2015

Effects of Hydrologic Modifications on Flooding in Bottomland Hardwoods

Erin Johnson
Louisiana State University and Agricultural and Mechanical College

EFFECTS OF HYDROLOGIC MODIFICATIONS ON FLOODING IN BOTTOMLAND HARDWOODS

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Science

in

The School of Renewable Natural Resources

by
Erin Johnson
B.S. University of Central Arkansas, 2012
August 2015

Acknowledgments

I would like to thank my adviser, Dr. Richard Keim, for his assistance and advice throughout my graduate career. I am thankful he told me to email him back in a couple of months because the funding is always changing. If I had not emailed him back, I would have missed out on a great opportunity. I would also like to thank Dr. Sammy King for being on my committee and providing me with some excellent learning opportunities on the field trips you organized. I would also like to thank Dr. Clint Willson for being on my committee and providing a lot of tutoring sessions for Fluid Mechanics.

Special thanks to my fellow lab mates: Scott Allen, Karen Latuso, Mary Grace Lemon, Brandon Edwards, and Lincoln Dugué for your companionship in the field, in the office, and outside of school. I also want to thank fellow RNR students, Whitney Kroschel and Wes Cochran, for their help in the field. Also, thanks to the student workers, Clay Lovelace and Michael Baker, for assisting with field work.

A hearty thank you goes to my patient and tolerant boyfriend, Justin Duke, who always looked on the bright side of things and encouraging me to stay positive through this process.

Thank you, Mom and Dad, for passing down generations of passion for water resources. Also, thank you for supporting me and pushing me outside my comfort zone. Thanks to my brother, Chris, for being the complete opposite because that’s one less person I have to compete with for a job in this field.

Table of Contents

Abstract

Complex fluvial processes influence floodplains. River modifications in the 1930s have affected hydrogeomorphic processes influencing the lower White River in southeastern Arkansas. The overall objective of this study was to better understand the hydrologic and geomorphic influence on the floodplain forest. We used the HEC-RAS model to quantify hydrologic relationships within the floodplain before and after 1930s river modifications. The model can replicate flooding within 3-5 m. Despite river modifications, HEC-RAS modeling showed headwater floods influenced the upper reach of the floodplain while backwater floods from the Mississippi River influenced the lower reach of the floodplain. Post-1930s incision that occurred from the confluence to the middle reach of the lower floodplain reduced the flooding extent primarily in frequent (< 5-year return interval) headwater floods. In contrast, incision only reduced flooding extent in the smallest (1-year return interval) backwater floods, and larger backwater events were largely unaffected. Modeled flooding regimes for PNV classes were more distinguishable among floodplain reaches than among PNV classes. The upper reach in the floodplain flooded more often from headwater floods, but the lower reach in the floodplain flooded deeper by backwater floods. Post-1930s incision reduced flooding depth and flooding extent the most in the riverine backwater upper zone , riverine backwater lower zone, and riverine overbank natural levee classes. The largest reductions in flooding depth and extent within these classes occurred during the more frequent floods, which are most important for ecological processes.

Chapter 1
Introduction

Complex fluvial geomorphic processes form floodplains (Nanson and Croke, 1992). River systems continuously respond to geomorphic and hydrologic changes to maintain dynamic equilibrium between water quantity and sediment load (Leopold and Maddock, 1953). Changes to the fluvial or geomorphic setting cause disturbances to the floodplain forest composition (Gurnell, 1995; Ward et al., 1999). Natural disturbances and variations in the hydrologic regime and river morphology help floodplain forests maintain high tree species diversity (McKnight, et al. 1981; Tockner and Standford, 2002). Vegetation composition within floodplain forests reflects individual responses of plant species to variations with hydrology (Wharton et al., 1982) and can be delineated into classes with similar soil types, geomorphology, and hydrology (Klimas et al., 2009).

Anthropogenic disturbances have severely altered the hydrologic and geomorphic processes that influence floodplain forests (Steiger et al., 2005). The hydrologic regime strongly influences vegetation communities that make up the forest composition (Junk et al., 1986; Ward et al., 1999; Tockner and Stanford, 2002). Variability in the flood regime such as flood frequency, duration, timing, and magnitude result in a mix of vegetation species with various germination times and various tolerance levels to flooding disturbance (Bornette and Armoros, 1996). Dams reduce the variability in the flood regime by reducing high flows and increasing low flows. A stabilized flooding regime reduces species diversity by continuously favoring certain species fit for that flood regime (Huston, 1979). River meander cutoffs increase water velocity which causes incision which also affects flood regime by eroding the channel bed reducing river connectivity to the floodplain. Reduced flooding due to loss of connectivity favors species that are adapted to fewer disturbances and do not require flooding for colonization or reproduction (Bendix and Hupp, 2000).

The White River is a tributary of the Mississippi River that has been affected by the geomorphic changes in the Mississippi River and also river modifications in the upper White River watershed. The

lower White River flows through a diverse floodplain forest that has been designated as a Ramsar Wetland of International Importance. Meander cutoffs in the Mississippi River shortened the length and steepened the gradient of the Mississippi River increasing water velocity triggering channel incision. The incision in the of the Mississippi then propagated upstream on the White River approximately 2-3 m at the confluence of the White and Mississippi rivers (Biedenharn and Watson, 1997) . Incision in the White River has migrated upstream to approximately the Big Creek confluence near St. Charles (Figure 1.1) (Schumm and Spitz, 1996). Modifications in the upper White River watershed include hydroelectric dams on the main channel of the White River and channelization of the Cache River, a major tributary to the White River (US Army Corps of Engineers, 1974).

Geomorphic and hydrologic modifications could change the flooding within the lower White River floodplain. An understanding of the hydrogeomorphic controls that influence the lower White River floodplain will provide insight on how geomorphology influences the hydrology within the floodplain and how hydrology structures the floodplain vegetation composition.

Quantifying changes in flooding extent before and after geomorphic changes can reveal patterns and relationships between geomorphic and hydrologic processes that influence the lower White River floodplain. Quantifying the hydrologic relationships among and within vegetation associations can reveal patterns and relationships that give insight as to how hydrology relates to distribution of vegetation. If we can characterize flooding characteristics of vegetation, we can estimate the location of various types of vegetation based on hydrology. Then assessments as to how changing hydrology could potentially change vegetation distribution due to hydrologic modifications in the White River. Also, quantifying hydrologic relationships can help identify changes in flooding depth and extent in each vegetation class to determine the impacts from the river modifications in the lower White River.

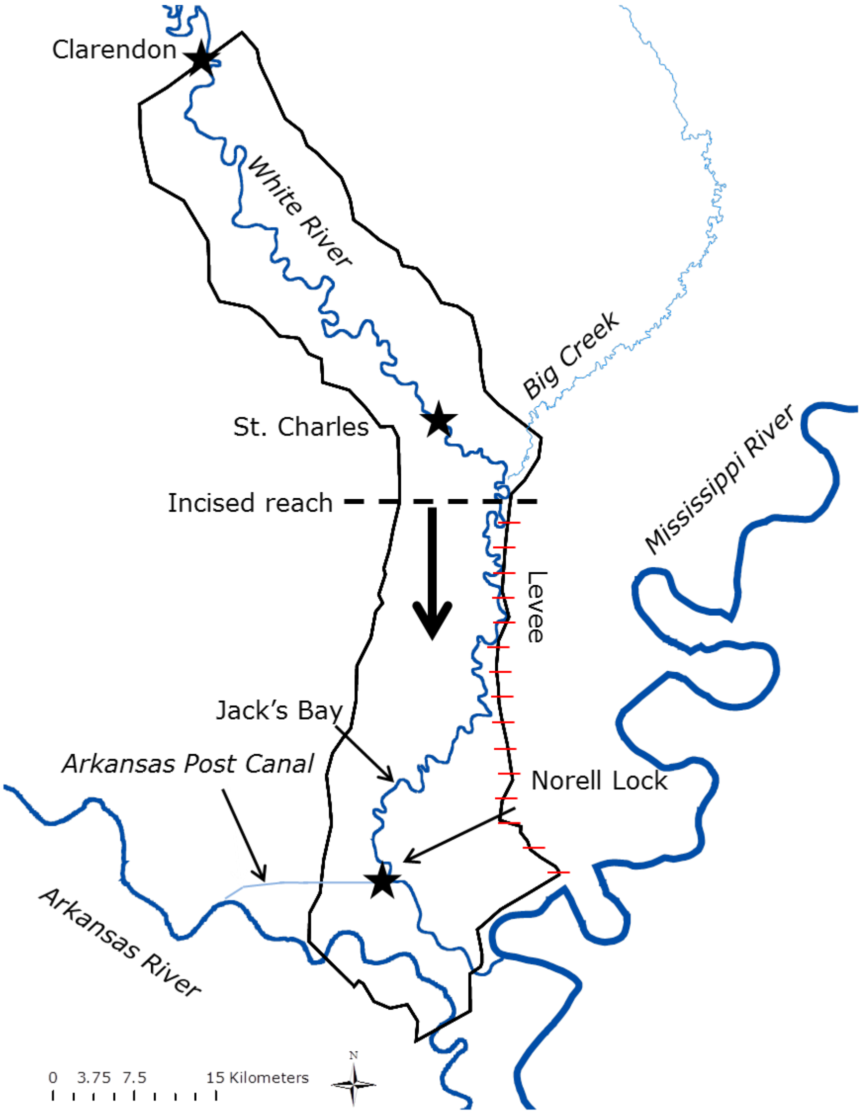


Figure 1.1. Lower White River study area in relation to Big Creek, Arkansas River, and Mississippi River. A levee (red dashed) confines the floodplain in the incised reach. Stars are river gauges.

Hydraulic modeling is a useful tool to quantify hydrologic relationships with vegetation and identify changes to flooding characteristics as a result of geomorphic change. One-dimensional (1D) hydraulic models such as HEC-RAS are widely used for river analyses and floodplain mapping (Tayefi et al. 2007). This study used the HEC-RAS model for the lower White River to quantify changes in hydrology and hydrologic relationships in vegetation in the floodplain.

The overall objective of this study is to better understand the hydrologic and geomorphic controls on floodplain forests. The specific objective of Chapter 2 is to determine changes in flooding extent in the

lower White River floodplain by modeling pre- and post-incision scenarios that reflect hydrogeomorphic changes. The specific objectives of Chapter 3 are(1) to determine whether the channel-parameterized HEC-RAS model can be used to replicate hydrologic relationships in the floodplain; (2) to use HEC-RAS to quantify current flooding characteristics among and within vegetation within the lower White River floodplain to identify hydrologic relationships that shape forest composition and vegetation distribution; and (3) to use HEC-RAS to quantify changes in flooding depth and flood extent before and after incision occurred on the White River to estimate the impacts incision has had on forest composition.

References – Chapter 1

Biedenharn, D., Watson, C., 1997. Stage adjustment in the lower Mississippi River, USA. Regulated Rivers: Research & Management, 13(6), 517-536.

Bendix, J., & Hupp, C. R. 2000. Hydrological and geomorphological impacts on riparian plant communities. Hydrological Processes, 14, 2977-2990.

Bornette, G., Amoros, C., 1996. Disturbance regimes and vegetation dynamics: role of floods in riverine wetlands. Journal of Vegetation Science, 7(5): 615-622.

Gurnell, A., 1995. The hydrological and geomorphological significance of forested floodplains. In Changing River Channels, Gurnell AM, Petts GE (eds). Wiley: Chichester, 237±260.

Huston, M., 1979. A general hypothesis of species diversity. American naturalist: 81-101.

Junk, W., Bayley, P., Sparks, R. 1989. The flood pulse concept in river-floodplain systems. Canadian Special Publication of Fisheries and Aquatic Sciences 106: 110-127.

Klimas, C., Murray, E., Foti, T., Pagan, J., Williamson, M., & Langston, H. 2009. An ecosystem restoration model for the Mississippi Alluvial Valley based on geomorphology, soils, and hydrology. Wetlands, 29(2), 430-450.

Leopold, L., and Maddock, T., 1953, The hydraulic geometry of stream channels and some physiographic implications: U.S. Geological Survey Professional Paper 252.

McKnight, J.S., Hook, D.D., Langdon, O.G. and Johnson, R.L., 1981. Flood tolerance and related characteristics of trees of the bottomland forests of the southern United States. In: J.R. Clark and J. Benforado (Editors), Wetlands of Bottomland Hardwood Forests. Elsevier, Amsterdam/Oxford/New York, pp. 29-69.

Nanson, G.and Croke, J. 1992. A genetic classification of floodplains. In: G.R. Brakenridge and J. Hagedorn (Editors), Floodplain Evolution. Geomorphology, 4, 459-486.

Schumm, S., Spitz, W., 1996. Geological influences on the Lower Mississippi River and its alluvial valley. Engineering Geology, 45(1), 245-261.

Steiger, J., Tabacchi, E., Dufour, S., Corenblit, D. & Peiry, J.L. (2005) Hydrogeomorphic processes affecting riparian habitat within alluvial channel-floodplain river systems: A review for the temperate zone. River Research and Applications, 21, 719– 737.

Tayefi, V., Lane, S., Hardy, R., Yu, D., 2007. A comparison of one and two dimensional approaches to modelling flood inundation over complex upland floodplains. Hydrological Processes, 21(23), 3190-3202.

Tockner, K., & Stanford, J. A. 2002. Riverine flood plains: present state and future trends. Biological Sciences Faculty Publications. Paper 166.

U.S. Army Corp of Engineers. 1974. Cache River Basin Project: Final Environmental Impact Statement. U.S. Army, Memphis District, Corp of Engineers, Memphis, TN, USA.

Ward, J. V., Tockner, K., & Schiemer, F. 1999. Biodiversity of floodplain river ecosystems: ecotones and connectivity. Regulated Rivers: Research & Management, 151, 125-139.

Wharton, C. H., W. M. Kitchens, E. C. Pendleton, and T. W. Sipe. 1982. The ecology of bottomland hardwood swamps of the southeast: a community profile. Report prepared for National Coastal Ecosystems Team. US Fish and Wildlife Service Biological Services Progam FWS/ OBS-81/37. Washington, DC.

Chapter 2
Modeling Hydrologic Changes Due to Geomorphic Modifications in the Lower White River, Arkansas

Introduction

Complex fluvial and geomorphic processes form floodplains (Nanson and Croke, 1992). River systems continuously respond to geomorphic and hydrologic changes to maintain dynamic equilibrium between water quantity and sediment load (Leopold and Maddock, 1953). Rivers attain equilibrium primarily by aggrading or degrading channel slope to provide enough water velocity required for transporting the drainage basin sediment load from upstream to downstream (Mackin, 1948). The constant adjustments to the river system influence the surrounding floodplain ecosystems. Changes to the fluvial or geomorphic setting cause disturbances to the floodplain forest composition (Gurnell, 1995; Ward et al., 1999). Natural disturbances and variations in the hydrologic regime and river morphology help floodplain forests maintain high tree species diversity (Tockner and Standford, 2002).

Anthropogenic disturbances have altered the hydrologic and geomorphic processes of river systems (Steiger et al., 2005). Dams, for example, reduce the variability in the flooding regime (Simon, 1989; Magilligan and Nislow, 2005). A homogenous flooding regime selects for the same species reducing species diversity (Bornette and Amoros, 1996) or alters the hydrology there is a significant change in vegetation communities (Oswalt and King, 2005). Channelization increases water velocity which incises the river bed (Simon, 1989). A lower bed elevation increases the elevation difference between river and floodplain reducing flooding. Overbank flows are required for the transfer of nutrients, organic matter, and sediment that influence species composition in floodplain ecosystems (Amoros and Roux, 1988; Ward, 1998). Less flooding reduces these interactions decreasing the species diversity and heterogeneity in the floodplain (Ward, 1998).

The Mississippi River has been highly modified (Kesel, 2003) with river modifications starting as early as the seventeenth century with levee construction for flood control (Schumm and Winkley, 1994). In the 1930s and 1940s, the Mississippi River and Tributary Project shortened the lower Mississippi River

30% for navigation and flood control through cut-offs and dredging (Biendenharn and Watson, 1997), thereby increasing the water velocity at the location of cutoff and downstream of the cutoff. Increased velocity downstream increased the amount of sediment the river can transport downstream (Lane, 1947). To satisfy a larger sediment carrying capacity, the higher velocity eroded the Mississippi River channel downstream of the cutoff lowering the elevation of the channel bed. This also stimulated entrenchment upstream of the cutoff as the channel slope incised to re-establish equilibrium with the lower channel elevation.

The decreased elevation of the Mississippi River bed also stimulated channel adjustment of the tributaries of the Mississippi River including a 2-3 m adjustment of the White River. Incision in the White River has migrated upstream to approximately the Big Creek confluence near St. Charles (Figure 1.1) (Schumm and Spitz, 1996). In addition to the incision stimulated by the entrenchment of the Mississippi River, the upper reach of the White River watershed is affected by hydroelectric dams in the main channel of the White River and channelization of the Cache River, a major tributary to the White River (US Army Corps of Engineers, 1974).

Quantifying changes in flooding extent before and after geomorphic changes can reveal patterns and relationships between geomorphic and hydrologic processes that influence the lower White River floodplain. Hydraulic modeling is a useful tool to quantify changes in flooding extent in response to geomorphic change. One-dimensional (1D) hydraulic models such as HEC-RAS are widely used for river analyses and floodplain mapping (Tayefi et al. 2007). While higher-dimensional models offer improved precision, 1D models like HEC-RAS require less precise data and have been found to equally predict flood extent as 2D models (Horritt and Bates, 2002; Pappenberger et al. 2005) and can easily be adjusted for different hydrologic and geomorphic scenarios.. Gergel et al. (2002) used HEC-RAS to

The overall objective of this study is to understand how geomorphic processes influence hydrologic processes in the lower White River floodplain forest. The specific objective here is to determine changes in flooding extent in the lower White River floodplain by modeling pre- and post-incision scenarios that reflect hydrogeomorphic changes.

Methods

Study Site

The lower White River is in southeastern Arkansas. The confluence of the White River and Mississippi River is north of the Arkansas-Mississippi River confluence (Figure 1.1). The floodplain in the lower White River is in the Dale Bumpers White River National Wildlife Refuge (DBWRNWR). Flooding occurs regularly on the floodplain of the White River by either headwater floods or backwater floods from the Mississippi River.

Hydraulic model

A HEC-RAS model parameterized for the White River by Lin (undated, unpublished report to the USACE Memphis District) consisted of channel cross-sections from a 2009 hydrographic survey performed by the USACE. The floodplain digital elevation model (DEM) was a composite of the USGS 10 m DEM and the Arkansas State 5 m DEM. Manning's *n* roughness coefficients for the floodplain and channel maximize agreement between observed and modeled channel flows 1965-2009. The model boundary includes the lower White River floodplain a levee southeast of St. Charles (Figure 1.1) and a terrace above St. Charles that confine flooding in the eastern portion of the floodplain. A terrace also confines flooding in the west side of the floodplain.

We modeled three scenarios to estimate floodplain inundation: current geomorphology and two hypothetical historic conditions prior to incision to bracket the range of uncertainty in magnitude of change. The historic scenarios were constructed by generalizing channel dimensions to conditions before incising either 2.1 m (low incision scenario) or 3.5 m (high incision scenario) at the Mississippi River, based on the limits of estimated incision by Schumm and Spitz (1996), Biedenharn and Watson (1997), and Shaffner (2012).

Estimating pre-incision channel dimensions

To model idealized pre-incision conditions, we modified current channel cross-sections using historical estimates of changes in depth and width, but the current channel location was not altered. We adjusted channel thalweg long profiles to pre-incision conditions by linearly interpolating between either

2.1 m or 3.5 m of incision at the confluence upstream to zero meters of incision at the Big Creek confluence just south of St. Charles (Figure 1.1). We then added the interpolated depth to the 2009 thalweg elevation to create estimated pre-incision thalweg profiles. To estimate channel width changes, we measured channel widths every 0.5 km from Clarendon to the Arkansas Post Canal on U.S Geological Survey (USGS) topographic maps from 1940 and on 2010 aerial photos. Channel locations were different in 1940 because of meandering so it was not possible to directly adjust channel widths to pre-incision conditions. Instead we generalized the channel width change from 1940 to 2010 using LOWESS smoothing (Cleveland, 1981) to model channel width change from 1940-2010. We used the same generalized channel widths for both the 2.1 m incision scenario and 3.5 m scenario. We modified channel cross-sections for both pre-incision scenarios by maintaining the location and shape of the current cross-section but proportionally adjusting each point in the cross-sectional diagram to the pre-incised thalweg elevation and channel width.

Modeling flood extents

For each of the three geomorphic scenarios, we modeled two types of flooding: pure headwater floods from the White River and pure backwater floods from the Mississippi River. Even though these two events never happen separately, the goal of the simulations was to estimate effects separately.

We ran the model for headwater floods with the three geomorphic scenarios. Flood return intervals for the 1-year (1,634 cms), 1.5-year (1,943 cms), 5-year (3,194 cms), 10-year (3,882 cms), and 32-year (7,552 cms) headwater floods were calculated using the Weibull plotting position of annual peak flow at the Clarendon gauge from 1983-2013. We used return interval flows for the upstream conditions. Because the Mississippi River stage can be high enough to backup flood waters, thus reducing the slope of the water surface elevation, we used normal depth as the downstream condition; i.e., the slope of the water surface elevation was parallel to the slope of the channel bed to eliminate the reduction of slope due to backwater flooding. We exported results to HEC-GeoRAS to model extent of inundation and flood depth for the three geomorphic scenarios.

We modeled backwater floods by calculating return intervals of stage for the 1-year (42.7 m), 1.5-year (46.0 m), 5-year (48.2 m), 10-year (48.8 m), and 32-year (51.8 m) floods using the Weibull plotting position of annual maximum stage of the Mississippi River at the confluence with the White River from the same time period (1983-2013). There was no long-term gauge data at the confluence so we interpolated stage between gauges at Helena, AR (USACE MS133) and Arkansas City, AR (USACE ARSA4) by a null model assuming linear hydraulic slope between Helena and Arkansas City. We corrected the null model for non-linearity using the relationship between null-modeled stages and observed stages at the Norrell Lock and Dam (Lock 1) gauge at the confluence of the Arkansas River Post Canal and White River (Figure WR) for 2005-2013 (dates gauge was in operation) (Figure 2.1). Because flood events were of interest, the model conditioning was restricted to periods of flooding (> 42 m).

To model backwater floods before incision, we added 2.1 m or 3.5 m to the stage at each return interval. For all three scenarios, we assumed all surface elevations below the corresponding water surface elevations were flooded, and that there was no contribution of headwater flow to flooding. To map the extent of inundation and flood depth, we assumed all land below the flood elevation was flooded.

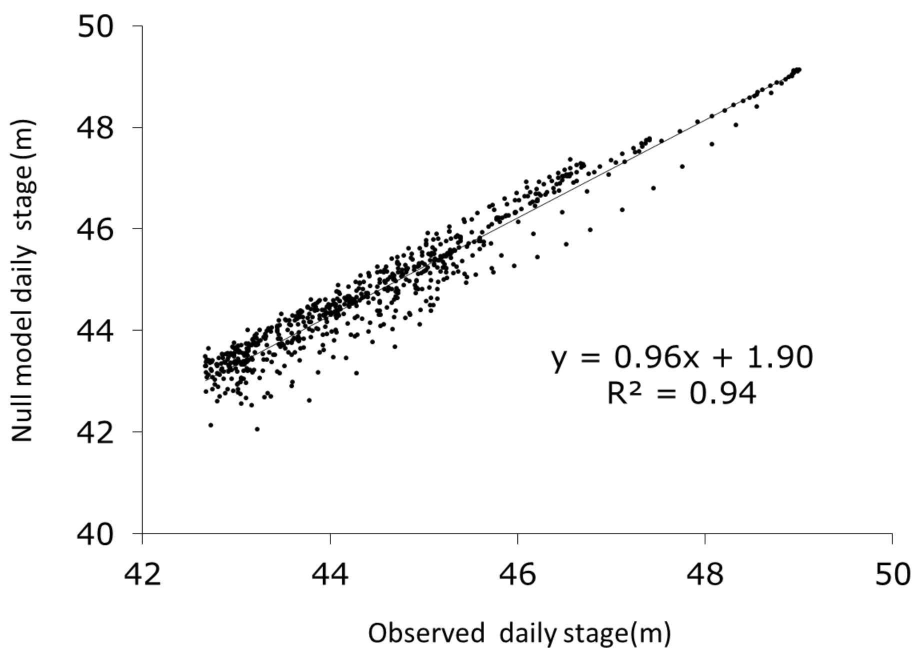


Figure 2.1. Relationship between observed daily stage at Norrell Lock 1 and null model daily stage interpolated between Helena, AR and Arkansas City, AR.

Results

Channel width change

Channel width change between 1940 and 2010 varied between Clarendon, AR and the Arkansas Post Canal (Figure 2.2). Channel width started to increase in the incised reach just above the knickpoint (~82 km south of Clarendon).

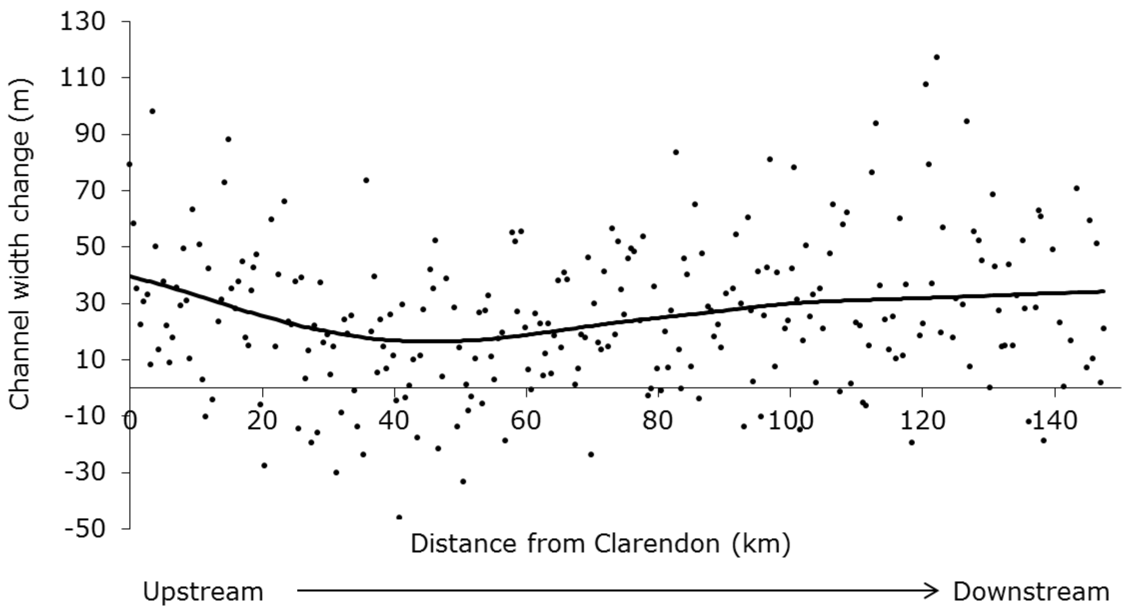


Figure 2.2. Channel width change between 1940 and 2010 between Clarendon (0 km) and Arkansas Post Canal (150 km) measured (dots) and generalized (line) with LOWESS smoothing ($\alpha = 0.5$). The knickpoint is at 82 km.

Headwater flooding

Modeling of headwater floods indicated that frequent floods inundate most of the floodplain in the unincised reach, but even the largest, 32-yr headwater flow did not completely flood the incised reach (Figure 2.3). Most of the reduction in total flooded area (i.e., flood extent) caused by incision occurred in the incised reach (Figure 2.3).

The greatest differences in total flooded area before and after incision occurred in the more frequent floods (Figures 2.3 and 2.4). Total flooded area in the 1-year flood decreased 20% after 2.1 m of incision and total flooded area decreased 25% after 3.5 m of incision (Figure 2.4). The area in the incised reach

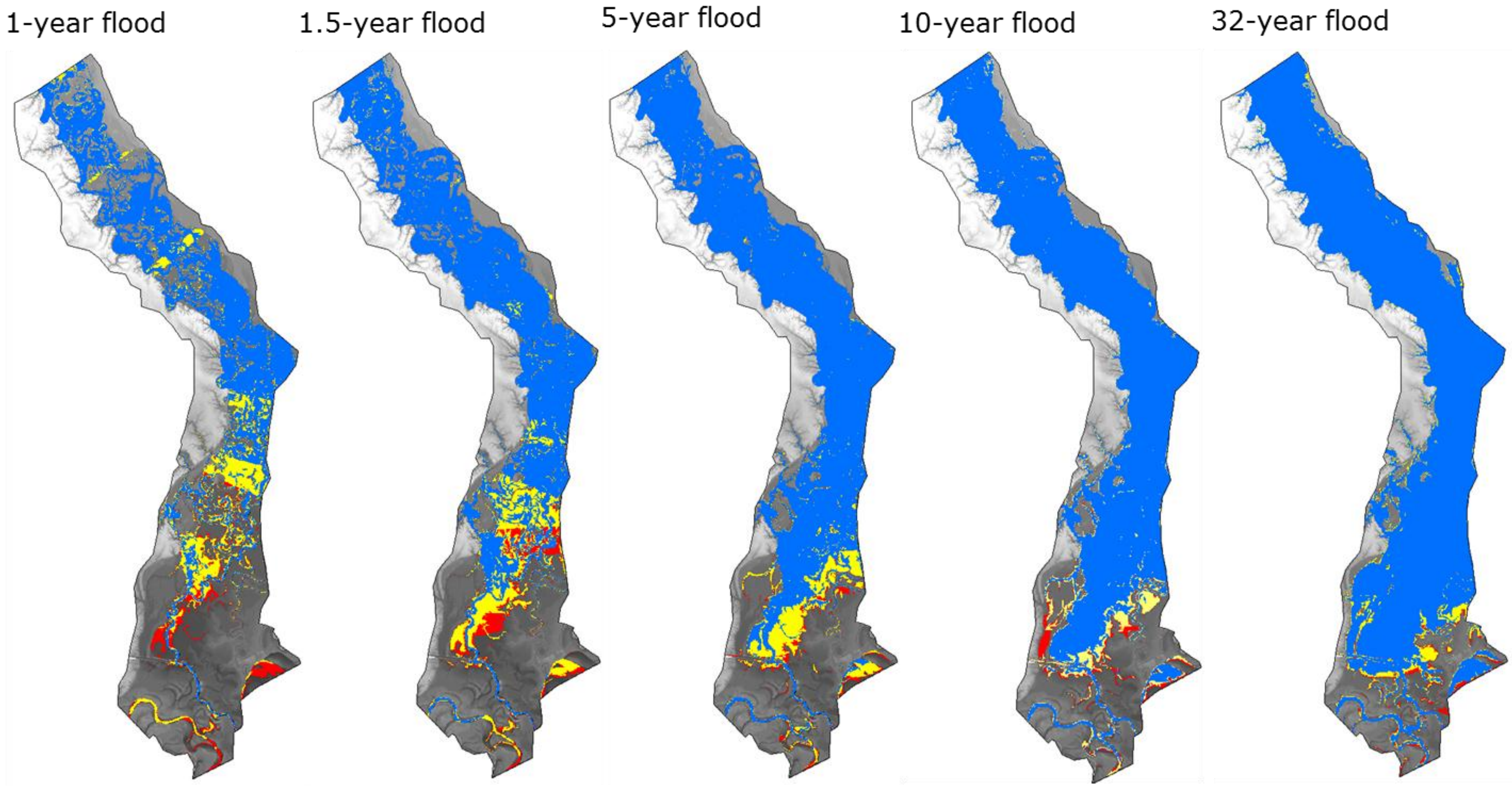


Figure 2.3. Total flood extent during a headwater flood for 2009 conditions (blue), before 2.1 m of incision (yellow), and before 3.5 m of incision (red).

during the 1-year flood decreased 35% after 2.1 m of incision and 44% after 3.5 m of incision (Figure 2.4). Infrequent floods have only a slight decrease in total flooded area after incision compared to pre-incision flood extent with only a decrease in flooded area of 4-5% in the 32-year flood (Figure 2.4).

The discontinuity in flooding extent (distinct lines) in the 1-year and 1.5-year flood extent (Figure 2.3) is an artifact of modeling because of shallow depths on the floodplain between cross-sections. The model does not have a fine enough scale to represent the localized floodplain connections. Therefore, the model may not be precise in the low magnitude floods so the inundated areas may not be precise, but remains accurate. However, the general flood trends still are relevant.

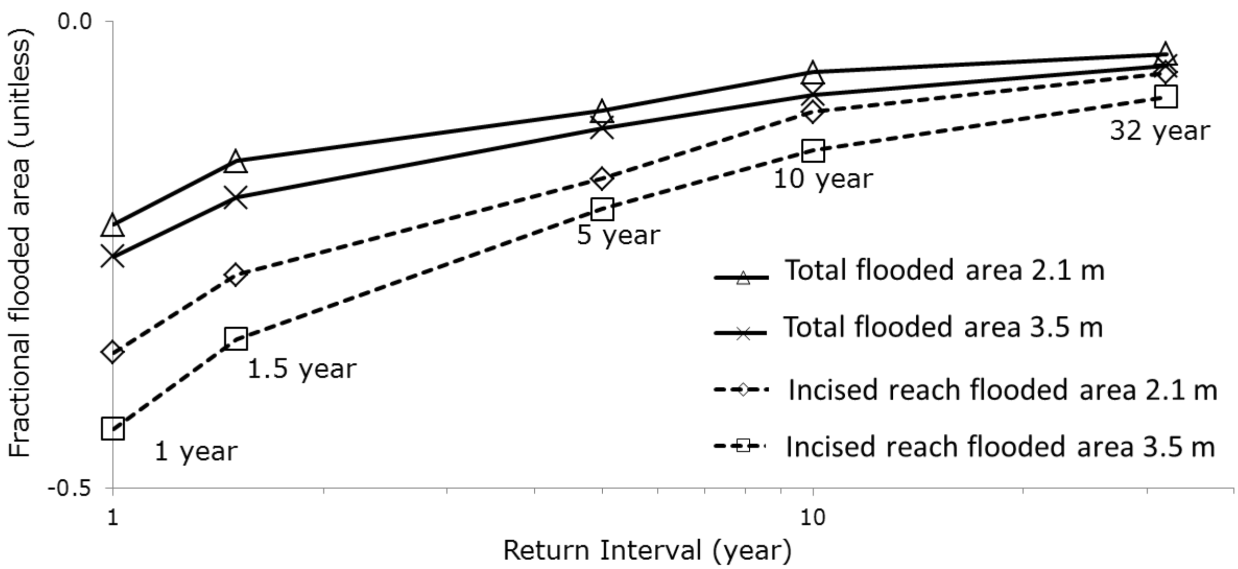


Figure 2.4. Fractional total flooded area and fractional flooded area in the incised reach during headwater floods after 2.1 m or 3.5 m of incision occurred

.

<u>Backwater flooding</u>

Modeling of backwater floods indicated incision reduced backwater flood extent in the unincised reach in all but the largest event, and mainly affected the incised reach in the 1-year flood (Figure 2.5). In contrast to headwater floods, backwater floods did inundate the lowermost sections of the floodplain (Figure 2.5). The largest backwater floods inundated the entire floodplain to the upstream limit of the study area. The regions inundated by headwater and backwater floods overlapped near the middle of the study area (Figures 2.3 and 2.5).

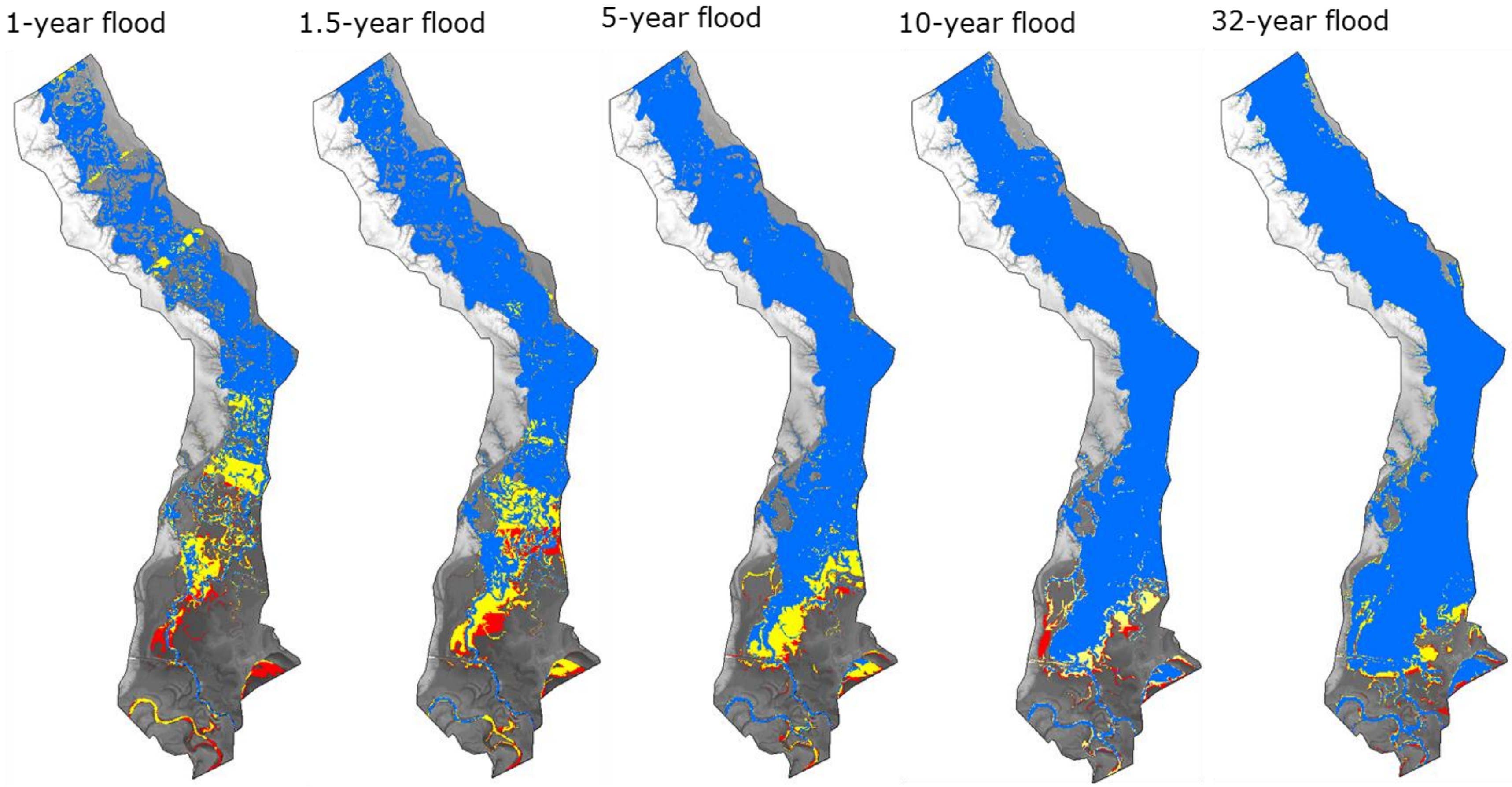


Figure 2.5. Total inundated area during a backwater flood for 2009 conditions (blue), before 2.1 m of incision (yellow), and before 3.5 m of incision (red).

The largest proportional decrease in total flooded area occurred in the 1-year flood (Figure 2.5, Figure 2.6). Total flooded area in the 1-year flood decreased 58% after 2.1 m of incision (Figure 2.6). Total flooded area decreased 73% after 3.5 m of incision (Figure 2.6). In just the incised reach, flooded area decreased 60% after 2.1 m of incision and 71% after 3.5 m of incision in the 1-year flood (Figure 2.6).

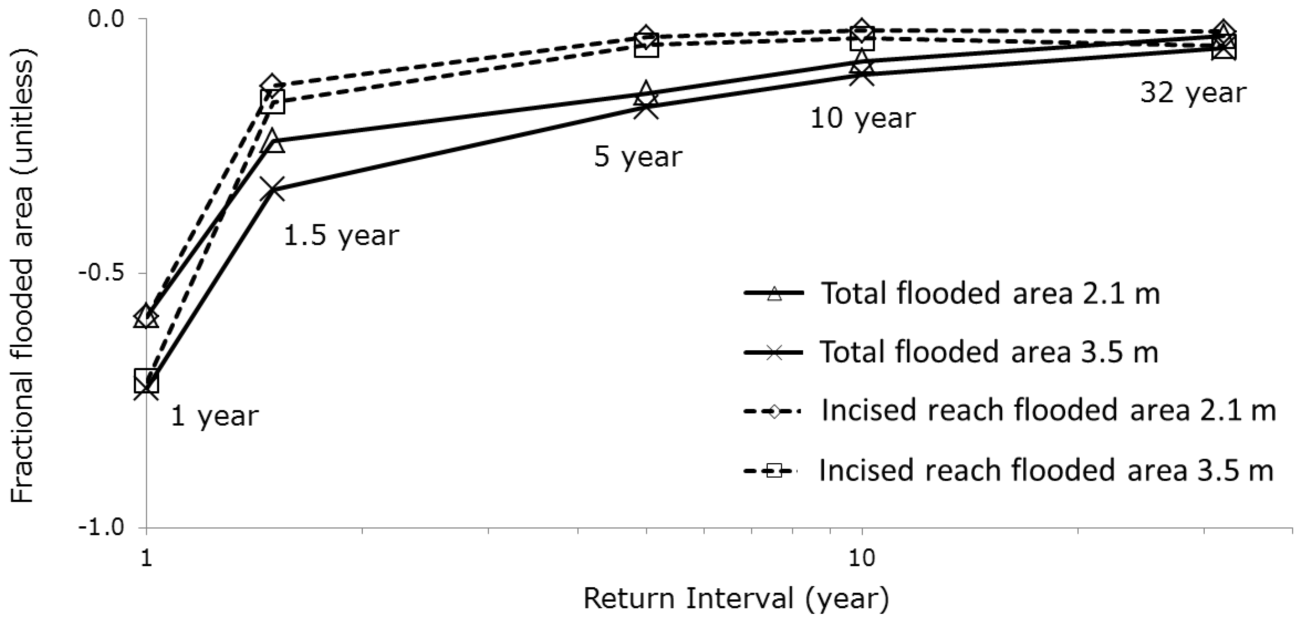


Figure 2.6. Fractional total flooded area and fractional flooded area in the incised reach during backwater floods after 2.1 m or 3.5 m of incision occurred.

Discussion

The results of this study indicate that geomorphic alterations to rivers can be transmitted throughout the watershed and affect overbank flooding patterns. Flooding in the incised reach of the lower White River channel has reduced flooding extent in more frequent floods. The overlap in the headwater-dominated reach and backwater-dominated reach indicates that the greatest impact of incision on the amount of flooded area was during the 1-year flood. The 1-year flood is important for the maintenance of the physical setting of the river (Wollman and Miller, 1960; Tockner et al., 1999) and is critical in influencing vegetation composition (Casanova and Brock, 2000, Townsend, 2001). Therefore, a loss of flooding during the 1-year flood in the incised reach could result in altered geomorphic processes and ecosystem change. Loss of flooding in the incised reach could also reduce the diversity of floodplain species as more upland species outcompete floodplain species. However, seasonality, duration, and depth

are other major factors in the hydrologic regime that also influence vegetation composition (Poff et al., 1997) but were not considered in this study.

Since we accounted for two geomorphic changes (channel widening through the entire lower White River and channel depth through the incised reach of the river), we determined changes in channel depth had more of an influence on the changes in flooding extent than did channel widening. If the channel widening had a larger effect, there would have been reduced flood extent from headwater floods in the unincised reach where channel depth did not change.

Based on results of modeling flows in pre-1930s geomorphic conditions, headwater floods likely did not generate frequent flooding in the lower reach even before incision. Alternatively, the lack of headwater flooding in the lower portion could be an artifact of incorrect assumptions about pre-incision conditions. We generalized the pre-incision geomorphic conditions since we could not be certain of the exact characteristics of the channel before incision. However, changes on the White River are more complex than simply incision caused by base-level lowering. Upstream dams and channelization have reduced sediment budgets (Kleiss, 1996) and flood magnitude (Bedinger, 1979). Even so, it is remarkable that the largest flood of 1983-2013 was apparently insufficient to generate headwater flooding at the confluence.

The lack of decrease in flooded area in the infrequent floods (Figures 4 and 5) could be due to the levee on the southeast side of the floodplain preventing propagation of floodwaters. Without the levee, the floodwaters would be able to inundate more of the area between the White River and Mississippi River. The confined floodwaters potentially increased flooding depth in the infrequent floods; however, it is difficult to attribute how much change in flooding depth there has been due to levees.

Backwater floods likely have had more influence on floodplain geomorphology in the lower reach than have headwater floods. It is also likely that backwater flow has always influenced the lowermost floodplain because the Mississippi River is a much bigger river that can easily overwhelm a smaller river such as the White. Thus, the lower White River floodplain potentially formed as a response to sediment transport in the presence of Mississippi River flow and sediments. The lowermost portion of

the modeling domain includes a former channel and natural levee of the Mississippi River as mapped by Fisk (1944), so it is probable that section has always been insusceptible to headwater flooding from the White River.

The modeled scenarios of incision and assumptions about floodplain development do not account for all downstream conditions that may have had significant influence on the lower boundary conditions for the White River. First, the White/Mississippi confluence zone also includes the confluence of the Arkansas River with the Mississippi River; the point of confluences among these three rivers has varied through time (Fisk, 1944). In addition, the Arkansas River carried a sediment load around 81 million metric tons until the construction of locks and dams from 1963-1970 decreased the average load to 10 million metric tons (Keown et al., 1986). The Arkansas River undoubtedly affected the geomorphic development of the confluence zone, but we modeled the effects of the Mississippi River because we assumed the large changes there likely overwhelmed any effects of the Arkansas River.

Secondly, previous work has given some insight on hydrologic changes at the confluence, but there is conflicting evidence about the nature and magnitudes of changes. Heine and Pinter (2012) found an increase in flood stage following levee construction, but channel incision resulting from confined flow and channel cutoffs may have offset some of the increase in flood stage (Remo et al. 2009). Finally, the Mississippi River has had reduced sediment yield from river modifications (Keown et al. 1986), which suggests the backwater now has less geomorphic influence than it once did on the lower White River. Uncertainties in the configuration of the Mississippi River prior to extensive modifications prevent fine interpretation pending more detailed work on, for example, stratigraphy of the lowermost floodplain of the White River.

Conclusions

Headwater floods dominate the unincised, upper reach of the floodplain while backwater floods dominate the unincised, lower, reach of the floodplain. Incision caused the greatest reduction in flood extent in the more frequent, headwater floods, and most of the reduced area of inundation occurred in the incised, lower reach. Incision decreased flood extent in the 1-year and 1.5-flood in backwater floods but

not in larger events. Prior to incision the 1-year flood had approximately double the total area flooded than the 1.5-year flood. Most of the reduction in flooded area from backwater events occurred in the unincised reach.

References – Chapter 2

Amoros, C. & Roux, A.L. 1988. Interaction between waterbodies within the floodplains of large rivers: function and development of connectivity. In: Schreiber, K. (ed.) Connectivity in landscape ecology. Münstersche Geogr.Arb, 29, 125-129.

Bedinger, M., 1971. Forest species as indicators of flooding in the lower White River Valley, Arkansas. US Geological Survey Professional Paper, 750-C 248-253.

Biedenharn, D., Watson, C., 1997. Stage adjustment in the lower Mississippi River, USA. Regulated Rivers: Research & Management, 13(6), 517-536.

Bornette, G., Amoros, C., 1996. Disturbance regimes and vegetation dynamics: role of floods in riverine wetlands. Journal of Vegetation Science, 7(5): 615-622.

Casanova, M. T., & Brock, M. A. 2000. How do depth, duration and frequency of flooding influence the establishment of wetland plant communities?. Plant Ecology, 1472, 237-250.

Cleveland, W., 1981. LOWESS: A program for smoothing scatterplots by robust locally weighted regression. American Statistician, 83, 828-836.

Fisk, H., 1944. Geological investigations of the alluvial valley of the Lower Mississippi River: Vicksburg, Mississippi River Commission. 78p

Gurnell, A., 1995. The hydrological and geomorphological significance of forested floodplains. In Changing River Channels, Gurnell AM, Petts GE (eds). Wiley: Chichester, 237±260.

Heine, R., Pinter, N., 2012. Levee effects upon flood levels: an empirical assessment. Hydrological Processes, 26(21), 3225-3240.

Horrit, M., and Bates, P. Evaluation of 1D and 2D numerical models for predicting river flood inundation. Jounral of Hydrology. 268(1), 87-99.

Kesel, R., 2003. Human modifications to the sediment regime of the Lower Mississippi River flood plain. Geomorphology, 56(3), 325-334.

Keown, M.P., Dardeau, E.A., Causey, E.M., 1986. Historic trends in the sediment flow regime of the Mississippi River. Water Resources Research, 22(11), 1555-1564

Kleiss, B.A., 1996. Sediment retention in a bottomland hardwood wetland in eastern Arkansas. Wetlands, 16(3): 321-333.

Lane, E.W., 1947. The effect of cutting off bends in rivers. University of Iowa Studies in Engineering. Proceedings of the Third Hydraulics Conference, Bulletin 31, University of Iowa, Iowa City, Iowa, pp. 239–240.

Leopold, L., and Maddock, T., 1953, The hydraulic geometry of stream channels and some physiographic implications: U.S. Geological Survey Professional Paper 252.

Lin, Liu. Final Report: White River Basin Comprehensive Study: Development of Unsteady-State Model. Unpublished report to US Army Corps of Engineers. http://www.mvm.usace.army.mil/Portals/51/docs/PPPMD/White%20River%20Study/unsteady-state_model_wrb.pdf

Llewellyn, D.W., Shaffer, G.P., Craig, N.J., Creasman, L., Pashley, D., Swan M. & Brown, C. 1996. A decision-support system for prioritizing restoration sites on the Mississippi River alluvial plain. Conservation Biology, 10,1446–1455.

Mackin, J.H., 1948. Concept of the graded river. Bull. Geol. Soc. Am. 59, 463–512.

Magillian F., and Nislow, K. 2005. Changes in hydrologic regime by dams. Geomorphology. 71, 61-78.

Nanson, G.and Croke, J. 1992. A genetic classification of floodplains. In: G.R. Brakenridge and J. Hagedorn (Editors), Floodplain Evolution. Geomorphology, 4, 459-486.

Oswalt, S. and King, S. 2005. Channelization and floodplain forests: Impacts of accelerated sedimentation and valley plug formation on floodplain forests of the Middle Fork Forked Deer River, Tennessee, USA. Forest Ecology and Management. 215, 69-83.

Poff, N., Allan, J., Bain, M., Karr, J., Prestegaard, K., Ricter, B., Sparks, E., and Stromberg. J. 1997. The natural flow regime. BioScience, 47, 769-784.

Remo, J., Pinter, N., Heine, R., 2009. The use of retro-and scenario-modeling to assess effects of 100+ years river of engineering and land-cover change on Middle and Lower Mississippi River flood stages. Journal of Hydrology, 376(3), 403-416.

Schumm, S., Spitz, W., 1996. Geological influences on the Lower Mississippi River and its alluvial valley. Engineering Geology, 45(1), 245-261.

Schumm, S., Winkley, B., 1994. The variability of large alluvial rivers. ASCE Press.

Simon, A. 1989. The discharge of sediment in channelized alluvial streams. Water Resource Bulletin. 25, 1177-1188.

Shaffner, A. 2012. Specific gage analysis on the lower White River, Arkansas. A Thesis. Southern Illinois University of Carbondale.

Steiger, J., Tabacchi, E., Dufour, S., Corenblit, D. & Peiry, J.L. (2005) Hydrogeomorphic processes affecting riparian habitat within alluvial channel-floodplain river systems: A review for the temperate zone. River Research and Applications, 21, 719– 737.

Tayefi, V., Lane, S., Hardy, R., Yu, D., 2007. A comparison of one and two dimensional approaches to modelling flood inundation over complex upland floodplains. Hydrological Processes, 21(23), 3190-3202.

Tockner, K., Stanford, J., 2002. Riverine flood plains: present state and future trends. Environmental conservation, 29(3), 308-330.

Townsend, P.A., 2001. Relationships between vegetation patterns and hydroperiod on the Roanoke River floodplain, North Carolina. Plant Ecology, 156(1): 43-58.

Twedt, D., Loesch, C., 1999. Forest area and distribution in the Mississippi Alluvial Valley: implications for breeding bird conservation. Journal of Biogeography, 26(6), 1215-1224.

U.S. Army Corp of Engineers. 1974. Cache River Basin Project: Final Environmental Impact Statement. U.S. Army, Memphis District, Corp of Engineers, Memphis, TN, USA.

Ward, J. 1998. Riverine landscapes: Biodiversity patterns, disturbance regimes, and aquatic conservation. Biological Conservation. 83(3), 269-278.

Ward, J., Stanford, J., 1995. Ecological connectivity in alluvial river ecosystems and its disruption by flow regulation. Regulated Rivers: Research & Management, 11(1), 105-119.

Ward, J., Tockner, K., & Schiemer, F. 1999. Biodiversity of floodplain river ecosystems: ecotones and connectivity. Regulated Rivers: Research & Management, 151, 125-139.

Wolman, M.G., Miller, J.P., 1960. Magnitude and frequency of forces in geomorphic processes. The Journal of Geology, 54-74.

Chapter 3
Modeling Relationships between Vegetation and Flooding Characteristics in the Lower White River Floodplain, Arkansas

Introduction

Floodplains are one the most diverse ecosystems due to high variability in the hydrologic regime (Tockner and Standford, 2002). Floodplain forests support the highest variation in tree species composition compared to other forest types (McKnight, et al. 1981). Vegetation composition is vital to the function of floodplain forests because it provides habitat for diverse wildlife species (Tockner and Standford, 2002). Vegetation composition also reflects individual responses of plant species to changes in hydrology (Wharton et al., 1982).

The hydrologic regime strongly influences vegetation communities that make up the forest composition (Junk et al., 1986; Ward et al., 1999; Tockner and Stanford, 2002). Variability in the flood regime such as flood frequency, duration, timing, and magnitude result in a mix of vegetation species with various germination times and various tolerance levels to flooding disturbance (Bornette and Armoros, 1996). Vegetation with similar soil types, flooding, and geomorphology delineate floodplain forests into vegetation classes (Wharton et al. 1982; Coller et al., 2000; Klimas et al. 2009). Understanding the hydrologic processes that influence vegetation patterns in floodplain forests is important because flooding is a primary factor influencing vegetation.

River modifications have altered the flooding regime and thus affected forest composition (Hughes, 1997; Hupp et al., 2009). Dams reduce variability in the flood regime by reducing high flows and increasing low flows. A stabilized flooding regime reduces species diversity by continuously favoring certain species fit for that flood regime (Huston, 1979). Channelization and incision also affect flood regime by reducing flooding in the floodplain. Reduced flooding favors species that are adapted to fewer disturbances and do not require flooding for colonization or reproduction (Bendix and Hupp, 2000).

The lower White River floodplain in southeastern Arkansas is one example of a diverse floodplain forest affected by river modifications. The river has been altered from modifications in the

Mississippi River and the upper part of White River. The floodplain is a Ramsar wetland of international importance and is the second largest tract of bottomland hardwoods in the United States (Twedt et al. 1999). Hydroelectric dams in the upper part of the watershed and channelization (US Army Corps of Engineers, 1974) threaten this important ecosystem. The lowering of the channel bed in the Mississippi River channel caused approximately 2-3 m of incision at the confluence. Incision has migrated upstream to approximately to the Big Creek confluence near St. Charles (Figure 1.1) (Schumm and Spitz, 1996). River modifications could change the flooding within the lower White River floodplain and alter the forest composition; thus it is important to understand the hydrologic relationships among and within vegetation.

There is little quantitative understanding of the flood processes that influence species composition of floodplain forests (Hughes, 1990). Klimas et al. (2009) delineated potential natural vegetation classes (PNV) in the lower Mississippi Alluvial Valley in Arkansas; Heitmeyer and Foti (2014) delineated vegetation classes for the study area, and identified six PNV classes in the lower White River floodplain (Table 1, Figure PNV). Relating these vegetation classes to flood regime can help identify if hydrology is enough to differentiate classes within the floodplain. Quantifying the hydrologic relationships among and within vegetation classes can reveal patterns and relationships that give insight as to how hydrology relates to vegetation distribution. If we can characterize flooding characteristics of vegetation, we can estimate the location of vegetation classes based on hydrology. Then assessments as to how changing hydrology could potentially change vegetation distribution due to hydrologic modifications in the White River. Also, quantifying hydrologic relationships can help identify changes in flooding depth and extent in each vegetation to determine the impacts from the river modifications in the lower White River.

Hydraulic modeling is a useful tool to quantify hydrologic relationships. One-dimensional (1D) hydraulic models such as HEC-RAS are widely used for river analyses and floodplain mapping (Tayefi et al. 2007). While higher-dimensional models offer improved precision, 1D models like HEC-RAS require less precise data (Pappenberger et al. 2005) and are more amenable to simple modification necessary for modeling the impacts to flood depth and extent from the river modifications in the White River. Lin

(unpublished report to USACE) parameterized a HEC-RAS model for the lower White River for in-channel flows. However, it is unknown how well the model replicates floodplain hydrology. First, usefulness of this model for evaluating eco-hydrological relationships to flooding depends on its ability to reproduce flood depths. If so, it is useful to quantify current hydrologic patterns among and within vegetation classes and for modeling effects of future hydrologic management scenarios on vegetation.

Our overall objective is to better understand the interactions between hydrology and forest composition to be able to understand the ecological responses of vegetation composition to flooding. The first objective of this study was to determine whether the channel-parameterized model can be used to replicate hydrologic relationships in the floodplain. The second objective was to use the model to quantify current flooding characteristics among and within vegetation within the lower White River floodplain to identify hydrologic relationships that shape forest composition and vegetation distribution. The third objective was to use the model to quantify changes in flooding depth and flood extent before and after incision occurred on the White River to estimate the impacts incision has had on forest composition.

Methods

Study Site

The lower White River is in southeastern Arkansas. The confluence of the White River and Mississippi River is north of the Arkansas-Mississippi River confluence (Figure 1.1). The floodplain in the lower White River is in the Dale Bumpers White River National Wildlife Refuge (DBWRNWR) which supports the largest black bear population in the Mississippi alluvial plain (Clark and Eastridge, 2006) and the second largest wintering mallard population in the USA (Johnsgard, 1961).

Flooding occurs from either headwater floods from the upper White River basin or backwater floods from the Mississippi River. A levee southeast of St. Charles (Figure 1.1) and a terrace above St. Charles confine flooding in the eastern portion of the floodplain. A terrace confines flooding in the west side of the floodplain.

The six PNV classes delineated by Heitmeyer and Foti (2014) in the White River floodplain are dominated by three main PNV classes with two sub-vegetation classes each (Table 1, Figure 3.1). The riverine overbank classes are mostly differentiated by geomorphic feature.

The Riverine Overbank Natural Levee (RONL) class consists of natural levees with typical dominate species included pecan, sugarberry and willow oak. Riverine Overbank Tributary Valley (ROTV) class is similar to natural levees only on smaller streams at higher elevations. Typical species of ROTV include nuttall oak, willow oak, and cherrybark oak. Riverine backwater subclasses are differentiated by elevation of the floodplain with respect to the river and are distinct in terms of species composition. The Riverine Backwater Lower Zone (RBLZ) class is nominally floods more frequently than every 2 years. Typical dominate species in RBLZ are overcup oak and bitter pecan. The Riverine Backwater Upper Zone (RBUZ) nominally floods every 3-5 years. Typical dominate species in RBUZ are nutall oak, willow oak and sugarberry. Geomorphic features subdivide the hardwood flats classes. The geomorphic feature is in their name: Hardwood Flats Holocene Point Bars and Backswamps (HFH) and Hardwood Flats Late Wisconsin Valley Train (HFLW). The typical dominant speces in HFH include cherrybark oak, water oak, and swamp chestnut oak. The HFLW class consists of sugar berry, cherrybark oak, and delta post oak. The HFH and HFLW classes are in the highest elevations and flood every 5+ years making them the driest classes.

Table 1. Potential natural vegetation classes in the lower White River floodplain.

Vegetation Class	Short ID*	Klimas et al. 2009 ID**	Area (km^2)
Riverine Backwater - Upper Zone	RBUZ	RB-2	228,717
Riverine Backwater - Lower Zone	RBLZ	RB-1	188,238
Riverine Overbank - Natural Levees	RONL	RO-2	84,768
Riverine Overbank - Tributary Valleys	ROTV	RO-3	63,809
Hardwood Flats - Late Wisconsin Valley Train	HFLW	F-3	71,584
Hardwood Flats - Holocene Point Bars and Backswamps	HFH	F-1	48,557

*Short name for PNV class in this chapter
**Short name for PNV class in Klimas et al. (2009)

Evaluation of HEC-RAS model

The HEC-RAS parameterized model for the White River by Lin (undated, unpublished report to the USACE Memphis District) consisted of channel cross-sections from a 2009 hydrographic survey

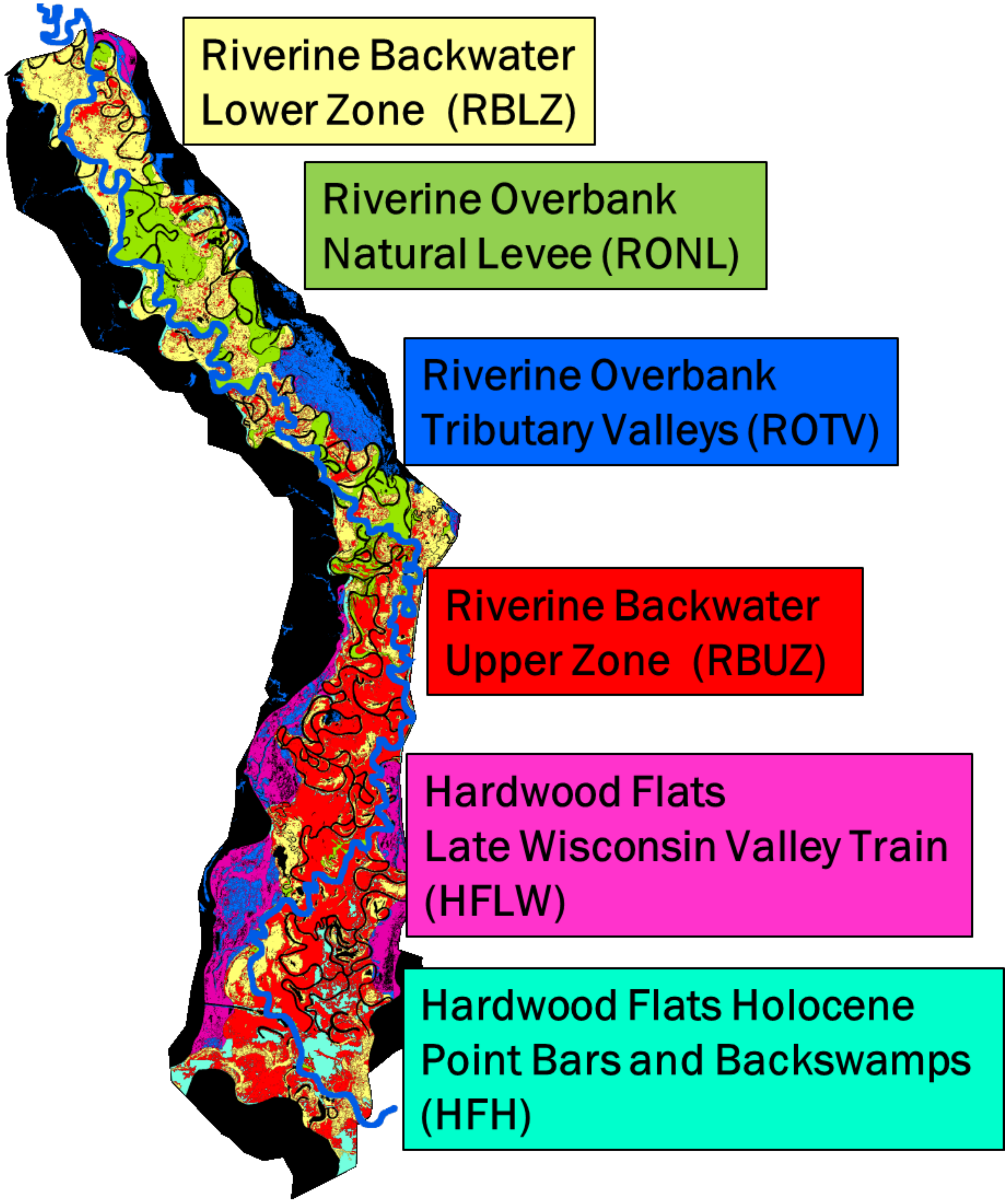


Figure 3.1. Vegetation classes within the lower White River floodplain. The black area is outside the floodplain.

performed by the USACE. The floodplain digital elevation model (DEM) was a composite of the USGS 10 m DEM and the Arkansas State 5 m DEM. Manning's *n* roughness coefficients for the floodplain and channel maximize agreement between observed and modeled channel flows 1965-2009. The model boundary includes the lower White River floodplain with a buffer of terraces or levees that do not flood (Figure 1.1).

Upper and lower boundary conditions are required parameters that specify the starting and ending water surface elevation. We used the daily stage from the Clarendon gauge (USACE WR116) for the upstream boundary and interpolated daily stage for the downstream boundary at the confluence of the White River and Mississippi River (Chapter 2) (Figure 1.1).

We installed 28 water-level monitoring stations in three reaches (Figure 3.2) and distributed among the three PNV classes that occupied the majority of the floodplain (Figure 3.3). Water monitoring stations were designed to also measure shallow water table depths, so were constructed as vented wells using 1 m long, slotted PVC pipe and installed to at least 0.5 m below the ground surface. At each station, water depth was monitored using pressure transducers (HOBO; Onset, Bourne, Mass., USA) hung by cables from the top of the wells to 10 cm above the bottom of the wells. The pressure transducers started recording data in September 2011 to December, 31, 2014 since. The recorded water level data created a history of observed flooding depths for each station for comparison to modeled depths

<u>Quantifying hydrology in vegetation classes</u>

To quantify hydrologic relationships among and within vegetation classes, we assigned 100 random points to each of the PNV classes within the WRNWR floodplain (Figure 3.4), and then used daily stage data from January 1, 1983 to December 31, 2013 (31 years) to model flood depths at those points. We calculated the percentage of days that exceeded flood depths (exceedance probability) for each point to quantify the range of flooding depth and duration of flooding within each PNV class.

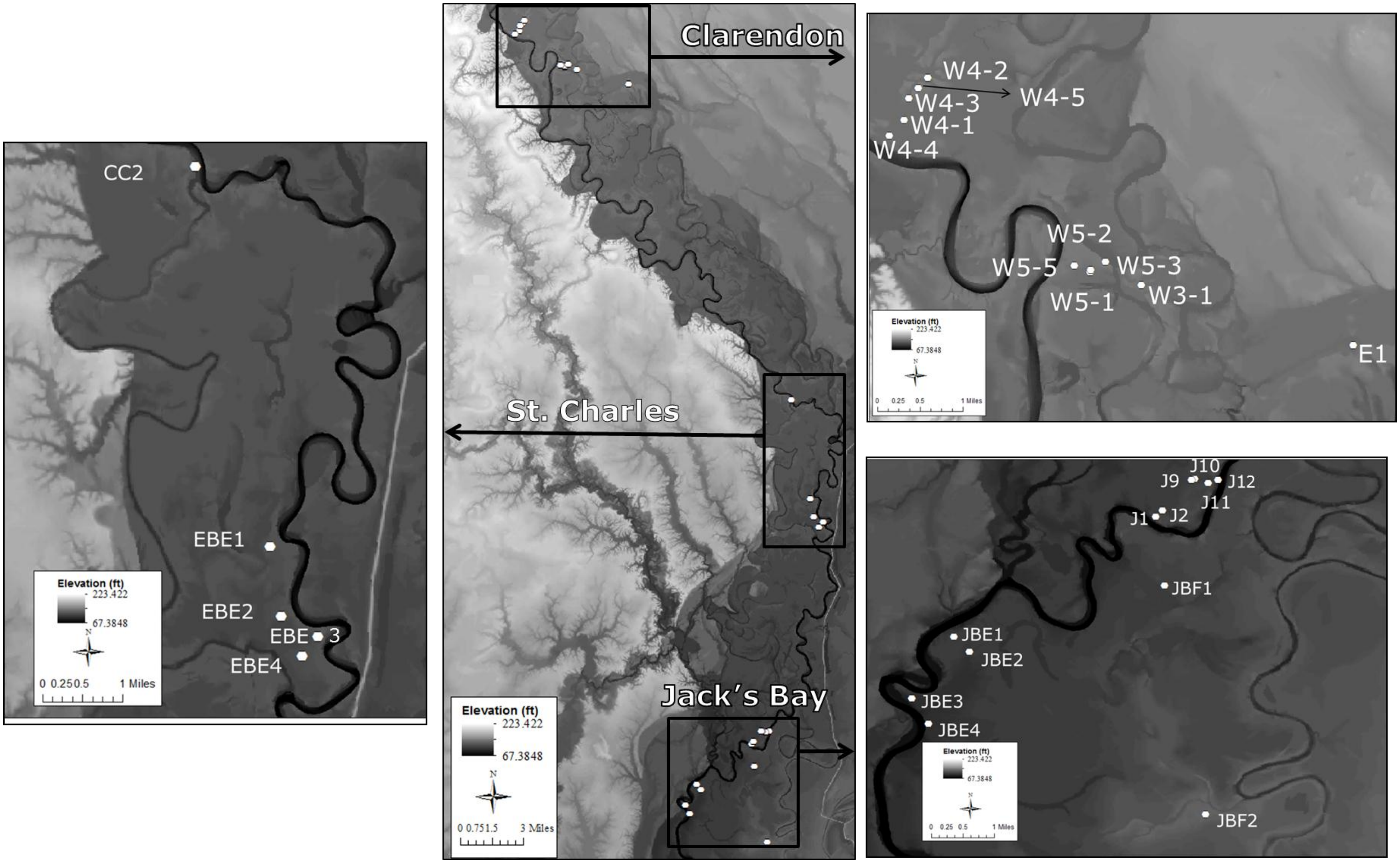


Figure 3.2. Distribution of water monitoring stations by reach: (A) overall distribution; (B) Clarendon reach; (C) St. Charles reach; and (D) Jack's Bay reach.

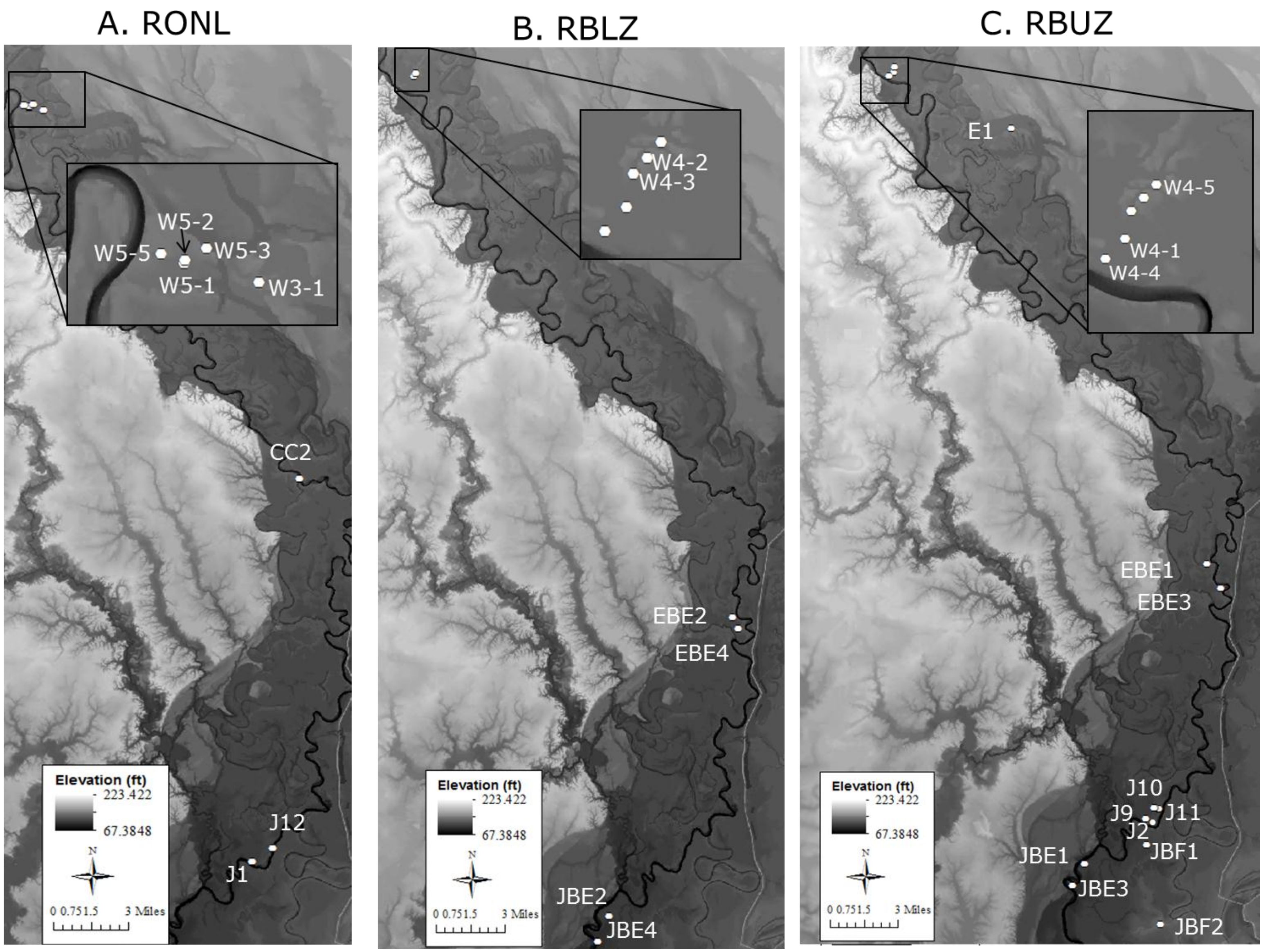


Figure 3.3. Distribution of water monitoring stations by vegetation class: (a) RONL; (b) RBLZ; and (c) RBUZ.

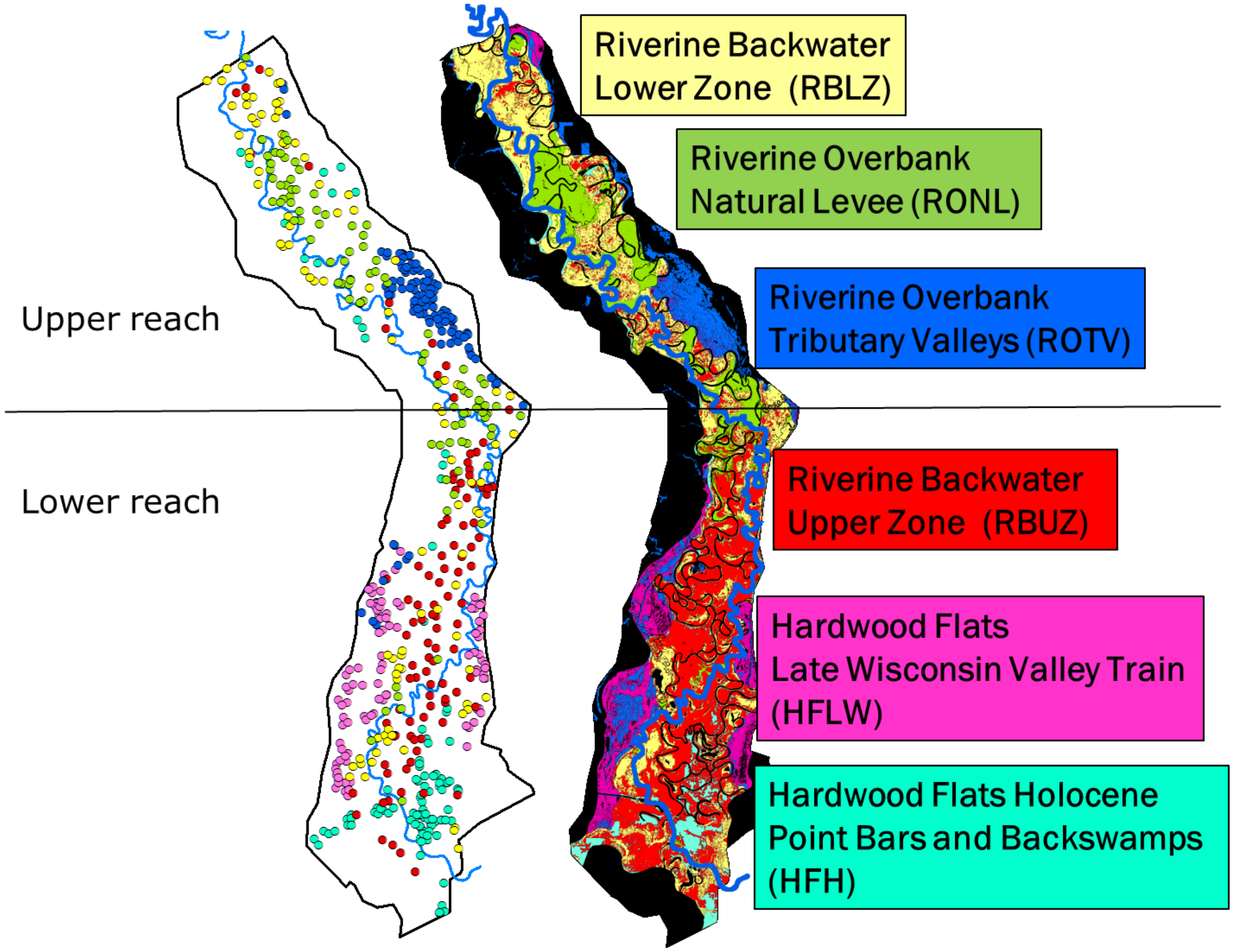


Figure 3.4. Vegetation classes and locations of 100 evaluation points for each vegetation class in each reach of the floodplain. Colors correspond to vegetation class.

Modeling incision

To quantify pre- and post- incision flooding changes, we modeled three geomorphic scenarios: one with current geomorphology and two hypothetical historic conditions prior to incision to bracket the range of uncertainty in magnitude of change. The historic scenarios were constructed by generalizing channel dimensions to conditions before incising either 2.1 m (low incision scenario) or 3.5 m (high incision scenario) at the Mississippi River, based on the limits of estimated incision by Schumm and Spitz (1996), Biedenharn and Watson (1997), and Shaffner (2012), and using channel widths from 1940 USGS maps (Chapter 2).

For each of the three geomorphic scenarios, we modeled two types of flooding: pure headwater floods from the White River and pure backwater floods from the Mississippi River. Even though these two events never happen separately, the goal of the simulations was to estimate effects separately.

We ran the model for headwater floods with the three geomorphic scenarios. Flood return intervals for the 1-year (1,634 cms), 1.5-year (1,943 cms), 5-year (3,194 cms), 10-year (3,882 cms), and 32-year (7,552 cms) headwater floods were calculated using the Weibull plotting position of annual maximum peak flow at the Clarendon gauge from 1983-2013. We used normal depth for the downstream conditions for modeling headwater floods in the three geomorphic scenarios; i.e., the Mississippi River was at a stage not changing the slope of the hydraulic grade line of the lower White River. We exported results to HEC-GeoRAS to map extent of inundation and flood depth for the three geomorphic scenarios.

We modeled backwater floods for current geomorphology by calculating return intervals of stage for the 1-year (42.7 m), 1.5-year (46.0 m), 5-year (48.2 m), 10-year (48.8 m), and 32-year (51.8 m) floods using the Weibull plotting position of annual maximum stage of the Mississippi River at the confluence with the White River from the same time period (1983-2013). To model backwater floods before incision, we added 2.1 m or 3.5 m to each return interval stage. For all three scenarios, we assumed all surface elevations below the corresponding water surface elevations were flooded, and that there was no contribution of headwater flow to flooding. To map the extent of inundation and flood depth, we assumed all land below the flood elevation was flooded.

We then used flooding maps for each geomorphic scenario and flood return interval (Chapter 2: Figures 2.3 and 2.5) along with the 600 evaluation points to quantify changes in flooding depth and flood extent by vegetation and flood magnitude before and after incision in headwater floods. For backwater floods, we only calculated flood extent in each vegetation class during each flood elevation before and after incision because systematically adding 2.1 m and 3.5 m of incision to backwater flooding depths made all the flooding depths exactly 2.1 and 3.5 m higher than current flooding depths.

Results

<u>Performance of HEC-RAS on the floodplain</u>

The range of error for all monitoring sites in modeled flooding depths was ±2.45 m. Removing the outlier sites, CC2 and J12, reduced the range of error to ±1.50 m. The average root mean square error (RMSE) was 1.11 m with a range of 3.42 m.

The model varied in its ability to accurately model flood depths by reach. The model replicated flood depths in the St. Charles reach (with outlier CC2 excluded) with the smallest difference from observed flood depth and replicated flood depths in the Jack's Bay reach with the largest difference from observed flood depth (Figure 3.5). Differences between the actual and modeled flood depths in the Clarendon reach were intermediate between the Jack's Bay reach and the St. Charles reach (Figure 3.5).

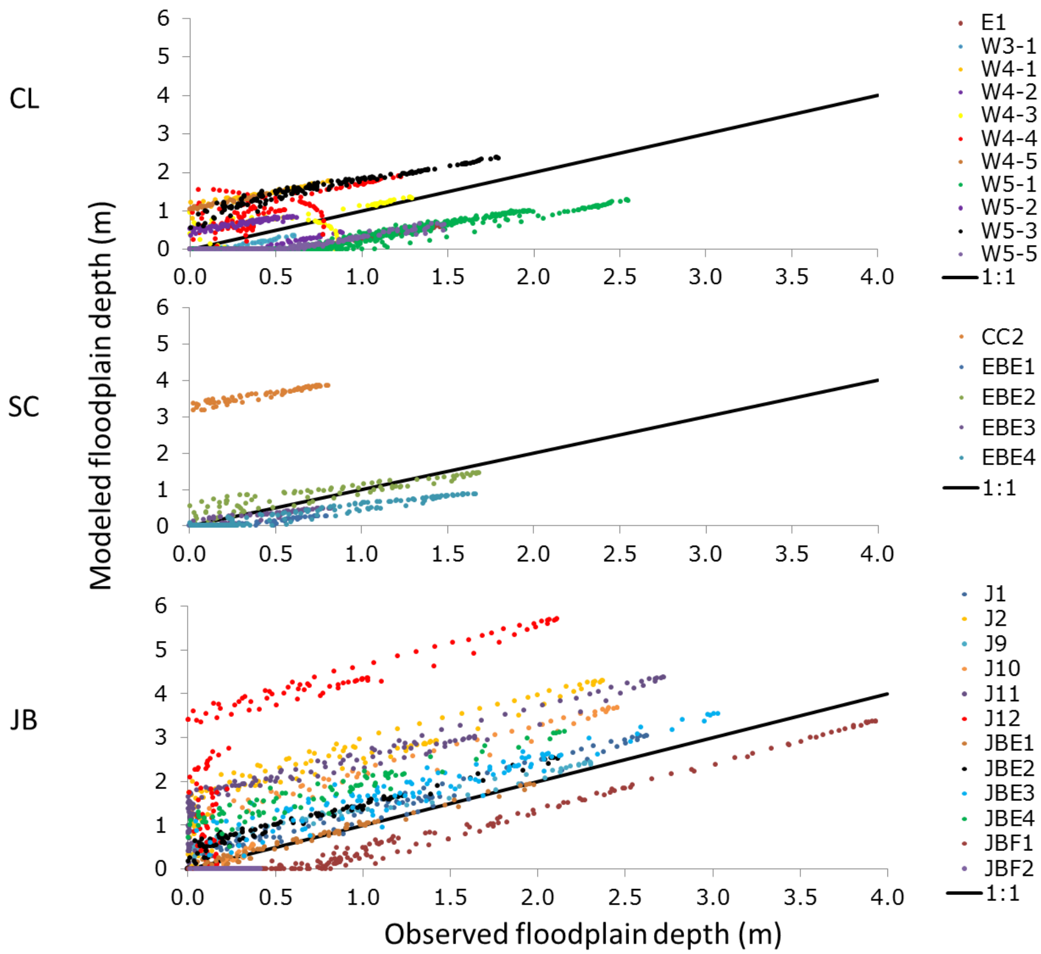


Figure 3.5: Observed floodplain depths compared to modeled floodplain depths at 28 well monitoring stations by reach (Figure 3): Clarendon (CL), St. Charles (SC), Jack's Bay (JB). Model matches observed if the slope is along the 1:1 line (solid black line).

The model also varied in its ability to accurately model flood depths by PNV class. The model replicated flood depths in the RBLZ class with the smallest difference from observed flood depth and replicated flood depths in the RBUZ class with the largest difference from observed flood depth (Figure 3.6). With the outliers, CC2 and J12, excluded, the model replicated flood depths in the RONL with less difference from observed flood depth than in the RBUZ class and more difference than in the RBLZ class (Figure 3.6).

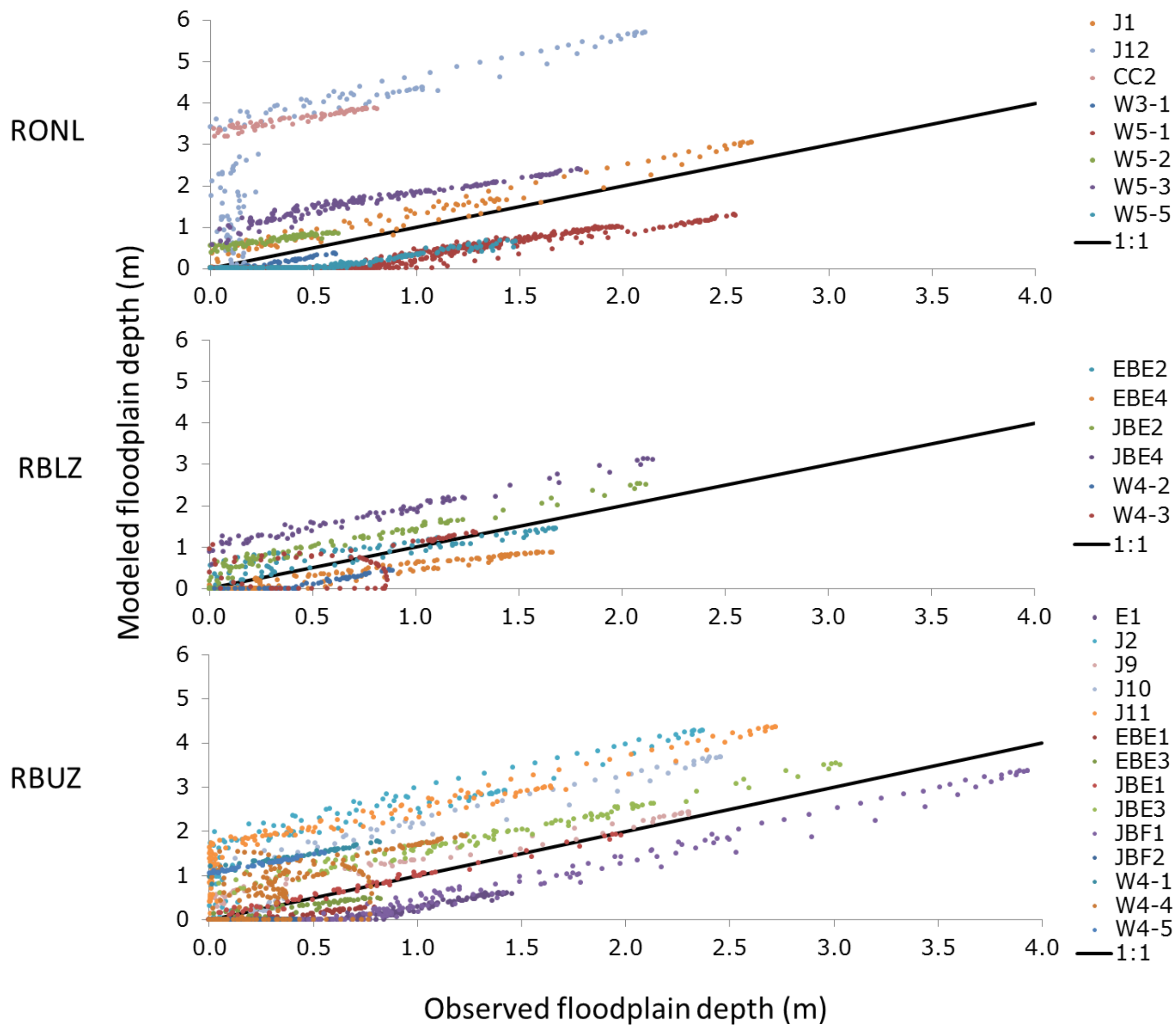


Figure 3.6. Observed floodplain depths compared to modeled floodplain depths at 28 well monitoring stations by vegetation class (Figure 4): Riverine Overbank Natural Levee (RONL), Riverine Backwater lower Zone (RBLZ), and Riverine Backwater Upper Zone (RBUZ). Model matches observed if the slope is along the 1:1 line (solid black line).

Despite the range of errors in modeled flood depths, the parameterization of HEC-RAS was successful in replicating observed water surface slopes as indicated by the 1:1 line (Figures 3.5 and 3.6). However, the model estimated more gradual slopes than the 1:1 line for all the monitoring stations the St. Charles reach except CC2 (Figure 3.5).

<u>Quantifying flooding by vegetation type</u>

Shapes of the median flooding depth exceedance probability (EP) curves indicated two general flooding patterns among PNV classes, depending on their location in the study area. The RONL, ROTV, and RBLZ classes are primarily in the upper reach, while the RBUZ, HFH, and HWLW are primarily in the lower reach (Figure 3.4). The upper reach floods shallower and more often, and the lower reach floods less often and deeper (Figure 3.7).

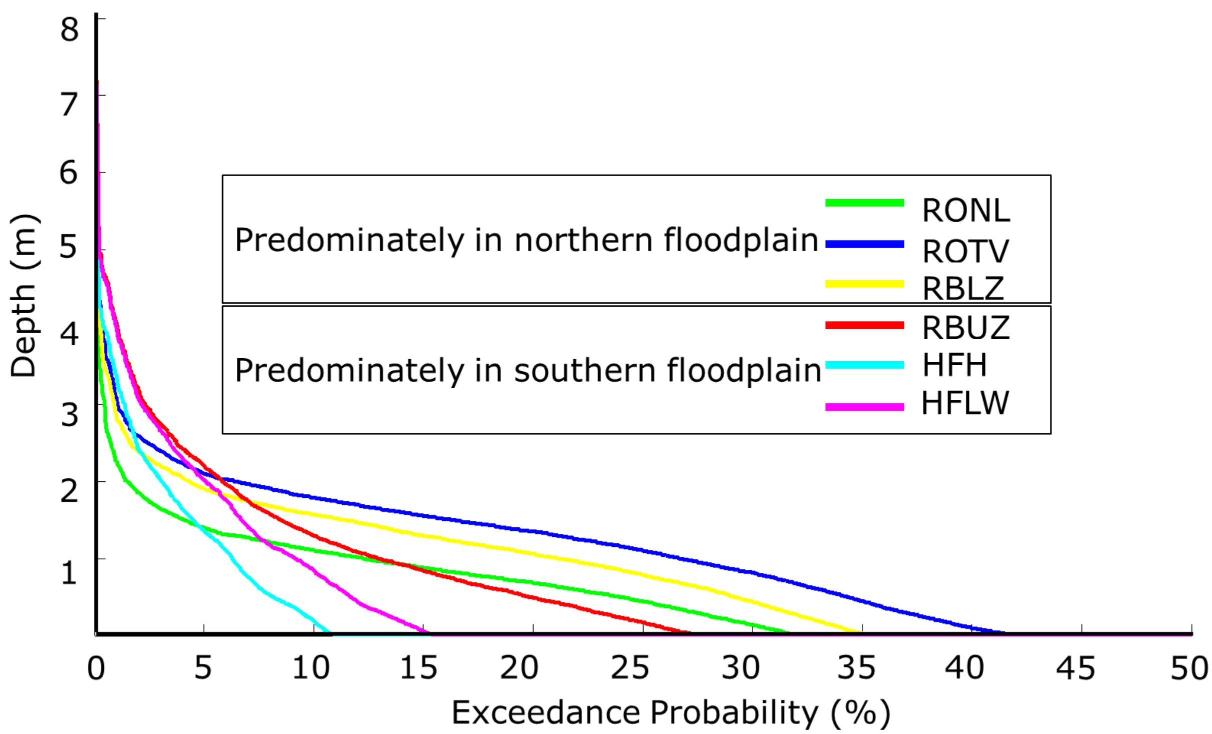


Figure 3.7. Median depth exceedance probability for the six vegetation classes.

Reaches within the floodplain divided EP curves of four of the PNV classes into subgroups. There were two flooding subgroups within the RONL and ROTV classes, divided by reach (Figure 3.8). There were five flooding subgroups of RBUZ, and four groups of RBLZ (Figure 3.9).

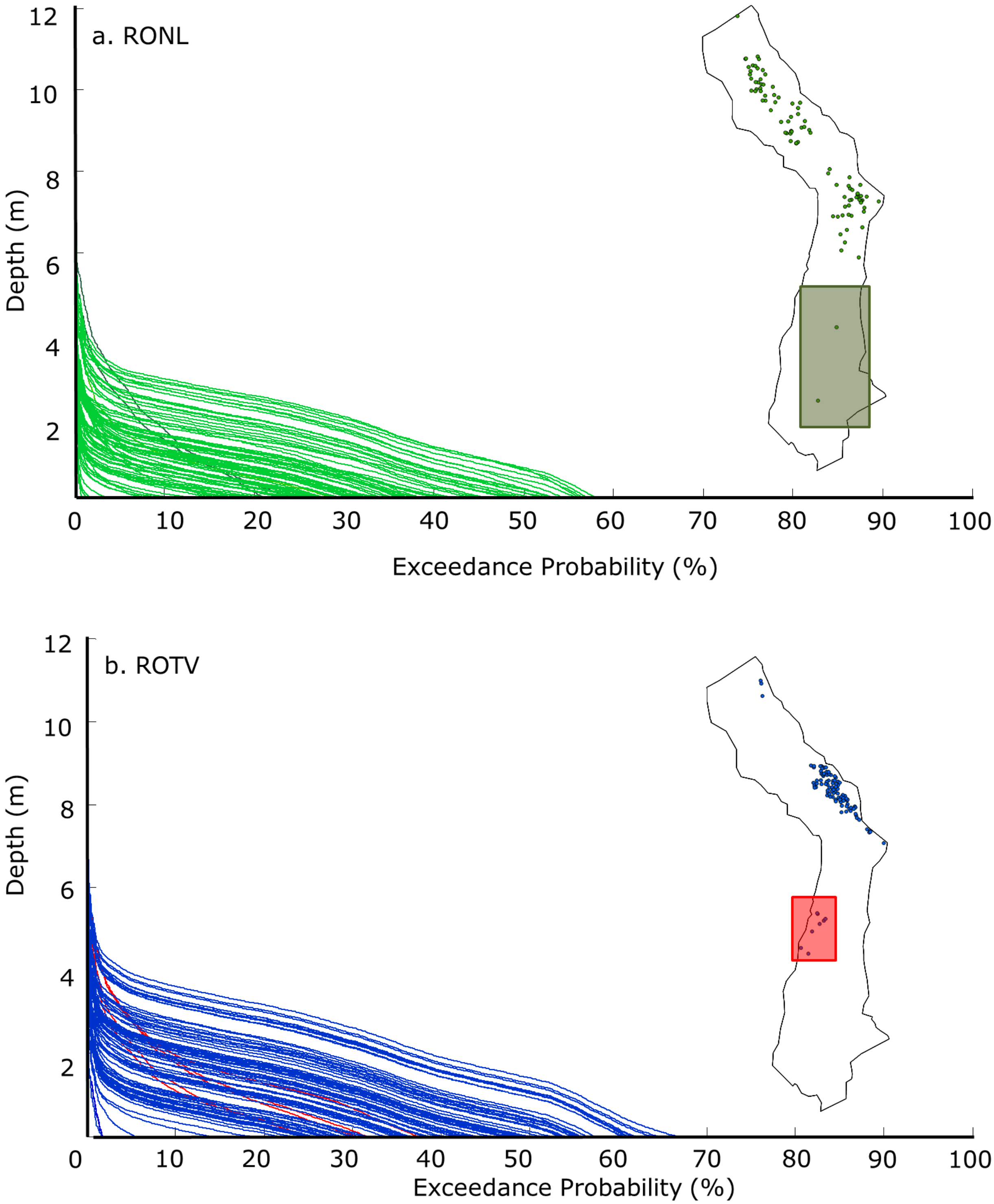
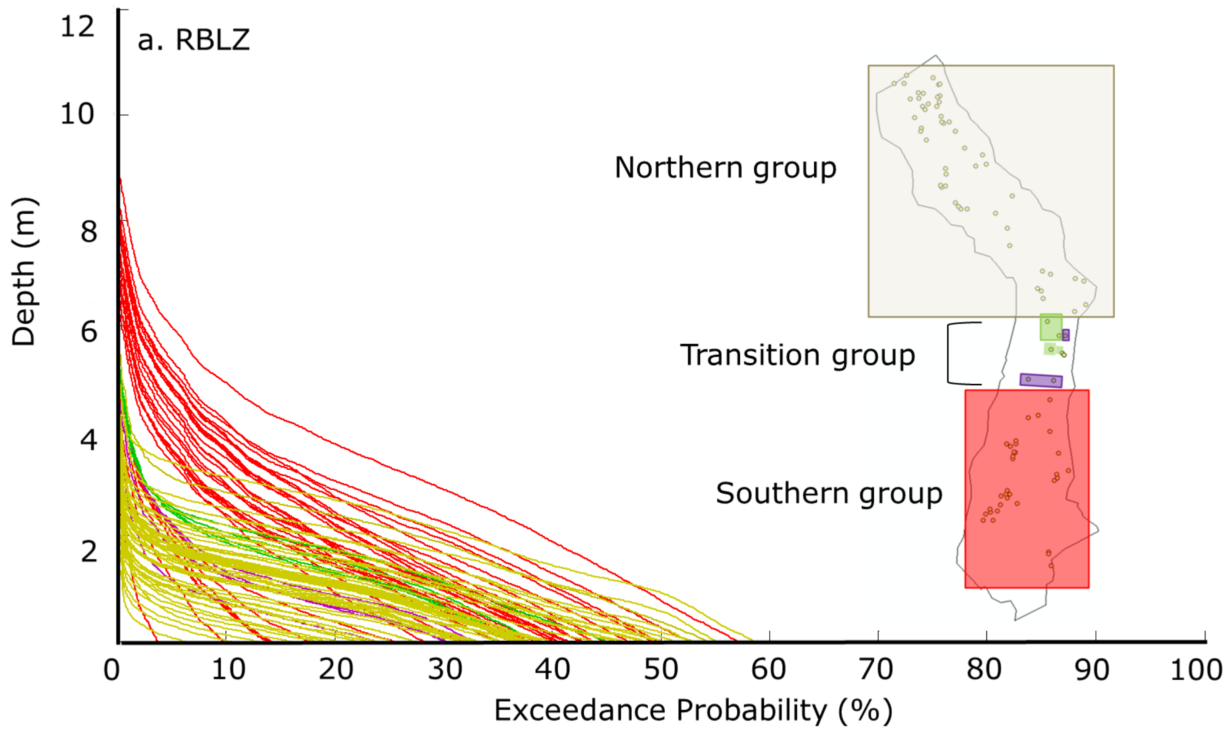


Figure 3.8. Flood depth exceedance of random points in (a) RONL and (b) ROTV. Colors of subgroups on inset maps correspond to exceedance probability lines.



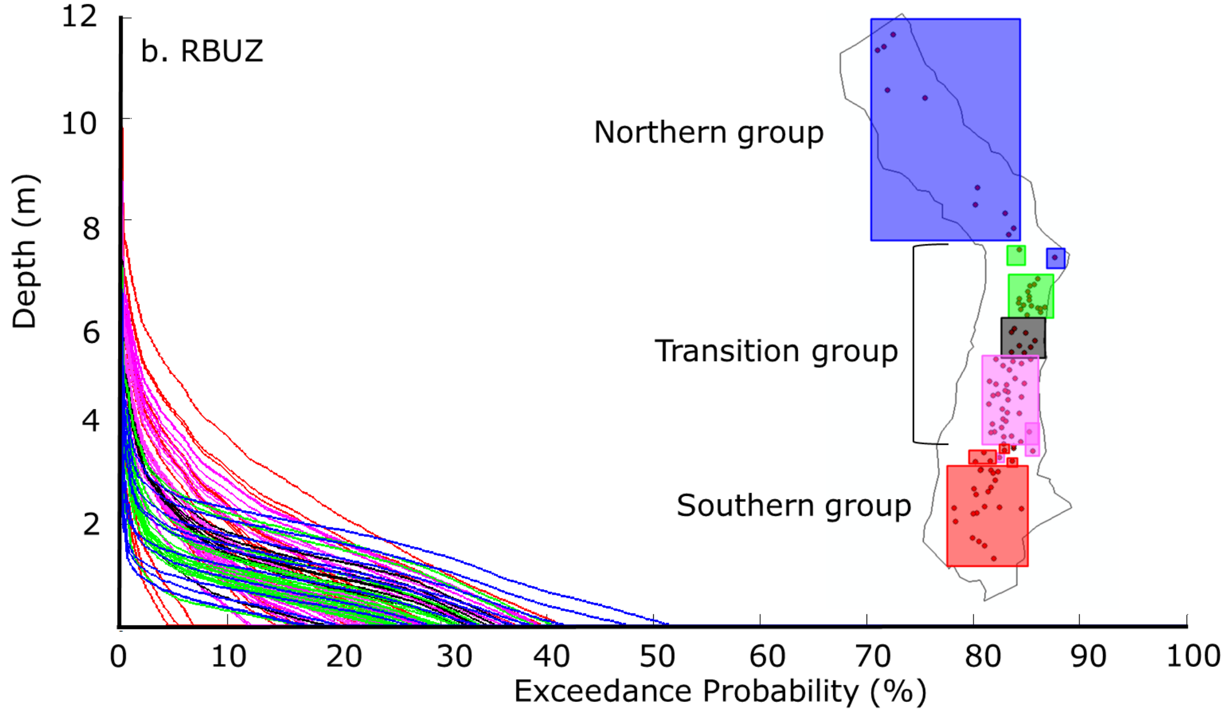


Figure 3.9. Flood depth exceedance of random points in (a) RBLZ and (b) RBUZ. Colors of subgroups on inset maps correspond to exceedance probability lines.

Reach also divided these classes, but they had transitional groups that had slightly different flooding patterns than the upper and lower groups (Figure 3.9). In RBUZ, for example, the flooding patterns for the northern group were similar to the flooding patterns of the transition group. The flooding patterns in the transitional group were similar to flooding patterns in the southern group (Figure 3.9). However, the overall flooding patterns within RBLZ and RBUZ were different. The flooding patterns in the RBLZ class were more similar to the flooding patterns in the riverine overbank classes and the flooding pattern in the RBUZ is more similar to the hardwood flat classes. Elevation differences between the points in each of the subgroups creates the variability in flooding within each of the subgroups.The flooding variability within each of these subgroups is However, the overall flooding patterns within RBLZ and RBUZ were different. The RBLZ class was more similar to the riverine overbank classes and the RBUZ is more similar to the hardwood flat classes.

Elevation differences within the floodplain divided the HFH and HFLW into two subgroups (Figure 3.10). The deviating group in the HFH class consisted of the highest elevation points in the PNV class, but did not vary by reach. The deviating group in the HFLW class consisted of the lowest elevation points in the class.

Flooding patterns alone were not sufficient to distinguish PNV classes in most cases because of substantial overlap in flooding patterns within classes. The flooding patterns in riverine overbank and hardwood classes differentiated them from each other, but there was too much variability in flooding patterns in the riverine backwater classes to identify a specific PNV class. However, the flooding pattern within RBLZ appeared similar to the riverine overbank classes which are predominately in the upper reach while the RBUZ flooding pattern appeared similar to the hardwood flats classes which are predominately in the lower reach. This indicates flooding patterns were distinct enough to identify differences between flooding patterns in the upper and lower reaches.

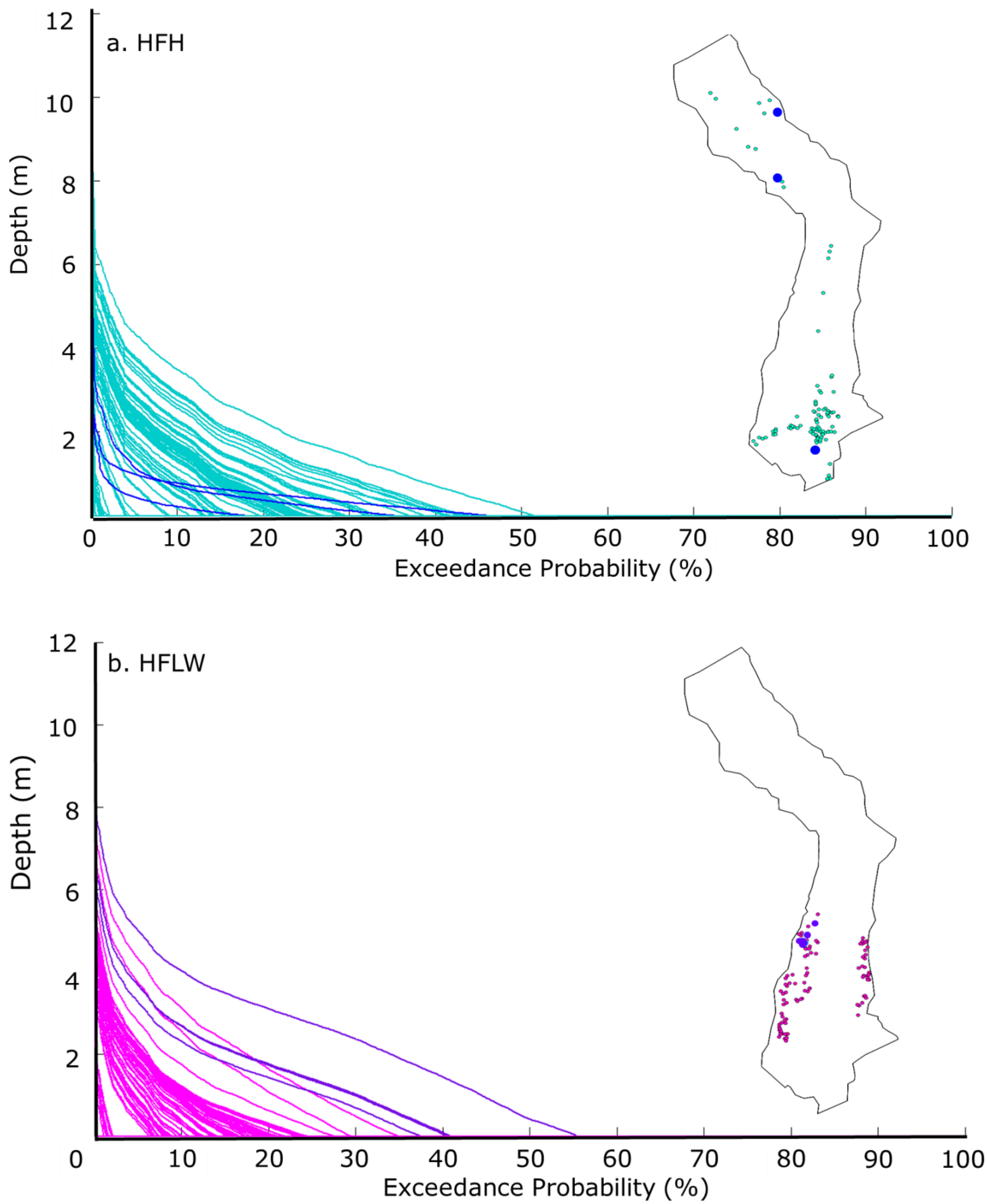


Figure 3.10. Flood depth exceedance of random points in (a) HFH and (b) HFLW. Colors of subgroups on inset maps correspond to exceedance probability lines.

Effects of incision on flooding by PNV class

Headwater flooding

Incision decreased flooding depth in some vegetation classes, and the largest decreases were in the more frequent floods. Incision decreased flooding depth in the riverine overbank natural levee (RONL) in the 1-year and 1.5-year floods (Figure 3.11). While the RONL class is mostly in the unincised reach, there are some points near the incised reach, and these experience a different flood regime (Figure 5). There was minimal effect of geomorphic change on flooding depth in the riverine overbank tributary (ROTV) class because it occurs only in the unincised reach (Figure 3.4) where incision affected flooding less (Chapter 2) (Figure 3.11). Incision decreased flooding depth in the HFH and HFLW classes in only the largest floods because they occur at the highest elevation of all the classes and are generally unflooded by small events (Figure 3.12).

Incision reduced flooding more in the lower reach of riverine backwater lower zone (RBLZ) class in the 1-year flood event than in the upper reach. The incision reduced flooding the upper reach in the 1-year and 1.5-year floods, but reduced flooding depth even more in the lower reach in the 1-year, 1.5- year and 5-year floods (Figure 3.13). Incision affected flooding depths in the riverine backwater upper zone (RBUZ) class the most in the 1-year, 1.5-year, and 5-year flood, but also reduced flooding in the 10-year and 32-year flood (Figure 3.14).

In addition to decreasing flood depth, incision decreased flooding extent in all vegetation classes (Table SUM, Figure 3.15). In the 1-year return interval, proportion of points flooded in RBLZ, RBUZ, RONL, ROTV all decreased after incision, with the least effect on ROTV. After incision, proportion of flooded points decreased in the RBLZ, RBUZ, RONL, and HFLW classes in the 1.5-year flood. After incision, proportion of flooded points decreased in the RBUZ, HFH, and HFLW classes in the 5-year flood. After incision, proportion of points flooded decreased in the 10-year and 32-year floods.

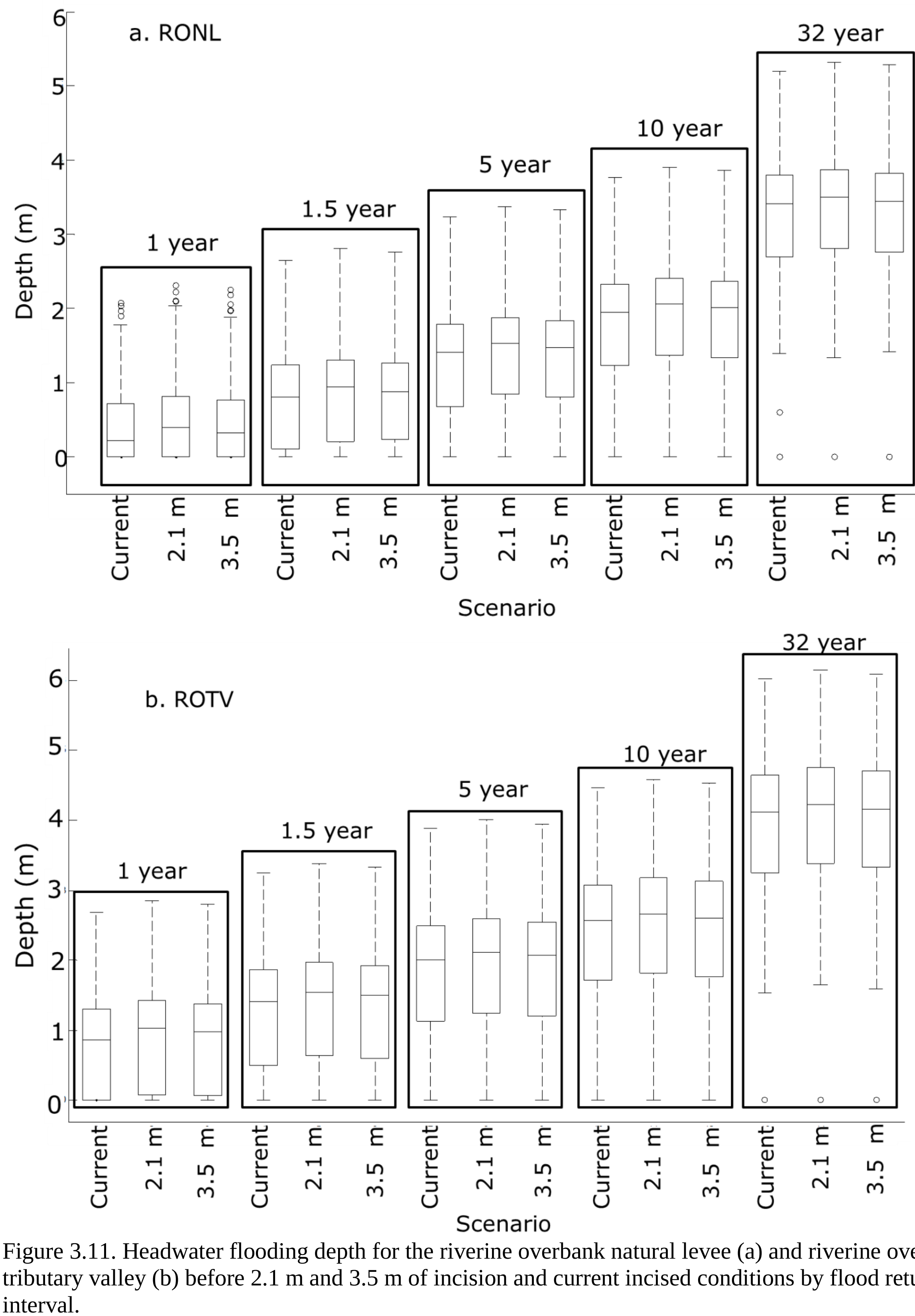


Figure 3.11. Headwater flooding depth for the riverine overbank natural levee (a) and riverine overbank tributary valley (b) before 2.1 m and 3.5 m of incision and current incised conditions by flood return interval.

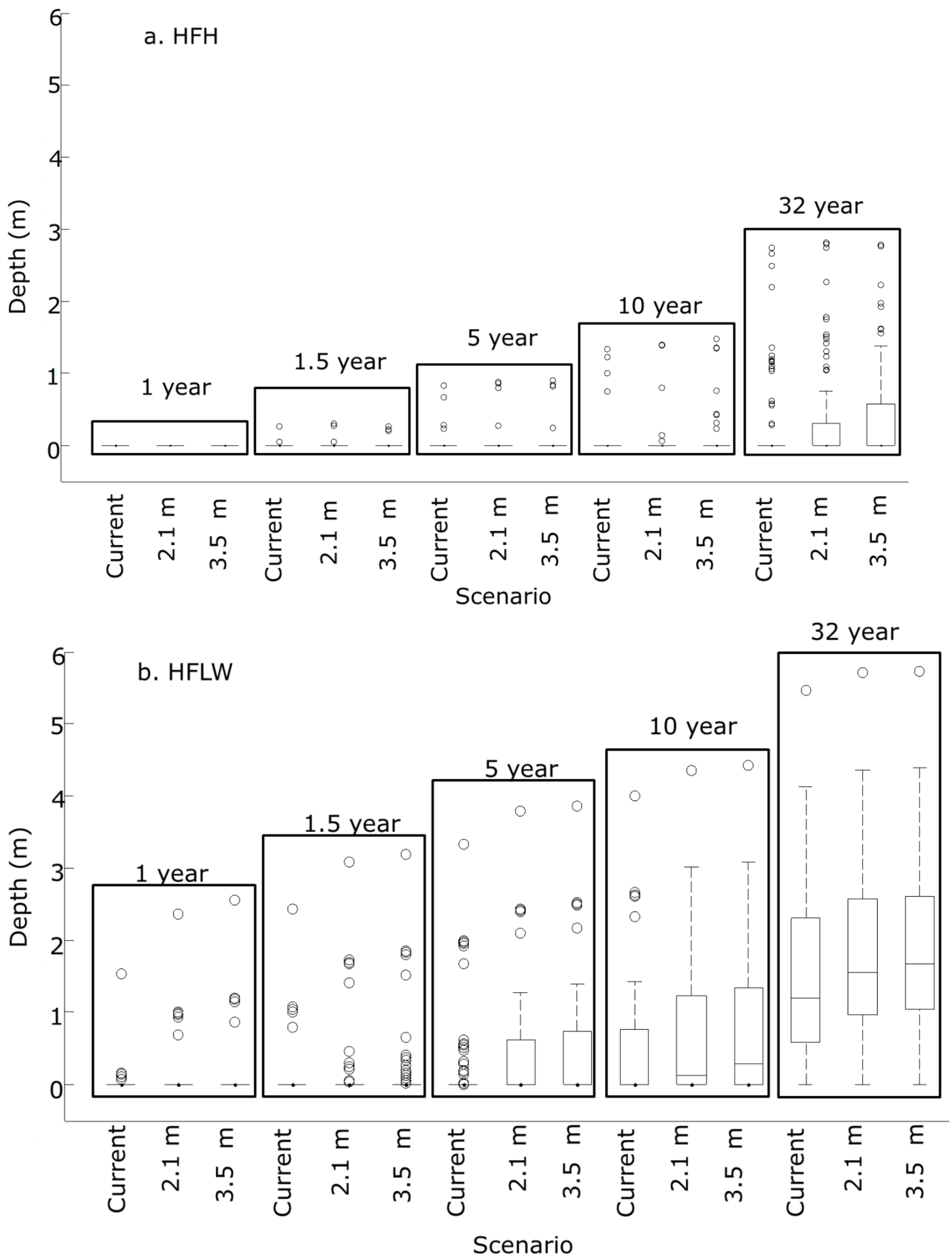


Figure 3.12. Headwater flooding depth for the (a) hardwood flat Holocene and (b) hardwood flat late Wisconsin before 2.1 m and 3.5 m of incision and current incised conditions by flood return interval

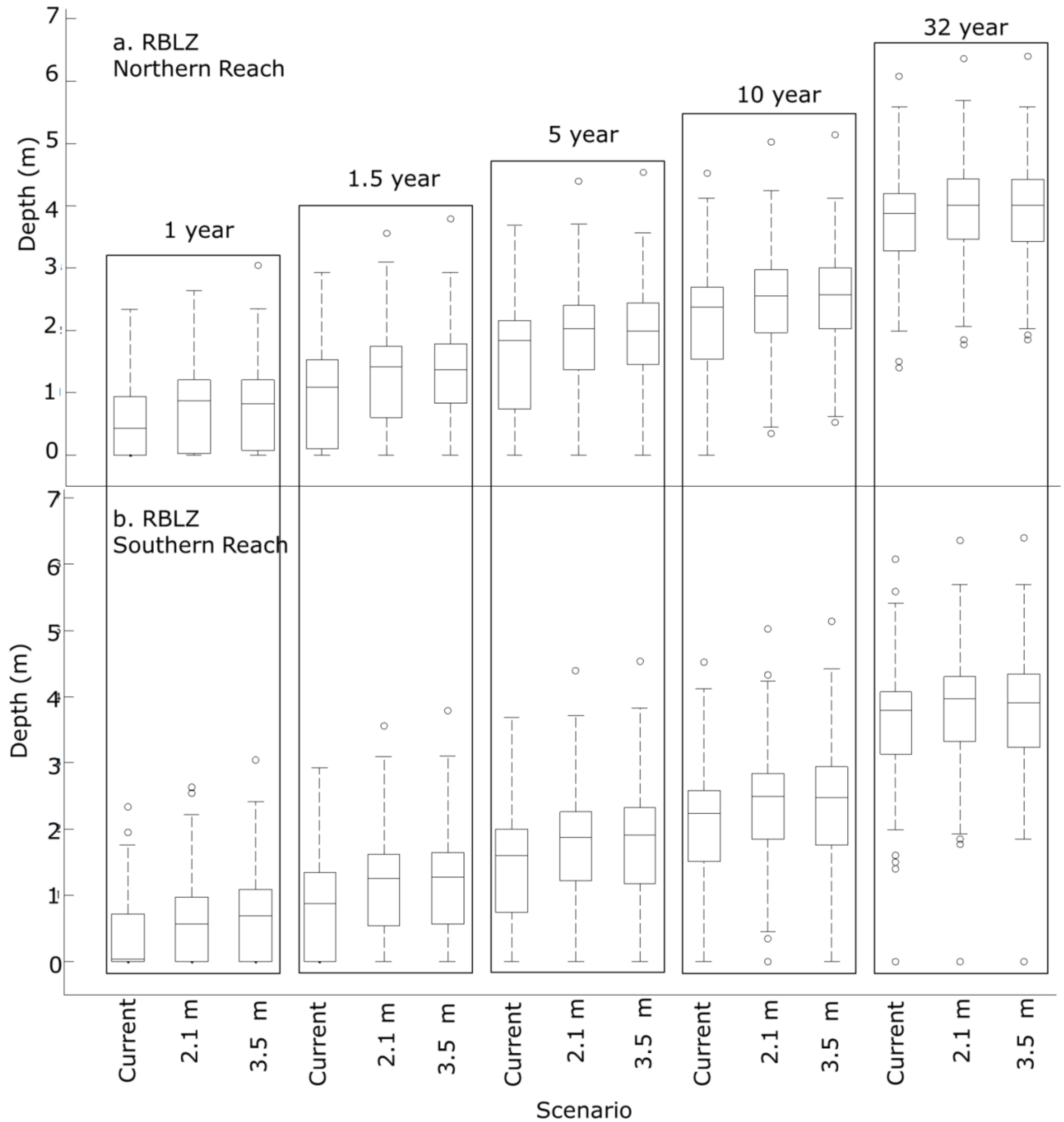


Figure 3.13. Headwater flooding depths for the (a) upper reach and (b) lower reach of riverine backwater lower zone before 2.1 m or 3.5 m of incision and current, incised conditions by flood return interval.

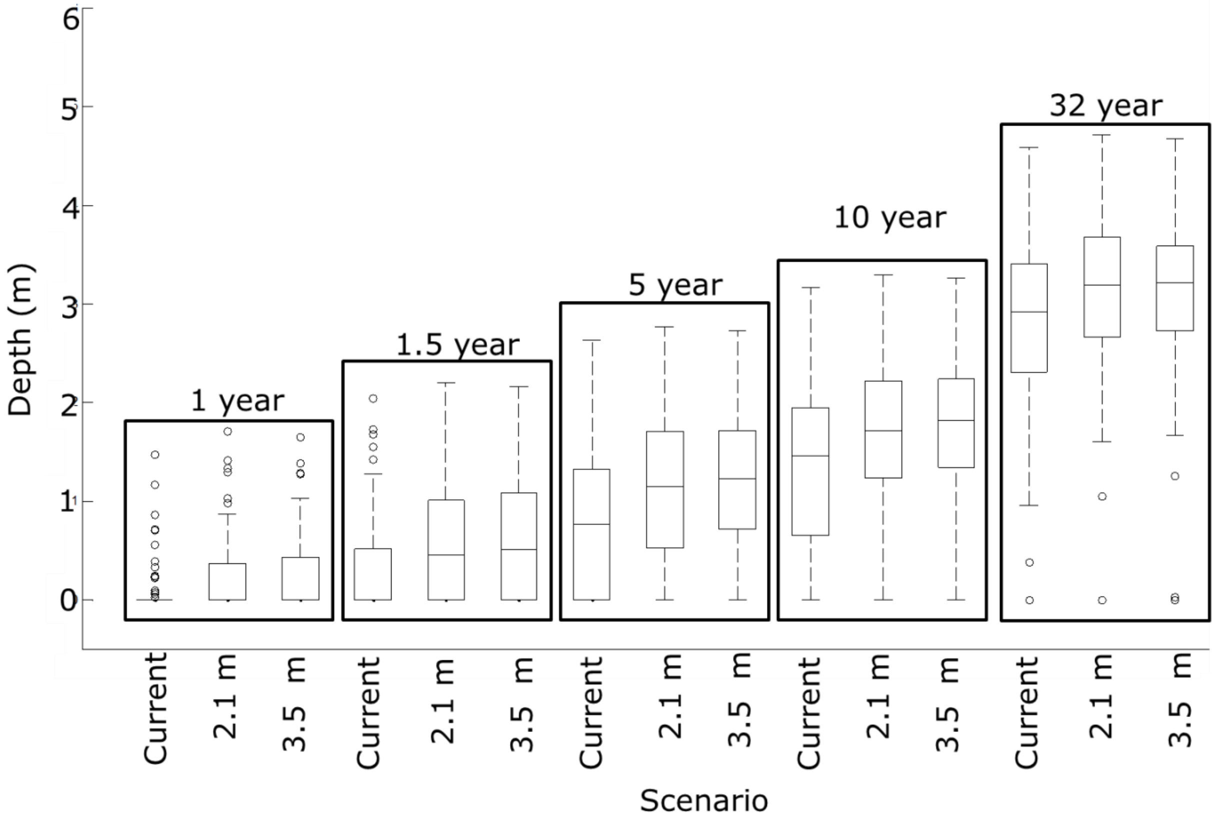


Figure 3.14. Headwater flooding depth of riverine backwater upper zone before 2.1 m and 3.5 m of incision and current incised conditions by flood return interval.

Backwater flooding

Before incision, the proportion of points flooded in all the vegetation classes in the 1-year and 1.5-year backwater flood events experienced the largest decrease in the more frequent floods after incision (Figure 3.16). After incision, proportion of points flooded decreased in the RBLZ, RBUZ, RONL, and HFLW classes in the 5-year backwater flood. After incision, the proportion of points flooded decreased in the RONL, RBLZ, and HFH classes in the 10-year backwater flood The 32-year backwater flood did not affect the extent of flooding because floodplain was almost completed flooded.

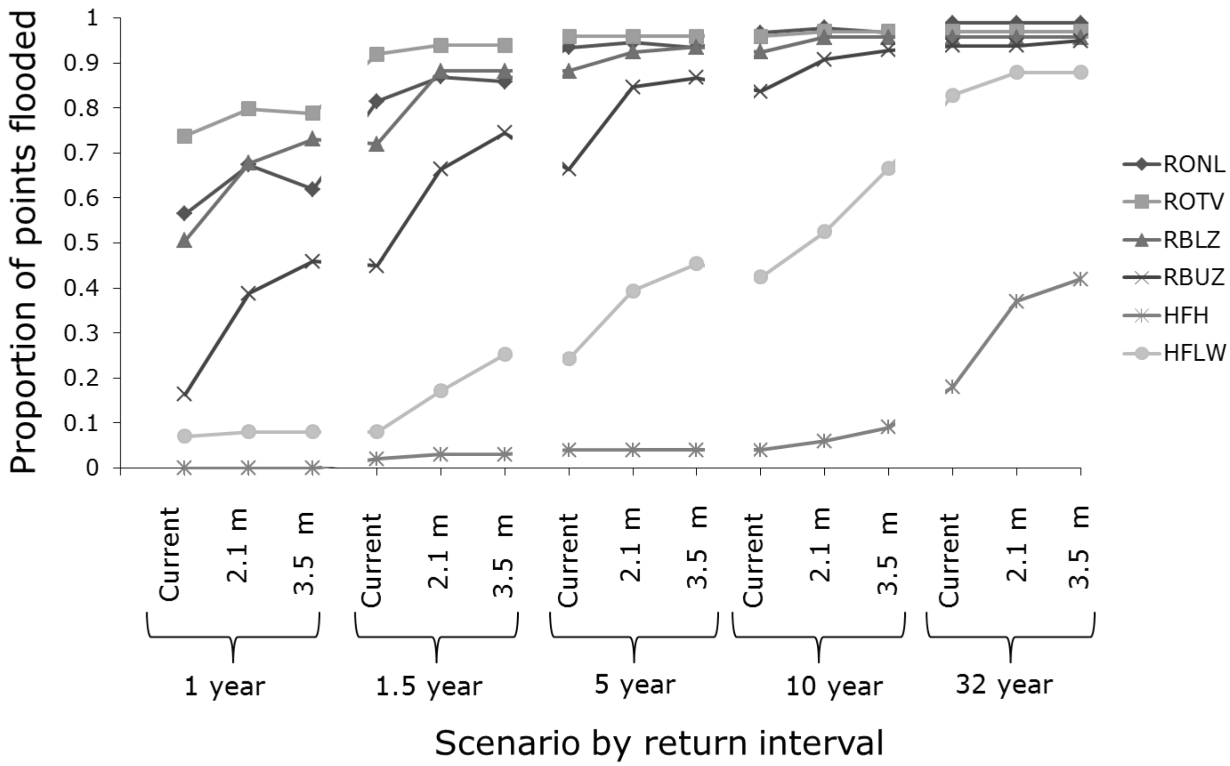


Figure 3.15. Proportion of points flooded in each vegetation class during a headwater flood by flood return interval and modeled scenario of channel incision amount.

Discussion

The parameterized HEC-RAS model performance was not ideal for estimating impacts on vegetation communities; however, understanding the limitations of the model can help improve the parameterization for better floodplain modeling. The modeled flood depth error had root mean square error of 1.11 m with a 3.41 m range of error which is not ideal for ecological modeling. Small spatial variations, on the scale of centimeters, influence the flooding regime of vegetation communities (Pollock et al. 1998). The range of modeled error brackets extreme variations for each vegetation class so the real range of behavior lies within the error. Knowing the range of error can narrow down the actual range of flooding variation. For example, the modeled hydrologic behavior for the RONL class ranges ±3 m (±25%), but floodplain monitoring stations suggest much of this is error. The actual flooding could

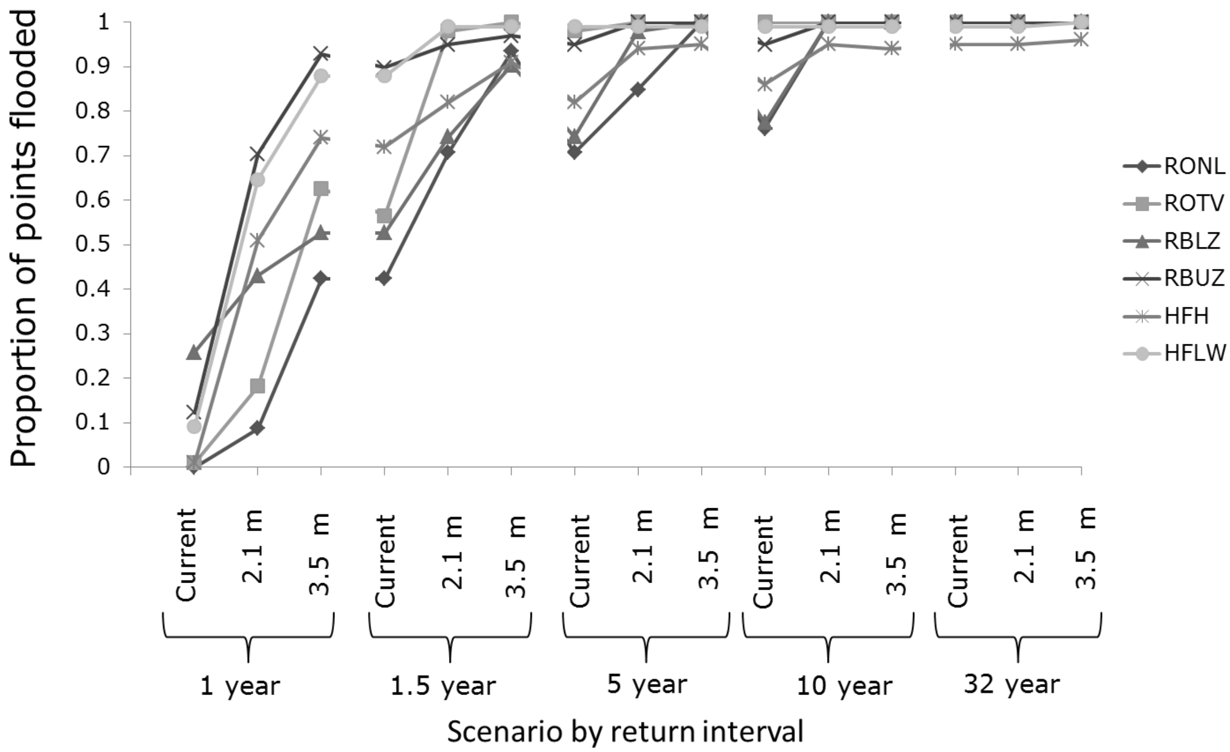


Figure 3.16. Proportion of points flooded in each vegetation class during a backwater flood and modeled scenario of channel incision amount.

potentially range from ±1.5 m (±10%) (Figure 12); however, there is considerable uncertainty on the actual hydrologic behavior in each vegetation class. Improvements to the parameterization of the model like using LiDAR for more accurate and precise floodplain elevations could help improve the model to be more helpful in understanding environmental impacts. The error in modeled flood depths is likely due largely to the low resolution of the DEM (Casas, 2006). The low resolution DEM does not reflect subtle topographic changes that influence spatial variations in flooding and species distribution (Franz and Bazzaz, 1977) so the errors in modeled flood depths are likely to be greater in areas with small topographic variability in topography. There is more pronounced microtopography in the Clarendon reach than in the Jack’s Bay reach; thus potentially explaining the range of estimated flood depths in the Jack’s Bay reach. Also, the coarseness of the DEM does not align with current bank positions. Monitoring stations close the river like J12 and CC2 had the highest error in flooding depth (Figures 3.5 and 3.6).

These points, on the DEM were on the bank; however, when compared to aerial imagery, the points were in the water or on a sandbar.

Table 2. Vegetation classes with a reduction in flooding in each analysis.

Return Interval	Headwater Flooding Depth	Headwater Extent of flooding	Backwater Extent of flooding
1 year	RBUZ	RBUZ	RBUZ
	RBLZ*°	RLBZ	RLBZ
	RONL	RONL	RONL
			ROTV
			HFLW
			HFH
1.5 year	RBUZ	RBUZ	RBUZ
	RBLZ*°	RBLZ	RLBZ
	RONL	RONL	RONL
			HFH
		HFLW	HFLW
5 year	RBUZ	RBUZ	RLBZ
	RBLZ°		RONL
		HFLW	
		HFH	HFH
10 year	RBUZ		RBLZ
			RONL
		HFH	HFH
	HFLW	HFLW	
32 year	RBUZ		
	HFH	HFH	HFH
	HFLW	HFLW	HFLW

*****affected in unincised reach
°affected in incised reach

Another improvements to the parameterization of the model would be more accurate downstream conditions. The interpolated stages at the confluence used for the downstream conditions were not as accurate as using observed stage data as at Clarendon. We could have altered the model boundary to only extend to the Arkansas Post Canal and use the stage data at the Norrell gauge, but the Norrell gauge history did not data back to 1983.

The modeled flooding regimes were more distinguishable among floodplain reaches than they were among PNV classes. Subgroups within PNV classes were also largely related to floodplain reach for classes in the primary floodplain. Vegetation dominantly in the upper reach flooded shallower and more frequently, and vegetation dominantly in the lower floodplain flooded deeper but less frequently.

Headwater floods dominate the upper reach while backwater floods dominate the lower reach and can sometimes inundate the entire lower White River floodplain in high magnitude floods (Chapter 2). Thus, differences in flooding regimes are closely related to the differences in headwater and backwater dominated reaches. The transition groups between the upper and lower reaches appear to indicate a mixed influence of headwater and backwater floods. As incision migrates upstream, the flooding regimes of the lower reach will also likely migrate upstream reducing the flood frequency.

One ecologically relevant factor that this study did not account for was the frequency of flooding. The exceedance probability curves show depth and percent of time inundated over 31 years, but they do not show how frequently the flooding occurs. The hardwood flat classes are much higher in elevation which requires a much larger flood to inundate the classes. When the hardwood flat classes are flooded, they are flooded for a continuous amount of time. However, lower elevation classes floods more frequently, but not continuously. For example, Riverine Overbank Tributary Valley (ROTV) class floods 40% of the days in the 31 years, while Hardwood Flat Late Wisconsin Valley Train (HFLW) class floods 15% of the days in 31 years (Figure 3.7). However, the majority of the 15% of flooded time in the HFLW class occurs during one large event while the 40% flooding in the ROTV class could happen periodically throughout the year in multiple high frequency events.

Incision had the greatest effect on riverine backwater upper zone class, riverine backwater lower zone class, and riverine overbank natural levee class. Incision also affected more frequent floods which are critical in influencing vegetation composition (Casanova and Brock, 2000, Townsend, 2001). Because incision affected the vegetation that occupies the majority of the floodplain and have reduced flooding patterns in the critical floods that influence vegetation composition, it is likely species within the hardwood flat classes like sugarberry (*Celtis laevigata)* and could eventually replace these classes (Hodges 1997).

Changes to forest composition in response to changes in flooding may not be immediate. The time between initiation of species selection processes and when forest composition starts to reflect these new selected species can be delayed for several decades (Hughes, 1997). Also, there are other factors

influencing forest composition such as sedimentation rates , depth to groundwater, and timing of flooding. Sedimentation creates new areas for pioneer species to establish (Hupp and Osterkamp, 1994) and also bury seeds reducing seedling emergence (Gleason et al. 2003). Depth to groundwater allows for access of water in the dry seasons. Incision can lower groundwater tables causing water stress to the vegetation that are not adapted to deep groundwater.(Naumburg et al., 2005).Timing of flooding selects influences which species survive (Streng et al. 1989).

Conclusions

The parameterized HEC-RAS model can be used to model hydrologic relationships in the vegetation classes. However, the RMSE was 1.11 m with and range of error in modeled flooding depths was ±2.5 m (±1.5 m without outliers). This quantified range of error in modeled flood depths can help to identify the actual range of flooding among and within vegetation classes. The modeled flooding regimes were more distinguishable among floodplain reaches than among PNV classes. The upper reach floods more often from headwater floods, but the lower reach floods deeper by backwater floods.

Post-1930s incision reduced flooding depth and flood extent most in the Riverine Backwater Upper Zone, Riverine Backwater Lower Zone, and Riverine Overbank Natural Levee classes. The largest reductions in flooding depth and extent within these classes occurred during the more frequent floods, which are most important for ecological processes.

References – Chapter 3

Bendix, J., & Hupp, C. R. 2000. Hydrological and geomorphological impacts on riparian plant communities. Hydrological Processes, 14, 2977-2990.

Biedenharn, D. S., & Watson, C. C. 1997. Stage adjustment in the lower Mississippi River, USA. Regulated Rivers: Research & Management, 136, 517-536.

Bornette, G., Amoros, C., 1996. Disturbance regimes and vegetation dynamics: role of floods in riverine wetlands. Journal of Vegetation Science, 7(5): 615-622.

Casas, A., Benito, G., Thorndycraft, V., and Rico, M. The topographic data source of digital terrain models as a key element in the accuracy of hydraulic flood modelling. Earth Surface Processes and Landforms, 31, 444-456.

Casanova, M. T., & Brock, M. A. 2000. How do depth, duration and frequency of flooding influence the establishment of wetland plant communities?. Plant Ecology, 1472, 237-250.

Clark, J. D., & Eastridge, R. 2006. Growth and sustainability of black bears at White River National Wildlife Refuge, Arkansas. Journal of Wildlife Management, 704, 1094-1101.

Coller, A. L., Rogers, K. H., & Heritage, G. L. 2000. Riparian vegetation environment relationships: complementarity of gradients versus patch hierarchy approaches. Journal of Vegetation Science, 113, 337-350.

Franz, E. H., & Bazzaz, F. A. 1977. Simulation of vegetation response to modified hydrologic regimes: a probabilistic model based on niche differentiation in a floodplain forest. Ecology, 58, 176-183.

Gleason, R.A., Euliss, N.H., Hubbard, D.E., Duffy, W.G., 2003. Effects of sediment load on emergence of aquatic invertebrates and plants from wetland soil egg and seed banks. Wetlands, 23(1), 26-34.

Heitmeyer, M. E., and T. L. Foti. 2014. Hydrogeomorphic evaluation of ecosystem restoration and management options for Dale Bumpers White River National Wildlife Refuge. Prepared for U. S. Fish and Wildlife Service, Region 4, Atlanta, GA. Greenbrier Wetland Services Report 14-06, Blue Heron Conservation Design and Printing LLC, Bloomfield, MO.

Hodges, J. D. 1997. Development and ecology of bottomland hardwood sites. Forest Ecology and Management, 90(2), 117-125.

Hughes, F. M. 1990. The influence of flooding regimes on forest distribution and composition in the Tana River floodplain, Kenya. Journal of Applied Ecology, 27, 475-491.

Hughes, F. M. 1997. Floodplain biogeomorphology. Progress in Physical Geography, 214, 501-529.

Hupp, C. R., Pierce, A. R., & Noe, G. B. 2009. Floodplain geomorphic processes and environmental impacts of human alteration along coastal plain rivers, USA. Wetlands, 292, 413-429.

Hupp, C.R., Osterkamp, W., 1996. Riparian vegetation and fluvial geomorphic processes. Geomorphology, 14(4), 277-295.

Huston, M., 1979. A general hypothesis of species diversity. American naturalist: 81-101.

Junk, W., Bayley, P., Sparks, R. 1989. The flood pulse concept in river-floodplain systems. Canadian Special Publication of Fisheries and Aquatic Sciences 106: 110-127.

Klimas, C., Murray, E., Foti, T., Pagan, J., Williamson, M., & Langston, H. 2009. An ecosystem restoration model for the Mississippi Alluvial Valley based on geomorphology, soils, and hydrology. Wetlands, 29(2), 430-450.

Lin, Liu. Final Report: White River Basin Comprehensive Study: Development of Unsteady-State Model. Unpublished report to US Army Corps of Engineers. http://www.mvm.usace.army.mil/Portals/51/docs/PPPMD/White%20River%20Study/unsteady-state_model_wrb.pdf

McKnight, J.S., Hook, D.D., Langdon, O.G. and Johnson, R.L., 1981. Flood tolerance and related characteristics of trees of the bottomland forests of the southern United States. In: J.R. Clark and J. Benforado (Editors), Wetlands of Bottomland Hardwood Forests. Elsevier, Amsterdam/Oxford/New York, pp. 29-69.

Naumburg, E., Mata-Gonzales, R., Hunter, R., McLendon, T., Martin, D. 2005. Phreatophytic vegetation and groundwater fluctuations: A review of current research and application of ecosystem

response modeling with an emphasis on Great Basin vegetation. Environmental Management. 35(6), 726-740.

Pappenberger, F., Beven, K., Horritt, M., & Blazkova, S. 2005. Uncertainty in the calibration of effective roughness parameters in HEC-RAS using inundation and downstream level observations. Journal of Hydrology, 302 (1), 46-69.

Pollock, M., Robert J Naiman, and Thomas Hanley. 1998. Plant species richness in riparian wetlands – a test of biodiversity theory. Ecology, 79(1) 94-105.

Schumm, S. A., & Winkley, B. R. 1994. The variability of large alluvial rivers. ASCE Press.

Shaffner, A. 2012. Specific gage analysis on the lower White River, Arkansas. A Thesis. Southern Illinois University of Carbondale.

Streng, D., Glitzenstein, J., & Harcombe, P. 1989. Woody seedling dynamics in an East Texas floodplain forest. Ecological Monographs. 59, 177-204.

Tayefi, V., Lane, S.N., Hardy, R.J., Yu, D., 2007. A comparison of one- and two-dimensional approaches to modelling flood inundation over complex upland floodplains. Hydrological Processes 21, 3190–3202.

Tockner, K., & Stanford, J. A. 2002. Riverine flood plains: present state and future trends. Biological Sciences Faculty Publications. Paper 166.

Townsend, P.A., 2001. Relationships between vegetation patterns and hydroperiod on the Roanoke River floodplain, North Carolina. Plant Ecology, 156(1), 43-58.

Twedt, D., Loesch, C., 1999. Forest area and distribution in the Mississippi Alluvial Valley: implications for breeding bird conservation. Journal of Biogeography, 26(6), 1215-1224.

U.S. Army Corp of Engineers. 1974. Cache River Basin Project: Final Environmental Impact Statement. U.S. Army, Memphis District, Corp of Engineers, Memphis, TN, USA.

Ward, J. V., & Stanford, J. A. 1995. Ecological connectivity in alluvial river ecosystems and its disruption by flow regulation. Regulated Rivers: Research & Management, 111, 105-119.

Ward, J. V., Tockner, K., & Schiemer, F. 1999. Biodiversity of floodplain river ecosystems: ecotones and connectivity. Regulated Rivers: Research & Management, 151, 125-139.

Wharton, C. H., W. M. Kitchens, E. C. Pendleton, and T. W. Sipe. 1982. The ecology of bottomland hardwood swamps of the southeast: a community profile. Report prepared for National Coastal Ecosystems Team. US Fish and Wildlife Service Biological Services Progam FWS/ OBS-81/37. Washington, DC.

Chapter 4
Conclusions

Headwater floods dominate the unincised, upper reach of the floodplain while backwater floods dominate the unincised, lower, reach of the floodplain. Incision caused the greatest reduction in flood extent in the more frequent, headwater floods, and most of the reduced area of inundation occurred in the incised, lower reach. Incision decreased flood extent in the 1-year and 1.5-flood in backwater floods but not in larger events. Prior to incision the 1-year flood had approximately double the total area flooded than the 1.5-year flood. Most of the reduction in flooded area from backwater events occurred in the unincised reach.

The parameterized HEC-RAS model can be used to model hydrologic relationships in the vegetation. However, the range of error in modeled flooding depths was ±2.5 m (±1.5 m without outliers). This quantified range of error in modeled flood depths can help to identify the actual range of flooding among and within vegetation classes. The modeled flooding regimes were more distinguishable among floodplain reaches than among PNV classes. The upper reach flood more often from headwater floods, but the lower reach flood deeper by backwater floods.

Post-1930s incision reduced flooding depth and flood extent most in the Riverine Backwater Upper Zone, Riverine Backwater Lower Zone, and Riverine Overbank Natural Levee classes. The largest reductions in flooding depth and extent within these classes occurred during the more frequent floods, which are most important for ecological processes.

Vita

Erin Johnson received her bachelor's degree in Environmental Science at the University of Central Arkansas in 2012. After graduation, she decided to go to graduate school to pursue a master's degree in the School of Renewable Natural Resources at Louisiana State University. She hopes to begin a career in water resources and attain her professional hydrologist certification.