GEOLOGIC FRAMEWORK FOR EVALUATING GROUND WATER RESOURCES IN THE SOUTHERN WORCESTER MOUNTAINS, CENTRAL VERMONT

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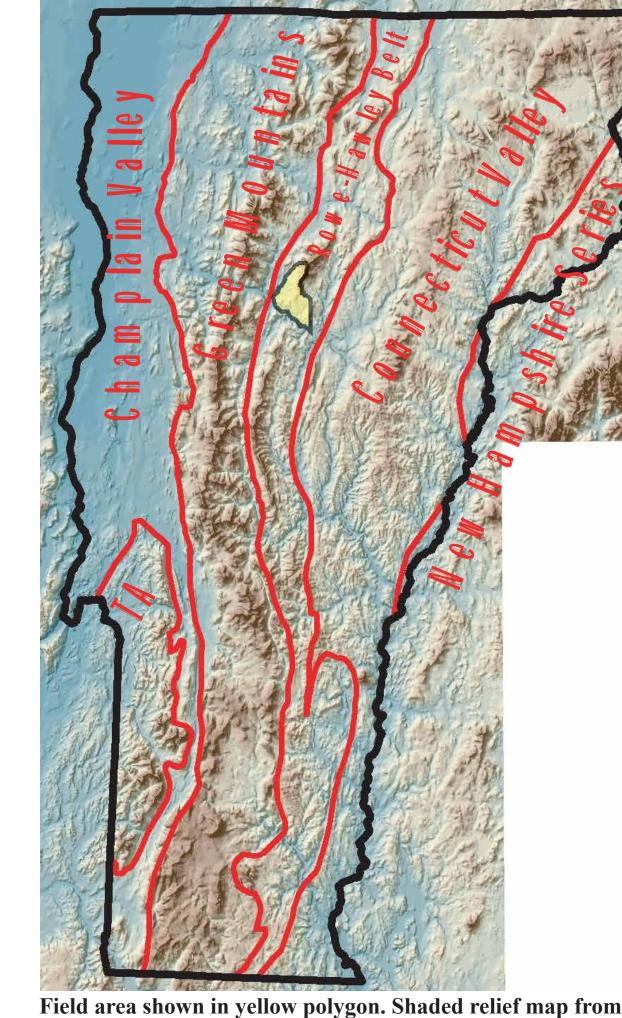
The identification and protection of ground water resources is an important issue in Vermont. We assembled a multi-disciplinary geologic framework to evaluate ground water resources in the watersheds surrounding the southern Worcester Mountains in central Vermont. These watersheds e underlain by Cambrian-Ordovician bedrock and Pleistocene and Holocene surficial deposits The data layers for this framework include: 1) bedrock geologic map, 2) surficial material map,) photolineament map with structural control, and 4) water well data. Through integration of these data sets, we will assess the factors that affect well yields in the bedrock and surficial aquifers" in this area. This study will be a prototype for further ground water investigations.

The Worcester Mts are the dominant topographic feature in the study area - a NNE trending, outh-plunging anticlinorial ridge cored by resistant schists; this lithology forms the steepest opes. The flanks and surrounding valleys are composed of generally less resistant amphibol hyllites, and granofels. Based on photolineament and structural analysis, the overall topographic grain is parallel to ductile structures, however, specific domains in quartz-rich lithologies are dominated by fractures orthogonal to ductile structures. Drainage patterns in recharge areas are fracture controlled

Surficial deposits include till, esker and other ice-contact deposits, lacustrine deposits ranging from silty clav to pebbly sand, alluvial fans and fan-terraces, stream terraces, and alluvium. Former lake shorelines range in elevation from 1230 feet down to 650 feet. An esker buried under lake deposits in the Winooski River valley bottom may be an important aquifer. Relatively impermeable ice contact and lacustrine deposits that directly overlie bedrock may serve as aquitards to locally reduce bedrock aquifer recharge and produce artesian conditions in nearby bedrock wells.

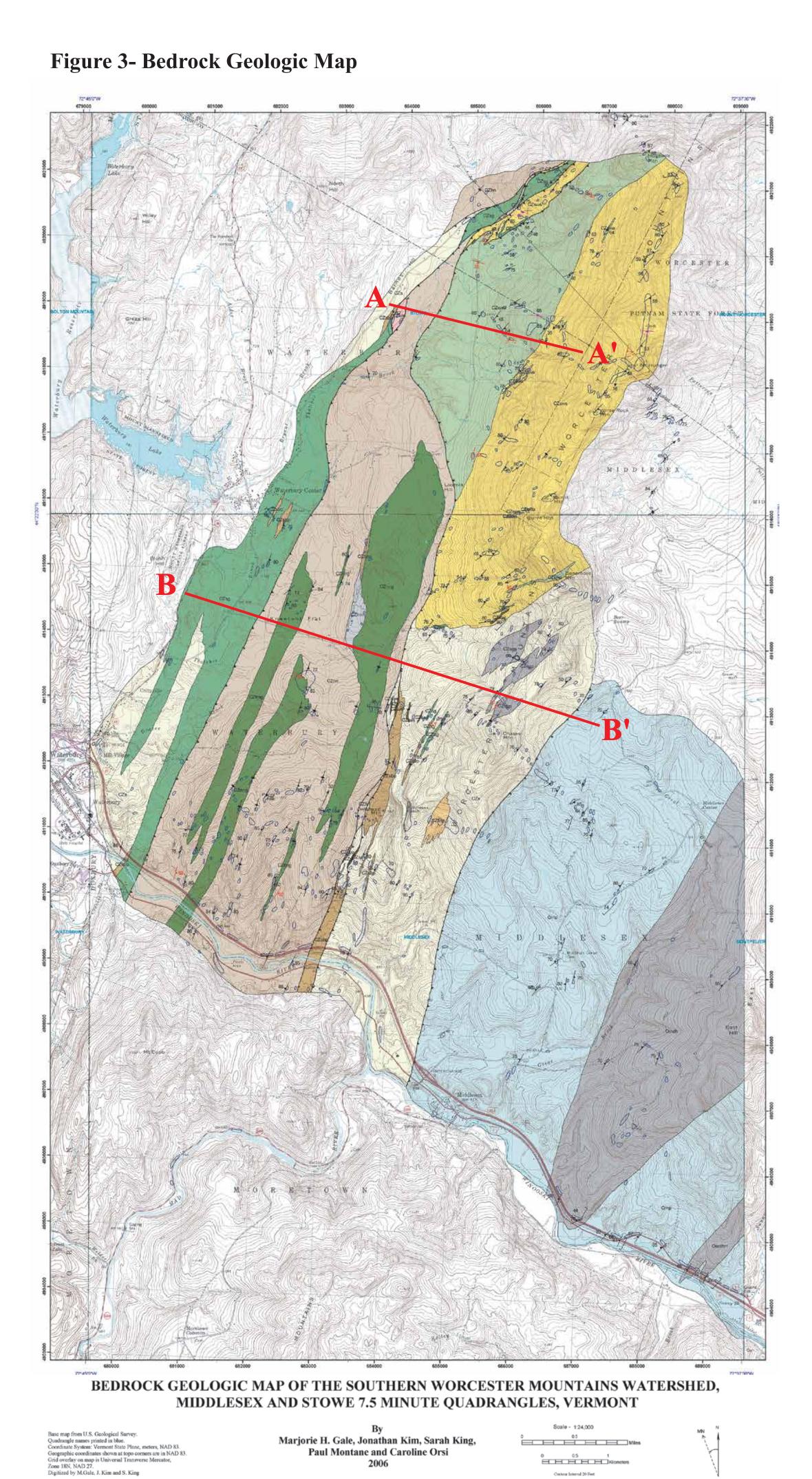
Our analyses seek to identify the relationship(s) between well yield and l) lithologic and surficial units 2) proximity to topographic lineaments, 3) surficial material thickness and permeability, 4) surface water proximity, 5) major bedrock structures, 6) slope and other topographic indices, 7) drainage area size.

Figure 1- Bedrock Provinces of Vermont



Vermont Dept. of Environmental Conservation GIS database.





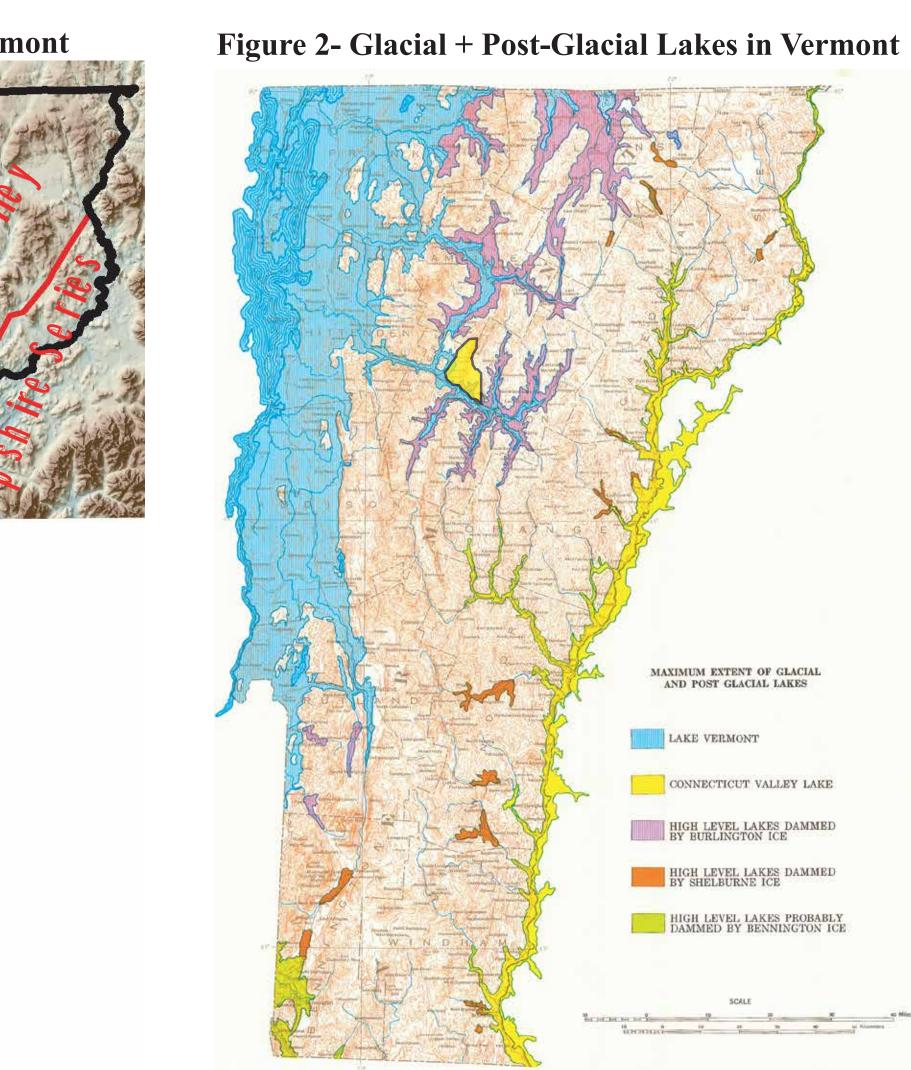
esearch supported by the Vermont Geological Survey, Dept. of Environmental Conservation, VT ANR. is geologic map was funded in part by the USGS National Cooperative Mapping Program. views and conclusions contained in this document are those of the authors and should not be interpreted as ssarily representing the official policies, either expressed or implied, of the U.S. Government.

	ption of Bedrock Map Units
Omdh	Dark to medium gray quartzite, laminated quartzite, phyllite, and granofels.
Omp	Interlayered gray and green quartz-sericite-chlorite-albite granofels, "pinstriped" granofels, and tan phyllite.
Ultramafic	Rocks (Ordovician to Late Proterozoic?)
OZum	One occurrence at the Barnes Hill Talc prospect; brown to white weathering, dark green, serpentinite and talc-carbonate rock.
Stowe For CZs	mation (Cambrian to Late Proterozoic) Green to gray quartz-sericite-chlorite phyllite and schist; black graphitic phyllite; abundant quartz veins; thin (1-10 m) interlayered greenstone is common at Chases Mountain.
CZssp	Gray -green laminated sandy schist and interlayered phyllite.
CZsgp	Gray quartz-sericite phyllite and schist.
CZsbp	Black, graphitic phyllite +/- pyrite.
CZsas	Dark gray, quartz-sercite schist with albite porphyroblasts.
CZsg	Light to dark green, massive to foliated chlorite-epidote-albite- actinolite greenstone and calcareous greenstone. Bluish-silver to white, medium-grained, spangly,
CZsws	chlorite-muscovite-quartz schist +/- albite, garnet, kyanite, and chloritoid with elongated quartz knots and pink coticule lenses. Dark green to black, massive, medium- grained,
CZswa	banded albite-epidote-hornblende amphibolite +/- garnet, contact with CZsws is generally sharp, and the units are interlayered.
Hazens No	tch Formation (Cambrian to Late Proterozoic) Dark gray and green, rusty-weathering, patchy graphitic, albitic
CZhn	Fine to medium grained, gray granofels and schist.
CZhon	Gray and rusty weathering, black graphitic, sulfidic phyllite.
CZhnp	Light to dark green, massive to foliated chlorite-epidote-albite-actinolite greenstone and calcareous greenstone; commonly displays
	compositional layering defined by epidote-rich layers and pods.
Descrip	otion of Surficial Geologic Units
ar	ar - Artificial Fill. Fill consists of sand, gravel, till, and a variety of other materials.
Hal	Hal - Holocene Alluvial Deposits. Silt, sand, pebble gravel, cobble gravel, and boulder gravel deposited by modern streams.
Hst	Hst - Holocene Stream Terrace Deposits and Alluvial Deposits, undifferentiated. Silt, sand, pebble gravel, cobble gravel, and boulder gravel deposited on terraces above the modern floodplains of streams. Many areas of modern alluvium are included in this unit.
Hw	Hw - Holocene Wetland Deposits. Clay, silt, sand, muck or peat of variable thickness. Common in valley bottoms and along streams.
Qaf	Qaf - Quaternary Alluvial Fan Deposits.
QR	Qft - Quaternary Fan-Terrace Deposits. Pebbly sand, sandy pebble gravel, and coarse sandy cobble gravel deposited on lacustrine terraces. The deposits have a sheet-like form. Fan terra are well-developed on surfaces just below the Lake Winooski shoreline (Waterbury Center) and Glacial Lake Mansfield I shoreline (Kneeland Flats). Thickness less than 10 feet.
Clim1g	QIm1g - Quaternary Gravel Deposits in Lake Mansfield I. Pebbly sand overlying lacustrine silt and sand. Exposed at Waterbury Center below the Glacial Lake Mansfield I shoreline. Thickness is less than 10 feet.
Qlwshb	Qlwshb - Quaternary Lake Winooski Shoreline Boulder Deposit. Boulder gravel deposit exposed on the Glacial Lake Winooski shoreline at approximately 1010 feet elevation east of Kneeland Flat. Thickness less than 10 feet.
Qlwd	Qlwd - Quaternary Lake Winooski Delta Deposit. Silt, sand, pebbly sand, and pebble gravel of formed by streams flowing into Glacial Lake Winooski. Examples are found north of Waterbur and east of Kneeland Flats. Thickness up to 40 feet.
Qld	Qld - Quaternary Deltaic Deposits. Silt, sand, pebbly sand, and pebble gravel deposits formed by streams flowing into glacial lakes. Not clearly assignable to one of the recognized lake levels. Thickness probably less than 30 feet.
Qis	QIs - Quaternary Lacustrine Shoreline and Shoaling Deposits. Fine to medium sand and pebbly fine to medium sand deposited in Glacial Lakes. The deposits are well-developed along the Lake Winooski shoreline. Thicknesses range locally up to at least 20 feet although these deposits are usually underlain by finer-grained lacustrine material at shallower
QIf	QIf - Quaternary Fine-grained Lake Deposits. Clay, silty clay, silt, silty very fine sand, and very fine sand, sometimes with pebbles, laminated and commonly varved, deposited in glacial lakes. Fine-grained lacustrine deposits formed in Glacial Lake Loomis occur below about 1200 feet on the west side of the Worcester Range and the deposits are widespread below the Lake Winooski shoreline at 990 -1010 feet elevati Thickness ranges widely from a few feet to greater than 100 feet.
QI	QI - Quaternary Lacustrine Deposits, Undifferentiated.
Qtr	Qtr - Quaternary Readvance Till. Extremely poorly sorted silt-matrix diamict with abundant cla ranging in size up to boulders up to 6' in diameter, moderately dense. Exposed above ice-contact lacustrine deposits at about 1200' on the west flank of the Worcester Mtns and also in the Great Brook valley at 1200'. Similar till overlies the outwash deposits south of Mide Commonly less than 10' thick.
Qow	Qow - Quaternary Outwash Deposits. Sand and gravel deposited from meltwater flowing sou through gaps at Middlesex Notch and the notch west of Owls Head Mountain. Includes coarse and fine-grained lacustrine material. Thickness exceeds 100' at the deposit south of Middlese
Qic	Qic - Quaternary Ice-contact Deposits. Includes Qicl (Quaternary Ice-contact Lacustrine). Stratified sand and gravel deposits showing indications of significant collapse. Thickness up to 200' on the bench at 1200' elevation west of the Worcester Range and north of Loomis I
Qt	Qt - Quaternary Till, undifferentiated. Extremely poorly sorted silt-matrix diamict with abundant angular to subangular clasts. Thickness highly variable, from less than 10' to locally at least 75'.
î	Ice Motion Indicators
_	Lake Thatcher Shoreline
	Lake Winooski Shoreline Lake Mansfield 1 Shoreline
_	Lake Mansfield 2 Shoreline
\square	Holocene Winooski River Meander Traces Study Area boundary
Frederic Central V Westerm Conferen high-lev and bour Winoosl William See Lars	shorelines rise 4.74 feet per mile to N 21 W as per Larsen, k, D., 1987, History of glacial lakes in the Dog River Valley, Vermont <i>in</i> Guidebook for Field Trips in Vermont, Volume 2, han, D.S., <i>ed.</i> ,: New England Intercollegiate Geological nce, Northfield, Vt., p. 213-236. Glacial Lake Loomis is a local, el lake graded to the north end of Middlesex Notch (1230 feet) nded on the west by ice in the Thatcher Brook valley. Glacial Lake ki and Lakes Mansfield I and II are regional lakes graded to the stown Gulf, Gillett Pond, and Hollow Brook outlets respectively. sen (1987) for details.
Environ funded i Program are those	h supported by the Vermont Geological Survey, Dept. of mental Conservation, VT ANR. This geologic map was in part by the USGS National Cooperative Mapping h. The views and conclusions contained in this document e of the authors and should not be interpreted as necessarily thing the official policies, either expressed or implied, of the

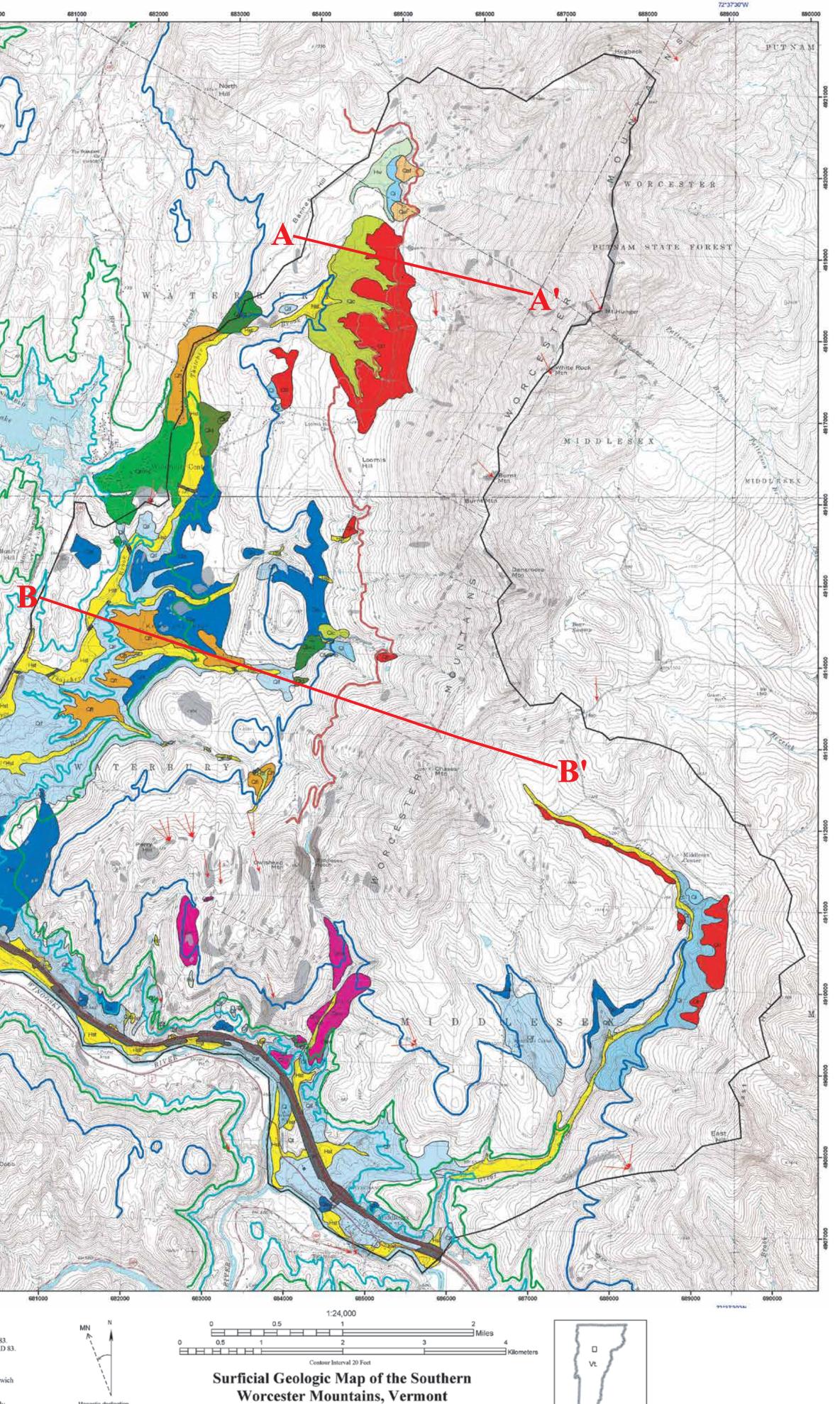
Magnetic-doclination 15.5 degrees west, 1988

uadrangle names printed in blue. oordinate System: Vermont State Plane, meters, NA eographic coordinates shown at topo corners are in rid overlay on map is Universal Transverse Mercato one 18N, NAD 27. Cartography and digitizing by George Springston of Norwich University Department of Geology and Sarah King. This map is not a survey and is for planning purposes only. March 9, 2006.

Magnetic declination 15.5 degrees west, 1968



Modified from Stewart and MacClintock (1970). Field area shown in yellow polygon.



by George Springston and Rick Dunn

Field Area Location

Figure 8- Isopach Map of Field Ar

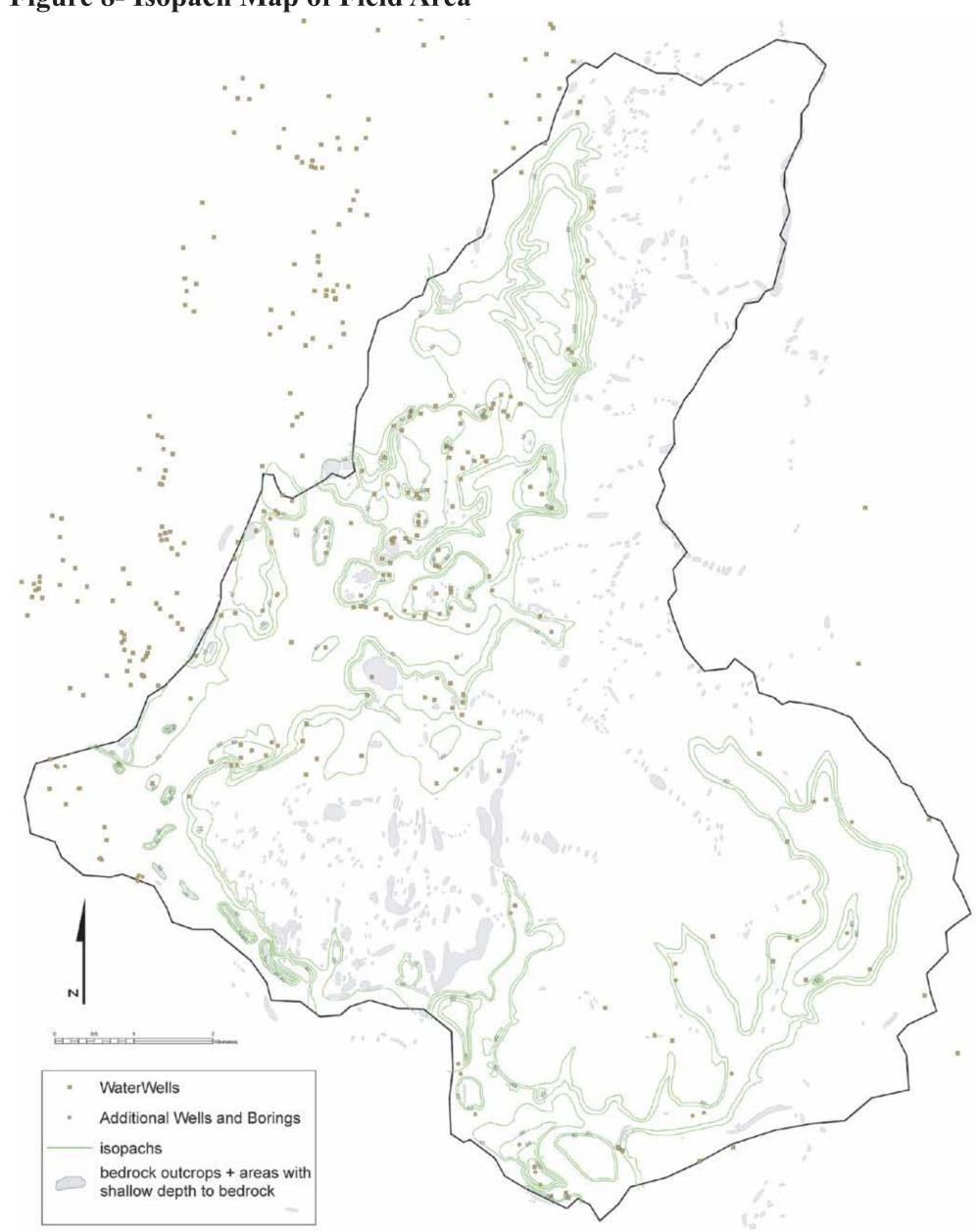
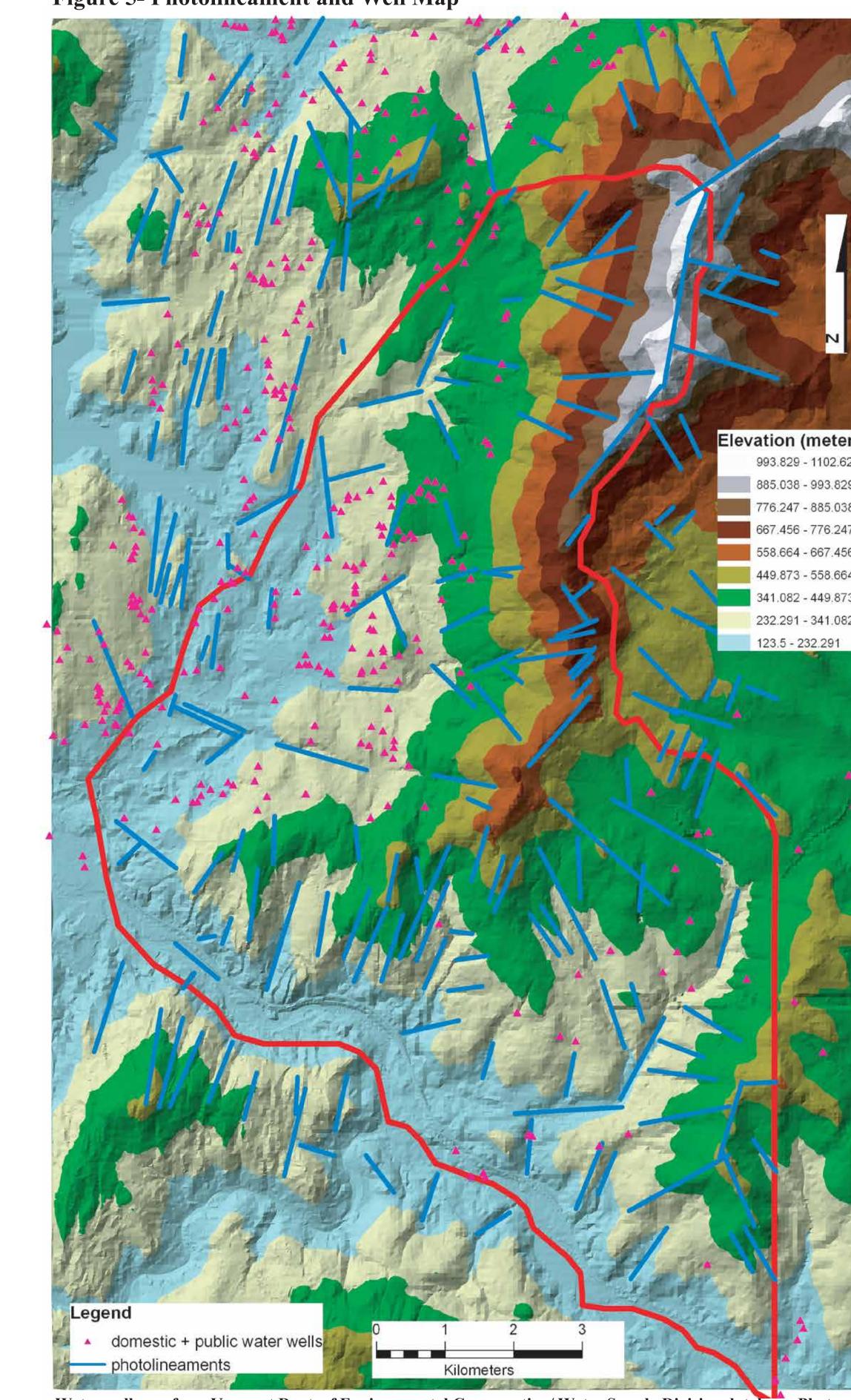


Figure 5- Photolineament and Well Map



Water wells are from Vermont Dept. of Environmental Conservation/ Water Supply Division database. Photolineaments from Montane et al. (2005). Study area boundary shown in red. Note the strong correlation between lineaments derived from the stereoscopic analysis of airphotos and the topographic features on the tin. The reconciliation of photolineaments with ductile and brittle structural data from the field is complete for the southeastern half of the field only. In general, north-northeast trending lineaments are parallel to ductile structures whereas east-west and northwest trending lineaments are parallel to brittle structures. See Montane et al. (2005) for a review.

Yields of wells in the study area shown on a shaded relief map. In general, wells

with higher yields are found near the topographic break on the west side of the spine of the Worcester Mts. This topographic break coincides with the lithologic change from schist to amphibolite (See Figure 10).

Figure 10- Well Yield and Bedrock Ma

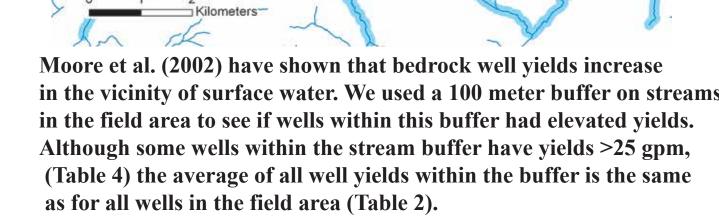
0 1 50 Yield (gallons/ minute (gpm))

Well yields shown on a bedrock geologic map of the field area. Most of the wells with highest yields (>50 gpm) are found in the amphibolite (CZswa) and easternmost greenstone (CZhng) units. The two wells completed in surficial materials are shown with blue dots. Well yields range from 0.3 - 100+ gpm and have a median of 10 gpm.

	<u>n</u>	<u>GPM</u>	DTB	<u>TD</u>	Specific Capacity	Yield/DTB	DTB/TD	(DTB/TD)*Yield
<u>Unit</u> CZs	8	12.9	23.0	249.6	0.09	2.2	0.1	0.6
CZsg	23	10.6	36.5	216.4	0.06	0.6	0.2	1.8
CZswa	8	33.4	46.4	166.5	0.22	3.1	0.3	9.3
CZsws	2	7.5	97	186	0.04	0.1	0.5	4.3
CZhn	58	13.2	33.2	210.2	0.08	0.9	0.2	2.3
CZhng	32	15.8	25.3	209.0	0.10	1.0	0.1	2.9
Om	22	14.7	31.3	229.8	0.09	1.1	0.2	5.9
= # of	wells	, GPM=	=gallor	ıs/min	ute, DTB=d	epth to	bedro	ock, TD=te

nGPMDTBTDSpecific CapacityField Area Wells17214.735.02200.09	Table 2- ave	rage well	parame	ters for	field	area and state	wide we
Field Area Wells 172 14.7 35.0 220 0.09		<u>n</u>	<u>GPM</u>	DTB	TD	Specific Capacity	
	Field Area Wells	172	14.7	35.0	220	0.09	
Statewide Wells 91,469 14.0 36.8 275	Statewide Wells	91,469	14.0	36.8	275		

Figure 13- Proximity to Streams: Buffered Streams and Well Yields



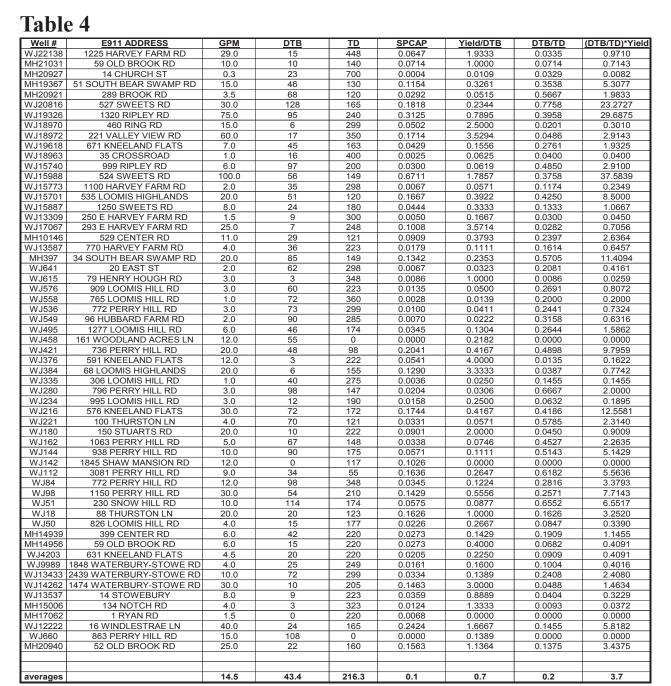
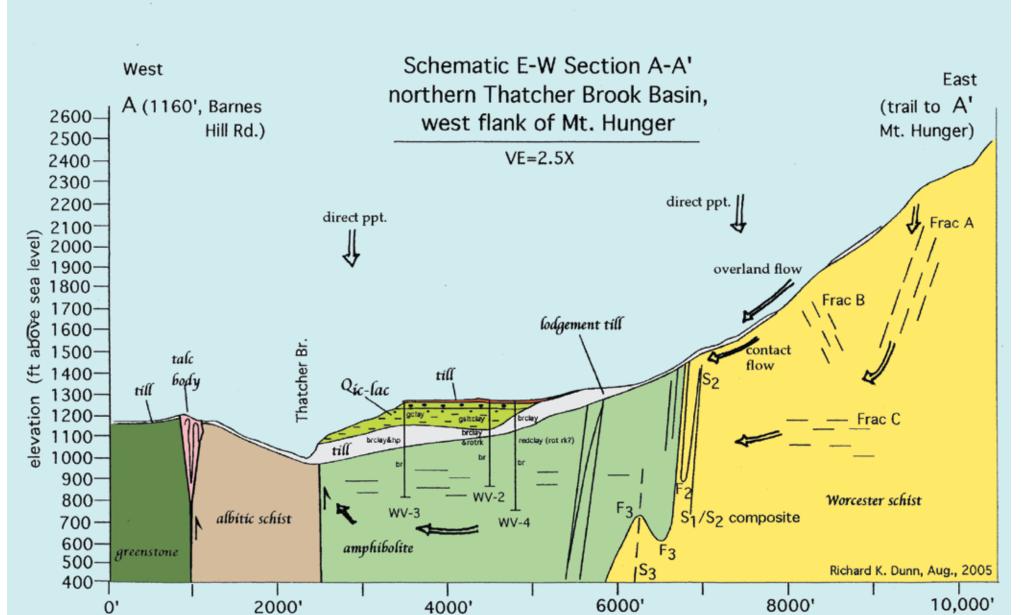
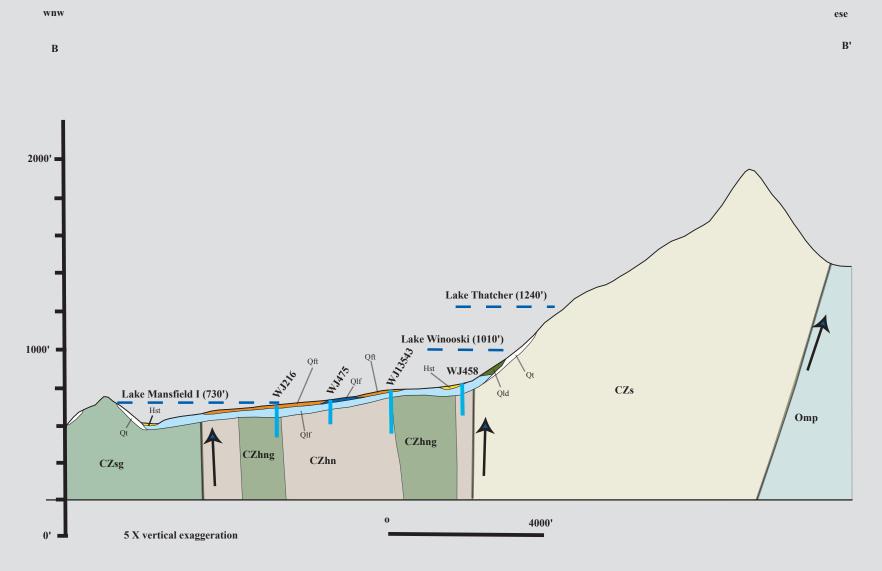


Figure 6- Cross Section A - A'

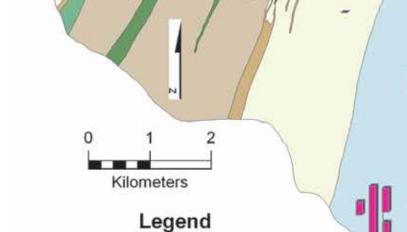


Line of section shown on Figures 3 and 4.





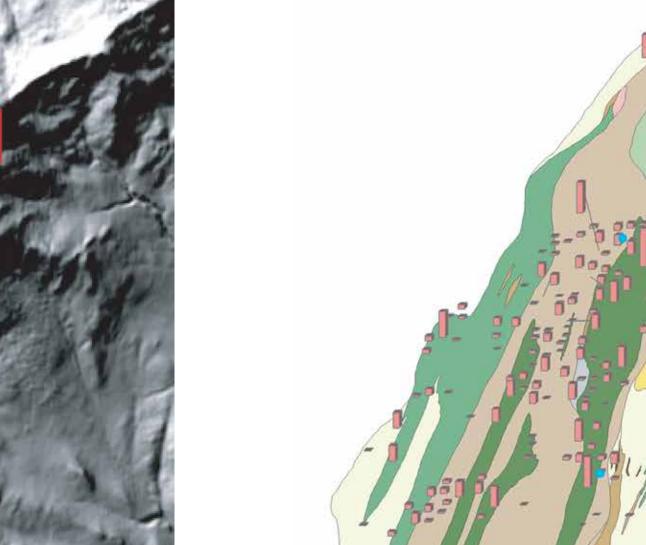
Line of section shown on Figures 3 and 4.

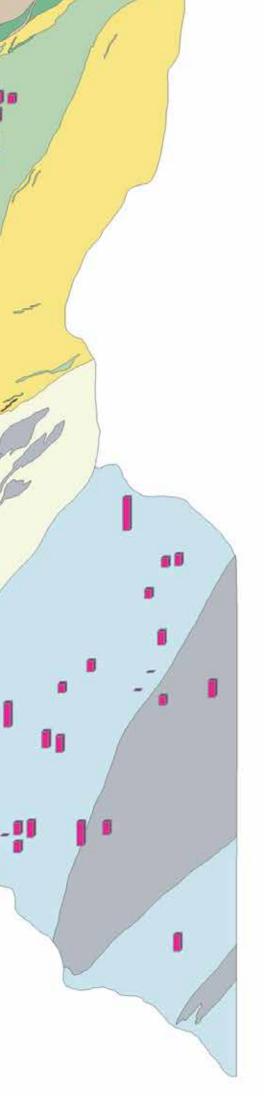


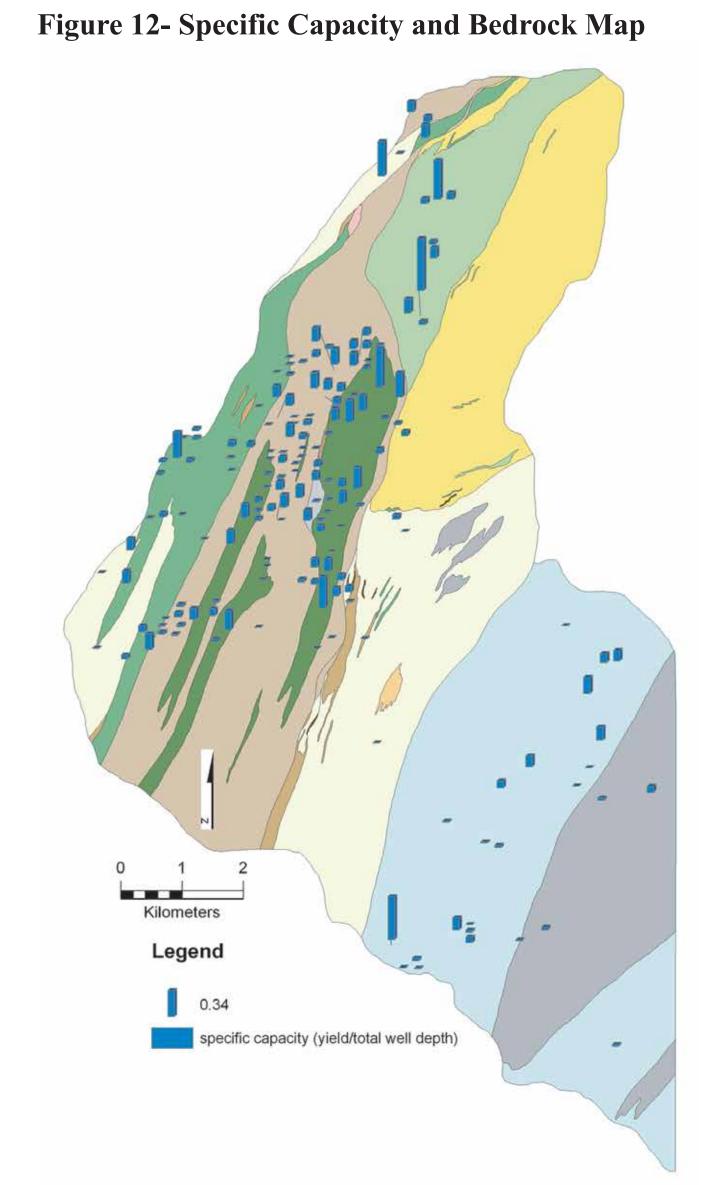
Total Well Depth (feet)

350

Overall well depths are variable. There are no obvious patterns in the distribution of deeper or shallower wells. Total well depths ra from 50' - 700' and have a median of 198'.

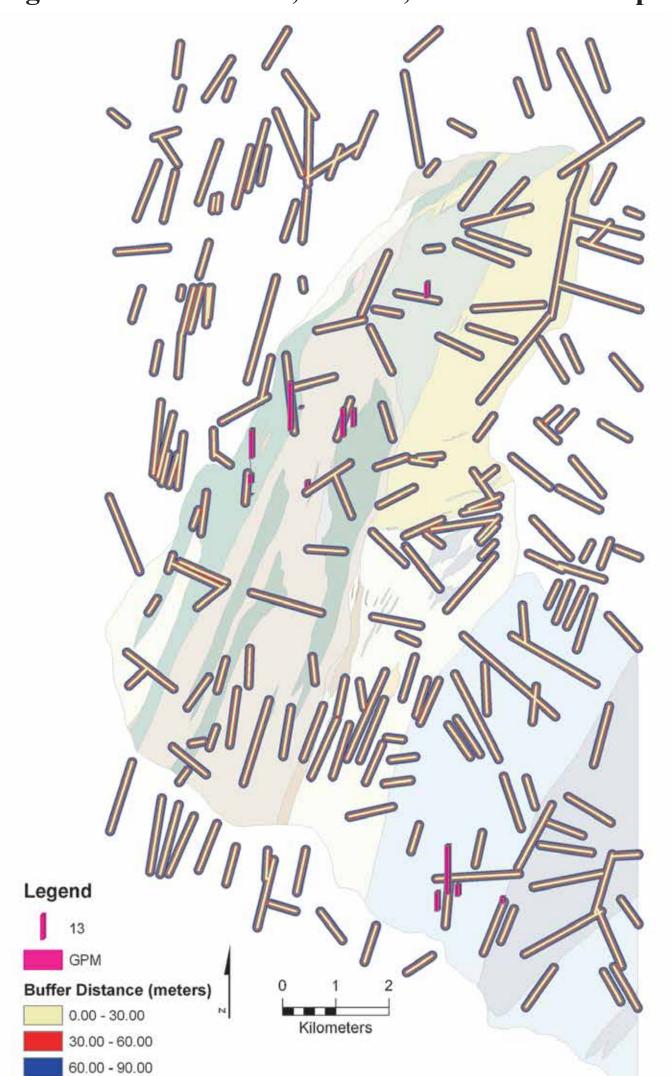






Specific Capacity is a measure of the productivity of a well on a per foot of total depth basis. Wells with higher specific capacities are located near the western slope break of the Worcester Mts. and in the amphibolite (CZswa) and greenstone (CZhng) units (see figures 9 + 10). Specific capacity values range from 0.0004 - 1.7857 gpm/foot and have a median of 0.0521 gpm/foot.

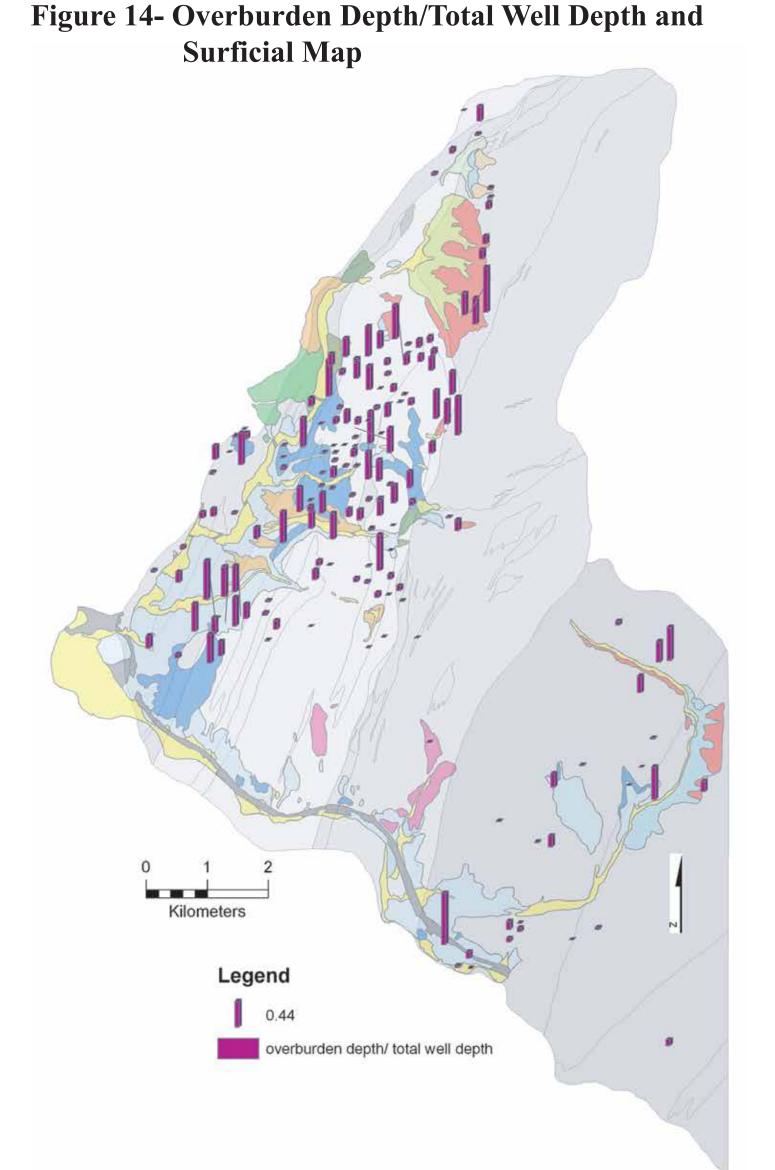
Figure 13- Lineaments, Buffers, and Bedrock Map



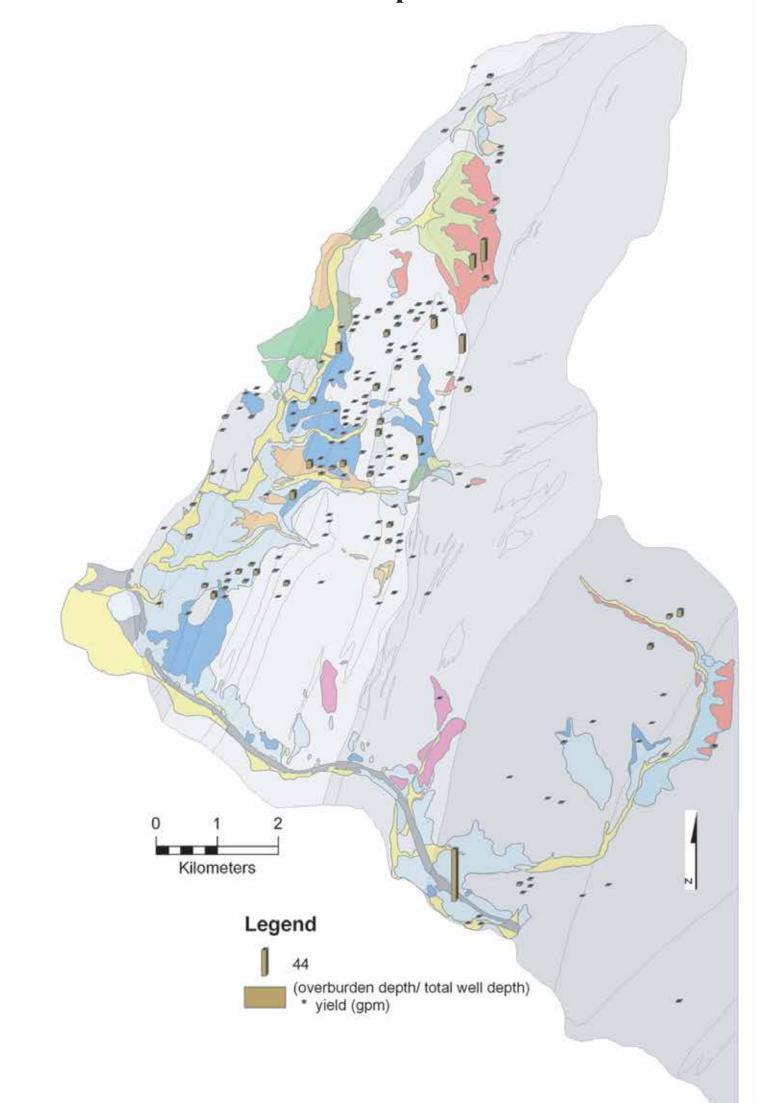
Lineaments were determined from the stereoscopic analysis of numerous airphoto pairs from the field area by Montane et al. (2005). The strong correlation between lineaments and topographic features can be seen on Figure 5. In general, north-northeast trending lineaments are parallel to ductile structures whereas east-west and northwest trending lineaments are parallel to brittle structures. See Montane et al. (2005) for a review. Concentric buffers of 30, 60, and 90 meters were drawn around each lineament to see there was any preliminary correlation between well yield and lineament proximity. Table 3 shows that only 14 wells fall within the largest 90 meter lineament buffer. Although 2 wells have yields of 25 gpm, the average for all of these wells is only 9 gpm, less than the average for all wells in the study area (Table 2).

Well #	<u>GPM</u>	DTB	TD	Specific Capacity	Yield/DTB	DTB/TD	(DTB/TD)*Yield
WJ22357	3.0	8	298	0.01	0.4	0.0	0.1
MH21031	10.0	10	140	0.07	1.0	0.1	0.7
MH20919	3.3	2	320	0.01	1.6	0.0	0.0
WJ15886	0.0	56	300	0.00	0.0	0.2	0.0
WJ15887	8.0	24	180	0.04	0.3	0.1	1.1
WJ558	1.0	72	360	0.00	0.0	0.2	0.2
WJ171	0.0	13	247	0.00	0.0	0.1	0.0
WJ42	9.0	11	98	0.09	0.8	0.1	1.0
WJ68	15.0	5	198	0.08	3.0	0.0	0.4
MH14956	6.0	15	220	0.03	0.4	0.1	0.4
WJ2618	5.0	3	340	0.01	1.7	0.0	0.0
WJ15016	25.0	108	173	0.14	0.2	0.6	15.6
WJ19342	15.0	0	173	0.09	0.0	0.0	0.0
MH20940	25.0	22	160	0.16	1.1	0.1	3.4
averages	9.0	25	229	0.05	0.8	0.1	1.6

Figure 15- (Overburden Depth/Total Well Depth) x Yield and Surficial Map



Because there are areas in Vermont where thick, porous, and permeable overburden (surficial material) enhances the yield of bedrock wells, we decided to assess the influence of the overburden on well yields in this field area. The first step was to delineate wells where the overburden thickness was a significant proportion of the total well depth. Average dtb/td =



The second step was to multiply the ratio of the overburden depth/ total well depth by the yield of each well. Although simplistic, this method allowed us to see which wells with significant proportions of overburden thickness also had higher yields. A number wells on the west side of the Worcester Mts. that sit near the slope break defined in Figure 9 and within the lithologic units defined in Figure 10 have adjusted yields suggestive of overburden influence.

Conclusions

- 1) Wells located at the slope break on the west side of the Worcester Mts. in amphibolite and greenstone units have -higher yields
- -higher specific capacities
- 2) Although some wells located within the buffers of lineaments and streams have higher yields, overall averages for these data sets are \sim the same as the averages for all field area wells.
- 3) With the exception of some wells described in #1, surficial material (overburden) thicknesses do not appear to positively affect well yields.
- 4) This study highlights a number of analysis tools that can be used to investigate the relationships between ground water, **Bedrock Geology, Surficial Geology, and Topography.**

