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RESEARCH PAPER

Comparison of Two- and Three-Dimensional Flow and Habitat Modeling in Pool–Riffle Sequences

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Abstract
Pool–riffle sequences are common bed forms in mountain rivers that have a significant effect on hydraulic and hydro-environment characteristics. Relatively few studies exist on the comparison of two and three dimensional modeling for bed forms in gravel channels. In this paper, flow structure and habitat modeling are performed in an urban river, by a two-dimensional depth-averaged finite element and a three-dimensional control volume model. Comparison of results showed that predicted velocities by SSIIM are lower than measurements data, while River2D simulations are at the same of measured magnitude. By comparing River2D-simulated shear stress and field data, we observed that estimated data are representative of field data, while the magnitude may be over-predicted compared with three-dimensional modeling. Habitat modeling showed maximum used area for River2D velocity modeling. In contrast, SSIIM simulations overestimate the depth of used area values in comparison with River2D.

Keywords Habitat modeling · Pool–riffle · Shear stress · Two- and three-dimensional modeling · Velocity

1 Introduction

Human activities, such as urbanization and wastewater treatment, have significantly altered the flow regime and channel dynamics such as river bed forms. Pool–riffle sequences are known as bed forms that normally occur in gravel-bed rivers. Despite a lack of spatially distributed hydraulic field observations, hydraulic-based theories have been formulated that seek to explain pool–riffle maintenance. Of these theories, a reversal in hydraulic conditions between pools and riffles arising from increasing discharge is the most common. Various forms of hydraulic reversal have been suggested, including water surface slope (Keller 1971; Caamaño et al. 2009); near-bed velocity (Carling 1991; Carling and Wood 1994); mean velocity (Keller and Florsheim 1993); and shear stress (Lisle 1979).

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Pool–riffle sequences are a fundamental component of the fluid–sediment interactions that control sediment transfer and deposition in rivers (Richards 1976; Carling 1991; Tonina and Buffington 2011). In some studies, researchers provided information on the distributions of mean velocity and turbulence intensity in large scale bed forms (MacVicar and Roy 2007a; Caamano et al. 2010; MacVicar and Rennie 2012). It is demonstrated that lateral flow convergence occurs despite the absence of lateral topographic variability. Also, Caamano et al. (2010) analyzed three-dimensional hydraulic simulations and field observations for two self-formed pool–riffle sequences. A model is used to visualize the spatial pattern of jets through the study reach. Also, coherent turbulent flow structures in large-scale bed forms is considered by some researchers (MacVicar and Roy 2007b; MacVicar and Rennie 2012).

The maintenance of pool–riffle sequences is an important topic, since engineers create the artificial pool and riffle habitats in laboratory scale (e.g., MacVicar and Rennie 2012; Fazlollahi et al. 2015a, b; Najafabadi et al. 2018), or to manipulate environmental flows to flush sediment out of existing pools (Arthington et al. 1999; Rutherfurd 2000). To investigate pools and riffles structures, it is necessary to understand the hydraulic and sediment transport processes in 2D and 3D flows (Moir et al. 2009; Caamaño et al. 2009; Tonina and Buffington 2011). Pools are important and essential for various aquariums. MacWilliams et al. (2006) showed that flow convergence in pools serves to transport sediment across the point bar rather than through the deepest part of the pool, while secondary currents in the pool cross section may cause transport of the fine particles in the deepest part of the pool.

In addition to flow structure investigations, habitat studies are attracted by many researchers (e.g., Moir et al. 2009). In traditional habitat modeling, distribution of flow depth and velocity is typically estimated using one-dimensional modeling techniques. One of the most common 1D techniques, PHABSIM, has been used by many scientists such as FAO (1998) and Michael et al. (1999). However, 1D habitat models neglect transverse flow and eddies, which are important components of the flow field and physical habitat. Accordingly, a 2D model is used for better understanding and predicting the aquatic habitat. This has been ascertained by many researchers such as Gard (2003), Lorangerand and Kenner (2004), Darby and Van de Wiel (2003) and Mussetter et al. (2004). Two-dimensional models simulate depths and velocities in complex channels more accurately than PHABSIM because they take into account local bed topography and roughness and use mechanistic processes (conservation of mass and momentum), rather than the Manning's formulation and an empirical velocity adjustment factor (Leclerc et al. 1995).

With respect to all of these previous researches, not only one- and two-dimensional, but three-dimensional hydrodynamics model have been adapted. In this paper, we evaluate whether the two-dimensional model used, River2D, is better than three-dimensional model, SSIIM, at predicting flow and habitat characteristics.

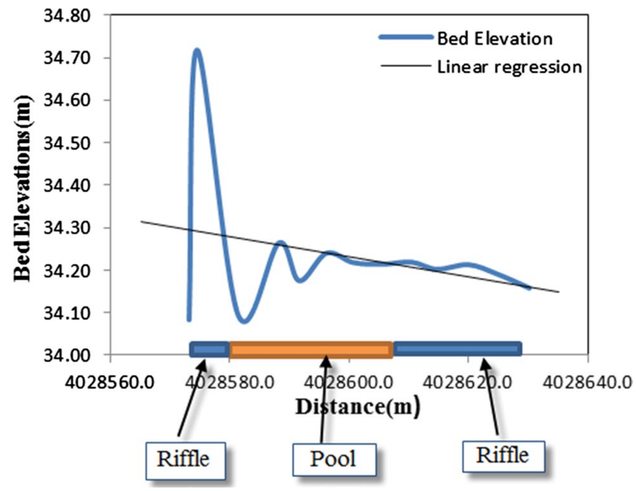

Fig. 1 Pool and riffles within a bed profile

Table 1 A summary of the channel characteristics

Attributes of channel reach	Approximate physical dimensions
Channel-bed gradient[a]	0.3%
Reach length	70 m
Pool width	19.40
Pool length	26
Maximum pool depth[a]	0.51
Riffle width	18.42
Riffle length	22

[a]Measured along the thalweg

2 Field Site and Measurements

2.1 Field Site

The field site for this research is Babolroud River, which is located in north region of Iran. The longitude location is 52°, 39′, 30″, latitude location is 36°, 43′ and the length of this river is approximately 78 km. Two approximately straight reaches (70 m) of this river were selected for study. Figure 1 shows a view of the position of pool–riffles in the centerline profile. Table 1 gives a summary of the channel characteristics. The site has no bed vegetation although short grass is present on the riverbanks.

2.2 Field Measurements

2.2.1 Channel Topography

The primary data used in the flow modeling include river topography, grain size, and field measurements of depth and velocity at a known discharge. Capturing the three-dimensional topography allows for fine-scale flow calculations, which is especially important in channels with rough boundaries. Detailed topography was collected with a total station surveying system in a 1 m × 1 m grid, including 2601and 2530 measurements over two reaches. Average point density over each region was approximately 2 points/m^2.

Each measurement was carried out under suitable accuracy of instrument. The sources of errors in this field wok are surveying river topography, the velocity measurement, the flow depth measurement, and the measurement of grain size of the river bed. The accuracy of Total station camera for surveying the topography of river is 1.7 s. The butterfly current meter has the accuracy of ± 1 mm/s. The measurement of depth by a rod is also a source of error with the accuracy of ± 1 mm. The measurement of grain size having an accuracy of ± 0.1 mm is a source of error. Considering these sources of errors, the authors conducted the experimental task to collect data with the minimum error.

Pool and riffle features including the longitudinal slope of pool in the entrance and the exit of each reach, and the side slopes of pools and riffles were measured by surveying the selected reaches in Babolroud river. Also, the distribution of grain size was determined for all cross sections at different distances from the river banks.

2.2.2 Hydraulic Data

Hydraulic data were measured at 13 and 15 cross sections over the first and second reach, respectively. At each section, depth and velocity profiles were measured at five distances from the right river bank. Depth was measured with a rod in all sections. Velocity readings were measured at each profile from the bed to the free surface water using a butterfly current meter with horizontal axes. The distance between measurement points was 1 cm in the 20% depth near the bed and 2–3 cm in the upper 80% depth. Values for velocity in each point were recorded as sixty seconds at three iterations.

There were some limitations for this study, including the water depth and river discharge measurements, where the bed material has a non-uniform distribution. The application of butterfly current meter is 3 cm above the bed, therefore, some velocity data may not be collected very near the river bed. Scatter of sediment particles and irregular variation in bed forms makes it difficult to measure velocity near the bed along the river.

2.2.3 Sediment Data

The distributions of grain sizes were measured in this study using a method of random pebble count (Wolman 1954). Three separate measurements of grain sizes were conducted along each transect located in the reaches. Results from the sediment count are reported in Table 2. Based on this data, the coarsest particles were found on the downstream riffle, with a d_{50} value of 58 mm. Bed material in the pool exit ranged from 16 to 95 mm with a d_{50} of 35 mm. The pool center and pool exit have similar median grain sizes, while the coarse fraction (d_{90}) in the pool center is nearly 1.5 times the value of the pool exit.

2.3 Hydraulic Modeling

The 2D numerical model was found to be very useful and effective in comparison with the 1D model, especially for spatially distributed phenomena, such as patterns of sediment erosion and fish habitat quality under low discharge (Clark et al. 2006; Brown and Pasternack 2008). Two and three flow modeling has only been compared for advantages and disadvantages by a few scientists (Dominikus 2010). However, there was no comparison between 2 and 3D modeling in habitat structures.

2.3.1 River2D

River2D (Steffler and Blackburn 2002) is a two-dimensional hydrodynamic and fish habitat model that solves the depth-integrated form of the St. Venant equations, using a finite element code. The River2D model uses a Boussinesq-type eddy viscosity formulation for modeling depth-averaged transverse turbulent shear stresses. Input data include channel bed topography, bed roughness, transverse eddy viscosity, and initial flow conditions. The initial values of bed roughness for the River2D model were set equal to five times the midpoint of the substrate range, e.g., a substrate range of 1–5 cm would have an initial bed roughness of 0.2 m (3 cm × 5). Five times the average particle size is approximately the same as 2–3 times

Table 2 Grain size distributions

First reach	D_{16} (m)	D_{50} (m)	D_{84} (m)	Second reach	D_{16} (m)	D_{50} (m)	D_{84} (m)
Section A	0.019	0.029	0.048	Section A′	0.020	0.029	0.047
Section B	0.017	0.030	0.052	Section B′	0.021	0.032	0.049
Section C	0.027	0.043	0.065	Section C′	0.023	0.035	0.058
Section D	0.034	0.058	0.084	Section D′	0.016	0.044	0.059
Section E	0.023	0.037	0.071	Section E′	0.030	0.038	0.060
Section F	0.022	0.030	0.048	Section F′	0.019	0.027	0.041
Section G	0.028	0.040	0.053	Section G′	0.021	0.033	0.052
Section H	0.025	0.035	0.053	Section H′	0.028	0.041	0.068
Section I	0.023	0.030	0.054	Section I′	0.029	0.043	0.064
Section J	0.026	0.039	0.056	Section J′	0.023	0.035	0.054
Section K	0.026	0.037	0.051	Section K′	0.019	0.028	0.044
Section L	0.025	0.040	0.072	Section L′	0.017	0.034	0.051
Section M	0.026	0.041	0.073	Section M′	0.021	0.030	0.053
–				Section N′	0.023	0.034	0.055
–				Section O′	0.020	0.030	0.045

the d_{85} particle size, which is recommended as an estimate of bed roughness height (Yalin 1977; Yen 1991; Julien 2010). The values of all other hydraulic parameters in River2D model were left at their default values (up winding coefficient = 0.5, minimum groundwater depth = 0.1 m, groundwater transmissivity = 0.1 m^2/s, groundwater storativity = 1, and eddy viscosity parameters epsilon1 = 0.01 m^2/s, epsilon2 = 0.5 m^2/s and epsilon3 = 0.1 m^2/s).

2.4 SSIIM (Simulation of Sediment Movements in Water intakes with Multiblock Option)

The utility of three-dimensional CFD (3D-CFD) applications can be enhanced by demonstrating the sensitivity of predictions to changes in the grid resolution (Hardy et al. 1999) and flow resistance (Nicholas 2001). For example, Booker (2003) demonstrated grid dependence experiments for CFD predictions for habitat assessments during high flows. The CFD code used for this investigation was SSIIM 2 (Olsen 1996). The model has been applied to a number of engineering situations for example simulation of flow dynamics in a river with large roughness elements (Olsen and Stokseth 1995).

In this research, we used SSIIM 2 which uses an unstructured grid. This program solves the Navier–Stokes equations using the control volume approach with the SIMPLE (Semi-Implicit Method for Pressure Linked Equations) algorithm and the k-ε turbulence model.

$$\frac{\partial U_i}{\partial t} + U_j \frac{\partial U_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial}{\partial x_j}\left(P\delta_{ij} + \rho\overline{u_i u_j}\right) \quad (1)$$

Symbol notation is given in Table 3.

The Navier–Stokes equations for turbulent flow in a general three-dimensional geometry are solved to obtain the flow velocity. The k–ε turbulence model is used for calculation the turbulent shear stress. The eddy–viscosity concept with the k–ε model is used to model the Reynolds stress term as illustrated in Eq. 3 (the first term on the right-hand side forms the diffusive term in the Navier–Stokes equation):

$$-\overline{u_i u_j} = \nu_T\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right) - \frac{2}{3}k\delta_{ij} \quad (2)$$

The k–ε model simulates the eddy–viscosity as:

$$\nu_T = C_\mu \frac{k^2}{\varepsilon} \quad (3)$$

where k is kinetic energy as defined by:

$$k \equiv \frac{1}{2}\overline{u_i u_j} \quad (4)$$

k is modeled as:

$$\frac{\delta k}{\delta t} + U_j\left(\frac{\delta k}{\delta x_j}\right) = \frac{\delta}{\delta x_j}\left(\frac{\nu_T}{\sigma_k}\frac{\delta k}{\delta x_j}\right) + P_k - \varepsilon \quad (5)$$

where P_k is given by:

$$P_k = \nu_T \frac{\partial U_j}{\partial x_j}\left(\frac{\partial U_j}{\partial x_i} + \frac{\partial U_i}{\partial x_j}\right) \quad (6)$$

And ε is modeled as:

$$\frac{\partial \varepsilon}{\partial t} + U_j\frac{\partial \varepsilon}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\frac{\nu_T}{\sigma_\varepsilon}\frac{\partial \varepsilon}{\partial x_j}\right) + C_{\varepsilon 1}\frac{\varepsilon}{k}P_k - C_{\varepsilon 2}\frac{\varepsilon^2}{k} \quad (7)$$

A SSIIM run should be started by reading input files. The program can produce many of the input files by itself. Most of the files are only used for special purposes. Two main input files are present when the program starts.

There is no grid sensitivity in SIIM 2. The grid sensitivity in SIIM 1 is related to regular mesh which is not suitable for the present study. However, the authors made an effort to present correct data and results by controlling all sources of errors.

2.5 Habitat Modeling

One of the goals of this study is to model fish habitats in an urban stream. To determine the suitability of the hydraulic environment, we modeled the hydrodynamics of each site by two and three-dimensional models. Bed topography, bed roughness, and substrate distribution data were entered into River2D to create hydraulic models. Also, habitat suitability curves are used in model to translate hydraulic and structural

Table 3 Notation for SSIIM numerical symbols

C_μ $C_{\varepsilon 1}$ $C_{\varepsilon 2}$ = constants in k–ε model	ν_T = turbulent eddy viscosity
k = turbulent kinetic energy (per unit mass)	x = 3d coordinate
P = pressure	ε = dissipation rate for k
P_k = term for production of turbulence	∇ = gradient operator (δ/δ_x, δ/δ_y)
t = time	δ_{ij} = Kronecker delta
U = average velocity	ρ = density
u = fluctuating velocity	σ_k, σ_ε = constant in the k–ε turbulence model

elements of rivers into indices of habitat quality called combined suitability indices, calculated as the product of the depth, velocity, and substrate suitability. On the other hand, bed topography distribution data and discharge value were entered into SSIIM.

The key differences between the models tested are that SSSIM is a three-dimensional model which simulates velocities using Navier–Stokes equations, while River2D is a two-dimensional model that simulates velocities using conservation of mass and momentum. During the habitat calculations, substrate is assigned to each River2D node based on the nearest substrate data point in the channel index file (either longitudinally or laterally), while SSIIM, with longitudinal cells, assigns substrate values based on the nearest vertical longitudinally.

3 Results

In this section we focus on the data set collected in one of the reaches in Babolroud river. In this reach, bed topography was measured at 2601 positions on the bed chosen to describe changes in topography. Figure 2 illustrates the computational grid used to simulate flow at the site. For River2D modeling, there were 609 nodes, 1004 elements in the mesh area, and mesh quality index was 0.35. It is notable that, the River2D model used a triangular irregular network (TIN) grid (Fig. 2a). On the other hand, for the SSIIM program this grid comprised 16,874 cells, 81 in the streamwise, 30 in the cross-stream and 11 non-equally spaced in the vertical dimension (Fig. 2b).

As for Fig. 3, it illustrates the discrepancies between bed topography measured (Fig. 3a), the topography that was set as a boundary condition for River2D program (Fig. 3b) and the topography that is applied for SSIIM model (Fig. 3c). The majority of points are represented in two models with a good accuracy in comparison of field measurements. Some little differences (0.07 m) in the beginning reach may be because of that simulated secondary circulation in this pool has a realistic form but that the discrepancies between topography caused it to be slightly lagged. Overall, model simulations replicate the observed hydraulics, although with discrepancies.

3.1 Model Calibration

Calibration of computer simulations with observed field data is an important step in the modeling process. Model calibration was performed using field measurements of depth, velocity, and water surface elevation. Comparison of calculated and observed water surface elevations was performed for a discharge of 6.09 m^3/s. Least squares linear regression for measured and predicted values of water surface elevation on all points produced an R^2 value of 0.74. Reasonable agreement exists between measured and predicted for depth and velocity data, demonstrated by an R^2 of 0.91 and 0.70 respectively.

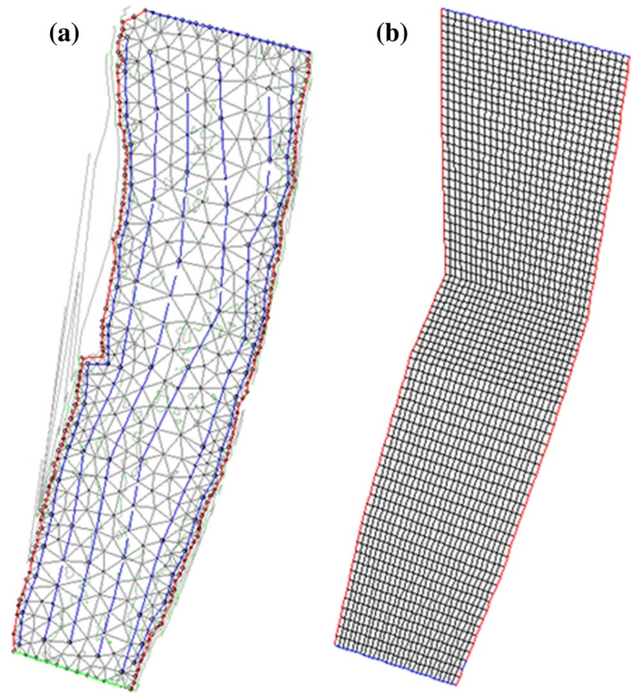

Fig. 2 Computational grid for **a** River2D, **b** SSIIM

3.2 Velocity

During the discharge 6.09 m^3/s, peak velocity of 1.12 and 0.88 m/s is found at the pool head and pool center, respectively, while the maximum velocity over the riffle is estimated at approximately 0.7 m/s (Fig. 4a). Simulations showed convergent flow is concentrated through the pool, creating a maximum velocity at the pool head (Fig. 4b). Lateral flow convergence occurs despite the absence of obstruction and is a by-product of flow deceleration rather than acceleration. Strong flow divergence can be seen on the pool exit. Flow entering the riffle showed divergent velocity contours but highly variable velocity vectors in response to irregular local topography.

Comparison of velocity contours showed that flow structure modeled by two-dimensional program (River2D) had the best consistence with measured data. Also the maximum velocity is about 1.1 m/s, and it occurs in the pool head for two cases. It is demonstrated that the high-velocity core is steered by the channel topography. On the other hand,

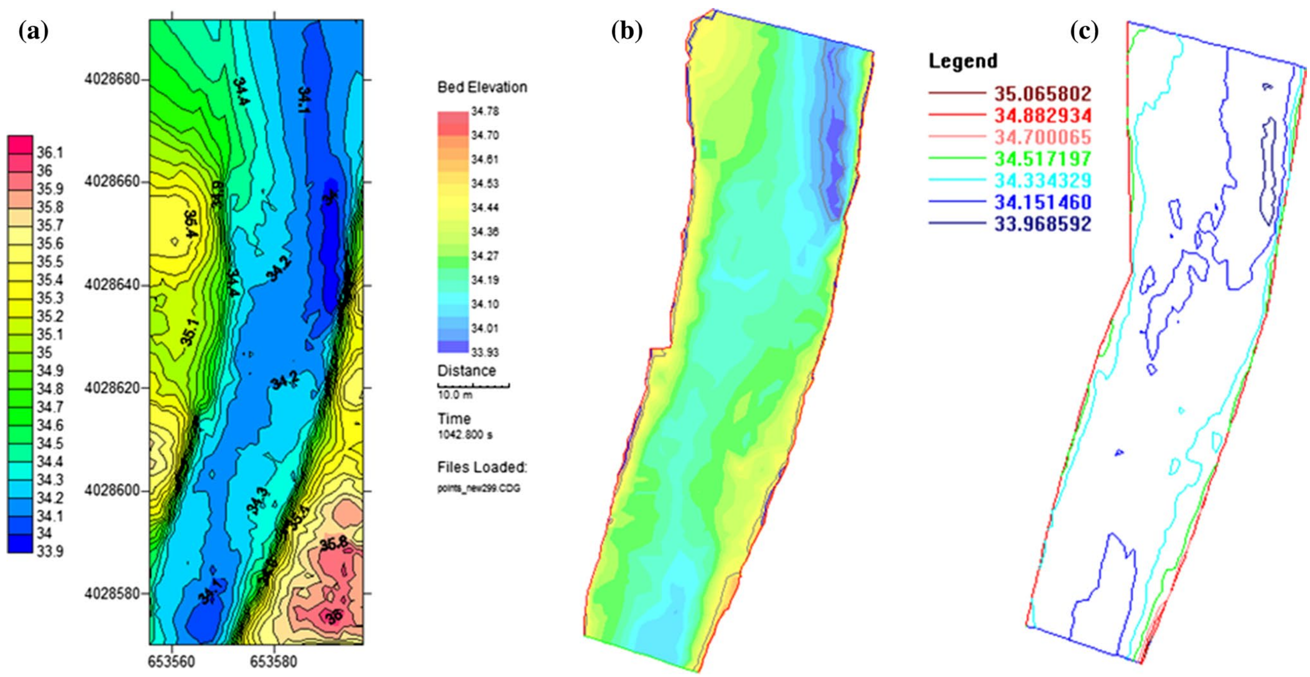

Fig. 3 Bed topography elevations **a** measured, **b** River2D model and **c** SSIIM model

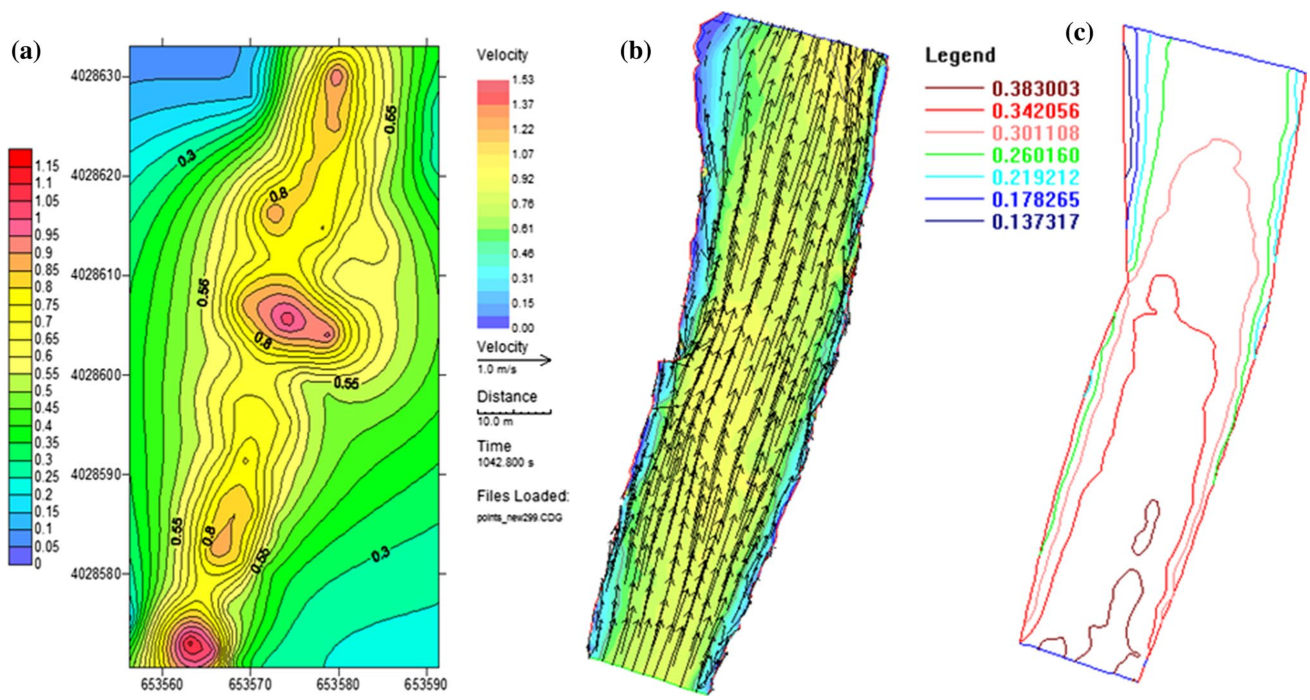

Fig. 4 Velocity magnitudes **a** measured mean, **b** River2D, **c** SSIIM

despite three-dimensional program (SSIIM) modeled the trend of flow velocity and moving core velocity in a good consistence with measured data, but the overall magnitude of velocities are lower than measured mean velocity (Fig. 4c).

3.3 Shear Stress

Figure 5 shows the comparison between shear stress measured (Fig. 5a) and calculated by two models. As regards, River2D provided depth-averaged velocity and depth values in each node, and output information were used to calculate bed shear stress following procedure of Julien (2010). The bed shear stress (τ_b) was determined by using the following equation (Julien 2010):

$$\tau_b = \frac{\rho u^2}{\left[5.75 \log\left(12\frac{H}{k_s}\right)\right]^2} \quad (8)$$

where ρ = density of fluid; u is the average velocity; H = depth of flow and k_s = the roughness height. The value of k_s was set equal to $5d_{50}$ where d_{50} is the median grain size. The value of $5d_{50}$ was calculated based on the best fitness (the highest coefficient of determination R^2) of the logarithmic law based on Eq. (8). The bed shear stress can be calculated by using the logarithmic law over gravel and cobble bed streams in turbulent flow. Equation (8) applies the depth-averaged velocity in numerator and relative submergence (H/k_s) in denominator to determine the bed shear stress. The required data to apply Eq. (8) is easily available for river engineers. The results of application the log law to determine the bed shear is in agreement with the other methods including the Reynolds stress method, the parabolic law and the boundary layer characteristics method (Afzalimehr 2010). In addition, Eq. (8) requires less data to calculate the bed shear stress (Yen 1991; Julien 2010).

Values for shear stresses generally demonstrate the same trend as the modeled velocity predictions. At measured and 2D modeling flow structures, shear stress is greater over the riffle than over the pool because of the low slope of the water surface (Fig. 5a, b).

Throughout modeled runs, a high degree of spatial variability was found in the data for shear stress because of the complex topography. In addition, surveying of individual cobbles over the riffle produces local highs of shear stress that may be an artifact of the modeling. Shear stress estimates, based on depth-averaged velocity, tend to provide overestimates of bed shear stress relative to three-dimensional predictions (Fig. 5c). Other scientists have also reported overestimates of bed shear stress based on two-dimensional model relative to three-dimensional predictions (Lane et al. 1999). Thus, we observed the estimated shear stress as being representative of the spatial distribution, while the magnitude may be over-predicted.

The Reynolds stress profile was not used to calculate the bed shear stress because it demands a lot of effort and it is time consuming to collect data in rivers. On the other hand, application of Eq. (8) is easy and suitable in rivers, presenting reasonable estimation of bed shear stress (Afzalimehr 2010; Julien 2010).

3.4 Habitats

Input information for habitat modeling in River2D is habitat suitability index (HSI) curves. The HSI indicates the suitability of habitats based on a single parameter, such as velocity, depth, and substrate. The HSI for the flow velocity, depth and channel index (substrate) were obtained from

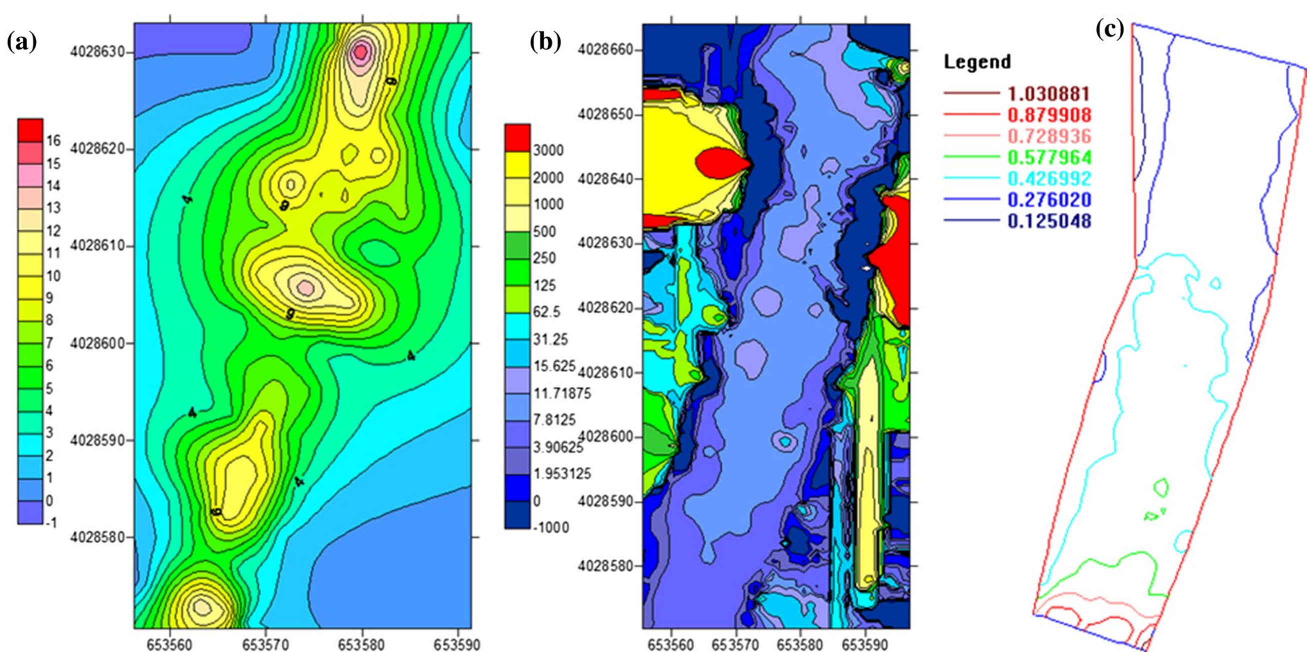

Fig. 5 Shear stress **a** measured; **b** River2D; **c** SSIIM

measurements. In contrast, SSIIM program did not need any extra input information for habitat modeling. It means that “Geodata” and “Control” files are only needed for simulation, although discharge value must be specified.

As previous research can state the maximum used area for velocity is occurred in the upper third of the velocity range (Dominikus 2010). In confirmation of previous researches, as it is showed in Fig. 6a, whether for River2D or SSIIM, maximum area is occurred in the upper third of velocity range, and this parameter occurred at 0.7616 m/s and 0.3579 m/s for River2D and SSIIM respectively. As shown in Fig. 4, since the velocity values are overestimated by River2D, although by lower intensity in comparison with shear stress, so the maximum usable area is situated in higher velocity for River2D compared to SSIIM code.

In depth modeling, the relatively similar values of River2D depth simulations and measured depth data are demonstrated, but higher depth values were modeled by SSIIM. It is shown in Fig. 6b that SSIIM simulations overestimate the depth used area values in comparison to River2D. Considering the principle of mass conservation and underestimating of flow velocity by SSIIM, this leads to overestimating of depth values by this code. Consequently, depth suitability area is overestimated by SSIIM. Maximum used area for SSIIM and River2D occurred in 0.9358 m and 0.4094 m respectively.

4 Discussion

The aim of this paper is to seek a process and comparison of flow structure and habitat modeling for a natural sequence of pools and riffles. The results showed flow convergence during deceleration section occurred despite no obstruction in the stream and that flow convergence during deceleration is in agreement with studies in field sites (e.g., MacVicar and Roy 2007a) and with observations of flow convergence in pools (MacWilliams et al. 2006; Sawyer et al. 2010). Also, compared to measured data and River2D simulations, the magnitude of flow velocities is predicted lower by SSIIM. Because this CFD code simulated flow depth higher than actual depth; so the simulated velocity range, 0.13–0.38, is lower than actual velocity range, 0–1.2. In the bed shear stress contours, there are overestimates in shear stress predicted by River2D. It seems the reason of this overestimate can be due to the difference of bed shear stress formulation. In River2D, universal velocity law and depth-averaged velocity are used to calculate bed shear stress, while the bed velocity is used for bed shear stress calculation in SSIIM. Comparing velocity contours indicates that although River2D overestimates the simulations, these values are closer to mean measured velocities compared with SSIIM simulations. With this argument we may deduce, as shown in Fig. 6a, used area values are closer to reality for River2D than SSIIM code.

5 Conclusion

The results of this paper can be applied and extended for a better determination of sediment transport and flow resistance estimation in gravel-bed rivers where the effect of pools on flow is significant.

In addition, similar patterns in laboratory and river can help to study the flow details in laboratory for 2D flow

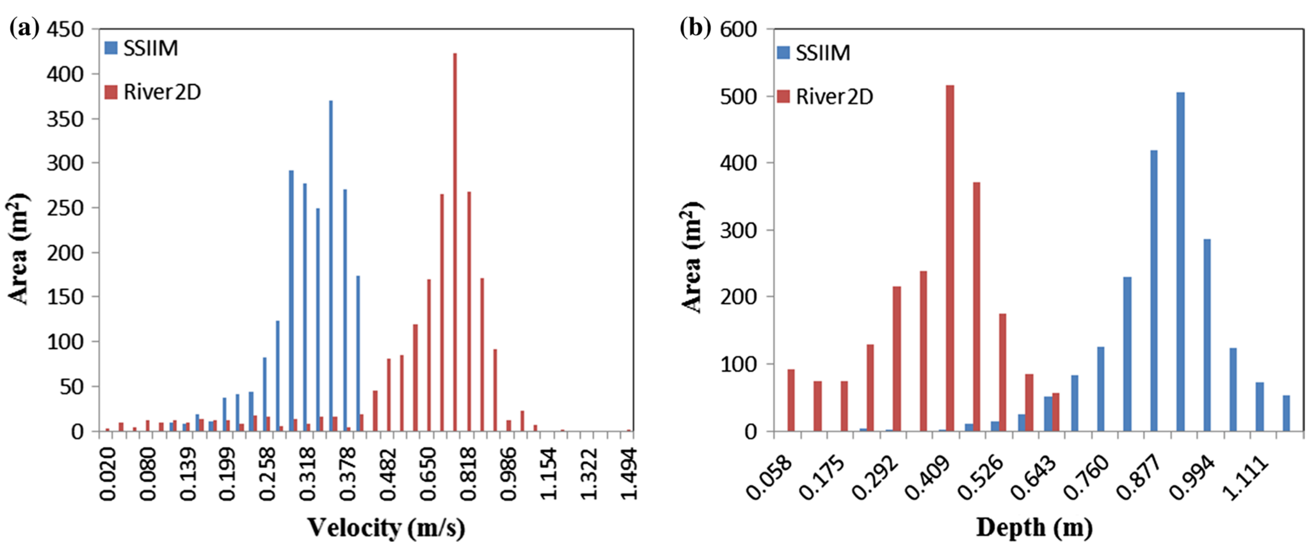

Fig. 6 Comparison of habitat area simulation by River2D and SSIIM **a** velocity area, **b** depth area

conditions and extend the results to 3D flow in rivers with some modifications.

The following results can be considered from this study:

1. Two- and three-dimensional models are used to simulate hydraulics and hydro-environment of natural pool–riffle sequences. The inputs of models are gained from field measurements. The model calculations were tested against field observations and were found to produce discrepancies. However these discrepancies are little and water surface at the boundary during a discharge of 6.09 m^3/s was in reasonable agreement with predicted values.
2. The simulations suggested that convergence during deceleration section occurred with no obstruction. Also, flow entering the riffle showed divergent velocity contours with highly variable velocity vectors. Flow velocities are predicted lower than field measurements by SSIIM. While River2D simulations were in good agreement with the measured velocities.
3. Due to the different bed shear stress formulation for calculations, there were overestimates in shear stress predicts by River2D compared to SSIIM. Albeit, we observed the estimated shear stress as being representative of the spatial distribution, while the magnitude may be over-predicted.
4. For the habitat modeling, it is demonstrated that maximum used area for velocity modeling is overestimated by River2D, and it is occurred at 0.7616 m/s and 0.3579 m/s by values of 423.58 m^2 and 370.48 m^2 for River2D and SSIIM respectively. In contrast, for depth modeling, SSIIM simulations overestimated depth used area values in comparison with River2D. These values are 505.86 m^2 and 516.35 m^2 and occurred in 0.9358 m and 0.4094 m for SSIIM and River2D, respectively.

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