Utilization of Remote Sensing to Study Sediment Transport and Deposition After Dam Removal on the Elwha River

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1. INTRODUCTION

The Elwha River Restoration Project is the largest dam removal project ever attempted in the United States. For over 100 years, the waterway of the Elwha has been blocked by 2 large hydroelectric dams- trapping an estimated 34 million cubic yards of sediment, preventing native Salmon from swimming upstream to spawn, and disrupting the ecological balance of the river system. This removal project is largely unprecedented due to the scope of the project and the sheer size of the dams.

Once the dams are removed, some of the sediment will remain in situ, but much of it will be discharged downstream. How much will be transported and where it will end up is still largely uncertain. Furthermore, the timeline for this sediment migration is also unknown. Some of the sediment load was removed with the initial release of water after the first dam was demolished in 2011, but much more will follow in subsequent years as the Elwha returns to a more natural state.

Turbidity is a measure of water clarity and suspended particulate in a body of water. The most common ways of measuring turbidity is by direct water sampling and lab analysis, Secchi disc, or reflectance measurements using a handheld spectroradiometer. These methods are laborious, time consuming, and require actual manpower in the field.

There have been several studies examining the use of satellite remote sensing of water turbidity in stream and shallow coastal settings. Due to the large time scale of the Elwha Restoration Project, field collection of turbidity data is impractical. If satellite imagery can accurately track sediment transport and deposition in the estuary and coastal environments of the Elwha, this could be a powerful tool for understanding how ecosystems behave to mitigations such as those undertaken during the Elwha River Restoration Project.

The purpose of this project is to investigate whether remote sensing can be used to track turbidity of river water (ie sediment transport,) and to assess deposition of sediments along coastal environments at the mouth of the Elwha using satellite imagery.

Hypothesis:

Landsat imagery will be useful in the study of the legacy of sediments released during the Elwha River Restoration Project. This method can be applied to similar future ecological mitigations.

Objectives:

1. Examine methods for determining turbidity of water using Landsat Imagery. Map turbidity concentrations of study area waters.
2. Study and map coastal morphology changes to determine where discharged sediments are being deposited.

2. BACKGROUND AND DESCRIPTION OF STUDY AREA

Fig. 1: Location of the Elwha River

The Elwha River watershed encompasses 321 miles of waterway on the Olympic Peninsula in the state of Washington. The Elwha flows north from the Olympic Mountains into the Strait of Juan de Fuca. The majority of the Elwha is located within the protected boundaries of Olympic National Park.

The river was once an important spawning ground for 5 species of salmon native to the Pacific Northwest. The 108 ft. tall Elwha Dam was constructed in 1910, effectively blocking the passage of salmon upstream to nesting areas. The second and larger dam, the 210 ft. Glines Canyon Dam, was finished in 1927 upstream of the Elwha Dam. Before dam removal began in 2011, the salmon population of the Elwha was estimated to be around 3,000 fish, representing 2 species. After dam removal, all 5 species of salmon are predicted to return to the Elwha in numbers reaching 400,000 within a decade. The dam removal will not only open up new territory for salmon spawning, but the released sediment is predicted to replenish the eroding estuary zone and coastal seashore adjacent to the Elwha's mouth. The dam removal will return the area back to a natural and balanced ecosystem.

The project began in 2011 with the demolition of the Elwha Dam, and is scheduled to be complete in late 2014 when the remainder of the footprint of the Glines Canyon Dam is removed.

Fig. 2: A sediment plume following Elwha Dam removal in Sept 2011

3. DESCRIPTION OF DATA AND METHODS

Landsat 8 is the newest in the series of Earth imaging satellites operated by NASA and the USGS. Landsat 8 follows a sun-synchronous orbits with an altitude of 705 km. It circles the Earth once every 98.9 minutes and has a temporal resolution of 16 days. This satellite carries 2 highly sensitive push broom sensors, The Operational Land Imager (OLI) and the Thermal InfraRed Sensor (TIRS). The OLI sensor is best utilized for this study. The OLI captures 9 spectral bands, including a panchromatic band and a band for viewing cirrus clouds. Landsat 8 has an increased Signal to Noise ratio and better radiometric resolution (12 bit) than previous satellites of the series. The high spatial resolution and temporal resolution make Landsat imagery a good fit for this study.

Range	Band	Spectral Range (µm)	Spatial Resolution (m)
Visible	1	0.43 – 0.45	30
Visible	2	0.45 – 0.51	30
Visible	3	0.53 – 0.59	30
Red	4	0.64 – 0.67	30
NIR	5	0.85 – 0.88	30
SWIR	6	1.57 - 1.65	30
SWIR	7	2.11- 2.29	30
Panchromatic	8	0.50 - 0.68	15
Cirrus	9	1.36- 1.38	30

Table 1: Landsat 8 Resolutions

Several studies have been conducted on the remote sensing of Total Suspended Matter Concentration (TSMc) using Landsat imaging in river, coastal, and estuarian environments. Landsat has been used for this type of remote sensing in the past because of its high spatial resolution and several decades of archived data. Relative concentrations of TSMc can be determined from satellite remote sensing by viewing the reflectance of sunlight at different wavelengths. More turbid water will reflect and backscatter more energy than clear water.

Several studies have also been conducted to develop quantitative relationships by calibrating remotely sensed reflectance measurements with field sampling of actual TSMc. The strongest correlation between TSMc concentrations and spectral reflectance has been found by taking the ratio of near-infrared (NIR) and visible (550nm) reflectance (Doxaran, 2002.) This relationship is represented by:

$$\frac{R_{rs}(850)}{R_{rs}(550)}$$

Where R_{rs} is the reflectance signal recorded at the given wavelength (in nm.) This can be plotted against field measurements of TSMc in g/L to obtain a calibration curve. Although no known field measurements exist, this formula will be used to look at relative values of turbity which will be made into a new raster dataset to be overlain on true color photographs of the area.

Coastline Morphology changes will also be assessed using the higher resolution panchromatic band. Again, a baseline image of the coastline along the Juan de Fuca Strait will be selected from the period shortly before the first dam was removed. This image will be overlain with the most current image available to assess any changes in erosion or deposition along shallow coastal water.

4. RESULTS

Results of this project will feature Landsat images of the study area with suspended sediment concentrations false colored to map sediment transport paths. Ideally, several images spanning the time frame will be analyzed to observe temporal changes over the span of the project. Overlain coastal images will also be featured to highlight any differences in coastal morphology due to sedimentation or erosion over the study period.

5. DISCUSSION AND CONCLUSIONS

Discussion will consider if the spatial resolution of Landsat imagery is an appropriate choice to monitor changes to the coastline over such a small time window. Temporal resolution will also be discussed to assess whether Landsat's 16 day window is accurate enough to track rapid sediment flow in this type of environment. Conclusion will focus on whether satellite imagery could be an accurate primary or supplemental way to track sediment transport for large sediment release situations like dam removals.

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