Science of the Total Environment 485–486 (2014) 252–262

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Tracing sources of organic matter in adjacent urban streams having different degrees of channel modification

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HIGHLIGHTS

- Wastewater is the major source of organic matter (OM) to urban streams in Houston.
- Channel lining changes the dynamics of OM in these urban bayous.
- Particulate OM in these urban streams does not resemble natural plant sources.

ARTICLE INFO

Article history:
Received 2 February 2014
Received in revised form 16 March 2014
Accepted 16 March 2014
Available online 12 April 2014

Editor: D. Barcelo

Keywords:
Urban streams
Channel modification
Wastewater
Organic matter
DOM
Stable isotopes

ABSTRACT

Urbanization and stream-channel modifications affect organic matter concentrations and quality in streams, by altering allochthonous organic matter input and in-stream transformation. This study uses multiple tracers ($\delta^{13}C$, $\delta^{15}N$, C/N ratio, and chlorophyll-a) to track sources of organic matter in two highly urbanized bayous in Houston (Texas, USA). Wastewater treatment plants (WWTPs) are located in headwaters of both bayous and contribute more than 75% to water flow. Low isotopic relatedness to natural end-members and enriched $\delta^{15}N$ values suggest the influence of WWTPs on the composition of all organic matter fractions. The two bayous differ in degree of channel improvement resulting in different responses to hydrological conditions. During high flow conditions, the influence of terrestrial organic matter and sediment resuspension was much more pronounced in the Buffalo Bayou than in the concrete-lined White Oak Bayou. Particulate organic matter (POM) in White Oak Bayou had similar values of enriched $\delta^{15}N$ in all subsegments, whereas in Buffalo Bayou, the degree of $\delta^{15}N$ enrichment was less in the subsegments of the lower watershed. The difference in riparian zone contributions and interactions with sediments/soils was likely responsible for the compositional differences between the two bayous. Phytoplankton inputs were significantly higher in the bayous, especially in slow-flowing sections, relative to the reference sites, and elevated phytoplankton inputs accounted for the observed stable C isotope differences between FPOM and high molecular weight dissolved organic matter (HMW DOM). Relative to POM, HMW DOM in the bayous was similar to WWTP effluents and showed minor longitudinal variability in both streams suggesting that WWTPs contribute much of the DOM in the systems. Urbanization has a major influence on organic matter sources and quality in these urban water bodies and these changes seem further enhanced by stream channel modifications.

1. Introduction

Urbanization is one of the most significant and dynamic human alterations of ecosystems (Grimm et al., 2000: Pickett et al., 2001), exerting a disproportionately large influence on stream water quality (Paul and Meyer, 2001; Walsh et al., 2005). It can increase the loading of total organic carbon and its labile components (e.g., carbohydrates) in streams (Frimmel and Abbt-Braun, 1999; McConnell, 1980) due to inputs from wastewater (Aitkenhead-Peterson et al., 2009) and/or elevated algal productivity (Busse et al., 2006; Catford et al., 2007; Taylor et al., 2004). These alterations may result in higher biological oxygen demand (Lu et al., 2013) and the presence of fecal bacteria in urban streams (Surbeck et al., 2010), which have always been a health and safety concern for commercial and recreational uses of water bodies (Faulkner et al., 2000; McConnell, 1980). Meanwhile, urban streams may be subjected to channel modification to different degrees to prevent flooding and bank collapse (Watson et al., 1999) resulting from increased surface run-off due to the expanding impervious surface cover in urban watersheds (e.g. Grimm et al., 2000; Olivera and DeFee, 2007). The narrowing and channel concrete lining (also called channel hardening), a typical channel alteration in urban streams, increases

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http://dx.doi.org/10.1016/j.scitotenv.2014.03.066
0048-9697/

hydraulic functionality but also flow velocity and downstream erosion, reduces the hydrologic connectivity between river channel and the riparian zone, influences stream metabolic characteristics (Kent et al., 2005; Laws and Roth, 2004), and the ability to retain contaminants (Bartone and Uchrin, 1999; Gallo et al., 2012). Relative to undisturbed ecosystems, source tracking of organic matter in urban streams and effects of channel modification on stream organic matter dynamics have received less attention (Gallo et al., 2012; Ulseth and Hershey, 2005).

The City of Houston has grown steadily since its establishment in 1836 on the site of the confluence of Buffalo Bayou and White Oak Bayou, located less than 25 miles west of upper Galveston Bay. In 2010, the population of Greater Houston exceeded 4 million (USCensus, 2013b). Between 1940 and 1970, Houston was the fastest growing city in the U.S. in terms of population increase (USCensus, 2013a, 2013b) as well as land annexation that extended its geographic boundaries by almost 70% (COH, 2013; HC, 2001; USDA, 1965). Much of this growth occurred west and northwest of downtown Houston in the watersheds of Buffalo Bayou and White Oak Bayou (henceforth BB and WOB, respectively). Flooding became an urgent priority in both watersheds and two flood control reservoirs were built in the upper BB watershed and >80% of the natural streams in the WOB watershed, including the primary, were modified and lined with concrete to accelerate the conveyance of storm water to the bay. Strong public opposition halted the concrete channelization of BB, however a few sub-segments in the upper watershed, just below the flood control reservoirs, and those flowing through downtown Houston were also modified, but retained their natural stream beds (HCFCD, 1998; Sipes and Zeve, 2012).

The aim of this study was to investigate how urbanization and associated channel modification affect sources of stream organic matter that could potentially support the chronically elevated numbers of fecal indicator bacteria observed in the bayous (TCEQ, 2009), by using multiple tracers including chlorophyll-a (Chl-a), carbon to nitrogen (C/N) ratio, stable carbon isotopes ($\delta^{13}C$) and stable nitrogen isotopes ($\delta^{15}N$; Bonn and Rounds, 2010; Kendall and McDonnell, 1998; Ogrinc et al., 2008; Ulseth and Hershey, 2005). These tracers for organic matter source identification have also been used to understand degradation processes and fractionation during phase transition (Aufdenkampe et al., 2007; Connin et al., 2001; Fellerhoff et al., 2003; Guo et al., 2003; Hedges et al., 2000). Organic matter is generally separated into several size fractions in order to better differentiate these effects, because organic matter size, sources, chemical composition, and biological availability are tightly linked (Amon and Benner, 1996; Amon and Meon, 2004; Amon et al., 2001; Hedges et al., 2000). To constrain organic matter source assignments within the bayous we collected organic matter fractions from a nearby rural stream (control site), several wastewater treatment plants, phytoplankton, and stormwater runoff (during a storm event). Our hypotheses are that a substantial amount of organic matter in these urban streams is derived from anthropogenic wastewater, and that channel modification with concrete lining further influences stream organic matter source and quality by changing the hydrologic connectivity between the channel and its riparian zone and watershed.

2. Experimental section

2.1. Site description and sampling

Together, the BB and WOB watersheds cover a total of 1204 km^2 within the San Jacinto River basin in Texas, USA (Fig. 1). BB, one of the longest bayous in the area, originates west of Houston and flows approximately 85 km from its upper watershed to downtown, transitioning into the Houston Ship Channel, then discharges into Galveston Bay and ultimately the Gulf of Mexico. WOB extends 37 km from its upper watershed in northwest Houston to the confluence with BB in downtown Houston. Each bayou has an average intermediate flow of ~31 MGD (TCEQ, 2009).

Urban land use in the BB watershed below the reservoirs (298 km^2) is similar to that of WOB (TCEQ, 2009; Table S1). Impervious surfaces cover ~50% of each watershed. Low intensity developed areas make

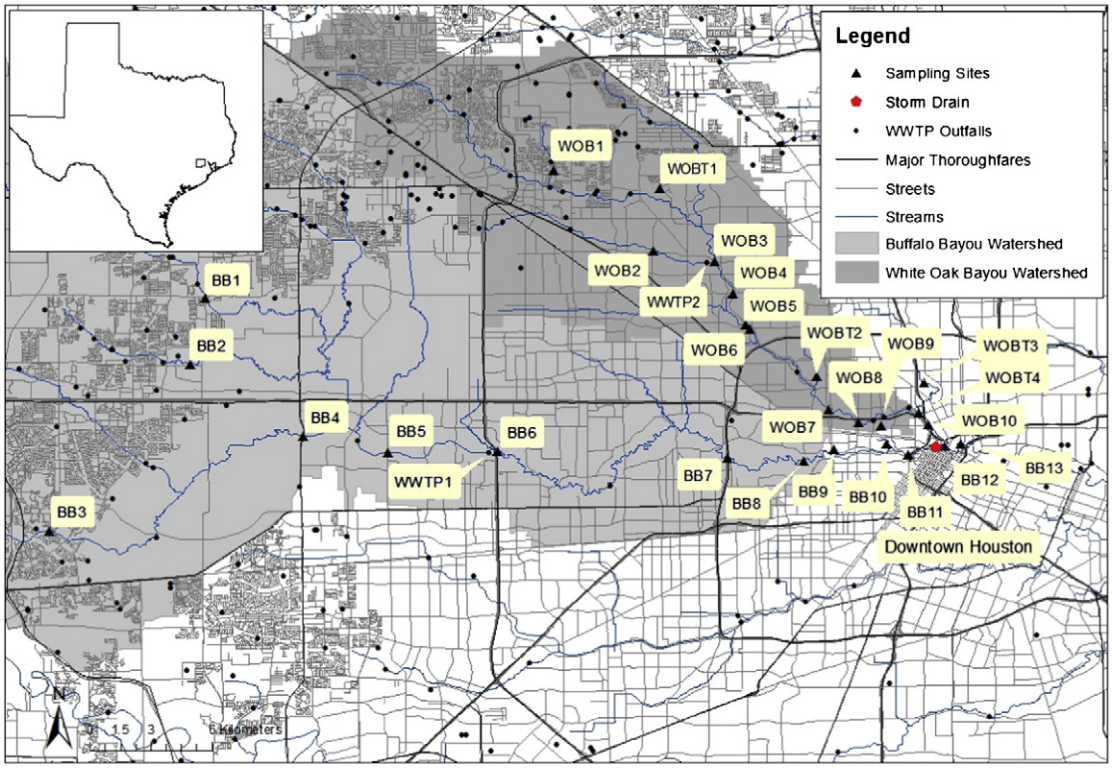

Fig. 1. Sampling sites in the Buffalou Bayou (BB1-BB13) and White Oak Bayou (WOB1–WOB10) watersheds with WWTP outfalls (WWTP 1 & 2 are labeled), and a stormwater outfall. Stations WT1–WT4 are located on White Oak Bayou tributaries with natural streambeds and are not influenced by WWTP outfalls.