Land-use impacts on the Bloody Brook subcatchment, Mill River Watershed, Franklin County, Massachusetts

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INTRODUCTION

Pollution of fresh water resources and land-use impacts on the environment represent one of the most costly and controversial issues that face policy makers and communities in the United States. Although many steps have been taken to understand anthropogenic influence on freshwater rivers, lakes, and streams, waterway degradation through mismanagement and faulty land-use policy continues to be a major problem. The subject of this study is the Bloody Brook subcatchment, a region of the Mill River Watershed believed to be impacted by a variety of different types of land use. Since previous work in the region is lacking, this study was initiated to investigate the environmental health of Bloody Brook and the consequences of current land-use policy on water and soil quality. These include components of land use such as agriculture and roadways which are built in close proximity to the brook and may be having an adverse effect on surface water, groundwater, and soils.

FIELD AND EXPERIMENTAL METHODS

Surface Water and Groundwater. Since previous work in the region only involved surface water sampling from one location in the subcatchment, the study was expanded to include a more comprehensive sampling of all sections of Bloody Brook, with an emphasis on the brook's main stem and its major tributary. Surface water samples were collected at sites near the source of the brook to areas in the southwest where the brook joins the Mill River (Fig. 1), as well as in the neighboring Sugarloaf Brook, outside the border of the Mill River Watershed. In addition, several groundwater samples were collected from temporary shallow PVC wells installed by hand auger.

Soils. Soils were sampled from many areas, from both agricultural and roadside settings (Fig. 1). To sample a soil, a pit was dug, approximately 20 to 50 cm in depth. Soil "horizons" were marked at regular depth intervals from the surface, and soils at those horizons were scooped out of the walls of the pit and collected.

Laboratory. All water samples were measured for pH, aqueous silica, alkalinity (using a Gran titration method), and specific conductance using an unaltered sample. Major cations Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+} were detected through the use of a Perkin Elmer 3030 atomic absorption (AA) spectrophotometer, with an air-acetylene flame. The concentrations of the anions SO_4^{2-}, Cl^-, and NO_3^- were determined using a Dionex 2000i ion chromatograph. For this analysis, all samples were suction filtered using a 0.45 μm filter to remove suspended sediment.

Soil samples were tested for their exchangeable basicity and exchangeable acidity. To measure exchangeable basicity, or the concentrations of the cations Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+} found on exchange sites, 10 g of soil was mixed with 40 mL of 1.0 N NH_4Cl to bring exchangeable cations from the soil surface into solution. The solution was then analyzed for each cation through AA. To measure exchangeable acidity, or the acidity of the soil due to H^+ and Al^{3+} on exchange sites, 10 g of soil was reacted with 25 mL of 1.0 N KCl, putting the H^+ and Al^{3+} into solution. Through a titration with 0.1 N NaOH and five drops of phenolphthalein indicator, the amount of base needed to neutralize the extract was considered in a total acidity calculation. The total cation exachange capacity of the soil is considered the sum of the exchangeable basicity and exchangeable acidity.

RESULTS

Stream Chemistry Alkalinity of the Main Stem and Major Tributary. In general, the major tributary and main stem of Bloody Brook have very different bicarbonate chemistries (Fig. 2). In the main stem, bicarbonate has a concentration of 597.9 μeq/L at site BB-310 (towards the headwaters), and increases with distance downstream to 772.2 μeq/L. However, the major tributary has a relatively high concentration of bicarbonate at site BB-330, and this decreases to 689.7 μeq/L with distance downstream, showing a different trend than in the main stem (Fig. 2). Sample BB-5-10, taken from a water-filled depression in a wheat field through which the major tributary flowed, had an alkalinity of 1270.1 μeq/L, the largest amount of bicarbonate measured in the subcatchment. Sample BB-F, also taken from this wheat field, had a relatively large amount of bicarbonate, measuring 862.9 μeq/L.

Sodium Chloride. Ratios of sodium to chloride (both in units of μeq/L) were calculated for surface waters, and are relatively high near the source of Bloody Brook, with values of 3.82, 3.18, and 2.49 for samples BB-550, BB-500, and BB-400, respectively. These ratios decrease with distance downstream, until the ratio reaches approximately 1:1 for most of the samples (Fig. 3). Plotting surface water chemistry on piper diagrams, both the

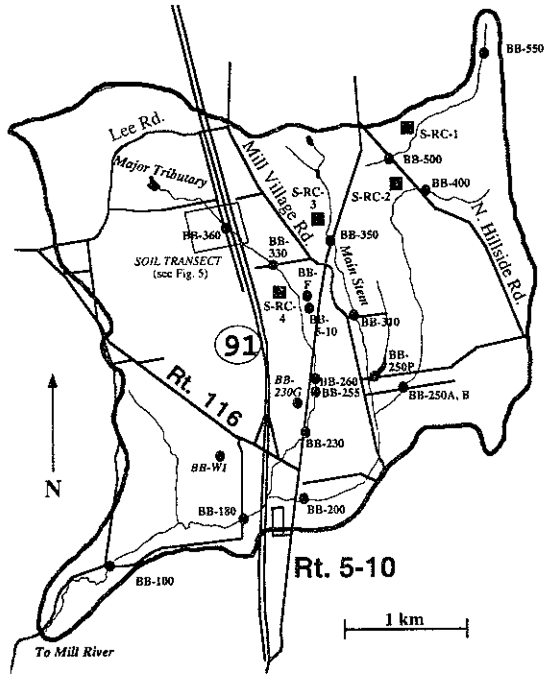

Figure 1. Approximate locations of water and soil sampling sites in the Bloody Brook subcatchment and Sugarloaf Brook. Water samples are indicated by circles, and soil pits are indicated as squares. Groundwater samples are italicized.

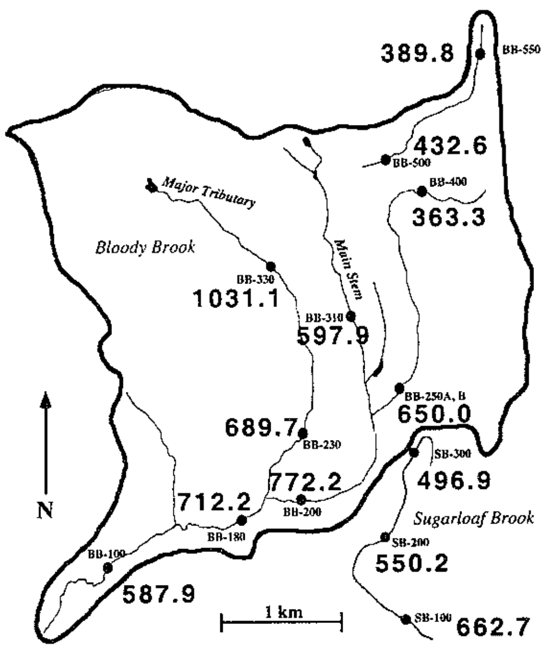

Figure 2. Approximate locations of sampling sites in the Bloody Brook subcatchment and their corresponding alkalinities, in µeq/L of bicarbonate. Samples from Sugarloaf Brook have also been indicated.

major tributary and the main stem show a progressive trend towards the $(Ca^{2+}+Mg^{2+})/(CO_3^{2-}+HCO_3^{-})$ vertex of the main quadrilateral, the sodic/potassic hydrochemical facies in the cation ternary, and the chloride hydrochemical facies in the anion ternary with distance downstream (Fig. 4). This trend is more pronounced in the major tributary, with sample BB-230 plotting closer to the vertices than any other sample. Samples BB-180 and BB-100 trend towards the center in each section of the diagram.

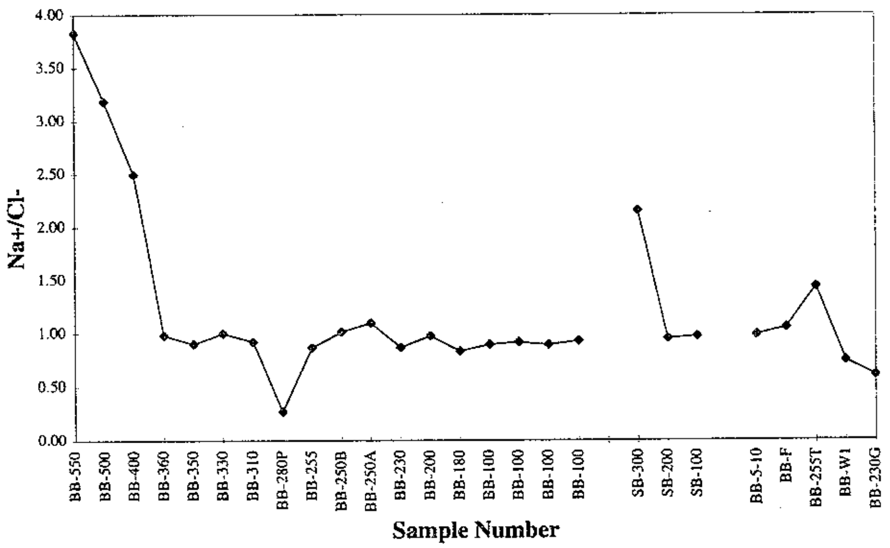

Figure 3. Sodium and chloride ionic concentrations (ratios) in Bloody Brook surface water and groundwater samples. Samples from Sugarloaf Brook are also indicated.

Soil Chemistry Exchangeable Sodium. In general, sodium concentrations are highest in the surface soils closest to the interstate, and decrease in 20-meter intervals away, with some local increases (Fig. 5).

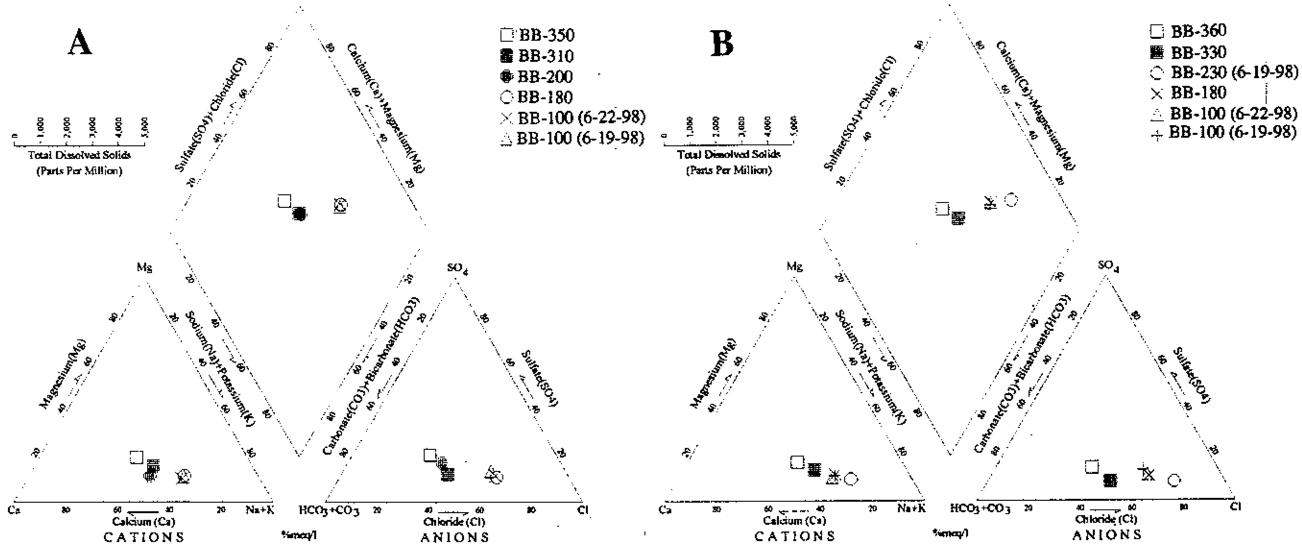

Figure 4. Piper diagrams showing chemistry of water samples from the (A) main stem and (B) major tributary of Bloody Brook.

The exchangeable sodium concentration of 0.774 meq/100 g measured closest to the road is more than 200% higher than any other exchangeable sodium measurement in any of the soils sampled, including agricultural soils.

Base Saturation. Defined as the percentage or ratio of the total exchangeable bases to the total cation exchange capacity of a soil, base saturation was calculated for every soil sample (Tan, 1982). Most soil samples taken within the subcatchment plot very close to 100% base saturation (Fig. 6). Notable exceptions are the Interstate 91 samples S-P1B-E, S-P5B-C, and deep (40-50 cm) agricultural soil samples from S-RC-2.

DETERMINATION OF LAND-USE IMPACTS

Agriculture. Since the major tributary of Bloody Brook displayed, on average, about twice as much bicarbonate in its source areas than in the main stem (Fig. 2), and several samples with very high bicarbonate levels (BB-F, BB-5-10) were in direct contact with agricultural soils of the major tributary, this indicates that agricultural practices could have a role in increasing the amount of bicarbonate in the surface water. The major tributary of Bloody Brook is largely dominated by agriculture. Increases in bicarbonate in surface waters of the major tributary could be the direct result of the hydrolysis of lime, which would run off fields and hydrolyze in the surface water of Bloody Brook. The main stem runs through mostly residential areas of South Deerfield and some agricultural fields along its path, and displays only a relatively slight increase in alkalinity with distance downstream.

Road Salt Contamination. The consistent sodium-chloride ratios of 1:1 throughout most of the water samples directly point to road salt (NaCl) contamination of Bloody Brook's surface water (Fig. 3). This conclusion is supported by the fact that these 1:1 ratios occur in water samples found near roadways, away from the source of the brook. Sources of sodium and chloride would tend not to include the bedrock of the subcatchment, making it doubtful that these ions could come from natural weathering processes.

Trends in the piper diagrams towards the $(Ca^{2+}+Mg^{2+})/(CO_3^{2-}+HCO_3^{-})$ vertex of the piper quadrilateral, as displayed with the data in both the main stem and the major tributary, have been interpreted to be indicative of salt-contaminated water (Siegel, 1996). The fact that the major tributary plots closer to the vertices of the piper diagram than the main stem only suggests that the major tributary is more influenced by road salt than the main stem. This is consistent with the observation that the major tributary runs under major roadways more frequently, while the main stem runs parallel to or completely avoids the major roadways (Fig. 1). Trends towards the center of the quadrilateral after the major tributary meets the main stem indicates surface water mixing.

Since exchangeable sodium is higher near Interstate 91 than in any other section of the soil transect, this is strong evidence that road salt is not confined to the interstate, and washes off the highway to be infiltrated into the soil (Fig. 5). This could also suggest the possibility that a salt lens might exist within 20 meters of Interstate 91.

Roadways. In general, base saturation of the soils indicate that many of the different kinds of soils are very fertile, and can sustain a variety of plant life or crops (Fig. 6). However, the fact that some of the soils, especially the soils sampled at S-P5 and S-P1 (the two pits closest to Interstate 91), were classified as medium fertile to non-fertile may suggest that interstate runoff is having a negative impact on those soils.

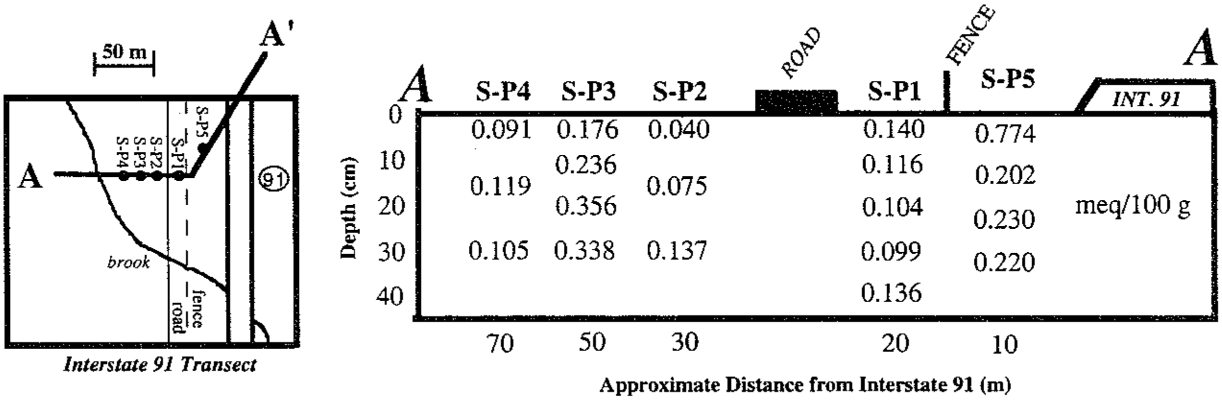

Figure 5. Exchangeable sodium concentrations (meq/100 g) of Interstate 91 soils with depth and distance away from the road.

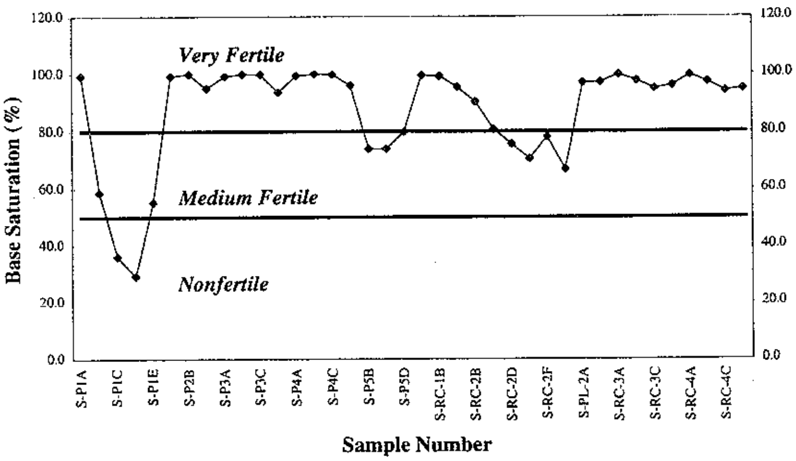

Figure 6. Base saturation of all Bloody Brook soils (expressed as a percentage). Soil fertility ranges have been indicated, as defined by Tan (1982).

IMPLICATIONS

A comparison of surface water chemistry with USPHS and USEPA drinking water standards reveals that surface water, during the time it was sampled, is fit for human consumption. All chemical constituents tested for during this study fall under established MCLs. Given standards established by Brooks *et. al.* (1997) which are determined by the tolerance of certain aquatic organisms to concentrations of certain chemical constituents, surface water also does not fall above these limits, indicating it has the ability to support a diverse community of fish and aquatic life. However, there are some areas of concern where sodium, chloride, and nitrates can reach levels that come very close to these limits, indicating the need for some improvement to make the brook more sustainable.

In conclusion, at the present time current land use does not appear to have a devastating effect on this environment in terms of water quality, although some improvement is warranted. In the future, if these land-use practices continue unabated, water and soil quality can only be expected to worsen. Studies in the subcatchment should continue to include further sampling of water and soils, and more diverse chemical tests to increase our understanding of other kinds of land-use impacts. This is essential for monitoring any changes in chemistry which could adversely affect this environment in the years to come.

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