Hydrogeochemistry of West Brook Watershed, Franklin County, MA

Reina L. Foxx
Department of Geological Sciences, California State University Fullerton, Fullerton, CA 2834-6850
Faculty sponsor: John D. Cooper, California State University, Fullerton

INTRODUCTION

The focus of this study was to collect water samples and conduct chemical analyses from the 16.3 km^2 West Brook Watershed, one of five major tributary systems of the Mill River in west-central Massachusetts (Figure 1). All samples were analyzed for specific conductance, pH, acid neutralizing capacity, aqueous silica analysis, major anions, and major cations to locate areas where agricultural and other human impacts could be affecting the water chemistry in this sub-catchment of the Mill River Watershed. This West Brook analysis constitutes part of a Mill River Watershed project funded by the Keck Geology Consortium, the W.M. Keck Foundation, and the National Science Foundation. The entire Mill River project involved nine undergraduate geology students, who focused on six smaller watersheds that comprise the 130 km^2 Mill River Watershed. Results from these undergraduate projects will contribute to an even larger Mill River Watershed Assessment Project, which will develop a comprehensive protection plan for the entire Mill River Watershed. The basis for the comprehensive protection plan stems from the concern that non-point source pollutants from local land uses are adversely affecting water quality in the Mill River Watershed, which includes West Brook.

West Brook Watershed is located approximately 7 kilometers northeast of the town of Williamsburg, in the Williamsburg 7.5×15-minute U.S.G.S. quadrangle. West Brook flows from north-northwest to south-southeast and is sourced partly from the Northampton Reservoir as well as from the area between High Ridge and Dry Hill, approximately 2 km west of the Northampton reservoir (Figure 1). West Brook ultimately joins the Mill River, which flows into the Connecticut River. Tributaries of West Brook include Jimmy Nolan Brook (JN), Ground Brook (GB), Mitchell Brook (MB), Stream AB, Potash Brook (PB), Hook Brook (HB), and Little Brook (LB) (Figure 1).

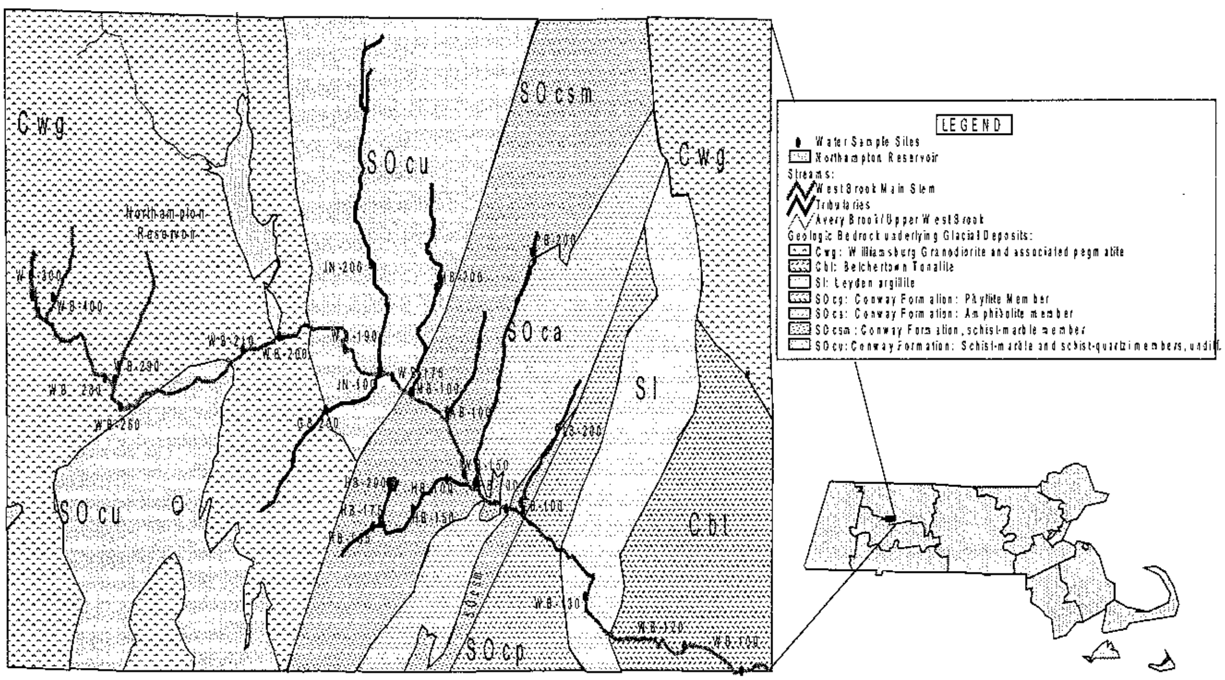

Figure 1. Map of West Brook Watershed showing bedrock geology (Willard, 1956) and streams. All stream sample locations are indicated by abbreviations for the stream name, followed by sample numbers, which increase in the upstream direction. Also, West Brook Watershed location within Massachusetts.

The West Brook Watershed occupies approximately 16.3 km^2 and includes dense forests, farmland, livestock fields, residential areas, several major roadways, and two small rock quarries. The weather during the study interval, mid-June to early July, was warm and humid with several storm events. Published work (Segerstrom, 1955) and field reconnaissance indicate that a variously thick veneer of glacial till and fluvial glacial sediments covers the area. These glacial deposits are underlain by seven geologic bedrock formations, including, from oldest to youngest, Paleozoic metamorphic and intrusive rocks that belong to: Silurian Conway Formation (schist, quartzite, marble, amphibolite, and phyllite); Silurian Leyden Argillite; Carboniferous Belchertown Tonalite; and Carboniferous Williamsburg Granodiorite and associated pegmatite. The sub-crop geologic map distribution of these bedrock units is shown in Figure 1.

METHODS

Field. Fieldwork involved collecting one-liter water samples from points along West Brook and its eight tributaries during June and July 1998. The 33 water samples were collected from 31 data collection sites that were accurately located by a Trimble GeoExplorer Global Positioning System (GPS) (Figure 1). The 31 sample sites included 15 on West Brook's main stem and 17 on its tributaries (Figure 1). The water collection sites were chosen based on necessity to sample areas near the confluence of the main stem and its tributaries as well as to get an even distribution of sites, both on the main stem and the tributaries themselves.

Laboratory. Laboratory analyses were conducted to provide a detailed chemical profile of stream water in West Brook Watershed. All water samples were analyzed at the Smith College Geochemistry Laboratory.

Specific Conductance (SC) is reported in mhos/cm or millisiemens (mS) per meter. SC was determined by use of a YSI specific conductance meter. It is the specific electrical conductance which gives a general measurement of total dissolved components in a water sample. SC contributes to the data on total components dissolved in the system, or total dissolved solids (TDS), from biologic and weathering sources.

The **pH** is the concentration of hydrogen ions, measured by a pH meter. After initial pH measurements, air-equilibration (AE pH) was conducted because CO_2 forms a weak acid and tends to lower the pH of the water, making it slightly more acidic.

The **acid neutralizing capacity** (ANC) of a water sample is determined by the use of the Gran Plot method, which involves titration of a water sample with a strong acid and calculating the amount of acid used to reach the equivalence point. Gran titration plots are represented in microequivalents per liter (μeq/L) of ANC. ANC values can indicate possible locations where bedrock is significantly impacting the water's chemical balance.

Analysis of **silica** content was conducted by a Spectronic 21 Spectrophotometer. This procedure involved the use of Molybdate Blue as a color indicator for varying silica levels, whereby the lighter the blue color, the lower the silica content. Silica represented as $SiO_{2\,(aq)}$, is an indirect measurement of silicate mineral weathering from bedrock such as argillite, schist, and plutonic rocks.

The elements calcium, magnesium, sodium, and potassium were determined by Flame **Atomic Absorption** (AA) Spectrometry by the use of a Perkin Elmer 3030 spectrometer. This data set indicates areas where cation levels are especially high, implying unusually high biologic activity and road salt dissolution. Also, areas where cation values increase downstream can indicate locations where greater amounts of biologic or possibly contaminating agents join stream waters.

Ion Chromatography (IC) was conducted by using a Dionex 2000i instrument to determine the concentration of the anions chloride, sulfate, and nitrate. A specific conductance instrument measured the separated ions in their acid forms. The data on the anion concentrations can indicate areas of nitrification, increased organic activity, or contamination effects.

RESULTS

To address the chemistry of the system and its implications, it is important to appreciate that the five-week study period is not representative of the system over an entire year. On a yearly cycle, watershed chemistry can vary significantly due to climatic changes, ecological changes, and from chemical reactions driven by environmental fluctuations such as deforestation (Likens, et al., 1977). The highest chemical values were recorded from Hook Brook and Little Brook samples. West Brook main stem (sites WB-200 through WB-400) (Figure 1) generally yielded the lowest chemical concentrations of the system (Table 1). Hook Brook (Table 1) samples exhibit chemical signatures that are extremely high for the entire system.

Table 1 presents all chemical data collected during mid June through early July, 1998.

Table 1. All units are in mg/L excluding pH, ANC which is ueq/L, and SC which is umho.

SAMPLE SITE NAME	pH	AE pH	ANC	HCO_3	SC	SiO_2	AA: Ca	AA: Mg	AA: Na	AA: K	IC: Cl	IC: SO_4^{2}	IC: NO^{3-}
GB-200	7.46	7.59	570.0	34.77	74.3	14.350	10.40	1.05	1.75	0.69	0.895	6.495	0.321
JN-100	7.61	7.91	574.0	35.01	85.4	13.459	12.20	1.00	1.62	0.71	1.319	7.543	0.374
JN-200	7.70	7.98	800.0	48.80	93.1	12.188	13.50	0.99	1.86	0.85	1.385	7.547	0.381
MB-100	7.20	7.79	503.0	30.68	79.7	11.509	11.20	0.69	1.36	1.06	0.863	9.742	0.000
MB-200	7.38	7.97	891.0	54.35	109.8	12.208	16.50	1.10	1.35	0.74	0.846	7.961	0.285
Stream AB	7.51	7.75	170.0	10.51	115.1	10.438	15.40	0.94	2.21	1.54	1.160	11.370	0.297
HB-100	7.81	8.09	700.0	42.70	151.4	16.710	15.40	1.61	7.70	1.60	17.240	9.260	3.350
HB-100	7.63	8.02	921.0	56.18	162.6	15.668	16.70	1.73	7.90	2.02	17.240	8.359	1.355
HB-150	7.57	7.95	1126.0	68.69	164.2	15.668	17.10	1.79	8.00	2.09	16.450	8.140	1.287
HB-165	7.62	7.98	669.0	40.81	108.3	16.553	13.40	1.56	3.35	1.13	4.244	9.496	0.836
HB-175	7.87	8.11	1194.0	72.83	147.1	16.491	18.00	1.86	5.10	1.38	7.597	4.984	0.459
HB-200	7.48	8.21	1405.9	85.76	204.0	15.853	22.10	2.05	8.30	1.31	16.010	0.486	0.000
PB-100	7.58	7.77	790.1	48.20	99.2	11.956	13.90	1.04	1.85	0.81	1.345	9.426	0.384
PB-200	7.54	7.88	681.7	41.59	110.7	10.355	16.60	1.09	1.54	1.15	0.992	10.127	0.297
LB-100	7.26	8.18	1122.0	68.44	145.5	9.037	20.20	1.83	9.30	0.82	12.290	6.797	0.000
LB-200	7.52	8.01	874.0	53.31	175.5	12.064	15.00	1.63	8.50	1.03	10.750	9.683	0.980
WB-100	7.58	7.70	432.0	26.35	70.5	11.224	8.30	0.89	2.85	0.84	2.997	6.663	0.593
WB-100	7.65	7.64	635.0	38.74	97.5	12.167	11.00	1.14	3.50	1.80	4.803	7.674	1.222
WB-100 (pipe)	7.14	7.68	571.0	34.83	229.0	14.473	15.40	2.09	22.40	1.55	40.180	11.850	7.426
WB-120	7.60	7.66	414.5	25.28	70.1	10.920	5.90	0.89	2.56	0.82	2.960	6.629	0.597
WB-130	7.48	7.63	389.0	23.73	70.0	10.940	8.30	0.86	2.48	0.81	2.913	6.527	0.501
WB-140	7.50	7.67	383.0	23.36	63.5	11.996	8.20	0.86	2.31	0.80	2.608	6.342	0.513
WB-150	7.51	7.61	442.0	26.96	68.8	10.541	8.10	0.90	2.58	0.92	2.707	6.381	0.666
WB-175	7.37	7.59	347.0	21.17	62.9	12.037	7.20	0.80	2.07	0.72	2.211	6.116	0.453
WB-190	7.29	7.47	295.0	18.00	50.8	11.529	5.80	0.71	1.96	0.68	2.076	5.514	0.452
WB-200	7.18	7.48	236.0	14.40	46.5	10.960	4.80	0.66	1.67	0.59	1.636	5.261	0.328
WB-210	7.05	7.50	231.0	14.09	47.6	14.231	4.54	0.70	2.11	0.55	1.974	5.276	0.356
WB-260	7.09	7.53	281.0	17.14	46.1	13.176	4.73	0.75	1.90	0.53	1.589	4.957	0.332
WB-280	7.18	7.49	214.0	13.05	39.4	12.991	3.79	0.64	1.95	0.58	1.040	5.207	0.227
WB-290	7.38	7.58	215.0	13.12	40.2	14.556	3.68	0.71	1.94	0.64	1.072	5.493	0.000
WB-300	7.00	7.47	195.0	11.90	37.5	12.682	3.54	0.60	1.73	0.44	1.060	4.935	0.287
WB-400	7.21	7.39	198.0	12.08	36.2	14.473	2.99	0.63	1.85	0.49	1.108	4.811	0.318
	7.43						3.50	0.99	2.23	0.91	1.444	5.722	0.329

DISCUSSION

Analyses of data collected from West Brook Watershed indicate that it is a system of fluctuating chemical components which vary through the entire watershed. General results from West Brook Watershed indicate that calcium is most abundant and nitrates the least abundant of chemical solutes in stream water samples. In terms of stream water chemistry in a baseline, pristine natural system, such as Hubbard Brook, NH (Likens, et al., 1977) it is expected that Specific Conductance (SC) *increases* downstream due to accumulation of chemicals in the water. This downstream *increase* is the result of accumulation of bicarbonate, sulfate, and chloride in water, resulting from ion exchange reactions that cause the evolution of stream water. The downstream *increase* with corresponding low acid neutralizing capacity values at the headwater regions is seen in the main stem of West Brook (WB) and the tributaries Little Brook (LB) and Potash Brook (PB) (Table 1)

The expected scenario also is demonstrated in a few of the tributaries of the West Brook Watershed; however, the opposite sequence showing a *decrease* in chemical levels downstream is also seen. Decreases in chemical concentrations/values downstream could be due to dilution of the base flow by direct runoff, which is low in dissolved solids (Hem, J.D., 1967) or by convergence with a smaller tributary. At Hook Brook (HB), Jimmy Nolan Brook (JN), and Mitchell Brook (MB), the downstream *decrease* in chemical components is evident. This is likely to be the result of swampy stagnant headwater locations which naturally become diluted by groundwater as downstream flow and groundwater percolation occurs. Overall, high acid neutralizing capacity values dominate the stream water, indicating a well-buffered system (*sensu* Chambers, L. 1986).

The measure of total dissolved ions in solution, or conductivity (SC), appears to be a good predictor of acid neutralizing capacity levels because of the general agreement with ANC patterns. The ANC and SC values for the main stem of West Brook follow the same pattern of increased concentrations downstream. In contrast, the ANC and SC trends for Hook Brook and Mitchell Brook both decrease downstream. However, Little Brook and Potash Brook have conflicting trends (Table1). The ANC values, as discussed earlier, increase downstream, whereas the SC values decrease downstream. The conflicting trends present an interesting problem that could be a result of bedrock interactions with water, whereby chemistry locally reflects carbonate bedrock such as marble, or silicate-rich bedrock such as argillite, schists, or plutonic rocks. In general the reaction $CO_2 + H_2O \Leftrightarrow H_2CO_3$ shows that bicarbonate is the product of weathering carbonate bedrock.

The system generally demonstrates randomly distributed pH levels, which are inconsistent with the increase and decrease trends as displayed by the ANC and conductance patterns because carbon dioxide does not affect ANC but does influence pH. Generally, pH variations are impacted by variations in dissolved carbon dioxide content in soils and stream water.

Silica values of the system increase downstream for Potash Brook, Mitchell Brook, and Jimmy Nolan Brook. Values for Hook Brook also increase downstream with the exception of a few points which depart from this pattern. This overall pattern of silica increase could be a result of stream channel downcutting into silicate rocks or weathering of soils rich in silicate minerals. West Brook main stem and Little Brook show a decrease downstream in silica concentrations. This could be an indication that groundwater dilution is dominant over streams' downcutting into carbonates or silicate soil weathering profiles. Also, the decrease in silica downstream could be the result of silicate mineral weathering at headwater sources, and less silicate weathering downstream, thus allowing dilution to occur over the length of the stream path.

The chemical results are important to the consideration of possible human, biological, and geologic effects on the water system. Specifically, high nitrate levels imply that there are some human factors affecting water chemistry. High nitrate levels can imply septic tank leakage, agricultural runoff from pastureland or fertilizer chemicals used to treat crops, condensing automobile exhaust fumes, other atmospheric deposition from both natural and anthropogenic sources. Also, phosphates can indicate septic tank leakage and chloride indicates domestic sewage input into the system. Increase in chloride content can occur in streams where domestic sewage is emptied (Hem, J.D., 1967). Sulfate levels can indicate areas of fertilizer runoff and possible areas where calcium-sulfate in till material is being weathered. These high chemical levels indicate unnatural conditions affecting water chemistry.

Adjacent to WB-100 is a possible aquifer contributing to the water supply of Westbrook and North Hatfield. The existence of an aquifer at this location would raise serious questions about whether construction and development in that locality would hinder aquifer recharge and contributions to town water supplies.

CONCLUSIONS

The West Brook Watershed system exhibits a variety of chemical trends. Contributions from bedrock, as well as agricultural runoff, street runoff, septic tank leakage, and various other impacts of human encroachment on the ecosystem are affecting the chemistry of the stream water. A major anomaly in this system is Hook Brook. This tributary of West Brook has high chemical values and is unique in comparison with the rest of the system. Further investigation of the entire watershed is necessary to determine specific causes for the chemistry observed in the system and to establish hypotheses on reasons for Hook Brook's abnormality. Furthermore, a year-long examination of the West Brook system is important for pinpointing areas of anomalous chemical values and exact pollutants. The seasonal impacts on the watershed could prove this June through July 1998 study to be abnormal in comparison with an entire seasonal year or a longer (e.g. 10 year) period. Despite these limitations, it is hoped that the data presented will contribute to the ongoing database for the Mill River Watershed Assessment project.

ACKNOWLEDGEMENTS

I would like to thank the Keck Geology Consortium and the National Science Foundation for their funding in allowing me the privilege to participate in this undergraduate geologic research. I would also like to thank Dr. John Cooper, CSUF, my faculty advisor, for field assistance and for his patience and editing efforts on the drafts of this paper. Thank you to Dr. Prem K. Saint, CSUF, for his hydrologic expertise and valuable insights. A special acknowledgement is extended to my project professors at Smith College: project director Dr. Robert Newton, Dr. Amy Larson-Rhodes, Anne Pufall, and Dr. Steve Archeampong from Summit Envirosolutions. Finally, thank you to my Mill River Keck colleagues and especially my field partner Lena Fletcher.

REFERENCES CITED

Chambers, L. W., 1986, The Geomorphology, Hydrology and Sensitivity to Acid Rain of Jimmy Nolan Brook Watershed, West Whately, Massachusetts [Undergraduate Thesis]: Smith College, Northampton, MA, 80p.

Hem, J.D., 1967, Study and Interpretation of the Chemical Characteristics of Natural Water: Washington D.C., Geological Survey Water-Supply Paper, United States Government Printing Office, 1473, 264 p.

Likens, G.E., Bormann, F.H., Pierce, R.S., Eaton, J.S., Johnson, N.M., 1977, Biogeochemistry of a Forested Ecosystem (1st ed.): New York, Springer-Verlag, 450 p.

Segerstrom, K., 1955, Surficial Geology of the Williamsburg Quadrangle, Massachusetts: U.S. Geological Survey, Quadrangle Maps of the United States, Map GQ. 80, scale 1:24000, 1 sheet.

Watson, I., Burnett, A.D., 1995, Hydrology an Environmental Approach: London, Lewis Publishers, Inc., 701p.

Willard, M.E., 1956, Bedrock Geology of the Williamsburg Quadrangle, Massachusetts: U.S. Geological Survey, Quadrangle Maps of the United States, Map GQ. 85, scale 1:24000, 1 sheet.