The South Fork of the Eel River: A Hydraulic Modeling Extravaganza

Cameron Bracken and Jason Roberts
ENGR 448: River Hydraulics Fall, 2007

1 Introduction

1D models cheap and efficient but may give a limited picture of a rive system. 2D hydraulic models are currently more expensive but do not assume a single flow direction. Though they give us more information about the river systems we model, the question remains, are 2D models worth the extra effort? 1D models are undeniably simpler but do they give us enough information? In this paper we seek to explore this question by developing 1 and 2D models of a reach of the South Fork of the Eel River. We also develop a method for obtaining cross sections from survey data for input into a 1D model.

In river restoration, many times a goal is to place some sort of obstruction in the flow to affect velocity distributions. Here we seek to qualitatively and quantitatively compare the differences in computational output provided by 1 and 2D models when a rootwad-like obstruction is placed in the flow.

2 The Eel River

The Eel River flows out of the Pacific Coast Range in Northern California. The River flows North out of Northern Mendocino and Southern Humboldt County for more than 100 miles before discharging into the Pacific Ocean (Figure 1). The combination of high seasonal rainfall, widespread tectonic deformation, and human disruption through historical land use have caused the Eel River to exhibit the highest recorded average suspended sediment yield of any river in the United States of equal or larger size (Lisle, 2007).

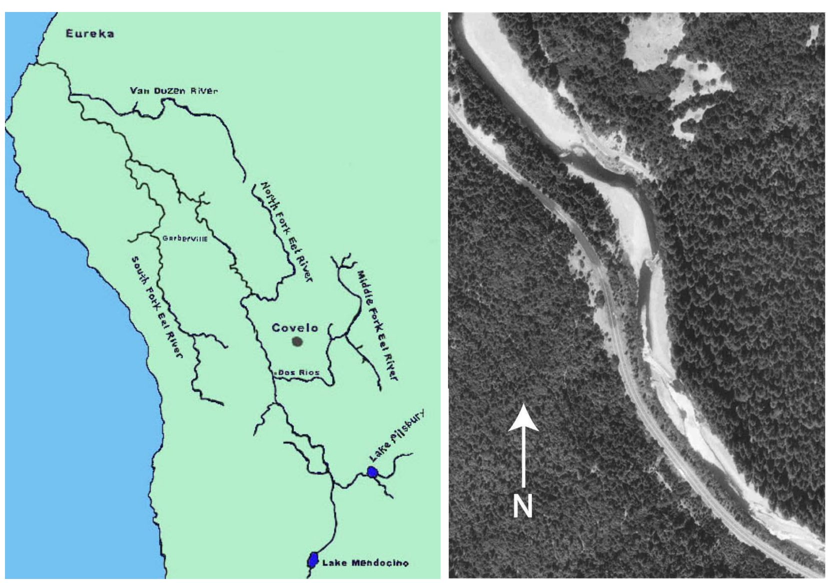


Figure 1: Map of the Eel River and plan view of the reach being modeled. (http://covelo.net/eel_river/eelriver_maps.shtml).

3 1D Open Channel Flow Modeling

Here we diverge slightly from the main focus of the paper to discuss the process of obtaining cross sections for input into a 1D numerical model. The process of 1D modeling hinges on defining cross sections from spatial data. In many cases it is possible to directly measure cross sections in the field but this process is time consuming and possibly expensive. In many situations a source of topographic data may be available in a preexisting form (such as (x,y,z) coordinates) though the original intent of the data was not for cross sections. In these cases the ability to define cross sections from existing data could save time and money. What ever the method for defining them, cross sections must be defined for 1D flow modeling. In this section we will describe the cross section definition process from a set of irregularly spaced points, and the numerical algorithm for predicting flow depth.

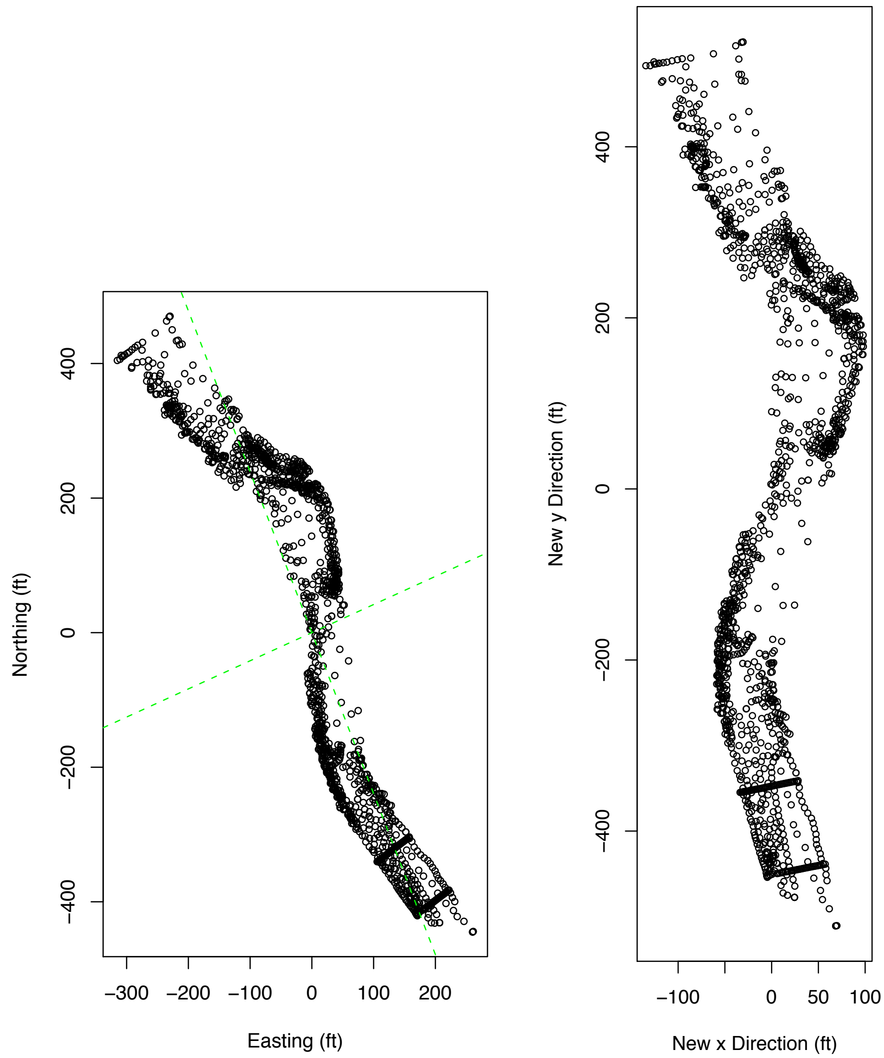
3.1 Working in Rotated Space to Define the Thalweg

When we think of a river, it is natural to think of it flowing in one predominant direction (at least over a short distance). It makes sense then to align our coordinate axes with the so called "predominant direction." For the sake of a general algorithm this step is necessary because an arbitrary reach could be oriented in any direction. The problem is how to (1) define this direction, (2) align (or rotate) the data along these new axes and (3) rotate back when we are done. Fortunately, all three of the problems can be taken care of with a procedure known as principal component analysis (PCA). PCA is traditionally a statistical technique used to reduce the dimensionality of the data but can be used effectively here for simply rotating the data. Briefly the process is:

1. Center the data by subtracting the mean in each direction. That is, if $\mathbf{x}_0$ is the vector of x coordinates corresponding to $\mathbf{y}_0$, the vector y coordinates, then let $\mathbf{x} = \mathbf{x}_0 - mean(\mathbf{x}_0)$ and $\mathbf{y} = \mathbf{y}_0 - mean(\mathbf{y}_0)$.
2. Calculate the covariance matrix of D. That is, if D is the data set, where $D = (\mathbf{x}, \mathbf{y})$, then let $C = cov(D)$. C is a 2×2 square matrix.
3. Calculate the eigenvectors of C (the covariance matrix). That is, let E be a matrix of with the eigenvectors v_1, v_2 as its columns, $E = (v_1, v_2)$. The eigenvectors are actually aligned along the directions of maximum variation in the data so one of them will be right down the middle of the stream! (Figure 2)
4. Now to rotate the data R, such that the y-axis is aligned longways down the middle of the stream calculate where $R = (C^t D^t)^t$ and t denotes transpose.
5. Find the thalweg in this position. This will level the playing field for any arbitrary data set as well as prevent edge bias when defining the thalweg.
6. If T is the thalweg defined in the rotated space, rotate it back by $T_{rotated\ back} = (CT^t)^t$ and then add the means to get back the coordinate axes.

3.2 The Cross Section Orientation and Flattening

Once the thalweg is defined we can define the orientation of the cross section. The assumption here is that the main flow is in the direction parallel to the thalweg. To determine the orientation of the cross section (1) pick a distance down the thalweg, (2) draw a line perpendicular to the



(a) (b)

Figure 2: (a) shows the data with the means subtracted plotted with the eigenvectors in green. (b) shows the data once it has been rotated.

thalweg at that distance, (3) identify k nearest points (in perpendicular distance) to the line and (4) flatten those points along the cross section line. Figure 3 graphically depicts the process.

3.3 Spline Smoothing

A problem is introduced when flattening points from up and down stream in that the points downstream will be at a lower elevation than the ones upstream. To correct for this a spline smoothing technique was used to sweep out the general trend in the cross section. This process is similar to interpolating the depth at points along the cross section line or fitting a surface to the data and taking slices out of it. Figure 4 show some examples of cross sections defined using the algorithm.

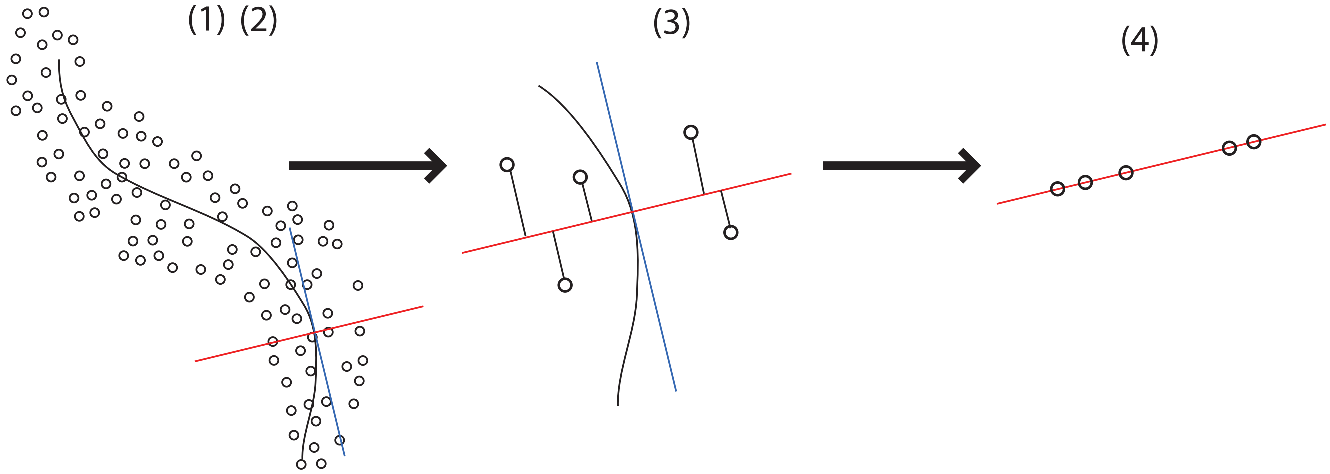


Figure 3: The Steps to defining cross sections: (1) pick a distance down the thalweg (intersection of red and blue line), (2) draw a line perpendicular to the thalweg at that distance (red line), (3) identify k nearest points (in perpendicular distance) to the line and (4) flatten those points along the cross section line.

3.4 Overall Cross Section Definition Algorithm

To define cross sections the process is:

1. Rotate the data so that the river is oriented longways parallel to the y-axis.
2. Define a thalweg throughout the entire reach using p points,
3. Rotate the data back to original coordinate axis,
4. Assume the direction of flow as tangent to the thalweg so that the cross section can be defined perpendicular to the flow,
5. Define a line perpendicular to the flow at a given distance along the thalweg,
6. Identify k nearest neighbors to the cross section line defined in step 5,
7. Flatten those k neighbors along the cross section line and define this set of k points as the preliminary cross section definition,
8. Smooth the elevation points to obtain the final cross section.
9. Repeat steps 5-8 for as many cross sections as desired.
10. Interpolate in between cross sections to obtain the geometry at any desired distance along the thalweg.

Figure 5 shows how the data is transformed into an idealized river for input into a numerical model.

3.5 Parameter Values

One additional problem remains which is the choice of the neighborhood size (k) and the number of thalweg points p. If the selection of the neighborhood size is too large, then points will be included which are too far away from the cross section and if it is too small then then information about the cross section will be left out. Here we used $k = 20$ based on visual verification.

The number of thalweg points (p) was defined slightly more objectively than the neighborhood size. In this case if p is too small then the thalweg will not follow the curves in the stream,

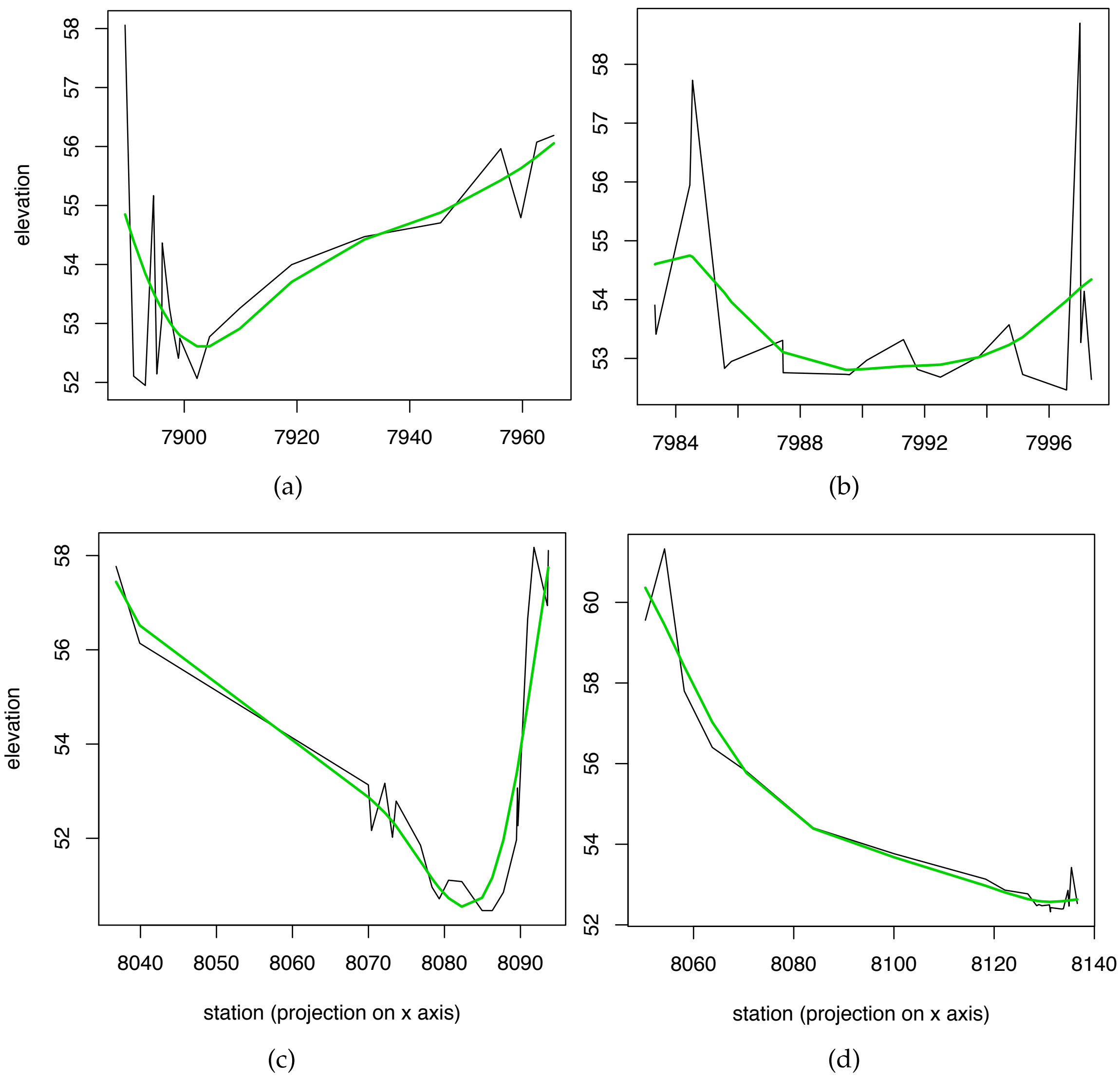


Figure 4: Four cross sections defined using flattening (black) and then spline smoothing (green).

and if p is too large then the thalweg will be too sinuous. To decide on an "optimal" value for p we plot p vs. the total thalweg length. We suppose that a region for which the the thalweg length doesn't change very much is a good choice for the p (Figure 6).

Aditionally, though we don't lump it in with the other two official parameters, the number of cross sections to define is important. Choosing a number of cross sections to define is a much more difficult problem than choosing the other parameters. We give a few reasonable criteria for choosing:

1. Cross sections should be evenly spaced if possible so that some areas don't get a sparsely represented while others are highly represented,
2. Cross sections should not be so close that the same points are used twice and
3. Cross sections should be close enough to represent the sinuosity of the river.

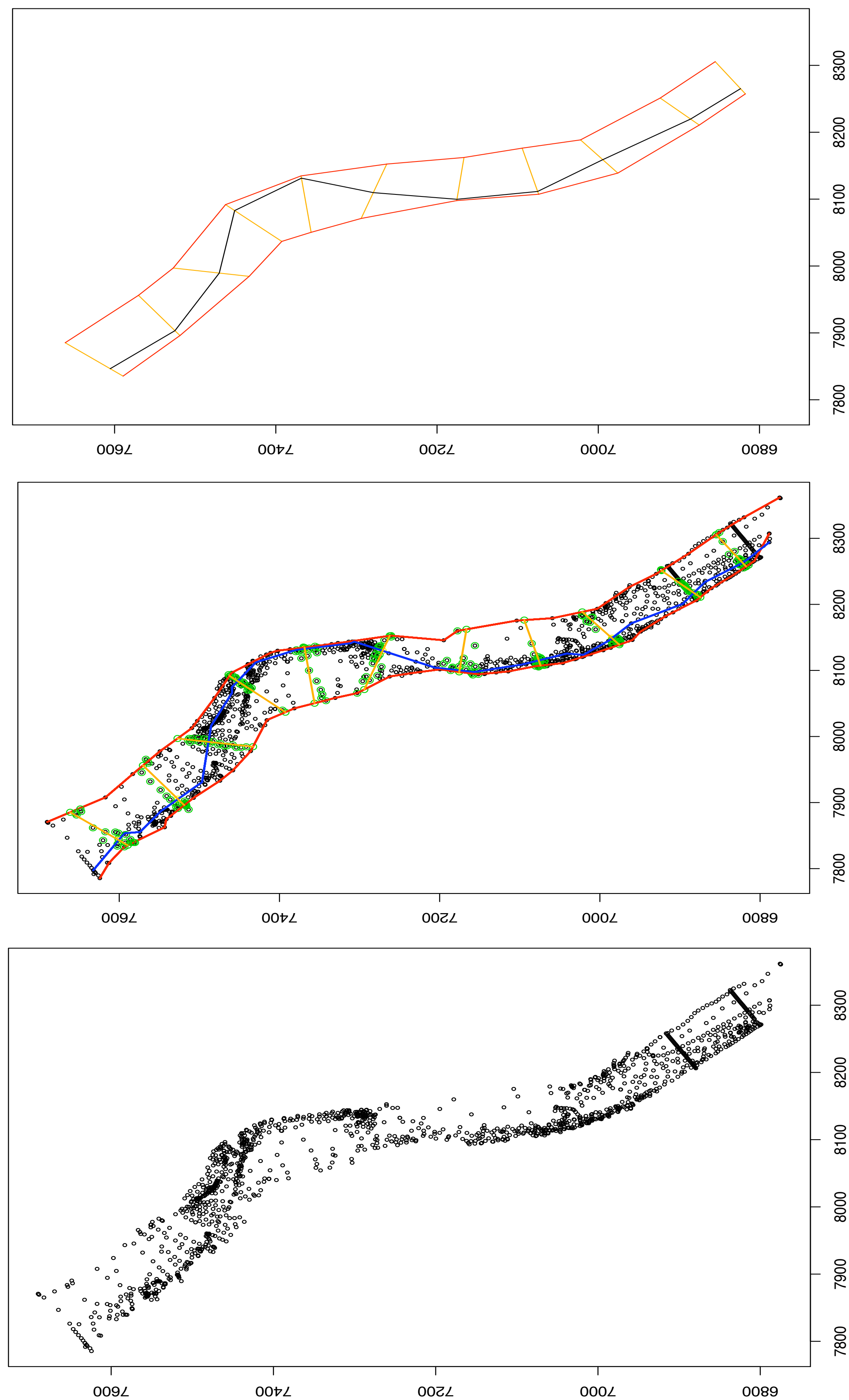


Figure 5: The cross section Definition Algorithm prepares the data for input to a numerical model. (a) is the original data, (b) shows the data with the banks defined in red the thalweg defined in blue, the *k* nearest cross section neighbors in green and the cross section lines in orange, (c) shows the idealized river system with banks (red) cross sections (orange) and thalweg (black) defined.

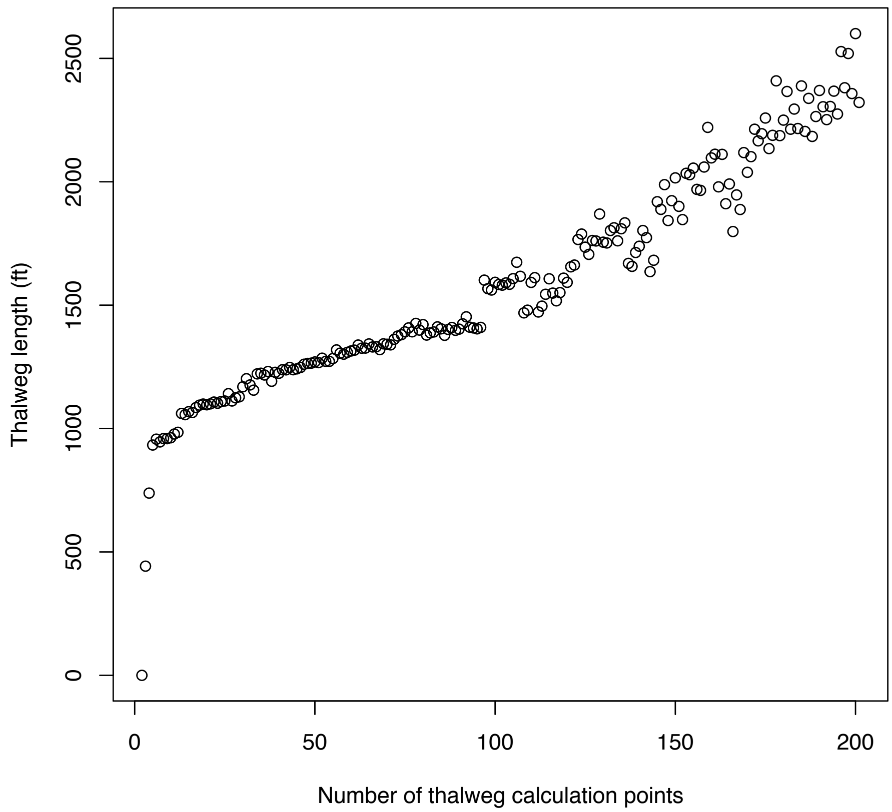


Figure 6: This plot shows how the length of the thalweg changes as the number of thalweg points changes. The hypothesized region of acceptable values is shown in between red lines.

3.6 Using the Cross Sections and Changing Resolution

The Once the cross sections are prepared all the hard work is done. The 1D open channel flow model, HEC-RAS was used to analyze the reach. When we talk about resolution in a 1D model we mean the distance between cross sections because computation occurs only where a cross section is defined. We are able to use the relatively few cross sections we defined from our algorithm as the most sparse or course resolution. We are also able to obtain very fine resolution by interpolating between existing cross sections.

4 Results

4.1 1D Results

Using the Cross section algorithm we defined 11 cross sections throughout the reach. These 11 cross sections were used as the most sparse resolution. Additionally for the fine resolution we interpolated cross sections at 5 ft intervals. Computations were made first with no obstructions in the channel and then with obstructions. All computations were made using a flow rate of 425 cfs.

Figure 8 shows the results with no obstructions. In these plots the water surface elevation (WSE) is significantly different thought the only difference is computational resolution. The sparse resolution is practically uniform where the interpolated WSE is highly variable. The velocity and plot shows agreement between the sparse and interpolated resolutions at most points where the sparse has a cross section. The interpolated resolution gives us information about the variation of velocity between cross sections that the sparse resolution simply leaves out. The sparse velocity also tends to predict consistently higher velocities than the interpolated resolution. The shear stress also shows a significant difference between the two resolutions. The sparse resolution predicts more than 5 lbf/ft^2 difference at the peak.

To more closely observe the sensitivity of the model we placed an obstruction at about 225 ft down the channel to simulate a structure such as a root wad. This was done in two ways: (1) for the sparse resolution an obstruction was defined at a single cross section and (2) for the interpolated resolution the an obstruction was placed at the same cross section as well as a wide obstruction that spanned multiple cross sections to simulate the width of the obstruction.

Figure 7 shows the results of the simulations with obstructions. As with no obstruction, the sparse resolution WSP is very different than the interpolated resolution. The sparse resolution shows an elevation drop at the obstruction that seems to change the WSP for about 300 feet but when the interpolated resolution is used, the effect is only seen over 20-50 feet. The velocity shows a similar effect as with no obstruction. Again with the velocity on sparse resolution, the effect of the obstruction seems to impact a large area but we see with the finer resolution that the effect is only local. The sparse resolution predicts a shear stress of nearly 40 lbf/ft^2 more than the interpolated resolution. The interpolated resolution shows the local nature of the shear forces as opposed to the large length of influence in the sparse resolution.

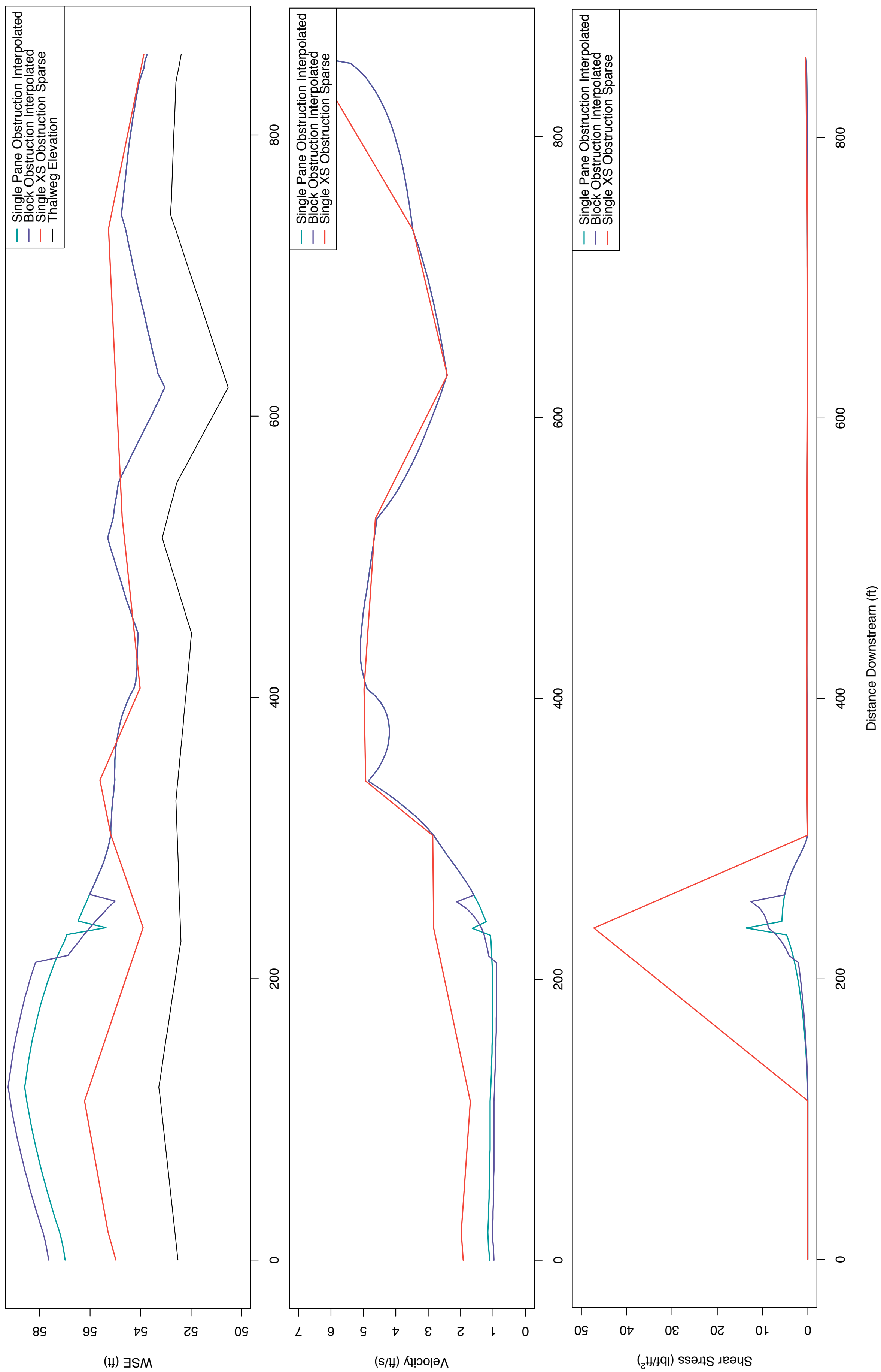


Figure 7: These graphs show the water surface elevation, Velocity and bed shear stress for the sparse (course) resolution of cross sections (red line) with an obstruction at one cross section, the fine resolution (interpolated) cross sections every 5 ft. with a single pane obstruction (light blue line) and a wide block obstruction (dark blue line).

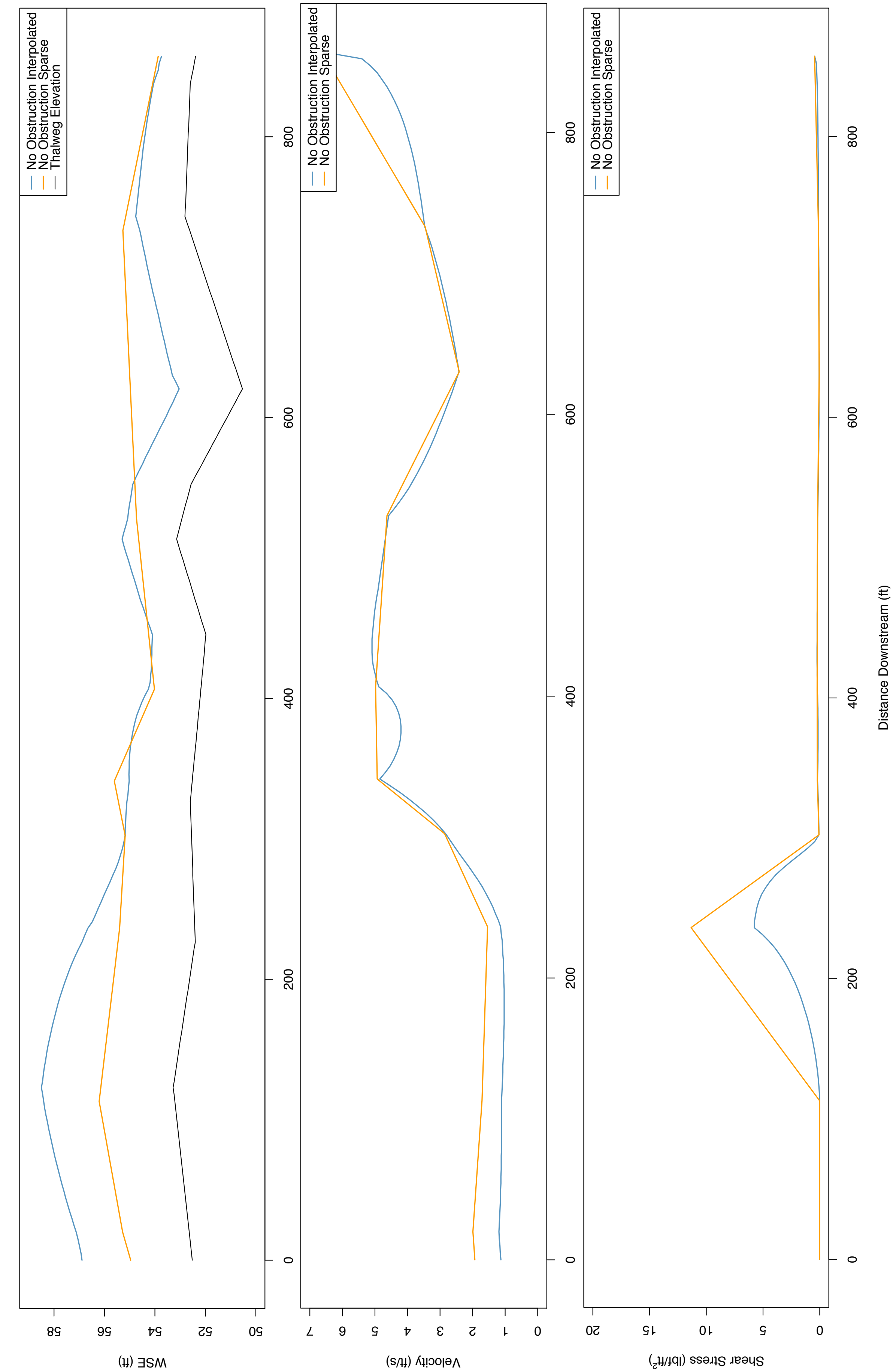


Figure 8: Same as figure 7 but for no obstructions. Sparse resolution shown in orange and interpolated fine resolution shown in blue.

4.2 2D Results

The reach was also modeled in 2D using the SMS modeling software with the RMA2 package. As in the 1D application, all computations were made at 425 cfs, and a global roughness of 0.025. Good mesh development is key to converging on a solution with relatively good error. For this reach of the river, a quadrangle mesh was chosen over a triangular mesh because of the increased stability of the quadrangle pattern in the finite element solution (Figure 9.) Rootwad obstructions were placed at the same location approximately 225 feet downstream.

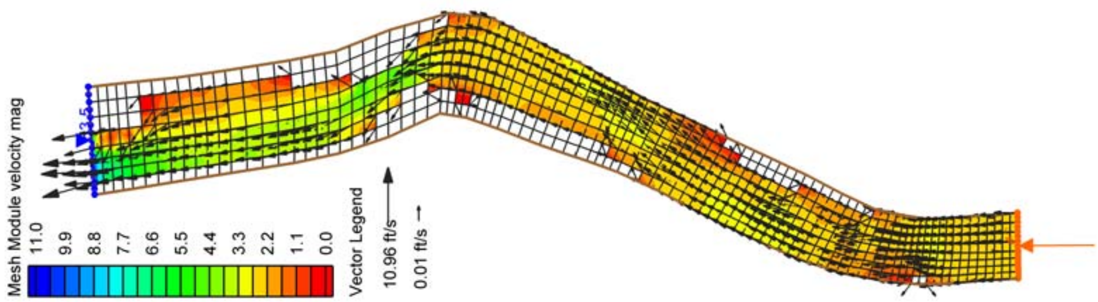


Figure 9: Initial solution for 2D model run.

The obstruction consists of elevation changes and increased roughness to mimic in stream rootwads (Figure 10.) The velocity results in Figure 10 are consistent with 1D results from Figure

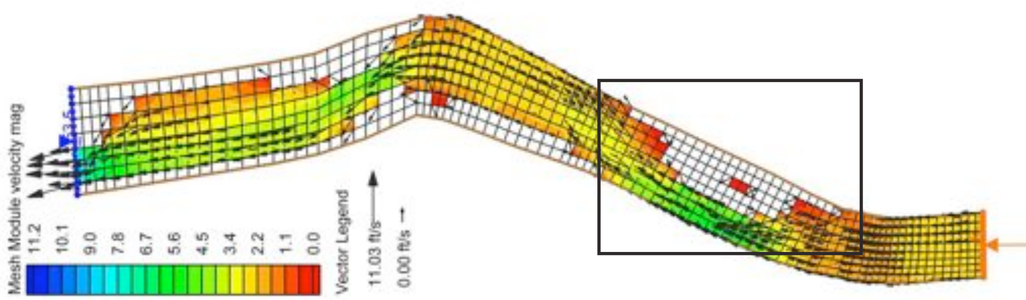


Figure 10: 2D solution for the rootwad obstruction with added roughness.

7. The velocity through the modified section of the 2D model is approximately 5.5 ft/s and the modifications to the 1D section is approximately 5.5 ft/s.

The 1 and 2D model solutions are consistent when primarily looking at downstream direction velocities. In this case, most of the velocity is in the downstream direction, leading to consistent results. Therein lies the difference in solutions between 1 and 2D models. The 1D model does not provide information about velocity directions other than directly downstream. 2D model results provide information about x and y component velocities, allowing for the analysis of lateral velocities and the identification of eddies. The amount spatial data necessary for a 2D model is significantly more than that needed for 1D model development, adding to project costs. When deciding between using a 1 or 2D model, the information being sought can be the deciding factor. If the parameters being investigated are water surface elevations and flowrates, then 1D modeling is sufficient. When velocity distributions and eddy identifications are necessary, 2D model development may be worth the extra effort.

Because of the high sediment transport currently going on in the Eel River watershed, another rootwad analysis was performed. The middle curve of the reach has the maximum and minimum elevations of the entire reach. As the reach turns left, a large rock causes an abrupt direction changes and increases in velocity, causing a scour hole to form. A rootwad was added to the right side of the reach, ending about 25 feet before the scour hole. Elevations were not modified because elevation modifications shown in Figure 10 caused velocities to increase even with the increase in roughness. For this run, only the roughness was modified to encourage water flow through the rootwad area (Figure 11). The rootwad obstruction was successful in

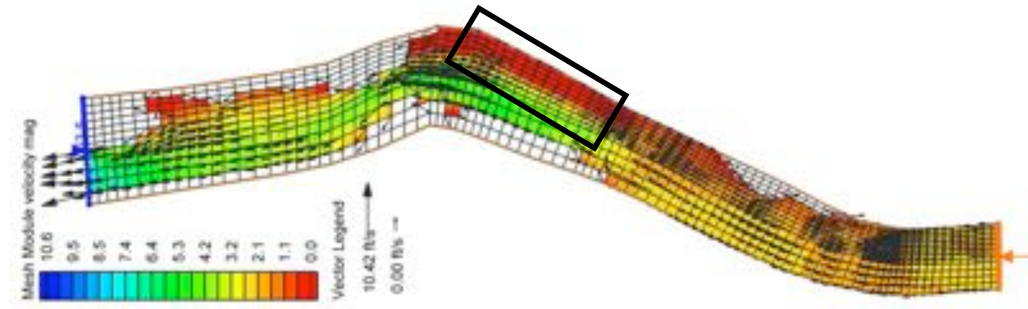


Figure 11: 2D solution for the reach with the new rootwad before the bend.

lowering velocities through the scour area by an average of 15% (Figure 12).

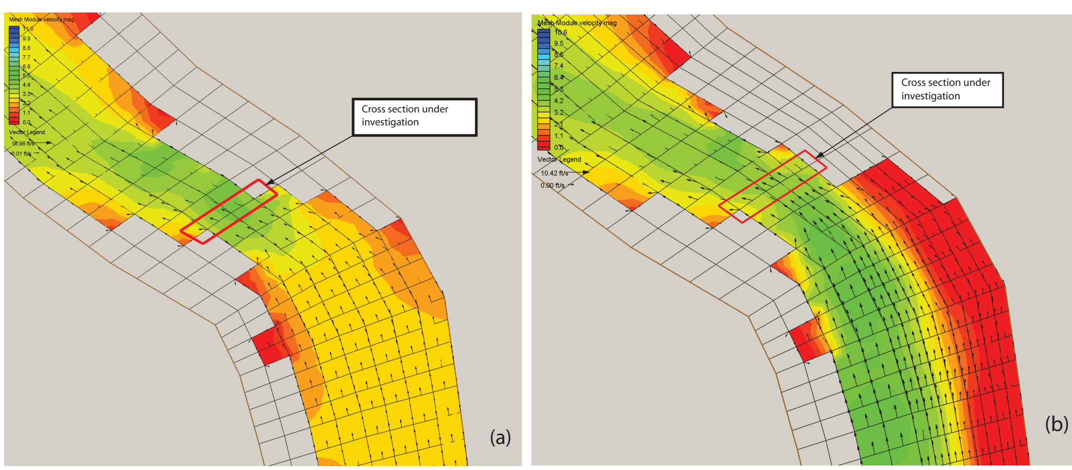


Figure 12: Cross section velocities before rootwad addition (a), and after rootwad addition (b).

4.3 Sediment Transport

Sediment transport analysis in SMS-SED2D was attempted, but no successful solution developed. To quantify the amount of bedload being transported, seven different transport equations were used. Only two of the equations produced results for the given parameters of the system, the Bagnold equation, and Copeland Modified Laursen (Table 1). The difference in the two results not surprising given the wide variability associated with sediment transport quantification. The Bagnold equation is applicable for sand and silt classified sediment, while

Table 1: Bedload transport results using the Bagnold Equation and Modified Copeland Laursen.

D50 (mm)	31
Length of reach (ft)	13
Vave (ft/s)	2.600
Water depth (ft)	3
Slope	0.00923
SG of sediment	2.65
Discharge (ft^3/s)	425
Kinematic viscosity (ft^2/s)	1.31E-05
Bagnold Equation Transport Rate (kg/s)	11.41
Copeland Modified Laursen (kg/s)	3580

the Copeland Laursen equation is applicable for gravel and sand, more conducive to existing conditions on the Eel.

5 Conclusions and Future Research

In this paper we developed 1 and 2D models of a reach of the south fork of the Eel River. We also developed an algorithm for defining cross sections from topographic data and briefly analyzed sediment transport. The application of 1D vs. 2D modeling depends on the situation. Both models gave similar results in regions where bulk fluid flow was primarily in one direction. The choice of which modeling approach to take depends of the application. The 1D model takes significantly less data but cannot capture eddy currents. 2D modeling is currently more expensive but potentially more accurate and in terms of human effort, 2D modeling may take significantly more. Currently 1D modeling is the industry standard and probably applied where lateral velocities are important but where 2D modeling is too expensive. As advanced, low man power surveying techniques become available, 1D modeling may become a way of the past.

References

USDA (2007). “The Eel River, Northwest California; High Sediment Yields From A Dynamic Landscape." USDA Forest Service. http://www.fs.fed.us/psw/publications/lisle/lisleGSA90.pdf