Analyzing the Effects of Mesh Resolution on Hydraulic Model Results and Habitat Estimates

D. Nathan Bradley, Ph.D., Geomorphologist, U.S. Bureau of Reclamation, Denver, CO, dnbradley@usbr.gov

Abstract

Two-dimensional hydraulic models are commonly used to estimate the quantity and quality of available aquatic habitat. The hydraulic conditions simulated by a 2D hydraulic model are averaged over the area of the mesh cell and vertically through the water column. Because of this averaging and other simplifications, the model results do not represent the full degree of hydraulic variability present in a real river. Reclamation conducted a systematic investigation of the effect of model resolution (cell size) on model hydraulics and habitat predictions.

Reclamation developed hydraulic models of varying cell size at three sites on the Klamath River using Reclamation's Sedimentation and River Hydraulics two-dimensional model, SRH-2D. The reference resolution (denoted as 1x) is the same as that of Reclamation's Iron Gate Dam to the Pacific Ocean Klamath River model. The other meshes were created by doubling the number of mesh nodes in both the streamwise and stream normal direction (2x), doubling again (4x), and doubling one final time (8x). The resulting meshes have channel elements that are approximately 1/4, 1/16th, and 1/64th the area of the 1x mesh.

The primary difference between a coarse model mesh with large cells and a higher resolution mesh with smaller cells is how well the mesh represents the river bathymetry. This study examined the effects of varying mesh resolution on channel cross sectional area, water surface elevation, bed elevation, model wetted area, model water depth and velocity, and juvenile salmonid habitat estimated using a habitat suitability index developed for the Trinity River, the largest tributary of the Klamath River.

Cross-sectional area tended to increase, and the bed elevation tended to decrease with increasing mesh resolution, which lowered water surface elevation. The increase in cross-sectional area resulted in a slight increase in total wetted area because shallow areas were better represented by the higher resolution meshes. The amount of slow, shallow water favored by juvenile salmonids increased with increasing mesh resolution. This increase in the amount of slow, shallow water in combination with the increase in wetted area, resulted in an increase in estimated juvenile salmonid habitat with increasing mesh resolution. For the highest resolution meshes, there was a 10-44% increase in estimated habitat relative to the lowest resolution mesh, depending on site and fish life stage.

Introduction

In 2020, Reclamation's WaterSMART program funded a proposal to update the statistical relationships between Klamath River flow and suitable salmonid habitat. These relationships are a key tool for evaluating river management decisions. The current flow-to-habitat relationships available for Klamath River are based on the Hardy Phase II study [*Hardy et al.*, 2006]. The study developed habitat suitability curves (HSC) to relate physical river characteristics to habitat quality based on data that are now nearly twenty years old. Newer techniques to analyze habitat quality and new data are now available. The capacity metric developed by *Som et al.* [2018] has been applied to estimate habitat in the Trinity River. A recent bathymetric survey of the entire Klamath River between Iron Gate and the Pacific Ocean and a hydraulic model based on that survey [*Bradley*, 2021] are also available. These factors, combined with a re-consultation under Section 7 of the Endangered Species Act for regional Coho Salmon in 2022 make updating the habitat to flow relationship timely and critical.

The proposal had two components. The first was the development of the data collection and analysis plan to create contemporary habitat availability models and flow-to-habitat relationships to be performed primarily by U.S. Fish and Wildlife and the U.S. Geological Survey. The second task was focused on developing methods to use a two-dimensional hydraulic model to quantify fish habitat availability. This report describes the second component of project.

The hydraulic conditions simulated by Reclamation's hydraulic model of the Klamath river are averaged over the area of the mesh cell and vertically through the water column. Because of this averaging and other simplifications, the model results do not represent the full degree of hydraulic variability present in a real river. In a real river, there may be areas of suitable depth and velocity that are not represented in the model and consequently, the model may underestimate the amount of habitat available. Increasing the model resolution by decreasing the size of the cells presumably improves the representation of the hydraulics, but this has not been systematically investigated. This report describes a systematic investigation of the effect of model resolution (cell size) on model hydraulics and habitat predictions.

Methods

Reclamation developed hydraulic models of varying cell size at three sites on the Klamath River using Reclamation's Sedimentation and River Hydraulics two-dimensional model, SRH-2D. The reference resolution (denoted as 1x) is the same as that of the original coarse mesh Klamath River model [*Bradley*, 2021]. The other meshes were created by doubling the number of mesh nodes in both the streamwise and stream normal direction (2x), doubling again (4x), and doubling one final time (8x). The resulting meshes have channel elements that are approximately 1/4, 1/16th, and 1/64th the area of the 1x mesh. The distributions of mesh element size for one site are shown in Figure 1.

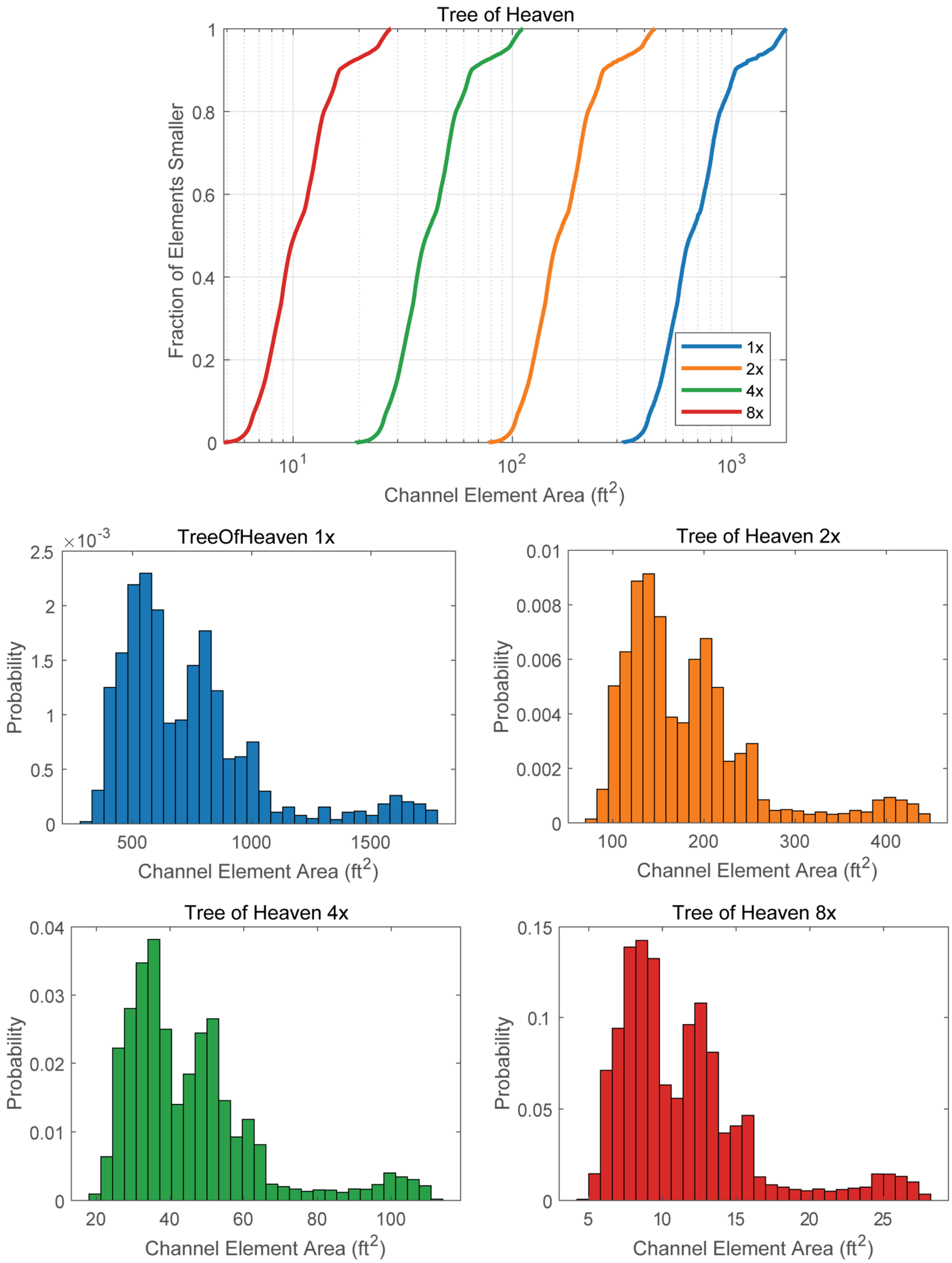

Figure 1. The Tree of Heaven distributions of mesh channel element size. The cumulative distribution function (CDF) of channel element area (top) and the histograms of element area for each mesh resolution. At each resolution level, mesh cell area is reduced by a factor of four from the previous level.

Cross-Sectional Area vs. Mesh Resolution

Elevations in an SRH-2D model mesh are assigned from a topo-bathymetric surface to the mesh nodes that define the corners of the mesh cells. The elevation of a mesh cell is the average of the elevation of the mesh nodes that define the cell. This leads to a less than perfectly faithful representation of the surface elevations in the mesh if node spacing is greater than the resolution of the surface. To examine the impact of mesh resolution on channel shape, I created triangular irregular network (TIN) bathymetric surfaces from the cell centers of the model meshes.

At each site, I generated cross section lines normal to a channel centerline and clipped the cross section lines to a polygon outlining the approximate bankfull channel. The cross sections were spaced every 20 feet. I converted the lines to points spaced 1 ft apart along the cross section lines and assigned an elevation from the underlying TIN at each mesh resolution to each point.

Examples of the cross sections are shown in Figure 2. I calculated the bankfull cross sectional area by finding highest point in the cross section on either side of the thalweg (the lowest point in the cross section) and then drawing a line from the lowest of the two bank points to the corresponding elevation on the opposite bank to create an approximate bankfull cross sectional polygon.

TIN Differencing

I compared the 2x, 4x, and 8x mesh TINs (the comparison TINs) to the reference 1x mesh TIN using ESRI's Surface Difference geoprocessing tool. Surface Difference builds an elevation difference TIN by subtracting the elevations in the reference TIN from the comparison TIN. Positive elevation differences indicate that the comparison TIN is higher than the reference TIN. The tool also generates a polygon shapefile that classifies areas as above, below, or the same as the reference TIN. For each polygon, the surface area, and the volume of the additional or missing 'material' between the surfaces was also calculated. I computed the total area where the comparison mesh was higher, lower, or the same by summing the areas in each category. I computed the average elevation change in each category by dividing the volume by the area.

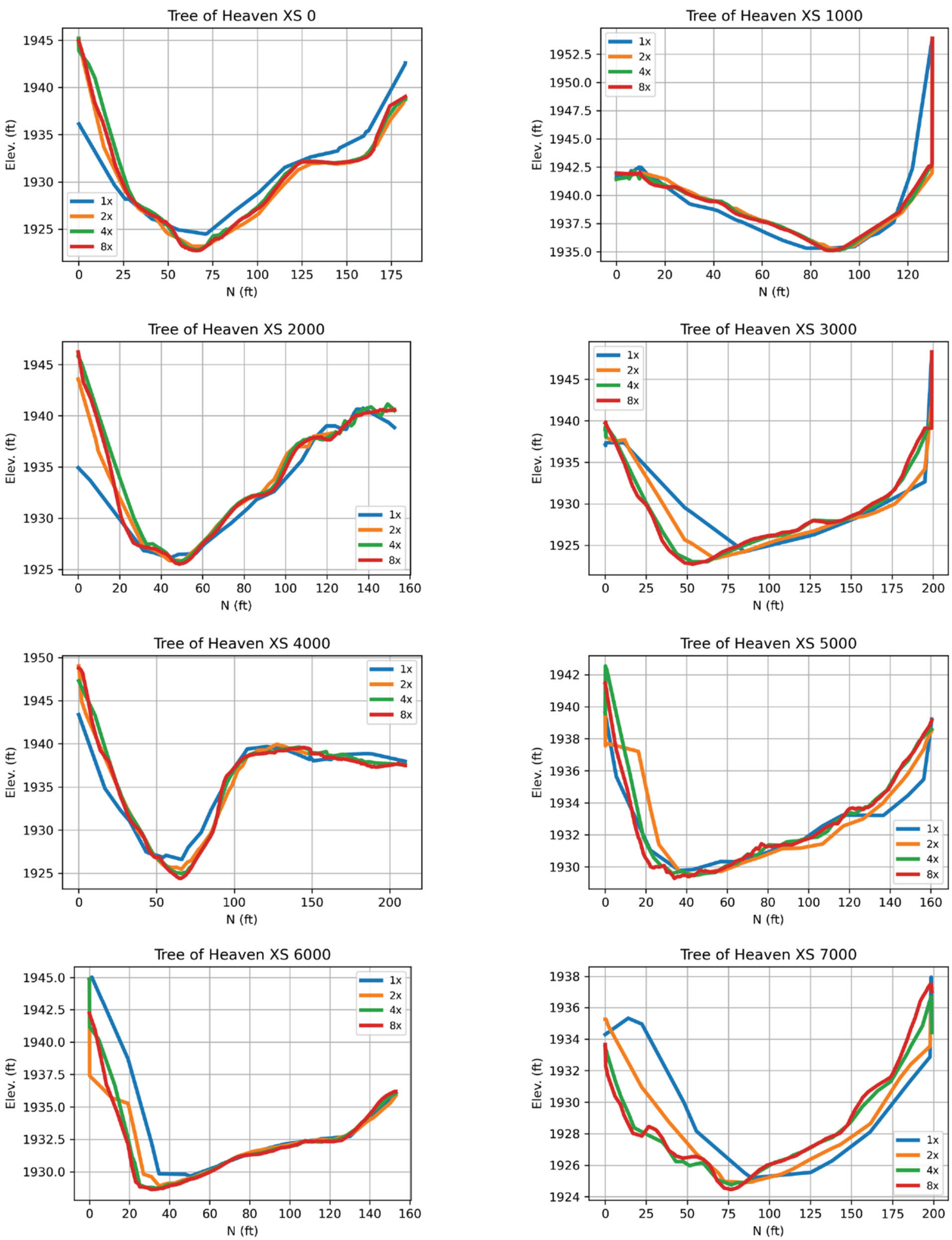

Figure 2. Example channel cross sections at the Tree of Heaven site. The x-axis is the distance from the left bank. The number in the plot title is the cross section stationing in feet from the upstream end of the site.

SRH-2D Modeling

I modeled the discharge that is exceeded 50% of the time (based on the four mainstem Klamath gage records) at each site. This flow is below bankfull. There are no tributaries in the full model between Tree of Heaven and the upstream end of the Beaver Creek site, so the same discharge was used at both sites. The Beaver Creek contribution to the total flow was not included in the Beaver Creek site model. For further details about how the hydrology was determined, see the Klamath River hydraulic model report [*Bradley*, 2021]. The outlet water surface elevation boundary condition for each site was extracted from the full hydraulic model. To limit the difference between meshes to only cell size, I used a bi-modal roughness distribution: all channel cells were assigned a Manning's n value of 0.033, floodplain cells were assigned n=0.08. These are the default roughness values used at the beginning of the full hydraulic model calibration process.

Water Surface Elevation Profiles

I created water surface profiles for each mesh resolution by extracting the model water surface elevations intersected by a channel centerline and plotting the elevations against the downstream distance along the centerline (the stationing). I also examined the water surface elevation differences by subtracting each of the higher resolution profiles from the 1x elevation profile.

Wetted Area vs. Mesh Resolution

Wetted area for each site and mesh resolution was determined by summing the area of mesh cells with a water depth greater than 0.1 ft. I also created wetted area polygons by converting the results to shapefiles, selecting all model cells with a water depth greater than 0.1 ft, and then using the ESRI Dissolve geoprocessing tool to create an inundation polygon.

Depth and Velocity

I computed area-weighted cumulative distribution functions (CDFs) of depth and velocity for each mesh resolution from the hydraulic results. The area-weighted CDF indicates how much area (the y-axis) at a particular site has a depth or velocity less than a particular value (the x-axis). This is of interest because juvenile salmonid habitat suitability indices (HSI) typically use depth and velocity as components.

Habitat

I computed the Trinity River weighted useable area (WUA) habitat metric for each mesh resolution at each site [*Som et al.*, 2016]. WUA is a function of water depth, velocity, and the distance to the nearest inundated vegetative cover. The combined HSI score is the arithmetic average of the three components.

Field verified vegetative cover layers have not yet been developed for the Klamath River, so I created a vegetative cover layer for each site using aerial imagery and a Green-Red Vegetation Index (GRVI) [*Yin et al.*, 2022]. The GRVI is computed from red and green bands of the aerial imagery raster.

$$GRVI = \frac{Green - Red}{Green + Red}$$

Areas of GRVI > 0 were exported as polygons and reliably outlined vegetated areas outside of the channel. The Klamath River water had a high GRVI, so the green river water was erased from the GRVI polygons using a wetted area polygon buffered by -10 ft. The result was a crude estimate of vegetative cover along the banks that formed the basis of the distance to cover calculation. The cover layers are not perfect, but because the same site layer is used for evaluating habitat at each mesh resolution, they should be adequate for comparing the effect of mesh resolution on habitat estimates.

The HSI score was computed for each model mesh cell and multiplied by the cell area to yield an estimate of the area of the cell that is suitable habitat. The cell based WUA was summed over each site for an estimate of the total habitat.

Results

The primary difference between a coarse model mesh with large cells and a higher resolution mesh with smaller cells is how well the mesh represents the river bathymetry. In a hydraulic model with spatially varying roughness (assigned on a cell-by-cell basis), the accuracy of the representation of roughness would also differ with mesh resolution, but that effect was not considered in this study.

Cross-sectional area tended to increase, and the bed elevation tended to decrease with increasing mesh resolution, which lowered water surface elevation. The increase in cross-sectional area resulted in a slight increase in total wetted area because shallow areas were better represented by the higher resolution meshes. The amount of slow, shallow water favored by juvenile salmonids increased with increasing mesh resolution. This increase in the amount of slow, shallow water in combination with the increase in wetted area, resulted in an increase in estimated juvenile salmonid habitat with increasing mesh resolution. For the highest resolution meshes, there was a 10-44% increase in estimated habitat relative to the lowest resolution mesh, depending on site and fish life stage.

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