Short Term Impacts of Two Dam Removals along the Elwha River

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History of the Elwha River

The Elwha River is located on the Olympic Peninsula in Washington. It is sourced from the snowy Olympic Mountains and flows north across Olympic National Park to Port Angeles and empties in the Strait of Juan de Fuca (NPS, 2019). The Elwha is an important spawning habitat for anadromous fish, including char, trout, and five different types of economically significant salmon. In 1910 the Olympic Power Company began constructing the Elwha Dam to supply energy to Port Angeles. To meet the demands of a growing economy, a second dam was constructed in 1927 (Glines Canyon Dam), eight miles upstream from the first. However, the contractors failed to consider fish passage and sediment flow when constructing the dams along the Elwha. This shortcoming led to decimated salmon populations and erosion of riverbanks and suitable spawning habitats downstream of the dams. In response to threatened salmon populations, Congress passed the Elwha River Ecosystem and Fisheries Restoration Act in 1992. This act authorized the US Department of the Interior to restore the Elwha River, which included removing the Elwha Dam in 2011 and the Glines Canyon Dam in 2014. Today, salmon are able to once again spawn in the Elwha and sediment is able to flow down the river to the shoreline.

Rationale

We chose to study the short term impact of dam removals on the Elwha River because this is one of the largest dam removal and river restoration projects in the country (USGS, 2020). The accessible data is very detailed and can tell us how the river changes instantly with the change in geomorphology. When the dams were removed, millions of tons of sediment were released back into the river channel, surrounding estuaries, beaches, and the river mouth, greatly impacting several ecosystems. In the short term, this sudden change is overwhelming to the ecosystems, but in the long term, the sediment will help to support life and ecological dynamics along the Elwha.

Research Questions

1. What is the correlation between sediment and water discharge in the Elwha River during the dam removal?
2. How does the trend of streamflow overtime relate to the trend of sediment discharge?
3. What is the trend of stream discharge overtime in the Elwha River during and after dam removal?
4. What is the trend of sediment discharge overtime in the Elwha River during and after dam removal?
5. How does sediment discharge compare before, during, and after dam removal in the Elwha River?

Dataset Information

The datasets we are using are publicly available from the U.S. Geological Survey. They include daily sediment loads and streamgage measurements before, during, and after dam removal, from 2011 to 2016 from gaging stations on the Elwha River at the diversion near Port Angeles, WA (downstream of dams).

The sediment dataset variables include: Date - date of the daily values Daily Discharge - measured in cubic meters per second Daily SSC - daily suspended-sediment concentration in milligrams per liter Upper SSC Bound - upper uncertainty bound, one standard deviation, of SSC Lower SSC Bound - lower uncertainty bound, one standard deviation, of SSC Average Fraction fines - average fraction of fine-grained particles (silts and clays) is suspension based on the data of two turbidimeters Daily Suspended-Sediment Load - daily suspended-sediment load in tonnes Daily SS Load of Fines - daily suspended-sediment load of fine-grained particles (silts and clays) in tonnes Daily SS Load of Sand - daily suspended-sediment load of sand-sized particles (in tonnes) Daily Total Gauged, less than 2-mm Bedload - daily total gauged bedload of particles larger than 2 mm (in tonnes) Daily Gauged Bedload for 2-16mm Particles - daily total gauged bedload of particles larger than 2 mm and smaller than 16 mm (in tonnes) Daily Gauged Bedload for Equal and Greater than 16mm Particles - daily total gauged bedload of particles larger than 16 mm (in tonnes) Estimated Daily Ungauged Bedload - estimated ungauged portion of particles in bedload flux that are less than 2 mm (in tonnes) Total Sediment Discharge - total daily sediment discharge. Included gauged suspended-sediment load, gauged bedload, and estimated bedload (in tonnes)

The streamgage dataset variables include: Date and Time - the date and time of measurement, in mm/dd/yyyy hh:mm format Stage Height - the stage height in meters relative to stream bed, in meters NAVD88 Height - the stage height in meters relative to North American Vertical Datum of 1988

Data Wrangling

The datasets downloaded included many columns that were not useful for this analysis. For the sediment load dataset, the date column was reclassified as a date, then the useful columns were selected and renamed. The Date column in the Stream Gage dataset included a date and time, so those pieces were extracted into separate columns and the Date was reclassified. Measurements that were flagged as Bad, Buried, or Noisy were removed. Next, an average stage height measurement for each day was calculated. With these wrangling steps complete, the datasets are ready for initial visualizations.

Exploratory Analysis

Exploratory Analysis: Sediment Loads Data

Table 1: Summary Statistics for the Sediment Data

Variable	Minimum	Median	Mean	Maximum
Date	2011-09-15	2014-03-24	2014-03-24	2016-09-30
Discharge m3/s	6.33	41.70	47.70	399.50
Suspended Sediment Concentration (mg/L)	0.227	169.500	945.363	13819.790
Average Fine SS Fraction	0.4100	0.6850	0.6896	0.9940
Total SS Load (tonnes)	0.1	634.4	7750.9	429806.7
Fine SS Load (tonnes)	0.1	457.9	4533.7	269484.4
Sand SS Load (tonnes)	0.00	186.70	3217.18	160322.30
Ungauged Bedload (tonnes)	-7710	139	1976	104444
Total Sediment Discharge (tonnes)	0.1	779.8	9886.9	466989.1

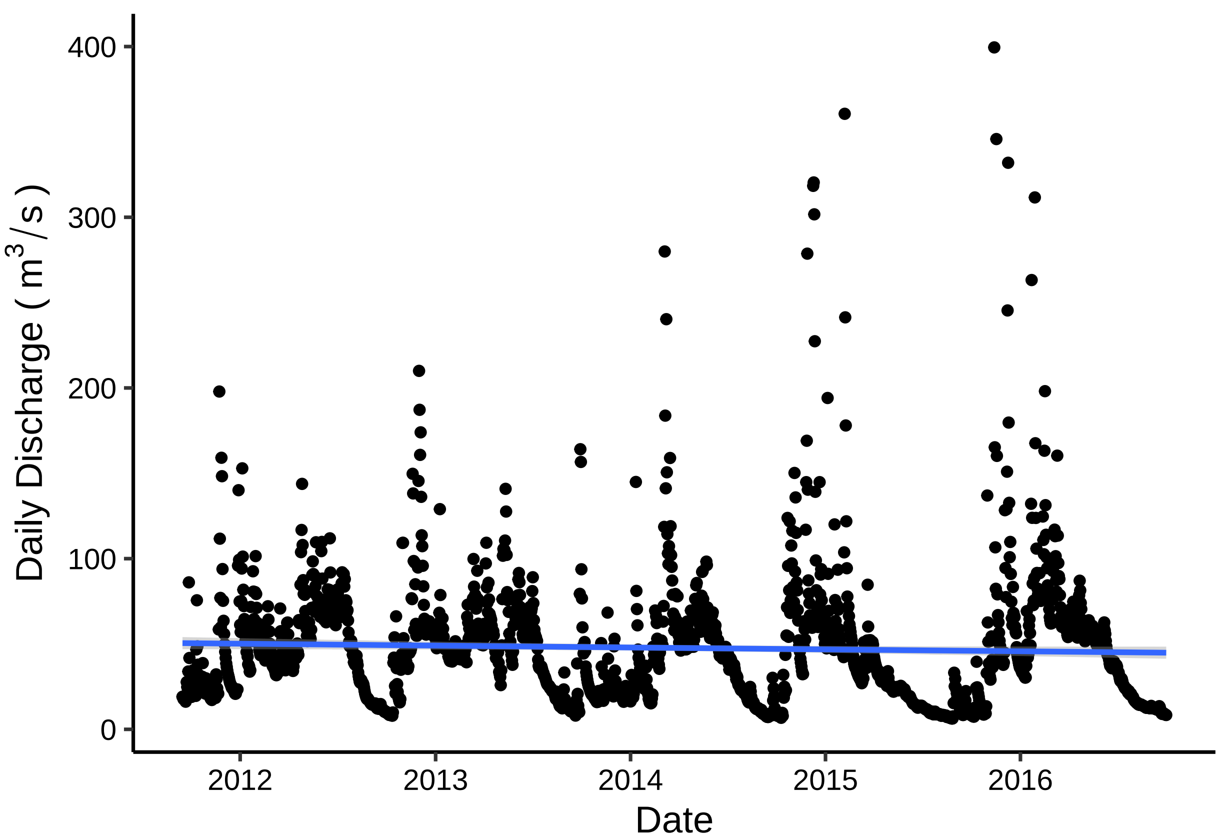

Figure 1: Daily Discharge over Time

Table 2: Regression Results for Daily Discharge Over Time

	Estimate	Std. Error	t value	`Pr(>|t|)`
Intercept	96.818629	27.387137	3.535	0.000418 ***
Date	-0.003041	0.001695	-1.794	0.072918 .
R-squared				0.001746
Adj R-squared				0.001204

Discharge shows strong seasonal trends, with an insignificant slight decrease over time (p value = 0.072918). Seasonal trends appear to become stronger with time. Time series analysis will remove seasonal trends in the data and reveal changes before and after dam removal.

Exploratory Analysis: Streamgage Data

Table 3: Streamgage Data Summary Statistics

Variable	Minimum	Median	Mean	Maximum
Date	2011-10-17	2013-11-27	2013-12-11	2016-05-11
Average Stage Height (m)	0.1608	0.9752	0.9908	2.6560

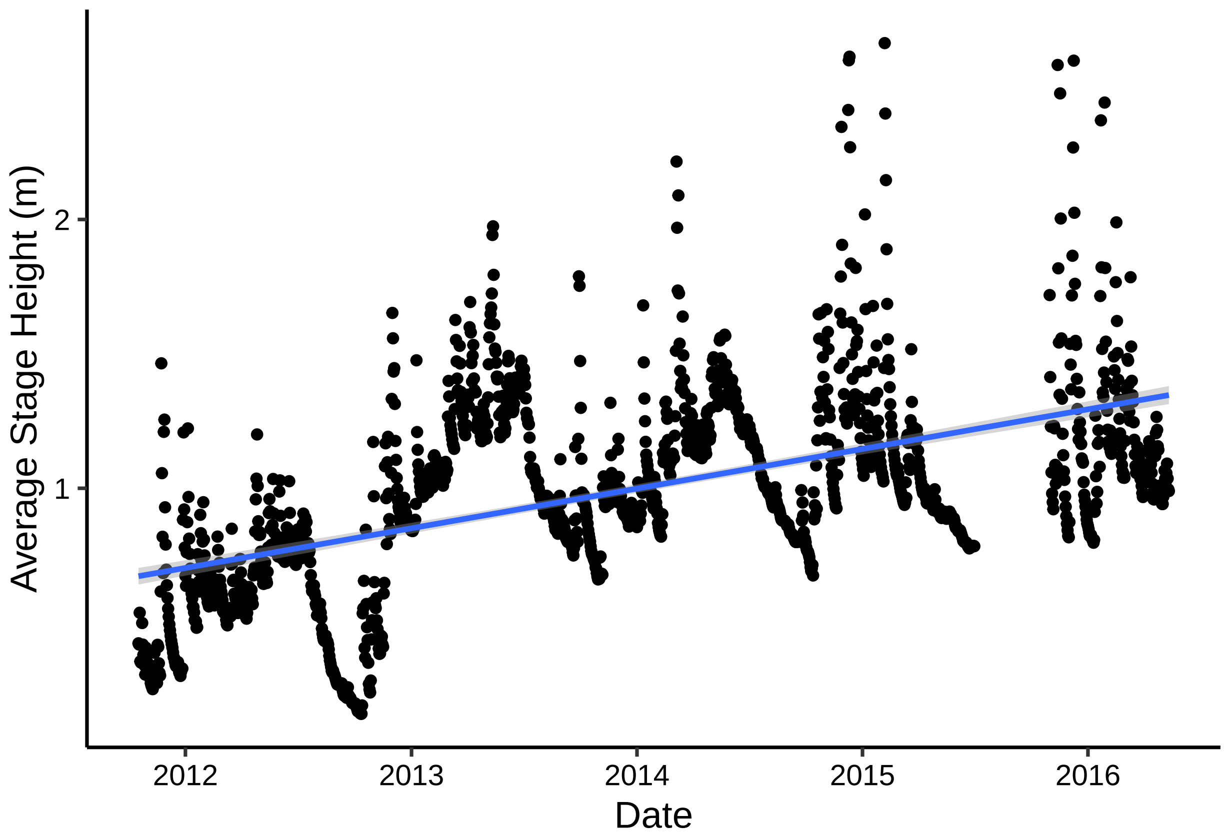

Figure 2: Average Stage Height Over Time

Table 4: Regression Results for Stage Height Over Time

	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	-5.493e+00	2.753e-01	-19.95	<2e-16 ***
Date	4.040e-04	1.715e-05	23.56	<2e-16 ***
R-squared				0.2646
Adj R-squared				0.2641

Stage height shows strong seasonal trends, with a significant increase over time (p value <2e-16) Time series analysis will remove seasonal trends and reveal changes before and after dam removal.

Analysis

Question 1: What is the correlation between sediment and water discharge in the Elwha River during the dam removal?

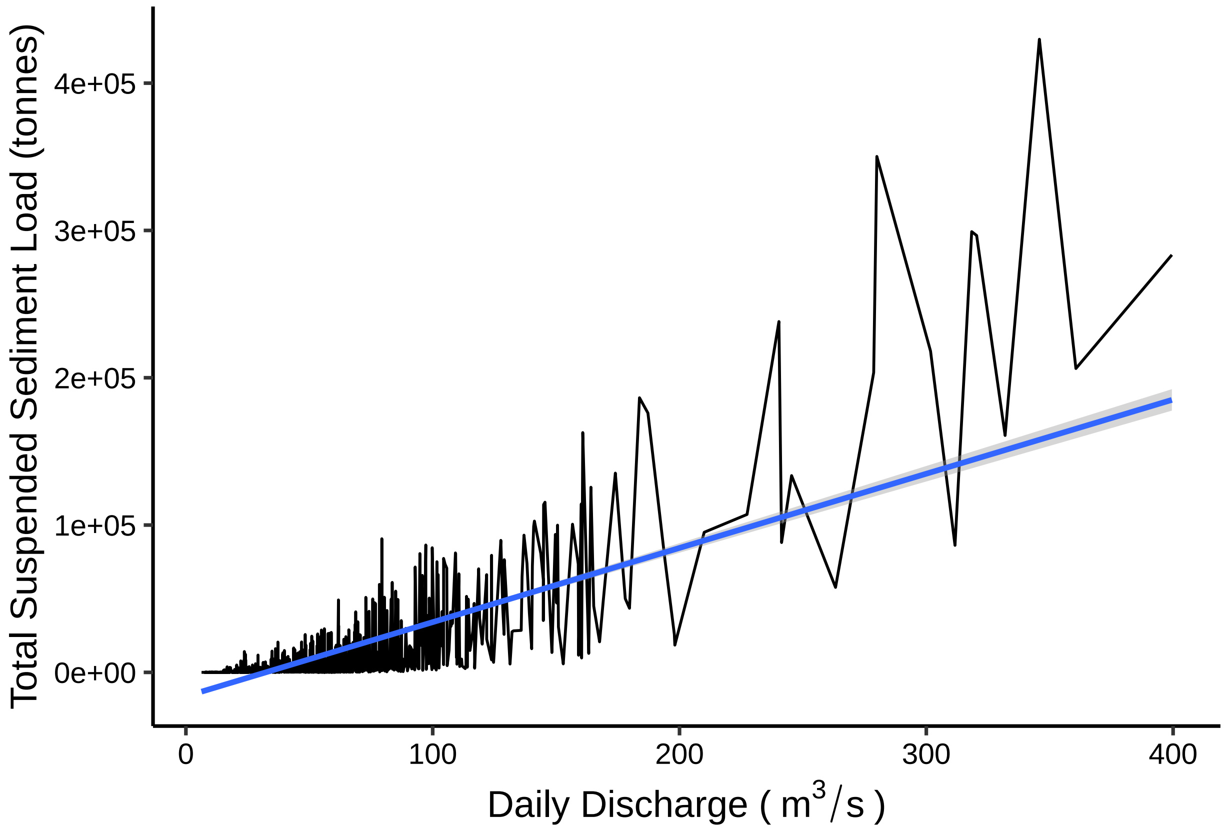

Figure 3: Total SS vs Discharge

Table 5. Regression Results for Total SS vs Discharge

	Estimate	Std. Error	t value	`Pr(>|t|)`
Intercept	-16278.35	644.40	-25.26	<2e-16 ***
Discharge	503.73	10.49	48.03	<2e-16 ***
R-squared				0.5561
Adj R-squared				0.5559

Daily discharge has a significant positive correlation with suspended sediment load (p<2e-16). As daily discharge increases, we can expect to see increases in suspended sediment loads.

Question 2: How does the trend of streamflow overtime relate to the trend of sediment discharge?

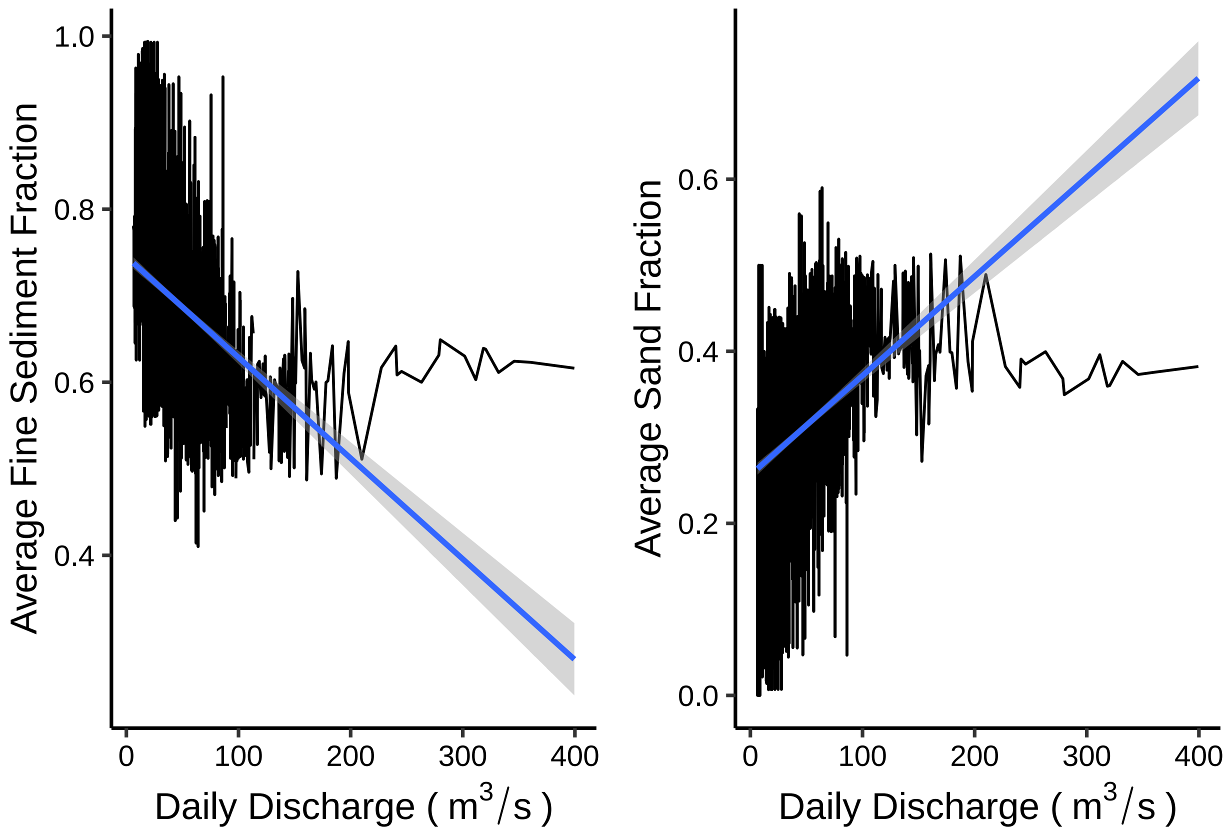

Figure 4: Fine and Sand SS Fraction vs Discharge

Table 6. Regression Results for Fine Fraction vs Discharge

	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	7.451e-01	3.693e-03	201.73	<2e-16 ***
Discharge	-1.165e-03	6.014e-05	-19.36	<2e-16 ***
R-squared				0.1699
Adj R-squared				0.1695

Table 7. Regression Results for Sand Fraction vs Discharge

	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	2.563e-01	3.804e-03	67.37	<2e-16 ***
Discharge	1.154e-03	6.191e-05	18.64	<2e-16 ***
R-squared				0.1588
Adj R-squared				0.1583

Increasing daily discharge has a significant negative correlation with the proportion of fine sediments in the total SS load (p<2e-16) and a significant positive correlation (p<2e-16) with the proportion of sand in the total SS load.

Question 3: What is the trend of stream discharge and gage height overtime in the Elwha River during and after dam removal?

```
## tau = 0.388, 2-sided pvalue =< 2.22e-16
```

For this time series, the seasonal component was removed in order to run a Mann Kendall test. The test produced a tau value of 0.388 and a p-value of $<$ 2.22e-16. Since the p-value is less than 0.05 and the tau is positive, there is a statistically significant increase in stream gage height from 2011 to 2015.

```
## tau = 1, 2-sided pvalue =< 2.22e-16
```

A Seasonal Mann-Kendall test was performed on the data producing a tau value of 1 and a p-value of 2.22e-16. There is a statistically significant increasing trend for discharge over time.

Question 4: What is the trend of sediment discharge overtime in the Elwha River during and after dam removal?

```
## tau = 0.69, 2-sided pvalue =< 2.22e-16
```

A seasonal Mann-Kendall test was performed on the data which produced a tau value of 0.69 and a p-value of $<$ 2.22e-16. These results indicate a statistically significant increasing trend in total sediment discharge in the Elwha River during and after dam removal.

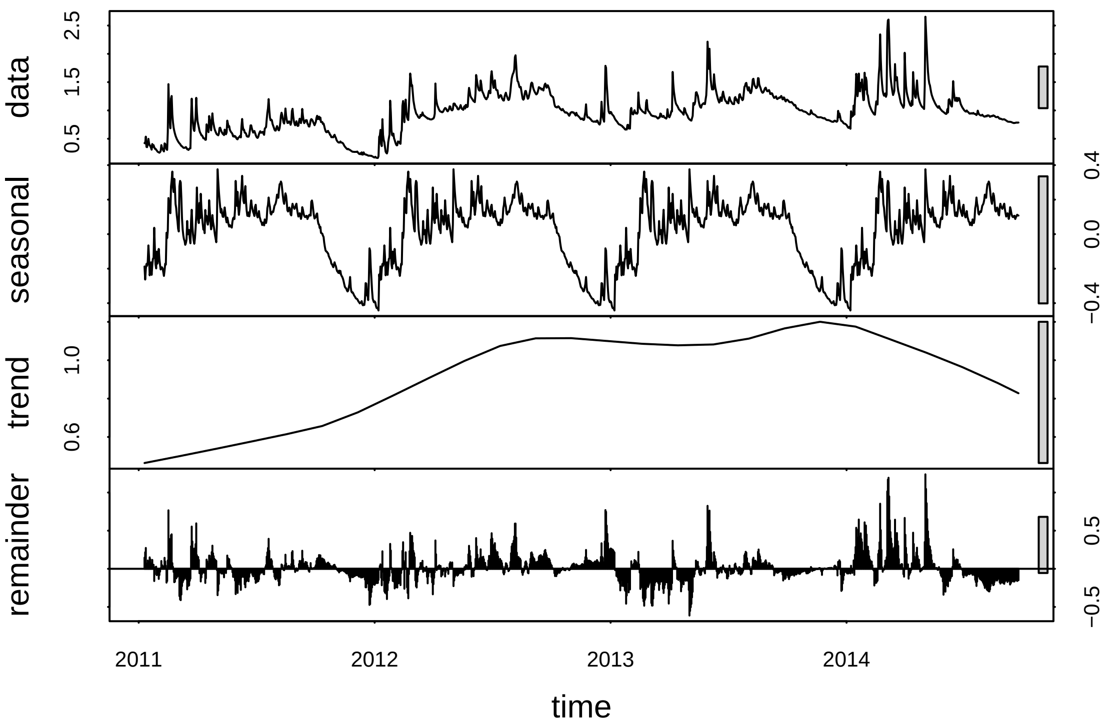

Figure 5: Decomposed Time Series of Daily Stream Gage Height

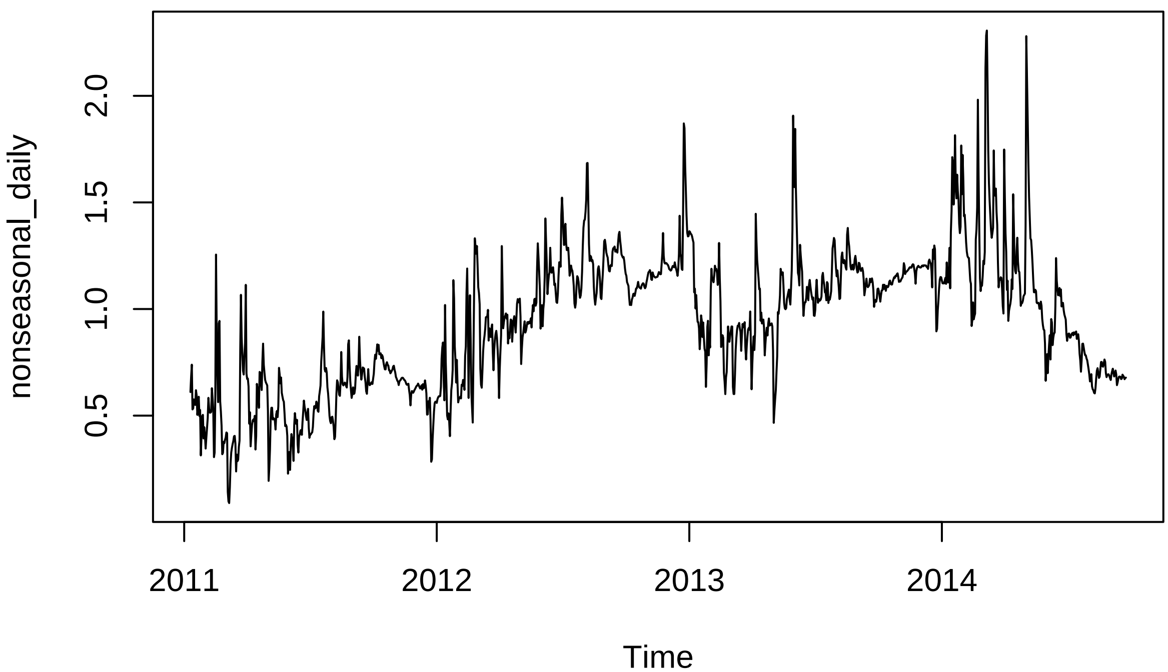

Figure 6: Non Seasonal Trend of Average Daily Stream Gage Height

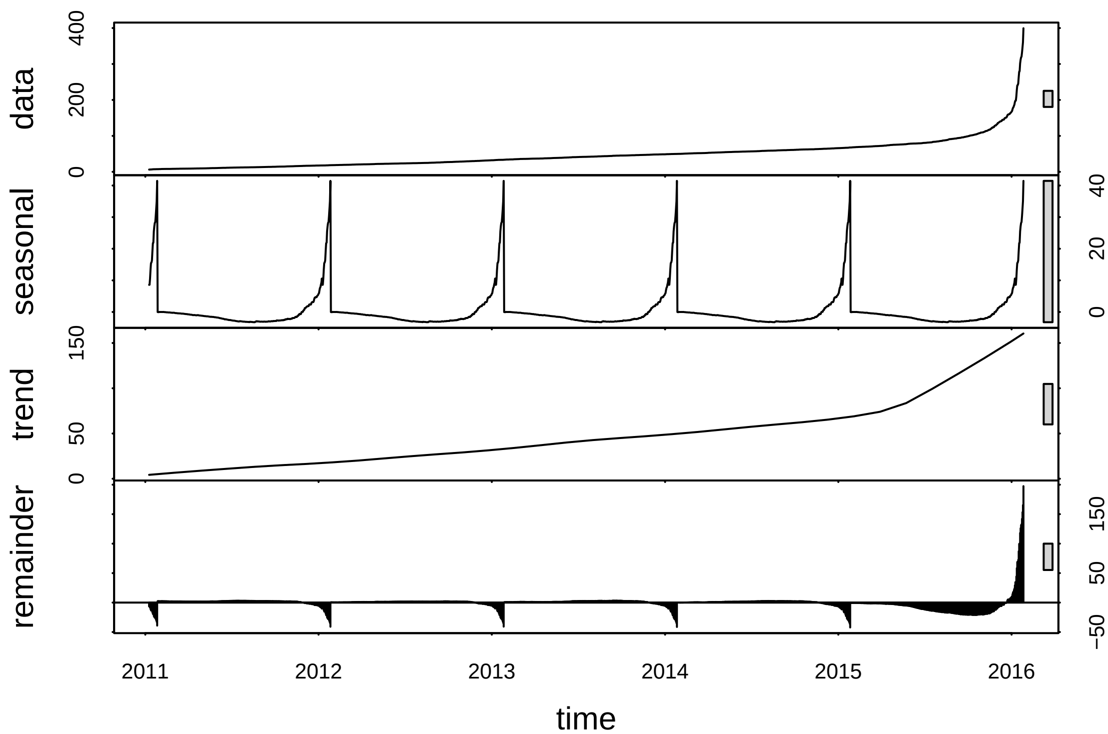

Figure 7: Decomposed Time Series of Daily Discharge

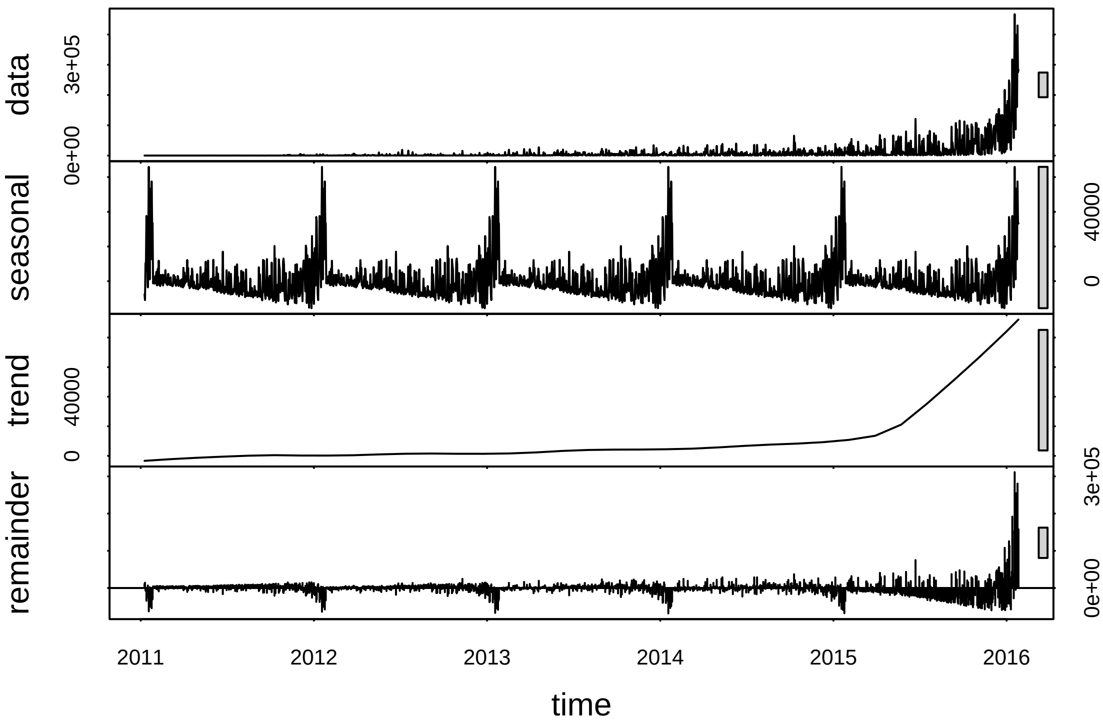

Figure 8: Decomposed Time Series of Sediment Discharge

Question 5: How does sediment discharge compare before, during, and after dam removal in the Elwha River?

Tp compare sediment discharge before, during, and after dam removal in the Elwha River we will use a Welch Two Sample T-test because we want to compare the means of two independent groups (years). We chose to use a Welch's T-test because we are assuming that both groups are sampled from populations that are normally distributed, but we are not assuming the populations have the same variance. This is a more robust test than a Student's T-test. This test can help us figure out if the differences we see in sediment discharge are real or just due to chance.

Comparing 2013 to 2015

First, plotting sediment over time to decide which years to compare.

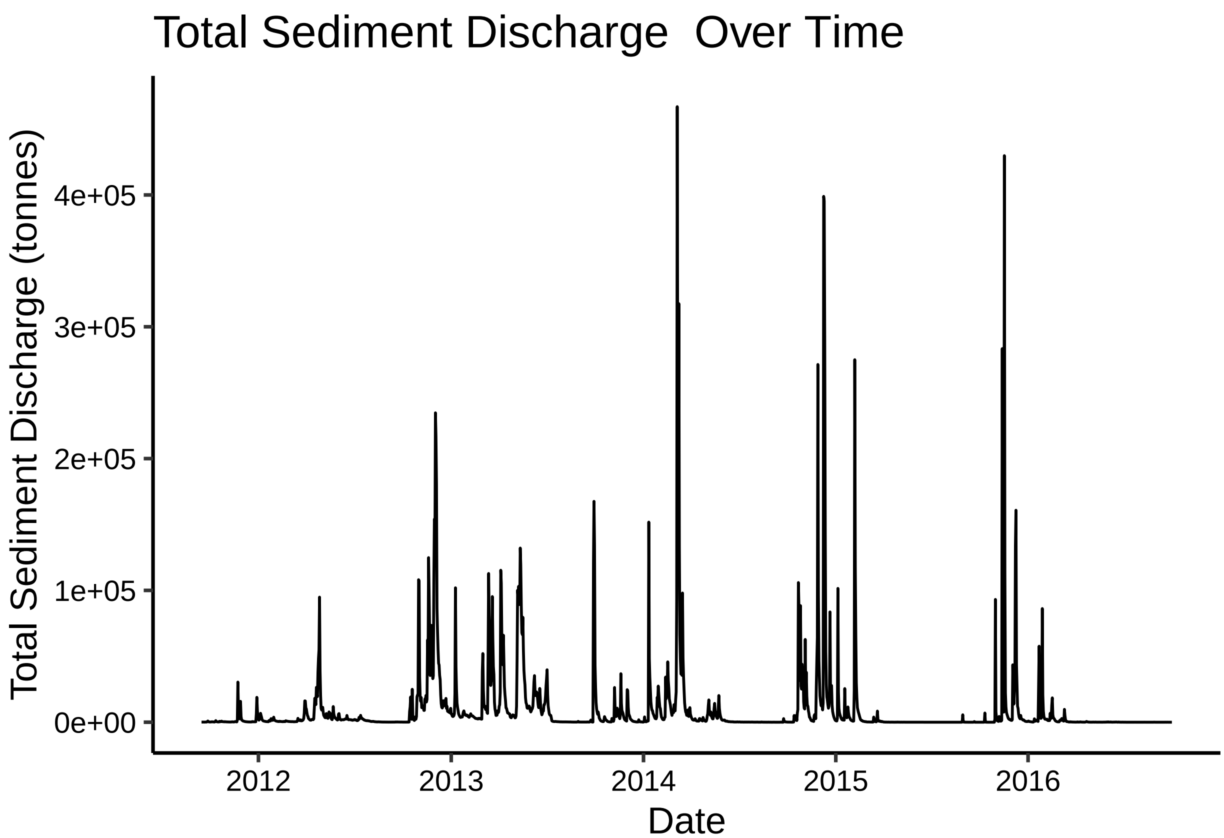

Figure 9: Total Sediment Discharge Over Time

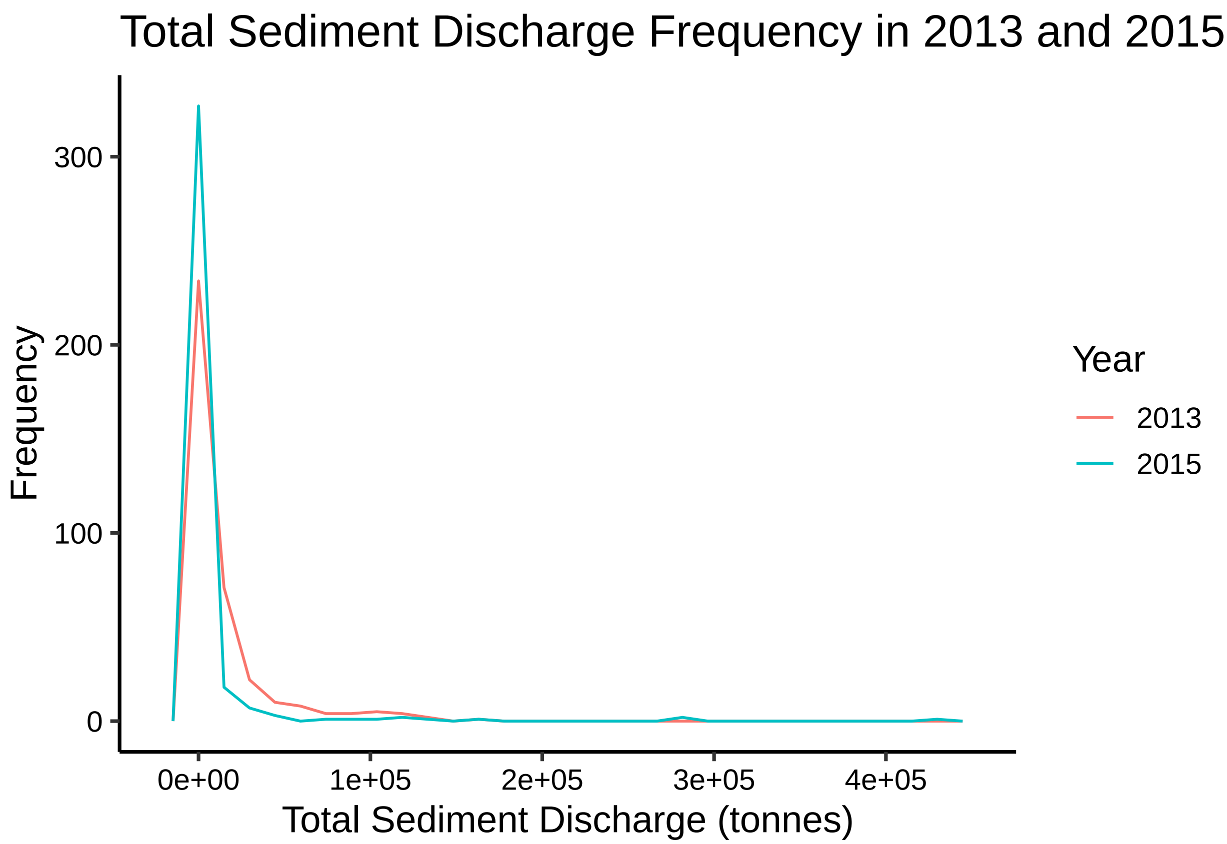

Figure 10: Total Sediment Discharge Frequency in 2013 and 2015

```
##
##  Welch Two Sample t-test
##
## data:  elwha_sediment_1315$Total_Sed_discharge by elwha_sediment_1315$Year
## t = 3.0328, df = 671.4, p-value = 0.002516
## alternative hypothesis: true difference in means between group 2013 and group 2015 is not equal to 0
## 95 percent confidence interval:
##   2399.33 11210.84
## sample estimates:
## mean in group 2013 mean in group 2015
##          13789.242           6984.158
```

The Welch Two Sample t-test comparing 2013 to 2015 has a t statistic of 3.0328, 671.4 degrees of freedom, and a p-value = 0.002516. This means that based on a 95% confidence interval, there is a statistical difference in the mean sediment discharge between 2013 and 2015, with 2013 having the greater mean.

Comparing 2012 to 2015

```
##
##  Welch Two Sample t-test
##
## data:  elwha_sediment_1215$Total_Sed_discharge by elwha_sediment_1215$Year
```

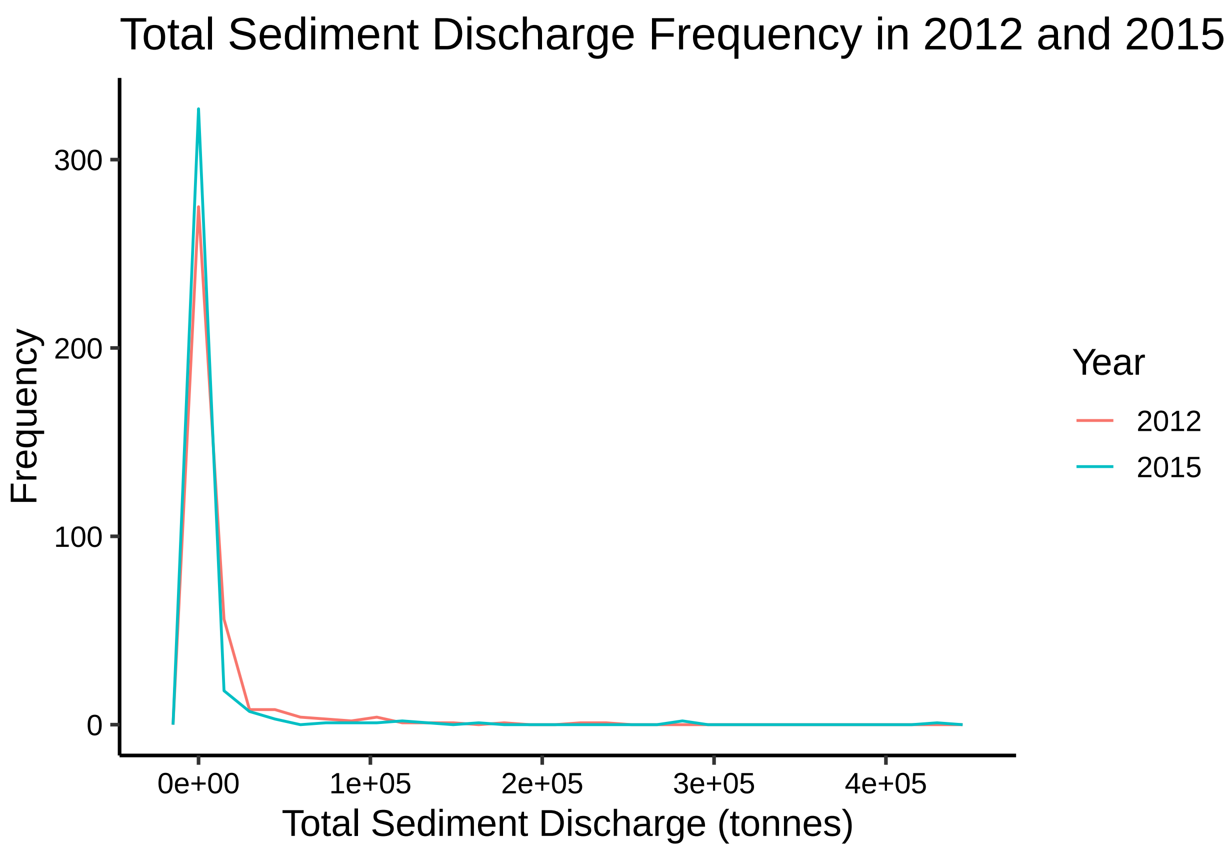

Figure 11: Total Sediment Discharge Frequency in 2012 and 2015

```
## t = 1.6112, df = 693.88, p-value = 0.1076
## alternative hypothesis: true difference in means between group 2012 and group 2015 is not equal to 0
## 95 percent confidence interval:
##  -811.5619 8236.6237
## sample estimates:
## mean in group 2012 mean in group 2015
##          10696.689           6984.158
```

The Welch Two Sample t-test comparing 2012 to 2015 has a t statistic of 1.6112, 693.88 degrees of freedom, and a p-value = 0.1076. This means that based on a 95% confidence interval, there is not a statistical difference in the mean sediment discharge between 2012 and 2015.

Comparing 2011 to 2016

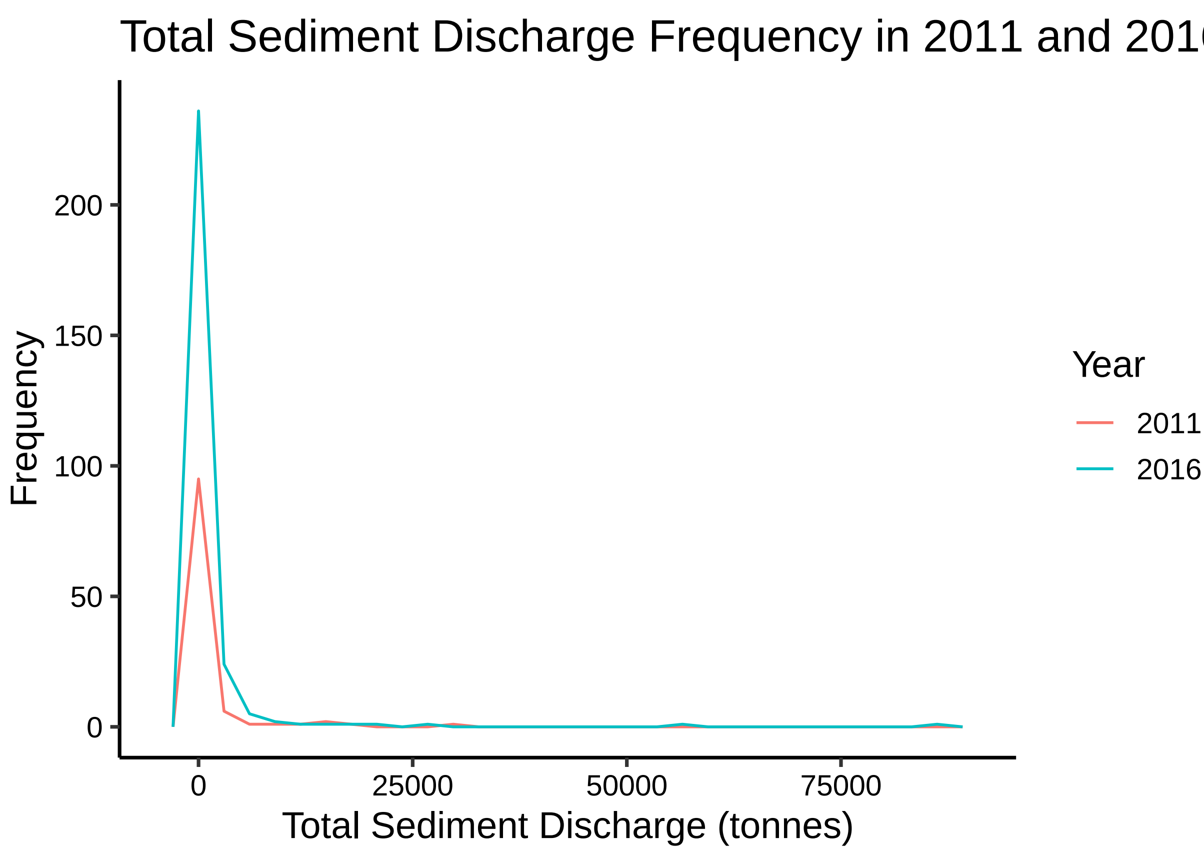

Figure 12: Total Sediment Discharge Frequency in 2011 and 2016

```
##
##  Welch Two Sample t-test
##
## data:  elwha_sediment_1116$Total_Sed_discharge by elwha_sediment_1116$Year
## t = 0.081339, df = 317.18, p-value = 0.9352
## alternative hypothesis: true difference in means between group 2011 and group 2016 is not equal to 0
## 95 percent confidence interval:
##  -1076.593  1169.449
```

```
## sample estimates:
## mean in group 2011 mean in group 2016
##           1437.731           1391.304
```

The Welch Two Sample t-test comparing 2011 to 2016 has a t statistic of 0.081339„ 317.18 degrees of freedom, and a p-value = 0.9352. This means that based on a 95% confidence interval, there is not a statistical difference in the mean sediment discharge between 2011 and 2016.

Summary and Conclusions

In summary, we were able to better understand the short-term impacts of two dam removals on the Elwha River with sediment and stream gage data. The removal of the Elwha Dam led to an increase in stream discharge (Figure 1) as well as total sediment discharge (Figure 3). Over time the average daily stream gage height increased indicating rising water levels after the removal of the Elwha Dam (Figure 2). Increased water discharge was positively correlated with total sediment discharge (Figure 3). Looking at the types of suspended sediment being discharged, as discharge increased the proportion of fine particles decreased, while sand proportions increased (Figure 4). This indicates that greater discharge magnitudes were able to suspend and carry larger particles. These particle distributions are important to consider in future investigations of water quality impacts due to suspended sediments. Sediment discharge somewhat changed before, during, and after dam removal in the Elwha River. There was a statistical difference in sediment discharge between 2013 and 2015 (Figure 10), but not a significant difference in sediment discharge between 2012 and 2015 (Figure 11) and 2011 and 2016 (Figure 12).

The main limitation of these datasets are that they do not include data from long before the dams were removed or long after. The first dam was removed in 2011, when the datasets begin, and the second dam was removed in 2014. Only two years of data after the removals is not sufficient to understand long-term impacts of the dam removal, but we can try to understand short term impacts. In addition, we are unable to accurately compare environmental parameters before and after dam removal because we do not have sufficient data before the removals. Looking forward, it could be beneficial to continue monitoring the Elwha River to understand the long-term impacts of dam removal. Scientists can also conduct further analyses to understand habitat destruction or reintroduction, based on turbidity and other water quality parameters in the Elwha.

References

"History of the Elwha." National Parks Service, U.S. Department of the Interior, 2 Oct. 2019, www.nps.gov/olym/learn/nature/history-of-the-elwha.htm.

"USGS Science Supporting the Elwha River Restoration Project." U.S. Geological Survey, 3 Nov. 2020, www.usgs.gov/centers/pcmsc/science/usgs-science-supporting-elwha-river-restoration-project.

GitHub Repository

Link to our repository: https://github.com/samantha-jensen/JEG_ENV872_EDA_FinalProject