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

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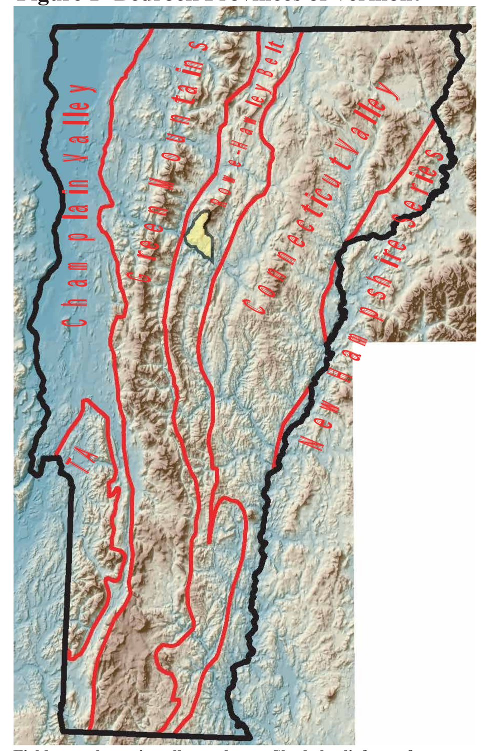
The identification and protection of ground water resources is an important issue in Vermont. We assembled a multi-disciplinary geologic framework to evaluate ground water resources in the watersheds surrounding the southern Worcester Mountains in central Vermont. These watersheds are underlain by Cambrian-Ordovician bedrock and Pleistocene and Holocene surficial deposits. The data layers for this framework include: 1) bedrock geologic map, 2) surficial material map, 3) 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, south-plunging anticlinorial ridge cored by resistant schists; this lithology forms the steepest slopes. The flanks and surrounding valleys are composed of generally less resistant amphibolite, phyllites, 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 clay 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.

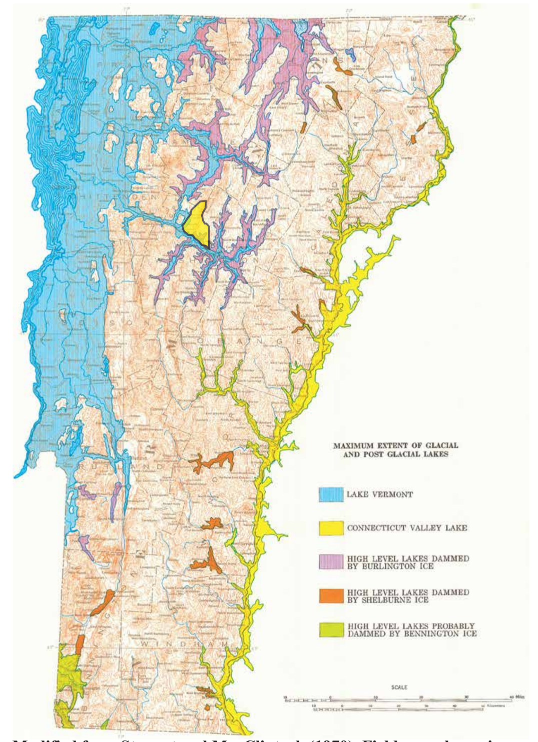
Our analyses seek to identify the relationship(s) between well yield and 1) lithologic and surficial units 2) proximity to topographic lineaments, 3) surficial material thickness and permeability, 4) surface water proximity, 5) major bedrock structures, 6) slope and other topographic indices, 7) drainage area size.

Figure 1- Bedrock Provinces of Vermont



Field area shown in yellow polygon. Shaded relief map from Vermont Dept. of Environmental Conservation GIS database.

Figure 2- Glacial + Post-Glacial Lakes in Vermont



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

Figure 8- Isopach Map of Field Area

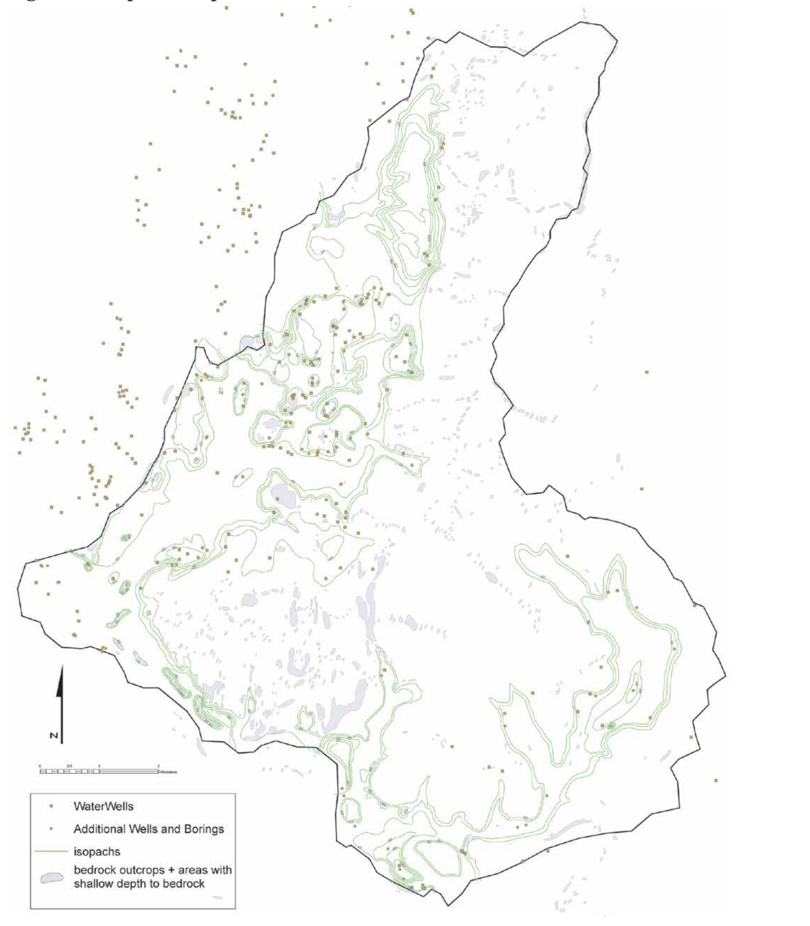
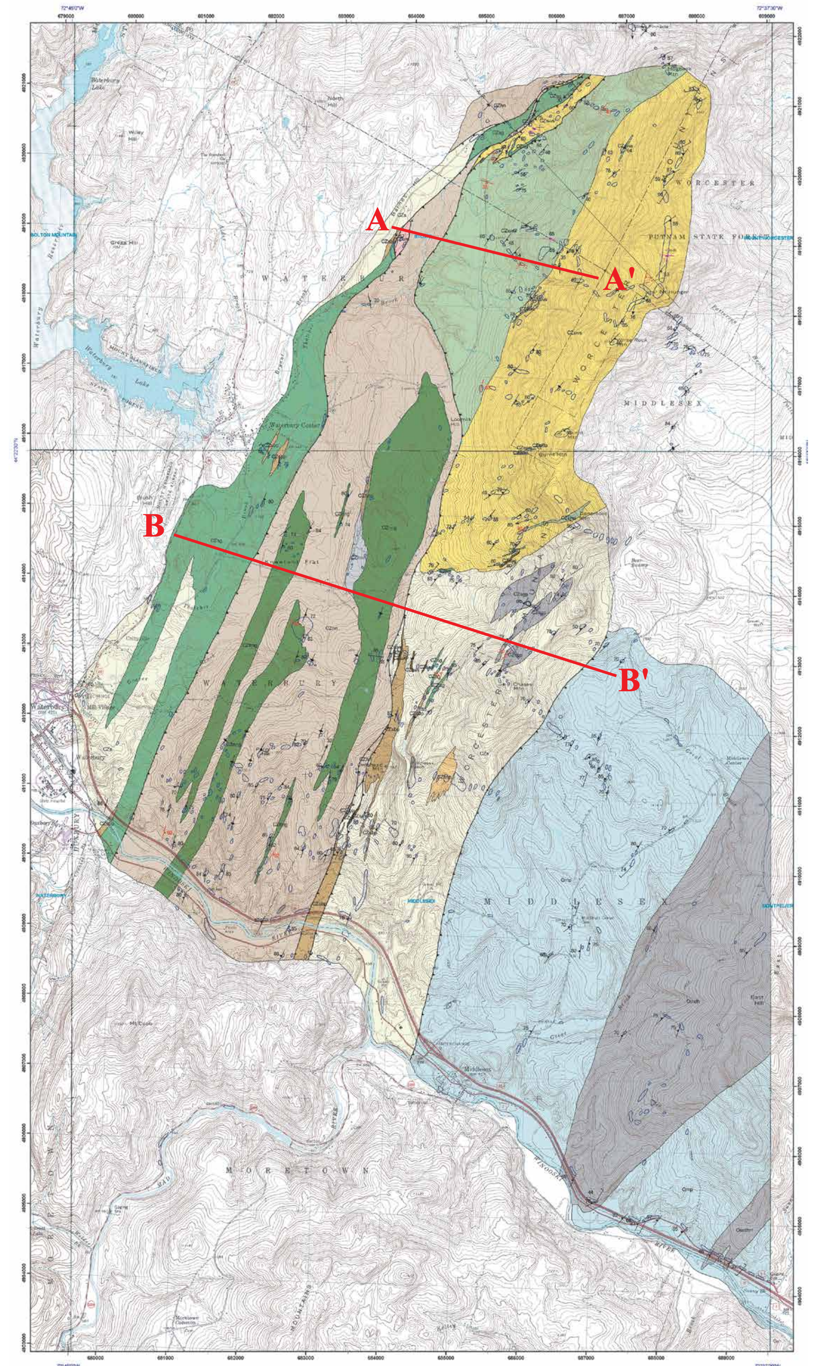
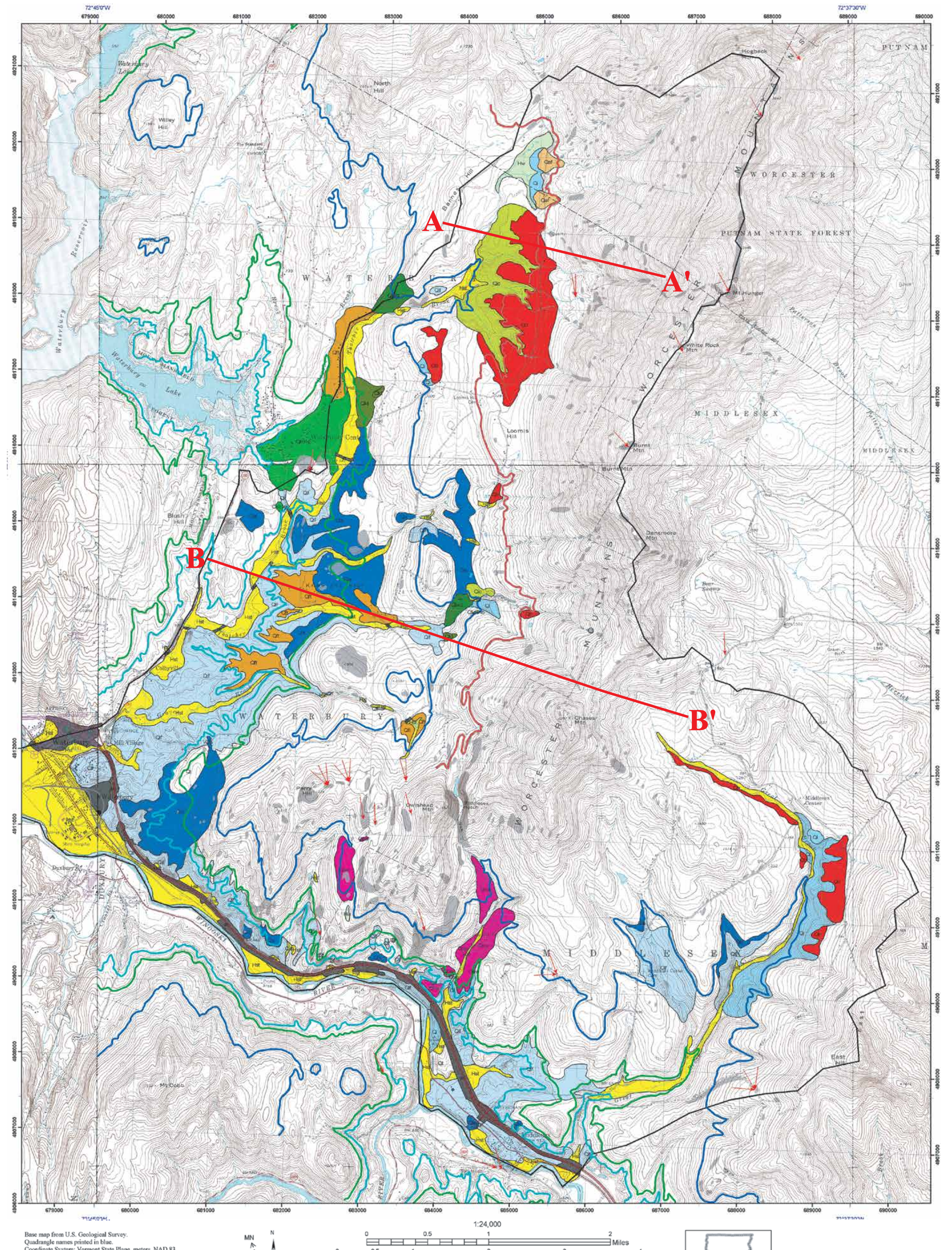


Figure 3- Bedrock Geologic Map



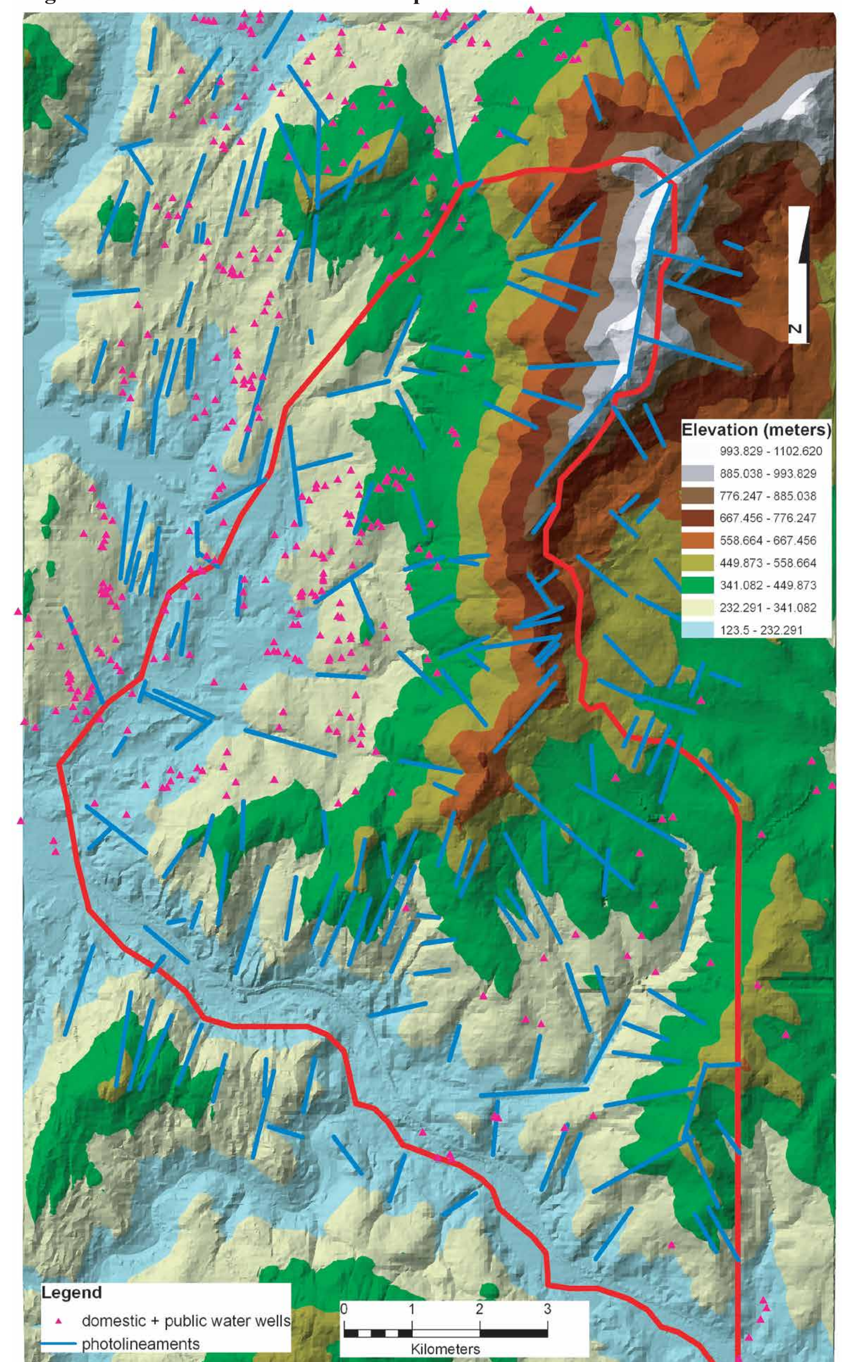
BEDROCK GEOLOGIC MAP OF THE SOUTHERN WORCESTER MOUNTAINS WATERSHED, MIDDLESEX AND STOWE 7.5 MINUTE QUADRANGLES, VERMONT

Figure 4- Surficial Geologic Map



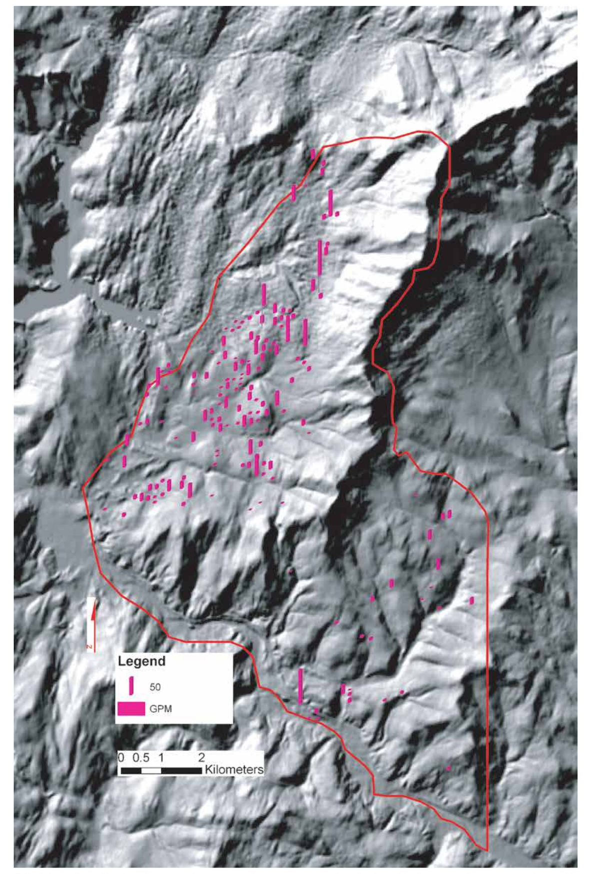
Surficial Geologic Map of the Southern Worcester Mountains, Vermont
by George Springston and Rick Dunn
2006

Figure 5- Photolineament and Well Map



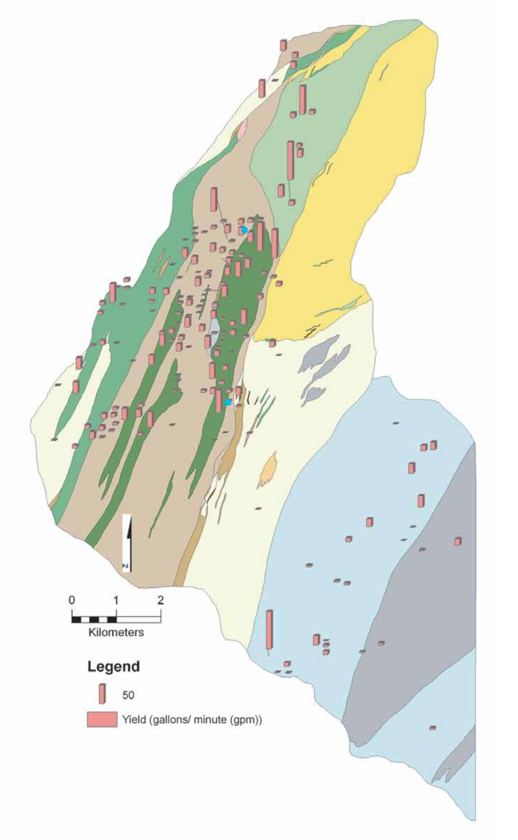
Water wells are from Vermont Dept. of Environmental Conservation/ Water Supply Division database. Photolineaments from Montane et al. (2005). Study area boundary shown in red. Note the strong correlation between lineaments derived from the stereoscopic analysis of airphotos and the topographic features 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.

Figure 9- Well Yield and Shaded Relief Map



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 [illegible]

Figure 10- Well Yield and Bedrock Map



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.

Table 1- average well parameters by major lithologic units

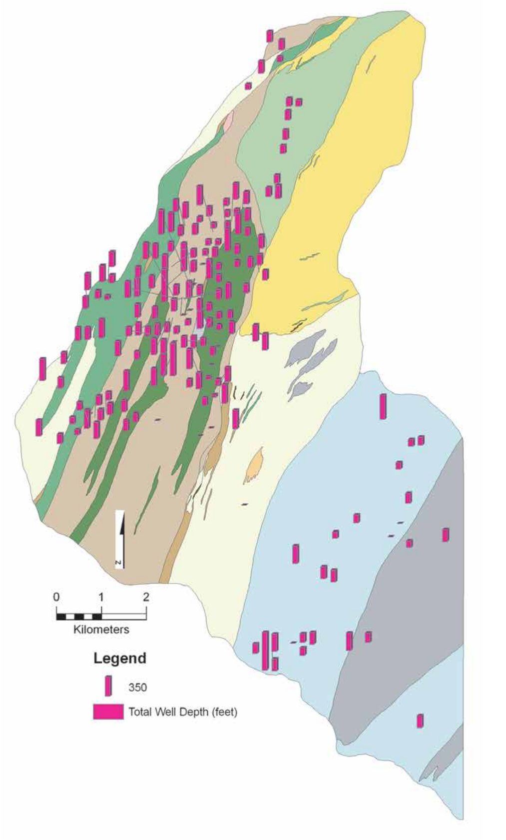
Unit	n	GPM	DTB	TD	Specific Capacity	Yield/DTB	DTB/TD	(DTB/TD)*Yield
CZs	8	12.9	23.0	249.6	0.09	2.2	0.1	0.6
CZsg	23	10.6	36.5	216.4	0.06	0.6	0.2	1.8
CZswa	8	33.4	46.4	166.5	0.22	3.1	0.3	9.3
CZsws	2	7.5	97	186	0.04	0.1	0.5	4.3
CZhn	58	13.2	33.2	210.2	0.08	0.9	0.2	2.3
CZhng	32	15.8	25.3	209.0	0.10	1.0	0.1	2.9
Om	22	14.7	31.3	229.8	0.09	1.1	0.2	5.9

n= # of wells, GPM=gallons/minute, DTB=depth to bedrock, TD=total well depth, specific capacity= yield/TD, Yield/DTB= Yield (GPM)/DTB,

Table 2- average well parameters for field area and statewide wells

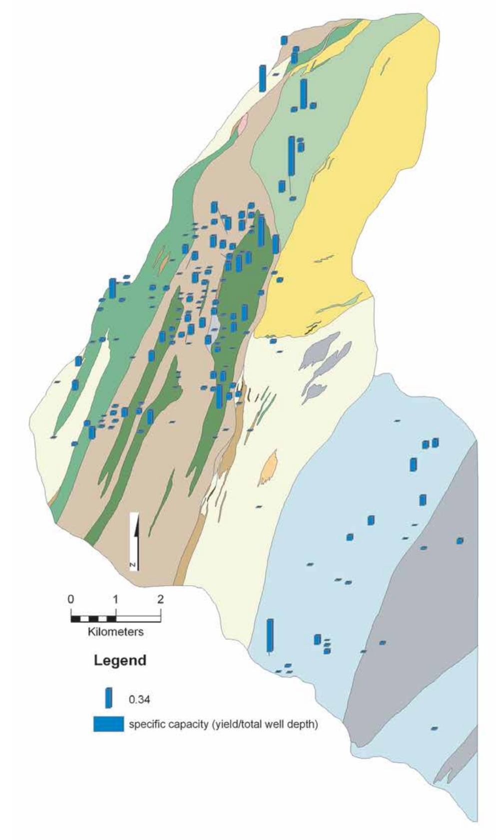
	n	GPM	DTB	TD	Specific Capacity
Field Area Wells	172	14.7	35.0	220	0.09
Statewide Wells	91,469	14.0	36.8	275	

Figure 11- Total Well Depth and Bedrock Map



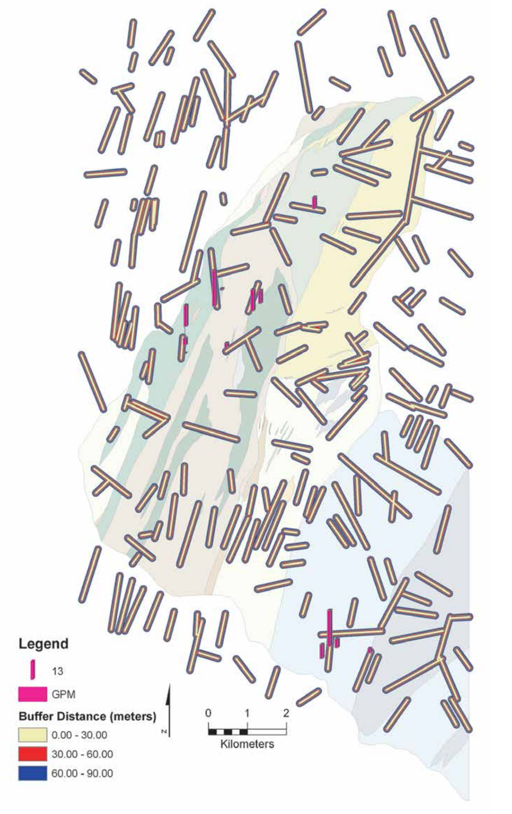
Overall well depths are variable. There are no obvious patterns in the distribution of deeper or shallower wells. Total well depths range from 50' - 700' and have a median of 198'.

Figure 12- Specific Capacity and Bedrock Map



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

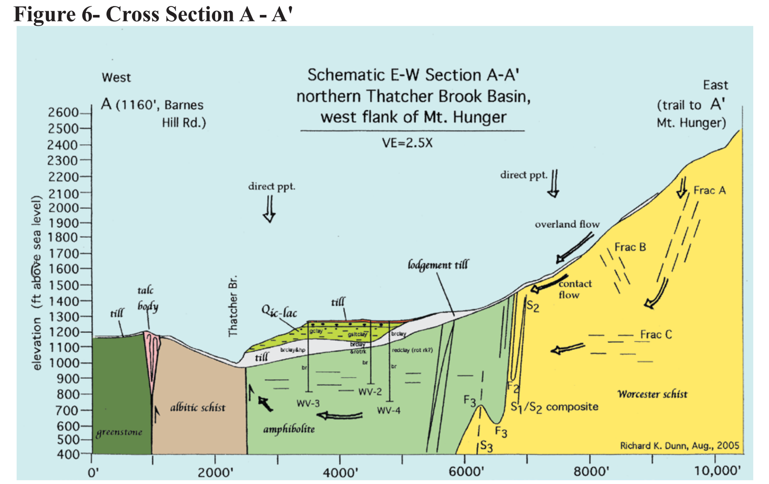


Lineaments were determined from the stereoscopic analysis of numerous airphoto pairs from the field area by Montane et al. (2005). The strong correlation between lineaments and topographic features can be seen on Figure 5. In general, north-northeast trending lineaments are parallel to ductile structures 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 if 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).

Table 3

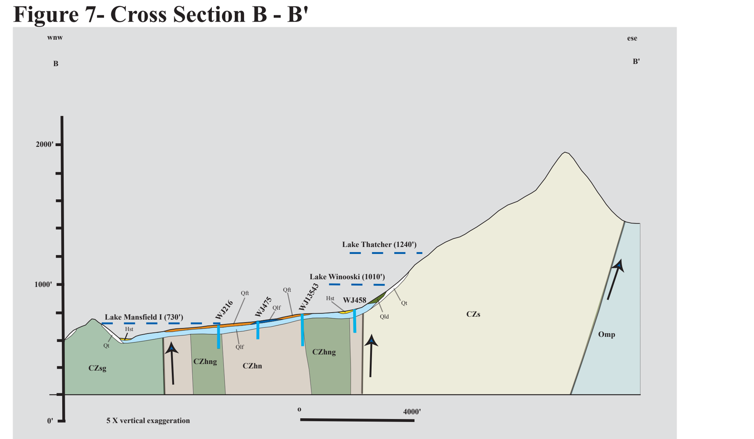
[illegible]

Figure 6- Cross Section A - A'



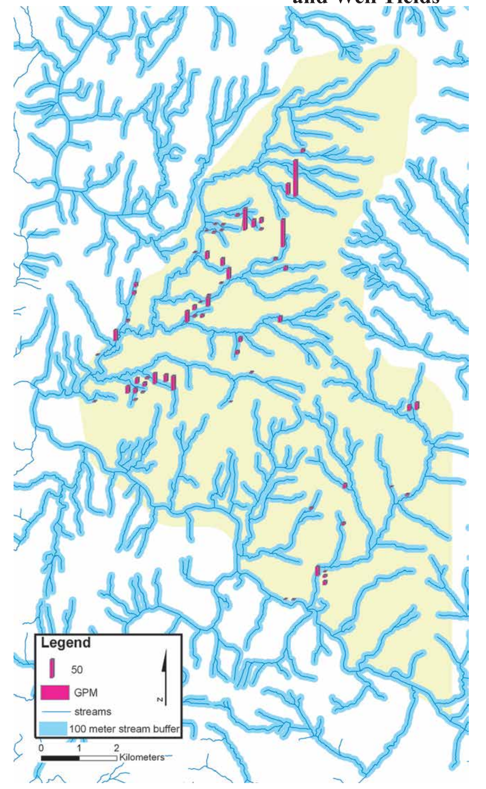
Line of section shown on Figures 3 and 4.

Figure 7- Cross Section B - B'



Line of section shown on Figures 3 and 4.

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

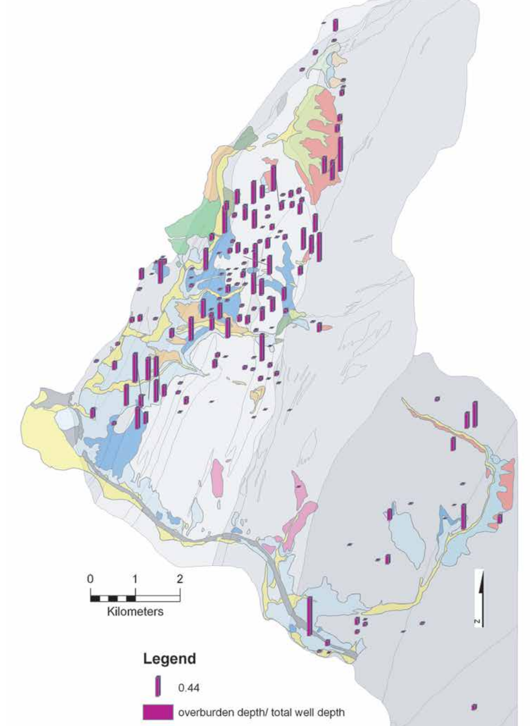


Moore et al. (2002) have shown that bedrock well yields increase in the vicinity of surface water. We used a 100 meter buffer on streams in the field area to see if wells within this buffer had elevated yields. Although some wells within the stream buffer have yields >25 gpm, (Table 4) the average of all well yields within the buffer is the same as for all wells in the field area (Table 2).

Table 4

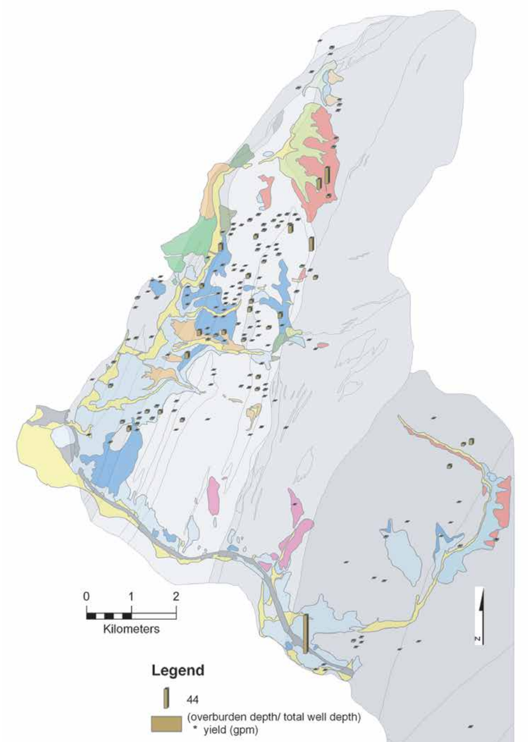
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
MH19367	51 SOUTH BEAR SWAMP RD	15.0	46	130	0.1154	0.3261	0.3538	5.3077
MH20921	289 BROOK RD	3.5	68	120	0.0292	0.0515	0.5667	1.9833
WJ20816	527 SWEETS RD	30.0	128	165	0.1818	0.2344	0.7758	23.2727
WJ19326	1320 RIPLEY RD	75.0	95	240	0.3125	0.7895	0.3958	29.6875
WJ18970	460 RING RD	15.0	6	299	0.0502	2.5000	0.0201	0.3010
WJ18972	221 VALLEY VIEW RD	60.0	17	350	0.1714	3.5294	0.0486	2.9143
WJ19618	671 KNEELAND FLATS	7.0	45	163	0.0429	0.1556	0.2761	1.9325
WJ18963	35 CROSSROAD	1.0	16	400	0.0025	0.0625	0.0400	0.0400
WJ15740	999 RIPLEY RD	6.0	97	200	0.0300	0.0619	0.4850	2.9100
WJ15988	524 SWEETS RD	100.0	56	149	0.6711	1.7857	0.3758	37.5839
WJ15773	1100 HARVEY FARM RD	2.0	35	298	0.0067	0.0571	0.1174	0.2349
WJ15701	535 LOOMIS HIGHLANDS	20.0	51	120	0.1667	0.3922	0.4250	8.5000
WJ15887	1250 SWEETS RD	8.0	24	180	0.0444	0.3333	0.1333	1.0667
WJ13309	250 E HARVEY FARM RD	1.5	9	300	0.0050	0.1667	0.0300	0.0450
WJ17067	293 E HARVEY FARM RD	25.0	7	248	0.1008	3.5714	0.0282	0.7056
MH10146	529 CENTER RD	11.0	29	121	0.0909	0.3793	0.2397	2.6364
WJ13587	770 HARVEY FARM RD	4.0	36	223	0.0179	0.1111	0.1614	0.6457
MH397	34 SOUTH BEAR SWAMP RD	20.0	85	149	0.1342	0.2353	0.5705	11.4094
WJ641	20 EAST ST	2.0	62	298	0.0067	0.0323	0.2081	0.4161
WJ615	79 HENRY HOUGH RD	3.0	3	348	0.0086	1.0000	0.0086	0.0259
WJ576	909 LOOMIS HILL RD	3.0	60	223	0.0135	0.0500	0.2691	0.8072
WJ558	765 LOOMIS HILL RD	1.0	72	360	0.0028	0.0139	0.2000	0.2000
WJ536	772 PERRY HILL RD	3.0	73	299	0.0100	0.0411	0.2441	0.7324
WJ549	96 HUBBARD FARM RD	2.0	90	285	0.0070	0.0222	0.3158	0.6316
WJ495	1277 LOOMIS HILL RD	6.0	46	174	0.0345	0.1304	0.2644	1.5862
WJ458	161 WOODLAND ACRES LN	12.0	55	0	0.0000	0.2182	0.0000	0.0000
WJ421	736 PERRY HILL RD	20.0	48	98	0.2041	0.4167	0.4898	9.7959
WJ376	591 KNEELAND FLATS	12.0	3	222	0.0541	4.0000	0.0135	0.1622
WJ384	68 LOOMIS HIGHLANDS	20.0	6	155	0.1290	3.3333	0.0387	0.7742
WJ335	306 LOOMIS HILL RD	1.0	40	275	0.0036	0.0250	0.1455	0.1455
WJ280	796 PERRY HILL RD	3.0	98	147	0.0204	0.0306	0.6667	2.0000
WJ234	995 LOOMIS HILL RD	3.0	12	190	0.0158	0.2500	0.0632	0.1895
WJ216	576 KNEELAND FLATS	30.0	72	172	0.1744	0.4167	0.4186	12.5581
WJ221	100 THURSTON LN	4.0	70	121	0.0331	0.0571	0.5785	2.3140
WJ180	150 STUARTS RD	20.0	10	222	0.0901	2.0000	0.0450	0.9009
WJ162	1063 PERRY HILL RD	5.0	67	148	0.0338	0.0746	0.4527	2.2635
WJ144	938 PERRY HILL RD	10.0	90	175	0.0571	0.1111	0.5143	5.1429
WJ142	1845 SHAW MANSION RD	12.0	0	117	0.1026	0.0000	0.0000	0.0000
WJ112	3081 PERRY HILL RD	9.0	34	55	0.1636	0.2647	0.6182	5.5636
WJ84	772 PERRY HILL RD	12.0	98	348	0.0345	0.1224	0.2816	3.3793
WJ98	1150 PERRY HILL RD	30.0	54	210	0.1429	0.5556	0.2571	7.7143
WJ51	230 SNOW HILL RD	10.0	114	174	0.0575	0.0877	0.6552	6.5517
WJ18	88 THURSTON LN	20.0	20	123	0.1626	1.0000	0.1626	3.2520
WJ50	826 LOOMIS HILL RD	4.0	15	177	0.0226	0.2667	0.0847	0.3390
MH14939	399 CENTER RD	6.0	42	220	0.0273	0.1429	0.1909	1.1455
MH14956	59 OLD BROOK RD	6.0	15	220	0.0273	0.4000	0.0682	0.4091
WJ4203	631 KNEELAND FLATS	4.5	20	220	0.0205	0.2250	0.0909	0.4091
WJ9989	1848 WATERBURY-STOWE RD	4.0	25	249	0.0161	0.1600	0.1004	0.4016
WJ13433	2439 WATERBURY-STOWE RD	10.0	72	299	0.0334	0.1389	0.2408	2.4080
WJ14262	1474 WATERBURY-STOWE RD	30.0	10	205	0.1463	3.0000	0.0488	1.4634
WJ13537	14 STOWEBURY	8.0	9	223	0.0359	0.8889	0.0404	0.3229
MH15006	134 NOTCH RD	4.0	3	323	0.0124	1.3333	0.0093	0.0372
MH17062	1 RYAN RD	1.5	0	220	0.0068	0.0000	0.0000	0.0000
WJ12222	16 WINDLESTRAE LN	40.0	24	165	0.2424	1.6667	0.1455	5.8182
WJ660	863 PERRY HILL RD	15.0	108	0	0.0000	0.1389	0.0000	0.0000
MH20940	52 OLD BROOK RD	25.0	22	160	0.1563	1.1364	0.1375	3.4375
averages		**14.5**	**43.4**	**216.3**	**0.1**	**0.7**	**0.2**	**3.7**

Figure 14- Overburden Depth/Total Well Depth 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 overburden thickness also had on well yields in this field area. The first step was to determine where the overburden thickness was a significant proportion of the total well depth. Average dtb/td = 0.16.

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



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 of wells on the west side of the Worcester Mts. that sit near the slope break defined in Figure 9 and 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 ~ 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.