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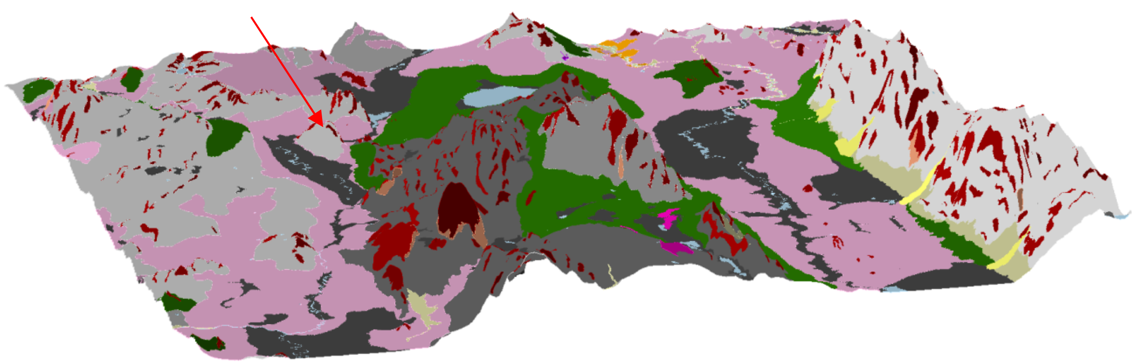
Final Report Summarizing the Surficial Geology and Hydrogeology of Monkton, Vermont

A view from Mt Florona looking East across Cedar Lake towards the Hogback Mountains and Green Mountains on the horizon.



A three-dimensional view of the surficial geology draped over topography illustrating the spatial distribution of surficial deposits. The red arrow illustrates the vantage point in the above photo.

John G. Van Hoesen
Green Mountain College
Department of Environmental Studies
Poultney, Vermont 05764

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1.0 – Executive Summary

During the summer and fall of 2016, I mapped the surficial geology and utilized spatially rectified 405 private and municipal wells provided by the Town of Monkton. I identified and mapped eleven distinct surficial units using traditional field and digital mapping techniques and information gathered from rectified wells. I also collected GPS coordinates for 301 bedrock outcrops, 142 surficial sites and three sites with well-preserved striations. Bedrock outcrop locations were collected and combined with well logs to help refine bedrock topography and facilitate the production of an overburden isopach map and two cross-sections.

Bedrock topography generally mimics surface topography and the well logs and isopach map suggest the valley containing Pond Brook and the Monkton Ridge region have the thickest surficial deposits. Unfortunately both surficial mapping and the lack of gravel wells in the rectified database suggest there is limited surficial aquifer potential and that the subsurface characteristics of unconsolidated aquifers in Monkton are poorly understood. Well yields are highest in the eastern half of town in those areas underlain by the Cheshire Quartzite and Dunham Dolomite. Static water levels from well log data were used to interpolate a potentiometric surface, which indicates groundwater generally flows from high to low gradient. The resulting map indicates the steepest gradient flows towards the valley containing Pong Brook from both the Hogback Mountains and from the hogback mountain northeast of East Monkton. In general, water flows from north to south, mimicking surface topography and drainage valleys.

Field mapping identified extensive deposits of a thin Wisconsinan age dense, clay-rich till occurring as a surface veneer mimicking the underlying topography and a less extensive thicker till mantling valley walls and creating gently sloping topography. Both till deposits are often frequently associated with small talus and alluvial fan deposits. The second most extensive surficial material is undifferentiated coarse-to-fine-grained lake deposits. This material is variable in thickness from a few meters to approximately 100 feet thick in the Pond Brook valley. Alluvium is present in numerous small brooks and most extensive east of Turkey Lane and north of Tyler Bridge Road and older stream terraces are located along Lewis Creek. Several small and isolated kame deposits occur along the southernmost stretch of Old Airport and Hardscrabble Roads. These landforms suggest supraglacial lakes may have formed and accumulated sediment that was deposited as glacial ice melted out in-situ supporting but their limited extent don’t support the “mass stagnation model” criticized by Franzi (1988). There are also three small well-sorted sandy Coveville-age shoreline deposits; these are limited in both extent and thickness.

The Monkton area contains a few well-preserved striations that – consistent with surrounding towns – indicate a northwest to southeast flow direction. Numerous crag and tail landforms are easily identified on the 1.6m LIDAR and most common in the Monkton and Cheshire Quartzites.

2.0 – Background

This report summarizes the results of surficial mapping and digital mapping efforts within the town of Monkton, Vermont. The mapping occurred over approximately 5 months during the summer and fall of 2015 and interpretation took place during the subsequent 4 months. I collected GPS coordinates for approximately 301 bedrock locations, 142 field sites and 3 sites with ice flow indicators (Figures 1 & 2). This effort was contracted by the Vermont Geological Survey and supported by the Town of Monkton and the United States Geological Survey, National Cooperative Mapping Program.

The purpose of this project was to develop a 1:24,000 scale map of the surficial geology and integrate this information with subsurface data derived from private well logs. This mapping project also produced 10 derivative maps that provide additional information regarding bedrock and unconsolidated aquifers, which can be used to inform land-use and water resource concerns within the town of Monkton (Table 1).

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

1. Bedrock Locations	7. Recharge Potential to Bedrock Aquifer
2. Field Station Locations	8. Potentiometric Surface + Flow Lines
3. Surficial Geologic Map	9. Favorability For Preventing Surface Infiltration
4. Isopach (Overburden) Map	10. Favorability For Recharge to Bedrock
5. Bedrock Topography	11. Favorability For High Yielding Surficial Aquifer
6. Hydrogeologic Units	12. Potential Aquifer Resources
7. Bedrock Well Yields	

The population of Monkton, Vermont grew by 12.5% between 2000 and 2010 (from 1,759 to 1,980 residents respectively) and another 3.5% between 2010 and 2014 (from to 1,980 to 2,047) (U.S. Census Bureau). This dramatic growth rate is linked with the proximity to and expansion of the Greater Burlington Area. The recent Vermont Gas System proposal to expand their regional gas pipeline and discovery of pentachlorophenol (PCP) in a residential well has fueled interest in develop a better understanding of subsurface hydrogeology in the town. Medalie and Horn (2010) report moderate groundwater and surface water withdrawal rates within the town of Monkton (Figure 3) in 2005 and minor changes projected for 2020.

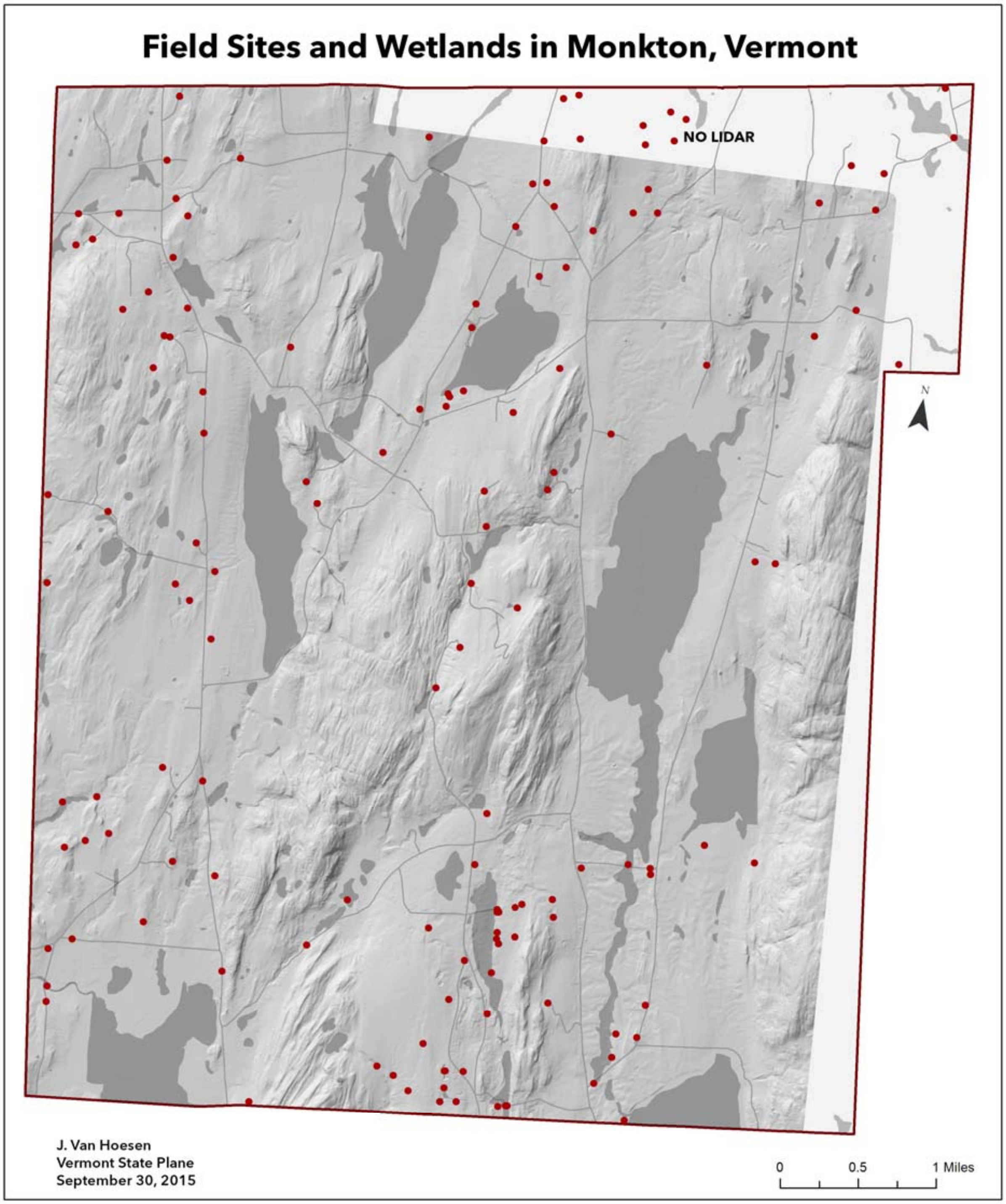

Figure 1: Spatial distribution of sampling sites where surficial material was either natural exposed or revealed using a shovel or soil auger and extensive wetland areas within Monkton, Vermont.

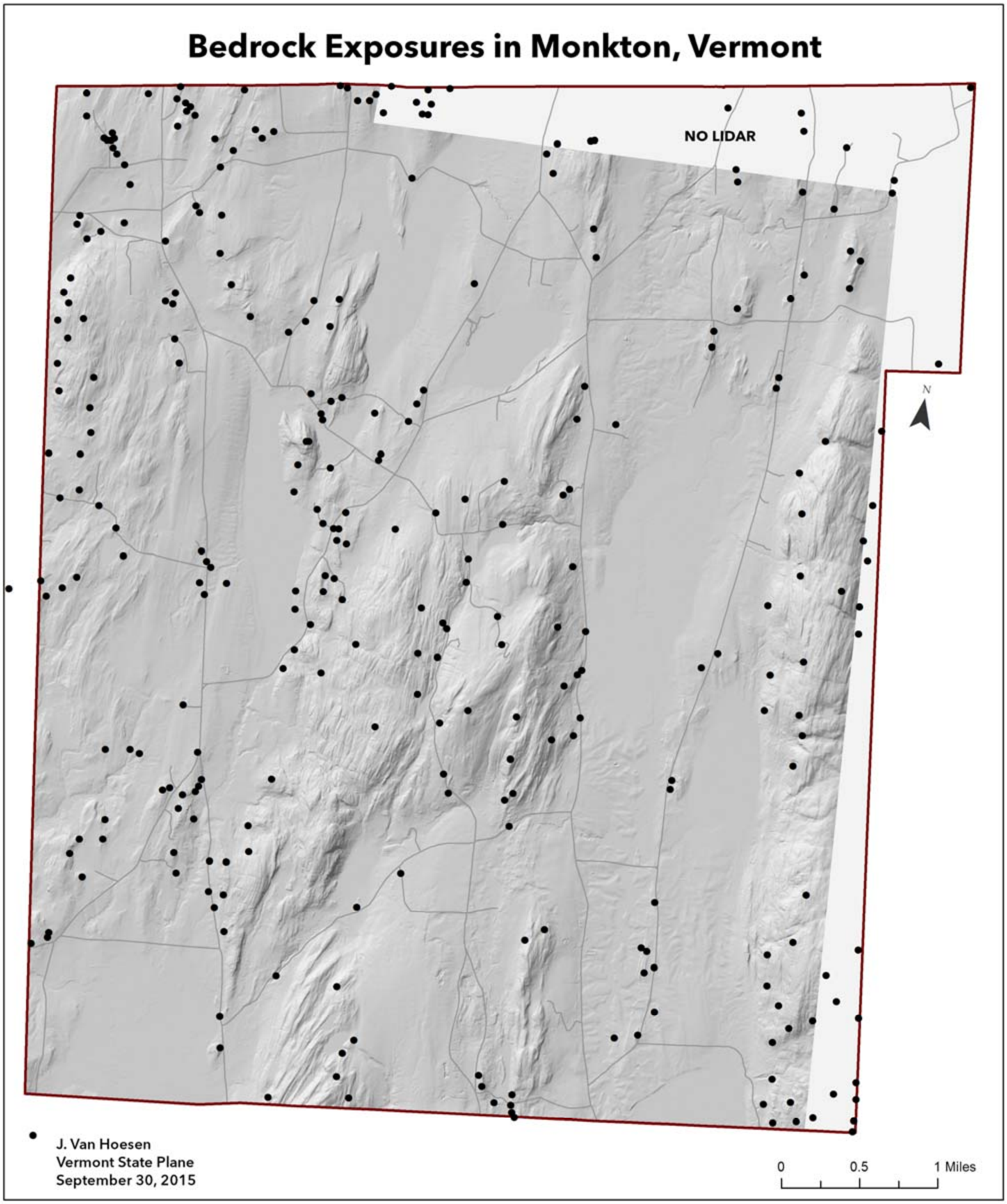

Figure 2: Spatial distribution of exposed bedrock locations within Monkton, Vermont.

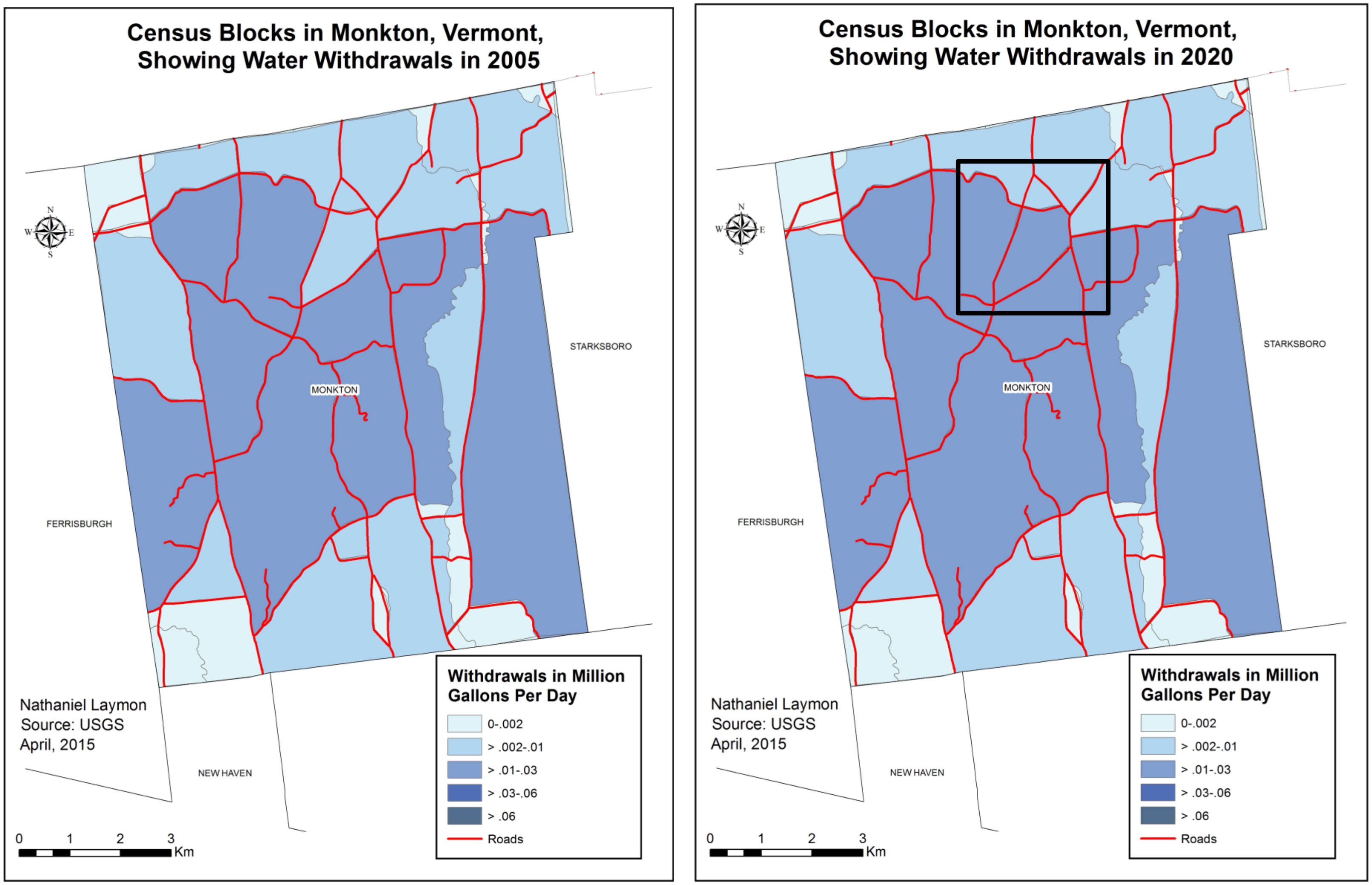

Figure 3: USGS map illustrating groundwater withdrawal in 2005 and projected withdrawals in 2020, suggesting an increase in high withdrawal rates (>0.01-0.03 Mgal/d) within one additional census block adjacent to the Monkton Ridge Area.

3.0 – Location and Geologic Setting

3.1 – Physiographic Characteristics

The town of Monkton covers approximately ~94km2 and is bordered by Ferrisburg to the west, Starksboro to the east, Charlotte and Hinesburg to the north, and Bristol to the south. Elevations range from approximately ~80 to 340 meters (~260 to 1,115 feet) with the greatest topographic relief occurring along the western edge of town. The eastern part of town is characterized by steep bedrock cliffs, is heavily wooded and largely undeveloped. The majority of the town is characterized by bedrock-cored hills, shallow depth-to-bedrock and valley-bottom topography exhibiting hummocky relief (Figure 3). The region is drained by small tributaries of Lewis Creek and Little Otter Creek, which both eventually flow westward into Lake Champlain.

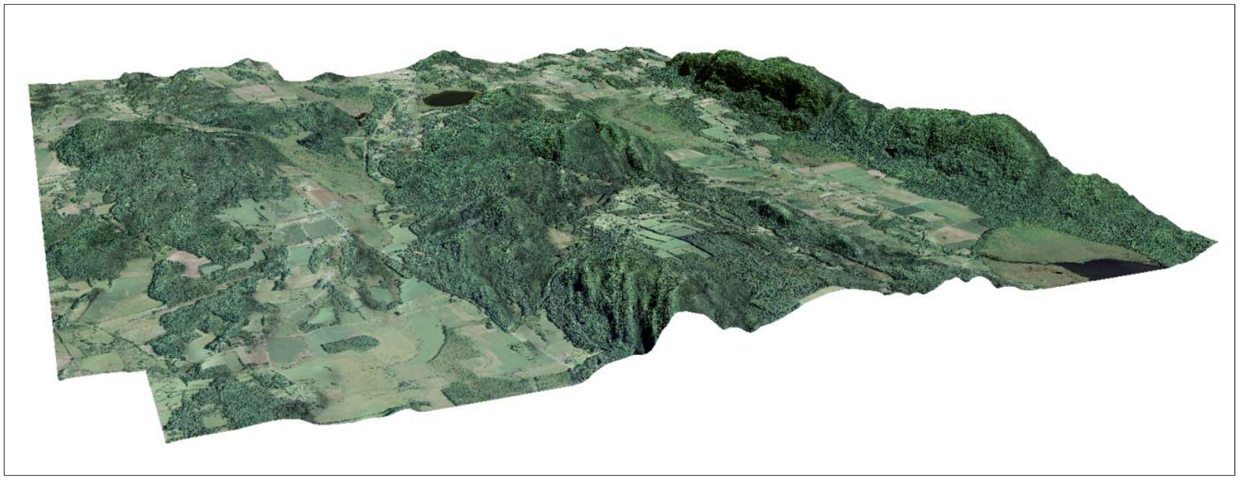

Figure 3: National Agriculture Imagery Program (NAIP) imagery draped over LIDAR to illustrate topographic relief throughout Monkton, Vermont.

The town is characterized by north-south trending valleys underlain by Paleozoic carbonates and quartzites. Exposures are dominated by the Monkton Quartzite (Cm), Cheshire Quartzite (Cc), Dunham Dolostone (Cdu), and Winooski Dolomite (Cw), with smaller outcrops of the Danby Formation (Dd), Crown Point Formation (Ocp), Black River Group (Obr), Glens Falls Limestone (Ogf) along the eastern edge of town (Ratcliffe et al., 2011). The Cheshire Quartzite is the dominant cliff forming lithology in the eastern half of the town. The Monkton Quartzite is more commonly found in the western half of town and sculpted into smaller, knobby hills and the lower elevation valleys are primarily underlain by the less resistant Dunham Dolostone (Figure 4).

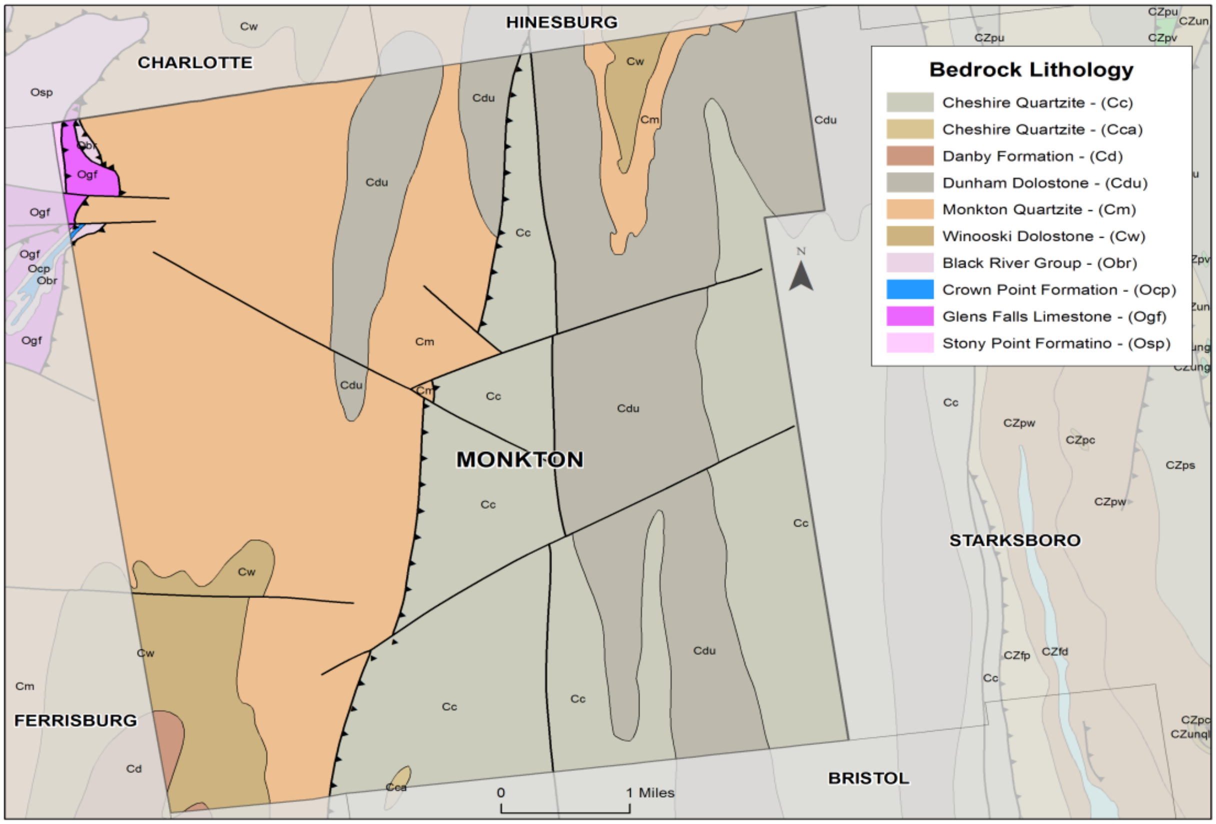

Figure 4: Bedrock geology of Monkton, Vermont - from the Bedrock Geologic Map of Vermont (2011).

3.2 – Previous Work

Early reconnaissance surficial mapping in the area was undertaken by (Calkin, 1965), reported on by Stewart and MacClintock (1969), and shown on the statewide surficial geologic map of Doll (1970). Donahue and others (2004) later mapped the surficial geology of the Middlebury River watershed to the southeast. Numerous studies have focused on various stages of glacial Lake Vermont in the region, including Chapman (1937) and Franzi et al. (2007). Models for deglaciation in this region consist of stagnation of ice along the western flank of the Green Mountains with oscillatory retreat of a stagnation zone ice margin in the Champlain Valley. This “mass stagnation model” has been questioned by Franzi (1988), who’s mapping between Bristol and Hinesburg led him to suggest that deglaciation, at least in his field area, is “more compatible with a systematic northward ice retreat model.”

Stewart (1973) and Donahue et al. (2004) mapped till, alluvium, various ice contact deposits, outwash deposits, and a variety of lacustrine sediments associated with various stages of glacial Lake Vermont described by Franzi et al. (2007). Springston and Kim (2013) mapped the surficial geology of the Bristol quadrangle to the east of the study area. The surficial geology of approximately ~10% of the southeastern portion of the Monkton Boro quadrangle that includes the Town of Bristol was previously mapped at 1:24,000 by Springston and Thomas (2014, unpublished mapping for the Vermont Geological Survey). The surficial geology of the South Mountain quadrangle was mapped by Springston and others (2014).

4.0 – Methodology

4.1 – Field Techniques

Traditional field techniques were employed to differentiate between deposits depicted on the final surficial geologic map. Road exposures, soil augers and hand-dug soil pits were used to sample below weathered soil horizons. I used an iPhone 6s running FulcrumApp (see Appendix 1) coupled with a Bad Elf GNSS GPS unit for an accuracy of 0.5-1 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. Even though LIDAR is available for most of Monkton, all interpolation and extrapolation techniques in this report used a 10-meter digital elevation model (DEM) so the northern and northeast sections of town weren't excluded from the analyses (Figure 5).

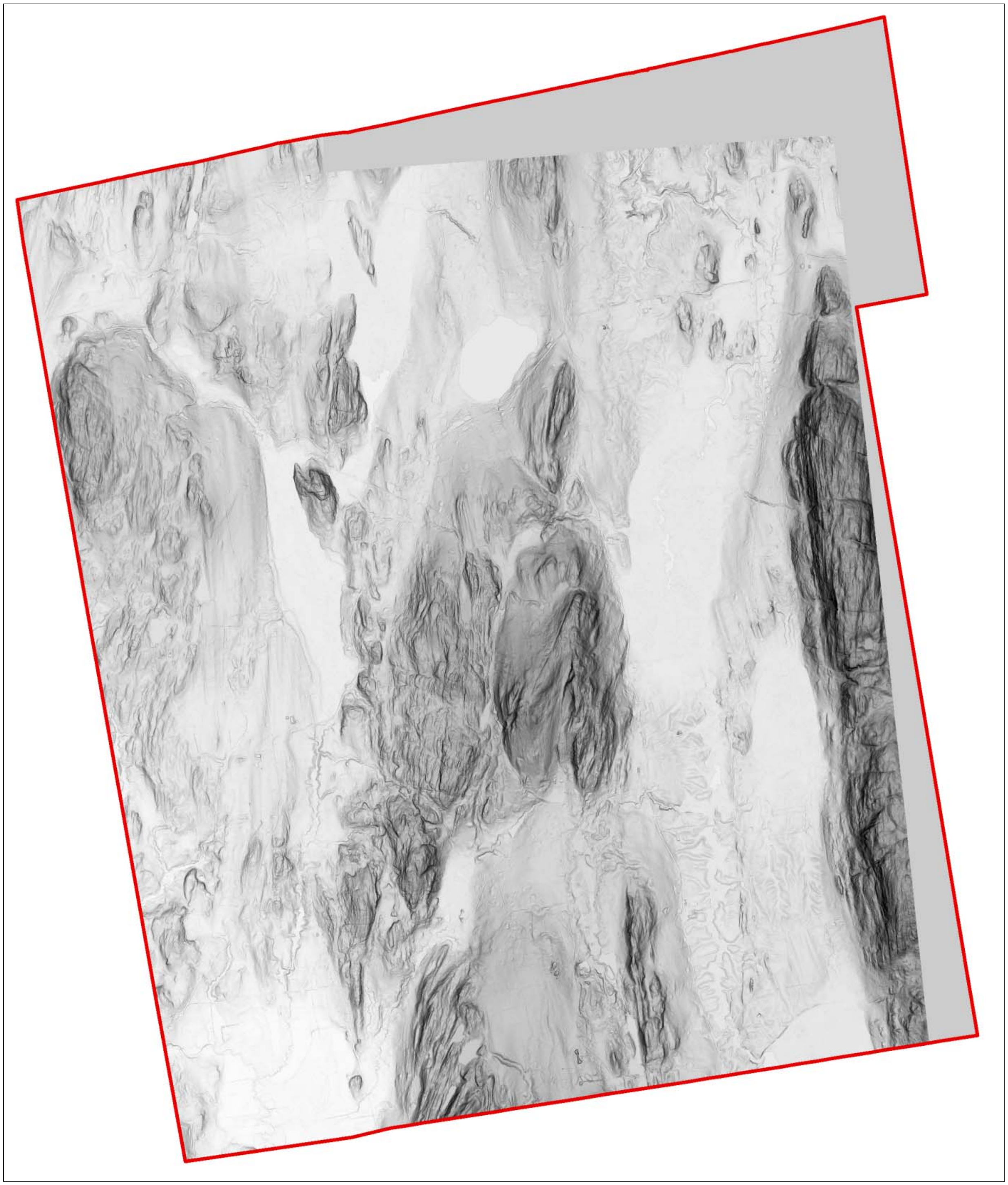

Figure 5: Image illustrating the gaps in LIDAR available for the Town of Monkton.

4.2.1 – Isopach Map

An isopach map was constructed using the overburden attribute provided in the well logs and 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 6 and 7) and there isn't a strong trend in one direction or another (Figure 8), 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 1.

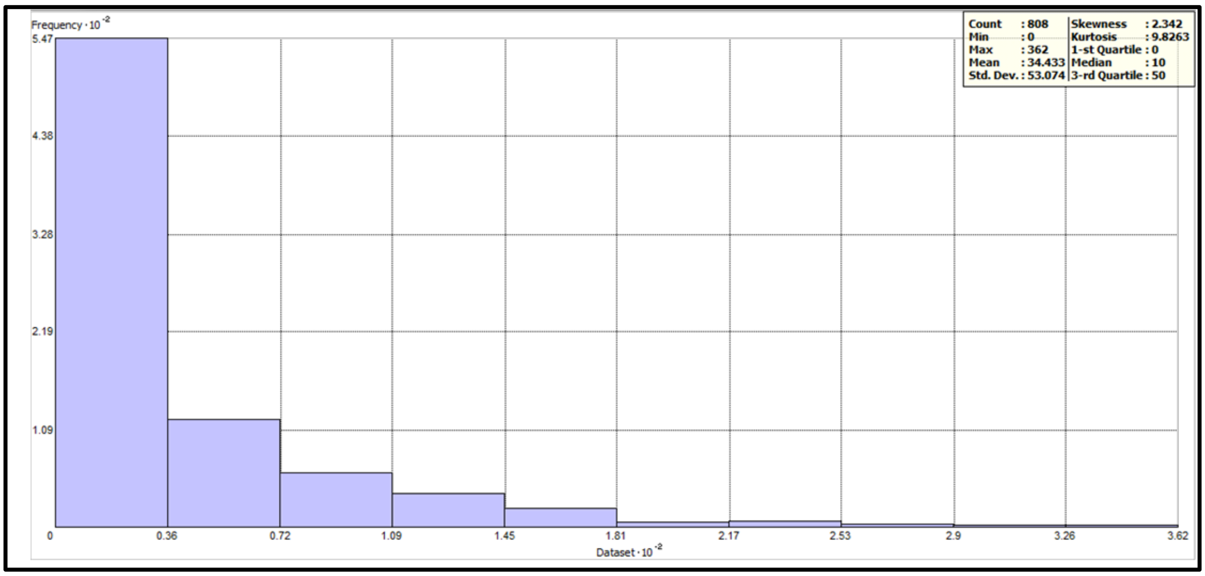

Figure 6: Histogram of well data and bedrock outcrop locations illustrating a non-normal distribution influenced by abundant thin till cover coupled with over-sampling of bedrock outcrops to increase control on overburden. However, the histogram is still strongly influenced by lower values when only using well data overburden (no outcrop values).

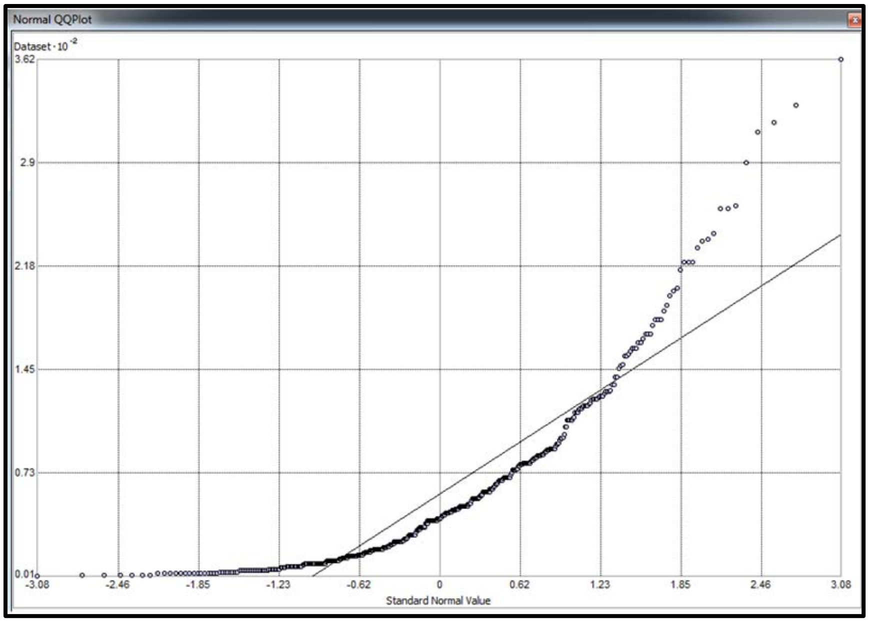

Figure 7: A general QQ plot is a graph on which the quantiles from two distributions are plotted versus each other. For two identical distributions, the QQ plot will be a straight line. This analysis also suggests the overburden values do not exhibit a normal distribution.

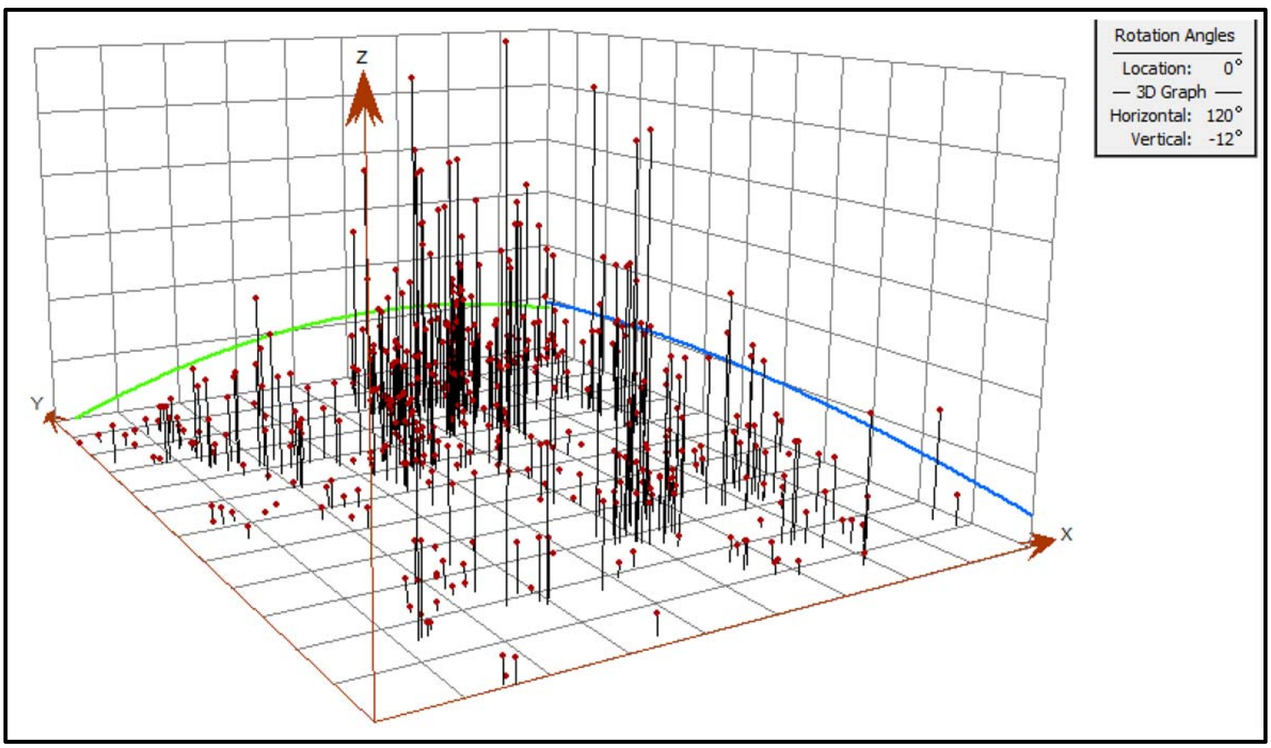

Figure 8: Trend analysis suggests the data exhibits a minor trend across the x and y axes with higher values towards the center of the field area. This suggests that

overburden is generally homogeneous across Monkton with thinning in the extreme western and southern areas of town.

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 1: 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 spherical 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 9). 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.

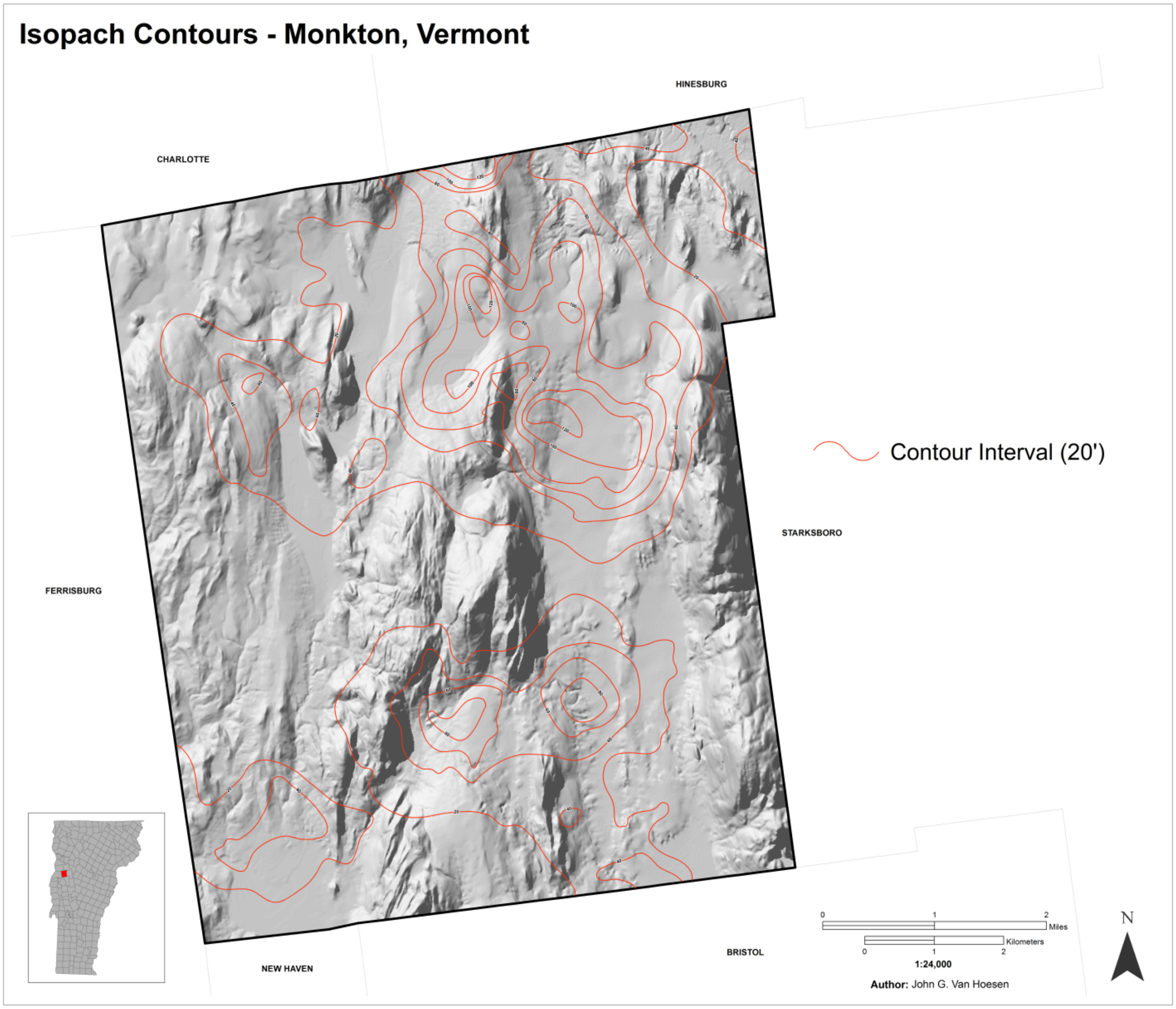

Figure 9: Isopach map of Monkton, Vermont extrapolated from well log data and bedrock exposures.

4.2.2 – Potentiometric Surface Map

A potentiometric surface was interpolated using the static water level attribute provided in both the public community water system (PCWS) database and private well logs and a 10-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 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, it is clear the data is not normally distributed and there are very subtle trends in the piezometric surface(Figure 10). The piezometric surface produced through IDW interpolation was contoured using 200 foot increments to illustrate the generalized hydraulic gradient (Figure 11).

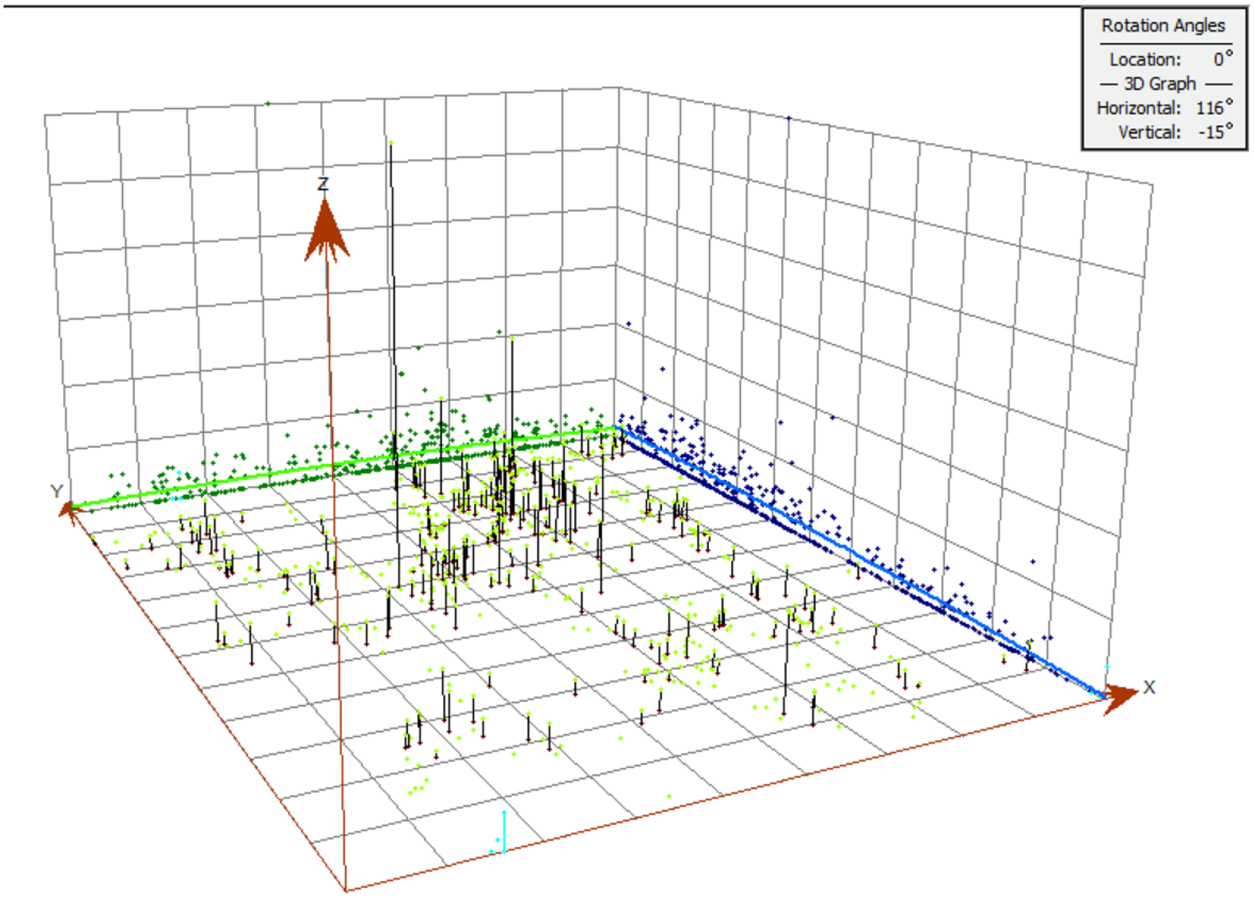

Figure 10: Trend analysis suggests the data very subtle trends suggesting the hydraulic gradient should result in water flowing from the center of town towards the West and East and from the northern part of town south.

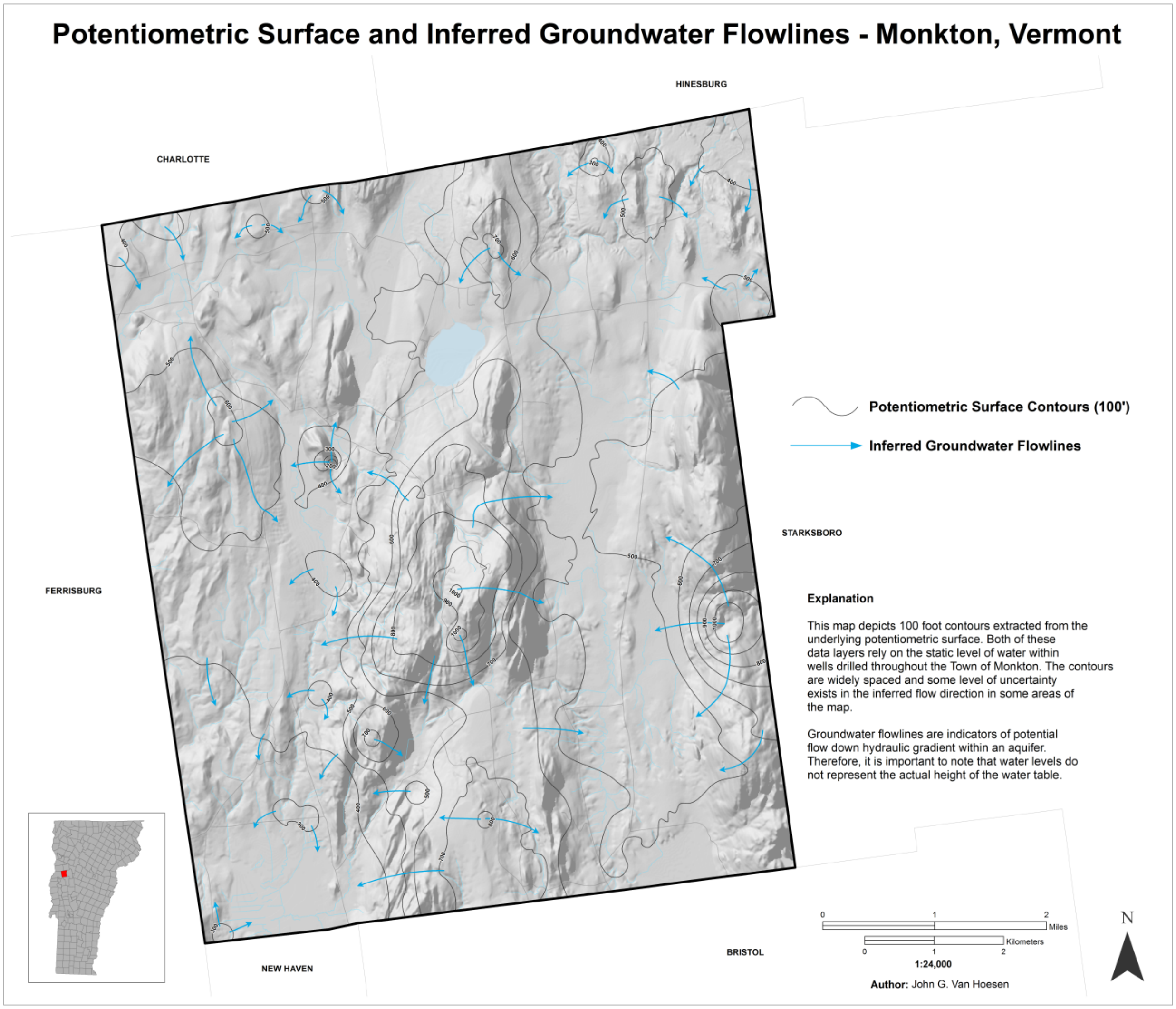

Figure 11: Potentiometric surface of Monkton, Vermont created using PCWS and private well log data.

4.2.3 – Bedrock Topography

A visualization of bedrock topography was created using the previously described overburden layer and a 10-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 and 500 foot contours were then produced using the bedrock DEM (Figure 12).

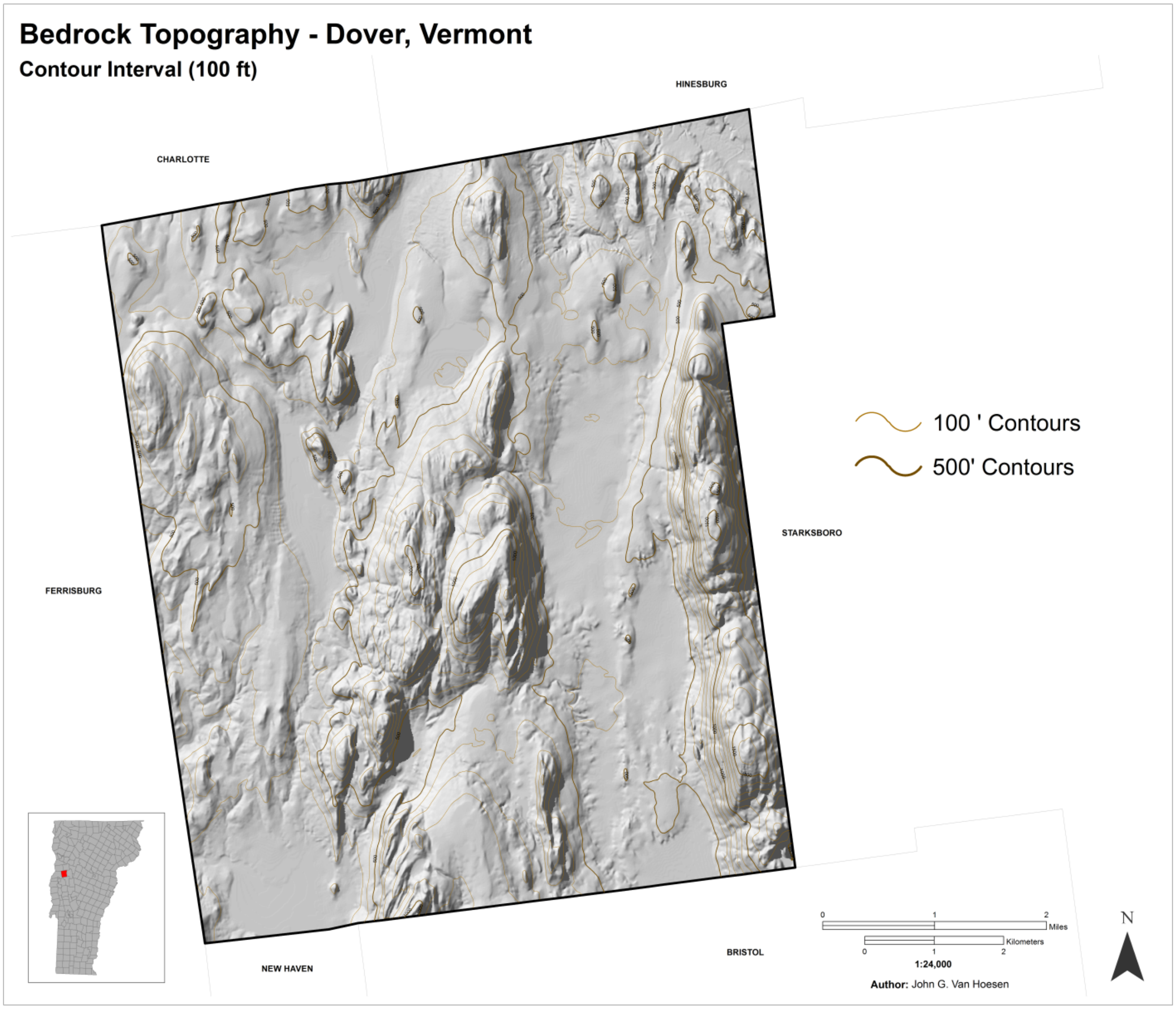

Figure 12: Bedrock topography of Monkton, Vermont creating by subtracting overburden from modern DEM.

5.0 – Results & Interpretations

5.1 – Surficial Units

Alluvium (Hal): 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 approximately 3-4 meters along Lewis Brook but less extensive and not as thick compared to surrounding towns (Figure 13).

Figure 13: Small sand bar along Lewis Brook and mixture of alluvium and till in small tributary to Lew Brook.

Fluvial Terraces (Hst): 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 concentrated in the northeastern corner of town associated with Lewis Brook.

Figure 14: Historical fluvial terrace observed due east of Barnum Road and Historical fluvial terrace exposed along Pond Brook.

Wetland Deposits, Peat or Muck (Hpm & Hw): well-sorted, well-stratified silt/clay deposits associated with concave topography lacking drainage (Figure 15). Predominantly occurs in valley, however many deposits occur in steeper uplands.

Figure 15: Wetland areas located along the southern edge of Mountain Road and near the northern intersection of Old Airport and Hardscrabble Roads.

Alluvial Fan Deposits (Haf): poorly developed and limited in extent deposits of boulders/cobbles/pebbles found near the inflection point of small tributaries draining steeper topography onto the valley bottom.

Colluvium and/or Talus (Htal): unconsolidated, unsorted cobbles/boulders found along the eastern uplands at the base of steep strongly weathered cliffs and at the base of smaller hogback hills in the central part of town.

Mix of Till, Colluvium, and Talus (Qtct): Heterogeneous deposits at the base of steep slopes along the Hogback Mountains and central hogback mountain.

Ice-Contact Deposits (Pic): moderately to well-sorted, well-stratified sand/silt/pebbles with irregular topography, limited in extent and most likely small, isolated kames. No evidence of coarser material commonly associated with kame terraces or eskers (Figure 17).

Figure 17: Exposure of linear ice-contact deposit running parallel to Hardscrabble Road. Too thin and fine-grained to be esker, more likely kame.

Lacustrine Sediments (Plu): undifferentiated, well-sorted, well-stratified silt/clay deposits associated with the Coveville or Fort Ann stages of glacial Lake Vermont (Figure 18), commonly forming distinctive topography in the valley bottoms (Figure 19).

Figure 18: Close-up of gleyed lake clay eroding into small tributary of Lewis Creek and dense and platy lake clay exposed throughout the valley bottoms, especially common in the eastern half of the town.

Figure 19: Characteristic dissected lobate topography associated with lake clay deposits.

Shoreline Deposits (Pls): Shallow water deposits comprised of well-sorted sand and or gravel (Figure 20). These are small deposits with variable thickness – although likely not thick or suitable as surficial aquifers.

Figure 20: Small sandy beach deposit exposed by house excavation at the intersection of Church and Mountain Roads and a slightly larger beach exposed due east of the intersection of Bennett and Hollow Roads.

Thin Till (Ptt): 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 21). 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. However, it is surprising how few striations were preserved within the field area.

Figure 21: Typical thin till topography with bedrock exposures (arrows) and smaller rock walls and an example of an oxidized sandy till exposure.

Thick Till (Pt): 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 22: Exposure of thick till in foundation and drainage ditch excavations.

5.2 – Cross Section Interpretations

Two 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 Monkton (Figure 23) 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.

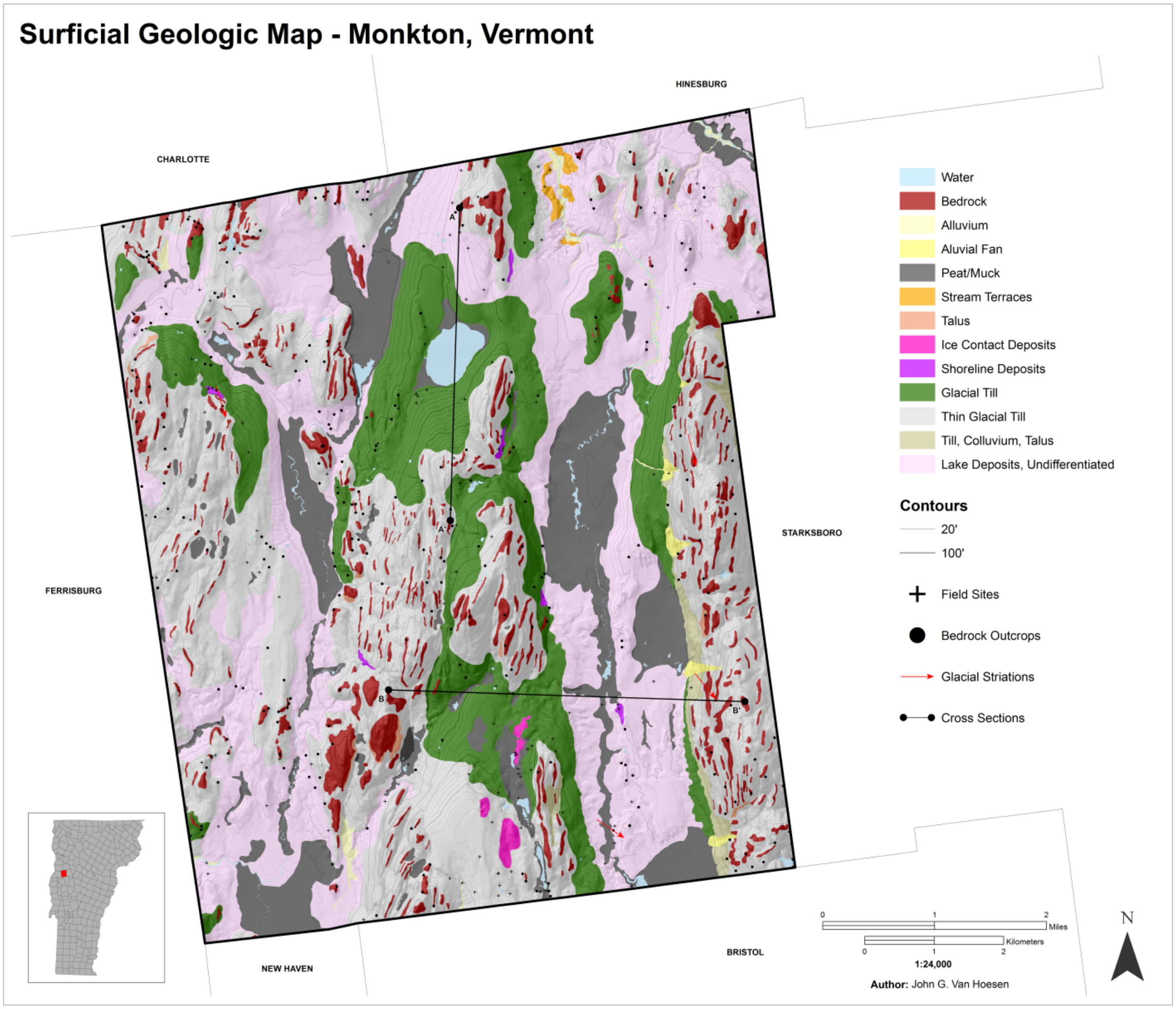

Figure 23: Surficial geologic map of Monkton, Vermont.

5.2.1 – Monkton Ridge Cross Section (A - A')

This cross section extends approximately 3 miles north to south across the Monkton Ridge area. Surficial deposits in the north part of section are dominated by thin till (Ptt) at higher elevations and transition into thicker deposits of undifferentiated fine-grained, lake sediments (Plu). Well logs suggest there is a thin and probably not extensive sand and gravel layer below the lake sediments, which eventually transition into a much thicker layer of glacial till. Thick glacial till dominates the remained of the cross section with a few areas of thin glacial till and exposed bedrock. All nine wells along this cross section pass through variable thickness overburden and terminate in bedrock (Figure 24).

5.2.2 – Pond Brook Valley Cross Section (B - B')

This cross section extends approximately 6 miles between the hogback ridge east of East Monkton across the Pond Brook Valley to the Hogback Mountains on the eastern edge of town. The surficial geology of the western portion of the section is dominated by thin till (Ptt) and bedrock exposures. Thick glacial till (Pt) is exposed until the cross section reaches Bristol Road and then changes to a thick unit of fine-grained lake sediments (Plu). Well logs again suggest there is a thin and probably not extensive sand and gravel layer below the lake sediments, which eventually return to lake sediments and then again back to thin glacial till with common bedrock exposures. All eight wells along this cross section pass through variable thickness overburden and terminate in bedrock (Figure 24).

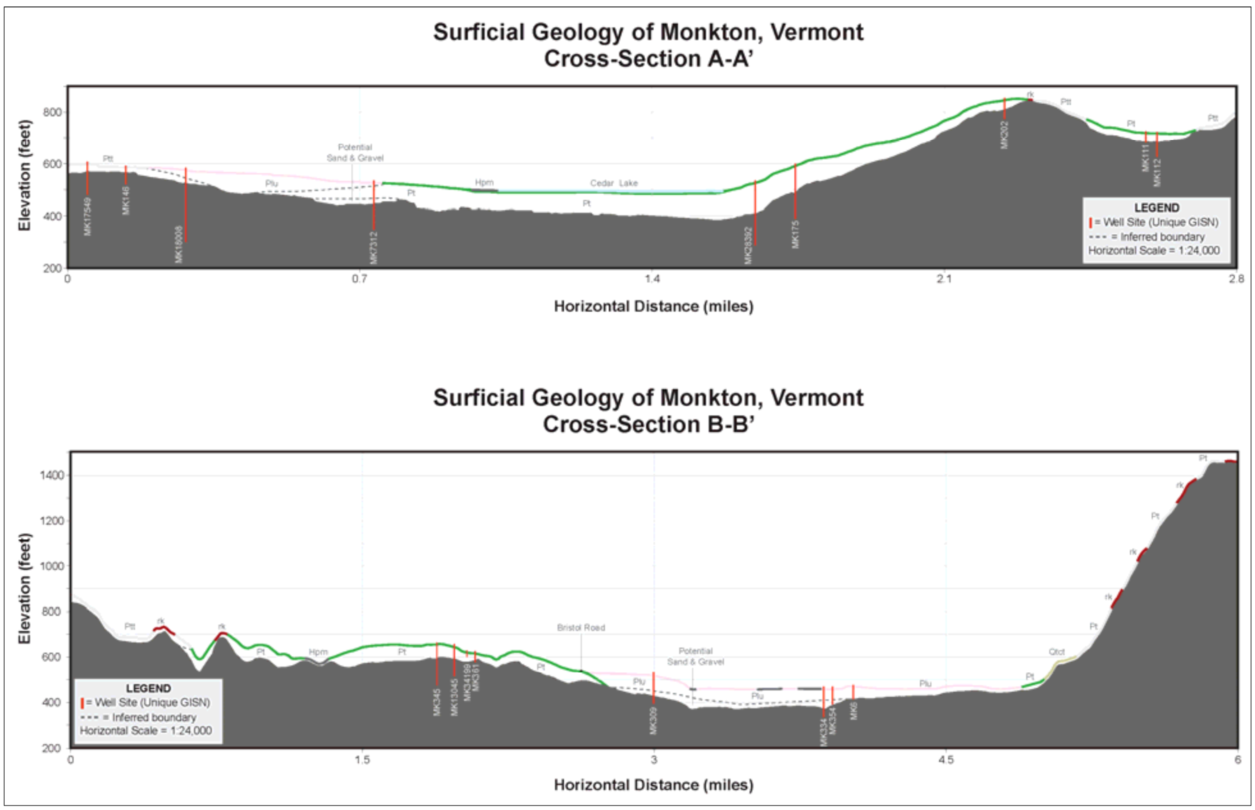

Figure 24: Cross-sections constructed using well-log data and surficial geologic map.

5.3 – Isopach Map

The isopach map is consistent with the well data, surficial deposits and bedrock outcrops (Figure 9). Areas of thin or no overburden are common throughout the town but most obvious along the ridge of the Hogback Mountains, the hogback ridge east of East Monkton and the southernmost flanks of Mt Fuller The lack of overburden predicted by the extrapolation in these areas 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 central hogback ridge, a few valley walls and fine-grained lake sediments dominate and fill the valley floors.

5.4 – Summary of Hydrogeologic Characteristics

All of the 513 rectified wells in the Town of Monkton terminate in bedrock. The bedrock wells were differentiated by the lithologic suitability for groundwater flow – (e.g. - carbonates, slates/phyllites, quartzites, and shales) (Figure 25). The primary hydrogeologic unit in the study area is classified as the Type I Sequence (510 wells), 2 wells occur in the Type II Sequence, and only one well occurs in the Type III Sequence. A summary of wells within each hydrogeologic unit and their associated geologic formations, yield and depth are summarized in Table 2.

Well yields are apparently slightly higher (mean = 23 gpm) in the Ordovician limestones than the Cambrian quartzites and dolostones of the Type I sequence (mean = 17 gpm), however there are very few wells in the Type II and III sequences; without additional data I wouldn’t assume this relationship holds true for future wells. The one well located in the Ordovician slates of the Type III sequence has a much lower yield and is much deeper than the other wells.

Table 2: Summary of well yield and depth for wells within specific hydrogeologic units.

Hydrogeologic Unit	**Well Yield (gpm)** Mean	**Well Depth (ft)** Mean
Type I Sequence (n = 510) Exposures of the Cheshire Quartzite, Monkton Quartzite, Dunham Dolostone and Winooski Dolostone.	17	296’
Type II Sequence (n = 2) Exposures of the Black River Group undifferentiated and the Glens Falls Limestone.	23	346’
Type III Sequence (n = 1) Exposures of Stony Point Formation	2	452’

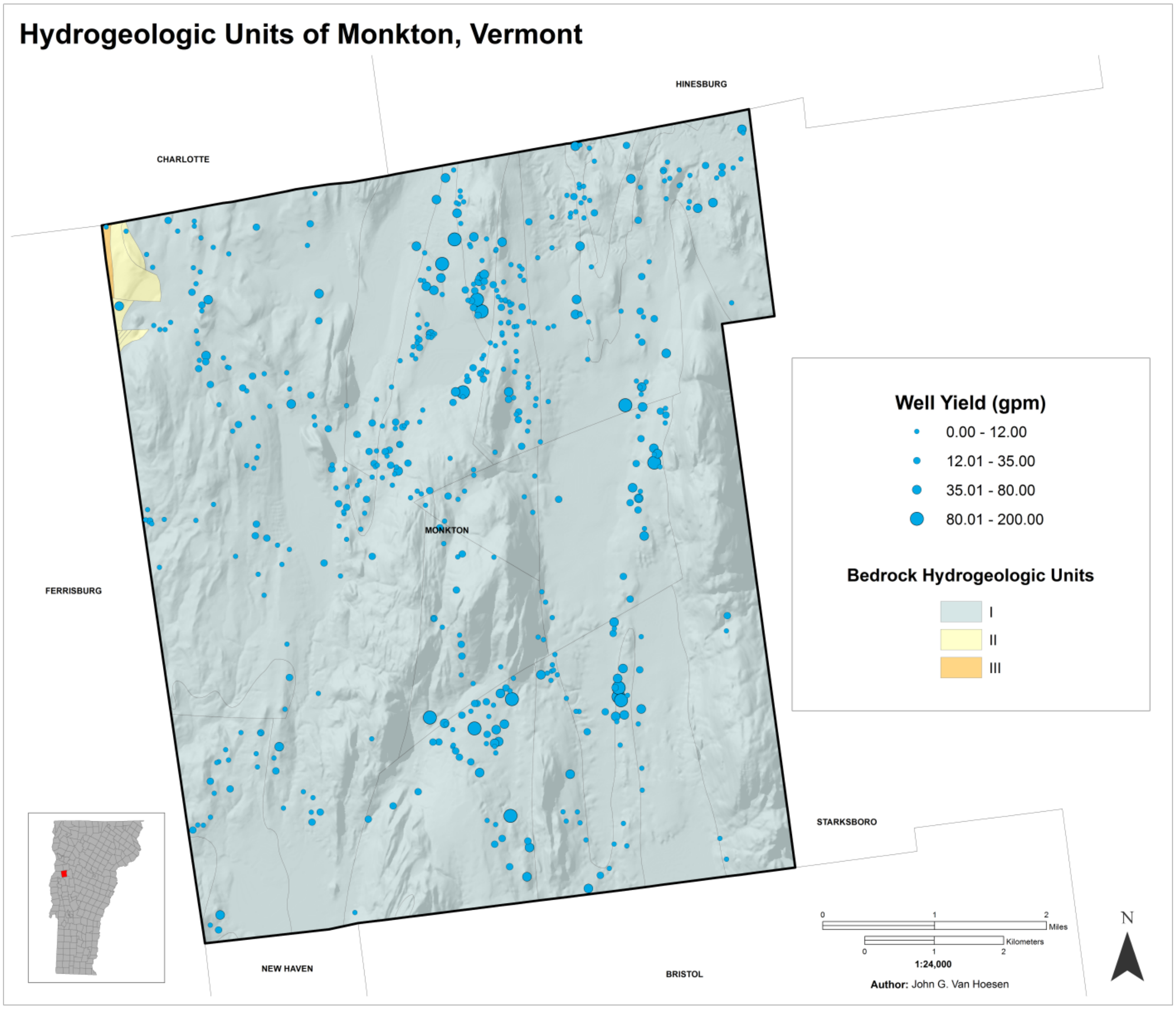

Figure 25: Classification of hydrogeologic units within the Town of Monkton.

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 100 foot contours extracted from the underlying potentiometric surface (Figure 11).

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 towards the valleys and north to south is readily apparent in both the trend analysis and the resulting interpolated surface.

5.6 – Bedrock Recharge

The Town of Monkton exhibits a bimodal distribution of recharge between high and low recharge potential (Figure 26). 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 extensive fine-grained lake 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 was not field-tested in this study area.

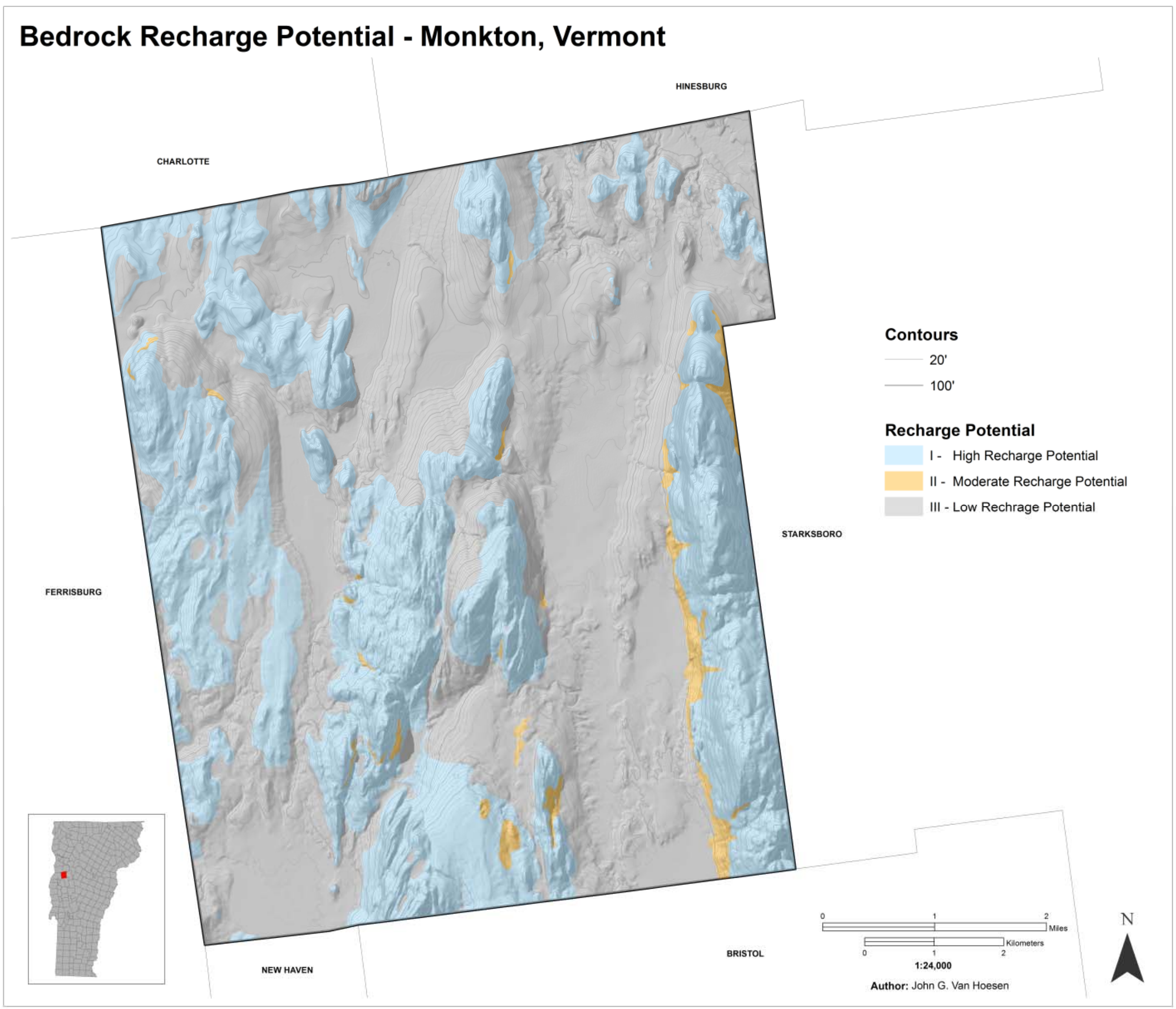

Figure 26: Map illustrating the bimodal distribution of bedrock recharge in Monkton.

5.7 – Hydrogeologic Classification of Well Logs

The rectified well database was classified following the hydrogeologic classification methodology described by Kim and Springston (2015) and listed in Table 3. The purpose of the hydrogeologic classification is to evaluate how easily groundwater can move through the surficial materials following the ranking provided in Table 5. These rankings resulted in the creation of three maps providing information about the potential for high yielding surficial aquifers (Figure 27), the potential favorability for prevention of direct surface infiltration (Figure 28) and the potential favorability for recharge of groundwater to bedrock (Figure 29). Integrating the information for high yielding bedrock wells and favorability for high yielding wells resulted an approximate map depicting those areas with the highest overall aquifer potential (Figure 30).

Table 3: 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.

Table 4: Hydrogeologic Classification Potential Favorability Rankings			
Hydrogeologic Class	**High yield from surficial aquifer**	**Prevention of direct surface infiltration**	**Recharge of groundwater to bedrock**
0	High	High	High
1	High	High	High
2	High	High	Low to Moderate
3	High	High	High
4	High	High	High
5	High	High	High
6	Moderate to High	Low	Moderate to High
7	Moderate to High	Low	Low to Moderate
8	Low to Moderate	Low	Low to Moderate
9	Low	N/A	Low
10	Low	N/A	Low
11	Low	N/A	Low
12	Low	N/A	Moderate to High
13	Unknown	Unknown	Unknown

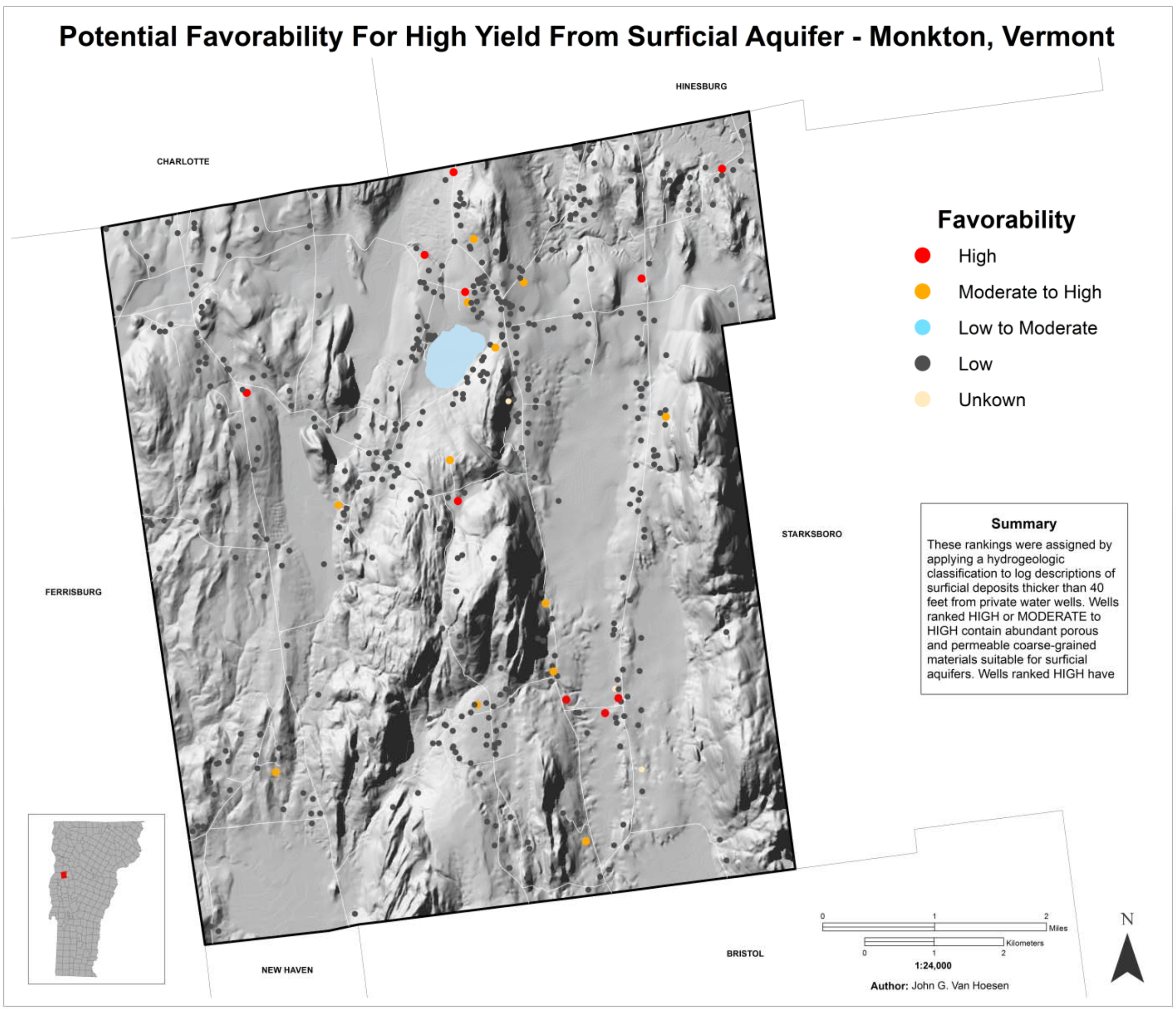

Figure 27: Map illustrating the potential favorability for high yield from surficial aquifers.

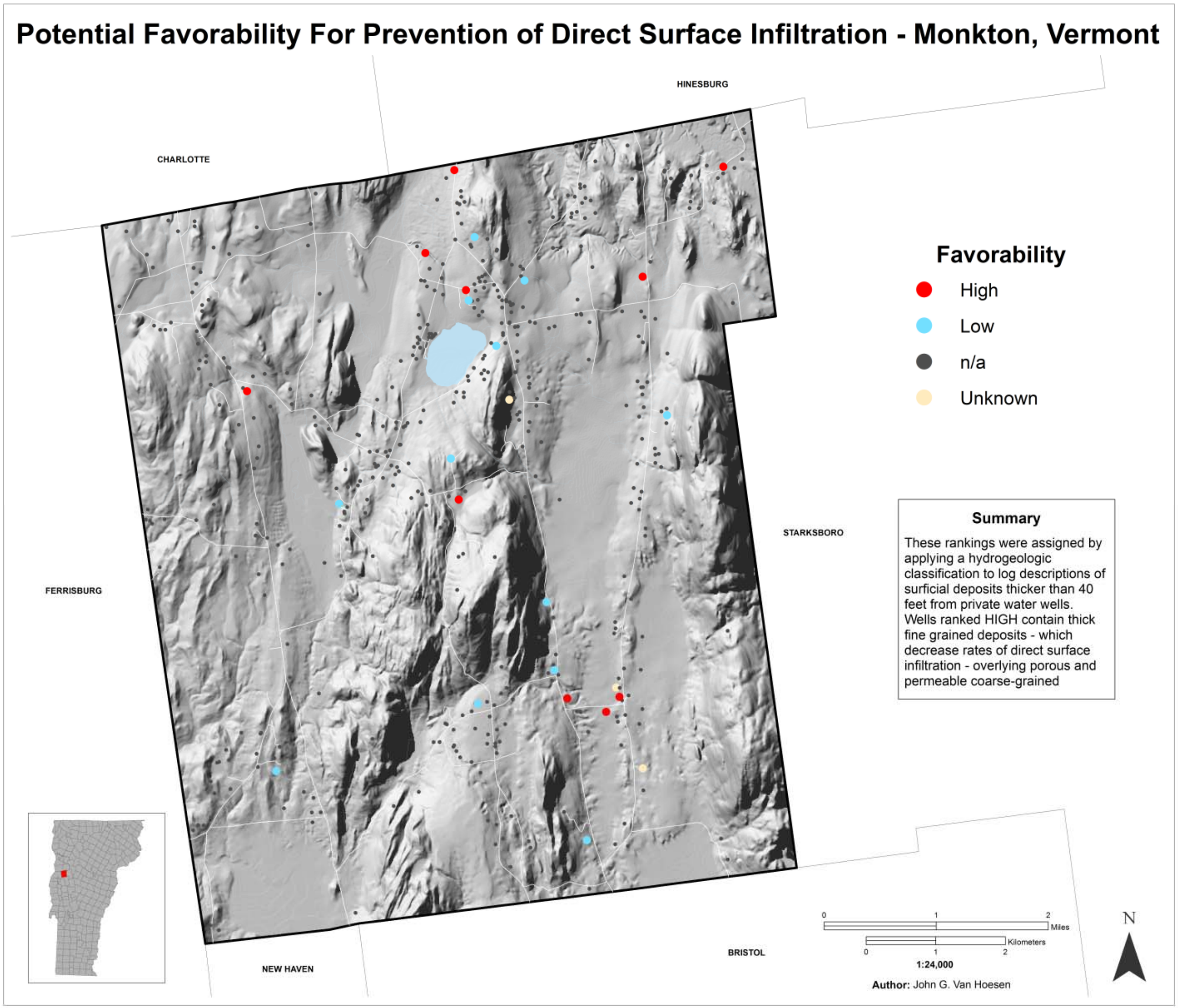

Figure 28: Map illustrating the potential favorability for the prevention of direct surface infiltration.

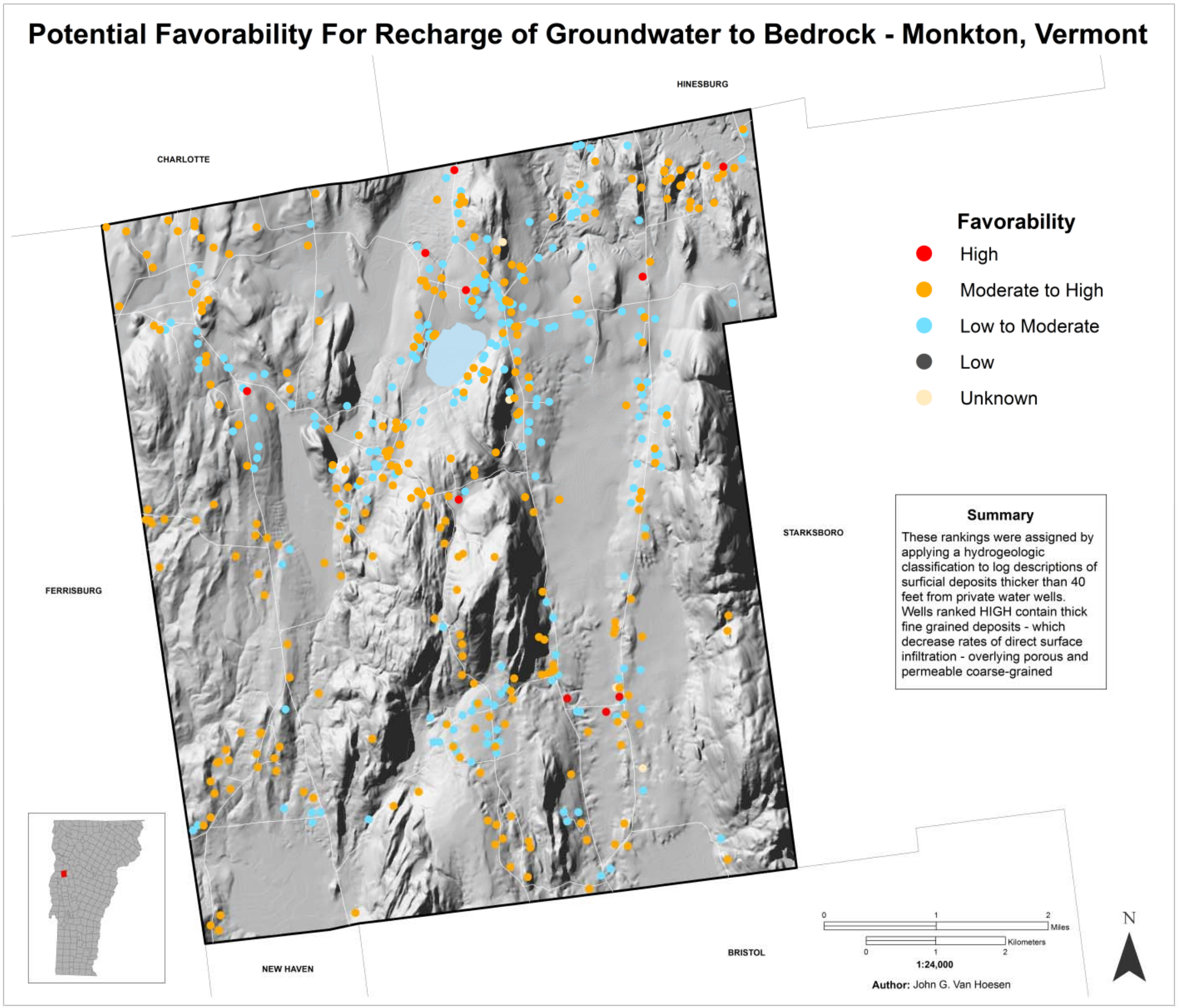

Figure 29: Map illustrating the potential favorability for recharge of groundwater to bedrock, which is consistent with the map of Bedrock Recharge Potential (Figure 26).

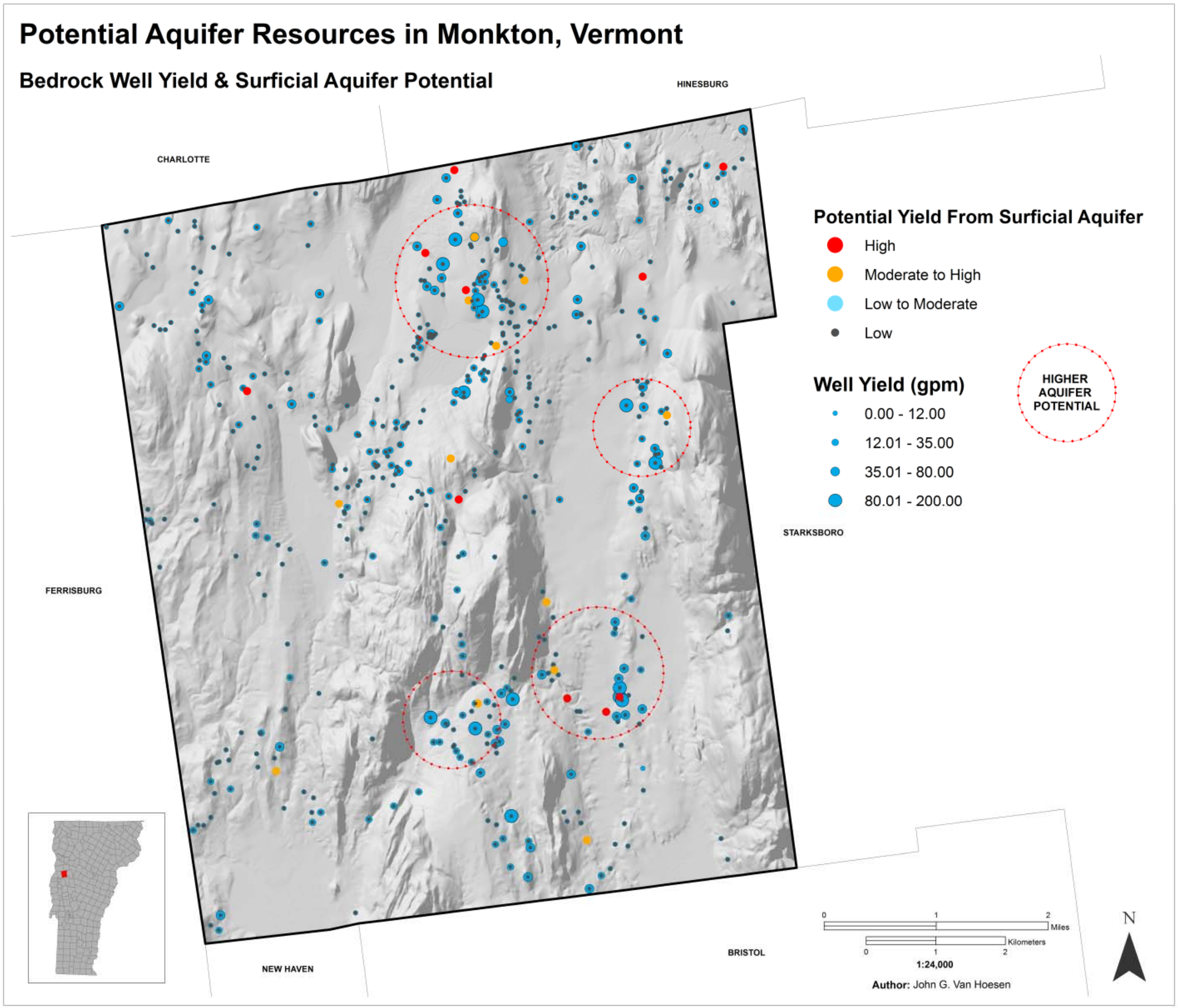

Figure 30: A generalized map showing the overlapping areas where there is higher yield from bedrock wells and higher potential yield from surficial aquifers. This is meant to be used as a general location map not as a definitive tool for high yielding areas.

6.0 – References

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