The SWOT Mission and river depth

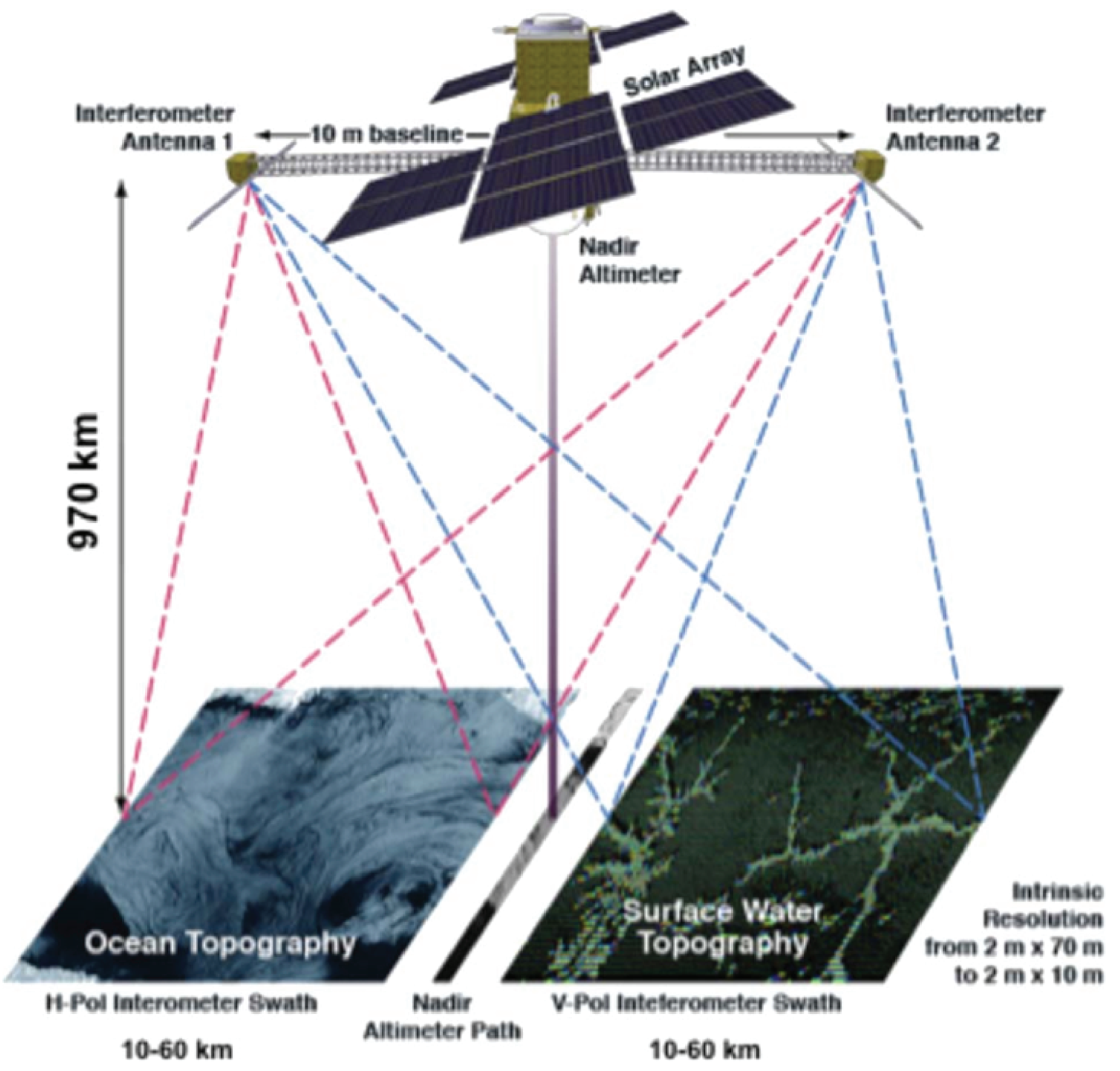

Figure 1. The Surface Water and Ocean Topography (SWOT) mission will measure inundated area and water elevation (h) for inland water surfaces, from which water slope ($\partial h/\partial x$) and temporal change ($\partial h/\partial t$) are derived. From these fundamental measurements, surface water storage change and river discharge will be calculated, two principal components of the water cycle. SWOT has been recommended by the Deacadal Survey (Alsdorf et al., 2007); probable launch date is 2019. A key technology of the SWOT mission is a Ka-band Radar INterferometer (KaRIN) which is a near-nadir viewing, 120 km wideswath based instrument that uses interferometric SAR processing of the returned pulses to yield single-look 5m azimuth and 10m to 70m range resolution, with an elevation accuracy of approximately 50 cm. Figure from Durand et al. (2010).

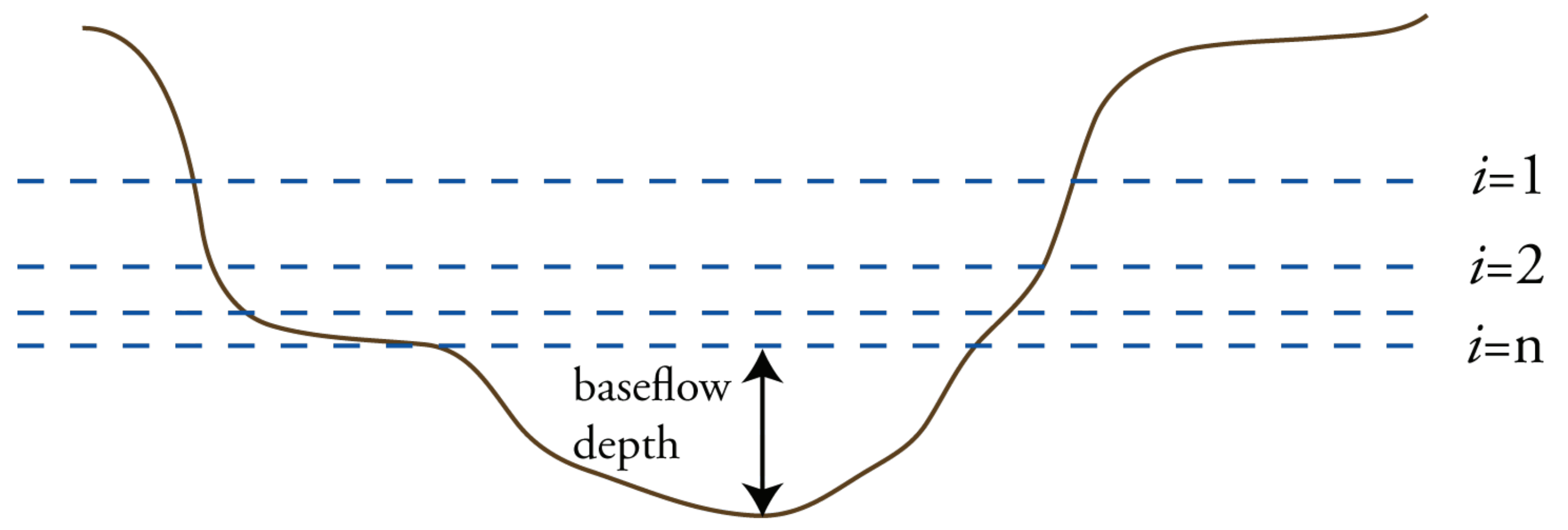

Figure 2. SWOT) will deliver measurements of storage change in rivers and lakes and of river discharge. River discharge as calculated, e.g., by the Manning equation is dependent on the total depth of flow. The figure illustrates an irregular cross-section (black line) at different water elevations (i=1, 2, … n) measured by SWOT. While SWOT will readily observe these changes in water elevation or depth ($\partial h/\partial t$), the baseflow depth will not be observed. Nonetheless, hydraulic information in the water slope and ($\partial h/\partial x$) and changes in top width can be utilized with the hydraulic constraints imposed by mass and momentum conservation in the context of a data assimilation scheme to constrain the baseflow depth. Moreover, the principles of at-a-station hydraulic geometry can also be utilized to provide information on baseflow depth. This project investigates these two methods of estimating depth.

Modeing the Rio Grande

Study Area, Data, and Model

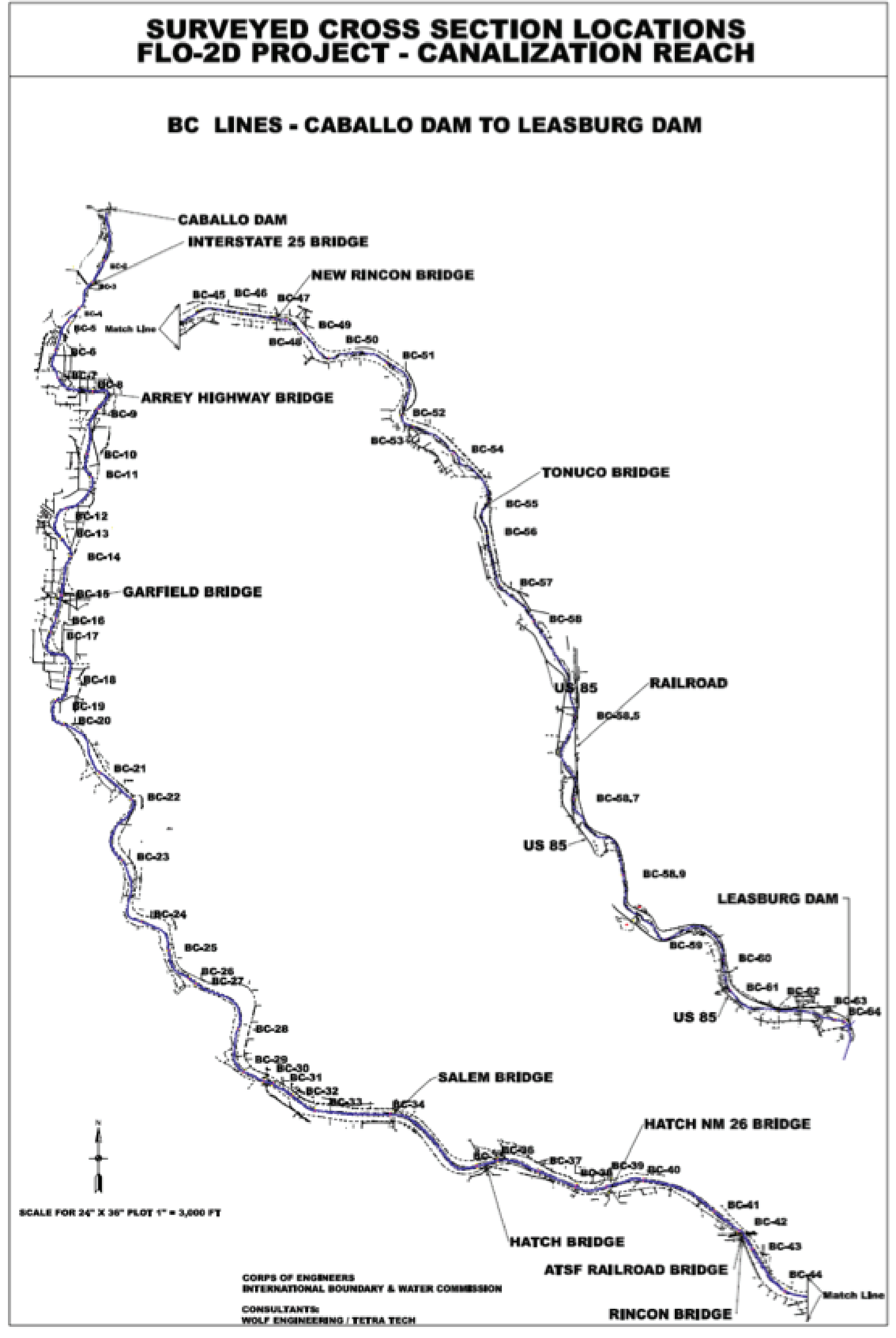

Figure 3. Our study area for testing these methodologies is the Rio Grande River, in the 180 km upstream of the American Dam and downstream of the Caballo Dam. This is a heavily managed river in a semi-arid region.

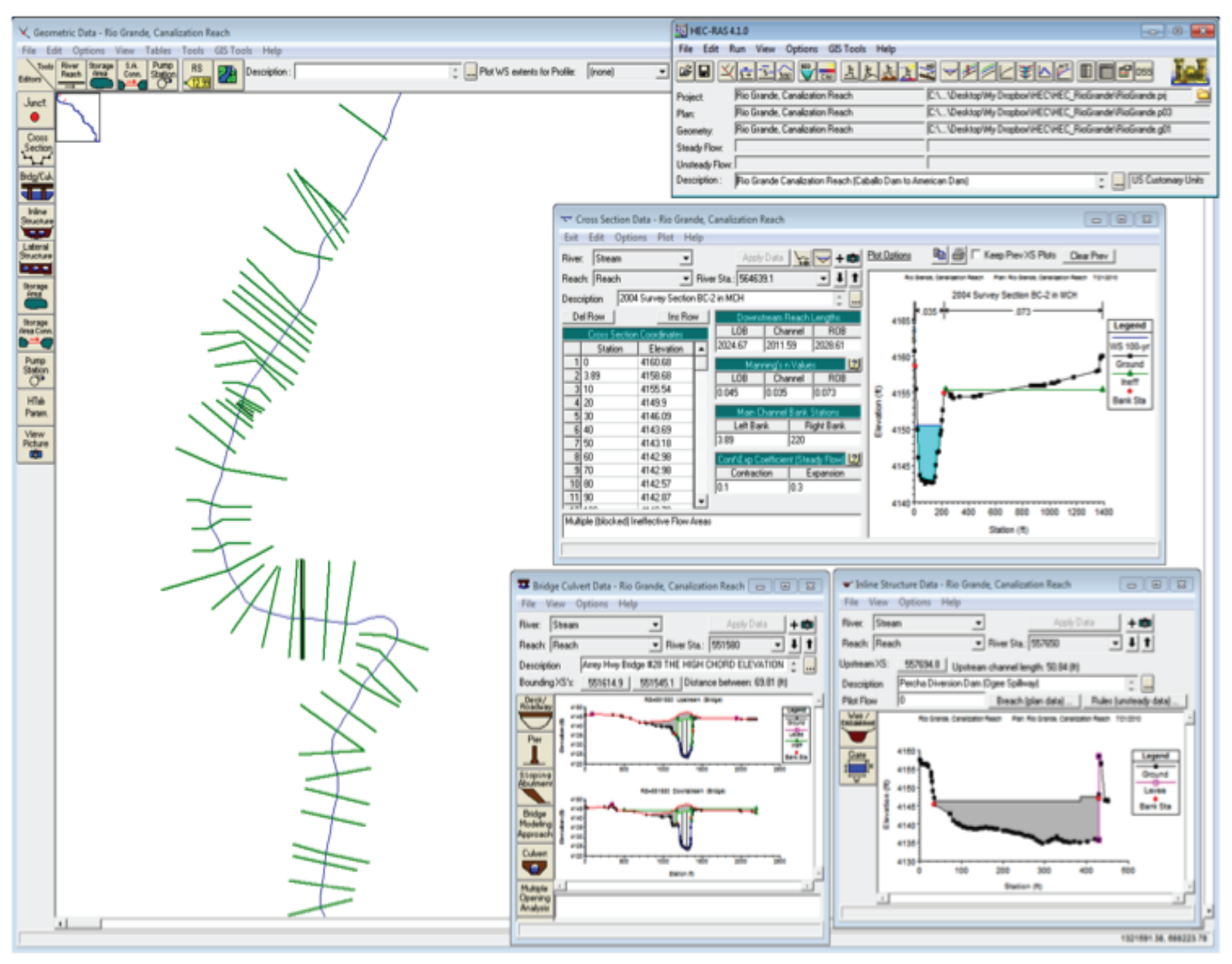

Figure 5. The HEC-RAS model was used to predict water elevations given the bathymetry and the flowrate (steady state simulation). The software includes the effects of dams and levees on flow hydraulics.

Figure 4. In an independent study, cross-section measurements were made at hundreds of cross-sections along the river. Instream bathymetry was measured via a small boat, and floodplain bathymetry was measured via Lidar. These bathymetry measurements were interpolated in space such that a cross-section exists approximately every 150 m, for a total of 1202 cross-sections in the reach.

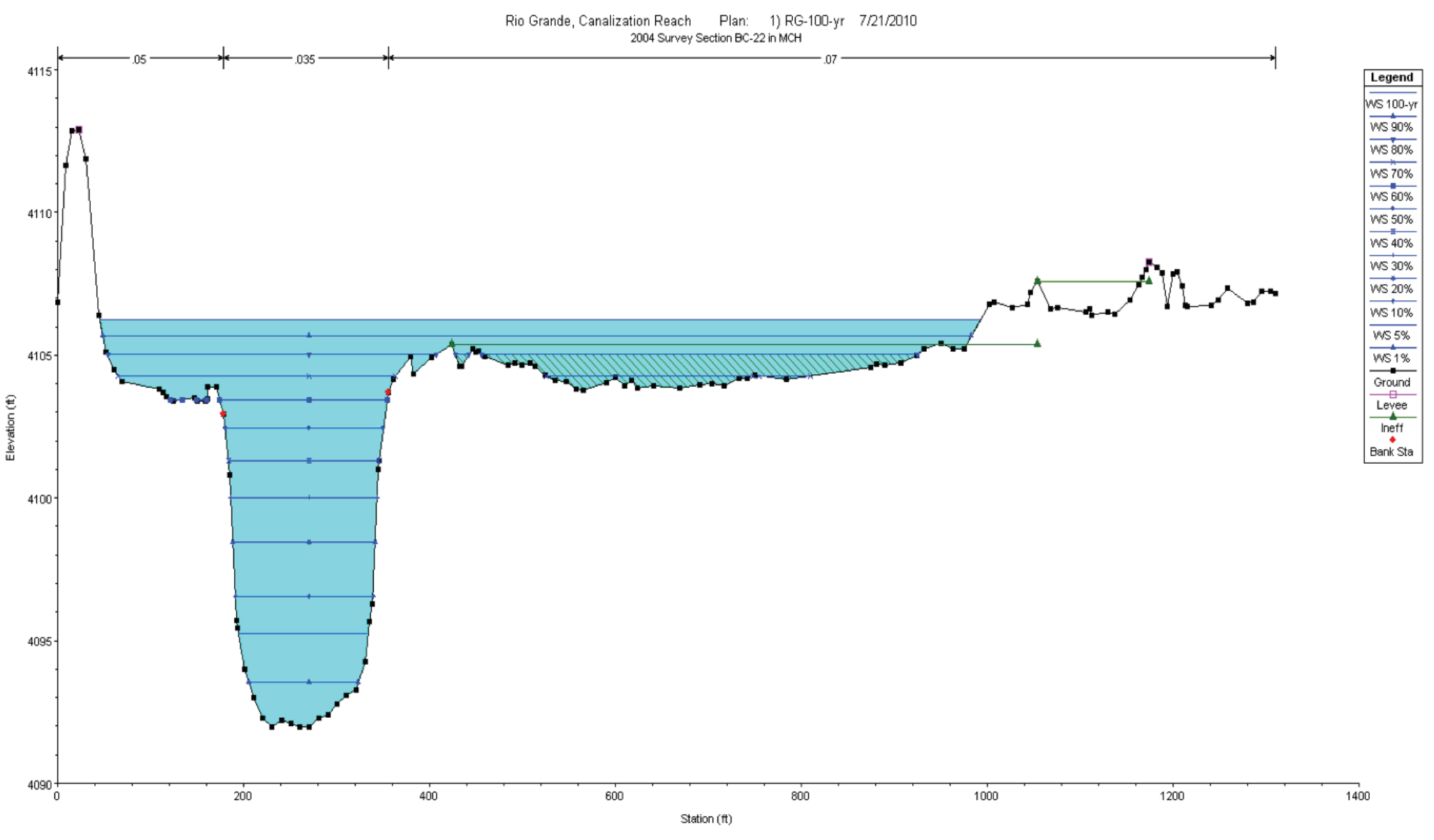

Figure 6. We calculated water surface elevation profiles at ten different flowrates, corresponding to different fractions of the 100-year flow. At each cross-section, the water elevation, top width, water slope, as well as total depth was predicted.

Assessing and Retiring Risk in SWOT Discharge Products: Two Methods for Characterizing River Depth

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Hydraulic Geometry

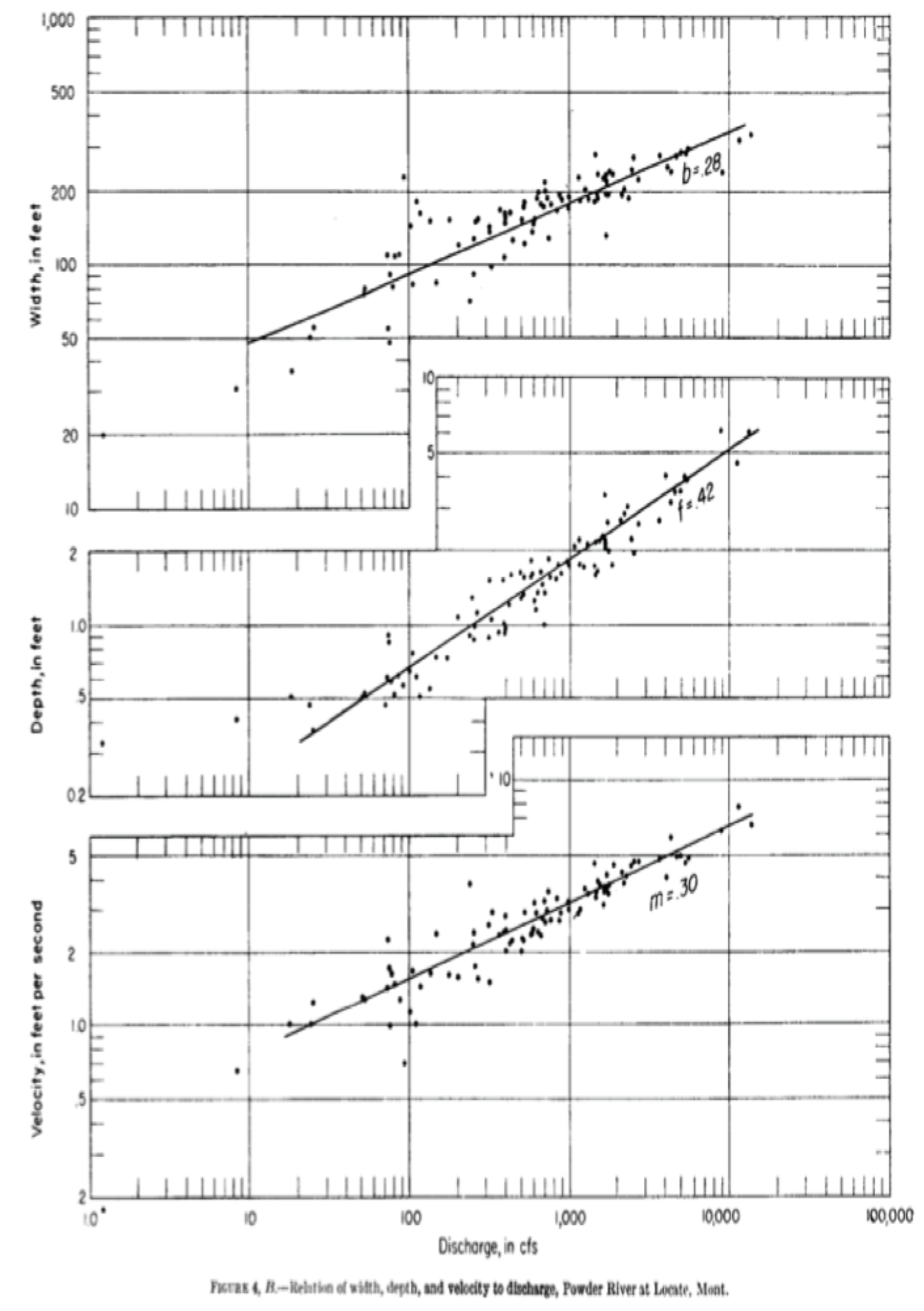

Figure 7.(above) The at-a-station hydraulic geometry is a tool that has been used for decades to study fluvial systems, beginning with Leopold and Maddock (1953). Power laws are used to represent the relationships between discharge and width, depth, and velocity. By noting height, slope, and top width variability, information can be extracted about baseflow depth.

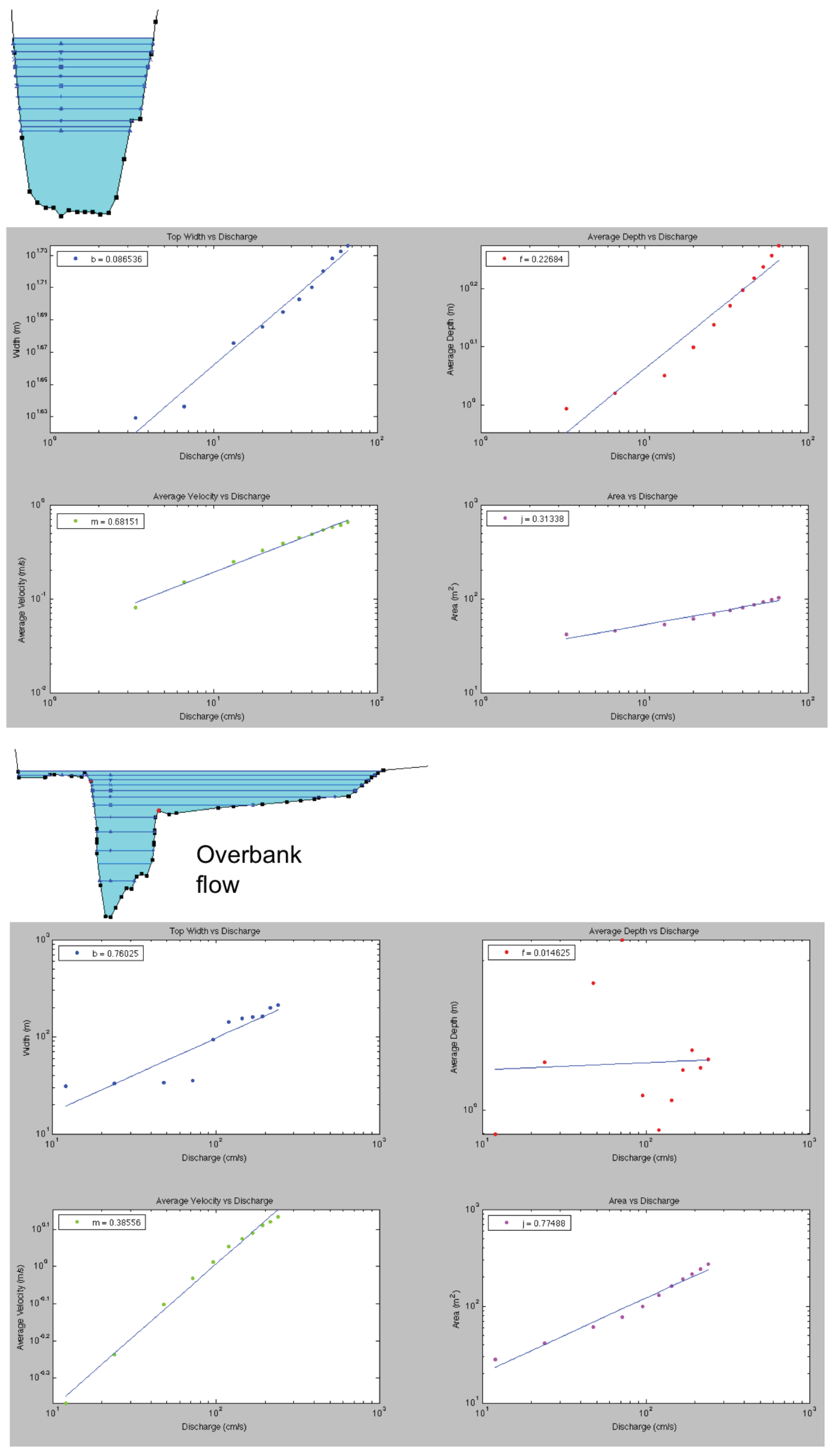

Figure 8.(right) The HEC-RAS output was used to derive the at-a-station hydraulic geometry at each station in the model. Results from two stations are shown. The top station has channel flow only, while the bottom station has significant out-of-bank flow. Note that the cross-sectional area still follows a power law for the bottom cross-section.

Acknowledgments

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Data Assimilation

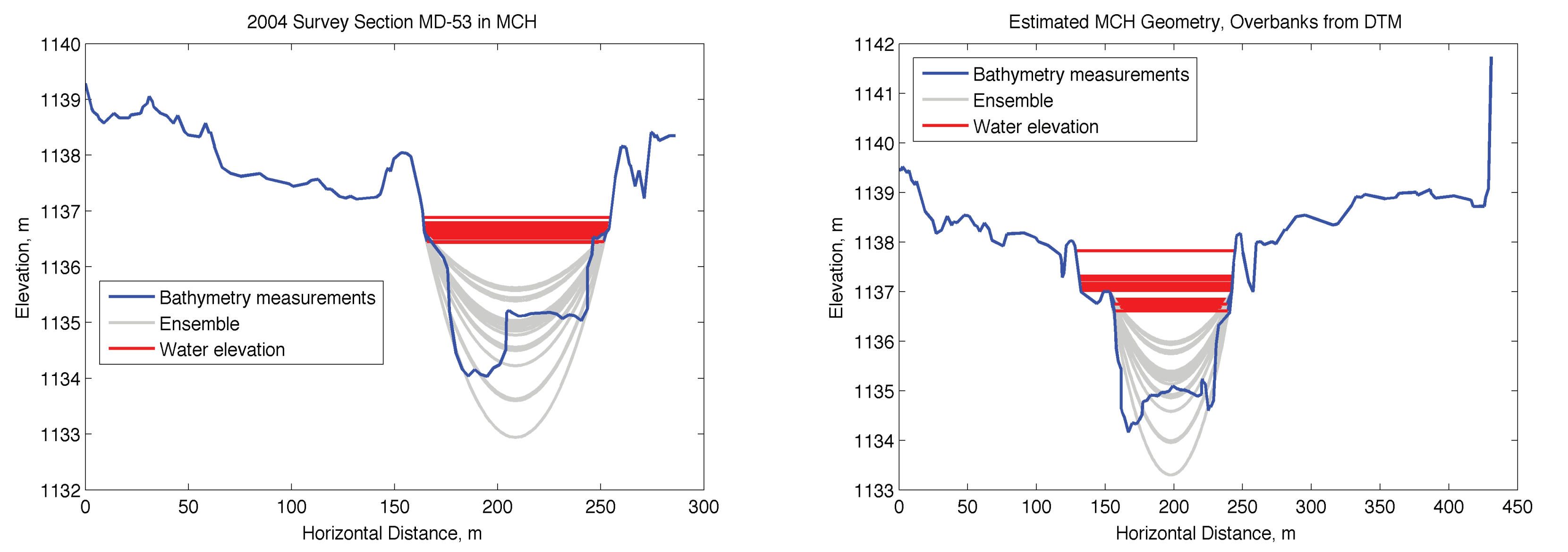

Figure 9. In a data assimilation system, we make some assumption about the unseen baseflow geometry. Here, we have assumed a parabolic shape. The parabola has a single parameter, the minimum channel elevation. We generated twenty different values of this minimum channel elevation at each cross-section, and calculated the resulting bathymetry (gray lines, above): this is referred to as the "prior ensemble" of bathymetry. We solved the energy conservation equation (Gradually Varied Flow equation) for each ensemble member (red lines, above). These water elevations can then be compared directly with the observed water elevations and top widths in order to calculate the optimal channel bathymetry. The equation is used to find the optimal minimum depth (z) given observed and modeled water elevations (h) for each ensemble member (k) using the covariance matrices (C) between model inputs and outputs.

$$z_k^+ = z_k^- + C_{zh}\left(C_{hh} + C_v\right)^{-1}\left(h_{obs} - h_k^-\right)$$

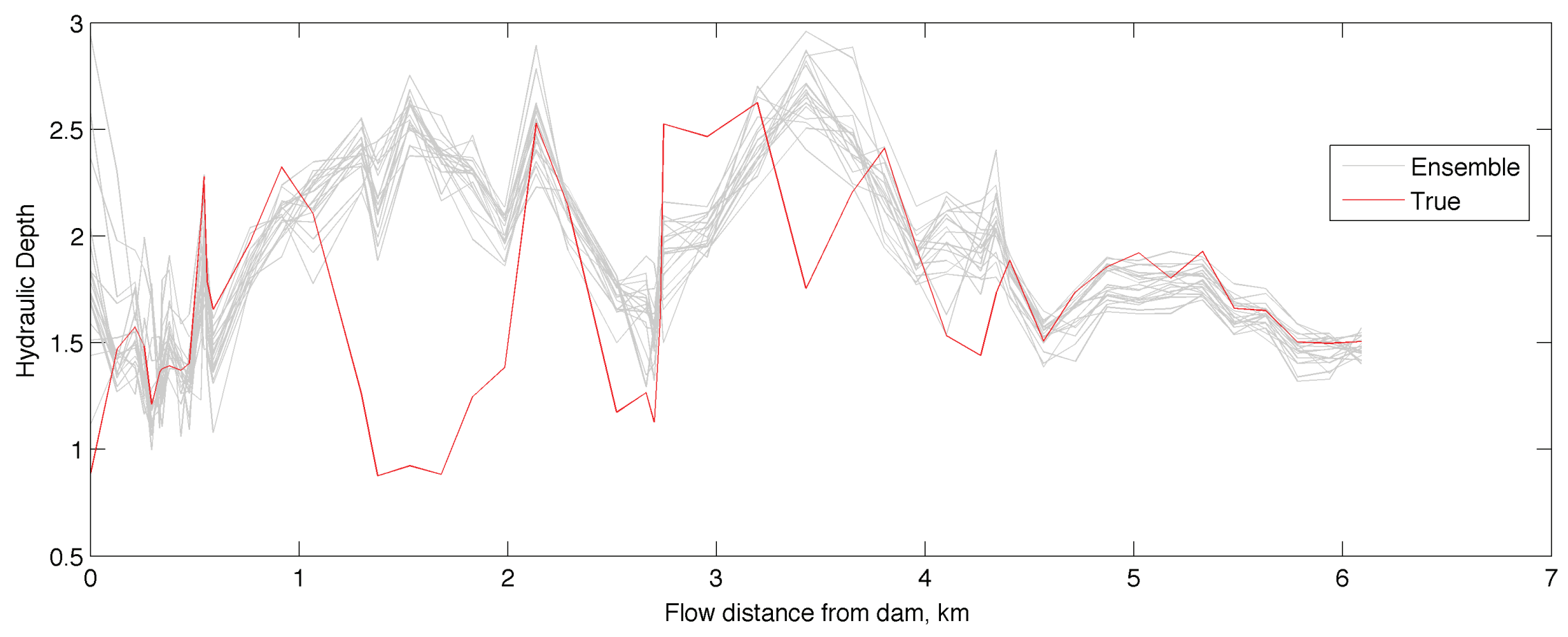

Figure 10. Here we show the hydraulic depth, defined as the cross-sectional flow area divided by the top width; this makes a fair comparison between cross-sections with different shapes. In the areas near flow control structures (near 0 km flow distance and around 3 km flow distance) depth estimates are poor. Upstream away from dam influence (greater than 4 km flow distance) the posterior hydraulic depth captures the true variability.

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