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AWSPs
Association of Watershed & Stormwater Professionals

Journal of the Association of Watershed & Stormwater Professionals

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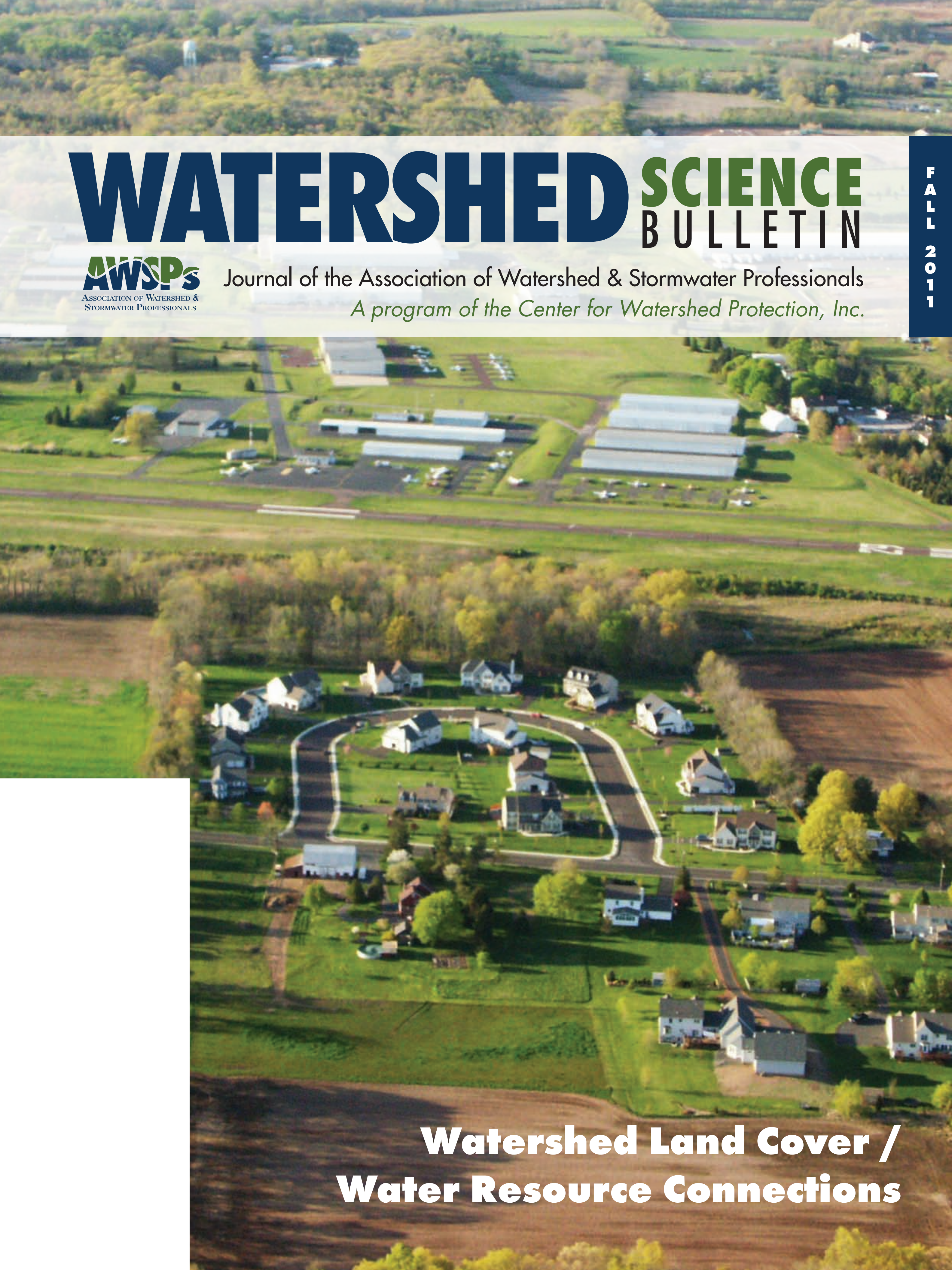

Watershed Land Cover / Water Resource Connections

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Cover photo courtesy of Dot Cappiella
This bird's-eye view of Bucks County, Pennsylvania, taken from a hot air balloon, shows the variety of land cover types on this rural and suburban landscape. Trees, turf, pavement, cropland, and even bare soil are present in this fast-developing suburb of Philadelphia.

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Bottomland Hardwood Forest Influence on Soil Water Consumption in an Urban Floodplain:

Potential To Improve Flood Storage Capacity and Reduce Stormwater Runoff

Jason A. Hubbart,[a] Rose-Marie Muzika,[b] Dandan Huang,[c] and Andrew Robinson[d]*

Abstract

Despite considerable interest in the rehabilitation of wetland and stream ecosystems, guidance for the restoration of forested urban floodplains is limited. This study provides baseline data 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. We quantified the dominant tree species composition, basal area, and leaf area index of a bottomland hardwood forest (BHF). We then estimated differences in soil infiltration, bulk density, porosity, volumetric water content (VWC), and water storage between paired BHF and agricultural sites within the floodplain. 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.

Introduction

Flood events cause more than $3.5 billion in property damage in the United States every year. Since 2004, more than 40% of annual natural disasters in the United States have been related to flooding (Federal Emergency Management Agency 2009). With increasing local, state, and federal expenditures for flood disaster relief, flood prediction and control have become critically important. A key turning point in floodplain management was the promulgation of the National Flood Insurance Program (NFIP) by the US government in 1968 through the enactment of the National Flood Insurance Act. Subsequent to the establishment of NFIP and the environmental movement of the 1970s, land use planners placed increasing emphasis on floodplain management to minimize flood damage (Mays 2001). In recent years, green infrastructure, including wetlands, ponds, rain gardens, and forested buffer strips, has become an increasingly popular alternative to classic engineered structures for flood and water quality mitigation (Mitsova et al. 2011). Nowhere are green alternatives more desirable than in urban environments, where compounded human disturbance dramatically alters natural resources (Gill et al. 2007). Unfortunately, little guidance is available for the restoration of forested urban floodplains. Methodologies for the assessment and restoration of the ecological functions of forested wetlands in wildland floodplains may be of limited value in urban settings. This is mainly due to the nature and magnitude of the modifications to the hydrologic regime and limitations to the restoration of a more natural regime in urban watersheds (e.g., Simmons et al. 2007; Ravit et al. 2008).

Most floodplain bottomland hardwood forests (BHFs) in the United States were removed in the nineteenth and twentieth centuries in efforts to harvest valuable timber resources and cultivate the rich underlying soils (Abernathy and Turner 1987). In many instances, this required the installation of drainage and flood control structures, such as drainage tiles, ditches, levees, and dams. The channels of many streams and rivers were straightened and enlarged to further reduce flooding. Drainage and flood control structures and channel alterations, coupled with changes in vegetation and soils, drastically altered the hydrology of streams, floodplains, and remnant BHFs (Carter and Biagas 2007). In the lower Midwest, restoration efforts in recent decades have mostly focused on wide alluvial floodplains of large rivers, especially in the lower Mississippi Alluvial Valley (Stanturf et al. 2001). However, riparian and floodplain BHFs along lower-order tributary streams also possess important hydrologic, biogeochemical, and habitat functions and provide ecosystem services. For example, Thomas and Nisbet (2007) showed through modeling that forested riparian zones in southwestern England increased the soil water level by 270 mm and increased flood storage by 15% to 71%; they argued that floodplain

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woodlands could be strategically located to reduce flooding. Additionally, forested stream buffers stabilize banks, improve water quality, maintain soil moisture, and ameliorate local microclimates (Seobi et al. 2005; Wynn and Mostaghimi 2006). Forested floodplain ecosystems are highly productive and often support high plant species richness. A variety of factors influence plant species composition, including soil nutrient status, topographic relief, and soil water flux (Lytle and Merritt 2004; Lytle and Poff 2004) as well as species life history characteristics (Holmes et al. 2005; Unger 2008). Numerous studies indicate that BHF vegetation is sensitive to environmental variability and perturbation (Grell et al. 2005; Tockner et al. 2010, and references therein). The effect of any one of the many floodplain attributes on vegetation structure is difficult to detect given interactions among physical processes, vegetative responses, and the stage of succession.

Urban riparian and floodplain forests of lower-order tributaries may play particularly important roles in the absorption, attenuation, and treatment of storm flows as a result of coupling to urban environments. However, lower-order floodplain capacity to attenuate flow and pollutants from source watersheds is largely unknown, especially in urban settings. An improved quantitative understanding of floodplain processes is critical for restoring the habitat and conditions of the Missouri and Mississippi Rivers as well as the hypoxic zone of the Mississippi Delta in the Gulf of Mexico (Alexander et al. 2008). Because of the tendency toward public ownership, urban floodplains are ideal candidates for restoration. In addition, their location in or near population centers make them well suited for public education and involvement in restoration activities. As a good example of this process, City planners in Portland, Oregon, are restoring the historic floodplain to improve flood storage and attenuation, habitat, and multiple other benefits (for more information, see Portland Bureau of Environmental Services [n.d.]).

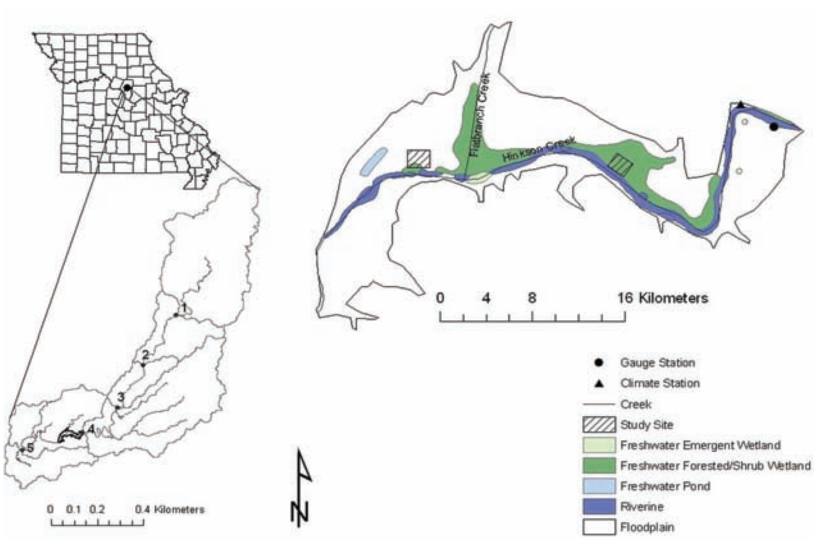

Figure 1. Locations of five nested gauge stations (left) and lower Hinkson Creek floodplain study sites (right, crosshatched boxes) in the Hinkson Creek watershed in central Missouri, USA.

Investigations that provide a quantitative understanding of floodplain and vegetation community process relationships and information for science-based urban land-use decisions are critically needed.

Objectives

The goals of this study were to (1) quantify the species presence, basal area, and canopy density of a section of second-growth BHF; (2) quantify the difference between the BHF site and an agricultural (Ag) site in soil infiltration capacity; and (3) estimate soil water storage differences between the two sites through a soil characteristics analysis. Such data are necessary to estimate the potential role of BHFs in flood attenuation by means of increased infiltration, storage capacity, and transpiration consumptive water use.

Methods

This project focused on an urban floodplain reach of Lower Hinkson Creek located in the city of Columbia (population 108,000; US Census 2011), in central Missouri, USA (Figure 1). The reach is located between two permanent hydroclimate gauge sites on the main channel that are part of an urban watershed study containing five nested gauge sites implemented in 2008 (Hubbart et al. 2010). The watershed contributing to the floodplain reach investigated in this study contains a large portion of the most intensively developed land in the city of Columbia.

The Hinkson Creek watershed (HCW), which is located within the Lower Missouri–Moreau River basin in central Missouri, is classified as a Missouri Ozark border stream located in the Outer Ozark Border Ecological Subsection (Nigh and Schroeder 2002). Average annual temperature and precipitation (from a 30-year record) is approximately 14°C and 980 mm. Soil types range from loamy till with a well-developed clay pan in the uplands (Chapman et al. 2002) to thin cherty clay and silty to sandy clay in the lower reaches. Land use in the watershed is approximately

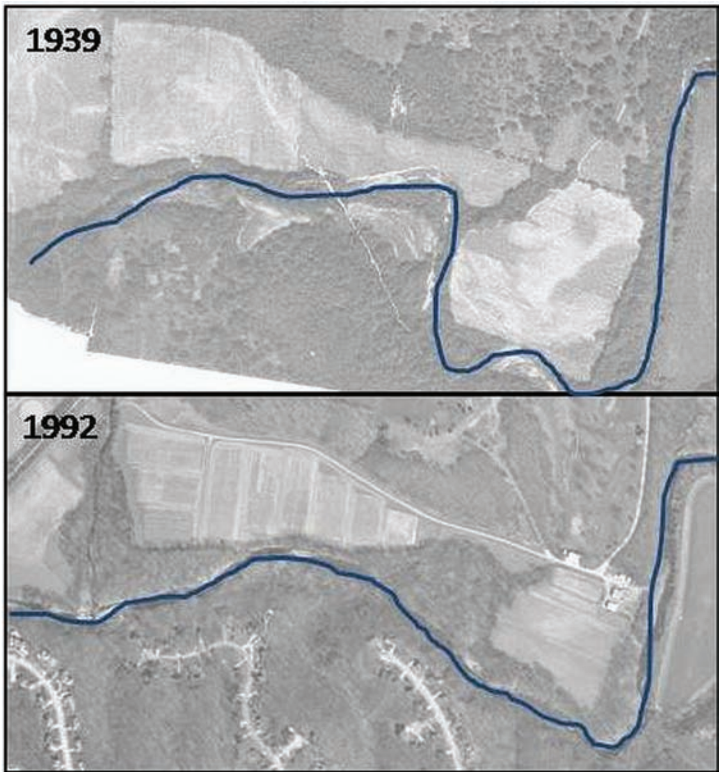

Figure 2. Aerial photographs of Hinkson Creek in 1939 and 1992 flowing through the floodplain study reaches in central Missouri, USA.

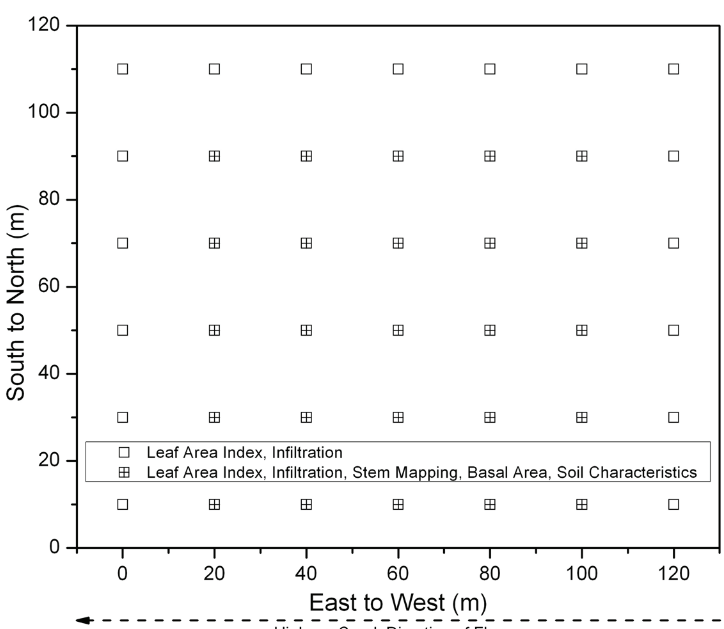

Figure 3. Study grid design of the current floodplain study in central Missouri, USA.

34% forest, 38% pasture or cropland, and 25% urban area; the remaining land area consists of floodplains, wetlands, and open or shrubland/grassland areas.

We located floodplain study grids within one large remnant section of BHF and one Ag section within the study reach (Figure 1, right) during the summer months of 2010 (July–August). The woody species *Acer saccharinum* (silver maple), *Acer negundo* (boxelder), *Ulmus americana* (American elm), *Populus deltoides* (eastern cottonwood), and *Juglans nigra* (black walnut) dominated the BHF site. A woody understory layer was absent, but *Urtica dioca* (stinging nettle) and several grass species of limited occurrence, such as *Elymus virginicus* (Virginia wild rye), dominated herbaceous vegetation. A comparison of historic photographs with photographs from 1992 indicate that Hinkson Creek was more sinuous in the early 1900s (Figure 2). Study grid dimensions included an inner 80 m x 80 m (6,400-m^2) grid equally subdivided for tree diameter measurements and soil sampling (n = 25). We used a larger 120 m (east–west) x 110 m (north–south; 13,200-m^2) grid encompassing the inner grid for canopy cover and soil infiltration work (n = 42; Figure 3). The southern 120-m side of the larger grid was located 10 m from and parallel to Hinkson Creek. We replicated infiltration and soil characteristics work within a grid of equal dimensions approximately 800 m downstream in an area of the floodplain that has been used for agriculture for at least the past century (Figure 1).

Basal Area and Leaf Area Index

This study used basal area and leaf area index (LAI) as a proxy for mass and energy exchange from the forest canopy (Running and Coughlan 1988; Santiago et al. 2000). LAI is defined as the ratio of the total upper leaf surface of vegetation divided by the surface area of the land over which the vegetation grows (Campbell and Norman 1998). Tree transpiration is positively correlated with LAI (Granier et al. 1996), which is a structural determinant of transpiration (Running and Coughlan 1988). Structural composition of forest canopies (i.e., stem diameter and basal area) is also important because of the relationships between boundary layer conductance (Campbell and Norman 1998) and plant water flux from forest soils by transpiration (Meinzer et al. 1997).

We identified each tree within the entire inner 80 m x 80 m BHF area to the species level and measured the diameter at breast height (dbh = 1.3 m) of every tree greater than 10 cm dbh. These data enabled a calculation of basal area (i.e., the cross-sectional area of each individual tree) by species and for the entire study area. To determine the age of dominant species and the establishment year for the study BHF, we used an increment borer to extract one core from each tree on the site with dbh greater than 10 cm (n = 142). We mounted and sanded the increment cores and counted the rings.

We used ceptometer and hemispherical methods to estimate LAI. The ceptometer method required the use of a Decagon Devices LP-80, which measures average photosynthetically active radiation (PAR) along an array of 80 sensors mounted on a 1-m light bar. The amount of PAR transmitted through a vegetative canopy is a direct function of canopy structure and density. We placed one ceptometer on a tripod approximately 1.6 m above ground level within a clearing to log the reference PAR. We compared the reference PAR to the PAR beneath the canopy to calculate the ratio between the two measurements. We collected PAR measurements in four cardinal directions at all 42 sampling locations within the BHF site (Figures 1 and 3; n = 168) and calculated the PAR according to methods described by Decagon Devices (2006). The hemispherical method required a Nikon D60 digital camera with a Sigma 4.5-mm circular fisheye lens. We took photographs at the same time and location as the PAR data with the lens pointing vertically upward and the camera base mounted 1.3 m above ground level. We analyzed hemispherical photographs using Gap Light Analyzer software (Frazer et al. 1999), which relates the gap fraction (the percentage open sky vs. leaf obstruction) to LAI (Stenberg et al. 1994).

Infiltration Capacity

This study used double-ring infiltrometers to measure soil infiltration. The purpose of the double-ring assemblage is to create a one-dimensional flow of water from the inner ring. An inner ring is driven into the soil and a second, larger-diameter concentric ring helps control the flow of water through the inner ring. Water is supplied either with a constant or falling head condition, and the infiltration rate of the inner ring is recorded over a given time period. This arrangement accounts for the lateral movement of water around the infiltration ring blades, thus improving the accuracy of infiltration estimates (Bodhinayake et al. 2004). For more information, please see ASTM International (n.d.).

Soil Water Storage

We estimated soil water storage based on analyses of soil characteristics (e.g., bulk density, porosity, and volumetric water content [VWC]), using the soil core method (Hillel 2003). The soil core method requires a cylindrical metal sampler to be driven into the soil to remove a known volume of soil (a core), which is weighed and then oven-dried at 105°C to remove nonstructural soil water. Oven-drying typically takes 24 to 48 hours, or until the sample mass no longer changes with additional drying. The oven-dried mass of the soil sample is then determined by weighing, and the indices listed above can be calculated (Hillel 2003). We retrieved soil cores from depths of 0, 15, 30, 50, 75, and 100 cm, enabling the computation of soil water to a depth of 1 m.

Analyses

Data analyses consisted of graphical, descriptive, and statistical comparisons. We conducted a two-sample *t*-test to identify statistically significant differences between the BHF and Ag floodplain sites in independent infiltration capacity samples (n = 25, each site; Figure 3; Zar 1999). Two-way analyses of variance (ANOVA) on soil characteristics tested for significant differences between population (site) means and independent soil depths (Zar 1999). After each two-way ANOVA, a Tukey's post hoc multiple-comparison test compared the nominal variables and measurement variable in all possible combinations (Zar 1999).

Results and Discussion

The climate over the period of study was typical for the region. The city of Columbia received 372 mm of precipitation between July 1 and August 31, 2010, and more than 1,346 mm of precipitation throughout 2010. The average temperature during the period of study was 26.3°C.

Silver maple, boxelder, and Amercian elm were the numerically dominant tree species at the BHF site (n = 41, 39, and 35 individuals, respectively). The frequency distributions for both tree dbh and basal area (Figure 4) reveal the negative exponential (i.e., few old or large trees vs. more young or small trees) of a forest with a relatively young cohort. Size (dbh) suggests that the young cohort consisted principally of silver maple and American elm. Eastern cottonwood, however, dominated in terms of basal area (9.01 m^2) in the study plot and was represented by few (n = 9), but large, individuals (Table 1). This observation may be of particular importance in floodplain management since cottonwoods are very successful in shallow groundwater environments

Table 1. Descriptive statistics for stem diameter (cm) and basal area (m^2) in a bottomland hardwood forest floodplain in central Missouri, USA.

Species	Number of Individuals	Average dbh (cm)	Average Basal Area (m^2)	Total Basal Area (m^2)
Acer negundo	39	26.98	0.07	2.55
Acer nigrum	1	21.20	0.04	0.04
Acer saccharinum	41	48.19	0.21	8.66
Aesculus glabra	3	10.90	0.01	0.03
Celtis occidentalis	2	9.25	0.01	0.01
Gleditsia triacanthos	2	23.75	0.05	0.09
Juglans nigra	7	42.49	0.15	1.06
Populus deltoides	12	95.78	0.75	9.01
Ulmus americana	35	19.97	0.04	1.25
Total				22.71

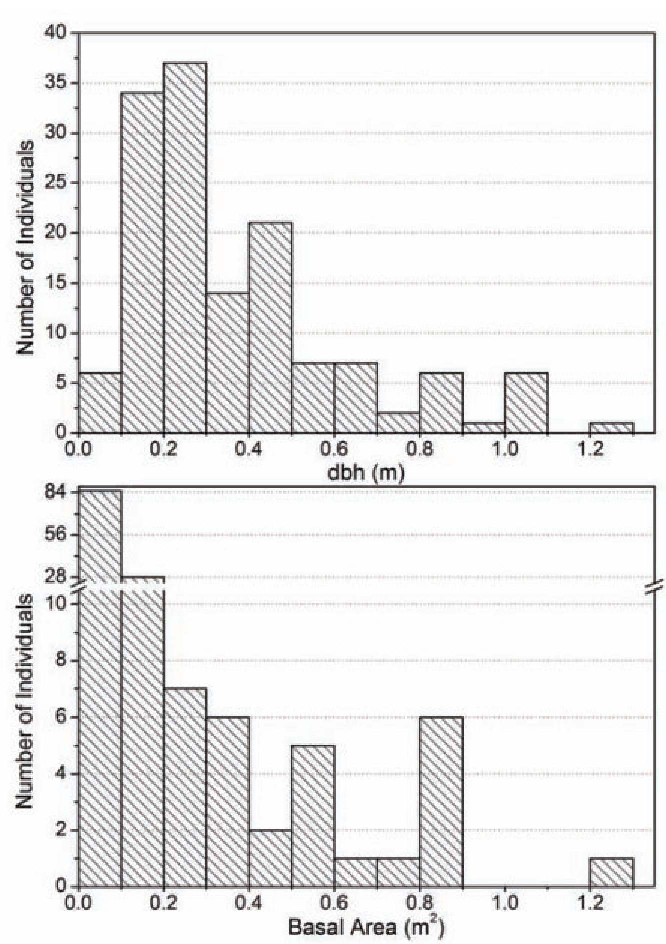

Figure 4. Frequency distribution plots of stem diameter (dbh) and basal area in a bottomland hardwood forest floodplain in central Missouri, USA.

and have high transpiration rates compared to other woody species. Vose et al. (2000) showed through sap flux experiments that cottonwoods transpire as much as 25 cm during the growing season. This holds important implications for floodplain management and possible restoration of BHFs in terms of annual plant water consumption.

Based on tree ring analysis, most tree establishment occurred between 1939 and 1962. One silver maple had an early pith date (center ring) of 1917, and thus represents the oldest individual in the study area. The species established somewhat sequentially, with silver maple establishing between 1939 and 1946, black walnut establishing between 1949 and 1960, and boxelder between 1951 and 1955. Other species were not cored, and the eastern cottonwoods were too hollow for accurate tree ring dating.

Average LAI was 3.11 (SD = 0.69), as calculated from the hemispherical and ceptometer methods (Figure 5), indicating an average of 3.11 canopy layers per unit soil surface area (see Methods). The two LAI estimates were in close agreement (n = 42 each), with an average hemispherical estimate of 3.24 (SD = 0.74) and an average ceptometer estimate of 2.98 (SD = 0.70), thereby increasing our confidence in results. Minimum and maximum LAIs were 1.31 and 4.96 for the hemispherical method and 1.24 and 4.18 for the ceptometer method.

Infiltration

Results of infiltration tests comparing the BHF and Ag sites (n = 42) indicated an average infiltration capacity (maximum steady state infiltration under saturated conditions) of 23 (SD = 21.0) and 38 (SD = 29.0) cm hour^{-1} in the Ag and BHF sites, respectively (Figure 6). Minimum and maximum infiltration values were 0.1 and 69.0 mm hour^{-1} for the Ag site and 3.0 and 126.0 cm hour^{-1} for the BHF site. Infiltration rates of the BHF and Ag sites differed significantly ($p < 0.05$). Maximum infiltration rates measured in the BHF site created a dramatic difference between the two sites (61%) in mean infiltration (Figure 6). Based on field observations, locations of high maximum infiltration rates were associated with locations of large trees (eastern cottonwoods). We therefore assumed that the associated root systems of those larger trees, which also corresponded to higher LAIs (Figure 5), were responsible for greatly increased soil infiltration rates. This conclusion is similar to previous work that showed forested floodplain infiltration rates 2 to 17 times greater around trees relative to bare ground (Bramely et al. 2003). Infiltration is an important benefit in urban floodplains since high infiltration rates of forested floodplains have been shown to normally exceed the highest rainfall intensities, thus preventing infiltration excess overland flow (Krause et al. 2007). On this basis, forested floodplains may not only increase the attenuation of urban stormwater flows and flooding, but also may provide a buffer for surface runoff by providing surface area for stormwater flows to infiltrate prior to reaching the stream.

Soil Characteristics

We extracted soil cores at depths of 0, 15, 30, 50, 75, and 100 cm every 20 m within the 80 x 80 study grid (Figure 2), for a total sample size of 150 soil cores from each floodplain study site. When we averaged soil core results from each depth over the total depth (100 cm), we found that average bulk density, porosity, and VWC were 1.3, 0.5, and 0.33 g cm^{-3}, respectively, in the Ag site and 1.31, 0.51, and 0.37 g cm^{-3} in the BHF site. Those averages equate to a 2% difference in bulk density and porosity, and an 11% difference in VWC between the sites (Table 2). Based on the results of a two-way ANOVA, the sites did not differ significantly in bulk density (n = 150, each site; $p > 0.05$). However, a comparison of the sites at all sampled soil depths (via a Tukey's post hoc multiple comparison) showed that bulk density was significantly lower in the BHF site at the 30-cm soil depth (n = 25, each site; $p = 0.01$). Similarly, porosity (n = 150, all depths, each site) did not differ significantly between sites ($p > 0.05$), but was greater in the BHF at the 30-cm depth (n = 25, each site; $p = 0.01$). ANOVA results indicated that

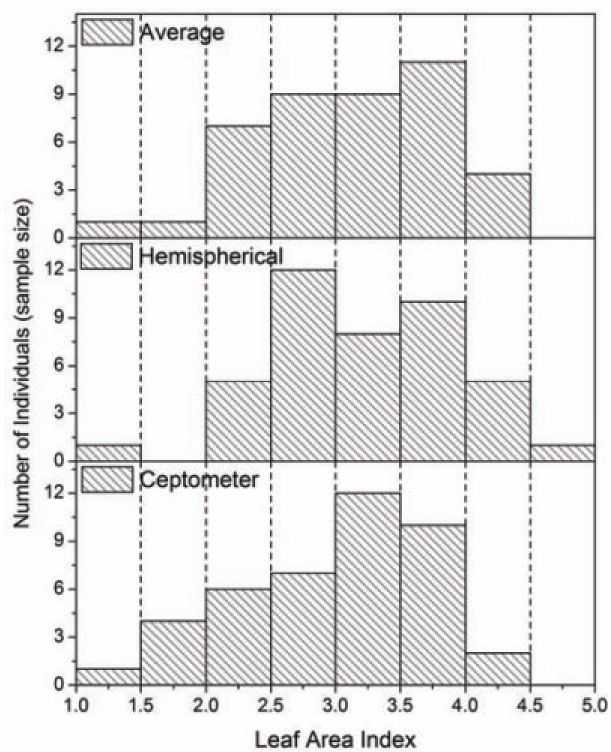

Figure 5. Frequency distribution plots of LAI in a bottomland hardwood forest of Lower Hinkson Creek in Columbia, Missouri, USA.

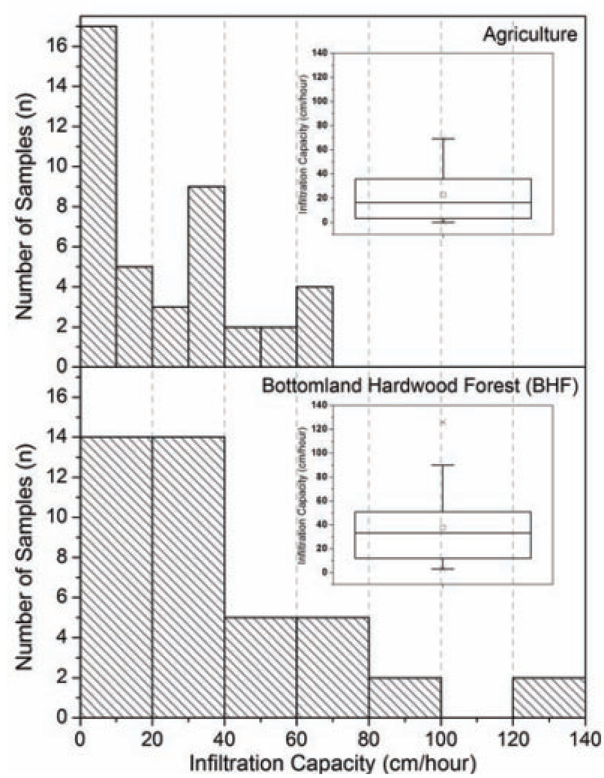

Figure 6. Infiltration capacity frequency distributions and nested box plots (n = 42) comparing bottomland hardwood forest and agricultural floodplain sites in the lower reaches of Hinkson Creek in the city of Columbia, Missouri, USA.

Table 2. Soil characteristics comparisons averaged from five soil depths between bottomland hardwood forest and agricultural floodplain sites in the lower reaches of Hinkson Creek in Columbia, Missouri, USA.

Site	Variable	Maximum	Mean	Minimum	Standard Deviation
Ag	ρdry	1.71	1.33	1.03	0.08
	Porosity	0.61	0.50	0.36	0.03
	VWC	0.48	0.33	0.13	0.03
BHF	ρdry	1.60	1.31	0.95	0.08
	Porosity	0.64	0.51	0.40	0.03
	VWC	0.52	0.37	0.10	0.04
% Difference	ρdry	−6	−2	−8	−5
	Porosity	5	2	12	−5
	VWC	9	11	−21	7

Notes: Ag, agricultural; BHF, bottomland hardwood forest; % Difference, (BHF–Ag/Ag) x 100; ρdry, dry bulk density (g cm^{-3}); Porosity (%); VWC, volumetric water content (g cm^{-3}).

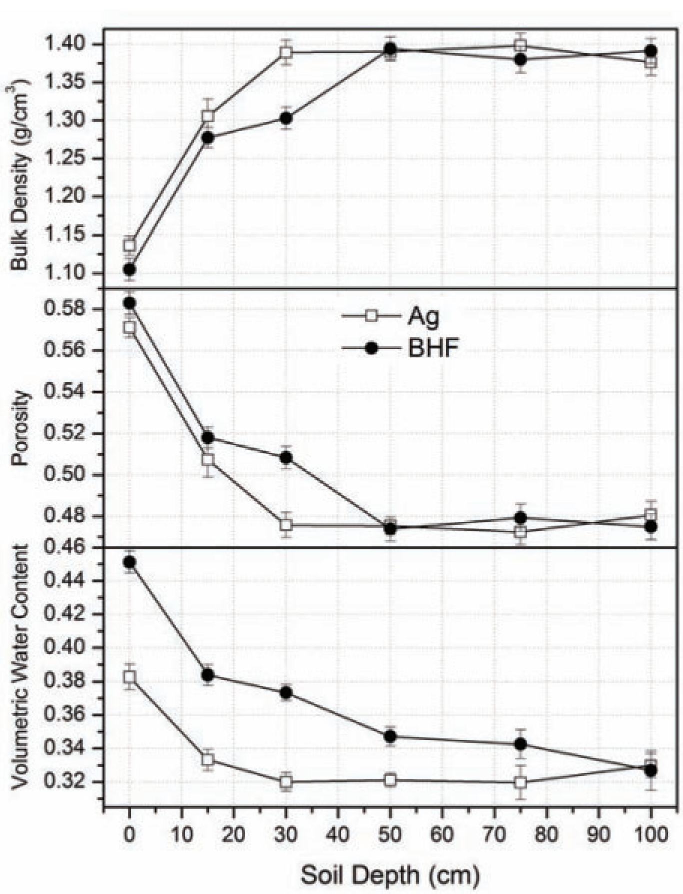

Figure 7. Comparison of soil characteristics (by depth with standard error bars) in an agricultural site and a bottomland hardwood forest site in Columbia, Missouri, USA. Porosity is expressed as a percentage and VWC units are g cm^{-3}.

soil VWC (n = 150, all depths, each site) averaged over the 100-cm profile differed significantly ($p < 0.05$) between the sites. However, the post hoc multiple-comparison test showed that specific significant differences were restricted to the 0-, 15-, and 30-cm depths (n = 25, each site; $p < 0.001$; Figure 7).

These results provide a strong argument for a vegetative effect on soil characteristics and, in particular, soil VWC above a soil depth of 50 cm (Figure 7). All soil characteristics diverge from 50 to 0 cm, and the standard error is negligible at depths less than 50 cm. Studies have shown that the majority of plant roots are found in the top 50 cm of soil (Barbour et al. 1999). Given that root systems increase soil infiltration by providing preferential flow paths for water, reducing bulk density and increasing soil VWC (Hillel 2003), these results may not be surprising. However, given the paucity of information pertaining to urban floodplain hydrology and forest relationships, these data are novel and provide support for efforts to restore BHF in urban areas to reduce stormwater runoff and flooding.

One of the most important results of this work pertains to the differences between the BHF and Ag sites in VWC, which equate to a nearly 11% difference in soil water over the 100-cm profile. An 11% difference could be substantial in terms of annual flood control. If one considers only the top 30 cm (as per statistical findings), the average difference between the BHF and Ag sites in VWC is 5%, or 57.6 mm (data not shown). However, tree roots penetrate soils deeper than 30 cm, and the rooting depths of many BHF species surpass 50 cm (Burke and Chambers 2003). On that basis, it is reasonable to assess the absolute differences between study sites in VWC in the entire profile since the transpiration effects of BHF VWC would translate to a reduced VWC at greater depths over the growing season. Previous researchers have noted that willow species can transpire as much as 4 to 6 mm day^{-1} (Hall et al. 1998; Granier et al. 1996; David et al. 1997). Considering the entire soil profile (100 cm), an 11% greater VWC in the BHF site equates to approximately 40 mm of storage difference over a soil depth of 1 m. Further, assuming a conservative value of 4 mm day^{-1} transpiration, a forested urban floodplain could easily consume (i.e., remove from the watershed) more than 720 mm of water per equivalent forested floodplain area, over only a six-month growing period. This could be substantial in urban watersheds like the HCW, where 700 mm is approximately two-thirds the long-term average annual precipitation (980 mm year^{-1}).

The baseline results presented in this article quantify the potential benefit of sustaining, or reestablishing, floodplain forests to enhance water storage capacity, attenuation, and consumptive use, thus reducing flooding and mitigating increased stormwater-related runoff and other effects of urbanization. The many other benefits to reestablishing BHF in urban floodplains include improvements in water quality and aquatic ecosystem health,the creation of inner city parks, and an improvement in human health. Carbon sequestration is an additional potential benefit of reestablishing BHFs. Forests play a significant role in carbon sequestration in aboveground woody biomass accumulation and, to an even greater extent, in forest soils (Cason et al. 2006); in this way, forests account for approximately two-thirds of the terrestrial carbon on the planet, excluding rock and sediment (Sedjo 2001). At least one-third of total forest carbon is contained in wetland and floodplain soils (Trettin and Jurgensen 2003). Thus, not only could the afforestation of converted floodplain lands dramatically improve flood safety and reduce losses, it could also significantly increase soil carbon sequestration.

Conclusions

At the watershed scale, the results presented here hold critically important implications for improvements in the attenuation of urban stormwater runoff and floodplain floodwave as well as consumptive water use. Results indicate that, for every hectare of forest reestablished in a floodplain, more than half of the precipitation falling on that hectare could be removed from the watershed by plant transpiration during the growing season. In that sense, successful restoration of urban forested floodplains may achieve a great deal more per unit area than other current upland stormwater mitigation practices (e.g., detention/retention ponds, rain gardens, or constructed wetlands). Investigations comparing BHF restoration to other contemporary flood mitigation practices are warranted. In 1987, Abernathy and Turner estimated that less than 25% of pre-European development BHF remains. Assuming that a majority of the other 75% of former BHF remains under historic floodplain land-use practices (drainage tiles, ditches, levees, dams, and so on), BHF floodplain restoration may be of critical importance as human populations continue to converge and grow in condensed urban centers.

In urbanizing watersheds such as the HCW, comprehensive management approaches, addressing stormwater runoff and streamflow regimes as well as the pollution load being transported, are imperative. For the HCW and other similar Clean Water Act Section 303(d)–listed North American watersheds, the work presented here is timely given legal mandates to provide quantifiable estimates of total maximum daily loads, improve water quality, reduce stormwater runoff, and decrease flood risk (Cappiella 2010). Given the size of the HCW and the scope of land uses therein, the HCW serves as a model urban watershed for similar studies. In continued work, we will seek to (1) quantify annual BHF transpiration and interception rates and (2) establish multiannual vadose and saturated zone water flux data; in this way, we will quantifiably demonstrate the benefits of reestablishing BHF in the urban floodplains of the American Midwest and elsewhere.

Acknowledgments

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