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 km^2, 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 km^2 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

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drainage from these formations is typically slightly acidic and moderately mineralized, yielding $CaSO_4$ dominated waters. Sams and Beer (2000) characterized the median SO_4 concentration of streams in the upper Ohio River drainage basin that are not underlain by coal at about 20 mg/l, with SO_4 yields of about ten tons/km^2/yr. Much higher median annual concentrations and yields can occur, however, in areas where coal is present and has been mined.

In addition to minerals associated with the underlying Pennsylvanian formations, various anthrogenic materials also influence the chemical composition of local urban runoff. These include extensive exposed cement surfaces, which can leach alkaline calcium salts. Also as a consequence of the industrial history of the region, steel mill slags are frequently utilized as aggregates in cement and bituminous asphalt construction, as well as placement of highway shoulder berms, driveway and parking lot fills, and as a railroad grade ballast. Slag leachates are typically calcium sulfate dominated and often extremely alkaline (U. S. Army Corps of Engineers, 1989 and 2000). A commonly used alternative to slag for fills and aggregate in the region is crushed limestone ($CaCO_3$). All of these contribute to a strong alkaline and $CaSO_4$ dominated chemical fingerprint for urban drainage.

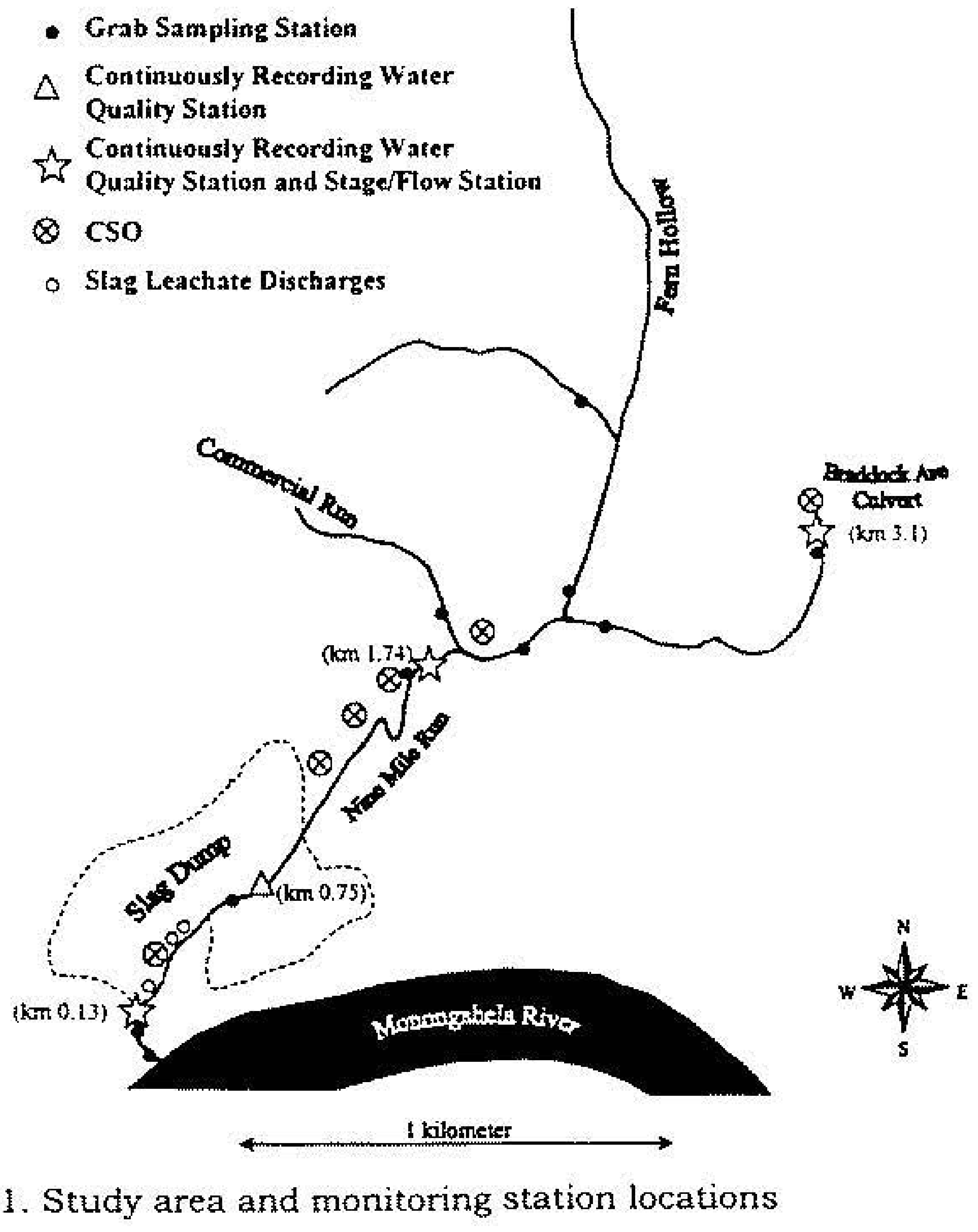

Figure 1. Study area and monitoring station locations

Besides ubiquitous dispersed $CaSO_4$ 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 km^2, 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 km^2. Upper Fern Hollow is urbanized; lower Fern Hollow is largely parkland. The second tributary, Commercial Run, drains only 0.28 km^2 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 recording period; interruptions occurred due to vandalism, burial by shifting stream sediments or dislodgement by storms, clogging of casing intakes by stream debris, and routine maintenance.

Stream stage was recorded at five-minute intervals with data-logging pressure transducers at three locations. Stage was converted to flow using a stage/flow rating curve developed from four measurements at each station.

RESULTS

Flow

Except for a modest rise along the lower stream on July 16, 1999, the mean daily flows at all stations during dry weather surveys only varied between 0.017 and 0.062 m^3/s. This range of base flow persisted through most of the study period, interrupted only sporadically by very sharp storm flow rises of short duration. Most of Nine Mile Run's flow was from the minimally diluted sewage from the Braddock Avenue Culvert. The bank-full channel discharge capacity of Nine Mile Run varies from about 5.7 m^3/s below the Braddock Avenue Culvert to 11.3 m^3/s at km 0.13. Peak flows at the km 0.13 gage during the five summer storm events ranged from 0.71 to 22.6 m^3/s.

Dry Weather Chemistry

During dry weather, Nine Mile Run was mineralized and alkaline, which was reflected by its elevated conductivity and total dissolved solids concentrations. The mean dry weather conductivity for upper Nine Mile Run (upstream of the slag dump) was 1,232 umhos/cm; the average total dissolved solids concentration was 782 mg/l. The major salts contributing to this mineralization were sodium chloride and calcium sulfate. The average concentrations of the major ions in the upper reach were 109 mg/l for sodium, 101 mg/l for calcium, 218 mg/l for chlorides, and 185mg/l for sulfates.

The mean dry weather conductivity of Fern Hollow was 984 umhos/cm, and its mean dissolved solids concentration was 644 mg/l. Average sodium and calcium concentrations were 45 and 118 mg/l, respectively, with chlorides and sulfates at 115 and 141 mg/l, respectively. The mean Ca/Na ratio for Fern Hollow was 2.7 compared to a ratio of 0.9 for upper Nine Mile Run. The Ca/Na ratio for Commercial Run, which captures little urban drainage, was 4.4.

During the winter season when deicing salts were utilized in the basin, the dominance of NaCl over $CaSO_4$ was much more pronounced. Nine Mile Run experienced shock loads of salt during winter thaws when conductivity sometimes exceeded 30,000 umhos/cm. Even during a January 25, 2000 low flow survey, however, at km 1.74 the concentration of chloride was 1030 mg/l compared with a sulfate concentration of 82 mg/l. Sodium was 580 mg/l and calcium was 133 mg/l (Ca/Na ratio=0.2).

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).

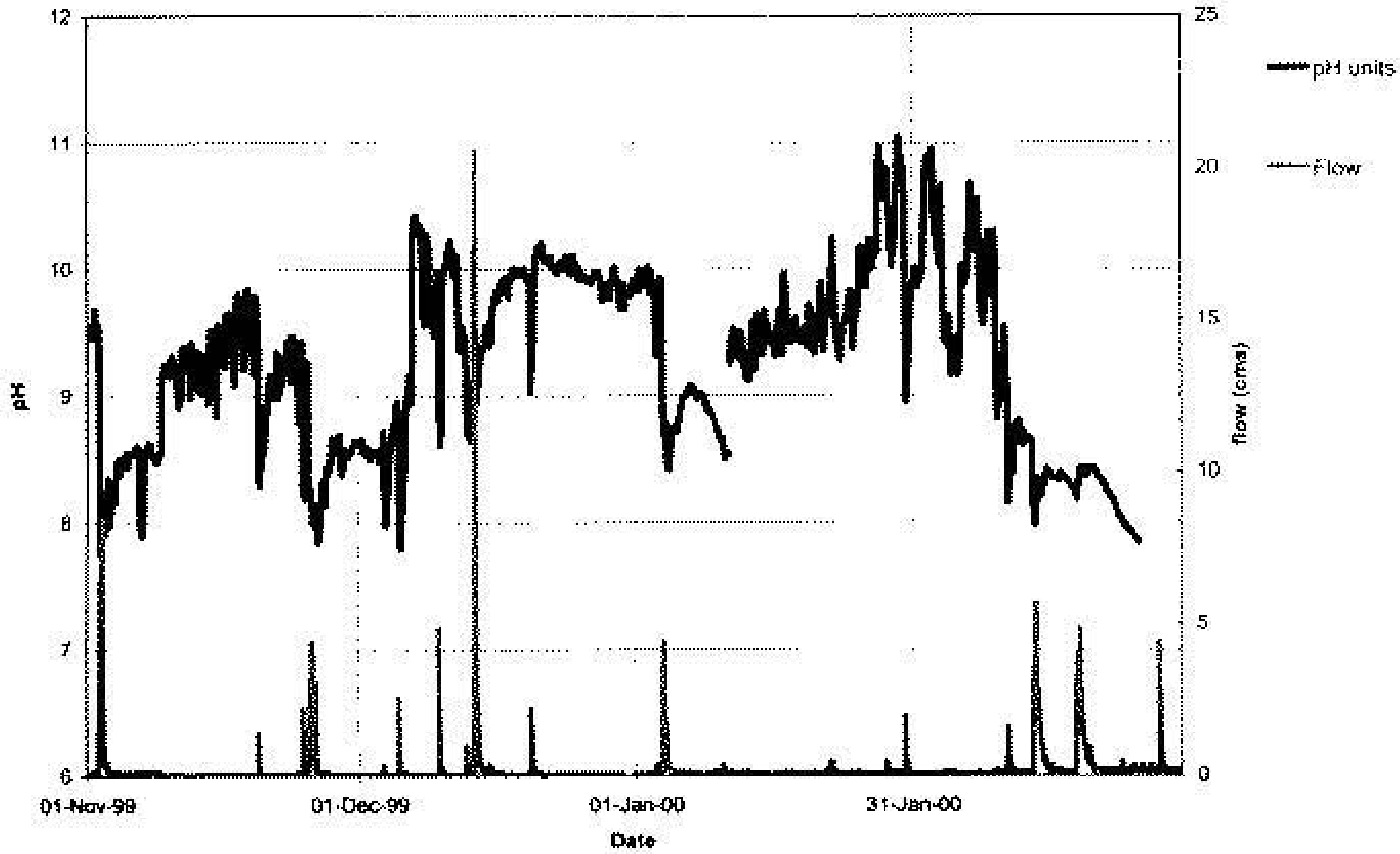

Figure 2. The pH and flow in Nine Mile Run at km 0.13, November 1999 to February 2000.

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

16,404 umhos/cm. Downstream at Nine Mile Run km 1.74, km 0.75, and km 0.13, however, these December event peak conductivity values were progressively and significantly attenuated to 5,182, 3,679, and 2,940 umhos/cm, respectively (Fig. 5). The late December road salt shock loads were of brief duration at km 3.1, but while highly attenuated in degree, were of a somewhat longer duration at the downstream locations.

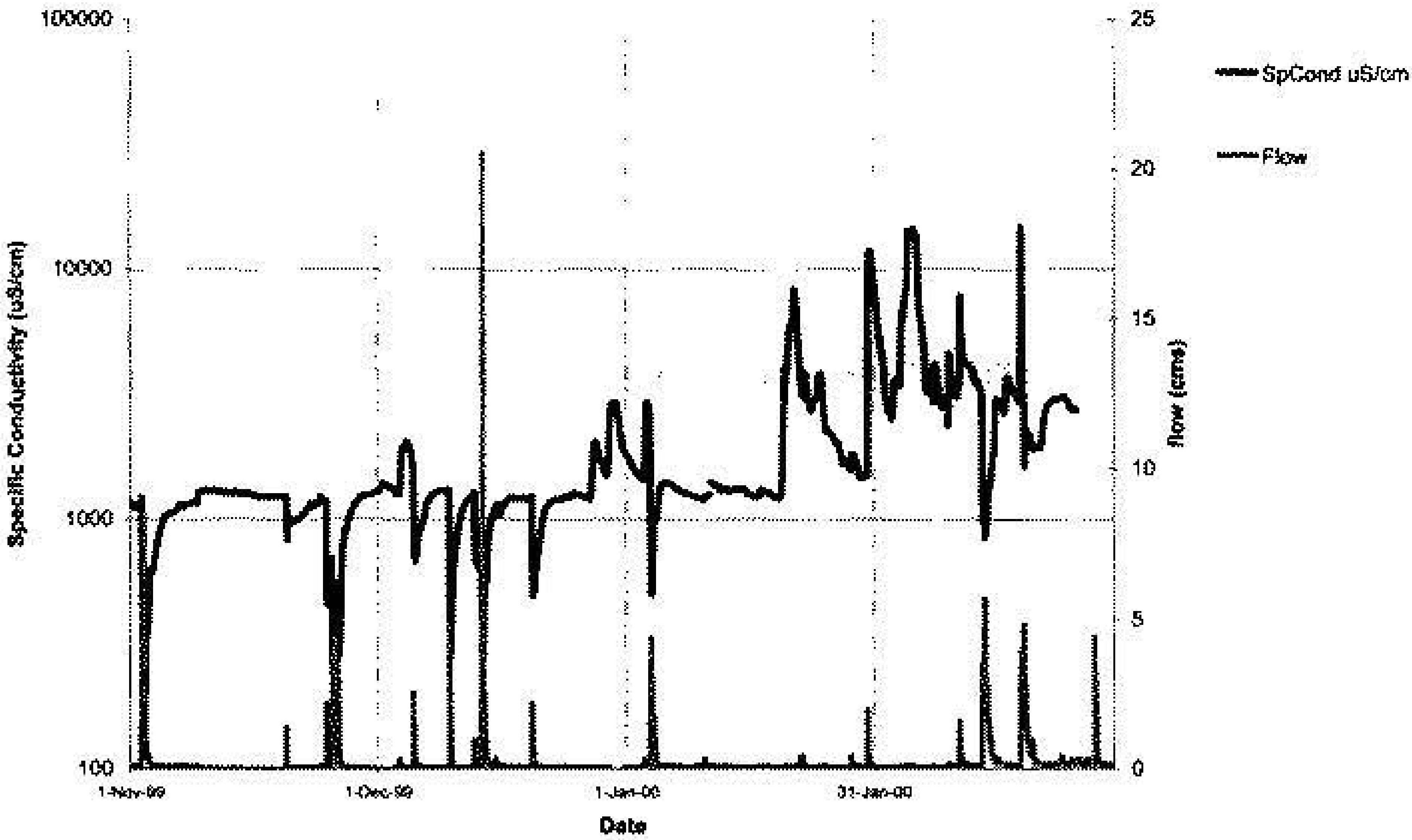

Figure 3. Specific conductivity and flow at Nine Mile Run at km 0.13 November 1999 to February 2000.

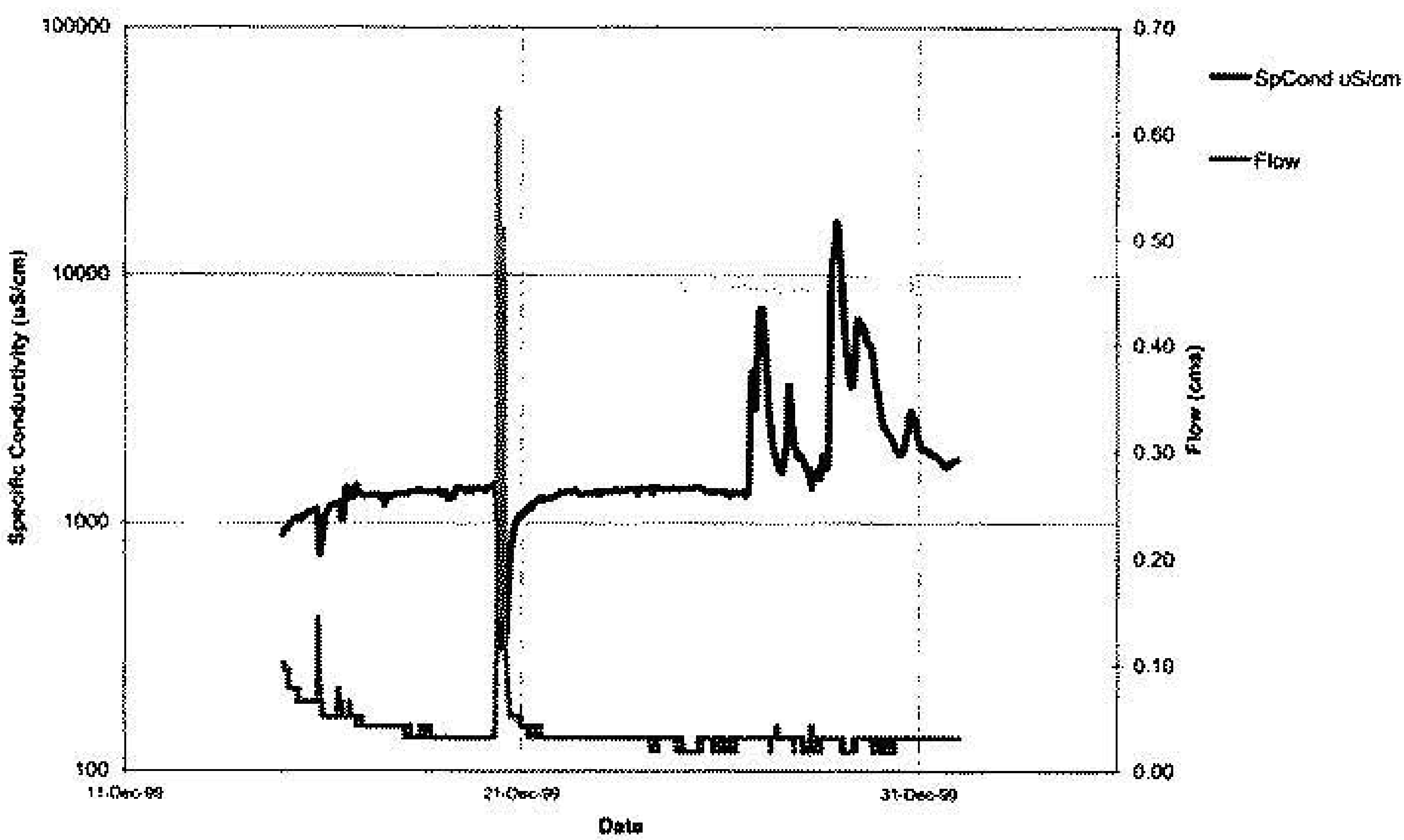

Figure 4. Specific conductivity and flow at Nine Mile Run at km 3.1 late December 1999.

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.

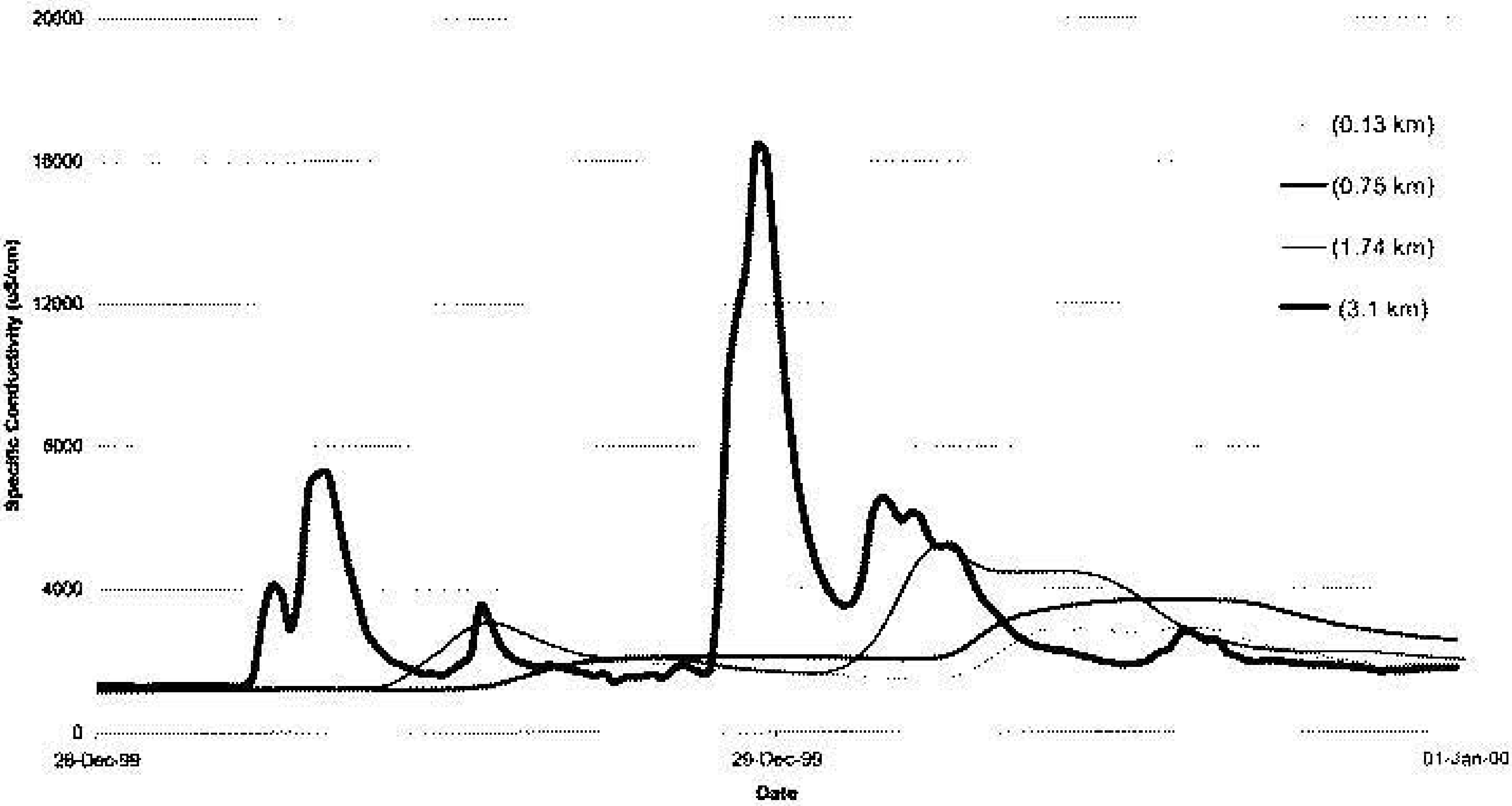

Figure 5. Specific conductivity at four stations along Nine Mile Run (km 3.1, 1.75, 0.75, and 0.13) showing downstream attenuation of late December 1999 deicing salt runoff event.

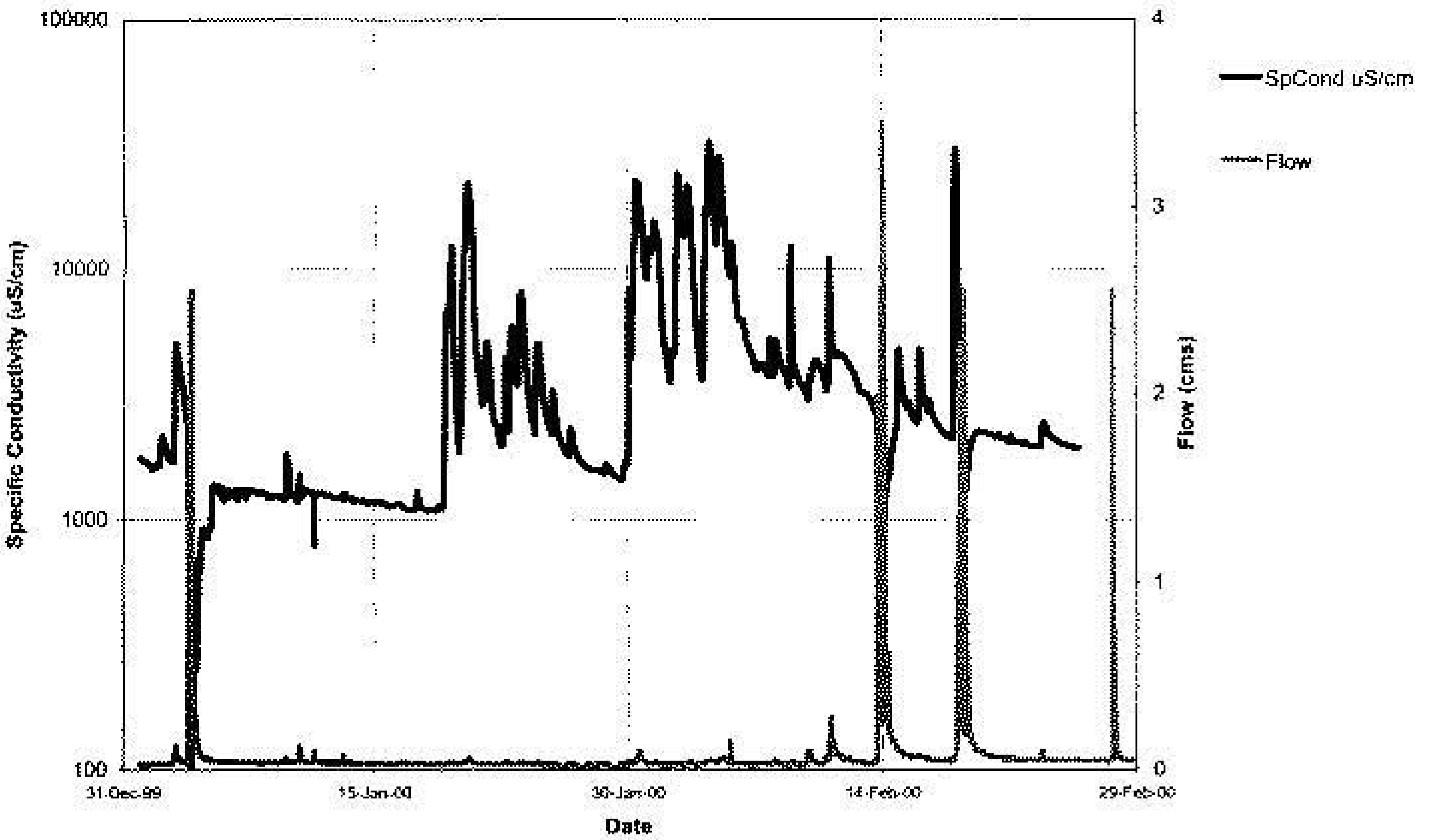

Figure 6. Specific conductivity and flow at Nine Mile Run at km 3.1 during January and February 2000.

Table 1. Duration (hours) of elevated conductivity values at four stations during winter of 1999-2000 thaw and road salt runoff events.

Event Period Date Conductivity Values (umhos/cm)	**Duration of Elevated Conductivity Values (hours)**			
	Station Stream Mile			
	1.9	**1.08**	**0.47**	**0.07**
29 Dec 1999				
Greater than 30,000	0	0	0	0
30,000 to 20,000	0	0	0	0
20,000 to 10,000	5	0	0	0
19-21 Jan 2000				
Greater than 30,000	0	0	0	0
30,000 to 20,000	5	0	0	0
20,000 to 10,000	17	18	21	0
30 Jan to 6 Feb 2000				
Greater than 30,000	4	0	0	0
30,000 to 20,000	25	10	5	0
20,000 to 10,000	91	93	123	42
10 Feb 2000				
Greater than 30,000	0	0	0	0
30,000 to 20,000	0	0	0	0
20,000 to 10,000	1	0	0	0
18 Feb 2000				
Greater than 30,000	1	0	0	0
30,000 to 20,000	3	1	1	0
20,000 to 10,000	7	3	4	4

DISCUSSION

Acknowledging that urban waterways like Nine Mile Run are complex and vulnerable to experience an array of insults, the moderation of winter salt concentrations in a downstream direction along Nine Mile Run is probably one factor influencing the distribution of aquatic life in the stream.

Osmoregulatory stress to freshwater organisms from salt washes, like most toxic influences, is dose, rate, and exposure duration dependant. Conductivities greater than 30,000 umhos/cm were experienced for about

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.

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LITERATURE CITED

Collins, T., et al. 1998. Nine Mile Run Watershed Rivers Conservation Plan. City of Pittsburgh, Carnegie Mellon University, Carnegie Museum of Natural History, Pennsylvania State University.

Josephson, G. W., et al. 1949. Iron Blast Furnace Slag: Production, Processing, Properties and Uses. U.S. Department of the Interior, Bureau of Mines, in cooperation with the National Slag Association, Washington D

Koryak, M., et al. 1998. The Impact of Airport Deicing Runoff on Water Quality and Aquatic Life in a Pennsylvania Stream. Journal of Freshwater Ecology. 13 3:287-298.

Lambert, D. and D.A. Dzombak. 1998. Water Quality Issues in the Nine Mile Run Watershed. Department of Civil and Environmental Engineering, Carnegie Mellon University, Pittsburgh, Pittsburgh, PA.

Mirani, U.J., 1997. Benthic Invertebrates and Water Quality of Nine Mile Run. M.S. Thesis, University of Pittsburgh, PA.

Pennsylvania Fish and Boat Commission. 1990. Results of a June 15, 1990 Survey of Nine Mile Run. Area 8, Somerset, PA.

Sams, J. I. and K. M. Beer. 2000. Effects of Coal-Mine Drainage on Stream Water Quality in the Allegheny and Monongahela River Basins- Sulfate Transport and Trends. 99-4208, U.S. Geological Survey. National Water Quality Assessment Program, Lemoyne, PA.

Stauffer, J.R. Jr. and T.D. Stecko. 1999. Progress Report, Nine Mile Run Fish Survey Http://slaggarden.cfa.cmu.edu/research/fisheries.html

U. S. Army Corps of Engineers. 1989. Steel Mill Slag Leachate Characteristics and Environmental Suitability for use as a Streambank Protection Material. U.S. Army Engineer District Pittsburgh, Corps of Engineers, Pittsburgh, PA.

U. S. Army Corps of Engineers. 2000. Nine Mile Run, Allegheny County, Pennsylvania, Aquatic Ecosystem Restoration, Water Quality and Aquatic Life. U.S. Army Engineer District Pittsburgh, Corps of Engineers, Pittsburgh, PA

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