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Delineation and Characterization of the Furnace Brook Watershed in Marshfield, Massachusetts: Potential Impact of Water Supply Extraction

Erik Croll

An understanding of conjunctive use of surface water and groundwater is essential to resource management, both for sustained public use and watershed conservation practices. The Furnace Brook watershed in Marshfield, Massachusetts supplies a coastal community of 25,132 residents with nearly 45% of its town water supply (Marshfield 2012a). As in many other coastal communities, development pressure in Marshfield has increased in recent years, creating a growing demand for freshwater extraction. It has been observed, however, that portions of the stream and Furnace Pond disappear entirely at certain times of year, generally between June and August, depending on the rate of groundwater extraction. This has created a conflict between protecting the designated wetland areas and meeting public pressure for water resources, even within what is traditionally viewed as a humid region. "Exchange of groundwater and surface water occurs in most watersheds and is governed by the difference between the water-table and surface water elevations" (Healy 2010), even though public water supplies and wetlands are often viewed legally as separate resource entities.

Questions have arisen as to whether the town's water extraction is excessively lowering the water table and potentially endangering the health of the stream. This study set out initially to characterize the lowered water table and identify possible anthropogenic and natural influences acting upon the watershed, including stream flow obstructions, water extraction, and geologic conditions. Water-table data were correlated with town pumping information, previous geologic surveys, and meteorological data. Previous analyses indicated that the stream behaved in an anomalous manner by decreasing in discharge, even while flowing downstream, despite normal precipitation inputs.

The behavior within this particular watershed appears to be influenced by four primary factors resulting in the stream "running dry" during the June-August period. These factors include: (1) A losing gradient induced by well pumping; (2) Obstructions to stream flow from the upper reaches to the lower reaches of the watershed; (3) A highly anisotropic layer of lower conductivity material regulating infiltration rates; and (4) Evapotranspiration that results in a deficit situation during the summer. Additionally, relationships between well pumping *and decreasing discharge, seepage flux loss rates, and hydraulic gradients, have demonstrated that even within humid regions, it cannot be assumed that aquifer recharge is sufficient to avoid conflict between surface water protection and groundwater utilization in watersheds. In other words, rainwater and melted snow do not provide sufficient public water supply. Timing of precipitation events combined with geological governance of aquifer recharge play critical roles in managing the conjunctive use of water resources and cannot be assumed to have a negligible effect, even within relatively humid regions.*

Introduction

The Furnace Brook is a three-mile, first-order stream that flows from its origins in the Marshfield and Carolina hills, proceeds along a valley southward and onto the southeastern Massachusetts glacial coastal outwash plain, before ultimately joining the South River. The associated drainage basin (or watershed) for Furnace Brook has an area of 2.25 square miles. Topographically, the basin elevations range from 260 feet to near sea level at the South River, with the stream elevations ranging from 90 feet at its head to 10 feet at its convergence with the South River. The surficial geology of the watershed is typical of Southern New England, comprised of glacial tills outwash, and ice channel deposits left during the retreat of the Buzzards Bay Lobe of the Laurentide ice sheet. The northern sections of the watershed have a poorly sorted, unstratified sediment mixture ranging from clay to boulders, while the outwash flowing southward is typically horizontally bedded, glaciofluvial sands and gravels (SAIC 1990). The climate is considered humid by the Koppen Index, with an average annual precipitation of 50-54 inches in the form of rain and snow inputs to the basin (NCDC 2012).

While it is not unusual for a stream to have sections go dry intermittently in the summer, the Furnace Brook exhibits an abnormal pattern in its behavior during the summer dry periods. While it would be expected that a normally behaving stream might dry up in response to lower precipitation during dry summer months, the stream response to lack of input would begin with the upper reaches and then proceed downstream, depending on the length and severity of the drought condition. Furnace Brook, however, does not show this pattern; in the Furnace Brook stream, the mid-reaches go intermittent first, followed by the upper reaches; the lowest reaches actually stay wet. This abnormally intermittent stream behavior indicates that some other factor(s) besides drought must be at work and serves as an indicator of imbalance within the watershed.

Additionally troubling is the annual disappearance of Furnace Pond, which is located adjacent to Furnace Brook Well #1. The Pond lies within a topographic low in the watershed and is bounded on its southerly discharge end by a dam. It is highly likely that the pond owes its existence to the dam impeding stream flow. The current watershed ecosystem appears to have developed in response to the presence of the dam and the pond that it formed. The disappearance of the pond every summer, as with the disappearance of sections of the stream, indicates a watershed system in imbalance. The question then emerges: if the water input is normal for this humid region, where has the water gone? Is there sufficient recharge of the aquifer to support growing groundwater extraction in conjunction with watershed ecosystem protection?

Traditional water accounting methods simply compare average precipitative inputs (assets) to groundwater extraction, stream discharge and, if known, average evapotranspirative (ET) effects (deficits). Any remaining volume of water input is assumed to recharge the aquifer at rates controlled by the hydraulic conductivity of the geologic material within the region. Following this methodology, assets in this humid-region watershed outweigh the deficits; therefore the watershed should provide adequate water for current and projected extraction needs. It becomes readily apparent, however, that there are two potential flaws in this approach to water resource availability. First, this approach assumes that conductivity is uniform throughout the basin, and any remaining water will infiltrate into the subsurface at a known rate. Second, this approach fails to take into account that while the extraction rates may not be exceeding the recharge potential for continued public-water supply use, the amount that can be safely extracted before negatively impacting watershed ecosystems is likely to be far less than the overall aquifer capacity.

The main objectives of this research are to (a) characterize and gain insight into abnormal stream behavior at Furnace Brook watershed, and (b) to examine whether or not the town's water-extraction volumes are inducing the losing nature of the stream.

Methods

To seek answers to these questions regarding pond and stream intermittency abnormalities and the town's water extraction, an initial characterization of the watershed, including stream flow parameters, geological conditions, and water balance inputs/outputs, was undertaken over a six-week period between May and July, 2012. The study region was narrowed to the output from Parsons Pond into the South River as its terminus, with the area of contribution subsequently plotted on the most recent USGS Topographic map (Chute 1965).

The basin perimeter and stream courses were evaluated in the field to check for obstructions and diversions and to verify the accuracy of the area of contribution delineations. This field survey was integrated with existing Town of Marshfield planning maps to create a watershed basin map for this study. Within this framework, the town extraction wells were plotted on the map, and sub-basin monitoring stations were established in relation to the areas of interest, i.e., the town wells, the disappearing reach designated as sub-basin #2, and Furnace Pond. At the terminus of each sub-basin the monitoring stations (MS-#) were established; they consisted of (a) an elevation reference baseline from which to measure depth to stream, depth to groundwater, and stream cross-section area; (b) a seepage meter for volume gain/loss through the streambed; and (c) mini-piezometers for groundwater level/gradient measurement. It should be noted that while each reference baseline was leveled and plotted by GPS for reference consistency, elevation measurements cannot be taken as absolutes since full survey teams were not employed.

Stream discharge calculations were made at each location utilizing a Marsh-McBirney Flowmate 2000 in conjunction with a wading rod. Due to stream depths being 2 feet or less, measurements were conducted in 1-foot, cross-sectional areas at 60% measured stream depth, in accordance with standard protocols (Carter and Davidian, 1968). Volume of stream discharge was thus calculated as: $Q=\sum (A_n * V_n)$ where the discharge Q is equal to the Sum of the Areas of sub-cross sections, A_n multiplied by the corresponding water velocity of that cross-section, V_n. The data were interpolated to fill in gaps created by the fact that physical measurements could not be conducted every day. A simple progressive/regressive average was utilized in graphing and analysis of trend behaviors. Station and basin discharges were then plotted in cubic feet per second (cfs) and in comparison with town extraction volumes in cubic feet per day (cfd).

Correlation analysis was conducted using a Pearson method correlation to determine if there was a statistical relationship between extraction rates and discharge responses.

Seepage meters were fabricated utilizing a modified design from Lee and Cherry (1978) and Rosenberry et al. (2008). Due to stream size, designs were modified to use a 1-gallon can with smooth sides rather than 55-gallon drums of the original design, to yield a cross-sectional area of seepage measuring 0.23 $feet^2$. The meter was sunk into the streambed to a depth of 8 inches. The outlet consisted of a ¼ ID hose barb sealed to the meter body with hose, a check-valve coupler, and impervious chemical media bag. At the start-time of seepage measurement, the chemical media bag, filled to half-capacity with 500ml of water, was attached to the hose to begin flow. One hour later the bag was removed, and the volume of water gained or lost through the meter was measured. The rate of water volume gained/lost through the streambed in the hour time (seepage flux rate or Q) was then calculated as: Q = dV/dt = Vfinal - Vinitial/Elapsed Time. This result was then converted into $foot^3$/day for comparison with other parameters, such as pumping-extraction volumes and stream discharges.

Mini-piezometers were constructed with ¾ in. PVC as described in Lee and Cherry (1978) and driven to a depth whereby the screen was within 4 inches of the surface water table, as indicated by the stream level at a lateral distance of 4 to 6 feet from the stream bank, as allowed by local geology. In cases where the groundwater was at lower elevation or dropped below original piezometer depth during the period, separate piezometers were added in 6-inch-depth increments to create a nest of piezometers for groundwater measurement. Meteorological data were provided by Stanwyck Avionics, Ltd at Marshfield airport (KGHG) and three nearby National Weather Service Stations (Stanwyck 2012; NWS 2012), while the water-extraction volumes were supplied by the Town of Marshfield for the five wells located within the study basin. Basin geologic data were obtained from geophysical and monitoring well studies conducted by SAIC Engineering, Inc. (1990).

FINDINGS

Stream Behavior

Field observations during the study period noted multiple factors affecting the watershed behavior. First, various obstructions to stream flow prevented normal contribution from the upper reaches to the lower reaches of the basin, resulting in free standing pools of water. The obstructions consisted of deadfalls and debris, perched culverts, modified flow channels, and the two dam structures located at Furnace Pond and Parson's Pond. It was observed that during most of the study period, the stream water level was too low to pass

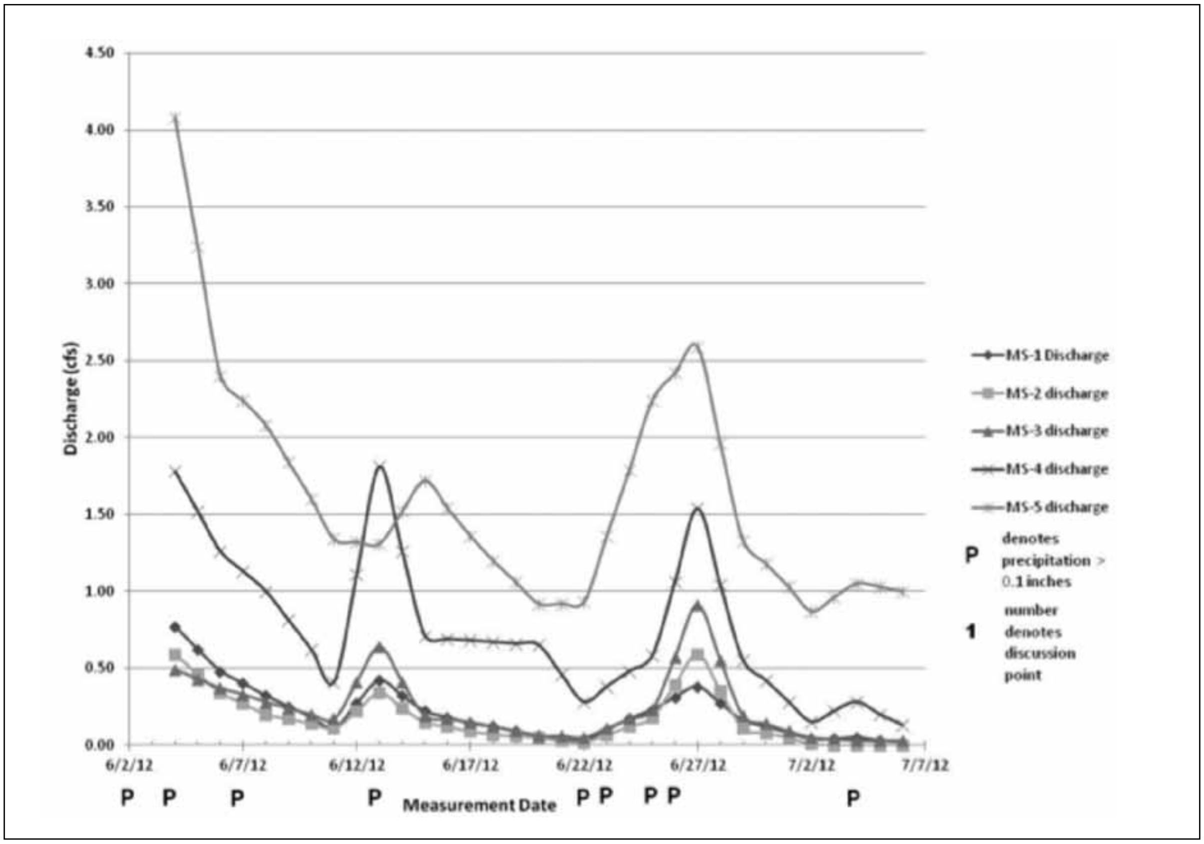

Figure 1. Furnace Brook Stream Discharge from June 4-July 6, 2012 at each sub-basin Monitoring station. Sources: field data collection.

these obstructions; therefore, surface water contributions from the upper reaches failed to get to the lower reaches, which reduced stream discharge. In Figure 1, the stream discharge pattern over the study period can be observed.

When overall stream discharge was correlated with basin extraction volumes, a pronounced negative correlation became apparent (Fig. 2).

Throughout the sub-basins, similar correlations could be observed in relation to the pumping rates. When this finding is further examined in relation to the rate of water loss through the streambed to groundwater throughout the basin (as seen in Table 1), it appears that stream losses are correlated with public water-supply extraction.

Table 1. Seepage Flux Basin Summary

Basin Mean:	-0.083
alpha:	0.050
Sample (n):	31.000
Correlation (r):	-0.568
r critical:	0.349

While seepage flux rates did not always correlate at individual sub-basin stations, this was expected due to the anisotropic nature of the glacial outwash and till throughout the basin, as reported by SAIC.

Gradient data from piezometers were inconclusive in providing a clear picture of surface and groundwater interaction. While it is interesting to note that, as could be expected, certain reaches had a gaining gradient, while others experienced a losing gradient, the few piezometers installed (in some cases only 1 or 2 per station), did not provide enough data to build a comprehensive groundwater flow picture. In addition, piezometers were not installed specifically at Furnace Pond to determine if there was a sharp losing gradient to the adjacent well. Data did show, however, that the reaches with the greatest losing gradients also happened to be in locations with the greatest pumping extraction volumes. Notably, the two stream reaches of greatest concern, that of the MS-2 sub-basin and the Furnace Pond, which both go dry annually, coincided with the highest town extraction volumes of 2,259,707 and 1,863,335 ft^3 extracted from the adjacent Furnace Brook #4 and Furnace Brook #1 wells (Marshfield 2012b).

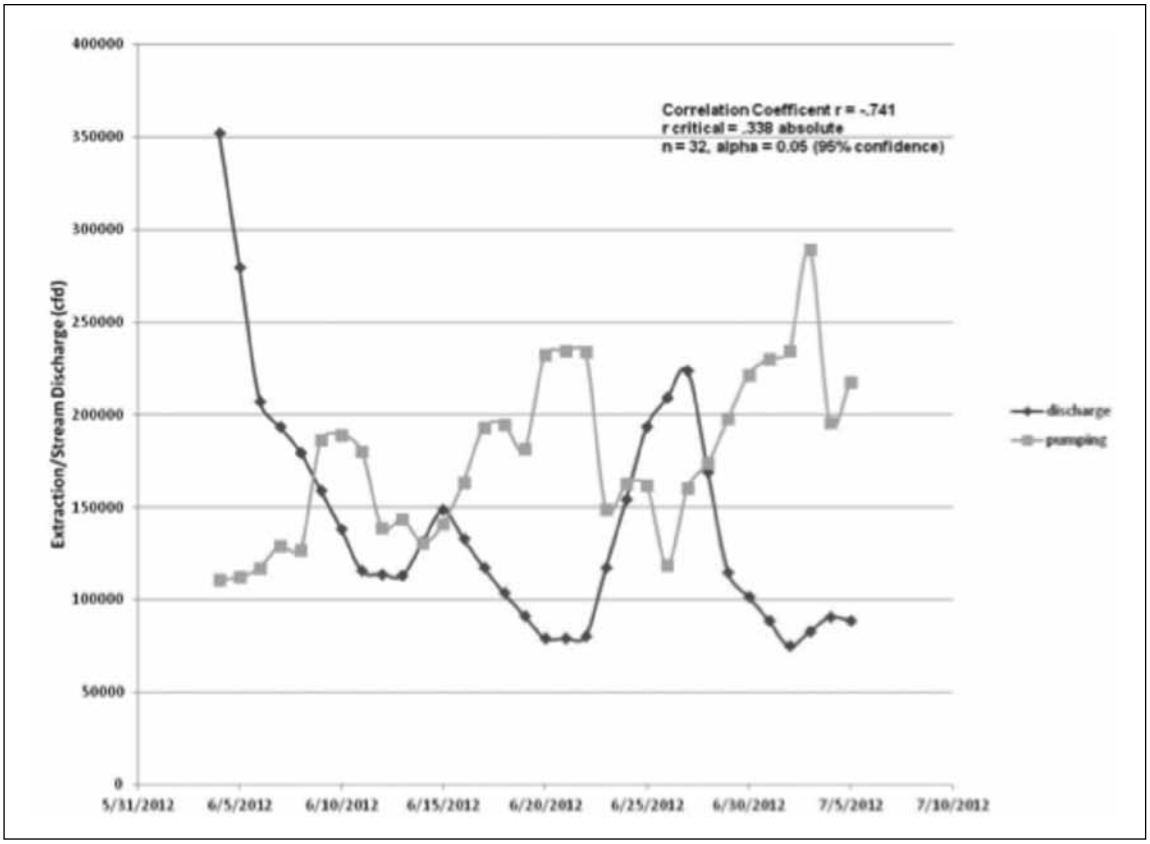

Figure 2. Pumping rate and stream discharge vs. time for the Furnace Brook in cubic feet/day for the Furnace Brook Watershed Basin from June 4-July 6, 2012. Sources: field data collection and Town of Marshfield unpublished raw data 2012.

Meteorological/Climate Data

Meteorological data indicate a normal rainfall input to the basin during the study period: 3.68 inches, or 0.31 ft (Stanwyck 2012; NWS 2012). This rainfall data is consistent with National Climate Data Center (NCDC) information that records an average June precipitation input of 3.55 inches (NCDC 2012). It should be noted, however, that average regional ET effects calculate that 4.49 inches, or 0.37 ft (GeoSyntec 2010), are lost during the June period, indicating that the basin is potentially in a deficit situation even without any aquifer extraction, as summarized in Table 2.

Sources: Stanwyck Avionics, Inc. Meteorological Data Reports, 2012. National Weather Service Daily Meteorological Reports, 2012. GeoSyntec Consultants 2012.

These data indicate that for recharge calculations, the annual precipitation trends, especially winter precipitation, become critical. Data collated from the NCDC regarding average annual precipitation indicated that 50.4 inches of precipitation fell the previous year. This precipitative input was found to be 3.63 inches lower than the normal median annual precipitation of 54.03 inches. When precipitation input to the basin over the preceding year was examined, it was found that the region received only 1.2 inches of precipitation in the form of melted snow, compared to the annual average of 5.49 inches of melted snow. (WeatherSource 2012).

Discussion

In observing Furnace Brook during the study period the most immediate aspect that became apparent was the extremely low contribution that the upper half of the basin makes to the lower reaches. This is quantified by examining the stream discharge patterns at MS-1 through MS-3 (Figure 1). Other than during actual precipitation events, the discharge at each station was extremely low. In the case of the MS-2, the most rapid disappearance of discharge was *downstream* (at the intermediate reach), which is highly unusual. It is concluded that very little if any contribution is being made to subsequent reaches of the stream. This decrease appeared, based on field observations, to be a condition created by numerous stream obstructions, including perched culverts, tree deadfalls, and in one case within the MS-1 sub-basin, a hiking trail built across the stream with a blocked or non-existent culvert. Due to these

Table 2. Precipitation/Evapotranspiration Summary June 4 – July 6, 2012

	Monitoring Stations/Sub-Basin					Total Study
	MS-1	MS-2	MS-3	MS-4	MS-5	Basin Area
Total Input EUD (ft):	0.31	0.31	0.31	0.31	0.31	0.31
Evapotranspiration (ET) (ft):	0.37	0.37	0.37	0.37	0.37	0.37
Sub-Basin/Basin Area (ft^2):	23,139,072	4,181,760	18,120,960	10,872,576	6,412,032	62,726,400
Precipitation Input Vol. (ft^3):	7,173,112	1,296,346	5,617,498	3,370,499	1,987,730	19,445,184
ET Output Vol. (ft^3):	8,561,457	1,547,251	6,704,755	4,022,853	2,372,452	23,208,768
Volume Gain/Loss (ft^3):	-1,388,344	-250,906	-1,087,258	-652,355	-384,722	-3,763,584

conditions, each of the upper sub-basins essentially became isolated, reducing overall stream flow throughout the system.

During precipitation events these obstructions could be overcome initially, but once water levels decreased, flow became isolated again, with only limited seep past the obstructions, which contributed in a normal pattern to subsequent reaches downstream. The net result was that each sub-basin was isolated in its area of contribution and if, as in sub-basin #2, there was a smaller geographic area of contribution, the isolated sub-basin became increasingly susceptible to negative impacts from groundwater extraction.

The stream discharge curves in Figure 1 show a rapid response to precipitation and an extremely sharp recession following peak events. This is indicative of a stream that is highly responsive. If stream flow were normal, gradual sloped recession curves would be expected; there would be phasing of flow peaks from the upper reaches to lower reaches over time. Instead, there are mirror images of increase and decrease on either side of the precipitation event, which highlights the isolated nature of each sub-basin caused by the obstructions. The erratic behavior of MS-4 discharge is believed to be a result of the dam structure at Furnace Pond; however, a more definitive study would need to be conducted on this structure to further investigate the stream behavior in relation to the dam condition.

By examining these discharge curves in relation to the surficial geology, the idea that the aquifer is comprised of an anisotropic mix of unstratified glacial till upstream with increasing outwash downstream, seems to be supported. An examination of the area of contribution for the lower reaches at MS-4 and 5 shows that despite their having small areas of contribution coupled with limited input from upper reach sub-basins, they retained the highest discharge flows and stream water levels.

In addition to those observations at MS-4 and 5 (small areas of contribution, limited input from upper reaches, yet high discharge flows and water levels), sub-basin seepage rates in those lower reaches are also slower. Slow seepage rates at MS-4 and 5 indicate that the lower reaches likely have lower conductivity layers of outwash silts/clays, which reduce the rate of infiltration from surface water to groundwater. Conversely, the upper reaches of the stream experienced the highest seepage loss rates; that is consistent with the upper half of the basin having a greater hydraulic conductivity of unsorted glacial material. While a further geologic survey is needed to determine the full extent of the lower conductivity regions, the limited data from the SAIC study of 1990 seems to support the idea that while the upper half of this basin is more suitable to groundwater extraction, it is also more susceptible to negative impacts from the extraction.

Given these observations, the question of whether town water-extraction influenced stream and pond loss the correlation between stream discharge, seepage flux loss rate, and town extraction volumes is hard to ignore. This, however, does not tell the whole story. It must be acknowledged that at the time of this study while the monthly rainfall input was normal, the preceding year was one of reduced input, especially with regard to water-equivalent snow input.

Further, the regional evapotranspiration (ET) effect indicates that during the primary growing season, ET exceeds precipitative input, which means that the watershed is in a deficit situation prior to any extraction of groundwater. This data is preliminary at best, however, and additional studies are needed to study the actual evapotranspiration within this watershed (rather than a regional average) to determine whether the basin truly is in deficit situations during the primary growing spring season.

Conclusion

The correlation between the town's increased water-extraction rates and decreased stream flow simply cannot be ignored. While correlation does not mean causation, in absence of other definitive explanations, the town's water pumping must be considered a significant factor in decreased stream flow. However, it is highly unlikely that the stream and pond disappearance observed in the Furnace Brook watershed are the result of this single cause (public-water extraction). While the town's water-extraction volumes do appear to be inducing seepage loss through the stream bed as a result of losing gradients, there are numerous other factors influencing the behavior of the stream and specifically the summer disappearance of the stream at the intermediate reach of sub-basin 2 and of Furnace Pond itself. The isolation of sub-basin areas caused by obstructions, variable hydraulic conductivity of geologic material, evapotranspiration effects, and climate/meteorological trends, all exert significant controls upon aquifer recharge and stream discharge; all of these factors should be taken into consideration when determining sustainable, safe yields that may be extracted from the watershed. While traditional methods of calculating aquifer recharge may be sufficient in estimating water available for extraction, these other controls appear to reduce the amount of water that may be safely extracted before there is a negative impact on overall watershed health. As seen in the Furnace Brook during this study, often the stream itself can be the first indicator of a conjunctive-use watershed being under stress, and therefore should be monitored in relation to the controlling factors presented in order to effectively balance the needs of both public-water supply demand and watershed protection.

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Works Cited

Carter, R.W. & Davidian, J. 1968. "General Procedures for Gauging Streams". *Techniques of Water-Resources Investigations of the United States Geological Survey (TWRI-USGS)*. Book 3, Chapter A6. U.S. Governmental Printing Office. 1989.

Chute, N.E. 1965. *Geologic Map of the Duxbury Quadrangle, Plymouth County, Massachusetts*. USGS Geologic Quadrangle Map GQ-466. Print.

GeoSyntec Consultants. 2010. "Effectiveness on Environmentally Sensitive Site Design and Low Impact Development on Stormwater Run-Off Patterns at Patridgeberry Place LID in Ipswich MA." 22.

Healy, R.W. 2010. *Estimating Groundwater Recharge*. Cambridge, UK: Cambridge University Press.

Lee, D.R. & Cherry, J.A. 1978. "A Field Exercise on Groundwater Flow using Seepage Meters and Mini-Piezometers." *Journal of Geological Education*. 27, 6-10.

Marshfield, Town of. 2012a. *Annual Water Quality Report for 2011.*

Marshfield, Town of. 2012b. Weekly Pumping Reports for Town Wells from June 1-July 8, 2012. Unpublished Raw Data.

National Climatic Data Center-NCDC. 2012. "Quality-Controlled Local Climate Data for 54769/PYM Plymouth Municipal Airport." Retrieved online. http://cdo.ncdc.noaa.gov

National Weather Service (NWS/NOAA). 2012. "Daily Precipitation Reports for Period May 25 to July 6, 2012." NWS Forecast Office-Boston/Taunton. Retrieved online. http://www.noaa.weather.gov

Rosenberry, D.O., LaBaugh, J.W., Hunt, R.J. 2008. "Field Techniques for Estimating Water Fluxes between Surface Water and Ground Water." *US Geological Survey Techniques and Methods*. 4-D2, 128.

SAIC Engineering, Inc. 1990. *Hydrogeologic Evaluation of the Furnace Brook and South River Aquifer, Marshfield, Massachusetts*. SAIC Project Number 19-802-02-238-01. 1-1 to 2-7.

Stanwyck Avionics, Inc. 2012. Daily Meteorological Reports at Marshfield Airport (KGHG): Period May 25 to July 6, 2012. Unpublished Raw Data.

WeatherSource. 2012. "National Climatic Data Center Compiled Reports January 1, 1991 to December 31, 2011." Retrieved online. http://weathersource.com via subscription.