

HINKSON CREEK WATERSHED

**Publications and Theses from the Interdisciplinary
Hydrology Laboratory (IHL)**

2010 – 2015

IHL Director:

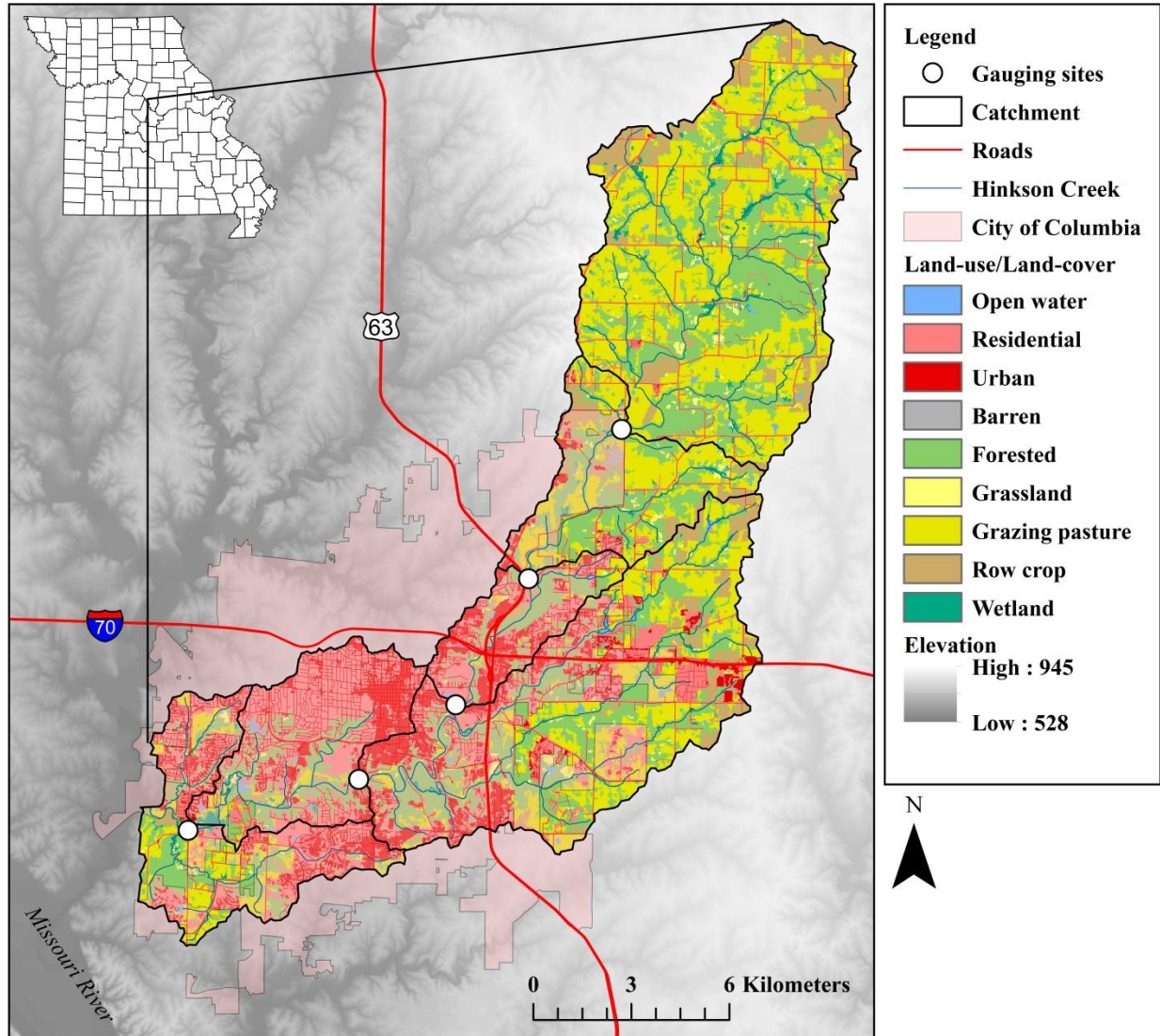
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Nested-scale experimental watershed study design including five gauging sites located in Hinkson Creek Watershed, Missouri, USA (Figure by Sean Zeiger).

INTRODUCTION

The Hinkson Creek Experimental Watershed (HCEW) study was initiated in 2008, anticipating that the science-based information generated will reduce error in water quality and delisting decision-making processes, while simultaneously improving stakeholder acceptance of those decisions in the Hinkson Creek Watershed (HCW). The project was developed by Dr. Jason Hubbart, at the time a new assistant professor of hydrology and water quality at the University of Missouri, who had been trained in experimental watershed studies in the Pacific Northwest, USA. Articles from the HCEW program were being published as early as 2010. To date there have been 17 publications in peer reviewed journals and 11 graduate student theses and dissertations. The primary sources of financial support for the project include the Environmental Protection Agency, the Missouri Department of Natural Resources, the Missouri Department of Conservation, the University of Missouri, Boone County Public Works, and the City of Columbia. Collaborators have included (but not been limited to) the United States Geological Survey, the Missouri Department of Transportation, and City of Columbia Parks and Recreation.

The Hinkson Creek Experimental Watershed now serves as a model experimental watershed program for mixed-land-use watersheds nationally. A unique characteristic of the program that speaks to its success is the Collaborative Adaptive Management (CAM) program, in place for the past few years in Hinkson Creek Watershed. CAM uses a science-based approach, information from the experimental watershed study, and results from other studies in the watershed to improve water quality and land-use best practices. The information that follows provides a very brief synthesis (followed by citations and abstracts) of the 28 publications, dissertations and theses produced to date by the Interdisciplinary Hydrology Laboratory (<http://www.forh2o.net/>), directed by Dr. Jason Hubbart.

SYNTHESIS OF RESULTS TO 2015

Studies show that prior to 2010 annual streamflow metrics (i.e. peak flow, baseflow) had not significantly increased or decreased in Hinkson Creek during the period of analysis (1967 to 2010). However, there was evidence that significant changes were imminent, and recent work (in preparation) indicates that significant changes in runoff volume and timing in the watershed (largely due to urbanization) have occurred in the past 5 years. A recent physical habitat assessment also shows that Hinkson Creek is altered by agricultural and urban land uses. Additionally, land use practices have altered macroinvertebrate assemblages in Hinkson Creek. Macroinvertebrates are key species indicating general aquatic ecosystem status. Recent work has also shown that urbanization (Columbia) has resulted in significantly altered stream water temperature regimes. Stream temperature increases in Hinkson Creek with both downstream distance *and* urban land use. Modeling with the Soil Water Assessment Tool (SWAT) was shown to produce satisfactory estimates of stream temperature at a daily time step in Hinkson Creek. The model has also been shown to accurately simulate Hinkson Creek flow during successive wet years. Total ammonia and total phosphorus levels in Hinkson Creek are high for the region. Chloride (paper in preparation) in Hinkson Creek reaches seasonally-mediated acute (860 mg/L) and chronic (230 mg/L) concentrations with lower concentrations persisting in streambed and banks year-round.

Suspended sediment levels in Hinkson Creek may be high for the region, and there is a disproportionately high contribution of fine sediment from the City of Columbia relative to Hinkson Creek. While the variability of spatiotemporal distributions of suspended sediment particle densities (e.g. organic material, etc.) in Hinkson Creek can confound loading estimations, work has shown conclusively that average suspended sediment particle size decreases in Hinkson Creek as cumulative urban land use increases in Hinkson Creek Watershed. For example, a doubling of streamflow more than doubles (i.e. a non-linear relationship) fine suspended sediment concentrations in Hinkson Creek. A study in 2011 showed that stream bank (Hinkson bottoms) erosion contributed approximately 67% of channel suspended sediment loading over the 2011 water year, illustrating the potential contribution of in-stream vs. terrestrial suspended sediment in the watershed.

Recent floodplain work indicates that bottomland hardwood forest soils in Hinkson Creek Watershed store larger amounts of carbon compared to non-woody floodplain sites (important for water quality and carbon sequestration and climate change offsets) in the urban environment. Studies have also shown that floodplain forests reduce subsurface shallow groundwater temperature fluctuations, can accept and thus process significantly (CI=0.05, ~120 mm/yr) more water to storage than Ag or grassland, significantly increase soil infiltration and soil volumetric water content holding capacity, increase consumptive use by vegetation, and improve fresh water routing, water quality, aquatic ecosystem conservation, and flood mitigation in mixed-land-use watersheds. Results repeatedly and conclusively support the reestablishment of floodplain forests where practicable for the conservation of both groundwater and surface water quality.

Finally, current research shows that there is an urban micro-climate gradient and an urban heat island (UHI) effect in the city of Columbia, and that urban land use management can be used to optimize carbon storage and cycling through strategically located urban forest patches.

PUBLICATIONS

1. Zeiger, S., and J.A. Hubbart. 2015. Quantifying Suspended Sediment Flux in a Mixed-Land-Use Urbanizing Watershed using a Nested-Scale Study Design. *Science of the Total Environment*. DOI: 10.1016/j.scitotenv.2015.10.096

In a nutshell: Suspended sediment levels in Hinkson Creek may be high for the region.

Brief abstract: Water samples were analyzed for suspended sediment (SS) using a nested-scale experimental watershed study design ($n = 836$ samples \times 5 gauging sites). Median SS concentrations decreased by 60% from the agricultural headwaters to the rural/urban interface, and increased by 98% as urban land use increased. Multiple linear regression analysis results showed significant relationships between SS, annual total precipitation (positive correlate), forested land use (negative correlate), agricultural land use (negative correlate), and urban land use (negative correlate). Estimated annual SS yields ranged from 16.1 to 313.0 t km⁻² year⁻¹, mainly due to differences in annual total precipitation. Overall, sediment yields were 54%, 80%, and 87% greater than sediment yields from the Ohio River, the Upper Mississippi River, and the Missouri River basins, respectively. The relatively high sediment yields may be attributable to high runoff rates from claypan soils in the headwaters, agricultural land use, impervious surfaces (urbanization), increased runoff volume and velocity and subsequent channel incision and bank erosion, and legacy effects of previous practices.

2. Kellner, E., and J.A. Hubbart. 2015. A Comparison of the Spatial Distribution of Vadose Zone Water in Forested and Agricultural Floodplains a Century after Harvest. *Science of the Total Environment*. DOI: 10.1016/j.scitotenv.2015.10.080

In a nutshell: Floodplain forest soils more effectively process water relative to grassland/agricultural systems.

Brief abstract: Automated, continuously logging capacitance–frequency probes were installed in a grid-like formation ($n = 6$) and at depths of 15, 30, 50, 75, and 100 cm within a historic agricultural field (Ag) and a remnant bottomland hardwood forest (BHF) to improve quantitative understanding of the long-term impact of historic forest removal on floodplain vadose zone water regime in the Hinkson Creek Watershed, Missouri, USA. Data were logged at thirty minute intervals for the duration of the 2011, 2012, and 2013 water years. Results showed volumetric water content (VWC) to be significantly different between sites ($p < 0.01$) during the study, with site averages of 33.1 and 32.8% at the Ag and BHF sites, respectively. Higher hydraulic conductivity of the more heterogeneous BHF subsurface likely results in a wetting of the deeper profile (75 cm) during climatically wet periods, and thus a more effective processing of hydrologic inputs. Collective results highlight the greater extent to which forest vegetation impacts subsurface hydrology, relative to grassland/agricultural systems, and point to the value of reestablishing floodplain forests for fresh water routing, water quality, and flood mitigation in mixed-land-use watersheds.

3. Zeiger, S., and J.A. Hubbart. 2015. Nested-Scale Nutrient Yields from a Mixed-Land-Use Urbanizing Watershed. *Hydrological Processes*. DOI: 10.1002/hyp.10716

In a nutshell: Total ammonia and total phosphorus levels in Hinkson Creek are high for the region.

Brief abstract: Water samples ($n = 858$ sample days per site, $n = 5$) were collected and analyzed for total inorganic nitrogen (TIN-N), nitrite ($\text{NO}_2\text{-N}$), nitrate ($\text{NO}_3\text{-N}$), ammonia ($\text{NH}_3\text{-N}$), and total phosphorus (TP-P) from 2010–2013 in Hinkson Creek, Missouri, USA. Mean nutrient concentrations were highest where agricultural land use comprised 58% of the drainage area ($\text{NH}_3 = 0.111$ mg/L; $\text{NO}_2 = 0.045$ mg/L; $\text{NO}_3 = 0.684$ mg/L; $\text{TIN} = 0.840$ mg/L; $\text{TP} = 0.127$ mg/L). Mean annual $\text{NH}_3\text{-N}$, $\text{NO}_2\text{-N}$, $\text{NO}_3\text{-N}$, TIN-N , and TP-P yields were 0.742, 0.400, 4.24, 5.38, and 0.979 $\text{kg ha}^{-1} \text{yr}^{-1}$, respectively, near the watershed outlet. Nutrient yields were dependent on annual precipitation of the preceding year (R^2 values from 0.87 to 0.91) thus enforcing the great complexity of variable mixed-land-use mediated source-sink nutrient yield relationships. Overall, $\text{NO}_3\text{-N}$ export ($4.24 \text{ kg ha}^{-1} \text{yr}^{-1}$) observed near the watershed outlet (site #5) was relatively low compared to other watersheds in the Midwest, but $\text{NH}_3\text{-N}$ yields ($0.742 \text{ kg ha}^{-1} \text{yr}^{-1}$) and TP-P yields ($0.979 \text{ kg ha}^{-1} \text{yr}^{-1}$) were high for the region. High levels of $\text{NH}_3\text{-N}$ observed in HCW were likely attributed to a combination of crop N fertilizer and livestock in the agricultural areas, and wastewater and lawn N fertilizers in urban areas.

4. Zeiger, S., and J.A. Hubbart. 2015. Quantifying urban stormwater temperature surges: A central US watershed study. *Hydrology*. 2(4): 193-209; DOI: 10.3390/hydrology2040193

In a nutshell: Urbanization (Columbia) has significantly altered stream water temperatures.

Brief abstract: Daily maximum stream water temperature (T_w) exceeded 35.0 °C (threshold for potential mortality of warm-water biota) at an urban monitoring site for a total of five days during the study period (2011–2013). Sudden increases of more than 1.0 °C within a 15 min time interval of T_w following summer thunderstorms were significantly correlated ($\text{CI} = 95\%$; $p < 0.01$) to cumulative percent urban land use ($r^2 = 0.98$; $n = 29$). Differences in mean T_w between monitoring sites were significantly correlated ($\text{CI} = 95\%$; $p = 0.02$) to urban land use practices, stream distance and increasing discharge. The effects of the 2012 Midwest USA drought and land use on T_w were also observed with maximum T_w 4.0 °C higher at an urban monitoring site relative to a rural site for 10.5 h. The current work provides quantitative evidence of acute increases in T_w related to urban land use.

5. Kellner, E., and J.A. Hubbart. 2015. Agricultural and Forested Land Use Impacts on Floodplain Shallow Groundwater Temperature Regime. *Hydrological Processes*. DOI: 10.1002/hyp.10645

In a nutshell: Floodplain forests reduce subsurface shallow groundwater temperature fluctuations.

Brief abstract: A floodplain study was implemented to improve understanding of rural land use impacts on shallow groundwater (SGW) temperature at a historic agricultural field (Ag) and bottomland hardwood forest (BHF) in Hinkson Creek watershed, Missouri, USA. Each site had an 80×80 m grid of nine piezometers equipped with pressure transducers to monitor SGW temperature and level at 30 min intervals during the 2011, 2012, 2013, and 2014 water years. Temperature range at the Ag site was 72% greater than at the BHF site. Results indicate a greater responsiveness to seasonal climate fluctuations in Ag site SGW temperature related to absence of forest canopy. Results suggest that contrasting rates of plant water use, groundwater recharge, and subsurface hydraulic conductivity are likely mechanistic causes for the observed SGW temperature differences. Results

also highlight the long-term impact of forest removal on subsurface hydrology and groundwater temperature regime.

6. Zeiger, S., J.A. Hubbart, S.H. Anderson, and Michael L. Stambaugh. 2015. Quantifying and modeling urban stream temperature: A central US watershed study. *Hydrological Processes*. DOI: 10.1002/hyp.10617

In a nutshell: Modeling with SWAT can produce satisfactory estimates of stream temperature at a daily time step in Hinkson Creek.

Brief abstract: A nested-scale experimental watershed study design was used to test stream temperature (Tw) model predictions in Hinkson Creek Watershed, located in the central USA. The linear regression Tw model used in the Soil and Water Assessment Tool (SWAT), a non-linear regression Tw model, and a process-based Tw model that accounts for watershed hydrology were evaluated. The non-linear regression Tw model tested at a daily time step performed significantly ($p < 0.01$) better than the linear Tw model currently used in SWAT. Both regression Tw models overestimated Tw in lower temperature ranges ($Tw < 10.0\text{ }^{\circ}\text{C}$) with percent bias (PBIAS) values ranging from -28.2% (non-linear Tw model) to -66.1% (linear regression Tw model) and underestimated Tw in the higher temperature range ($Tw > 25.0\text{ }^{\circ}\text{C}$) by 3.2% , and 7.2% , respectively. Conversely, the process-based Tw model closely estimated Tw in lower temperature ranges (PBIAS = 4.5%) and only slightly underestimated Tw in the higher temperature range (PBIAS = 1.7%). Findings illustrate the benefit of integrating process-based Tw models with hydrologic models to improve model transferability and Tw predictive confidence in urban mixed-land use watersheds.

7. Zell, C., E. Kellner, and J.A. Hubbart. 2015. Land Use Impacts on Subsurface Floodplain Storage Capacity: A Midwest Case Study of Agricultural and Remnant Hardwood Forest Land Use Types. *Environmental Earth Sciences*. DOI: 10.1007/s12665-015-4700-4

In a nutshell: Floodplain forests can accept significantly ($\sim 120\text{ mm/yr}$) more water to storage than Ag or grassland.

Brief abstract: A floodplain study was implemented to better understand land use effects on floodplain storage capacity at a heavily instrumented historic agricultural field (Ag) and a remnant bottomland hardwood forest (BHF) located in Hinkson Creek Watershed, Missouri, USA. The groundwater flow model MODFLOW was used to simulate hydrology for the study. The model performed similarly well for both sites and is considered robust given optimization constraints, as supported by model fit for head (BHF: Root Mean Square Error or RMSE = 0.40 m ; and Ag: RMSE = 0.31 m), volumetric water content (VWC) (BHF: RMSE = 2.5% ; and Ag: RMSE = 2.3%), and evapotranspiration (ET) (BHF: RMSE = 0.74 mm ; and Ag: RMSE = 0.84 mm). Model predictions for the full vertical profile at the BHF site (median = 520 mm) indicated 28% more vadose zone storage than the Ag site (median = 409 mm) on a median percent difference basis. On a cumulative basis, the BHF site accepted 117 mm (75%) more water into storage than the Ag site. Results highlight several important differences in hydrology between the two land use types and support the reestablishment of riparian forests in floodplains of the Midwest as a strategy to address increasing flood concerns.

8. Kellner, E., J.A. Hubbart, A. Ikem. 2015. A Comparison of Forest and Agricultural Shallow Groundwater Chemical Status a Century after Land Use Change. *Science of the Total Environment*. 529:82-90. DOI: 10.1016/j.scitotenv.2015.05.052.

In a nutshell: Findings support the use of floodplain forests for the conservation of both groundwater and surface water resource quality.

Brief abstract: Piezometer grids were installed in a remnant bottomland hardwood forest (BHF) and a historic agricultural field (Ag) to compare groundwater chemical composition (49 physiochemical metrics) between sites with contrasting land use histories from June 2011 to June 2013 located in Hinkson Creek watershed, Missouri, USA. Compared to the Ag site, BHF groundwater was characterized by significantly ($p < 0.05$) lower pH, higher electrical conductivity, and higher concentrations of total dissolved solids and inorganic carbon. BHF groundwater contained significantly ($p < 0.05$) higher concentrations of all nitrogen species except nitrate, which was higher in Ag groundwater. BHF groundwater contained significantly ($p < 0.05$) higher concentrations of nutrients such as sulfur, potassium, magnesium, calcium, and sodium, relative to the Ag site. Ag groundwater was characterized by significantly ($p < 0.05$) higher concentrations of trace elements such as arsenic, cadmium, cobalt, copper, molybdenum, nickel, and titanium. Comparison of shallow groundwater chemical composition with that of nearby receiving water suggests that subsurface concentration patterns are the result of contrasting site hydrology and vegetation. This study is among the first to comprehensively characterize and compare shallow groundwater chemical composition at sites with contrasting land use histories, and findings support the use of floodplain forests for the conservation of both groundwater and surface water resource quality.

9. Hubbart, J.A., E. Kellner, L. Hooper, A.R. Lupo, P.S. Market, P.E. Guinan, K. Stephan, N.I. Fox and B.M. Svoma. 2014. Localized Climate and Surface Energy Flux Alterations across an Urban Gradient in the Central U.S. *Energies*, 7: 1770-1791.

In a nutshell: There is an urban micro-climate gradient and an Urban Heat Island effect in the city of Columbia.

Brief abstract: Long-term urban and rural climate data spanning January 1995 through October 2013 were analyzed to investigate the Urban Heat Island (UHI) effect in a representative mid-sized city of the central US, located in Hinkson Creek Watershed. Long-term analyses (1995–2013) indicate significant differences ($p < 0.001$) between average air temperature (13.47 and 12.89 °C, at the urban and rural site, respectively), relative humidity (69.11% and 72.51%, urban and rural, respectively), and average wind speed (2.05 and 3.15 m/s urban and rural, respectively). Significant differences ($p < 0.001$) between urban monitoring sites indicate an urban microclimate gradient for all climate variables except precipitation. Results of analysis of net radiation and soil heat flux data suggest distinct localized alterations in urban energy budgets due to land use intensity. Results also reinforce the need for distributed urban energy balance investigations.

10. Kellner, E., and J.A. Hubbart. 2014. Quantifying Urban Land-Use Impacts on Suspended Sediment Particle Size Class Distribution: A Method and Case Study. *Stormwater Journal*, 15(2):40-50.

In a nutshell: There is a disproportionately high contribution of fine sediment from the City of Columbia relative to Hinkson Creek.

Brief abstract: Stormwater samples were analyzed from 17 urban monitoring sites ($n = 272$) during spring 2011 to better understand urban land use suspended sediment contributions to receiving waters in Hinkson Creek watershed, central Missouri, USA. Samples from receiving water bodies (i.e. Hinkson and Flat Branch creeks) had higher total concentrations of suspended sediment (323 $\mu\text{L/L}$ and 319 $\mu\text{L/L}$, respectively) relative to urban sites (205 $\mu\text{L/L}$), which contained approximately 35% less total sediment. However, mean particle size was significantly lower ($p < 0.001$) from urban sites (59 μm) relative to receiving waters (167 μm and 131 μm , respectively). Receiving waters had higher silt volumes (173 $\mu\text{L/L}$ and 148 $\mu\text{L/L}$, respectively) relative to urban sites (124 $\mu\text{L/L}$). Collectively, results indicate a disproportionate contribution of fine sediment from the urban environment. Receiving waters' particle size class dynamics suggest the presence of a climate-driven punctuated equilibrium of sediment transport, which was not apparent in urban areas.

11. Hubbart, J.A., and C. Zell. 2013. Considering Streamflow Trend Analyses Uncertainty in Urbanizing Watersheds: A Case Study in the Central U.S. *Earth Interactions*, [17\(5\):1-28](#).

In a nutshell: Prior to 2010, annual streamflow metrics had not significantly increased or decreased in Hinkson Creek (period of analysis, 1967 to 2010).

Brief abstract: The authors used two dissimilar automated baseflow separation algorithms and Monte Carlo techniques to evaluate urban baseflow and estimation uncertainty using data from Hinkson Creek Watershed in the central United States. Three uncertainties affecting trend determinations were assessed, including algorithm structure, precipitation–runoff relationships, and baseflow algorithm parameterization. Results indicate that, despite ongoing population growth and development, annual streamflow metrics in the authors' representative watershed have not significantly increased or decreased ($p > 0.05$) from 1967 to 2010. However, several streamflow metrics featured shallow insignificant ($p > 0.05$) slopes in the direction hypothesized for an urbanizing (less pervious) watershed, including a downward slope for baseflow index (BFI) and increases in runoff volume coefficient. Median annual baseflow estimations differed by 29% between techniques (85.3 versus 118.9 mm yr^{-1}). In the absence of direct tracer measurements, uncertainties associated with precipitation–runoff relationships, algorithm structure, and parameterization should be included in analyses evaluating alterations from baseline hydrologic conditions in urban watersheds.

12. Hubbart, J.A., Kellner, E., and G. Freeman. 2013. A Case Study Considering the Comparability of Mass and Volumetric Suspended Sediment Data. *Environmental Earth Sciences*. [10.1007/s12665-013-2788-y](#)

In a nutshell: The variability of spatiotemporal distributions of suspended sediment particle densities (e.g. organic material, etc.) in Hinkson Creek can confound loading estimations.

Brief abstract: Water samples from rural, suburban, and urban stream reaches located in Hinkson Creek Watershed were analyzed for suspended sediment concentration using laser diffraction and wet sieving methods to assess the accuracy of three methods commonly used to convert volumetric data to mass. Average observed mass (mg/L) and volumetric ($\mu\text{l/L}$) suspended sediment concentration for the rural, suburban, and urban gauging sites were 68 mg/L and 57.3 $\mu\text{l/L}$; 82.5 mg/L and 65.7 $\mu\text{l/L}$; and 104.8 mg/L and 97.9 $\mu\text{l/L}$, respectively. Using the assumed particle density (Pd) of 2.65 g/cm^3 , estimated mass data differed from observed mass data by as much as 60%. Using a calculated Pd of 2.17, 1.99, 1.76 g/cm^3 , estimated mass data differed from observed mass data by as much as 45%. Paired sample t tests showed observed and estimated mass values to be significantly different ($p < 0.01$), showing the imprecision of conversion methods and highlighting possible estimation errors assuming idealized conditions. Conversion difficulties likely result from temporal and spatial variations of Pd.

13. Hubbart, J.A., R-M. Muzika, D. Huang, and A. Robinson. 2011. Improving Quantitative Understanding of Bottomland Hardwood Forest Influence on Soil Water Consumption in an Urban Floodplain. *The Watershed Science Bulletin*, 3:34-43.

In a nutshell: Floodplain forest significantly increases soil infiltration and soil volumetric water content holding capacity.

Brief abstract: Baseline data are presented describing floodplain vegetation and soil characteristics relationships in lower Hinkson Creek, a Clean Water Act Section 303(d)-listed impaired stream located in Columbia, Missouri. Infiltration rates varied but were significantly greater in the BHF site with a 61% difference in mean infiltration between the two sites. Locations of high maximum infiltration rates were associated with locations of large trees (namely, eastern cottonwood). Vegetative influence on soil characteristics is apparent, particularly soil VWC above a soil depth of 50 cm. Results demonstrate the potential benefit of sustaining or reestablishing floodplain forests to enhance storage capacity, attenuation, and consumptive water use, thus reducing flooding and mitigating stormwater runoff problems in rapidly developing urban environments.

14. Hubbart, J.A. 2011. Urban Floodplain Management: Understanding Consumptive Water-Use Potential in Urban Forested Floodplains. *Stormwater Journal*, 12(6):56-63.

In a nutshell: More than a 10% improved floodplain attenuation capacity is possible in a bottomland hardwood forest floodplain relative to agriculture or grassland sites.

Brief abstract: Results indicate that with a single two-month snapshot, more than a 10% improved floodplain attenuation capacity is possible in a bottomland hardwood forest (BHF) floodplain. Continued work will seek to quantify annual BHF transpiration and interception rates and to establish multiannual vadose and saturated zone water flux data to show quantifiably the benefits of reestablishing bottomland hardwood forests in the floodplains of the American Midwest.

15. Hubbart, J.A., and N.A. Gebo. 2010. Quantifying the Effects of Land-Use and Erosion by Particle Size Class Analysis in the Central U.S. *Erosion Control Journal*, 17(7):24-36.

In a nutshell: Average suspended sediment particle size decreases in Hinkson Creek as cumulative urban land use increases in Hinkson Creek Watershed.

Brief abstract: This case study was among the first quantification of sediment transport by particle size class from a dynamic urbanizing watershed located in the central US. This study demonstrated that during typical March rainfall in central Missouri, total suspended sediment nearly doubled from the headwaters to a point approximately 40 kilometers downstream. On average, particle classes transported were almost twice as large (2.0 to 500 μm size range) in the headwaters, where land use is primarily forest and agriculture. Eighty percent of the total sediment at the headwaters site (site 1) was between 216 and 357 μm , while that number was reduced to almost 40% at site 5, approximately 40 kilometers downstream. These results illustrate the need to better understand fine-particle suspended sediment concentrations in stormwater runoff from urbanizing systems relative to that from agricultural and/or forest environments.

16. Hubbart, J.A., and G. Freeman. 2010. Sediment Laser Diffraction: A New Approach to an Old Problem in the Central U.S. *Stormwater Journal*, 11(7):36-44.

In a nutshell: A doubling of streamflow more than doubles fine suspended sediment concentrations in Hinkson Creek.

Brief abstract: Watershed studies, such as the Hinkson Creek Watershed, utilizing established study design protocols (i.e., nested-scale design) will provide new information to stormwater managers wishing to make science-based decisions to meet water-quality standards. This work showed that a 13.2 mm (0.52 in.) rainfall event resulted in a doubling of streamflow (1.4 m^3/s (51 ft^3/s) to 2.9 m^3/s (102 ft^3/s), but resulted in more than doubling the concentration of particle size classes ranging from 0.2 to 67.65 μm . This result illustrates the need to better understand fine particle suspended sediment concentrations in stormwater runoff from urbanizing systems relative to that flowing from agricultural and/or forest environments. In watersheds the size of Hinkson Creek, comprehensive management approaches that examine not only the volume of water causing impairments and the variable use landscape, but also the pollution load being transported, are imperative.

17. Hubbart, J.A., J. Holmes, and G. Bowman. 2010. TMDLs: Improving Stakeholder Acceptance with Science-Based Allocations. *The Watershed Science Bulletin*, 01:19-24.

In a nutshell: Science-based information can reduce error in TMDL decision-making processes while improving stakeholder acceptance.

Brief abstract: Although mitigating water quality impairment through total maximum daily load (TMDL) implementation can sustain natural resource commodities and development practices, it is challenging. Research-based land use planning can substantially reduce or eliminate error in TMDL decision-making processes while improving stakeholder acceptance. To address water quality issues in the central United States, the Hinkson Creek Watershed was equipped with state-of-the-art monitoring instrumentation in 2008. Results from this and similar studies will support future urban development by validating engineering strategies that may overlook land use, topography, and site-specific development constraints.

DISERTATIONS AND THESES

1. Elizabeth Spiegel. December 2015. M.S. Forestry. Estimating Above and Below Ground Vegetation Biomass and Carbon Storage across an Intra-Urban Land-Use Gradient in Mid-Missouri.

In a nutshell: Bottomland hardwood forests store large amounts of carbon compared to non-woody floodplain sites.

Brief abstract: In order to further understanding of the impacts of urbanization on vegetative communities and carbon storage, six intra-urban 50 m x 50 m plots were surveyed for vegetation characteristics such as species richness, basal area, proportion invasive species, and species morphometrics in Hinkson Creek Watershed, central Missouri, USA. Morphometric data were used to quantify vegetative biomass and carbon storage. Results of the vegetation survey showed species richness was highest at the rural urban interface, but this location also contained the largest number of invasive species. Total estimated carbon storage, quantified from estimated dry weight biomass of vegetation, was largest within a bottomland hardwood forest (38,990.2 kg) and smallest within a bottomland floodplain grassland site (15.9 kg). Estimates made with I-tree eco were significantly smaller ($p = 0.00013$) than estimates made with allometric biomass equations. This study will increase understanding of vegetative communities' composition, biomass and carbon storage across an intra-urban gradient, as well as compare models of estimating carbon storage in order to improve urban forestry practices.

2. Katlin Beaven. December 2015. M.S. Forestry. Investigating Soil Carbon, Nitrogen and Respiration Across an Intra-Urban to Forested Gradient in Mid-Missouri.

In a nutshell: Urban land use management can be used to strategically optimize carbon storage and cycling.

Brief abstract: This study investigated soil total organic carbon (TOC), total nitrogen (TN), and soil respiration as well as surface organic matter inputs, air temperature, soil volumetric water content, and soil temperature across six study sites including one rural reference forest, one urban reference forest, and four additional intra-urban sites of varying land use and vegetation including a floodplain grassland, a natural regeneration plot, an older residential plot, and a high intensity urban parking area in Boone County, Missouri, USA. The highest intensity urban sites, the residential site and the parking area, contained the greatest average quantities of TOC and TN in a 5 cm increment from 0-35 cm with 2.29 kg TOC/m² and 144.55 g TN/m² and 3.69 kg TOC/m² and 203 g TN/m² respectively. The urban forest contained an average of 1.16 kg TOC/m² and 95.99 g TN/m² in a 5 cm increment from 0-35 cm and the rural forest contained an average of 1.18 kg TOC/m² and 100.85 g TN/m² in a 5 cm increment from 0-35 cm. Average growing season soil respiration rates across sites ranged from 7.96 $\mu\text{mol}/\text{m}^2 \text{ s}$ at the rural forest to 12.92 $\mu\text{mol}/\text{m}^2 \text{ s}$ at the most intensely urban parking area site. High and low soil temperatures (Ts) corresponded to sites with the highest and lowest rates of soil respiration, with an average growing season Ts of 18.71°C at the rural forest and 23.72°C at the parking area site. Results indicate that varying urban land use has the potential to impact C storage and cycling in that soils

under more intense urban land use may contain more C and N, but those soils also appear to be respiring C at higher rates than less urban sites.

3. Elliott Kellner. November 2015. Ph.D. Natural Resources, Water Resources. Dissertation: The Long-Term Impacts of Forest Removal on Floodplain Subsurface Hydrology.

In a nutshell: Floodplain forests reestablishment benefits include improved fresh water routing, water quality, aquatic ecosystem conservation, and flood mitigation in mixed-land-use watersheds.

Brief abstract: A study was implemented in fall 2010, in the Hinkson Creek Watershed, Missouri, USA to improve quantitative understanding of the long-term impact of forest removal on floodplain hydrology. Automated volumetric water content (VWC) probes and piezometers equipped with pressure transducers to monitor shallow groundwater (SGW) temperature and level were installed in a gridded study design within a historic agricultural field (Ag) and a remnant bottomland hardwood forest (BHF). Groundwater was analyzed for 49 physiochemical metrics. Results showed VWC to be significantly different between sites ($p < 0.01$) during the study, with site averages of 33.1 and 32.8% at the Ag and BHF sites, respectively. SGW temperature range at the Ag site was 72% greater than at the BHF site. BHF groundwater contained significantly ($p < 0.05$) higher concentrations of nutrients, while Ag groundwater was characterized by significantly ($p < 0.05$) higher concentrations of trace elements. Collective results highlight the greater extent to which BHF vegetation impacts subsurface hydrology, relative to grassland/agricultural systems, and point to the value of reestablishing floodplain forests for fresh water routing, water quality, aquatic ecosystem conservation, and flood mitigation in mixed-land-use watersheds.

4. Lynne Hooper. August 2015. M.S. Natural Resources, Water Resources. Thesis: A Stream Physical Habitat Assessment in an Urbanizing Watershed of the Central U.S.A.

In a nutshell: A physical habitat assessment shows that Hinkson Creek is altered by agricultural and urban land uses.

Brief abstract: Longitudinal variations in aquatic biological habitat in a watershed (frequently associated with land use in mixed-land-use watersheds) can be quantified by means of a physical habitat assessment (PHA). PHA indices include but are not limited to width (channel, bankfull, and wetted), bank height and thalweg depth. Hinkson Creek (Boone County, Missouri) was placed on the Missouri Department of Natural Resources list of impaired waters (Section 303d) of the Clean Water Act in 1998. A PHA conducted in 2013-2014 provided quantitative data characterizing physical habitat characteristics every 100 m of the 56 km channel. Bankfull width ranged from a maximum of 74 m to a minimum of 1.8 m (mean = 24.2 m, SD = 9.4 m). Bank height ranged from 5.8 m to 0.3 m (mean = 2.8 m, SD = 1 m). Increases in bankfull width and bank height were variable with stream distance. Trench pools were the dominant channel unit at 70% of sample transects. Thalweg depth at low to median flow ranged from 330 cm to 0 cm (mean = 50.3 cm, SD = 38.7 cm). Streambed size classifications included 58.4% small (< 16 mm),

33.6% intermediate (16 mm to 1000 mm, vegetation, wood), 7.8% large (> 1000 mm, riprap, bedrock). Study results better inform land use planners in Hinkson Creek Watershed and similar multi-use watersheds of the central United States for future management decisions and development scenarios.

5. Sean Zeiger. May 2014. M.S. Natural Resources, Water Resources. Thesis: Measuring and Modeling Stream and Air Temperature Relationships in a Multi-Land Use Watershed of the Central United States.

In a nutshell: Stream temperature increased in Hinkson Creek with downstream distance and urban land use in Hinkson Creek Watershed.

Brief abstract: A nested-scale experimental watershed study design approach was used in an urban watershed of the central U.S. to investigate stream water temperature (T_w) variability during water years 2011, 2012, and 2013 in Hinkson Creek Watershed. Drought conditions were observed during water year 2012 when total annual precipitation was approximately 340 mm less than the 30 year record. Sudden increases of >1 °C within a 15 minute time interval in T_w (T_w surges) following summer thunderstorms were observed at urban sites. Differences in mean T_w between gauging sites were significantly ($p=0.02$) correlated to urban land use and downstream distance as discharge increased. Additionally, significant ($p>0.05$) differences in model efficiency were not found between the linear T_w model used in SWAT and the new process-based T_w model. Results from this study will provide land managers with quantitative information and T_w models needed to make informed management decisions and improve water quality in urban watersheds.

6. Keith Brown. December 2014. M.S. Natural Resources, Water Resources. Thesis: Quantifying Bottomland Hardwood Forest and Agricultural Grassland Evapotranspiration in Floodplain Reaches of a Mid Missouri Stream.

In a nutshell: Bottomland forests ameliorate flood events by increasing consumptive losses from floodplain soils.

Brief abstract: A bottomland hardwood forest (BHF) and Agricultural Grassland (AG) were instrumented with microclimate stations and water year 2012 evapotranspiration (ET) was estimated. Six out of seven methods of ET calculation show higher rates of ET in BHF than AG, within the Hinkson Creek Floodplain. Widely applied methods of ET calculation estimated BHF ET to be from 802mm yr^{-1} (Penman-Monteith) to 975mm yr^{-1} (Surface Energy Balance). Agricultural grassland site ET values were estimated to be 720mm yr^{-1} (Surface Energy Balance) and 719mm yr^{-1} (Penman-Monteith). The difference of these ET estimates between the BHF and AG sites yield an additional 83mm yr^{-1} to 255mm yr^{-1} of soil moisture consumed. Coupled with the increased infiltration capacity of forest soils, the enhanced evapotranspiration of bottomland forests could play a role in ameliorating flood events.

7. Elliott Kellner. May 2013. M.S. Forestry. Thesis: Quantifying Urban Stormwater Suspended Sediment Particle Size Class Distribution in the Central U.S.

In a nutshell: There is a disproportionate contribution of fine sediment from the urban environment in Hinkson Creek watershed.

Brief abstract: Stormwater samples were analyzed from 17 urban monitoring sites ($n = 272$) during spring 2011 to better understand urban land use suspended sediment contributions to receiving waters in Hinkson Creek Watershed, central Missouri, USA. Samples from receiving water bodies (i.e. Hinkson and Flat Branch creeks) had higher total concentrations of suspended sediment (323 $\mu\text{L/L}$ and 319 $\mu\text{L/L}$, respectively) relative to urban sites (205 $\mu\text{L/L}$), which contained approximately 35% less total sediment. However, mean particle size was significantly lower ($p < 0.001$) from urban sites (59 μm) relative to receiving waters (167 μm and 131 μm , respectively). Receiving waters had higher silt volumes (173 $\mu\text{L/L}$ and 148 $\mu\text{L/L}$, respectively) relative to urban sites (124 $\mu\text{L/L}$). Collectively, results indicate a disproportionate contribution of fine sediment from the urban environment. Receiving waters' particle size class dynamics suggest the presence of a climate-driven punctuated equilibrium of sediment transport, which was not apparent in urban areas.

8. John R. Nichols. December 2012. M.S. Forestry. Thesis: Land-Use Impacts on Aquatic Invertebrate Assemblages in a Dynamic Urbanizing Watershed of the Central U.S.

In a nutshell: Agricultural and urban land use affects macroinvertebrate assemblages in Hinkson Creek watershed.

Brief abstract: Five replicated study sites were established across an agricultural to urban land use gradient to investigate land use effects on macroinvertebrate assemblages using a nested-scale experimental watershed study design in Hinkson Creek Watershed, central Missouri, USA. Missouri Biotic Index was higher ($p < 0.05$) in urban sites (6.77) compared to rural sites (6.26). Percentage of fine substrate increased 328% from the headwaters to the lower reaches. Submerged woody rootmats were 78% smaller in the lower reaches of the stream. Average winter Chloride concentrations were 126% higher in urban reaches of the stream compared to rural reaches (116.6 mg/L and 51.5 mg/L respectively). Results indicate that the influence of disturbance regimes associated with local hydrogeomorphology may be as important in structuring benthic community composition as anthropogenic effects associated with agriculture and urbanization.

9. Dandan Huang. 2012. M.S. Forestry. Thesis: Partitioning Aquatic and Terrestrial Sediment Loading in an Urbanizing Watershed.

In a nutshell: Stream bank erosion contributed approximately 67% of channel suspended sediment loading over water year 2011.

Brief abstract: Streambank erosion and deposition rates were quantified using the erosion pin method comparing a remnant Bottomland Hardwood Forest (BHF) streambank to an Agricultural

(Ag) streambank (922 m apart) in a lower reach of the Hinkson Creek Watershed, located in Boone County, Missouri, USA. Results indicated that during a drier (762 mm) than average (10yr avg=1077 mm) rainfall year 15.6 and 177.7 tonnes of soil erosion occurred on the right stream bank alone of the BHF and Ag sites, respectively (water year 2011). Average erosion depth of the BHF and Ag was 18 and 112 mm/yr, respectively. The greatest average depth of erosion occurred during the winter season (44.7 mm), followed by summer (13.1 mm) and spring (6.3 mm), fall had the lowest average erosion rate (1.1 mm). The stream bank erosion contributed approximately 67% of channel suspended sediment loading over water year 2011. Results hold important implications for land use and land managers wishing to improve land use practices, water quality, and natural resource sustainability in dynamic urbanizing watersheds.

10. Graham Freeman. May 2011. M.S. Forestry. Thesis: Quantifying Suspended Sediment Loading in a Mid-Missouri Urban Watershed Using Laser Particle Diffraction.

In a nutshell: Urban land use is associated with increased suspended sediment concentrations and decreased particle size in Hinkson Creek.

Brief abstract: The following research used laser diffraction particle analyzers to quantify suspended sediment concentration (SSC) and particle size at three nested-scale gauging sites each with different dominant land uses (rural, suburban, and urban) in Hinkson Creek watershed during the spring of 2010. Mean SSCs were estimated to be 66.0, 70.0, and 86.0 $\mu\text{l/L}$ for the rural, suburban, and urban sub-basins (respectively). Mean sediment size was estimated to be 151.0, 111.0, and 79.0 μm for the headwater, suburban, and urban sub-basins respectively. This study illustrates how mean SSCs and sediment particle size are affected by land use change in an urbanizing agricultural watershed of the central USA. As land use continues to change, the ability to protect and enhance water quality will depend on how well scientists, land managers, and policy makers understand the relationships between land use and hydrological processes.

11. Daniel Scollan. May 2011. M.S. Forestry. Thesis: A Multi-Configuration Evaluation of the Soil and Water Assessment Tool (SWAT) in a Mixed-Use Watershed in the Central U.S.A.

In a nutshell: the Soil Water Assessment Tool (SWAT) accurately simulated Hinkson Creek flow during successive wet years.

Brief abstract: This study presents a practical framework for use of the Soil and Water Assessment Tool (SWAT). Nine goodness-of-fit indicators were tested, including four new indices (R-RMSE, R-MAE, R-NSE, and R-NSE1) designed to quantify model fit with flow distribution. Sixteen of 20 configurations achieved satisfactory monthly streamflow fit ($\text{NSE} > 0.5$, $\text{PBIAS} < 25\%$) without calibration. Watershed and soil resolution had negligible impact; climate input had considerable impact. Single climate station input is best used for applications requiring monthly predictions; distributed climate station input is needed for daily predictions. SWAT multi-objective auto-calibration better predicted monthly flow ($\text{PBIAS}=1\%$, $\text{NSE}=0.8$) than single-objective calibration ($\text{PBIAS}=16\%$, $\text{NSE}=0.5$).