Sources, Fate, and Transport of Organic Matter in Urban Waters

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ABSTRACT

Major sources of (OM) in urban water bodies include vegetation, sediments, and wastewater. These sources are affected by urbanization due to the removal of vegetation and extent of impervious surfaces. The process of OM decomposition releases nutrients and alters the oxygen levels of urban water bodies. The terrestrial vegetation is a major source of OM in urban water bodies. Research utilizing carbon and nitrogen stable isotopes has shown that organic-rich fine sediments from erosion of geomorphic banks, hilltops and landslides are a significant source of OM. Wastewater can become the primary source of OM in urban environments due to discharges from wastewater treatment plants WWTPs. Studies indicate that wastewater can potentially affect urban water bodies due to the decomposition of OM and the mineralization of nutrients, which in turn, will elevate nutrients and support algae growth. Organic matter continually decomposes in the downstream direction due to biogeochemical processes into humic and fulvic-like components. Research has shown that OM can be deposited in the sediment, resulting in humic and fulvic components in the aquatic system. The OM is transported to the ocean and accumulates in the ocean sediment from riverine systems. In summary, urbanization has the potential to impact the sources, fate, and transport of OM in urban water bodies by causing low dissolved oxygen conditions from decomposition of natural and anthropogenic OM.

Keywords: organic matter; sources; fate; transport

1. INTRODUCTION

The sources, fate, and transport of organic matter (OM) in urban water bodies are influenced by urbanization. Organic matter is a source of carbon, energy and nutrients for microorganisms and biota in water bodies. Additionally, OM in urban water bodies mineralizes nutrients due to the decomposition by microorganisms and invertebrates, which are then utilized by vegetation and biota in water bodies (Figure 1). Natural OM is derived from vegetation and biota that is located within aquatic and terrestrial environments, while organic-rich fine sediments contain organic carbon components. Wastewater is defined as used water discharged by WWTPs in streams and rivers. The primary sources of OM in urban environments include natural OM, organic-rich fine sediment, and wastewater. The sources, fate, and transport of OM have been traced from autochthonous and allochthonous sources in urban environments. Urbanization can alter water bodies by changing the flow of water and sources of OM, which can then influence the physical, chemical, and biological properties of urban water bodies.

2. SOURCES OF ORGANIC MATTER

2.1 Natural Organic Matter

The literature sites numerous studies of heterogeneous mixtures of natural OM in urban water bodies. The OM originates from various terrestrial and aquatic sources, including leaf litter, algae, organic-rich soils, bed sediments and storm water (Sobieszczyk et al., 2014). Natural OM is a common and often dominant source of OM in urban water bodies. The sources of OM depend on primary productivity that is within and adjacent to aquatic ecosystems (Wetzel et al., 1992). Detrital OM of flocculent material is regulated by the local vegetation inputs (Neto et al., 2005). They provide carbon and therefore, energy to microorganisms and invertebrates. Organic matter is the base of the food web, providing energy to heterotrophic organisms (Jaffe et al., 2008). Multiple studies have been conducted on terrestrial OM as a source of OM to urban water bodies and they have established a link between urban water bodies and terrestrial ecosystems (Abelho, 2001; Benfield, 1997; Meyer et al. 1998). The primary productivity of emergent aquatic plants and epiphytic algae of submerged plants is much greater than that of plant communities on land (Wetzel et al., 1992). The ubiquitous presence of natural OM in aqueous environments is due to the interaction of the terrestrial and aquatic ecosystems (Slomber et al. 2017).

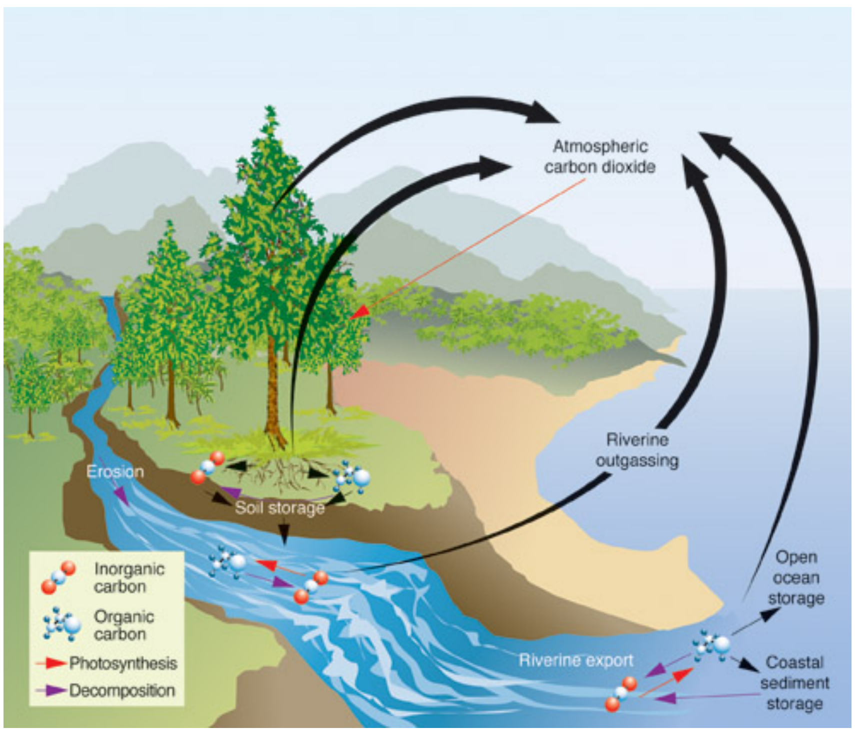

Figure 1. Carbon is transformed between the planet's land, ocean and atmosphere from the carbon cycle. Source: Lawerence Livermore National Laboratory.

Terrestrial OM, such as leaf litter from trees, has been known to enter urban water bodies and researchers have utilized numerous techniques to study terrestrial OM in water bodies. Further, several methods have been utilized to determine the relationship between channel processes and above channel vegetation. These methods demonstrate a greater applicability towards deciduous dominant settings, and does not account for the variations in land cover (Sobieszczyk et al., 2014). A new approach that is being used by Sobieszczyk et al. (2014) is to utilize a hybrid remotely sensed and field-based technique to quantify foliar biomass production that has variable land cover, such as deciduous-dominant riparian corridor, which allows for information on the origination of leaf litter, amount of material produced, and approximate amount of leaf litter that enters the stream in any given year. For example, Table 1 shows that approximately 991 metric tons of OM was available in Fanno Creek floodplain as potential leaf litter, with a large percentage located in reaches where there is a large abundance of deciduous trees. The heavily forested Reach 13 has produced 640 t/km^2, whereas Reach 5 and 12 each produced 500 t/km^2. Finally, the two wetland-dominant reaches, Reach 7 and 8, produced the least biomass, 170 t/km^2 and 150 t/km^2, respectively. The research demonstrates that land cover follows overall trends in biomass production in the upper, middle, and lower reaches of the creek (Sobieszczyk et al., 2014).

Table 1.Foliar biomass (tons) by reach for both the floodplain and annual overstream extent along Fanno Creek, Oregon. Source: Sobieszczyk et al. (2014).

Reach	Name	Annual Foiler Biomass Floodplain		Over Stream		
		(t)	(t/km^2)	(t)	(t/km)	(t/km^2)
1	Beaverton-Hillsdale	66	380	23	4.9	1100
2	Oleson	55	460	9	6.1	1000
3 (Upper)	Oregon Episcopal School Wetlands	53	240	5	5.0	830
4	Portland Golf Club	57	350	5	4.7	950
5	Vista Brook	140	500	17	6.0	860
6	Wonderland	48	320	5	2.8	580
7	Green Way	68	170	7	3.0	730
8 (Middle)	Englewood	22	150	1	0.5	400
9	Woodard	90	410	13	5.5	820
10	Fanno Creek Park	34	250	6	3.8	700
11	Bonita	100	450	12	5.6	870
12 (Lower)	Gentlewoods	88	500	9	4.2	740
13	Durham	170	640	25	10.4	940
Total		991(±2.2%)		136(±24%)		

The production of foliar biomass is much greater in the upper and lower sections than the middle when normalized for vegetation area dominance (Table 2). The upper section of Fanno Creek produces biomass that is proportional to its area, while the lower section produces 36% of foliar biomass for over 25% of its area (Sobieszczyk et al., 2014). Meanwhile, the middle section is inconsistent and produces 26% of foliar biomass for over 39% of its floodplain area.

Table 2. Land cover percentages for 13 stream reaches of the Fanno Creek floodplain, Oregon (Sobiezczyk, 2011 b,c). Source: Sobiezczyk et al. (2014).

Reach Information			Dimensions		
Reach	Name	Section	Floodplain	Stream	
			(km^2)	(km)	(km^2)
1	Beaverton-Hillsdale		0.17	4.7	0.021
2	Oleson		0.12	1.5	0.009
3	Oregon Episcopal School Wetlands	Upper	0.22	1.0	0.006
4	Portland Golf Club		0.16	1.1	0.005
5	Vista Brook		0.28	2.9	0.020
6	Wonderland		0.15	1.8	0.009
7	Greenway		0.41	2.3	0.010
8	Englewood	Middle	0.14	1.5	0.002
9	Woodard		0.22	2.4	0.016
10	Fanno Creek Park		0.18	1.4	0.008
11	Bonita		0.22	2.2	0.014
12	Gentlewoods	Lower	0.18	2.1	0.012
13	Durham		0.26	2.4	0.027

Therefore, the biomass distribution is related to the sources of vegetation that are adjacent to the creek. For example, there are forested areas in the upper and lower sections compared to wetlands or grassy areas in the middle section. The results from the study have shown that remotely sensed data can be used in combination with field measurements to effectively determine the approximate annual foliar biomass in a deciduous-dominant area and, as a result, provide assessment of terrestrial OM with land cover entering water bodies.

2.2 Organic-rich Fine Sediments

Sediment sources are often associated with erosional geomorphic features, such as banks, hilltops, and landslides (Keith et al., 2014). The decomposition of organic-rich fine sediment consumes oxygen, which can adversely affect the levels of dissolved oxygen (DO) in the surface waters. Studies have also determined that land-use changes, such as conversion of wetlands to agriculture cause changes in carbon and nitrogen content. Land-use changes, including reclamation and development, can increase export of soil-derived carbon stored in sediments (Bianchi et al., 2011). The movement of sediments originating from rivers or streams is another significant source of OM to other water bodies, such as the ocean. Urbanization increases flow velocity and downstream erosion from modification of channels of streams (Duan et al., 2014). The erosion of channels generally produces organic-rich fine sediments that do not have a significant amount of OM. Quantifying sources of organic-rich fine sediment can help guide management decisions to increase DO levels in water bodies (Keith et al., 2014). Past studies have indicated that the OM in urban water bodies needs to be identified and quantified properly for better assessment of urban water quality.

The research at Fanno creek studied the sources and quantities of sediment OM in an urban stream. A component of the study examined the organic-rich fine sediment in decomposed OM and depleted oxygen in the stream (Goldman et al. 2014). The research assessed the sources and quantified OM by utilizing: 1) optical instruments to calculate the transport and basin export of dissolved, particulate, and total organic carbon, 2) florescence spectroscopy and stable isotopes of carbon and nitrogen to characterize the sources and chemical properties of OM throughout the basin, and 3) synoptic sampling to investigate seasonal and hydrological variation characteristics and quantity of OM. The carbon and nitrogen stable isotope data and the carbon-to-nitrogen ratios were utilized to determine the potential sources of particulate OM to the urban stream. The sources of OM were quantified by estimating the amount of OM that was exported from the Fanno Creek watershed during the year within specific seasons and hydrologic conditions. The concentrations of particulate organic carbon (POC), dissolved organic carbon (DOC), and total organic carbon (TOC) were measured, along with stream flow and turbidity.

Results from the discrete samples were used to develop regression models that converted fine dissolved organic matter (FDOM) into time-series estimates of POC and DOC. The fraction of carbon load that was measured for POC, DOC, and TOC was used to calculate the total amount of OM that was being transported through and exported from the watershed. The results are consistent with findings of Keith et al. (2014) demonstrating that channel erosion provided a considerable amount of OM to the creek from organic-rich soil and organic-poor subsoil. The research study on bank sediments showed that large amounts of sediments, approximately 1900 tons/year, were transported through the creek, but the water contained relatively low amounts of OM (Kieth et al., 2014). Only 4% of the 1900 tons/year of suspended sediment was organic (Goldman et al., 2014). The monthly loads of total carbon were positively correlated with higher monthly discharge averages (Goldman et al., 2014).

Figure 2 shows that OM from streambeds was a significant source from the “first flush” storm by the POC that had accumulated in the streambed from microbial activity and productivity by algae. During the initial Fall flush event on October 12, 2012, the carbon concentration peaked at a significantly higher concentration to indicate the transport of large amounts of OM within the Fanno Creek watershed. The $\delta^{15}N$ values of 7 to 12 per mil from the study and higher C:N ratios indicate soil as OM source.

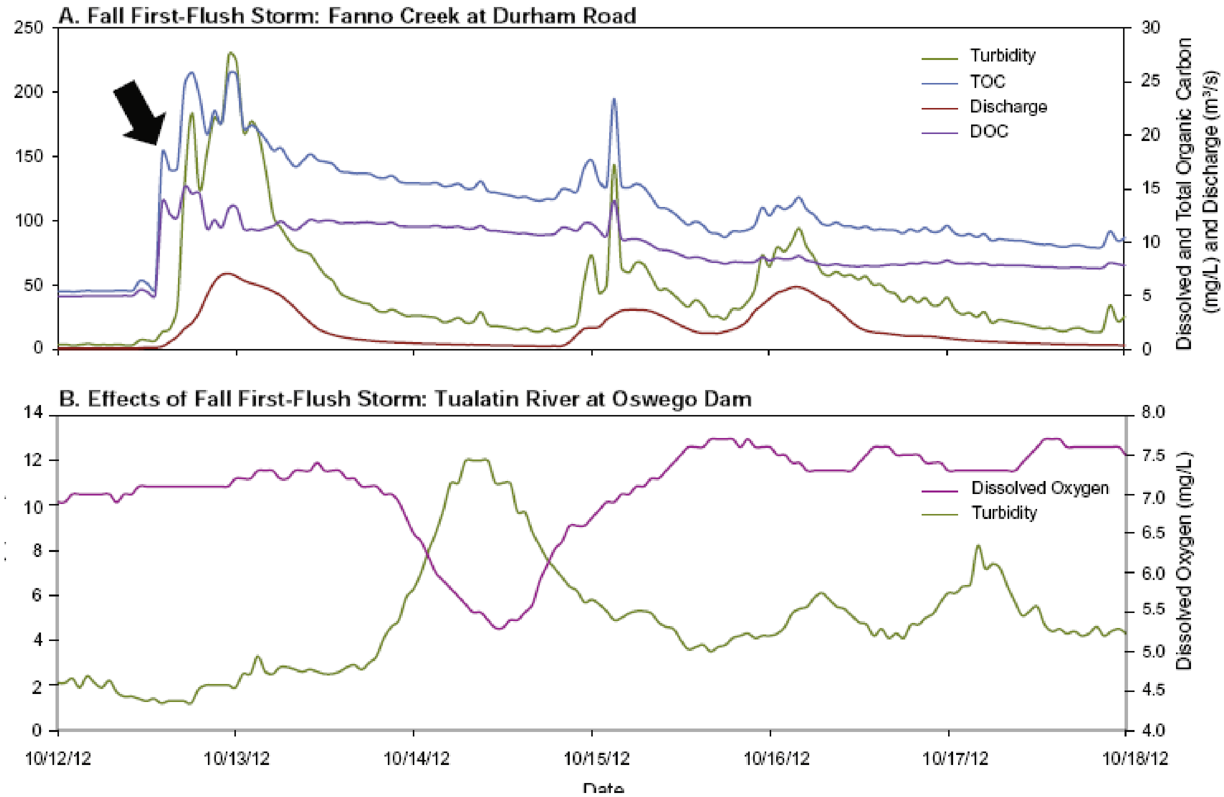

Figure 2. Fall first-flush storm dynamics in Fanno Creek and Tualatin River downstream in Northwest Oregon. Discharge, turbidity, and organic carbon patterns at Durham Road in October 2012. Arrow indicates the peak in carbon preceded the peaks in discharge and turbidity. Source: Goldman et al. (2014).

2.3 Wastewater

Inputs of wastewater can be a significant source of OM in urban water bodies. Urbanization can increase the loading of labile OM and its components into streams (Frimmel and Abbt-braun, 1999; McConnell et al., 1980) due to inputs from wastewater (Aitkenhead and Peterson et al., 2009). Typical sources of OM are anthropogenic sources such as inputs of sewage (Goldman et al. 2014). Urbanization changes the OM sources and dynamics in streams, draining urban areas by reducing inputs from riparian soils and plants and increasing inputs from WWTPs and autochthonous sources (Duan et al., 2014). Urbanization reduces natural terrestrial sources from structures and impervious cover and introduces anthropogenic sources of OM into streams from WWTPs, sanitary sewage flows, and sewage leaks (Kaushal and Belt, 2012; TCEQ et al., 2009). The alteration of the inputs of OM from urbanization increases with development, which may increase inputs of anthropogenic sources of OM, while reducing inputs of natural sources of OM, and influences the quality and quantity of OM.

Duan et al. (2014) hypothesized that OM in urban streams is also derived from wastewater and channel modifications with concrete linings may influence stream OM by influencing the hydrologic connectivity. The study utilized multiple tracers to track the sources of OM, including the wastewater from WWTPs that are located at the headwaters of two bayous in Houston, TX. The study measured the chemical composition of the organic particles in both bayous that were natural sources of OM that included terrestrial OM. Algae and organic-rich fine sediment particles were not identified as sources of OM. The chemical composition of the organic particles in the study resembled OM derived from wastewater in both bayous. Figure 3 demonstrates that urbanization reduced natural terrestrial sources of OM, while effluents of WWTPs were the dominant sources of OM in both bayous. This was reflected in the similarity of the $\delta^{13}C$ value of high molecular weight dissolved OM between the bayous and WWTP effluents (bottom panels of Figure 3). Urbanization alters the source of OM in streams draining large cities, which reduces the proportion of riparian buffers and plant OM and increases the proportion from WWTPs and autochthonous sources (Duan et al., 2014).

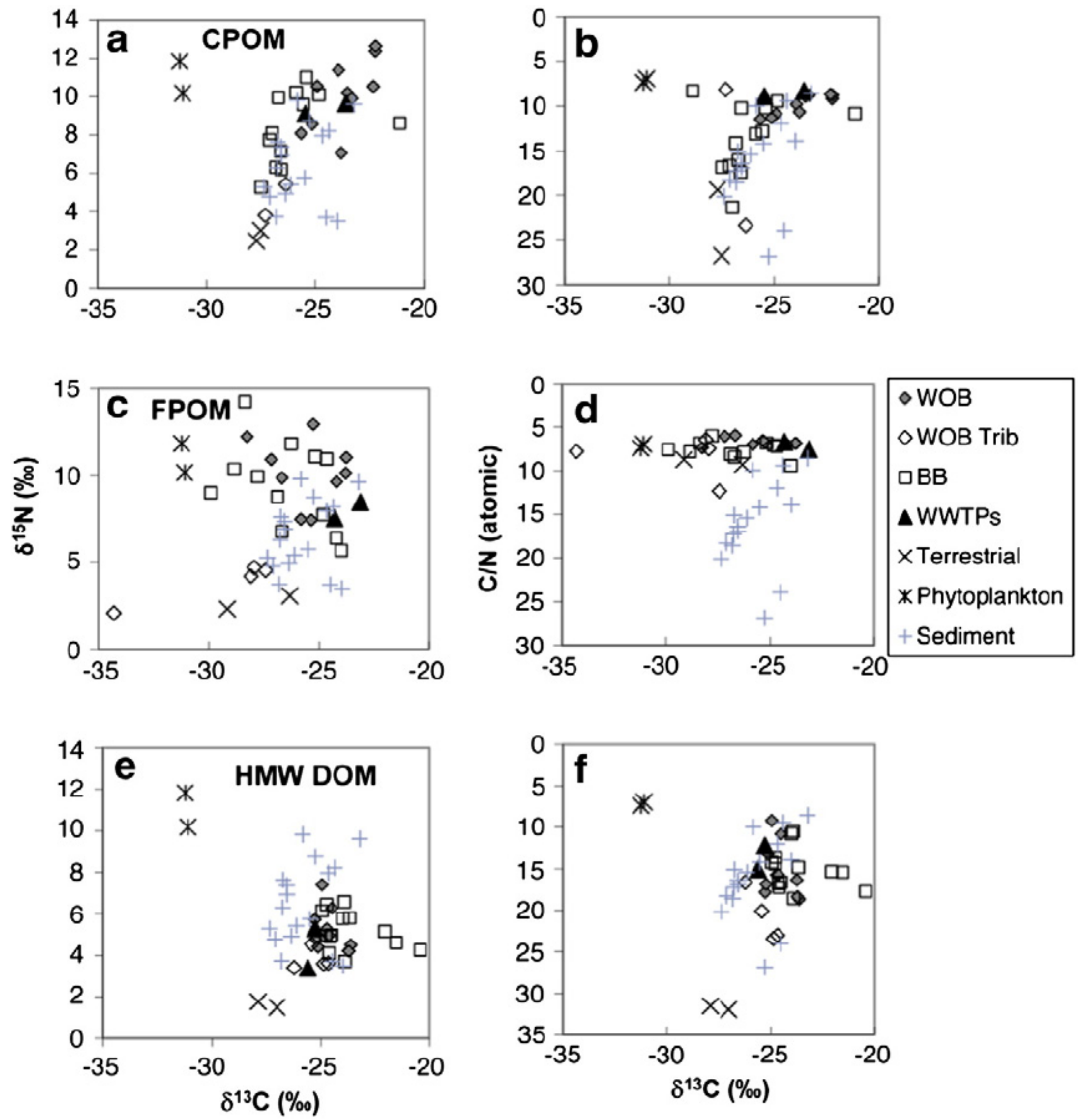

Figure 3. Plots of δ^{13} N or C:N ratio versus δ^{13} C for crude particulate organic matter (CPOM), fine particulate organic matter (FPOM) and high molecular weight dissolved organic matter (HMWDOM) from White Oak Bayou (WOB), WT (without WWTP input), and Buffallou Bayou (BB) sediment organic matter and three end members are added for organic matter source estimation-WWTPs, terrestrial (control sites stream water), phytoplankton (FPOM collected from tidal zone of BB and WOB). Source: Duan et al. (2014).

3. TRANSPORT OF ORGANIC MATTER

3.1 Natural Organic Matter

Organic matter is transported from both allochthonous and autochthonous sources. The predominant source of OM that is transported in urban water bodies originates from terrestrial sources, such as leaf litter. Multiple studies have linked terrestrial ecosystems with urban water bodies. The transport of OM in urban water bodies plays an active role in the carbon cycle that interacts with terrestrial sources. Approximately 10 to 30% of the carbon that is exported to fresh water bodies from terrestrial ecosystems is stored, transformed, and released to the atmosphere or towards the ocean (Rasilo et al., 2017). The productivity of vegetation from terrestrial sources from adjacent terrestrial areas may produce OM that is transported to water bodies and is affected by decomposition by microorganisms.

Granskog et al. (2012) used source water fractionation techniques to assess the amount of crude dissolved organic matter (CDOM) exported from riverine and terrigenous sources to the North Atlantic through the Fran Strait, which indicated OM losses of approximately 49-59% due to decomposition. The amount of sediment OM that is transported is less from urban water bodies such as banks, hilltops, and landslides than the amount of vegetation OM that is transported from terrestrial sources. The first flush of rain storm transports most the OM to urban water bodies. The research at Fanno Creek examined the transport of OM after the first storm of Autumn by analyzing the turbidity, total organic carbon, and organic carbon patterns in Fanno Creek in 2012. The pools of OM that included POM and DOM, were decomposed by microorganisms as the OM was transported downstream.

Numerous studies have indicated OM is exported to urban water bodies from allochthonous and autochthonous sources in the downstream direction. When terrestrial OM enters a stream or stream bottom, microorganisms decompose OM and oxygen is consumed from the water column through the process of biological oxygen demand (BOD) and sediment oxygen demand (SOD) (Sobieszczyk et al., 2014). The OM is transported from upstream to the downstream is unique in spatial linkage that integrates the ecosystem processes throughout the entire network (Tank et al. 2010). The mean POM decreases in the downstream direction (Webster et al., 1995) via decomposition and degradation processes. A study concluded that many of the stream reaches are net exporters of OM (Meyer et al., 1979).

Decomposition of OM by microorganisms generates inorganic components, such as carbon dioxide and nitrate from biogeochemical processes. Rasilo et al. (2016) demonstrated accounting of stream CO_2 fluxes by matching the observed differences in concentrations of the three carbon species, CH_4, CO_2, and dissolved organic matter (DOC), between soil and stream waters. They also utilized mass balance and analysis of temperature, pH, conductivity, and dissolved oxygen. Since streams are, usually, supersaturated with carbon dioxide and methane, and are important components of regional carbon emissions from northern landscapes, the study sought to determine the delivery of carbon to the streams (Rasilo et al., 2016). The contribution of direct carbon dioxide injection versus oxidation of soil-derived DOC and methane in supporting carbon dioxide super-saturation in boreal streams was, then, assessed. The mass balance approach showed the three major pathways. Also, the mineralization of soil-derived DOC, and methane to carbon dioxide accounted for the majority of carbon dioxide that was emitted from streams. The carbon that was emitted from streams were mainly, derived from terrestrial sources.

3.2 Organic-rich Fine Sediments

Studies have demonstrated that sediment OM is transported in aquatic systems and is a component of the total OM in water bodies. Soils from different landscapes are major sources of OM in urban rivers (Li et al., 2016). The organic-rich fine sediments from bank erosion, hilltops, and terrestrial sediments are major sources of OM (Keith et al., 2014) that can adhere to or become a component of fine, cohesive sediments that can be transported (Huang et al., 2016). A recent study concluded that carbon dioxide emissions from rivers mainly originate from terrestrial sources (Rasilo et al., 2016). The delivery, reaction and burial of organic carbon are dependent on transport-reaction cycles (Blair and Aller, 2012) within urban water bodies. The quantification of erosion and deposition of these features at specific locations allow the determination of sediment cycles at other locations in the basin for transport processes (Keith et al., 2014). The organic-rich fine sediment is eroded, deposited, and transported throughout a stream (Keith et al. 2014). The sediment OM is continually decomposed from biogeochemical processes throughout the transport-reaction cycle as the sediment travels downstream. The OM degradation is driven by decomposition processes and is, also, degraded by photolysis. Also, studies have indicated that OM transport may depend on water flow and seasons. The study by Keith et al. (2014) demonstrated that suspended sediments were transported during high-flow events, following larger storm events. The study shows that the amount of sediment transported in Fanno Creek was consistent with independent calculations of suspended sediment loads at Durham Road streamflow-gaging station (Keith et al. 2014). Sediments have lower OM content compared to the bulk materials, which have OM content that is mainly composed of vegetation can also be transported.

3.3 Wastewater and Combined Sewer Overflows

Wastewater may become the dominant source of OM, depending on the degree of urbanization. Wastewater effluent is a direct input source of OM, which can be stored in the streambeds, and may be released and transported later (Chahinian et al., 2011). Rivers and streams are the main receiving water bodies for soils and sediments of terrestrial and aquatic ecosystems (Viers et al., 2008). The change in OM flow to sediment resuspension is dependent on the flow conditions of the receiving stream. The flux of OM from wastewater is influenced by stream flow. Quijano et al. (2016) used 3D modeling with a detailed numerical model for understanding the flows of combined sewer overflows (CSOs) from heavy rain events in the Chicago area. They found that the concentration of sewage was impacted by extreme events at the river boundaries. The POM from wastewater is decomposed by microorganisms in the downstream direction (Duan et al., 2016). The quantitative inputs of large concentrations of wastewater affect the inputs of OM in urban water bodies and can affect nutrient status of streams from mineralization during OM decomposition. The nutrient concentrations in rivers are controlled by a multitude of biogeochemical reactions that may occur during transport (Chahinian et al., 2012). The particles of OM from wastewater are mobilized from WWTPs during floods and deposited on streambeds and released slowly (Duan et al., 2014). Also, observations have indicated that during large storm events biosolids are released from thick biosolid blankets at WWTPs (Duan et al., 2014). The transport of wastewater by rivers affects other water bodies through biogeochemical processes and hydrological conditions further downstream.

4. FATE OF ORGANIC MATTER

4.1 Natural Organic Matter

Natural OM is retained, processed, and stored throughout the urban aquatic system. The retention and storage of OM occurs in stream and river channels (Elosegi et al., 2016). Riverine OM is abundant and diverse and consists of POM and DOM. Deposits with POM near sites of production undergo decomposition into humic compounds in the shallow areas and the littoral zones (Wetzel et al., 1992). The local vegetation inputs from both allochthonous and autochthonous sources of OM that include periphyton, emerged and submerged plants, and terrestrial plants such as mangroves are incorporated into soils and sediments as organic detrital particles (Neto et al., 2016).

A large fraction of nutrients is stored in OM that is leached and decomposed to stream and river systems from stream and river sediment. Fluvial networks process large amounts of organic carbon (Vilmin et al., 2016), and are important sites of carbon storage (Omengo et al., 2016). Also, the organic matter, including terrestrial sources, may be exported to seas, and transformed and stored in the coastal regions as recalcitrant pools in sink regions. A significant positive correlation between the $\delta^{13}C$ and $\delta^{13}N$ in the Yellow river coastal plain-plume-bay region was observed, which indicated that the flux of OM from the labile pool in source regions to the recalcitrant pool in the sink regions (Li et al., 2016).

Floodplains are recognized as important sites of carbon storage within fluvial networks, where floodplains are particularly productive ecosystems (Hoffman et al. 2009). The study by Twilley et al. (1992) indicated that the continental margins are important depositories of OM. The input of terrigenous organic carbon and marine carbon produces abundant carbon that is buried from high sedimentation rates near the sediment-water interface, which causes preferential burial (Berner et al., 1982; Deuser et al., 1988, Dagg et al., 1991). Coastal wetland sediments and biomass represent large reservoirs of organic carbon (Twilley et al., 1992). Further, the majority of the OM that reaches the ocean is deposited in the estuaries and continental margins (Twilley et al., 1992). The study by Koch et al. (2014) showed floc OM was stored in the Taylor River ponds and was also exported to Northeastern Florida Bay, which may have increased with improved flow rates. These studies indicate OM is decomposed and deposited in the channels and floodplains of rivers and streams, ultimately reaching ocean sediments.

4.2 Organic-rich Fine Sediments

Studies have demonstrated the fate and deposition of sediment-associated organic carbon occur by sedimentation in inland waters or the ocean. A significant loss is via the deposition of sediments containing OM in flood plain environments from the fluvial networks (Hunsinger et al., 2010). High OM mineralization rates were due to the higher temperatures and more wet and dry cycles than what is found in temperate regions (Omengo et al., 2016).

Organic carbon that is trapped by floodplains or wetlands can be stored for long-term. The deposited organic material accumulates in the channels and floodplains, but may also be remobilized during high flow rates. Organic carbon that is associated with sediments is buried by sedimentation processes and stored, possibly for centuries in floodplains (Omengo et al., 2016). According to Blair et al. (2002), approximately half of the fine-grained organic carbon delivered to the oceanic shelf, an underwater land mass that extends from the continent, in Northern California is derived from ancient sedimentary organic carbon of the uplifted Mesozoic-Tertiary Franciscan Complex of the watershed of Eel River in Northern California (Blair et al., 2002).

Organic matter that originates from rivers may also accumulate in ocean sediments. The Tana River floodplains trap substantial amounts of sediment and organic carbon, thereby regulating transport to the Indian Ocean (Omengo et al., 2016). Using organic carbon, total nitrogen, elemental ratios and isotope ratio data, Yi et al. (2016) showed that the fate of organic-rich fine sediment from rivers and coastal plains was in the bulk sediment in oceans as a recalcitrant pool. Assuming the organic carbon in the subsoil is derived from riverine particulate organic carbon, and the riverine sediments contain, on average, approximately 1.55% of organic carbon, the carbon burial efficiency may approach 80% (Omengo et al., 2016).

Sinks within channels may also store large amounts of organic-rich sediment, compared to floodplains. According to the research conducted by Keith et al. (2014), sinks within the active channel, including bars, low benches or deposits near dams and blockages probably sequester a large proportion of sediment and OM relative to the more distal floodplain areas. The OM that is associated with sediments continues to decompose (Salas et al., 2015), but only if the OM is accessible after burial.

4.3 Wastewater

The OM content of rivers and streams has been impacted by human activities due to the urbanization. The WWTPs effluents discharged into rivers accumulates in the riverbed where the OM continues to undergo biogeochemical processes. The riverine continuum concept postulates metabolic linkages between upstream and downstream ecosystems (Vanote et al., 2008). Rauter et al. (2005) showed that the sewage derived particulate OM from WWTPs is removed within short distances from the water column in the stream and is deposited and metabolized in the streambeds resulting in reduced downstream export. This particulate OM continues to fuel metabolism of streambeds via biogeochemical processes.

The effluents cause changes in instream concentrations of OM, and also the composition of the riverbed sediments (Vilmen et al., 2016). Urban wastewater effluents induce accumulation of POC and microorganisms (Trinh et al., 2007), and can cause changes in the biogeochemical functions of the riverine system (Vilmen et al., 2016). Quijano et al. (2017) showed that inflow of combined sewer overflows (CSOs) significantly increased chemical biological oxygen demand (CBOD) and ammonia in different regions; however, external inflows increase proportionately with rainfall to reduce the impact of nutrients on the urban water body due to the presence of organic matter in CSOs. The WWTPs derived OM may increase algal growth from the release of nutrients via mineralization in urban water bodies when compared to natural water bodies.

5. CONCLUSIONS

A review on the sources, fate, and transport of OM in urban water bodies indicates that urbanization has the potential to affect water quality. The impact of OM can potentially cause low dissolved oxygen conditions from the decomposition of vegetation, organic-rich fine sediment, as well as decomposition of OM present in wastewater. The first flush caused by rainfall delivers OM from both natural and anthropogenic sources and flows into urban water bodies. The primary source of OM in urban water bodies is vegetation that originates from terrestrial sources. However, wastewater can become the primary source of OM in urban watersheds. Simulations have demonstrated that combined sewer overflows are diluted by the increase in volume of water from other flows during rain storms, reducing the concentrations of

OM in urban water bodies. Particulate OM generally decomposes from the upstream to downstream locations with spatial linkages in the downstream direction. The OM continuously decompose into humic- and fulvic-like components in the riverbeds as the OM is transported and deposited in sinks on the bottoms of urban water bodies. The OM will continually accumulate on the bottoms of urban water bodies and can be mobilized, depending on the flow of water. Organic matter is also transported and deposited on the ocean floor from the riverine deposits in the riverbed. Studies have concluded that carbon dioxide is emitted from decomposition of OM in the riverbeds from, mainly, terrestrial sources, however, more research is needed to understand the pathways and emissions of gasses from riverine systems. Studies have determined that the concentrations of OM and nutrients observed in the downstream locations are affected by the inputs of OM upstream. OM is constantly decomposed by microorganisms and invertebrates, during transport and deposition in sinks; and undoubtedly continues to be a challenge in urban water bodies. More research is needed to understand the decomposition of OM from terrestrial sources in urban areas that cause reduced water oxygen concentrations. The problem of organic matter in urban water bodies requires better understanding of the link between soil-stream carbon pathways from terrestrial sources.

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