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EFFECTS OF 2D AND 1D MODELING ON MAPPING AQUATIC HABITAT QUALITY

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The distribution of aquatic habitat at the organism scale, i.e. 1 by 1m or smaller is typically predicted from local physical characteristics of stream flow, bed, banks and sediment characteristics and a set of biological preference curves. The flow properties are typically predicted with numerical modeling whereas stream bed and bank characteristics defined from interpolated DEM generated by topographical surveys and field observations. Information on the effects of flow properties and streambed morphology due to numerical modeling dimensionality on aquatic habitat modeling is limited. Two-dimensional (2D) modeling is becoming the most popular method to map micro-habitat but its application is still limited to short reaches and at steady state conditions. One-dimensional (1D) modeling here used in their extended version as pseudo 2D are still applied in aquatic habitat especially where only cross-sectional information is available and the reach domain is several km long. Pseudo 2D modeling predicts velocities along the cross-section from uniform flow relationships and local depths from water surface elevation and local DEM of the streambed. Values between cross-sections are then interpolated. The advantage of pseudo 2D modeling over the full 2D is that it is very efficient and can run at the stream network scale under unsteady conditions. Thus there is still some usefulness in comparing the prediction of these two approaches. We hypothesize that pseudo 2D modeling with very fine spaced cross-sections supported by detailed bathymetry may predict micro-habitat distributions similar of those of 2D modeling. Here, we compared local micro-habitat distributions predicted with a pseudo 2D and fully 2D numerical models of a pool-riffle complex and simple reach. Our results showed that difference in WUA derived from the pseudo 2D and fully 2D modeling is small but the difference in spatial distribution of cell suitability can be considerable under a strict cell-by-cell comparison.

INTRODUCTION

One of the most common approaches to assess the quality of aquatic habitats is the in-stream flow incremental methodology, IFIM [1], which evaluates the habitat quality based on physical properties such as water depth and flow velocity within a range defined by the biological requirements of a specific organism. The method has been used to analyze riverine habitat status for stream rehabilitation, enhancement and restoration [2]. Usually, habitat models utilize flow properties simulated by one-dimensional (1D) and two-dimensional (2D) hydrodynamic models. One-dimensional models solve the cross-sectional averaged Reynolds Averaged Navier Stokes Equations (RANS) to predict water surface elevation (WSE) and cross-sectional averaged flow velocity. Conversely, two-dimensional models require the complete stream bathymetry to predict flow properties by solving the vertically averaged RANS equations. Typically, in aquatic habitat modeling, 1D model is actually applied as a pseudo 2D numerical model. These are 1D models with simplified equations to determine the velocity and depth distribution along each cross-section at specified stations. Local depths are estimated as the difference between predicted water surface elevation and the streambed elevation and local velocities are scaled with depth using uniform flow type of equations.

Advances in new surveying technology like the Experimental Advance Airborne Research Lidar, EAARL, allows acquiring relatively high-resolution and accurate stream bathymetry, floodplain bare earth topography over a large range of spatial scales [3]. Comparison of flow properties predicted with 1D and 2D hydraulic numerical models are sparse and its propagation on habitat prediction is unclear. Additionally, aquatic habitat quality may vary spatially, thus comparison of WUA and Hydraulic Habitat Suitability (HSS) alone lacks spatial consideration. In this study, we quantified the difference in water depths and velocities simulated with 1D and 2D hydrodynamic models and investigated their effect on WUA and HHS values and on habitat quality spatial distribution. We hypothesized that 1D models supported by close-spaced cross-sections, extracted from high-resolution and detailed bathymetry may provide habitat distribution comparable to 2D models. To test our hypothesis, we used a complex and a simple straight reach of the South Fork Boise River, Idaho, USA, and two discharges. Furthermore, we also compared spatially distributed cell suitability index (CSI) on cell-by-cell basis using error matrix technique.

METHOD

Study site

The South Fork Boise River is located in south-western Idaho and the basin hydrologic regime is snowmelt dominated (Figure 1). The regulated flow varies from 5.5 to 71 m^3/s in the study reach and it has an average width and slope of 41 m and 0.0043, respectively. The reach is generally broad and shallow and characterized by riffles and runs with cobble dominated substrate. The study reach is 1350 m long and we divided into a simple and a complex reach with threshold sinuosity index of 1.2 and reach morphology.

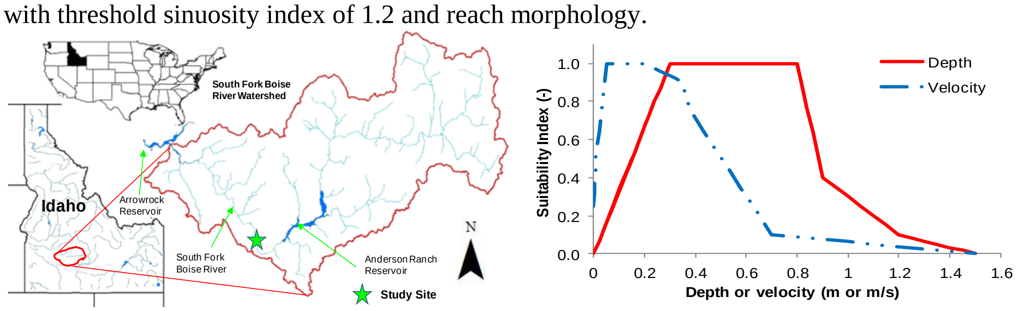

Figure 1. Study area (left) and rearing habitat suitability curves (depth and velocity) for Chinook salmon (right).

Hydraulic model development

We used MIKE11[DHI, 4] and MIKE21[DHI, 5] software package as a 1D and 2D models, respectively. MIKE11 utilizes an implicit, finite-difference scheme for computing unsteady flows in rivers and estuaries. MIKE 21 flow model simulates unsteady two-dimensional depth averaged hydraulic properties (e.g., water level variation, flow velocity and shear stress) using a finite difference algorithm. We extracted cross-sections every 5 m longitudinally and 1 m transversely from high-resolution DEMs surveyed using the EAARL Lidar [3] for the 1D model set up. We adopted “Map generation” tool of MIKE11[DHI, 4] to generate spatially distributed water depths and velocities at each cell, whose size equal that of the 2D model. We set up the model utilizing high-resolution DEMs and boundary conditions. We assign a uniform Manning’s roughness for the entire study sites in both 1D and 2D models. We simulated channel hydraulics and aquatic habitat with flow magnitudes of 10.65 and 63.43 m^3/s. We adjusted the roughness parameter of the models until the water surface elevations of the 1D and 2D models closely matched along the channel thalweg. The final water surface elevation root mean square errors (RMSE) were 0.06 and 0.10 m for the low and high discharges, respectively[6].

Habitat model development

Habitat suitability is a dimensionless index ranging between 0 (poor quality) and 1 (excellent quality). We used univariate habitat preference criteria of rearing Fall Chinook salmons [7], which is one of the native species for Pacific Northwest of United States. We used geometric product of the individual suitability indexes of each physical parameter (e.g., velocity and depth) to determine the cell suitability index (CSI) for each cell. Later, weighted useable area (WUA) and the hydraulic habitat suitability (HHS) were calculated to provide habitat quality at the reach scale.

Model comparison

We used grid-based maps (raster format) to analyze the difference in results from 1D and 2D models. These raster maps also describe the spatial variation of each hydraulic variables and CSI. The first analysis is the comparison between simulated hydraulic variables (flow depths and velocities) on cell-by-cell basis. Area weighted mean and standard deviation (SD) were calculated in order to quantify the difference between the two sets of maps. Finally, we also assess the difference between 1D and 2D estimated WUA and HHS because those are commonly used indexes in habitat analysis. Furthermore, we compared spatially distributed CSI by the error matrix (cell-by-cell basis) [8].

RESULT AND DISCUSSION

Hydraulic variables

The differences in average depths between 1D and 2D were similar for both for simple and complex reaches and discharges (Table 1). However, the differences in velocity are larger for the complex than of the simple reach for both discharges (Table 1). Despite, relatively small differences in flow depth, velocity differences were relatively large. This underscores the capability of a 2D model to simulate complex flow distribution, which a 1D model cannot. Unlike water surface elevation, the flow velocity varies rapidly in magnitude and direction, in space and time [9].

Table1. Differences in flow depths and velocities for high and low discharges

Reach	LQ_depth				HQ_depth				LQ_velocity				HQ_velocity			
	Mean	Δ	SD	φMd	Mean	Δ	SD	φMd	Mean	Δ	SD	φMd	Mean	Δ	SD	φMd
	m	%	m	m	m	%	m	m	m/s	%	m/s	m/s	m/s	%	m/s	m/s
S	0.03	5	0.01	0.03	0.09	8	0.05	0.08	0.12	23	0.11	0.09	0.27	25	0.24	0.20
C	0.03	5	0.02	0.03	0.09	8	0.05	0.09	0.25	50	0.25	0.18	0.40	38	0.37	0.30

HQ High discharge   C Complex reach   S Simple reach   φ Median (50 percentile)

Δ Ratio between residual of water depth and velocity to area weighted mean value (based on 2D simulation)

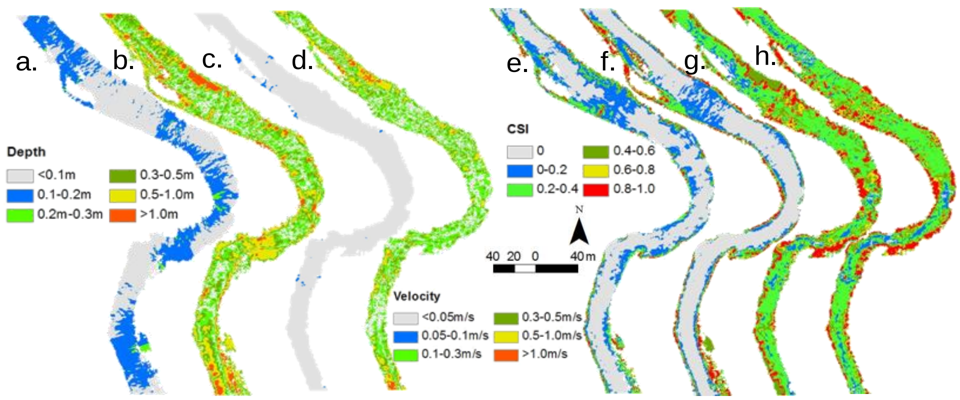

Figure 2. Spatially distributed hydraulic characteristics and habitat suitability for the complex reach. Sub-figures are: a. depth for high discharge (HQ), b. velocity for HQ, c. depth for low discharge (LQ), d. velocity for LQ, e. cell suitability index (CSI) from 1D model for HQ, f. CSI from 2D model for HQ, g. CSI from 1D model for LQ, f. CSI from 2D model for LQ.

Habitat suitability

The weighted usable area (WUA) differences for 1D and 2D models were less than 5% for the low discharge, but relatively higher (38%) for the high discharge (Table 2). Although the difference in WUA was about 38%, the difference in HHS values were relatively small less than 0.06.The WUA was greater for the 2D than 1D model in both the simple and complex reaches (Table 2). However, there are no theoretical nor numerical reasons that suggest 2D models may consistently report higher aquatic habitat quality [10,11].

Table 2. Differences between 1D and 2D model predicted WUA and HHS for high and low discharges and agreement between the maps from error matrix analysis.

Reach	Low Q							High Q						
	WUA (1000 m^2)		δ	Agreement (-)		HHS (-)		WUA (1000 m^2)		δ	Agreement (-)		HHS (-)	
	1D	2D	%	K	OA	1D	2D	1D	2D	%	K	OA	1D	2D
S	10.14	10.57	4	0.50	0.63	0.61	0.64	1.94	3.16	38	0.54	0.72	0.10	0.16
C	12.34	12.55	2	0.19	0.42	0.45	0.45	3.86	5.60	31	0.38	0.62	0.10	0.16

C Complex reach   S Simple reach   WUA Weighted usable area   HHS Hydraulic habitat suitability

δ Difference in WUA between 1D and 2D models   K Kappa coefficiet   OA Overall accuracy

The error matrix analysis showed that agreement (K) and overall accuracy (OA) between 1D and 2D simulated CSI were higher for simple reach than for the complex reach. The values were higher than 50%, except for the low discharge in the complex reach. The noticeable differences in spatially distributed CSI were near the bank of the channel, where 2D model predicted higher CSI class.

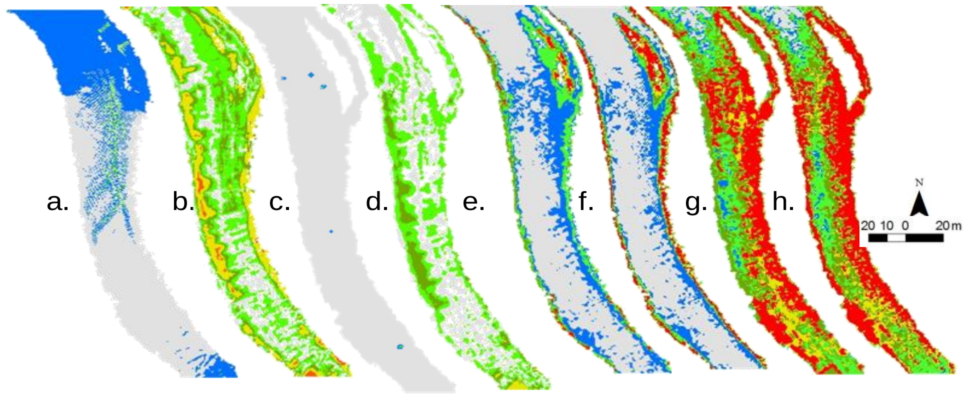

Figure 3. Spatially distributed hydraulic characteristics and habitat suitability for the simple reach. Refer, Figure 2 for sub-figures and color legends.

CONCLUSION

Reach-scale aquatic habitat indexes such as WUA and HHS showed small differences between 1D and 2D modeling supporting 1D modeling coupled with high-resolution bathymetry provides comparable to 2D modeling. Thus, hydraulic variables simulated with 1D models coupled with high-resolution bathymetry could be a useful first order analysis to derive aquatic habitat considering its efficiency in large-scale studies, although application of 1D or 2D models depends on many factors such as computational time, available resources, spatial resolution, required accuracy and hydraulic variables.

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