HYDROGEOCHEMISTRY OF THE BATTEN KILL HEADWATERS

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GOALS

Conduct a hydrologic and general geologic study of the headwaters of the Batten Kill in order to understand, (at least as a first approximation), the meteoric and groundwater inputs and outputs of this ecologically valuable waterway.

INTRODUCTION

The Batten Kill River flows southwest through the Vermont Valley which is bordered to the west by the Taconic Mountains and to the east by the Green Mountains (Figure 1). North of Manchester, Vermont, four major tributaries of the Batten Kill are recognized with watershed areas that vary in size, gradient, type of bedrock and surficial deposits, temperature of the water, and man-caused interferences or obstructions.

We hypothesize that the carbonate bedrock provides a proportionally larger aquifer to the Batten Kill than the granitic or phyllitic bedrock. We also believe that the groundwater from the carbonate bedrock aquifer is a stronger source than the surface runoff provided by the stratified drift. In order to distinguish the type of bedrock aquifer and to determine the interaction between groundwater and surface runoff in a valley with both a high potential for aquifers and large surface run-off, five stations were intensively studied. Data was collected by taking specific conductivity and temperature readings, discharge measurements and stream samples for chemical analysis.

METHODS

Four techniques were used to achieve the goals of the study: specific conductivity and temperature measurements over time, stream width, depth and velocity measurements over time, chemical analysis of water samples and topographical, surficial and bedrock map analysis.

Measurements of specific conductivity (mho's) and temperature (Celsius) were taken at 50 sites. The specific conductivity measurements of the streams were taken in order to indicate the amounts of ions present; this directly correlates to the type of rock with which the water has been in contact. The temperature also indicates the source of the water: a higher temperature implies that the source of the water is surface run-off while a lower temperature implies that the water, which could not have been heated by sunlight, is from a groundwater source.

Five stations were identified for intensive hydrologic study based upon an analysis of the temperature and conductivity data (Figure 1). Here seven discharge (width, depth and velocity) measurements were taken over an eight day period. The measurements were performed in a cross section of the stream which was often directly adjacent to a bridge, usually downstream. This exact site was repeated as closely as possible from day to day, with one exception at site five. These data were then converted into discharge units (m^3/sec).

Ion Chromatograph and Atomic Absorption Spectrophotometer analyses were run on undiluted and 1:20 diluted samples to determine the type of ions and other molecules, such as silica (aq), present.

Watershed area for each of the streams was calculated using 7.5 minute topographical maps. This area was then used in determining the percentage of stratified drift and the percentage of carbonate bedrock for each of the five areas from 1:250,000 and 1:62,500 maps. Area calculations determine the relative influences of surficial and bedrock geology on the tributaries and the Batten Kill itself.

HYDROGEOCHEMISTRY

The bedrock formations in the Vermont Valley can be simplified into three lithologies: quartzite, dolostone, and limestone. The quartzite, which is composed of quartz (SiO_2), is very resistant to weathering, and in the scope of this study, is considered geochemically inert. The dolostone weathers into calcium (Ca^{2+}), magnesium (Mg^{2+}), bicarbonate (HCO_3^-) and quartzite. The limestones weather to give mainly calcium and bicarbonate ions.

The Green Mountains are composed primarily of granitic gneiss which weathers to sodium (Na^+), potassium (K^+), silica (aq) and lesser amounts of calcium (Ca^{2+}).

The Taconic Mountain Range consists largely of phyllite predominantly composed of muscovite ($K\,Al_3\,Si_3\,O_{10}\,(OH)_2$) and chlorite ($(Mg, Fe, Al)_6(Si, Al)_4\,O_{10}\,(OH)_8$). When phyllite weathers, the distinctive products are magnesium (Mg^{2+}) and potassium (K^+). Muscovite is resistant to weathering, as opposed to chlorite, which weathers rapidly to vermiculite, releasing magnesium (Mg^{2+}) and silica (aq).

SOURCES OF DISSOLVED CONSTITUENTS

Granite weathering primarily releases Na^+, K^+, and SiO_2 as shown by the following reactions.

$$2NaAlSi_3O_8 + 9H_2O + 2H^+ \Rightarrow Al_2Si_2O_5(OH)_4 + 2Na^+ + 4H_4SiO_4 \quad \text{(Eq1)}$$

$$2KAlSi_3O_8 + 9H_2O + 2H^+ \Rightarrow Al_2Si_2O_5(OH)_4 + 2K^+ + 4H_4SiO_4 \quad \text{(Eq2)}$$

Carbonate weathering releases HCO_3^-, Ca^{2+}, and Mg^{2+}

$$Ca\,Mg\,(CO_3)_2 + 2H_2O + 2CO_2 \Rightarrow Ca^{2+} + Mg^{2+} + 4HCO_3^- \quad \text{(Eq3)}$$

$$Ca\,CO_3 + H_2O + CO_2 \Rightarrow Ca^{2+} + 2HCO_3^- \quad \text{(Eq4)}$$

The phyllite consists of chlorite and muscovite. The chlorite weathers to give Mg^{2+}, vermiculite and water. Since vermiculite ($(Mg, Fe, Al)_6\,(Si, Al)_4\,O_{10}\,(OH)_2$) exists as a solid-solution, only one example of the weathering of a chlorite to a typical vermiculite is given.

$$Mg_5Fe\,(Si_3\,Al\,O_{10})\,(OH)_8 + H^+ \Rightarrow Mg_2\,Fe\,(Si_3\,Al)\,O_{10}\,(OH)_2 + 3\,Mg^{2+} + 6H_2O \quad \text{(Eq5)}$$

Since muscovite is very chemically resistant to weathering, it is considered chemically inert for the purposes of this project.

ANALYSIS

Stations CB3, CB6 and CB7 are located in the western portion of the Valley. Their drainage mostly comes from limestone and dolomite. Stations CB2 and CB9 are located in the eastern portion of the Valley. These stations are located closest to the granite. These two stations have the lowest percentages of carbonate bedrock in their watershed areas.

The discharge for station CB3 was significantly lower than expected (see Figures 4 and 6). Upon inspection we found that the flow upstream of the station had been dammed or diverted by construction. Although the discharge was affected, the geochemical relationships remain valid since they are independent of discharge (see Figures 3 and 5).

Since the carbonate bedrock aquifer has a much larger capacity than the stratified drift, precipitation should affect the tributaries that are more dependent on the surface runoff than those dependent on the groundwater source. Our data reflect this phenomenan in the unit discharge hydrograph (Figure 2) which shows the reactions of the stations after precipitation that occurred on days 22 and 23. Stations CB7 and CB6 were not as affected by this precipitation since their discharge is controlled by the larger carbonate aquifer and not the stratified drift. Stations CB2 and CB9 exhibited a less stable reaction to the precipitation since they rely more on the surface runoff as their source.

Figure 3, the graph of calcium versus percent carbonate bedrock, shows conclusive evidence that the main source of calcium ions is the carbonate bedrock.

The graph of calcium versus unit discharge (Figure 4) indicates that the source of the discharge is carbonate. From this we deduce that the aquifer must also be carbonate.

Figure 5, displaying calcium versus specific conductivity, shows that the calcium and bicarbonate are the controlling factors of the specific conductivity (assuming that the pH of the water systems are about neutral).

The graph of percent carbonate bedrock versus unit discharge (Figure 6) exhibits one of the strongest relationships among our data. Since we find that the amount of carbonate bedrock is directly proportional to the amount of discharge, our hypothesis that the aquifer is primarily carbonate bedrock rather than granitic or phyllitic bedrock is upheld.

The cations considered in Figure 7 are Ca^{2+}, Mg^{2+}, Na^+ and K^+. The anions considered are Cl^-, SO_4^{2-} and NO_3^-. Stations CB3 and CB6 contain the largest cation concentrations because they have the highest percentages of carbonate bedrock in their watershed areas which weathers into the cation Ca^{2+}. The silica concentrations for CB2 and CB9 are among the highest since the high percentage of granitic bedrock in their watershed areas liberates silica and other products upon weathering. There can be no definitive geological conclusions drawn from the anion concentrations since the nitrates and sulfates are greatly affected by biological organisms. Furthermore, the chloride concentrations are heavily influenced by industrialization, such as chlorination for water purification.

CONCLUSION

As we hypothesized, the carbonate bedrock does provide a larger aquifer than the other bedrock types. This is evidenced by the fact that the stations containing a higher percentage of carbonate bedrock in their watershed areas also exhibited proportionally larger discharges. The other stations, namely CB2 and CB9, had the lowest percentage of carbonate bedrock and consequently lower discharge values. We therefore deduce that these stations rely more upon surface runoff, which confirms our second hypothesis.

DATA

Figure 2

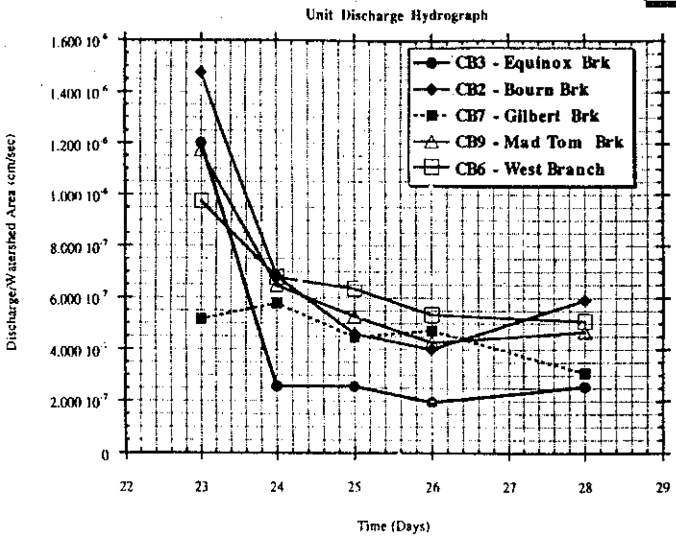

Figure 3

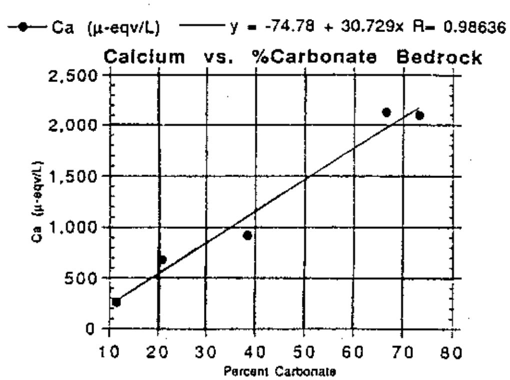

Figure 5

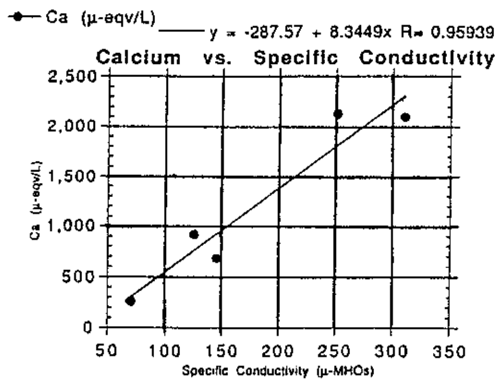

Figure 7

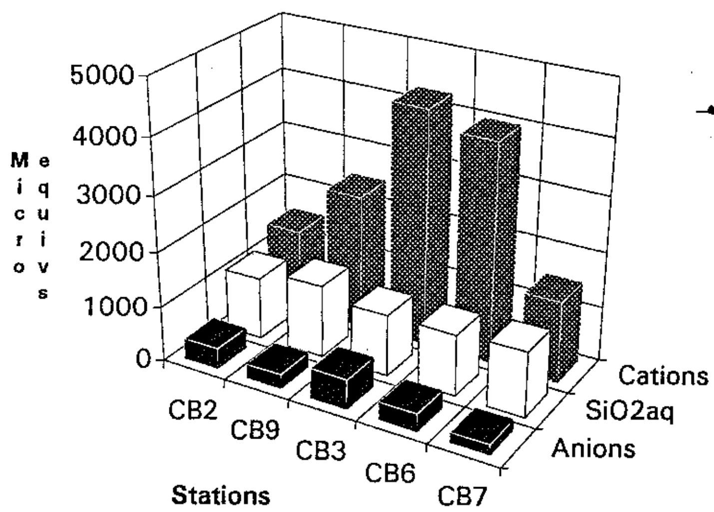

Figure 4

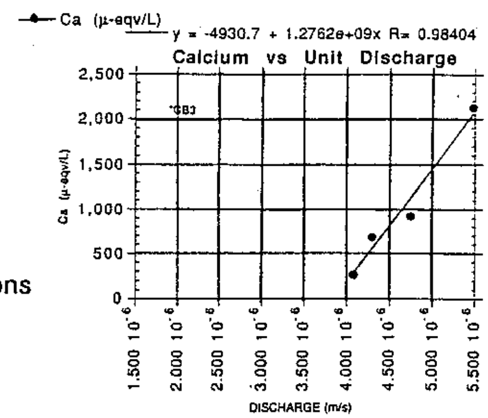

Figure 6

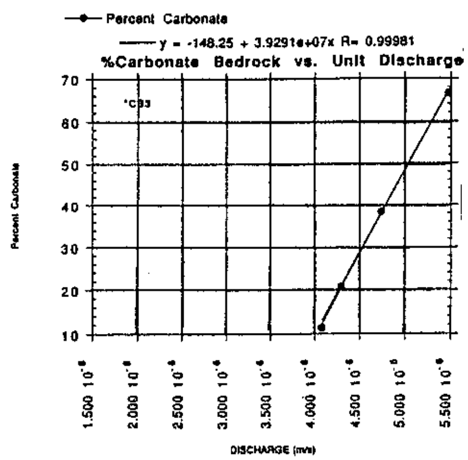

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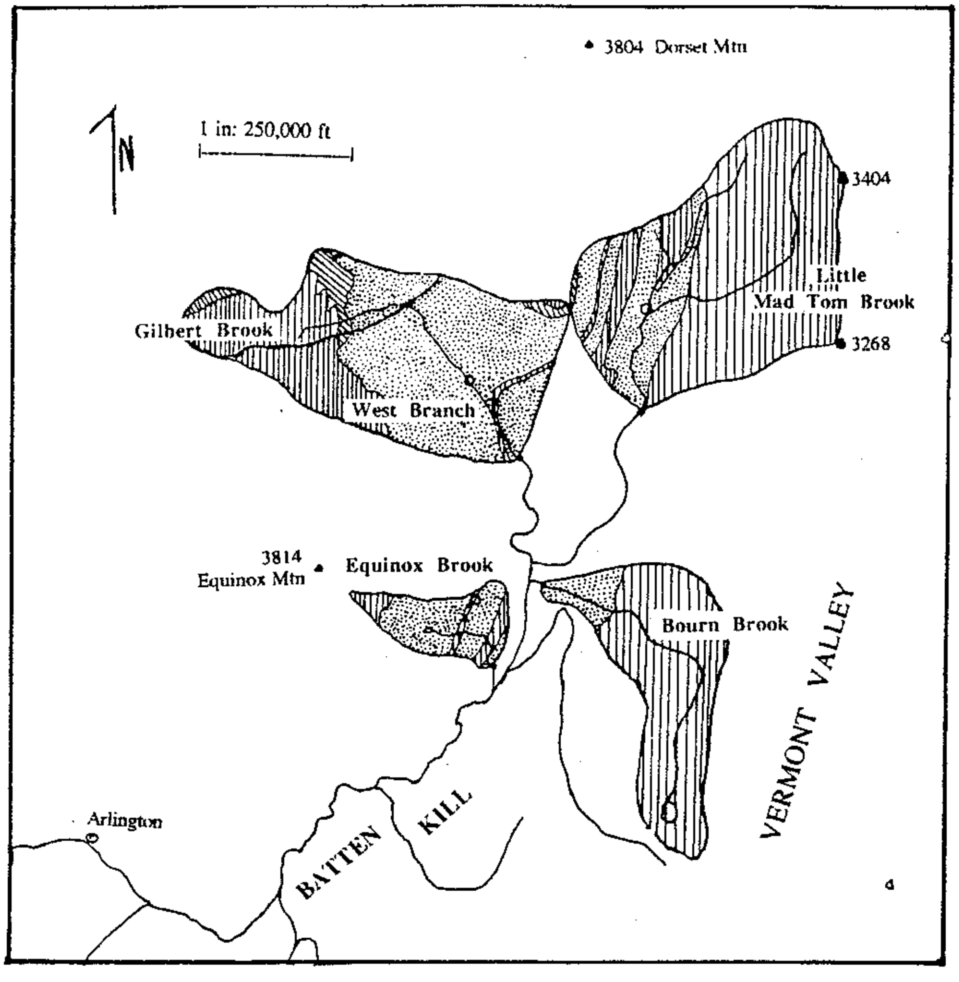
FIGURE 1

Generalized Bedrock Weathering Types in Watershed Areas of Tributaries of the Batten Kill River, Vermont Valley, Southern Vermont.

This map shows our watershed areas and the proportions of soluble/ relatively insoluble bedrock below them. This proportion was important in its' relationship to the chemistry of the year- round streams.



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Carbonate bedrocks include limestone, dolomite, and marble.

Insoluble bedrocks include Cheshire (white, pink, tan) or red or marblaceous quartzite, slate, phyllite, and a granitic gneiss.

An interbedded quartzite/ dolomite that was assumed insoluble for the study.