EVIDENCE OF A CHANGING CLIMATE IMPACTING THE FLUVIAL GEOMORPHOLOGY OF THE KAUTZ CREEK ON MT. RAINIER

by

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ABSTRACT

Evidence of a Changing Climate Impacting the Fluvial Geomorphology of the Kautz Creek on Mt. Rainier

Melanie Graeff

Carbon dioxide emissions have stimulated the warming of air and ocean temperatures worldwide. These conditions have fueled the intensity of El Nino-Southern Oscillation and Atmospheric River events by supplying increased water vapor into the atmosphere. These precipitation events have impacted the fluvial geomorphology of a creek on the southwestern flank of the Kautz Creek on Mt. Rainier, Washington. Using GIS software was the primary means of obtaining data due to the lack of publications published on the Kautz Creek. Time periods of study were set up from a 2012 publication written by Jonathan Czuba and others, that mentioned observations of the creek that dated from 1960 to 2008. In combining those observations of the Kautz and weather data from the weather station in Longmire, Washington, this allowed for a further understanding of how climate change has affected the fluvial geomorphology of the Kautz Creek over time. GIS software mapping showed numerous changes on the creek since 2008. The warming of seasonal temperatures and precipitation has increased aggradation of the creek due to the melting of the Kautz glacier. The maps show definite sediment movement with increased erosion near the upper half of the creek near the glacier terminus. The increased widening of the creek channel due to sedimentation is influencing waterflow; threatening downstream infrastructure and public access spaces with flooding. With the likelihood of these heavy precipitation events impacting the region in the future, continued monitoring and mapping of this creek and other tributaries need to take place to ensure the public safety and accessibility of the park.

Keywords: Kautz; Mt. Rainier; GIS; LiDAR; atmospheric river; el nino-southern oscillation; climate change; sedimentation.

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Acknowledgements

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I) Introduction

Anthropogenic climate change due to greenhouse gas emissions is altering weather conditions all over the globe. On the North American west coast, the altering of these weather patterns is leading to changing the seasons that now include frequent, precipitation-heavy storms in the winter and drier, hotter conditions in the summer months in the Pacific Northwest (USFW, 2011). The weather of the Pacific Northwest (PNW) is driven by the interactions between the regional terrain, ocean convection currents, the atmosphere, and ocean temperatures. These interactions are carving out and shaping the landscape itself.

Located in the Cascade mountain range in western Washington State stands Mt Rainier. The stratovolcano stands at over 14,000 feet tall and is the highest mountain in Washington. Mt Rainier is encircled by twenty-five glaciers that serve as sources for high elevation tributaries that runoff into some of the largest rivers draining into the Puget Sound (NPS, Aggradation 2017). The weather and temperature fluctuations are putting stress on the tributary channels by increasing the water and sediment volume transport. The one mountain tributary that will serve as the main focus of this study will be the Kautz Creek on the southwestern flank (Figure 1).

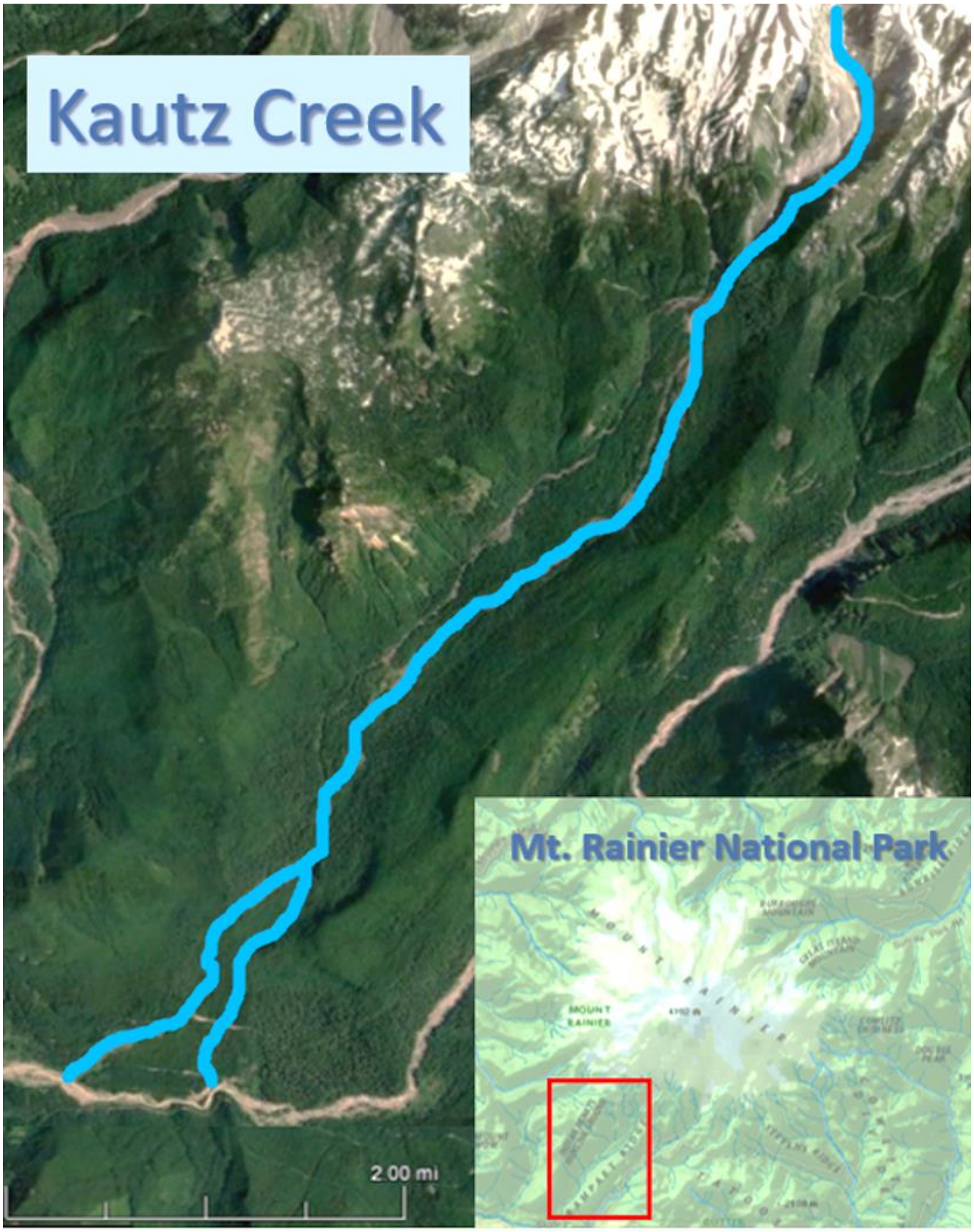


Figure 1. The map shows the Kautz Creek and its surrounding area on the southwestern flank of Mt Rainier (Map credits: ESRI, 2017).

The tributary has not been a main study concern for these particular climate change effects until recently. With the help of LiDAR imagery and other climate data, can significant in-channel erosion progression from increased precipitation and glacial melting from this last decade be detected and mapped on the Kautz Creek on Mt Rainier?

The increased atmospheric temperatures cause surface warming in the oceans as well as on the land. The effects of this warming impact weather systems with massive amounts of water vapor now being evaporated into the atmosphere. This water vapor eventually condenses and falls to the Earth as precipitation. The PNW is accustomed to rain and snowfall during the winter months, but these storms have gotten more intense and are occurring more frequently (Warner et al, 2015). These storms bring with them heavy precipitation which can lead to flooding once the storm makes landfall. The two weather patterns that contribute the majority of this extreme precipitation to the PNW are the El Nino-Southern Oscillation (ENSO) events and with Atmospheric River (AR) events.

El Nino-Southern Oscillation (ENSO) is an irregular and periodic series of weather patterns that stem from variations in ocean and atmospheric temperatures. ENSO occurs every two to seven years and consists of both warming and cooling seasons that are often referred to as "El Nino" and "La Nina" (NOAA, Climate.gov, 2017). The shifts in the temperature and water vapor gradients make regions in the Pacific that normally would experience seasonally cold and dry conditions, instead experience intense rainfall and flooding during ENSO events (Cai et al, 2014). The last few ENSO events to hit the PNW occurred in 1982/83, 1997/98, and 2015/16. These were classified as extreme events and were characterized by exceptional warming and high precipitation. Climatologists conclude that if this warming continues, these types of extreme ENSO events will repeat more frequently in the future (Cai et al, 2014).

Another weather pattern that can be formed and sustained from ENSO and other oscillations in the Pacific are Atmospheric Rivers (AR). ARs are responsible for an estimated 30-

50% of the precipitation in the winter months in the PNW (Payne and Magnusdottir, 2014); (Gimeno et al, 2014). The weather oscillations play a role in modulating ARs prior to landfall by supplying high amounts of water vapor into the lower troposphere (Payne and Magnusdottir, 2014). The geography and landscape of the PNW make the area susceptible to flooding from ARs. This is apparent in Washington State where the region is lined with flat coastal terrain that is hemmed in by the Cascade mountain range to the east. This terrain controls where the precipitation falls regionally. When a vapor-rich AR encounters mountainous terrain, the AR is then forced upwards, at which point the orographic enhancement of rainfall can occur producing precipitation events and catastrophic flooding (Gimeno et al, 2014). In Washington, the area to the west of the Cascade Mountains receives more precipitation compared to the eastern half.

The Cascade Mountains in western Washington state is comprised of tall mountains and volcanoes, the tallest being Mt. Rainier. The climate-altering effects on the mountain are constant throughout the year ranging from the dry, summer months to the wet, winter months. Generally warmer and drier conditions during the summer months are melting the many glaciers sitting atop the mountain at a faster rate than has ever been recorded. This melting is releasing tons of rocks and sediment down the mountain tributaries in a process called aggradation (NPS, Aggradation, 2017). The massive volume of material begins to erode the tributary channel as gravity pulls it downstream, eventually choking the channels and raising the water levels. Then during many winter months, the region is experiencing heavy rainfall from an AR or the seasonal ENSO. The onslaught of torrential precipitation washes more rock and sediment down the already choked tributaries, eventually causing flooding.

Considering all the factors at play for studying this tributary, I will study 1) whether the range of increasing temperatures and whether have caused increased aggradation of the creek from the melting glaciers, 2) whether precipitation on the mountain has increased significantly over this last decade than the previous few decades starting from the 1960s, and 3) whether and to what extent aggradation and erosion have taken place affecting the elevation and geomorphology of the Kautz Creek. This study will use topographical maps, aerial imagery, and Light Detection and Ranging (LiDAR) imagery to see at what extent aggradation and erosion have taken place. If a correlation can be found with hotter temperatures and higher precipitation contributing to increased aggradation and erosion of the creek over this last decade then it is possible that we can quantify the effects of climate change on this creek.

II) **Literature Review**

A. Warming Summer Months

The summer months in the PNW are frequently dominated by dry air masses and hot temperatures. Over the last few decades, the NOAA records report that the summer months have gotten drier and hotter, as shown in Figure 1 below. According to Mote and others (2014) in their third National Climate Assessment Report of Climate Changes in the US, temperatures across the PNW region have increased at an average of 1.3 degrees F from 1895 to 2011 for all seasons. The time series provided by NOAA below (Figure 2) shows the mean summer temperatures from 1895 to 2015 have increased approximately 2.3 degrees F, from 60.7 to 63 degrees F.

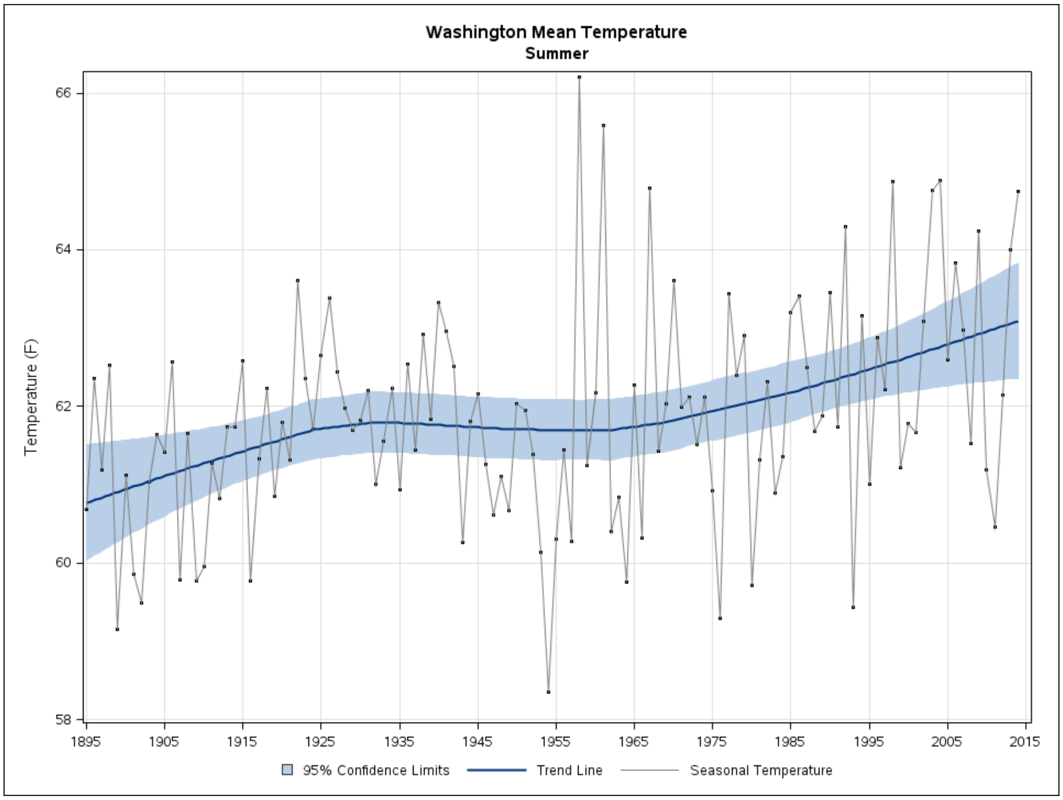


Figure 2. A time series showing an increase in the mean summer temperatures in Washington from 1895 to 2015 (NOAA, National Climatic Data Center, 2016).

Mote and others also project that an increase in average annual temperature of 3.3 to 9.7 degrees Fahrenheit is projected from 2070 to 2099. The amount that occurs will depend largely on emissions of heat-trapping gases (Mote et al, 2014). Researchers also reiterate that as summer temperatures increase, precipitation is expected to decrease. However, this prediction seems to be at slight odds with the precipitation trends from 1950 to 2015 in the western Cascades which have shown increasing trend, particularly from 1995 to 2015, of summer precipitation over that time (Figure 3). According to Littell and others (2009), all seasons will experience a warming trend with the highest being in the summer months. They also speculate in these models that this summer warming will produce more drying and infrequent precipitation (Littell et al 2009).

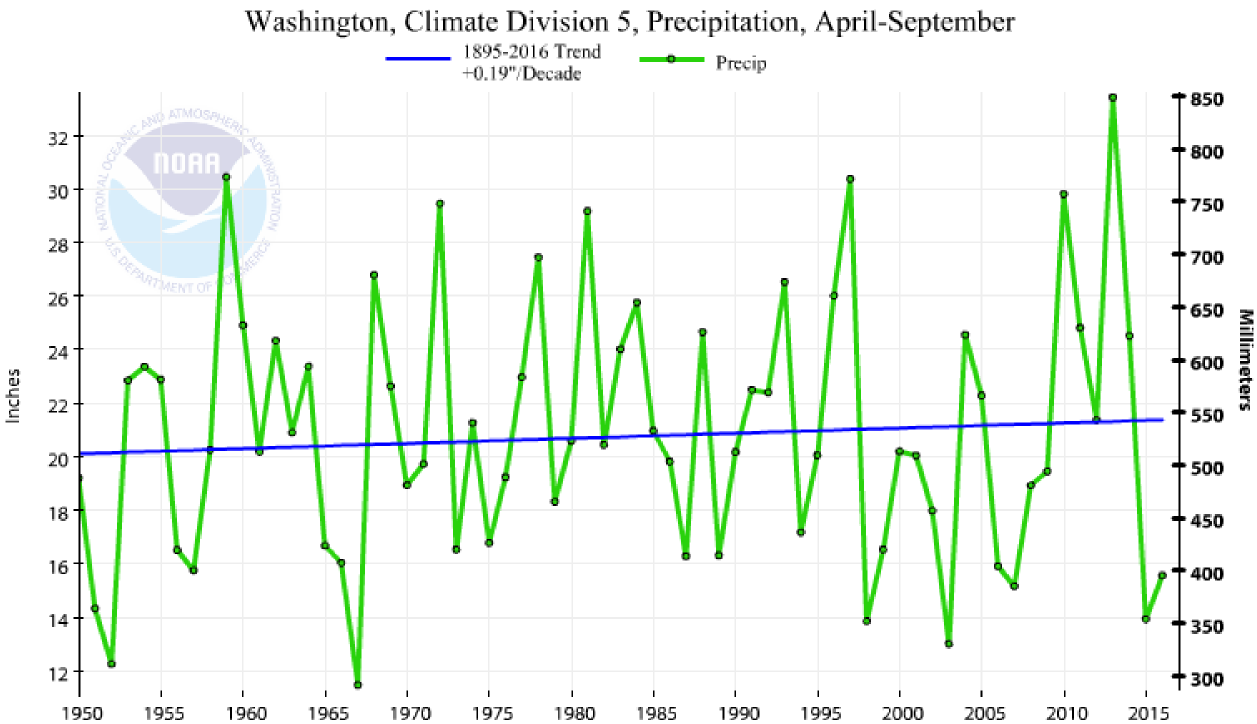


Figure 3. Summer precipitation trends in the western Cascades show a slight increase in precipitation from 1950 to 2015 but also a high degree of variability in the period 1995 through 2015 (NOAA National Centers for Environmental Information, 2016).

1. Warming Oceans in the PNW

The weather conditions for the PNW are driven by Pacific Ocean temperatures and the interactions of ocean waters with the atmosphere. In 2013, the waters off the west coast were measured to be significantly warmer than usual, by about 5 to 7 degrees F in some places (Welch, 2016). The warm mass was coined "the blob" and has since been referred by that name in publications (Johnson 2015; Welch, 2016). The name was coined by Nick Bond, a climate scientist and researcher at the University of Washington's Joint Institute for the Study of the Atmosphere and the Ocean (Welch, 2016).

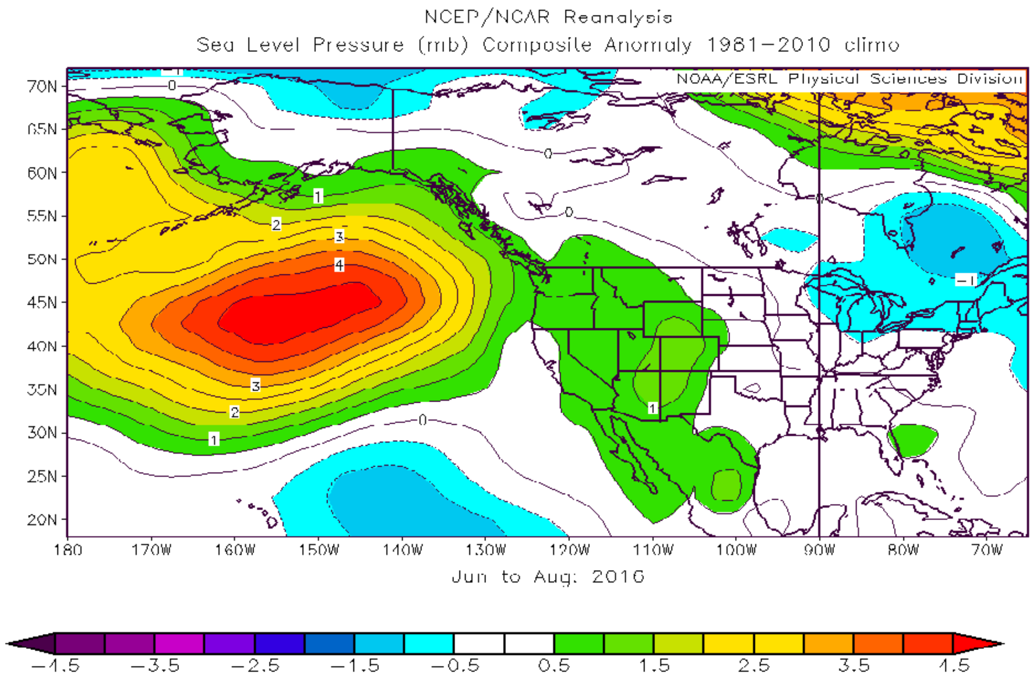


Figure 4. The yellow and red shadings show the extent of "the blob" of warmer water forming in the Eastern Pacific Ocean (Belles, 2016).

The blob formed in late 2013 from systems of high pressure over the Gulf of Alaska. The blob has since influenced the weather by preventing the ocean from cooling off in the PNW for the last few years (Figure 4) (Johnson, 2015; Welch, 2016). Since its formation, the region has experienced fewer clouds, light winds, less precipitation, and diminished snowpack amounts in the summer months. Bond surmises that the blob was not caused by climate change, but by natural fluctuations in the atmosphere-ocean interactions from the warm tropical conditions that migrated into the northeastern Pacific (Johnson, 2015). However, scientists are worried that increasing greenhouse gas emissions could perpetuate warming oceans and make these warming conditions more frequent (Welch, 2016; Hickey, 2015).

2. Disappearing Glaciers

Scientists say that the speed at which Mt Rainier's glaciers are melting is clear evidence of climate change (Carson, 2014). The temperature increase and precipitation decrease during the summer months does not bode well for the glaciers sitting atop Mt. Rainier. The mountain has twenty-five named glaciers with a combined surface area of more than thirty square miles; the largest glacial system on a single mountain in the United States outside of Alaska (NPS, 2017). Climate change is melting Mt. Rainier's glaciers at six times the historical rate (Figure 5) (Carson, 2014). According to geological surveys conducted between 2003 and 2009, up to 18% of the total volume of ice and snow (about 200 billion gallons) had drained from Mt. Rainier's glaciers and into its tributaries (Carson, 2014). Thomas Sisson, a U.S. Geological Survey scientist who has studied the glaciers on the mountain stated to Carson (2014) that, "the ice volume has been declining since the end of the Little Ice Age, about 1850. But there were periods of stasis or modest advance that appear to correlate the strong cool phases of the decadal oscillations. The glaciers are getting smaller, so it looks like near average temperature and near average snowfall are insufficient to maintain ice volume."

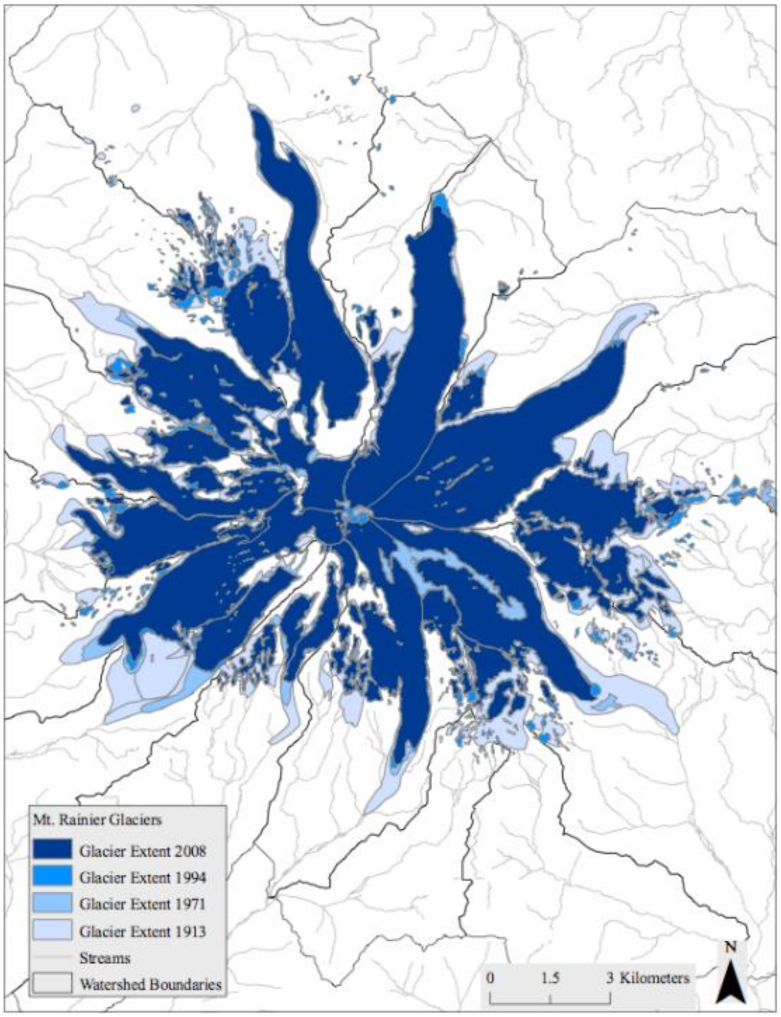


Figure 5a. The map displays the total glacial recession from 1913 to 2008 on Mt. Rainier (Copeland, 2009; Nylen, 2004).

The climate and geography can influence the different types of heat sources (equation below) and their varying influences on glacial melt (Harr, 1981; Parker, 2009).

$$Mt = Mrs + Mg + Mrl + Mce + Mp$$

In the equation above, Mt is represented as the total melt, Mrs is melt from short-wave radiation, Mg is melt from ground heat, Mrl is melt from long-wave radiation, Mce is melt due to convection and condensation, and Mp is melt from the latent heat transfer caused by rain on snow (Harr, 1981; Parker, 2009). Snowpacks that are at or near 32 degrees F are easily melted by latent heat energy from warm rain events (Marks et al, 1998). These warm rain events and subsequent melting of the snowpack can increase the amount of runoff into mountain tributaries due to its low storage capacity for water during melting (Harr, 1981). These types of conditions make it hard for rebuilding of the glacial ice with the increased warming temperatures and increased precipitation during ENSO and AR events that will be discussed later on in the paper.

The glaciers serve as sources for these high elevation tributaries that runoff into rivers that drain into the Puget Sound. This melting is releasing many tons of rocks and sediment down the mountain tributaries in a process called aggradation (NPS, Aggradation, 2017; Czuba et al, 2012). The rock and sediment was once trapped within the glaciers as it was picked up by glacier movement over the mountain top through plucking and abrasion (Czuba et al, 2012). The massive volume of material begins to erode and widen the tributary channel as gravity pulls it downstream, eventually choking the channels (Anderson and Pitlick, 2014). According to Scott Beason, a geologist at Mt. Rainier National Park, states that Mt. Rainier's "glaciers act like giant conveyor belts for sediment" (Carson, 2014). Higher amounts of rocks and sediment in river beds mean less space for water to flow. Water then finds that path of least resistance as it flows down the mountain damaging park roads, campgrounds, and trails (Carson, 2014). These floods end up costing the park millions of dollars in repairs (Carson, 2014).

a. Effects of Melting Glaciers on Kautz Creek

All of the glaciers on Mt. Rainier have been shrinking in the last century (Nylen, 2004; Copeland, 2009). According to Czuba et al (2012), the glacier response on Mt. Rainer is indicative of the warming regional trends. The highest degree of glacial retreat has occurred on the southern flank of the mountain (Czuba et al, 2012). Figure 5 below display the lighter shades of blue as the historical extent of the glaciers and show roughly one-hundred years of glacial retreat (Nylen, 2004; Copeland, 2009). According to Nylen and Copeland, the Kautz Glacier that feeds the Kautz Creek, had retreated by 1589 meters from 1913 to 1971. And in measuring recent data, the glacier had retreated another 500 meters from 1971 to 2008 (Copeland, 2009).

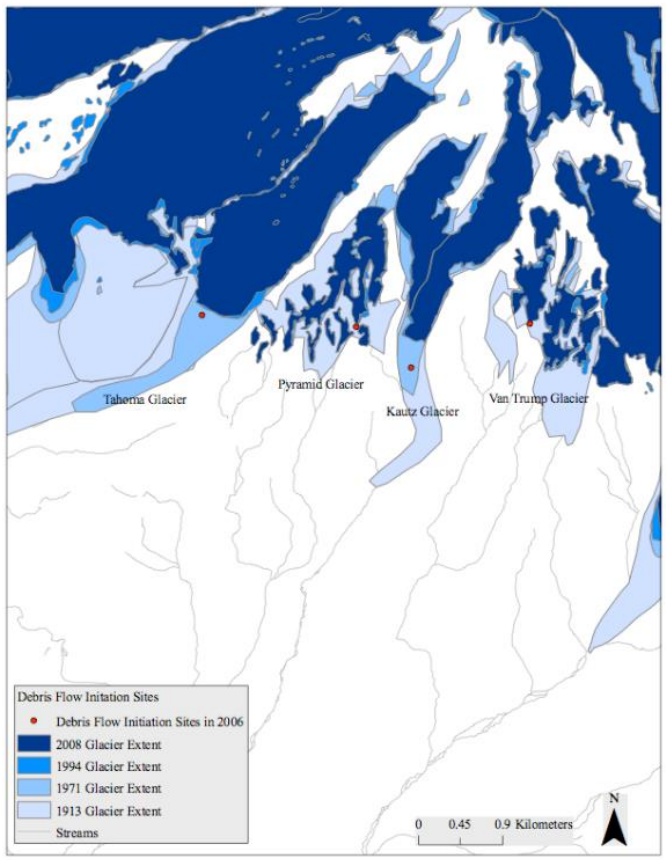


Figure 5b. The map is a close up of the retreat of the Kautz Glacier which drains into the Kautz Creek. The lighter shades of blue show the previous glacier extents and how far they have retreated from 1913 to 2008 (Copeland, 2009; Nylen, 2004).

Rivers may go through cycles of "aggradation," which leads to more abundant sedimentation and wider channels and "recovery," which leads to narrower channels more deeply incised. The Kautz Creek has experienced geomorphic changes in its channel width due to variations in sediment and rock levels from aggradation. According to Czuba and others (2012), the creek recovered from its 1947 debris flow by narrowing the channel width. The width of the channel diminished from 116 to 63 meters from 1960 to 1994. This was evidenced by low meltwater and vegetation growth along the channel. But the researchers state that because of increased glacial retreat and high precipitation in winter months from 1994 to 2008, the Kautz Creek channel has since widened another 38 meters (Figures 6a and 6b) (Czuba et al, 2012). This widening is indicative of aggradation, signaling an increase in sediment loads.

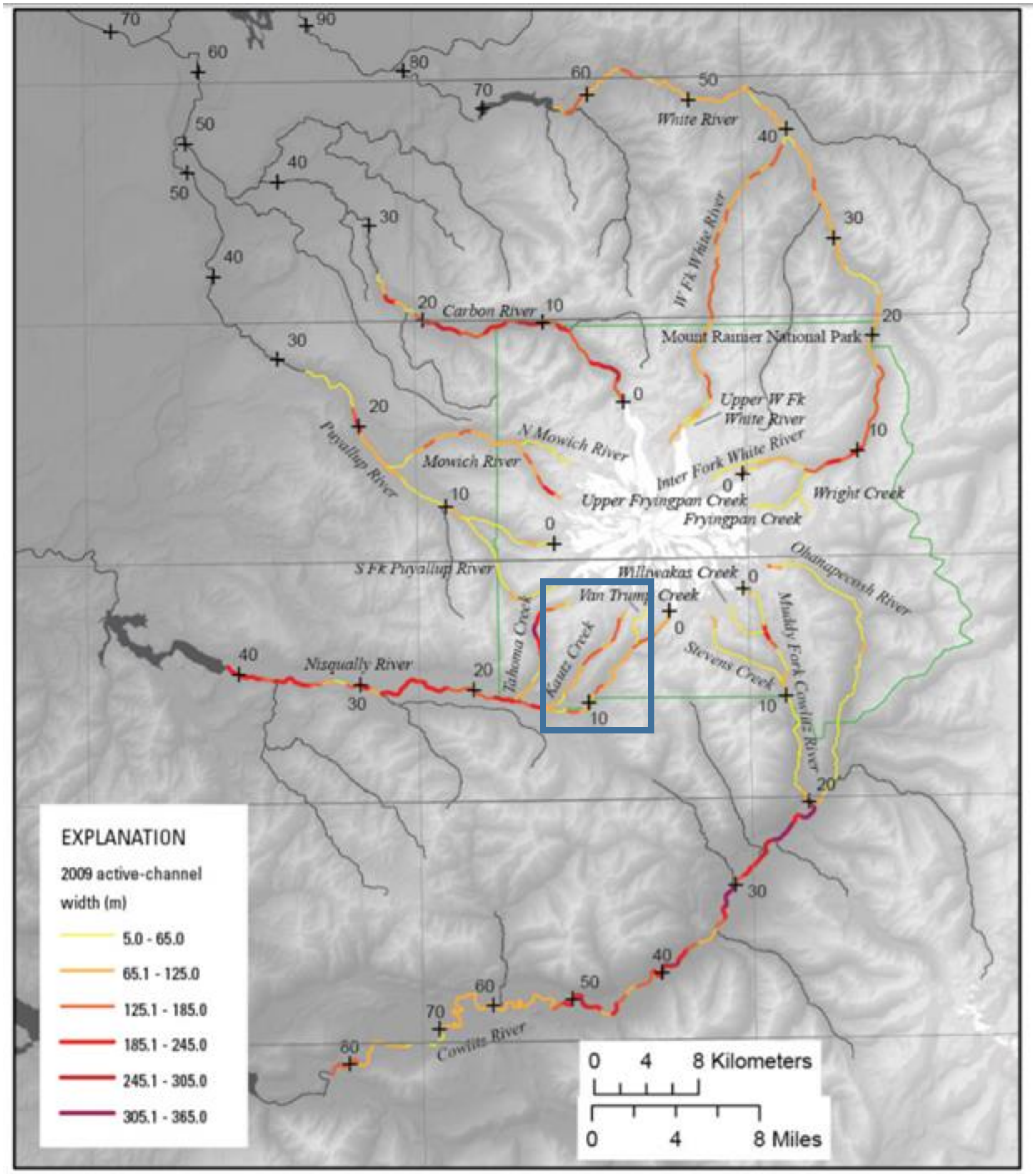


Figure 6a. The map shows active-channel changes to its width in 2009, the Kautz Creek is highlighted in a blue box (Czuba et al, 2012).

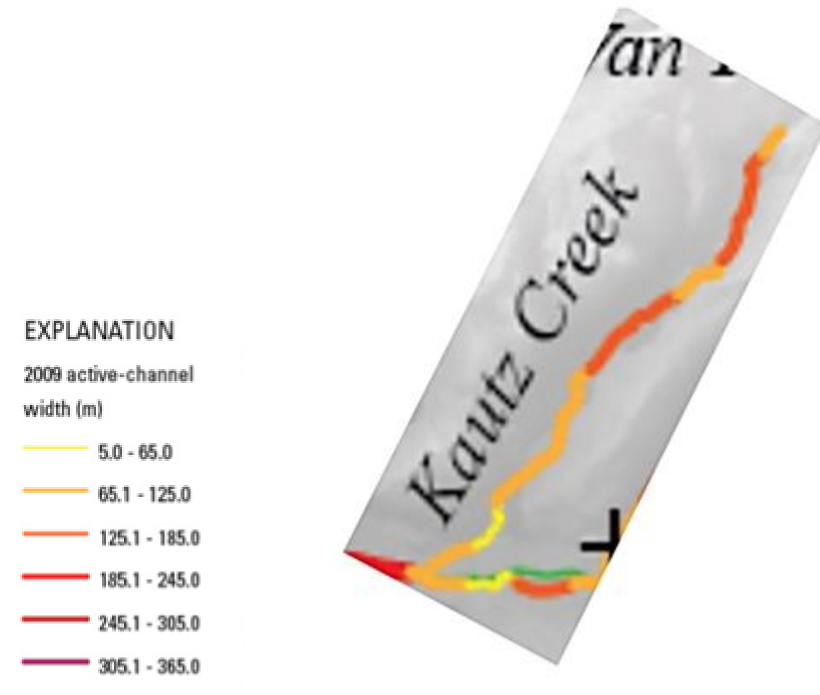


Figure 6b. (Bottom) A close-up view of the Kautz Creek area shown in the blue boxed portion of Figure 6a. The legend indicates that the upper half of the creek fluctuates between 65 to 185 meters of active channel width variation (Czuba et al, 2012).

3. Unstable Slopes

These summer debris flows occur from increased melting of the glaciers and increases the probability of glacial outburst floods that can occur from hot and dry weather (Czuba et al, 2012; Vallence et al, 2003). As snow and ice melt, water can get trapped on or underneath glaciers. This increased melting coupled with tectonic activity from the volcano can trigger this water to flow down the stream channels on the slope. The water in a glacial outburst event is fast and voluminous, so it is capable of picking up sediment, rocks, trees, and other debris along its way as it flows down the mountain. These debris flows have happened substantially on the channels of the southern slope of Mt Rainier because of the increased melting of the glaciers that source the creeks, including Kautz Creek.

The most recent summer debris flow on the Kautz Creek happened on August 14 and 15, 2001. The summer of 2001 was very hot and dry, with little precipitation during the summer months on Mt Rainier. The meltwater from the Kautz Glacier diverted into the Van Trump drainage basin, a subset of the Kautz Creek (Vallance et al, 2003). The water diversion triggered several debris flows accumulation in over 2.5 million cubic meters of debris and displaced earth (Vallance et al, 2003). While summer debris flows can be deadly and unexpected, they can also occur during the wetter winter months in higher abundance.

Torrential rain events are responsible for a majority of the winter debris flows on Mt Rainier. The influx of excess water can loosen sediment and soil on the slope and debris flows can occur. The most intense debris flow ever recorded on Mt Rainier occurred in the Kautz Creek. The mountain experienced a period of heavy rain from October 1 until October 3, 1947 (Vallance et al, 2003). It is unclear whether this rain storm originated from an ENSO or an AR event since weather record keeping was not advanced back then. The influx of precipitation triggered four debris flows over a period of twelve-hours in the Kautz Creek channel on October 3 (Vallance et al, 2003). According to Valance et al (2003) and Czuba et al (2012), the total accumulation from the debris flows in 1947 amounted to approximately 38 to 40 million cubic meters of displaced earth. The creek was in a state of recovery after this event for more than forty-years after this event occurred before it was degraded by increased aggradation.

B. Wetter Winter Months

A majority of the precipitation for the PNW occurs during the winter months. The region is accustomed to rain and snowfall during the winter but in recent decades winter storms have gotten more intense and are occurring more frequently (Warner et al, 2015). The weather of the Pacific Northwest is strongly influenced by the interactions of the convection currents and sea-surface temperatures of the Pacific Ocean, and the atmosphere. These interactions can cause a multitude of different weather conditions and storms in the PNW. Over the last century, increased carbon dioxide emissions into the atmosphere have raised temperatures while also altering weather patterns. To put it simply, hotter air and ocean temperatures impacts weather systems by evaporating massive amounts of water vapor into the atmosphere. This water vapor condenses when the air masses are lifted to higher elevations and cooled around the Cascades mountains, including around Mt Rainier. Cooler air leads to condensation of the water vapor, into rain and snow precipitation.

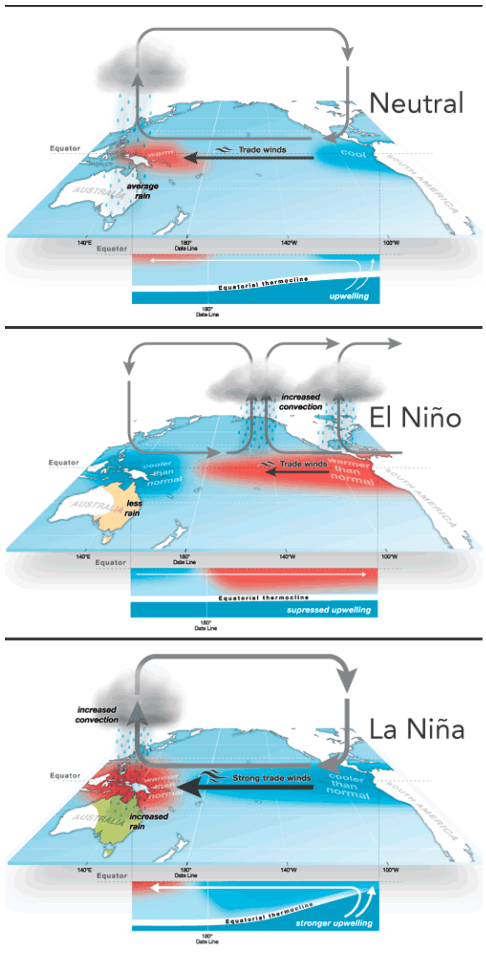


Figure 7. Models of ENSO and neutral weather patterns over the Pacific Ocean. The El Nino is expressed in the PNW as a period of warmer and wetter conditions while the La Nina is generally colder (Commonwealth of Australia, Bureau of Meteorology, 2017).

1. El Nino-Southern Oscillation in the PNW

The El Nino-Southern Oscillation (ENSO) is a series of complex weather patterns coming from variations in ocean and atmospheric temperatures (Figure 7). They are recurring climate patterns across the tropical Pacific that include both the warming and cooling seasons named "El Nino" and "La Nina" (NOAA, Climate.gov, 2017). The weather patterns occur every two to seven years and help to shape and influence global weather. However, the increasing warming of the atmosphere and ocean waters has altered these weather patterns, turning seasonal oscillations into extreme storm events. In recent decades, the warming conditions in the cycle led to large shifts in the weather in places all over the Pacific. The shifts in the temperature and water vapor gradients made places that normally would experience seasonally cold and dry conditions during ENSO events, instead to experience intense rainfall and flooding (Cai et al, 2014). Wenju Cai, a climate modeler for Australia's Commonwealth Scientific and Industrial Research Organization, used twenty climate models to simulate ocean temperatures and rainfall in the Pacific with and without changes in greenhouse gases (Khan, 2014). The last few ENSO events to hit the PNW (1982/83, 1997/98, and 2015/16) were classified as very strong and were characterized by exceptional warming and high precipitation in the winter months due to greenhouse gas emissions annually (Cai et al, 2014). Cai and others (2014) conclude that these extreme ENSO events are likely to occur twice as frequently in the future.

The two previous ENSO events that impacted the PNW that were classified as extreme were in 1982/83 and 1997/98. The ENSO events caused major weather changes across the globe by bringing heavy rains to regions that were accustomed to dry conditions during ENSO and vice versa (Khan, 2014). The 2015/16 ENSO event was on par with these previous extreme events by measuring as a very strong El Nino (Figure 16) that brought very heavy rainfall and warmer temperatures to the PNW region (Figure 8). Climatologists theorize that the likelihood of these super ENSO events will double from one every twenty years in the previous 20th century to one every ten years in the 21st century (Cai et al, 2014; Khan, 2014).

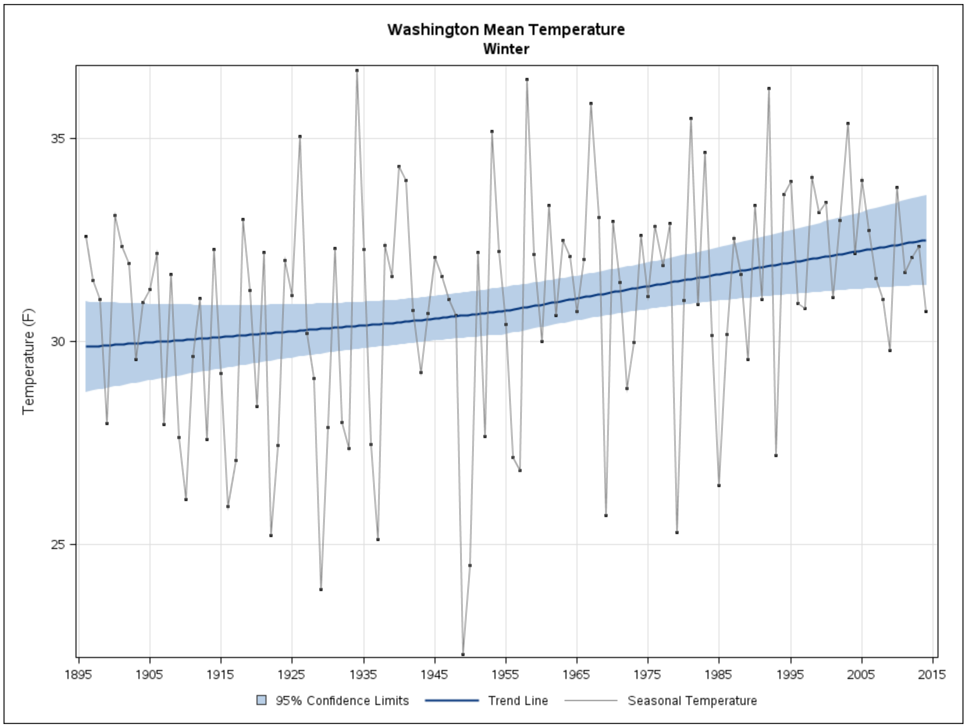


Figure 8. A time series showing the warming of the mean temperatures of the PNW during the winter months (NOAA, National Data Climate Center 2016).

However, Cai and others (2014) study has received much dispute from a number of scientists in recent years. Kevin Trenberth, a senior scientist for the National Center for Atmospheric Research, argues that some of the models used in the study overestimate the past number of ENSO events by a wide margin and do a poor job of representing them, their impacts, and other natural climate patterns that might influence the events (Khan, 2014). He continues that, "this seriously undermines the confidence that the models do an adequate job in ENSO (El Nino-Southern Oscillation) simulations and so why should we trust their future projections?"(Khan, 2014). Another scientist, Lisa Goddard, director of the International Research Institute for Climate and Society provided a similar assessment of some of the models used in Cai and others (2014) study (Khan, 2014). However, she confirms that the methodology in the study was sound and if the results are accurate they could provide helpful information for scientists making forecasts around the world and government officials who rely on them (Khan, 2014).

Goddard later states,

[“Since the majority of skill in seasonal forecasts is realized during El Nino events (and predictions become more skillful over more of the world's land areas), we would be able to prepare much better for the impacts of these events.”

“Adverse and costly climate happens in all years. We are just better able to predict that in years with strong El Nino and La Nina events."(Khan, 2014)]

If no consensus can be reached on whether Cai and others (2014) study was altogether precise or not, at least scientists can agree that this study provides a good start toward modeling these climate behaviors around the world.

ENSO activity at the equator influences the winter climate in the PNW. El Nino, the warmer phase of ENSO has been under particular scrutiny by climatologists in the region. According to Kathie Dello, the Deputy Director of Oregon's state climate office, the El Nino years tend to produce warmer than average temperatures with lower than average precipitation in the PNW. However, the 2015/16 ENSO along with the 1982/83 and 1997/98 events stand out because of their warmer than normal temperatures and higher than normal precipitation (Dello, 2015). The 2015/16 ENSO year has set a record high in sea-surface temperatures (Figure 10) in the Nino3.4 region (Figure 9), where these events are measured in the Pacific (Dello, 2015; Halpert, 2016).

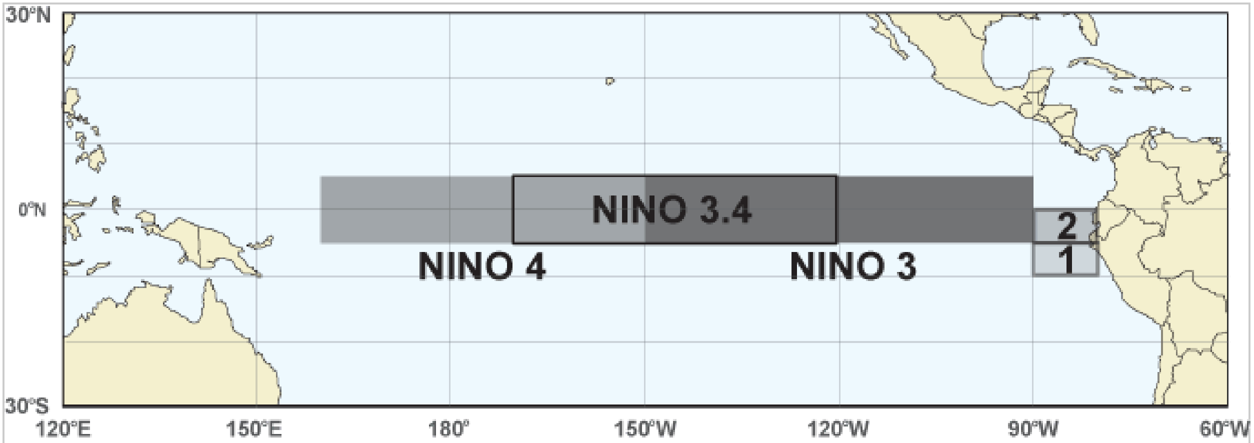


Figure 9. The map depicts the Nino3.4 region spanning from 5°N to 5°S, from 170°W to 120°W. *This region has large variability on El Niño time scales, and is close to the region where changes in local sea-surface temperature are important for shifting the large region of rainfall typically located in the far western Pacific (COA Bureau of Meteorology, 2017; Weatherzone, 2017).*

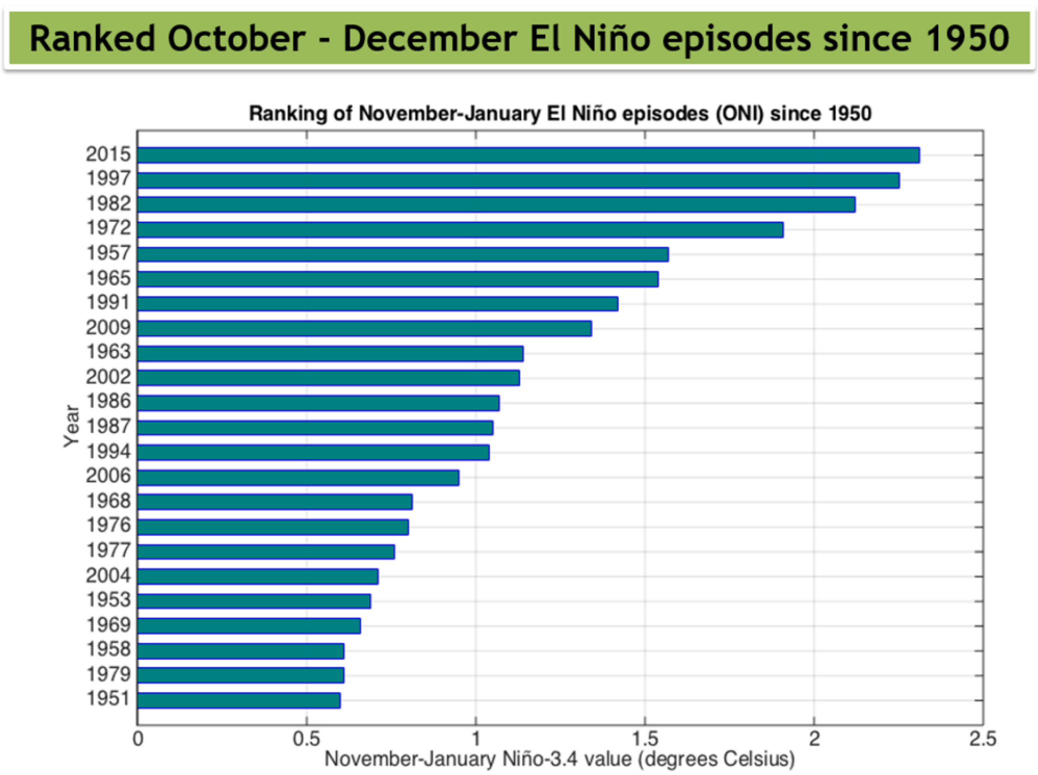


Figure 10. Sea-surface temperatures of El Nino events along the Nino3.4 ranked from warmest to coolest from 1950-2015 (Halpert, 2016).

However, not all El Nino events are alike and it is difficult to compare them all (Dello, 2015). Dello does state that the region has experienced warming over the last two decades and that climatologists can agree that winters and early springs will be warmer than normal in the PNW. But whether higher precipitation will be a big factor is still up in the air for future predictions of El NIno events (Dello, 2015).

2. Atmospheric Rivers in the PNW

The other storm pattern that is responsible for heavy precipitation events in the PNW are Atmospheric Rivers (AR). ARs can be formed and sustained from within ENSO and other oscillation events in the Pacific Ocean. The weather oscillations play a role in dynamics in modulating ARs prior to landfall by supplying high amounts of water vapor into the lower troposphere (Payne and Magnusdottir, 2014). A majority of ARs hit the west coast in the winter months and contribute an estimated 30-50% of the wet season precipitation (Payne and Magnusdottir, 2014); (Gimeno et al, 2014).

Geography is not the only factor in making the west coast vulnerable to ARs, the landscape also affects the susceptibility of many west coast lands to flooding. The west coast is characterized by flat coastal terrain that is hemmed in by large mountain ranges to the east, like the Cascades. This terrain essentially controls where the precipitation falls (Figure 11). When a vapor-rich AR encounters mountainous terrain, the AR is then forced upwards, at which point the orographic enhancement of rainfall can occur producing precipitation events and catastrophic flooding (Gimeno et al, 2014). This occurrence is very apparent in Washington State; where the western half of the state receives more precipitation compared to the eastern half because the Cascade mountains divide the state.

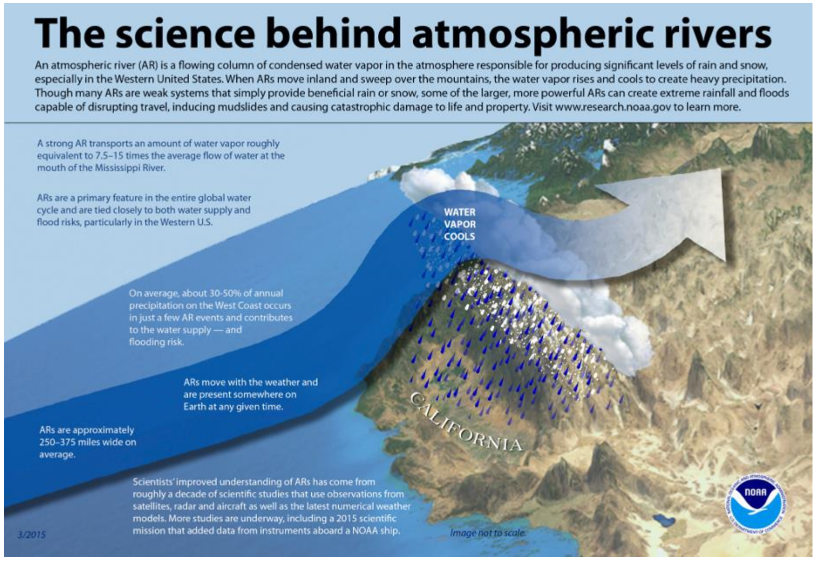


Figure 11. Information of how atmospheric rivers impacting the west coast (NOAA, Earth Systems Research Laboratory, 2017).

a. November, 2006 Atmospheric River

On November 6 and 7, 2006, a large AR hit Washington from the southwest (Figure 12)(Neiman et al, 2008). This AR had a significant impact on Mt. Rainier and its mountain streams. Over the 42-hour period, this AR dropped approximately 45 cm (nearly 18 inches) of rain (Legg et al, 2014; Neiman et al, 2008).

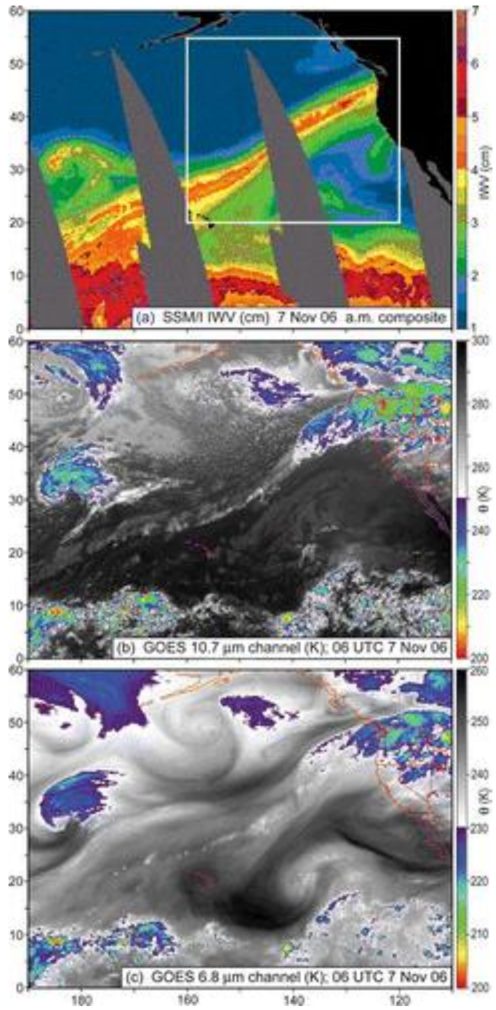


Figure 12. Satellite images of the November, 2006 AR (Neiman et al, 2008). The top picture is a composite of the integrated total column of water vapor (IWV) stretching across the Pacific and impacting Washington. The middle picture is a weather satellite image showing infrared of cloud temperatures. The bottom picture is an infrared image of the water vapor in the AR.

The record-setting precipitation was so great that gaging stations along the Nisqually and Carbon Rivers “recorded greater than 100-year discharges and floods of record” (Legg et al, 2014). The heavy rainstorm triggered more than six debris flows along the mountain, three of which were in the Kautz sub drainage basin and the creek itself (Copeland, 2009; Legg et al, 2014). The resulting flooding and debris flows eroded fluvial channels and important park infrastructure. The Kautz Creek channel overflowed its banks and split into two flows a mile up the channel before it reached the main roadway (Figures 13 and 14) (NPS, 2006).

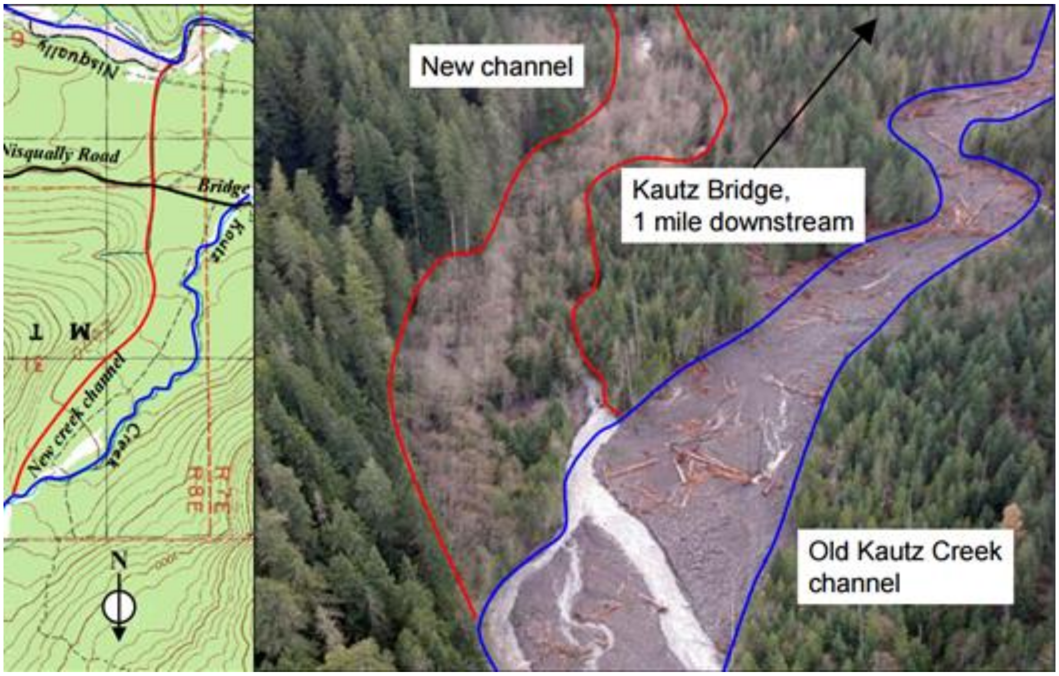


Figure 13. A new channel was formed on the Kautz Creek from the increased precipitation a mile upstream from the roadway (NPS, 2006)

Figure 14. The Kautz Creek flooding the main roadway east of the bridge. (NPS, 2006).

This new split channel damaged the helibase and research facility roads near the edge of the Nisqually River. The AR impacts resulted in over $50 million in damage to park and regional infrastructure. With the splitting of the Kautz Creek, two new culverts had to be put in to accommodate the new channel (Figure 15a) and directed the flow away from the research facilities and roads. Reinforcements were also made along the main channel, particularly under the main road bridge. The heavy rain and debris flows from the November 2006 AR altered the landscape on and around the Kautz Creek. These events increased iron-rich sedimentation to aggregate and wash downstream; causing the banks and waters to appear red in coloration (Figure 15b) (NPS, 2006). The split channel has redirected a majority of the water to flow away from the active channel and emptying it into the Nisqually River.

Figure 15a (top) and 15b (bottom). The top picture shows the Kautz split channel flow under the main roadway through two newly built culverts. The bottom picture is a view of the iron oxidation of the main channel of the Kautz from the road bridge (Photos by Melanie Graeff, April 2017).

III. Methods

A. Obtaining LiDAR and GIS data

A Geographic Information System (GIS) provides good visual tools to present the changes in Kautz Creek caused by recent ENSO and AR events. In a previous paper, *Using repeat lidar to estimate sediment transport in a steep stream* by Scott Anderson, the author studied sediment change on the Tahoma Creek on Mt. Rainier from using LiDAR data. The thesis author, Scott Anderson, attended the University of Colorado and was writing his thesis on this creek. His paper showed that LiDAR data could provide the highest precision of detail for elevation change and sediment patterns for my research on the Kautz Creek. I contacted Scott and discussed his methods and experience using LiDAR and GIS in his study of the nearby Tahoma Creek.

I examined the other creeks of Mt Rainier and decided on mapping the Kautz Creek. I chose that creek because 1) I could not find much data or many publications on this particular creek and 2) Kautz Creek is located in between the Tahoma Creek and the Nisqually River, both of which have been the subject of many publications and research projects. After reading some of these publications, I noticed that climate change never really came up in relation to the sediment transport and changing of elevation. In further discussion with Scott Anderson he mentioned that he thought of mentioning climate change but decided against it because his primary focus for his thesis was mapping the sediment with the LiDAR rather than the causes of increased sediment. This presented an opportunity to map the Kautz Creek from a hypothesis that climate change was changing elevation and increasing sediment loss on the steep mountain channel. I contacted Paul Kennard and Scott Beason, both geologists and geographers at the National Park Service at Mt. Rainier. They provided me with two LiDAR data sets of the area, one from 2008 and another from 2012. After obtaining the LiDAR sets I found more GIS data of Mt. Rainier from public sources including maps of streams and glacier boundaries.

B. Analyzing Climate for Summer and Winter Months in PNW

If a pattern of warming and increased precipitation could be found then that would need to be observed in reference to several decades of prior climate data. Recent climate change could then be shown as a contrast to the baseline climate records dating back to into the 1950’s. The observations of glacier recession on Mt. Rainier provided a basis to assess the melting of glaciers and associated release of sediment into the glacial streams. Glacial extents have been compiled into GIS layers that can illustrate a time series of glacial recession. Separate from analyzing the climate patterns, it is possible to analyze the patterns of seasonal storms that hit the region using records of El Nino Southern Oscillation (ENSO) and Atmospheric River (AR) events. These storms are also influenced by air and ocean temperatures and also produce high precipitation.

C. Elevation Differences from 2008 and 2012 LiDAR layers

The LiDAR layers provided for 2008 and 2012 covered too large an area and had to be cut down to just the borders of the Kautz Creek. To achieve this, a 500-meter buffer was made alongside the banks of the creek. Then that buffer layer was used as a guide in order to clip the raster LiDAR layers by the dimensions of that buffer. Once those clips were made on both layers, then a comparison could be made in elevation differences. ArcGIS Desktop provides a tool called "minus" which allows the user to subtract the elevation points from the 2008 layer from the 2012 layer. The resulting map showed the differences, either loss or gain, of sediment on the new layers in that time span from 2008 to 2012.

D. Drawing New Glacial Extent for 2015

The regression of the Kautz glacier on Mt Rainier is an indicator of increased melting and thus increased water released into the Kautz Creek channels, which are fed by the glacier. An understanding of the increases in water volume can support the estimates of sediment loading the creek is experiencing along with geomorphic changes of the channel. The most recent available image of the visible Kautz glacier on Mt Rainier was from July, 2015 in the National Agriculture Imagery Program (NAIP) images. NAIP images are available to the public online and allowed me to draw a polygon over the borders of the Kautz, Pyramid, and Van Trump glaciers. I then fit the polygon I drew with the previous glacial extents used by Copeland (2009) in her thesis that included the glacier GIS layers from Nylen (1994). The glacial extent layers already on that map dated from 1913, 1971, and 2008. The results of my compilation of glacial extents are shown in Figure 19.

E. Channel Width Measurements from Google Earth

To measure the channel widths of the Kautz Creek, I looked to Google Earth and found a time series of aerial photographs. Since the channel width had been studied in depth from 1960-1994 and from 1994-2008, I decided to only measure the channel from photographs dating from 2008 to present. There were three photographs available for me to measure the channel width dated 2009, 2012, and 2014. I plotted forty points total on the creek that were about 200-250 meters apart from each other and I did my best to measure the width on each point on the aerial photographs. Some small inaccuracies may result since these are aerial photographs on Google Earth without specific documentation of the methods used to rectify the images onto the mountainous surface.

After obtaining my forty points from each of the three aerial photographs, I made pictograms to display the various channel widths in a more visual format rather than just a table or graph display. I made scales using lines to represent channel widths on the various points on the creek. While measuring on or near the same points on the creek, any differences (widening or narrowing of the channel) should be documented by reference to the line measurements.

F. Graphing Precipitation and Average Temperature Data from Longmire, Washington

The Western Regional Climate Center has a historical weather record for Longmire, Washington, which is only 2 kilometers away from the Kautz Creek. Since the channel width had been studied in depth from 1960-1994 and 1994-2008, I decided to stick with those time scales and also look for trends in the precipitation and temperature data. I measured the precipitation and temperatures from 1960-1994, 1994-2008, and 2008-present for the winter months (October-March) and the warmer months (April-September) for each of the time periods. The weather data shows “spikes” which may be attributed to an unusual rain event or temperature event. The graphic in Figure 16 labels ENSO and AR events that are mentioned in the literature review (above).

G. Measuring the Kautz Creek main and split channels

During a visit to the Kautz Creek in early April I measured channel widths that were accessible without risk of physical danger. Using a viewfinder and measuring tape it was possible to take some channel width measurements from direct measure. Photos of the Kautz Creek split channel that formed from the November, 2006 AR storm show the main channel from the road bridge as evidence of significant channel changes.

IV. Results and Discussion

A. Precipitation and Temperatures

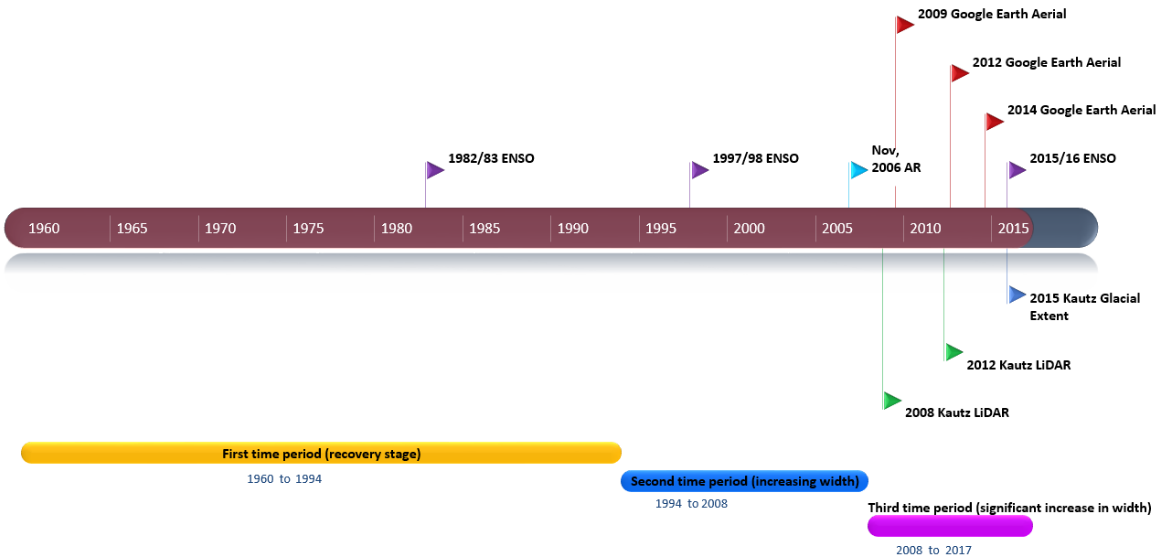


Figure 16a. This timeline combines the time periods of study, significant precipitation events, and compiled data and maps of the Kautz Creek for this thesis.

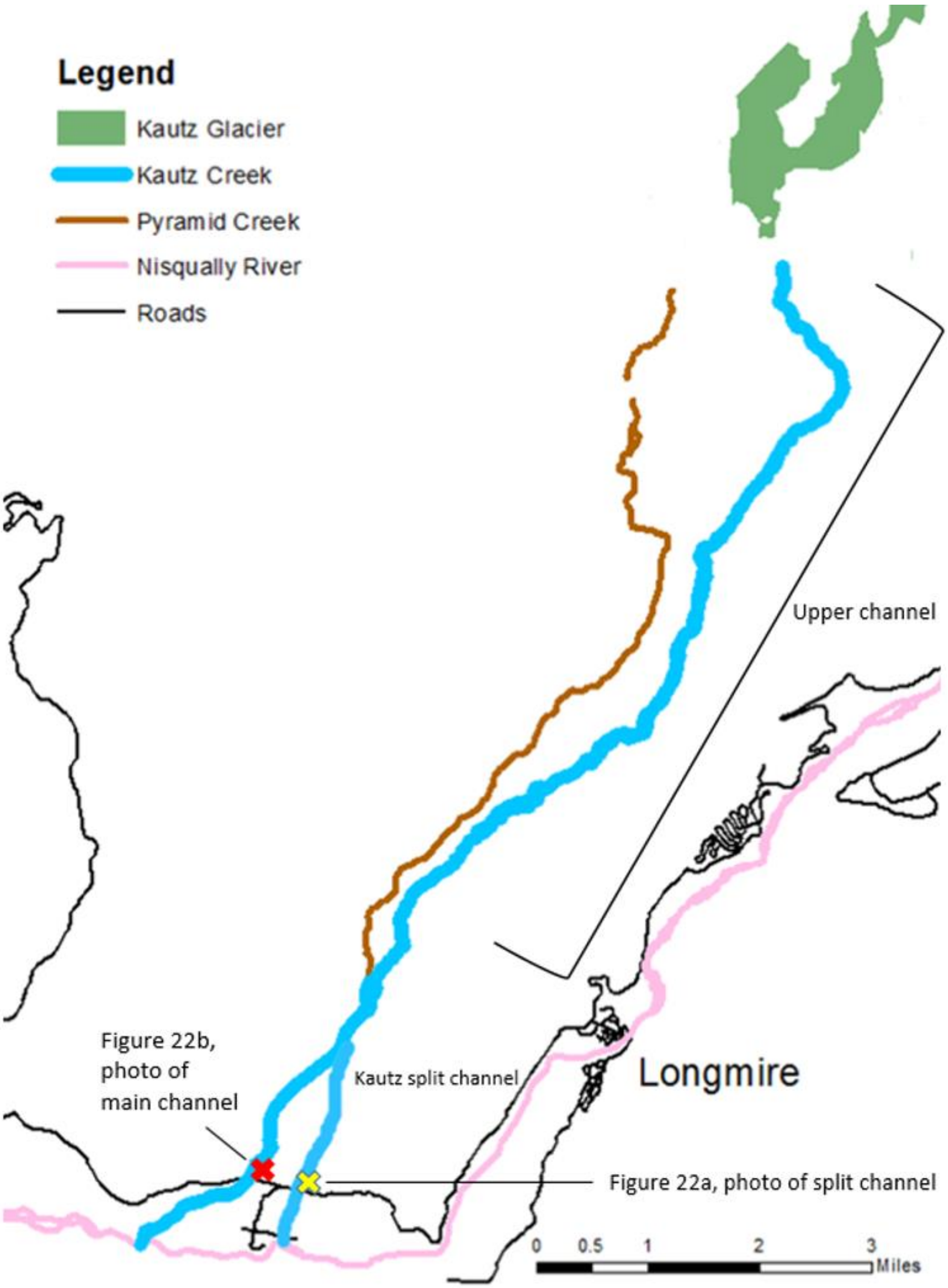


Figure 16b. A sketch map representation of the study area: Kautz Creek, the Kautz glacier, and the surrounding tributaries (Map Credits: Melanie Graeff, 2017; ESRI, 2017; NPS, 2016).

Longmire, Washington sits on Mt Rainier and is the closest weather gaging station to the Kautz Creek, about 2 kilometers away (WRCC, 2017). The temperature records collected at that station are shown in Figures 24a-h and precipitation records in Figures 25a-h. These figures are a graphic summary of the records of weather conditions nearest to the Kautz Creek area. As discussed in the Literature Review section, Czuba et al 2012 researched the Kautz Creek channel and divided the research into two time periods: 1960-1994 and 1994-2008. During the first time period, 1960-1994, the Kautz Creek is considered to be in a recovery stage following the 1947 debris flow, characterized by the shrinking of the channel width and increased vegetation growth (Czuba et al, 2012). During the second time period, 1994-2008, the Kautz Creek channel is widening again (Czuba et al, 2012). Climate data from the Longmire station can help establish that the climate, specifically temperatures and precipitation, was a significant factor in the altering of the Kautz Creek shape and vegetation growth during that period.

The temperatures and precipitation from 1960-1994 showed little to no variability during the winter and warmer months (Figures 24c-d and Figures 25c-d). During this time period, little to no changes were recorded on the Kautz Creek drainage morphology. From 1994-2008, while temperatures remained steady, large instances of precipitation are seen because of the strong El Nino in 1997/98 and the intense AR on Mt. Rainier in November, 2006 (Figure 25e).

This thesis adds a third time period, 2008-2017, to distinguish whether significant changes occurred after Czuba's original findings ended in 2008 (Figure 17). During the last time period, 2008-2017, climate data shows significant changes in temperatures and precipitation patterns, as compared to the previous years. Winter precipitation trend increased from 50 to 65 inches (Figure 25g), while summer precipitation got dryer by decreasing from 26 to 19 inches (Figure 25h). The temperature trend during the summer months in this time also increased from

51.1 to 56 degrees F. According to ENSO timeline (Figure 18), from 2008 the region experienced a constant variation of El Nino and La Nina events year after year. This explains the large increase of precipitation on the trend line. From 2014 to 2015, the region experienced unusually warm and dry conditions leading up to the strong 2015/16 El Nino that winter. These numbers show that the last nine years the region has shown great variations that have altered the climate around the Kautz Creek. The following sections show how precipitation and temperature alter the glacial ice supply and the overall geomorphology of the Kautz Creek.

Timeframe	Stage	Temperature Patterns	Winter Precipitation Patterns	Summer Precipitation Patterns
1960-1994	In recovery from 1947 debris flow. Shrinking of active channel width, increased vegetation growth.	No significant changes	Trend shows a decrease from 65 to 52 inches.	Trend holds steady at 22 inches.
1994-2008	Widening of active channel width in upper half of creek.	Increased variability.	Trend shows decrease from 71 to 55 inches, higher variability due to high ENSO and AR activity.	Trend shows decrease from 21 to 18 inches.
2008-2017	Continued widening and increased sedimentation in upper channel.	Significant increases.	Trend shows increase from 50 to 65 inches due to high ENSO and AR activity.	Trend shows decrease from 26 to 19 inches.

Figure 17. A table summarizing the temperature and precipitation patterns of the study area. Over time the trends show an increase in annual temperatures, an increase in winter

precipitation perpetuated by ENSO and AR events, and a decrease in summer precipitation (Czuba, 2012; WRCC, 2017).

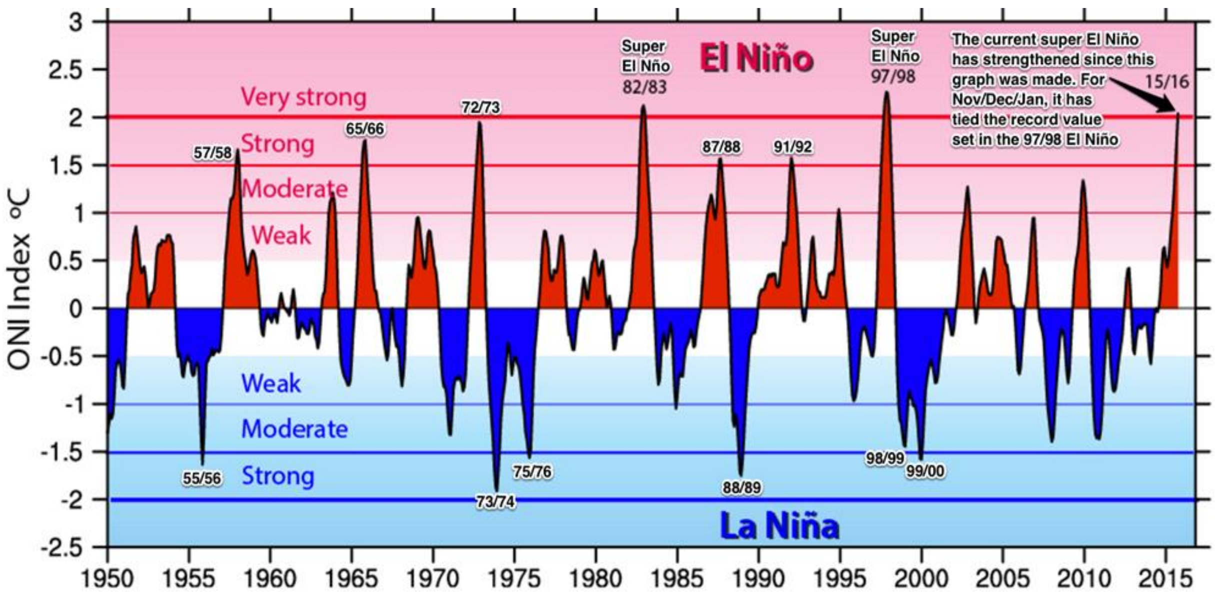


Figure 18. This graph shows the Oceanic Nino Index (ONI) which is used to monitor ENSO. The ONI is calculated by averaging sea surface temperature anomalies in the Nino-3.4 region of the Pacific Ocean (Trenberth, 2014; Yulsman, 2016; NOAA, 2017).

B. Glacial Retreat

Imagery provided by the National Agriculture Imagery Program (NAIP) helps to document the recent glacier extents and the recession of the Kautz Glacier. Added to the summary provided by Czuba, the pattern of rapid recession is continuing the trend shown from 1913 to 2015 (Figure 19).

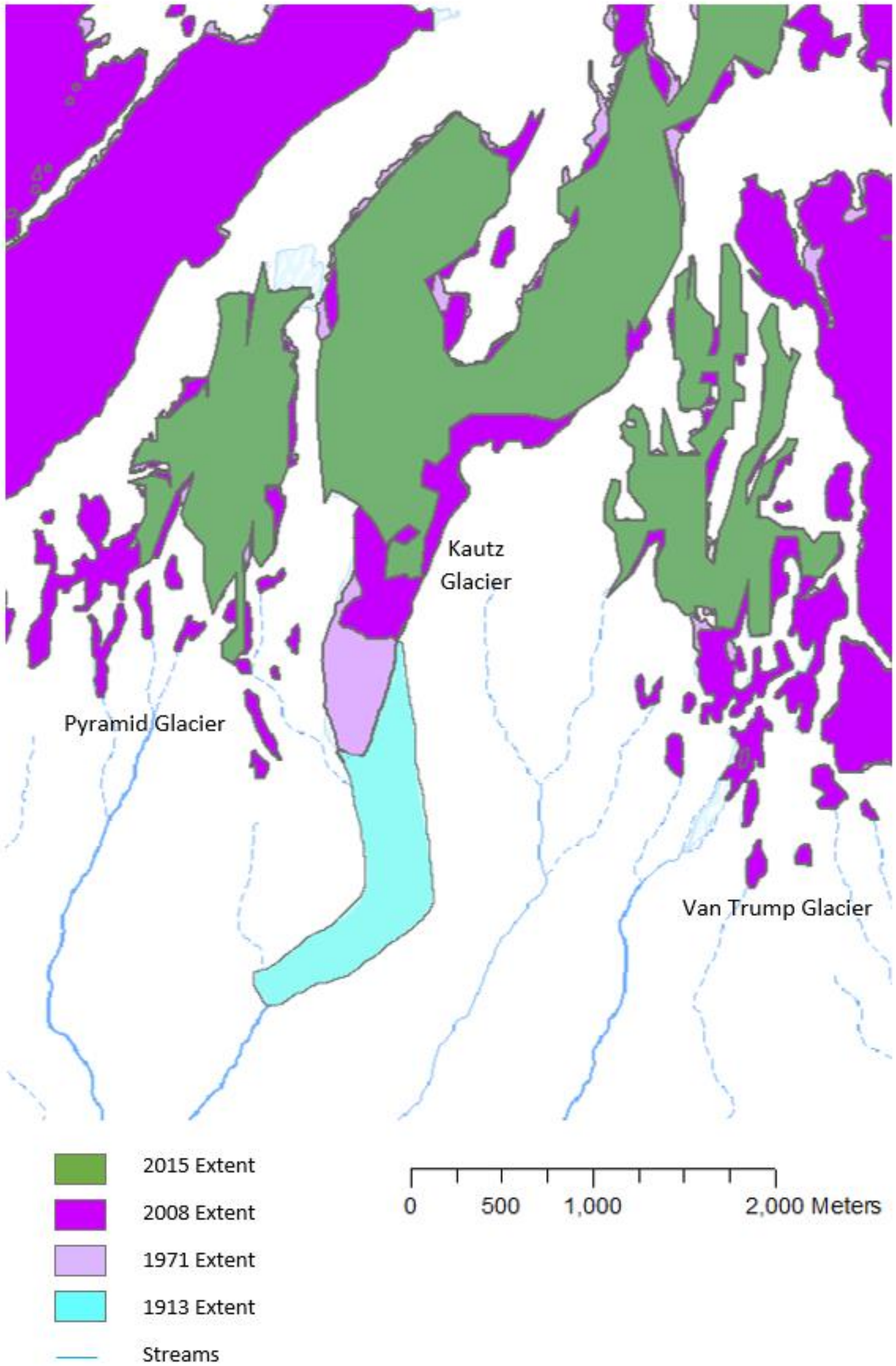


Figure 19. Focusing on the Kautz Glacier in the middle, the map shows the receding glacial extents from 1913 to 2015. The green polygon on the map below represents the extent of the Kautz glacier (middle) in July, 2015. This layer is then superimposed onto the map of previous glacier extents from 1913, 1971, and 2008 (Map credits: ESRI, 2017; NPS, 2016).

The summer of 2015 was a particularly warm and dry summer with only 13.35 inches of rain total from April to September with average temperatures reaching 64.82 degrees F according to the Longmire weather data (Figures 24h and 25h). In Section 2 of the Literature Review, Copeland (2009) and Nylen (2004) had compiled GIS data to show previous glacial extents. Their findings showed that the Kautz Glacier had retreated at least 500 meters between 1971 and 2008. In my findings through adding their layers onto the newer 2015 glacial extent, the Kautz Glacier has retreated at least another 350 meters from 2008 to 2015. This shows that from lack of precipitation to replenish the glacier coupled with warmer temperatures significantly shrank the Kautz glacier during this seven-year time span.

C. Channel Width

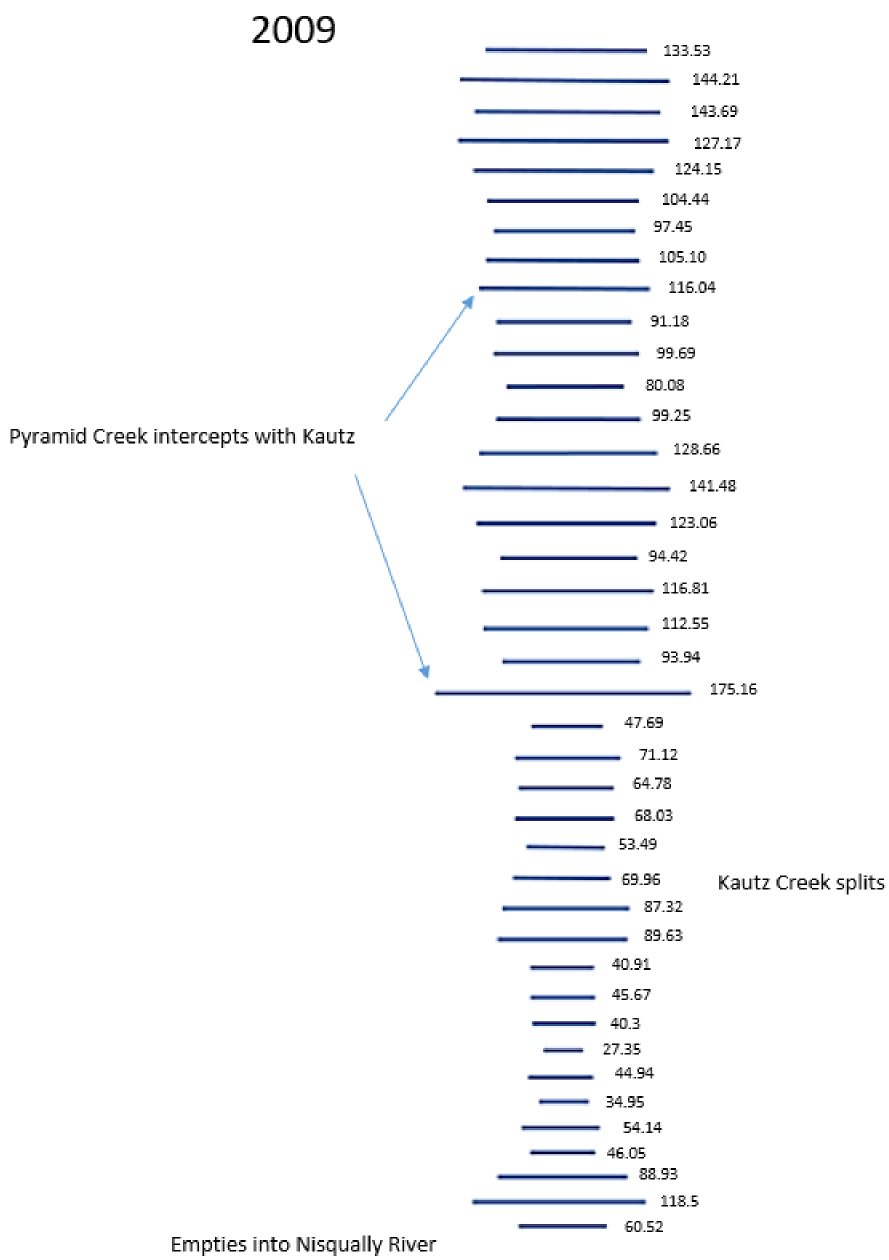
The rapid melting of the summer of 2015 released significant quantities of built up sediment into the Kautz Creek and this led to altering the channel geomorphology. Measurements of the channel width of the Kautz Creek can provide evidence of the dynamic changes that precipitation and increased glacial melt rates on the stream geomorphology.

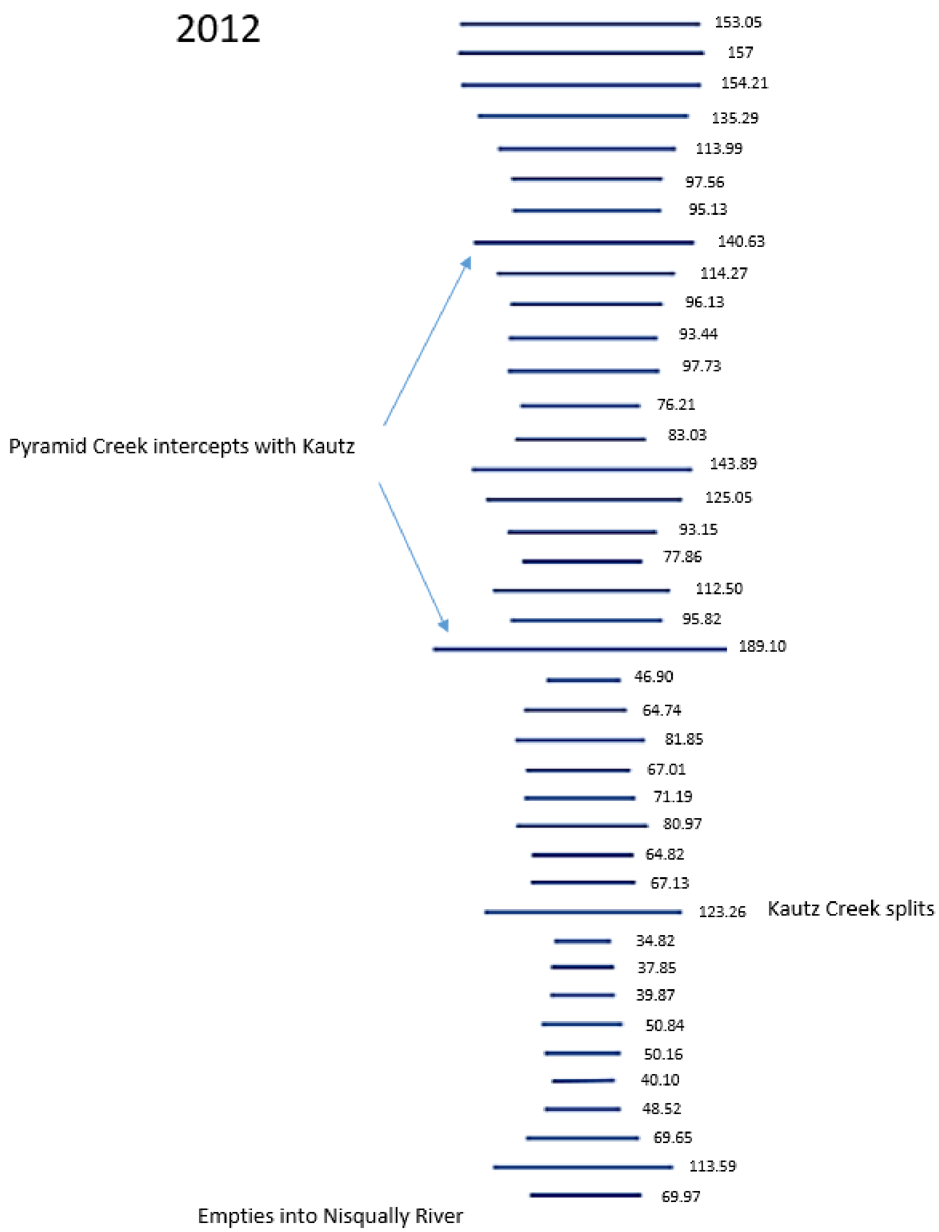
Historical aerial images are available from Google Earth for the use of the general public. Czuba et al (2012) researched and measured the active channel widths from 1960 to 2008. I measured more recent images available after 2008 to the present day to add changes to the record that Czuba established in prior work. Three images were available for this desired time period and they date from 2009, 2012, and 2014.

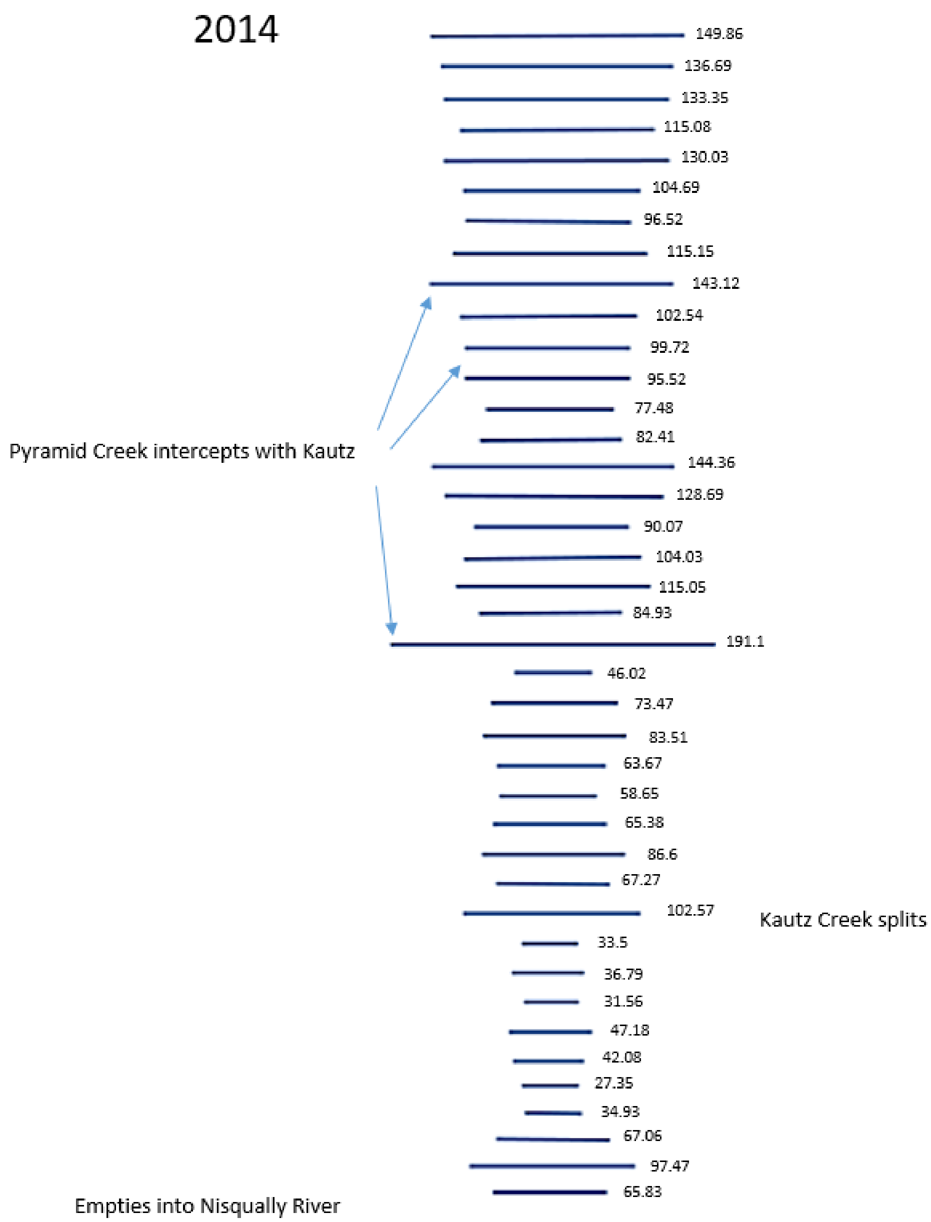
Figure 20. The 40 reference lines, sitting about 200-250 meters apart, that I measured the channel widths on each the Google Earth images from 2009, 2012, and 2014 (Google Earth, 2017).

The active channel is characterized where water is flowing and sediment is being deposited along its banks in the tributary channel. According to the map of the Kautz channel from Czuba et al, 2012, the geomorphically active sections where the stream meanders through depositing sediment, with observable effects in the upper half of the creek. The lower half of the creek is comparatively less active since there is little or no observable evidence of sediment deposition. The active channel measurements from the 2009, 2012, and 2014 aerial photographs range from 65-145 meters wide, which is generally in agreement with Czuba's reported widths in section 2a of the Literature Review.

The following pictograms provide a summary of the widths I measured from forty points on the creek spaced at about 200-250 meters apart (Figure 20). The left-right size of the lines in the following pictograms show the channel width variations from year to year (Figures 21a, 21b, 21c).




2012
153.05
157
154.21
135.29
113.99
97.56
95.13
140.63
114.27
96.13
93.44
97.73
76.21
Pyramid Creek intercepts with Kautz
83.03
143.89
125.05
93.15
77.86
112.50
95.82
189.10
46.90
64.74
81.85
67.01
71.19
80.97
64.82
67.13
123.26
Kautz Creek splits
34.82
37.85
39.87
50.84
50.16
40.10
48.52
69.65
113.59
69.97
Empties into Nisqually River



Figures 21a, 21b, and 21c. These pictograms represent the channel width measurements taken from the same locations by manual interpretation of the 2009 (21a), 2012 (21b), and 2014 (21c) aerial photographs of the Kautz Creek.

The upper half of the Kautz Creek channel becomes exceptionally wider and filled with sediment compared with the lower half of the channel. The retreating glacier had carved out a “V” shape into the gully. Once the water flows further downstream out of the steep gully, the channel becomes flatter and wider allowing for water to spill over the banks into the Pyramid Creek (and vice versa) and into the new Kautz Creek split channel.

D. Comparison of the Kautz Split to the Main Channel

Figure 16b maps out the positions of the Kautz and Pyramid Creeks, along with the new Kautz split channel. Along the main roadway, the split channel is about 300 meters away from the Kautz. Since the Kautz Creek split from the November, 2006 AR event, that channel has taken on the transport of a majority of the water and glacial melt from the main channel. Though the main channel width measures an average of about 40 meters downstream from the split, its transports little to no water since 2006 (Figure 22b). The split channel has taken on a majority of the water and glacial melt transport and measures an average of about 7 to 10 meters in width (Figure 22a). Since the transfer of water from the main to the split channel, the main channel has turned orange from iron oxidation. This oxidation occurred from the weather and exposure of iron ore and sediment deposited during the 2006 AR (NPS, 2007).

Figures 22a and 22b. The pictures show the differences in water volume and stream coloration in the new split channel (top) and the main channel (bottom). The orange staining visible in the lower image illustrates the alteration of iron oxides that were deposited in the main channel, then left dry to oxidize following the diversion of the Kautz Creek water from the main channel into the split channel during the 2006 AR event (Photo credits: Melanie Graeff, 2017).

E. 2008 and 2012 LiDAR Comparison

The map below (Figure 23) is a result of the comparison of the 2008 and 2012 LiDAR images provided by the National Park Service at Mt. Rainier. In completing the full analysis of the map, it was apparent that significant changes occurred between the 2008 and 2012 LiDAR layers. These changes support the results shown earlier in the channel width measurement analysis in Section C. The LiDAR data provides more detail along the entire channel that could be shown in the channel width measurements.

The map shows significant sediment movement along the entire length of the creek channel. The sediment losses are shown in red while the sediment gains are symbolized in gray. The upper half of the creek showed the most sediment loss, especially near the glacier terminus in the gully (Figure 23b) where the Kautz Creek begins to flow down Mt. Rainier. The gully was carved out from previous glacial extents (Figure 19) that have slowly receded over the last few decades. The sharp curve of the active channel makes the outer wall of the gully susceptible to sediment loss as the water channel turns and flows down the mountain. A few areas (shown in yellow) showed as much as 26.7 meters of sediment loss. These high loss areas are mainly in the gully near the glacier terminus. A large majority of the loss does not go beyond 15 meters of sediment loss in the upper half of the channel.

Though the sediment loss is more apparent in the upper half of the channel, the map also displays a pattern of erosion and deposition of sediment throughout the lower active channel as well. This result was expected as precipitation runoff and glacial melt will shift and carry sediment downstream leading to erosion in some areas and deposition in other areas, changing constantly over time with different river flow conditions. With the increasing release of more sediment into the creek channel due to glacial retreat, the forces of the water along with gravity will tend to funnel that sediment through the active channel. The increasing amount of sediment that does not get carried downstream will tend to be deposited in the banks of the active channel: widening the channel over time. This is the pattern previously documented in the pictograms of channel width measurements (Figures 21a, 21b, and 21c). In Figure 23c, the increased sediment has raised and widened the Kautz channel along with the neighboring Pyramid Creek channel.

The Pyramid channel intercepts the Kautz Creek at least two times and most recently a third interception has formed in between the years 2012 and 2014 according to the channel width pictograms section (Figure 21c). The Pyramid Creek interceptions are probably also responsible for the splitting of the Kautz Creek in November, 2006. The increased sedimentation raised water levels in both tributaries, causing a redirection of active channel water flow away from the main channel and into the new split (Figures 22a and 22b). It is also apparent that increased sedimentation is also occurring in the Kautz split channel. According to Figure 23c, there have been increases in sediment elevation as the active channel water flow carries sediment into the split channel.

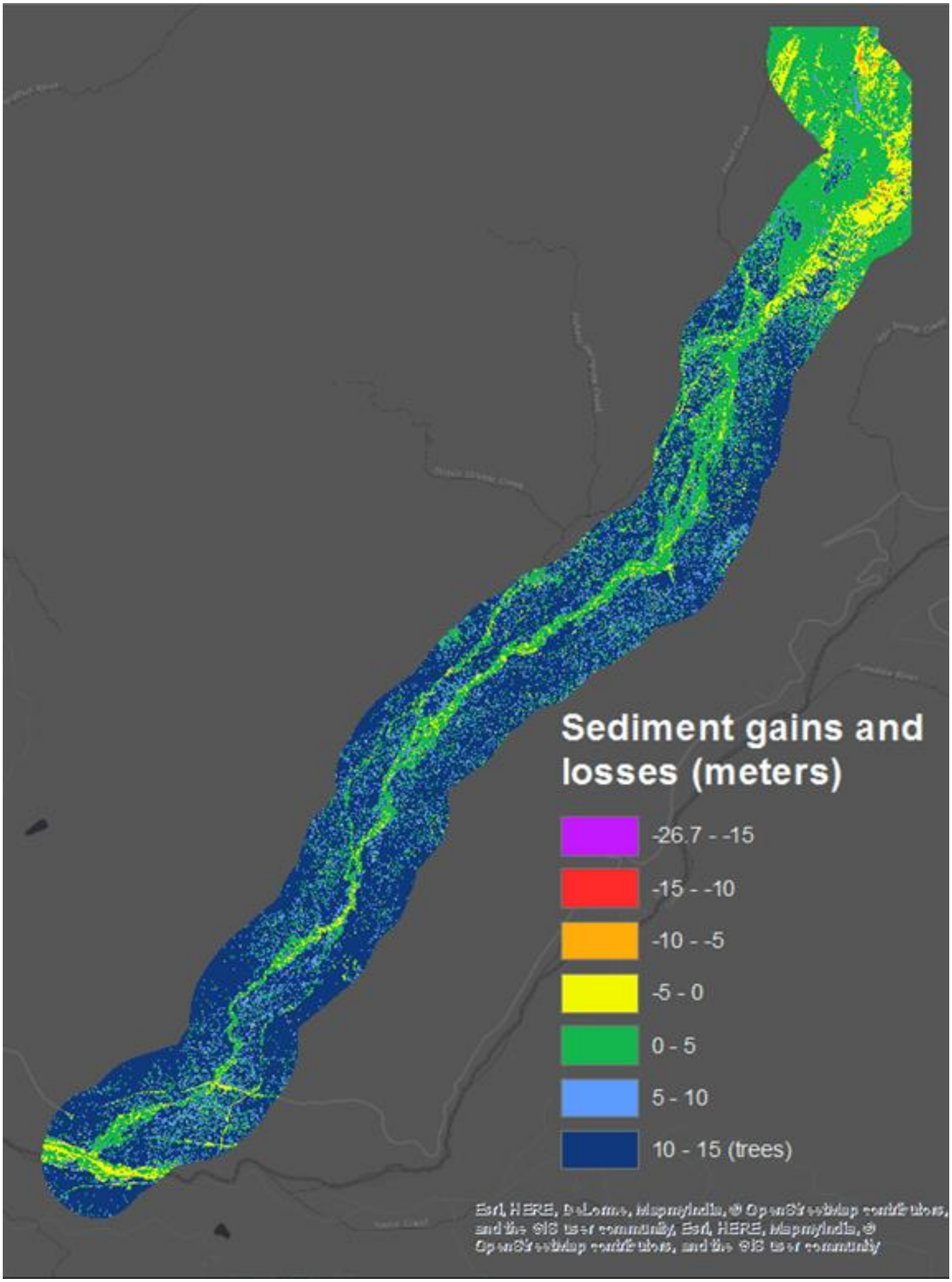

Sediment gains and losses (meters)
-26.7 - -15
-15 - -10
-10 - -5
-5 - 0
0 - 5
5 - 10
10 - 15 (trees)
Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community, Esri, HERE, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

Figure 23a. A comparison of the changes in elevation from the 2008 and 2012 LiDAR images on the Kautz Creek. The purple, red, orange, and yellow symbolize an overall loss in elevation due to sediment erosion and the green and light blue represent gain in elevation due to sediment deposition. The red boxes highlight the zoomed-in images of that map which are elaborated on in figures 23b, 23c, and 23d (Map credits: Melanie Graeff, 2017; ESRI, 2017; NPS, 2016).

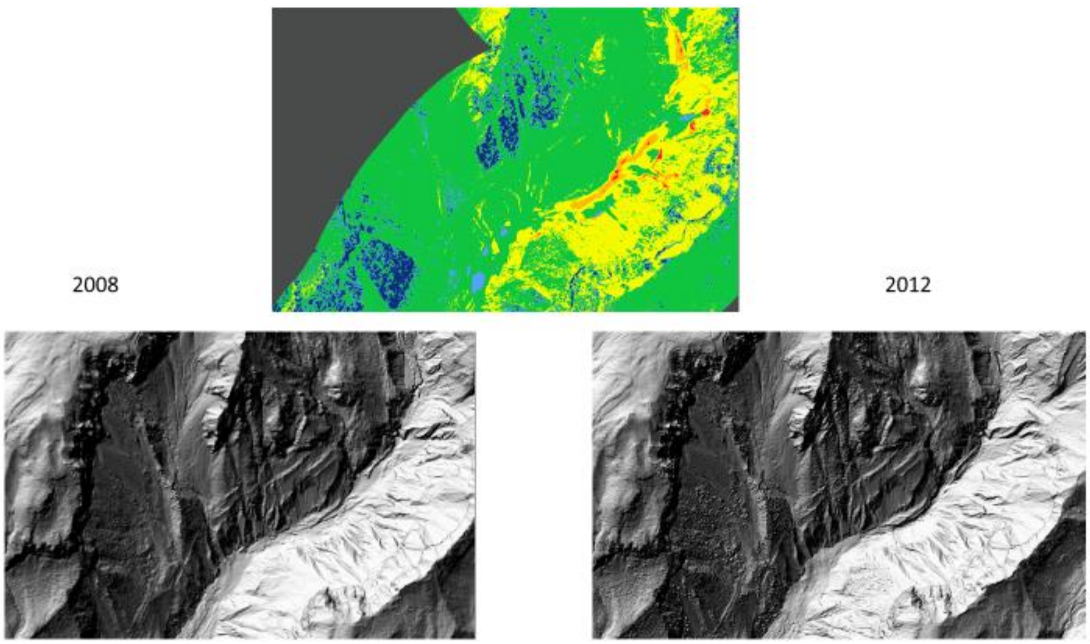


Figure 23b. A zoomed-in image of the gully on the upper region of the Kautz Creek. The colored comparison of the differences in elevation between the LiDAR images depict high levels of sediment erosion (purple, red, orange, yellow) and sediment deposition (green, light blue) in the active channel from 2008 to 2012. The increased glacial melt is releasing sediment down the active channel and is carving into the gully wall as it turns to flow down the valley (Map Credits:

Melanie Graeff, 2017; ESRI, 2017; NPS, 2016)

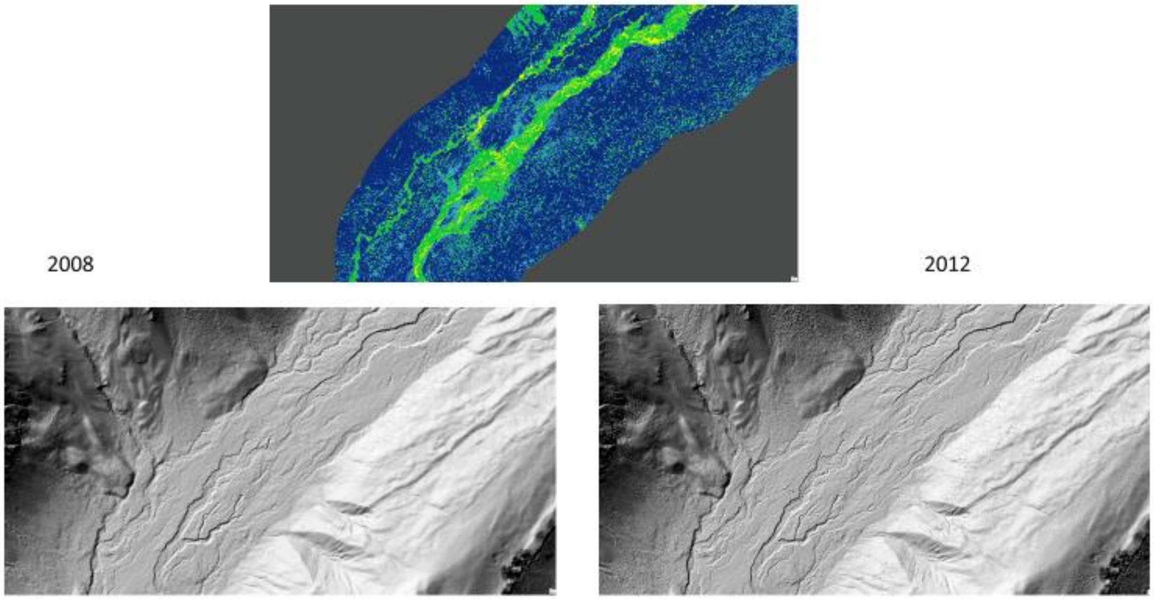


Figure 23c. A zoomed-in image of the middle region of the valley where the Pyramid Creek (sits to the northwest of the Kautz) intercepts the Kautz Creek. The colored comparison of the differences in elevation between the LiDAR images depict high levels of sediment erosion (purple, red, orange, yellow) and sediment deposition (green, light blue) in the active channel from 2008 to 2012. The increased sediment movement is causing flooding and shifting the Pyramid Creek closer to the Kautz Creek (Map Credits: Melanie Graeff, 2017; ESRI, 2017; NPS, 2016).

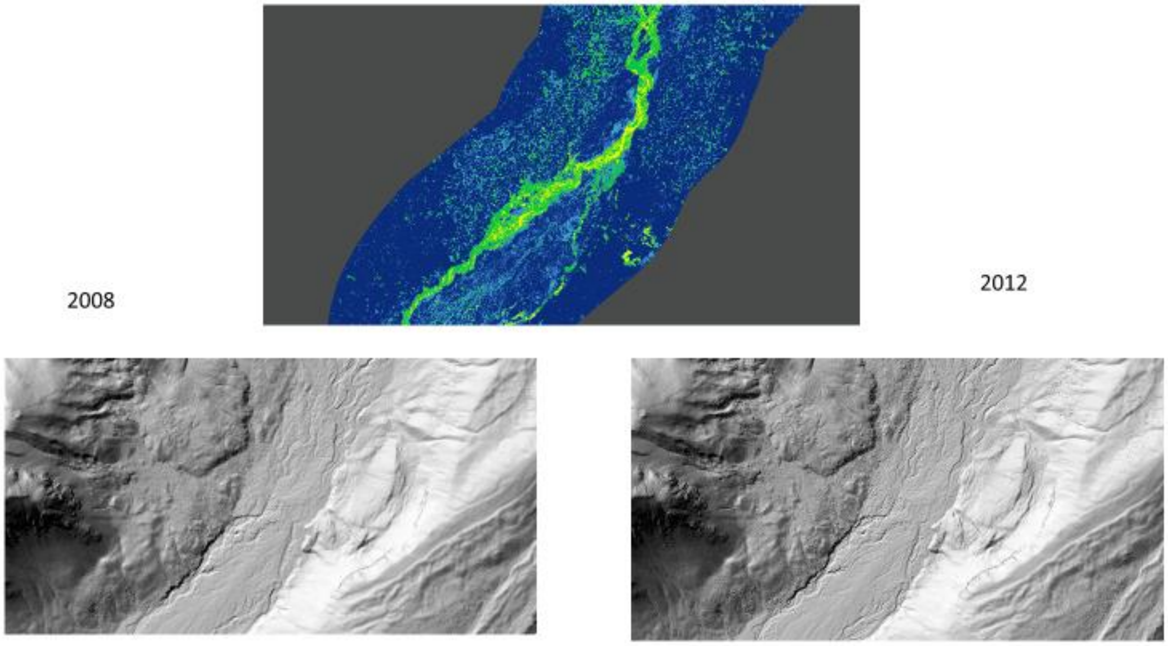


Figure 23d. A zoomed-in image of the lower region where the Kautz Creek active channel split from the November 6, 2006 AR. The colored comparison of the differences in elevation between the LiDAR images depict high levels of sediment erosion (purple, red, orange, yellow) and sediment deposition (green, light blue) in the active channel from 2008 to 2012. An increased amount of sediment is being directed into the split channel (east of Kautz main channel) (Map Credits: Melanie Graeff, 2017; ESRI, 2017; NPS, 2016).

Temperature (Figures 24a-h) and Precipitation (Figures 25a-h) Figures

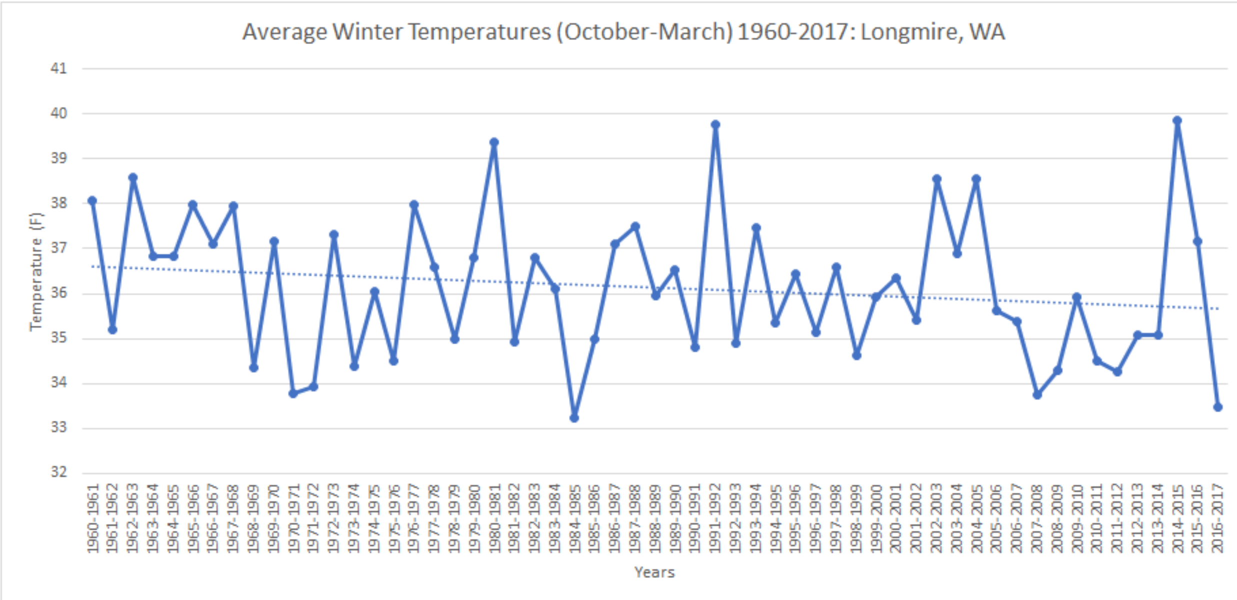


Figure 24a. The line graph shows winter temperatures from 1960-2017 with an overall decrease of 1 degree F (37.7 to 36.7) (WRCC, 2017).

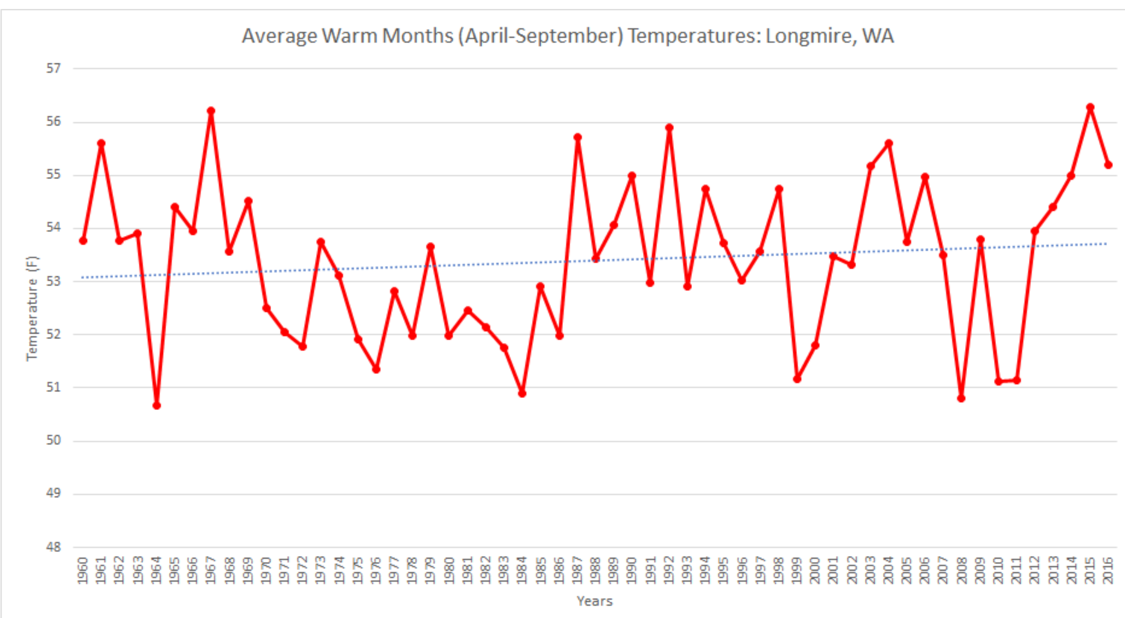


Figure 24b. The graph shows warm month temperatures from 1960-2017 showing an overall increase from 53.1 to 53.7 degrees F (WRCC, 2017).

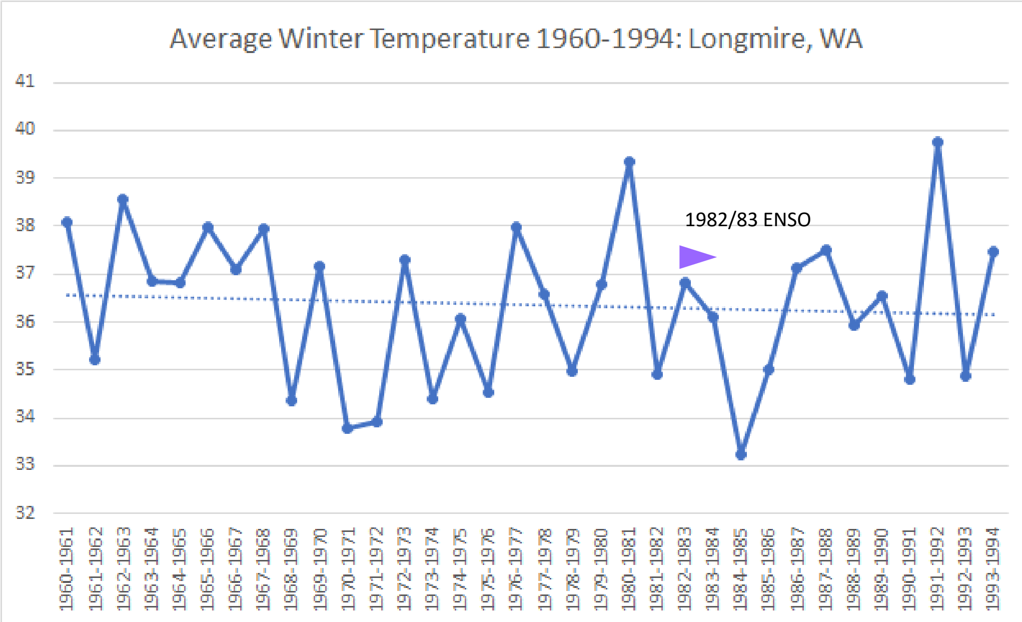


Figure 24c. The graph shows winter temperatures from 1960-1994 decreased from 36.6 to 36.1 degrees F, with an average of 36.35 degrees F. The 1982/83 ENSO event is marked with the purple flag (WRCC, 2017).

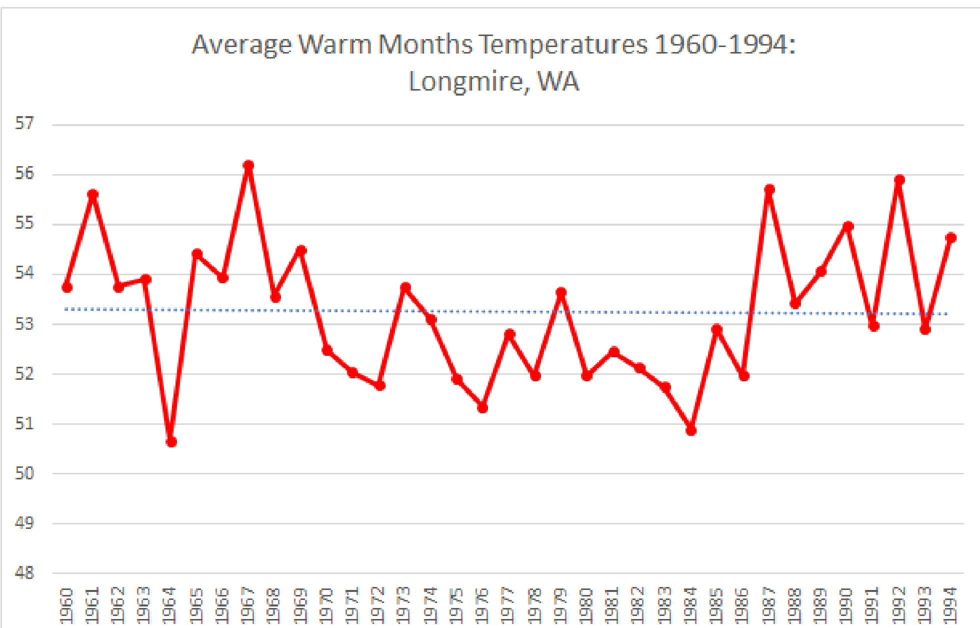


Figure 24d. The graph shows winter temperatures during warmer months from 1960-1994 hold steady at 53.3 degrees F, with an average temperature of 53.26 degrees F (WRCC, 2017).

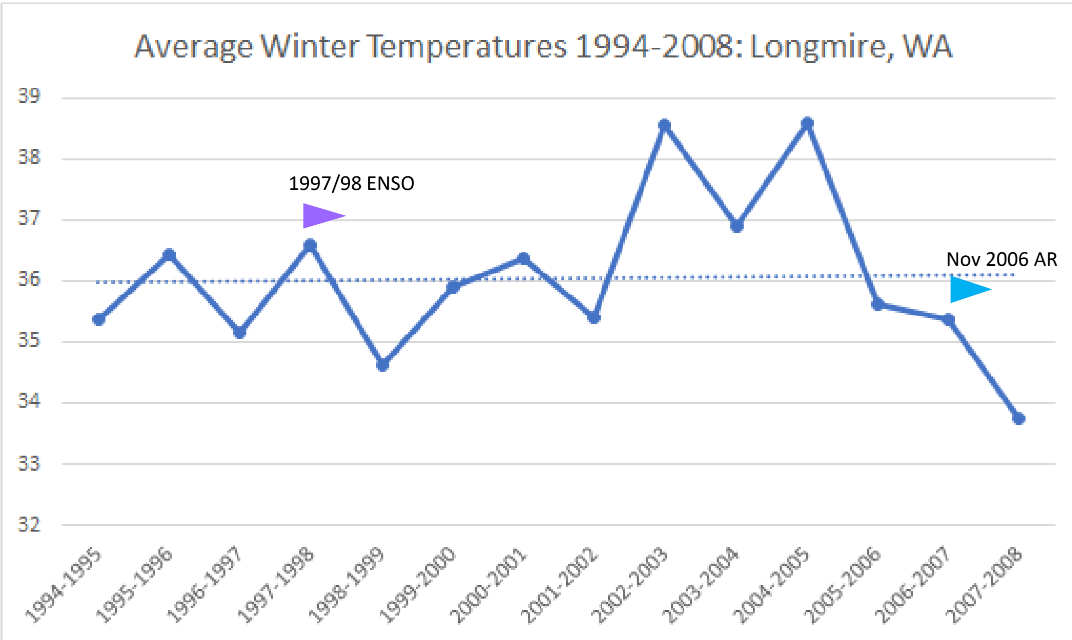


Figure 24e. The graph shows that winter temperatures from 1994-2008 slightly increased from 36 to 36.1 degrees F, with an average temperature of 36.04 degrees F. The 1997/98 ENSO event is labelled with a purple marker and the November 6, 2006 AR event is labelled with a blue marker (WRCC, 2017).

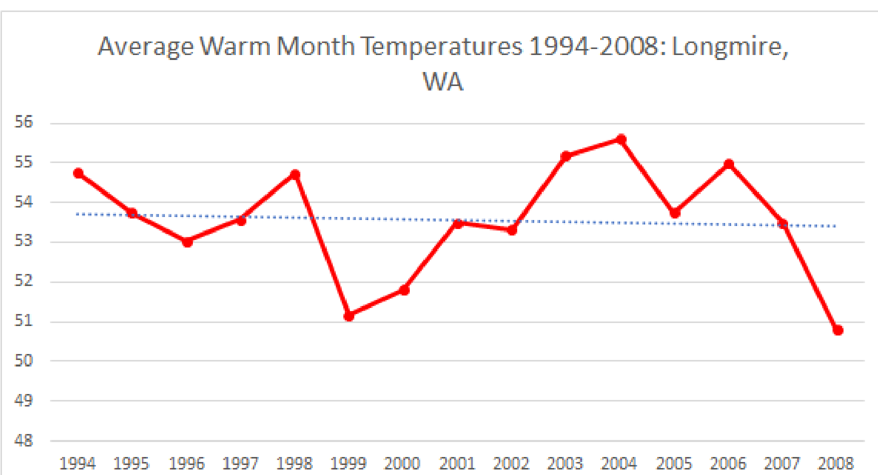


Figure 24f. The graph shows those warmer months from 1994-2008 decreased slightly from 53.8 to 53.3 degrees F, with an average temperature of 53.5 degrees F (WRCC, 2017).

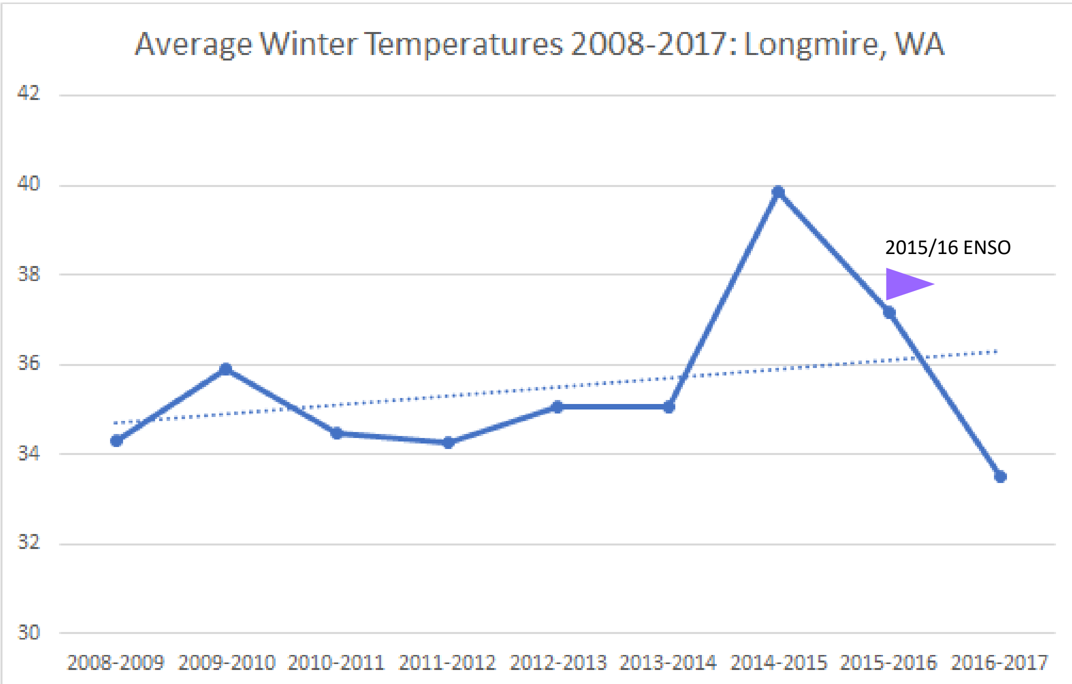


Figure 24g. The graph shows winter temperatures from 2008-2017 increased from 34.8 to 36.3 degrees F, with an average temperature of 35.5 degrees F. The 2015/16 ENSO event is labelled with a purple marker(WRCC, 2017).

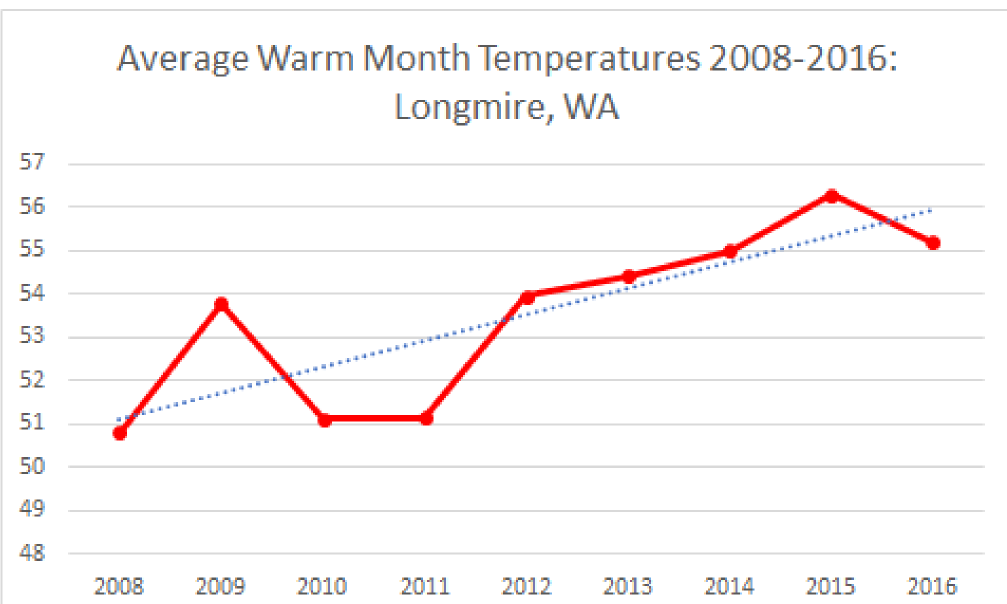


Figure 24h. The graph shows that warmer month temperatures from 2008-2016 increased significantly from 51.1 to 56 degrees F, with an average temperature of 53.5 degrees F (WRCC, 2017).

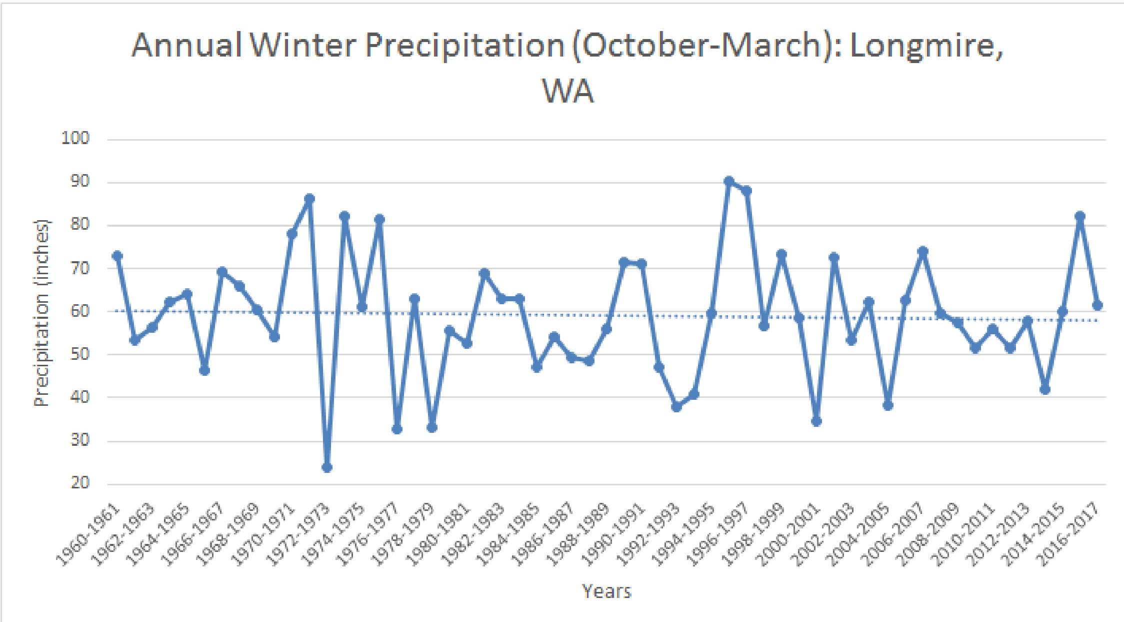


Figure 25a. The graph shows annual winter precipitation from 1960-2017 with an overall decrease from 60 to 58 inches, and an average of 59.3 inches (WRCC, 2017).

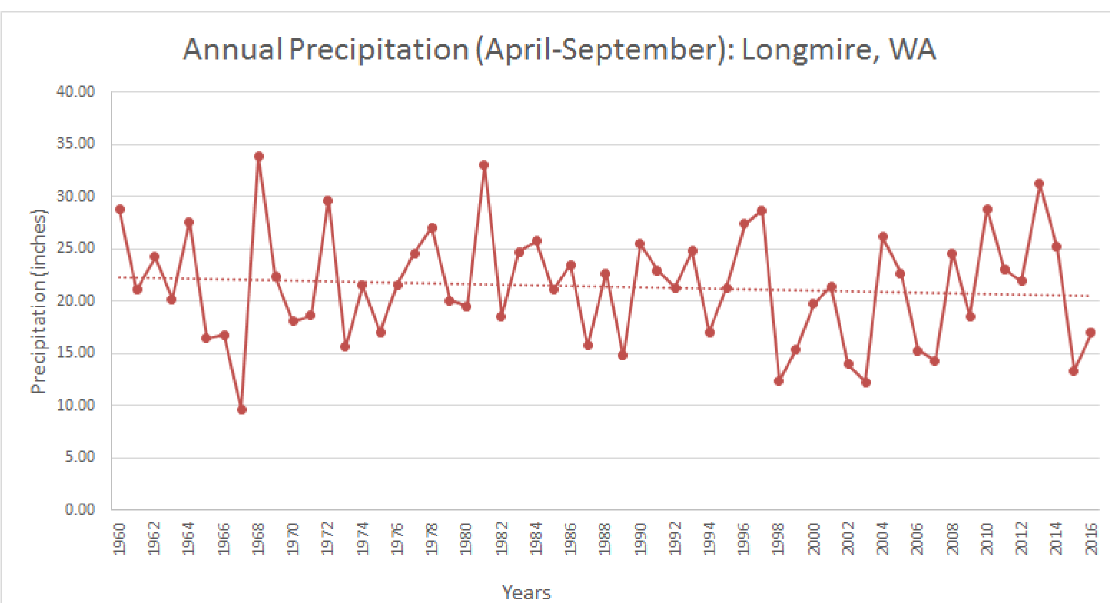


Figure 25b. The graph shows annual warm month precipitation from 1960-2016 with an overall decrease from 23 to 21 inches, and an average of 21.4 inches (WRCC, 2017).

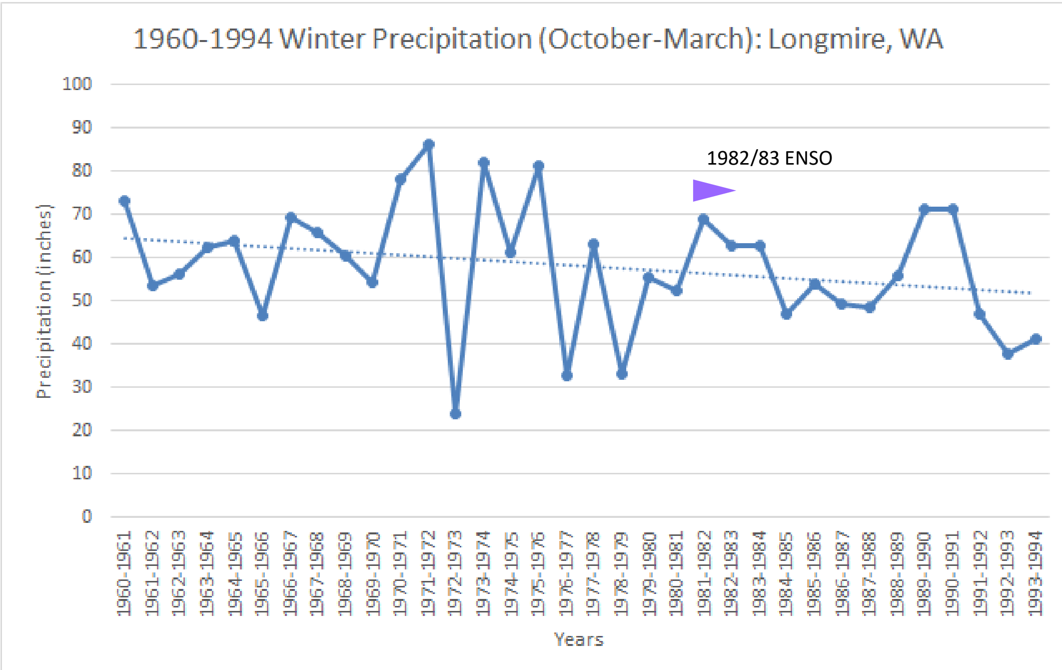


Figure 25c. The graph shows winter precipitation from 1960-1994 decrease from 65 to 52 inches, and an average of 58.1 inches. The 1982/83 ENSO event is marked with a purple flag(WRCC, 2017).

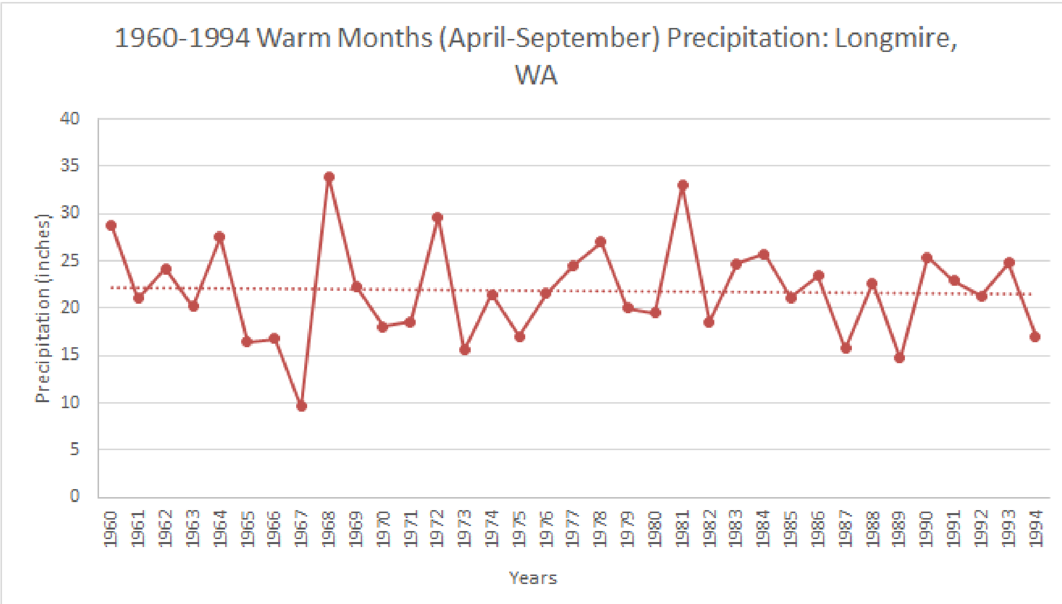


Figure 25d. The graph shows warm month precipitation from 1960-1994 that held steady around 22 inches, with an average of 21.8 inches (WRCC, 2017).

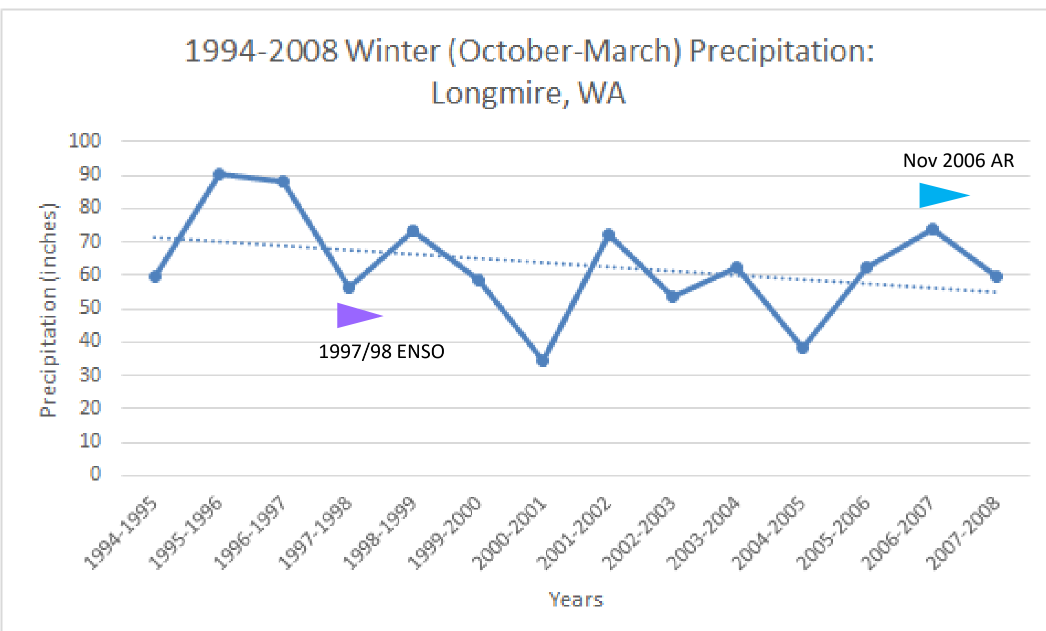


Figure 25e. The graph shows winter precipitation from 1994-2008 decreased significantly from 71 to 55 inches, with an average of 63.1 inches. The 1997/98 ENSO event is labelled with a purple marker and the November 6, 2006 AR event is labelled with a blue marker (WRCC, 2017).

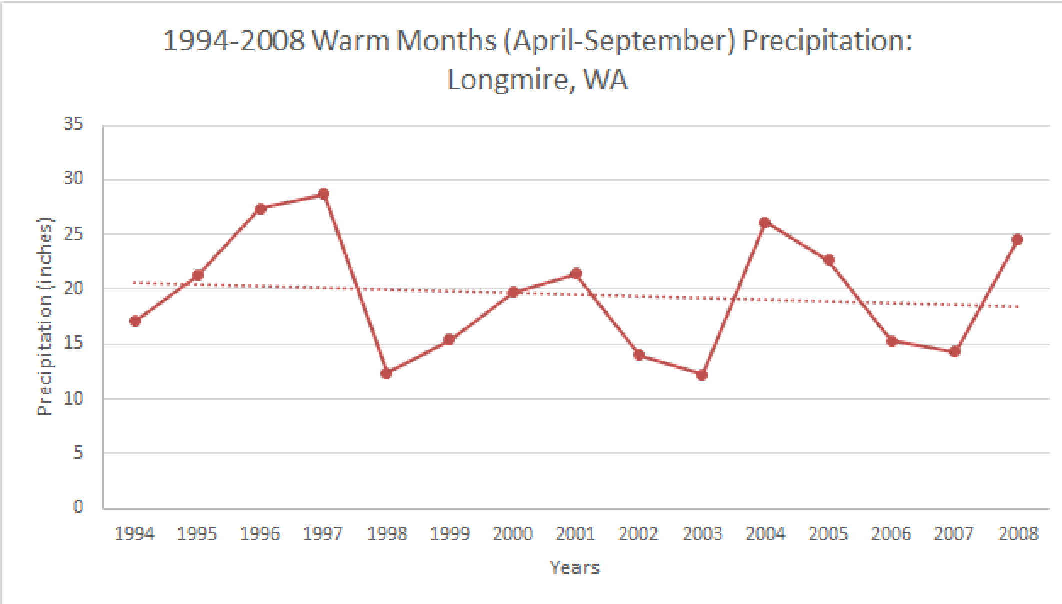


Figure 25f. The graph shows warm month precipitation from 1994-2008 decreased from 21 to 18 inches, with an average of 19.5 inches (WRCC, 2017).

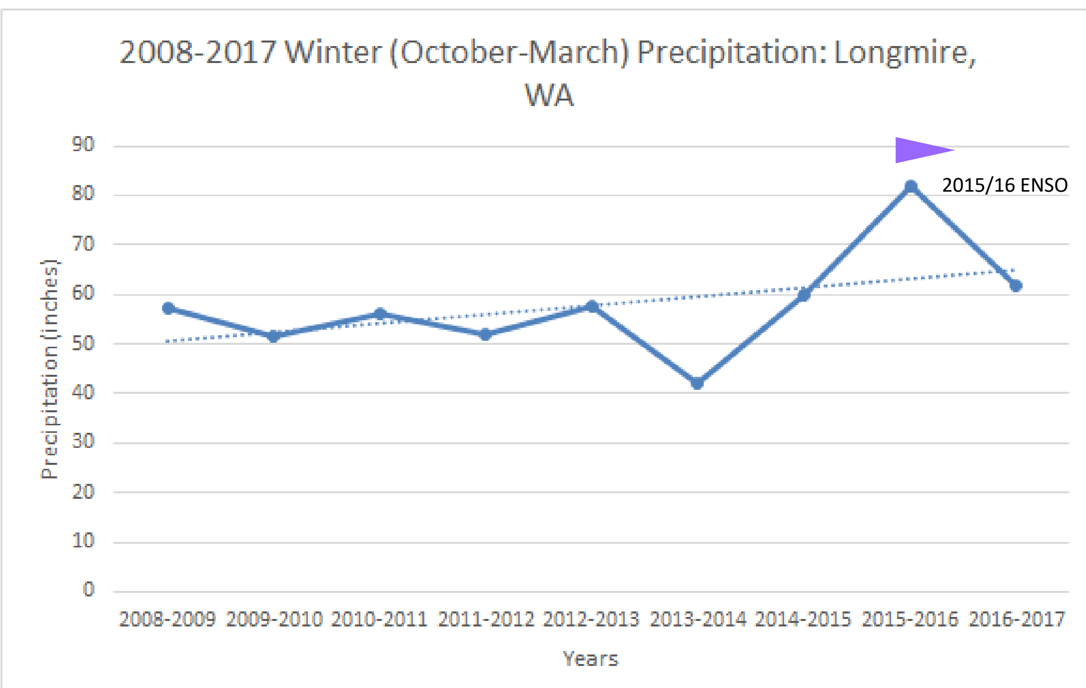


Figure 25g. The graph shows winter precipitation from 2008-2017 increased significantly from 50 to 65 inches, with an average of 57.8 inches. The 2015/16 ENSO event is labelled with a purple marker (WRCC, 2017).

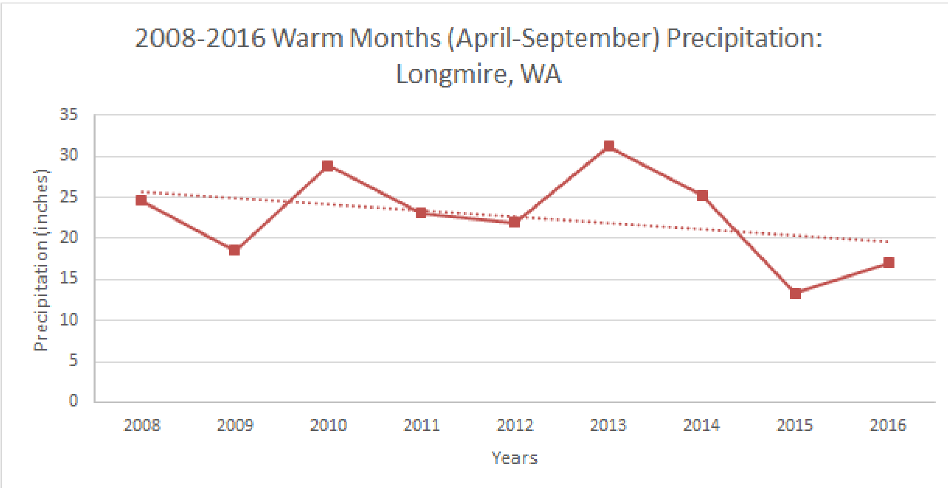


Figure 25h. The graph shows warm month precipitation from 2008-2016 decreased significantly from 26 to 19 inches, with an average of 22.64 inches (WRCC, 2017).

V. Conclusion

The combination of warmer temperatures and higher precipitation brought on by ENSO and AR events had contributed to significant melting of the Kautz glacier. This subsequent melting of the glacial ice released a significant amount of sediment into the creek, filling up the channels to make them wider and shallower for active channel water flow. These conditions combined with high precipitation events increase the likelihood of active channel shifting and flooding of the surrounding area and downstream. Such an event occurred on November 6 and 7, 2006 when a strong AR dumped very heavy rain on the mountain. This flood led to infrastructure loss and damages that equated to millions of dollars.

With these types of storms taking place at Mt Rainier National Park it is imperative that continued monitoring and surveying of not only the Kautz Creek, but all of the mountain tributaries. Also, more infrastructure improvements need to be built or reinforced if the park wants to remain accessible to the public in the future (Carson, 2014). Unfortunately, the lack of funding and environmental support from the government has put strains on repairing important infrastructure as the climate altering conditions continue to affect Mt. Rainier. The Kautz Creek continues to be one of the primary concerns because its channels cross the main roadway that leads in and out of the park. The future effects of climate change on this creek remains to be seen but continued monitoring is important for the safety and future of this area of the park.

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