

# THE INFLUENCE OF AN INTERSTATE HIGHWAY ON THE HYDROLOGY AND GEOCHEMISTRY OF A WETLAND: THE GREAT SWAMP OF WHATELY, MASSACHUSETTS

**Andrew Logan**

Department of Geology, Amherst College, Amherst MA 01002  
*faculty sponsor: Peter Crowley, Amherst College*

## INTRODUCTION

The Great Swamp is a sub-catchment of the Mill River, which drains a 130 km<sup>2</sup> region in the Connecticut River Valley of western Massachusetts. The Great Swamp occupies 5 km<sup>2</sup> in a lowland area within the watershed. It formed in sandy glaciofluvial deposits which overlie the glaciolacustrine silt and clay deposited by glacial Lake Hitchcock. The swamp is drained by Great Swamp Brook, which has an average gradient of less than 2 meters per kilometer. The terrain is hummocky, with local relief of less than a meter. The only significant relief within the watershed is supplied by a small drumlin, measuring 0.6 km (north-south) by 0.25 km (west-east) which rises approximately 10 m above the surrounding terrain and forms part of the western boundary for the watershed.

The catchment is bounded to the east by Interstate 91, and is transected by a smaller, two-lane road, Route 5/10. There is a gas station/truck stop/diner complex located at the intersection of the two roads; otherwise, there is relatively little human activity within the swamp.

Great Swamp Brook is formed from three tributaries (western, central and eastern) which drain areas of the swamp differing only in their proximity to the highway (Figure 1). They are similar in area (draining 0.7 km<sup>2</sup>, 1.0 km<sup>2</sup>, and 0.9 km<sup>2</sup>, respectively) and have similar slopes, vegetation cover and soil type (soil survey of Mott and Fuller, 1967). The western and central tributaries flow through undeveloped regions. The eastern tributary flows near Interstate 91 for much of its course; during storms it receives a large amount of engineered runoff from the highway. The Great Swamp watershed, then, provides the opportunity to study the impact of an interstate highway within a single watershed, allowing for significant control of other variables.

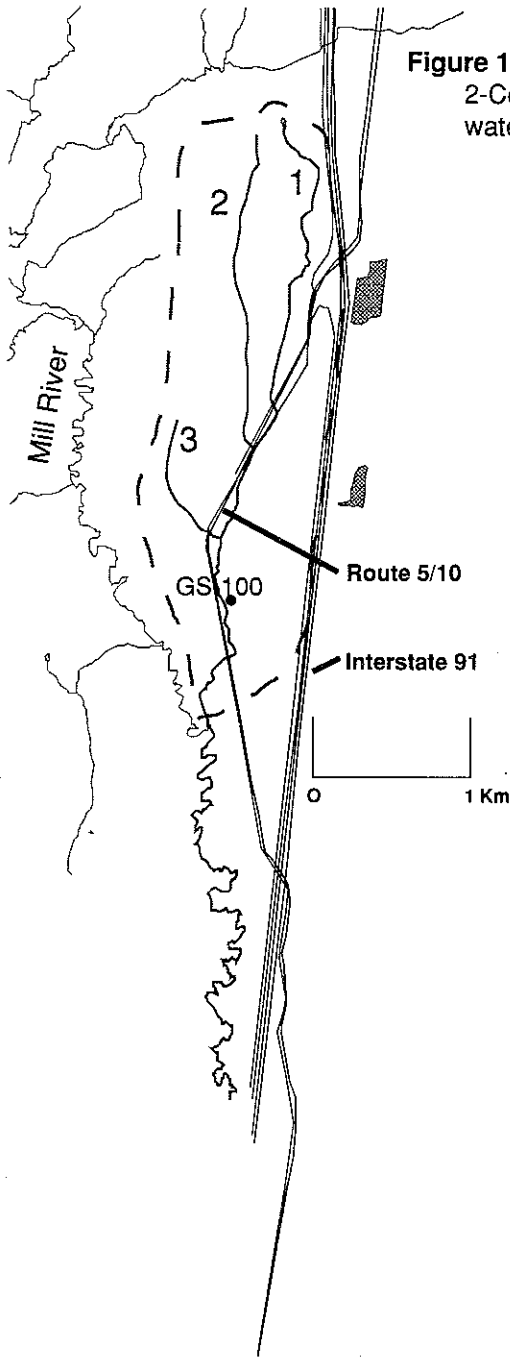
## METHODS

Surface water samples have been taken regularly since October 1996 from a single site on the main branch of Great Swamp Brook (site GS-100) as part of the larger Mill River monitoring project (Newton and Rhodes, this volume). In addition, samples were collected throughout the watershed from June to November 1998. Rainfall was collected at two sites for three rain events in October-November, 1998. All water samples were filtered (0.45 µm cellulose acetate membrane) in the laboratory within 24 hours of collection. An aliquot of each sample was acidified for later cation analysis. Major ions were determined by ion chromatography, atomic absorption and inductively coupled plasma spectrometry; trace metals (Cd, Zn, Fe, Cu, Mn, B, Co, Pb, Ni, Ba) were determined by inductively coupled plasma spectrometry. Samples were analyzed for acid neutralizing capacity (ANC) by the Gran Plot method (Newton, 1998).

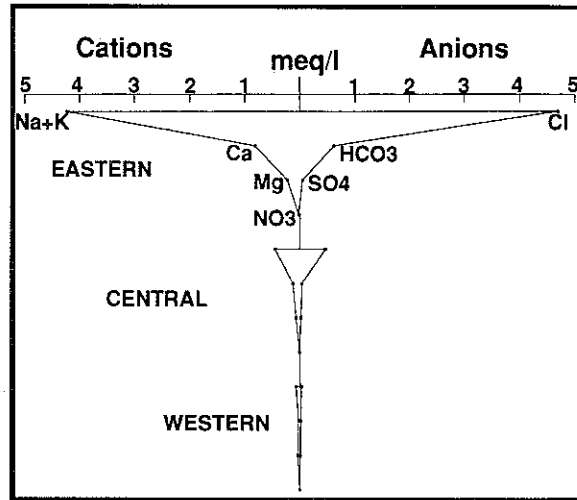
Soil samples were taken along a series of east-west transects beginning at Interstate 91. Samples were dried at 40°C and homogenized using a cone-and-quarter method. Base saturation was determined using 1N unbuffered NH<sub>4</sub>Cl, while exchangeable acidity was determined by titration with 0.1M NaOH.

## RESULTS

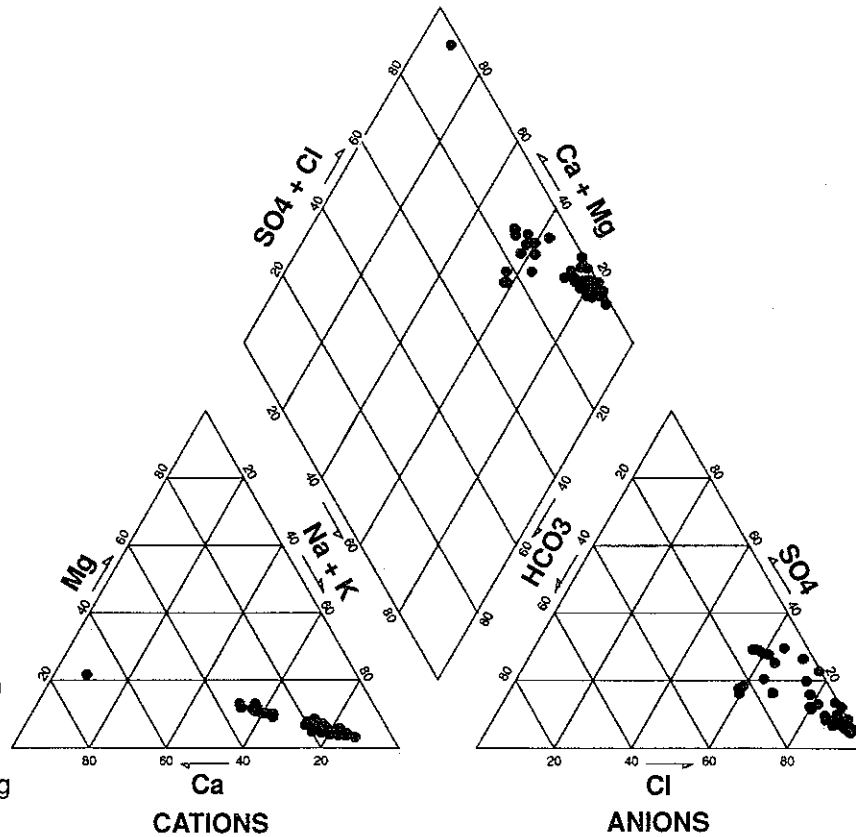
Regular sampling in the lower reaches of the brook, beginning in 1996, revealed that its chemical characteristics fluctuate over a wide range. Conductivity values ranged from 17 to 75 mS/m, while ANC varied from -90 to 800 µeq/L. Further sampling during the summer of 1998 suggested that these downstream fluctuations are the result of the varying input of three upstream tributaries that differ significantly in both geochemistry and hydrology. The central tributary flows through a relatively unspoiled region in the interior of the swamp. Its waters are acidic and mineralization is low (conductivity <10 mS/m). The eastern tributary flows near Interstate 91 and receives engineered runoff from the highway. Its response time to storm events is significantly faster than the central and western tributaries. Conductivity values and ANC are an order of magnitude greater in the eastern tributary. The dominant ions in both streams are Na<sup>+</sup> and Cl<sup>-</sup>, though the eastern tributary also contains significant



**Figure 1.** Great Swamp Brook and its Tributaries: 1- Eastern Tributary; 2-Central; 3-Western. Dashed line represents the approximate watershed boundary.



**Figure 2.** Stiff diagram comparing the chemistry of the east, central and western tributaries, using a representative sample from each. Note the order of magnitude difference in mineralization between adjacent tributaries.



**Figure 3.** Piper plot showing chemical variation at GS-100 from 1996-1998. Note the relatively linear distribution of points, suggesting a mixing relationship.

amounts of  $\text{Ca}^{+2}$ . The western tributary is chemically quite different from the 2 streams to its east. This stream has acidic water and the lowest conductivity values of any site (3-4 mS/m). While  $\text{Na}^+$  and  $\text{Cl}^-$  are still the predominant ions, the relative concentrations of  $\text{SO}_4^{-2}$ ,  $\text{Mg}^{+2}$  and  $\text{Ca}^{+2}$  are higher here (Figure 2).

Throughfall was collected at two sites: one in the center of the swamp and the other in the east, approximately 20 meters from Interstate 91. Throughfall chemistry differed significantly between the two sites, with the eastern region recording substantially higher conductivity levels (5-6 mS/m in the eastern region, compared to ~1 mS/m in the east, with the disparity especially great in  $\text{Cl}^-$  levels (5-12 mg/l  $\text{Cl}^-$  vs. <1 mg/l in the center). In the east, throughfall ion distribution was  $\text{Cl}^- > \text{SO}_4^{-2} > \text{NO}_3^-$  and  $\text{K}^+ > \text{Ca}^{+2} > \text{Mg}^{+2} \approx \text{Na}^+$  whereas at the central rainfall collector,  $\text{SO}_4^{-2} > \text{NO}_3^- > \text{Cl}^-$  and  $\text{K}^+ > \text{Ca}^{+2} \approx \text{Mg}^{+2} \approx \text{Na}^+$ . Precipitation chemistry was more dilute in November, once the leaves had fallen from the trees. Chemistry and ion balances were essentially the same for both sites after leaf-fall, with conductivity <1 mS/m and the concentrations of all ions <1ppm.

Field observations indicate that the organic mucks of the swamp are highly impermeable. In addition, a clay layer found beneath the organic soils in much of the swamp suppresses exchange between groundwater and surface water, creating an isolated surface water table.

Cation exchange capacity (CEC) varied widely among the samples, ranging from 0.67 to 13.68 meq/100g in the organic and A horizons. Base saturation varied from 2.3% to 93.4%. At higher base saturations,  $\text{Ca}^{+2}$  and  $\text{Na}^+$  dominated the exchange sites, while  $\text{Mg}^{+2}$  dominated base sites when base saturation was lower. In general, high base saturations occurred adjacent to the roadway, with soils becoming markedly more acidic away from the highway; by ~500m to the west of Interstate 91,  $\text{H}^+$  dominates CEC.

Heavy metals were only detected in significant quantities around the diner/truck stop/gas station complex located at the intersection of Rt. 91 and Rt. 5/10. Zinc accounted for up to 5% of base saturation, while lead occupied up to 3% of the sites.

## DISCUSSION

The data suggest that the temporal chemical fluctuations observed in the main tributary (site GS-100) are the result of mixing between two water types—high ANC, high conductivity water from the eastern tributary, and the acidic, relatively dilute waters of the western and central tributaries. When plotted on a trilinear diagram, the GS-100 data points fall on a straight line (Figure 3), suggesting that chemistry at this point is controlled by the mixing of two waters.

The eastern tributary is bordered by Interstate 91, a large impermeable surface that drains into the stream via a ditch system. The replacement of permeable areas with impervious surfaces, which are designed to remove precipitation as quickly as possible from an area, inhibits the infiltration of precipitation into groundwater and surface water storage, as well as the amount subject to removal by evapotranspiration (Lull, 1969). The hydrologic buffering capacity of the system is reduced, making it flashier with higher peak flows and higher overall flow variability, as well as higher overall flow volume (Bingham, 1994). The addition of impermeable surfaces also decreases the rate of groundwater recharge, causing groundwater and surface water storage levels to decrease. Such decreases in storage lower the water level in streams during dry times of the hydrologic year, when stream flow is dominated by base flow (Spinello and Simmons, 1992). In a wetland, where the groundwater table is located at or near the surface and gradients are low, small changes in groundwater level might have a significant impact on stream discharge from the area. Thus it might be expected that the eastern tributary would dominate during storm and high water events, while at low flow the western and central streams should have the greater influence. This interpretation is supported by the surface water chemistry: ANC at GS-100 is highest in the spring and early summer, when overall flow is at its peak, and low in the winter and early spring, when base flow might be expected to prevail.

The three streams surveyed (western, central and eastern) have similar slopes, vegetation cover and soil type. They differ chiefly in their distance from Interstate 91. The western stream is the most dilute and least enriched in  $\text{Na}^+$  and  $\text{Cl}^-$ , and thus is probably most representative of the pre-development state of the swamp. It differs from the other streams not only in its overall conductivity, but also in its ionic ratios. Most significantly, the equivalence ratio of Na:Cl in the western tributary has a mean of 1.7, compared to 0.91 and 0.84 in the central and eastern regions, respectively. It has been traditionally assumed (e.g. Yuretich and Batchelder, 1988) that road salts are unreactive and are conservatively flushed from the watershed. If this were the case, the Na:Cl ratio in surface water should be greater than 1; road salt input into the system has a Na:Cl ratio of nearly 1 (Shanley, 1994), and weathering in the basin should increase the ratio, since the minerals which dominate the glaciofluvial sands of the region (Liu, 1989) would release  $\text{Na}^+$  with weathering, but not significant quantities of  $\text{Cl}^-$ . The rest of the Mill River drainage, of which Great Swamp is a part, has a relatively high Na:Cl ratio, with a weighted mean of 1.46

(Newton and Rhodes, this volume). The only other catchment in the system that has a low ratio is Bloody Brook (mean of 0.91) (Newton and Rhodes, this volume), which also passes along and under Interstate 91, and so is likely affected by road salting. The absence of excess  $\text{Na}^+$  in these areas suggests that there is a sink for  $\text{Na}^+$  in these watersheds. Soil chemistry data suggests that the sink is the soil cation exchange complex. The percentage of soil exchange sites occupied by  $\text{Na}^+$  increases toward the highway, implying that  $\text{Na}^+$ , rather than passing conservatively through the system, is exchanging with other ions, primarily  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$ .

The low Na:Cl ratio and high relative concentrations of  $\text{Na}^+$  and  $\text{Cl}^-$  in the central region of the swamp suggest that it has been affected by road salt contamination. The eastern region has still higher concentrations of  $\text{Na}^+$  and  $\text{Cl}^-$ , which is not surprising given its closer proximity to the interstate; it also, however, has significantly higher concentrations of  $\text{Ca}^{2+}$ , as well as markedly higher ANC values. ANC in the watershed is strongly correlated with  $\text{Ca}^{2+}$  concentrations when the acidifying effect of sulfate oxidation is accounted for (Figure 4), suggesting that ANC is controlled by mineral weathering. The most significant difference in weathering patterns between the two regions would likely come from the large amounts of road fill that underlie the raised highway. Soil cation exchange data supports this conclusion.

The fraction of exchange sites occupied by  $\text{Ca}^{2+}$  increases toward the interstate, suggesting that the source of  $\text{Ca}^{2+}$  is on or near the road. Since  $\text{CaCl}_2$  is used infrequently as a deicing agent in Massachusetts (Shanley, 1994), and since storm runoff from the road itself contains high concentrations of  $\text{Na}^+$  but little  $\text{Ca}^{2+}$ , it seems unlikely that deicing agents are a significant source of  $\text{Ca}^{2+}$ .

There is a sharp drop in the percentage of exchange sites occupied by  $\text{Ca}^{2+}$  immediately to the west of the eastern tributary. This suggests that the channel itself acts as a barrier to the transport of  $\text{Ca}^{2+}$ , not allowing the perched soil water to reach the perched water on the other side of the channel. Such is not the case with  $\text{Na}^+$ , perhaps due to the different means of ion transport— $\text{Ca}^{2+}$ , if it results from weathering, would travel in aqueous solution and would be subject to hydrologic barriers, while  $\text{Na}^+$  (from road salt) can be blown across ice and snow cover by wind up to several hundred meters from a roadway (Pugh et al., 1995). Thus we would expect  $\text{Na}^+$  contamination to extend further from the roadway, jumping hydrologic boundaries where  $\text{Ca}^{2+}$  cannot.

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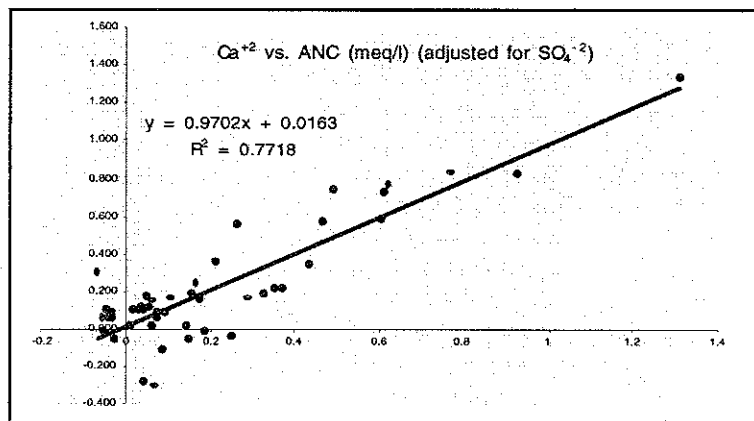


Figure 4. A near 1:1 relationship between  $\text{Ca}^{2+}$  and ANC is obtained when the acidifying effect of sulfate oxidation is accounted for (by subtracting  $\text{SO}_4^{2-}$  from  $\text{Ca}^{2+}$  on an equivalence basis). This strongly suggests that ANC in the swamp is derived from mineral weathering.