Surficial Geology and Hydrogeology of the Southern Half of the Proctor 7.5-Minute Quadrangle, Vermont

A view from the Proctor-Pittsford boundary looking southwest from Corn Hill Road over slopes of thin till that lead down to coarse lake sediments filling the Otter Creek Valley.

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1.0 – Executive Summary

During the summer and fall of 2017, I mapped the surficial geology and utilized 145 spatially rectified private water wells. I identified and mapped ten distinct surficial units using traditional field and digital mapping techniques and information gathered from the rectified wells. I also collected GPS coordinates for 382 bedrock outcrops and 196 surficial field sites. 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 one cross-section.

Bedrock topography generally mimics surface topography in the highlands and both the well logs and isopach map suggest the northern reach of the Otter Creek Valley contains the thickest surficial deposits. The lack of gravel wells in the study area suggests there is limited surficial aquifer potential, however the thickets surficial deposits are comprised of course lake sand resting on clay-rich lake deposits and glacial till. Well yields are highest in the northeastern quadrangle where these surficial deposits are underlain by the Winooski and Dunham Dolomites. A few wells in the Castleton River Valley have moderate yields and clay to sandy alluvium is underlain by the Ira Formation. Static water levels from well log data were used to interpolate a potentiometric surface, which indicates groundwater generally flows from west to east and south to north, mimicking surface topography and drainage valleys. All of this suggests the area with the highest aquifer potential is in the northernmost reach of the Otter Creek Valley, consistent with the findings of Stewart (1972).

Field mapping identified deposits of a thin Wisconsin 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. The second most extensive surficial material is coarse sandy lake deposits. This material is variable in thickness from approximately 10 to greater than 200 feet. Alluvium is present in numerous small brooks but the most extensive deposits are found filling the Castleton and Otter Creek Valleys. There is one small, isolated kame deposit and a similarly small and isolated lacustrine shoreline deposit.

The quadrangle is dominated by bedrock that doesn't preserve striations well. However, numerous crag and tail landforms are easily identified on the 0.7-m LIDAR and most common in the western highlands surrounding Grandpa's Knob.

2.0 – Background

This report summarizes the results of surficial mapping and digital mapping efforts within the southern half of the Proctor 7.5-minute quadrangle. Field mapping occurred over approximately 5 months during the summer and fall of 2017. I collected GPS coordinates for approximately 382 bedrock locations and 196 field sites (Figure 1) and interpretation took place during the subsequent 4 months. Of the 426 private water wells within the quadrangle, 145 (i.e., 34%) were rectified by Griffin Shelor, an undergraduate at Green Mountain College, during spring of 2018.

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 none derivative maps that provide additional information regarding bedrock and unconsolidated aquifers, which can be used to inform land-use and water resource concerns for towns within the Proctor quadrangle (Table 1).

Table 1: Summary of Map Layers Produced for This Report.

1. Surficial Geology of Proctor	8. Potential Aquifer Resources
2. Overburden (isopach)	9. Hydrogeologic Units
3. Potentiometric Surface + Flow Lines	10. Location of well, bedrock & field sites
4. Depth to Bedrock	
5. Bedrock Geology + Well Yields	
6. Recharge Potential to Shallow Aquifers	
7. Recharge Potential to Deep Aquifers	

Figure 1: Spatial distribution of rectified water wells, exposed bedrock, and field sites where surficial material was either naturally exposed or revealed using a shovel or soil auger.

3.0– Location and Geologic Setting

3.1 – Physiographic Characteristics

The mapping area covers approximately 70 km^2 and includes the towns of Castleton, Hubbardton, Ira, Pittsford, Proctor, Rutland Town, Rutland City, and West Rutland. Elevations range from approximately ~95 to 642 meters (~310 to 2,105 feet) with the greatest topographic relief occurring along the western edge of the quadrangle (Figure 2). There are two narrow valleys running north-south through the quadrangle filled with fluvial and lacustrine sediment. The eastern margin of the quadrangle is also characterized by steep bedrock cliffs, bedrock-cored hills, and shallow depth-to-bedrock. The central region of the quadrangle is drained by numerous tributaries feeding the Castleton River to the west and Otter Creek to the east, which both flow north into Lake Champlain.

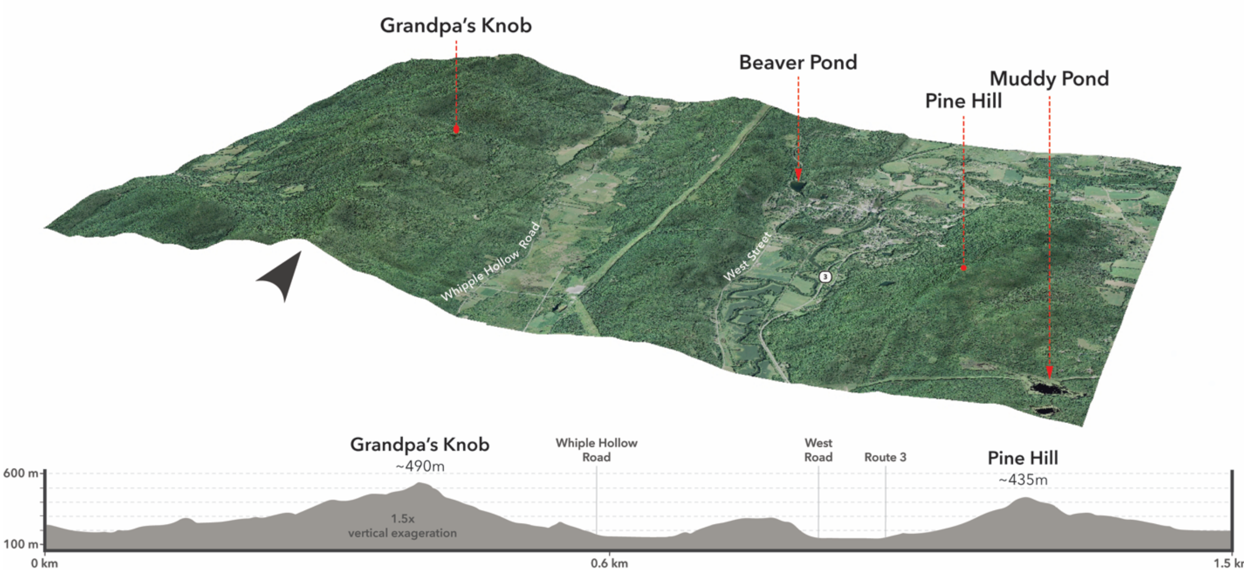

Figure 2: A National Agriculture Imagery Program (NAIP) imagery draped over LIDAR and an elevation profile illustrating topographic variation throughout the study area.

The region is primarily underlain by Paleozoic carbonates, conglomerates, phyllites, slates, and quartzites with rare exposures of Precambrian rocks (Figure 3). The western third of the quadrangle is dominated by rocks associated with the Taconic Allochthon; phyllites and quartzites of the Bull Formation (CZbb, Czbm & CZzh), the Biddie Knob quartzite (CZbk) and predominantly slates of the West Castleton Formation (Cwc). The central valleys are mostly rocks of the Vermont Valley Sequence and Middlebury Synclinorium; primarily limestones, shales and phyllite of the Ira Formation (Oi, Oii), rare outcrops of limestones of the Bascom Formation (Ob) and limited outcrops of Shelburne Marble (Os) and dolostone of the Clarendon Springs Formation (Csp). The eastern edge of the quadrangle is comprised of rocks associated with the Green Mountain massif. This region is dominated by the Winooski Dolostone (Cw), Cheshire Quartzite (Cc), dolostone of the Danby Formation (Cd) with limited exposures of Precambrian schists and quartzites of the Dalton Formation (CZd, CZdfq, CZdq, CZds), meta-conglomerates of the Tyson Formation (CZt), and granite gneiss of the Mt Holly Formation (Y3Ag).

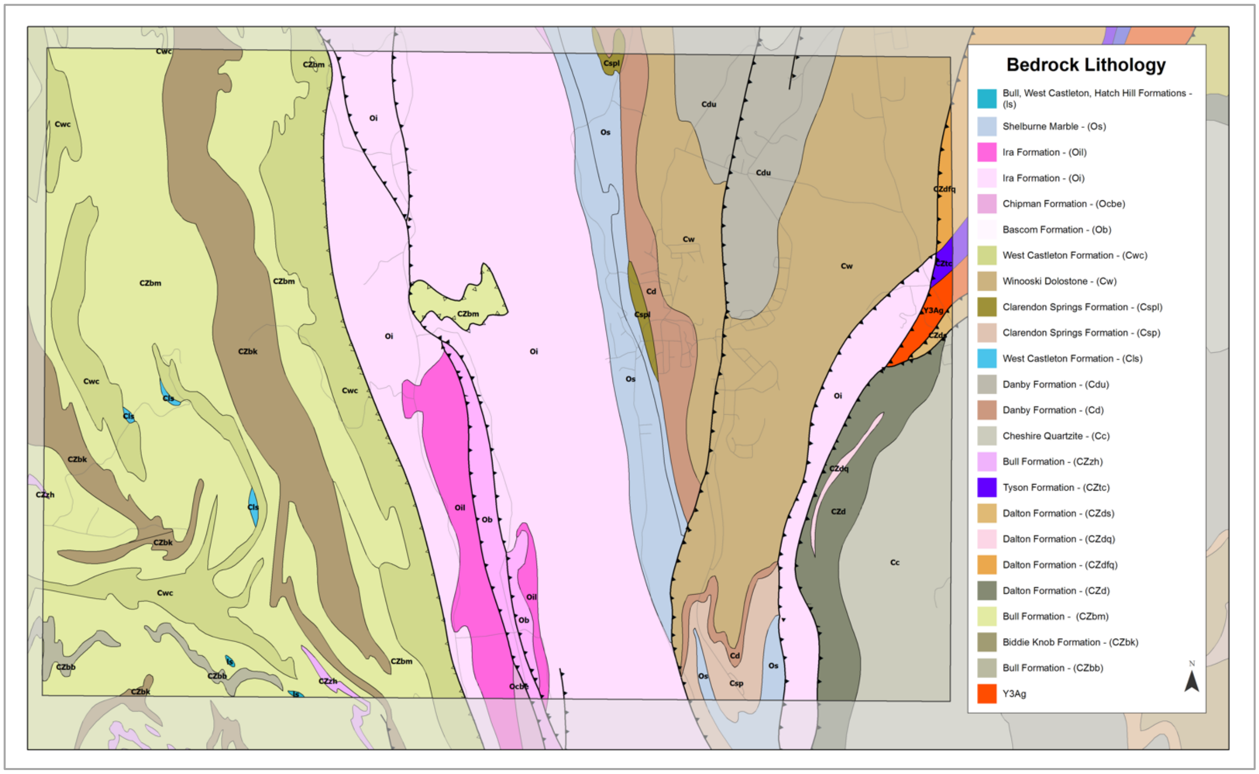

Figure 3: Bedrock geology of the southern half of the Proctor 7.5-minute quadrangle - from the Bedrock Geologic Map of Vermont (2011).

3.2 – Previous Work

Early reconnaissance surficial mapping in the area was undertaken by Stewart (1956–1966), which was incorporated into the Surficial Geologic Map of Vermont by Stewart and MacClintock (1970). Later work by Stewart (1972), De Simone (2006) and Van Hoesen (2009) provided regional context for surficial mapping conducted in this quadrangle. Van Hoesen (2009) mapped the surficial geology of the Town of Rutland, which overlaps a small portion of the quadrangle.

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 10 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. Most 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 numerous outcrops for glacial striations – with no 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 ancillary derivative maps. All interpolation and extrapolation techniques in this report used 0.7-meter LIDAR data obtained from the Vermont Open GeoData Portal.

4.2.1 – Isopach Map

An isopach map was constructed using both the overburden attribute provided in the well logs and location of bedrock outcrops. 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 ArcPro and 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 4 and 5) and there isn't a strong trend in one direction or another (Figure 6), so ordinary kriging was used following Gao et al. (2006), Locke et al. (2007) and Van Hoesen (2014). The J-Bessel variogram model was identified as the best choice using the ArcPro 'Parameter Optimization' function because it provided the best fit based on minimizing the mean square error (Johnston et al. 2001).

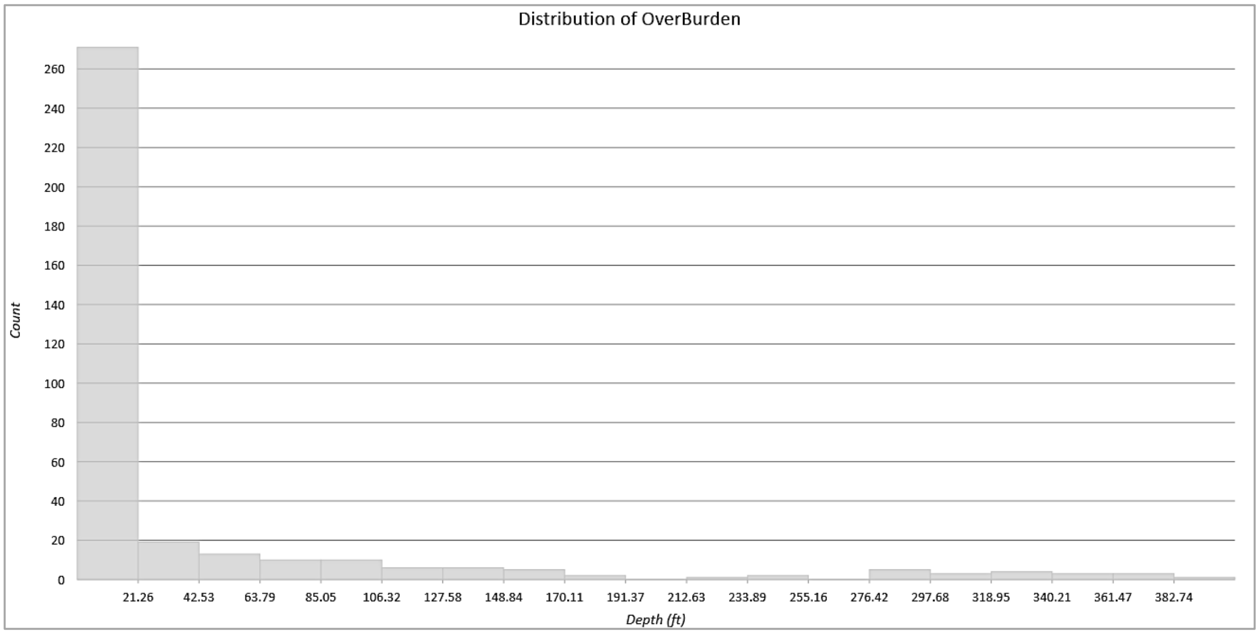

Figure 4: A histogram of well data and bedrock outcrop locations illustrating a non-normal distribution influenced by abundant thin till cover coupled with over-sampling of bedrock outcrops to increase control on overburden. However, the histogram is still strongly influenced by lower values when only using well data overburden (i.e., no outcrop points).

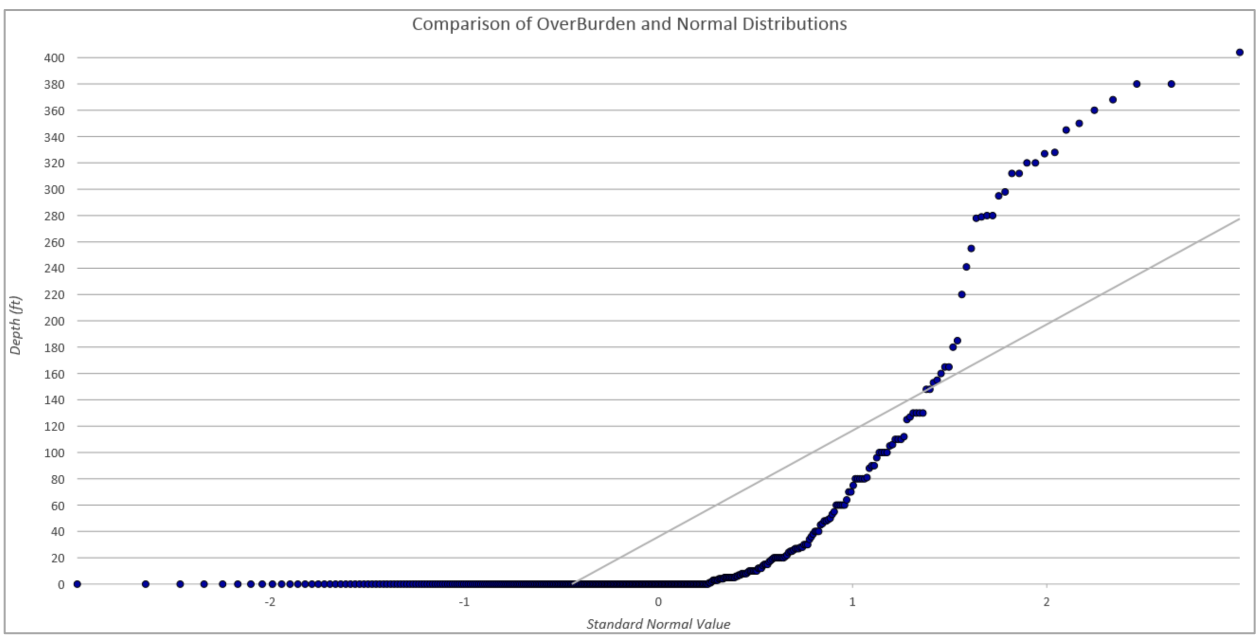

Figure 5: A general QQ plot is a graph on which the quantiles from two distributions are plotted versus each other. For two identical distributions, the QQ plot will be a straight line. This analysis also suggests the overburden values do not exhibit a normal distribution.

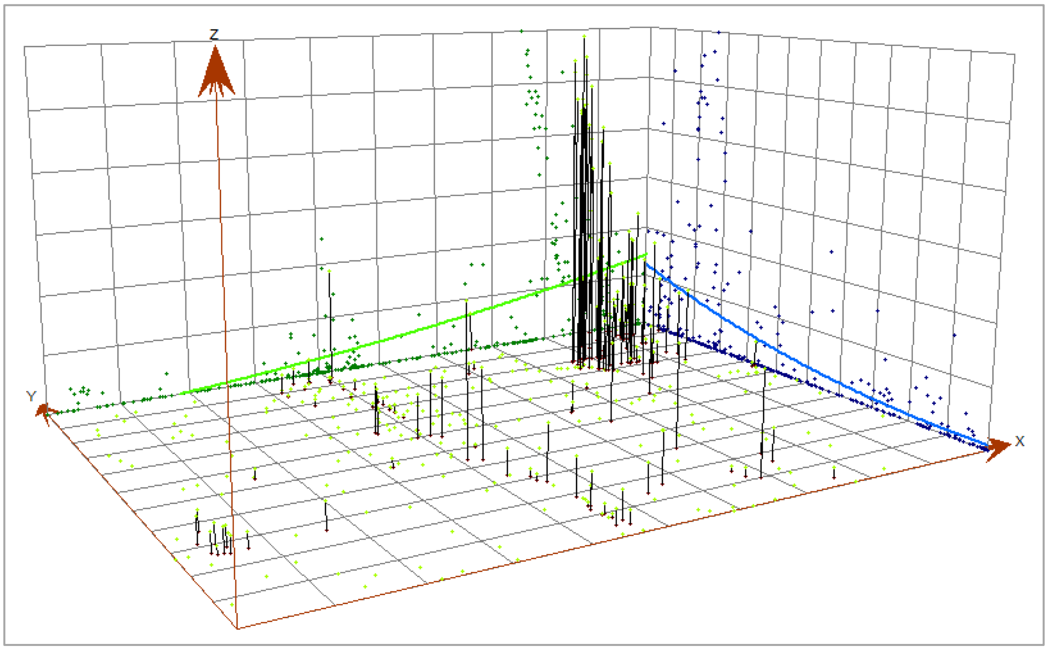

Figure 6: A trend analysis that suggests the data exhibits a minor trend across the x and y axes with higher overburden values towards the northeastern corner of the quadrangle.

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 7). 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.

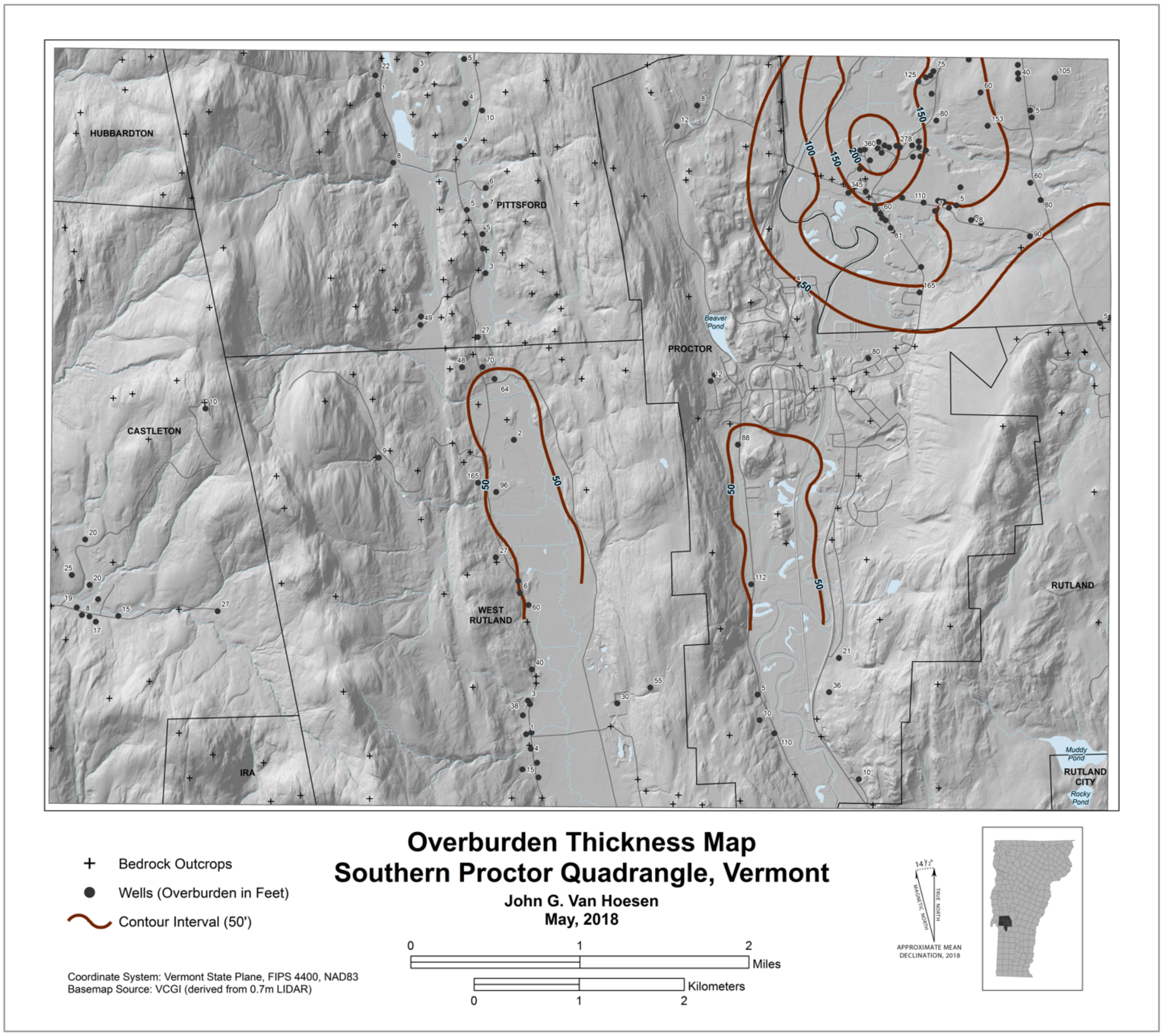

Figure 7: Overburden thickness (isopach) map of the southern Proctor Quadrangle extrapolated using ordinary kriging from well log data and bedrock exposures.

4.2.2 – Potentiometric Surface Map

A potentiometric surface was interpolated using the static water level attribute provided in the and private well logs and a 0.7-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 continuous 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 using automated functions within a GIS following Van Hoesen (2014), Hamad (2008), Spahr et al. (2007), and Bajjali (2005).

Using the Geostatistical Analyst to explore data, it is clear the data is not normally distributed (Figures 8 and 9) and there are very subtle trends in the piezometric surface (Figure 10). The piezometric surface produced through IDW interpolation was contoured using 40-foot increments to illustrate the generalized hydraulic gradient (Figure 11).

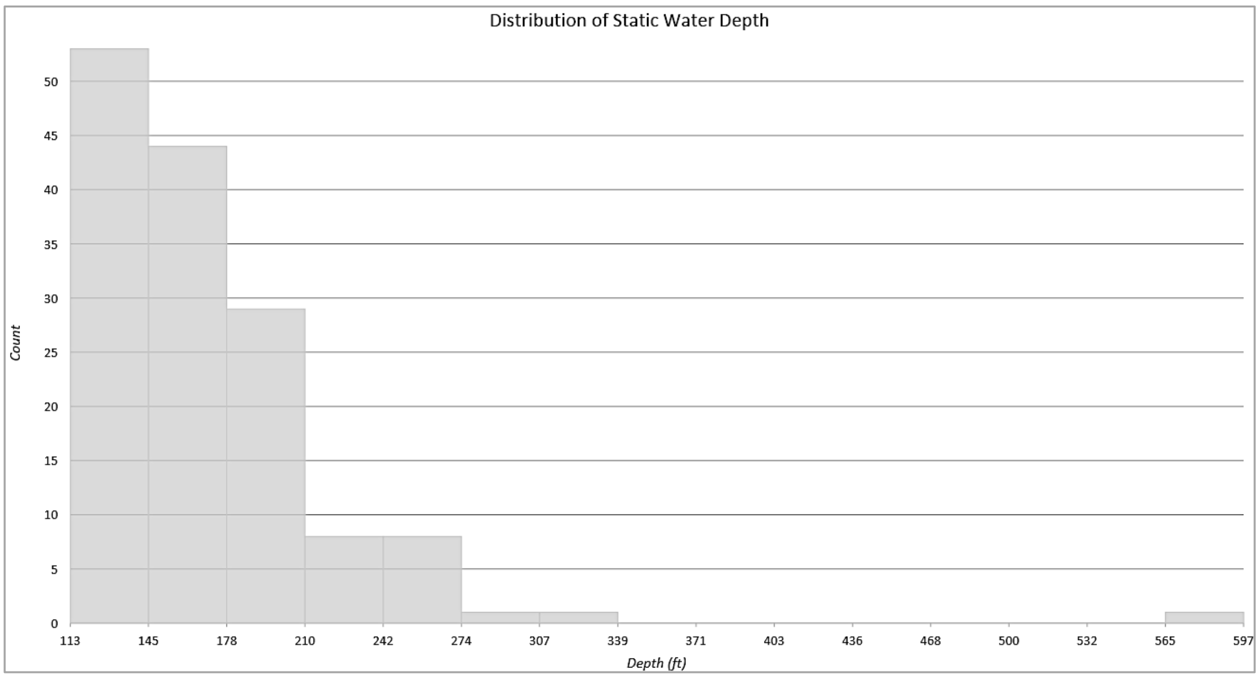

Figure 8: A histogram of static water depth that illustrates a more evenly distributed range of values.

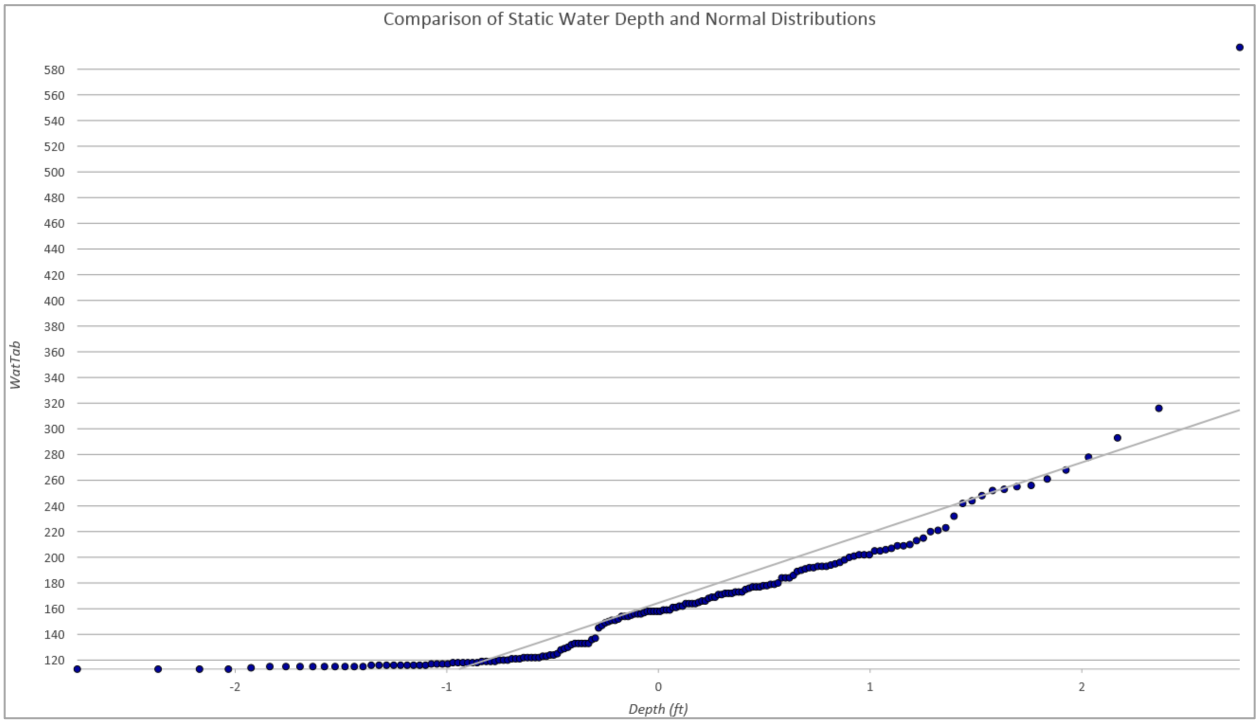

Figure 9: A general QQ plot is a graph on which the quantiles from two distributions are plotted versus each other. For two identical distributions, the QQ plot will be a straight line. This analysis suggests the static water depth values have a close to normal distribution.

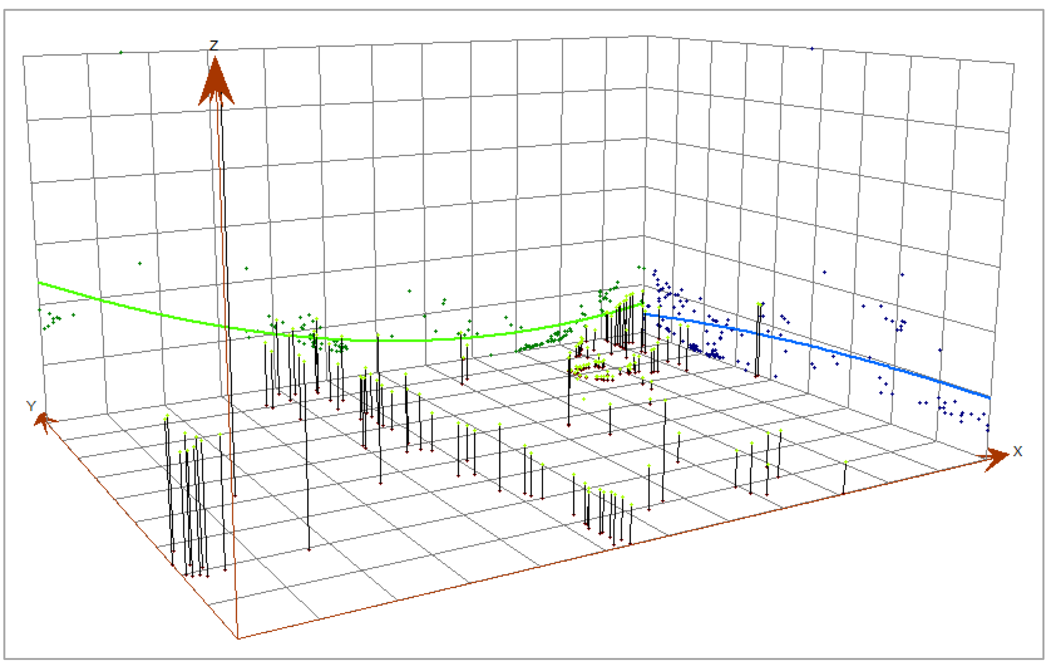

Figure 10: A trend analysis that suggests the data exhibits a distinct trend indicating the hydraulic gradient flows from the western highlands, across the quadrangle with a gentle south to north flow.

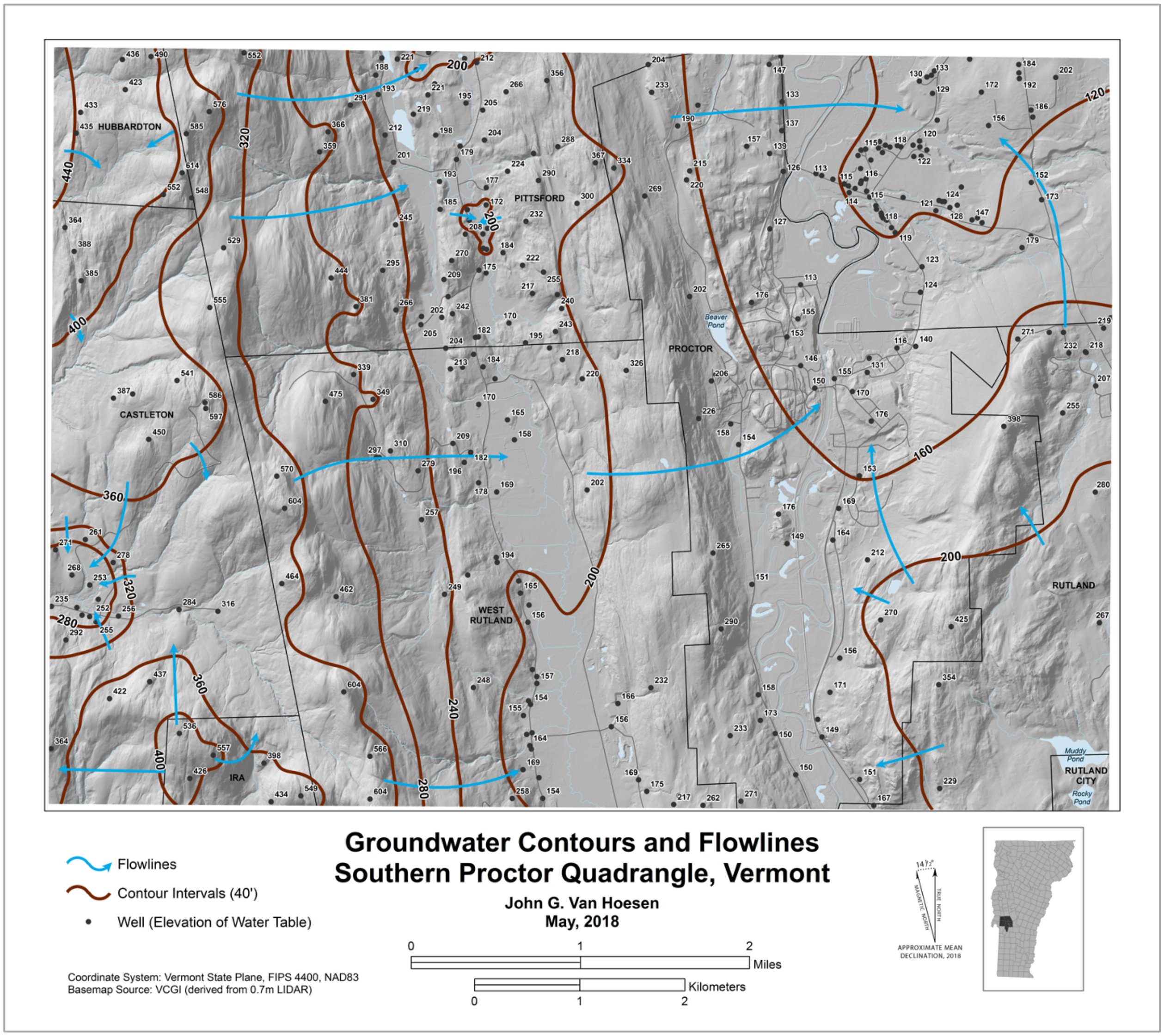

Figure 11: Groundwater contours (potentiometric surface) and flowlines for the southern Proctor Quadrangle created using private well log data.

4.2.3 – Depth to Bedrock

A visualization of depth to bedrock was created using the previously described overburden layer and a 0.7-meter DEM. The overburden layer - representing the thickness of sediment throughout the quadrangle – created using the Geostatistical Analyst was exported as filled contours. This continuous layer was then draped over modern topography to identify depth to bedrock rather than contouring the bedrock surface (Figure 12).

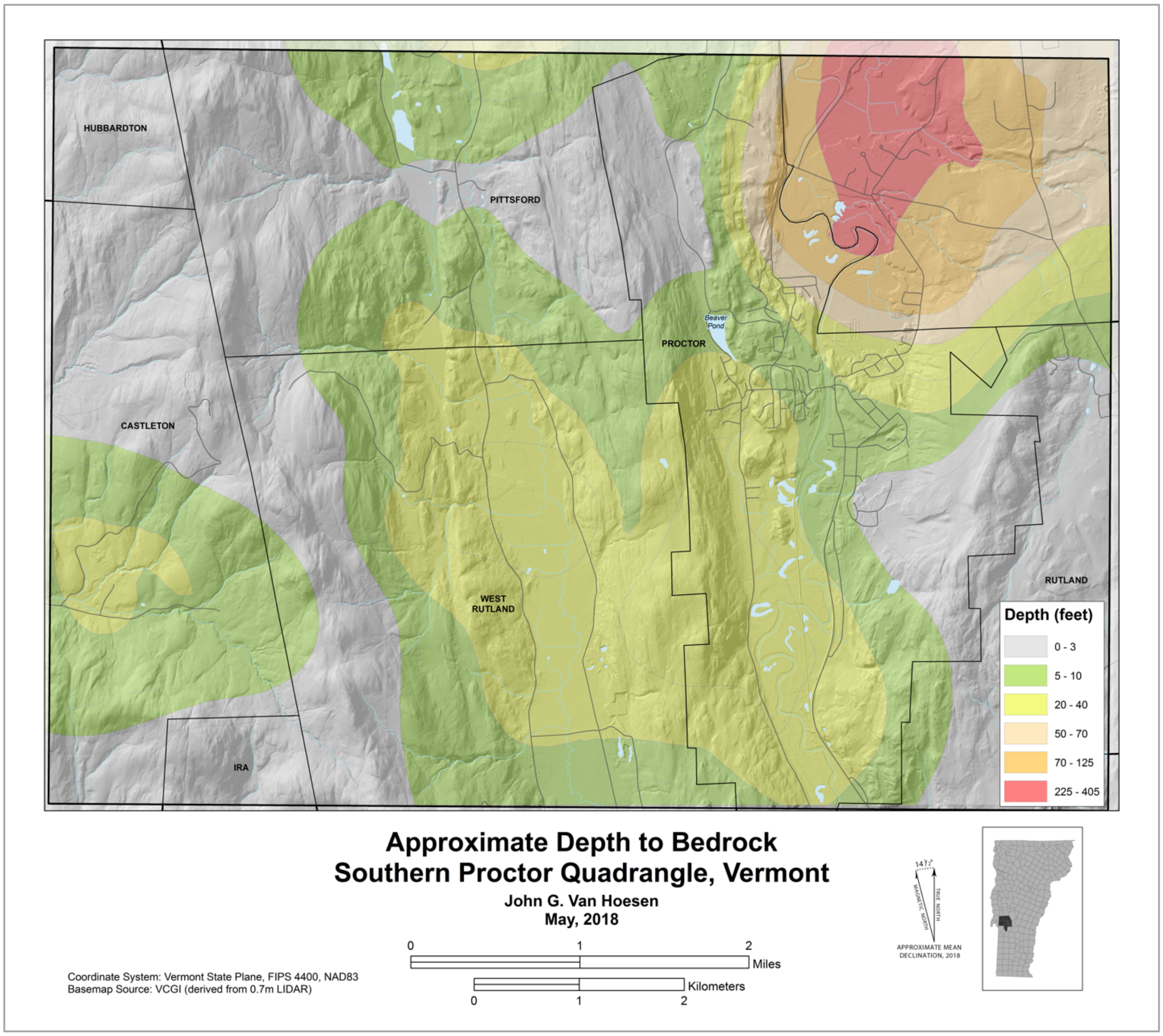

Figure 12: Depth to bedrock in the southern Proctor quadrangle created using private wells and bedrock exposures.

5.0 – Results & Interpretations

5.1 – Surficial Units

Artificial Fill (af): artificially-emplaced material in developed areas. Material varies from sand to gravel and is concentrated around the electrical substation at the end of Pleasant Street, West Rutland.

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.

Wetland Deposits (Hw): well-sorted, well-stratified silt/clay deposits associated with concave topography lacking drainage. There are extensive deposits covering the Castleton and Otter Creek valleys, which are underlain by alluvium and course lake sediments. However, many deposits also occur in the uplands.

Alluvium (Ha): 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 within mountain streams to more extensive and thicker deposits filling the Castleton and Otter Creek valleys (Figure 13).

Figure 13: Characteristic level topography associated with extensive alluvium and wetland deposits filling the Castleton and Otter Creek Valleys. Taken in Otter Creek Valley looking west.

Colluvium and/or Talus (Hc): unconsolidated, unsorted cobbles/boulders found in the upland regions at the base of steep strongly weathered cliffs and at the base of small hogback hills throughout the quadrangle.

Alluvial Terrace Deposits (Hat): well-sorted, well-stratified sand, silt, pebbles, cobbles that represent historical floodplain sediments above - and often dissected by - modern streams (Figures 14). They are concentrated in the Castleton River valley.

Figure 14: Historical alluvial terraces observed along a tributary that joins the Castleton River near the intersection of Whipple Hollow and Bristol Roads.

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.

Lacustrine Sediments, Coarse-grained (Plc): well-sorted silt-to-sand deposited in shallow water (Figure 15) that commonly forms distinctive lobate topography in the valley bottoms (Figure 16).

Figure 15: Exposure of laterally extensive lake sand (left) and close-up of easily erodible lake sand (right) exposed along Corn Hill Road.

Figure 16: Characteristic lobate topography associated with lake sand deposits.

Lacustrine Deposits, Shoreline (Pls): well-sorted sand to cobble gravel deposited in shallow nearshore environment (Figure 17). There is a single small deposit with variable thickness located southeast of Williams Street in Proctor, VT.

Figure 17: Small isolated shoreline bench deposit exposed in borrow pit.

Till (Pt): exposures of dense to unstratified clay-dominated till ranging in thickness from less than 3 meters to greater than 30 meters. Area of thin till are characterized by frequent bedrock exposures, abundant surface cobbles or boulders of varying lithology, with common rock walls and, a veneer that mimics topography (Figure 18). Areas of thicker till create rolling hills and streamlined topography.

Figure 18: Typical thin hummocky topography associated with thin till (left) and characteristic streamlined topography of regions mantled with thick glacial till located on the slopes of Grandpa's Knob (right).

5.2 – Cross-Section Interpretations

One cross-section was created using well log data and surficial geologic mapping observations. The location of the cross-section is noted on the Surficial Geologic Map of the Southern Proctor 7.5-minute quadrangle (Figure 19) and was chosen to illustrate the subsurface relationships of surficial deposits within the study area.

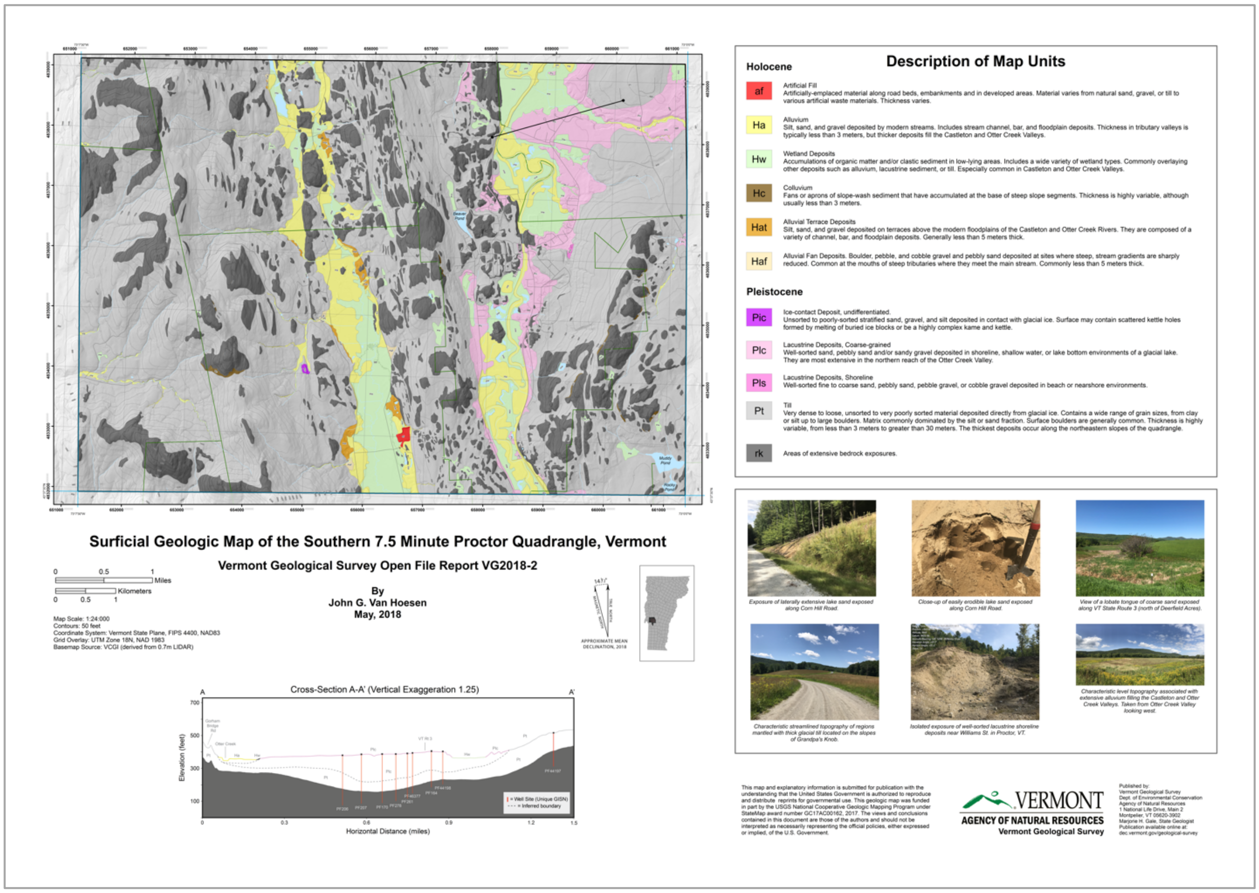

Figure 19: Surficial geologic map of the southern Proctor quadrangle, Vermont.

5.2.1 – Otter Creek Cross-Section (A-A')

This cross section extends approximately 1.5 miles west to east across the northern reach of the Otter Creek Valley. Surficial deposits in the western section are dominated by slopes of thin to thick till (Pt) and transition into valley-filling deposits of well-sorted and well-stratified alluvium (Ha) and minor wetland deposits (Hw). The majority of the valley is filled with thick deposits of undifferentiated coarse-grained, lake sediment (Plc), which rests on a mixture of finer-grained lake clay and clay-rich glacial till. East of Vermont Route 3, wetland deposits lie over alluvium, which is likely deposited on course lake sand and glacial till. Thick glacial till dominates the remainder of the cross section with a few areas of thin glacial till and exposed bedrock. All eight wells along this cross-section pass through variable thickness overburden and terminate in bedrock (Figure 20).

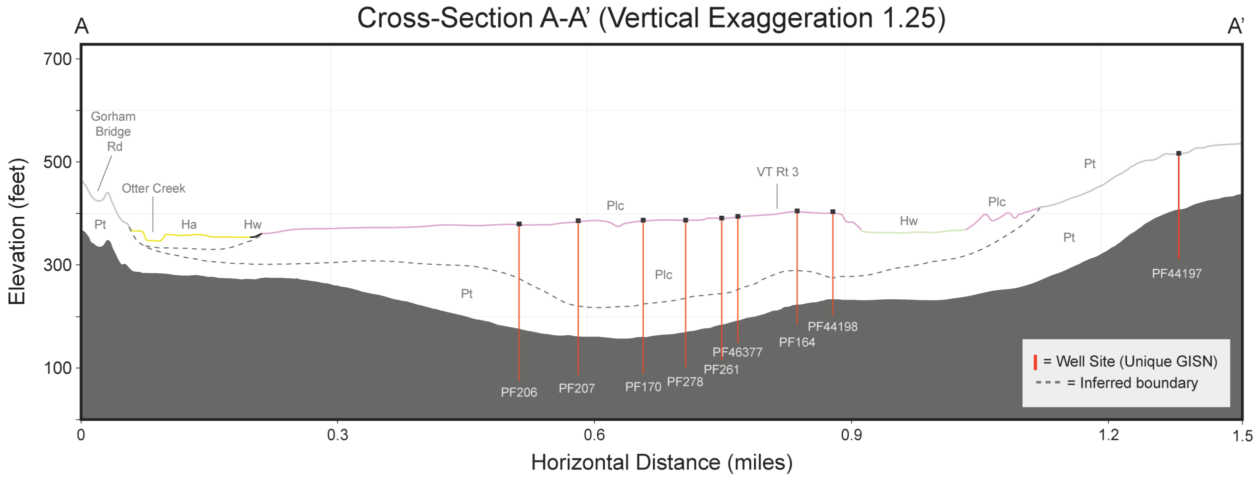

Figure 20: Cross-section constructed using well-log data and surficial geologic map.

5.3 – Overburden Thickness (isopach) Map

The isopach map is consistent with well data, surficial deposits, and the distribution of bedrock outcrops. Areas of thin or no overburden are common throughout the town but most obvious along the western and central highlands of the quadrangle. Areas of thicker till mantle occur are found throughout the region. However, the thickest deposits occur as alluvium and coarse-grained lake sediments that fill the Castleton and Otter Creek Valleys. The northern terminus of the Otter Creek valley contains sandy lake sediments ranging from approximately 20 to > 200 feet thick. This area was explored by Stewart (1972) and after conducting seismic profiling, suggested this area "has probably the highest water potential of any area in the Rutland-Brandon region." In contrast, even though there are a few high-yielding wells in sediments filling the central Castleton River Valley, they are predominantly clay overlying sand and gravel. This region may offer potential aquifer opportunities, but seismic profiling by Stewart (1972) suggest it is less likely.

5.4 – Summary of Hydrogeologic Characteristics

All of the 145 rectified wells in the quadrangle terminate in bedrock except one, which is located along the western edge of the Castleton River Valley. Four bedrock hydrogeologic units were delineated based on rock properties and mean well yields (Figure 21). The primary hydrogeologic unit in the study area is the Type I sequence (110 wells), sixteen wells occur in the Type II sequence, there are no wells in the Type III sequence, and only two well occurs in the Type IV 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 highest (mean = 13 gpm) in the Type I sequence, however there are very few wells in the Type II and IV sequences; without additional data I wouldn't assume this relationship holds true for future wells. The one gravel well (Unique GISN #: WV114) has a yield of 20 gallons per minute, is 80 feet deep, and terminates in sand overlain by clay and underlain by gravel.

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 = 110) Exposures of carbonates, quartzite, and conglomerate of the Shelburne, Danby, Winooski, Dunham, and Ira Formations.	13	360′
Type II Sequence (n = 16) Exposures of slate, phyllite, and minor limestone of the Bull Formation.	3	537′
Type III Sequence (n = 0) Exposures of quartzite, schist and phyllite of the Dalton Formation.	n/a	n/a
Type IV Sequence (n = 2) Exposures of gneiss and conglomerate of the Mt Holly Complex and Tyson Formation.	7	323′

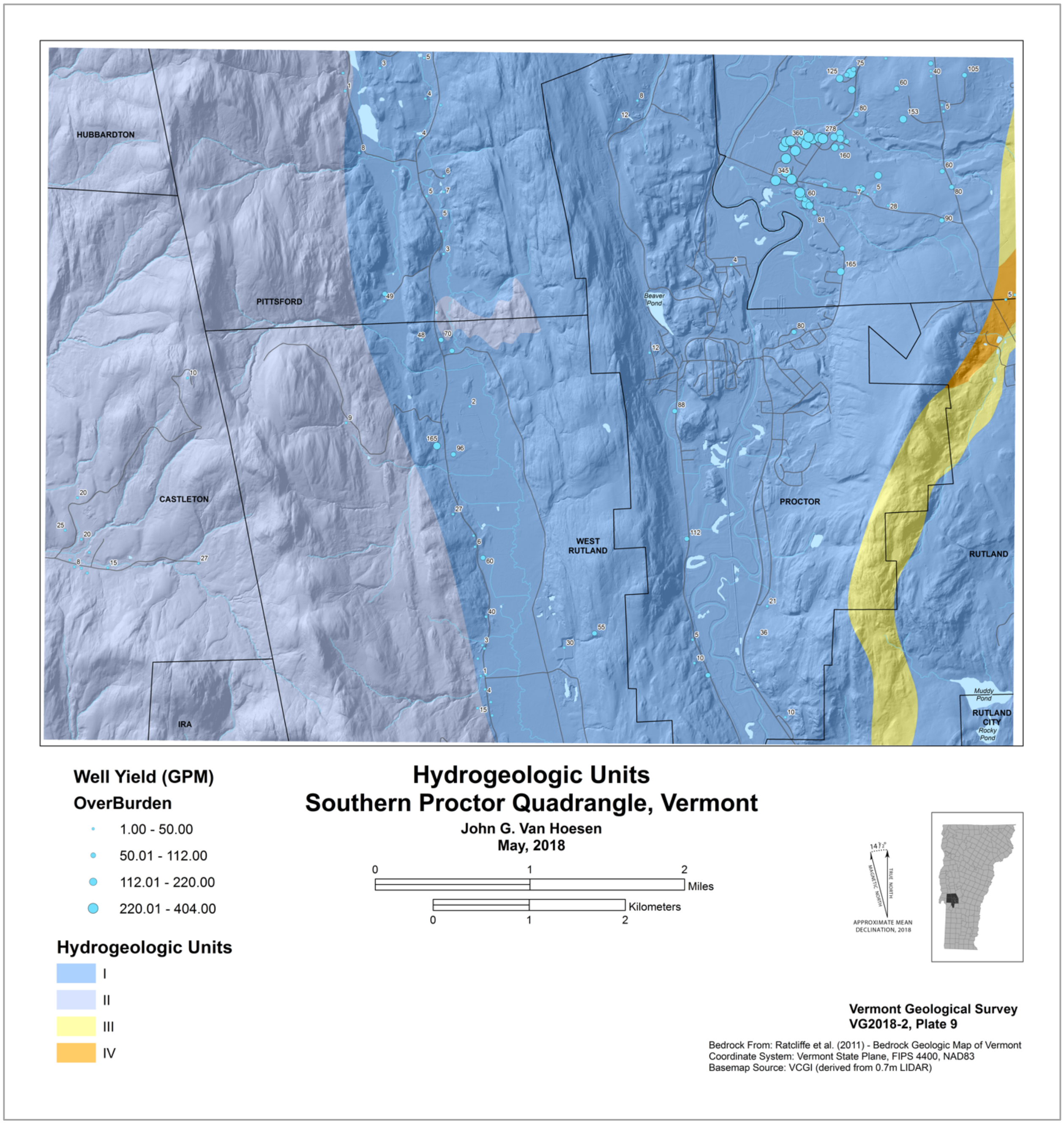

Figure 21: Classification of hydrogeologic units.

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 40-foot contours extracted from the underlying potentiometric surface (Figure 7).

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 south to north is readily apparent in the resulting interpolated surface.

5.6 – Recharge Potential to Shallow and Deep Aquifers

Areas of highest recharge potential to shallow aquifers occur in the valleys where there are gentle slopes and extensive deposits of alluvium, wetlands, and coarse lake sediments (Figure 22). This combination of sediment with high permeability and increased surface ponding leads to higher rates of infiltration.

Areas of highest recharge potential to shallow aquifers occur in the highlands, which are primarily covered by thin till and frequent rock outcrops (Figure 23). 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, and wetland areas. 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.

The integration of information about high-yielding wells and the areas with the highest potential recharge allows for the approximation of those locations in the quadrangle with the highest overall aquifer potential (Figure 24).

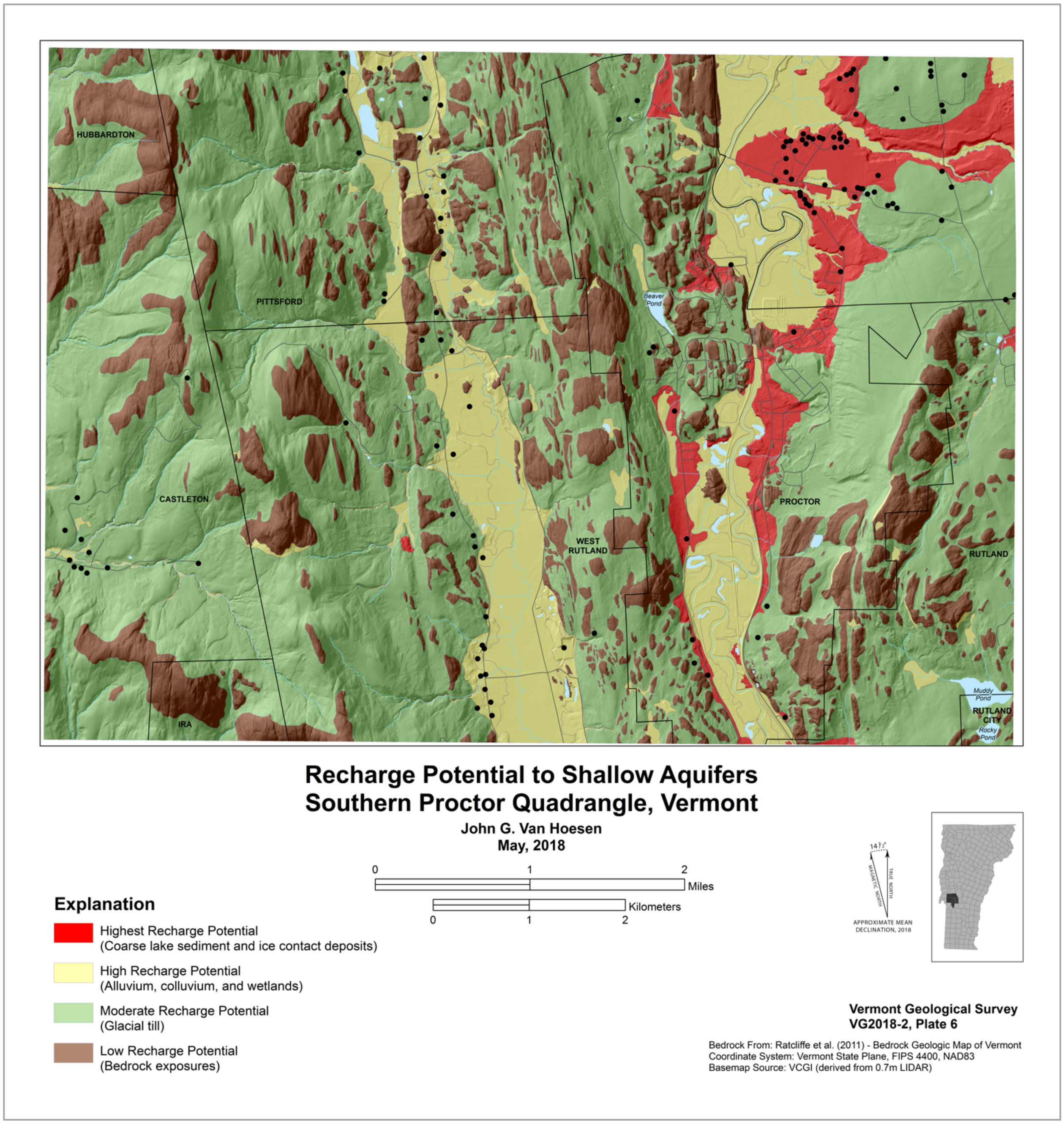

Figure 22: Map illustrating the potential favorability for recharge of groundwater to shallow aquifers.

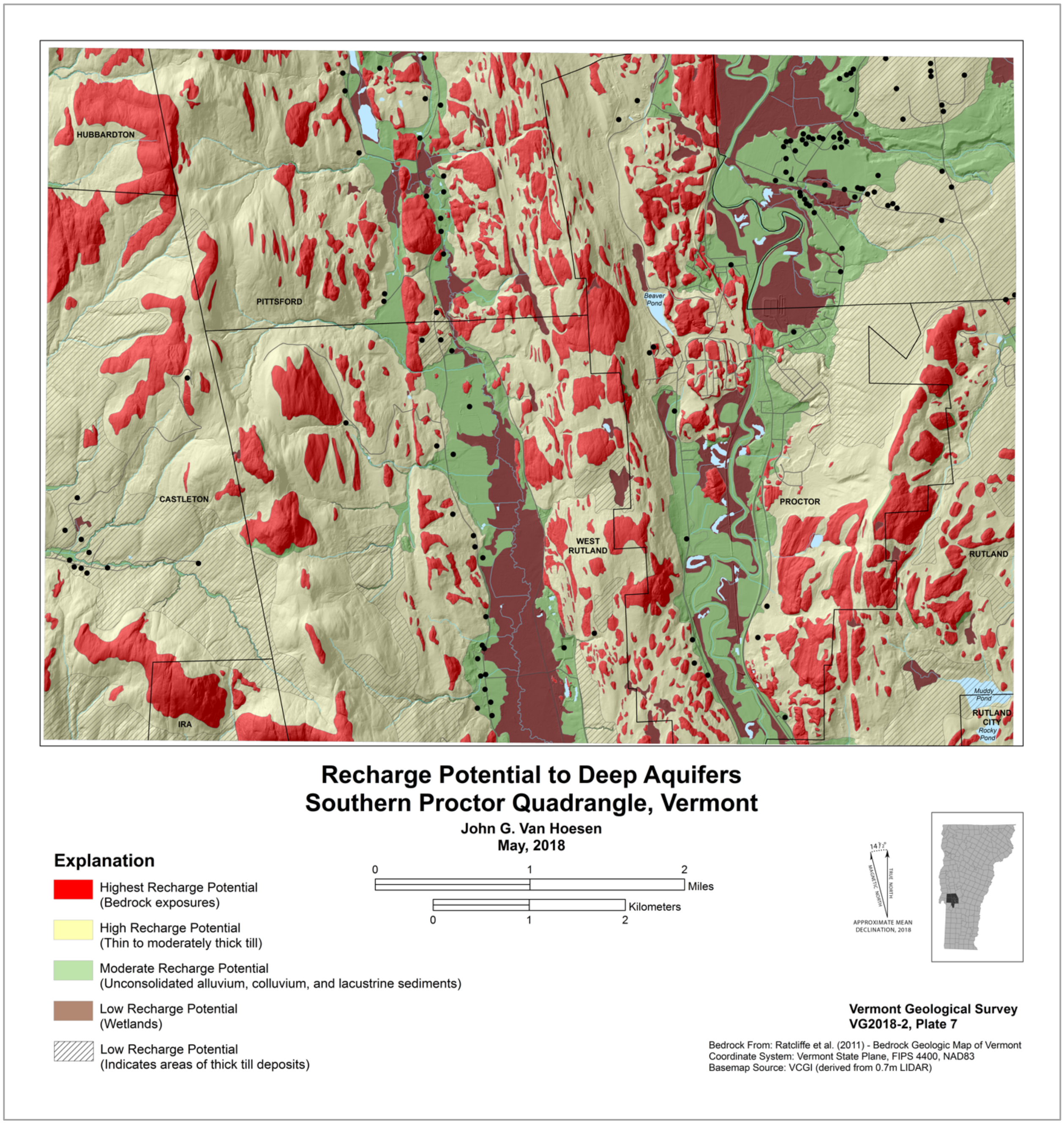

Figure 23: Map illustrating the potential favorability for recharge of groundwater to deep aquifers.

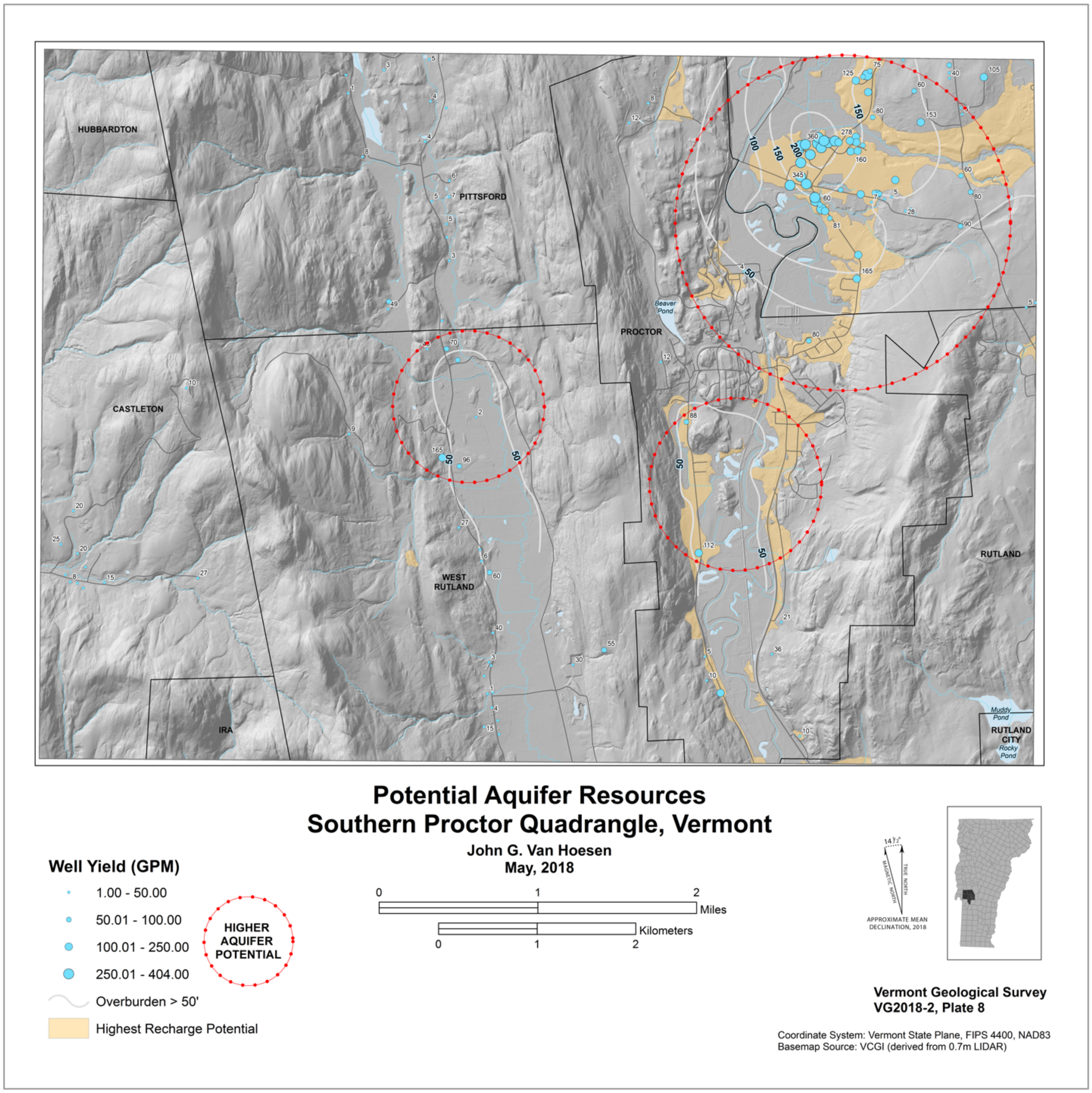

Figure 24: A generalized map showing the overlapping areas where there is high yield from wells and potential yield from - and recharge of - surficial aquifers. This is meant to be used as a general location map not as a definitive tool for high-yielding areas.

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