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Causes of toxicity to *Hyalella azteca* in a stormwater management facility receiving highway runoff and snowmelt. Part I: Polycyclic aromatic hydrocarbons and metals

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ABSTRACT

The Terraview–Willowfield Stormwater Management Facility (TWSMF) receives inputs of multiple contaminants, including metals, polycyclic aromatic hydrocarbons (PAHs), road salt, and nutrients, via highway and residential runoff. Contaminant concentrations in runoff are seasonally dependent, and are typically high in early spring, coinciding with the snowmelt. In order to investigate the seasonal fluctuations of contaminant loading and related changes in toxicity to benthic invertebrates, overlying water and sediment samples were collected in the fall and spring, reflecting low and high contaminant loading, respectively, and four-week sediment toxicity tests were conducted with *Hyalella azteca*. The effects of metals and PAHs are discussed here; the effects of salts, nutrients, and water quality are discussed in a companion paper. Survival and growth of *Hyalella* after exposure to fall samples were variable: survival was significantly reduced (64–74% of controls) at three out of four sites, but there were no significant growth effects. More dramatic effects were observed after *Hyalella* were exposed to spring samples: survival was significantly reduced at the two sites furthest downstream (0–75% of controls), and growth was significantly lower in four out of five sites when comparing *Hyalella* exposed to site sediment with overlying site water versus site sediment with overlying control water. These seasonal changes in toxicity were not related to metals or PAHs: 1. levels of bioavailable metals were below those expected to cause toxicity, and 2. levels of PAHs in sediment were lowest at sites with the greatest toxicity and highest in water and sediment at sites with no toxicity. Although not associated with toxicity, some metals and PAHs exceeded probable and severe effect levels, and could be a cause for concern if contaminant bioavailability changes. Toxicity in the TWSMF appeared to be primarily associated with water-borne contaminants. The cause(s) of these effects are discussed in our companion manuscript.

1. Introduction

Stormwater runoff from urbanized areas can cause numerous adverse effects on water quality in the receiving environment, such as deposition of contaminated sediments (Marsalek et al., 2005), toxicity from contaminants related to traffic (Han et al., 2006; Roger et al., 1998), nutrient enrichment and eutrophication, and overall water quality degradation (Marsalek et al., 2003). Major toxicants in urban runoff include traffic byproducts such as trace metals (Cr, Cu, Pb, Pt, and Zn), several polycyclic aromatic hydrocarbons (PAHs), and chloride from road salt, which is used in winter road maintenance in regions experiencing significant snowfall (Maltby et al., 1995; Rokosh et al., 1997; Wei and Morrison, 1994). The strength of highway pollution is related to traffic intensity (Viklander, 1999), with environmental effects from highway runoff likely occurring when traffic intensity exceeds 35,000 vehicles/day, but rarely occurring at traffic intensities as low as 20,000 vehicles/day (Waara and Farm, 2008).

The awareness of stormwater pollution and increasing concern regarding the impacts on the receiving environment resulted in the development of methods for controlling such pollution and removing

Abbreviations: ACE, acenaphthene; ACY, acenaphthylene; ANOVA, analysis of variance; ANT, anthracene; APHA, American Public Health Association; AVS, acid volatile sulfide; BaA, benzo(a)anthracene; BaP, benzo(a)pyrene; BbF, benzo(b)fluoranthene; BEI, bioavailable:effect index; BkF, benzo(k)fluoranthene; BMP, best management practice; BPE, benzo(g,h,i)perylene; CALA, Canadian Association for Laboratory Accreditation; CCME, Canadian Council of Ministers of the Environment; CHR, chrysene; CI, confidence interval; CWQG, Canadian Water Quality Guideline; DBA, dibenzo(a,h)anthracene; DO, dissolved oxygen; EC, Environment Canada; EDTA, ethylenediaminetetraacetic acid; FLT, fluoranthene; FLU, fluorene; HS-SAM, high-salt standard artificial media; IND, indo (1,2,3-cd)pyrene; ISQG, interim sediment quality guideline; LBC25, lethal body concentration causing 25% mortality; LC25, lethal concentration causing 25% mortality; LEL, lowest effect level; MDL, method detection limit; MOE, Ministry of the Environment; MOEE, Ministry of Environment and Energy; NAP, naphthalene; OR, odds ratio; PAH, polycyclic aromatic hydrocarbon; PEL, probable effect level; PHE, phenanthrene; PWQO, provincial water quality objective; PYR, pyrene; SAM, standard artificial media; SEL, severe effect level; SPI, sediment pollution index; TOC, total organic carbon; TRCA, Toronto Region Conservation Authority; TWSMF, Terraview–Willowfield Stormwater Management Facility; USEPA, United States Environmental Protection Agency; WEL, water effect level; WPI, water pollution index.

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chemicals from stormwater by best management practices (BMPs). One of the more common BMPs is the construction of stormwater management ponds; these ponds are used to treat stormwater from various sources, including relatively polluted highway runoff (Starzec et al., 2005), but also serve as aquatic habitats attracting various biological communities, including benthos, fish, amphibians, and birds (Bishop et al., 2000a). While some facilities in areas with relatively clean runoff may perform this ecological function reasonably well, other facilities with habitats degraded by contaminated sediments and chloride accumulations may pose ecological risks (Marsalek, 2003). The Terraview–Willowfield Stormwater Management Facility (TWSMF) in the Toronto area is one such facility from the latter category that was studied by Grapentine et al. (2008); it receives runoff from a 30 ha residential area and a 9 ha transportation corridor of a major multi-lane divided highway (Highway 401) with a traffic intensity over 340,000 vehicles/day. The facility exhibited depauperated benthic communities, with some sites limited to the presence of only one species, compared to typical urban sites with 8–15 species (Grapentine et al., 2008). Poor habitat quality at the TWSMF was attributed to elevated concentrations of metals and PAHs, and it was suggested that salinity in the overlying water from road salt could influence toxicity, particularly in deeper sections of the ponds (Grapentine et al., 2008).

There are many challenges associated with measuring stormwater toxicity, including the intermittent nature of stormwater discharges (Brent and Herricks, 1999), the delayed effects of some contaminants (Brent and Herricks, 1998), and the high variability of seasonal and intra- and inter-event stormwater quality and toxicity (Kayhanian et al., 2008; Marsalek et al., 1999). Seasonal changes in stormwater composition are important, particularly in climates receiving significant snowfall during the winter season. The winter months may produce 60% of the annual load of pollutants, which accumulates in the snowpack and is then released in pulses during intermittent snowmelts, the final snowmelt, and rain events during and immediately following the snowmelt period (Marsalek et al., 2003). Although seasonal changes in contaminant concentration have been monitored (Bäckström et al., 2004), and toxicity of contaminants in stormwater pond facilities has been studied (Marsalek et al., 2002), research on seasonal changes in contaminant bioavailability and toxicity is lacking.

The focus of this study is to identify sources and seasonal differences in toxicity within the TWSMF, contrasting lower contaminant loadings in the fall with higher contaminant loadings in the spring, and discerning among contaminant sources such as metals and PAHs typical for highway runoff, chloride from winter road maintenance, nutrient enrichment from residential runoff, and water quality, particularly anoxia in bottom water layers. Toxicity tests were conducted on water and sediment samples collected from the TWSMF using *Hyalella azteca*, a freshwater amphipod invertebrate widely distributed throughout North America and extensively used in sediment toxicity tests (Borgmann et al., 1989; Environment Canada (EC), 1997). Measures of toxicity and bioaccumulation were combined with water and sediment chemistry in order to determine the cause(s) of toxicity in this facility. This manuscript discusses the effects of metals and PAHs, while a companion manuscript (Bartlett et al., 2012-this issue) describes the effects of salts, nutrients, and water quality.

2. Materials and methods

2.1. Site description

The TWSMF is located in Toronto (West Scarborough), Ontario, Canada and forms the headwaters to the Taylor and Massey Creek systems, draining into the Don River and eventually into Lake Ontario approximately 15 km downstream. It was constructed in 1999 and its surface flow treatment train consists of a pre-treatment sediment forebay, two ponds arranged in series (Terraview and Willowfield are the upstream and downstream ponds, respectively), and several connecting channels and wetland areas which encompass a flow path of over 400 m (Fig. 1). These ponds and channels, with a total surface area of less than 1 ha, were installed to replace the original concrete-lined drainage channel which provided no flow attenuation and offered no visual or recreational amenities. The two ponds range in depth from 0.5 to 2.5 m, providing large areas of open water, wetlands, and bird nesting islands, which provide habitat for wildlife as well as parkland and recreational areas for local residents. This facility receives runoff from 9 ha of a 16-lane freeway (Highway 401, 95% imperviousness, 340,000 vehicles/day) and 30 ha of residential lands (40% imperviousness). A stormwater exfiltration sand filter provides some local groundwater recharge from a portion of the residential runoff (10 ha), prior to discharging into the facility. A series of proposed pre-treatment shallow detention basins and wetlands designed to control highway runoff flows and pollutants prior to discharge into the facility were never constructed, so the Terraview Pond forebay receives the full impact of the highway stormwater input.

2.2. 2007–2008 field sampling

Two sampling campaigns were performed, one in the fall (October 2007) and one in the following spring (April 2008, during the spring snowmelt). Each site was assigned a letter and number identifier, with "T" and "W" denoting Terraview and Willowfield Ponds, respectively (Fig. 1). The sites for the fall collection (T18, T5, W10, and W4) were chosen to provide an overview of upstream to downstream effects, and to include sites representing deep pockets in the bottom profile (T5 and W4), which may exhibit deteriorated water quality due to retention of a denser chloride-laden water layer and/or reduced vertical mixing resulting in low dissolved oxygen (DO). Sites T23, T5, T2, W15, W4, and W5 were sampled in the spring, to provide an increased range of upstream (T23, the sediment forebay) to downstream (W5, Willowfield Pond outlet) effects while still including two of the deeper sites in the TWSMF (T5 and W4). Water depths ranged from 0.8 to 1.8 m and 0.25 to 1.9 m for fall and spring collections, respectively.

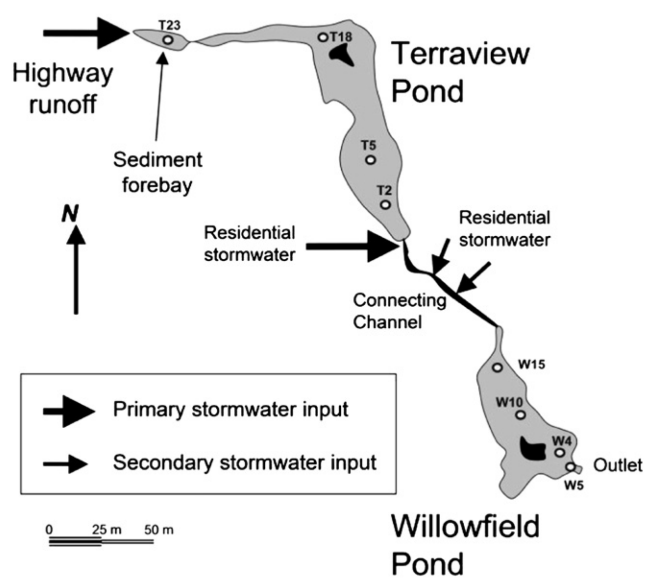

Fig. 1. The Terraview–Willowfield Stormwater Management Facility in Toronto, Ontario. Water and sediment samples were collected in Fall 2007 and Spring 2008 and used in four-week sediment toxicity tests with *Hyalella azteca*. Fall sampling included two sites from Terraview Pond (T18 and T5) and two sites from Willowfield Pond (W10 and W4). Spring sampling included three sites from Terraview Pond (T23, T5, and T2) and three sites from Willowfield Pond (W15, W4, and W5).