Effectiveness of environmental site design in protecting stream channel stability

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Abstract

Environmental site design (ESD) seeks to minimize the impacts of urbanization on stream systems by conserving natural drainage features, minimizing the use of impervious surfaces, and slowing runoff through the use of infiltration-based stormwater management practices to increase lag time, infiltration, and evapotranspiration. While there are numerous studies documenting improvements at the level of individual stormwater control measures (also known as best management practices or BMPs), fewer studies have evaluated benefits at the watershed level. The goal of this project was to compare the impacts of different types of stormwater management on watershed hydrology and channel stability.

Tributary 109 is a first-order riffle-pool, gravel-bed channel with an average channel slope of 1.1%. The 0.33 mi^2 watershed is located in Montgomery Co., Maryland and was developed from 2006 to 2017, during which impervious cover increased from 5% to 38%. To minimize the impacts of the development on Trib 109, intensive stormwater management approaches were implemented, including the use of multiple infiltration structures to capture urban runoff generated from all impervious cover within the developed area, as well as end-of-pipe retention/detention systems. A total of 70 stormwater control measures (SCMs) were installed (26 micro bioretention, 10 infiltration trenches, 5 ponds, 11 sand filters, 18 underground storage facilities). The entire riparian zone was also left undeveloped and can be considered a nonstructural BMP (Sparkman et al., 2017). During development of the watershed, the required water quality and channel protection volumes were considered additive, resulting in high levels of runoff storage.

To assess the impact of different levels and types of stormwater management practices on channel stability, a Storm Water Management Model (SWMM) model was developed and calibrated using discharge data from the U.S. Geological Survey (USGS) streamflow station 01644372 on Little Seneca Creek Tributary at Brink, Maryland for 2004-2020. Stormwater practices represented in the model were then removed to simulate the hydrologic response from reduced levels of stormwater management. These 5-minute flow time series were then used to simulate the channel response using the Hydrologic Engineering Center-River Analysis System,

version 6.3 (HEC-RAS). A 1-D quasi-steady model was developed. Sediment transport was modeled using the Wilcock and Crowe method (Wilcock et al., 2003), as the bed material within the study reach is well-graded and contains both sand and gravel. An initial sediment rating curve for the study reach was constructed using suspended sediment discharge data from six nearby USGS streamflow stations located in small watersheds with urban development. The sediment rating curve and channel mobility factor were then calibrated based on measured channel cross-sections in the reach. For comparison to undeveloped conditions, discharge records from a nearby 1.17 mi^2 forested watershed (USGS 01643395, Soper Branch at Hyattstown, MD) were scaled based on watershed area.

Study results show that infiltration practices were more effective at reducing peak runoff from more frequent storm events than storage practices alone; however, storage practices are necessary to minimize increases in peak flows for larger, less frequent storm events (Table 1, Figure 1). While environmental site design maintained overall runoff volumes similar to the forested control, the fraction of runoff that occurred as storm flow increased, regardless of the extent of stormwater management and the maximum flow more than doubled.

Table 1. Comparison of flow metrics for different stormwater management strategies, as described by Kermode et al. (2020), where MF = the median flow for the forested control watershed.

Flow metric	Environmental Site Design	Storage Practices Only	Infiltration Practices Only	No Stormwater Management	Forested control
Yearly flow volume (acre-ft/yr)	8.7	10.1	9.4	11.0	8.2
Baseflow index	0.51	0.47	0.53	0.47	0.74
Number of events/yr with mean flow > 3*MF	39	50	42	45	14
Percent of time > 3*MF	8.9	7.4	9.4	5.3	12.1
Median flow (cfs)	0.3	0.4	0.4	0.4	0.4
Maximum flow (cfs)	589	597	757	777	281

Initial and final channel profiles from the 1-D HEC-RAS model for different levels of stormwater management are shown in Figure 2. Regardless of the volume of stormwater storage or the number of infiltration practice present, regions of degradation and aggradation are predicted to occur. In the upstream reach, the channel bed degrades. A steep riffle forms when cobbles are deposited upstream of a channel contraction at river station 793 (RS 793). Downstream of RS 793, additional bed degradation and downstream aggradation occur. Model results are supported by field observations of increased pool depths and shortening and steepening of riffles. While implementation of ESD reduced the extent of channel degradation over the 15-yr simulation period, it is anticipated the channel will continue to incise until bedrock is reached.

While data analysis is ongoing, initial study results indicated that channel degradation occurs regardless of the level of implemented stormwater management. It is recommended that future stormwater regulations targeted at maintaining channel stability address maintaining sediment transport capacity over a range of stream flows, rather than basing stormwater designs on hydrologic criteria for a single recurrence interval design storm.

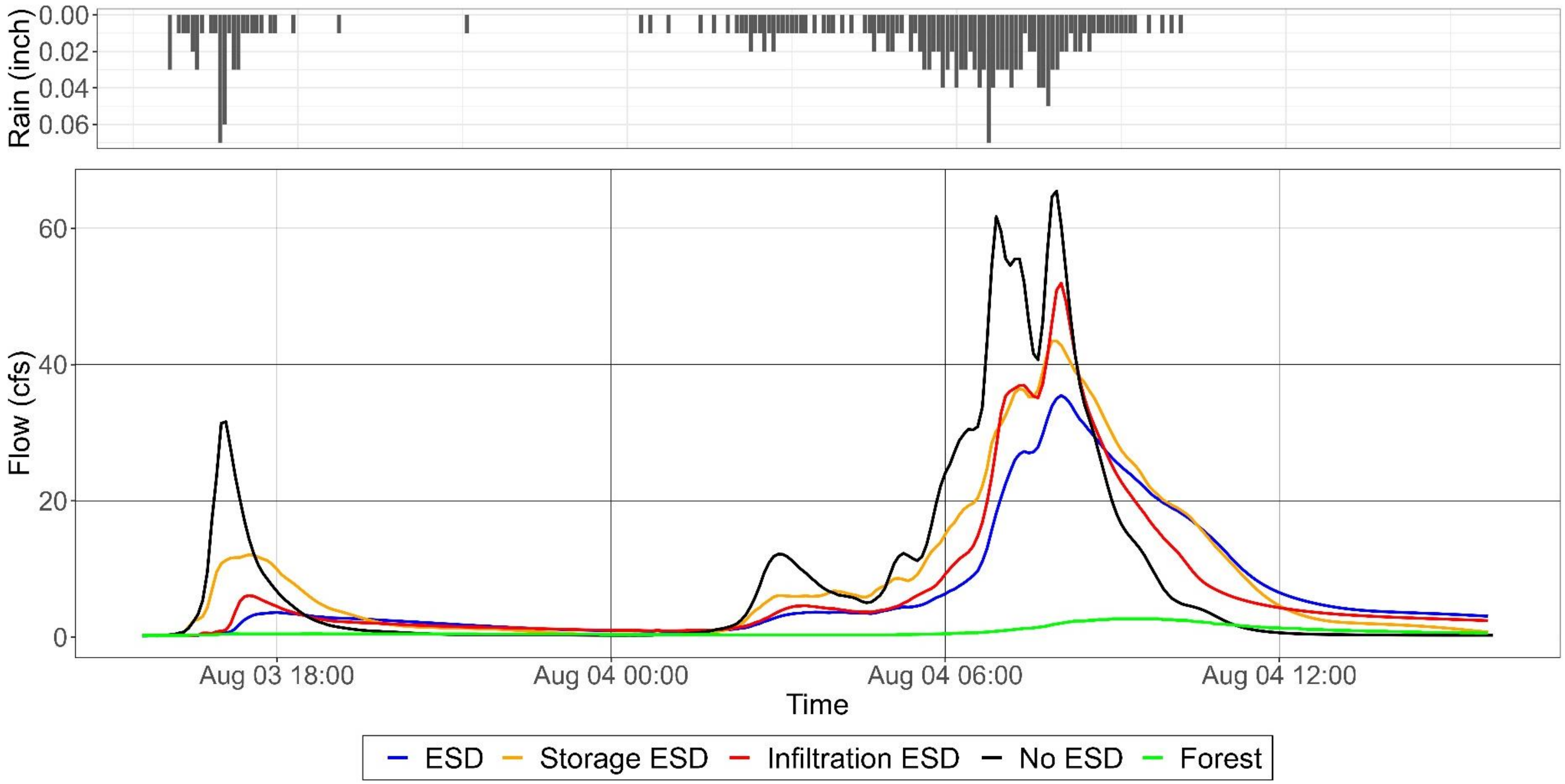

Figure 1. Measured hyetograph and simulated hydrographs for a storm event on August 3, 2020. Total rainfall was 2.13 in. ESD = Environmental site design.

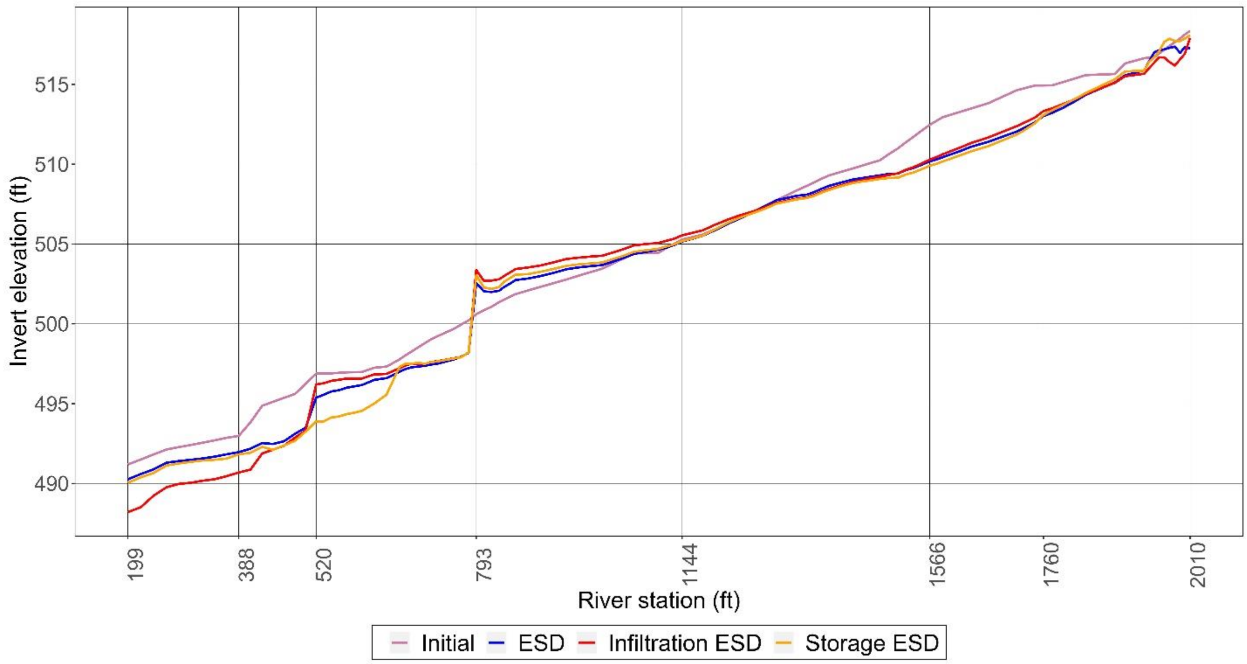

Figure 2. Predicted channel profiles after 15 years under different stormwater management levels. ESD = Environmental site design.

References

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