XVIII International Conference on Water Resources
CMWR 2010
J. Carrera (Ed)
CIMNE, Barcelona 2010

THE EFFECT OF DATA DENSITY ON HYDRAULIC CONVEYANCE CALCULATIONS

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Key words: Hydraulic models, data density, conveyance, model predictions

Summary. The estimation of coefficients of roughness (**n**) for open channel hydraulics remains largely an art. In the absence of an adequate quantitative procedure, the ability to determine roughness coefficients must be developed through practice and experience. With the growing availability and increasing detail of high resolution geospatial data, it is necessary to examine the effect this will have on computed water surface elevations.

1 INTRODUCTION

Hydraulic modeling has advanced to multi-dimensional unsteady flow models that require geographic data that are several orders more dense than has been historically used. Widespread use of these models has only been possible due to significant advances in LiDAR, remote sensing, and GIS, which has provided the means to efficiently collect, manage, manipulate, store and display spatial data. Although modern models are more sophisticated, they still require the same flow equations and resistance to flow variables that were used in the 19th and 20th century to relate hydraulic geometry and boundary roughness to velocity [1].

Since dense data is relatively easy to obtain, it is assumed that the quality of any open channel model will be improved by using denser data. A preliminary assessment of this assumption indicates that denser data does not automatically lead to superior results because hydraulic conveyance is sensitive to spatial data density. Therefore, resistance to flow parameters must be varied based on data density. This finding has implications to all open-channel hydraulic computation because regardless of level of complexity, all hydraulic models rely on resistance to flow equations that are over a century old.

2 BACKGROUND

Regardless of the origin, flow equations relate discharge (or velocity) to a as a function of hydraulic geometry (i.e. depth, cross-sectional area, wetted perimeter) and boundary roughness [2, 3]. In even the simplest of channel geometries and flow conditions an analytical description of flow resistance has been elusive. After over a century and a half of a testing, study, conjecture, and argument, hydraulic modeling remains both art and science because of the empirical nature of determining flow resistance, and accounting for it in hydrodynamic models.

The Chezy and Manning equation are the most commonly used equations for turbulent open channel flow. In 1889 Robert Manning initially presented his monomial open channel flow equation (Eq. 1).

$$V = C\, S^{1/2}\, R^{2/3} \tag{1}$$

In this equation V is the velocity, S is the channel slope, and R is the hydraulic radius. Manning introduced C to account for the composition of the boundary [4]. The hydraulic radius represents the cross-sectional geometry of the flow divided by the wetted perimeter.

The evolution of the flow resistance factor, C, pre-dates Manning's equation by approximately 20 years. Eventually, C was replaced by 1/**n** where **n** was "Kutter's **n**". In the United States, **n** is referred to as "Manning's **n**". In 1869 Ganguillet and Kutter [5] proposed that roughness be represented by a single parameter that was a function of boundary roughness and hydraulic radius. These authors understood that overall resistance to flow varied as a function of hydraulic radius and roughness of the boundary. However, when they considered the variables (α and β) describing resistance to flow for an equation proposed by Bazin, Ganguillet and Kutter stated:

> "With regard to the coefficient α and β of M. Bazin's formula, we observe that there could be established between them, in connection with R, a relation remaining constant for all degrees of roughness, and thus rendering it possible to replace them by a single variable constant." [4]

These early researchers understood that the resistance to flow parameter (i.e. C or n) would vary with both boundary roughness and hydraulic radius, but advocated for using a resistance to flow parameter that was independent of R.

Ganguillet, Kutter, Bazin, Manning and others could not have envisioned the technological breakthroughs in physics, optics, and electronics that would lead to the ability to remotely survey channels and floodplains at sub-meter spatial resolution. Instead, their efforts were focused on steady-uniform flow in relatively small prismatic channels. For them, using a resistance variable that only varied with boundary roughness was reasonable. However, through the 20th and early 21st century the Chezy and Manning equations have been adapted to analyze of open channel flow of ever increasing size, and complexity.

3 LIDAR STATE OF TODAY

Light Detection and Ranging (LiDAR) is a remote sensing technique that provides high resolution elevation data with a vertical accuracy of +/- 0.09 meters on a 1 meter grid. The technology has been increasingly used open channel projects. Figure 3.1 presents a triangulated irregular network (TIN) build from LiDAR data gathered and processed for the Yellowstone River near Glendive, Montana.

Figure 3.1 Yellowstone River LiDAR (2006)

Cross sections with several hundred x-y data pairs each can be easily extracted from TIN's like Figure 3.1 to augment or replace existing surveyed cross sections for one-dimensional steady or unsteady models. Alternatively, the TIN's can be used by a mesh generation scheme to build a finite element mesh with several thousand elements for two-dimensional unsteady modeling. In most cases, modelers will not modify the resistance to flow parameters (**n**) based on data or mesh density. Given that the hydrodynamic modeling of today is far different than the parameters for which the fundamental flow equations were developed nearly 150 years ago, the usage of a single variable constant to describe resistance to flow requires reexamination.

4 CASE STUDIE / EXAMPLE

To illustrate the sensitivity to cross-sectional data density, a case study of Lone Tree Creek near Victoria, Texas is presented. An existing Federal Emergency Management Agency (FEMA) model contains approximately one x-y data pair for every 80 feet and is typical of FEMA models created in the 1980's using classical survey techniques. By comparison, the LiDAR cross-sections for this particular reach, contains approximately one x-y data pair for every 8 feet (Figure 4.1).

In Figure 4.1, the cross-sections derived from the LiDAR and surveyed data are nearly identical. For the evaluation, a total of four cross-sections (all essentially identical to the surveyed cross-sections) were updated with newly captured LiDAR data.

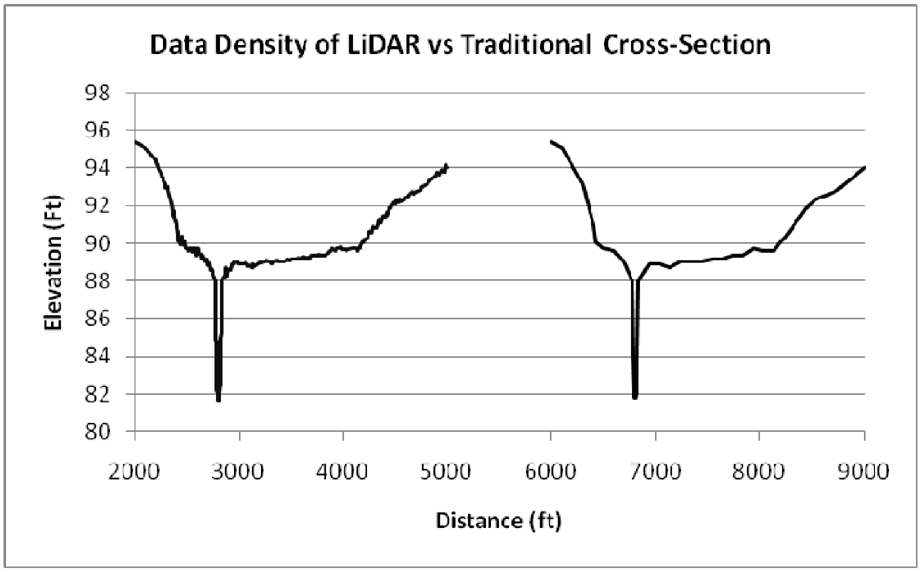

Figure 4.1 Comparison of LiDAR (left) and Surveyed (right) Cross-Section for Lone Tree Creek, Texas.

The two data sets were evaluated one-dimensionally in the HEC-RAS version 3.1.3. The two sets of data contained the same discharges, boundary conditions, reach lengths, and roughness coefficients. The overall length of the models were approximately 1500 feet. The results of the study indicated that the water surface elevations increased approximately 0.2 feet to 0.5 feet in the LiDAR cross-section model. As the hydraulic depth of the case study was approximately 12 feet, this indicates an increase in flow depth of 2% to 4%. As all other parameters were unchanged, the increase in water depth is attributed solely to the increase in data density.

5 CONVEYANCE vs DATA DENSITY

Consider two identical trapezoidal channels as depicted in Figure **5**.1. The channel on the left (Channel A) has approximately 300 data pairs in which sampling noise was simulated by randomly varying Y using a random number generator. The maximum amplitude of the noise was fixed using the variable +/- α. Geometric parameters (cross-sectional area, A, wetted perimeter, P and hydraulic radius, $R=A/P$, and $AR^{2/3}$) of this channel were computed and compared to a similar channel consisting of only 4 x-y data pairs (Figure 5.1) [6].

In Figure 5.2 the variability of the geometric parameters is presented as a percentage of the corresponding variables computed using the 4-point cross-section. The results show that although the cross-sectional area is not sensitive to the data density and vertical precision, the

$AR^{2/3}$ (conveyance at a constant resistance parameter) of the section deteriorates as the data density increases. The deterioration of the conveyance is solely attributed to the increase in wetted perimeter at higher data density.

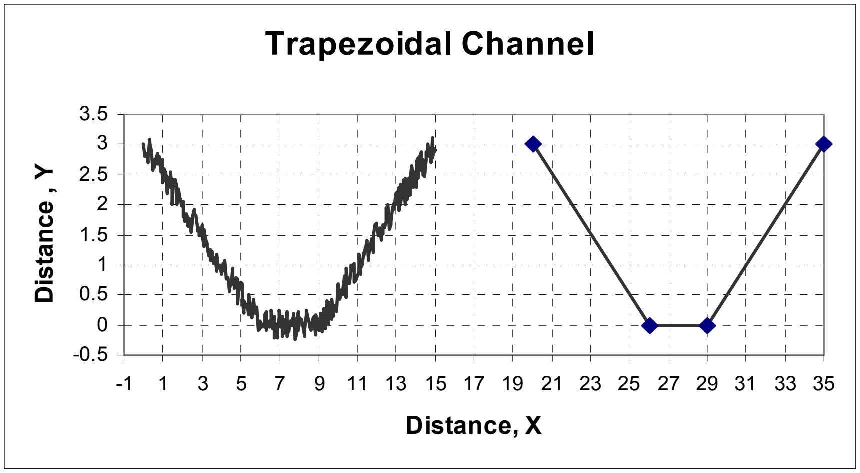

Figure 5.1 Identical Trapezoidal Sections With Different Data Density.

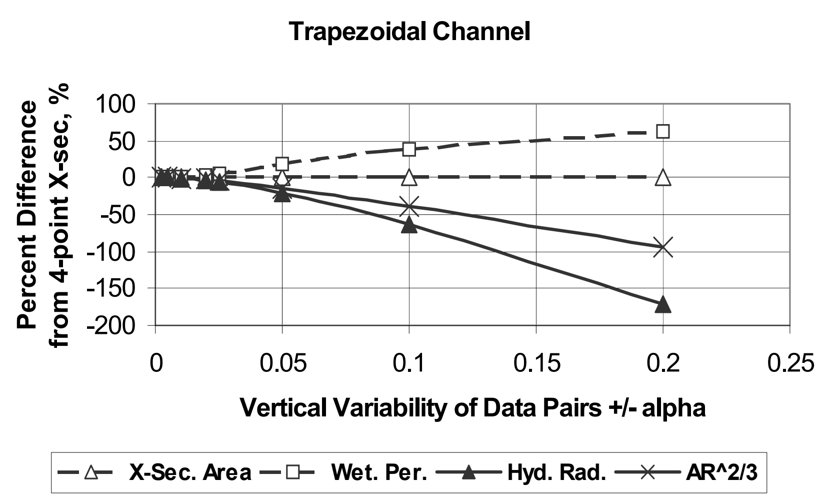

Figure 5.2 Variability of Hydraulic Parameters to Data Density and Vertical Precision.

Although this simple example illustrates how noise in dense sampling affects conveyance, the conveyance of a channel modeled using a sparse set of geometric data will always be larger than if a dense set of data was used to describe the geometry, even if an ideal “noiseless” dense data set could be obtained. For this ideal case, the wetter perimeter would still vary directly with the number of spatial data points.

The sensitivity illustrated in Figure 5.2 indicates that actual total conveyance of a section will decrease as the data density increases unless resistance to flow parameters are modified to compensate for the reduction caused by the increase in wetted perimeter. To maintain a constant conveyance at different data densities, the resistance to flow parameter would have to vary with the hydraulic radius R. This finding is consistent with the findings of Ganguillet and Kutter [5]. Otherwise, as was seen in Section 4, simulations using dense data will yield higher water surface elevations with lower velocities.

6 IMPLICATIONS TO MULTI-DIMENSIONAL UNSTEADY FLOW MODELS

Multi-dimensional unsteady models are becoming more and more common for floodplain and channel flow studies. Regardless of the numerical method, or the level of simplification of the momentum equation these models require assigning resistance parameters (typically Kutter's n) to relate flow velocity (or discharge) to hydraulic geometry, boundary roughness, and resistance to flow. Because of this, the need to adjust resistance to flow parameters with regard to data density cannot be ignored.

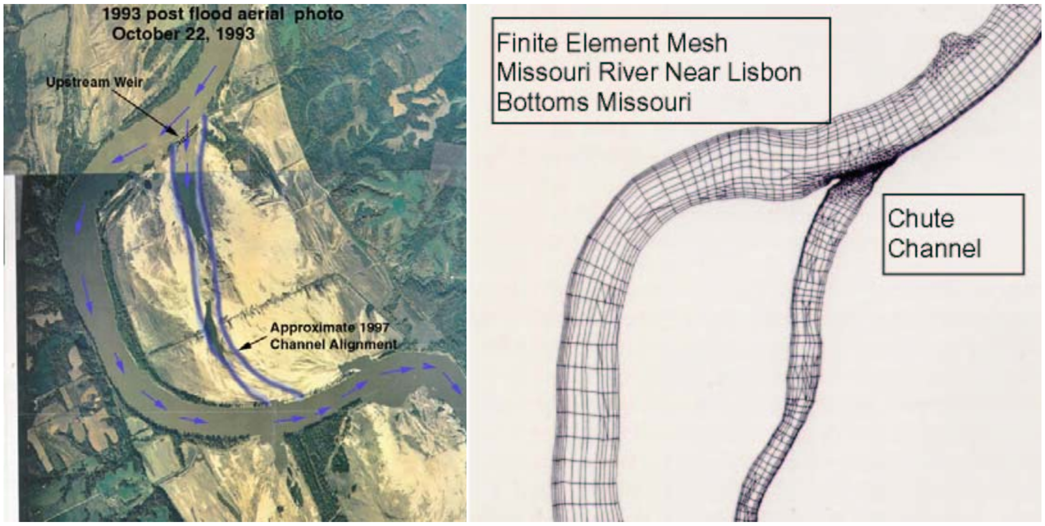

Figure 6.1 Lisbon Bottoms, Missouri and Finite Element Mesh

Figure 6.1 presents an aerial photo and the finite element mesh that was developed for the Missouri River near Lisbon Bottoms, Missouri. This model was developed to study the hydraulics near the entrance of a chute channel which enlarged as a result of the 1993 flood. As is typical of these studies the finite element mesh size varied from approximately 10 meters to as small as 1 m with the highest density of elements near the bifurcation of the river. At the time this channel was modeled (1995), no consideration of the affect of data density on the conveyance was considered. Given the considerations of this paper, it would have been more proper to vary the resistance to flow parameter (in this case Manning's or Kutter's n) in direct proportion to the size of the individual element.

In this case the mesh generator that was used did not have the ability to vary resistance parameters as a function of mesh size because no studies or methodologies currently exist to do this. Consequently additional research is needed to better understand how resistance parameters vary with mesh size, and model developers need to incorporate these findings into mesh generating software.

7 DATA FILTERING VS RESISTANCE PARAMETER MODIFICATION

The examples in Sections 3 - 5 lead to the issue of how models of differing data densities can be correlated, resolving scale and resistance to flow issues between models with dense and sparse data. Ideally, data filtering would modify the hydraulic variables consistent with Figure 5.2. As the data density is decreased (due to filtering) the cross-sectional area would remain constant and the wetted perimeter decreased. In this way the resistance to flow for the two models could be the same.

Data filtering of dense cross-sectional data was investigated for a research project funded by NASA in 2001 [6]. A floodplain model for Springfield, Missouri was remodeled by replacing the existing cross-sections with filtered dense data. The dense cross sections were obtained using a dual frequency portable differential GPS survey system.

Various schemes were investigated to filter the dense data. One method (denoted horizontal filtering) retained only those cross-sectional data points located a prescribed distance away from each other. This scheme let to a loss of specificity in the major breaks in grade. As the density decreased, the cross-sectional area deteriorated in a non-predictable manner and the conveyances between the two modes varied inconsistently from section to section.

Alternatively a filtering method that retained data pairs that deviated more than the average vertical variation from a moving mean was successful in significantly reducing the number of data pairs, while preserving the shape and cross-sectional area of the cross-section. This scheme also tended to preserve the original (dense data) wetted perimeter. Consequently, $AR^{2/3}$ increased by a modest 7% in contrast to the anticipated increase predicted by Figure 5.2. When the HEC-RAS simulations were compared from models built using the surveyed and for the filtered dense cross-sections, the model using the filtered data increased computed water surface elevations.

These results indicate that the vertical filtering preserved both the cross-sectional area and the magnitude of $AR^{2/3}$. Previous sections of this paper indicate that dense data will reduce overall conveyance and that denser data will result in larger water surface elevations unless resistances to flow parameters are modified. However, the findings in this section indicate that filtering of data can be achieved without significantly changing conveyance. Modifications to the resistance parameter may be needed if the source of a sparse data set is filtered LiDAR or GPS data.

8 SUMMARY AND CONCLUSION

This paper was written to foster a discussion of the appropriate methods to model steady and unsteady free surface flows where engineers are inundated with geometric data. For most of the history of water resources, obtaining geometric data has been time consuming, costly, laborious and often dangerous. Consequently, research and development of the 19th and 20th century focused on methods whereby reasonably accurate estimates of flow (depth, velocity) could be determined using the least amount of input data. This paucity of data paradigm underlies the development of all the fundamental flow equations (i.e. the Chezy and Manning equation) that are critical to computational water resources.

Older hydraulic engineers are astounded by the ease and speed in which high-quality dense geometric data can be assimilated into a hydraulic model. Younger engineers accept dense data sets as a matter of course. Both groups run the risk of assuming that more data will yield improved results. As illustrated in this paper, the idea that more-is-better is a fallacy. Modeling with dense data sets can produce superior results if it is clearly understood how hydraulic variables such as wetted perimeter and conveyance are affected by data density.

Research is needed to better understand how resistances to flow parameters are affected by geometric data density. Although interpolation and extrapolation methods are still important, there is need to develop means to filter and reduce the density of geometric data. This filtering must be carefully considered so that conveyance parameters are not significantly altered as a result of data filtering.

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