Resource Brief

National Park Service
U.S. Department of Interior

Mount Rainier National Park
Division of Natural and Cultural Resources
MORA Geology & Imminent Threats Group

The Nisqually River

Risk Assessment and recommendations for future actions

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The Nisqually River at the Cougar Rock Picnic Area, looking upriver in the Nisqually watershed. (Photo: NPS/Jessica Bersson)

This report is intended to assess the Nisqually River, identifying problem areas threatening park infrastructure, recommending further work, and note deficiencies and improvements to be made for the next actions taken on the project. Any edits, missing information, or questions regarding this document should be directed to either Taylor Kenyon, Robert Jost or Scott Beason, NCR Geology Division.

1.0 Background

Mount Rainier is a 4,392 m (14,410 ft.) stratovolcano located in southwest Washington State, approximately 90 km (56 mi) south-southeast of Seattle. The volcano occupies most of the 956 km^2 (369 mi^2) of Mount Rainier National Park (MORA) and is visible from much of western Washington State (Figure 1). As a heavily glaciated peak, MORA is home to fluvial systems with intense sediment fluxes and increasing discharge levels due to glacial recession (Beason et al., 2015). Glacial recession at Mount Rainier is attributed to higher river discharges due to increases in glacial melt, and increases in sediment transport through the watersheds due to newly exposed glacial sediment stockpiles in the form of moraines (Beason, 2017; George and Beason, 2017; Magirl et al., 2017). These new conditions have led to a general trend of river aggradation and floodplain widening (Beason et al., 2015; Beason, 2006). As a result the design condition upon which much of the park's infrastructure was built has changed, placing many roads and other structures at risk of flooding or exposure to mass wasting events.

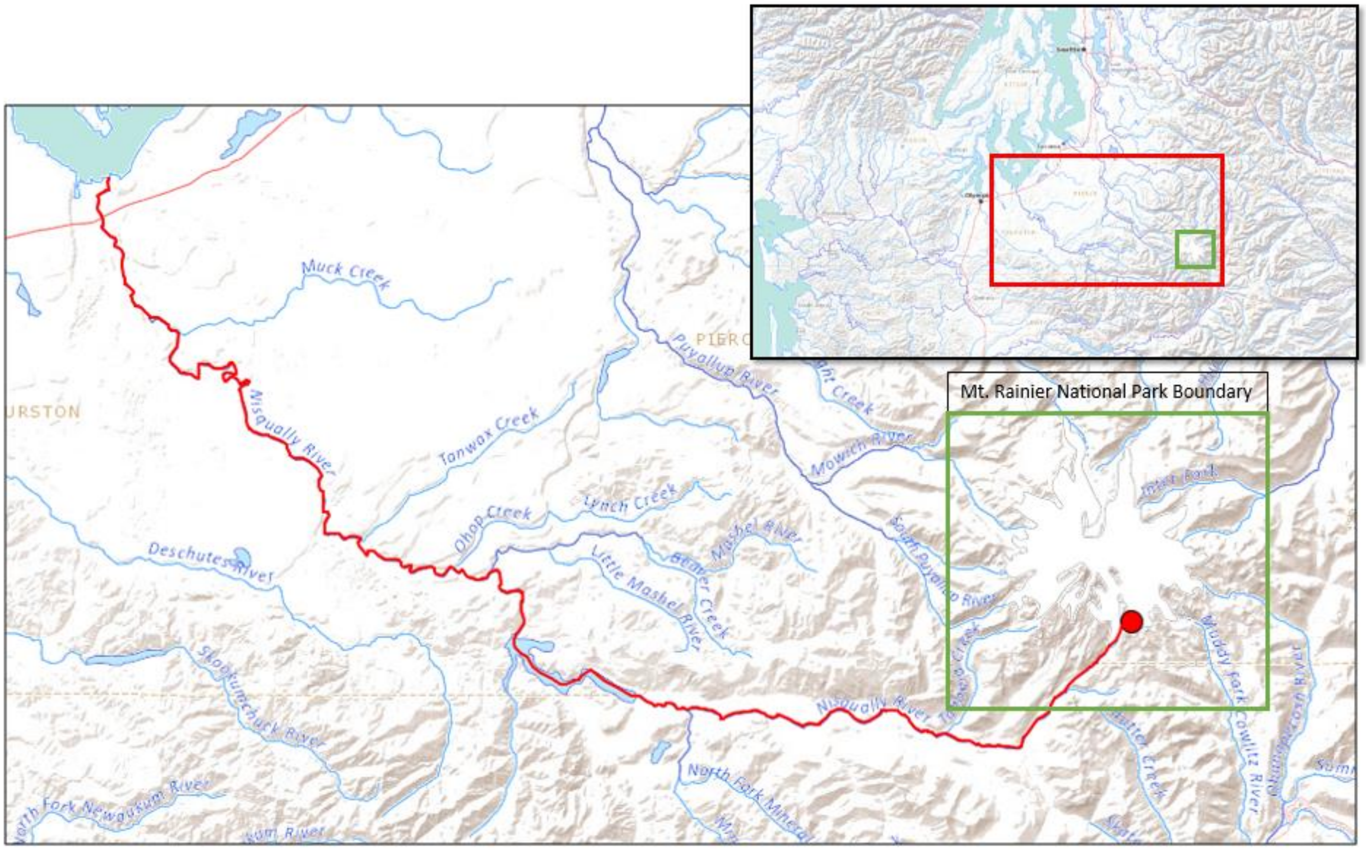


Figure 1: Map showing the Nisqually River in relation to the National Park, Seattle, and greater Washington Area. (NPS/Shelby Cutter)

The Nisqually flows from the park, to the west, where it was dammed at what it now Alder Lake. After the dam it flows northwest to the Puget lowland near Olympia. The Nisqually River transports a tremendous amount of sediment that would normally go to the Puget lowlands, however, Alder Dam traps most of the sediment so it can't travel further downstream. Excluding the Nisqually a minimum of 60 percent the sediment that enters the Puget Lowland being sourced from within the park boundary (Czuba et al., 2012). This condition is resultant of and compounded by predicted trends in climate.

Models predict up to 12 percent increases in precipitation from October-March and 18 percent decreases in precipitation totals from April-September within the next 25 years (Czuba et al., 2012). These trends are expected to exacerbate an already increasing trend of sediment transport and storage on the Nisqually River, with most appreciable increases in storage and channel width are contained within the park boundary (Czuba et al., 2012). Much of this change in storage is expressed by increases in channel width in the high reaches of the Nisqually River, continually leading to greater exposure of local infrastructure to fluvial hazards. The total sediment load in the Nisqually River between 1945 and 2011 was 1,200,000±180,000 tones/yr (Czuba et al., 2012).

Aggradation and channel widening are an issue within the park because it leads to the destruction of old growth forests that line the river and are often the only buffer between the road and the flood plain. Aggradation creates a convex floodplain and increases the channel migration frequency. Historically, the Nisqually River was a single thread anastomosing channel, but has since transitioned into a multi-thread braided channel. This destruction narrows the forest buffer between park infrastructure and the river, which leads to increased risk for the infrastructure.

Mt. Rainier is a very well-studied area in regards to its glaciers, volcanic activity and climate change. Climate change is severely impacting the rivers and the size of floods and debris flows that take place every year. Some of the other rivers on Rainier, such as the Carbon and Tahoma have been studied in-depth in recent years because of natural events. This study on the Nisqually will be the first of its kind at Mt. Rainier, as it will be mapping fluvial landforms over a large reach of river and will be a first attempt at relating the occurrence of fluvial landforms and structural elements to areas of enhanced bank erosion. This assessment is very important to the park because of the proximity to a heavy use area and in the larger study of climate change and how different locations are affected.

1.1 Purposes and Need

The first official road was built between 1904 and 1915, and was 12ft in width (Griffith, 1998). The road was later reconstructed in 1918, widening the road to 16ft and enlarging the parking lots at Narada falls and Paradise. A second reconstruction took place over 16 years from 1925-1941, adding new features of naturalistic design, but did not change the overall alignment or character of the original 1915 road. Since 1941 the road has been updated with modern engineering techniques, and all of the original bridges have been replaced multiple times over the years due to damages sustained during flood events. All of the bridges, except for the historic Longmire Bridge, are presently made with concrete and steel as opposed to the original wooden bridges. The Nisqually-Paradise highway that runs along the Nisqually River is the only year-round access to Mt. Rainier National Park. Visitation to the park totaled 2,255,662 in 2018 and most of these people used the Nisqually Paradise Hwy at some point during their visit (NPS, 2018). It provides the closest access to Paradise, the

Figure 2: Map created via Google Earth of the problem areas, red markers, and important park features. (Map: NPS/Shelby Cutter)

most popular destination in the park, to Cougar Rock Campground, the most visited campground, at an average of 39,000 visitors a year, and to Longmire, where the National Inn and many of the park's administrative, maintenance, and research personnel work and live. This entrance also provides a substantial source of fee revenue for the park.

In 2006, MORA experienced the flood of record, with a total of 18 inches of rain fall in 36 hours (Bullock et al., 2007) Resulting floods were observed in every watershed within the park, and every roadway near a river experienced some degree of damage. The Nisqually-Paradise Hwy was severely undercut at various locations, Longmire suffered severe flooding and damaged buildings and roads. The park had to be closed down for repairs for six months.

The Geology division has identified the channel widening south of Longmire, and flattening of the flood plain as the most basic controlling factor for the problems at the various sites, other than Cougar Rock. Up-river from Longmire, the river plain has higher confining features on both the right and left sides, varying in type (i.e. bedrock, hillslopes, and old flood deposit terraces), which helps the river incise instead of aggrade. Down-river of Longmire the channel widens and flattens out, allowing for the main channel to move more easily from one side to the other. This is problematic because during a flood, even if the river is on the side away from the road there's a high likely hood of it switching over and start causing severe erosion to already damaged zones.

1.3 Future Work

This document is intended to serve as a baseline data set to be repurposed for multiple projects and track changes in the river over time. The reason this project is being performed is because the geology division decided that such baseline information will be necessary in the future. The hope is that there can be a baseline set of data for each major river in the park and new data sets can be made, tracking changes over many years. Standardizing the data collection methods and data presentation will streamline the process of monitoring changes in the rivers.

2.0 Methods

2.1 Tiered System

The main mapping method we used was derived from Wheaton et al. (2015) paper on geomorphic mapping and describes the river system in terms of the influences on flow. It outlines a tiered system (see Figure 3), where each tier categorizes different types of structures, starting from a broad lens in tier one to a detailed lens in tier three. This method enabled us to assess the rivers potential on multiple scales, but also presents challenges. This method was developed for relatively small and stable

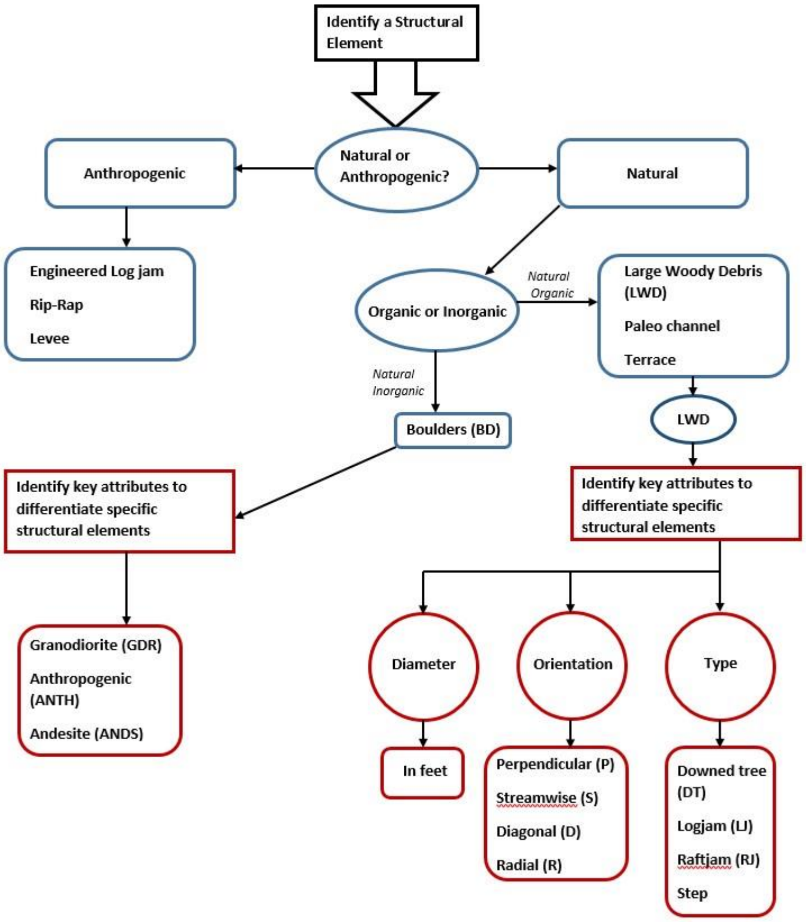


Figure 3: This figure shows how each feature was defined and with what other attributes such as orientation and size (Figure: NPS/Shelby Cutter)

river systems. The Nisqually River, being a glacial river with ample sediment supply, is the opposite, very large and unstable. Wheaton's method of mapping was thus adapted to fit the large scale and dynamic nature of the Nisqually River, testing a robust and repeatable approach to assessing the potential of glacial rivers within Mount Rainier National Park. Wheaton's method uses a tiered system to describe the river, allowing us to map the influences on flow at multiple stage levels. The Nisqually River is in a constant state of change. These tiered maps are not meant to describe the long-term state of the river, but to describe the current assemblage and configuration of geomorphic units as they relate to processes that may threaten park
infrastructure.

2.2 Bank Erosion and Channel Widening

The Nisqually River runs parallel to important park infrastructure such as roads, houses, and administrative buildings with a generally narrow forest buffer. Thus, tracking the bank erosion and subsequent channel widening over time is key. Using old aerial imagery from Google earth, the 2006 channel could be traced and turned into a polygon (Appendix A, Figure 1). The same process can be used for 2018 imagery, leaving two polygons to compare. This method tracks the rate at which the bank/forest buffer is being eroded away.

Average bank erosion can be calculated for individual sites, which in turn can provide average "lifespan" estimates of the bank until it erodes to the road or other infrastructure. Some of the sites have had work done such as bank reconstruction thus that affects the measurements and the accuracy of this method. However, in places where bank reconstruction has occurred, the "lifespan" has already been reached and infrastructure was damaged, thus it's apparent that these places are high risk (Appendix A, Table 1).

2.3 Average Cross Valley Slopes

Cross-valley gradient mapping of the Nisqually River floodplain was used to quantitatively validate current sites of concern and to identify potential future challenge areas. Two stretches of the Nisqually were mapped, from Longmire to milepost 5, and from the Van Trump-Nisqually confluence to Cougar Rock pull-out (Appendix A, Figure 2). These two stretches include observed challenge areas where the Nisqually-Paradise Highway appears to be threatened.

In order to calculate average slopes, using ArcPro and the most recent digital elevation model from 2012, a centerline was drawn down the floodplain and bins spanning the floodplain were created every 50 meters, with an elevation profile at the center of each bin and perpendicular to the floodplain centerline. A linear trend line across each elevation profile was used to represent the average cross-valley slope within each bin. This map shows which direction the river plain is dipping and how severe the slope is.

3.0 Results

3.1 Tiered mapping

Tier 1

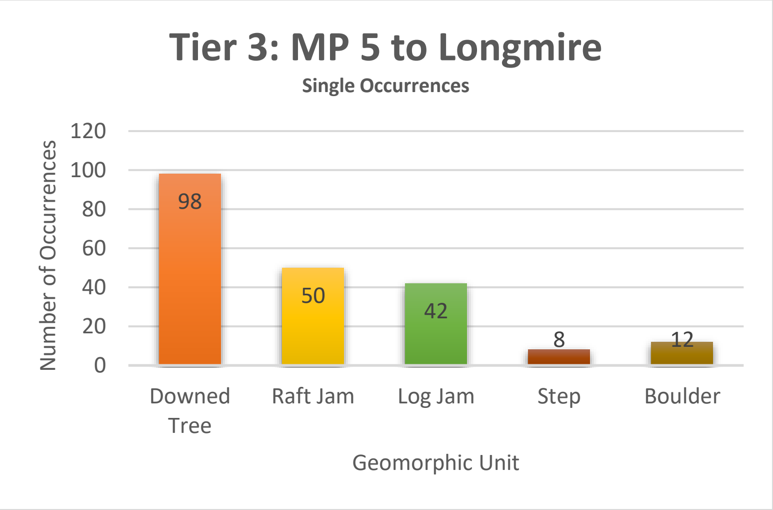
The Nisqually River is completely of natural origin with a few structures of anthropogenic origin, that are where past events have damaged the bank and construction intervention took place. This was completed on the entire reach of interest (Appendix A, Figure 3). Both main sections of the river, MP5 to Longmire and Cougar Rock to Van Trump Creek, were similar in anthropogenic vs. natural occurrences and there are no discernable difference between the two in this regard.

Tier 2

Tier 2 is a differentiation of shapes of the geomorphic units. There were many convexities like bars in the channel, while abandoned channels are concavities, and the main and secondary channels are planar features. This was completed on the entire reach of interest (Appendix A, Figure 4). Upstream of Longmire, there were more obvious convexities from 2006 flood deposits and less abandoned channels, whereas downstream of Longmire is the opposite in both regards. This is most likely due to the channel downstream of Longmire flattening in slope and widening, as it becomes less confined by the valley walls.

Tier 3

Tier 3 is the location and details of specific structural elements. This was completed only on certain sections of the reach of interest, since it is extremely detail oriented. Maps of the main areas were made (Appendix A, Figure 5 and 6) and additionally, single occurrence counts are represented in Figure 4. Using the maps and graphs, there is an obvious difference between the two sections of river. Milepost 5 to Longmire has more LWD (large woody debris) than Cougar Rock to Van Trump, however, Cougar Rock to Van Trump as a considerably higher number of boulders. The boulders are most likely higher in population farther upriver because the river is unable to carry most of them down farther as the river slope and sediment carrying capacity decreases. The LWD's on the other hand, are able to be carried farther downriver and are often jam together creating the other units referred to as raft jams and log jams, raft jams are made up of small branches and young trees and logjams are made up of full-grown trees of varying sizes. The fact that there are a total of 198 LWD features downriver of Longmire is concerning because they all had to have come from the forest buffer lining the river, showing active bank erosion. They also add roughness to the channel, affecting the velocity and sediment carrying capacity.



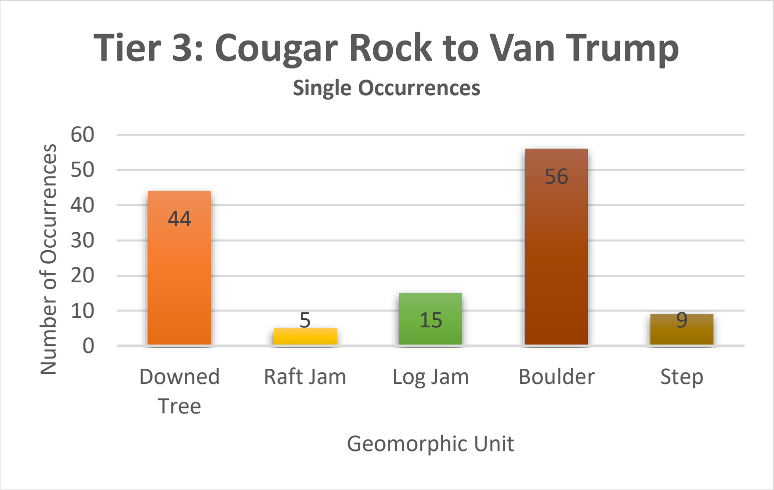


Figure 4: Bar graphs depicting the amount of geomorphic units in the two separate stretches of river where tier three mapping was completed. (Figure: NPS/Shelby Cutter)

3.2 Bank Erosion Results

For the bank erosion, four stretches of river were chosen that were already areas of interest: the old Sunshine Point campground, milepost 5.3 to Longmire, between Longmire and Cougar Rock, and Cougar Rock to Van Trump Creek (Appendix A, Table 1, Figure 1). All of the areas saw bank erosion, some more severe than others. The Sunshine Campground area, while not in our two areas of study, lost 6+ acres of area in the 2006 floods. The other sections of river lost similar amounts, supporting the overall trend of river channel widening and forest buffer thinning. More information can be found in Paul Kennard's memo, cited in the references.

3.3 Average Cross Valley slopes

The average cross valley slopes for both sections of the river were a majority negative (Appendix A, Figure 2). Negative slopes represent a westward sloping gradient. High negative slopes should be considered potential areas of concern, as negative slopes favor the routing of water toward the Nisqually-Paradise Hwy. Positive slopes represent an eastward sloping gradient. High positive slopes may represent lower priority areas, as positive slopes favor the routing of water away from the Nisqually-Paradise Hwy. Milepost 5 to Longmire has a majority of the river dipping towards the road, while Cougar Rock to Van Trump Creek has roughly half of the river dipping towards the road.

4.0 Problem areas

Using the various methods above, multiple areas have been identified has places of risk for damage in the chance of a flood event. Some of these places have already had hazard mitigation construction completed due to past debris flow and flood damages. The following locations are areas that have been in the past/presently a risk to infrastructure and employee/visitor safety.

Figure 5: Milepost 5.3: Anthropogenic riprap on the right and the road is right on top of it as the tree line. (Photo: NPS/Jessica Bersson)

4.1 Mile post 5.2 to 5.3

History

This area was severely damaged in the November 2006 flooding and needed extensive repairs. Two hundred sixty feet of stream bank supporting the roadway was washed away by the Nisqually River during the channel migration and floodplain widening (NPS, 2006b). The resulting slope was standing at a steep angle up to 60ft high and was undercut at the edges. The Nisqually-Paradise Highway was closed to a one lane access for administrative use only. The park decided in December 2006 to pursue the option of repairing the embankment that was lost via the flood. This was completed by placing rip rap, sediment, erosion control blankets, and planting willow and alder trees to stabilize the new slope.

Results

The average bank erosion for this area on both sides of the channel was 87.8ft since 2006 and average erosion for the just the road side is 62ft. If no repairs were made to build out the road platform the bank erosion would be higher. Using the roadside average of 62ft, the average yearly erosion rate from 2006 to 2018 is calculated to be 5.14ft. The shortest distance from the flood plain to the road in this area is 50ft, which would mean that there is roughly 9.7 years until the river erodes the bank to the road. Since there was already bank reconstruction, the river has already technically eroded to the road, which tells us already alerts us to this spot as a problem zone.

The average cross valley slope for this area is generally towards the road, which can present a problem because the river is more like to flow to that side (Appendix A, Figure 2).

Recommendations

At present time, the rip rap is holding together and has been since 2006 with minimal maintenance. In the future, if it were to be damaged again, the use of trees in the embankments, such as tree bundles or toe-roughened rip rap, similar to the work on the West Side road, may prove more effective.

4.2 Milepost 6.0

History


Figure 6: Milepost 6.0: Looking upstream at the engineered logjam (ELJ) placed in 2010. The road is directly above the ELJ. (Photo: NPS/Shelby Cutter)

In December 2009, it was noted by park employees that the Nisqually bank erosion in this area had accelerated (NPS, 2010). Two trees that had been identified as “at risk” had fallen into the river, probably during heavy rains in the days preceding. Seeing that the road was at risk of being damaged, a project to install a flood protection structure was proposed. The resulting structure was an engineered log jam or log/rock crib wall. It extends along the river bank for roughly 150ft and is 45ft wide and was installed spring 2010.

Results

The average bank erosion for this area on both sides of the channel was 96ft since 2006 and average erosion for the just the road side is 89ft. If no repairs were made to this section then the average erosion rate would be higher. Using the roadside average of 89ft, the average yearly erosion rate from 2006 to 2018 is calculated to be 7.43ft. The shortest distance from the flood plain to the road in this area is 45ft, which would mean that there is roughly 6.1 years until the river erodes the bank to the road. Since this area has already suffered from severe erosion that required an engineered logjam, it’s known to be a problem area.

The average cross valley slope is 1.5-2.5 degrees, dipping towards the road. This presents a large problem as the whole area above and below milepost 6 is dipping severely towards the road, increasing the probability that the river will flow on that side eroding the banks further (Appendix A, Figure 2).

Recommendations

While the log jam itself is still structurally sound, the problem of the river eroding the slope near the road just moved downstream. This causes the same problem as before just in a different place. If long-term work is to be done, then something needs to be done for the whole area above and below the milepost, not just “spot treatments”.

4.3 South of Longmire Bridge on both sides

Figure 7: Left: Longmire levee June 2019 river right eroding away with equipment parked on top (Photo: NPS/ Shelby Cutter). Right: 2006 flood event at Longmire Emergency Operations Building (Photo: NPS).

History

During the 2006 floods there was severe damage to Longmire infrastructure. Phone Lines and power lines were damaged or severed, the area between the Emergency operations center building and the river, was completely taken out, and Longmire's fresh water system at the treatment plant was filled with sediment (NPS, 2006c). These are just a few of the damages that took place in 2006. There was also damage on the other side of the river near the community building that wasn't able to be repaired with non-emergency armoring until Sept 2007.

Between 2006 and 2009 there were a number of flood events that continued to damage the Longmire Levee and require repairs to be completed (NPS, 2012). Currently there is a levee running from the Longmire Bridge to the end of the equipment yard. This levee is still stable but has been eroded away over the past few years and will undoubtedly need a repair or complete rebuild in the next 5-10 years depending on flood events. The community building side parking lot was damaged and emergency armoring was placed in 2006 and additional armoring was added in 2007.

Results

This area is at severe risk because it is at this point where the river plain flattens out and widens. At this point the velocity of the flow will slow down, dropping out any larger sediment sizes that were being transported by the river. Thus, during a debris flow or other event, this area will be likely to aggrade, which can, after some time, lead to water overtopping the levee, inundating Longmire.

The average bank erosion for this area on both sides of the channel was 43ft since 2006 and average erosion for the just the road side is was ~0ft due to the levee/bank reconstruction being built. If no repairs were made to this section then the average erosion rate would be higher. Due to the fact there's not a good average bank erosion for the road side, an average yearly erosion rate cannot be calculated, which is a deficiency of this method. However, the damages from the 2006-2009 debris flows are well documented and were severe. Additionally, just downriver from the community building is an area of 2.05 acres (~89,000ft/-2) that was taken out in the 2006 floods, it was not repaired or reconstructed because there were no structures directly in the area, but this speaks to the destructive power of debris flows in this area. The likelihood of more damage occurring is high for this area.

The average cross valley slope running along the whole of Longmire is 1.5-2.5 degrees, dipping towards Longmire (westside) (Appendix A, Figure 2) This presents a large problem as the river will be more likely to flow on that side, if it's not already, and risks eroding the levee or undercutting it.

Recommendations

For future repairs or rebuilds on the Longmire levee, it should be considered to construct barbs, or toe-roughened rip rap similar to the west side road. They have been proven to work during debris flows and can be built out over time to further protect infrastructure. Additionally, Longmire is a difficult location because both banks need to be protected as Longmire is on the west side and the historic community building and Longmire campground are on the east side. More studies will need to be done to design a sufficient construction plan for this complicated area.

4.4 Wonderland Trail North of Longmire

History

This area has no significant damage from past floods as there is enough of a buffer between the flood plain and road. However, while the road presently has a sufficient buffer, the wonderland trail runs between the road and the flood plain. The buffer between the trail and the river is much smaller and hikers on the trail are at an increased risk due to the close proximity of undercut banks. If this area were to undergo any significant erosion, the trail could be damaged and closed. An event like this would most likely result in moving or relocating the trail, which is an involved and expensive process.

Results

The average bank erosion for this area on both sides of the channel was 41ft since 2006 and average erosion for the just the road side is 33ft. Using the roadside average of 33ft, the average yearly erosion rate from 2006 to 2018 is calculated to be 2.77ft. The shortest distance from the flood plain to the wonderland trail in this area is 30ft, which would mean that there is roughly 10.8 years until the river erodes the bank to the trail. Then, there is 50ft to the road making it 18.1 years until it erodes there.

Cross valley slope calculation was not completed for this area.

Recommendations

This area is not at a high risk in relation to the other areas on this list, but the proximity of the Wonderland trail to the bank is small and historically, the Wonderland has had to be rerouted a number of times in this area. This could lead to a large cost in the future depending on how far the trail needs to be rerouted.

4.5 Cougar rock picnic area

History

The Cougar Rock picnic area has no recorded damages from the 2006 or subsequent floods, however, it is still located close to the river's edge. This bank is made up of old lahar deposits that are easily erodible when/if the river flows up against the bank, undercutting it. This could present a problem in the future as the eroding bank gets closer to the picnic area, threatening it.

Figure 8: Cougar Rock Picnic area looking downstream at steep, unstable banks. (Photo: NPS/Jessica Bersson)

Results

The average bank erosion for this area on both sides of the channel was 56ft since 2006 and average erosion for the road side is 37ft. Using the roadside average of 37ft, the average yearly erosion rate from 2006 to 2018 is calculated to be 3.06ft. The shortest distance from the flood plain to the rough area of the picnic area is 45ft, which means it would take on average 32.6 years until the river erodes the bank to the picnic area. This obviously shows that this area is not at a huge risk of damaging infrastructure. The average cross valley slope for the area is mostly in the 1.0 to 2.5 range tilting towards the at risk bank, which is something to worry about but it historically has not been a problem and there it a good forest buffer between the picnic area and the river plain.

In the field it is apparent that this bank is very over hung, and poses a danger to visitors using the above picnic area. While in the field, Jessie Bersson and I observed young children going down the bank into the river plain and then struggling to climb back out. There are many large boulders in the bank that are unstable and could have easily come lose and injured them or someone below them.

Recommendations

This specific area isn't threatening any roads or other necessary infrastructure, however, it does post a threat to people who are unaware about the dangers of the overhung, unstable slope face. There are often visitors going down the slope face to the river and then they try to climb up the slope to get out and this can be dangerous as many people aren't aware of the dangers of the unstable slope and could be injured by falling rocks. Signs should be placed on top of the bank that warn of the dangers and tell visitors to not go down into the river bed.

4.6 Milepost 9.0

History

During the November 2006 flood events, this bank was undermined. Approx. 240ft of the 25ft high embankment was washed away by the Nisqually River (NPS, 2006a). This area was very similar to Milepost 5.3 and was repaired in a very similar way, by placing rip rap, sediment, erosion control blankets, and planting willow and alder trees to stabilize the new slope.

Figure 9: Milepost 9.0 Rip rap looking upstream at Mt. Rainier (Photo: NPS/Jessica Bersson).

Results

The average bank erosion for this area on both sides of the channel was 43ft since 2006 and average erosion for the road side was difficult to calculate because of the bank reconstruction post 2006. If no repairs were made the average erosion would be much higher. Conducting the calculation on the section just upriver from the reconstruction, it showed there was 82ft of erosion on the road side. Using the roadside average of 82ft, the average yearly erosion rate from 2006 to 2018 is calculated to be 6.88ft. The shortest distance from the flood plain to the rough area of the road is 60ft, which means it would take on average 8.7 years until the river erodes the bank to the road. While the section of bank reconstruction is stable, just upriver it is not. If the bank upriver is damaged, it can affect the rip rap placed in 2006 by flow and sediment getting behind the rip rap, "unzipping" it and eroding it away.

The average cross valley slope for this area is a mix of slightly tilting towards the road and away from it (Appendix A Figure 2). Directly upriver and down river it's severely (2.0 to >2.5 degrees) tilting towards the road, which is important to note, as this can increase the chances of the river flowing on the road side. This further raises the risk of this area becoming damaged due to the high bank erosion up river and in the high slope towards that bank.

Recommendations

This location is similar to MP5.3 in damages it sustained in 2006 and repairs that were made. Like MP5.3, this area is also a high risk area for future damages. The rip rap itself is stable but due to the average bank erosion and slope directly upriver and the history of damage it raises the risk considerably. In the future, is it were to be damaged again, the use of trees in the embankments, such as tree bundles similar to the work on the West Side road, may prove effective.

4.7 Lower Van Trump Curve

History

The Lower Van Trump curve was damaged in a flood in fall 2005. Flood waters jumped the bank and crossed the road resulting in a road closure for 24 hours (NPS, 2005). In Nov. 2005 a rock berm was constructed to help divert flow during high-water incidents. Also in Nov. 2005, there was a log installation on the first floor above the lower Van Trump curve. This added roughness, or energy dissipaters to reduce the erosive powers of the water following debris flows. There was no recorded damages during the 2006 or subsequent floods. This area has also been affected by debris flows from Van Trump Creek, which is just upriver and landslides from Ricksecker point, just across the flood plain.

Results

There was little to no bank erosion to this area but directly upriver, there was an average 55ft of erosion on the road side. Using the roadside average of 55ft, the average yearly erosion rate from 2006 to 2018 is calculated to be 4.56ft. The shortest distance from the flood plain to the rough area of the road is 35ft, which means it would take on average 7.7 years until the river erodes the bank to the road. This may seem like a concern, however, after the debris flows from Van Trump there was a significant amount of sediment deposited on the road (west) side creating a tall terrace of considerably large material. This makes the average cross valley slope for the area is 1.5 to 2.5 degrees tilting away from the road (Appendix A, Figure 2). The river is currently running on the east side of the river and is at a significantly lower elevation than the top of the terrace on the west side. There is a low probability that the river would ever be able to overtop in the terrace in the near future. The other side of the river is Ricksecker point which is a hillslope and confining feature. The only concern with Ricksecker point is that it's common got have landslides and rock fall from the eroding cliff faces which adds more material to the system, can affect the flow path of the river, or possibly dam the river creating a temporary lake behind it.

Recommendations

Due to the average bank erosion and cross valley slope, this location is not currently high risk. The high deposit created by the Van Trump debris flow and the opposite hillslope are sufficient confining features for the river. This could potentially change but would most likely require a much larger than average rock fall from Ricksecker or debris flow from the Nisqually or Van Trump, larger than that of 2006 at the very least.

5.0 Project challenges and resulting deficiencies

Completing an in-depth study on the entire Nisqually River is a large project to undertake. It requires a large amount of field work, as each side of the river needs to be examined and many places are difficult to access on foot. An effort was made to use up to date aerial imagery to fill in spots where foot-travel was difficult.

When performing a detailed study on large-scale reach of river, such as the Nisqually, it is extremely valuable to have a recent DEM (Digital Elevation Model) for the area of study. It allows for higher accuracy when executing studies via ArcPro, such as cross valley slopes, which is an invaluable quantitative figure in discerning risk to park infrastructure and hazard ratings. The most recent DEM on file is from 2012, there have been multiple floods and other geologic events within the Nisqually watershed that would have changed the elevation in places along the river. A current DEM would make studies such as this a much more useful for a longer period of time.

Calculating the average bank erosion was straight forward for many of the locations, however there are some inconsistencies with using google earth and drawing polygons so the measurements are not as precise if compared to polygons drawn using an RTK GPS system. Additionally, for the locations where there had been prior bank reconstruction, the current bank is obviously not representative of the erosion in that area. However, any calculations would be unhelpful anyway, as we are already aware that the river can and has eroded to the road and damaged it. In locations such as these (i.e. Milepost 5.3 and milepost 9.0) the banks upstream and downstream offered a more accurate bank erosion estimate.

6.0 Conclusions/Recommendations

The Nisqually River is one of the parks most important rivers to study annually over time as it runs parallel to the most used road in the park and adjacent to the largest collection of administration buildings and employee housing. In recent years there has been an uptick in debris flow/flood events in the park, contributed to climate change, which further supports the need for continuous review, especially at the areas that have been affected by past events. The higher temperatures are causing the glaciers to recede, exposing more material from the glacial moraines. There is also an increased amount of precipitation. These two factors contribute to aggradation, which in turn increases the risk of flooding and overtopping banks.

After conducting a reach-wide survey there were seven locations along the Nisqually river identified to be possible hazard zones. Out of the seven locations there were four that should be considered high risk for infrastructure, another two are moderate risk for infrastructure, and one for high risk to visitors.

High Risk to Infrastructure

Locations	Why?	Recommendations
• Milepost 5.3 • Milepost 6.0, at the Engineered logjam • Longmire • Milepost 9.0	The high risk to infrastructure locations were classified this way mostly because these are areas where past mitigation/repair construction has been completed and factors such as cross valley slope, amount of tier three debris, and average bank erosion are contributing to the deteriorating condition of these zones.	Given this information the entire stretch from Milepost 5 to the Longmire Bridge should be constantly monitored, and plans should be in place for when the road is damaged, which will undoubtedly take place within the next decade. Additionally, downstream of Longmire, the flood plain flattens out and opens up a significant amount, increasing the probability that the river will oscillate across the flood plain leading to unpredictable erosion near Longmire, community building, and the entire stretch of road.

Moderate Risk to Infrastructure

Locations	Why?	Recommendations
• Upriver of Longmire bridge near Wonderland Trail • Lower Van Trump Curve	The two moderate risk to infrastructure locations were classified this way because there has not been any reconstruction to the places, other than at the Lower Van Trump Curve. However, the lower van trump curve has sufficient barriers made by the old Van trump debris flow deposits. The zone up river from the Longmire Bridge near the Wonderland has never needed construction, and the average bank erosion lifespan isn't as concerning as the high risk locations.	Given this information, these areas should be continued to be monitored but neither pose a large threat to infrastructure at this current time.

High Risk to Visitors

Locations	Why?	Recommendations
• Cougar Rock Picnic Area	The last location showed to have no high or moderate risk to infrastructure, but an increased risk to visitors. This area is where visitors are on foot and many of them do not usually have the amount of outdoor experience that one may have on the Wonderland trail, since this is a drive-in public picnic area. This leads to inexperienced visitors not being aware of the dangers of the river bank directly next to the area. This bank is extremely unstable and hard to get back up once in the river plain. There are also extremely large precarious boulders in the bank that could fall out if disturbed by an unknowing visitor.	Given this information and the nature of this site, it is the only place on this entire list where proactive work can be done. Signs should be put up on top of the bank 10-20ft back from the edge warning visitors to stay back from the edge and to not go down into the flood plain.

6.1 Mitigation Work for the Future

Historically, the treatment for the destroyed banks, like at milepost 5.3 and 9.0, has been to rebuild the bank with rip rap, instead of moving the road, or using different materials for the bank. This may have been because when these specific events took place there were park wide floods and damages that needed to be addressed so, the park was in emergency mode and they needed the most efficient fix to get the park back up and running before losing too much fee revenue. There had also been no push to use wood enforced structures at the time of the 2006 floods and repairs. It wasn't until 2010 that the engineered log jam was put in place at milepost 6.0, and that marked the parks turn towards using more wood then boulder rip rap.

Looking towards the future, using more wood in mitigation structures and repairs would be much more reliable and lasting than boulder rip rap. During the summer of 2019, Tahoma Creek suffered from a debris flow and the prior installments of toe-roughened wood rip rap bundles at barrel curve proved effective and should studied further, as it’s possible of being the preferred future method for erosion mitigation (NPS, 2016) . These types of mitigation techniques could be used at any of the locations identified and may prove more effective than the rip rap or a combination of the two would be most effective. Adopting proactive practices like planning possible repairs ahead of time, or placing wood bundles/barbs before a devastating debris flow or flood, will save the park time and money down the line.

For more information:

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See Also:

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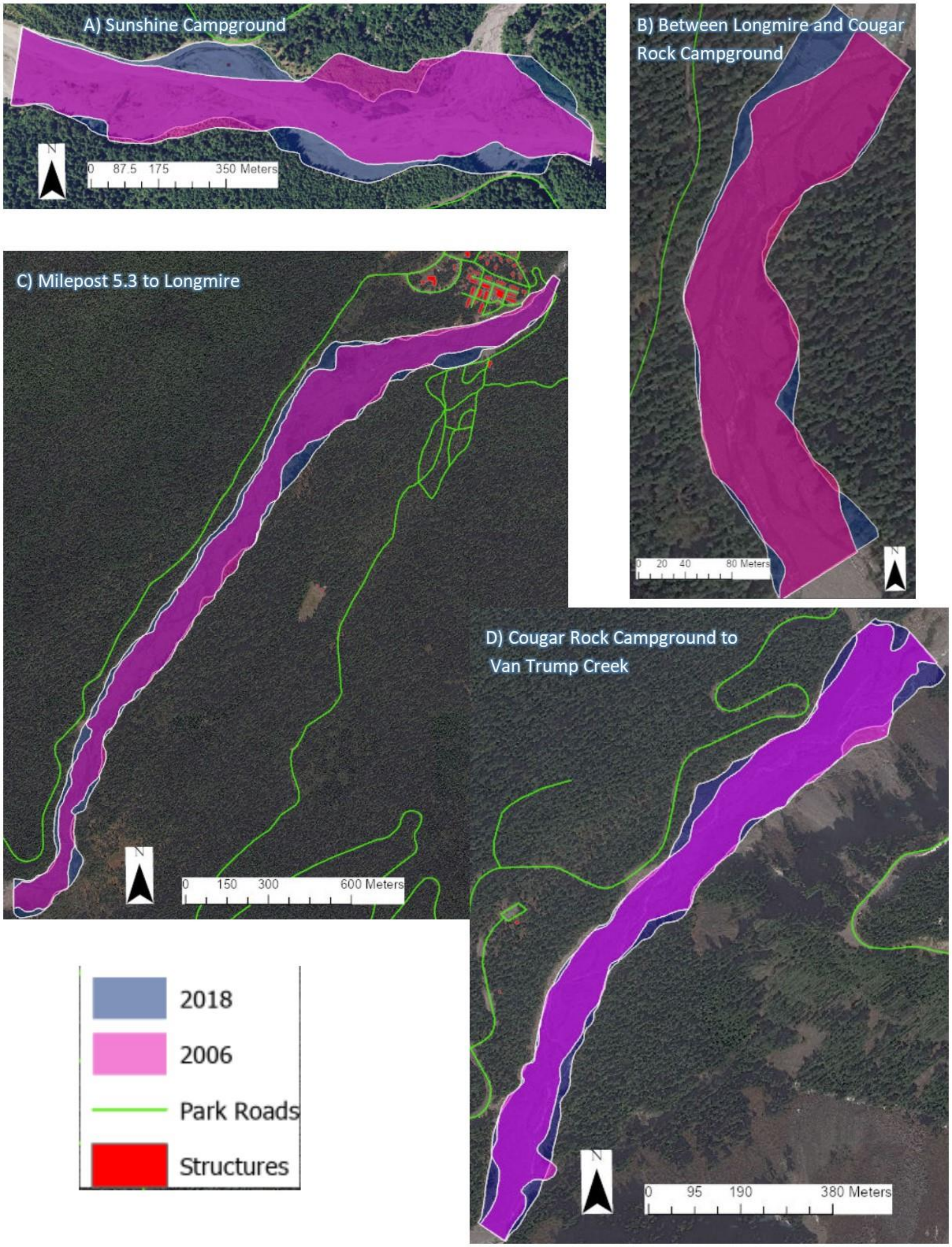
Appendix A

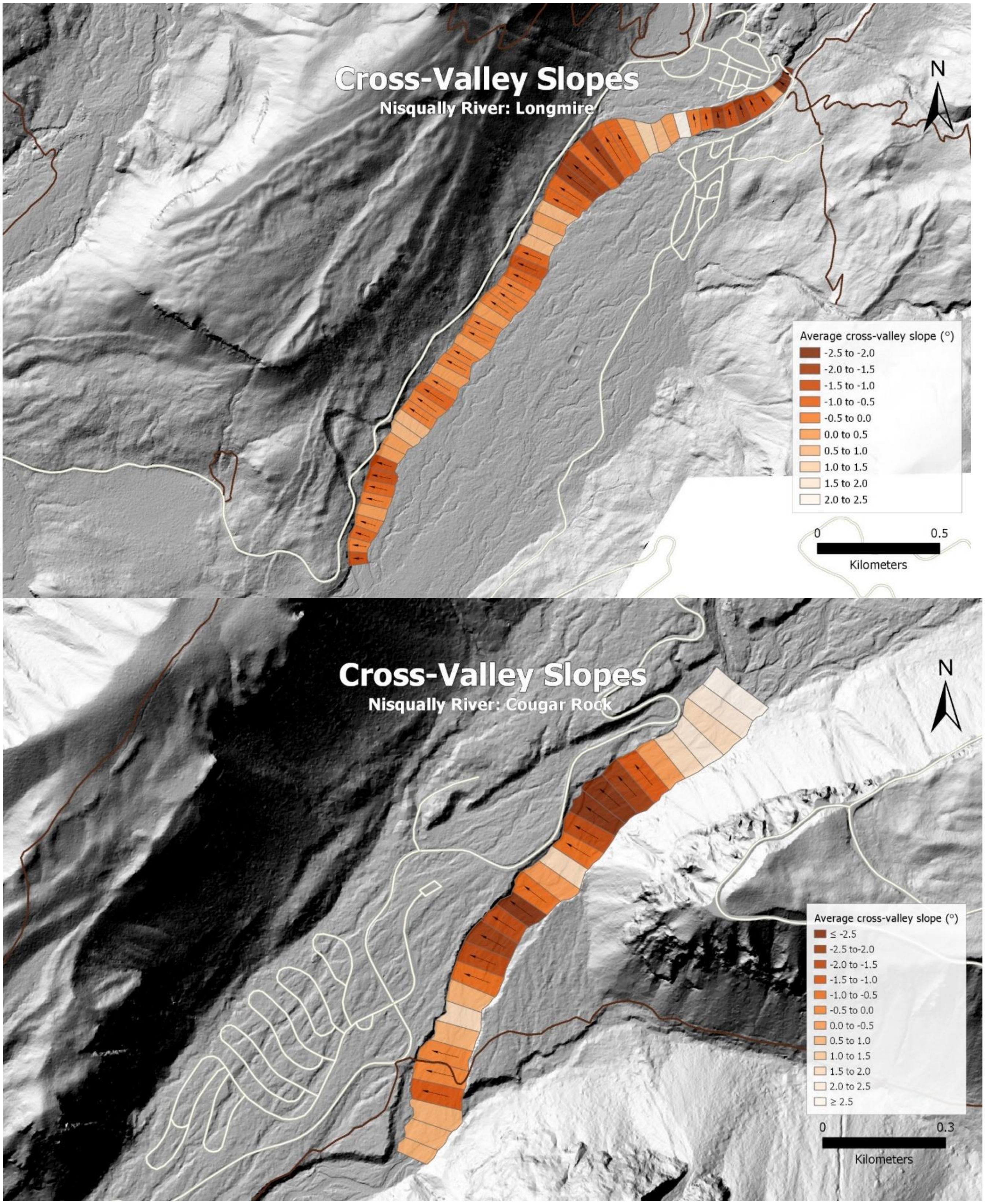
Appendix Table 1: Average life span calculations for the river right (roadside) banks at problem areas along the Nisqually. Data is based on measurements made in google earth between separate polygons showing the river channel in 2006 and 2018. Table created in Excel.

	Milepost 5.3	**Milepost 6.0**	**Upstream of Longmire**	**Milepost 9.0**	**Van Trump Creek**	**Cougar Rock Picnic Area**
Average Erosion (ft)	62	89.2	33	82.5	55	36.78
Average Yearly Erosion (ft)	5.14	7.43	2.77	6.88	4.56	3.06
Current distance from road to river (ft)	50	45	50	60	35	100
Average Lifespan (years)	**9.7**	**6.1**	**18.1**	**8.7**	**7.7**	**32.6**

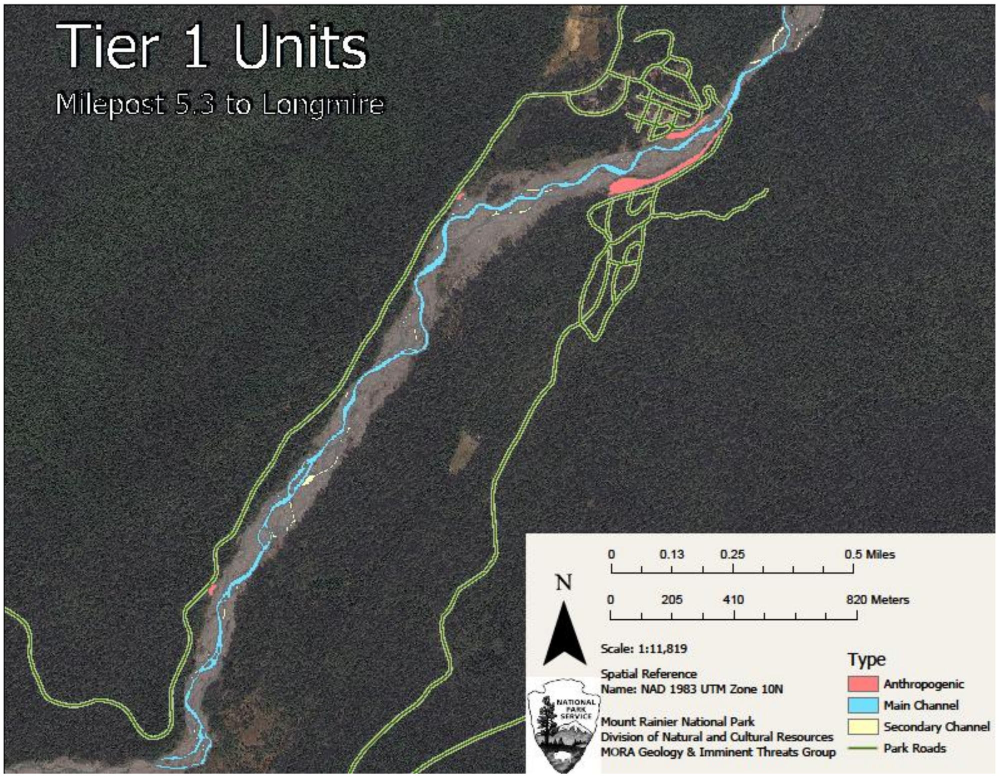
Appendix Figure 1: Collections of maps created in Google Earth showing the two polygons created to show bank erosion from 2006 to 2018. The pink polygons represent river plain in 2006 and blue represents river plain in 2018.

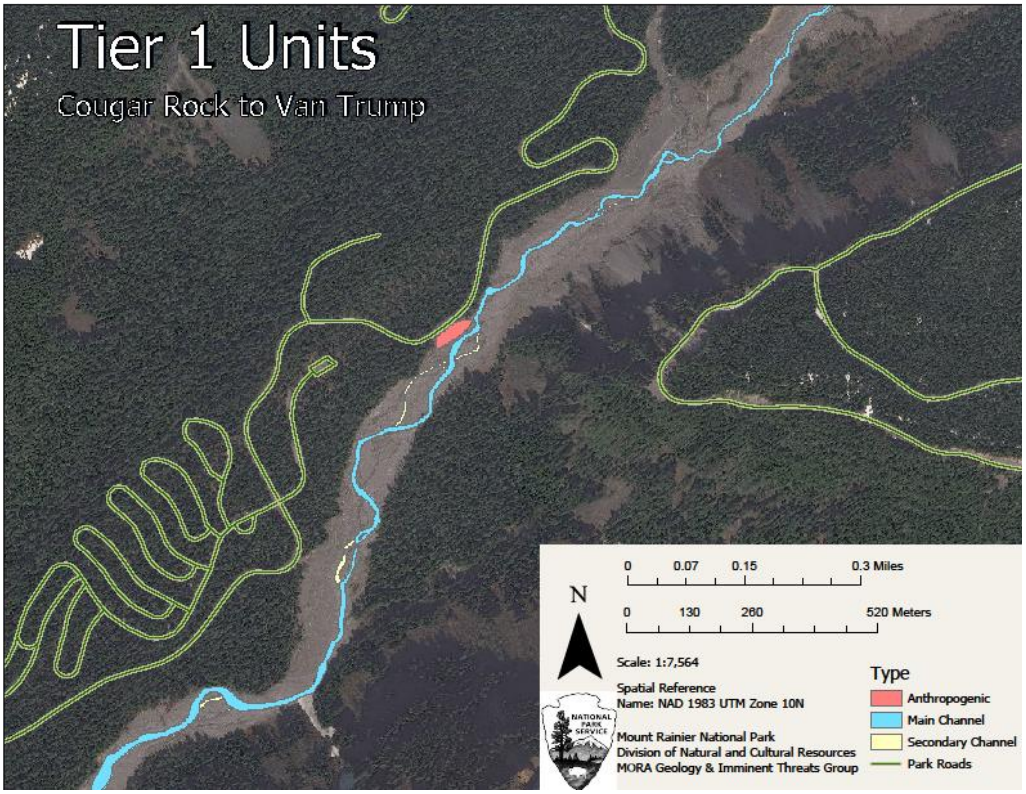


Appendix Figure 2: Average cross valley slopes map from milepost 5.0 to the Longmire Bridge and Cougar Rock Campground to Van Trump Creek. Darker colors mean the slope is negative and dipping towards the road, the arrows also show which way the section is dipping. Sections without an arrow are flat or dipping away from the road.

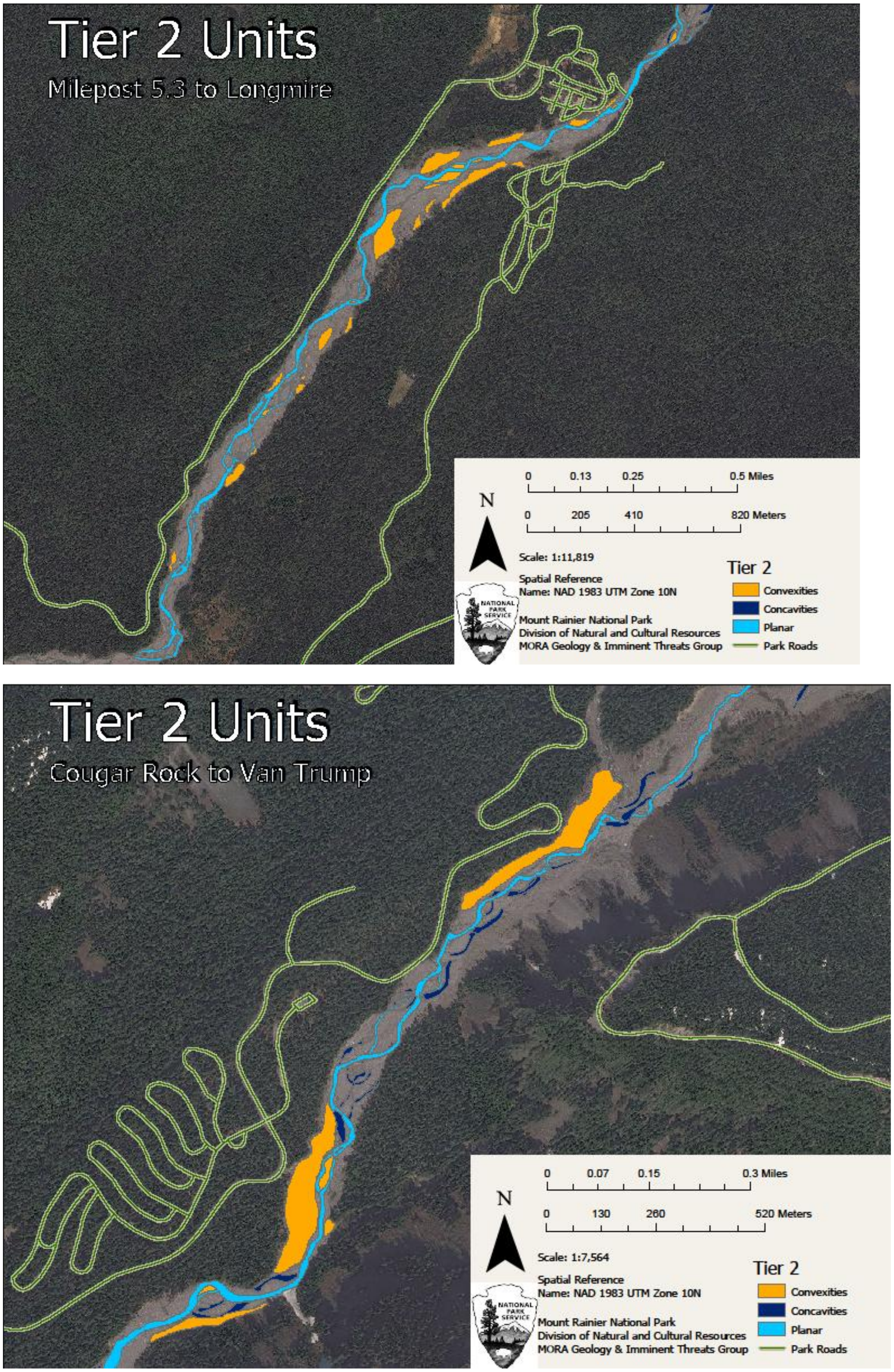


Appendix Figure 3: Map showing the tier one locations of both sections of river. Polygons either represent anthropogenic or natural origin.

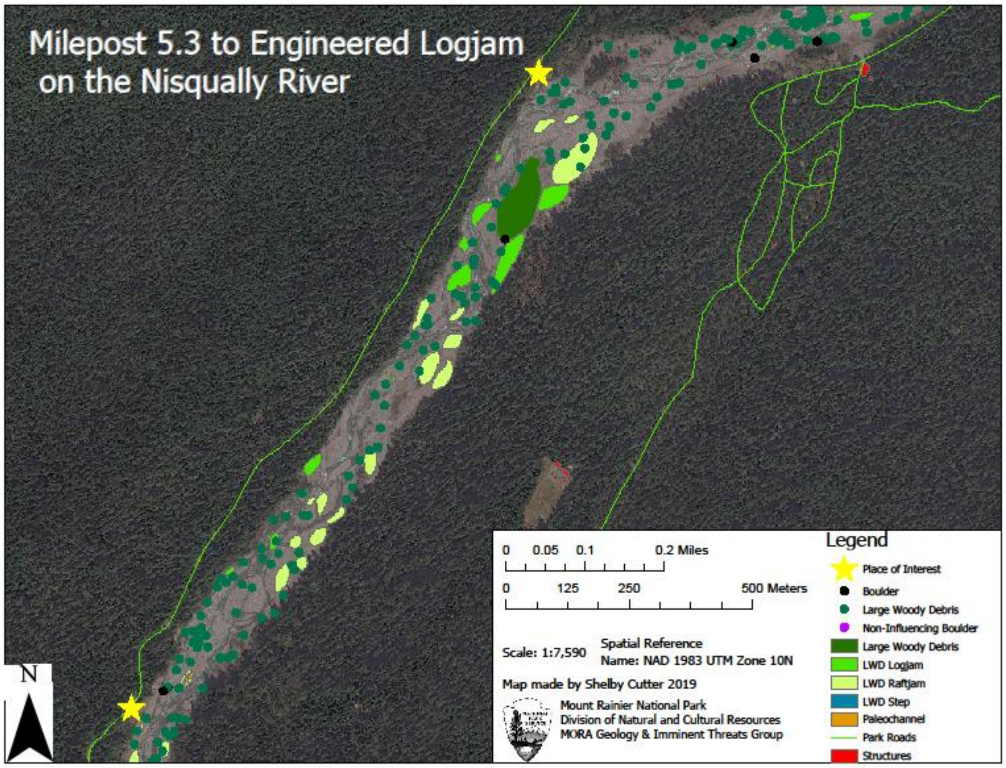


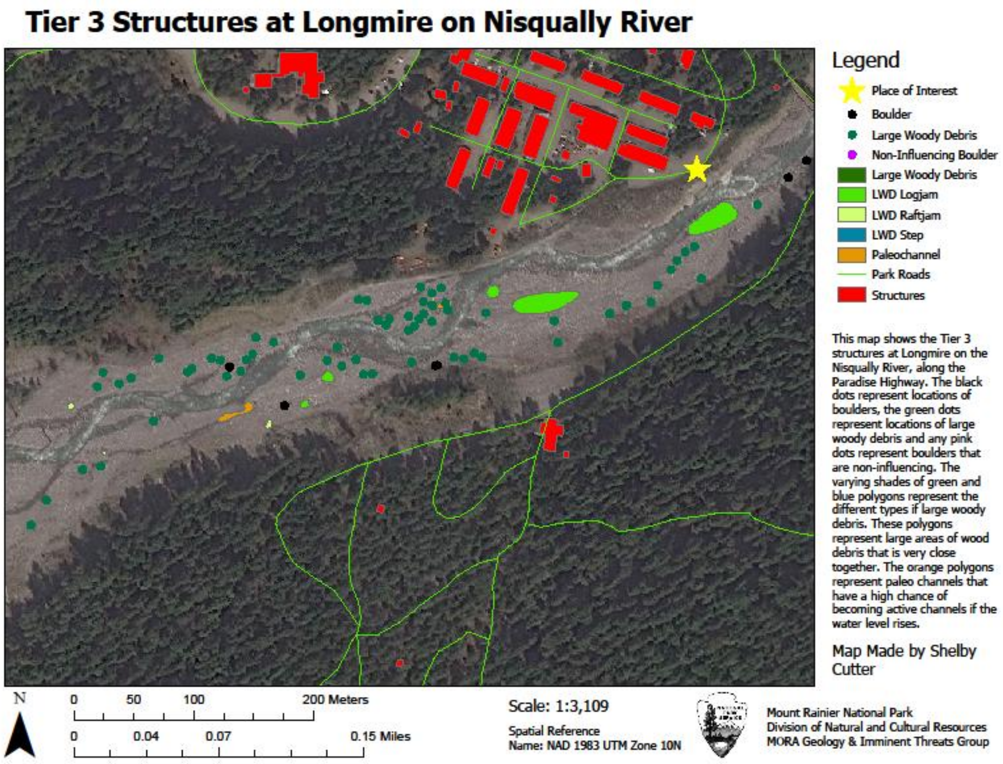


Appendix Figure 4: Map showing the tier two locations of both sections of the river.



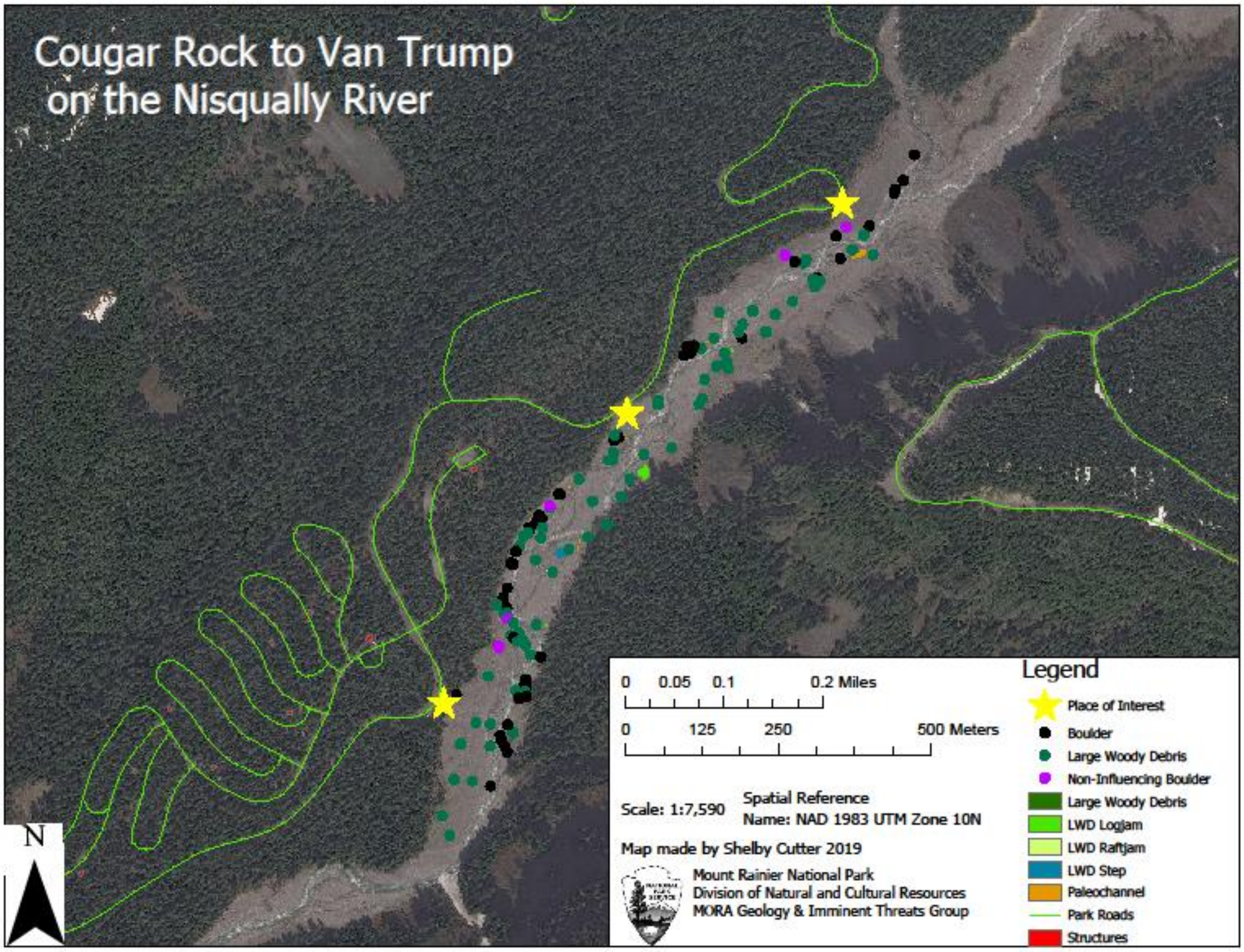
Appendix Figure 5: Map showing the tier 3 locations of both sections of the river.



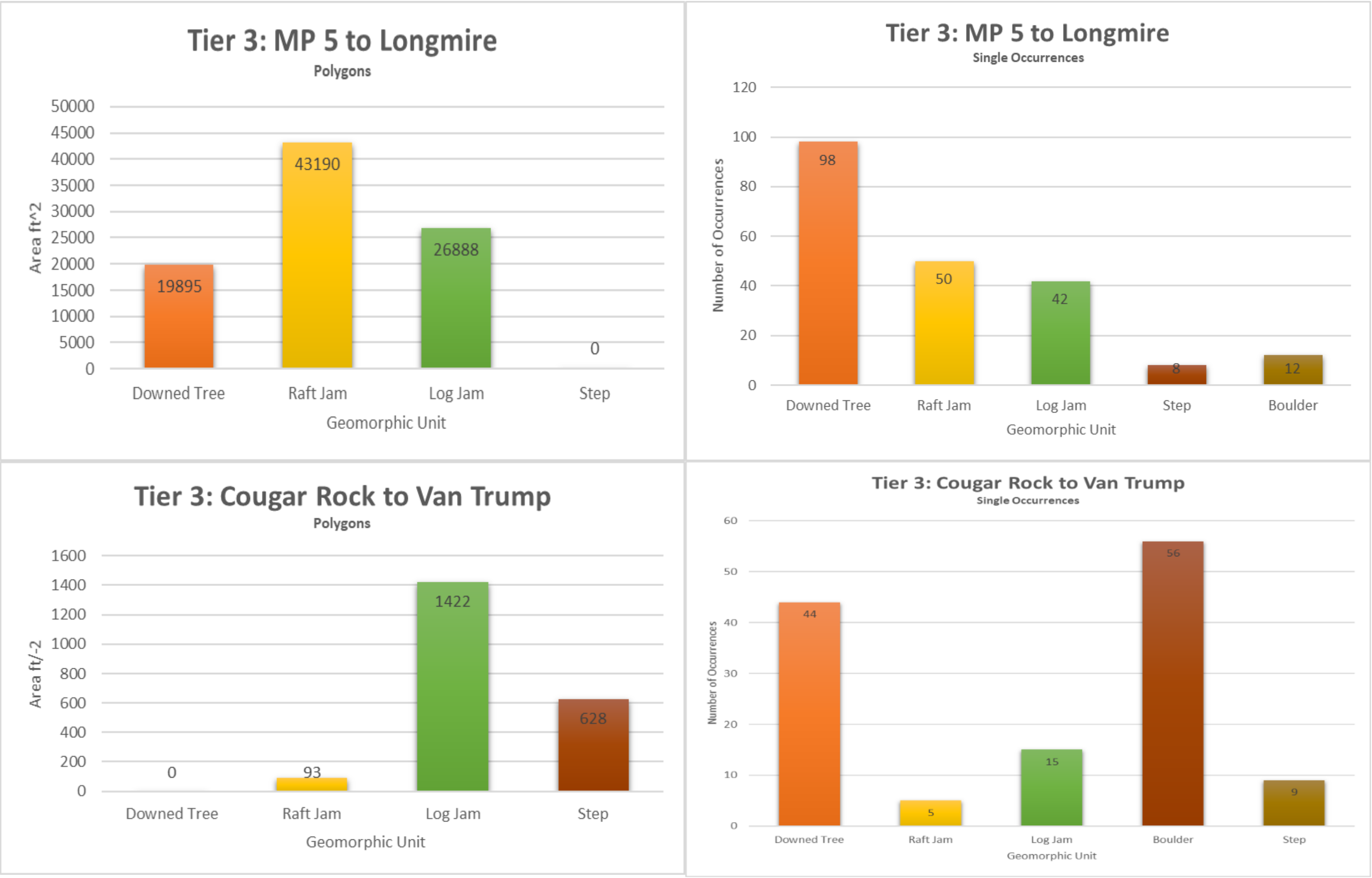


This map shows the Tier 3 structures at Longmire on the Nisqually River, along the Paradise Highway. The black dots represent locations of boulders, the green dots represent locations of large woody debris and any pink dots represent boulders that are non-influencing. The varying shades of green and blue polygons represent the different types if large woody debris. These polygons represent large areas of wood debris that is very close together. The orange polygons represent paleo channels that have a high chance of becoming active channels if the water level rises.

Appendix Figure 6: Tier 3 locations Cougar Rock to Van Trump.



Appendix Figure 7: Tier 3 bar graphs showing the amount of single occurrences in the two sections along with area amounts, as there were some larger areas that were NOT counted but lumped together as a wide swath of the geomorphic unit.



Appendix Figure 8: Definitions of various acronyms.

Acronyms	**Definitions**
LWD	Large Woody debris
BD	Boulder
NIBD	Non-Influencing Boulder
RJ	Raft Jam
LJ	Log Jam
S	Streamwise
P	Perpendicular
D	Diagonal
R	Radial
ANDS	Andesite
ANTH	Anthropogenic
GDR	Granodiorite
PC	Paleochannel
ELJ	Engineered Log Jam