Highway Deicing Salt Runoff Events and Major Ion Concentrations along a Small Urban Stream

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ABSTRACT

Highway deicing activities can influence the quality of waters draining urban areas that experience multiple winter season freeze/thaw cycles. However, because of the flashy hydrology of smaller urban streams, and the unpredictable nature of deicing runoff, these events are difficult to fully document by traditional monitoring approaches. The frequency, duration, intensity and downstream attenuation of highway deicing salt runoff events were captured by remote continuous flow and conductivity monitoring, in combination with dry and wet weather grab sampling, at four stations along a three-kilometer-long unculverted reach of an urban Pennsylvania stream, Nine Mile Run.

Base flow dry weather conductivity values along Nine Mile Run averaged 1,232 umhos/cm and could drop as low as 61 umhos/cm following summer storms. However, at a major storm sewer discharge, which drains a highly urbanized and almost completely culverted subbasin of 9.8 km², short duration winter thaw peak conductivity values as high as 32,457 umhos/cm were documented. While such peaks tended to occur during very minor winter flow pulses, and were highly attenuated by channel storage at downstream stations, the shock loads of salt experienced were sufficiently elevated to cause concern about osmoregulatory stress to freshwater organisms. Even during base dry weather summer flow conditions, the major ion composition of the waters of Nine Mile Run was dominated by sodium chloride, rather than calcium sulfate, as occurs in nearby drainages.

INTRODUCTION

Nine Mile Run drains an area of 19.4 km² in the eastern portion of the city of Pittsburgh, Pennsylvania and adjacent urbanized communities (Fig. 1). The basin is located in a highly dissected portion of the unglaciated Appalachian Plateaus Physiographic Province, with total relief in the drainage basin of 180 m. Normal total annual precipitation is 93 cm, and the monthly normal is highest in July (9.5 cm) and lowest in February (6.1 cm). Average annual snowfall is 111.2 cm, and snow cover is subject to melting throughout the winter season. In other words, the basin is located in a very hilly “ice belt,” where repeated and copious applications of deicing salts in the winter would be anticipated.

Cyclic sequences of Pennsylvanian sandstone, shale, and claystone, with thin beds of limestone and coal are exposed in the watershed. Local
Besides ubiquitous dispersed CaSO₄ yielding minerals in the upper urban environment of Nine Mile Run, a 95 hectare, 20 million ton steel mill slag dump, located along the banks of the lower 1.4 km reach of Nine Mile Run, discharges calcium sulfate leachate directly into the stream.

While at least six documented combined sewer overflows (CSO) discharge into Nine Mile Run, overwhelmingly the stream is impacted by urban runoff from a single source, which terminates at the Braddock Avenue Culvert (km 3.1). The drainage area upstream of this culvert is 9.8 km², more than 50% of the total Nine Mile Run drainage basin. Storm events over the hilly topography result in very high and sharp hydrographs and introduce a variety of urban materials into the stream. Downstream of the culvert, Nine Mile Run receives two perennial tributaries and flows through a city park and the slag dump to its confluence with the Monongahela River. The first tributary is Fern Hollow, which has a total drainage area of 4.9 km². Upper Fern Hollow is urbanized; lower Fern Hollow is largely parkland. The second tributary, Commercial Run, drains only 0.28 km² but is the only perennial stream in the watershed that does not drain any paved surfaces. There are several spring seeps at the toe of the slag dump, which also influence the quality of the water of Nine Mile Run.

Our objectives were to characterize the basin chemistry of Nine Mile Run, and to relate variations in that chemistry to episodic runoff of highway deicing salts.

**METHODS AND MATERIALS**

Water chemistry data collection involved: (1) continuous electronic recording at four stations along Nine Mile Run, (km 0.13, 0.75, 1.74, and 3.1); (2) grab sampling from ten stations for more detailed chemical analyses on six different dry weather days; and (3) wet weather grab sampling during five storm events, where at least five sample sets were collected throughout the duration of each storm from at least two stations simultaneously (km 0.13, km 3.1 and once also at km 1.74).

Dry weather surveys were conducted during base flow conditions in 1999 (July 16, Aug 19, Sept 14, Oct 19, Nov 17) and in 2000 (Jan 25). Storm events were sampled on July 28, Aug 24, Aug 25, Sept 20, and Sept 29, 1999. Chemical parameters measured were acidity, alkalinity, pH, dissolved solids, turbidity, conductivity, suspended solids, chlorides, sulfates, calcium, magnesium, and sodium.

Continuous remote sensing monitoring was initiated at two stations (km 0.13 and km 1.74) on Aug 8, 1999. Two additional monitoring units were installed at km 0.75 and km 3.1 on Sept 14, 1999. All four units were operated until Mar 1, 2000. Multi-parameter sondes were installed in 10.2 cm diameter anchored plastic pipes, perforated with 1.3 cm wide holes along submerged lengths. The sondes were programmed to measured water temperature, pH, and conductivity at hourly intervals. The records from the sondes were not absolutely continuous for the entire
In lower Nine Mile Run, where discharges from spring seeps along the toe of the slag dump enter, pH, alkalinity, acidity, calcium, and magnesium were parameters that were significantly altered. For example, while the mean dry weather pH of the four combined upper reach stations was 7.6, the mean pH at km 0.13 was 9.2 (Fig. 2). Mean total acidity dropped from 3.8 to 0.0 mg/l as CaCO$_3$ and alkalinity declined from a mean of 96 to 58 mg/l as CaCO$_3$. A sharp fall in alkalinity might not initially appear to be a phenomenon consistent with a sudden rise in pH. However, the alkalinity results from buffering by bicarbonate and carbonate, and the chemical equilibrium shift created by the high pH slag leachates causes the carbonate to form salts with calcium and magnesium which fall out of solution. This process is evident not only from the increased local turbidities caused presumably by colloidal particles of CaCO$_3$ and MgCO$_3$, but also from the very obvious growths of smooth carbonate rock flowstones at the seeps and in the streambed downstream of the seeps. Mean calcium concentration between the upper reach at km 1.74 and km 0.13 at the mouth dropped 17% (from 101 to 84 mg/l) and mean magnesium concentration dropped 64% (from 25 to 9 mg/l).

![Figure 2. The pH and flow in Nine Mile Run at km 0.13, November 1999 to February 2000.](image-url)

**Wet Weather Chemistry**

A strong pattern was apparent during low flows where pH and conductivity were relatively elevated but decreased sharply when flows increased (Figs. 2 and 3, respectively). Sharp drops in pH in lower Nine Mile Run during higher flows were especially notable. By late December, however, with the initiation of deicing activities in the watershed, the strong negative relationship between flow and conductivity demonstrated some variation. During the series of snow, ice, and thaws that occurred December 18-30 1999, for instance, sharp peaks in conductivity values were apparently associated with flushing of road deicing salts (Fig. 4). The highest December conductivity recorded at Nine Mile Run km 3.1 was
A series of even more extreme deicing salt runoff incidents were documented in January and February of 2000 (Fig. 6). During two of these incidents conductivity values in excess of 30,000 umhos/cm were recorded at the km 3.1 Braddock Avenue Culvert station (Table 1). The highest values always occurred at the culvert (km 3.1) and, on average, were attenuated to 42.8%-69.1% at the downstream stations.

Figure 5. Specific conductivity at four stations along Nine Mile Run (km 3.1, 1.75, 0.75, and 0.13) showing downstream attenuation of late December 1999 deicing salt runoff event.

Figure 6. Specific conductivity and flow at Nine Mile Run at km 3.1 during January and February 2000.
5 h during the season at km 3.1, and not at all at any other station. Conductivities between 30,000 and 20,000 umhos/cm occurred for a seasonal total of 33 h at km 3.1, and 11.6, 6, and 0 h at the respective three downstream stations. For values in the range between 20,000 and 10,000 umhos/cm, organisms were exposed for 121 h at km 3.1, 114 h at km 1.74, 148 h at km 0.75, and a total of 46 h at km 0.13. Conductivities of 10,000, to 30,000 umhos/cm are equivalent to 18-55% seawater, and many native fish species are hyperosmotic and thus sensitive to the extreme salinities of Nine Mile Run waters.

Fishery surveys conducted by the Pennsylvania Fish and Boat Commission (1990), Stauffer and Stecko (1999) and the U. S. Army Corps of Engineers (2000), showed a pattern where fish were totally absent from the upper reaches of Nine Mile Run, but stressed and limited fish communities were present along the lower half of the stream, although fish were not present in the slag leachate reach during low flow periods when very high pH conditions existed. Similarly, Mirani (1997) and the U. S. Army Corps of Engineers (2000) demonstrated that only very tolerant invertebrates were present along the upper 1.5 km of Nine Mile Run, but somewhat more productive and diverse invertebrate communities, with more sensitive species, were able to survive along the lower 1.5 km of the stream.

Channel storage is probably the primary stream morphology feature contributing to the ability of Nine Mile Run to attenuate short duration shock loads. Therefore, channel modifications on this and other small urban streams should be designed not to diminish but rather preserve or enhance channel storage as a method to enhance chemical quality and aquatic life resources.

ACKNOWLEDGEMENTS

This study was part of an investigation, which was initiated and supported by the City of Pittsburgh, Pennsylvania, Tom Murphy, Mayor. The investigation was performed under the authority of Section 206 of the Water Resources Development Act of 1996.

LITERATURE CITED

