Floodplain Hydraulics: LiDAR Applications

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ICTAS
Institute for Critical Technology and Applied Science

CENTER for WATERSHED STUDIES at VIRGINIA TECH

Since the invention of artificial fertilizers in the 1950's, the US has been transporting increased amounts of Nitrogen (N) and Phosphorus (P) through its riverine networks. This has led to degraded water quality in both local waters and larger receiving bodies (e.g. The Gulf of Mexico and the Chesapeake Bay). In naturally functioning systems, many of these pollutants can be attenuated through microbial mediated processes (e.g. denitrification). Floodplains are a hotspot for nutrient attenuation, especially in low gradient rivers found in the southeastern coastal plain. These rivers have very large floodplains and most are inundated for weeks to months on an annual basis. Through development activities, many of these floodplains have been disconnected from their rivers, and thus the value of their ecosystem services has diminished. However, the benefit of reconnecting these areas is largely unknown. Part of this problem is understanding the floodplain water balance, which is very difficult to estimate in low-relief landscapes. This study focuses on the use of Light Detection and Ranging (LiDAR) technology to enhance modeling of floodplain water budgets.

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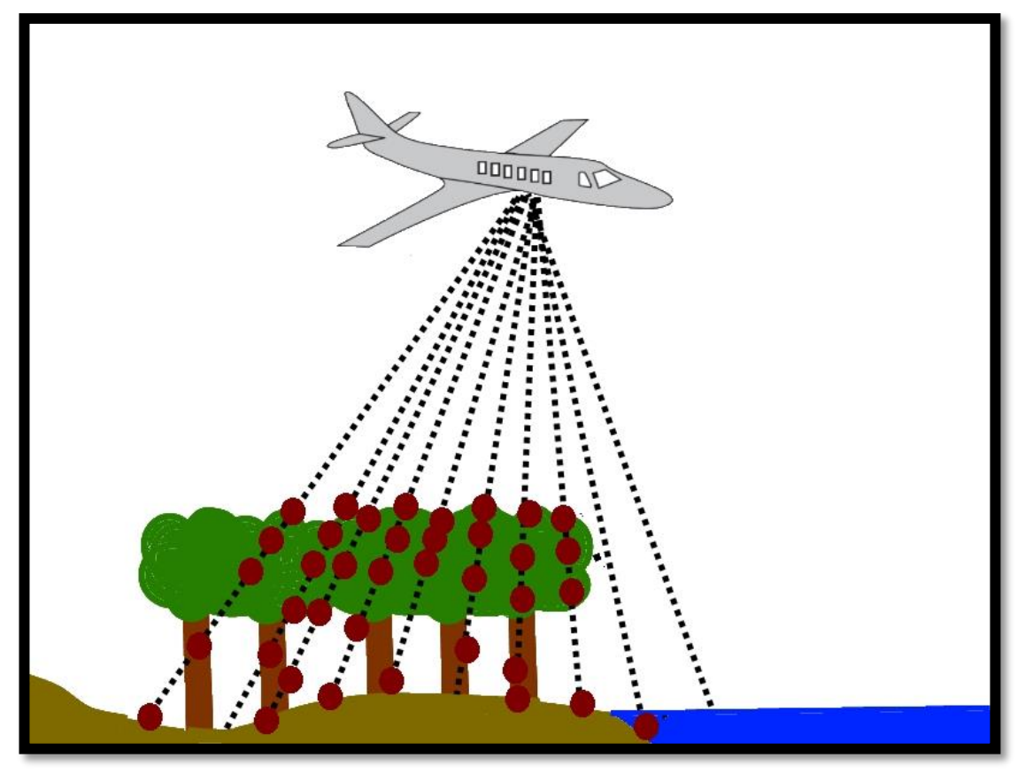
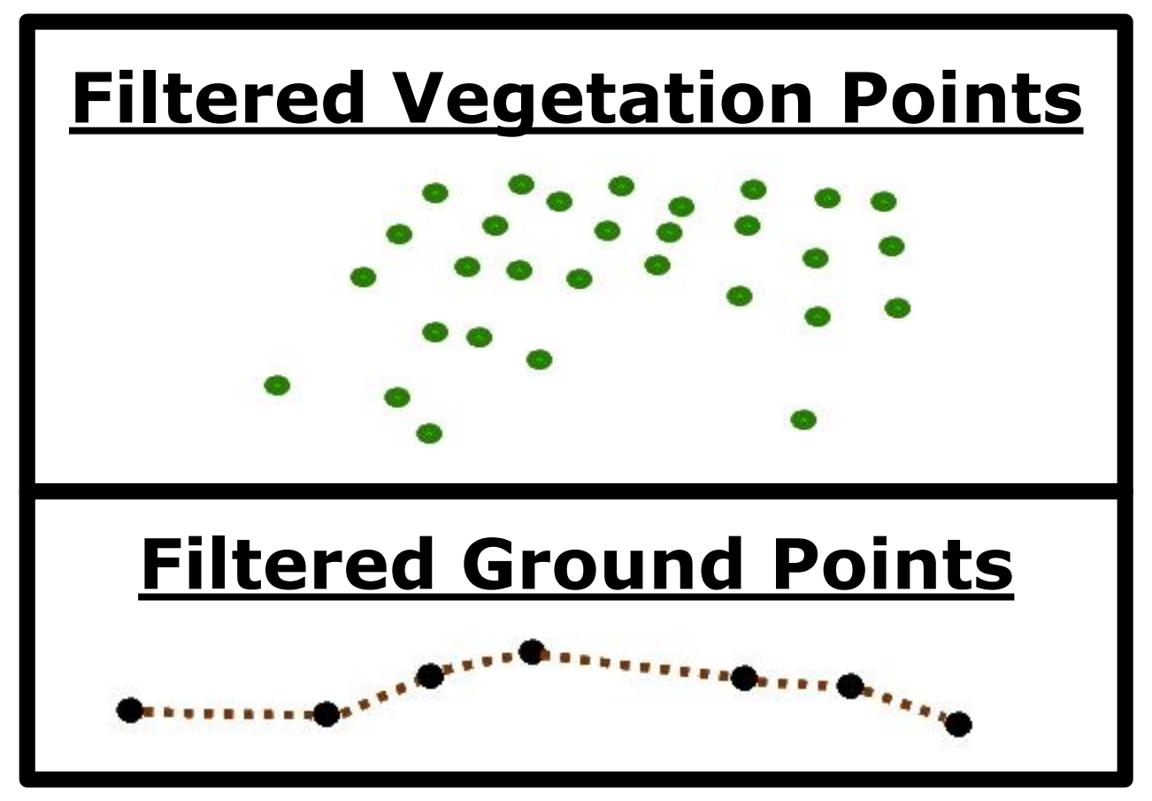
Study Objectives

- Use LiDAR to develop the following inputs for a floodplain hydraulics model:
  - Estimate of Static Inundation Extent
  - Storage Zones within the Floodplain
  - Surface Roughness Estimate (Manning's N)

LiDAR

Airborne LiDAR systems collect high densities of explicit 3D data usually used to describe surface features (topographic data, vegetation distribution, urban infrastructure). Both the flood modeling and wetland scientist communities use LiDAR because of its ability to detect fine resolution microtopography on a large scale. Foresters also utilize LiDAR to model timber distribution and merchantable biomass.





(Left) Illustration describing LiDAR acquisition. Red points describe "returns," or points the LiDAR system recorded. (Right) Illustration showing 2D representation after vegetation and ground points have been separated by a filtering process.

Floodplain Hydraulics

Engineers are very good at estimating flood extent. However, there has been little work done to understand the flux of water in and out of the floodplain. Most of the models used to describe water flow rely on a combination of Manning's Equation and the Saint Venant Equation.

Saint Venant Equation

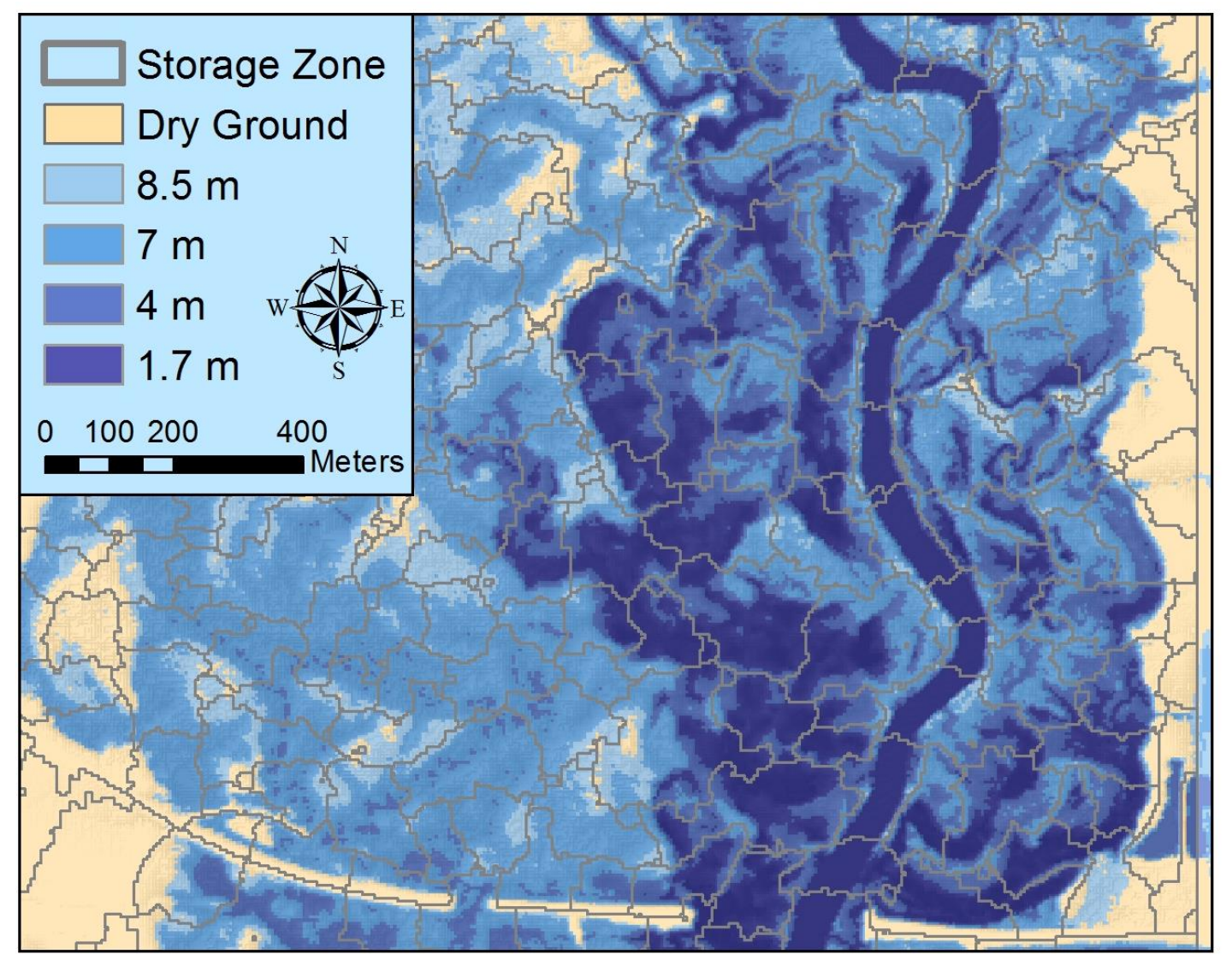
$$\frac{1}{A_C}\frac{\mathrm{dQ}}{\mathrm{dt}}+\frac{1}{A_C}\frac{d}{dx}\left(\frac{Q^2}{A_C}\right)+g\frac{dy}{dx}-g\left(S_0-S_f\right)=0$$

Manning's Equation

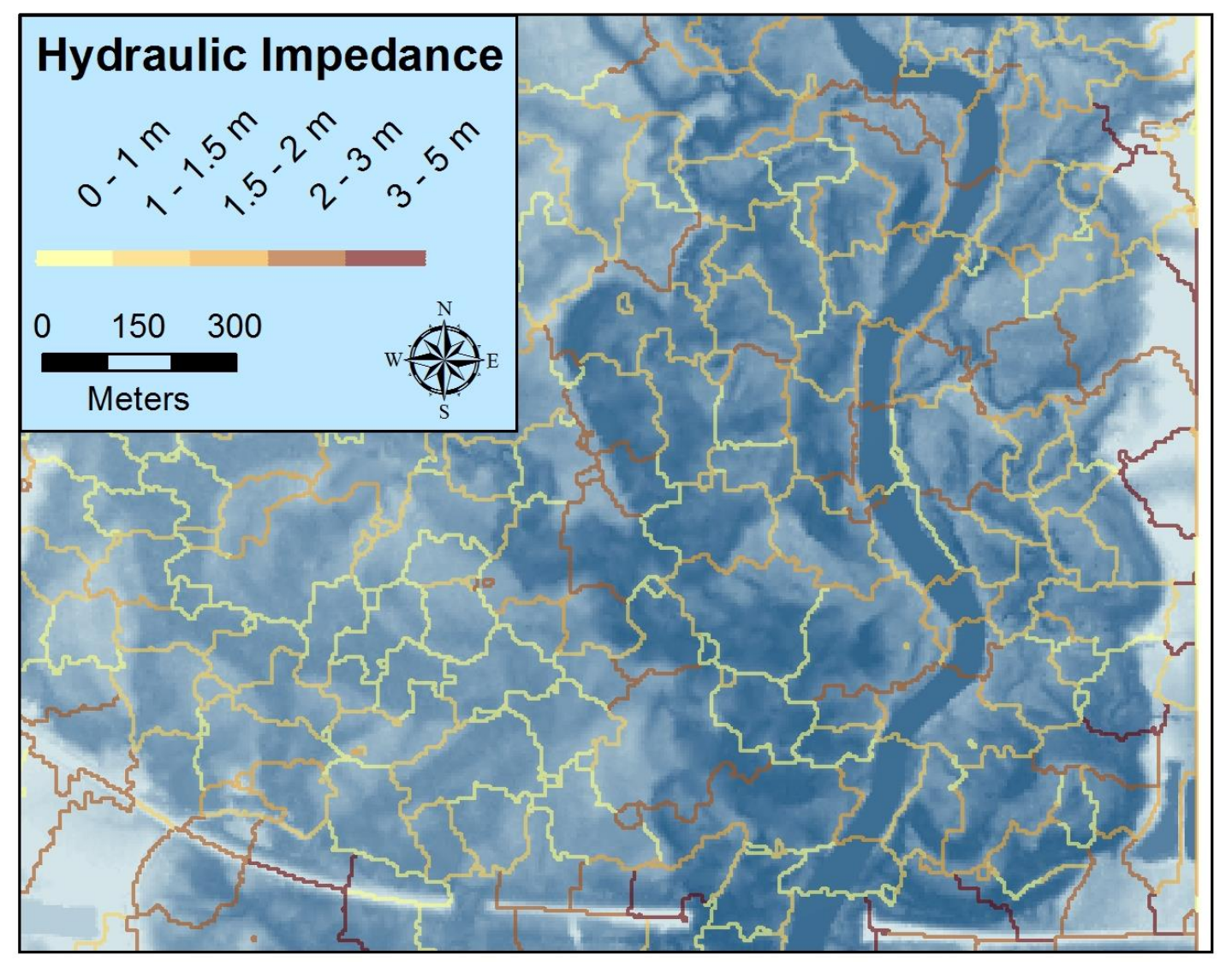
$$Q=\frac{1.49}{n}R^{\frac{2}{3}}S^{\frac{1}{2}}A$$

In most engineering applications, models are parameterized based on Manning Roughness Coefficient (n), where the floodplain is assigned a bulk roughness or different landcover types are assigned individual roughness values. These values typically come from a lookup table. While this is adequate for modeling flood extent, this approach poorly represents water flow across the floodplain.

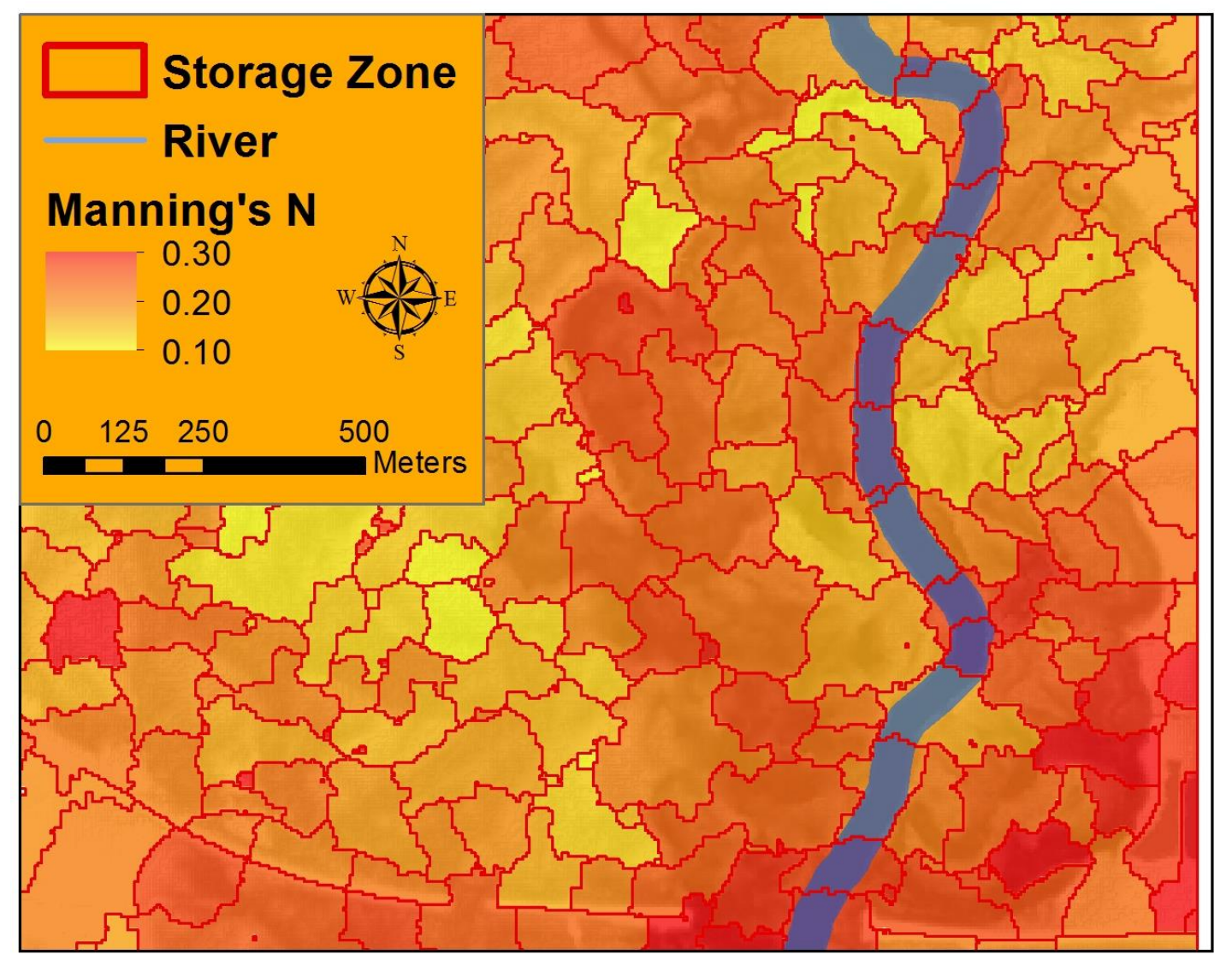
Inundation Estimate



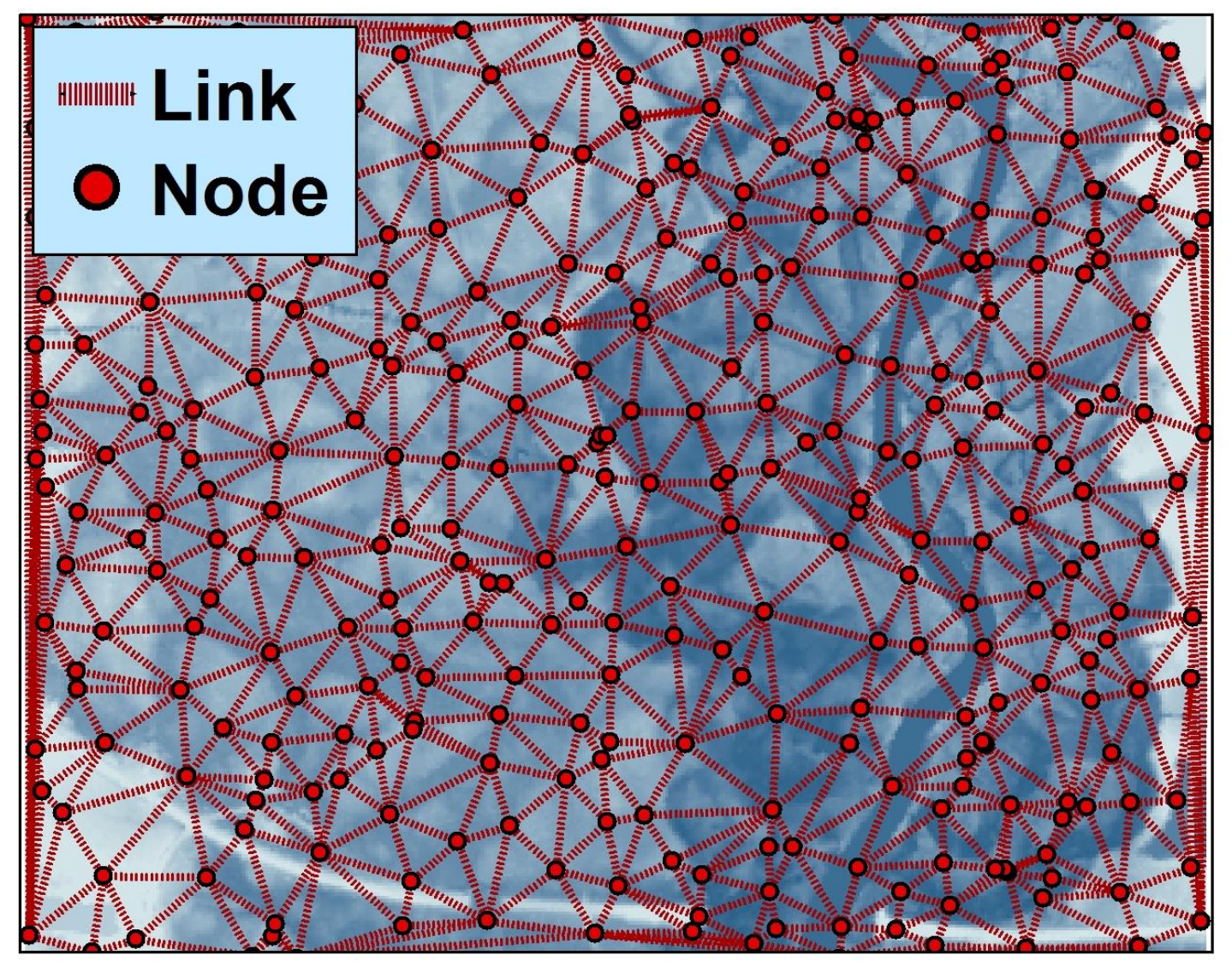
Storage Zone Delineation



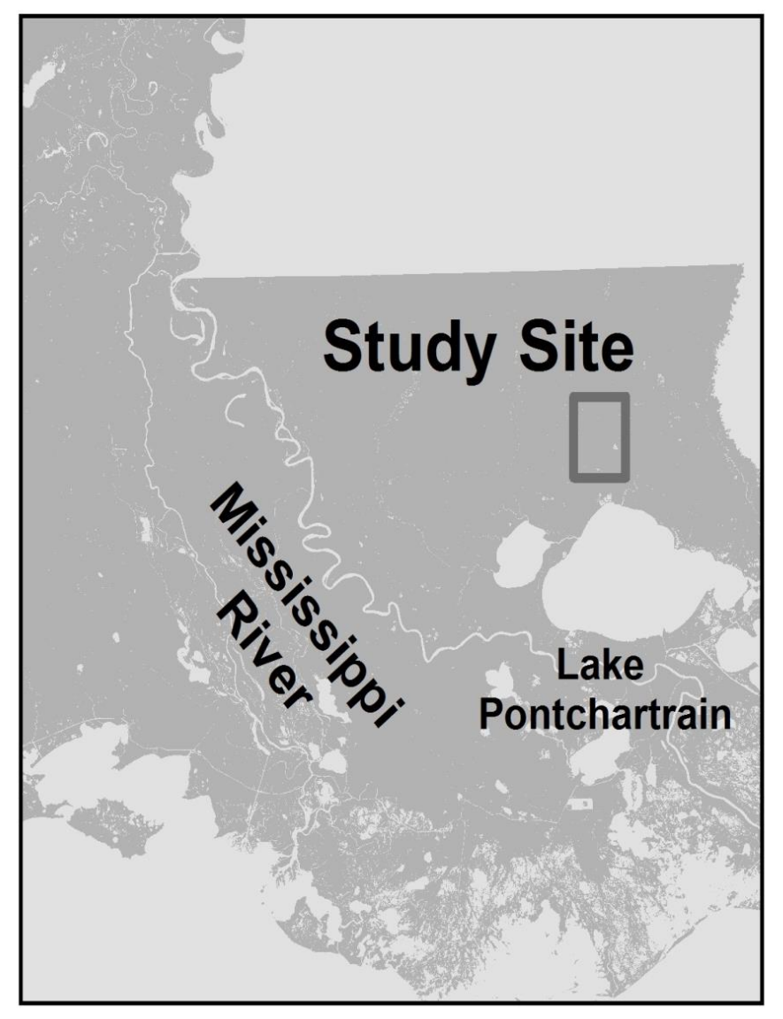
Floodplain Roughness

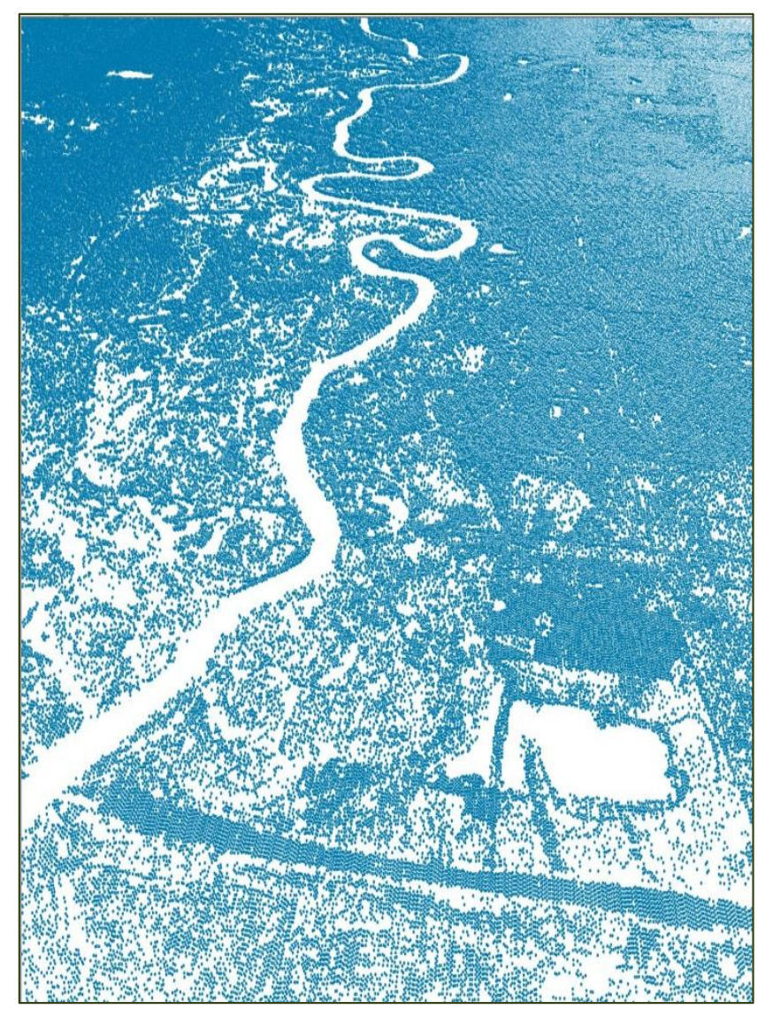


Ecohydraulic Model Input



Site Location and Data Acquisition

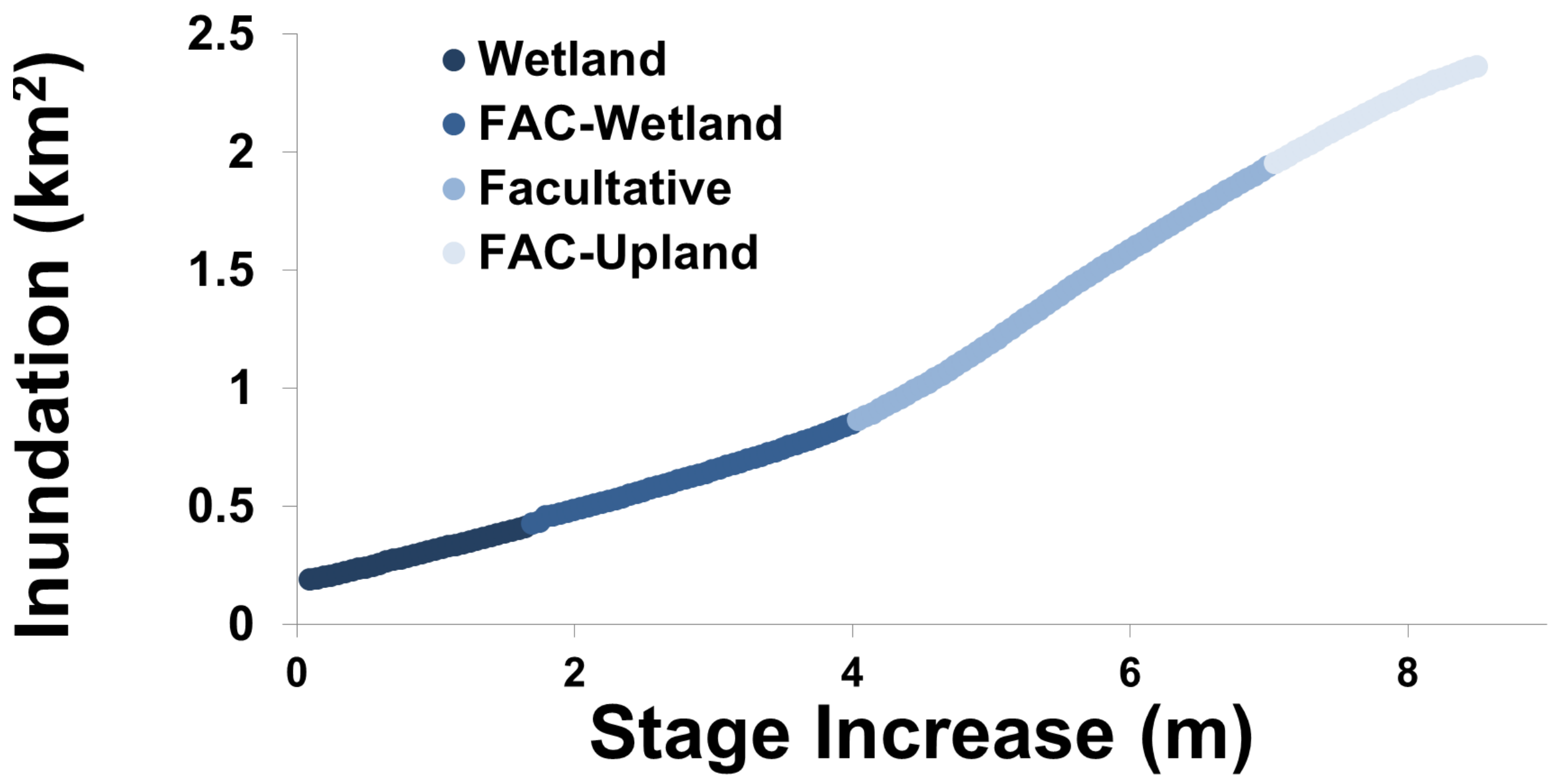




The study site is located on the Tangipahoa River in Southern Louisiana. This is a long term study site for the Hydroecology Lab at Virginia Tech. LiDAR was obtained through the Louisiana Statewide LiDAR Project. It has a vertical accuracy of 1' and a horizontal accuracy of 3'. Both filtered bare earth data (see middle picture above) and unfiltered data are available. A DEM was created from the bare earth points.

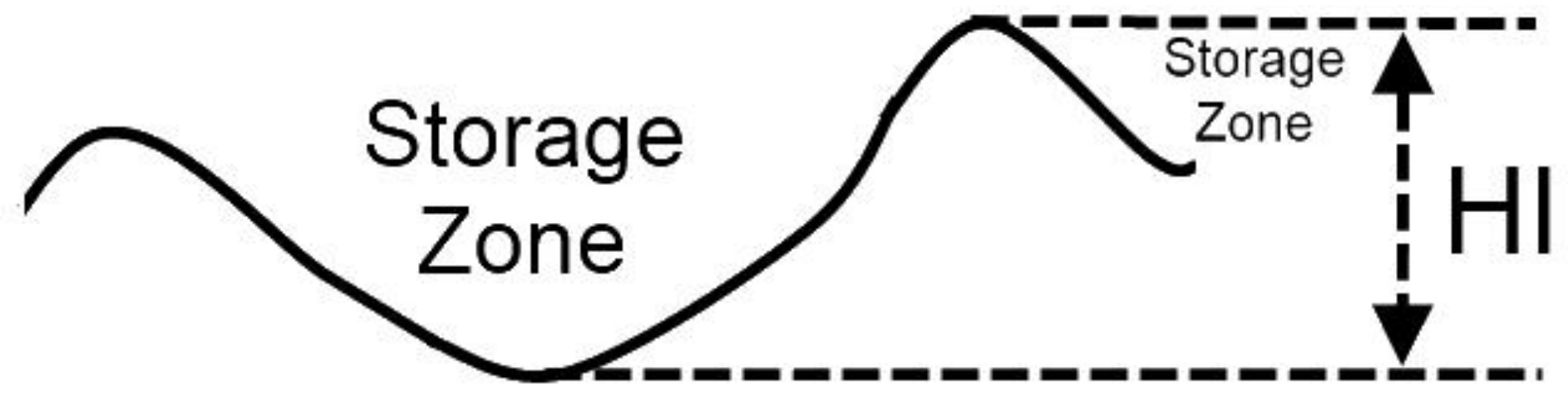
Inundation Estimate

Inundation Areas were estimated utilizing a cost surface (derived from the floodplain DEM) and conditional raster algebra. As stage increased, there were breakpoints in the stage-area curve. These were artificially assigned wetland plant classifications. See stage-area plot below:



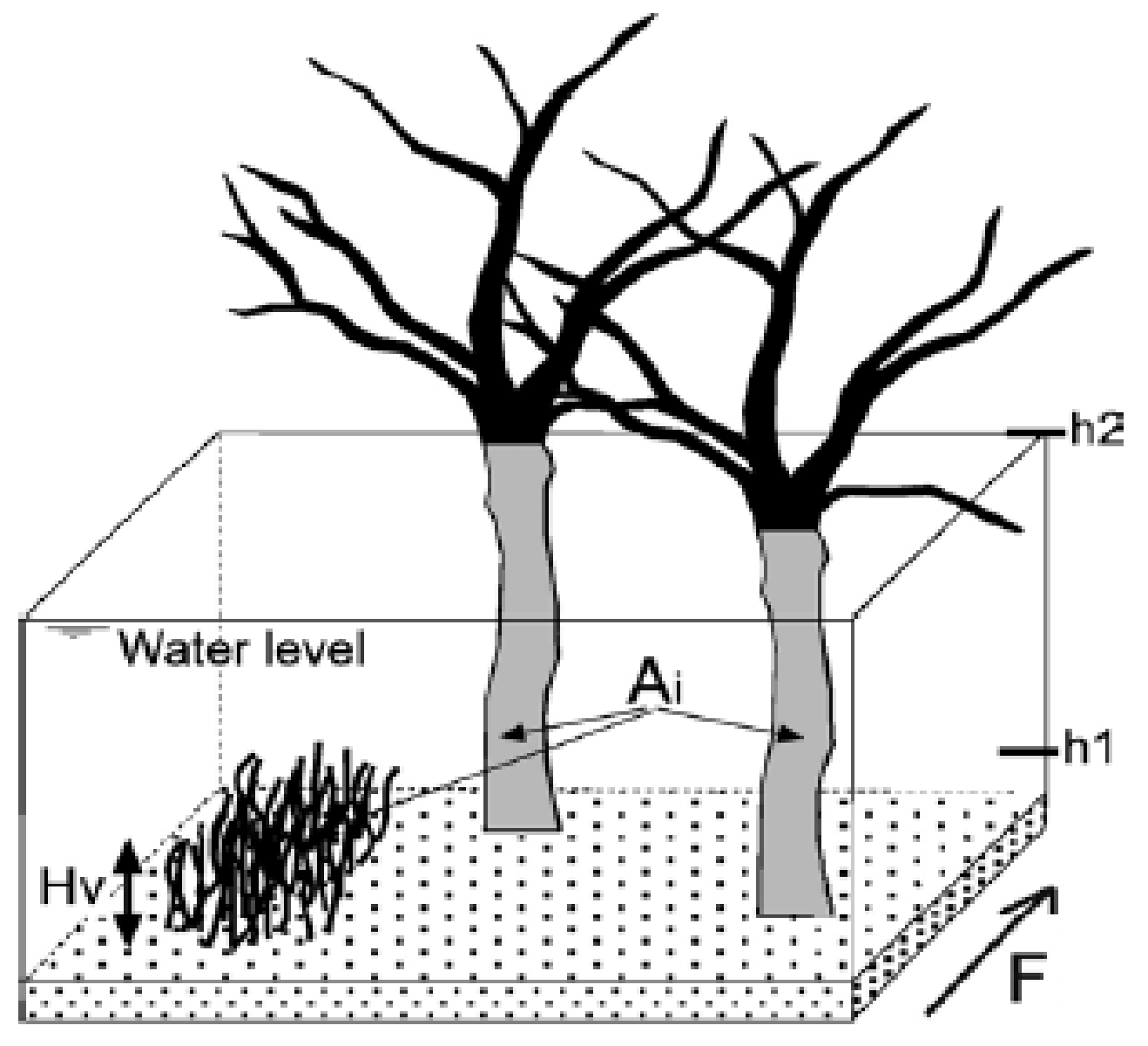
Storage Zone Delineation

Utilizing the technique developed Jones et al. (2008), hydraulic divides were identified and given a hydraulic impedance (HI) value. HI represent maximum depth of each storage zone. Through an iterative process, divides with an HI less than one meter were removed. See figure above for the resulting storage zones.



Roughness Estimate

This technique was based on the "Forest" model developed by Straatsma and Baptist (2008). The roughness estimate relies on a estimate of momentum dampening zones, or areas where flow is slowed due to obstruction. This is estimated using the Percent Index derived from LiDAR (illustrated below.) The information was then summarized and incorporated into the link-node model shown above.



****Taken from Straatsma and Baptist (2008)**

$$PI=\left(\frac{1}{h2-h1}\right)\left(\frac{N_{h1-h2}}{N_{tot}}\right)$$

$$D_v=1.36\,PI+0.008$$

$$C_R=\sqrt{\frac{1}{C_b^{-2}+(2g)^{-1}C_D D_V H_V}}$$

References

Jones, K.L.; Poole, G.C.; O'Daniel, S.J.; Mertes, L.A.K.; Stanford, J.A. Surface hydrology of low-relief landscapes: Assessing surface water flow impedance using LIDAR-derived digital elevation models. Remote Sensing of Environment. 112:4148-4158; 2008

Straatsma, M.W.; Baptist, M. Floodplain roughness parameterization using airborne laser scanning and spectral remote sensing. Remote Sensing of Environment. 112:1062-1080; 2008