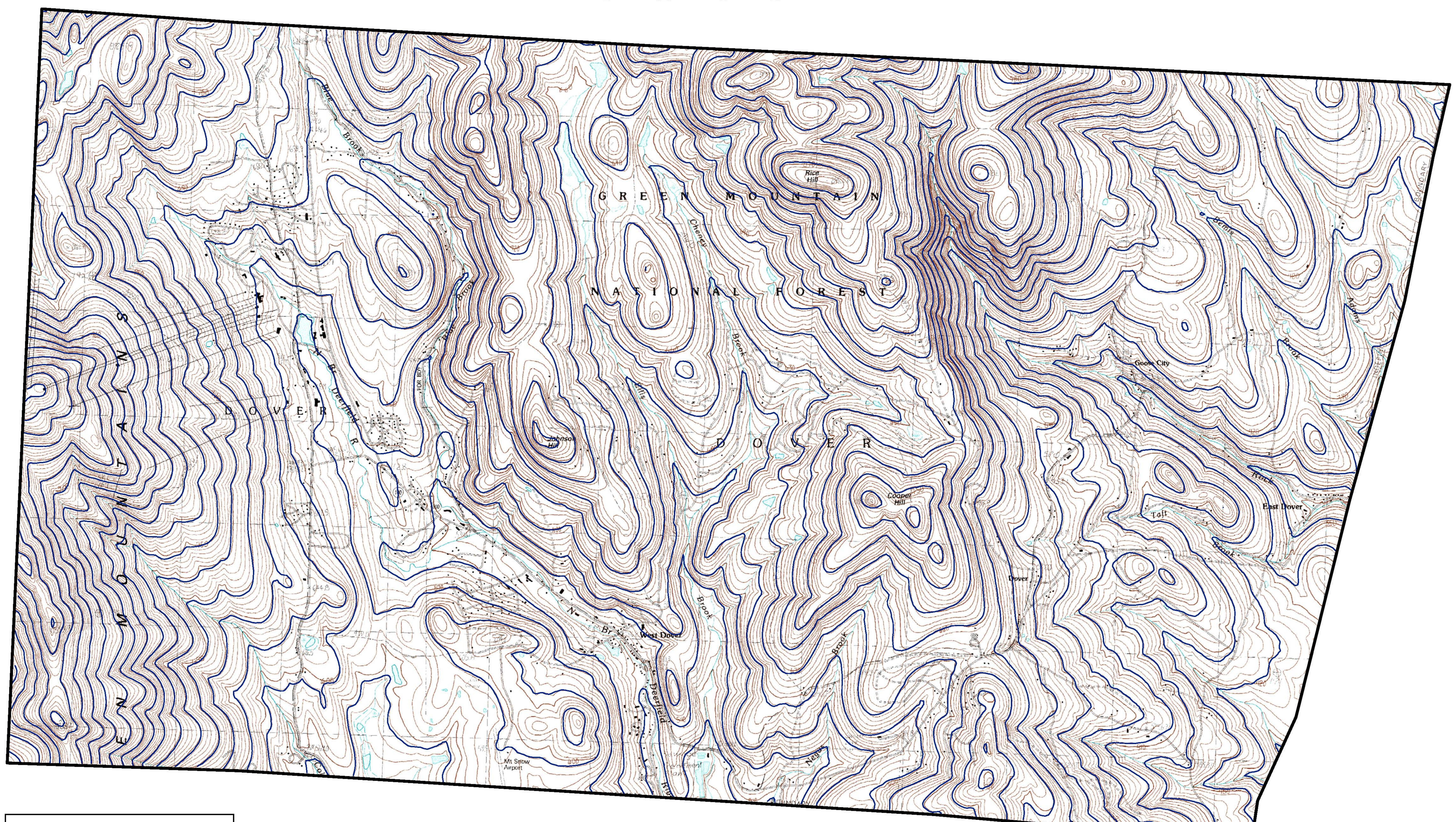
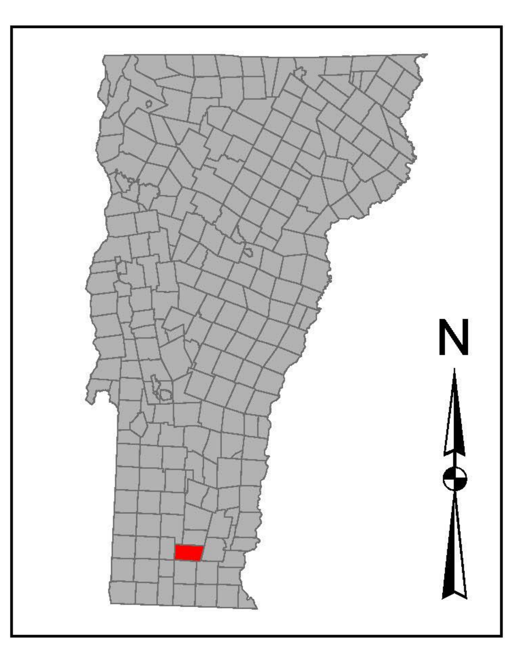
Bedrock Topography - Dover, Vermont





0 0.4 0.8 1.6 2.4 3.2 Miles

0 0.4 0.8 1.6 2.4 3.2 Kilometers

1:24,000

Author: John G. Van Hoesen

Legend

Town Boundary

Bedrock Countours (100ft)

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