Channel Slope and Whitewater Class Ratings on the Upper Klamath River

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Introduction

Four dams on the Upper Klamath River have been forfeited by the utility and will be removed to improve water quality and fish passage. If successful this will be the most extensive dam removal project to date, and the Klamath will become the longest unencumbered wild and scenic river in The Lower 48. Can desktop techniques be used to evaluate post-dam removal whitewater characteristics for reservoir reaches in the Upper Klamath River hydro project? Recreation planners and stakeholders want to know where there are clear breaks between river segments with different difficulty/class ratings. Appropriate placement of access sites is important to create a good "fit" between segment characteristics and the kinds of opportunities users want, and boaters generally want to put in and take out in places that are efficient for them. Well placed access sites reduce conflict between groups (eg. fishers, tubers, kayakers) who desire different river characteristics. If access sites are poorly placed, users will find a different way to put in and take out at these natural breaks, resulting in user created trails, bank erosion, trash and other problems at informal sites. At present there is no established system for predicting whitewater challenge based on available data, instead recreation planners are forced to "wait and see" what emerges from the reservoir reaches. It would be more useful to identify breaks in whitewater challenge in advance of removal to plan sites and allocate resources.

Rapids are formed by a combination of water volume and velocity, constriction, gradient and obstacles. These factors are interrelated (for example gradient increases velocity) but sometimes it only takes one or two factors (Howard and Dolan 1981; Kiefer 1987; Webb et al. 1999). Whitewater in the United States is rated on a I-VI scale based on navigation difficulty and potential consequences of failure. Class I is easily navigated by novice boaters with little to no consequences, and VI as deadly rapids not runnable except by a team of experts at the perfect flow (see descriptions of whitewater class ratings here https://www.americanwhitewater.org/content/Wiki/safety:start?#vi).

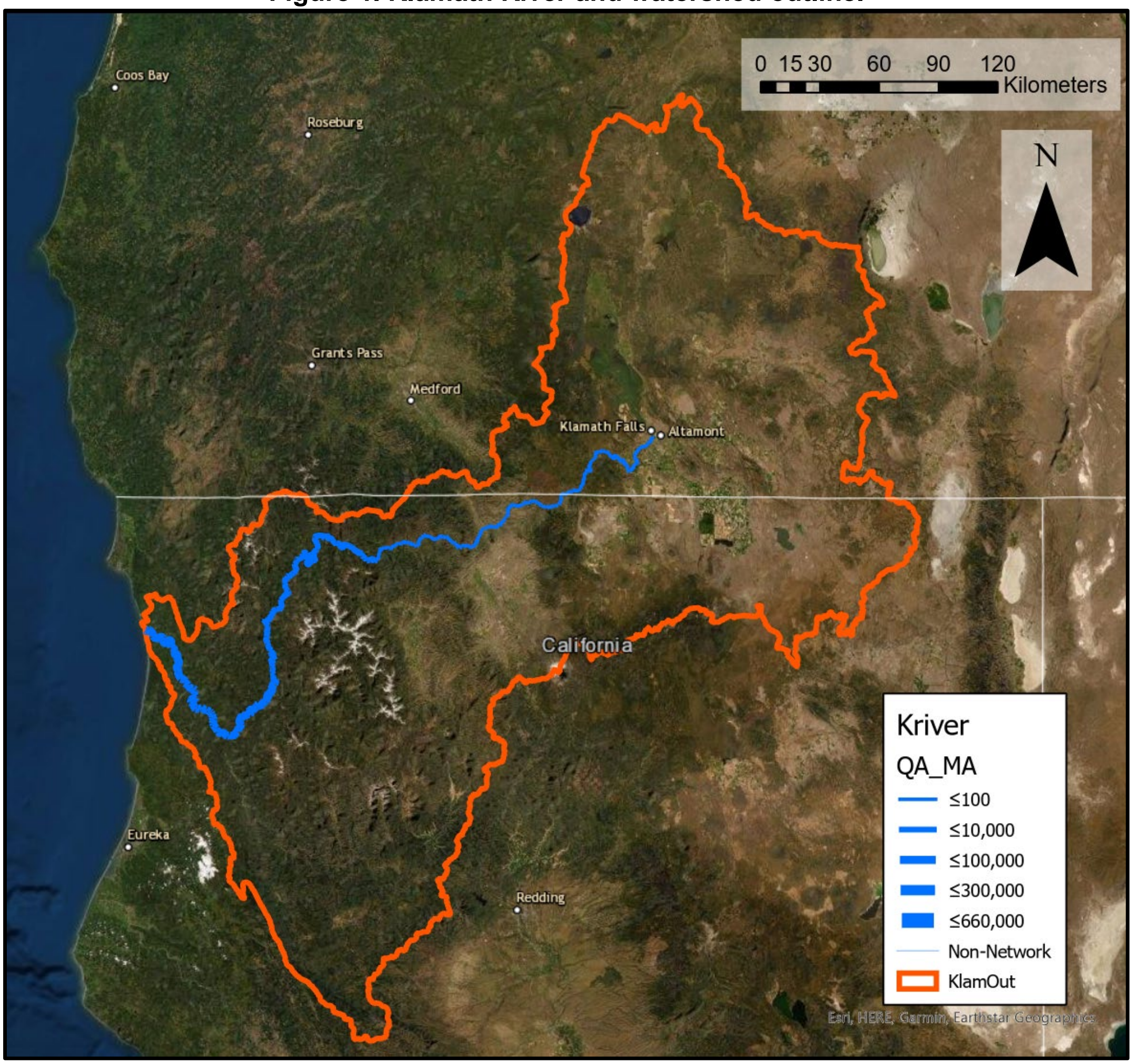
The goal of this project is to find out what readily available data can be used to predict whitewater characteristics. Based on preliminary research, some common GIS layers are promising. Steeper rivers have faster flow which can result in bigger, more continuous hydraulics. Drop per mile is often used in whitewater guidebooks as a metric to describe whitewater. Does the steepness of the Klamath River correlate with whitewater characteristics?

Site Description

The Klamath river is the second largest in California and one of only 3 rivers that breaches the Cascade range (see Figure 1 and Map 1). It is over 250 miles from the headwaters to the coast and will become the longest wild and scenic river in the United States after removal (Kruse 2006).

The Klamath has been described as having an inverted profile because the headwaters are lower gradient and high impact because of extensive agricultural development in the vicinity of Klamath Falls. After passing through Keno Dam the river has higher gradient and little development, as it passes through the Cascade and Coast range. Klamath Lake is a shallow lake that has intense nutrification because of agricultural inputs. Warming in the lake and downstream reservoirs exacerbates nutrification which leads to harmful algal blooms at the end of the summer. Warmer temperatures and nutrification have allowed the parasite *C. Shasta* which lives part of its life cycle in anadromous salmon to flourish in the Klamath. This parasite was responsible for mass salmon wasting events including one well publicized event in 2012 (Oliver, Dahlgren, and Deas 2014).

Figure 1. Klamath River and watershed outline.



The Klamath River Hydropower project, owned and operated by Pacificorp, was up for relicensing in 2006. The dams were aging and required millions of dollars in repairs and maintenance. Installation of fish ladders and screen turbines required by the Endangered Species Act would cost an additional $100 million. Pacificorp worried that other costly measures to improve water quality in the four reservoirs would also be required as a condition of the new license. Given that the project only generates 151 megawatts of Pacificorp's 8,300 megawatt portfolio, they decided to surrender their license instead of continuing operation (Kruse 2006). In 2012, Pacificorp signed an agreement with Klamath Irrigation District, Klamath Tribes, and the Klamath River Renewal Corporation (KRRC) to transfer the license to KRRC for removal.

Methods

Data

Table 1. Data features and sources.

Data	Source
NHD plus flowlines	ArcGIS living atlas
NHD plus watershed boundaries	ArcGIS living atlas
NED 10m DEM	USGS

NHD plus flowlines

The NHD plus flowlines feature is part of the National Hydrography Dataset (NHD). It contains vector flowlines for the United States with a variety of attributes including channel slope. The NHD is readily available on the ArcGIS living atlas. The projection of this dataset is WGS 1984 Web Mercator (auxiliary sphere).

NHD plus watershed boundaries

The NHD plus watershed feature is part of the National Hydrography Dataset. It contains vector basin outlines for the United States. The NHD is readily available on the ArcGIS living atlas. The projection of this dataset is WGS 1984 Web Mercator (auxiliary sphere).

NED 10m DEM

The National Elevation Dataset 10m DEM contains raster elevation data at 10m resolution. It was downloaded from The National Map data viewer and downloader tool online. The Klamath River spans six tiles that are one degree by one degree each. The projection of this feature is NAD 1984.

GIS Processing

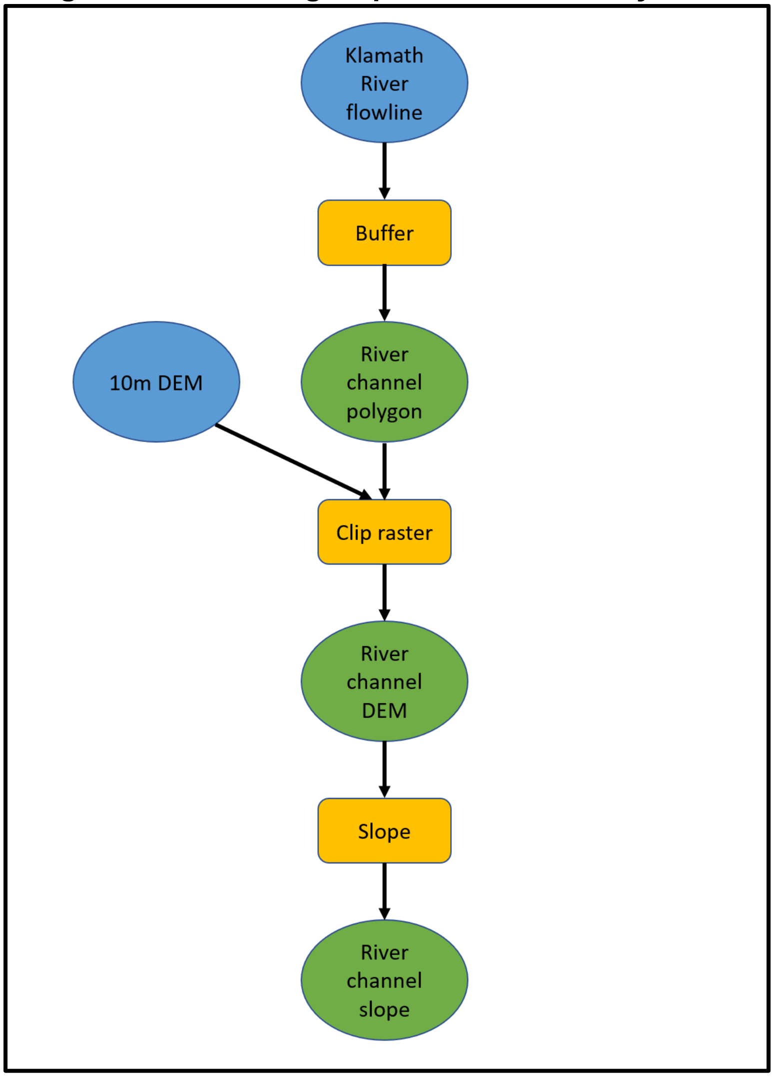
First analysis

See Figure 2 for a flowchart of processing steps used in the first analysis.

1. Bring all the features into Arcgis.
2. Isolate the Klamath Basin from the NHD plus watershed boundaries using the export data tool.
3. Isolate the Klamath River from the NHD plus flowlines using the export data tool.
4. Merge the six NED 10m DEM tiles into one feature using the mosaic to new raster tool.

5. Clip the merged NED 10m DEM feature to the Klamath basin outline
6. Add a 15m buffer to the Klamath River feature class to create a polygon that is roughly the same width as the river channel and contains enough pixels to run the slope tool.
7. Clip the DEM to the buffered flowline resulting in a continuous raster feature that contains elevation data for the river channel.
8. Use the slope tool to create a slope feature from the clipped DEM using the geodesic method.

Figure 2. Processing steps for the first analysis

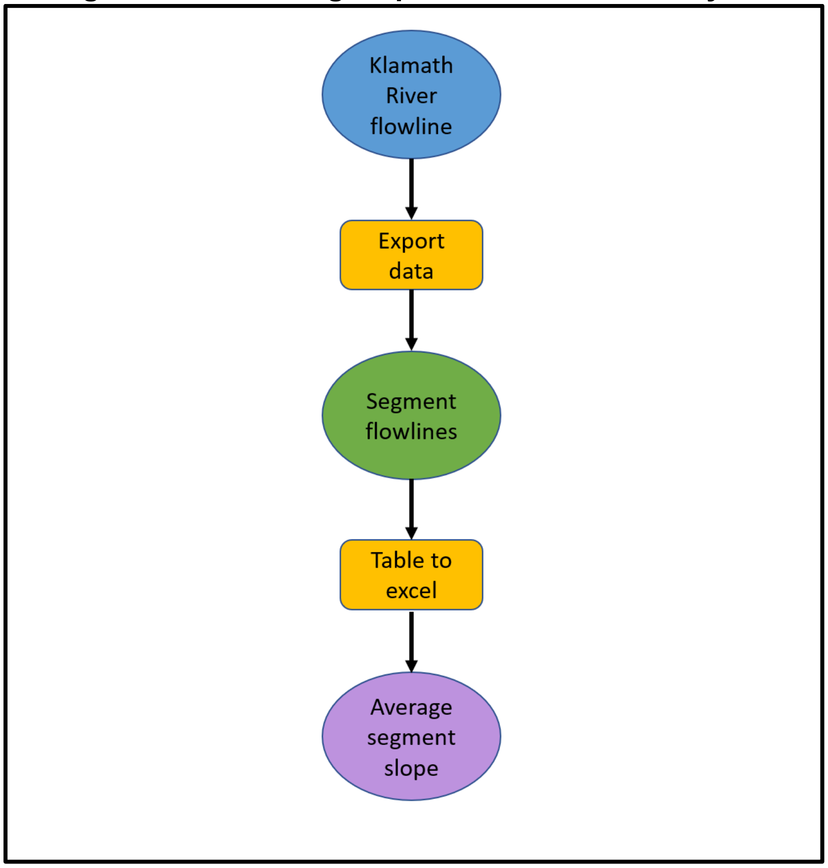


Second analysis

See Figure 3 for a flowchart of processing steps used in the second analysis.

1. Select subsets of the NHD flowlines that represent river segments with similar whitewater characteristics and make each one into a new feature using the export data tool.
2. Export the data for each segment flowline to an excel table using table to excel.
3. Calculate the average slope for each segment in excel.
4. Compare the segment slopes with established whitewater class ratings.

Figure 3. Processing steps for the second analysis.

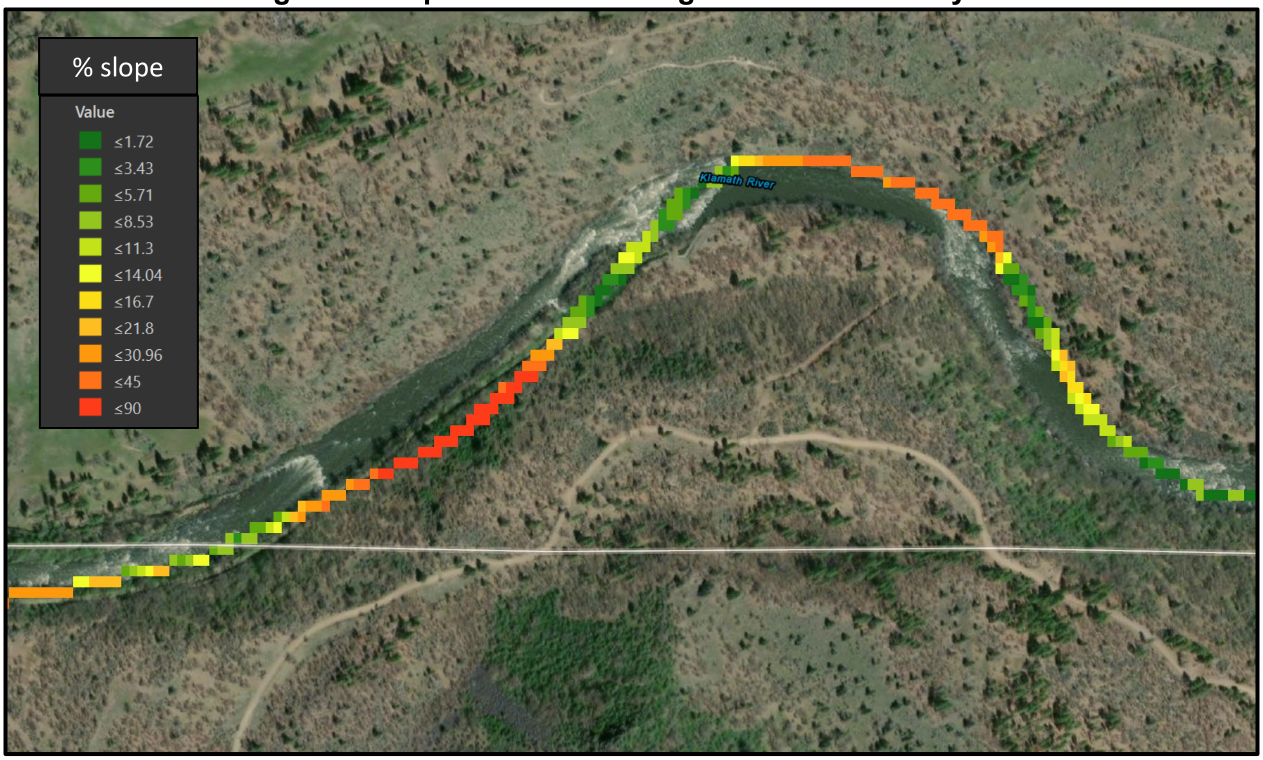


Results

First analysis

The first analysis resulted in a slope feature with channel slopes over 90% in some places, which is way too high for a Klamath channel slope. See Figure 4 for an example of this slope feature.

Figure 4. Slope feature resulting from the first analysis



Second analysis

Results from the second analysis are shown in Table 2 and Map 2.

Table 2. Average segment slope and class ratings.

Row Labels	Average slope	Class rating
Above Keno	0.0%	I
Above Copco	0.5%	II
Hell's Corner 1	0.8%	III
Hells Corner 2	1.3%	IV+
Keno	1.4%	III
Boyle	1.6%	IV+
Wards Canyon	1.8%	IV

Discussion

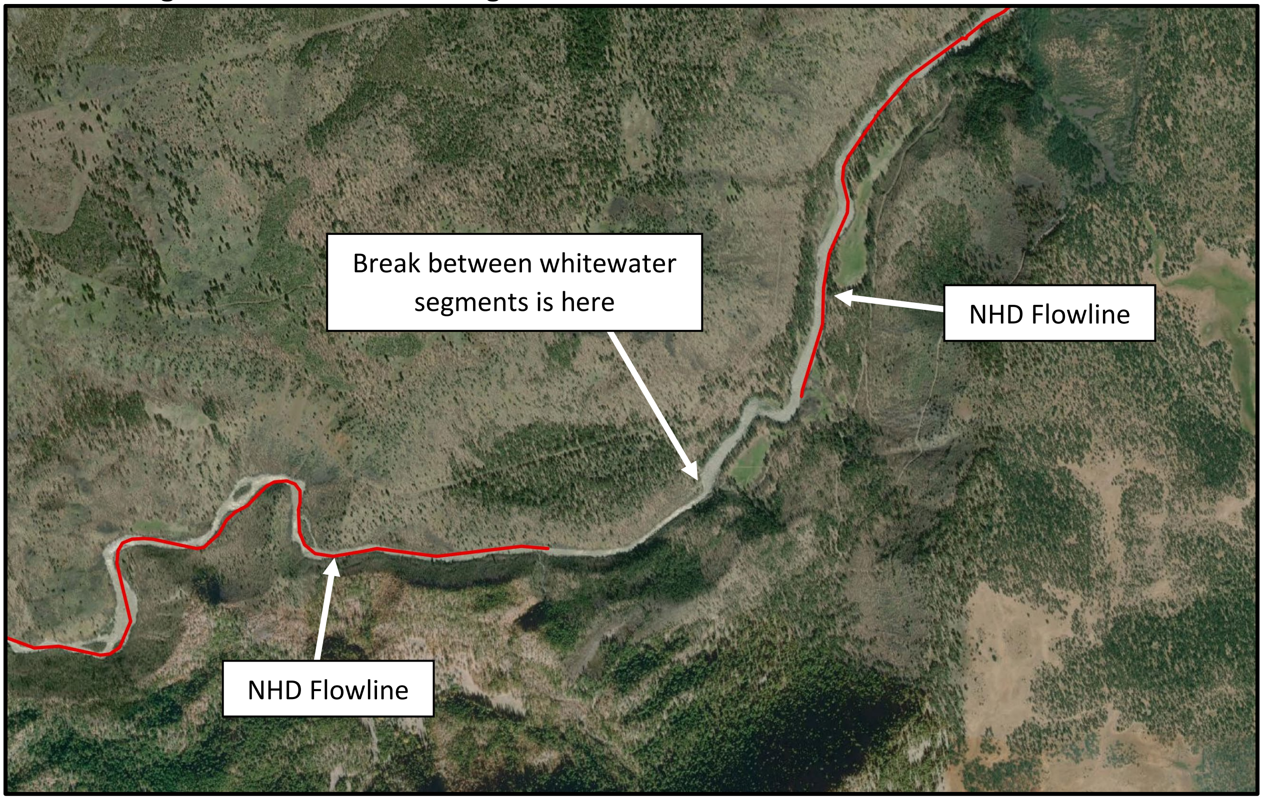
First analysis

The slope feature resulting from the first analysis was not useful. The NHD plus flowline was not aligned with the 10m DEM so the slope feature based on the buffered flowline captured the river banks in many places.

Second analysis

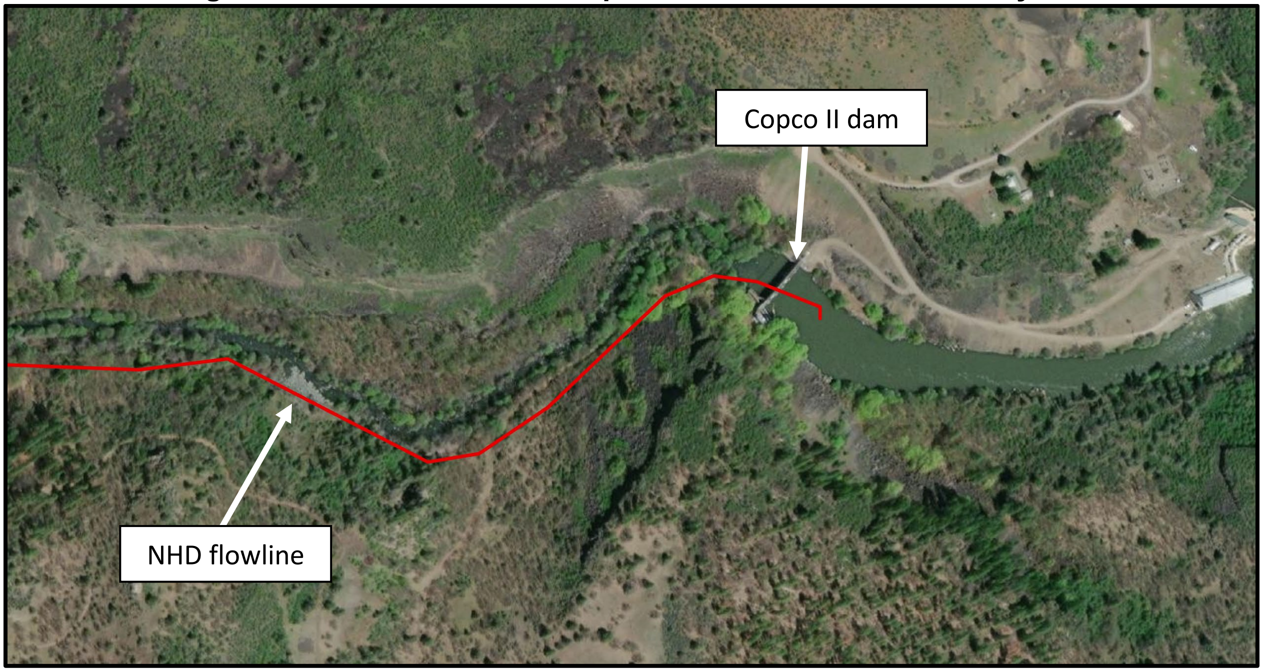
The slope data from the NHD flowlines supports the hypothesis that channel slope is correlated with whitewater class ratings. River segments with steeper slopes generally had higher whitewater class ratings. While this analysis is good enough for a proof-of-concept pilot study, there are some problems with using the slope attribute from NHD plus flowlines. Because the flowline segments are separated by tributary locations, they sometimes spanned a segment break. Figure 5 shows a break between whitewater segments in the middle of an NHD flowline. Such flowlines had to be excluded from the analysis.

Figure 5. A whitewater segment break in the middle of an NHD flowline.



Another example of poor fit is illustrated in in Figure 6. The figure shows the upstream extent of Ward's Canyon, directly below Copco II dam. The NHD flowline starts upstream of Copco II so the dam's head is included in the slope calculation. Note that Ward's Canyon had the steepest slope despite having whitewater that was less difficult than Hell's Corner or Boyle Bypass (see Table 2).

Figure 6. NHD flowline at the upstream extent of Ward's Canyon.



Many NHD flowlines were also longer than the unit of analysis. The upper portion of the Keno segment is class III, with a pool-drop character (stepped profile) that is similar to other whitewater reaches on the Klamath. The lower portion of the Keno run is continuous class II (continuous profile) resulting in constant moderate flow velocities. Segments like these can have very steep overall slopes without producing distinct drops and difficult whitewater features. The continuous class II portion of the Keno segment may have biased the data, resulting in a slope that was steeper than other, more challenging segments (see Table 2). The configuration of the NHD flowlines did not facilitate separation of the Keno segment into two pieces which would have allowed comparison of the class III upstream reach with other pool-drop whitewater reaches.

Future steps

The results of this pilot study are good proof of concept but are not rigorous enough for a scientific publication. Higher resolution slope data is needed for an appropriate unit of analysis. Lidar bathytopo data with 1m resolution is available for the entire Klamath River from the National Oceanic and Atmospheric Administration. The next step of this research project is to build a raster stream network based on the lidar elevation data. Using a raster derived stream network will ensure that the flowlines are aligned with the river channel, thus resolving the problem with the first analysis. Using elevation data with 1m resolution will allow the slope tool to work on a river channel polygon with a smaller buffer, which will help eliminate error introduced by the stream banks.

The bathytopo lidar data is integrated with reservoir acoustic surveys and shows bathymetry. This data will allow comparison of channel slope and whitewater features between free-flowing river segments and those that currently lie beneath reservoirs.

Another problem with this analysis is the classification of whitewater features. Class ratings are well established in the whitewater community but they still have a subjective nature. Class ratings are not always consistent between rivers, regions, and countries. If more experienced boaters are establishing the ratings they may assign a lower difficulty to the segment compared to novices. Class ratings can also change depending on the flow conditions. A more rigorous whitewater classification system based on scientifically established channel geomorphology is more desirable.

Conclusion

This polit study explores the relationship between channel slope and whitewater characteristics on segments of the Klamath River based on readily available data. Results support the hypothesis that there is a relationship between slope and whitewater challenge, with steeper slopes producing more difficult whitewater features. Limitations of this analysis include insufficient resolution of the slope data and arbitrary break locations between slope features. Future efforts will address these limitations with higher resolution elevation data and a raster derived stream network.

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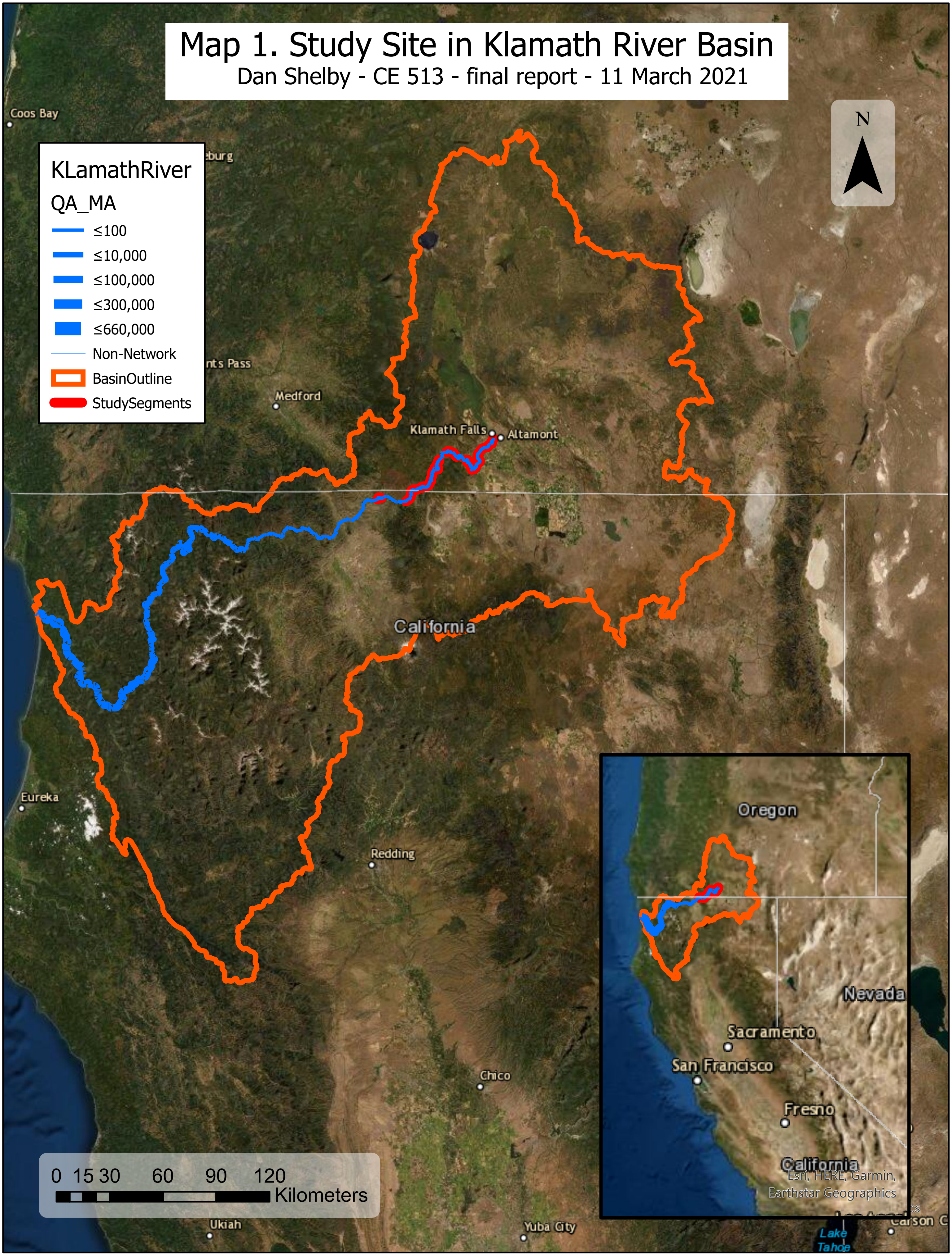

Map 1. Study Site in Klamath River Basin
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N
KLamathRiver
QA_MA
≤100
≤10,000
≤100,000
≤300,000
≤660,000
Non-Network
BasinOutline
StudySegments
Coos Bay
Medford
Klamath Falls
Altamont
California
Eureka
Redding
Chico
Ukiah
Yuba City
Oregon
Nevada
Sacramento
San Francisco
Fresno
California
Esri, HERE, Garmin, Earthstar Geographics
Lake Tahoe
0 15 30 60 90 120
Kilometers

Map 2. Slope of NHD Flowlines and Klamath River Segments

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