Projecting Floodplain Depositional Patterns using Long-term 1D Sediment Modeling Results and Short-term 2D Hydraulic Model Output

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Abstract

Locust Creek is a perched channel that flows through Pershing State Park, an ecologically sensitive area in north-central Missouri. Over the past two decades, excessive floodplain deposition from Locust Creek has smothered unique and important habitats in the park. An analysis tool was needed to assess multiple options for reducing the floodplain deposition. A 1D mobile bed model by itself was insufficient, as it could not correctly distribute the sediment laterally in the floodplain. A 2D mobile-bed model for the area was untenable due to the large spatial extent of the system and the long time frame (50 years) for desired projections. In order to model this system, outputs from an HEC-RAS 1D, long-term mobile bed model simulation and an HEC-RAS 2D hydraulic model output from three discreet, synthetic flood hydrographs were combined.

Introduction

Locust Creek is a perched, sand-bed channel that flows through Pershing State Park in north-central Missouri (Figure 1). Over the past two decades cycles of channel aggradation and log jams has caused Locust Creek to abandon its historic channel, cut new channels in the floodplain, and flow into an undersized drainage ditch. This process has deposited tremendous quantities of sediment on sensitive wet prairie habitats in the park. A U.S. Army Corps of Engineers feasibility study is currently assessing potential habitat restoration solutions.

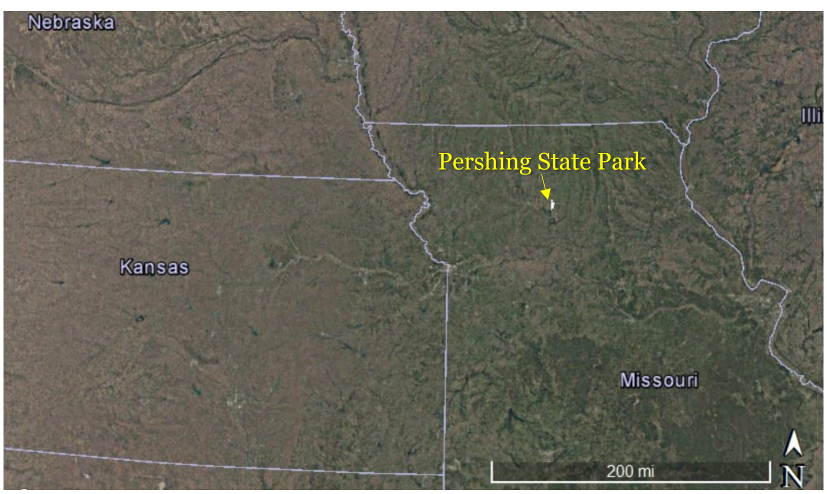

Figure 1. Location of Pershing State Park (Left).

As a part of the study, a modeling tool was needed to assess how potential alternatives would impact floodplain deposition. The complex hydraulics clearly called for a 2D modeling framework. However, the large surface area and desired long-term projections (50 years) made 2D mobile-bed modeling untenable.

For practicality, a modeling framework was developed which includes an uncoupled HEC-RAS 1D sediment model and 2D hydraulic model. The 2D model provides important flow inputs used to develop 1D model boundary conditions. The 2D model was also used as a "post-processor" to more realistically distribute the modeled 1D sediment floodplain deposition volumes.

The graphs and figures presented here are drafts provided to demonstrate the modeling process. The final analyses and results will be documented in the Grand River Basin Ecosystem Restoration Study feasibility report, which may differ from those presented here.

HEC-RAS 2D Hydraulic Model for Flow Boundary Conditions

The model domain begins in a relatively straight channel at a gaged location. Just upstream of Pershing State Park, however, flow bleeds off from the main channel through multiple "pirate channels" into Higgins Ditch (see Figure 2). RAS 2D, by computing hydraulics on sub-grid bathymetry, allowed a workable way to compute the combined effect of many small "pirate channels." The 2D model was used to generate flow-split rating curves that were used to create the upstream boundary condition for the 1D sediment model.

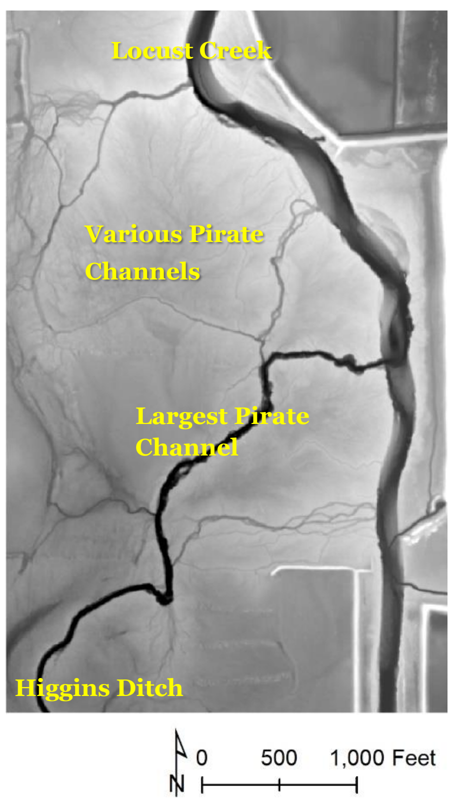

Figure 2. LIDAR indicating pirate channels that steal water from Locust Creek. Flow is from top to bottom.

HEC-RAS 1D Mobile-bed Sediment Model for Long-term Projections

The HEC-RAS 1D sediment model was used to simulate two channels (Higgins Ditch and the old Locust Creek) through Pershing State Park to predict channel change and floodplain sedimentation volumes. The 1D model results in longitudinal cumulative volume change curves, such as in Figure 3.

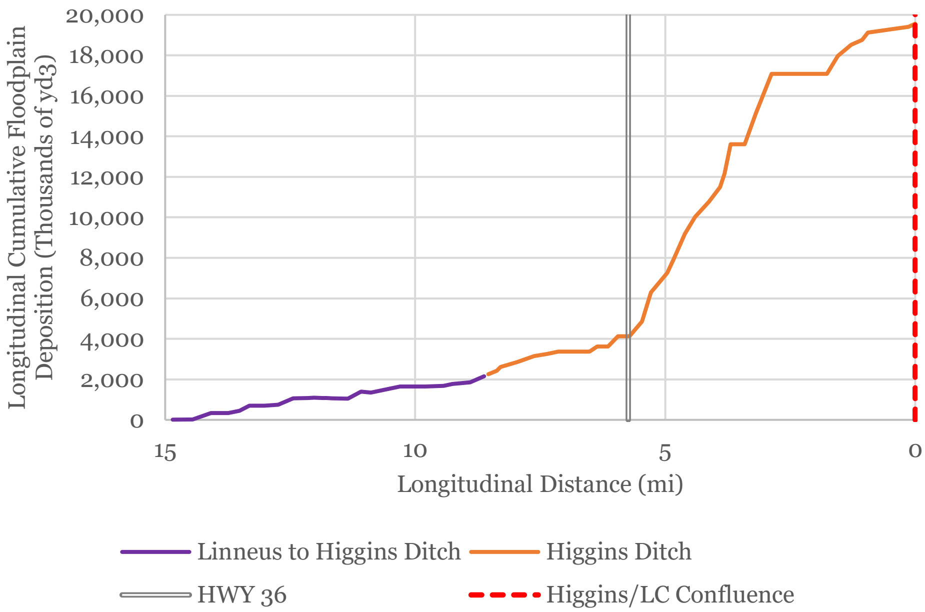

Figure 3. Longitudinal Cumulative Volume Curve

HEC-RAS 2D Hydraulic Model for Lateral Floodplain Deposition

HEC-RAS 1D uses the “veneer method” for distributed floodplain sediment; RAS spreads the deposition volume over all wetted nodes equally, resulting in an even veneer of sediment. Such an approximation can inadequately describe the patterns of overbank sediment deposition in complex floodplains. In order to provide more realistic floodplain deposition locations and amounts, the HEC-RAS 2D model was used to approximate the sediment distribution following these steps:

1. Three representative overbank hydrographs were run through the 2D hydraulic model, with a 10%, 20%, and 50% annual exceedance probability (i.e. a 10 year, 5-year, and 2-year flow, respectively).
2. The 2D model produced raster output for the duration of inundation of at least 0.1 ft and for the maximum depth.
3. A weighting factor was generated in GIS according to the following equation:

$$W = 0.2 * D_{10}t_{10} + 0.2 * D_5t_5 + 0.6 * D_2t_2$$

Where W = the weighting factor for an individual cell within a habitat area.

> t = the duration of inundation for a given cell for the 10-year, 5-year, or 2-year hydrograph
>
> D = the maximum depth of inundation for a given cell for the 10-year, 5-year, or 2-year hydrograph

This weighting accounts for the relative frequency of each event in a hypothetical 10-year period with one 10-year event, one 5-year event, and three 2-year events. This conforms to the definition of each of these statistically-defined flows (i.e. the 10-year flow has an annual exceedance probability of 0.1, the 5-year has an annual exceedance probability of 0.2, and the 2-year has an annual exceedance probability of 0.5.)

This weighting produces reasonable lateral trends in that areas more frequently inundated will deposit more and that areas inundated to greater depths will deposit more. (See Figure 4.)

4. Sum the weighting factors in each habitat area.
5. Use these summed weighting factors to laterally apportion sediment volume from the 1D sediment model in locations where the model cross section spans more than one habitat area.
6. Divide each weighting factor value by the summed weighting factor for the habitat area to create a raster of normalized weighting factors which define the fraction of the total deposition volume in the habitat area assigned to each cell. (See Figure 4.)
7. Multiply the normalized weighting factor (fractional volume) for each cell by the total deposition volume for the habitat area to create a per-cell deposition volume.
8. Divide by the cell area to create a per-cell deposition depth.

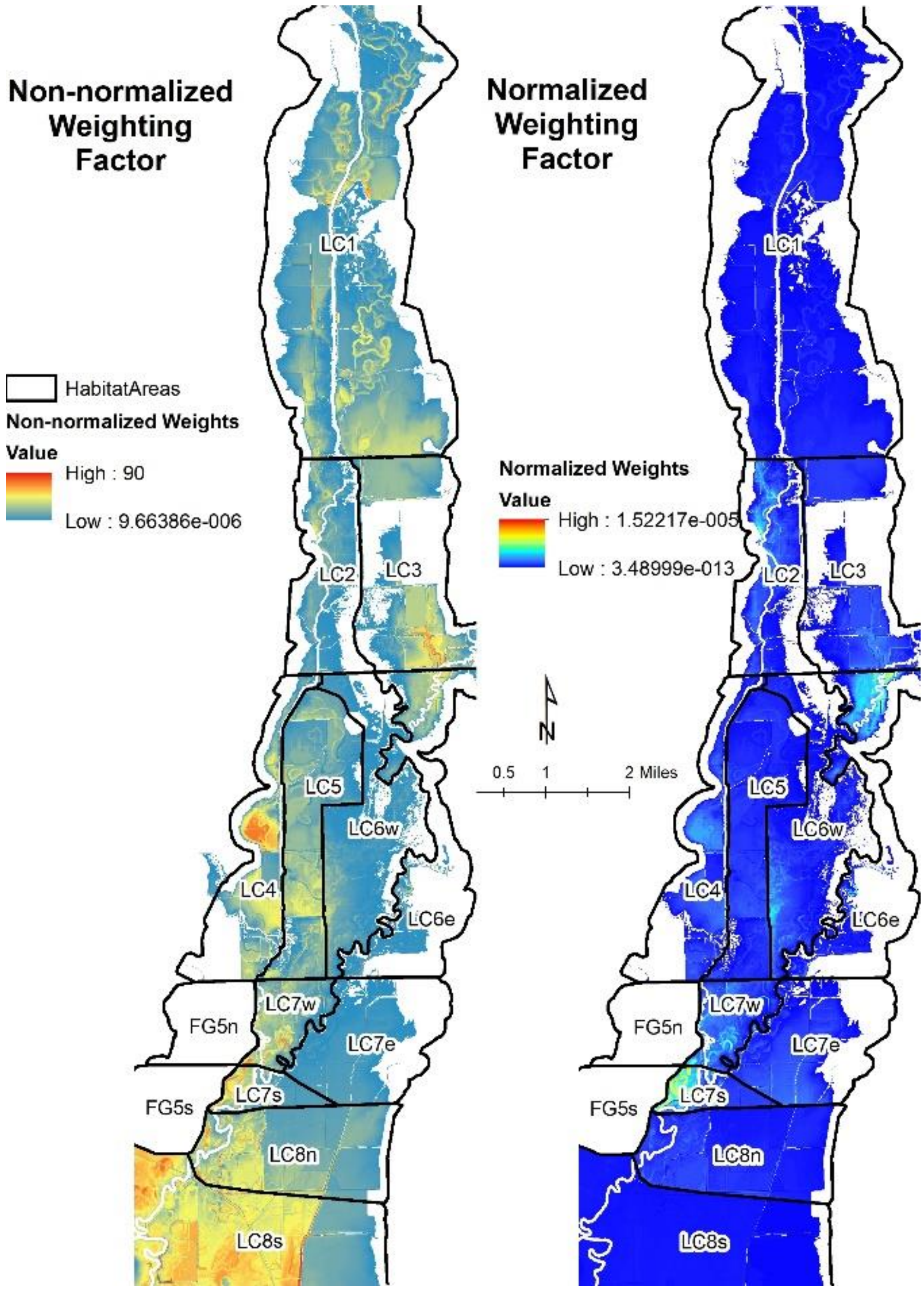

Figure 4. Weighting Factors from Steps 3 and 6

The result of this analysis is that the upstream-to-downstream distribution of sediment is a function of the 1D sediment model. The lateral distribution of sediment is a function of the 2D hydraulic model. The deposition depths (Figure 5) are reasonable estimates for testing alternatives and assessing future habitat values.

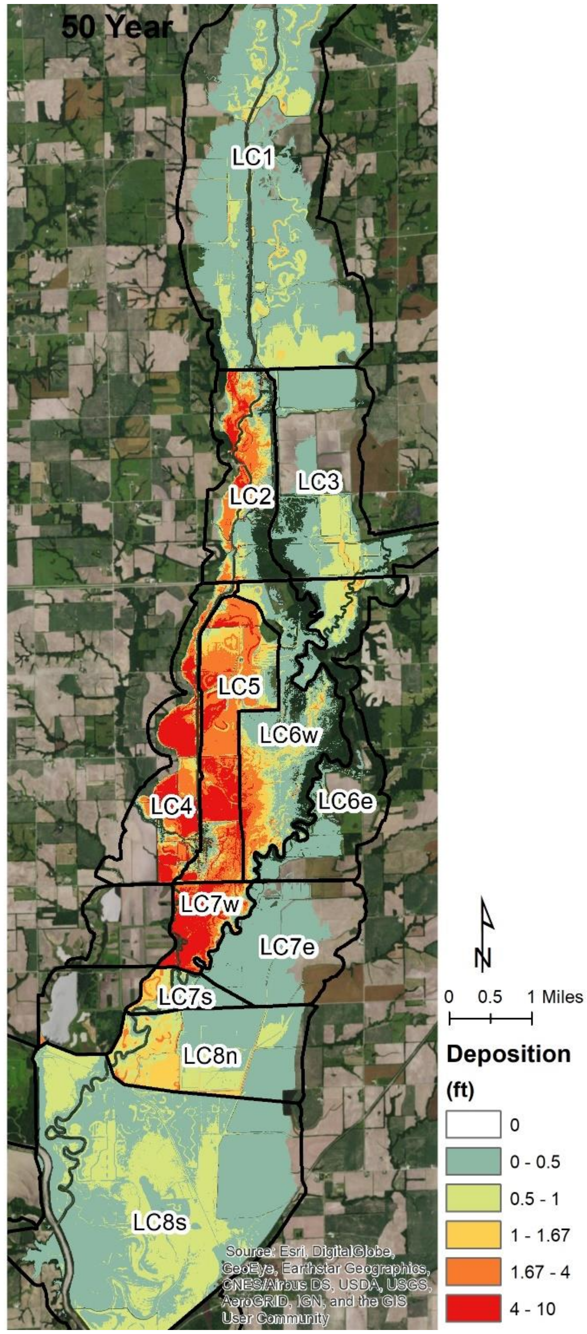

Figure 5. Floodplain Deposition

Conclusions and Limitations

This approach is not as accurate as a fully-coupled 2D flow/sediment model. In addition, it required the extra work of updating two models every time assumptions or alternatives changed. However, the 50-year sediment simulation ran in under three hours on a personal computer, which was faster than running even a single year of fixed-bed hydraulics through the 2D model.

Notwithstanding the limitations, the approach documented in this paper provided more reasonable and actionable results than a 1D modeling approach by itself could provide.

Acknowledgements

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