Examining Terrestrial and Subterranean Sediment Sources and Transport Processes in an Urban Sewershed with an Entirely Buried Stream Network, Washington, D.C., United States

Zach Clifton, Physical Scientist, US Geological Survey, Baltimore, MD, zclifton@usgs.gov

Allen Gellis, Hydrologist, US Geological Survey, Baltimore, MD, agellis@usgs.gov

Leah Staub, Physical Scientist, US Geological Survey, Baltimore, MD, lstaub@usgs.gov

Matt Cashman, Supervisory Hydrologist, US Geological Survey, Baltimore, MD, mcashman@usgs.gov

Chris Conaway, Research Chemist, US Geological Survey, Menlo Park, CA, cconaway@usgs.gov

Cecilia Lane, Environmental Protection Specialist, Department of Energy and the Environment, Washington, D.C., Cecilia.lane@dc.gov

David Pilat, Branch Chief, Department of Energy and the Environment, Washington, D.C., David.pilat@dc.gov

Abstract

Excessive fine-grained sediment runoff due to anthropogenic activities is a major environmental concern for watersheds worldwide, especially so for urban areas such as Washington, D.C. Dated grey infrastructure, i.e., the network of buried pipes and reservoirs managing water resources, can amplify existing issues with sediment runoff and associated pollutants. This infrastructure, which is generally designed to quickly transport stormwaters away from urban areas, contributes to urban stream syndrome. Recent studies have suggested aging subterranean infrastructure may be an unaccounted-for source of sediments. The composition of this possible sediment source, and the extent to which it contributes to urban sediment runoff, is poorly understood. Our study seeks to examine sediment sources and transport processes in an urban watershed with an entirely buried drainage network using sediment fingerprinting, with specific attention paid to differentiating between terrestrial and subterranean sources. We demonstrate here multiple novel approaches to sampling subterranean sources including augering and entering the buried drainage network itself. The results of this study may inform sediment managers and infrastructure engineers and allow for targeted sediment reduction responses.

Introduction

Fine-grained sediment runoff due to anthropogenic activities is a major concern for the ecological health of watersheds worldwide (Owens, 2005). Fine sediments (<63µm in diameter) can increase light attenuation in the water, and stimulate phytoplankton growth (Orth & Moore, 1983). Fine sediments are frequently transport vectors for excess nutrients such as nitrogen and phosphorus in addition to heavy metals, polycyclic aromatic hydrocarbons, and other contaminants from anthropogenic activities (Larsen et al., 2010).

This is especially true of urban areas, where industrial pollution and dated grey infrastructure designed to transport stormwaters away from urban areas can quickly amplify existing issues with sediment runoff. Flashier, high-peak flows during storm events, higher stream power, and increased erosion rates are direct results of urbanization and the burial of a watershed's existing stream network (Walsh et al., 2005). Notably, Gellis et al. (2020) found that while sediment from impervious surfaces make up a large portion of sediment runoff, a significant amount of sediment even in an entirely buried system with no exposed streambanks was sourced to streambank material in the urbanized Dead Run watershed. This was hypothesized to be the result of cracking and breakup of the watershed's grey infrastructure system, a common issue. As these systems breakdown, the surrounding soil can infiltrate, form cavities, and in some cases sinkholes (Ali & Choi, 2019). A sediment fingerprinting study that directly targets material surrounding and stored within aging grey infrastructure along with other sediment sources in an urban watershed is needed to understand urban sediment sourcing and transport dynamics.

Sediment fingerprinting uses the unique "fingerprints", i.e., a sediment's geochemical, physical, and radio signature, of a watershed's sediment sources to quantify the amount of sediment contributed by each source as it exits the watershed via suspended sediment. After identifying possible sources, the fingerprints of each source are compared to the outgoing sediment's composite "fingerprint". The proportion of each source present in the composite fingerprint is then identified by an unmixing model. This information is vital to sediment management strategies as different sources require different management approaches (Gellis et al., 2020).

This study seeks to examine sediment sources and transport processes in an urban watershed with an entirely buried drainage network, with specific attention paid to subterranean sources originating from soil surrounding historical stormwater drainage networks. This study asks three key questions: (a) Do subterranean sources contribute significant amounts of material relative to more common surficial sources? (b) How does transit time vary between sources, and is there sediment storage within the underground system?

Study Area

To address these questions, the US Geological Survey's Maryland-Delaware-D.C. Water Science Center (USGS MD-DE-DC WSC) and Washington D.C.'s Department of Energy and the Environment (DOEE) partnered to study the Hickey Run watershed. This watershed is 2.66 km^2 in size located northeast of the National Arboretum. It is part of the Chesapeake Bay Watershed and lies within the Coastal Plain physiographic province. The watershed's grey infrastructure network varies in age, with some of the oldest sections dating to 1910 and an average known date of construction in the early-1940s. Construction material likewise varies with age but is generally brick-and-mortar and/or concrete. The stream network is entirely underground via the city's stormwater drainage network, with no daylighted channels before it drains into the National Arboretum and a Terre Kleen™ TK 45 best management practice (BMP) trash collection system. USGS gage 01651770 is stationed immediately downstream of the BMP and has operated since October 2012. Hickey Run then flows for approximately 1.5 km before emptying into the Anacostia River. The BMP was installed in late 2011 but requires quarterly cleanouts due to high rates of sedimentation precipitated from sediment runoff throughout the watershed. DOEE seeks to reduce the frequency of said cleanouts by targeting sediment reduction management efforts at the major sediment sources identified by this study.

Methods

Samples were collected between 3/2021 and 7/2022 and classified as target or source samples. 112 source samples were collected from sources including pavement, topsoil from areas such as parks and construction sites, and from the material surrounding DC's buried stormwater network. 34 target samples were collected at the BMP from both the bed during baseflow and from the water column during storm events via ISCO samplers stationed at the USGS gage.

Pavement samples were collected following storm events from a several road types including commercial, residential, and parking lots. Following Gellis et al. (2020)'s sampling procedure, pavement sediment was collected with a broom and pan. These samples were collected near curbs and upslope from storm drains. Surfaces varied in sediment buildup so the area swept varied across samples, but at least 3g of fine sediment was swept per sample, and swept clean. Random sample points were generated for topsoil inside open spaces and construction sites and were later visited for sampling post-storm events. A 5-meter by 1-meter rectangle was measured in the immediate vicinity of the point, in which 3-5 subsamples of the top 1 cm of soil were collected via a plastic trowel and composited into a single sample.

Sampling the material surrounding the stormwater drainage network involved hand-augering and entering the stormwater network. DOEE's map of the city's stormwater drainage network, historic construction documents, and historic topoquads were utilized to assess network accessibility. After identifying a pipe's location, auger samples were collected from the material surrounding the pipe with a bucket auger. Drainage pipes large enough to enter were inspected visually for cracks. Where cracks were identified, a plastic trowel was inserted and used to scrape material. Some cracks were too small to access via trowel, however deposits identified immediately in front of said cracks were sampled.

Bed samples were collected prior to DOEE cleanouts of the BMP during baseflow conditions. These samples were collected with a stainless-steel spatula following Gellis et al. (2020) 's procedure at multiple points within the BMP. ISCOs collected suspended sediment samples during storm events and were equipped with automatic pumps set to trigger when the flow stage reached a preset stage according to hydrograph rises attributed to stormflow conditions.

After collection all samples were transported to the USGS MD-DE-DC WSC for processing and analysis. Samples were wet-sieved with deionized water using a 63-µm polyester sieve-cloth, the slurry collected in bowls, and dried according to ASTM-D1140-17. Once dried, fine sediments were mechanically disaggregated and sent for analysis of radionuclides, elemental composition, and carbon content. Grain size distributions were analyzed with a laser-diffraction particle size analyzer following ISO-13320:2020.

Results and Discussion

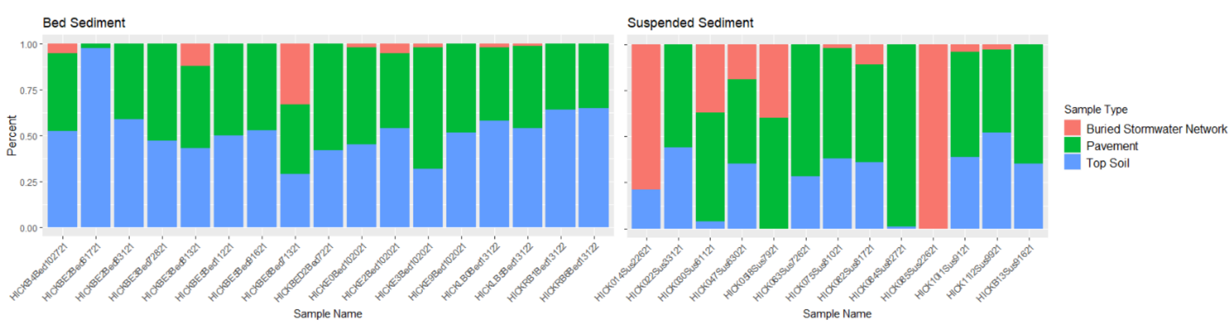

Figure 1. Sediment sourcing for each target sample according to the Sediment Source Assessment Tool ([Sed_SAT]).

Sediment sources were approportionated for each target sample through Sed_SAT, a USGS mixing model program developed to streamline sediment fingerprinting analysis (Sanisaca et al., 2017). After correcting for size, identifying outliers and the most discriminatory tracers, Sed_SAT quantified the relative contributions of each source for each target sample. The most effective discriminants were Cobalt, Lithium, Carbon, Magnesium, and excess ^{210}Pb. The mean proportional contributions from sources for target samples collected from the bed of the BMP were 4% from the buried stormwater network, 44% from pavement, and 53% from topsoil, with Sed_SAT's discriminant functional analysis (DFA) correctly identifying a mean of 85% of source samples. Results for suspended sediment samples collected during storm events were similar, with 23%, 52%, and 26% from the same fields respectively. The DFA for suspended sediments correctly identified a mean of 84% of source samples.

Regarding radionuclide activity, high levels of excess ^{210}Pb activity (produced in the atmosphere and deposited by rainfall) and low levels of ^{137}Cs activity (a by-product of nuclear testing) were observed in pavement sediments. In contrast, the opposite was observed in topsoil and the buried stormwater network (low in ^{210}Pb but high in ^{137}Cs). Shorter lived radionuclides like ^{7}Be (also produced in the atmosphere and deposited via rainfall), see a similar trend: active on pavements, dead in topsoil. Given the higher ^{7}Be activity in pavement samples and the relatively high ^{7}Be activity in bed/suspended sediments, it can be posited that sediment generated on the pavement moves through the system relatively quickly. In contrast, the relatively "dead"-in-^{7}Be topsoil may take months to years from mobilization to reach the outlet.

When Sed_SAT's model of each sources' relative contributions is combined with transit times modeled by radionuclide decay, these results suggest a system defined by erosion of sediments found on roadways and topsoil, with some input from aging grey infrastructure. The two dominant sediment sources for the watershed, pavements and topsoil, are to be expected in urban watersheds according to prior studies (Gellis et al., 2020). The magnitude of sediment eroded from the buried stormwater network was unexpected, especially as a non-negligible portion of suspended sediments leaving the watershed. Inputs from aging grey infrastructure should be considered as a possible source of sediment for urban watersheds in the future. These findings will be invaluable to sediment managers in urban watersheds with or without aging grey infrastructure and will allow for targeted sediment reduction responses.

References

Ali, H., & Choi, J. (2019). A Review of Underground Pipeline Leakage and Sinkhole Monitoring Methods Based on Wireless Sensor Networking. *Sustainability*, *11*(15), 4007.

Gellis, A. C., Fuller, C. C., Van Metre, P. C., Mahler, B. J., Welty, C., Miller, A. J., Nibert, L. A., Clifton, Z. J., Malen, J. J., & Kemper, J. T. (2020). Pavement alters delivery of sediment and fallout radionuclides to urban streams. *Journal of Hydrology*, *588*, 124855.

Larsen, M. C., Gellis, A. C., Glysson, G. D., Gray, J. R., & Horowitz, A. J. (2010). *Fluvial sediment in the environment: A national challenge*.

Orth, R., & Moore, K. (1983). Chesapeake Bay: An Unprecedented Decline in Submerged Aquatic Vegetation. *Science*, *222*(4619), 51–53.

Owens, P. (2005). Conceptual Models and Budgets for Sediment Management at the River Basin Scale. *Journal of Soils and Sediments*, *5*, 201–212. https://doi.org/10.1065/jss2005.05.133

Sanisaca, L. E. G., Gellis, A. C., & Lorenz, D. L. (2017). *Determining the sources of fine-grained sediment using the Sediment Source Assessment Tool (Sed_SAT)* (No. 2017-1062). US Geological Survey.

Walsh, C. J., Roy, A. H., Feminella, J. W., Cottingham, P. D., Groffman, P. M., & Morgan, R. P. (2005). The urban stream syndrome: Current knowledge and the search for a cure. *Journal of the North American Benthological Society*, *24*(3), 706–723.