Changes on the Elwha River During Dam Removal

https://github.com/kfm20/DataProject_ElwhaRiver.git

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1 Rationale and Research Questions

Dams were popping up across America in the early 1900's as ways to control river flows for water usage, and power. However, in the late 1900's and early 2000's dams no longer serve an important role, and caused more harm than good. Whether limiting sediment deposition downstream, increasing algal blooms or evaporation in the reservoirs, or restricting upstream access for fish species, dams are more frequently being removed. Removal of dams can change the form and function of a river or stream. The Elwha River flowing through Washington state, underwent a two part dam removal process. The Glines Canyon and Elwha Dam were removed by 2014 after a 3 year project. With the Glines Canyon Dam in place for 90 years, 30 million tons of sediment input from the upstream Olympic Mountians had accumulated behind the dam (USGS 2018). With more frequent dam removal projects, it is increasingly important to understand the potential effects dam removal can have on a river ecosysem. Whether these effects stem from the buildup of sediment or water behind a dam, or a newly forming floodplain along the river or at the delta from these flow and discharge changes. While every river will respond differently to dam removal, understanding the effects from the project on the Elwha River can add to a greater understanding and analysis of stream response to dam removal.

Part of the mission of the U.S. Geological Survey is focused on water resources. They are dedicated to researching and documenting streamflow, and water use and availability. As a credible research agency, the daily sediment loads dataset was collected for the purpose of understanding the changes within flow and sediment occuring during the dam removal process along the Elwha. The dam was collected at a gage station downstream of both dams, which is useful to see the downstream impact of the water and sediment that had been captured behind the dams. The dataset is part of a larger USGS study that created a 5 year sediment budget and morphodynamic analysis of the Elwha River following the two dam removals. My analysis uses the USGS sediment load dataset to understand the potential changes in water flow and sediment occuring in the Elwha River during and after the two part dam removal process from 2011 to 2016.

Research Questions:

*How does water and sediment discharge in the Elwha River differ during and after the two part dam removal process?

*Can sediment discharge be predicted from water flow on the Elwha River?

*Does daily water discharge predict total sediment discharge during and after the two part dam removal process?

2 Dataset Information

Data was collected daily at the USGS gaging station with identification number 12046260, located on the Elwha River at the diversion near Port Angeles, Washington. This gage site is located downstream of both the Elwha and Glines Canyon Dam. Data was published February 7, 2020 by USGS and accessed April 20, 2020. The data was collected from September 15, 2011 to September 30, 2016. The dataset contains daily measurements and estimates of discharge and various parameters of sediment loads. Sediment load parameters include suspended concentration, loads of suspended fine-grained particles and sand particles, and gauged bedload for particles from 0mm to 16mm. The dataset is part of a larger study that created a 5 year sediment budget and morphodynamic analysis of the Elwha River following the two dam removals. Research into the time frame of the two part dam removal process supplied dates for time stamps and classification of "during" the dam removal process, and "after" completion of the project. Removal of the Glines Canyon Dam began on September 15, 2011, and September 17, 2011 for the Elwha Dam (NPS 2019). The entire project was completed on August 26, 2014 (National Park Trips 2015).Therefore, "during" is classified as September 15, 2011 to August 26, 2014, and "after" is classified as August 27, 104 until the end of sampling, September 30, 2016.

The dataset, coming from USGS, was already pretty neat, no NAs or unneeded symbols were found. The dataset was simply wrangled for a best fit in order to perform useful analyses answering the research questions at hand. To wrangle the data, the most important variables for an analysis focused on observing general changes on the Elwha River during and after the dam removal project were selected. The date column was specified as a date so R could properly understand its role in the dataset. Columns were recoded with shorter and more coding friendly names. The names were made more succinct and without the units in the name. The next big wrangling task included dividing the data into two new datasets by date, following the "during" and "after" time stamps mentioned. A new column was created with a character class of text, with the appropriate "during," or "after" notation signified by the date time frame. These two individual datasets were saved as new processed files to be used in an analysis question later. They were also combined again, giving a dataset of all the sampling points across the entire 5 year sampling period, just with the new time stamp column.

Column name	Data Description	Associated Units
Date	Date of daily recording	YYYY-MM-DD
DailyDischarge	Daily water discharge from the river	m3/s
DailySSC	Daily suspended sediment concentration	mg/L
DailySuspendedSediment	Daily total suspended sediment load	tonnes
DailySSfines	Daily suspended fine grained sediment load	tonnes
DailySSsand	Daily suspended sand sediment load	tonnes
TotalSedimentDischarge	Total daily sediment discharge	tonnes
Projectyear	Year of sampling project, extending from 1-5 years	year
TimeStamp	Distinguishes time frame in the dam removal process	“during” or “after”

3 Exploratory Analysis

An initial exploratory analysis is conducted to see general trends in data related to water and sediment discharge, and suspended concentrations in Elwha River during and after the dam removal process. Daily water discharge from the river, *Figure 1*, appears to have higher peaks of discharge in 2015 and 2016, the years after the dam removal project was complete. Embedding the dates involved with the dam removal process, such as start of removal, and completion of each dam removal will help differentiate differences in discharge related to more open flows with dams removed. This data might need to be looked at a different scale, instead of daily, maybe monthly averages will show a different relationship, or a similar one at a different magnitude.

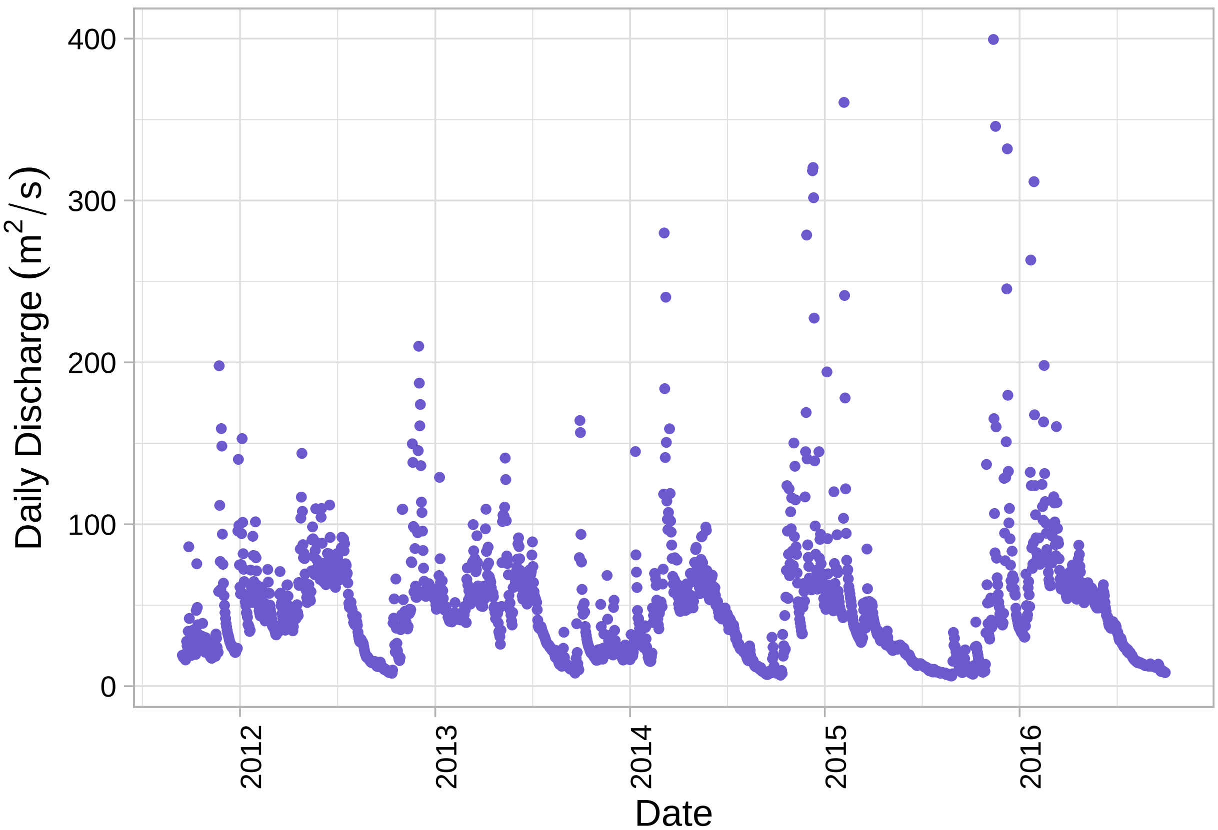

Figure 1: Daily water discahrge of the Elwha River, WA, from September 15, 2011 to September 30, 2016.

Suspended sediment concentrations might give a sense of the velocity of the flow heading downstream, and how much sand was stuck behind the dams that is then in movement after their removal. Looking at suspended concentrations over time may show how long it takes for the sediment behind the dam to resettle in the river, allowing the river to reach a new morphological norm. General trends of suspended sediments, *Figure 2*, show more tonnes happening around the year 2013, which is during the removal of the Elwha Dam, and the Glines Canyon Dam had already been removed. However, there still exists some high

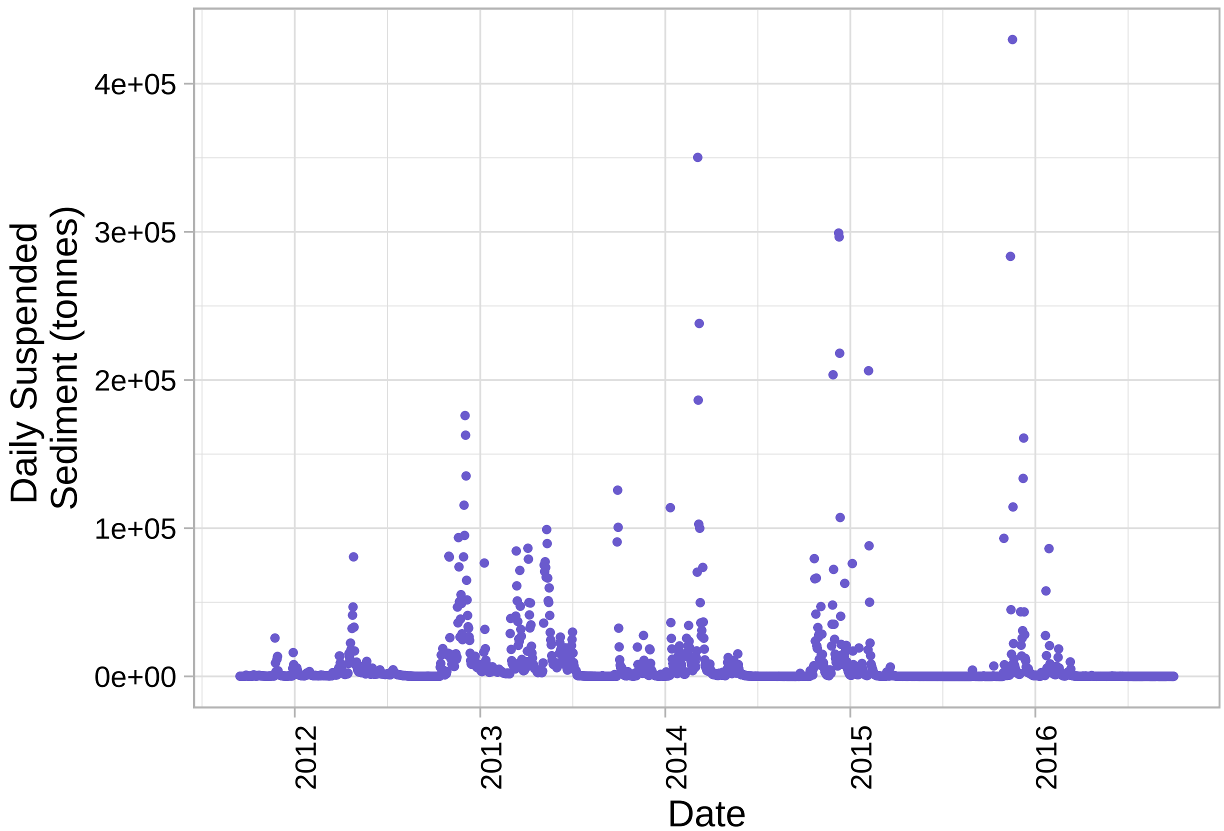

Figure 2: Daily suspended sediment in the Elwha River, WA, from September 15, 2011 to September 30, 2016.

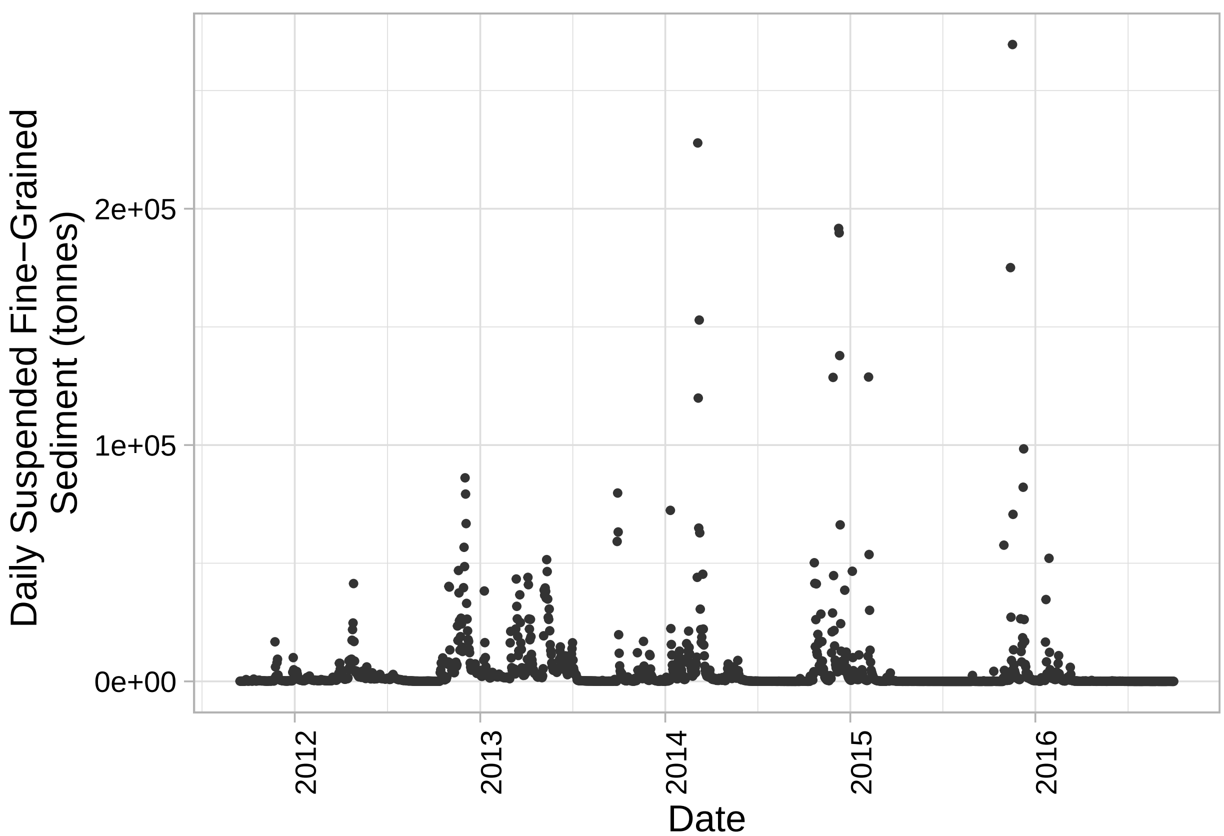

Figure 3: Daily suspended sediment of fine-grained particles in the Elwha River, WA, from September 15, 2011 to September 30, 2016.

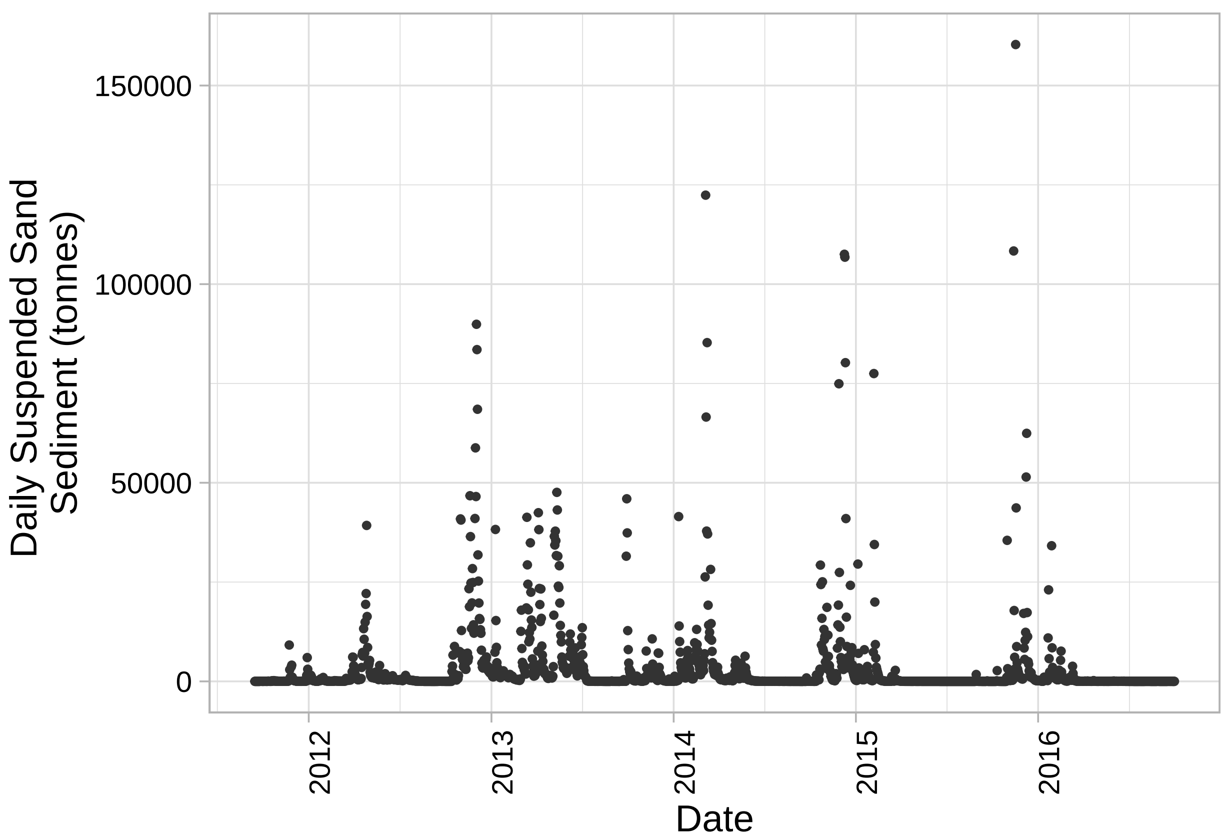

Figure 4: Daily suspended sediment of sand particles in the Elwha River, WA, from September 15, 2011 to September 30, 2016.

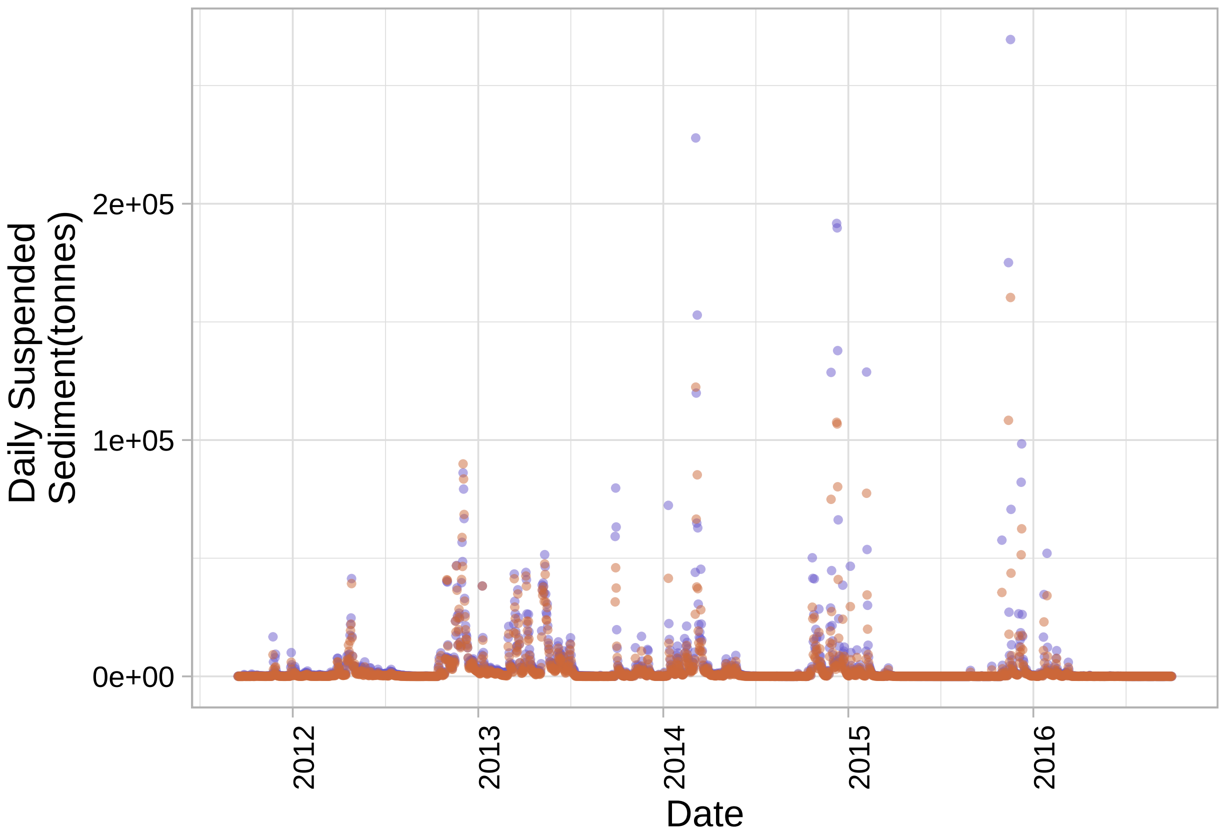

Figure 5: Daily suspended sediment of fine-grained particles (blue) and sand particles (gray) in the Elwha River, WA, from September 15, 2011 to September 30, 2016.

recordings of suspended sediment later on through the project years. However, these might have to do with the high water discharge. Further analysis will compare the relationship between daily suspended sediment and water discharge over time. The dataset also has daily suspended sediment of fine-grained particles, and sand particles. Their general point plots are shown individually, *Figures 3 and 4* and together in one plot, *Figure 5*, where we see there doesn't appear to be much difference between the makeup of the suspended sediment, although a further test can prove this.

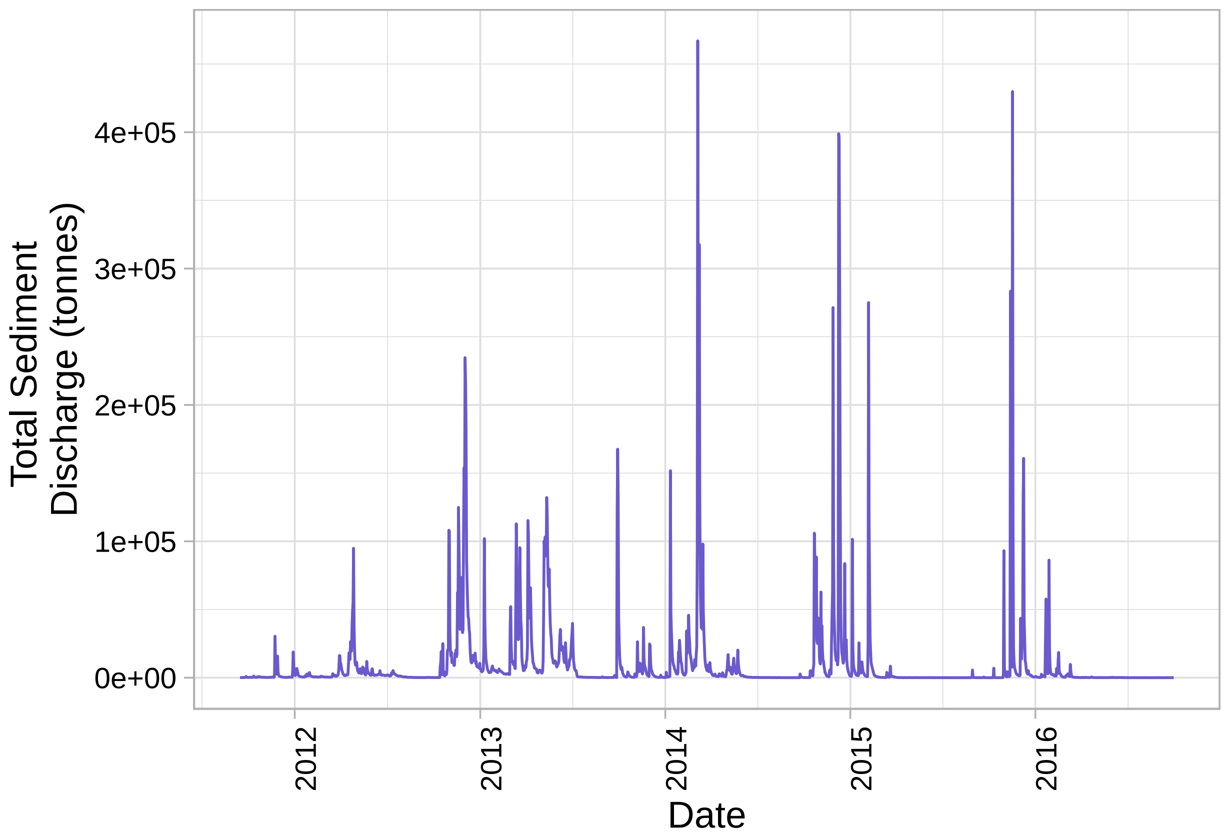

Figure 6: Daily total sediment discharge from the Elwha River, WA, from September 15, 2011 to September 30, 2016.

While there are multiple parameters highlighting the sediment traveling downstream, daily sediment discharge is a straight forward parameter of moving sediment in the Elwha River during and after the dam removal processes. From a general line plot of total sediment discharge over time, *Figure 6*, shows a peak discharge in 2013 and multiple large peaks as well as what appears like a larger avergae sediment discharge happening after 2014. These seem to make sense with the time stamps of the dam removal process, but combining the time stamps and this relationship in one graph will help better visualize the relationship with dam removal over time. Calculating the mean discharges during removal and after would be useful to show changes in discharge across the dam removal process.

With daily water discharge and total sediment discharge being important parameters for

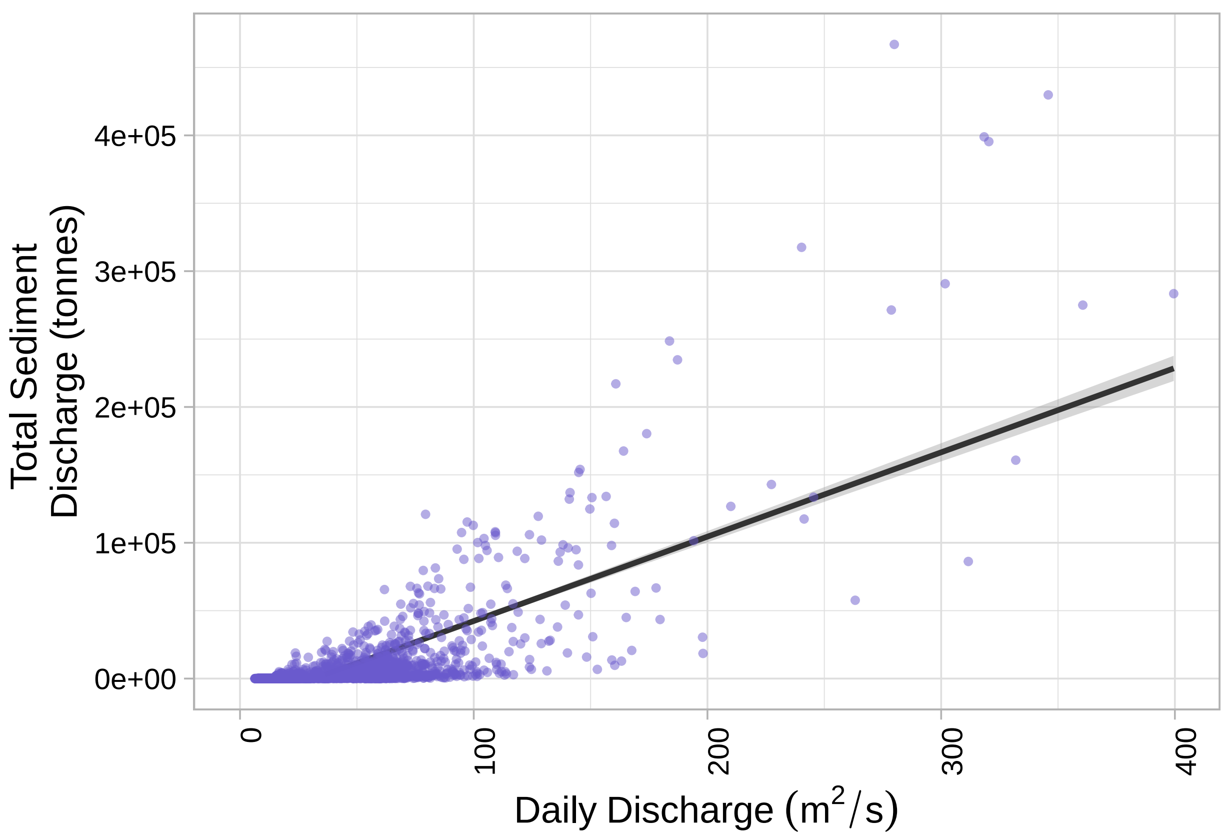

Figure 7: Daily total sediment discharge and water discharge on the Elwha River, with a linear model, from September 15, 2011 to September 30, 2016.

showing changes in the Elwha River following dam removal, the relationship between them was graphed with a linear model to show a relationship, *Figure 7*. It makes sense that increased flow would generate increased sediment discharge, which we see from the positive linear relationship. It would be interesting to see this relationship graphed out for during and after dam removal and see how this relationship might change.

4 Analysis

4.1 Question 1: How does water and sediment discharge in the Elwha River differ during and after the two part dam removal process?

A closer look into total sediment discharge and daily discharge of water from the Elwha River with attention on the time stamps of when the dam removal project begigs, and when it is completed, *Figures 8 and 9*, prompted an in depth analysis of trends. Data was separated into during the dam removal process and after its completion, September 26, 2014. Part one of this analysis hoped to determine whether the means of daily water discharge were equivalent during and after the dam removal process. similarly, part two hoped to determine whether the means of daily total sediment discharge were equivalent during and after the dam removal process.

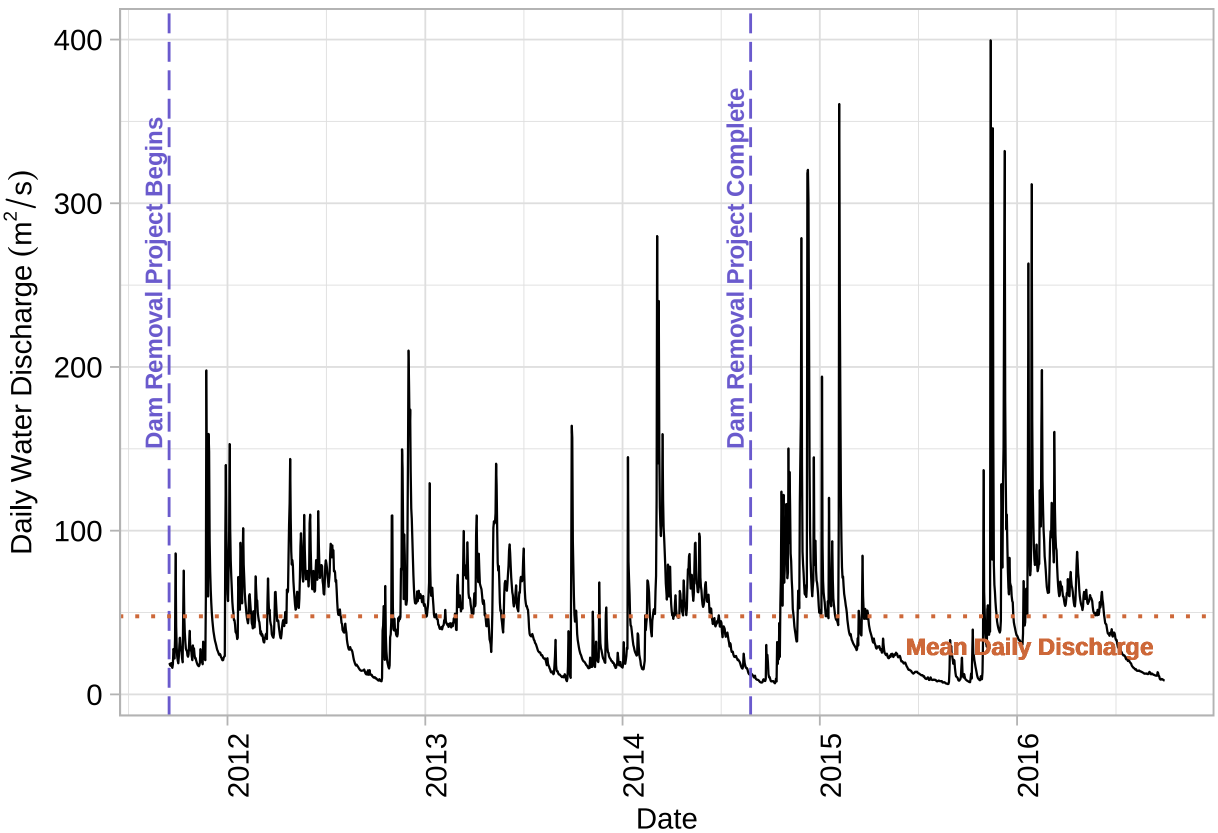

Figure 8: Daily water discharge from the Elwha River from September 15, 2011 to September 30, 2016 measured at the U.S. Geological Survey gaging station 12046260 at the diversion near Port Angeles, Washington. A project to remove the Elwha and Glines Canyon Dam began on September 15, 2011, and was completed on August 26, 2014. Mean Daily discharge across the whole time range was 47.7.

Daily water discharge data, *Figure 8*, was classified as during or after the dam removal process

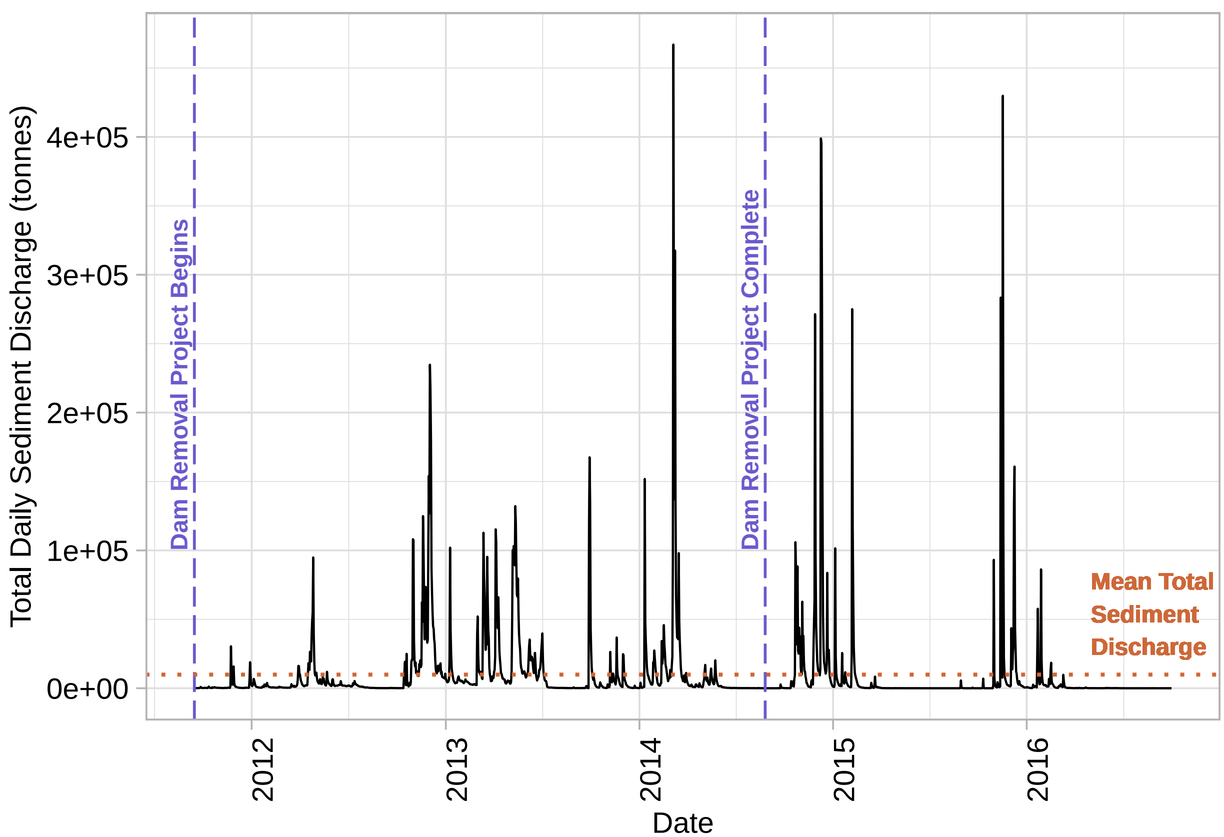

Figure 9: Daily total sediment discharge from the Elwha River from September 15, 2011 to September 30, 2016 measured at the U.S. Geological Survey gaging station 12046260 at the diversion near Port Angeles, Washington. A project to remove the Elwha and Glines Canyon Dam began on September 15, 2011, and was completed on August 26, 2014. Mean Daily sediment discharge across the whole time range was 9886.876 tonnes.

based on dates. September 26, 2014 was the dividing date. A two-sample t-test was run to determine if means are equivalent during and after dam removal. This test assumes equal variance, however, results showed there is not an equal variance, meaning the assumption of normality is not met (p-value < 0.05; Shapiro-Wilk normality test). Similarly, Daily total sediment discharge data, *Figure 9*, was classified as during or after the dam removal process based on dates, and a two-sample t-test was also run. Daily total sediment discharge over time does not have equal variance as well (p-value <0.05; Shapiro-Wilk normality test).

To avoid the assumption or normality, a non-parametric method, Wilcoxon rank sum, is used to determine if means are equivalent during and after dam removal for both water and sediment discharge. The mean daily discharge during the dam removal process is 48.31 m2/s, and 46.9 m2/s after the completion of the project. There is a significant difference between the means of daily water discharge during and after dam removal (*Figure 10*, $W = 349134$, p-value < 0.0001, Wilcoxon rank sum test). The mean daily total sediment discharge during the dam removal process is 11,319.0 tonnes, and 7,888.0 tonnes for after completion of dam removal. There is a significant difference between the means of daily total sediment discharge during and after dam removal (*Figure 11*, $W = 209858$, p-value <0.0001, Wilcoxon rank sum test).

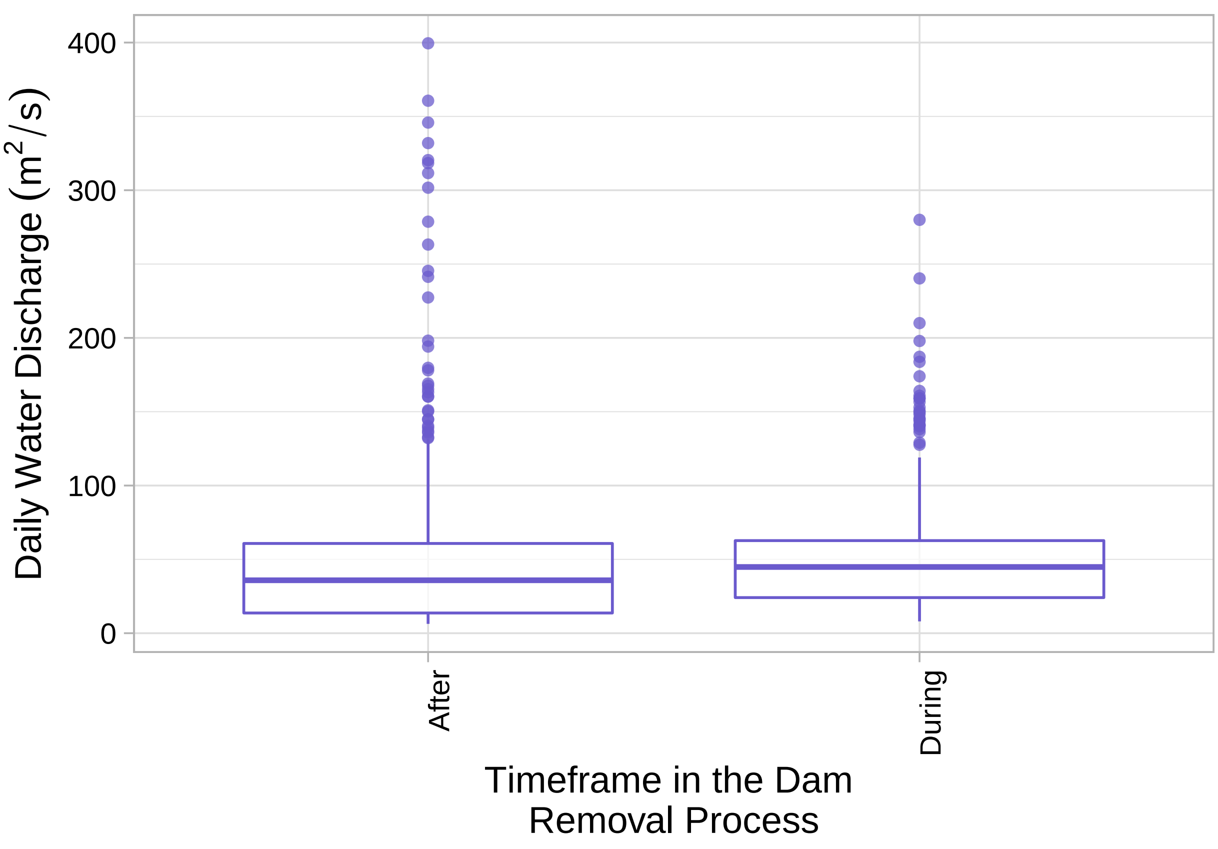

Figure 10: Daily water discharge distribution during and after the Elwha River two dam removal process. During the dam removal is classified by dates from September 15, 2011 to August 26, 2014, and after is from then until September 30, 2016.

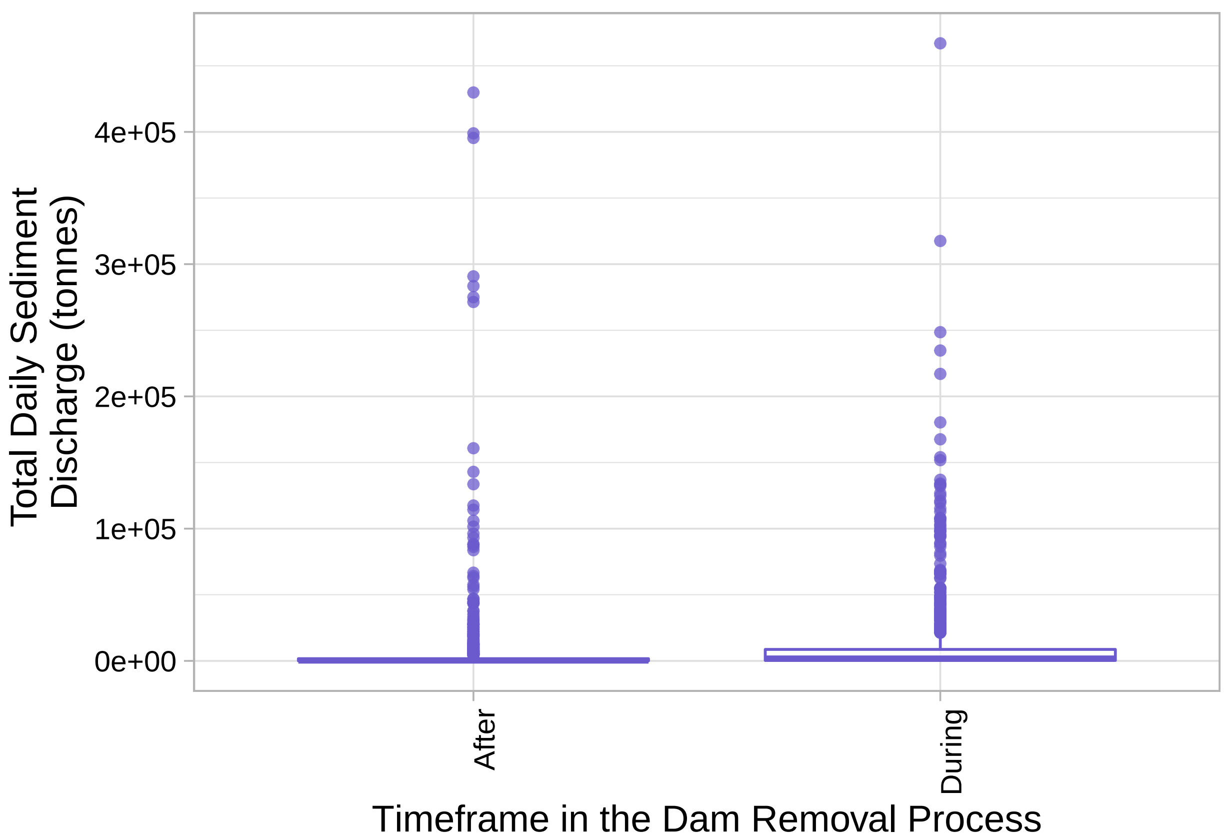

Figure 11: Daily total sediment discharge distribution during and after the Elwha River two dam removal process. During the dam removal is classified by dates from September 15, 2011 to August 26, 2014, and after is from then until September 30, 2016.

4.2 Question 2: Can sediment discharge be predicted from water flow on the Elwha River?

Increased water flow on a river should carry more sediment, producing more overall sediment discharge. An analysis of water discharge and sediment discharge is performed over the entirity of the sampling period to find a general trend of the relationship of these two parameters over time on the Elwha.

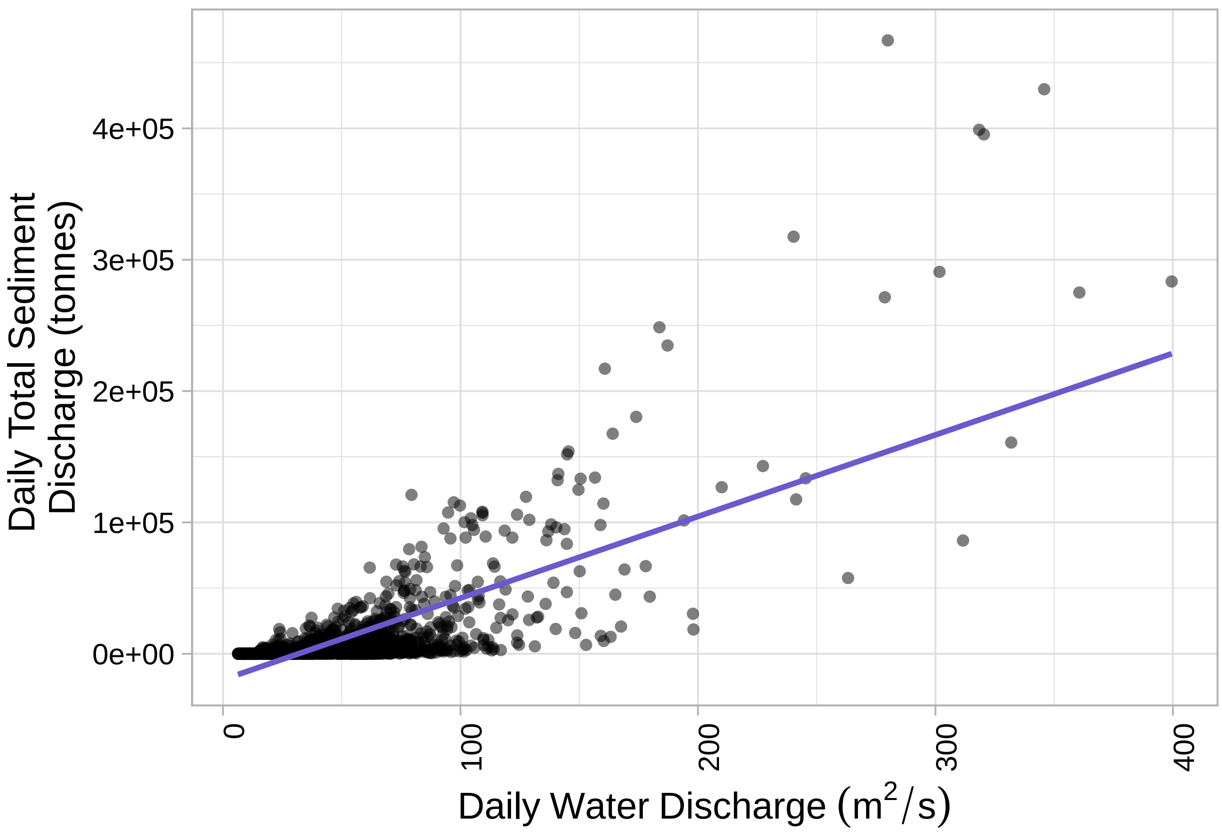

Figure 12: Daily water discharge as an indicator for daily total sediment discharge on the Elwha River, with a linear regression.

A linear regression model determines a line of best fit between two continuous variables, in this case, daily water discharge and total sediment discharge. There is a strong, significant positive correlation between water and sediment discharge during the entirity of the sampling period (cor= 0.73, p-value < 0.0001, pearson's correlation test). Therefore, water discharge is an effedctive predictor for sediment discharge (*Figure 12*, p-value < 0.0001, R2= 0.54, linear regression). Each square meter per second of water discharge accounted for 0.0008 tonnes of sediment discharge.

4.3 Question 3: Does daily water discharge predict total sediment discharge during and after the two part dam removal process?

Data recorded during the dam removal process, and data recorded after were separated. Separate linear regressions were run on each to determine if water discharge is still an effective predictor of sediment discharge during these separate periods, and to what extent.

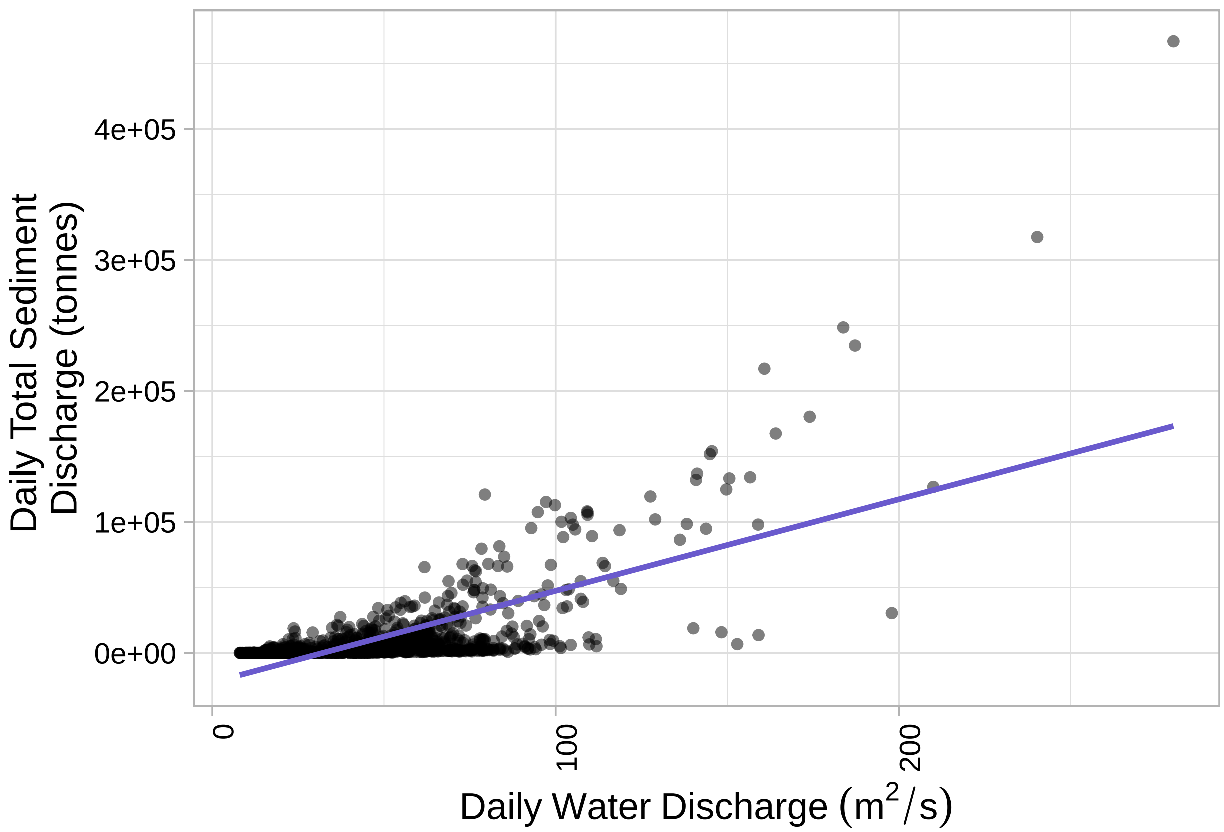

Figure 13: Daily water discharge as an indicator for daily total sediment discharge on the Elwha River during the two part dam removal process, with a linear regression.

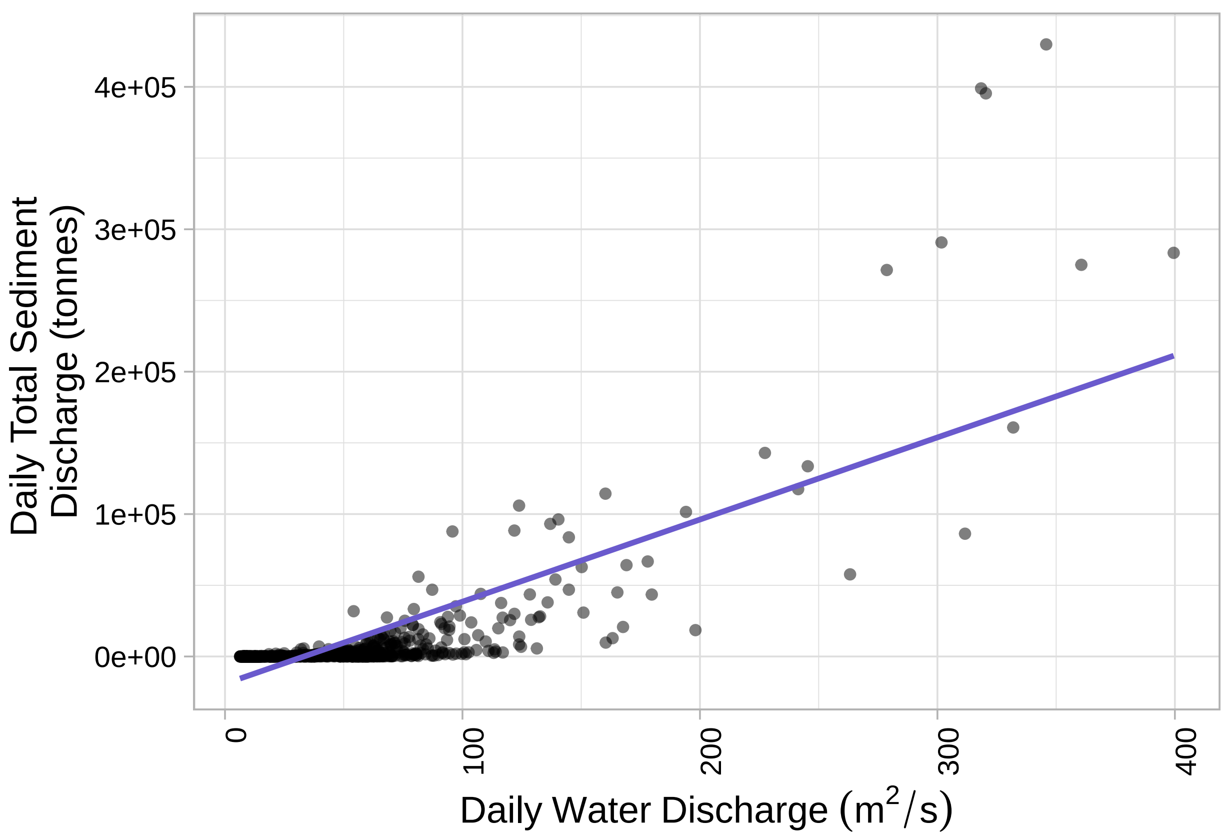

Figure 14: Daily water discharge as an indicator for daily total sediment discharge on the Elwha River after completion of the two part dam removal process, with a linear regression.

There is a strong, significant positive correlation between water and sediment discharge during the dam removal process (cor= 0.70, p-value < 0.0001, pearson's correlation test). During dam removal, water discharge is an effective predictor for sediment discharge (*Figure 13*, p-value < 0.0001, R2= 0.50, linear regression). Each square meter per second of water discharge accounted for 0.0007 tonnes of sediment discharge.

After the completion of dam removal, there is still a strong, significant positive correlation between water and sediment discharge (cor= 0.77, p-value < 0.0001, pearson's correlation test). Water flow serves as an effective predictor for sediment discharge (*Figure 14*, p-value < 0.0001, R2= 0.59, linear regression). Each square meter per second of water discharge accounted for 0.001 tonnes of sediment discharge.

There is a stronger correlation after dam removal completion, making water discharge a better predictor of sediment discharge after dam removal compared to during the process. The model accounts for a larger percentage of variance by the explanatory variable of water discharge after dam removal completion.

5 Summary and Conclusions

There were significant differences in parameters measured during dam removal and after the projects completion. While daily water discharge appeared similar in their reported means, there was still a significant difference between during and after dam removal. After completion, there appears to be more high peaks of flow, *Figures 8 and 10*. This makes sense because there is no longer two dams in place that would have controled flows to have less of high peak flow events. Now without a dam to create a reservoir stock of water, the Elwha River might experience more high peak flow events, especially as the form of the river and floodplain re-adjust to recieving new water and sediment input.

Water discharge is an effective predictor of sediment discharge. Through analysis this was proven to be true throughout the entirity of the sampling time frame, as well as during the dam removal process and after it's completion. After completion of the project, each unit of water flow accounted for higher amounts of sediment discharge compared to during. Again, this may be due to the higher peak flows carrying more sediment downstream, as well as the higher sediment discharge that occured after the dams were fully removed.

Overall, it makes sense that sediment discharge and water discharge reach higher peaks without the dams in place. Not only are the dams not in place to hold back water and sediment, but now after it's removal, everything that was behind the dam is released. While this analysis provides an understanding of changes in discharge during and a couple years after completion with a fully flwoing river, more years of data collection can be useful. Two years of data does not seem to be enough time to see graphically a new stability of water flow and sediment discharge. More years of data may be useful to see the Elwha River reach a new mean daily norm of these discharge parameters following dam removal.

Lastly, a lot can be learned from the steady increase of both peak sediment and water discharge in the early stages of the removal process. Specific attention should be given to total daily sediment discharge over time, *Figure 9*, and the drastic changes in peaks since the start of dam removal. With 30 million tons of sediment recorded to be held behind the dams, from this figure the release of it is graphically displayed. Additionally, increased flows following dam removal might cause more erosion from the floodplain it may be newly interacting with. This would add more sediment to the total discharge, on top of what was already stored behind the dam. Sediment load is important because of the ecological impacts on species, and the formation of floodplains and the delta the Elwha River drains into.

6 References

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