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Constraining River Baseflow Depth from Swath Altimetry and Classic Hydraulic Geometry: Initial Results

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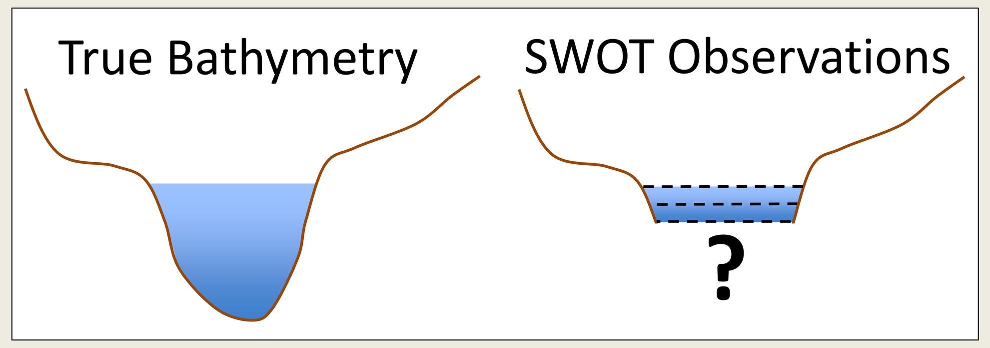
Problem Statement

How can depth, and ultimately discharge, be estimated from remotely sensed measurements of water surface elevation and width?

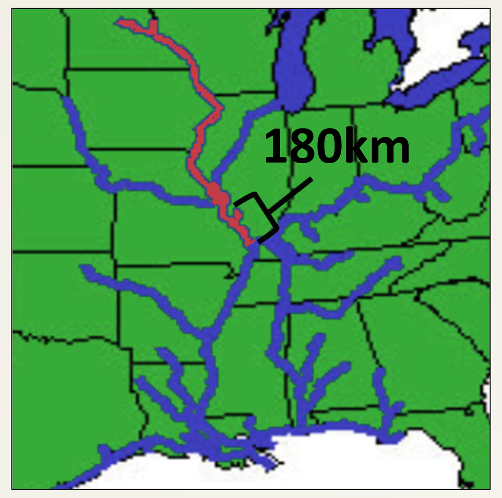
The Surface Water and Ocean Topography (SWOT) satellite is a swath-mapping radar interferometer that will measure water elevations over inland water bodies as well as over the ocean. SWOT will observe channel bathymetry down to the lowest water level encountered over the mission lifetime, but cannot observe the depth of flow beneath this level. Therefore, while changes in water surface elevation and width can be measured, estimates of total discharge (m3/s) are limited by the unknown cross-sectional area in addition to velocity.



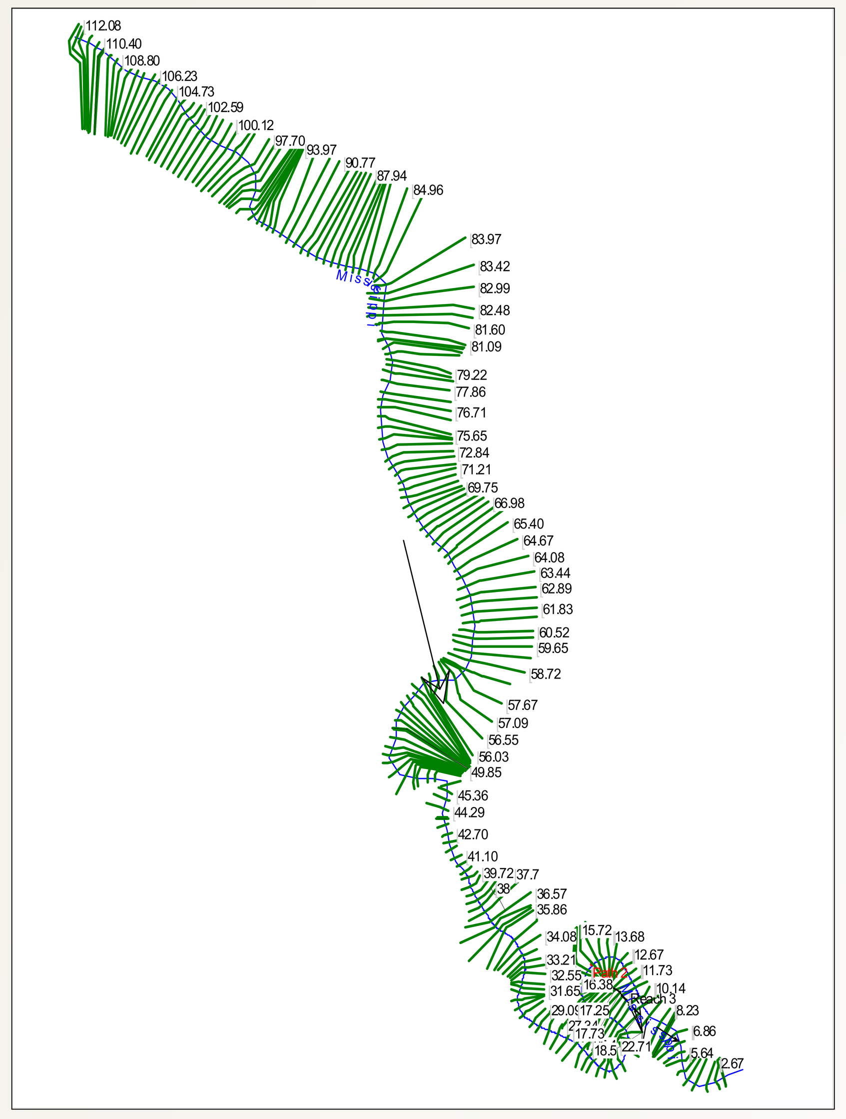
Here we adapt traditional hydraulic geometry (HG) concepts to a remote sensing framework, and explore the extent to which remotely sensed measurements of water surface elevation and width can be used to constrain estimates of river depth and discharge.

1. Study Areas

Rio Grande River (146 Surveyed Cross-sections)



Upper Mississippi River (233 Cross-sections)

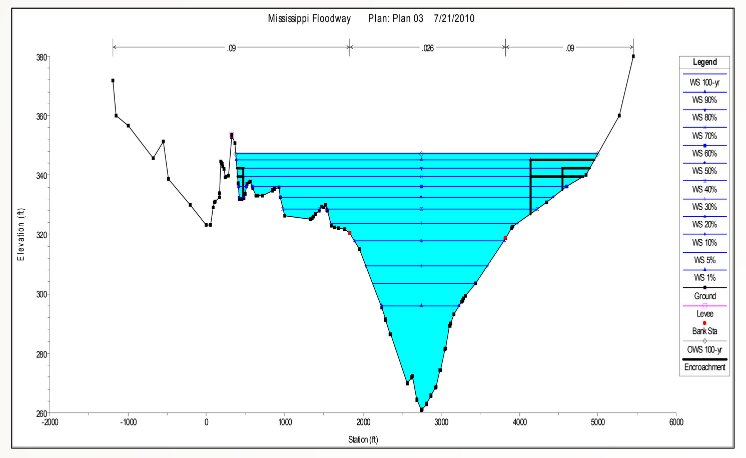


Methods

We used the Army Corps of Engineers river hydraulics model, HEC-RAS, to produce a range of steady flow water surface profiles along a reach of the middle Rio Grande River (172km) and a reach of the Upper Mississippi River (180 km). For each steady state profile, model outputs of water surface elevation, top width, average depth, average velocity, and discharge were extracted at each cross-section.

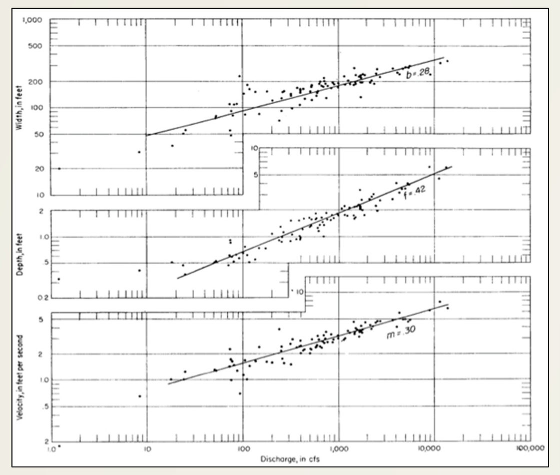
The ability to produce a wide range of flow profiles at spatially dense cross-section locations makes this an ideal method for exploring the interrelationships of hydraulic characteristics of stream channels. The modeled values of water surface elevation and width were treated as synthetic SWOT observations for the purposes of this study. HEC-RAS outputs were imported into Matlab for plotting and analysis.

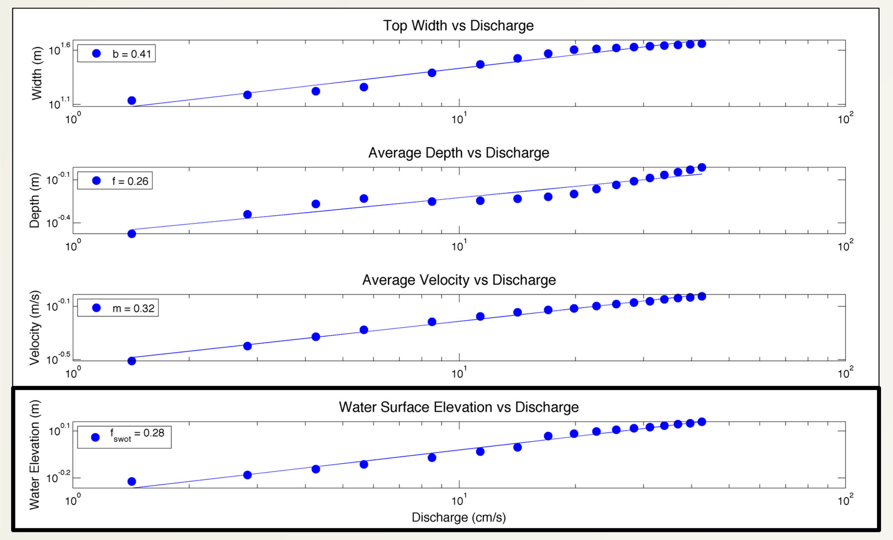
HEC-RAS Water Surface Profile Modeling



2. Adapting Classic At-A-Station Hydraulic Geometry to SWOT

Leopold and Maddock, 1953



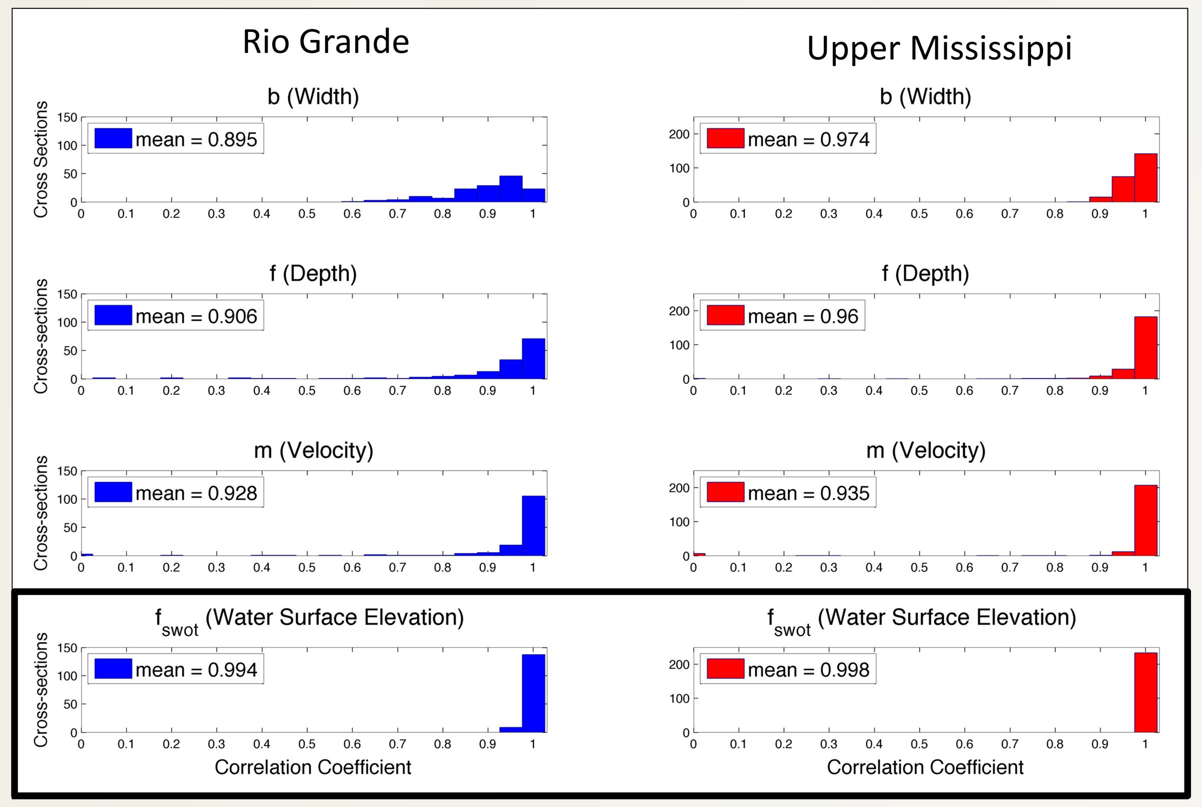


Leopold and Maddock described at-a-station hydraulic geometry as the interrelationship of hydraulic characteristics of stream channels and their variation with respect to discharge as "simple power functions at a given river cross section," explained by the forms:

$$w=aQ^b \quad d=cQ^f \quad v=kQ^m$$

where w, d, and v are top width, average depth, and average velocity, respectively, and Q is discharge in m/s. The exponents b, f, and m indicate the "sensitivity" of each hydraulic variable with respect to discharge. SWOT will retrieve a global inventory of water surface elevation measurements, providing a catalyst for exploring the relationship between water surface elevation and discharge, borrowing from the approach of traditional hydraulic geometry. We find that in two rivers, on average at a given cross-section, water elevation has a tighter correlation to discharge than either width, depth, or velocity.

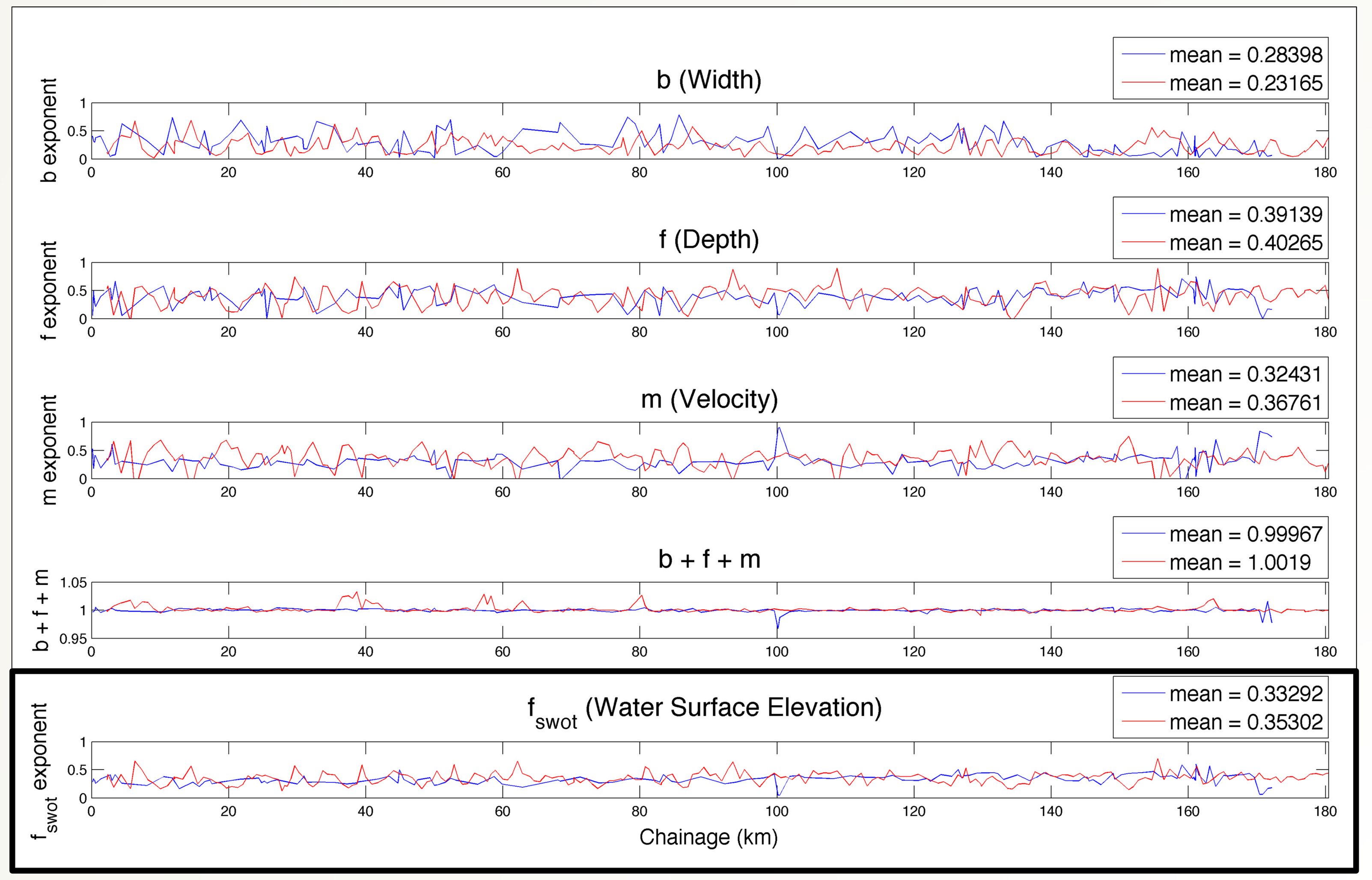
Goodness of Fit of At-A-Station Exponents



Classic HG

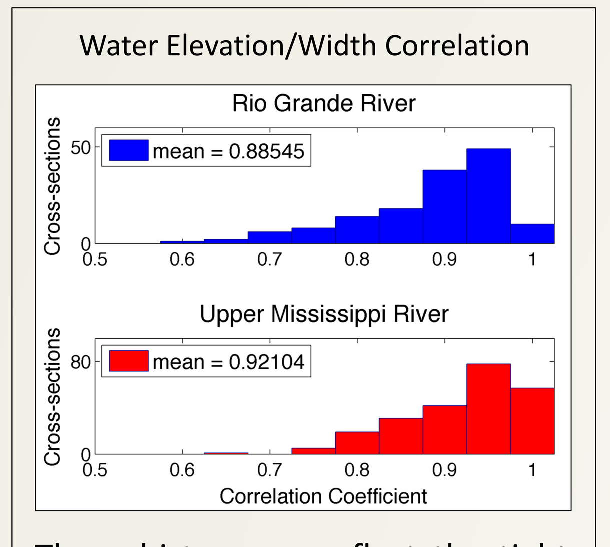
Adapted to SWOT

Longitudinal Profile of At-A-Station Exponents

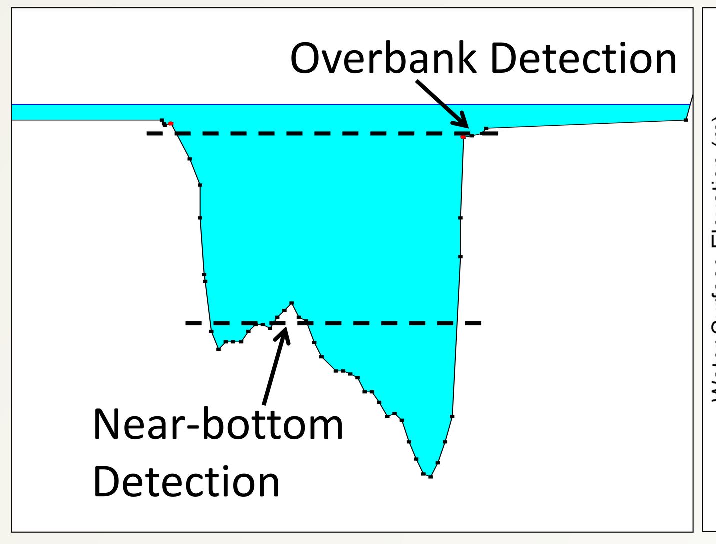


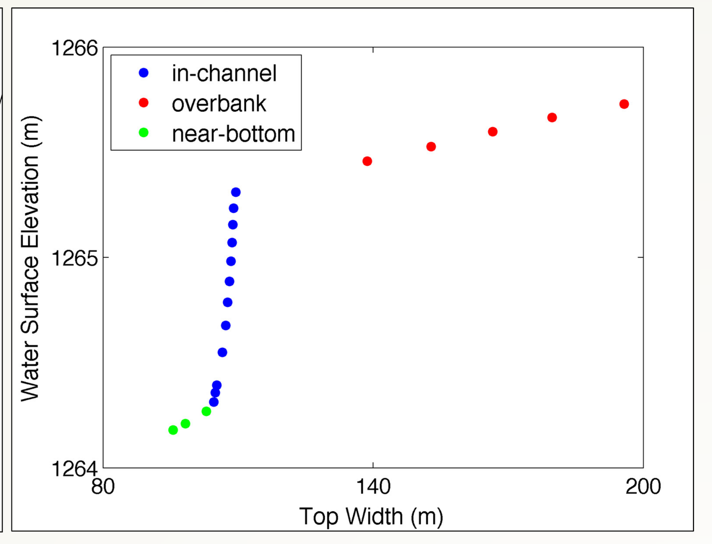
3. Can remotely sensed measurements of water surface elevation and width be used to constrain estimates of river depth?

Overbank and Near-bottom Detection



These histograms reflect the tight linear relationship between water surface elevation and width, for two rivers, when restricted to within-bank flows.





Multi-temporal measurements of water surface width and elevation can be used to detect within-bank vs. overbank flows. The relationships between remotely sensed channel characteristics (water surface width and elevation) and variables of interest (channel depth, velocity, and discharge), are strongly correlated when restricted to within-bank flows, but not for overbank flows. Additionally, at sufficiently low flow levels, significant breaks in water surface width/elevation ratios can indicate the nearing proximity of the channel bottom.

Conclusions / Future Work

- The fundamentals of classic hydraulic geometry can be applied to remote sensing retrievals to explore the relationship between water surface elevation and discharge. When restricted to within-bank flows, water surface elevation displays a high correlation with stream discharge in the rivers studied.
- At-a-station HG's are highly variable downstream, therefore remotely sensed HG relationships are useful locally, not universally.
- Surprisingly high m exponents suggest velocity retrievals pose a challenge to SWOT discharge retrievals. On average, velocity adjustments comprise 32% and 37% of discharge for the Rio Grande and Upper Mississippi rivers, respectively
- The correlation between remotely sensed measurements of water surface elevation and width can be used to detect overbank versus within-bank flows, and the nearing proximity of a channel's bottom.
- The preliminary findings presented here suggest promising potential for SWOT discharge estimates given the tight relationship between water surface elevation (a SWOT observable) and stream discharge.
- Further work will expand to larger datasets of surveyed cross-sections in order to determine the consistency of these findings among varied river types and locations.

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http://swot.jpl.nasa.gov/

Leopold, L. B., and J. Thomas Maddock (1953), The Hydraulic Geometry of Stream Channels and Some Physiographic Implications, Geological Survey Professional Paper.

Tetra Tech, Inc. (2005), FLO-2D Model Development Below Caballo Dam URGWOM Prepared For: U.S. Army Corps of Engineers.

U.S. Army Corps of Eng. (2004), Upper Miss. River System Flow Frequency Study.