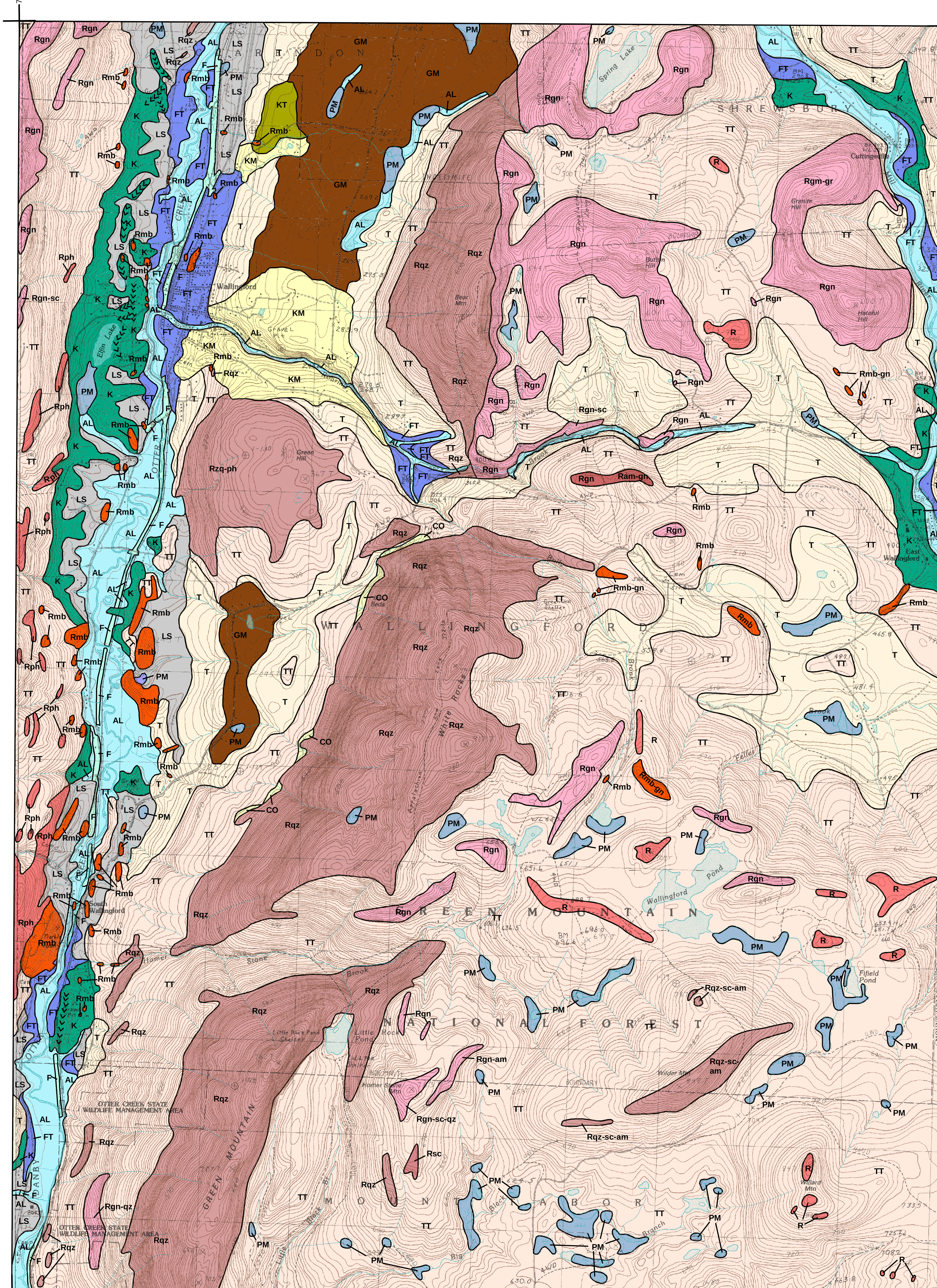

Surficial Geologic Map of the Wallingford Quadrangle, Vermont

VGS Open File Report 2006 - 1

Author: David J. DeSimone

Map Produced: September 22, 2005

Digitized and map layout by Information & Visualization Services

RECENT DEPOSITS

- F — Fill; artificial, rail and road beds
- PM — Peat & muck; swamp/wetland; silt & clay; low-lying flat lands
- AL — Alluvium; stream flood plains, fine sand, silt & gravel; river bottom lands
- FT — Fluvial terrace, old flood plains; sand, silt & gravel; flat lands
- CO — Colluvium; primarily talus of boulders at base of white rocks ridge; relict rock glacier form in some area; moderately sloping lands

LATE PLEISTOCENE GLACIAL DEPOSITS

- LS — Lake sand; lake bottom deposits; fine sand; gently sloping to flat lands
- K — Kame, undifferentiated; gravel, sand & boulders - cobbles; rolling, hilly lands
- >>> — Esker; subglacial-englacial meltwater stream channel deposits; gravel & sand; prominent elongate ridges
- KM — Kame morraine; ice contact, meltwater & ice derived deposits; gravel, sand & glacial till; rolling, hilly, ridged lands with flat areas
- GM — Ground morraine; ice contact stagnation, meltwater & ice flow derived deposits; till, gravel & sand; streamlines to kamic to flat lands
- KT — Kame terrace; ice contact meltwater & sediment flow deposits; gravel, sand & silt; flat to nearly flat lands
- T — Till; ice-derived deposits; subglacial; hardpan silt, gravel & sand with boulders; hill slopes & streamlined hills
- TT — Till; thin, with frequent rock outcrops & colluvium areas, less than 3 meters or 10 feet thick over ledge; hill slopes & summit areas

PRE-CAMBRIAN & PALEOZOIC BEDROCK

- R — Rock outcrop
- Rmb — Rock outcrop, marble; all carbonate rocks termed marble here
- Rqz — Rock outcrop, quartzite
- Rph — Rock outcrop, phyllite
- Rsc — Rock outcrop, schist
- Ram — Rock outcrop, amphibolite
- Rgn — Rock outcrop, gneiss

Map published by: Vermont Geological Survey
Laurence Becker, State Geologist
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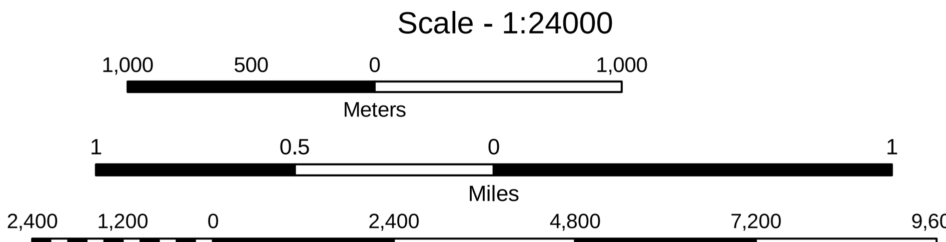
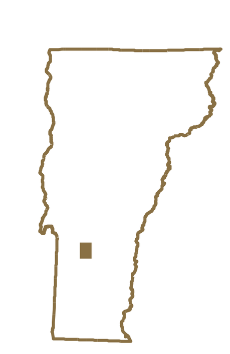
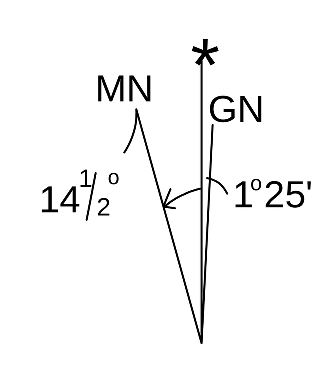
laurence.becker@state.vt.us
http://www.anr.state.vt.us/dec/geo/vgs.htm

Scale - 1:24000







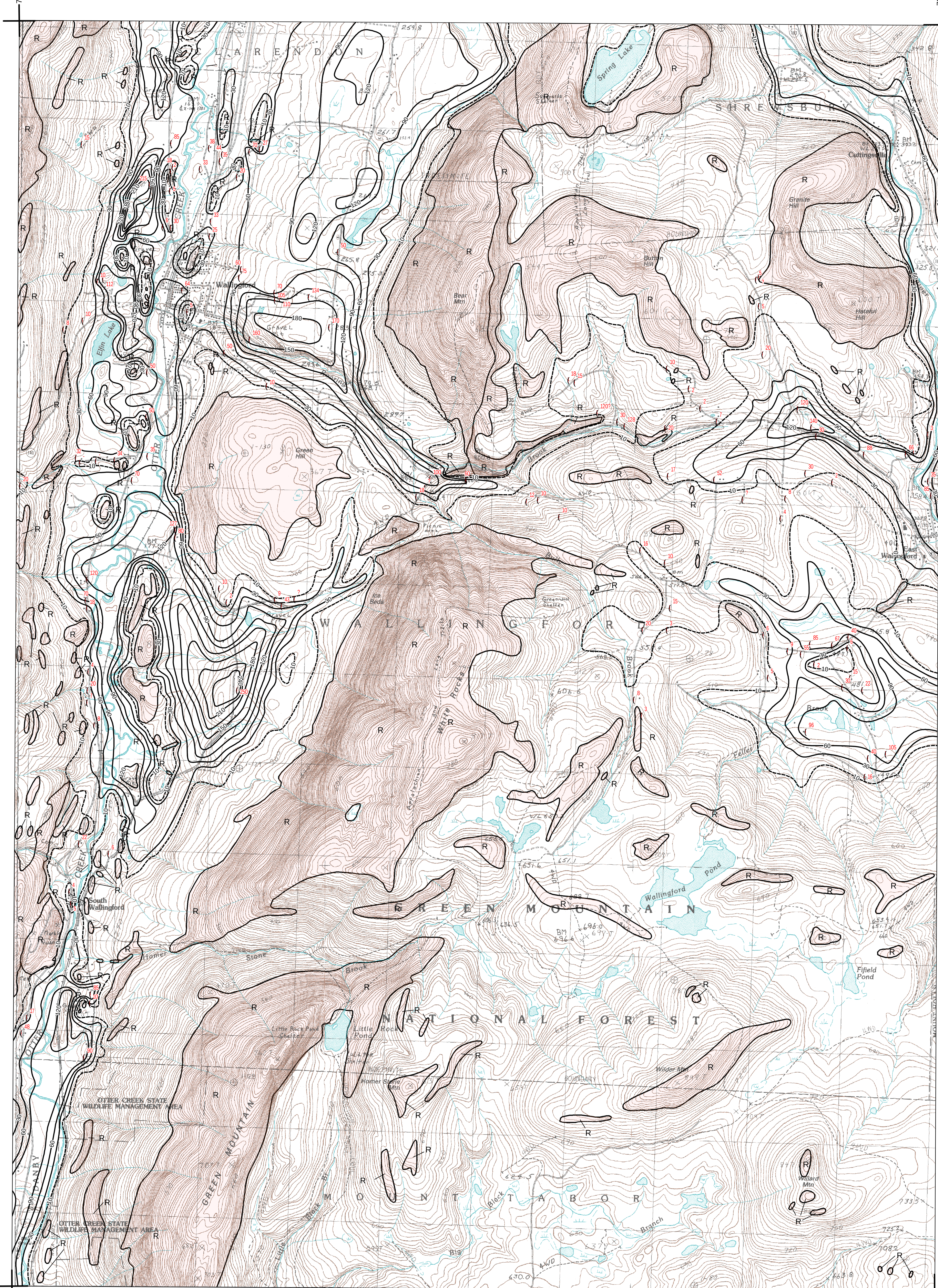
Research supported by the U.S. Geologic Survey, National Cooperative Mapping Program under USGS award number 04HQAG0070. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, other expressed or implied, of the U.S. Government.

73° 00' 00"

72° 52' 30"

43° 30' 00"

43° 30' 00"



43° 22' 30"

43° 22' 30"

73° 00' 00"

72° 52' 30"

Overburden Thickness Map of the Wallingford Quadrangle, Vermont
VGS Open File Report 2006 - 1
Author: David J. DeSimone

Map Produced: September 22, 2005

Digitized and map layout by Information & Visualization Services

(21 Depth to rock at well; "-" denotes NO DATA

(R) Rock at surface

30 Overburden thickness contours at 30, 60, 90, 120 & 150 feet

10 Thin drift limit at 10 feet (3 meters)

*Wells located by Vermont Geological Survey

Map published by: Vermont Geological Survey
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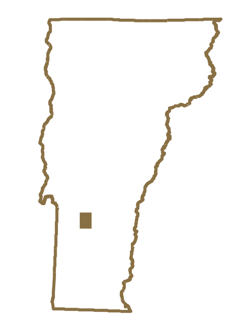
Scale - 1:24000

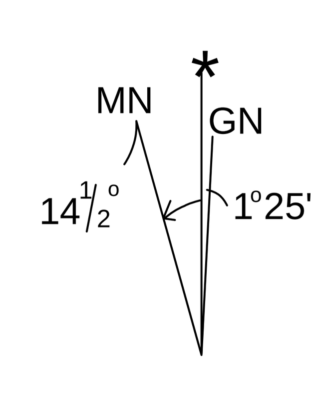
1,000 500 0 1,000 2,000
Meters

1 0,5 0 1
Miles

2,500 1,250 0 2,500 5,000 7,500 10,000
Feet



QUADRANGLE LOCATION



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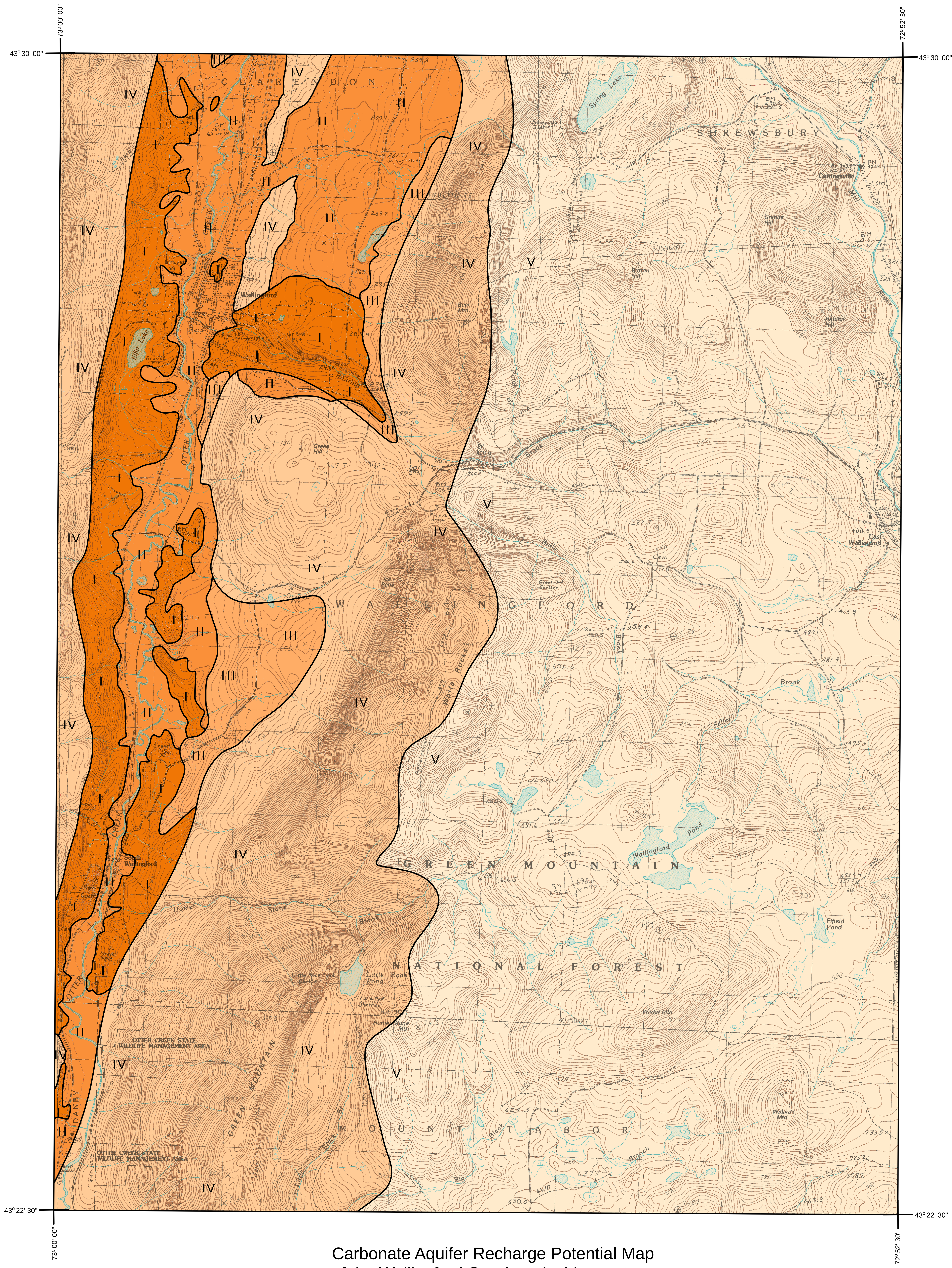

Carbonate Aquifer Recharge Potential Map of the Wallingford Quadrangle, Vermont

VGS Open File Report 2006 - 1

Author: David J. DeSimone

- I Highest
- II High
- III Moderate
- IV Low
- V Lowest

Map Produced: September 22, 2005

Digitized and map layout by Information & Visualization Services

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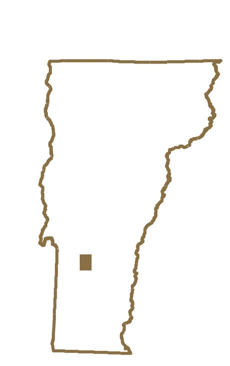

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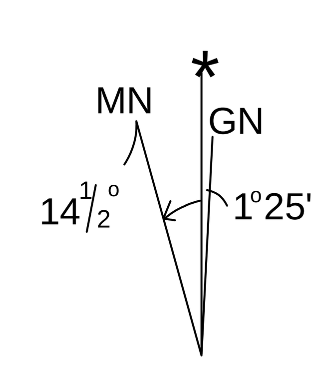
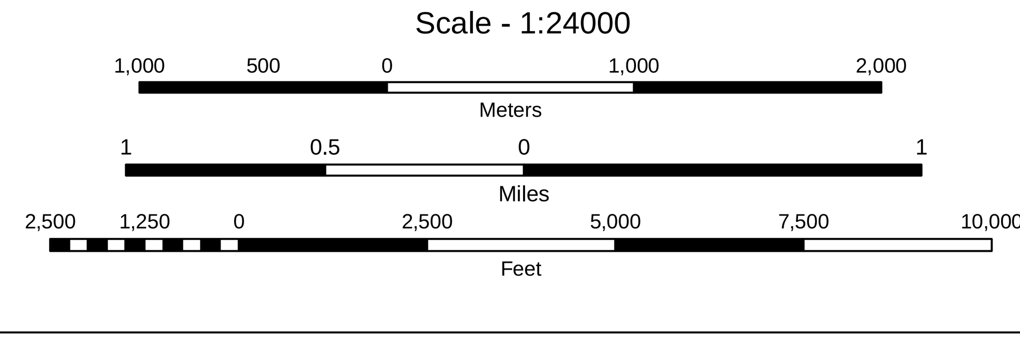


Scale - 1:24000



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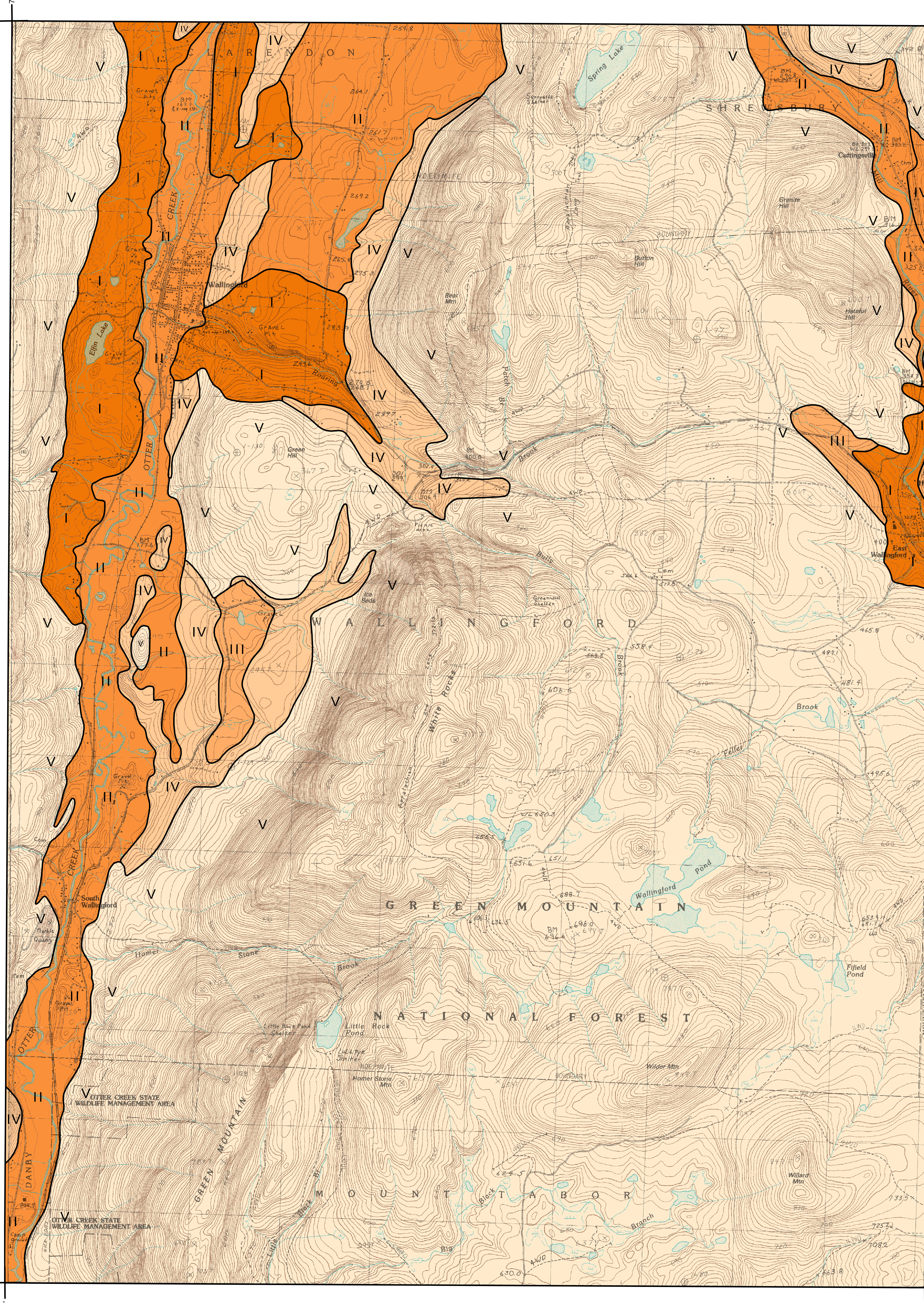

Overburden Aquifer Recharge Potential Map of the Wallingford Quadrangle, Vermont

VGS Open File Report 2006 - 1

Author: David J. DeSimone

Map Produced: September 22, 2005

Digitized and map layout by Information & Visualization Services

- I Highest
- II High
- III Moderate
- IV Low
- V Lowest

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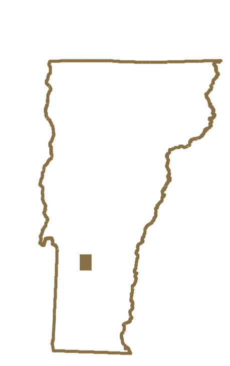

QUADRANGLE LOCATION

MN GN 14½° 1°25'

Scale - 1:24000

1,000 500 0 1,000 2,000
Meters

1 0,5 0 1
Miles

2,500 1,250 0 2,500 5,000 7,500 10,000
Feet

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Surficial Geology and Hydrogeology

Of

Wallingford, Vermont

A Technical Discussion

With

Executive Summary

By

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Prepared under Contract to the Vermont Geological Survey

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103 South Main Street, Old Laundry Bldg.
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Contract EC 33-04

Executive Summary

The primary objective of this investigation was to provide a modern inventory of surficial and hydrological data illustrated through a series of GIS formatted maps explained in this discussion. These maps can thus be easily modified as new data are generated and new interpretations invoked in the years ahead. This report and accompanying maps are meant to serve as a baseline for our current knowledge of the surficial geology and hydrogeology of the Wallingford area. While the discussion is highly technical, there are appendices which make the data useful to the average layman, farmer, gravel resource extractor, land use planner or developer. The surficial geologic mapping units are accordingly explained in the context of their encompassing soils, slope stabilities, permeabilities, drainage, and gravel/sand resource potential. Indeed, a separate non-technical discussion and the unit descriptions mentioned above have been packaged into an accompanying report and history for Wallingford residents.

The results of the mapping enabled me to decipher details of the deglaciation of the quadrangle unrecognized by previous workers. Three ice margins - South Wallingford, Wallingford and Haven Hill - were delineated on the basis of ice marginal sediment such as kame moraines, ground moraines and esker/kame systems. A retreat of a largely active valley glacier is supported by the mapping and a steep calving margin may have existed along the Otter Creek glacier which fronted a Glacial Lake Emerald. Extensive deposition of a unit termed ground moraine occurred in two areas east of Wallingford and east of South Wallingford especially and this suggests the presence of a stagnating margin attached to the edge of the actively retreating valley glacier. Fine sands accumulated in a glacial lake here termed Glacial Lake Emerald. These sands drape over the kames, eskers, till and bedrock hills which dot the valley floor. Finer sediments such as silt and clay appear in drillers logs. However, no deltaic sediment was observed. This indicates that the retreating glacier never paused for a period of time lengthy enough to build a delta into the Lake. No tributary deltas to the lake were observed. This also indicates that Lake Emerald may never have maintained a stable water level. I surmise that the waters of Lake Emerald were continually falling as the Otter Creek glacier retreated toward Rutland. The dam for Lake Emerald was at the threshold to the south where there are ice contact deposits and a narrowed section of valley in the vicinity of present Lake Emerald where the present threshold is at about 720 feet +/- 10 feet. Remnant ice and/or sediment may have retained water at a higher level initially as lake sediment occurs above the threshold level on the Wallingford quadrangle.

Both an overburden aquifer developed in glacial gravels and a bedrock aquifer developed in carbonate rock exists and these represent extremely valuable sources of potable water. The average yield from Otter Creek Valley overburden wells is 19.7 GPM (gallons per minute) while the average yield from the carbonate aquifer wells is 11.6 GPM. The data hint that these two aquifers may be hydraulically connected. The subsurface data indicate that a basal lodgement till layer is largely absent from the valley region. Gravel is often recorded by drillers immediately atop limestone. Any overlying impermeable overburden units appear to be thin and discontinuous. Drillers logs report some infilling of the deeper parts of the preglacial valley with finer lake sediment and this may locally confine the carbonate aquifer. The 3 overburden wells static water level data mesh nicely with the carbonate aquifer piezometric surface map and this supports the notion that the two aquifers share a common water table. The areas of kame moraine, ground moraine, kame and lake sand at the surface indicate that considerable recharge of the overburden and carbonate aquifers is occurring through direct infiltration of water through these variably but relatively permeable sediments. The carbonate aquifer may be only locally isolated from the overburden aquifer by impermeable till or diamicton units.

A surprisingly high average yield from quartzite wells was calculated at 13.2 GPM, reduced to 11.6 GPM if the highest and lowest values are ignored. However, the number of quartzite wells is small and 4 of these are drilled at or near the contact with the carbonate and record carbonate rock in the drillers' logs. These 4 wells have an average yield of 21.5 GPM.

The black shale/phyllite rock unit along the western edge of the quadrangle represents an aquitard/aquiclude and is in thrust fault contact with the carbonate aquifer to its east. This black shale/phyllite rock may be hydraulically isolated from the carbonate by an impermeable thrust fault boundary. This prospect is one which may warrant further study. The author is unaware of any water quality concerns in the black shale/phyllite but suggests that the possibility for sulfur and/or radon content in the ground water from the black shale/phyllite should discourage use of this rock as a ground water resource and that further study of the water quality here may be valuable.

Contents

Physiography and Bedrock Geology

The Wallingford quadrangle encompasses portions of 3 physiographic subdivisions - the Green Mountains, the Taconic Highlands, and the Vermont Valley as outlined in Stewart and MacClintock (1969, page 18). Map 1 illustrates the topography of the quadrangle depicted at a scale of 1:24000 and also displays all located water wells on the quadrangle. The narrow north-south trending and northernmost extension of the Vermont Valley occupied by Otter Creek slices the uplands along the western 1/7 of the map area. Glacial sediments fill the valley floor and Otter Creek has established a sinuous northward path by down cutting through these overburden materials. Mill River, a minor tributary to Otter Creek, flows northwest and joins Otter Creek just beyond the quadrangle to the north. Within the valley floor, there are numerous rounded and elongate knobs of protruding marble and interlayered quartzite. These are more resistant members of the prevailing marble underlying the valley. One major quarry exploits perhaps the largest marble knob in the valley.

Map 2 depicts the major and minor surface drainages, areas of wetlands, and the larger named ponds on the quadrangle. Roaring Brook flows westward out of the Green Mountains and joins Otter Creek in the village of Wallingford. Homer Stone Brook, Hartsboro Brook, Ice Bed Brook, Bear Mountain Brook and numerous small brooks flow westward and drain the western flank of the Green Mountains. Hartsboro Brook/Ice Bed Brook and the lower reach of Roaring Brook flank Green Hill, an outlier of Cheshire Quartzite which forms a resistant large knob in an otherwise more broad section of the valley. A few short brooks drain the narrow slice of uplands along the western edge of the quadrangle. This system of tributaries to Otter Creek forms an overall subparallel drainage network. A more dendritic network of tributaries drains the Green Mountain uplands which dominate the eastern half of the quadrangle. The more striking surface feature of these uplands is the abundance of small to large ponds and numerous wetlands. The numerous peaks appear to stand above a peneplain or plateau-like surface where most of the wetlands and ponds are found. Irregardless of the source of the flatter area between the summits, the flatter area served as a locale for isolation of thin ice sheet remnants during deglaciation. The last ice blocks became the pond and wetland basins.

Recent bedrock mapping by Burton and Ratcliffe (2000) provides a modern framework for the extent of different lithologies and offers one explanation for the structural geology. Map 2 distills the major lithologic and structural elements of their map in order to define the hydrogeological units discussed below.

Carbonate rocks – limestone, dolostone and marble, underlie the valley. The extreme westernmost sliver of higher terrain adjoins the Dorset Mountain region that separates the Otter Creek and upper Batten Kill drainage basins on the east from the Mettawee and West Branch drainage basins on the west. Based upon Burton and Ratcliffe's recent map, Lytle's (1995) map of the Arlington quadrangle, and from the author's knowledge, the rocks of both these regions were emplaced by thrust faulting during the Ordovician Taconian Orogeny. Sometime later, extension activated a normal fault along the west side of the Vermont Valley as indicated on the map of Burton and Ratcliffe. Foliations and/or bedding generally dips gently to moderately eastward throughout these areas with only localized westward dip angles, presumably along minor drag fold axes. Vermont Valley rocks consist of comparatively thin slivers of thrusted carbonates with the thicker Giddings Brook slice of the Taconic Mountain schist to the west that all lie in shingled fashion with east-dipping low angle thrust faults. Deeper beneath these rocks there may be an underlying major basal thrust fault, following the model of Karabinos et al (1996).

The Green Mountain physiographic province dominates much of the quadrangle. A steep western flank faces the Vermont Valley and is underlain predominantly by Cheshire Quartzite. The bedding in the quartzite also dips eastward at low to moderate angle as it does in regions to the south. This flank approaches a broad summit that extends eastward to the limits of the quadrangle. The summit is dotted with numerous ponds interspersed with several modest peaks that top out below 850 meters. The Mount Holly complex of pre-Cambrian gneissic bedrock underlies the Green Mountains. The western flank of the mountains consists of three massifs arranged en echelon along the east side of the Otter Creek Valley. These massifs – the Bear Mountain massif, the White Rocks mountain massif, and the Green Mountain massif – present an imposing and steep eastern flank of the Otter Creek valley. Homer Stone Brook flows between the latter two massifs while Roaring Brook flows between the former two massifs. In the northeastern corner of the quadrangle, a granitic pluton was emplaced sometime during the Cretaceous and underlies Granite Hill. Burton and Ratcliffe also show some pre-Cambrian basement in the northwest corner of the quadrangle composed of the same schist with amphibolite as can be found in the Green Mountains.

Ice Bed Brook heads in the Ice Beds, a curious and intriguing "anomaly" at the base of White Rocks Mountain. This will be discussed in a later section.

Field Data Sites

Map 3 depicts the location of field data sites such as observed bedrock and overburden exposures. Sites which yielded some useful data are numbered from WAL04-1 through WAL04-03, a small number of such sites due to a lack of observed natural or man-made exposures. Descriptions of the numbered filed data sites can be found in Appendix 1. Smaller sites are identified by an "x" and a notation as to the type of overburden material present. Lithology is noted for most outcrops.

Ice flow direction indicators are shown on Map 3. The measured compass orientation of striations and grooves in bedrock is recorded alongside the head of the arrow symbol. In addition, the orientation of prominent streamline molded landform features such as drumlins, rock drumlins and related forms are depicted. A dashed line at the 1,500 foot elevation contour separates valley ice flow from upland ice flow indicators. The most obvious feature of Map 3 is the strong alignment of valley ice flow indicators parallel to valley orientation. This verifies the latest ice in these valleys was thin and actively flowing valley ice.

Esker systems are depicted on Map 3 by a series of ">>>>>" showing the extent of the esker segments. A short esker is present in South Wallingford and has associated kames/kame moraine material. A longer esker system is present through Wallingford and extends to the northern limit of the quadrangle. It has extensive associated kame/kame moraine material. I have divided this system into a southern or Elfin Lake segment and a northern or Haven Hill segment. Nearly all of the eskers and kames have a somewhat subdued appearance due to the later accumulation of lake sand around their flanks and bases and even thinly over the top of the landforms.

Bedrock Hydrogeology

Hydrogeologic units: Our region is underlain by several distinct bedrock types. I have lumped together the rock types into their major subdivisions because we are primarily interested in understanding how water moves into and through the different major rock types. What rock types are most likely to yield the greatest amount of water to us if we drilled a well into them? This is the question we want to address in our understanding of bedrock types. I have distinguished four major bedrock groupings on the Wallingford quadrangle and depicted their aerial extent on Map 2.

Unit II is the primary bedrock aquifer, a good source of underground water that is tapped by most well drillers. Unit II is carbonate rock and it includes different layers composed of limestone, dolostone or marble. This aquifer underlies the Otter Creek Valley portion of the quadrangle and extends eastward at the base of Green Hill on both the north and south flanks of the hill. The eastward extension of the carbonates continues north of Roaring Brook along the lowest flanks of Bear Mountain generally below 1000ft elevation. Burton and Ratcliffe depict the contacts between the carbonate rocks and the adjacent rocks to the east and west.

The western limit of the Unit II carbonate aquifer is marked by a major fault with the carbonates on the downthrown block of the fault. The up-thrown block of the fault is composed of relatively impermeable shale-phyllite-schist-amphibolite, all of which can be lumped for hydrogeologic purposes into a single unit of fine grained bedrock. This is Unit III, a grouping of predominantly black shale-phyllite and represents an aquiclude.

The eastern limit of the Unit II carbonate aquifer is identified by Burton and Ratcliffe as alternately following a thrust fault and a lithologic contact with a band of predominantly quartzite containing minor amounts of interlayered phyllite and a basal conglomerate. This is Unit IQ and it occupies the western flank of the Green Mountains to the summits of White Rocks, Green and Bear Mountains. The quartzite is a unit of generally low porosity and is generally considered a poor aquifer or aquitard. However, the wells drilled into this unit have an average yield comparable to those drilled into the carbonate. This suggests that there are sufficient fractures in the quartzite to enable water to move through the rock and into a drilled well. Good yields are possible but the high yields possible in the carbonates are unlikely.

East of this is Unit I, a grouping of schist, gneiss, and minor amphibolite, marble and quartzite. There is also an area of granite beneath Granite Hill in the northeast corner of the quadrangle. These are very different rock types but all are usually poor sources of underground water except for the marble and perhaps the quartzite layers and represent an aquiclude aquifer.

The best chance of finding a good underground water supply is to drill a well into Unit II. However, there is no guarantee that drilling a well into the carbonate rock of Unit II will yield a lot of water. This material holds and transports water through a network of fractures in the rock and some of these fractures may be enlarged into wider openings by dissolution of the rock. That is why many wells drilled into it can yield water in dozens or even more than a hundred gallons per minute. The driller has been lucky enough to "hit" many fractures and many of these are enlarged by dissolution.

The lithologic groups depicted on Map 2 represent the 3 bedrock hydrogeologic units I distinguished. These distinctions are useful. While lithologies other than the carbonates may yield water to wells, the majority of the wells are drilled into the carbonate rocks simply because the valley areas underlain by the carbonate rocks are the areas which have been developed.

Recharge potential and well yields: The carbonate aquifer described earlier is a wonderful and precious source of drinkable ground water. I've attempted to rate the land in terms of its likely capacity to recharge this aquifer with water on Map 5. Recharge of the carbonate aquifer comes largely through the direct infiltration of surface water through a thin cover of overburden or glacial sediment masking the carbonate rock and through the thicker and permeable regions of kamic and lake sediment. Recharge potential is ranked from I-V with I being the highest recharge potential.

Recharge potential is lowest beneath the overburden-mantled Green Mountains underlain by Unit I. The carbonate aquifer is not present here and a hydraulic connection between the Green Mountain schist-gneiss-amphibolite-granite aquiclude and the carbonates of the valley is unlikely. To be sure, the minor areas of marble and quartzite and the scattered areas of more dense rock fractures enable wells drilled into Unit I to produce yields sufficient for homes. Map 10 shows the yields of wells throughout the quadrangle and compares well yields with the bedrock hydrogeologic units identified on Map 2. Average well yields in Unit I are surprisingly high at 8.5 GPM (gallons per minute), 7.0 GPM if the highest and lowest values are ignored. The single high well yield of 100 GPM is reported for a well in the Mill River Valley. It is adjacent to an overburden well and records 35 feet of boulder sand before penetrating 340 feet of "bluestone", a descriptor I have interpreted to be gneiss in this location. I question whether the data are correct for this well. Might it be that the values for the static water level at 10 feet and for the flow at 100 GPM have been reversed? Too many wells here have yields less than 5.0 GPM with more than a handful of well yields less than 2.0 GPM. Therefore, I see the prospects of a good well in Unit I as improbable.

Unit III and a small area of Unit I occur along the western edge of the quadrangle. This area of black shale-phyllite and schist is ranked as having a low recharge potential for the carbonate aquifer of Unit I. The rocks have low permeability – how easily water can flow through the fractures and pore spaces in the rock. Also, these rock types have very low porosity and only where there are numerous fractures is there much chance of getting good well yields. Indeed, the average yield of wells in Unit III is the lowest of all the bedrock hydrogeologic units at 6.1 GPM, 5.0 GPM when the highest and lowest values are ignored. However, only a few wells drilled into the black shale-phyllite are located on Map 1, a plot of all located wells of the Wallingford quadrangle. Therefore, there is little validity to these average well yield values. My feeling is that if more wells were drilled into Unit III, the average yield would drop noticeably, perhaps down toward 2-4 GPM. Additionally, there is always a potential for water quality issues in black shale-phyllite rock. Sulfur can be prevalent in the ground water from this rock type and a distinct sulfur odor can sometimes be discernible in such well water. Additionally, black shale-phyllite rock can contain above average amounts of uranium and the presence of radon, an intermediate decay product of uranium, can be present in the ground water. For these reasons, it is not recommended that wells be sited in Unit III.

Unit IQ is also ranked as providing low recharge potential to the Unit I carbonate aquifer. Yet, there is a more plausible prospect that some recharge of the carbonate aquifer occurs through the fractures in the quartzite of Unit IQ along the flanks of Bear, White Rocks and Green Mountains. Recharge of the Unit I aquifer is less likely through thicker till covered areas of Unit IQ and this is predominant along the lower slopes of these mountain ridges. Thus, the entire area was designated as having low recharge potential. Nevertheless, Unit IQ is a pretty good aquifer. The average well yield shown on Map 10 is 13.2 GPM, 11.6 GPM when the highest and lowest values are ignored. These values are higher than or match the average yield from the designated primary aquifer of Unit I on the Wallingford quadrangle. However, there are only a handful of wells drilled into Unit IQ and most of these are very close to the contact with the Unit II carbonate aquifer. The possibility thus exists that some of these wells actually are drilled partly into carbonate rock. This is true for 4 of the wells and the water flowing to these 4 wells probably comes largely from the carbonate aquifer. These 4 wells have an average yield of 21.5 GPM. Higher permeability along the contact between the Unit II and Unit IQ rock is also possible and could account for the excellent yields in wells drilled near and/or intersecting this contact.

In the valley region, recharge potential is more varied. The Unit II carbonate aquifer is here. Recharge is largely dependent upon the interplay of 2 factors – the thickness of the overburden cover, especially of till, and upon the relative permeability of the overburden material. The recharge potential is highest where the till cover is thin and less where the till cover is thick on any small bedrock cored ridge in the valley. This is because till is a sediment with very low permeability and water flows downward poorly through this layers of till to recharge the carbonate aquifer below.

Higher recharge potential reflects the different nature of the overburden material. Areas of more permeable material called ground moraine which is composed of a mixture of till and more permeable gravel-sand have a greater potential to recharge the carbonate aquifer. Such areas have moderate to high recharge potential. Areas mapped as lake sand on Map 8 also have a high recharge potential due to the permeable nature of sand. However, this designation does not consider that at depth the sand may change and become more silty or clayey which would lower the permeability and reduce the rate of downward flow of ground water toward the carbonate aquifer below. Several well logs indicate thick "clay" layers but it is unknown how much clay versus silt versus fine sand is actually present in these few wells as drillers typically may not differentiate between these sediment types.

Other areas of highest recharge potential occur in the kamic or ice contact sediments of Map 8. This is generally sand or sand and gravel sediment of very high permeability and water can readily flow downward to the carbonate aquifer below. The western side of the valley has a continuous band of kamic material all designated as having the highest recharge potential for the carbonate aquifer below.

All of the recharge potential rankings must be used with due recognition that each area will have internal variations that cannot be discerned on the basis of the field work and analysis done by me. Thus, all areas ranked as having a recharge potential of II because of the presence of ground moraine will not be equally important in their contribution of water to the underlying carbonate aquifer. The thickness and permeability of the ground moraine unit is variable. The thickness and permeability of every overburden mapping unit is variable as well. In conclusion, the recharge potential map must be considered as a broad first step in identifying aquifer recharge areas and in establishing any possible aquifer protection zones to preserve the integrity of the carbonate aquifer.

That said, the carbonate aquifer of Unit II is a valuable water resource. Most wells located on Map 1 with yields plotted on Map 10 are drilled into this valley aquifer. The average well yield is 11.6 GPM. Values range from 0-40 GPM and this wide range reflects the uneven distribution of water-bearing fractures even in this fine aquifer unit. One well may yield 3 GPM while the neighbor's well may yield 30 GPM. As yet, there is no way to identify the distribution of water-bearing fractures beneath the ground other than to identify areas that have the best chance of producing good yields. I have shaded such areas on Map 10 as a very crude guide for future aquifer water use decisions.

Carbonate aquifer piezometric surface: Map 4 depicts the depth to the water table or piezometric surface for the Unit II carbonate aquifer. There may be some value in anticipating how far down the water may be in your well if drilled into the carbonate aquifer and Map 4 provides the data for such a prediction. More data from more wells and better measurements of static water level in a well reported by drillers will improve this map. It must be remembered that a single well where the static level was measured too soon after pumping and thus before the water level had recovered in a well, will severely distort the contours on Map 4.

Yet Map 4 does portray the contours of the water table/piezometric surface in a satisfying manner. Areas of higher water table/piezometric surface elevation are areas where the carbonate aquifer is receiving recharge. These data are consistent with and have been incorporated into the recharge potential shown on Map 5.

As we examine the surficial geology and the nature and extent of an overburden aquifer in later sections, I must address the question of whether the static water level reported for carbonate aquifer wells represents a water table for an unconfined aquifer or a true piezometric surface for a confined bedrock aquifer. At this time, the data indicate the carbonate aquifer is unconfined and the piezometric surface is actually the water table. The 3 overburden wells in the Otter Creek Valley have static water levels which mesh very nicely with the static levels in the surrounding carbonate wells. The drillers' logs also suggest that the overburden stratigraphy contains no widespread confining layer of till or lacustrine silt-clay. I therefore conclude that the carbonate aquifer is unconfined and the zero pressure surface is the water table encountered during drilling.

Glacial Geology

Previous work and framework for this study: Surficial geologic mapping and hydrogeologic assessment of the overburden and bedrock within the Wallingford, VT, 1:24,000 scale quadrangle was begun in summer of 2004 and completed in 2005.

Stewart (1956-1966) mapped the overburden of the Wallingford 15-minute quadrangle for inclusion into the Vermont Surficial Geologic Map (Stewart and MacClintock 1970). As with mapping elsewhere in the Vermont Valley region completed for the State map (Behling, 1966, Shilts, 1966), the surficial geologic maps are extremely outdated and lack sufficient detail for current aquifer mapping and land use planning needs. The reported glacial geologic history of the Vermont Valley region (Stewart and MacClintock, 1969) is similarly in need of revision as our collective understanding of Pleistocene Glaciations has improved over the last 30 years. The historical context gleaned from Stewart (1956-1966), Stewart and MacClintock (1969, 1970), Shilts and Behling (1967), Shilts (1966), and Behling (1966) still serve as a framework, raising questions to be addressed, hypotheses to be investigated, and interpretations to be challenged. The glacial geologic history needed to accurately understand aquifers in glacial sediments can only be deciphered by detailed mapping of the quadrangles at 1:24,000 or larger scale.

My work over many years has updated the mapping in much of the Vermont Valley and in adjacent portions of the Taconic Mountains and Hudson Lowland and much of this mapping has been accompanied by aquifer studies (La Fleur and De Simone, 1992, 1991, De Simone and La Fleur, 1990, Dethier, De Simone and Oelkers, 1989, De Simone and La Fleur, 1988, De Simone and Dethier, 1987). The results of these applied studies and other work in the region has provided a more modern context within which we can view the regional glacial geologic history (Dethier and De Simone, 1996, Karabinos et al, 1996, De Simone and Newton, 1994, Small and De Simone, 1993, De Simone, 1992, De Simone and Dethier, 1992, De Simone and Sedgwick, 1992, De Simone, 1989, Dineen, De Simone and Hanson, 1988, De Simone and La Fleur, 1986, 1985). This is the framework that provides the basis for my continued mapping of glacial sediments in New York, Vermont and Massachusetts. Collectively and for better or worse, this body of work has colored my interpretations of field observations, provided insights into the nature of ice retreat in our region, prompted questions to be addressed and re-addressed with each new study, proven work of previous mappers, challenged the mapping and interpretations of previous workers, and hopefully added to our general understanding of regional glacial geologic history.

More recently, De Simone (2001, 2004, 2005) mapped the glacial geology of the Arlington and Manchester quadrangles to the south. The results of these mapping efforts have greatly changed the details of our understanding of the deglaciation of the region.

There is only one short paragraph of discussion on the glacial history of the Otter Creek valley (Stewart and MacClintock, 1969, page 159) and it simply refers to the presence of lake deposits below 625 feet elevation and the obvious former existence of a glacial lake. There are no other details. How extensive and deep was this lake? Can a delta be found? The surficial map reveals an expanse of lake sand, silt and clay extending from South Wallingford through Wallingford. The full extent of the fine- grained lake sediments and their implication for the valley's hydrogeology remain to be discovered. An extensive area mapped as moraine looks suspicious as there is certainly much more detail there to be discerned through careful mapping and use of any subsurface data. Finally, an area of kame moraine is shown along the lower flank of the Green Mountains east of Wallingford. How extensive and thick are these deposits and what hydrologic connection might they have with glaciofluvial and glaciolacustrine sediments in the valley floor, especially the sediments beneath the lake silts and clays? Are there confined overburden aquifers in this valley? What was the nature of ice disintegration both here in the valley floor and in the Green Mountains?

What was the nature of ice disintegration in the valley floor and in the Green Mountains? The numerous lakes in the mountains suggest the possibility of ice abandonment and in situ stagnation, similar to interpretations made by the author as a result of casual observations in the Woodford and Stamford quadrangles much farther to the south. However, kame moraine is shown in the East Wallingford area and this deposit might indicate the presence of an active ice margin with or without a narrow stagnation zone. The small Mill River valley might offer additional clues as to the nature of upland ice disintegration. Numerous kame terraces are shown on the existing map from East Clarendon, just beyond the quadrangle to the north, and through Cuttingsville. What is the nature of these deposits and what might their hydrogeological significance be? The Mill River flows northwest and the valley may have held a high level glacial lake previously unrecognized. Are the kame terrace and kame moraine sediments associated with subaqueous deposition in this lake? Are there any high level deltas to verify the existence of this lake and identify a stable lake level?

Late Woodfordian glaciation:

The Hudson-Champlain Ice Lobe of the Late Wisconsinan (Woodfordian) Laurentide Ice Sheet advanced over the region from the NNW as revealed by the upland ice flow indicators oriented approximately 167 degrees. Topographically controlled thinner valley ice flowed parallel to the trend of the Dorset Valley, Danby Valley and Vermont Valleys. Subsurface data discussed below reveal some information about the advancing Woodfordian ice sheet. The "fingers" of thin ice advancing first into the valley troughs mimic the alpine type glaciations we see today in such varied places as Alaska, the Alps and Himalayas. My own experiences with the glaciers in southeast Alaska has colored my perception of the field and subsurface evidence I see for past glaciations.

Deglaciation: Valley striations were not numerous and did not reveal any crossing striations. Thus, there are no hard data to verify that the latest ice flow was the thin valley parallel ice flow. However, this situation was determined conclusively by me during examination of striations in the Arlington quadrangle to the south (De Simone, 2001a, 2001b).It is therefore correct to envision an active retreat of confined valley ice from the lowlands of the quadrangle. This ice likely behaved similar to today's alpine and outlet glaciers. Our understanding of processes at modern alpine glacier environments is thus applicable to the evidence we see for Woodfordian deglaciation in terrain similar to alpine or outlet glacier settings. I shall apply my knowledge of processes at glaciers such as the Mendenhall and Herbert in southeast Alaska to interpretation of the evidence for past glaciation I mapped in the Manchester quadrangle.

A thin veneer of lodgement till accumulated over the higher elevations of the quadrangle as the Woodfordian ice sheet thinned and exposed this higher terrain. Thicker till accumulated on the lower flanks as the ice sheet continued to thin. There was no evidence for higher glacial lakes which may have formed between the ice sheet and the mountain flanks.

As the ice sheet continued to thin, the Vermont Valley sublobe became established as a classic outlet glacier being nourished by the thick Woodfordian ice sheet to the north.

Glacial history: For a geologist trained to understand the nature of glacial sediments, their distribution tells a story of the last cycle of glacier advance and retreat from our area. And the landforms of our region add to this story by revealing the past history of erosion by streams as they cut down into the glacial deposits and formed terraces on the flood plains. Map 9 depicts the approximate locations of the border or margin of the retreating glacier. The story of the retreating glacier and the sediment it left behind is best told by explaining the sequence of ice margins seen on this map.

The first part of the glacier to advance into the area some 25,000 years ago was thin and the ice flowed slowly into the Otter Creek Valley from north of Rutland. The ice flowed parallel to this valley and scoured the valley sides wider and deepened the valley bottom as it advanced. The general shape of the valley became more U in profile rather than V in profile after many glacier advances over the last 2,000,000 years. The thicker portion of the glacier slowly advanced through the valley and finally the glacier was so thick it covered the tops of the mountains. This very thick type of glacier is known as an ice sheet and the one which last covered eastern North America was approximately the same size as the ice sheet covering Antarctica today. When this ice sheet reached its maximum extent, the edge of it stood at Long Island and well out beyond Cape Cod, having advanced out onto dry exposed portions of the continental shelves, dry because sea level was some 130 meters lower. All of that water was now stored as ice and flowing as part of numerous large ice sheets across northern Europe, Asia and North America. The tops of the Green Mountains were probably covered with more than 1,500 feet of glacier ice.

By 22.000 years ago, the large ice sheets around the world began to melt. Their margins slowly shriveled back. The melt waters flowed away from the glaciers in rushing torrents. Many geologists, including me, have observed the process happening today at the margins of glaciers in Alaska, for example. What we see happening along these glacier margins informs us about how the same process occurred here in Wallingford.

When a glacier melts, the sediment it carried within it is transported and deposited at or near the edge of the glacier. This sediment can be carried there by rivers of melt water flowing under the ice or along its edge, by slumping and sliding of mixtures of sediment and ice at the edge of the glacier, and by sediment being plastered onto the underlying bedrock directly by the ice. Once at the margin of the glacier, different environments might exist. Their may be a broad plain extending away from the glacier which is criss-crossed by streams carrying sediment away from the glacier. There may be a large or small lake at the glacier edge where water and sediment spew into the lake from those rivers beneath the ice. There may be ridges and mounds of sediment piling up at the glacier edge, sediment pushed there by the glacier or dumped there by slumps and slides and rivers.

As the glacier over the Wallingford region thinned, the mountains became free of ice first. Their summits and steeper slopes were plastered with a very thin coat of sediment deposited directly from the ice. This is till, a mixture of silt and sand and gravel and boulders all compressed together tightly by the weight of the glacier. We often call this hardpan when we dig into it in our garden or when drillers bore through it looking for water under ground. Once left by the glacier, the coat of till armoring our mountain slopes began to erode away rapidly and much of it slumped and slid down the mountain slopes. Remember, at this time there were no trees or even grasses on the land and soil had yet to form in the till. Our mountain slopes were left with a spotty covering of till with many exposed areas of bedrock.

Over the broad summit region of the Green Mountains, it is likely that many thin portions of the ice sheet were stranded and left behind to melt in place. A few areas accumulated gravel and sand deposits from small streams leading from the melting glacier remnants. The last vestiges of the ice sheet in the mountains were blocks of ice that eventually melted and were replaced by lake and pond waters. The waters of Wallingford, Fifield, Little Rock and Spring Lake ponds all came into existence in this manner. Surrounding these ponds are areas where the last sediment contained in the glacier blocks came to rest as a sandier version of the till that armors the steeper mountain flanks and veneers the mountain summits.

The thinner parts of the retreating ice sheet were much like those first fingers of ice to reach into the valleys when the glacier advanced. These were a lot like the valley glaciers we see in Alaska, the Alps, Andes and in other mountainous regions where glaciers exist today. The valley glacier in the Vermont Valley melted back through the valley from Bennington through Manchester and northward through the Otter Creek Valley toward Rutland. As it retreated, it left behind a complex package of sediment that I have mapped. There was till deposited over the valley floor but our well drillers have recorded only patches of it in the Wallingford area. The till was apparently only dumped by the glacier in local areas. Much of the sediment carried by the glacier was spread out into the waters of a glacial lake that fronted the retreating glacier margin in the Otter Creek Valley. We have clay or clay with boulders recorded by well drillers in some sections of the valley and all sections of the valley are mantled with a coat of fine sand deposited in this lake I've named Glacial Lake Emerald.

A. South Wallingford ice margin; The first marginal sediment in the valley is represented by the ground moraine deposited over a flat area south of Ice Bed Road. The sediments were deposited along the eastern edge of the valley glacier. Ground moraine sediment consists of a mixture of stratified and unstratified sediment. The stratified sediment is gravel and sand while the unstratified sediment is a till-like hardpan deposit we call diamicton. The diamicton may be deposited by one or more of several processes. Wasting ice may slough off accumulated material on the surface of the glacier and this slumped sediment contributes to the ground moraine. The stratified sediment probably came from a melt water stream flowing through the notched melt water channel above the Ice Beds at White Rocks.

Along the north flank of Green Hill, the earliest deposits of kame moraine accumulated at the higher elevations south of Church Street. The actual margin of the glacier across the valley is hard to determine. Geologists like to find a delta of sediment deposited from a glacial melt water river flowing beneath the ice. However, through the Wallingford quadrangle, I found no such deltas. This can frequently occur when the glacier is retreating fairly rapidly and there is no time when a stationary ice margin exists to allow a delta to build into the lake.

Yet, we do have the South Wallingford esker and associated kames which tell us the glacier did have a typical river of melt water flowing under the ice and emptying into Glacial Lake Emerald. The linear ridge of stream gravel and sand is the esker which preserves the glacial river sediment. The mounds of sand with gravel are the kames which are infillings of holes on and under the melting glacier. Lake Emerald expanded northward along the edge of the receding glacier margin and fine lake sand and silt-clay accumulated over the lake bottom.

B. Wallingford ice margin; Two distinct positions of the front of the glacier can be discerned based upon my interpretation of the field data. Two positions of the lateral or side glacier margin can also be discerned by me. Since all of these positions are closely related both physically and temporally, I have chosen not to subdivide them into separate ice margins. The minor retreats associated with this ice margin should be discussed as a continuum of events related to a glacier margin likely retreating sporadically but never being stationary long enough for a delta to accumulate in Lake Emerald.

The Wallingford kame moraine accumulated along present Roaring Brook. An extensive area of ground moraine began to accumulate along the base of Bear Mountain. The toe of the glacier is not marked by any esker sediment. However, an area of kame moraine accumulated along the western edge of the glacier. Kame moraine is a ridge or series of ridges of sediment deposited at the edge of the glacier. Mostly, it consists of stream deposits mixed with slumped stream deposits...a hardpan material that is a gravelly diamicton. Lake sand continued to accumulate on the lake bottom. Lake sediment reaches up to elevations high enough to suggest the lake level may have been approximately 810 feet with a wide range of error here of +/- 20 feet.

B1; The toe of the glacier retreated to the position marked by the Elfin Lake esker and associated kames. The Bear Mountain ground moraine and Wallingford kame moraine continued to accumulate along the eastern margin of the glacier. A low kame moraine ridge through the cemetery south of Church Street helped locate the lower margin and toe of the glacier.

Glacial Lake Emerald may have lowered as the glacier reached and retreated from this margin. The Elfin Lake deposits record an area where the glacier stagnated. A section of the valley glacier became thin and was detached from the remainder of the glacier which continued to retreat toward Rutland.

C. Haven Hill ice margin; The last area of the Bear Mountain ground moraine accumulated at the lower elevations of the ground moraine shown on Map 8. This sediment blends into a flatter area of more sandy and gravelly sediment I've called a kame terrace because of its flat surface and more sandy texture. Below the kame terrace is a sloping area of sandy and gravelly sediment along Haven Hill Road I've called a kame moraine. This marks the lowest elevation ice edge deposits along the eastern margin of the glacier. Across the valley on the western margin, a low area of kamic or ice contact sediment accumulated. This area includes the northern segment of the Elfin Lake esker and associated kames.

The kame terrace at only 700 feet +/- 20 feet elevation and the low elevation of the kamic sediment on the west side of the valley suggest that the level of Glacial Lake Emerald had certainly lowered to somewhere around 700-725 feet +/- 20 feet elevation. I am unable to narrow down the lake elevation because I could not find any delta to more conclusively determine the lake level. Again, this suggests to me that the lake may have had a falling level throughout the retreat of the glacier from the Wallingford quadrangle. Lake sand accumulated around and over much of the esker and kame sediment, thinly draping over the higher mounds and ridges while more thickly burying the lower elevations.

Overburden hydrogeologic units:

Overburden aquifers occur in regions of permeable overburden sediment composed of gravel, sand or gravel and sand. The depositional environments for these materials may be ice contact, non-ice contact proglacial such as outwash, and proglacial lacustrine. In Wallingford, the potential overburden aquifers may exist in the ice contact ground moraine, kame moraine and minor kame terrace complex along and north of Roaring Brook at the foot of the Green Mountains, specifically Bear Mountain. A lack of producing gravel wells in the town limits our ability to prove the existence and extent of any overburden aquifer. Sections AA' and BB' reveal the possible thickness and extent of the sediment that might represent a viable overburden aquifer. More data are needed.

The smaller ground moraine complex south of Green Hill and west of White Rocks may be another overburden aquifer area if the well log depicted in section FF' is correct.

The Elfin Lake ice contact gravel and sand complex and the adjacent lacustrine sand and fluvial terrace sand sediments may constitute a very useful overburden aquifer that has not been proven or developed. While the thicknesses of sediment are not substantial, the aerial extent of the sediment is large and there may be sufficient volume of permeable material with adequate recharge suitable for aquifer development.

Smaller and isolated areas of ice contact sediment and lacustrine sand in the southern part of town may be local overburden aquifers suitable for development where moderate producing wells are needed.

Stratigraphic sections and overburden thickness; The well log data indicate the thickness of overburden in the Otter Valley is not substantial. Overburden thickness was contoured using a 30ft interval and is shown on Map 7. There is generally 60-90ft of overburden in a narrow band along the valley floor. Greater thicknesses of overburden accumulated where there are discrete areas of kamic sediment, the ice contact sediment primarily west and north of the village of Wallingford. Overburden thicknesses greater than 100ft occur east and north of the village in the ground moraine complex and the sediment thickness exceeds 150ft east of the village and north of Roaring Brook. It is in this material that there is some potential to develop an overburden aquifer and some effort might be made to assess this potential.

A single well log reporting 250ft of overburden in the ground moraine area south of Ice Bed Brook may record infilling of a pre-glacial Ice Bed Brook valley or may be an incorrect drilling report. Additional subsurface information is needed to accurately assess the overburden thickness and any aquifer potential here.

Stratigraphic cross sections were drawn at 6 locations across the Otter Valley and are shown on Map 6. Section AA' depicts a thick sequence of overburden reported to be fine grained lacustrine sediment not suitable as an aquifer. The ice contact sediment on the west and the ground moraine and kame terrace sediment on the east along this section may be good local overburden aquifers. However, the thicknesses of sediment are not substantial and the overburden aquifer is likely small and local.

Section BB' reveals the thick basal section of valley fill to be till which is overlain by the kamic sediment capped by the esker shown on the section. The ice contact sediment of the kame and esker complex is another good but localized aquifer resource. The extensive ground moraine sediment on the high elevations in the eastern portion of section BB' is likely of variable permeability and may contain abundant till. Additional data are needed to assess this material for its overburden aquifer potential.

Section CC' depicts a gravel, sand and boulder sand valley infill on the west which may be a good aquifer resource. On the east, a Roaring Brook infill of gravel and/or ground moraine or till represents an area that requires considerable more information to determine the aquifer potential.

Section DD' and section FF'' were not drawn at this time due to insufficient subsurface data. Section EE' was drawn as the best of the last 3 section lines. Although there are only 3 well logs along this section, it depicts the possible thick section of overburden south of Ice Bed Brook mentioned above. The well log reveals a thick section of material interpreted to be ice contact ground moraine that overlies sandy sediment and possible a basal till or moraine deposit. There is an undetermined aquifer potential here as additional subsurface data are needed to assess the overburden stratigraphy.

Overburden recharge potential; If the potential overburden aquifers discussed in the previous sections are proven to exist, then the recharge potential to these aquifers can be better understood. Recharge to any overburden aquifer must come through direct infiltration of water through permeable material. So, the areas discussed above as composed of gravel, sand or gravel and sand are the materials which have the highest potential to recharge the aquifer. They represent the aquifer material. Additionally, perhaps extensive recharge to a valley bottom overburden aquifer can come from laterally adjacent but hydraulically connected permeable upland materials such as kame moraine, kame terrace and ground moraine units. A better knowledge of the stratigraphy is required before these connections can be stated with confidence. Unfortunately, there is insufficient subsurface knowledge at this time to assess the full nature and extent of the overburden aquifers and their recharge areas at this time. The overburden recharge potential depicted on Map 11 represents a best case scenario where all the permeable surface materials are useful and viable aquifers.

Conclusions and Recommendations

* Surficial geologic mapping enabled the delineation of 3 ice margins through the Town of Wallingford. The sediment accumulated along and in front of these ice margins confirms the retreat of a largely active glacier in the Otter Valley. Further, this retreating ice fronted a proglacial lake here named Glacial Lake Emerald as the spillway was at the threshold to the south of the Wallingford quadrangle. Here there are ice contact deposits blocking a narrowed section of valley in the vicinity of Emerald Lake where the present threshold is at about 720 feet +/- 10 feet. Lacustrine sands cap most of the ice contact sediments observed in exposures in the valley floor.

* The nature and extent of overburden aquifers in these glacial sediments is not fully understood because there are insufficient subsurface data. Overburden thicknesses and aerial distribution of permeable overburden suggest that a single, large extensive unconfined overburden aquifer may not exist in the Wallingford region. Separate, small overburden aquifers may exist in the lacustrine sand veneered overburden on the valley floor. However, the average yield from the 3 overburden wells in town is 19.7GPM and this represents the highest yield among aquifers in the town. Stratigraphic cross sections and overburden thickness analysis reveal the potential for overburden aquifers that await full assessment. The areas of kame moraine, ground moraine, kame and lake sand at the surface indicate that considerable recharge of the overburden aquifers is occurring through direct infiltration of water through these variably but relatively permeable sediments.

* Bedrock wells from the carbonate and quartzite lithologies have average yields of 11.6GPM. Wells drilled near the carbonate – quartzite contact have an average yield of 21.5GPM and suggest enhanced secondary porosity and permeability in the vicinity of the contact due to fractures in both lithologies and perhaps due to dissolution of the carbonate bedrock.

* The black shale/phyllite rock unit along the western edge of the quadrangle represents an aquitard/aquiclude and is in thrust fault contact with the carbonate aquifer to its east. This black shale/phyllite rock may be hydraulically isolated from the carbonate by an impermeable thrust fault boundary. This prospect is one which may warrant further study. The water quality concerns typical in black shale/phyllite such as sulfur and/or radon content should discourage use of this rock as a ground water resource and further study of the water quality here may be valuable.

Appendices

1. Data Sources: description of numbered exposures;

WAL04-1; 2 small pits just north of Scottsdale Road and on the west side of Rte 7 reveal approximately 5060ft of total exposure. The sediment consists primarily of cross bedded, cross laminated and ripple cross laminated sand with minor pebble gravel occurring as isolated clasts in the sand matrix. There is no faulting or deformation of the bedding. The sediment is interpreted to represent lacustrine sand deposited in the Otter Valley lake dammed to the south at Emerald Lake. The pebbles are likely ice rafted debris.

WAL04-2; An exposure west of the village and north of Elfin Lake cuts into an esker. Interbedded pebble through cobble gravel with medium, coarse and fine sand represents the ice tunnel deposits. Beds have gentle dips and are traceable for several meters. There is little or no deformation in the bedding due to ice contact. The sediment here represents part of an esker splay or subaqueous fan were the esker spread into the Otter Valley glacial lake. The upper facies consists of fine grained lake sand deposited as the ice withdrew leaving an open water environment.

WAL04-3; This exposure is in the ice contact sediment complex north of South Wallingford and east of the rail line. Access is via the dirt road crossing the railroad tracks. The basal facies consists of lenses and pods of diamicton in an interbedded gravel and sand unit. The diamictons are of a silt rich lodgement till type material or are derived from re-sedimented gravel and sand. The diamictons are interpreted to represent flow tills – sediment flow diamictons in a lacustrine environment. The basal facies generally fines upward to the interbedded gravel and sand facies without diamictons. All of the sediment is highly deformed by faulting and slumping in an ice contact environment. Deposition may have been at or beneath the ice margin in a subaqueous kame fan setting.

2. Mapping Unit Descriptions:

Recent;

F **Fill; variable materials used as artificial fill along rail beds, road beds, embankments and low lying areas.** The material may be demolition/construction debris, crushed stone or gravel/sand quarry sediment. Most of the fill is along the path of Rte 7 and along railroad grades, especially to elevate the rail bed above flood plain level. Soils on these disturbed lands are Udorthents and Udisamments. Embankments may be prone to failure.

PM **Peat & Muck; organic sediment, mostly silt and clay in wetlands and swamps; low lying flat lands.** These sediments are rich in decomposing organic matter including grass, leaves and wood. Soils are typically waterlogged, dark or mottled in color and deficient in oxygen. Carlisle muck is the primary soil unit with lesser areas of Copake, Raynham and Fredon soils. Water may intermittently or permanently cover the surface. Unsuitable for development.

AL **Alluvium; stream flood pains; fine sand, silt and gravel of river channel, bar, and bank areas; river bottom lands; variable permeability but usually intermediate to low; often wet sites.** These are low lying terraces within the 100 year planning flood plain and may be seasonally flooded. Soils are often wet and the water table may be encountered at very shallow depth. Organic matter may be locally abundant. The freshest deposits with little or no soil development are Udifluvents. Older deposits with soils are of the Copake, Raynham, Hero and Pootatuck types and are excellent for agricultural uses. The high water table and wet soils impeded the flow of water and render these sites less suitable for development. They may not perc adequately or there may be insufficient thickness of sediment above the water table for conventional septic systems. Embankments along rivers and streams may be prone to failure.

FT **Fluvial Terrace; old flood plains; fine sand, silt and gravel generally less than 5 meters thick overlying other material; flat to gently sloping lands; variable permeability but usually intermediate.** These are old stream terrace deposits above the flood plain. The soils are often deep, well drained loams suitable for agriculture. The water table may be sufficiently deep to allow for conventional septic systems. However, perc rates may be locally variable and wet areas are not uncommon. Groton, Raynham, Hero, Copake and Fredon soil types are found. Bank edged above streams may be prone to failure.

CO **Colluvium; slump, slide and avalanche debris materials composed of boulders, cobbles, gravel, sand and silt; sloping lands.** These are in slide prone areas on mountain slopes or along embankments, especially along streams. Active erosion sites such as these are unsuitable for development.

Late Pleistocene;

OW **Outwash; glacial melt water deposits of well sorted gravel and sand typically greater than 5 meters thick; gently sloping to flat lands; intermediate to high permeability; high gravel-sand resource potential.** Water percolates very rapidly through these deposits making these lands suitable for development with septic systems. Major recharge areas for the overburden aquifer and a pronounced vulnerability to contamination argue for caution in land use decisions. Groton is the major soil type.

K **Kame, undifferentiated; glacial deposits from streams, slumps and deposition by ice; stratified and unstratified sand, gravel and boulders with variable silt; rolling, hilly lands; intermediate to high permeability; high gravel-sand resource potential; local steep slopes pose slope stability problem.** Sediment thickness is variable and rock outcrops may occur within this unit. Percolation rates are generally satisfactory for conventional septic systems. These are aquifer recharge areas and are prone to contamination from infiltration. Groton and Danforth soils are typical.

>>> **Esker; subglacial/englacial melt water stream deposits of moderately well sorted gravel and sand with boulders; prominent elongated and curving narrow ridges with steep sides and heights reaching 60+ feet; intermediate to high permeability; high gravel-sand resource potential; steep slopes pose a major slope stability problem.** Individual eskers occur within areas of kame, kame moraine or ground moraine mapping units. Due to their steep slopes and narrow crested summits, these landform features are best left undeveloped or may be used for their gravel-sand resources. Groton soils are typical.

KM **Kame Moraine; ice contact melt water and sediment flow deposits of stratified and unstratified gravel and sand with silt and boulders; rolling, hilly ridged lands with local flat areas; intermediate to high permeability; high gravel-sand resource potential; local steep slopes pose slope stability problem.** Sediment thickness is variable but typically exceeds 10 meters. Percolation rates are generally satisfactory for conventional septic systems. These are aquifer recharge areas and are prone to contamination from infiltration. Groton soils are typical and are suited farming, grazing and woodlot uses. Lesser areas with Galway-Farmington soils may contain abundant silt which will decrease drainage and affect development potential with septic systems.

GM **Ground Moraine; ice contact sediment flow, melt water and ice deposited sediments of variable texture ranging from stratified and well sorted gravel and sand to unstratified and poorly sorted silt, sand, gravel and boulders; thickness is variable and rock outcrops may protrude; low to high permeability; limited local slope stability problems; gently rolling hills and elongate smoothed hills are possible.** Percolation rates will vary widely over short distances. There is some gravel-sand resource potential here but the possibility of hardpan sediments makes these areas of lower resource potential than kame or outwash deposits. Soils vary widely and include areas of Nellis, Amenia and Galway-Farmington types. These areas are suitable for development, farming, grazing and woodlot uses.

KT **Kame Terrace; ice contact melt water and sediment flow deposits of stratified and unstratified gravel, sand, boulders and some silt; flat to nearly flat lands; intermediate to high permeability; high gravel-sand resource potential; slopes at edges of these areas may pose a stability problem.** Sediment thickness is variable but typically exceeds 10 meters. Percolation rates are generally satisfactory for conventional septic systems. These are aquifer recharge areas and are prone to contamination from infiltration. Groton soils are typical and are suited farming, grazing and woodlot uses. Lesser areas with Galway-Farmington soils may contain abundant silt which will decrease drainage and affect development potential with septic systems. These are similar in characteristics to KM unit above.

M **Moraine; ice contact ice deposited, sediment flow and melt water materials of unstratified and stratified silt, sand, gravel and boulders; broad ridges and swales with rolling low hills; variable permeability; local slopes may pose a stability problem.** Sediment thickness is variable and rock outcrops may occur. Percolation rates will vary considerably but may be adequate for development with conventional septic systems. Some areas may not drain well and wet soils can be found here. Other areas will drain well. Nellis, Amenia, Massena and Stockbridge soils may occur.

T **Till; ice derived deposits of hardpan silt, boulders, gravel and sand which are unsorted and unstratified and deposited beneath the glacier; thickness greater than 3 meters but rock outcrops may be common; surface boulders or erratics are common; smoothed and streamlined hills in the valley and gently undulating slopes on the lower mountain flanks; low permeability; unstable slopes may result in excavations.** Percolation rates are poor and the ground is typically pocked with wet areas making these areas generally unsuitable for development with conventional septic systems. Perched water tables less than 3 feet down may be encountered during excavations. Galway-Farmington, Nellis and Pittsfield soil types prevail.

TT **Till, thin; ice derived deposits of hardpan silt, boulders, gravel and sand which are unsorted and unstratified and deposited beneath the glacier; thickness less than 3 meters with rock outcrops or ledge frequent; surface boulders or erratics are common; moderate to steep mountain slopes and summit areas; low permeability; steep slopes are unstable and slides are common.** Percolation rates in the till are poor but areas devoid of till are common and percolation through thin soil into bedrock may occur at higher rates. Steep slopes, poor percolation and high elevation make these regions unsuitable for development. Land uses are limited to forestry and woodlot management. Valley and mountain areas of thin till are carbonate aquifer recharge zones. Rawsonville-Houghtonville, Dummerston, Taconic-Macomber, Taconic-Macomber, Houghtonville, Berkshire, Tunbridge-Lyman and similar soil types prevail.

Pre-Cambrian & Paleozoic Bedrock;

R **Rock outcrop. Marble (Rmb), quartzite (Rqz), and schist (Rsc) are the types observed in the field. These include areas of predominantly outcrop with patches of till or slump or slide debris. Outcrop areas serve to recharge the bedrock units with ground water. Poor sites for septic systems prevail. Slopes are generally stable. Development potential is low. Scenic views are common**

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Surficial Geology and Hydrogeology

Of

Wallingford, Vermont

A Report and History

For

Wallingford Residents

By

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Contract EC 33-04

Surficial Geology

A map of the surficial geology of the Wallingford quadrangle is available for your examination. It is designated Map 8 because it is one of a large set of maps I produced of the Wallingford quadrangle. I encourage you to consult this map as you read this manual. A surficial geologic map depicts the extent of all of the different types of materials that are found at the surface. This includes the unconsolidated or loose sediments deposited as the last major glacier moved over the region, the sediments deposited as this glacier melted in the region and the stream deposits which have accumulated since that time. It also includes the landslide debris on our mountain slopes and the artificial material we have dumped to fill in low ground.

Lastly, the map shows the major outcrops of bedrock, the "ledge" or consolidated material that lies underneath all of the unconsolidated materials. This bedrock is exposed on parts of our mountain slopes and summits and on the crests or steep sides of many ridges in the valley. The unconsolidated sediments have simply not covered up all of the bedrock or streams have exposed it through erosion. The last section of this manual provides you with a description of all of the unconsolidated surficial materials you'll find on the surficial geologic map.

Perhaps of more value, the description of each surface material mapping unit also includes useful information related to permeability, percolation rates, soil types and slope stability problems. The potential for aquifer recharge through each type of surface material is also mentioned. All of these factors affect the development potential of any site of interest on the map. The value of each material for gravel-sand resources is also rated.

Bedrock types: Our region is underlain by several distinct bedrock types. Geologists finely distinguish more rock layers based upon characteristics less easily observed by the average person. Therefore, I have lumped together the rock types into their major subdivisions. This is more useful to us because we are primarily interested in understanding how water moves into and through the different major rock types. What rock types are most likely to yield the greatest amount of water to us if we drilled a well into them? This is the question we want to address in our understanding of bedrock types.

I have distinguished four major bedrock groupings on the Wallingford quadrangle. The complete set of maps available for examination at your local Town office includes Map 2. On this map, you can see the distribution of the 4 bedrock groupings identified as Bedrock Hydrogeologic Units. Unit II is our region's primary bedrock aquifer, a good source of underground water that is tapped by most well drillers. Unit II is carbonate rock and it includes a number of different layers named by geologists and composed of limestone, dolostone or marble. All 3 of these are types of carbonate rocks and in our region they all are part of the same bedrock aquifer. This aquifer underlies the Otter Creek Valley portion of the quadrangle and extends eastward at the base of Green Hill on both the north and south flanks of the hill. The eastward extension of the carbonates continues north of Roaring Brook along the lowest flanks of Bear Mountain generally below 1000ft elevation.

East of this is Unit IQ, a band of predominantly quartzite with minor amounts of phyllite and conglomerate. This unit occupies the western flank of the Green Mountains to the summits of White Rocks, Green and Bear Mountains. The quartzite is a unit of generally low porosity and is generally considered a poor aquifer or aquitard. However, the handful of wells drilled into this unit have an average yield comparable to those drilled into the carbonate. This suggests that there are sufficient fractures in the quartzite to enable water to move through the rock and into a drilled well. Good yields are possible but the high yields possible in the carbonates are unlikely.

East of this is Unit I, a grouping of schist, gneiss, and minor amphibolite, marble and quartzite. There is also an area of granite beneath Granite Hill in the northeast corner of the quadrangle. These are very different rock types but all are usually poor sources of underground water except for the marble and perhaps the quartzite layers and are termed here an aquiclude, a word meaning very poor aquifer. Basically, the rocks of the Green Mountains don't yield a lot of water when we drill a well into them. In the northwest corner of the quadrangle is another small area of Unit I composed of schist and gneiss.

West of Unit II is Unit III, a grouping of predominantly black shale-phyllite. These are similar rock types in appearance and in their usually poor ability to yield water to us in a well. They are termed here an aquiclude, a word close in meaning to an aquitard. Basically, Unit III is a very poor aquifer. Unit III underlies the hills to the west of the Otter Creek Valley and is exposed as a thin strip along the western edge of the quadrangle.

Your best chance of finding a good underground water supply is to drill a well into Unit II. However, there is no guarantee that drilling a well into the carbonate rock of Unit II will yield you a lot of water. This material holds and transports water through a network of fractures in the rock and some of these fractures may be enlarged into wider openings by dissolution of the rock. By its nature, carbonate rock dissolves in water. That is why many wells drilled into it can yield water in dozens or even more than a hundred gallons per minute. The driller has been lucky enough to "hit" many fractures and many of these are enlarged by dissolution. A geologist might be able to predict where the best fractures and enlarged fractures might be but there is no guarantee. Yet, another person may drill a well and their yield may be much less than a dozen gallons per minute. Perhaps their yield isn't even enough to supply the water needs of a typical home. This is just pain bad luck, not the fault of a driller or anyone.

Later in this discussion, I'll examine the well yields in each of these different rock groupings.

Glacial geology: For a geologist trained to understand the nature of glacial sediments, their distribution tells a story of the last cycle of glacier advance and retreat from our area. And the landforms of our region add to this story by revealing the past history of erosion by streams as they cut down into the glacial deposits and formed terraces on the flood plains. Map 9 depicts the approximate locations of the border or margin of the retreating glacier. The story of the retreating glacier and the sediment it left behind is best told by explaining the sequence of ice margins seen on this map.

The first part of the glacier to advance into the area some 25,000 years ago was thin and the ice flowed slowly into the Otter Creek Valley from north of Rutland. The ice flowed parallel to this valley and scoured the valley sides wider and deepened the valley bottom as it advanced. The general shape of the valley became more U in profile rather than V in profile after many glacier advances over the last 2,000,000 years. The thicker portion of the glacier slowly advanced through the valley and finally the glacier was so thick it covered the tops of the mountains. This very thick type of glacier is known as an ice sheet and the one which last covered eastern North America was approximately the same size as the ice sheet covering Antarctica today. When this ice sheet reached its maximum extent, the edge of it stood at Long Island and well out beyond Cape Cod, having advanced out onto dry exposed portions of the continental shelves, dry because sea level was some 130 meters lower. All of that water was now stored as ice and flowing as part of numerous large ice sheets across northern Europe, Asia and North America. The tops of the Green Mountains were probably covered with more than 1,500 feet of glacier ice.

By 22.000 years ago, the large ice sheets around the world began to melt. Their margins slowly shriveled back. The melt waters flowed away from the glaciers in rushing torrents. Many geologists, including me, have observed the process happening today at the margins of glaciers in Alaska, for example. What we see happening along these glacier margins informs us about how the same process occurred here in Wallingford.

When a glacier melts, the sediment it carried within it is transported and deposited at or near the edge of the glacier. This sediment can be carried there by rivers of melt water flowing under the ice or along its edge, by slumping and sliding of mixtures of sediment and ice at the edge of the glacier, and by sediment being plastered onto the underlying bedrock directly by the ice. Once at the margin of the glacier, different environments might exist. Their may be a broad plain extending away from the glacier which is criss-crossed by streams carrying sediment away from the glacier. There may be a large or small lake at the glacier edge where water and sediment spew into the lake from those rivers beneath the ice. There may be ridges and mounds of sediment piling up at the glacier edge, sediment pushed there by the glacier or dumped there by slumps and slides and rivers.

As the glacier over the Wallingford region thinned, the mountains became free of ice first. Their summits and steeper slopes were plastered with a very thin coat of sediment deposited directly from the ice. This is till, a mixture of silt and sand and gravel and boulders all compressed together tightly by the weight of the glacier. We often call this hardpan when we dig into it in our garden or when drillers bore through it looking for water under ground. Once left by the glacier, the coat of till armoring our mountain slopes began to erode away rapidly and much of it slumped and slid down the mountain slopes. Remember, at this time there were no trees or even grasses on the land and soil had yet to form in the till. Our mountain slopes were left with a spotty covering of till with many exposed areas of bedrock.

Over the broad summit region of the Green Mountains, it is likely that many thin portions of the ice sheet were stranded and left behind to melt in place. A few areas accumulated gravel and sand deposits from small streams leading from the melting glacier remnants. The last vestiges of the ice sheet in the mountains were blocks of ice that eventually melted and were replaced by lake and pond waters. The waters of Wallingford, Fifield, Little Rock and Spring Lake ponds all came into existence in this manner. Surrounding these ponds are areas where the last sediment contained in the glacier blocks came to rest as a sandier version of the till that armors the steeper mountain flanks and veneers the mountain summits.

The thinner parts of the retreating ice sheet were much like those first fingers of ice to reach into the valleys when the glacier advanced. These were a lot like the valley glaciers we see in Alaska, the Alps, Andes and in other mountainous regions where glaciers exist today. The valley glacier in the Vermont Valley melted back through the valley from Bennington through Manchester and northward through the Otter Creek Valley toward Rutland. As it retreated, it left behind a complex package of sediment that I have mapped. There was till deposited over the valley floor but our well drillers have recorded only patches of it in the Wallingford area. The till was apparently only dumped by the glacier in local areas. Much of the sediment carried by the glacier was spread out into the waters of a glacial lake that fronted the retreating glacier margin in the Otter Creek Valley. We have clay or clay with boulders recorded by well drillers in some sections of the valley and all sections of the valley are mantled with a coat of fine sand deposited in this lake I've named Glacial Lake Emerald.

A. South Wallingford ice margin; The first marginal sediment in the valley is represented by the ground moraine deposited over a flat area south of Ice Bed Road. The sediments were deposited along the eastern edge of the valley glacier. Ground moraine sediment consists of a mixture of stratified and unstratified sediment. The stratified sediment is gravel and sand while the unstratified sediment is a till-like hardpan deposit we call diamicton. The diamicton may be deposited by one or more of several processes. Wasting ice may slough off accumulated material on the surface of the glacier and this slumped sediment contributes to the ground moraine. The stratified sediment probably came from a melt water stream flowing through the notched melt water channel above the Ice Beds at White Rocks.

Along the north flank of Green Hill, the earliest deposits of kame moraine accumulated at the higher elevations south of Church Street. The actual margin of the glacier across the valley is hard to determine. Geologists like to find a delta of sediment deposited from a glacial melt water river flowing beneath the ice. However, through the Wallingford quadrangle, I found no such deltas. This can frequently occur when the glacier is retreating fairly rapidly and there is no time when a stationary ice margin exists to allow a delta to build into the lake.

Yet, we do have the South Wallingford esker and associated kames which tell us the glacier did have a typical river of melt water flowing under the ice and emptying into Glacial Lake Emerald. The linear ridge of stream gravel and sand is the esker which preserves the glacial river sediment. The mounds of sand with gravel are the kames which are infillings of holes on and under the melting glacier. Lake Emerald expanded northward along the edge of the receding glacier margin and fine lake sand and silt-clay accumulated over the lake bottom.

B. Wallingford ice margin; Two distinct positions of the front of the glacier can be discerned based upon my interpretation of the field data. Two positions of the lateral or side glacier margin can also be discerned by me. Since all of these positions are closely related both physically and temporally, I have chosen not to subdivide them into separate ice margins. The minor retreats associated with this ice margin should be discussed as a continuum of events related to a glacier margin likely retreating sporadically but never being stationary long enough for a delta to accumulate in Lake Emerald.

The Wallingford kame moraine accumulated along present Roaring Brook. An extensive area of ground moraine began to accumulate along the base of Bear Mountain. The toe of the glacier is not marked by any esker sediment. However, an area of kame moraine accumulated along the western edge of the glacier. Kame moraine is a ridge or series of ridges of sediment deposited at the edge of the glacier. Mostly, it consists of stream deposits mixed with slumped stream deposits...a hardpan material that is a gravelly diamicton. Lake sand continued to accumulate on the lake bottom. Lake sediment reaches up to elevations high enough to suggest the lake level may have been approximately 810 feet with a wide range of error here of +/- 20 feet.

B1; The toe of the glacier retreated to the position marked by the Elfin Lake esker and associated kames. The Bear Mountain ground moraine and Wallingford kame moraine continued to accumulate along the eastern margin of the glacier. A low kame moraine ridge through the cemetery south of Church Street helped locate the lower margin and toe of the glacier.

Glacial Lake Emerald may have lowered as the glacier reached and retreated from this margin. The Elfin Lake deposits record an area where the glacier stagnated. A section of the valley glacier became thin and was detached from the remainder of the glacier which continued to retreat toward Rutland.

C. Haven Hill ice margin; The last area of the Bear Mountain ground moraine accumulated at the lower elevations of the ground moraine shown on Map 8. This sediment blends into a flatter area of more sandy and gravelly sediment I've called a kame terrace because of its flat surface and more sandy texture. Below the kame terrace is a sloping area of sandy and gravelly sediment along Haven Hill Road I've called a kame moraine. This marks the lowest elevation ice edge deposits along the eastern margin of the glacier. Across the valley on the western margin, a low area of kamic or ice contact sediment accumulated. This area includes the northern segment of the Elfin Lake esker and associated kames.

The kame terrace at only 700 feet +/- 20 feet elevation and the low elevation of the kamic sediment on the west side of the valley suggest that the level of Glacial Lake Emerald had certainly lowered to somewhere around 700-725 feet +/- 20 feet elevation. I am unable to narrow down the lake elevation because I could not find any delta to more conclusively determine the lake level. Again, this suggests to me that the lake may have had a falling level throughout the retreat of the glacier from the Wallingford quadrangle. Lake sand accumulated around and over much of the esker and kame sediment, thinly draping over the higher mounds and ridges while more thickly burying the lower elevations.

Wallingford Aquifer Resources

Bedrock aquifer: That carbonate aquifer described earlier is a wonderful and precious source of drinkable ground water. I've attempted to rate the land in terms of its likely capacity to recharge this aquifer with water. This is Map 5 in the set of maps available at the Town office. Recharge of the carbonate aquifer comes largely through the direct infiltration of surface water through a thin cover of overburden or glacial sediment masking the carbonate rock and through the thicker and permeable regions of kamic and lake sediment. Recharge potential is ranked from I-V with I being the highest recharge potential.

Recharge potential is lowest beneath the overburden-mantled Green Mountains underlain by Unit I. The carbonate aquifer is not present here and a hydraulic connection between the Green Mountain schist-gneiss-amphibolite-granite aquiclude and the carbonates of the valley is unlikely. To be sure, the minor areas of marble and quartzite and the scattered areas of more dense rock fractures enable wells drilled into Unit I to produce yields sufficient for homes. Map 10 shows the yields of wells throughout the quadrangle and compares well yields with the bedrock hydrogeologic units identified on Map 2. Average well yields in Unit I are surprisingly high at 8.5 GPM (gallons per minute), 7.0 GPM if the highest and lowest values are ignored. Yet, too many wells here have yields less than 5.0 GPM with more than a handful of well yields less than 2.0 GPM. Therefore, I see the prospects of a good well in Unit I as iffy at best.

Unit III and a small area of Unit I occur along the western edge of the quadrangle. This area of black shale-phyllite and schist is ranked as having a low recharge potential for the carbonate aquifer of Unit I. The rocks have low permeability – how easily water can flow through the fractures and pore spaces in the rock. Also, these rock types have very low porosity and only where there are numerous fractures is there much chance of getting good well yields. Indeed, the average yield of wells in Unit III is the lowest of all the bedrock hydrogeologic units at 6.1 GPM, 5.0 GPM when the highest and lowest values are ignored. However, only a few wells drilled into the black shale-phyllite are located on Map 1, a plot of all located wells of the Wallingford quadrangle. Therefore, there is little validity to these average well yield values. My feeling is that if more wells were drilled into Unit III, the average yield would drop noticeably, perhaps down toward 2-4 GPM. Additionally, there is always a potential for water quality issues in black shale-phyllite rock. Sulfur can be prevalent in the ground water from this rock type and a distinct sulfur odor can sometimes be discernible in such well water. Additionally, black shale-phyllite rock can contain above average amounts of uranium and the presence of radon, an intermediate decay product of uranium, can be present in the ground water. For these reasons, it is not recommended that wells be sited in Unit III.

Unit IQ is also ranked as providing low recharge potential to the Unit I carbonate aquifer. Yet, there is a more plausible prospect that some recharge of the carbonate aquifer occurs through the fractures in the quartzite of Unit IQ along the flanks of Bear, White Rocks and Green Mountains. Recharge of the Unit I aquifer is less likely through thicker till covered areas of Unit IQ and this is predominant along the lower slopes of these mountain ridges. Thus, the entire area was designated as having low recharge potential. Nevertheless, Unit IQ is a pretty good aquifer. The average well yield shown on Map 10 is 13.2 GPM, 11.6 GPM when the highest and lowest values are ignored. These values are higher than or match the average yield from the designated primary aquifer of Unit I on the Wallingford quadrangle. However, there are only a handful of wells drilled into Unit IQ and most of these are very close to the contact with the Unit II carbonate aquifer. The possibility thus exists that some of these wells actually are drilled partly into carbonate rock. This is true for 4 of the wells and the water flowing to these 4 wells probably comes largely from the carbonate aquifer. These 4 wells have an average yield of 21.5 GPM. Higher permeability along the contact between the Unit II and Unit

IQ rock is also possible and could account for the excellent yields in wells drilled near and/or intersecting this contact.

In the valley region, recharge potential is more varied. The Unit II carbonate aquifer is here. Recharge is largely dependent upon the interplay of 2 factors – the thickness of the overburden cover, especially of till, and upon the relative permeability of the overburden material. The recharge potential is highest where the till cover is thin and less where the till cover is thick on any small bedrock cored ridge in the valley. This is because till is a sediment with very low permeability and water flows downward poorly through this layers of till to recharge the carbonate aquifer below.

Higher recharge potential reflects the different nature of the overburden material. Areas of more permeable material called ground moraine which is composed of a mixture of till and more permeable gravel-sand have a greater potential to recharge the carbonate aquifer. Such areas have moderate to high recharge potential. Areas mapped as lake sand on Map 8 also have a high recharge potential due to the permeable nature of sand. However, this designation does not consider that at depth the sand may change and become more silty or clayey which would lower the permeability and reduce the rate of downward flow of ground water toward the carbonate aquifer below. Several well logs indicate thick "clay" layers but it is unknown how much clay versus silt versus fine sand is actually present in these few wells as drillers typically may not differentiate between these sediment types.

Other areas of highest recharge potential occur in the kamic or ice contact sediments of Map 8. This is generally sand or sand and gravel sediment of very high permeability and water can readily flow downward to the carbonate aquifer below. The western side of the valley has a continuous band of kamic material all designated as having the highest recharge potential for the carbonate aquifer below.

All of the recharge potential rankings must be used with due recognition that each area will have internal variations that cannot be discerned on the basis of the field work and analysis done by me. Thus, all areas ranked as having a recharge potential of II because of the presence of ground moraine will not be equally important in their contribution of water to the underlying carbonate aquifer. The thickness and permeability of the ground moraine unit is variable. The thickness and permeability of every overburden mapping unit is variable as well. In conclusion, the recharge potential map must be considered as a broad first step in identifying aquifer recharge areas and in establishing any possible aquifer protection zones to preserve the integrity of the carbonate aquifer.

That said, the carbonate aquifer of Unit II is a valuable water resource. Most wells located on Map 1 with yields plotted on Map 10 are drilled into this valley aquifer. The average well yield is 11.6 GPM. Values range from 0-40 GPM and this wide range reflects the uneven distribution of water-bearing fractures even in this fine aquifer unit. One well may yield 3 GPM while the neighbor's well may yield 30 GPM. As yet, there is no way to identify the distribution of water-bearing fractures beneath the ground other than to identify areas that have the best chance of producing good yields. I have shaded such areas on Map 10 as a very crude guide for future aquifer water use decisions.

Map 4 depicts the depth to the water table or piezometric surface for the Unit II carbonate aquifer. The water table is the upper surface of the saturated layer of the aquifer. Often in a rock aquifer, this surface may be higher than the actual top of the aquifer if there is pressure in the aquifer which pushes water up the well until the pressure equalizes to the air pressure. Geologists call this surface of zero pressure the piezometric surface. There may be some value in anticipating how far down the water may be in your well if drilled into the carbonate aquifer and Map 4 provides the data for such a prediction. More data from more wells and better measurements of static water level in a well reported by drillers will improve this map. It must be remembered that a single well where the static level was measured too soon after pumping and thus before the water level had recovered in a well, will severely distort the contours on Map 4. Yet Map 4 does portray the contours of the water table in a satisfying manner. Areas of higher water table/piezometric surface elevation are areas where the carbonate aquifer is receiving recharge. These data are consistent with and have been incorporated into the recharge potential shown on Map 5.

Overburden aquifer: Drillers information and the surficial geologic map all depict an extensive area of kamic sediment and ground moraine sediment throughout the valley portion of the quadrangle. However, only 3 wells are overburden wells in the Otter Creek Valley. These wells have a very high average yield of 19.7 GPM. Overburden aquifer wells typically yield higher amounts of water than carbonate aquifer wells. There are an insufficient number of overburden wells to clearly define the extent of the overburden aquifer. I must infer its widespread occurrence because the appropriate sandy and gravelly sediments exist in several areas of the valley. And the 3 wells drilled into the overburden aquifer are insufficient to allow me to contour the water table for this aquifer. However, the static water level in these 3 wells is consistent with the static water level in the carbonate aquifers. Thus, the 2 aquifers likely are connected, unconfined and share a common water table.

Yet it must be remembered that the extent of the overburden aquifer is broad and likely discontinuous, its thickness is highly variable, and its nature is very heterogeneous or non-uniform. The porosity and permeability of the sediments varies both laterally and vertically within the aquifer. Porosity refers to the amount of pore space in the sediment...all of the empty spaces between the grains of sand and pieces of gravel which can be filled with water. The more pore space, the higher the porosity and when the porosity is high there is a good likelihood of getting water from a well *if the water can move through the sediment easily.* This latter property of the sediment is permeability. In hydrologic terms, permeability is a measure of the rate at which water moves through the material. A fancier term for permeability is hydraulic conductivity. At the local scale of your back yard, this rate of water movement determines the feasibility and design of a septic system. The percolation rate done in a perc test is the way your local contractor or engineer will determine how effectively your land can accept and biodegrade the effluent which trickles from your leach field.

Map 11 depicts an overburden aquifer recharge potential map drawn following the same procedures as for Map 5, the carbonate aquifer recharge potential map. The mountain summit areas and upper flanks have the lowest potential for recharge of the overburden aquifer. Impermeable thick till areas along the lower flanks have low recharge potential. Similarly, within the broad valley floor, areas of thick or thin till cover over low protruding rock ridges have low recharge potential. Areas of ground moraine have a high recharge potential as do areas of lake sand. Highest recharge potential exists in areas of kamic sediment. While the recharge potential map suggests priorities in protection areas for aquifer recharge, it must be remembered that the entire aquifer is unconfined, meaning that it is not covered by a layer of low permeability material such as clay, and that recharge occurs directly from precipitation infiltrating the permeable ground.

If the potential overburden aquifers discussed in the previous sections are proven to exist, then the recharge potential to these aquifers can be better understood. Recharge to any overburden aquifer must come through direct infiltration of water through permeable material. So, the areas discussed above as composed of gravel, sand or gravel and sand are the materials which have the highest potential to recharge the aquifer. They represent the aquifer material. Additionally, perhaps extensive recharge to a valley bottom overburden aquifer can come from laterally adjacent but hydraulically connected permeable upland materials such as kame moraine, kame terrace and ground moraine units. A better knowledge of the stratigraphy is required before these connections can be stated with confidence. Unfortunately, there is insufficient subsurface knowledge at this time to assess the full nature and extent of the overburden aquifers and their recharge areas at this time. The overburden recharge potential depicted on Map 11 represents a best case scenario where all the permeable surface materials are useful and viable aquifers.

Conclusions and Recommendations

* Surficial geologic mapping enabled the delineation of 3 ice margins through the Town of Wallingford. The sediment accumulated along and in front of these ice margins confirms the retreat of a largely active glacier in the Otter Valley. Further, this retreating ice fronted a proglacial lake here named Glacial Lake Emerald as the spillway was at the threshold to the south of the Wallingford quadrangle. Here there are ice contact deposits blocking a narrowed section of valley in the vicinity of Emerald Lake where the present threshold is at about 720 feet +/- 10 feet. Lacustrine sands cap most of the ice contact sediments observed in exposures in the valley floor.

* The nature and extent of overburden aquifers in these glacial sediments is not fully understood because there are insufficient subsurface data. Overburden thicknesses and aerial distribution of permeable overburden suggest that a single, large extensive unconfined overburden aquifer may not exist in the Wallingford region. Separate, small overburden aquifers may exist in the lacustrine sand veneered overburden on the valley floor. However, the average yield from the 3 overburden wells in town is 19.7GPM and this represents the highest yield among aquifers in the town. Stratigraphic cross sections and overburden thickness analysis reveal the potential for overburden aquifers that await full assessment. The areas of kame moraine, ground moraine, kame and lake sand at the surface indicate that considerable recharge of the overburden aquifers is occurring through direct infiltration of water through these variably but relatively permeable sediments.

* Bedrock wells from the carbonate and quartzite lithologies have average yields of 11.6GPM. Wells drilled near the carbonate – quartzite contact have an average yield of 21.5GPM and suggest enhanced secondary porosity and permeability in the vicinity of the contact due to fractures in both lithologies and perhaps due to dissolution of the carbonate bedrock. Bedrock wells with greater than average yields might be expected if drilled near the carbonate quartzite contact.

* The black shale/phyllite rock unit along the western edge of the quadrangle represents an aquitard/aquiclude and is in thrust fault contact with the carbonate aquifer to its east. This black shale/phyllite rock may be hydraulically isolated from the carbonate by an impermeable thrust fault boundary. This prospect is one which may warrant further study. The water quality concerns typical in black shale/phyllite such as sulfur and/or radon content should discourage use of this rock as a ground water resource and further study of the water quality here may be valuable.

Mapping Unit Descriptions:
Recent;

F **Fill; variable materials used as artificial fill along rail beds, road beds, embankments and low lying areas**. The material may be demolition/construction debris, crushed stone or gravel/sand quarry sediment. Most of the fill is along the path of Rte 7 and along railroad grades, especially to elevate the rail bed above flood plain level. Soils on these disturbed lands are Udorthents and Udisamments. Embankments may be prone to failure.

PM **Peat & Muck; organic sediment, mostly silt and clay in wetlands and swamps; low lying flat lands.** These sediments are rich in decomposing organic matter including grass, leaves and wood. Soils are typically waterlogged, dark or mottled in color and deficient in oxygen. Carlisle muck is the primary soil unit with lesser areas of Copake, Raynham and Fredon soils. Water may intermittently or permanently cover the surface. Unsuitable for development.

AL **Alluvium; stream flood pains; fine sand, silt and gravel of river channel, bar, and bank areas; river bottom lands; variable permeability but usually intermediate to low; often wet sites.** These are low lying terraces within the 100 year planning flood plain and may be seasonally flooded. Soils are often wet and the water table may be encountered at very shallow depth. Organic matter may be locally abundant. The freshest deposits with little or no soil development are Udifluvents. Older deposits with soils are of the Copake, Raynham, Hero and Pootatuck types and are excellent for agricultural uses. The high water table and wet soils impeded the flow of water and render these sites less suitable for development. They may not perc adequately or there may be insufficient thickness of sediment above the water table for conventional septic systems. Embankments along rivers and streams may be prone to failure.

FT **Fluvial Terrace; old flood plains; fine sand, silt and gravel generally less than 5 meters thick overlying other material; flat to gently sloping lands; variable permeability but usually intermediate.** These are old stream terrace deposits above the flood plain. The soils are often deep, well drained loams suitable for agriculture. The water table may be sufficiently deep to allow for conventional septic systems. However, perc rates may be locally variable and wet areas are not uncommon. Groton, Raynham, Hero, Copake and Fredon soil types are found. Bank edged above streams may be prone to failure.

CO **Colluvium; slump, slide and avalanche debris materials composed of boulders, cobbles, gravel, sand and silt; sloping lands.** These are in slide prone areas on mountain slopes or along embankments, especially along streams. Active erosion sites such as these are unsuitable for development. The sole prominent area mapped consists of large boulders in the Ice Beds, a possible relict rock glacier/solifluction lobe of slowly moving boulder and ice mixture.

Late Pleistocene;

LS **Lake Sand; lake bottom deposits of fine sand on gently sloping to flat lands.** Fine sand accumulated on the bottom of Glacial Lake Emerald. The layer drapes over kamic hills and till or rock ridges, typically leaving the top of the hill or ridge uncovered or very thinly covered with sand. Drillers' logs show that in places the sand persists for many feet while in other places the sand becomes finer and grades downward to silt and clay. Groton and Danforth soils are typical.

K **Kame, undifferentiated; glacial deposits from streams, slumps and deposition by ice; stratified and unstratified sand, gravel and boulders with variable silt; rolling, hilly lands; intermediate to high permeability; high gravel-sand resource potential; local steep slopes pose slope stability problem.** Sediment thickness is variable and rock outcrops may occur within this unit. Percolation rates are generally satisfactory for conventional septic systems. These are aquifer recharge areas and are prone to contamination from infiltration. Groton and Danforth soils are typical.

>>> **Esker; subglacial/englacial melt water stream deposits of moderately well sorted gravel and sand with boulders; prominent elongated and curving narrow ridges with steep sides and heights reaching 60+ feet; intermediate to high permeability; high gravel-sand resource potential; steep slopes pose a major slope stability problem.** Individual eskers occur within areas of kame, kame moraine or ground moraine mapping units. Due to their steep slopes and narrow crested summits, these landform features are best left undeveloped or may be used for their gravel-sand resources. Groton soils are typical.

KM **Kame Moraine; ice contact melt water and sediment flow deposits of stratified and unstratified gravel and sand with silt and boulders; rolling, hilly ridged lands with local flat areas; intermediate to high permeability; high gravel-sand resource potential; local steep slopes pose slope stability problem.** Sediment thickness is variable but typically exceeds 10 meters. Percolation rates are generally satisfactory for conventional septic systems. These are aquifer recharge areas and are prone to contamination from infiltration. Groton soils are typical and are suited farming, grazing and woodlot uses. Lesser areas with Galway-Farmington soils may contain abundant silt which will decrease drainage and affect development potential with septic systems.

GM **Ground Moraine; ice contact sediment flow, melt water and ice deposited sediments of variable texture ranging from stratified and well sorted gravel and sand to unstratified and poorly sorted silt, sand, gravel and boulders;**

thickness is variable and rock outcrops may protrude; low to high permeability; limited local slope stability problems; gently rolling hills and elongate smoothed hills are possible. Percolation rates will vary widely over short distances. There is some gravel-sand resource potential here but the possibility of hardpan sediments makes these areas of lower resource potential than kame or outwash deposits. Soils vary widely and include areas of Nellis, Amenia and Galway-Farmington types. These areas are suitable for development, farming, grazing and woodlot uses.

KT **Kame Terrace; ice contact melt water and sediment flow deposits of stratified and unstratified gravel, sand, boulders and some silt; flat to nearly flat lands; intermediate to high permeability; high gravel-sand resource potential; slopes at edges of these areas may pose a stability problem.** Sediment thickness is variable but typically exceeds 10 meters. Percolation rates are generally satisfactory for conventional septic systems. These are aquifer recharge areas and are prone to contamination from infiltration. Groton soils are typical and are suited farming, grazing and woodlot uses. Lesser areas with Galway-Farmington soils may contain abundant silt which will decrease drainage and affect development potential with septic systems. These are similar in characteristics to KM unit above.

T **Till; ice derived deposits of hardpan silt, boulders, gravel and sand which are unsorted and unstratified and deposited beneath the glacier; thickness greater than 3 meters but rock outcrops may be common; surface boulders or erratics are common; smoothed and streamlined hills in the valley and gently undulating slopes on the lower mountain flanks; low permeability; unstable slopes may result in excavations.** Percolation rates are poor and the ground is typically pocked with wet areas making these areas generally unsuitable for development with conventional septic systems. Perched water tables less than 3 feet down may be encountered during excavations. Galway-Farmington, Nellis and Pittsfield soil types prevail.

TT **Till, thin; ice derived deposits of hardpan silt, boulders, gravel and sand which are unsorted and unstratified and deposited beneath the glacier; thickness less than 3 meters with rock outcrops or ledge frequent; surface boulders or erratics are common; moderate to steep mountain slopes and summit areas; low permeability; steep slopes are unstable and slides are common.** Percolation rates in the till are poor but areas devoid of till are common and percolation through thin soil into bedrock may occur at higher rates. Steep slopes, poor percolation and high elevation make these regions unsuitable for development. Land uses are limited to forestry and woodlot management. Valley and mountain areas of thin till are carbonate aquifer recharge zones. Rawsonville-Houghtonville, Dummerston, Taconic-Macomber, Taconic-Macomber, Houghtonville, Berkshire, Tunbridge-Lyman and similar soil types prevail.

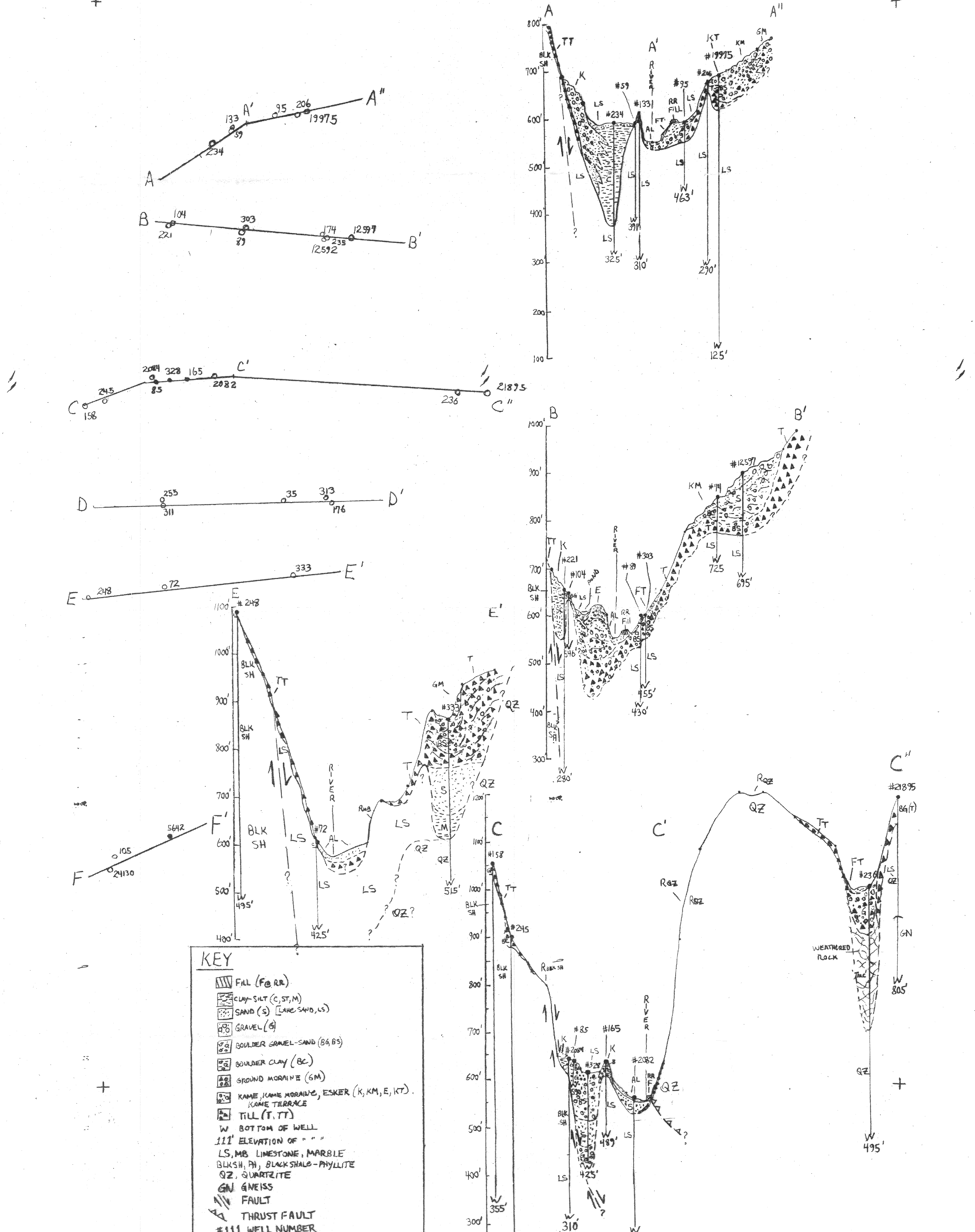
Pre-Cambrian & Paleozoic & Mesozoic Bedrock;

R **Rock outcrop. Marble (Rmb), quartzite (Rqz), phyllite (Rph), schist (Rsc), gneiss (Rgn), granite (Rgr), amphibolite (Ram) are the types observed in the field and/or recorded on the bedrock map of Burton and Ratcliffe. These include areas of predominantly outcrop with patches of till or slump or slide**

debris. Outcrop areas serve to recharge the bedrock units with ground water. Poor sites for septic systems prevail. Slopes are generally stable. Development potential is low. Scenic views are common.

MAP 6

STRATIGRAPHIC CROSS SECTIONS



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