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FIELD EVALUATION OF A TWO-DIMENSIONAL HYDRODYNAMIC MODEL NEAR BOULDERS FOR HABITAT CALCULATION[†]

TERRY WADDLE*
Hydrologist, U.S. Geological Survey, Fort Collins Science Center, 2150 Centre Ave., Fort Collins, CO 80526, USA

ABSTRACT

Two-dimensional hydrodynamic models are now widely used in aquatic habitat studies. To test the sensitivity of calculated habitat outcomes to limitations of such a model and of typical field data, bathymetry, depth and velocity data were collected for three discharges in the vicinity of two large boulders in the South Platte River (Colorado) and used in the River2D model. Simulated depth and velocity were compared with observed values at 204 locations and the differences in habitat numbers produced by observed and simulated conditions were calculated. The bulk of the differences between simulated and observed depth and velocity values were found to lie within the likely error of measurement. However, the effect of flow simulation outliers on potential habitat outcomes must be considered when using 2D models for habitat simulation. Furthermore, the shape of the habitat suitability relation can influence the effects of simulation errors. Habitat relations with steep slopes in the velocity ranges found in similar study areas are expected to be sensitive to the magnitude of error found here. Comparison of habitat values derived from simulated and observed depth and velocity revealed a small tendency to under-predict habitat values. Published in 2009 by John Wiley & Sons, Ltd.

KEY WORDS: two-dimensional; hydrodynamic model; habitat simulation; simulation error; data error

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INTRODUCTION

Two-dimensional vertically averaged hydrodynamic models (2D models) have come into widespread use in a variety of applications for habitat evaluation (Tharme, 1996, 2003; Wheaton *et al.*, 2004; Stewart *et al.*, 2005; Mingelbier *et al.*, 2008). Frequently such models have been validated in the controlled conditions available in laboratory studies such as described by Jia and Wang (1998). Application of such models in rivers presents difficulties in both sampling and modelling that can influence the outcome of habitat calculations. Pasternack *et al.* (2006) evaluated error propagation for velocity and shear stress using 2D models and noted that such errors may have implications for related environmental variables.

Riverine salmonid species use flow obstructions as velocity shelters to minimize exertion and thus expend the minimum amount of energy while foraging and resting (Bjornn and Reiser, 1991). Boulder placement is one form of stream rehabilitation that is commonly used to provide increased diversity of velocity patterns in generally uniform stream channels. Accurate modelling of such areas can provide better information about the habitat in existing streams and tools for design of constructed habitats.

In this study, an investigation of the ability of River2D (Ghanem *et al.*, 1996; Steffler and Blackburn, 2002) to represent the flow field near boulders was undertaken to evaluate the potential degree of influence of model and data inaccuracies on calculated physical habitat values. The ability of the vertically averaged model to reproduce typical field data used in modelling studies was evaluated using data obtained at three discharges. The habitat results for adult brown trout (Salmo trutta) calculated from field measurements obtained at those discharges were compared with those calculated from hydrodynamic simulations of the same flows.

*Correspondence to: Terry Waddle, Hydrologist, U.S. Geological Survey, Fort Collins Science Center, 2150 Centre Ave., Fort Collins, CO 80526, USA E-mail: waddlet@usgs.gov

METHODS

The Colorado Division of Wildlife (CDOW) has modified a portion of the South Platte River channel approximately 1.5 km east (downstream) of Spinney Mountain Reservoir (38°58′20″ N, 105°37′19″ W). The modifications include treatments to reduce channel width and bank erosion, excavate pools, elevate riffles add woody debris in the form of log spurs and root wads, and place boulders individually and in clusters using methods described in Van Velson (2002). These treatments were designed to increase diversity of channel morphology and improve trout habitat. This site provided an opportunity to evaluate how accurately a vertically averaged 2D model was capable of representing the flow field in the vicinity of boulders.

Field data collection

Bathymetric, stage and discharge data were collected for a 900 m study site. Detailed depth and velocity data in the vicinity of two large boulders were collected for three different discharges. Three-dimensional topographic data were obtained using Javad Odyssey L1/L2, Trimble 4800 and 5800 survey grade global positioning system (GPS) receivers employing real time kinematic position recording and multi-path reduction (Javad Navigation Systems, http://www.javad.com, Trimble Navigation, Ltd., http://www.trimble.com) and a 3-s Leica 6100 total station. All data were collected in Universal Transverse Mercator (UTM) coordinates (zone 13 north, vertical datum WGS 1984). Figure 1 shows the extent of the study site and the intensely studied boulder segment described below.

A total of 6330 bathymetric observations were obtained from 2003 to 2006 by following major topographic features such as top of bank, toe of bank and thalweg of primary and secondary channels. The areas between these feature lines were filled with irregularly spaced observations as needed. Boulders and other large objects were defined by tracing the object as it intersected with the bed and measuring several points on the object to define the object shape. A triangulated irregular network (TIN) was applied to the data to construct a digital elevation model (DEM) of the study site.

Discharge data were collected at transects selected to be safely wadeable at four controlled discharges between 1.416 and 11.327 $m^3 s^{-1}$ (50 and 400 $ft^3 s^{-1}$) using a top-set wading rod and Marsh McBirney digital velocity meter. Velocities and depths were recorded in feet and later converted to metric units. The lone tributary to the stream in this vicinity did not flow during the study period so the discharge measurements were deemed representative of the entire study site. Water surface profile data were collected simultaneously with discharge measurements and a rating curve was constructed for the downstream boundary of the study site.

In addition to the full site data, velocity and depth data were collected at 218 irregularly spaced locations in the vicinity of two large boulders on three occasions at discharges of 1.133, 1.529 and 4.531 $m^3 s^{-1}$ (40, 54 and 160 $ft^3 s^{-1}$) for comparison with model results. Due to turbulence in the vicinity of the boulders, velocity observations were conducted until the digital meter ceased major fluctuations, typically 1–2 min. Nineteen and 12 observations, respectively, were collected on discharge measurement transects downstream of the boulder field at the 1.133 and 4.531 $m^3 s^{-1}$ discharges. Twenty-five observations were collected on three transects upstream of

Figure 1. Spinney Mountain study site (red line) and Boulder sub-model segment (yellow). This figure is available in colour online at www.interscience.wiley.com/journal/rra

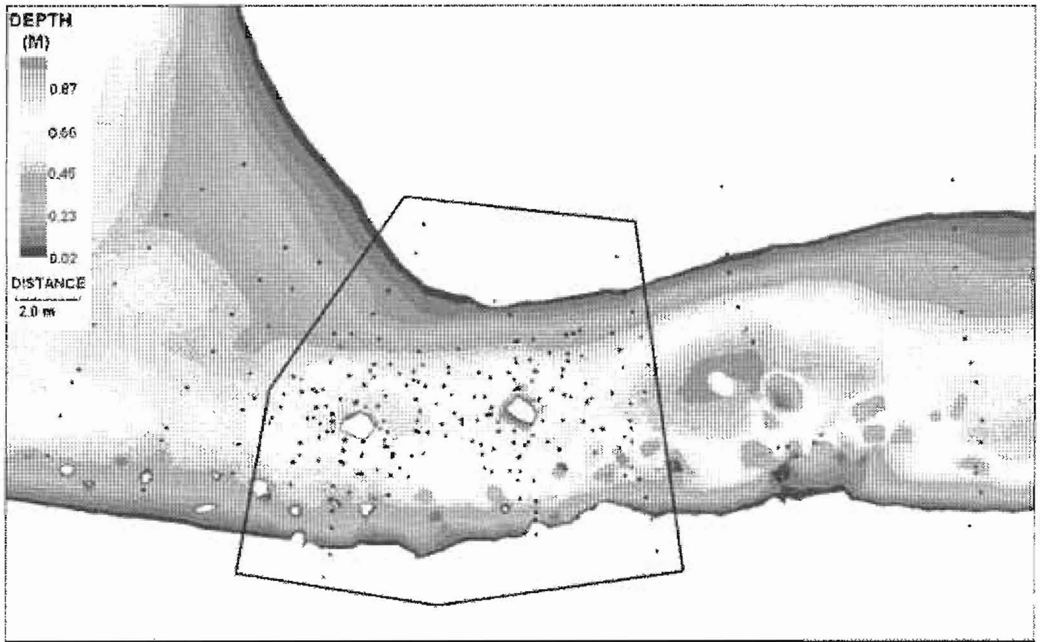

Figure 2. Location of depth and velocity measurements showing sample locations near boulders (within polygon) and transects outside of the boulder area. This figure is available in colour online at www.interscience.wiley.com/journal/rra

the boulders at 1.529 $m^3 s^{-1}$ for calculation of discharge and for evaluation of areas without boulder influence. Figure 2 shows the boulder velocity evaluation area as a polygon and locations of the measurements. A bracket was fitted to a top-set wading rod to mount the GPS antenna allowing the wading rod to function as a range pole. Thus, the topographic location of each velocity measurement was simultaneously obtained with velocity and depth.

Data quality control

Closure of the GPS survey was verified by including previously established benchmarks in each day's position data. Discharge data used to construct the full-site rating curve were compared with release discharges provided by the City of Aurora, Colorado (Brian Fitzpatrick, personal communication 2006) and recorded discharge at a stream gage (06695000. S. Platte R. Above 11-Mile Canyon Reservoir) located 2 km downstream from the study site.

Additional steps were taken to evaluate measurements made in the vicinity of the two boulders. An approximate water surface elevation was calculated for each velocity/depth measurement made near the boulders by adding depth to the measured bed elevation. The constructed water surface was compared with water's edge elevations measured nearby. Deviation of this constructed water surface from the observed water's edge elevation of more than 8 cm (rod reading error plus turbulent depth fluctuation range) resulted in rejection of six of the measurements. Eight measurements that showed apparent depth recording errors of even increments of one foot were also removed from the analysis.

Development of the bathymetric (bed) model

In the DEM of the study site, breaklines were used to connect sequential points collected along major features. This approach allows major stream features to be defined using fewer field observations and relies on the breakline algorithm to ensure that feature contours are enforced in the final DEM. Triangulation anomalies were removed by inspection using additional breaklines to connect measured points. The final DEM was compared with on-site and high resolution aerial photographs to ensure consistency with the photographed topography.

Hydrodynamic modelling

Model structure. The River2D model uses the finite element method to solve the basic equations of vertically averaged 2D flow incorporating mass and momentum conservation in the two horizontal dimensions (Steffler and Blackburn, 2002). The finite element solution regime allows the user to vary the density of the computational mesh in different portions of the study area. In this study, the computational mesh in the vicinity of the two large boulders was structured such that the average nodal spacing was 0.04 m across a 1.2 m diameter boulder. Burrows and Steffler (2005) indicate the inter-nodal spacing must be at least 7.5 nodes per boulder diameter to obtain adequate fit of modelled velocities to laboratory observations. The computational mesh used in this study distributed nodes over the two large boulders at approximately four times the density (here 4–5 cm elements) identified by Burrows and Steffler (2005) and at approximately twice that node density (9 cm elements) in the wake of the 1.2 m diameter boulders. Thus mesh structure is expected to have introduced minimal discretization error near the two boulders.

Model calibration. The model was initially calibrated for the entire 900 m long study site using data obtained for the 6.088 $m^3 s^{-1}$ (215 $ft^3 s^{-1}$) discharge by adjusting bed roughness height until good agreement between measured and simulated water's edge elevations was obtained for 176 water's edge locations. Additional calibration adjustments of roughness at 2.83 and 11.33 $m^3 s^{-1}$ were used to obtain a log-linear relationship for roughness height as a function of discharge. The whole-site water surface profile for several discharges was used to create a supplemental rating curve for the short model segment near the middle of the study site encompassing the boulders that are the focus of the present work. The boulder model segment is shown as a sub-region of the whole study site in Figure 1. The roughness-discharge function was refined in this region to obtain a best fit of modelled depths and velocities to the observed data.

Simulation of flow conditions near boulders. The model was run for the three intensively sampled discharges: 1.133, 1.529 and 4.531 $m^3 s^{-1}$ (40, 54 and 160 $ft^3 s^{-1}$) for comparison with observed depth and velocity values. Simulated depth and velocity values were extracted from the model results at the x, y location of each measurement by interpolation from a TIN of those fields on the computational mesh. These simulated values were compared with the observed and the differences were tabulated.

Depth and velocity observations were obtained along three arcs crossing the channel upstream of the boulders at the 1.529 $m^3 s^{-1}$ discharge. Simulated depth and velocity values were also extracted from the 1.529 $m^3 s^{-1}$ model results for those locations and compared with the observations to contrast model performance in an area without boulder influence.

Simulation of habitat. The default habitat calculation method contained in River2D integrates habitat suitability indices for depth, velocity and channel characteristics such as substrate and cover over the entire area of a study site to quantify weighted useable area (WUA) based on the concepts implemented in the physical habitat simulation system (PHABSIM, Milhous *et al.*, 1989). A widely cited set of habitat suitability criteria (a set of such indices) for brown trout adults was obtained from Raleigh *et al.* (1986). The depth and velocity suitability criteria are shown in Figure 3. Because depth and velocity measurements were not obtained for the entire domain of the hydrodynamic simulation and at different density than the points in the final computational mesh, habitat was not integrated over

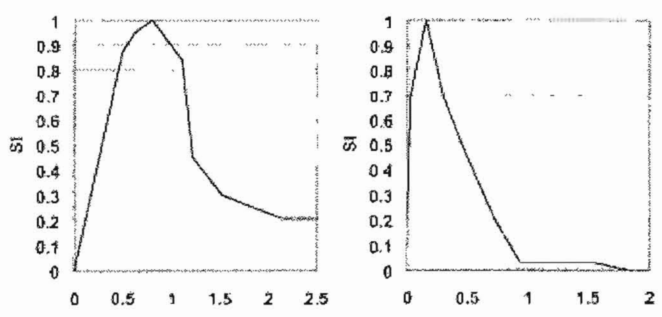

Figure 3. Depth and velocity habitat suitability criteria for adult brown trout used in this study

the entire study site. Rather, a small area (0.1 m^2) was arbitrarily assigned to each measured point location to ensure each point had equal weighting and habitat was evaluated for only those points. An area of 0.1 m^2 was considered small enough to characterize the conditions around the point and provided computational convenience. Depth and velocity were extracted from the simulation results at the same locations as the measurements and habitat was calculated for the simulated conditions using the same 0.1 m^2 areas.

Physical habitat was calculated as in PHABSIM using the product sum:

$$\mathrm{WUA} = \sum_i s_v \times s_d \times s_{ci} \times a_i \tag{1}$$

where s_v is the habitat suitability index for velocity, s_d the habitat suitability index for depth, s_{ci} the habitat suitability index for channel index and a_i is the tributary area to node i. In this example, the channel index suitability was omitted to force the habitat values to be derived from depth, velocity and the 0.1 m^2 areas alone, thus reflecting the effects of the differences in depth and velocity between observed and simulated conditions.

RESULTS

Agreement of observed and modelled depths and velocities

Comparison of observed and modelled depths and velocities revealed a similar error scatter pattern for all three measurements. Table I contains a summary of modelled and observed differences (simulated minus observed values) near the boulders for depth and velocity for the three intensively studied discharge conditions. Velocity simulation errors are generally larger than depth simulation errors.

Depth and velocity errors for the observations made upstream of the boulders are shown in Table II. Depth error appears to be similar in average magnitude and range, as would be expected. While this is a small sample it shows smaller average velocity error and a velocity standard deviation that is about one-half that of the region near the boulders. The per cent of depth and velocity error values falling within ± 1 standard deviation is similar to the boulder region.

Figure 4 shows the frequency distribution of the near-boulder velocity differences for a composite of all three discharges. This distribution is approximately symmetrical about a zero median value suggesting a small likelihood of systematic bias in the sample.

Figures 5 and 6 show scattergrams of simulated and observed depths and velocities for measurements made at the 4.531 m^3 s^{-1} discharge. A larger degree of scatter can be seen in the velocity plot; which is expected due to the nonlinearity of velocity phenomena. Error scatter was similar for the other two discharges.

Figure 7 shows the distribution of depth and velocity error for the 1.133, 1.529 and 4.531 m^3 s^{-1} discharges.

Table I. Summary of simulated minus observed values near boulders[1]

	1.133 m^3 s^{-1}, $n=63$		1.529 m^3 s^{-1}, $n=69$		4.531 m^3 s^{-1}, $n=72$	
	Depth	Velocity	Depth	Velocity	Depth	Velocity
Minimum	−0.11530	−0.38870	−0.06318	−0.21840	−0.08796	−0.23350
Average	−0.00441	0.03096	−0.01180	0.02552	0.00267	0.02260
Maximum	0.08760	0.38750	0.02184	0.31030	0.12326	0.39556
Standard deviation	0.02879	0.11163	0.01885	0.11882	0.03357	0.11665
Number outside ± 1 SD	16	15	17	25	9	21
Number within ± 1 SD	47	48	52	44	63	51
Per cent within ± 1 SD	75.8%	76.2%	75.4%	63.8%	87.5%	70.8%
Average per cent absolute depth error	3.36%	2.98%	6.21%			
Average per cent absolute velocity error	30.11%	24.21%	6.08%			

[1]Depth in meters and velocity in meters per second.

Table II. Simulated minus observed values upstream of boulders (1.529 $m^3 s^{-1}$)[1]

	Upstream of boulders, $n = 25$	
	Depth	Velocity
Minimum difference	−0.06140	−0.10860
Average difference	−0.00219	0.00584
Maximum difference	0.04698	0.10510
Standard deviation	0.02366	0.05542
Number outside ± 1 SD	5	7
Number within ± 1 SD	20	18
Per cent within ± 1 SD	80.0%	72.0%

[1]Depth in metres and velocity in metres per second.

The error distributions described in Figures 4–7 suggest there is no strong systematic bias in the results. However, these figures show some skew at the lower discharges and a plot of velocity differences (simulated minus observed) as a function of measured velocity exhibits a weak tendency for the modelled velocities to be lower than observed above 0.6 $m s^{-1}$ and greater than observed below 0.6 $m s^{-1}$ as shown in Figure 8. A similar evaluation of velocity differences as a function of depth revealed no apparent trend.

One other form of possible systematic bias, spatial bias, was evaluated. Figure 9 displays the magnitude of simulated minus observed velocities proportional to size of circle for the 1.529 $m^3 s^{-1}$ discharge (see Figure 7 for error distribution). The largest differences occur in the region near the boulders, but some of the smallest differences also occur there. The three arcs upstream of the boulders and their velocity patterns generally have small errors. The velocity magnitude shown in the wetted area was generated by the River2D model.

Habitat derived from measured and simulated hydraulic variables

The habitat calculation described in Equation (1) combines the effects of depth and velocity by multiplying their respective suitability indices. The results of applying that equation with the s_{ci} term removed are shown in Table III. The larger per cent difference noted at the high discharge is partly due to a larger number of observations located

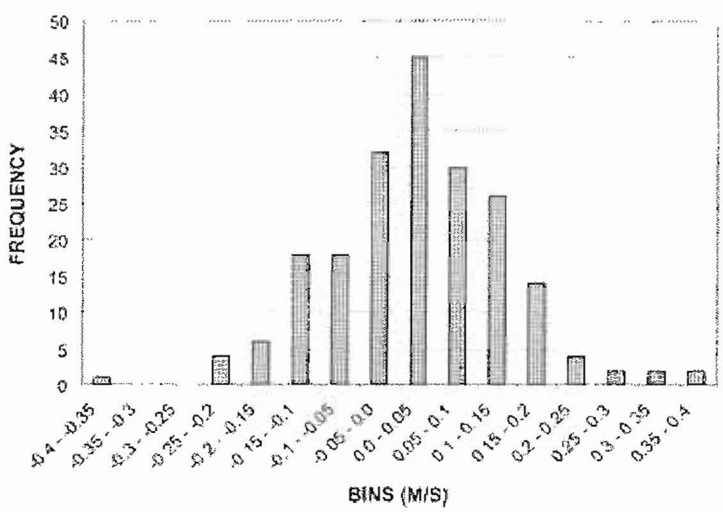

Figure 4. Frequency histogram of simulated minus observed velocity values, composite sample ($n = 204$)

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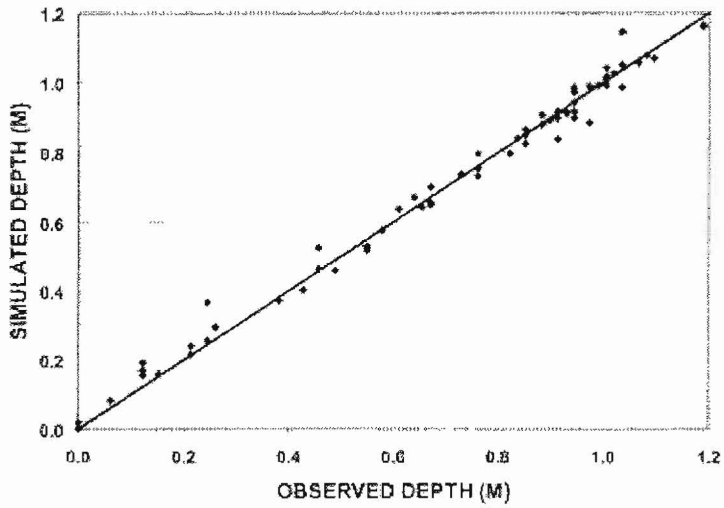

Figure 5. Simulated versus observed depth for the 4.531 $m^3 s^{-1}$ discharge

near the edge of the stream and in areas where the computational mesh discretization may have influenced simulation accuracy. The differences in habitat values calculated from simulated depth and velocity compared to those calculated from observed depth and velocity are summarized in Figure 10. Calculated habitat errors for the selected habitat suitability criteria have even a stronger central tendency than the velocity errors, though a larger proportion of the simulated values are less than the observed values.

DISCUSSION

Sources of error

Differences between simulated and observed velocities can be attributed to several possible sources of error including measurement error and model error. Measurement error includes operator blunders, equipment problems, discretization error and location error. Model error can be divided into discretization error, spatial averaging and

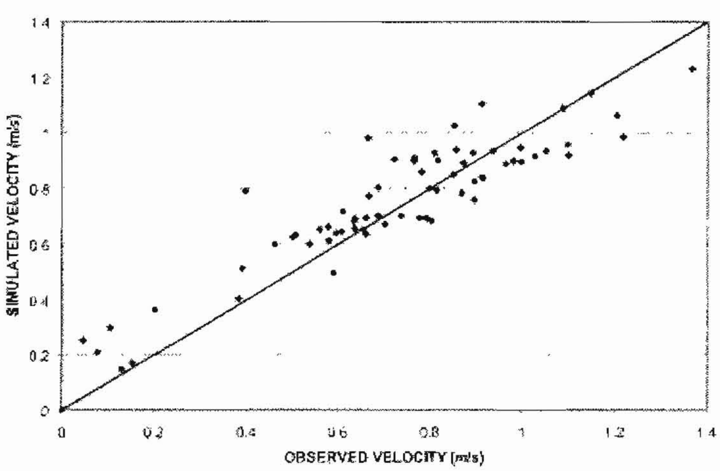

Figure 6. Simulated versus observed velocity for the 4.531 $m^3 s^{-1}$ discharge

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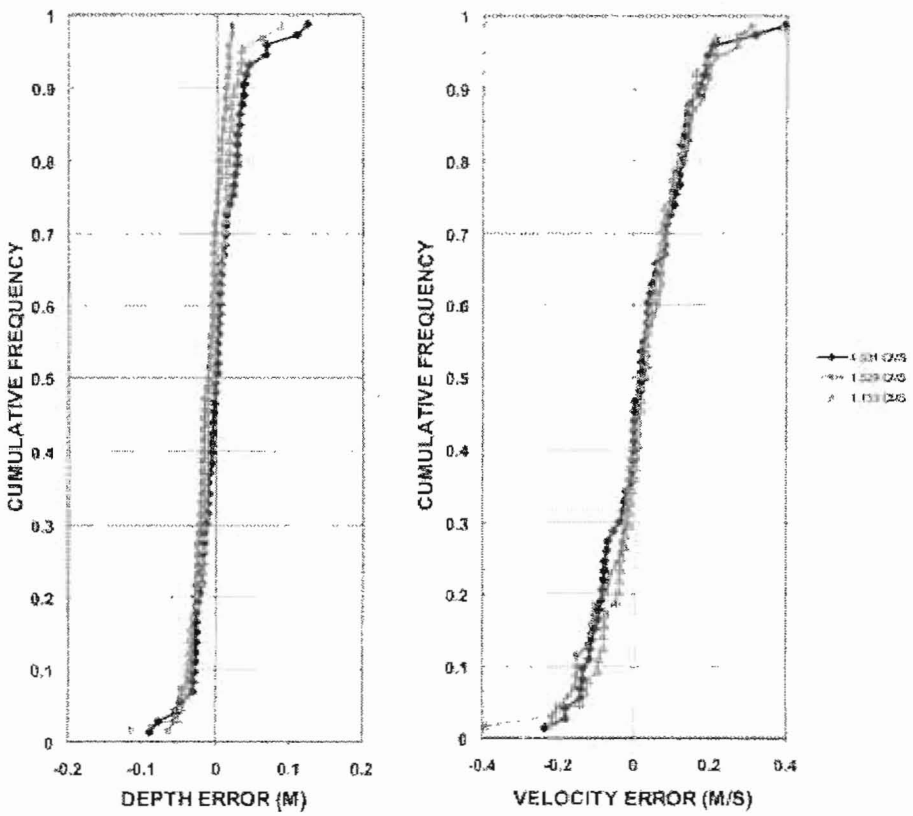

Figure 7. Cumulative frequency distribution of depth and velocity error for three discharges. This figure is available in colour online at www.interscience.wiley.com/journal/rra

error inherent in the model formulation. Each of these sources of error can influence the apparent goodness of fit of observed data and model results.

Operator blunders include failure to properly set up or field test equipment, misreading of the instrument, improper recording of observations, errors in setting the wading rod to the correct depth and standing so the

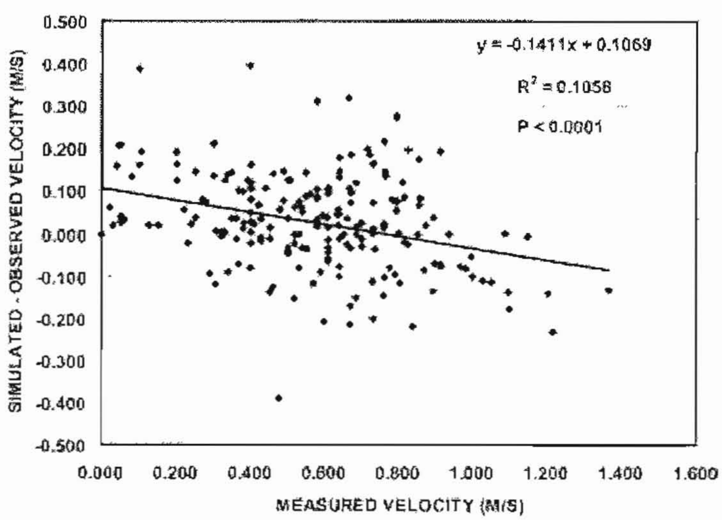

Figure 8. Velocity error as a function of measured velocity, composite sample ($n = 204$)

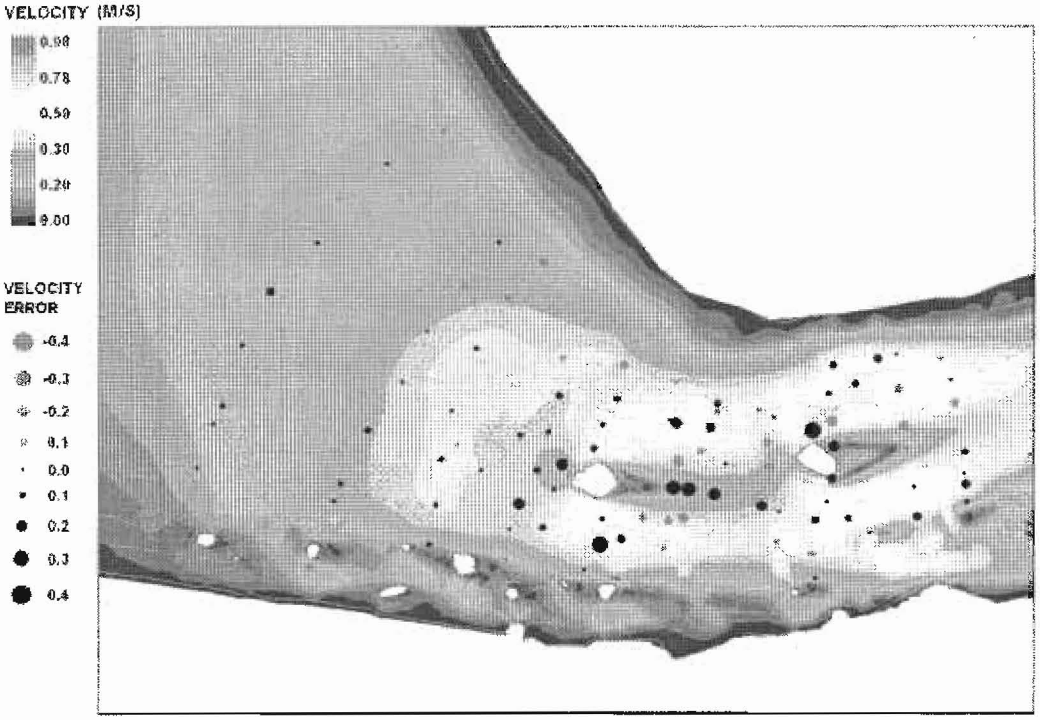

Figure 9. Velocity simulation error location and magnitude for the 1.529 $m^3 s^{-1}$ discharge

operator's body wake disturbs the velocity measurement. Equipment problems include instruments that are out of calibration, insufficient averaging period for turbulent conditions, inherent GPS position error and undetected fouling of velocity meters. Location error includes difficulties obtaining a single representative velocity value in areas with substantial secondary (vertical) current components: alternate vortex shedding from left and right sides of objects and turbulent fluctuations in the water surface, leading to poor depth estimates.

Discretization error occurs in both the field measurements and model representation of the channel. Widely spaced topographic observations may miss locally significant objects or depressions in the stream bed. Field crews must trade-off the time required for more densely spaced measurements against the limits of time available for the overall field effort. Similarly, when abstracting field observed topography into a computationally efficient model, model users must trade-off the length of time required to run the model against the spacing between modelled nodes. Close node spacing to ensure minimum difference between measured and modelled topography invariably incurs substantial computational effort and can increase the elapsed time to produce a model product.

Table III. Summary of weighted usable area calculations for three discharges[1]

Discharge	1.133 $m^3 s^{-1}$, $n=63$		1.529 $m^3 s^{-1}$, $n=69$		4.531 $m^3 s^{-1}$, $n=72$	
	Observed	Simulated	Observed	Simulated	Observed	Simulated
Total area	6.3	6.3	6.9	6.9	7.2	7.2
Average depth HSI	0.947	0.946	0.925	0.919	0.785	0.796
Average velocity HSI	0.608	0.592	0.493	0.501	0.254	0.222
Weighted usable area	3.636	3.533	3.150	3.195	1.270	1.098
Per cent difference	−2.84%	1.42%	13.59%			

[1]All areas are in square meters, HSI are dimensionless.

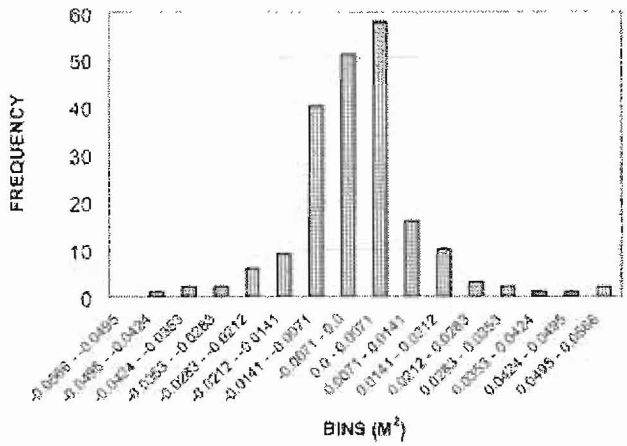

Figure 10. Frequency histogram of habitat derived from simulated depth and velocity minus habitat derived from observed depth and velocity, discrete 0.1 m^2 areas, $n = 204$

Models represent phenomena occurring over a discrete area with computations performed at a point. Thus comparisons such as those performed here unavoidably compare measured point values with spatially averaged simulated values. Increasing node density in the simulation should reduce errors caused by spatial averaging by reducing the area contributing to each simulation node. In this study, mesh density at the one-half of the scale described in Burrows and Steffler (2005) was expected to have introduced both minimal discretization error and spatial averaging error near the two boulders. Using yet higher mesh density may somewhat reduce the error; however, the author believes location error is a larger cause of the velocity differences noted here.

During both data collection and modelling, analysts are unavoidably introducing some discretization error due to the spacing of field observations and of computational nodes. Both kinds of discretization error are present in this study. Such error can only be minimized, not eliminated.

Velocity error near the boulders. In Table II, it can be seen that the depth error is both of smaller magnitude and smaller range of variation than the velocity error. The measured conditions exhibited substantial water surface fluctuation with vortex shedding from the boulders. The largest depth error (approximately 6 cm) was similar to the author's experience measuring turbulent streams with boulders and the depth error range was deemed acceptable for the observed conditions.

In contrast, there was a greater magnitude and variation in the velocity errors. The velocity errors noted herein appear to be predominantly due to location error and discretization error. That is, they are generally larger near edges of objects, the stream margin or in areas where the mesh is coarse relative to the change in depth associated with the nearby object. Error scatter similar to that found here was reported in Lacey and Millar (2001, 2004) and as simulated and observed cross-sectional profiles in Wagner and Mueller (2001). Crowder and Diplas (2000) note that boulder wake patterns produced by a 2D model are similar to patterns photographed from the shoreline suggesting that the overall ability of such models to produce boulder wakes appears realistic. Pasternack *et al.* (2006) report an average depth deviation of 21% and an average velocity deviation of 29%. The differences between simulated and observed depths and velocities obtained here are similar. The difficulties in obtaining precise, well-controlled measurements in natural streams and the unavoidable effects of spatial averaging suggest that the error distributions noted here may be typical of 2D model applications, particularly those where large objects (object height is greater than one-half depth) are present.

Implications for habitat modelling

Use of the momentum equations in 2D hydrodynamic models ensures that the forces causing lateral components of flow are recognized, though the vertical averaging produces certain limits. Thus, 2D modelling tools can describe the overall flow field in complex channels and are attractive for use in habitat simulation. The realistic plan view

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maps of depth and velocity produced by 2D models are useful in analysing and explaining habitat occurrence in rivers; however, the error characteristics noted above must be recognized when performing physical habitat calculations.

One would expect modelled velocities to better agree with observed velocities in areas with fully developed flow and minimal opportunity for development of strong secondary currents. That is, areas in regular channels away from large objects. Figure 9 shows that the relatively small average velocity simulation errors occurring upstream of the boulders appear to bear this out.

The differences in modelled and observed depth and velocity values described here cannot be specifically attributed to the model, but to a combination of issues including undetected blunders, depth and velocity sampling method, flow field complexity and model simplification. Both slack water (wakes) and high velocity areas shown in the model results correspond to those observed in the field. The majority of velocity differences were near or within the estimated error of measurement ($\pm 0.1\ \mathrm{m\,s^{-1}}$) for turbulent conditions, but some were quite large.

The equipment and procedures used to measure depth and velocity used in this example are typical of that used to measure streamflow variables when developing biological response criteria for habitat modelling and in studies applying these concepts in a decision support role. Thus the forms, frequencies and magnitudes of measurement error described here are also likely to exist in habitat studies.

The shape of the habitat suitability criteria strongly influences the effects of depth and velocity simulation error. When an organism can fully utilize a broad range of a variable (e.g. depth from 0.5 to 1.1 m in Figure 3) the effects of simulation errors are minimized. In contrast, when the habitat suitability index exhibits a large change, such as from 0.0 to $0.15\ \mathrm{m\,s^{-1}}$ as shown for the velocity criteria in Figure 3, simulation errors may result in substantially different calculated habitat values. Though the largest deviation in habitat values derived from measured compared to simulated conditions (13.59%) occurred at the high flow, the trend of declining habitat with increasing discharge was the same for both observed and simulated conditions. This suggests that, though simulation error is present, it does not dominate the calculated habitat response.

The overall symmetry of the depth and velocity error distributions described in Figures 4 and 7 above suggests that the differences between habitat values derived from observed and simulated conditions will exhibit similar symmetry. However, Figure 10 shows there is some tendency toward under-prediction of habitat values in this study. This bias is likely related to the locations sampled at the high flow as noted above. Care taken in all of the data collection, synthesis, model calibration and simulation steps will act to reduce the magnitude of depth and velocity simulation error and thus potential differences in calculated habitat outcomes.

Is the 2D approach accurate?. When using a 2D hydrodynamic model to describe aquatic habitat conditions, care must be taken to recognize that the response function that translates physical conditions into a biotic variable may be sensitive to the magnitudes and varieties of error described in this study. In particular, response functions with high rates of change over the range of velocity conditions found in the stream need particular scrutiny. The symmetry of positive and negative velocity errors found in this study suggests that the overall flow field produced by River2D, even in areas of known difficulty due to secondary currents, is represented without substantial systematic bias. The weak tendency to under-predict lower and over-predict higher velocities should be addressed in other, more uniform channels to determine if the River2D model (or other 2D models) introduces systematic bias into the velocity simulations or if this is an artefact of the collected data set.

As noted earlier, the overall accuracy expected from 2D models of rivers depends on accuracy of the data, the model set-up and the model formulation. In this example, errors found in data collection were removed from the sample, differences between simulated and observed conditions that appeared to be due to discretization of the computational mesh were noted, and differences that may be due to model formulation were considered. The relative magnitudes of the latter two sources of error are about the same, thus they are not clearly distinguishable using the data reported here. And they may be difficult to extract from other data as well.

The habitat differences found here have strong central tendency but reflect the under-prediction seen at the high flow in Table III. When using aggregate metrics such as WUA, such errors would be masked by summation. However, spatially explicit models such as individual based models (Grimm and Railsback, 2005) may be more sensitive to these errors. When adequate quality control is exercised at the data collection and synthesis stages, and at the model set-up and calibration stages, the overall effect of the kinds of error discussed above can be minimized. The errors found here suggest that applications of 2D models in channels with structures such as boulders are likely to be generally accurate in representation and appropriately scaled in magnitude when considering habitat response over a range of discharges, though point variation can be high.

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