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

John G. Van Hoesen

Green Mountain College
Department of Environmental Studies
Poultney, Vermont 05764

A view looking northwest at the edge of a well-exposed kame terrace on Amanda Lane in northeastern Rutland Town.

Table of Contents

1.0 – Executive Summary:

During the summer of 2008, I located and spatially rectified 552 private, municipal and exploratory boring wells within the town and city of Rutland, Vermont. I also mapped the surficial geology of the area during the 2008 and 2009 summer field season. I identified and mapped 15 different surficial units using traditional field and digital mapping techniques and information gathered from rectified wells. I also collected GPS coordinates for 946 bedrock outcrops, 644 surficial sites and 3 sites with well-preserved striations. These bedrock locations were collected and used with well logs to help refine bedrock topography and facilitate the production of an overburden isopach map and 5 cross-sections.

Bedrock topography generally mimics the surface topography and the well logs and isopach map suggest the eastern edge and southwestern corner of Rutland Town is buried by thick kame terraces and glacial till, respectively. The kame terraces have the highest potential for both high yielding wells and recharge to an unconsolidated aquifer – there are a number of existing wells tapping these deposits with yields over 50gpm. Well yields are highest in bedrock associated with carbonates of the Champlain Valley Sequence (mean = 22gpm) and gneiss of the Mt Holly Complex (mean = 29gpm). While the carbonates appear to have slightly lower yields, they are not as deep as wells in the gneiss and there is a limited sample size for wells in pre-Cambrian rock within the town. Additional areas with high yield and recharge potential include a large isolated kame deposit in the northwestern corner of town and moderately thick deposits of alluvium mantling the valley floor now occupied by Otter Creek. A buried valley below Otter Creek supports a high yield well currently under investigation by the town for a bottled water facility. Static water levels in the well log data were also used to interpolate a potentiometric surface, which indicates groundwater generally flows from high potentiometric potential in the northwestern part of town to the southwest. Groundwater in the south-central part of town also appears to flow south out of the valley.

Field mapping identified extensive deposits of a Wisconsinan age dense, clay-rich till overlain in places by younger sandy ground moraine, primarily found in the western highlands of town. The till is variable in thickness ranging from a thin veneer to thicknesses exceeding 50 meters. The ground moraine suggests stagnation as glacial ice retreated out of the valley and off the highlands. Thick kame terraces along the western flank of the Green Mountains lie on glacial till and are also indicative of ice retreat. The thickness of these terraces suggestions an extended period of stagnation of stability and lack evidence for a re-advance. The town contains three areas of lacustine sediment; two areas are at elevations in excess of 625 feet suggesting the presence of high-level lakes and the most extensive deposit is located lower in the valley in the southwest region of the town. As glacial ice retreated northward up the Otter Creek Valley, these sediments likely developed behind the location of an inferred ice dam on the western edge of town near the intersection of Business Route 4 and the Town/City boundary (near Evergreen Cemetery). The Rutland area contains a surprisingly low number of ice flow indicators given the extensive occurrence of Prospect Mountain Quartzite; however striations that were identified indicate a northwest to southeast transport direction.

2.0 – Background:

This report summarizes the results of surficial mapping and digital mapping efforts within the boundary of Rutland, Vermont. The mapping occurred over approximately 5 months during the summers of 2008 and 2009 and interpretation took place during an additional 2-3 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, identify glacial and postglacial landforms, and integrate this information with subsurface data inferred from private well logs. This mapping project also produced numerous derivative maps providing additional information regarding bedrock and unconsolidated aquifers, which can be used to address land-use questions and water issues concerns within the Town of Rutland (Table 1). Residential development within the town is tied to an expansion of bedroom communities,

vacation homes, and commercial lodging that supports tourism associated with local ski resorts and these derivative maps will likely play an important role in helping manage town-related water resources.

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

1. Bedrock Locations	7. Possible Shallow 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. Well Yield Versus Bedrock
5. Bedrock Topography	11. Well Lithology
6. Hydrogeologic Units	12. Potentiometric Surface + Flow Lines

3.0 – Location and Geologic Setting:

3.1 – Physiographic Characteristics:

Rutland Town and Rutland City have a total area of approximately 70km^2 and are bordered by Proctor to the west, Pittsford to the north and Chittenden to the east (covering both the Chittenden and Proctor U.S.G.S quadrangles). Elevations range from approximately 145-435 meters (470-1430 feet) with the greatest topographic relief occurring along the western edge of town (Figure 1 and Appendix 8.2 and 8.3). This area of town is heavily wooded and largely undeveloped with rare exceptions. However, the field area is characterized by lower elevations dominated by rolling hills and subdued topography. The region is drained by East Creek and its tributaries, draining southward to Otter Creek and then northward to Lake Champlain. Otter Creek traverses approximately 15km (9 miles) across the town, flowing from the southeast to the northwest with a relief of approximately 15 meters (50 feet). The creek meanders through Holocene alluvium and lacustrine sediment over its entire course and is underlain by approximately 25-30 meters (80-100 feet) of courser sand and gravels.

The town is located in a north-south trending valley primarily underlain by the Paleozoic Shelburne, Danby, Winooski, Monkton, Dunham and Dalton Formations, rare outcroppings of Ordovician Hortonville and Bascom Formations, and Proterozoic gneiss of the Mt Holly Complex (Ratcliffe 1988 and Doll 1961) (Figure 2).

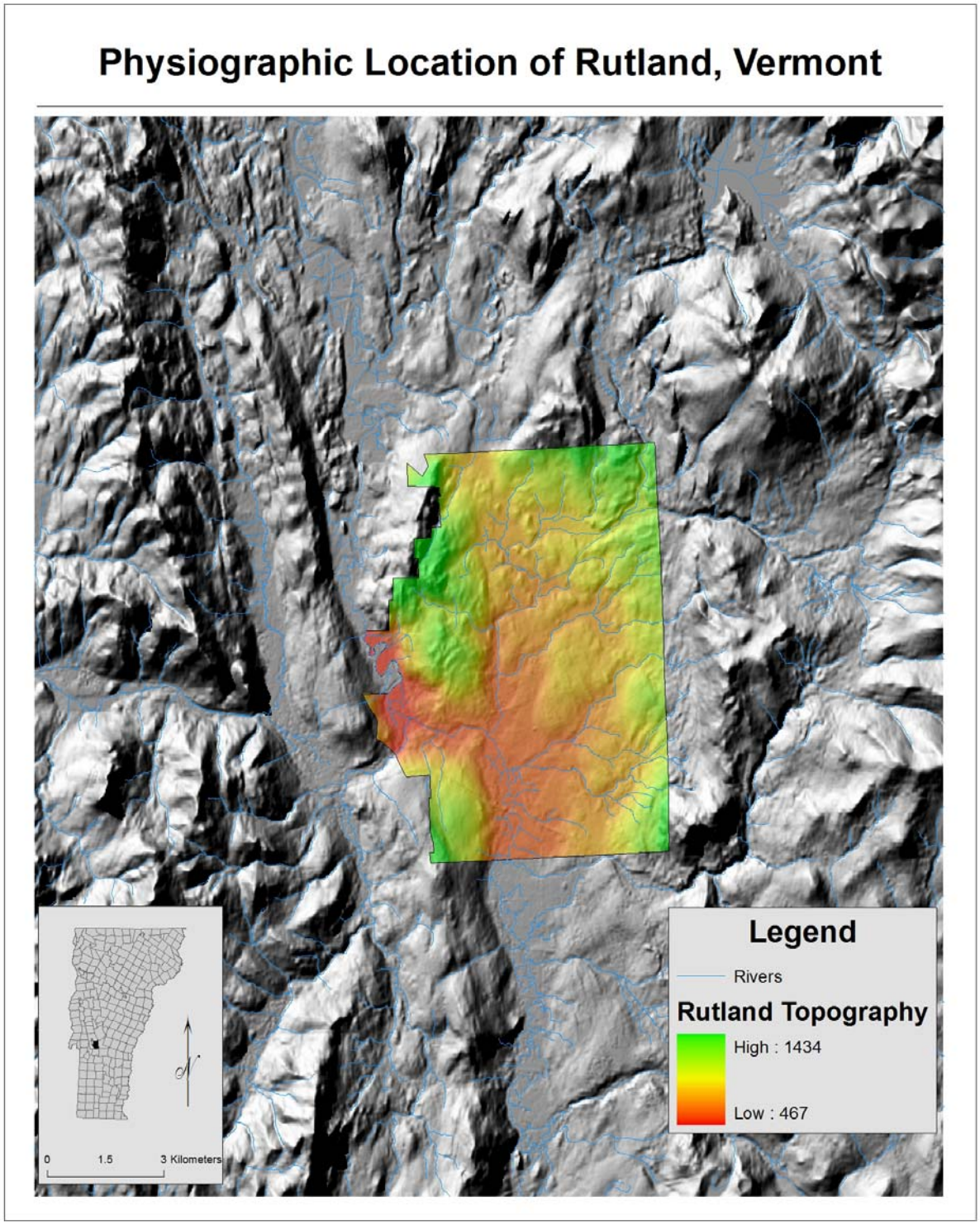


Figure 1: Map depicting the physiographic location of Rutland, Vermont draped over a shaded-relief map derived from a 30-meter digital elevation model.

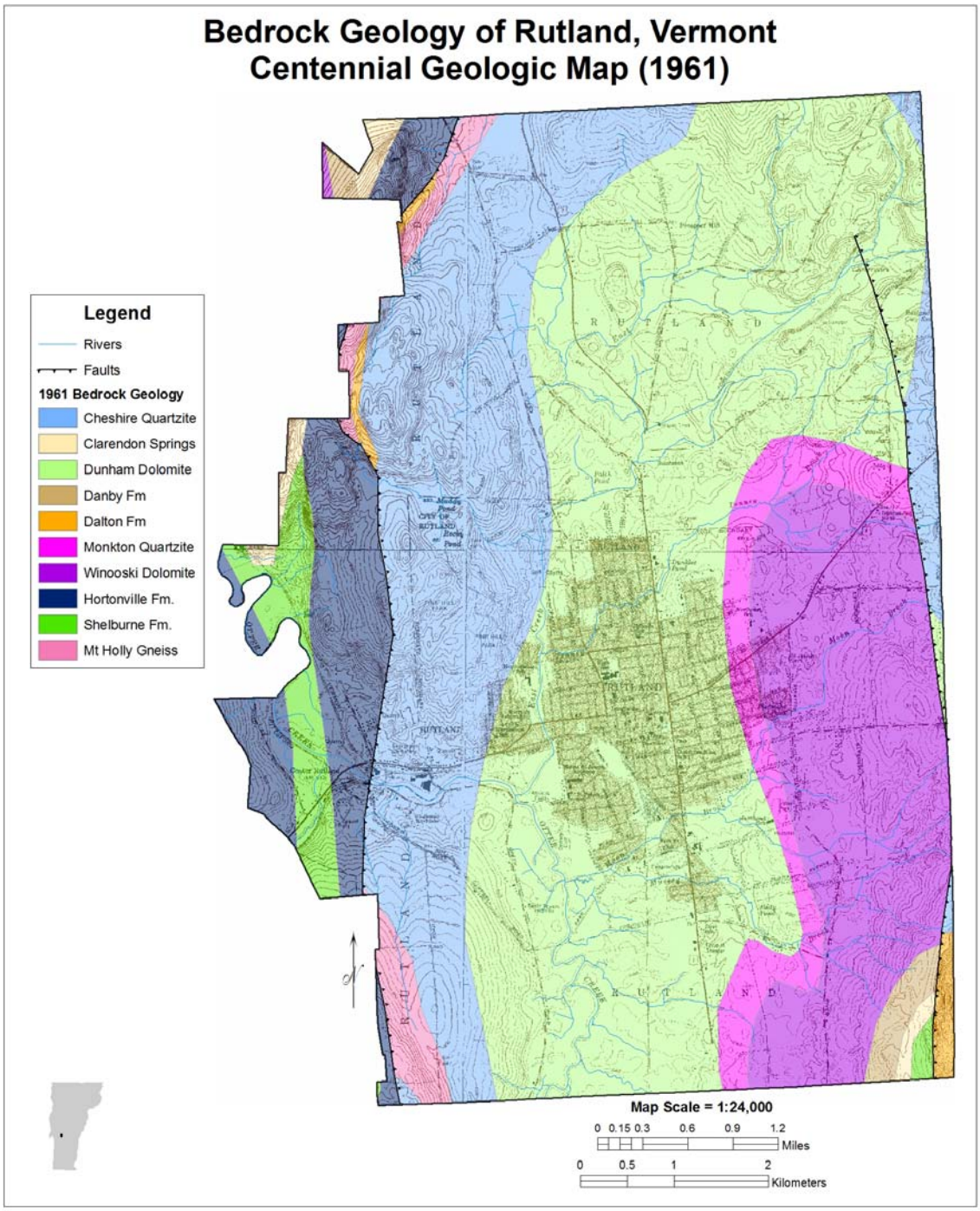


Figure 2: Generalized bedrock geology of Rutland Town based on the Centennial Geologic Map of Vermont produced by Doll et al. (1961) and data digitized by Nicholson et al. (2006).

3.2 – Previous Work:

Brace (1953) mapped the bedrock geology of the 15' Rutland Quadrangle and incorporated into the Centennial Geologic Map complied by Doll et al. (1961) and both the Chittenden and Rutland Quadrangles were later mapped at 1:24,000 by Ratcliffe (1997 and 1998). Preliminary surficial mapping was undertaken in Rutland Town by Stewart (1966), integrated into "The Surficial Geology and Pleistocene History of Vermont" by Stewart and MacClintock (1969) and later modified by Stewart (1972). Stewart and MacClintock (1969) posited that Otter Creek should have supported a high-elevation lake but found no lacustrine deposits above 625 feet.

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. A Trimble JunoST running TerraSync and 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 GPS coordinates of almost every bedrock exposure I encountered and the outcrops were inspected 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) an extensive network of 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 kriging functions and contour the data using automated functions within the GIS.

Ordinary kriging and universal kriging techniques produced similar error prediction values; however the final visual product varied considerably. The ordinary kriging technique, while more commonly cited in the literature (Gao et al. 2006; Locke et al., 2007; Logan et al. 2001), produced more jagged contours regardless of the chosen variogram model or extent of smoothing. For both techniques, I used the J-Bessel variogram model because it provided the best "fit" based on predicted error results. The universal kriging technique produced a more smoothed surface and resulted in less abrupt looking contours (Gold, 1980; Chang, 2004). However, I manually smoothed the contour lines to produce the final version seen on the map. I believe this smoothing process can be improved upon whether via manual digitizing or making better use of the smoothing function in ArcGIS Advanced Editing tools. Xang and Hodler (2002) argue that certain techniques may be more "visually faithful to reality" even though their statistical behavior is not always the best. Both models are statistically similar, so I chose the least visually jagged product. However, both approaches quickly produce a good representation of the overburden when compare with field and well data. I believe either could be manually digitized or further smoothed to create a more refined product.

4.2.2 – Potentiometric Surface Map

A potentiometric surface was interpolated using (1) the static water level attribute provided in 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) functions and contour the data in 50 foot increments using automated functions within the GIS following Spahr et al. (2007), Bajjali (2005), and Desbarats et al. (2002). I chose 50 foot contours because the change in gradient across the field area is quite subtle and required greater detail within certain areas of town.

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.

5.0 – Results

5.1 – Surficial Units

Alluvium primarily occurs as well-sorted, well-stratified, fluvial deposits adjacent to or in stream channels, sand/silt/pebbles/cobbles. Variable thickness depending on location in field area can range from a thin veneer limited to floodplains or occur as thick (> 15 meters) deposits covering locally extensive lowlands (Figures 3 and 4).

Figure 3: View looking west from Route 3 across an alluvial floodplain along Otter Creek.

Figure 4: Typical alluvial sediment found within alluvial floodplains.

Kame: moderately-sorted, well-stratified sand/silt/pebbles representing an ice contact deposit exhibiting topographic reversal and irregular topography (Figure 5). Kame deposits are uncommon but the few occurrences are well-exposed and topographic reversal associated with these deposits indicates they were deposited in a surface depression within glacial ice, probably during stagnation and retreat.

Figure 5: Moderately extensive sandy kame deposit in the northwestern corner of Rutland to the east of North Grove Street between Cedar Avenue and Pinnacle Ridge Road.

Kame Terrace: moderately-sorted, well-stratified sand/silt/pebbles/cobbles representing an ice contact deposit, exhibiting steep marginal slopes (see cover photo), flat lying topography within irregularly shaped landforms (Figure 6). These are the most extensive and thickest of all ice-contact sediments and indicate a significant episode of stagnation during retreat in addition to an abundant source of sediment to the east and northeast along the western flank of the Green Mountains. These deposits also pose moderate stability issues associated with their high permeability, relief, and unconsolidated nature.

Figure 6: View looking southwest from Chittenden-East Pittsford Road over the surface of a kame terrace in the northeastern corner of Rutland Town.

Lacustrine Sediments: well-sorted, well-stratified clay/silt/sand lake deposits that delineate flat lying topography in the valley bottom (Figures 7 and 8). There are three distinct areas of deposition within the town: (1) a higher elevation lake in the north, (2) an extensive thicker deposit in the central and southern part of town, and (3) the smallest deposit along Otter Creek in the west-central portion of town. Sediments associated with the higher elevation lake are found above 625 feet and addressed the issue posed by Stewart and MacClintock (1969) concerning the lack of a high level lake. They hypothesized the valley had an outlet "possibly around the ice margin or even under the ice" but these deposits support the existence of a higher elevation lake, albeit a small one. The most extensive deposits probably developed when the narrowest constriction along Otter Creek (currently called Center Falls) was filled with ice. The smallest deposits to the east and west of Otter Creek were probably deposited as ice continued to retreat up the Otter Creek valley.

Figure 7: Extensive lacustrine deposits in northern Rutland Town looking east from North Grove Street, between McKinley Avenue and Cedar Avenue.

Figure 8: Exposure of clay-rich lacustrine sediment in Rutland City at the intersection of South Strongs Avenue and Main Street.

Ground Moraine: poorly-sorted, weakly-stratified medium to very coarse sandy till characterized by hummocky topography and deep orange oxidation. Primarily found in the uplands with rare occurrences in the valley bottom (Figure 9). The hummocky nature of these deposits is characteristic of 'dead ice' deposits and a higher a higher resolution map of meltwater channels could be used to refine deglaciation in the highlands. It is possible that more extensive ground moraine was deposited but as the ice continued to retreat off the highlands, it was washed into the valleys, which may account for the sandy/pebbly nature of many lacustrine sediments.

Figure 9: Typical oxidized sandy sediment associated with ground moraine deposits found exclusively in the western highlands of the town.

Thin Till: thin (3m), unsorted, unstratified silty/clay till, characterized by frequent bedrock exposure, few cobbles/boulders of varying lithology, with rare rock walls and rock piles and deposits that mimic topography. Thin till cover also provided access to bedrock exposures exhibiting striations (Figures 10). It was very surprising how few striations were preserved in either the Cheshire or Monkton Quartzites, both of which typically act as a suitable substrate for preservation.

Figure 10: Bedrock exposure in thin till on the highlands running N-S along North Grove Street. Inset dashed rectangle corresponds to the photo on the right, which illustrates the location of striations exposed in the Cheshire Quartzite.

Till: unsorted, unstratified, dense clay-rich/silty till containing common pebbles/cobbles/boulders of varying lithology, predominantly found on gently sloping, often streamlined hills with common rock walls and rock piles (Figures 11 and 12).

Figure 11: Exposure of dense till in Rutland City on Lincolin Avenue mantling a N-S ridgeline.

Figure 12: Typical surface morphology of dense till exhibiting abundant surface boulders and extensive ~1-meter high rock walls.

Wetland/Peat: well-sorted, well-stratified silt/clay deposits associated with concave topography lacking drainage. Predominantly occurs in lower-lying valley, however many deposits occur in steeper uplands (Figure 13).

Figure 13: View looking northeast towards Muddy Pond in the highlands of north Rutland Town.

Fluvial Terraces: well-sorted, well-stratified sand/silt/pebbles/cobbles that represent historical floodplain sediments dissected by modern streams. These alluvial deposits are relatively uncommon and not extensive in any region of the study area (Figure 14).

Figure 14: View looking northeast atan historical fluvial terrace along East Creek in north Rutland Town. East Creek is ~ 3 meters lower than terrace, running along the hedgerow.

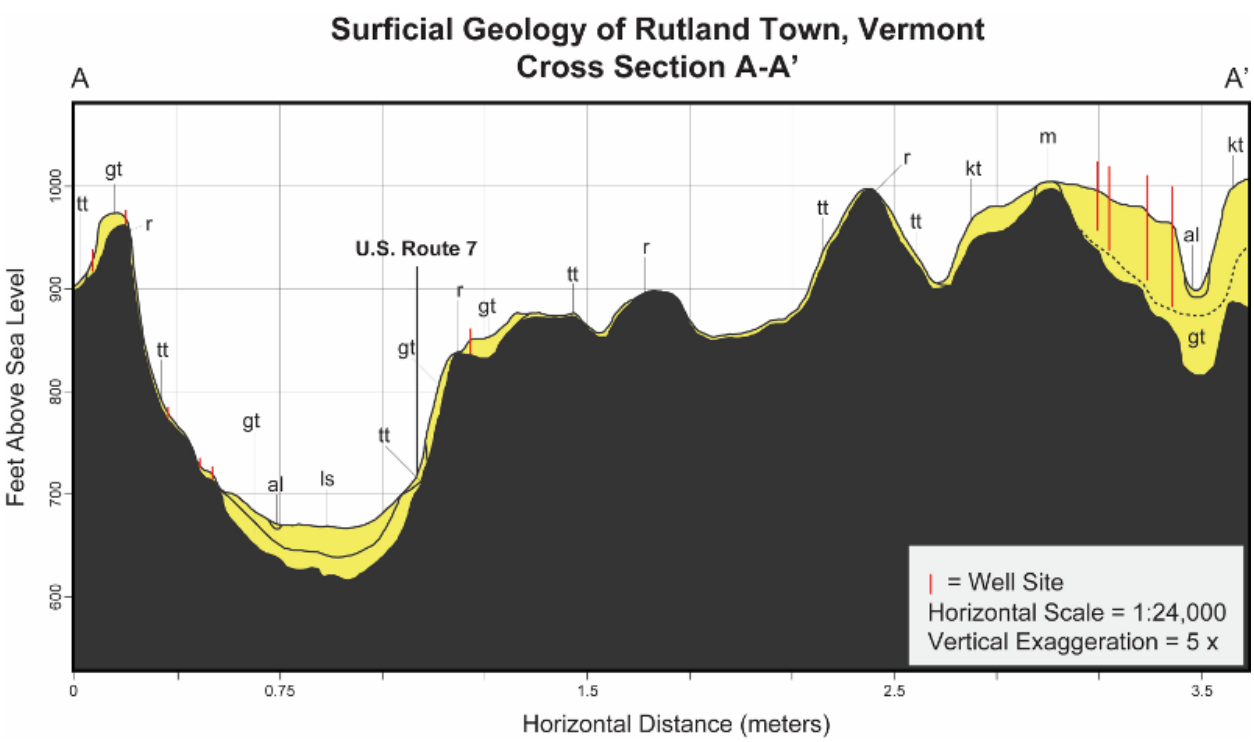
5.2 – Cross Section Interpretations

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 Rutland and each section was chosen to illustrate the subsurface relationships of important 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.

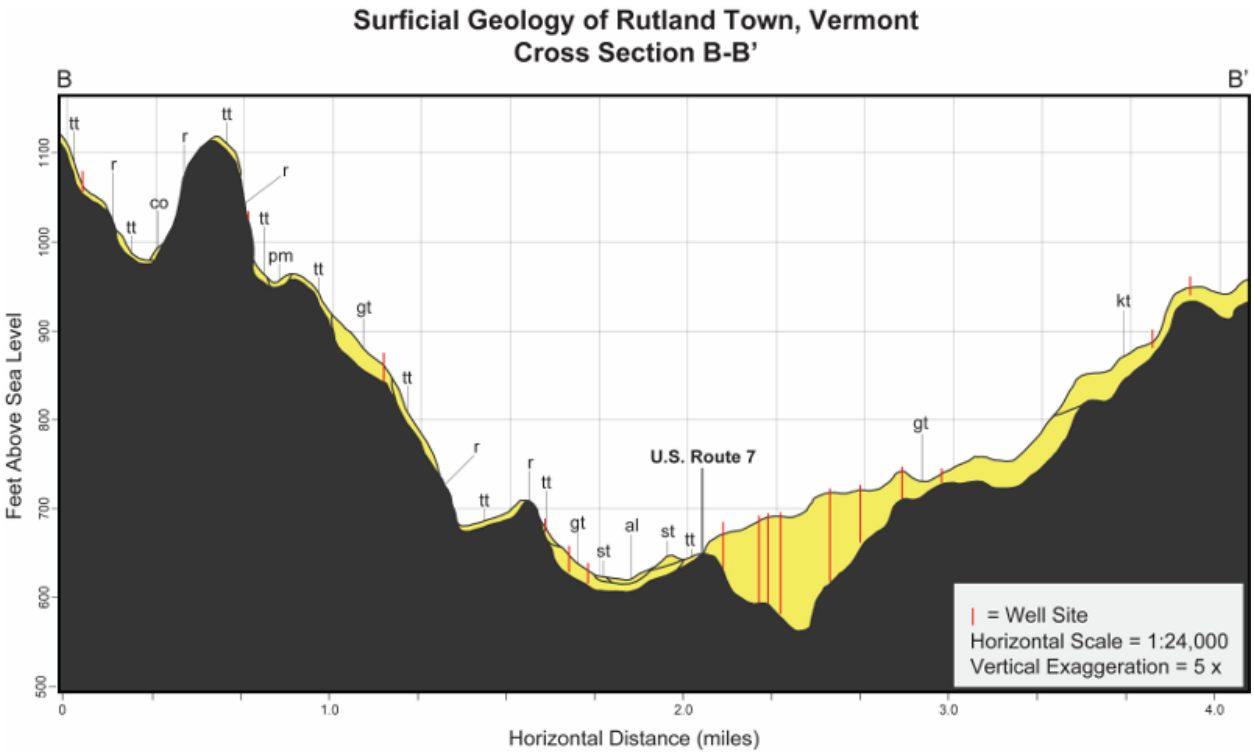
5.2.1 – North Rutland Cross-Section I (A-A')

This cross section extends from the higher elevation highlands in the west to the higher western flank of the Green mountains. Glacial till in the western part of the cross section is approximately 130 feet thick, lacustrine sediment in the middle of valley to the west of Route 7 is approximately 60 feet thick and probably underlain by dense lodgement till, and the eastern edge of the cross section illustrates the thickest surficial deposits. This region is covered by kame terraces ranging from 25 to 250 feet in thickness, again probably underlain by lodgement till.



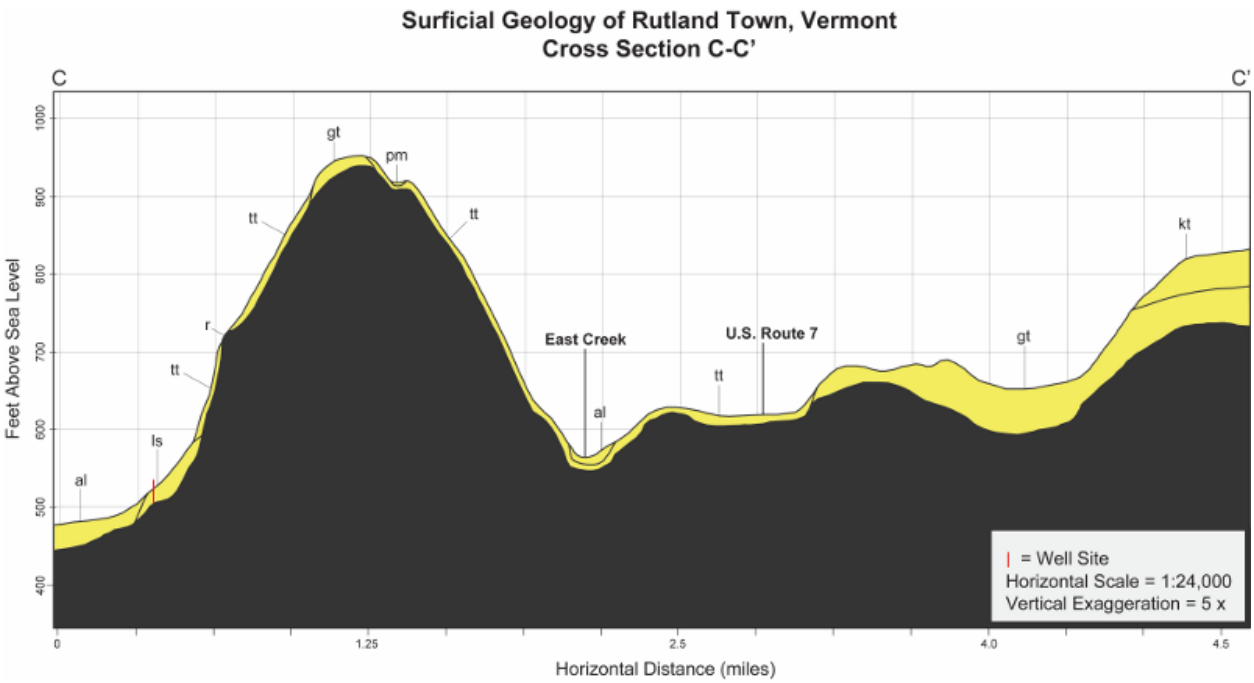
5.2.2 – North Rutland Cross-Section II (B-B')

This cross section also extends from the higher elevation highlands in the west to the higher western flank of the Green mountains. Surficial deposits in the western portion of the section are dominated by thin till and colluvium and the deposits in the valley to the west of Route 7 are approximately 20 to 50 feet thick. However, on the east side of Route 7, there is an incised bedrock channel filled with till varying in thickness from approximately 80 to 200 feet thick overlain by kame terrace deposits ranging from 50 to 250 feet in thickness. Most of the wells along this cross section terminate in glacial till and kame terrace deposits.



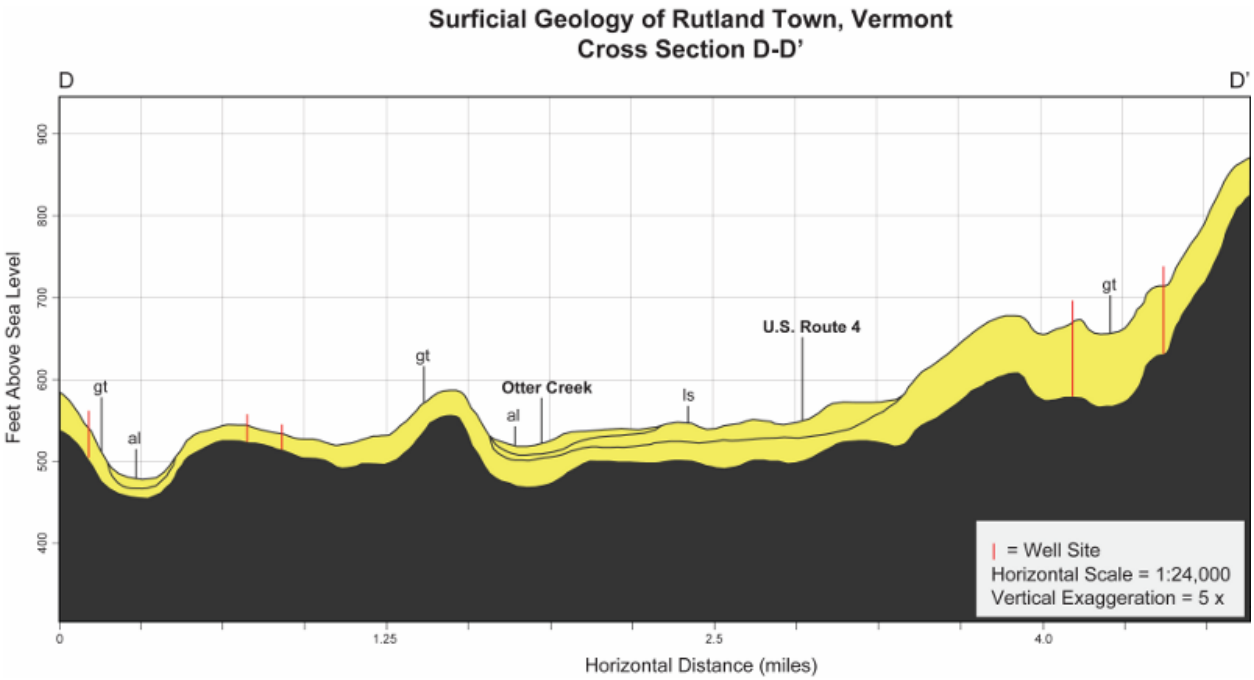
5.2.3 – Center Rutland Cross-Section (C-C')

This cross section traverses both Otter Creek Valley to the west of the western highlands in Rutland Town and the valley housing Rutland City. The surficial deposits in the western edge of the section are dominated by alluvium and lacustrine sediment ranging in thickness from 20 to 60 feet, deposits underlying East Creek are approximately 20 to 40 feet thick, while glacial till and kame deposits to the east of Route 7 range in thickness from 100 to 200 feet thick. Most wells in the eastern section of the cross section area are low yielding (10 to 20 gpm) gravel wells



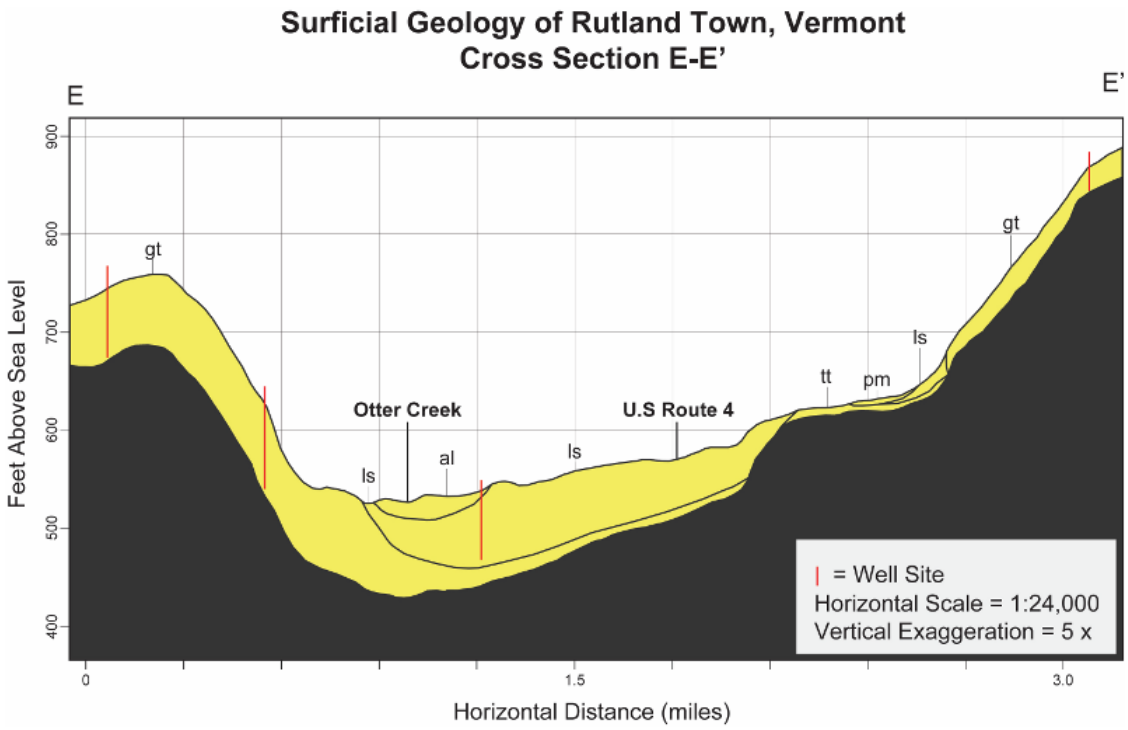
5.2.3 – South Rutland Cross-Section I (D-D')

This cross section begins on a gentle slope on the western border of the town, crosses a small tributary to Otter Creek, crosses the Otter Creek Valley and terminates on the western flank of the Green Mountains. Glacial till on the western edge of the section ranges from approximately 15 to 100 feet thick, alluvial sediments associated with aggradation within the Otter Creek Valley range in thickness from 50 to 90 feet, and glacial till covering the Green Mountains is approximately 25 to 110 feet thick. Relatively few private wells penetrate the lower elevations of Otter Creek Valley, therefore estimates of overburden thickness in this region were derived from isopach modeling and test wells described by Caswell et al. (1994 and 1995) installed to identify a secondary town water supply.



5.2.3 – South Rutland Cross-Section II (E-E')

This cross section begins on the eastern slope of a ridge running north south along the western margin of the town boundary, crosses a wide section of the Otter Creek Valley, and terminates on the western flank of the Green Mountains. The glacial till mantling the slopes to the west range in thickness from 50 to 150 feet thick, the alluvium and lacustrine sediments filling the Otter Creek Valley are 25 to 125 feet thick, and glacial till covering the eastern slopes of the section is approximately 20 to 60 feet thick. Similar to cross section D-D', relatively few wells exist in this area and estimates of overburden thickness in this region were derived from isopach modeling and test wells described by Caswell et al. (1994 and 1995).



5.3 – Isopach Map

The isopach map matches is consistent with both the well data and surficial deposits. The thickest areas of overburden occur in the northeast corner of the town, along the eastern edge of town and in the in southwestern corner of town. These areas are covered by thick kame terrace deposits in the east and thick glacial till in the southwest. 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 prediction of overburden in this area of the map and ultimately the bedrock topography (Figure 15).

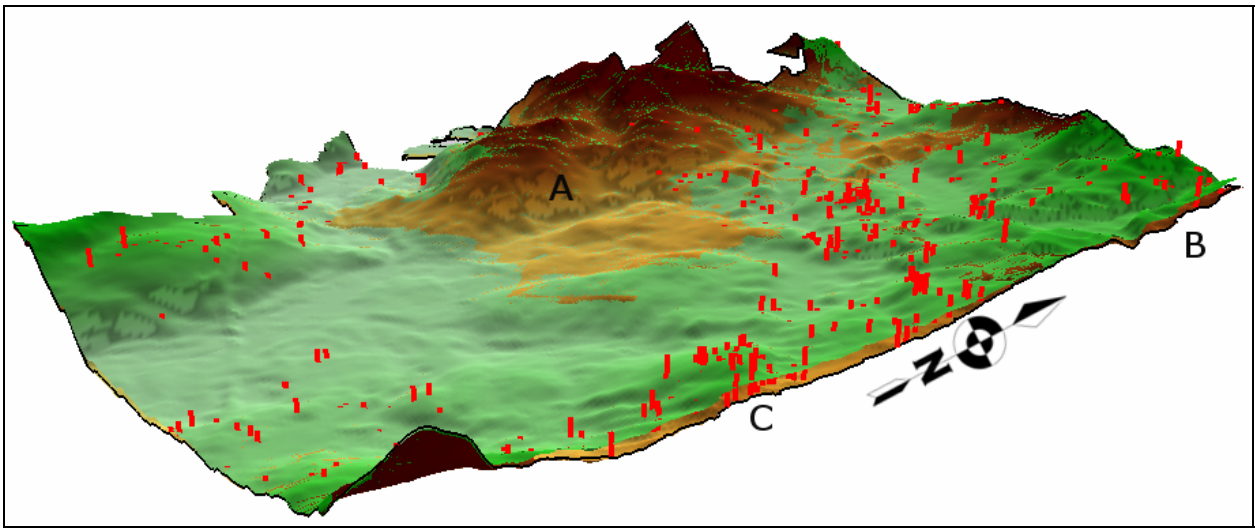


Figure 15: Two dimensional representation of bedrock topography relative to surface topography. Green hues represent overburden and brown hues represent inferred bedrock topography while wells are extruded in red. The area strongly influenced by extensive bedrock outcropping is visible in the center of the image (A) and two areas of thickest overburden are visible in the far northeastern corner of town (B) and the east-central areas of town (C) indicated by the vertical gap between the green and brown layers.

5.4 – Summary of Hydrogeologic Characteristics

Of the 552 rectified wells in Rutland Town, 493 of them terminate in bedrock and 69 terminate in unconsolidated sediment or gravel. The bedrock wells were differentiated by the lithologic suitability for groundwater flow – (e.g. - carbonates, slates/phyllites, quartzites, and crystalline rocks). The two main hydrogeologic units identified within the study area are rocks associated with the Type I Champlain Valley Sequence and those associated with the Type II Green Mountain Sequence. A summary of wells within each hydrogeologic unit and their associated yield and depth are summarized in Table 2.

Well yields are apparently highest in bedrock associated with gneiss of the Mt Holly Complex (mean = 29gpm) and carbonates of the Champlain Valley Sequence (mean = 22gpm). However, while the carbonates appear to have slightly lower yields, they are not as deep as wells in the gneiss and there is a limited sample size for wells terminating in the Mt Holly Complex.

Table 2: 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 - Champlain Valley Sequence (n = 343) Exposures of carbonates, quartzite, and conglomerates within the, Shelburne Danby, Winooski, Monkton, Dunham, and Dalton Formations.	22	10	303’	265’
Type Ib - Champlain Valley Sequence (n = 21) Exposures of slate and phyllite within the Hortonville Formation.	14	5	338’	303’
Type Ic - Champlain Valley Sequence (n = 113) Exposures of Cheshire Quartzite	15	10	231’	222’
Type II - Green Mountain Sequence (n = 6) Exposures of biotite gneiss of the Mt Holly Complex	29	17	367’	370’

5.5 – Potentiometric Surface + Flow Lines

The interpolated potentiometric surface is consistent with well data, surficial geology, and bedrock 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 50 foot contours extracted from the underlying potentiometric surface. Both of these data layers rely on the static level of water within wells drilled throughout Rutland Town. Because the hydraulic gradient is gentle, the contours are widely spaced and therefore uncertainty exists in the inferred flow direction in some areas of the map. However, the general trend of flowing east to west and northeast to southwest is readily apparent. This potentiometric surface and resulting flow lines are consistent with groundwater flow directions described by Caswell et al. (1994). Groundwater flow lines are indicators of potential flow down hydraulic gradient within an aquifer. These flow lines are typically drawn perpendicular to potentiometric contours, however because of the gentle hydraulic gradient throughout the field area, some flow lines were not drawn across all contours of lower elevation.

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 areas are of potential interest:

1. Mapping dead ice and meltwater channel features within the western highlands in greater detail to refine our understanding of deglaciation.

2. Developing a better understanding of the relationship between the high level and valley lake system along East and Otter Creeks.

3. Characterizing the sedimentology and stability of the kame terraces along the eastern edge of Rutland Town.

4. Mapping the surficial geology of adjacent areas, especially to the east, to help characterize the high volume source of sediment that helped build such extensive kame terraces.

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.

Brace, W.F., 1953, The geology of the Rutland area, Vermont [Rutland VT 15' quadrangle]. Vermont Geological Survey Bulletin #6, 120 p., 3 plates.

Caswell, Eischler, and Hill, Inc., 1994, Hydrogeologic evaluation of 8-inch well on Otter Creek, Town of Rutland, Vermont, prepared for, Dufresne-Henry, Inc.

Caswell, Eischler, and Hill, Inc., 1995, Report of exploration drilling Otter Creek Site, Town of Rutland, Vermont, prepared for, Dufresne-Henry, Inc.

Chang, K., 2004, Introduction to Geographic Information Systems. McGraw Hill Publisher, New York, NY, 400p.

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.

Doll, C.G., Cady, W.M., Thompson, J.B., and Billings, M.P., 1961, Centennial geologic map of Vermont. Vermont Geological Survey, 1:250,000.

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.

Gold, C.M., 1979, Drill-hole data validation for subsurface stratigraphic modeling, in, Computer Mapping of Natural Resources and the Environment, Harvard University, Laboratory for Computer Graphics and Spatial Analysis: 52-58.

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., 1997, Preliminary bedrock geologic map of the Chittenden quadrangle, Rutland County, Vermont: U.S. Geological Survey Open-File Report 97-703, 1:24,000.

Ratcliffe, N.M., 1998, Digital and preliminary bedrock geologic map of the Rutland quadrangle, Vermont: USGS Open-File Report 98-121, 1:24000.

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.

Yang, X. and Hodler, T., 2000, Visual and statistical comparisons of surface modeling techniques for point-based environmental data. Cartography and Geographic Information Systems, v. **27**, N.2, 165-175.

Stewart, D., 1972, Geology for environmental planning in the Rutland-Brandon region, Vermont. Montpelier, Vermont. Vermont Geological Survey Environmental Geology Series, 49p, 7 plates.

8.0 – Appendix

8.1 – Kriging Workflow:

1. Import uncompressed and rectified well data

2. Convert Chittenden bedrock contact polygons to points by:
    a. Calculate centroid using Xtools extension

3. Merge Chittenden bedrock points with well data and bedrock GPS points
    a. Remove duplicate features using TypeConvert extension
    b. Bedrock overburden = zero
    c. Update overburden values in gravel wells
    d. Remove erroneous wells

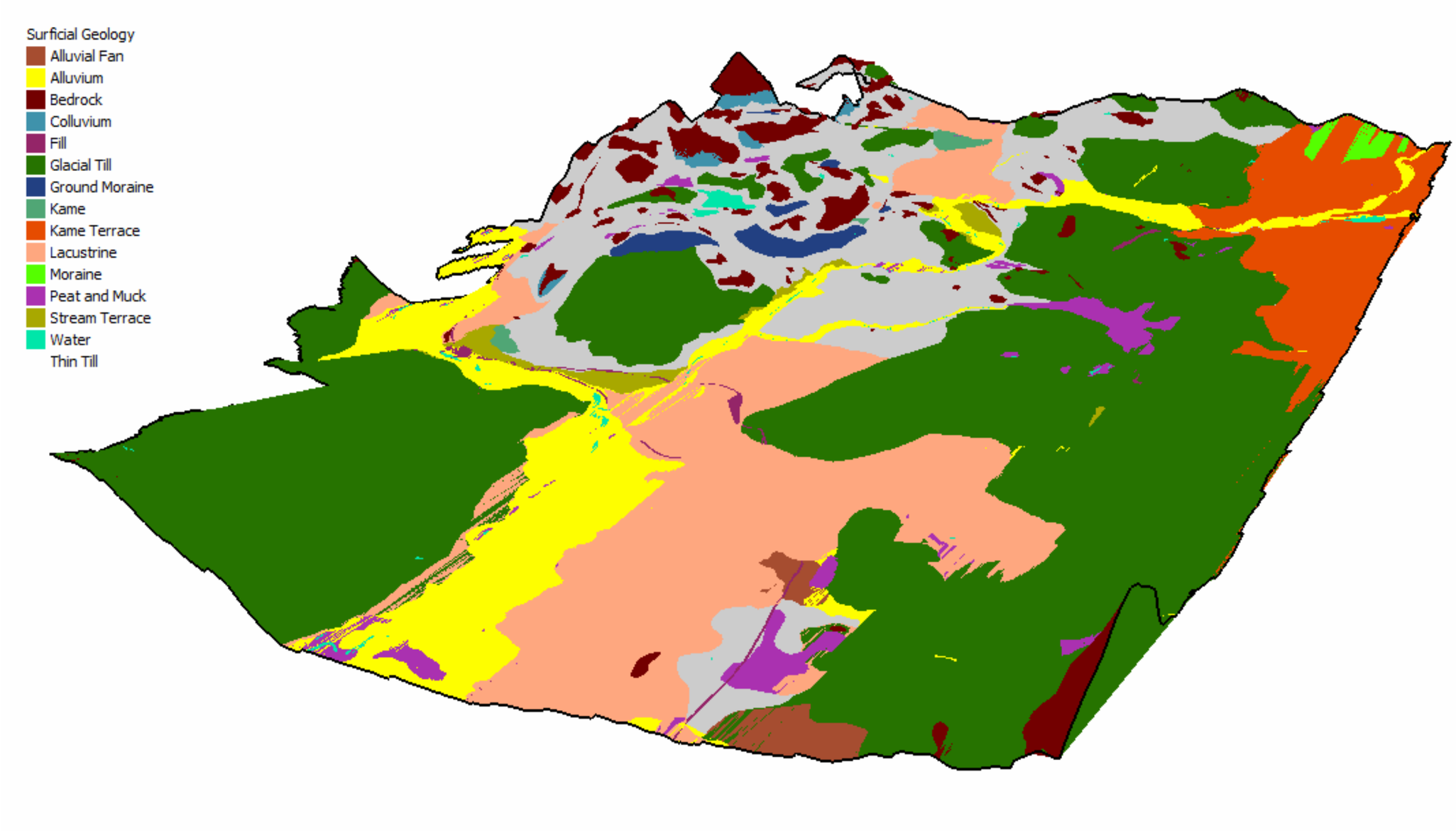
4. Use ESRI Geostatistical Analyst to:
    a. Evaluate whether a trend exists
        i. Increase # of points ArcGIS can process to create variogram that evaluates what range the measured values deviate from the model used to predict unknown values.
    b. Use ordinary and/or universal kriging following previous workers
    c. Evaluate model root mean square error
    d. Create subset for validation (in this case an 80/20% split)
        i. Training subset is used to create model
        ii. Testing subset is used to validate model
    e. Create filled contour and contour map
        i. Smooth final version of contours to minimize jagged edges
    f. Create a Prediction Standard Error Map to identify areas with most variance

5. Look at each and ever well to evaluate in-situ errors and re-contour if necessary

8.2 – Rutland 3D Aerial Visualization

Visualization of 2008 NAIP draped over the topography of Rutland Town illustrating the local physiographic variations relative to visual landmarks.

8.2 – Rutland 3D Surficial Geology



Visualization of surficial geology draped over the topography of Rutland Town illustrating the variations in major surficial deposits relative to visual landmarks.