Hinkson Creek Experimental Watershed, Missouri, USA: Findings, Information and the Future

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Abstract

Managers are often inadequately informed to make decisions for municipal watersheds, in which sources of impairment are shifting due to the combined influences of land use change, rapid ongoing human population growth, and changing environmental conditions. To progressively pursue best-managed, science-based futures, municipal watersheds can be studied using an experimental watershed approach. To demonstrate this approach in a contemporary watershed, a nested-scale experimental watershed study design was implemented in a representative, mixed-use watershed located in the Midwestern USA. Results to date show that urban/suburban development and agriculture are primary (often combined) drivers of alterations to watershed hydrology, streamflow regimes, transport of multiple water quality constituents, and stream physical habitat. However, several natural processes and watershed characteristics, such as surficial geology and stream system evolution, are likely compounding observed water quality impairment and aquatic habitat degradation. Given the varied and complicated set of factors contributing to issues in the study watershed, watershed restoration is likely subject to physical limitations and should be conceptualized in the context of achievable goals/objectives. Results demonstrate the capacity of the experimental watershed approach to objectively identify causal factors, target critical source areas, and provide the science-based information, and shared data, necessary to make effective, collaborative, and adaptive management decisions. Results further demonstrate the immense, globally transferable value of the experimental watershed approach to address municipal watershed management challenges.

1. Hinkson Creek Experimental Watershed

There is a great need for adaptive watershed management approaches, given rapid succession of intermingled impacts related to human population growth and landscape development in recent decades. Experimental watershed study designs have been shown to be effective approaches for quantitatively characterizing hydrologic and water quality perturbations at watershed and sub-watershed scales (Hewlett et al., 1969; Leopold, 1970; Likens et al. 1977; Bosch & Hewlett, 1982; Stednick, 1996; Brown et al., 2005; Hubbart et al., 2007; Hubbart et al. 2010; Zeiger et al., 2015; Nichols et al., 2016; Zeiger & Hubbart, 2016a; Tetzlaff et al., 2017). However, despite the potential for experimental watershed studies to yield valuable information for land and water resource managers (Kellner et al., 2018), the approach is rarely applied in contemporary, mixed-land-use watersheds.

To date, one of the few examples of a mixed-land-use experimental watershed study is that of Hinkson Creek Watershed (HCW), located within the Lower Missouri-Moreau River Basin (LMMRB) in central Missouri, USA (Figure 1) (Hubbart et al., 2010). The main channel, Hinkson Creek, is a 3rd order stream that flows through a basin of approximately 231 km^2 (Hubbart et al., 2010). Land use in the watershed is approximately 32% forest, 37% pasture or cropland, and 29% urban with progressive commercial expansion from the City of Columbia (population approximately 122,000) (Zeiger & Hubbart, 2018a) (Figure 2). In 1998, Hinkson Creek was one of the first water bodies in Missouri to be placed on the Clean Water Act (CWA) 303(d) list.

Figure 1.

Figure 2.

Hinkson Creek was 303(d)-listed due to many challenges, including (but not limited to), (1) larger and more frequent floods; (2) lower baseflows; (3) increased soil erosion in construction and development areas with subsequent transport of sediment to streams (i.e. altered suspended sediment regimes); (4) water contamination from urban stormwater flows; (5) degradation of aquatic habitat via the processes listed above; and (6) degradation of aquatic habitat due to physical alteration of stream channels and riparian corridors (Hubbart & Zell, 2013; Nichols et al., 2016; Kellner & Hubbart, 2018a,b; Zeiger & Hubbart, 2018a,b,c; Hubbart et al., 2019). In 2008, the watershed was instrumented with a nested-scale experimental watershed study design (Hubbart et al., 2010) to generate data to address the uncertainties of the 303(d) listing, advance a scientific basis for developing TMDL targets, investigate the problems suspected to have led to impairment, and to improve understanding of the impacts of contemporary land-use on hydrologic processes, water quality, and biological community status. Each nested monitoring site was equipped to monitor stream stage and a complete suite of climate variables. A United States Geological Survey gauging station in the watershed (USGS-06910230; Site #4, Figure 1) has collected stage data intermittently since 1966. Multiple water quality variables (e.g. suspended sediment, nitrogen, phosphorus, chloride, pH, etc.) were monitored at the nested sites shortly after implementation of the study. Publication of articles from the Hinkson Creek Experimental Watershed (HCEW) program began in 2010, currently totaling over 50 peer reviewed articles. Finally, in 2011, a Collaborative Adaptive Management (CAM) program was developed with federal, municipal, and local agencies and various stakeholder groups to provide direction and support for the 303(d)-delisting process (www.helpthehinkson.org) (Hubbart et al., 2018; Hubbart et al., 2019).

2. Synthesized Results from HCEW

Published analyses, to date, include work indicating significant changes in runoff volume and timing have occurred in the watershed, largely due to urbanization (Wei et al., 2018). However, streamflow observations also showed annual streamflow metrics (i.e. peak flow, baseflow) had not significantly increased or decreased in Hinkson Creek from 1967 to 2010 (Hubbart & Zell, 2013), thereby highlighting the impact of early 20th century land use changes (e.g. forest clearing). Event-based (30-minute interval) rainfall-streamflow response relationships were characterized by increased explained-variance at urban sites relative to rural sites (Zeiger & Hubbart, 2018a; Zeiger & Hubbart, 2018b). A positive relationship between developed land uses (i.e. urban and suburban) and volumetric streamflow was consistently observed through various analyses (Zeiger & Hubbart, 2017; Kellner & Hubbart, 2017a,b; Kellner & Hubbart 2018a; Wei et al., 2018; Kellner & Hubbart, 2019a,b), emphasizing developed land use impacts on streamflow characteristics, and thus sediment transport (Zeiger & Hubbart, 2016a,b; Kellner & Hubbart, 2017a,c; Zeiger & Hubbart, 2017; Kellner & Hubbart 2018a; Kellner & Hubbart, 2019a). Of particular interest, research discovered a disproportionately high contribution of fine-grained sediment from the City of Columbia to Hinkson Creek (Kellner 2013; Kellner & Hubbart 2014; Freeman 2011; Hubbart & Freeman, 2010). Moreover, a doubling of streamflow more than doubled (i.e. a non-linear relationship) fine-grained suspended sediment concentration in Hinkson Creek (Hubbart & Gebo, 2010; Hubbart et al. 2013). Stream bank erosion was shown to contribute approximately 67% of channel suspended sediment (Huang, 2012), and Kellner and Hubbart (2019b) showed that channel widening and incision in Hinkson Creek were spatially correlated to developed land uses, and associated streamflow characteristics.

Alterations to multiple nutrient constituent regimes, driven by land use practices, were observed (Zeiger & Hubbart, 2016b, 2017). Total inorganic nitrogen and nitrate concentrations were relatively higher in the agricultural headwaters. Total ammonia yields greater than 1.25 kg ha^{-1} yr^{-1} and total phosphorus yields exceeding 2.0 kg ha^{-1} yr^{-1} in Hinkson Creek were shown to be high for the Mississippi River Basin (Zeiger & Hubbart, 2016b). Elevated nutrient levels attributed to wastewater and lawn fertilizer applications were also observed in the lower urbanized reaches, where total phosphorous concentrations exceeded 1.13 mg L^{-1} (Zeiger & Hubbart, 2016b, c). Urban land uses correlated with adverse physicochemical characteristics in Hinkson Creek, including toxic chloride concentrations (Hubbart et al., 2018), dissolved oxygen saturations both above and below established water quality standards, and increased pH and total dissolved solids (Kellner & Hubbart, 2017c). Chloride in Hinkson Creek was shown to reach seasonally mediated acute (860 mg L^{-1}) and chronic (230 mg L^{-1}) concentrations, attributed to local road salting practices, with concentrations persisting in floodplain shallow groundwater year-round (Hubbart et al., 2018), and was found to be correlated with observed differences in macroinvertebrate community metrics (Nichols, 2012; Nichols et al., 2016).

Stream water temperature regimes were shown to be significantly altered in Hinkson Creek (Zeiger, 2014; Zeiger et al., 2015; Zeiger & Hubbart, 2015), with daily maximum stream temperature exceeding a threshold of potential mortality for warm-water biota (i.e. 35.0 °C). Similarly, studies identified an urban micro-climate gradient and an urban heat island (UHI) effect in the city of Columbia and showed that strategically located urban forest patches can be used to optimize carbon storage and cycling (Hubbart et al., 2014).

Floodplain research indicated that bottomland hardwood forest soils in HCW store larger amounts of carbon than non-woody floodplain sites in the urban environment (Beaven, 2015; Spiegel, 2015). Studies further showed that floodplain forests reduce subsurface shallow groundwater temperature fluctuations (Kellner & Hubbart, 2015a), can accept and process significantly ($p < 0.05$, ˜120 mm yr^{-1}) more water to subsurface storage than agricultural or grassland areas (Zell et al. 2015), significantly increase soil infiltration rates and soil volumetric water content holding capacity (Hubbart et al. 2011), increase consumptive water use by vegetation (Hubbart, 2011), and improve freshwater routing, water quality, aquatic ecosystem conservation, and flood mitigation in mixed-land-use watersheds (Brown, 2014; Kellner, 2015; Kellner & Hubbart, 2015b; Kellner et al. 2015). A recent physical habitat assessment (PHA) in Hinkson Creek showed that agricultural and urban land use impacts (Hooper, 2015; Zeiger & Hubbart, 2019) have impacted macroinvertebrate assemblages (Nichols, 2012; Nichols et al., 2016), and have increased the spatial frequency of fine-grained streambed sediments and substrate embeddedness in urbanized stream reaches (Hubbart & Freeman, 2010; Hubbart & Gebo, 2010; Hubbart et al. 2013).

Several modeling studies benefitted from the high spatiotemporal-resolution data collection in the HCEW program. For example, modeling with the Soil Water Assessment Tool (SWAT) was shown to produce satisfactory estimates of streamflow that improved with various modes of calibration (Scollan, 2011; Zeiger & Hubbart, 2016c). The SWAT model was also used to successfully simulate daily stream temperature in Hinkson Creek (Zeiger & Hubbart, 2015). Results substantiate the usefulness and reliability of the model, verifying that (when properly calibrated) SWAT can generate critical municipal watershed information, including forecasts of hydrologic responses to urban growth and climate change (Sunde et al. 2016, 2017, 2018). Sunde et al. (2016, 2017, and 2018) simulated potential hydrologic consequences of increased impervious surfaces and climate change by integrating the Imperviousness Change Analysis Tool (I-CAT) (Sunde et al. 2014) and results from the Coupled Model Intercomparison Project – Phase 5 (CMIP5) multimodel ensemble as model forcings in SWAT. The SWAT model was also used to simulate pre-settlement hydrologic conditions in terms of (1) daily streamflow metrics (Zeiger & Hubbart, 2018b), and (2) pollutant loading (Zeiger & Hubbart, 2018c) in HCW. Results suggested restoration of historic (i.e. pre-settlement) streamflow regimes may not be feasible targets in HCW and similar watersheds. Furthermore, Kellner & Hubbart, (2017d, 2018a) showed that historical land-use (coal mining), surficial geology, and natural landscape processes (e.g. stream system evolution) comprise cumulative, yet unconsidered legacy effects that contribute systemically to observed hydrologic changes. Considering these findings, results of the HCEW program suggest possible physical limitations to restoration efforts and support the reconceptualization of delisting/restoration in terms of achievable, realistic goals.

3. A Growing Data Repository

Core datasets of the HCW include long-term hydro-climatological data for five gauged sub-watersheds and corresponding nutrient, suspended sediment, and physicochemical data, with measurements starting in 1966 at the United States Geological Survey gauging station (USGS-06910230). Timeseries from the five sub-watersheds include (but not limited to) daily time series of air temperature, precipitation, streamflow, and stream water temperature, and weekly timeseries of pH, dissolved oxygen saturation, and concentrations of nitrogen (i.e. total nitrogen, nitrate, and ammonia), total phosphorus, total dissolved solids, and chloride. USGS site (site #4, Figure 1) data are publicly available at the following web address: https://waterdata.usgs.gov/nwis/uv?site_no=06910230. Data are also publicly available at Help the Hinkson (http://www.helpthehinkson.org/), and Boone County Stormwater Management (https://www.showmeboone.com/stormwater/education/watershed-info.asp).

Additional developing databases are available via the recently established West Virginia University Research Repository, Institute of Water Security and Science (https://researchrepository.wvu.edu/iwss-datasets/), and through the ResearchGate profile of the Principle Investigator (Dr. Jason Hubbart): https://www.researchgate.net/profile/Jason_Hubbart2/publications

4. Conclusions and Future Directions

Results from work to date affirm the experimental watershed study approach for contemporary mixed-use (municipal) watersheds. Salient takeaways from the HCEW program include, (1) the identification of land use practices (e.g. agriculture, urban/suburban development) as primary drivers of water quality and aquatic habitat degradation in mixed-use watersheds; (2) the emphasis on land-use-altered streamflow regimes as a fundamental mechanism contributing to channel erosion, aquatic habitat disruption, and the transport of several constituents of concern (e.g. suspended sediment, excess nutrients); (3) the importance of riparian forest (re)establishment as an effective management strategy to mitigate adverse physical and ecological impacts from anthropogenic activities and climate variability; and (4) the suggestion of physical limitations to restoration, given the varied and complicated set of factors contributing to impairment.

Despite the many achievements to date, abundant avenues remain for future work in HCW. Additional analyses should endeavor to build upon existing works and provide mechanistic explanations for past descriptions. For example, stable isotope and sediment fingerprinting techniques could be used to conclusively identify the source of observed water quality impairment. Future work should also include ongoing monitoring to verify the effectiveness of urban and agricultural best management practices (BMPs) in HCW. Such information could boost stakeholder confidence in BMPs included in soil and water conservation cost-share programs. In addition, modeling studies incorporating proposed land management strategies could be conducted to help verify whether those approaches would be efficacious for advancing management goals within the HCW.

Work to date has demonstrated that the nested-scale experimental watershed study in HCW has served as a scalable, globally transferrable model for studying natural and anthropogenic influences on water quantity, water quality, and stream physical habitat in contemporary mixed-use watersheds.

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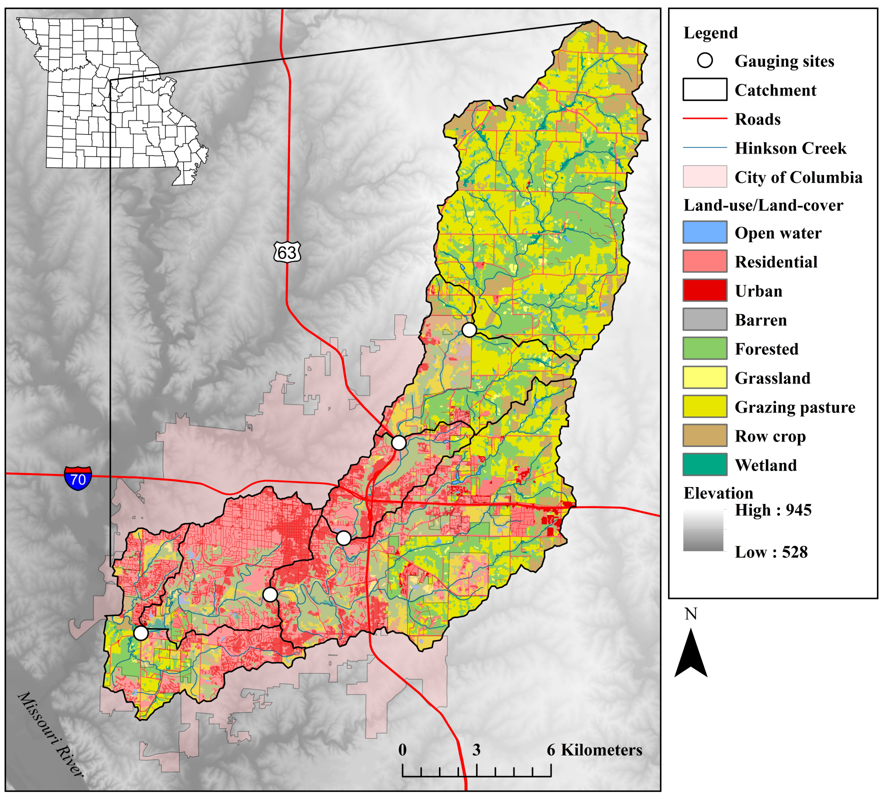
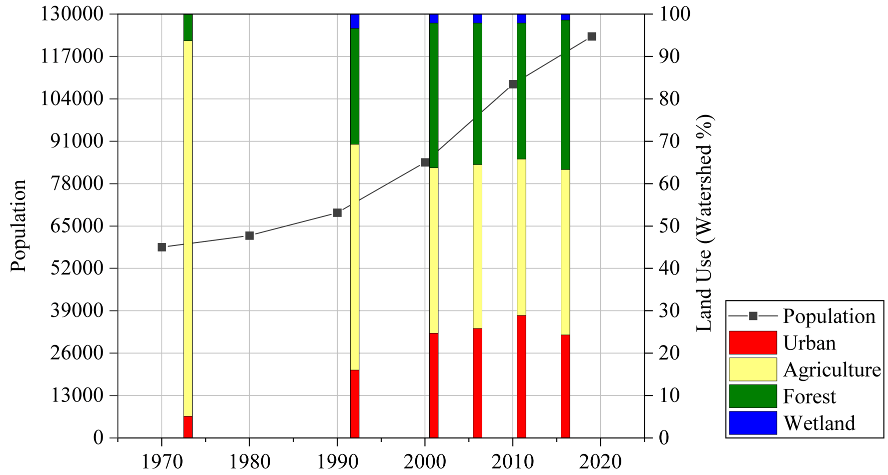
6. Figure Headings

Figure 1. Locations of five gauge sites (where #4 includes the USGS gauging station) and corresponding drainage area to each gauge (bold line) in the Hinkson Creek Watershed (HCW), in Central Missouri, USA. A model urban nested-scale experimental watershed study.

Figure 2. Timeline of population in Columbia, MO, and land use percentage in Hinkson Creek Watershed (1973-2016). Population data were sourced from US Census Bureau. Land use data were sourced from US Geological Survey Land Cover Trends Dataset (Soulard et al., 2014), and National Land Cover Database (Yang et al., 2018).

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Land Use (Watershed %)
1970
1980
1990
2000
2010
2020
Population
Urban
Agriculture
Forest
Wetland