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1D VERSUS 2D MODELING IN HEC-RAS FOR A BRAIDED RIVER SYSTEM

Manthan Kumar[*1], **Panchami R**[*2], **Rishika Ranjan**[*3], **Sarvagya Chaudhary**[*4]

[*1,2,3,4]Department Of Civil Engineering Dayananda Sagar College Of Engineering,
Bangalore, Karnataka, India.

ABSTRACT

The use of 2D hydraulic models for the prediction of instream habitat has drawn a lot of attention, especially for complex hydraulic circumstances like those seen in braided rivers. It is generally believed that 2D models with higher spatial resolution and associated hydraulic modelling will provide more accurate forecasts of instream habitat. We apply a 1D model, two 2D models, and compare the predicted and measured water depths and velocities at two flows, as well as the anticipated habitat over a range of flows, to a portion of a braided river. The correlation between predicted and measured depths and velocities was higher for the 1D models compared to the 2D models. The subjectivity involved with 2D calibration and practical constraints on topographic characterization led to mistakes in anticipated water levels that might either cause braids to flow or cease flowing. Although there were discrepancies in the magnitudes, locations of maxima, and changes in gradient, all three models largely anticipated the same patterns in habitat (weighted useable area) variation with flow. Because there were as many discrepancies between the 1D and 2D habitat-flow relationships as there were between the two 2D models, the differences between the predictions of the 1D and 2D models could not be explained by the higher spatial resolution of the 2D models. The fact that they need more information does not automatically mean that they are better, and many scenarios do not call for the time and effort needed to create an effective 2D model. Their practical use is constrained by the challenge of obtaining sufficient and precise bed topography and the expertise needed to calibrate 2D models. The primary benefit of 2D models over 1D models is that, especially at high flows in braided rivers, they should be able to produce forecasts that are more accurate outside of the 1D models' calibration range. However, better calibration and validation approaches are needed.

I. INTRODUCTION

Models of instream habitat are used to forecast how the habitat will change as the flow varies and to help decide on an appropriate flow regime, typically focusing on the minimum flow needs. In order to estimate water depth and velocity for a range of flows, the habitat models first employ hydraulic models, after which they evaluate the habitat's compatibility for these flows. It is customary, although not always, to characterise the habitat's suitability in terms of water depth, velocity, substrate composition, and cover. From simple models based on hydraulic geometry to more complex ones based on 2D and 3D hydraulic equations, hydraulic models can be of varying degrees of complexity (Jowett, 1998). (Leclerc et al., 2003; Olsen and Stokseth, 1995; Pasternack et al., 2004).More complicated hydraulic models are now more readily available thanks to advances in computing power and accessibility, and the use of 2D hydraulic models for instream habitat studies has been encouraged (Leclerc et al., 1995). The type of hydraulic model that best fits a practitioner's needs and budget must be chosen. The spatial resolution of the models differs significantly; a hydraulic geometry model forecasts the mean cross-section depth and velocity, whereas a 1D model forecasts depth and mean vertical velocity at points across the river, a 2D model forecasts depth and magnitude and direction (X, Y) of mean vertical velocity at points, and a 3D model forecasts depth and magnitude, direction, and vertical distribution (X, Y, Z) of velocity at points. Three techniques can be used to estimate water levels in 1D models: the water surface profile (WSP) model, the "IFG-4" model, and MANSQ. A WSP approach uses mean cross-section geometry to predict water surface levels and is based on energy conservation. In great part, the "IFG-4" and MANSQ approaches are empirical. The former uses a stage-discharge relationship established from a log-log fit to calibration stage and discharge observations to forecast water surface levels. The latter calculates the stage-discharge relationship for each cross section using Manning's equation after using calibration measurements of stage and discharge to estimate the relationship between Manning's N and discharge. Utilizing water levels and conveyance, it is possible to forecast the transverse distribution of velocity for each of the three approaches (Milhous et al., 1989; Mosley and Jowett, 1985).

II. METHODOLOGY

Many of the east coast rivers of the South Island It flows through the hill region in a single channel, then braids when it crosses plains. After examining the river from the air, a study reach in the braided part was chosen. The braided nature of the reach was the primary criterion for selection, and the number of braids and total water surface width in the selected reach was about average for the section of river considered in the study.

Access and the necessity for the reach to have a single thread at its upstream end to facilitate 2D modeling were also taken into consideration. The study site's basin size is 1640 km2, with mean annual low flows of 19 m3/s and a mean flow of around 70 m3/s. There were between one and five braids, with an average of three. The reach measured 1295 meters downstream and 600 meters across the stream, with a gradient of 0.05 and an average water surface width of 71 meters. The flow throughout the three days of the survey ranged from 26 m3/s to 45 m3/s.

Using the Wolman (1954) approach, a surface substrate sample was taken, and at least 100 clasts were graded using a standard template with square holes spaced at half-phi intervals from 8 mm to 256 mm. The armor size (d84) was 72 mm, while the median particle size (d50) was 23.5 mm. A 1D survey (2.2). Along the study stretch, we created 24 transects for the 1D model at roughly 50 m intervals (Fig. 1). Each transect contained one to five distinct channels. For the sake of the 1D model, each stream channel that the transect intersected was then considered as a single cross-section. To ensure that the model's assumption of linear interpolation between points was true, water depths, velocities, and substrate composition were recorded at intervals (0.3-2 m) across the cross-section, with extra measurements at abrupt changes in bed level and/or water velocity. The transects' average point spacing was 1.6 meters. In order to locate the cross-sections for upcoming calibration and validation experiments, they were marked. For the 1D method used here, measuring stage multiple times at various flows is necessary to collect enough data to establish stage-discharge connections. To establish correlations between braid flow and overall river flow in a braided river like this one, it is also important to monitor the flow in each individual braid. It could be challenging to create precise stage-discharge curves if there are significant floods that alter the bed topography between measurement dates.

2D-Survey

The 2D model's river bed topography was measured using a survey-grade global positioning system (GPS). Elevations were measured at least every meter laterally and roughly every 4 meters longitudinally in water shallower than around 0.4 m. Since the river is quick, wading deeper than 0.4 m proved dangerous, especially if you were hauling pricey GPS equipment. Data of elevation included high points like riffle controls and were spaced apart so that linear interpolation between measurements would provide an accurate depiction of the topography of the bed. Deeper areas of the riverbed were monitored using GPS-located echo-soundings from either a dinghy or a jet boat. Points were recorded at least every meter across transects situated at changes in river grade, with a maximum distance of around one channel width between transects. The elevation accuracy ranged from 27 to 41 mm. The locations and bed elevations were measured by wading and boating at an average rate of one measurement point per 0.23 m2 for the bathymetric data. 23 measurement points were found for every 100 m2 of water surface area, or 2048 points for every 100 m of river length, on average. Although in this study, flow predictions were made at flows lower than those at which the survey was carried out, additional points above water level were obtained from an aerial photogrammetric survey (scale 1:4000) to enable predictions to be made at flows higher than those at which the survey was made. The specified standard error in elevation for the digital photogrammetry was 0.15 m, and the point density was >1 per m2

Calibration and validation measurements.

On two separate occasions, when the flows were 19.7 and 12.8 m3/s, respectively, and 9 and 17 days following the initial survey, calibration and model validation measurements were made on a declining hydrograph. For information on water levels and flow in each channel, as well as to give depth and velocity data for model validation, these observations included water depth and velocity measurements over specified transects. The

1D model was developed and validated using the stages and discharges in each braid, but not the depths and velocities.

A 2D model River2D and Hydro2de were both utilized as 2D models. A standard 1 m2 grid for Hydro2de was derived from the topographic information. With the flow variables positioned at the cell center, Hydro2de uses finite volume techniques to solve the depth averaged shallow-water equations for a grid. The model's ability to remain numerically stable in the presence of supercritical flow is one of its features. Connell et al. and Beffa and Connell (2001) both provide descriptions of the model (2001). The size of the triangular elements was changed to reduce disparities between the elevations of the triangular element and bed for River2D using a finite element method with a variable-size triangular grid. Since there was no discernible fluctuation in the bed's main small cobble composition throughout the reach, only one roughness parameter was used. Despite the fact that the substrate composition was recorded at each measurement point for the 1D surveys, the transects were too far apart to use those data to precisely map the bed composition for the 2D model.

It's feasible that a better calibration would have resulted from local or zonal roughness variation. Within conceivable boundaries, the outputs were unaffected by the choice of roughness value. This is due to at least two factors: first, the flow is only impacted by roughness values to the power of 1/6; and second, the depths and speeds of pools and run segments affected by backwaters are not directly impacted by the roughness of the underlying bed. By adjusting the roughness parameters, the models were calibrated until there was satisfactory agreement between the measured and anticipated depths and velocities. Additionally, braiding patterns captured on camera at flows of 14 m3/s and 40 m3/s were contrasted with those predicted. In a few spots along the reach, where data were scant or bank limits were overlooked, there were abnormal depths or flow patterns. In order to fix these errors, the topographic data were modified. The failure to capture enough detail of the bed morphology during the field study is the most likely reason for flaws in the model.

1D Model

The "IFG-4" model (Milhous et al., 1989), where stage-discharge relationships were constructed for each channel, was comparable to the 1D model. Assuming that the change in depth indicated by the stage-discharge curve applies across the cross-section, water depths were estimated across the channel, and velocities were predicted from the distribution of conveyance over the cross-section (Mosley and Jowett, 1985). The measured water level and flow in each channel—specifically, the water level and flow at the time of the survey and the water levels and flows for the two sets of water level calibration measurements—were used to fit the stage-discharge relationships. RHYHABSIM's survey methods and analysis don't presume that cross-sections are parallel to the flow (although they usually are). The current directions, however, are thought to remain constant with flow. It is not necessary for the water surface to be horizontal across the cross-section, and when water depths rather than bed elevations are used to define the cross-section, it is believed that the same change in water level with flow takes place throughout the whole cross-section. By creating logarithmic relationships between the flow in the channel and the entire river flow and fitting curves using survey and calibration measurements of the channel and total river flow, RHYHABSIM (Clausen et al., 2004) expands the traditional 1D technique to braided river channels. In order to forecast the water level for a given river flow, one must first calculate the flow in a channel for that flow and then apply the stage-discharge relationship for the channel to do so. In order to forecast the water level for a given river flow, one must first calculate the flow in a channel for that flow and then apply the stage-discharge relationship for the channel to do so. Although the composition of the substrate was determined visually at each measurement point, the habitat analyses were conducted under the assumption that the entire substrate consisted of small cobbles. This made any habitat study comparable with 2D habitat analyses. Despite the fact that the substrate was recorded for each measurement site, the distance between the measurement cross sections—about 50 m—made it impossible to adequately map the bed for 2D modeling.

Hydraulic and habitat prediction

The predicted depth and velocity along transects at flows of 19.7 and 12.8 m3/s and the actual values at those flows were compared. The expected depth and velocity at each validation measurement point were determined using linear interpolation, and the observed cross-sections for both the 1D and 2D models were graphically aligned with the projected cross-sections. Because the validation data were generally but not precisely positioned on the 1D survey transects, longitudinal interpolation was only necessary for 2D survey data, giving the 1D survey an advantage in the comparison. As indicators of how well the predictions fit the data, the average absolute error and correlation coefficients (r2) were determined. The three hydraulic models were used to predict each weighted usable area (WUA) for a variety of New Zealand fish and invertebrate species for flows of 5–50 m3/s. The criteria for determining habitat suitability made the assumption that marginal habitats would receive intermediate values instead of the full weight of ideal habitat, which would receive a weight of 1. Cobble and gravel substrates were thought to be excellent and had no bearing on how WUA was calculated. To analyze the similarities in the shape of the associations as well as the magnitude of predictions over the estimated flow range, relationships between WUA and flow for the three models were examined.

III. RESULTS

The 1D survey needed more survey work (22 person days) than the 2D survey (12 person days), however the 1D model application required less overall effort when the analysis effort was taken into consideration. The first field survey collected 1626 data points for 24 transects across a 1295 m reach, and the succeeding calibration surveys collected measurements of stage at each transect and discharge in each braid. These measurements made up the data for the 1D model. A 42KB file contains the topography and model calibration data. The 2D topography data, on the other hand, consisted of >670,000 irregularly spaced measurement points that were used to create 784,080 one-meter square grid elements for Hydro2de and 46,915 variable-size triangle components over an irregular region of 170,500 m2 for River2D, respectively. Because data points were gathered along the same cross-sections, the 1D survey's depth estimates and cross-section profiles closely matched the validation data (Fig. 2). It should come as no surprise that there was less agreement between 2D depth estimates and cross-section profiles and the validation data, with the 2D profiles being generally smoother than the field measurements (Fig. 2). Despite using the same fundamental topographical data to create their grids, the River2D and Hydro2de cross-section profiles were substantially different. The 2D model representation and the comparison with the validation data may have been enhanced if the cross-section data were included in the 2D topography. Since the 1D survey measured water depths rather than elevation at each measurement site, these data could not be integrated.

IV. DISCUSSION

We experienced practical challenges in accurately describing the bed topography and calibrating the models for the work that is detailed here because it was a realistic field investigation. During the survey work, a fresh flood occurred with a maximum flow of 63.5 m3/s compared to a mean flow of 52.6 m3/s and a mean annual flood of 525 m3/s. Variable River flow made calibration of the 1D model more challenging and uncertain, but it had no effect on the 2D topographical survey because the freshness was too small to alter the bed morphology. The accuracy of the topographic and hydrographic fieldwork, as well as the calibration of the model, will determine the quality of the results in any hydraulic model. This is especially true for 2D models, where estimates of depth and velocity are significantly more accurate when the topographic model is accurate. In braided rivers, where the elevation of the water surface at a flow divergence will decide whether a braid is flowing or not, the accuracy of the topographic data and calibration of the 2D model are particularly crucial. In particular, for velocity, the 1D model demonstrated higher agreement between prediction and validation data than the 2D models. The braid flows and water levels in the channels were determined in the 1D model using empirical relationships established from validation data (the stages of which were also utilized for calibration). There was a 3-6% overestimation of depth and a 10-11% underestimating of velocity when these equations were applied to predict depths and velocities during validation flows. We would have anticipated greater 1D model calibration and subsequent increases in prediction power if flows had remained constant throughout the initial survey. In the 2D models, the calibration procedure was essentially an iterative, subjective process that established the value of bed roughness from the best overall fit to observed water levels. To enhance forecasts, we did not try to locally modify bed roughness. In research conducted in the Kananaskis River, 2D (River 2D) fish habitat estimates were compared to those of a 1D model, according to Katopodis (2003). Gard (2009) compared the predictions of the Physical Habitat Simulation System (PHABSIM) and River2D instream flow habitat models for spawning habitat and discovered that there was little difference in the habitat-flow relationships predicted by the two models. However, Gard came to the conclusion that River2D should be used instead of PHABSIM because it can model complex flow conditions that cannot be simulated with PHABSIM. In a subsequent discussion, Gard, 2010; Gard (2010) noted that with more experience and better topographic definition (at least 40 points/100 m2), he was able to obtain velocity correlations ranging from 0.64 to 0.82, which is slightly less than what we achieved in this study (r = 0.23 and 0.46, respectively). He also noted that with more experience and better topographic definition (at least 40 points/100 m2), he was able to obtain velocity correlations. In a 50 m stretch of the Bere Stream, Booker et al. (2004) created a 3D model and found that the anticipated and measured water surface elevations had excellent agreement (average absolute error = 0.003 m), while the predicted and observed velocity profiles had fair agreement (r2 = 0.69). The errors in velocity prediction of the 2D and 1D models have been shown to be similar in the gravel bed rivers of New Zealand. Mosley and Jowett (1985) used a 1D model of the Ashley River to forecast depths to within 0.03 meters and speeds with an average absolute error of roughly 0.15 meters per second at flows ranging from 14.4 m3/s to 0.083 m3/s. Duncan and Hicks (2001) discovered average absolute depth and velocity errors of 0.063 m and 0.18 m/s in a 2D model of the Rangitata River.

V. CONCLUSION

We can summarize that 2D model is more relevant and useful as compared to 1D model. Having said that, there are still numerous situations in which it will be strongly disputed whether or not utilising a 1D or 2D modelling method for a particular application will be relevantly accurate. There are several factors to take into account in addition to the simple question of "should I solve the entire Saint Venant equations in one dimension or two dimensions?" I think there are both tool gaps and knowledge gaps in terms of knowing when to use 1D versus 2D. I think that in the near future, combining 1D/2D models will be crucial to our modelling efforts. The hydraulic modelling tools require improvement in this area. It holds the opinion that hydrologic modelling, which frequently includes sizable portions of untapped areas where little to no calibration could be done, and poor rainfall estimation, both spatially and temporally, are the main causes of the majority of uncertainty and the inability to accurately forecast stages and flows in river systems. When compared to variations resulting from using 1D or 2D models, this can frequently be a considerably bigger factor in forecasting or modelling mistake.

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