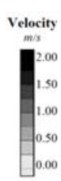
2D Hydrodynamic Modeling

2D models use a computational "mesh" of points and areas to solve the St. Venant equations from fluid mechanics.

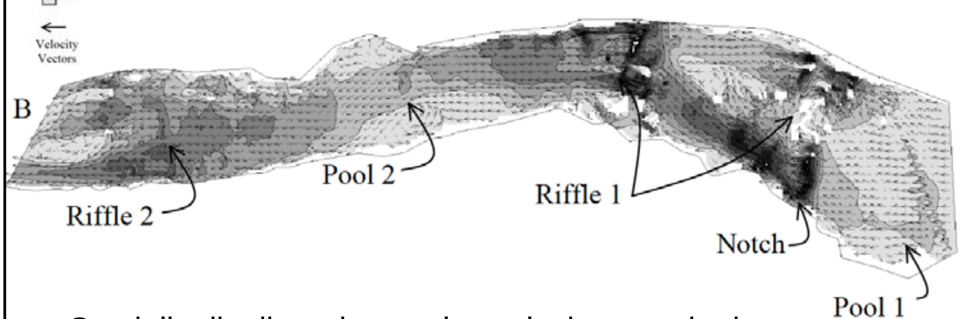
2D models need to know all inflowing discharges, topography, the water surface elevation at all flow outlets, a bed roughness parameter, and one or more turbulence parameters.

Model output is the water surface elevation and the depth-averaged velocity vector at each point in the mesh.

Typical Model Results



Lower Mokelumne River, Fall 2003



- Spatially distributed, complex velocity magnitudes
- Recirculating flows (aka "eddies")
- Arrows show flow direction

What Makes a Good 2D Model?

THERE ARE NO AGRED UPON STANDARDS FOR DECIDING WHETHER A 2D MODEL IS ACCURATE OR NOT.

Kinds of things one can check:

Compare WSE and depths against observations at points

Compare velocity magnitude against observations at points

Compare spatial pattern of flow against qualitative drawings of flow patterns, such as eddies behind boulders.

Problems With Observational Data

Point-based velocity sensors do not measure depth averaged velocity.
Need to make assumptions about vertical velocity profile.
Commonly measure once at 0.4*D up from the bed, twice using average of 0.2D and 0.8D up from the bed, or three times using average of 0.2D, 0.4D, and 0.8D.
Each point measurement requires 40-60 sec times # of measurements in the vertical.

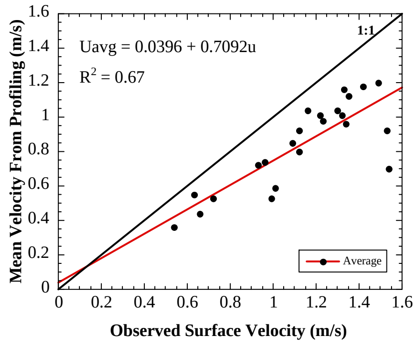
Point sensors often measure a tiny volume of water, which makes them very sensitive to the impacts of pebble clusters and other impediments to flow. 2D models are not intended to capture that tiny scale of variability, so comparison is not a test of 2D model performance.

ADCP does yield depth-averaged measurements and uses a larger volume, but is very time consuming and difficult to integrate with positional accuracy.

Cannot wade in high flows.

Rapid Velocity Data Collection Idea

Surface velocity is commonly ~0.7-0.8 times depth-averaged velocity.



Mount an RTK GPS on a kayaker, have kayaker get into the and moving at the same speed, record GPS position every 5 sec. Back in office, calculate distance between positions and divide by 5 sec to get surface velocity. Can also calculate flow direction.

Can do this over a wide range of non-wadable flows.

Benchmarks for 2D Velocity Predictions

R^2 ⌫ How well the model predicts fluctuations in observed velocity. Not a test of accuracy, but of predictability.

Deviation statistics ⌫ Stats for absolute values of differences between observed and predicted velocities. Look at percent of deviations within pre-defined limits. Tests of model accuracy

1:1 ⌫ How close is the slope of the linear regression equation to a value of 1.00? A test of model accuracy in terms of bias at the high and low ends of the distribution.

Zero base ⌫ does the model predict zero velocity?

XS accuracy ⌫ How well does the model predict the cross-channel pattern of velocity?

Flow direction ⌫ How well does model predict the direction of flow?

Scatter Plot Analysis

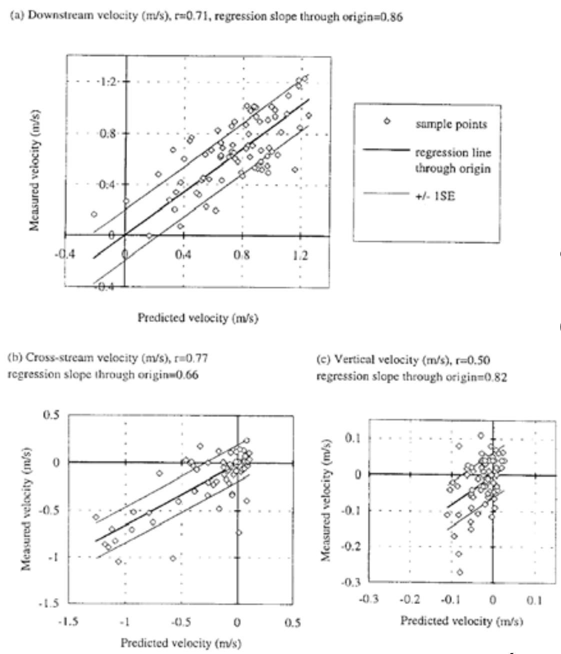
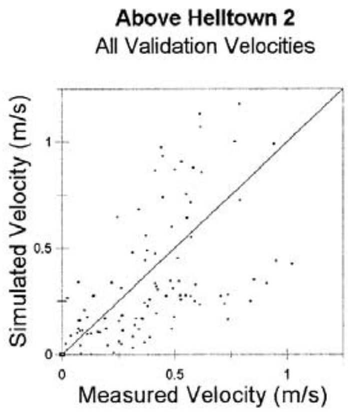


Fig. 2. Comparison of model predictions with field observations.

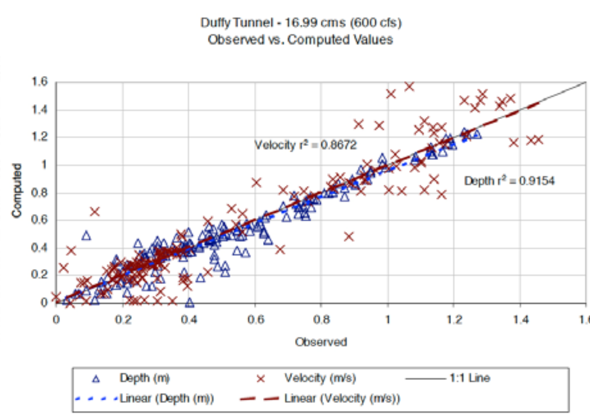
(Lane, 1999)

Plot all observations against corresponding predictions, compute R or R^2.

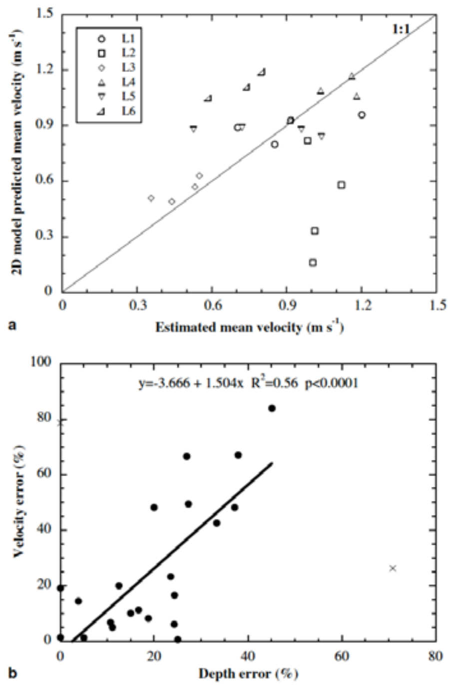
More Scatter Analyses



(Gard, 2003)



(Stewart, 2000)



Explaining Scatter Deviations

Errors in the topographic map that cause depth errors explained 56% of the errors in predicted velocity.

When depth is too high, the velocity has to compensate and be too low.

(Pasternack, 2006)

Statistics of Scatter Analysis

Table III. Results from comparison of model predictions with distributed velocity information

	Correlation with flow model velocities	Regression analysis			
		Slope	Standard error	Intercept	Standard error
$\bar{U}$-velocity	0·717	0·799	0·121	−0·139	0·0589
$\bar{V}$-velocity	0·566	0·404	0·0919	0·0551	0·0248
Resultant velocity	0·783	0·913	0·113	0·0555	0·0628

(Lane, 1998)

APPENDIX F
VELOCITY VALIDATION STATISTICS

Measured Velocities less than 3 ft/s

Difference (measured vs. pred. velocities, ft/s)

Site Name	Number of Observations	Average	Standard Deviation	Maximum
Whiskey Flat	76	0.52	0.49	1.81
Above Helltown 1	88	0.73	0.62	3.09
Above Helltown 2	96	0.68	0.50	1.93
Helltown	77	0.42	0.45	2.05
Homestead	86	0.07	0.80	2.49
Richbar	64	0.87	0.78	3.23
Tailings	35	0.68	0.49	1.97

Measured Velocities greater than 3 ft/s

Percent Difference (measured vs. pred. velocities)

Site Name	Number of Observations	Average	Standard Deviation	Maximum
Whiskey Flat	14	14%	8%	28%
Above Helltown 1	2	68%	15%	83%
Above Helltown 2	3	39%	24%	58%
Helltown	8	40%	22%	78%
Homestead	9	25%	15%	51%
Richbar	17	37%	19%	80%
Tailings	21	13%	12%	43%

All differences were calculated as the absolute value of the difference between the measured and simulated velocity.

Analysis of Deviations: ABS(Obs-Pred)

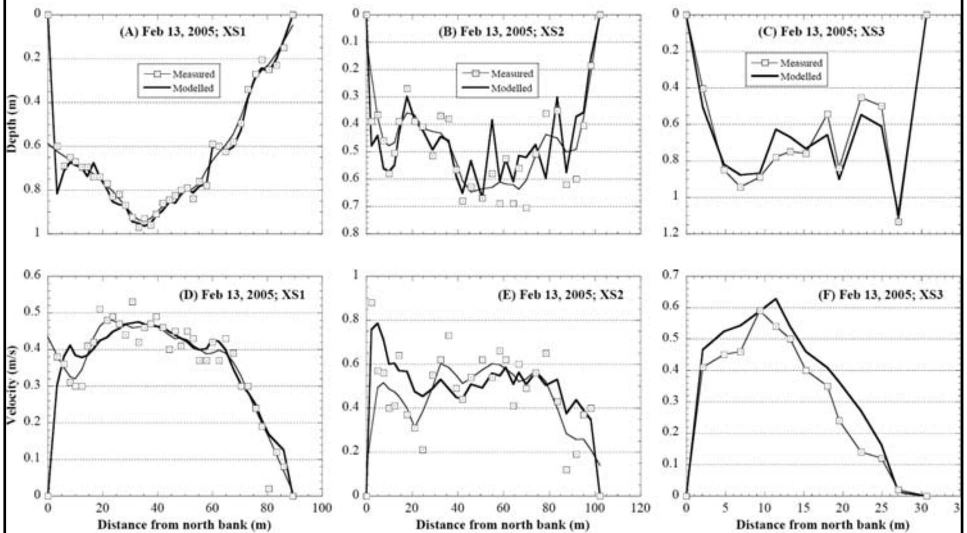
(Gard, 2003)

Deviation and Scatter Analyses

	Velocity				Depth			
	Ave. Error	SSE	r^2	slope	Ave. Error	SSE	r^2	slope
DCal1	0.026	3.30	0.872	0.864	-0.003	1.28	0.912	0.939
DCal2	0.026	3.29	0.873	0.865	-0.003	1.28	0.912	0.939
DCal3	0.026	3.56	0.862	0.859	-0.002	1.30	0.911	0.940
DCal4	0.025	3.46	0.866	0.858	-0.002	1.28	0.912	0.938
DCal5	0.031	4.22	0.874	0.854	-0.007	1.30	0.911	0.939
DCal6	0.026	3.28	0.873	0.866	-0.003	1.28	0.912	0.938
DCal7	0.015	3.61	0.862	0.929	0.005	1.27	0.913	0.943
DCal8	-0.003	3.89	0.864	0.995	0.016	1.29	0.915	0.947
DCal9	-0.003	3.77	0.866	0.988	0.016	1.29	0.915	0.947
DCal10	-0.005	3.77	0.867	0.992	0.017	1.28	0.916	0.948
DCal11	-0.008	4.01	0.860	0.992	0.019	1.29	0.915	0.947
DCal12	0.022	3.80	0.855	0.911	-0.006	1.27	0.913	0.948
DCal13	0.020	3.94	0.849	0.906	-0.005	1.27	0.913	0.948
DCal14	0.007	3.78	0.860	0.956	0.008	1.26	0.914	0.946
DCal15	0.004	4.04	0.850	0.947	0.008	1.28	0.913	0.947
DCal16	-0.005	3.89	0.865	0.999	0.018	1.29	0.915	0.948

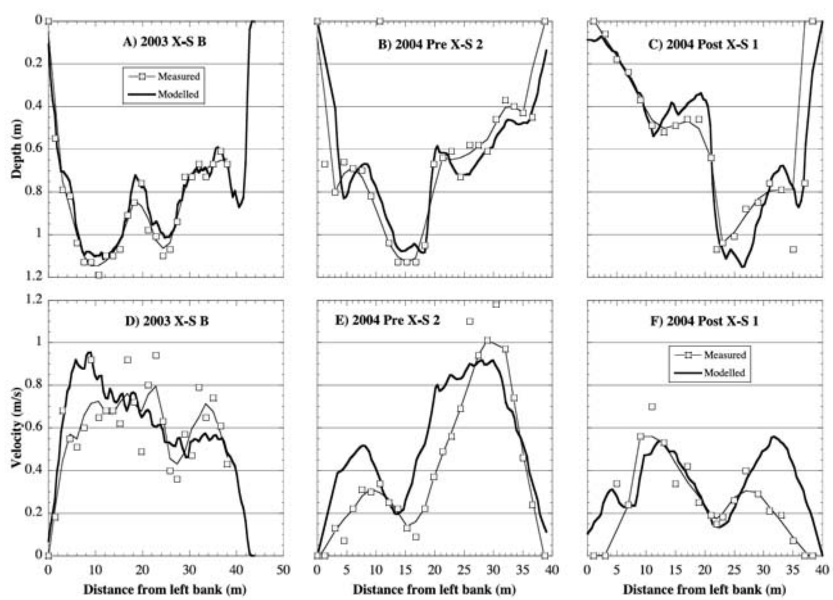
(Stewart, 2000)

Yuba TBAR Cross-section Analysis



(Moir and Pasternack, 2008)

Mokelumne XS Analysis



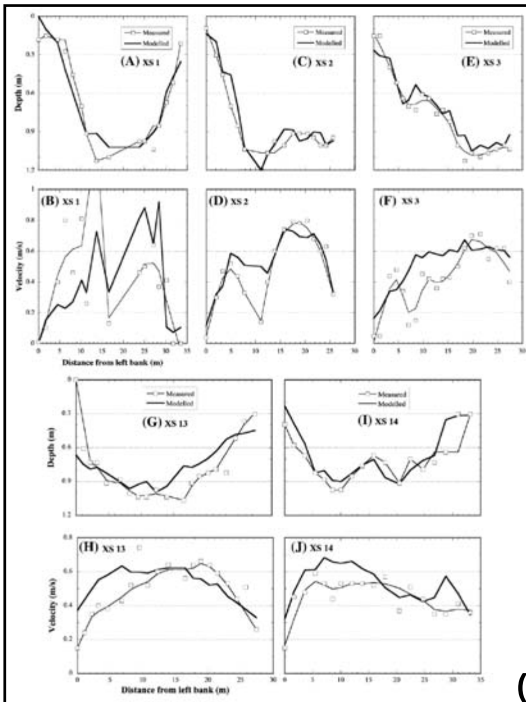


Fig. 9. Validation cross sections comparing 2D model predictions with field measurements.

Trinity XS Analysis

(Brown et al., 2008)

Summary of Metrics

R^2 ⌫ 0.4-0.9 (watch out for reports of R, not R^2)

Deviation statistics ⌫ average error of 20-30%, with range up to 200 % for low velocities.

1:1 ⌫ not commonly used, but should be >0.9 if no bias present

Zero base ⌫ not commonly used, but should be < 5% of V_{max}

XS accuracy ⌫ visually looks “good”.

Flow Direction ⌫ not commonly tested. Within 10° ?

Secondary Calibration of Model Output

Several XS-based approaches and 1D numerical approaches add an extra calibration in which the regression relation from the raw comparison is used to adjust model predictions.

Use half of comparisons selected at random to calibrate regression equation and the other half to test it.

Based on preliminary tests, this can reduce error by ~50%, which is a significant improvement.

Need to make sure calibration data spans the necessary range of discharge the model will be used for.

2D Model Conclusions

2D models, like all other predictive models, have limitations.

Model performance can be assessed in many ways and using more different analyses provides a broader appreciation for what is working well and what is not.

2D models are especially good at obtaining cross-channel velocity patterns and longitudinal flow accelerations for flows with no obstructions.

They are especially bad for complex banks, submerged wood, waterfalls, and perhaps “pocket water” with lots of exposed boulders.