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Flow class analyses of suspended sediment concentration and particle size in a mixed-land-use watershed

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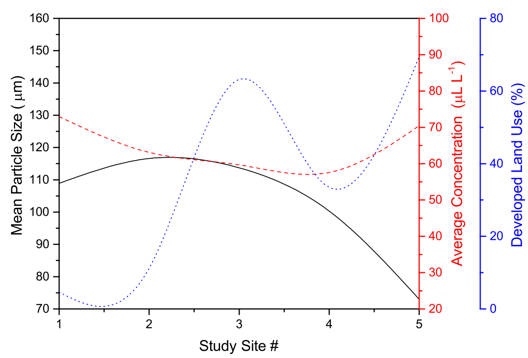
HIGHLIGHTS

- Stream samples were analyzed for suspended sediment characteristics on a flow-class-basis.
- Sediment concentrations suggest greater sensitivity of urban sites to streamflow variability.
- Particle size showed a decreasing trend with increasing streamflow at every site.
- Size results are likely attributable to variable sediment sources during high and low flows.
- Results highlight the compounding impacts of flow variability and land use on suspended sediment.

GRAPHICAL ABSTRACT



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ABSTRACT

Knowledge gaps remain concerning fundamental suspended sediment physical processes/relationships, such as particle size class dynamics and hydroclimatic variability. Streamwater grab samples were collected four times per week (Oct. 2009–Feb. 2014) at nested-scale gauging sites ($n = 5$), representing contrasting dominant land use practices. Streamflow was monitored in situ. Grab samples were analyzed for total suspended sediment concentration and mean particle size using laser particle diffraction. Comparisons were performed of suspended sediment parameters corresponding to different streamflow classes (i.e. 20th, 40th, 60th, 80th, and 99th percentile flows). Average suspended sediment concentrations displayed a decreasing trend from the predominately agricultural headwaters to the urbanized mid-watershed, and a subsequent increase to the suburban lower watershed. Results indicated significant ($p < 0.05$) differences in concentrations corresponding to different flow classes, with concentrations at more urban sites displaying greater "sensitivity" to streamflow variability. Significant ($p < 0.05$) differences between concentrations at different sites were found, but concentrations became progressively more similar ($p > 0.05$) at higher flows. Mean particle size results displayed significant differences ($p < 0.05$) between flow classes at every site. Notably, results showed a decrease in particle size during progressively higher flows, despite expectations based on stream velocity/competence relationships. Significant ($p < 0.05$) spatial differences in particle size were found between sites, specifically for flows within the 20th and 40th percentile flow class. However, the spatial pattern was weakened at higher flows (60th, 80th, and 99th percentile flow classes) as sites displayed greater statistical similarity. Collectively, results highlight the compounding influences of streamflow variability and land use practices on suspended sediment regimes; and considering unexpected

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results regarding relationships between particle size and flow, emphasize the need for continued research concerning particle size dynamics.

1. Introduction

Suspended sediment is a natural constituent of aquatic ecosystems, serving fundamental roles in biogeochemical, geomorphological, and ecological processes (Wass and Leeks, 1999; Vercruysse et al., 2017). Consequently, alterations to sediment regimes can result in cascading effects on lotic system functioning. However, despite the implicit relevance of suspended sediment to aquatic ecosystem health and water quality, substantial knowledge gaps remain concerning suspended sediment particle size variation (Walling and Moorehead, 1987; Hubbart and Freeman, 2010; Hubbart and Gebo, 2010; Kellner et al., 2014). As noted by Frostick et al. (1983), Slattery and Burt (1997), and Thompson et al. (2016), there has been relatively little research concerning the particle size class characteristics of suspended sediment, despite the potential of such work to improve understanding of fluvial transport dynamics and sediment/chemical transport relationships (Walling et al., 2000). Much of the existing research on suspended sediment particle/grain size distribution has been performed in a laboratory setting, by physicists and mathematicians seeking to better understand the dynamics of fluid-particle relationships (e.g. Ghoshal and Debasish, 2014). According to Sadeghi and Singh (2017), regular *field* sampling of suspended sediment particle size can be costly, and thus investigations of the spatiotemporal variability of environmental particle size distributions remain rare in the literature. Furthermore, the majority of (the few) previous studies analyzed particle size characteristics via dispersion methods that destroy natural aggregates, in order to determine the ultimate particle size distribution (Slattery and Burt, 1997). Given evidence that a large portion of suspended sediment moving through a watershed is transported in aggregate form (Walling et al., 2000; Martilla and Kløve, 2015), it is important to consider the "effective" (i.e. undispersed) particle size distribution in order to fully understand the biogeochemical implications of suspended sediment, and by extension, pollutant transport processes and aquatic ecosystem condition (Slattery and Burt, 1997). It is therefore clear that investigations of suspended sediment particle size variation are needed to advance understanding of suspended sediment regimes and dynamics, improve pollutant transport prediction (Martilla and Kløve, 2015), and increase the efficacy of sediment control practices (Selbig and Fienen, 2012).

In a recently published study, Kellner and Hubbart (2017a) investigated suspended sediment characteristics of a mixed-land use watershed of the central U.S., utilizing total concentration (μL L^{-1}), and mean particle size (μm) and silt volume (μL L^{-1}) as general particle size parameters. They reported statistically significant ($p < 0.05$) differences between sub-watersheds for all parameters, attributing results to spatial patterns of land use and surficial geology in the study watershed. In addition, results indicated strong seasonality of particle size characteristics. In a follow-up study concerning suspended sediment particle size class distributions (PSD) specifically, Kellner and Hubbart (2018) showed significantly different ($p < 0.05$) suspended sediment PSDs at monitoring sites throughout the course of the study. For example, results indicated greater proportions of silt (2.43–57.29 μm) at a suburban site located in the lower watershed, relative to other sites. Likewise, results showed greater proportions of sand and aggregates (≥67.65 μm) at high density urban sites located in mid-watershed reaches, relative to other sites. PSD displayed consistent seasonality during the study, characterized by peaks in the proportion of sand (and aggregates) during the winter (i.e. 70–90%), and minimums during the summer (i.e. 12–38%); and peaks in the proportion of silt particles in the summer (i.e. 61–88%) and minimums in the winter (i.e. 10–23%). Likely explanations of results include seasonal streamflow differences. However, neither study addressed event-based dynamics of general suspended sediment parameters, instead utilizing a monotonic measure (i.e. Spearman's Correlation Test) to describe relationships between sediment parameters and hydroclimatic variability (e.g. streamflow). Thus, additional questions remain including a) what is the contribution of streamflow variability to previously observed spatiotemporal variability of suspended sediment parameters? And, b) are there spatial differences (e.g. sub-watershed scale) in flow-based suspended sediment dynamics? Thus, despite the progress of Kellner and Hubbart (2017a), Kellner and Hubbart (2018), and other previous studies, additional research is necessary to improve understanding of suspended sediment particle size dynamics, prioritization of mitigation resources, and efficacy of land and water resource management practices, and to advance understanding and modeling of sediment/contaminant transport processes.

Given meteorological events (e.g. precipitation, high streamflow) are the primary drivers of sediment transport from point and non-point sources (Novotny and Olem, 1994), a consideration of streamflow-based dynamics is fundamental to a comprehensive understanding of suspended sediment regime. However, traditional methods for event-based investigations typically comprise high-frequency (e.g. hourly) stream sampling during select events (i.e. opportunistic sampling). In light of previous results indicating strong seasonality of particle size characteristics and annual hydrologic variability (Kellner and Hubbart, 2017a; Kellner and Hubbart, 2018), attempting to capture the full-range of temporal variability of suspended sediment regimes via such an approach would likely be infeasible. Moreover, few studies have included "non-flood" periods in investigations of suspended sediment dynamics, despite the occurrence of contributing processes (e.g. sediment mobilization, supply, and deposition) throughout the water year (i.e. across the low to high flow spectrum) (Lefrançois et al., 2007). Ultimately, land and water resource managers need logistically feasible methods for quantifying event-based sediment dynamics.

Considering current knowledge gaps (e.g. mixed-land-use impacts on event-based particle size dynamics, and spatiotemporal variability of particle size dynamics), the primary objective of the study was to investigate suspended sediment dynamics in a contemporary mixed-land-use watershed using a methodology both scientifically rigorous (i.e. routine, long-term) and logistically feasible (e.g. daily time scale, sub-weekly sampling frequency). Sub-objectives included evaluating suspended sediment results relative to a) observed hydroclimatic data, and b) watershed land use patterns, in order to elucidate the influence of distinct natural and anthropogenic factors on suspended sediment regime.

2. Materials and methods

2.1. Study site description

This investigation took place in Hinkson Creek Watershed (HCW) located in central Missouri, USA (Table 1, Fig. 1). Land use in HCW is approximately 34% forest, 38% agriculture, and 25% urban (Hubbart et al., 2011), making it a regionally representative watershed for studying the effects of mixed-land-use types on water quality. Agricultural practices in the watershed include row cropping (e.g. corn and soybean production) and pasture (e.g. beef cattle) (Zeiger and Hubbart, 2016), while the majority of forested land is privately-owned and not intensively managed (i.e. no plantations or large-scale forest harvesting). In