GEOLOGY OF DORSET SPRINGS

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Introduction

Dorset contains numerous springs already in use as water supply sources. Two springs are currently in use by fire districts and others supply or previously supplied water to residences. A descriptive classification of the springs was completed by Becker (1984) and serves as the only summary of these springs to date. As part of a study of Dorset surficial geology and hydrogeology, the Vermont Geological Survey has re-examined the springs of the Becker study to better understand the geologic setting of each spring. An additional 13 springs and seeps were identified and located.

Becker presented a geologically based method of proposing potential recharge areas for each spring. Revell (1991) examined the McNamara spring and calculated a potential recharge area for this spring and the nearby Ethan Allen spring using an average flow and water budget; Revell assumed conduit flow of subsurface water in a karst setting. One goal of this study was to determine if buried karst terrain has a strong probability of existence in the carbonate rock of the valleys and hill slopes. If true, this karst terrain would be a strong contributing factor to the springs. The nature of the overburden overlying such buried karst terrain and the topography might additionally determine the setting for the town's springs. Thus, we hoped to better understand the geology of the town in general and to specifically study the geology of individual springs. All of this needed to be accomplished within the constraints of a time and budget limited investigation. Therefore, there remains much to be learned about the town's geology and the geology of the springs.

Improved location of all observed springs using GPS methods was a major goal of this study. The determined locations are included later in this section as part of a classification of the springs based upon estimates of observed and/or reported discharge.

Another goal of this study was to better delineate inferred recharge areas for the Dorset springs; however, this goal was hampered by a lack of reliable spring discharge data.

Historical Perspective for Dorset Springs

The State of Vermont (1983) determined the criteria used to delineate recharge area for springs in both overburden and bedrock. Overburden springs are distinguished according to the up gradient slope above the spring. Springs with a high relief up gradient slope have groundwater divides which are assumed to match surface water divides. Springs with a low relief up gradient slope have groundwater divides which are placed along a possible losing stream and the recharge boundaries may exceed shallow surface water divides because groundwater flow is assumed to pass beneath shallow surface water divides. Bedrock springs have recharge areas outlined along up slope drainage divides but these can be adjusted for local bedrock structural parameters such as fracture plane orientation and bedding orientation. A 200ft isolation distance is declared a safe distance around all springs in the down gradient direction.

These criteria do not take into consideration the discharge or flow rate of the spring and no water budget calculations are used to determine recharge area. Consequently, a 2000gpm spring may not have a significantly larger recharge area than a 200gpm spring in the same geologic setting. This limitation in the determination of recharge area is likely due to a general lack of spring flow rates, particularly for undeveloped springs where flow has not been captured into pipes and/or cisterns.

Becker (1984) completed a report on Dorset springs and used the 1983 Vermont criteria to delineate recharge areas for 13 springs. Becker used field techniques, map interpretation and air photo analysis to locate these springs on a 1:24,000 topographic base. In accordance with the Vermont (1983) criteria, he classified the springs as either overburden springs with a high relief up gradient slope, overburden springs with a low relief up gradient slope, or as bedrock springs.

Smith (1989) presented a study of Dorset groundwater resources and summarized the glacial geology and bedrock geology of the town as known at the time. While no new bedrock geology maps have been completed since his report, this study reports on the glacial/surficial geology of the town and provides an updated context in which to understand the springs of Dorset. Smith did not re-examine the springs but duplicated the Becker (1984) study as an appendix to his report.

Revell (1991) evaluated the McNamara spring. He used an infiltration model and estimates of spring flow to determine a revised recharge area for this spring. He interpreted the geology of the area to indicate this spring likely represented conduit flow in a karst terrain developed in the underlying carbonate bedrock. The implication of conduit flow is that recharge to this spring comes from a much larger area than previously delineated due to the rapid flow rates for groundwater in conduit settings.

State of Vermont ACT250 proceedings related to the McNamara Spring (VT Environmental Board, 1992, 1993; Heindel & Noyes, 1992; Revell, 1991) report their conclusion this spring was in a karst setting and that conduit flow was likely. They determined the recharge area for this spring was much larger than previously determined but could not state the recharge area extended westward from the summit of Mother Myrick Mountain due to a lack of agreement among hydrogeological experts giving testimony.

Important questions to be addressed in understanding Vermont springs

This historical context suggests important questions that should be addressed for the Dorset springs, and by analogy, for all Vermont springs. The historical data indicate that detailed geologic mapping needs to be undertaken for each spring in order to better understand the inferred recharge area to each spring. Flow rates for each spring need to be determined so that numerical calculations of potential recharge area can be attempted using water budget models that incorporate known annual precipitation and inferred infiltration rates. Inferred recharge area outlines should take into consideration any available spring discharge information from field observations and estimates from previous studies. Caution must be exerted regarding the accuracy of discharge measurements not made by standard methods.

The determination of potential recharge area outlines for bedrock springs should attempt to incorporate bedrock structural data. However, the degree to which these structural data can be useful remains uncertain. For example, how should multiple fracture plane orientations be reconciled when considering groundwater flow directions? In karst settings, how can we enhance the delineation of potential recharge to the spring by incorporating prominent fracture orientations that may control the development of conduits for rapid groundwater flow in the subsurface? There must be discussion and agreement as to how much or how far to increase recharge from one direction and decrease recharge from another direction based upon fracture orientations. To date, such manipulations of recharge area shape have been largely arbitrary and reflect personal preference.

Surficial mapping of Dorset reveals the boundary between thin till with much exposed rock in high elevation areas versus thick till with less exposed rock areas at lower elevations along mountain flanks. These different regions have strongly different potential to recharge the underlying rock aquifer. Yet, in the past, no such distinctions have been incorporated into the delineation of spring recharge area shape. We are currently investigating a method to incorporate the results of the surficial mapping into the delineation of spring recharge shape.

Finally, and of great importance for the Dorset springs, how can we make useable determinations of potential recharge area outlines when the geology of the spring strongly indicates that flow is occurring in conduits in a karst terrain which is buried beneath glacial overburden? In such cases, the determination that the spring is even a bedrock spring is not 100% positive as the spring is more than likely to be an occluded spring where the actual bedrock water source is masked by overburden.

Should the additional research needed to address these questions be carried out at a spring, and, if so, at which springs should limited resources be expended? Such research might include introducing tracer substances into the groundwater system at presumed up gradient locations within an hypothesized recharge area in order to detect the tracer at the spring sometime later.

The criteria currently being used to outline potential recharge areas for springs is mainly a crude first attempt and may need improvement to be valid for policy decisions. The additional study at the McNamara Spring has demonstrated that detailed study of one spring can lead to a new and often better understanding of the potential recharge area for a spring. Detailed mapping is a vital tool to improve our understanding of springs and furnishes valuable data for more informed policy decisions.

Summary of additional research needed at all Vermont springs

* Accurate discharge measurements made throughout the year.
* Geologic mapping of each spring as needed to further understand each spring.
* Use of tracer dyes to aid in determination of spring recharge area.
* Calculation of potential spring recharge area size using both the catchment-area and water-budget methods.
* Methods to incorporate geologic data such as fracture and bedding plane orientations for each spring into determination of potential recharge area shape.

Methodology

Location

Each spring was visited on at least one occasion and several springs were visited more than once. A hand held Garmin GPS76 was used to determine the location of each spring in NAD 1927 latitude and longitude coordinates. The precision and accuracy of the Garmin unit was casually observed by making multiple determinations of location with the same GPS unit at a few springs and by using a second global positioning satellite receiver at many locations to compare latitude and longitude. This second unit was a Garmin Foretrex 101 wrist watch style device. These multiple measurements indicate that the GPS readings are only accurate to +/- 0.05 minutes of latitude or longitude, despite the GPS devices providing readings to the nearest thousandth of a minute of latitude and longitude. Only the Garmin GPS76 device data are presented. Based upon the casual observation of GPS accuracy and precision, the actual location of each spring must be reconciled with the observed topographic setting of each spring. The actual location of each spring may differ slightly from the GPS data and should be reconciled using field data on the topographic setting of each spring.

Although elevation values were obtained by the GPS device along with latitude and longitude for most of the springs, these values were almost always determined to be incorrect based upon the latitude and longitude coordinates and based upon field observation of elevation. Thus, the elevation of each spring is approximated by its latitude and longitude position and by reconciliation with field observation of map location.

Geology

The topographic setting and geology of each spring was determined in the field. The nature of the surficial material at each spring was assessed and the occurrence of rock outcrop at any spring was noted. If a rock outcrop was present at the spring, then data on the orientation of the rock layers and on the orientation of any observed fracture planes was collected using a Brunton compass. The discussion of each spring's geology below includes the data for each spring. In addition, the area surrounding each spring was traversed using available trails and/or bushwhacking techniques. The objective was to assess the topography and hydrogeology surrounding each spring. Measurements of the orientation of bedding planes and fracture planes at rock outcrops within a reasonable distance of each spring were made in order to incorporate bedrock structural data into the assessment of spring hydrology. Most springs do not issue directly from bedrock and most springs had no nearby outcrops so the incorporation of bedrock structural data into the spring hydrology assessment must be viewed with appropriate caution.

Location and Classification of Dorset Springs

Below is the location data for the studied springs. The springs are grouped into general categories based upon observed flow estimates. Below each spring name is the waypoint number, NAD 1927 latitude and longitude coordinates in degrees and decimal minutes, and the magnitude of each spring[1].

High flow springs:

1. COLD SPRING.
   WP 040; N 43° 15.442´ W 073° 02.877´ (Third, 450-4500gpm)
2. GILBERT BROOK SPRING.
   WP 056; N 43° 14.364´ W 073° 07.446´ (Third, 450-4500gpm)
3. Mc NAMARA SPRING.
   WP 019; N 43° 13.101´ W 073° 05.225´ (Third, 450-4500gpm)
4. EVANS-deKNOTBECK SPRING.
   WP 021; N 43° 16.473´ W 073° 05.164´ (Fourth, 100-450gpm)
5. WALKER LOT SPRING.
   WP 032; N 43° 14.060´ W 073° 00.045´ (Fourth, 100-450gpm)
6. DORSET FIRE DISTRICT SPRING.
   WP 044; N 43° 15.013´ W 073° 06.884´ (Fourth, 100-450gpm)
7. ETHAN ALLEN SPRING.
   WP 045; N 43° 14.027´ W 073° 05.502´ (Fourth, 100-450gpm)

[1] Classification of spring magnitudes is based upon Meinzer's (1923) classification of spring discharge converted to GPM from FT^3/SEC (1 FT^3 = 7.48 Gal). Spring flow estimates for a few springs were found in Becker (1984) and the remainder were inferred based upon visual observation of flow. No spring discharge measurements were made.

Moderate flow springs:

8. EAST DORSET FIRE DISTRICT SPRING.
WP 012; N 43° 15.130´ W 072° 59.428´ (Fifth, 10-100gpm)
9. MT AEOLUS SPRING.
WP 030; N 43° 14.075´ W 073° 00.923´ (Fifth, 10-100gpm)
10. CULVER-O'NEAL SPRING.
WP 046; N 43° 12.848´ W 073° 00.904´ (Fifth, 10-100gpm)
11. COLONEL LANE SPRING.
WP 035; N 43° 15.754´ W 072° 59.317´ (Fifth, 10-100gpm)
12. OWL'S FOOT SPRING. (formerly South Dorset or Owl's Head spring)
WP 063; N 43° 14.082´ W 073° 04.366´ (Fifth, 10-100gpm)
13. HISTORICAL PARSONS SPRING.
WP 036; N 43° 16.060´ W 072° 59.410´ (Fifth, 10-100gpm)

Minor flow springs:

14. NEW PARSONS SPRING.
WP 037; N 43° 16.005´ W 072° 59.240´ (Sixth, 1-10gpm)
15. OTTER CREEK TRAIL SPRING.
WP 038; N 43° 16.186´ W 072° 59.205´ (Sixth, 1-10gpm)
Spring is uphill from this waypoint at the NFS boundary on north side of trail.
16. NETOP FARM TRAIL SPRING.
WP 041; N 43° 15.914´ W 073° 02.888´ (Sixth, 1-10gpm)
17. BOWEN HILL ROAD SPRING.
WP 011; N 43° 15.973´ W 073° 00.125´ (Sixth, 1-10gpm)
18. MAD TOM ROAD SPRING.
WP 033; N 43° 15.616´ W 072° 59.414´ (Sixth, 1-10gpm)

Seeps (Seventh or Eighth magnitude, < 1gpm):

19. OWL'S FOOT AREA.
WP 062; N 43° 14.028´ W 073° 04.140´
20. TOWER ROAD TRAIL.
WP 045; N 43° 14.040´ W 073° 05.517´
21. WALKER LOT AREA.
WP 031; N 43° 14.096´ W 073° 00.060´
22. DORSET HILL EAST A.
WP 028; N 43° 15.440´ W 073° 00.804´
23. DORSET HILL EAST B.
WP 027 N 43° 15.487´ W 073° 00.657´
24. BOWEN HILL ROAD A.
WP 010; N 43° 15.844´ W 073° 00.150´
25. BOWEN HILL ROAD B.
WP 007; N 43° 15.955´ W 073° 00.134´

Geology of Individual Springs: High Flow Springs

Cold Spring

Field observation places this spring at an elevation of 1380 +/- 20ft. The setting is of a very high flow boiling from the base of a steep 12-16ft bank composed of till. Although a previous description states this spring emanates from an outcrop, no confident rock outcrop is evident to the author. There are boulders and cobbles in the lag of debris at the base of the slope. The steep gully head and banks of the gully down stream from the spring are composed of till. The trail to the spring and the area around the spring reveal no rock outcrop. There are several small seeps along the trail leading to the spring from the west. Uphill from the spring on the opposite side of the trail, there are strong indications of mantled karst topography. Several small sinkholes, including one with observed surface flow entering into it, occur across the gently sloping till blanket north of the spring. The linear trend of the sinkholes is 195°, consistent with the regional structural grain of the carbonate rock throughout the majority of the town. The Surficial Geologic Map of the Town of Dorset, Vermont locates the thin till veneer versus thick till blanket contact just north of the spring at the base of the steer slopes uphill from the mantled karst terrain. The Depth to Bedrock map indicates <20ft to bedrock at the spring. The Hydrogeologic Units Map indicates the major Taconian thrust fault that separates Taconic Sequence (TS) slate and phyllite with minor interbedded carbonate and quartzite from underlying carbonate rocks with interbedded quartzite of the Champlain Valley Sequence (CVS) lies just above this spring. The spring is located within the Bascom Formation limestone.

The field geologic setting strongly indicates that flow occurs through karst and the spring is an occluded spring where thick till blankets a karst carbonate rock surface, likely a step or terrace in the carbonate rock below the steeper thin till veneer cover on the slopes of Dorset Hill. The extremely high flow of this spring was estimated in a previous study to be approximately 2000gpm and this high flow typically occurs in conduit flow settings. Of all the observed springs, this spring had the highest observed flow. The hydrology of this spring is likely that of groundwater flow through solutionally enlarged conduits with a possible primary conduit oriented approximately 195° immediately uphill from the spring as indicated by the direction of minor karst features in the terrain up hill from this spring. The role of the major thrust fault in the hydrology of this spring is uncertain. However, it may contribute to the location of this spring by providing a base below which the infiltrating waters on Dorset Hill cannot penetrate.

Gilbert Brook Spring

Field observation to reconcile GPS data places this spring at an elevation of approximately 1470 +/-40ft. The setting is of very high flow emanating from the base of 2 adjacent steep, classic spring headed gullies 12-20ft high. A 3rd spring headed gully to the east is currently dry; yet, this gully is the largest of the 3 gullies and suggests it was the initial spring site. Most flow currently comes from the center gully with a substantial flow coming from the third or western gully, primarily from the gully flank adjoining the center gully. On one occasion, moderate flow was observed coming from the head of the western gully; on another occasion, this gully head was dry and flow was coming through the gully flank between the western and center gullies. These characteristics suggest that flow has shifted from the first or eastern gully to the second or center gully. The third or western gully appears to be siphoning flow from the center gully and carries more flow at higher flow times while the center gully appears to carry steady flow. Flow is estimated to exceed 1000gpm based upon visual comparison with the Cold Spring and McNamara Spring.

The center gully head appears to be bedrock. The base of the gully face exposes a dark gray, thinly laminated, very soft, weathered, dolomitic rock. The rock is fractured and appears to be loosened due to weathering which may have slightly displaced the rock from a true orientation. Nevertheless, the carbonate rock has a strike of 323° and a NE dip of 37°. Surficial geologic mapping places the thin till veneer over thick till blanket contact just south of the spring at the base of the steeper slopes along the ridge dividing Gilbert Brook from Goodman Brook. The area around the spring shows no obvious signs of karst topography as the slopes consist of a smooth till blanket. The carbonate rock at the spring has open near vertical fractures and open flow was observed along the intersection of one vertical fracture and the bedding plane of the rock. The fracture orientation could not be measured but appears to be approximately parallel to bedding strike.

A seep was noted far to the west of the spring at an elevation of approximately 1750ft along the high south bank of Gilbert Brook. During one visit during a dry period, Gilbert Brook upstream of the confluence with the spring outflow was nearly dry. During another visit after a wet summer period, Gilbert Brook flowed along its entire length from the middle slopes of Spruce Peak to the west.

Down stream from the confluence of the spring outflow with Gilbert Brook, the brook has eroded a rugged and steep valley into thick till with no rock outcrop. At Cabin Falls, just northwest and upstream from the Dole residence, Gilbert Brook flows through a narrow carbonate rock gorge with a stepped waterfall. The rock here is the same dark gray and thinly laminated dolomitic rock as at the spring. However, the rock strikes 035° and dips SE at 11°.

The spring is at the thick till versus thin till contact. The Depth to Bedrock map confirms the spring is in an area with <20ft of overburden. The Hydrogeologic Units map places this spring very close to but slightly above the inferred position of the major Taconian thrust fault. The high flow of this spring indicates conduit flow through karst bedrock. The geologic setting strongly indicates the spring is an occluded spring where thick till blankets the underlying carbonate rock but has eroded spring headed gullies which are now exposing the underlying rock. The spring is at or very close to the contact between thick and thin till. Flow at this spring has apparently shifted westward over time. Flow is migrating up the dip of the bedrock but the down dip dry eastern gully appears to head at a higher elevation than the center and western gully heads. Thus, flow in the underlying bedrock appears to be shifting over time in response a lowering base level indicated by the gully heads, despite implying flow has migrated up the dip of the bedrock. In conclusion, the hydrology of this spring is likely that of groundwater flow through solutionally enlarged conduits with a primary conduit oriented along bedrock strike nearly N-S immediately uphill from the center spring. The apparent association of this spring with the thrust fault is similar to that for Cold Spring. The spring is located within carbonate of the Brezee Formation.

McNamara Spring

Field observation and GPS data place this spring at an elevation of 1255 +/- 40ft. In an earlier report, the State of Vermont estimated the elevation of the spring to be 1225ft. Field observation alone suggests an elevation of 1240ft while GPS data places the spring at 1270ft. The setting is of very high flow emanating from the base of a steep, classic spring headed gully approximately 10-14ft high. Flow was reported in an earlier report by the State of Vermont to be 900-3400gpm with a proven flow of 3000gpm (VT, 1992, 1993). A reservoir has been scraped into the overburden and masks the actual spring flow from the base of the slope. No outcrops were observed near the spring. The area up hill from the spring flattens to form a hummocky till or ground moraine terrace. This terrace extends westward to the base of the steep slopes of Mother Myrick Mountain. The thin till veneer over thick till blanket contact has been mapped along this slope break. The surficial sediment along the terrace above the McNamara Spring is notably more variable in texture than at either the Cold Spring or the Gilbert Brook Spring. There is sandy till on the terrace above the McNamara Spring not observed at the other 2 springs. This sandy till is the northernmost extension of the complex ground moraine sediment mapped on the Manchester quadrangle (De Simone 2004, 2005).

Becker (1984) noted this spring occurs near the contact between the Bascom and Shelburne formations. Revell (1991) has studied the geology of this spring and suggests flow occurs in a conduit setting in carbonate bedrock, perhaps along the Shelburne-Bascom contact (Revell, personal communication, 2006).

In addition, Revell (1991) shows a thrust fault contact near the spring. Although this thrust fault is shown on the 1961 Centennial Geologic Map of Vermont, it is not shown on the forthcoming bedrock map or on the 1:62,5000 scale map of the Equinox Quadrangle from 1961.

East of the spring at a much lower elevation of approximately 1000ft, the rock bedding strikes 330° and dips 15° SW while south of the spring the bedding at an elevation of approximately 1200ft strikes 22° and dips 30° NW. Revell (1991) shows fracture traces in the region oriented NE-E and NNW.

The slopes of Mother Myrick Mountain west of the spring may exhibit some evidence for karst topography. Revell cites the likely occurrence of conduit flow in a karst setting for this spring. Based upon the high flow of the spring, this seems likely.

The geology of the spring strongly indicates the spring is an occluded spring where thick till, locally sandy and permeable, blankets the underlying. The Surficial Geology map indicates the thin till contact is at or very near to the spring. The spring occurs in the Bascom limestone, close to the contact with the Shelburne Fm.. The Depth to Bedrock map indicates <20ft to bedrock in the area. The hydrology of this spring is likely that of groundwater flow through solutionally enlarged conduits with flow to the surface occurring at or near the thick till-thin till contact within the Bascom limestone. A final conduit to the surface may be oriented approximately parallel to the 022° strike of the nearby bedding and nearly parallel to one prominent fracture direction.

Evans-deKnotbeck Spring

Map and GPS data place this spring at an approximate elevation of 1200 +/- 40ft. The setting is of very high flow emanating from the base of a steep slope littered with angular boulders and cobbles. Flow is estimated from the rate observed sinking into a sinkhole up gradient of the spring and by comparison of this flow with the flows of the other third order springs discussed above. There is a reservoir which masks the actual spring flow. The location of the spring is down hill from the location on a previous map (Becker, 1984). The intervening terrain consists of a strongly karst rock terrace with numerous small sink holes and a stream which sinks vertically into a sink hole to emerge again at the final spring. There is no spring headed gully here as the spring emerges from the base of a steep and high slope that appears to be very thinly mantled rock. It is presumed that the earlier spring location was at an uphill spring along the same sinking stream and not at the final spring whose outflow then remains at the surface until its confluence with South Dorset Brook.

The strongly developed karst topography between the upper and lower springs here was an eye-opening observation. This is the most strongly developed karst seen by the author in our region outside of the prominent karst and commercial caverns of Albany and Schoharie County, NY. The upper spring apparently spills out of thin till at the base of a steeper slope. The stream soon sinks down a vertical sinkhole that appears to have formed at the junction of 2 prominent fracture directions. The limestone pavement that the sinking stream flows across is stripped of overburden and shows evidence of dissolution along fracture planes.

Prominent near vertical fractures in the carbonate rock are oriented NNW, nearly parallel to the strike of the beds which generally dip at low angles on the exposed rock terrace. The till veneer on this rock terrace is exceptionally thin and is attributed to erosion by ice marginal melt water combined with meteoric water from Kirby Hollow Brook. Removal of the till blanket along this section of carbonate rock pavement was a localized event as the till is thick at comparable elevations along the base of the mountains to the west and east or the till is covered by ice marginal melt water deposits forming several stepped kame terraces. Here, however, melt water has scoured the rock pavement nearly clean of overburden and exposed the karst terrain. There is strong evidence of solutional weathering of the rock across the top of the plateau.

The geology of the spring strongly indicates flow through karst carbonate rock and the final spring is an occluded spring where till and a lag of boulders masks the rock. The hydrology of this spring is verifiably flow through solutionally enlarged conduits with the primary conduit orientation approximately NNW to SSE along the strike and major fracture direction in the rock. The spring is within the Bascom limestone but is located far below the major Taconic thrust fault.

Walker Lot Spring

GPS data places this spring at an approximate elevation of 855 +/- 60ft. Field observation locates the spring an elevation of 900ft +/- 20ft. The spring outflow forms a perennial stream which flows along the access trail to the spring.

The setting is of high flow issuing from the base of a 10-20ft high steep slope which has a lag of moss covered cobbles and a few boulders along the outflow. Above the spring is a depression which is aligned with the general strike of the carbonate rock. The depression may be an abandoned melt water channel, a dry former distributary channel of Mad Tom Brook, or a collapsed conduit in-filled with overburden. The topography above the spring and to the east consists of a terrace underlain by sand, gravel and cobbles which likely represents a ground moraine or kame terrace. Higher still, the terrain becomes very steep and the slope consists of thick till. The sediment on the slope of the spring is likely till modified by slumping on the steep face of the slope. Farther north and east of the spring is Mad Tom Brook which flows out of the mountains generally from east to west but hooks to the south along the western side of the spring.

The spring is within the area mapped as carbonate rock of the Dalton Formation. The contact with the Cheshire quartzite is to the east. Carbonate rock outcrops north, west and south of the spring at distances of 3000-5000ft from the spring and bedding strikes 007-033°. The rock dips moderately steeply westward and folding can be seen in the outcrop nearest to the spring on the north. More recent bedrock mapping (USGS, 2006) indicates the presence of a thrust fault along the boundary between the carbonate rocks and the Cheshire and Dalton formations to the east.

The Depth to Bedrock map indicates the spring is in an area of <60ft overburden.

The high flow of the spring suggests possible flow through karst carbonate rock and the spring is an occluded spring where till capped by ice marginal permeable sediment obscures the underlying rock. However, the high flow could also indicate the spring is receiving flow from the bed of Mad Tom Brook to the north and that spring flow is shallow and confined to the permeable sand and gravel of the fan sediment and ice contact sediment that caps the till here. If the spring has this more shallow and overburden based groundwater source, then the spring would likely fluctuate in its discharge along with the fluctuating discharge of Mad Tom Brook. Monitoring of the spring flow might address this question. Additionally, monitoring of stream and spring temperatures might contribute useful data as to the origin of the flow. Warmer temperature than other more definitively bedrock sourced springs and/or fluctuating temperatures with the seasons would support a shallow overburden source of the flow.

Walker Lot spring does not fit the similar geologic settings of the Cold, Gilbert Brook and Evans-de Knotbeck springs in having a positive correlation with a thick-thin till contact, occurrence in the Bascom limestone and confirmed or inferred karst conduit conditions.

Dorset Fire District Spring

Map and GPS data confidently place this spring at an elevation of 1250 +/- 20ft. The setting is of a combined high flow issuing from at least 5 closely spaced sources spread along an arcuate shaped shallow gully. Additionally, at least 2 springs at the highest elevations only flow during highest flow times. Inside the spring shelter discharging the apparently highest individual flow, an outcrop or large boulder of carbonate rock is visible. The area between the individual springs has been covered with a blanket of crushed stone to provide better access to the springs for monitoring and maintenance of equipment. The area around the spring is underlain by till. The reservoir below the spring is sited on a flatter till covered terrace presumed to be underlain by a rock bench.

A large carbonate rock outcrop at the gate to the spring trail and another outcrop a short distance north of the spring reveal the bedding strike varies from 005° uphill from the gate to 335° at the lower elevation of the gate. Bedding dip ranges from 15-30° to the east at the gate below the spring. The outcrop nearest to the spring is too poor to obtain strike and dip but fractures at this outcrop strike 033° with a vertical dip and another set at a strike 334° and dip 83° NE. At the gate, multiple near vertical fracture sets strike generally NW, NE, and E.

The Depth to Bedrock map indicates <20ft of overburden in the area. The Surficial Geology map indicates the spring is in an area of thin till. The Hydrogeologic Units map indicates the major Taconic thrust fault is at or just above the spring and the spring is within the Bascom limestone.

Flow may be in fractured rocks in the thin till veneered slopes above the spring with the outflow directed to the surface along the topographic bench below the spring where the reservoir was sited. This topographic bench may cause the piezometric surface to intersect the ground surface. It is uncertain here if karst conditions exist beneath the site. It is likely the thrust fault plays a role in the hydrology of the spring by delivering waters that infiltrated the rock fractures higher up the mountain slopes to the thrust fault zone or by acting as an impermeable layer or seal above the Bascom limestone.

Ethan Allen Spring

Map and GPS data confidently place this spring at an elevation of 960 +/-20ft. The spring flows upward through mapped outwash composed of sand and gravel. The Surficial Geology map indicates the spring is at the contact between outwash and ice contact sediment but both these units are similar and permeable sand and gravel. The outflow is pooled along the driveway of a residence and flows eastward into a large wetland. The underlying bedrock is mapped as the Bascom limestone and is close to the Shelburne Fm. contact. The Depth to Bedrock map indicates <40ft of overburden present at the spring. Well logs suggest this overburden is entirely permeable sand and gravel.

There were no outcrops within approximately 1000ft of the spring and the association of spring flow with outwash is unmistakable. No outcrop was observed at the spring. There is no appreciable slope at the spring or near the spring. A few water well logs in the vicinity of but not very close to the spring record approximately 20ft of generally permeable overburden atop carbonate rock. Thus, it is likely the depth to bedrock at the spring is approximately 20-30ft, more likely to be closer to 20ft than to 30ft.

The geology of this spring appears to be distinct from the geology of the other springs discussed so far in this study. This spring appears to bubble up through glacial sand and gravel and has no clear association with the underlying bedrock and represents an occluded or overburden spring. However, it must be noted that the spring may be sourced in rock and its occluded nature – flowing upward through outwash sediment – could mask an underlying rock cause for the location of the spring. This is a real possibility due to the inferred 20-30ft depth to rock beneath the spring. If the association with bedrock is real, then this spring would issue from the Bascom limestone and flow up through the permeable overburden.

Recharge to the Ethan Allen spring likely comes from the up-gradient areas to the south and west of the spring extending up slope along the prominent ridge buttressing the lower flank of Mother Myrick Mountain.

General Features for Dorset High Flow Springs

The high flow springs examined in this study have no single common feature. There are common features shared by most of the springs. Most occur at the base of a fairly steep to steep slope developed in till with a nearby contact between thin till above and thick till below the spring. The topographic break in slope causes the piezometric surface to intersect the ground surface and result in subsurface flow being directed to the surface at the locations of these springs. The Walker Lot spring has the topographic slope break but not the thin-thick till contact. The Dorset Fire District spring has the topographic slope break but not the thin-thick till contact. There is no appreciable slope above the Ethan Allen Spring and this spring issues from outwash sand and gravel on comparatively flat terrain.

All of the high flow springs with the exception of the Walker Lot spring have a positive correlation to the Bascom limestone. This rock formation is known to produce high yield wells throughout its occurrence in Vermont. This may be due to its degree of interconnected and developed fractures. If so, this same condition would make the Bascom limestone suitable for development of karst. Karst terrain develops throughout an area of carbonate bedrock where the bedrock exists and the climatic conditions of sufficient precipitation occur. It is inferred that karst topography underlies the mantled carbonate bedrock throughout the lower valley flanks and valley bottom portions of town. The karst topography is largely hidden by overburden. Most springs with such high flows occur in carbonate bedrock and are associated with conduit flow (Davis & De Wiest, 1966).

The Cold, Dorset Fire District and Gilbert Brook springs all occur very close to the major Taconic thrust fault on the Hydrogeologic Units map. All 3 springs are below this thrust fault. The McNamara and Ethan Allen springs are both located very close to the contact of the Bascom and Shelburne Formations. Walker Lot spring is located near to and below a new thrust fault indicated by recent mapping (USGS, 2006).

Implications of high flow springs for potential spring recharge

The possible occurrence of conduit flow for the Evans-de Knotbeck, McNamara and Cold springs implies that recharge to these springs may be coming from a wider area than currently believed. The other springs with a possible association with the Bascom limestone may involve relatively open flow in enlarged fractures, if not in karst.

The delineation of spring recharge areas for each of these high flow springs must take into account the orientation of the rock and karst. The strike and dip of the bedding and the strike of the fractures in the rock within the vicinity of these springs may preferentially carry groundwater toward the springs through the up-gradient portions of the bedrock.

It is possible that recharge to these high flow springs occurs under hydraulic gradients from areas outside of topographic divides traditionally used to delineate spring recharge areas. One model for recharge to the McNamara Spring (Revell, 1991) demonstrates this possibility. While the results of the recharge model necessarily outline a geometric shaped recharge area, the reality is likely a more complicated outline based upon bedding, fractures and karst in carbonate rock.

Work needed at all of the high flow springs

Reliable values of spring discharge must be obtained in order to quantify the approximate area of recharge. Routine discharge measurements are only being made at the Dorset Fire District Spring. Construction of a weir at each of the other high flow springs is necessary to direct spring outflow over a constricted opening in the weir so basic discharge measurements could be obtained (Brassington, 1988). Electronic measurement of discharge across each weir would be ideal but would likely be prohibitively expensive. Therefore, it is recommended that crude measurements of discharge be made at any weir using basic measuring devices such as buckets. Revell (1991) attempted to use a rough approximation of discharge at the McNamara Spring to determine the recharge area of this high flow spring. The calculation techniques of Revell could be repeated for each of the high flow springs once appropriate measurements of spring discharge are available.

More accurate discharge measurements might be made at springs as the occasion arises. Such occasions might be the study of an individual spring as part of a local development or conservation effort. In this instance, it would be most valuable to establish a weir with an automatic recording device to measure discharge. Variations in spring discharge with the change of seasons and with the occurrence of precipitation events would add extremely valuable data that may aid in understanding the source of the spring.

In addition to spring discharge measurements made over a relatively long time period, other techniques to determine spring recharge area should be undertaken. Tracer studies using dyes have proven effective. Dyes can be placed into the ground at different inferred spring recharge sites. Sampling of the spring after dye insertion and detection of the dyes by laboratory techniques for each of the water samples would be done. Repetition of the tracer studies at different distances from the spring can add data that may aid in delineating recharge area extent and shape. Tracer dyes are a comparatively inexpensive technique to assess spring recharge area.

Geology of Individual Springs: Moderate Flow Springs

East Dorset Fire District Spring

This spring is a line of approximately 5 closely spaced springs occurring along the base of a steep bluff at approximately 1150 +/- 30ft. The slope consists of thin till but no outcrops were observed leading up to the spring. However, the slope was covered in relatively angular quartzite boulders suggesting they were deposited by glacier ice and/or came down slope from higher positions along the steep bluff. There is seepage from the till at several places down slope from the spring toward the reservoir which holds the collective spring outflow at an approximate elevation of 1050 +/- 30ft. This reservoir is sited in an area of thick till. Therefore, the thick till contact with the thin till of the steep bluff occurs between an elevation of 1050ft and 1150ft. Spring flow could not be directly observed as all of the flow is captured and piped down hill to the reservoir. Therefore, the estimated flow for this spring and its placement as a 5th order spring is uncertain.

Carbonate rock outcrops occur along Mad Tom Road north of the spring at lower elevations. Bedding strikes N-NE and beds dip 25-35° E. Along Mad Tom Brook to the south of the spring, the bedding strikes N and the beds dip 20-26° E. Farther east along Mad Tom Brook, the rock becomes quartzite at an elevation of approximately 1200ft.

The Hydrogeologic Units map locates this spring in the “1b” CVS rocks, predominantly Cheshire quartzite. The spring is very close to the contact with the CVS carbonate rocks of the valley bottom. Recent work (USGS, 2006) indicates this contact may be a thrust fault.

The Depth to Bedrock map indicates <20ft of overburden along the slopes at the spring, consistent with field observations.

This geologic setting suggests the spring is associated with the contact between quartzite and carbonate rock, whether this contact is a fault or not. The slope between the spring and the spring reservoir is a slightly stepped slope with several minor steps and risers. It is interesting to note that the occurrence of the spring near the contact between the quartzite and carbonate rock along the lower flank of the Green Mountains coincides with an observed area of higher yield wells sited in a similar geologic setting extending from Manchester north through Wallingford and with a similar occurrence of higher yield wells at the same setting in Brandon. These data suggest the quartzite-carbonate contact zone is one with enhanced groundwater flow, perhaps due to an unrecognized higher density of fractures and/or enlargement of fractures in the carbonate due to dissolution near the contact with the quartzite. Alternatively, in view of the recent mapping data (USGS, 2006), the springs and higher groundwater flow from this contact may relate to the presence of a newly recognized thrust fault that may facilitate groundwater flow to the surface.

Recharge to the East Dorset Fire District Spring likely comes from the steep till veneered slopes extending east, east-northeast and east-southeast of the line of springs here. Infiltration through the thin till veneer should be relatively uninhibited and the steep slopes afford a high hydraulic gradient on the flank of the Green Mountains.

Mt. Aeolus Spring

This spring is located at the head of a well defined broad gully at an elevation of 835 +/-20ft. Outflow is collected in a pool at the spring and flows under a trail via a culvert. Flow appeared slow through this culvert and the estimation of this spring as a 5th

order spring is uncertain. The spring occurs at the base of a steep slope developed in an area mapped a thin till. The slope above contains seeps to the north and below Dorset Hill Road. The Depth to Bedrock map indicates <20ft of overburden present.

The Hydrogeologic Units map reveals bedrock to be the Dalton formation. The layers strike N-NNE and dips are generally shallow from 10-20° E. The carbonate knoll east of the spring offers useful data. The top of the knoll has been eroded nearly clean of till by melt water and exposes several small NE trending marble ledges with evidence of solutional enlargement of near vertical fractures.

The geologic setting of the spring indicates a source in the Dalton interbedded carbonate and quartzite rocks with a possible enhancement of flow due to solutionally enlarged fractures as observed in the rock outcrop adjacent to the spring at the junction of Rte 7 and Rte 7A.

Recharge to the Mt. Aeolus Spring likely comes largely from the steep slopes to the west, south and northwest of the spring. These slopes are largely veneered with thin till. The recharge area may extend west to Dorset Hill Road and perhaps across the road. Additionally, minor recharge may flow from the bedrock knoll to the southeast and east of the spring. There is little overburden on the knoll and precipitation can easily infiltrate the rock here, especially through the solutionally enlarged fracture openings observed on the top of the knoll.

Culver-O'Neal Spring

This spring is at an elevation of 740 +/- 30ft along the base of a steep slope composed of outwash sand and gravel sediment on the valley floor. Small kettles are interspersed in the outwash south of the spring and north of Bullhead Pond. The moderate spring flow observed pools at the source in front of a large dead tree and flows as a perennial stream generally eastward across a broad flat sandy alluvium area. The spring outflow joins the Batten Kill a short distance south of the Batten Kill confluence with Little Mad Tom Brook. West of Route 7A is an extensive area of ice contact sand and gravel and an overburden well log in this material records a minimum of 50ft of permeable sediment. No well logs are located closer to the spring and no outcrops were observed within 2000-3000ft of the spring.

The Depth to Bedrock map indicates 40-60ft of overburden present. Well logs indicate this overburden is entirely composed of permeable sand and gravel. The Hydrogeologic Units map indicates the underlying bedrock is the Dalton formation. This geologic setting suggests the Culver-O'Neal Spring is most likely an occluded overburden spring developed in permeable outwash sediment composed of sand and gravel.

Recharge to the spring most likely comes from the up-gradient ice contact sediment to the west, west-southwest and west-northwest of the spring, perhaps including some or all of the South Village Cemetery. Additionally, recharge may be coming to the spring through the outwash south of the spring extending to the drainage divide along the old access road to Bullhead Pond. An intervening small kettle may disrupt direct recharge from the high outwash south of the spring although this kettle may be at a higher elevation than the spring and still serve to direct groundwater flow toward the spring. Accurate elevation data obtained by surveying techniques would be needed to answer this question.

Colonel Lane Spring

Map and GPS data place this spring at an elevation of 1300 +/-20ft adjacent to the home at the end of Colonel Lane. A small basin has been dug to collect the spring flow and the spring provides water to the adjacent house. The spring is along the base of a steep slope to the east becoming a more moderate slope north and slightly west of the spring. A shallow and dry depression extends northeast from the spring. The overburden consists of thick till blanket exposed west of the spring. The exposure reveals a weathered section of bouldery lodgement till, weathered and oxidized to an orange brown color. The matrix is silty with minor sand and the boulders and cobbles are sub-angular to sub-round in shape.

The Hydrogeologic Units map reveals this spring is at the contact between the Dalton formation and the Cheshire formation and the above discussion related to the East Dorset Fire District spring applies. The Depth to Bedrock map indicates <20ft of overburden present. The Surficial Geology map indicates the spring is at or very near the thin-thick till contact.

Recharge to the Colonel Lane Spring likely comes through the thin till veneer along the flank of the Green Mountains to the east and possibly extends a long distance up this slope and east-northeast along the shallow depression leading uphill from the spring. Two outcrops below the spring along Mad Tom Road provide data for the local orientation of bedrock. Strike ranges from 014-022° with dips ranging from 25-35° east. One fracture set parallels strike; another is oriented at 340° and crossing fractures strike at 085° and 040°. All fracture planes dip more than 80°.

Owl’s Foot Spring

This spring has been referred to as the Owl’s Head Spring and the South Dorset Spring in older reports. However, accurate placement using map and GPS and aerial photo data locate this spring at an elevation of 1320 +/-40ft within the proposed Owl’s Foot development. The spring outflow passes via culvert under the development road. The spring is most readily accessed from the end of the Lot #6 driveway. The driveway trends approximately 330° and parallels the spring outflow. The spring flows from beneath a large boulder in thick lodgement till at the base of a steep 10-16ft high slope in the till. The spring has formed a traditional spring headed gully here. Outflow is exposing fresh lodgement till along a shallow step in the topography below the spring. The outflow has formed thin limy concretions atop the lodgement till and suggests a carbonate bedrock source for the groundwater. No outcrops were observed within the development area but a carbonate rock exposure was observed along the trail leading up Owl’s Head from the end of the development. This outcrop has a strike of 350° and dips east at approximately 10°. A small seep occurs above the outcrop in the thin till along the trail.

The Hydrogeologic Units map indicates the spring occurs within the Bascom limestone and is near to the contact with the Shelburne formation. The spring shares a geologic setting similar to the McNamara spring.

The Depth to Bedrock map indicates <20ft of overburden present. The Surficial Geology map indicates the spring is at or very near to the thin-thick till contact. This geologic setting suggests a source in Bascom carbonate rock and a location where the piezometric surface intersects the ground surface along a break in slope. This is an occluded spring developed in till overburden along a thin till contact with thick till which occurs at a distinct break in slope in the topography.

Recharge to the Owl’s Foot Spring likely comes from the thin till veneered slopes extending upward from the spring to the north and northeast and east. The NNW-N strike of the bedding suggests a possible stronger component of recharge coming from bedrock in a general northerly up slope direction. There are insufficient fracture data to suggest additional preferred flow directions in the underlying bedrock.

Historical Parsons Spring

This spring is at an elevation of 1320 +/- 40ft just east of Mad Tom Road and is the largest of several small springs which flow from the gently west sloping portion of the alluvial fan of Otter Creek. Dave Parsons reports the spring flow declines by as much as 50% during the dry season but flows year round. This is the original Parsons family spring that was developed by Dave Parsons' grandfather more than 70 years ago to supply water for the family needs. The springs and seeps collect at the road elevation and flow into Otter Creek to the south of the main spring. Otter Creek can be heard in the distance east of the spring.

The spring flows from a relatively flat terrain composed of alluvial gravel, sand, silt, cobbles and boulders deposited as an alluvial fan by Otter Creek. The spring is at approximately the same elevation as Otter Creek. The sloping terrain above the alluvial fan is composed of thick till.

The Hydrogeologic Units map indicates the Dalton formation underlies the spring. The Depth to Bedrock map indicates 80-100ft of overburden present.

This geologic setting indicates this is an overburden water table spring likely hydraulically linked to Otter Creek. It is possible that water seeps through the bottom of Otter Creek to the east of the spring and some of this groundwater flows out along the west sloping surface of the alluvial fan. The fan sediment may be relatively thin here and likely caps a thick till blanket deposited along the flank of the Green Mountains. Therefore, recharge to this spring must take into account all up slope portions of the alluvial fan and till and also a possible strong component of recharge coming from the bottom of Otter Creek.

The Historical Parsons Spring described here is different from the Parsons Spring mentioned in earlier reports. That spring is situated on the opposite side of Otter Creek and up slope from the Historical Parsons Spring. It is recommended that the designation Parsons Spring be used only for the Historical Parsons Spring and that the more newly named Parsons spring be re-named.

General Features for Dorset Moderate Flow Springs

The Culver-O'Neal Spring flows from permeable outwash sediment. It is considered to be an occluded overburden spring not positively associated with a bedrock water source. Smith (1989) incorporated the results of the Becker (1984) spring study and noted the likely presence of overburden aquifers in both valleys in the Town. The Culver-O'Neal Spring demonstrates the viability of overburden aquifers as a water resource.

The Historical Parsons Spring flows from permeable overburden represented by alluvial fan sediment overlying an impermeable till. Thus, 2 of the moderate flow springs are related to an overburden groundwater source and not to a bedrock groundwater source.

The East Dorset Fire District Spring, the Mt. Aeolus Spring, the Owl's Foot Spring and the Colonel Lane Spring all share a common setting of being located at the base of a steep slope composed of till. The Owl's Foot and Colonel Lane springs are situated near or at the mapped contact between thin till above and thick till below the spring. The East Dorset Fire District and Mt. Aeolus springs are within an area mapped as thin till. The topographic break in slope for these 4 springs allows the piezometric surface to intersect the ground surface and produce a spring.

Discussion of common elements in Dorset springs

A brief analysis of the combined high and moderate flow spring geologic settings offers some insights into the general occurrence of significant springs in Dorset. While no single common element is shared by all of the springs, some features are shared by many of the springs and possibly account, in part, for the occurrence of the spring. The most commonly shared feature of these springs is a prominent tendency for them to occur at the base of a topographic break in slope. This topographic element brings the piezometric surface to an intersection with the ground surface. Remember, the piezometric surface is the surface to which water will rise to in a well or if naturally allowed to flow, as in a spring.

Many of the springs occur at a break in slope where the Surficial Geology map indicates there is a thin-thick till contact. Numerous minor springs and seeps also occur along this same contact. The latter may relate to shallow groundwater flow reaching the surface at the base of a steep slope where thin till becomes thick till.

Occurrence of springs in specific lithologies or along formation contacts

The Cold, Gilbert Brook, McNamara, Evans-de Knotbeck, Ethan Allen and Owl's Foot springs occur in the Bascom limestone. Further, the McNamara, Owl's Foot and Ethan Allen springs occur near the contact between the Bascom and Shelburne formations. Note, however, the Ethan Allen spring may be an overburden spring that coincidently occurs in sand and gravel that overlies the Bascom limestone in the valley bottom.

The East Dorset, Colonel Lane and Walker Lot springs occur along the Dalton-Cheshire formation contact. Note, however, the Walker Lot spring may be an overburden spring. A few minor springs and seeps also occur along this Cheshire contact. It has already been noted that this contact is a region of higher yield wells based upon mapping in other locations in the Vermont Valley.

Occurrence of springs in association with thrust faults

The Cold, Gilbert Brook and Dorset Fire District springs occur at or just slightly below the major Taconic thrust fault that separates the TS rocks above from the CVS rocks below the fault. The fault is likely an impermeable surface. Groundwater infiltrating the TS rocks above the fault may not be able to flow through the fault plane into the rocks below the thrust fault. Consequently, groundwater may flow laterally and emerge at the surface as a spring where other conditions such as topography and a thin-thick till contact permit. The Upper Spring along the flank of Mt. Equinox to the south is in a similar geologic setting.

It has already been discussed that recent mapping (USGS, 2006) indicates the contact between the Dalton and Cheshire formations, basically, the boundary between "1" and "1b" on the Hydrogeologic Units map, may be a newly interpreted fault. If true, then there may be an interesting enhancement to our understanding of the occurrence of the East Dorset Fire District and Colonel Lane springs along with the numerous minor springs and seeps at this same contact.

Geologic mapping is an ongoing process and as more data accumulate, the interpretations change. This is the basic nature of science and has proven illustrative in the discussion of several springs. The McNamara, Owl's Foot and Ethan Allen springs all align approximately with the Bascom-Shelburne contact which has been interpreted as a stratigraphic contact (1961, 2006) and as a fault contact (Doll, 1961). However, this fault is not interpreted to exist along the Bascom-Shelburne contact across the valley bottom on the more recent mapping of the USGS.

Recommendations

***Discharge measurements -** More accurate discharge measurements need to be made at springs. It would be most useful to establish a weir with an automatic recording device to measure discharge. Variations in spring discharge with the change of seasons and with the occurrence of precipitation events would add extremely valuable data that may aid in understanding the source of the spring.

***Tracer dyes -** In addition to spring discharge measurements made over a relatively long time period, tracer dye studies to determine spring recharge area may be attempted. Different dyes can be placed into the ground at inferred spring recharge sites. Sampling of the spring at hours to days or even weeks after dye insertion would be necessary. Detection of the dyes by laboratory techniques would need to be done for each of the water samples. Tracer dyes are a comparatively inexpensive and effective technique to assess spring recharge area, especially if there are dye introduction sites already available. However, small diameter drilling can be done at a relatively low cost compared to water well drilling and could serve as tracer dye input sites.

***Recharge areas -** Delineation of potential recharge areas for high and moderate flow springs is problematic due to a lack of accurate discharge measurements. General recharge considerations apply to these springs. Any open conduit or enlarged fracture flow necessitates the potential recharge area for these springs may greatly differ from currently delineated recharge areas. New recharge area outlines will not necessarily follow topographic divides currently used. Models of recharge areas based upon calculations will improve our estimation of potential recharge area size but not recharge area shape. Bedrock data for strike and dip of layering and fracture orientation should be incorporated into models of recharge area extent to produce an outline of recharge area shape that best reflects bedrock structure. Determination of potential recharge area shape needs to incorporate the results of this thorough geologic investigation of each spring. Data from surficial mapping needs to be added to other existing structural and lithological bedrock data in order to determine the best possible outline of potential recharge area for each spring. A mechanism to mesh the surficial and bedrock data for the springs still needs to be determined and this process awaits spring discharge data availability.

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