SHUTESBURY AQUIFER RESILIIENCY IN THE FACE OF CLIMATE CHANGE

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ABSTRACT

The climate is rapidly changing due to human activity, and these changes will impact our water resources. In the town of Shutesbury, Massachusetts, a municipal water supply does not exist. Instead, water comes from private wells that tap into a vast and complex bedrock groundwater system. Prior to this study, little information existed regarding the seasonal fluctuations, the sensitivity of the aquifer to short or prolonged drought, or the ability of the aquifer system to support future development in Shutesbury. Still less was known regarding how the aquifer system could potentially be impacted by climate change. Reports of lowering water levels in New Hampshire and the neighboring town of Pelham were a cause for concern. In 2014, eight monitoring wells were drilled at four locations in order to monitor seasonal changes in water level and to establish a baseline for future levels. Water levels were found to fluctuate seasonally, and despite a snow-heavy winter and summer drought, spring static water levels returned to similar levels each year. Based on the small amplitude of seasonal fluctuations, the lack of a lasting impact of the drought of 2016, and expected future increases in rainfall, it appears that the shared aquifer should continue to serve as a viable source for the town.

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1 | INTRODUCTION

In New England, as with most of the United States, our relationship with local water resources is based on the assumption that the resource in question will be consistent and predictable. In most temperate latitudes, water levels are typically high in the spring because of rainfall and snowmelt, and drop throughout the summer as the weather gets hotter and drier, water use increases, and vegetation claims its fair share (Whately et al 2012). Typically, rain shifts to snow during the late fall, snowpack begins to melt during the spring, and the summers are warm and dry with occasional interruptions by intense thunder storms. However, because of climate change, these expected patterns are changing and are predicted to continue to change. Temperatures are rising, precipitation trends are shifting (Table 1), and surface and ground water resources are becoming less predictable.

The resilience of groundwater systems in New England became a concern in the early 2000s as statements from drillers in New Hampshire began to report that wells were needing to be drilled deeper and that static water levels were decreasing. A study in 2010 found that, between 1984 and 2007, the average static water level in New Hampshire wells lowered by 13ft (Ayotte et al 2010; Kernen 2010; Figure 1). About 50% of New Hampshire residents get their water from bedrock wells, and 80% of these wells are private, so the only consistent reporting came from the initial drilling and complaints of individual wells running dry. Further exacerbating the situation, the population of New Hampshire has been growing, and the resulting increase in water use caused concern about the resilience of their groundwater resource and the potential impacts of climate change (Mack 2009).

WESTERN MASSACHUSETTS INDICATORS	30 YEAR AVERAGE* 1980–2009	CHANGE FROM 30 YEAR AVERAGE 1980–2009 (+ OR –)					
		SHORT TERM 2010–2039		MEDIUM TERM 2040–2069		LONG TERM 2070–2099	
		LOW EMISSIONS	HIGH EMISSIONS	LOW EMISSIONS	HIGH EMISSIONS	LOW EMISSIONS	HIGH EMISSIONS
MINIMUM TEMPERATURE (°F)							
Annual TMIN	35.4	1.6	2.0	2.8	5.1	3.7	8.7
Winter TMIN	14.2	2.1	2.5	3.4	5.4	4.7	8.9
Spring TMIN	33.3	2.9	1.5	4.7	4.1	5.8	7.3
Summer TMIN	55.5	1.5	2.1	2.7	5.6	3.4	9.8
Fall TMIN	38.2	0.1	1.9	0.3	5.3	0.8	8.7
MAXIMUM TEMPERATURE (°F)							
Annual TMAX	57.7	1.6	1.7	3.0	4.7	3.9	8.1
Winter TMAX	34.0	1.7	1.6	2.5	3.6	3.6	6.1
Spring TMAX	56.0	2.6	1.6	5.1	4.8	6.8	8.7
Summer TMAX	79.7	1.6	1.9	3.1	5.4	3.9	8.9
Fall TMAX	60.5	0.8	1.8	1.2	5.3	1.3	8.5
TEMPERATURE EXTREME (DAYS PER YEAR)							
<32°F	158	-9	-11	-15	-25	-19	-43
<0°F	13	-4	-4	-6	-9	-7	-12
>90°F	6	4	5	11	20	16	45
>95°F	1	1	1	2	5	5	18
TMAX on hottest day of the year	92.5	1.7	1.1	3.0	4.4	4.8	8.0
TMIN on coldest day of the year	-14.1	3.6	4.3	6.0	9.9	7.9	16.8
GROWING SEASON (DAYS)	168	12	12	19	29	20	51
PRECIPITATION (IN.)							
Annual Mean	46.2	4.9	4.0	5.7	6.2	7.5	9.3
Winter Mean	10.3	1.1	0.9	1.4	1.2	1.8	2.7
Spring Mean	11.8	1.3	1.4	1.8	1.9	2.3	3.2
Summer Mean	12.4	1.9	1.6	1.6	2.4	2.4	2.2
Fall Mean	11.6	0.5	0.1	0.8	0.6	1.0	1.2
EXTREME PRECIPITATION (EVENTS PER YEAR)							
1" in 24 hours	11.5	2.0	1.7	2.0	2.8	3.0	4.2
2" in 48 hours	5.7	1.5	1.4	2.0	2.4	2.8	4.3
EXTREME PRECIPITATION (EVENTS PER DECADE)							
4" in 48 hours	4.8	2.6	1.6	4.7	4.1	6.2	7.8
SNOW COVERED DAYS	87	-13	-13	-18	-33	-25	-44

Table 1: Western Massachusetts Climate. Minimum and maximum temperatures, temperature extremes, length of growing season, precipitation, extreme precipitation events, and snow covered days averaged from 1980 to 2009 for Western Massachusetts. Includes the short, medium, and long term high and low emission predictions for these categories as well (Climate Solutions New England).

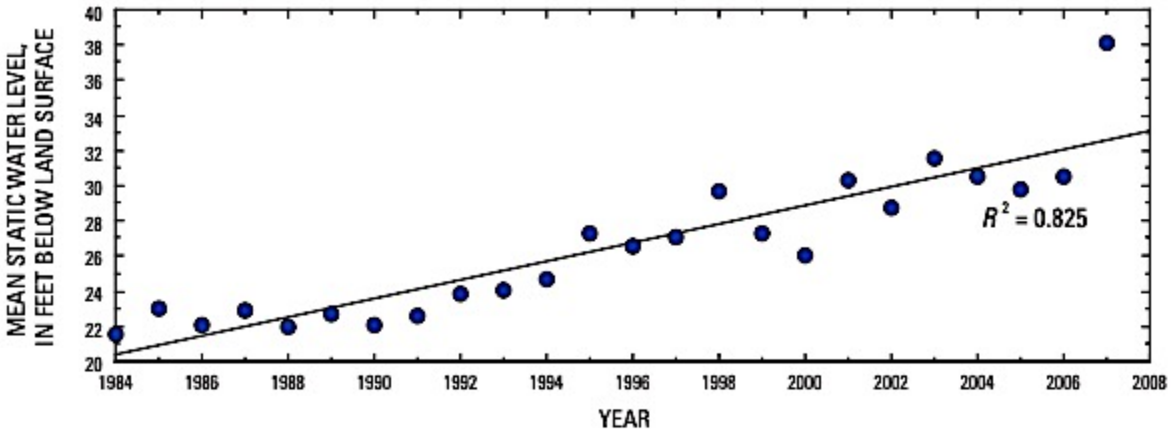

Figure 1: New Hampshire Water Levels. The mean quarterly static water levels in bedrock wells in New Hampshire, 1984-2007. The graph measures feet below land surface, so the upward trend indicates an increase in distance beneath the surface, demonstrating a lowering water level (Ayotte et al 2010).

Five miles to the south of Shutesbury is a USGS monitoring well located in Pelham, Massachusetts (Figure 2) that shows a similar downward trend in static water levels (Figure 3). Since 1982, the water level has fallen by approximately 8ft. The downward trend seen in New Hampshire in conjunction with the falling levels of a well in an adjacent town prompted the town of Shutesbury, Massachusetts, to take stock of the state of their primary water source. In Shutesbury, as in most of rural New England, a municipal water supply doesn't exist. Instead, water is produced from private wells that tap into a vast and complex bedrock groundwater system. This is the reality for about 40% of the New England population (NE Drinking Water 2017). These private wells have no municipal management plan or system in place to monitor the water level or quality besides the individual homeowner and the well driller. As such, little information exists regarding the seasonal fluctuations, sensitivity to short or prolonged drought, or ability of the aquifer system to support future development.

Figure 2: Pelham Well. The green triangle shows the location of the Pelham Well in relation to the town of Shutesbury. The blue circles are 3 of the 4 well sites for the study, with the fourth one being farther north beyond the limits of this figure (USGS 2018).

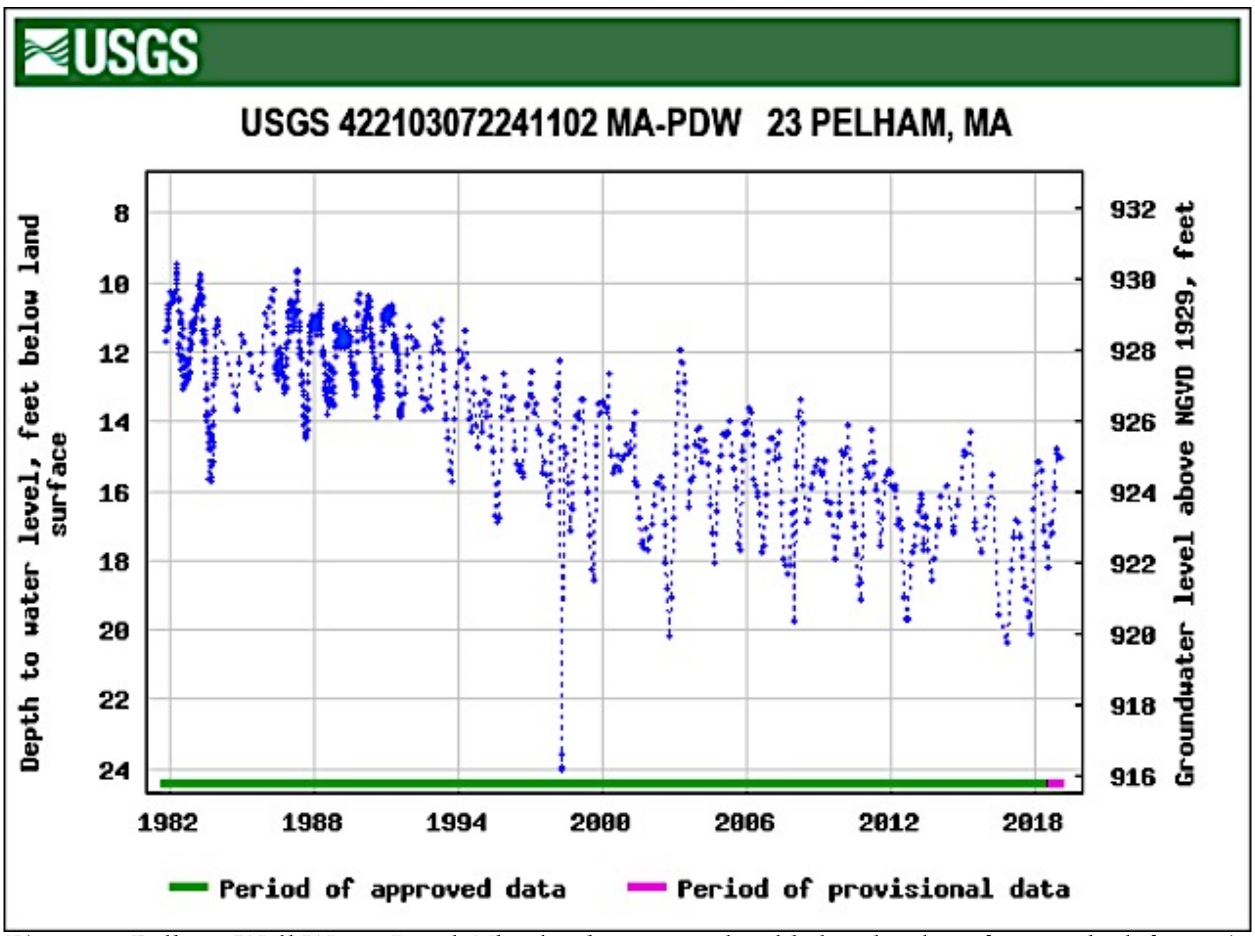

Figure 3: Pelham Well Water Level. The depth to water level below land surface on the left y axis and groundwater level above the logger on the right y axis, both in feet, from 1982 to 2018 (USGS 2018).

2 | PROJECTED IMPACTS OF CLIMATE CHANGE IN MASSACHUSETTS

2.1 | Historical Climate

Using the 30-year average from 1980 to 2009, the average daily low and high temperature in Western Massachusetts is 35.4F and 57.7F, respectively. The average winter low is 14.2F and the average summer high is 79.7F. The annual mean precipitation is 46.2", with approximately 16 extreme precipitation events (defined as more than 1" of rain falling over a period of 24 hours) per year. During this time, there were an average of 87 snow covered days (Table 1). Historical records indicate the occurrence of a major drought in the 1960's and a less severe one in the early 1980s. Drought periods were recorded consistently in Massachusetts, starting in 2001, with a major drought occurring in 2002 and during the course of this study in 2016 (DCR 2017).

2.2 | Climate Predictions for Massachusetts

2.2.1 | Future Temperatures

Average temperatures in Massachusetts are predicted to rise 1-5 degrees C by the end of the century (Figure 4), with winter temperatures rising at a faster rate than summer temperatures (NE EPA). This has increased the length of the shoulder seasons (fall and spring), has shortened the time in which there is potential for snowfall and subsequent snowpack, and increased the duration of the summer season. These changes in temperature are predicted to be greater in areas that have been historically colder (Pourmokhtarian et al 2017), so higher elevations in Massachusetts and the more northern regions of the state are projected to feel the most change. Climate Solutions New England shows Massachusetts as having summers that are similar to the current climate of South Carolina by 2100 (higher emission scenario) (Figure 5).

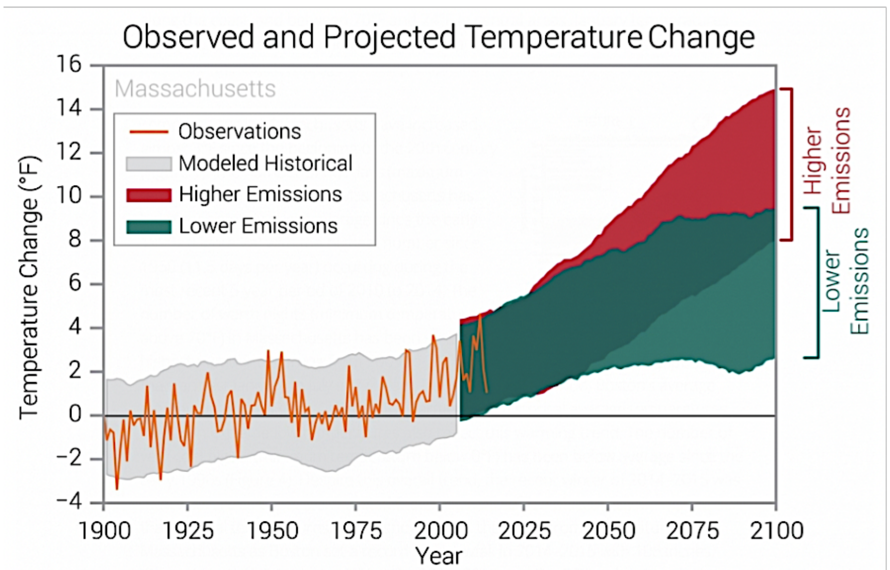

Figure 4: Observed and Projected Temperature Change. The increase in Massachusetts air temperature over the last century and two-model based projections for future temperature for low and high emission scenarios (Runkle et al 2017).

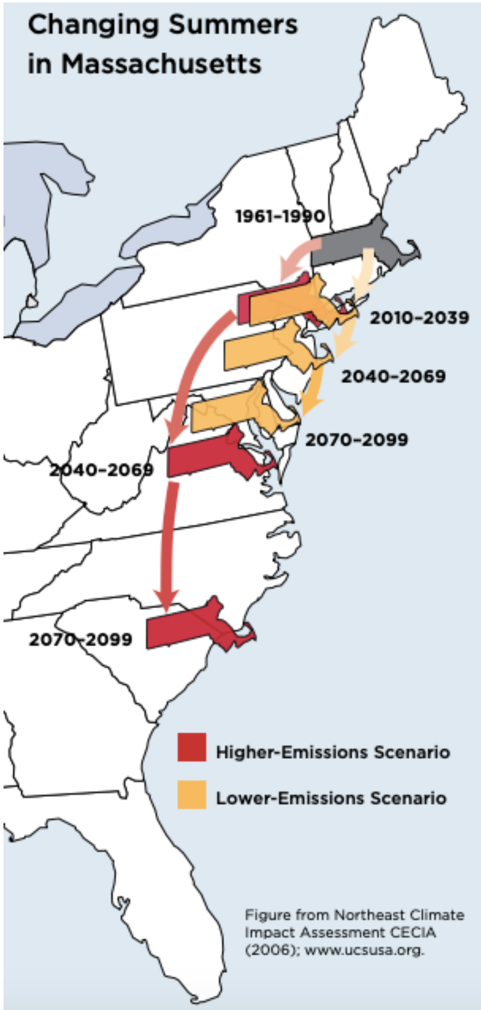

Figure 5: Changing Summers in Massachusetts. In the high emission scenario (red), Massachusetts summer climate is predicted to shift to feel like that of South Carolina by 2100. The low emissions scenario is shown in yellow.

2.2.2 | Future Precipitation

Precipitation in Massachusetts has been increasing over the last century (Figure 6), but as with temperature, the increase has not been uniform throughout the year. While annual precipitation has increased by about 10% in the last century, it has increased at a higher rate in winter months. Winter precipitation is predicted to increase by another 11-14%, whereas summer rain is expected to decrease slightly (Mack 2009). One report goes so far as to suggest that winter precipitation will increase by as much as 30% by 2100 (Mass.gov). Because of the increasing temperature, most of this increase in winter precipitation will occur in the form of rainfall (Hayhoe et al 2006).

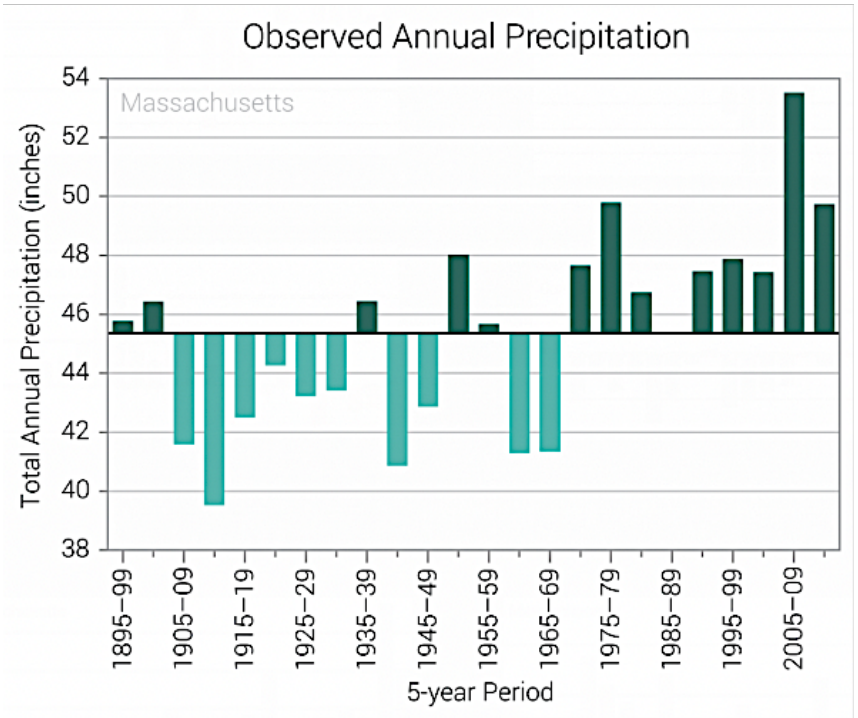

Figure 6: Observed Annual Precipitation. The total annual observed precipitation in the state of Massachusetts grouped in 5 year periods over the last century, showing a steady increase (Runkle et al 2017).

The increased heavy rainfall will increase local runoff in the winter, leading to worsening flooding (Hayhoe et al 2006; Pourmokhtarian et al 2017). The peak streamflow in the spring is expected to come earlier, which has implications for a lengthened the low flow period in the summer and reduced groundwater recharge potential. Precipitation from intense storms, in which a large amount of rain falls in a relatively short amount of time, has likewise increased since the 1960s (Figure 7), and another 13% increase is predicted by 2100 (Mack 2009). Intense rainfall events have a significant implication for the environment, because intense rain can produce runoff when the soil is completely saturated and cannot absorb more water, or when the rainfall rate exceeds the infiltration rate of water into the soil. This increase in runoff can lead to an increase in local flooding, and can limit the groundwater recharge potential of these precipitation events (Hayhoe et al 2006; Mack 2009).

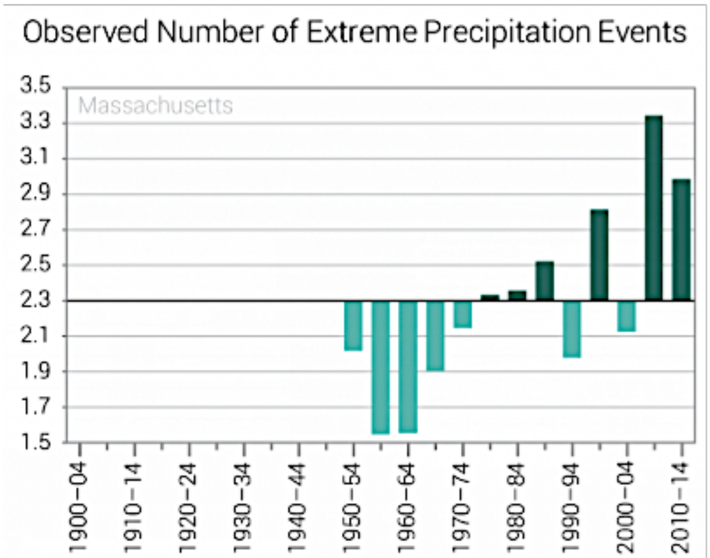

Figure 7: Observed Number of Extreme Precipitation Events. The number of intense precipitation events greater than 2 inches in the state of Massachusetts grouped in 5 year periods over the last century, showing a steady increase.

2.2.3 | Future Snow

Massachusetts is projected to lose between 25-50% of its snow covered days by the end of the century (Mass.gov) due to the increase in winter temperature and the resulting shift to rainfall from what has historically been snowfall. The time in which snow will exist is predicted to be reduced, due to delayed snowfall and earlier melting (Hayhoe et al 2006).

Snowpack will melt earlier, eliminating the reserves that would otherwise melt into the early summer. This will potentially have a major impact on spring base flow in streams (Whately et al 2012), increasing frequency and duration of low flow periods and lowering the availability for groundwater recharge from infiltration from surface water (Dudley et al 2010).

The volume of water available for infiltration earlier in the melting season is expected to increase. However, frozen ground could increase runoff into surface water systems (Hayhoe et al 2006). Soil freezing is an important factor in the hydrology of Western Massachusetts, as soil that is concretely frozen has been shown to cause up to

100% of precipitation and snowmelt to runoff and not infiltrate (Storey 1955). Additionally, snow cover is a major player in whether or not the ground freezes, as well as the depth of the frost (Storey 1955, Dudley et al 2010). The predicted lowering of snow pack volume increases the likelihood of a frozen, impermeable ground, but the higher air temperatures increase the likelihood that it will be too warm for the ground to freeze (Dudley et al 2010, Whately et al 2012). As such, with warmer air temperatures and reduced frozen ground, it is most likely that the net affect will be an increase in winter recharge.

3 | SETTING AND GEOLOGY

Shutesbury is located on a topographic ridge just east of the Connecticut River and west of the Quabbin Reservoir, and precipitation that falls on either side of the ridgeline flows to those bodies of water. The aquifer relies on recharge from direct precipitation, and because even the deepest wells in town are above these levels, the Connecticut River and the Quabbin Reservoir are not considered sources of water for the town (Figure 8).

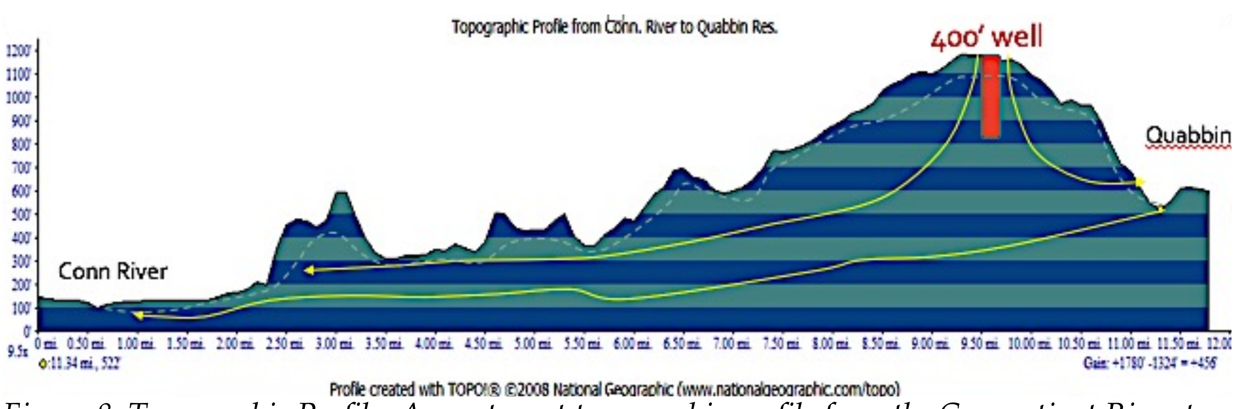

Figure 8: Topographic Profile. An east-west topographic profile from the Connecticut River to the Quabbin Reservoir showing that the Shutesbury ridge is a groundwater recharge area.

3.1 | Geology

3.1.1 | Bedrock Geology

Shutesbury is located in the south-central part of the Pelham Dome (Zen 1983, Figure 9). Most of the region is mapped as undifferentiated Poplar Mountain and Dry Hill Gneiss with a band of biotite-tourmaline schist and quartzite that is classified as pelitic (Zen 1983, Figure 10, Figure 11). The bedrock is Proterozoic in age and records the convergent tectonics associated with the formation of Pangea. The region has been mapped as Pelham Gneiss, which is metamorphosed granite, and is referred to as granite by the well drillers in the well driller reports.

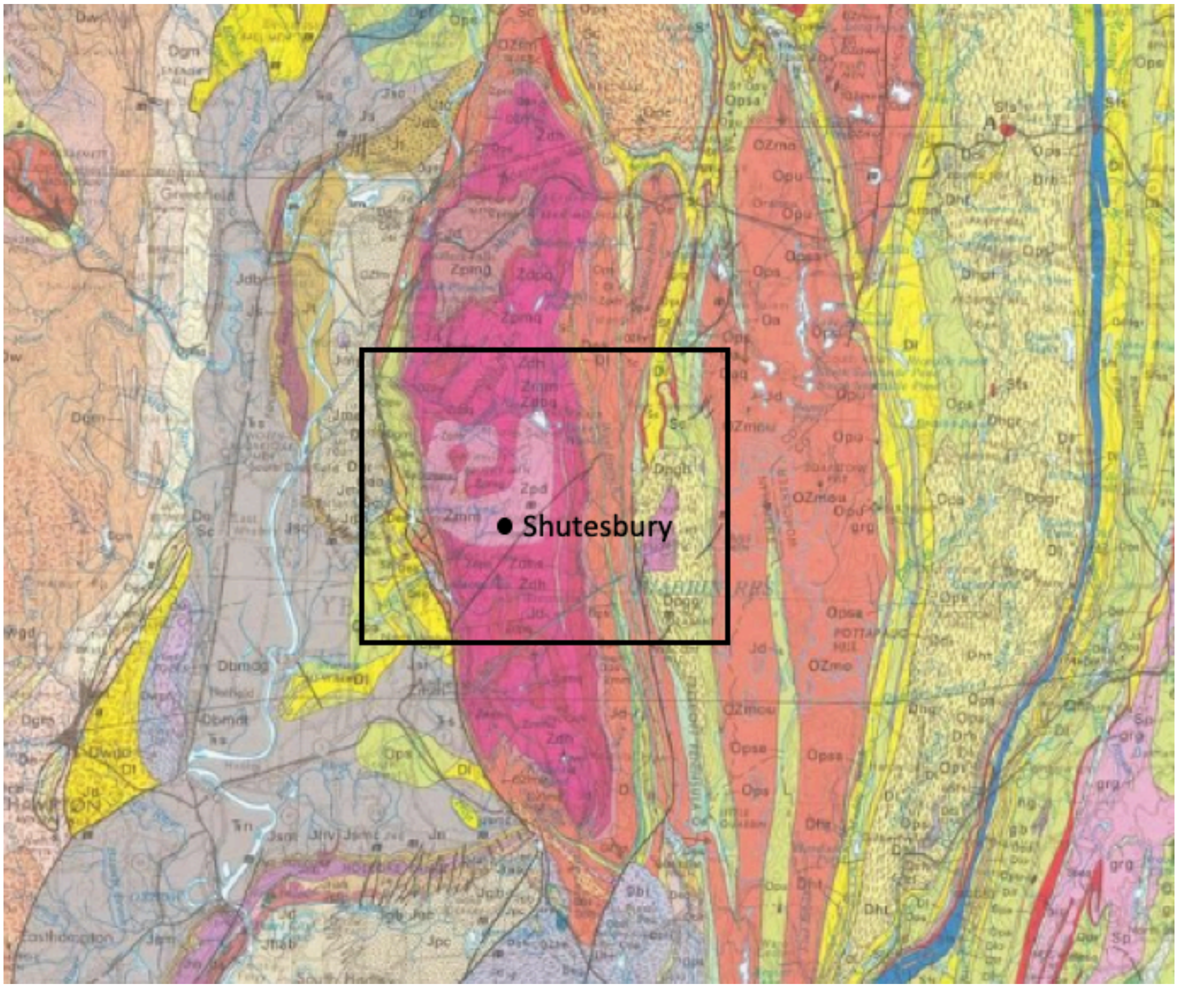

Figure 9: Pelham Dome. A portion of a map of the bedrock geology of Western Massachusetts (Zen et al 1983) that places Shutesbury in the south-central portion of the Pelham Dome.

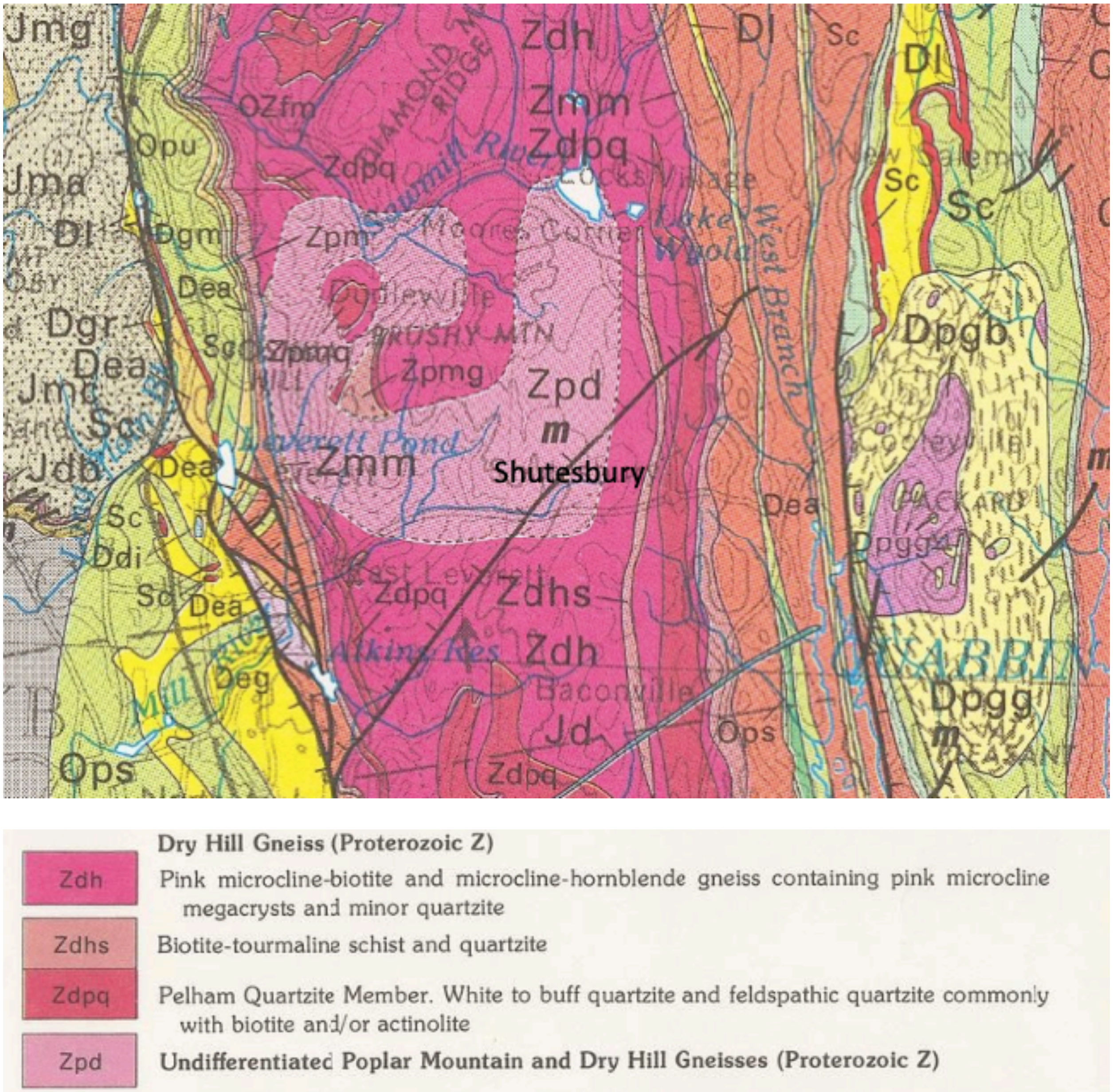

Figure 10: Bedrock Geology of the Pelham Dome. The snapshot from Figure 8 identifies the bedrock in the regions where the wells are located as pink microline-biotite and microline-hornblende gneiss containing pink microline megacrysts and minor quartzite, undifferentiated Poplar Mountain and Dry Hill Gneisses, and a small band of Biotite-tourmaline schist and quartzite, all of which are Proterozoic Z (Zen et al 1983).

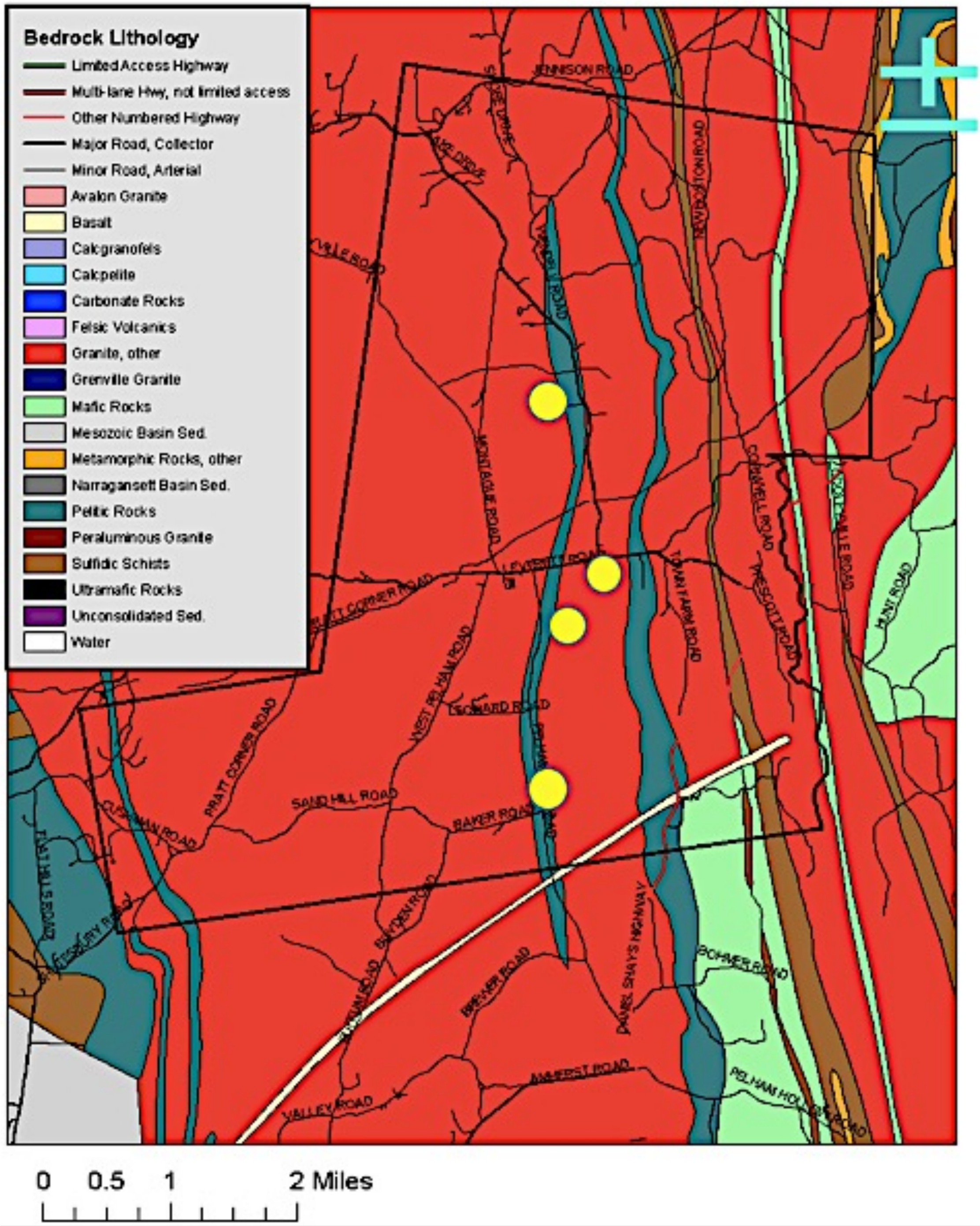

Figure 11: Bedrock Geology. Map of the bedrock geology in the town of Shutesbury. The wells in the groundwater study are located in Granite and Pelitic Rocks, and are marked by a yellow circle (Mass GIS).

3.1.2 | Fractures

Gneiss is a crystalline rock and has a relatively low hydraulic conductivity (Ozbek et al, 2018). The principal paths for groundwater flow are therefore various types of fractures such as fracture zones, faults, shear zones, and joints (Hansen and Simcox 1994). Fractures in the area consist of regional N—S trending fractures and subhorizontal fractures at shallow depths associated with "unroofing" the bedrock (Al Werner, pers comm, 2019). The width of these fractures can range from barely visible to several inches, but the fracturing of the coarser gneiss tends to be wider and more continuous (Hansen and Simcox 1994). The isotropic structure of the Dry Hill Gneiss allows it to fracture anywhere and in any direction. The anisotropic structure of the schist, on the other hand, occurs along the foliation of the rock, limiting the pathways for water to travel.

3.1.3 | Surficial Geology

The surficial geology in this region is mostly thin glacial till, and has abundant outcropping and shallow bedrock (Mass GIS, Figure 12). Glacial till is a mixture of clay, silt, sand, gravel, and some larger rocks that were deposited directly by glacial ice. In much of Massachusetts, it's relatively thin (50ft thick or less) (Mass GIS, Figure 12). The stratified drift deposits are made up of the same ingredients, but are better sorted, have a higher hydraulic conductivity, and were also deposited during deglaciation by meltwater processes. From the well drillers reports (Appendix A), the till in the region of the study can be generalized as poorly sorted silty gravel. The till was deposited around 16,000 years ago, during deglaciation of New England (Ridge et al 2012).

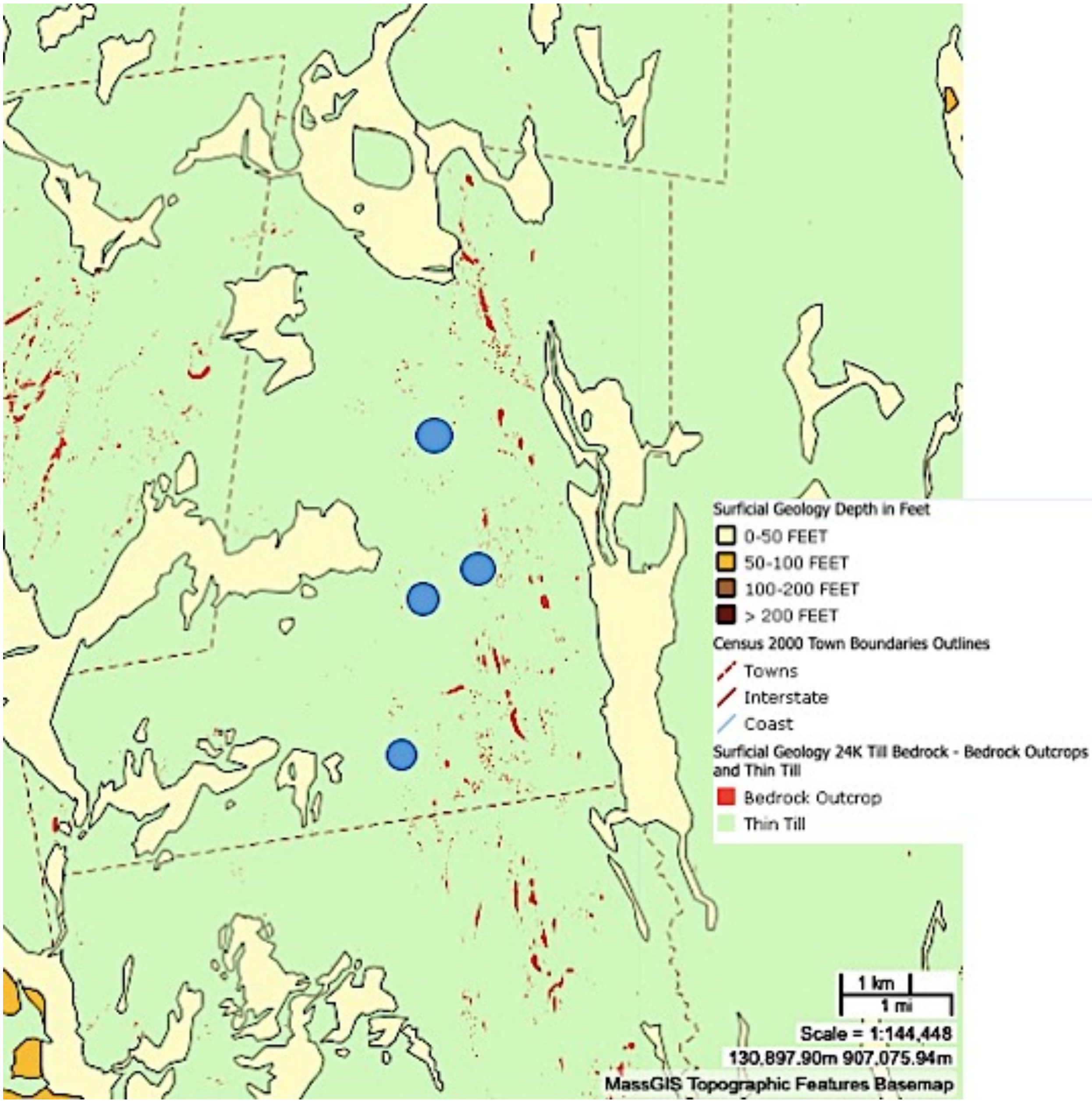

Figure 12: Surficial Geology. Map of the surficial geology in the town of Shutesbury. The wells in the groundwater study are marked by a blue circle (Mass GIS).

3.1.4 | Hydrology

In New England, groundwater is usually found fairly close to the surface of the land, up to about 50ft deep. It occurs in three major geologic units: glacial till, stratified-drift deposits, and bedrock (Mack 2009). Beneath the surficial deposits is the bedrock, consisting of crystalline igneous rocks and metamorphic rocks, like granitic gneiss (Mack 2009). Crystalline bedrock is not very permeable, so it is not considered to be a prolific source of groundwater. However, groundwater can be stored in glacial till, or in subhorizontal fractures in the bedrock (Simcox 1994).

Recharge of these aquifers comes in the form of rainfall and snowmelt. The groundwater that is stored in the glacial till and stratified-drift layers make up a large portion of the water that is available to the bedrock aquifer. The amount that enters the bedrock at any given place depends on the location of that point within the flow of the entire aquifer and the connectivity of the fractures within the bedrock (Mack 2009, Hansen and Simcox 1994). After spring rain and snowmelt, groundwater slowly discharges into streams throughout the summer, and accounts for a large percentage of the surface water flow during lower flow periods in the summers (Dudley et al, Hansen and Simcox 1994). The system is recharged by precipitation at the land surface and then discharges into streams, flowing from topographic high areas to low areas.

4 | MONITORING WELL LOCATIONS

The town of Shutesbury installed 8 wells drilled at 4 sites located along the ridgeline along a roughly N-S transect (Figure 13). Each of the sites has one monitoring well that was drilled to bedrock (between 4 and 26 feet), and one deep well that is 100ft deep (except at site 3 where the deep well reaches 300ft).

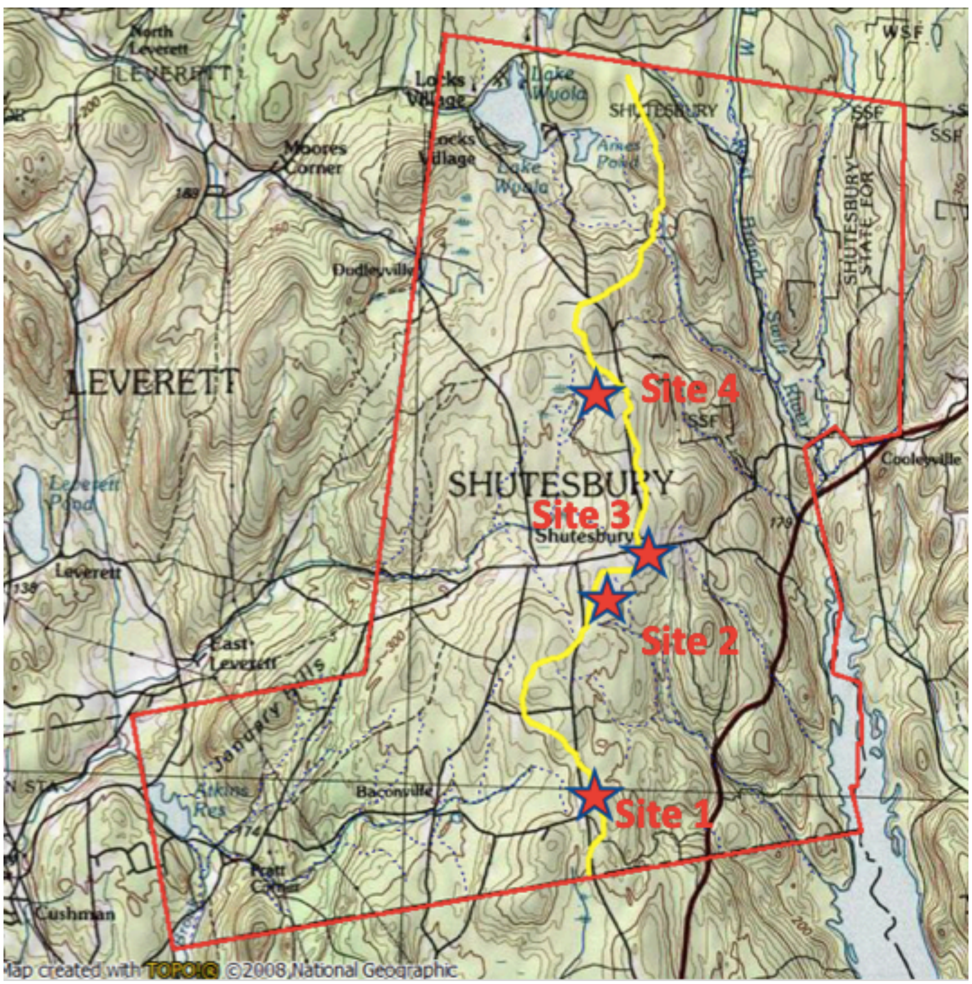

Figure 13: Well Locations. A map of the town of Shutesbury with the four wells marked by red stars. The ridgeline is indicated by a meandering yellow line.

4.1 | Site 1

Site 1 is located off of Pelham Hill Road in a level forested area (Figure 13). Drilling for the bedrock well was completed on 8/23/2014, and the monitoring well was completed on 8/22/2014. Water levels took two weeks to recover after the drilling (Al Werner, pers comm, 2019). The total depth of the bedrock well is 100ft, and the casing length is 40ft. The monitoring well was drilled 25ft deep to the top of the bedrock. The well lithology from 0-25ft is a gravel/silty clay mix, and from 25-100ft is a quartz/granite. No significant fractures were detected during the drilling process (Appendix A).

4.2 | Site 2

Site 2 is located near an old military navigation site that was once considered as a site for a library, and is home to a small cranberry bog (Figure 13). The area is level, partially forested, and frequently has a shallow amount of standing water on the surface. Drilling for both wells was completed on 8/21/2014. The total depth of the bedrock well is 100ft, and the casing length is 40ft. The monitoring well was drilled until hitting bedrock at a depth of 26ft. The well lithology is silty sands from 0-4ft, gravel from 4-26ft, weathered rock from 26-34ft, and granite from 34-100ft. Fractures were detected at depths of 44ft and 58ft during the drilling process (Appendix A).

4.3 | Site 3

Site 3 is located behind the Shutesbury Town Hall (Figure 13) in a grassy field, and both UMass Amherst and the USGS have monitored this well. Drilling for the bedrock well was completed on 8/27/2014, and the monitoring well was completed on

8/24/2014. The total depth of the bedrock well is 300ft, and the casing length is 30ft. The monitoring well was drilled until hitting bedrock at a depth of 13ft. The well lithology from 0-13ft is described as dry gravel, and granite from 13-300 ft. Significant fractures were detected at depths of 234, 260, 267, 269, 282, and 288ft during the drilling process (Appendix A).

4.4 | Site 4

Site 4 is located up a slight hill in a forested area behind the Shutesbury Athletic Club (Figure 13). Drilling for the bedrock well was completed on 8/25/2014, and the monitoring well was completed on 8/26/2014. The total depth of the bedrock well is 100ft, and the casing length is 20ft. The monitoring well was drilled until hitting bedrock at a depth of 4ft. The lithology from 0-4ft is described as dry gravel, and granite from 4-100ft. Fractures were detected at depths of 41, 61, and 94ft during the drilling process (Appendix A).

5 | METHODS

Water levels were measured in two ways during the study: seasonal manual measurements and high frequency measurements using automated data loggers. Manual measurements were collected to validate the logger data, whereas level loggers using a 15 min interval were used to record small and rapid changes in water level.

5.1 | Manual Water Level Measurements

A weighted measuring tape was used to measure from the top of the well casing to the top of the water and measurements were made to the nearest 1/10 of a foot. These data were recorded in a spread sheet for comparison to the water levels recorded by the water level loggers. This is supplementary data and is not discussed as part of this study.

5.2 | Level Logger Measurements

In order to collect water level data from the eight wells, HOBO Onset water level loggers (model U20L-01) with a range of 0 to 30ft were suspended by a thin stainless-steel cable from the top of the well casing to below the seasonal low water levels. These loggers function by recording the total pressure above the sensor, which includes both the weight of the water and the atmospheric pressure, and have a water level accuracy of 0.1%. The loggers were programmed to take recordings every 15 minutes, and their memory capacity required downloading every four months using Hoboware Pro. This program has an embedded barometric correction wizard that efficiently uses a separate barometric data file to correct for atmospheric pressure, affording absolute water level determinations. A dedicated baro-logger was used to monitor and record these atmospheric pressure changes from a station near the Town Hall in Shutesbury.

Well	Well Elevation (ft)	Casing Height (ft)	Cable Length (ft)	Water Logger Elevation (ft)
Site 1 MW	1208	1.74	4.23	1205.51
Site 1 DW	1208	1.25	29.1	1180.15
Site 2 MW	1183	2.36	19.78	1165.56
Site 2 DW	1183	2.02	19.95	1167.07
Site 3 MW	1188	2.23	14.57	1175.66
Site 3 DW	1188	1.67	69.8	1119.87
Site 4 MW	1190	1.57	19.9	1186.64
Site 4 DW	1190	3.07	29.1	1171.67
Water Logger Elevation = well elevation + casing height - cable length				
Water Table Elevation = water logger elevation + water level above logger				

Table 2: Elevation Corrections. The water logger elevation was determined by taking the well site elevation plus the well casing height, and subtracting the length of the cable that the logger hangs from. The water table elevation was calculated by adding the water level logger elevation and adding it to the recorded water level above the logger. The equations in the bottom of the table show this.

The format of the raw data was feet of water over the water level logger. Because this is impossible to contextualize with the other wells, the data were normalized by translating the relative water-level data to water elevation values. After discussion with professor Eugenio Marcano, a DEM (digital elevation model) was used to determine the elevation at each site. The casing height was added to the well elevation, and then the cable length was subtracted from that value to determine the elevation of the level logger (Table 2). This constant value was then added to the raw data in Microsoft Excel. In order to put the normalized data back into Hoboware Pro, it was saved as a text file.

Other data corrections were necessary in a handful of occasions in which data were missing, or barometric data were not available to correct the pressure reading. These intervals show up as data gaps in the time series. There were also intervals where there is an abrupt increase in water level between two points that has no weather or pressure related explanation. It appears that the logger had become stuck on a ledge in the well and eventually became dislodged and then fell to its full potential depth at the end of the cable, accounting for the abrupt change. In these instances, the difference between the two data points in question was calculated, and the difference was added to the lodged portion of the data to account for the change in elevation.

5.3 | Pumptest

On November 12, 2018, a pumptest was performed at sites 1, 2, and 4. A submersible pump was used for 30 minutes, or until the drawdown reached the limits of the sensor. The level loggers were set to record pressure changes at a 1 second interval, and then 1 minute intervals for the duration of the test. The wells were left to recover for 7 days, at which point they were collected and downloaded. For site 3, a drawdown event in September of 2017 was used. Using the slug test software in Aqtesolv, the recovery data was uploaded and processed. Curve matching was used to determine K-values for each well. The K-value is the hydraulic conductivity, or the flow rate of the aquifer. The program assumes that the entire well is porous, not that the water is coming from a few productive fractures, so the K-value is, in a sense, averaged over the entirety of the well-bore.

5.4 | Weather Data

With the help of a local resident, air temperature and precipitation recorded at 5 minute intervals for the span of the study were collected from a weather station located on West Pelham Rd. Daily snowfall data from the Quabbin Reservoir located just to the east of Shutesbury was kindly provided by the Department of Environmental Protection. Both sets of data were imported into Microsoft Excel files and then saved as text files and uploaded to Hoboware Pro.

6 | RESULTS

Data collection for this study began in early fall of 2014. Missing data is the result of either the well logger running out of battery or storage, or because of missing barometric data that prevented barometric correction. The monitoring well data at site 4 was used for barometric correction on occasions when there were no significant rainfall events.

6.1 | Climate Results

6.1.1 | Temperature

The maximum temperature for the duration of the study was 94.89F, and the minimum temperature was -17.60F. The average was 48.19F. Annual high temperatures for the duration of the study ranged between 89F and 95F, whereas the annual lows ranged from -17F to -6F. Between November of 2014 and April of 2015, there were 132 days where the temperature was below freezing. From November of 2015 to April of 2016, there were 137 days where the temperature was below freezing. From November of 2016 to April of 2017, there were 158 days where the temperature was below freezing. From November of 2017 to April of 2018, there were 160 days that were below freezing (Figure 14).

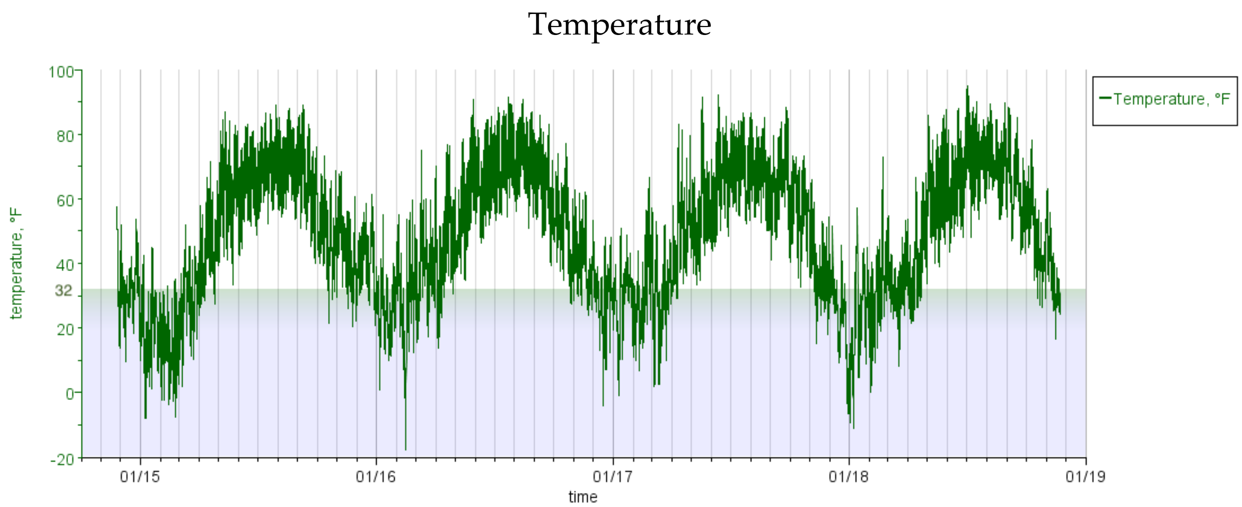

Figure 14: Temperature. Outdoor temperature in Fahrenheit from Sept. 2014 — Nov. 2018.

6.1.2 | Precipitation

The highest intensity of rainfall was a rate of 11in/hr in late August of 2016 (Figure 15). In general, the higher intensity (5in/hr) rainfall events occurred between May and October. The larger rainfall events happen in the summer and fall months when water levels in the wells are lowering (Figure 16). There is a lower volume of rain in the winter and fall. The amount of snow that fell in a 24-hour period was recorded at the Quabbin Reservoir between November and April. The snowfall coincides with the timing of below freezing temperatures, and peaks where the rainfall decreases (Figure 17).

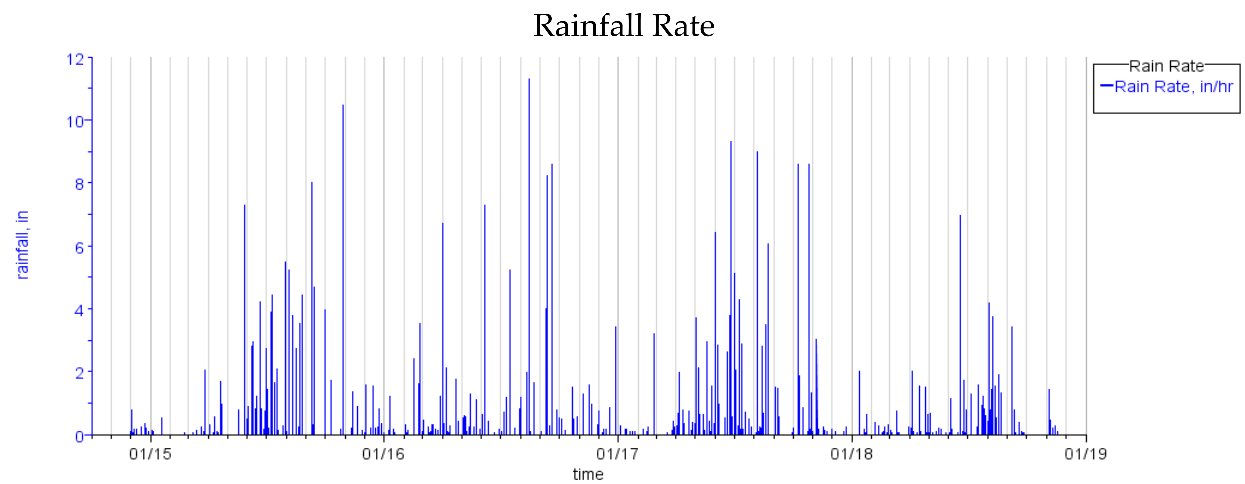

Figure 15: Rainfall Rate. Measured in inches per hour from Sept. 2014 — Nov. 2018.

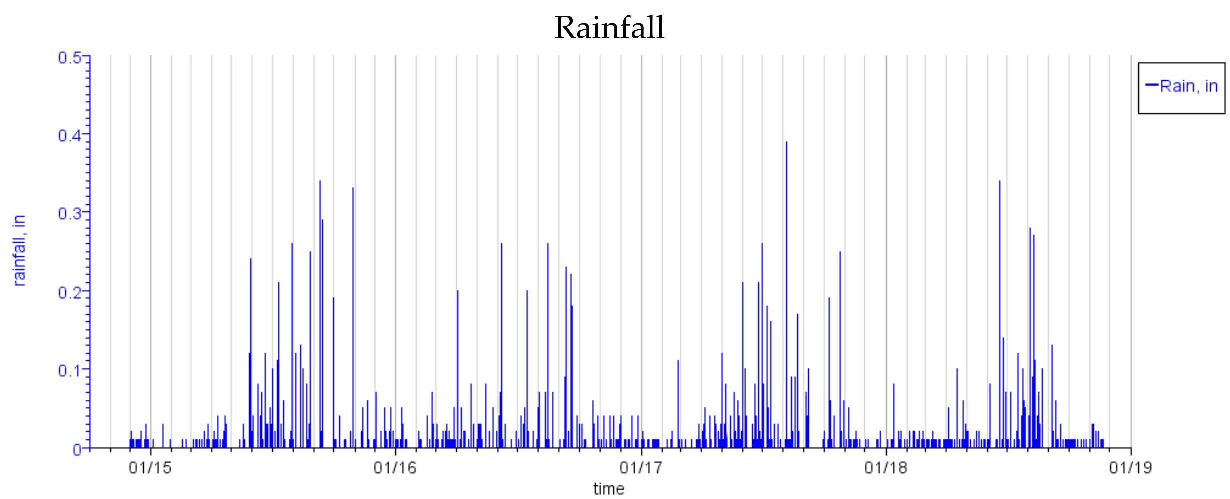

Figure 16: Rainfall. Amount of rain in a 5-minute interval from Sept. 2014 — Nov. 2018.

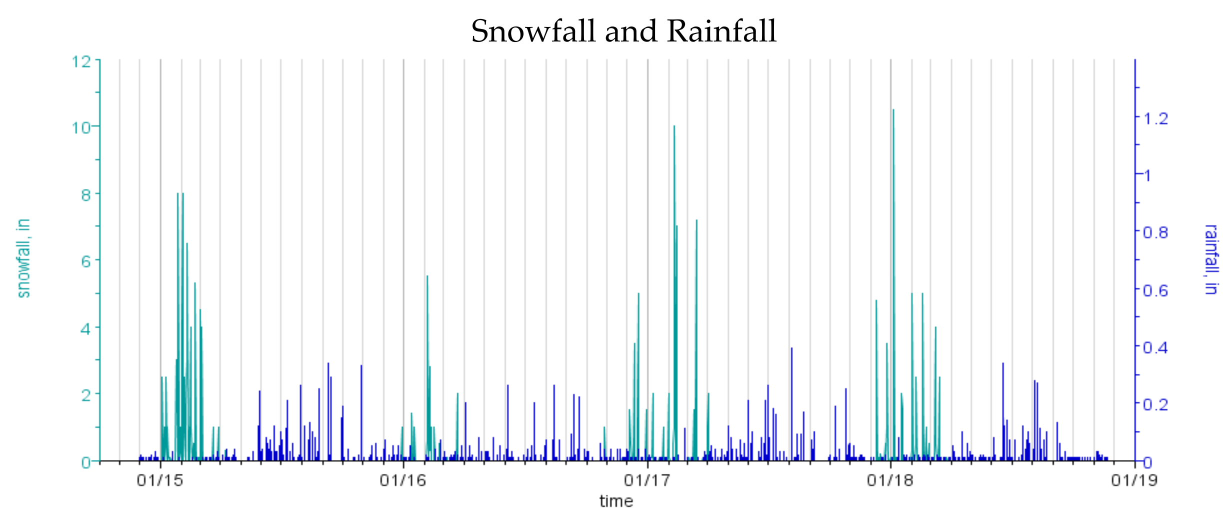

Figure 17: Snowfall and Rainfall. A composite graph of the snowfall (light blue) and rainfall (dark blue) data measured in inches from September 2014 through November 2018.

6.1.3 | Isolated Rainfall Event

An isolated rainfall event was selected to analyze the response of the monitoring and bedrock wells to direct precipitation. The rainfall events between October 24th, 2017 and November 1, 2017 are preceded by approximately 9 days of dry conditions (Figure 18). The first rainfall event in this sequence has the highest volume, with the other events appearing to be much less significant. This event is used to evaluate ground water level response to a discrete rain event (see Interpretations – below).

Specific Rainfall Event

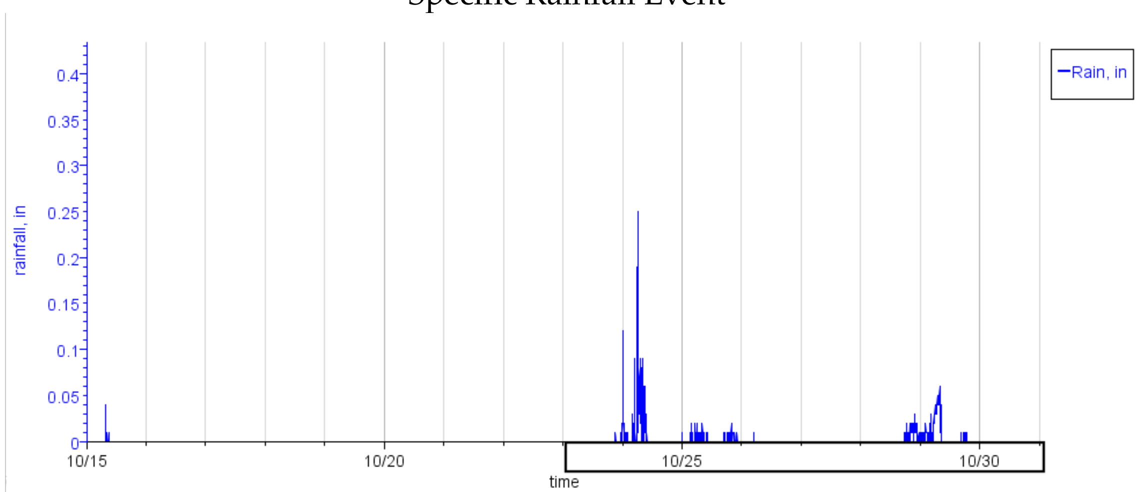

Figure 18: Specific Rainfall Event. A subset of the rainfall data from October 15 through November 1 of 2017.

6.2 | Water Level Results

6.2.1 | Comparison of Monitoring Wells

A composite graph of all four monitoring wells shows the respective elevations of their water levels in relation to each other (Figure 19). Site 1 is approximately 30 ft higher than the others, with site 4, 3, and 2 following respectively. Sites 4, 3, and 2 inhabit a range in elevation of approximately 1170ft to 1190ft. Sites 1, 2, and 3 have similar temporal patterns, maintaining a relatively consistent spacing between them, and site 4 displays changes in water level when the other three wells are at their highest levels. Site 4 is the shallowest, at only 4ft deep, and is frequently dry. This well only contained water during the highest peaks in water level throughout the duration of the study. The other sites have similar magnitude of seasonal fluctuations, with the greatest drop in water level occurring in 2016.

The higher water levels occur between January and June. Low levels occur September through December. In 2015, each of the wells experience a peak in December/January, fall to a lower level in March, and rise again in late April. These fluctuations happen on smaller scales in the following years. Recovery from the summer low levels begins around November. Water levels in 2018 don't have a distinct, singular low period, but rather consistently fluctuated in a much more limited range of variability than previous years (Figure 19).

Monitoring Well Composite Graph

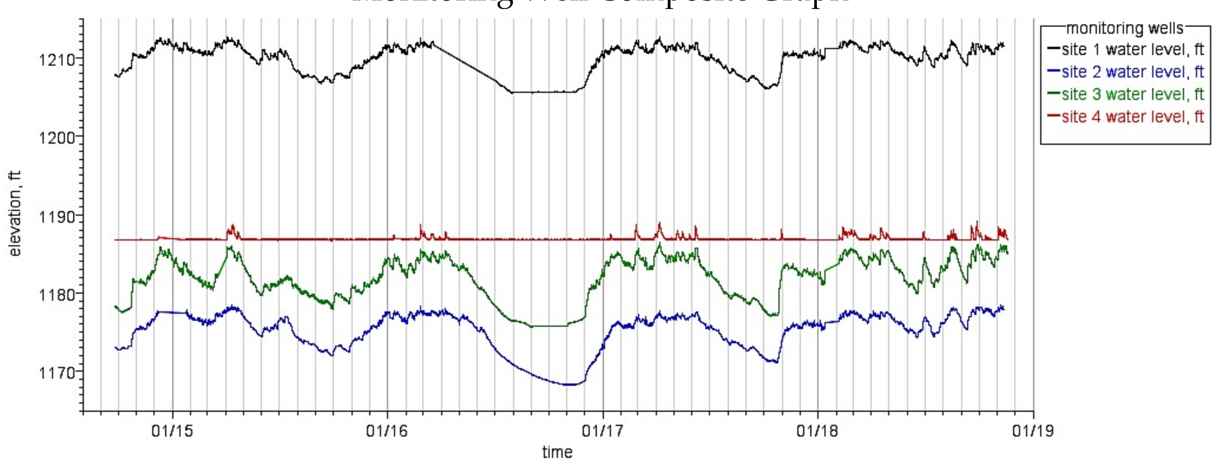

Figure 19: Monitoring Well Composite Graph. Site 1 is in black, site 2 is blue, site 3 is green, and site 4 is red.

6.2.2 | Comparison of Bedrock Wells

A composite graph of all four bedrock wells shows the respective elevations of their water levels in relation to each other (Figure 20). Site 3 is approximately 45ft lower than the other three wells. Site 4 is consistently at the highest elevation, while sites 1 and 2 are about the same. All four sites have similar temporal patterns, maintaining a relatively consistent spacing between them. Site 1 has the most stable water levels of the four. All four wells have a similar magnitude of seasonal fluctuations, with the greatest drop in water level occurring in 2016. Trends in high and low water levels throughout the seasons mirror those in the monitoring wells (Figure 20).

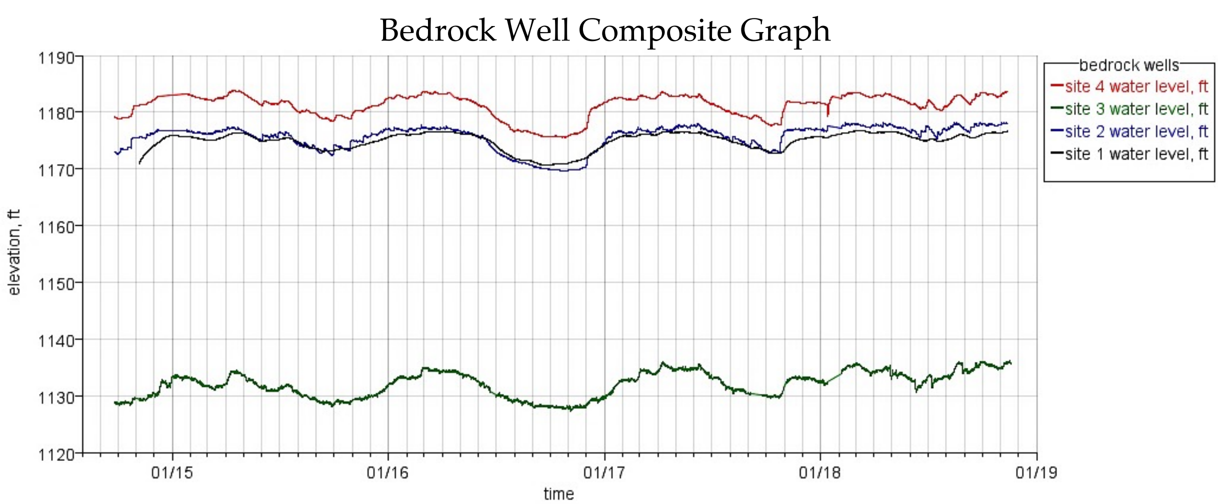

Figure 20: Bedrock Well Composite Graph. Site 1 is in black, site 2 is blue, site 3 is green, and site 4 is red.

<u>6.2.3 | Site 1</u>

A composite graph of the monitoring and bedrock wells at site 1 shows the 35ft difference in water table elevation between the two wells. There is a similar magnitude in water level fluctuation and temporal variations. The monitoring well is much more responsive to short term fluctuations, whereas the bedrock well is more stable (Figure 21).

Site 1 Monitoring and Bedrock Wells

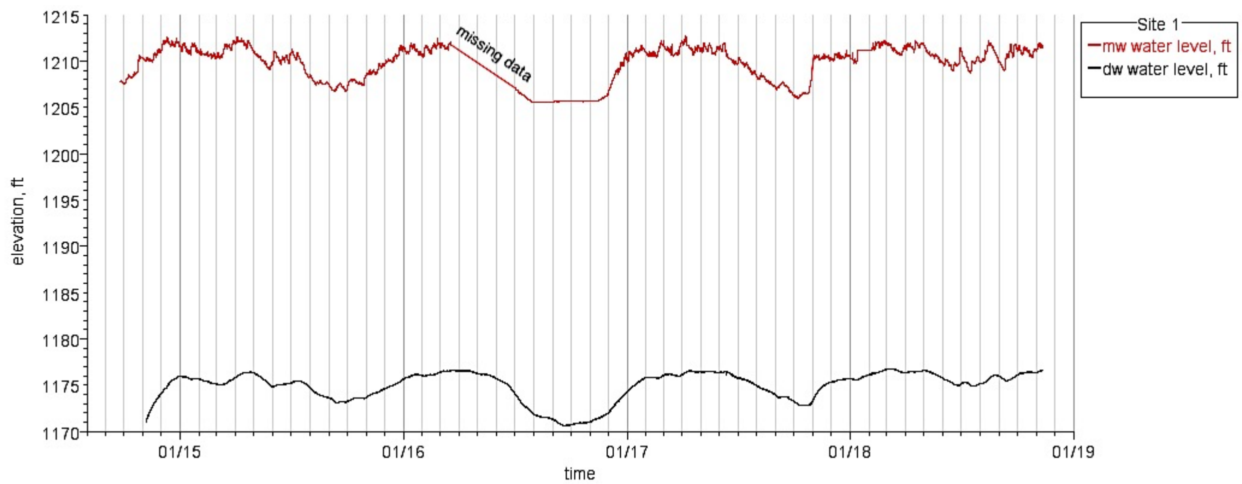

Figure 21: Site 1 Monitoring and Bedrock Wells. A composite graph of the water elevation from September of 2014 through November of 2018 from both the monitoring and bedrock wells at site 1. The monitoring well (mw) is in red, and the bedrock well (dw) is in black.

6.2.3.1 | Site 1 Bedrock Well

The annual maximum water levels of the bedrock well occurred during the late fall and early spring months, and the lows occurred in the late summer and early fall months (Table 3). The maximum water levels during the 5 years of study varied by 0.36ft, while the minimum water levels had a larger range of variability at 5.38ft. The highest difference between high and low water levels occurred in 2016, whereas 2018 had the smallest difference. The bedrock well at site 1 has the most stable water level in the study. Rainfall coincides with the downward slope of the seasonal fluctuations (Figure 22).

Table 3: Site 1 Bedrock Well			
year	maximum water level	minimum water level	**annual range**
2015	1,176.41	1,173.07	**3.34**
2016	1,176.60	1,170.58	**6.02**
2017	1,176.54	1,172.74	**3.80**
2018	1,176.77	1,175.96	**0.81**
full study	*1,176.77*	*1,170.58*	*6.19*
range	**0.36**	**5.38**	

Table 3: depicts the maximum and minimum water level values for each year as well as for the entire study for the bedrock well at site 1. The right column lists the range of water levels for that time period, and the bottom row shows the variability in maximum and minimum water levels in feet for the duration of the study.

Site 1 Bedrock Well and Rainfall

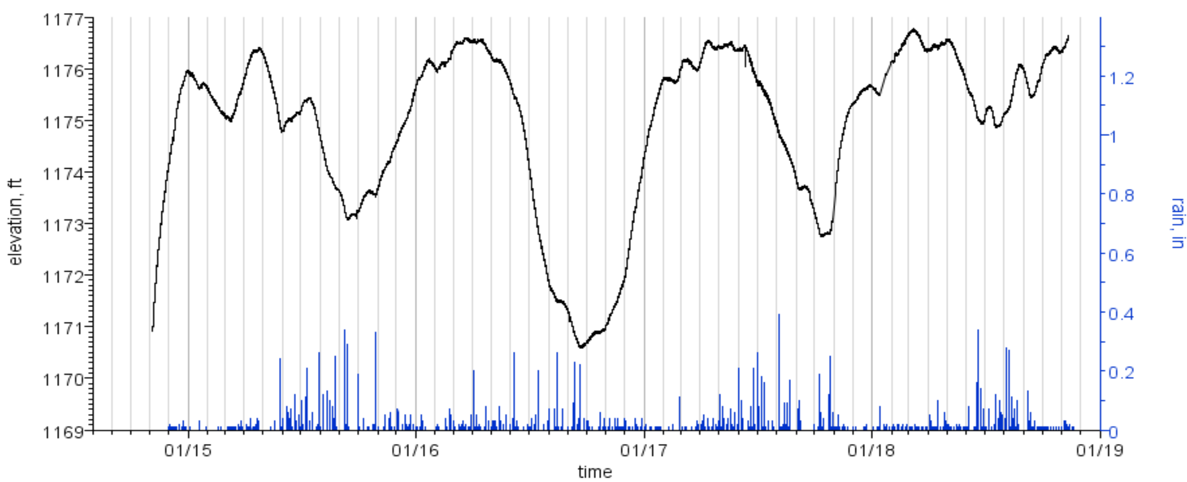

Figure 22: Site 1 Bedrock Well and Rainfall. Water level elevation from September of 2014 through November of 2018 of the bedrock well at site 1 along with the rainfall data shown previously. The well is in black and the rainfall is in blue.

6.2.3.2 | Site 1 Monitoring Well

The monitoring well is missing data from March through June of 2016 (Figure 23). The annual maximum water levels occurred during the late fall and early spring months, and the lows occurred in the late summer and early fall months (Table 4). The maximum water levels varied by 0.48ft, while the minimum water levels had a larger range of variability (3.19ft). 2016 had the highest difference between high and low water levels, while 2018 had the lowest difference. Rainfall coincides with the downward slope of the seasonal fluctuations (Figure 23). The lowest water level for this monitoring well is unknown because the water level was below the data logger for a three-month period from August through mid-November, as indicated by the relatively flat line. This occurred during a period of drought in the region.

Table 4: Site 1 Monitoring Well			
year	maximum water level	minimum water level	**annual range**
2015	1,212.65	1,206.78	**5.87**
2016	1,212.47	1,205.51	**6.96**
2017	1,212.66	1,205.97	**6.69**
2018	1,212.18	1,208.70	**3.48**
full study	*1,212.66*	*1,205.51*	*7.15*
range	**0.48**	**3.19**	

Table 4: depicts the maximum and minimum water level values for each year as well as for the entire study for the monitoring well at site 1. The right column lists the range of water levels for that time period, and the bottom row shows the variability in maximum and minimum water levels in feet for the duration of the study.

Site 1 Monitoring Well and Rainfall

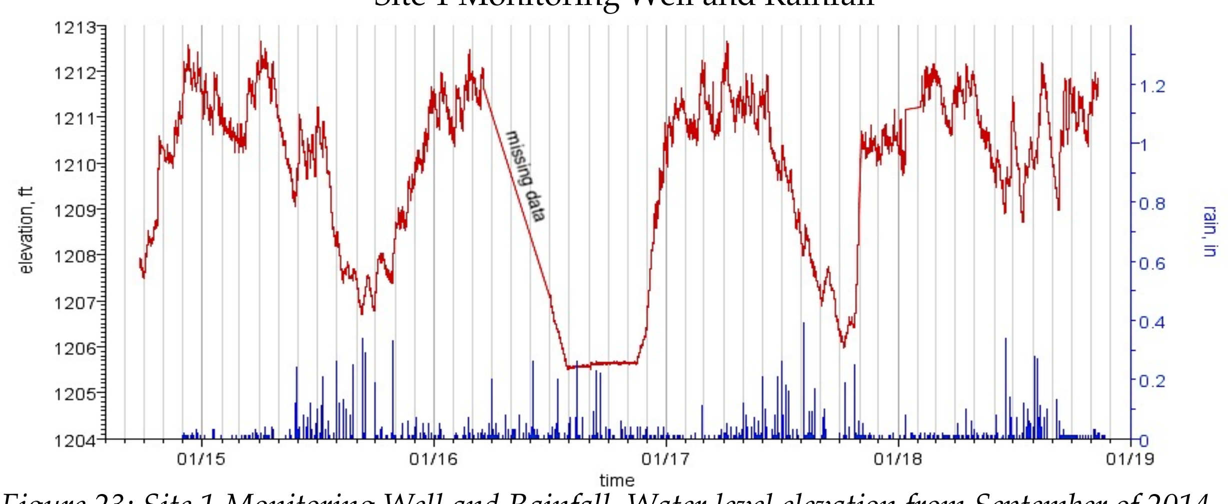

Figure 23: Site 1 Monitoring Well and Rainfall. Water level elevation from September of 2014 through November of 2018 of the monitoring well at site 1 along with the rainfall data shown previously. There is a period of missing data from March through June of 2016 that is labeled on the graph, and a 30-day period of missing data in February of 2018. The well is in red and the rainfall is in blue.

6.2.4 | Site 2

A composite graph of the monitoring and bedrock wells at site 2 shows that the water levels for these two wells are very similar. While the monitoring well is usually at a lower water level than the deep well, they frequently overlap (Figure 24). There is a similar magnitude in water level fluctuation and similar temporal variations. Both wells are missing data from mid-December of 2014 through January of 2015 and again in February of 2018.

Site 2 Monitoring and Bedrock Wells

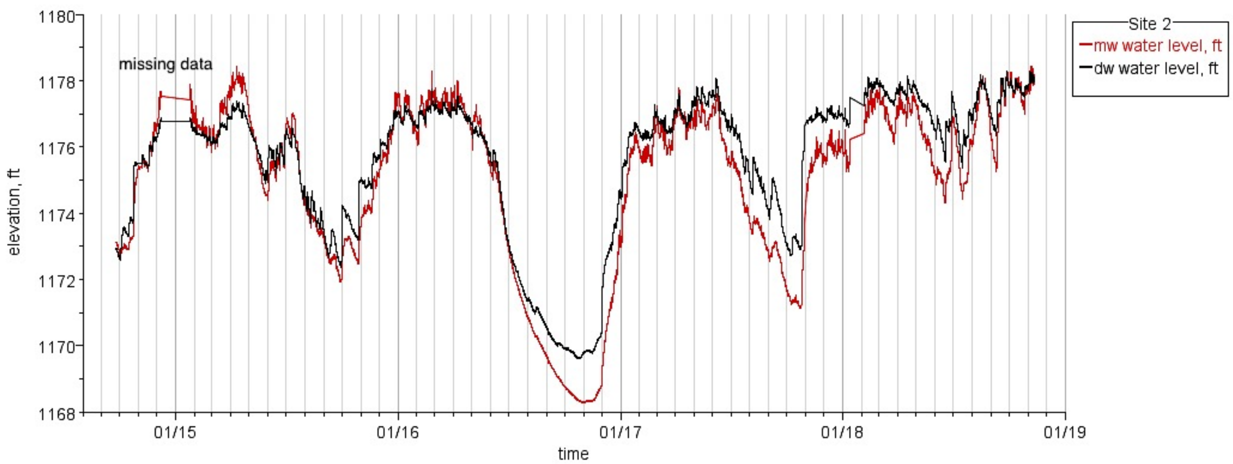

Figure 24: Site 2 Monitoring and Bedrock Wells. A composite graph of the water elevation from September of 2014 through November of 2018 from both the monitoring and bedrock wells at site 2. The monitoring well (mw) is in red, and the bedrock well (dw) is in black.

6.2.4.1 | Site 2 Bedrock Well

The annual maximum water levels in the bedrock well at site 2 occurred during the late fall and early spring months, and the lows occurred in the late summer and early fall months (Table 5). The maximum water levels varied by 0.92ft, while the minimum water levels had a larger range of variability at 5.73ft. The highest difference between high and low water levels occurred in 2016, while 2018 had the lowest difference. Rainfall coincides with the downward slope of the seasonal fluctuations (Figure 25).

Table 5: Site 2 Bedrock Well			
time	maximum water level	minimum water level	**annual range**
2015	1,177.37	1,172.37	**5.00**
2016	1,177.73	1,169.61	**8.12**
2017	1,178.07	1,172.71	**5.36**
2018	1,178.29	1,175.34	**2.95**
full study	*1,178.29*	*1,169.21*	*9.08*
range	**0.92**	**5.73**	

Table 5: depicts the maximum and minimum water level values for each year as well as for the entire study for the bedrock well at site 2. The right column lists the range of water levels for that time period, and the bottom row shows the variability in maximum and minimum water levels in feet for the duration of the study.

Site 2 Bedrock Well and Rainfall

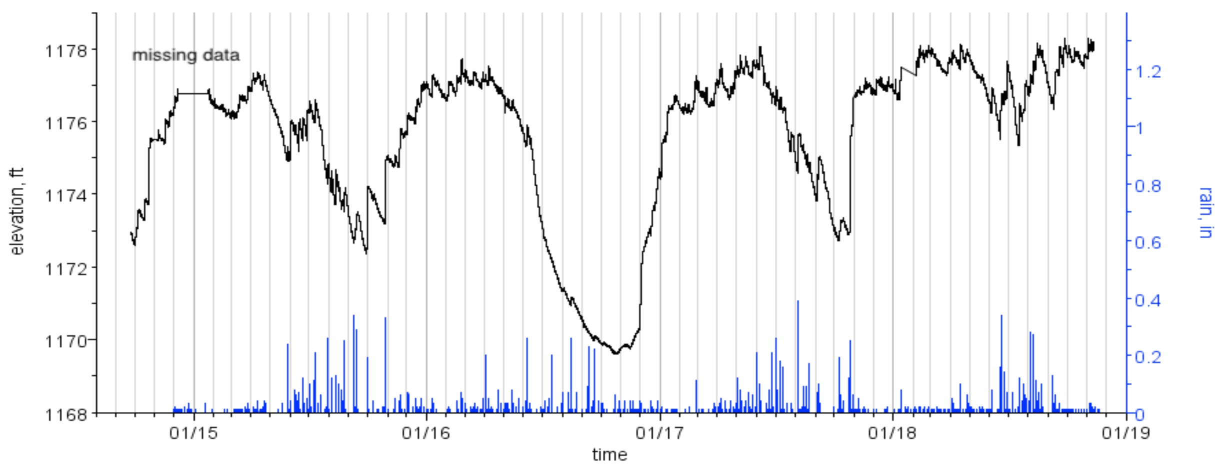

Figure 25: Site 2 Bedrock Well and Rainfall. Water level elevation from September of 2014 through November of 2018 of the bedrock well at site 2 along with the rainfall data shown previously. There is a period of missing data in early 2015 that is labeled on the graph, and a period of missing data in February of 2018. The well is in black and the rainfall is in blue.

6.2.4.2 | Site 2 Monitoring Well

The annual maximum water levels at the monitoring well occurred during the late fall and early spring months, and the lows occurred in the late summer and early fall months (Table 6). The maximum water levels varied by 0.66ft, while the minimum water levels had a larger range of variability at 6.02ft. The highest difference between high and low water levels was in 2016, while 2018 had the lowest difference. Rainfall coincides with the downward slope of the seasonal fluctuations (Figure 26).

Table 6: Site 2 Monitoring Well

time	maximum water level	minimum water level	**annual range**
2015	1,178.42	1,171.93	**6.49**
2016	1,178.28	1,168.27	**10.01**
2017	1,177.76	1,171.12	**6.64**
2018	1,178.42	1,174.29	**4.13**
full study	*1,178.42*	*1,168.27*	*10.15*
range	**0.66**	**6.02**	

Table 6: depicts the maximum and minimum water level values for each year as well as for the entire study for the monitoring well at site 2. The right column lists the range of water levels for that time period, and the bottom row shows the variability in maximum and minimum water levels in feet for the duration of the study.

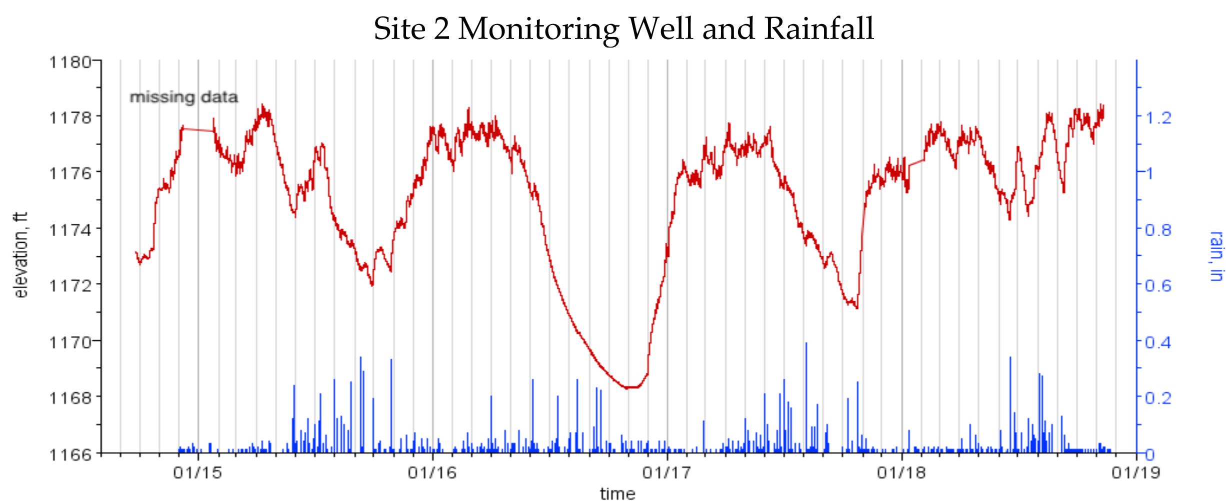

Figure 26: Site 2 Monitoring Well and Rainfall. Water level elevation from September of 2014 through November of 2018 of the monitoring well at site 2 along with the rainfall data shown previously. There is a period of missing data in early 2015 that is labeled on the graph, and a period of missing data in February of 2018. The well is in red and the rainfall is in blue.

6.2.5 | Site 3

A composite graph of the monitoring and bedrock wells at site 3 shows 50ft difference in water levels between the two wells (Figure 27). There is a similar magnitude in water level fluctuation and similar temporal variations. Both wells are missing data in February of 2018.

Site 3 Monitoring and Bedrock Wells

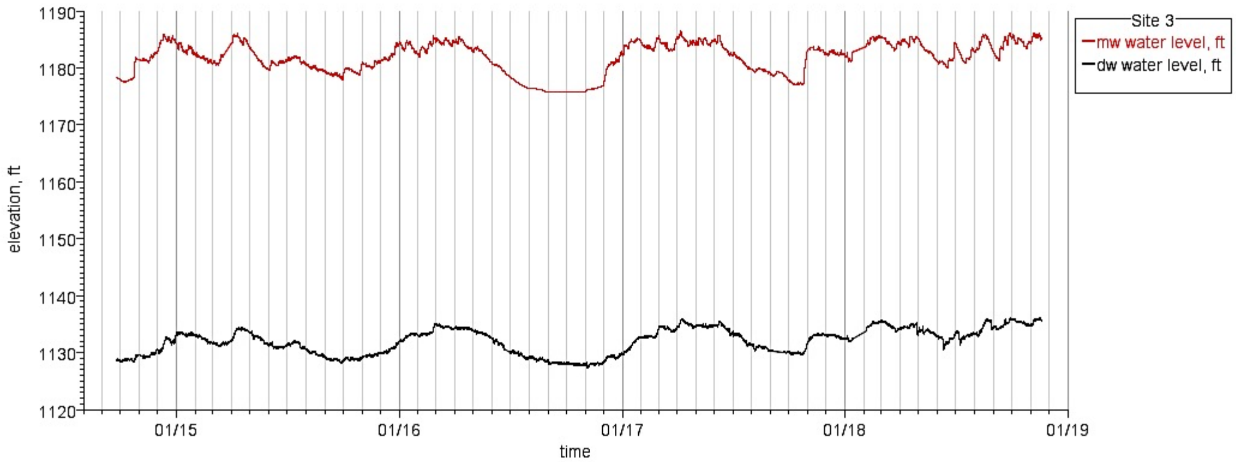

Figure 27: Site 3 Monitoring and Bedrock Wells. A composite graph of the water elevation from September of 2014 through November of 2018 from both the monitoring and bedrock wells at site 3. The monitoring *well (mw) is in red, and the bedrock well (dw) is in black.*

6.2.5.1 | Site 3 Bedrock Well

The annual maximum water levels in the bedrock well occurred during the late fall and early spring months, and the lows occurred in the late summer and early fall months (Table 7). The maximum water levels varied by 1.7ft, while the minimum water levels had a larger range of variability at 3.19ft. 2016 had the highest difference between high and low water levels, while 2018 had the lowest difference. The bedrock well at site 3 shows consistent daily fluctuations that may be attributed to tidal influences, which could easily be the subject of its own study. Rainfall coincides with the downward slope of the seasonal fluctuations (Figure 28).

Table 7: Site 3 Bedrock Well			
time	maximum water level	minimum water level	**annual range**
2015	1,134.43	1,128.05	**6.38**
2016	1,135.04	1,127.30	**7.74**
2017	1,135.90	1,129.55	**6.35**
2018	1,136.13	1,130.49	**5.64**
full study	*1,136.07*	*1,127.30*	*8.77*
range	**1.70**	**3.19**	

Table 7: depicts the maximum and minimum water level values for each year as well as for the entire study for the bedrock well at site 3. The right column lists the range of water levels for that time period, and the bottom row shows the variability in maximum and minimum water levels for the duration of the study.

Site 3 Bedrock Well and Rainfall

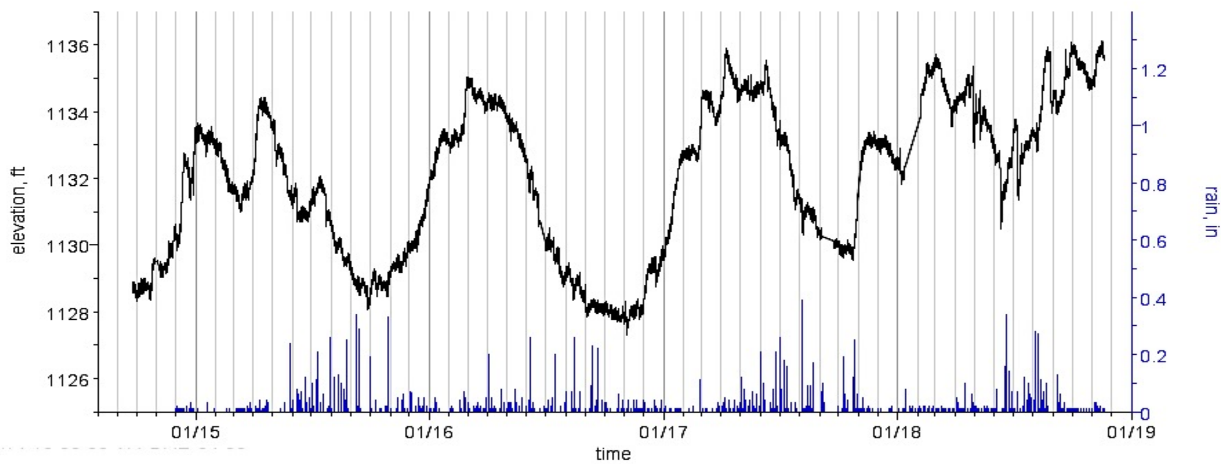

Figure 28: Site 3 Bedrock Well and Rainfall. Water level elevation from September of 2014 through November of 2018 of the bedrock well at site 3 along with the rainfall data shown previously. There is a period of missing data in February of 2018 that isn't labeled as it is quite brief. The well is in black and the rainfall is in blue.

6.2.5.2 | Site 3 Monitoring Well

The annual maximum water levels at the monitoring well occurred during the late fall and early spring months, and the lows occurred in the late summer and early fall months (Table 8). The maximum water levels varied by 0.86ft, while the minimum water levels had a larger range of variability at 4.23ft. 2016 had the highest difference between high and low water levels, while 2018 had the lowest difference. Water levels dropped below the level logger in the late summer of 2016, as depicted by the flat line at the lowest point on the graph (Figure 29).

Table 8: Site 3 Monitoring Well			
time	maximum water level	minimum water level	**annual range**
2015	1,186.04	1,177.86	**8.18**
2016	1,185.59	1,175.67	**9.92**
2017	1,186.45	1,177.02	**9.43**
2018	1,186.15	1,179.90	**6.25**
full study	*1,186.45*	*1,175.67*	*10.78*
range	**0.86**	**4.23**	

Table 8: depicts the maximum and minimum water level values for each year as well as for the entire study for the monitoring well at site 3. The right column lists the range of water levels for that time period, and the bottom row shows the variability in maximum and minimum water levels for the duration of the study.

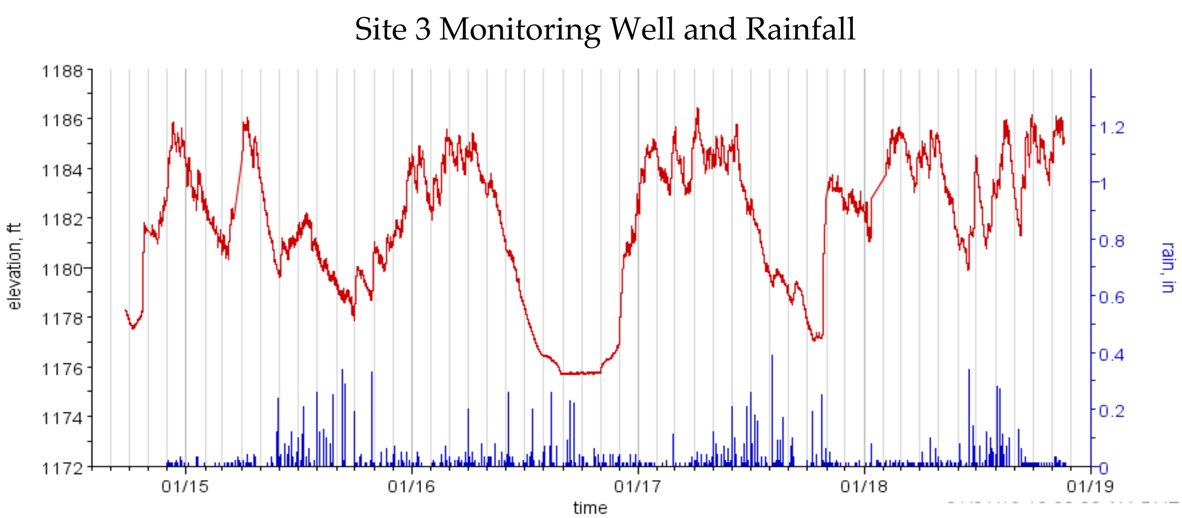

Figure 29: Site 3 Monitoring Well and Rainfall. Water level elevation from September of 2014 through November of 2018 of the monitoring well at site 3 along with the rainfall data shown previously. There is a period of missing data in February of 2018. The well is in red and the rainfall is in blue.

<u>6.2.6 | Site 4</u>

A composite graph of the monitoring and bedrock wells at site 3 shows 50ft difference in water levels between the two wells (Figure 30). There is a similar magnitude in water level fluctuation and similar temporal variations. Both wells are missing data in early 2015 and again in February of 2018. The monitoring well is missing data from late-September and early-October of 2017. There are large fluctuations in the relationship between the water levels in the monitoring and deep wells at this site. The monitoring well is dry for the majority of the duration of the study.

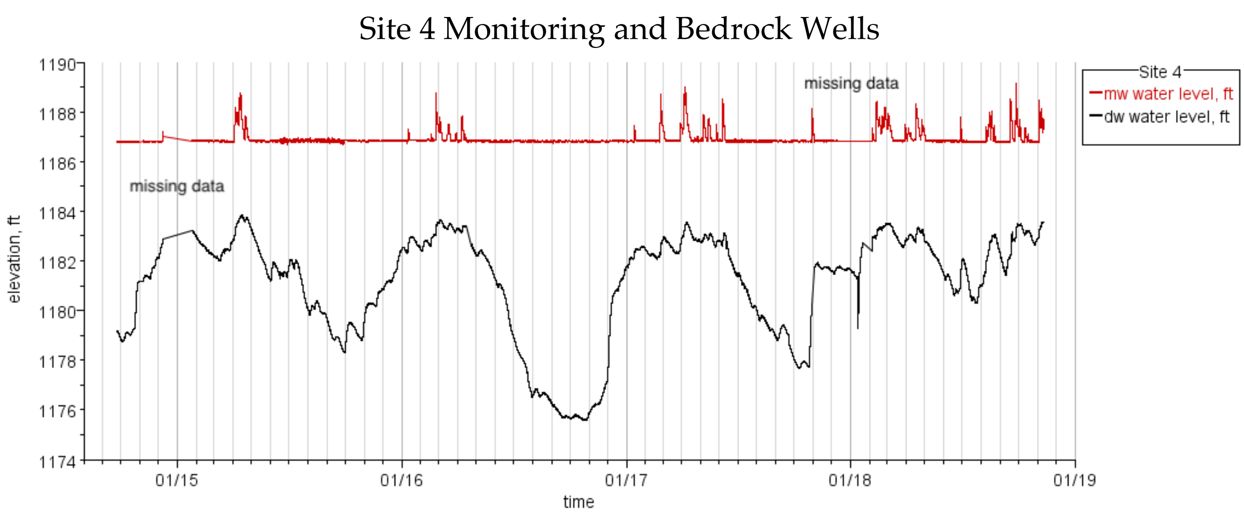

Figure 30: Site 4 Monitoring and Bedrock Wells. A composite graph of the water elevation from September of 2014 through November of 2018 from both the monitoring and bedrock wells at site 4. The monitoring well (mw) is in red, and the bedrock well (dw) is in black.

6.2.6.1 | Site 4 Bedrock Well

The annual maximum water levels in the bedrock well occurred during the late fall and early spring months, and the lows occurred in the late summer and early fall months (Table 9). The maximum water levels varied by 0.27ft, while the minimum water levels had a larger range of variability at 3.73ft. 2016 had the highest difference between high and low water levels, while 2018 had the lowest difference. In mid-January, there is a drop in water level in the bedrock well that is the result of a UMass class using the well for a pumptest. Rainfall coincides with the downward slope of the seasonal fluctuations (Figure 31).

Table 9: Site 4 Bedrock Well

time	maximum water level	minimum water level	**annual range**
2015	1,183.84	1,178.30	**5.54**
2016	1,183.64	1,175.57	**8.07**
2017	1,183.57	1,177.65	**5.92**
2018	1,183.58	1,179.30	**4.28**
full study	*1,183.84*	*1,175.57*	*8.27*
range	**0.27**	**3.73**	

Table 9: depicts the maximum and minimum water level values for each year as well as for the entire study for the bedrock well at site 4. The right column lists the range of water levels for that time period, and the bottom row shows the variability in maximum and minimum water levels for the duration of the study.

Site 4 Bedrock Well and Rainfall

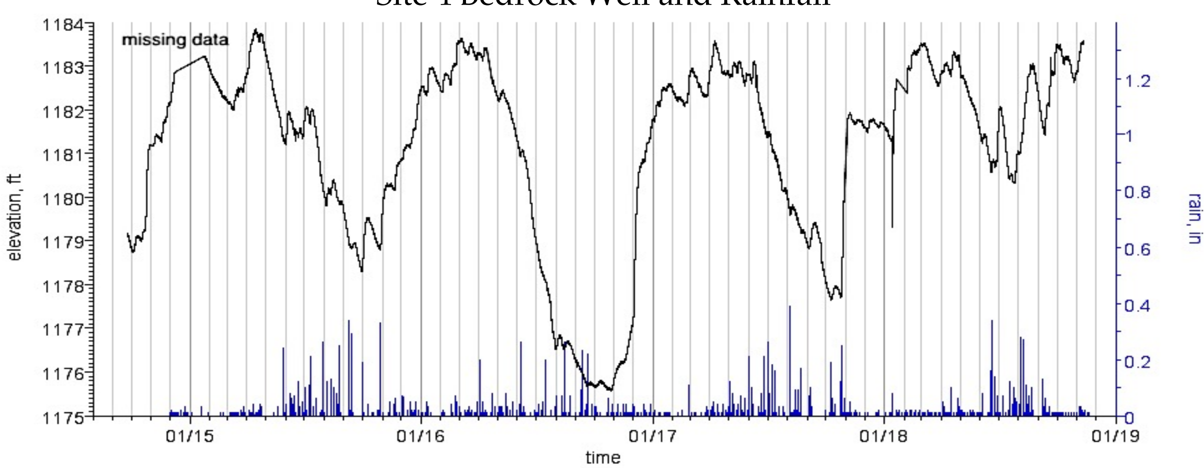

Figure 31: Site 4 Bedrock Well and Rainfall. Water level elevation from September of 2014 through November of 2018 of the bedrock well at site 4 along with the rainfall data shown previously. There is a period of missing data in early 2015 that is labeled. The well is in black and the rainfall is in blue.

6.2.6.2 | Site 4 Monitoring Well

The monitoring well at site 4 is frequently dry (Figure 32). The annual maximum water levels occurred during the late fall and early spring months, and the dry periods occurred in the late summer and early fall months (Table 8). The maximum water levels varied by 0.41ft, while the minimum water levels had a smaller range of variability at 0.11ft. The well had water in it during the late fall and early spring months. This well has the most occurrences with missing or oddly corrected data, with data missing in early 2015 and in February of 2018.

Table 10: Site 4 Monitoring Well

time	maximum water level	minimum water level	**annual range**
2015	1188.78	1,186.66	**2.12**
2016	1,188.76	1,186.73	**2.03**
2017	1,189.02	1,186.75	**2.27**
2018	1,189.17	1,186.77	**2.40**
full study	*1,189.17*	*1,186.66*	2.51
range	**0.41**	**0.11**	

Table 10: depicts the maximum and minimum water level values for each year as well as for the entire study for the monitoring well at site 4. The right column lists the range of water levels for that time period, and the bottom row shows the variability in maximum and minimum water levels for the duration of the study.

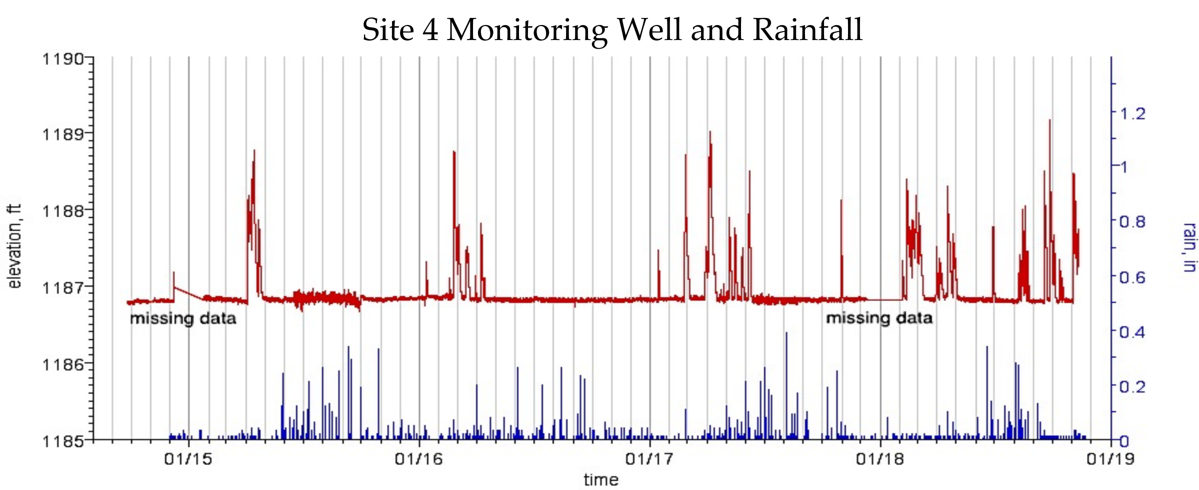

Figure 32: Site 4 Monitoring Well and Rainfall. Water level elevation from September of 2014 through November of 2018 of the monitoring well at site 4 along with the rainfall data shown previously. There is a period of missing data in early 2015 that is labeled, as is missing data in February of 2018. The well is in red and the rainfall is in blue.

6.3 | Pumptest and Blowtest Results

6.3.1 | Site 1

The pumptest and subsequent Aqtesolv analysis resulted in a K value of 0.00006132m/day. This very low flow rate coincides with the well drillers blow test that resulted in 0gpm of water (Appendix A).

6.3.2 | Site 2

The pumptest and subsequent Aqtesolv analysis resulted in a K value of 0.02008m/day, and is the highest rate of the four wells. This flow rate coincides with the well drillers blow test that resulted in 4gpm of water (Appendix A).

6.3.3 | Site 3

The pumptest and subsequent Aqtesolv analysis resulted in a K value of 0.00006032m/day. This very low flow contradicts the well drillers blow test that resulted in 2.25gpm of water (Appendix A).

6.3.4 | Site 4

The pumptest and subsequent Aqtesolv analysis resulted in a K value of 0.0004667m/day. This low flow rate coincides with the well drillers blow test that resulted in 0.25gpm of water (Appendix A).

7 | INTERPRETATION AND DISCUSSION

7.1 | Site 1

The bedrock well at site 1 is likely located in the pelitic schist (Figure 9, 10, 11), which is thought to have a lower permeability than the granitic gneiss that the other wells are located in. The low K value, blow test yield of 0gpm, and lack of significant fractures found during the drilling process support this theory. The well could also simply be isolated from any prolific fracture zones. The deep well at site 1 has the most stable water level response, suggesting that the bedrock aquifer at that location isn't very responsive to precipitation events. The monitoring well is similar to the other monitoring wells in the study, with many smaller fluctuations throughout the larger trends of the water level changes. The monitoring well at this site had the highest water level elevation in relation to the other wells (Figure 19), whereas the bedrock well water level was a similar elevation to the majority of the other bedrock wells (Figure 20). Both had comparable ranges in fluctuations to the other wells, and their highs and lows occurred at similar times. In comparison to each other, their overall response to seasonal water level fluctuations were generally similar in magnitude (Figure 21).

After the rainfall events that occurred between 10/24/2017 and 11/1/2017, the water level in the monitoring well began to rise in the midst of the initial rainfall event, and rose 3ft by the end of the period (Figure 33). The bedrock well rose by <0.5ft during the same period (Figure 34), indicating that the monitoring well is much more responsive. The bedrock well has a barely perceptible change in water level of <0.5ft to four cumulative rainfall events, whereas the monitoring well experiences a 3ft increase in water level. While the change is gradual over a period of a week, there is no lag in initial response in the monitoring well. The change in water level in the bedrock well is so small that it is difficult to visualize when it begins. This further suggests a lack of responsiveness of the bedrock aquifer at this location, as well as a lack of direct communication between the surficial and bedrock aquifers.

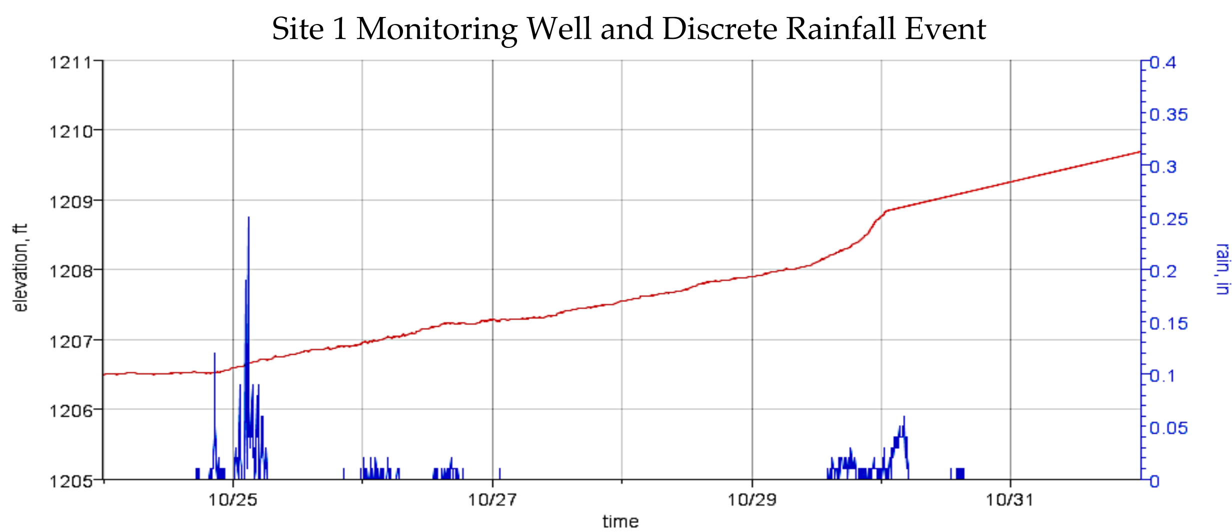

Figure 33: Site 1 Monitoring Well and Discrete Rainfall Event between 10/24/17 and 11/01/17. Water level is measured in ft on the left x-axis at a 6ft scale. Rainfall is measured in inches on the right x-axis.

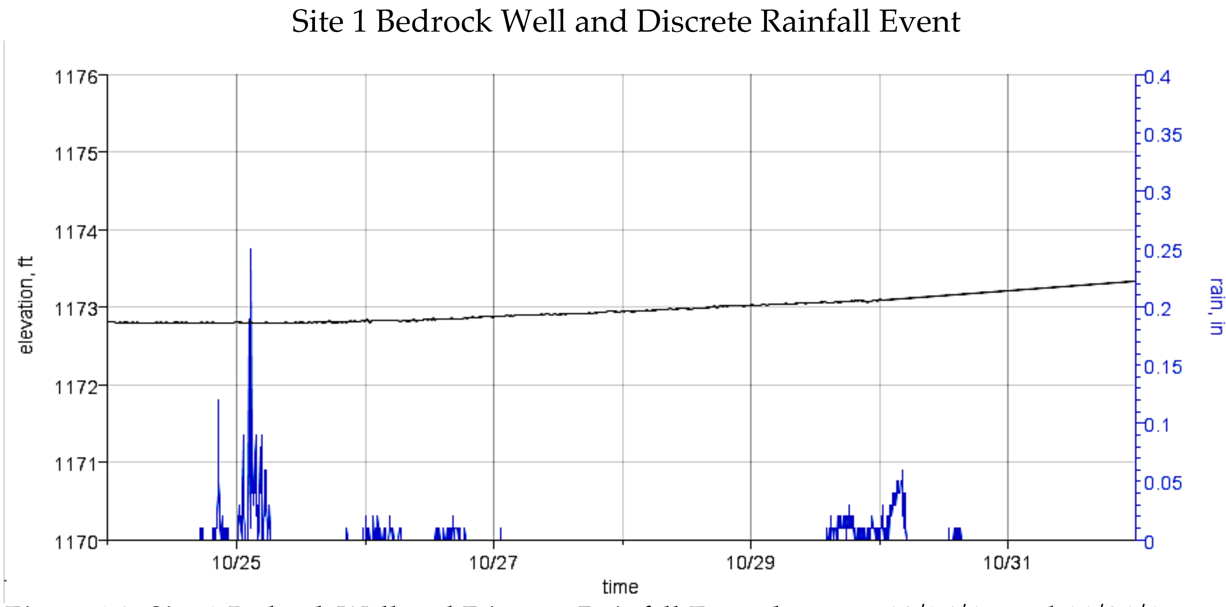

Figure 34: Site 1 Bedrock Well and Discrete Rainfall Event between 10/24/17 and 11/01/17. Water level is measured in ft on the left x-axis at a 6ft scale. Rainfall is measured in inches on the right x-axis.

7.2 | Site 2

The wells in site 2 are located in the Dry Hill Gneiss (Figure 9, 10, 11). This location is unique because it is located in a cranberry bog that frequently has shallow standing water, suggesting that the ground is frequently saturated. The composite graph of the two wells is unique in comparison with the other three sites because they frequently overlap, and the monitoring well is not at a consistently higher elevation like it is at the other sites. This suggests that the bedrock aquifer may in fact be recharging the glacial aquifer on some occasions.

The monitoring well had the lowest elevation of all the monitoring wells, but it still followed the trends of the other monitoring wells and had many smaller fluctuations throughout the larger trends of the water level changes (Figure 19). The bedrock well had a similar water level elevation to the majority of the other bedrock wells, and had the same seasonal trends as well (Figure 20). Both had comparable ranges in water level fluctuations to the other wells, and their highs and lows occurred at similar times. In comparison to each other, their overall response to water level fluctuations were generally similar in magnitude (Figure 24).

Both the monitoring and bedrock wells responded similarly to the precipitation events between 10/24/2017 and 11/01/2017 (Figure 35). The water level of the bedrock well rose sharply by 1.5ft within 8 hours of the initial rainfall event, and the monitoring well rose by .5ft in the same period. Both wells were similarly responsive to the smaller 10/29/2017 rainfall event, and rose by approximately 3ft by the end of the monitoring period. While the magnitude of change may not be as large as it was in some of the other sites, the immediacy and steepness of the increase suggests that this portion of the aquifer is more responsive to precipitation events than the other locations and that there is a significant amount of communication between the surficial and bedrock aquifers, perhaps due to the water table being so near the surface at that location. This well is also more prolific than some of the other locations, as the initial blow test produced 4gpm, and two significant fractures were noted during drilling. This is further enforced by the hydraulic conductivity of 0.02008m/day. These wells are highly connected.

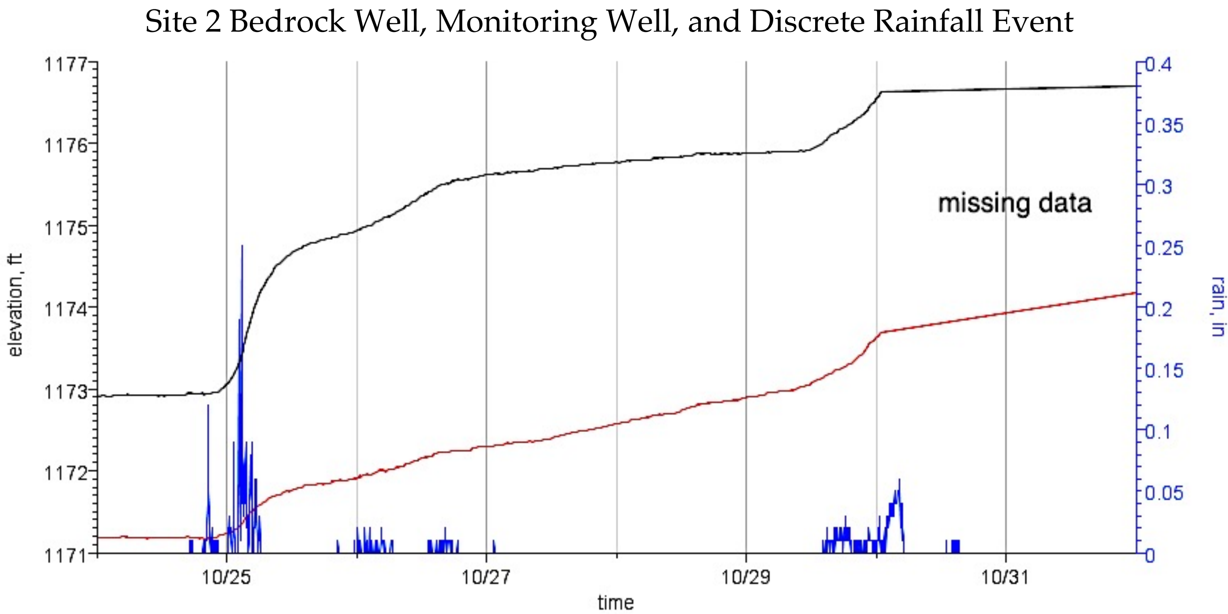

Figure 35: Site 2 Bedrock Well, Monitoring Well, and Discrete Rainfall Event. The bedrock well is in black, the monitoring wel isl in red, and rainfall between 10/24/17 and 11/01/17. Water level is measured in feet on the left x-axis at a 6ft scale. Rainfall is measured in inches on the right x-axis. There is data missing starting on 10/30/2017.

7.3 | Site 3

The wells at site 3 are located in the Dry Hill Gneiss (Figure 9, 10, 11). The bedrock well at this site is 300ft deep, while the other bedrock wells were only drilled to 100ft. The water level elevation of the bedrock well is approximately 50ft lower than the monitoring well, which is the largest difference between monitoring and bedrock wells in the study. The distance between water levels in the monitoring and bedrock wells suggests a lack of connection between the surficial and bedrock aquifers. The elevation of the water table of the bedrock well is significantly lower than the other three bedrock wells, which could be due to development in the town center area. Both the monitoring and bedrock wells follow the same seasonal fluctuations as the other sites (Figure 19, Figure 20). The monitoring well has a larger range of response than the bedrock well does.

The monitoring well doesn't begin to respond to the initial rainfall event until approximately 8 hours after the start of the event. By the end of the 10/24/2017 to 11/01/2017 monitoring period, the water level of the monitoring well rises by 5.5ft (Figure 36). Throughout the entire period, the bedrock well rises by almost 2ft (Figure 37). Unlike with the monitoring well, however, there is no immediacy to the response. The water level in the bedrock well is already on a generally upward trend before the precipitation event even occurs, so it is hard to say if the continued rise in water level is in response to these events or is simply a continuation of that upward trend.

The blow test of the bedrock well yielded 2.25gpm, which suggests that the well isn't the least productive of the four, but the pumptest yielded the lowest K-value of 0.00006032m/day, suggesting that it has the lowest hydraulic conductivity. The reason for this contradiction is likely a programming issue in Aqtesolv. The program distributes hydraulic conductivity evenly over the entirety of the well bore, and since site 3 has a wellbore depth that is the three times the depth of the other bedrock wells, this is most likely the cause of this discrepancy. Because these wells are located in granitic gneiss, the water that feeds these wells is coming from distinct fractures, not continuous porosity. The significant fractures that were found while drilling were located between 230ft and 290ft. While the bedrock and monitoring wells have similar fluctuations, the lack of response to the precipitation event and the depth of the fractures suggest that there is a lower level of communication between the surficial and bedrock aquifer systems in this region.

Site 3 Monitoring Well and Discrete Rainfall Event

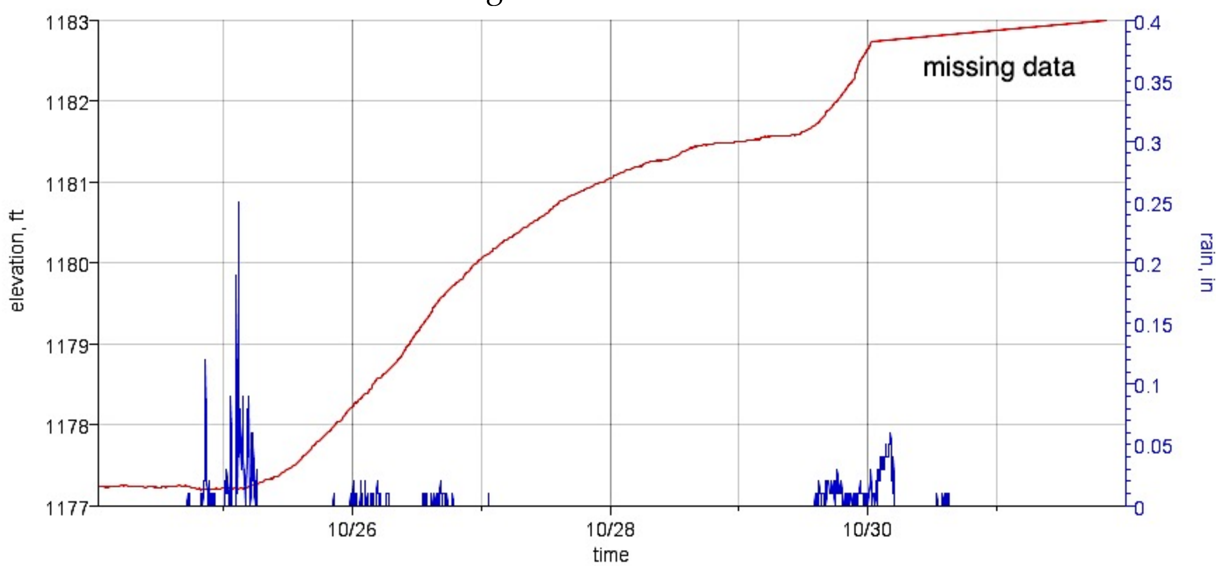

Figure 36: Site 3 Monitoring Well and Discrete Rainfall Event between 10/24/17 and 11/01/17. Water level is measured in feet on the left x-axis at a 6ft scale. Rainfall is measured in inches on the right x-axis. Data is missing starting at 10/30/2017.

Site 3 Bedrock Well and Discrete Rainfall Event

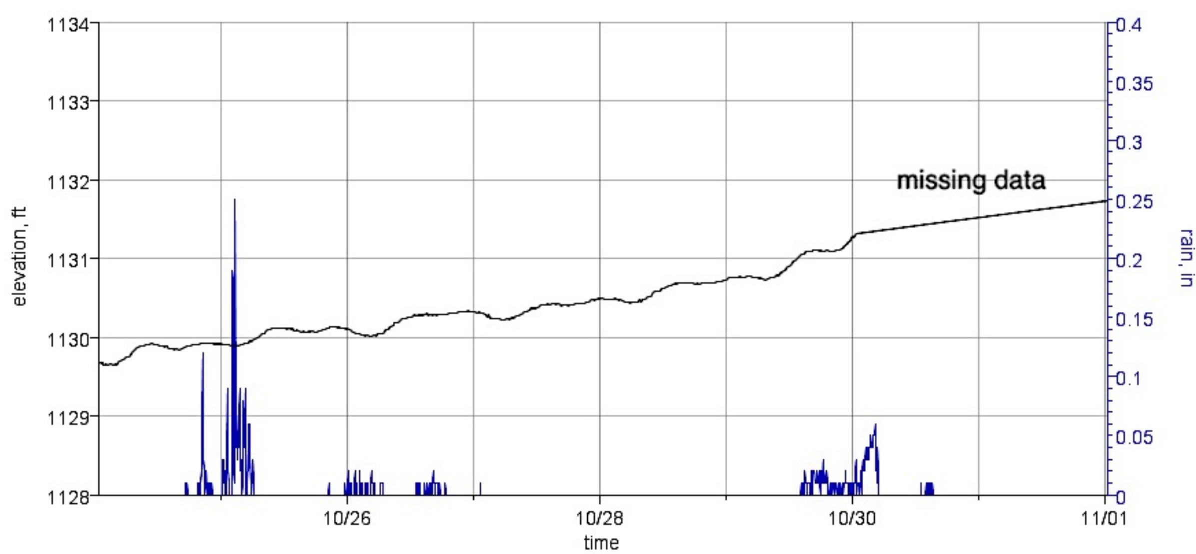

Figure 37: Site 3 Bedrock Well and Discrete Rainfall Event between 10/24/17 and 11/01/17. Water level is measured in feet on the left x-axis at a 6ft scale. Rainfall is measured in inches on the right x-axis. Data is missing starting at 10/30/2017.

7.4 | Site 4

Site 4 is likewise drilled into the Dry Hill Gneiss (Figure 9, 10, 11). The monitoring well at this location was only drilled to a depth of 4ft before encountering bedrock. The elevation of the water level of both the monitoring well and bedrock well fits in with the majority of the other wells, and the bedrock well has similar fluctuation in water level to the other bedrock wells. The monitoring well only has water in it for a few occasions out of the year, usually between February and May, though there was water in the well for extended periods between August and November of 2018.

Site 4 is missing data in the monitoring well for the majority of this rainfall event, so there is no data available for analysis. The bedrock well starts to respond to the initial rainfall event just a few hours after its completion (Figure 38). By the end of the monitoring period, the water level of the bedrock well has risen by 3ft and hasn't yet leveled off. There isn't much of a surficial aquifer in this location, which can be attributed to a thin veneer of glacial till. The magnitude and timing of the response of the deep well suggests that the precipitation is making it to the bedrock aquifer at site 4, as opposed to ending up in surface water or being transpired by plants. This suggests that, while there may not be a significant volume of water in the surficial aquifer, there is decent communication between surface water and the bedrock aquifer.

Site 4 Deep Well and Discrete Rainfall Event

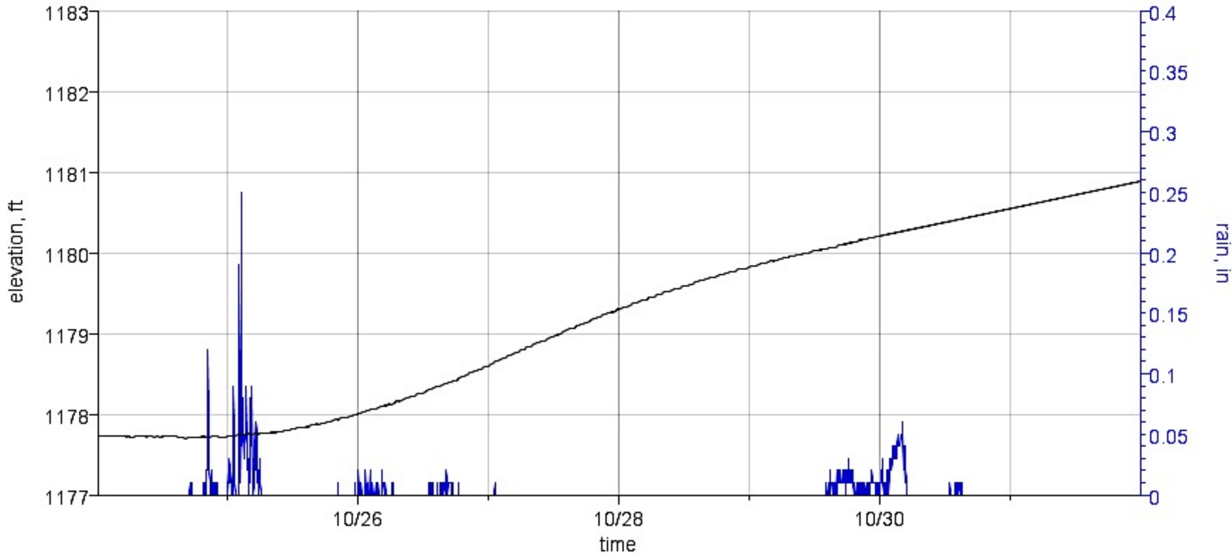

Figure 38: Site 4 Deep Well and Discrete Rainfall Event between 10/24/17 and 11/01/17. Water level is measured in feet on the left x-axis at a 6ft scale. Rainfall is measured in inches on the right x-axis.

7.5 | Annual cycles

The annual high water levels at each of the sites have very little variability throughout the duration of the study, whereas the summertime low water levels at each sites vary by an average of approximately 5ft. This suggests that, regardless of drought conditions, human use patterns, or snowmelt, the aquifer is resilient in its ability to recharge to a consistent level. The amplitude of the seasonal fluctuations is different from year to year, but each well seems to have a consistent upper limit. The consistency is likely due to the fact that Shutesbury is located on a ridge, and the steepness of the slope toward the Quabbin reservoir is likely preventing the system from retaining large volumes of water as it drains into the reservoir. The study can only speak to the responses during the last 4 years, but these years have included a summer drought of 2016, an unusually snowy winter in 2015, and an impressively wet summer in 2018, and provide a diverse set of scenarios to compare.

Each of the wells display fairly consistent seasonal changes in water level. The double headed recharge that was particularly defined in early 2015 reflects a rise in water level with fall recharge, a fall in water level that corresponds to frozen ground, and water levels rise again with spring snowmelt and precipitation. Late summer and early fall months have the lowest water levels, and the water level begins to increase again during the winter and early spring. Summer rain doesn't appear to be a major recharge factor, as water levels consistently lower in the summers of 2015, 2016, and 2017, with little change to the downward slope even when large rainfall events do occur. The rapid increase of water level in the fall is likely attributed more to the seasonal shift in water use patterns as temperatures cool and plant transpiration slows than a seasonal increase in rainfall. This spring plateau is likely due to the combination of snowmelt and rainfall infiltrating into the groundwater system as temperatures rise and the ground thaws.

7.6 | Response to a Discrete Rainfall Event

Only one rainstorm event between 10/24/2017 and 11/01/2017 is used for analysis because it was the most discrete and was not immediately preceded by another rainfall event (Figure 18). Because of its timing in mid/early fall, there was no snowmelt to factor into the magnitude of recharge, and, based on air temperature at the time, it is highly unlikely that the ground was frozen. The lack of interference from previous rainfall events and absence of snowmelt made a discrete event a priority over analyzing the response to many events. Some of the other events may have ended up saturating the dry soil, but the Fall has lower rates of transpiration and evaporation relative to summer events.

The bedrock wells at sites 1, 2, 3, and 4 responded to the event with 0.5ft, 3ft, 2ft, and 3ft increases in water level, respectively. The monitoring wells at sites 1, 2, and 3 (4 has no data) responded to the 10/24/2017 to 11/01/2017 precipitation events with 3ft, 3.5ft, and 5.5ft increases. The bedrock and monitoring wells at site 2 respond similarly to the rainfall event because the water table appears to be close to ground level. The glacial till at site 4 is so shallow that it only responds to large rainfall events. The monitoring wells at sites 1 and 3 had significantly higher responses to the precipitation events than their respective bedrock wells, which indicates that a lower amount of water is entering the bedrock aquifer system. The water that is not percolating downward is likely ending up in springs, vernal pools, is being used by people, or is being transpired by plants.

7.7 | Drought vs Wet Summer

The summer of 2016 was a period of severe drought for Western Massachusetts (Dumcius 2016). This is reflected in the observation that the lowest water levels in all wells for the duration of the study occurred during this period, in addition to the water levels dropping below the reach of the data logger in the monitoring well at site 1. Despite this significant drought, the water levels did not fall more than 10ft below their peak level, and began to recover in the late fall of that year. The precipitation levels during 2016 were lower, the frequency of rainfall events was reduced (Figure 15), and hotter days began sooner and ended later than in the other years (Figure 13). However, by the following spring, water levels returned to the same level as in previous years. The wells at all of the sites continually demonstrate an ability to fully recharge even following a severe drought.

In contrast, the summer of 2018 was wetter than previous summers in the study, and as of November 8th, 2018, the region had received 137% of the normal annual precipitation volume, and likely put the year in the top 3 rainiest years since the 1890's (Rawlins, pers comm, 2018). The lowest water levels in 2018 were significantly higher than the lows of the other years, and had the smallest range in water level fluctuations. While the study doesn't carry into the spring months, the late fall water levels were comparable to the late fall water levels of the previous years. Because the late fall water levels didn't increase in tandem with the record high rainfall amounts, it is possible that the aquifer is reaching an upper limit and, when exceeded, water in storage is lost to springs and seeps into bodies of water like the Quabbin Reservoir or vernal pools. The ability of this aquifer to consistently return to the same water levels every winter suggests an overall resiliency in the system in the face of drought.

7.8 | Climate Change and the Shutesbury Water Supply

The predicted changes to the climate of Massachusetts will impact the timing and amount of aquifer recharge. Precipitation will affect the total amount of water that is available for recharge, as well as the timing of recharge events. The projected warmer and wetter winters are expected to be a major factor in the changing patterns of recharge as well. Frozen ground could increase winter runoff (Dudley et al 2010, Runkle et al 2017). Ground water recharge is inversely related to runoff in that by definition, water that runs off is water that does not infiltrate, and therefore is unavailable to the groundwater system. However, it is likely that warmer temperatures will result in earlier thaws and later freezes (Storey 1955), meaning that the increase in winter rainfall will lead to a higher recharge potential.

Because the Shutesbury aquifer can be characterized as relatively thin glacial sediments over crystalline bedrock with low storage capacity, snowmelt will also likely be a key component of future recharge (Dudley et al 2010), and could cause overall recharge to be greater than precipitation volumes in late winter and early spring. The earlier snowmelt, heavier winter rainfall, increased spring evapotranspiration, and longer drier summers are expected to increase the duration of evapotranspiration (Hayhoe et al 2006). Recharge may increase in the winter, but water levels may fall more in the summer. Collectively, this suggests a longer period in which the region may be vulnerable to drought.

The longer, warmer summers will likely cause a greater magnitude of lowering water levels, potentially larger than occurred during the summer of 2016. Heavy rain during a drought often doesn’t fully replenish groundwater systems because of the reduced capacity for infiltration. Because of the response to the discrete rainfall events, it is clear that some amount of water is making it to the bedrock wells from precipitation. The difference in magnitude between the monitoring and bedrock well responses does suggest that some of that water is being lost to transpiration, human use, or other causes. Coupled with the recovery patterns in the late fall, this suggests that precipitation isn't the only factor in water level changes in this region.

Given the timing and intensity of the recovery from the annual low points, it is possible that vegetation is a bigger factor than rainfall driving goundwater levels. Summer rain doesn't appear to be a major recharge factor, as the water levels at all four sites fell in 2015-2017, even in the face of major rainfall events. Major storms could potentially become runoff and smaller storms could be used by vegetation, preventing water from making its way into the bedrock aquifer. When the plants go dormant in the fall and winter months, they decrease their water uptake. Lower transpiration rates and lower temperatures in the fall months are likely cause for evapotranspiration rates (Hayhoe et al 2006, Whately et al 2012), which is likely what is allowing the groundwater system to recover so rapidly. A more targeted study should be done to examine the impact of evapotranspiration on the recharge of the bedrock and surface aquifers in this region.

8 | CONCLUSION

The aquifer system that supports the town of Shutesbury has proven itself to be resilient during the course of this study. The wells consistently recovered to a similar water level each spring with minimal yearly variability, even in the case of the relatively severe drought. There was also a fairly small, less than 10ft range in water levels within each year, suggesting that the system can be considered reliable.

While the K-values and the blow test results suggest that the aquifer isn't particularly productive, the consistency of the surface and bedrock aquifer's ability to recover from diverse seasonal drawdowns suggest that the aquifer is a robust source of water for the town. However, the comparably low water levels in the bedrock well at site 3 suggest that a cautious approach to development around the town center would be wise. Thankfully, none of the wells showed a similar downward trend to the Pelham well or the New Hampshire study, although the time scale of this study was much shorter, so it is harder to draw conclusions about long term trends.

Long term predictions for the impacts of climate change in the region suggest that an increase in awareness regarding water use would be beneficial. The potential increase in winter recharge from snowmelt and precipitation will likely outweigh the impacts of the predicted summer drought periods. More research on how growing seasons will shift and how those changes will impact groundwater recharge would be helpful to better understanding the system. Overall, this study suggests that the aquifer is resilient. The levels do fluctuate seasonally, which can likely be attributed to human use patterns and vegetation. This study supports the conclusion that the aquifer is able to recharge to a consistent water level in a variety of climate scenarios. However, the town would benefit from comprehending how their community interacts with the ecosystem and the groundwater levels so that they can foster an understanding of what is influencing the aquifer that they depend on.

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Water Wells and Systems
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Town of Shutesbury
ATTN: Al Werner, Becky Torres
1 Cooleyville Rd.
Shutesbury, MA 01072

8/29/14

RE: Billing for Monitor Well Project

This is the billing and day sheets for the work we performed recently. The billing is as follows:

Contract Base Price for Work:		$ 18,480.00
Extra drilling, 200 ft. @ $10.00/LF		2,000.00
Extra 6" casing and grout site 1-D and 2-D, 16 ft. @ $21.00/LF		336.00
Machine Time, Stand by:		
Site 2-D: 1 hr. 40 min.		
Site 3-D: 5 min.		
Site 4-D: 1 hr.		
Total 2.75 hrs. @ $285.00/hr.		783.75
Additional well materials left on site:		
5 bgs. sorted silica sand	$ 75.00	
1 bg. bentonite chips	24.80	
10 ft. .010" 2"Sch 40 PVC FJ screen	62.80	
10 ft. 2"Sch 40 PVC FJ riser	49.00	
1 ea. 2" PVC plug	7.13	
Total materials:		218.73
Total amount due:		**$ 21,818.48**

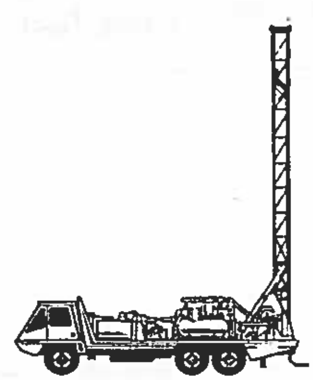
If acceptable, kindly process for payment. Any questions do not hesitate to call.

Sincerely,

Bart C. Cushing

Bart C. Cushing

Office: 631 Rt. 12N, Keene, NH 03431 Mailing: PO Box 668, Walpole, NH 03608
Phone: 800-831-8883 603-352-8866 Fax: 603-357-8572



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800-831-8883 / 603-352-8866 / FAX: 603-357-8572

DAILY WORK REPORT

Customer: Shutesbury Monitoring Well project Phone ______

Contact person: ______

SITE: Shutesbury Mass Weather Conditions: ______ DATE 8-20-14

Rig and Number: 203

Support Equip. 223

Site Person: AL Werner

Driller: Shawn Beal

Striker: Dan Winslow

X ______ Approval Signature

Time on site: 8:00

Time off site: 3:15

Description of Work and Times:

6:00 - 8:00 Mob Surry NH to Shutesbury Mass

8:00 - 8:45 look at sites

~~8:45~~ - 9:45 Mud Matt on to site S2-D

9:45 - 10:30 8 7/8 air down 21' wet gravels

10:30 - 12:00 Set up for mud rotary waite for pit to be dug

12:00 - 3:00 8 7/8 Mud bedrock at 26', 8 7/8 to 38' BGS set 40' of 6" T+C casing, rotary drive shoe, seat shoe into rock, Portland grout via tremmie 60 gallons. Set up for 6" drilling in the A.M

3:00 - 3:15 secure site

3:15 offsite

drill Log

0'-4' silty Sands

4'-26' gravels

26'-34' weathered

34'-38' Compitentrock

Materials

40' of 6" T+C 19# casing

1) Rotary Drive shoe

2) Bgs of Mud

1) Benseal

6) Portland I+II

1) 6" locking cap

M/I

2.5 hr.

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DAILY WORK REPORT

Customer: Shutesbury Monitoring wells Phone
Contact person:
SITE: Shutesbury Mass Weather Conditions: DATE 8-21-14
Rig and Number: 203
Support Equip. 223
Site Person: AL Werner
Driller: Shawn Beal
Striker: Dan Winslow

X ______ Approval Signature

Time on site: 8:00
Time off site: 3:45

Description of Work and Times:

8:00 on site S2-D
8:00 - 8:50 6" air 38' to 100' BGS
8:50 - 9:00 Blow test 4 gpm
9:00 - 9:45 Trip out set up S2-S
9:45 - 12:00 6" mud 0' - 25' BGS
set 2" well, 10 slot screen 25' to 15' BGS
Riser 2' ABGS
#1 Sand 13' BGS
Betonite chips 2' BGS

Matarials
10' of 10 slot screen | 3) Bgs of chips | 1) Protective Riser
20 of riser | 1) Bg of Mud | 1) 2" push point
4) Bgs # Sand | 1) J Plug

12:00 - 1:45 set up S1-D get load of H2O
1:45 - 3:45 8 7/8 air 0' to 25 BGS Bedrock 25'
set 40' of 6" T+C casing 1) drive shoe
drive + seat casing, Grout via tremmie
80 gallons, secure site
3:45 off site

Matarials
40' of 6" casing | 1) Bg Benseal
1) Rotary Drive shoe | 1) 6" Locking Cap
8) Bgs Portland I+II

MT: 10 min 2-D

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800-831-8883 / 603-352-8866 / FAX: 603-357-8572

DAILY WORK REPORT

Customer: Shutesbury Monitor Wells Phone
Contact person:
SITE: Shutesbury Ma Weather Conditions: DATE 8-22-14
Rig and Number: 203
Support Equip. 223
Site Person: Al Werner
Driller: Shawn B
Striker: Dan W

X [signature] Approval Signature

Time on site: 7:45
Time off site: 3:00

Description of Work and Times:

7:45 on site S1-D
8:00 - 8:45 6" air 38' to 100' Bgs
8:45 - 9:00 Blow test 0 gpms
9:00 - 9:45 Trip out Mud matt to S1-S set up
9:45 - 11:00 6" air to 25' BGS Bedrock 25', set well
10 slot screen 25 to 15' BGS
Riser 2' ABGS
#1 Sand 12 BGS
Chips 2' BGS

Materials
10' of 10 slot screen 4) Bgs chips 1) 2" push point
20' of 2" Riser 1) J Plug
6) Bgs #1 Sand 1) Protective Standpipe

11:00 - 12:15 Move to S3-D
12:15 - 2:15 8 7/8 air to 28' BGS Bedrock at 13' BGS
Set 30' of 6" T+C pipe 1) drive shoe, grout
via tremmie 60 gallons drive + seat casing.
2:15 - 3:00 Stage materials Next hole, Secure site
3:00 off site

Materials
30' of 6" T+C casing 1) Benseal
1) Rotary drive shoe 1) 6" locking cap
6) Portland I + II

M/T 10: 15 min
15: 15 min

Pg 1

Cushing & Sons

DRILLING, BORING, & PUMP CONTRACTORS

OFFICES: Route 12 North, Keene, NH 03431 • MAIL: PO Box 200, Walpole, NH 03608
800-831-8883 / 603-352-8866 / FAX: 603-357-8572

DAILY WORK REPORT

Customer: Shutesbury Monitor Wells Phone

Contact person:

SITE: Shutesbury Ma Weather Conditions: DATE 8-25-14

Rig and Number: 203

Support Equip. 223

Site Person: Al Werner

X [signature] Approval Signature

Driller: Shawn B

Striker: Dan W

Time on site: 7:45

Time off site: 3:30

Description of Work and Times:

7:45	on site
7:45	S3-D 6" air 28' to 100'
9:00 - 9:25	Blow test check static in S1-D 91.2 BGS
9:25 - 9:55	6" air 100' to 120'
9:55 - 10:05	Blow test ∅
10:105 - 10:25	6" air 120' to 140'
10:25 - 10:35	Blow test ∅
10:35 - 10:45	6" air 140' - 160'
10:45 - 10:55	Blow test ∅
10:55 - 11:10	6" air 160' to 180'
11:10 - 11:20	Blow test ∅
11:20 - 11:45	Trip out set up S3-S
11:45 - 12:20	6' air 0'-13' Bedrock 13' set well
	10 slot screen 13' to 5'
	Riser 2' ABG
	#1 sand to 3' ; chips 1' BGS.
Materials	10' of 10 slot screen
	10' of riser
	1 push plug
	7) #1 Sand
	1) chip
	1) J Plug
	1) Protective Riser

M/T 1D : 65

M/T 3-D : 0

Pg #2

Cushing & Sons

DRILLING & BORING CONTRACTORS

OFFICES: Route 12 North, Keene, NH 03431, Rte. 114, Lyndonville, VT 05851
MAIL: PO BOX 200, Walpole, NH 03608
1-800-331-8683 / 802-254-4850 / FAX: 603-357-8572

DAILY WORK REPORT

Customer: Shutesbury Monitor Wells Phone

Contact person:

SITE: Shutesbury Ma Weather Conditions: DATE 8-25-14

Rig and Number: 203

Support Equip. 223

Site Person: AL Werner

Driller: Shawn B

Striker: Dan W

X [signature]
Approval Signature

Time on site: 7:45 Mob/Demob Times at shop:

Time off site: 3:30 Miles to Site:

Description of Work and Times:
Keep track of all times and materials used.

12:20 - 1:30 Move to S4-D trim branches set up.
1:30 - 2:30 S4-D 8 7/8 air 0'-28' BG Bedrock at 4'
set 20' of 6" T+C with drive shoe, 40 gallons
of grout 4 bgs Portland, via tremmie, drive
+ seat into rock.

2:30 - 3:30 Well development with pump, won't work
Need bailer, check station on wells.

3:30 off site

Materials 20' of 6" casing
1) drive shoe
4) bgs of portland
1) Bewseal
1) 6" locking cap.

Cushing & Sons

DRILLING & BORING CONTRACTORS

OFFICES: Route 12 North, Keene, NH 03431, Rte. 114, Lyndonville, VT 05851
MAIL: PO BOX 200, Walpole, NH 03608
1-800-331-6883 / 802-254-4850 / FAX: 603-357-6572

DAILY WORK REPORT

Customer: Shutesbury Monitor wells Phone

Contact person:

SITE: Shutesbury Ma Weather Conditions: DATE 8-26-14

Rig and Number: 203

Support Equip. 223

Site Person: Al Werner

Driller: Shawn B.

Striker: Dan W

X Approval Signature

Time on site: 7:30 Mob/Demob Times at shop:

Time off site: 4:00 Miles to Site:

Description of Work and Times:

Keep track of all times and materials used.

7:30 on site

7:30-8:45 S4-D 6" air 18' to 100' BGS

8:45-9:30 Blow test, let recover, check statics on S3-D, S3-S, S1-D, S1-S.

9:30-10:45 Blow well some recovery, Trip out.

S4-S hand dig to 4' BGS bedrock set well

Screen 4' to 3'

Riser 4' ABGS

sand to 1' BGS

chips 6" BGS

cement in stand pipe

Materials 1' of 10 slot screen

10' of 2" riser

3) #1 Sand

1) chip

1) push plug

1) J plug

1) protective riser

1) Sakrete.

Materials left for future well by AL

5) Bgs #1 Sand 1) push plug

1) Bg chips

10' of 10 slot screen M/T

10' of riser 4-D: 2 hr.

Cushing & Sons

DRILLING & BORING CONTRACTORS

OFFICES: Route 12 North, Keene, NH 03431, Rte. 114, Lyndonville, VT 05851
MAIL: PO BOX 200, Walpole, NH 03608
1-800-331-6683 / 802-254-4850 / FAX: 603-357-8572

DAILY WORK REPORT

Customer: Shutesbury Monitor Wells Phone
Contact person:
SITE: Shutesbury Mass Weather Conditions: DATE 8-26-14
Rig and Number: 203
Support Equip. 223
Site Person: Al Werner
Driller: Shaw B
Striker: Dan W

X [signature]
Approval Signature

Time on site: 7:30 Mob/Demob Times at shop:
Time off site: 4:00 Miles to Site:

Description of Work and Times:
Keep track of all times and materials used.

10:45 - 11:30 Park at TownHall cement stand pipe, well development S3-S

11:30 - 12:30 Set over S3-D, get load of $H^{2}O$

12:30 - 2:30 6" air 180' to 285', problem with hammer
Blow test Ø

2:30 - 3:00 Trip out strip hammer, broken piston

3:00 - 4:00 Cement Standpipes S2-S, S1-S, develope wells.

Materials 4 Sakrette.

DRILLING & BORING CONTRACTORS

OFFICES: Route 12 North, Keene, NH 03431, Rte. 114, Lyndonville, VT 05851
MAIL: PO BOX 200, Walpole, NH 03608
1-800-331-8883 / 802-254-4650 / FAX: 603-357-8572

DAILY WORK REPORT

Customer: Shutesbury Monitor wells Phone

Contact person:

SITE: Shutesbury MA05 Weather Conditions: DATE 8-27-14

Rig and Number: 203

Support Equip. 223

Site Person: Al Werner

Driller: Shawn B

Striker: Dan W

X [signature] Approval Signature

Time on site: 7:30 Mob/Demob Times at shop:

Time off site: 9:30 Miles to Site:

Description of Work and Times:

Keep track of all times and materials used.

7:30 - 8:15 Repairs, down hole with 6" hammer

8:15 - 8:25 6" air 285' to 300'

8:25 - 8:40 Blow test 2 1/4 gpm

8:40 - 9:30 Trip out, pick up demob

(3)

N 42° 23' 41.2",
W072° 25' 095

CUSHING & SONS, INC.
WATER WELL DRILLERS
Job Report

Customer

TOWN of SHUTESBURY

AL WERNER, PM

Pump By:

Date Signed contract by BCC

Date Completed 8-22-14 by S Beal #203

Phone: 413 687-8046 res work 413 251 3048

Well Data			
Total Depth 100' ft.	yield Ø gpm		
Casing Length 40' ft.	static ft.		
Depth to Bedrock 25' ft.	off-set ft.		

Other Materials: 8) Bgs Portland
1) Benseal
1) 6" Locking cap

Bit 51720

Pump Data

Type installation:

Sub Cont.: Ph.#

Foundation Stone Cement Slab

R. Hammer yes no

Panel to C. Box: ft.

Elec. Type:

Type Plumbing: PVC Copper Iron

Well Location: SITE # 1-D
380 Pelham Hill Rd. (1.8 mi from Jct. Leverett + Pelham Hill Rd.

0'- 25' gravels / silty clay mix
25'- 100' Quartz / granite

Map:

Note: Sketch pressure tank location, electrical service panel location, and other helpful information.

N 42° 25. 463'
W 072° 25. 109'

CUSHING & SONS, INC.
WATER WELL DRILLERS
Job Report

Customer
TOWN of SHUTESBURY
AL WERNER, PM

Pump By: ____
Date Signed contract by BCC
Date Completed 8-22-14 by SBeal #203
Phone: 413-687-8046 res work 413 256 3048

Well Data

Total Depth 25' ft. yield ____ gpm
Casing Length ____ ft. static ____ ft.
Depth to Bedrock 25' ft. off-set ____ ft.
Other Materials: 10' of 10 slot screen 20' of riser
6) Bgs #1 Sand, 4) Bgs chips, 1) 5 Plug
1) Push point 1) Protective Casing

Pump Data

Type installation: ____
Sub Cont.: ____ Ph.# ____
Foundation ____ Stone ____ Cement ____ Slab
R. Hammer ____ yes ____ no ____
Panel to C. Box: ____ ft. ____
Elec. Type: ____
Type Plumbing: ____ PVC ____ Copper ____ Iron

Well Location: SITE # 1-S
Pelham Hill Rd.
0'-25' gravels / silty clay mix

Map:

Note: Sketch pressure tank location, electrical service panel location, and other helpful information.

Well Construction Schematic

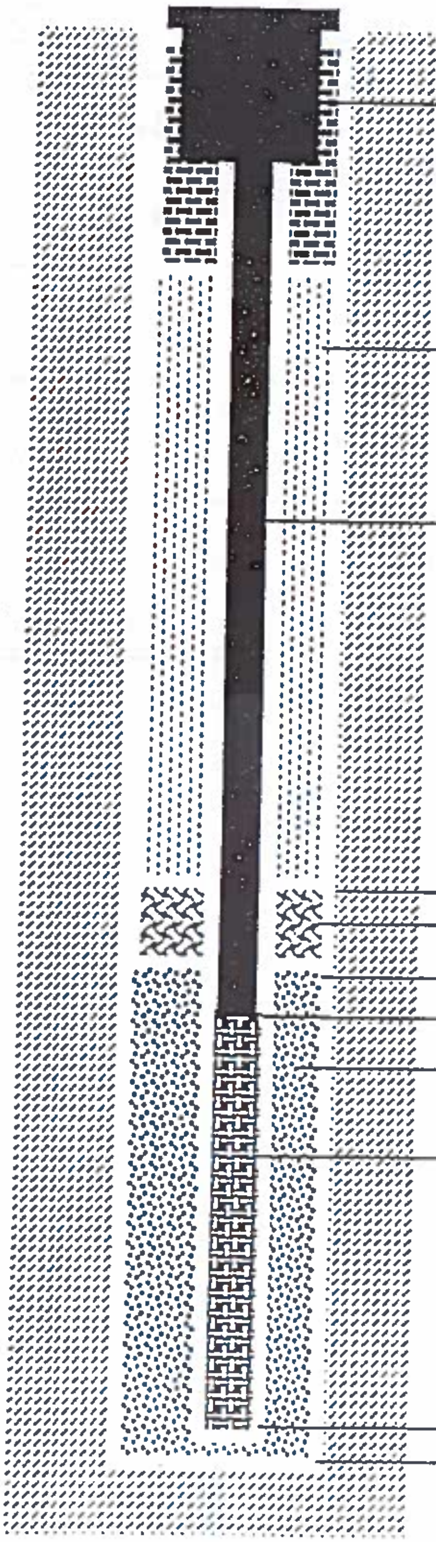
Larry G. Cushing & Sons, Inc.

Keene, NH 800-831-8883

Customer Shutesbury Ma Date ______ Well # 51-5

Site, Town ______ Driller and Striker ______

Rig Number: ______



2' ABG

______ Grade ______ Curb Box or Steel Protector (circle)

Sakrete

Backfill material: ______

2" PVC Sch 40 FJ Riser

3/8 ft. top of bentonite

Bentonite: type: 2'

13 ft. top of sand

15' ft. top of screen

Sorted silica sand Grade: #1

2" Sch 40 FJ Slotted Screen Slot: 10

25' ft. bottom of screen

25' ft. boring bottom

① N42° 26.954'
W072° 24.992'

CUSHING & SONS, INC.
WATER WELL DRILLERS
Job Report

Customer
TOWN of SHUTESBURY
AL WERNER, PM

Pump By:
Date Signed Contract by BCC
Date Completed 8-21-14 by S. Beal #203
Phone: 413-687-8046 Res work 413 256 3048

Well Data

Total Depth 100' ft. yield 4 gpm
Casing Length 40' ft. static ft.
Depth to Bedrock 26' ft. off-set ft.
Other Materials: 2 Bgs Mud
1 Benseal
6 Portland I+II
17 6" locking Cap Bcl 5,720

Pump Data

Type installation:
Sub Cont.: Ph.#
Foundation Stone Cement Slab
R. Hammer yes no
Panel to C. Box: ft.
Elec. Type:
Type Plumbing: PVC Copper Iron

Well Location: SITE # 2-D 64 Leverett Rd
Across from DPW out in woods.

0-4' silty sands
4'-26' gravels
26'-34' weathered rock
34'-100' granite

H^{20} fractures 44'. 58'

Map:

Note: Sketch pressure tank location, electrical service panel location, and other helpful information.

N42° 26. 953'
W072° 24. 988'

CUSHING & SONS, INC.
WATER WELL DRILLERS
Job Report

Customer
TOWN of SHUTESBURY
AL WERNER, PM

Pump By:
Date Signed contract by BCC
Date Completed 8-21-14 by S. Beal #203
Phone: 413-687-8046 Res work 413 256 3048

Well Data

Total Depth 25' ft. yield ______ gpm

Casing Length ______ ft. static ______ ft.

Depth to Bedrock 25' ft. off-set ______ ft.

Other Materials: 10' of 10 slot Screen 20' riser
4) #1 Sands, 3 bags chips, 1) mud
1) J Plug 1) Protective Riser

Pump Data

Type installation:

Sub Cont.: ______ Ph.# ______

Foundation ______ Stone ______ Cement ______ Slal

R. Hammer ______ yes ______ no ______

Panel to C. Box: ______ ft. ______

Elec. Type:

Type Plumbing: ______ PVC ______ Copper ______ Iron

Well Location: SITE # 2-S

0' - 4' silty sands
4' - 25' gravels

Map:

Note: Sketch pressure tank location, electrical service panel location, and other helpful information.

Well Construction Schematic

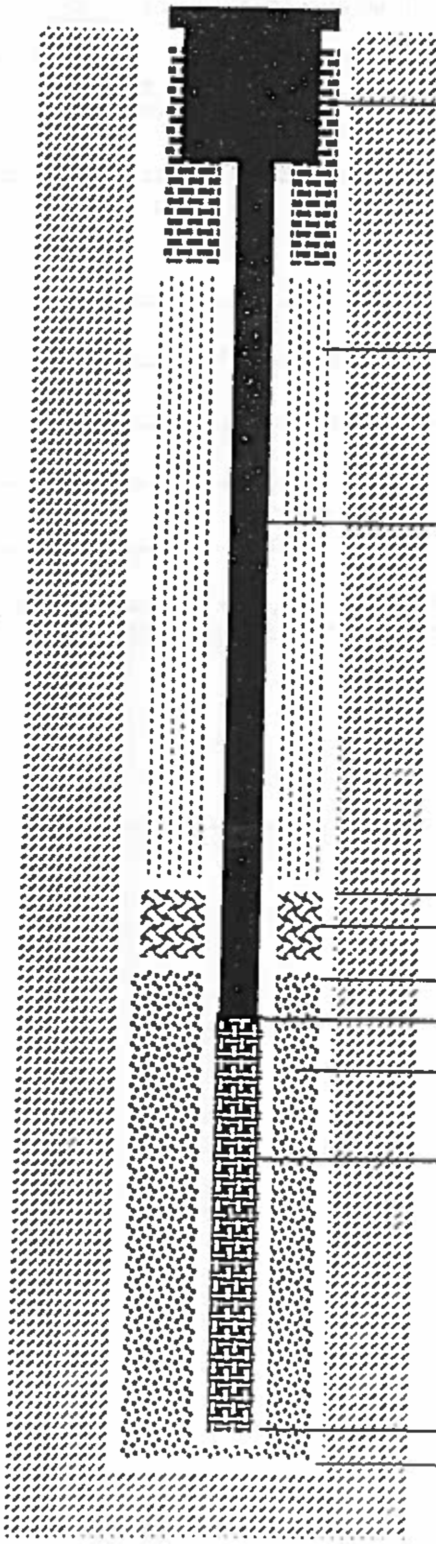
Larry G. Cushing & Sons, Inc.

Keene, NH 800-831-8883

Customer: Shrewsbury Ma. Date: ______ Well # S2-5

Site, Town: ______ Driller and Striker: ______

Rig Number: 203



2' AGG

Grade ______ Curb Box or Steel Protector (circle)

Sakrete

Backfill material: ______

2" PVC Sch 40 FJ Riser

3/8 ft. top of bentonite

Bentonite: type: 2'

13 ft. top of sand

15 ft. top of screen

Sorted silica sand Grade: #1

2" Sch 40 FJ Slotted Screen Slot: 10

25 ft. bottom of screen

25 ft. boring bottom

N42° 27.061',
W072° 24.576'

4
TBD

CUSHING & SONS, INC.
WATER WELL DRILLERS
Job Report

Customer
TOWN of SHUTESBURY
AL WERNER, PM

Pump By:
Date Signed contract by BCC
Date Completed 8-22-14 by S Beal FF203
Phone: 413-687-8046 res work 413 256 3048

Well Data		Pump Data	
Total Depth 300' ft. yield 2 1/4 gpm		Type installation:	
Casing Length 30' ft. static ft.		Sub Cont.:	Ph.#
Depth to Bedrock 13' ft. off-set ft.		Foundation Stone Cement Slat	
Other Materials: 30' of 6" T+C 1) locking cap.		R. Hammer yes no	
1) Drive Shoe		Panel to C. Box: ft.	
6) Portland		Elec. Type:	
1) Benseal Bit 5.720		Type Plumbing: PVC Copper Iron	

Well Location: SITE # 3-D
TOWN COMMON Behind Church
Go IN ON dirt, not pavement
BRING CURB BOX

Map:

0'-13' dry gravels
13'-300' granite

Fractures 234'
260'
267'
269'
282'
288'

Note: Sketch pressure tank location, electrical service panel location, and other helpful information.

N42° 27 065'
W072° 24 569

CUSHING & SONS, INC.
WATER WELL DRILLERS
Job Report

Customer
TOWN of SHUTESBURY
AL WERNER, PM

Pump By: ______
Date Signed Contract by BCC
Date Completed 8-14-14 by S Beal #203
Phone: 413 687-8046 Res work 413 256 3048

Well Data	Pump Data
Total Depth 13' ft. yield ____ gpm	Type installation: ____
Casing Length ____ ft. static ____ ft.	Sub Cont.: ____ Ph.# ____
Depth to Bedrock 13' ft. off-set ____ ft.	Foundation ____ Stone ____ Cement ____ Slab
Other Materials: ~~8~~' 8' of 10slot screen	R. Hammer ____ yes ____ no ____
10' of riser 1) Push Plug	Panel to C. Box: ____ ft. ____
7) #1 Sand 1) J Plug	Elec. Type: ____
1) chip 1) Protective Riser	Type Plumbing: ____ PVC ____ Copper ____ Iron

Well Location: SITE # 3-S

Map:

0'-13' Dry gravels

Note: Sketch pressure tank location, electrical service panel location, and other helpful information.

Well Construction Schematic

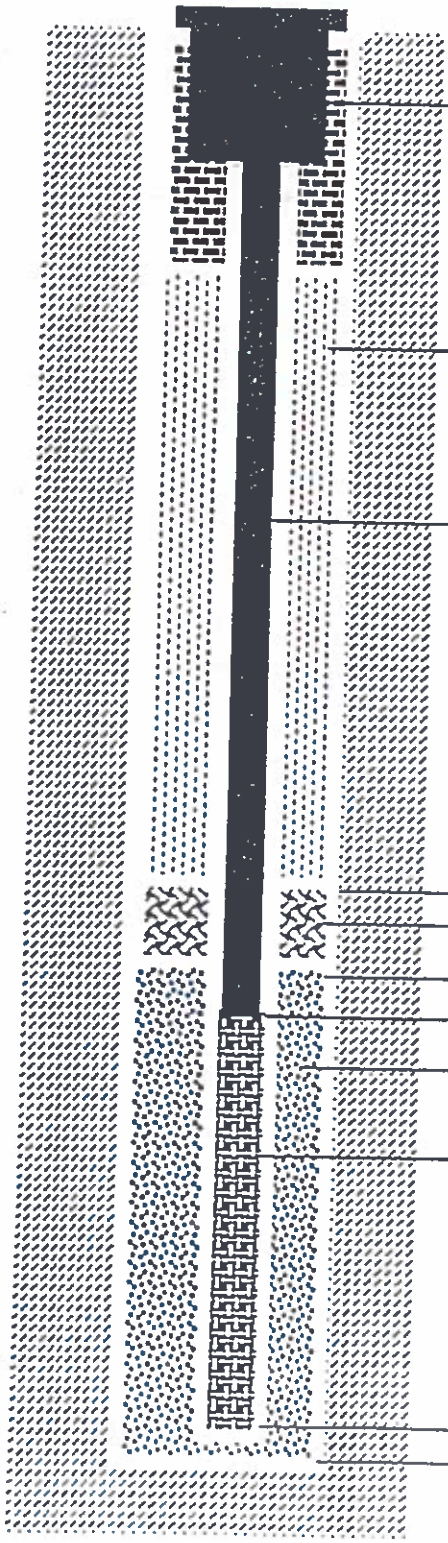
Larry G. Cushing & Sons, Inc.

Keene, NH 800-831-8883

Customer Shutesbury Ma. Date ____ Well # 53-5

Site, Town ____ Driller and Striker ____

Rig Number: ____



2' ABG

Grade ____ Curb Box or Steel Protector (circle)

Sakrete

Backfill material: ____

2" PVC Sch 40 FJ Riser

3/8 ft. top of bentonite

Bentonite: type: 1'

2' ft. top of sand

5 ft. top of screen

Sorted silica sand Grade: #1

2" Sch 40 FJ Slotted Screen Slot: 10

13' ft. bottom of screen

13 ft. boring bottom

(2)

N42° 28.251'
W072° 24.871'

CUSHING & SONS, INC.
WATER WELL DRILLERS
Job Report

Customer
Town of Shutesbury
Al Werner, PM

Pump By: ____
Date Signed contract by BCC
Date Completed 8-26-14 by Shawn B #203
Phone: 413-687-8046 [?] work 413 256 3048

Well Data		Pump Data	
Total Depth 100' ft.	yield 1/4 gpm	Type installation:	
Casing Length 20' ft.	static ____ ft.	Sub Cont.:	Ph.#
Depth to Bedrock 4' ft.	off-set ____ ft.	Foundation ____ Stone ____ Cement ____ Slab	
Other Materials: 4 Portland		R. Hammer ____ yes ____ no ____	
1 Benseal		Panel to C. Box: ____ ft. ____	
1 6" locking cap		Elec. Type:	
Bit 5.720		Type Plumbing: ____ PVC ____ Copper ____ Iron	

Well Location: Site # 4-D
Behind Athletic Club At
Wendell Rd / Plaza Rd

Map:

Fractures
41'
61'
94'

0'-4 dry gravel
4'-100' granite

Note: Sketch pressure tank location, electrical service panel location, and other helpful information.

Well Construction Schematic

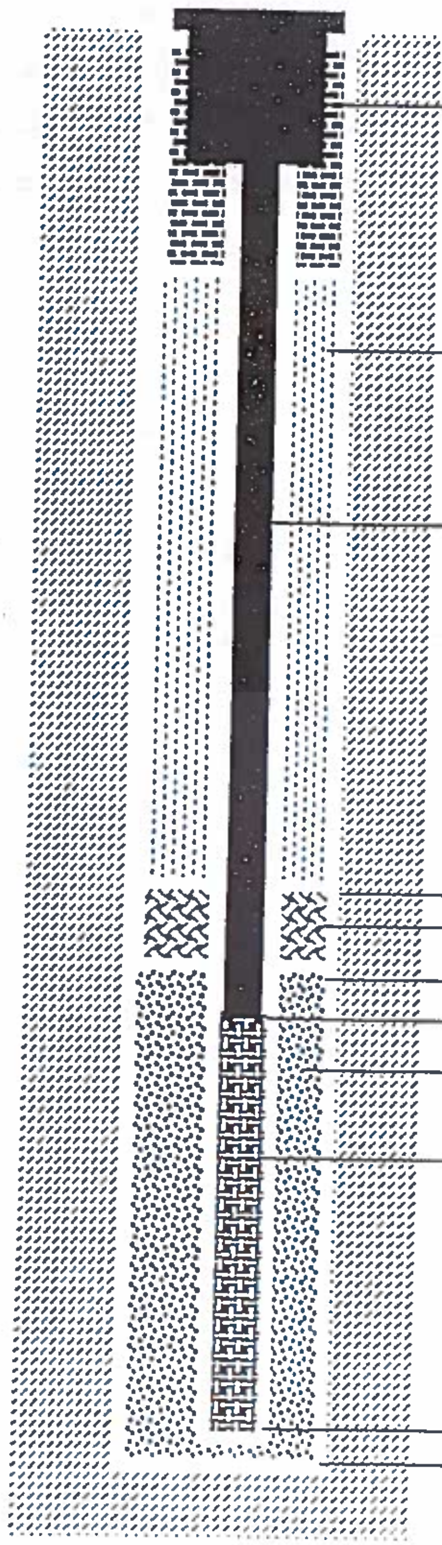
Larry G. Cushing & Sons, Inc.

Keene, NH 800-831-8883

Customer: Shutesbury Ma Date: ______ Well #: S4-5

Site, Town: ______ Driller and Striker: ______

Rig Number: ______



2A86 Grade ______ Curb Box or Steel Protector (circle)

Sakrete

Backfill material: ______

2" PVC Sch 40 FJ Riser

3/6 ft. top of bentonite

Bentonite: type: 6"

1' ft. top of sand

3' ft. top of screen

Sorted silica sand Grade: #1

2" Sch 40 FJ Slotted Screen Slot: 10

4 ft. bottom of screen

4 ft. boring bottom

N42° 27.057'
W072° 24.572'

CUSHING & SONS, INC.
WATER WELL DRILLERS
Job Report

Customer
TOWN of SHUTESBURY
AL WERNER, PM

Pump By:
Date Signed contract by BCC
Date Completed 8-26-14 by Shawn B #203
Phone: 413 687-8046 125 work 413 256 3048

Well Data

Total Depth 4 ft. yield gpm
Casing Length ft. static ft.
Depth to Bedrock 4' ft. off-set ft.
Other Materials: 1' of 10 slot Screen, Protective Riser
10' of Riser
1) chip
3) Bgs #1 sand

Well Location: SITE # 4 - 5

0'- 4' dry gravels

Pump Data

Type installation:
Sub Cont.: Ph.#
Foundation Stone Cement Slab
R. Hammer yes no
Panel to C. Box: ft.
Elec. Type:
Type Plumbing: PVC Copper Iron

Map:

Note: Sketch pressure tank location, electrical service panel location, and other helpful information.

Massachusetts Department of Environmental Protection
Bureau of Resource Protection
MONITORING WELL REPORT

Site: 3 D

Note: GPS coordinates must be in WGS84 datum, in decimal degrees.

1. WELL LOCATION GPS (Required) North 42°.27061 West 72°.24576

Address at Well Location: 1 Cooleyville Rd. ☒ Property Owner: Town of Shutesbury

Subdivision/Property Description: ☐ Engineering Firm

City/Town: Shutesbury MA In public right-of-way? N Mailing Address: 1 Cooleyville Rd.

Assessors Map: Assessors Lot #: City/Town: Shutesbury State: MA

Board of Health permit obtained ☐ Yes ☒ Not Required Permit Number: Date Issued:

2. WORK PERFORMED	3. DRILLING METHOD Overburden	3. DRILLING METHOD Bedrock	4. PERMIT INFORMATION
N W	A H	A H	DEP 21E site #: DEP Groundwater Discharge #:

6. ADDITIONAL WELL INFORMATION

Developed	☒ Y ☐ N	Are these wells nested	☐ Y ☒ N
Well finished in bedrock	☒ Y ☐ N	Surface Seal Type	C M
Number of wells in group	2	Area of group (sq. ft)	20
Total Well Depth	300'	Depth to Bedrock	13'

5. WELL LOG — OVERBURDEN LITHOLOGY

From (ft)	To (ft)	Code	Color	Comment	Drop in Drill Stem	Extra Fast or Slow Drill Rate	Loss or Addition of Fluid
0	13	G	BR		☐ Y ☒ N	☐ F ☐ S	☐ L ☐ A

7. CASING

From	To	Type	Thickness	Diameter
+2	30	S	19#	6

8. SCREEN

From	To	Type	Slot Size	Diameter
—	—			

5. WELL LOG — BEDROCK LITHOLOGY

From (ft)	To (ft)	Code	Comment	Drop in Drill Stem	Extra Large Chips	Extra Fast or Slow Drill Rate	Loss or Addition of Fluid	Visible Rust Staining
13	100	GR		☐ Y ☒ N	☐ Y ☒ N	☐ F ☐ S	☐ L ☐ A	☐ Y ☒ N
100	200	GR		☐ Y ☒ N	☐ Y ☒ N	☐ F ☐ S	☐ L ☐ A	☐ Y ☒ N
200	300	GR	fractured *	☐ Y ☒ N	☐ Y ☒ N	☐ F ☐ S	☐ L ☐ A	☐ Y ☒ N

9. WATER-BEARING ZONES

From	To	Yield (gpm)
234'	288'	2 1/4

10. WATER LEVEL

Date Measured	Static Depth BGS (ft)	Flowing Rate (gpm)
NOT	MEASURED	

11. ANNULAR SEAL / FILTER PACK

From (ft BGS)	To (ft BGS)	Material 1	Weight	Material 2	Weight	Water (gal)	Batches	Method of Placement
0	28'	C M	564#			39	1	T R

12. COMMENTS * fractures @ 234', 260', 267', 269', 282', 288'

13. WELL DRILLERS STATEMENT This well was drilled or altered under my direct supervision, according to the applicable rules and regulations, and this report is complete and accurate to the best of my knowledge.

Driller: Shawn Beal Supervising Driller Signature: [signature] Certification #: 558

Company: Cushing & Sons Inc Date Job Complete: 8/27/14 Rig Permit #: 496

NOTE: Well Completion Reports must be filed by the registered well driller within 30 days of well completion.

Massachusetts Department of Environmental Protection
Bureau of Resource Protection
MONITORING WELL REPORT

Site: 3-S

Note: GPS coordinates must be in WGS84 datum, in decimal degrees.

1. WELL LOCATION GPS (Required) North 42° 27 061 West 72° 24 576

Address at Well Location: 1 Cooleyville Rd.
☒ Property Owner: Town of Shutesbury
Subdivision/Property Description:
☐ Engineering Firm
City/Town: Shutesbury MA
In public right-of-way? N
Mailing Address: 1 Cooleyville Rd
Assessors Map: Assessors Lot #:
City/Town: Shutesbury State: MA
Board of Health permit obtained ☐ Yes ☒ Not Required
Permit Number: Date Issued:

2. WORK PERFORMED: N W

3. DRILLING METHOD: Overburden: A H | Bedrock: ☐ ☐

4. PERMIT INFORMATION: DEP 21E site #: | DEP Groundwater Discharge #:

6. ADDITIONAL WELL INFORMATION

Developed ☒ Y ☐ N | Are these wells nested ☐ Y ☒ N
Well finished in bedrock ☐ Y ☒ N | Surface Seal Type: C T
Number of wells in group: 2 | Area of group (sq. ft): 20
Total Well Depth: 13 | Depth to Bedrock: 13

5. WELL LOG — OVERBURDEN LITHOLOGY

From (ft)	To (ft)	Code	Color	Comment	Drop in Drill Stem	Extra Fast or Slow Drill Rate	Loss or Addition of Fluid
0	13	G	BR	DRY	☐ Y ☒ N	☐ F ☐ S	☐ L ☐ A

7. CASING

From	To	Type	Thickness	Diameter
+2	5	PVC	Sch 40	2"

8. SCREEN

From	To	Type	Slot Size	Diameter
5	13	PVC	.010	2"

5. WELL LOG — BEDROCK LITHOLOGY

From (ft)	To (ft)	Code	Comment	Drop In Drill Stem	Extra Large Chips	Extra Fast or Slow Drill Rate	Loss or Addition of Fluid	Visible Rust Staining
				☐ Y ☐ N	☐ Y ☐ N	☐ F ☐ S	☐ L ☐ A	☐ Y ☐ N

9. WATER-BEARING ZONES

From	To	Yield (gpm)
NONE		

10. WATER LEVEL

Date Measured	Static Depth BGS (ft)	Flowing Rate (gpm)
NONE		

11. ANNULAR SEAL / FILTER PACK

From (ft BGS)	To (ft BGS)	Material 1	Weight	Material 2	Weight	Water (gal)	Batches	Method of Placement
0	1	CT	80#					TR
1	2	BC	50#					TR
2	13	SD	350#					TR

12. COMMENTS

13. WELL DRILLERS STATEMENT This well was drilled or altered under my direct supervision, according to the applicable rules and regulations, and this report is complete and accurate to the best of my knowledge.

Driller: Shawn Beal
Supervising Driller Signature: [signature]
Certification #: 558
Company: Cushing & Sons, Inc
Date Job Complete: 8/24/14
Rig Permit #: 496

NOTE: Well Completion Reports must be filed by the registered well driller within 30 days of well completion.

Massachusetts Department of Environmental Protection
Bureau of Resource Protection
MONITORING WELL REPORT

Site: 4-D

Note: GPS coordinates must be in WGS84 datum, in decimal degrees.

1. WELL LOCATION GPS (Required) North 42°. 28 251 West 72°. 24 871

Address at Well Location: Jct Wendell Rd & Plaza Rd. ☒ Property Owner: Town of Shutesbury

Subdivision/Property Description: ☐ Engineering Firm

City/Town: Shutesbury MA In public right-of-way? N Mailing Address: 1 Cooleyville Rd.

Assessors Map: Assessors Lot #: City/Town: Shutesbury State: MA

Board of Health permit obtained ☐ Yes ☒ Not Required Permit Number: Date Issued:

2. WORK PERFORMED	3. DRILLING METHOD Overburden	Bedrock	4. PERMIT INFORMATION
N W	A H	A H	DEP 21E site #: DEP Groundwater Discharge #:

6. ADDITIONAL WELL INFORMATION

Developed	☒ Y ☐ N	Are these wells nested	☐ Y ☒ N
Well finished in bedrock	☒ Y ☐ N	Surface Seal Type	C M
Number of wells in group	2	Area of group (sq. ft)	20
Total Well Depth	100	Depth to Bedrock	4

5. WELL LOG — OVERBURDEN LITHOLOGY

From (ft)	To (ft)	Code	Color	Comment	Drop in Drill Stem	Extra Fast or Slow Drill Rate	Loss or Addition of Fluid
0	4	G	Br	Dry	☐ Y ☒ N	☐ F ☐ S	☐ L ☐ A

7. CASING

From	To	Type	Thickness	Diameter
+2	18	S T L	19#	6"

8. SCREEN

From	To	Type	Slot Size	Diameter
—	—			

5. WELL LOG — BEDROCK LITHOLOGY

From (ft)	To (ft)	Code	Comment	Drop In Drill Stem	Extra Large Chips	Extra Fast or Slow Drill Rate	Loss or Addition of Fluid	Visible Rust Staining
4	100	Gr		☐ Y ☒ N	☐ Y ☒ N	☐ F ☐ S	☐ L ☐ A	☐ Y ☒ N

9. WATER-BEARING ZONES

From	To	Yield (gpm)
Small fractures not detected		1/4 gpm

10. WATER LEVEL

Date Measured	Static Depth BGS (ft)	Flowing Rate (gpm)
Not	Recorded	

11. ANNULAR SEAL / FILTER PACK

From (ft BGS)	To (ft BGS)	Material 1	Weight	Material 2	Weight	Water (gal)	Batches	Method of Placement
0	18	C M	376			26	1	T R

12. COMMENTS

13. WELL DRILLERS STATEMENT This well was drilled or altered under my direct supervision, according to the applicable rules and regulations, and this report is complete and accurate to the best of my knowledge.

Driller: Shawn Beal Supervising Driller Signature: [signature] Certification #: 558

Company: Cushing & Sons, Inc Date Job Complete: 8/2 Rig Permit #: 496

NOTE: Well Completion Reports must be filed by the registered well driller within 30 days of well completion.

Massachusetts Department of Environmental Protection
Bureau of Resource Protection
MONITORING WELL REPORT

Site: 4-S

Note: GPS coordinates must be in WGS84 datum, in decimal degrees.

1. WELL LOCATION GPS (Required) North 42° 28 251 West 72° 24 871

Address at Well Location: Jct Wendell Rd. & Plaza Rd — [X] Property Owner: Town of Shutesbury
Subdivision/Property Description: — [ ] Engineering Firm
City/Town: Shutesbury MA — In public right-of-way? N — Mailing Address: 1 Cooleyville Rd.
Assessors Map: — Assessors Lot #: — City/Town: Shutesbury — State: MA
Board of Health permit obtained [ ] Yes [X] Not Required — Permit Number: — Date Issued:

2. WORK PERFORMED: N W

3. DRILLING METHOD: Overburden: A H — Bedrock: – –

4. PERMIT INFORMATION: DEP 21E site #: — DEP Groundwater Discharge #:

6. ADDITIONAL WELL INFORMATION

Developed	[X] Y [ ] N	Are these wells nested	[ ] Y [X] N
Well finished in bedrock	[ ] Y [X] N	Surface Seal Type	C T
Number of wells in group	2	Area of group (sq. ft)	20
Total Well Depth	4	Depth to Bedrock	4

5. WELL LOG — OVERBURDEN LITHOLOGY

From (ft)	To (ft)	Code	Color	Comment	Drop in Drill Stem	Extra Fast or Slow Drill Rate	Loss or Addition of Fluid
0	4	G	BR	Dry	[ ] Y [X] N	[ ] F [ ] S	[ ] L [ ] A

7. CASING

From	To	Type	Thickness	Diameter
+2	3	PVC	Sch 40	2"

8. SCREEN

From	To	Type	Slot Size	Diameter
3	4	PVC	.010	2"

5. WELL LOG — BEDROCK LITHOLOGY

From (ft)	To (ft)	Code	Comment	Drop In Drill Stem	Extra Large Chips	Extra Fast or Slow Drill Rate	Loss or Addition of Fluid	Visible Rust Staining

9. WATER-BEARING ZONES

From	To	Yield (gpm)
None		

10. WATER LEVEL

Date Measured	Static Depth BGS (ft)	Flowing Rate (gpm)
None		

11. ANNULAR SEAL / FILTER PACK

From (ft BGS)	To (ft BGS)	Material 1	Weight	Material 2	Weight	Water (gal)	Batches	Method of Placement
0	1	C T	80#					T R
1	4	S D	150#					T R

12. COMMENTS

13. WELL DRILLERS STATEMENT This well was drilled or altered under my direct supervision, according to the applicable rules and regulations, and this report is complete and accurate to the best of my knowledge.

Driller: Shawn Beal — Supervising Driller Signature: [signature] — Certification #: 558
Company: Cushing & Sons, Inc — Date Job Complete: 8/26/14 — Rig Permit #: 496

NOTE: Well Completion Reports must be filed by the registered well driller within 30 days of well completion

Massachusetts Department of Environmental Protection
Bureau of Resource Protection
MONITORING WELL REPORT

Site: 1-D

Note: GPS coordinates must be in WGS84 datum, in decimal degrees

1. WELL LOCATION GPS (Required) North 42°. 23 412 West 72°. 25 095

Address at Well Location: 380 Pelham Hill Rd.
☒ Property Owner: Town of Shutesbury
Subdivision/Property Description:
☐ Engineering Firm:
City/Town: Shutesbury MA — In public right-of-way? N
Mailing Address: 1 Cooleyville Rd
Assessors Map: — Assessors Lot #:
City/Town: Shutesbury — State: MA
Board of Health permit obtained ☐ Yes ☒ Not Required — Permit Number: — Date Issued:

2. WORK PERFORMED: N W

3. DRILLING METHOD: Overburden: A H — Bedrock: A H

4. PERMIT INFORMATION: DEP 21E site #: — DEP Groundwater Discharge #:

6. ADDITIONAL WELL INFORMATION

Developed	☒ Y ☐ N	Are these wells nested	☐ Y ☒ N
Well finished in bedrock	☒ Y ☐ N	Surface Seal Type	C M
Number of wells in group	2	Area of group (sq. ft)	20
Total Well Depth	100	Depth to Bedrock	25

5. WELL LOG — OVERBURDEN LITHOLOGY

From (ft)	To (ft)	Code	Color	Comment	Drop in Drill Stem	Extra Fast or Slow Drill Rate	Loss or Addition of Fluid
0	25	G	BR		☐ Y ☒ N	☐ F ☐ S	☐ L ☐ A

7. CASING

From	To	Type	Thickness	Diameter
+2	38	STL	19#	6

8. SCREEN

From	To	Type	Slot Size	Diameter
—	—			

5. WELL LOG — BEDROCK LITHOLOGY

From (ft)	To (ft)	Code	Comment	Drop In Drill Stem	Extra Large Chips	Extra Fast or Slow Drill Rate	Loss or Addition of Fluid	Visible Rust Staining
25	100	GR		☐ Y ☒ N	☐ Y ☒ N	☐ F ☐ S	☐ L ☐ A	☐ Y ☒ N

9. WATER-BEARING ZONES

From	To	Yield (gpm)
NONE	NOTED	

10. WATER LEVEL

Date Measured	Static Depth BGS (ft)	Flowing Rate (gpm)
NOT	RECORDED	

11. ANNULAR SEAL / FILTER PACK

From (ft BGS)	To (ft BGS)	Material 1	Weight	Material 2	Weight	Water (gal)	Batches	Method of Placement
0	38	C M	752#			52	1	

12. COMMENTS

13. WELL DRILLERS STATEMENT This well was drilled or altered under my direct supervision, according to the applicable rules and regulations, and this report is complete and accurate to the best of my knowledge.

Driller: Shawn Beal — Supervising Driller Signature: [signature] — Certification #: 558
Company: Cushing & Sons, Inc — Date Job Complete: 8/23/14 — Rig Permit #: 496

NOTE: Well Completion Reports must be filed by the registered well driller within 30 days of well completion

Massachusetts Department of Environmental Protection
Bureau of Resource Protection
MONITORING WELL REPORT

Site 1-S

Note: GPS coordinates must be in WGS84 datum, in decimal degrees.

1. WELL LOCATION GPS (Required) North 42 ° 23 412 West 72 ° 25 095

Address at Well Location: 380 Pelham Hill Rd.
☒ Property Owner: Town of Shutesbury
Subdivision/Property Description:
☐ Engineering Firm:
City/Town: Shutesbury MA
In public right-of-way? N
Mailing Address: 1 Cooleyville Rd.
Assessors Map: Assessors Lot #:
City/Town: Shutesbury State: MA
Board of Health permit obtained ☐ Yes ☒ Not Required
Permit Number: Date Issued:

2. WORK PERFORMED: N W

3. DRILLING METHOD: Overburden: A H; Bedrock: A H

4. PERMIT INFORMATION: DEP 21E site #: ; DEP Groundwater Discharge #:

6. ADDITIONAL WELL INFORMATION

Developed	☒ Y ☐ N	Are these wells nested	☐ Y ☒ N
Well finished in bedrock	☐ Y ☒ N	Surface Seal Type	C T
Number of wells in group	2	Area of group (sq. ft)	20
Total Well Depth	25	Depth to Bedrock	—

5. WELL LOG — OVERBURDEN LITHOLOGY

From (ft)	To (ft)	Code	Color	Comment	Drop in Drill Stem	Extra Fast or Slow Drill Rate	Loss or Addition of Fluid
0	25	G	BR		N		

5. WELL LOG — BEDROCK LITHOLOGY

From (ft)	To (ft)	Code	Comment	Drop In Drill Stem	Extra Large Chips	Extra Fast or Slow Drill Rate	Loss or Addition of Fluid	Visible Rust Staining

7. CASING

From	To	Type	Thickness	Diameter
+2	15	PVC	Sch 40	2"

8. SCREEN

From	To	Type	Slot Size	Diameter
15	25	PVC	.010"	2"

9. WATER BEARING ZONES

From	To	Yield (gpm)
NOT RECORDED		

10. WATER LEVEL

Date Measured	Static Depth BGS (ft)	Flowing Rate (gpm)
NOT RECORDED		

11. ANNULAR SEAL / FILTER PACK

From (ft BGS)	To (ft BGS)	Material 1	Weight	Material 2	Weight	Water (gal)	Batches	Method of Placement
0	2	C T	80#					T R
2	13	B C	200#					T R
13	25	S D	300#					T R

12. COMMENTS

13. WELL DRILLERS STATEMENT This well was drilled or altered under my direct supervision, according to the applicable rules and regulations, and this report is complete and accurate to the best of my knowledge.

Driller: Shawn Beal
Supervising Driller Signature: [signature]
Certification #: 558
Company: Cushing & Sons, Inc.
Date Job Complete: 8/22/14
Rig Permit #: 496

NOTE: Well Completion Reports must be filed by the registered well driller within 30 days of well completion.

Massachusetts Department of Environmental Protection
Bureau of Resource Protection
MONITORING WELL REPORT

Site 2-D

Note: GPS coordinates must be in WGS84 datum, in decimal degrees.

1. WELL LOCATION

GPS (Required) North 42°. 26 954 West 72°. 24 992

Address at Well Location: 64 Leverett Rd.

☒ Property Owner: Town of Shutesbury

Subdivision/Property Description: —

☐ Engineering Firm

City/Town: Shutesbury MA — In public right-of-way? N — Mailing Address: 1 Cooleyville Rd.

Assessors Map — Assessors Lot # — City/Town: Shutesbury — State: MA

Board of Health permit obtained ☐ Yes ☒ Not Required — Permit Number — Date Issued

2. WORK PERFORMED

N W

3. DRILLING METHOD

Overburden: M R — Bedrock: A H

4. PERMIT INFORMATION

DEP 21E site #

DEP Groundwater Discharge #

6. ADDITIONAL WELL INFORMATION

Developed	☒ Y ☐ N	Are these wells nested	☐ Y ☒ N
Well finished in bedrock	☒ Y ☐ N	Surface Seal Type	C M
Number of wells in group	2	Area of group (sq. ft)	20
Total Well Depth	100	Depth to Bedrock	26

5. WELL LOG — OVERBURDEN LITHOLOGY

From (ft)	To (ft)	Code	Color	Comment	Drop in Drill Stem	Extra Fast or Slow Drill Rate	Loss or Addition of Fluid
0	4	FS	BR		N		
4	26	G	BR		N		

7. CASING

From	To	Type	Thickness	Diameter
+2	38	S T L	19#	6

8. SCREEN

From	To	Type	Slot Size	Diameter
—	—			

5. WELL LOG — BEDROCK LITHOLOGY

From (ft)	To (ft)	Code	Comment	Drop In Drill Stem	Extra Large Chips	Extra Fast or Slow Drill Rate	Loss or Addition of Fluid	Visible Rust Staining
26	34	GR	weathered	N	Y			Y
34	100	GR	fracture 44.5	N	N			N

9. WATER-BEARING ZONES

From	To	Yield (gpm)
44	45	4

10. WATER LEVEL

Date Measured	Static Depth BGS (ft)	Flowing Rate (gpm)
NOT MEASURED		

11. ANNULAR SEAL / FILTER PACK

From (ft BGS)	To (ft BGS)	Material 1	Weight	Material 2	Weight	Water (gal)	Batches	Method of Placement
0	38	C M	564#			39	1	T R

12. COMMENTS

13. WELL DRILLERS STATEMENT

This well was drilled or altered under my direct supervision, according to the applicable rules and regulations, and this report is complete and accurate to the best of my knowledge.

Driller: Shawn Beal — Supervising Driller Signature: [signature] — Certification #: 558

Company: Cushing & Sons, Inc — Date Job Complete: 8/21/14 — Rig Permit #: 496

NOTE: Well Completion Reports must be filed by the registered well driller within 30 days of well completion.

Massachusetts Department of Environmental Protection
Bureau of Resource Protection
MONITORING WELL REPORT

Site 2-5

Note: GPS coordinates must be in WGS84 datum, in decimal degrees.

1. WELL LOCATION GPS (Required) North 42°. 26 954 West 72°. 24 992

Address at Well Location	64 Leverett Rd.	☒ Property Owner	Town of Shutesbury
Subdivision/Property Description		☐ Engineering Firm	
City/Town	Shutesbury MA — In public right-of-way? N	Mailing Address	1 Cooleyville Rd.
Assessors Map	Assessors Lot #	City/Town	Shutesbury State MA
Board of Health permit obtained	☐ Yes ☒ Not Required	Permit Number	Date Issued

2. WORK PERFORMED: N W

3. DRILLING METHOD: Overburden: M R; Bedrock: – –

4. PERMIT INFORMATION: DEP 21E site #: ; DEP Groundwater Discharge #:

6. ADDITIONAL WELL INFORMATION

Developed	☒ Y ☐ N	Are these wells nested	☐ Y ☒ N
Well finished in bedrock	☐ Y ☒ N	Surface Seal Type	C T
Number of wells in group	2	Area of group (sq. ft)	20
Total Well Depth	25	Depth to Bedrock	—

5. WELL LOG — OVERBURDEN LITHOLOGY

From (ft)	To (ft)	Code	Color	Comment	Drop in Drill Stem	Extra Fast or Slow Drill Rate	Loss or Addition of Fluid
0	4	FS	BR		☐ Y ☒ N	☐ F ☐ S	☐ L ☐ A
4	25	G	BR		☐ Y ☒ N	☐ F ☐ S	☐ L ☐ A

7. CASING

From	To	Type	Thickness	Diameter
+2	15	PVC	Sch 40	2"

8. SCREEN

From	To	Type	Slot Size	Diameter
15	25	PVC	.010	2"

5. WELL LOG — BEDROCK LITHOLOGY

From (ft)	To (ft)	Code	Comment	Drop in Drill Stem	Extra Large Chips	Extra Fast or Slow Drill Rate	Loss or Addition of Fluid	Visible Rust Staining
				☐ Y ☐ N	☐ Y ☐ N	☐ F ☐ S	☐ L ☐ A	☐ Y ☐ N

9. WATER-BEARING ZONES

From	To	Yield (gpm)
NOT RECORDED		

10. WATER LEVEL

Date Measured	Static Depth BGS (ft)	Flowing Rate (gpm)
NOT RECORDED		

11. ANNULAR SEAL / FILTER PACK

From (ft BGS)	To (ft BGS)	Material 1	Weight	Material 2	Weight	Water (gal)	Batches	Method of Placement
13	25	S D	200#					T R
2	13	B C	150#					T R
0	2	C T	80#					T R

12. COMMENTS

13. WELL DRILLERS STATEMENT This well was drilled or altered under my direct supervision, according to the applicable rules and regulations, and this report is complete and accurate to the best of my knowledge.

Driller: Shawn Beal — Supervising Driller Signature: [signature] — Certification #: 558

Company: Cushing & Sons, Inc — Date Job Complete: 8/21/14 — Rig Permit #: 496

NOTE: Well Completion Reports must be filed by the registered well driller within 30 days of well completion.