Predicting grain sizes with ArcGIS, Klamath River, CA

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Introduction

The goal of this study was to use a surface roughness raster to predict sediment grain sizes along a 300-km section of the Klamath River. If successful, having access to grain sizes at such a high resolution along such a long river segment would provide a hugely powerful modeling tool and if repeated after the dam removals, a powerful method to evaluate how dam removal changes river channels.

Site Description

This study took place on a 313-km section of the Klamath River in California from just downstream of Iron Gate dam to the Klamath River estuary. In 2024, Iron Gate dam will be removed along with two upstream dams. Together, these dams will represent the largest dam removal in the world and are will be an unprecedented opportunity to explore the intersection of engineering, geomorphology and ecology that dam removal represents.

The Klamath River is California's second largest stream by annual runoff volume and once supported one of the largest steelhead and salmon runs in the lower 48. Warm water, declining flows, disease and algae blooms have drastically reduced the number of returning anadromous fish (Ayres 1999 and Stillwater Sciences 2010).

The Klamath River drainage is somewhat unique in that it is an "inverted" basin. The higher reaches of the watershed are low relief and contain natural lakes that capture sediment and store water, releasing flows slowly through groundwater through the summer months. Most of the rivers discharge and sediment load is contributed in the lower basin (Stillwater Sciences 2010).

Datasets- Vector/raster, source, map projection, resolution

The datasets used in this study were as follows, all used a linear unit of meters:

Surface_Roughness_Map_Klamath_River_California_2018

- Raster
- NAD83 (2011) UTM Zone 10N
- Source: Baseline Geomorphic Map and Land Surface Parameters Klamath River California 2018

This layer assigns each pixel a surface roughness value based on the standard deviation of the variability of the surround 3x3 grid of pixels.

Relative_Elevation_Model_Klamath_River_California_2018

- Raster
- NAD83 (2011) UTM Zone 10N

- Source: Baseline Geomorphic Map and Land Surface Parameters Klamath River California 2018

Each pixel is assigned an elevation relative to the nearest water surface elevation (WSE) datapoint which were taken at 10 m intervals along the entire section of river.

Reaches_1km_Klamath_River_California_2018

- Vector
- NAD83 (2011) UTM Zone 10N
- Source: Baseline Geomorphic Map and Land Surface Parameters Klamath River California 2018
- Resolution: 0.001 meters

Channel_Centerline_Klamath_River_California_2018

- Vector
- NAD83 (2011) UTM Zone 10N
- Source: Baseline Geomorphic Map and Land Surface Parameters Klamath River California 2018
- Resolution: 0.001 meters

A compilation of several field studies taking place between 1999 – 2008 was provided by Jennifer Curtis of the USGS and was used as an accuracy check for the Arc workflow.

Methods

The first step in the ArcGIS analysis was to clip the surface roughness layer to an approximate bankfull width. The raw raster contained overbank roughness which I didn't want to include as I was only interested in the channel grain sizes. The Relative Elevation Model (REM) was the solution. This allowed me to convert the REM to contour lines and then export the 1-meter contour, which I determined roughly approximated the bankfull elevation along the course of the river. Because elevations were relative to the nearest centerline WSE, the contour was a continuous line 1 meter above the river the throughout the entire area of interest. Using the polygon of the 1 m contour, I clipped the surface roughness raster and 1 km reaches layers to a bankfull width for the rest of the analysis, as shown in the model builder snippet in Figure 1.

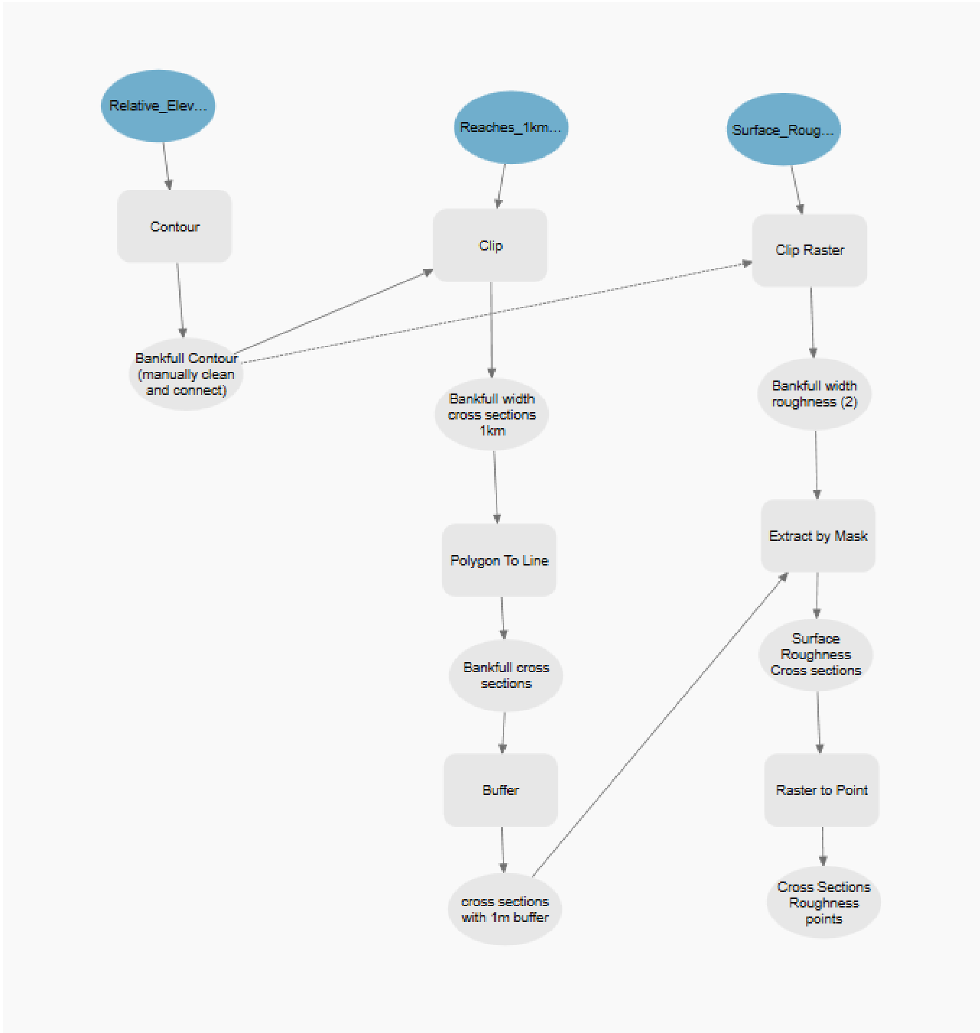

Figure 1: Model Builder flow chart

After stepping through the workflow in Figure 1, I used a spatial join to connect each point in "cross sections roughness points" to its corresponding 1 km cross section, "Bankfull cross sections". Each data point now had a roughness value and a cross section value (i.e. surface roughness of 0.004 mm at 34 km). I then used Matlab to calculate the 16, 50 and 84^{th} percentiles of each cross section.

Results

The resulting D16, D50 and D84 grain sizes for each cross section are plotted in Figure 2 against river kilometers from the mouth of the river.

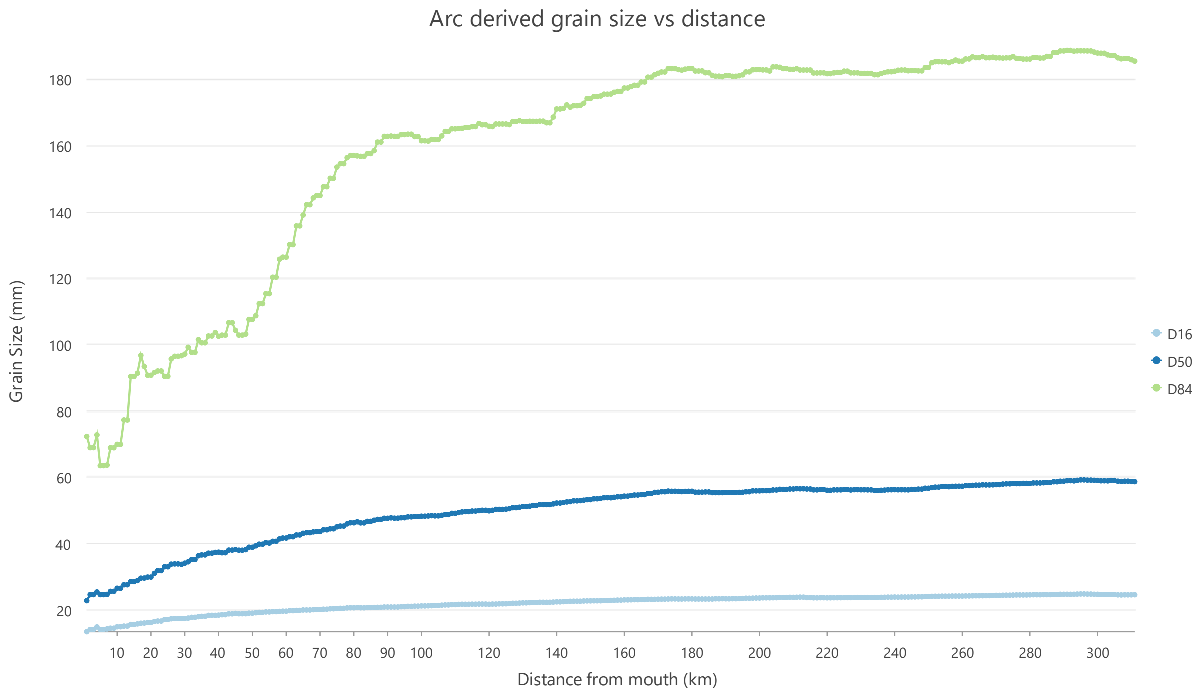

Figure 2: Arc workflow results

We can observe that a distinct fining trend occurs between river kilometer (RKM) 100 and the mouth of the river. Otherwise, there is little variability, especially in the D16 and D50 sizes.

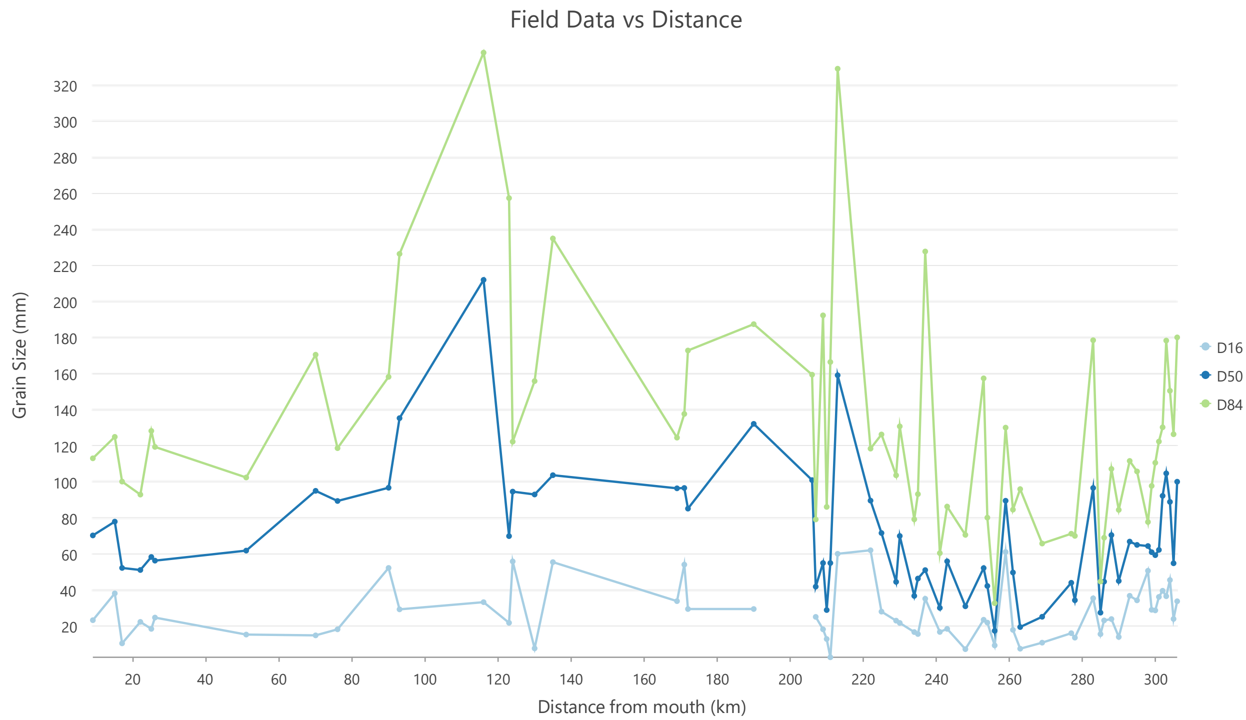

Figure 3: Field Results

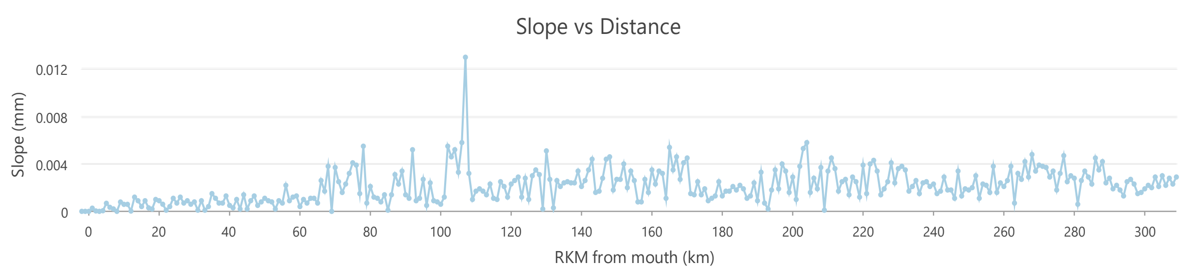

Figure 4: Reach slope profile

Field data in Figure 3 shows much more variability in all sizes, but we can still observe a downstream fining trend occurring around RKM 100. The field derived grain size distribution appears to capture real-world variability in the river and aligns well with the slope profile in Figure 4. Spikes in slope generally correspond with spikes in grain sizes which is what we would expect, and the fining trend downstream of RKM 100 aligns with a noticeable slope break in Figure 4 and is near the confluence of the Trinity River which supplies nearly 57% of the annual suspended sediment load (SSL) to the Klamath (Stillwater Sciences 2010).

The Arc model performance was poor when compared to the field derived grain size distributions. As shown in Figure 5, the Arc-derived data points were not correlated with the field collection.

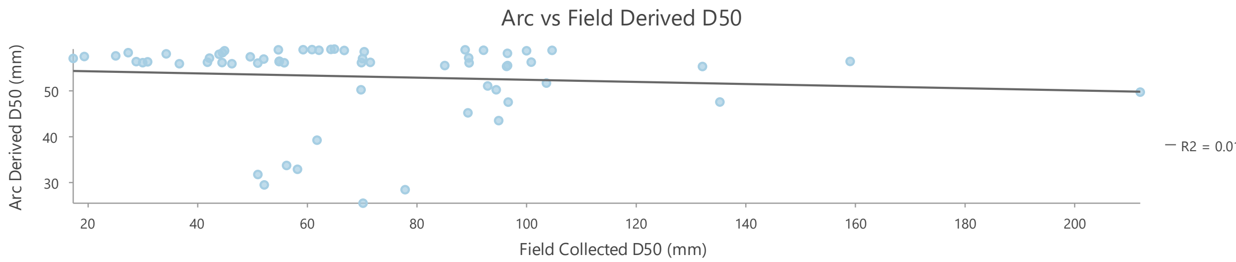

Figure 5: Relationship between Arc and field results

The Arc model performed especially poorly with grain sizes above about ~60 mm. Conclusions and possible sources of error will be discussed in the following sections.

Sources of Error

Non-alignment of Arc and field cross section locations

A brief exploration into the location of the field cross sections revealed that they may be as much as 7 km up or downstream of the Arc cross section with the same RKM value. As there can be tremendous variability in grain size at the reach scale (i.e. taking a measurement in a pool tail vs within a riffle) this is likely a significant contributor of error.

Poor sonar returns in high-velocity or shallow areas

The bathymetric sonar that was used to collect the surface roughness layer performs poorly when velocities are high or the depth is shallow. These two conditions are often correlated with flow over larger grain sizes and may explain part of the Arc model's lack of variability.

Subjective and constant bankfull height

The bankfull height of 1 meter was selected arbitrarily and was held constant throughout the 313-km reach. In reality, bankfull height above WSE likely varies with slope, width, and channel confinement.

Poorly documented field data

The field data that was used as an accuracy check had no metadata and little is known about collection methods and location of samples.

Poor relationship between surface roughness and grain size

The surface roughness raster was calculated by taking the standard deviation of variability for a 3x3 grid around the pixel of interest. If pixel size is small and the particle is large or bedrock, the entire grid may land on the same particle and return a low variability even though the particle size is large, disproving the implicit assumption this study made that they would be directly correlated. This is likely the single largest source of error.

Conclusions and Next Steps

A direct relationship between surface roughness and grain size could not be identified by this study. Still, there are a couple important conclusions to be drawn. First, despite its poor overall performance, the Arc workflow did capture the distinct fining trend downstream of RKM 100, giving some hope for the potential of using surface roughness to predict grain size changes. Second, given the amount of uncertainty in the field data and the possibility for exploration and improvement in the Arc workflow, the failure of this study to produce accurate grain size predictions should not discourage further exploration into this topic.

The next step would be to develop an algorithm to quantify the relationship between surface roughness and grain size. Pearson et. al (2017) emphasizes that these relationships are often site-specific so performing a well-constrained field study on the Klamath with a much smaller scale than this project would likely be necessary. Flume experiments could be useful as well. Of most importance would be developing an algorithm or machine learning to classify bedrock and large boulders as large grain sizes despite their low variability. Pearson et. al found that under the right circumstances, grain sizes can be predicted very accurately from surface roughness but a more complex methodology is likely needed than what was explored here.

Appendix

Ayres and Associates, 1999, Geomorphic and sediment evaluation of the Klamath River, California, below Iron Gate Dam: Fort Collins, Colo.

Holmquist-Johnson, & Milhous. (2010). *Channel maintenance and flushing flows for the Klamath River below Iron Gate Dam, California* [Open File Report]. USGS. https://pubs.usgs.gov/of/2010/1086/pdf/OF10-1086.pdf

Pearson, E., Smith, M. W., Klaar, M. J., & Brown, L. E. (2017). Can high resolution 3D topographic surveys provide reliable grain size estimates in gravel bed rivers? *Geomorphology*, *293*, 143–155. https://doi.org/10.1016/j.geomorph.2017.05.015