Analyzing the effect of flood events on the temporal change of stream grain size distribution in the Western Cascade Mountains, Oregon

Malia Gonzales EISI Stream Networks August 25, 2017

Abstract

This study investigates the effects flood events have on the temporal change of stream grain size distribution in lower Lookout Creek, middle Lookout Creek, and Mack Creek, located in the H.J. Andrews Experimental Forest. Current and historical cross-sectional grain size data were collected every 10 to 50 meters using the Wolman Pebble count in a 3rd to 5th order stream with longitudinal segments varying from 250 meters to 1,400 meters. Field data, two-sample t-test, log pearson type III flood frequency analysis, and a regression analysis were all used to examine if flood events cause a change in the surface grain size. The regression analysis showed that there was little to no correlation between annual peak flows and changes in grain size. However, there were trends that appeared when graphing the return intervals and the average change in D_{16}, D_{50}, and D_{84} for the years that were significantly different. Results indicate that lower Lookout Creek and Mack Creek grain size percentiles became coarser while middle Lookout Creek grain sizes became finer as the event increased. Mack Creek is a 3rd order stream with a steep gradient (9.93%), a narrow active channel width (9.20 m), and has the largest average volume of wood per 50 meters (124.11 m^3/m). Middle Lookout Creek is a 4th order stream that has a low gradient (2.75%), a wide active channel width (18.5 m), has the second largest average volume of wood per 50 meters (81.32 m^3/m), and is located upstream and downstream of confluences. Lower Lookout Creek is a 5th order stream that has a similar gradient and active channel width as middle Lookout Creek (1.28% and 18.2 m), however has the least average volume of wood per 50 meters (23.37 m^3/m). The channel characteristics and fluvial transport processes were examined and compared to historical data to understand how these complex mountainous stream networks function temporally during flood events.

1 Introduction

Throughout the Pacific Northwest there has been a decline in native anadromous salmonids (National Marine Fisheries Service 2003). This reduction can be caused by the amount of sediment loading and deposition of finer sediments that cause impairment for spawning and rearing habitat (Kenwyn et. al. 2004). An increase in sediment load can be caused by flood events and these events can potentially change the surface streambed by making it coarser or finer. Understanding how flood events affect the surface material of a streambed may have the potential to help prevent reduction for native andadromous salmondis.

The Western Cascade streams in Oregon often have grain sizes that vary longitudinally, from silt/clay to bedrock. This variability in grain sizes can have an influence on sediment transport, deposition, channel gradient, and channel width and implies that grain size is an important factor for river hydraulics and morphology (Chang and Chung 2012). Furthermore, floods can also have an impact on sediment transport, deposition, and changes in channel morphology. As the flows increase in a steam bed it is apparent that the grain size becomes more mobilized and each size fraction is affected differently from the strength of the flow (Clayton and Pitlick 2008, Pitlick et. al. 2008, and Powell et. al. 2001). Whether these events make the streambed surface finer or coarser is dependent on the sediment load (Clayton and Pitlick 2008). However, other studies have shown that there is little to no change in surface grain size during a flood event because scour and fill occur, allowing for the streambed to form back into its dynamic equilibrium (Wilcock and DeTemple 2005). Other studies have stated that all grain size fractions are affected by the same amount of flow in a well mixed gravel streambed (Andrews and Erman 1986).

The aim of this study was to analyze the effect of flood events on the temporal change of stream grain size distribution in the Western Cascade Mountains, Oregon. If there was a significant change in grain size from flood events would it make the streambed finer or coarser? What factors might cause the streambed to be finer or coarser? To answer these questions analysis was done on field data were collected in the H.J. Andrews Experimental Forest.

2 Study Site

The H.J. Andrews Experimental Forest is approximately 80 km east of Eugene, Oregon and encompasses Lookout Creek Watershed (Figure 1). The watershed is a tributary to Blue River Reservoir and has a drainage area of 64 km^2 and elevations ranging from 410 to 1620 m (USGS 2017). The geology of the basin are characterized by volcanic terrain and has been sculpted by glacial deposits, earth flows, bedrock, mass movement, debris flows, and other processes (Swanson and Jones 2002). The average annual precipitation in the lower basin is 2.1 m and has snowpacks in the higher elevations (H.J.A 2017). The streams that inhabit the watershed have surface bed material varying from silt/clay to bedrock with abundant amount of large woody debris, which is a huge geomorphic feature in the basin.

Historical grain size data were collected from 1995-2007, 2009, and 2011 for lower Lookout Creek and middle Lookout Creek and from 1995-1997, 2000, 2005, and 2011 for Mack Creek (Figure 1). Current cross-sectional grain size data were collected in summer 2017 in lower Lookout Creek, middle Lookout Creek, and Mack Creek. Mack Creek is a 3rd order stream with a drainage area of 8.6 km^2, middle Lookout Creek is a 4th order stream with a drainage area of 34.2 km^2, and lower Lookout Creek is a 5th order stream with a drainage area of 62.4 km^2.

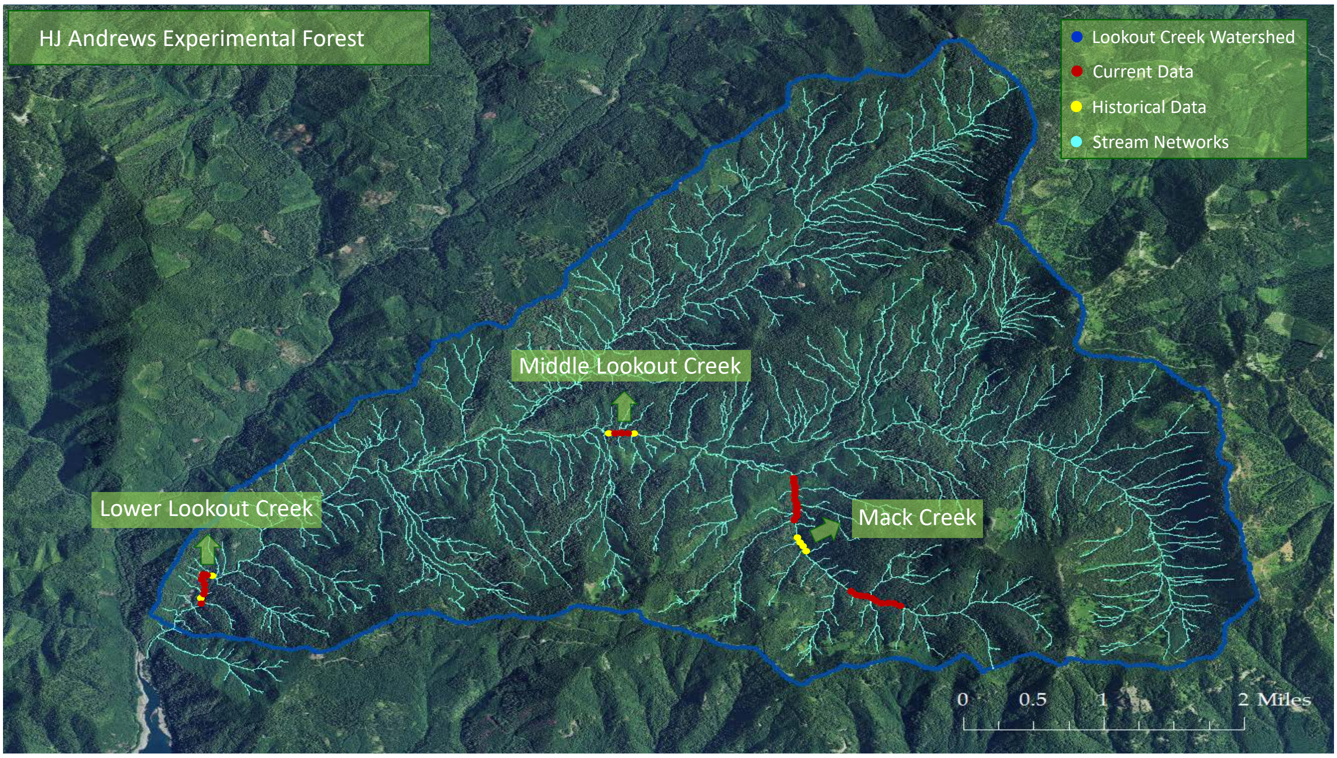

Figure 1: The H.J. Andrews Experimental Forest with the blue line indicating Lookout Creek Watershed. The yellow dots are areas where historical cross-sectional grain size data were collected and the red dots are current (2017) cross-sectional grain size data that were collected.

3 Methods

The Wolman Pebble Count procedure was used for collecting 100 surface grain sizes in lower Lookout Creek, middle Lookout Creek, and Mack Creek.The procedure consists of using a gravelometer to measure the particle size and using the Wentworth sediment classification to record the size. The pebble counts were acquired every 50 m throughout a segment and had a total distance of: 450 m for lower Lookout Creek, 250 m for middle Lookout Creek, and 1400 m for Mack Creek. The longitudinal distances were not consistent due to matching the area where historical pebble counts were collected. Historical data for Mack Creek were in an exclusion zone, thus data were collected upstream and downstream of the exclusion zone.

Historical grain size data were collected using the Wolman Pebble Count procedure. However, the data collectors did not use gravelometers, instead pebble counts were measured with a measuring tape, meaning the particle sizes where a specific value rather than classified under the Wentworth sediment classifications. Thus, to do analysis between historical and current data, the historical data were categorized to match the current data format. Also the historical data were collected in varied intervals from 10 to 50 m while the current data were collected every 50 m. Since these cross-sectional grain size data do not overlay each other, the cross-sectional data were aggregated to create one grain size distribution to represent a given year in that segment.

3.1 Grain Size Distribution

The D_{16}, D_{50}, and D_{84} were calculated for each year in the three segments.Equation 1 considers the upper and lower end of the range when calculating the D_{16}, D_{50}, and D_{84} (ODNR 2017). This equation uses the upper end of each range (denoted as S) and the cumulative percentage of particles less than the upper limit of each range (denoted as P).

$$S = 2^{\log_2(S^+)+[P-P^-]*\frac{[\log_2(S^+)-\log_2(S^-)]}{[P^+-P^-]}} \tag{1}$$

Where:

$$S = \text{Size [mm]}$$
$$S^+ = \text{Size at the top of the range [mm]}$$
$$S^- = \text{Size at the bottom of the range [mm]}$$
$$P = \text{Percent smaller than (i.e. } D_{50}\text{) [\%]}$$
$$P^+ = \text{Percent of particles smaller than } S^+ \text{ [\%]}$$
$$P^+ = \text{Percent of particles smaller than } S^- \text{ [\%]}$$

3.2 Log Pearson Type III Distribution

A Log Pearson Type III (LP3) Distribution is recommended by the Water Resources Council for frequency analysis (Singh 1998). The LP3 distribution applies a logarithm transformation on the annual peak flows and calculates the mean, standard deviation, and coefficient of skewness (Bobbe and Ashkar 1988). The coefficient of skewness and frequency factors table can determine the k-values to use to calculate the flow rate associated with their recurrence interval. A graph can be created (flow rates vs. recurrence interval) to receive an equation to predict the recurrence interval for a specific peak flow. This analysis was used on the annual peak flows from the H.J. Andrews gauging stations, located at Lookout Creek and Mack Creek for the years 1995-2017. Some of the annual peak flows used were estimates due to large flood events (i.e. 1996).

3.3 Statistical Analysis

A Two-Sample t-Test was used to test for a significant difference between two grain size distributions. Each year was was compared to see how significant the grain size has changed. If there was a significant difference in the data then further analysis was conducted to see what might have caused a change in the data.

A regression analysis was used to test for a relationship between the change in grain size to peak flows. The dependent variable were the changes in size fractions (i.e. ΔD_{16}, ΔD_{50}, and ΔD_{84}) and the independent variable were the annual peak flows. The regression analysis was applied to each location: lower Lookout Creek, middle Lookout Creek, and Mack Creek.

4 Results

A Log Pearson Type III flood frequency plot was created for Lookout Creek and Mack Creek (Appendix A). These plots produced a logarithmic regression equation by fitting a trend line to the data points. This equation was used to calculate the return interval for a given annual peak flow (Table 1).

Table 1: The annual peak flows with its corresponding return interval for Lookout Creek and Mack Creek.

Lookout Creek		
Water Year	**Peak Flow (cfs)**	**RI (Year)**
1995	1770	2.1
1996	8000	61.4
1997	2980	4.0
1998	1470	1.8
1999	3380	5.0
2000	3180	4.5
2001	377	1.0
2002	1830	2.1
2003	1420	1.7
2004	2040	2.4
2005	1250	1.6
2006	3060	4.2
2007	2240	2.7
2008	1130	1.5
2009	2800	3.6
2010	925	1.3
2011	4600	9.7
2012	2430	3.0
2013	2530	3.1
2014	2360	2.9
2015	2370	2.9
2016	1270	1.6
2017	1530	1.8

Mack Creek		
Water Year	**Peak Flow (cfs)**	**RI (Year)**
1995	168	1.0
1996	346	15
1997	254	3.7
1998	185	1.3
1999	210	1.9
2000	338	13
2001	55	0.2
2002	207	1.8
2003	169	1.0
2004	160	0.9
2005	166	1.0
2006	245	3.3
2007	245	3.3
2008	151	0.8
2009	226	2.4
2010	111	0.4
2011	321	10
2012	195	1.5
2013	192	1.4
2014	226	2.4
2015	245	3.2
2016	164	0.9
2017	140	0.7

The annual peak flows and return intervals were graphed with box plots of the grain size percentiles for lower Lookout Creek, middle Lookout Creek, and Mack Creek (Figure 2, 3, and 4). These box plots graph the D_{16} (minimum), D_{25} (1st quartile), D_{50} (median), D_{84} (3rd quartile), and D_{90} (maximum). These 5 percentiles were chosen because they are commonly used to compare the grain size distribution. The blue box plots indicate years where there was a significant change in the grain size distribution from using the two-sample t-test (Appendix B). Years that were significantly different were further examined by plotting a linear regression analysis of the changes in percentiles and peak flow events (Appendix C). The R^2 values for lower and middle Lookout Creek were small, implying that there is no strong correlation. However, the R^2 values for Mack Creek were higher but there were fewer data points due to less data being collected. This still can mean there is a correlation between peak flows and ΔD_{16}, ΔD_{50}, and ΔD_{84} but more field data should be collected at this area.

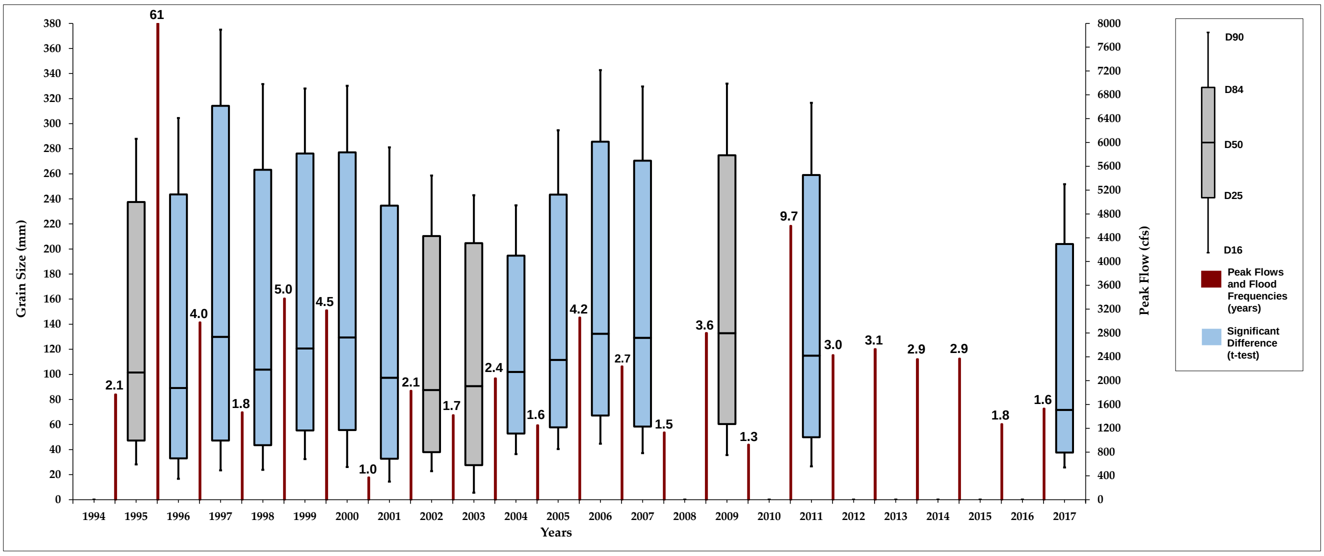

Figure 2: Lower Lookout Creek boxplot illustrating the change in D_{16}, D_{25}, D_{50}, D_{84}, D_{90} over a time period of 1995-2007, 2009, and 2011 along with the the peak flows and flow frequencies for that water year.

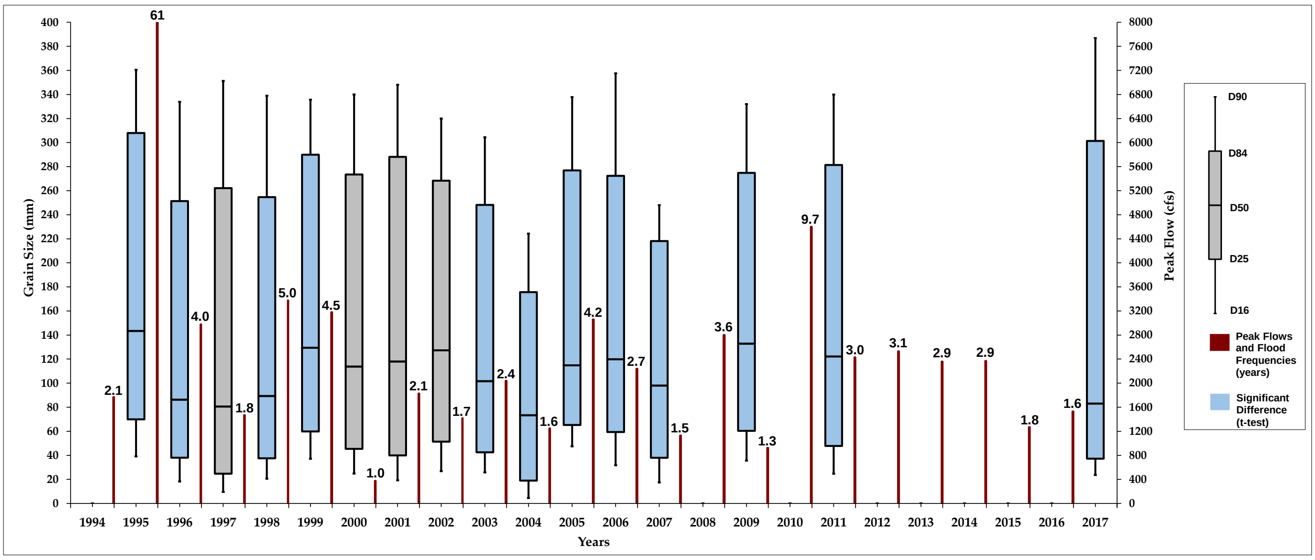

Figure 3: Middle Lookout Creek boxplot illustrating the change in D_{16}, D_{25}, D_{50}, D_{84}, D_{90} over a time period of 1995-2007, 2009, and 2011 along with the the peak flows and flow frequencies for that water year.

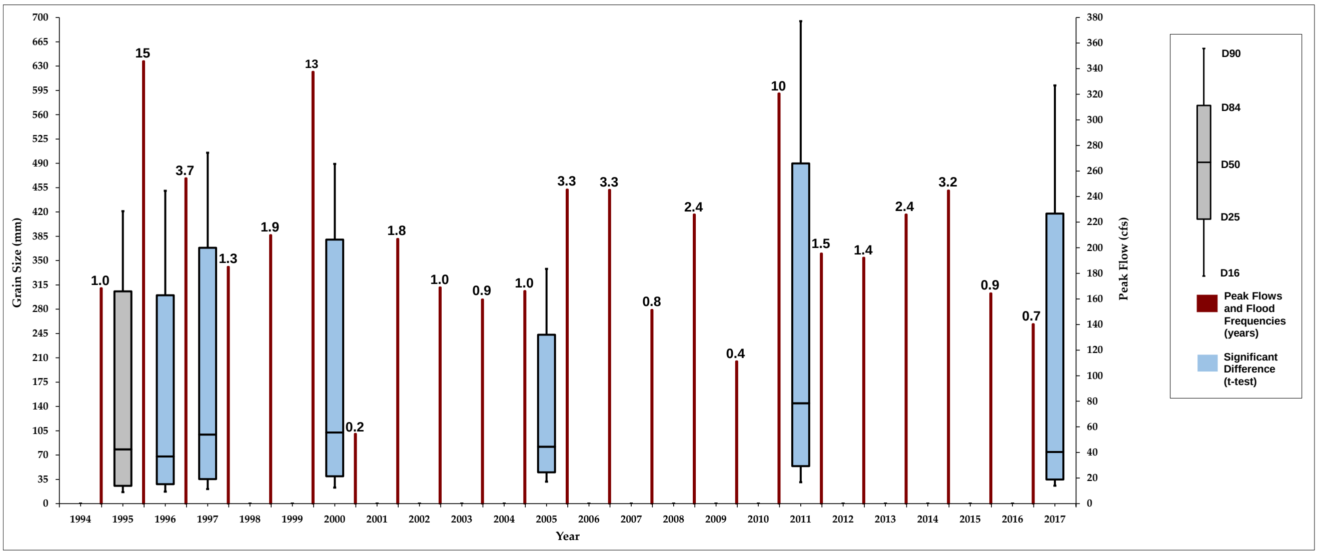

Figure 4: Mack Creek boxplot illustrating the change in D_{16}, D_{25}, D_{50}, D_{84}, D_{90} over a time period of 1995-1997, 2000, 2000, 2011, and 2017 along with the the peak flows and flow frequencies for that water year.

Since there was not a strong correlation between peak flows and changes in percentiles, trends were examined to see if peak flows coarsened or made the bed surface finer. The average change in ΔD_{16}, ΔD_{50}, and ΔD_{84} were categorized into three categories: a less than 2 year event, 2 to 4 year event, and greater than 4 year event (Figure 5, 6, and 7). There were no obvious trend for the average ΔD_{16} for lower Lookout Creek and Mack Creek. However, for middle Lookout Creek as the event increased the ΔD_{16} became finer.

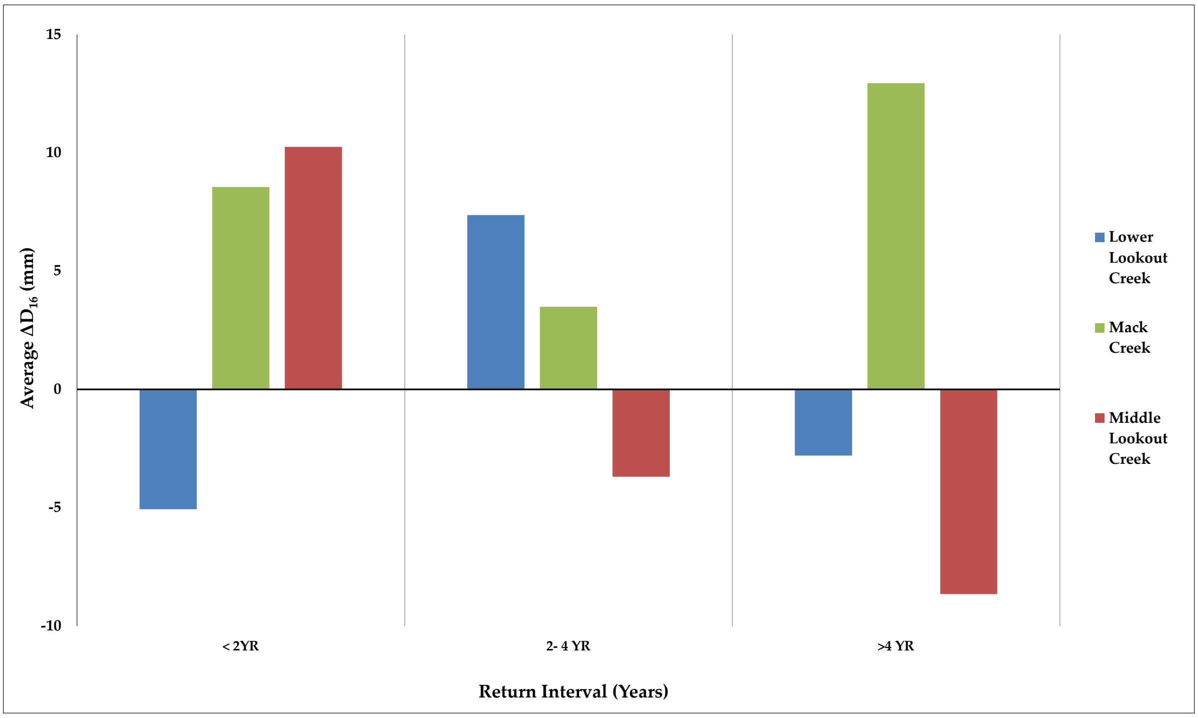

Figure 5: The average change in D_{16} and the corresponding category of return intervals.

Patterns start to appear for the average ΔD_{50} and ΔD_{84} for lower Lookout Creek, middle Lookout Creek, and Mack Creek. The grain size became coarser as the event increased for lower Lookout Creek and Mack Creek. For middle Lookout Creek the grain size percentiles still became finer as the event increased.

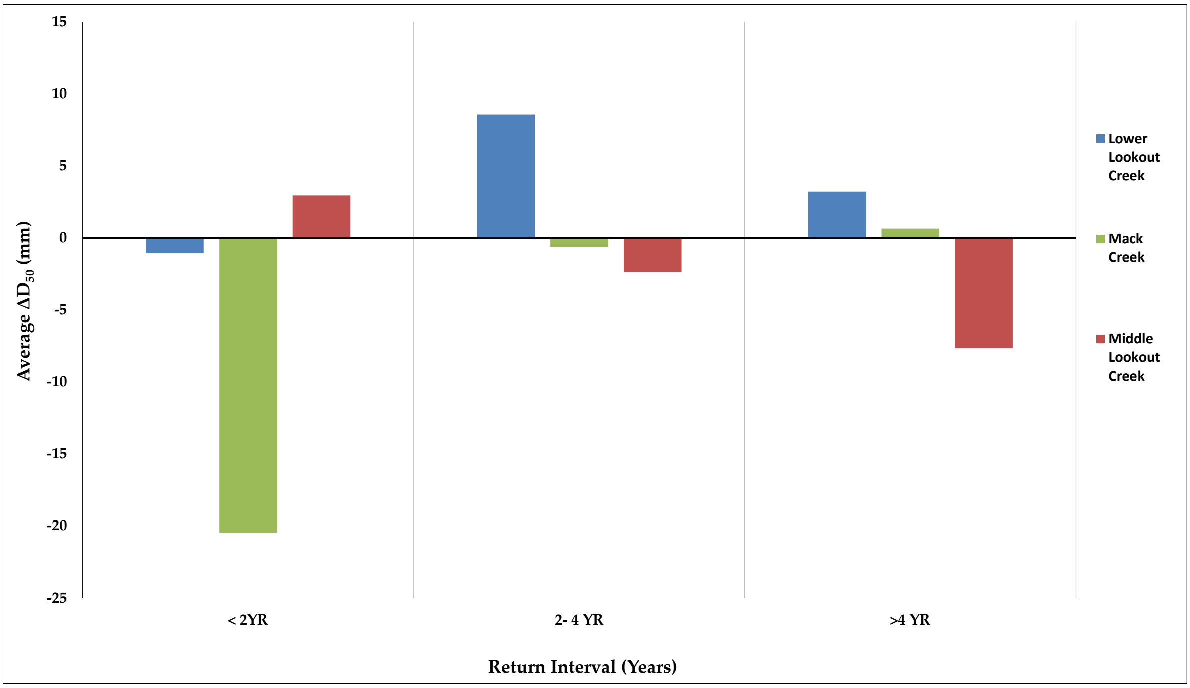

Figure 6: The average change in D_{50} and the corresponding category of return intervals.

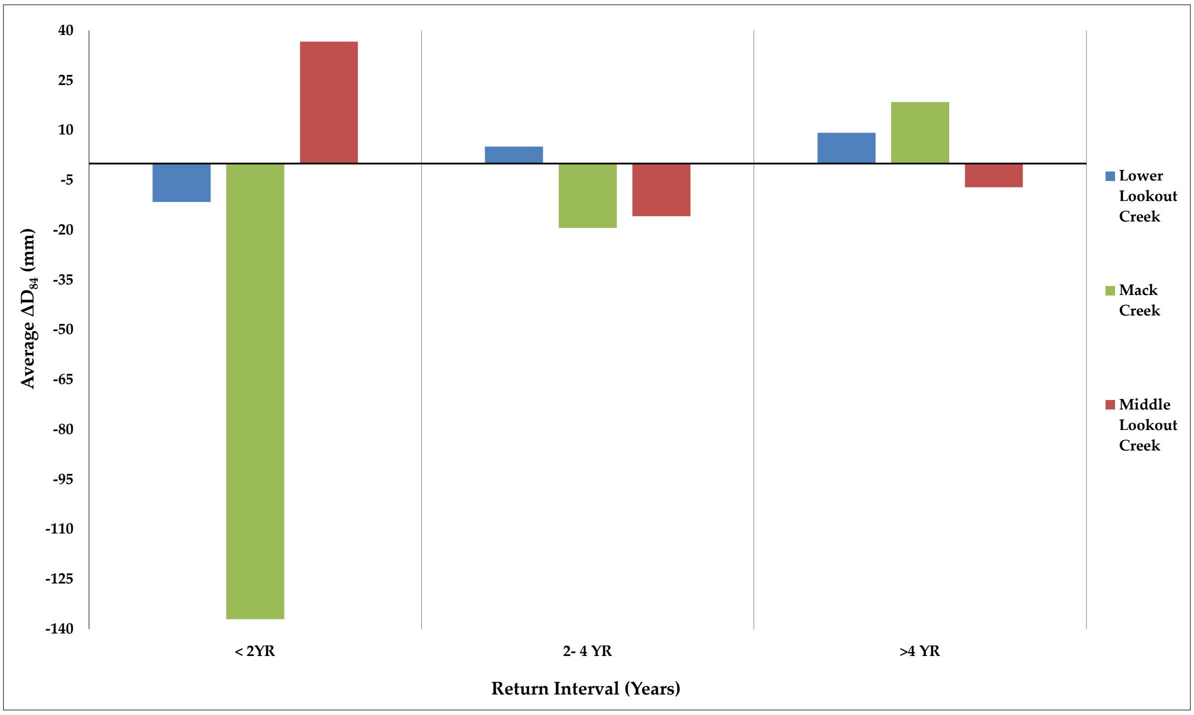

Figure 7: The average change in D_{84} and the corresponding category of return intervals.

5 Discussion

The trends that appear in Figure 5, 6, and 7 were further examined by looking at the channel characteristics and morphology measured from the field. Mack Creek is a 3rd order stream with a steep gradient (9.93%), a narrow active channel width (9.20 m), and has the largest average volume of wood per 50 meters (124.11 m^3/m). The average ΔD_{16} in Mack Creek stayed coarse as the flood events increased. Smaller sediments may be easily transported in a steep terrain thus leaving behind a coarser bed. For the average ΔD_{50} and ΔD_{84} the surface streambed was finer and became coarser as the event increased. A stronger stream flow could allow for larger particles to be transported, however as flood events increase the particles might get stuck behind large woody debris and glacial deposits. This rock jam could accumulate particles during an event and be less likely to transport larger particles.

Middle Lookout Creek is a 4th order stream with a lower gradient (2.75%), a wide active channel width (18.5 m), and has the second largest average volume of wood per 50 meters (81.32 m^3/m). This creek is located upstream of Lookout Creek and McRae Creek confluence, which can have the potential for backwatering and transporting material upstream. Middle Lookout Creek is located downstream of Lookout Creek and Mack Creek confluence, which receives the sediment load from the upper creeks. During an increasing flood event in middle Lookout Creek the average ΔD_{16}, ΔD_{50}, and ΔD_{84} become finer. This may be due to the accumulation of sediment load from the higher elevation creeks and from backwatering. Finer sediments are more able to settle in a lower gradient and wide channel, and this area has an abundant amount of large woody debris that creates scours and pools. As the event increases large particles may be more able to be transported while the finer materials are depositing and filling scours and pools.

Lower Lookout Creek is a 5th order stream with the lowest gradient (1.28%), similar channel width as middle Lookout Creek (18.2 m), however has the least average volume of wood per 50 meters (23.37 m^3/m). Lower Lookout Creek has the greatest flow volume because it is the lowest point in the stream network. It also receives all the sediment load that makes it down the network. The average ΔD_{16} did not have a trend that appeared as the event increased. However, the average change in ΔD_{50} and ΔD_{84} for this area became coarser as the event increased. This may be due to the flow volume having the potential to wash out all the finer materials, leaving behind the larger particles. Also there is less areas for smaller particles to be deposited, which can have the potential for these particles to be easily transported.

The surface grain sizes changed as the flood event increased for all three locations in Lookout Creek Watershed. This change implies that flood events do have the potential to change the streambed material. However, there was a lack of evidence for a correlation between the change in grain size percentiles and peak flows. Thus, further examination should be done on other disturbances that may cause an affect on surface grain size (i.e. large woody debris, forest harvest, road crossings, debris flows, etc.).

6 Conclusion

Current and historical cross-sectional grain size data were used for analyzing the effect flood events have on the temporal change in grain size distribution in lower Lookout Creek, middle Lookout Creek, and Mack Creek. Field data, a two-sample t-test, a log pearson type III flood frequency analysis, and a regression analysis were used to determine if there was a correlation between annual peak flows and changes in grain size percentiles. The regression analysis proved that there was no correlation, thus the change in grain size percentiles and flood frequency events were investigated to see if there were patterns in the surface material during flood events. Lower Lookout Creek and Mack Creek average ΔD_{50} and ΔD_{84} became coarser as the flood event increased and for middle Lookout Creek the average ΔD_{16}, ΔD_{50}, and ΔD_{84} became finer as the event increased. The channel characteristics and morphology of these three areas were examined to determine why these patterns were occurring in these locations. Lookout Creek Watershed is a very complex stream network that involves many disturbances that have the potential to change the surface grain sizes. Further analysis should be done on how large woody debris, road crossings, forest harvest, and debris flows have an affect on the change in grain size.

References

Andrews, E. D., and Erman, D. C. (1986). "Persistence in the Size Distribution of Surficial Bed Material During an Extreme Snowmelt Flood." *Water Resources Research*, 22(2), 191-197

Bobee, B., and Askhar, F. (1988). "Generallized Method of Moments Applied to LP3 Distribution." *Journal of Hydraulic Engineering*, 114(8).

"Calculating D50".(2017). *ODNR Division of Water Resources*, <http://water.ohiodnr.gov/> (Aug. 10, 2017).

Chang, F. J., and Chung, C. H. (2012). "Estimation of riverbed grain-size distribution using image-processing techniques." *Journal of Hydrology*, 440-441, 102-112.

Clayton, J. A., and Pitlick, J. (2008). "Persistnece of the surface texture of a gravel-bed river during a large flood." *Earth Surface Processes and Landforms*, 33, 661-673.

"Fast Facts." (2011). *H.J. Andrews Experimental Forest Long-Term Ecological Research*, <https://andrewsforest.oregonstate.edu/about/fast-facts> (Aug. 18, 2017).

Pitlick, J., Mueller, E. R., Segura, C., Cress, R., Torizzo, M. (2008). "Relationship between flow, surface-layer armoring and sediment transport in gravel-bed rivers." *Earth Surface Processes and Landforms*, 33, 1192-1209.

Powell, D. M., Reid, I., and Laronne, J. B. (2001). "Evolution of bed load grain size distribution with increasing flow strength and the effect of flow duration on the caliber of bed load sediment yield in ephemeral gravel bed rivers." *Water Resources Research*, 37(5), 1463-1474.

Rice, S., and Church, M. (1998). "Grain size along two gravel-bed rivers: statistical variation, spatial pattern and sedimentary links." *Earth Surface Processes and Landforms*, 23(4), 345-363.

Singh, V. P. (1998). "Log-Pearson Type III Distribution." *Entropy-Based Parameter Estimation in Hydrology Water Science and Technology Library*, 30, 252–274.

USGS. (2017). "StreamStats". <https://water.usgs.gov/osw/streamstats/> (Aug. 18, 2017).

Swanson, F. J., and Jones, J. A. (2002). "Geomorphology and Hydrology of the H.J. Andrews Experimental Forest, Blue River, Oregon".

Appendix A: Log Pearson Type III Distribution

A Log Pearson Type III Distribution plot for Lookout Creek and Mack Creek. These plots were used to calculate the return interval for a given annual peak flow.

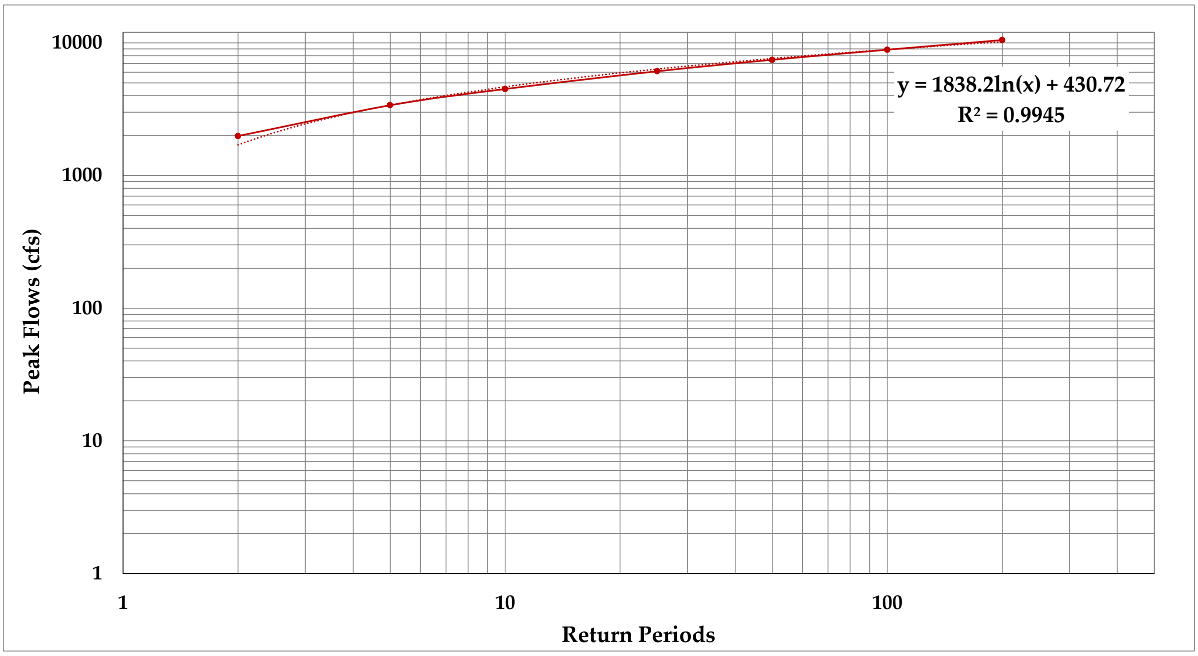

Figure A-1: Log Pearson Type III Flood Analysis for Lookout Creek.

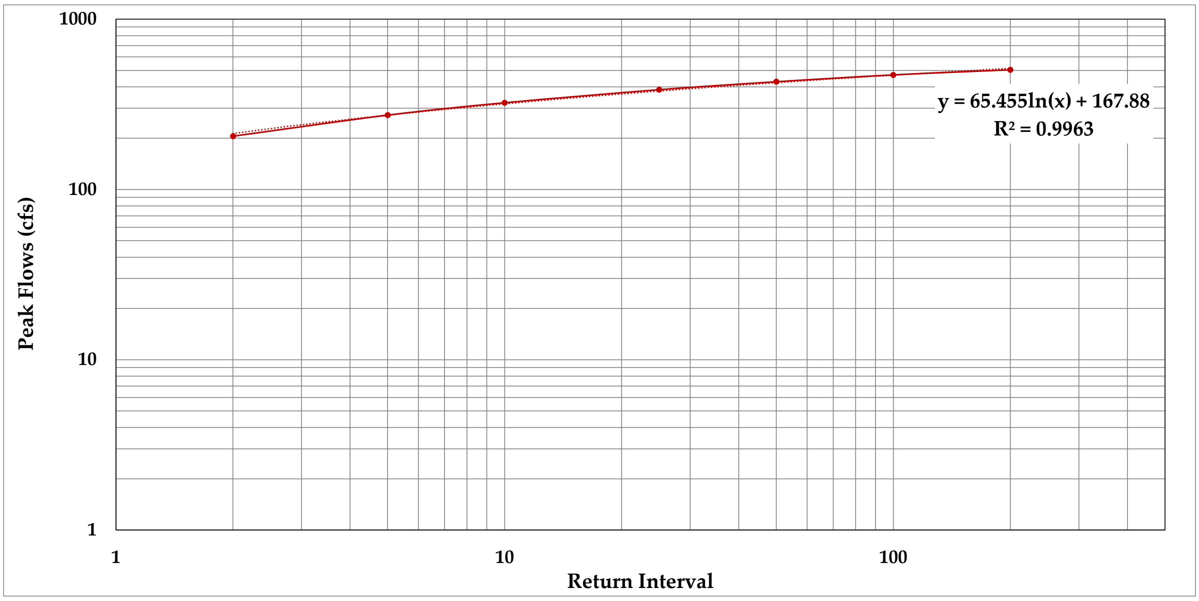

Figure A-2: Log Pearson Type III Flood Analysis for Mack Creek.

Appendix B: Two-Sample t-Test

Two-Sample t-Test statistic for each consecutive year for lower Lookout Creek, middle Lookout Creek, and Mack Creek.

Table B-2: Two-Sample t-Test for lower Lookout Creek.

X	Y	Significantly Different?	t	df	p-value	X 95% Confidence Interval	Y 95% Confidence Interval	X Mean (mm)	Y Mean (mm)
1995	1996	No	0.213	2553	0.83	-11.2	14.0	158.4	157.0
1996	1997	Yes	-6.90	2703	6.3E-12	-66.1	-36.9	157.0	208.5
1997	1998	Yes	3.84	2769	1.3E-04	14.6	45.2	208.5	178.6
1998	1999	Yes	-2.01	2784	0.04	-30.4	-0.38	178.6	194.0
1999	2000	No	0.226	2770	0.82	-13.1	16.5	194.0	192.3
2000	2001	Yes	4.10	1017	4.5E-05	18.9	53.6	192.3	156.0
2001	2002	No	1.63	979	0.10	-3.21	34.5	156.0	140.4
2002	2003	No	0.388	1086	0.70	-13.9	20.8	140.4	136.9
2003	2004	No	-0.696	960	0.49	-23.3	11.1	136.9	143.0
2004	2005	Yes	-3.76	757	1.9E-04	-41.9	-13.1	143.0	170.5
2005	2006	Yes	-5.50	2680	4.2E-08	-51.3	-24.3	170.5	208.4
2006	2007	Yes	2.21	1399	0.03	2.23	37.5	208.4	188.5
2007	2009	No	-0.603	820	0.55	-29.4	15.6	188.5	195.4
2009	2011	No	20.4	399	2.2E-16	167.5	203.2	195.4	10.1
2011	2017	Yes	4.5553	1987	5.5E-06	24.8	62.5	185.2	141.5
2011	2017	Yes	-2.949	858	3.2E-03	-62.5	-12.5	192.6	230.1

Table B-3: Two-Sample t-Test statistics for middle Lookout Creek.

X	Y	Significantly Different?	t	df	p-value	X 95% Confidence Interval	Y 95% Confidence Interval	X Mean (mm)	Y Mean (mm)
1995	1996	Yes	6.18	2119	7.8E-10	35.7	69.0	216.0	163.6
1996	1997	No	-0.826	2104	0.41	-24.9	10.2	163.6	171.0
1997	1998	No	0.403	2133	0.69	-13.6	20.7	171.0	167.5
1998	1999	Yes	-3.59	2055	3.4E-04	-45.2	-13.3	169.0	198.2
1999	2000	No	1.44	2188	0.15	-4.1	26.9	198.2	186.8
2000	2001	No	0.07	741	0.94	-20.4	22.0	186.8	186.0
2001	2002	No	0.14	833	0.89	-21.8	25.1	186.0	184.4
2002	2003	No	0.954	360	0.34	-14.8	42.8	184.4	170.4
2003	2004	Yes	3.71	291	0.00	28.1	91.7	170.4	110.6
2004	2005	Yes	-6.92	167	0.00	-104.6	-58.2	110.6	192.0
2005	2006	No	-0.629	2169	0.53	-22.1	11.4	192.0	197.3
2006	2007	Yes	4.97	415	9.8E-07	33.8	78.0	197.3	141.5
2007	2009	Yes	-4.16	524	3.7E-05	-79.5	-28.5	141.5	195.4
2009	2011	No	0.259	744	0.80	-18.3	23.9	195.4	192.6
2011	2017	No	0.175	2523	0.86	-13.0	15.6	192.6	191.4
2011	2017	Yes	-2.949	858	3.27E-03	-62.5	-12.5	192.6	230.1

Table B-4: Two-Sample t-Test for Mack Creek.

X	Y	Significantly Different?	t	df	p-value	X 95% Confidence Interval	Y 95% Confidence Interval	X Mean (mm)	Y Mean (mm)
1995	1996	No	-0.335	2421	0.738	-30.2	21.4	205.1	209.5
1996	1997	Yes	-3.45	2364	5.81E-04	-78.0	-21.4	209.5	259.2
1997	2000	No	0.966	2384	0.334	-14.8	43.6	259.2	244.8
2000	2005	Yes	5.36	2142	9.00E-08	42.0	90.5	244.8	178.5
2005	2011	Yes	-10.50	1639	2.20E-16	-220.3	-150.9	178.5	355.7
2011	2017	Yes	4.26	1850	2.17E-05	41.7	113.0	364.1	286.8

Appendix C: Regression Analysis

A regression analysis performed for lower Lookout Creek, middle Lookout Creek, and Mack Creek to distinguish if there is a correlation between peak flows and the changes in grain size.

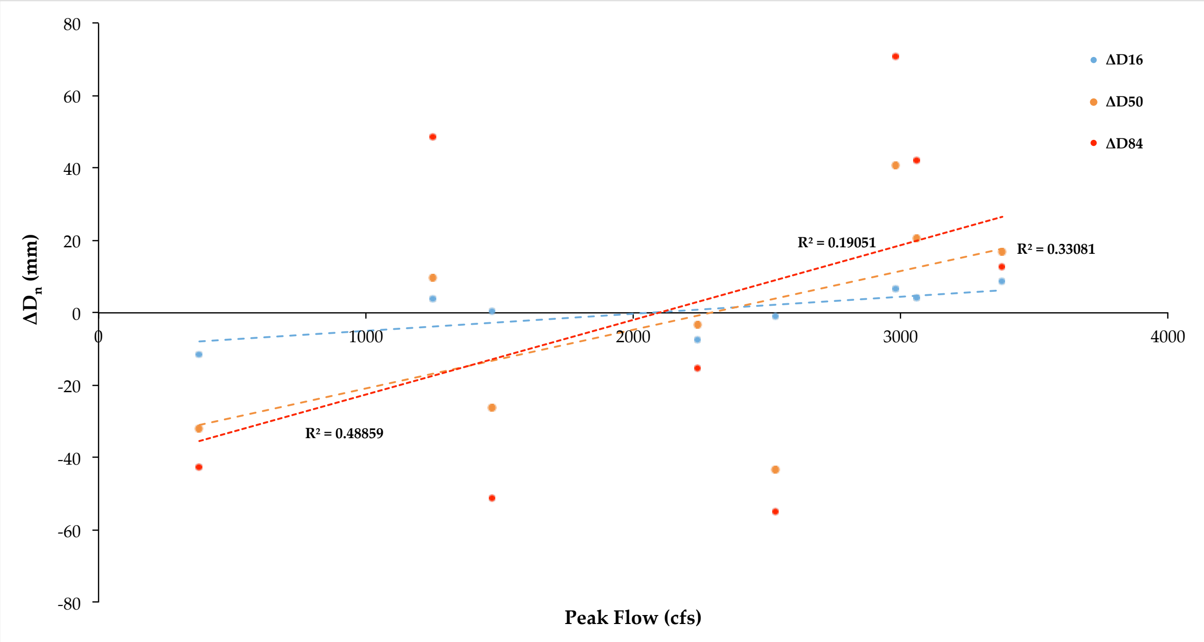

Figure C-1: The change in D_{16}, D_{50}, and D_{84} on the y-axis and peak flows on the x-axis for lower Lookout Creek.

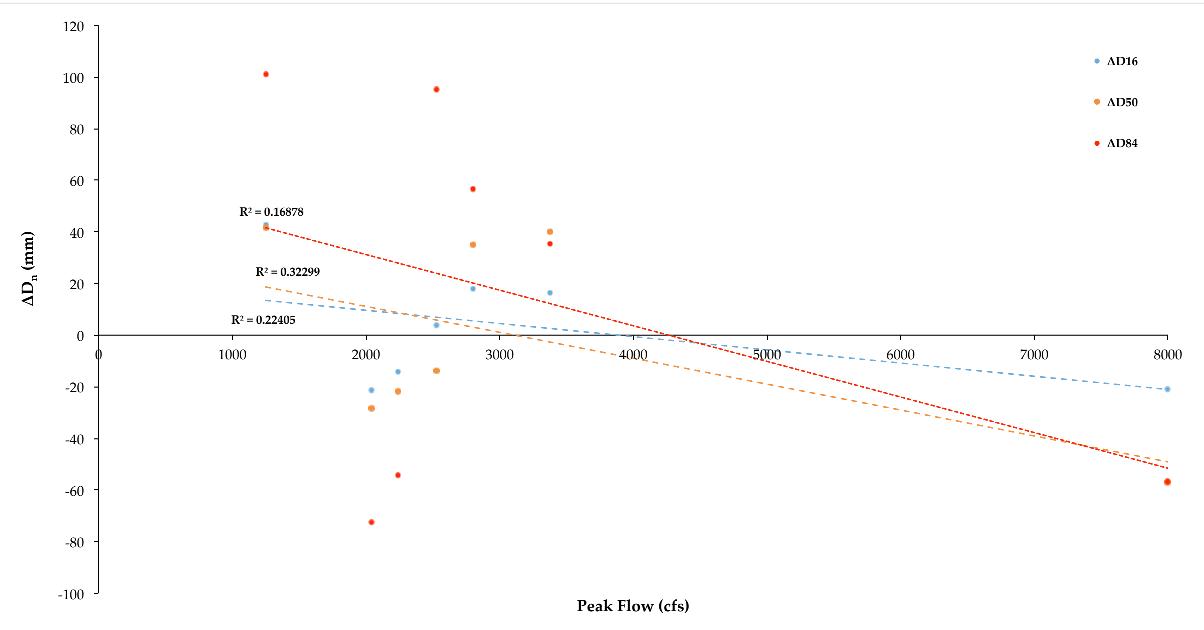

Figure C-2: The change in D_{16}, D_{50}, and D_{84} on the y-axis and peak flows on the x-axis for middle Lookout Creek.

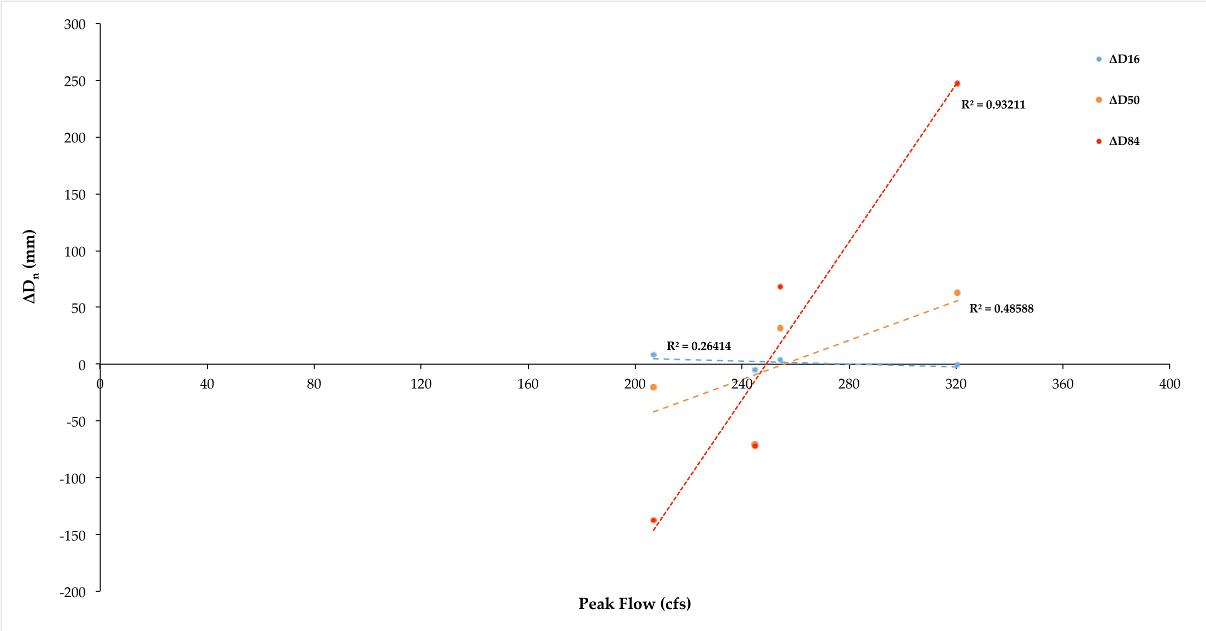

Figure C-3: The change in D_{16}, D_{50}, and D_{84} on the y-axis and peak flows on the x-axis for Mack Creek.