Spatiotemporal dynamics of a chute cutoff on the Embarras River, Illinois

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Introduction

A meander bend on the Embarras River south of Charleston, IL has developed a chute cutoff across the point bar. Despite being present for decades, the cutoff channel has not captured the flow of the main channel. The cutoff and main channels are now separated by an island that accumulated large woody debris at its head. The purpose of this field study is to examine changes in the morphology, bed-material texture, and flow of the channels over time to gain insight into the spatiotemporal dynamics of cutoff development in a low-energy, low-gradient meandering river. Surveys of bed topography with a total station and bed-material sampling followed a series of flow events during late winter-autumn 2018. Recent flow events have pushed the large woody debris onto the island, revealing a large bar extending upstream from the head of the island. In the main channel, pools associated with meander bend curvature are adjacent to this bar. On the cutoff side of the bar, bed scour and upper bank erosion and failure occur upstream and into the entrance of the cutoff channel. Surficial flow data collected using particle image velocimetry will relate spatial patterns of surficial flow dynamics to channel morphology.

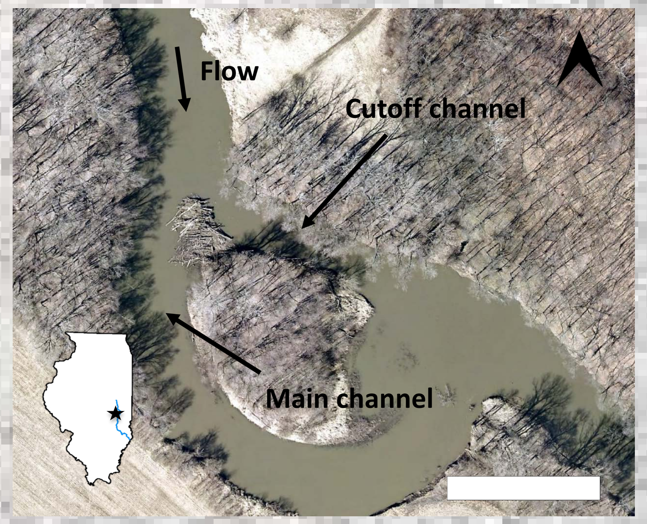

Figure 1. Aerial image of meander bend and site of study, with channels labeled and direction of flow indicated. Imagery captured in 2016.

Field Site

The study site (Figure 1) is a compound meander loop on the Embarras River, a tributary of the Wabash River, located 5 km south of Charleston, Illinois. The site is situated within a terminal moraine complex deposited during the glacial retreat of the Wisconsin Glacial Episode. The low-gradient river drains 2,308 km2 of till plains upstream of the site (StreamStats). Channel width is 35 m upstream of the bend and narrows to 30 m downstream. There is a chute cutoff (Figure 2) across the point bar that has failed to capture the main flow for many years. A bar separates flow between the main and cutoff channels on which large woody debris can accumulate (Figure 3). Bed sediments at this site range from muddy clay to coarse gravel.

Figure 2. Channel of investigation; chute cutoff (left) and main channel (right). Photo taken facing downstream February 16, 2018.

Figure 3. Close-up of large woody debris pile. Photo taken February 16, 2018.

Methods

The study site was surveyed with a Leica TS02 manual total station (Figure 4). This method employed electro-optical scanning from a reference point with known x, y, and z coordinates at a target located a known height above the bed to find coordinates at that location. The site was surveyed on February 16, and twice again on March 12 and June 7 following high flow events using the same equipment and methods to collect hundreds of data points both in the channel and on the banks. Three maps of channel bathymetry were created by spatially interpolating the elevation data using the kriging method in ESRI ArcGIS.

Bed sediment was sampled at five different locations on March 12 and June 7 (Figure 6 and 8). The samples were dried and sorted with a series of sand and gravel sieves. The weight of each grain size was used in conjunction with the phi value of its diameter to produce two graphs displaying the cumulative weight percentage of each grain size for each sample (Figures 7 and 9).

Large-scale particle image velocimetry (LSPIV) was used to resolve velocity magnitude and direction of surficial flow (Lewis and Rhoads, 2015). The river was seeded upstream of the study site with pine shavings. A DJI Phantom 3 Professional unmanned aircraft system filmed the transport of particles through the study site. PIVlab was used to analyze mean flow patterns from a series of frames from the aerial video (Thielicke, 2018).

Figure 4. Survey of the site using the TS02 total station. Photo taken on March 12, 2018.

Results

The most significant scour is along the outer bank of the upstream bend at the entrance to the cutoff channel and the outer bank of the downstream bend of the main channel (Figures 5, 6, and 8). Bank failure at the entrance of the cutoff channel has contributed sediment and woody debris to the channel, changing the geometry of the upstream portion of the cutoff. The exposure of a gravel bar between the channels at the head of the island is also evident between the data sets (Figures 10 and 11). There is also scour related to the thalweg as channel curvature forces it across the channel from the upstream outer bank to the downstream outer bank. The sediment samples collected nearest the channel centerline (TPS0004, TPS0005, and TPS0007) have a greater composition of fine to medium gravel compared to the finer-grained samples collected along the scoured banks of both sides of the channel (TPS0003 and TPS0008). These locations are primarily composed of sands, silts, and, in the case of the sample collected at TPS0006, clays. The second round of bed sampling followed a large-flow event and found the samples to share similar grain-size distributions, suggesting deposition of larger grains across the channel. The sample nearest the upstream outer bank (TPS0316) is slightly more fine-grained due to the clay composition of this unstable bank (Figure 9).

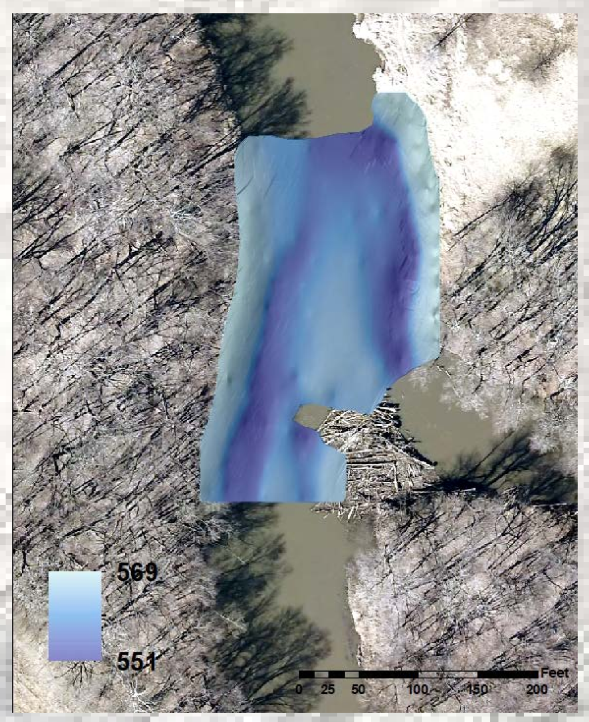

Figure 5. Map of bathymetry of channel showing scour along cut banks. Data collected February 16, 2018.

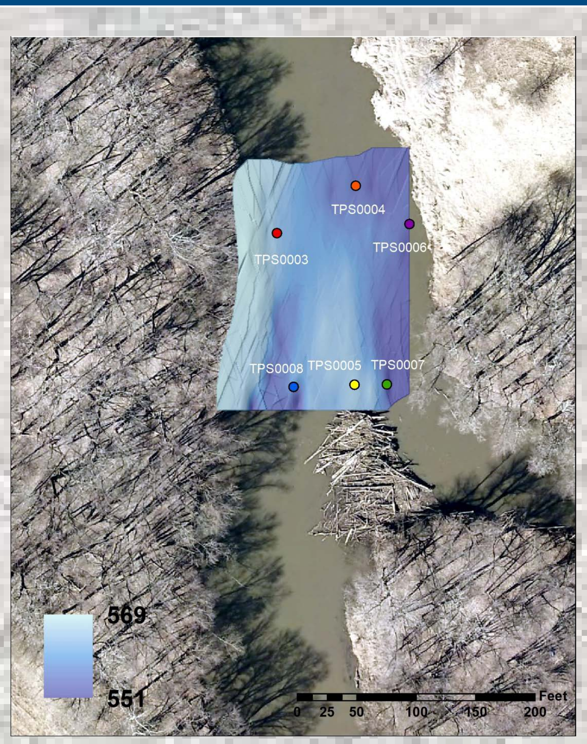

Figure 6. Map of bathymetry of channel and locations of sediment sample collection. Data collected March 12, 2018.

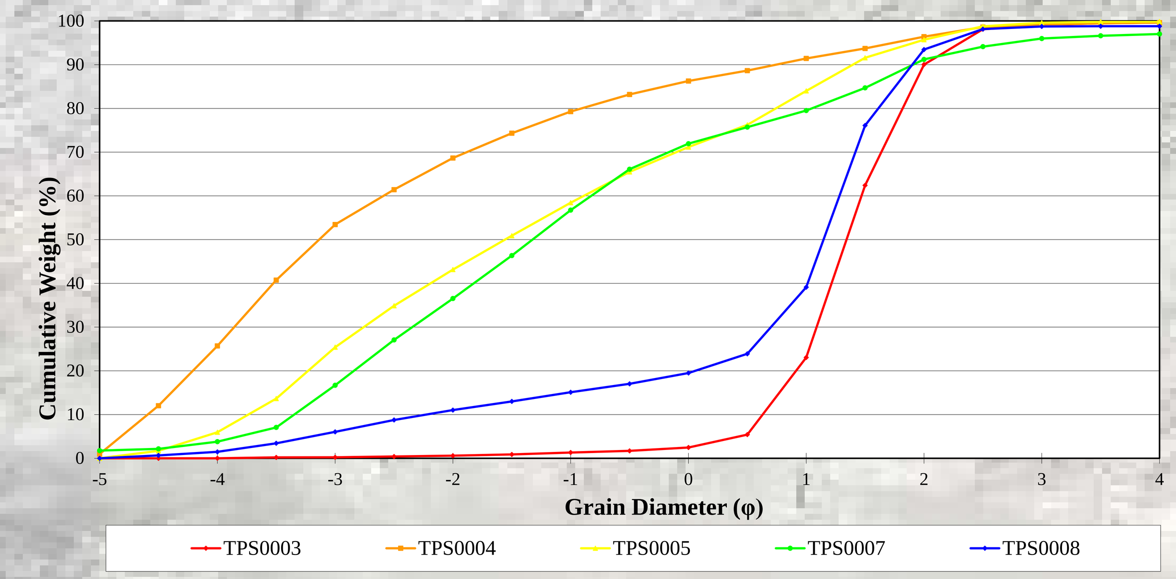

Figure 7. Graph of grain diameter vs cumulative weight for five sediment samples. Data collected on February 16, 2018.

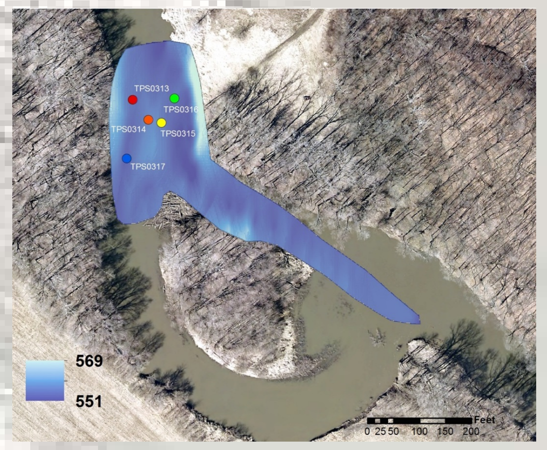

Figure 8. Map of bathymetry of channel and locations of second sediment sample collection. Data collected June 7, 2018.

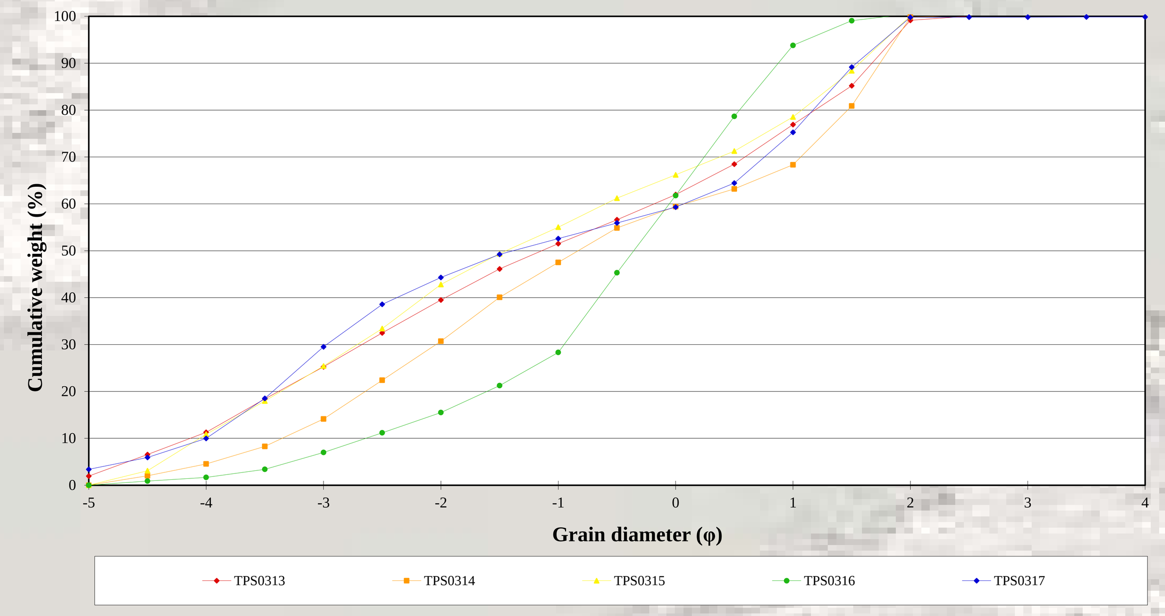

Figure 9. Graph of grain diameter vs cumulative weight for five sediment samples. Data collected on June 7, 2018.

Figure 10. Exposure of a gravel bar upstream of the woody debris pile. Photo taken February 3, 2018

Figure 11. Gravel bar fully submerged. Photo taken March 12, 2018.

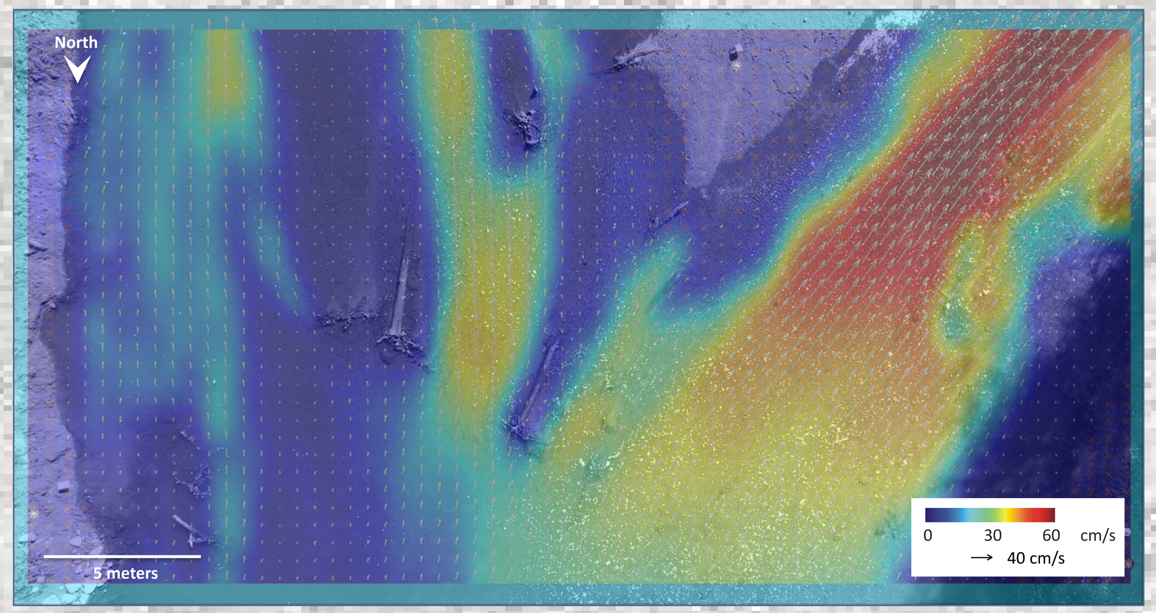

Figure 12. Flow data collected using large-scale particle image velocimetry. Data collected on October 25, 2018.

The flow data in Figure 12 clearly show the highest surficial velocities are oriented through the main channel, approaching 60 cm/s. The zones of greatest scour and erosion correlate with the highest velocity flow as well as the spatial distribution of grain sizes across the channel. The cutoff channel has significantly lower surface velocity. Some of the lowest velocity magnitudes occur downstream of uprooted trees, which may act as future key members for the accumulation of more woody debris.

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