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EVALUATING SURFACE WATER AND GROUNDWATER INTERACTIONS IN A STRESSED AQUIFER SYSTEM USING AN ECOHYDROLOGICAL APPROACH[1]

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Abstract. Ecohydrology involves an integrated approach to determine the interactions of the groundwater, surface water, and wetlands to the withdrawal of groundwater from an aquifer. The development of a new groundwater well as a public water supply historically involved a relatively uncomplicated technical and permitting process. However, as environmental concerns have increased, site evaluations and associated permitting requirements have taken on a new and more complicated appearance along with a much higher project development cost.

An ecohydrological approach was used for the development of a new groundwater source in the Town of Concord, Massachusetts. The Town needed to develop a new groundwater source in response to a growing population. A suitable location was identified adjacent to the Concord River, a major river that flows through the town. Preliminary groundwater exploration indicated that the proposed site was capable of yielding one million gallons per day.

Of interest for the ecohydrological approach was that the site contained two historically important ponds, the Concord River, potential vernal pools, and both rare and endangered species (both flora and fauna). To address these site complexities, an aquifer pumping test plan was developed for this site that included a three well withdrawal configuration, 33 groundwater observation wells, 7 piezometers, and 8 staff gauges. After the aquifer pumping test was completed, the thickness of the organic layer was measured along the bottom of several suspected vernal pools and two of the ponds.

The results of the aquifer pumping test and resource area monitoring indicated minimal impacts to the Concord River, ponds, and suspected vernal pools. Two of the three rare and endangered species were identified at the site.

The withdrawal of groundwater from this site was maximized and adverse ecological impacts minimized as a result of implementing an ecohydrological approach for developing these new groundwater wells. Short and long-term monitoring of the aquifer and overlying water resources is recommended to validate this approach.

Additional Key Words: Aquifer Pumping Test, Concord River, Ecohydrology, Groundwater, Surface Water, Wetlands

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INTRODUCTION

Ecohydrology is a term used to describe the interactions of the groundwater, surface water, and wetlands to the withdrawal of groundwater from an aquifer (Talkington, 2003). As the demand for groundwater has increased over the past several years, knowledge of these relationships is paramount. Because of the proximity of surface water bodies (i.e. Concord River, ponds, and kettle hole depressions) as well as the presence of rare and endangered species habitat (i.e. Blue-spotted salamander, Britton's Violet, and Blanding's Turtle), it is important to understand how and to what extent these water resources interact and, therefore, are affected by the withdrawal of groundwater from this site. For many groundwater withdrawal points, the long-term impacts may not be readily apparent after only a short-term aquifer pumping test. However, a short-term aquifer pumping test typically provides valuable information on how each system reacts under highly-stressed aquifer conditions.

Over thirty years ago, the Town of Concord, MA, through its long-range planning efforts, realized the importance of ensuring its residents would be supplied with an adequate supply of quality water then and into the future. At that time, they began assessing a potential groundwater well site known as the Brewster well site on Balls Hill Road (Figure 1). In 2000, the right of first refusal for this property was triggered upon land purchase negotiations initiated between the owner and a residential developer. At a 2001 Special Town Meeting, the Town voted unanimously to authorize the Water Fund to purchase the 27 acres of land located off Balls Hill Road for groundwater supply development.

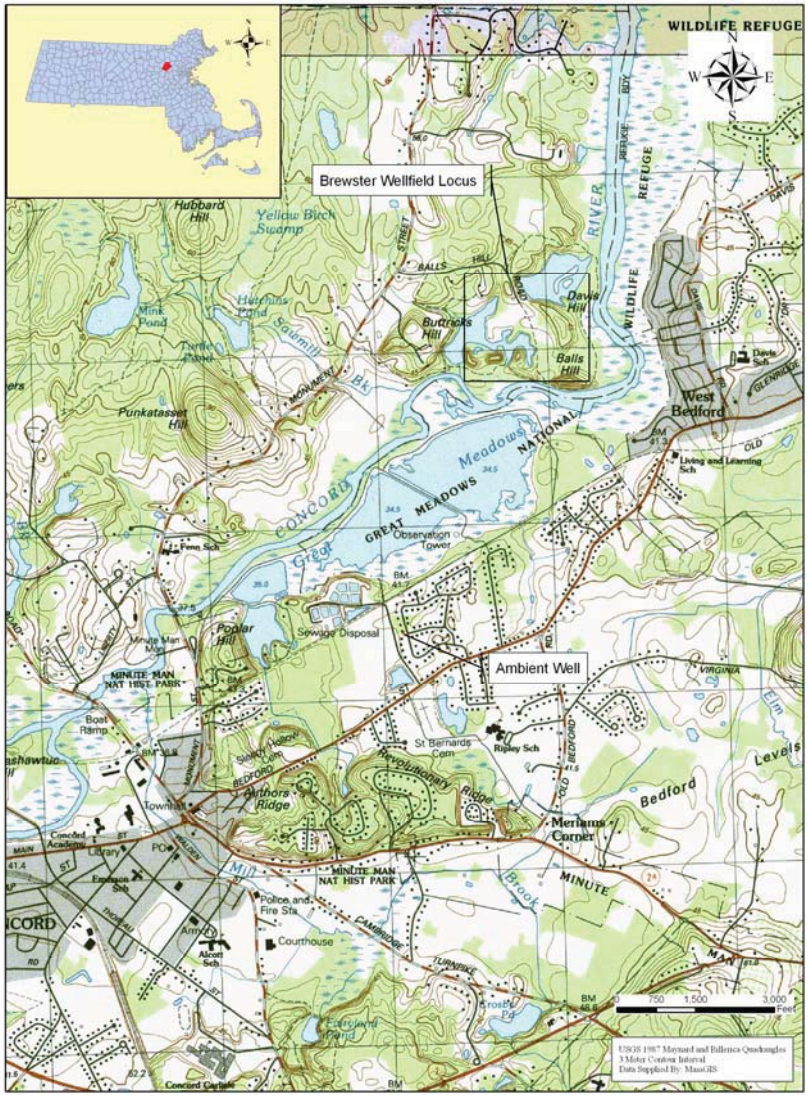

Figure 1. Location Map of Brewster Wellfield, Concord, MA.

TOPOGRAPHY AND SURFACE DRAINAGE

The Brewster well site (wellfield) is located approximately 1,000 feet west and north of the Concord River and approximately 2.0 miles northeast of downtown Concord, Massachusetts (see Figure 1). The topography in the area surrounding the wellfield generally slopes toward the east in the direction of the Concord River. Surface water drainage in the area of the wellfield is generally from northwest to southeast toward the Concord River. The elevation of the Concord River at the wellfield is approximately 113 feet above Mean Sea Level (MSL) with ground surface elevations in the area ranging from approximately 120 feet - 125 feet (MSL) to approximately 160 feet at Balls Hill and Davis Hill. The Concord River flows to the north. The wellfield is located in the Concord River Drainage Basin.

REGIONAL BEDROCK GEOLOGY

According to the Bedrock Geology Map of Massachusetts, the wellfield is underlain by the Shawsheen Gneiss of the Nashoba Zone (Zen, 1983). The Shawsheen Gneiss is a sillimanite gneiss derived from either a sedimentary or volcanic parent. This formation contains sulfide mineralization at its base. Minor amphibolite has been recognized in the formation. No exposures of bedrock were identified in proximity to the wellfield. However, refusal was encountered in several of the 2 ½ -inch diameter observation wells at depths of up to 65 feet below ground surface (bgs).

REGIONAL SURFICIAL GEOLOGY

Approximately 25,000 years ago, the Town of Concord, and all of New England, was covered with an ice sheet. This period of glaciation was known as the Wisconsin Glaciation. As the glaciers receded approximately 12,000 years ago, they left behind a variety of sedimentary deposits on the underlying bedrock surface either directly by the ice or material melted from the ice and transported and deposited by the glacial melt water. These glacial deposits include till and outwash plain/stratified drift deposits.

Till, consisting of unsorted sand, silt, clay, gravel, and boulder-size debris, was deposited atop the bedrock surface. Typically, till forms a thin, compact mantle overlying the bedrock and is thicker in valleys and thinner on hills. Till has low hydraulic conductivity and yields low quantities of groundwater.

Outwash plain and stratified drift deposits consist of fine to very coarse-grained sand, gravel, and cobbles. Locally at Balls Hill, these types of glacial deposits are up to 83 feet thick according to geophysical surveys (Kick, 1979). No scouring of the bedrock to form depressions was identified by Kick (1979). Rather, the bedrock surface appears relatively flat and sloping in a direction toward the Concord River. These types of glacial deposits have high, but variable hydraulic conductivities and typically yield moderate to large quantities of groundwater.

The locations of subsurface geological cross-sections for the Brewster Wellfield are shown on Figure 2. North-south and east-west cross-sections through the Brewster wellfield are shown on Figures 3 and 4, respectively. Based on observations made during the advancement of the soil borings for the observation wells, the subsurface soils at the wellfield consist of sand and gravel glacial material. In the central portion of the wellfield, there is an approximately 40-foot thick layer of sand that overlies a sand and gravel horizon. At Davis Hill, there is an approximately 70-foot thick horizon of sand and gravel that may represent part of an esker. All of the production wells were screened in the sand and gravel horizon. Till was not encountered atop the bedrock surface, and may have been scoured away by meltwater deposits before the sand and gravel were deposited.

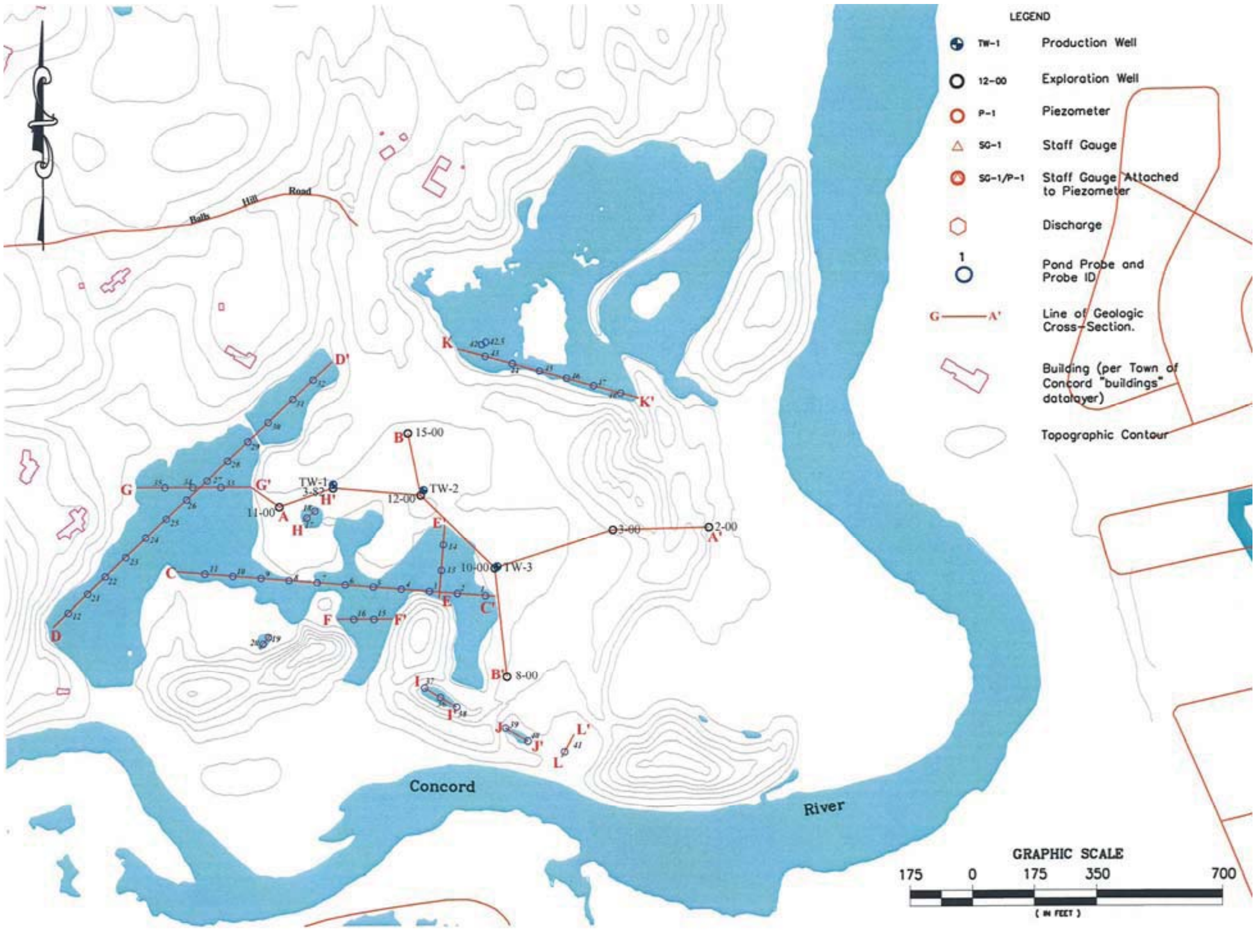

Figure 2. Locations of Subsurface Geological Cross-Sections, On-Site Ponds, and Kettle Hole Ponds, Brewster Wellfield.

PRODUCTION WELLS

Three areas of the wellfield were selected for the installation of 16-inch by 10-inch diameter gravel-packed wells. The wells range in depth from 33 feet, 51 feet, and 49 feet for TW-1, TW-2, and TW-2, respectively. Although the combined aquifer pumping test was performed at 725 gpm, the final safe yield for each well is 99 gpm (TW-1), 419 gpm (TW-2), and 172 gpm (TW-3) for a combined groundwater withdrawal rate of 690 gpm.

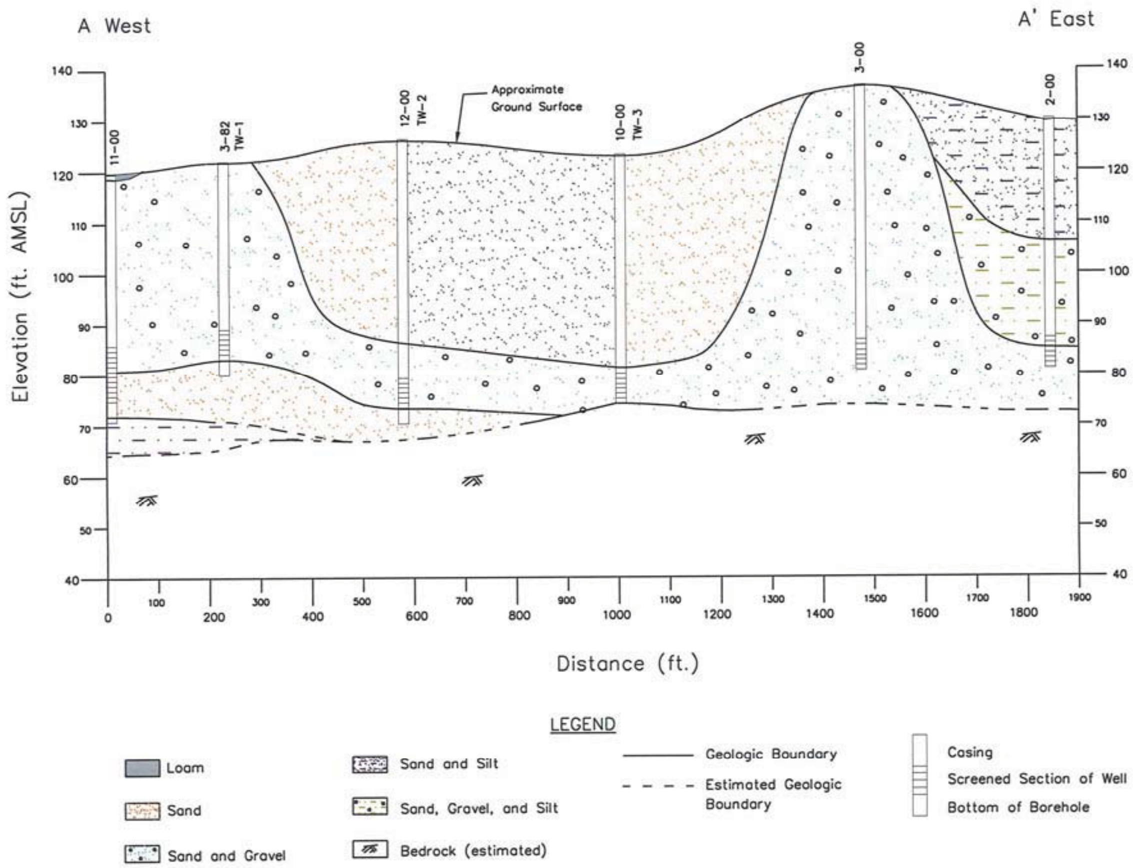

Figure 3. Geologic Cross-Section A-A', Brewster Wellfield.

SURFACE WATER AND GROUNDWATER MONITORING LOCATIONS

Thirty three (33), 2 ½-inch diameter observation wells, seven (7), 1-inch diameter piezometers, and eight (8) staff gauges were installed at the Balls Hill Road site. Construction details for these monitoring points are compiled in Table 1.

TABLE 1. Construction details for wells, ground water, and surface water monitoring locations.

Observation Well ID	TOC Elev. (ft. asl)	Casing Height Above Ground (ft.)	Ground Elev. (ft. asl)	Monit. Well Const.	Screened Section of Pipe (ft. btoc)*	Screen Elevation (ft. asl)	Refusal/ Bedrock Depth (ft. bgs)	Refusal/ Bedrock Elev. (ft. asl)	Installed By:	Date Installed
11-81	118.89	1.85	117.04	2.5" CI	35 - 41.00	83.89 - 77.89	71.0	46.0	D.L. Maher	11/25/1981
11-81 Obs	118.32	1.45	116.87	2.5" CI	29 - 42.00	89.32 - 76.32	-	-	D.L. Maher	11/25/1981
1-82	123.04	0.30	122.74	2.5" CI	49 - 56.00	74.04 - 67.04	91.0	31.7	D.L. Maher	6/9/1982
1-82 Obs	123.32	0.50	122.82	2.5" CI	38 - 44.00	85.32 - 79.32	-	-	-	-
3-82 (fmr 2-82)	121.47	0.70	120.77	2.5" CI	28 - 35.00	93.47 - 86.47	62.0	58.8	D.L. Maher	6/10/1982
3-82 Obs (fmr 2-82 Obs)	121.79	1.20	120.59	2.5" CI	33.00 - 39.00	88.79 - 82.79	-	-	D.L. Maher	11/7/2000
2-82 (fmr 3-82)	132.63	0.50	132.13	2.5" CI	37 - 43.00	95.63 - 89.63	96.0	36.1	D.L. Maher	6/14/1982
unknown (fmr 3-82 Obs)	119.23	0.50	118.73	2.5" CI	28.60 - 34.60	90.63 - 84.63	-	-	D.L. Maher	11/17/2000
4-82	123.93	0.84	123.09	2.5" CI	55.00 - 61.00	68.93 - 62.93	-	-	D.L. Maher	11/17/2000
1-00	124.36	0.85	123.51	2.5" CI	50.00 - 56.00	74.36 - 68.36	-	-	D.L. Maher	8/15/2000
2-00	130.77	0.75	130.02	2.5" CI	43.00 - 49.00	87.77 - 81.77	-	-	D.L. Maher	8/15/2000
3-00	137.43	1.25	136.18	2.5" CI	50.00 - 56.00	87.43 - 81.43	-	-	D.L. Maher	8/16/2000
6-00	119.67	0.55	119.12	2.5" CI	36.00 - 42.00	83.67 - 77.67	-	-	D.L. Maher	8/21/2000
8-00	125.58	0.70	124.88	2.5" CI	29.00 - 35.00	96.58 - 90.58	43.0	81.9	D.L. Maher	8/21/2000
10-00	122.83	0.60	122.23	2.5" CI	37.00 - 49.00	85.83 - 73.83	-	-	D.L. Maher	11/16/2000
10-00 Obs	123.01	0.75	122.26	2.5" CI	37.00 - 49.00	86.01 - 74.01	49.0	73.3	D.L. Maher	11/16/2000
11-00	119.67	0.10	119.57	2.5" CI	34.00 - 46.00	85.67 - 73.67	-	-	D.L. Maher	10/19/2000
11-00 Obs	121.83	2.20	119.63	2.5" CI	34.00 - 46.00	87.83 - 75.83	-	-	D.L. Maher	11/2/2000
12-00	125.88	0.50	125.38	2.5" CI	47.00 - 53.00	78.88 - 72.88	-	-	D.L. Maher	11/7/2000
12-00 Obs	126.19	0.85	125.34	2.5" CI	41.00 - 53.00	85.19 - 73.19	-	-	D.L. Maher	11/7/2000
13-00	128.22	0.80	127.42	2.5" CI	27.00 - 33.00	101.22 - 95.22	-	-	D.L. Maher	11/14/2000
14-00	122.09	2.00	120.09	2.5" CI	21.00 - 27.00	101.09 - 95.09	-	-	D.L. Maher	11/15/2000
15-00	125.66	3.30	122.36	2.5" CI	29.00 - 33.00	96.66 - 92.66	33.0	89.4	D.L. Maher	11/15/2000
82-X	143.46	1.50	141.96	2.5" CI	54.00 - 60.00	89.46 - 83.46	-	-	D.L. Maher	1982
1-03	119.53	2.05	117.48	2.5" CI	40.00 - 46.00	79.53 - 73.53	-	-	D.L. Maher	9/16/2003
2-03	121.61	1.80	119.81	2.5" CI	35.00 - 41.00	86.61 - 80.61	41.0	78.8	D.L. Maher	9/16/2003
3-03	128.89	2.00	126.89	2.5" CI	35.00 - 41.00	93.89 - 87.89	-	-	D.L. Maher	9/17/2003
4-03	124.14	1.80	122.34	2.5" CI	43.00 - 49.00	81.14 - 75.14	51.0	71.3	D.L. Maher	9/15/2003
5-03	118.85	2.70	116.15	2.5" CI	25.00 - 26.00	93.85 - 92.85	-	-	D.L. Maher	9/15/2003
6-03S	118.48	0.10	118.38	2.5" CI	20.00 - 21.00	98.48 - 97.48	-	-	D.L. Maher	9/16/2003
6-03D	121.47	3.00	118.47	2.5" CI	29.00 - 35.00	92.47 - 86.47	-	-	D.L. Maher	9/16/2003
7-03S	120.23	2.50	117.73	2.5" CI	18.00 - 19.00	102.23 - 101.23	-	-	D.L. Maher	9/17/2003
7-03D	120.28	2.40	117.88	2.5" CI	29.00 - 35.00	91.28 - 85.28	-	-	D.L. Maher	9/17/2003
Gravel-Packed Test / Production Wells										
TW-1	123.97	3.00	120.97	10" SS	30.00 - 36.00	93.97 - 87.97	-	-	D.L. Maher	7/29/2003
TW-2	127.54	2.45	125.09	10" SS	44.00 - 54.00	83.54 - 73.54	-	-	D.L. Maher	7/18/2003
TW-3	124.65	3.00	121.65	10" SS	42.00 - 52.00	82.65 - 72.65	-	-	D.L. Maher	7/11/2003

Piezometer ID	TOC Elev. (ft. asl)	Riser Height Above Ground (ft.)	Ground Elev. (ft. asl)	Monit. Well Const.	Screened Section of Pipe (ft. btoc)	Screen Elevation (ft. asl)	Refusal/ Bedrock Depth (ft. bgs)	Refusal/ Bedrock Elev. (ft. asl)	Installed By:	Date: Installed
P-1	115.17	2.68	112.49	1.25" CI	5.00 - 6.00	107.49 - 106.49	-	-	D.L. Maher	9/18/2003
P-2	116.52	2.65	113.87	1.25" CI	5.00 - 6.00	108.87 - 107.87	-	-	Geosphere	9/18/2003
P-3	116.73	2.85	113.88	1.25" CI	6.00 - 7.00	107.88 - 106.88	-	-	D.L. Maher	9/18/2003
P-4	117.30	3.10	114.20	1.25" CI	5.00 - 6.00	109.20 - 108.20	-	-	Geosphere	9/18/2003
P-5	116.66	2.74	113.92	1.25" CI	5.00 - 6.00	108.92 - 107.92	-	-	Geosphere	9/18/2003
P-6	114.65	2.65	112.00	1.25" CI	5.00 - 6.00	107.00 - 106.00	-	-	Geosphere	9/18/2003
P-7	113.92	2.79	111.13	1.25" CI	5.00 - 6.00	106.13 - 105.13	-	-	Geosphere	9/18.03

Staff Gauge ID	TOG Elev. (ft. asl)	Gauge Height Above Water Surface (ft.)	Installed By:	Date: Installed
SG-1	115.80	0.78	D.L. Maher	9/18/2003
SG-2	114.91	1.88	Geosphere	9/18/2003
SG-3	116.53	0.39	D.L. Maher	9/18/2003
SG-4	115.58	1.40	Geosphere	9/18/2003
SG-5	115.22	1.70	Geosphere	9/18/2003
SG-6	114.17	0.84	Geosphere	9/18/2003
SG-7	112.56	1.62	Geosphere	9/18/2003
SG-River	112.04	2.21	Concord	10/17/2003

All elevations are in feet above sea level (amsl)(National Geodetic Vertical Datum)
Elevation survey conducted on 10/10/03, 10/17/03, and 11/5/03 by Colonial Surveying of Belmont, MA.

btoc	=	Below top of casing
bgs	=	Below ground surface
TOC	=	Top of cast iron or steel casing
TOG	=	Top of staff fauge - 3.00 ft. mark
CI	=	Cast iron pipe with galvanized steel wound screen (except piezometers and test wells, stainless steel wound screen)
Underlined	=	Estimated
-	=	Not available

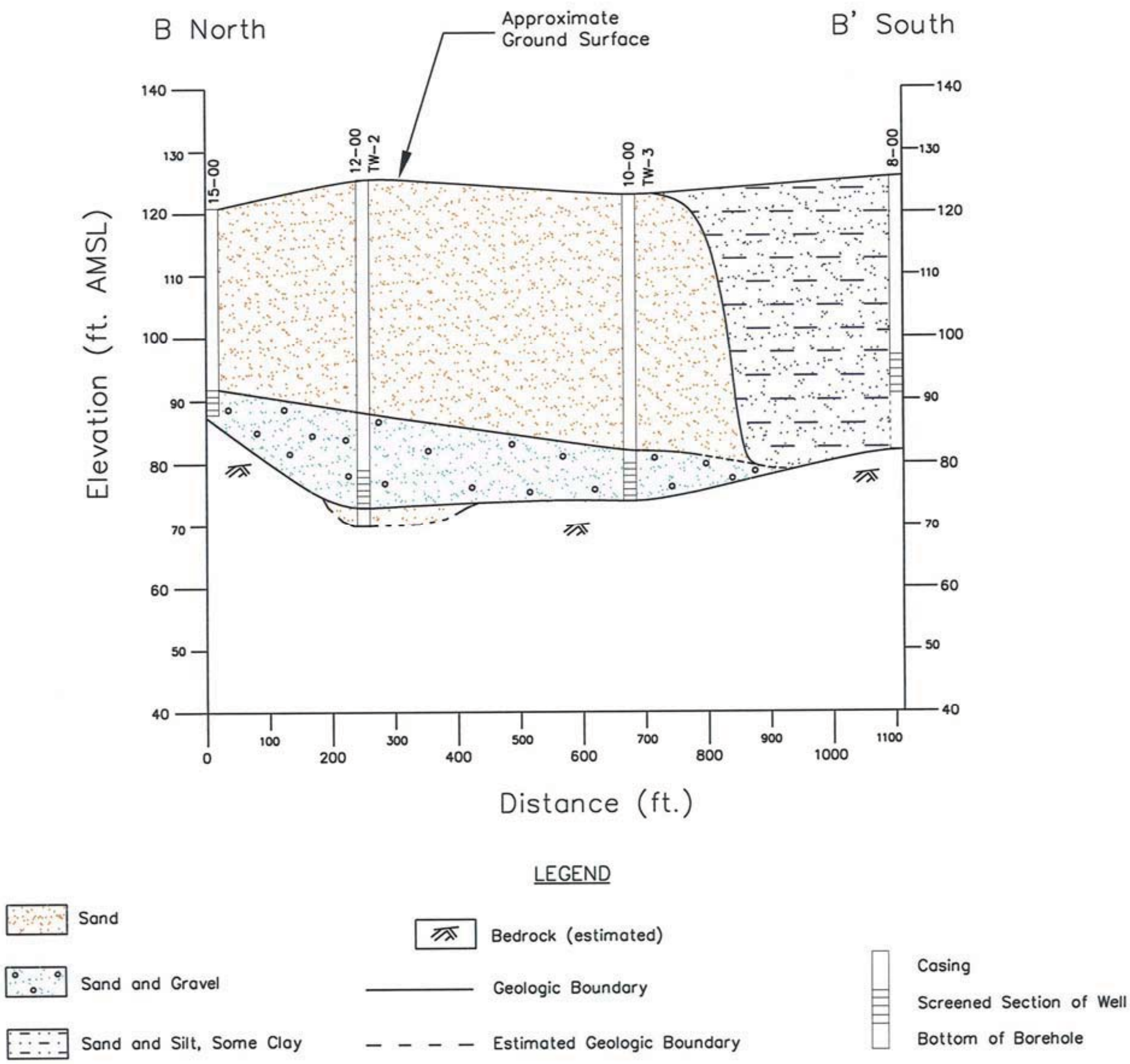

FIGURE 4. Geologic Cross-Section B-B', Brewster Wellfield.

AQUIFER PUMPING TEST

A combined pumping test was conducted at the site. Recording of pumping test-related measurements commenced up to 1½ weeks prior to the combined test and continued for approximately 17-days after the test. In addition, 8-hour individual pumping tests were performed on each of the three (3) pumping wells TW-1, TW-2 and TW-3 as well as a 5-day recovery period.

During the individual 8-hour pumping tests, groundwater was extracted from individual test wells at their proposed initial pumping rates as determined during preliminary testing and well development and adjusted as necessary. Recovery readings were recorded until water table levels in the pumping wells reached 95% of their pre-pumping test water table levels.

For the combined pumping test, groundwater was simultaneously extracted from the three test wells (TW-1, TW-2 and TW-3). Initial flow rates were adjusted to potential safe rates as determined during the individual 8-hour tests. The groundwater extraction rates recorded over the last three (3) days of the pumping test remained constant with TW-1 at 125 gpm; TW-2 at 400 gpm; and TW-3 at 200 gpm or a combined extraction rate of 725 gpm.

ECOHYDROLOGY AND THE IMPACTS TO RESOURCE AREAS

Ecohydrology is a term used to describe the effects of groundwater withdrawals on wetland resource areas. The following is a description of the nearby surface water bodies and how each reacted during the prolonged aquifer pumping test.

CONCORD RIVER

The Concord River flows by the wellfield to the south and east and at the closest point is approximately 800 feet. As shown on Figure 2, the Concord River nearly surrounds the wellfield on three sides. A body of water such as the Concord River has the potential to be a large source of recharge to the underlying sand and gravel aquifer, provided the pumping of the wells causes induced infiltration. If this is the case, then the Concord River represents an important hydrogeologic boundary.

The results of the aquifer pumping test indicate that after several days of continuous groundwater withdrawal at approximately 700 gpm (or 1 million gallons per day), the hydraulic gradient between the wells and the Concord River reversed such that there is measurable induced infiltration from the Concord River. Preliminary stream flow calculations indicated that the 1 million gallon per day groundwater withdrawal from the wellfield represents approximately 1.3 percent of the August median flow [111 cubic feet per second (cfs)] for the Concord River. Of equal consideration, the Town of Concord discharges approximately 1 million gallons of treated effluent per day to the Concord River. The discharge location is approximately 1 mile upstream.

The proposed groundwater withdrawal from the wellfield and the Town's discharge to the Concord River results in no net loss from this portion of the watershed. Throughout the course of a year, at times when the wells are not withdrawing groundwater from the aquifer, there will be a net gain of water to the watershed as a result of the upstream discharge of the treated effluent from the wastewater treatment plant.

PONDS AND POND PROFILES

There are two ponds that are contiguous to the wellfield (see Figure 2). These ponds are best characterized as combination emergent/shrub wetlands with interspersed areas of open water. According to local residents, the ponds were constructed over a hundred years ago and were apparently used for recreational purposes. There are engineered structures on each pond that allow water to be diverted from the Concord River into the ponds. The reason for these structures, other than for diverting river water, is not known.

A subsurface profiling investigation of the ponds and kettle hole depressions in the vicinity of the wellfield was performed because of the lack of drawdown in the pond during the aquifer pumping tests. To determine whether this lack of response of the pond to groundwater withdrawal was due to poorly installed piezometers or some feature peculiar to the pond, a subsurface probe was used to determine if there was an organic layer on the base of the ponds. During the winter, a subsurface probe was advanced through holes in the ice layer at 49 locations, along 11 transects. The pond probing locations (1-49) and transects (A-A' through L-L') are depicted on Figure 2.

At each location a gas-powered ice auger was used to bore through the ice layer. A metal probe with a pointed end and one-foot markings was allowed to come to rest at the bottom of the water body (i.e. top of organic layer) and a measurement was taken to the top of the ice. The probe was then hand driven into the organic material until sand was encountered or the probe could no longer be driven. A measurement was again taken to the top of the ice. The height of the ice layer at each staff gauge location was recorded on the dates probing was conducted, allowing for the calculation of the elevation of the ice in feet above mean sea level. The probe depth measurements for the top and bottom of the organic layer were then graphed to provide cross-sections for each of the 10 transects. Representative cross-sections are presented in Figures 5 through 7. As shown on these cross-sections, the organic layer deposited at the bottom of each of the ponds and kettle hole depressions is up to 30 feet in thickness in the larger ponds.

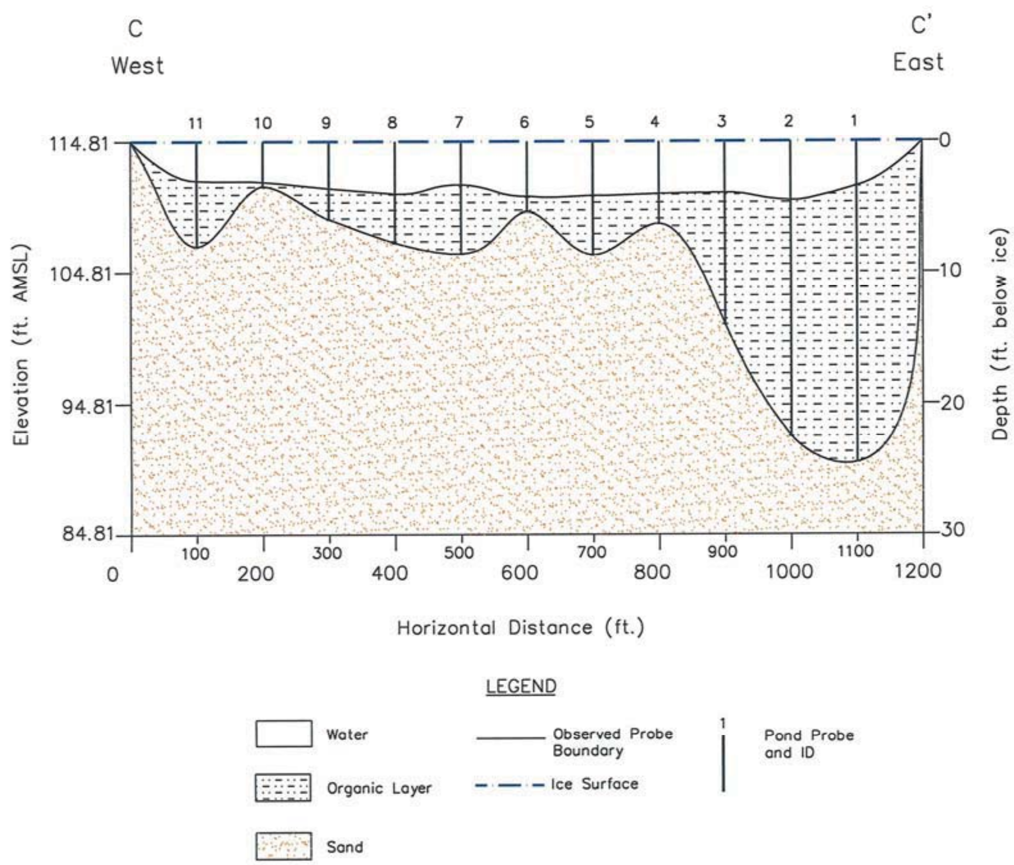

FIGURE 5. Geologic Cross-Section C-C' of On-Site Pond, Brewster Wellfield.

As indicated above, there is a thick layer of organic material that has accumulated on the bottom of each pond. In places, this organic layer is in excess of 30 feet in thickness. The "average" thickness of this organic layer is approximately 10 feet. However, it appears to be thickest closest to the Brewster wellfield (closer to 15 – 20 feet thick). Although the organic layer is laterally extensive and thick, it is not very dense as evidenced when the probe is advanced through it.

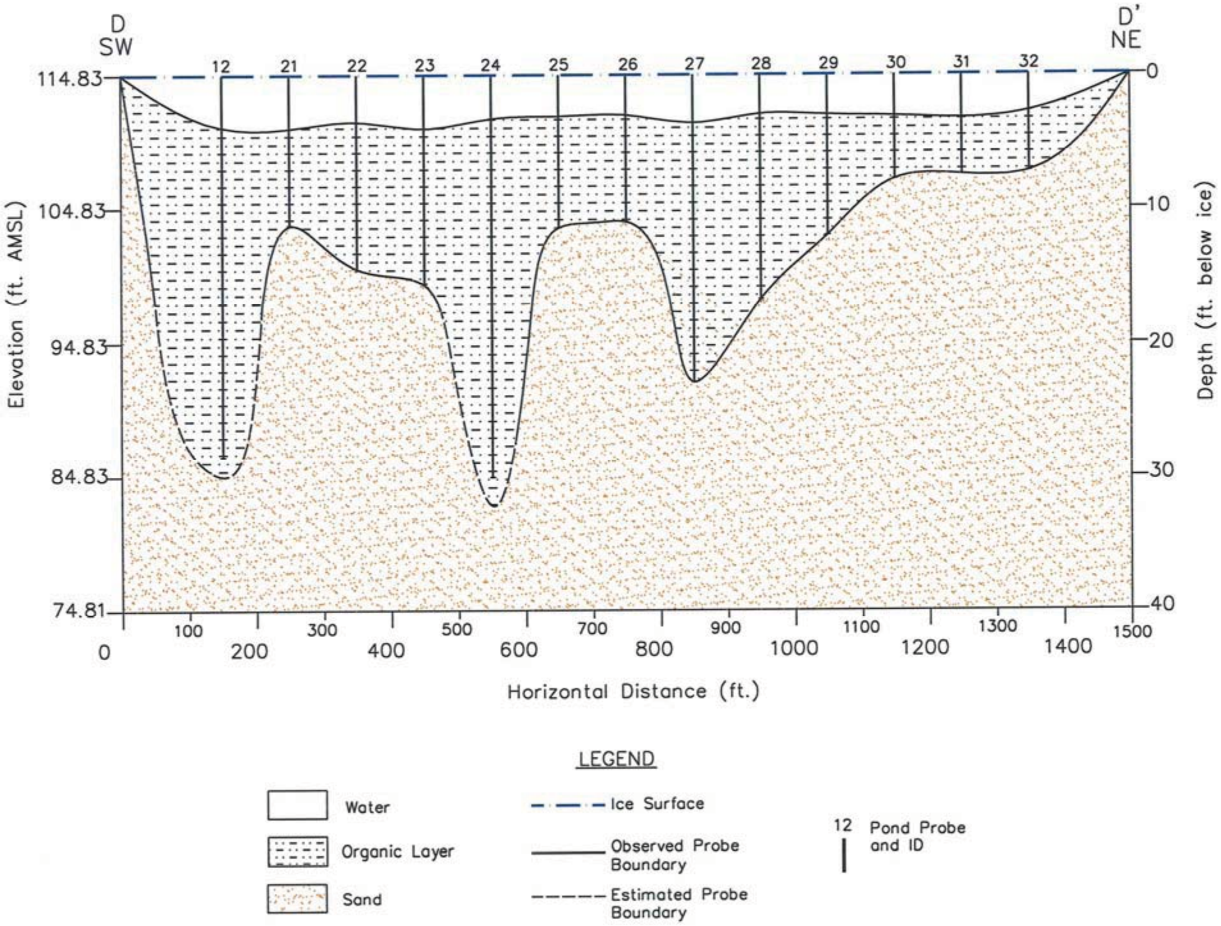

FIGURE 6. Geologic Cross-Section D-D' of On-Site Pond, Brewster Wellfield.

Is this organic material the cause of the poor communication between the sand and gravel aquifer and the pond? To understand the relationship between the pond and recharge to the aquifer, we looked at the hydraulic conductivity of the organic material.

The horizontal hydraulic conductivity (k_h) of organic material (i.e. peat) varies several orders of magnitude [e.g. 5 x 10^2 feet/day – 1 x 10^1 feet/day (Walton, 1987), and 10^{-5} to 10^5 feet/day (Rycroft et al., 1975)] and the vertical hydraulic conductivity (k_v) has been reported to be 1 to 10 times lower (Price et al, 2008). The withdrawal of groundwater from the wellfield causes the vertical and horizontal hydraulic gradients in the aquifer to increase. However, because of the different physical properties between the sand and gravel of the aquifer and the organic layer, the flow of water through them will be different. Darcy's law ($Q = k \times dh/dl$) can be used to calculate the flow of water through the organic layer to the aquifer. For example, using the groundwater level data presented in Tables 2A - C, an estimate can be made of the

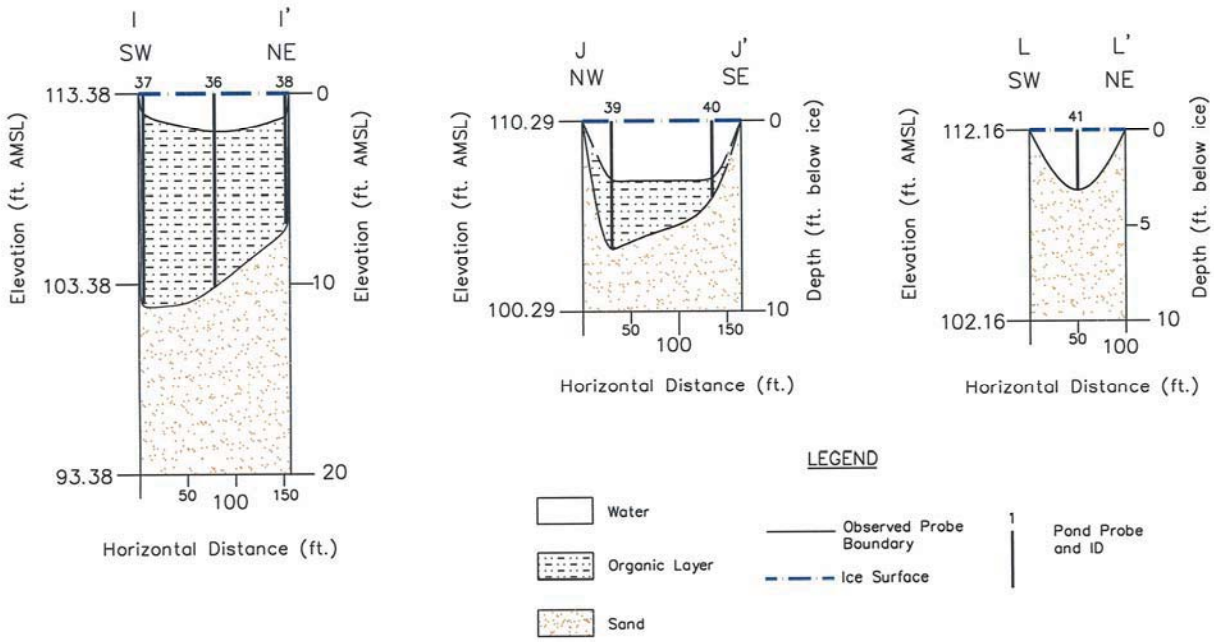

FIGURE 7. Geologic Cross-Sections I-I', J-J', and L-L' of On-Site Kettle Hole Ponds, Brewster Wellfield.

loss of water from the organic layer. The estimate for the average thickness of the organic layer is 10 feet. The difference in hydraulic head between piezometer P-3 and observation well 6-03S during non-pumping conditions is 2 feet (i.e. 113.84 feet – 111.84 feet). Using a hydraulic conductivity of 10^{-1} feet/day, the loss of water through the organic layer is 0.02 feet/day. A less conservative k of 1 x 10^{1} feet/day will result in a water loss through the organic layer of 2 feet/day. This latter value for Q appears high given the water level change observed at P-3 during the combined pumping test (0.29 feet, or 0.03 feet/day). Taking into consideration the antecedent trend of approximately 0.01 feet/day, a k of 10^{-1} feet/day for the organic layer appears reasonable.

TABLE 2A. Initial (static) and projected groundwater level data for observation wells.

Observation Well ID	TOC Elevation (ft. asl)	Static Depth to Water (ft. btoc)	Static Groundwater Elevation (ft. asl)	Projected Groundwater Elevation at 180 days (feet asl)	Projected Drawdown at 180 Days (ft.)
11-81	118.89	7.52	111.37	101.36	10.01
11-81 Obs	118.32	6.97	111.35	101.67	9.68
1-82 Obs	123.32	11.82	111.50	102.25	9.25
3-82	121.47	9.56	111.91	99.64	12.27
3-82 Obs	121.79	9.89	111.90	99.68	12.22
2-00	130.77	19.40	111.37	106.17	5.20
3-00	137.43	25.52	111.91	105.14	6.77
6-00	119.67	8.13	111.54	105.92	5.62
10-00	122.83	11.25	111.58	100.00	11.58
10-00 Obs	123.01	11.45	111.56	100.68	10.88
11-00	119.67	7.82	111.85	102.97	8.88
11-00 Obs	121.83	10.06	111.77	102.75	9.02
12-00	125.88	14.90	110.98	93.08	17.90
12-00 Obs	126.19	14.40	111.79	93.52	18.27
82-X	143.46	29.64	113.82	110.03	3.79
1-03	119.53	9.05	110.48	104.64	5.84
3-03	128.89	16.86	112.03	101.60	10.43
5-03	118.85	7.13	111.72	101.19	10.53
6-03S	118.48	6.64	111.84	102.70	9.14
6-03D	121.47	9.58	111.89	102.94	8.95
7-03S	120.23	8.01	112.22	105.34	6.88
7-03D	120.28	7.81	112.47	105.77	6.70
TW-1(125 gpm)	123.97	12.10	111.87	95.16	16.71
TW-2(400 gpm)	127.54	15.78	111.76	89.32	22.44
TW-3(200 gpm)	124.65	13.13	111.52	84.28	27.24

TABLE 2B. Initial (static) and projected groundwater level data for piezometers.

Piezometer ID	TOC Elev. (ft. asl)	Static Depth to Water (ft. btoc)	Static Groundwater Elev. (ft. asl)	Projected Groundwater Elevation at 180 days (feet asl)	Projected Drawdown at 180 Days (ft.)
P-1	115.17	3.00	112.17	108.50	3.67
P-2	116.52	2.89	113.63	112.55	1.08
P-3	116.73	2.89	113.84	112.94	0.90
P-4	117.30	3.41	113.89	111.04	2.85
P-5	116.66	3.55	113.11	110.34	2.77
P-6	114.65	2.85	111.80	108.96	2.84
P-7	113.92	3.55	110.37	107.54	2.83

TABLE 2C. Surface water level data for staff gauges.

Staff Gauge ID	TOSG Elev. (ft. asl)	BOSG Elev. (ft. asl)	Static Water Level Height (ft. above BOSG)
SG-1*	115.80	112.80	0.75
SG-2	114.91	111.91	1.78
SG-3*	116.53	113.53	0.29
SG-4	115.58	112.58	1.34
SG-5	115.22	112.22	1.60
SG-6*	114.17	111.17	0.65
SG-7	112.56	109.56	1.43
SG-River	112.04	109.04	0.79

All elevations are in feet above sea level (amsl)(National Geodetic Vertical Datum)

btoc	=	Below top of casing
bgs	=	Below ground surface
TOC	=	Top of cast iron or steel casing
TOSG	=	Top of staff gauge (3.00 ft. mark)
BOSG	=	Bottom of staff gauge (0.00 ft. mark)
*	=	Staff gauge is a yard stick, water levels converted from inches.
-	=	Not available

The projected drawdown in the ponds at piezometers P-1, P-2, P-3, and P-5, at 180-days of continuous pumping with no recharge, ranges from 0.9 to 3.67 feet. Given the average depth of water in the ponds is approximately 4 feet, the change in pond water level should not result in the drying up of the ponds under average seasonal conditions.

The summer months are when groundwater demands are the greatest. If all three wells are withdrawing groundwater at their permitted safe yield for the months of July and August, the change in water level in the ponds should be no greater than 1.24 feet (i.e. 62 days x 0.02 feet/day).

The organic layer in the ponds creates a condition called perched wetlands. This means that the surface waters and wetlands supported by the organic layer are in limited hydraulic contact with the underlying aquifer. This is evident in the measured and projected water level data for the staff gauges and piezometers relative to the surrounding observation wells. As shown on Figure 8, the water levels in the ponds are approximately 2 feet higher than those in the underlying/surrounding aquifer. The difference is even more dramatic when reviewing the maximum water levels measured at the end of the combined pumping test and the projected 180-day water levels.

KETTLE HOLE DEPRESSIONS

There are five isolated kettle hole depressions in proximity to the wells. One of these depressions is located approximately 100 feet from TW-1. These depressions have been investigated and all appear to contain species (wood frog) that would qualify them to be

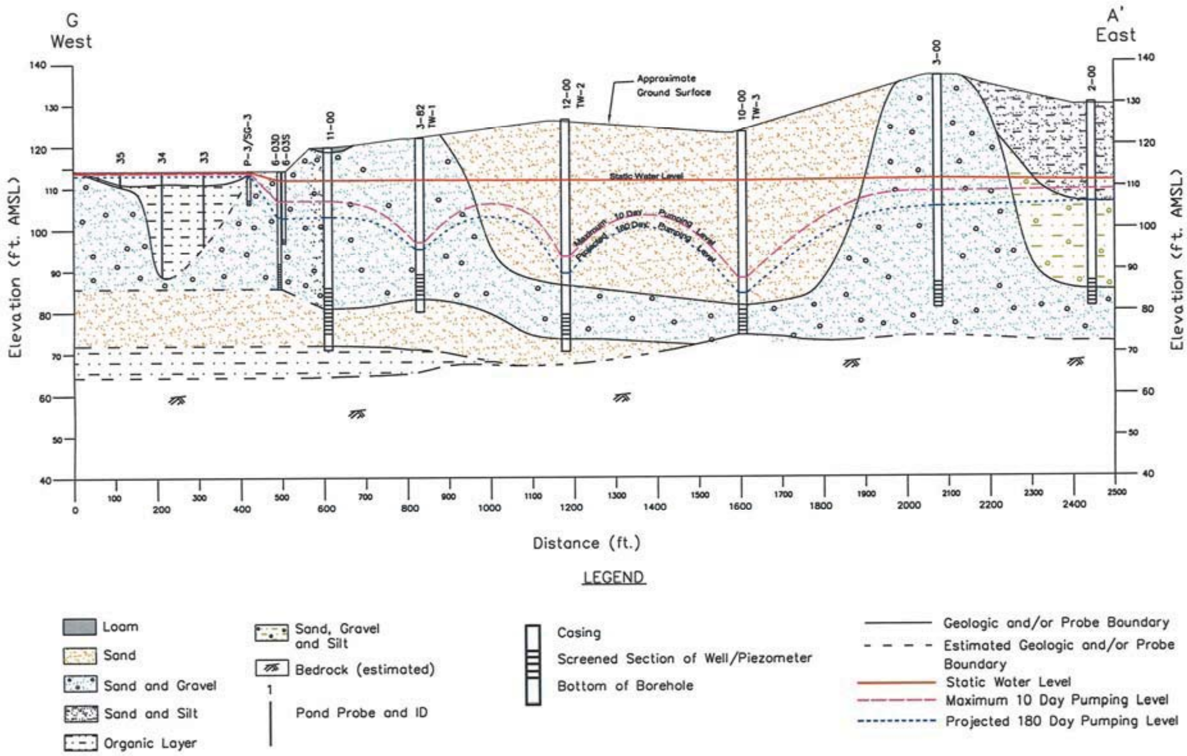

FIGURE 8. Geologic Cross-Section G-A', Brewster Wellfield.

"certified" as vernal pools according to the Massachusetts Natural Heritage and Endangered Species Program's *Certification Criteria Guidance* (Spring, 2000). Wood frog tadpoles were consistently identified in each of the kettle holes. Based upon field investigations completed by the Town, the organic layer is present in four of the five kettle hole depressions, with a measured range in thickness of 1 to 10 feet. The depth of standing water in the kettle hole depressions ranged from 1 to 3.5 feet.

As with the ponds, the organic layer in the kettle hole depressions has created a perched wetland condition such that drawdown in the water table observed and/or projected in these surface water features is significantly less than those observed or expected in the underlying/surrounding sand and gravel aquifer.

SUMMARY OF GROUNDWATER/SURFACE WATER IMPACTS ON WETLANDS RESOURCES

Of great importance to these three wells is the interaction of the groundwater in the aquifer to the overlying surface water features during groundwater withdrawal events. The field data indicate that there is an extensive organic layer that is present along the bottom of the two ponds and four kettle hole depressions. This organic layer has a hydraulic conductivity that is much lower than the underlying sand and gravel aquifer. Leakage calculations using Darcy's Law indicate that drainage through the organic layer is approximately 0.02 feet/day.

Given the organic layer's characteristics (i.e. thickness, low k), combined with the measured and projected changes in water levels observed at the staff gauges and piezometers during the combined pumping test, we are of the opinion that the withdrawal of groundwater from these wells is not anticipated to have an adverse impact on any of the wetland resource areas (ponds and kettle hole depressions) on or in the vicinity of the wellfield.

To determine if over time, the withdrawal of groundwater from the wells is causing a distinct change in vegetative community in the immediate vicinity of these resource areas, a vegetative monitoring program will be designed and implemented. The specific monitoring plan will be formalized once all necessary permits have been obtained and agency-recommended monitoring requirements have been reviewed and synthesized into one comprehensive monitoring program.

RARE AND ENDANGERED SPECIES: IMPACT ASSESSMENT AND MITIGATION STRATEGY

Both short-term and long-term monitoring of the rare and endangered species will be required to verify the findings drawn from the prolonged aquifer pumping test. These short-term and long-term monitoring programs will be formalized through the groundwater withdrawal permit process for the wells as a public water supply and will provide for assessment and mitigation of rare and endangered species, where appropriate, during construction and then subsequent operation of the wells.

The primary objective of monitoring programs will be to focus on local surface water level fluctuations with specific attention placed on:

1. The Blue-spotted salamander's breeding season and the subsequent larval development;
2. Blanding's Turtle's aquatic habitat; and
3. Representative wetland flora including the Britton's Violet, should it be identified.

In addition, short-term site disturbance impacts attributed to future water supply construction activities, as well as long-term impacts resulting from permanent site infrastructure will also take into account potential impacts on the indigenous flora and fauna. There are no documented occurrences of the Britton's Violet in potential areas of site disturbance; this will be reassessed prior to initiating and finalizing actual construction activities.

CONCLUSIONS

An aquifer pumping test was performed at the Brewster Wellfield to determine whether the withdrawal of one mgd of groundwater would have an adverse impact on the ecosystem of the area. We designed an ecohydrology approach of the Brewster Wellfield in order to better understand the interactions between the surface water resources and the underlying sand and gravel aquifer. Groundwater and surface water levels were monitored as part of this integrated approach before, during, and after the aquifer pumping test. In addition, an inventory of rare and endangered species, recommended by the state, was taken of the Brewster Wellfield.

The results of this ecohydrological approach indicate that because of the presence of an extensive thickness of organic material mantling the base of the ponds and kettle holes, there is limited hydraulic communication between these surface water features and the underlying sand

and gravel aquifer. In addition, a large percentage of water recharging the wells is from induced infiltration from the nearby Concord River. However, this induced infiltration is small (i.e. 1.7% of the 7Q10 or 1.3% of the August Median Flow) in comparison to the flow in the river.

These encouraging results should not be considered the final statement. Rather, long-term monitoring of water levels in the Concord River, ponds, and kettle holes is recommended to ensure that this groundwater withdrawal does not create an adverse impact on the water resources of this area.

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