SPATIAL AND TEMPORAL VARIABILITY IN FLOODPLAIN SEDIMENTATION DURING INDIVIDUAL HYDROLOGIC EVENTS ON A LOWLAND, MEANDERING RIVER: ALLERTON PARK, MONTICELLO, ILLINOIS

BY

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THESIS

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Abstract

Floodplains are major sinks and sources for sediment within the fluvial system and are constructed through two main processes: lateral and vertical accretion. In fine grained systems, vertical accretion dominates. Overbank flooding and floodplain inundation are dependent on bank height and local topographic variability and this leads to highly variable deposition both spatially and temporally. In order to better understand the dynamics of flooding, single flooding events need to be observed and characterized. Using artificial turf mats as sediment traps, I measured floodplain deposition during five flood events on the floodplain of the Sangamon River at Allerton Park in Monticello, Illinois. The five events observed had peak discharges of 40-250 m^3/s. During each event, deposition was found to occur most frequently and with greatest magnitude in and adjacent to floodplain channels. Sediment thicknesses accumulated during each flood event vary from 0-4.5 mm with the largest deposition, equivalent to ~14 mm/year, being observed near a crevasse splay which may be evolving toward a meander cut-off. Flow simulations using the iRIC open source 2-dimensional solver of the St-Venant shallow water equations show how water inundates the floodplain during the rising limb of the largest discharge event observed. Geomorphic features such as floodplain channels, scroll bar topography, and, depressions drastically impact the routing of water over the floodplain and, ultimately, the location and amount of deposition.

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Introduction

The state of a floodplain along a meandering river results from long-term migration of the river channel, erosional and depositional processes associated with this migration, and variation in hydrological conditions (Howard, 1996). Treating the floodplain and channel as fixed simplifies understanding of fluvial processes on the floodplain, but the dynamic nature of the channel should not be ignored. It is now recognized that channel and floodplain morphology change significantly over the time scale of decades (Howard, 1996). Understanding the processes acting on the floodplain during individual events provides insight into the development and evolution of landforms over time.

Classification of floodplains has traditionally focused on case studies of specific rivers, for example, the Mississippi (Fisk, 1947) and the Brahmaputra (Coleman, 1969) and the importance of these systems was over emphasized as indicative of the majority of floodplains. Recent research has suggested that floodplains are constructed from a range of fluvial processes creating many floodplain types (Nanson and Croke, 1992). They also suggest that due to such diversity each case study (river) may need its own model of development. Identification of the mode of development is important in determining the past and potential future behaviors of the channel. Two primary modes of floodplain development exist: lateral and vertical accretion (Knighton, 1993). Lateral accretion is driven by deposition of sand creating point bars on the inside of meander bends and erosion of the outer bank. The net movement of the channel is laterally across the river valley ultimately consuming floodplain along the outer bank and at the same time creating a floodplain along the inner bank in the form of point bars (Lauer and Parker, 2008). Lateral migration becomes evident in surface topography as well developed scroll patterns on the inside of meander bends (Nanson and Croke, 1992). Vertical accretion results from overbank deposition of fine sediment (silts and clays) during flood events causing the floodplain to slowly aggrade as thin veneers of sediment are added in succession. This mode of development has been shown to dominate in low gradient, single thread, meandering channels (Schumm, 1968). Because of the past emphasis on large, actively migrating rivers, lateral accretion was viewed as the dominant mode of floodplain development and little attention was focused on fine grained systems and vertical accretion (Wolman and Leopold, 1957).

Recent studies have begun to focus on fine grained vertical accretion of floodplains which is estimated to comprise between 10 and 20 % of sediment deposition in natural alluvial systems (Wolman and Leopold, 1957), and, importance has been placed on determining the effect of individual flood events on the floodplain for sediment- associated contaminants and flood risk analysis (Nicholas and Walling, 1995). Where lateral migration is inhibited fine-sediment deposition will be the dominant agent in floodplain development (Walling and He, 1997). Floodplains dominated by fine grained deposition tend to have their topographic features mantled by a thin veneer of sediment. This results in preservation of topographic variation instead of rapid flattening that occurs during lateral migration processes. However, high levels of overbank deposition will also begin to flatten out topography as low areas become locations of preferential deposition (Howard, 1992). Topographic variations direct flow over the floodplain and impact the pattern of inundation and spatial pattern of deposition.

Topographic variability on a floodplain influences floodplain evolution because it controls spatial patterns of floodplain inundation, flow, and water storage on the floodplain surface. The flow and ponding of water on the floodplain determines sediment transport, erosion and deposition. When floodplains have very little topographic variability, water enters the floodplain by spilling over the bank and deposition decreases with distance from the channel (Howard, 1992). In contrast, topographic variability of the floodplain provides distinct pathways for water to enter, flow and pool on the floodplain (Mertes, 1997). Low elevation floodplain features accumulate precipitation falling on the floodplain and store water while the water table is elevated. As the floodplain becomes inundated, flow across the floodplain may enter these areas of ponded water where it will slow down, facilitating deposition. Spatial and temporal variability in floodplain topography and water storage creates variability in flow pathways and velocities that, in turn, causes patchy and intermittent deposition. Additionally, variable floodplain topography provides more concentrated pathways for flow than the widespread inundation of flat floodplains. The concentration of flow into preferred flood channels favors localized erosion of the floodplain and facilitates meander bend cutoffs (Constantine, 2008). Therefore, floodplain topography is tied to planform evolution of the channel via meander cutoff formation.

Of the several different styles of meander cutoff that have been described, chute cutoffs are most clearly influenced by floodplain topography. Chute cutoffs are channel segments that cut across meander bends to connect the two limbs of the meander. At least three distinct mechanisms of chute cutoff have been described: 1) headward extension of a chute from the downstream meander limb, 2) evolution of swales from flood channels into chutes, and 3) downstream extension of embayments from the upstream meander limb. Headward extension of the chute from the downstream limb has been observed in association with natural woody dam production forcing flow onto the floodplain above the meander bend and chute cutting initiating as water plunges over the bank to re-enter the main channel (Keller and Swanson, 1979; Gay et al, 1998). The formation of chute cutoffs from floodplain swales reflects frequent inundation and flow within swales (Fisk, 1947). Concentrated flow within swales during multiple flood events may cause them to gradually become the preferred pathway and act as chute cutoffs. Formation of a chute cutoff by extension of an embayment on the upstream limb of the meander bend was recently described on the Sacramento River in the absence of scroll bar sand other variations in floodplain topography (Constantine, 2010).

This study focuses on a fine-sediment dominated system with significant variability in floodplain topography and aims to characterize the spatio-temporal variability in floodplain inundation, deposition, and erosion and evaluate the potential impact of this variability on the evolution of the floodplain and channel morphology. The study area is in Allerton Park, Monticello, Illinois where the 3,690 km^2 drainage area Sangamon River freely meanders. Floodplain topography in Allerton Park is complicated and consists of overbank flood channels, closed depressions and chute cut-offs that become inundated during different river discharges. The study area includes a crevasse splay and assesses the potential for this feature to evolve into a chute cutoff via downstream extension to meet the downstream meander limb. A two-dimensional flow model was used to route water over the floodplain through a flood hydrograph and combined with field observations to locate areas of concentrated flow and ponding. Sediment traps were strategically placed to measure spatial variability in floodplain deposition during five flood events that occurred between May 2014 and October 2014. These data allow for evaluation of the relationships among floodplain topography, flow on the floodplain, and spatial patterns of deposition and erosion. They also suggest extension of the crevasse splay is occurring and may ultimately facilitate chute cutoff via embayment extension in a much smaller and more topographically variable setting than that described by Constantine (2010).

Background

Where floodwaters exit the channel at local lows in bank height, flow over the floodplain is initiated, leading to sediment transport and the potential for deposition (Constantine et al, 2010). Variability in bank heights causes spatially non-uniform inundation of floodplains. As the river stage increases, water first moves from the channel to the floodplain where bank heights are the lowest. Water moving onto the floodplain experiences rapid changes in velocity along the flow path reducing the transport capacity of the flow and forcing deposition. Heterogeneous floodplain topography routes water over the landscape and creates areas of pooling in low elevation features including closed depressions, flood channels, and swales along the inside of meander bends (Mertes, 1997). Deposition occurs in areas of ponded water because water flowing in from the floodplain loses momentum, and therefore, the ability to transport sediment. Deposition is increasingly likely with increasing persistence of standing water. In summary, floodplain topography causes spatial and temporal variability in flow velocity on the floodplain that creates spatial and temporal patterns in erosion, sediment transport and deposition.

The role of floodplain topography in chute cutoff processes provides an extreme example of potential impact of floodplain topography on fluvial system evolution (Figure 1). Chute cutoff is the creation of a new channel within a floodplain which requires the production of significant topographic variability on the floodplain surface. In some cases, pre-existing topographic variability in the form of scroll bar topography is enhanced to create a chute cutoff (Fisk, 1947). In other cases, the chute forms as a new channel extends headward from the downstream limb of the meander bend. This new channel is initiated when a natural dam upstream of the meander forces water onto the floodplain in the location where floodplain water plunges over the channel bank to re-enter the main channel or simple overbank flow during a flood (Zinger et al, 2011). The dam can be woody debris (Swanson, 1979) ice (Gay et al., 1998) or channel bed aggradation forced by increases in sediment load, or decreases in discharge (Thompson, 2003). A new mechanism of chute cut-off, recently proposed by Constantine et al. (2010), consists of downstream extension of an embayment to form a chute cutoff. In this model, an embayment on the outer bank downstream of the apex of a meander bend forces water onto the floodplain at high stage, facilitating erosion of the floodplain. Embayments may be pre-cursors to cutoff since they provide a topographically low area for water to flow through at increased discharges (Constantine, 2010).

Floodplain topography influences not only erosion of the floodplain, but also moderates patterns of deposition. The contrast in flow depth between the channel and floodplain itself is a primary driver of deposition on floodplains. During flood events, suspended sediment that had been in transport within the confines of the main channel may be deposited on floodplains (Nicholas and Walling, 1996). The interaction between the deeper, confined flow of the main channel with slower, shallower flow over the floodplain leads to a transfer of momentum that is apparent in turbulent eddies at the surface (Patra and Kar, 2000). The transfer of momentum and sediment to the floodplain coupled with differences in flow velocity between the channel-floodplain enhance both erosion and deposition (James, 1985). As flow enters the floodplain, the water loses its ability to carry large particles. This decrease in competence is due to the reduction in flow velocity and depth, and the increase in roughness encountered by the flow (Nicholas and Walling, 1996). Transfer of sediment from a region of high suspended sediment concentration to those of low concentration is analogous to a diffusion process (James, 1985). This diffusion of suspended sediment leads to preferential deposition of large grain sizes near the channel and a gradual fining as distance from the channel increases (Pizzuto, 1987). The amount of deposition also tends to decline exponentially with distance from the channel. These simple relationships between the channel and floodplain are complicated in the case of variable topography within the floodplain.

Floodplain relief leads to spatial heterogeneity in hydrodynamics and sedimentation (Walling *et al*., 1992). The tendency for lesser amounts and finer grain sizes of sediment with distance from the channel is less pronounced in systems with complex floodplain topography (Nicholas and Walling, 1996). In these systems variations in topography create discrete patches of high and low sedimentation rates which result from predictable patterns of inundation. Horritt and Bates (2002) found when testing two models of floodplain inundation that topography is the major component of the system which dictates the observed inundation pattern. When modeling with high-resolution digital elevation models (DEMs) from LIDAR observations, the influence of topography can be visualized. Earlier work by Bates and Roo (2000) also concluded that topography is the driver of floodplain inundation patterns. Small variations in topography can have drastic effects on the areal extent of flooding effects. This strong dependence on topography drives the variability of sedimentation on the floodplain.

Measurement of sedimentation during individual flood events is one way of characterizing spatial variability in floodplain sedimentation. Sediment traps provide a relatively simple method of measuring sediment deposition across variable floodplain topography. Studies using sediment traps have mainly focused on European lowland rivers with an interest in how the floodplain stores pollutants adsorbed to fine sediment (Walling and He, 1997; Asselman and MIddlekoop, 1995). Simm (1995) reports deposition rates between 0.2 -13.5 mm/year with the greatest deposition occurring in bank breaches (crevasse splays) and the least deposition on flat areas distal from the main channel. Swanson *et al* (2008) found deposition rates between 1 and 51 mm/yr with the greatest rates proximal to the main channel and the lowest rates far from the channel. Sediment traps may not provide a representative measurement of floodplain deposition, especially where topographic variability is high. Not identifying the geomorphic landforms correctly leads to misrepresentation of the spatial patterns of deposition because of the incorrect placement of the traps (Baborowski et al, 2007). Sediment traps are inherently limited to short timescale measurements and, therefore, have a limited ability to address how spatial patterns of sedimentation are integrated in to floodplain deposits.

Study Location

The Upper Sangamon River Basin (USRB) drains an area of 3690 km^2 above Lake Decatur and the river flows through intensively managed agricultural land (77%), urbanized and built-up land (12%) and riparian forests and grassland (10%). The Sangamon River sits in a valley which was incised at the end of the Wisconsin glacial episode during retreat of the glacier. Geologically, the Upper Sangamon basin is bordered by multiple moraines of the Wisconsin glacial episode (30-14 ka). The Newton and Gifford moraines border the basin in the North. The Cerro Gordo Moraine bounds the river valley in the southeast as the river travels through Piatt County. The Cerro Gordo moraine is also breached by Camp Creek resulting in drainage of lands on both sides of the moraine. The Champaign Moraine borders the basin in northwestern Champaign County and is bisected by the Sangamon River Valley. The Bloomington moraine intersects the basin in the North-West corner (ISGS Moraine Map, 2000). The basin area is dominated by un-consolidated glacial till of the Wedron Group (ISGS Quaternary Map, 2005) and is overlain with highly productive Alfisol and Mollisol soils (USDA and NRCS soils map).

The floodplain of the Sangamon River at Allerton Park in Piatt County, Illinois was targeted for investigation of floodplain sedimentation and erosion on a topographically-variable floodplain. The drainage area of the Sangamon River at Allerton Park is ~1500 km^2. Large portions of the basin are tile drained and much of the drainage network has been artificially straightened, deepened and extended via the construction of drainage ditches. The main stem of the Sangamon River and lower reaches of major tributaries meander through riparian forests. Allerton Park located in Piatt County, Illinois (Figure 2) and is approximately 1,500 acres which has been owned by the University of Illinois since

1946. The Sangamon River flows through the park and there has been little human modification of the floodplain since the construction of the Allerton private residence in 1900. Allerton Park consists of straight drainage ditches, channelized sections of headwaters, and meandering natural sections with riparian vegetation and forested sections. The floodplain within the park is forested and the channel is able to freely migrate. Original survey records of the area indicate that Allerton Park lands were almost entirely forested pre-settlement and selective logging took place post-settlement (Bourdo, 1956, Hutchison, 1988). This minimal disturbance is in stark contrast with the heavily modified upper reaches of the river since settlement. Floodplain channels are present throughout the floodplain and impact the drainage and sediment transport. An elevation profile through one of the flood channels shows the topographic variability which is characteristic of the study area as well as a prominent scour hole. This scour hole is an area of erosion and creates a hydrologic barrier to flow across the floodplain creating a positive feedback, deepening the hole along (A-A') (Figure 3).

A United States Geologic Survey (USGS) maintained stream gauge directly upstream of Allerton Park (Monticello Gauge, USGS 05572000) provides real-time stage and discharge data for the Sangamon River. Flood stage at this gauge is nominally 4 m (13 feet). Field observations indicate that water enters the floodplain in the study area at local bank height minima when the gauged stage is between 2.8 m to 3.4 m (9-11 feet). Inundation of the floodplain in the study area is frequent. From January – December 2014 a total of 9 events occurred that would inundate the floodplain at the study site. The entire hydrologic record for the Monticello gauge averages ~33 events per decade that exceed the minimum stage of 2.8m since 1908. The frequency of inundation does not appear to be changing over the last 100 years and the number of events per decade ranges from 24-45 (Figure 4).

A geomorphic map created using LIDAR-based high resolution topography and field observations highlights the complexity and topographic variability of the Sangamon floodplain at Allerton Park (Figure 5). The most prominent features creating topographic variability on the floodplain are a number of channels which convey water across the floodplain at high flow herein termed "floodplain channels". Floodplain channels tend to occur near the edges of the floodplain and many convey water at discharges well below the average bankfull stage. Floodplain channels are differentiated from chute cutoffs by their length and connection to the main channel. Floodplain channels are long relative to the meander wavelength and do not necessarily connect limbs of a single meander bend. Several chute cutoff channels are also present in the study area and these are short channels directly connecting two limbs of the same meander. Ridge and swale (scroll bar) topography is evident within several meander bends, suggesting typical meander migration processes have also shaped the study area.

Erosion of the main channel banks is evident through tree fall and undercutting of banks and is evident on the floodplain surface where scour holes are present in floodplain channels. However, the rates of erosion and channel migration are exceptionally slow. Migration rates are highly variable depending hydrologic conditions, channel planform, soil properties, presence of vegetation and human impact and can range from 0.10 – 41 m per year for small rivers (Hickin and Nanson, 1986), Large rivers like the Mississippi average ~20 m per year but can be as high as 125 m per year (Hudson and Kesel, 2000). Lauer and Parker (2008) found migration rates to be between 0.23 -1.23 m per year for rivers ranging from 12-146 m wide. Hickin and Nanson (1983) studied a similar size river to the Sangamon River and found migration rates that averaged 0.42 m per year for 16 different bends and in some years as high as 1.2 m per year for the Beatton River in Canada. The planform of the Sangamon River is quite stable within the study area with little movement detected since 1820 (Rhoads et al., 2015). Aerial photos reveal very little migration of the channel since 1940 (Figure 6) and have estimated migration rates of the order of tens of centimeters per year with ~1-2m of migration occurring from 1940-present.

Methodology

Sediment Trap Sampling, Grain Size Analysis and Deposition Rate Estimation

Sediment traps were used to quantify the amount of sediment deposited from March 2014 through November 2014. Sediment traps consisted of 0.25m x 0.25m squares of plastic outdoor carpeting anchored to the ground using two to four 0.1 m long garden staples. After each flood event, traps were collected for analysis and replaced with new traps in the same locations.

In order to characterize the spatial variability of deposition across the floodplain, twenty-three traps were installed along three transects (Figure 7). Two transects were located in the upstream portion of the floodplain, Upper Short and Upper Long. Upper Short (US) consisted of five sediment traps spaced equally at 40 m intervals parallel to the channel atop the natural levee (Figure 7). Sediment trap US3 along this transect was the beginning of Upper Long (UL). UL had a total of eight sediment traps spaced 40m apart to capture the variability in sedimentation across a broad, flat area. In the downstream portion of the study area, Lower transect (L) consisted of eleven traps spanning the floodplain from the channel bank to an area at the elevation of mean annual flood located near the valley wall. Traps on transect L were positioned in order to sample deposition rates across the local variability in topography. Specifically, traps were sited at ridge crests and the bottoms of swales and flood channels within an area of ridge and swale topography.

After each event the traps were retrieved and placed into large plastic re-sealable bags. Traps were stored in a freezer until processing commenced. Material was washed off each sediment trap into an aluminum pan and allowed to settle for 48 hours. Clean water was manually removed from the pans and remaining water was removed by oven drying at 100ºC for 24 hours. This methodology follows Friese et al, (2000), and Keestra (2007). Dried samples were weighed using an analytical balance accurate to the nearest 0.01g.

The total mass for each sediment trap was converted to a depth of deposition by modeling the sample as consisting of a characteristic grain size (7.5 microns) based on the particle size of the material and assuming constant average density (2798 kg/m^3) for silt sized particles. The volume of each grain size fraction was computed by dividing the mass of each size fraction by the assumed density of that fraction. The volumes were summed to compute a total sediment volume and divided by the area of the sediment trap (0.0625 m^2) to estimate the thickness of the sediment deposit.

Samples were prepared for grain size analysis following the Illinois State Water Survey (ISWS) protocol (ISWS, 2014). Samples were disaggregated, mixed and subsampled. Subsamples were weighed to 0.0001g, bleached and bathed at 80ºC for 15 minutes to oxidize the organic matter. Samples were centrifuged for 10 minutes at 2500 RPM to separate organic matter for manual removal. Samples were washed through a 62 micron sieve isolate the sand fraction (> 62 micron diameter). The fine fraction was dried at 90ºC for 48 hours and weighed using an analytical balance. The resulting material was ground with a mortar and pestle. Once ground, the distributions of fine grain sizes were measured with x-ray diffraction in a Sedi-Graph particle size analyzer.

Surface Sediment Sampling and Grain Size Analysis

During installation of the sediment traps, sand was identified on the floodplain surface near trap L7. The sand was present near an embayment on the upstream limb of the meander bend sampled in transect L. Six surface samples were collected for grain size analysis along a path connecting this embayment with trap L7 and continuing toward the downstream limb of the meander bend (Figure 8). Depth of the sand was first obtained using a soil probe. Surface samples were then scooped from the surface and placed in bags and tagged with location along transect and dated

The surface sediment samples were mixed, subsampled and weighed using an analytical balance to the nearest 0.0001g. Sample were washed through a 62 micron sieve to separate finer particle from sand size particles then dried for 24 hours at 100ºC. The samples were then re-weighed to get the percentage of the sample which was sand. The sand-sized fraction of each sample was dry sieved to separate it into size fractions using a micro sieve with mesh sizes ranging from 1000 - <63 microns. Summary statistics of the grain size distribution were computed using GradiSTAT software (Blott and Pye, 2001).

Flow Simulation

Flood simulations were run using the Nays2DFlood model developed by Yasuyuki Shimizu in the early 1990's. It was later improved by Ichiro Kimura and Toshiki Iwasaka of Hokkaido University and incorporated into the International River Interface Cooperative (iRIC) project in 2011. The model analytically solves the shallow water flow equations

(Saint-Venant) that are derived from the 2D form of the Navier-Stokes equations. It relies on unsteady 2-dimensional plane flow simulation and uses boundary fitted coordinates in general curvilinear form. The flow simulation was run over a LIDAR generated digital elevation model (DEM) with a 2m rectangular grid overlayed with inflow and outflow occurring at the boundary of the grid. Initial flow conditions are imposed until a steady state is reached after (7200 s). Once steady state is reached, it is maintained for a single timestep and discharge is then increased through a range of discharges representing flood magnitudes that occurred in the Sangamon River during the study period. The initial steady state condition is a discharge of 35 m^3/s, corresponding to approximately the bankfull condition. The discharge is increased incrementally to a value of 250 m^3/s, which corresponds to the 5-year flood event.

Results

Flood event sedimentation

Sediment trap deposition rates were measured for five flood events which occurred between May 2014 and October 2014 (Figure 9). Deposition was spatially variable with no measureable deposition occurring along transects US and on traps L1-5 and L11 during the study period. The relative differences in sedimentation rates between traps remained fairly constant across events (Figure 9). In all events, the greatest deposition occurred at L7, deposition rates roughly half of the maximum rate were observed at L9 and L10, and traces of sediment were deposited at L6 and L8. The thickness of sediment deposited over the course of the study at L7 was 14 mm.

The majority of sediment deposited on the traps (90-98% of each sample) was finer than sand (<62 microns) (Figure 10). The median grain size (d_{50}) for all subsamples varied between 5 and 10 microns, indicating that silt is the characteristic grain size. Grain size correlates with deposition rates: finer sediment dominates where deposition rates are low and the result of overbank deposition. The finest d_{50} values (5-7 microns) were measured at L6 and L8, where only trace amounts of deposition were measured. The d_{50} values at L9 and L10 are slightly larger (8-10 microns), but still in the fine silt range. The coarsest d_{50} (10 microns) was measured at L7 and the overall grain size distribution is coarsest here and L7 is also the location with the most abundant sand in the samples.

Surface sediment size distributions

Surface grab samples taken near trap L7 are dominated by sand. This location is the only area of the floodplain where sand was observed in the field and sediment caught by L7 has the highest percentage of sand amongst the trap samples (10-15%). Trap L7 is close to a large scour hole that connects to the main channel on the upstream limb of the meander via a narrow, low elevation channel. This feature is interpreted as a crevasse splay because the river bank is low in this area and the scour hole indicates erosion of the floodplain by fast moving water exiting the channel. Downstream of the scour hole the floodplain channel becomes un-confined and gently sloping towards the main channel. Sand is distributed throughout the area in a fan-shaped deposit. A thin 5-10 cm layer of sand exists and spreads out immediately downstream of the scour hole near L7. This is the characteristic shape of a crevasse splay deposit (Van de Lageweg et al., 2013). The percentage of sand decreases with distance from the scour hole, presumably along the direction of water flow. Samples closest to the scour hole had the highest percentage of sand and there is generally an inverse relationship between distance from the main channel and sand content (Figure 10). The composition of sediment varied slightly from but remained consistently in the fine sand to medium sand range captured by a sieve sizes of 0.125-0.250 mm with the most abundant grain size being <0.125 mm (Figure 11). Samples 1-6 and 3-10 include very coarse sand and very fine gravel fragments ranging from 1-3 mm.

Flow Routing

Multiple values for discharge were chosen to simulate typical flood magnitudes for the Sangamon River at Allerton Park using the USGS stream gauge on the Sangamon River at Monticello, Illinois (USGS 05572000). The smallest discharge modeled, 35 $m^{3/}$s, is approximately the bankfull discharge for the Sangamon at Allerton Park (Figure 12).

The largest discharge modeled, 250 m^3/s, corresponds to a five year flood recurrence interval similar to that observed in the July 2014 event. At a discharge of 35 $m^{3/}s$, flow is mostly contained within the main channel within the park, however, low elevation flood channels are beginning to have water in them (Figure 12). At an intermediate discharge of 100m^3/s, all flood channels contain water at depths close to 1m (Figure 12). Portions of transect L are inundated including the locations of traps L7, L9 and L10. Areas surrounding the large meander loop in the northeast portion of the park are also under ~1.5m of water. At a modeled discharge of 250 m^3/s, most of the floodplain is under water (Figure 12). Transect L has areas with water depths of ~2m including the traps at L7, L9 and L10. Transects US and UL show some shallow inundation during the simulation along UL, but US does appear get inundated at any point. UL8 at the northern end of transect (L) is inundated at low flows and for the remainder of the simulation. Low areas near the large meander loop with the cutoff in the north end of the park are under ~2.3m of water. Field observations from a limited number of locations at a range of discharges confirms the presence of flowing water within flood channels as predicted by the model.

Discussion

Floodplain Inundation

Variable topography is a strong influence on the observed inundation pattern at Allerton Park. Modeling of a large flood event indicates that a relict meander bend and floodplain channels create avenues for flow of sediment-laden water onto the floodplain. The maximum observed deposition occurs in and adjacent to these areas. During each flood event the floodplain is quickly inundated first at L7 then L9 and L10 due to the relatively low bank height along the outer bank of the main channel (Figure 12). This provides a direct sediment pipeline from the main channel to the floodplain at L7, L9 and L10 for the duration of the flood event. During the falling limb of the hydrograph, flow on the floodplain becomes disconnected from the main channel resulting in the appearance of sediment laden pools. Two pools occur, one in the chute splay at L7, and the second in a relict meander bend at L9 and L10 where sedimentation occurs similar to that observed by Lambert and Walling (1987). Along the flow path near L7 water exits the main channel and flows in a confined floodplain channel until a deep scour hole (pool) where bed elevation abruptly increases. After the increase, flow inundates an unconfined area where at L7 during the falling limb of the hydrograph along (A-A'). This area is in contrast to transect (B-B') where elevation varies in a regular scroll bar pattern along its entirety. We see a slow, small increase in overall elevation from L11 to the main channel with regularly spaced highs (ridges) and lows (swales) that appear to be from past meander migration.

The elevation profile (B-B') along transect L shows that the floodplain elevation is highest near the main channel and gently slopes towards the lowest areas at sites L7, L9 and L10 (Figure 3). Variability in elevation is small (~1 m); thus, inundation of the entire transect should be likely during large magnitude events. However, no deposition occurred on sediment traps L1 to L5 suggesting that inundation was not occurring or there was not sufficient time for sedimentation to occur, if inundated. This suggests that floodplain inundation is possibly limited by the ability of floodplain channels to convey water efficiently across the bend and reducing the areal extent of inundation and deposition. In addition, the patterns of deposition and flow simulations demonstrate that water does not enter the floodplain along Lower transect in the traditional sense of overbank flooding from the main channel but instead it uses the floodplain channels. Sediment traps located near the main channel captured no sediment during the study period and no evidence of the sediment traps being inundated was found during field visits. Flow simulations suggest that bank heights along this short reach are too high for water to enter the floodplain, further supporting the idea that flow onto the floodplain begins along distinct flow pathways using floodplain channels at L7 and L10.

Flood hydrographs typically have a fast rising limb and slower falling limb. A steep rising limb drives erosion from an increase in discharge, velocity and shear stress along flow paths on the floodplain. Decreasing discharge on the falling limb favors deposition when flow velocities slow to a level which allows deposition to occur and pooled water is then disconnected from the main channel along (A-A') across the meander bend at L7. Long residence times of quiescent water are necessary for deposition of fine sediment in the pools and this occurs as flood waters recede. This can occur from a short or long duration flood because sediment concentration, transport capacity and hydraulic conditions on the floodplain are more important than flood duration. Field observations and model simulations both find that traps L7, L9 and L10 were underwater for periods much longer than other portions of the floodplain resulting in substantial spatial heterogeneity in deposition.

Floodplain deposition during low-magnitude events along this reach of the Sangamon River is primarily a result vertical accretion in discrete low lying portions of the floodplain. Deposition is limited to small areas and occurs at very slow rates. The presence of floodplain channels limits the areal extent of deposition by efficiently conveying water across the floodplain. Since lateral migration of the main channel is occurring slowly, low-relief topographic variability of the floodplain due to past meander positions is preserved. Minimal meander migration has occurred during the last 200 years and aggradation has been occurring slowly. To gain a better understanding of the long-term behavior of the river in Allerton Park it would be beneficial to date the scroll bars on the inside of the meander bend and determine the timing of the apparent channel migration. Also a deeper look into the sedimentology of the floodplain would further constrain the timing of channel migration and help to fully characterize the Holocene history of the Sangamon River Valley in Allerton Park.

Floodplain Sedimentation

The spatial patterns of sedimentation observed are a function of floodplain topography and connectivity to the main channel. A consistent pattern characterized by maximum deposition close to a crevasse splay at location L7 and a relict meander at traps L9 and L10 was observed. The pattern of deposition is dependent on areas of low relative floodplain elevation (i.e. pools). Traps L6 and L8 were elevated 0.2-0.4 m relative to L7, L9, and L10 and captured much less sediment as a result. Deposition does not follow a simple diffusion model of over bank deposition (Howard, 1992) where deposition is maximized on the natural levee and decreases with distance from the channel. The presence of variable floodplain topography complicates this relationship and shifts the depositional centers to areas of low elevation without regard to distance from the main channel. Maximum deposition was observed far from the main channel in low areas. Transect (US) in the northeastern portion of the park experienced no deposition during this study and this is attributed to its elevated position along the natural levee. The lack of deposition on the levee is also in contrast to the Howard (1992) model which predicts maximum deposition near the main channel. Transect (UL) also experienced minimal deposition during all events. It appears that one trap UL8 may have become inundated during flood event 1 event but its location remained inundated for the duration of the season once flooded, making retrieval impossible.

Two-dimensional flow simulations suggest that low elevation areas observed to have maximum deposition rates are directly connected to the main channel by flow in floodplain channels and are inundated for long periods of time during flood events. Two areas intersected by transect L are modeled to have long durations of inundation (Figure 12). One area, including traps L8 to L10 is a former meander scar. The other area, including sites L6 and L7 is a crevasse splay. Both of these areas are connected to the main channel during flooding by flow paths allow sediment-laden water to penetrate deep into the floodplain far from the main channel banks. The spatial pattern of sedimentation suggests that the role of flood channels in providing a source of sediment to the interior of the floodplain is crucial in driving sedimentation: maximum deposition is observed in areas which are connected to the main channel during flood events.

The grain size distributions observed in floodplain deposits is dependent on both elevation and proximity to flood channels. High elevation traps L6 and L8 received only silt and clay. Relatively little sand was found at L9 and L10 (5-10% of the sediment). In contrast, the sediment was 40-70% sand at L7 near an area of levee failure on a crevasse splay. Abundant sand as L7 indicates that flow velocity and transport capacity through the chute splay is high enough to move coarse sediment. Grain size distributions on the sediment traps along transect L do not vary significantly between events or traps, indicating similar hydraulic conditions across events. Sand on trap 7 and the grain-size distribution of surface grab samples suggest that this area represents a crevasse splay, resulting from a previous bank failure. Aerial photos indicate the crevasse splay developed around 2005-2008, but are inconclusive for determining the exact timing (Figure 13). The crevasse splay acts as a source of sand in two ways. First, the breach in the channel bank promotes erosion of the floodplain deposits which may be a local source of sand. . Second, the lowered bank height it makes it easier for course sediment to be transported out of the main channel and into the crevasse splay. This feature has the potential to fully develop into a chute cut-off as in Constantine (2010), where the dominant flow of the main channel diverts across the neck of the meander bend and erodes an embayment from upstream to downstream.

Sediment deposition rates show an average increasing tendency with increasing flood magnitude. However, the areal extent of deposition was consistent throughout all observed flood events. The relationship between deposition-discharge at L7 is due to the fact that increasing the discharge in the floodplain channel requires an increase in velocity to accommodate the larger discharge. During a 5–year flood event the flow in the chute splay is likely to impart greater shear stress on the bed relative to a smaller event, therefore increasing erosional capability and deposition downstream of the scour hole. Sediment traps L6 and L8, located at slightly higher elevations than trap L7 experienced minimal deposition suggesting there was similar inundation levels as smaller events, or water was moving too fast for deposition to occur.

Future Work

Much work can be done to further understand the development and exact timing of the meander cut-off located at trap seven. A comprehensive floodplain architectural and sediment dating analysis would be helpful to further constrain the development of the geomorphic features on the Sangamon River floodplain along with the historical activity of the channel. Quantifying erosion along Lower Transect (L) would also help to identify the over net behavior of the floodplain, is it aggrading or degrading? Combining these results with Cs-137 and fly-ash dating from the park will aid in determining the depth of the post settlement alluvium in the Sangamon River valley and the contribution of sediment to the floodplain as a result of European settlement.

Conclusion

The floodplain of the Sangamon River at Allerton Park consists of complex topography which routes water through and focuses deposition in low elevation areas. Sediment traps record significant deposition during flood events in low areas where there is sufficient residence time for sediment laden water in pools for deposit after flow recedes. Higher elevations on the floodplain do not experience significant deposition and this contributes to the maintenance of present day floodplain morphology. Events with large discharges generally had increased sedimentation, although this was not true for all cases, nor did it indicate more widespread deposition. Geomorphically, the Sangamon River appears to be stable within its floodplain since there has been little migration over the past 200 years. Although we see a number of flooding events occurring on a yearly basis that are capable of depositing sediment, it does not appear to be enough sediment to significantly alter the morphology of the floodplain.

References

Asselman, N. E. M., Middlekoop, H. 1995. Floodplain sedimentation: Quantities, Patterns and Processes. *Earth Surface Processes and Landforms* 20, 481-499

Baborowski, M., Buttner, O., Morgenstern, P., Kruger, F., Lobe, I., Rupp, Tumpling, W.V. 2007. Spatial and temporal variability of sediment deposition on artificial-lawn traps in a floodplain of the River Elbe. *Environmental Pollution* 148, 770-778

Bates, P.D., De Roo, A.P.J. 2000. A simple raster-based model for flood inundation simulation. *Journal of Hydrology 236, 54-77*

Bourdo, E. A. 1956. A review of the General Land Office survey and of its use in quantitative studies of former forests. *Ecology*, 754-768

Blott, S.J. and Pye, K. (2001) GRADISTAT: A grain size distribution and statistics package for the analysis of unconsolidated sediments. *Earth Surface Processes and Landforms* 26, 1237-1248

Coleman, J.M. 1969. Brahmaputra River: Channel processes and sedimentation. *Sedimentary Geology-special issue 3(2/3),* 129-239

Constantine, J.A., McLean, S.R., Dunne, T. 2010. A mechanism of chute cutoff along large meandering rivers with uniform floodplain topography. *Geological Society of America 122, No 5/6, 855-869*

Constantine, J.A., Dunne, T. 2008. Meander cutoff and the controls on the production of oxbow lakes: *Geology* 36, 23–26

Fisk, H.N. 1947. Fine-grained alluvial deposits and their effect on Mississippi River Activity, Waterways Experiment Station, U.S. Army Corps of Engineers, 82 pp.

Friese, K., Witter, B., Brack, W., Buttner, O., Kruger, F., Kunert, M., Rupp, H., Miehlich, G., Grongro¨ft, G., Schwartz, R., van der Veen, A., Zachmann, D.R. 2000.

Distribution and fate of organic and inorganic contaminants in a river floodplain: results of a case study on the River Elbe, Germany. In Wise, D.L., Trantolo, D., Cichon, E.J., Inyang, H.I., Stottmeister, U. (Eds*.), Remediation Engineering of Contaminated Soils, 375-428*

Gay, G.R., Gay, H.H., Gay, W.H., Martinson, H.A., Meade, R.H., Moody, J.A. 1998. Evolution of cutoffs across meander necks in Powder River, Montana, USA. *Earth Surface Processes and Landforms 23, 651-662*

He, Q., Walling, D.E. 1996. Use of fallout Pb-210 measurements to investigate longer term rates and patterns of overbank sediment deposition on the floodplains of lowland rivers. *Earth Surface Processes and Landforms 21, 141-154*

Horritt, M.S., Bates, P.D. 2002. Evaluation of 1D and 2D numerical models for predicting river flood inundation. *Journal of Hydrology 268 87-99*

Howard, A.D. 1992. Modeling channel migration and floodplain sedimentation in meandering streams. *Lowland Floodplain Rivers: Geomorphological Perspectives. Chapter 1 1-40.*

Howard, A.D., 1996, Modelling channel evolution and floodplain morphology, *in* Anderson, M.G., Walling, D.E., and Bates, P.D., eds., Floodplain Processes: New York, John Wiley & Sons, p. 15–62.

Hudson, P.F., Kesel, R.H. 2000. Channel migration and meander-bend curvature in the lower Mississippi River prior to major human modification. *Geology 28(6), 531-534.*

Hutchison, M. 1988. A guide to understanding, interpreting, and using the Public Land Survey field notes in Illinois. *Natural Areas Journal 8, 245-255*

Illinois State Geological Survey Staff (ISGS). 2005. Quaternary Deposits Map

Illinois State Geological Survey Staff (ISGS). End Moraines of the Wisconsin Glacial episode Map.

Illinois State Water Survey. 2014. Standard operation protocol 10. Prepared by Kim Attig

James, C.S. 1985. Sediment transfer to overbank sections. *Journal of Hydraulic Research 23(5), 435-452*

Keestra, S. D. 2007. *Impact of natural reforestation on floodplain sedimentation in the dragonja basin, SW Slovenia.* Earth Surface Processes and Landforms. 32, 49-65

Keller, E.A., Swanson, F.J. 1979. Effects of large organic material on channel form and fluvial processes. *Earth Surface Processes* 4(4) 361-380

Knighton, A.D. 1998. Fluvial forms and processes. New York, John Wiley & Sons, 383 p

Lambert, C.P., Walling, D.E. 1987. *Floodplain sedimentation: A preliminary investigation of contemporary deposition within the lower reaches of the River Culm, Devon, U.K.* Geografiska Annaler. 69, 393-404.

Lauer, J.W., Parker, G. 2008. Net local removal of floodplain sediment by river meander migration. *Geomorphology* 96, 123–149

Mertes, L.A.K. 1997. Documentation and significance of the perirheic zone on inundated floodplains. *Water Resources Research, 33/7 1749-1762*

Nanson, G.C., Hickin, E.J. 1986. A statistical analysis of bank erosion and channel migration in western Canada. *Geological Society of America Bulletin 97, 497-504*

Nanson, G.C., Hickin, E.J. 1983. Channel migration and incision on the Beatton River. *Journal of Hydraulic Engineering* 109, 327-337

Nanson, G.C., Croke, J.C. 1992. A genetic classification of floodplains. *Geomorphology 4, 459-486*

Nicholas, A.P., Walling, D.E. 1996. The significance of particle aggregation in the overbank deposition of suspended sediment on river floodplains. *Journal of Hydrology 186, 275-293*

Nicholas, A.P., Walling, D.E. 1997. Modelling flood hydraulics and overbank deposition on river floodplains. *Earth Surface Processes and Landforms 22, 59-77*

Patra, K.C., S.K, Kar. 2000. Flow interaction of meandering river with floodplains. *Journal of Hydraulic Engineering 126, 593-604*

Pizzuto, J.E. 1987. Sediment diffusion during overbank flows. *Sedimentology 34, 301-317*

Rhoads, B.L., Lewis, Q., Andresen, W. 2015. Historical channel change in an Intensively Managed Landscape: Natural versus Human induced effects. *Geomorphology* (Accepted)

Schumm, S.A. 1968. Speculations concerning paleohydrologic controls of terrestrial Sedimentation. *Geological Society of America Bulletin 79, 1573-1588*

Simm, D.J. 1995. The rates and patterns of overbank deposition on a lowland floodplain *Sediment and water quality in river catchments, 247-264*

Swanson, K.M., Watson, E., Aalto, R., Lauer, J., Bera, M.T., Marshall, A., Taylor, M.P., Apte, S.C., Dietrich, W.E. 2008. Sediment load and floodplain deposition rates: Comparison of the Fly and Strickland rivers, Papua New Guinea. *Journal of Geophysical rsearch: Earth Surface (2003-2012) 113(F1)*

Thompson, D.M. 2003. A geomorphic explanation for a meander cutoff following channel relocation of a coarse-bedded river. *Environmental Management 31, 385–400*

United States Department of Agriculture, Natural Resources Conservation Service. Soil Datamart. 2015. http://soildatamart.nrcs.usda.gov

Walling, D.E., He, Q. 1998. The spatial variability of overbank sedimentation on river floodplains. *Geomorphology 24, 209-223*

Walling. D.E., He, Q. 1997. Investigation spatial patterns of overbank sedimentation on river floodplains. *Water, Air and soil Pollution 99, 9-20*

Walling, D.E., Quine, T.A., He, Q. 1992. Investigating contemporary rates of floodplain sedimentation. *Lowland floodplain rivers: Geomorphological perspectives, 165-184*

Wolman, M. G., Leopold, L. B. 1957. *River floodplains: some observations on their formation.* Unites States Geological Survey Professional paper 282-C, p. 109

Zinger, J.A., Rhoads, B.L., Best, J.L. 2011. Extreme sediment pulses generated by Bend cutoffs along a large meandering river. *Nature Geoscience 4(10) 675-678*

Van de Lageweg, W.I., Van Dijk, W.M., Kleinhans, M.G. 2013. Channel belt architecture Formed by a meandering river. *Sedimentology 60, 840-859*

Figures

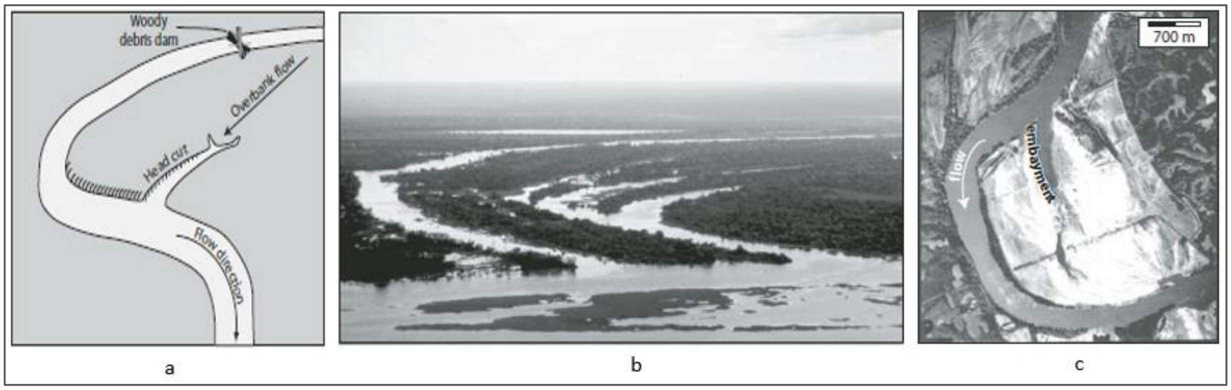


Figure 1 Three mechanisms of chute cut off formation. a) Upstream head cutting resulting from a woody debris dam (Gay et al, 1998). b) Flood channel in swales on a meander bend, Photo by T. Dunne in (Constantine, 2010). (c) Embayment formation and development into a chute cutoff (Constantine, 2010)

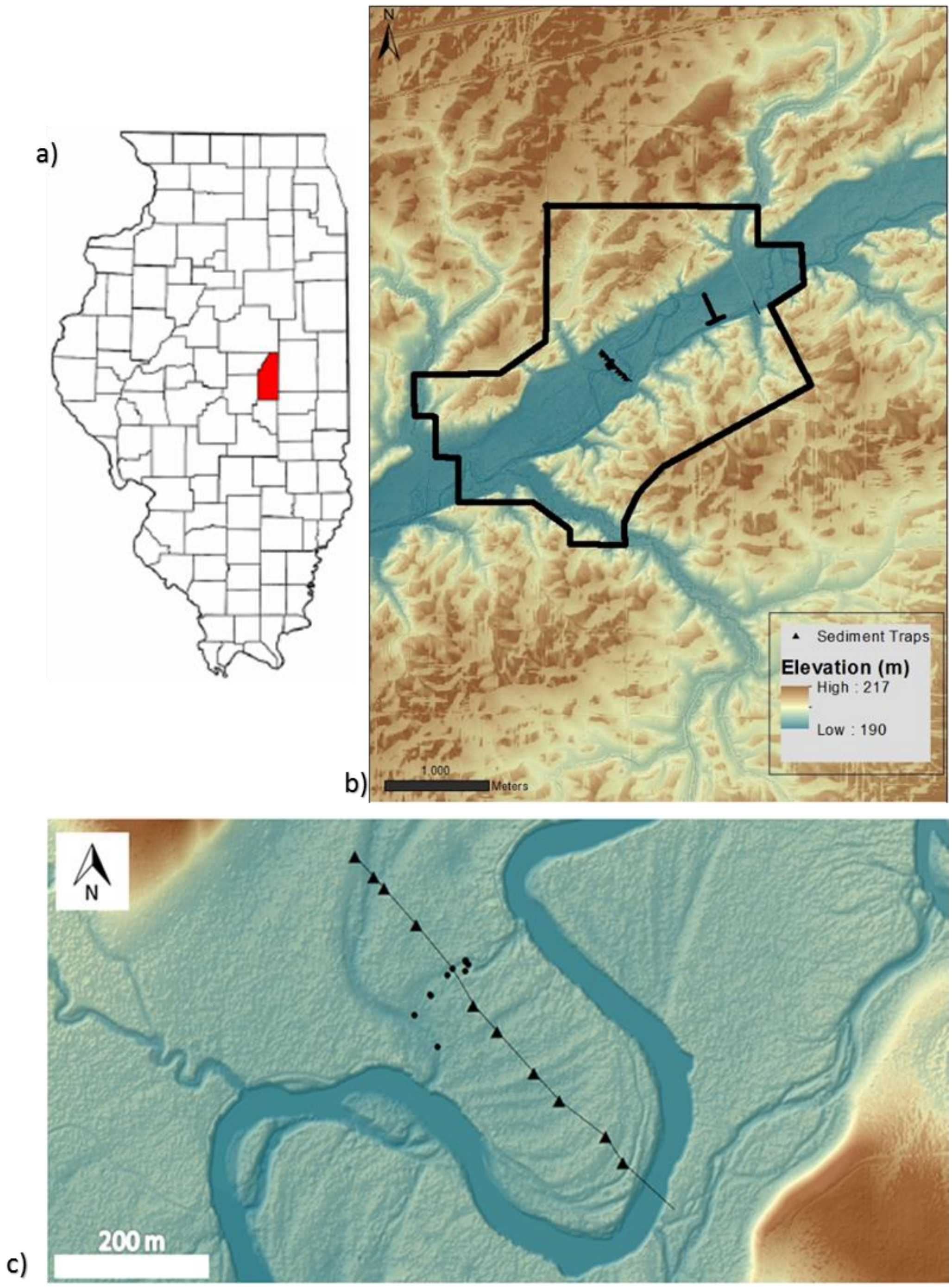


Figure 2 Study location. a) Map of Illinois highlighting Piatt County in East Central Illinois. b) The boundary of Allerton Park (black line) imposed on LIDAR topography of Piatt County. c) Enlarged LIDAR view of Lower transect (L), trap locations and grab samples indicated by black dots.

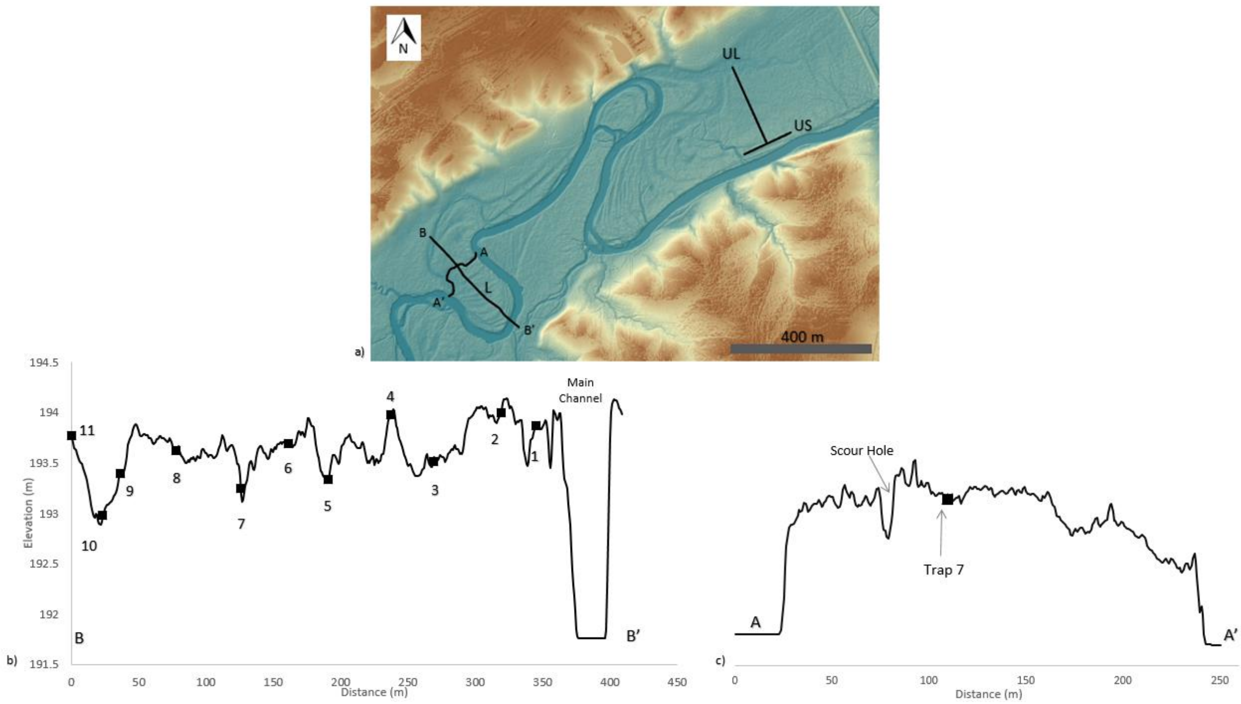
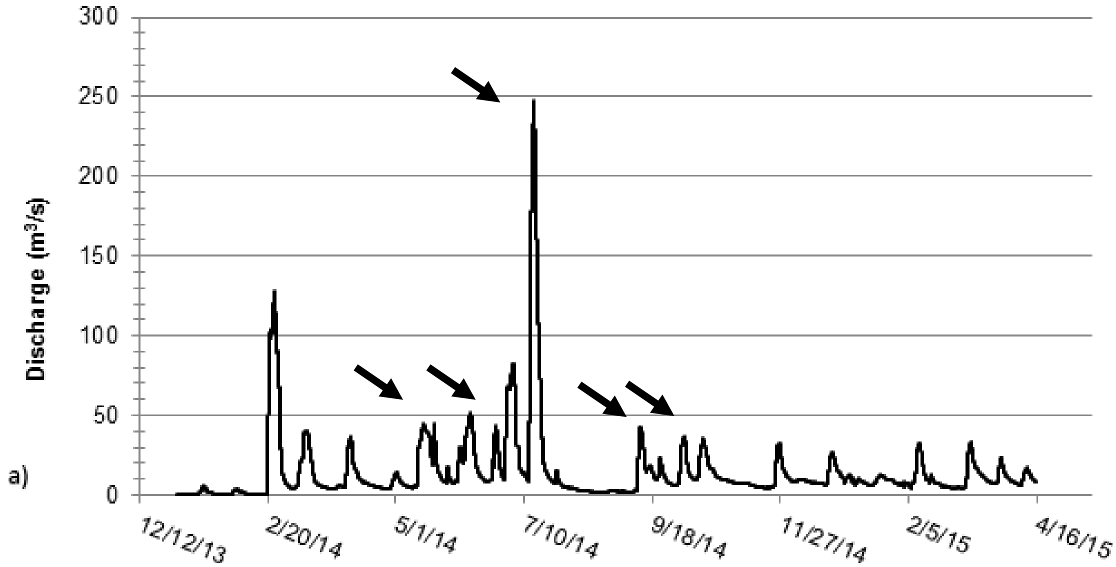


Figure 3 a) Overview of study area on Allerton Park Floodplain. Transects US, UL, and L are shown along with elevation profiles along Transect L (B-B') and across the bend (A-A') b) The topographic profile along B-B' is shown and highlighted are the locations of each sediment trap from 1-11 c) shows the topographic profile across the meander bend along A-A' with trap 7 and the location of the scour hole highlighted.



b)

Frequency of Inundation above 15 m^3/s				
Decade	# events		Decade	# events
1908-18	37		1960-69	24
1919-29	45		1970-79	30
1930-39	35		1980-89	31
1940-49	36		1990-99	30
1950-59	32		2000-09	29

Figure 4 a) Stream hydrograph from USGS gauge at Monticello, Illinois from Jan 2014 – April 2015 with events that were sampled and marked by arrows. b) Shows the frequency of inundation from 1908-2009 above a threshold value of 15 m^3/s where water begins to inundate the floodplain.

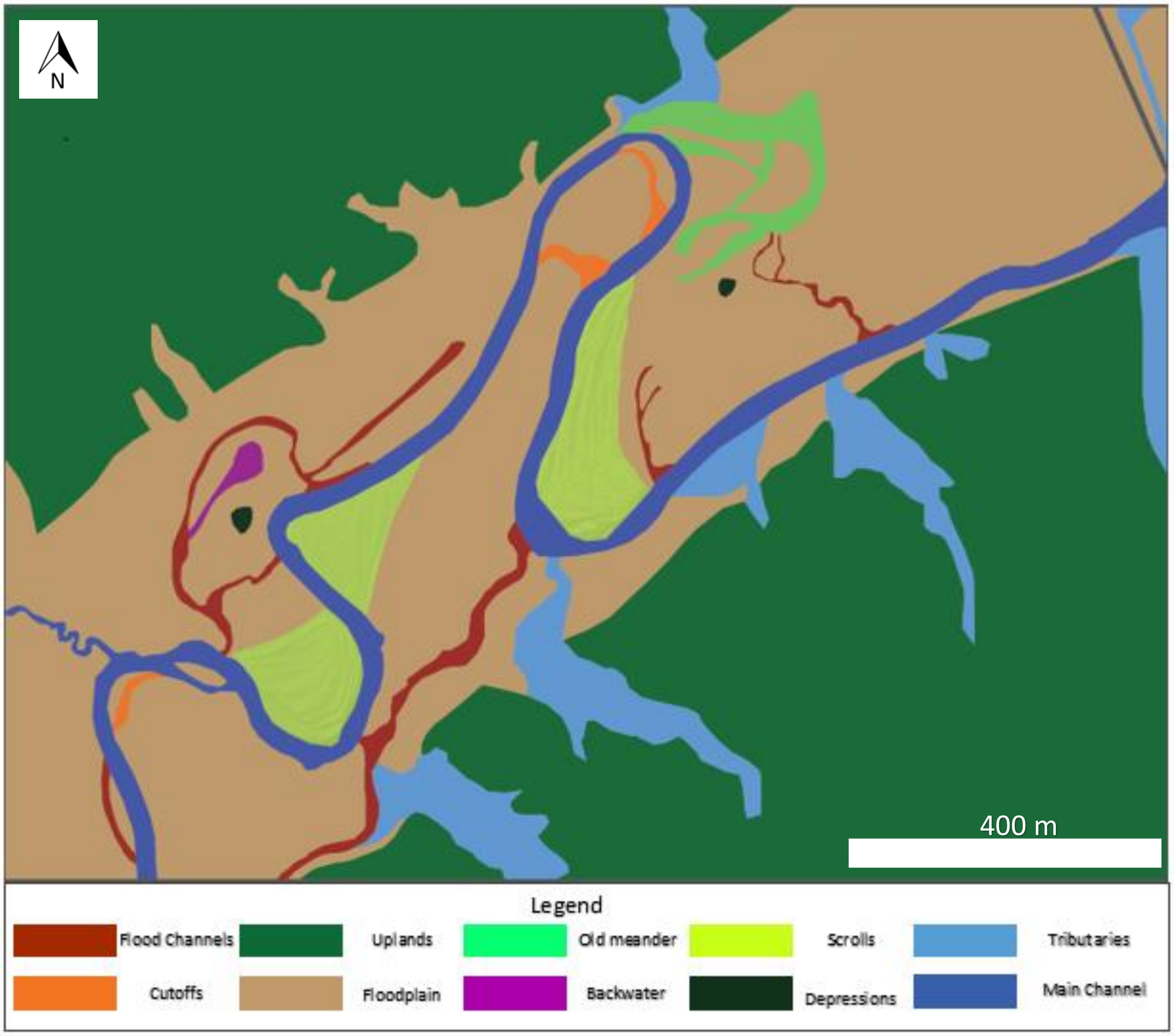


Figure 5 Geomorphic Map of Allerton Park. Derived from 2012 ISGS Lidar DEM. Each color represents a different geomorphic feature of the floodplain. The main channel is dark blue and channels occupied by flood waters are delineated in red. Circular areas are closed depressions which will fill with water during heavy rains. Relict meanders are noted in light green are past locations of the main channel. Scroll bars are located on the inside of meander bends in yellow and track the past lateral migration of the river.

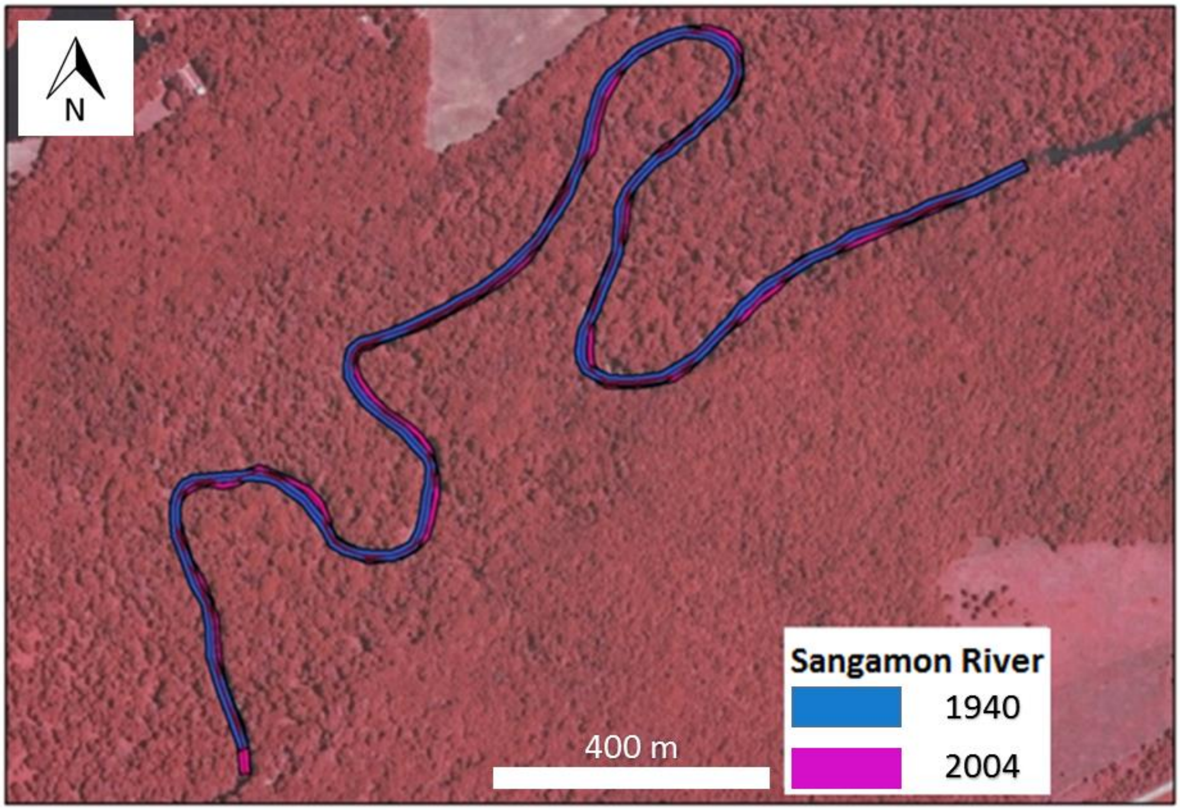


Figure 6 Channel changes along the Sangamon River from 1940-2004 showing very little migration of the channel. Modified from Lewis and Neal, 2013.

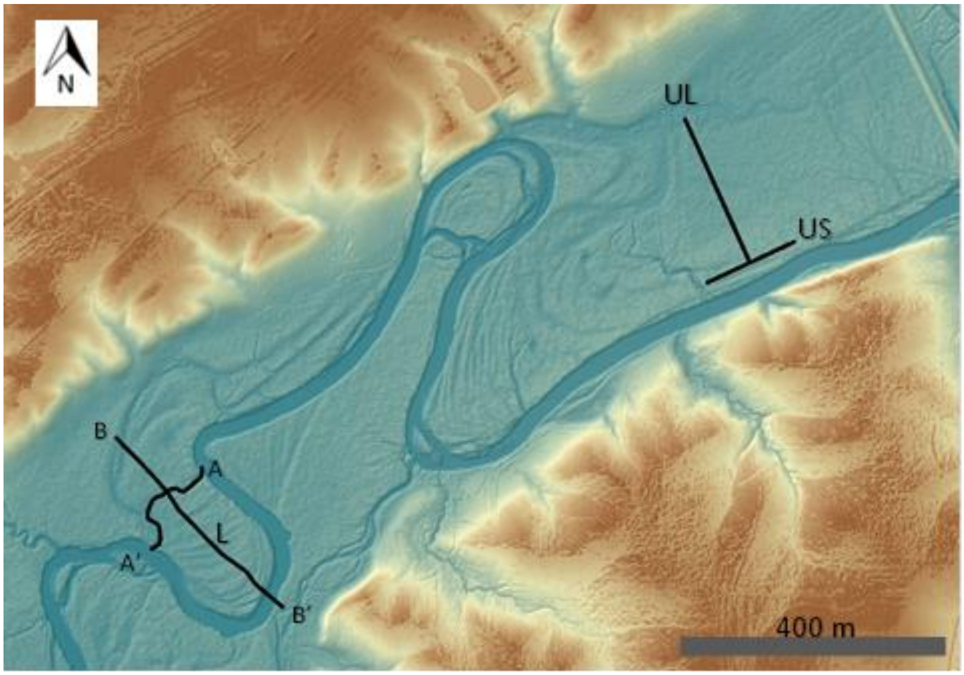


Figure 7 Lidar image of transect locations Lower (L), Upper Short (US), Upper Long (UL), along with locations of elevation profiles (A-A') and (B-B').

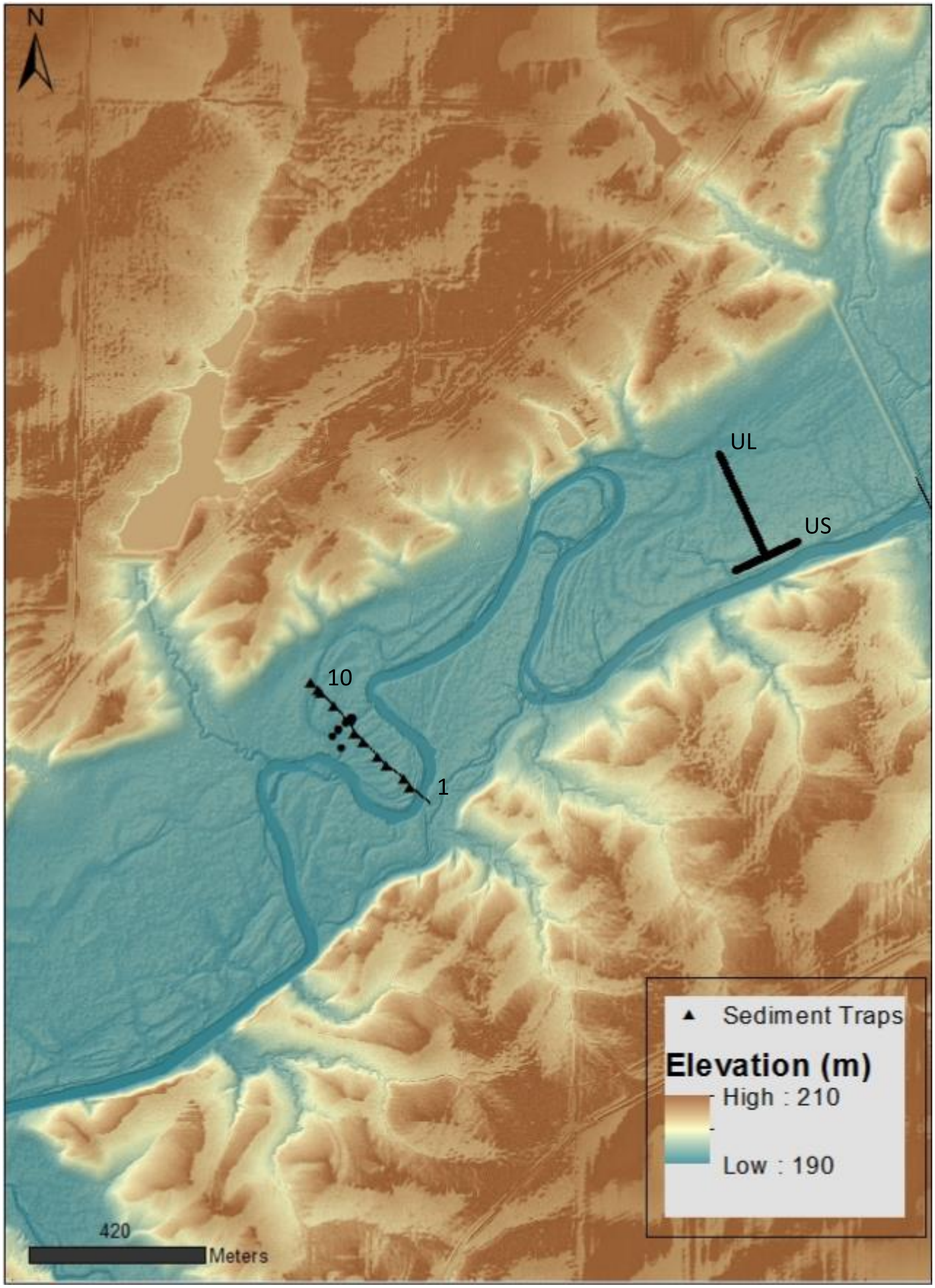


Figure 8 Lidar Map showing the locations of each sediment trap (Triangles) and surface grab samples (circles) along transect (L). Transect UL and US are also shown.

a)

Flood Parameters			Transect L depositional thicknesses/event						
Event	Peak Q (m^3/s)	Stage (m)	L5	L6	L7	L8	L9	L10	L11
May	44	3.69	0	0.03	3.74	0.033	1.37	2.17	0
June	51	3.85	0	0.03	4.06	0.047	1.5	2.26	0
July	248	5.14	0	0.01	4.35	0.02	2.13	1.81	0
Sep	83	4.15	0	0	0.98	0.02	0.77	0.57	0
Oct	42	3.6	0	0.01	0.85	0.02	0.31	0.24	0

b)

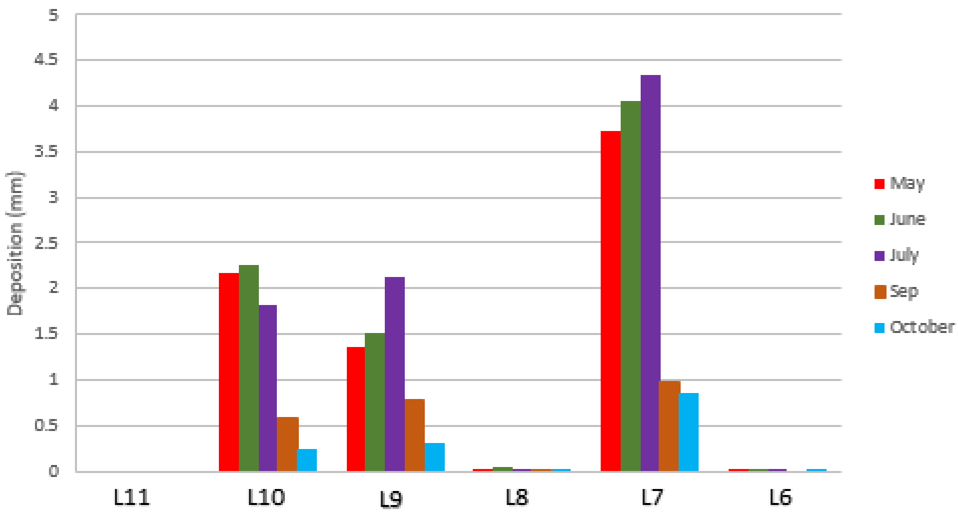


Figure 9 a) Table breakdown of measured events during the study. Each value for the deposited thickness on each trap during each event is shown b) The deposited thickness are represented graphically showing the relationship between discharge and deposition. Increasing the magnitude of the event generally increases deposition along transect (L).

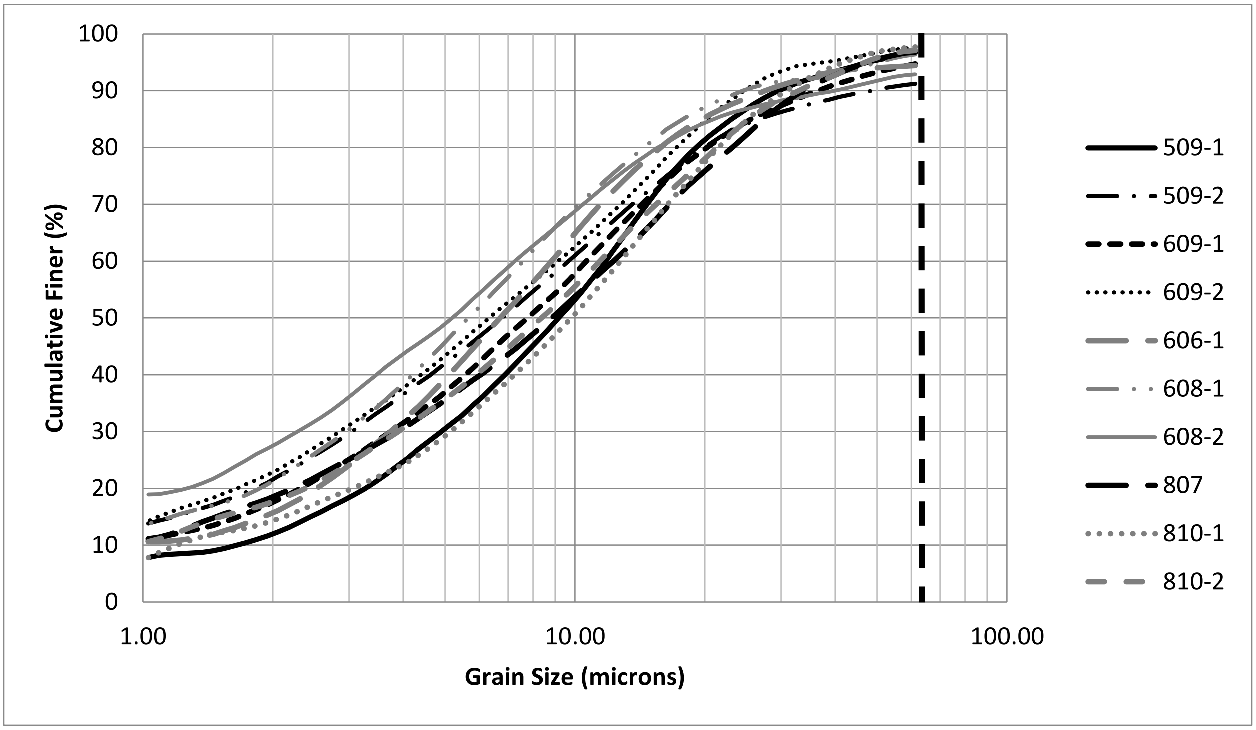


Figure 10 Grain size distributions from samples deposited on traps along transect L for different flood events during 2015 with the sand/silt transition highlighted at 62 microns. The first digit represents the month the event occurred and the second two digits represent the trap location along transect L. The fourth digit is the replicate number.

a)
b)

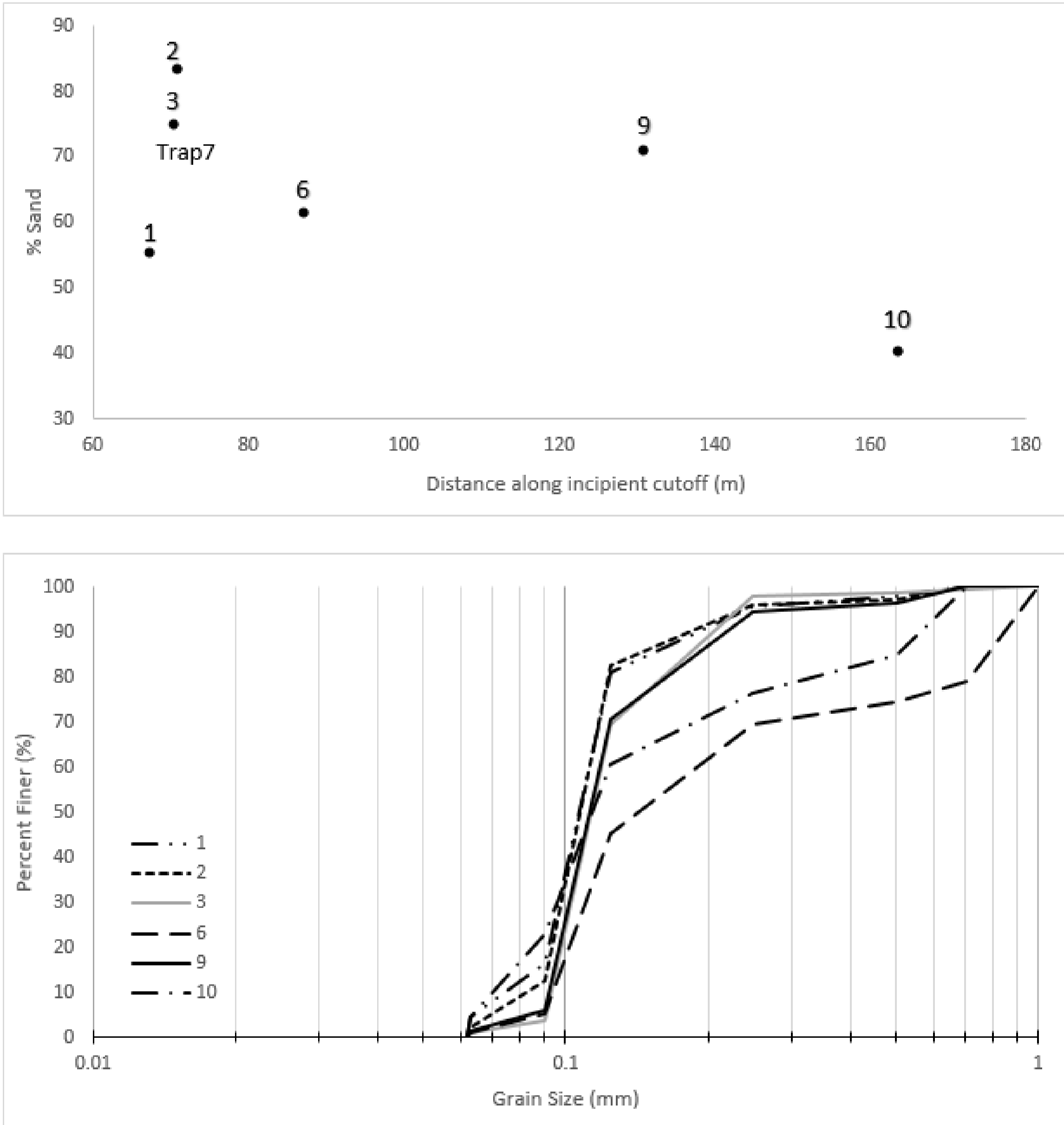


Figure 11 a) The relationship between percentage of sand in surface grab sample and distance from a scour hole in chute splay is shown. Samples closer to the scour hole show a higher percentage of sand in the sample. The location of trap 7 is also shown near sample 3. b) The cumulative distribution of grain sizes for the surface grab samples showing the distribution of sand sizes for each sample.

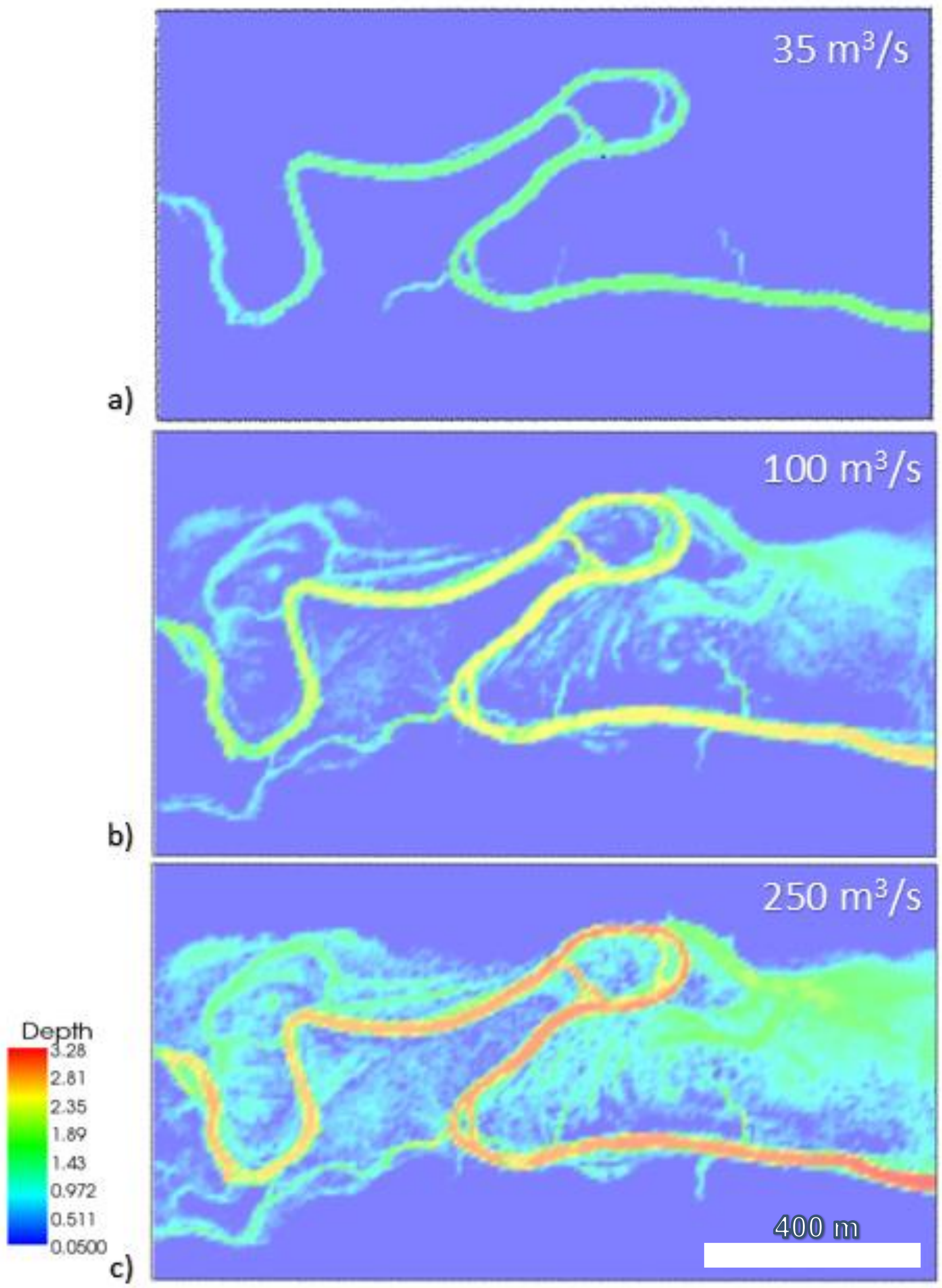


Figure 12 Three snapshots from the flow simulation from 35 cms to 250 cms. a) The initial condition of bankfull discharge and there is water starting to flow into floodplain channels. b) Discharge of 100 m^3/s where water is flowing in many places of the floodplain including floodplain channels and relict meanders. c) Much of the floodplain has water flowing on it during the largest flow event of 2014. Some areas still do not have water.

Figure 13 Two aerial photos of study site from a) 2005 and b) 2008. The large flood channel noted in white is visible from photos but there is no evidence of the chute splay, suggesting that it has formed since 2008. Photos (Google Earth)