The Influence of Multiple Velocity Calibration Sets on the PHABSIM Habitat Index

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Abstract:

One hundred instream flow study data sets with three or more complete measured velocity sets were analyzed using the Physical Habitat Simulation Model (PHABSIM) to evaluate the influence of multiple velocity data sets on habitat index results. Four generic sets of habitat suitability criteria were processed through PHABSIM using multiple velocity set regression, high, middle, and low single-velocity set Manning's simulation, and depth calibration. Percentage differences in habitat indexes for each method were calculated at each calibration flow using the result from each single-velocity set as a standard. Percentage differences at the extrapolation boundaries were computed for each method using the extrapolation indexes from the low and high single-velocity sets as standards. The three-velocity calibration mode for interpolation within the range of measurement and the single-velocity calibration mode for extrapolation beyond the highest and lowest velocity sets generates the least difference from the standards. Use of a single, highest-velocity data set, however, will generate habitat index results that deviate only slightly from those incorporating three or more velocity sets. This analysis indicates that the acquisition of additional velocity calibration data requires an expenditure that might be better used on other aspects of an instream flow study.

Introduction

Instream Flow Information Paper No. 5. Hydraulic Simulation in Instream Flow Studies: Theory and Techniques (Bovee and Milhous 1978) was the culmination of an intense effort to research, develop, and test a number of methodologies for assessing the instream flow needs for fish, wildlife, water quality, recreation, and aesthetics (Milhous et al. 1984). This and subsequent papers by the Instream Flow Group described three hydraulic simulation models and one habitat simulation model (in various forms) for evaluating the effects of water diversion on species of interest. Collectively known as PHABSIM (physical habitat simulation), the models simulate water depth, water velocity, and substrate composition or cover over a range of flows and match these variables with respective suitability criteria for aquatic species of interest. The three hydraulic models, WSP (Water Surface Profile), MANSQ (Manning's Stage Discharge), and IFG4 (Instream Flow Group Model #4) use various algorithms to simulate stream depths, IFG4 is used to simulate water velocities, and the HABTAE model (and variants) combines the hydraulics with biological criteria to compute a weighted index to habitat suitability.

Of the three hydraulic models, IFG4 is the more versatile combined model for assessing impacts on riverine fish species (Wesche and Rechard 1980). Unlike WSP, IFG4 is not restricted to use on low gradient rivers or streams, single transects can be used, and calibration of the data is generally simpler. While MANSQ can also be used on single transects, it is most applicable to hydraulic control transects. Whichever model is used to simulate stage-discharge rating curves (including HEC-2 or other external models), IFG4 is used for velocity simulation. IFG4 has remained in use from the time of its development in

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1978 and, with refinements, has become the most commonly applied PHABSIM model today. It is used under a wide range of conditions and for all riverine habitat types worldwide (Mosley and Jowett 1985; Moyle and Baltz 1985).

The IFG4 model was originally configured to use three or more sets of stage and transect velocity measurements taken at high, middle, and low flow. These data sets computed the least-squares regression fit of log stage against log discharge for each transect and log velocity against log discharge for each vertical on each transect. This method of transect-vertical velocity calibration can be checked internally for quality control with errors of regression (velocity prediction errors) and the slope of the regression line, and subsequently used to simulate velocities for other flows. When fewer than two calibration velocities are available at a vertical, Manning's equation (Bovee and Milhous 1978) is used by IFG4 for velocity simulation at that vertical for all flows. Negative velocities are simulated with a semi-log fit of velocity against log of discharge, and dry cell velocities are simulated (when they become wetted) with Manning's n values borrowed from adjacent cells.

Two other velocity simulation methods are optionally available within IFG4, one using a single velocity set and the other no measured velocities. The "IFG4A", "one-flow", or "one-velocity" technique uses one set of measured velocities for all verticals at a calibration flow and solves Manning's equation on an individual cell basis (with depth in place of hydraulic radius) to derive a roughness or velocity distribution factor. The Manning's n values derived from the calibration flow are used as a template to predict velocities at all other discharges. Change in roughness with discharge is compensated by the use of the velocity adjustment factor, which changes the discharge first computed by the Manning's values (and applicable only to the calibration flow) to the new simulated discharge. The one-velocity IFG4 method can be used with any number of velocity sets, either restricted to near the calibration flows or extrapolated over the range of flows allowed by the model rating curves.

The third method, called the "no-velocity" or depth calibration option, requires only a rating curve and bottom profile and uses no velocity measurements. Instead, velocities at verticals for any flow are predicted by the Manning's equation and depth at that vertical. A default Manning's n value (0.06), common to all verticals, is used to compute initial discharge, and this discharge is changed by the velocity adjustment factor to equal the simulated discharge. In effect, neither the default Manning's n nor the velocity adjustment factors are relevant to the resulting velocities, since a known stage, known discharge, and known bottom profile can have only one velocity pattern. This option lacks "starting point" velocities and produces a velocity pattern the mirror image of the bottom profile, where greater depths have higher velocities. Depth calibration is most useful in deep pools where accurate velocity measurement is difficult and at very high extrapolation flows where measured patterns of velocity are unlikely to be retained.

When the three-flow regression configuration of IFG4 is applied to high gradient streams or streams containing many large bed elements (e.g. boulders), regression errors in velocity prediction can be large. Errors can be caused by moving counter-currents and shear zones around large boulders, high velocity chutes between boulders or over falls, and an abundance of local hydraulic controls that alter "normal" patterns of velocity change with discharge. Under these conditions, the regression model performs poorly, and both extrapolative and interpolative capabilities are more limited than on low gradient, valley-type rivers (Milhous 1985). With increasing realization that the assumptions behind three-flow IFG4 regression are often violated, the Instream Flow Group issued an advisory against further use of velocity regression (Milhous and Schneider 1985). Washington State instream flow study guidelines, however, still specify preferred use of three-flow velocity regression (Beecher et al. 1996).

Although some model-users have had misgivings about the overall accuracy of velocity simulation from single "point velocities", others believe the one-velocity option in many cases has a wider range of predictive capability than three-velocity regression (Milhous 1984, Payne 1987). Several researchers have compared either cell-by-cell velocities or the overall habitat indexes resulting from the different model options (Hilgert 1982, Trihey and Baldrige 1985, Bremm 1988, Payne 1988). The current practice regarding the number of velocity sets to be obtained is mixed and depends on varying state requirements and the experience of participants. Most instream flow studies since the late 1980's have used only a single velocity calibration set collected at either a high or middle flow, which is used to simulate velocities over the full range of flows. In some cases, both high and low flow velocity sets are required by participating resource agencies, with the low flow set intended to provide validation to the downward habitat index extrapolations. The purpose of this study is to provide a statistical evaluation of net differences in habitat indexes to judge the value of collecting multiple velocity sets.

Methods

One hundred IFG4 data files containing at least three complete sets of velocity measurements on all transects were extracted from the PHABSIM study archive library maintained by Thomas R. Payne & Associates. Approximately 40% of the studies which produced the files were for hydroelectric projects on small, high gradient streams, 35% were on large, lower gradient rivers for either water rights or irrigation/hydropower project evaluation, some were intermediate, and some could not be classified due to insufficient information (Table 1).

Table 1. Stream size, gradient, sample size, and median number of transects per study site for 100 test reaches.

Stream Category (size/gradient)	Sample Size
Small/High Gradient	40
Small/Low Gradient	4
Small/Unknown Gradient	2
Medium/High Gradient	7
Medium/Low Gradient	2
Large/High Gradient	5
Large/Low Gradient	35
Unknown Size/Unknown Gradient	5
Total	100
Median Number of Transects	8

Each data file was minimally re-calibrated to produce realistic velocities over the range of flow from 40% of the measured low flow to 250% of the measured high flow. When the calibration of all the data sets was complete, the hydraulic files were linked with generic habitat suitability criteria (Table 2). The criteria were created to represent the range of possible actual criteria, including deep/slow, deep/fast, shallow/slow, and shallow/fast. The third standard variable in a PHABSIM study (substrate and/or cover) was not included, since (with some exceptions) it functions only as a scaling factor for the resulting habitat index. Habitat index values were computed for both continuous flows over the full range (for graph comparisons) and for only the three calibration flows and two extrapolation-limit flows (for statistical comparisons).

Table 2. Generic habitat suitability criteria for combinations of depth and velocity in deep/slow, deep/fast, shallow/slow, and shallow/fast.

Slow		Fast	
Velocity m/s	Suitability	Velocity m/s	Suitability
0.0	1.0	0.0	0.0
0.1	1.0	0.25	1.0
0.5	0.0	0.50	1.0
		1.0	0.0
Shallow		**Deep**	
Depth m	Suitability	Depth m	Suitability
0.0	0.0	0.0	0.0
0.25	1.0	.25	0.0
0.5	1.0	.50	1.0
1.0	0.0	1	1.0
		10	0.5

Tables of results were prepared containing the habitat index values produced by the five velocity simulation methods for the four generic HSC. The differences between habitat index values were then calculated using each one-velocity index result and the 40% and 250% low and high one-velocity extrapolation index results as standards for comparison. These differences were expressed in percent, and the absolute values for the mean percent difference, standard deviation of the mean, and the median were calculated, along with the true median. Absolute values were used to show the magnitude of differences and true values were used to show over or under-simulation bias. A similar analysis was performed on the data sets after they were stratified by small/high gradient (n=40) and large/low gradient (n=35) classification to test the effect of hydraulic complexity on differences.

Comparison of results among the various velocity methods was done with the habitat index rather than with cell-by-cell velocities because the habitat index is the decision making metric of PHABSIM under the Instream Flow Incremental Methodology (Bovee et al. 1998). If any differences in velocity created by the methods do not translate into differences in the habitat index (Bremm 1988), the differences are then irrelevant for all practical purposes and excessive concern for accurate cell-by-cell velocities would be misplaced.

Results

An example of the results from one of the 100 test data sets is shown in the upper portion of Figures 1-4 for the four generic HSC, respectively. These graphic results are fairly typical and representative of the remaining 396 graphs. The response of the habitat index for the three-velocity regression method using deep/slow HSC (Figure 1) shows good general correspondence with the three one-velocity methods, except for the range for upwards extrapolation. The low flow one-velocity method and the mid flow one-velocity method both over-estimate the habitat index on extrapolation, while the depth-calibration method under-estimates. All five methods show strong convergence with extrapolation to flows below the low calibration flow. The divergence of each method from the five "target" flow level habitat index values is shown in the lower half of each paired figure.

The deep/fast HSC results in this case (Figure 2) show close correspondence between the three-velocity and the high-flow one-velocity methods, and the low and mid-flow one-velocity methods slightly under-estimate the habitat index over the higher flow range. The depth calibration method over-estimates within the range of the measured data and under-estimates at the high extrapolation range. The flow where the index maximizes is similar for all methods and the indexes also all converge with downwards extrapolation. Results for shallow/slow (Figure 3) and shallow/fast (Figure 4) HSC are roughly the same as for the other criteria.

Numeric results comparing the various HSC and methods against target values are shown in Tables 3 and 4. Using deep/slow HSC as an example, the three-velocity method simulates the 40% low target (produced by extrapolation from the low-flow one-velocity method) within an absolute value mean of 2.85% (SD 4.73), absolute value median of 0.82%, and true median of −0.12%. The high-flow one-velocity method simulates the same 40% low target within an absolute value mean of 1.27% (SD 1.82), absolute value median of 0.48%, and true median of 0.08%. Both of these methods show high accuracy at simulating the target, with the high-flow one-velocity method being slightly better. At the higher extrapolation range, the three-velocity regression method simulates the 250% target (produced by extrapolation from the high-flow one-velocity method) within an absolute value mean of 29.53% (SD 34.44), absolute value median of 20.13%, and true median also of 20.13%. The depth-calibration method simulates the target within an absolute value mean of 87.71% (SD 122.50), absolute value median of 89.82%, and true median of –88.17%. The absolute value median and true median being nearly the same for the regression prediction indicates close to universal over-prediction of the target, and for the depth-calibration method, where the two values are nearly the same but opposite in sign, means close to universal underprediction.

Frequency histograms of the numeric results comparing the various HSC and methods against target values are shown in Figures 5-8. Again using the example of the three-velocity regression method for deep/slow HSC to predict the 40% low extrapolation target, Figure 5 (upper left corner) shows the pattern of percent difference to be clustered around zero, which is consistent with an absolute median value of 0.82%. Only a few differences are greater than 10% for this method in simulating the low target. The results from the high-flow one-velocity simulation in Figure 5 top row, middle left) shows a pattern consistent with an absolute value median difference of 0.48%, and few differences are much greater than 5%. On the high end, the three-velocity regression method can be seen (Figure 5, lower left corner) to consistently over-predict the 250% extrapolation target, and the depth-calibration method (Figure 5, lower right corner) consistently under-predicts. All other tables and figures can be similarly interpreted.

Stratification of the 100 test data sets into small high-gradient and large low-gradient stream-type classifications generated results shown in Tables 5-8 for the four HSC types. The differences from targets for the two strata are presented side-by-side in each table for direct comparison. Almost all percent differences for the methods, the HSC, and the targets tend to be lower for large low-gradient rivers than for small high gradient streams. Since larger rivers are not as influenced by large bed elements and have fewer complex hydraulic controls (and therefore less localized variability in depth and velocity), this result should not be unexpected.

Discussion

Interpretation of this data shows that the three-velocity regression index always has the lowest median percentage difference from the index at the target calibration flows of any method. For extrapolation to higher flows, however, three-velocity regression can generate differences from the target as high as an absolute value median of 20%. For extrapolation to lower flows there appears to be little difference in any of the methods, including depth calibration. Using either the high or mid-flow one-velocity to extrapolate downwards will do slightly better than either the three-velocity regression or depth calibration methods. These conclusions are the same as stated in Payne (1988), which relied on a smaller number of data sets, used only two HSC, and made no comparison of statistics.

The most accurate method overall is the use of each separate one-velocity set to extrapolate downwards to the next lower flow; absolute value median and true median differences are generally lower than three-velocity regression. There does remain some difference between the simulated habitat index and the target index with this method, which leaves the need to join the lines at the point of overlap. When the Instream Flow Group dropped support for three-velocity regression, they suggested using the one-velocity method to interpolate from each calibration flow halfway to the next (Milhous 1985a). Since neither the low or mid-flow one-velocity methods matches the habitat index well for the next higher flow, the line matching problem becomes more difficult with this approach.

The high flow one-velocity method over the full range of flow does not lead to line-overlap problems and still simulates each interpolation target habitat index nearly as well as the three-velocity regression. Absolute value median differences between the two methods are all within 4% and several are within 1%. Upwards extrapolation with the high flow one-velocity method is clearly superior to the three-velocity regression (statistically and visually) and the method also does not need as much field effort for data acquisition. The minor improvement in habitat index simulation produced by three full velocity data sets must be balanced against study costs. In many cases, more transects could be included in a study for the same price as multiple velocity sets and are likely to yield a better product. Collection of a low flow set of velocities adds little to a study – all methods simulate downwards exceptionally well and low flow velocities alone (without high and mid flow velocities also) are not sufficient to yield even the minor improvements of three-velocity regression.

The downwards convergence of the habitat indexes for all velocity algorithms might be surprising but has a logical explanation. For any study using the three habitat variables of depth, velocity, and substrate and/or cover, only velocity has the potential to be different and affect the habitat index. Depth at each sample point is computed from the bottom profile and the rating curve (which is calibrated independently), and will be the same regardless of velocity simulation method. The channel index for substrate/cover is fixed in the data at each sample point and does not change with either stage or velocity method. The only remaining variable is velocity and, as flows tend toward zero, all velocities will also approach zero (through the function of the IFG4 velocity adjustment factor), and all velocity methods will result in nearly identical habitat indexes.

References

1. **Beecher, H.A., B.A. Caldwell, and J. Marti. 1996.** Instream flow study guidelines. Washington State Department of Fish and Wildlife and Department of Ecology Water Resources Program, Olympia, Washington. Memorandum dated 5/16/95. 58pp.

2. **Bovee, Ken D. and Robert T. Milhous. 1978.** Hydraulic Simulation in Instream Flow Studies: Theory and Techniques. Instream Flow Information Paper No. 5. Cooperative Instream Flow Service Group, Fort Collins, CO. 131pp.

3. **Bremm, D.J. 1988.** Comparison of stream velocity simulations for the IFG4 model three-flow, one-flow, and no-velocity options. M.S. Thesis, Humboldt State University, Arcata, CA. 54pp.

4. **Hilgert, P. 1982**. Evaluation of instream flow methodologies for fisheries in Nebraska. Nebraska Technical Series Number 10. Nebraska Game and Parks Commission, Lincoln, Nebraska.

5. **Mosley, M.P., and I.G. Jowett. 985.** Fish habitat analysis using river flow simulation. New Zealand Journal of Marine and Freshwater Research 19:293-309.

6. **Milhous, R.T. 1984.** Technical Note No. 4: the use of one velocity calibration data set with IFG4. United States Fish and Wildlife Service, Fort Collins, Colorado. 6 pp.

7. **Milhous, R.T. 1985a.** Seminar on hydraulics in PHABSIM, IFG 402. U.S. Dept. Interior, Instream Flow Group. Nov. 13-14, 1985, Seattle, WA.

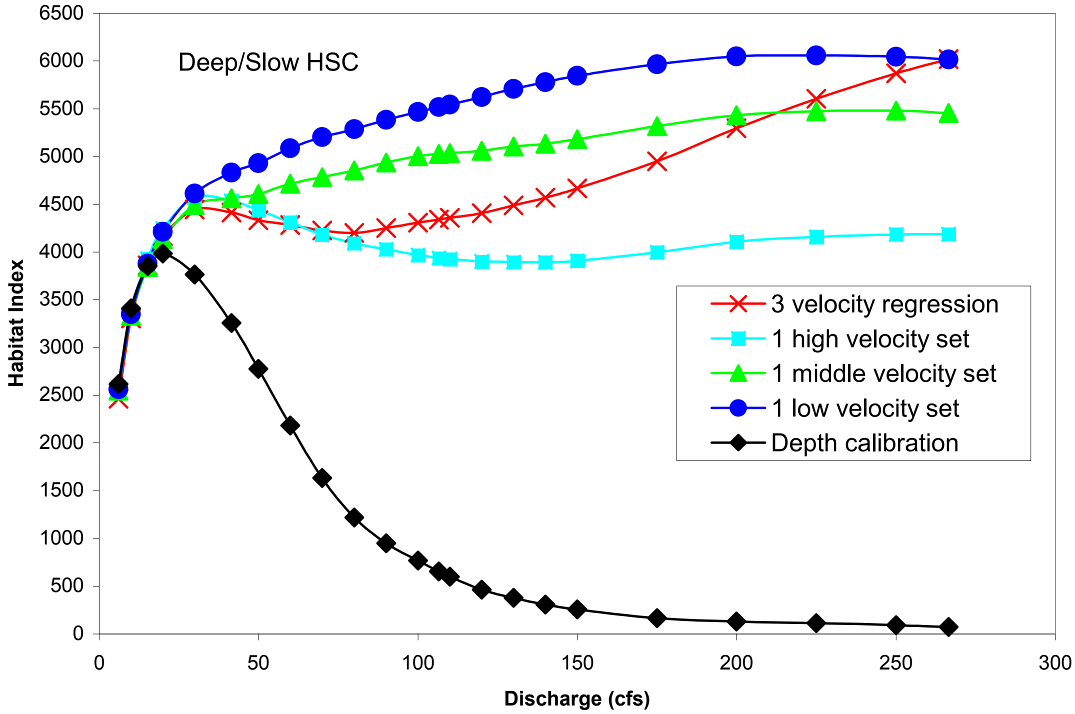
8. **Milhous, R.T. 1985b.** Technical Note No. 19: impact of alternative assumptions in hydraulic simulation on the results from Physical Habitat Simulation System. Cooperative Instream Flow Group, Ft. Collins, Colorado.

9. **Milhous, R.T. and D.M. Schneider. 1985.** Memorandum to PHABSIM users concerning PHABSIM modifications and use of IFG4. Dated October 4, 1985. U.S. Dept. Interior, Instream Flow Group, Ft. Collins, CO. 3pp.

10. **Payne, T.R. 1987.** One-flow IFG4 - what it is and how it works. Instream Flow Chronicle 4(1):1-2. Colorado State University, Fort Collins, Colorado.

11. **Payne, T.R. 1988.** A comparison of weighted usable area calculations using four variations of the IFG4 hydraulic model. Paper presented at AFS Bioengineering Symposium, October 24-27, 1988, Portland, Oregon.

12. **Trihey, E.W., and J.E. Baldrige. 1985.** An empirical approach for evaluating microhabitat response to streamflow in steep-gradient, large bed-element streams. Pages 215-222 *in* F.W. Olson, R.G. White, and R.H. Hamre, editors. Proceedings of the Symposium on Small Hydropower and Fisheries. 1-3 May, Aurora, Colorado. American Fisheries Society, Bethesda, Maryland. 497pp.



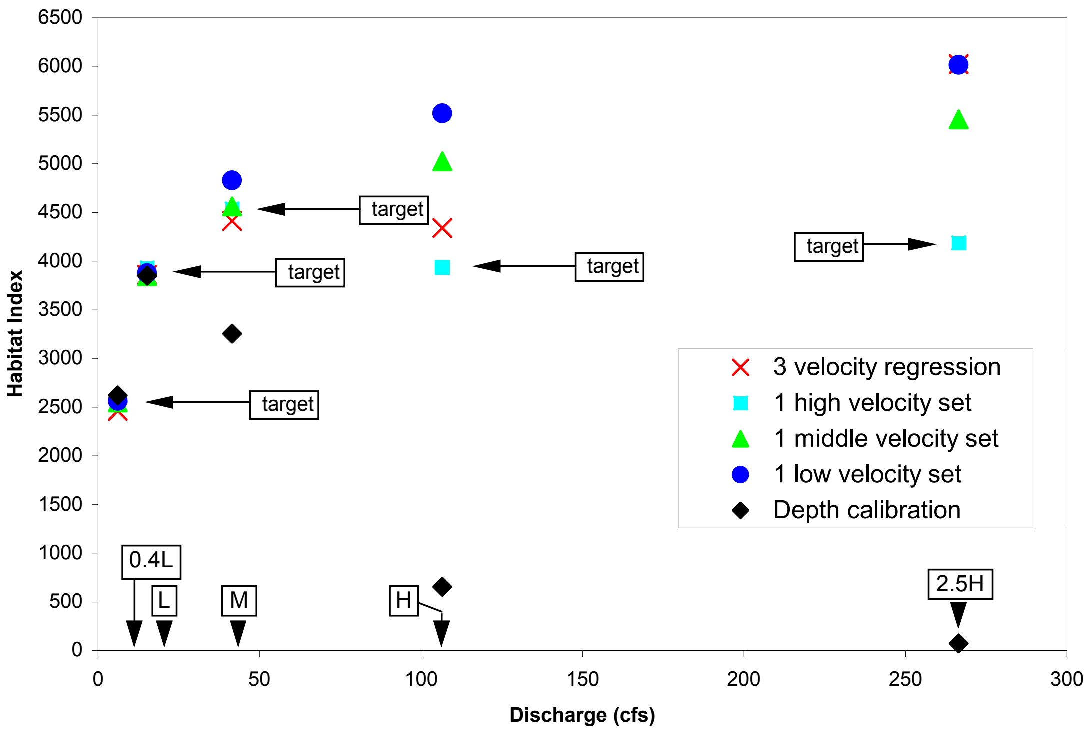


Figure 1. Example of habitat index predictions for five velocity simulation methods over a range of flows (top) and five target flow levels consisting of each calibration flow and 40% of low and 250% of high calibration flow (bottom) for deep/slow habitat suitability criteria.

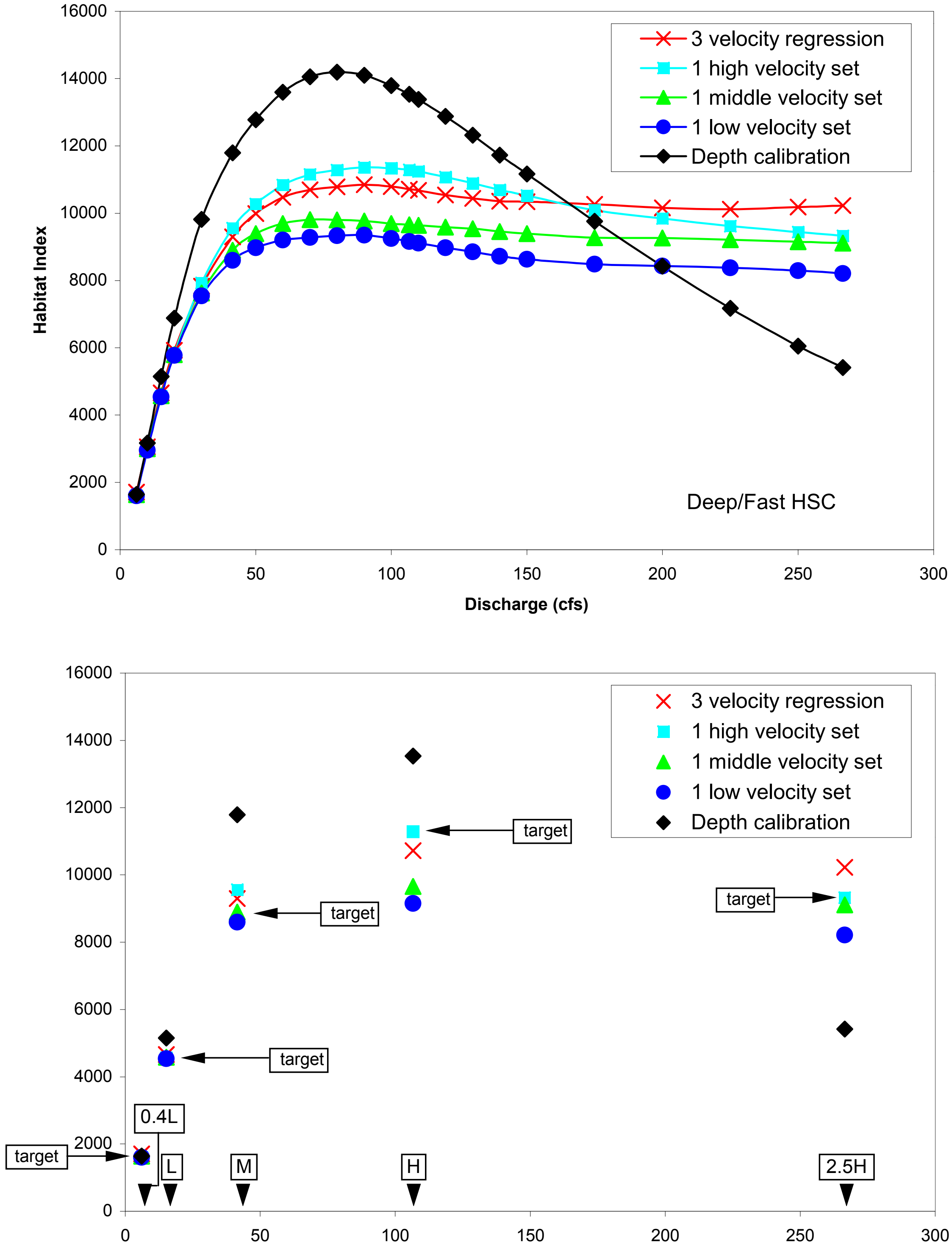
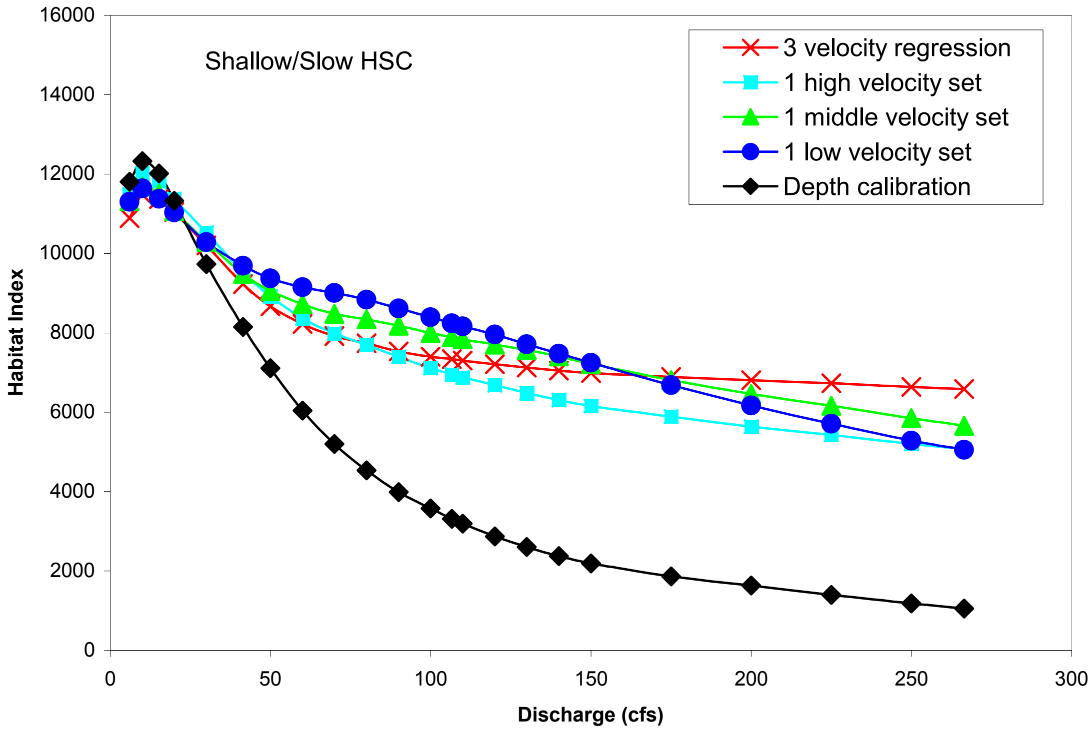


Figure 2. **Example of habitat index predictions for five velocity simulation methods over a range of flows (top) and five target flow levels consisting of each calibration flow and 40% of low and 250% of high calibration flow (bottom) for deep/fast habitat suitability criteria.**



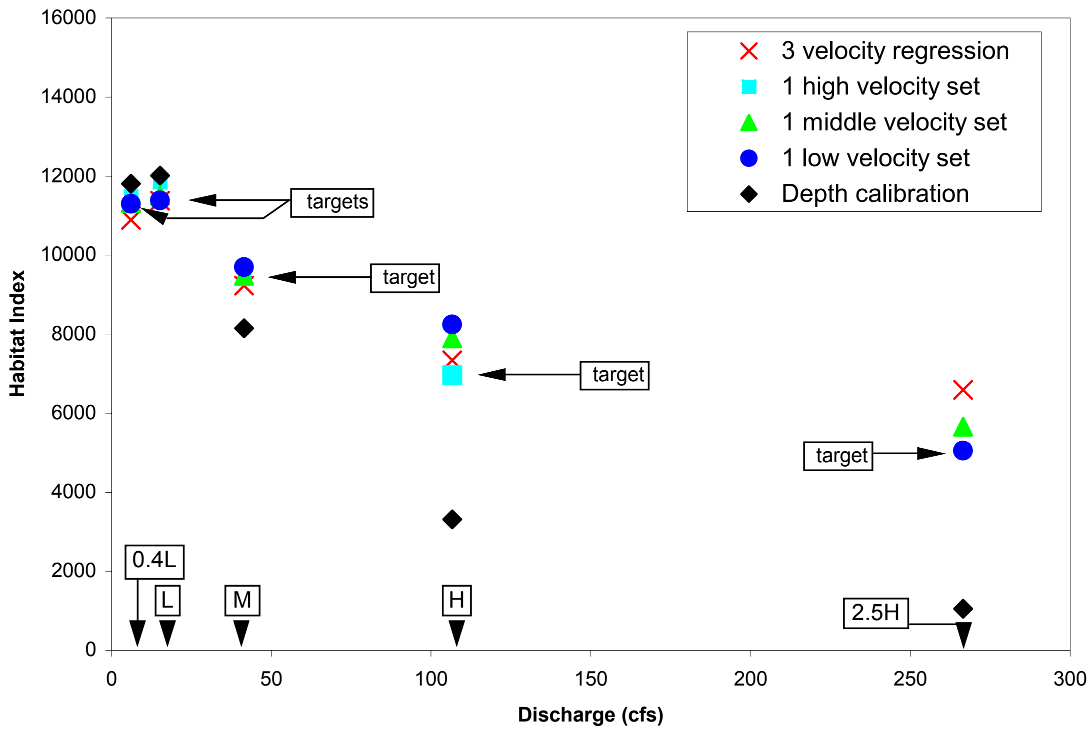


Figure 3. Example of habitat index predictions for five velocity simulation methods over a range of flows (top) and five target flow levels consisting of each calibration flow and 40% of low and 250% of high calibration flow (bottom) for shallow/slow habitat suitability criteria.

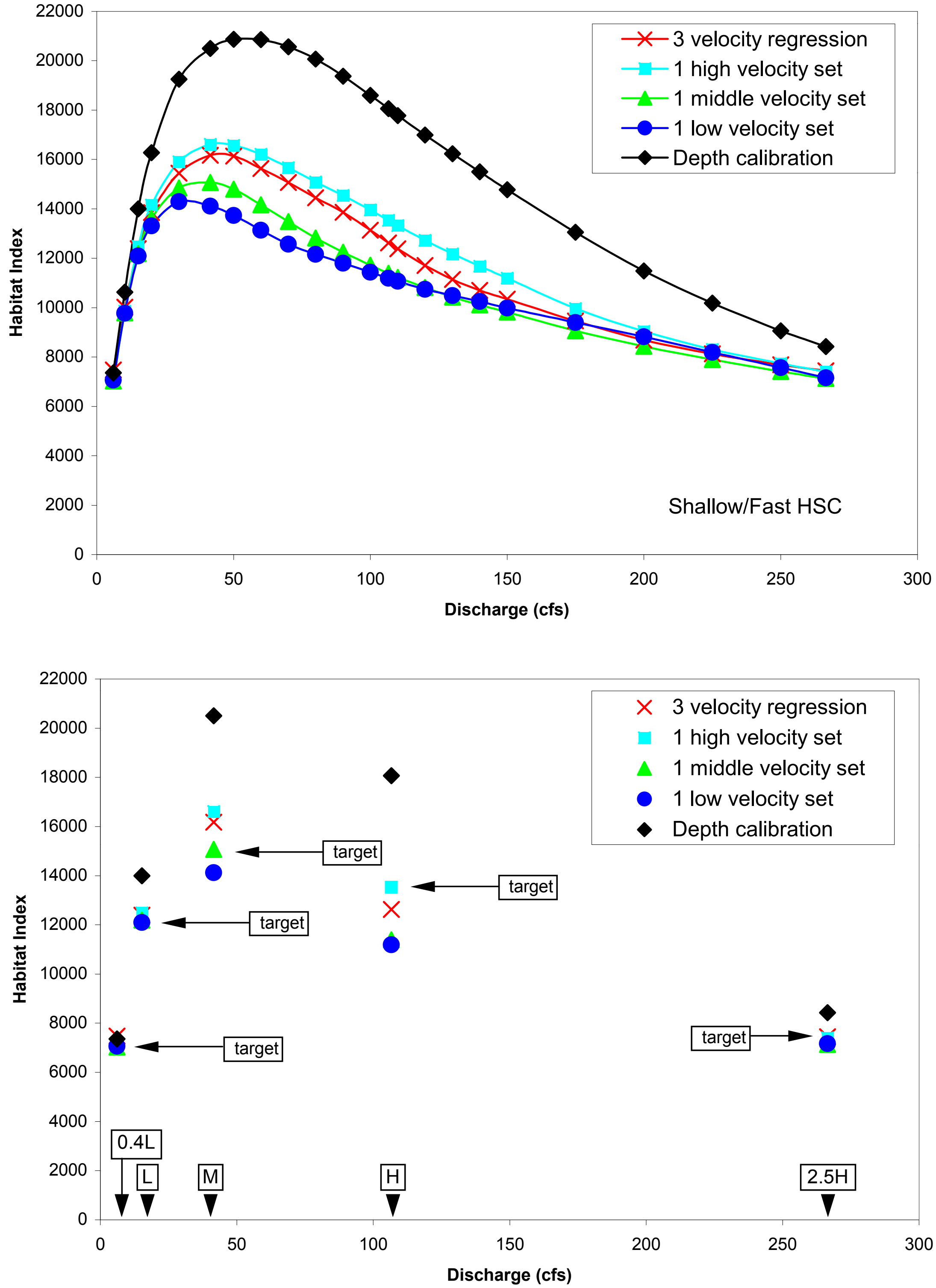


Figure 4. Example of habitat index predictions for five velocity simulation methods over a range of flows (top) and five target flow levels consisting of each calibration flow and 40% of low and 250% of high calibration flow (bottom) for shallow/fast habitat suitability criteria.

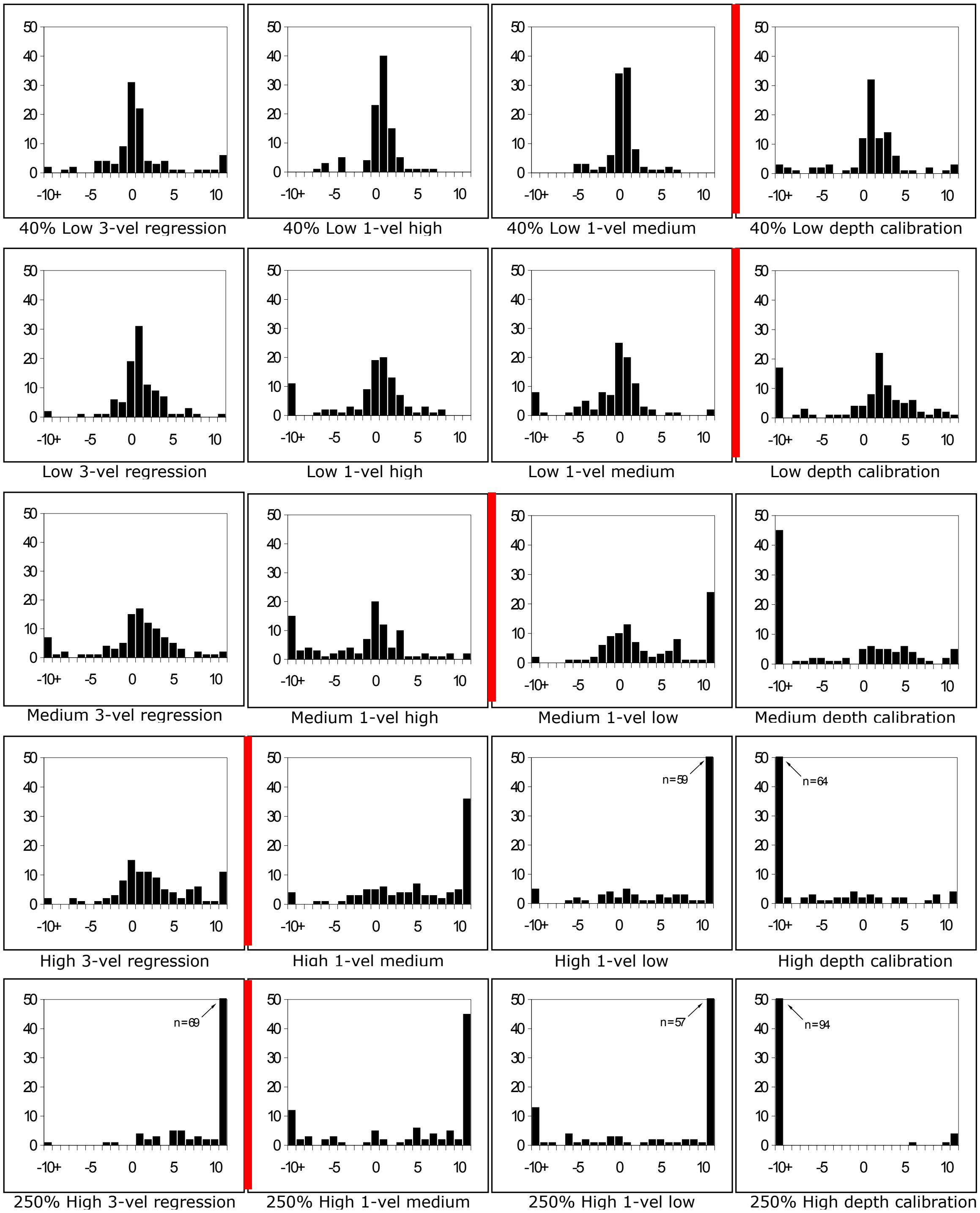


Figure 5. Frequency histograms of percent difference in habitat index predictions for five velocity simulation methods and five target flow levels for deep/slow habitat suitability criteria. Red lines denote missing histogram for target-target comparison.

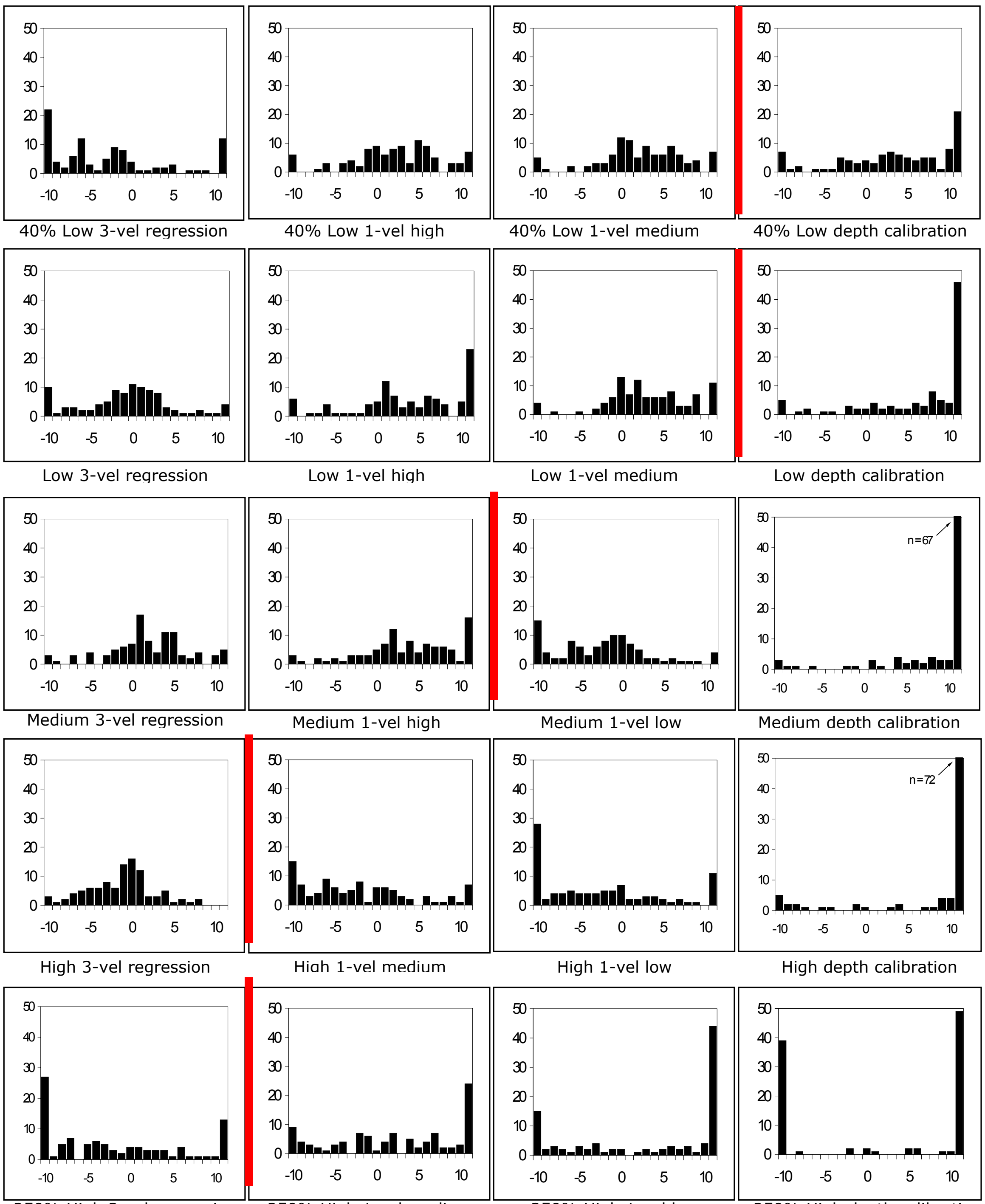


Figure 6. Frequency histograms of percent difference in habitat index predictions for five velocity simulation methods and five target flow levels for deep/fast habitat suitability criteria. Red lines denote missing histogram for target-target comparison.

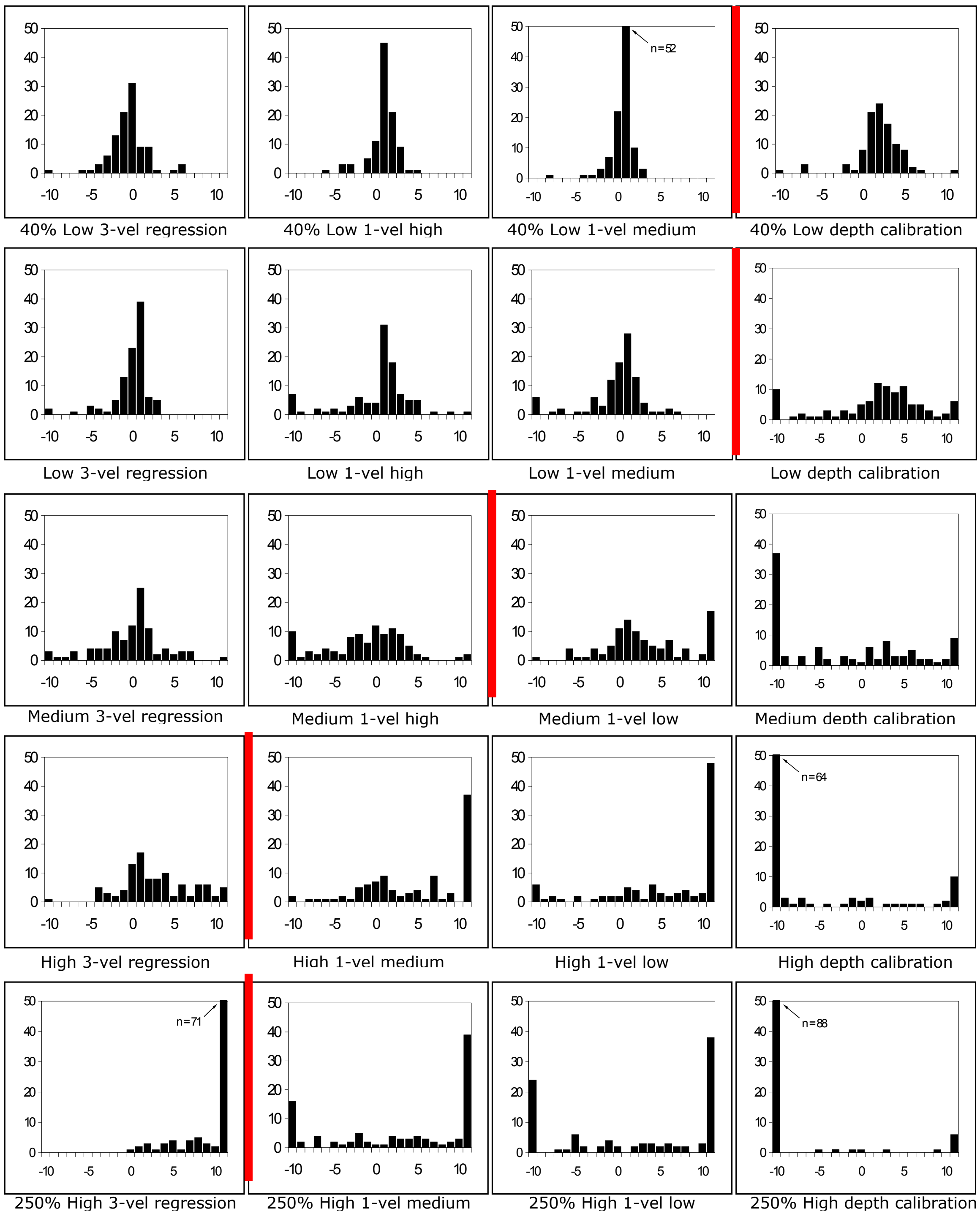


Figure 7. Frequency histograms of percent difference in habitat index predictions for five velocity simulation methods and five target flow levels for shallow/slow habitat suitability criteria. Red lines denote missing histogram for target-target comparison.

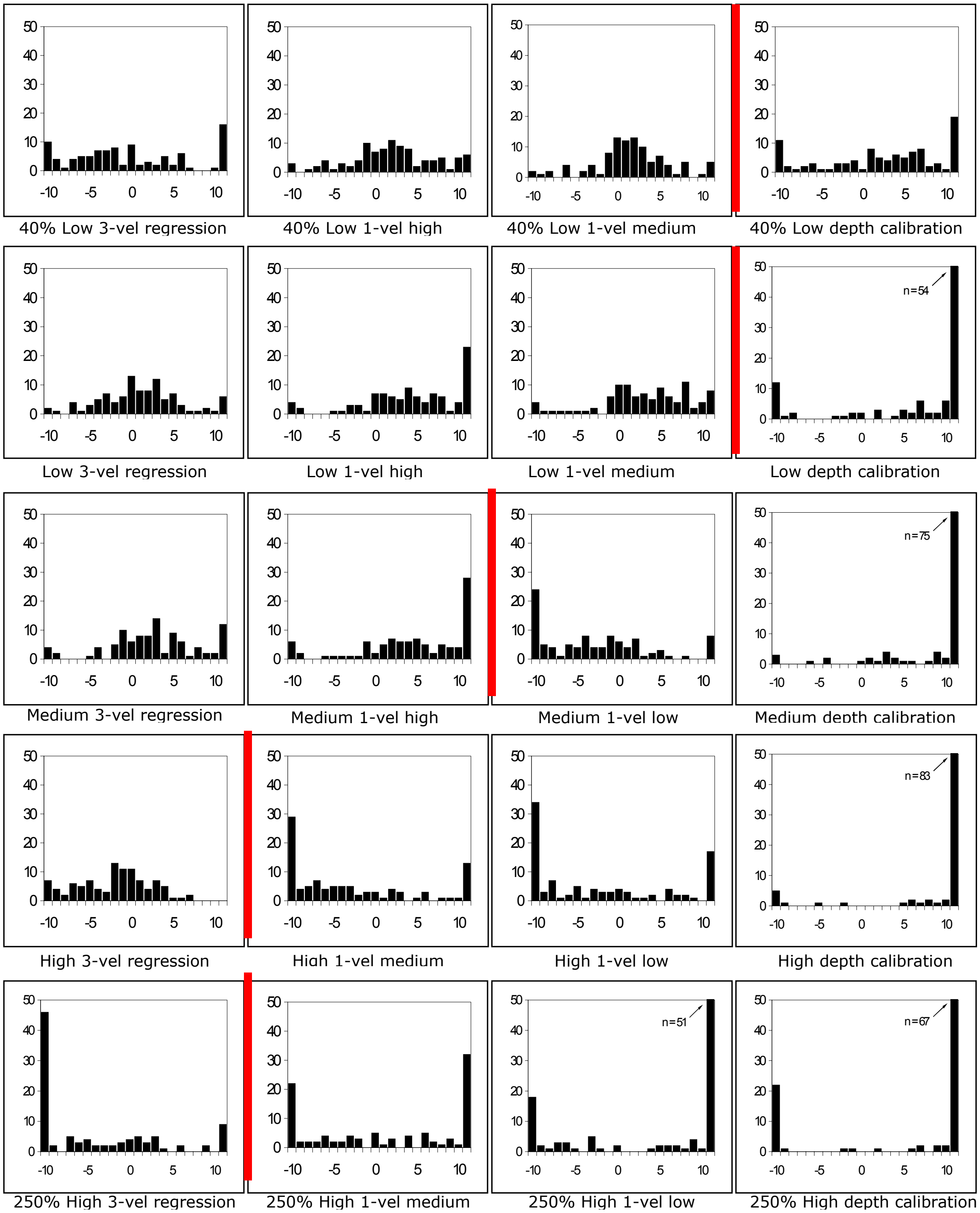


Figure 8. Frequency histograms of percent difference in habitat index predictions for five velocity simulation methods and five target flow levels for shallow/fast habitat suitability criteria. Red lines denote missing histogram for target-target comparison.

Table 3. Absolute value mean, standard deviation and median, and true median of percent difference between habitat index for five velocity methods and habitat index for target flows for deep/slow and deep/fast habitat suitability criteria in 100 test reaches.

Deep Slow

40% Low		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
	AV mean	2.85	1.27	1.10	0.00	22.23
	AV SD	4.73	1.82	1.59	0.00	194.54
	AV median	0.82	0.48	0.39	0.00	1.24
	True median	-0.12	0.08	0.01	0.00	0.41

Low		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
	AV mean	1.96	3.82	3.28	0.00	26.04
	AV SD	2.91	6.49	5.56	0.00	170.42
	AV median	1.01	1.26	1.17	0.00	2.94
	True median	0.27	0.01	-0.37	0.00	1.35

Medium		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
	AV mean	3.86	5.73	0.00	11.68	38.34
	AV SD	6.17	8.17	0.00	28.45	164.69
	AV median	2.09	2.58	0.00	3.05	9.83
	True median	0.42	-0.59	0.00	1.59	-5.17

High		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
	AV mean	4.42	0.00	15.50	36.36	56.96
	AV SD	6.02	0.00	26.32	92.57	139.60
	AV median	2.23	0.00	7.54	15.07	40.47
	True median	1.37	0.00	5.92	14.46	-30.48

250% High		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
	AV mean	29.53	0.00	26.90	43.63	87.71
	AV SD	34.44	0.00	33.59	90.55	122.50
	AV median	20.13	0.00	15.48	19.99	89.82
	True median	20.13	0.00	8.41	13.97	-88.17

Deep Fast

40% Low		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
	AV mean	13.57	5.37	4.92	0.00	16.51
	AV SD	20.44	6.61	5.72	0.00	81.35
	AV median	6.91	4.11	3.45	0.00	6.09
	True median	-3.78	2.04	2.01	0.00	3.81

Low		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
	AV mean	5.24	7.32	5.36	0.00	17.25
	AV SD	7.39	7.29	6.51	0.00	35.82
	AV median	2.64	5.94	3.38	0.00	10.20
	True median	-0.67	3.82	2.09	0.00	9.16

Medium		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
	AV mean	4.27	6.25	0.00	6.09	22.88
	AV SD	4.91	5.84	0.00	6.67	22.66
	AV median	3.29	5.05	0.00	4.01	19.54
	True median	1.17	3.71	0.00	-2.57	19.54

High		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
	AV mean	3.34	0.00	7.20	9.83	25.85
	AV SD	3.30	0.00	5.97	9.42	16.89
	AV median	2.27	0.00	6.33	7.44	23.29
	True median	-1.36	0.00	-3.44	-4.50	22.56

250% High		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
	AV mean	10.46	0.00	11.56	20.55	39.93
	AV SD	10.27	0.00	13.86	24.31	27.97
	AV median	7.85	0.00	6.93	13.24	31.79
	True median	-4.12	0.00	1.86	7.78	9.20

Table 4. Absolute value mean, standard deviation and median, and true median of percent difference between habitat index for five velocity methods and habitat index for target flows for shallow/fast and shallow/slow habitat suitability criteria in 100 test reaches.

Shallow Fast

40% Low		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
	AV mean	9.88	4.71	3.71	0.00	8.14
	AV SD	16.97	4.94	3.85	0.00	7.21
	AV median	5.27	3.23	2.49	0.00	6.35
	True median	-2.30	1.37	1.19	0.00	3.08

Low		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
	AV mean	4.48	7.60	5.47	0.00	16.36
	AV SD	6.52	7.06	5.53	0.00	13.07
	AV median	3.00	5.26	4.27	0.00	12.51
	True median	0.37	4.03	2.86	0.00	10.95

Medium		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
	AV mean	5.80	8.00	0.00	7.93	26.33
	AV SD	7.21	6.41	0.00	7.23	18.27
	AV median	2.91	6.60	0.00	5.58	25.37
	True median	2.09	4.80	0.00	-4.28	24.19

High		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
	AV mean	4.79	0.00	10.04	14.40	37.89
	AV SD	7.08	0.00	7.17	15.74	37.06
	AV median	2.72	0.00	8.47	10.17	32.22
	True median	-2.04	0.00	-5.82	-5.29	31.88

250% High		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
	AV mean	13.10	0.00	16.49	22.49	47.98
	AV SD	11.38	0.00	18.17	19.59	42.28
	AV median	11.05	0.00	10.73	16.83	35.14
	True median	-7.22	0.00	1.24	10.62	25.91

Shallow Slow

40% Low		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
	AV mean	1.78	1.20	0.85	0.00	2.50
	AV SD	1.85	1.20	1.13	0.00	3.24
	AV median	1.27	0.91	0.59	0.00	1.87
	True median	-0.89	0.49	0.17	0.00	1.51

Low		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
	AV mean	1.52	3.23	2.40	0.00	6.95
	AV SD	2.82	4.52	3.86	0.00	10.40
	AV median	0.76	1.65	1.16	0.00	4.06
	True median	0.01	0.69	0.01	0.00	2.32

Medium		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
	AV mean	2.83	4.32	0.00	7.03	14.79
	AV SD	3.15	5.15	0.00	12.07	16.28
	AV median	1.55	2.35	0.00	3.21	9.32
	True median	0.06	-0.91	0.00	1.69	-4.29

High		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
	AV mean	3.80	0.00	11.25	20.64	30.02
	AV SD	4.03	0.00	13.83	31.16	23.17
	AV median	2.75	0.00	6.62	11.62	24.92
	True median	1.71	0.00	5.82	9.35	-23.63

250% High		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
	AV mean	23.48	0.00	18.76	26.76	56.83
	AV SD	21.65	0.00	19.19	35.63	26.60
	AV median	16.69	0.00	11.68	14.87	63.30
	True median	16.69	0.00	5.04	4.25	-60.58

Table 5. **Absolute value mean, standard deviation and median, and true median of percent difference between habitat index for five velocity methods and habitat index for target flows for deep/slow habitat suitability criteria in 40 small high gradient streams and 35 large low gradient rivers.**

Deep Slow small high gradient (n=40)

40% Low		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
Small high	AV mean	3.25	1.31	1.28	0.00	52.25
	AV SD	4.64	1.71	1.70	0.00	307.44
	AV median	1.41	0.78	0.57	0.00	1.82
	True median	-0.47	0.11	-0.01	0.00	1.28

Low		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
Small high	AV mean	2.28	2.62	2.77	0.00	50.56
	AV SD	2.32	3.48	3.58	0.00	268.90
	AV median	2.03	1.28	1.42	0.00	2.64
	True median	1.17	0.22	-0.81	0.00	1.72

Medium		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
Small high	AV mean	3.72	5.31	0.00	5.05	61.05
	AV SD	3.56	6.41	0.00	4.81	258.39
	AV median	2.73	2.53	0.00	3.16	10.29
	True median	1.36	-0.58	0.00	2.63	-7.20

High		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
Small high	AV mean	4.39	0.00	14.25	21.56	80.99
	AV SD	4.19	0.00	17.12	21.08	215.08
	AV median	2.89	0.00	7.38	14.62	50.34
	True median	2.46	0.00	5.22	14.46	-46.40

250% High		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
Small high	AV mean	29.65	0.00	23.99	37.87	106.15
	AV SD	23.58	0.00	24.88	40.36	189.85
	AV median	26.24	0.00	14.52	25.62	92.13
	True median	26.24	0.00	13.34	21.28	-91.13

Deep Slow large low gradient (n=35)

40% Low		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
Large low	AV mean	2.01	1.06	0.79	0.00	1.78
	AV SD	3.66	1.73	1.17	0.00	2.53
	AV median	0.39	0.38	0.32	0.00	0.52
	True median	0.02	0.08	0.07	0.00	0.29

Low		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
Large low	AV mean	1.64	4.90	3.99	0.00	9.05
	AV SD	3.47	8.46	7.72	0.00	15.59
	AV median	0.39	0.93	0.76	0.00	2.67
	True median	0.00	-0.03	-0.15	0.00	1.07

Medium		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
Large low	AV mean	4.05	6.07	0.00	14.64	19.08
	AV SD	9.31	11.14	0.00	29.33	26.42
	AV median	1.01	1.55	0.00	1.54	4.77
	True median	0.16	-0.47	0.00	0.43	-2.21

High		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
Large low	AV mean	4.28	0.00	16.58	49.28	32.06
	AV SD	8.32	0.00	37.58	148.07	34.74
	AV median	1.43	0.00	6.49	12.83	13.12
	True median	0.31	0.00	5.63	12.83	-13.12

250% High		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
Large low	AV mean	22.11	0.00	28.64	53.42	69.29
	AV SD	23.96	0.00	45.83	139.37	26.69
	AV median	18.11	0.00	10.36	14.82	73.04
	True median	18.11	0.00	4.17	4.32	-73.04

Table 6. Absolute value mean, standard deviation and median, and true median of percent difference between habitat index for five velocity methods and habitat index for target flows for deep/fast habitat suitability criteria in 40 small high gradient streams and 35 large low gradient rivers.

Deep Fast small high gradient (n=40)

40% Low		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
Small high	AV mean	23.50	6.23	6.65	0.00	10.28
	AV SD	28.23	6.29	5.92	0.00	9.93
	AV median	11.50	4.50	5.35	0.00	7.62
	True median	-4.35	-0.16	2.95	0.00	2.75

Low		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
Small high	AV mean	6.22	8.22	5.89	0.00	16.17
	AV SD	5.81	6.58	5.21	0.00	12.29
	AV median	4.19	7.22	4.59	0.00	13.76
	True median	-1.08	2.55	3.82	0.00	12.26

Medium		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
Small high	AV mean	5.25	8.06	0.00	5.85	29.03
	AV SD	5.29	6.82	0.00	5.41	15.05
	AV median	4.24	6.85	0.00	5.70	26.37
	True median	3.51	6.74	0.00	-2.29	26.37

High		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
Small high	AV mean	4.39	0.00	8.47	10.86	27.88
	AV SD	3.55	0.00	5.76	7.62	14.42
	AV median	3.25	0.00	7.39	8.73	29.02
	True median	-3.08	0.00	-7.19	-7.08	29.02

250% High		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
Small high	AV mean	10.51	0.00	8.07	12.89	38.57
	AV SD	7.48	0.00	6.30	9.88	20.81
	AV median	9.22	0.00	7.44	10.77	31.79
	True median	-5.38	0.00	-2.15	-2.75	1.30

Deep Fast large low gradient (n=35)

40% Low		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
Large low	AV mean	4.36	3.59	2.58	0.00	29.15
	AV SD	3.21	2.84	2.19	0.00	137.22
	AV median	3.02	2.47	1.76	0.00	5.36
	True median	-2.58	1.94	0.97	0.00	4.67

Low		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
Large low	AV mean	3.29	5.76	4.32	0.00	20.13
	AV SD	4.58	4.84	6.22	0.00	58.37
	AV median	1.85	5.26	2.78	0.00	7.49
	True median	-0.12	4.85	1.61	0.00	7.49

Medium		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
Large low	AV mean	2.22	3.82	0.00	4.71	19.34
	AV SD	2.23	3.24	0.00	5.10	32.38
	AV median	1.42	2.70	0.00	2.70	11.49
	True median	0.17	1.47	0.00	-2.50	11.10

High		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
Large low	AV mean	2.35	0.00	5.19	7.07	25.16
	AV SD	3.33	0.00	4.14	7.60	19.65
	AV median	1.05	0.00	4.11	4.69	21.78
	True median	-0.32	0.00	-0.22	-1.17	18.95

250% High		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
Large low	AV mean	9.54	0.00	15.17	24.90	37.44
	AV SD	9.11	0.00	17.27	22.36	27.50
	AV median	7.41	0.00	7.13	16.98	32.72
	True median	-4.84	0.00	6.83	15.82	12.18

Table 7. Absolute value mean, standard deviation and median, and true median of percent difference between habitat index for five velocity methods and habitat index for target flows for shallow/slow habitat suitability criteria in 40 small high gradient streams and 35 large low gradient rivers.

Shallow Slow small high gradient (n=40)

40% Low		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
Small high	AV mean	1.92	1.11	0.82	0.00	2.71
	AV SD	1.53	0.94	1.01	0.00	2.00
	AV median	1.36	0.90	0.49	0.00	2.54
	True median	-1.15	0.78	0.19	0.00	1.98

Low		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
Small high	AV mean	0.83	2.36	1.79	0.00	7.12
	AV SD	0.92	3.03	2.01	0.00	9.68
	AV median	0.48	1.49	1.13	0.00	4.86
	True median	0.18	0.97	0.03	0.00	3.71

Medium		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
Small high	AV mean	2.80	3.61	0.00	4.55	13.38
	AV SD	3.17	4.47	0.00	4.88	14.01
	AV median	1.43	2.20	0.00	2.99	8.17
	True median	0.43	-0.18	0.00	2.41	-4.81

High		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
Small high	AV mean	3.49	0.00	10.25	17.66	31.23
	AV SD	2.95	0.00	12.88	19.04	22.87
	AV median	2.81	0.00	5.57	9.47	30.74
	True median	2.29	0.00	4.51	9.47	-27.78

250% High		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
Small high	AV mean	26.96	0.00	16.78	28.88	59.12
	AV SD	17.65	0.00	20.95	35.96	26.58
	AV median	25.48	0.00	10.86	14.65	66.50
	True median	25.48	0.00	10.03	10.38	-63.95

Shallow Slow large low gradient (n=35)

40% Low		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
Large low	AV mean	1.73	1.18	0.86	0.00	2.13
	AV SD	2.46	1.50	1.50	0.00	4.58
	AV median	1.03	0.76	0.57	0.00	1.41
	True median	-0.56	0.25	0.03	0.00	0.60

Low		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
Large low	AV mean	2.47	4.71	3.10	0.00	6.92
	AV SD	4.43	6.14	5.66	0.00	12.15
	AV median	0.79	2.48	0.70	0.00	3.35
	True median	-0.24	0.16	-0.12	0.00	1.13

Medium		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
Large low	AV mean	2.87	5.17	0.00	7.91	14.67
	AV SD	3.60	6.66	0.00	15.99	15.70
	AV median	1.45	3.01	0.00	1.91	10.72
	True median	0.28	-0.64	0.00	0.89	-5.27

High		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
Large low	AV mean	4.13	0.00	12.06	20.45	23.92
	AV SD	5.45	0.00	17.22	40.39	21.12
	AV median	2.40	0.00	6.46	9.69	13.08
	True median	0.56	0.00	3.31	4.01	-11.57

250% High		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
Large low	AV mean	17.42	0.00	18.00	23.83	51.79
	AV SD	17.78	0.00	18.26	40.40	27.56
	AV median	13.67	0.00	9.41	12.49	48.14
	True median	13.67	0.00	2.22	-5.24	-48.14

Table 8. Absolute value mean, standard deviation and median, and true median of percent difference between habitat index for five velocity methods and habitat index for target flows for shallow/fast habitat suitability criteria in 40 small high gradient streams and 35 large low gradient rivers.

Shallow Fast small high gradient (n=40)

40% Low		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
Small high	AV mean	11.98	4.43	3.68	0.00	8.47
	AV SD	18.44	3.88	3.25	0.00	7.42
	AV median	5.39	3.24	2.49	0.00	6.35
	True median	-2.16	0.89	0.87	0.00	3.19

Low		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
Small high	AV mean	3.62	6.90	4.42	0.00	16.75
	AV SD	2.72	6.41	3.56	0.00	12.69
	AV median	3.12	4.63	4.16	0.00	12.62
	True median	-0.08	4.03	1.85	0.00	11.08

Medium		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
Small high	AV mean	4.84	8.61	0.00	6.15	29.80
	AV SD	4.35	6.30	0.00	4.91	15.91
	AV median	3.36	7.51	0.00	4.97	29.47
	True median	2.25	7.51	0.00	-4.82	29.22

High		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
Small high	AV mean	5.15	0.00	9.38	12.84	33.20
	AV SD	3.78	0.00	6.15	8.01	13.03
	AV median	5.02	0.00	8.12	10.57	33.12
	True median	-5.02	0.00	-8.12	-9.76	32.76

250% High		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
Small high	AV mean	11.87	0.00	10.81	16.79	38.25
	AV SD	8.54	0.00	7.63	10.54	24.97
	AV median	10.81	0.00	9.77	16.27	32.91
	True median	-7.35	0.00	-4.07	-0.08	22.92

Shallow Fast large low gradient (n=35)

40% Low		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
Large low	AV mean	9.76	5.64	4.08	0.00	7.83
	AV SD	20.14	6.04	4.36	0.00	7.20
	AV median	4.05	3.54	2.83	0.00	6.35
	True median	-0.62	1.37	1.69	0.00	3.09

Low		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
Large low	AV mean	5.45	8.01	6.27	0.00	16.71
	AV SD	8.85	7.84	7.18	0.00	14.41
	AV median	3.00	6.51	4.24	0.00	12.15
	True median	1.52	1.83	2.75	0.00	10.92

Medium		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
Large low	AV mean	7.25	7.68	0.00	8.88	25.90
	AV SD	10.42	7.36	0.00	8.64	22.95
	AV median	2.60	4.83	0.00	5.44	21.40
	True median	0.38	1.61	0.00	-1.37	21.40

High		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
Large low	AV mean	5.45	0.00	9.99	15.78	47.34
	AV SD	11.02	0.00	7.27	22.87	58.36
	AV median	2.27	0.00	7.87	8.12	29.28
	True median	-0.81	0.00	-3.30	-0.51	29.28

250% High		3-Vel	1-Vel High	1-Vel Med	1-Vel Low	Depth Calib.
Large low	AV mean	16.69	0.00	25.48	31.16	58.89
	AV SD	14.83	0.00	23.60	26.08	59.05
	AV median	12.63	0.00	17.76	24.86	38.37
	True median	-10.78	0.00	8.65	17.34	27.04