Evaluating Uncertainty in Manning's Roughness Coefficients in One-dimensional Steady HEC-RAS Modeling

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Abstract

The step-backwater solution of the one-dimensional shallow water equations has been a popular approach to model water-surface elevations for flood-inundation mapping. U.S. Army Corps of Engineering Hydrologic Engineering Center River Analysis System (HEC-RAS) is a nationally accepted hydraulic model used to simulate flood inundation. Model simulation results will vary depending on selection of the Manning's roughness coefficients. In this study, the effects of uncertainty in Manning's roughness coefficients were investigated for a 23-mile reach of the Medina River near Bandera, Texas. One-parameter (uniform), two-parameter (main channel and floodplain), and three-parameter (main channel, left floodplain, and right floodplain) scenarios are being tested to see how multiple roughness coefficients affect the uncertainty in the model for the study area that is being developed. Model performance will be evaluated using the root-mean-square-error of water-surface elevation differences between the model result and the stage-discharge rating curve at the U.S. Geological Survey streamflow gaging station at the Medina River at Bandera, Texas (station number 08178880). Uncertainty in Manning's roughness coefficients will be determined through Monte Carlo simulation of randomly distributed roughness coefficient values for each parameter test from 0.001 to 0.3 for 10,000 runs.

Introduction

The step-backwater solution of the one-dimensional energy equation has been a popular approach to model water-surface elevations for flood-inundation mapping owing to its simplicity and stability. One of the most widely used models is U.S. Army Corps of Engineers Hydrologic Engineering Center's River Analysis System (HEC-RAS) (U.S. Army Corps of Engineers Hydrologic Engineering Center, 2016). HEC-RAS is a nationally accepted hydraulic model for the National Flood Insurance Program of Federal Emergency Management Agency (Federal Emergency Management Agency, 2019), and U.S. Geological Survey (USGS) Flood Inundation Maps are often produced using HEC-RAS (U.S. Geological Survey, 2019).

HEC-RAS is used to solve the one-dimensional energy equation to get the backwater water-surface elevations of steady uniform flow. To solve these equations, the HEC-RAS model requires input datasets about the surface elevation topography (including cross sectional surveys), streamflow in the reach of interest, and the roughness of the stream channel.

One of the largest sources of uncertainty in one-dimensional hydraulic models involves the selection of values for Manning's roughness coefficient, commonly referred to as "n" values. The uncertainty of *n* values has been studied by many including Pappenberger et al. (2005, 2008), Warmink et al. (2010), and Yang et al. (2014). The *n* values are often selected as a model calibration parameter because of its critical impact on water-surface elevations. By calibrating Manning's roughness coefficients to measured water-surface elevation data, one-dimensional models like HEC-RAS can often produce accurate maps of flood inundation.

For HEC-RAS modeling, an *n* value is assigned to each model cross-section which reflects various channel conditions at that location—vegetation, obstacles, and surface irregularities for example. There are many different methods to estimate *n* values from available data such as photographs, tables, composite formulae, or measurement programs (Arcement and Schneider, 1989)). A single realization of a HEC-RAS model geometry can have as many *n* values as the number of modeled cross-section points, which makes determining realistic *n* values a challenge. This paper provides an overview of ongoing research to assess the uncertainty in simulated water-surface elevations resulting from using multiple *n* value representations of cross-section roughness in a HEC-RAS model for a reach of the Medina River in Texas.

Model Development

The study area includes a 23-mile reach of the Medina River near Bandera, Tex. from the confluence of the Medina River and Winans Creek downstream to English Crossing Road near Pipe Creek, Tex. (Figure 1). Bandera is between two meander bends of the Medina River near the intersection of State Highways 16 and 173 in the Texas Hill Country. A USGS streamflow-gaging station on the Medina River at Bandera, Tex. (station number 08178880, hereinafter referred to as the Bandera station) is downstream from the Main Street bridge that is part of Highway 173. Land cover in the study area consists of patches of ashe-juniper, live oaks, and mesquite trees intermingled with grass-covered rangeland; steep and rocky areas of exposed limestone dot the landscape. The climate in the area is semi-arid, and many tributaries to the Medina River are dry most time of the year (Bomar, 1983). The combination of steeply sloping terrain and the tendency for tropical cyclones from the Gulf of Mexico to move inland across the area during summer and fall contribute to frequent episodes of flash flooding (Caran and Baker, 1986).

Modeled channel cross-sections were extracted from a digital elevation model (DEM) derived from light detection and ranging (lidar) data collected during historically low-flow conditions in December 2013 (Texas Natural Resources Information System, 2014). Field measurements of the depth of water in the channel near the Bandera station and English Crossing Road during low-flow conditions were used to adjust elevations of cross-section points that were submerged when the lidar data were collected.

Streamflow discharges at the Bandera station are being modeled and calibrated by using the USGS Bandera Station stage-discharge rating curve. The model-targeted streamflows range from 2,370 cubic-feet-per-second (ft^3/s, 67.1 cubic-meter-per-second [m^3/s]) to 248,000 ft^3/s (7,040 m^3/s) corresponding to gage heights of 10 feet (ft, 3.05 meter [m]) to 38 ft (11.59 m). The rating curve at the Bandera station (fig. 2; solid black line) and 29 flow stages (gage heights) (fig. 2; red circles) ranging from 10 ft to 38 ft in one-foot increments that are being modeled using HEC-RAS. The HEC-RAS model calibration will be considered "acceptable" when the computed root-mean-square-error (RMSE) between the modeled and observed water-surface elevations are less than one foot.

Uncertainty Analyses

The model performance will be tested with three different scenarios of *n* values: one-parameter (uniform *n* value), two-parameter (two *n* values, one for the main channel and one for the floodplains), and three-parameter (three *n* values, one for the main channel, one for the left floodplain, and one for the right floodplain). Uncertainty in Manning's roughness coefficients will be determined through Monte Carlo simulation of randomly distributed values of *n* for each parameter test from 0.001 to 0.3 for 10,000 runs. The tested *n* value range will cover the normal range of expected *n* values of natural streams. Natural streams and associated floodplains exhibit *n* values from 0.025 to 0.2 (Chow, 1959). This roughly matches with the "observed" *n* value range of 0.016–0.213 from Conyers and Fonstad (2005) for their work in the Texas Hill Country. The model fit for each Monte Carlo simulation is being evaluated by computing the root-mean-square-error (RMSE).

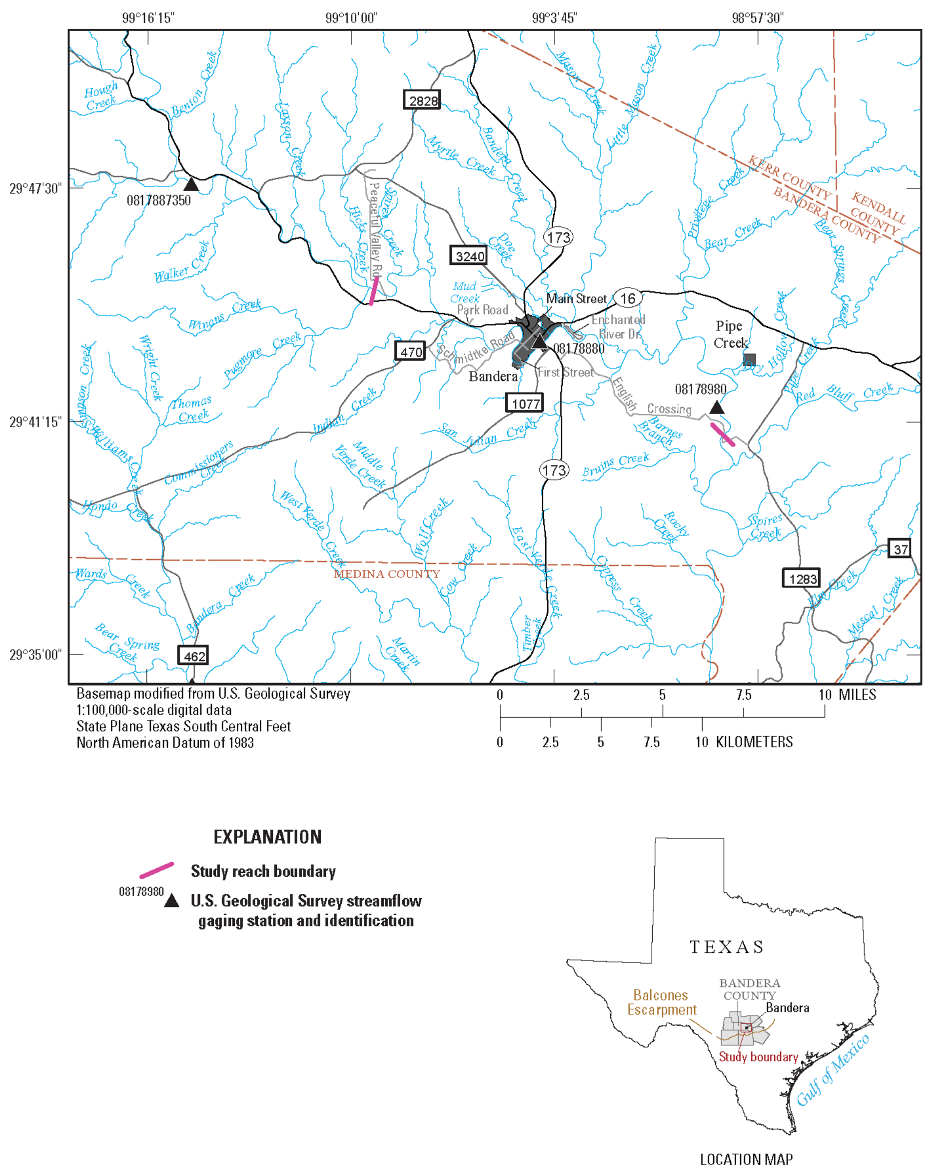

Figure 1 Study site map of the study area, which includes a 23-mile reach of the Medina River near Bandera, Texas.

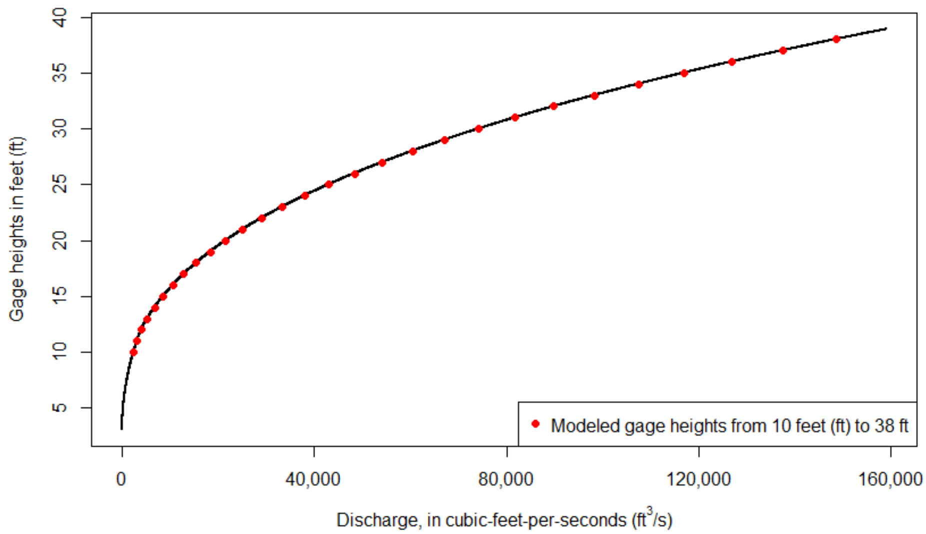

Figure 2 Stage-discharge rating curve at the U.S. Geological Streamflow gaging station 08178880 at Medina River at Bandera, Texas, with 29 modeled flow stages (gage heights) ranging from 10 feet to 38 feet.

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