Aquifer Analysis:

A Comparative Study of Five Springs

by Mac Harman '98

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Introduction

This study is being made under the auspices of ES 102, "Introduction to Environmental Science," a class offered by the Center for Environmental Studies at Williams College in Williamstown, Massachusetts. The purpose of this project is to quantitatively collect and analyze water samples at five springs near Williamstown to qualitatively interpret the geologic contexts of their sources. The interpretation of laboratory chemical analyses is being made with respect to field observations of the springs and surrounding surficial geology as well as with respect to topographic and bedrock maps of the area.

Setting and Spring Locations

The Center for Environmental Studies at Williams College is situated in a valley surrounded by both the Green and Taconic Mountains. This project centers around the College's Hopkins Memorial Forest, a 2,400 acre research forest located to the northwest of campus. In addition to encompassing land in three states, the forest spans from the Hoosic River Valley to the Taconic Crest -- an increase in elevation greater than 550 meters (Dunlavey 1994).

The bedrock geology of the area is complex and littered with westward thrust faults as a result of the Taconic Orogeny 470 million years ago. The Taconic thrust sheets lifted phyllite bedrock lithified during the Late Proterozoic Period above the Cambrian Stockbridge Formation, a formation of marble lithified approximately 500 million years ago. The Dalton and Cheshire formations of quartzite -- lithified during the Late Proterozoic and Lower Cambrian Periods (500-900 million years ago) -- are also exposed in the area, notably on the summits of Stone Hill and Pine Cobble. All of these formations were subject to the effects of widespread glaciation most recently during the Pleistocene epoch (0.01-1.6 million years ago); furthermore, at elevations lower than approximately 400 meters, glacial sedimentation further obscures the landscape that once contained Lake Bascom's glacial meltwaters. (Harman 1994, USGS, Ratcliffe)

The five spring sites under consideration are expected to represent a diversity of qualitative differences. The Route 7 Spring as well as the Taconic Crest Spring are easily-accessible examples of low-flow, high elevation springs assumed to be flowing from the phyllite of the Taconics. These two springs are complimented by the Outlaw Cabin Spring, which is slightly lower in elevation and much greater in flow than the other high elevation springs suspected to flow from phyllite.

The fourth spring site has been referred to as the Perrier Spring, Watercress Spring, and Mac's Spring, but will be known in this paper as the Northwest Hill East Spring (NW Spring). It is located on the edge of the east face of Northwest Hill near the Hoosic River, and is suspected to be flowing from calcitic bedrock. David Dethier proposed that I consider this spring not because of its inaccessibility (I think), but rather because it -- as well as the Outlaw Cabin Spring -- has never been chemically assessed prior to this project. Finally, Sand Spring, though it has been analyzed many times in the past, is the final spring in the project. It is assumed to be a deeply plumbed thermal spring that is flowing out of bedrock lithified during the Lower Cambrian Period.

Methods

Water samples were collected in 500 cc polyethylene plastic bottles from the springs on three dates in April, 1995, and were subsequently stored in a cold room until they were analyzed in a laboratory on various dates throughout April, 1995. "Splits" -- or identical samples -- were collected at least once for each spring site and subsequently analyzed to allow for calculation of error. Observations were recorded at the springs as to their size, temperature, relative flow, and surficial geology. Temperature was measured with either a Hach digital pH meter or a Hach digital conductivity meter. Flow observations are mainly relative; as the Williams College portable weir committed suicide during the project, flow measurements were taken by measuring the time taken for a 500 cc bottle to fill at various places in the discharge of the springs. These flow measurements are highly unreliable, but the field observations should be fairly accurate as they were conducted within a short interval of time.

The samples were analyzed in the laboratories of Williams College. pH was measured on a digital pH meter, and acid neutralizing capacity (ANC) was determined by adding sulfuric acid (either 1.6M or 0.16M) to titrate the samples to pH 4.5. Specific conductivity was measured with a Hach digital conductivity meter, and the samples were filtered through 0.45 μm filters prior to their testing for specific ion concentrations. The samples were diluted tenfold and run through an atomic absorption spectrophotometer to quantify their sodium, potassium, calcium, and magnesium cation concentrations. Both the dilutions and the straight filtered samples were run through an ion chromatograph to quantify their fluoride, chloride, nitrate, phosphate, and sulfate anion concentrations.

Results

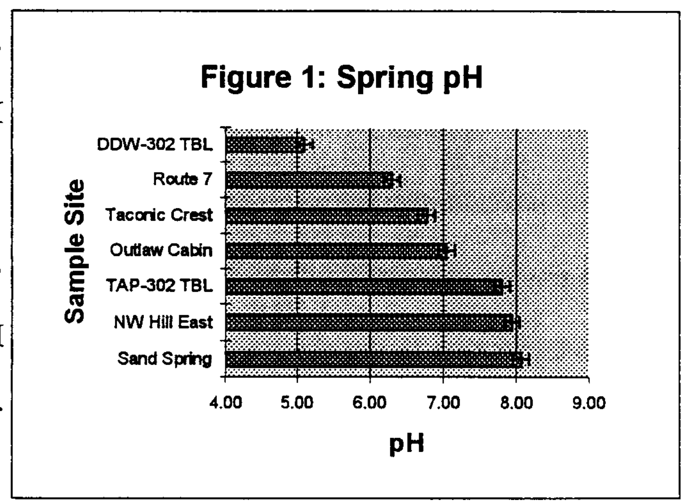
Appendix 1 (page 27) plots the location and elevations of the five springs on a Williams Outing Club map of the area. Appendix 2 (page 28) charts the complete data for the nineteen water samples, adjusted for repeated pH and ANC runs to ensure accuracy. It should be noted that pH values of the second series of samples (with the exception of BU3, the second series samples end in a number equal or greater to 3) are slightly and consistently lower than the first series due to overzealous pH stabilization time allotted in the laboratory. Though this slightly affects ANC, it is insignificant in the averages for the sites which are presented in Appendix 3 (page 29). Both Appendices 2 and 3 include DDW and tap water as references; these controls were analyzed in the laboratory by the entire ES 102 consortium in March, 1995.

An important result that is not recorded with the raw data in the appendices is the outdoor temperature on the three days during which samples were collected. Temperature varies throughout the elevations at which the springs are located, but in general, the temperatures were as follows: April 8, 0°C (accompanied by a light snow); April 12, 10°C; and April 25, 18°C.

Complimented by pictures, field sketches, and topographic maps, the above data is presented graphically throughout the discussion section below. Where appropriate, error bars are plotted from average deviation as calculated in Appendix 4 (page 30) from the splits.

Discussion

As the five springs sites are already selected with respect to their anticipated bedrock types, the chemical analyses of the water samples is the starting point for comparison of the five springs. Figure 1, a plot of spring pH (right), visually contrasts the differences in pH among the five springs and two standards. All of the springs have a pH greater than 6, much more alkaline than the average pH value of regional precipitation, 4.4 (Dethier et al 1992), or local soil, 4.5 (ES 102 1995).



With the exception of the two low-flow, high elevation suspected phyllite springs, the pH values are neutral or slightly alkaline.

Figure 2:
Spring Temperature

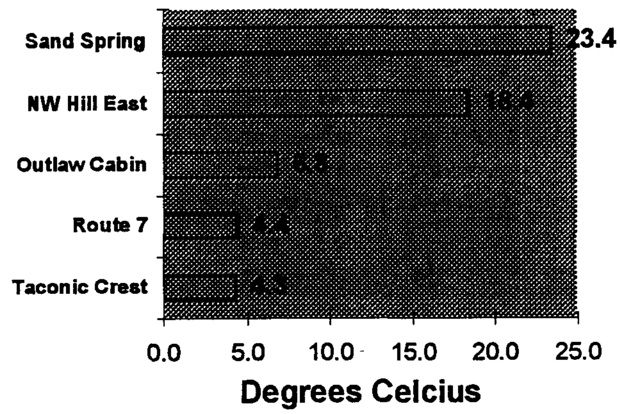


Figure 2, right, is a plot of spring temperature. The cold, variable temperatures of both the Route 7 and Taconic Crest Springs suggest that they are not deeply plumbed but rather are either outlets for throughflow or for shallow perched watertables. For example, over a period of thirteen days, the temperature of Taconic Crest spring water had increased from 4.1°C to 4.7°C. This increase is proportional to outside temperature (during the thirteen days, the sporadic snowcover remaining on the crest had melted, and the outside daily temperature had increased by approximately 8°C) and reveals that the spring is a shallow one.

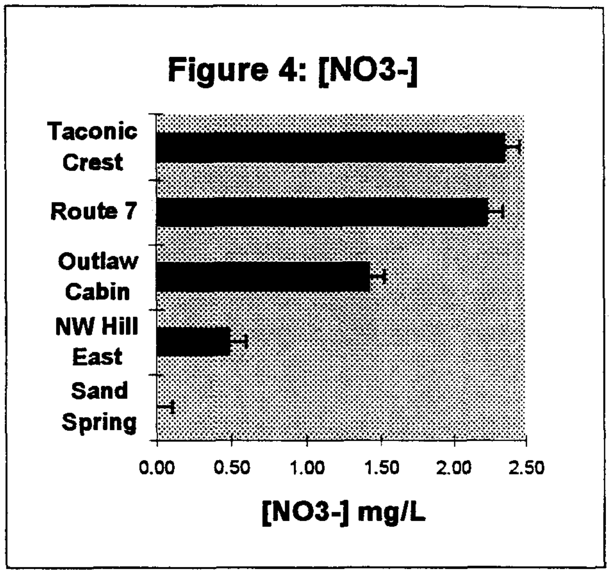
Figure 3 (below) includes pictures of the two Taconic Crest Springs. In both cases, the water is flowing down and outward from a slope of till rather than upward. These observations suggest that the springs are not flowing up from a perched watertable, but rather are throughflow outlets for their respective watersheds. Though precipitation events during the period studied were too few to measure flow fluctuations with respect to precipitation, it is evident from field observations that the flow is not constant. The proportional increase between spring water and

Figure 3:
Springs of the Taconic Crest

The Taconic Crest Spring, pictured at left, flows west out of the slope from assorted cobbles into a small pool built up from phyllite. The pool is approximately 50cm in diameter and 4cm deep. The Route 7 Spring, pictured at right, flows out of a $2m^2$ region of phyllite-rich soil and drips down into a small natural pool. The pool is covered with a 4' by 4' sheet of waferboard and is drained by a black plastic pipe so that the water is easily accessible to Route 7 passersby. The steel drain feeding the black pipe is visible in the middle of the pool.

Taconic Crest Spring **Route 7 Spring**

outdoor temperature as well as a fluctuation in flow substantiates the hypothesis that the springs are simply throughflow outlets.



The low pH also suggests that the water flowing from these springs is not part of a large water table; for it is more similar in pH to the acidic precipitation and acidic soil of the area than to water neutralized by prolonged exposure to bedrock. Regional precipitation is known to be contaminated with "substantial amounts of SO_4 and NO_3 derived from combustion products" (Dethier et al 1992), and the plot of NO_3^- concentrations [Figure 4, above] shows that these two springs are significantly higher in NO_3^- concentrations than the other springs. These data support the hypothesis that the two springs are influenced more by NO_3^- deposition in the soil than by a bedrock aquifer.

The acidic pH combined with the cool, variable temperatures of the springs lead me to conclude that they are not deeply plumbed into phyllite bedrock but rather are outlets for throughflow; yet how do these characteristics compare to the Outlaw Cabin Spring that is also suspected to be flowing from the parent phyllite material? The Outlaw Cabin Spring is different in many respects: it has a much greater flow (in fact it starts a large stream [see Figure 5, below]), it is located at a lower elevation, and as can be seen in Figures 1 and 2 (above), it has a near neutral pH and a temperature of 6.8°C.

The perhaps surprising element of the Outlaw Cabin Spring is that its temperature is constant. 6.8°C is far from a value that is high enough to suggest that the spring is deeply

Figure 5:
The Outlaw Cabin Spring

The Outlaw Cabin Spring, above, starts a large stream as it emerges from a two-meter-wide line of fine phyllite till.

plumbed, but the fact that it is constant through an outdoor temperature change of 18°C reflects that the spring is flowing from an aquifer rather than serving as an outlet for throughflow. Furthermore, the spring is flowing upward from a line of fine phyllite till two meters in width [Figure 5, above] rather than downward out of a slope. The constant temperature and high-volume upward flow lead to my conclusion that the spring is an outlet to a perched watertable in the phyllite bedrock. The hydraulic head provided by the crest of the Taconics is probably forcing the water out of the aquifer through a fracture in the phyllite, which explains the line of till from which the water flows.

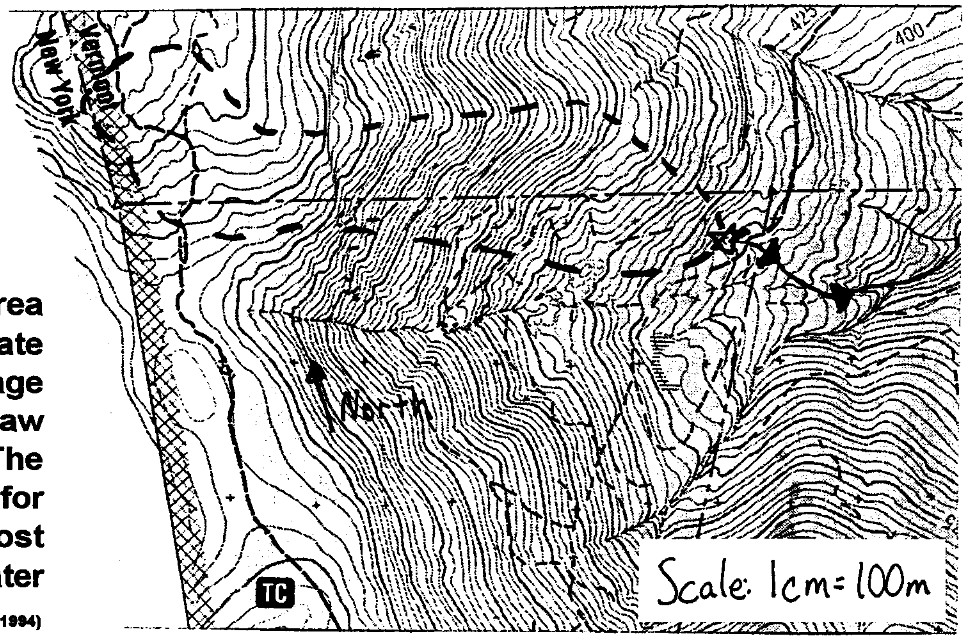
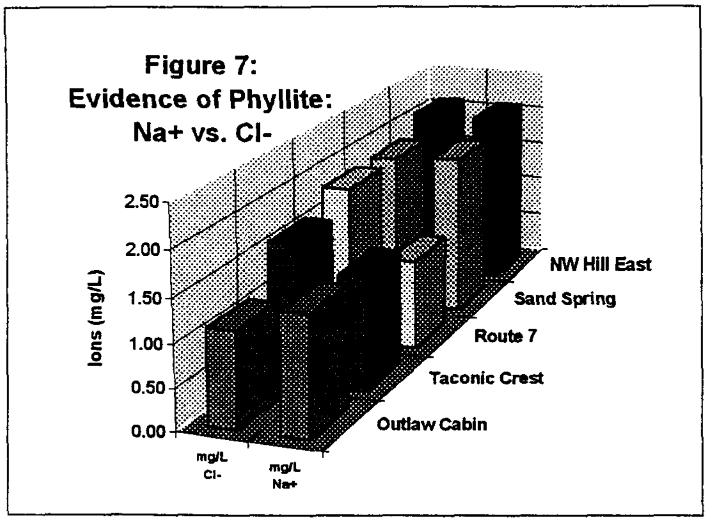


Figure 6: Outlaw Cabin Spring Drainage

The enclosed area is the approximate area of drainage for the Outlaw Cabin Spring. The recharge area for the aquifer is most likely much greater in area. (Map - Dunlavey 1994)

This hypothesis is further supported by the topography of the area: Figure 6 (above) outlines the theoretical drainage of the spring, which is not large enough to produce the high flow of the spring (visible in Figure 5, page 9) when compared to field observations of surficial streamflow in adjacent drainages. The presence of dry or nearly dry stream beds surrounding the area of the Outlaw Cabin Spring further suggests that with the exception of spring run-off and thunderstorms, much of the precipitation recharges the perched watertable and flows through the Outlaw Cabin Spring as hypothesized above.

Although flow fluctuation data is difficult to quantify for this spring, regardless of whether there was a fluctuation in flow during the seventeen day observation period, this spring is definitely a high volume aquifer which is only slightly affected if at all by precipitation events. In addition to this observation, the hypothesis that this spring purges a perched watertable confined by phyllite bedrock is supported by its near neutral pH. If the spring merely drained throughflow



from the above watershed, not only would it have a fluctuating and lower volume flow, it would be expected to have a more acidic pH.

Finally, this hypothesis is also supported by a comparison to the other Taconic springs (Taconic Crest and Route 7). In contrast to their variable temperature and acidic pH, the Outlaw Cabin Spring has both a constant temperature, a near neutral pH, and a chemical signature of prolonged exposure to phyllite. A spring in contact with phyllite bedrock is expected to have low Cl^- concentrations and medium to high concentrations of Na^+ (Dethier); Figure 7 (above) shows that this is the case for the Outlaw Cabin Spring, but is in fact the opposite for the other two Taconic springs which were expected to flow through aquifers confined by phyllite bedrock. Therefore, Figure 7 supports both the conclusion that the Outlaw Cabin Spring discharges a perched water table as well as the conclusion that the other two Taconic springs are outlets for throughflow rather than phyllite aquifers.

In contrast to the high elevations and obscure locations of the Taconic springs, Sand Spring flows from the Williamstown valley at an elevation of 230 meters above sea level. "The Waters of Sand Spring" are now commercially bottled and have been exploited for over a century. The bottlers claim that the spring maintains a flow of 400 gallons per minute and a constant temperature of 72°F (22.2°C). The temperature read by the Hach digital pH meter on April 12, 1995, was 23.4°C -- which is comparable to 22.2°C considering that the higher temperature was taken in a four meter deep man-made pool enclosed in an insulated building.

Using a generic geothermal gradient, this temperature suggests that the water flows from an aquifer at a depth of approximately 670 meters below ground level.[1] It is important to note that this gradient provides only an approximate depth for the aquifer, as there is no way to determine the speed at which the water is rising from the aquifer. However, based on the constant high temperature, it is assumed that the spring flows from some type of fault in order to facilitate the rise of the thermal waters. As the Eph Pond and Hemlock Brook thrust faults lie directly below Sand Spring (Ratcliffe et al 1993), it is likely that the spring water rises along one or both of these faults.

The chemical analyses of Sand Spring date back at least to 1914 when J. E. Schrader of the Williams College Department of Physics published a paper on the radioactivity of the spring. (Dale 137) To facilitate an accurate comparison with the other four springs, Sand Spring water was collected and analyzed in the same manner as the other springs rather than relying on historical data for comparison. Sand Spring has the highest pH of the springs, 8.07, which results from ions carried through deep plumbing from the Stockbridge marble and Cheshire quartzite that lies below.

Figure 8, below, shows the calcium to magnesium molar ratios for the concentrations of their respective cations in the averaged spring samples from Sand Spring and NW Spring. It is this ratio that is useful in determining the presence of dolomite when Ca^{+2} is abundant; dolomite is

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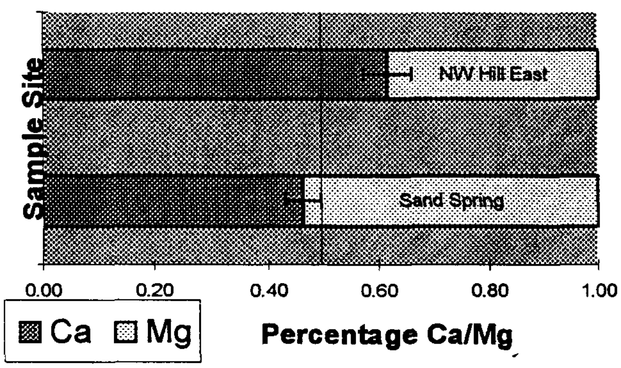
[1] The gradient used is as follows: assuming a water temperature of 0°C at the surface, for each kilometer of depth the water warms 20°C. Therefore, subtracting the approximate local groundwater temperature, 10°C, from 23.4°C yields a temperature of 13.4°C. This translates into approximately 670 meters of depth for the source of the spring. (The water temperature at 670m is actually higher than 23.4°C, but cools to the surficial temperature as it ascends to the surface.)

Figure 8: Ca+2 to Mg+2 Molar Ratios of NW Spring and Sand Spring



signified when the ratio of Ca^{+2} to Mg^{+2} approaches 1:1 (Hem 90). Both of these springs are high in Ca^{+2}, and the calcium to magnesium ratios show that both springs pick up at least 2/3 of their calcium from dolomite, $CaMg(CO_3)_2$, rather than calcite, $CaCO_3$.

An interesting segue between Sand Spring and NW Spring dates back to the unpublished autobiography of T. Nelson Dale. He conducted geologic research in the Williamstown area for the USGS around 1900, and reported that "the Rich Spring, 1/2 mile W.NW. of the Sandspring and 800 feet below it at the surface, is very probably connected with the Sandspring at some point" (Dale 137). Whether the "Rich Spring" is in fact the NW Spring is unknown; it is closer to a mile W.NW. of Sand Spring.[2] In any event, if the Rich Spring and the NW Spring are one and the same, I conclude that T. Nelson Dale is "very probably" wrong.

Historical puzzles and Taconic springs aside, there is no question that the most exciting part of this project stems from the analysis of the NW Hill Spring. Though David Dethier has been a consultant to the economic potential of the spring in the past, it was not until this study that the waters were chemically analyzed nor was it realized that the spring is of constant

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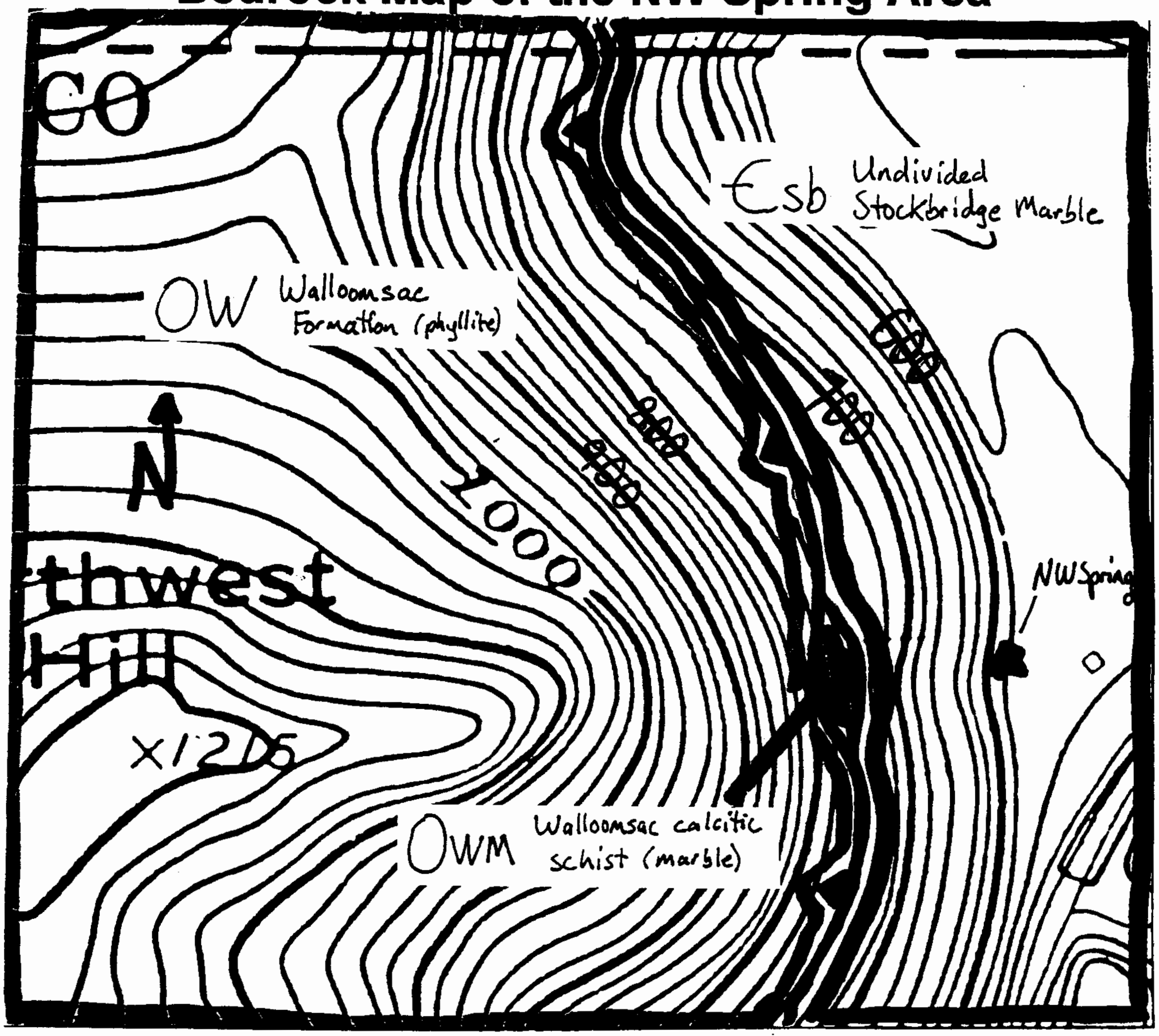
2 It is impossible to judge whether the Rich Spring is in fact the NW Spring. T. Nelson Dale could very well be off in his estimate of distance; it would be consistent with the many typos in his unpublished manuscript. (Interestingly, he reports the temperature of "Sandspring" to be "a uniform temperature of 62.65 °F." I am guessing that this is a typo from an actual temperature of 72.65 °F, it is unlikely that the temperature has increased exactly 10 °F since the turn of the century.) Then again, the springs may well be one and the same as he is very close with his estimate that the second spring lies 800 feet in elevation below Sand Spring.

Figure 9:
Bedrock Map of the NW Spring Area



Bedrock data is extracted from Ratcliffe and plotted on the USGS base map. Approximate scale: 1cm to 50m.

temperature.[3] This important discovery that the spring is of a constant temperature, 18.4°C, leads to much debate over the aquifer and its plumbing to the spring. Two alternate models for the plumbing of the spring are presented below following a general analysis of the surficial geology.

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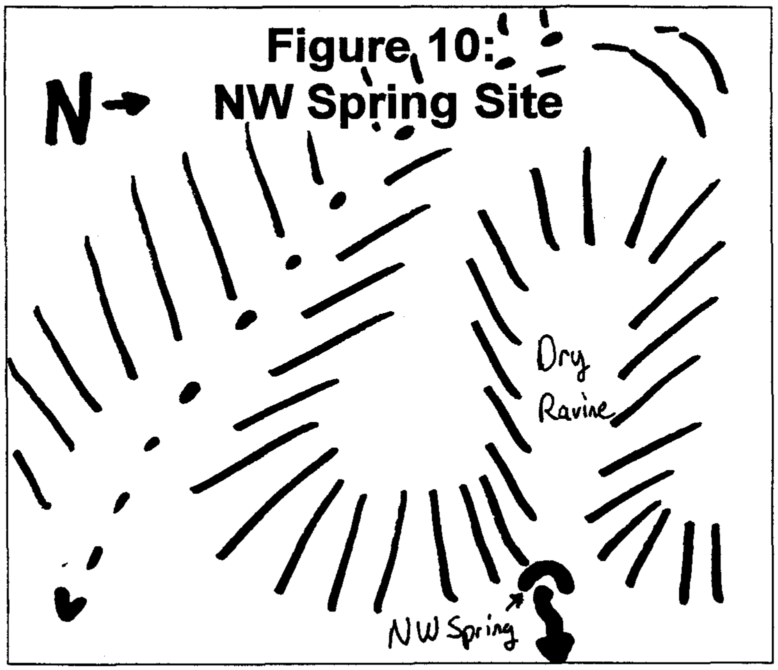
[3] I am assuming that the spring has not been analyzed in the past based on discussions with David Dethier, the local expert on Williamstown spring lore. If an analysis has in fact been conducted other than my research, it is at least a not very widely published one.

My interpretation of the spring is that it is an occluded thermal spring flowing from an aquifer within some layer of marble. The bedrock geology map [Figure 9, above] suggests that the spring is fed from an aquifer either within the phyllite or the Stockbridge marble, or perhaps both (Ratcliffe et al 1993). Though the exact underground deformation pattern of the contact between the Walloomsac and Stockbridge formations is still unknown (Paul Karabinos hopes to shed light on this question during the summers of 1995-96 through a research project funded by a Keck Foundation grant), the aquifer is assumed to be within some marble layer, as marble is the most porous of the local bedrock.

As for the surficial geology, the spring is located at the bottom of a steep slope, 70 meters in elevation below where Ratcliffe maps a Taconic thrust sheet that uplifted Walloomsac phyllite westward over Stockbridge dolomitic marble in an early Taconic allochthon. His map also depicts a sliver of Walloomsac calcitic schistose marble that lies along this fault plane due west and exactly above the NW Spring. (Ratcliffe et al 1993)

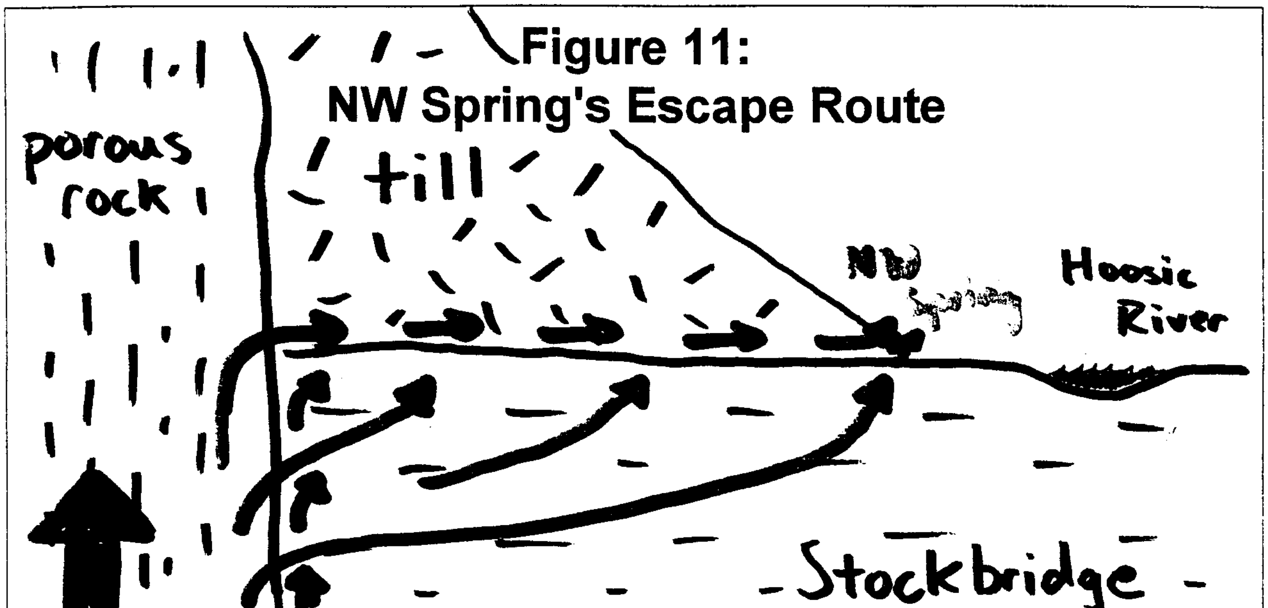
Paul Karabinos, the structural geology guru at Williams College, questions the existence of Ratcliffe's fault. "I would not want to bet any amount of money on the existence of that fracture," said Karabinos. He feels that the small thrust fault plotted by Ratcliffe is an overinterpretation of surficial geology; furthermore, as the fault is plotted only along half of the unconformity between the Walloomsac phyllite and Stockbridge marble, it leaves the other half of the contact unexplained. Karabinos suggests that the contact between the phyllite and the marble is more likely to have been the result of gradual erosion and deformation processes that have left the bedrock without a defined contact between these two formations.

Where does that leave the NW Spring? Field observations suggest that the water rises from some sort of east-west fracture line, flows along the top of the fracture under a dry ravine, and emerges at the base of the eastern face of NW Hill. This hypothesis is based on the dry circuitous ravine due west of the spring that is carved into the hillside next to a larger ravine that drains the hill to the southwest. [see Figure 10, above] The east-west fracture is further supported by the observation that the ravine continues gradually west behind the spring, but that the walls along the north and south sides of the east-west ravine are extremely steep and immediately adjacent to the hypothesized fracture line.



As the water flows upward through whatever medium is carrying the water to the fracture line, it reaches a deposit of mixed till on top of the bedrock. The till along the base of NW Hill is probably a glacial feature that was deposited during the Pleistocene epoch (Harman 1994), the most recent period of regional glaciation. As the water flows up to the spring's elevation, it is possible that the bedrock medium carrying the waters continues higher than this elevation. However, as it is easier for the water to flow through the unstratified till than the bedrock, the water emerges from the medium and forms the dry ravine leading to the spring [Figure 11, below]. This reasoning explains the observation that water is not only flowing up from mixed till

Figure 11: NW Spring's Escape Route



Water rises through a porous bedrock until it reaches the unstratified till. The water then escapes the earth by abandoning the bedrock for the till and flowing out along the base of NW Hill to the spring. This model explains both the slumping ravine (formed as the water moves underneath) and the fact that water is flowing both outward and upward in the spring, as pictured below in Figure 12.

Figure 12: NW Spring Discharge

NW Spring. The discharge of the aquifer is flowing both out from under the slumping till as well as up from the 2m wide spring head. The stream and ravine are full of mixed till including phyllite, calcite, dolomite, quartzite, and fractured quartz vein. The marble boulder in the upper left of the picture slumped forward approximately 40 cm in under a month.

in the exposed discharge region of the spring, but also out from under till at the base of the intersection of the spring with the ravine [see Figure 12, above].

This occluded spring hypothesis is supported by a number of other factors. First, there is no logical explanation for the existence of the dry ravine unless it served the hillside before the drainage was diverted to the southwest. This is unlikely due to the steep circuitous dead-end of the ravine. Second, during the initial 17 day interval of observation, a portion of the spring's intersection with the ravine eroded. A marble boulder under which water flowed on April 8 had moved forward 20cm and was part of the visible discharge area of the spring on April 25. By May 9, the boulder had moved forward another 20cm. All of these observations suggest that the spring does indeed emerge along an east-west fracture, causing the slumping ravine to form and deposit the eroded mixed till observed in the stream initiated by the spring.

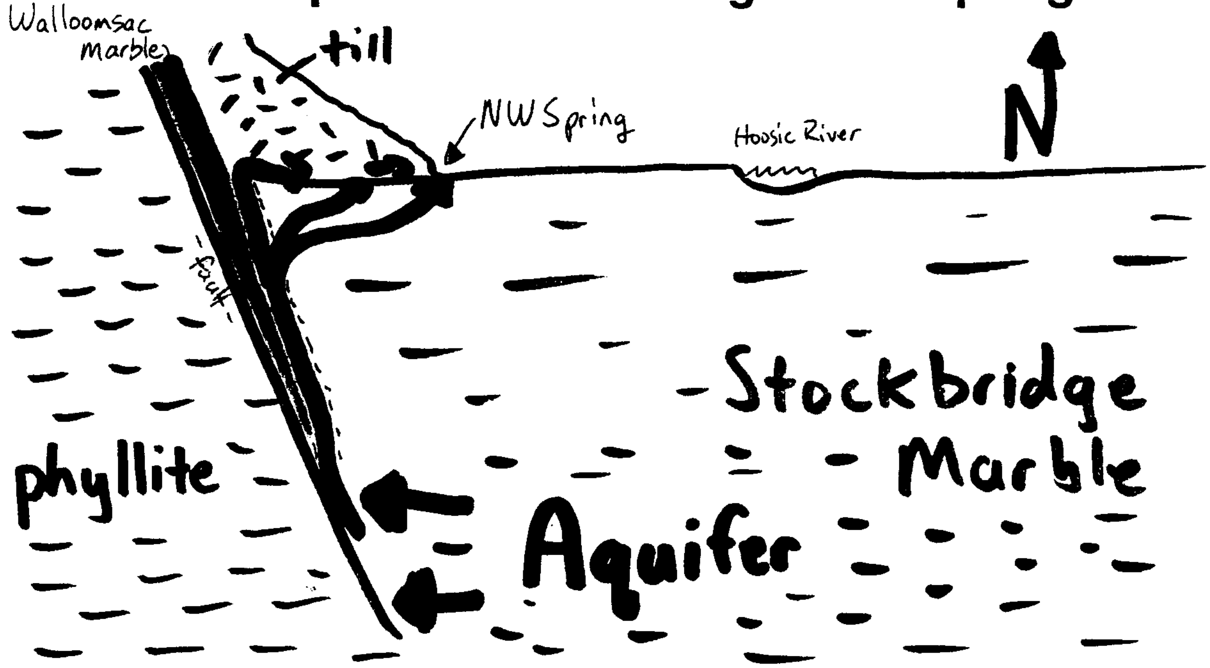
The real question, however, is as to the spring's plumbing mechanism feeding the proposed east-west fracture. It seems likely that the spring is somehow connected with the Walloomsac marble sliver, located immediately west of the spring and dry ravine. One theoretical model for the plumbing (proposed by Paul Karabinos) suggests that the spring flows up from the four undivided Stockbridge marble layers. The alternating sequences of marble layers create series of aquifers and aquacludes due to the permeability contrast between the porous dolomitic layers and the confining quartzite layers under the valley surface. In this model, the occluded spring is simply discharging from an aquifer confined within the Stockbridge layers through some medium in the uppermost layers of the Stockbridge Formation.

A contrary model suggests that the water flows upward from a deep aquifer along the planar surface of a highly fractured thrust fault. This model is contingent on the existence of some fault, Ratcliffe's or otherwise, that resulted as the Taconic thrust sheets lifted the Ordovician phyllite westward above the Cambrian marble. This model is strongly supported by the constant 18.4°C temperature of the spring. Using the generic geothermal gradient which does not take into account hindrances that might affect the speed of the water rising to the surface, the water is rising approximately 420 meters from its source to the spring. It is only through this fault model that a viable mechanism exists for water to rise from a 420 meter depth at a speed sufficient to release the water at 18.4°C, it does not seem likely that enough pressure is created within the first model's aquifer to heat the water to 18.4°C.

As for the coincidental position of the isolated Walloomsac marble sliver, it may tie into these models in two ways. One possibility is that the east-west fracture line is within the Stockbridge marble, and that the fracture occurred as the Walloomsac marble was thrust upward with the phyllite. Therefore, the sliver is not functionally connected to the plumbing of the spring. This explanation is questionable as a soft and pliable marble is not likely to cause a fracture. Another more likely possibility is that the unconformity of this marble sliver is the precise reason for the existence of the spring.

As this calcitic marble sliver is more porous than any of the surrounding bedrock, I propose that the spring water does not flow from an east-west fracture in the Stockbridge marble, but rather that the water flows up to the surface through the medium of the Walloomsac sliver and corresponding fractures. This hypothesis supports the occluded nature of the spring: water flows through the marble aquifer until it reaches the fault plane with the less porous phyllite, which forces the water up along the plane. The water is soaked up by the more porous Walloomsac marble unconformity along the fault plane and carried either within the marble or in

Figure 13:
The Aquifer and Plumbing of NW Spring



Water flows through the marble aquifer westward until it contacts the less porous phyllite. The water moves up the contact of the Walloomsac phyllite and Stockbridge marble along the fault plane, and merges in toward the Walloomsac marble sliver, the most porous of the local bedrock. The water is channeled along the marble sliver until it reaches an elevation at which it may flow through the till to the spring [see Figure 11, page 17].

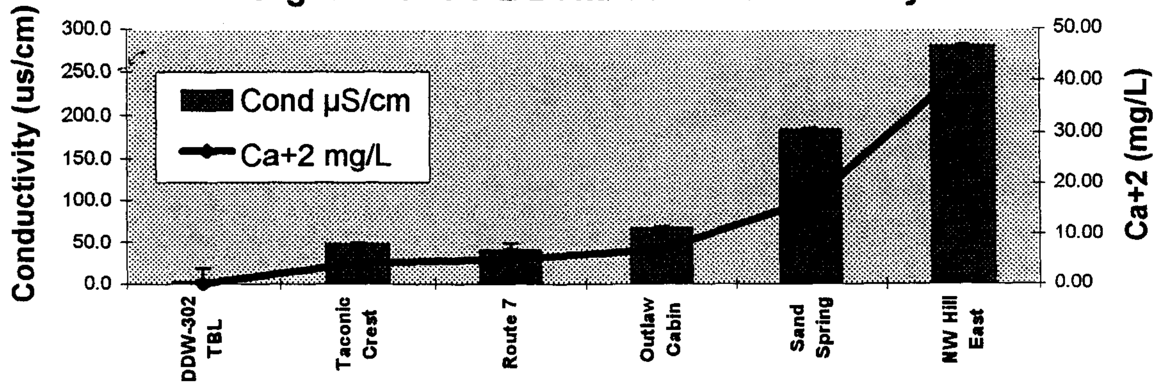
channels eroded out along the contact between the Walloomsac and the other bedrock to the elevation at which the water flows out under the dry ravine and into the spring. [see Figure 13, above] This model of the water emerging from the aquifer along a highly fractured fault plane not only provides a link among the Walloomsac unconformity, the ravine, and the spring; but it also facilitates the rapid ascent of the 18.4°C water.

Though this model is contingent on the existence of a fault and leaves the unconformity questioned by Paul Karabinos largely unexplained, I conclude that the fault model is the most likely candidate for the spring's plumbing. Even if Ratcliffe is carried away in his delineation of a definite thrust fault contact, some sort of contact exists to separate the two bedrock formations. As only the fault model for the plumbing mechanism of NW Spring accounts for the thermal temperature of its waters, I conclude that a fault along this contact does exist in some capacity.

The chemical analysis validates the assumption that the aquifer is based in marble and also favors the fault model for the plumbing of the spring. The saturation index of the sample (calculated from Hem) is approximately zero, which is indicative of water that stays in residence in the presence of calcium for months (Hem 93). Therefore, this evidence substantiates the assumption that the aquifer is located within some marble layer. Figure 8 (page 13) shows that the NW Spring has a 3:2 molar ratio of calcium to magnesium. The high concentrations of magnesium evince that the water is in contact with dolomite; nevertheless, some of the even higher Ca^{+2} concentration suggests that the water is in contact with other marbles.

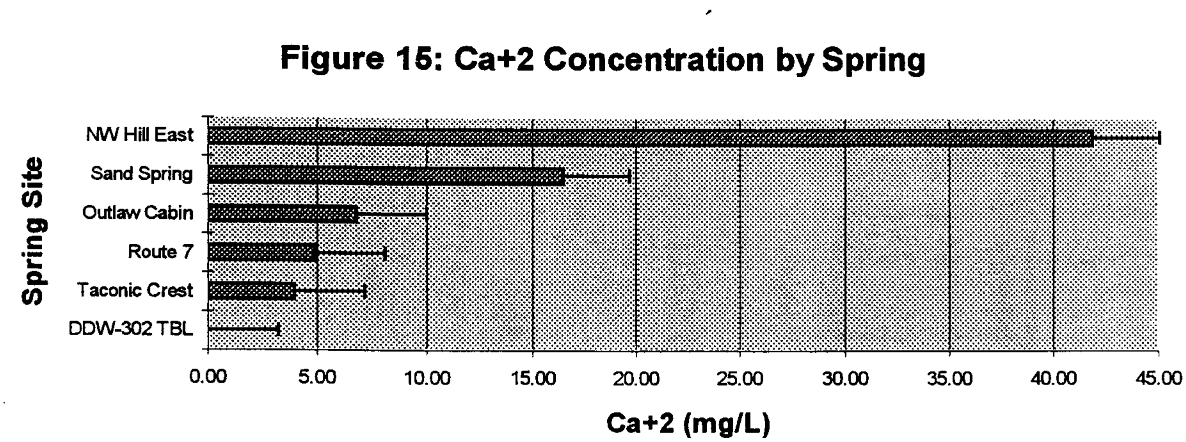
The Walloomsac calcitic schist sliver is undoubtedly a source for some of this extra Ca^{+2}; but the high concentration of SO_4^{-2} relative to the other spring samples suggests that the aquifer is also in contact with gypsum ($CaSO_4$*$2H_2O$). The dolomite, calcite, and gypsum combine to give

Figure 14: Ca+2 Dominates Conductivity



the NW Spring its Ca^{+2} signature, securing NW Spring a high conductivity. Figure 14 (above) shows that NW Spring not only has the highest conductivity of the assayed springs, but also that Ca^{+2} is the dominating ion contributing to the conductivity values.

Does this chemical signature, quite different from that of Sand Spring, rule out the possibility that the two are connected at great depth? Although the springs may flow from a common aquifer through two separate bedrock outlets that vary the temperature and chemical signature, it does not appear that the two are connected. The saturation index for Sand Spring is approximately 0.3 (as calculated from Hem), slightly higher than the value for NW Spring. As both of the water samples are saturated with calcium, the spring water sits in its aquifer for months. Thus the springs are expected to have similar saturation concentrations of Ca^{+2} should they be from a common aquifer. Figure 15 (below) demonstrates that this is obviously not the case; in fact, it is the opposite. NW Spring is expected to be slightly less saturated with calcium than Sand Spring based on their respective saturation indexes, but it is over double Sand Spring in $[Ca^{+2}]$.



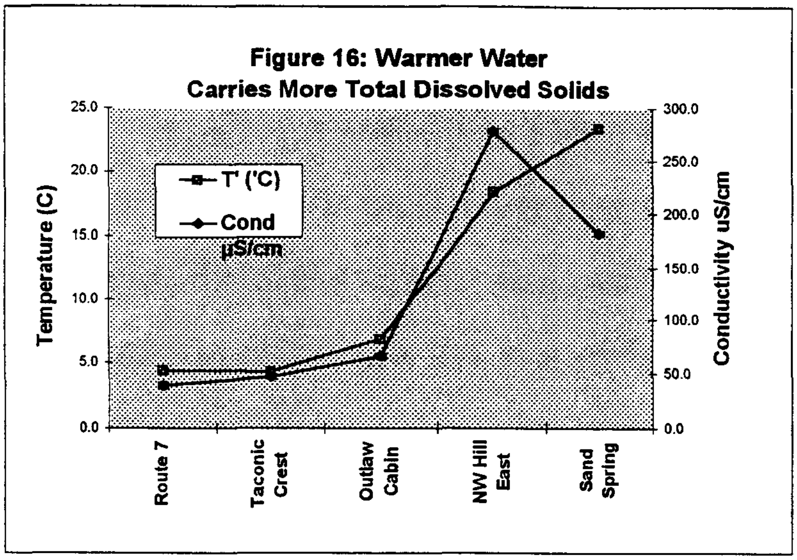


Figure 16 (right) shows not only that the conductivity for Sand Spring is lower than that of NW Spring, but also that Sand Spring strays from the trend that warmer water carries more dissolved solids. In general, it is expected that warmer water carries more total dissolved solids (Dethier). Therefore, if Sand Spring is an outlet from the same aquifer as NW Spring, it's conductivity should be in same the ballpark as the conductivity of NW Spring rather than off by 100µS/cm. The variance between ion concentrations of the two springs -- as revealed in their saturation indexes and conductivity levels -- leads me to conclude that the springs are unconnected. Silica tests should substantiate this conclusion; Sand Spring is expected to have a higher dissolved silica content as compared to NW Spring as its aquifer is likely to be confined by the Cheshire Quartzite.[4]

Summary

Perhaps the only similarity among the five springs aside from their geographic locations is that they all appear to be safe to drink based on my chemical analyses. Though heavy metal concentrations are not considered, all of the springs are much more pure than local tap water.[5]

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[4] Testing to quantify dissolved silica is not currently available at Williams College; however, samples are being saved should the testing become feasible during the summer of 1995.

[5] One of the splits for the NW Spring is significantly higher in Ca^{+2} concentration and slightly higher in SO_4^{-2} and Mg^{+2} concentrations than the tap water average; this sample raises the average for the spring to values slightly higher than those of the tap average. These variances are almost accounted for by the average deviations; regardless, the spring is still as "pure" as tap water, just slightly harder.

Variation in the chemical signatures of the two springs flowing from the marbles of the Williamstown valley are the subject of a large portion of discussion in this paper, yet it is important to note that they are quite similar in most respects. Though I have concluded that Sand Spring and NW Spring do not flow from the same aquifer, they are both likely to be thermal springs flowing from thrust faults that plunge deep into the marble valley. The three springs along the crest of the Taconics are also very different from each other in that the Outlaw Cabin Spring is a high-volume outlet for a perched water table in the phyllite bedrock, whereas the other two springs are simply throughflow outlets. Nevertheless, all three springs are quite distinct from the marble-based springs of the adjacent valley.

Deciphering the chemical signatures of the five Williamstown springs through the lens of their surficial geology is a very successful method for determining the bedrock sources of the springs. It is only through the combination of geology and chemistry that accurate conclusions may be drawn as to the nature of the springs. This synthesis of two natural sciences in the Williamstown area not only reveals the differences between the throughflow outlets of the Taconic Crest springs and the perched water table of the Outlaw Cabin Spring, reveals the thermal nature of the NW Hill Spring, and disproves the hypothesis that Sand Spring and NW Hill Spring are connected; but it also proves to be an exciting interdisciplinary scientific investigation.

Acknowledgments

Many individuals related to Williams College in some capacity have been essential to this report. I would like to acknowledge Mr. Whitman of NW Hill Road for the generous use of his property; Edward Nelson '97 for transport into Vermont; the professors, teaching assistants, and fellow students of ES 102 1995 for their laboratory analyses used both as references and as controls for my analyses; Jim Heyes of the Williams writing workshop for editing an initial draft of this report; Professor Jay Thoman of the Chemistry Department for laboratory instruction; Professor Paul Karabinos of the Geology Department for his "local expertise"; and Professor Bud Wobus, also of the Geology Department, for his generous and unsolicited research of T. Nelson Dale.

I would also like to acknowledge three individuals at Williams' Center for Environmental Studies; without their help, this project would not have taken place. David Dethier not only recommended interesting springs for my research, but also serves as a valuable sounding board for interpretation of the chemical analyses. (I also enjoyed meeting all of his neighbors and trespassing over their respective properties!) Dave DeSimone, the primary advisor for this project, is invaluable in his realistic approach to this comparative study and in his repeated assistance in my dilemmas. Finally, I would like to especially single out Sandy Brown, without whom I would be reduced to a blustering idiot. Her tireless dedication in instruction, laboratory maintenance, IC and AAS operation, and her gentle kindness and encouragement are invaluable to this project.

What a marvelous piece of geochemical & geological detective work, Mac! Your reasoning on the separate nature of the SS & the deep aquifers is sound and convincing. Your models of the W spring origin/setting are intriguing. I favor — as we discussed — the fault model you propose or some variant of a fault model. While not a structural geologist I believe the fault is there and probably, the entire length of The Stockbridge — Walloomsac contact is of fault nature (and reinterpretation of surficial geology on my part). Just as a oversight in your text — that Petersburg Pass Taconic spring is along Rte 2 (Ha!) ⟶

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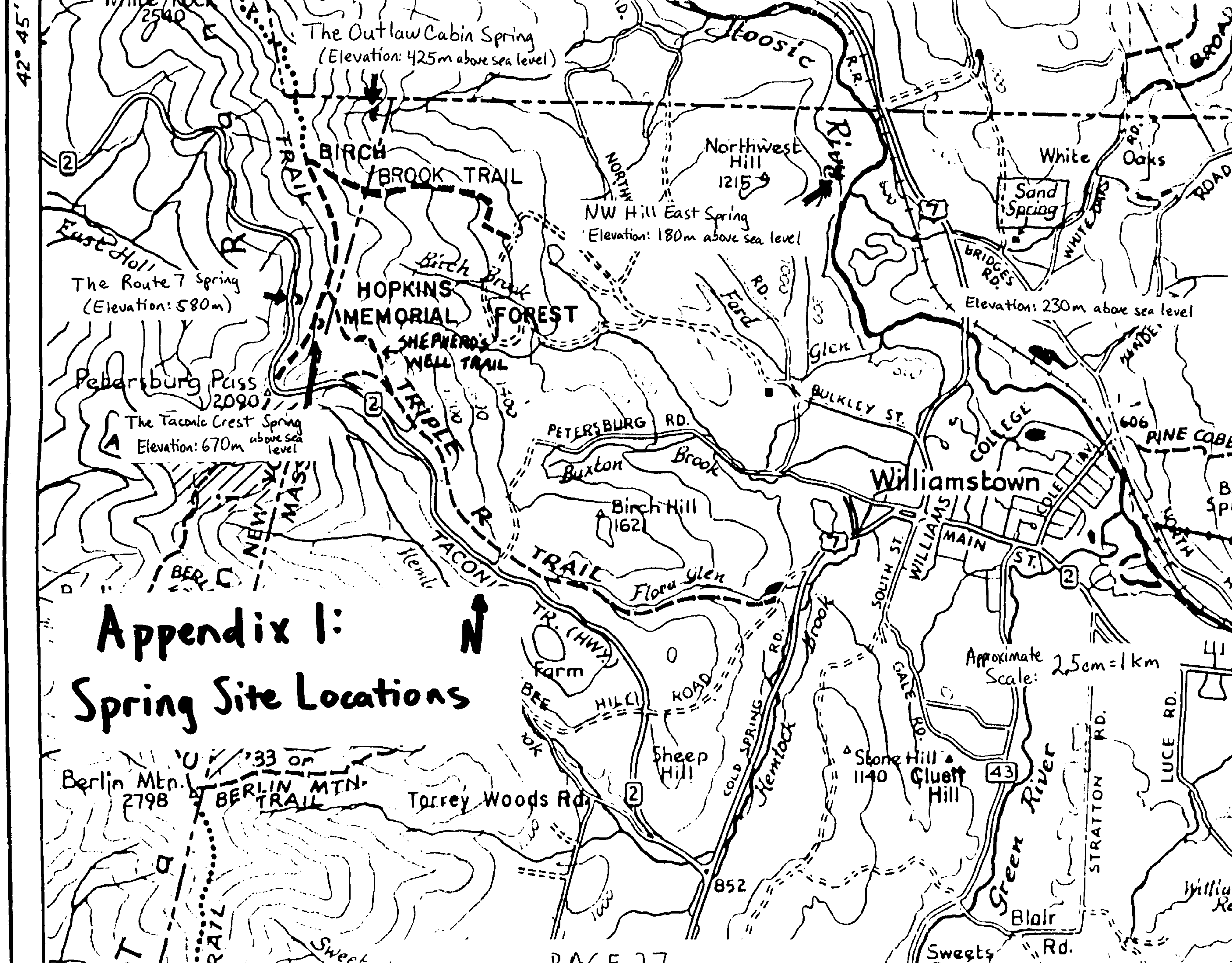
Appendix I: Spring Site Locations



Appendix 2:
Complete Data (Adjusted)

Mac Harman Indy Project -- ES 102																	
ID	Date	Sample Site	Comments	T'	pH	ANC	Cond	F-	Cl-	NO3-	PO4-3	SO4-2	Na+	K+	Ca+2	Mg+2	ID
	Sampled			('C)		mg/L	µS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	
DDW	Mar-95	302 TBL	DDW average	20.0	5.10	1.3	2.2	0.00	0.10	0.00	0.00	0.00	0.10		0.00	0.10	DDW
TAP	Mar-95	302 TBL	TAP average	20.0	7.80	34.0	278.5	0.00	1.20	0.00	0.32	11.70	3.40		35.50	15.60	TAP
OC1a	8-Apr	Outlaw Cabin	2m from source	6.8	7.22	17.5	62.6	0.00	1.10	1.38	0.00	9.40	1.10	0.40	6.40	3.00	OC1a
OC2a	8-Apr	Outlaw Cabin	same site as OC1	6.8	7.40	28.3	67.1	0.00	1.03	1.37	0.00	9.60	0.50	0.10	8.10	2.70	OC2a
OC3	25-Apr	Outlaw Cabin	17 days later	6.8	6.77	20.0	60.2	0.00	1.09	1.94	0.00	8.90	2.40	0.80	4.30	2.80	OC3
OCS1	8-Apr	Outlaw Cabin	source of spring	6.9	7.05	18.4	63.3	0.00	1.17	0.50	0.00	10.20	1.00	0.50	7.60	3.10	OCS1
OCS2	8-Apr	Outlaw Cabin	same site as OCS1	6.9	6.57	24.4	76.8	0.00	1.16	1.34	0.00	9.10	0.50	0.20	8.80	2.60	OCS2
OCS3	25-Apr	Outlaw Cabin	17 days later	6.8	6.77	20.6	65.7	0.00	1.20	1.99	0.00	11.20	2.90	0.60	5.40	2.80	OCS3
TC1	12-Apr	Taconic Crest	pool at source	4.1	6.81	9.6	47.3	0.00	1.70	2.27	0.00	7.10	0.60	0.20	5.50	1.90	TC1
TC2a	12-Apr	Taconic Crest	same site as TC1	4.1	6.89	9.3	48.0	0.15	1.63	2.23	0.00	7.20	1.30	0.40	3.90	2.00	TC2a
TC3	25-Apr	Taconic Crest	13 days later	4.7	6.49	10.4	46.7	0.00	1.51	2.55	0.00	7.20	0.80	0.30	3.10	1.70	TC3
BU1	12-Apr	Route 7	pool at source		6.29	8.0	41.0	0.00	1.87	0.94	0.00	6.60	0.80	0.30	3.30	1.00	BU1
BU2	12-Apr	Route 7	same as BU1		6.38	7.4	38.8	0.00	1.99	1.01	0.00	6.60	0.70	0.40	4.00	1.20	BU2
BU3	12-Apr	Route 7	from black pipe		6.36	7.0	36.6	0.00	1.82	1.64	0.00	6.50	1.00	0.40	10.30	1.70	BU3
BU4	25-Apr	Route 7	13 days later, pipe		6.25	5.6	40.8	0.00	1.74	4.12	0.00	6.80	0.60	1.20	2.50	1.10	BU4
BU5	25-Apr	Route 7	13 days later, pool	4.4	6.20	5.8	38.0	0.00	1.78	3.42	0.00	6.80	2.20	0.60	4.30	1.50	BU5
WC1	8-Apr	NW Hill East	middle of flow	18.4	7.88	134.0	281.0	0.11	2.03	0.34	0.00	13.90	1.90	0.70	63.00	19.50	WC1
WC2a	8-Apr	NW Hill East	same as WC 1	18.4	8.16	138.0	277.0	0.10	2.24	0.00	0.26	11.80	1.90	0.90	35.10	14.40	WC2a
WC3	25-Apr	NW Hill East	17 days later	18.4	7.87	148.0	278.0	0.07	1.98	1.12	0.00	10.60	2.40	0.80	27.50	13.60	WC3
SS1a	12-Apr	Sand Spring	deep manmade pool	23.4	8.06	84.0	184.8	0.16	1.75	0.00	0.00	7.90	2.10	1.40	16.70	11.60	SS1a
SS2	12-Apr	Sand Spring	same as SS1	23.4	8.03	87.0	180.0	0.16	1.92	0.00	0.00	7.50	1.70	1.10	16.30	11.70	SS2
ID	Date	Sample Site	Comments	T'	pH	ANC	Cond	F-	Cl-	NO3-	PO4-3	SO4-2	Na+	K+	Ca+2	Mg+2	ID
	Sampled			('C)		mg/L	µS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	

Appendix 3:
Averages of the Seven Sites as Calculated from Splits

Mac Harman Indy Project -- ES 102															
ID	**Sample Site**	**T'**	**pH**	**ANC**	**Cond**	**F-**	**Cl-**	**NO3-**	**PO4-3**	**SO4-2**	**Na+**	**K+**	**Ca+2**	**Mg+2**	**ID**
		('C)		**mg/L**	**µS/cm**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	
DDW	DDW-302 TBL	20.0	5.10	1.3	2.2	0.00	0.10	0.00	0.00	0.00	0.10		0.00	0.10	DDW
TAP	TAP-302 TBL	20.0	7.80	34.0	278.5	0.00	1.20	0.00	0.32	11.70	3.40		35.50	15.60	TAP
OCavg	Outlaw Cabin	6.8	7.04	21.9	66.0	0.00	1.13	1.42	0.00	9.73	1.40	0.43	6.77	2.83	OCavg
TCavg	Taconic Crest	4.3	6.77	9.7	47.3	0.05	1.61	2.35	0.00	7.17	1.33	0.48	3.95	1.87	TCavg
BUavg	Route 7	4.4	6.30	6.8	39.0	0.00	1.84	2.23	0.00	6.66	1.06	0.58	4.88	1.30	BUavg
WCavg	NW Hill East	18.4	7.94	140.0	278.7	0.09	2.08	0.49	0.09	12.10	2.07	0.80	41.87	15.83	WCavg
SSavg	Sand Spring	23.4	8.07	85.9	182.4	0.16	1.84	0.00	0.00	7.70	1.90	1.25	16.50	11.65	SSavg
ID	**Sample Site**	**T'**	**pH**	**ANC**	**Cond**	**F-**	**Cl-**	**NO3-**	**PO4-3**	**SO4-2**	**Na+**	**K+**	**Ca+2**	**Mg+2**	**ID**
		('C)		**mg/L**	**µS/cm**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	

Appendix 4:
Calculated Average Deviation

Mac Harman Indy Project -- ES 102													
ID	**pH**	**ANC**	**Cond**	**F-**	**Cl-**	**NO3-**	**PO4-3**	**SO4-2**	**Na+**	**K+**	**Ca+2**	**Mg+2**	**ID**
		mg/L	**µS/cm**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	
OCadev	0.22	4.60	4.68	0.00	0.05	0.32	0.00	0.33	0.28	0.15	0.73	0.20	OCadev
TCadev	0.11	1.20	0.35	0.08	0.04	0.02	0.00	0.05	0.73	0.31	0.84	0.05	TCadev
BUadev	0.04	0.30	1.10	0.00	0.06	0.04	0.00	0.00	0.05	0.05	0.35	0.10	BUadev
WCadev	0.13	2.00	2.00	0.01	0.11	0.17	0.13	1.05	0.00	0.10	13.95	2.55	WCadev
SSadev	0.03	1.24	2.40	0.00	0.09	0.00	0.00	0.20	0.20	0.15	0.20	0.05	SSadev
Avg. Dev.	0.11	1.87	2.11	0.02	0.07	0.11	0.03	0.33	0.25	0.15	3.21	0.59	Avg. Dev
ID	**pH**	**ANC**	**Cond**	**F-**	**Cl-**	**NO3-**	**PO4-3**	**SO4-2**	**Na+**	**K+**	**Ca+2**	**Mg+2**	**ID**
		mg/L	**µS/cm**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	