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Toxicity characterization of urban stormwater with bioanalytical tools

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ABSTRACT

Stormwater harvesting has become an attractive alternative strategy to address the rising demand for urban water supply due to limited water sources and population growth. Nevertheless, urban stormwater is also a major source of surface water pollution. Runoff from different urban catchments with source contributions from anthropogenic activities and various land uses causes variable contaminant profiles, thus posing a challenging task for environmental monitoring and risk assessment. A thorough understanding of raw stormwater quality is essential to develop appropriate treatment facilities for potential indirect potable reuse of stormwater. While some of the key chemical components have previously been characterized, only scarce data are available on stormwater toxicity. We benchmarked stormwater samples from urban, residential and industrial sites across various Australian capital cities against samples from the entire water cycle, from sewage to drinking water. Six biological endpoints, targeting groups of chemicals with modes of toxic action of particular relevance for human and environmental health, were investigated: non-specific toxicity (Microtox and combined algae test), the specific modes of action of phytotoxicity (combined algae test), dioxin-like activity (AhR-CAFLUX), and estrogenicity (E-SCREEN), as well as reactive toxicity encompassing genotoxicity (*umuC*) and oxidative stress (AREc32). Non-specific toxicity was highly variable across sites. The baseline toxicity equivalent concentrations of the most polluted samples were similar to secondary treated effluent from wastewater treatment plants. Phytotoxicity results correlated well with the measured herbicide concentrations at all sites. High estrogenicity was found in two sampling events and could be related to sewage overflow. Genotoxicity, dioxin-like activity, and oxidative stress response were evident in only three of the samples where the stormwater drain was beside a heavy traffic road, confirming that road runoff is the potential source of contaminants, while the bioanalytical equivalent concentrations (BEQ) of these samples were similar to those of raw sewage. This study demonstrates the benefit of bioanalytical tools for screening-level stormwater quality assessment, forming the basis for the evaluation of future stormwater treatment and reuse schemes.

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Abbreviations

-S9	without rat S9 metabolic activation
+S9	with rat S9 metabolic activation
2AA	2-Aminoanthracene
4NQO	4-Nitroquinoline-N-oxide
BA	Banyan
BEQ	Bioanalytical equivalent concentration
DEQ_{chem}	Diuron equivalent concentration$_{chemically}$
DEQ_{bio}	Diuron equivalent concentration$_{bioassay}$
DOC	Dissolved organic carbon
EEQ	Estradiol equivalent concentration
EMC	Event mean concentration
$EC_{IR1.5}$	Effect concentration causing induction ratio of 1.5
EC_{50}	Effect concentration inducing 50% of the maximum effect
EU	European Union
FG	Fitzbiggon
HB	Hornsby
HDPE	High density polyethylene
I-PAM	Imaging pulse-amplitude modulated fluorometry
IR	Induction ratio
KU	Ku-ring-gai
LC–MS/MS	Liquid Chromatography–Mass Spectrometry/Mass Spectrometry
LC–OCD	Liquid Chromatography–Organic Carbon Detector
MA	Makerston street
NATA	National association of testing authorities
OR	Orange
PAH	Polyaromatic hydrocarbon
PD	undisclosed industrial site
PS-II	Photosystem II
QHFSS	Queensland health forensic and scientific services
REF	Relative enrichment factor
SPE	Solid phase extraction
SS	Smith Street
tBHQ	t-butylhydroquinone
TCDD	2,3,7,8-Tetrachloro-dibenzo-dioxin
TEQ	Toxic equivalent concentration
TIE	Toxicity identification evaluation
TSS	Total suspended solids

1. Introduction

Urban stormwater runoff is considered a major source of water pollution (Estebe et al., 1997; Hatt et al., 2006; Zgheib et al., 2011b). Stormwater is the discharge from separate drainage systems of urbanized catchments and should not be confused with combined sewage discharges. Uncontrolled and untreated discharges have caused changes to hydrology (Carlson and Arthur, 2000), stream functioning (Meyer et al., 2005) and species composition (Serena and Pettigrove, 2005). Concurrently, pressure on water resources in urban areas is increasing, with growing demand due to population growth and limited availability of water resources. As a result stormwater has gained recent attention due to its potential to provide a new source of water for irrigation and non-potable use (Hatt et al., 2006, 2007; Fletcher et al., 2008).

When stormwater washes over impervious surfaces such as roads, houses and buildings, it collects a wide variety of pollutants from the surface. Substantial stormwater quality data has been collected across the world, and worldwide data sets have been analyzed for trends in traditional pollutants such as suspended solids, metals, and nutrients (e.g., Duncan, 1999; Smullen et al., 1999; Göbel et al., 2007). An attempt was made to differentiate stormwater quality based on land use, region, and season. There was a tendency toward higher metal concentrations and lower nutrient levels in stormwater discharges from industrial and commercial sites than from residential sites (Smullen et al., 1999; Francey et al., 2010). Often for some pollutants – in particular, total suspended solids (TSS) and associated sorbed metals – concentrations were higher during storm discharges than during dry-weather flows found in stormwater drains (Deletic and Maksimovic, 1998; Francey et al., 2011); however, for some (like nutrients) the opposite was observed (Francey et al., 2010). Another important recent finding in relation to these traditional pollutants, stormwater quality is better than it was 20–30 years ago (Smullen et al., 1999; Francey et al., 2010). Underlying reasons are unclear and hypotheses were made that this may be due to improvements in land and air pollution management, but also due to improvements in stormwater monitoring techniques.

Variability of stormwater quality is very high (Eriksson et al., 2007; Zgheib et al., 2011a, 2011b), and determining factors could be grouped in the following categories: (i) climate (rainfall intensity, antecedent dry period between storm events, evaporation), (ii) catchment characteristics (size, impervious surface fraction, connectivity of paved surfaces, land use, atmospheric deposition), (iii) drainage infrastructure (separate or combined, open channels/streams or pipes, age, cross-connections, sewer overflows, connection to surrounding groundwater or existing septic tanks, etc). Literature on impacts of these characteristics is abundant, showing high variability in their importance from site to site (Duncan, 1999; Zgheib et al., 2011a).

Stormwater as a potential water resource is far less researched than the impacts it has on environment (Wong et al., 2012). In Australia, the current Australian Guidelines for Water Recycling: Stormwater Harvesting and Reuse (NWQMS, 2009) only encompass a limited number of stormwater quality parameters. Scarce information is available on stormwater toxicity to environmental and human health impacts (Burton et al., 2000; Scholes et al., 2007; Mayer et al., 2011). For example, early exploratory studies of stormwater toxicity only addressed the overall toxic potential (i.e., *Daphnia magna* mortality and Microtox) and genotoxicity (Marsalek et al., 1999a, 1999b, 2002), but did not address the specific sources of pollutants. Moreover, research on stormwater harvesting has focused to date mainly on pathogen identification (e.g. Sidhu et al., 2012) than on toxic chemicals. The most relevant work would be the studies that focused on