RECLAMATION

Managing Water in the West

Geomorphic Investigation of Quinault River, Washington

18 Km Reach of Quinault River Upstream from Lake Quinault

U.S. Department of the Interior
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1.0 Introduction

In an effort to better understand what opportunities exist to restore sockeye salmon habitat, the Bureau of Reclamation (Reclamation) was asked to undertake a geomorphic evaluation of the Upper Quinault River on the Olympic Peninsula in northwest Washington State (Figure 1). The Upper Quinault River as described in this report extends for 18 river kilometers (RK) (11.2 miles) from the upstream end of Lake Quinault (RK 0) to the junction of the North and East Forks of the Quinault River ("forks") near the National Park Service Bridge (RK 18). The East Fork Quinault River is also commonly referred to as the mainstem fork of the Quinault Report.

Biologists working in the Quinault River system have documented a decline in the number of sockeye salmon in the Upper Quinault River (Figures 2 and 3) (QIN, 2002). Biologists hypothesize that this decline is in part a result of human activities within the upper river valley during the last hundred years, along with a decline of water quality in Lake Quinault. A recent watershed analysis study (QIN, 1999) hypothesized the possibility that clearing of large trees within the floodplain in the early 1900s altered natural sediment loads, channel patterns, and ultimately reduced the quantity of suitable sockeye habitat in the Upper Quinault River. The study also noted that a reduction in suitable spawning habitat could occur gradually over time, ultimately resulting in the decline in sockeye habitat. Additionally, the question has been posed as to whether high rates of bank erosion and the wide extent of flooding experienced in the Upper Quinault are simply natural hazards that arise from living near a river, or have been exacerbated by human activities. Others view the Upper Quinault River as a relatively pristine natural area relative to other Pacific Northwest rivers, and that the river is simply naturally dynamic accounting for the rapid rates of channel change and bank erosion. The north side of the river has been part of Olympic National Park (see Figure 1) since 1938.

In 2001, the Quinault Indian Nation asked Reclamation for technical assistance to further evaluate the Upper Quinault River sockeye habitat and human disturbances hypotheses and questions posed in the Watershed Analysis. Reclamation has no management responsibility in the Quinault Valley, but it provided technical assistance to obtain scientific information that resource managers and stakeholders could weigh as they determine how the river should be managed in the future. Other stakeholders in the valley that have involvement with the river are the National Park Service (NPS), U.S. Forest Service, Grays Harbor County, Jefferson County, fisheries agencies, and private property owners. Funding for the study was provided by Reclamation and a Salmon Recovery Fund Grant that was part of a cooperative agreement with the Quinault Indian Nation, Reclamation, and the Salmon Recovery Fund Board.

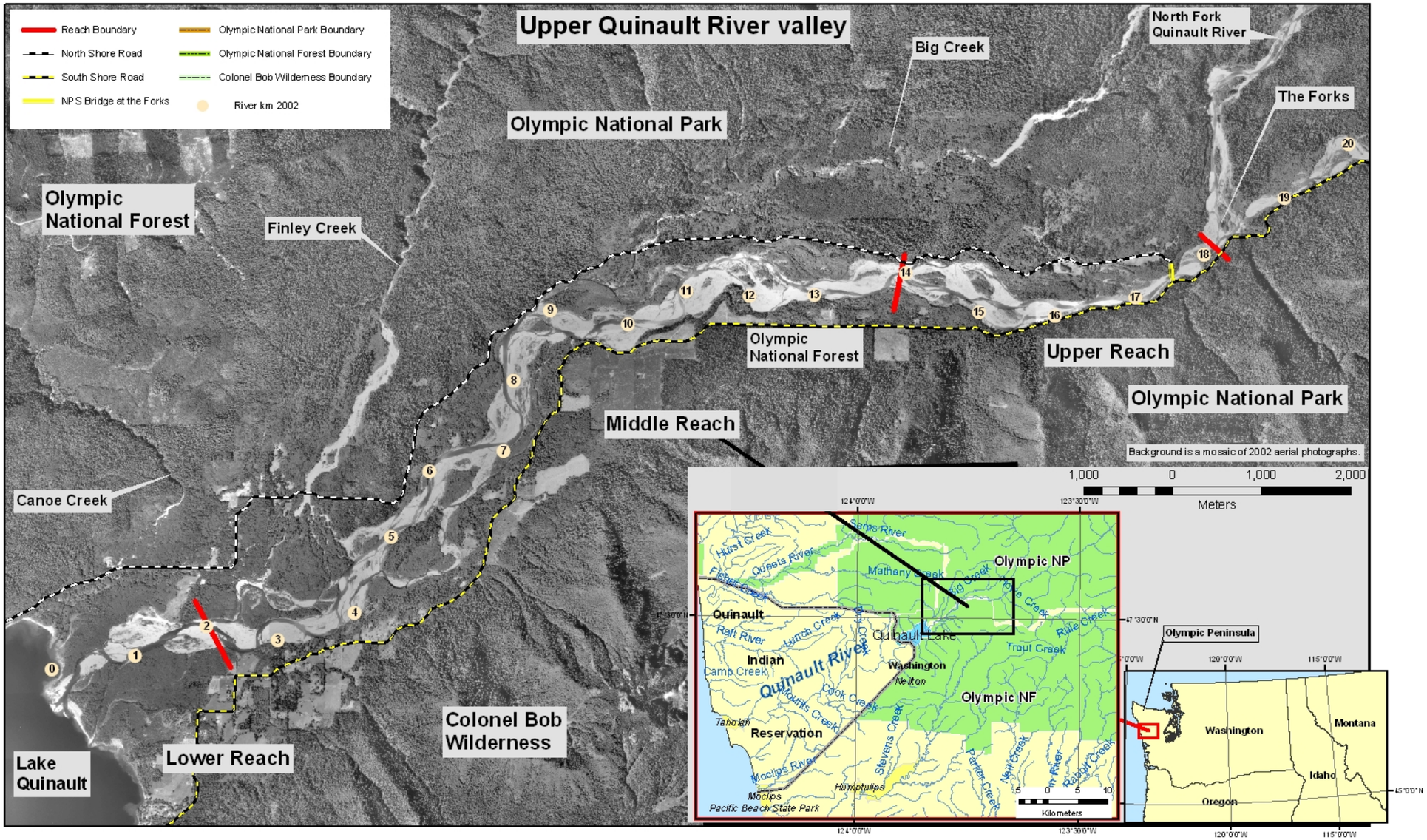

Figure 1. Location of the study reach, between Lake Quinault and the confluence of the North and East (or mainstem) of the Quinault River.

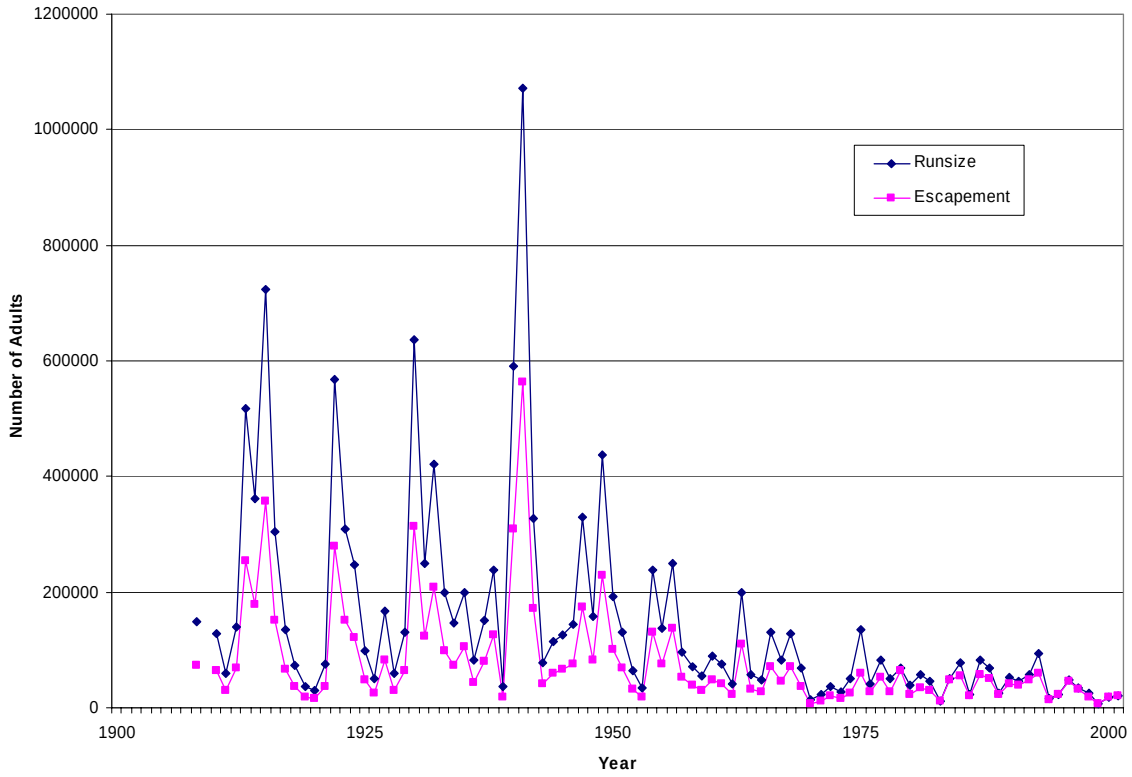

Figure 2. Annual sockeye data for last hundred years from Quinault Department of Fisheries.

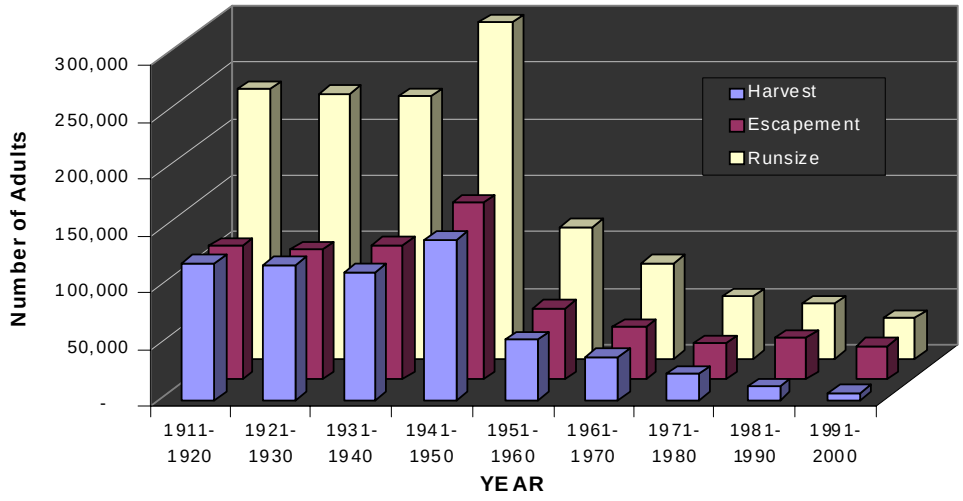

Figure 3. Average numbers of sockeye in the Quinault River shown by decade from Quinault Department of Fisheries.

1.1 How This Report Is Organized

The main report (Sections 1 to 11) provides overview information about our study as described below. More detailed documentation on data collected and technical analyses accomplished is provided in appendices at the back of this report.

Section 1.0: The first section of this report discusses who asked for this study, lists the questions that we studied, and provides a brief summary of the entire study.

Section 2.0: The second section explains how we gathered the data used to answer the study questions.

Section 3.0: The third section describes how the Upper Quinault River looked before significant human disturbances. We have assumed that Native American occupation of the Upper Quinault River Valley, before the arrival of Euro-American settlers in the 1890s, represents the "natural setting" to which more recent changes are compared. This natural setting (before settlement) is formally termed the "reference condition."

Sections 4.0 and 5.0: The fourth and fifth sections documents the timing and extent of disturbances (both natural and human) in the river corridor since about 1890, and how the river has responded to these disturbances.

Section 6.0: Section six tries to predict how the river is likely to evolve in the future, if land use in the Upper Quinault River Valley remains about the same as it is today.

. **Section 7.0:** On the basis of information gathered in this study, section seven describes ideas about how the river could be restored to more closely resemble its pre-settlement condition.

Section 8.0: Section eight provides conceptual ideas on projects that could be implemented in sockeye habitat reaches of the river most in need of immediate restoration to protect it from irrecoverable damage.

Section 9.0: Section nine lists recommendations for future studies necessary to support the next phase of implementation of restoration projects.

Sections 10.0 and 11.0, and Appendices: The remaining sections provide a list of references, a glossary, and appendices that contain detailed technical information and figures that are referenced in the main body of the report.

1.2 Study Questions

A multi-disciplined team with backgrounds in biology, geology, hydraulic engineering, and geomorphology from Quinault Indian Nation, Reclamation, and Herrera Environmental Consultants developed the following 12 study questions, which guided the investigation.

Questions about the Upper Quinault River:

1. What were the natural river processes on the Upper Quinault River before settlement in the valley in the late 1800s and early 1900s?
2. Is the existing system different from that which existed prior to human settlement?
3. If differences exist, has the magnitude and frequency of change steadily increased with time, or has it varied in a more complex fashion?
4. What natural or human activities have taken place in the watershed and valley, and to what extent has each of these altered the system?
5. What might the river and its adjacent floodplain look like during the next 50 to 100 years?
6. If river conditions today differ from pre-settlement conditions and if today's land-use practices remain the same in the valley for some time into the future, what is the potential that the river will recover on its own? How long might recovery take?

Questions about sockeye habitat:

1. How does each of the natural and human influences assessed (Question 4 above) affect the sockeye's side-channel and terrace-channel habitat?
2. Why has the sockeye habitat remained more highly productive in the reach extending from Big Creek to the confluence of the two forks, while it has become much less productive in the reach between Big Creek and Lake Quinault?
3. On the basis of information gathered in this study, what restoration strategies for improving fish habitat are feasible, and which locations in the Upper Quinault would they most greatly increase habitat?
4. How might sockeye restoration strategies additionally reduce bank erosion?
5. It may take decades or centuries for fluvial processes to generate a natural channel, even if a long-term restoration plan is implemented. During this interval, are there short-term strategies that could protect existing habitat, property, and infrastructure?
6. What is the risk of destruction for existing side-channel and terrace-channel habitat, and what restoration strategies would be recommended specifically for each of these sites to protect, enhance, or restore sockeye habitat?

1.3 A Summary of What We Found

The following text summarizes key conclusion points from the geomorphic investigation. Supporting data and analyses can be found in the main report and appendices following this section.

1.3.1 River Condition in Late 1800s

The Quinault River functioned as a natural, undisturbed river system through most of the 1800s. This natural system existed amid active mountain uplift and river downcutting, frequent floods, dense forest, and abundant large woody debris. The river channel had a

large, coarse sediment and large woody debris load and migrated relatively slowly across its floodplain (the area between terraces or bedrock boundaries) because the floodplain's dense forest helped it to resist erosion. This migration and channel shifting resulted in a continual cycle of erosion of older surfaces while at the same time building of new surfaces. New surfaces would start as sediment bars, but could eventually develop into stable, vegetated terraces when large woody debris anchored the surface from being eroded. These anchored bars became vegetated terrace surfaces and provided a continual source of large woody debris over long periods of time, along with forested terrace banks on either side of the floodplain. Much of the recruited woody debris was transported through the system during floods, but supply levels were high enough that a few key pieces would remain stable and form "hard points" in the system (points that resisted erosion and slowed migration).

The river typically consisted of one, or sometimes two, narrow (relative to the total floodplain width) and deep main channels with many side channels winding through the forested floodplain. Side channels were generally located in areas where the main channel had last occupied, and lasted anywhere from a few years to several decades. Side channel entrances that plugged with sediment and woody debris provided salmon habitat during low flow periods through groundwater or tributary-fed water connections. During higher flows the channels would be flushed out of fine sediment to keep spawning gravels from plugging. Beaver ponds may have also played a role in side channels helping to trap fine sediment and providing additional wetted areas. Small, narrow channels also dissected portions of the higher, forested terraces on either side of the active floodplain. These terrace channels provided significant amounts of habitat that had less risk of being reworked by the river than side channels. These terrace channels may have persisted for several centuries in some places. Salmon would have utilized all of these channel regions in different capacities, such that the Upper Quinault offered a wide, complex variety of habitat features.

1.3.2 River Changes during Twentieth Century

The river has changed markedly since the late 1800s, largely as a result of clearing of mature forests and large woody debris in and around the river area in the late 1800s and early 1900s. We propose the river was in a state of transition to a new "altered" condition in the early 1900s in response to the removal of large woody debris and increased sediment load from vegetated islands and terraces that were eroded. Areas that were clear cut changed river processes to a greater degree than did areas where only the largest trees were selectively cut. After vegetation was removed, relatively stable hard points were gradually lost along the course of the river and have not been naturally replaced due to the lack of mature forest from which to develop new stable hard points. Once these hard points were gone, the river was free to migrate across the floodplain at a faster rate. The more rapidly migrating river liberated large amounts of sediment that had been stored in bars, vegetated islands, and the floodplain. The sediment supply quickly increased above natural levels. At about the same time, removal of vegetation on the adjacent terraces made terrace banks more vulnerable to erosion by the river during floods. This bank erosion, in addition to destroying property and roads, further increased

the amount of sediment input to the river and resulted in a large loss of historically stable terrace channels.

Since 1939, our analysis indicates the river has remained relatively consistent in this altered channel state and has not recovered back to a natural state. The mature vegetated islands and large woody debris have not yet been restored to the system in enough quantity to recreate the reference conditions. The river responded to this new load by making its channel wider and shallower and, overall, more uniform. The new channel has fewer pools and less complexity. The present sediment load is thought to be higher than it would be naturally, due to accelerated bank erosion and reworking of channel and floodplain deposits within the study reach. A recent observation by the National Park Service in the upper watershed above the confluence of the two forks of the Quinault River suggest that bank erosion rates in some areas may be increasing, which would increase sediment loads to the study reach and exasperate any accelerated sediment loads caused by human disturbance. Additional analysis would need to be done to further explore this hypothesis. In contrast to the significant changes to the floodplain forest and channel response, no significant, measurable changes have occurred in mass wasting in the upper watershed above the confluence of the two forks of the Quinault River, or geologic processes (such as uplift or the influence of Lake Quinault) during the twentieth century.

1.3.3 Flood Peaks

Lake Quinault naturally dampens flood peaks generated from the upstream Quinault River. Flood peak values recorded at the USGS gage at the outlet of Lake Quinault are estimated to be 30 to 40% lower than the river flow near the inlet to Lake Quinault. Flows would reduce in magnitude in the upstream direction as the drainage basin area reduces. The 2- to 100-year floods at the confluence of the two forks of the Quinault River at RK 18 (upstream end of study reach) are estimated to increase by roughly 20% by RK 8 (Big Creek confluence), and by a total of 30% at RK 0 at the lake inlet.

An analysis of USGS gaging station data at the outlet of Lake Quinault indicate the largest peak floods have not appeared to change, but the frequency and magnitude of common flood events were greater in 1951 to 2002 (inclusive) than during 1911 to 1950. The 2-year flood between 1911 and 1950 was 19,989 ft^3/s and between 1951 and 2004 was 24,504 ft^3/s, indicating it has increased about 23%.

Determination if flood stage immediately upstream from the lake shoreline is increasing or decreasing over time as a result of increased sediment loads could not be quantified in this study. The quantity of additional sediment contributed from measured bank erosion between 1939 and 2002 would tend to increase the rate of delta deposition. However, some of the sediment contributed from bank erosion is stored (at least temporarily) in the expanded HCMZ between 1939 and 2002. At the downstream end of Lake Quinault, the moraine which controls the lake elevation is incising at an estimated amount of 0.5 m per hundred years. A lowering of the lake level would cause incision of the river channel in the delta area and tend to reduce flood stage in the upstream river channel influenced by the delta.

1.3.4 Sockeye Response to Changes in River Processes

Monitoring data show the Quinault sockeye produced cyclic, but substantial runs in the first fifty years of the twentieth century, but beginning in the 1950s experienced a decline that has not yet recovered. It is not known why the overall sockeye population numbers continued to be high into the 1950s when the most significant response of the main river to disturbance is thought to have peaked in the 1920s to 1930s and remained relatively consistent since that time. It is possible that remaining tributary channels and protected terrace channels provided sufficient premium habitat to sustain the sockeye population at high levels until cumulative effects of river disturbance degraded the overall habitat productivity.

In addition to cumulative effects of river channel instability and migration, the decline of sockeye population size after 1950 could have been influenced by increasing frequencies of channel reworking flood events. The more frequent and slightly larger flood flows occurring on a disturbed, unstable floodplain could have eliminated any remaining premium habitats for sockeye, and would have further degraded the over all habitat productivity in the system.

Increased channel migration, channel bank and terrace erosion, and the consequent reduction of the number of spawning salmon in the Upper River would also cause a decline in water quality and trophic productivity within the rearing environment of Lake Quinault. This is a critical phase for over all productivity of the system, and poor conditions in the Lake would act as a bottleneck that would limit production. Deteriorating conditions in Lake Quinault likely occurred simultaneously with changes occurring in the Upper River to affect and limit the capacity of the system to produce sockeye salmon.

The river can no longer sustain the same quantity of quality sockeye habitat for decades to centuries as it did in the reference conditions. Tributary channels that are less susceptible to river processes presently provide the most stable habitat in the present system. Terrace channels that were historically stable for several decades to centuries are now at a higher risk to erosion by the river. The presently wide, shallow river with a general lack of large, stable woody debris does not provide adequate holding pools that can remain wetted during low flow periods. These pools are essential for sockeye survival to help them survive between hatching and migration down to Lake Quinault. The few areas that are available are at high risk for being washed out by the river during subsequent high flows.

Prior to the completion of this study, sockeye habitat was believed to have been more highly productive in the reach extending from Big Creek to the confluence of the two forks of the Quinault River, and less productive in the reach between Big Creek and Lake Quinault. Through this study, biologists have identified habitat areas of importance to sockeye in both reaches, but downstream of Big Creek there are still some natural factors that limit habitat. First, the Finley Creek alluvial fan has historically limited the amount of habitat on the north side due to recurrent debris flows. However, NPS biologists have

recently observed fish in the upper portion of Finley Creek above the Finley Creek Bridge. Also, a new side channel has recently formed in the toe of the alluvial fan where the river reworked the area and then shifted to the south. Dredging has been occurring for several years to control aggradation occurring at the Finley Creek Bridge. These activities may limit the location of the Finley Creek confluence with the Quinault River and the amount of sediment that passes down into the Quinault River channel relative to reference conditions. Second, the one to two mile reach just above Lake Quinault is a depositional zone (delta) that also limits the availability of more typical terrace and side channels found in the upstream sections of our study reach. However, this delta area has a lot of complexity due to the deposition of woody debris and offers some unique habitat both in the active floodplain and in terrace channels not found in other parts of the study reach.

1.3.5 Land Management Considerations

Landowners whose property and infrastructure directly abut the active channel run the greatest risk of continued bank erosion and loss of land. Surfaces on the south shore near Lake Quinault may contain old lake bed deposits (clay) that have more ability to resist erosion than upstream more erodible alluvial terrace surfaces. Landowners within the backwater influence of Lake Quinault have also been subjected to repeated flooding. However, while some degree of flooding can be tolerated, eroded property cannot be easily recovered. Over the last century river-front landowners have responded to loss of property and endangered infrastructure by re-arranging or removing large woody debris and log jams in the river and placing cabled logs and rock riprap along the river bank to try and limit erosion. This approach has in places worked, but can also cause unanticipated effects to other land across or downstream from the site protected. In some cases this has limited habitat availability because entrances to side channel become blocked with fill or levees. Recently some landowners have begun replanting of forest along bank lines and are interested in additional short-term protection strategies that would help limit erosion risk.

1.3.6 Restoration Need and Strategy

The Quinault River is lacking large trees that serve to protect terrace banks and provide large woody debris to the river channel. The channel migration rates of the Quinault River are believed to be much faster than under natural conditions and large areas of river terraces have eroded during the 20th century. These terrace areas cannot be recovered through a self-healing process. A more aggressive strategy is needed to protect what habitat is left and recover a portion of what has been lost. In order to restore slower rates of channel migration and bank erosion it is necessary to improve mature riparian and terrace forest conditions. If nothing is done, we predict that terrace vegetation on the north (Olympic National Park) side of the river may eventually mature, begin to contribute large woody debris to the river, and slow the rates of lateral migration. However, it could take centuries for the forest to mature and have any significant effect. In the mean time, accelerated rates of bank erosion and channel migration will persist, particularly on the south side where there is less chance of establishing mature vegetation under present land use practices. Other, more localized structures such as levees, bridges,

roads, and areas where channels have been artificially filled in can also reduce sockeye habitat. These structures may require mitigation if restoration is implemented.

We propose both short-term and long-term restoration strategies to improve the ability of the river to sustain habitat features vital to sockeye salmon and to protect adjacent property. Short-term strategies would protect the most vulnerable terrace banks and sockeye side channel and terrace habitat areas. Long-term strategies would restore the mature forest on both terrace banks and patches within the active floodplain to provide an adequate recruitment source of large woody debris. This would re-establish the ability of the river to build stable hard points and terrace surfaces that have been lost over the last century. We believe that this approach will help prevent further loss of sockeye salmon habitat and property while also promote a self-sustaining fluvial and valley ecosystem that eventually would not require further intervention. If the future types of human disturbances of the river, land use around the river, hydrology, sediment loads, or even geologic processes change significantly, then the restoration strategy and long term vision would need to be re-visited and adapted to account for these changes.

1.3.7 Project Prioritization and Implementation

The Quinault Indian Nation has adopted an integrated restoration approach that includes enhancing the habitat in Lake Quinault and the Upper Quinault River system (Sims, 2002). The primary goal of restoring fish habitat in the Upper Quinault River is to increase the quantity and quality of sockeye spawning habitat; i.e., increase the capacity of the habitats to hold more spawning sockeye and produce greater numbers of emergent juveniles for recruitment into Lake Quinault. Eight side channels (sloughs) and six terrace channel complex areas were identified in the study reach as significant sockeye habitat areas in the present system that could be prioritized for restoration action. A reach-based restoration approach is recommended that will lead towards a more self-sustaining system, but also consider upstream and downstream implications of any actions. Within the vicinity of each side channel and terrace channel complex, specific restoration actions recommended include:

1. Engineered log jams at channel entrances to slow rate of being overtaken by the main channel (some rate of reworking is necessary over several decades)
2. Protection (engineered log jams and/or rock) of young vegetated bars within the active floodplain that have a chance at developing into mature forest (stable hard points)
3. Replanting (long-term) and protection (short-term) of cleared terrace surfaces most at risk to erosion, mainly on the south side of the active floodplain
4. Further evaluation of any infrastructure that could be modified to enhance sockeye habitat areas and manage flooding issues such as road crossings on the Finley and Kestner Creek fan complexes, fill areas and/or undersized crossings in terrace channels, Bunchfield Levee, riprapped areas, etc.

Areas of highest priority for sockeye habitat channel protection are tributary and terrace channel complexes that historically have provided the most stable habitat, and if lost would take the longest amount of time to re-develop. Young vegetated bars (identified in

the report) containing trees that are two to three decades old are recommended for the highest priority for protection where there is a lack of large woody debris already present. Areas of highest priority for bank protection are the south side surfaces because the north side vegetation is generally recovering faster, although the north side will still be at some risk for the next few decades. The planting of trees could be considered on the north side in areas where grasses have replaced the native forest, or in areas where non-native trees have established in place of the natural forest species.

The next step recommended is to develop a plan to implement restoration strategies on a site-specific basis. Herrera Environmental Consultants is assisting the Quinault Indian Nation in taking this next step. This plan would be formulated to work with existing constraints and processes, and utilize existing resources in the river basin where possible. The information provided in this document provides the justification, baseline information, and strategies needed to implement a reach-scale restoration plan. Additional, more detailed data may be needed at specific sites to develop adequate engineering designs.

2.0 Methodology

Before we can develop ideas concerning what to do about the river, we must determine what the river looked like in the past (before Euro-American settlement) and what differences exist between its past and present condition. The key has been establishing two aspects of the river: its past and present shape (morphology) and the rates of change in that morphology. Once we understand these two aspects, then we can understand how the river will continue to function in the future, either on its own or in response to restoration strategies. For instance, if logging and clearing of woody debris from the channel and floodplain has increased rates of channel migration, placing woody debris in the river to dissipate energy may help restore more natural, slow rates of channel migration and help restore sustainability of sockeye habitat. However, if the river channel is filling up (aggrading), restoration strategies would need to accommodate channel braiding, a usual response of rivers to aggradation. Managing land or habitat without considering morphology and morphological change would, in the long term, be unsustainable and might actually worsen current river management problems.

2.1 General Approach of This Study

To evaluate to what extent the existing river system is disturbed relative to its pre-settlement condition, we compared existing river processes with river processes that existed before settlement within the valley. We assume that the condition of the river during Native American occupation of the Upper Quinault River Valley, prior to the arrival of Euro-American settlers in the 1890s, represents the reference condition or "natural setting" with which more recent changes are compared. First, we studied the geologic history of the valley and historical changes in the river during the last century. We sought differences in morphology in the river at two time points: just before settlement and during this study (2002). Second, we determined whether those differences were best explained by natural processes operating in the fluvial system or by human activities in the watershed and valley.

We then applied insights gained from these studies to predict how the river would tend evolve in the future under two sets of conditions: if no action were taken and if restoration activities were undertaken. For processes that were shown to have been altered by human activities, we identified activities that could help restore natural processes while working within the present natural and human constraints. This study focuses on large-scale river processes and morphology as influenced by the hydrology, sediment supply, vegetation, and geologic controls on the valley system. The timeframe evaluated ranges from thousands of years, the period during which the river valley formed, to roughly the last century, the period within which human changes in the river system can be observed. The study reach was broken into three sections (upper, middle, and lower) based on geomorphic differences (see Figure 1). The boundary between the

upper and middle sections occurs at the location of a large bedrock feature on the north side of the Quinault River (RK 14). The boundary between the middle and lower sections occurs at a location thought to be near the upstream end of present delta processes occurring as a result of Lake Quinault (RK 2). The boundary between the lower and middle section is also unique in that it as the downstream end of a large, historic alluvial fan from the Finley Creek drainage.

For this study, habitat side channels are defined as areas within the active floodplain of the Quinault River that are subject to being reworked by the main Quinault River at some point in the near future. In the natural setting, side channels are typically vegetated on either side of the channel or can be bound by older geologic surfaces (terrace, bedrock, etc) or a river bank within the active floodplain. Terrace habitat channels are also areas where the Quinault River has occupied in the past, but the last time the channel occupied these locations is thought to be a much longer time ago (several decades to centuries) when compared to the active floodplain reoccupation rate of a few years to decades. Both side and terrace channels can receive flow from tributaries, a surface water connection with the main Quinault River, or groundwater connections (hyporheic flows). Tributary channels are paths that originate from a tributary on the hillslope of the valley wall and eventually drop onto the valley floor and into the Quinault River active floodplain.

2.2 Review of the Quinault River Studies

Two studies were available on the Quinault River that discuss possible river responses to the Quinault as a result of human disturbances, and how the river differs from reference conditions. These studies helped us formulate working hypotheses that guided tasks outlined for our study.

A recent watershed analysis compiled by several agencies used historical aerial photographs and maps to analyze the Upper Quinault River at a watershed scale (QIN, 1999). The river was described as having a rapid average rate of lateral channel migration of 13 m/yr and an expanding channel migration zone (the region in which the river moves its channel around). The 1999 study documented some of the early historical accounts of the river that characterized a much different system: a channel confined by mature riverbank (riparian) forest bounding the banks on either side and slow lateral migration rates. To explain these channel changes, the study hypothesized several possible natural and human causes and it considered management issues raised by the findings. Our study questions were in part formed to determine if the hypotheses presented in the watershed analysis could be verified.

The watershed analysis study noted that channel slope decreases in downstream direction, which, combined with the backwater influence from Lake Quinault, may in part explain recurrent flooding and rapid channel changes within the area influenced by Lake Quinault. The study also noted timber clear-cutting in the upper basin that may have increased landsliding and flood runoff during storm events. However, the watershed analysis also determined that flood peaks during the last hundred years or so are

dominantly related to changes in precipitation rather than to clear-cutting in the upper basin. Further, a comparison of aerial photographs from 1939 and the 1990s (references) found no significant increases in either the number or extent of landslides in the upper basin. Because the magnitude of flood peaks and number of landslides upstream of the confluence of the two forks of the Quinault River have not steadily increased in the past hundred years, we infer that the sediment loads supplied to our study reach of the Quinault River from the upper basin have not significantly increased during this time.

O'Connor (2003) quantitatively compared river features on the Upper and Lower Quinault and Queets Rivers over the last century (Table 1). The Queets is thought to provide an analog of reference conditions that should have existed on the Quinault River prior to human disturbances (see Section 3.5.4 for further discussion on ability to use Queets as an analog). Because of differing geology and flood magnitudes, quantitative values on the Queets are expected to be different than Quinault, but should provide relative trend comparisons on an order of magnitude scale. For purposes of comparison O'Connor (2003) lumps the entire Queets measurements from the mouth to RK 39.4.

On average for the two river reaches compared, the Quinault is steeper than the Queets. The upper Quinault does have reaches with a .0022 slope (average slope of Queets) as measured from Reclamation's 2002 river channel survey (See Appendix A). The number of low flow channels were measured by O'Connor (2003) to be greater on the Quinault supporting the notion that the present channel is more braided than in reference conditions. The average width of the active channel and floodplain in Table 1 is greater on the Upper Quinault River than the Queets (RK 41 to 0). O'Connor (2003) points out that below RK 20, the Upper Quinault has a notably faster migration rate than the Queets. The Queets was noted to have areas of channel bound by mature vegetation on either side, but the present Quinault channel does not. O'Connor's study results provide additional evidence for hypotheses presented in the Watershed Analysis that the Quinault may be migrating at a faster rate than natural conditions.

The lower portion of Queets that O'Connor used includes two confined, stable reaches, totaling about 8-10 km. The channel in these reaches has not moved appreciably over the period of record based on recent analysis (Latterell, J., written communication, 2005). Latterell et al estimated that the primary low-flow channel of the upper Queets River (above the campground, which was the terminus of O'Connor's study) moves an average of 9.9 m/year (+/- 7 SD). After correcting for the bias introduced by comparisons of channel position over different time intervals, the mean annual channel movement rate estimated by Latterell et al is 11.9 m/year. This suggests that rates of the lateral low flow channel movement on the Upper Quinault measured by O'Connor (2003) may on average be similar to the Upper Queets. More integration work would be needed between these studies to further compare and understand the Upper Queets channel movement and floodplain reworking rates relative to the data developed for the Upper Quinault from Reclamation's study.

Table 1. Documentation from paper comparing Upper Quinault River to Queets River by O'Connor (2003).

Characteristic	**Upper Quinault (Confluence with North Fork Quinault River to Lake Quinault; RK 56.6-84.3)**	**Queets River (Confluence with Sams River to Pacific Ocean)**
Length (km)	18.0	41.2
Base level	Lake Quinault (RK 51.6 to RK 56.6)	Pacific Ocean
Slope (m/m)	0.0035	0.0022
Number of low-flow channels present at a typical cross-section	1.41 ± 0.73 (2 or 3 channels common; 4 or 5 present for short sections)	1.30 ± 0.62 (2 or 3 channels common; 4 or 5 present for short sections)
Width of active channel (m) (low-flow channels and bare gravel bars) at a typical cross-section	240 ± 104	165 ± 89
Gravel bars	Bars nearly always present	Several sections with no unvegetated or vegetated bars; flow within vegetated floodplain surfaces
Mean floodplain width (m)	2470	1286
Mean average migration rate (m/yr)	12.7 ± 3.3	7.5 ± 2.9
Highest decade-scale migration rates	1930s (20 m/yr)	1930s (10 m/yr)

2.3 Summary of Analyses Methods

This section presents an overview of methodology used to accomplish the geomorphic study of the Quinault River.

2.3.1 Existing River System

To characterize the existing river system, new aerial photography and survey data were collected during October 2002 (Appendix A). Light distance and ranging (LiDAR) data was collected to provide elevations along the floodplain and terraces within the valley walls in the study reach. The LiDAR data also defined channel alignments in heavily vegetated areas that would have been very difficult to survey on the ground. The remotely-sensed data was used to generate a digital elevation model of the valley, from which cross sections could be extracted. A hydraulic model was generated to allow us to estimate the hydraulic properties of the river channel and to provide input data for assessing the sediment transport capacity of the river at selected locations (Appendix B). The bathymetry of the river bed was investigated by boat. During the river survey trip, we also measured the size of sediment present on the surface of gravel bars (the "armor layer").

2.3.2 Geology and River Setting in the Late 1800s

To evaluate the influence of geologic controls on the river system in both the short term (decades) and the long term (hundreds to thousands of years), a timeline of the geologic history was developed (Appendix C). The formation of the Quinault Valley during the Pleistocene and Holocene epochs was established by researching published literature, collecting and analyzing new radiocarbon samples from terrace and deltaic lake surfaces (Appendix D), and using the LiDAR data to define terrace edges and the extent of bedrock outcrops in the valley. The first written accounts of the valley were produced by non-native explorers who crossed the Olympic Mountains from 1878 to 1890; these accounts were researched to help characterize the Quinault River in the late 1800s before settlers moved into the valley. These accounts provide several descriptions of the relatively undisturbed river setting.

2.3.3 Wood Debris

Large woody debris (LWD) forming snags and log jams has been repeatedly removed from the Upper Quinault River for two reasons: the salvage value of the wood and because it was believed that a clear channel would convey water faster and reduce the risk of flooding and channel migration. Documentation of LWD clearing was compiled to the extent possible from published historical accounts, anecdotal information, and aerial photographs (Appendix E). The sizes of wood present in the existing system were measured and contrasted with what is predicted would have been present in the pre-disturbance setting. Additionally, areas of high wood density were tracked over time to assess the size and density of wood accumulation necessary to form stable hard points that would help limit channel migration. This tracking also helped us evaluate whether the sizes of individual pieces and accumulations of wood within the present system are capable of forming hard points. The number of stable hard points in the present system was qualitatively compared with the number of hard points that could be documented by aerial photography dating back to 1939. Herrera Environmental Consultants (a contractor) addressed these woody-debris issues using a combination of GIS mapping and field work. Time-lapse photography during a winter flood season on the Upper Quinault River above the confluence of the two forks of the Quinault River (Appendix F) was also used to qualitatively characterize transport and deposition patterns of woody debris and their relation to growth or removal of gravel bars.

2.3.4 Vegetation

We hypothesize that clearing old-growth, mature riparian and terrace forest reduced the erosion resistance and mass stability of river and terrace banks and the amount of large woody debris that can be recruited by the river. If this hypothesis is true, clearing would, in turn, affect channel morphology, rates of bank erosion and channel migration, and extent of sockeye habitat that depends on large woody debris. To address this question, areas that appeared to have been cleared or thinned of old growth trees were delineated on aerial photographs dating back to 1939. These areas were then compared with locations where the river has eroded into a terrace to determine if areas with older, more mature forest have, in fact, been more resistant to erosion. The terrace surfaces for the 2002 aerial photograph were characterized in generalized vegetation classes to determine

which areas now have trees. For surfaces with trees, the typical age of trees within each area was estimated based on when the surface was last thought to have been disturbed (cleared or thinned) based on the aerial photography. This gave a rough idea of the age of trees along terrace surfaces, but more detailed field work would need to be done to verify these approximations. Vegetation classes were also grouped within the active floodplain to assess which areas with trees have eroded and if any new surfaces with trees have remained stable. Vegetation classes were also used to assess the risk of future erosion to terrace areas, to identify areas that may have a head start on growing a mature forest, and to assess whether those areas would need to be protected until they reach maturity.

2.3.5 Sediment Processes

The watershed analysis (QIN, 1999) described the study reach as having a wide, aggrading channel, particularly in the areas influenced by Lake Quinault. If the Quinault River is aggrading, it would tend to increase the rate at which the channel shifts across its floodplain. Our study attempts to verify whether the Quinault River between the confluence of the two forks of the Quinault River (RK 18) and Lake Quinault (RK 0) is in an aggradational state, and, if so, whether it has been induced by human activities over the last hundred years or simply part of natural processes (Appendix G). For Reclamation's study, a variety of sediment transport analyses techniques were used to see if there was any evidence to support the notion the river is aggrading, and, if so, on what order of magnitude. Techniques included using a sediment budget, stream power (energy) computations, observations of sediment sizes present in the river bed, channel planform and active channel width between 1939 and 2002, and a longitudinal profile comparison between 1929 and the present (2002) measured channel slope. A sediment budget is a way of tracking how much sediment is available for transport in the study reach versus how much is transported out of the reach. If the input sediment volume is larger than the amount of sediment making it out of the study reach, this indicates aggradation may be occurring. The sediment budget analysis included measuring the amount of sediment in storage in the study reach (in gravel bars) and the amount of sediment prograding the delta. Because no sediment load measurements were available for the incoming sediment, this component of the sediment budget was estimated (see Appendix G for more details).

2.3.6 Changes in River System over the Last Century and Future Predictions

To evaluate changes in the Quinault River during the twentieth century, historical aerial photography between 1939 and 2002 and historical maps dating back to 1897 were rectified to the same scale and compared (Appendix H). Image dates for the historic aerial photographs include 1939, 1952, 1958, 1962, 1973, 1982, 1994, 1998, 2001, and 2002. Historical map dates include 1897/1906, 1929, and the USGS quadrangles which are based on a variety of aerial photograph dates. Geomorphic features in each aerial photograph were mapped and compared to look for trends over time (see Appendix I). The mapping was used to evaluate changes in channel position, sediment bars, vegetation, historic channel migration zone (see Appendix J) and general characteristics of the channel to identify trends that could indicate morphological response to changes in

sediment supply and transport capacity. The type and extent of human disturbances to the Quinault River valley was determined by reviewing the relevant literature, interviewing local residents, obtaining anecdotal information from government agencies involved with the valley, and evaluating evidence of human activities along the river corridor that is visible in the historical aerial photographs.

2.3.7 Hydrology

To understand when the majority of river channel changes occurred, we characterized the hydrology of the watershed (Appendix K). Given the possibility that in-channel restoration projects may be implemented as part of future studies, it is also important to know the probability and magnitude of flood flows. The U.S. Geological Survey (USGS) has measured river flows at the outlet of Lake Quinault from 1912 to present. Because it is expected that Lake Quinault has a dampening effect on flood peaks, the flows measured at the gage at the lake outlet are likely smaller than those experienced in the Upper Quinault River. We made a cursory hydrologic analysis to predict the equivalent river flows for standard flood-frequency intervals in the Upper Quinault watershed, using three methods for comparison.

2.3.8 Sockeye Habitat

To characterize the potential effect of altered river processes on sockeye habitat, we identified the physical river features most important to sockeye habitat. Because side channels were the main location of habitat that could be affected by river migration and flooding, side channels were mapped on historical aerial photographs. The stability of these areas during the twentieth century was evaluated and then compared with duration of stability predicted to have existed during the late-1800s in the undisturbed river setting. Additionally, the risk of the river overtaking these channels in the next 50 to 100 years was assessed and strategies identified based on whether these habitat areas needed to be protected, enhanced, or restored to maintain or increase habitat areas within the main channel migration area. This task was accomplished by working with biologists at the Quinault Indian Nation to map existing habitat areas and areas on historic photographs that would have potentially had the same characteristics. Habitat channels cut within vegetated surfaces could not be readily identified on aerial photography or in the field due to the complexity of which they interconnected with each other and the main channel. LiDAR data was used to examine the extent and connection paths of these channels (Figure 4).

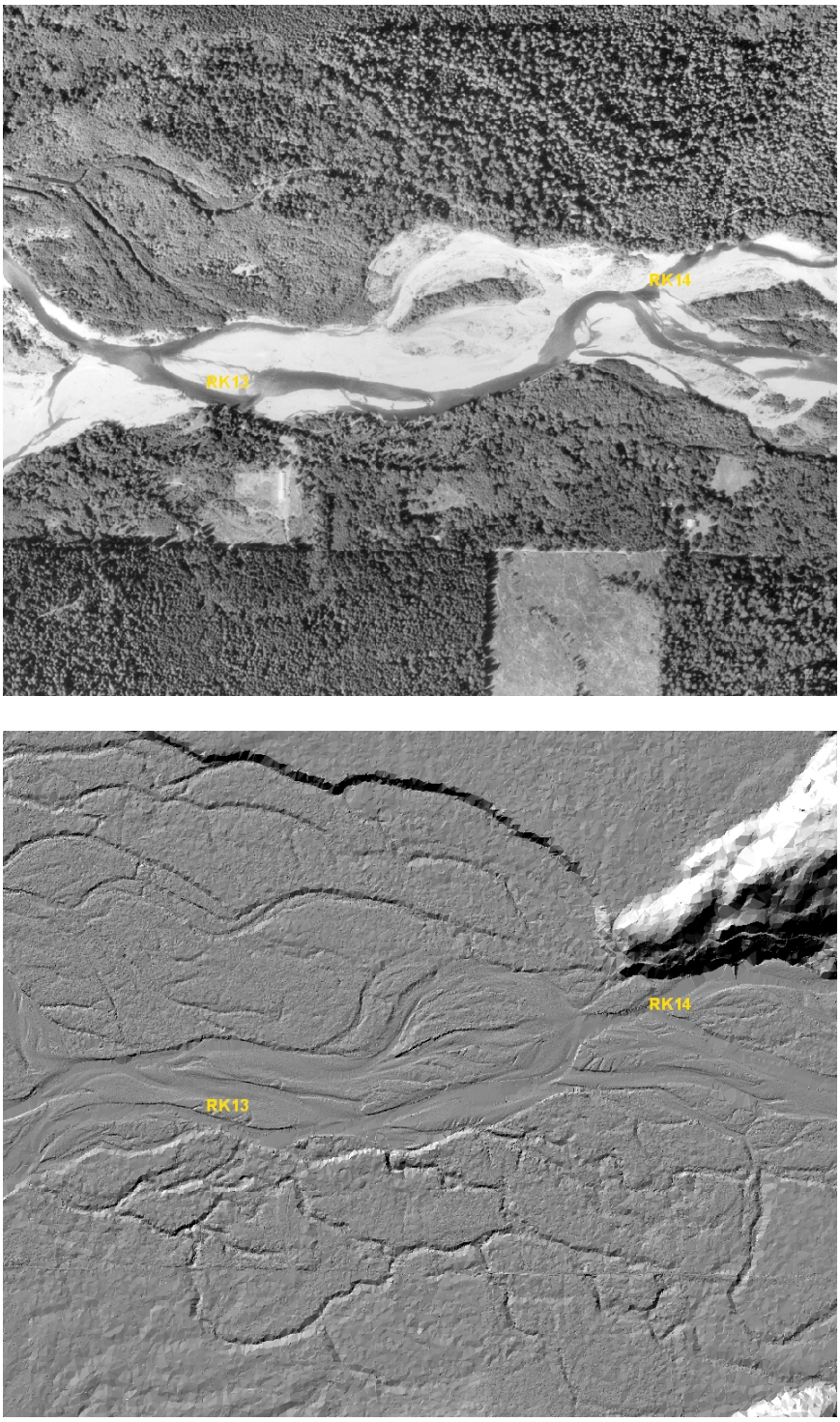

Figure 4. Comparison of channel representation on 2002 aerial photography (top photo) versus bare-earth hillshade (bottom photo) created from 2002 LiDAR data.

3.0 Reference Conditions: River Setting Before Disturbance

This section describes conditions of the river believed to exist in its natural setting, prior to any disturbance in the last century. The majority of discussion focuses on the conditions in the late 1800s, but a description of the geologic formation of the Quinault River Valley over the last several thousands of years is also provided.

3.1 Geologic Development

This section contains an overview of the geologic processes that played a role in establishing the geomorphic features present in the Upper Quinault River Valley based on available literature and new observations. For a more complete summary of the geology of the valley the reader is referred to Appendix C. The most important geologic controls on the present Upper Quinault River system are Quinault Lake, the bedrock outcrops, alluvial fans, and debris flows.

The Quinault River Valley has been carved-out by at least two major glacial advances that occurred during the Late Pleistocene (140,000 to 10,000 years ago). Moore (1965) has described these two glacial advances as the Humptulips and Chow Chow glaciations. The Humptulips glacier was the most extensive advancing to within 4 km of the Pacific Ocean. Following the retreat of the Humptulips glacier, there was a period when interglacial conditions persisted and a lacustrine environment developed west of present day Quinault Lake. After the interglacial period, ice again advanced to within 12 km of the Pacific Ocean during the Chow Chow glaciation where it constructed broad arcuate moraines. As the glacier retreated, it either re-advanced or stagnated near the foot of the Olympic Mountains constructing the terminal moraine that impounds Quinault Lake.

Climatic changes during the Holocene (about 10,000 years ago to present) brought about warmer and drier conditions resulting in the glaciers withdrawing up their respective valleys. In fact, Neoglacial studies conducted by Spicer (1989) on Blue Glacier, the largest of the Olympic Mountain glaciers, shows that Blue Glacier has retreated about 1200 m since the early 19th century. Similar retreats are believed to have occurred in the Quinault River watershed, only now the glacial valleys are headed by small cirque glaciers preserved on Mt. Seattle, Mt. Christie, Mt. Anderson and White Mountain. The decreased volume of perennial ice and glaciers in the watershed has likely reduced the moderating influence such ice fields have on stream flow regimes. Studies along the Tlikakila River, Alaska, show that there are three primary runoff components associated with glaciers (Brabets et al, 2004). These components are (1) snowmelt caused by rising temperatures in the spring, (2) glacier ice melt and rainfall during the summer and fall, and (3) groundwater flow during the winter. These studies also determined that the majority of runoff contributions to the river are from glacier ice melt, snowmelt and

rainfall. However, groundwater was found to be very important to salmonids because it provides a source of relatively warmer water and maintains a minimum stream flow critical for fish survival. Similar runoff components are believed to be present in the Quinault River watershed upstream of the current study area. If it is desired to further characterize these relationships on an ecosystem basis, additional investigations would be required.

Quinault Lake forms a base level for the Upper Quinault River. The lake's water surface elevation is interpreted to have been near elevation 110 m above average mean sea level (amsl) about 10,000 years ago (Figure 5). The lake has since receded down to elevation 57 m (amsl). This suggests that the Quinault River has been incising through the terminal moraine at about 5 mm per year and the base level for the upper river has been lowered at a corresponding rate enabling the Upper Quinault River to incise into its floodplain. These interpretations further suggest that the Holocene intermediate and upper surfaces (shown in Figure 6) are most likely cored by deltaic and/or glacial outwash deposits and mantled by lake and flood deposits.

Tectonic uplift has significantly affected the river as measured in thousands of years, but has not likely influenced the changes seen during the past century. Contemporaneous with the lowering of the higher lake level to its current position, the Quinault River upstream of Lake Quinault was likely a large, braided river that extended across its floodplain. Over time, the river has incised into the valley leaving behind a series of terraces (abandoned floodplains). The oldest terrace in the valley is of Late Pleistocene-age and was deposited during the latter part of the Chow Chow glaciation (Figure 6). Two Holocene surfaces are also prominent in the valley. The higher of these surfaces (upper surface) is a terrace that has not had the active river channel flowing over it for a few thousand years and is no longer inundated by flood flows from the river. The lower of the two surfaces is younger (intermediate surface), but it has not had the active river channel passing through it for at least a hundred years. However, both of these surfaces contain small overflow channels dissected through them and may at times be still inundated by large flood flows.

The bedrock in the Upper Quinault River Valley is comprised of predominantly metasedimentary rocks that are very resistant to fluvial erosion. The bedrock affects the river in two ways: (a) by deflecting the river's flow direction and (b) by forming a valley width constriction that narrows the river's floodplain and channel migration zone. The bedrock was not observed to control the channel bed features (such as forming hydraulic drops in the river), except for one location at the NPS bridge just downstream of the confluence of the two forks of the Quinault River where an outcrop in the channel bed is visible. The Quinault River flows against bedrock along the south bank from RK 15.5 to RK 18.3. Other bedrock outcrops can be found along the north bank at RK 5.5 (narrow margin of terrace between bedrock and river), RK 8.3 to RK 11.0, and RK 14.0. Outcrops on the north side at RK 8.3 to RK 11.0 and RK at 14.0 generally deflect the river's course towards the south bank. Near RK 15.5 to RK 17.1 the river appears to have become incised along the south bank, which directs flow toward the upper surface along the south bank near RK 15.4. Flow downstream of this point is deflected towards

the bedrock outcrop at RK 14.0 to RK 15.0. The outcrop near RK 14.5 forms a constriction with the upper Holocene surface and has most likely backed-up large floodwaters in the past. This backwater may result in the flood flows overtopping the terrace surfaces upstream of this point, but no flood inundation data was available to investigate this.

There are two prominent alluvial fans that encroach on the Quinault River in the study area. These fans are the Finley Creek fan between RK 2.3 to RK 5.4 (see Appendix L for more information on this tributary) and the North Fork fan RK 16.3 to RK 19.0. The Finley Creek fan was dated to be several thousand years old (Appendix D). No dates are available for the North Fork fan, but it is likely also at least several thousand years old. The surfaces of both alluvial fans have channels incised into them and are still active along these channels. The interaction between the fans and the river are poorly understood and there have been several human disturbances on both fans that make it difficult to know the influence of these fans on the river in reference conditions. The Finley Creek fan may be forcing the Quinault River southward, however the southward migration is also somewhat offset by the ability of the river to move the material downstream. The North Fork fan also appears to have forced the East Fork and mainstem of the Quinault River toward the south bank, however there is currently a small terrace between the toe of the North Fork fan and the present Quinault River.

Mass wasting in the Upper Quinault River Watershed has not significantly increased in the last 60+ years based on aerial photograph interpretations (QIN, 1999). However, there has been significant logging in our study reach that has resulted in increases to mass wasting areas (QIN, 1999). These mass wasting events are thought to increase fine sediment delivery to the Quinault River, but generally are not close enough to the Quinault River to significantly increase coarse sediment within a decadal timescale.

The debris flows that do occur in the study reach (between the confluence of the two forks of the Quinault River and Lake Quinault) tend to be in confined valleys containing tributaries to the Quinault River. The majority of debris flows travel to the valley floor where sediment and wood is preferentially deposited across alluvial fans within a few hundred yards of the valley edge. While most of this sediment and wood does not immediately reach the Quinault River from debris flows, tributary floods would be expected to gradually rework this material and transport it to the Quinault River. Fletcher Creek and Finley Creek are the only tributary channels where we observed debris flow material reaching the Quinault River in 2002. Further studies would be needed to quantify the effects of debris flows and the amount of spawning gravel they transport to the Quinault River relative to the total coarse sediment load. It is likely sediment supplied from debris flows has the most effect on sediment sizes within a small locality of the debris flow fan, and becomes insignificant relative to total loads of the river a short distance downstream.

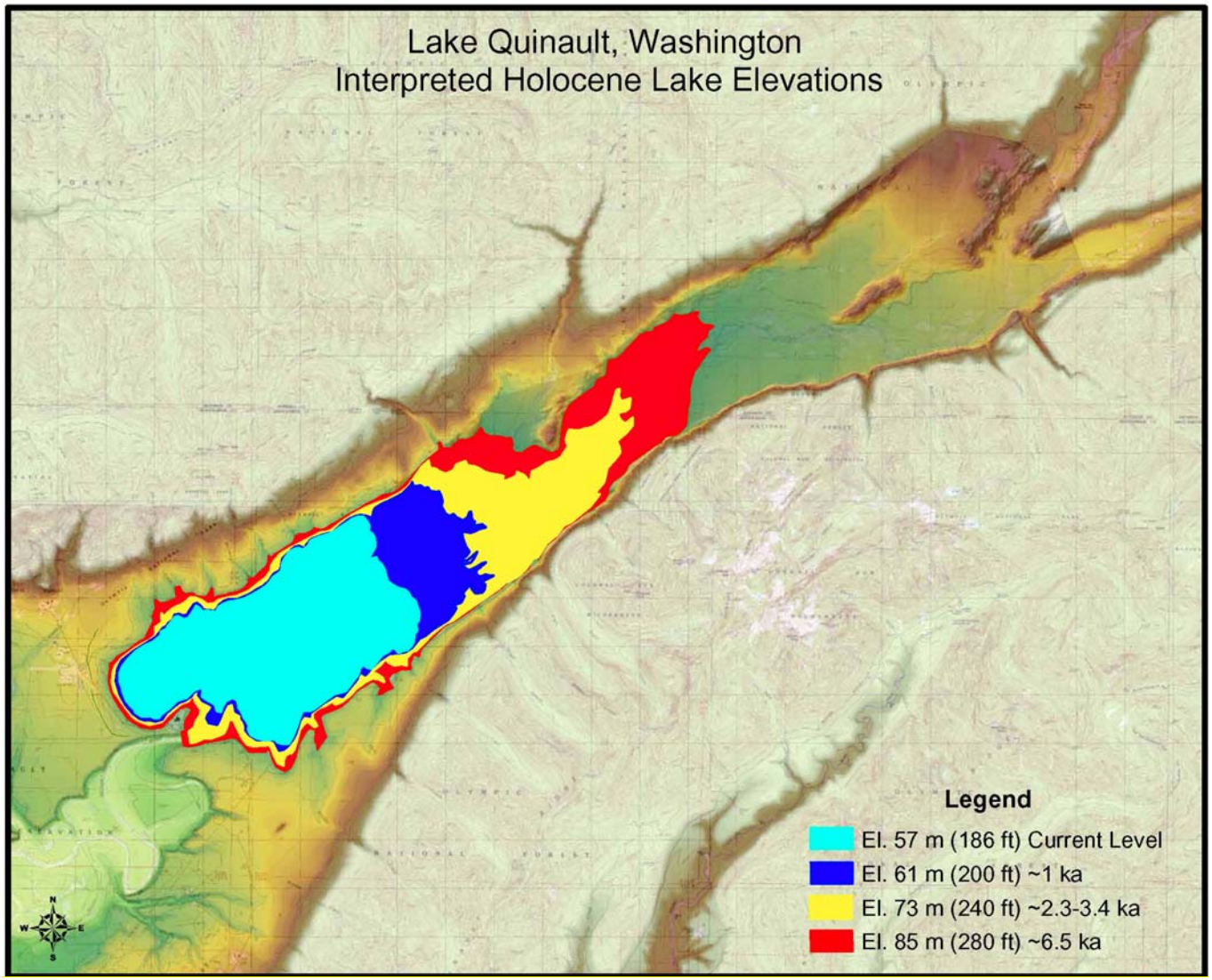

Figure 5. Interpretation of Quinault Lake's rate of regression based on radiocarbon ages and the elevation of where the sample was obtained.

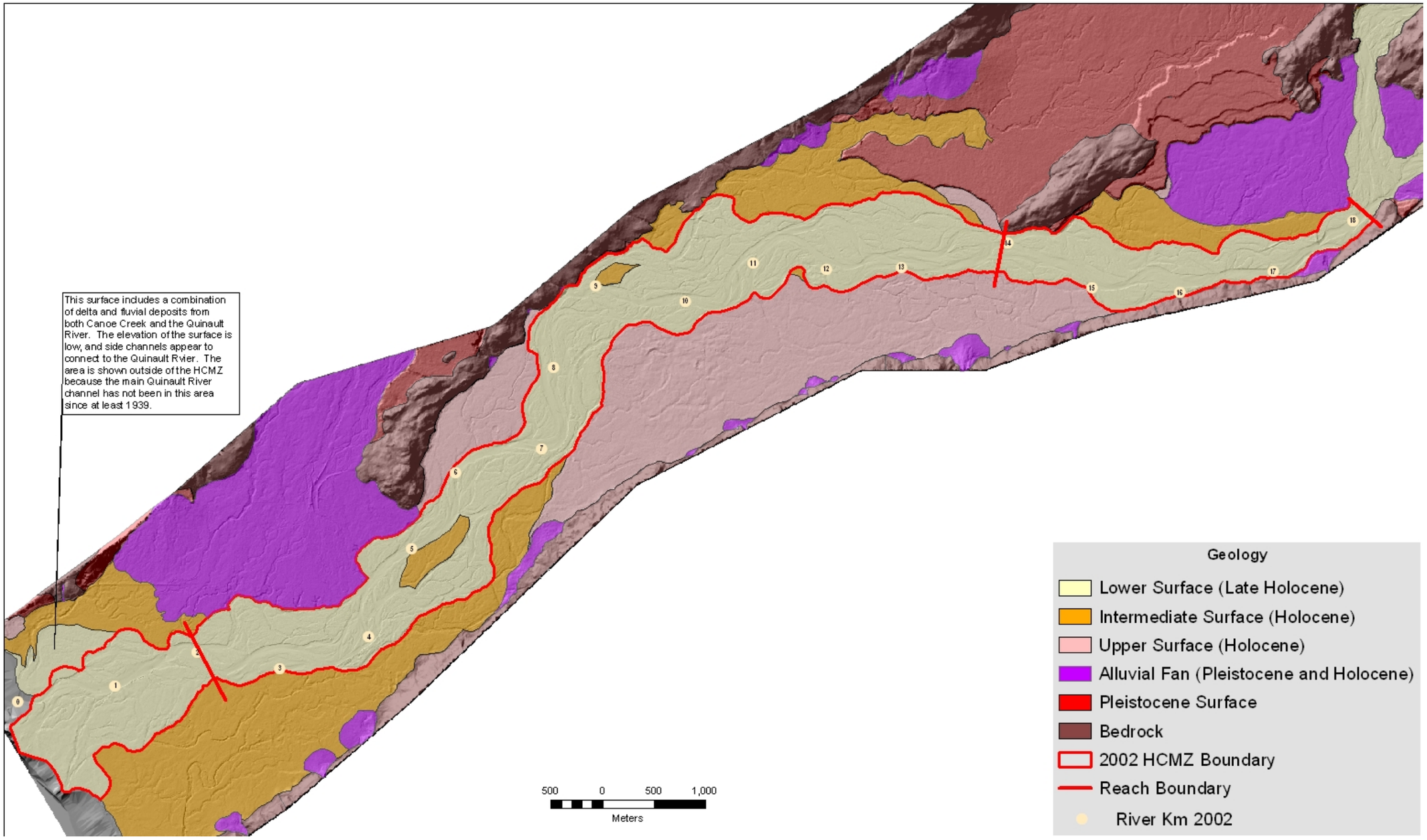

Figure 6. Overview map of geologic surfaces in study area.

3.2 Hydrology

The Quinault River drains from the glaciated Olympic Mountains in northwest Washington State, with a total drainage area above the outlet of Lake Quinault of 684 km^2 (264 mi^2), and 606 km^2 (234 mi^2) above the inlet of Lake Quinault. About 18 km upstream from the inlet to Lake Quinault, two stems of the Quinault River join together informally referred to as the Forks (see Figure 1). Above the Forks, the North Fork Quinault has a drainage area of 208 km^2 (80.3 mi^2), and the East Fork has a drainage area of 234 km^2 (90.3 mi^2). Precipitation was measured at the Quinault Ranger Station from 1961 to 1990, and shows average monthly precipitation varied between 3 to 24 inches during this time period (QIN, 1999). The average annual precipitation is 146 inches. This section lists key points related to the hydrology discussion from Appendix K. A more detailed discussion of hydrology can be found in the Quinault Watershed Analysis (QIN, 1999).

It is not known what the threshold flow is that results in channel modifications. However, the majority of large floods that are likely to result in channel shifting occur in the Upper Quinault River during the winter months. The largest sub-basins between the Forks and Lake Quinault that contribute water and sediment to the Quinault River are Big Creek and Finley Creek. Many other small sub-basins drain onto terrace surfaces in the study reach. Some of these terrace channels eventually join the Quinault River and others flow into Lake Quinault.

3.2.1 Flood Events

River flows have been measured at the outlet of Lake Quinault from October 1, 1911 to the present time by the USGS (Gage 12039500) with the exception of water years 1923 to 1925 where no data is available. The average annual flow is 2,876 ft^3/s (81.4 m^3/s). Figure 7 shows the recorded floods above 15,000 ft^3/s between 1909 and 2002 relative to the aerial photographs and historical maps used in this study (1909 flood estimated by USGS). Almost all time periods between aerial photographs we evaluated had at least one flood greater than the 5-year flood except for 1962 to 1973, and 1998 to 2001. This indicates there was at least one flood capable of inducing channel change between aerial photographs evaluated.

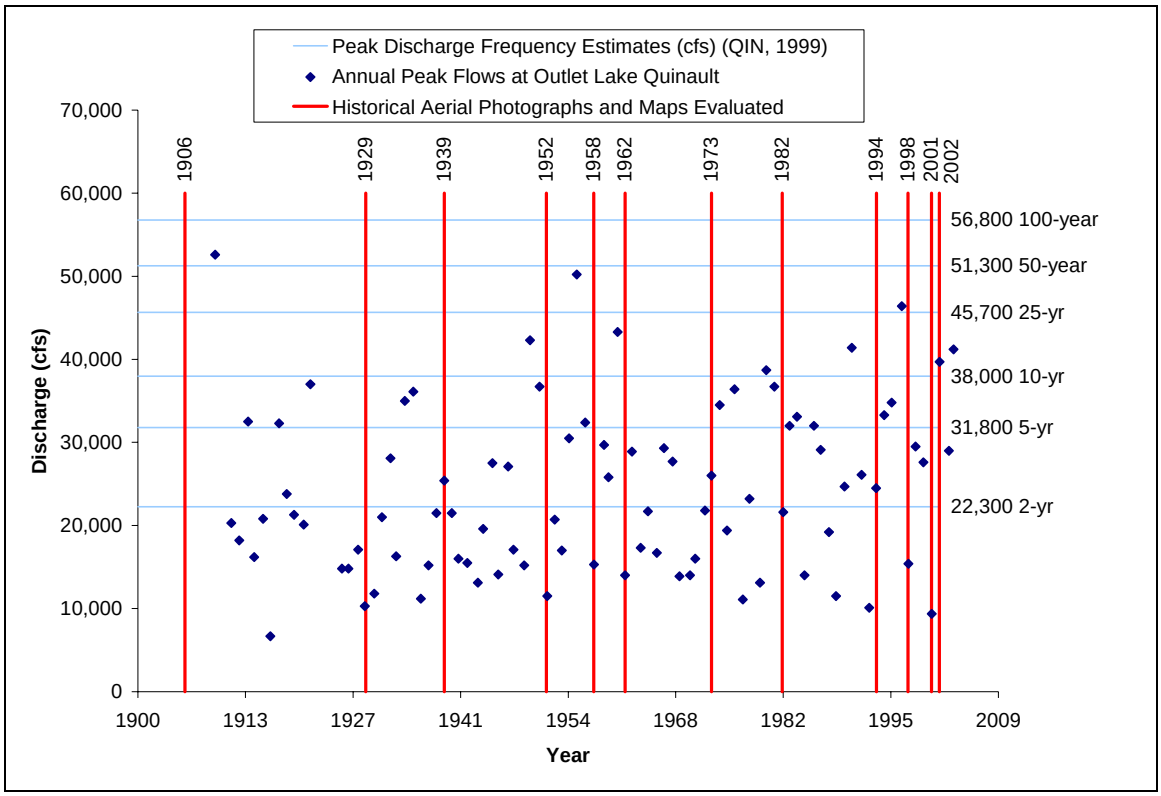

Figure 7. Annual peak discharges measured at USGS gaging station at outlet of Lake Quinault. Blue lines provide a reference for flood frequency values (QIN, 1999) and red lines provide a reference for date of aerial photographs we analyzed.

It is of interest for potential restoration design to estimate peak river flows in the ungaged study reach. In general river flows would be expected to increase in the downstream direction through the watershed as drainage basin area increases. The exception is Lake Quinault, which dampens both peak and low flows between the inlet (downstream portion of study reach) and the outlet where the USGS gaging station is located (QIN, 1999). Lake Quinault is a natural unregulated reservoir with a surface area of approximately 15.1 km^2 (3,729 acres). A 1995 survey documented a maximum depth of 73 m (240 ft) (Gubala, 1995). Quinault Lake water stage influences the extent of land inundated during heavy rainfall; highest lake levels do not necessarily occur at the same time the river is at its highest flood stages.

A USGS approach incorporating drainage basin area and average precipitation estimates were used to develop flood frequency estimates for two ungaged locations within the study reach (Appendix K). The USGS approach indicates the 2- to 100-year floods at the Forks are increased by roughly 20% by RK 8 (Big Creek confluence), and by a total of 30% at RK 0 at the lake inlet. This data does not account for the dampening effect of the lake and is difficult to relate to measured flow data.

Two methods of analysis document the potential dampening effect on peak flows once they enter Lake Quinault: 1) comparing normalized discharges for a series of floods on the Queets and Quinault Rivers which showed 31 to 38% decrease (QIN, 1999); and 2)

computing a reverse reservoir routing and comparing average inflow to average outflow of the lake which showed about a 41% decrease for hourly values (peaks above 15,000 ft^3/s) recorded during the October 2003 flood (see Figure 8 and Appendix K). For future hydrologic analysis, reverse reservoir routing could be used to develop discharge estimates at the inlet to Lake Quinault, and the USGS drainage basin approach could then be used to estimate how flows decrease in the upstream portions of the study reach as drainage basin areas decreases. This indicates that values recorded at the USGS gage at the outlet of Lake Quinault may be about 30 to 40% lower than the river flow in the upstream river near the inlet to Lake Quinault. Flows would reduce in magnitude in the upstream direction from the inlet to the Forks as the drainage basin area reduces.

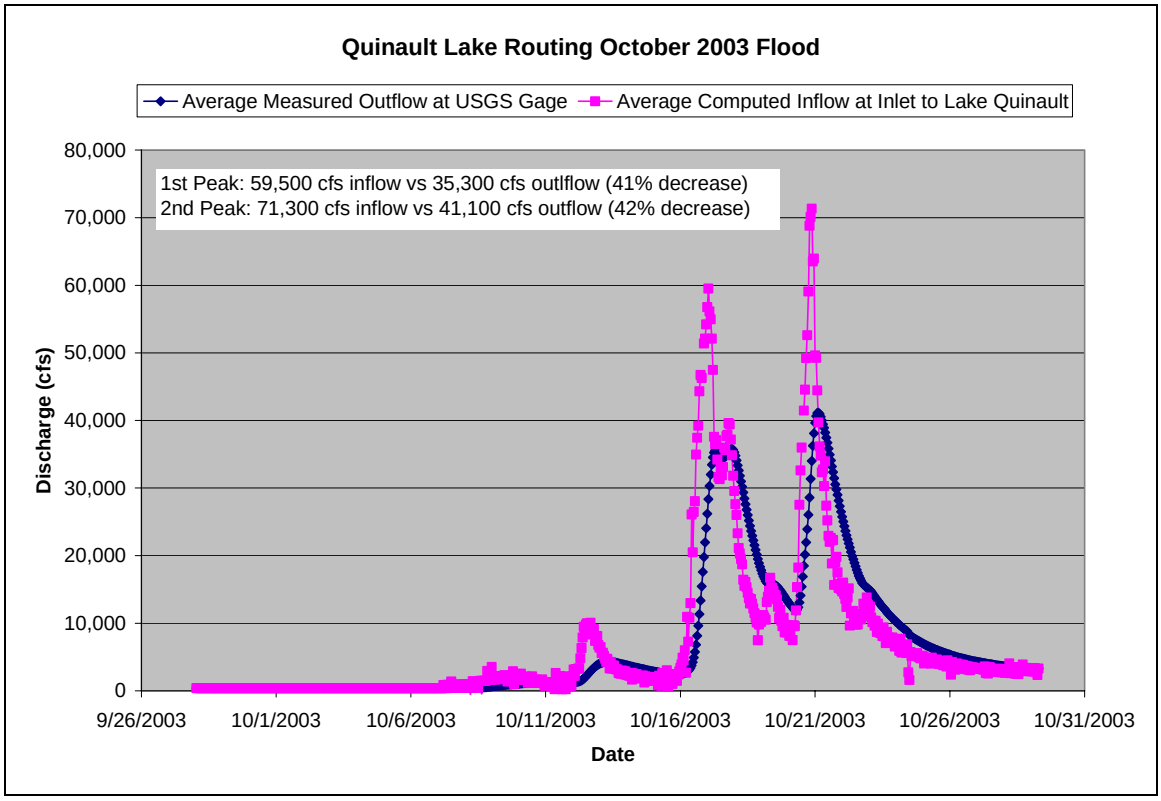

Figure 8. Reverse reservoir routing results for October 2003 flood.

3.2.2 Hydrologic Trends

Analysis of sockeye by the Quinault Department of Fisheries indicates that numbers started to substantially decline between 1950s (see Figures 2 and 3 in main report), yet the majority of disturbance to the watershed occurred in the early part of the twentieth century. If floods have occurred at a greater frequency or magnitude since 1950 relative to the first part of the twentieth century it could help explain the timing of channel response to human disturbance.

The Watershed Analysis (QIN, 1999) noted that a relatively dry climate period ended in the late 1940's in the Pacific Northwest, and was followed by a relatively wet period that ended in 1977. From 1977 to 1998, another dry period was occurring (QIN, 1999).

However, it is noted in the Watershed Analysis that these are multi-year trends based on long-term precipitation records. A particular year within the dry or wet designated periods could actually be fairly wetter or drier than overall trend during that time period. The Watershed Analysis (QIN, 1999) concluded that trends in monthly flows were closely tied to fluctuations in precipitation and not likely influenced by human disturbance in the basin. Peak flow data was not analyzed for trends.

The peak flow data from the USGS gaging station at the outlet of Lake Quinault indicates the first and largest documented flood occurred in 1909, probably when human disturbance in the river channel area was still fairly localized (see Figure 7). The second two largest flood peaks that occurred in 1955 and 1997 are of similar order of magnitude and do not indicate that the largest flood peaks have changed over the last century.

Annual peak flows and all peak flows above 15,000 ft^3/s were broken out into time periods between 1911 to 1950 and 1951 to 2002. For all flows above 15,000 ft^3/s, the occurrence of more common floods (2-, 5-, and 10-yr) floods were compared between the two time periods (Table 2). When averaged out per year floods greater than the 2-, and 5-, and 10-year floods appear to be occurring more often between 1951 to 2002 than in 1911 to 1951 (Table 2). From 1911 to 1950 the 2-year flood occurred about once every two years, and between 1951 and 2002 occurs almost annually.

Table 2. Comparison of the occurrence of common floods between 1911 to 1950 and 1951 to 2002.

Flood Frequency	Total Number of Floods Greater than Flood Frequency Value		Flood Occurrence Per Year for Floods Greater than Flood Frequency Value	
	1911 to 1950	1951 to 2002	1911 to 1950	1951 to 2002
2-yr flood	18	49	0.51	0.96
5-yr flood	7	19	0.20	0.37
10-yr flood	1	7	0.03	0.14

Another way to compare the two time periods is to compute the 2-year flood for each time period using a Log Pearson III computation for the annual peak floods. Using this method, the 2-year flood between 1911 and 1950 was 19,989 ft^3/s and between 1951 and 2004 was 24,504 ft^3/s, indicating it has increased about 23%.

3.3 Vegetation and Landforms

The Quinault River valley is comprised of metasedimentary rocks that have been uplifted since the Tertiary and subsequently eroded by glaciers and rivers throughout the Pleistocene and Holocene. The Upper Quinault River valley is characteristic of many U-shaped glacial troughs along the western flank of the Olympic Mountains except that it still contains a glacial lake (Lake Quinault) that was impounded during the late Pleistocene. The persistence and slow regression of Lake Quinault throughout the Holocene are very significant because the lake forms the base level for the Upper Quinault River. As the terminal moraine impounding the lake is incised by the Quinault River, the lake level (and base level) lowers and surfaces become exposed along the

valley walls and floor. These surfaces, which are underlain by fluviolacustrine sediments, are subsequently reworked by the Upper Quinault River.

Throughout the Holocene the Quinault River valley has been dominated by a warm-temperate, maritime climate (Henderson et al, 1989). It receives high annual precipitation and moderate temperatures as moisture-laden Pacific air masses flow eastward into the valley. These climatic conditions generally control the species composition and their succession in the Quinault River rainforest.

The current study considers the vegetative succession of the Holocene surfaces in the Upper Quinault River valley. The older surfaces (upper and intermediate surfaces) are associated with the regression of Lake Quinault and are underlain by fluviolacustrine deposits. The younger surface (lower surface) is coincident with the HCMZ and is comprised of fluvial sediments associated with the migration of the Upper Quinault River. The following sections discuss the vegetative reference conditions along the older, lacustrine-dominated surfaces and the younger, fluvial-dominated surface.

3.3.1. Reference Conditions for the Older Surfaces (Upper and Intermediate Surfaces)

The upper and intermediate surfaces bounding the HCMZ have not been reworked by the Upper Quinault River since they have been exposed by the regression of the Lake Quinault. This interpretation suggests that these surfaces have remained stable for a thousand or more years, and that the vegetation was allowed to reach its climax stage prior to anthropogenic disturbances.

When a geologic surface remains stable and its vegetation remains undisturbed for an extended period of time, the vegetation reaches a climax stage that has a predictable species composition. This successional climax is classified as a vegetation series. These series are named for the climax dominant or codominant tree species. The series are an indication of a uniform environment and are an abstract grouping of plant communities that have similar successional development (QIN, 1999).

The Potential Natural Vegetation (PNV) is the theoretical successional climax and partly defines the direction and rate of succession (QIN, 1999). Based on the PNV principles it is possible to describe the theoretical successional climax forest for the upper and intermediate surfaces in the Quinault River study area.

The climax stage for the lowlands and lower mountains in the western portion of the Quinault River Watershed is the sitka spruce series. It currently covers about 33.9 percent of the watershed from sea level to elevation 150 m (QIN, 1999). Productivity is very high in the sitka spruce series. With the warm, wet weather, and frequent morning fog the sitka spruce series is the fastest growing vegetation series within the Quinault Watershed and rapidly produces large trees, snags and logs. The climax dominant tree species for this series are the sitka spruce [*Picea sitchensis*], western red cedar [*Thuja plicata*], and western hemlock [*Tsuga heterophylla*] (QIN, 1999). Sitka spruce commonly attains heights of 50.0 m and basal widths of 1.5 m, but can grow much larger

(Whitman, 1986, p. 50). The western red cedar commonly attains heights of 50.0 m and basal widths of 2.4 m (Whitman, 1986, p. 26). The western hemlock commonly attains heights of 45.0 m and basal widths of 1.2 m (Whitman, 1986, p. 40).

Incorporating the above information with the anecdotal accounts of reference conditions described in section 3.4.3, the climax or old-growth forest in the Upper Quinault River valley during the 1800's would have been the sitka spruce series. Furthermore, the old-growth forest would have had the following characteristics: (1) a multi-storied canopy reaching in excess of 50.0 m high, (2) the canopy would have high closure with numerous large holes from felled trees or top breakage, (3) a continuous distribution of tree ages and tree heights, (4) moderate-to-high accumulation of large snags and downed logs in varying stages of decompositions, and (5) moderate-to-high accumulations of fungus, lichens, and bryophytes (i.e., mosses).

3.3.2. Reference Conditions for the Younger Surface (Lower Surface)

The lower surface is within the Quinault River's HCMZ and is continually being reworked by the river. The fluvial landforms that comprise the lower surface and their associated vegetation stages have theoretical successional cycles (Figure 9). In the reference setting, the fluvial landforms of the lower surface had the most potential of being reworked by the river. The interactions between the channel system, floodplain, and fluvial terraces have definitive cycles and successional stages (Latterell et. al., 2005).

Current studies along the Queets River about 18 km north of the Quinault are focused on the successional stages associated with fluvial (or river) landforms (Latterell et al., 2005). These studies suggest there are definitive successional cycles that occur on a scale of tens to hundreds of years along unconfined alluvial reaches. The fluvial landforms associated with these cycles are as follows: 1) primary and secondary channels, 2) pioneer bars, 3) developing floodplains, 4) established floodplains, 5) transitional fluvial terraces, and 6) mature fluvial terraces. It is our contention that the same successional cycles have occurred along the Quinault River within the HCMZ prior to Euro-American occupation.

The primary and secondary channels are comprised of the low-flow channel areas where the river actively flows on an annual basis. These areas are generally devoid of topsoil and contain abundant woody debris that is stored in logjams. Logs with diameters greater than 1 m and 25 m long typically form the key members upon which other woody debris is trapped (J. Latterell, unpublished data).

Pioneer bars form adjacent to and within the primary and secondary channels. These bars are generally comprised of coarse aggregate with lesser amounts of sand and fines. Pioneering species like red alder and willow rapidly become established on these bars forming dense stands less than 2 m in height. Bars that are headed by logjams have increased preservation potential as the jam deflects the river's flow and encourages sedimentation downstream.

If the pioneer bars are able to persist without being reworked by the river, they become developing floodplains. These floodplains have a thin mantling of topsoil (10-40 cm) in

which red alders and willows are well-established. The trees are generally 5 to 20 years old and reach heights of 2-20 m tall forming a closed canopy. Log jams are relatively abundant with prominent key pieces although the smaller woody debris is decomposing.

The developing floodplains eventually evolve into established floodplains if they can persist for about 20 years without being reworked by the river. These floodplains have relatively deep topsoil (greater than 1 m) in which open stands of red alders (15-40 years old) are well established. The willows have died-off and sitka spruce becomes the prominent understory specie as they grow on the decaying large woody debris (nurse logs), and in abandoned channels with thin soils.

As the river incises through its floodplain, transitional fluvial terraces are gradually elevated above the active river channel and floodplain. These terraces are mantled with deep, weakly developed topsoil and are covered with open stands of hardwood and conifers. The sitka spruce has colonized the decaying large woody debris and the forest succession has switched from the allogenic processes to autogenic processes.

Once the fluvial terrace is elevated and preserved above the floodplain it is called a mature fluvial terrace. These terraces have well-developed, deep soils that are mantled with large woody debris that has accumulated from dead and toppling trees. The vegetation on the mature fluvial terrace has reached its theoretical successional climax forest. The climax forest is represented by the sitka spruce series and is the same as previously described for the upper and intermediate surfaces.

Figure 9. Photo on Queets River illustrating some of the vegetation succession stages present. Photo reproduced with permission from J. Latterell.

3.3.3. Hyporheic Zone

The ecological impacts of the surface water and groundwater interface in the hyporheic zone were not addressed in this study. The hyporheic flow is assumed to transport vital nutrients throughout much of the active floodplain. However, determining the hyporheic zone's extent and the hydrogeologic controls that govern its zone of influence were beyond the scope of this study. The following are some generalizations that can be made with respect to the hyporheic zone.

The hyporheic zone occurs beneath and adjacent to streams where there is mixing of the surface water and groundwater. The extent of this zone is dependent on the hydraulic gradient of the groundwater system and the permeability of the underlying geologic formation (USGS, 2004; UOW, 2005). Water flux, or bi-directional flow, in the hyporheic zone is temporally and spatially controlled by fluctuations in the force potential (hydraulic head) between the stream and the water table. The residence time for water within the hyporheic zone is dependant on the hyporheic flow path's length and the geologic formation's hydraulic conductivity (OSU, 2005).

Hyporheic zones are biologically and chemically very important to the ecologic system. These zones provide hydrologic connections between the stream and catchments, and also link the aquatic and terrestrial systems (OSU, 2005; UOW, 2005). Intermixing of oxygen rich surface water and oxygen depleted groundwater creates an environment within the substrate where microbes and algae proliferate. Biogeochemical processes that take place within these microbial communities include intensive nitrogen and carbon cycling that helps filter the water. The rate at which this cycling occurs is influenced by the diffusion, dispersion, and advection of the nutrients in the hyporheic flow (Sheibley et al., 2003).

Spawning salmon and their decomposing carcasses release nutrients into the stream. The organic material is subsequently broken down by the microbes. Sequential reduction of the dissolved nitrates to nitrogen gas (denitrification) by several microbial processes release nitrogen into the hyporheic zone (Knowles, 1982). The nitrogen acts as a fertilizer and promotes the rapid growth of the epilithic algae mats. Larger aquatic organisms consume the epilithon and are in turn the food source for fish fry and amphibians (UOW, 2005).

3.4 Sockeye Salmon Lifecycle and Habitat

The Quinault sockeye salmon (locally known as the blueback salmon) was especially important to the Quinault people, their culture, and as a dominant component in the local ecosystem (Sims, 2002). Populations of Chinook, silver, chum, and steelhead salmon in the Quinault River were also believed to be historically large and diverse (Sims, 2002). Sockeye salmon are of particular interest to the Quinault Indian Nation and the focus of this study because of the stock's cultural importance, its historic ecosystem role, and because the status of this stock and the habitats supporting its freshwater life-history stage are believed to be in a critical state (Sims, 2002).

3.4.1 Quinault Sockeye Spawning Habitat

Sockeye spawn in habitat reaches consisting of side channels, sloughs, and the lower reaches of several tributaries between Lake Quinault and the forks of the Quinault River. Very limited spawning occurs in the margins and braided channels of the mainstem Quinault River. The availability, quantity, and quality of mainstem river habitats are inconsistent and highly variable year to year. Although the total length of habitat reaches where spawning occurs could be considered extensive, the actual quantity of suitable, quality spawning habitat within most reaches is limited.

The majority of spawning occurs in low gradient, low velocity glides and still water pools of moderate depth. The spawning habitats are characterized as having a combination of surface water, hyporheic or interstitial flow, and loosely packed porous sediments. Habitat reaches with physical characteristics such as forested stream banks, an erodible sediment source, wood debris, and small log jams provide the highest quality. Small beaver dams also compliment some habitat reaches and provide for consistent streamflow that helps to reduce scouring of preferred sediment sizes. Based on sediment measurements and field observations during 2004 to 2005, sediment in sockeye spawning habitats contain a mixture of size classes that range from sand (2 mm) to small cobble (76 mm) (Armstrong, written communication, 2005). Preferred sizes for spawning range from 2 mm to 53 mm with an average size of 27.5 mm. It is common for female sockeye to clear a shallow surface layer of fine sediment (sand and silt <0.2 mm in diameter) in order to spawn in the preferred sediment sizes.

Most productive side channel sockeye habitat presently observed correlates with beaver activity in the side channel. The beaver build new dams or build upon existing logs to back water up. In some places the ponded areas capture fine-sized sediment that otherwise would have been transported through the side channel. In one instance it was noted that a side channel with a sandy channel bed not utilized by salmon became more gravel dominated after upstream beaver use.

3.4.2 Quinault Sockeye Life History

There are 4 distinct phases of freshwater migration and spawning by adult sockeye in the Quinault River watershed encompassing the period of river entry to spawning:

- Migration from the Pacific Ocean through the lower Quinault River to Lake Quinault occurs from February through July with peak river entry in early June.
- Maturation period in the lake is August to October.
- Migration up the Quinault River from the lake and into the spawning grounds occurs from October to January.
- Spawning begins in November and continues into March. The peak spawning period is December through January.

There are 3 distinct phases of juvenile sockeye freshwater migration and rearing in the Quinault River watershed encompassing the period of fry emergence to smolt migration:

- Emergence and migration of fry from spawning habitats through the Quinault River to the lake from May to August.
- Juvenile sockeye rear in the lake for 1 to 2 years.
- Smolt migration from Lake Quinault through the lower Quinault River to the Pacific Ocean occurs each spring from April through July.

Lake Quinault is a critical habitat component for the juvenile and adult phases of the sockeye life cycle. The lake is currently being fertilized with low levels of nitrogen and phosphorus to improve trophic level productivity.

Historically, portions of the study reach would be reworked over time as the river shifted into a new location, but this reworking would not occur in all areas at once. Several side channels thus were able to remain stable and provide habitat at any given time. Habitat side channels are defined as areas within the active floodplain of the Quinault River that are subject to being overtaken by the main Quinault River in the near future. Side channels are typically vegetated on either side of the channel and can be bound by older geologic surfaces (terrace, bedrock, etc) or a river bank within the active floodplain. Terrace habitat channels are also areas where the Quinault River has occupied in the past, but the last time the channel occupied these locations is thought to be a much longer time ago (several decades to centuries) when compared to the active floodplain reoccupation rate of a few years to decades. Terrace channels were critical to salmonids because they provided stable habitat for several decades to centuries. Both side and terrace channels can receive flow from tributaries, a surface water connection with the main Quinault River, or groundwater connections (hyporheic flows). Tributary channels are paths that originate from a tributary on the hillslope of the valley wall and eventually drop onto the valley floor and into the Quinault River active floodplain.

3.5 River Setting in Late 1800s

In this section we provide our conceptual picture of the Quinault River in its natural setting, based on expedition accounts and maps from the late 1800s and early 1900s. This reference condition has substantial differences from the present Quinault River. Therefore, we also attempt to verify the likelihood of this described river condition by comparing it to present conditions on the nearby Queets River (see Figure 1). The upper-most portion of the Queets has experienced much less human disturbances than many other Northwest rivers, and is thought to have many similar physical processes as the Upper Quinault River in the late 1800s.

3.5.1 River morphology, large wood debris, and sediment

The Quinault River functioned as a natural gravel-bed river system in the late 1800s. This natural system consisted of mountain uplift and river downcutting, frequent floods, dense forest, large woody debris, and channel migration across the floodplain. The river channel consisted of typically one, and sometimes more, main channels and many side channels winding through the forested floodplain. Side channels were also incised into

the forested terraces adjacent to the floodplain. The active river channel was deep and tended to be lined with mature vegetation on one or both banks of the channel.

Most of the active channels were inundated by river flows much of the year and were too deep to wade across. The channel alignment was straight in some places and had large bends in other places. In sections where the floodplain widened, large unvegetated sand and gravel bars were present that were prone to being reworked during high-flow events. These bars often contained piles of drift wood and were exposed (not wetted) during low to normal flow periods.

Mature riparian forest and large woody debris played an important role in limiting the rate of channel migration and bank erosion in the Quinault River. Mature vegetation within the densely forested floodplain tended to help resist and slow the rate of river bank erosion. Large woody debris was recruited into the river as these forested banks lining the river were slowly eroded over time. Once recruited into the river, large woody debris could impact local channel hydraulics, but typically did not cross the entire width of the active wetted channel. The snags and log jams formed by the large woody debris created roughness and complexity in the river, which created and helped sustain numerous areas of sockeye habitat.

Log jams that formed at the entrances to side channels resisted smaller floods and protected side channels from being overtaken by the river for a period of time. Log jams that remained stable in the river often formed downstream bars, which over time became vegetated. These areas, often islands, created fairly stable hard points with mature riparian forest that also helped limit the rate of channel migration and kept the main channel confined to a narrow and deep channel.

During large enough floods, the log jams and mature vegetation would be blown out and the river would shift to a new path, often into a side channel or slough that had been occupied by the river at some point in the past. When this shifting occurred, the old path of the river would develop into a side channel, maintaining the river floodplain complexity. Channel migration occurred in a relatively small percentage of the floodplain at any given time.

Sediment was supplied to the river from the upper basin, river banks, mass wasting (landslides and debris flows), and sediment in storage in the bed. In the middle and upper parts of the reach, the river channel was deep and narrow and water moved at high velocity during floods; these characteristics promoted a high sediment transport capacity. A large amount of sediment was stored in the floodplain as either bars or below relatively stable, vegetated surfaces. In the lower part of the reach near the inlet to Lake Quinault, the river slope gradually flattened to create a natural depositional zone and delta.

3.5.2 Historical Photographs and Maps

We used historical mapping and ground photographs, expedition accounts, and descriptions of the Queets River to create a conceptual image of how the Upper Quinault River might have looked prior to 1939, the first available aerial photograph set. This

section documents some of these images. The next section documents key quotes from expedition accounts.

Three photographs of the early river conditions are presented, one in the upstream-most third of the study reach and two in the downstream-most third closer to Lake Quinault (Figures 10, 11, and 12). Vegetation can be observed in each photograph, but the photograph at upstream end of study reach (RK 15) exhibits a narrower channel and the photographs closer to Lake Quinault (RK 3.6 and 3) exhibit a wider channel with large sediment bars. Even in the 1912 photograph, a cow can be seen wading in the river channel. Unfortunately, there are no photographs in the middle section of our study reach.

A 1909 cadastral survey map shows what is believed to be the extent of the active floodplain (HCMZ) of the Quinault River between RK 7 to 18 (Figure 13). The map does not document vegetation or terrace boundaries. However, this map is believed to show the typical width of the river, including vegetated islands that may have been present before large-scale disturbance of the Quinault River. Between Lake Quinault (RK 0) and RK 7, an 1897 cadastral survey map shows a very rough outline of the Quinault River that appears in places to be too straight to be realistic. This map may have oversimplified the planform of the Quinault River, but it is possible the typical width of the river is shown correctly. In general, the two maps show a much narrower active channel and floodplain than is present today on the Quinault River.

ANTRIM AND HIS GUIDES.

"May 18, 1890. This photograph was the last to be taken by Barnes prior to the loss of the camera in the Quinault River that same day. The view depicts three men in a canoe: Frederick S. Antrim of Aberdeen, his Quinault Indian guide Willie, and another Quinault Indian guide. Antrim is the central, seated, figure in the canoe, as the canoe was propelled by the two Indians." (Majors, vol. 2, 156)

Figure 10. May 18, 1890. This photograph was taken near RK 15 where the Press party constructed a raft that crashed on a log jam just downstream (Photograph from Lien, 2001).

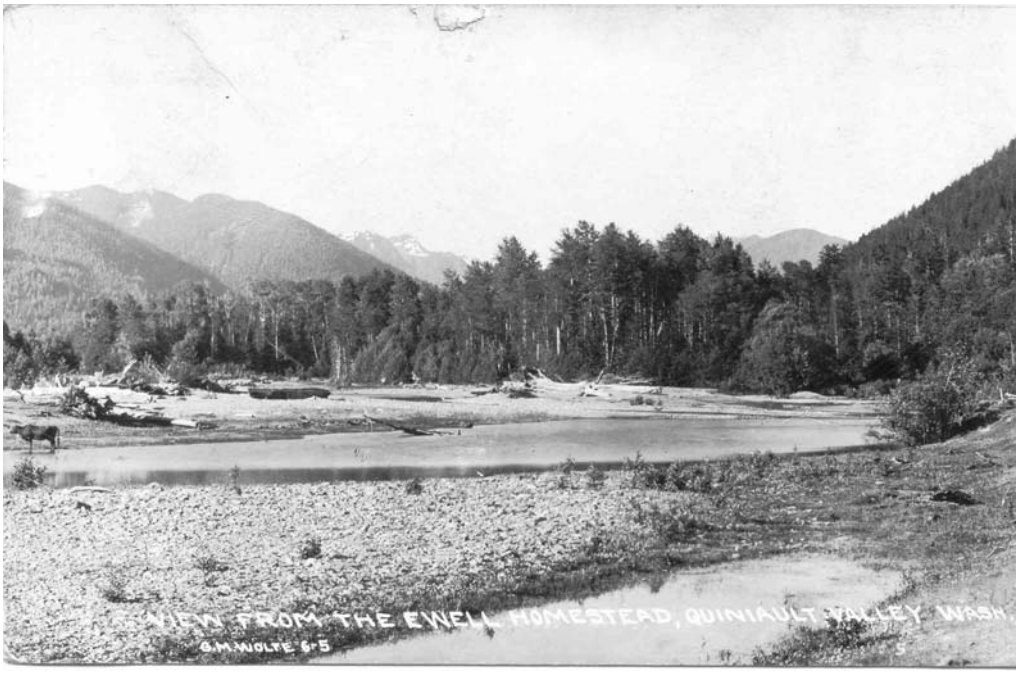

Figure 11. View of Quinault River thought to be taken from south side looking upstream near RK 3.6. Postmarked 1912, titled "View from the Ewell Homestead, Quiniault Valley Wash". Photographer was G.M. Wolfe. Photograph copy courtesy of Walt Devaney.

Figure 12. Undated photograph of suspension bridge thought to be located about RK 2.5. The bridge is thought to be shown crossing the southern most of two main channels, separated by a vegetated island shown on the right side of the photograph. There was a second suspension span from the island to the north shore that is not shown in the picture. Bridge was documented to exist two times in 1920s (washed out by floods each time). Photograph copy courtesy of Walt Devaney.

Figure 13. Planform of what the early river looked like based on the 1897 and 1909 cadastral survey maps.

3.5.3 Journal Accounts during Late 1800s

Support for the reference condition described above is provided from several historical expedition accounts between 1878 to 1890 that describe the Upper Quinault River (Appendix M). At this time, Quinault Indians used the upper river for hunting and traveling by canoe, but did not have any known villages. One European homesteader was present on north side of the river just downstream of the Forks, but the rest of the valley remained fairly undisturbed except near the lake, where a few homes and a store had been built. In 1888, Alfred Noyes is documented to have been the first white settler in the Upper Quinault (Cleland, 1973).

Journal accounts from the Watkinson Expedition in 1878 describe their trip on the Quinault River between the Forks and Lake Quinault in early September as:

"The river was becoming too deep to ford" and *"There were many indications of very heavy freshets here. In some places, the bars are one quarter of a mile wide, with great drift piles on top of them" (Lien, 2001).*

Journal accounts from the Gilman Explorations in October 1890 between Lake Quinault and the Forks described their observations. There were two men on this expedition who hired Indian guides to take them up the Quinault to the Forks by canoe.

"The adventurers found the river very swift and were constrained to walk most of the time, while the Indians pulled the canoe. Occasionally they would strike an obstruction on the bank and then the Indians would ferry them to the other side where they pursued their course until they were compelled to cross over again. They continued up the river until the afternoon of the next day, October 25, when they reached the forks about 4:30 pm" (Lien, 2001).

The DeFord Party Expedition in August of 1890 described the upper river as:

"Above the lake they found the canoeing difficult, it being necessary in many places to drag their canoes over the shoals (stretch of shallow water) and jams," (Lien, 2001).

The O'Neil Expedition, also in August 1890, mentioned:

"After a very heavy tramp of five days we reached Lake Quinault….After the junction of the North and East Forks, about 10 miles from the lake, the river becomes a large-sized stream, in spring very rapid…The North Fork is a stream nearly as large as the East Fork, rising just south of Mount Olympus" (Lien, 2001).

Journal accounts from the Press Expedition in May 1890 (Lien, 2001) provide the most detailed account of the Upper Quinault River between RK 18 and 15. The Press party document an occasion when the group camped on a river island along the North Fork of the Quinault River within a one-day travel distance upstream from the confluence with the East Fork (see Figure 1). Between the Forks at RK 18 to about RK 15, the Press

Expedition documents the great difficulty of traveling by foot along the Quinault River because of dense vegetation throughout the floodplain and along the river bank and because of the deep river flow against large woody debris. The expedition party was forced to walk along drier sloughs through the forested floodplain:

"…The river was now large and broad….The bank of the river becoming now so dense with underbrush as to be almost impenetrable, we struck backward from the river and found dry sloughs, which we followed. They led us again to the river about one mile below and there we made camp on a sand bar..." (Lien, 2001).

Near RK 15, the Press Expedition constructed a log raft thinking it would be easier to reach Lake Quinault than walking, but they lost nearly all of their gear after wrecking on a log jam a few river miles downstream.

"as we rounded a sharp bend in the river we were suddenly horrified to see the whole current sweep in toward the right (assumed north) bank and pass under a great pile of drift timber which lay upon the bank and projected half way across the stream" (Lien, 2001).

After the wreck, the expedition party was split on opposite sides of the river. The two members on the south (left) side of the river had to struggle through dense vegetation while the rest of the party who reached the north (right) side had an easier time walking along unvegetated gravel bars. The party of the south side did eventually reach a large sand bar on which they camped. Neither party could cross the river. The party was rescued by two members of the Quinault Indian Nation and a Mr. Antrim who was on a hunting trip. It is estimated the start of their canoe journey was just upstream of the present confluence with Big Creek. The expedition party was safely transported downstream by canoe. The journal describes the skillful canoe navigation around numerous log jams by the tribal members, but multiple channels (split flow around river islands) is not described:

"Piles of driftwood were frequent. In fact, it soon became evident to us that it would have been impossible for us to have descended the river on a raft. If we had not been wrecked where we were it would have been impossible to escape it half a mile below. As we neared the lake drift piles became still more numerous, and it required most skillful handling to clear them with the canoe" (Lien, 2001).

Given the time of year of these expeditions, we believe the uncrossable river channel condition was due to the presence of a deep and narrow channel rather than high flows. During the period of record from 1911 to 2004, mean-daily river flows during the month of May (Press Expedition) have not been especially high: they have always been between 2,685 and 3,042 ft^3/s, with a monthly mean streamflow of 2,837 ft^3/s. Typical river flows during the Watkinson Expedition in September would have been a little less than 900 ft^3/s. At similar river flows today (2004), an individual can easily find many areas to cross the now wide and shallow river channel and there are many areas of unvegetated

sediment bars. Very few floodplain areas are so densely vegetated today that you would have difficulty traversing through them.

3.5.4 Queets River as an analog for reference conditions on the Quinault River

Although each river basin on the Olympic Peninsula is unique, the Queets River has many physical characteristics that are similar to those of the Quinault River. The two rivers are located in the same geographic region and both have had limited human disturbances in the upper portions of their basins. The Queets River is located just north of the Quinault River; a large portion of its drainage area has been within Olympic National Park since the 1938 (see Figure 1). Although portions of the Upper Queets River were disturbed in the early part of the Twentieth Century, they have been undisturbed since being incorporated into Olympic National Park. Thus, the morphology of the Upper Queets River, the portion within Olympic National Park, as observed on historical maps and on historical aerial photographs and in its present condition, was used to support the inferred morphology of the Upper Quinault River in the late 1800s.

Although both the Queets and Quinault Rivers have similar overall settings, the characteristics of individual reaches vary significantly depending upon local geology. Although the rock types in the two basins are similar, predominantly metasedimentary rocks, several characteristics of the drainages basins do differ:

1. The base level for the Queets River is the Pacific Ocean rather than a moraine-impounded lake (Lake Quinault), which is the base level for the Upper Quinault River.
2. The Queets River valley is bounded by Pleistocene glacial moraines along most of its length to the Pacific Ocean. In contrast, the Upper Quinault River valley is bounded primarily by bedrock and Pleistocene outwash deposits. Both the Queets and Upper Quinault River channels are bounded by Holocene, mostly, and Pleistocene terraces.
3. A moraine-impounded lake that formed on the Queets River about 27,000 years ago probably drained before the Holocene (~10,000 years ago). The moraine that impounds Lake Quinault was likely deposited about 18,000 years ago, during a younger glacial advance or stagnation of ice. Unlike the moraine-impounded lake on the Queets River, Lake Quinault has persisted through the Holocene to the present and still influences processes on the Quinault River.
4. As a result of the relatively young moraine-impounded lake on the Quinault River, outwash and (or) deltaic deposits probably underlie the Holocene surfaces adjacent to the Upper Quinault River. These deposits are, in turn, overlain by lacustrine sediments that were deposits during various stands of Lake Quinault since about 18,000 years ago. Clay-rich lacustrine deposits may not be as common under the surfaces adjacent to the Queets River; however, patchy lacustrine deposits are readily visible along some meander bends and in the middle of the channel (J. Latterell, written commun., 2005). These lacustrine deposits have been observed to be fairly erosion resistant in places.

Although differences between the Upper Quinault River and the Queets River exist, the Queets River is the best analog we could find for processes for the reference Upper Quinault River system. However, quantitative comparisons of the rates of these processes should take into consideration the differences in the characteristics of the drainage basins, especially the influence of Lake Quinault on the Upper Quinault River

The characteristics of the channel and floodplain of the Upper Queets River, as inferred from discussions with scientists working in the Queets basin are described below (verbal conversation with J. Latterell, T. Abbe, and K. Fetherston, February 16, 2005; Latterell, J. et al, 2005). These characteristics support the reference vegetation conditions of the Upper Quinault River, which are described in Section 3.3.

The Upper Queets River is complex and has a variety of channel forms (Figure 14). There is typically one or two low-flow channels, and a large number of interconnected side, overflow and terrace channels are present throughout the floodplain. The active channel may or may not contain unvegetated or vegetated bars. Surfaces on both sides of the active channel generally have mature vegetation Side channels have a wide range of stability from a few years to several decades or more. Side channels are generally present in areas that the main river channel has recently abandoned. Flow is sustained in side channels during low-flow periods most commonly from hyporheic flow that may start downstream of the channel entrance. However, during higher-flow periods the majority of the channels within the complex floodplain become inundated.

The long-term stability of the side channels along the Upper Queets River depends upon the local reach morphology, their location in the system, the formation of stable hard points that help stabilize the channel, and the rates at which vegetation encroaches from adjacent banks. Visual observations by the study team have noted that side channels that have large woody debris jams at their entrances tend to be more stable for longer periods of time than side channels without such jams. Side channels that have long-term stability are not as common as side channels that are more frequently reworked by the river. Some rate of reworking is needed to sustain the dynamic patch mosaic of the floodplain forest by initiating regeneration of vegetation.

Large woody debris is a critical component in the Upper Queets River system. Large woody debris forms numerous habitat areas within the floodplain and initiates the formation of stable surfaces that will eventually develop into mature fluvial terraces (Figure 15). Stable surfaces may also be created by channel abandonment after a meander cutoff or channel avulsion. Not all wood available to the system is of adequate size to form stable hard points, and even wood that is large enough to become a key member in a log jam may still be very mobile (J. Latterell, unpublished data). Therefore, a sustained supply of wood large enough to act as key members is necessary to ensure that stable hard points form (and re-form) – this demands a high degree of connectivity among upstream and downstream reaches within the mainstem river.

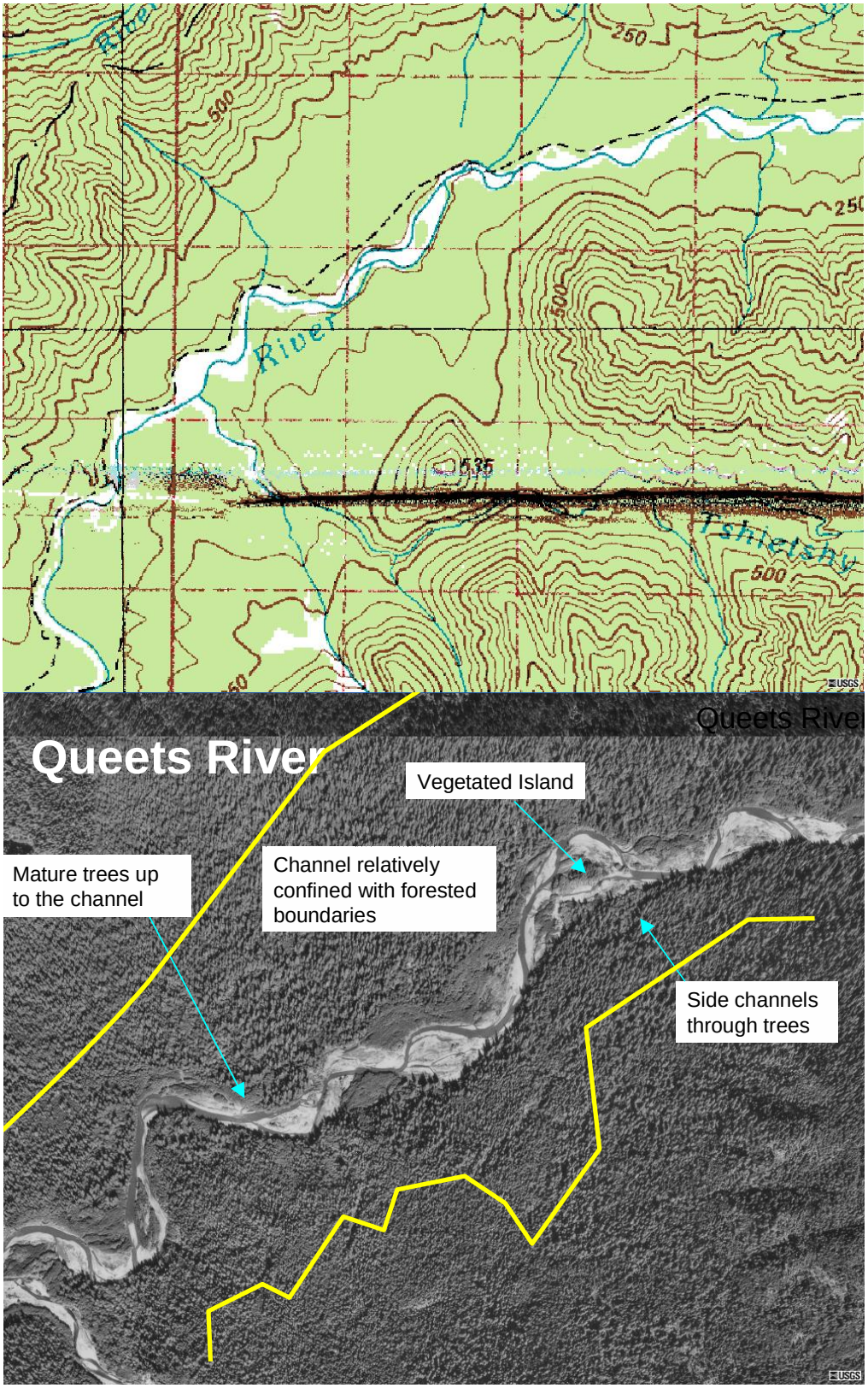

Figure 14. USGS quadrangle and aerial view of Queets River at Tshietshy River confluence (RK 50) (shown in lower left corner). This is upstream of Sam's River confluence (RK 41).

Figure 15. Example of buried wood under vegetated surface and large key piece of woody debris on a gravel bar of Queets River. Photographs reproduced with permission from J. Latterell, 2005.

The Upper Queets River generally reoccupies and reworks the same areas within a somewhat stable floodplain. There does not appear to have been a rapid expansion of this floodplain area into older bounding terraces since 1939 as has been seen on the Quinault River. The exponential erosion rates for fluvial landform surfaces in the Queets River were measured by Latterell et al (2005). The erosion and development of these surfaces is thought to represent "a successional cycle that transforms aquatic fluvial deposits into terrestrial conifer forests over years to centuries" (Latterell et al, 2005). This successional cycle and resulting surfaces are thought to have existed on the Quinault River in the reference conditions as cited in Section 3.3 of this report. However, the present Quinault River is not able to make it to the stage of developing mature fluvial terraces, which will be discussed in more detail in Section 5.0 of this report.

Aerial photographs from 1939 to 2002 and field measurements were used to document potential half-life and time to 95% loss of various surfaces in the Queets River study. The data indicate a continual cycle of erosion and formation of fluvial surfaces within the floodplain. While the younger surfaces may be reworked over a period of a few years to several decades, portions of the established floodplain can last several decades to a few centuries. Mature fluvial terraces may last a few centuries to over a thousand years. Radiocarbon dates on the Quinault River (Appendix D) support the notion that mature

terraces can last several hundred to over a thousand years, but erosion rates since 1939 show these surfaces are getting eroded at fast enough rates that do not seem to match rates of reworking on the Queets River.

The Upper Queets River is thought to be in a quasi-equilibrium that may have some tendencies toward long-term incision during the Holocene (since about 10,000 years ago). Since 1939, local changes, both higher and lower, in the elevation of the channel bed have been observed on the Upper Queets River. These changes are the result of the continuing processes of landform development and erosion (see Section 2).

4.0 Human Influences during the Last Century

This section addresses how human activities (anthropogenic influences) have changed the Upper Quinault River's fluvial geomorphology during the last century. It describes:

(a) How the resources in the upper valley were used,
(b) The historic effects of human activity on the fluvial system,
(c) Observations of the magnitude and rates of fluvial change,
(d) The characteristics of the current fluvial system, and
(e) How this information may influence decisions of those who manage the river.

Our discussion of anthropogenic influences is based primarily on published literature, anecdotal accounts, aerial photographs, and field investigations. The aim is to provide the reader with a chronology of how the natural resources were used in the Upper Quinault River valley throughout the last century. We have assumed that Native American occupation of the Upper Quinault River Valley, before the arrival of Euro-American settlers in the 1890s, represents the reference condition or "natural setting" to which more recent changes with time are compared.

The Quinault River valley was rapidly settled between 1900 and 1920, and we expect that the river would already have begun responding to human disturbances by the time of the earliest (1939) aerial photographs. Human disturbances that have most directly changed river processes are clearing of riparian vegetation in and adjacent to the historic channel migration zone, and, to a lesser degree, maintenance of infrastructure (roads, bridges, levees) along the river corridor. For most of the twentieth century documentation of human disturbances is limited to anecdotal information and observations on aerial photographs. Starting in the 1970s, a number of environmental policies were put in place that required permits and analysis before major structures such as roads, bridges, or levees could be installed. A timeline of documented activities in the Upper Quinault River study reach is presented in Appendix N.

4.1 Native American Occupation

The first known human occupation of the Olympic Peninsula began in the late Pleistocene about 12,000 years B.P. (McNulty, 1996). These earliest occupants subsisted by hunting and gathering food in the Quinault River region (QIN, 1999); they probably were nomadic and did not build perennial settlements.

It is unknown if the Quinaults and other Olympic Peninsula tribes are direct descendants of these ancient, nomadic people. However, the central belief of Quinault culture is that that their people have always lived within the Quinault River watershed. Traditionally,

the semi-nomadic tribes of the Quinault River watershed were hunters and gatherers. They harvested both marine and terrestrial plants and animals for subsistence and for cultural purposes (QIN, 1999).

The Quinault people lived in about 30 to 40 small villages downstream of Lake Quinault and used the Upper Quinault River Valley for hunting and fishing (Olson, 1936). They used the waterways as their thoroughfares. Their principal mode of transportation was a double-bow, shovel-nose canoe that was specially adapted to navigate around the log jams that frequently choked the waterways (QIN, 1999).

During the salmon runs, families would set up seasonal base camps around the lake and along the riverbanks in the Upper Quinault watershed. These camps were located where the salmon could be harvested and processed. The Quinaults harvested a variety of salmon species, but the principal specie they sought was the sockeye (or blueback) (QIN, 1999).

4.2 Euro-American Homesteading

In the 1850s, a series of treaty negotiations between the United States and the Quinault people culminated in the Quinault River Treaty, which was proclaimed on April 11, 1859, by President Buchanan (QIN, 1999). Essentially, the treaty opened the Upper Quinault River Valley to Euro-Americans for exploration and homesteading.

Towards the end of the Nineteenth Century, numerous expeditions traveled into the Upper Quinault River Valley, such as the Watkinson Expedition of 1878, the Press Expedition of 1889–1890, the Gillman Expedition of 1889–1890, the DeFord Party Expedition of 1890, and the O'Neil Expedition of 1890 (Lien, 2001; Appendix M). By the 1890s, Euro-American homesteaders arrived in the valley and began clearing lots for farming and grazing livestock. Soon after the homesteaders began to arrive, several hotels were constructed and services were established to accommodate the influx of settlers and travelers (Jones, 1997). To further promote development of the area, the Quinault Township Company was formed in 1890 (Evans, 1983).

The homesteaders began occupying the bottomlands from Lake Quinault upstream to the confluence of the North and East Forks of the Quinault River. The rapid development of the area prompted President Cleveland to establish the Olympic Forest Reserve in 1897, setting aside the unsettled lands north and east of Lake Quinault (Dodwell and Rixon, 1902). Between 1891 and 1900 more than 30 new homesteads had been established in the Upper Quinault River Valley (Evans, 1983).

In the early twentieth century the population of settlers and developments on the western peninsula markedly expanded and, recognizing this growth, President Theodore Roosevelt (1909) preserved the interior of the Olympic Mountains, designating them the Mt. Olympus National Monument. A section of the Upper Quinault River watershed was included in the national monument. In the early 1900s there was a fundamental shift from agriculture to tourism and logging. Summer home lots were surveyed for

development and a road system connected Lake Quinault to the towns of Hoquiam, Neilton, and Humptulips (QIN, 1999).

With the onset of World War I, raw materials for the war effort were needed. The increase in demand for wood products stimulated the timber industry and logging intensified within the Quinault River watershed. By the mid-1920s, railroads had been constructed in the Lower Quinault River Valley and a road connection between the lower valley and the north shore area of Lake Quinault was complete (QIN, 1999). In 1922, the Quinault Recreation Area was designated and the tourism industry began to expand. New campgrounds were constructed or improved (Buck, 1924), access roads and trails were completed (Armstrong, 2002; QIN, 1999), and such famous hotels as Lake Quinault Lodge (1926), Low Divide Chalet (1927), and Enchanted Valley Chalet (1931) were constructed (Evans, 1983).

4.3 Preservation of Resources

Early in the 1930s the notion of conservation and active management of the forest resources began to emerge with the designation of the Quinault Research Natural Area (1932). However, it was not until the late 1930s that natural resources were widely understood to be limited and Olympic National Park was designated in 1938. The new park contained lands from the Mt. Olympic National Monument, National Forest Service System lands along the North Shore of Lake Quinault, and much of the Upper Quinault River Valley which also included 4,538 acres of private land. By the 1940s and 1950s, timber harvesting along the North Fork of the Quinault River was terminated owing to Olympic National Park land acquisitions (QIN, 1999).

With the onset of World War II, a renewed demand for wood products led to an expansion of timber harvesting activities. In fact, salvage logging within Olympic National Park near Camp Kiwanis (near Highway 101 at downstream end of Lake Quinault) was conducted twice—in 1940 and 1944 (Wagner, 2003, written communication).

4.4 Resource Management Prior to 1980s

From the 1950s through the 1980s, many roads were constructed in the Upper Quinault Valley. The Multiple Use-Sustained Yield Act (1960) mandated that national forests were to be managed for many uses. One of the results was a general increase in timber harvests. Typically, the clear-cutting method was used, in which all trees were completely removed from a designated lot, broadcast burning removed the remaining slash, and the lot was reseeded.

In the 1960s, Jefferson County, Grays Harbor County, and Olympic National Forest began to actively manage the Quinault River. Prior to this, homesteaders manipulated (or removed) log jams in the river to re-direct flows. The counties' early attempts included placing riprap for bank protection and excavating (deepening or redirecting) the river

channel (Grays Harbor County memo dated August 22, 1961; Jefferson County memo dated February 7, 1964; State of Washington Hydraulics Project Approval memo dated October 4, 1965). It was also common in the late 1970s to clean streams of woody debris thought to be limiting fish production, pool formation, and water quality.

4.5 Ecological Approach to Resource Management

The 1970s, informally known as the "Decade of the Environment," brought about dramatic changes to national environmental policies (Owen and Chiras, 1995, p. 8). Major acts pertaining to air quality, noise control, toxic substances, solid waste, energy, land use, water quality and wildlife were passed. The more renowned acts included the following:

1. The Endangered Species Act of 1973, whose primary purpose was to conserve the ecosystems upon which endangered and threatened species depend;
2. The National Forest Management Act of 1976, which provided that management decisions must be based on multiple-use, sustained-yield principles; and
3. The Clean Water Act (1977), which required the classification of surface waters according to their designated use and to meet water quality standards.

Beginning in the 1980s, ecological (or sustainable) approaches to resource management were widely adopted. For example, it was found that LWD left on the ground following a timber harvest was beneficial to the ecosystem. Consequently, the National Forest Service instituted the practice of removing small woody debris after a harvest but leaving about 20 percent of the coarse woody debris on the ground. Large woody debris was also found to be beneficial to the fluvial systems because it stabilized river banks, diversified stream dynamics, and creating fishery habitat. Additionally, it was determined that riparian corridors provided riverbank stabilization along with many other benefits to aquatic and terrestrial ecosystems (QIN, 1999).

Resource managers have adjusted to the ecological systems approach. Currently, it is being applied in the design phases of bank protection and other river channel manipulations. Additionally, environmental effects must be analyzed in order to minimize (or mitigate) harm to the ecosystem. Recent local projects have incorporated the use of large woody debris and fish passable culverts to make river banks more stable (Jefferson County memos dated May, 1, 1987, and August 1, 1996; Olympic National Forest memo dated September 30, 1987). The addition of LWD and fish passable culverts provide habitat and migration passageways for the salmon.

5.0 Present River Setting and Effects of Historical Human Activity

The present river setting is remarkably different that those described under the reference conditions (Section 3). We propose that the most significant human activity that changed the undisturbed river system to its present condition is the clearing of old growth forest on terrace banks and the removal of large woody debris in the channel migration zone. Areas that were clear cut changed river processes more greatly than did areas where only the largest trees were selectively harvested. Natural changes in basin hydrology (QIN, 1999), mass wasting in the upper basin above Lake Quinault (QIN, 1999), and geologic processes were investigated but they were not found to be significant during the last century. This section describes the initial river response to disturbance in the late 1800s and early 1900s (Section 5.1), how the river has functioned since that time (Section 5.2), characteristics of the present river (Section 5.3), and the effect of historical river changes on management actions (Section 5.4). Predictions of future river processes are discussed in Section 6.

5.1 Initial river response to disturbance

The following river responses are predicted to have occurred during the early part of the twentieth century in response to human caused disturbance along the study reach. These responses were interpreted based on historical journal accounts, anecdotal accounts, reports, and maps up to 1939. Between 1939 and 2002, aerial photographs are used to interpret the rate of continuing river change as described in Section 5.2.

1. Homesteading and logging activities cleared forested islands and large woody debris in the active floodplain, which in turn led to rapid erosion of the islands and an increased sediment supply.
2. Once the sediment stored in the islands was available to the river, deep pools and channel areas quickly filled in to accommodate the increased sediment supply.
3. Even with pool storage utilized, the river could still not accommodate the increased sediment supply and the active channel widened and aggraded, causing the river to evolve to a more braided planform.
4. The largest flood of record occurred between 1900 and 1939, which would have resulted in substantial reworking of the channel area (see Figure 7 in hydrology section 3.2).
5. The braided channel was overly wide and unstable, so the low-flow channels rapidly migrated across the new braid plain. Large, wide gravel bars were frequently reworked by floods.
6. As the channel widened and shifted across the floodplain more rapidly, it put more pressure on adjacent terrace banks that historically bound the channel migration zone. Concurrent removal of mature vegetation on these terrace banks

made them more vulnerable to erosion and less stable, leading to significant loss of property and infrastructure.

7. As the sediment supply from the eroding islands began to reduce, the width of the active channel would have tended to narrow within the wider floodplain, but this tendency was at least partially offset by the increase in terrace bank erosion.
8. On the 1929 map, the channel appears to be relatively confined and has only one or two flow paths. This configuration is as would be expected given the accounts of late-1800s expeditions. On the other hand, the 1929 map illustrates few of the vegetated islands that are described in expedition accounts of 40 to 50 years earlier. There do appear to be several side channels, although these are not detailed in the mapping to a great extent.
9. By 1939 (first aerial photograph available), the active channel was wide, braided, and flanked by very little mature riparian vegetation or side channels within the active area of the floodplain (Figure 16).
10. Because there was very little mature vegetation in the floodplain, it is assumed the channel migrated across the floodplain at a rapid rate, hence the reason for very few vegetated side channels in 1939.

Davidson and Barnaby describe the conditions of the Quinault River (1936) in two places of a U.S. Fisheries Report published shortly before the 1939 aerial photograph that supports the above statements. They describe the river as being recently changed in the 1930s from earlier conditions, alluded to as the early 1900s:

"In connection with observations in the territory drained by the Upper Quinault River, the constant shifting of the channels has been particularly noticed. It is worthy of note that this feature is a matter of comparatively recent years and has developed at an alarming rate during the past twenty years. Statements set forth by the early settlers picture the Upper Quinault river as a stream of narrow proportion, banked by miles of heavily timbered soil" (Davidson and Barnaby, 1936).

"The early settlers and inhabitants of this region describe the Upper Quinault River as a large stream that flowed between two rather narrow heavily wooded banks. This condition, however, does not prevail at the present time for the logging off of the watersheds of the river has caused excessive washing to the extent that there is no definite river bed but a wide river valley through which the stream frequently changes its course with the winter and spring freshets. At the present time the devastated area caused by shifting of the channels varies in width from one-quarter to one-half mile and is noticeable the entire distance of twelve miles to the main forks" (Davidson and Barnaby, 1936).

The 1939 aerial photograph also provides evidence that much of the valley had been cleared of vegetation by this time (Figure 16) and that logging was a common practice for both private and commercial reasons. We also observed numerous old stumps of cedar and conifer trees throughout the floodplain and terrace and lake deposit surfaces, which provides additional evidence of the historic logging. Trees of the same diameter as the stumps observed were generally not present. Although the north side of the river is now

Olympic National Park as shown in the bottom half of Figure 16 from a 2001 photo, this land preservation did not occur until 1938 and many areas were still in private ownership until many years later (some areas are still privately held even today). The 1939 channel is wide and unvegetated, much different from the confined reference channel conditions described in Section 3.

True stability never exists in natural rivers, which frequently change their position and must continue to pass a range of discharges and sediment loads (Knighton, 1999). However, rivers can be classified as relatively stable if they tend to maintain characteristic equilibrium forms, processes, and measurable variables. Sediment supply and transport capacity play a large role in whether a river is in a stable state or adjusting to a new state. A river channel will adjust its sediment transport capacity to accommodate a change in sediment supply and volume of flow by changing its width, depth, and slope relationship (narrowing or widening) or by aggrading or eroding the channel bed. The disturbance to a wide channel by 1939 is believed to have occurred from a large input of sediment to the system from accelerated bank erosion and reworking of channel and floodplain deposits.

The question was asked if landslides and debris flows could have been large and frequent enough to cause a noticeable increase to sediment load and change to the channel form observed in the 1939 aerial photograph in addition to or in place of sediment supplied from clearing of vegetated islands. The Quinault Watershed Analysis compared landslides in the 1939 and 1998 aerial photographs in the upper basin but did not find any significant differences that would suggest 1939 had a larger amount of mass wasting occurrences than the present day. A 1936 report (Davidson and Barnaby, 1936) did mention three large slides in association with a large rain event. Inspection of the 1939 aerial photos indicates that these referenced slide areas may have been on the Finley Creek and Big Creek tributaries and the Quinault Ridge area within the Upper Quinault study reach. The size of the slides in 1939 relative to the watershed was small and the tributary channels downstream of the slides were narrow. This indicates that a large amount of coarse sediment did not get immediately transported to the main Quinault River channel, and, therefore, it is difficult to presume it could have caused a reach scale change in channel planform. Fine sediment loads could have temporarily increased from these events and caused changes in water quality (turbidity) but this would not have resulted in a wider active channel.

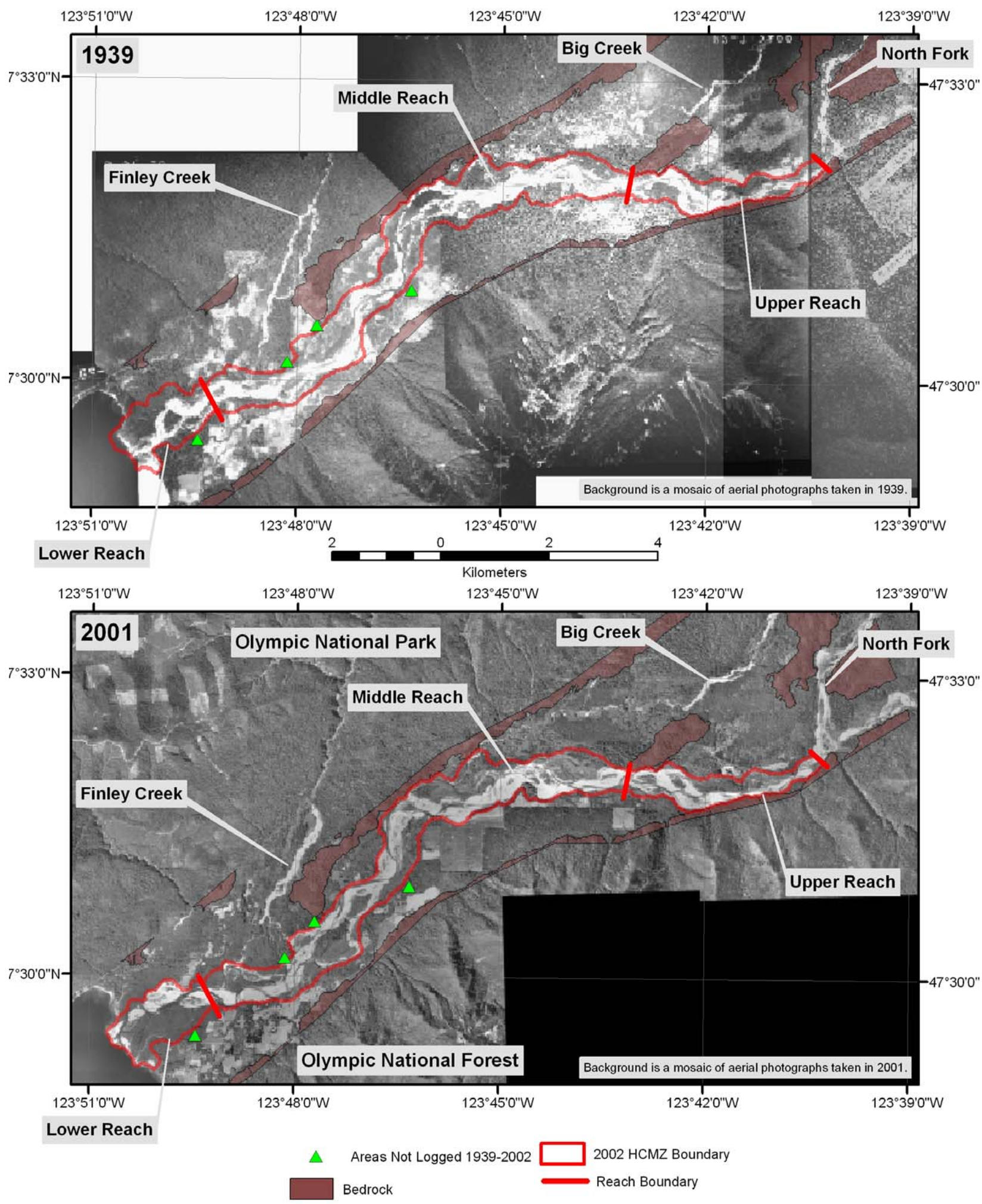

Figure 16. The Upper Quinault River valley as it was in 1939 (upper photograph) and in 2001 (lower photograph). The majority of erodible (non-bedrock) surfaces have been logged between 1939 and 2001, except for the four locations shown with green triangles. Some of the areas logged in 1939 have partially re-vegetated by 2001, and other areas have remained cleared. The few areas not cleared in 1939 were eventually cleared at some point between 1939 and 2001.

5.2 Magnitude and rate of change of river processes

This section discusses how the river has functioned since the initial disturbance in the late 1800s and early 1900s. We propose the river was in a state of transition to a new disturbed condition in the early 1900s in response to increased sediment load from vegetated islands that were cleared, and has remained relatively consistent in channel characteristics since that time because mature vegetated islands and large woody debris have not yet been restored to the system in enough quantity to recreate the reference conditions.

5.2.1 Active Channel

The active channel is defined as the channel area transporting the majority of sediment during a given flood. Although the active channel shifts locations, since 1939 the active channel width has remained fairly constant, with no detectable trends of increasing or decreasing width that would indicate a response to changing sediment loads (Table 3). It is presumed that by 1939 the river had adjusted to a new state following the short-term overloading of sediment from islands that had been cleared in the early 1900s. Because the mapping of the active channel can be subject to interpretation, the widths of all unvegetated channels apparent in each aerial photograph were also compared for any evidence of trends (Table 4). The additional channel areas included unvegetated channel paths that were recently active channel locations and were still reworked enough that vegetation had not established. These width values also do not show a trend in decreasing or increasing width that would indicate an adjustment in the channel due to a change in sediment loads since 1939. Note that the total unvegetated average channel width for each study reach (last row in Table 4) is about twice the average active channel widths (last row in Table 3).

Table 3. Average width of the active Quinault River channel as measured on aerial photographs for each reach of the study area.

Year	Average Width Unvegetated (Active) Channel (m)		
	Upper Reach	Middle Reach	Lower Reach
1939	100	142	112
1952	80	114	157
1958	134	160	134
1962	162	159	145
1973	98	118	160
1982	93	109	107
1994	96	137	105
1998	82	124	98
2001	117	160	167
2002	113	109	123
Average for all years measured	107	133	131

Table 4. Average width of all unvegetated Quinault River channels as measured on aerial photographs for each reach of the study area.

Year	Average Width Unvegetated (Active) Channel (m)		
	Upper Reach	Middle Reach	Lower Reach
1939	190	260	251
1952	141	178	229
1958	231	299	273
1962	258	279	240
1973	139	225	246
1982	177	235	220
1994	205	273	232
1998	312	298	257
2001	210	288	266
2002	197	271	286
Average for all years measured	206	261	250

5.2.2 Historic Channel Migration Zone Expansion

The 2002 historic channel migration zone (2002 HCMZ) is defined in our study as the area the river has occupied over approximately the last century (see Appendix J for more information about the HCMZ). We used historical aerial photographs to document that the HCMZ boundary has continually expanded since at least 1939 as a result of erosion by the river, causing a loss of terrace bank property at an average rate of 34,000 m^2 per year (Figures 17, 18, and 19; Table 5). The areas that have not eroded are generally either composed of bedrock, have been protected by human-placed bank protection, or have not had the active river channel running along them since 1939. There is no significant trend in decreasing or increasing bank erosion along the HCMZ boundary between 1939 and 2002. The Quinault Watershed analysis (QIN, 1999) did not find any distinct trend in flood flows getting higher peaks or more frequent in magnitude over the period of record (see Hydrology Section).

Table 5. Percent of historic channel migration zone boundary that has eroded between 1939 and 2002 along both sides of the active floodplain.

	% of HCMZ Boundary Eroded		
	Upper Reach	Middle Reach	Lower Reach
Left (South) Side	29	67	39
Right (North) Side	64	65	83

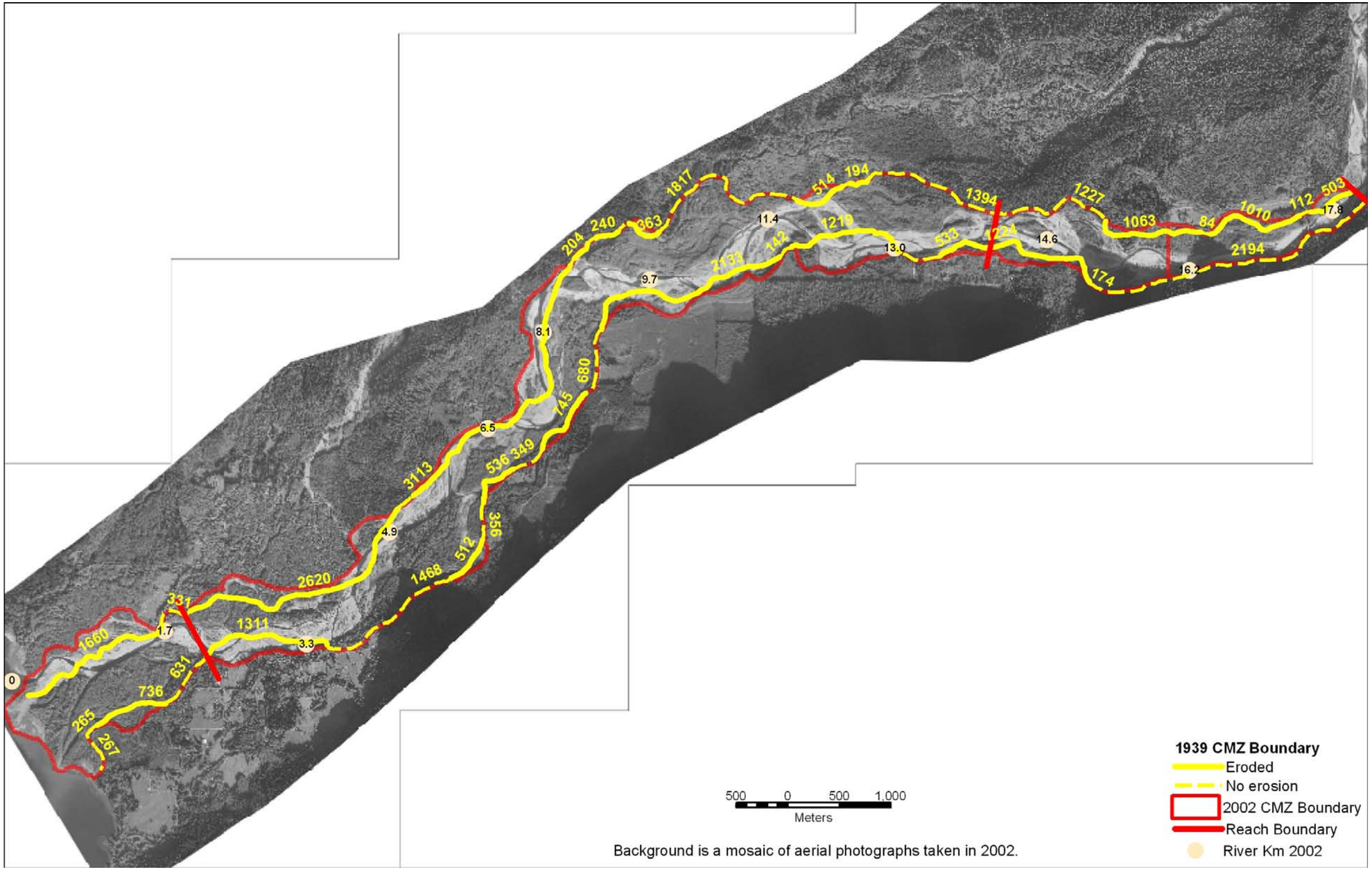

Figure 17. Sections of 1939 HCMZ boundary that eroded between 1939 and 2002. Lengths of each section (in meters) are shown by the yellow numbers.

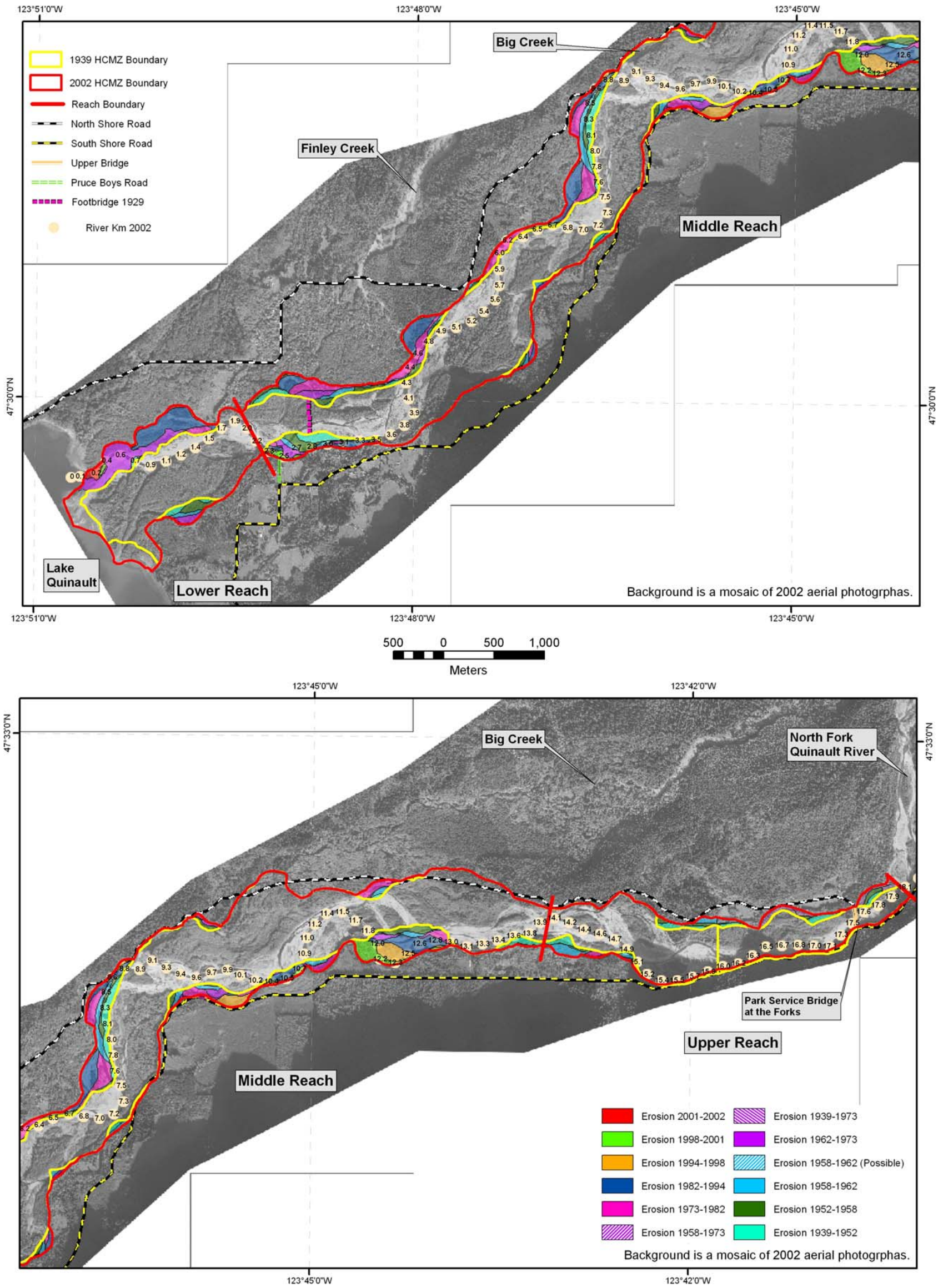

Figure 18. Areas eroded along the HCMZ boundary by time period between 1939 and 2002 for the downstream portion of the study reach (upper figure) and upstream portion of the study reach (lower figure). The two figures overlap. The North Shore Road is shown in black and white, and the South Shore Road is outlined in yellow and black.

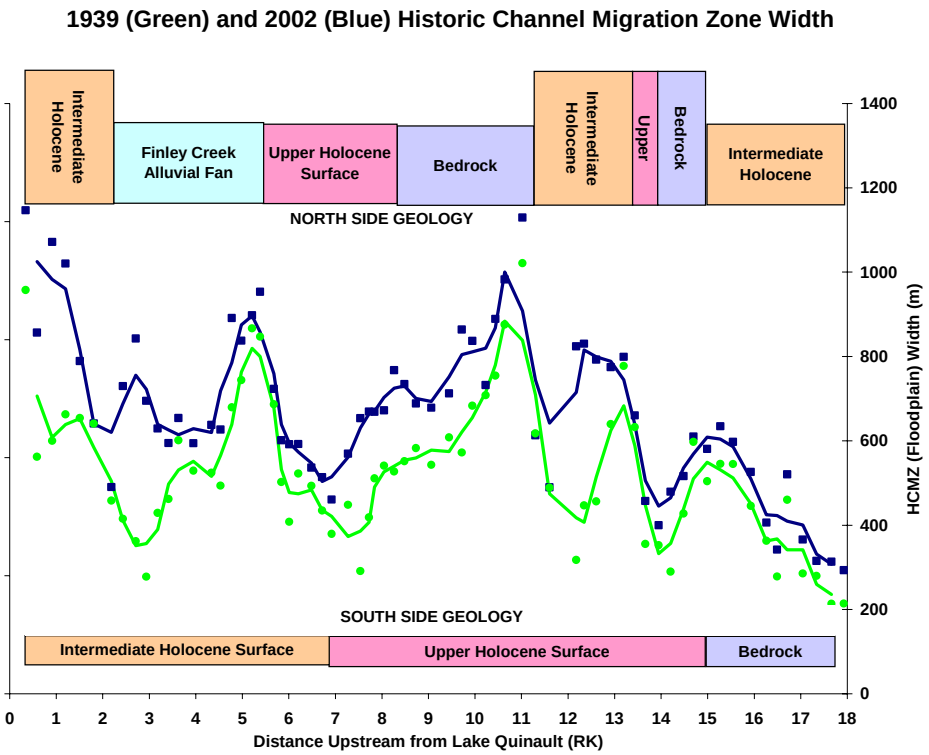

Figure 19. Increase in total width of HCMZ between 1939 and 2002. Measurements were taken approximately every 0.5 km apart on aerial photographs and compare to the location of geologic controls.

All terrace areas that eroded were thinned or cleared of old-growth forest prior to erosion. The cleared areas experienced the greatest lateral amounts of erosion. Areas that were only thinned and still had some trees were hypothesized to be more resistant to erosion than cleared areas. However, evaluation of the river position in relation to when these areas eroded indicates that in most cases an upstream cleared area would be eroded allowing the river to be oriented directly into the thinned section. When this occurred the trees provided little protection to the surface from being eroded because river velocities and energy were much greater than if the river was running parallel to the bank surface.

Because the HCMZ has expanded between 1939 and 2002, the lengths of the active and unvegetated channel that run against the terrace bank (HCMZ boundary) might be expected to decrease. The HCMZ in 2002 has a larger area than it did in 1939, so the amount of time that the channel is along a boundary may have decreased. The decrease in the lengths of active and unvegetated channel that coincide with the HCMZ boundary, in turn, might reduce the total length of the HCMZ boundary that erodes in any given flood, because the part of the channel carrying the most flow and doing the most erosion would not be along as much of the boundary. However, localized areas could still experience high rates of erosion in places where the channel and boundary do coincide.

The sections of active and unvegetated channel running against the historical channel migration zone boundary were mapped on each aerial photograph and compared to see if

the lengths of the sections where channel and HCMZ boundary coincide have increased or decreased since 1939. There is a slight decrease in the total length of channel running along the HCMZ boundary in the middle and upper reaches since 1939 (Table 6).

Table 6. Percent of the total HCMZ boundary occupied by the unvegetated channel (including the active channel) for each year

Percent of Total HCMZ Boundary (includes right and left boundaries)			
Year	**Lower Reach**	**Middle Reach**	**Upper Reach**
1939	28	43	41
1952	27	18	5
1958	25	32	42
1962	27	39	30
1973	31	26	29
1982	16	33	24
1994	25	34	32
1998	26	24	23
2001	22	24	28
2002	23	24	21

In the Lower Reach (RK 0 to 2), the channel has flowed on either the left or right side of a large vegetated surface that has not been reworked since 1939. Consequently, the channel has flowed along either the right (north) or left (south) HCMZ boundary at any given time. The length of HCMZ on either side with channel running against it has typically ranged from 20 to 50% (see Appendix I). There has been no significant trend in this computation since 1939.

In the Upper Reach (RK 14 to 18), the channel has generally run along the left HCMZ boundary more than the right boundary. Since 1973, when the Bunch Field Levee was visible, the channel has run against left boundary more than the right one.

In the Middle Reach (RK 2 to 14), the channel alternates between running along the left and right HCMZ boundaries, but there is no general trend that the channel has run along one boundary more than the other. In 1939, the channel ran along a greater length of the left boundary than it has since then. About 63% of the left HCMZ boundary had the unvegetated and active channel along it and 46% of this boundary had the active channel alone along it. Since 1952, the lengths of the left HCMZ boundary having active and (or) unvegetated channel running against it have been about half of the length in 1939.

We propose that the river had the most dramatic response to vegetation clearing in the early part of the twentieth century, prior to our first aerial photograph in 1939. Unfortunately, historical maps from 1897, 1906, and 1929 do not clearly indicate terrace boundaries or vegetation types and age that could be used to delineate terrace boundaries. However, the maps do show the locations of the main channel, constructed roads and houses. In some cases, there are roads or houses in the area between the older channel and the 1939 HCMZ boundary, which suggests that the area was outside of the active

channel area. However, in many places, there aren't any cultural features between the older channel and the 1939 HCMZ boundary to use as indicators of terrace areas.

The assumption was made that the terrace boundaries coincided with the channel boundaries on the earliest maps (1897 and 1906) and that houses and roads were built on terrace surfaces to make a calculation of the possible additional terrace erosion between 1897 or 1906 and 1939. There is much more uncertainty in this terrace erosion mapping exercise than the erosion measurements made on sequential aerial photographs between 1939 and 2002, but it allows for an order of magnitude comparison of possible erosion levels in the time period thought to most influence river morphology from reference conditions. This mapping exercise indicated that the amount of terrace bank erosion that could have occurred between 1906 and 1939 was 2 to 3 times the amount that has occurred between 1939 and 2002. Although there is a lot of uncertainty in this calculation, it suggests that the largest amount of erosion and channel response to human disturbances occurred in the early part of the twentieth century.

5.2.3 Side Channels

Side channels were mapped in two categories: 1) prominent channels that are easily visible in aerial photography; 2) narrow channels that pass through densely vegetated areas. Side channels fed solely from the Quinault River and side channels originating from tributary channels were both included, as long as the side channel was contained within the historic channel migration zone. Sockeye occupation in the historic side channels mapped is not known, but it is known that many of the present prominent side channels do function as viable habitat for salmon. The side channel mapping provides an indicator of potential habitat areas over time. Overall, both prominent and narrow side channels increased in length from 1939 to 2002 (Figures 20 and 21). The Big Creek channel, downstream of where it enters the historic channel migration zone, has fluctuated in length from 800 to 3700 feet. While this can have a large influence on the total length results for the Middle Reach, the trend of increasing length over time is the same with or without this channel included.

Another interesting twist to the side channel story is that there are more side channels today than in 1939 in part because of human impacts on the system. The historic channel migration zone has been widening at an accelerated rate. This widening allows new areas for the main channel to occupy rather than reworking the same areas of the floodplain. Some side channels have persisted for the last few decades or were newly formed because the river has been eroding large areas of terrace bank on the opposite side of the floodplain. In these cases, the vegetation along the side channel has had a chance to mature and helps protect the channel from lateral erosion by the river when it does shift back over to that side of the floodplain. At Bunch Field Slough, a slough formed in a former river position when the river was pushed to the south through construction of a levee. This levee has protected the slough from being overtaken by the river, but also prevented natural migration and reworking processes in this section.

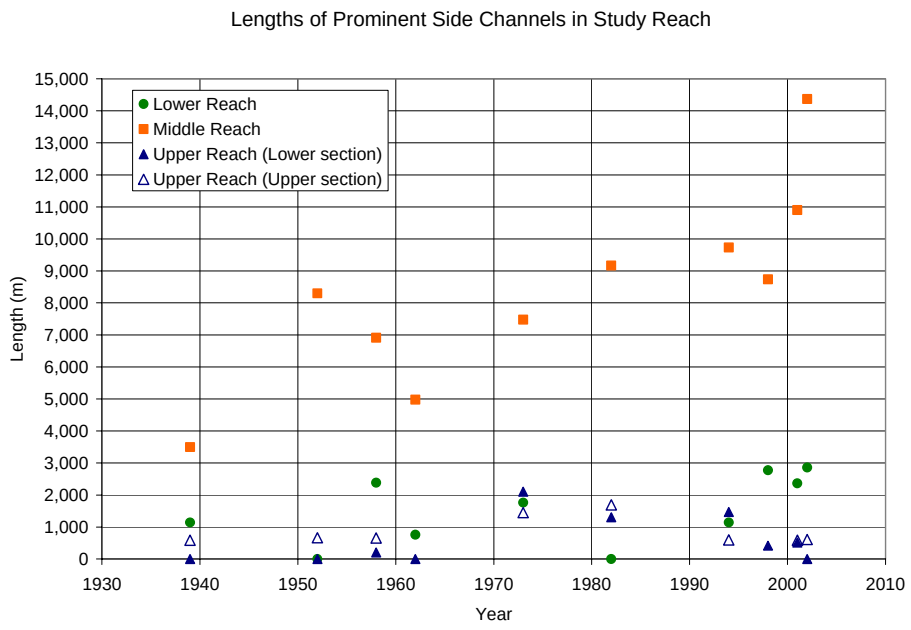

Figure 20. Length of prominent side channels from 1939 to 2002 for study reach. The upper reach was divided into two sections because of a lack of aerial photography in 1998 and 1962 in the upstream-most portion of study reach.

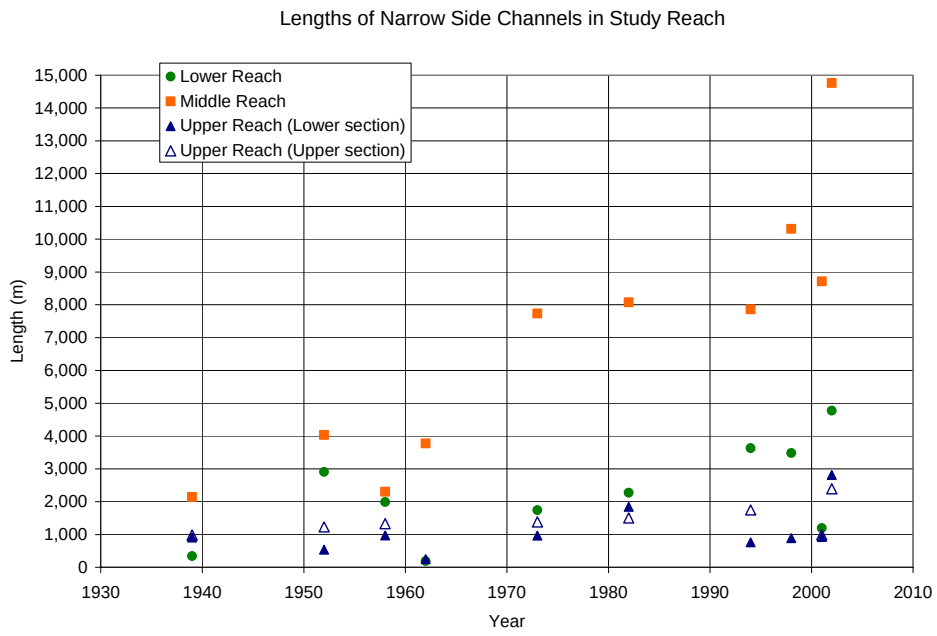

Figure 21. Length of narrow side channels from 1939 to 2002 for study reach. Upper reach was divided into two sections because of a lack of aerial photography in 1998 and 1962 in upstream-most portion of study reach.

The trend of increasing side channels is a positive sign that the river is starting to heal itself toward more natural processes. However, the lack of large woody debris and mature vegetation at the entrances and along the boundaries of side channels continues to allow the side channels to be vulnerable to being overtaken by the main Quinault River on a frequent basis. Many of the side channels mapped are not in consistent locations on sequential aerial photographs, so even though numbers are increasing their sustainability is still poor. The geomorphic history of each prominent side channel location utilized by sockeye is further discussed in Section 8 and is documented in Appendix O.

5.2.4 River Migration Rates

The frequency at which the river has occupied each portion of the floodplain (HCMZ) was evaluated using the mapping of the active, unvegetated channel on each aerial photograph (Figure 22). This result represents a minimum number of times the channel has occupied a particular location, because it is likely additional channel shifts occurred in years we do not have aerial photographs. The areas most frequently occupied by the main channel are where the HCMZ is constricted (relative to other sections) and the river has not eroded either boundary along the HCMZ. Two examples of this are at the boundary between the middle and upper reach and between the middle and lower reach (see red areas in Figure 22). In other areas, the river has continually expanded the HCMZ allowing former river occupation areas of the floodplain to be occupied less frequently.

Constricted areas can occur naturally from geologic controls such as bedrock or clay banks, or can occur artificially from human intervention to protect banks from erosion. Anecdotal information suggests that the apparent stretch of stable channel just at the boundary between the lower and middle reach (RK2.0) may be the result of human intervention. A gravel bar in this area was noted to be used in the past as a source of fill rock and gravel and was accessible from Pruce Boys Road for most of the period covered by the aerial photographs. Heavy equipment was probably used to keep the river in a restricted channel until the gravel mining stopped, thought to be around 1980.

The Quinault River reworked the majority of the 2002 historic channel migration zone in about a hundred years (Figures 23 and 24). A few areas of riparian vegetation have not been eroded by the river since 1939, but these areas of stable vegetation are limited. The rate at which the Quinault River reworks the historic channel migration zone was determined by computing the incremental increase in floodplain area occupied by the active, unvegetated channel starting in 1939. Because this did not show channel occupation in all areas of the floodplain, the historic maps were also included in the computations. In the initial condition (1906), between about 30 and 45 percent of the HCMZ is unvegetated channel. After about 20 years, between about 50 and 65 percent of the HMCZ has been reworked (has been unvegetated channel). After about 50 years, between about 75 and 85 percent has been occupied by the active, unvegetated channel. By 100 years, nearly all of the HCMZ has been occupied by the active channel.

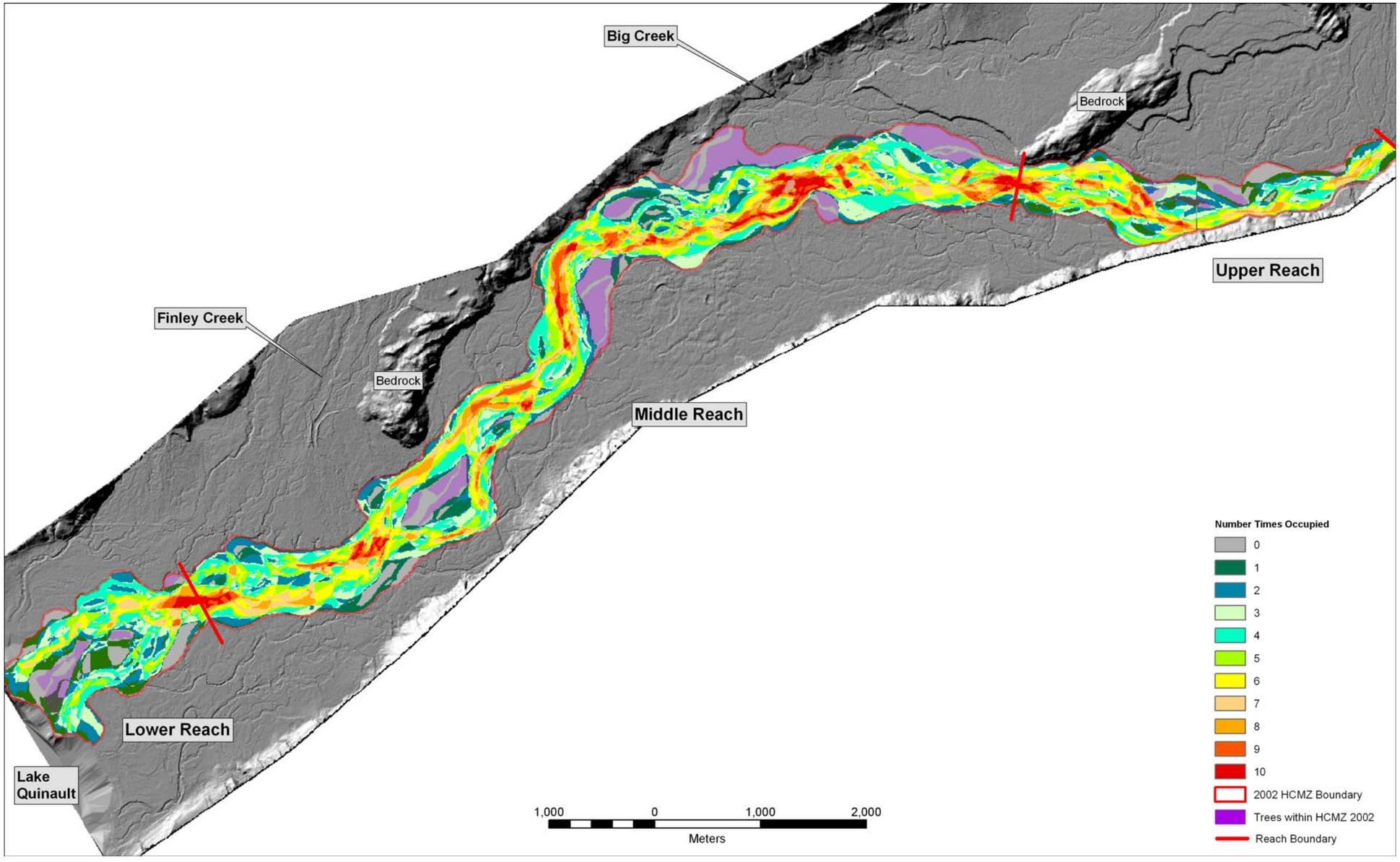

Figure 22. The number of times the active, unvegetated channel of the Quinault River has been located at a particular location as observed on aerial photography spaced about a decade apart. Red and orange areas within the HCMZ are areas where the unvegetated channel has been the most. Gray areas within the HCMZ area are where the unvegetated channel has not been in at least 64 years. Some of these areas were mapped as main channel on the historical maps but were not included in the frequency computations due to uncertainty between active channel and side channel or overflow areas on these maps. Of those areas, the purple areas show areas of conifer type forest that are visible on the 2002 photograph (most stable areas). Gray areas without conifer forest in 2002 have been the locations of side channels or tributary channels in recent years and therefore do not yet have stable vegetation.

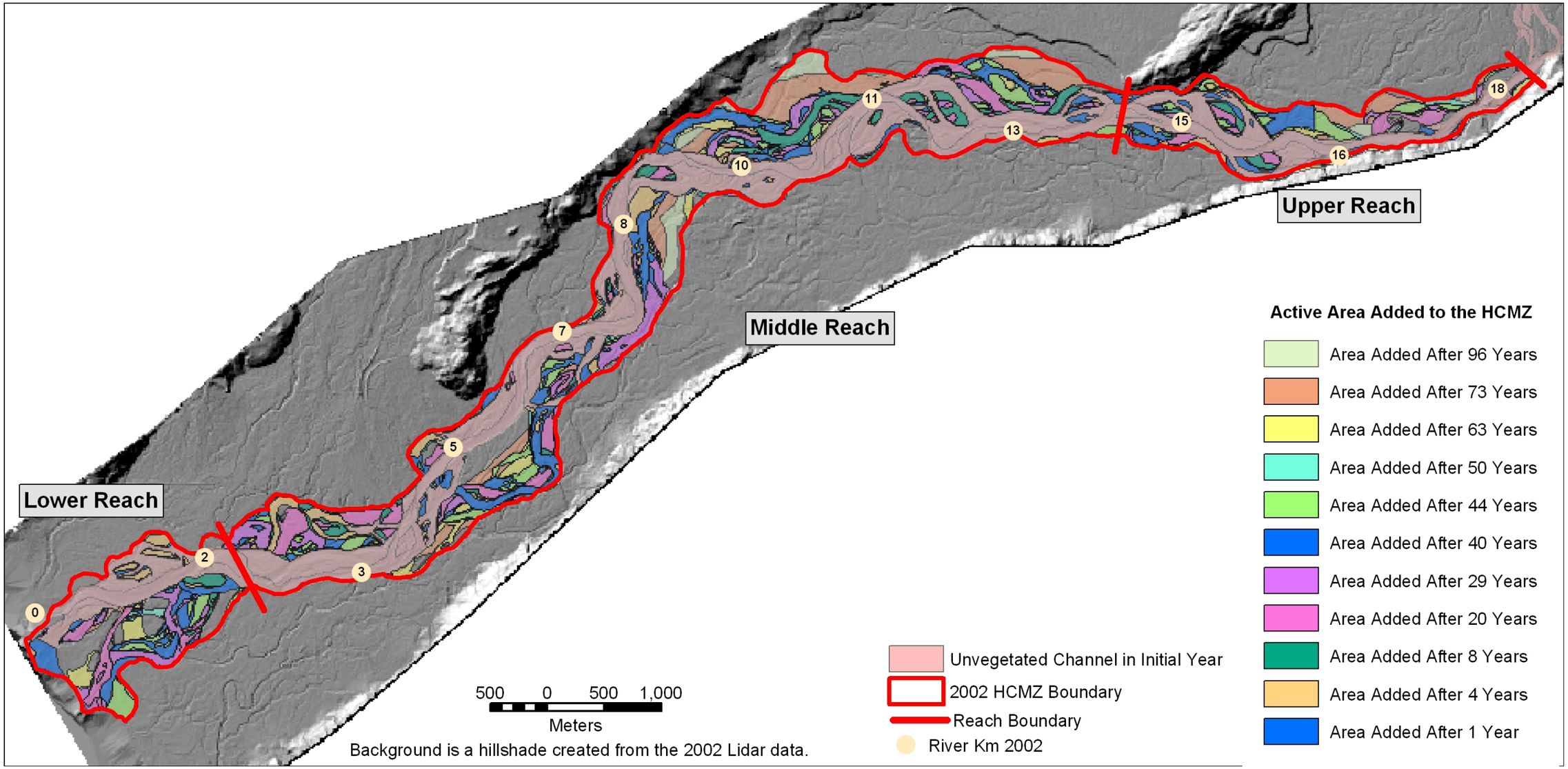

Figure 23. Incremental increases in the portion of the HCMZ that becomes part of the unvegetated channel of the Quinault River.

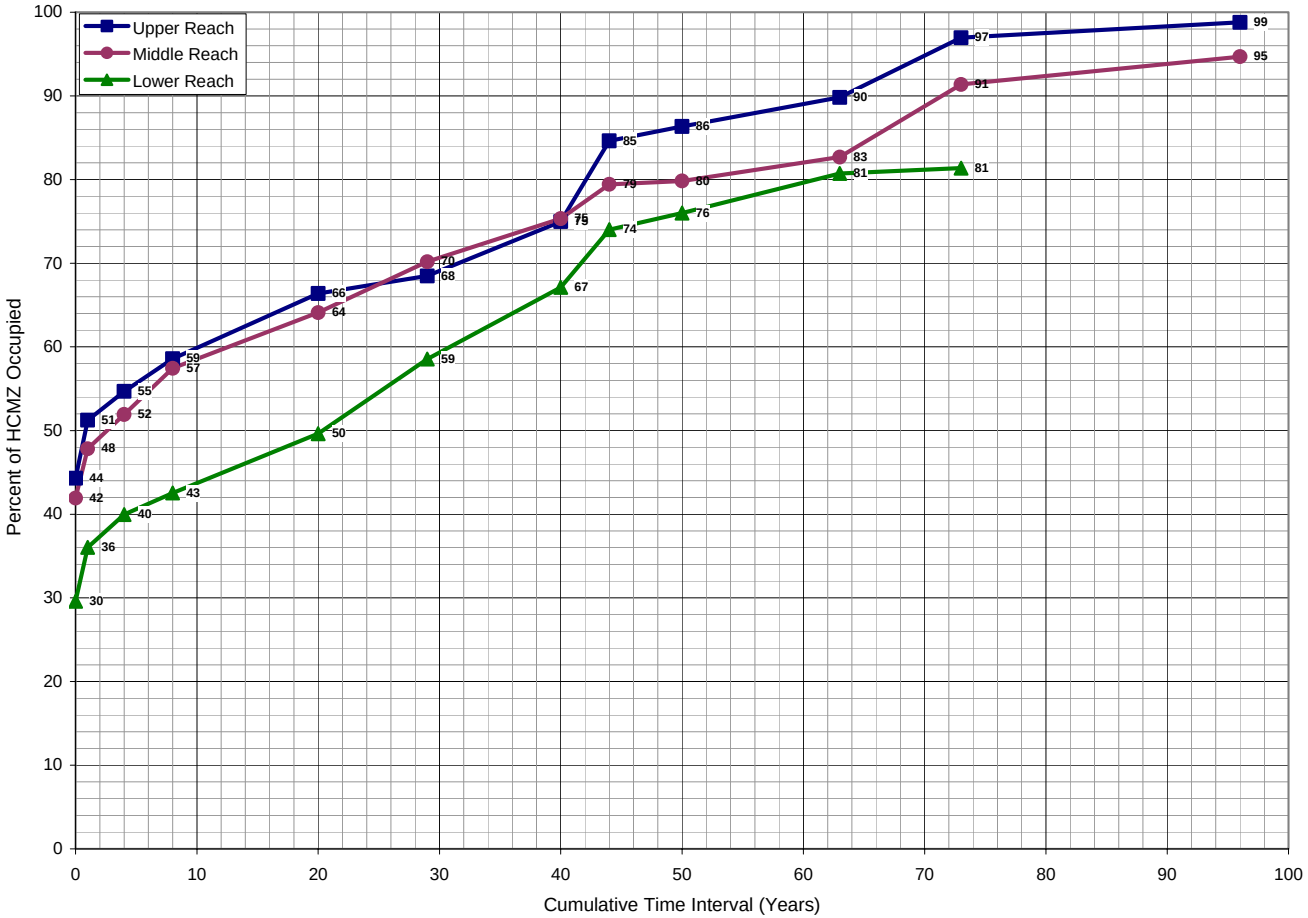

Figure 24. The cumulative percentage of the HCMZ that has been occupied by the unvegetated channel of the Quinault River between 1906 and 2002.

5.2.5 Vegetation

The amount of riparian forest (areas with trees) present within the historic channel migration zone has increased between 1939 and 2002. However, there are limited vegetated areas old enough in age to be classified as mature or old growth (over a century old) equivalent to what was present in the reference conditions. This limits the ability of the riparian forest areas with trees to resist river erosion and form hard points in the river system.

Different vegetation categories within the historic channel migration zone were mapped for each aerial photograph between 1939 and 2002 (see Appendix I). Two categories were distinguished that contained trees, one type with mostly trees visible and the other with a mixed canopy of lower elevation vegetation and trees. These areas represent floodplain areas that have not been reworked by the river in a long enough time that trees have begun to form. These areas serve as an indicator of areas that have the potential of becoming old enough in age that they can form stable vegetated areas similar to reference conditions. Within all sections of the historic channel migration zone, the total area categorized as having trees has been increasing since 1939 (Table 7).

Table 7. Percent of historic channel migration zone for each photo year containing riparian vegetation with trees.

Year	Lower Reach (RK 0 to 2)	Middle Reach (RK 2 to 14)	Upper Reach 1 (RK 14 to 16)	Upper Reach 2 (RK 16 to 18.1)
1939	32	10	4	20
1952	10	18	24	42
1962	17	12	8	No data
1973	14	16	11	20
1982	9	10	7	11
1994	26	20	14	16
2002	43	31	26	40

To better understand which areas within the historic channel migration zone have repeatedly been riparian forest areas, a raster analysis was performed to see how many times an area was categorized as having trees (Figure 25). Very few areas (red areas in Figure 25) presently (2002) have trees older than 65 years that have persisted since 1939 (have not been eroded by the river). More commonly, floodplain areas have had trees for a period less than 65 years, and may or may not presently (2002) be categorized as riparian forest. This is in contrast to the reference conditions which were thought to have old growth trees on much of the river banks binding the active channel. In the natural system, these old growth islands would have gradually been eroded in some areas while being replaced with new forest in other areas. Since 1939, there does appear to be a trend of increasing forest areas, but these areas are still fairly young in age (see Section 5.5 for an estimate of present ages).

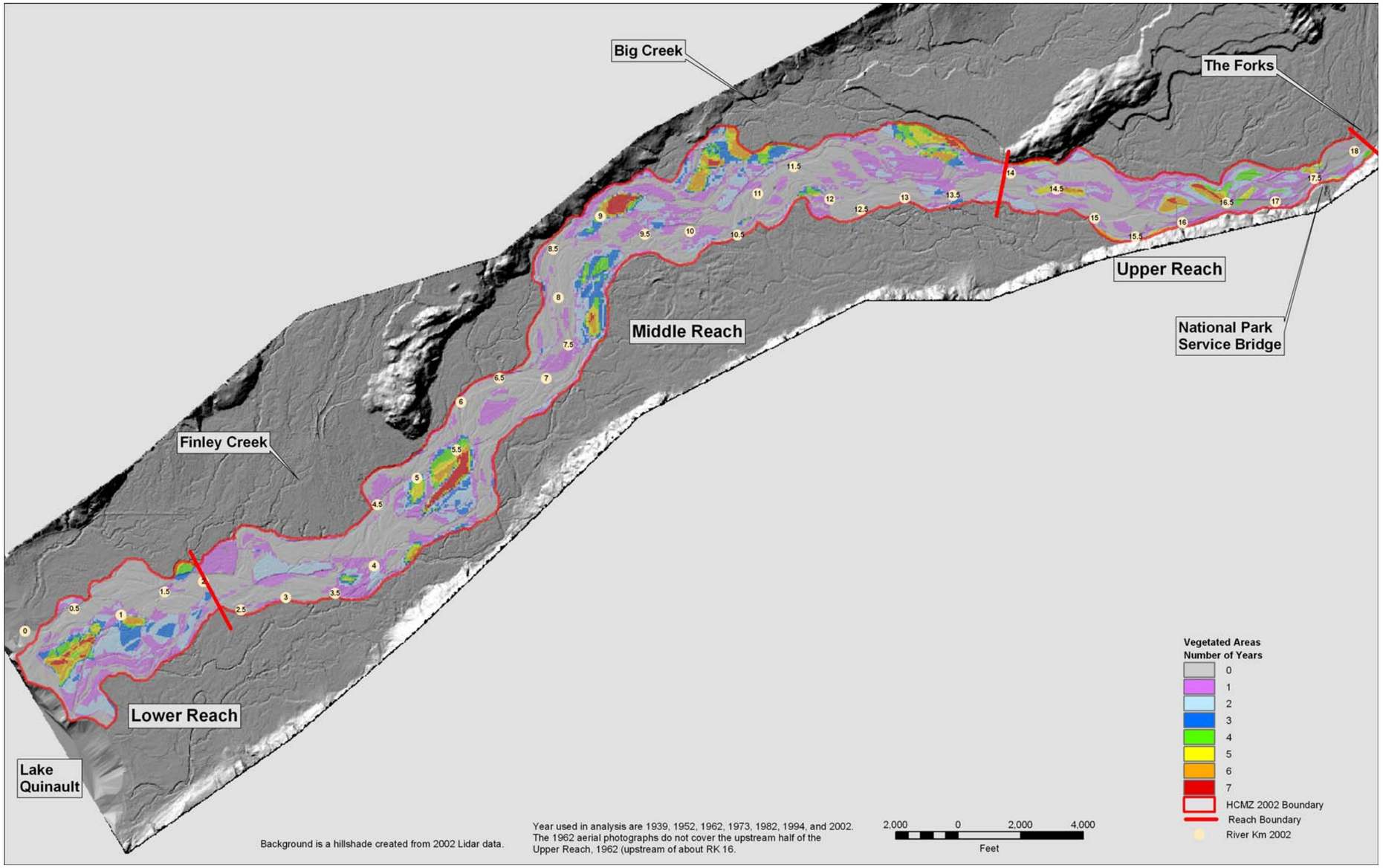

Figure 25. Number of times an area has been categorized as mixed or mature vegetation (containing trees).

The question was posed as to whether the amount of vegetation influencing channel patterns has increased over time. If an increase has occurred, then the river may be self-healing as reflected by an increase in more stable, vegetated surfaces. Figure 25 indicates that most of the vegetation being established within the HCMZ is subsequently destroyed by erosion, and so does not have a chance to mature.

The total lengths of active or unvegetated channel split by vegetated surfaces of any age were mapped to see if vegetated surfaces in the channel area have increased between 1939 and 2002. This analysis did not show any increase or decrease in the lengths of vegetated surfaces that split either the active or vegetated channels between 1939 and 2002.

5.2.6 Large Woody Debris

Stable wood jams, composed of large woody debris (LWD), create and maintain complex side channel networks that are critical salmon spawning and rearing habitat in forested mountain river valleys. The objective of the woody debris analysis was to evaluate the current and historical characteristics of large woody debris, wood jams, and side channels in the Upper Quinault River. Herrera Environmental Consultants, Inc accomplished the woody debris evaluation presented in this document. The approach combined the results of analyses of archival aerial photography (1952–2002), the results of a topographic survey conducted in 2002 by means of light detection and ranging (LiDAR), and an evaluation of current field conditions to assess (1) side channel characteristics, (2) channel complexity, (3) large woody debris loading, and (4) wood jam frequency. Key points of the analysis are listed below, and a much more detailed report prepared by Herrera is attached in Appendix E.

The most significant historical change to the Upper Quinault River has been the removal of the old-growth riparian forest that once covered much of the valley bottom. Valley deforestation and historical channel clearing have led to a loss of large key member logs that are necessary for the creation of stable wood jams and associated side channel habitat. The results of this study show a historical channel migration zone populated by young ephemeral side channels that are frequently disturbed because of a lack of protection by stable wood jams. Field observations further indicate that many of the remaining persistent side channels are associated with relic wood jams. These results illustrate that new wood jams are no longer being generated in the Upper Quinault River. Historical aerial photographs and the LiDAR digital elevation model show a dense network of old side channels within the historically forested floodplains and terraces. Old side channels may persist for hundreds of years in the forested river valleys of the Olympic Mountains. In a representative subreach of the Quinault River that is 1 kilometer long, channel expansion between 1939 and 2002 resulted in an estimated loss of over 2,000 meters of old side channels. The loss of valley forest sources of new large wood and stable wood jams coupled with the continued loss of remaining old floodplain and terrace side channels indicate that the degradation of critical salmon side channel habitat will continue for potentially hundreds of years.

5.2.7 Sediment

A river channel can adjust its sediment transport capacity to accommodate a change in sediment supply and volume of flow by changing its width, depth, and slope relationship (narrowing or widening) or by aggrading or eroding the channel bed. Our study attempts to verify whether the Quinault River between the Forks and Lake Quinault is in an aggradational state, and if so, whether aggradation has been induced from increased sediment supply as a result of human activities over the last hundred years or is simply part of natural processes in this system. There can be a lot of uncertainty associated with sediment analyses, particularly in a dynamic system like the Quinault River. We used a suite of sediment transport analysis indicators to look for evidence of river aggradation or incision within the study reach between the early part of the twentieth century and 2002. General conclusions from our sediment analysis are presented below followed by a reach specific summary for the Upper, Middle, and Lower Reaches. A more detailed documentation on our methods and results is provided in Appendix G.

Sediment is supplied to the study reach from several sources. As the glaciers in the headwaters of the Quinault River melt, silt (rock flour) and coarser sediments are transported downstream. Sediment deposits already present in the riverbed and low elevation alluvial bars within the HCMZ are also constantly being reworked and transported downstream during floods. As the channel migrates, it also sometimes erodes the terraces that bound the HCMZ and this contributes additional sediment to the river. Tributaries throughout the watershed also deliver sediments to the Quinault River during storm events. Finally, mass wasting events (landslides, debris flows, etc) can supply additional sediment to the Quinault River.

Fine-sized sediments ranging from clay to fine sand are transported in suspension in the Quinault River. They do not affect channel form by inducing channel changes, but can affect the water quality (turbidity) and aquatic habitat in the river. The smallest sediments, including silt and clay sizes, are often referred to as washload because they typically remain in suspension even at low flows. Slightly larger sediments including medium to fine sand will usually remain in suspension during high flows, but as floods recede they may deposit in areas of low velocity, such as overflow and side channels. If substantial, the fine-sized sediments can fill the interstitial spaces between the gravels and cobbles in the channel bed material.

Larger-sized sediment ranging from coarse sand to cobbles is transported as bedload and is referred to in this report as coarse-sized sediment. In contrast to fine-sized sediment which can be transported all the way to Lake Quinault, coarse-sized sediment is usually transported short distances along the active channel bed. A small amount of coarse-sized sediment transported into a reach can cause the existing channel path to fill with sediment and result in the channel flowing in a new direction if it is an area of low transport capacity, such as a meander bend ready for a cutoff. In this case, the net deposition and erosion within a reach is not usually significant and there is not an impact in supply to the next downstream reach. If the capacity of the river is not sufficient to transport coarse-sized sediment or if the supply increases thus exceeding the capacity, sediment will deposit on the bed.

The upstream sediment supply entering the Quinault River at the Forks should not have significantly changed between 1939 and 2002. The watershed analysis (QIN, 1999) concluded that there have been no significant changes in large-scale sediment sources associated with landslides in the upper basin above the Forks. The frequency of flooding has increased for the 2-year flood from 1951 to 2002 relative to the period between 1911 and 1950. This increased flooding could have increased the amount of sediment delivery to the study reach, but would also increase the rate at which sediments are reworked and transported downstream through the study reach. Visual observations in the study reach indicate the Quinault River has multiple sources of sediment. A question was posed to our study team as to the potential impact on sediment loads from the upstream watershed of retreating glaciers at the headwaters of the Quinault River. There is no measured data for the Quinault watershed glaciers, but if the glaciers at the headwaters of the Quinault River are retreating (see Section 3.1), they would be expected to release more sediment. If this did occur, fine-sized sediment that is easily suspended may have increased in volume to Lake Quinault during 1939 to 2002. Any increase to coarse sediment load from 1939 to 2002 would be expected to be gradual and take several decades to centuries to be detectable in the study reach. More data collection and analysis would be needed in the upper basin to verify these hypotheses. A recent observation by the National Park Service did note certain areas of rapidly occurring bank erosion in the upper watershed. One hypothesis is that this rapid bank erosion is a channel widening response to increased sediment loads. More detailed investigation would need to be done to further evaluate this hypothesis, but increased sediment loads from the upstream watershed could over longer periods of time exasperate any accelerated sediment loads in the study reach.

There is no obvious evidence that the magnitude of coarse sediment contributed from tributaries in our study reach has changed between 1939 and 2002 in a significant amount that would alter the sediment supplied during debris flow events. Below the Forks, both Finley Creek and Big Creek drain from the north and have natural debris fans that contribute sediment to the Quinault River. Historically, the Finley Creek alluvial fan periodically provided sediment to the Quinault River during debris flows. In recent decades the upstream Finley Creek channel has been dredged and now little Finley Creek sediment likely reaches the Quinault River. This hypothesis is supported by the fact that the Quinault River has eroded a significant portion of the toe of the fan in recent years. The other major tributary in this reach is Big Creek. Although Big Creek does contribute sediment to the Quinault, no large fan is visible in the Quinault River. Thus Big Creek's sediment contribution is small relative to the sediment load and transport capacity on the Upper Quinault. Other smaller drainages do periodically have debris flows, some of which reach the Quinault River, but the coarse sediment that they contribute was estimated to be a small portion of the total coarse sediment load in the system.

There has been significant logging on the hill slopes of the Upper Quinault valley during this time period which could accelerate the rate and volume of sediment delivered to the Quinault River, particularly fine sediment that is easily transported. Evaluation of this potential impact was beyond the scope of our study.

It is most plausible that the HCMZ expansion (bank erosion) and reworking of sediment bars in the floodplain have had the most measurable impact on sediment loads and subsequent changes to channel form in the study reach. The volume of bank erosion exceeds the amount of sediment in floodplain storage, so some aggradation of the floodplain from bank erosion is possible. Our sediment analysis suggests that the aggradation is likely on the order of a few feet rather than several feet, and only in localized areas and not across the entire floodplain in the eighteen kilometers of study reaches.

Upper Reach (RK 14 to 17)

Since the early part of the twentieth century the Quinault River between RK 14 and 17 has incised (eroded) on the order of a few meters or less. The HCMZ in this reach is naturally more constricted than downstream sections of the study reach suggesting it has always had higher sediment transport capacity than downstream sections, but the channel was more meandering from 1939 to 1973. The south side of the HCMZ is lined by a road and bedrock. The north side of the HCMZ boundary is terrace and has had some measurable expansion, but since 1973 the channel has remained mostly on the south side. This resulted from a constriction (beyond natural influences) imposed by the NPS Bridge and a levee constructed just downstream. This narrowing of the channel and floodplain area would likely increase sediment transport capacity and could result in incision. Evidence of incision was found in our analysis from:

1. the comparison of the 1929 to 2002 profile showing the main channel lower today than in 1929;
2. cross section comparisons showing the present main channel about 1 m lower than adjacent side channels (which is not typical in braided, aggrading channels);
3. unit stream power computations that show a higher transport capacity in this section than all other areas of the study reach; and
4. pebble count data that indicate the coarsest-size particles are present in this section.

Middle Reach (RK 2 to 14.7)

Aggradation would be expected in areas where the HCMZ is widest, the channel migrates rapidly, sediment transport capacity decreases relative to upstream sections, and there is accelerated delivery of sediment relative to natural conditions. This is what we observed between RK 2 to 14.7 in the Middle Reach. Sequential aerial photography shows the rapid migration of the river between 1939 and 2002, which is supported by regime equations that note the river is dominantly braided (with meandering tendencies), and channel cross-sections which show the channel is equal in elevation across the floodplain indicating depositional tendencies. A longitudinal profile comparison of water surface elevation from the 1929 USGS map and the measured 2002 channel indicates there is a higher channel bed today than in 1929. Stream power and pebble count results shows a lower transport capacity in this reach relative to the upstream reach even with an increase in discharge, which supports the theory that portions of this reach may have experienced aggradation.

Above natural sediment loads have been supplied to the Middle Reach over the last century which also supports potential for aggradation, at least temporarily. Sediment supplied above natural levels is thought to have occurred:

1. during early disturbance in the twentieth century when stable islands were cleared and released large, localized sediment sources,
2. from the channel bed in the upstream reach following incision in latter part of twentieth century,
3. and from high rates of bank erosion occurring in the Middle Reach along the HCMZ boundary since at least 1939.

On the other hand, the HCMZ has expanded between 1939 and 2002 and the active channel has remained a consistent width. This indicates the additional HCMZ area provides more floodplain storage as it expands. The amount of sediment contributed to the Middle Reach from upstream incision and early twentieth century island disturbance could not be quantified and compared to the increase in storage area. Changes in floodplain storage and bank erosion were quantified as part of the sediment budget exercise, but the increase in storage does not account for all of the terrace bank sediment that has been contributed. This indicates there is a potential for aggradation in the Middle Reach just from bank erosion without even considering other sediment sources that may have added to natural levels.

The amount of aggradation that has occurred over the last century is thought to be on the order of a few feet over the entire Middle Reach, but may be higher or even near zero in localized areas. The 1929 versus 2002 profile suggest it is on the order of zero to two meters between RK 2 to 10, but has been relatively minimal between RK 10 to 14. This is also supported by the unit stream power plots which show between RK 10 to 14 sediment transport capacity gradually decreases, and then levels off between RK 10 to 2. Further, the sediment budget indicates the upstream sediment load to the study area is large relative to the amount contributed from bank erosion or other smaller localized sources. A significant change in the balance between sediment load and river flow can change the river's sediment transport capacity and produce a change in the width of the active channel. We compared average active channel widths from 1939 to 2002 but did not find any significant trends that would indicate a change in sediment transport capacity. This provides some evidence that the aggradation rates have not increased dramatically since 1939, such that channel width increased. The regime equations indicate the present study reach is more prone to a braided channel which is a sign of aggradation, but that there are some meandering tendencies which also indicates it may not be aggrading at a rapid rate.

Results from the woody debris transport analysis also indicate that there are high and low transport reaches within the Middle Reach (see Appendix E). The majority of wood present and being mobilized in the system is small, and is thought to be qualitatively comparable to coarse sediment transport processes. Large woody debris jams may locally cause scour and aggradation, but because they are limited in number and do not

persist for long periods of time, their overall influence on sediment transport in the system since 1939 is thought to be limited.

The Middle Reach may naturally have been prone to deposition to some degree even before disturbance since the HCMZ was wider with a flatter slope than upstream sections, but it is difficult to know without more topographic information of the reference channel conditions. Presently, channels in the middle reach aggrade as they fill with sediment and result in channel shifting. We conclude, however, that when the river later re-occupies this former channel area, the deposited sediment is reworked and transported downstream, and the average floodplain elevation does not increase a significant amount. Our interpretation suggests that future aggradation can occur in the widest sections of the middle reach as long as the channel remains wide and shallow and bank erosion volumes continue to outweigh increase in floodplain storage areas. However, the amount of aggradation would be expected to continue to be small on the order of a few feet over several decades due to the large area of available storage.

Lower Reach (RK 0 to 2)

The lower section of our study reach (RK 0 to 2) is part of a delta that forms as the Quinault River flows into Lake Quinault. The highest lake stage recorded (QIN, 1999) backs water up to almost river kilometer 3, near the downstream end of the Finley Creek alluvial fan. As the slope of the channel flattens at the inlet to Lake Quinault, the river responds by depositing sediment that creates a delta. Over time the delta extends further into the lake (progrades) until the river channel has lengthened so much that the slope is too flat to continue to transport sediment. At this point the channel shifts laterally to a new location and begins to prograde the delta at the new channel position. The channel has to occupy all lateral positions across the delta before the leading (downstream-most) edge of the delta can continue to advance downstream. For a constant lake level, the channel upstream from the lakeshore would be expected to aggrade once the delta has deposited across the width of the lake. Aggradation of the upstream river channel within the influence of the delta would increase flood levels on adjacent land surfaces.

Between 1939 and 2002, the aerial photograph sets indicate the Quinault River has occupied the majority of possible locations at the inlet to Lake Quinault (Figure 26). Additional progradation is expected to occur along the 2002 location before the channel shifts to a new location. The amount of time until the leading edge of the delta begins to move farther downstream is expected to occur over a period of several decades to a century.

Determination if flood stage immediately upstream from the lake shoreline is increasing or decreasing over time could not be quantified in this study. The quantity of additional sediment contributed from measured bank erosion between 1939 and 2002 tends to increase the rate of delta deposition. However, some of the sediment contributed from bank erosion is stored (at least temporarily) in the expanded HCMZ between 1939 and 2002 (see Appendix G). At the downstream end of Lake Quinault, the moraine which controls the lake elevation is incising at an estimated amount of 0.5 m per hundred years (see Appendix C). A lowering of the lake level would cause incision of the river channel

in the delta area and tend to reduce flood stage in the upstream river channel influenced by the delta.

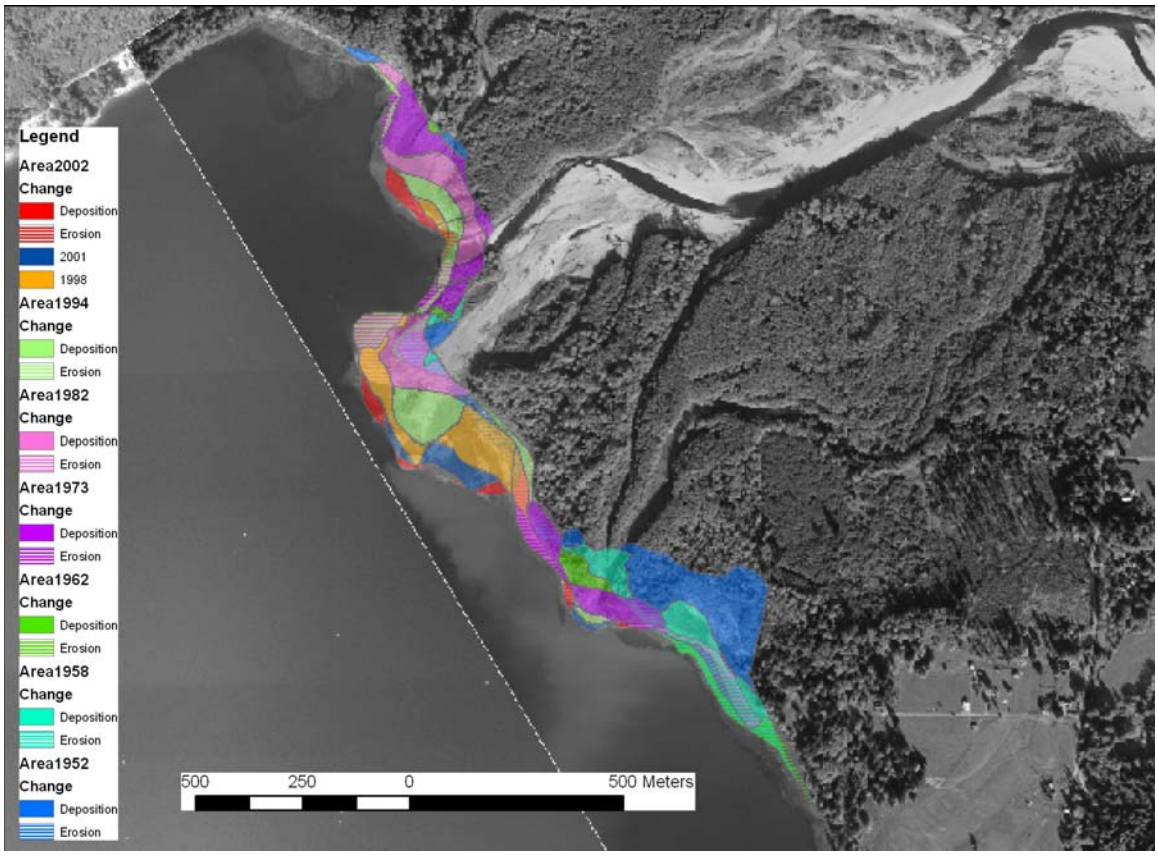

Figure 26. Erosion and deposition of delta sediments as measured from aerial photography between 1939 and 2002.

Additional Study

There was sufficient evidence to qualitatively describe incision and aggradation processes in the study reach over the last century, but there is less evidence and more uncertainty in our ability to quantify these conclusions. Comparing future LiDAR and channel surveys to 2002 topographic data would help monitor and refine our interpretations. Another technique that could be tried is a new GIS analysis that recreates topographic elevations on historical aerial photography. Although beyond the scope of our study, this technique may allow generation of elevation data on exposed bars in older aerial photography, such as the 1939 or 1952 photographs. These floodplain elevations could be compared to present floodplain elevations from the 2002 LiDAR data over the study reach to look for changes and trends that would better quantify our conclusions.

5.3 Summary of Present River System Characteristics

The characteristics of the present river system compared to inferred reference conditions are summarized in Table 8 and described in more detail below.

Table 8. Comparison of the characteristics of the reference conditions and present conditions on the Quinault River.

	Characteristics of Quinault River	
Property	**Reference Conditions[1]**	**Present Conditions**
Main Channel	One or two dominant low-flow channels; in places, the channel is confined by vegetated surfaces	Multiple low-flow channels; unvegetated bars common adjacent to the channel
Unvegetated Channel	Relatively narrow	Relatively wide
Vegetated Surfaces	Range in age from pioneer bars to mature terraces	Range in age, but limited mainly to pioneer bars and developing floodplain; only a few transitional terraces; mature terraces are virtually absent
Woody Debris	Numerous large logs available to be recruited as key members, which in some cases initiate the formation of large jams	Few large logs available, so the river system lacks large jams because potential key members are absent
Side Channels Within HCMZ	Variable location within the river system; stability ranges from only a few years to tens of years; mature vegetation along boundaries limits the rate at which the main channel erodes into the side channel; large woody debris at entrances can help limit the rate at which the main channel shifts into the side channel	The wider HCMZ allows for more side channels to persist but generally with less stability than reference conditions due to more rapid shifting of main channel and less large woody debris; a few side channels appear to have lower risk than reference conditions due to wider HCMZ with more places for main channel to occupy
Terrace Side Channels	Stable for several centuries; very slow erosion and reworking rates of these areas	Large portion of the network of terrace channels has been lost and not replaced because of expansion the HCMZ; remaining terrace channels are at risk for erosion due to cleared banks; many terrace channels modified at entrances and at road crossings
Habitat Quality and Quantity	Diverse network of interconnected side and terrace channels that provided a wide range of habitat sustained from only a few years to centuries	Remaining habitat areas generally have less complexity and higher risk of being lost over a faster timeframe than in reference setting

[1]Reference conditions have been inferred from historical accounts and photographs and from the present characteristics of the Queets River (see Section 3.5.4)

The river migrates across the floodplain at a very rapid rate, sometimes changing positions yearly. This was evident between our last aerial photograph in October 2002 and observations of channel changes since 2002 during a field visit in August 2004. The

side channels and downstream sections of tributary channels utilized by sockeye are in active areas of the floodplain, which the main Quinault River channel occupies with a relatively high frequency. Consequently, these areas are less stable than they were historically. When the river shifts into a side channel used by sockeye for habitat, the velocities often increase such that the channel is no longer suitable for habitat. Areas where the channel has just shifted from can form into ideal habitat if the river does not reoccupy them before they have a chance to develop vegetation and woody debris. Unfortunately, the river changes course so frequently that the new area of potential habitat may be destroyed before it can be developed.

The river has some braiding tendencies, but still possesses a low flow meandering channel in many areas (Figure 27). The larger active river channel (including sediment bars) is shallow and wide and contains very little large woody debris, mature vegetation, or complexity such as pools associated with large woody debris. The majority of pools formed from large woody debris were observed in the downstream portion of the study reach below the confluence with Big Creek. Some additional deep pools exist above the confluence with Big Creek where the river runs against bedrock outcrops.

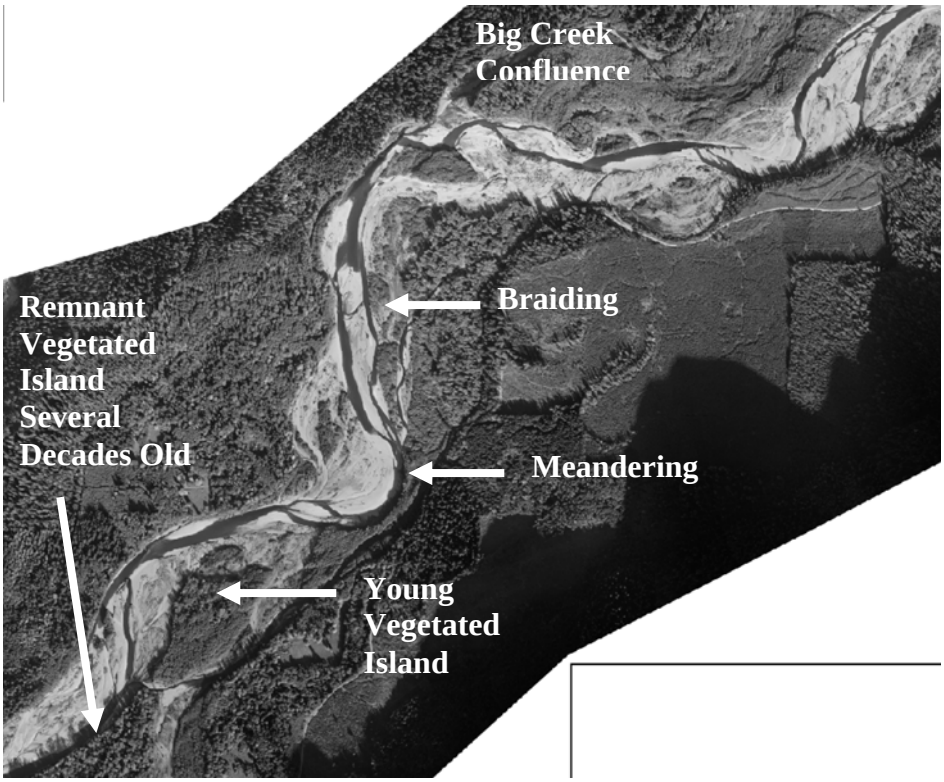

Figure 27. Example of present river features within the study reach (2002 aerial photograph).

Very few vegetated islands remain stable within the historic channel migration zone for more than a few years at a time. To get an indicator of the present age of all forested areas within the 2002 historic channel migration zone, areas with trees were categorized by how many sequential years they have been mapped as forest without being eroded by the river (Figure 28 and Table 9). Less than 2 percent of the areas mapped are presently (2002) older than 65 years and have persisted since 1939. These legacy wood areas are

currently eroding, but replenishment areas are still fairly young in age and susceptible to river erosion. Two notable areas that have persisted since 1939 are located at RK 5 and 9. The vegetated island at RK 5 has buried wood beneath the island and at the upstream end that help to slow erosion by the river and may explain why this island has persisted since 1939 (Figures 29 and 30).

Table 9. Percent of 2002 study reach containing each age group of vegetated surfaces with trees. The remaining areas consist of unvegetated channel or vegetated areas with no trees.

Minimum Age of Trees	Lower Reach (RK 0 to 2)	Middle Reach (RK 2 to 14)	Upper Reach 1 (RK 14 to 16)	Upper Reach 2 (RK 16 to 18.1)
8	17.1	9.3	6.2	4.7
20	0.2	1.8	0.8	1.1
30	1.1	0.3	0.1	3.0
40	2.0	0.6	0.0	0.0
50	0.0	1.1	0.0	1.5
63	1.0	1.5	0.5	1.2

There is a general lack of old growth vegetation along the terrace banks that bind the historic channel migration zone because the majority of areas have been logged at least once in the last century (Figure 31). Erosion of terrace banks during floods is common and frequently is rapid, continually expanding the historic channel migration zone. On the erodible terrace and alluvial fan surfaces, only four areas are thought to never have been logged and they are very small relative to the total study reach. The other old growth areas that remain are on bedrock. On the north side of the historic channel migration zone, most areas are re-vegetating with trees and are now 40 to 60 years in age. A few areas remain cleared with only grasses and scrub vegetation.

On the south side, cleared areas binding the historic channel migration zone are much more common than on the north side. There are a few areas interspersed between the clearings where trees are becoming several decades old because they have not been logged since replanting. While these trees are not equivalent to the old growth forest, they provide some opportunity to eventually become mature enough to provide large woody debris. However, they are still at high risk to be eroded by the river, particularly when the section of land sticks out in the historic channel migration zone and there are clearings upstream (see RK 9 and 12 in Figure 31).

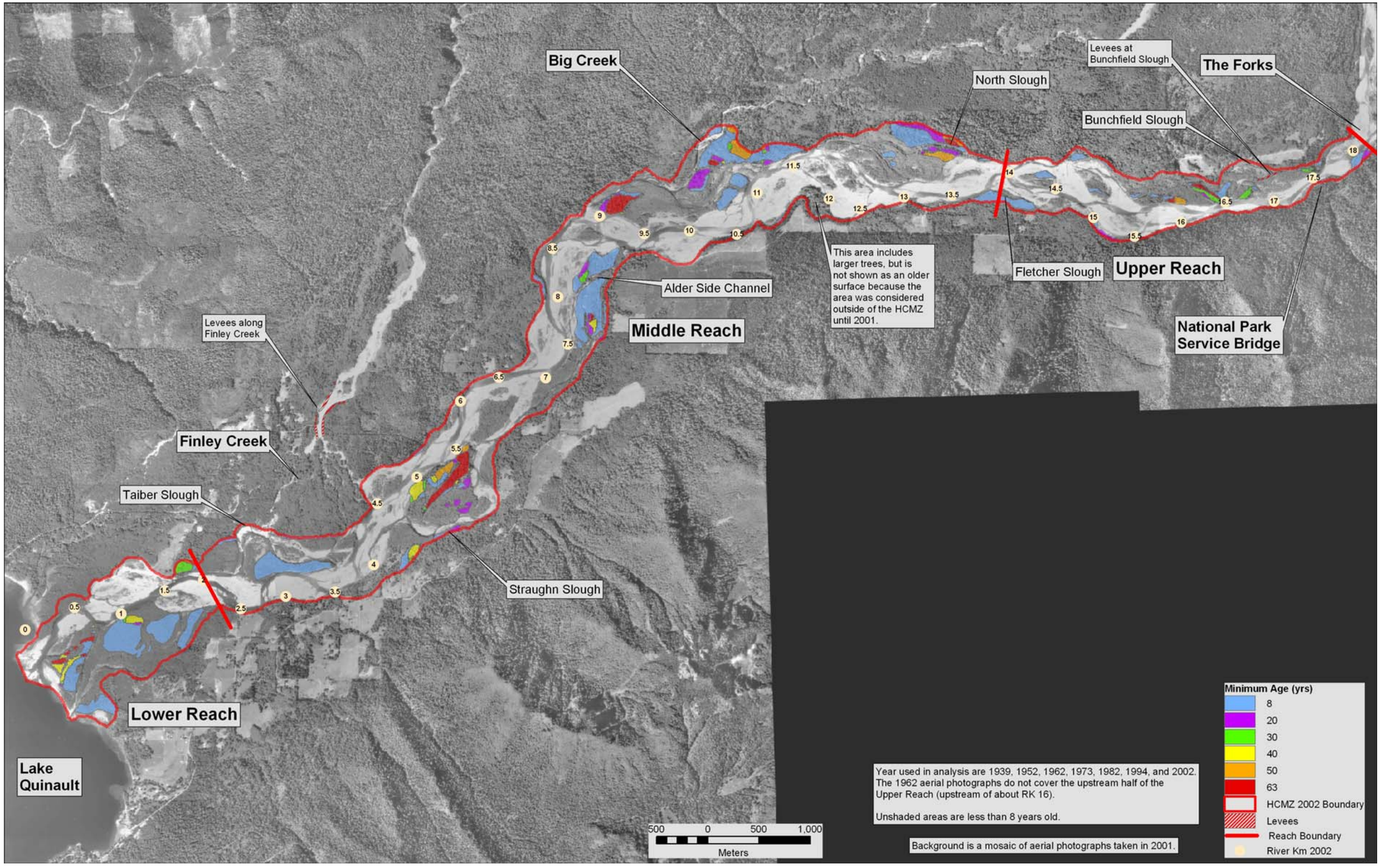

Figure 28. Minimum age of areas containing trees within the 2002 HCMZ. Note the area at RK 12 does have mature trees of significant age but did not get captured in the raster age analysis because it was considered terrace until the main channel recently punched through one of the terrace channels.

Figure 29. Example of buried wood helping to stabilize vegetated island banks from river erosion along island located at RK 5.

Figure 30. Log jam located at upstream end of vegetated island near RK 5.

One location where trees are several years old upstream of RK 12 did supply fairly large trees to the river when the river eroded the bank between 2002 and 2004 (Figures 32, 33 and 34). These trees helped limit the rate of erosion and provided a few key members to form a log jam at the entrance to a channel dissected through a terrace surface just downstream. Downstream of the log jam some very productive sockeye habitat has formed. This process emulates what might have happened in the reference conditions.

Overall, there are very few large log jams or large snags in the channel migration area, although there is abundant smaller-sized woody debris. Generally, this smaller wood can be easily transported by large floods. The lack of large wood is due to the limited availability of mature forest that can be recruited into the river. Because of the rapid channel shifting, it is difficult for sediment bars within the migration zone to remain stable and allow mature vegetation to establish.

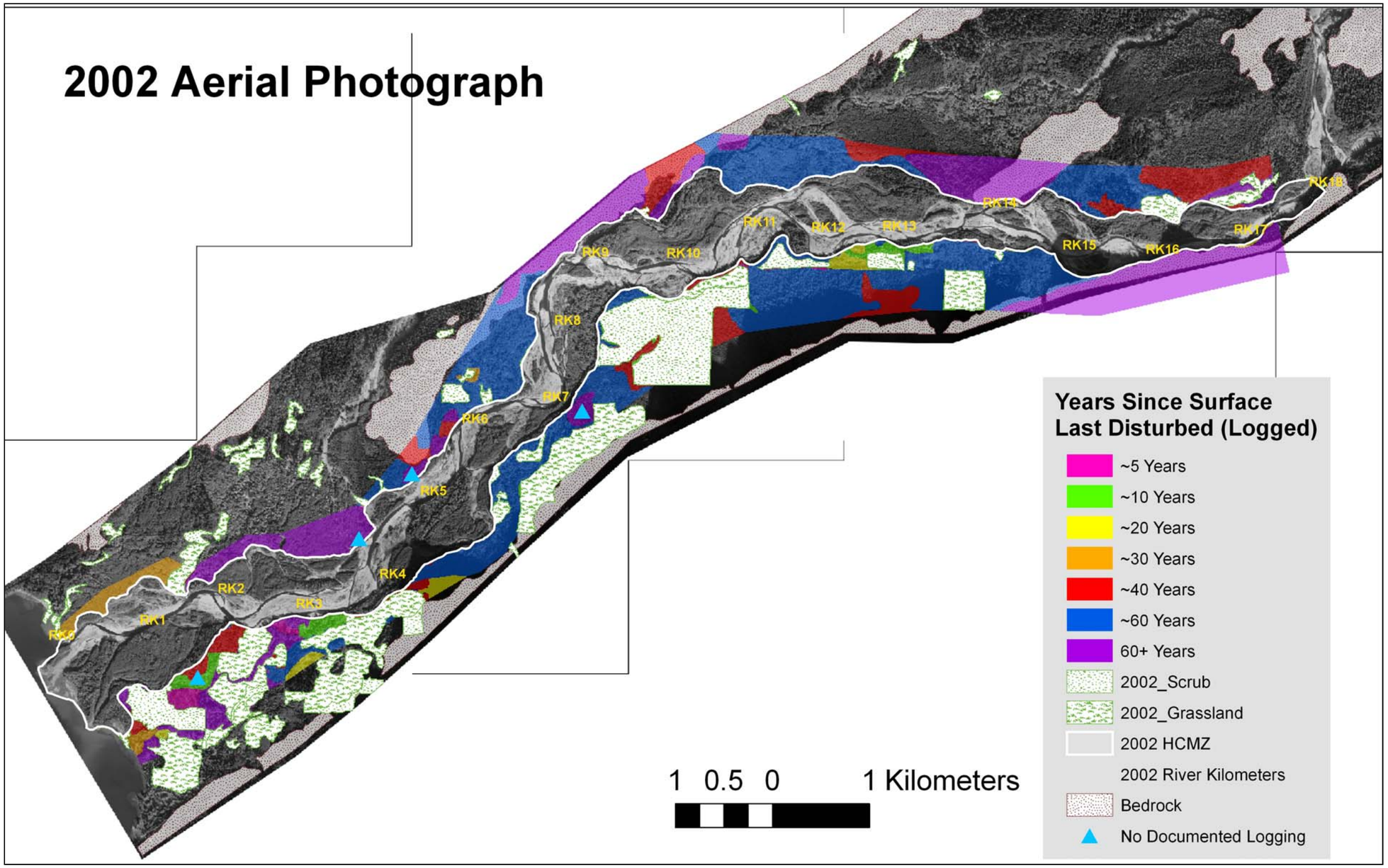

Figure 31. Estimated minimum age of vegetated surfaces on valley floor outside the 2002 HCMZ. Areas that presently contain no trees are shown as scrub or grassland. Bedrock areas are shown to distinguish these surfaces from erodible surfaces (alluvial fans and terraces).

Figure 32. Looking downstream at the entrance to the new Quinault River path at RK 11.8 in August 19, 2004. A new log jam spans the entrance to this channel. The key member of the jam is a tree with two large diameter trunks that grew together. The tree is thought to have originated from the south bank when the river eroded the area between 2002 and 2004 before it shifted into the location as shown in this photograph. The Quinault River cut through the south terrace surface into an existing terrace channel and formed a forested island complex adjacent to flow from the Quinault River. Photograph taken August 19, 2004.

Figure 33. Photograph taken about 50 ft downstream from log jam in previous figure looking downstream into sockeye habitat channel area. Photograph taken January 2005.

Figure 34. Photograph of an additional side channel in the vicinity of the previous two photographs. Photograph taken January 2005.

5.4 Effect of river changes and management response

The response of the river to human disturbances has resulted in accelerated bank erosion, migration rates, and flooding which has prompted a variety of management actions from hatcheries to bank protection as discussed below.

5.4.1 Sockeye Habitat

The Quinault Department of Fisheries relies on the following summary of observations and data to assert that the present habitat conditions in the Upper River are disturbed and that the degradation and loss of habitats caused the decline in Quinault sockeye salmon abundance (Gilbertson, written communication, 2005):

1. Sockeye production in the Quinault River is less today than it was historically;
2. Spawning escapements in the Upper Quinault River have decreased since 1950 based on historic escapement counts in the 1920's, escapement counts made every year since 1973, and run reconstruction models;
3. The present amount of spawning habitat available for sockeye salmon is less that what would be necessary to support the numbers of sockeye that spawned in the system historically;
4. Contemporary and historic data demonstrate show that loss of sockeye production has not been caused by fisheries harvests;
5. Regardless of fisheries harvests, large escapements have occurred throughout the historic record. The Data indicate there has been a gradual, consistent loss of production regardless of the level of spawning escapements;
6. Most of the current preferred and utilized spawning habitat is in the mainstem floodplain, including relatively inactive side channels and the lower reaches of

tributary systems. These areas are presently at high risk of being washed out due to rapid migration of the river channel.

7. Contemporary loss and degradation of sockeye spawning habitat due to mainstem channel migration has been observed;
8. Fry recruitment to Lake Quinault has declined based on historic records of adult run size and escapement;
9. Lake Quinault is nutrient limited and could not adequately support numbers of juveniles that were in the system historically.

Historic records from Federal agencies and monitoring and management data from the Quinault Department of Fisheries provide valuable data to analyze the effect of river changes on sockeye salmon. By 1936, most spawning took place in tributary and terrace channels such as Big Creek, Merriman Creek, and Inner Creek, with only two locations in the main Quinault River noted to have sockeye usage known as Bausely Slough and Holtine Slough (Davidson and Barnaby, 1936). It was noted in the 1936 report that the majority of main river channel habitat had been lost due to accelerated rates of lateral migration. Big Creek was considered the best habitat, but the 1936 report notes that it was subject to washing of the riverbed during freshets which could impact spawning success. The Holtine Slough is thought to have been located near RK 7.5 near the Holtine homestead (documented on 1929 USGS map) and the present location of Alder Side Channel. The Bausely Slough location could not be identified.

Monitoring data show the Quinault sockeye produced cyclic, but substantial runs in the first fifty years of the twentieth century, but beginning in the 1950s experienced a decline that has not yet recovered (see Figures 2 and 3 in Section 1 of this report). It is not known why the overall sockeye population numbers continued to be high into the 1950s when the most significant response of the main river to disturbance is thought to have peaked in the 1920s to 1930s and remained relatively consistent since that time.
It is possible that remaining tributary channels and protected terrace channels provided sufficient premium habitat to sustain the sockeye population at high levels until cumulative effects of river disturbance degraded the overall habitat productivity.

In addition to cumulative effects of river channel instability and migration, the decline of sockeye population size after 1950 could have been influenced by increasing frequencies of channel reworking flood events. Although the largest peak floods have not appeared to change, the frequency and magnitude of common flood events were greater in 1951 to 2002 (inclusive) than during 1911 to 1950 (inclusive; Table 2). For all flows above 15,000 ft^3/s, the 2- and 5-year floods appear to be occurring about twice as often between 1951 to 2002 than in 1911 to 1951 (see Table 2). The 2-year flood between 1911 and 1950 was 19,989 ft^3/s and between 1951 and 2004 was 24,504 ft^3/s, indicating it has increased about 23%. The more frequent and slightly larger flood flows occurring on a disturbed, unstable floodplain could have eliminated any remaining premium habitats for sockeye, and would have further degraded the over all habitat productivity in the system.

A second factor that could have caused loss of sockeye production starting in the early 1950's was the closure of a U.S. Bureau of Fisheries hatchery that operated on Falls

Creek, a tributary to Lake Quinault, from 1914 through 1947. The hatchery collected up to 19,000,000 eggs per year from fish returning to Falls Creek and other tributaries to Lake Quinault and the Upper Quinault River. Big Creek was the most consistent and largest contributor of fish for the egg takes. The success of this hatchery production is uncertain (Quinault Department of Fisheries 1981). It is clear that survival to returning adults was sufficient to establish a new stock that returned to the hatchery location on Falls Creek, but whether the hatchery contribution was sufficient to maintain the high over all production observed in the Quinault River is still under investigation. Based on detailed examination of reported hatchery operations and fish planting methods, and on the lack of correlation between the sizes of juvenile releases and subsequent adult run sizes, it is doubtful the hatchery had a large effect on annual run sizes (Larry Gilbertson, personal communication, 2005).

Armstrong (2002) described the early hatchery operations as follows:

"The speculations about deterioration and changes that may have occurred in the floodplain of the upper Quinault River were thought to have negatively influenced the quality and quantity of sockeye spawning habitats. Therefore, during the period of 1914-1947, the U.S. Bureau of Fisheries operated a hatchery at the lake to enhance sockeye production. The hatchery collected salmon eggs from fish caught in the tributaries of the lake and upper Quinault River. The egg take ranged from 2,000,000 to 19,000,000 per year with the majority of the fry planted directly to the lake."

Increased channel migration, channel bank and terrace erosion, and the consequent reduction of the number of spawning salmon in the Upper River would cause a decline in water quality and trophic productivity within the rearing environment of Lake Quinault. The sockeye salmon are dependent on conditions in Lake Quinault for successful early juvenile growth and survival. This is a critical phase for over all productivity of the system, and poor conditions in the Lake would act as a bottleneck that would limit production. Deteriorating conditions in Lake Quinault likely occurred simultaneously with changes occurring in the Upper River to affect and limit the capacity of the system to produce sockeye salmon.

Tributary channels that are less susceptible to river processes presently provide the most stable habitat in the present system. Terrace channels that were historically stable for several decades to centuries are now at a higher risk to erosion by the river. The presently wide, shallow river with a general lack of large, stable woody debris does not provide adequate holding pools that can remain wetted during low flow periods. These pools are essential for sockeye survival to help them survive between hatching and migration down to Lake Quinault. The few areas that are available are at high risk for being washed out by the river during subsequent high flows (Figure 35). In the reference setting, root wads and log jams formed scour pools and provided a mixture of high and low velocity areas along with cover and shading of the water important for maintaining diversity of aquatic habitat. In the present system, the lack of large woody debris and mature forest limits the amount of complex habitat formed by root wads and log jams

along channel banks, both on banks within the historic migration zone and along the boundaries of it.

Figure 35. Looking upstream near RK 8 at an area of active floodplain containing sockeye spawning habitat. Prior to 2003, this section of the floodplain was occupied by the Quinault River. The area currently receives flow from Big Creek and a terrace channel on the north side of the HCMZ. After the Quinault River shifted to the south, the reach from RK 7.6 to 9.1 has provided habitat for sockeye spawning. This type of habitat is at a high risk for being reworked by the river during the following winter flood season, but can provide short-term habitat. Photograph taken August 19, 2004.

5.4.2 Bank Erosion along Property and Roads

Possibly the greatest risk to landowners and roads has been the shifting of the river such that the main channel runs against property, erodes the bank, and causes loss of land or infrastructure. Although the river is constantly eroding and building new surfaces within the active floodplain, property lost to the river cannot be recovered during any reasonable time interval (a few to several decades). In the case of roads, bank erosion can endanger vehicles and people when the erosion happens suddenly during a flood. In response to loss of property and threatened infrastructure, bank protection devices have been placed. Bank erosion protection measures used have generally consisted of rock riprap or cabling large logs to the bank. Historic maps from 1897, 1906, and 1929 show road positions in many areas that are now river, indicating much of the original roads were lost and new roads had to be built. Anecdotal accounts also document that log jams were removed or re-situated in the river area to redirect the main channel away from threatened property. Although this practice may have been more common prior to in-water work permitting

requirements, when a log jams puts a property at risk for flooding permits have been obtained to remove the log jam and reduce the risk of local erosion and flooding.

The Bunch Field Slough side channel formed in 1973 when a man-made levee was constructed and forced the main channel (then located where Bunch Field Slough is now present) to the opposite side of the historic channel migration zone (Figure 36). It is believed the levee was placed to protect the property from flooding and erosion by the river. During a site visit we noted there are two to three human-placed check structures (weirs across channel) along Bunch Field Slough that appear to have been modified at some point by beavers. This is an example of how even though the north side of the river became Olympic National Park in 1938, some areas were still modified by human activities in subsequent years.

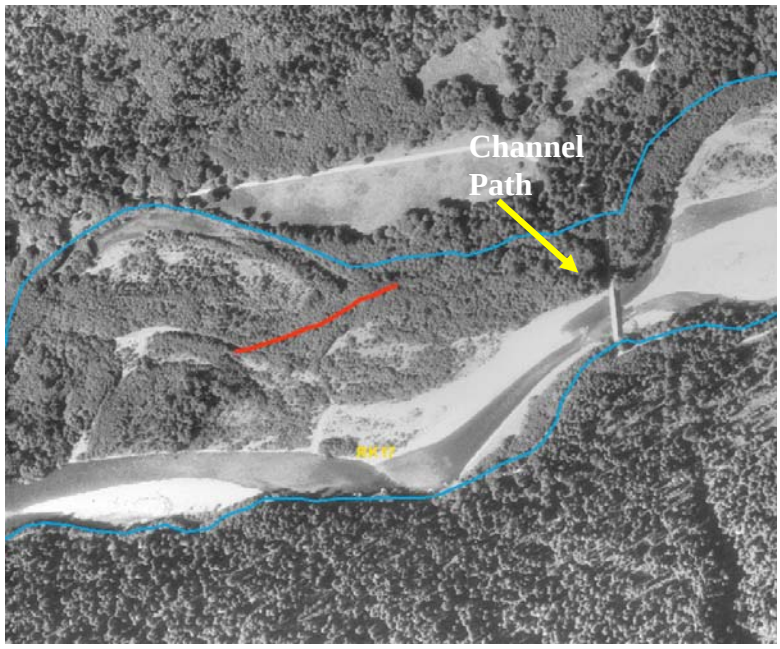

Figure 36. Bunch Field Levee (red line) and NPS bridge location figure on 2002 aerial photography.

The embankment for the bridge (located just downstream of the confluence of the two forks) constructed in the 1950s also constricts the natural active floodplain width on the north side of the river, thereby cutting off an old channel path (see Figure 36). More sediment is now transported through the constricted bridge section and a backwater pool forms upstream of the bridge that becomes a depositional area. The channel appears to have incised due to the high transport capacity. There is bedrock exposed along the channel bed at the bridge, the main channel is lower in elevation than side channels (more typical is to have all channels at similar elevations), and a comparison with a 1929 profile indicates incision likely due to the constricted channel (see Appendix G). There is a culvert allowing water to pass under the embankment through the old channel, but a levee constructed just downstream (shown in Figure 36) in combination with the bridge prevents the natural migration processes of the river in this area. A meandering channel is visible on the 1939 aerial photograph. The history of this section is discussed in more

detail in Appendix O for Bunch Field Slough and restorations strategies are discussed in Section 8. The overall conclusion is that natural river migration processes are limited by the combination of the NPS Bridge and Bunch Field Levee.

Cabled logs that we observed along the 2002 historic channel migration zone are shown in Figure 37. Along the South Shore Road, repeated erosion has occurred between RK 2.5 to 3. Some cabled logs are still in tact on portions of the present bank, but much of the bank is still actively eroding when the river runs against it. Cabling of logs to bank as a means of bank protection may, in some cases, have accelerated bank erosion. Areas that were unsuccessfully cabled can be identified by the numerous abandoned cables that now lay within the active channel and floodplain. A few landowners have begun to plant trees in the last decade that, if not eroded by the river and allowed to mature, may provide some line of defense to help slow river migration.

The South and North Shore Roads have been washed out by the Quinault River (along with surrounding property) at certain locations in the past, and had to be setback farther away from the river. Riprap has also been placed at several locations where the South Shore or North Shore Road comes into contact with the Quinault River and there is a high risk of erosion (see Figure 37).

The North Shore Road is protected by riprap just downstream of the confluence with Big Creek, near RK 8.5 to 9. This section is actually underlain by bedrock, but when the road embankment was washed out it was protected. The North Shore Road runs through the 2002 historic channel migration zone adjacent to RK 10.5 and 13. These road sections are also elevated above the floodplain and create a small levee during overbank flow periods. Riprap and cabled logs have been placed at some point in the past at the site near RK 10.5.

The South Shore Road has riprap and cabled logs between RK 7 and about 7.8, most of which runs adjacent to what is known as Alder Side Channel. Much of this bank protection now has young vegetation growing up through it, but there is only a very narrow width of riprap between Alder Side Channel and the road. There is also riprap adjacent to RK 9 and 9.5 to 10 from when the river historically ran against the road. This riprap helps redirect the river north and protect the downstream south bank but may also aggravate the erosion on the North Shore Road near RK 8.5 to 9. Finally, there is also riprap along the South Shore Road adjacent to RK 15.5. Like the area near Big Creek on the North Shore Road, this area is also bedrock but because the road embankment has been subject to erosion it has been protected with rock.

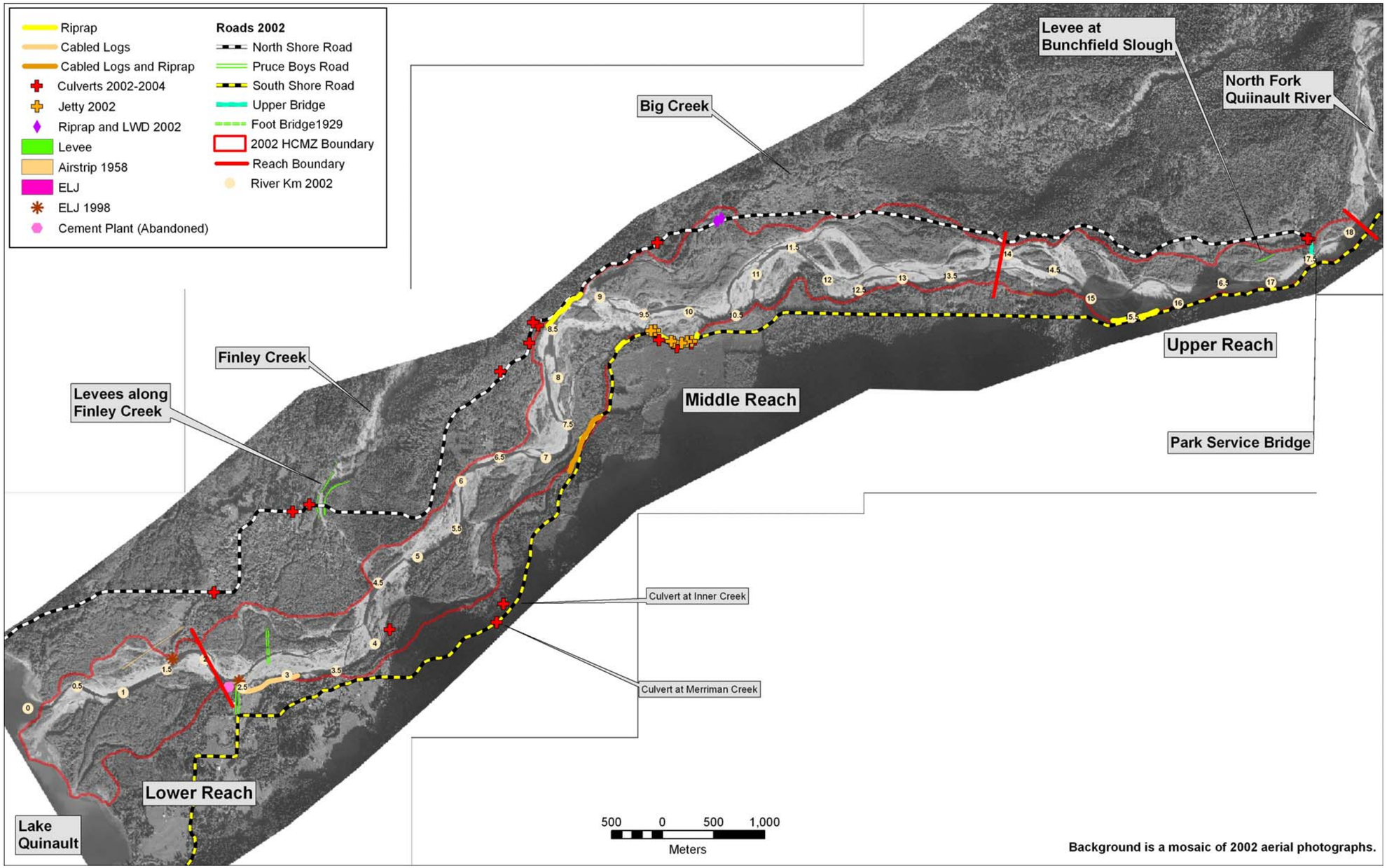

Figure 37. Bank and flood protection, culverts, bridges, and roads present along Quinault River in 2002.

5.4.3 Flooding Issues and Protection Measures

Flooding occurs in the Upper Quinault valley from the river during high flows, from tributary drainages during high precipitation events, and from backwater from Lake Quinault. A flood inundation map was beyond the scope of our study. However, the LiDAR and channel data collected in 2002 for our study would provide a good set of baseline topographic data from which to accomplish numerical flood modeling (combined with local accounts and high water marks) to attempt a flood inundation map in a future study. General accounts of flooding and human responses are discussed below. Additional information can be found on flooding issues in the Watershed Analysis (QIN, 1999).

There are presently no significant flood protection structures within the Quinault valley to protect landowners from flooding. No flood warning system or large-scale flood protection measures have been implemented at the time of writing of this report. There are a few cases where small, private levees that have been built to block off entrances to channels dissected through the terrace and lake deposit surfaces. In a few places the North Shore Road has been built higher than the surrounding ground to limit overtopping during flooding. Many landowners try to reduce the effect of flooding from the river by removing log jams that locally raise the elevation of the water surface near their property during floods. Landowners may also fill the entrances of channels that pass through their property. This channel filling reduces the amount of flow that can enter these channels and may reduce the risk that the main channel will shift into these locations. However, filling of side channel and terrace channel entrances forces more flow to remain in the active floodplain area during floods and could result in accelerated bank erosion (locally) for a nearby property.

Flooding of property within the influence of backwater from Lake Quinault (lower reach) may be increasing over the last century (see Section 5.2.7). Local accounts note that the backwater presently extends at least as far up as Pruce Boys Road near RK 2.5 and possibly further. A plot of the highest lake stage recorded in relation to the river channel bottom indicates backwater from Lake Quinault extends up to RK 2.9.

It is difficult to detect any longer-term flooding impacts in the middle and upper portions of the study reach. The surfaces most at risk in the middle and upper study sections are the intermediate Holocene surfaces because they are lowest in elevation relative to the Quinault River. Upper Holocene surfaces with channels dissected through these surfaces can also be locally at a higher risk for flooding. Above the zone of influence of Lake Quinault, short-term increased flooding may have occurred following the initial disturbance to the river and aggradation in the early 1900s. When the vegetated islands were cleared and the large volumes of sediment released in a short amount of time, it is likely the river became temporarily aggradational, particularly in the Middle Reach (RK 2 to 14). This would have locally resulted in higher water surface elevations for a given discharge. Overall, the natural channel was narrower and deeper and could convey more flow than the wide, shallow channel now present. However, there was more roughness in the natural channel than exists today. A reduction in roughness would tend to decrease

flood stages. Also, the existing migration zone is wider and should be able to convey more flow than the historic channel without overtopping the terrace surfaces. Localized flooding where log jams form or where channels fill in and temporarily raise the river bed can be a significant problem. The effect is temporary, however, as eventually the log jams are washed away and the river re-scours the channel.

5.4.4 Finley and Kestner Creek Flooding and Aggradation Issues

The Finley and Kestner Creek drainage complex is a large, alluvial fan complex that has several flow paths according to the LiDAR data. Although it was not a major focus of this study, some discussion is presented in this section and a historical geomorphic documentation of the Finley Creek area is provided in Appendix L. Kestner Creek has flow paths that drain into Lake Quinault and Finley Creek drains into the Upper Quinault River between RK 2 and 5. Parts of the Finley Creek alluvial fan are very old, dating several thousand years ago (Appendix D). The flow originates from a canyon reach in the Finley Creek basin and then naturally splits off into several channels in the downstream direction. Because of the multiple flow paths, flooding was a recurring problem for the numerous landowners and roads built within the drainage complex. Along Kestner Creek, flooding of property and the road continues to be a problem even today.

Anecdotal information and field observations suggest sometime after 1939 (possibly by the 1950s) an engineered log jam (ELJ) was placed to cut off the western-most flow path of Finley Creek, which is thought to have been done to try and solve the recurrent flooding issues. This forced more flow to remain in the eastern-most channel path of Finley Creek. By 1994, the main path of upper Finely Creek had migrated eastward and may have started incising the high exposure of glacial deposits along the east side. At some time, perhaps between 1973 and 1982 (although it could have been earlier), the channel of Finley Creek near the bridge started aggrading and levees were constructed on both sides of the channel near the bridge with the excavated channel sediment. These levees directed the flow eastward into the multiple and branching east paths to the Quinault River. The National Park Service has continued dredging operations at the bridge located on Finley Creek to help maintain adequate conveyance during high flows. Much of the year this aggradational reach is dry on the surface because the flow goes subsurface. Resource managers from the National Park Service are currently evaluating alternative long-term solutions for the bridge area, but no decision has been made upon the writing of this report. The bridge provides access for several private landowners who still live within Olympic National Park on the north side of the Upper Quinault River. Small “push up” levees have been built on the County Road along the Kestner Creek channels in the past, but these levees are easily breached because they are made of river bed material that cannot be adequately compacted to prevent erosion. There have been no other known solutions to the flooding issues that persist where the road crosses the Kestner Creek channels.

It is not certain what the impact of the channel filling and dredging activities on Finley Creek have had on flow connections and the amount of sediment currently being transported to the Upper Quinault River compared with historic reference conditions. A

new habitat side channel (Taiber Slough) has formed in the last several years at the toe of the Finley Creek alluvial fan in a former main channel flow path.

6.0 Future Trends under Current Management Practices

This section addresses the following study questions:

1) If current land-management practices continue, how will the river evolve?
2) Will the river eventually heal itself and return to reference conditions and if so, how long might this take?

6.1 River Migration Rates and Large Woody Debris

Without any management intervention to provide large woody debris, several decades to centuries may be required to slow the river's lateral migration and increase channel stability. Presently there are only three stable islands with "legacy" buried wood (wood thought to be deposited prior to disturbance) that help stabilize these areas. Over time this wood will decay and these few remaining islands will eventually erode. In the time before large-scale changes in the basin (reference conditions), new log jams and vegetated surfaces were always being formed, so that vegetated surfaces were continually lost and gained at a natural rate. The availability of large woody debris in the system has been limited since at least 1939, and therefore the creation and maintenance of new stable hard points have been limited also. These trends will continue in the future. The few remnant vegetated areas with buried wood are gradually being eroded. If rapid river migration rates continue, the river will struggle to re-establish mature vegetated islands within the historic channel migration zone. The Olympic National Park (north) side may contribute some large woody debris as some of these areas re-establish native forest, but the south side will continue to provide only limited large woody debris because much of this has been cleared.

6.2 Riparian Terrace Forest and Expansion of 2002 Historic Channel Migration Zone Boundary

Maintaining minimal vegetation on surfaces adjacent to the historic channel migration zone allows continued expansion of the active floodplain, continued increases to the sediment supply, possibly drives localized aggradation, delays channel evolution to a more stable condition, and perpetuates the present planform. Presently, there are only two locations on the north side where the old growth terrace forest remains intact. However, most of the forested areas on the north HCMZ boundary are between 40 to 60 years in age which eventually will provide mature stands of conifer and other important species necessary to re-establish sources of large woody debris recruitment. If no management action is implemented, we anticipate that areas with trees on the north side of the Upper Quinault River, which are now part of Olympic National Park, will

eventually mature to a point that they will be able to slow the rate of bank erosion. Channel migration rates will continue to be high, until some of the trees on the north side can grow to substantial size, so that when they enter the river they are large enough to be key members, which initiate formation of log jams, which in turn create hard points. A few locations, such as near RK 1, 6, and between 16 and 17, have been cleared. Vegetation will need to be planted in these areas to re-establish native forest species.

There are only two locations along the south side historic channel migration zone boundary that have never been thinned, cleared, or had a road placed. If current land use practices continue on the south side of Upper Quinault River, we anticipate that rapid bank erosion will continue in non-bedrock areas, which includes the surfaces between Lake Quinault and about RK 15.3. As the channel migration zone continues to widen (expand), it will eventually reach a width beyond which it will expand only slowly, because the channel will not run against the banks as often as when it was narrower. Additionally, the channel must maintain a certain slope relative to the valley slope. When the channel begins to flow more perpendicular to the valley slope during periods of expansion of the historic channel migration zone, it will eventually cut itself off and follow the valley slope more closely to maintain sediment transport capacity toward Lake Quinault. This limits the lateral distance the channel can travel away from the active floodplain, as long as it must reconnect to the floodplain at some downstream point. If the channel avulses into a new location along the South Side, it could theoretically travel that path all the way to Lake Quinault, but this would likely take decades to centuries to accomplish and probably would be prevented given the large amount of residents on the south side.

The rate and extent at which the river will continue to expand the historic channel migration zone can be inferred from the historic erosion between 1939 and 2002 (Figure 38), the potential future river paths, the type of material in the bank, the height of the bank, the vegetation on the surface of the bank, and the angle at which the river intersects the bank. Bank areas on the outside of meander bends are expected to experience the highest rates of erosion for a given bank type and vegetation cover. Areas least at risk are those protected from the river running against them because of upstream bedrock controls or bank protection that redirects the river away from the bank toward the opposite side of the floodplain (such as on the north side downstream of the bedrock outcrop at RK 14).

At one time the Quinault River occupied the majority of the valley bottom in our study reach. The Holocene surfaces represent our interpretation of areas most recently occupied by the Quinault River in geologic time. Alluvial fans can be of the same age as the Holocene surfaces or in other cases, such as Finley Creek, even older or associated with lake deposits when Lake Quinault was larger and filled a larger area of the valley (see Appendix C for more detailed discussion). All non-bedrock surfaces composed of erodible material within the valley bottom are at risk for erosion by the Quinault River. Areas closest to the 2002 historic channel migration zone boundary are obviously more at risk for being eroded in the near future than areas farther away and closer to the valley edge. An exception is areas where channels are dissected through terrace surfaces. These channels are readily visible on the hillshade created from 2002 LiDAR data (see

Figure 38). Although these channels have been relatively stable during the last century, they have a higher risk of being occupied by the Quinault River because their upstream ends are often connected to the active floodplain, which increases the chance that the Quinault River will shift into these channels when it migrates near the channel entrances.

6.3 Risk to Infrastructure

Major river or constructed features, such as abandoned terrace channels, altered tributary channels, and protected areas where bridges, bank or road protection, and levees are expected to be maintained, will continue to affect natural processes locally.

Between Lake Quinault and RK 8, only one section of the North Shore Road, which is near RK 5.5, is fairly close to the river and could be at risk of erosion. Between RK 8 and the NPS Bridge, there are several areas of the North Shore Road that could be at risk in the future. In particular, the highest risk areas may be sections of the North Shore Road not already protected, such as a section where the road is within the 2002 historic channel migration zone near RK 10.5 and 13 (see Figures 38).

Along the South Shore Road, areas closest to the river are also likely to be at risk for erosion in the future, particularly near RK 3.5 and 4 and between 7 and 10. Upstream of RK 10, the South Shore Road is located on the Holocene Upper terrace. This surface is higher in elevation than the downstream Holocene Intermediate surface. Because it is higher above the channel bed, it requires more energy by the river to erode the same lateral distance of terrace bank than the lower surface (relative to the channel bed). This may help slow the future rates of erosion toward the South Shore Road above RK 10 in a natural setting. However, much of this area has little mature vegetation to slow rates of erosion, and the South Shore Road could be at risk in several spots in the future between RK 10 and the start of the bedrock at RK 15.3.

6.4 Delta Processes

River flood stage near the delta would be expected to increase over time to due continued delta progradation, but measured incision at the moraine at the outlet to Lake Quinault would slow or may prevent the flood stage from increasing (see Section 5.2.7).

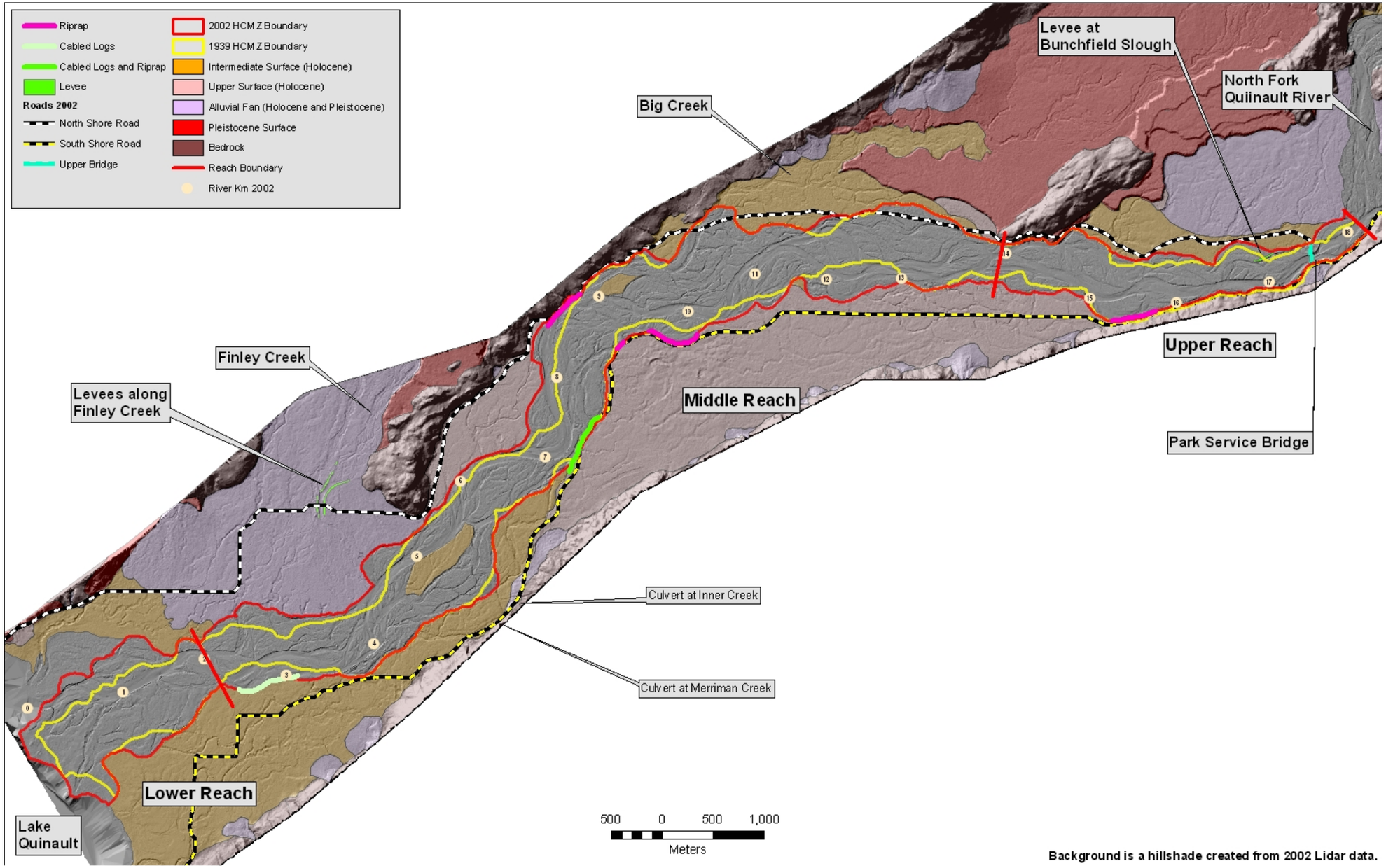

Figure 38. Illustration of extent of geologic surfaces binding the 2002 historic channel migration zone and channel development in these surfaces developed from Lidar data.

6.5 Side Channel Habitat Formation

There are more side channels in 2002 than in 1939, which was during the earliest phase of river response to human disturbances. Some of these channels have persisted for long periods because the main channel has rapidly expanded on the opposite side of the historic channel migration zone. Although this process does allow vegetation to establish along the side channel, the substantial distance of the main channel prevents connectivity of water between the two channels. Some viable habitat areas have also formed by terrace dissection and, in at least one location (near RK 12 on south side), where the terrace had mature trees large enough to act as key members, a large log jam has formed across the main low-flow channel that has dissected a portion of the upper terrace. The large trees in these areas improve the likelihood that habitat channels will form and be maintained in the future. However, as long as there is a general lack of large woody debris, a lack of stable side channels, and a lack of mature forest that can provide large woody debris, habitat side channels are expected to be at a higher risk for erosion relative to pre-settlement conditions. There will continue to be a fast rate of reoccupation of side channels by the main river, which limits the duration of time the side channel can function as habitat. There will also continue to be limited complexity in the river due to the reduced quantity of large woody debris and mature vegetation both in the river channel area and along the banks lining the wetted areas. Additionally, localized areas where levees, bridges, inadequate culvert crossings, channel blocks, and other alterations have occurred will continue to disrupt channel processes and habitat productivity.

7.0 Restoration of Processes & Preservation of Property and Habitat

A restoration strategy is needed that will facilitate the preservation of sockeye habitat, existing property, and infrastructure in the short term, while re-establishing natural processes to facilitate a self-sustaining ecosystem during the long term. This section describes a reach scale restoration approach based on the findings of this study and the previously published watershed analysis (QIN, 1999).

7.1 Restoration Objectives

The Quinault Indian Nation has adopted an integrated restoration approach that includes enhancing the habitat in Lake Quinault and the Upper Quinault River system (Sims, 2002). The primary goal of restoring fish habitat in the Upper Quinault River is to increase the quantity and quality of sockeye spawning habitat; i.e., increase the capacity of the habitats to hold more spawning sockeye and produce greater numbers of emergent juveniles for recruitment into Lake Quinault. Although the focus of this study is on sockeye salmon and the habitats they utilize, restoration approaches that increase general channel stability and habitat complexity, such as the approaches suggested in this report, will benefit all salmonids found in the system.

7.2 Restoration Strategies

To restore salmon habitat in the Upper Quinault River, the natural physical and biological processes that generate and maintain the riverine ecosystem must be recovered. In the forested river valleys of the west side of the Olympic Mountains two critical ecological processes have been identified that together strongly influence the development of alluvial valley landforms and floodplain forests (Fetherston 2005): stable wood jam development, and floodplain conifer reproduction. First, large floodplain conifers are recruited to the channel and hydraulically organized into stable wood jams (Abbe and Montgomery 1996). Stable wood jams are the structures that generate and maintain multiple side-channels, an anastomising channel planform, and a patchwork of elevated floodplain surfaces 2 to 4 m above the active channel (Abbe and Montgomery 1996; Abbe 2000; Montgomery et al., 2002). Second, floodplain conifer reproduction in the humid temperate river valleys of the Olympic Mountains occurs predominantly on the decayed wood of stable wood jams (Fetherston 2005). Therefore, stable wood jams are the limiting factor controlling floodplain conifer reproduction. The process linking floodplain conifer reproduction and stable wood jam formation is called the forest river large wood cycle (Fetherston 2005). Long term restoration of the Quinault River aquatic habitat will be dependent upon reestablishing this cycle of floodplain conifer reproduction. Therefore, we propose a restoration strategy with measures designed to:

1. Restore floodplain conifer reproduction to slow rates of bank erosion and channel migration to match the interpretation of reference conditions from the late 1800s.
2. Restore stable wood jam generated forested islands.
3. Restore mature (late-success ional stage) floodplain forests.
4. Restore the sources of large woody debris (mature floodplain forests).
5. Restore stable wood jam and floodplain forest to create a deeper, narrower channel with more morphological complexity than the wide, shallow channel that exists today.
6. Modify existing infrastructure (roads, bridges, levees) that cut off historical channel paths and floodplains to allow natural flow paths to occur.

The land-use generated disturbance of the river valley has occurred throughout the entire study reach. This makes implementation of the above restoration strategies challenging from a funding and logistical standpoint, but at the same time also offers multiple opportunities for implementing projects. This section describes restoration strategies that can be applied in a phased approach. In the near term, it is proposed that engineered log jams (ELJs) and bank protection measures be used to (1) protect existing side channel habitat (2) protect existing terrace property and terrace habitat channels, and (3) accelerate the recovery of floodplain forest development within the historical channel migration zone. A phased restoration approach is proposed to allow flexibility for the annual restoration work to be implemented in the most cost-effective manner. Once the conifer forests throughout the valley reach maturity, the natural cycle of large wood recruitment and conifer forest regeneration will be self-sustaining. At that point, large-wood-generated processes that form channels and floodplains will occur naturally without any additional restoration interventions. A comprehensive large-scale restoration of the Quinault riverine ecosystem will take decades to accomplish. Therefore, a phased approach over 50 years is proposed. The present system has been highly altered and there are many land use activities that will continue to persist in the future; it could be said that these strategies are more geared at rehabilitation. However termed, the long-term goal is to restore a system that more closely functions like the reference conditions prior to disturbance.

It is important to point out that all of the first five restoration strategies need to be implemented concurrently to improve channel function on a reach scale level, even when implemented on a site-by-site basis. The sixth objective deals with more localized impacts, but is important within the area affected. Implementing only one restoration strategy may help improve habitat for a given river position, but ultimately will not be effective over the long run as river changes occur. For instance, if side channels are stabilized within the active floodplain but bank erosion is allowed to continue, the river will continue to expand the active floodplain and occupy new areas. Although side channel protection measures are helpful, allowing the river to migrate across the rest of the floodplain makes the side channel at risk for losing its connection with the main channel and become isolated from river processes. It is important the side channel remain part of river processes to allow flushing of the side channel and maintain

hyporheic flow connections with the main flow path. Flushing prevents the side channel from being clogged with fine sediments that can plug the spaces between sediment particles or bury spawning gravels. The restoration strategies are discussed on a broad scale conceptual level in the rest of this section. In Section 8, the restoration strategies are applied to specific side channel sites identified by QIN that presently provide some level of viable habitat.

7.2.1 Bank Erosion and Terrace Forest and Channels

The rates of bank erosion and loss of property and terrace habitat channels over the last century are believed to have been accelerated well beyond natural levels. Therefore, it is justifiable to slow these rates of bank erosion to restore the complexity along the boundary of the channel migration zone and reduce the risk of losing additional habitat and property. Additionally, all bank erosion continues to increase sediment loads to the river at an accelerated rate and perpetuates the instability and rapid rate of channel movement. This will also provide a sustainable source of large woody debris necessary to increase stability within the active floodplain. By restoring the terrace forest, this effort would also facilitate restoration of the floodplain hyporheic zone productivity to pre-disturbance levels in order to restore productivity and sustainability of the naturally occurring chemical and biological processes of the Quinault Valley ecosystem.

Where terrace bank has already been eroded owing to human disturbances, it is nearly impossible to restore the area and habitat channels lost within human time scales. The only option would be to completely rebuild the terrace along the affected reach, and because there would be no mature riparian forest to help limit erosion, the terrace bank would need to be protected until a mature riparian forest could be established. This strategy would require a very large amount of fill material and is probably not feasible. There are short-term and long-term strategies that will help to re-stabilize the surfaces that bound the historic channel migration zone, which will also benefit habitat areas as described below. In some cases if the river channel has migrated away from the eroding bank, a combination of rock and/or large logs with fill material can be used to make a crib structure that re-builds the terrace bank a small amount (rather than cutting into the existing bank).

The short-term strategy should use bank-erosion mitigation measures that are self-sustaining and that allow for a natural degree of river migration, primarily through the establishment of a mature riparian forest (Figure 39). Prioritization of bank protection project locations could be given based on the potential for erosion. All HCMZ boundaries are at high risk to the river running against them based on our historical analysis of channel position. Therefore, the potential risk for erosion is most sensitive to bank height, bank material composition, and vegetation cover. Within the same bank material composition, the bank height affects the potential lateral extent of erosion more than the risk of erosion itself. The higher the bank, the less likely vegetation on the surface will help resist erosion. A thorough investigation of bank material composition was beyond the scope of this study, but mapping of bedrock versus erodible terrace areas are shown in Figure 38. The alluvial fans can also be eroded by the river, as observed at the toe of the Finley Creek alluvial fan. General observations suggest that the Holocene

surface in the Lower Reach (closest to the Quinault Lake) may contain more clay (old lake deposits) than the terrace surfaces in the Middle and Upper Reaches. If this is true, these banks may still erode but could have a stronger resistance to river erosion.

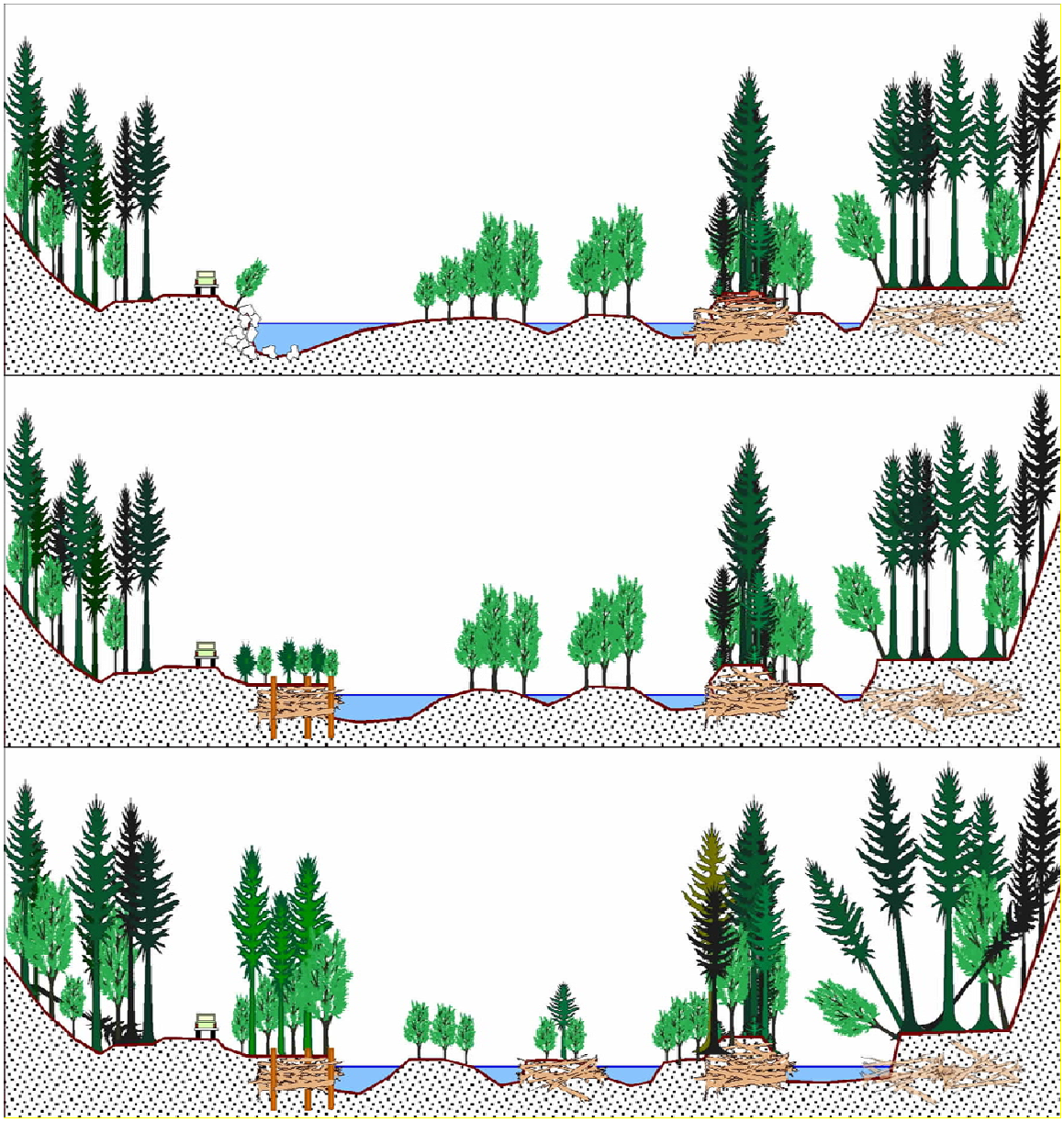

Figure 39. Using native materials to emulate natural boundaries on the channel, buffer zones can be established along banks at high risk for erosion to re-establish complexity along margins of the channel and to provide a source for large woody debris. The top image shows a typical riprapped bank with very little buffer between a road and the river channel. The middle image shows a short-term solution of rebuilding the bank with woody debris and planting native vegetation. The bottom image shows the long-term goal of growing mature forest on the bank to create a buffer between the river and the road. This may take a few decades. Graphics created by Herrera Environmental Consultants.

Areas that already have documented bank protection are shown in Figure 37. The highest priority for new or modification of existing bank protection projects could be given to areas that have been cleared of vegetation. These areas are shown in Figure 31 as shrubs or grasses and are more extensive on the south side of the study reach. The next priority could be given to areas that have some young vegetation with trees that if prevented from being eroded by the river will evolve into a mature forest that can serve the purpose of slowing bank erosion and providing a source of large woody debris. Figure 31 gives a first cut at areas that contain trees and the average age of these trees based on when the area was observed to be last cleared or thinned from the aerial photographs. In general the north side, which has been national park for several decades, is now developing into older aged forest stands about 40 to 60 years old. Although there are some older trees on the south side they are more sporadic and south side terrace banks could be given a higher priority for protection than the north side. Some of the areas on the south side that do have older trees stick out into the HCMZ making them more vulnerable to river erosion. Other areas are very narrow and when the thin line of trees erodes there will not be anything left to protect the bank. These areas would also benefit from some bank protection strategies combined with replanting of native vegetation where possible. More detailed field checking could be done to further prioritize areas and get a better estimate on tree ages within areas that might be protected. If large woody debris is used in the bank protection, this will provide added complexity to the channel where it runs against these banks and help improve habitat in the study reach.

A long-term strategy is to create buffer zones along the surfaces that bound the channel migration zone where these surfaces no longer have conifers. A late successional stage coniferous forest will restore the following: (1) appropriate rates of surface erosion, bank erosion, and channel migration resulting in an increase in the longevity of smaller terrace and overflow channels used by salmonids for spawning and rearing, (2) supply large woody debris sufficient to sustain complexity and diversity of aquatic and terrestrial habitats, (3) biological, physical, and chemical processes necessary to support healthy ecosystems, and (4) composition and diversity of plant communities to provide thermal regulation and nutrient filtering necessary to maintain water quality.

This will help slow the rates of channel migration over the long-term and help restore a source of mature vegetation that can be recruited into the river to provide large woody debris. In some cases the areas have been logged long ago and only grasses have established and planting is needed to get native vegetation growing again. If it is desired to go beyond the short-term protection strategy, these buffer zones could be planted to allow larger, native old growth forest to be restored, which would help slow rates of bank erosion and supply the large woody debris to the river. Areas beyond the buffer zones could be left cleared. Establishment of more stable vegetated surface will help reduce sediment impacts associated with lateral migration because as the vegetation matures in age it will slow the rate of channel migration thus reducing the amount of sediment contributed to the river from bank erosion.

Berg et al (2003) suggests aggregated planting on elevated surfaces to recover large tree sizes as soon as possible. A silvaculturtist should be consulted to develop a specific plan for planting that considers vegetation types, density, thinning, and timing.

Some of existing rules and suggestions for buffer zones may not be adequate because the remaining trees may not be of adequate age as existed in the natural setting. At RK 10.2 to 10.7 a forested riparian buffer zone, as required by forest practice rules, was preserved along the reach and was present in 2001. The buffer zone consisted of second growth forest estimated on average to be about 50 years old based on aerial photography (see 2002 aerial photograph in Figure 1). However, during the winter of 2002 to 2003 the buffer zone was lost due to erosion of the south bank by the Quinault River. Additionally, there are many areas with channels dissected through these terrace and lake deposit surfaces that increase the risk the Quinault River may shift into these channels. The watershed analysis (QIN, 1999) suggests positioning a buffer zone either of 100 foot (horizontal) buffers or of the horizontal distance corresponding to the maximum height of a mature tree typical for that location (whichever distance is greatest). We observed lateral erosion distances greater than 100 feet, suggesting a wider buffer zone may be needed in some areas.

Using the information from our study, buffer zones could be developed based on historical bank erosion rates observed between 1939 and 2002. This strategy could be implemented in potentially erodible areas, which includes most surfaces in the study reach except where bedrock persists. The buffer zone will take decades to a century to establish, so it would be beneficial to protect areas in the short-term that already have a head start on riparian vegetation growth if those areas would be subject to river erosion before they have a chance to establish a mature stand. Otherwise, these surfaces would continue to be lost due to river erosion.

Old cables from bank protection structures (cabled logs) that are abandoned in the active floodplain and no longer serving a bank protection purpose could be removed as part of a restoration strategy. Although a complete inventory of cabled logs was not accomplished, observations in the field suggest the majority of abandoned cables are located between RK 2 and 9. It is not known if the cables provide any function in the present river setting. In some places they were observed in the active river floodplain and could eventually be buried or transported down into Lake Quinault. In other places the cables were intertwined with old logs, likely from a historic attempt to protect a bank or create a log jam to redirect the river in the floodplain.

7.2.2 Floodplain Forest and Large Woody Debris

There are very few areas of mature vegetation in the present river system equivalent in age to what would have existed in the reference conditions (several decades to a century old). At least one of these remnant vegetated areas still present has buried wood at the upstream end of the island and along the bank of the island that helps the surface resist erosion by the river (see Figures 28, 29, and 30). More common are areas of vegetation that are a few decades old, but if attacked by the river could still be easily eroded. Part of the restoration strategy is to recreate hard points within the active floodplain to slow the

rate of channel migration. The vegetated island with buried wood is thought to be a remnant hard point feature of the reference condition. The exact density of wood that may have been present in the reference conditions is not documented on the Quinault other than the journal accounts discussed earlier in our report. A recent investigation by Fox et al (2003) documented reference in-stream wood conditions for Western Washington that could be used as a starting guideline for re-establishing wood densities in the Quinault River over the long-term.

To emulate natural woody debris functions in the Quinault River, ELJs could be constructed at key locations to allow young vegetation to establish to a more mature state before being eroded by the river (Abbe et al, 2003, Figure 40).

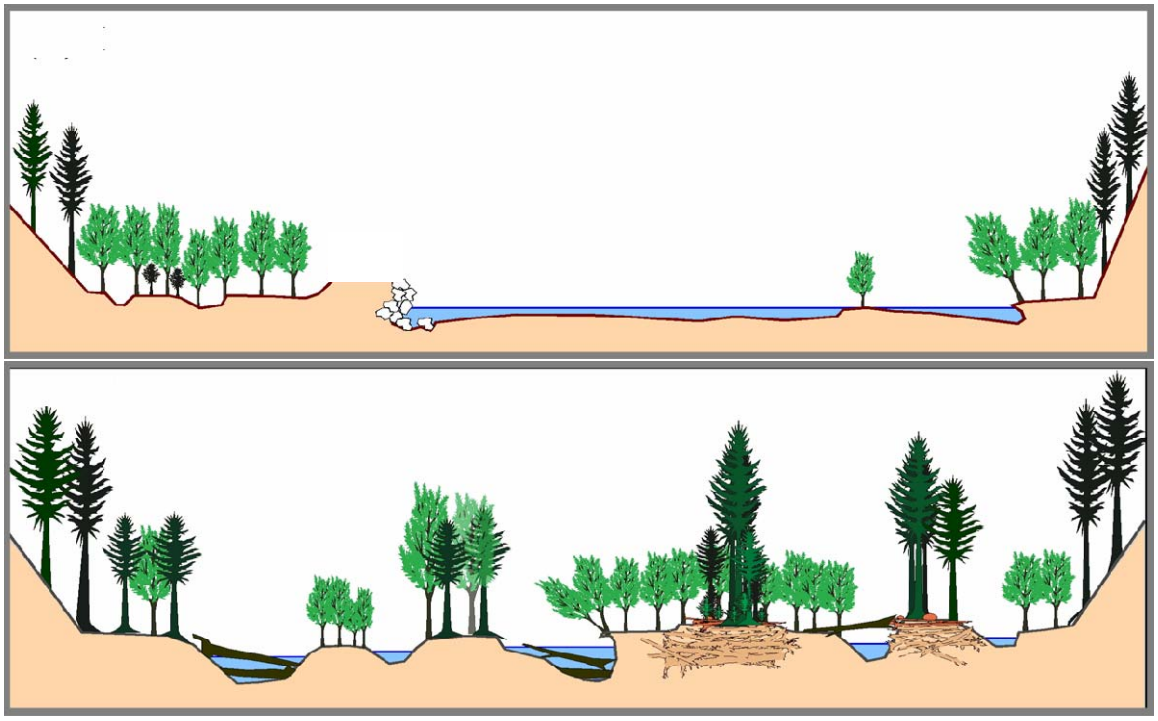

Figure 40. Using ELJs to emulate natural hard points in the channel will restore habitat complexity, create a more confined channel condition, and develop vegetated surfaces that will provide a source of large woody debris. The top image shows a wide shallow river section with little complexity or mature forest. The bottom image shows a river section several decades after implementation of ELJs to create forested islands and planting of native vegetation. Graphics created by Herrera Environmental Consultants.

Creating log jams at the upstream end of these locations allows the downstream surface to become a depositional zone and result in a high floodplain surface ideal for development of vegetation. The ideal construction locations would be areas not currently occupied by the main channel at low flows, but where a bar has formed that can be developed into a higher elevation surface ideal for growing vegetation. As the river shifts towards these hard points they will begin to help slow the rate of channel migration providing more sustainability to habitat side channels. As more hard points are constructed in the system, over the long-term it is hoped that these surfaces would not

only help slow the rate of channel migration, but also provide a source of large woody debris and complexity in the river that is currently lacking.

7.2.3 Channel Form and Migration Rate

Restoring the riparian vegetation on both river banks will produce slower rates of channel migration, and side channels used by sockeye would also be stabilized for longer periods. This will be accomplished as strategies of creating mature forest on the boundaries of the historic channel migration zone and on island surfaces occurring within the floodplain. The smaller river width and deeper channel described in the reference conditions can be restored by using large woody debris to form stable hard points in the system that can grow to become vegetated islands. These islands would be expected to remain in place for several decades, but would not be permanent, because any natural river system is dynamic.

Areas within the HCMZ that contain vegetation with trees are shown in Figure 27 by approximate age. The largest percentages of vegetated areas with trees are about 8 to 20 years old. These areas could be prioritized for stabilization if there is no large woody debris already protecting them at the upstream end of these surfaces.

7.2.4 Side Channels Utilized for Sockeye Habitat

One strategy is to protect the entrances to existing side channels that provide potential sockeye habitat to prevent the river from overtaking them. In the natural setting, log jams often form at the entrance to these side channels. Using a log jam rather than completely blocking off the channel allows some flow to still get into the side channel, but helps limit the amount of sediment transported in and the potential for the main channel to shift into the channel. ELJs could be used for this purpose. Large woody debris for the log jams could consist of wood imported from other areas or wood currently in the system that might otherwise wash out because it is temporarily deposited in a high transport reach of the study area.

Many side channels are also repeatedly at risk for being destroyed as a result of the rapid migration of the river along other areas besides the entrance. Implementing ELJs as protection at high risk areas of the channel would allow the channel to be sustained until the migration of the main channel can be slowed to reference condition rates, allowing side channels to exist and persist over a greater portion of the floodplain at any given time. Side channels within the HCMZ of interest to QIN are evaluated in Section 8 with a first cut at potential erosion locations.

The watershed analysis (QIN, 1999) suggests placing in-stream habitat structures (large woody debris) within side channels utilized by sockeye but notes that this measure would be only temporary and should not substitute for long-term restoration actions. Those streams that are the most lacking in large woody debris potential and shade were recommended to receive the highest priority for treatment. The long-term restoration action would be to develop a riparian corridor that would allow recruitment of mature trees suitable for providing habitat features in the channel.

7.2.5 Flooding

Flood control structures would be difficult to implement successfully, owing to the large scale of flooding on Lake Quinault, Quinault River, and drainages on the valley walls, which is promoted by the high water table around the lake. Property and infrastructure currently at risk from flooding could be purchased or relocated through grants aimed at restoration. Local authorities could also implement a flood control warning system and an elevated evacuation route in the immediate future to help ensure the ability of residents to be quickly notified and safely evacuated in the event of a potential flood.

7.2.6 Existing Infrastructure

Roads

Section 5.5.2 discusses which sections of road are currently riprapped and Section 6.3 discusses which areas are likely to be at risk in the future due to their close proximity to the river (see Figure 37). The watershed analysis (QIN, 1999) states that the following objectives would be desirable for areas involving roads:

- Stabilize or remove unstable road-fill slope material on all roads.
- Consider selective abandonment of roads.
- Inventory culverts on roads to assess culvert condition and function.
- Relocate some roads and improve drainage crossings.
- Conduct a geotechnical evaluation of stream bank and slope stability before locating and designing roads.

Most road culverts in our study reach are shown on Figure 37, but a complete inventory of impacts was beyond the scope of this study. In channels that provide habitat, culvert crossings should be investigated to ensure they provide adequate fish passage and do not disrupt the ability of the channel to convey water and sediment. It was observed during our field visits that some of the culverts on floodplain and tributary channels within our study reach and from drainage basins on the south side of the East Fork of the Quinault River (above the Forks) are undersized for water and sediment loads. These areas should be further evaluated and considered for replacement with an adequately-sized drainage crossing structure. In some cases larger culverts may be appropriate while in other cases a bridge may be needed.

Rock riprap has been placed intermittently between bedrock outcrops to protect the road embankment from erosion in one section of the South Shore Road and one section of the North Shore Road. In this situation the river will likely behave similarly along the riprap as it would along the continuous bedrock outcrops that were exposed prior to the road construction. However, in some cases bedrock outcrops can form scour pools that provide depth and cover that is not always present along riprap banks. Additionally, bedrock can be a recruitment source for large woody debris if forested on the surface like it is in the Quinault River. Sections of road along riprap may not be candidates for restoration strategies such as a road setback (realignment) because of the risk of inducing hill slope instability if moved farther away from the river up on the hillside.

In other cases the riprap is on an erodible surface (terrace, alluvial fan, or lake deposit). In some areas vegetation has begun to re-establish on top of the riprap which provides some shade and native vegetation cover along the channel when it runs against these banks. Much of the vegetation is young in age and there is only a thin buffer of this vegetation on riprap between the road and the river. Where the road is in contact with the river, having a wider vegetated buffer zone between the road and the river would benefit both the road and habitat areas. Even presently protected areas are likely to be subjected to erosion again in the future. By setting the road back farther away from the river in high risk areas, stabilizing the bank, and planting a buffer zone of vegetation there will be less risk to the road during future floods. This would also result in more complexity along the channel bank that will improve habitat and increase areas the river can recruit large woody debris. Each site is unique and the amount of road setback needs to be individually assessed depending on geologic controls, likelihood of river erosion, and other considerations such as land ownership and safety issues.

Bridges and Levees

If it is desired to restore natural river migration processes in the upstream-most portion of the study reach, the NPS Bridge could be lengthened and the Bunch Field Slough Levee could be setback or breached. If river migration could be restored in this area, a more meandering channel is likely to evolve which will create side channels and habitat. These structures are discussed in more detail in the Bunch Field Slough evaluation in Section 8.

The Finley Creek Bridge is not directly on the main Quinault River, but does have a major aggradation issue that will continue under current management practices. A separate ongoing investigation by the National Park Service is being accomplished for the Finley Creek area.

A bridge on the North Shore Road that crosses Big Creek is located within the 2002 historic migration zone. This bridge constricts the Big Creek channel and riprap has been placed where erosion has occurred in the past. This bridge could be evaluated to see if lengthening would be beneficial by evaluating the natural channel width versus the present bridge opening.

7.2.7 Mass Wasting

This topic was not evaluated for Reclamation's study, but it should be included in any restoration strategies at the watershed level. The watershed analysis (QIN, 1999) provides more information on this topic and suggests avoiding clearcut harvesting in intermittent channels and concave-shaped areas that are prone to mass wasting. Area that have mass wasting resulting from past logging activities in Olympic National Park could take several decades to begin healing and re-establishing vegetation.

7.3 Restoration Action Plan

This section was developed by Herrera Environmental Consultants and is reproduced from Appendix E.

Short-Term Action Plan (1 to 2 Years)

I. Community and stakeholder involvement

A. Public presentation of recent studies

B. Identification of stakeholder concerns

C. Presentation of potential benefits for stakeholder benefits

1. Bank protection for roads and property that also restore riparian forests, side channel habitat, and pool frequency in the main stem channel

2. Long-term benefit of more stable multi-channel system versus unstable single large channel

II. Restoration plan for the Upper Quinault River valley historical channel migration zone

A. Restoration plan

1. Historical habitat loss

2. No action versus implementation of restoration plan over next 100 years

3. Long-term (longer than 50 years) programmatic restoration plan

a. Valley-scale plan founded on cumulative benefits of implementation of individual projects throughout 10-mile valley reach over decades (approximately 50+ years)

b. Actions confined to historical channel migration zone with no adverse impacts on property or infrastructure and potential benefits

c. Relatively simple and economical plan that will deliver both short-term and long-term benefits

d. Plan based on reintroducing stable wood jams that will increase pool frequency, habitat complexity, available salmonid habitat (increasing cumulative channel length), side channel formation and longevity, and allow riparian forests to mature within historical channel migration zone

e. Reversal of the historical and ongoing loss of stable side channels

f. Reestablishment of mature conifer riparian forest patches

g. Adaptive strategy taking advantage of local conditions that provide the greatest cost-benefit in any given year (site selection in any given year is dependent on supply of woody debris, minimal construction impacts and avoidance of work in wetted, low-flow channel, and opportunities to accelerate habitat recovery and benefit local community)

B. Typical plans and specifications and regulatory compliance

1. Presentation of typical plans and specifications (approximately 50 percent)

2. Regulatory compliance

a. Regulatory stakeholders (local, state, and federal)

b. Description of compliance

c. Case for long-term regulatory streamlining (application of programmatic restoration permit(s)

C. Template for pilot project cost estimate and unit cost estimate for implementing basic plan at individual site

1. Final engineering and forest restoration designs, specifications, and estimates
2. Risk assessment (site specific)
3. Permitting (with or without programmatic permits in place)
4. Materials
5. Construction
6. Monitoring

Mid-Term Strategy (2 to 3 Years)

I. Application, negotiation, and acquisition of programmatic permit(s) or long-term regulatory streamlining for long-term restoration actions

II. Implementation of pilot project(s) described in short-term action plan

III. Delineation of regulatory channel migration zone outside the historical channel migration zone

III. Development of long-term strategy for reconnecting floodplain and channel migration zone areas isolated by roads (development of road maintenance and relocation plan with County Public Works, Olympic National Park, and Olympic National Forest)

IV. Development of long-term riparian reforestation plan for channel migration zone

Long-Term Strategy (3 to 50+ Years)

I. Implementation and performance monitoring of the restoration plan for historical channel migration zone

II. Implementation of reforestation plan for channel migration zone.

8.0 Geomorphic Evaluation of Present Sockeye Habitat and Conceptual Restoration Projects

The majority of this report has focused on reach scale processes of the Upper Quinault River. This section evaluates the geomorphic history at individual habitat side channels within the historic channel migration zone that have been most subjected to changes in river processes over the last century. Although the river is dynamic and constantly changing, by understanding how key habitat side channels have functioned in the last several decades, we can generate concepts to integrate the reach-scale restoration strategies at these sites even if the river changes in the future. The objective of this section is to provide the reader with a better understanding of the following:

1. When were these habitat sites in existence during the period between 1939 and 2002?
2. How have these habitat sites been impacted by the rapid river migration within the historic channel migration zone and erosion of terrace surfaces along the HCMZ boundary?
3. Which areas of the habitat channels are most in need of short-term preservation?
4. What are conceptual project ideas that could be implemented at these sites using the guidelines provided in Section 7?

8.1 Side and Terrace Channel Habitat Locations

Side channels are the most vulnerable to the main Quinault River channel processes and, therefore, provide the largest opportunities for improving habitat that has been degraded due to past disturbance in the system. The evaluation of side channel habitat focused on known (and suspected) areas that were believed to contain habitat characteristics required by sockeye for spawning and have sustained production in recent years (shown in Figures 41 and 42):

1. Bunch Field Slough (RK 15 to 17)
2. Fletcher Creek side channel (RK 13.8 to 14.4)
3. Joe Culvert Creek (RK 14.5)
4. North Slough (RK 11.5 to 13.6)
5. Downstream portion of Big Creek (RK 8 to 11)
6. Alder Side Channel (RK 5.7 to 9)
7. Straughn Side Channel (RK 4.7 to 5.1)
8. Taiber Side channel near Finley Creek alluvial fan (RK 2.5 to 3.5)

Terrace channels are also at risk of being eroded by or overtaken by the Quinault River. Erosion of terrace channels is important because once reworked, these habitat areas may

not redevelop for several decades to centuries. Habitat channels in terraces outside the 2002 HCMZ are briefly discussed within each side channel discussion at the following locations (can consist of multiple channels):

1. Terrace channels on the south side of the Quinault River between RK 12.5 and RK 15
    a. Fletcher Creek complex between RK13.5 and RK 15 (located on south side terrace near Fletcher Creek)
    b. North Slough complex between RK 12.5 and RK 13.5 (located on south terrace opposite North Slough)
2. Channel complex in the Big Creek area on the north side between RK 9.5 and RK 13 (located upstream of Big Creek)
3. Inner Creek Slough on south side terrace between RK 5.4 to 7.2
4. Unnamed terrace channel on the north Holocene terrace between RK 6 and 8.1
5. Homestead Slough on south side terrace between RK 3.5 to 1

Each side channel area within the historic channel migration zone was evaluated for potential short-term restoration projects to give the reader some perspective on how the short-term strategies presented in Section 7 can be applied at specific locations. These ideas are only conceptual and more design data and analysis for a specific site would be needed. Each side channel area was evaluated based on risk of being overtaken by the main channel, likelihood of continuing to provide sockeye habitat, and amount of large woody debris or islands already present that could aid restoration. The terrace channel complexes were evaluated for the risk of erosion of the terrace and elimination of the terrace channels.

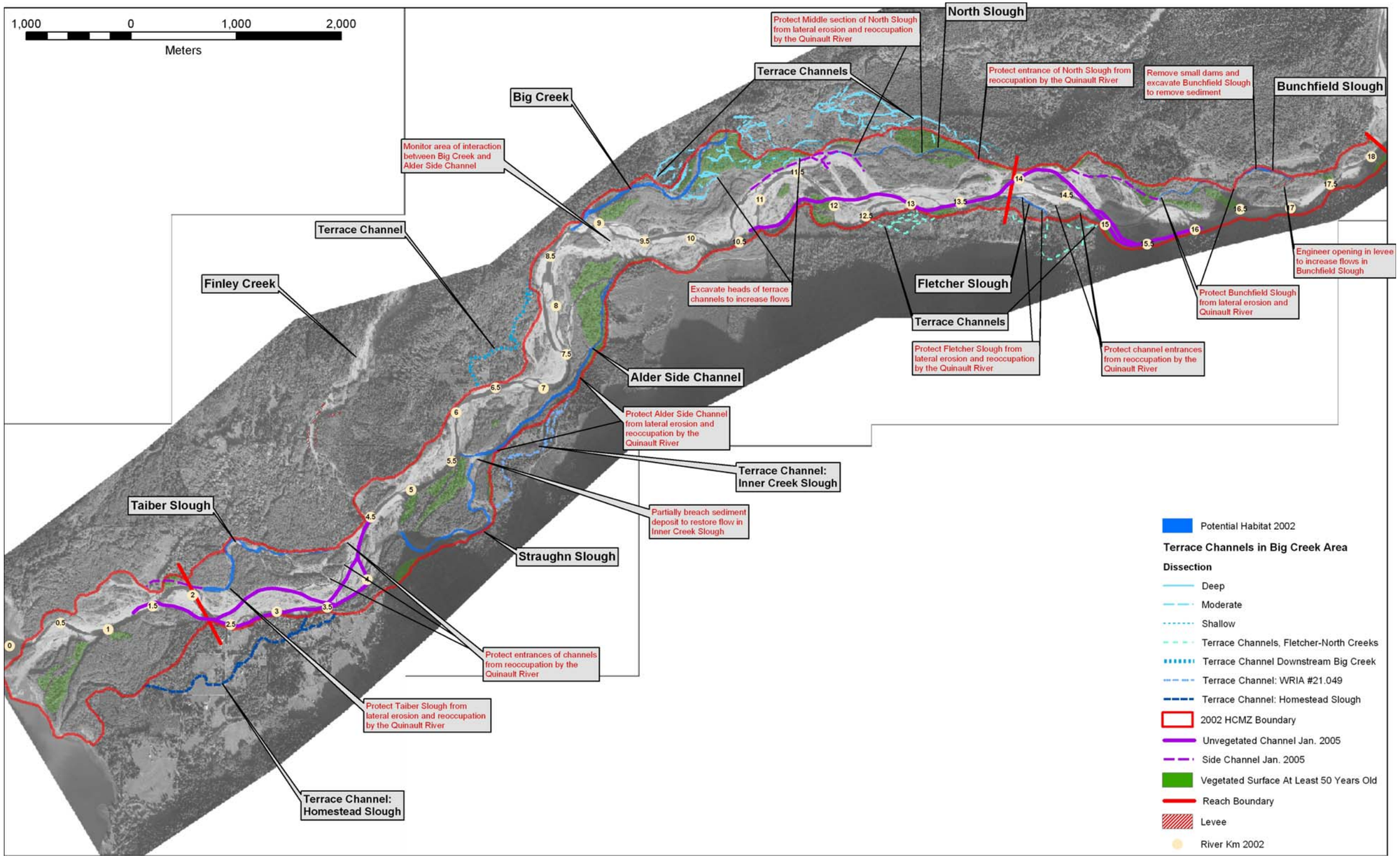

Figure 41. Locations of habitat side and terrace channels on 2002 aerial photograph. The 2005 locations were drawn on the 2002 aerial photograph based on field observations.

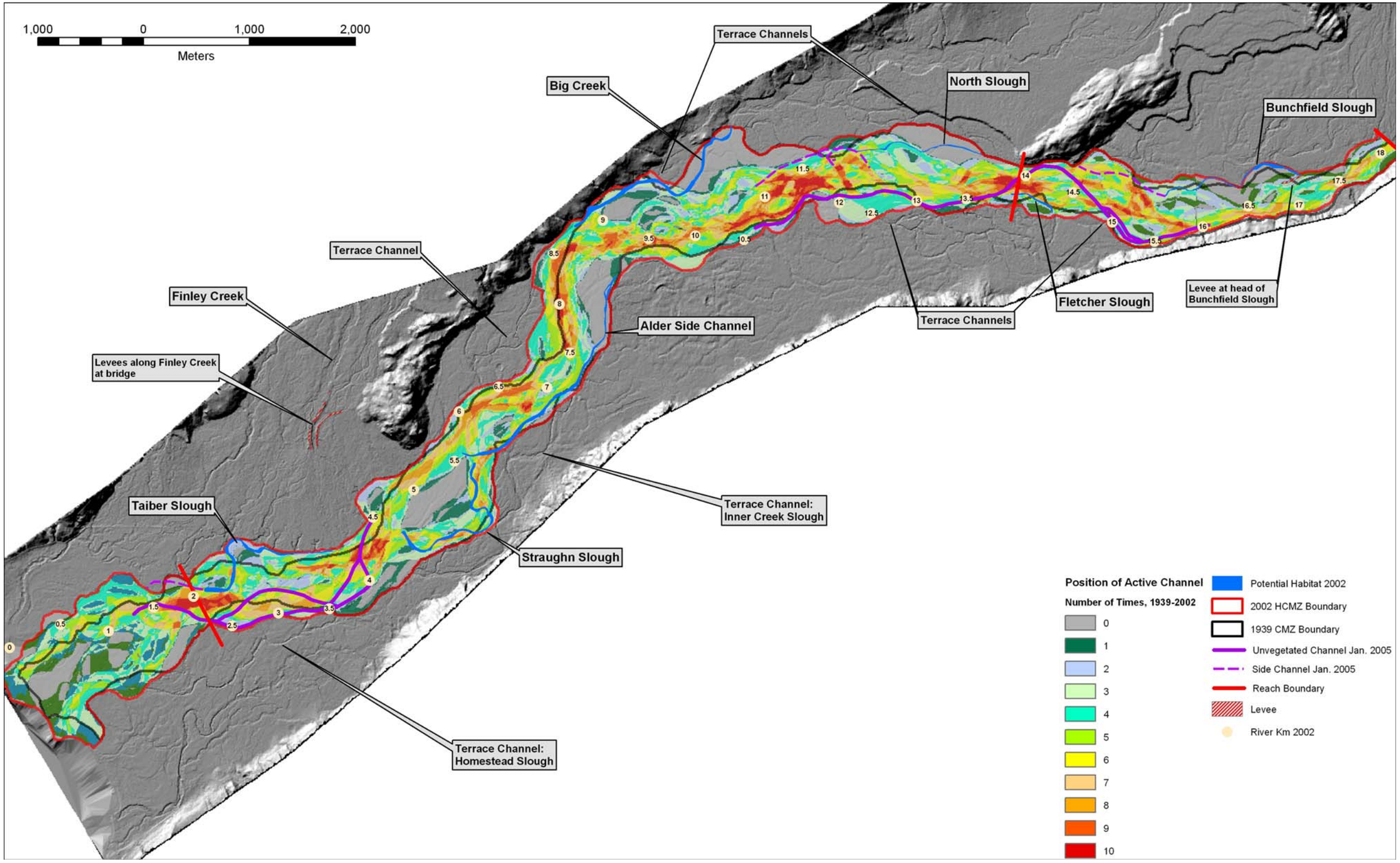

Figure 42. Location of side channels relative to reoccupation rate of historic main channel between 1939 and 2002.

8.2 Side and Terrace Channel Evaluation Methods

The history and geomorphology of the habitat side channels were interpreted using historical aerial photographs. The objective was to evaluate when each habitat side channel was formed, how long the area has persisted as a side channel, the risk that the channel will be reworked by the main Quinault River in the future, and when (and if) the area became more stable as a result of vegetation establishment. The river is dynamic and additional changes to these side channels will continue to occur. However, knowledge of how these channels have functioned over the past several decades can be applied to future channels that may form under the same geomorphic conditions.
In Appendix O, the habitat channel areas are shown on aerial photographs between 1939 and 2002, and the changes in the habitat areas between the photograph years are described. The erosion of the channel migration zone boundary between photograph years is also shown in the area of each habitat channel in Appendix O. This was done to determine if expansion of the channel migration zone was responsible for the formation, maintenance, or destruction of the habitat channel. A summary of this information for each habitat side channel is provided in Section 8.3 of this chapter, along with a timeline that provides an interpretation of each side channel's geomorphic history and whether the channel provided stable habitat. The criteria that were used to interpret the presence or absence of habitat using the historical aerial photographs are shown in Table 10. It is important to note that this evaluation was meant to look for presence of stable side channel habitat that is sustainable over several years. Stable habitat generally implies that there is adequate vegetation and/or large woody debris to protect the channel from being easily reoccupied by the main Quinault River for a certain period of time (several years to decades). Observations in the Quinault River indicate that spawning habitat for sockeye and other salmonids can exist temporarily in unvegetated channel areas within the HCMZ, but because these areas are highly susceptible to river processes, they are unsustainable over the long term.

For all of the habitat channels studied except Bunch Field Slough, the formation and destruction of the channel is tracked on aerial photographs taken in 1939, 1952, 1958, 1962, 1973, 1982, 1994, 1998, 2001, and 2002. The 1962 and 1998 aerial photographs do not extend upstream far enough to include the Bunch Field Slough area, so that interpretations in this area are limited to the other years of photographs.

In addition, cadastral survey maps made in 1906 and 1929 are used to extend the record beyond the time period covered by the aerial photographs. Only the low-flow and unvegetated channels can be interpreted from the cadastral survey maps. It is not possible to actually observe the side and overflow channels that form the habitat channels or vegetation present. The presence or absence of the habitat channels is interpreted from the position of the unvegetated channel. If the channel of the Quinault River or a surface containing buildings was in the location of the future habitat channel, it is assumed that the habitat channel did not exist. If the future habitat channel fell between these two areas, then presence or absence of the channel is shown as unknown, because the area could have been part of the channel migration zone at the time and may have included overflow or side channels that are not delineated on the maps.

Table 10. Criteria used to interpret potential side channel habitat conditions using the historical aerial photographs.

Classification	Criteria	Interpretation
Stable Side Channel Habitat	Narrow overflow channel that flows through an area of trees, especially when the channel has been present for some time and the vegetation on the surfaces adjacent to the channel have evolved from riparian, to mixed riparian and trees, to trees	Vegetation appears to large enough and dense enough that it may be more difficult for the active channel of the Quinault River to reoccupy the channel and destroy the habitat
Side Channel Habitat (potential habitat)	Narrow or wide overflow or side channel of the Quinault River that flows through an area with some vegetation, usually riparian; for wide channels, water is usually visible; water source may be a surface connection to the Quinault River or groundwater; at least some vegetation is present to protect the channel and habitat conditions	This is potential habitat as it is not known whether the channel was actually used for reproduction or rearing; the presence of riparian or mixed riparian vegetation and trees suggests that the channel has not received large flows from the Quinault River in the recent past
Possible Side Channel Habitat	A surface with riparian is in the area of the potential habitat channel; a channel may or may not (usually) be visible on the aerial photographs	A channel may be present, but the vegetation or quality of the historical photographs does not allow for a conclusive interpretation; because the area is outside of an active or recently active channel of the Quinault River, habitat may be present is this area of the channel migration zone
Initial Conditions (Phase) of Side Channel Habitat Development	A surface with sparse vegetation is in the area of the potential habitat channel; a small channel may or may not be visible on the aerial photographs	The vegetation is so sparse that the presence of potential habitat seems unlikely; however, the area may be evolving to better habitat conditions with an increase in the density and (or) size of the riparian vegetation; alternatively, the vegetation is so sparse that it would likely do little to prohibit the Quinault River from reoccupying the area
No Side Channel Habitat	Active, unvegetated, or slightly vegetated channels of Quinault River	The lack of or presence of only sparse vegetation suggests that flows in the recent past have been too large to maintain favorable conditions for habitat, even though a channel is present
	Surface outside of the channel migration zone (no channel); surface may be vegetated or cleared of vegetation	Because the future habitat channel is not visible across the surface outside of the channel migration zone, excavation of the future habitat channel by the Quinault River is assumed to have not yet occurred

8.3 Side Channel Evaluation & Restoration Concepts

Each side channel evaluation presented in the following discussion contains an overview of present habitat value, key geomorphic conclusions about the site, geology, woody debris, risk of being overtaken by the Quinault River in the future, and suggestions on short-term and long-term restoration strategies. Also included for each site are a location map and a timeline of the side channel illustrating how it has functioned over time (see Table 10).

All of the habitat side channels within the historic channel migration zone are at high risk for reoccupation by the river due to the lack of mature vegetation in the system which would have naturally helped many of these areas remain stable for decades. Restoration strategies that may be discussed and shown on a map for each side channel and terrace channel complex are broken into three general categories in relation to their predicted benefit to salmon habitat:

1. Preservation
2. Enhancement
3. Restoration

Preservation involves protecting this existing habitat from being overtaken by the river until mature vegetation and hard points can be re-established. An example would be placing ELJs at side channel entrances or other vulnerable locations along the channel to limit the ability of the river to shift into the side channel location. Another example may be to use ELJs at the upstream end of bar surfaces that have young to middle age vegetation that might be subjected to erosion if not protected. The ELJs would serve as hard points in the river to slow the rate at which the river laterally migrates and could erode into a particular habitat area. An additional strategy would be to protect terrace banks from further erosion to prevent further loss of terrace channels and property.

Enhancement means improving existing habitat and processes. An example might be to improve the water flow into a habitat channel that currently is dry (due to manmade features) during critical sockeye usage periods. Another example might be to place large woody debris in a habitat channel to slow velocities, develop scour holes that can sustain water during low flow periods, and increase complexity.

Restoration strategies discussed are generally considered to be activities that restore natural processes which improve sustainable sockeye habitat potential. These strategies are meant to emulate ideas presented in Chapter 7 and mitigate for past human disturbances in the study reach. Example strategies might involve slowing rates of channel migration and bank erosion back to natural rates through the initiation of stable areas that can sustain mature vegetation and provide recruitment sources of large woody debris. Restoration could also involve recapturing floodplain area such as at NPS Bridge or the Bunch Field Levee. It could also entail restoring channel connectivity in areas where culverts, channel blocks or other man-made features have artificially blocked flow connections between side or terrace channels and the main channel.

After evaluation of the individual habitat side and terrace channel areas, it became evident that many of these areas are interconnected in processes because there are not very many geologic controls that “reset” the river position in our study area. In other words, river position and processes in any given reach are affected by the river position and processes in the upstream and downstream reaches. This means that protecting one side channel may affect the ability of another side channel to persist. Therefore, a reach-scaled restoration approach to restore processes was presented in Chapter 7 as the long-term overall objective, rather than site-specific solutions. However, accomplishing

restoration of processes on a large-scaled reach will take time and cannot realistically be implemented all at once at all locations. For this reason, the following sections provide short-term restoration strategies that can be used to protect and enhance existing habitat that might otherwise be lost more quickly than should occur in the natural system. When pieced together, the short-term strategies form the foundation for a long-term strategy because each short-term project includes implementation of features that will build the stable hard points currently lacking in the system. For each site, long-term strategies are presented if there are other man-made features that need to be addressed to restore processes in addition to the short-term strategies documented.

8.3.1 Bunch Field Slough

Bunch Field Slough is a side channel of the Quinault River located between RK 17 to 15 (Figures 45 and 46; Jefferson County, Washington: Township 24 North, Range 8 West, Sections 27, 28, 33 and 34). Bedrock lines the south side of the HCMZ, and the north side is bounded by the intermediate surface (Holocene). The North Fork alluvial fan (historic) forms drainage paths leading toward Bunch Field Slough. This may help provide water in the slough even though the main Quinault river channel is slightly incised (lower) than Bunch Field Slough.

Bunch Field Slough was an important sockeye spawning area in the HCMZ from the 1980s to 2002 (Figures 43 and 44). Despite major changes to channel morphology and hydrologic conditions since the river reworked the habitat in 2003, the lower reach of Bunch Field Slough from RK 15.2 to 15.7 supported significant numbers of spawning sockeye during the winter of 2004 (B. Armstrong, QIN, personal commun. 2005).

Bunch Field Slough is located about 2 km downstream of the NPS Bridge at RK 17.5 which was constructed in the 1950s. The bridge forms a man-made channel constriction just downstream of the confluence of the North and East Forks of the Quinault River (Figure 47). After the bridge was constructed, the mainstem reoccupied a pre-1939 channel along the north bank where Bunch Field Slough is located. The upper portion of the side channel (RK 16 to 17) was present in a vegetated state as early as 1939. By 1958, it began to erode as a result of migration of the main channel into the side channel. By 1973, the Bunch Field Slough channel area was almost completely reworked and had limited vegetation but the main channel was now on the south side of the HCMZ. As a result of channel reworking and terrace bank erosion on the north side, a levee was constructed which is believed to have pushed the main channel to the south. The north side of the HCMZ has since re-vegetated. The levee and upstream bridge prevents the main channel from shifting into the upstream-most portion of Bunch Field Slough (RK 16.5 or perhaps 16.0 to 17.0), making it a low risk for river reworking.

Figure 43. Spawning habitat in Bunch Field Slough at RK 15.6. The photo was taken in October of 2002 prior to avulsion and reworking of the channel by the Quinault River later that year.

Figure 44. Spawning habitat in Bunch Field Slough at RK16.3. The photo was taken in October of 2002 and was not impacted by the Quinault River.

The lower portion of Bunch Field Slough presently exists in an area that was in part terrace surface prior to 1939. By 1952 the main channel began migrating into the terrace and the area remained part of the active, unvegetated channel until at least 1962. By 1973, coincident with the upstream levee placement, the main channel flowed on the southern side of the HCMZ. The river did not reoccupy Bunch Field Slough again until 2003 when river processes eroded a remnant terrace surface, destroyed spawning habitat and reworked the lower reach from RK 14.6 to 15.8 before moving back to the south side

in 2004 (B. Armstrong, QIN, 2004, oral commun.). Lower Bunch Field Slough from RK 15.2 to 16.5 remains vulnerable to river avulsion, even though the present channel appears to be locked into the south side and somewhat incised relative to the side channel and surrounding floodplain. This may be partially a result of the upstream NPS Bridge constriction, the constriction resulting from the levee, and a constriction caused by two patches of terrace surface with mature trees. As long as the channel remains incised, there may be less likelihood of the channel remaining for long periods on the north side in the lower Bunch Field Slough section. However, this section of slough is in places along the outside of a meander bend which makes it more at risk for lateral erosion and reworking from the Quinault River than the upstream section of Bunchfield Slough.

The adjacent north terrace was generally cleared of all vegetation up to the boundary of the HCMZ by 1939. This was the first documented clearing for homestead purposes by Euro-American settlers in the Upper Quinault Valley above the lake area (Appendix M). The north HCMZ boundary has periodically eroded since 1939 when the river ran against it. This surface eroded a maximum of 125 m, and on average 75 m, in lateral width between 1939 and 1973 (prior to the placement of the levee). The north terrace presently has a thin line of mature trees along about 40% of the total Bunch Field Slough channel length. In two other sections there is no vegetation and one of those sections runs along the North Shore Road. Unless the Bunch Field Levee is removed, the north side is generally protected from river erosion. The south side of the HCMZ boundary has mature coniferous trees and does not appear to have been logged. However, the South Shore Road runs along the bedrock, is partially riprapped, and limits any vegetation buffers from being in contact with the river.

Three areas between RK 16.0 and RK 16.7 within the HCMZ have been vegetated with mixed vegetation or trees for at least the last 30 to 63 years (see Figure 28). These patches were present as islands of shrubby or mixed vegetation in the 1958 photos prior to construction of the levee.

No action is needed in the immediate future to protect the upper section of Bunch Field Slough from RK 16.5 to 17.0 from being overtaken by the river. However, the reach extending from RK 15.2 to 16.5 is at immediate risk of reworking by the Quinault River if the channel does not remain incised along the south side from RK 15.5 to 16.2. This area should be monitored in the near future. One short-term strategy would be to leave the existing levee in place and promote additional surface flow into the side channel that could also be combined with an engineered sockeye spawning channel if the levee and bridge were to remain in place (see Figure 45). Presently the water table of the river may be lower than the side channel because the main channel is incised. This limits the amount of flow derived from the mainstem, but some flow is likely fed into Bunch Field Slough from the North Fork alluvial fan drainage on the north side. If more flow is desired, the levee could be modified to include an engineered opening that allows some portion of main channel surface or groundwater flow into the side channel. This opening could also be designed to facilitate fish passage if desired. Costs would involve breeching the structure or channel around it. There also appears to be check dams placed in the channel about the time of levee construction that now may be utilized by beaver. These

structures could be further evaluated to see if they are beneficial to fish, and if not, considerations could be made to enhance or remove them.

The current levee limits the natural migration process that was historically present at this site, as observed by historical maps and aerial photography (see Appendix O). A long-term strategy would be to restore the historic meandering channel processes. This would require the levee to be removed, coupled with an evaluation to determine if the NPS Bridge would also need to be lengthened to make the project successful. This strategy may result in a temporary elimination of the Bunch Field Slough as the main channel reoccupies the north side of the HCMZ. Ideally, a side channel would exist throughout this reach for some period of time if a natural rate of channel migration occurred and mature vegetation could establish. The benefit would be a more dynamic system that has the potential to increase salmonid habitat. A long-term strategy should also include restoring a late-successional stage coniferous forest where homesteaders have cleared pastureland along the north terrace bank and grasses are now dominant. This would need to be done prior to the levee removal to allow time for the forest to mature. The forest would also provide recruitment sources of large woody debris over several decades timeframe once the channel is allowed to reoccupy the north side of the HCMZ. A consideration to setback the North Shore Road could also be incorporated if restoration of channel migration processes might endanger the road where it is close to the HCMZ boundary, particularly at RK 16.7. Although the South Shore Road does have riprap and reduces the ability of large woody debris to fall into the river from the south hillslope, there are limited opportunities to set back the road in this location without inducing other issues such as mass wasting.

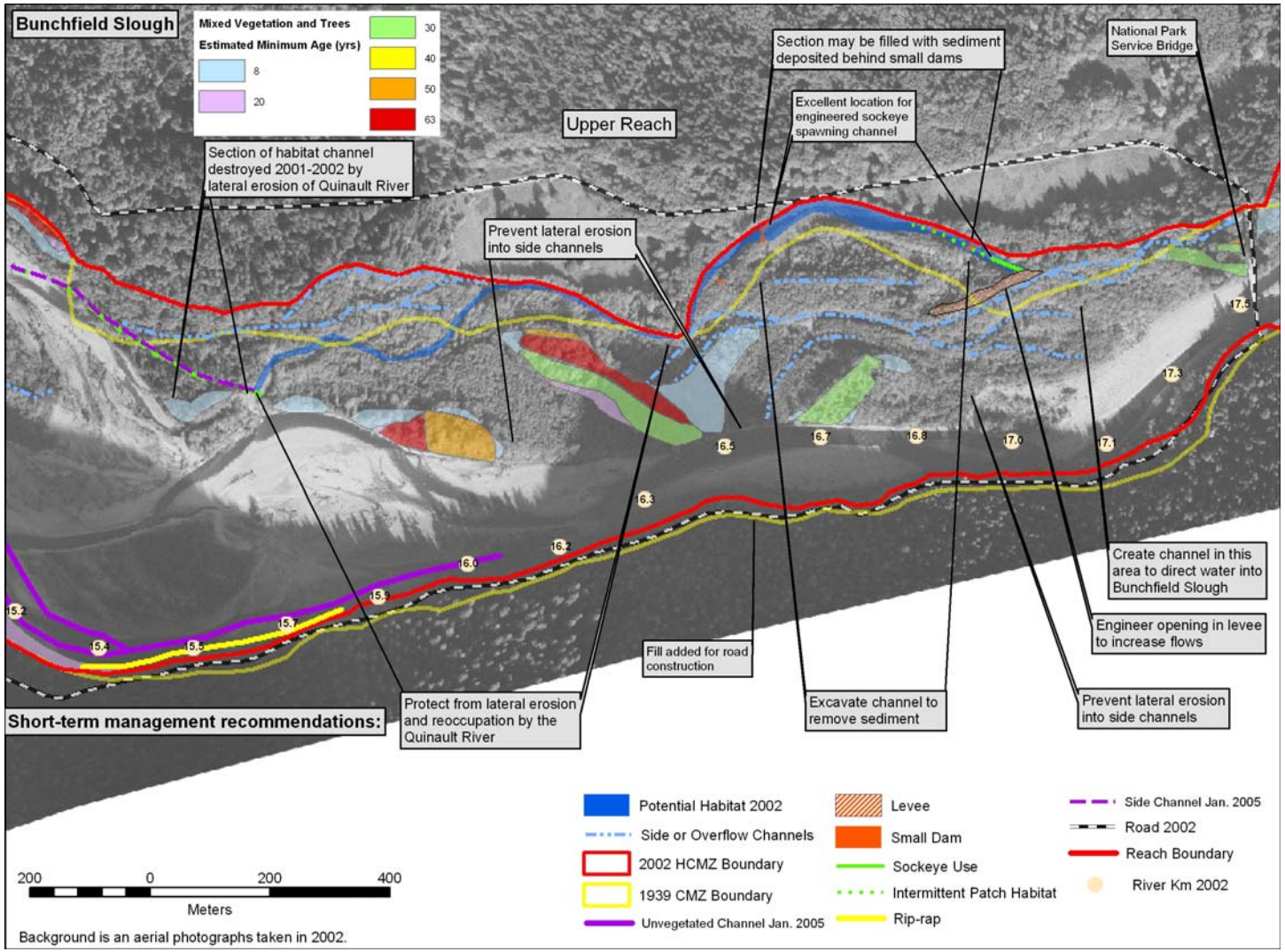

Figure 45. Potential short-term restoration strategies and current habitat at Bunch Field Slough. Long-term strategy is to remove the levee and widen the bridge to restore natural migration of the river and develoment of habitat side channels.

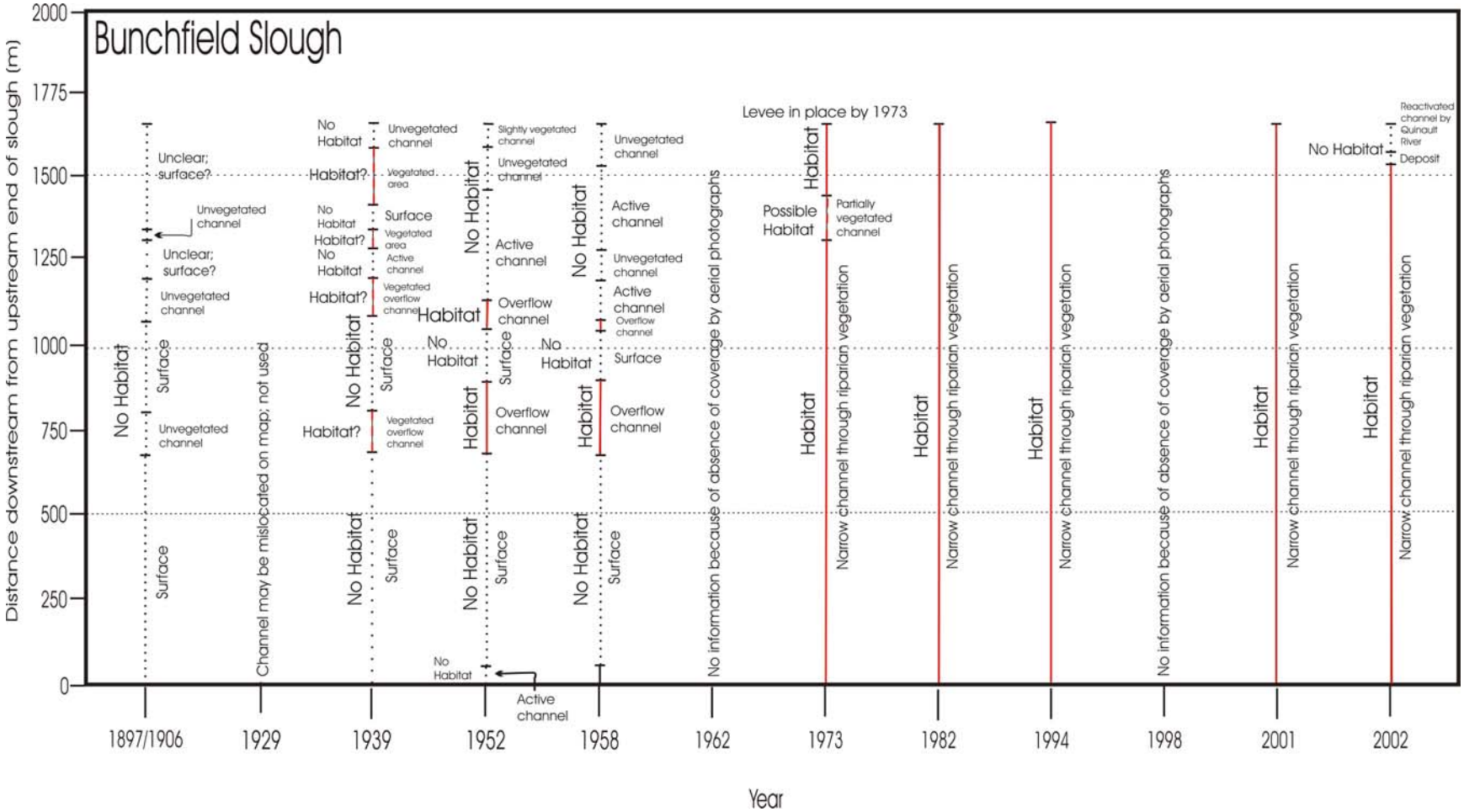

Figure 46. Historical habitat evaluation at Bunch Field Slough.

Figure 47. Looking downstream at bridge just upstream of Bunchfield Slough area, 2002.

8.3.2 Fletcher Slough

Fletcher Slough is located on the south side of the HCMZ between RKs 13.8 to 14.4 (Figures 48 and 49; Jefferson County, Washington: Township 24 North, Range 8 West, Sections 28 and 29). The north boundary of the HCMZ is protected by bedrock, which forms a constriction at the lower end of Fletcher Slough with the upper surface (Holocene) on the south side of the river. Water is supplied to this channel via groundwater, surface water, and from the Fletcher Creek tributary channel. During a 2002 site visit, a debris flow deposit was observed at the mouth of Fletcher Creek where it enters the upper Fletcher Slough area.

Fletcher Slough was not considered viable habitat for spawning sockeye prior to the late-1990s (B. Armstrong, QIN, written commun., 2005). Fletcher Slough is fed by hyporheic groundwater presumed to originate from the Quinault River and Fletcher Creek. Surface flows entered the slough mainly from Fletcher Creek and occasionally the Quinault River during flood events since 2003. An early-successional forest of red alder and conifer is developing on the islands between the Quinault River and the slough since 2002.

Fletcher Slough has been consistently in or near the active and unvegetated channels of the Quinault River after 1952. In 1906 and 1929, the present location of Fletcher Slough is thought to have been a terrace outside of the HCMZ. By 1939, the terrace had begun to be eroded by the Quinault River and the downstream half of Fletcher Slough was within the active channel of the Quinault River. The upstream half was still outside of the HCMZ in 1939. Between 1962 and 1982, the downstream about 150 m of Fletcher Slough crossed a slightly vegetated channel of the Quinault River and appeared to be potential habitat that improved as the riparian vegetation became thicker and larger during this 20-year period. However, by 1994, this downstream section was once again

part of the active channel and the vegetated area had been eroded. It wasn't until 2002 that the active and unvegetated channel moved away from the Fletcher Slough area leaving a relatively wide side channel in the upstream about 500 m of Fletcher Slough. The downstream about 100 m was still in the active channel in 2002 and did not appear to provide potential stable habitat. By 2005, the main Quinault River channel had moved farther to the north, leaving all of Fletcher Slough as a side or overflow channel.

Most of the vegetation within the HCMZ along the length of Fletcher Creek Slough is immature and ranges in age from about 5 to 10 years or more. Much of the south terrace was cleared of vegetation and homesteaded prior to 1939 and has eroded many times between 1939 and 2002. The South Shore Road is set back a fair distance away from the boundary of the HCMZ. However, the road does cross several terrace channels, which also provide habitat. Erosion of the south bank from RK 15.1 to 15.4 between 2002 and 2005 has caused large, mature conifers to fall into the river and deposited downstream forming a series of log jams from RK 14.6 to 15.1. The log jams have redirected the river to the north against a bedrock knob at RK 14.4. A remnant log jam is also present downriver in the vegetated islands between RK 14.2 and 14.6.

The Quinault River's flow is currently directed away from the head of the slough, but is directed at the lower section of the slough. The main channel of the Quinault River has flowed through the Fletcher Creek Slough numerous times and this pattern is most likely to continue, particularly because the bedrock knob on the opposite side forms a constriction with the terrace on the south side, limiting the places the river can flow. An interconnected network of terrace channels is incised into the upper surface south of Fletcher Slough and outside of the HCMZ. This channel complex is further described in Section 8.3.5.

The recently formed Fletcher Slough could be protected using the short-term strategy of implementing ELJs at vulnerable spots to limit the rate at which the river migrates to the south side of the HCMZ in the near future (see Figure 48). Fletcher Slough and associated terrace surfaces from RK 15.2 to 13.2 could be protected by enhancing and stabilizing the log jams that have recently formed in the reach. The north side of the HCMZ is protected by bedrock, so implementing protection on the south side to mitigate for past erosion and rapid river migration rates should not put the North Shore Road at risk. The downstream portion of Fletcher Slough near the constriction at RK 14 will always be at high risk for river occupation and is not recommended for a protection strategy. Presently the river is incised along the south bedrock and road upstream of Fletcher Slough and is directed to the north around RK 15. If the upstream Bunch Field Slough Levee was removed or breached and the NPS Bridge widened to restore a meandering channel, the river would likely approach the Fletcher Slough area from a variety of directions, similar to how the river behaved in the early part of the Twentieth Century. This would put the Fletcher Slough at a higher risk for being eroded in the short-term, but over the long-term if migration processes could be restored there should be more opportunity to sustain side channels in this section.

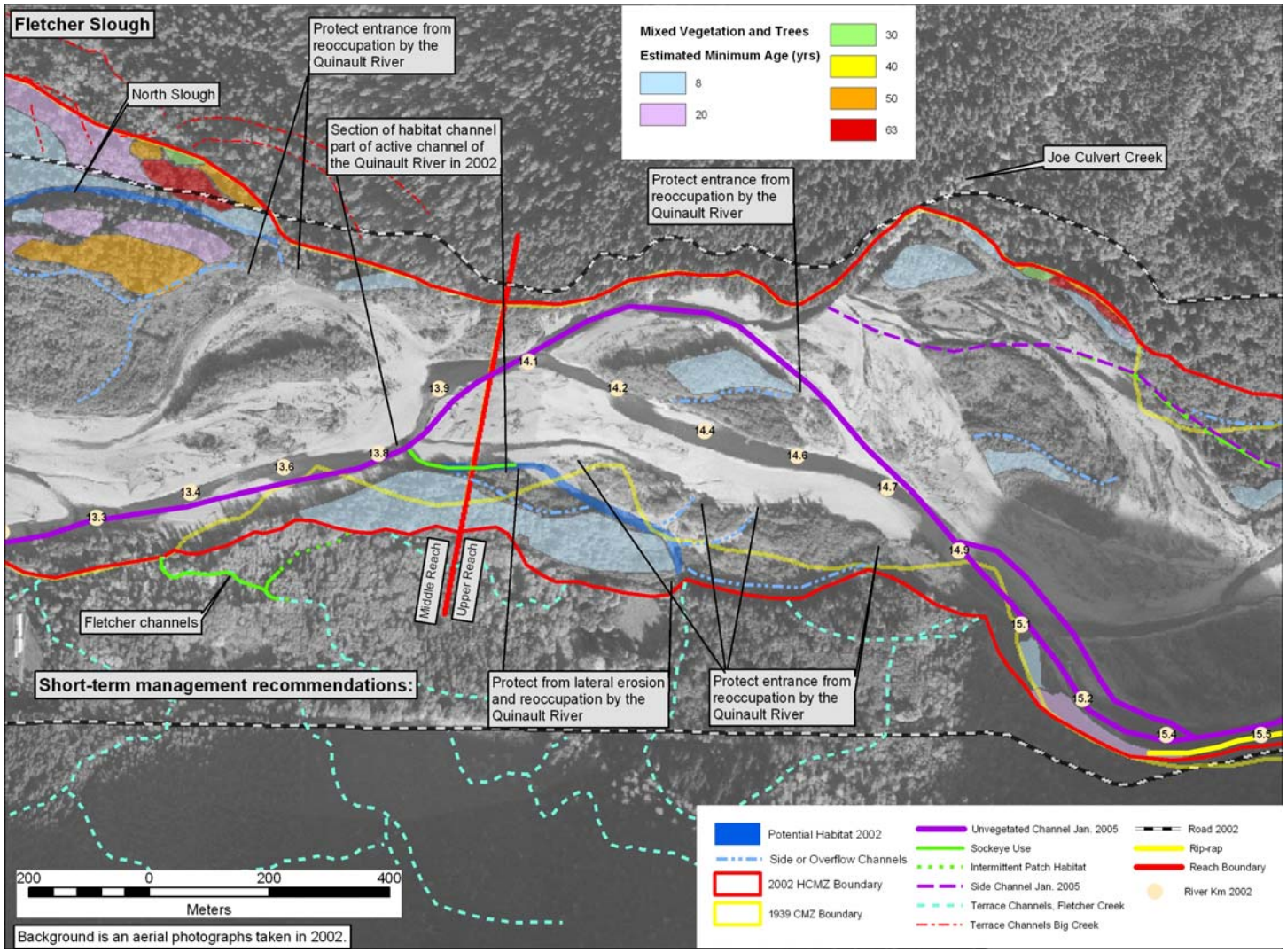

Figure 48. Potential restoration strategies and current habitat at Fletcher Slough.

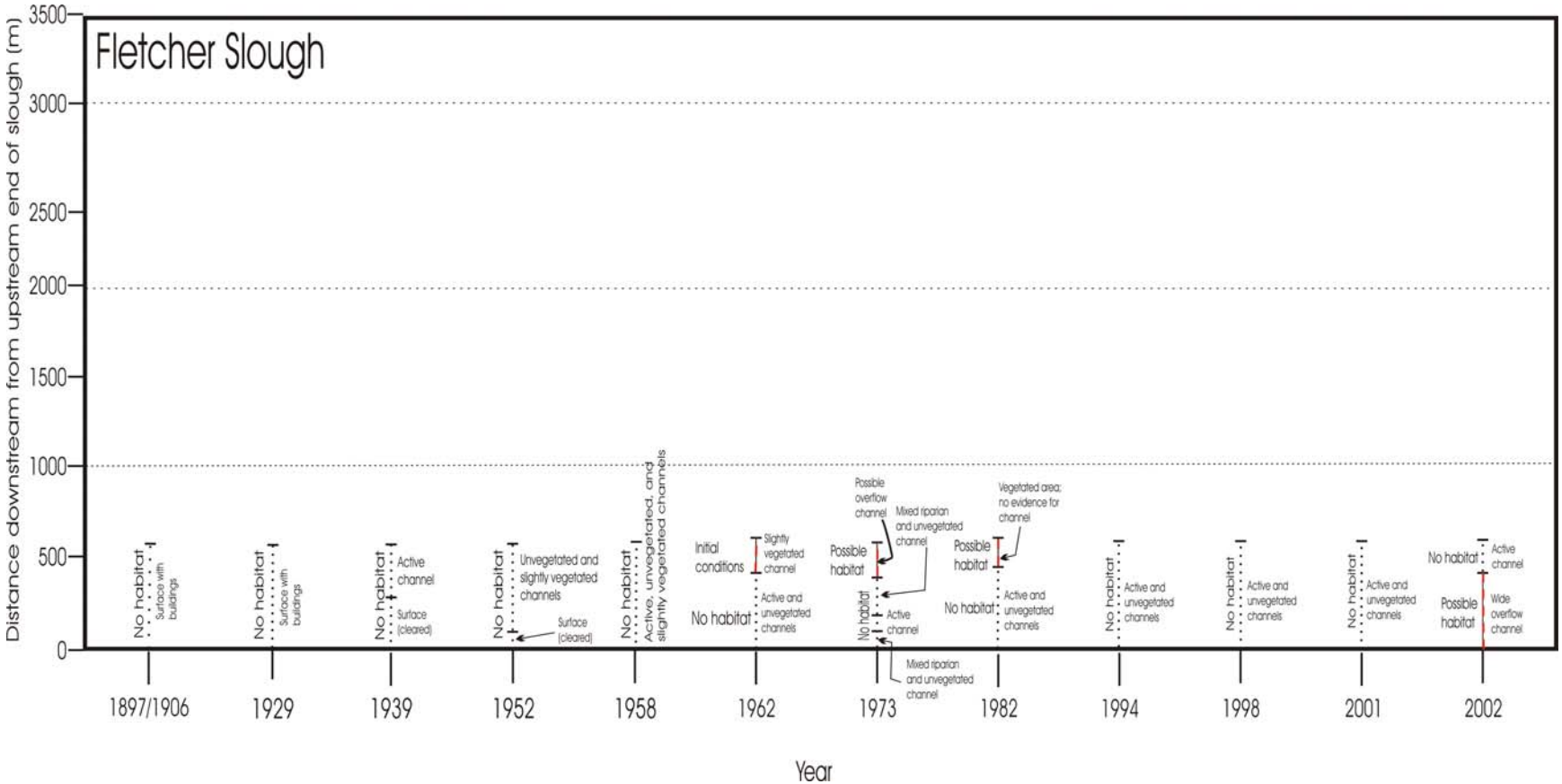

Figure 49. Historical habitat evaluation at Fletcher Slough.

8.3.3 Joe Culvert Creek

Joe Culvert Creek is a tributary channel to the Quinault River located at RK 14.5 (see Figure 48; Jefferson County, Washington: Township 24 North, Range 8 West, Sections 27 and 28). Joe Culvert Creek habitat area consists of two parts: a downstream part that is about 200 m long within the HCMZ and an upstream part about 200 m long outside of the HCMZ. The upstream part is a tributary, which drains from a bedrock ridge west of the North Fork. Because the HCMZ boundary in this area has not eroded between 1939 and 2002, the boundary between the downstream and upstream parts of Lower Joe Culvert Creek has not changed during that time.

The downstream part of Lower Joe Culvert Creek was part of the unvegetated channel in 1939 (perhaps in 1929 also). The upstream half was a partially vegetated channel by 1952, but was once again within the unvegetated channel of the Quinault River by 1958. By 1962, the channel had become partially vegetated. The surface surrounding this part of Lower Joe Culvert Creek became increasing more vegetated between 1973 and 1982. In these years the creek appeared as a narrow channel through vegetation. It appeared to be part of a much longer (700 to 800 m) narrow channel that continued downstream to join the Quinault River near RK 14. This downstream extension was reoccupied by the unvegetated or active channel of the Quinault River by 1994 and remained that way through 2002. During these years, the downstream part of Lower Joe Culvert Creek was a secondary or side channel that was connected to the Quinault River at its upstream and downstream ends, at least during higher flows.

Most of the vegetation on the north bank of the lower section of the creek presently ranges in age from 40 to 65+ years. The north terrace vegetation was thinned in places by 1939, but does not appear to have been logged since that time. A large bedrock outcrop forces the river to the south just downstream of Joe Culvert Creek. This causes the channel to run up against the bedrock and helps limit the likelihood the river will occupy this area for a long period of time. Although it may not occupy the area for long periods of time, there is still a moderate risk for channel reoccupation, particularly downstream of the confluence of Joe Culvert Creek with the active channel. This area has repeatedly been reworked and is though to have been channel area even on early 1906 and 1929 maps.

Mature conifers are relatively abundant along the creek outside the HCMZ but are being encroached upon by deciduous species. Recruitment of woody debris appears to be sufficient along the upper section of the channel outside the HCMZ, and is augmented by beaver activity. Predominant sediment sizes within the creek bed range from fine sand to cobbles suitable for coho and sockeye spawning. The upper section of Joe Culvert Creek is outside the HCMZ and has not been affected by channel processes, but has been negatively impacted due to other anthropogenic modifications.

An old, abandoned dirt road leading to a gravel quarry crosses Joe Culvert Creek about 600 m upstream of the North Shore Road. Road fill and culvert related sediment, hydraulic, and fish passage issues at the crossing are undocumented but probably existed

prior to the 1980s. The blocked culvert and beaver dam have caused channel flows to spill over onto the road instead of being conveyed into the downstream natural channel. Erosion along the roadbed has also occurred and was noted to start during the winter of 2000-01 and accelerated during the winter of 2001-02. Consequently, the loss of streamflow to the original channel downstream of the culvert resulted in changes to the sediment and hydraulic characteristics in the reach, causing a loss of sockeye (spawning) and coho (spawning and rearing) habitat (B. Armstrong, QIN, 2004, oral commun.). Spawning sediments in much of the 225 m reach below the blocked culvert is covered with silt and decomposing organic material.

By 2004, surface flow from the beaver pond goes over the road and forested surface and has incised two channel paths through the roadbed that re-enter the original channel approximately 175 and 225 m below the blocked culvert and pond. Beginning in 2003, shallow channels cut into the surface of the roadbed were passable by adult coho only during high flows. The channels provided limited access for adult coho to the beaver pond and the tributary channel upstream.

The road and blocked culvert has disrupted fish passage and reduced spawning habitat in the upper section of Joe Culvert Creek. The road is no longer in service and the road prism could be breeched to restore habitat in the original channel. Engineered log jams could be used to add stability to vegetated surfaces within the HCMZ near Joe Culvert Creek that will help these areas mature in age and resist erosion by the river.

8.3.4 North Slough

North Slough is a side channel with several overflow channels present on the surface between the main channel and North Slough. It is located between RK 11.5 to 13.6 (Figures 50 and 51; Jefferson County, Washington: Township 24 North, Range 8 West, Sections 29 and 30). The south bank is believed to have been protected between 1939 and 1962 to limit erosion along homesteads and pastures that were present. The south bank has experienced significant erosion since 1952. This erosion was detrimental to property and habitat on the south side, but because the river has remained on the south side it has allowed North Slough to persist and vegetation along the habitat channel to mature in age.

North Slough is an important habitat reach within the HCMZ. The slough is comprised of a complex network of channels that have supported spawning sockeye over the past 10 years. The area has been identified by Quinault Department of Fisheries as a “high priority” reach for spawning habitat protection, enhancement, and restoration (B. Armstrong, QIN, personal commun. 2004). Like other spawning habitat reaches, beaver activity in North Slough has provided benefit to spawning habitat and channel complexity in recent years.

North Slough has been subdivided into three sections for discussion, primarily on the basis of the history of formation of different parts of the slough. The upper section is about 630 m long beginning at the upstream end of the slough. The middle section extends between 630 m and about 1330 m downstream. The lower section extends from

1330 m to about 2000 m, which is at the downstream extent of the habitat channel as delineated by B. Armstrong (QIN, written commun., 2003).

The entire North Slough appears to have been part of the unvegetated channel of the Quinault River in 1906 and 1929. Remnants of the Quinault River channel developed into North Slough. By 1939, the upper section was a narrow channel that flows through riparian vegetation and appears to have been potential habitat. The middle section was part of either the active or unvegetated channel of the Quinault River until 1973, by which time the Quinault River had abandoned this north channel path and vegetation had begun to be established. Part of this channel was reactivated some time before 1982, and any potential habitat in the downstream half of the middle section was destroyed. Habitat began to reform by 1998, and appears to be progressively more stable through 2002. The lower section has been recurrently part of the active and unvegetated channels of the Quinault River. Short (200 to 300 m) portions of the lower section had some vegetation in some years and may have provided some habitat. However, all of these portions have been reworked by the Quinault River, so that the lower section appears to have lacked stable habitat during the last about 100 years.

The upper section of North Slough is in an area that has mature vegetation that probably became established shortly after 1929. The mid-section of the slough is in an area that has immature vegetation that became established between 1962 and 1973. The lower section of the slough is mostly unvegetated. The north terrace vegetation had been thinned in places by 1939. A narrow buffer zone of mature trees was left in-place and has persisted where the terrace has not eroded.

Most of the North Slough is at or near the Quinault River channel bed elevation suggesting there is a potential for channel reoccupation. The bedrock outcrop about 1 km upstream of North Slough directs the Quinault River flows to the south which protects the upstream most portion of North Slough from being reworked by the river.

The middle and upper sections of North Slough could be protected from being reoccupied by the Quinault River by restricting the flow at the channel heads using ELJs (see Figure 50). Vulnerable locations were identified based on present channel paths into the North Slough area where the Quinault River could most easily reoccupy (RK 13.6, RK 13.0, and RK 12.5). The lower section could not be easily protected in the short-term, but would benefit from the long-term strategy of getting more stable hard points established in this area. On the south side of the HCMZ there is a complex network of terrace channels that will be discussed further in Section 8.3.5.

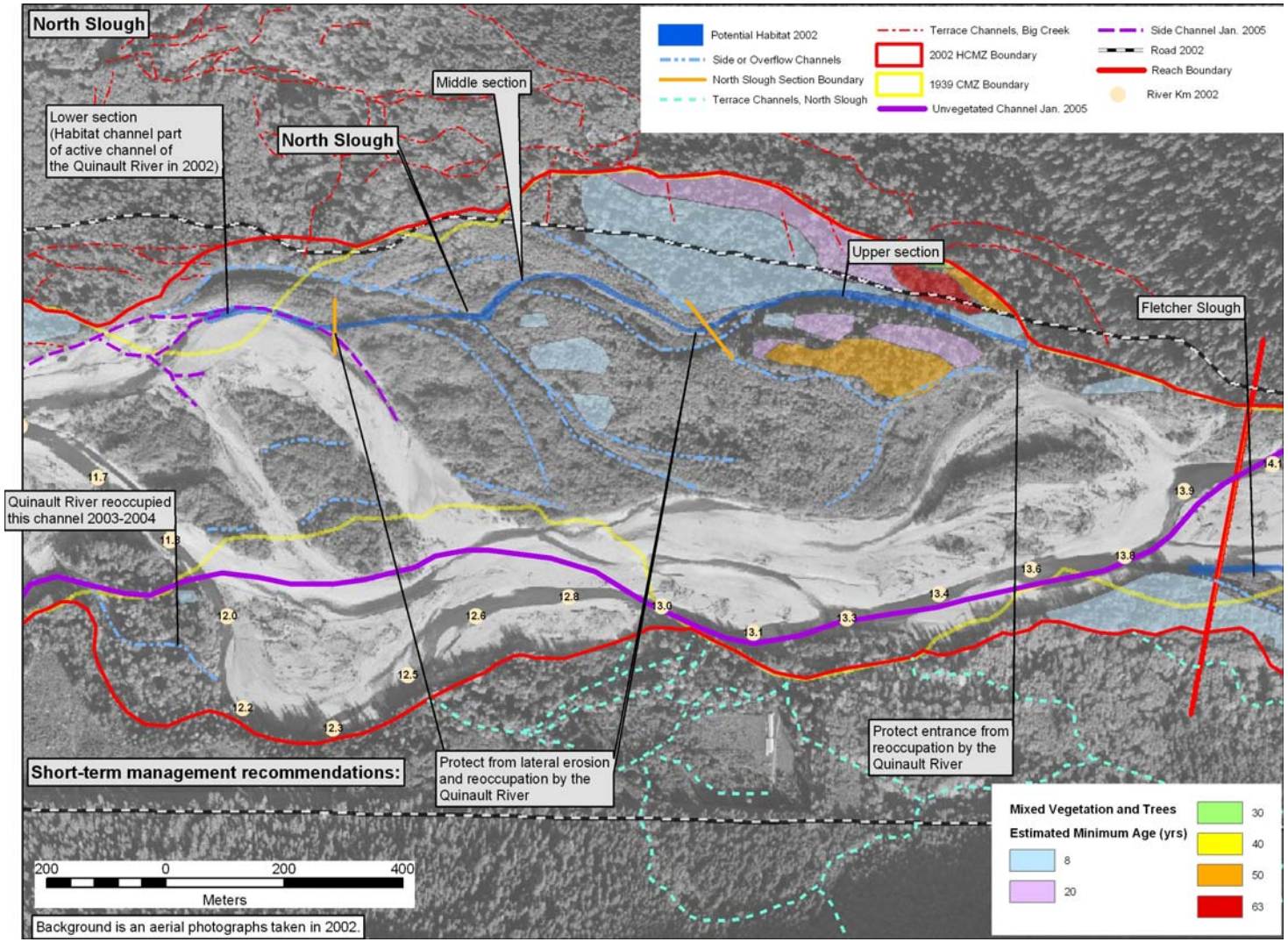

Figure 50. Potential restoration strategies and current habitat at North Slough.

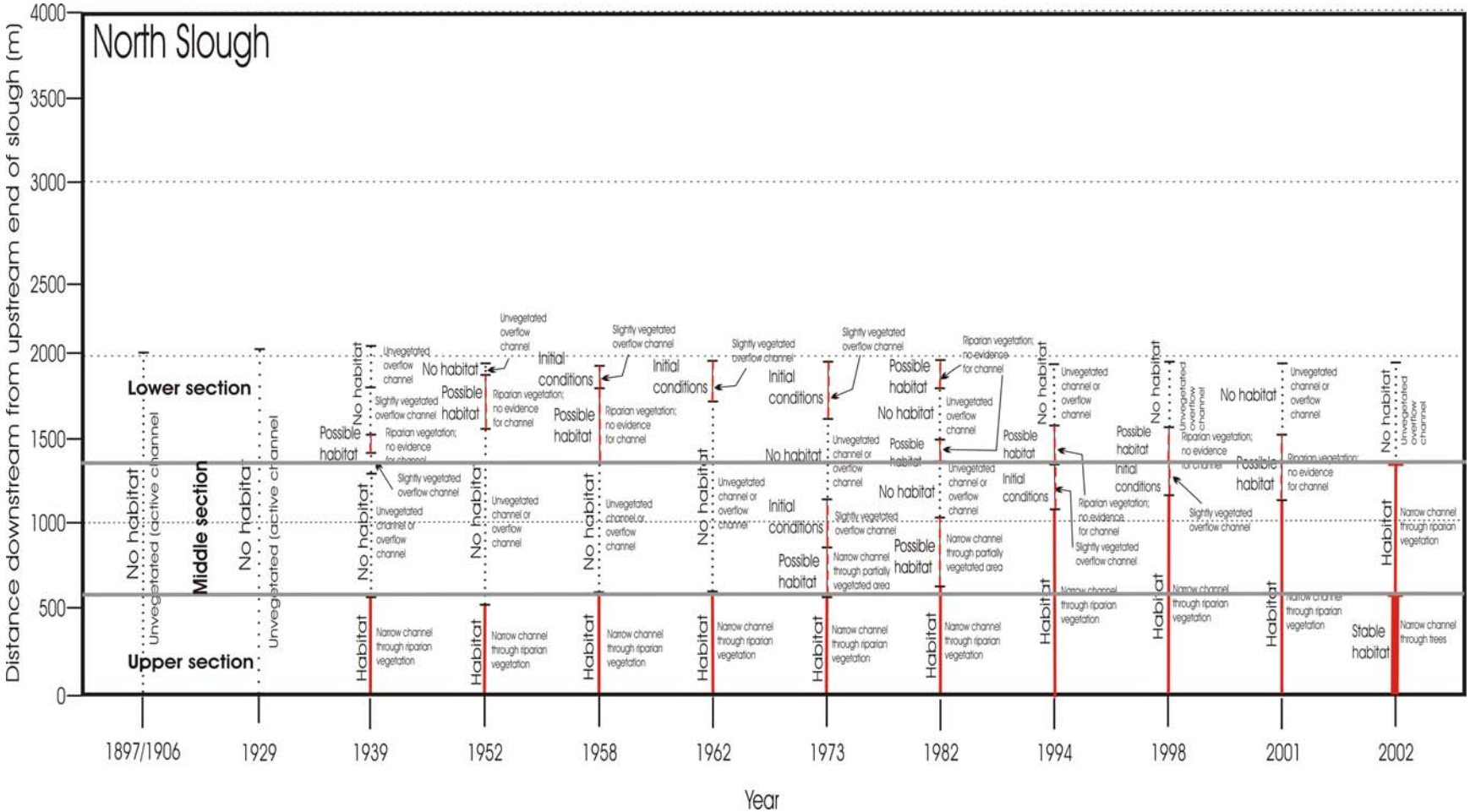

Figure 51. Historical habitat evaluation at North Slough.

8.3.5 Terrace Channels on the Upper Surface South of the Quinault River between North and Fletcher Sloughs

Terrace channels are present on the upper surface south of the Quinault River from upstream of Fletcher Slough (near RK 15.4) to downstream of North Slough (near RK 10.5) (see Figures 41 and 42). The terrace channels form a complex network which is connected to the Quinault River at both upstream and downstream ends. However, not all of the channels are connected directly to the Quinault River. In many places the terrace channels are deeply dissected within the terrace surface (up to about 5 m) so that the bed of the terrace channels is near the same as the elevation of the present main Quinault River channel (Figure 52). Alternating gravelly alluvium (channel deposits) and fine-grained silt and sand beds (floodplain deposits) are exposed in the banks of the terrace channels. Wood is common in the terrace channels. Root wads have created scour pools in the channel beds. Large single logs or jams form hydraulic controls. At times of low flow in the Quinault River, water is still present in the scour pools. Flow in the terrace channels is fed from both the surface connections to the river and groundwater. The upper surface adjacent to the terrace channels has vegetation of various ages, including areas of mature forest. Field observations made periodically over the past 20 years indicate that the upper surface terrace channels between RK 12 and 15 have provided important, sustainable sockeye spawning habitat (B. Armstrong, QIN, 2004, oral commun.). Some of the terrace channels have been altered by undocumented human activities that are thought to have occurred to maintain access across property and control flooding. For example, a bridge with a culvert is present across a terrace channel near Fletcher Creek.

The terrace channel complex has been identified by Quinault Department of Fisheries as a “high priority” reach for spawning habitat protection, enhancement, and restoration (B. Armstrong, QIN, personal commun. 2004). Flow in the terrace channels is fed from numerous sources including surface connections with the Quinault River, Fletcher Creek, several unnamed tributaries, and hyporheic groundwater. The upper surfaces adjacent to the terrace channels have vegetation of various ages, including areas of mature forest. The terrace channels provide important, sustainable sockeye habitat, especially in channel reaches closest to the Quinault River (B. Armstrong, QIN, 2004 oral communication). Some of the terrace channels have been altered by undocumented human activities (bridges and culverts) that are though to have occurred to maintain access across property and control flooding.

For the terrace channels south of Fletcher Slough, ELJs and other methods could be implemented to help protect the Quinault River from eroding valuable habitat and any further loss of private property on the terrace surface. Where the South Shore Road exits the bedrock reach, about RK 15.4, the south side terrace has been experiencing erosion in recent years. This may be in part because the upstream Bunch Field Levee and NPS Bridge have resulted in the river being trapped on the south side of the HCMZ upstream. This may have lengthened the amount of time the river has occupied the south side and directs the river right into the upper terrace surface between RK 15.4 to 15.1. This could put the terrace channels in the vicinity of this section at risk for erosion. The terrace

channels could be protected by protecting the terrace between RK 15.1 to 15.4 from further erosion and by restoring channel processes in the upstream section.

Figure 52. Bank exposure along one of the terrace channels on the south side of the Quinault River between RK 10.5 and RK 15.4. Note the depth of the incision and the alternating gravelly channel deposits and fine-grained floodplain deposits exposed in the bank.

Across from North Slough, the river has been eroding the south terrace at rapid rates in recent years (see 1939 vs. 2002 HCMZ boundary erosion areas in Figure 38). This means many terrace habitat channels have also likely been lost. Strategies to begin to create hard points and limit the migration of this river could be combined with efforts to restore mature vegetation on the terrace banks in this area. An example of what the channel has the potential to look like is where the Quinault River cut through a terrace bank between RK 12.2 to 11.7 (see Figures 32, 33 and 34). The channel is lined with mature vegetation and has recruited some large woody debris into the channel area forming complexity and habitat conditions favorable to sockeye.

8.3.6 Lower Big Creek Tributary and Terrace Channels

Big Creek, a major tributary of Quinault River system, is located on the north side of the Quinault River valley (Jefferson County, Washington: Township 24 North, Range 9 West, Sections 25 and 36; Township 24 North, Range 8 West, Sections 29 and 30). It enters the Quinault River between RK 7.5 and about RK 10 (Figures 53 and 54). Bedrock limits the west migration of lower Big Creek; the upstream section of Big Creek is incised into Pleistocene and Holocene surfaces (Figure 6). The lower section of Big Creek and terrace channels between Big Creek and the Quinault River provide sockeye habitat (B. Armstrong, QIN, written commun., 2003). A section of Big Creek about 5 km upstream of the Quinault River is dry for much of the year as flow goes into the subsurface.

Big Creek and the terrace channels are arguably the most important sockeye spawning areas in the HCMZ. Big Creek and adjacent terrace channels have supported large

numbers of spawning sockeye since at least the 1930s and probably earlier. The area has been identified by Quinault Department of Fisheries as a "high priority" reach for spawning habitat protection, enhancement, and restoration (B. Armstrong, QIN, personal commun. 2004).

Based on the positions of lower Big Creek and the Quinault River channel since 1906, it appears the lower about 1.5 km of Big Creek recurrently interacts with the main Quinault River within the HCMZ (see Appendix O). In 1906, the confluence with Big Creek and the Quinault River active channel was at the north HCMZ boundary. By 1929, the Quinault River channel had moved to the south, leaving a section of lower Big Creek between the HMCZ boundary and the unvegetated channel of the Quinault River. This section of lower Big Creek had a relatively consistent length between 675 and 845 m between 1929 and 1994, but the maximum length of potential sockeye habitat was highly variable. After 1994, the Quinault River shifted south at RK 11.5, resulting in a marked increase in the lower Big Creek channel within the HCMZ by 1998. This length of channel between RK 9 and 11.5 within the HCMZ has been maintained since 1994. The section of Big Creek within the HCMZ downstream of RK 9.5 has grown in length following a shift of the Quinault River to the south into the upstream part of Alder Side Channel between 2002 to 2003. This migration to the south occurred within the HCMZ where the Quinault River had naturally flowed prior to human disturbances.

A few areas within the north surface have continually had overflow channel connections between Big Creek and the mainstem Quinault that were most evident in 1939, 1958 and 1962 aerial photographs. This washing of the river into Big Creek was also noted to have occurred in a 1936 fish survey report (Davidson and Barnaby, 1936). Timber harvesting that occurred within the HCMZ prior to 1939 removed the majority of old-growth forest of conifers (Sitka spruce and western cedar) and now a hardwood forest predominates. Two small patches of vegetation have persisted since at least 1939 in this area and are at least 63 years old. Homestead sites were present in the area during the early 20th century and some of the banks along the overflow channels were protected with rock.

Numerous other channels exist on the high surface between the main Quinault River and Big Creek. The terrace channels in the Big Creek area are very different than the deep, dissected channels found on the south side between Fletcher and North Slough. The Big Creek terrace channels are fairly shallow at the upstream ends, and gradually become deeper as they coalesce together in the downstream direction. These channels are, therefore, mostly fed by groundwater, and only have a surface flow connection to the mainstem river during high flows when the surface is overtopped. These channels provide valuable sockeye habitat, but at times have limited flow. Timber harvesting on the terrace surface did occur by 1939 which has altered the succession of vegetation on this surface and likely impacted the quality of sockeye habitat. There has been limited erosion of the HCMZ boundary on the north side so not many of these terrace channels have been lost since 1939, except for at RK 11.7 to 12.3.

Erosion of the road embankment endangered the North Shore Road where it runs along bedrock between RK 8.3 to 8.9 which required bank protection (riprap) (observed in

2004). North Shore road crosses Big Creek via a bridge at one location. The road acts like a levee in several other places where it runs across the surface within the HCMZ between Big Creek and the Quinault River, and on the terrace surface outside of the HCMZ. There are several culverts which connect overflow channels which in places appear to be undersized.

Big Creek is presently lower in elevation than the adjacent mainstem river. A channel shift is very possible between RK 11 and 9, particularly via the overflow channels that remain persistent from when the main channel was directed into the upstream portion of this Big Creek area in the past. The section of Big Creek downstream of RK 9 is very vulnerable to being overtaken by the main channel. The river was on this side of the HCMZ in 2002, but in 2003 shifted back to the south side wiping out portions of Alder Side Channel.

Protection strategies in this sockeye habitat reach would require either Big Creek or Alder Side Channel to function as a side channel while the other must allow occupation of the main channel. The long-term strategy would be to slow the rate at which the main channel reoccupies each of these side channels, so they can function as viable sockeye habitat for longer periods of time.

Older coniferous trees on the intermediate surface that separates Big Creek from the Quinault River between RK 9 to 11 could be protected as part of the long-term objective to restore a late-successional stage forest to reference conditions. The 1939, 1958 and 1962 unvegetated channels could be protected from being reoccupied by the Quinault River by restricting the flow at the channel heads using ELJs. Clear-cutting was employed in the Big Creek area in the early twentieth century. Deciduous trees are now established and form a closed canopy which is deleterious to the growth of conifers. The spatial and temporal connectivity of the terrace channels located between Big Creek and Quinault River could be increased. The North Shore Road bisects the floodplains of the Quinault River and Big Creek. In order to improve the connectivity of the terrace channels it may be necessary to install and maintain culverts of suitable size and configuration to link the two floodplains. Another potential strategy to enhance sockeye habitat in the terrace channels is to excavate a portion of the upstream, shallow channel to increase groundwater flow and the time sockeye habitat is sustained. Care should be taken to avoid digging to close to the main channel in order to not increase the potential for these areas to be eroded by the river.

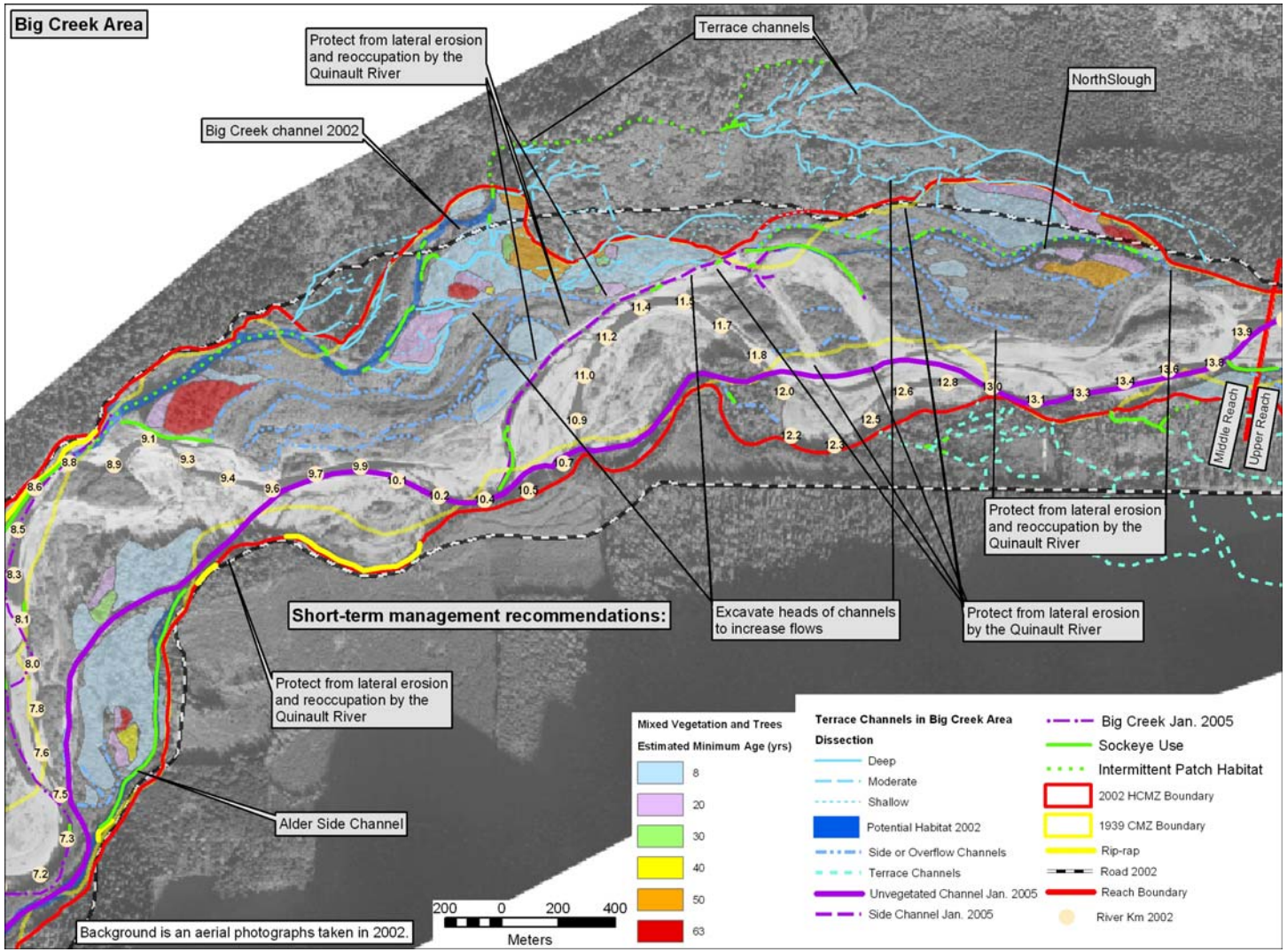

Figure 53. Potential restoration strategies and current sockeye habitat at Big Creek.

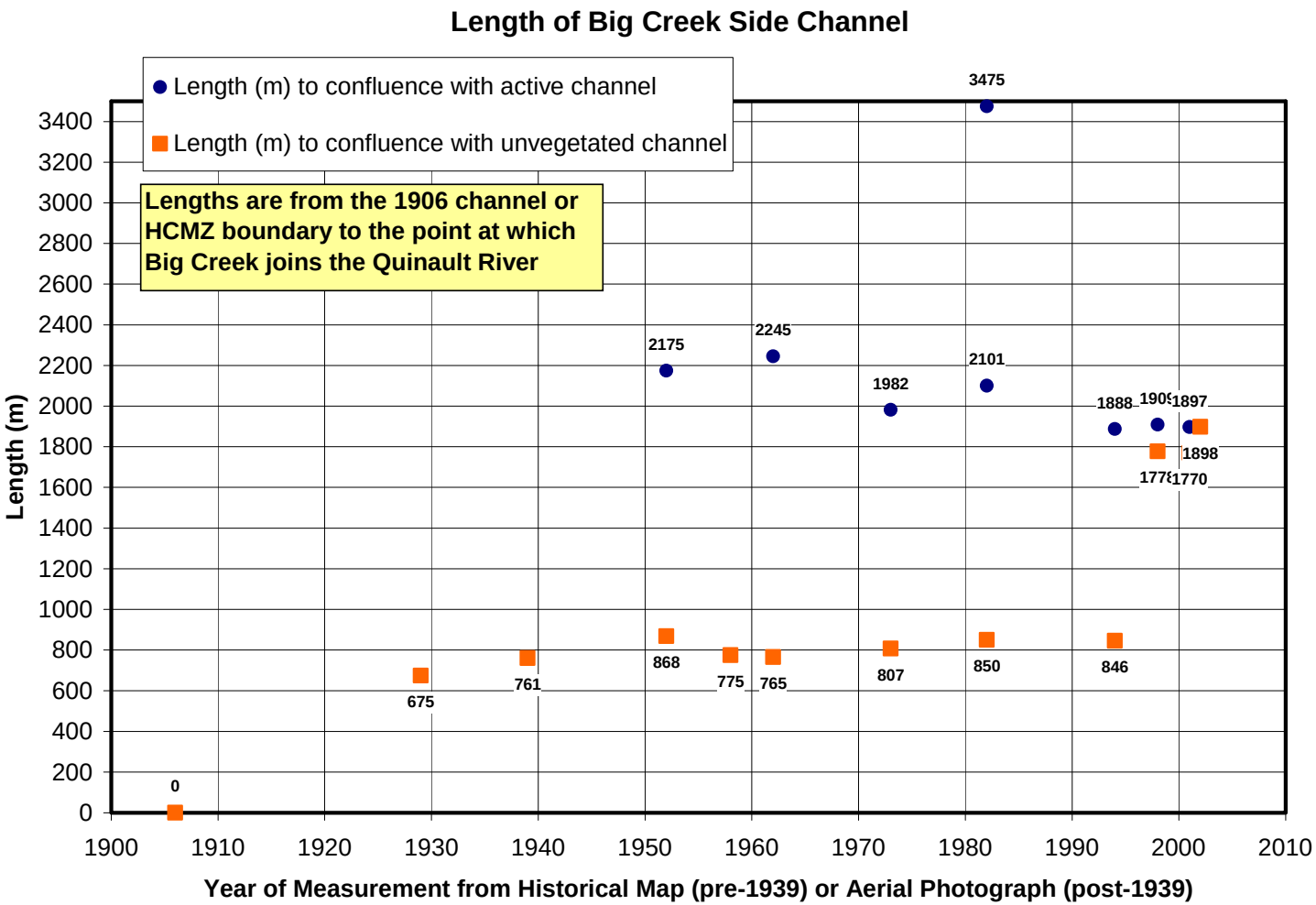

Figure 54. Distance of potential sockeye habitat in Big Creek where it flows through HCMZ. Upstream of the HCMZ boundary, Big Creek is considered to have always had the potential to provide habitat since it has not been at risk for being washed out by the Quinault River.

8.3.7 Alder Side Channel

Alder Side Channel is located between RK 5.7 to 9 (Figures 55 and 56; Jefferson County, Washington: Township 24 North, Range 9 West, Sections 35 and 36). It is an overflow channel of the Quinault River. A terrace channel, Inner Creek Slough, flows through the south side Holocene terrace between Alder Side Channel and Straughn Slough. Another unnamed terrace channel flows through the north Holocene terrace between RK 6 and 8.1 (Figure 57). Both terrace channels have been relatively unaffected by river processes since at least 1939.

The upstream portion of Alder Side Channel has existed since at least 1939. This section was about 300 m long in 1939 and has progressively lengthened over time to about 1000 m in 1962 and 1973 and to about 2000 m since 1982. A downstream section about 650 m long appeared to be potential sockeye habitat in 1952 and 1958. However, this section was reoccupied by the river by 1962 and became part of Alder Side Channel again only after the upstream section lengthened to include this downstream section. The downstream section of Alder Side Channel and Straughn Slough (about 2000 m long) has been part of the active or unvegetated channel of the Quinault River since 1939. By 2002, a sediment deposit near the downstream end of Alder Side Channel (near RK 5.6) blocked an overflow channel. In 2002, only the downstream about 900 m of this otherwise dry overflow channel had water. The wetted section was Straughn Slough and probably received water from Inner Creek, a tributary, or groundwater. During the winter of 2002 to 2003, the active channel of the Quinault River flowed into Alder Side Channel at RK 9.4. This eliminated the side channel sockeye habitat between RK 9.4 downstream to RK except for a small side channel shown with a green line in Figure 55.

The lower section of Alder Side Channel was logged and homesteaded prior to 1939. After the Quinault River eroded the river bank in the lower section, bank protection was placed along the road in 1961. In 1998 the terrace land adjacent to Alder Creek Slough head was logged and a small buffer zone left. The Quinault River eroded through the buffer zone and washed out the road. Bank protection was constructed along the roadway between RK 9.5 to 10 which appears to at times direct the river to the north. Coincidently, bank protection has also been placed along North Shore Road on the opposite side. This bank protection may have a small influence on channel position when it runs along this bank, but the road on the north side is very close to the bedrock valley wall.

The upper section of Alder Side Channel has already been captured by the main channel. The middle section of Alder Side Channel at RK 7.3 is located on the outside of a meander bend and has repeatedly been washed out by the main river, disconnecting the upper and lower sections of Alder Side Channel. The main channel of the Quinault River has also flowed through the lower section of Alder Side Channel numerous times. This pattern of channel reoccupation is most likely to continue in the future making the side channel at high risk for being reworked by the river.

Restoration strategies in this habitat reach would require either Big Creek or Alder Side Channel to function as a side channel while the other must allow occupation of the main channel. Given that the main flow is now passing down Alder Side Channel, a short-term restoration strategy is to place large woody debris along the upper portion of the channel between RK 9 and 7.3. Placement of large woody debris would reduce velocities and increase complexity. The long-term strategy is to reduce the rate at which the channel shifts back and forth between Alder Side Channel and the opposite side of the floodplain where the Big Creek tributary channel enters. This would be accomplished by increasing the amount of mature forest and large woody debris along these channels and within the floodplain adjacent to these channels. This strategy would also provided needed buffer zones of mature vegetation along the south side of Alder Side Channel.

Between RK 7.2 to the upstream entrance to Alder Side Channel, the South Shore Road runs very close to the channel. This is also an area where the main channel repeatedly wipes out the side channel between the upper and lower portions of Alder Side Channel. Along with a strategy to recreate hard points in the HCMZ, this area would also benefit from a road setback or strategy to create a buffer zone between the channel and the road. Downstream of this point, the road is setback away from Alder Side Channel, but becomes close to Inner Creek Slough in the upstream half.

The impacts to Inner Creek Slough are less documented, but there has been significant clearing of terrace vegetation that could be restored. It is not known if the channel itself has been altered through excavation activities or plugging of channel entrances, but this could be further investigated to evaluate its potential for habitat. The unnamed terrace channel on the north side appears to be functioning from a process standpoint. Any strategies to limit the rate of channel migration would reduce the risk of erosion of the terrace channel.

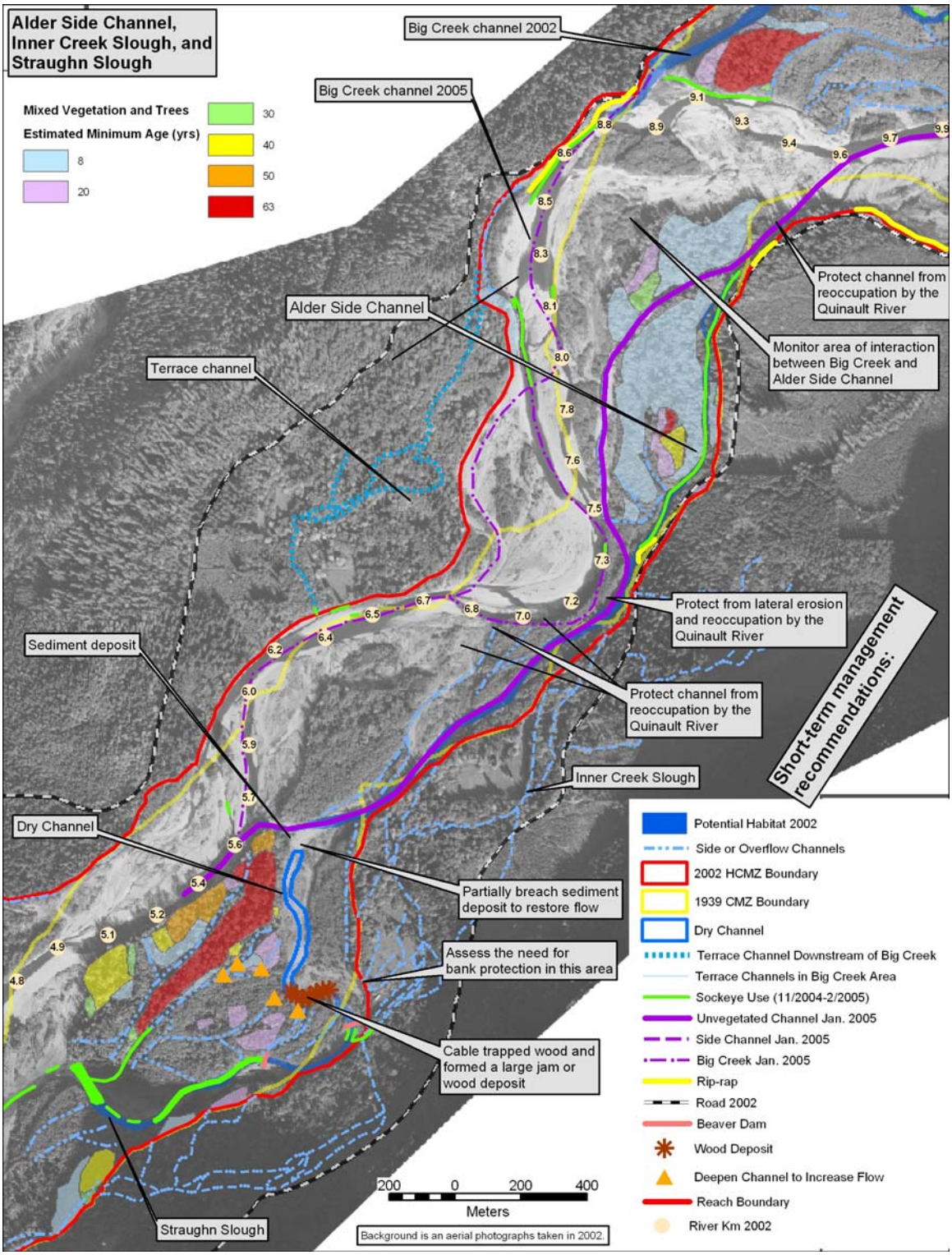

Figure 55. Potential restoration strategies and current habitat at Alder Side Channel and Straughn Slough.

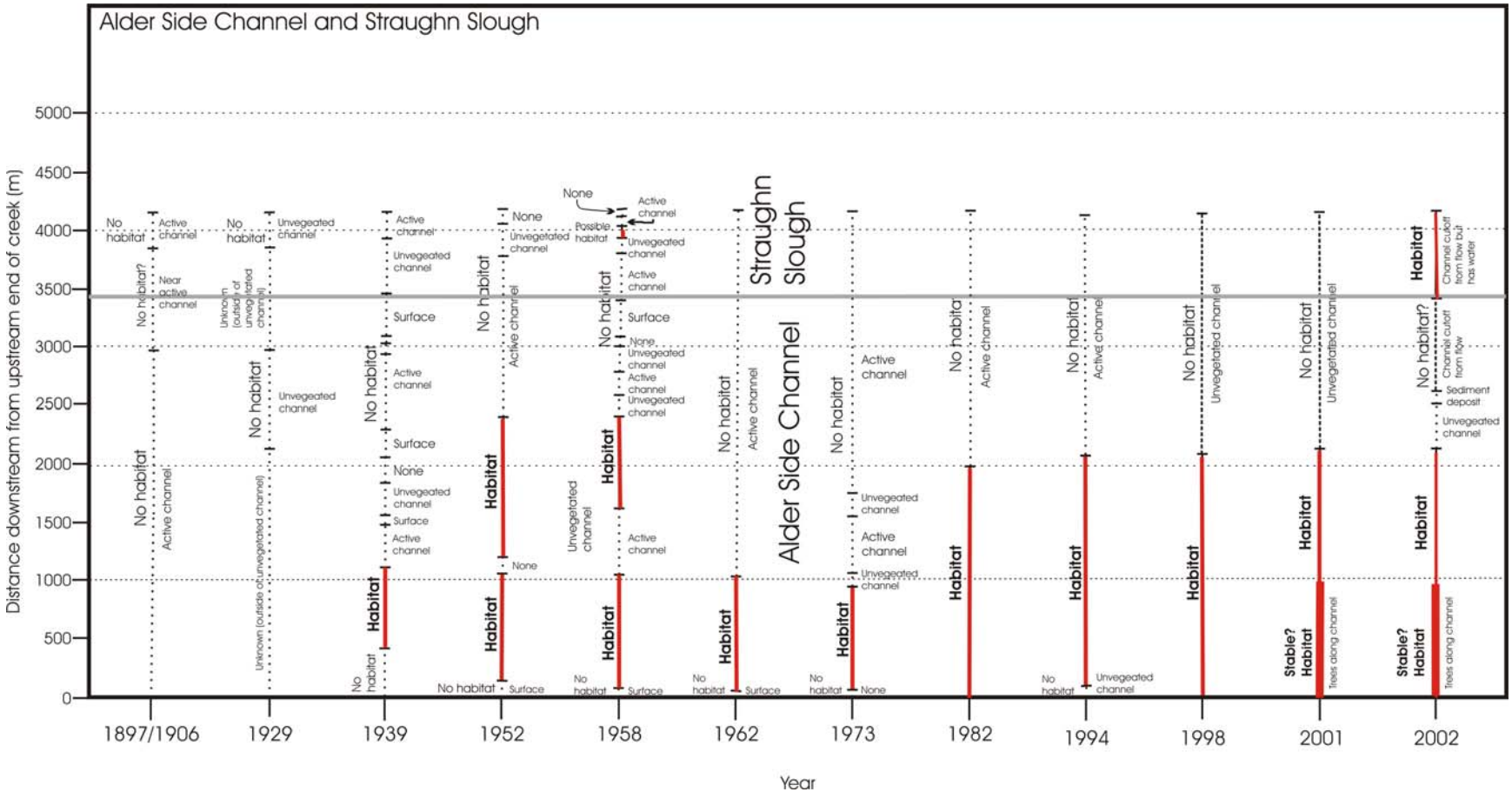

Figure 56. Historical habitat evaluation at Alder Side Channel and Straughn Slough.

Figure 57. Looking downstream into unnamed terrace channel that flows through Upper Holocene surface on north side of HCMZ across from Alder Side Channel.

8.3.8 Straughn Slough

Straughn Slough is a remnant channel of the Quinault River that was active from 1939 to 1982. The channel extends from RK 4.1 to 5.6 (Figures 55 and 56; Grays Harbor County, Washington: Township 23 North, Range 9 West, Sections 2 and 3). The active Quinault River abandoned the channel about 20 years ago.

Straughn Slough is presently one of the most important sockeye spawning areas in the HCMZ. The Slough, terrace channel, and island channels have supported large numbers of spawning sockeye over the past 10 years. The area has been identified by Quinault Department of Fisheries as a "high priority" reach for spawning habitat protection and restoration (B. Armstrong, QIN, personal commun. 2004). Like other productive spawning habitat reaches, beaver activity in Straughn Slough has improved the quality of spawning habitat and channel complexity in recent years.

In the earliest photographs, the Quinault River flowed through a channel south of a forested island that has been present since 1939. By 1962 the flow had split around the island. A side channel developed north of the island prior to 1939. In the 1939 to 1982 aerial photographs the channel on the north side of the island progressively widened as the channel on the south side progressively narrowed and became what is now called Straughn Slough. Several shallow terrace channels exit the middle reach of the Straughn Slough between RK 5.2 and 5.4 and connect with Inner Creek Slough. Historically, these

channels would have probably provided a surface water connection from the Quinault River to lower Inner Creek Slough.

Presently the Quinault River flows north of the island and the entrance to Straughn Slough near RK 5.6 has plugged with sediment. The reach from RK 4.1 to 4.6 flows through open, sparsely vegetated floodplain and is somewhat protected from the active Quinault River by a series of natural log jams and sediment deposits with early-successional vegetation between RK 4.3 and 4.8. The upper reach of the channel from RK 4.7 to 5.7 is protected from the Quinault River by one of the few remaining forested islands in the HCMZ. The island is forested with a mix of mature conifer and deciduous vegetation that has persisted for at least 63 years. An early-successional forest of red alder and conifer is developing along the channel of the slough and on the sediment deposit. Straughn Slough receives surface flow from a terrace channel connection with Inner Creek Slough and hyporheic groundwater presumed to originate from the Quinault River.

Reoccupation of Straughn Slough by the Quinault River at some point in the future is likely. Straughn Slough has benefited from the remnant, forested island. Although the island is gradually eroding, it provides some stability between the main channel and Straughn Slough. If and when Straughn Slough is reoccupied by the Quinault River, Taiber Slough would also be at risk for reoccupation (Section 8.3.9).

A short-term strategy to protect Straughn Slough could incorporate protection of terrace banks to slow erosion, and reforestation of cleared terrace surfaces between RK 4.6 to 7.0 are recommended. Side channels should be investigated to assess whether or not deepening the upper ends of the channels would increase hyporheic groundwater input and surface flow necessary to increase spawning habitat surface area in the upstream portion that is currently plugged with sediment. Constructing hard points that protect the forested island, entrances to island channels, and future flows into Straughn Slough should be considered to meet this objective. Any short-term approach that would allow more flow into the side channel would need to be controlled in such a way that it did not disrupt habitat in the lower portion of the slough.

8.3.9 Taiber Slough and Finley Creek Drainage

Taiber Slough is a remnant channel of the Quinault River located on the north side of the Quinault River valley between RK 2.5 and 3.3 that was active from 1958 to 1994 (Figures 58 and 59; Grays Harbor County, Washington: Township 23 North, Range 9 West, Sections 9 and 10). Taiber Slough flows along a large alluvial-fan deposit (purple area in Figure 1). Taiber Slough is located downstream of a bedrock knob that extends into the valley from the north near RK 5.2.

Spawning habitat in Taiber Slough was not considered viable for sockeye use until the winter of 2001 when a large pulse of sediment and LWD deposited at the active channel entrance at the upstream end of the slough from RK 3.3 to 3.6 (B. Armstrong, QIN, personal commun. 2004). The event decreased surface flows from the Quinault River and helped to create the hyporheic flows and appropriate sediment sizes suitable for

sockeye spawning in the slough. An early-successional forest of red alder and conifer is developing on the island between the Quinault River and the slough. Beaver activity in the channel has also helped to improve the quality and complexity of habitat since 2001 (B. Armstrong, QIN, personal commun. 2004).

The river progressively created the channel path by eroding the alluvial-fan deposit from Finley Creek between 1958 and 1994. The upstream reach of the channel formed first, and the rest formed by migration of a meander in the Quinault River that progressively moved downstream and to the north. The Quinault River maintained this channel path in 1994. By 1994 the Quinault River had vacated an active channel upstream of Taiber Slough at RK 4.6 to 5.6 (Straughn Slough) which caused the river to begin a meander south and away from the active channel that became Taiber Slough by 1998.

Taiber Slough was an unvegetated overflow channel in 1998 and probably did not contain much spawning habitat except for a narrow, riparian forested channel in the uppermost 300 m of the slough (fig. 8, Appendix O). The movement of the active river channel away from the entrance to what is now Taiber Slough is surmised to have been caused by the river shifting position and the deposits of alluvial material from the Finley Creek drainage (see Appendix L) and the Quinault River plugged the channel entrance at RK 3.4 and 4.3 and 3) Levees at the Finley Creek Bridge appear to have altered the flow paths and sediment transport across the fan, directing more flow and sediment to the upstream most portion of the fan. This sediment may have provided an additional sediment source to the Quinault River that could have contributed to the plugging of Taiber Slough entrance.

During low flow periods, the majority of water in Taiber Slough originates from hyporheic flow connections presumed to originate from the Quinault River, Finley Creek, and the Finley Creek alluvial fan. The slough also has surface water connections via several small unnamed tributaries that originate on the fan (B. Armstrong, QIN, oral commun. 2004). By 2002, the overflow channel at RK 2.8 provided surface flow from the Quinault River to the lower reach of Taiber Slough only during floods.

Upstream of Taiber Slough and along the south bank from RK 4.6 to 5.6 is Straughn Slough. If the Quinault River were to re-enter Straughn Slough, river flows leaving Straughn Slough would be directed toward the entrance of Taiber Slough. Consequently, if reoccupation of Straughn Slough by the Quinault River was to occur, Taiber Slough would be at high risk for reoccupation by the Quinault River.

Restoration projects to create hard points in the reach of the Quinault River between RK 2.8 to 5.7 and in the vicinity of Straughn Slough must be carefully considered because such actions will likely impact flows and sediment movement, possibly causing the Quinault River to shift back into Taiber Slough. Protection structure locations for Taiber Slough include the island that separates Taiber Slough from the mainstem of the Quinault River, the channel entrances to the slough, the north bank of the Quinault River upstream of the slough, and at the island upstream of the slough between RK 4.6 and 5.6 (Figure 58). In-stream habitat and riparian restoration should also be considered.

Finley Creek is a tributary that originates from the north hillslope and enters the Quinault River at RK 4.4 (Appendix L). Homesteads and associated pasture lands were established on the Finley Creek alluvial fan prior to 1939. Most of the old-growth conifer forest on the alluvial fan was clearcut prior to 1939. Visual observations on 2002 aerial photographs and from the field indicate grasslands and early to mid-successional deciduous forests now dominate the area.

Historic blocking of channel paths have resulted in increased bank erosion and subsequent channel aggradation near the Finley Creek Bridge (Appendix L). To maintain conveyance through the Finley Creek Bridge and safe access across the Finley Creek channel, the National Park Service has been excavating the channel for the last few decades. The excavated sediment is placed along the channel banks as levees. The North Shore Road transects across Finley Creek alluvial fan prohibiting sediment movement downslope resulting in retrogradation of the fan. Both aggradation and incision occurs on and adjacent to a terrace surface (terrace surface on fan?) downstream of the manmade channel below the bridge (B. Armstrong, QIN, personal commun. 2004).

The North Shore Road transects across the Finley Creek alluvial fan prohibiting sediment movement down slope resulting in retrogradation of the fan. Aggradation occurs in the vicinity of the bridge during high flows and the material is later excavated to the channel bank to form levees. Prior to channel management in (1978?), debris flows would have commonly been transported down the tributary channels of the fan and the historic Finley Creek channel to the active channel of the Quinault River. Presently, the right bank levee blocks streamflow and debris from entering the historic Finley Creek channel located approximately 90 meters downstream of the bridge. Consequently both streamflow and debris are diverted to the southeast over an incising forested surface, entering the Quinault River at RK 4.3.

A long-term objective to restore the sediment supply on the Finley Creek alluvial fan to background levels could be considered. Modifications to the North Shore Road would be required where it crosses Canoe, Kestner, and the Finley Creek drainages. Private property may have to be acquired as this approach would likely cause localized flooding and sediment deposition prior to incision of channels on the alluvial fan. Benefits would include improved sediment transport, hydraulic connectivity of tributary channels (Canoe, Kestner, Finley Creeks, and unnamed tributaries), and restoration or stabilization of salmonid habitat.

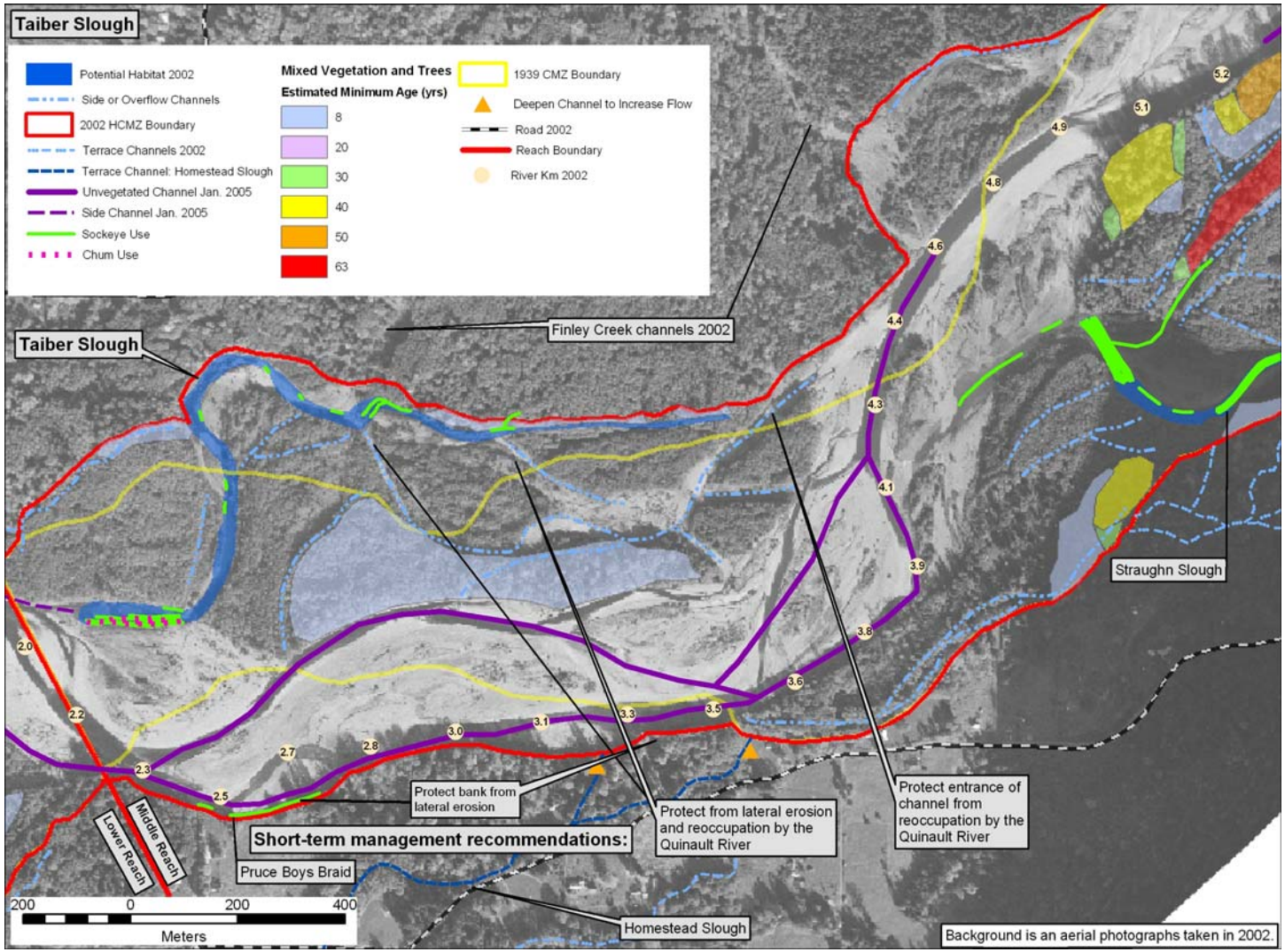

Figure 58. Potential restoration strategies and current habitat at Taiber Slough.

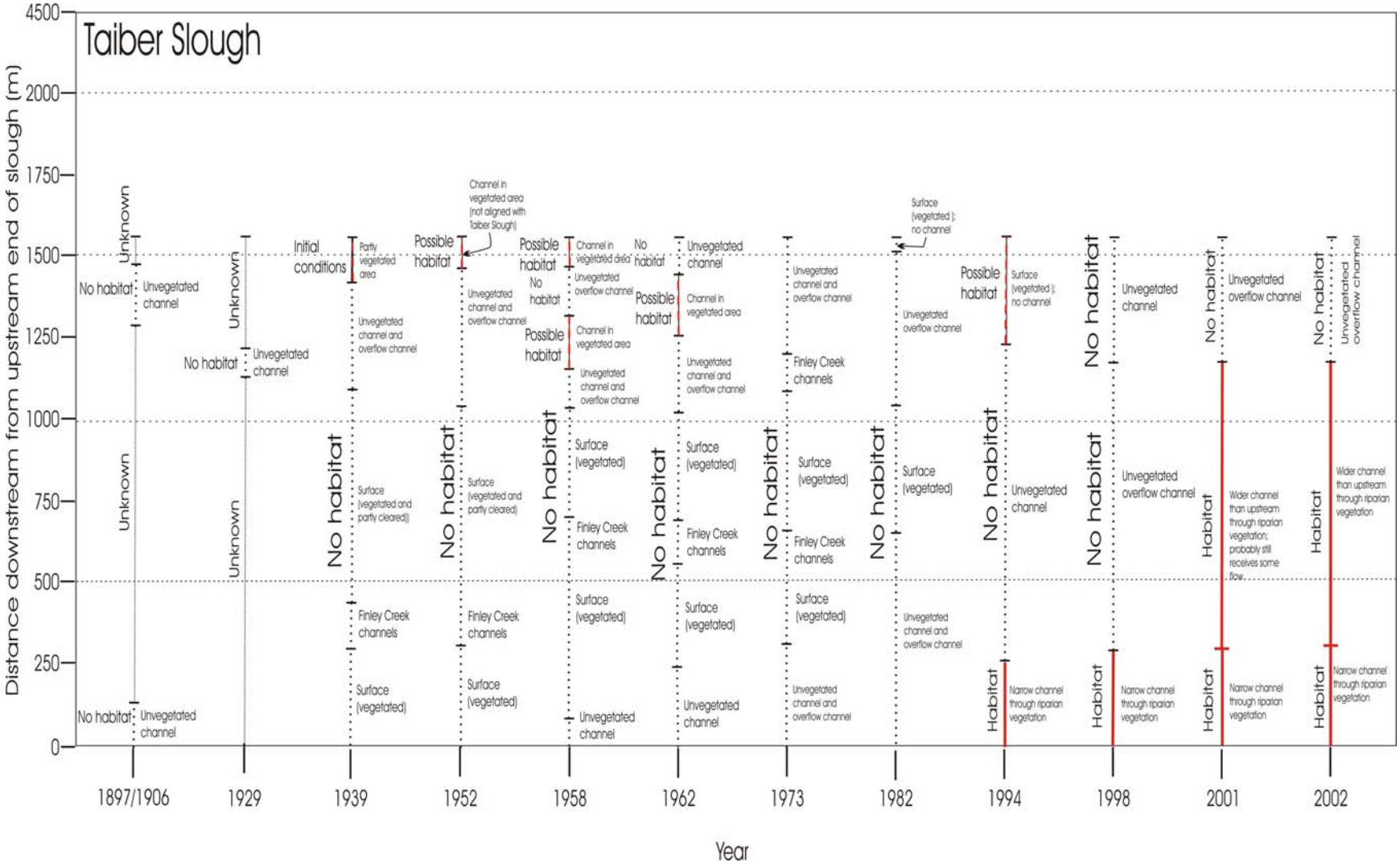

Figure 59. Historical habitat evaluation at Taiber Slough.

8.3.10 Homestead Slough

Homestead Slough is located on the south terrace between RK 1.0 to 3.5 (see Figures 41, 42, and 58). The terrace surface is presumed to have formed from a combination of fluvial and lake delta processes. A significant portion of the terrace between RK 2.3 and 3.6 has eroded since 1939 with over 250 lateral meters of surface lost in one location. The South Shore Road parallels the south bank of the channel from RK 2.5 to 3.5. Vegetation on either side of the channel has been logged and grasslands now dominate the surface. The lands adjacent to the channel are the most heavily populated in the valley. Land use on the terrace includes tourism, residential and commercial use, farming, and livestock grazing.

Historically, Homestead Slough was known as the lower reach of Inner Creek Slough (also called Merriman Creek) until isolated from a surface water connection due to erosion of the terrace by the Quinault River at RK 3.5. Once isolated, the channel was referred to as Homestead Slough. The upstream end of Homestead Slough has since been artificially filled at RK 3.9 apparently to cut off surface water entry into the slough and reduce flooding. The stream bank was also armored by local landowners to protect property, effectively isolating Homestead Slough from Inner Creek Slough and the Quinault River (Figure 60). As of 2004, only flood waters from the Quinault River that overflow the terrace surface contribute surface water to the slough. A terrace channel connection to the Quinault River at approximately RK 3.2 also appears to have been filled or altered to block Quinault River flow from entering the slough.

Homestead Slough contains strong hyporheic groundwater and appropriate sediment sizes for sockeye spawning (B. Armstrong, QIN, personal commun. 2004). Anecdotal accounts from local landowners indicate that the channel was used by sockeye for spawning prior to isolation from Merriman Creek (B. Armstrong, QIN, personal commun. 2004). However, no sustained use by sockeye has been observed in recent years. The upper end of the slough at RK 3.5 and the adjacent private lands that parallel the upper reach of the slough are at immediate, high risk for erosion and inundation by the Quinault River. A large portion of Homestead Slough from RK 1.0 to 2.8 is prone to flooding caused by a combination of river and backwater effect from Lake Quinault.

Possible habitat restoration strategies for Homestead Slough include:

1. installation of bank protection possibly through the construction of hard points along the south bank of the Quinault River,
2. reforesting the binding soil surfaces between Homestead Slough and the Quinault River,
3. constructing an engineered opening at the upstream end of the slough to allow for reconnection with Merriman Creek,
4. deepening the upstream end of the channel to allow for increased in-flow of groundwater, and
5. in-stream habitat restoration such as addition of large woody debris and creation of pools.

Figure 60. Looking upstream at the confluence of Inner Creek Slough, the Quinault River, and Homestead Slough at RK 3.6 behind the house location. Bank protection and fill have been historically used to modify this area. Flooding has also been a recurrent problem in this section for landowners.

9.0 Potential Future Investigations

The next step to recover processes in the Upper Quinault is to develop a detailed restoration plan addressing how to implement restoration strategies discussed in this report on a reach-scale basis. This plan would be formulated to work with existing constraints and processes and utilize existing resources in the river basin where possible. The information provided in this document provides the justification, baseline information, and strategies needed to implement a reach-scale restoration plan. Additional, more detailed data may be needed at specific sites to develop adequate engineering designs.

A monitoring plan for restoration projects could be developed to allow an adaptive management approach. This approach would be desirable in a dynamic river system like the Quinault River. The monitoring plan would also provide feedback of positive or negative change in channel processes and sockeye habitat that would allow scientists to learn and improve upon each successive restoration project.

Coordination with local stakeholders and permitting agencies will be needed to create public awareness and to address concerns prior to implementing restoration projects. It may be useful to form a watershed group specific to this purpose that would link scientists making recommendations with the above-mentioned groups. The watershed group would meet regularly to discuss potential projects, concerns, funding, and any new issues that materialize. WRIA 22 is a watershed group already in place that would be able to utilize information from this report and possibly serve this role.

During this investigation, additional study questions were posed that focus on establishing the relationship between the groundwater table and wetted areas used for habitat and how this interaction may have been impacted by past vegetation clearing. We do not have any quantitative data or enough information on the subsurface geology to understand the hyporheic zone and to fully evaluate the impact of human activities on the interaction of the hyporheic zone with the river. This could be accomplished with a different study focus to evaluate the influence of lake deposits versus fluvial deposits on the erosion potential and flow interaction between the terrace surfaces and the active channel migration zone. The results might help prioritize where to focus restoration efforts on terrace surfaces.

Vegetation studies may be useful to refine the age classification of trees both along terrace surfaces and within the HCMZ, and to better understand the role of non-native vegetation areas that may need to be locally managed. Tree coring and mapping of vegetation types would be a good way to improve the mapping done in this study.

Many landowners have suggested the development of a watershed model that could be used to evaluate local hydrology, flooding risk and potential solutions.

Questions related to the potential for increased sediment loads and possible channel response in the upstream watershed were posed during our study, but could not be addressed within our scope of work. It may be of interest to do a similar analysis approach in the upper watershed at a more cursory scale to see if there is evidence to support the possibility of increased sediment loads.

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11.0 Glossary

Active channel - The unvegetated channel that conveys the majority of the river's bed-material load. Does not include overflow or side channels.

Active floodplain - The zone of active channel, side channels, overflow channels and intervening surfaces that receive some flow at annual intervals and have been reworked by the active channel at least once within approximately the last century. It is synonymous with the boundaries of the 2002 historical channel migration zone (HCMZ).

Aggradation – The building up by a stream by deposition of sediment in order to establish or maintain uniformity of grade or slope (Bates and Jackson, 1987, p. 11).

Allogenic – An ecologic succession that resulted from factors that arise from outside the natural community and alter its habitat, such as an allogenic drought of prolonged duration.

Alluvium – A general term for clay, silt, sand, gravel, or similar unconsolidated detrital material, deposited during comparatively recent geologic time by a stream or other body of running water, as a sorted or semisorted sediment in the bed of the stream or on its flood plain or delta (Bates and Jackson, 1987, p. 18).

Alluvial fan – A low, outspread, relatively flat to gently sloping mass of loose rock material, shaped lake an open fan or a segment of a cone, deposited by a stream at the place where it issues from a narrow mountain valley upon a plain or broad valley, or where a tributary stream is near or at its junction with the main stream, or wherever a constriction in a valley abruptly ceases or the gradient of the stream suddenly decreases; it is steepest near the mouth of the valley where its apex points upstream, and it slopes gently and convexly outward with a gradually decreasing gradient (Bates and Jackson, 1987, p. 17).

Anadromous fish species – Anadromous fish, such as salmon and steelhead, migrate or swim from their freshwater place of birth to the saltwater ocean and then return to their freshwater home stream as an adult to breed.

Autogenic – An ecologic succession that resulted from factors originating within the natural community and altering its habitat.

Bar – Accumulations of bed load (sand, gravel, and cobble) that are deposited along or adjacent to a river as flow velocity decreases. If the sediment is reworked frequently, the deposits will remain free of vegetation. If the surface of the bar becomes higher than the largest flows, vegetation stabilizes the surface making further movement of the sediment in the bar difficult.

Base level – The level below which a stream cannot erode its bed. The general or ultimate base level for the land surface is sea level, but temporary base levels may exist locally. [From p. 57 in Bates, F.L., and Jackson, J.A. eds., 1987, Glossary of Geology (Third Edition): Alexandria, Virginia, American Geological Institute, 788 p.]

Bed material – Sediment that is preserved along the channel bottom and in adjacent bars; it may originally have been material in the suspended load or in the bed load.

Bedload – The sediment that is transported intermittently along the bed of the river channel by creeping, rolling, sliding, or bouncing along the bed. Typically includes sizes of sediment ranging between coarse sand to boulders (the larger or heavier sediment).

Bedrock – Areas where rock is present; includes Core and Peripheral rocks (Tabor and Cady, 1978), which are igneous, sedimentary, and metasedimentary rocks (basalt, sandstone, conglomerate, siltstone, argillite); hard and resistant to fluvial erosion.

Braided – A channel that contains, within one active channel segment, several channel paths that are separated by bars or islands.

Center line – A line drawn along the center of the active or unvegetated channel; visually placed to be at the center of all channel paths.

Channel deposits – Sediment that is deposited in the channel as flow subsides; usually consists of gravel and sand.

Channel Migration Zone (CMZ) – the valley area susceptible to reoccupation by the river through channel erosion and reworking processes. The CMZ encompasses the HCMZ (area of historical occupation over a given timeframe) and adjacent areas that may currently be terrace, glacial deposits, lake-bed deposits, or man-made surfaces but are at risk for being eroded by the river.

Channel planform – Characteristics of the river channel that determine its two-dimensional pattern as viewed on the ground surface, aerial photograph, or map.

Channel sinuosity – The ratio between the length of the channel, as measured along the centerline of the channel, and the centerline length of the valley. For this study, the ratio was measured between the length of the channel and the centerline of the future channel migration zone. The higher the sinuosity value, the more curving the channel pattern.

Channel width – The average channel width calculated for the active and unvegetated channels by dividing the channel area by the length of the channel center line.

Cleared – Areas within the HCMZ where it appears that the vegetation has been artificially removed by human activity (e.g., logging, clearing for residential property, roads); areas are often covered with grass.

Coarse sediment – Boulders to coarse sand (2 to 4096 mm); sizes that are usually transported as bed load and are too large to be deposited outside of the channel on the flood plain by overbank flow.

Control point – A survey station that provides horizontal or vertical position data, or both, that can be identified on aerial photographs and used to ortho-rectify the photographs or to correlate data.

Cubic meter per second (m^3/s) – The rate of water flow passing any point equal to a volume of one cubic meter of water every second.

D_{50}– The median particle-size diameter for a sediment sample, such that 50 percent of the sample is larger than this value.

Debris flow – A moving mass of rock fragments, soil, and mud, more than half of the particles being larger than sand size.

Delta – A low, nearly flat, alluvial tract of land at or near the mouth of a river (in this study the delta is at Lake Quinault), commonly forming a triangular or fan-shaped plain crossed by many distributaries of the river, and resulting from the accumulation of sediment supplied by the river; delta sedimentation is partly subaerial and partly below water.

Discharge – The volume of water in a river that flows through a given cross section of the river channel per unit time. In the United States, it is usually measured in cubic feet per second (ft^3/s).

Engineered Log Jam (ELJ) – Interconnected pile of large logs engineered to mimic natural log jams in a river system; usually creates a hard point in the channel and provides habitat for salmon; may be designed to be temporary or relatively permanent depending upon the size of the logs and the amount and type of anchors.

Fine sediment – Fine sand, silt, and clay (< 2 mm); sizes that can be transported as suspended sediment and are often deposited outside of the active channel in areas of low velocity and on the floodplain by overbank flow.

Floodplain – The zone interpreted to include the active floodplain and additional surfaces outside the active floodplain that are inundated by peak river flows, tributary channel flows, and backwater flooding from Lake Quinault.

Fluvial geomorphology – The study of river channel geometry and planform, and how it changes over time.

Forset bed – A bed of unconsolidated sand and (or) gravel that is part of a set of inclined (gently dipping) layers that are usually crossbedded; sediment is deposited along an

advancing or relatively steep slope, such as the outer margin of a delta, and progressively buries the lower beds; the sediment is, in turn, buried and truncated by younger beds as deposition continues.

GIS – Geographical information system. An organized collection of computer hardware, software, and geographic data designed to capture, store, update, manipulate, analyze, and display all forms of geographically referenced information (McCoy and Johnston, 2002).

Grass vegetation – Areas outside of the HCMZ where the canopy is homogeneous in appearance, open, and of very low relief; areas have been cleared artificially by human disturbances; mainly on low surfaces (Holocene) adjacent to the HCMZ.

Hillshade – A hypothetical illumination of a surface that is created in Arc using x, y, and z values for an area.

Historical channel migration zone (HCMZ) – An area where the main river channel occupies and transports sediment and woody debris within a specified timeframe.

Holocene – The geologic time interval between about 10,000 years ago and the present.

Hydraulics – The physical laws governing water movement.

Immature vegetation – Area outside of the HCMZ where the canopy is homogeneous in appearance, single-storied, and of low to moderate relief ; consists of either conifers or deciduous trees; areas are present on all surfaces and bedrock.

Incision – The process by which a downward-eroding stream deepens its channel or produces a relatively narrow, steep-walled valley (Bates and Jackson, 1987, p. 331).

Intermediate Holocene surface – Surface that is outside of the HCMZ, but is commonly inundated by overbank flow; composed of surfaces of several heights, but most are between about 1 and 2 m above the active channel of the Quinault River; surfaces are commonly dissected by side channels that convey flow all or part of the year (terrace channels); surfaces are commonly covered by alders and spruce with diameters up to 1 ft and Sitka spruce with diameters up to 2 ft; associated deposits may include delta deposits below thin (usually < 1 m) of overbank deposits; late Holocene.

Key member – An individual piece of wood that is large enough to become stable within the channel.

Lacustrine – Sediment deposited in a lake; usually very fine (silt and clay); often dark gray because of the organic material present in the sediment

Large woody debris (LWD) – Large downed trees that are transported by the river during high flows and are often deposited on gravel bars or at the heads of side channels

as flow velocity decreases. The trees can be downed through river erosion, wind, fire, or human induced activities.

Late-successional forest - A forest stand usually less than 150 years old that has had natural or anthropogenic disturbances and generally has a high canopy closure. These forests contain a relatively high density of large trees but do not exhibit the many old-growth characteristics including an advanced state of decadence or diverse species composition.

Levee – A natural or artificial embankment that is built along a river channel margin; often constructed to protect an area from flooding or confine water to a channel. Often referred to as a dike.

Loess – A deposit of wind-blown silt.

Longitudinal bar – An elongated gravel bar that extends along and roughly parallel to a relatively straight section of river channel. It grows in a downstream direction, with its steep side toward the channel bank and with a narrow trough between the bar and the bank.

Low-flow channel – The channel that carries water during times of low flow. It tends to follow the deepest part of the channel.

Lower Holocene surface – Surface that is frequently inundated with flow (at least on nearly a yearly basis); includes surfaces of several heights, but the highest ones included in the lower surface are about 1 m above the active channel of the Quinault River; commonly covered with alder, willow, and small conifer; synonymous with the HCMZ.

Mass wasting – General term for the dislodgement and downslope transport of soil and rock under the influence of gravitational stress (mass movement). Often referred to as shallow-rapid landslide, deep-seated failure, or debris flow.

Mature forest – Area where the canopy is generally heterogeneous in appearance, multi-storied, and of high relief (tall) consisting predominantly of conifers; although small remnants remain on the lower surfaces (Holocene), the most expansive areas are found on bedrock and Pleistocene surfaces.

Mid-channel bar – A ridge-shaped or somewhat arcuate gravel bar that is preserved between branches of a low-flow channel.

Mixed vegetation – Vegetation within or outside of the HCMZ that includes both shrubby vegetation and scattered trees; may include small areas of dense or nearly continuous trees; trees appear to be mostly deciduous; vegetation often appears to follow old channels that receive little or no flow.

Moraine – A mound or ridge composed of unsorted, unstratified glacial drift, predominantly till, deposited chiefly by direct action of glacier ice (Bates and Jackson, 1987, p. 433).

Old channel – Channel that is essentially covered with vegetation, but is still recognizable as a channel; it does not convey enough flow to disrupt vegetation, and may no longer receive surface flow from the Quinault River.

Old growth forest – A forest stand usually at least 180-220 years old with moderate to high canopy closure; a multilayered, multispecies canopy dominated by large overstory trees; high incidence of large trees, some with broken tops and other indications of old and decaying wood (decadence); numerous large snags; and heavy accumulations of wood, including large logs on the ground. Any evidences of man's activities may be present, but do not significantly alter the other characteristics and would be a subordinate factor in a description of such a stand (USDA, 1998).

Ortho-rectified photograph – An aerial photograph that has been corrected for the geometries and tilt angles of the camera when the image was taken and for topographic relief using a digital elevation model, flight information, and surveyed control points on the ground.

Overbank deposits – Fine sediment (fine sand, silt, and clay) that is deposited outside of the channel on the floodplain or terrace by overbank flow.

Overflow channel – A channel, often adjacent to the active channel, that carries water only during high flows (floods). The channel can be dry for much of a year, but receives flow frequently enough that it is generally unvegetated. It is synonymous with flood-flow channel.

Partially cleared and (or) regrowth – Areas within the HCMZ where it appears that the vegetation has been partially cleared artificially by human activity; areas often include several types of vegetation in artificially appearing patterns (e.g., linear sections of a different vegetation type that appear to follow old roads); includes areas that were once entirely cleared artificially, but vegetation has begun to regrow.

Pleistocene – The geologic time interval between 1.6 million years ago and 10,000 years ago.

Pleistocene surface – Surface that is not inundated by overbank flow; composed of surface of several heights and ages, but most are greater than 5 m above the active channel of the Quinault River; commonly covered by mature ferns, and large-diameter (4 ft or larger) Sitka spruce, Douglas fir, and bigleaf maple; large-diameter stumps are present in some areas; surface are interpreted to be Pleistocene on the basis of their relationship to glacial deposits.

Point bar – A sand or gravel bar that is deposited at the inside of a meander bend as a result of secondary currents related to changes in velocity at a bend in the channel. It is usually found where sediment is supplied from upstream, so that the bar grows in the downstream direction as sediment continues to be added to the inside of the bend.

Potential habitat – Narrow or wide overflow or side channel of the Quinault River that flows through an area with some vegetation, usually riparian; for wide channels, water is usually visible; water source may be a surface connection to the Quinault River or groundwater; at least some vegetation is present to protect the channel and habitat conditions. This is potential habitat as it is not known whether the channel was actually used for reproduction or rearing; the presence of riparian or mixed riparian vegetation and trees suggests that the channel has not received large flows from the Quinault River in the recent past.

Quaternary – The geologic time interval between 1.6 million years ago and the present. It includes both the Pleistocene and the Holocene.

Raster – A file that uses a grid structure to store geographical information; represents information as an array of equally sized square cells (or pixels) arranged in rows and columns; each grid cell is referenced by its geographic x, y location (McCoy and Johnston, 2002).

Raster calculator – A function in Spatial Analyst in Arc that performs mathematical calculations and queries on raster files using numeric values assigned to each pixel.

Redd – Also known as spawning beds, or nests, redds are areas in the stream bottom dug out by female salmon in preparation for spawning. After fanning out a redd with her tail, a female will deposit her eggs and then cover them with more gravel.

Regime equation – An equation developed by comparing channel discharge (typically bankfull) to average slope of several measured rivers. The equation is generally used to classify rivers in a common geomorphic context, such as meandering or braided.

Riparian – Pertaining to areas of land directly influenced by water. Riparian areas usually have visible vegetative or physical characteristics reflecting this water influence. Stream sides, lake borders, or marshes are typical riparian areas (USDA, 1998).

Riprap – Large angular rocks that are placed along a river bank to prevent or slow erosion.

River kilometer (RK) – The distance in kilometers measured along the centerline of the river channel upstream from the mouth or other established point of origin (e.g., confluence).

Scattered vegetation – Areas outside of the HCMZ where the canopy is heterogeneous in appearance, partially open, and has low to moderate relief; areas generally have

deciduous trees, but conifers can be numerous; areas are mainly on low surfaces (Holocene) adjacent to the HCMZ.

Scour – Local erosion of sediment from the channel bed during high-velocity flows.

Scrub vegetation – Areas outside of the HCMZ where the canopy can be heterogeneous or homogeneous in appearance, predominantly open, and of low relief; includes areas where vegetation has regrown after timber harvesting; common on low surfaces (Holocene) adjacent to the HCMZ.

Shapefile – A format for vector data for storing the location, shape, and attributes of geographic information (McCoy and Johnston, 2002)

Shrubby vegetation – Low vegetation within the HCMZ where individual plants are not visible on the aerial photographs; often appears to follow old channels, which receive little or no flow so that vegetation has become established.

Side channel – A secondary channel that nearly always carries flow and is located in the active flood plain and may be fed from groundwater or tributaries much of the time.

Slightly vegetated channel – A channel that has scattered vegetation, but is still recognizable as a channel; it is an overflow channel that may still receives some flow, but not often enough for it to remain free of vegetation; it carries water only at the highest flows.

Smolts – The point in a juvenile salmon's lifecycle when their bodies are changing in preparation for surviving in salt water, enabling them to migrate from freshwater to the sea.

Stage – The height of the water surface above the channel bed; referenced either by depth or to a vertical datum.

Suspended-sediment load – The fine sediment (fine sand, silt, and clay) that is transported in suspension above the channel bed. It is the sediment that is light enough or small enough to be transported in suspension much of the time, in contrast to the bed load that is primarily moved along the bed.

Terrace – A relatively stable, flat surface formed when the river abandons the floodplain that it had previously deposited. It often parallels the river channel, but is high enough above the channel that it rarely, if ever, is covered by water and sediment. The deposits underlying the terrace surface are alluvial, either channel or overbank deposits, or both. Because a terrace represents a former floodplain, it can be used to interpret the history of the river.

Terrace channel – Side channel or overflow channel that is incised into a terrace surface; incision ranges between <0.5 m to 5 m; channel widths are a few meters to tens

of meters; banks reveal alternating beds of gravelly (channel deposits) and fine (overbank deposits) alluvium; unvegetated bars of gravelly alluvium may be present along the channel; may include LWD; the channel usually, but not always, connects to the main channel at its upstream and downstream ends, either directly or through a network of terrace channels; channels may be quite sinuous and complexly interconnected.

Transport capacity – The ability of the river to move sediment. It depends upon channel gradient or slope, discharge, size of the available sediment, and channel form (e.g., width, depth, roughness).

Transverse bar – A gravel bar that extends roughly perpendicular across the direction of flow. It is often associated with split, branching flow and can create steps in the channel bed.

Tree vegetation – Areas within the HCMZ that are covered nearly continuously with trees, either deciduous or conifer, or both; little other vegetation is visible on the aerial photographs; on surfaces that have not been part of the unvegetated channel recently, so that they have stabilized and revegetated.

Tributary channel – The channel of a stream feeding, joining, or flowing into a larger stream (e.g., the Quinault River); same as tributary; referred to as a tributary channel to distinguish it from the main, side, or overflow channels of the Quinault River.

Unvegetated channel – The unvegetated area adjacent to the active channel; it includes the active channel and unvegetated bars adjacent to it; it includes overflow channels that are unvegetated; it is the area that conveys flow at higher discharges often enough to remain unvegetated; it probably receives flow at least once, but probably several times, a year.

Upper Holocene surface – Surface that is infrequently inundated by overbank flow; composed of surfaces of several heights, but most are between 3 and 5 m above the active channel of the Quinault River; commonly dissected by mostly ephemeral and perennial channels (terrace channels); commonly covered by mature ferns, and large-diameter (4 ft or larger) Sitka spruce, Douglas fir, and bigleaf maple; large-diameter stumps are present in some areas; Holocene.

Appendix A: Topographic Data of Upper Quinault River

This appendix describes new LiDAR and channel survey topographic data collected in 2002 for this study. Also discussed are a topographic survey from 1929 and the comparison of this data to 2002 river elevations.

2002 LiDAR and Channel Survey Data

Data Collection Reach

The longitudinal extent of data collected was between the upper end of Lake Quinault to the confluence of the North and East Forks of the Quinault River, about 12 km upstream from the lake (see Figure 1 in main report). The lateral extent of topographic data collected was across the valley floor from valley wall to valley wall, on average about 2 miles.

Establishment of Permanent Survey Control Network and Project Datum

During the week of September 23, 2002, a permanent survey control network was established along the study reach from the Forks Bridge to Lake Quinault by Reclamation surveyors using global positioning system (GPS) equipment (see attachment 1 for more documentation). The network was tied to a National Geodetic Monument and referenced to *UTM 1983, National Geodetic Vertical Datum 1988, Zone 10, meters*. Both the river survey data and LiDAR data collected utilized this network so the data could be properly integrated. This network can also be used in any future data collection along the Quinault River to allow direct comparison of data in the same projection and datum. All GIS data mapped for our study was accomplished in this datum.

Acquisition of Aerial Photography and LiDAR Data

Aerial photographs were acquired on October 23, 2002 by Walker Associates and LiDAR data was acquired on October 30, 2002 by Horizon, Inc. It was desired to have the LiDAR and aerial photography overlap the low flow channel bottom survey data collected boat in early October 2002 so a continuous digital terrain surface of the valley bottom could be generated. Because winter flooding can often result in changes of the channel geometry, the data can be better integrated if collected all at the same time. The aerial photography and LiDAR acquisition date was chosen based on when the leaves were beginning to fall off the trees allowing for more penetration to the ground, photo panels were in place, river flows were low, and weather was favorable. Photo panels were placed within the study reach for the photogrammetric process of rectifying the aerial photography during the week of September 23, 2002. Due to the dense vegetation and narrow valley along the study reach, there were limited locations where photo panels could be easily visible in the aerial photography. As a result, some photo panels were

located in areas along the active river channel bars that were vulnerable to winter flooding.

Processing of LiDAR data and new aerial photography

Processing of the new 2002 LiDAR data and aerial photography was completed by Horizon and delivered to Reclamation in the following formats:

1. Multiple return ascii data
2. First return ascii data
3. Bare earth ascii data (final processed ground elevation data)
4. Bare earth 2m grid data
5. Breakline work for LiDAR processing
6. Metadata for data

River Channel & Delta Survey

A river channel survey was accomplished by Bureau of Reclamation with a boat equipped with a depth sounder, GPS equipment and total station tracking equipment from September 28, 2002 to October 2, 2002 (Figure 1). In some sections of shallow flow where the boat could not be floated, channel bottom was measured by walking rather than using depth sounding equipment on the boat. The goal of the survey was to map the topography of the low flow wetted channel which can not be acquired by commercially available LiDAR techniques. By combining the underwater data with the LiDAR data, a continuous topographic map of the river and floodplain can be generated. A survey of the upstream portion of Lake Quinault delta was also accomplished on October 3, 2002. The data from the river channel and upstream portion of the reservoir survey is available in ASCII format geo-referenced to the same datum as the LiDAR data. The average discharge at the outlet of Lake Quinault during the survey was 407 ft^3/s (Table 1).

Figure 1. Bill Armstrong and Tim Randle on survey raft equipped with depth sounder and GPS survey equipment. Photograph taken September 30, 2002.

Table 1. Discharge estimates for channel and reservoir survey period from USGS gage "12039500 QUINAULT RIVER AT QUINAULT LAKE, WASHINGTON".

			Daily
	Estimated	Estimated	Average
Survey	Start	End	Gage Q
Date	Collection	Collection	(ft3/s)
9/28/2002	10:00 AM	6:00 PM	423
9/29/2002	10:00 AM	6:00 PM	411
9/30/2002	10:00 AM	6:00 PM	403
10/1/2002	10:00 AM	6:00 PM	393
		Total Average Q	407

A longitudinal profile of the thalweg and water surface elevation measured was produced (see Attachment 3). This profile was used to compute the average hydraulic slopes of the river (Table 2), and characterize the presence of pools and hydraulic controls. The average hydraulic slopes were computed by connecting a straight line between the top of hydraulic controls (riffles and rapids). Where the line exhibited a significant shift in alignment over several hydraulic controls, a new slope was computed. Two small sections of 0.2 kilometers in length appeared to be transition sections between steeper to flatter slopes, and slope values were not computed.

Table 2. Average hydraulic slopes of river channel based on water surface elevation data from October 2002 channel survey (see Attachment 3 for profile plots).

KM	Elevation (m)	Slope (m/m)	Slope (%)	Distance (km)
0.109	56.014			
0.1 to 2.7	61.668	0.0022	0.22	2.57
2.7 to 2.9	62.852	0.0058	0.58	0.21
2.9 to 4.6	66.356	0.0021	0.21	1.68
4.6 to 6.3	71.460	0.0029	0.29	1.76
6.3 to 6.6	71.536	0.0002	0.02	0.31
6.6 to 12.6	90.900	0.0032	0.32	6.00
12.6 to 14.0	95.665	0.0034	0.34	1.39
14.0 to 15.4	102.255	0.0047	0.47	1.41
15.4 to 17.3	107.924	0.0031	0.31	1.83

The largest rapid (or drop) in water surface elevation measured in October 2002 was 2.8 meters in height between river kilometer 15.1 to 15.4. The deepest pool measured was 5 meters in depth at river kilometer 17.1. From river kilometer 0 to 7.5, the profile shows a combination of shallow riffle sections with water depths less than 1 meter interspaced with rapid and pool complexes. The rapids measured 0.3 to 0.8 meters of drop and pools at the downstream end of the rapids had 1 to 2.3 meters in depth. From river kilometer 7.5 to 8.3, there is a steeper rapid and pool complex (relative to the downstream reach) with a 0.0068 slope. Between river kilometers 8.3 to 9.0, the river in 2002 had one deep pool and flatter slope of 0.0014 (relative to rest of study reach). The deep pool existed where the river ran east across the valley into a riprapped section of road. This section of river shifted to the south side of the floodplain in a flood following the survey. Between river kilometer 9 to 14.4, a rapid and pool complex is again interspaced with shallow riffles, but the pools are only 1 to 1.5 meters in depth. Between river kilometer 14.4 to 18, a rapid and pool complex were measured with deepest pools existing where the river ran along bedrock outcrops on the south side of the river (along the South Shore Road) (see Figure 2). Additional scour pools existed in the study reach where log jams interacted with the low flow river channel. In some cases the maximum depth of these scour pools could not be measured because the boat had to be portaged around the log jams and the depth was too deep to wade by foot.

Figure 2. Example of deep pool near bedrock outcrop along South Shore Road. Note the riprap placed to protect South Shore Road on either side of the bedrock. Photograph taken September 28, 2002.

Digital Terrain Surface (DTM)

A digital terrain model (DTM) was generated by combining the LiDAR data with the river survey data. This was accomplished by blocking out areas of wetted channel in the LiDAR data set and, where available, replacing it with channel bottom data. This DTM (TIN surface) represents a continuous surface of the study reach from valley wall to valley wall, from Lake Quinault upstream to the Forks. Contour data (2m) was also generated from the DTM surface, along with a hillshade representation of the topography.

Quality Control Check on LiDAR Data

The vertical accuracy of the LiDAR data was of interest because elevation differences within the study reach were used to distinguish geologic surfaces, historic channels, and many other floodplain features. The LiDAR data contract was written to establish topographic data of the ground that could generate an accurate 2m-contour interval. This is a generally accepted standard for this geographic region in the Pacific Northwest based on the presence of dense vegetation where it is difficult for LiDAR data to penetrate to the valley floor. The 2002 rectified aerial photographs were used by the contractor to process the data and determine areas where LiDAR could not be generated due to wetted channel or heavy vegetation.

To provide a cursory test of the accuracy of the data, the bare earth LiDAR data elevations were compared to two other elevation data sets: 1) elevation data collected by GPS survey equipment at unique points throughout the study reach where photo panels were surveyed, and 2) at four cross-sections surveyed by total stations all roughly located

in the middle of the study reach and linked to the same GPS network. The points at photo panel locations were collected using static GPS methods (high level of accuracy due to longer occupation time) and generally in open, unvegetated areas with a clear view of the sky where LiDAR data should do reasonably well. The four cross sections contained a mixture of open, unvegetated areas and areas both covered in vegetation and some areas of wetted channel within the floodplain forest.

A total of 374 GPS elevation data points were compared to LiDAR results (Figure 3). Using a standard testing procedure indicates that contours developed from this data should be accurate to .42 meters 95% of the time (Federal Geographic Data Committee, 1998). Although this is better than the estimated 2-m accuracy, because only a small number of points within the study area were compared, many of which were in open relatively unvegetated areas, it may have come out differently with more data. However, it does indicate the LiDAR data should provide a reasonable interpretation of the topography in the study area at an appropriate level of accuracy for this study.

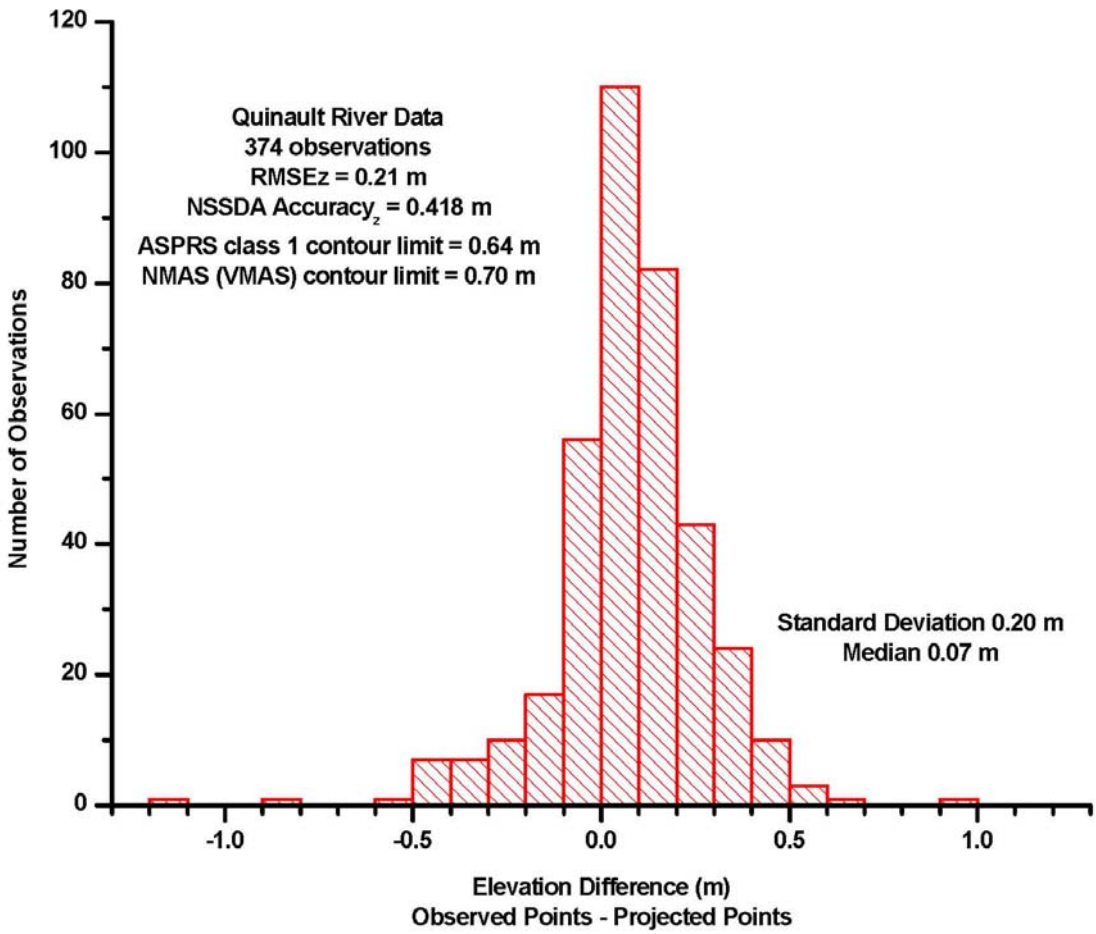


Figure 3. Results of point comparison between LiDAR data and GPS points.

As an additional check, the ground survey data from the four cross-sections were compared to LiDAR data processed into a 2m grid, and to a digital terrain surface (TIN surface) created from a combination of the river channel survey data and all LiDAR data points (see Attachment 2 for cross section plots). In general, the LiDAR data compared to ground survey data within 0.5 meter, which is reasonable given the natural variation in ground surface in this region that can be observed in the field.

The LiDAR did a good job of indicating breaks in terrace surfaces and historical channel paths. Where multiple survey data points were available of the channel bottom within a small area, the TIN correctly represents the thalweg better than the 2m grid LiDAR data alone. However, when there is only one thalweg data point the tin appeared to often average out the elevation with surrounding points which would create a higher elevation thalweg than exists in reality. A more robust tin generation method could help eliminate this problem. The typical error in thalweg measurements from the TIN was not much greater than the diameter of a typical cobble sized particle on the bed. Most larger ponded areas or inundated river sections were identified as "no data" areas by the contractor (Horizon) and no LiDAR data is available. In these areas the processed TIN and 2m LiDAR grid “connects the dots” between closest areas where data was available, and ground survey data is more representative of the actual topography. In some small ponded areas, LiDAR data is provided and most likely represents the water surface rather than actual ground elevation. In cross section 1 the LiDAR was lower in elevation than the ground survey data and when combined into a TIN created an uneven (unrealistic) surface that differed by about 1 meter.

It is concluded that using a combination of measured river channel and LiDAR data did a reasonable job of representing the topography and was appropriate for developing cross-sections over a large lateral area to represent average reach topography. However, cross sections or surfaces generated for modeling should be evaluated for possible modification in areas where the data looks non-typical of other similar topographic areas. Areas in dense vegetation or wetted channel showed the most differences. Subsequent design level analysis for restoration projects may require additional ground survey data in wetted or densely vegetated areas.

Historical River Channel Survey Data

A copy of a historical U.S. Geological Survey (USGS) map was acquired from the University of Washington library (call number G4282.Q52 1929.G4) that documents planview and a longitudinal profile survey of the river surface accomplished in 1929 (Jones, 1929). The contour interval shown on the map is 50 feet for land areas, and 5 feet on the river surface. The vertical datum of the map is mean sea level, shows township and section lines, and an approximate mean declination of 1929. The river surface appears to represent the low flow channel(s) as delineated within the active channel. Gravel bars are denoted on the map, along with prominent roads and infrastructure, but vegetation is not illustrated. The planview map appears to be tied to section lines, although the planview copy obtained does not show square quarter sections

which may imply some error in the original map or the copying process. A longitudinal profile plot of the river surface in 10 foot intervals from the same 1929 survey (referred to as Sheet B by USGS) was also available that did not have any visible distortion on the photocopy.

Adjustment of 1929 horizontal datum

It was of interest to compare the 1929 channel position to positions generated from other historical aerial photographs and maps, and the 1929 water surface profile to survey data collected in October 2002. This meant the horizontal and vertical datum of the 1929 map had to be adjusted to match the present datum of survey data collected in October 2002 (Horizontal: UTM 1983, Zone 10, meters; Vertical: NGVD 1988, meters). The 1929 planview image was georeferenced to electronic versions of 1:24,000-scale topographic maps of the U.S. Geological Survey (Lake Quinault East, Finley Creek, and Bunch Lake quadrangles) to allow mapping of channel position. The topographic maps had an original or native projection of UTM, Zone 10, NAD 27, meters, but had been reprojected into UTM, Zone 10, NAD 83, meters. The RMS errors for the projection were not documented and the map would need to be re-georeferenced to determine the accuracy. However, the plotted position after our georeferencing showed the channel passing through areas known to be bedrock, so there was a substantial error known to exist. The 1929 channel position was manually adjusted based on our best interpretation and judgment call as to where the channel would have flowed. Comparisons were made to previous maps from 1906 and 1897 and to 1939 aerial photographs the closest documentation of channel position prior to and after the 1929 map.

Adjustment of 1929 vertical datum

The 1929 vertical map datum was recorded as mean sea level, but not enough information was given to provide a known transformation to the present vertical datum and, therefore, had to be manually adjusted to match 2002 elevation data. As a first step the 1929 elevations were adjusted to the 1988 datum by adding 3.48 feet, the standard conversion from 1929 to 1988 vertical datum for this region as determined from Corpscon datum conversion program (compiled by Army Corps of Engineers, http://crunch.tec.army.mil/software/corpscon/corpscon.html). The elevations were then converted from feet to meters. This resulted in a lake elevation of 58.4 m, significantly higher than the lake elevation of 55.9 m measured in 2002 (river discharge of 400 ft^3/s in 2002). As an alternative approach, it was determined the elevations could be adjusted using landmarks that would have the least likelihood to have not drastically changed within the study reach between 1929 and 2002, mainly the Quinault lake elevation.

The lake elevation is controlled by a naturally formed moraine at the outlet of Lake Quinault. If the channel bed near the moraine has not vertically changed significantly since 1929, it can be assumed the influence on the lake surface elevation for a given discharge should be similar between 1929 and 2002. By comparing the stage-discharge relationship with measured stages and discharges, a comparison can be made that implies the channel bed has shifted. This analysis was done by USGS and is shown in Figure 4

below. The shift is the amount that needs to be added or subtracted from the stage in order for the discharge indicated by the rating table being used to most closely agree with the measured discharge. The rating used for this analysis (Rating 9) is currently in use at the station.

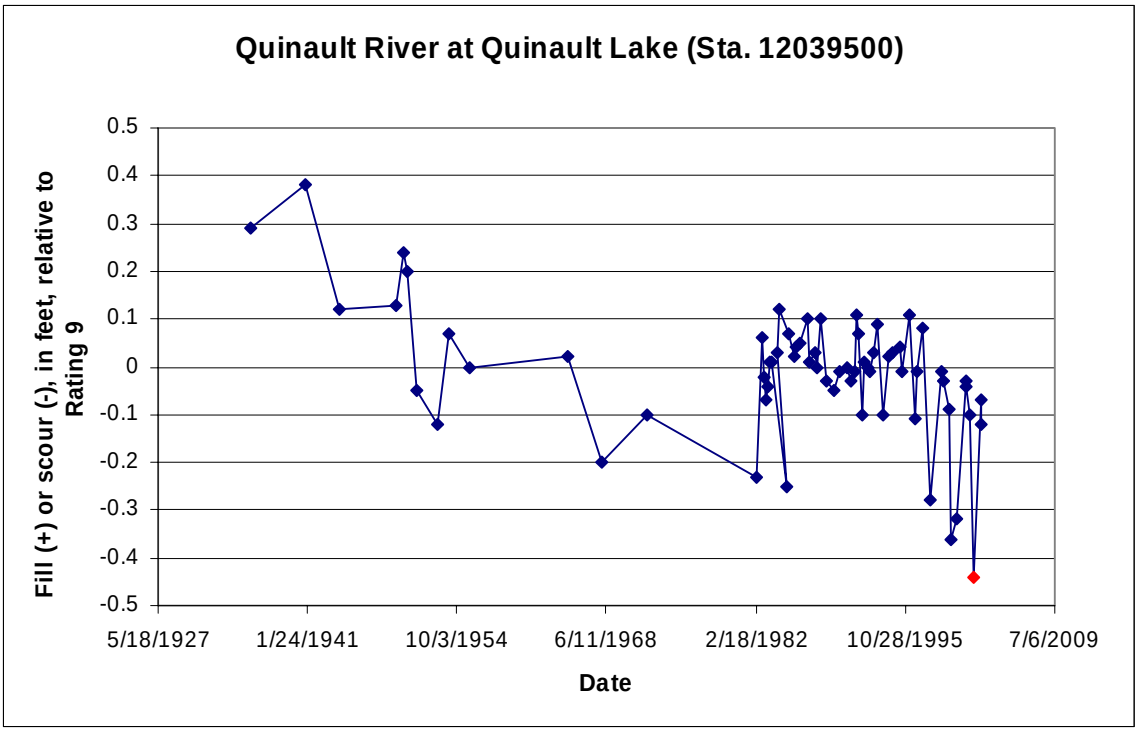


Figure 4. Shift analysis at USGS gage at outlet of Lake Quinault that indicates a possible lowering of channel bed at gaging station.

The analysis indicates there has been a gradual bed lowering at the USGS gaging station between 1935 and 2002 of about 0.5 foot (written communication from USGS). This indicates the lake elevations for a given discharge may be slightly lower today than historically. The current bed appears to fluctuate within 0.5 foot and this may be due to high flows scouring out the bed and re-deposition during subsequent lower flow periods. This can be observed from the January 2002 flood of 35,000 ft^3/s (shown as red dot in figure 1) which scoured the bed almost 0.5 foot, but the bed subsequently re-deposited in the next couple of years after the flood. However, because the change in bed elevation is small (< 0.5 foot), the 1929 and 2002 lake elevations should be close for a similar discharge. Additional evaluation of the data show that the bed can also fluctuate do to reworking during high flows.

The river discharge during the 1929 survey at the same gage location is not known because the month and day of survey are not given in the 1929 maps. However, assuming the 1929 survey was done during low flow conditions, as was the October 2002 survey the 1929 lake elevation should be similar to the 2002 level. This is a good assumption based on the split flow channels, mid-channel bars and other features delineated in the 1929 planview map. The 1929 elevations were all lowered by the difference between the 1929 and 2002 lake elevations (-2.5 m) to make a best attempt at

matching the vertical datums as close as possible. Therefore, the comparison of elevations between 2002 and 1929 should be reasonable, but interpreted only on a qualitative basis since the exact 1929 to 2002 datum conversion is not known.

Comparison of 1929 to 2002 channels and river surface elevations

The 1929 channel between the lake inlet and the confluence of the North and East Fork Quinault branches was 16.8 km in length. The 2002 channel was 17.9 km in length, a little more than 1 km longer than the 1929 path. One explanation for the difference in river channel lengths could be from progradation (longitudinal growth) of the delta at the inlet to the lake. However, as a result of channel avulsions, although the delta has grown in length since 1929, the particular 2002 channel location is laterally very similar to the position of the 1929 inlet due to a recent channel avulsion. Other possible explanation for the difference in channel length is error in the 1929 survey, or that there actually was a straighter channel in 1929 that resulted in a shorter length.

Because the possible error of the 1929 survey can not be quantified, it was assumed the relative change in elevation was correct and by adjusting the vertical datum to match at the lakes, the data sets were comparable. A longitudinal profile was generated by pulling 2002 and 1929 points from GIS along the valley axis at locations of 1929 contour crossings (Figure 5). Measured water surface elevations from 2002 were used, in hope of being most comparable to elevations from1929 assumed to be representative of the low flow channel surface at a comparably low discharge.

The profile comparison indicates that, qualitatively, there has been some channel incision (bed lowering) between 1929 and 2002 between river kilometer 14 and 17 of the study reach, and that the remainder of the study reach has, on average, remained relatively stable. There do appear to be a few areas where 2002 is slightly higher than the 1929 water surface between river kilometer 3 and 10. This may be indicative of sediment waves being transported in the system more evident in 2002 due to the more detailed, continuous survey data collected as opposed to the 5-foot intervals on the 1929 river water surface. There does not appear to be any evidence of large-scale aggradation between 1929 and 2002 from this profile comparison.

References

Federal Geographic Data Committee. 1998. Geospatial Positioning Accuracy Standards Part 3: National standard for Spatial Data Accuracy, National Spatial Data Infrastructure, Subcommittee for Base Cartographic Data, Federal Geographic Data Committee, FGDC-STD-007.3-1998.

Jones, E.E. 1929. Plan and profile of Quinault River from mouth to Rustler River and Quinault Lake Dam Site, Washington, Printed in 1930, U.S. Geological Survey, Department of Interior.

Kresch, D.L. 2004. Written communication regarding shift analysis at USGS gages on Quinault River, transmitted via email.

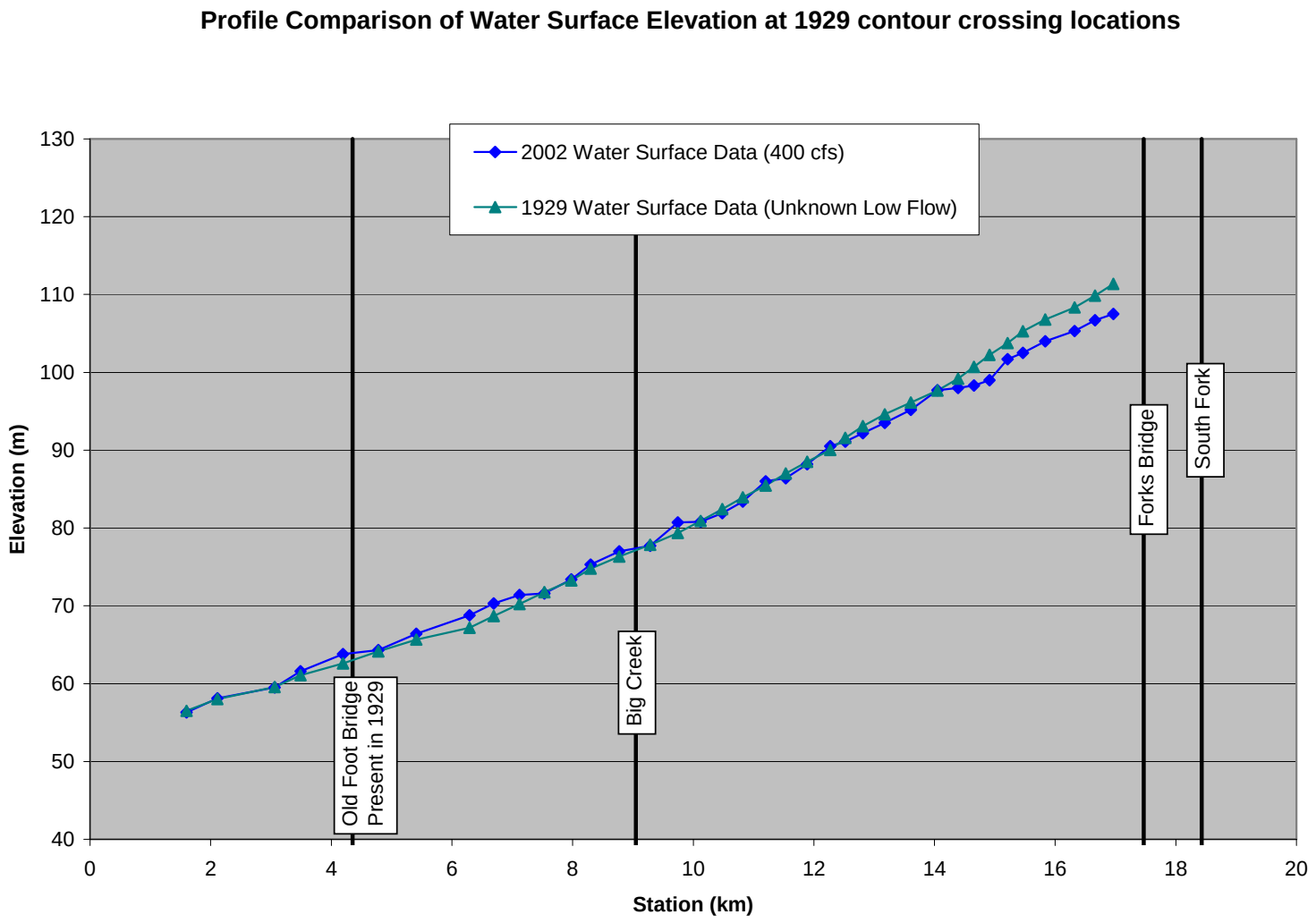


Figure 5. Qualitative comparison of 1929 to 2002 water surface profile data.

Attachment 1: Quinault 2002 Survey Control Report

The GPS control points and photography points for the Quinault survey were set and surveyed under less than ideal conditions. The area of the survey is a rain forest with heavy canopy in most places. Care and diligence were taken in point placement to assure the survey would meet the requirements of the project. Considerations for future access to the points were also deliberately considered. All necessary permissions were gained when private property was used for point placement.

The primary control points used to define the horizontal components of the survey were TEN OCLOCK (PID SY1510) and HATCHERY (PID SY5644). Both points are part of the Federal Base Control Network. TEN OCLOCK is 4.5 miles west of Amanda Park. HATCHERY is 17 miles south of Amanda Park. Note: HATCHERY is less than ideal due to vegetation restricting sky visibility.

A secondary, onsite control point 3 was also established. Point 3 has excellent sky visibility and is in a relatively secure area. Point 3 was tied to the primary control points with many hours of observation over the course of several days.

Average horizontal errors for the control points were 10 mm in the north and south components calculated at 2-sigma. Average horizontal errors for the photography points were 15 mm in the north and south components calculated at 2-sigma.

Average vertical errors for the control points were 10-12 mm in the ellipsoid heights calculated at 2-sigma. Average vertical errors for the photography points were 15-18 mm in ellipsoid heights calculated at 2-sigma.

Elevations (orthometric heights) were calculated by holding the elevation of one point, TEN OCLOCK, fixed and utilizing GEOID 99 in the adjustment. An eccentric point 9 was set and observed with an elevation transferred from H 476 (PID SY1497) to use as an elevation check. This check was satisfactory and accepted. A rigorous determination of orthometric heights was determined not to be necessary for the project. In the future, relative elevations within the project area can be obtained by using the same technique.

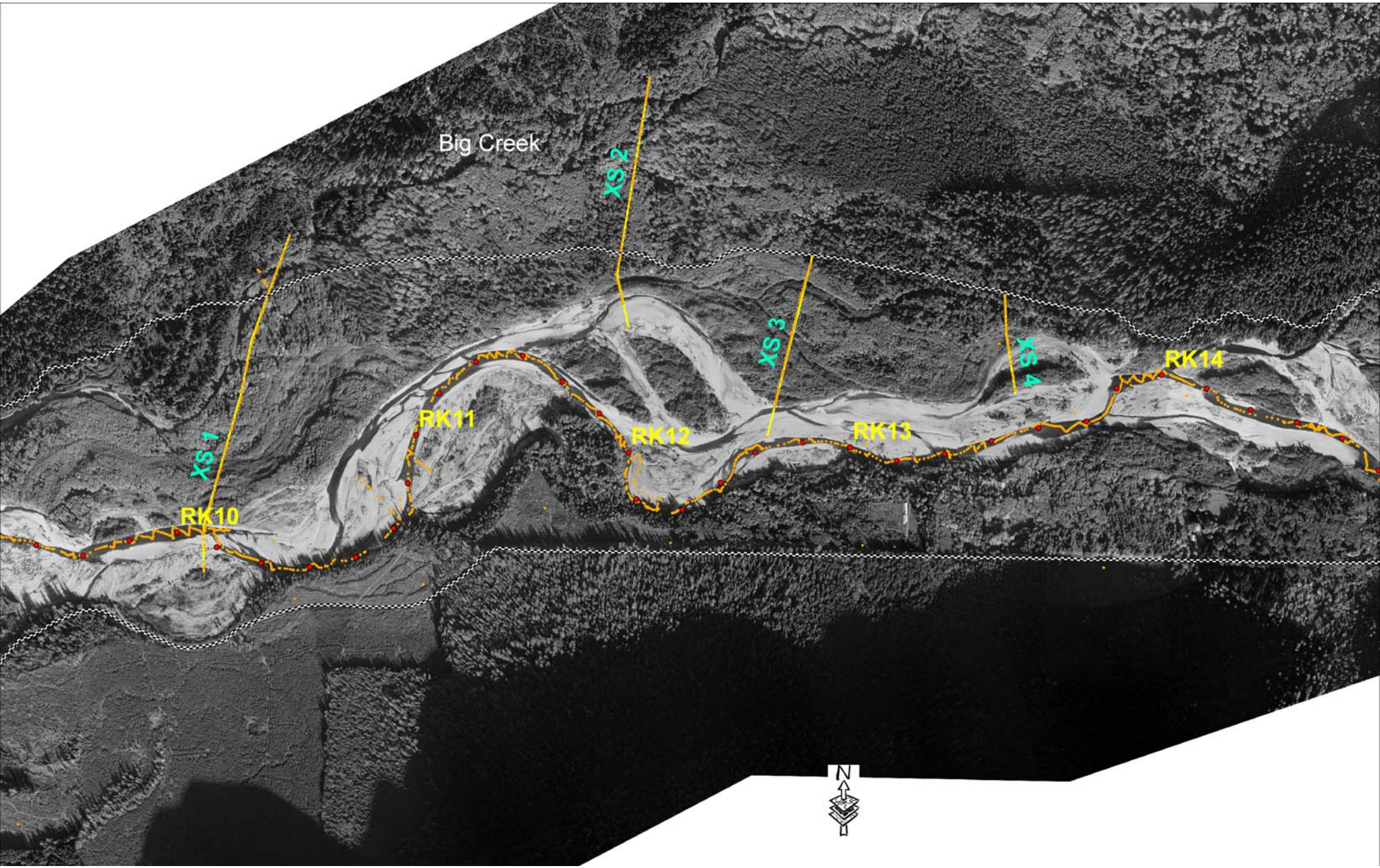
Checks performed during the hydrographic fieldwork provided checks to the GPS network and were found to be satisfactory.

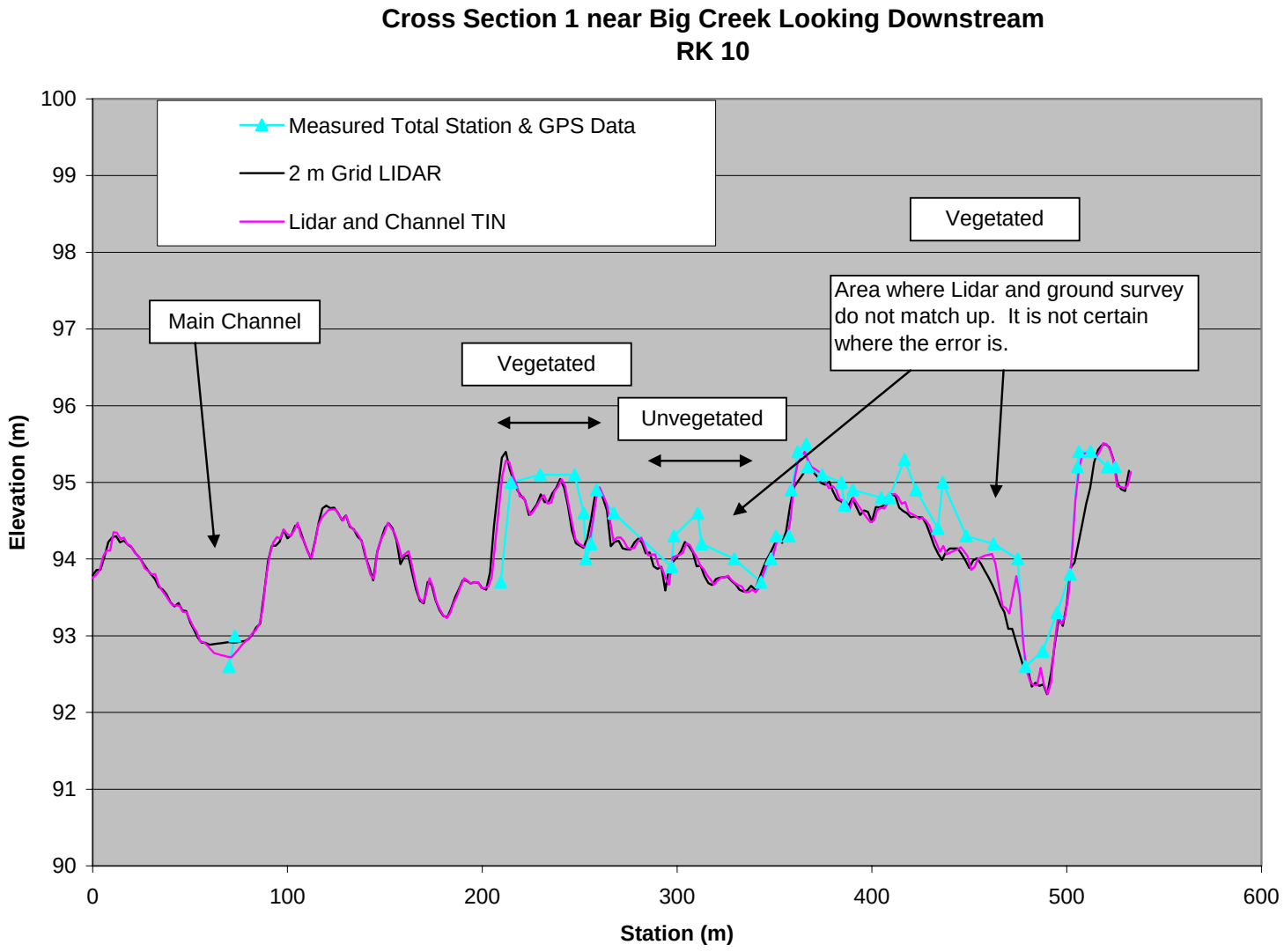
Photo Panel Point	Northing_UTM83m	Easting_UTM83m	Elevation_88m
2	5264267.446	441629.272	87.34
3	5259225.02	437604.275	59.571
5	5260623.411	439889.424	67.643
6	5262174.661	441573.417	75.169
1	5258856.384	425727.793	156.321
7	5231364.338	425406.47	36.477
102	5264801.381	447852.181	107.233
100	5264203.799	442803.656	81.832
101	5264110.853	442943.485	83.879
QUIN-8	5260622.932	436391.864	57.264
QUIN-10	5268483.316	449207.311	161.287
QUIN-7	5264105.989	445767.059	97.629
QUIN-9	5264845.238	445421.199	95.076
GPS8	5261523.884	438162.884	67.024
104	5264897.714	448548.678	112.085
105	5264683.585	448950.849	116.424
4	5260461.727	439361.876	63.693
9	5255407.016	433884.484	124.851
103	5264951.487	448744.834	113.234
106	5264714.97	448947.814	116.347
11	5262873.233	440889.612	75.113
QUIN-11	5262247.523	438395.254	77.635
QUIN-13	5266004.044	445588.733	102.958
QUIN-15	5261236.461	437797.598	63.114
QUIN-14	5267067.405	449537.839	130.356
QUIN-16	5266069.029	451335.038	125.483
QUIN-12	5266160.906	451905.943	128.275

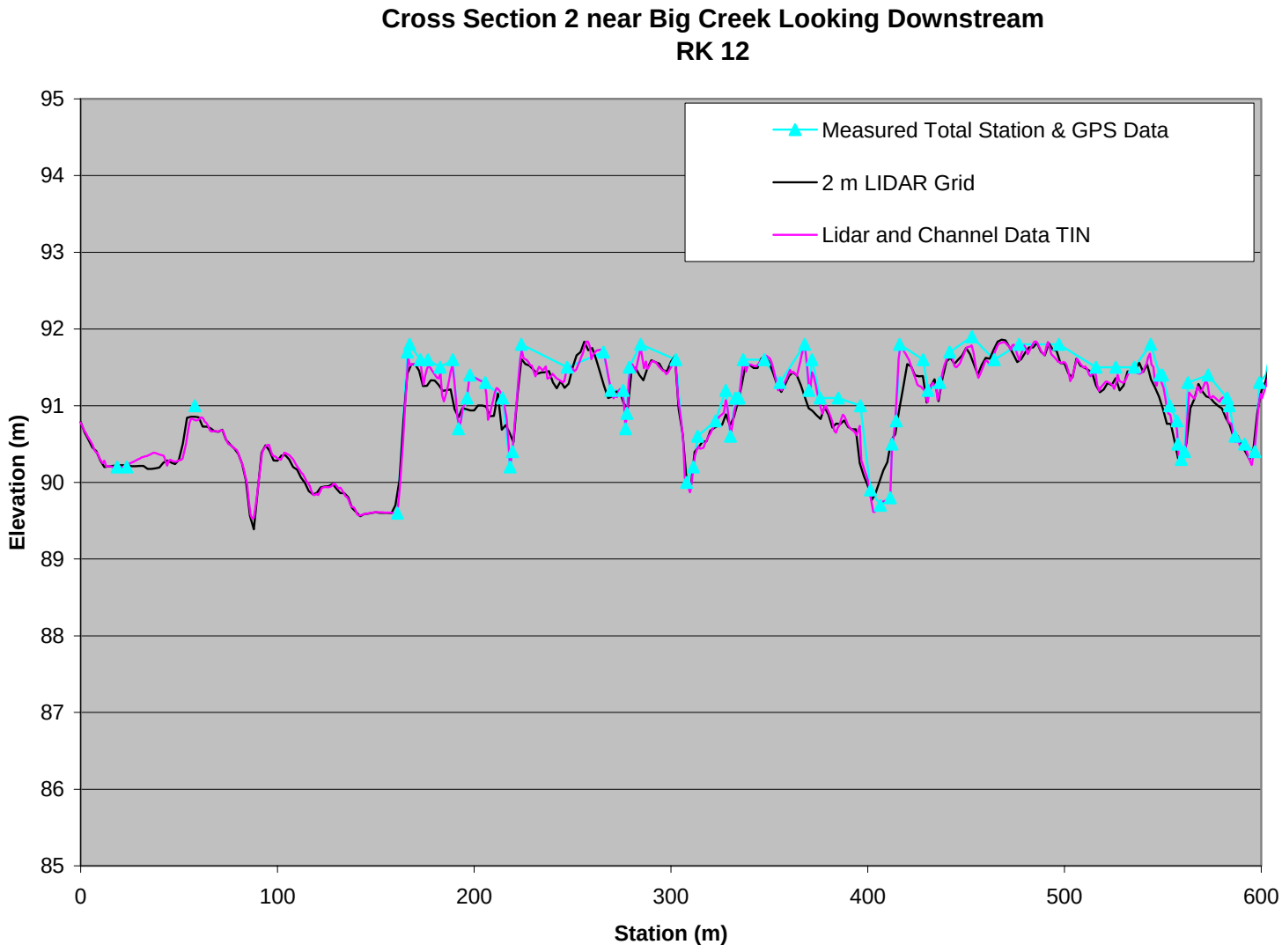
Attachment 2: Comparison of LiDAR data to ground survey data at four cross sections

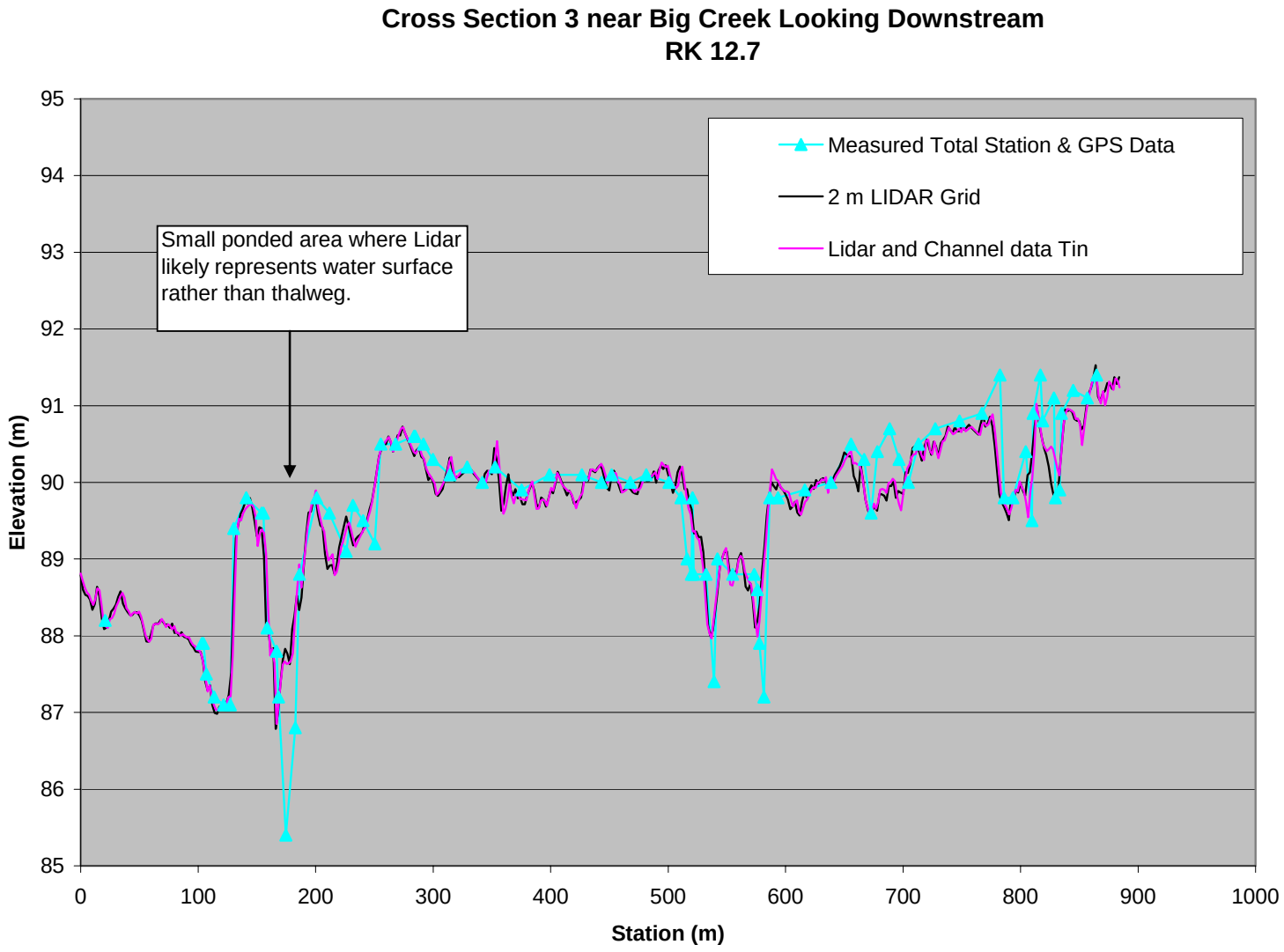
Figure Shown on Next Page:

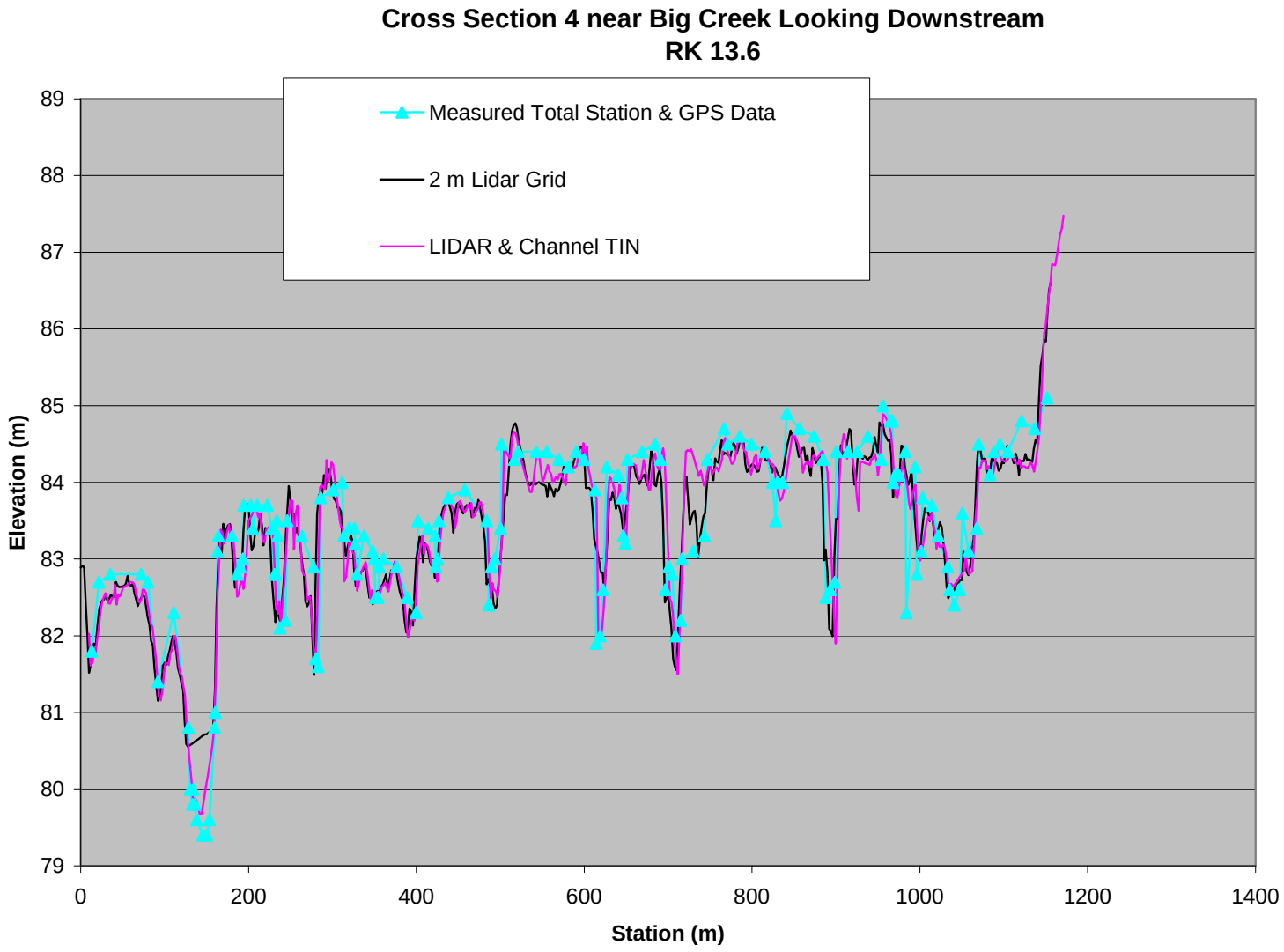
Figure 6. Location of four cross sections where LiDAR data (not shown) was compared to ground survey data (collected where orange dots and yellow lines are shown). River is flowing from left to right in photograph. River kilometers as assigned to the 2002 low flow channel are shown in yellow text and red dots.


Big Creek
XS 1
XS 2
XS 3
XS 4
RK10
RK11
RK12
RK13
RK14
N

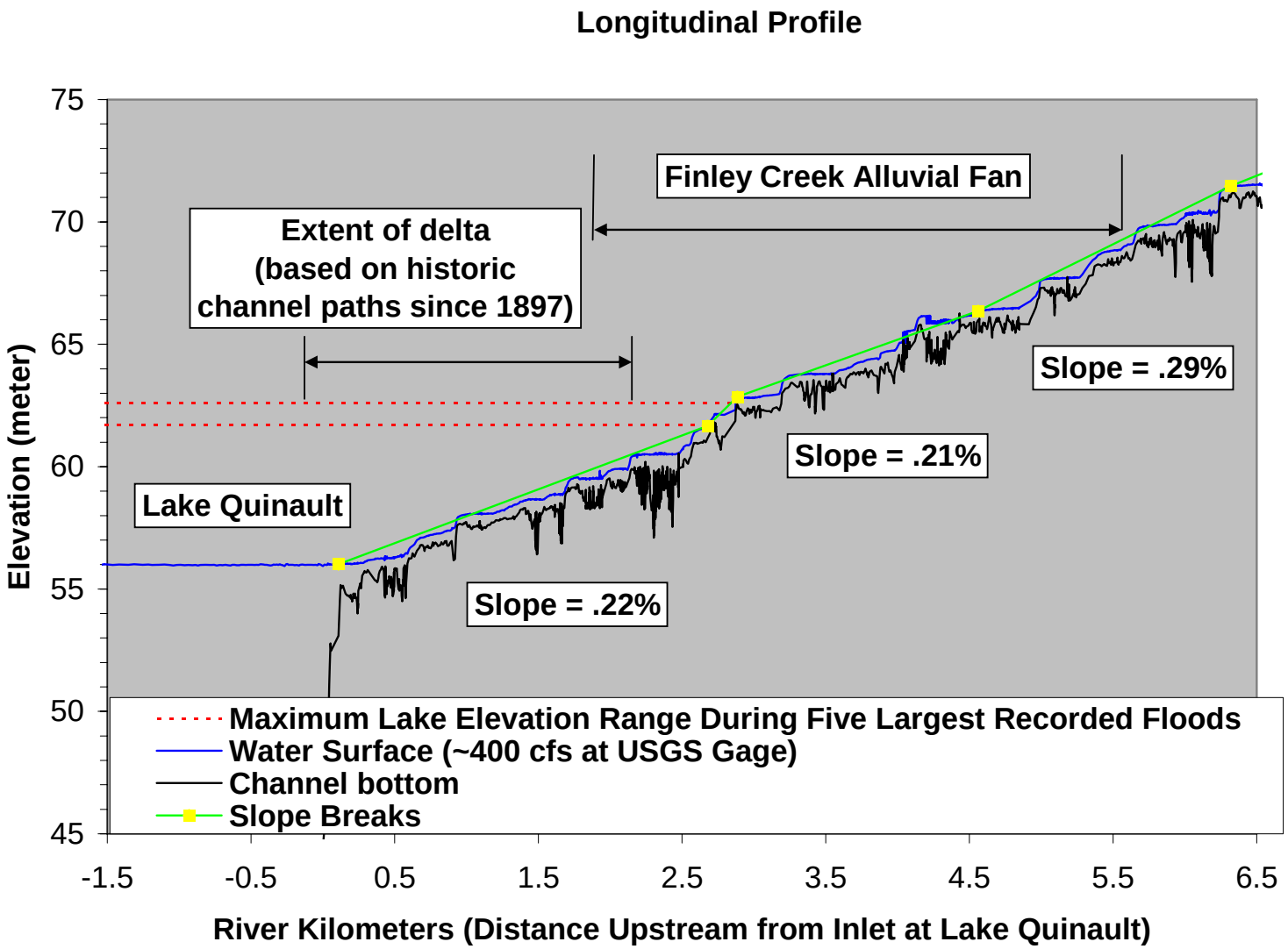

Cross Section 1 near Big Creek Looking Downstream
RK 10
Measured Total Station & GPS Data
2 m Grid LIDAR
Lidar and Channel TIN
Main Channel
Vegetated
Unvegetated
Vegetated
Area where Lidar and ground survey do not match up. It is not certain where the error is.
Elevation (m)
Station (m)
100
99
98
97
96
95
94
93
92
91
90
0
100
200
300
400
500
600

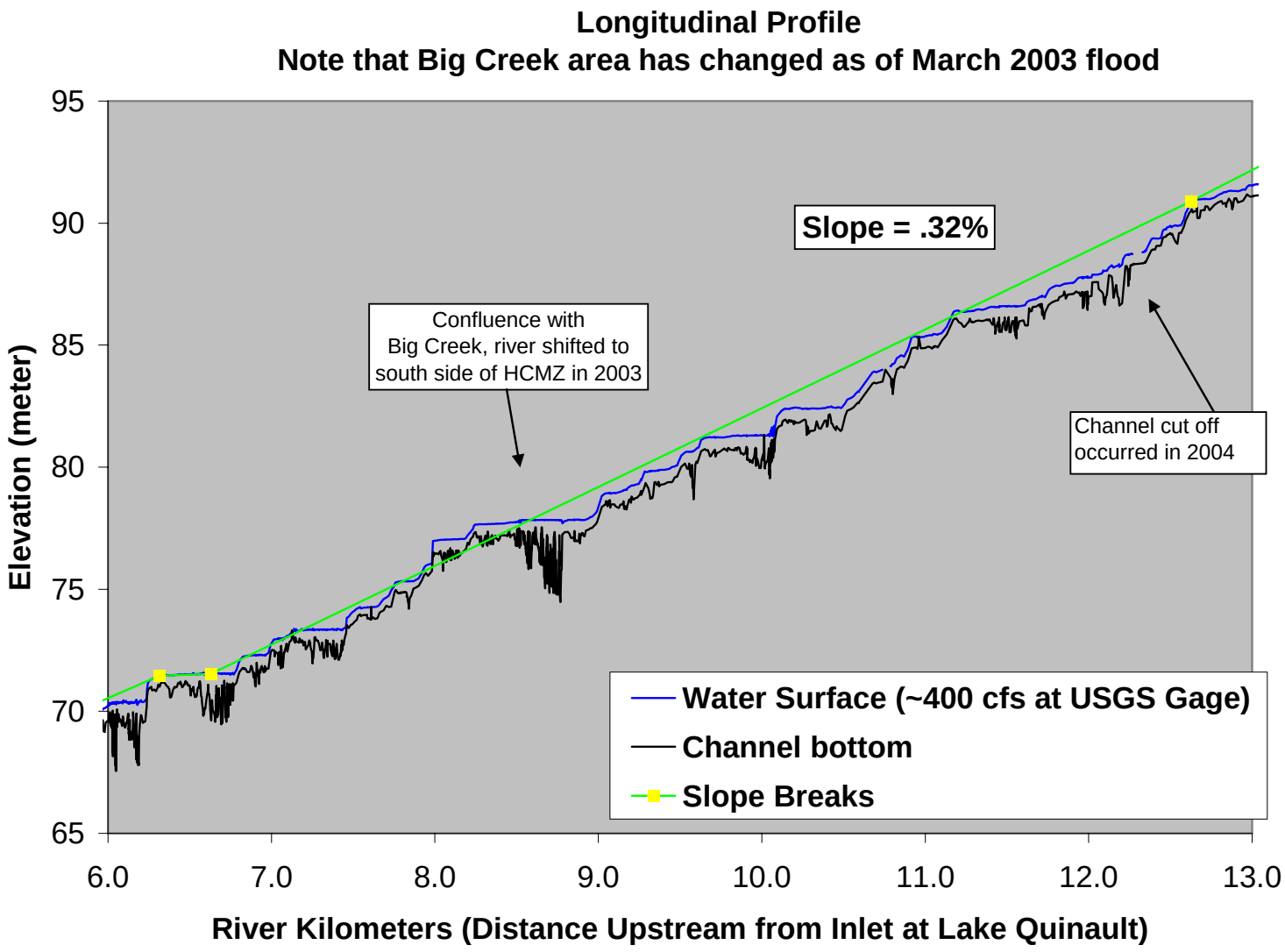

Cross Section 2 near Big Creek Looking Downstream
RK 12
Measured Total Station & GPS Data
2 m LIDAR Grid
Lidar and Channel Data TIN
Elevation (m)
95
94
93
92
91
90
89
88
87
86
85
0
100
200
300
400
500
600
Station (m)

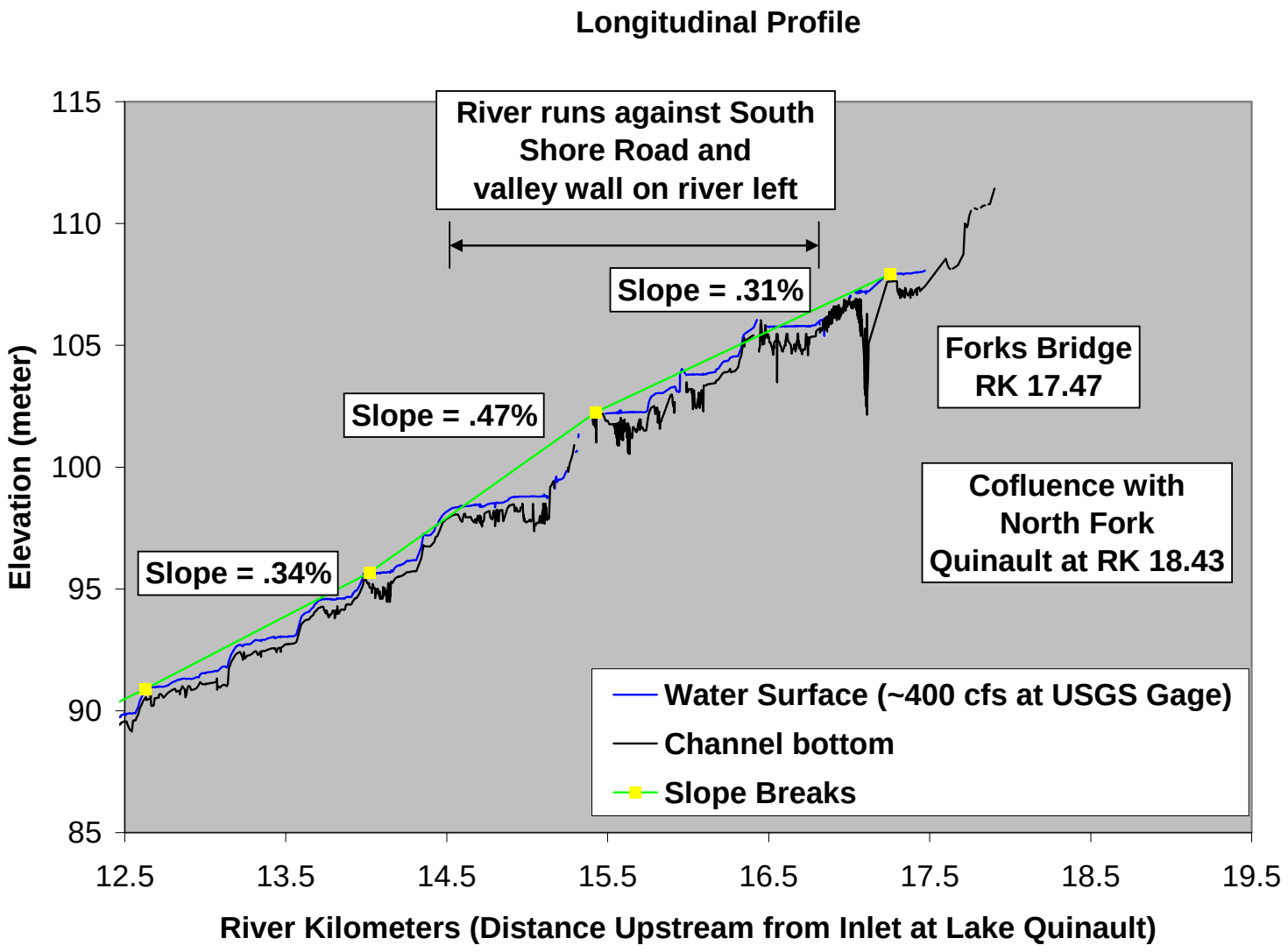

Cross Section 3 near Big Creek Looking Downstream
RK 12.7
Measured Total Station & GPS Data
2 m LIDAR Grid
Lidar and Channel data Tin
Small ponded area where Lidar likely represents water surface rather than thalweg.
Elevation (m)
Station (m)
95
94
93
92
91
90
89
88
87
86
85
0
100
200
300
400
500
600
700
800
900
1000


Cross Section 4 near Big Creek Looking Downstream
RK 13.6
Measured Total Station & GPS Data
2 m Lidar Grid
LIDAR & Channel TIN
Elevation (m)
89
88
87
86
85
84
83
82
81
80
79
0
200
400
600
800
1000
1200
1400
Station (m)

Attachment 3: Longitudinal profile summaries of low flow Quinault River channel.


Longitudinal Profile
Finley Creek Alluvial Fan
Extent of delta
(based on historic
channel paths since 1897)
Slope = .29%
Slope = .21%
Lake Quinault
Slope = .22%
Maximum Lake Elevation Range During Five Largest Recorded Floods
Water Surface (~400 cfs at USGS Gage)
Channel bottom
Slope Breaks
Elevation (meter)
75
70
65
60
55
50
45
-1.5
-0.5
0.5
1.5
2.5
3.5
4.5
5.5
6.5
River Kilometers (Distance Upstream from Inlet at Lake Quinault)


Longitudinal Profile
Note that Big Creek area has changed as of March 2003 flood
Slope = .32%
Confluence with
Big Creek, river shifted to
south side of HCMZ in 2003
Channel cut off
occurred in 2004
Water Surface (~400 cfs at USGS Gage)
Channel bottom
Slope Breaks
Elevation (meter)
95
90
85
80
75
70
65
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
River Kilometers (Distance Upstream from Inlet at Lake Quinault)


Longitudinal Profile
River runs against South Shore Road and valley wall on river left
Slope = .31%
Slope = .47%
Slope = .34%
Forks Bridge RK 17.47
Cofluence with North Fork Quinault at RK 18.43
Water Surface (~400 cfs at USGS Gage)
Channel bottom
Slope Breaks
Elevation (meter)
115
110
105
100
95
90
85
12.5
13.5
14.5
15.5
16.5
17.5
18.5
19.5
River Kilometers (Distance Upstream from Inlet at Lake Quinault)

APPENDIX B. CROSS SECTIONS & HYDRAULIC MODEL DOCUMENTATION

Typical representations of the topography along the valley bottom, river channel, and floodplain in the Upper Quinault River were needed for the sedimentation and geologic investigations of our study. Cross-sections were used to evaluate difference in ground surface elevation between side channels, main channel(s), and other geologic surfaces described in the report. Cross-sections were also utilized to estimate the depth of sediment in storage in gravel bars and vegetated surfaces (depth above average main channel bottom). The cross sections were input to a hydraulic model. The model was used to get a cursory level approximation of: 1) if hydraulic controls present in the low flow channel get drowned out at higher flows; and 2) how average hydraulic parameters (velocity and slope) changed throughout the study reach at the 2-year flood level. The hydraulic model was not calibrated and verified to a level that would be done in standard engineering practice, which would be necessary if the model is to be used for design level application in future studies or restoration project implementation.

Cross-section generation

Cross-sections were generated approximately every 0.5 kilometer from Lake Quinault to just upstream of the Forks (Figure 1). Cross-section data was generated in a geographical information system (GIS) from a digital terrain model (DTM) that represented the channel and flood plain topography (see topographic data appendix for discussion on accuracy of DTM and Lidar data). The program utilized by Reclamation to generate the cross-sections is called Georas, which is beta version software developed by the Corps of Engineers to provide an interface between GIS data and their hydraulic model Hec-Ras (see next section). Summary plots of each cross-section are provided in Attachment 1. Note that the cross-sections are labeled by corresponding river distance in meters along the 2002 low flow channel increasing in the upstream (see Figure 1), and are in SI (metric) units. Three cross-sections were added beyond the extent of the river channel to incorporate the lake geometry at the downstream end of the model (and study reach) based on measured survey from October 2002. These cross sections are labeled 100, 200, and 300. Nine cross sections were interpolated using an interpolation program in Hec Ras between the end of the lake cross-sections and the start of the first river cross-section (between cross section river stations 300 and 343).

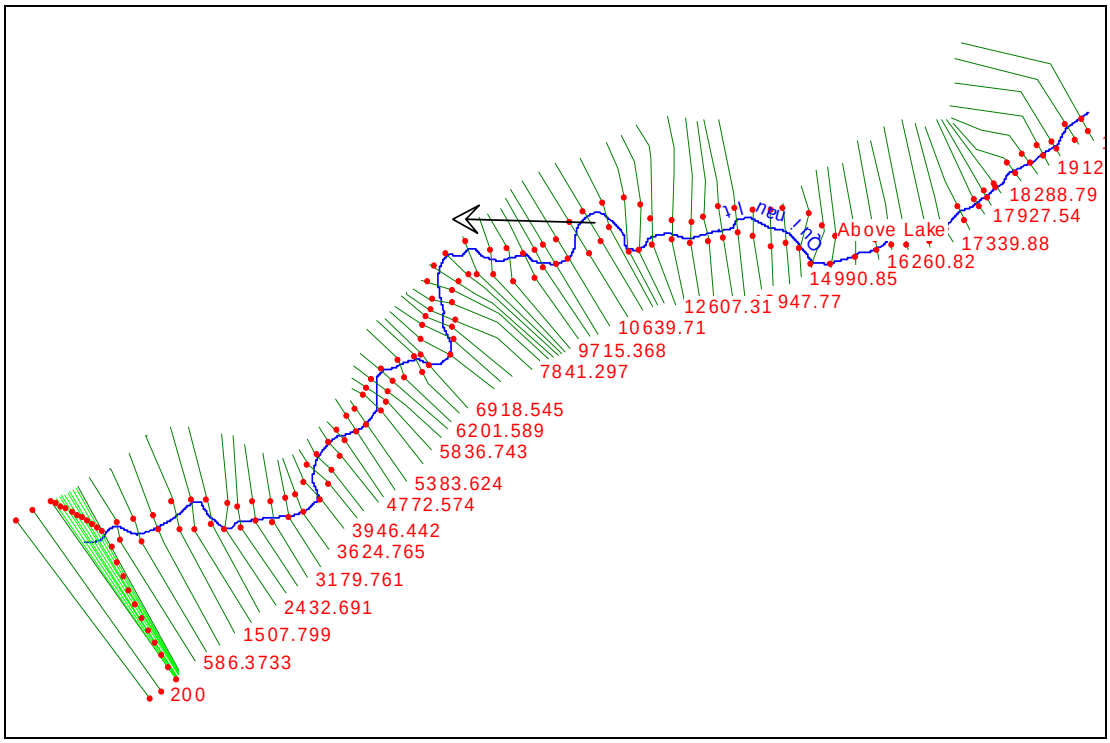


Figure 1. Cross-section identification drawing. Cross-section stationing shown in red numbers which represents the distance in meters upstream from Lake Quinault. Red dots represent width of unvegetated active channel.

Model Documentation

The one-dimensional U.S. Army Corps of Engineers numerical HEC-RAS computer model (Hydraulic Engineering Center - River Analysis System, version 3.1.1, Brunner, May 2003) was applied to the Quinault River to predict average hydraulic properties (water surface elevation, depth, mean velocity, and channel capacity). The HEC-RAS model performs water surface profile and other hydraulic calculations for one-dimensional steady flow. The model was forced to work in the sub-critical and critical flow regimes. The model predicts river stage and other hydraulic properties at each cross section along the river for any specified discharge. Water discharges used in the model were the measured discharge during the river channel survey and flood frequencies developed at the USGS gage at the outlet of Lake Quinault ranging from the 2- to the 100-year flood. Note that cross-sections and discharges in the model are in SI (metric) units.

Several types of energy loss coefficients are utilized in the HEC-RAS model. The primary one is friction losses associated with channel bed roughness, which is set using the Manning's *n* value. Manning's *n* values are determined based on the surface roughness, vegetation, channel irregularities, channel alignment, scour and deposition, obstructions, size and shape of the channel, stage and discharge, seasonal change, temperature, and suspended load and bedload. No measured Manning's n data was available for the Quinault River, and therefore, best estimates were made based on past

experience in other gravel bed rivers. A Manning's n of .04 was used in the active channel areas, and .08 in the overbank areas. These roughness estimates could be further refined to identify localized areas where roughness differs from the average roughness within the active channel or floodplain if additional modeling is needed at a more detailed level for future studies (create more roughness breaks across each section).

Two flows were modeled for our study: 1) the measured flow of 11.5 m^3/s to get a rough idea of the model's ability to replicate measured flow conditions; and 2) a 2-year flood to provide estimates of velocity for unit stream power computations we did in our sedimentation analysis. An additional rating curve set of flows was also modeled that ranged from a low flow of 10 m^3/s to near the 100-year flood of 1600 m^3/s. Hydraulic results from the rating curve analysis were used in our study to evaluate sediment transport capacity at particular cross-sections.

The 2-year flood was modeled two ways. The first approach was to use one 2-year flood value of 630 m^3/s determined from the measured gaging station data for the entire study reach (no change in magnitude in downstream direction as a result of tributary and runoff flow contribution). The second approach was to use 2-year flood values determined from using a USGS empirical approach that incorporates basin size and precipitation data (Table 1) (see attachment 2 of hydrology appendix for methodology).

Table 1. Flow values for 2-year flood based on empirical USGS equation that accounts for change in drainage basin size in downstream direction of study reach. The associated river kilometer (RK) location indicates the point at which the flow value is applied based on the cumulative basin size upstream of that location.

Return Period (years)	Location 1 (RK 18) (peak m^3/s)	Location 2 (RK 8) (peak m^3/s)	Location 3 (RK 0) (peak m^3/s)
2	530	630	700

This second approach results in an increase in discharge in the downstream direction of the study reach due to the increase in drainage basin size. In reality the 2-year flood would gradually increase in magnitude in the downstream direction from smaller tributaries and runoff from hillslopes, and have larger increases at the confluence with major tributaries. However, due to the limited hydrology and river flow data available, only the key points where the flow is assumed to increase the most were incorporated into the model. The largest increases in basin size occur when the two forks of the Quinault River join together at what is know as the Forks (river kilometer 18), at the confluence with Big Creek at river kilometer 8, and at the confluence with the Finley Creek alluvial fan located between river kilometer 2.5 to 4.5. Our hydrology analysis provided estimates of flow increase at the confluence with Big Creek and at the inlet to Lake Quinault. Because flow paths from Finley Creek extend for 2 kilometers across the main channel, a specific confluence location was not identified, but the value at the inlet to Lake Quinault would incorporate the additional increase in drainage basin size from Finley Creek. The flow values from the empirical hydrology analysis were incorporated into the hydraulic model by applying the discharges to three reaches:

1. River kilometer 0 to 4.5 using Location 3 flow value (700 m^3/s);
2. River kilometer 4.5 to 8 using Location 2 flow value (630 m^3/s); and
3. River kilometer 8 to 20 using the Location 1 flow value (530 m^3/s).

The downstream boundary condition in the model used was the recorded lake elevation (56 meters) during the survey for the measured survey data flow modeled (11.5 cms). For the 2-year flood, a relationship between river gage height and lake elevation developed by USGS was used to get a typical lake elevation of 59 meters recorded during 2-year flood magnitudes (~630 m^3/s) (see Chapter 2, p. 2.4 of watershed analysis for more information on USGS analysis, QIN, 1999). The highest lake level recorded was 62.7 meters associated with the flood of record of 52,600 m^3/s in November 1909. For all other model parameters such as constriction width coefficient, friction loss computation method, etc, the default parameters in Hec-Ras were utilized.

Existing Conditions Model Discussion

The existing conditions model was not calibrated or verified. However, a cursory level calibration check on the model was made by comparing the modeled water surface values to measured values for the October 2002 water surface elevation data collected by Reclamation during an average recorded discharge of 11.5 m^3/s (400 ft^3/s) (discharge as recorded at USGS gage at outlet of Lake Quinault). The comparison of the two data sets appeared reasonable given the data was collected at a fairly low flow (figures 2, 3, and 4). Because the model cross sections were spaced 0.5 kilometers apart the model does not always capture the influence of hydraulic controls (riffles and rapids) if they fall between cross section locations. These hydraulic controls are important at low flows when they have an influence on the water surface elevation upstream, but are less important when flows are high enough that these controls become drowned out (figure 5). Additionally, the model assumes a constant water surface elevation across each cross section, which in reality is not always true, particularly at split flow locations.

The model is presently most useful for qualitatively assessing hydraulics at larger flows that inundate the majority of the active channel and floodplain. Smaller flows on the Quinault River tend to be more complex and can follow several flow paths. If predictions are needed during low flow periods, a different modeling approach would be needed that incorporates closer spaced cross sections and would possibly require a two or three-dimensional model and/or groundwater components depending on the objective of the modeling. The present hydraulic model needs more calibration work and closer spaced cross sections if quantitative values are needed for smaller scale design purposes. However, using the model for relative comparisons of channel hydraulics at higher flows should provide reasonable results for reach scale comparisons (reaches several kilometers in length).

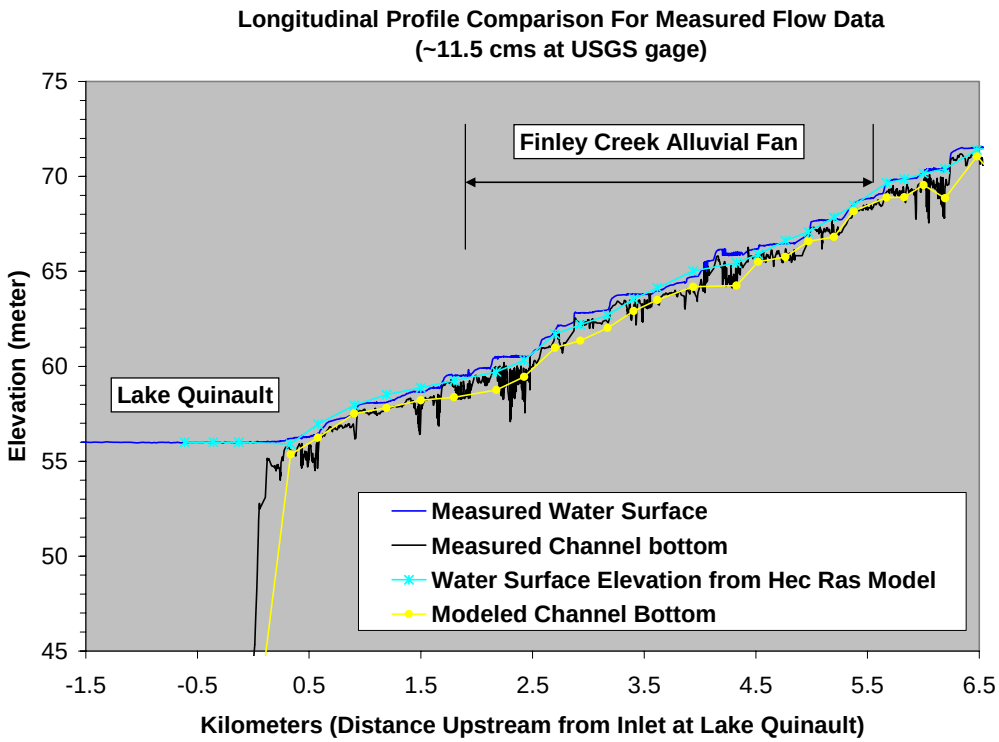


Figure 2. Comparison of measured to modeled water surface elevations in lower study reach.

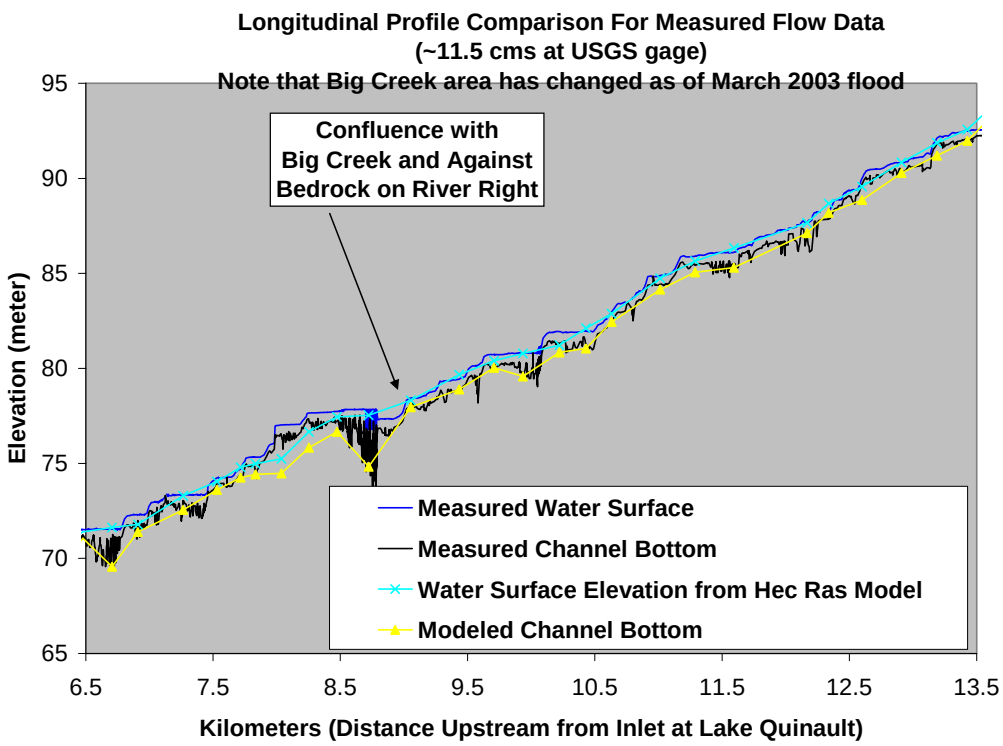


Figure 3. Comparison of measured to modeled water surface elevations in middle study reach.

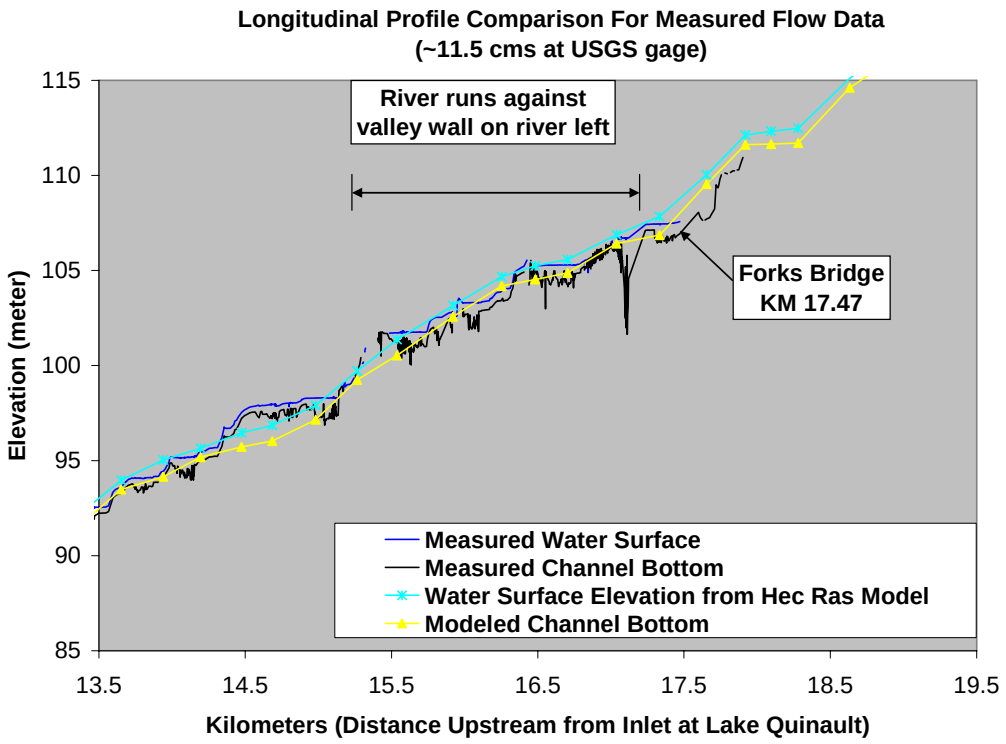


Figure 4. Comparison of measured to modeled water surface elevations in upper study reach.

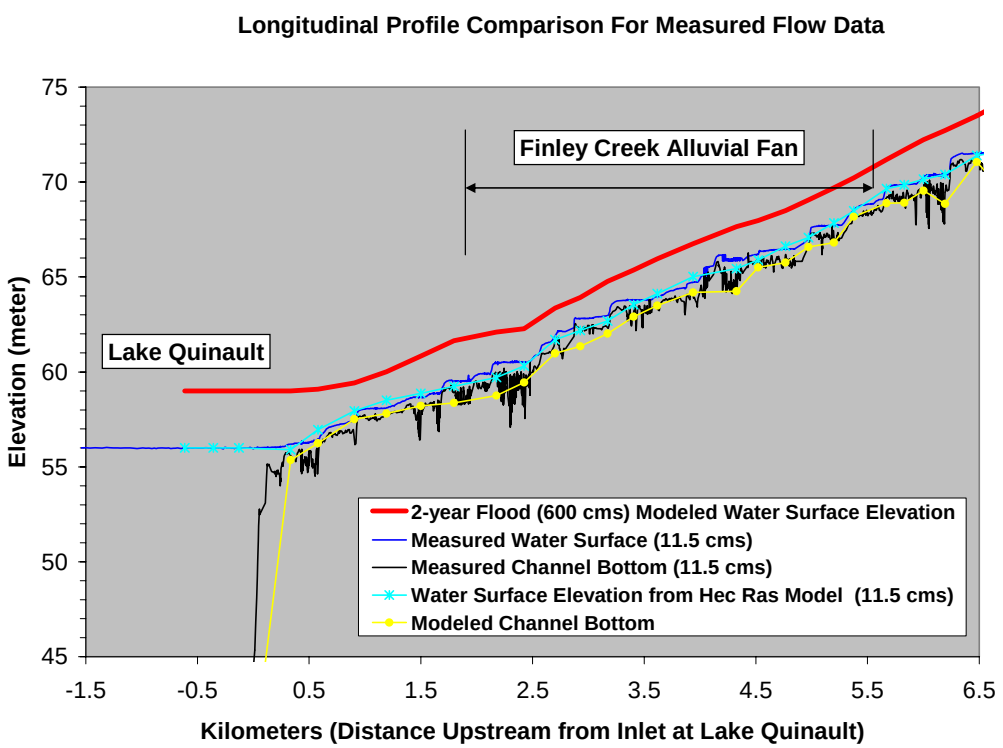
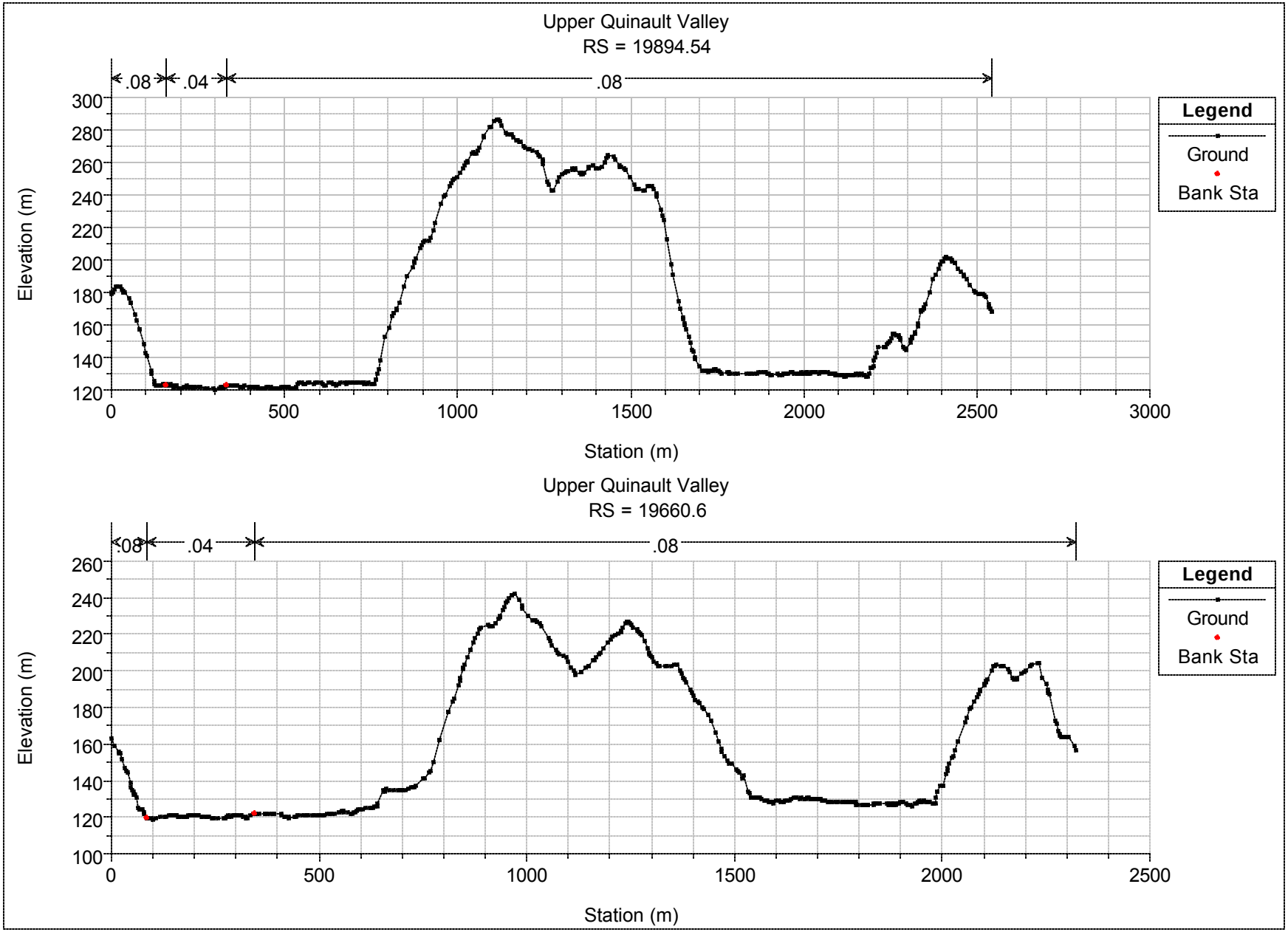
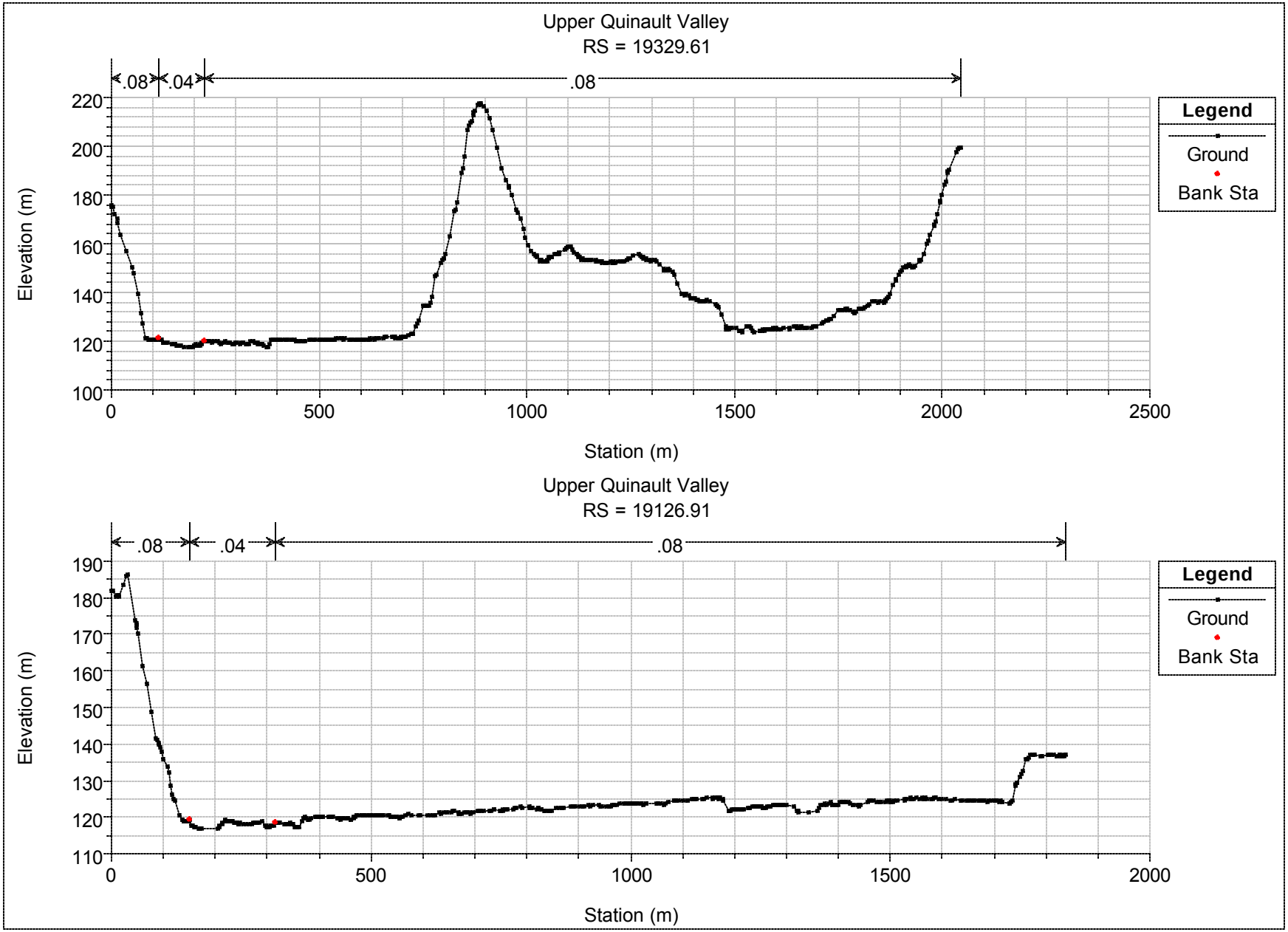
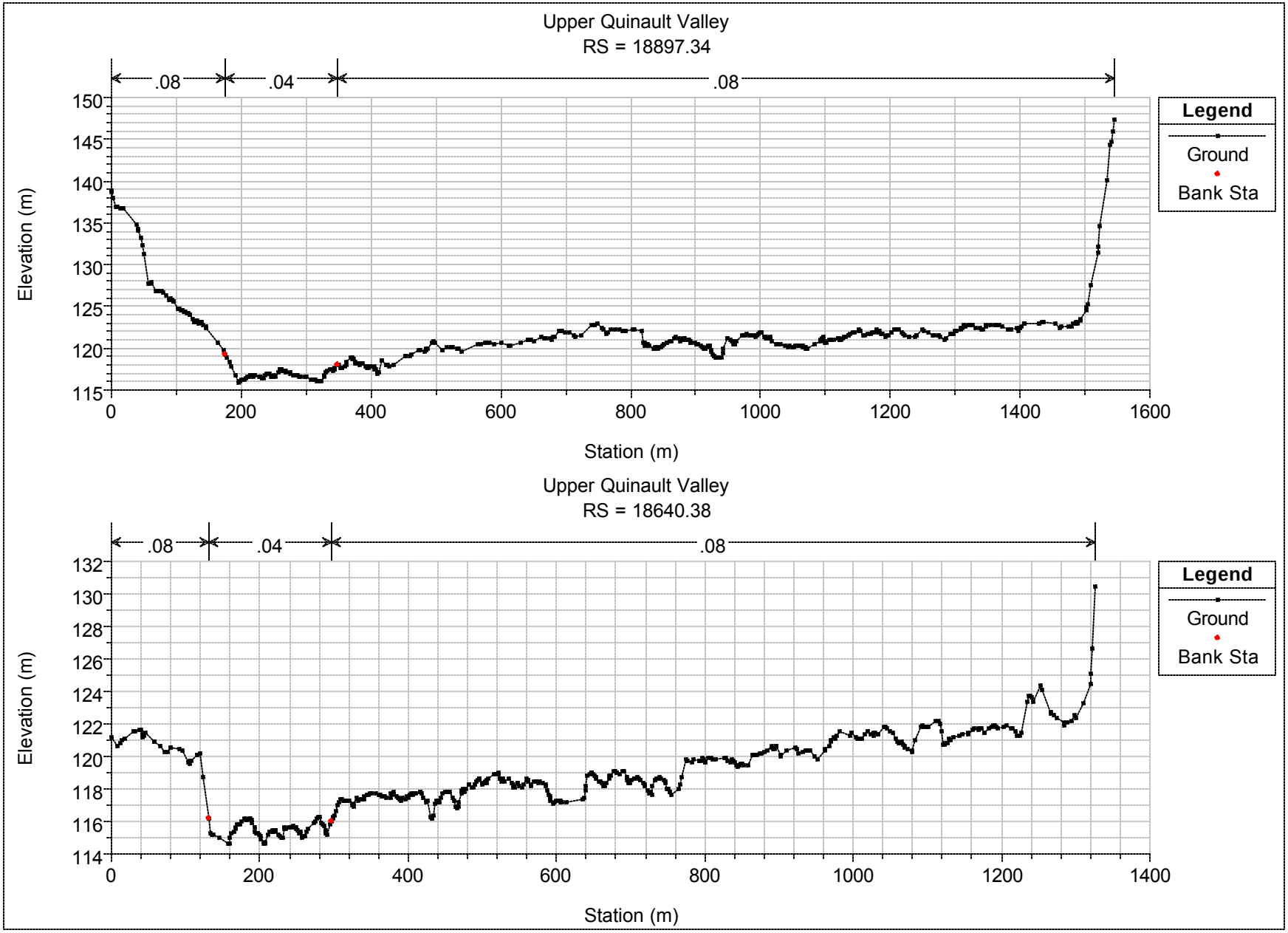


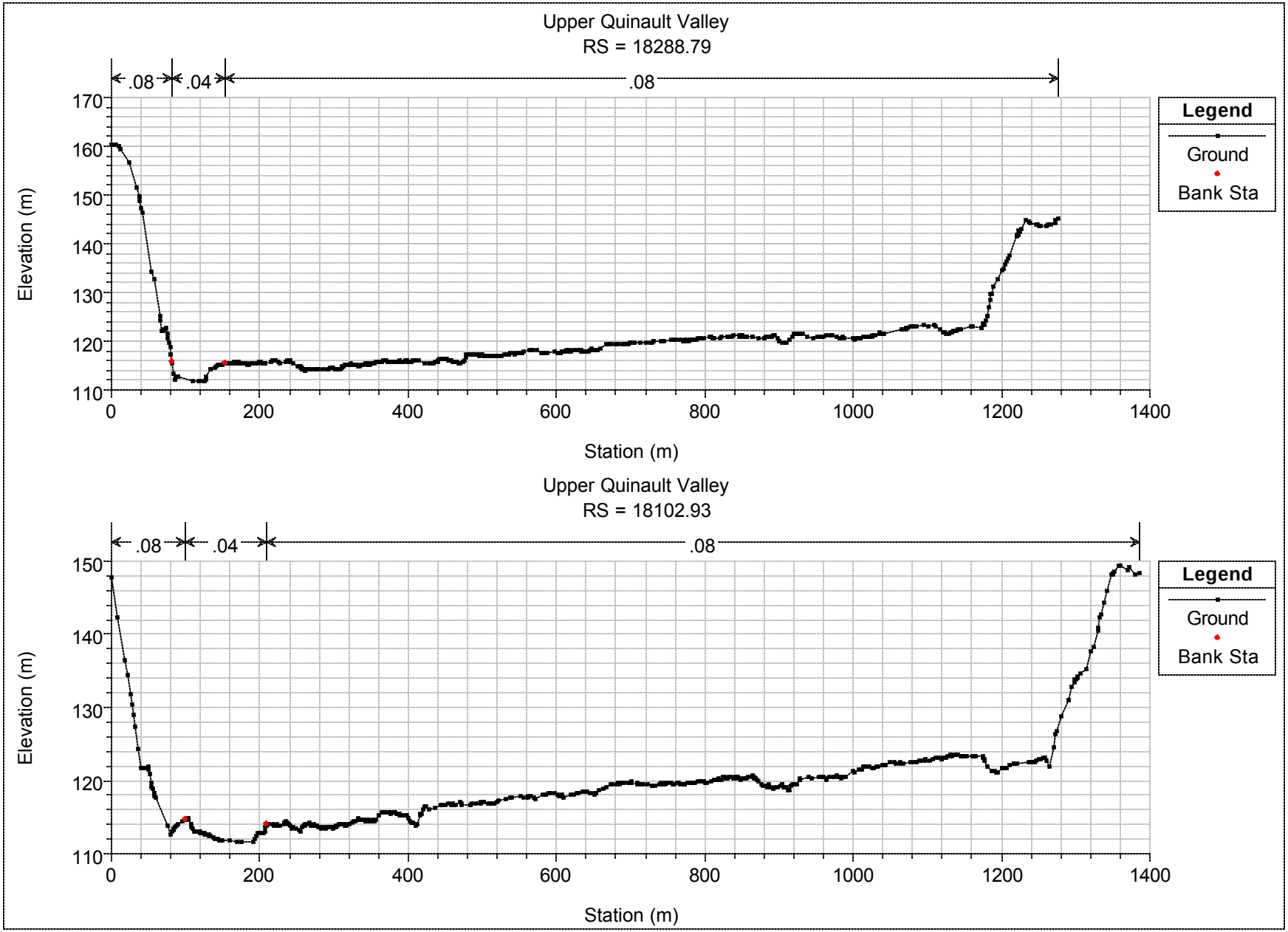
Figure 5. Comparison of 2-year flood to low flow water surface elevation demonstrating how most hydraulic controls get drowned out at larger flows.

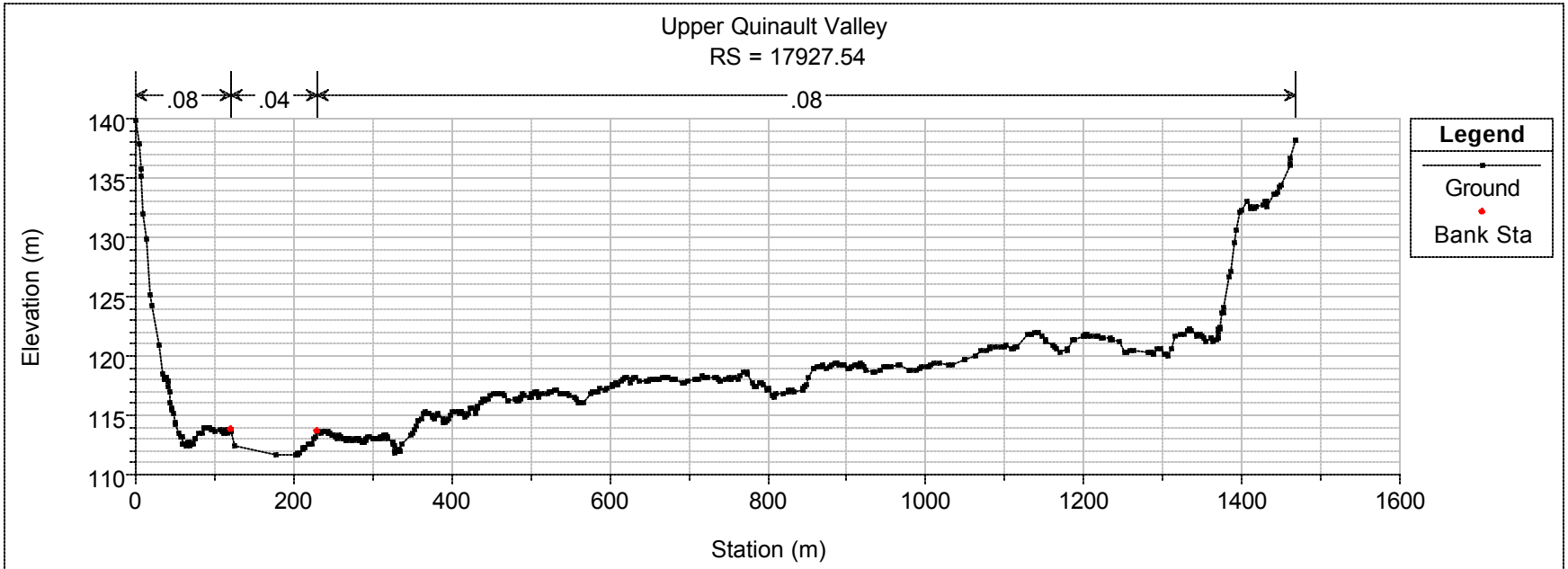
ATTACHMENT 1 - CROSS SECTION PLOTS

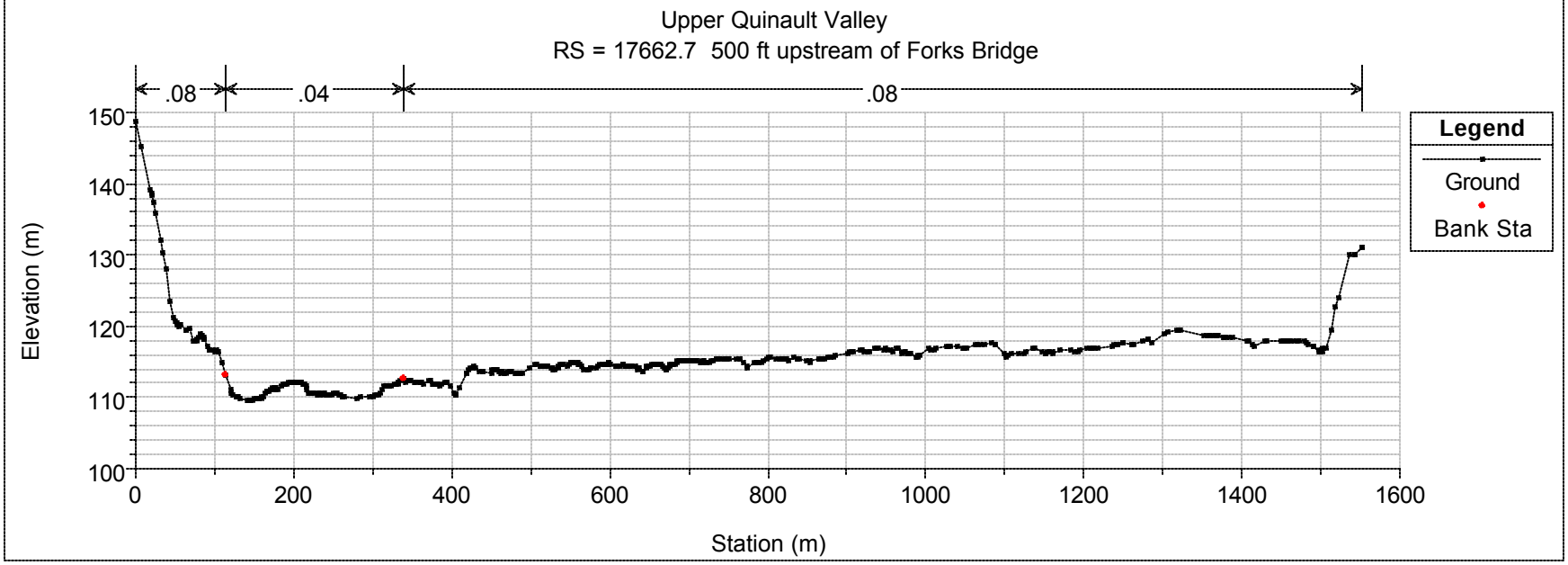

Upper Quinault Valley
RS = 19894.54
.08
.04
.08
Elevation (m)
Station (m)
Legend
Ground
Bank Sta
Upper Quinault Valley
RS = 19660.6
.08
.04
.08
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

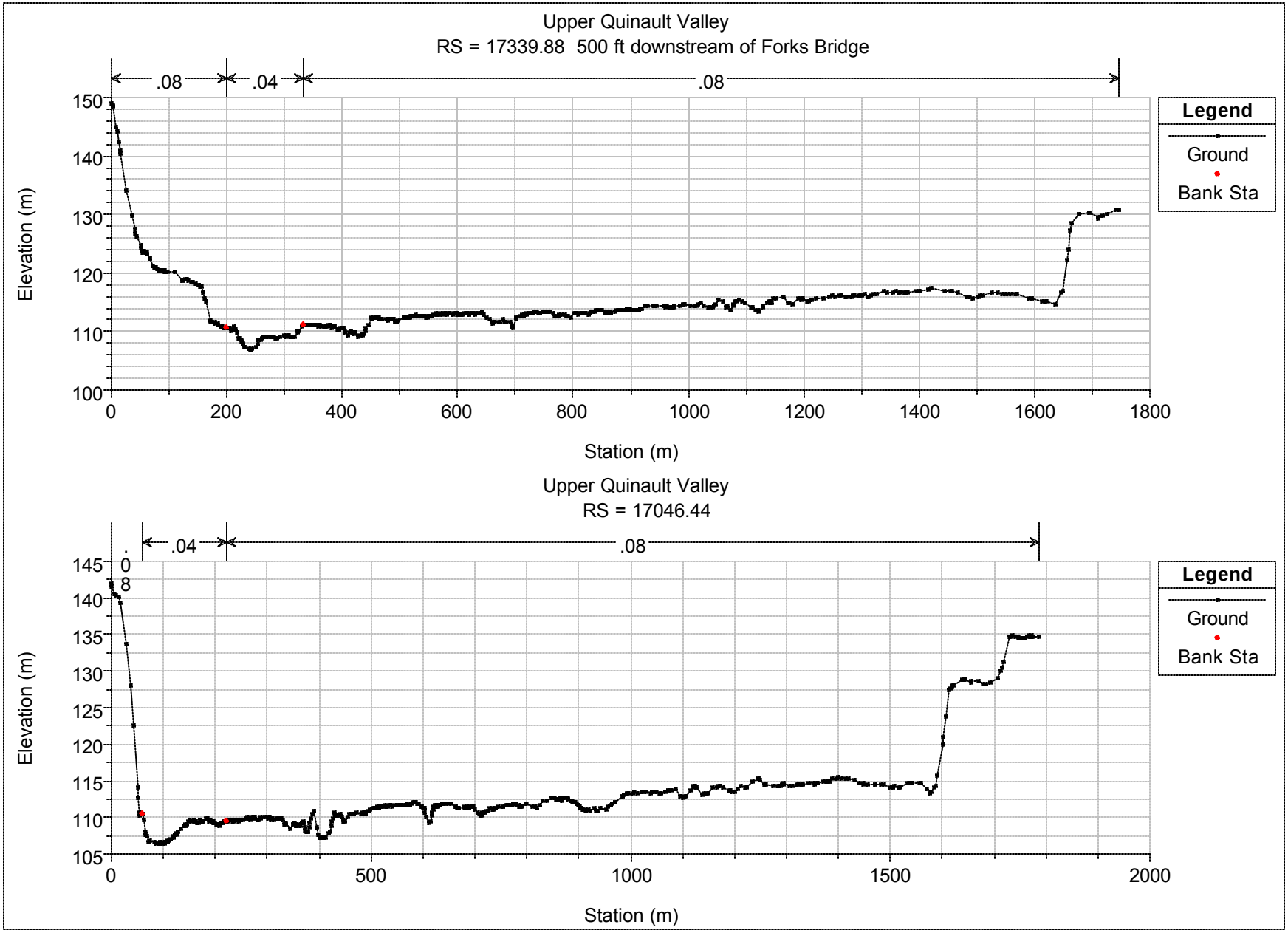

Upper Quinault Valley
RS = 19329.61
.08
.04
.08
Elevation (m)
Station (m)
Legend
Ground
Bank Sta
Upper Quinault Valley
RS = 19126.91
.08
.04
.08
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

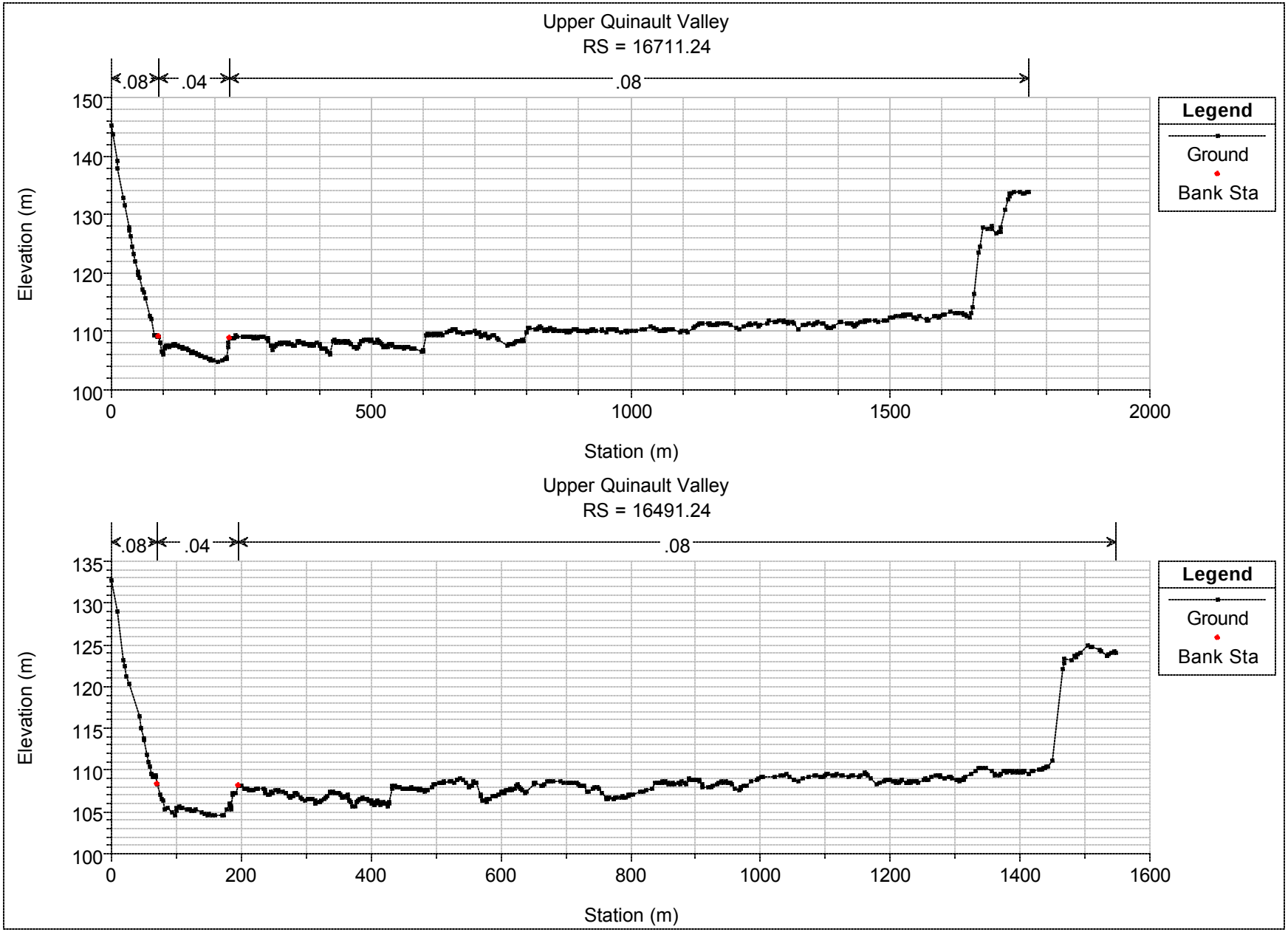

Upper Quinault Valley
RS = 18897.34
.08
.04
.08
Elevation (m)
Station (m)
Legend
Ground
Bank Sta
Upper Quinault Valley
RS = 18640.38
.08
.04
.08
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

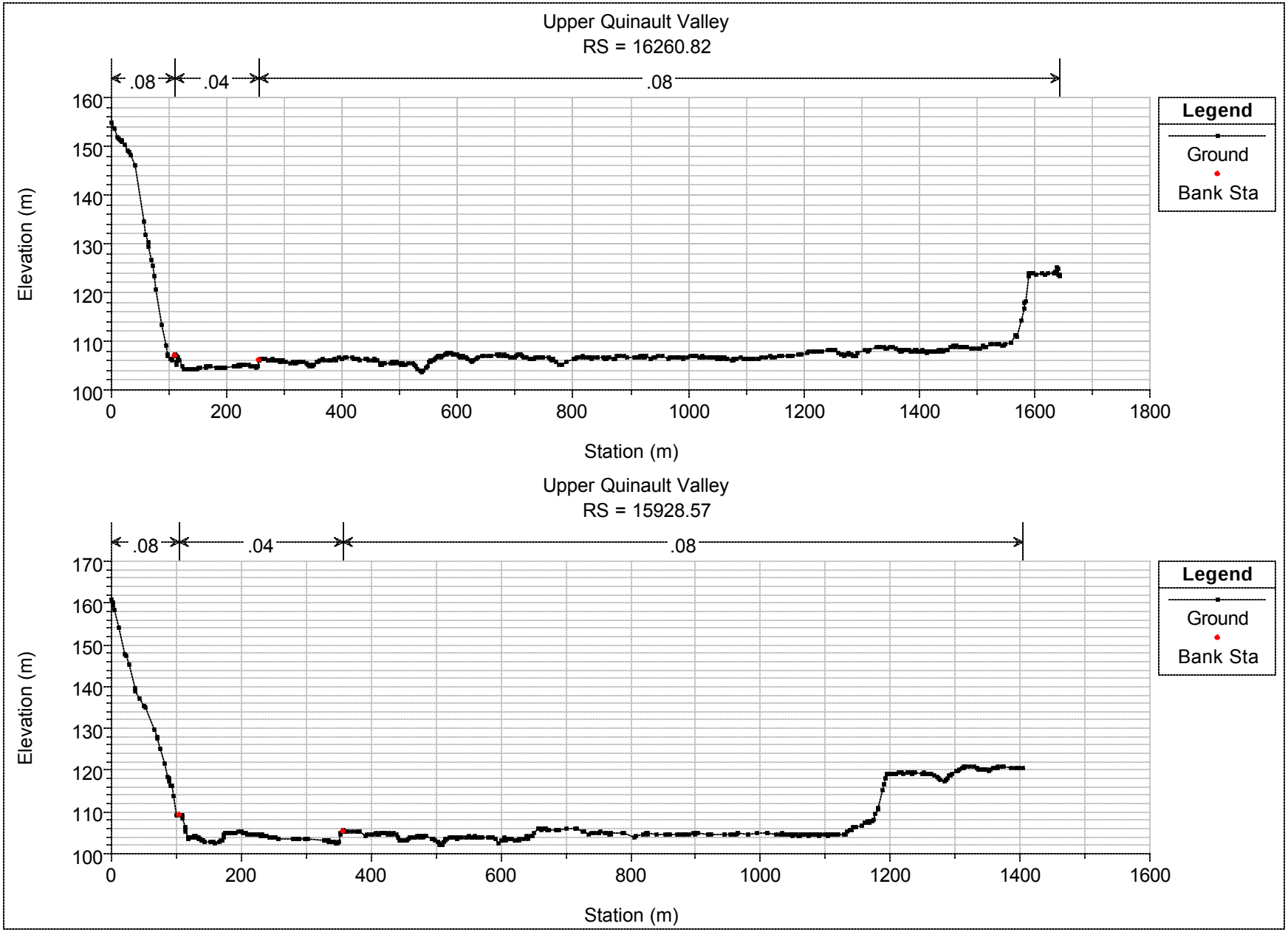

Upper Quinault Valley
RS = 18288.79
.08
.04
.08
Elevation (m)
Station (m)
Legend
Ground
Bank Sta
Upper Quinault Valley
RS = 18102.93
.08
.04
.08
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

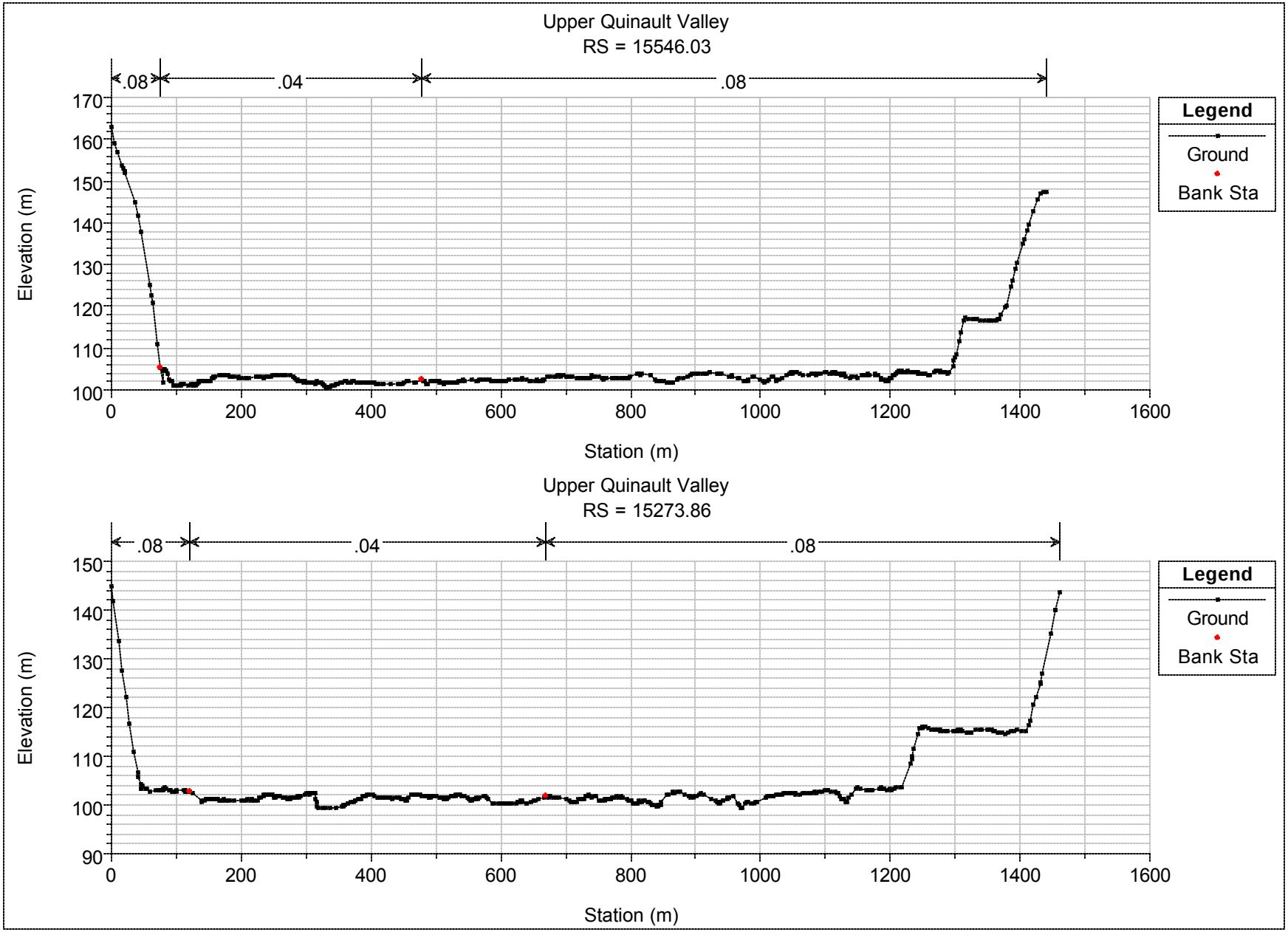

Upper Quinault Valley
RS = 17927.54
.08
.04
.08
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

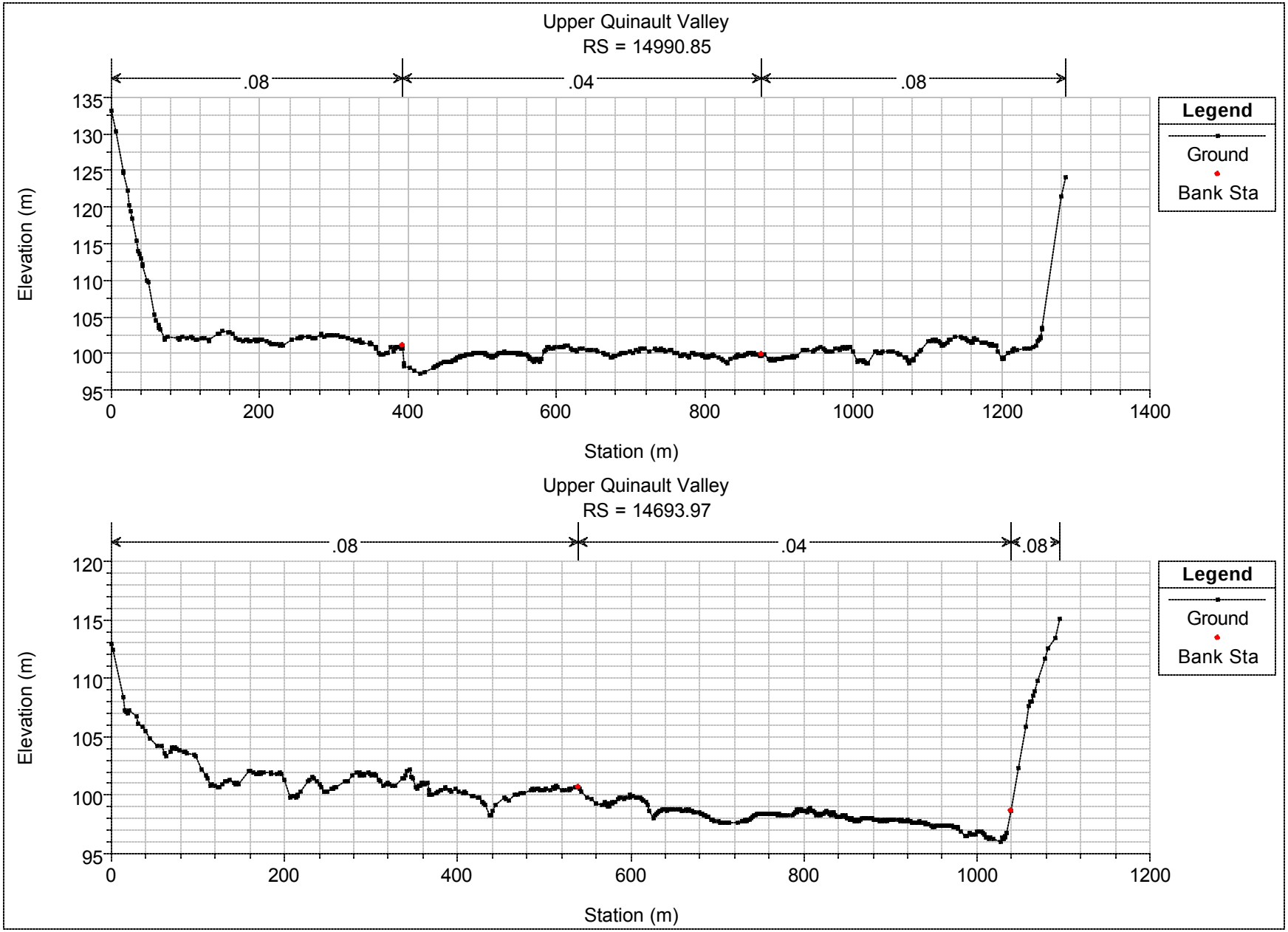

Upper Quinault Valley
RS = 17662.7 500 ft upstream of Forks Bridge
.08
.04
.08
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

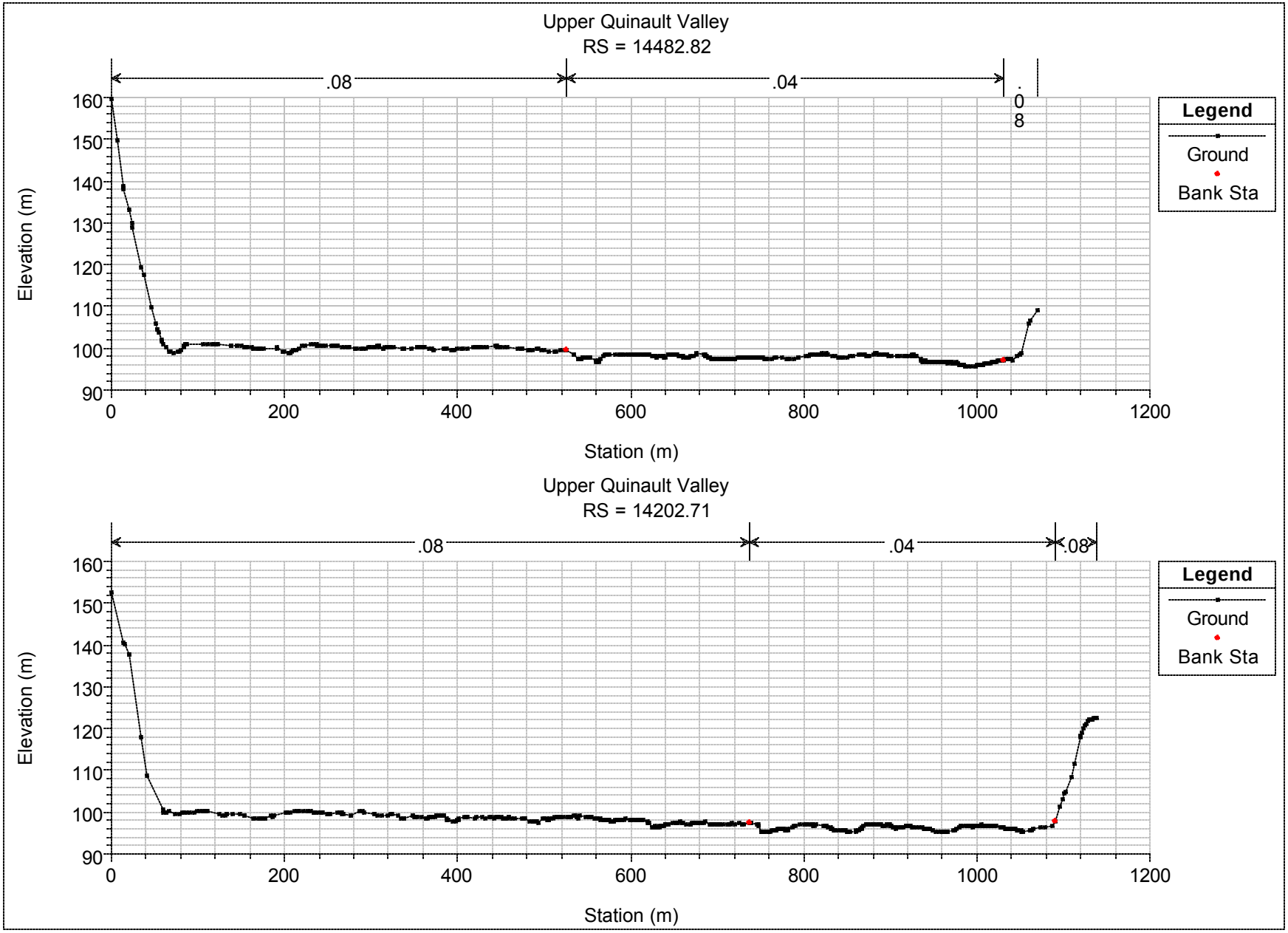

Upper Quinault Valley
RS = 17339.88 500 ft downstream of Forks Bridge
.08
.04
.08
Legend
Ground
Bank Sta
Elevation (m)
Station (m)
Upper Quinault Valley
RS = 17046.44
.04
.08
.08
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

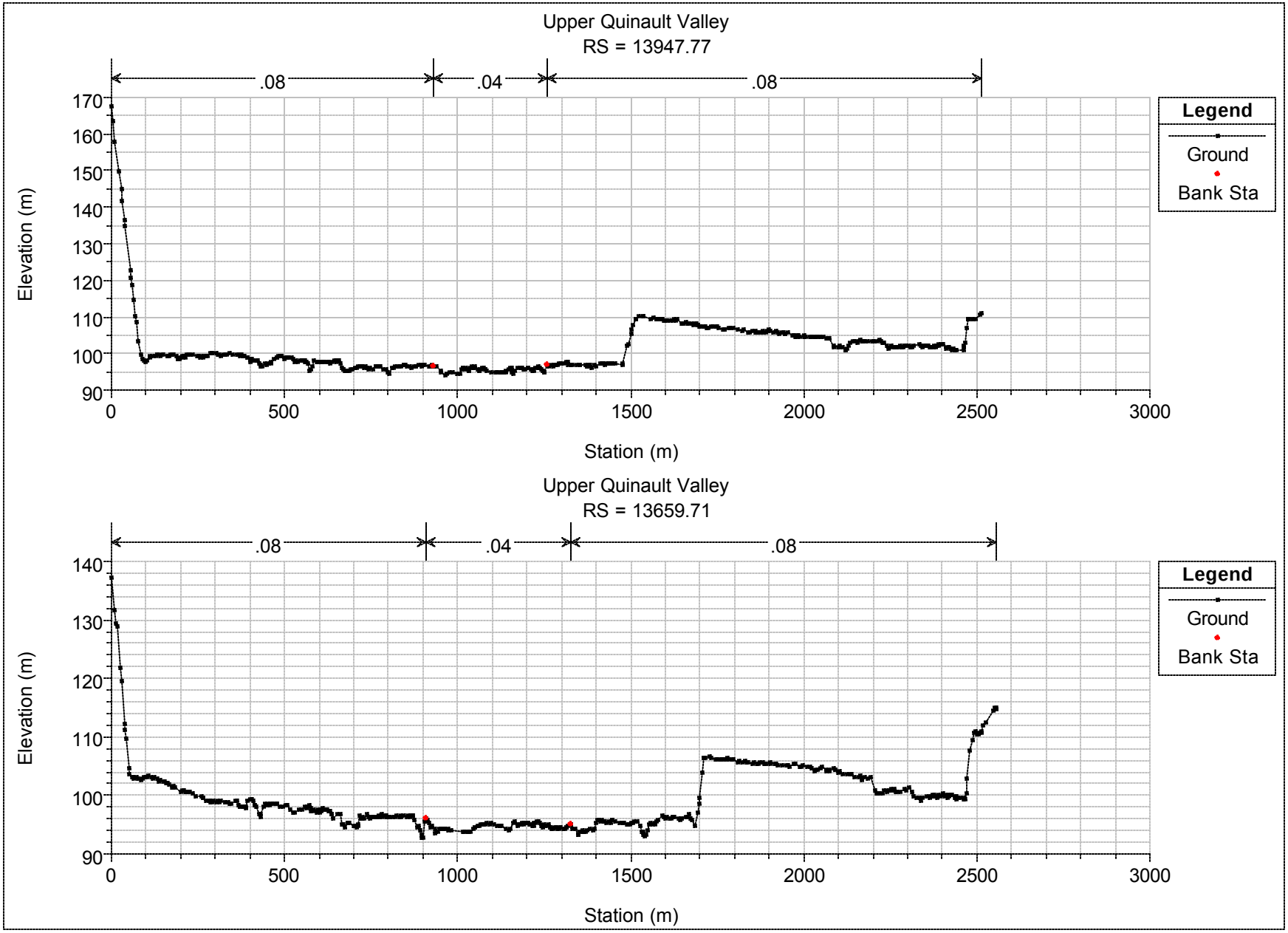

Upper Quinault Valley
RS = 16711.24
.08
.04
.08
Elevation (m)
Station (m)
Legend
Ground
Bank Sta
Upper Quinault Valley
RS = 16491.24
.08
.04
.08
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

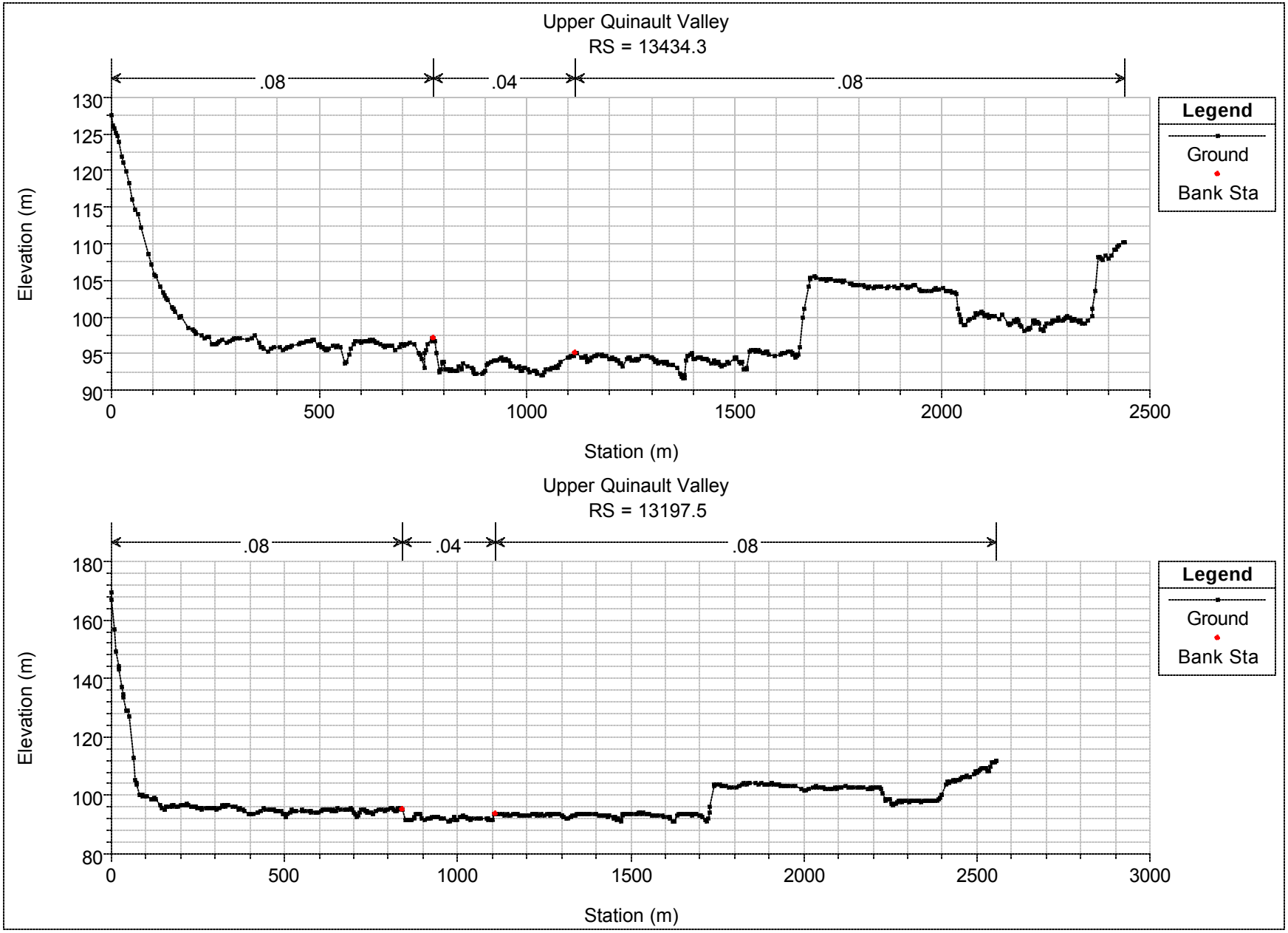

Upper Quinault Valley
RS = 16260.82
.08
.04
.08
Elevation (m)
Station (m)
Legend
Ground
Bank Sta
Upper Quinault Valley
RS = 15928.57
.08
.04
.08
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

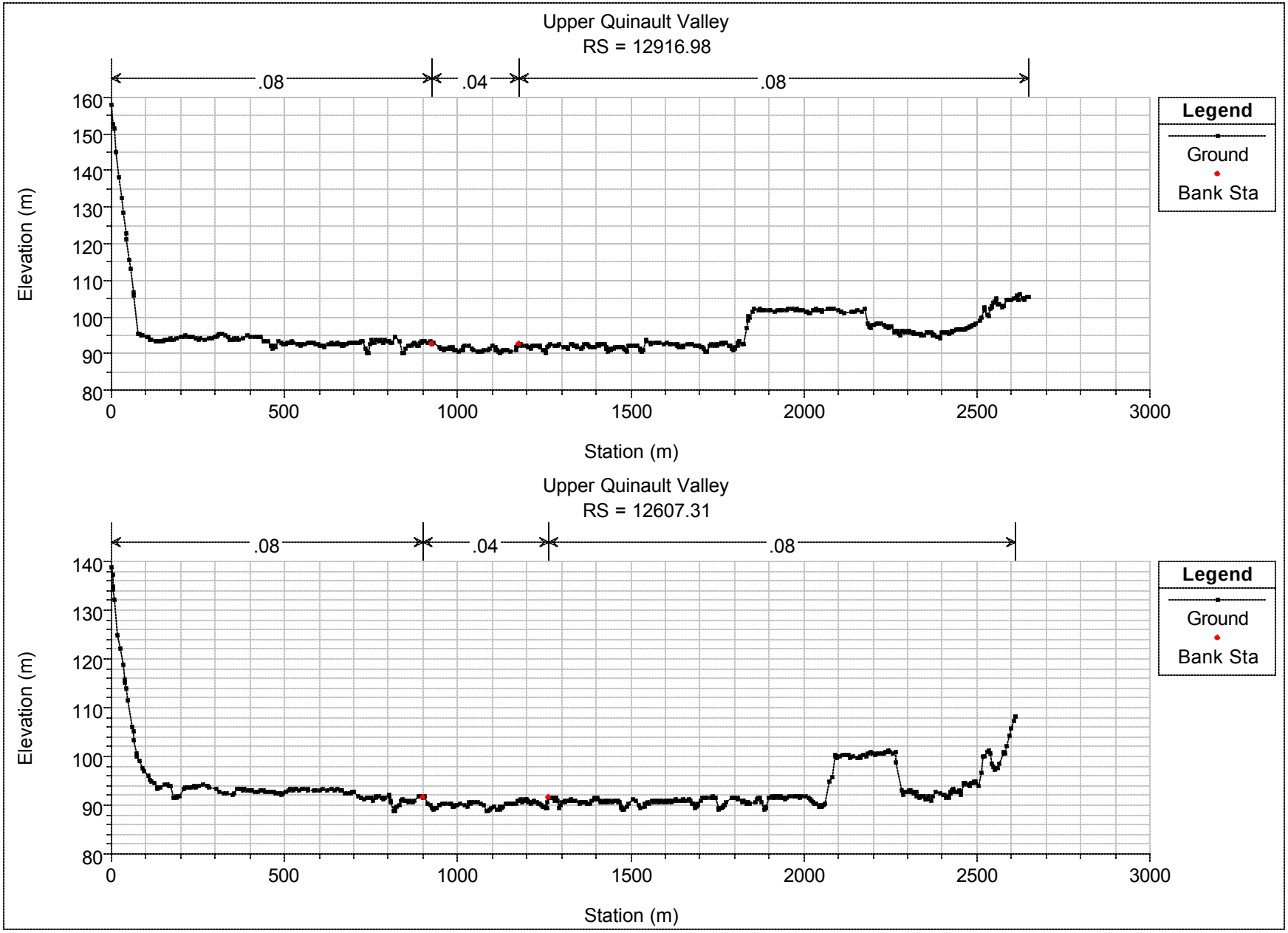

Upper Quinault Valley
RS = 15546.03
.08
.04
.08
Elevation (m)
Station (m)
Legend
Ground
Bank Sta
Upper Quinault Valley
RS = 15273.86
.08
.04
.08
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

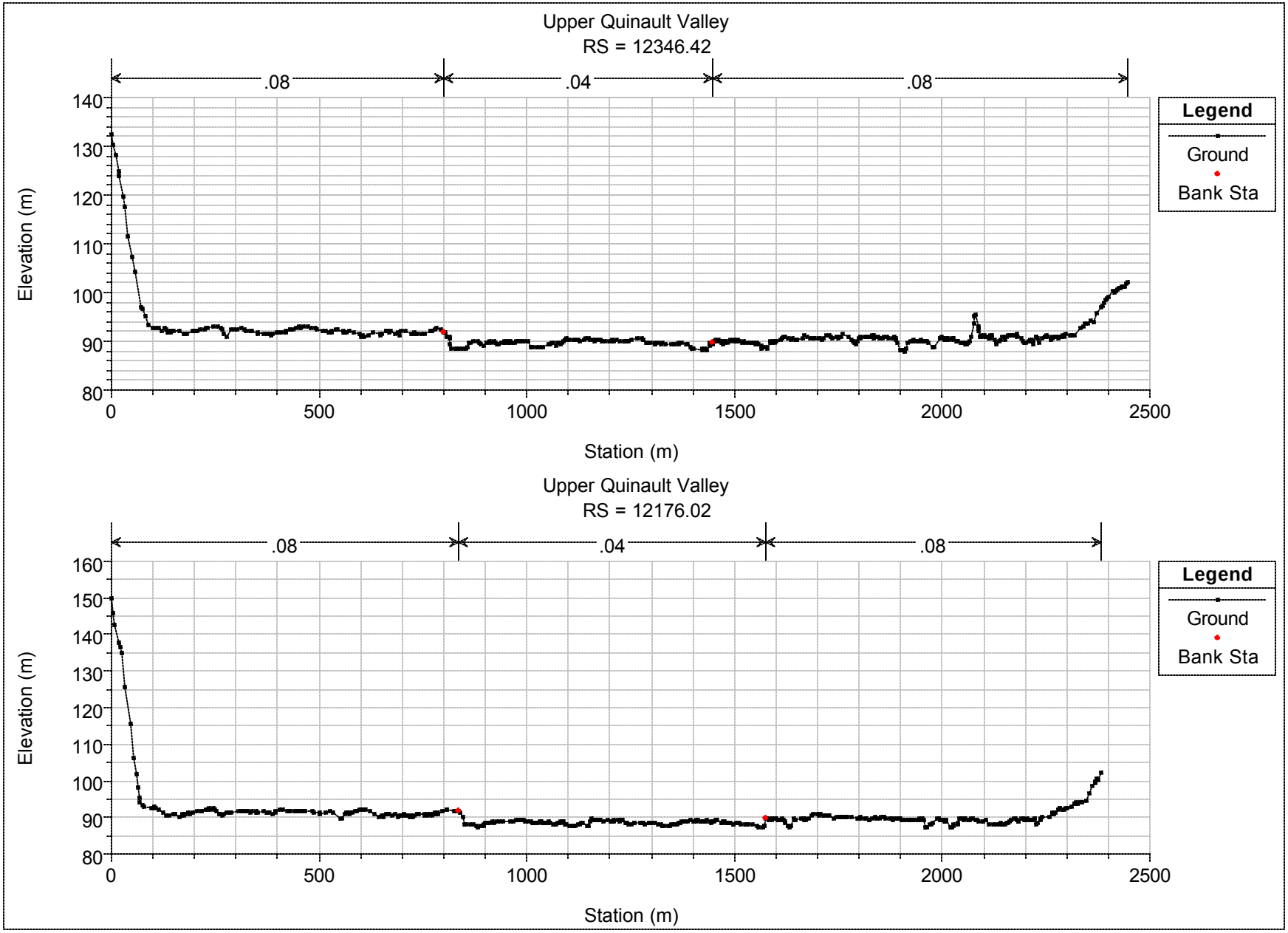

Upper Quinault Valley
RS = 14990.85
.08
.04
.08
Elevation (m)
Station (m)
Legend
Ground
Bank Sta
Upper Quinault Valley
RS = 14693.97
.08
.04
.08
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

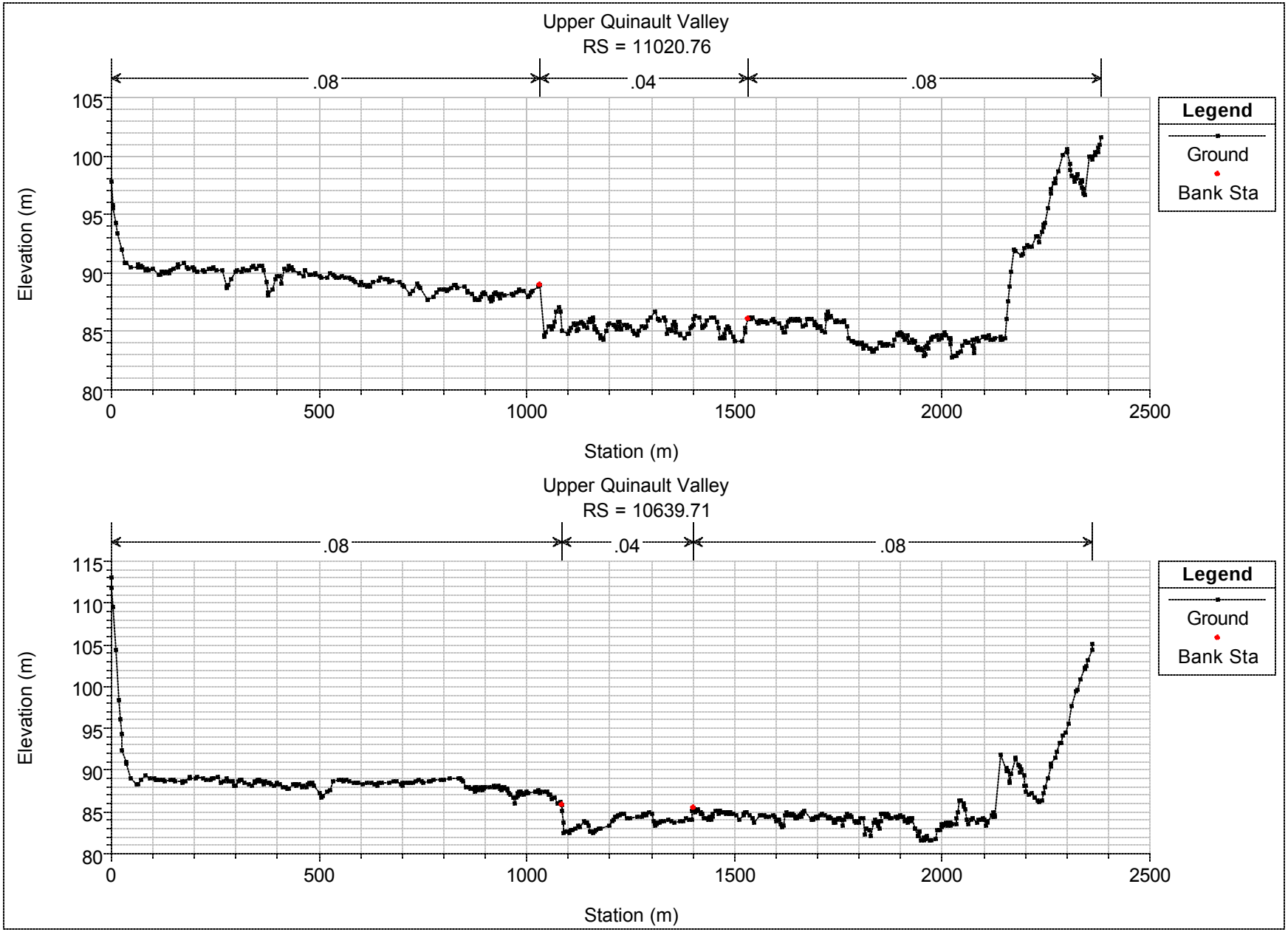

Upper Quinault Valley
RS = 14482.82
.08
.04
.08
Legend
Ground
Bank Sta
Elevation (m)
Station (m)
Upper Quinault Valley
RS = 14202.71
.08
.04
.08
Legend
Ground
Bank Sta
Elevation (m)
Station (m)

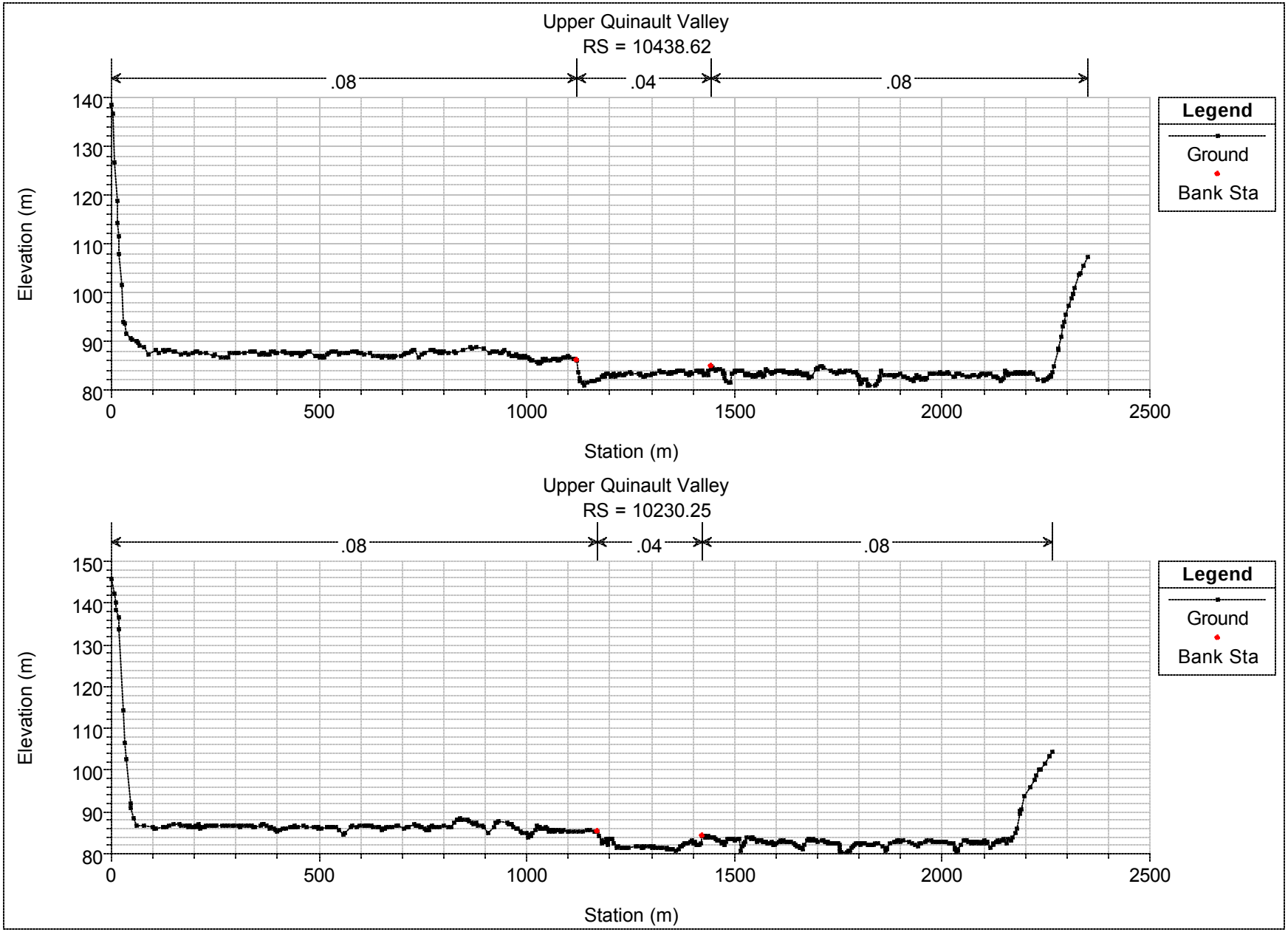

Upper Quinault Valley
RS = 13947.77
.08
.04
.08
Elevation (m)
Station (m)
Legend
Ground
Bank Sta
Upper Quinault Valley
RS = 13659.71
.08
.04
.08
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

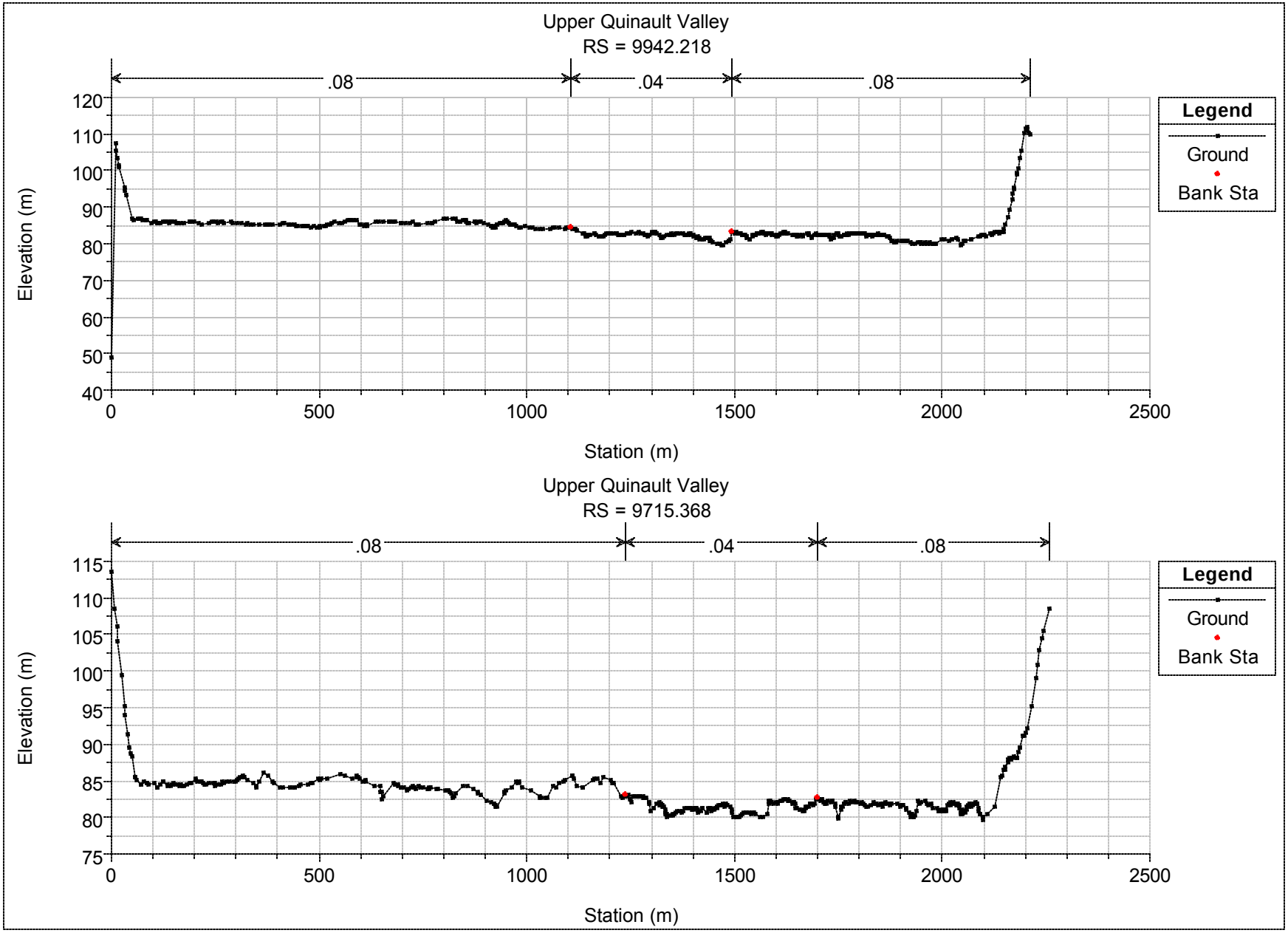

Upper Quinault Valley
RS = 13434.3
.08
.04
.08
Elevation (m)
Station (m)
Legend
Ground
Bank Sta
Upper Quinault Valley
RS = 13197.5
.08
.04
.08
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

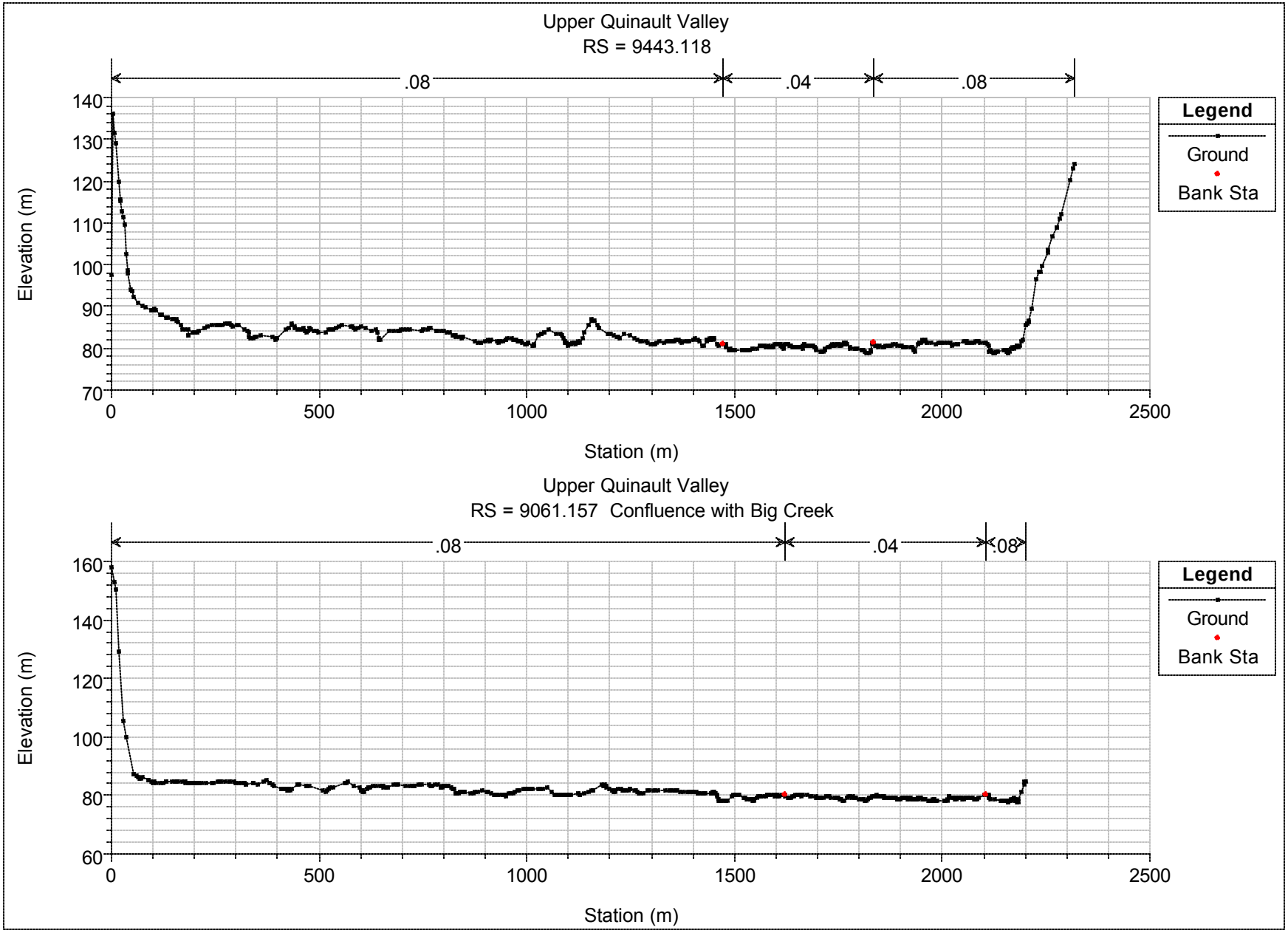

Upper Quinault Valley
RS = 12916.98
.08
.04
.08
Elevation (m)
Station (m)
Legend
Ground
Bank Sta
Upper Quinault Valley
RS = 12607.31
.08
.04
.08
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

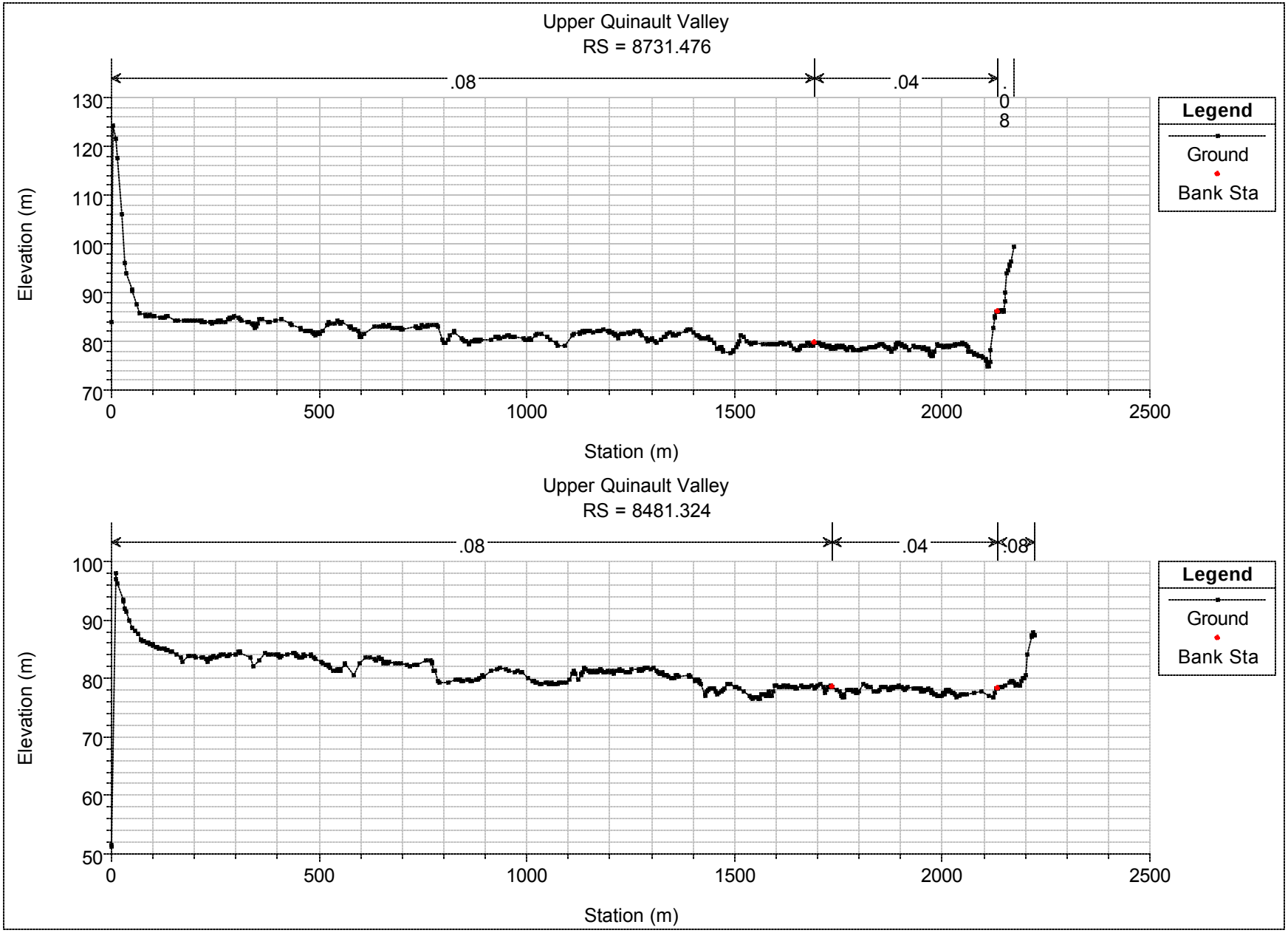

Upper Quinault Valley
RS = 12346.42
.08
.04
.08
Elevation (m)
Station (m)
Legend
Ground
Bank Sta
Upper Quinault Valley
RS = 12176.02
.08
.04
.08
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

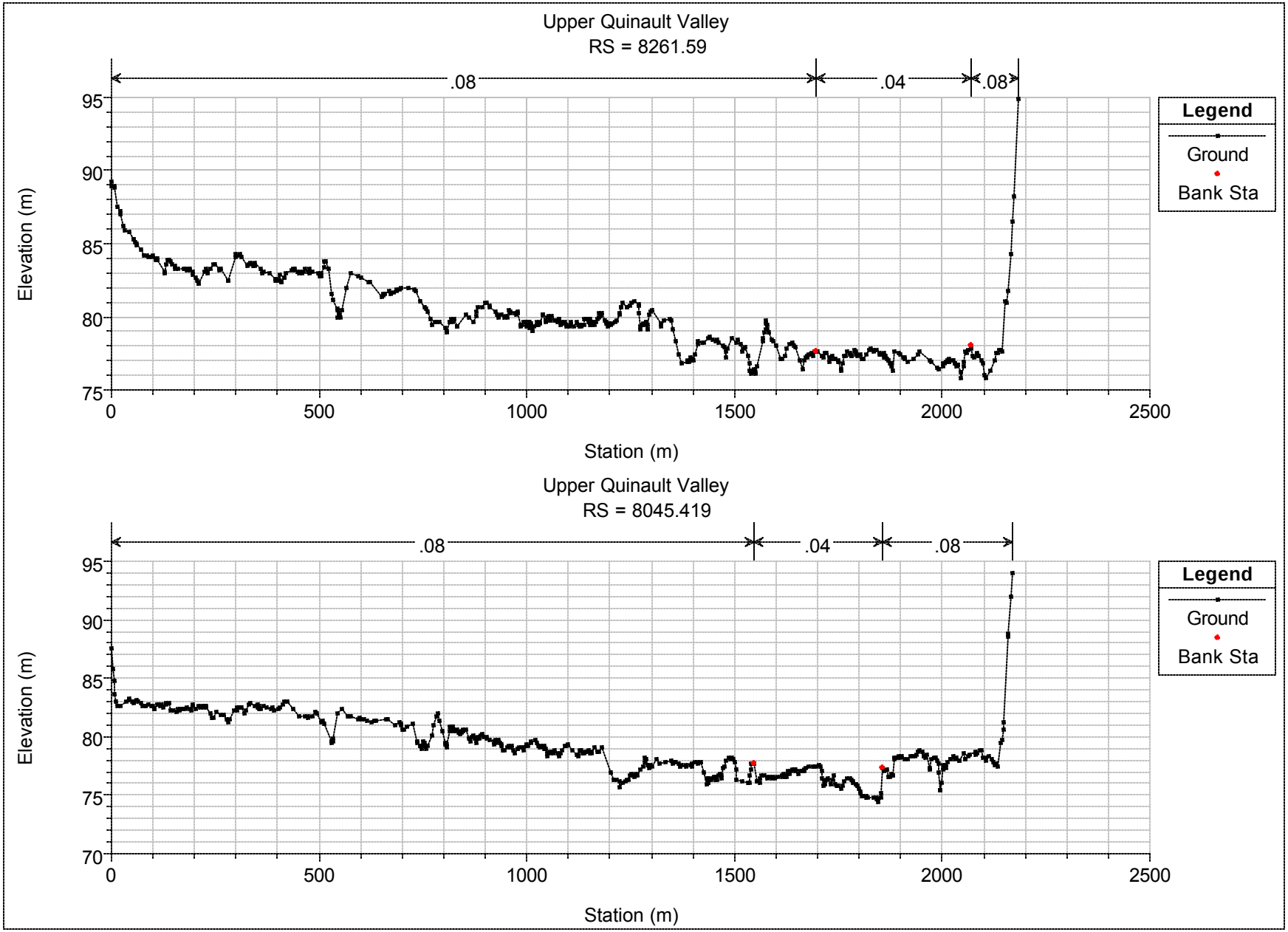

Upper Quinault Valley
RS = 11020.76
.08
.04
.08
Elevation (m)
105
100
95
90
85
80
0
500
1000
1500
2000
2500
Station (m)
Legend
Ground
Bank Sta
Upper Quinault Valley
RS = 10639.71
.08
.04
.08
Elevation (m)
115
110
105
100
95
90
85
80
0
500
1000
1500
2000
2500
Station (m)
Legend
Ground
Bank Sta

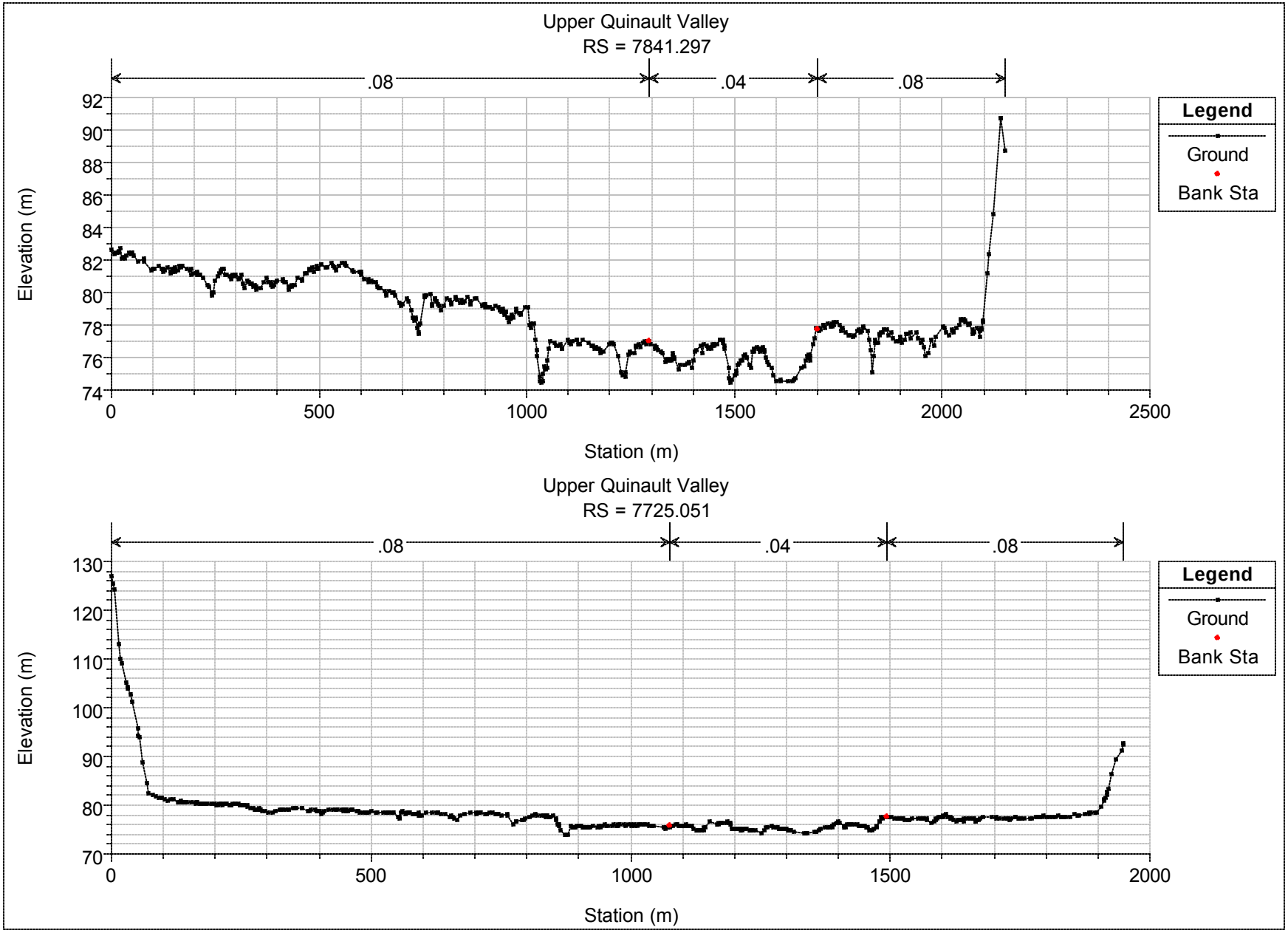

Upper Quinault Valley
RS = 10438.62
.08
.04
.08
Elevation (m)
Station (m)
Legend
Ground
Bank Sta
Upper Quinault Valley
RS = 10230.25
.08
.04
.08
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

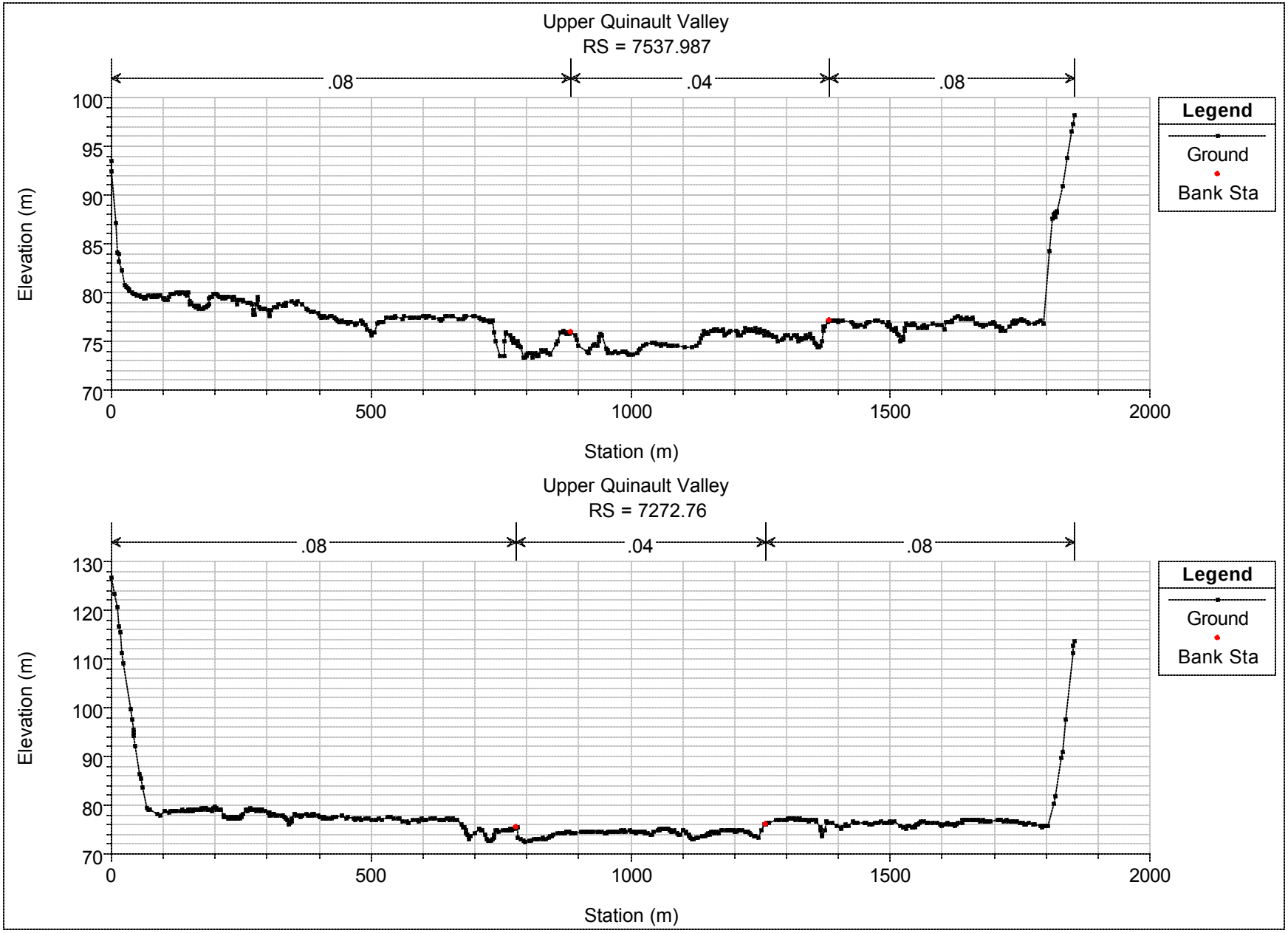

Upper Quinault Valley
RS = 9942.218
.08
.04
.08
Elevation (m)
Station (m)
Legend
Ground
Bank Sta
Upper Quinault Valley
RS = 9715.368
.08
.04
.08
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

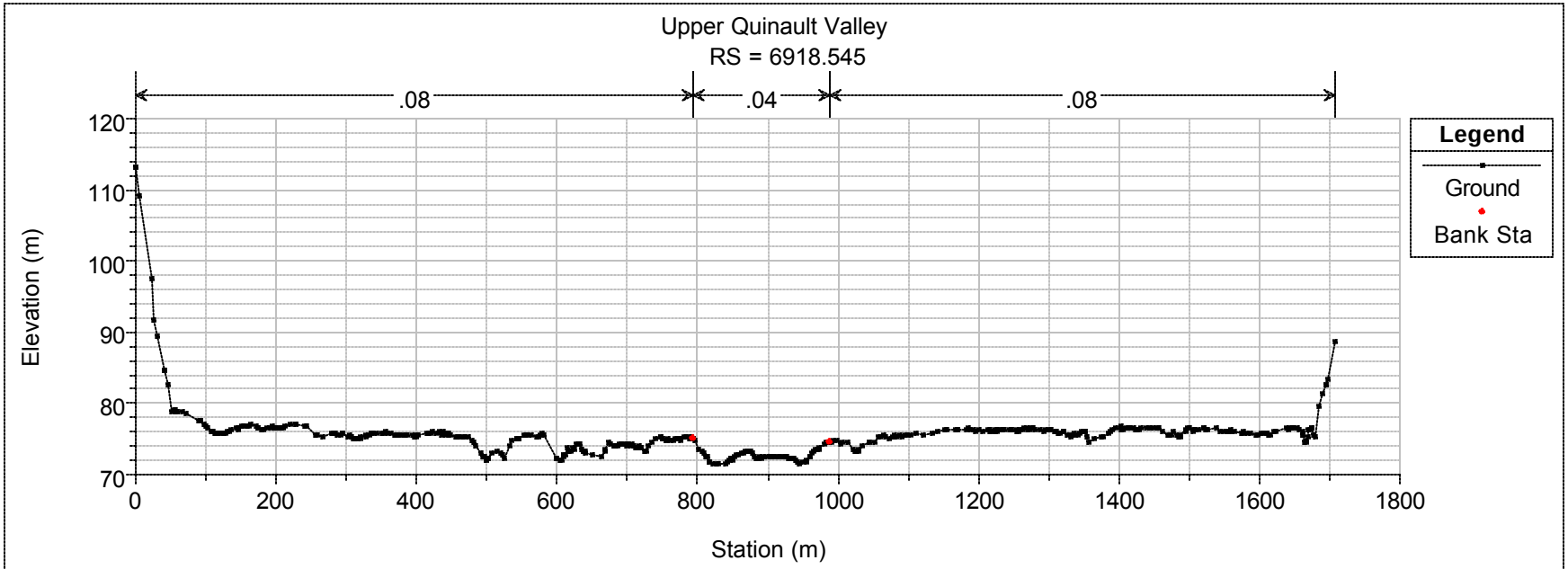

Upper Quinault Valley
RS = 9443.118
.08
.04
.08
Legend
Ground
Bank Sta
Elevation (m)
Station (m)
Upper Quinault Valley
RS = 9061.157 Confluence with Big Creek
.08
.04
.08
Legend
Ground
Bank Sta
Elevation (m)
Station (m)


Upper Quinault Valley
RS = 8731.476
.08
.04
.08
Legend
Ground
Bank Sta
Elevation (m)
130
120
110
100
90
80
70
0
500
1000
1500
2000
2500
Station (m)
Upper Quinault Valley
RS = 8481.324
.08
.04
.08
Legend
Ground
Bank Sta
Elevation (m)
100
90
80
70
60
50
0
500
1000
1500
2000
2500
Station (m)


Upper Quinault Valley
RS = 8261.59
.08
.04
.08
Legend
Ground
Bank Sta
Elevation (m)
95
90
85
80
75
0
500
1000
1500
2000
2500
Station (m)
Upper Quinault Valley
RS = 8045.419
.08
.04
.08
Legend
Ground
Bank Sta
Elevation (m)
95
90
85
80
75
70
0
500
1000
1500
2000
2500
Station (m)


Upper Quinault Valley
RS = 7841.297
.08
.04
.08
Elevation (m)
92
90
88
86
84
82
80
78
76
74
0
500
1000
1500
2000
2500
Station (m)
Legend
Ground
Bank Sta
Upper Quinault Valley
RS = 7725.051
.08
.04
.08
Elevation (m)
130
120
110
100
90
80
70
0
500
1000
1500
2000
Station (m)
Legend
Ground
Bank Sta


Upper Quinault Valley
RS = 7537.987
.08
.04
.08
Elevation (m)
100
95
90
85
80
75
70
0
500
1000
1500
2000
Station (m)
Legend
Ground
Bank Sta
Upper Quinault Valley
RS = 7272.76
.08
.04
.08
Elevation (m)
130
120
110
100
90
80
70
0
500
1000
1500
2000
Station (m)
Legend
Ground
Bank Sta


Upper Quinault Valley
RS = 6918.545
.08
.04
.08
Legend
Ground
Bank Sta
Elevation (m)
Station (m)
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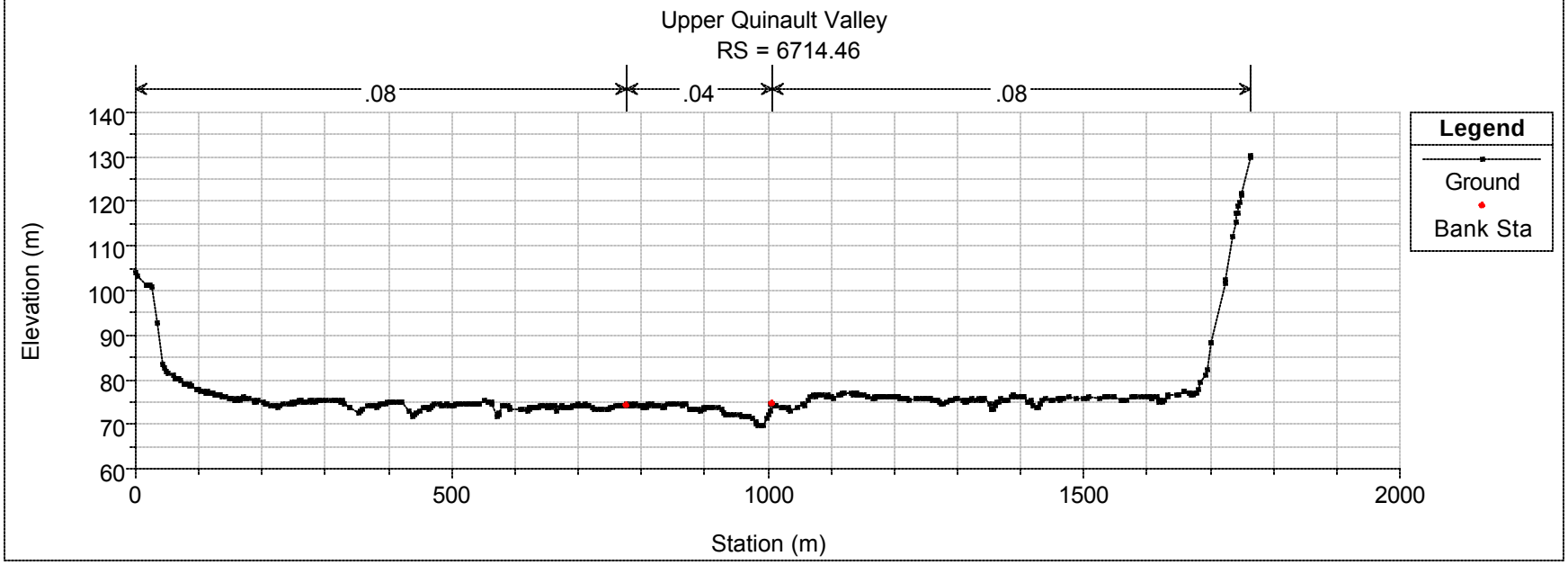
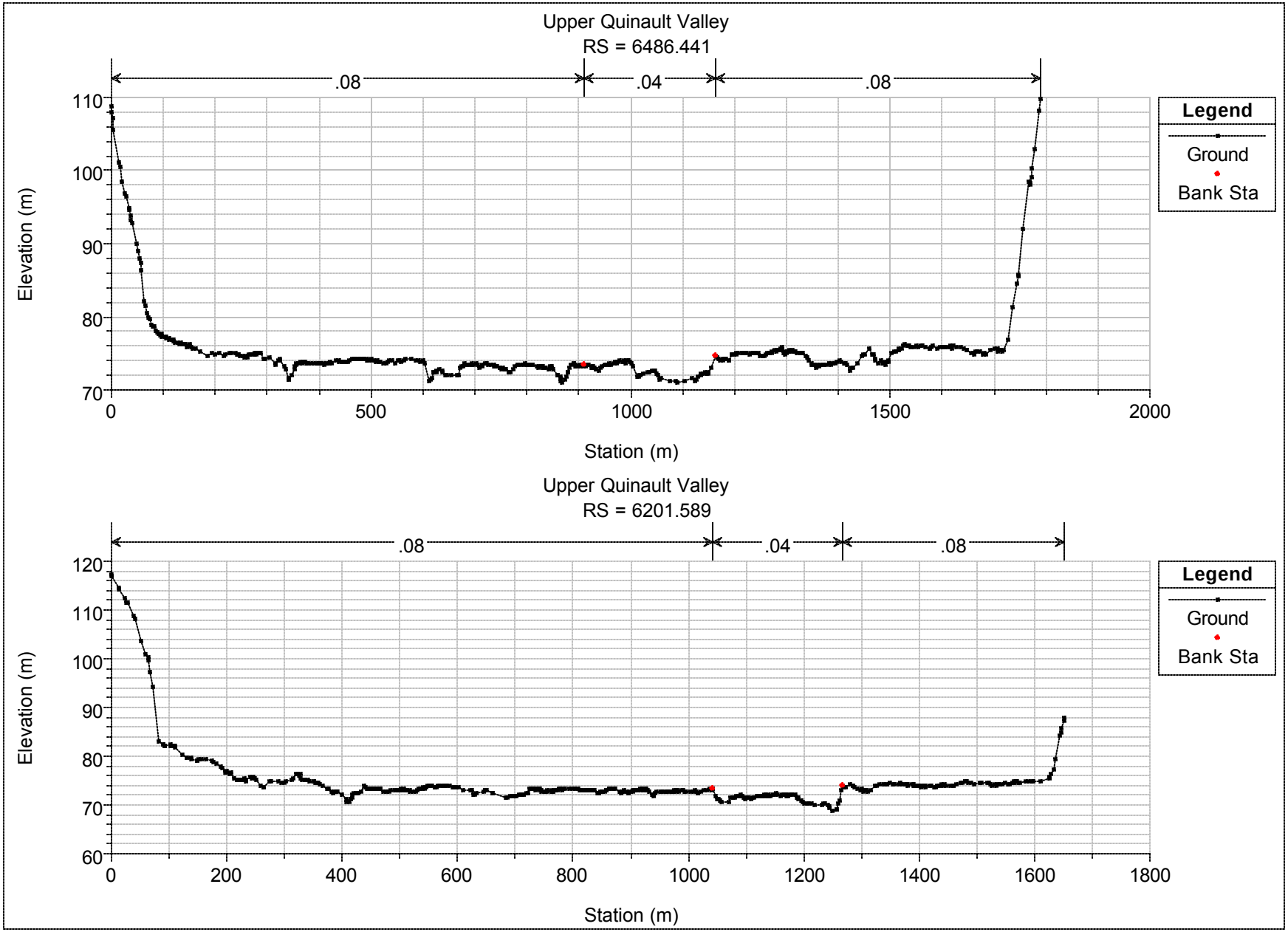
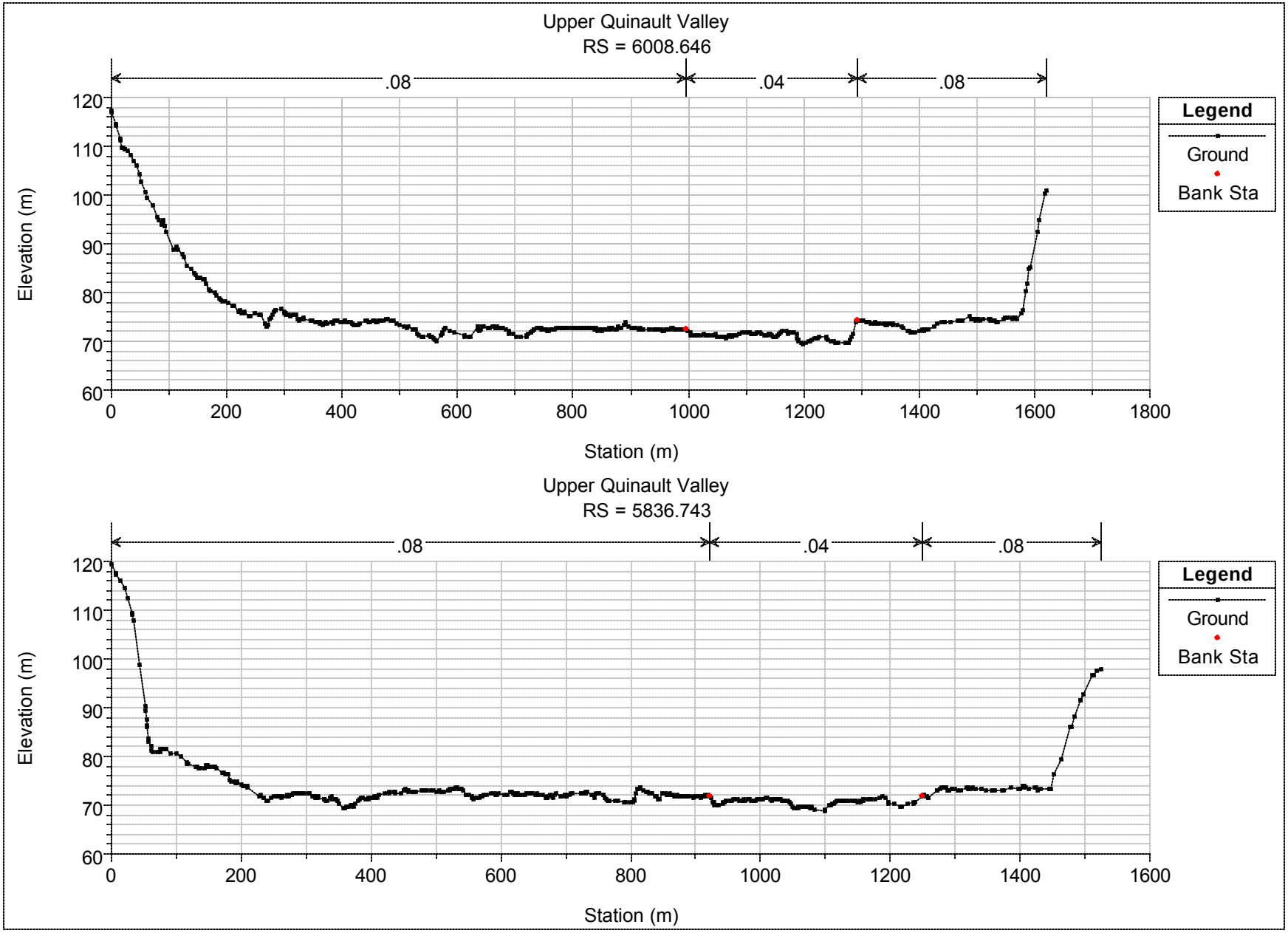
110
100
90
80
70
0
200
400
600
800
1000
1200
1400
1600
1800


Upper Quinault Valley
RS = 6714.46
.08
.04
.08
Legend
Ground
Bank Sta
Elevation (m)
Station (m)
140
130
120
110
100
90
80
70
60
0
500
1000
1500
2000


Upper Quinault Valley
RS = 6486.441
.08
.04
.08
Legend
Ground
Bank Sta
Elevation (m)
110
100
90
80
70
0
500
1000
1500
2000
Station (m)
Upper Quinault Valley
RS = 6201.589
.08
.04
.08
Legend
Ground
Bank Sta
Elevation (m)
120
110
100
90
80
70
60
0
200
400
600
800
1000
1200
1400
1600
1800
Station (m)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.08
.04
.08
Legend
Ground
Bank Sta
Elevation (m)
Station (m)
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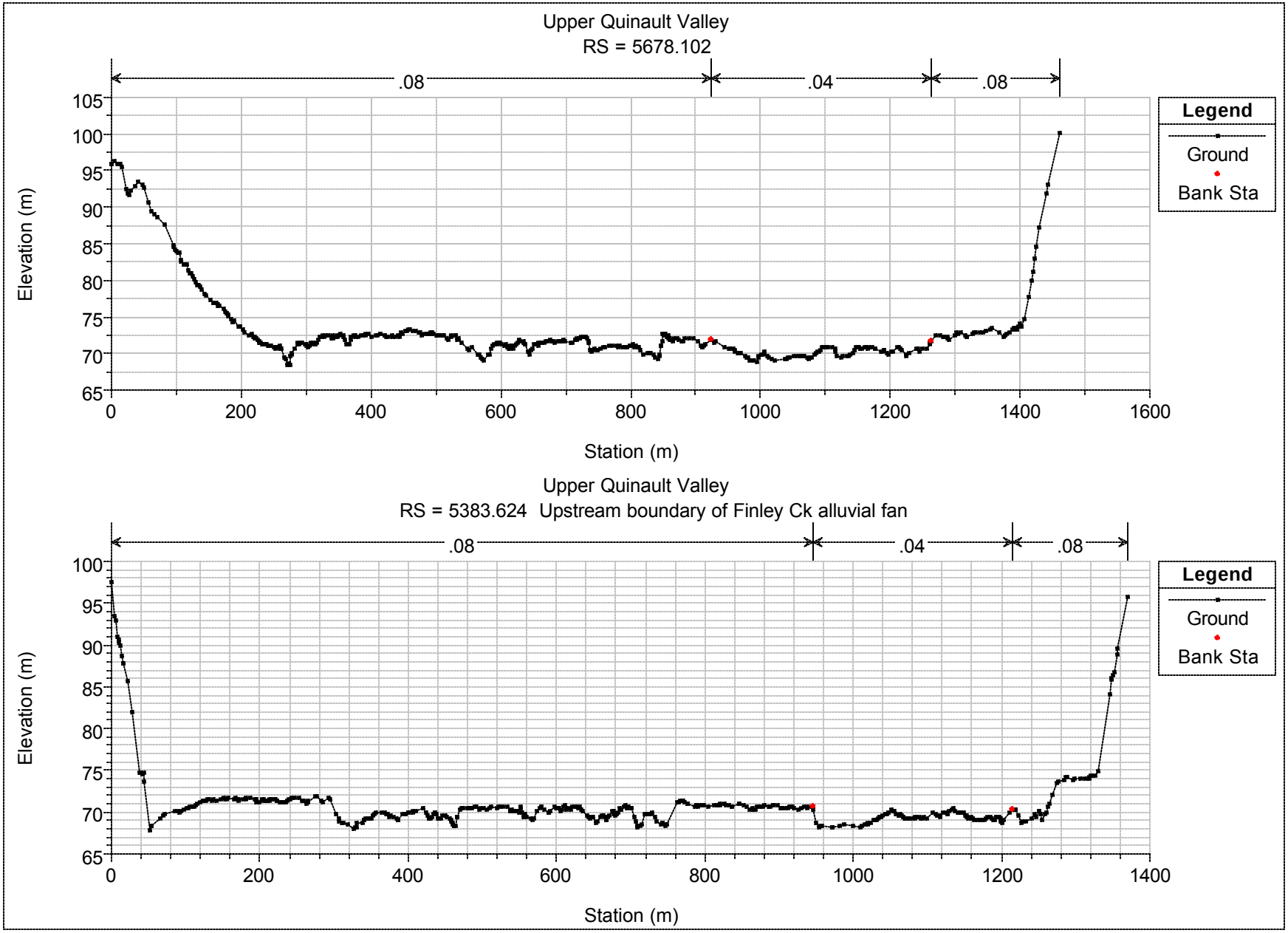
.08
.04
.08
Legend
Ground
Bank Sta
Elevation (m)
Station (m)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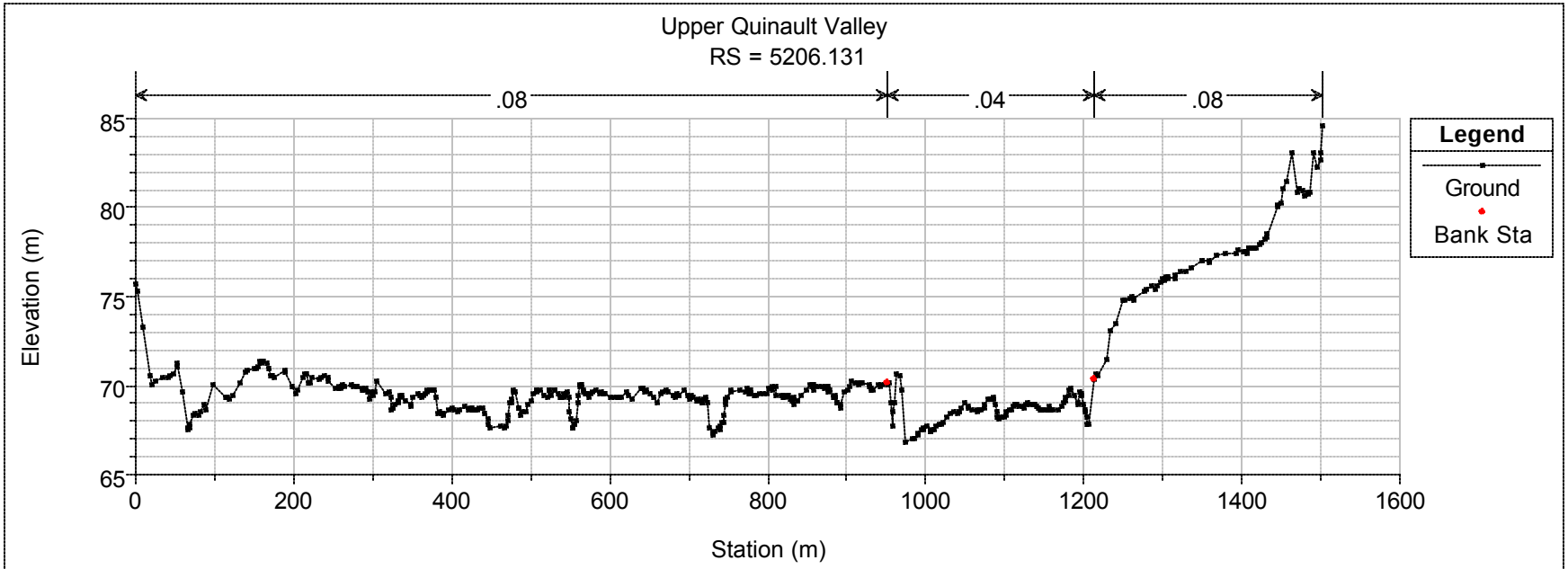
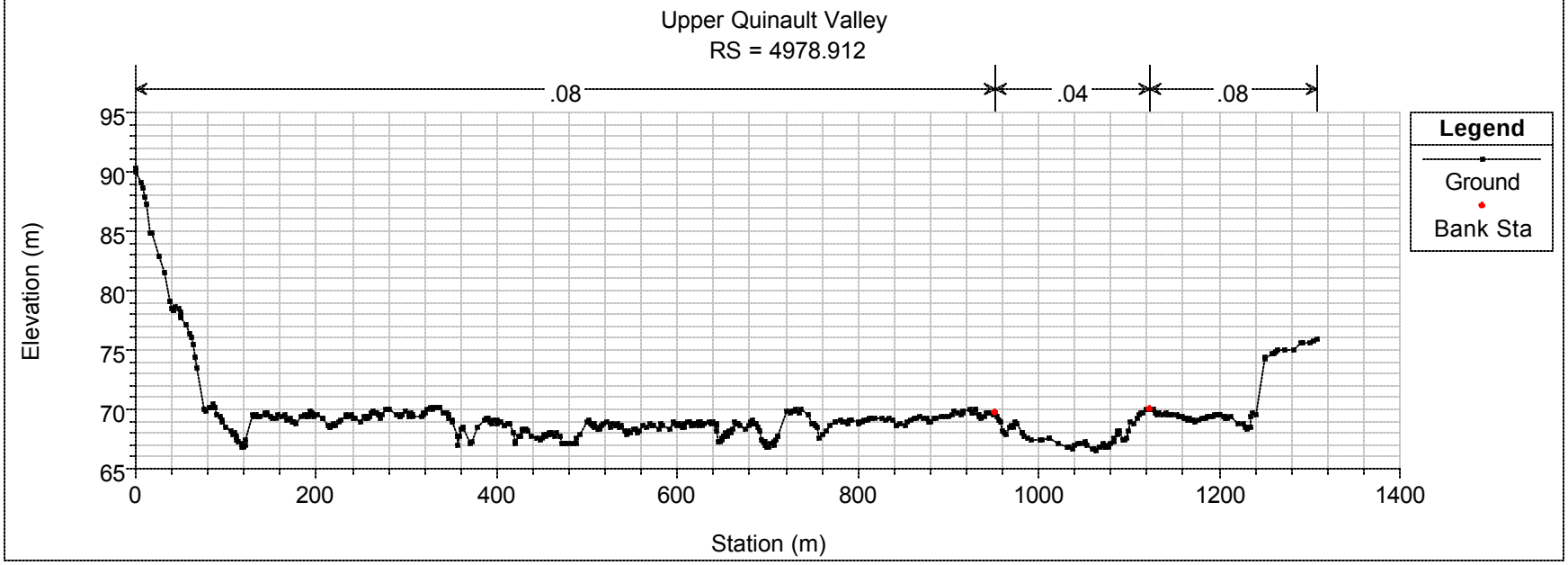
RS = 5678.102
.08
.04
.08
Elevation (m)
Station (m)
Legend
Ground
Bank Sta
Upper Quinault Valley
RS = 5383.624 Upstream boundary of Finley Ck alluvial fan
.08
.04
.08
Elevation (m)
Station (m)
Legend
Ground
Bank Sta


Upper Quinault Valley
RS = 5206.131
.08
.04
.08
Legend
Ground
Bank Sta
Elevation (m)
85
80
75
70
65
0
200
400
600
800
1000
1200
1400
1600
Station (m)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.08
.04
.08
Legend
Ground
Bank Sta
Elevation (m)
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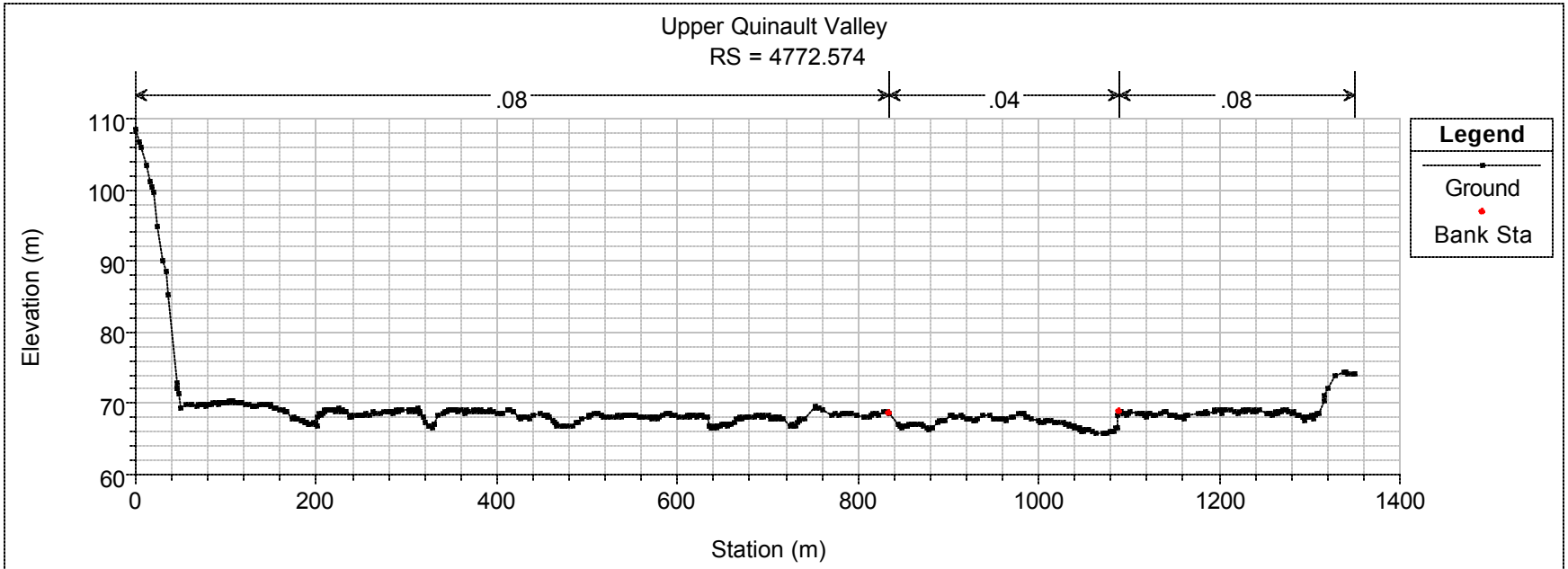
90
85
80
75
70
65
0
200
400
600
800
1000
1200
1400
Station (m)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.08
.04
.08
Legend
Ground
Bank Sta
Elevation (m)
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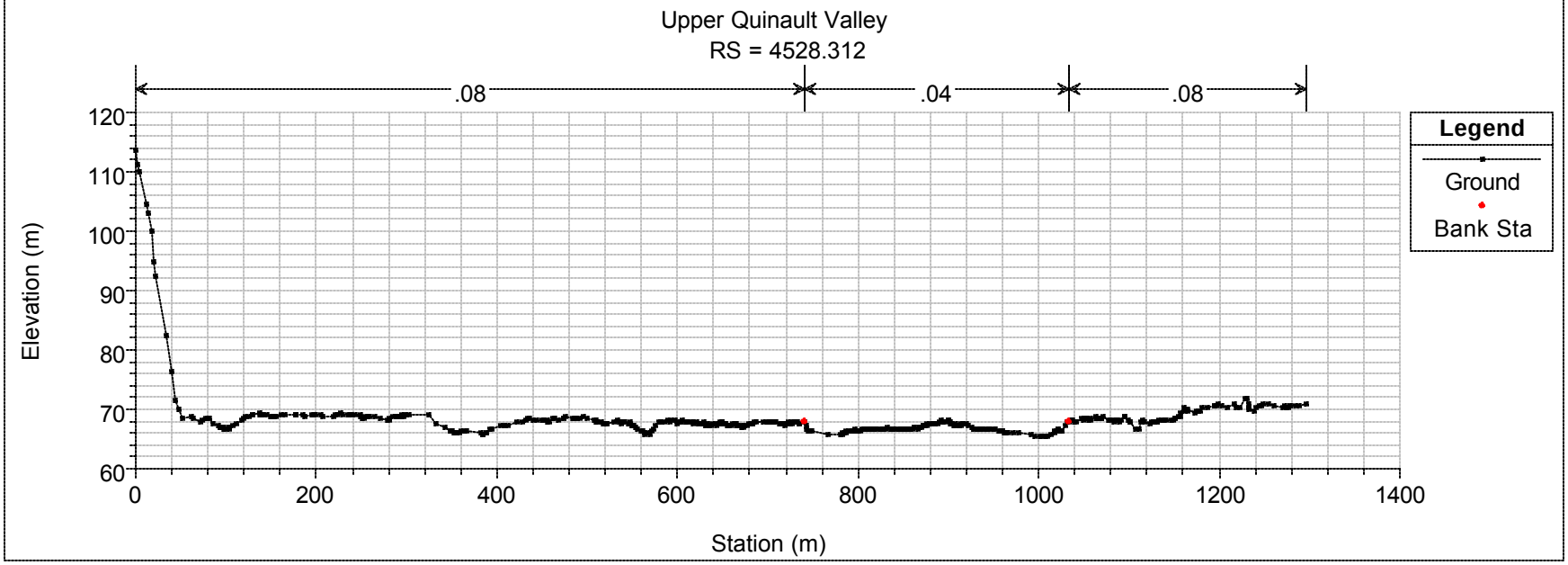
100
90
80
70
60
0
200
400
600
800
1000
1200
1400
Station (m)


Upper Quinault Valley
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.08
.04
.08
Legend
Ground
Bank Sta
Elevation (m)
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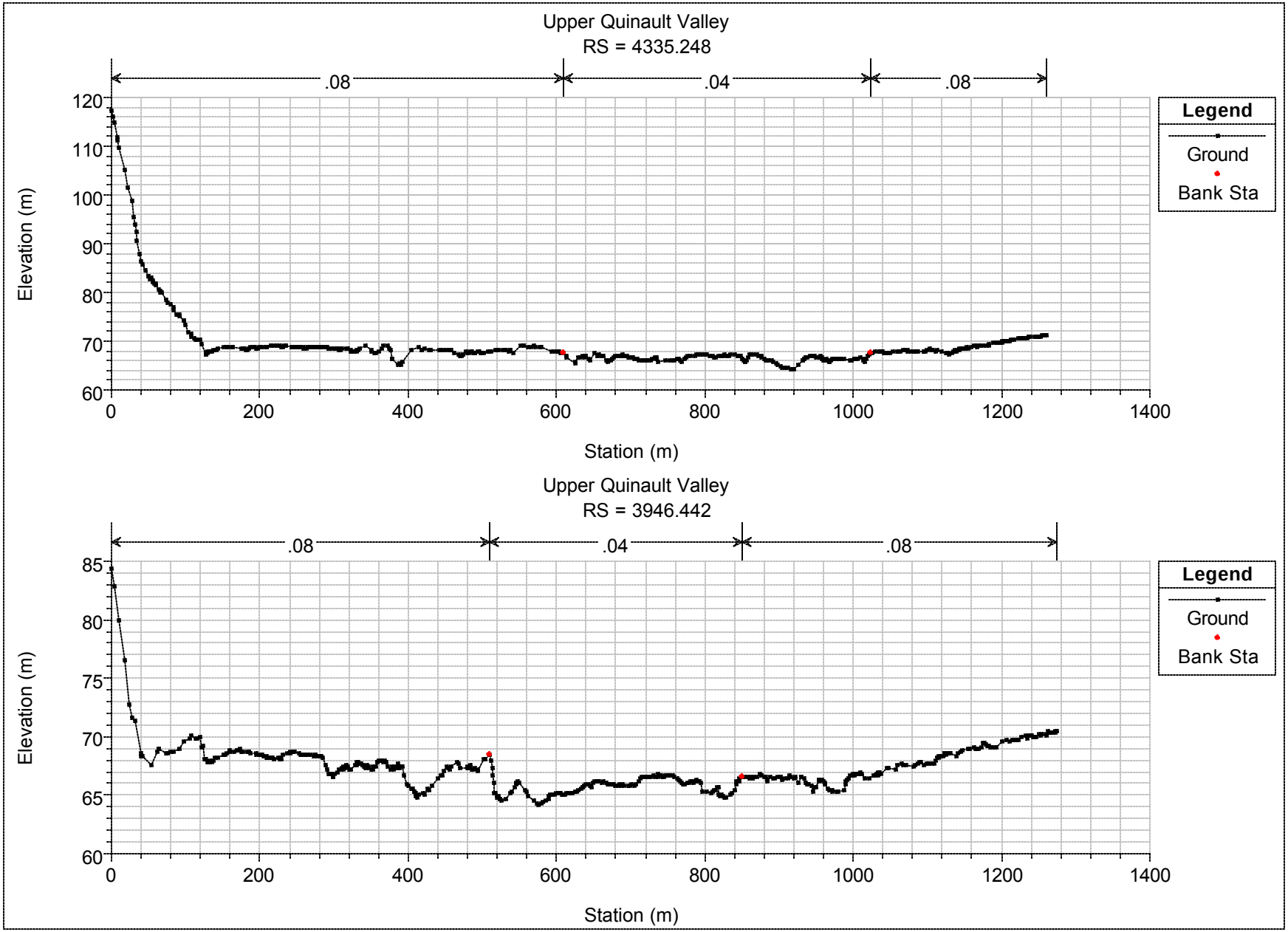
110
100
90
80
70
60
0
200
400
600
800
1000
1200
1400
Station (m)


Upper Quinault Valley
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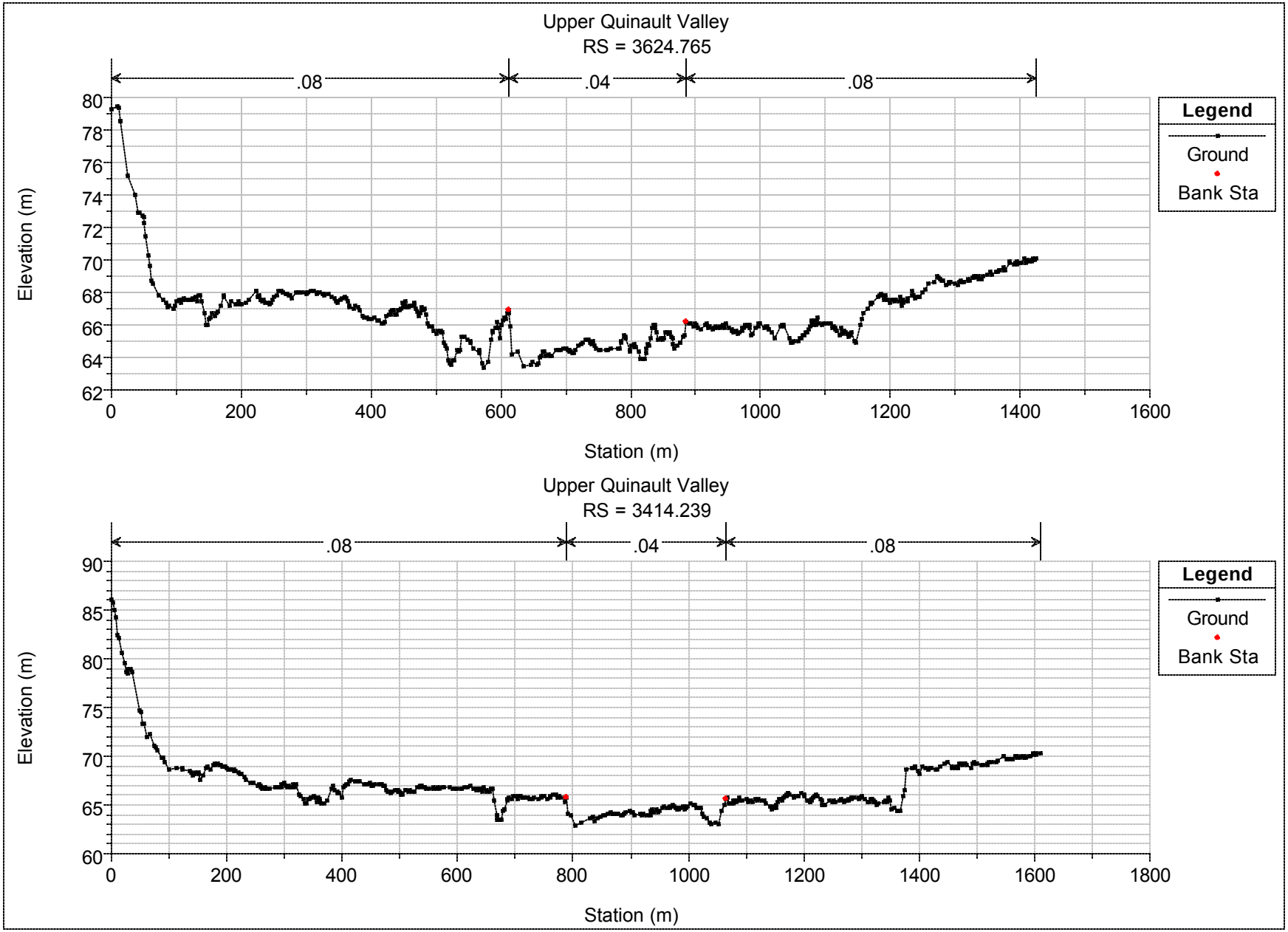
.08
.04
.08
Elevation (m)
Station (m)
Legend
Ground
Bank Sta
Upper Quinault Valley
RS = 3946.442
.08
.04
.08
Elevation (m)
Station (m)
Legend
Ground
Bank Sta


Upper Quinault Valley
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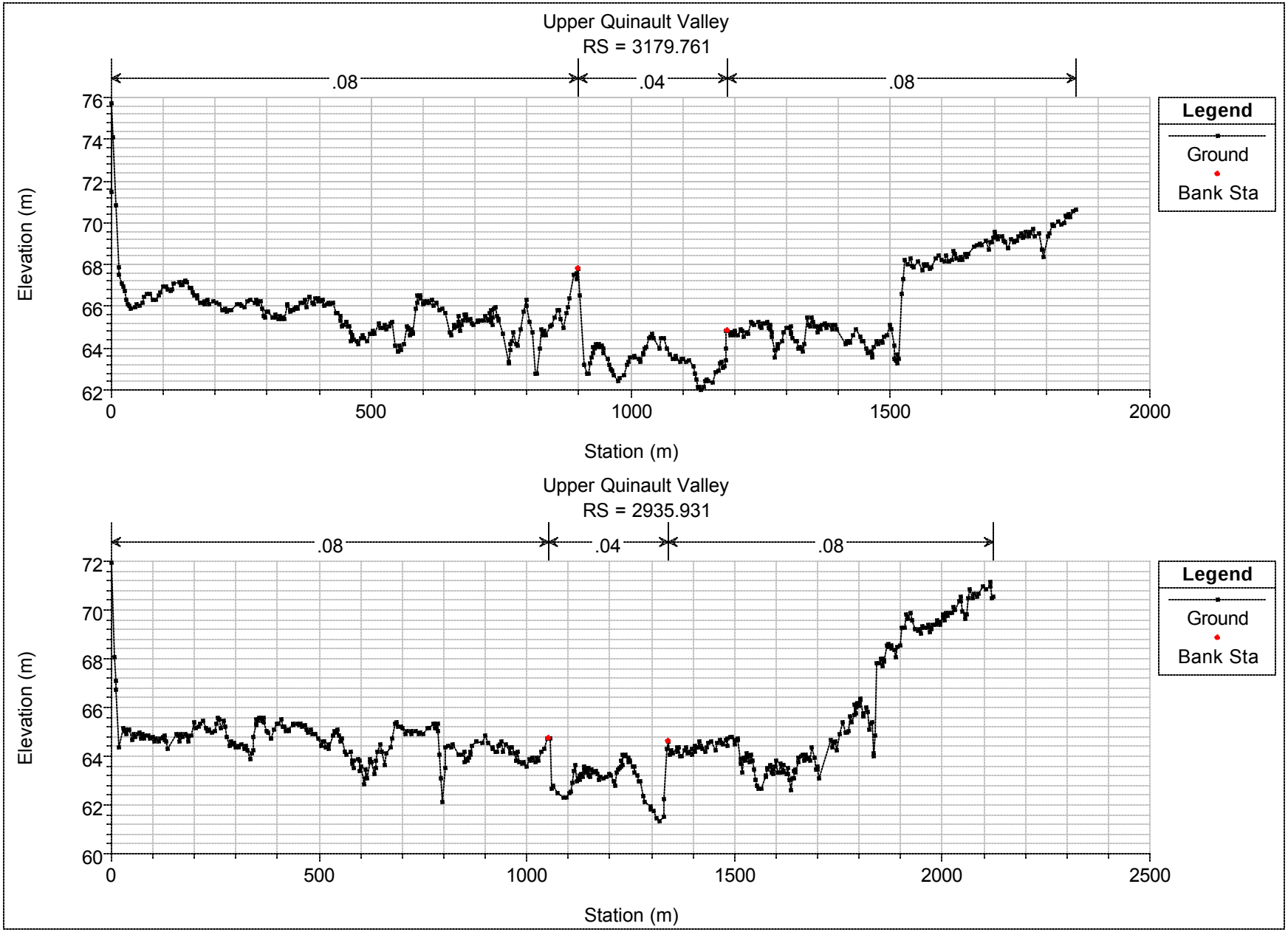
.08
.04
.08
Elevation (m)
Station (m)
Legend
Ground
Bank Sta
Upper Quinault Valley
RS = 3414.239
.08
.04
.08
Elevation (m)
Station (m)
Legend
Ground
Bank Sta


Upper Quinault Valley
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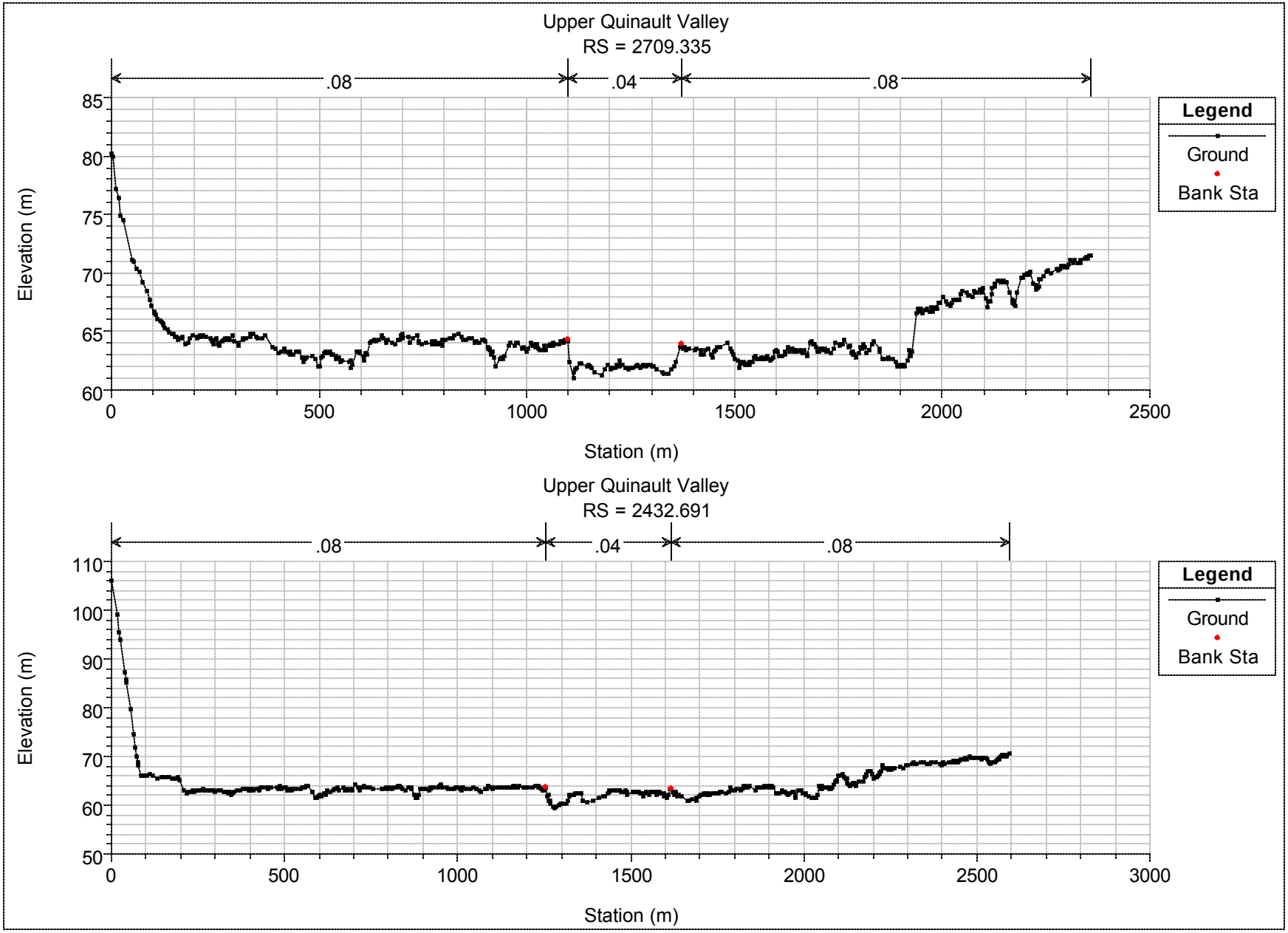
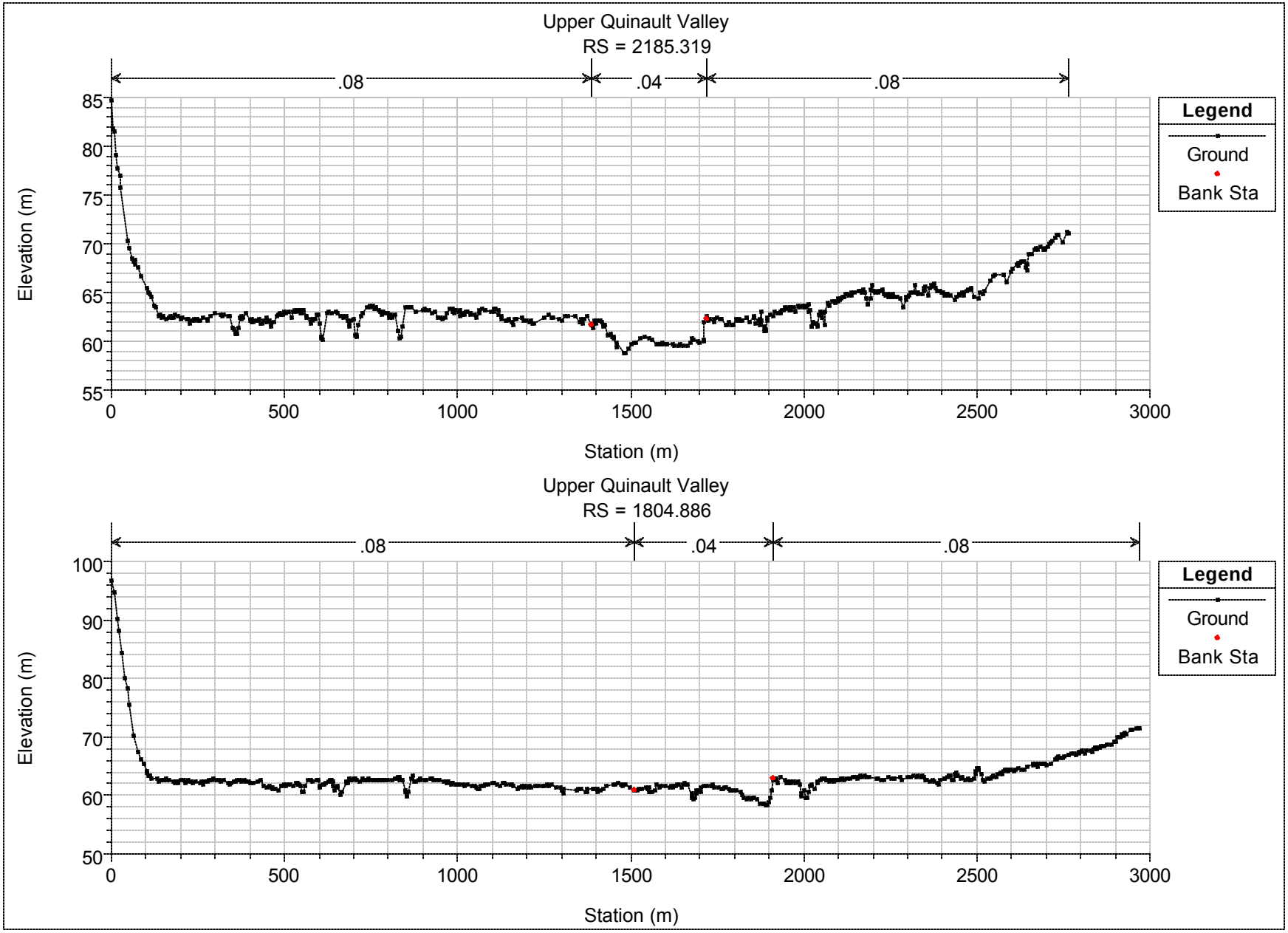
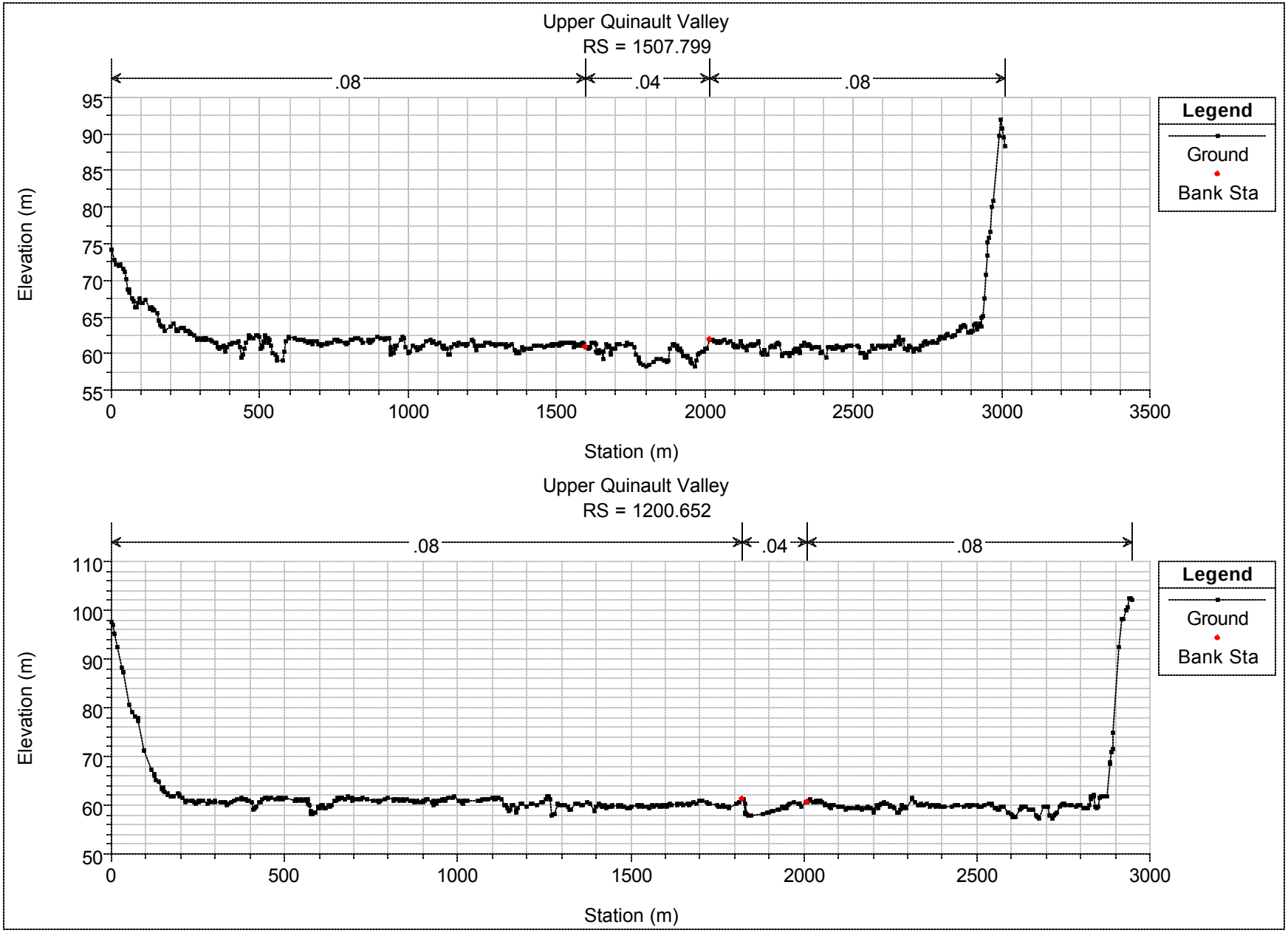
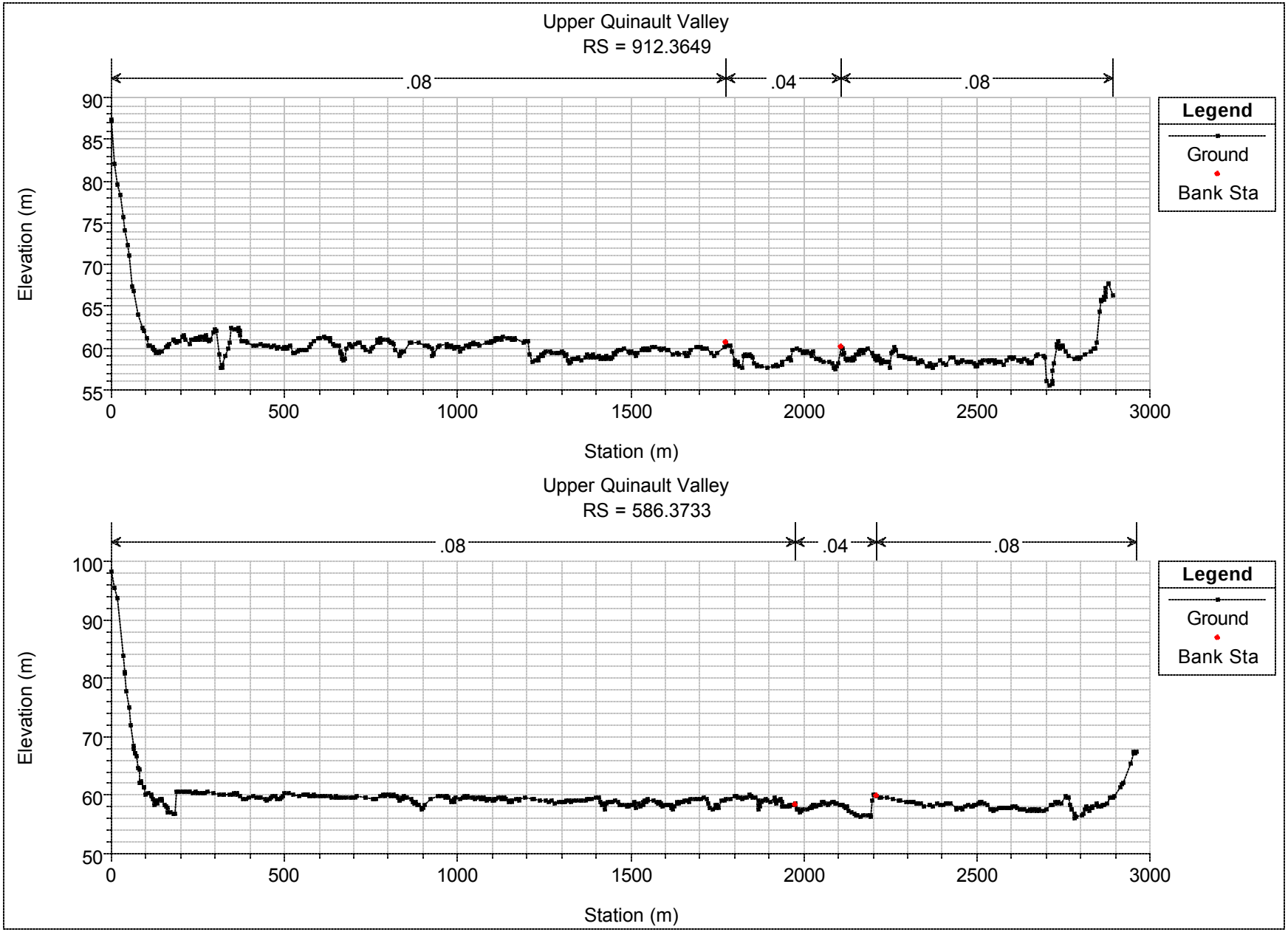
.08
.04
.08
Elevation (m)
76
74
72
70
68
66
64
62
0
500
1000
1500
2000
Station (m)
Legend
Ground
Bank Sta
Upper Quinault Valley
RS = 2935.931
.08
.04
.08
Elevation (m)
72
70
68
66
64
62
60
0
500
1000
1500
2000
2500
Station (m)
Legend
Ground
Bank Sta


Upper Quinault Valley
RS = 2709.335
.08
.04
.08
Legend
Ground
Bank Sta
Elevation (m)
85
80
75
70
65
60
0
500
1000
1500
2000
2500
Station (m)
Upper Quinault Valley
RS = 2432.691
.08
.04
.08
Legend
Ground
Bank Sta
Elevation (m)
110
100
90
80
70
60
50
0
500
1000
1500
2000
2500
3000
Station (m)


Upper Quinault Valley
RS = 2185.319
.08
.04
.08
Elevation (m)
85
80
75
70
65
60
55
0
500
1000
1500
2000
2500
3000
Station (m)
Legend
Ground
Bank Sta
Upper Quinault Valley
RS = 1804.886
.08
.04
.08
Elevation (m)
100
90
80
70
60
50
0
500
1000
1500
2000
2500
3000
Station (m)
Legend
Ground
Bank Sta


Upper Quinault Valley
RS = 1507.799
.08
.04
.08
Elevation (m)
Station (m)
Legend
Ground
Bank Sta
Upper Quinault Valley
RS = 1200.652
.08
.04
.08
Elevation (m)
Station (m)
Legend
Ground
Bank Sta


Upper Quinault Valley
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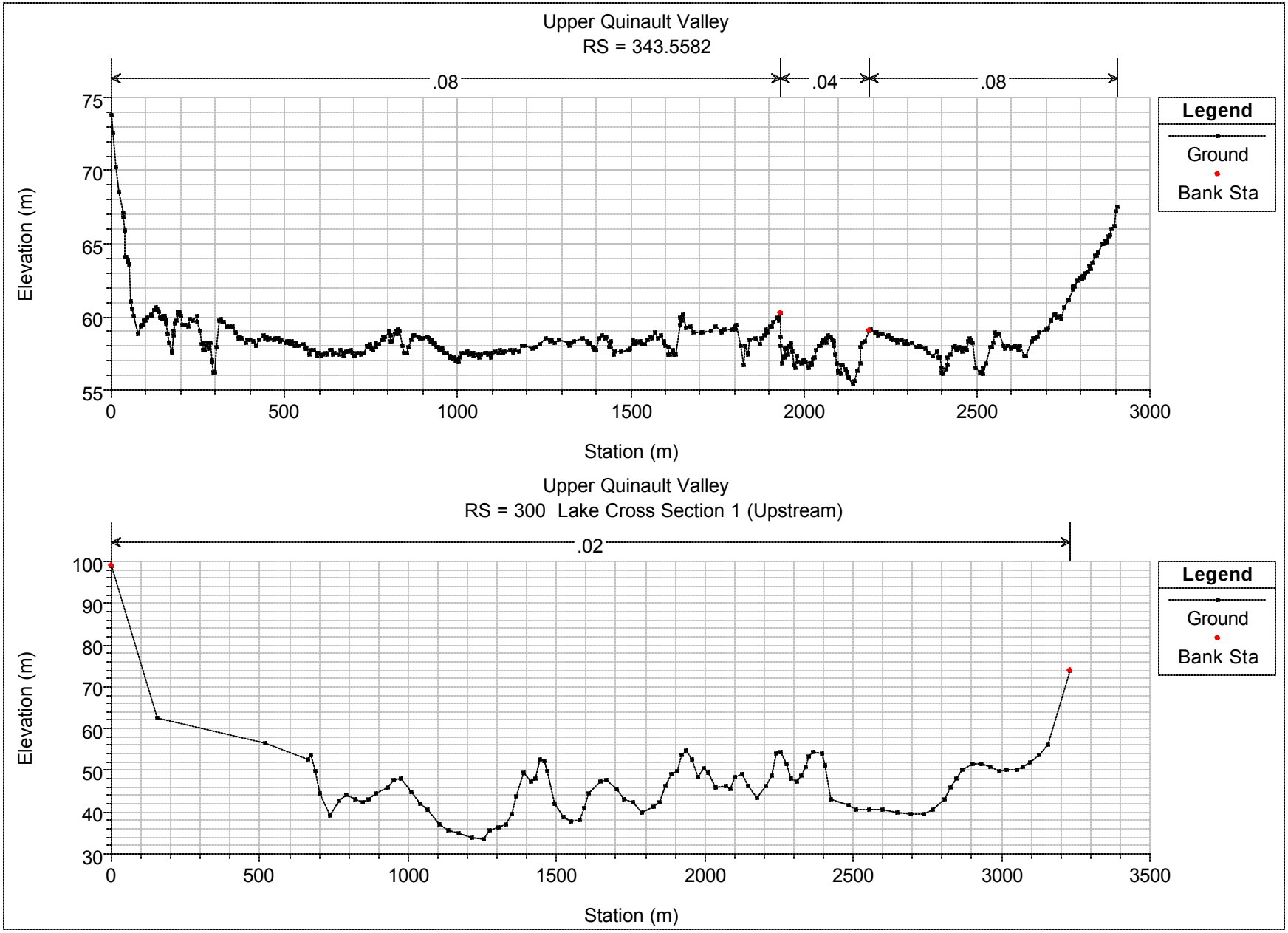
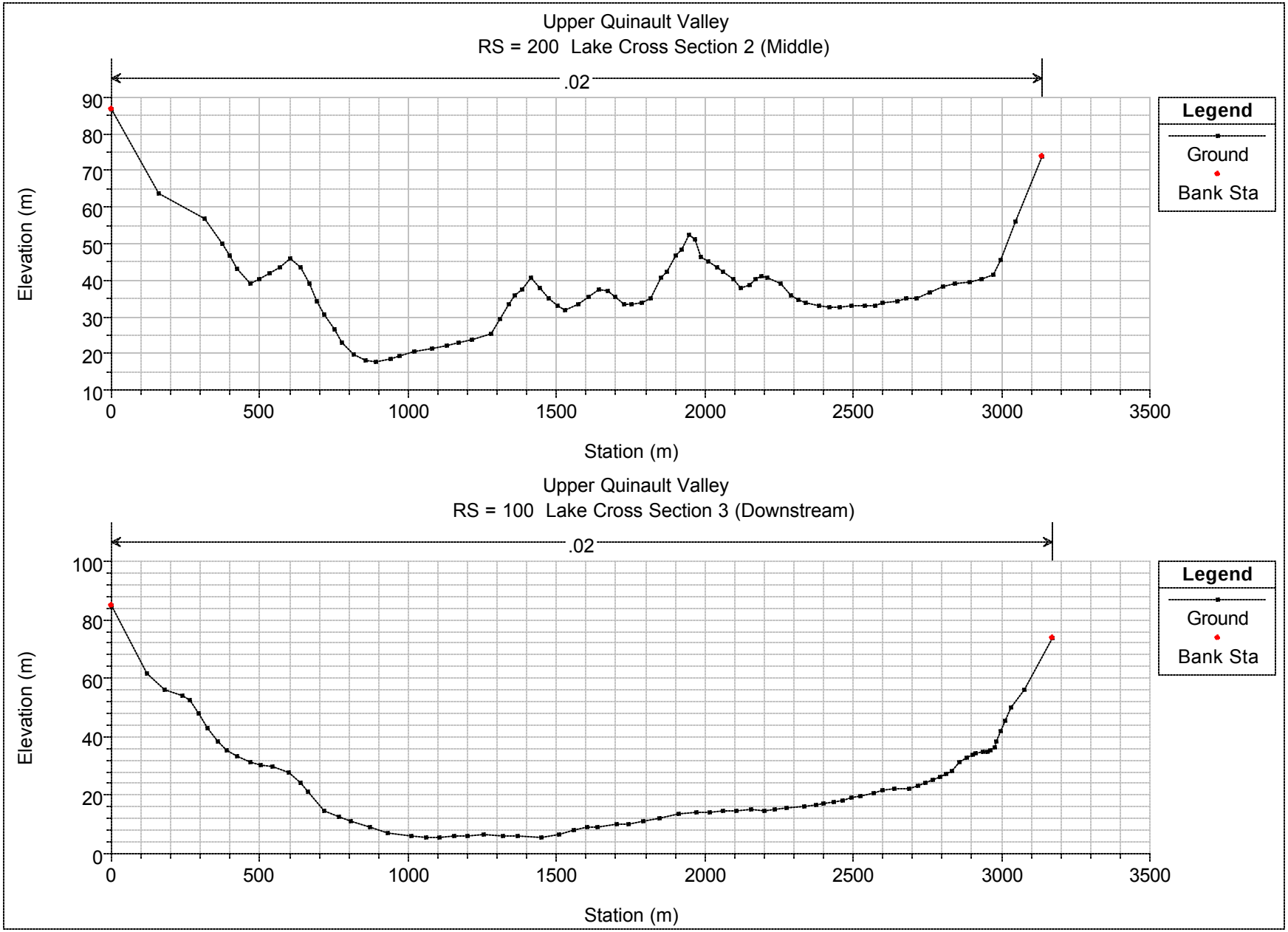
.08
.04
.08
Legend
Ground
Bank Sta
Elevation (m)
90
85
80
75
70
65
60
55
0
500
1000
1500
2000
2500
3000
Station (m)
Upper Quinault Valley
RS = 586.3733
.08
.04
.08
Legend
Ground
Bank Sta
Elevation (m)
100
90
80
70
60
50
0
500
1000
1500
2000
2500
3000
Station (m)


Upper Quinault Valley
RS = 343.5582
.08
.04
.08
Legend
Ground
Bank Sta
Elevation (m)
75
70
65
60
55
0
500
1000
1500
2000
2500
3000
Station (m)
Upper Quinault Valley
RS = 300 Lake Cross Section 1 (Upstream)
.02
Legend
Ground
Bank Sta
Elevation (m)
100
90
80
70
60
50
40
30
0
500
1000
1500
2000
2500
3000
3500
Station (m)


Upper Quinault Valley
RS = 200 Lake Cross Section 2 (Middle)
.02
Elevation (m)
Station (m)
Legend
Ground
Bank Sta
Upper Quinault Valley
RS = 100 Lake Cross Section 3 (Downstream)
.02
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

Appendix C: Geologic Setting

Introduction

The current study was conducted in the Upper Quinault River Valley (Figure 1) that contains a complexity of geologic and geomorphic features. Previous studies have focused on the structural, bedrock, and glacial geologic aspects (i.e. Brandon and Calderwood, 1990; Tabor and Cady, 1978; Moore, 1965; Harvey, 1959), and the fluvial geomorphology of the Quinault River (O'Connor et. al, 2003). The current study concentrates on (1) a tentative correlation between the Hoh River glacial chronology (Thackray, 1996) and the Quinault River glacial chronology (Moore, 1965); and (2) Quinault Lake's surface elevation during the Late Pleistocene and the lake's subsequent regression during the last 6.5 ka.

The glacial chronology of the Quinault River Valley is very significant because it is responsible for the constructive landform (terminal moraine) that impounds Quinault Lake. The lake, in turn, forms the base level that directly influences the fluvial geomorphology of the Upper Quinault River. As such, a basic understanding of the geologic processes responsible for the Upper Quinault River Valley's geomorphology is necessary so that their impacts to the Upper Quinault River system can be better understood.

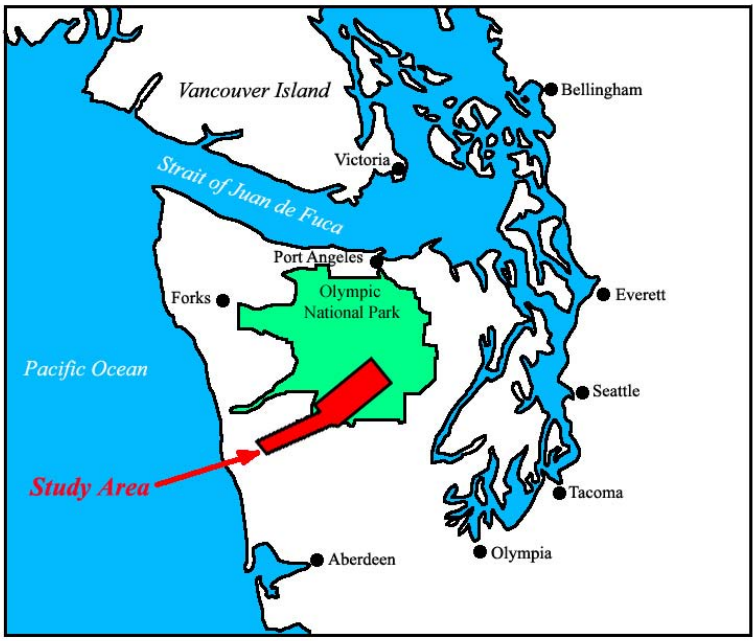


Figure 1. Location map of Upper Quinault River study area on the Olympic Peninsula, Washington.

Structural and Bedrock Geology

The Olympic Peninsula represents a small section of the Cascadia subduction zone's accretionary complex called the Olympic subduction complex (OSC). Since the Middle Miocene, the OSC has been tectonically uplifting above sea-level forming the Olympic Mountains (Brandon and Calderwood, 1990). Based on geodetic data, the tectonic uplift rates tend to increase eastward from the Pacific coastline toward the Inner Olympics (Savage et al., 1991; Dragert et al., 1991). Contemporaneous with the increase in the rate of uplift, there is a respective increase in the rate of erosion. This suggests that the Olympic Mountains have reached a long-term steady-state condition in which uplift is offset by erosion (Pazzaglia and Brandon, 2001).

There are two primary rock groups within the Olympic Peninsula (Figure 2). The core rocks associated with the accretionary wedge and the peripheral rocks that form an eastward plunging antiform (Tabor and Cady, 1978; Tabor, 1987; Brandon and Calderwood, 1990). Contemporaneous with the uplifting of the antiform, erosion has exposed the accretionary wedge and has created an arcuate (horseshoe shaped) structure comprised of the peripheral rocks (Tabor and Cady, 1978; Brandon and Calderwood, 1990).

The exhumed core rocks of the accretionary wedge are predominantly sedimentary rocks that are highly deformed, stratigraphically discontinuous, and partially metamorphosed. Conversely, the peripheral rocks of the antiform are predominantly extrusive igneous rocks that are mildly deformed, stratigraphically continuous, and unmetamorphosed (Tabor and Cady, 1978). The core rocks juxtapose the peripheral rocks by the Peripheral Fault. The fault is comprised of the Calawah Fault segment to the north and the Southern Fault Zone (SFZ) to south (Brandon and Calderwood, 1990; Tabor and Cady, 1978). The core rocks enclosed by the Peripheral Fault exhibit metamorphic zonation, with the intensity of metamorphism increasing from west to east, and the metamorphic facies grading from Laumonite (western extent) to Chlorite-Epidote (eastern extent) [Tabor and Cady, 1978].

The Quinault River Valley is bounded by the SFZ along its southern margin between Quinault Lake and Canning Creek. The peripheral rocks of the Crescent Formation outcrop along the south valley wall (hanging wall of the SFZ) from Willaby Creek to Bunch Canyon. The Crescent Formation is predominantly comprised of unmetamorphosed, massive basalt flows and thick-bedded sandstones. The bedrock, within the remainder of the upper valley area including the North and East Forks, is comprised of core rocks mapped as the Western Olympic Lithic Assemblage, Elwha Lithic Assemblage and other undifferentiated sedimentary rocks (Tabor and Cady, 1978).

The core rocks progressively increase in metamorphic grade from Quinault Lake to Anderson Glacier. From the Quinault Lake outlet to the Canning Creek area, the core rocks are of Pumpellyite metamorphic grade and are represented by highly deformed sandstones and shales with minor conglomerates and basalt. Further up the Quinault River drainage, above Canning Creek and including the North and East Fork drainages,

the core rocks are represented by highly deformed slates, phyllites, foliated and lineated sandstones, granule conglomerates, and semi-schists of Pumpellyite to Chlorite-Epidote metamorphic grades (Tabor and Cady, 1978).

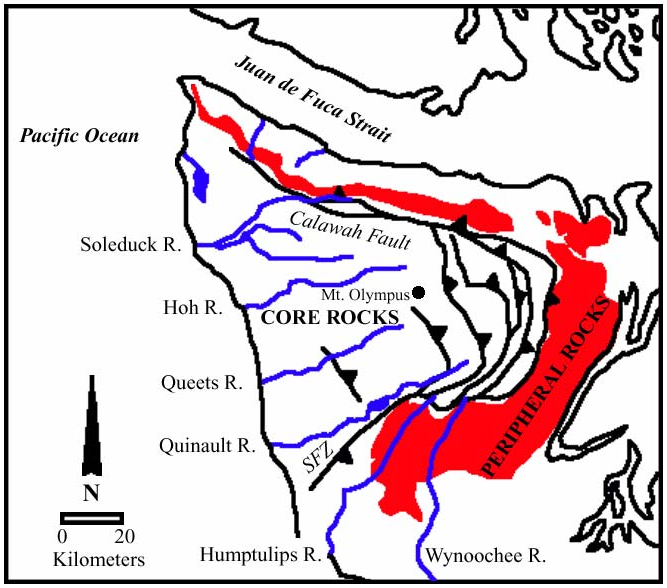


Figure 2. Generalized structure map of the Olympic Peninsula, Washington. Compiled from Tabor (1987) and Johnson et. al. (1999).

Glacial Geology

Valley glaciers have advanced at least six times down the western flanks of the Olympic Mountains in the Hoh and Queets River valleys (Thackray, 1996, 2001). Similarly, six glacial advances have been recorded along the southern flanks of the Olympic Mountains in the Chehalis, Satsop, and Wynoochee River valleys (Carson, 1970). In the Quinault River Valley, Moore (1965) has documented at least two major glacial advances that occurred during the Late Pleistocene, the Humptulips and Chow Chow glaciations respectively. The Humptulips glacier was the most extensive. It advanced to within 4 km of the Pacific Ocean leaving behind broad arcuate moraines.

Following the Humptulips glacial retreat, there was a period when interglacial conditions persisted and a lacustrine environment developed west of present day Quinault Lake. Moore (1965) collected two samples of wood for radiocarbon dating from an organic layer believed to be associated with this interglacial period. The two samples returned radiocarbon ages of greater than 35.0 ka and 32.0 ka, respectively (Moore, 1965). These results provide limiting ages for both the Humptulips and Chow Chow glaciations.

After the interglacial period, ice again advanced to within 12 km of the Pacific Ocean during the Chow Chow glaciation where it constructed broad arcuate moraines (Moore, 1965). As the glacier retreated, it either re-advanced or stagnated constructing the

terminal moraine that impounds Quinault Lake. Moore (1965) acknowledged that this re-advance or stillstand could represent a different, distinct glaciation, but could not justify such a division based on his study.

Presently, Quinault Lake forms a base level at an elevation of 57 m above average mean sea-level (amsl). The lake has an average surface area of 1510 hectares and is one of the largest natural lakes on the peninsula. The geologic history of Quinault Lake and its geomorphic influence on the Upper Quinault River were unrecognized until the present study. Based on field observations, new radiocarbon dates, and tentative correlations with the Hoh River glaciations, this study provides insight into the interactions between Quinault Lake and the Chow Chow glacier during the last glacial cycle.

Last Glacial Cycle

In the Quinault River Valley the last glaciation is referred to as the Chow Chow Glaciation (Moore, 1965). Based on glacial stratigraphy and limiting radiocarbon ages obtained by Moore (1965), this study tentatively correlates the Chow Chow Glaciation to the Hoh Oxbow Glaciation studied by Thackray (1996) in the nearby Hoh River Valley. This correlation between the Quinault River and Hoh River glaciers is useful in that it provides a temporal framework of regional glacial-interglacial cycles in which to work. However, further studies are needed to establish chronologic controls for the Quinault River glacier's advances and retreats.

At its maximum, the Chow Chow ice reached to within 12 km of the Pacific Ocean. This study makes the assumption that this Chow Chow glacial maximum correlates to the Hoh Oxbow I glacial maximum about 29.0 ka. The correlation is based on two radiocarbon dates (32.0 ka and greater than 35.6 ka) obtained by Moore (1965) that limits the maximum age of the glacial advance to less than 32.0 ka.

The Chow Chow glacier probably began its retreat about 29.0 ka and withdrew from the coastal piedmont. At the foot of the Olympic Mountains the glacier re-advanced (or stagnated) building up the terminal moraine that impounds Quinault Lake. This stade is most likely equivalent to Thackray's (1996) Twin Creeks I re-advance of the Hoh River glacier that occurred about 18.0 ka.

As the Chow Chow glacier resumed its retreat up the Quinault River Valley, the ice melted-back asymmetrically with the north side withdrawing at a more rapid rate than the south side. This asymmetry resulted from hanging valley glaciers coalescing with the main glacier along the southern valley wall (Photograph No. 1 and 2).

Contemporaneous with the valley glacier's retreat, Quinault Lake began filling behind the terminal moraine. The Late Pleistocene highstand of Quinault Lake was at least elevation 135 m (amsl). This interpretation is based on the elevation of deltaic deposits discovered along Finley Creek (Photograph No. 3 and 4). Determining the aerial extent of the

Photograph No. 1. View of the Upper Quinault River Valley looking southwest toward the Southern Fault Zone (SFZ). Also in the photograph there is a hanging valley visible left of center, the significance of the hanging valley is that the Chow Chow ice must have filled the valley to that elevation.

Photograph No. 2. View of the Upper Quinault River Valley looking northwest at the north valley. Note there are no hanging valleys although most of the tributary drainages were headed by glaciers. Also note the bench along the base of the mountain just above center of photograph. This bench is a depositional feature that can be traced from the terminal moraine that impounds Quinault Lake upstream to the Finley Creek area (valley in the right center of photo).

Photograph No. 3. Delta foreset beds dipping toward the Upper Quinault River Valley exposed along the Finley Creek drainage in Township 24 North, Range 9 West, Section 35, elevation is approximately 134 m (amsl).

Photograph No. 4. View of delta foreset beds looking upstream along the Finley Creek channel (Township 24 North, Range 9 West, Section 35).

glacial lake was beyond the scope of this study, but based on elevation profiling the lake may have extended upstream to the confluence of the North and East Forks of Quinault River.

The limit of the last Chow Chow glacial advance or stagnation in the Upper Quinault River Valley was most likely downstream of the confluence of the North and East Forks of the Quinault River (this study). This stade is believed to be equivalent to Thackray's (1996) Twin Creeks II re-advance of the Hoh glacier about 10.0 ka. During this time, each fork of the Quinault River (North and East) contained a valley glacier and these glaciers coalesced at the confluence. It is likely the ice intercepted Quinault Lake because the glacier's trimline along the south valley wall terminates just downstream of the confluence and there is no evidence of a terminal moraine. Additionally, the outwash plain in the lower section of the Big Creek drainage suggests the North Fork glacier surmounted the bedrock outcrop that separates Big Creek from the North Fork near Irely Lake. However, the glacier advanced only a short distance down the lower section of the Big Creek drainage and its meltwater deposited copious amounts of outwash sediments.

Climatic changes during the Holocene brought about warmer and drier conditions resulting in the North Fork and East Fork glaciers withdrawing up their respective valleys. These valleys are now headed by the small cirque glaciers preserved on Mt. Seattle, Mt. Christie, Mt. Anderson and White Mountain. Contemporaneous with the Holocene retreat of the Quinault River glaciers was the reduction in available meltwater flowing into Quinault Lake. Based on topographic cross-sections of the terminal moraine impounding Quinault Lake, there is an abrupt change from a wide outlet to a narrow outlet (Figures 3 and 4). This change in fluvial geomorphology is interpreted to represent the lake's highstand 10.0 ka at about elevation 110 m (amsl).

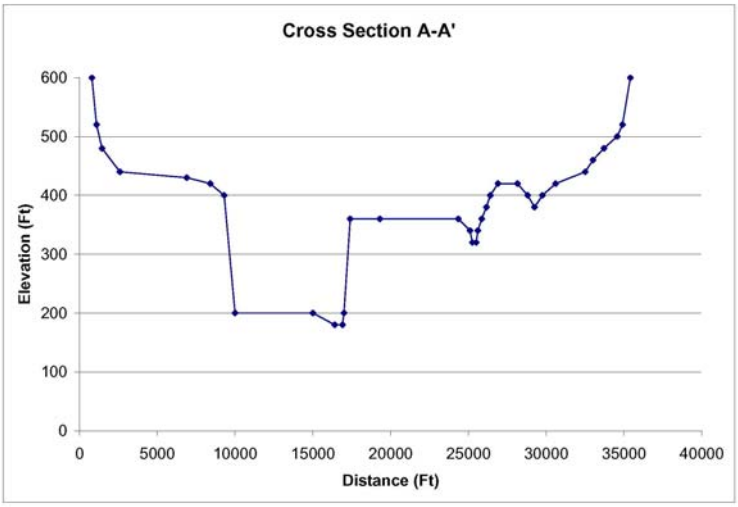


Figure 3. Topographic profile across the crest of the terminal moraine impounding Quinault Lake.

Quinault Lake's Rate of Regression

Quinault Lake forms a base level for the Quinault River. This base level has lowered in elevation through time due to regression of the lake (Figure 4). The lake's regression is controlled by the rate of fluvial incision through the terminal moraine that impounds Quinault Lake. Thus, as the base level is lowered, the river is able to incise into the fluviolacustrine deposits that have filled the valley bottom since the Late Pleistocene.

Organic materials found in numerous lacustrine deposits at varying elevations were radiocarbon dated during this study. The radiocarbon ages provide temporal constraints on Quinault Lake's minimum lake elevations and its approximate aerial extent based on topography. There were three key sample locations analyzed in this study, (1) elevation 61 m (~200 feet) near Pruce Boys Road [Photograph No. 5], (2) elevation 73 m (~240 feet) along the north bank of the Quinault River [Photograph No. 6], and (3) elevation 85 m (~280 feet) in an exposure downstream from the Finley Creek bridge [Photograph No. 7]. The significance of these locations is that they returned radiocarbon ages of 6.5 ka or less implying that the Quinault River valley glaciers would have already retreated and that the glaciers would not have a meaningful impact on the lake's elevation. Figure 4 illustrates Quinault Lake's regression through time and the crest of the terminal moraine that impounds the lake.

Pleistocene-age terrace treads and scarps are well preserved and definable near the confluence of the North and East Forks of the Quinault River. Conversely, Holocene-age terrace treads and scarps are not well preserved and do not appear to be continuous. The interactions between the Quinault River and Quinault Lake since the last glacial cycle have left relatively minor terrace treads that are not continuous on aerial photographs or in the field. Because mapping and correlating these terraces was problematic, this study describes surfaces that are subdivided based on elevation, dissection, and to a lesser degree on vegetation. Within the present floodplain there are three primary surfaces defined as, (1) the upper surface, (2) intermediate surface, and (3) lower surface (Figure 5 and Attachment 1).

The upper surface is elevated about 3 m to 5 m above the normal water surface in the active channel. The surface is infrequently inundated and is dissected predominantly by ephemeral and perennial streams. It is covered with mature ferns, and also large diameter (+1 m) Sitka Spruce, Douglas Fir, and Bigleaf Maple. Large stumps (+1 m) can generally be found in areas where the mature trees have been harvested. Radiocarbon ages collected during this study suggest the fluvial deposits mantling the upper surface are 1.4 to 1.6 ka. Three water wells have been drilled within the limits of the upper surface (Township 23 North, Range 9 West, Section 1). The well logs record about 2 m to 5 m of clayey material with sand and gravel overlying 2 m to 4 m of fine gravel and sand (water well logs can be found on the Washington State Department of Ecology website). This stratigraphy is interpreted to represent lacustrine sediments overlying glacial outwash and/or deltaic sediments.

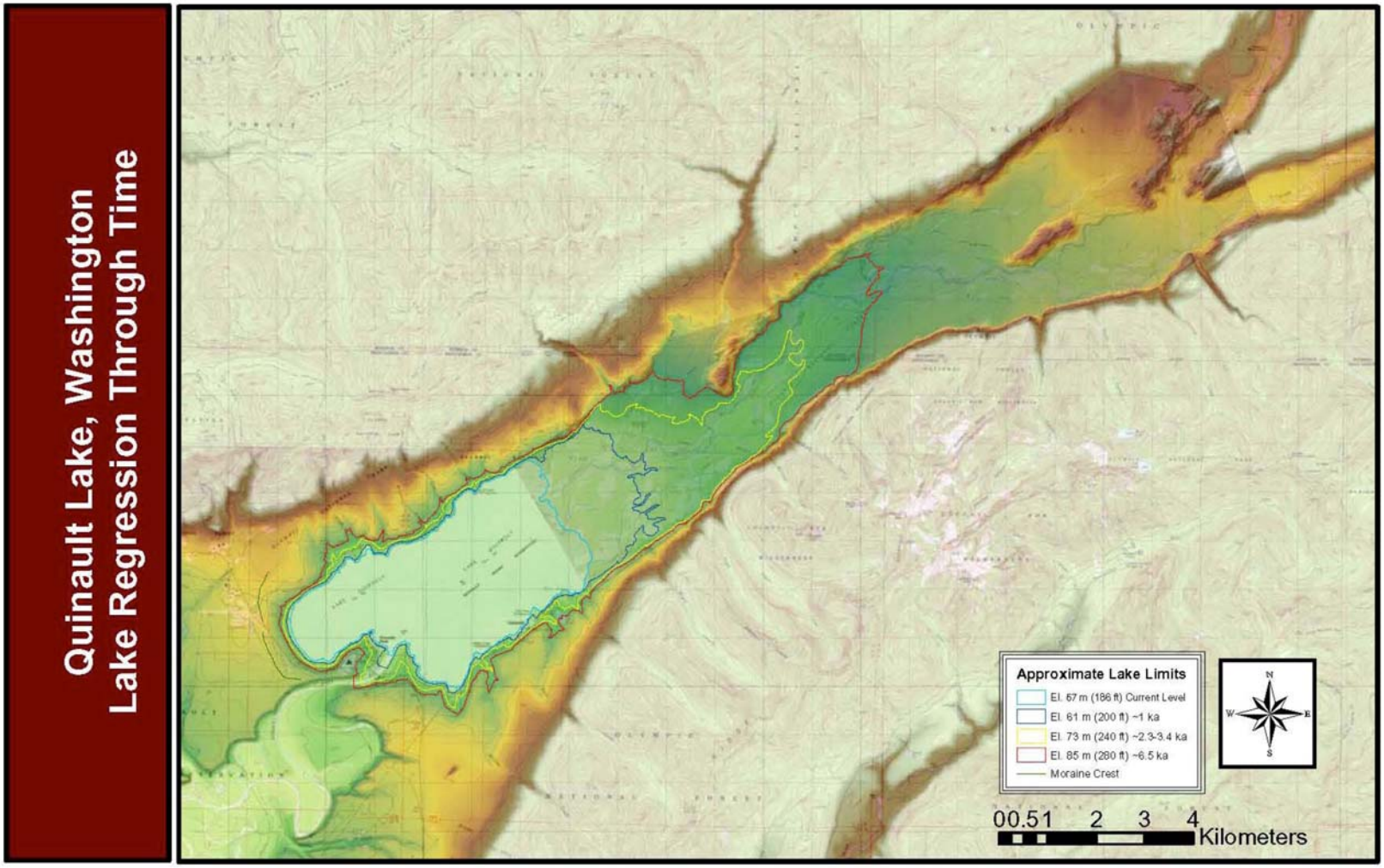


Figure 4. Interpretation of Quinault Lake's rate of regression based on radiocarbon ages and the elevation of where the sample was obtained.

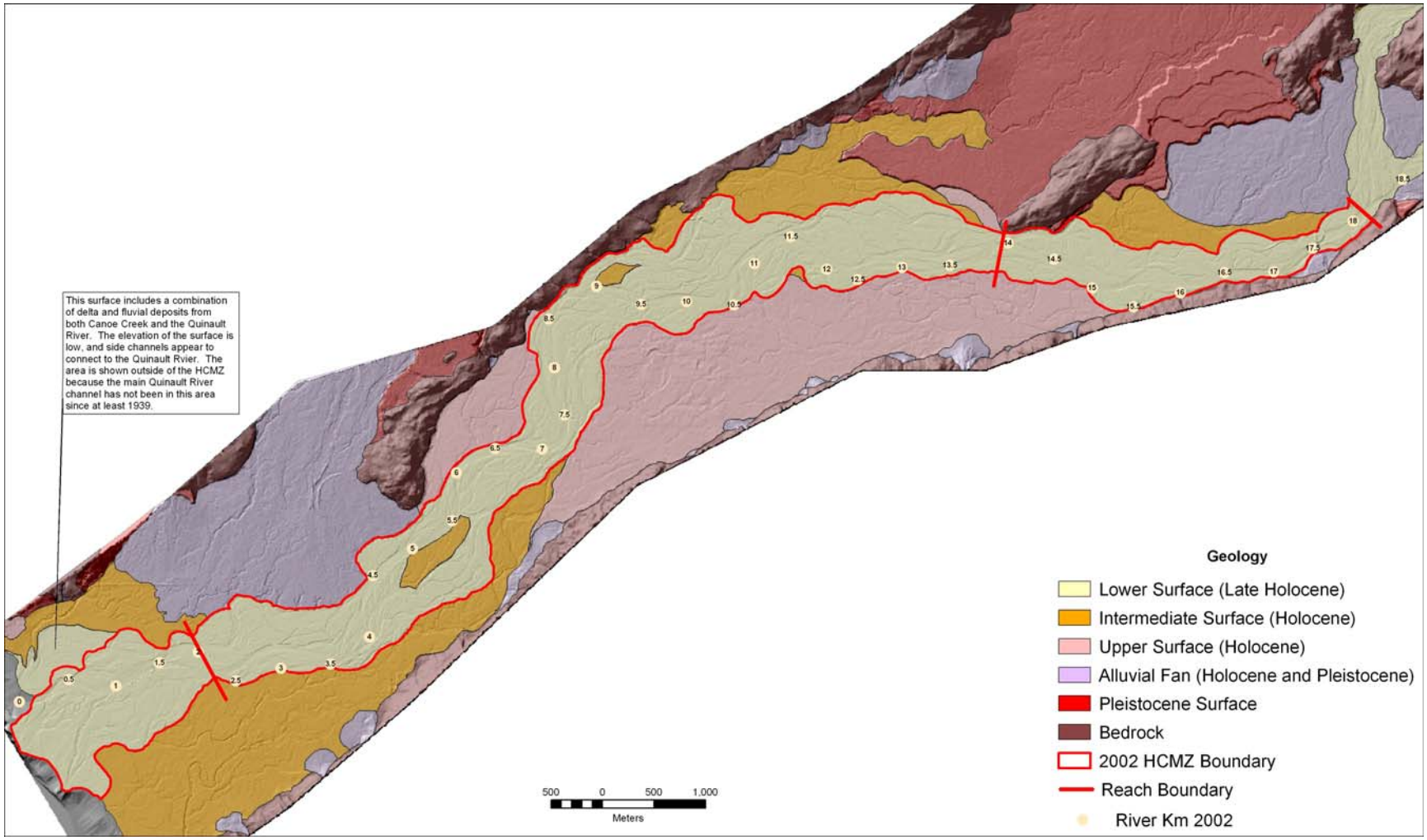


Figure 5. Overview map of geologic surfaces in study area.

Photograph No. 5. Lacustrine sediments exposed along the Quinault River near Pruce Boys Road (Township 23 North, Range 9 West, Section 9, elevation 61m [amsl]). An organic layer within the silt beds returned a radiocarbon age of 1080 ± 40 C14 yr. BP (Sample No. 81904-1-1CO).

Photograph No. 6. Lacustrine sediments containing gravel lenses exposed along the north bank of the Quinault River near the mouth of Finley Creek (Township 23 North, Range 9 West, Section 3, elevation 73 m [amsl]). Bulk samples returned radiocarbon ages of 3250 ± 50 C14 yr. BP, 3720 ± 40 C14 yr. BP, 2480 ± 40 C14 yr. BP, and 3040 ± 40 C14 yr. BP (Sample Nos. 92802-3-1CO, 92802-3-2CO, 92902-1-1CO, and 92902-1-2CO).

Photograph No. 7. Lacustrine sediments containing gravel lenses exposed along the Finley Creek channel (Township 23 North, Range 9 West, Section 3, elevation 85 m [amsl]). Bulk sample returned a radiocarbon age of 5650 ± 50 C14 yr. BP (Sample No. 92902-1-3CO).

The intermediate surface is elevated about 1 m to 2 m above the normal water surface in the active channel. The surface is commonly inundated and is strongly dissected by overflow channels. Vegetation consists primarily of alders and firs up to 30 cm diameter and Sitka Spruce trees up to 50 cm diameter. Radiocarbon ages collected during the current study suggest the fluvial deposits are 0.6 ka to 1.0 ka. Ten water well logs were reviewed from water wells that had been drilled within the limits of the intermediate surface (Township 23 North, Range 9 West, Section 10). The well logs record 1 m to 2 m of "soil" overlying 5 m to 22 m of gravel and sand. One well log also records "lotsa wood" in the gravel and sand. This stratigraphy is interpreted to represent lacustrine and/or floodplain sediments overlying glacial outwash and/or deltaic sediments.

The lower surface generally corresponds to the 2002 Historical Channel Migration Zone (HCMZ). The surface includes the active channel to about 1 m above the active channel. It is frequently inundated on nearly an annual basis and is commonly vegetated with alders, willows, and small conifers. Radiocarbon ages collected during this study suggest the lower surface is less than 0.5 ka.

Discussion

During the last glacial cycle, the Chow Chow glacier reached its maximum extent about 29.0 ka (Moore, 1965). The glacier soon withdrew from the coastal piedmont, but re-advanced or stagnated at the foot of the Olympic Mountains about 18.0 ka where it constructed the terminal moraine that impounds Quinault Lake (based on tentative

correlation to the Hoh River glaciations). Deltaic deposits discovered in the Finley Creek drainage suggest the lake reached its highstand during the Late Pleistocene at about elevation 135 m (amsl). The aerial extent of the lake was not determined in this study, but the elevation suggests the lake may have extended at least to the confluence of the East and North Forks of the Quinault River.

Based on elevation cross sections of the terminal moraine that impounds Quinault Lake, this study suggests that about 10.0 ka Quinault Lake's surface was at approximately elevation 110 m (amsl) and has since been lowering at a long-term rate of ~5 mm/yr. The significance of Quinault Lake is that it establishes a base level that has slowly been lowered since the Late Pleistocene. Regression of Quinault Lake also suggests that the intermediate and upper surfaces are comprised of fluviolacustrine sediments overlying deltaic and/or glacial outwash. This interpretation is further supported by subsurface data reported on water well logs.

Conclusions

During the Late Pleistocene, the Quinault glacier (Chow Chow glaciation of Moore, 1965) constructed the terminal moraine that impounds Quinault Lake. Since its impoundment, the lake has formed a base level for the Upper Quinault River. However, the lake has been slowly regressing since the Late Pleistocene due to fluvial incision of the terminal moraine. During its Late Pleistocene highstand, Quinault Lake reached approximately elevation 135 m (amsl) based on deltaic deposits discovered in the Finley Creek drainage. Radiocarbon dating of organic material found in lacustrine deposits at differing elevations and locations show that Quinault Lake has slowly regressed from elevation 85 m to 57 m (amsl) in the last 6,500 years.

Quinault Lake's regression and water well logs suggest that the planar surfaces described in this study as the upper and intermediate surfaces are primarily of lacustrine origin and cored by deltaic and/or glacial outwash deposits. Based on this interpretation, the upper and intermediate surfaces are probably not stream terraces and the lower surface most likely represents the limits of the Historical Channel Migration Zone (HCMZ).

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Attachment 1: Geologic Units Description

The seven surficial geologic units encountered in the study area are designated as follows: (1) lower surface, (2) intermediate surface, (3) upper surface, (4) lacustrine deposits [not mapped], (5) alluvial fan, (6) Pleistocene surface, and (7) bedrock. These units were categorized based on geomorphic expression, age, elevation, material composition, and the process that resulted in their formation. The methodology used to distinguish these units was a combination of field investigation, topographic data (Lidar and USGS quadrangles), and the GIS version of a generalized geologic map based on Tabor and Cady (1978) geologic map (scale 1:125,000) of the Olympic Peninsula. Field investigations focused on distinguishing surfaces based on exposures, observed features, vegetation types (indicating a difference in location and height above Quinault River), and land use.

QUATERNARY GEOLOGIC UNITS

LOWER SURFACE (Holocene) – The lower surface corresponds to the historical channel migration zone (HCMZ) and is comprised of younger alluvium deposited by the Quinault River. The surface is frequently inundated on nearly an annual basis. The unit includes surfaces of several heights and relative ages. Maximum elevation is about 1.0 meter above normal water surface in the active channel. This surface is commonly vegetated with alders, willows and small conifers. The lower surface should be considered unstable and part of the active floodplain.

INTERMEDIATE SURFACE (Holocene) – Composed of fluviolacustrine deposits that are evident as a series of small terrace risers and terrace treads that are elevated about 1.0-2.0 meters above normal water surface in the active channel. This surface is commonly inundated and is strongly dissected by overflow channels. Vegetation consists of alders and firs up to 30 cm in diameter and Sitka Spruce trees up to 60 cm diameter. The intermediate surface should be considered relatively stable on a decadal time scale.

UPPER SURFACE (Holocene) – Composed of fluviolacustrine deposits that form terrace risers that are elevated about 3.0-5.0 meters above the normal water surface in the active channel. This surface is infrequently inundated and is dissected predominantly by ephemeral and perennial streams. The treads are covered with mature ferns, and also large diameter (+1 m) Sitka spruce, Western redcedar, Douglas Fir, and Bigleaf maple. Large stumps can be found where the mature trees have been harvested. The upper surface has been and should remain relatively stable for centuries.

LACUSTRINE DEPOSITS (Pleistocene to Holocene) – The observed lacustrine deposits were not mapped during this project because it was out of the scope of the study. These deposits are directly related to the transgression and regression of Lake Quinault from its impoundment during the Pleistocene to Present. The lakebed deposits are interbedded with or bury the alluvium associated with the intermediate and upper surfaces and are generally bluish grey in outcrop. They are generally comprised of silt and fine sand with lesser amounts of gravel and cobbles. Holocene lakebed deposits have been observed

along the Quinault River near Pruce Boys Road, at the Ziegler Creek Bridge, along the North Shore Road, and downstream of the Finley Creek Bridge. Charcoal from the deposits at the site near Pruce Boys Road was dated 1980 ± 40 cal yrs BP, and charcoal from the deposits downstream of Finley Creek Bridge was dated 6500 to 6300 cal yr BP (Appendix L).

The interaction between glacial Lake Quinault and the Quinault valley glacier during the Chow Chow glaciation resulted in the deposition of deltaic deposits observed in the Finley Creek drainage as foreset beds. The significance of the deltaic deposits is that they suggest the minimum glacial Lake Quinault highstand was at about elevation of 135 m (amsl) during the late Pleistocene.

ALLUVIAL FAN (Pleistocene to Holocene) – Alluvium that has been deposited by ephemeral and perennial streams that create fan-like features that prograde from the valley walls onto the valley floor. The abundant glacial deposits along the valley walls and floor are re-worked by fluvial processes and transported downstream by sediment laden streams where they generally form conical features. Deposits associated with the alluvial fan consist of interfingering beds of gravel and sand with cobbles.

PLEISTOCENE SURFACE (Pleistocene) – Consists of a mixture of clay, silt, sand, gravel, and cobbles with occasional boulders deposited by alpine glaciers during the Chow Chow glaciation. This unit is comprised predominantly of glacial outwash deposits but may include till and moraine deposits. The outwash deposits are generally unconsolidated and composed of silt, sand, and gravel making them very susceptible to erosion. Terrace risers and terrace treads are generally 9.0+ meters above the normal water surface in the active channel. Downstream of the map area, a terminal moraine was constructed by the Chow Chow ice and this moraine presently impounds Lake Quinault.

TERTIARY DEPOSITS

BEDROCK (Paleocene to Miocene) – Contains Tabor and Cady's (1978) Core and Peripheral Rocks which are comprised of igneous, sedimentary, and metasedimentary rocks. These rocks are predominantly basalts, sandstones, conglomerates, siltstones, and argillites. They are generally hard and considered to be resistant of fluvial erosion.

Appendix D
Radiocarbon Dates

1. Purpose

- To determine the ages of terraces along the Middle Section of our study reach
- To determine the last time that the channel of the Quinault River (as indicated by gravelly alluvium) was in an area that is now terrace
- To determine the age of the alluvial fan at Finley Creek
- To better understand the geologic history of the Quinault River system

2. Methods

- Twenty samples were collected from the terrace or alluvial-fan deposits (figure 1; attachment 1)
    - Nineteen samples were collected in 2002; one was collected in 2004
    - Sixteen of the samples were bulk sediment samples, some of which contained visible charcoal
        - Samples were from fine-grained (silty sand or sand, primarily) deposits
        - Six samples were from floodplain deposits that overlie gravelly channel deposits beneath terraces
        - Four samples were from sandy beds that interfinger with gravelly alluvium within alluvial-fan deposits at Finley Creek
        - One deposit was from silty beds that may be lacustrine deposits that are exposed on the Finley Creek alluvial fan
        - One deposit was from a silty unit that may be lacustrine deposits that are exposed along the Quinault River near Pruce Boys Road
    - Four samples were from logs that were partially buried in the alluvial deposits; none of these were submitted for dating
        - The logs were embedded in cobbly or gravelly alluvium deposited in the Quinault River channel

- All sixteen of the bulk sediment samples were submitted to Paleo Research Institute (Denver, Colorado) for cleaning, separation, and identification of any charcoal (attachment 2)
    - Of these sixteen samples, two did not contain any charcoal

- Of the remaining fourteen samples that contained enough charcoal for dating, twelve were submitted to Beta Analytic, Inc (Miami, Florida) for radiocarbon dating (attachment 3); charcoal samples that showed rounding (transport) were not submitted for dating
    - Explanation of ages and errors indicated are at the back of Attachement 3

3. Results

- Calibrated radiocarbon ages are shown in Tables 1 and 2, and on Figure 2
- Floral remains that were found in the bulk sediment samples are shown in Tables 2 and 3 in Attachment 2

3.1. Dates Obtained

- Two dates are from floodplain deposits beneath the Upper Surface map unit
    - These samples are from the north side of the Quinault River near RK 7.5
    - These dates range between 660 and 1290 cal years BP (figures 2 and 3, table 2)

- Three dates are from floodplain deposits beneath the Intermediate Surface map unit
    - These samples are from the north side of the Quinault River between RK 11.2 and RK 11.7
    - Two dates range between 540 and 940 cal years BP (figures 2 and 3, table 2)
    - One date from a separate site ranges between 1350 and 1540 cal years BP (figures 2 and 3, table 2)

Two samples are from deposits beneath the Lower Surface map unit
- One of these is from floodplain deposits on the north side of the Quinault River near RK 11.7
- The date for this sample is ≤430 cal years BP (figures 2 and 3, table 2)
- One of these is from a silty deposit that may be a lacustrine unit exposed beneath the Lower Surface on the south side of the Quinault River near RK 2.3
- The date obtained from this unit is 930 to 1060 cal years BP (figures 2 and 3, table 2)

- Four samples are from alluvial-fan deposits exposed near the toe of the Finley Creek alluvial-fan complex
    - The results from these samples range between 2350 and 4220 cal years BP (figures 2 and 3, table 2)

- One sample is from silty beds exposed along Finley Creek about 0.5 km downstream from the bridge. These deposits may be lacustrine deposits.
    - The date from this sample is between 6300 and 6500 cal years BP (figures 2 and 3, table 2)

3.2. Relationship Between Dates, Map Units, and Location Along the Quinault River

- Dates from the alluvial-fan deposits are older and are topographically higher than the dates from the surfaces adjacent to the Quinault River.

- This suggests that the dated terraces are inset into the Finley Creek alluvial fan.

- In general, topographically higher deposits yield older dates (figure 4).
  - This would be expected if the Quinault River has been generally downcutting during the last several thousand years.
  - The date from the Lower Surface near RK 11.7 is an exception, but may be higher than expected because of local variations in the elevations of the surface or the Quinault River.

- Deeper samples at a single locality or in an area yield younger dates than overlying or higher samples (figure 5).
  - This is the inverse of the relationship that is expected on the basis of the apparent stratigraphic relationships, which suggest that overlying deposits should be younger than underlying deposits

4. Problems In the Interpretations of the Radiocarbon Dates

Several factors may influence the dates obtained

- The dates are limited and widely spaced within the valley. Date are lacking from the south side of the river. It is difficult to interpret the numerous minor surfaces within our map units on the basis of the data

- The locations of the sample sites were determined for most sites with a GPS receiver in the field.
  - The dense trees at some sites, and the sparse satellite coverage at certain times made obtaining a GPS location impossible for some of the sample sites. These sites were located using maps, aerial photographs, and field description of the site. Some of the locations may have considerable error. This is particularly true for Samples 92802-3-1CO and 92802-3-2CO, where the GPS information and field location description did not match. The samples are located as best we could given the information that we had.

- The potential inaccuracies in the locations affect the elevations and heights that have been used.
  - The elevations of the surfaces and the Quinault River (and the derived heights) are from a TIN created in Arc from the 2002 Lidar data.
  - The exact point that is chosen for the location can markedly change the elevation.
  - The elevation data were collected at the study-area scale; the samples were taken at a specific point location.

- The irregularities in the surfaces and in the river also contribute to the errors in the elevations and heights.

- In addition, the elevations were taken from data collected in 2002, and conditions may not have been the same at the time the samples were collected, especially for the sample collected in 2004.

- The samples were collected with the idea of dating the gravelly alluvium, or the time that the channel of the Quinault River last occupied a position under the given surface.
  - Samples were collected from the floodplain deposits that overlie the gravelly alluvium, because the chances of obtaining charcoal were thought to be greater from slower-water (fine-grained) deposits than from the high-energy gravelly alluvium. The goal at the time of sample collection was not dating of the surfaces themselves, which are likely much younger than the dates that we obtained.

- The relationship between depth below the surface and age, which is the inverse of the relationship that is expected on the basis of the apparent stratigraphic relationships is troublesome.
  - Samples that we thought were stratigraphically lower (or older) yielded dates that are younger than higher (or supposedly younger) samples.
  - Several explanations are possible, but they cannot be resolved on the basis of our present work.
    - Older charcoal could be incorporated into the younger floodplain deposits
      - This is a very likely explanation in a dynamic river system, like the Quinault River
      - This calls into question all of the dates that we obtained, even the ones that appear to be stratigraphically correct.
      - The consistency of the older dates always above the younger ones is puzzling, but may be a result of the limited number of samples given the length of the study reach.
    - Inset stratigraphic relationships that were not detected in the field could account for the seemingly older dates from units overlying younger units.
      - This is possible for the alluvial-fan deposits, where discontinuous and irregular cut-and-fill sequences are common.
      - This is a less likely explanation for the layered floodplain deposits underlying the surfaces adjacent to the Quinault River.
    - Some of the samples may have been contaminated with younger carbon and, therefore, yield dates that are younger than the time of deposition
      - Samples were cleaned, and charcoal was separated from the bulk sediment samples in order to minimize contamination by younger organic matter (e.g., roots)
      - Samples closer to the present ground surface might be expected to have a greater chance for contamination (greater chance for

roots, bioturbation), but the samples that are higher stratigraphically yielded older dates than the lower samples

- The dates obtained do not appear to show a strong relationship to our map units.
  - Each map unit includes terraces, or surfaces, at various heights. Our map units are an attempt to distinguish between the main levels of terraces (or surfaces) related to the Quinault River. However, the elevation, or height above the Quinault River, at any single location may vary from the general elevation, or height, of the map unit (figures 6 and 7).
    - The elevations and heights above the Quinault River for each map unit appear to vary across the valley and upstream to downstream (figures 6 and 7).
    - Without additional detailed work in the field, it is difficult to verify correlations.
  - The samples were collected in order to document the time since the active channel of the Quinault River occupied the area beneath the terrace surface (not to determine the age of the surface).
    - The timing of channel occupation several meters below a surface indicated by a map unit is likely highly variable along and across the river for any given surface.
  - The terrace channels (figures 6 and 7) indicate that the surfaces are highly active environments, where flow, incision, and deposition have and continue to occur at regular intervals. Dating deposits in these environments is difficult.

5. Conclusions

- In order to resolve the apparent discrepancies in the radiocarbon dates that we obtained, a more detailed examination of the deposits, stratigraphy, and map units for the reach and at each site is needed, perhaps along with additional radiocarbon dates. These tasks were beyond the scope of our present study. However, the dates can be used in a general interpretation of surface age
- The Lower Surface (the youngest one) is likely younger than 500 years.
  - This is reflected in the ages of trees and other vegetation that are present on this surface.
- The Intermediate Surface and the Upper Surface are difficult to distinguish on the basis of the radiocarbon dates.
  - This is also reflected in the similar elevations of the two surfaces in at least some areas (especially downstream of Big Creek in the Middle Reach) (figures 6, 7, and 8).
  - The lower portions of the floodplain deposits (just above gravelly alluvium) are at least 500 to 1500 years old, in at least some locations. This suggests that the main Quinault River channel has not been in these areas in at least a few hundred to a couple of thousand years.
- The alluvial-fan deposits at Finley Creek are probably at least a few thousand years old.

- Lacustrine deposits may have existed at least two different times in the Quinalt River valley in the Finely Creek area (figure 8).
  - The older lake may date from about 6000 to 6500 years (middle Holocene) or older. (The date is from the upper part of the deposit; however, an angular unconformity indicates at least some portion of the deposits has been removed.)
  - The younger lake may date from about 1000 years and extended upstream from the present Lake Quinault to at least the Pruce Boys Road area (RK 2.3).

Table 1. Ages for Quinault River samples submitted to Beta Analytic, Inc. for radiocarbon analysis

Field sample number	Laboratory sample number	Type of material	C13/C12 ratio	Radiocarbon age (C^{14} yr. BP ± 1 σ)	Calibrated age range (cal yr. BP ± 2 σ)
92502-1-2CO	Beta-183376	Conifer charcoal	-24.6	620 ± 40	660 to 540
92502-1-3PI	Beta-183377	*Picea* charcoal	-26.2	970 ± 40	940 to 760
92502-2-2CO	Beta-183378	Conifer charcoal	-24.9	1560 ± 40	1540 to 1350
92502-3-1CO	Beta-183379	Conifer charcoal	-26.4	860 ± 40	890 to 860; 800 to 680
92502-3-2CO	Beta-183380	Conifer charcoal	-25.5	1300 ± 40	1290 to 1160
92702-4-1PO	Beta-183381	*Populus* charcoal	-25.5	270 ± 40	430 to 360; 330 to 280 180 to 150; 10 to 0
92802-3-1CO	Beta-183382	Conifer charcoal	-21.8	3250 ± 50	3640 to 3400
92802-3-2CO	Beta-183383	Conifer charcoal	-25.0	3720 ± 40	4220 to 4210; 4170 to 3970
92902-1-1CO	Beta-183384	Conifer charcoal	-26.9	2480 ± 40	2730 to 2350
92902-1-2CO	Beta-183385	Conifer charcoal	-24.6	3040 ± 40	3360 to 3150
92902-1-3CO	Beta-183386	Conifer charcoal	-26.5	5650 ± 50	6500 to 6300
81904-1-1CO	Beta-197492	Conifer charcoal	-23.4	1980 ± 40	1060 to 930

See the data sheets for the original data from Beta Analytic, Inc. (attachment 3)

Table 2. Radiocarbon ages and geologic setting for Quinault River samples

Field sample number	Radiocarbon age (C^{14} yr. BP ± 1 σ)	Calibrated age range (cal yr. BP ± 2 σ)	Location	Map Unit; Deposit	Type of sediment	Depth Below Surface	Height above gravelly channel alluvium
92502-1-2CO	620 ± 40	660 to 540	North side of Quinault River upstream of Big Creek confluence	Intermediate surface; intermediate floodplain deposit exposed in bank of terrace channel	Sandy silt	89 cm (35 in)	89 cm (35 in)
92502-1-3PI	970 ± 40	940 to 760	North side of Quinault River upstream of Big Creek confluence	Intermediate surface; upper floodplain deposit exposed in bank of terrace channel	Sandy silt	58 cm (23 in)	119 cm (47 in)
92502-2-2CO	1560 ± 40	1540 to 1350	North side of Quinault River upstream of Big Creek confluence	Intermediate surface; upper floodplain deposit exposed in bank of terrace channel along contact with a lower terrace	Sandy silt	76 cm (30 in)	79 cm (31 in)
92502-3-1CO	860 ± 40	890 to 860; 800 to 680	North side of Quinault River upstream of Finley Creek confluence	Upper surface; floodplain deposit exposed in bank of terrace channel	Silt	163 cm (64 in)	107 cm (42 in)
92502-3-2CO	1300 ± 40	1290 to 1160	North side of Quinault River upstream of Finley Creek confluence	Upper surface; floodplain deposit exposed in bank of Quinault River	Silty sand	119 cm (47 in)	10 to 15 cm (4 to 6 in)
92702-4-1PO	270 ± 40	430 to 360; 330 to 280 180 to 150; 10 to 0 (≤430)	North side of Quinault River upstream of Big Creek confluence	Lower surface (about 6 ft above Quinault River); lower floodplain deposit exposed in bank of secondary channel between Big Creek and Quinault River	Silt	66 to 79 cm (26 to 31 in)	2.5 cm (1 in)
92802-3-1CO	3250 ± 50	3640 to 3400	North side of Quinault River upstream of Finley Creek confluence	Alluvial-fan; alluvial-fan deposits exposed in bank along Quinault River; lower sand	Sand	213 to 226 cm (84 to 89 in)	--
92802-3-2CO	3720 ± 40	4220 to 4210; 4170 to 3970	North side of Quinault River upstream of Finley Creek confluence	Alluvial-fan; alluvia-fan deposits exposed in bank along Quinault River; upper sand	Sand	152 to 168 cm (60 to 66 in)	--
92902-1-1CO	2480 ± 40	2730 to 2350	North side of Quinault River upstream of Finley Creek confluence	Alluvial-fan; alluvial-fan deposits exposed in bank along Quinault River	Silt with pebble bed	457 cm (180 in)	--
92902-1-2CO	3040 ± 40	3360 to 3150	North side of Quinault River east of Finley Creek	Alluvial-fan; alluvial-fan deposits exposed in bank along Quinault River	Sand and silt beds	305 cm (120 in)	--
92902-1-3CO	5650 ± 50	6500 to 6300	Finley Creek alluvial fan about 0.5 km downstream of bridge	Alluvial-fan; lacustrine/delta deposit(?) exposed in bank along Finley Creek	Sand and silt beds	213 to 226 cm (84 to 89 in)	--
81904-1-1CO	1080 ± 40	1060 to 930	South side of Quinault River near Pruce Boys Road	Lower surface; lacustrine deposit(?) exposed in bank along Quinault River	Silt	260 cm (101 in)	>40 cm (>16 in)

See the data sheets for the original data from Beta Analytic, Inc. (attachment 3)

Table 3. Elevations, heights, and depths of sample site along the Quinault River

Map Unit	Site Number	River km 2002	Elevation Site (m)	Elevation River (m)	Height above QR (m)	Minimum Calibrated Age (cal yr BP)	Maximum Calibrated Age (cal yr BP)	Depth below surface (m)	Corrected Elevation (m)	Height Above Gravelly Alluvium (m)
Alluvial Fan	92902-1-3CO	4.4	79.921	67.34	12.581	6300	6500	2.2	77.721	
Alluvial Fan	92902-1-1CO	4.9	74.912	67.34	7.572	2350	2730	4.57	70.342	
Alluvial Fan	92902-1-2CO	4.9	74.912	67.34	7.572	3150	3360	3.05	71.862	
Alluvial Fan	92802-3-1CO	5.2	72.241	67.606	4.635	3400	3640	2.2	70.041	
Alluvial Fan	92802-3-2CO	5.2	72.241	67.606	4.635	3970	4220	1.6	70.641	
Intermediate Surface	92502-1-2CO	11.3	87.445	85.069	2.376	540	660	0.89	86.555	0.89
Intermediate Surface	92502-1-3PI	11.3	87.445	85.069	2.376	760	940	0.58	86.865	1.19
Intermediate Surface	92502-2-2CO	11.5	89.377	85.253	4.124	1350	1540	0.76	88.617	0.79
Upper Surface	92502-3-1CO	7.62	76.764	74.382	2.382	680	890	1.63	75.134	1.07
Upper Surface	92502-3-2CO	7.6	76.532	74.315	2.217	1160	1290	1.19	75.342	0.12
Lower Surface	92702-4-1PO	11.6	89.228	85.382	3.846	0	430	0.73	88.498	0.03
Lower Surface	81904-1-1CO	2.3	62.835	59.458	3.377	930	1060	2.6	60.235	0.4

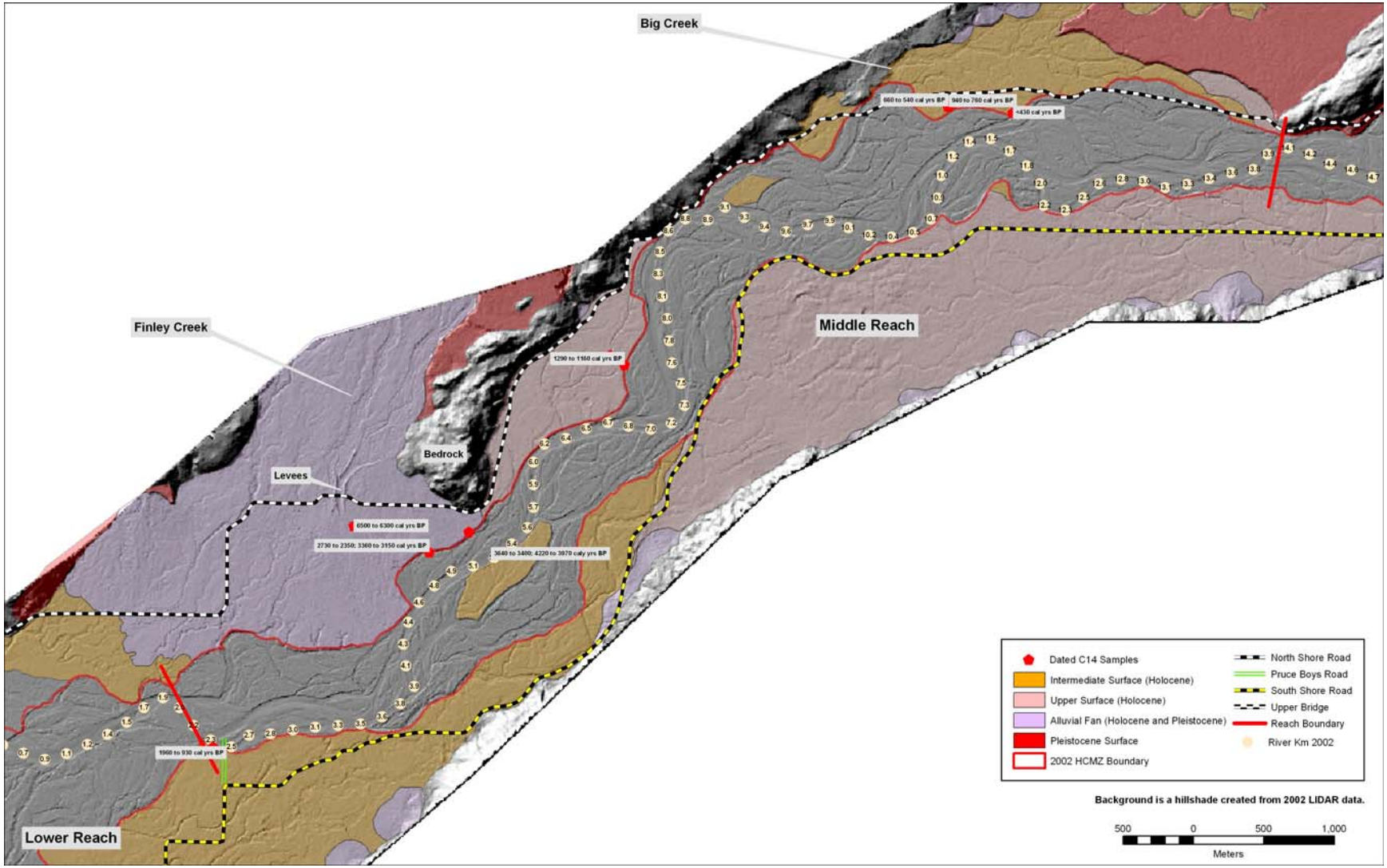

Figure 1. Locations and sample numbers for all of the samples collected for radiocarbon dating along the Middle Reach of the Quinault River. Information on each site is shown in Attachment 1.

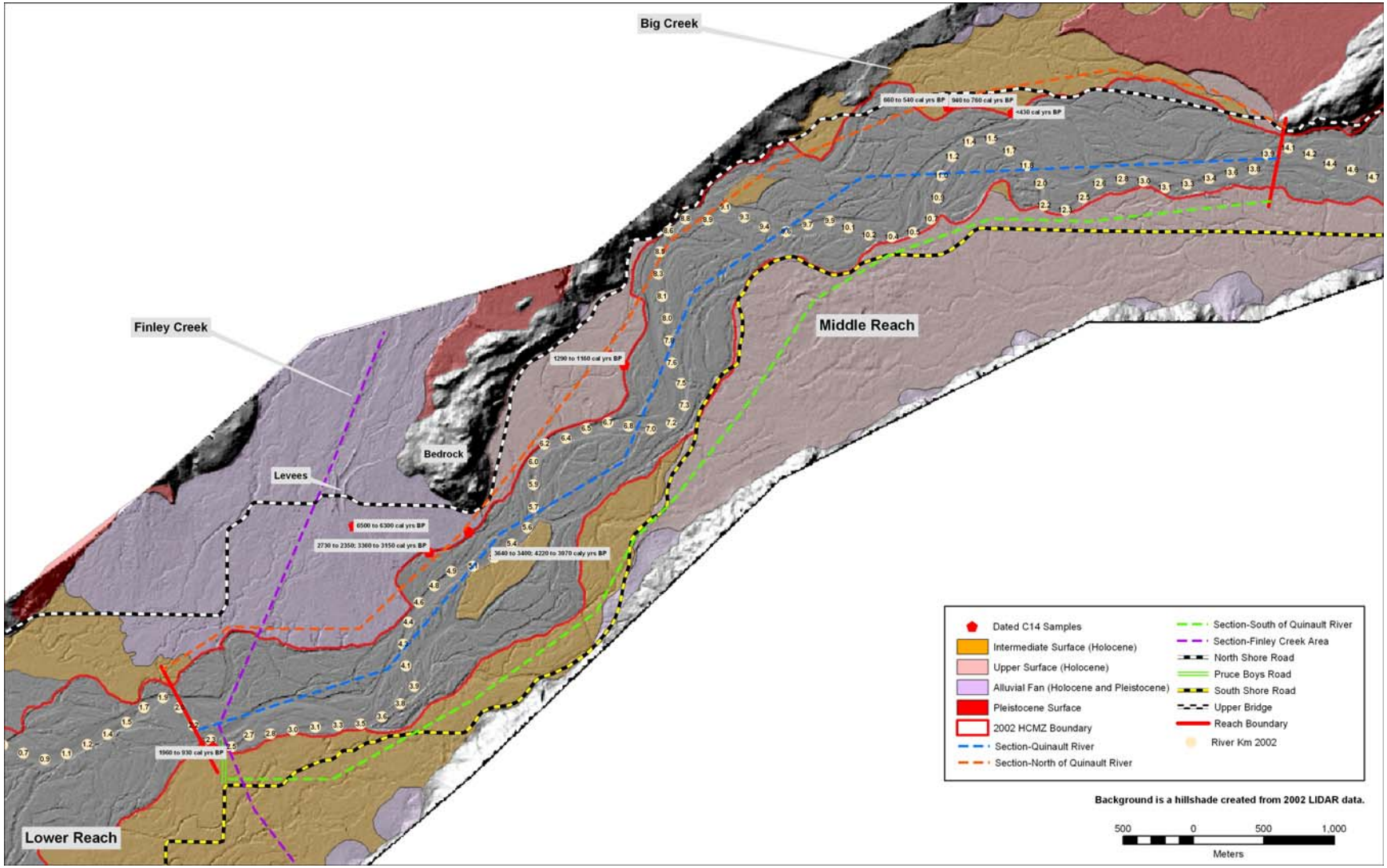

Figure 2. Locations and radiocarbon dates for the twelve samples submitted for radiocarbon dating along the Middle Reach of the Quinault River. Information on the dates is in Tables 1 and 2. The locations of the sections shown in Figures 6, 7, and 8 also are shown.

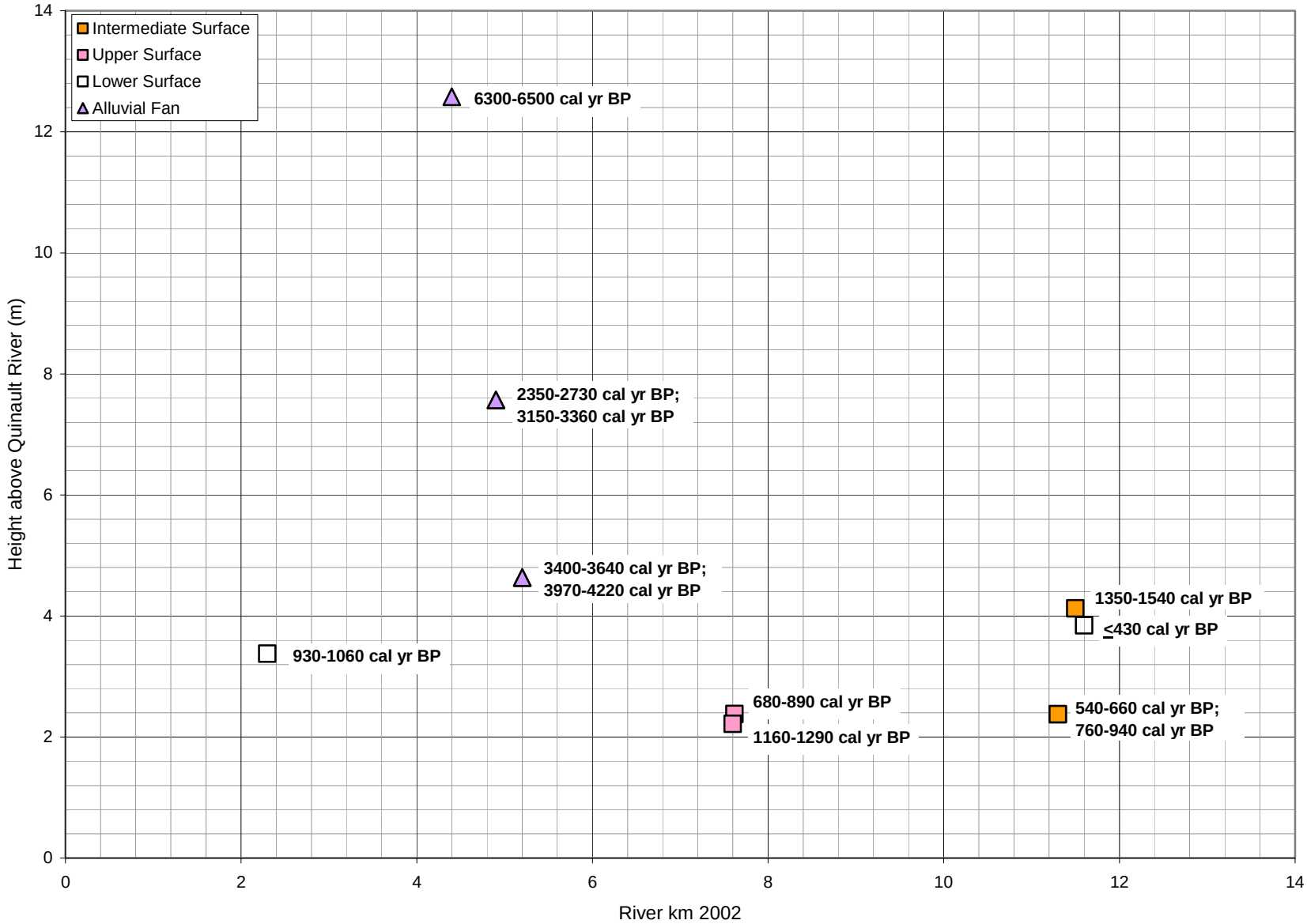

Figure 3. Radiocarbon ages plotted by location along the Middle Reach and height above the Quinault River (tables 2 and 3). Points with multiple dates indicate that more than one sample was collected and dated at the site.

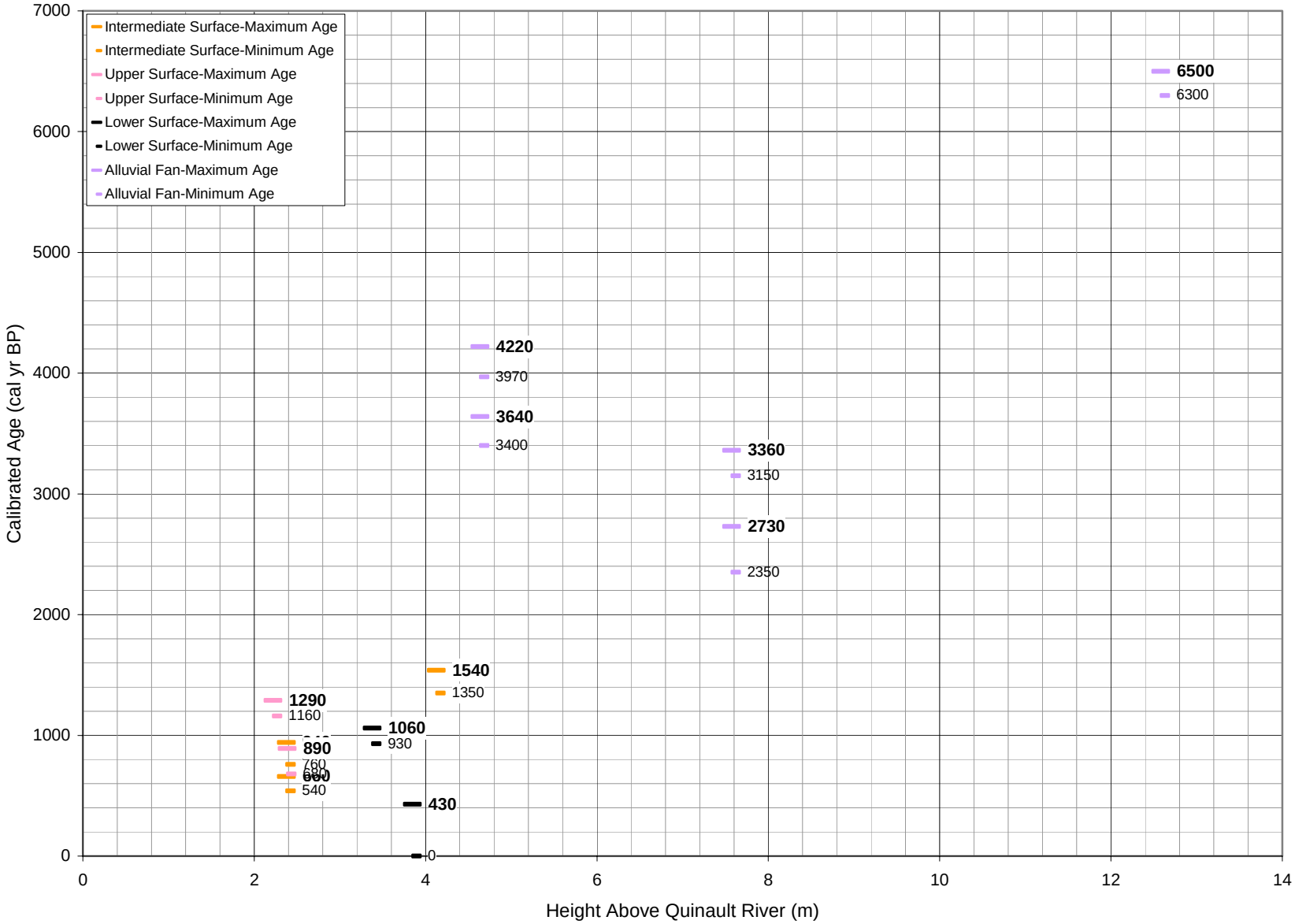

Figure 4. Radiocarbon ages plotted by the height of the samples above the Quinault River (tables 2 and 3).

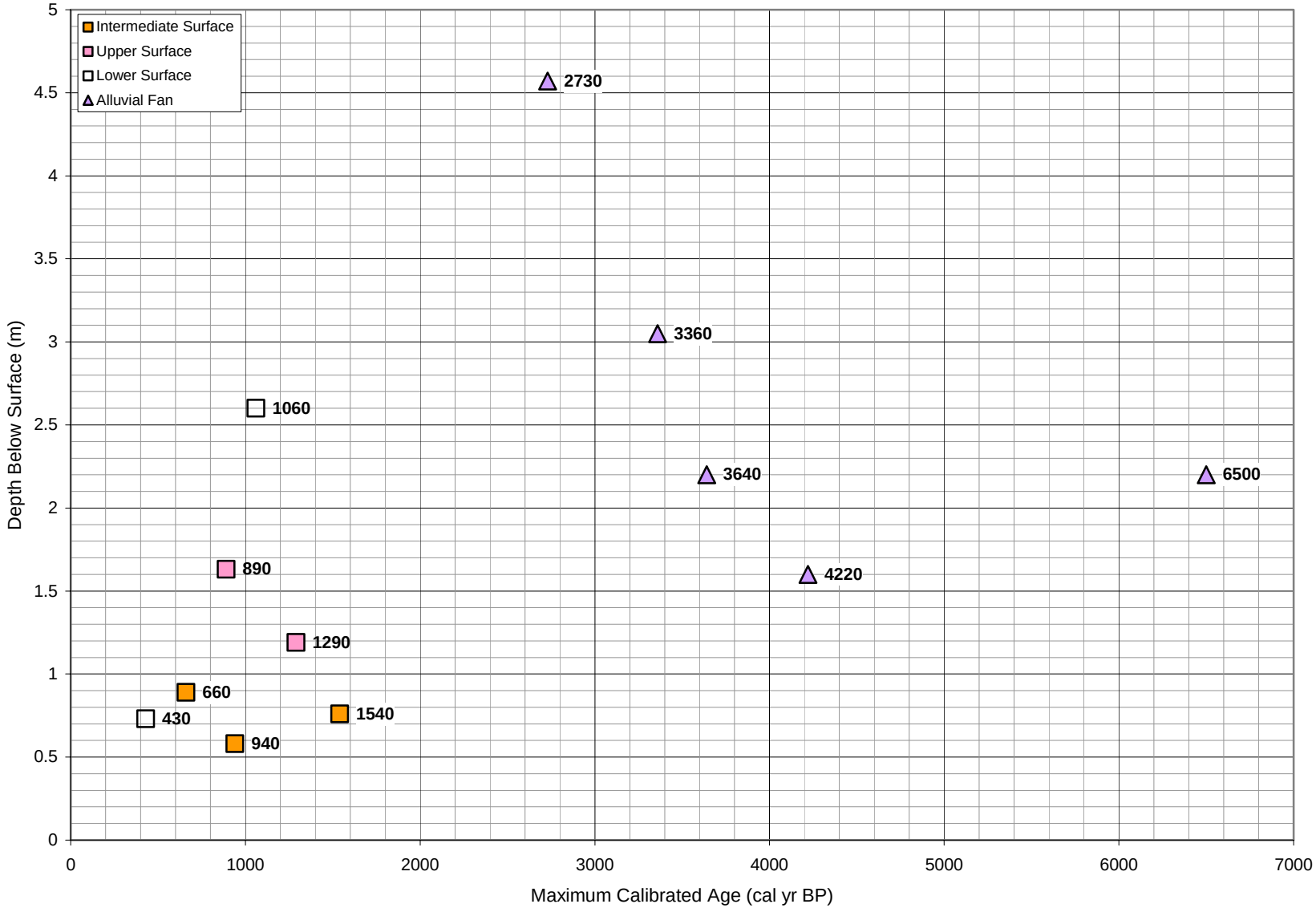

Figure 5. Maximum radiocarbon age plotted by sample depth below the ground surface (tables 2 and 3). For a given surface, samples stragraphically lower yielded younger dates, which is opposite to the expected trend (see text).

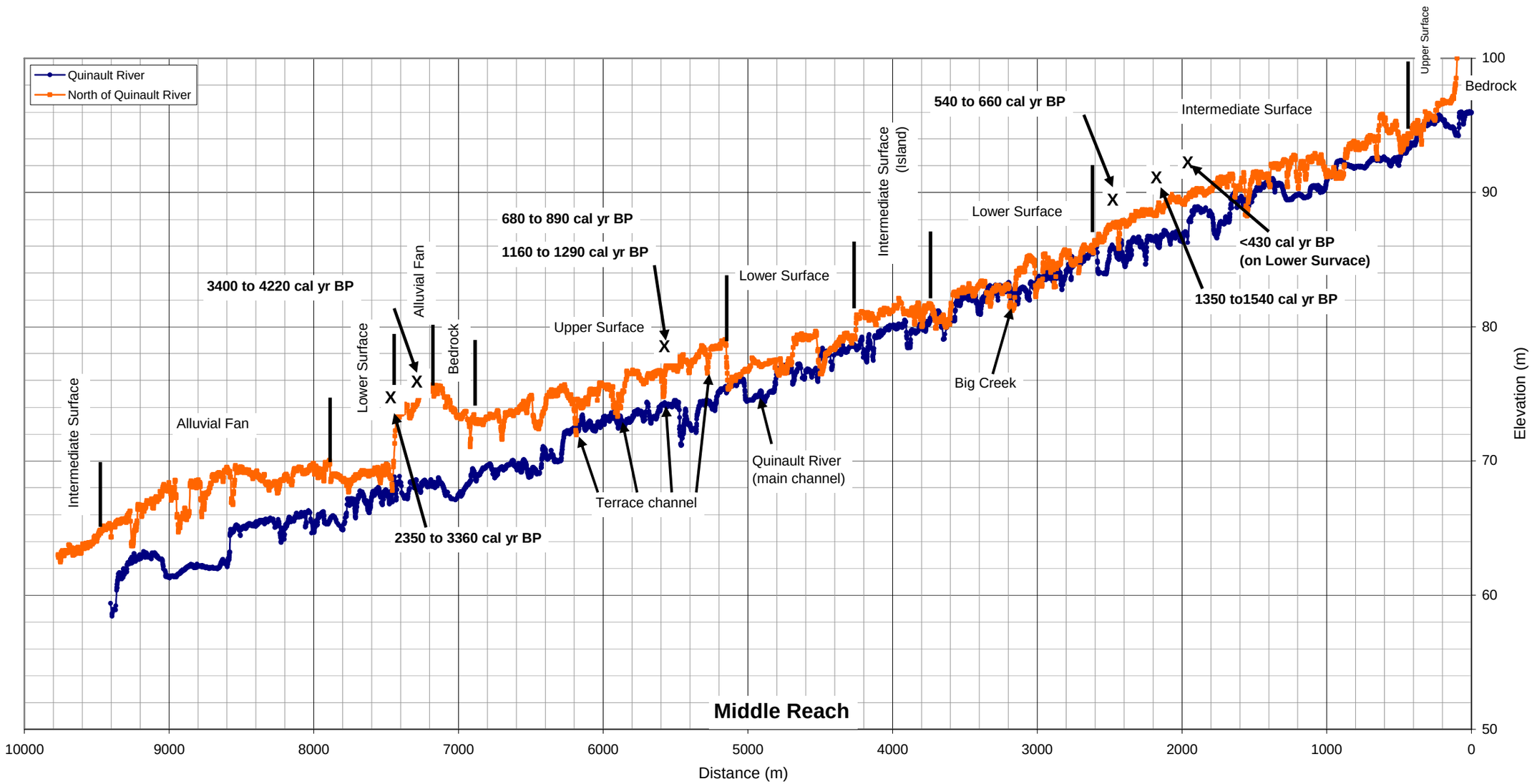

Figure 6. Longitudinal profiles along the Quinault River and surfaces along the north side of the valley as shown on Figure 2. Elevations and heights are from a TIN created from the 2002 Lidar data.

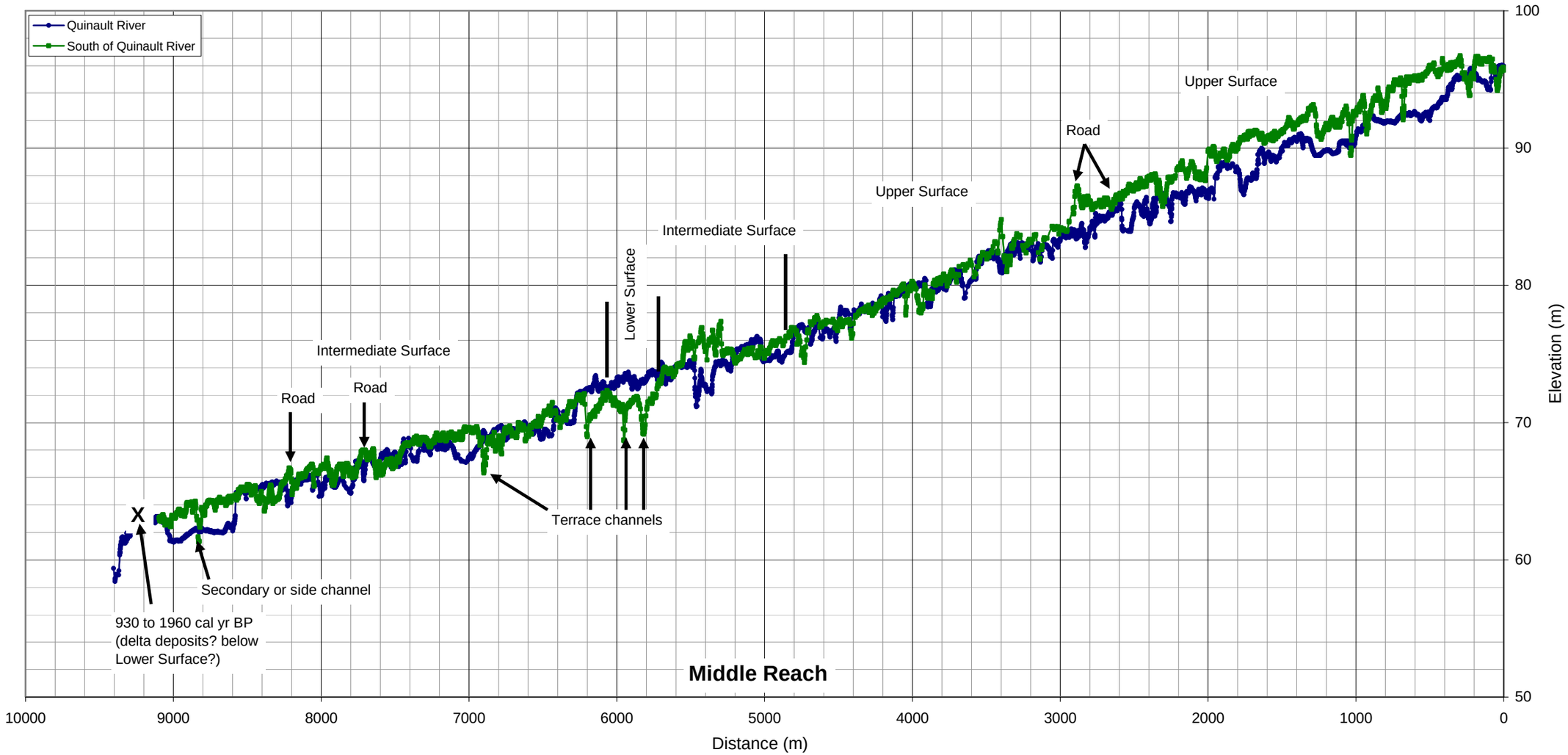

Figure 6. Longitudinal profiles along the Quinault River and surfaces along the south side of the valley as shown on Figure 2. Elevations and heights are from a TIN created from the 2002 Lidar data. The map unit along the south profile is on the Upper Surface upstream and the Intermediate Surface downstream. The height above the river for this surface varies across the valley (fig. 5) and along the valley.

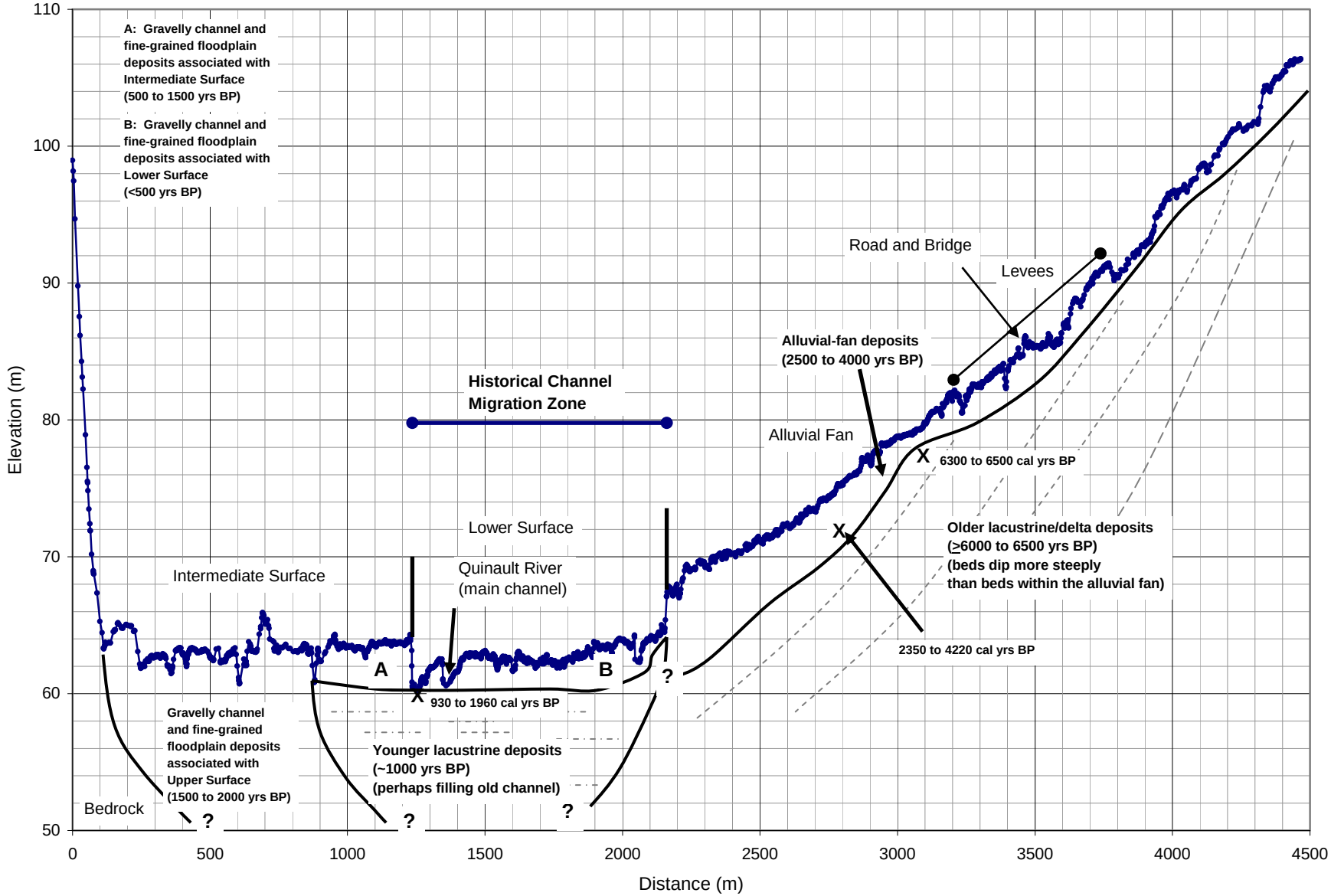

Figure 8. Generalized cross section in the Finley Creek area (fig. 2) showing the radiocarbon dates and an interpretation of the deposits dated and their stratigraphic relationship. Topography is from a TIN created from the 2002 Lidar data. See Appendix C (Geology) for a more detailed discussion.

Locations and Characteristics of Samples Collected for Radiocarbon Dating Along the Quinault River

Sample Number	Waypoint	Ref No	Location	Landform/deposit	Terrace	Type of Sample
92502-1-1		500	On north side of Quinault River east of Big Creek	Intermediate terrace (T2?); lowest floodplain deposit; exposed in channel	Terrace T2	Bulk sediment
92502-1-2		501	On north side of Quinault River east of Big Creek	Intermediate terrace (T2?); intermediate floodplain deposit	Terrace T2	Bulk sediment
92502-1-3		502	On north side of Quinault River east of Big Creek	Intermediate terrace (T2?); upper floodplain deposit	Terrace T2	Bulk sediment
92502-2-1	RT. 2, WP 2	2	On north side of Quinault River east of Big Creek; bank of highest terrace (T1?) in channel along contact with intermediate terrace (T2?)	Highest terrace (T1?); lower floodplain deposit	Terrace T1	Bulk sediment
92502-2-2	RT. 2, WP 3	3	On north side of Quinault River east of Big Creek; bank of highest terrace (T1?) in channel along contact with intermediate terrace (T2?)	Highest terrace (T1?); upper floodplain deposit	Terrace T1	Bulk sediment
92502-3-1	RT. 2, WP 21	21	On north side of Quinault River east of Finley Creek; bank of terrace (T2?) along intra-terrace channel	Intermediate terrace (T2?)	Terrace T2	Bulk sediment
92502-3-2	RT. 2, WP 22	22	On north side of Quinault River east of Finley Creek; bank along Quinault River?	Low terrace (T3)	Terrace T3	Bulk sediment
92602-1-1	RT. 3, WP 30	30				
92702-2-1	RT. 4, WP 72	72	On north side of Quinault River just east of Finley Creek; in bank along Quinault River	Terrace T3; gravelly alluvium	Terrace T3	Core from log
92702-4-1	RT. 4, WP 74	74	On north side of Quinault River east of Big Creek; bank of intra-terrace channel connecting Quinault River and Big Creek	Terrace T3?; terrace about 6 ft (1.8 m) above the Quinault River; lower floodplain deposit about 7 in (18 cm) thick	Terrace T3	Bulk sediment
92702-5-1	RT. 4, WP 89	89	On north side of Quinault River east of Big Creek; in bank of side channel of the Quinault River; just upstream of riprap along bank	Terrace T2?	Terrace T2	Bulk sediment

Locations and Characteristics of Samples Collected for Radiocarbon Dating Along the Quinault River

Sample Number	Waypoint	Ref No	Location	Landform/deposit	Terrace	Type of Sample
92802-1-1	RT. 5, WP 106	106	On north side of Quinault River along Survey Line #1 east of Big Creek	Terrace T2?	Terrace T2	Log
92802-3-1	RT. 5, WP 118	118	Bank in alluvial-fan deposits from Finley Creek; east of creek and north of Quinault River	Alluvial-fan deposits of Finley Creek		Bulk sediment
92802-3-2	RT. 5, WP 118	118	Bank in alluvial-fan deposits from Finley Creek; east of creek and north of Quinault River	Alluvial-fan deposits of Finley Creek		Bulk sediment
92802-5-1	RT. 6, WP 134	134	South side of Quinault River in bank along Harrington side channel	Terrace T2?	Terrace T2	Core from log
92902-1-1	RT. 6, WP 137	137	North side of Quinault River; bank along river at Finley Creek	Alluvial-fan deposits of Finley Creek		Bulk sediment
92902-1-2	RT. 6, WP 138	138	North side of Quinault River; bank along river at Finley Creek	Alluvial-fan deposits of Finley Creek		Bulk sediment
92902-1-3	RT. 6, WP 136	136	North side of Quinault River; in bank of incised drainage along Finley Creek; about 0.5 km downstream of bridge over Finley Creek	Lacustrine/delta deposits(?) of an ancestral Lake Quinault		Bulk sediment

Locations and Characteristics of Samples Collected for Radiocarbon Dating Along the Quinault River

Sample Number	Waypoint	Ref No	Location	Landform/deposit	Terrace	Type of Sample
93002-3-1	RT. 6, WP 190	190	South side of Quinault River; in bank at Pruce Boys Road	Terrace T1?	Terrace T1	Bulk sediment
81904-1		200	South side of Quinault River; in bank just downstream of Pruce Boys Road	Lacustrine deposits(?) of an ancestral Lake Quinault preserved beneath the Lower Surface		Bulk sediment

Abbreviation at end of sample number	Type of Charcoal Sample	Identifcation
ABR	*Abies* - Rounded	Fir, rounded edges (transported?)
AC	*Acer*	Maple, box elder
AL	*Alnus*	Alder
CO	Conifer	Cone-bearing
COR	Conifer - Rounded	Rounded edges (tranported?)
PI	*Picea*	Spruce
PO	*Populus*	Aspen, cottonwood
TS	*Tsuga*	Hemlock
UC	Unidentified charcoal	
UH	Unidentified hardwood	

Locations and Characteristics of Samples Collected for Radiocarbon Dating Along the Quinault River

Type of Sediment	Depth Below Surface (in)	Depth Below Surface (cm)	Height Above Gravelly Alluvium (in)	Height Above Gravelly Alluvium (cm)	Material > 2 mm	Sediment Color (Munsell; d, dry; m, moist)	Surface Vegetation
Silty clay	69	175	1	3	None	Mottled; Dark red (2.5YR 3/6 (d) and dark gray (gley chart 1, 4N)	
Sandy silt	35	89	35	89	None	Dark grayish brown (10YR 4/2 (d))	
Sandy silt	23	58	47	119	None	Very dark gray (10YR 3/1 (d))	
Silt	47	119	14	36		Mottled; Dark yellowish brown (10YR 4/4 (d)) and dark gray (10YR 4/1 (d))	Big-leaf maple with 4-ft diameters, alder, ferns, large stumps; lots of deadfall; ferns thick and tall
Sandy silt	30	76	31	79			
Silt	64	163	42	107		Dark gray (2.5Y 4/1 (d))	Fairly large alder, big-leaf maple (especially along channel)
Silty sand	47	119	4 to 6	10 to 15		Gray (2.5Y 5/1 (d))	Alder, Douglas fir, big-leaf maple
Cobbly gravel	52	131	NA	NA			Alder ≤1ft (30 cm) diameters
Silt	26 to 31	66 to 79	1	2.54		Mottled	
Silt	41 to 44	104 to 112	≤3	≤8			

Locations and Characteristics of Samples Collected for Radiocarbon Dating Along the Quinault River

Type of Sediment	Depth Below Surface (in)	Depth Below Surface (cm)	Height Above Gravelly Alluvium (in)	Height Above Gravelly Alluvium (cm)	Material > 2 mm	Sediment Color (Munsell; d, dry; m, moist)	Surface Vegetation
Gravelly alluvium	24	61	NA	NA	75% cobbles		Mostly unvegetated
Lower sand	84 to 89	213 to 226	NA	NA			
Upper sand	60 to 66	152 to 168	NA	NA			
Gravelly alluvium	65	165	NA	NA			
Silt (includes a bed of pebbles one-pebble thick)	180	457	NA	NA	60% small cobbles to pebbles		
Sand and silt beds	120	305	NA	NA			
Sand and silt beds			NA	NA			

Locations and Characteristics of Samples Collected for Radiocarbon Dating Along the Quinault River

Type of Sediment	Depth Below Surface (in)	Depth Below Surface (cm)	Height Above Gravelly Alluvium (in)	Height Above Gravelly Alluvium (cm)	Material > 2 mm	Sediment Color (Munsell; d, dry; m, moist)	Surface Vegetation
Silt	45 to 52	114 to 132	1	3		Mottled	
Silt	101	260	>16	>40			

Locations and Characteristics of Samples Collected for Radiocarbon Dating Along the Quinault River

Additional Notes	Charcoal Sample Number	Charcoal Sample Weight (g)
Underlying gravel is pebbly sand; sample taken at scour hole in intra-surface channel	92502-1-1UH	0.001
Underlying gravel is pebbly sand; sandier than sample 92502-1-3; sample taken at scour hole in intra-surface channel	92502-1-2AL	0.004
	92502-1-2CO	0.003
Underlying gravel is pebbly sand; siltier than sample 92502-1-2; sample taken at scour hole in intra-surface channel	92502-1-3PI	0.058
Underlying gravel is cobbly; above gravel, 28 in (71 cm) of silt buried by 33 in (84 cm) of loose sandy silt; sample is 14 in (36 cm) below top of silt unit; lots of roots (difficult to dig)		
Underlying gravel is cobbly gravel; above gravel, 28 in (71 cm) of silt buried by 33 in (84 cm) of loose sandy silt; sample is in sandy silt unit 3 in (8 cm) above top of silt unit; lots of roots (difficult to dig)	92502-2-2CO	0.007
	92502-2-2COR	0.003
Gravel is at a depth of about 67 in (170 cm); channel is about 72 in (183 cm) deep	92502-3-1CO	0.003
Underlying gravel is cobbly; gravel is at a depth of 51 in (130 cm); silty sand is loose	92502-3-2AL	0.012
	92502-3-2CO	0.009
Log at depth of 17 in (43 cm) from top of gravel; dimensions of exposed portion of log: diameter is 20 in (51 cm); length is 198 in (503 cm); partial core recovered; could not identify species		
Underlying is cobbly; sample from silt unit just above gravel; about 2 in (5 cm) above the sample, an upper unit of cross-bedded sand 24 in (61 cm) thick is present; bank appears to have eroded in the winter of 2001-2002	92702-4-1PO	0.005
	92702-4-1UC	0.004
Underlying gravel is cobbly; sample from lowest floodplain deposit; sandy unit and sand and silt unit are above the silt unit where sample was collected; lots of roots	92702-5-1AC	0.001

Locations and Characteristics of Samples Collected for Radiocarbon Dating Along the Quinault River

Additional Notes	Charcoal Sample Number	Charcoal Sample Weight (g)
Log (probably alder 10 yr old) is in cobbly gravel; log is 62 in (157 cm) above low water elevation; top of surface is 86 in (218 cm) above low-water elevation; about 5 in (13 cm) of sand and silt are at top of surface where log was collected; sand/sit bed to right is buried by cobbly gravel about 1 ft (30 cm) thick (flood deposit)		
Sand bed within alluvial-fan deposits that include gravel beds; top of alluvial-fan surface is 146 in (371 cm; 3.7 m)? above water level	92802-3-1COR 92802-3-1CO 92802-3-1TSR	0.011 0.003 0.009
Sand bed within alluvial-fan deposits that include gravel beds; top of alluvial-fan surface is 146 in (371 cm; 3.7 m)? above water level	92802-3-2CO 92802-3-2COR 92802-3-2ABR	0.016 0.027 0.023
Log located 15 cm below top of gravelly alluvium; diameter of log is 21 cm		
Silt unit is below alluvial-fan gravelly alluvium (60% SR-R small cobbles to pebbles); exposure is mostly silt with beds and lenses of gravel; depth estimated (could not measure); silt bed sampled is 30 in (76 cm) thick; bank is about 20 ft (6.1 m) high		
Sample is from a unit of sand and silt beds (thin) within the alluvial-fan deposit; sample about 60 in (152 cm) above Sample 92902-1-1; one piece of charcoal was noted and collected; bank is about 20 ft (6.1 m) high	92902-1-2AL 92902-1-2CO 92902--1-2COR 92902-1-2TS	0.006 0.013 0.003 0.007
Sample is from a unit that includes lenses of both sand and silt; approximately the same height as a gravel bed or lens that pinches out upstream of sample site	92902-1-3CO 92902-1-3COR	0.008 0.005

Locations and Characteristics of Samples Collected for Radiocarbon Dating Along the Quinault River

Additional Notes	Charcoal Sample Number	Charcoal Sample Weight (g)
Lowest floodplain unit; upper 18 in (46 cm) of gravel is iron stained; upper 4 ft (1.2 m) of gravelly alluvium is weakly cemented above a more strongly cemented bed; bank is 10.5 ft (3.2 m) high above water in the low-water channel; terrace is probably correlative with Terrace T1; height is lower than it is upstream, but terraces may be converging toward Lake Quinault; bank is at the outside of a meander bend and has		
	81904-1-1CO	0.005

Attachment 2, Appendix (Radiocarbon Dates)

EXAMINATION OF BULK SEDIMENT FOR RADIOCARBON DATABLE MATERIAL FROM ALONG THE QUINALT RIVER IN THE WESTERN OLYMPIC PENINSULA, WASHINGTON

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Denver, Colorado

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INTRODUCTION

A total of 15 bulk sediment samples from the Quinault River drainage basin in the western Olympic Peninsula, Washington, were floated to recover organic fragments suitable for radiocarbon analysis. Samples were recovered from floodplain deposits on terraces inset into a glacial moraine that dams Lake Quinault, as well as from sand and silt beds within alluvial fan deposits from Finley Creek, a major tributary in this section of the Quinault River. Botanic components and detrital charcoal were identified, and potentially radiocarbon datable material was separated.

METHODS

The bulk samples were floated using a modification of the procedures outlined by Matthews (1979). Each sample was added to approximately 3 gallons of water. The sample was stirred until a strong vortex formed, which was allowed to slow before pouring the light fraction through a 150 micron mesh sieve. Additional water was added and the process repeated until all visible macrofloral material was removed from the sample (a minimum of 5 times). The material which remained in the bottom (heavy fraction) was poured through a 0.5 mm mesh screen. The floated portions were allowed to dry.

The light fractions were weighed, then passed through a series of graduated screens (US Standard Sieves with 4 mm, 2 mm, 1 mm, 0.5 mm and 0.25 mm openings to separate charcoal debris and to initially sort the remains. The contents of each screen were then examined. Charcoal pieces larger than 0.5 to 2 mm in diameter were broken to expose a fresh cross-section and examined under a binocular microscope at a magnification of 70x. Some pieces were further examined at 400-800x using a Nikon Optiphot 66 microscope. The remaining light fraction in the 4 mm, 2 mm, 1 mm, 0.5 mm, and 0.25 mm sieves was scanned under a binocular stereo microscope at a magnification of 10x, with some identifications requiring magnifications of up to 70x. The material which passed through the 0.25 mm screen was not examined. The coarse or heavy fractions also were screened and examined for the presence of botanic remains. Remains from both the light and heavy fractions were recorded as charred and/or uncharred, whole and/or fragments. Individual detrital charcoal/wood samples also were broken to expose a fresh cross-section and examined under a binocular microscope at a magnification of 70x.

Macrofloral remains, including charcoal, were identified using manuals (Core *et al.* 1976; Martin and Barkley 1973; Panshin and Zeeuw 1980; Petrides and Petrides 1992) and by comparison with modern and archaeological references. The term "seed" is used to represent seeds, achenes, caryopses, and other disseminules. Because charcoal and possibly other botanic remains were to be sent for radiocarbon analysis, clean laboratory conditions were used during flotation and identification to avoid contamination. All instruments were washed between samples, and samples were protected from contact with modern charcoal.

DISCUSSION

Bulk sediment samples were recovered from the Quinault River drainage basin in the western Olympic Peninsula, Washington. The lower river terraces are vegetated with a variety of riparian species, primarily alder (*Alnus*) and some cottonwood (*Populus*). The higher terraces contain rain forest species such as bigleaf maple (*Acer macrophyllum*), sitka spruce (*Picea sitchensis*), western hemlock (*Tsuga heterophylla*), western red cedar (*Thuja plicata*), Douglas-fir (*Pseudotsuga menziesii*), and sword fern (*Polystichum*).

Twelve samples were collected from natural exposures on stream terraces adjacent to the Quinault River between RK56 and R. 84. This section of the Quinault River drains the western Olympic mountains and flows into Lake Quinault, which is dammed by a glacial moraine. The samples are from floodplain deposits on terraces inset into the moraine.

Sample 92502-1-1 was taken from silty clay above gravelly sand at a depth of 5' 9" below the surface (Table 1). This sample contained very small fragments of unidentified hardwood charcoal weighing 0.001 g (Table 2, Table 3). The minimum requirement of charcoal for standard AMS radiocarbon analysis reported by Beta Analytic, Inc. is 5 mg or 0.005 g; however, Beta now offers an AMS-MS dating technique for very small sample sizes. It now is possible to date charcoal weighing 1 mg or 0.001 g. Pieces of conifer charcoal, including a piece exhibiting rounded edges, weighed less than 0.001 g. Recovery of insect eggs, insect chitin fragments, and several uncharred remains from modern plants indicates some subsurface disturbance and introduction of modern material into this area. A few sclerotia also were present.

Sclerotia are commonly called "carbon balls". They are small, black, solid or hollow spheres that can be smooth or lightly sculpted. These forms range from 0.5 to 4 mm in size. Sclerotia are associated with mycorrhizae fungi, such as *Cenococcum graniforme*, that have a mutualistic relationship with tree roots. Sclerotia are the resting structures of the fungus, identified by Dr. Kristiina Vogt, Professor of Ecology in the School of Forestry and Environmental Studies at Yale University. Many trees are noted to depend heavily on mycorrhizae and may not be successful without them. "The mycelial strands of these fungi grow into the roots and take some of the sugary compounds produced by the tree during photosyntheses. However, mycorrhizal fungi benefit the tree because they take in minerals from the soil, which are then used by the tree" (Kricher and Morrison 1988:285). Sclerotia appear to be ubiquitous and are found with coniferous and deciduous trees including *Abies* (fir), *Juniperus communis* (common juniper), *Larix* (larch), *Picea* (spruce), *Pinus* (pine), *Pseudotsuga* (Douglas fir), *Acer pseudoplatanus* (sycamore maple), *Alnus* (alder), *Betula* (birch), *Carpinus caroliniana* (American hornbeam), *Carya* (hickory), *Castanea dentata* (American chestnut), *Corylus* (hazelnut), *Crataegus monogyna* (hawthorn), *Fagus* (beech), *Populus* (poplar, cottonwood, aspen), *Quercus* (oak), *Rhamnus fragula* (alder bush), *Salix* (willow), *Sorbus* (chokecherry), and *Tilia* (linden) (McWeeney 1989:229-130; Trappe 1962).

Sample 92502-1-2 from sandy silt at a depth of 2' 11" below the surface yielded one piece of *Alnus* charcoal weighing 0.004 g and conifer charcoal weighing 0.003 g that can be submitted for radiocarbon analysis. The sample also contained four charred *Picea* needle fragments weighing less than 0.001 g, a piece of *Pseudotsuga menziesii* charcoal weighing less than 0.001 g, unidentified charcoal fragments, uncharred wood, uncharred remains from modern plants, a moderate amount of sclerotia, and a few insect chitin fragments.

One piece of *Picea* charcoal weighing 0.058 g was present in sample 92502-1-3 from a depth of 1' 1" below the surface and can be submitted for AMS radiocarbon analysis. Several uncharred seeds and rootlets from modern plants, as well as several insect chitin fragments, reflect bioturbation and the closer proximity of this sample to the modern surface.

Sample 92502-2-1 was recovered from the T1 terrace upstream of Big Creek at a depth of 3' 11" below the surface. This sample contained very small fragments of conifer charcoal and unidentified hardwood charcoal with rounded edges weighing less than 0.001 g. One charred *Picea* needle fragment and two uncharred needle fragments, an uncharred *Pseudotsuga* needle fragment, and a few uncharred *Thuja* leaf fragments represent local spruce, Douglas-fir, and western red cedar trees. In addition, the sample contained an uncharred *Scirpus* seed, numerous uncharred rootlets, a few sclerotia, uncharred wood, insect eggs, insect chitin fragments, and a small amount of rock/gravel.

Sample 92502-2-2 was taken from sandy silt on the T1 terrace upstream of Big Creek at a depth of 2' 9". Small fragments of conifer charcoal weighing 0.007 g were present and can be submitted for AMS radiocarbon analysis. Pieces of conifer charcoal with rounded edges weighing 0.003 g, pieces of *Pseudotsuga* charcoal weighing less than 0.001 g, unidentified hardwood charcoal weighing less than 0.001 g, unidentified charcoal and unidentified wood also were present. One piece of charred, vitrified tissue might represent charcoal or other plant tissue too vitrified for identification. Vitrified material has a shiny, glassy appearance due to fusion by heat. Uncharred remains from modern plants, sclerotia, insect chitin fragments, and a small amount of rock/gravel and sand complete the record.

Sample 92502-3-1 from a depth 5' 4" contained several small fragments of conifer charcoal weighing 0.003 g, as well as two pieces of hardwood charcoal too small for further identification weighing 0.001 g, one partially charred piece of conifer charcoal weighing less than 0.001 g, *Pseudotsuga* charcoal weighing less than 0.001 g, and unidentified charcoal. Plant remains noted in this sample include a charred conifer needle fragment weighing 0.001 g, one charred *Rubus* seed and several uncharred *Rubus* seeds, an uncharred *Chenopodium* seed, several uncharred *Sambucus* seeds, and numerous uncharred rootlets. The sample also contained a few sclerotia, a piece of charred unidentified organic tissue, and a few insect chitin fragments.

Several charcoal types were present in sample 92502-3-2 from a depth of 3' 11", including *Alnus* charcoal weighing 0.012 g, *Picea* charcoal weighing 0.003 g, *Pseudotsuga* charcoal weighing 0.017 g, conifer charcoal weighing 0.009 g, unidentified hardwood charcoal weighing less than 0.001 g, and unidentified charcoal. The sample also contained charred *Picea* needle fragments weighing 0.004 g, charred conifer bark fragments weighing 0.030 g, charred unidentified bark fragments weighing 0.006 g, charred unidentified organic tissue, a piece of charred vitrified tissue, a charred *Sambucus* seed, several uncharred *Sambucus* and *Rubus* seeds and seed fragments, numerous uncharred rootlets, a moderate amount of sclerotia, and a few pieces of uncharred wood. Non-floral remains include several insect chitin fragments and sand.

Sample 92702-4-1 was recovered from silt at a depth of 2' 2" to 2' 7". This sample yielded a piece of *Populus* charcoal weighing 0.005 g that can be submitted for AMS radiocarbon analysis. The sample also contained unidentified charcoal and wood, a few charred *Picea* needle fragments, a few uncharred seeds and numerous rootlets from modern plants, a few sclerotia, several insect chitin fragments, and a small amount of sand.

Sample 97502-5-1 was taken from a depth of 3' 5" to 3' 8" below the surface. This sample contained one piece of *Acer* charcoal weighing 0.001 g, three small fragments of conifer charcoal weighing less than 0.001 g, a piece of *Pseudotsuga* charcoal weighing less than 0.001 g, and unidentified wood. A few charred *Picea* needle fragments, uncharred seeds and rootlets from modern plants, uncharred moss fragments, a few sclerotia, a few insect chitin fragments, and a small amount of rock/gravel and sand also were present.

Sample 92802-3-1 was collected from the lower sand and diatomite layer just below the sand at a depth of 7' to 7' 5" below the surface. This sample contained a partially charred piece of *Tsuga* charcoal with rounded edges weighing 0.009 g, several small fragments of conifer charcoal weighing 0.003 g, pieces of conifer charcoal with rounded edges weighing 0.011 g, unidentified charcoal, and a charred unidentified bark fragment weighing 0.008 g. Two small *Picea sitchensis* needle fragments weighing less than 0.001 g represent local sitka spruce trees. The sample also yielded uncharred unidentified plant fibers, a few uncharred rootlets from modern plants, a moderate amount of rock/gravel, and an abundance of sand.

Sample 92802-3-2 from the upper sand at a depth of 5' to 5' 6" contained pieces of conifer charcoal weighing 0.016 g, conifer charcoal with rounded edges weighing 0.027 g, pieces of *Alnus* charcoal with rounded edges weighing 0.023 g, unidentified charcoal, and charred bark fragments weighing 0.010 g. A few uncharred rootlets, a few sclerotia, two insect chitin fragments, and a small amount of sand complete the record.

Sample 93002-3-1 at depth of 3' 9" to 4' 4" contained very small fragments of conifer charcoal weighing less than 0.001 g. A moderate amount of uncharred bark fragments were present in this sample, including bark exhibiting an orange coating. The sample also contained numerous uncharred rootlets, a few sclerotia, a few insect chitin fragments, and a moderate amount of rock/gravel and sand.

Samples 92902-1-1, 92902-1-2, and 92902-1-3 were recovered from sand and silt beds within alluvial fan deposits from Finley Creek, a major tributary in this section of the Quinault River. Sample 92902-1-1 represents a silt bed below the alluvial fan gravel at a depth of 15'. Pieces of conifer charcoal weighing 0.006 g were present and can be submitted for AMS radiocarbon analysis. Pieces of conifer charcoal with rounded edges and a yellowish-orange coating weighing 0.003 g, unidentified charcoal, one charred conifer needle fragment weighing less than 0.001 g, a few uncharred *Picea* and *Tsuga* needles, numerous uncharred rootlets, a few insect chitin fragments, and a small amount of sand also were present.

Sample 92902-1-2 was collected from sand/silt in the alluvial fan deposit at a depth of 10' below the surface. This sample contained a variety of charcoal types including a piece of *Alnus* weighing 0.006 g, small fragments of conifer weighing 0.013 g, conifer charcoal with rounded edges weighing 0.003 g, a piece of *Tsuga* charcoal weighing 0.007 g, unidentified charcoal, and charred bark weighing 0.057 g. One charred insect fecal pellet was present and might indicate that some of the burned wood contained insects. Recovery of several insect chitin fragments and a few rodent fecal pellets indicates some subsurface disturbance from insect and rodent activity. The sample also contained uncharred unidentified plant fibers, a moderate amount of uncharred rootlets, a few sclerotia, and a small amount of sand.

Sample 92902-1-3 was taken from sand/silt beds about one-quarter mile downstream of the Finley Creek Bridge. This sample contained several small fragments of conifer charcoal weighing 0.008 g than can be submitted for AMS radiocarbon analysis, as well as conifer charcoal with rounded edges and a yellowish-orange coating weighing 0.005 g. Several fragments of what appear to be coal also were present. In addition, the sample yielded a few uncharred rootlets, a few sclerotia, and three insect chitin fragments.

SUMMARY AND CONCLUSIONS

Flotation of bulk sediment samples from along the Quinault River in western Washington resulted in recovery of charcoal and other charred botanic remains that can be sent for radiocarbon analysis. The identified charcoal types represent trees found in the local vegetation community. Several fragments of charcoal exhibiting rounded edges suggest transport of charcoal from farther away.

TABLE 1

PROVENIENCE DATA FOR SAMPLES FROM THE QUINAULT RIVER GEOMORPHIC STUDY

Sample No.	Depth below surface	Provenience/ Description	Analysis
92502-1-1	5' 9"	Bulk sediment; Silty clay above gravelly sand	Float/Charcoal ID for C14 Analysis
92502-1-2	2' 11"	Bulk sediment; Sandy silt, T2 upstream of Big Creek	Float/Charcoal ID for C14 Analysis
92502-1-3	1' 11"	Bulk sediment; Sandy silt, T2 upstream of Big Creek	Float/Charcoal ID for C14 Analysis
92502-2-1	3' 11"	Bulk sediment; T1 upstream of Big Creek	Float/Charcoal ID for C14 Analysis
92502-2-2	2' 9"	Bulk sediment; Sandy silt, T2 upstream of Big Creek	Float/Charcoal ID for C14 Analysis
92502-3-1	5' 4"	Bulk sediment; Above gravel beneath Terrace T2 upstream of Finley Creek	Float/Charcoal ID for C14 Analysis
92502-3-2	3' 11"	Bulk sediment; Just above gr. Terrace T3	Float/Charcoal ID for C14 Analysis
92702-4-1	2' 2" - 2' 7"	Bulk sediment; Silt	Float/Charcoal ID for C14 Analysis
92702-5-1	3' 5" - 3' 8"	Bulk sediment; Side channel of Quinault River of Big Creek, T2?	Float/Charcoal ID for C14 Analysis
92802-3-1	7' - 7' 5"	Bulk sediment; Lower sand and diatomite layer just below sand	Float/Charcoal ID for C14 Analysis
92802-3-2	5' - 5' 6"	Bulk sediment; Upper sand	Float/Charcoal ID for C14 Analysis
93002-3-1	3' 9" - 4' 4"	Bulk sediment; Silt above gravel, Pruce Boys Rd., T1?	Float/Charcoal ID for C14 Analysis
92902-1-1	15'	Bulk sediment; Silt bed below alluvial fan gravel at Finley Creek	Float/Charcoal ID for C14 Analysis
92902-1-2	10'	Bulk sediment; Sand/silt in alluvial fan deposit	Float/Charcoal ID for C14 Analysis
92902-1-3		Bulk sediment; Sand/silt beds about 1/4 mile downstream of Finley Creek Bridge	Float/Charcoal ID for C14 Analysis

TABLE 2 (Continued)

TABLE 2
MACROFLORAL REMAINS FROM THE QUINALT RIVER GEOMORPHIC STUDY

Sample No.	Identification	Part	Charred W	Charred F	Uncharred W	Uncharred F	Weights/ Comments
92502-1-1	Liters Floated						2.00 L
5' 9"	Light Fraction Weight						11.40 g
	FLORAL REMAINS:						
	Alnus ≥ 1mm	Seed			90	12	
	Alnus < 1mm	Seed			X	X	Moderate
	Calandrinia	Seed				9	
	Conifer	Male cone			2		
	Picea sitchensis	Needle				X	Few
	Rubus	Seed			1		
	Thuja plicata	Leaf				X	Few
	Unidentified	Seed			2	1	
	Rootlets					X	Numerous
	Sclerotia				X	X	Few
	CHARCOAL/WOOD:						
	Unidentified hardwood	Charcoal		6			0.001 g
	Conifer - rounded	Charcoal		1			< 0.001 g
	Conifer	Charcoal		4			< 0.001 g
	NON-FLORAL REMAINS:						
	Insect	Egg				40	
	Insect	Chitin				27	
	Rock/Gravel					X	Moderate
92502-1-2	Liters Floated						2.40 L
2' 11"	Light Fraction Weight						6.32 g
	FLORAL REMAINS:						
	Picea	Needle		4			< 0.001 g
	Calandrinia	Seed			1	1	
	Rubus	Seed				38	
	Sambucus	Seed			2	15	
	Rootlets					X	Moderate
	Sclerotia				X	X	Moderate
92502-1-2	CHARCOAL/WOOD:						
2' 11"	*Alnus*	Charcoal		1			0.004 g

TABLE 2 (Continued)

Sample No.	Identification	Part	Charred W	Charred F	Uncharred W	Uncharred F	Weights/ Comments
	Conifer	Charcoal		12			0.003 g
	Pseudotsuga menziesii	Charcoal		1			< 0.001 g
	Unidentified ≥ 1mm	Charcoal		X			0.001 g
	Unidentified	Wood				X	0.07 g
	NON-FLORAL REMAINS:						
	Insect	Chitin				15	
	Rock/Gravel and Sand					X	Few
92502-1-3	Liters Floated						2.60 L
1' 11"	Light Fraction Weight						2.63 g
	FLORAL REMAINS:						
	Calandrinia	Seed			8	64	
	Caryophyllaceae	Seed			3	5	
	Rubus	Seed				2	
	Sambucus	Seed			1	1	
	Rootlets					X	Numerous
	Sclerotia				X	X	Few
	CHARCOAL/WOOD:						
	Picea	Charcoal		1			0.058 g
	NON-FLORAL REMAINS:						
	Insect	Chitin				65	
	Sand					X	Few
92502-2-1	Liters Floated						2.10 L
3' 11"	Light Fraction Weight						18.94 g
	FLORAL REMAINS:						
	Picea	Needle		1		2	
	Pseudotsuga menziesii	Needle				1	
	Scirpus	Seed			1		
	Thuja plicata	Leaf				X	Few
	Rootlets					X	Numerous
	Sclerotia				X	X	Few
92502-2-1	CHARCOAL/WOOD:						
3' 11"	Conifer	Charcoal		1			< 0.001 g
	Unidentified hardwood - rounded	Charcoal		1			< 0.01 g

TABLE 2 (Continued)

Sample No.	Identification	Part	Charred W	Charred F	Uncharred W	Uncharred F	Weights/ Comments
	Unidentified ≥ 1mm	Wood				X	0.017 g
	NON-FLORAL REMAINS:						
	Insect	Egg			5	15	
	Insect	Chitin				33	
	Rock/Gravel					X	Few
92502-2-2	Liters Floated						3.10 L
2' 9"	Light Fraction Weight						12.03 g
	FLORAL REMAINS:						
	Vitrified tissue			1			0.002 g
	Conifer	Needle				1	
	Picea sitchensis	Needle				1	
	Picea	Seed			2		
	Sambucus	Seed			2	1	
	Rootlets					X	Numerous
	Sclerotia				X	X	Few
	CHARCOAL/WOOD:						
	Conifer	Charcoal		30			0.007 g
	Conifer - rounded	Charcoal		5			0.003 g
	Pseudotsuga menziesii	Charcoal		3			< 0.001 g
	Unidentified hardwood	Charcoal		2			< 0.001 g
	Unidentified ≥ 0.5 mm	Charcoal		X			0.004 g
	Unidentified ≥ 1mm	Wood				X	0.022 g
	NON-FLORAL REMAINS:						
	Insect	Chitin				26	
	Rock/Gravel					X	Few
	Sand					X	Scant
92502-3-1	Liters Floated						2.20 L
5' 4"	Light Fraction Weight						5.17 g
	FLORAL REMAINS:						
	Conifer	Needle		1			0.001 g
	Rubus	Seed	1		10	11	
	Unidentified organic tissue		1				0.001 g
	Chenopodium	Seed			1		

TABLE 2 (Continued)

Sample No.	Identification	Part	Charred W	Charred F	Uncharred W	Uncharred F	Weights/ Comments
	Sambucus	Seed			10	76	
	Rootlets					X	Numerous
	Sclerotia				X	X	Few
	CHARCOAL/WOOD:						
	Conifer	Charcoal		15			0.003 g
	Conifer	Charcoal		1			< 0.001 g
	Pseudotsuga menziesii	Charcoal		2			< 0.001 g
	Unidentified hardwood	Charcoal		2			0.001 g
	Unidentified ≥ 0.5 mm	Charcoal		X			0.004 g
	NON-FLORAL REMAINS:						
	Insect	Chitin				3	
92502-3-2	Liters Floated						2.60 L
3' 11"	Light Fraction Weight						12.73 g
	FLORAL REMAINS:						
	Picea	Needle		16			0.004 g
	Unidentified organic tissue			7			0.004 g
	Vitrified tissue			1			< 0.001 g
	Rubus	Seed			1	12	
	Sambucus	Seed	1		3	20	
	Rootlets					X	Numerous
	Sclerotia				X	X	Moderate
92502-3-2	CHARCOAL/WOOD:						
3' 11"	*Alnus*	Charcoal		11			0.012 g
	Conifer	Charcoal		12			0.009 g
	Picea	Charcoal		3			
	Pseudotsuga menziesii	Charcoal		7			
	Unidentified hardwood	Charcoal		3			
	Unidentified ≥ 1mm	Charcoal		X			
	Conifer bark			7			
	Unidentified bark			5			
	Unidentified	Wood				X	Few
	NON-FLORAL REMAINS:						
	Insect	Chitin				32	
	Sand					X	Few

TABLE 2 (Continued)

Sample No.	Identification	Part	Charred W	Charred F	Uncharred W	Uncharred F	Weights/ Comments
92702-4-1	Liters Floated						2.00 L
2' 2" - 2' 7"	Light Fraction Weight						6.82 g
	FLORAL REMAINS:						
	Picea	Needle		x			Few
	Calandrinia	Seed			1		
	Rubus	Seed				2	
	Sambucus	Seed			1		
	Rootlets					X	Numerous
	Sclerotia					X	Few
	CHARCOAL/WOOD:						
	Populus	Charcoal		1			0.005 g
	Unidentified ≥ 0.5 mm	Charcoal		X			0.004 g
	Unidentified	Wood					0.041 g
	NON-FLORAL REMAINS:						
	Insect	Chitin				39	
	Sand					X	Few
92702-5-1	Liters Floated						1.10 L
3' 5" - 3' 8"	Light Fraction Weight						3.77 g
	FLORAL REMAINS:						
	Picea	Needle		X			Few
	Calandrinia	Seed				21	
	Rubus	Seed			1	7	
	Moss				X		Moderate
	Rootlets					X	Numerous
	Sclerotia					X	Few
	CHARCOAL/WOOD:						
	Acer	Charcoal		1			0.001 g
	Conifer	Charcoal		3			< 0.001 g
	Pseudotsuga menziesii	Charcoal		1			< 0.001 g
	Unidentified ≥ 2mm	Wood				X	0.204 g
	NON-FLORAL REMAINS:						
	Insect	Chitin				12	
	Rock/Gravel					X	Few
	Sand					X	Scant

TABLE 2 (Continued)

Sample No.	Identification	Part	Charred W	Charred F	Uncharred W	Uncharred F	Weights/ Comments
92802-3-1	Liters Floated						2.30 L
7' - 7' 5"	Light Fraction Weight						0.89 g
	FLORAL REMAINS:						
	Picea sitchensis	Needle		2			< 0.001 g
	Unidentified plant fibers					X	0.003 g
	Rootlets					X	Very few
	CHARCOAL/WOOD:						
	Conifer - rounded	Charcoal		8			0.011 g
	Conifer	Charcoal		11			0.003 g
	Tsuga - rounded	Charcoal		1			0.009 g
	Unidentified ≥ 0.5 mm	Charcoal		X			0.008 g
	Unidentified bark			1			0.008 g
	NON-FLORAL REMAINS:						
	Rock/Gravel					X	Moderate
	Sand					X	Abundant
92802-3-2	Liters Floated						1.00 L
5' - 5' 6"	Light Fraction Weight						3.05 g
	FLORAL REMAINS:						
	Bark			6			0.010 g
	Rootlets					X	Few
	Sclerotia				X	X	Few
	CHARCOAL/WOOD:						
	Conifer	Charcoal		5			0.016 g
	Conifer - rounded	Charcoal		4			0.027 g
	Abies - rounded	Charcoal		4			0.023 g
	Unidentified ≥ 1mm	Charcoal		X			0.072 g
	NON-FLORAL REMAINS:						
	Insert	Chitin				2	
	Sand					X	Few
93002-3-1	Liters Floated						2.10 L
3' 9" - 4' 4"	Light Fraction Weight						4.63 g
	FLORAL REMAINS:						
	Unidentified bark ≥ 2mm					32	0.319 g
	Unidentified bark < 2mm					X	Moderate

TABLE 2 (Continued)

Sample No.	Identification	Part	Charred W	Charred F	Uncharred W	Uncharred F	Weights/ Comments
	Bark with orange coating ≥ 2mm					42	0.457 g
	Bark with orange coating < 2mm					X	Moderate
	Rootlets					X	Numerous
	Sclerotia					X	Few
	CHARCOAL/WOOD:						
	Conifer	Charcoal		10			< 0.001 g
	NON-FLORAL REMAINS:						
	Insect	Chitin				17	
	Rock/Gravel					X	Moderate
	Sand					X	Moderate
92902-1-1	Liters Floated						2.20 L
15'	Light Fraction Weight						7.88 g
	FLORAL REMAINS:						
	Conifer	Needle		1			< 0.001 g
	Picea	Needle				X	Few
	Tsuga	Needle			2		
	Rootlets					X	Numerous
	CHARCOAL/WOOD:						
	Conifer	Charcoal		12			0.006 g
	Conifer - rounded, coated	Charcoal		5			0.003 g
	Unidentified ≥ 0.5 mm	Charcoal		X			0.030 g
	NON-FLORAL REMAINS:						
	Insect	Chitin				18	
	Sand					X	Few
92902-1-2	Liters Floated						2.20 L
10'	Light Fraction Weight						14.43 g
	FLORAL REMAINS:						
	Unidentified plant fibers					X	Moderate
	Rootlets					X	Moderate
	Sclerotia					X	Few
	CHARCOAL/WOOD:						
	Alnus	Charcoal		1			0.006 g

TABLE 2 (Continued)

Sample No.	Identification	Part	Charred W	Charred F	Uncharred W	Uncharred F	Weights/ Comments
	Conifer	Charcoal		15			0.013 g
	Conifer - rounded	Charcoal		4			0.003 g
	Tsuga	Charcoal		1			0.007 g
	Unidentified ≥ 0.5 mm	Charcoal		x			0.030 g
	Bark	Charcoal		18			0.057 g
	NON-FLORAL REMAINS:						
	Insect fecal pellet		1				
	Insect	Chitin				60	
	Rodent fecal pellet				1	X	Few
	Sand					X	Few
92902-1-3	Liters Floated						2.60 L
	Light Fraction Weight						5.10 g
	FLORAL REMAINS:						
	Rootlets					X	Few
	Sclerotia					X	Few
	CHARCOAL/WOOD:						
	Conifer	Charcoal		12			0.008 g
	Conifer - rounded, coated	Charcoal		5			0.005 g
	Unidentified ≥ 0.5 mm	Charcoal		X			< 0.001 g
	NON-FLORAL REMAINS:						
	Coal ≥ 0.5 mm					71	
	Insect					3	
	Sand					X	Moderate

W = Whole
F = Fragment
X = Presence noted in sample
g = grams

TABLE 3
INDEX OF MACROFLORAL REMAINS RECOVERED FROM THE
QUINAULT RIVER GEOMORPHIC STUDY

Scientific Name	Common Name
FLORAL REMAINS:	
Alnus	Alder
Calandrinia	Calandrinia, Red maids
Caryophyllaceae	Pink family
Chenopodium	Goosefoot
Conifer	Cone-bearing, gymnospermous trees and shrubs, mostly evergreens, including the pine, spruce, fir, juniper, cedar, yew, and cypress
Picea sitchensis	Sitka spruce
Picea	Spruce
Thuja plicata	Western red cedar
Rubus	Raspberry, Blackberry, etc.
Sambucus	Elderberry
Sclerotia	Resting structures of mycorrhizae fungi
CHARCOAL/WOOD:	
Acer	Maple, Box elder
Alnus	Alder
Conifer	Cone-bearing, gymnospermous trees and shrubs, mostly evergreens, including the pine, spruce, fir, juniper, cedar, yew, and cypress
Picea	Spruce
Pseudotsuga menziesii	Douglas-fir
Thuja	
Tsuga	Hemlock
Populus	Aspen, Cottonwood

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EXAMINATION OF SEDIMENT FOR RADIOCARBON DATABLE MATERIAL FROM ALONG THE QUINAULT RIVER, WASHINGTON

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INTRODUCTION

A single sediment sample from along the Quinault River in the western Olympic Peninsula, Washington, was floated to recover organic fragments suitable for radiocarbon analysis. This sample was recovered from a natural exposure along the river and is believed to represent silt that was likely deposited in Lake Quinault when it was higher than at present. Botanic components and detrital charcoal were identified, and potentially radiocarbon datable material was separated.

METHODS

The sediment sample was water-screened through a 250-micron mesh sieve and allowed to dry. The dried sample was scanned under a binocular stereo microscope at a magnification of 10x. Charcoal fragments were separated and examined under a binocular microscope at a magnification of 70x. Macrofloral remains, including charcoal, were identified using manuals (Core, et al. 1976; Martin and Barkley 1961; Panshin and Zeeuw 1980; Petrides and Petrides 1992) and by comparison with modern and archaeological references. The term "seed" is used to represent seeds, achenes, caryopses, and other disseminules. Because charcoal and possibly other botanic remains were to be sent for radiocarbon analysis, clean laboratory conditions were used during water-screening and identification to avoid contamination. All instruments were washed between samples, and samples were protected from contact with modern charcoal.

DISCUSSION

The Quinault River study site is located near river kilometer 2.5 (measured upstream from Lake Quinault). This section of the Quinault River drains the western Olympic Mountains and flows into Lake Quinault, which is dammed by a glacial moraine. Local vegetation in the area is dominated by a variety of riparian plants, including alder (*Alnus*), cottonwood (*Populus*), maple (*Acer*), and grasses (Poaceae).

Sample 81904-1 was collected from silt in a natural exposure at a depth of 2.6 m (Table 1). This sample contained a few fragments of conifer charcoal weighing 0.005 g that can be submitted for AMS radiocarbon analysis (Table 2, Table 3). Several types of uncharred plant remains and wood fragments reflect components of the modern vegetation community. The sample also yielded a few insect chitin fragments.

SUMMARY AND CONCLUSIONS

Flotation of sediment from a natural exposure along the Quinault River in the western Olympic Peninsula, Washington, resulted in recovery of conifer charcoal that can be sent for AMS radiocarbon analysis. Conifers likely are found growing in the Olympic Mountains, which are drained by the Quinault River.

TABLE 1
PROVENIENCE DATA FOR A SINGLE SAMPLE
FROM ALONG THE QUINAULT RIVER, WASHINGTON

Sample No.	Depth	Provenience/ Description	Analysis
81904-1	2.6 m	Bulk sediment in a natural exposure along the Quinault River upstream of Lake Quinault; from silt believed to have been deposited in the lake when it was higher than at present	Float/Charcoal ID prior to C-14 analysis

TABLE 2
MACROFLORAL REMAINS FROM ALONG THE QUINAULT RIVER, WASHINGTON

Sample No.	Identification	Part	Charred W	Charred F	Uncharred W	Uncharred F	Weights/ Comments
81904-1	Volume Water-screened						<0.10 L
	Water-screened Sample Weight						4.20 g
	FLORAL REMAINS:						
	Abies/Pseudotsuga	Needle			4	16*	
	Betula	Seed			112*		
	Carex	Seed			1		
	Caryophyllaceae	Seed			1	1	
	Picea	Needle			10	56*	
	Potentilla	Seed			1		
	Unidentified deciduous	Leaf				X	Moderate
	Moss	Leaf/ Branch				X	Few
	Rootlets					X	Moderate
	CHARCOAL/WOOD:						
	Conifer	Charcoal		5			0.005 g
	Conifer	Wood				4	0.015 g
	Conifer twig	Wood				1	0.003 g
	Abies	Wood				1	0.003 g
	Pseudotsuga menziesii	Wood				1	0.006 g
	NON-FLORAL REMAINS:						
	Insect	Chitin				20	

W = Whole
F = Fragment
X = Presence noted in sample
L = Liters
g = grams
* = Estimated frequency

TABLE 3
INDEX OF MACROFLORAL REMAINS RECOVERED
FROM ALONG THE QUINAULT RIVER, WASHINGTON

Scientific Name	Common Name
FLORAL REMAINS:	
Abies/Pseudotsuga	Fir/Douglas fir
Betula	Birch
Carex	Sedge
Caryophyllaceae	Pink family
Picea	Spruce
Potentilla	Cinquefoil
CHARCOAL/WOOD:	
Conifer	Cone-bearing, gymnospermous trees and shrubs, mostly evergreens, including the pine, spruce, fir, juniper, cedar, yew, and cypress
Abies	Fir
Pseudotsuga menziesii	Douglas-fir

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Petrides, George A. and Olivia Petrides
1992 *A Field Guide to Western Trees*. The Peterson Field Guide Series. Houghton Mifflin Co., Boston.

FROM: Darden Hood, Director (mailto:mailto:dhood@radiocarbon.com)
(This is a copy of the letter being mailed. Invoices/receipts follow only by mail.)

October 16, 2003

Dr. Lucy Piety
Bureau of Reclamation
Denver Federal Center
D-8330
P.O. Box 25007
Denver, CO 80225
USA

RE: Radiocarbon Dating Results For Samples 92502-1-2CO, 92502-1-3PI, 92502-2-2CO, 92502-3-1CO, 92502-3-2CO, 92702-4-1PO, 92802-3-1CO, 92802-3-2CO, 92902-1-1CO, 92902-1-2CO, 92902-1-3CO

Dear Dr. Piety:

Enclosed are the radiocarbon dating results for 11 samples recently sent to us. They each provided plenty of carbon for accurate measurements and all the analyses went normally. The report sheet also contains the method used, material type, applied pretreatments and, where applicable, the two sigma calendar calibration range.

As always, this report has been both mailed and sent electronically. All results (excluding some inappropriate material types) which are less than about 20,000 years BP and more than about ~250 BP include this calendar calibration page (also digitally available in Windows metafile (wmf) format upon request). The calibrations are calculated using the newest (1998) calibration database with references quoted on the bottom of each page. Multiple probability ranges may appear in some cases, due to short term variations in the atmospheric 14C contents at certain time periods. Examining the calibration graphs will help you understand this phenomenon. Don't hesitate to contact us if you have questions about calibration.

We analyzed these samples on a sole priority basis. No students or intern researchers who would necessarily be distracted with other obligations and priorities were used in the analyses. We analyzed them with the combined attention of our entire professional staff.

Information pages are also enclosed with the mailed copy of this report. If you have any specific questions about the analyses, please do not hesitate to contact us.

Our invoice is enclosed. Please, forward it to the appropriate officer or send VISA change authorization. Thank you. As always, if you have any questions or would like to discuss the results, don't hesitate to contact me.

Sincerely,

Darden Hood

Dr. Lucy Piety

Report Date: 10/16/2003

Bureau of Reclamation

Material Received: 9/25/2003

Sample Data	Measured Radiocarbon Age	13C/12C Ratio	Conventional Radiocarbon Age(*)
Beta - 183376 SAMPLE : 92502-1-2CO ANALYSIS : AMS-Standard delivery MATERIAL/PRETREATMENT : (charred material): acid/alkali/acid 2 SIGMA CALIBRATION : Cal AD 1290 to 1410 (Cal BP 660 to 540)	620 +/- 40 BP	-24.6 o/oo	630 +/- 40 BP
Beta - 183377 SAMPLE : 92502-1-3PI ANALYSIS : AMS-Standard delivery MATERIAL/PRETREATMENT : (charred material): acid/alkali/acid 2 SIGMA CALIBRATION : Cal AD 1010 to 1180 (Cal BP 940 to 760)	970 +/- 40 BP	-26.2 o/oo	950 +/- 40 BP
Beta - 183378 SAMPLE : 92502-2-2CO ANALYSIS : AMS-Standard delivery MATERIAL/PRETREATMENT : (charred material): acid/alkali/acid 2 SIGMA CALIBRATION : Cal AD 410 to 600 (Cal BP 1540 to 1350)	1560 +/- 40 BP	-24.9 o/oo	1560 +/- 40 BP
Beta - 183379 SAMPLE : 92502-3-1CO ANALYSIS : AMS-Standard delivery MATERIAL/PRETREATMENT : (charred material): acid/alkali/acid 2 SIGMA CALIBRATION : Cal AD 1060 to 1080 (Cal BP 890 to 860) AND Cal AD 1150 to 1270 (Cal BP 800 to 680)	860 +/- 40 BP	-26.4 o/oo	840 +/- 40 BP
Beta - 183380 SAMPLE : 92502-3-2CO ANALYSIS : AMS-Standard delivery MATERIAL/PRETREATMENT : (charred material): acid/alkali/acid 2 SIGMA CALIBRATION : Cal AD 660 to 790 (Cal BP 1290 to 1160)	1300 +/- 40 BP	-25.5 o/oo	1290 +/- 40 BP

Dr. Lucy Piety

Report Date: 10/16/2003

Sample Data	Measured Radiocarbon Age	13C/12C Ratio	Conventional Radiocarbon Age(*)
Beta - 183381	270 +/- 40 BP	-25.5 o/oo	260 +/- 40 BP
SAMPLE : 92702-4-1PO			
ANALYSIS : AMS-Standard delivery			
MATERIAL/PRETREATMENT : (charred material): acid/alkali/acid			
2 SIGMA CALIBRATION : Cal AD 1520 to 1590 (Cal BP 430 to 360) AND Cal AD 1620 to 1670 (Cal BP 330 to 280) Cal AD 1770 to 1800 (Cal BP 180 to 150) AND Cal AD 1940 to 1950 (Cal BP 10 to 0)			
Beta - 183382	3250 +/- 50 BP	-21.8 o/oo	3300 +/- 50 BP
SAMPLE : 92802-3-1CO			
ANALYSIS : AMS-Standard delivery			
MATERIAL/PRETREATMENT : (charred material): acid/alkali/acid			
2 SIGMA CALIBRATION : Cal BC 1690 to 1450 (Cal BP 3640 to 3400)			
Beta - 183383	3720 +/- 40 BP	-24.6 o/oo	3730 +/- 40 BP
SAMPLE : 92802-3-2CO			
ANALYSIS : AMS-Standard delivery			
MATERIAL/PRETREATMENT : (charred material): acid/alkali/acid			
2 SIGMA CALIBRATION : Cal BC 2270 to 2260 (Cal BP 4220 to 4210) AND Cal BC 2220 to 2020 (Cal BP 4170 to 3970)			
Beta - 183384	2480 +/- 40 BP	-26.9 o/oo	2450 +/- 40 BP
SAMPLE : 92902-1-1CO			
ANALYSIS : AMS-Standard delivery			
MATERIAL/PRETREATMENT : (charred material): acid/alkali/acid			
2 SIGMA CALIBRATION : Cal BC 780 to 400 (Cal BP 2730 to 2350)			
Beta - 183385	3040 +/- 40 BP	-24.6 o/oo	3050 +/- 40 BP
SAMPLE : 92902-1-2CO			
ANALYSIS : AMS-Standard delivery			
MATERIAL/PRETREATMENT : (charred material): acid/alkali/acid			
2 SIGMA CALIBRATION : Cal BC 1410 to 1200 (Cal BP 3360 to 3150)			

Dr. Lucy Piety

Report Date: 10/16/2003

Sample Data	Measured Radiocarbon Age	13C/12C Ratio	Conventional Radiocarbon Age(*)
Beta - 183386	5650 +/- 50 BP	-26.5 o/oo	5630 +/- 50 BP

SAMPLE : 92902-1-3CO
ANALYSIS : AMS-Standard delivery
MATERIAL/PRETREATMENT : (charred material): acid/alkali/acid
2 SIGMA CALIBRATION : Cal BC 4550 to 4350 (Cal BP 6500 to 6300)

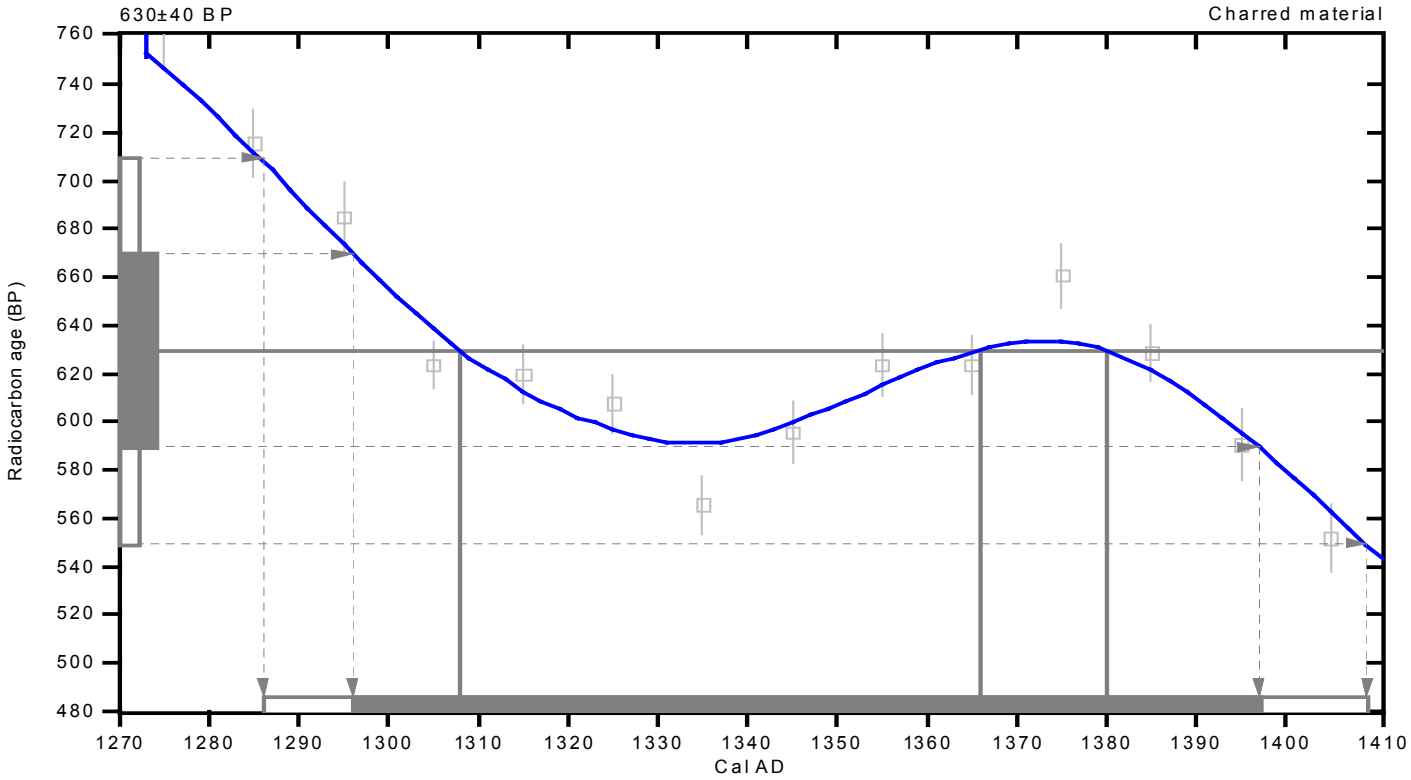
CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12=-24.6:lab. mult=1)

Laboratory number:	**Beta-183376**
Conventional radiocarbon age:	**630±40 BP**
2 Sigma calibrated result: (95% probability)	**Cal AD 1290 to 1410 (Cal BP 660 to 540)**

Intercept data

Intercepts of radiocarbon age with calibration curve:	Cal AD 1310 (Cal BP 640) and Cal AD 1370 (Cal BP 580) and Cal AD 1380 (Cal BP 570)
1 Sigma calibrated result: (68% probability)	Cal AD 1300 to 1400 (Cal BP 650 to 550)



References:

Database used

Calibration Database

Editorial Comment

Stuiver, M., van der Plicht, H., 1998, Radiocarbon 40(3), pxii-xiii

INTCAL98 Radiocarbon Age Calibration

Stuiver, M., et. al., 1998, Radiocarbon 40(3), p1041-1083

Mathematics

A Simplified Approach to Calibrating C14 Dates

Talma, A. S., Vogel, J. C., 1993, Radiocarbon 35(2), p317-322

Beta Analytic Inc.

4985 SW 74 Court, Miami, Florida 33155 USA • Tel: (305) 667 5167 • Fax: (305) 663 0964 • E-Mail: beta@radiocarbon.com

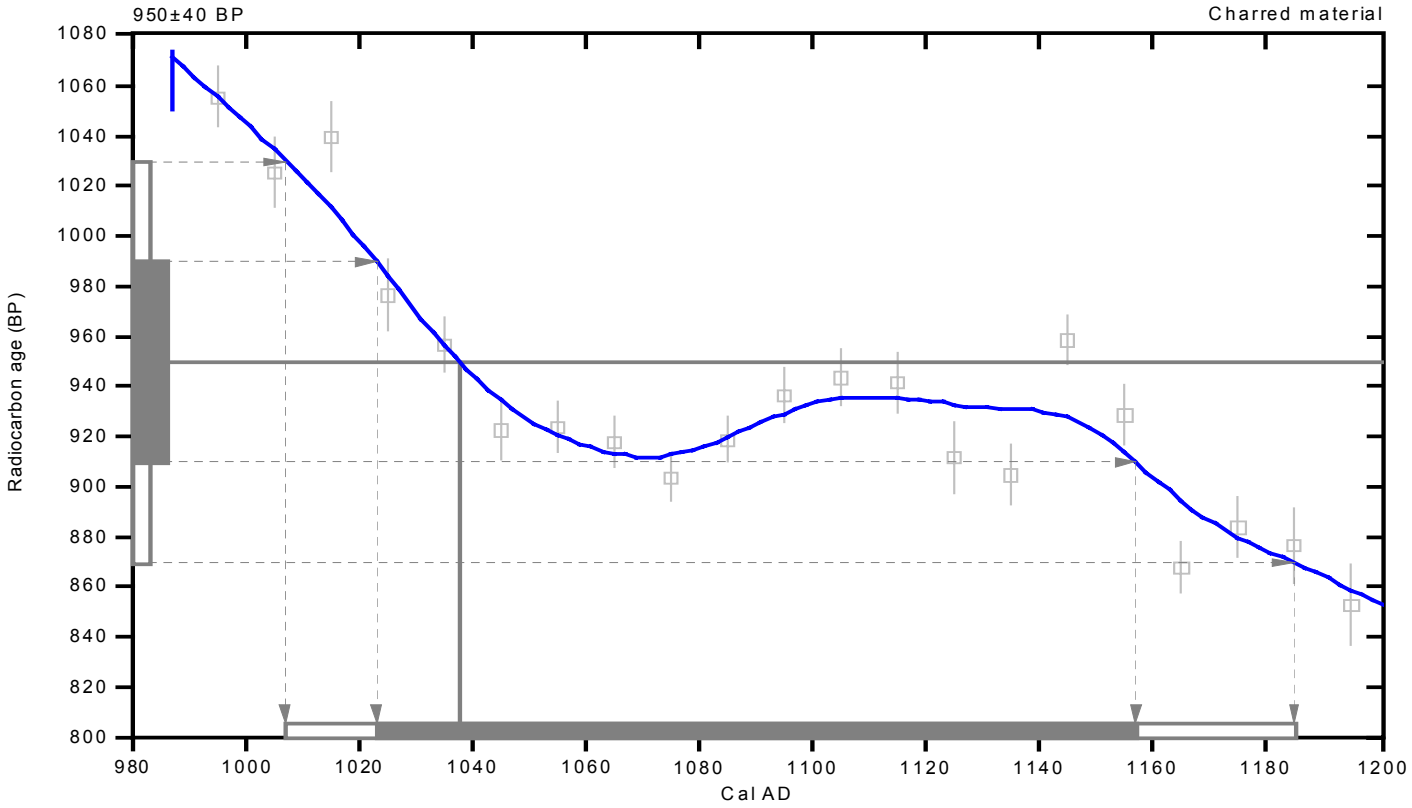
CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12=-26.2:lab. mult=1)

Laboratory number:	**Beta-183377**
Conventional radiocarbon age:	**950±40 BP**
2 Sigma calibrated result: (95% probability)	**Cal AD 1010 to 1180 (Cal BP 940 to 760)**

Intercept data

Intercept of radiocarbon age with calibration curve:	Cal AD 1040 (Cal BP 910)
1 Sigma calibrated result: (68% probability)	Cal AD 1020 to 1160 (Cal BP 930 to 790)



References:

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Calibration Database

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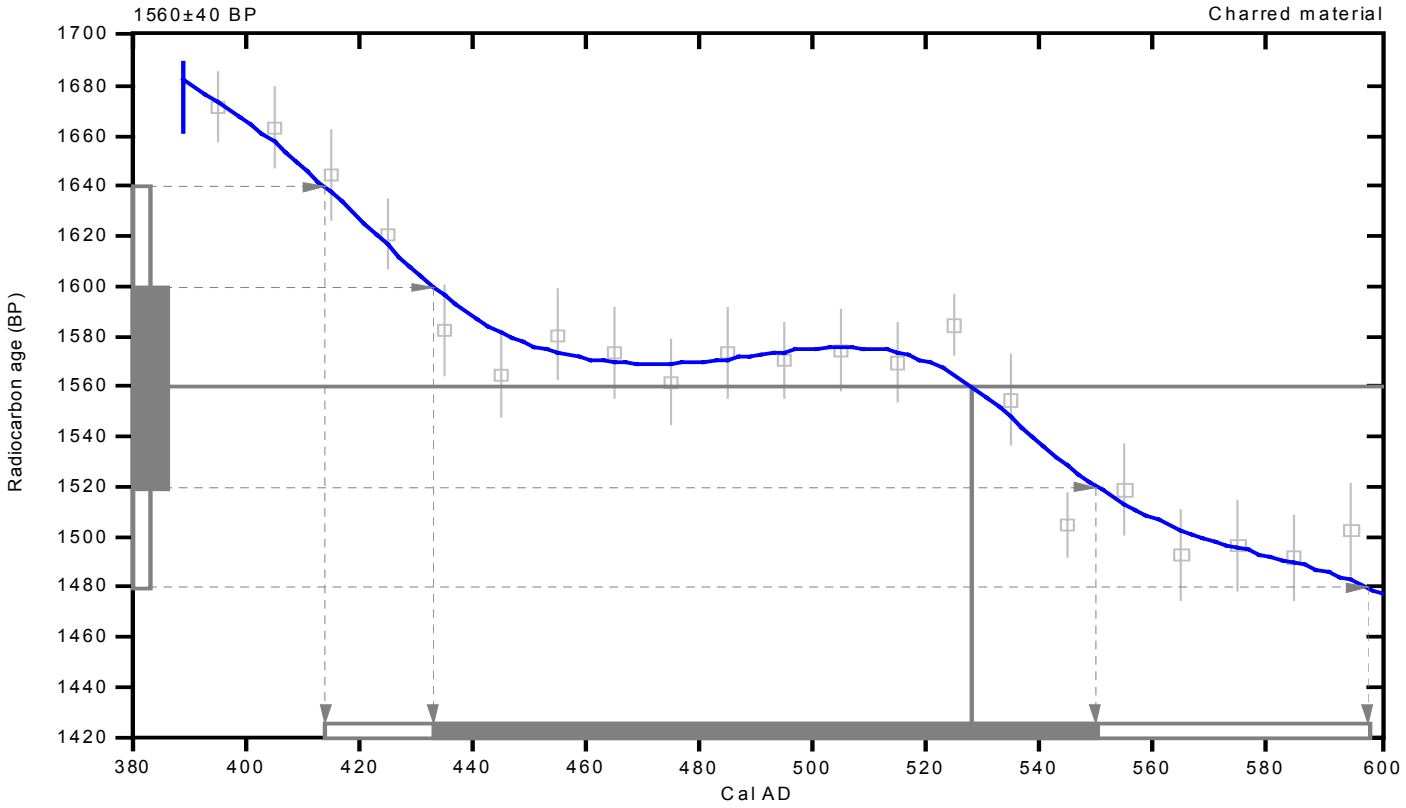
CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12=-24.9:lab. mult=1)

Laboratory number:	**Beta-183378**
Conventional radiocarbon age:	**1560±40 BP**
2 Sigma calibrated result: (95% probability)	**Cal AD 410 to 600 (Cal BP 1540 to 1350)**

Intercept data

Intercept of radiocarbon age with calibration curve:	Cal AD 530 (Cal BP 1420)
1 Sigma calibrated result: (68% probability)	Cal AD 430 to 550 (Cal BP 1520 to 1400)



References:

Database used

Calibration Database

Editorial Comment

Stuiver, M., van der Plicht, H., 1998, Radiocarbon 40(3), pxii-xiii

INTCAL98 Radiocarbon Age Calibration

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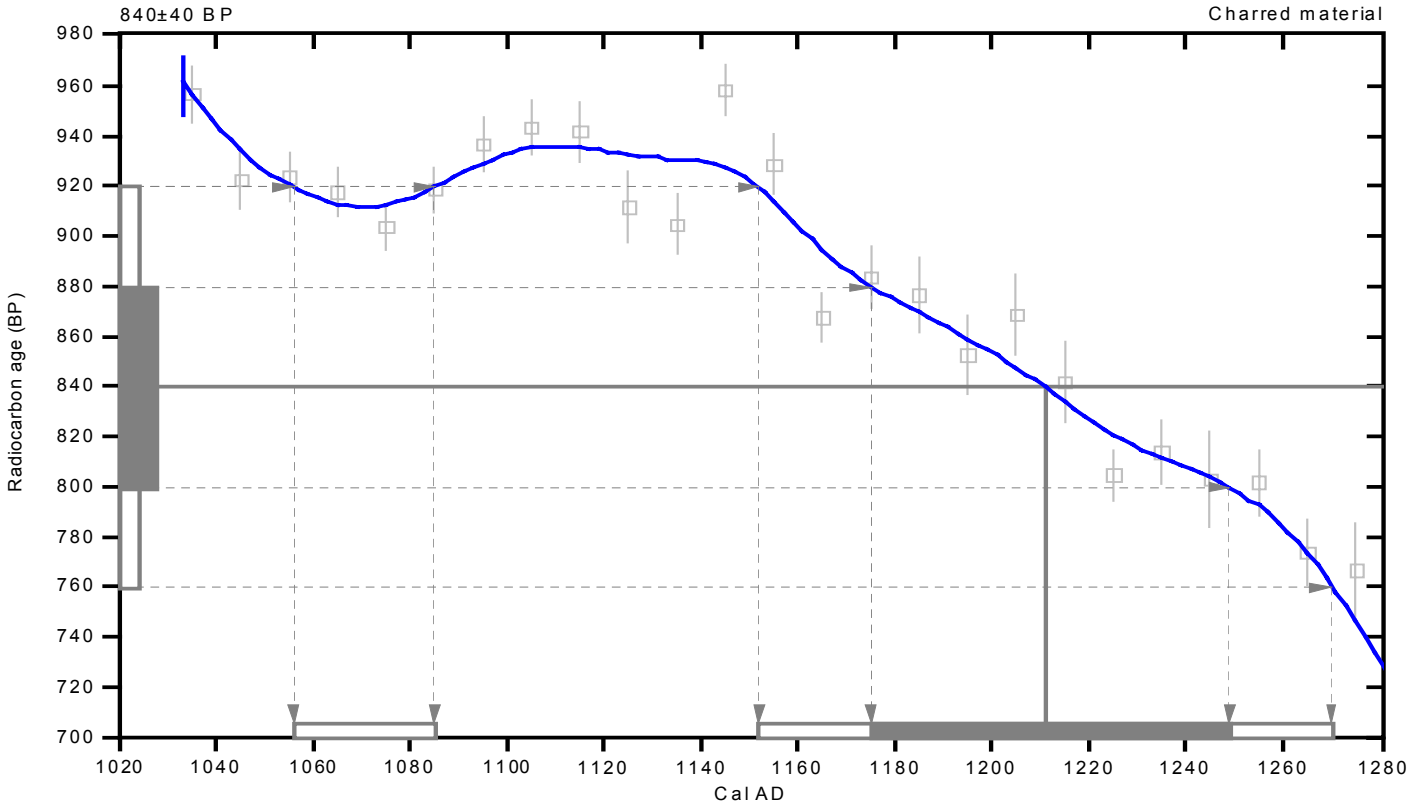
CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12=-26.4:lab. mult=1)

Laboratory number:	**Beta-183379**
Conventional radiocarbon age:	**840±40 BP**
2 Sigma calibrated results: (95% probability)	**Cal AD 1060 to 1080 (Cal BP 890 to 860) and Cal AD 1150 to 1270 (Cal BP 800 to 680)**

Intercept data

Intercept of radiocarbon age with calibration curve:	Cal AD 1210 (Cal BP 740)
1 Sigma calibrated result: (68% probability)	Cal AD 1180 to 1250 (Cal BP 780 to 700)



References:

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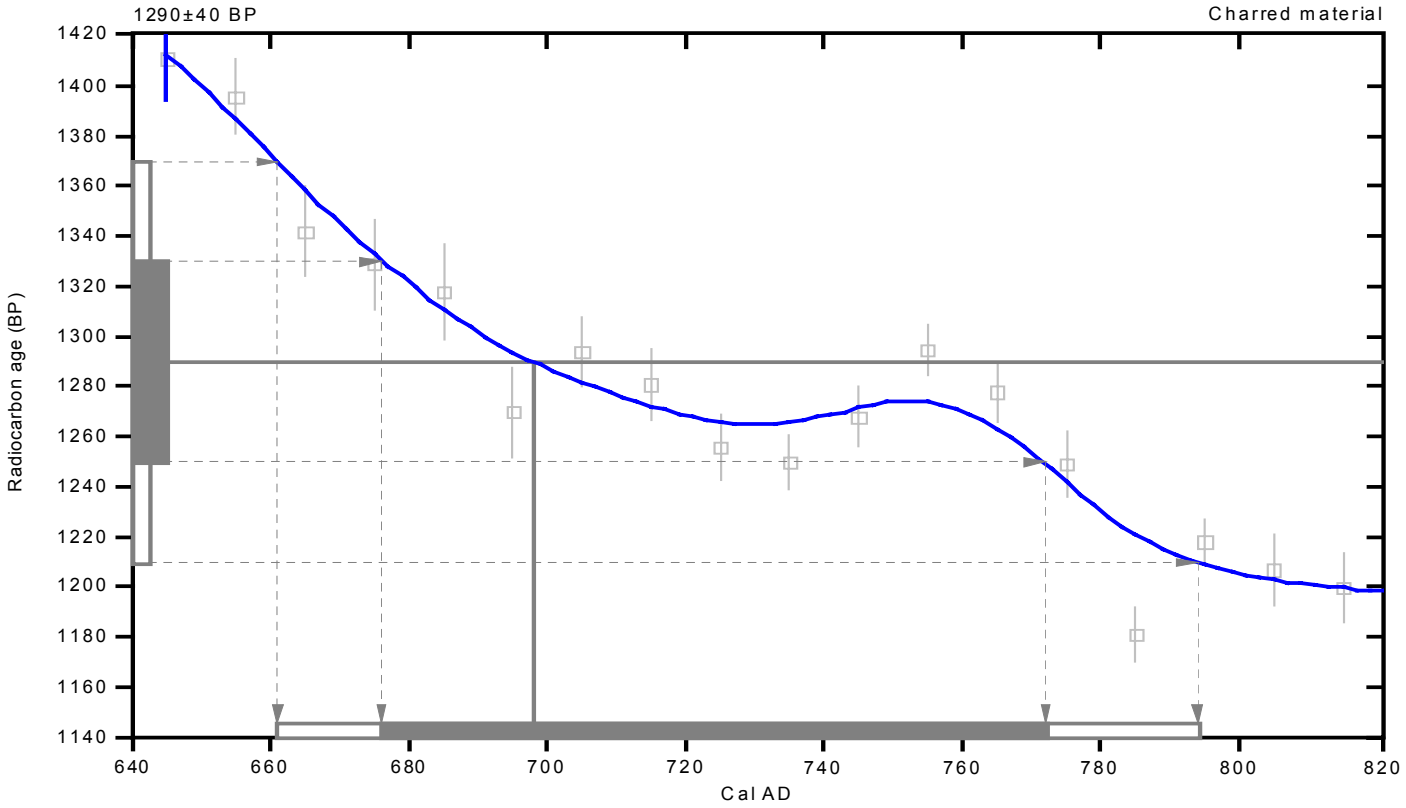
CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12=-25.5:lab. mult=1)

Laboratory number:	**Beta-183380**
Conventional radiocarbon age:	**1290±40 BP**
2 Sigma calibrated result: (95% probability)	**Cal AD 660 to 790 (Cal BP 1290 to 1160)**

Intercept data

Intercept of radiocarbon age with calibration curve:	Cal AD 700 (Cal BP 1250)
1 Sigma calibrated result: (68% probability)	Cal AD 680 to 770 (Cal BP 1270 to 1180)



References:

Database used

Calibration Database

Editorial Comment

Stuiver, M., van der Plicht, H., 1998, Radiocarbon 40(3), pxii-xiii

INTCAL98 Radiocarbon Age Calibration

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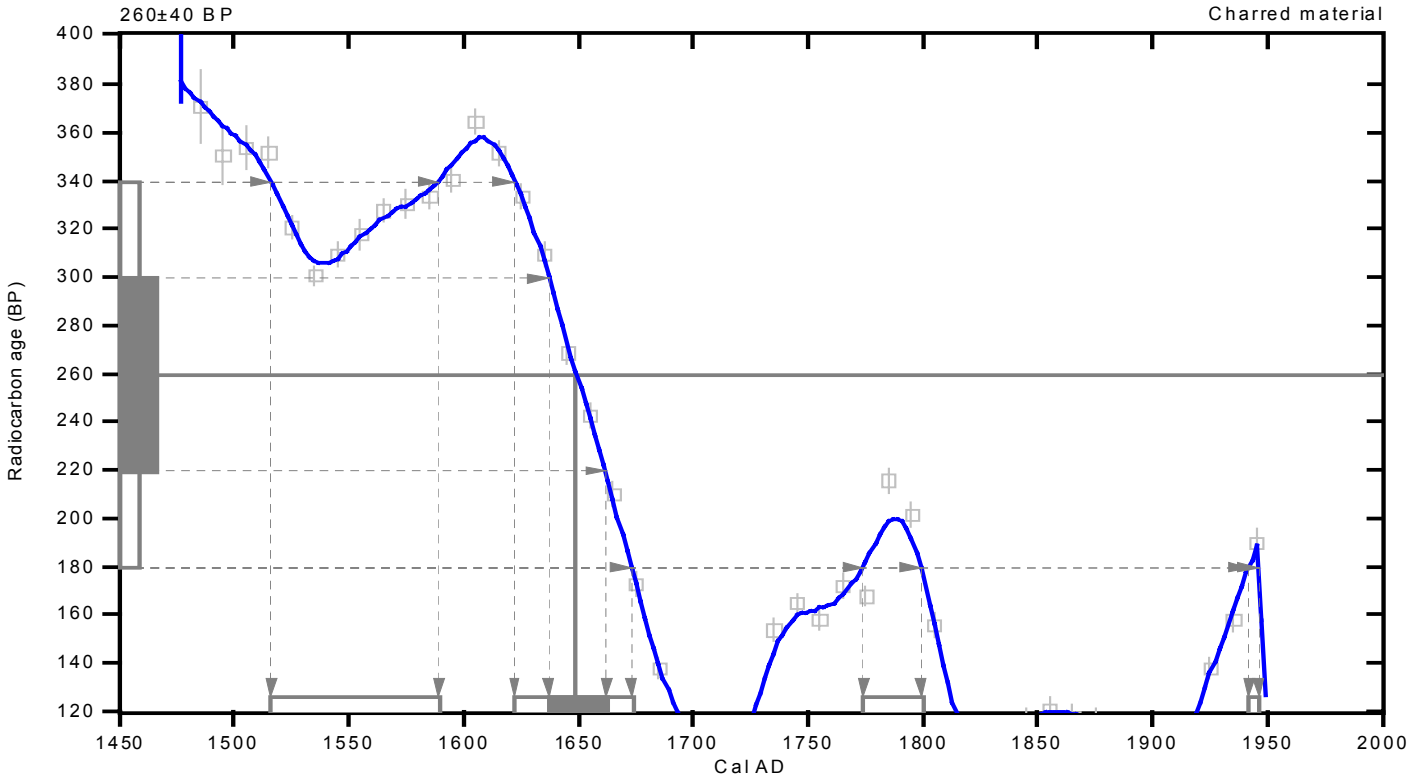
CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12=-25.5:lab. mult=1)

Laboratory number:	**Beta-183381**
Conventional radiocarbon age:	**260±40 BP**
2 Sigma calibrated results: (95% probability)	**Cal AD 1520 to 1590 (Cal BP 430 to 360) and Cal AD 1620 to 1670 (Cal BP 330 to 280) and Cal AD 1770 to 1800 (Cal BP 180 to 150) and Cal AD 1940 to 1950 (Cal BP 10 to 0)**

Intercept data

Intercept of radiocarbon age with calibration curve:	Cal AD 1650 (Cal BP 300)
1 Sigma calibrated result: (68% probability)	Cal AD 1640 to 1660 (Cal BP 310 to 290)



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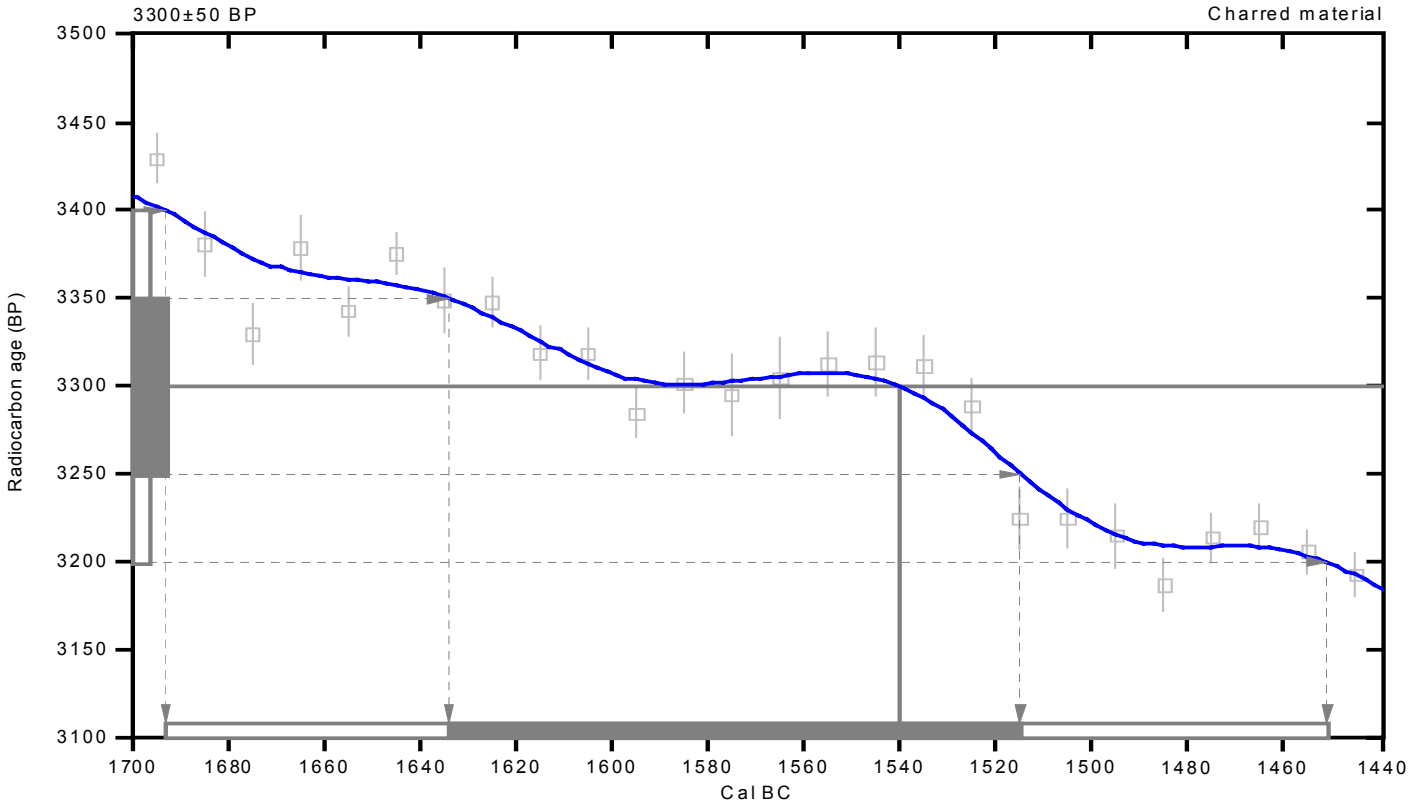
CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12=-21.8:lab. mult=1)

Laboratory number:	**Beta-183382**
Conventional radiocarbon age:	**3300±50 BP**
2 Sigma calibrated result: (95% probability)	**Cal BC 1690 to 1450 (Cal BP 3640 to 3400)**

Intercept data

Intercept of radiocarbon age with calibration curve:	Cal BC 1540 (Cal BP 3490)
1 Sigma calibrated result: (68% probability)	Cal BC 1630 to 1520 (Cal BP 3580 to 3460)



References:

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INTCAL98 Radiocarbon Age Calibration

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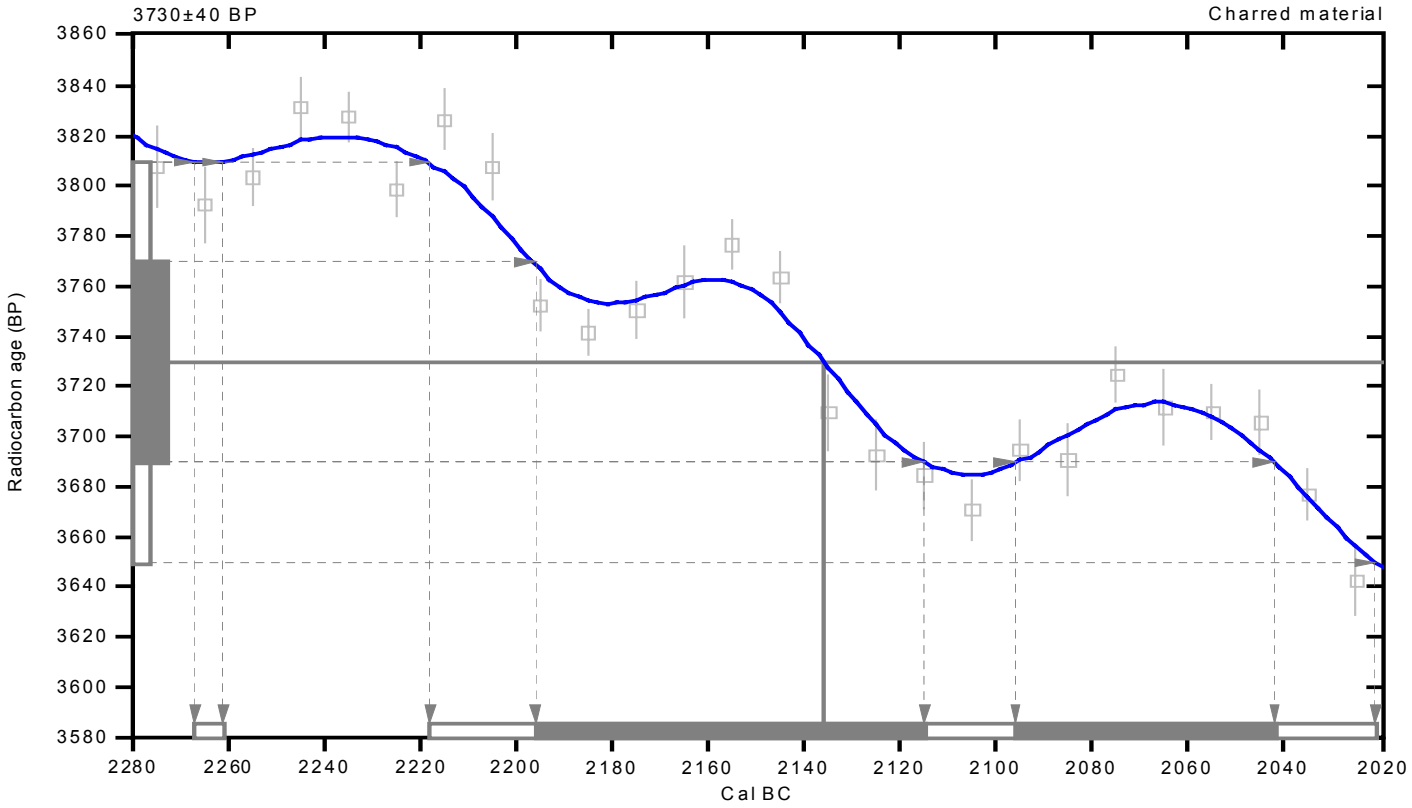
CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12=-24.6:lab. mult=1)

Laboratory number:	**Beta-183383**
Conventional radiocarbon age:	**3730±40 BP**
2 Sigma calibrated results: (95% probability)	**Cal BC 2270 to 2260 (Cal BP 4220 to 4210) and Cal BC 2220 to 2020 (Cal BP 4170 to 3970)**

Intercept data

Intercept of radiocarbon age with calibration curve:	Cal BC 2140 (Cal BP 4090)
1 Sigma calibrated results: (68% probability)	Cal BC 2200 to 2120 (Cal BP 4150 to 4060) and Cal BC 2100 to 2040 (Cal BP 4050 to 3990)



References:

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INTCAL98 Radiocarbon Age Calibration

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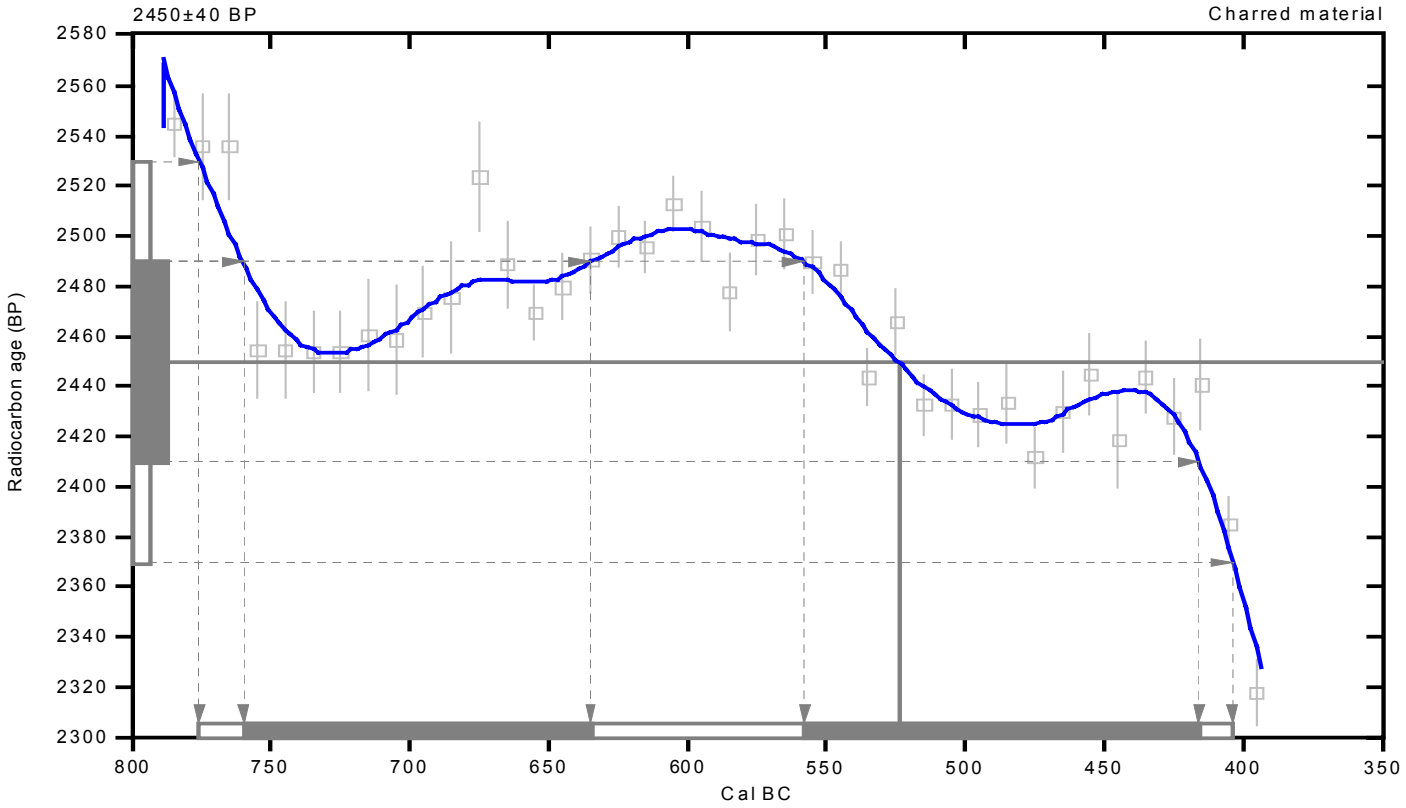
CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12=-26.9:lab. mult=1)

Laboratory number:	**Beta-183384**
Conventional radiocarbon age:	**2450±40 BP**
2 Sigma calibrated result: (95% probability)	**Cal BC 780 to 400 (Cal BP 2730 to 2350)**

Intercept data

Intercept of radiocarbon age with calibration curve:	Cal BC 520 (Cal BP 2470)
1 Sigma calibrated results: (68% probability)	Cal BC 760 to 640 (Cal BP 2710 to 2580) and Cal BC 560 to 420 (Cal BP 2510 to 2370)



References:

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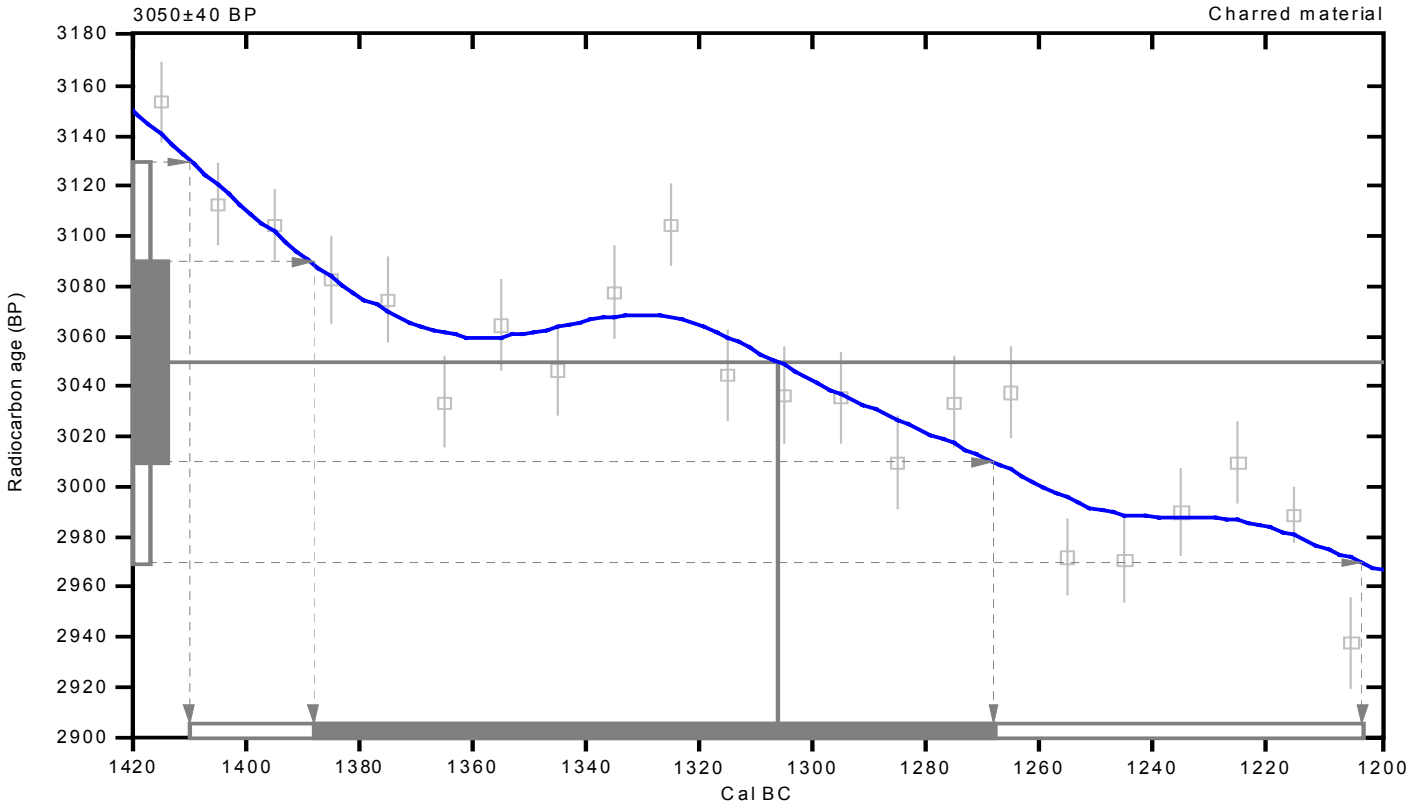
CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12=-24.6:lab. mult=1)

Laboratory number:	**Beta-183385**
Conventional radiocarbon age:	**3050±40 BP**
2 Sigma calibrated result: (95% probability)	**Cal BC 1410 to 1200 (Cal BP 3360 to 3150)**

Intercept data

Intercept of radiocarbon age with calibration curve:	Cal BC 1310 (Cal BP 3260)
1 Sigma calibrated result: (68% probability)	Cal BC 1390 to 1270 (Cal BP 3340 to 3220)



References:

Database used

Calibration Database
Editorial Comment
Stuiver, M., van der Plicht, H., 1998, Radiocarbon 40(3), pxii-xiii
INTCAL98 Radiocarbon Age Calibration
Stuiver, M., et. al., 1998, Radiocarbon 40(3), p1041-1083
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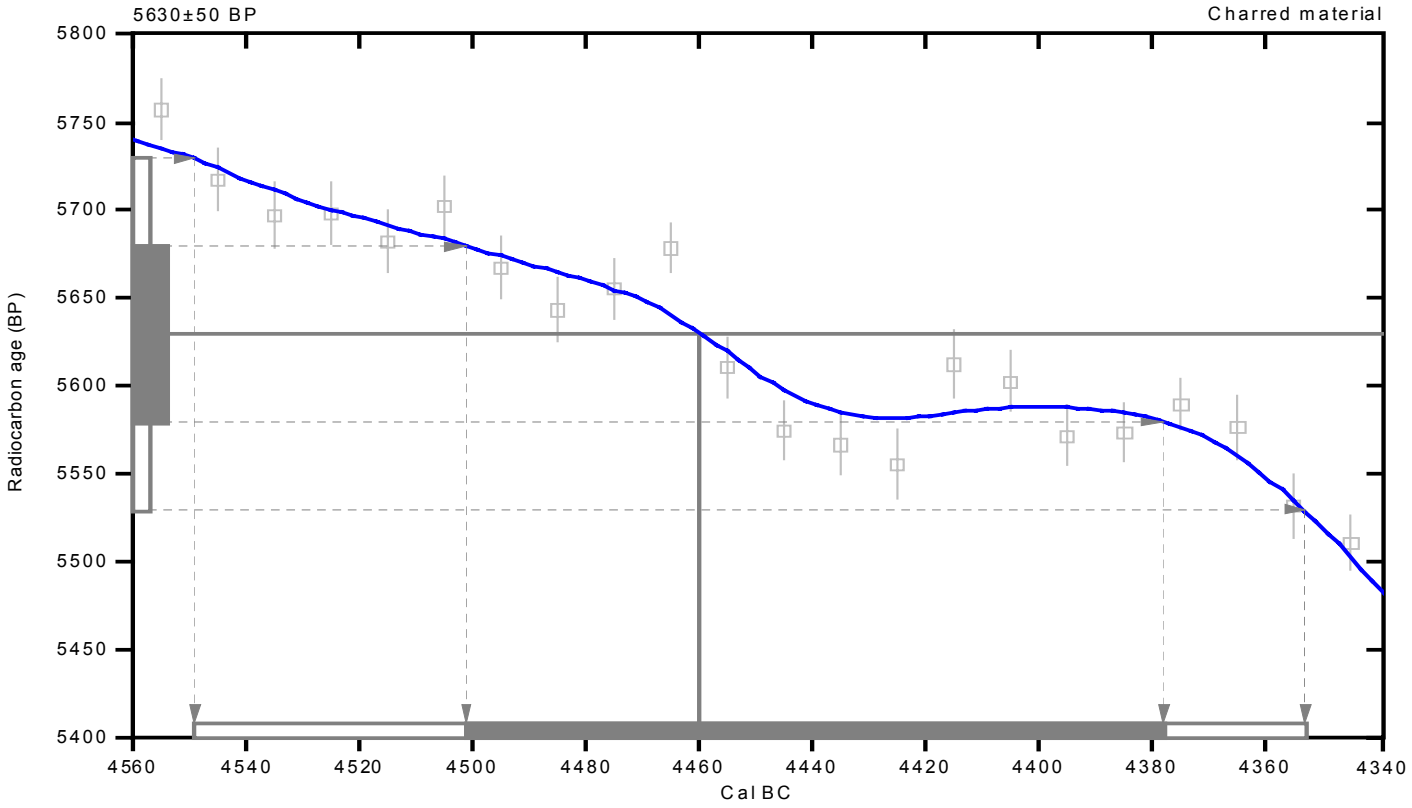
CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12=-26.5:lab. mult=1)

Laboratory number:	**Beta-183386**
Conventional radiocarbon age:	**5630±50 BP**
2 Sigma calibrated result: (95% probability)	**Cal BC 4550 to 4350 (Cal BP 6500 to 6300)**

Intercept data

Intercept of radiocarbon age with calibration curve:	Cal BC 4460 (Cal BP 6410)
1 Sigma calibrated result: (68% probability)	Cal BC 4500 to 4380 (Cal BP 6450 to 6330)



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FROM: Darden Hood, Director (mailto:mailto:dhood@radiocarbon.com)
(This is a copy of the letter being mailed. Invoices/receipts follow only by mail.)

December 3, 2004

Dr. Lucy Piety
Bureau of Reclamation
Denver Federal Center
D-8330
P.O. Box 25007
Denver, CO 80225
USA

RE: Radiocarbon Dating Result For Sample 81904-1-1CO

Dear Dr. Piety:

Enclosed is the radiocarbon dating result for one sample recently sent to us. It provided plenty of carbon for an accurate measurement and the analysis went normally. As usual, the method of analysis is listed on the report sheet and calibration data is provided where applicable.

As always, no students or intern researchers who would necessarily be distracted with other obligations and priorities were used in the analysis. It was analyzed with the combined attention of our entire professional staff.

If you have specific questions about the analyses, please contact us. We are always available to answer your questions.

The cost of the analysis was charged to the MASTERCARD card provided. A receipt is enclosed. Thank you. As always, if you have any questions or would like to discuss the results, don't hesitate to contact me.

Sincerely,

Darden Hood

Dr. Lucy Piety

Report Date: 12/3/2004

Bureau of Reclamation

Material Received: 11/2/2004

Sample Data	Measured Radiocarbon Age	13C/12C Ratio	Conventional Radiocarbon Age(*)
Beta - 197492	1050 +/- 40 BP	-23.4 o/oo	1080 +/- 40 BP

SAMPLE : 81904-1-1CO
ANALYSIS : AMS-Standard delivery
MATERIAL/PRETREATMENT : (charred material): acid/alkali/acid
2 SIGMA CALIBRATION : Cal AD 890 to 1020 (Cal BP 1060 to 930)

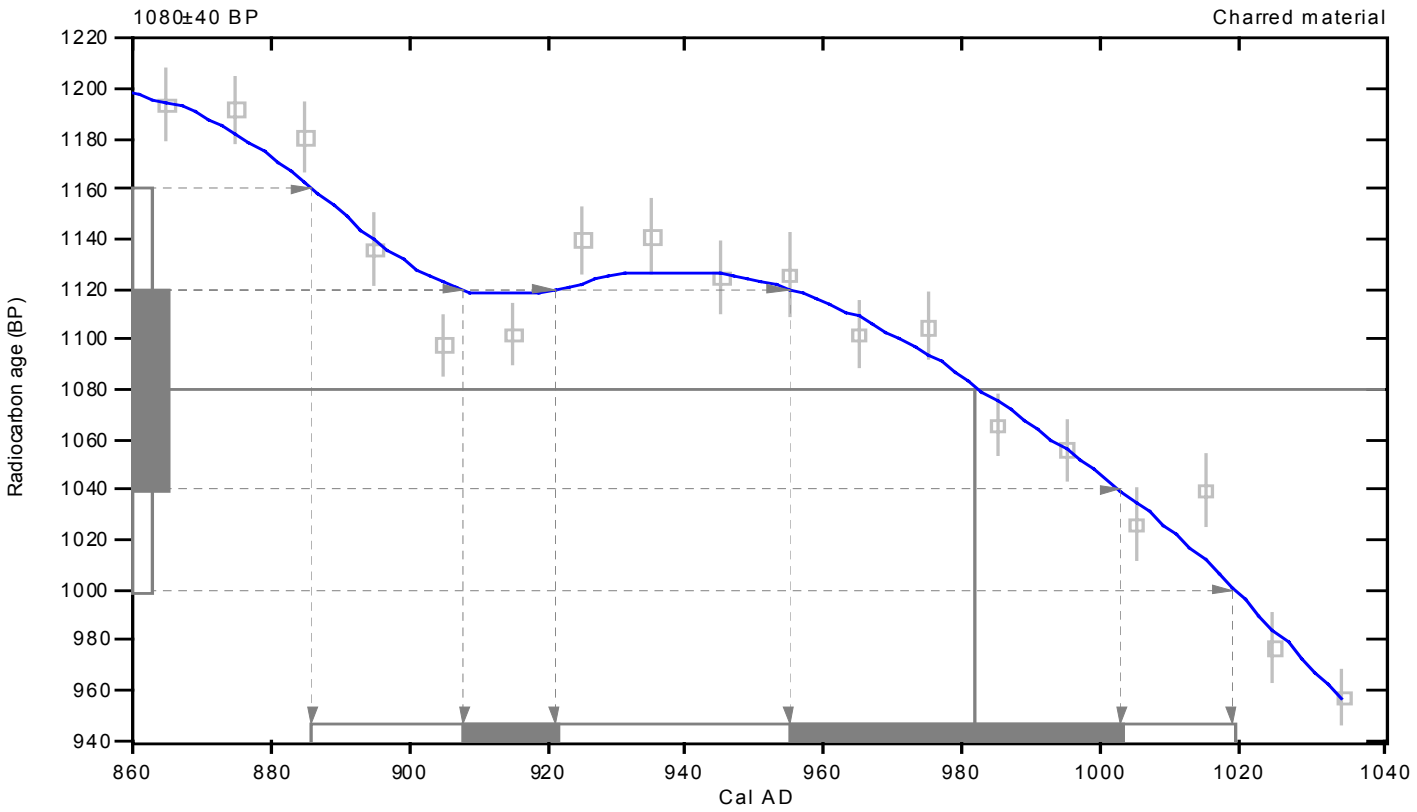
CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12=-23.4:lab. mult=1)

Laboratory number:	**Beta-197492**
Conventional radiocarbon age:	**1080±40 BP**
2 Sigma calibrated result: (95% probability)	**Cal AD 890 to 1020 (Cal BP 1060 to 930)**

Intercept data

Intercept of radiocarbon age with calibration curve:	Cal AD 980 (Cal BP 970)
1 Sigma calibrated results: (68% probability)	Cal AD 910 to 920 (Cal BP 1040 to 1030) and Cal AD 960 to 1000 (Cal BP 1000 to 950)



References:

Database used

INTCAL98

Calibration Database

Editorial Comment

Stuiver, M., van der Plicht, H., 1998, Radiocarbon 40(3), pxii-xiii

INTCAL98 Radiocarbon Age Calibration

Stuiver, M., et. al., 1998, Radiocarbon 40(3), p1041-1083

Mathematics

A Simplified Approach to Calibrating C14 Dates

Talma, A. S., Vogel, J. C., 1993, Radiocarbon 35(2), p317-322

Beta Analytic Radiocarbon Dating Laboratory

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CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

Variables used in the calculation of age calibration → (Variables: est. C13/C12=-25:lab. mult=1)

Laboratory number: **Beta-123456**

The uncalibrated Conventional Radiocarbon Age (± 1 sigma)

Conventional radiocarbon age[1]: **2400±60 BP**

The calendar age range in both calendar years (AD or BC) and in Radiocarbon Years (BP)

2 Sigma calibrated result: **Cal BC 770 to 380 (Cal BP 2720 to 2330)**
(95% probability)

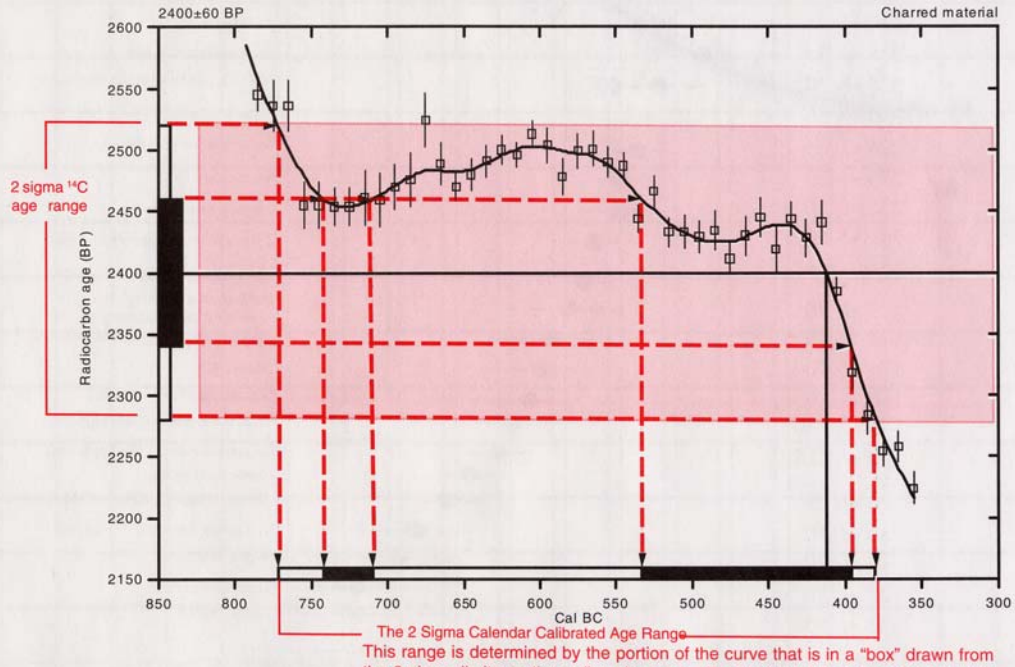
[1] *C13/C12 ratio estimated*

Intercept data

The intercept between the average radiocarbon age and the calibrated curve time scale. This value is illustrative and should not be used by itself.

Intercept of radiocarbon age with calibration curve: Cal BC 410 (Cal BP 2360)

1 Sigma calibrated result: (68% probability) Cal BC 740 to 710 (Cal BP 2690 to 2660) and Cal BC 535 to 395 (Cal BP 2485 to 2345)



The 2 Sigma Calendar Calibrated Age Range

This range is determined by the portion of the curve that is in a "box" drawn from the 2 sigma limits on the radiocarbon age. If a section of the curve goes outside of the "box", multiple ranges will occur as shown by the two 1 sigma ranges which occur from sections going outside of a similar "box" which would be drawn at the 1 sigma limits.

References:

Database used
Intcal 98
Calibration Database
Editorial Comment
Stuiver, M., van der Plicht, H., 1998, Radiocarbon 40(3), pxii-xiii
INTCAL98 Radiocarbon Age Calibration
Stuiver, M., et. al., 1998, Radiocarbon 40(3), p1041-1083
Mathematics
A Simplified Approach to Calibrating C14 Dates
Talma, A. S., Vogel, J. C., 1993, Radiocarbon 35(2), p317-322

References for the calibration data and the mathematics applied to the data. These references, as well as the Conventional Radiocarbon Age and the 13C/12C ratio used should be included in your papers.

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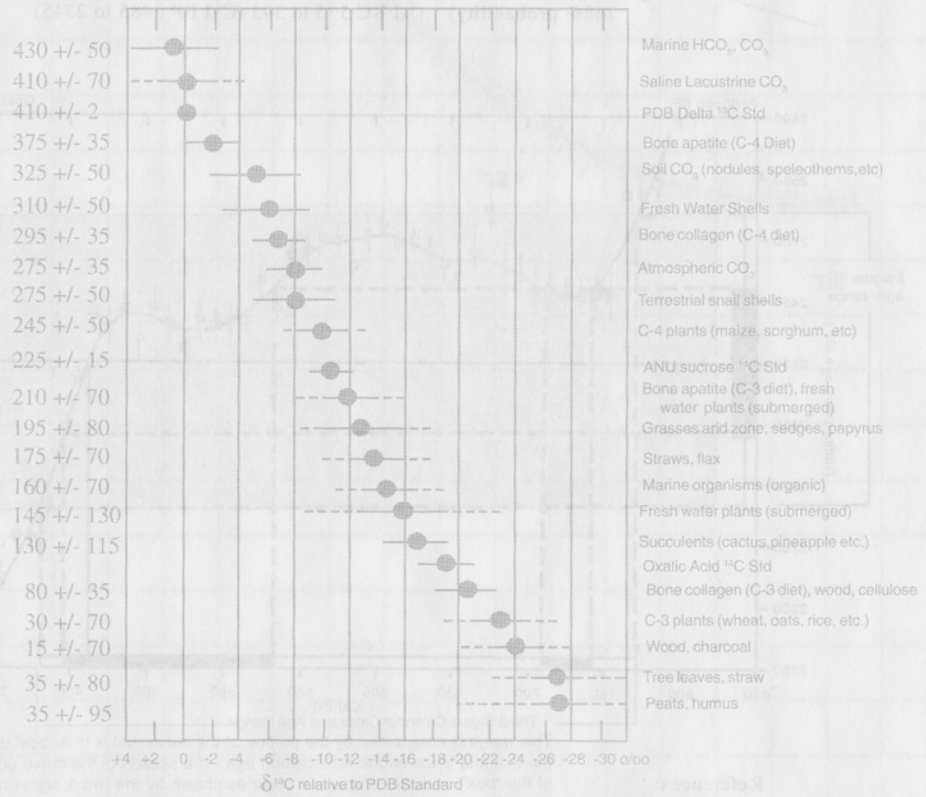
Derivation of a radiometric or accelerator dendro-calibrated (CALENDAR) date requires use of the CONVENTIONAL radiocarbon date (Stuiver and Polach)[1]. The conventional date is a basic radiocarbon date that has been normalized to the modern standard through the use of $^{13}C/^{12}C$ ratios* (analyzed or estimated). The statistical error (+/-) on an analyzed $^{13}C/^{12}C$ value is quite small and does not contribute significantly to the combined error on the date. However, use of an estimated $^{13}C/^{12}C$ ratio for an unknown sample may incur a large combined error term. This is clearly illustrated in the figure below (Gupta & Polach;modifiec by J. Head)[2] where the possible range of $^{13}C/^{12}C$ values for a particular material type may be so large as to preclude any practical application or correction.

In cases where analyzed $^{13}C/^{12}C$ values are not available, we provide (for illustration) dendro-calibrations assuming a mean "chart" value, but without an estimated error term.

Where a sample carbon reservoir different from that modern oxalic acid/wood modern standard is involved (e.g. shell), further reservoir correction must be employed: the variables used in each calibration displayed on each individual calibration sheet.



[1] Suiver, M. and Polach, H.A., 1977, Discussion: Reporting of 14-C data, Radiocarbon 19, 355-363.

[2] Gupta S.K. and Polach H.A., 1985, Radiocarbon Dating Practices at ANU Handbook, p. 114, Radiocarbon Laboratory, Research School of Pacific Studies, ANU, Canberra

*Radiocarbon is incorporated into various materials by different pathways and this introduces differing degrees of isotopic fractionation. The $^{13}C/^{12}C$ ratio of any material is the millesimal difference of the sample to the carbonate PDB standard and is directly related to the $^{14}C/^{12}C$ ratio. The degree of sample ^{14}C enrichment or depletion then is normalized to that of the modern standard.

APPENDIX E: GEOMPORHIC ASSESSMENT OF LARGE WOODY DEBRIS

GEOMORPHIC ASSESSMENT OF LARGE WOODY DEBRIS

Upper Quinault River

Prepared for

Bureau of Reclamation

and

Quinault Indian Nation

July 2005

Note:
Some pages in this document have been purposefully skipped or blank pages inserted so that this document will copy correctly when duplexed.

GEOMORPHIC ASSESSMENT OF LARGE WOODY DEBRIS

Upper Quinault River

Prepared for

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Hydraulic and Sedimentation Group
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July 21, 2005

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Executive Summary

This report was prepared in support of the geomorphic analysis of the Upper Quinault River, in Jefferson County, Washington, conducted by the U.S. Department of Interior, Bureau of Reclamation. The report presents the findings of a geomorphic analysis of channel habitat and large woody debris conditions in the 18-kilometer reach of the Quinault River that is directly upstream of Lake Quinault. Stable wood jams, composed of large woody debris, create and maintain complex side channel networks that are critical salmon spawning and rearing habitat in forested mountain river valleys. The objective of this study was to evaluate the current and historical characteristics of large woody debris, wood jams, and side channels in the Upper Quinault River. The study approach combined the results of analyses of archival aerial photography (1952–2002), the results of a topographic survey conducted in 2002 by means of light detection and ranging (lidar), and an evaluation of current field conditions to assess (1) side channel characteristics, (2) channel complexity, (3) large woody debris loading, and (4) wood jam frequency.

The most significant historical change to the Upper Quinault River has been the removal of the old-growth riparian forest that once covered much of the valley bottom. Valley deforestation and historical channel clearing have led to a loss of large key member logs that are necessary for the creation of stable wood jams and associated side channel habitat. The results of this study show a historical channel migration zone populated by young ephemeral side channels that are frequently disturbed because of a lack of protection by stable wood jams. Field observations further indicate that many of the remaining persistent side channels are associated with relic wood jams. These results illustrate that new wood jams are no longer being generated in the Upper Quinault River. Historical aerial photographs and the lidar digital elevation model show a dense network of old side channels within the historically forested floodplains and terraces. Old side channels may persist for hundreds of years in the forested river valleys of the Olympic Mountains. In a representative subreach of the Quinault River that is 1 kilometer long, channel expansion between 1939 and 2002 resulted in an estimated loss of over 2,000 meters of old side channels. The loss of valley forest sources of new large wood and stable wood jams coupled with the continued loss of remaining old floodplain and terrace side channels indicate that the degradation of critical salmon side channel habitat will continue for potentially hundreds of years.

To restore salmon habitat in the Upper Quinault River, the natural physical and biological processes that generate and maintain the riverine ecosystem must be recovered. Long-term restoration of Quinault River aquatic habitat will be dependent on reestablishing a mature self-sustaining forest throughout the active valley channel migration zone. In the near term, it is proposed that engineered logjams be used to (1) protect existing side channel habitat (2) create new side channels, and (3) accelerate the recovery of floodplain forest development within the historical channel migration zone. A phased restoration approach is proposed to allow flexibility for the annual restoration work to be implemented in the most cost-effective manner. Once the conifer forests throughout the valley reach maturity, the natural cycle of large wood recruitment and conifer forest regeneration will be self-sustaining. At that point, large-wood-generated

processes that form channels and floodplains will occur naturally without any additional restoration interventions. A comprehensive large-scale restoration of the Quinault riverine ecosystem will take decades to accomplish. Therefore, a phased approach over 50 years is proposed.

Introduction

This report was prepared in support of a geomorphic investigation of the Upper Quinault River conducted by the U.S. Department of the Interior, Bureau of Reclamation, in response to a request from the Quinault Indian Nation. The report presents the results of a geomorphic assessment of historical and current conditions of large woody debris, forests, and side channels within the 18-kilometer reach of the Quinault River directly upstream of Lake Quinault ("Upper Quinault") in Jefferson County, Washington. It discusses the results of the evaluation of wood dynamics in the Upper Quinault River, summarizes the implications of these findings, and proposes a broad strategy for both the short-term protection of existing side channel habitat and the long-term recovery of the riverine ecosystem. The proposed restoration strategy is based on the results of this study and the broader geomorphic investigation conducted by the Bureau of Reclamation (BOR 2005)

Study Objectives

This study was initiated to evaluate the impacts and future implications of historical land use practices of the late nineteenth and twentieth centuries on the dynamics of large woody debris and associated channel complexity in the Upper Quinault River valley. The overall goal of the study was to analyze recent historical and current conditions as the basis for developing a restoration strategy for the Upper Quinault River. This investigation evaluated the characteristics, quantity, stability, and geomorphic function of large woody debris in the unvegetated active channel of the Upper Quinault River. The results of this analysis were used to make interpretations of landforms and forest development in the Upper Quinault River valley, with a focus on understanding how large woody debris directly and indirectly influences salmon habitat.

The study elements included (1) an evaluation of channel complexity and its association with large woody debris, (2) measurement of wood jam frequency, (3) measurement of floodplain and terrace side channel length, (4) measurement of wood-loading dynamics between 1952 and 2002, and (5) measurement of changes in the amount and stability of wood in the active channel. The remainder of this report is organized into the following sections: Methods, Results, Discussion, Conclusion and Implications for Restoration, and References.

Geomorphic and Ecological Background

The Quinault River, directly upstream of Lake Quinault, is characterized by a braided and branching channel that is subject to frequent changes in position due to a very high sediment load from the adjacent Olympic Mountains (Figure 1). The valley bottom consists of a complex mosaic of channels and floodplain and terrace forests that is subject to frequent disturbance due to flooding and channel migration. Young floodplains are dominated by red alder (*Alnus rubra*),

with successively older floodplain and terrace surfaces dominated by a mixture of Sitka spruce (*Picea sitchensis*), western hemlock (*Tsuga heterophylla*), big-leaf maple (*Acer macrophyllum*), and red alder. The young floodplain forests are most susceptible to disturbance by the river because they have less established root cohesion (i.e., root diameter and density). The older mixed conifer/deciduous forested islands and floodplain and terrace forests are inextricably linked to aquatic habitat because these forests provide canopy cover for the channel, floodplain and channel stability, and in-channel large woody debris.

Large woody debris is a critical structural element that generates and maintains channel, floodplain, and terrace morphology and associated aquatic habitat in forested river networks (Sedell and Froggatt 1984; Abbe and Montgomery 1996; Montgomery et al. 2003). Specifically, pieces of large woody debris act as "key members" that form the primary anchoring structure of stable wood jams (Figure 2; Abbe and Montgomery 1996). Stable wood jams form scour pools, split stream flow into multiple side channels, and constitute sites of forest vegetation colonization within the hydraulically stressful channel environment (Fetherston et al. 1995; Abbe and Montgomery 1996). As forest vegetation becomes established, both adjacent to and downstream of stable wood jams, sediment aggradation creates a local elevated floodplain surface, resulting in the formation of forested islands. Forested islands, if left undisturbed, may grow in size by means of forest colonization and establishment, coalescing into the larger floodplain forest (Fetherston et al. 1995; Abbe and Montgomery 1996). In the forested river valleys of the coastal Olympic Mountains, key member trees in wood jams, acting as nursery logs, are the nearly exclusive site of floodplain conifer reproduction and therefore are the limiting factor that controls the conifer population in the valley bottom, the source of future key member trees (Fetherston 2005). This forest cycle is maintained by channel migration recruitment of key member trees from mature floodplain and terrace forests (Fetherston et al. 1995; Fetherston 2005). The linkages between floodplain forest regeneration, stable wood jam formation, and the generation and maintenance of channel complexity are critical to the protection and restoration of habitat for sockeye salmon in low-gradient forested alluvial valleys of the coastal Olympic Mountains.

In the Upper Quinault River, high channel complexity forms the critical habitat of sockeye salmon, a species of concern to the Quinault Indian Nation (BOR 2005). Channel complexity refers to the physical structure of the river corridor. Low channel complexity is characterized by uniform channel topography, low wood loading, little variation in substrate, low sinuosity, and limited floodplain and terrace forest sources of large woody debris. Wood loading is defined as the quantity of large woody debris (number of wood pieces longer than 10 meters) per unit area of unvegetated channel. In contrast, high channel complexity is characterized by numerous ephemeral and perennial channels, large variation in substrate and topography, high pool frequency and wood loading, high channel sinuosity, and a mature mixed conifer/deciduous floodplain and terrace forest. Significantly, fisheries biologists from the Quinault Indian Nation have identified areas of high channel complexity, characterized by side channels protected by wood jams, and scour pools generated by wood jams, as critical sockeye spawning and rearing habitat in the Upper Quinault River (Figure 3) (BOR 2005).

Although the Upper Quinault remains a rural river valley with a relatively low human population, it has undergone significant changes, particularly in terms of the condition of the valley forest. Historical reports of late eighteenth century predisturbance conditions describe an upper Quinault River valley of dense forest, abundant large woody debris, and forested islands. The river channel planform (map view of the channel) was described as having one to two main channels, with multiple side channels coursing through the floodplain forest (BOR 2005). These conditions are similar to the pristine unlogged reaches of the adjacent Queets and Hoh River valleys (Fetherston et al. 1995; Abbe and Montgomery 1996; Abbe 2000; O'Conner et al. 2003). Therefore, research concerning the processes generating and maintaining the pristine river valley channel, floodplain, and floodplain forests of the Queets and Hoh Rivers may serve not only as a description of historical reference site conditions but as a model upon which to develop science-based restoration strategies for the degraded Upper Quinault River valley.

Historical land use practices in the upper Quinault River valley (logging and land clearing) have resulted in a total loss of mature floodplain and terrace forests, the source of in-channel large woody debris, within the historical channel migration zone (HCMZ) (Figure 4) (BOR 2005). In addition to forest clearing, large woody debris was systematically removed from the active channel during the twentieth century (BOR 2005). The result of these losses has been a simplification of channel complexity, a loss of forested islands, and a subsequent reduction in the amount of sockeye salmon habitat. Significantly, the loss of the valley bottom forest sources of large key member trees has not only diminished complex channel habitat but has stunted the recovery of the conifer forest for potentially hundreds of years.

Methods

The study approach combined analyses of archival and current aerial photographs, the results of a topographic survey conducted in 2002 by means of light detection and ranging (lidar), and an evaluation of current field conditions to assess channel complexity and the abundance, stability, and function of large woody debris in the unvegetated channel between 1952 and 2002.

Fluvial Landforms

Aerial photographs, the lidar digital elevation model (DEM), a 1906 Government Land Office map, and field inspections were used to describe distinctive fluvial landforms within the Upper Quinault River valley. Delineation of landforms was necessary to quantify particular habitat conditions such as the historical changes in side channel length and channel migration rates of the river. Descriptions of the fluvial landforms addressed in this report are presented in the results section. Additional information on landform definitions is included in the Upper Quinault River geomorphic assessment (BOR 2005).

Channel Complexity

Channel complexity was measured throughout the 18-kilometer reach. Channel complexity was defined as the frequency of forested-island-associated channel "splits" in the unvegetated channel. A channel split was defined as the point where a single channel is split into two separate channels by a forested island measuring at least 30 by 50 meters (1,500 square meters). The presence of large woody debris, either as "racked wood" or wood jams, at each island apex was noted. Mobile woody debris found accumulating on flow obstructions (i.e., key member snags, trees, and boulders) is referred to as "racked wood." Racked wood typically consisted of relatively small trees and logs with little or no rootwad. Racked wood is typically found in logjam formations where it accumulates on an existing flow obstruction but is also found as dispersed deposits on top of bars. To qualify as a split, the associated side channels must have been continuously unvegetated, at least 10 meters wide, and reconnected downstream of the island. Many small side channels visible in the aerial photographs did not satisfy these criteria and could not be consistently documented through time because of variations in photographic resolution and changes in forest canopy structure. The dimensions and characteristics of side channels identified in the 2002 aerial photographs were confirmed in the 2-meter pixel lidar DEM. A lidar hillshade image was created by shining an artificial light source onto the lidar DEM using ArcView 9.0 Spatial Analyst. The hillshade representation facilitates the interpretation of the lidar DEM.

Change in split frequency over time was estimated by comparing the number of splits per unit length of channel that existed in 1952 with the number of splits observed in 2002. Splits in 1952

were identified using the same 2002 protocol, although island/wood association was not recorded due to the low resolution of the 1952 aerial photographs.

Side Channels and Forests

To characterize the length and planform of the valley side channels, side channels in the alluvial valley south of the main channel along the reach from river kilometer (RK) 12.5 to RK 13.6 were mapped using 2002 lidar data. Total side channel length was measured. Side channel dimensions were illustrated using a cross-section of the lidar data. Floodplain and terrace disturbance over the period of 1906–2002 was assessed to illustrate the potential loss of historical side channel habitat from RK 12.5 to RK 13.6. The 2002 floodplain and terrace side channel length per unit area was used as a proxy to calculate the total side channel length that was disturbed during this period: estimated loss of old side channel (km) = side channel diversity in 2002 (km/km^2) X area eroded 1906–2002 (km^2).

Wood Loading

To assess temporal changes in wood loading in the unvegetated channel, the amount of in-channel large woody debris (LWD) was estimated in the 1952 and 2002 aerial photographs. Because of their poor photographic resolution, photographs prior to 1952 were not used in this analysis (Figure 5).

Wood-loading zones were defined as high or low. The high-wood-loading zone was defined as a channel area in which the majority of the pieces of LWD (pieces longer than 10 meters) were in physical contact with each other (Figure 6). The low-wood-loading zone was defined as a channel area in which scattered LWD pieces were not in contact with each other (Figure 6). The total number of LWD pieces within all high-wood-loading-zone polygons was divided by the total polygon area to estimate the average number of LWD pieces per unit area within two reaches of the study area (RK 23.6 to RK 24.7 and RK 24.8 to RK 26.8). The trend lines for wood loading within digitized polygons are presented in Figure 6. The average number of LWD pieces in the low-wood-loading zone was calculated by the same method.

Wood loading in 1952 could not be estimated in the same manner as that in 2002 because of lower photographic resolution and contrast in the 1952 aerial photographs (Figure 7). In order to compare the 1952 photographs with the higher resolution 2002 photographs, the quality of the 2002 photographs was degraded to approximate that of the 1952 photographs (Figure 7). The degradation was accomplished by reexamining the 2002 photographs with a coarser pixel (i.e., changing the pixel size of the photograph from 0.2 meters to 4 meters) using ESRI Spatial Analyst (ArcView 9.0). Then the contrast of the 2002 photographs was reduced and the brightness was increased to approximate the qualities of the 1952 photographs. Finally, the 1952 high- and low-wood-loading zones were delineated and wood loading was estimated using the 2002 multiplier for wood density.

Wood Jam Frequency

For this study, wood jams were defined as having (1) accumulations of interlocking wood at least 15 meters in width, (2) accumulations of racked wood at the upstream apex of the jam, and (3) visible effects on the channel planform. Wood jams in the high- and low-wood-loading zones were identified in the 2002 aerial photographs.

Fate Analysis of High-Wood-Loading Areas

In order to estimate the fate of wood accumulations in the unvegetated channel over time, the fate of high-wood-loading polygons delineated in the 1952 aerial photographs was tracked through the period of the aerial photographic record (1958, 1962, 1973, 1982, 1990, 1994, 1998, and 2002). For each sequential year, the high-wood-loading polygons were examined and categorized according to the following categories:

1. **No change**. At least 50 percent of the 1952 polygon remained in a state of high wood loading (implying that most of the 1952 wood volume either remained intact or was replaced during the intervening time period).

2. **Riparian forest**. At least 50 percent of 1952 polygon had been converted to riparian forest.

3. **Channel reoccupation**. At least 50 percent of 1952 polygon had changed to a low-wood-loading state (implying a net loss of the wood volume that was present in 1952).

Polygons that fell into category 1 were then tracked to the next sequential aerial photograph. Polygons that had been converted to category 2 continued to be tracked to determine how long the riparian forest persisted. When a polygon changed to category 3, it was no longer tracked in subsequent photographs.

A field verification visit was conducted on August 17, 18 and 19, 2004. A set of the wood jams identified in the 2002 aerial photographs were inspected to assess (1) wood jam stability, (2) presence of stable key member pieces, and (3) presence of underlying relic wood jams.

Results

Fluvial Landforms

Based on interpretations of aerial photographs, the lidar DEM, and field inspections, several distinctive fluvial landforms integral to the analysis and interpretations were identified based on the following definitions (Figures 8 and 9):

- **Unvegetated channels** are areas recently occupied by the river where channel bed disturbance has either removed vegetation or prevented it from becoming established. The wetted channel in aerial photographs corresponds to low-flow periods and thus lies within the unvegetated channel. The unvegetated channel is assumed to provide a more consistent approximation of the bankfull channel through time than the wetted channel, which corresponds to different discharges in each aerial photograph.

- **"Active" channels** are areas of primary flow conveyance within unvegetated channel as interpreted by the Bureau of Reclamation (BOR 2005). Active channel polygons are used in report figures to illustrate historic channel locations.

- **Historical channel migration zone (HCMZ)** is the area occupied by the active river channel in the recent past. This does not include areas where the river may potentially migrate in the future (e.g., the larger channel migration zone [CMZ]). Delineation of the HCMZ in the earliest aerial photographs (1939) was accomplished with the use of forest patterns that reflected past positions of the river and historical channel mapping (e.g., 1906 Government Land Office map (BOR 2005). For recent aerial photographs (2002), the HCMZ is simply the area occupied by the active river channel through the historical photographic record (BOR 2005).

- **Active valley bottom/channel migration zone (CMZ)** is defined as the broader valley area where the river has flowed in the geologic past and may potentially flow in the future. It includes perennial and ephemeral side channels directly or indirectly connected to the active river both inside ("young" side channel areas) and outside the HCMZ ("old" side channel areas). Both "young" and "old" side channels regularly convey water and sediment from and to the main channel and are integral parts of the river (Figures 8 and 9):

    - **Young side channel** areas were classified as areas where side channels are typically associated with recent disturbance within the HCMZ.

- **Immature alder side channels** are recently occupied by the active river channel, bordered by patches of immature red alder less than 10 years old and having a high ratio of channel width to depth (Figure 9). These are very prone to flood inundation and being reoccupied by the active channel.
- **Mature alder side channels** that are bordered by patches of red alder more than 40 years old and are partially covered by forest canopy (Figure 9). These have a lower ratio of width to depth than immature alder side channels, and are also prone to main channel disturbance.

□ **Old side channels** are classified as areas with side channels set within mature mixed conifer/deciduous forests more than 100 years old (Figure 9). Since almost all of the old-growth forests within the study reach have been cleared, these areas currently are set within forest plantations or agricultural lands that may or may not retain mature trees along the side channels. Old side channels tend to have a significantly lower ratio of width to depth than "young" side channels. Old side channels also tend to be relatively stable and persist for hundreds of years before being significantly disturbed or reoccupied by the main river channel.

Channel Complexity

Within the 18-kilometer study reach, the Quinault River is characterized by a wide braided channel subject to frequent change. The main stem channel migrates at an annual rate of approximately 13 meters and has gradually been expanding the width of its historical migration zone (BOR 2005). The width of the active channel has slightly increased (as defined by in the geomorphic assessment [BOR 2005]) from 217 meters in 1939 to 233 meters in 2002 (Table 1). Channel complexity, defined as the frequency of forested island channel "splits" in the unvegetated channel, increased from 44 to 62 during the period between 1952 and 2002 (Table 2). The number of total channel splits per square kilometer of unvegetated channel increased during this period from 11 to 14 (Table 2). This a good trend with regards to increasing habitat diversity within the river. But much of the LWD associated with these splits is unlikely to persist more than a few decades and thus not re-create more stable side channels.

At the apex of 84 percent of the forested island channel splits identified in the 2002 aerial photographs, accumulations of LWD were identified either as racked wood or wood jams (Table 3 and Figure 10). Three of five forested island channel splits observed in the field in 2004 (out of a total of 62 identified in the 2002 aerial photographs) had underlying relic wood jams buried in the floodplain that were subsequently exposed (Figures 11, 12, 13, and 14). The presence of buried wood jams beneath alluvial surfaces with old-growth trees or stumps indicates that some natural jams are capable of lasting centuries. A patch of old-growth red cedar (*Thuja*

plicata) stumps was found situated on the floodplain above a buried wood jam exposed in an eroding bank at RK 2.5 (Figures 13 and 14). Carbon dating of wood fragments taken from the alluvium in which the wood jam is deposited had a calibrated radiocarbon date of 930–1060 years before the present (BP) (BOR 2005).

Table 1. Area and width of Quinault active valley/channel migration zone, historical channel migration zone, and active channel in 1952 and 2002.

Attribute	1952	2002
Area of Quinault active valley/CMZ study reach (square kilometers)	23.9	23.9
Area of HCMZ[a] (square kilometers)	8.0	10.3
Area of "active" channel [a] (square kilometers)	3.9	4.2
Active channel area/alluvial valley area (%)	16	18
Active channel area/HCMZ area (%)	49	41
HCMZ area/CMZ area (%)	33	43
Increase in HCMZ area (square kilometers)	NA	2.3
Approximate CMZ width (meters)	2,000	2,000
Average "active" channel width (meters)	217	233
Active channel width/CMZ width (%)	11	12

[a] As defined in the geomorphic assessment (BOR 2005).
CMZ = channel migration zone.
HCMZ = historical channel migration zone.
NA = not applicable.

Table 2. Changes in channel split frequency, 1952–2002.

River Kilometer	Number of Channel Splits (1952)	Number of Channel Splits (2002)	Change in Channel Split Frequency	Area of Unvegetated Channel in 1952 (sq. kilometers)	Area of Unvegetated Channel in 2002 (sq. kilometers)	Number of Channel Splits per Square Kilometer (1952)	Number of Channel Splits per Square Kilometer (2002)
0 - 1	1	6	500%	0.25	0.28	4.0	21.4
1 - 2	2	3	50%	0.28	0.25	7.1	12.0
2 - 3	2	1	-50%	0.25	0.27	8.0	3.7
3 - 4	2	3	50%	0.31	0.32	6.5	9.4
4 - 5	3	7	133%	0.21	0.31	14.3	22.6
5 - 6	2	6	200%	0.29	0.32	6.9	18.8
6 - 7	3	2	-33%	0.21	0.21	14.3	9.5
7 - 8	1	5	400%	0.17	0.25	5.9	20.0
8 - 9	2	3	50%	0.23	0.17	8.7	17.6
9 - 10	5	5	0%	0.22	0.26	22.7	19.2
10 - 11	4	5	25%	0.29	0.28	13.8	17.9
11 - 12	4	2	-50%	0.22	0.26	18.2	7.7
12 - 13	3	2	-33%	0.21	0.25	14.3	8.0
13 - 14	2	3	50%	0.25	0.26	8.0	11.5
14 - 15	2	4	100%	0.20	0.25	10.0	16.0
15 - 16	2	4	100%	0.17	0.27	11.8	14.8
16 - 17	1	0	-100%	0.10	0.10	10.0	0.0
17 - 18	3	1	-67%	0.09	0.10	33.3	10.0
0 - 18	44	62	41%	3.95	4.41	11.1	14.1

Table 3. Frequency of large woody debris at the apex of channel splits.

Condition Immediately Upstream of Channel Split	Number of Channel Splits Associated with Condition	Percentage of Total Channel Splits Associated with Condition
Wood jam	36	58%
Racked wood	16	26%
No wood	5	8%
Obscured in aerial photo	5	8%

Source: 2002 aerial photograph provided by Bureau of Reclamation.

Alluvial valley side channels are evident on the 2002 lidar hillshade representation of the DEM in nearly all areas of the alluvial valley bottom outside of the historical channel migration zone (Figures 15 and 16). These channels are not visible on aerial photographs due to their size, typically 10 meters in width, and overlying forest canopy cover.

Side Channels and Forests

Approximately 3,185 linear meters of side channels with a low ratio of width to depth were measured on the 2002 lidar DEM along the reach from RK 12.5 to RK 13.6 (Figure 17). Between 1906 and 2002, lateral migration of the channel eroded 0.47 square kilometers of floodplain and terrace (Figure 17). Using the channel length in 2002 as a proxy for historical length of the floodplain and terrace side channels, more than 2,000 meters of old side channel would have been lost to channel migration during this time period.

Old channels have several important distinctions when compared with the active main channel and young channels (Figure 9). Old side channels have stable banks with canopy of mature conifers and deciduous trees covering most of the channel. The channels tend to have lower ratios of width to depth and more complexity (Figure 9). Ground photographs illustrating old side channels in the area delineated in Figure 17 (RK 12.5 to RK 13.6) are presented in Figures 18, 19, and 20.

When the river encounters a patch of mature riparian forest, it can create a great deal of complex habitat within a relatively small area. During the 2004 field inspections, the river was directly hitting one of the only remaining patches of riparian forest that was more than 100 years old, including Sitka spruce over 2.0 meters in diameter. Several wood jams formed at the upstream end of the old forest patch. In 2002, the river still flowed along the upstream margin and then around the forest patch to the north (Figure 21). In comparison, the river upstream of the old forest patch is typical of much of the Upper Quinault River study reach: a wide, shallow channel of little complexity and little forest canopy cover (Figure 22). In August 2004, the low-flow channel of the river flowed directly into the forest patch through a channel-spanning wood jam (Figure 23). The river side channels within the old forest patch were dramatically different from the main river channel upstream, to the north, and downstream (Figure 24). The exposure of

relic old-growth LWD buried in the bed of the side channel indicates that this mature forest was established near a stable wood jam (Figure 25).

To evaluate the relationship between channel splits and LWD loading, the relationship between the observed number of splits per kilometer in 2002 and the estimated number of LWD pieces (Figure 26) and LWD jams was analyzed (Figure 27). Neither regression demonstrated a significant relationship, implying that most of the LWD currently in the system is unstable material deposited on bar tops as opposed to stable material deposited in the channel and capable of bifurcating (splitting) flow. These results indicate that currently LWD is not a significant influence on channel morphology as it was historically.

Wood Loading

High- and low-wood-loading areas in 2002 averaged 4,567 and 210 pieces of LWD, respectively. Between 1952 and 2002, wood loading per channel area increased in 14 of 18 river kilometer segments (Table 4). Overall wood loading increase 33 percent from 1952 to 2002, probably reflecting changes in river management that has discouraged channel clearing and better protection of riparian forests.

Wood Jam Frequency

Over the entire 18-kilometer study reach, a total of 92 wood jams were identified on the 2002 aerial photographs, 90 in high-wood-loading zones and 2 in low-wood-loading zones. Thirty-six of these wood jams were associated with channel splits. Normalized by wood-loading-zone unit area, there were approximately 110 wood jams per square kilometer (1.10 per hectare) in high-wood-loading zones.

Fate Analysis of Woody Debris Accumulations

Over the period from 1952 to 2002, the characteristics of the high-wood-loading zones changed to either unvegetated channel with no wood (35 percent of total area) or floodplain forest (65 percent total area) (Table 5). None of the areas of high wood loading present in 1952 persisted more than 30 years. The majority were lost within 10 years (Table 5). After 50 years, 78 percent of the high-wood-loading areas were reoccupied by the river channel (low-wood-loading areas within unvegetated channel). The remaining 22 percent persisted as floodplain forest that is unlikely to reach maturity. This analysis clearly indicates that areas of high wood loading in 1952 have not had a long-term influence on channel or floodplain forest structure. Under historical and current conditions almost all of the wood entering the study reach channel is unstable.

Table 4. Changes in estimated wood loading within the unvegetated channel from 1952 to 2002.

River Kilometer	Estimated Number of LWD Pieces in 1952	Wood Loading 1952 (Number of LWD Pieces per Square Kilometer)	Estimated Number of LWD Pieces in 2002	Wood Loading 2002 (Number of LWD Pieces per Square Kilometer)	Change in Unvegetated Area-Normalized Wood Loading (1952–2002)
0 - 1	345	1380	231	825	-40%
1 - 2	208	743	265	1060	43%
2 - 3	241	964	252	933	-3%
3 - 4	248	800	295	922	15%
4 - 5	61	290	280	903	211%
5 - 6	233	803	319	997	24%
6 - 7	179	852	316	1505	77%
7 - 8	66	388	225	900	132%
8 - 9	186	809	126	741	-8%
9 - 10	134	609	358	1377	126%
10 - 11	257	886	345	1232	39%
11 - 12	178	809	399	1535	90%
12 - 13	124	590	153	612	4%
13 - 14	177	708	179	688	-3%
14 - 15	107	535	148	592	11%
15 - 16	68	400	282	1044	161%
16 - 17	11	110	15	150	36%
17 - 18	28	311	59	590	90%
0 – 18	2,850	722	4247	963	33%

Note: Both the number of LWD pieces and wood jam frequency were correlated with split frequency (Figures 26 and 27).
LWD = large woody debris.

Table 5. Fate of 1952 high-wood-loading zones.

Year	Percentage of High-Wood-Loading Area in 1952 Still Remaining	Percentage of High-Wood-Loading Area in Previous Air Photo Converted to Forest that also Existed in 1952	Percentage of High-Wood-Loading Area in 1952 Connected to Forest	Percentage of High-Wood-Loading Area in 1952 Converted to Low-Wood-Loading
1952	NA	–	0.0%	0.0%
1958	58.8%	4.4%	4.4%	36.8%
1962	35.3%	13.2%	17.6%	47.1%
1973	5.9%	16.2%	32.4%	61.8%
1982	1.5%	1.5%	27.9%	70.6%
1994	0.0%	0.0%	23.5%	76.5%
2002	0.0%	0.0%	22.1%	77.9%

Discussion

Valley Forest, Stable Wood Jams, and Channel Complexity

The most significant historical change to the Upper Quinault River has been the removal of old-growth riparian forest that once covered much of the valley bottom. Historical channel clearing and deforestation have further led to a loss of large key member logs in the river channel. The removal of the forest source of large trees coupled with channel clearing has eliminated the principal elements capable of forming stable wood jams and channel complexity in the Upper Quinault River.

Stable wood jams are sites of old-growth forest patches, which constitute the source of future key members capable of forming stable wood jams (Fetherston et al. 1995; Abbe and Montgomery 1996; Fetherston 2005). They also cause bifurcation of river flow, resulting in the typical branching channel system found in the old-growth alluvial valleys of the Olympic Mountains (Abbe and Montgomery 1996). In the Upper Quinault River, old-growth forest patches and wood jams historically created and sustained a complex system of large and small channels throughout the alluvial valley bottom.

The disturbance of the Upper Quinault River began in the late 1800s and significant changes had occurred by the time aerial photographs of the valley were first taken in 1939. Descriptions of the Upper Quinault River valley prior to European settlement have to be inferred from early historical accounts and information related to relatively pristine river valleys in Olympic National Park. Unfortunately, west side Olympic Mountain rivers with drainage areas similar to that of the Upper Quinault have all undergone significant forest clearing. However, portions of the Quinault, Queets, and Hoh River valleys remain in relatively pristine condition and are examples of unconfined low-gradient gravel bedded rivers that can provide a reference model for determining the possible appearance of the Upper Quinault River study reach before its historical disturbance. Directly upstream of the study reach the Quinault River enters the Olympic National Park, and the valley exhibits a very different character, similar to the upper reaches of the nearby Queets River valley (Figure 28). As noted, the most significant impact on the Upper Quinault River study reach has been the loss of old-growth riparian forests, which once covered much of the valley bottom or channel migration zone (Figure 29). The resulting floodplain forest is characterized by young small-diameter red alder trees and an absence of large conifers (Figures 4 and 30). This has reduced the local supply of large trees capable of forming the stable wood jams necessary for the regeneration of old-growth conifer forest within the historical channel migration zone.

Field observations showed that the apex of forested island channel splits are often found in association with underlying relic wood jams, recently exposed through channel erosion. These observations support the findings from the Queets River (Abbe 2000), indicating that stable wood jams act as “hard points” in the channel, controlling channel splitting over decades to hundreds of years.

The results of the 2002 lidar topographic survey show an extensive network of side channels outside the historical channel migration zone, extending laterally hundreds of meters within the larger forested alluvial valley (Figures 15 and 16). The floodplain and terrace side channels were often found associated with relic and contemporary wood jams. These side channels may be stable over hundreds of years as indicated by the historical composition and structure of the mature forest (BOR 2005). Together, these results support the model of forest island, floodplain, and terrace formation developed from research in the adjacent Queets River valley (Fetherston et al. 1995; Abbe and Montgomery 1996; Abbe 2000; Fetherston 2005). Key to this model is the role of wood jams in generating and maintaining not only forest islands, and the associated channel splits, but also the larger floodplain side channel complex that is clearly illustrated by the lidar topographic survey. These findings indicate that relic buried wood jams function to create channel complexity over decades to hundreds of years (Abbe 2000). Although the frequency of stable wood jams was extrapolated at 110 wood jams per square kilometer in high-wood-loading zones, there are no historical reference data with which to compare this finding.

Influence of Channel Complexity on Hyporheic Functions

Increasing and sustaining side channel complexity will improve and sustain a productive floodplain hyporheic zone by increasing lateral hydraulic gradients across the valley bottom. This results from varying surface water elevations in side channels and local gradients due to wood-induced flow obstructions. Main stem and floodplain (side channels) areas with hyporheic flows are typically preferred by salmon and bull trout for spawning. For example, Geist and Dauble (1998) found that in the Hanford Reach of the Columbia River, fall chinook salmon redds are usually aggregated in definite cluster even when areas of suitable spawning habitat are widely distributed. They also found that the selection of salmon-spawning sites is associated with areas of upwelling and downwelling flows and that hydraulic processes greatly influence where salmon spawn (Geist and Dauble 1998). In addition, studies have noted that stream habitats selected by bull trout for spawning are often influenced by ground water (Graham et al. 1981; Weaver and White 1985)

The selection of areas of hyporheic flows for spawning may increase the salmonid egg-to-fry survival rate. For example, upwelling and downwelling areas tend to improve the survival of eggs and emergent fry by moderating the egg incubation environment and increasing the water exchange around the egg pocket, thereby replenishing oxygen and removing metabolites (Bjornn and Reiser 1991; Freeze and Cherry 1979). Depending upon the geographical location of a river system, hyporheic flows moderate the temperature inside redds through subsurface-surface water exchange by helping to reduce summer peak temperatures and/or increase winter low temperatures. This water temperature moderation helps to protect the eggs during periods of extreme high or low temperature thus ensuring fry emergence at optimal times (Berman and Quinn 1991).

Restoring floodplain forests and floodplain side channels will significantly increase the macroinvertebrate population, which is the salmon food base. The area of side channel habitat

lost due to historical forest removal is large. During the past century the lower 18-kilometer of the Upper Quinault has lost over 30-kilometers of "old" side channel (Figure 16) due to accelerated rates of mainstem channel migration and expansion of the historical channel migration zone. This represents a major loss of an important salmon habitat that has also disappeared in many other Pacific Northwest rivers due to diking, deforestation, and development.

Extrapolating over the 19-kilometer valley, this represents a vast amount of hyporheic-flow-supported side channel habitat. Also, red alder floodplain forests contribute large amounts of nitrogen that leaches into the ground water, again increasing side channel productivity. Complex floodplain forest can create geomorphic bed forms at the sediment-water interface that promote the development of localized hyporheic flows. In turn, this hydraulic process influences where salmon spawn in side channels (Geist and Dauble 1998; Bolton and Shellberg 2001). Downwelling hyporheic flows occur mainly at high-pressure zones in areas of aggraded sediments such as channel inflection points or at the upstream end of riffles. At these high-pressure zones, surface water downwells into the sediments and displaces interstitial water, mostly as a function of riverbed topography relative to water depth (Brunke and Gonser 1997). The interstitial water then flows through the aquifer and upwells at low-pressure zones such as the upstream end of pools (Brunke and Gonser 1997).

Current Wood Loading and Stability

Large-diameter trees with large root wads are key elements that determine in-channel wood stability (Abbe and Montgomery 1996; Abbe 2000). Within the river valleys of the Olympic Mountains, Sitka spruce, the primary key member tree species, may reach 1 meter in diameter within 120 years (Fetherston 2005). Findings from the Queets River indicate that, in general, trees larger than 1 meter in diameter function as key members, forming stable wood jams within low-gradient alluvial channels (Abbe 2000; Fetherston 2005). Therefore, conifer forests significantly less than 100 years old are not sources of wood jam key members. Because of the young age of the forests in the Upper Quinault River valley, it was expected that in-channel LWD would be very mobile during annual high flows.

The wood loading analysis showed a wide range in variability of LWD density throughout the study reach. High-wood-loading zones averaged 4,567 pieces of LWD per square kilometer and low-wood-loading zones averaged 210 pieces. The majority (65 percent) of the high-wood-loading area identified in 1952 was colonized by forest vegetation and incorporated into the floodplain forest by 2002. The remaining area (35 percent) became low-wood-loading areas. On average, high-wood-loading zones that were not incorporated into the floodplain forest persisted less than 12 years, illustrating the mobility of recent LWD accumulations.

Only 22 percent of the high-wood-loading areas mapped in 1952 existed as riparian forest in 2002, while the other 78 percent was reclaimed as low-wood-loading areas of the active unvegetated channel. The average age of this riparian forest was 35 years with a standard

deviation of 8 years. For LWD to have an influence on river morphology and channel hydraulics, large pieces of wood must enter and be deposited in the river and some pieces must be large enough to form stable wood jams. Presently, the Quinault River has large quantities of woody debris but very few pieces that are large enough to form stable wood jams. The stable jams that do exist in the Quinault River are often underlain by partially buried historical relic wood jams that were deposited when there were larger pieces of wood in the system, likely before human disturbance of the river network. The key pieces in the vast majority of the observed stable wood jams were not derived from the forests that currently border the Quinault River.

Since the 1950s, the unvegetated channel has widened, unearthed more relic floodplain wood jams, and consequently created more splits. As noted earlier, most hard points observed in the Quinault River have relic wood jams at their base. This increase in channel splits is likely to increase for the near term until most of the relic floodplain wood jams are exposed; then the number of splits could potentially decrease as the relic wood jams decay. Currently, split frequency is probably on the decline; field observations indicate that many relic wood jams are exposed and are being weakened. The number of LWD pieces probably increased between 1952 and 2002 due to high erosion rates of the riparian forest, the temporary increase in relic hard points upon which LWD can accumulate, and the lack of clearing of LWD from the channel.

The wood jams that currently form in the Quinault River are transient; the majority (61 percent) support little or no vegetation. Additionally, many of the largest and seemingly most stable wood jams identified in the 2002 aerial photographs no longer existed by the time field observations were conducted in 2004 . The likely reason for their disappearance is that most wood jams are bar top accumulations where large quantities of mobile woody debris are deposited along channel banks and unvegetated channel surfaces. These wood deposits have a limited impact on channel morphology or bed texture because the debris is likely to become mobile and continue downstream with each consecutive high-flow event. These deposits commonly consist of a chaotic assemblage of racked and loose woody debris with a large variation in the orientation of pieces. Under historical conditions, wood would have accumulated as racking material on key member pieces, forming stable wood jams. It is assumed that the correlation between the number of LWD pieces and split frequency and between the number of wood jams and split frequency would be stronger if more key-piece-sized wood (and consequently more wood jams) were in the channel.

Relic wood jams have been observed at the base of a number of the relatively limited floodplain surfaces that support riparian vegetation in excess of 60 years in age. These areas are associated with enduring side channels and valued salmonid habitat. Additionally, where erosion has recruited key-piece-sized trees from the limited areas of mature riparian stands, stable wood jams and complex side channels have been observed. The wood jams that form in these isolated areas, however, may not be as stable as they might have been in a system with many other flow-diverting wood jams.

Conclusions and Implications for Restoration

Historical forest and river clearing in the Upper Quinault River has adversely affected salmonid habitat. There has always been a relatively distinct main channel that migrated across the valley bottom, but not to the extent seen in the twentieth century. Prior to European settlement old-growth riparian forest extended across much of the valley bottom.

The river is capable of migrating anywhere within the 2,000-meter-wide glacial valley. The main channel currently runs along the southern margin of the valley from RK 15.4 to RK 18. All of the Upper Quinault River alluvial valley can potentially be occupied by either the main channel or one of its side channels. This area corresponds to the natural channel migration zone (CMZ). While most of the river's discharge and sediment are conveyed through the HCMZ, side channels outside the HCMZ also convey river flow and sediment. Floodplain forests and side channels within the HCMZ are repeatedly reset by a rapidly migrating main channel (at an average rate of approximately 13 meters per year [BOR 2005]). Therefore, these areas within the HCMZ are extremely unlikely to persist for more than 80 years. Whereas side channels within the CMZ but outside the HCMZ tend to persist until they are eroded by the river as the HCMZ expands.

The HCMZ of the Upper Quinault River study reach increased in width from approximately 500 meters in 1939 to more than 600 meters in 2002. Historically, mature riparian forests likely resulted in reduced channel migration rates. The removal of these forests may have contributed to the accelerated expansion of the HCMZ. Where the HCMZ is not artificially constrained, it is expanding and is likely to continue to do so unless actions are taken to reintroduce stable wood jams within and along the margins of the HCMZ. Past trends clearly indicate that the HCMZ will continue to expand, eliminating stable old side channel areas. These are very unlikely to be replaced within the HCMZ without intervention to restore the system.

Although side channels do currently form within the HCMZ and the total length of these channels appears to have increased since 1939, these young channels do not provide the complex habitat found in old channels. Young side channels tend to be relatively wide and deep and bordered by young deciduous trees that provide only limited canopy over the channel. In contrast, old side channels tend to be relatively narrow and deep and bordered by large mature trees whose canopies entirely cover the channel.

Prior to European settlement, the study reach consisted of a branching channel system of large and small and young and old channels set within a complex riparian forest that included old-growth conifers throughout the CMZ and HCMZ. By early in the twentieth century, the study reach had been transformed into a system dominated by a larger, more dynamic main channel and young unstable side channels set within vast gravel bars and immature deciduous forests. If no restoration actions are taken, the historical trends are likely to continue, and there will be a continued loss of old side channel habitat and insignificant regeneration of mature riparian forests within the HCMZ. Under current Washington State Forest Practice Rules, there should

be recovery of mature riparian forests in the greater CMZ, except where they are removed by further expansion of the HCMZ.

Quinault River Restoration Strategy

To expedite the recovery of salmonid habitat in the Upper Quinault River, the natural physical and biological processes that generate and maintain the riverine ecosystem must be restored. It is recommended that a long term restoration plan for the river be developed. The foundation of any restoration effort must be the recovery of a self-sustaining valley bottom forest. Long-term restoration of aquatic habitat in the Quinault River is dependent on reestablishing a mature riparian forest within the active valley or channel migration zone. For the foreseeable future, the main stem Quinault River will continue to be a very dynamic channel with floodplain forests and side channels that are subject to frequent turnover as the main stem channel migrates over the valley bottom. These conditions will further inhibit the development of mature riparian forests and the more stable side channels found in these forests. Despite a large flux of woody debris throughout the study reach, stable wood jams are not forming and therefore not creating hard points of long-term forest refugia within the channel migration zone.

A phased approach to restoring salmon habitat in the Upper Quinault River should be developed to allow flexibility for the annual restoration work to be implemented in the most cost-effective manner. The fundamental structure of the Quinault River must be restored throughout the study reach and ultimately the mature riparian forests must be reestablished throughout the channel migration zone. Once the conifer forests throughout the valley reach maturity, the natural cycle of large wood recruitment and conifer forest regeneration will be self-sustaining. At that point, the channel- and floodplain-forming processes that are generated by large woody debris will occur naturally without any additional restoration interventions. To reach this goal, a comprehensive restoration strategy needs to address cultural, regulatory, scientific, design, and implementation objectives. A comprehensive large-scale restoration of the riverine ecosystem associated with the Upper Quinault River will take decades to accomplish. An outline of a recommended phased approach over a 50 year period is presented in Appendix A.

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FIGURES

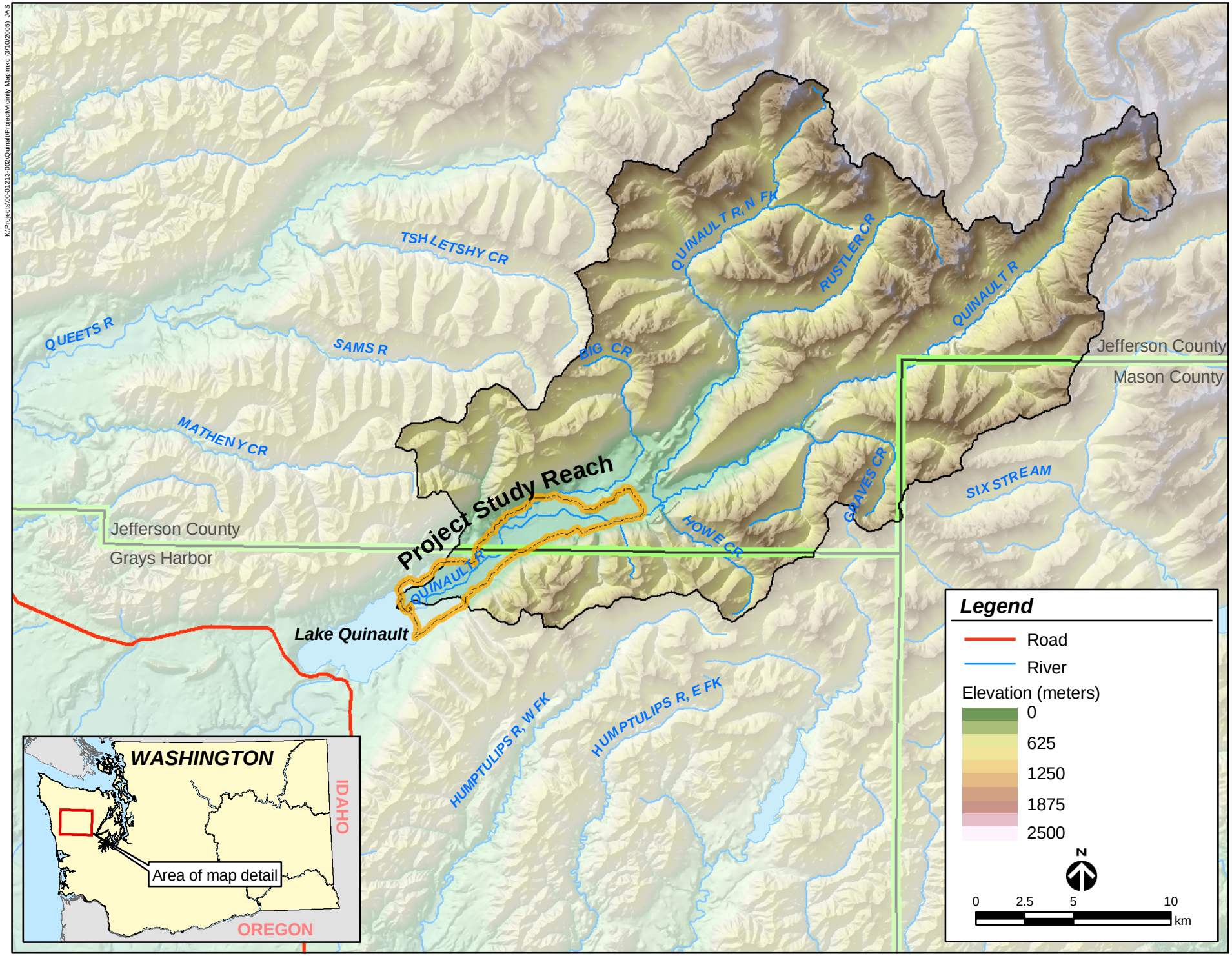


Figure 1. Project study reach in the Upper Quinault River valley.

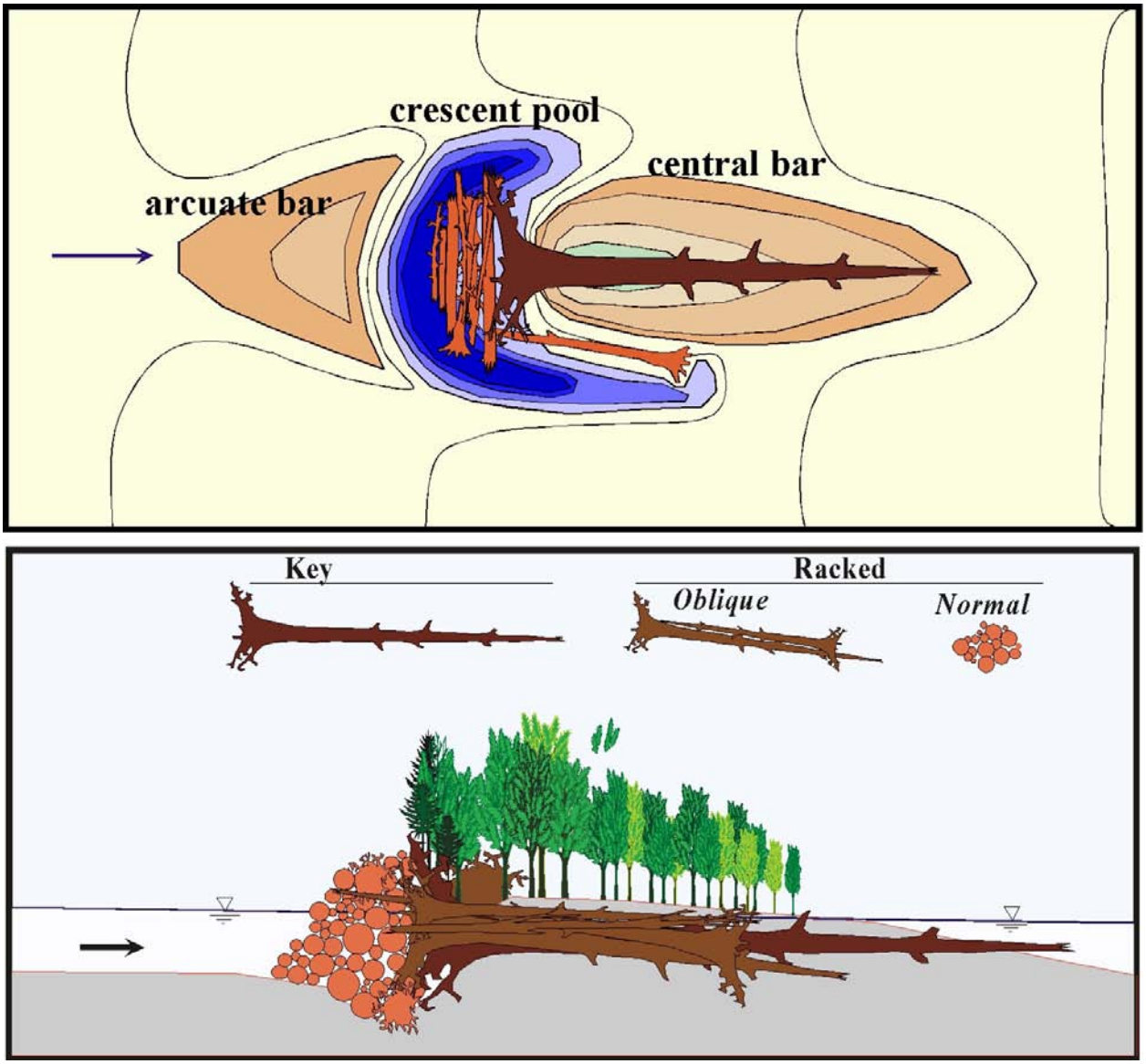
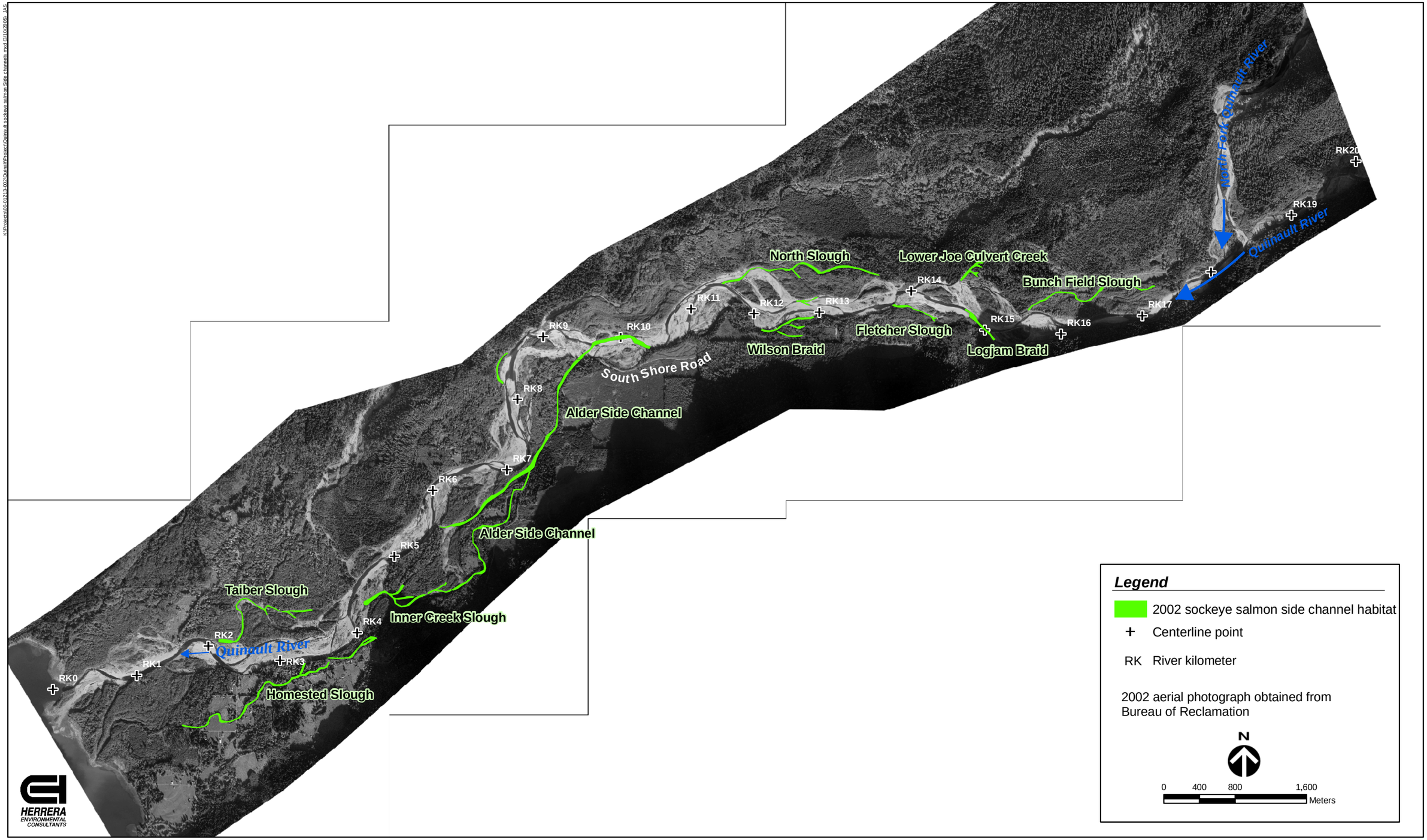


Figure 2. Bar apex wood jam and forest island development.



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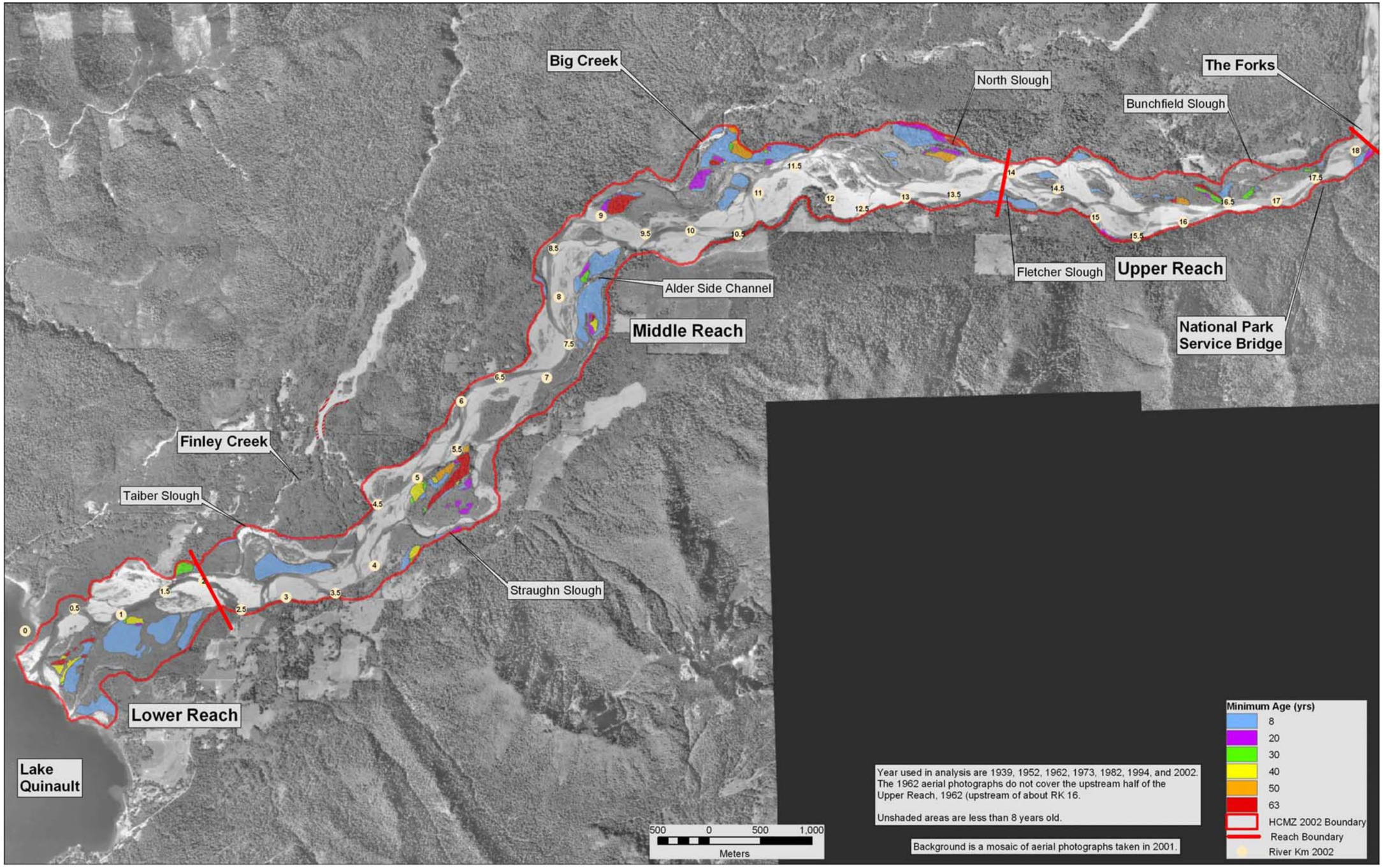

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Figure 5. Aerial photographs of the Upper Quinault River from 1939 and 1952, with low photographic quality on the 1939 aerial photograph making identification of large woody debris impossible.

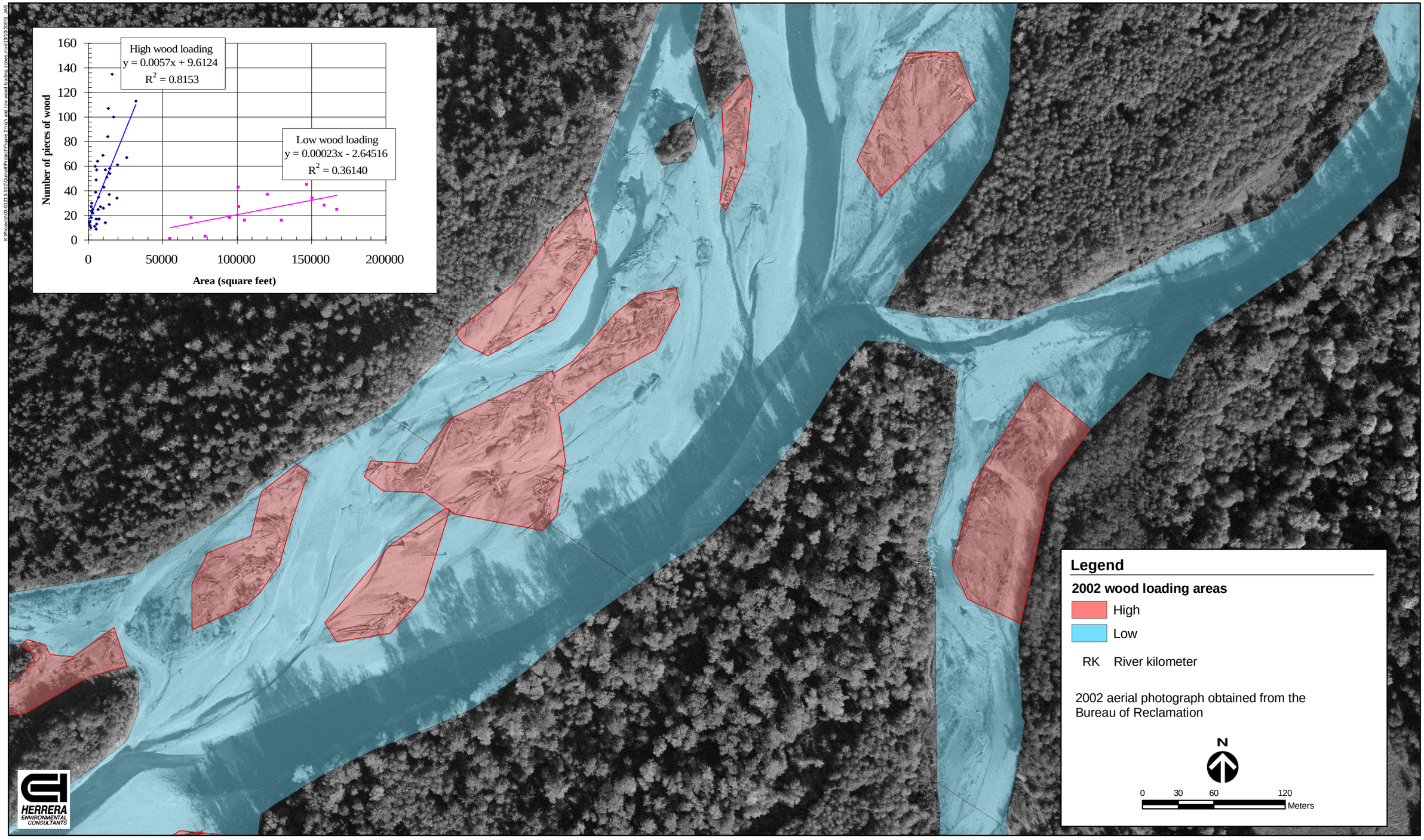
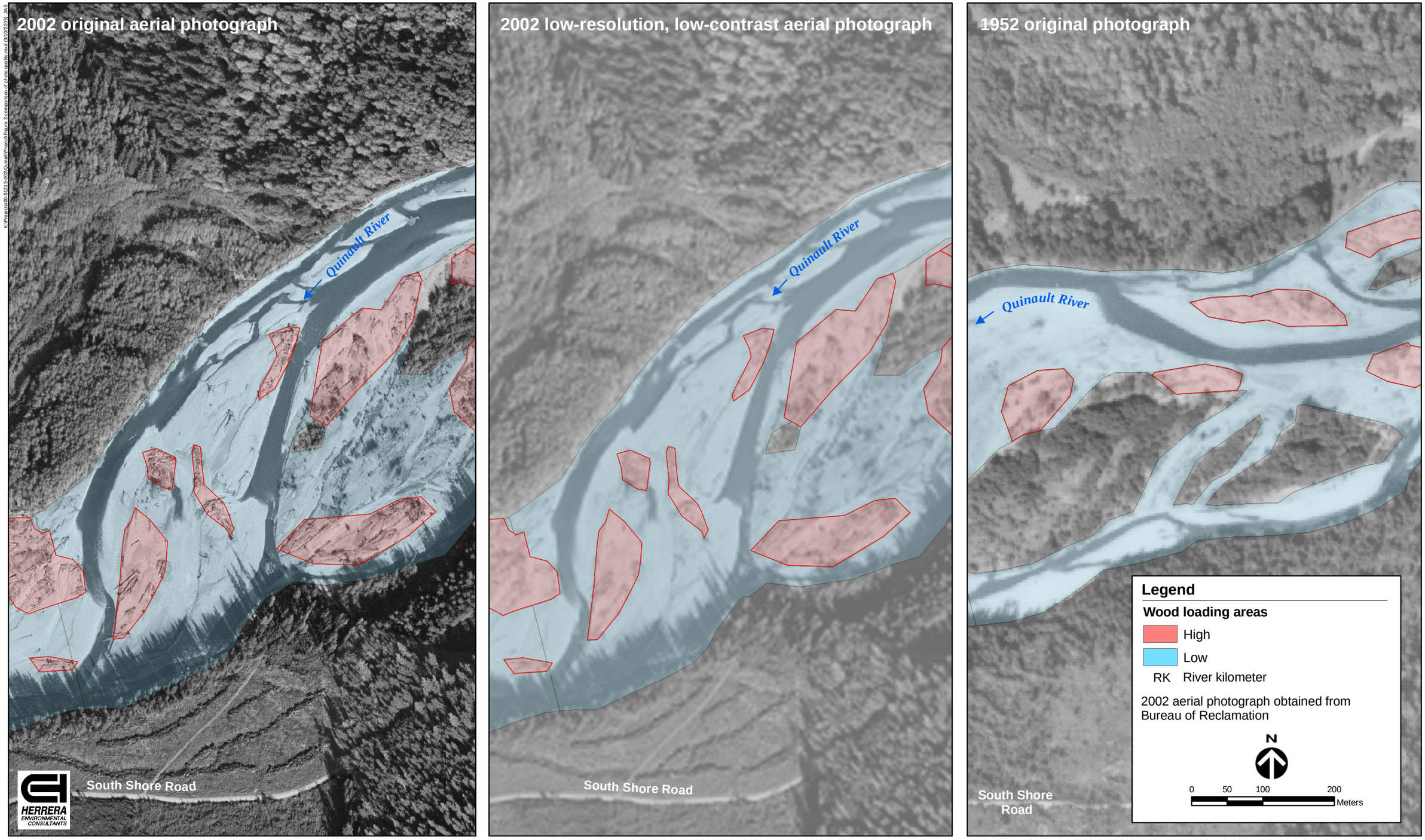


Figure 6. Illustation of high- and low-wood-loading zones within the unvegetated channel of the Upper Quinault River from RK 5 through RK 5.9 and wood quantity per unit area in these zones.



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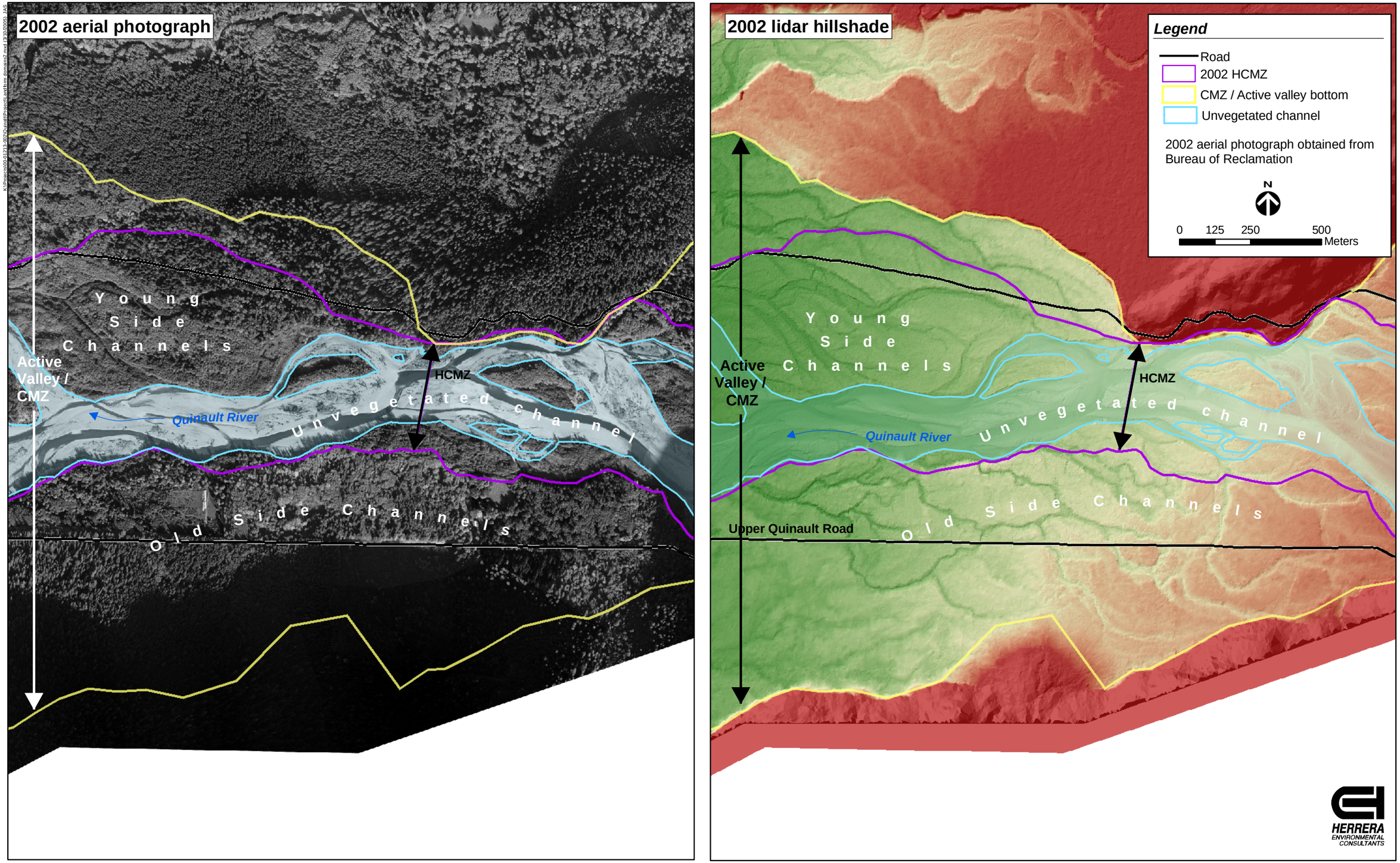
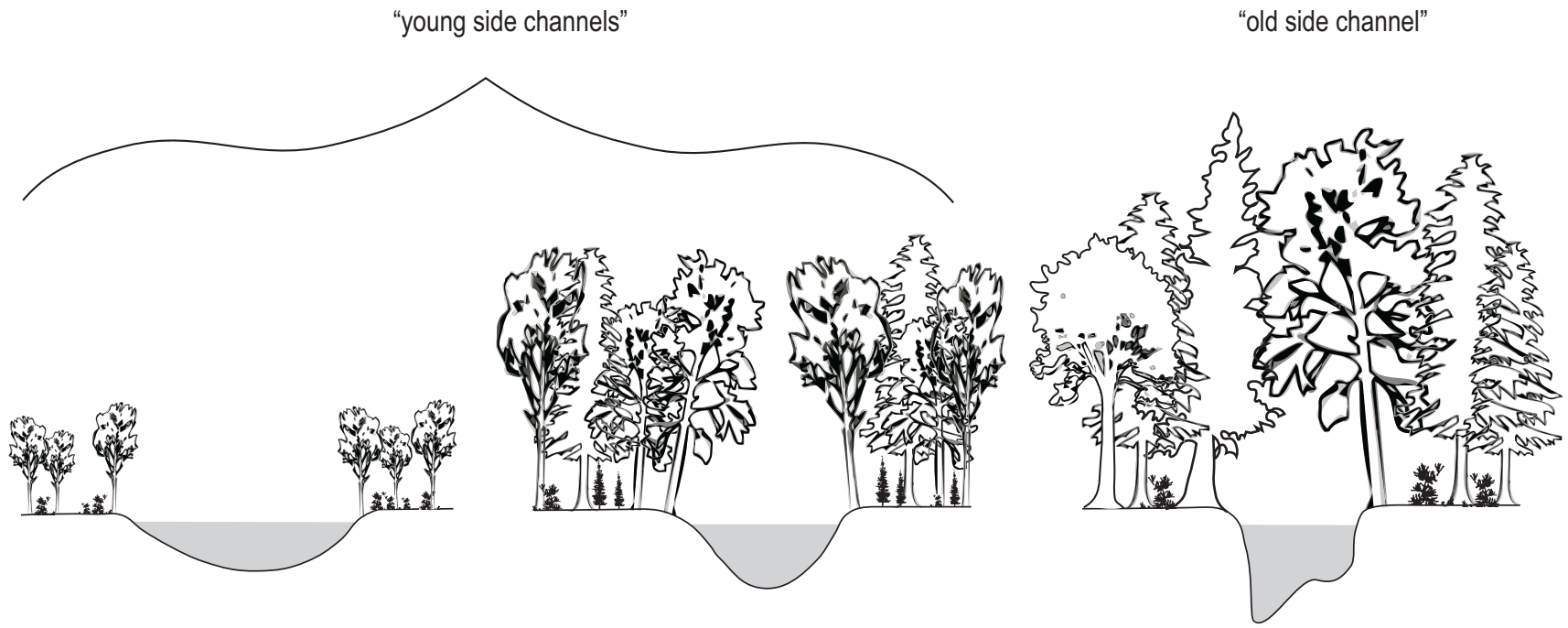


Figure 8. Fluvial landform domains in the Upper Quinault River valley.

03-09-05/rtb/HEC-R/00-01213-002-006-001/



Immature Alder Side Channel (<10 years)

$$\left(\frac{W}{d}\right) >$$

- Very prone to channel disturbance
- Little or no canopy cover

Mature Alder Side Channel (>40 years)

$$\left(\frac{W}{d}\right) >>$$

- Less prone to channel disturbance
- Partial canopy cover

Old CMZ Side Channel (>100 years)

$$\left(\frac{W}{d}\right)$$

- Relatively stable channels, potentially hundreds of years old
- Full canopy cover

Legend

$$\frac{W}{d} = \frac{\text{Channel width}}{\text{Channel depth}}$$

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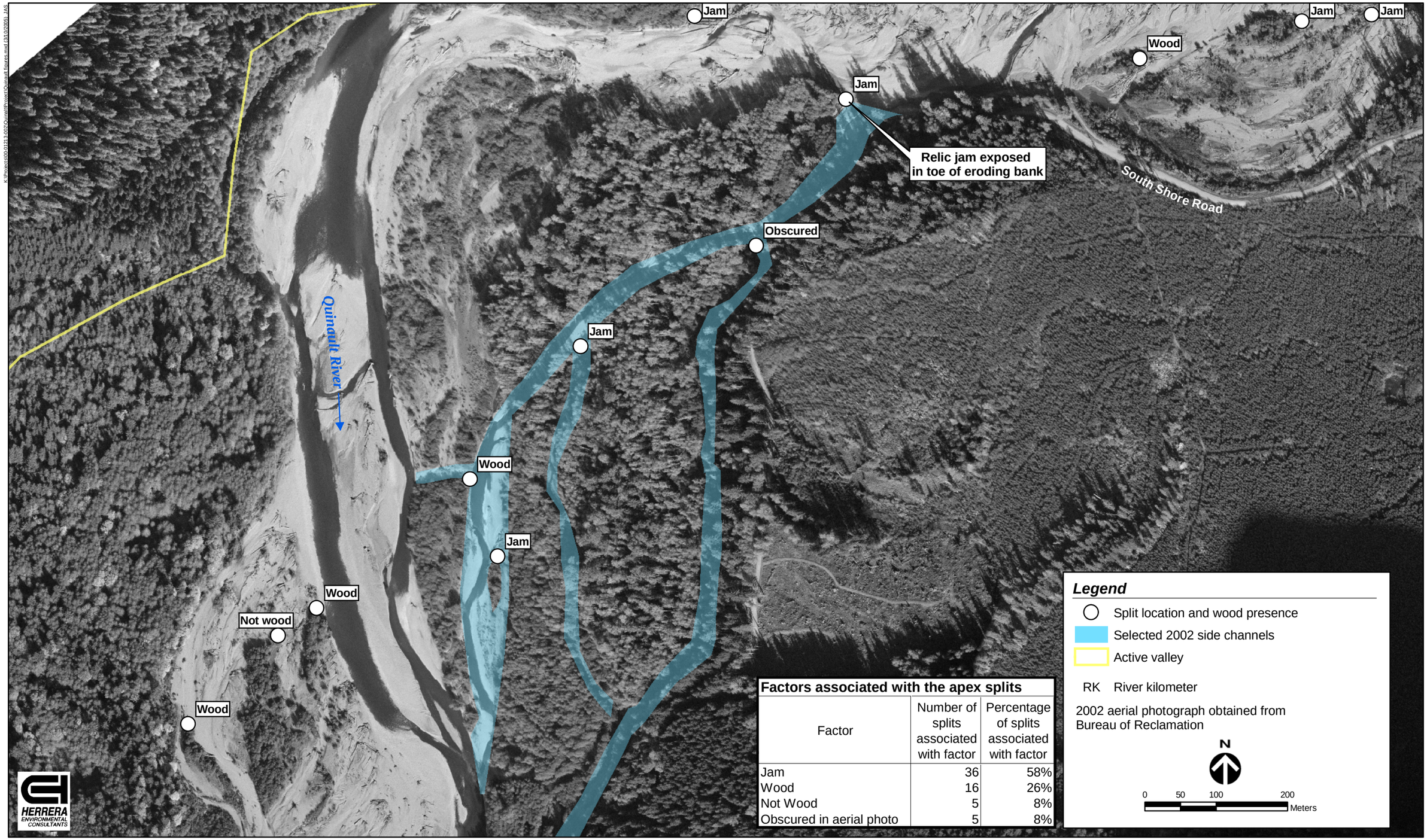
Figure 9. Forest side channel development in the Upper Quinault River valley.



Factors associated with the apex splits

Factor	Number of splits associated with factor	Percentage of splits associated with factor
Jam	36	58%
Wood	16	26%
Not Wood	5	8%
Obscured in aerial photo	5	8%

Figure 10. Illustration of channel splits, forested islands, and large woody debris associated with channel splits shown in 2002 aerial photographs of the Upper Quinault River from RK 4.6 to RK 6.3.

Figure 11. View of the Upper Quinault River at RK 5.4, looking downstream at the left side of the forest island and showing an exposed historical wood jam forming a "hard point" at the apex of a forest island channel split, with the ends of logs in the old wood jam visible (August 2004).

Figure 12. View of the Upper Quinault River at RK 3.6, showing an exposed relic wood jam in a pool along an eroding bank of mature alder forest (approximately 60 years old) near the apex to Taiber Slough (August 2004).

Figure 13. View of the Upper Quinault River at RK 2.5, showing an exposed buried wood jam "hard point" along the eroding left bank, estimated to be several hundred years old on the basis of old red cedar stumps on the ground above that are approximately 2 meters in diameter (August 2004).

Figure 14. View of the Upper Quinault River at RK 2.5, showing the same buried wood jam (Figure 13), which is approximately 1,000 years old based on radiocarbon dating of a wood fragment taken from riverbank (sample 81904-1-1CO [BOR 2005], with a calibrated radiocarbon date of 930 to 1,060 years before present) (August 2004).

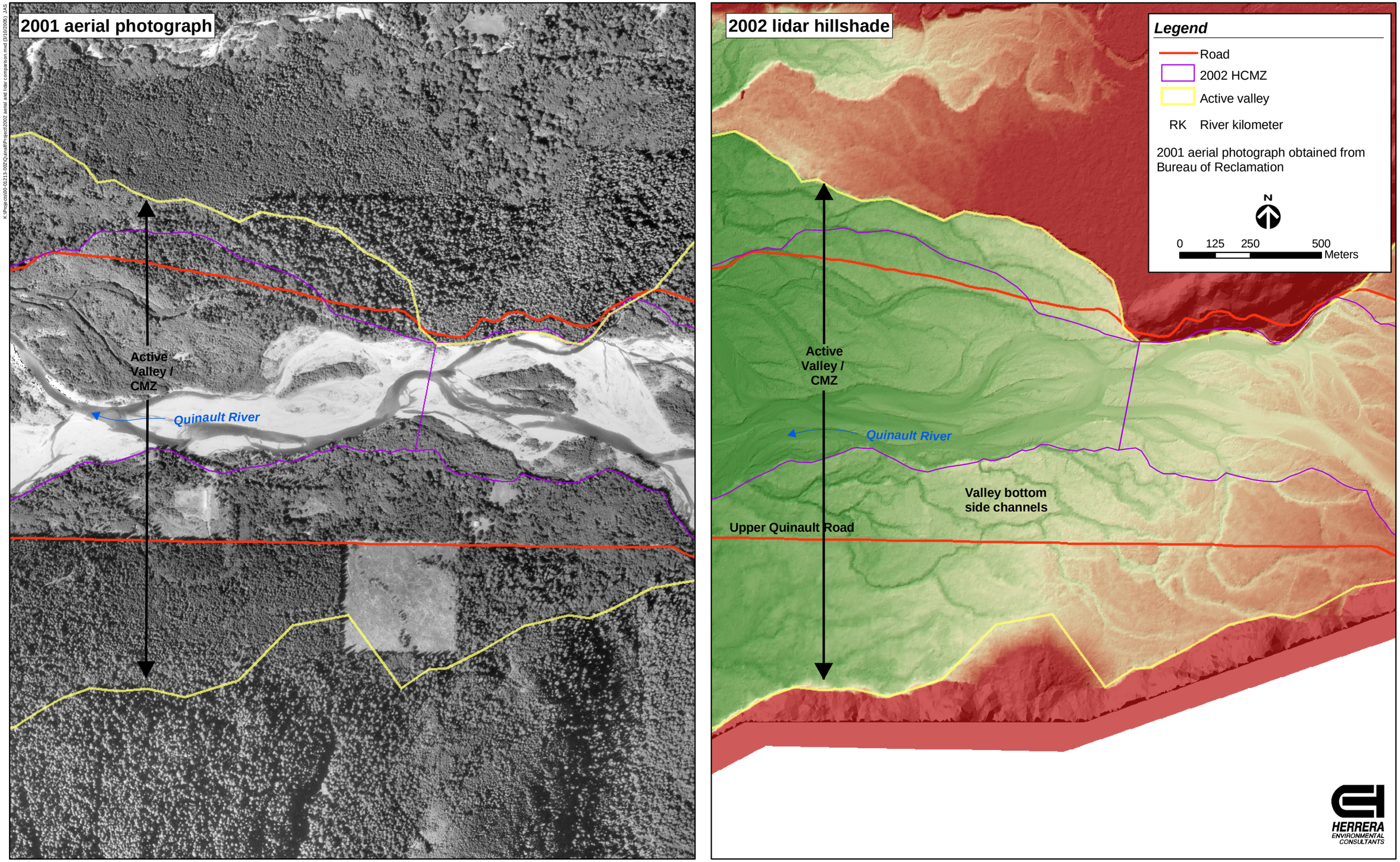


Figure 15. Illustration of narrow, deep channels identified outside the 2002 historical channel migration zone on the 2002 lidar hillshade image that are not apparent on the 2001 aerial photographs, RK 12.5 to RK 15 of the Upper Quinault River.

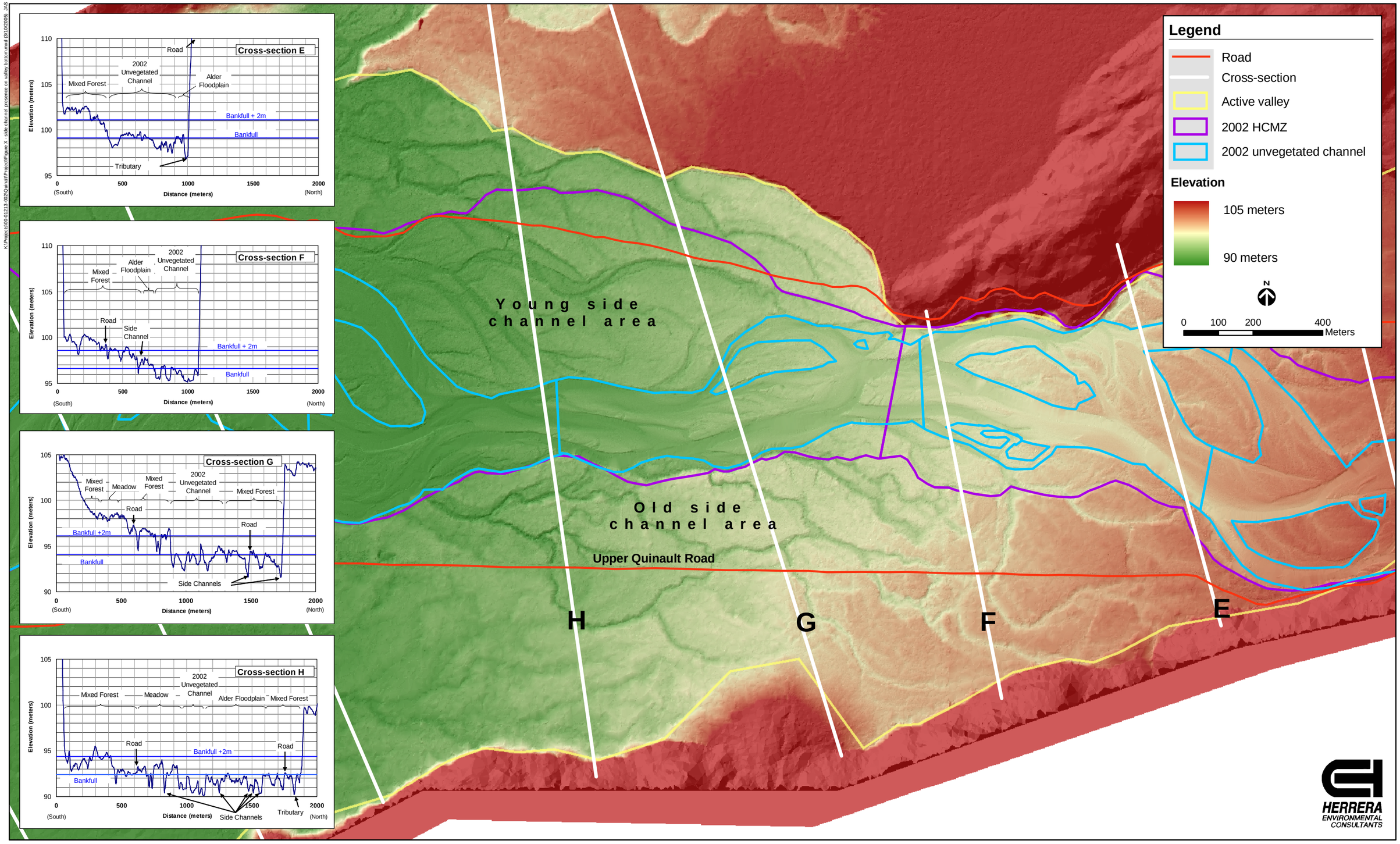


Figure 16. Illustration of side channels on the 2002 lidar hillshade image and lidar cross-sections, showing side channels throughout the valley bottom outside of the historical channel migration zone of the Upper Quinalt River.

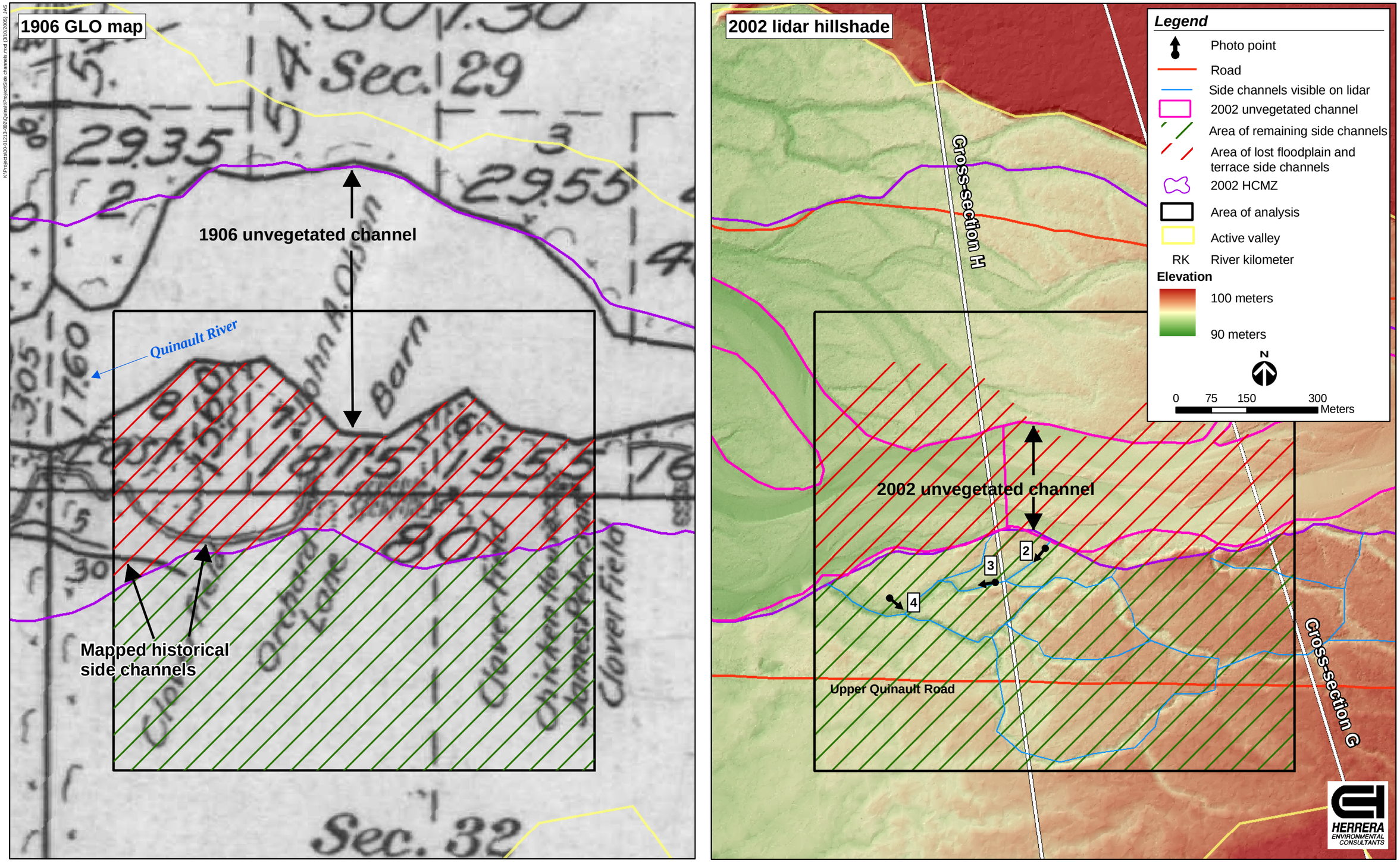


Figure 17. Comparison of 1906 Government Land Office map and 2002 lidar hillshade image showing the unvegetated channel and terrace side channels, RK 12.5 to RK 13.6 of the Upper Quinault River.

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Figure 19. Photo point 3 in Figure 17, showing "old" side channel (frequently inundated throughout the fall, winter, and spring) in mature conifer-alder riparian forest outside the historical channel migration zone (August 2004).

Figure 20. Photo point 4 in Figure 17, showing the confluence of two "old" side channels and a perennial pool in mature conifer-alder forest outside the historical channel migration zone (August 2004).

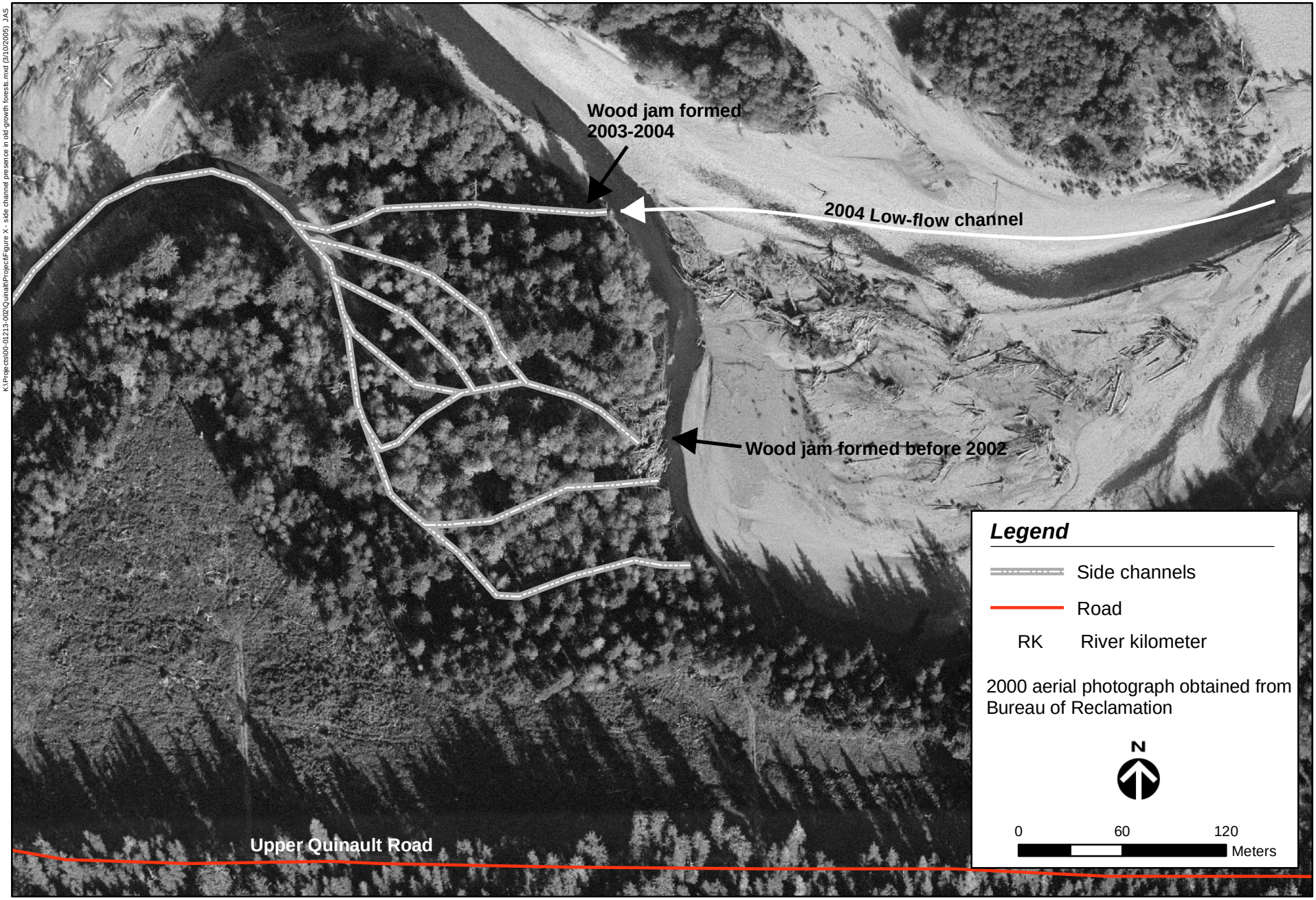

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Figure 23. View of an "old" side channel bordered by one of the few remaining patches of mature forest, showing a wood jam spanning the side channel entrance (August 2004).

Figure 24. "Old" side channel in mature riparian forest actively engaged by the river during low flow at RK 12.0 of the Upper Quinault River (August 2004). Note abundant woody debris and complex habitat (e.g., high pool frequency, abundant in-water and overhanging cover, and diverse hydraulic conditions and substrates).

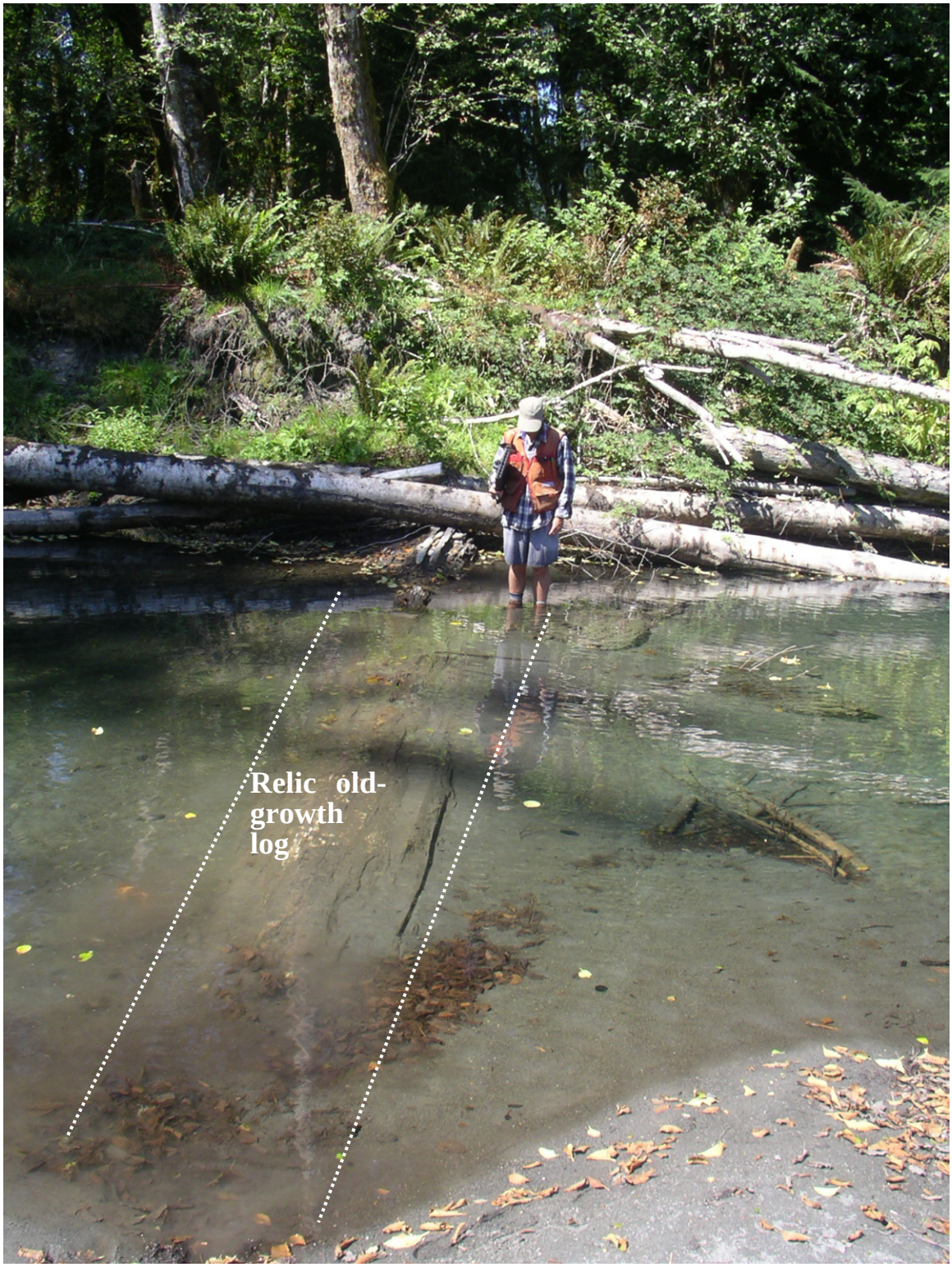


Figure 25. Exposed relic old-growth log in bed of "old" side channel at RK 11.8 of the Upper Quinault River (August 2004).

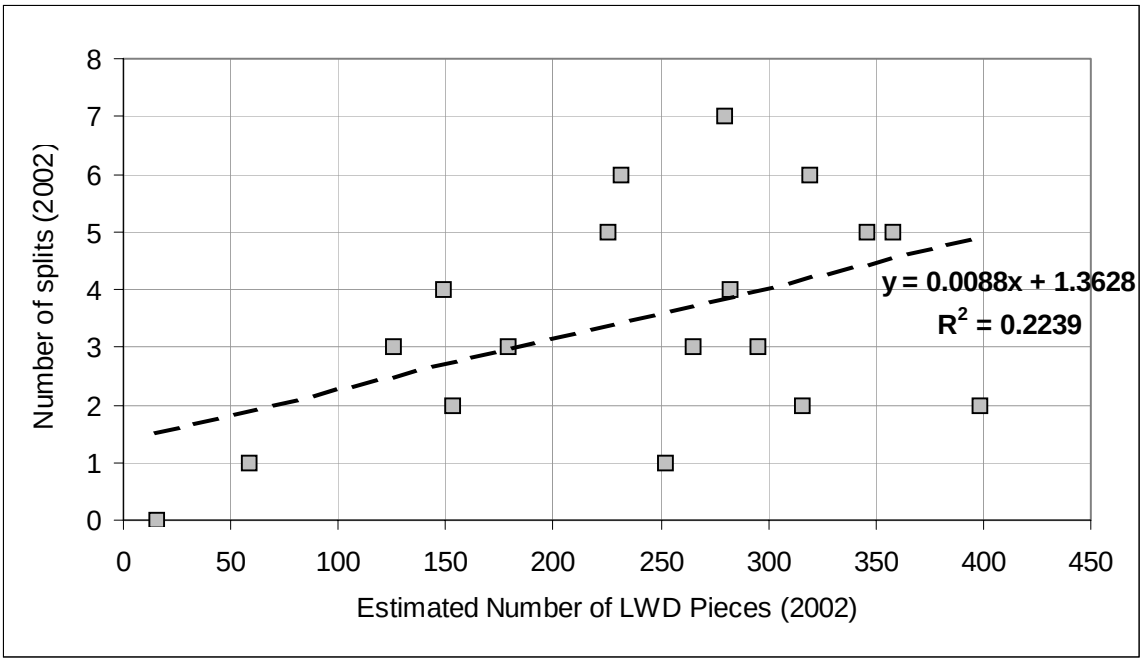


Figure 26. Relationship between the number of channel splits (unvegetated channel bifurcating at forest patch) and the number of pieces of large woody debris.

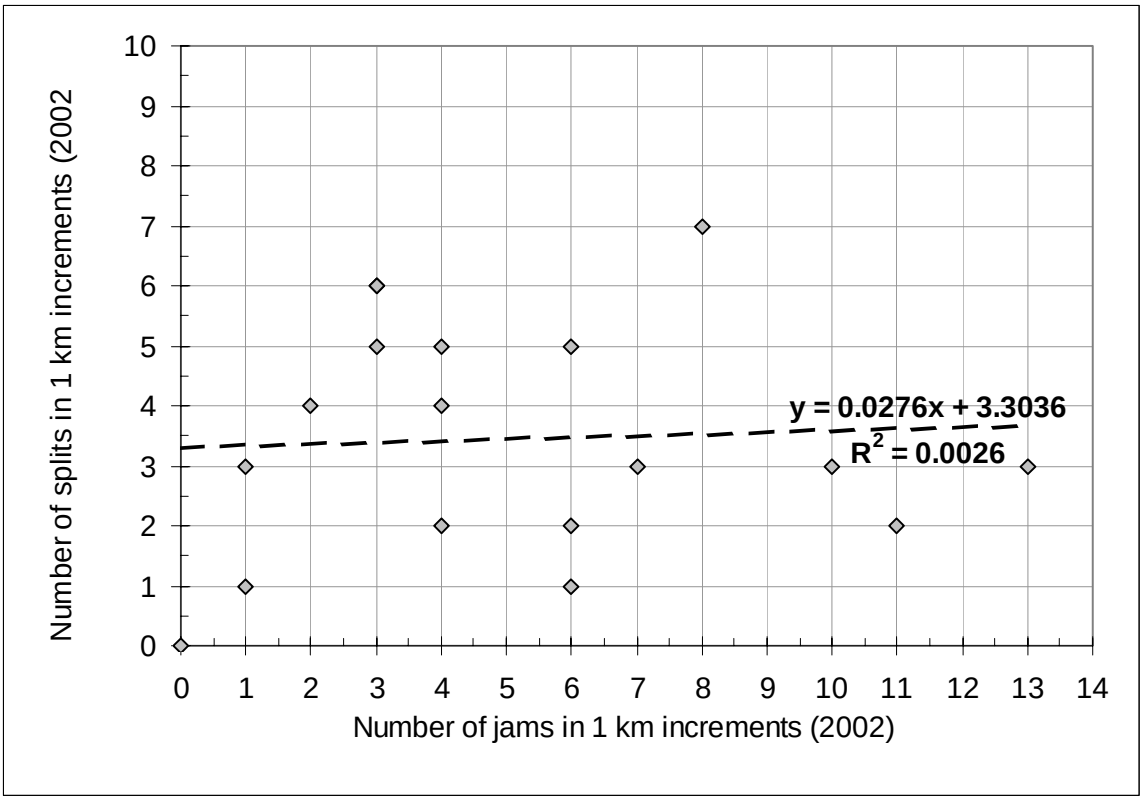
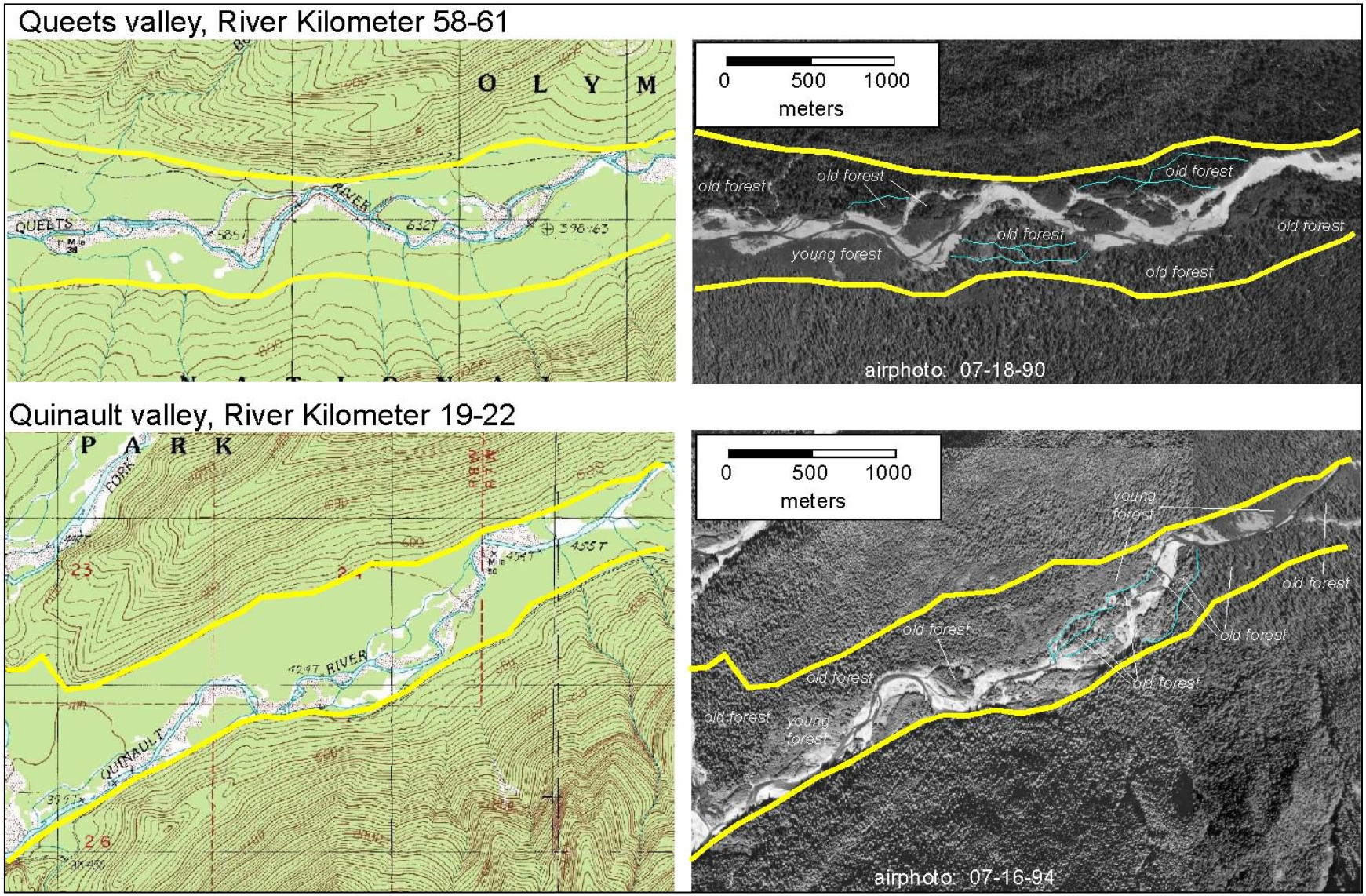


Figure 27. Relationship between the number of wood jams per river kilometer and the number of splits per river kilometer.



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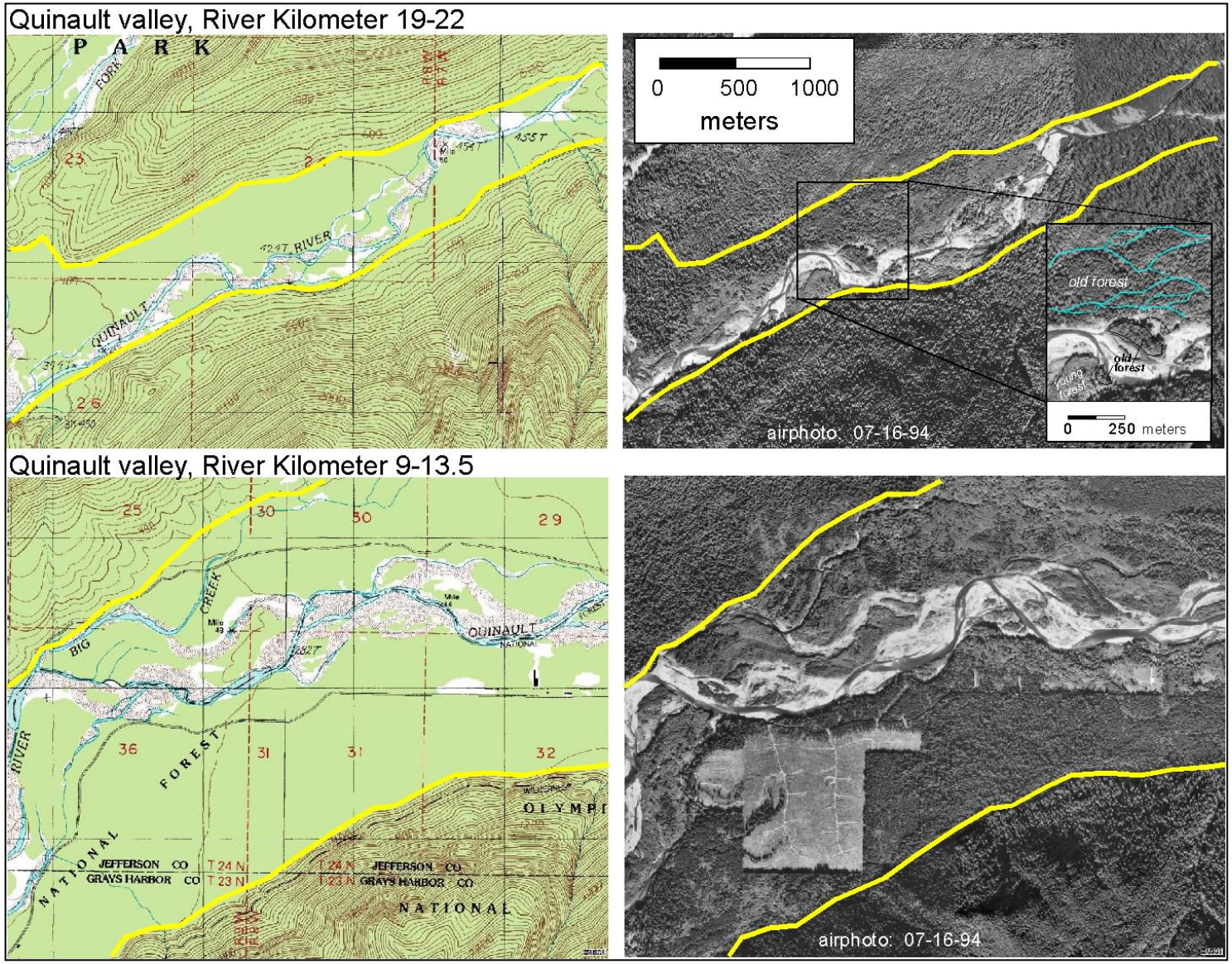

Figure 29. Comparison of subreach of the Upper Quinault River study reach and a relatively undisturbed section of the Quinault River several kilometers upstream (Figure 28). Note the major change in the riparian forest structure in the valley bottom, the significant increase in width of the unvegetated channel, and the loss of mature forest islands within study reach.

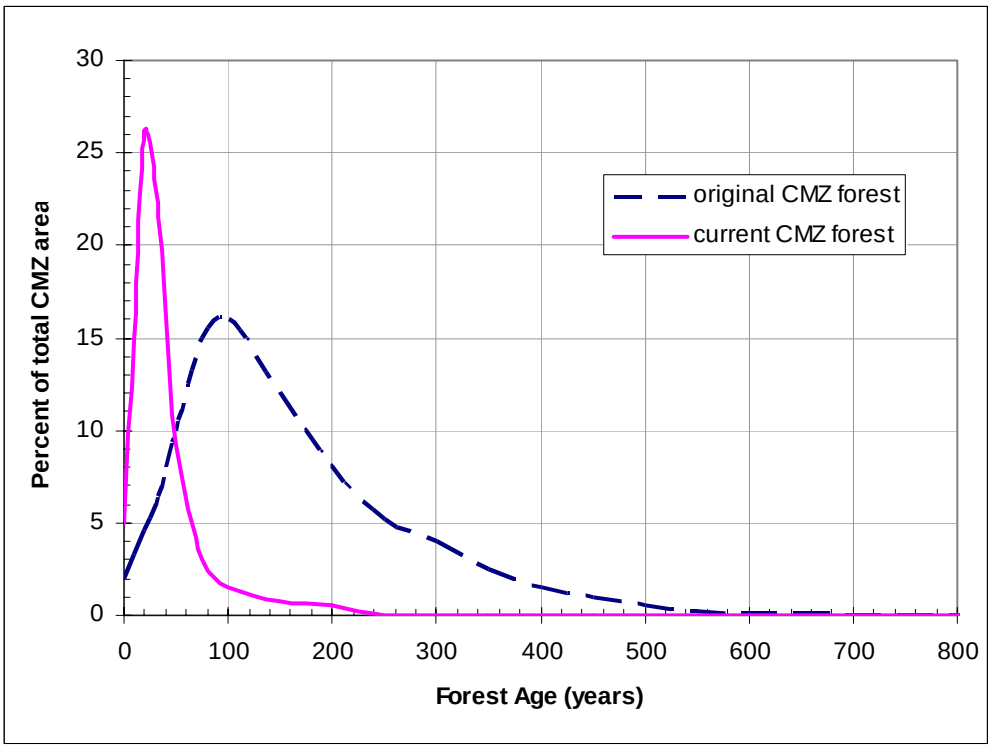

Figure 30. Hypothetical graph of change in forest conditions within the Upper Quinault River valley.

APPENDIX F: QUINAULT RIVER TIME-LAPSED PHOTOGRAPHY

PURPOSE

Cameras were installed on October 27, 2001 to take time-lapsed photography of the Quinault River during the 2001-2002 winter flood season at two sites along Graves Creek Road. The time-lapsed photography provides researchers and biologists at the Bureau of Reclamation, Olympic National Park, and the Quinault Indian Nation information to better understand the process linkages of flooding, bank erosion, and the transport and deposition of large woody debris. This will help provide resource decision makers with information to help implement fish habitat structures that both improve fisheries while also protecting important infrastructures such as roads and bridges.

BACKGROUND

In 2001, Reclamation was asked by the National Park Service and Quinault Indian Tribe to investigate bank erosion issues associated with river and hillslope processes along Graves Creek Road. Although the main sockeye restoration study was later moved into the downstream study reach below the Forks and Graves Creek Road, time-lapse cameras were installed along Graves Creek Road prior to this adjustment in study reach. Information gathered from these two sites along Graves Creek Road is still very useful to the downstream study reach to show how the river interacts with large woody debris during high flows.

The cameras utilized were 35-mm cameras (Nikon N90S) that have programmable backs to allow for “unmanned” operation except for changing of the film. At each site one photograph per day was taken. This allowed local staff from National Park Service to only change the film once per month, which was necessary due to the difficult access at this site. The more photographs that are taken per day, the more often the film must be changed in the cameras.

CAMERA LOCATIONS

Two camera locations were chosen along Graves Creek Road, which runs along the south (left looking downstream) side of the east fork of the Quinault River (upstream of the Forks). Site 1 represents an area where the left bank adjacent to the park road is made up of primarily bedrock and is therefore naturally protected (Figure 1 and 3). Site 2 represents an area where the river is eroding the left bank along the park road and rock protection has been used to protect the bank (Figure 2 and 4).

Figure 1. Planview location of camera 1.

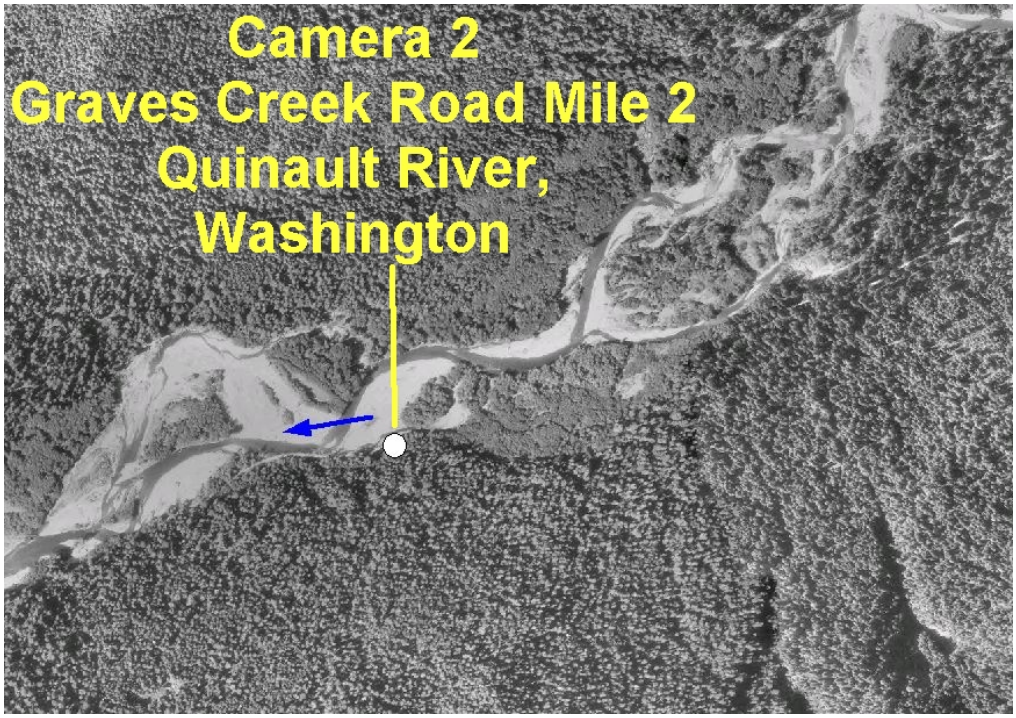

Figure 2. Planview location of Camera 2.

Figure 3. Site 1 River View - Looking upstream at Quinault River at upstream site with bedrock banks adjacent to park road. The goal of the camera is to observe natural interaction between woody debris transport and gravel bar formation.

Figure 4. Site 2 River View -Looking downstream at Quinault River from camera 2 where barbs have been placed and additional bank protection is likely to be implemented, about 2 miles downstream from Site 1. The goal of the camera is to observe any additional impacts from high flow events and migration of the channel due to existing barb structures or additional bank protection if placed.

River Flows during Camera Operation

There is no river gage presently in operation on the Upper Quinault River (above Lake Quinault). The closest gage is located at the outlet of Lake Quinault. This gage provided an estimate of the occurrence of floods during the time-lapse photo project and a rough idea of the magnitude of flow, at least in a relative sense. In other words, by determining if a flow value at the gage was near a 2-year flood, it could be estimated that the flow at the time-lapse photo location was also a "2-year flood" when the photos were taken during the same flood peak. The actual flow at the time-lapse photo locations would likely be less than at the outlet of Lake Quinault because the locations are above the confluence of the two main stems of the Quinault River. Additionally, the timing of when the peak of the flood occurred at the time-lapse photo locations should occur sooner than when it occurs at the outlet of Lake Quinault due to the travel time of the flood wave. Based on a simple approach of observing when the highest stage occurred at the time-lapse photography locations versus when it was recorded at the gage outlet, there appeared to be an approximately one day difference in flood peak occurrence for the time period noted in figure 5.

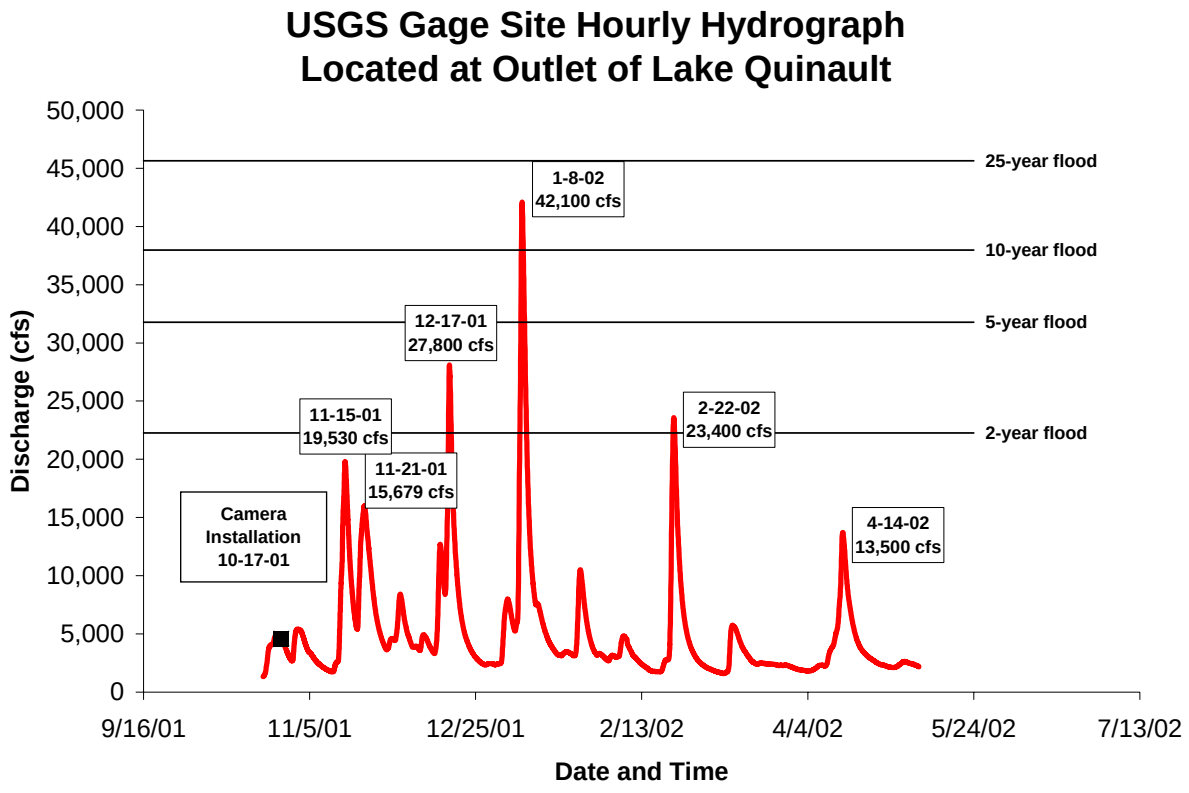

Figure 5. Hourly flow hydrograph for period of time-lapse photography. Note that data was downloaded in a provisional state and may have been updated by USGS since 2002.

Videos of Photographs

A time-lapse video was composed from the photographs taken for each of the two camera sites. These videos are available upon request from Reclamation. Both videos document a hydrograph that shows the mean daily flow recorded at the outlet of Lake Quinault, or in the case when floods occur, the video documents the peak flow recorded from the hourly gage data at the outlet of Lake Quinault.

Summary Photographs

Each site showed significant transport and reworking of gravel bars and large woody debris. The video is the best way to see the day to day dynamics, but the before and after photographs are shown below for each site, along with an in-between photograph time showing the highest flood recorded at the USGS gage on January 8, 2002 (highest stage observed at each camera site on January 7, 2002).

CAMERA 1 SUMMARY PHOTOGRAPHS (Date recorded shown on photograph)

CAMERA 2 SUMMARY PHOTOGRAPHS (Date recorded shown on photograph)

APPENDIX G: SEDIMENT ANALYSIS

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Introduction

True stability never exists in natural rivers, which frequently change their position and must continue to pass a range of discharges and sediment loads (Knighton, 1999). However, rivers can be classified as relatively stable if they tend to maintain characteristic equilibrium forms, processes, and measurable variables. Sediment supply and transport capacity play a large role in whether a river is in a stable state or adjusting to a new state. A river channel will adjust its sediment transport capacity to accommodate a change in sediment supply and volume of flow by changing its width, depth, and slope relationship (narrowing or widening) or by aggrading or eroding the channel bed. The watershed analysis (QIN, 1999) described the Upper Quinault study reach as having a wide, aggrading channel, particularly in the areas influenced by Lake Quinault. If the Quinault River is aggrading, it would tend to increase the rate at which the channel shifts across its floodplain. The rate at which the channel shifts has an implication on how quickly side channels utilized by sockeye are overtaken by the main channel. Additionally, if the river is in an aggradational state, it is important to understand if it is a natural process (more sediment naturally supplied than can be transported) or human-caused situation (accelerated sediment supplied to river from human activities). Understanding sediment processes over the last century will help determine if the river is aggrading and shifting at a rapid rate, why, and what might be done as part of a restoration strategy for sockeye.

Methods

Our study attempts to verify whether the Quinault River between the Forks and Lake Quinault is in an aggradational state, and if so, whether aggradation has been induced from increased sediment supply as a result of human activities over the last hundred years or is simply part of natural processes in this system. There can be a lot of uncertainty associated with sediment analyses, particularly in a dynamic system like the Quinault River. Our approach was to use a variety of sediment transport analysis techniques from conceptual to quantitative to better understand the sedimentation processes in the Quinault River. Results from these analyses were evaluated to see if any evidence exists to support the notion the river is aggrading and, if so, in what reaches and on what order of magnitude (and, if not, what condition the evidence does lead towards). Techniques utilized include:

1. Comparison of reference channel geometry from late 1800's and early 1900's (conceptual) to channel conditions between 1939 to 2002 to look for trends in channel width and planform that might indicate a change in sediment loads or transport capacity. These trends were also linked to the timing and types of human disturbance in the riverine areas.
2. Application of regime theory to determine if the present Quinault River is classified as an aggradational, braided stream
3. Computation of total and unit stream power to see if particular reaches have more or less transport capacity when compared to each other.

4. Evaluation of sizes of sediment being transported through the study reach using pebble count data collected on surfaces of point bars.
5. Comparison of 1929 to 2002 longitudinal profile surveys of the Upper Quinault to look for changes in water surface elevation that would result from changes in channel bed elevation.
6. Evaluation of delta processes to evaluate the potential for aggradation within the influence of Lake Quinault.
7. Development of a sediment budget to evaluate the potential for aggradation between 1939 and 2002 based on computing the volume of sediment contributed to the river, the amount of sediment in storage, and the amount of sediment being transported out of the river into Lake Quinault over this timeframe. Bank erosion along surfaces binding the historic channel migration zone is thought to be occurring at accelerated rates due to clearing of vegetation. The sediment budget will be used to see how the volume of sediment from bank erosion compares to changes in sediment storage as the historic channel migration zone expands. The sediment budget was also used to evaluate what levels of system-wide aggradation over the study reach are plausible given the quantified sediment sources in the system.

Input data utilized and results from each of the above analysis methods are individually presented in the following sections, and then integrated in the results and conclusions section of this appendix. There have been no trends observed in the peak or frequency of floods that have occurred between the timeframe evaluated based on discharge data collected at a USGS gaging station at the outlet of Lake Quinault (QIN, 1999). Additionally, there have been flows significant to rework the channel between all aerial photograph and maps evaluated. The largest recorded peak occurred in 1909 (see Figure 5 in main report). The second largest flood occurred in the 1950s and was near a 50-year flood. Between 1909 and 1950, several floods occurred but nothing greater than a 10-year flood.

Definitions

The following table describes the classes of sediment referred to in our study.

Table 1. Sediment size class and particle diameter range referred to in report (Julien, 1995).

Sediment Size Class	Particle Diameter Range (mm)
Clay	< .004
Silt	.004 to .062
Sand	.062 to 2
Gravel	2 to 64
Cobble	64 to 256
Boulder	256 to 4096

Fine-sized sediments ranging from clay to fine sand are transported in suspension in the Quinault River. They do not affect channel form by inducing channel changes, but can affect the water quality (turbidity) and aquatic habitat in the river. The smallest sediments, including silt and clay sizes, are often referred to as washload because they typically remain in suspension even at low flows. Slightly larger sediments including medium to fine sand will usually remain in suspension during high flows, but as floods recede they may deposit in areas of low velocity, such as overflow and side channels. If substantial, the fine-sized sediments can fill the interstitial spaces between the gravels and cobbles in the channel bed material.

Larger-sized sediment ranging from coarse sand to cobbles is transported as bedload and is referred to in this report as coarse-sized sediment. In contrast to fine-sized sediment which can be transported all the way to Lake Quinault, coarse-sized sediment is usually transported short distances along the active channel bed. A small pulse of coarse-sized sediment transported into a reach can cause the existing channel path to fill with sediment and result in the channel flowing in a new direction if it is an area of low transport capacity, such as a meander bend ready for a cutoff. In this case, the net deposition and erosion within a reach is not usually significant and there is not an impact in supply to the next downstream reach. Large increases in coarse-sized sediment over a long enough period of time can actually cause the channel form to change from a meandering to straight channel in order to increase the slope and transport capacity to maintain a balance with the increased supply. If the balance can still not be obtained by running straight or if the river channel alignment is already straight, additional sediment deposits will result in a braided river with multiple channels.

Sediment Transport in Relation to Human Activities

As mentioned earlier, a river channel can adjust its sediment transport capacity to accommodate a change in sediment supply and volume of flow by changing its width, depth, and slope relationship (narrowing or widening) or by aggrading or eroding the channel bed. This section discusses how human activities in the floodplain could have affected sediment loads and initiated channel responses based on evaluation of historical maps and journal accounts of the channel, and channel widths and planform trends on aerial photography between 1939 and 2002.

Early journal accounts document a deep Quinault River that was lined with mature vegetation on either bank and was too deep to wade across (see Appendix M for documentation). The accounts also document frequent large woody debris and sediment bars that increased in number in the downstream direction of our study reach. The 1929 map also indicates a fairly narrow active floodplain, with one to two channels in most areas separated by bars or islands. Where there was split flow on the 1929 map, one of the two channels was often narrow and could be interpreted to be a slough. A 1936 fisheries survey report notes the rapid shifting of the river as a recent change to river dynamics and that the majority of main channel salmon habitat had been lost in recent years. The 1939 channel visible in aerial photography, however, was mostly unvegetated across the historic channel migration zone with only a few vegetated islands and side

channels visible. This wide, unvegetated floodplain present between 1939 and 2002 could have resulted from disturbance in the river system and/or a significant increase to the sediment supplied to the system. Three major landslides were noted to occur in the early 1930s which could have contributed large volumes of sediment to the Quinault River. However, after evaluation of the landslide areas on 1939 aerial photographs, it does not appear plausible that these slides or other smaller tributaries in the drainage basin could have delivered enough sediment to result in the channel widening evident in the 1939 aerial photograph.

On the other hand, the 1939 aerial photograph shows widespread evidence of logging of hillslopes and the valley floor. Anecdotal accounts also describe removal of log jams and large woody debris in the channel. Clearing of vegetation in the floodplain and on surfaces binding the historic channel migration zone in the early twentieth century is believed to have destabilized the channel and increased both the rate of river migration and the rate of terrace bank erosion. Vegetated islands that had been stable before disturbance would have suddenly shed a large volume of easily mobilized sediment to the system. This abundant sediment would have forced the channel to change from a deeper, narrower channel to a wider, shallower channel to accommodate the increase in sediment supply and increase transport capacity. The channel in the 1939 aerial photograph illustrates this sudden increase of sediment removed from floodplain storage; the river may have temporarily been in an aggradational state in 1939 in many sections.

Following this channel destabilization, the river migrated and terrace banks eroded more rapidly. Terrace banks have provided a continual source of additional sediment to the Quinault River that is believed to be accelerated from the beginning of human-induced disturbance to the present day (see sediment budget section).

Geomorphic Channel Characteristics

We compared average active channel widths from 1939 to 2002 for roughly every decade, but did not find any significant trends that would indicate a change in sediment transport capacity (see GIS appendix I for plots of width measurements). We also did not observe any trends in planform changes, but rather found a combination of meandering, braided, and split channel flow throughout the reach between 1939 and 2002. The 1939 channel does appear to have minimal mature vegetation. We propose that by 1939 the channel had already responded to early twentieth century disturbance and has remained in a wider, shallower geometry as a result of that disturbance since that time.

Cross sections generated from 2002 survey data indicate there are many channels within the active floodplain (see Hydraulic Model Appendix for cross-section plots). In general the active channel bed is near the same bottom elevation as other channels, evidence of the constant shifting of the channel. The exception is the upstream portion of the study reach where the active channel is lower than the adjacent side channels. The upstream portion of the study reach is constricted by a bridge and levee, and it is possible the channel has incised as a result of the constriction. Constrictions generally cause a higher

water stage and faster velocities resulting in an increase to sediment transport capacity. The middle reach has experienced numerous channel shifts since 1939, predicted to occur due to the lack of stable hard points (vegetated surfaces and large woody debris) in the system. The rate of channel occupation is discussed in more detail in the main report.

Holocene terrace and lake deposit surfaces represent areas where the Quinault River historically occupied, but presently only are overtopped by large flood flows. The 1897, 1906, and 1929 maps document homesteads on these surfaces, and radiocarbon dates suggest they are at least several hundred years old, possibly older. The height of these surfaces was compared to the average floodplain elevation and the maximum floodplain elevation at cross-sections spaced roughly 0.5 kilometers apart (Attachment 1). The south (left) and north (right) binding surfaces are plotted separately. Areas where there is a gap in the data are where alluvial fans or bedrock are present along the boundary. The elevation of the Holocene surfaces was taken at the boundary of the 2002 historic channel migration zone. The profile plots indicate that Holocene surface heights above the channel migration zone vary between 1 to 3 meters (see Geology and Radiocarbon appendices for more information on the development of these surfaces). There are several areas where the maximum floodplain elevation is higher than these surfaces. Many of these maximum elevation areas correlate to vegetated surfaces within the active floodplain that would be expected to be higher than the unvegetated surfaces that compose the majority of the floodplain area.

A plot of the 2002 historic channel migration width along the study reach was compared to geologic mapping to look for natural constrictions that may affect sediment transport capacity (Figure 1). The 2002 historic channel migration zone width varies along the study reach from constricted, narrow sections to wider sections. The sections of the widest 2002 historic channel migration zone are the delta area downstream of RK 2, and areas in the Middle Reach (RK 2 to 14) that have eroded (expanded) since 1939. The narrowest HCMZ widths are in the upstream-most section of the study reach. The bedrock areas mapped are only located on one side of the active floodplain, and while they will limit future expansion on that side, they do not constrict both sides creating the narrow floodplain widths. These areas seem to be more a function of where the river has not yet expanded the historic migration zone boundary.

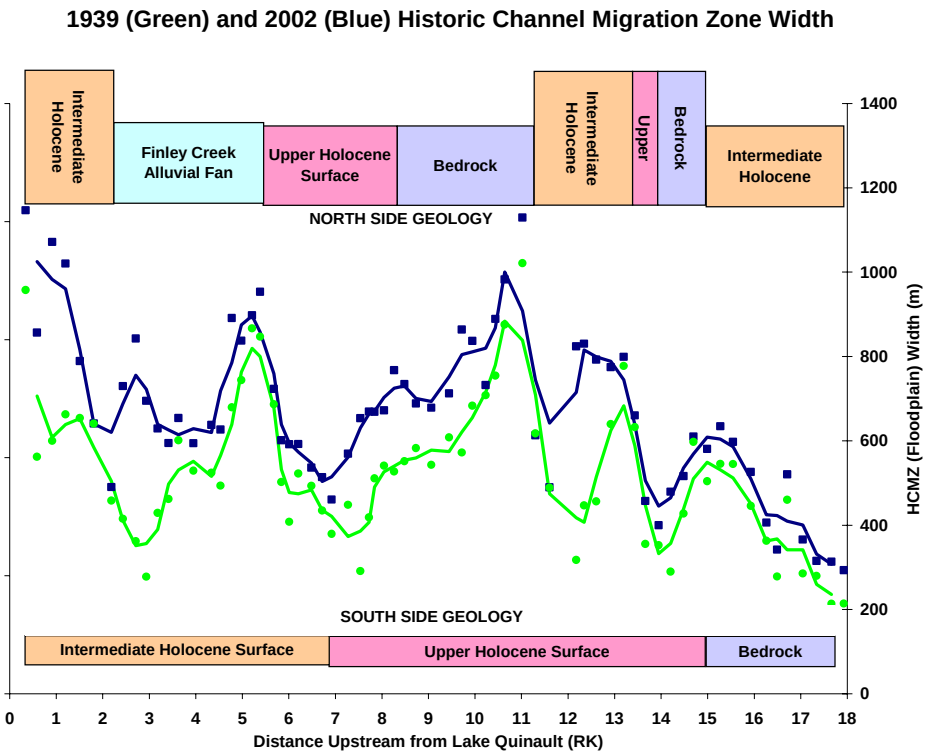

Figure 1. Plot of 1939 and 2002 historic channel migration zone (HCMZ) width for study reach. Lines represent a 3-point moving average of the points presented in figure. Areas where the 2002 HCMZ is wider represent sections where the HCMZ has expanded (eroded) between 1939 and 2002 on either the south or north side of the river (or both).

How Classification Systems and Regime Theory Describe the Present Upper Quinault River

Classification of channel pattern is used to provide a description of our study reach that puts the Quinault River in perspective with other channel types. Classification allows scientists to talk on common terms about characteristics of the river. Regime equations use measured data to develop relationships between form and process variables to further understand the characteristics of a particular channel in relationship to other channels. Regime theory assumes channel geometry can be largely defined in terms of width, depth, slope, and meander properties.

River Classification

Streams are generally characterized as straight, meandering, braided, or anastomosed (Figure 2). Braided channels can contain, within one active channel segment, several channel paths that are separated by bars or islands. Anastomosed channels are defined as having channels longer than a curved channel segment around a single braid or point bar, and their width-scale flow patterns behave substantially independent of adjacent

segments (Knighton, 1999). These channels are often separated by stable bars or islands, or they can contain large wetland areas between channel segments.

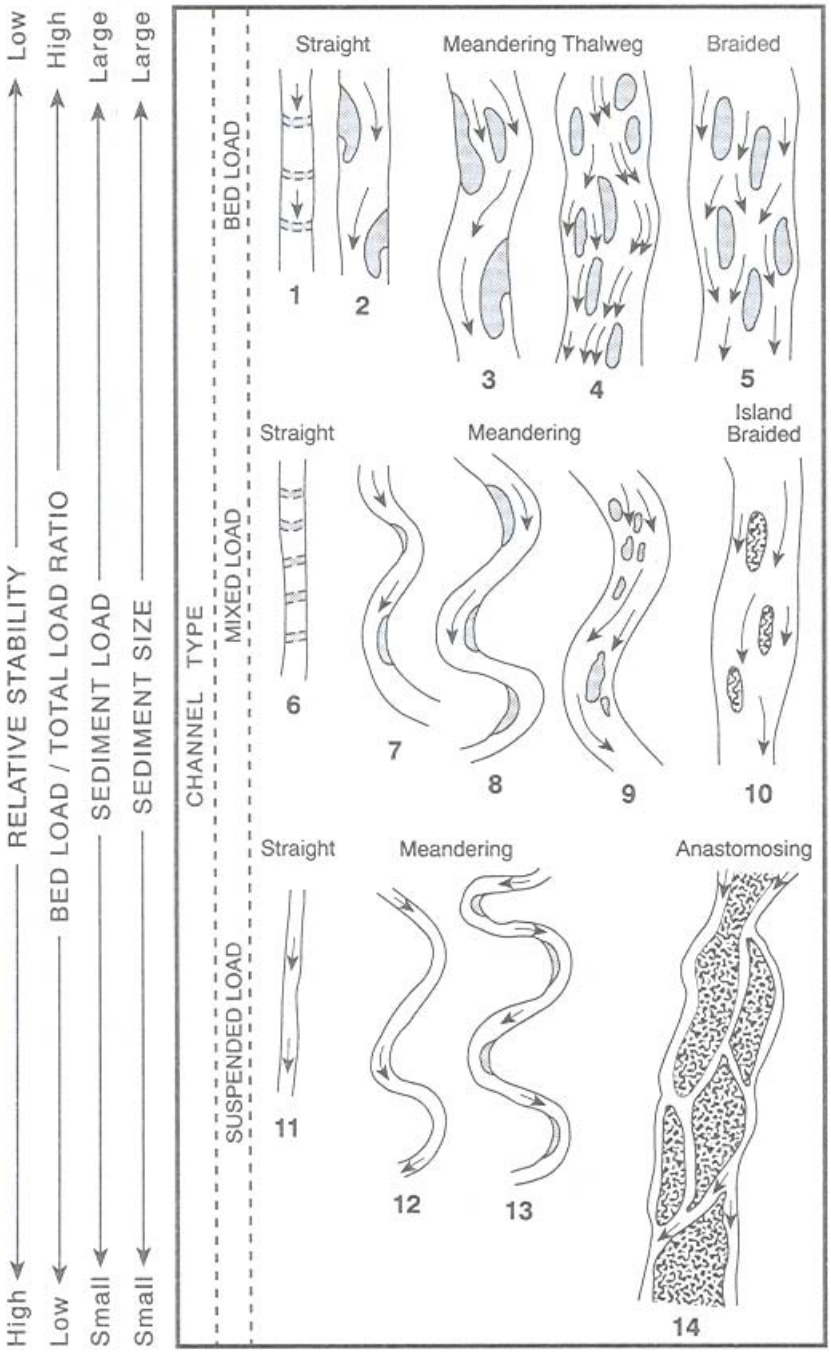

Figure 2. Classification system of channel pattern (after Schumm, 1981, 1985) taken from Knighton (1999). Indexes on left axis are meant to provide a relative comparison between categories rather than absolute values. Large sediment load generally indicates the majority of total load is composed of bedload sediment, and low sediment load indicates the majority is composed of suspended load sediment. Bedload sediment is generally sand, gravel, and cobble in size. Suspended load sediments can range from fine sand to silt and clay sized particles. Stippled sections indicate stable bars or islands that may or may not be vegetated. Grey colored areas represent bars that are dynamic and are reworked during high flows.

As is the case for many rivers, the present Quinault River system does not fit easily into a single classification category (Figure 3). Meandering low flow channels, areas of braiding, and vegetated islands are all part of the present system. O'Connor et al (2003) described the Upper Quinault and nearby Queets River as "irregular wandering" or "irregular meandering" as described by Church (1992), with shorter reaches of braided and anastomosed channels. In reference to Figure 2, the present channel contains Type 3, 4, and 5 channel areas in the study reach, with high bed load (supply equal to or greater than transport capacity) and large sediment sizes (gravel and cobble) in the channel bed. The reference channel from the late 1800s is thought to have been more confined with a higher density of stable vegetated bars within the active channel. Using the classification from Figure 2, the reference channel might have had more dominant characteristics of Type 10 or 14 channels.

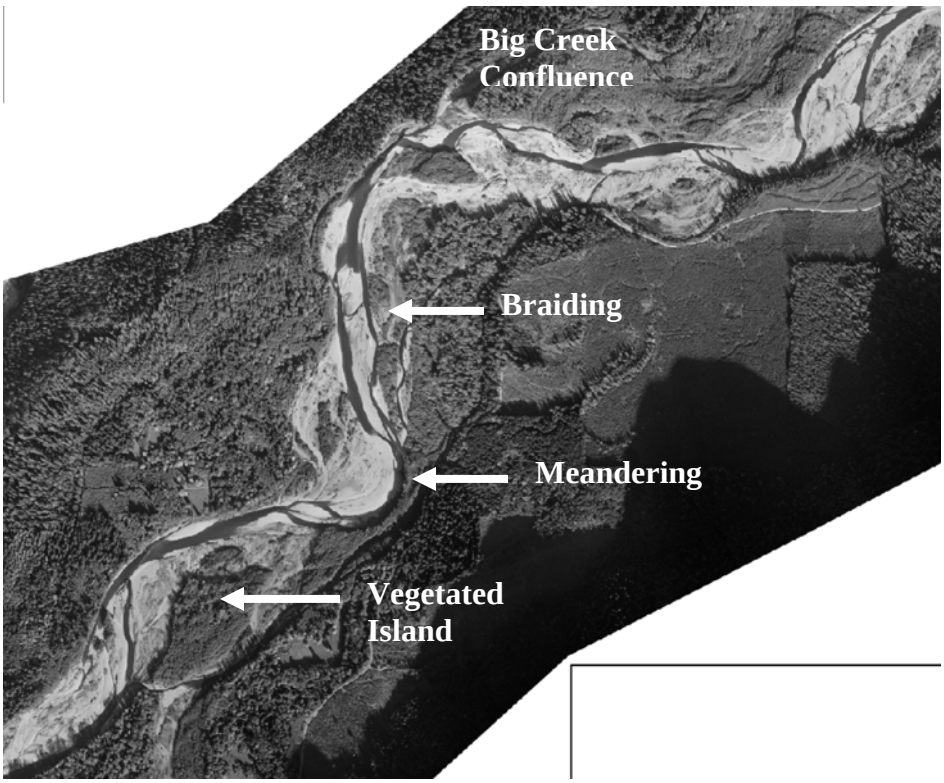

Figure 3. Example of present river features within the study reach (2002 aerial photograph).

Montgomery and Buffington (1997) developed a classification system specifically for Pacific Northwest Rivers in mountain drainage basins that incorporates the role of large woody debris in channel morphology. On the basis of our field observations, the dominant features of the Upper Quinault River would be described under this system as a pool-riffle system with exposed bars, highly turbulent flow through riffles, and more tranquil flow through pools. Montgomery and Buffington (1997) note that large woody debris can be highly mobile in a pool-riffle system. Additionally under this system, pools are typically spaced five to seven channel widths apart, but they can be spaced closer

together with high loading of large woody debris. The dominant substrate size is gravel, which matches well with our measured Wolman pebble counts and field observations of the channel bed (average size measured was 56 mm, a very coarse gravel). Montgomery and Buffington (1997) describe these channels as having heterogeneous beds that commonly have a coarse surface layer and a finer subsurface that is reworked only after surface layer particles have been mobilized. This observation also matches our observations of existing sediment bars on the Quinault River.

River Regime Theories

Three widely used regime theories were analyzed to describe the existing Upper Quinault River. Regime equations based solely on discharge and slope, such as those of Leopold and Wolman (1957) and Lane (1957) would characterize the present river as braided (Knighton, 1998) (Figure 4). Another equation by Chang (1985) incorporates sediment particle size and would denote the Quinault River as a braided river within a wider, sinuous channel planform. For these regime equations, it is necessary to assume a typical bankfull channel discharge and average slope and, for Chang's equation, the dominant sediment size present in the bed. Because it is difficult to determine the bankfull discharge on a braided system like the Quinault River, a 2-year discharge based on gage data at the outlet of Lake Quinault was used. Even though this value may be slightly larger than the actual 2-year discharge in the study reach, owing to the damping effect of Lake Quinault, even if the discharge is reduced by half Figure 3 indicates that the Quinault would still be categorized as braided by Leopold and Wolman and Lane's classification systems. A range of average slope values were plotted from .0022 to .0039 which encompasses measured 2002 slopes in the study reach. For Chang's 1985 equation, the average sediment particle size of 56 mm measured from Wolman pebble counts was used. Chang's classification system would characterize the present Quinault River as braided with some sinuosity. Chang's classification fits well with the visual observations as shown in Figure 3. Leopold and Wolman and Lane's classification indicate that braiding is a more dominant feature in the study reach, but it does not capture any localized variations that may occur.

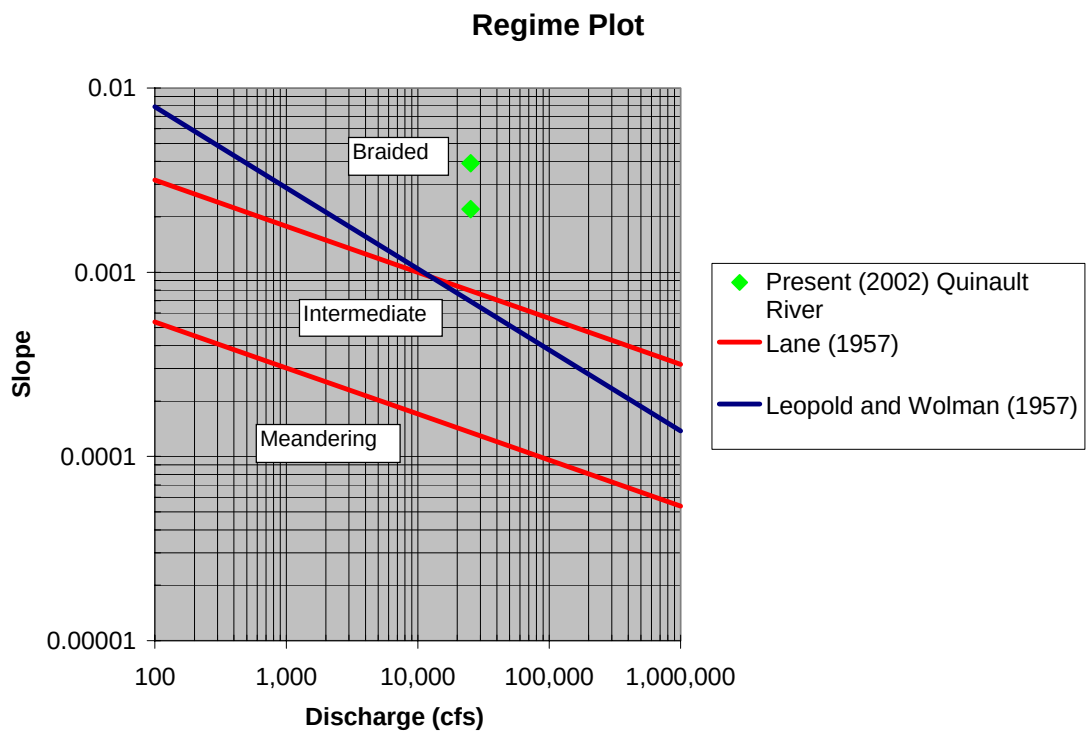

Figure 4. Regime theory application for meandering vs. braided rivers.

Stream Power

Stream power calculations provide a measure of the river's energy as a function of discharge and slope (total stream power) or velocity and slope (unit stream power). In sediment analyses, stream power is used to compare the river's sediment transport capacity (or energy level) between geomorphic reaches. Reaches with low stream power values cannot transport as much sediment as reaches with higher stream power values. There are no existing bedload measurements or numerical sediment transport models for the Quinault River to evaluate sediment transport capacity throughout the study reach. Because these numerical measurement and modeling tasks were beyond the scope of our study, we used stream power computations as an indicator of whether the sediment transport capacity in the Upper Quinault River remains about the same, increases, or decreases throughout our study reach.

Total Stream Power

Total stream power (product of discharge, slope, and specific weight of water (γQS)) is used to document how a change in discharge in the downstream direction does or does not offset changes in channel bed slope (Chang, 1992). As discharge increases, total stream power (and sediment transport capacity) would be expected to increase. On the other hand, as slope decreases total stream power (and sediment transport capacity)

would be expected to decrease. In our study reach, discharge gradually increases in the downstream direction as a result of tributaries entering the Quinault River, but slope also decreases. Total stream power was used to evaluate how these two parameters balance each other out.

Discharge values for the 2-year flood frequency were computed at the Forks (RK 18), at the confluence with Big Creek (RK 9), and at the inlet to Lake Quinault (RK 0) based on an empirical USGS equation incorporating drainage area and precipitation (see hydrology Appendix K). The discharge value for Lake Quinault was implied to be greater than at Big Creek confluence mostly due to the Finley Creek drainage. Therefore, the downstream–most discharge value was applied in total stream power computations between the upstream confluence with the Finley Creek alluvial fan (RK 4.6) and Lake Quinault. Although the discharge values provided from this empirical approach may not be precisely correct, the relative change in discharges at different locations can be used to evaluate if there is a change in total stream power. Average channel slope values along the Quinault River were determined from the October 2002 river channel survey data by connecting the top of hydraulic controls to form straight lines between locations of discharge breaks (see Topographic Data Appendix A for plot of surveyed profiles from 2002).

Total stream power results for the study reach were computed at breaks in slopes (Table 2). The total stream power results suggest there is slightly less sediment transport capacity between RK 4.6 to Lake Quinault than in the upstream reaches. However, in general there are both high and low reaches of transport throughout the study reach rather than a consistent decreasing trend. Future analysis could refine these numbers by doing a higher resolution analysis of change in drainage basin size along the downstream direction to get more detailed change in the 2-year flood along the study reach. However, the two largest basins that would most affect the 2-year flood peak value are incorporated in our results.

Table 2. Total stream power results.

KM	Slope (m/m)	Distance (km)	Peak 2-year flood (m^3/s)	Specific Weight of Water (kN/m^3)	Total Stream Power ($QS\gamma$)
0.1 to 2.7	0.0022	2.6	700	9.81	15
2.9 to 4.6	0.0021	1.7	700	9.81	14
4.6 to 6.3	0.0029	1.7	630	9.81	18
6.6 to 9	0.0032	2.4	630	9.81	20
9 to 12.6	0.0032	3.6	530	9.81	17
12.6 to 14.0	0.0034	1.4	530	9.81	18
14.0 to 15.4	0.0047	1.4	530	9.81	24
15.4 to 17.3	0.0031	1.9	530	9.81	16

Unit Stream Power

Unit stream power is defined as the rate of potential energy dissipated per unit weight of water, which is expressed by the velocity and slope product (Yang, 1996). Rather than just looking at the change in discharge and slope, unit stream power incorporates velocity which is a function of the geometry and sediment transport occurring in the river channel. Unit stream power was determined for the reach based on velocity output data from the hydraulic model (see hydraulic model Appendix B), and average slope values generated from 2002 river topography data (see topographic data Appendix A and Table 3). Unit stream power was computed for the active channel at each cross-section in the model for the 2-year flood (Figure 5). Discharge values were increased in the downstream direction to account for increasing drainage area as shown in reach breaks in Table 3. Cross-section spacing for this purpose was approximately 0.5 kilometers apart.

Table 3. Reference Slope Measurements from River Survey in October 2002

KM	Elevation	Slope	Slope	Distance
	(m)	(m/m)	(%)	(km)
0.109	56.014			
0.1 to 2.7	61.668	0.0022	0.22	2.57
2.9 to 4.6	66.356	0.0021	0.21	1.68
4.6 to 6.3	71.46	0.0029	0.29	1.76
6.6 to 12.6	90.9	0.0032	0.32	6
12.6 to 14.0	95.665	0.0034	0.34	1.39
14.0 to 15.4	102.255	0.0047	0.47	1.41
15.4 to 17.3	107.924	0.0031	0.31	1.83

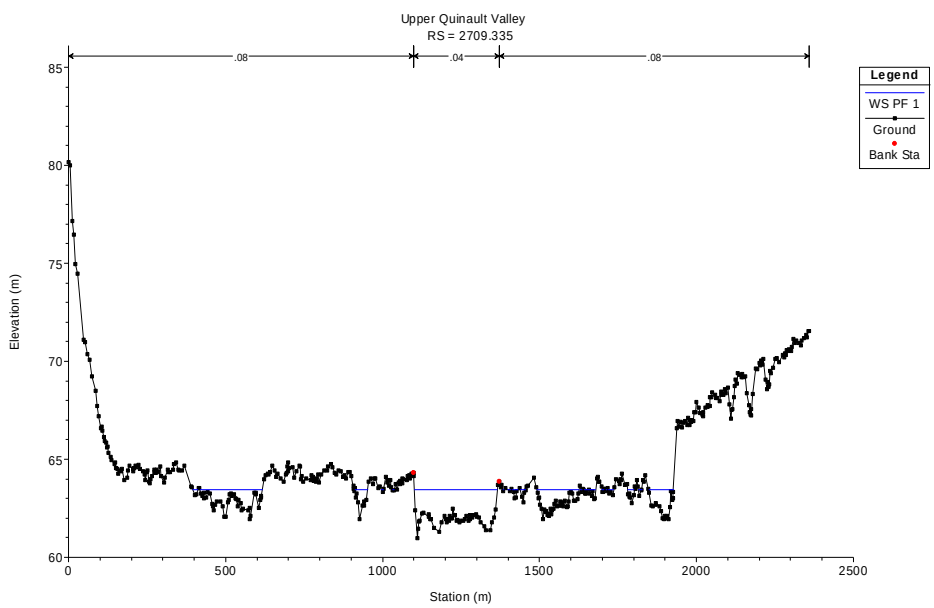

Figure 5. Example cross-section at RK 2.7 with 2-year flood modeled water surface elevation. The red dots define the right and left boundary of what was considered active channel.

On average unit stream power is highest between RK 17 to 14, decreases between RK 14 and 11, is fairly consistent between RK 11 to 6, and then decreases from RK 6 to Lake Quinault (Figure 6). Within these three trends, there are small fluctuations of higher and lower stream power throughout the study reach. Even with the increase in discharge, the unit stream power shows an overall reduction in the downstream direction, indicating a potential for aggradation, particularly downstream of RK 14. RK 14 represents a constricted section downstream of which the active floodplain width widens.

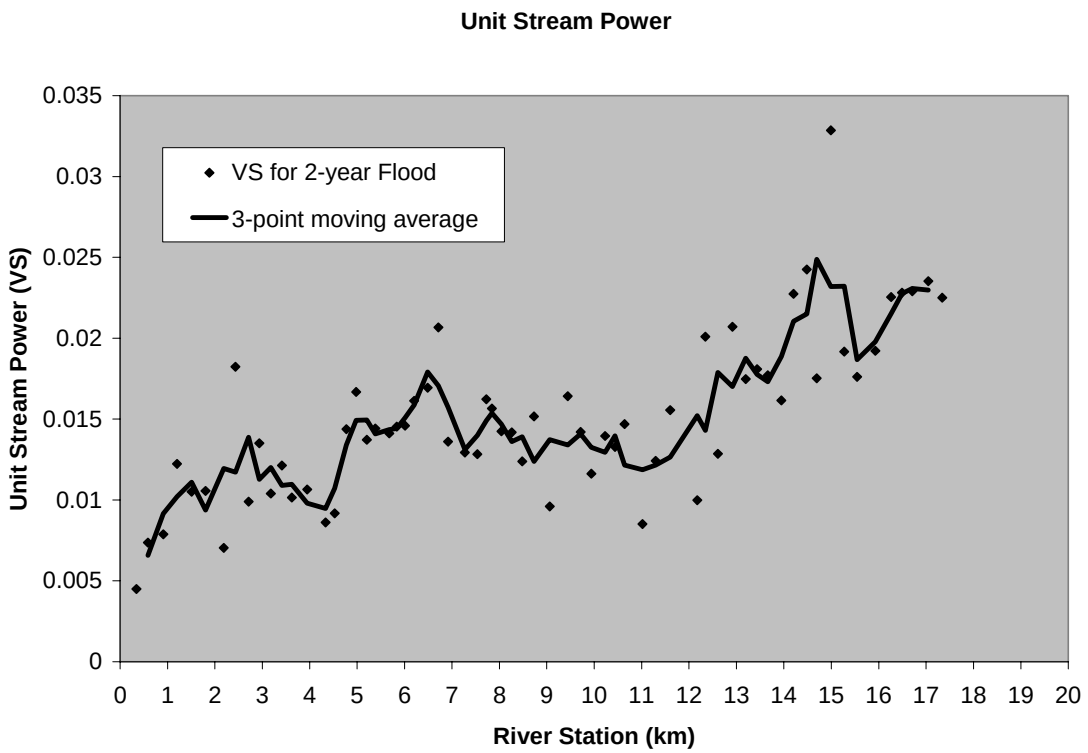

Figure 6. Unit stream power results along active channel in study reach for 2-year flood.

Observations of Sediment Sizes Present In the River Bed

An inventory was done to determine what sizes of sediment were being transported in the river during high flows, if there was any trend in the sizes measured that could be related to other geomorphic characteristics of the system. If the sizes of sediment being transported were decreasing in the downstream direction, this would indicate a decrease in sediment transport capacity. Overall, the measurements indicate gravel and cobble-sized sediment are transported throughout the study reach. There are some localized variations in sizes measured indicating a response to wider or more constricted sections of the historic channel migration zone. There is a small overall trend of a reduction in sizes being transported that would indicate a reduction in sediment transport capacity in the downstream direction of the study reach. This matches with the computation of decreasing unit stream power in the downstream direction. This may be a function of the

pebble counts being measured on bars within the active channel that maintain higher sediment transport capacity than other adjacent areas of the floodplain for a given location. Once a particular location of the active channel loses sediment transport capacity, it is likely to shift to a new location to maintain the ability to transport coarse sediment.

Wolman pebble counts were used to measure sediment particle sizes on ten gravel bar surfaces adjacent to the low flow channel (Bunte and Abt, 2001). For our measurements, we stretched a 100-foot tape from the water edge along a gravel bar in a direction perpendicular to the flow in the channel (Figure 7). Locations on gravel bars were chosen that were generally in the middle of point bars on the inside of meander bends during the October 2002 survey (see Attachment 2 for locations). These sites were intended to represent areas of the gravel bar that were recently reworked during high flows because they were unvegetated and near the water's edge. Sediment sizes present of the surfaces of gravel bars can often be coarser in size than sediment trapped below the top layer of the bar, and finer than sediment present in riffles and rapids where higher velocity exist. For this reason, the sediment sizes measured do not provide a complete representation of sizes of sediment being mobilized during high flows, but can be compared to each other to determine what sizes of sediment make it through the system.

Figure 7. Tim Randle and Jennifer Bountry collecting pebble count data on Quinault River gravel bar. Photograph taken September 29, 2002.

Along each tape line, a sediment particle was randomly chosen at each one-foot mark such that 100 pieces of sediment were inventoried for each line. Measurements of each particle diameter were taken along the intermediate particle axis, which is the axis that would prevent the particle from passing through a square sieve. The total range of sediment measured was coarse sand (~2 mm) to boulder size (>256 mm). If the particle

at a particular one-foot mark was less than 2 mm, a size was estimated based on visual observation of type of sediment or a zero entered into the pebble count data.

The D_{10} (90% of particles greater than this size), D_{50} (50% of particles greater than this size), D_{90} (10% of particles greater than this size), and maximum sizes recorded for each site are shown in Figure 8 and the particle size distribution for each sample is shown in Figure 9. The average particle size (d_{50}) on the surface of sediment bars for the study reach was measured to be 56 mm, very coarse gravel. In general, the D_{50} appears to remain relatively constant around the boundary between coarse gravel and small cobble size sediment for all sites. The two upstream-most sites between RK 15 and 17 had the largest sizes of sediment measured on the bar surface. The two sites closest to Lake Quinault did have slightly smaller measured sizes relative to the majority of the upstream study reach. RK 12.5 is a section of the historic channel migration zone that widens considerably from a constriction point located around RK 14 (at RK 14 no measurements were made). Although there are localized variations, linear trend lines indicate overall a slight trend in decreasing sediment sizes. In the downstream direction, the maximum particle size decreases 10 mm in size per RK, the D_{90} decreases 9 mm per RK, the D_{50} decreases 3 mm per RK, and the D_{10} decreases 1 mm per RK.

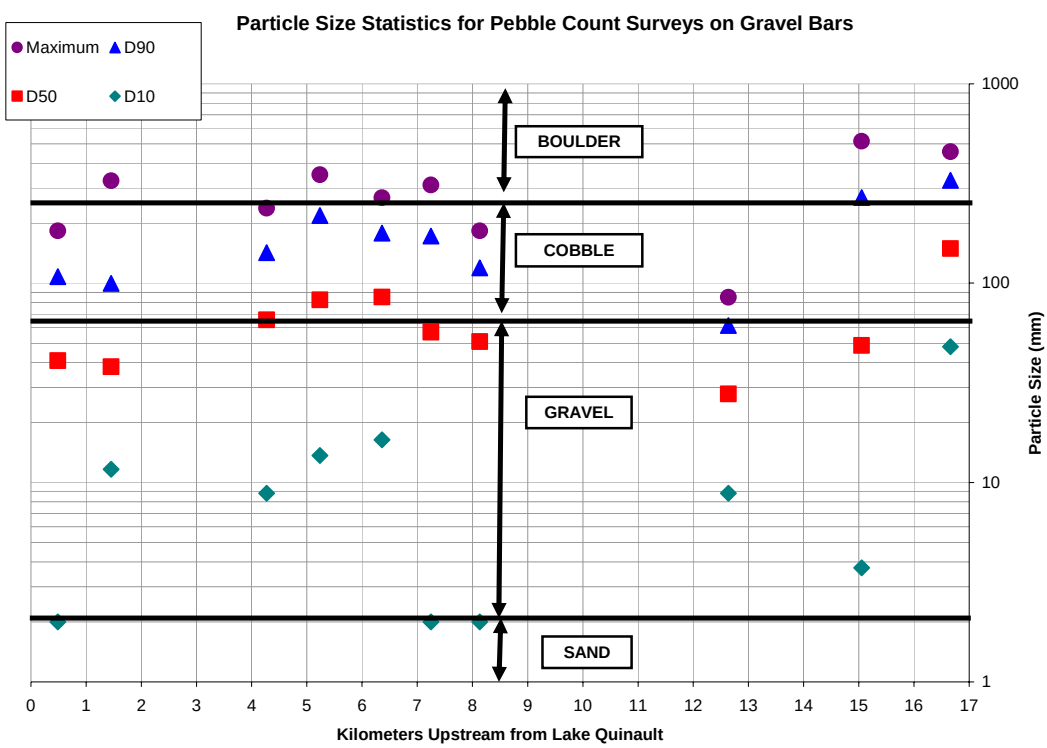

Figure 8. Particle sizes measured at each Wolman pebble count sample site.

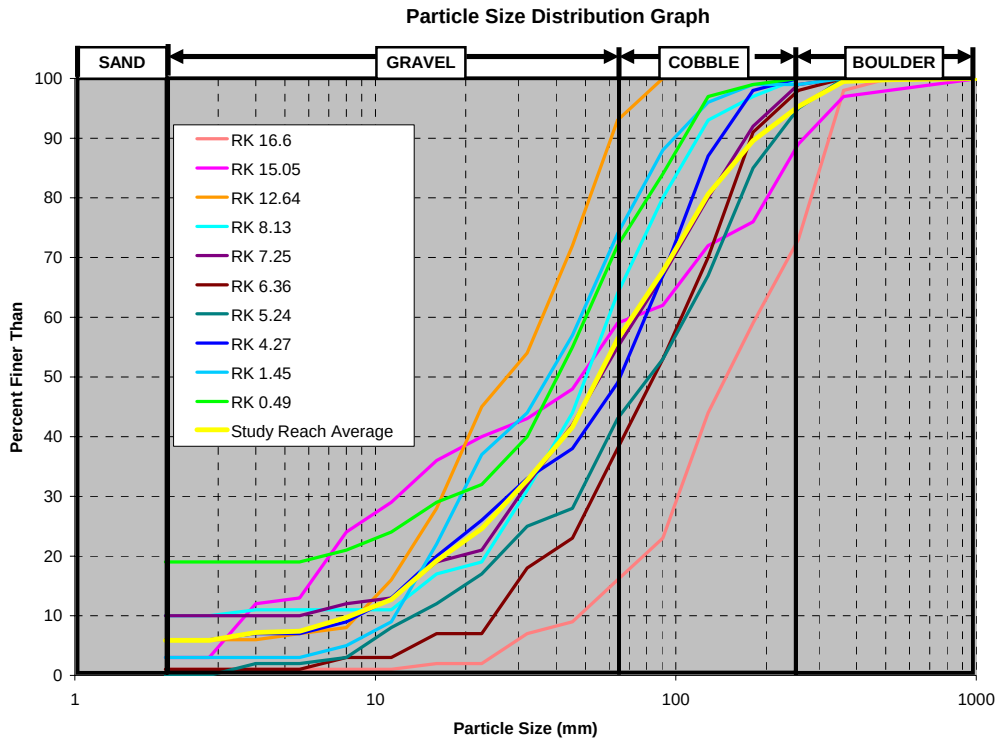

Figure 9. Particle size distribution for each sample site and average for all sample sites.

Longitudinal Profile Comparison

A historic river water surface elevation survey from 1929 was compared to water surface elevation data collected in 2002. There is some uncertainty in the datum and flow of the 1929 data (see topographic data Appendix A), and, therefore, the results presented in this section are interpreted on a qualitative rather than quantitative approach. However, it is believed that the 1929 survey was taken at a relatively low flow comparable to the 2002 survey, and should provide a reasonable comparison if the 1929 datum was correctly converted.

A profile of the difference in water surface elevation between the 1929 and 2002 surveys was developed (Figure 10). Areas with positive change indicate channel sections that are higher in elevation than in 1929, and areas with negative change indicate channel sections that are lower. The results show that there is some evidence for potentially up to 3 meters of channel bed lowering (incision) between RK 14 and 17 (Forks Bridge). The potential for incision is plausible because the Forks Bridge and a levee located just downstream have cut off a portion of the natural river channel width. This constriction may have increased the velocities and river stage, resulting in an increase to sediment transport capacity. In this situation, the channel bed could have lowered. However, the absolute amount of incision of up to 3 meters shown seems high, and may be due to datum conversion issues.

Between RK 14 to 8, the comparison indicates not much change since 1929. The unit stream power computation also indicates this is a reach of fairly consistent sediment transport capacity, with a small trend in decreasing transport. Between RK 8 to 3 the profile comparison shows the most evidence for aggradation since 1929. There is local fluctuation within any reach compared. This could indicate that some reaches with wider, un-constricted floodplain sections tend toward deposition as sediment pulses are transported through the system, and other more constricted reaches are relatively higher transport reaches that are not aggradational. There does not appear to be any evidence of large-scale aggradation of several meters over the entire study reach between 1929 and 2002 from this profile comparison.

It is possible that the 1929 profile was incorrectly adjusted since the datum was not established. Because the amount of incision in the upstream end between RK 14 to 17 seems high, the most likely potential adjustment would be to shift the 1929 profile up, which would lessen the incision amount and increase the downstream aggradation shown in Figure 9. While this might change the magnitude of incision and aggradation, it would not change the conclusions of this comparison, except for between RK 8 to 14. This reach would show more evidence for aggradation than illustrated in Figure 10, but probably only on the order of a meter.

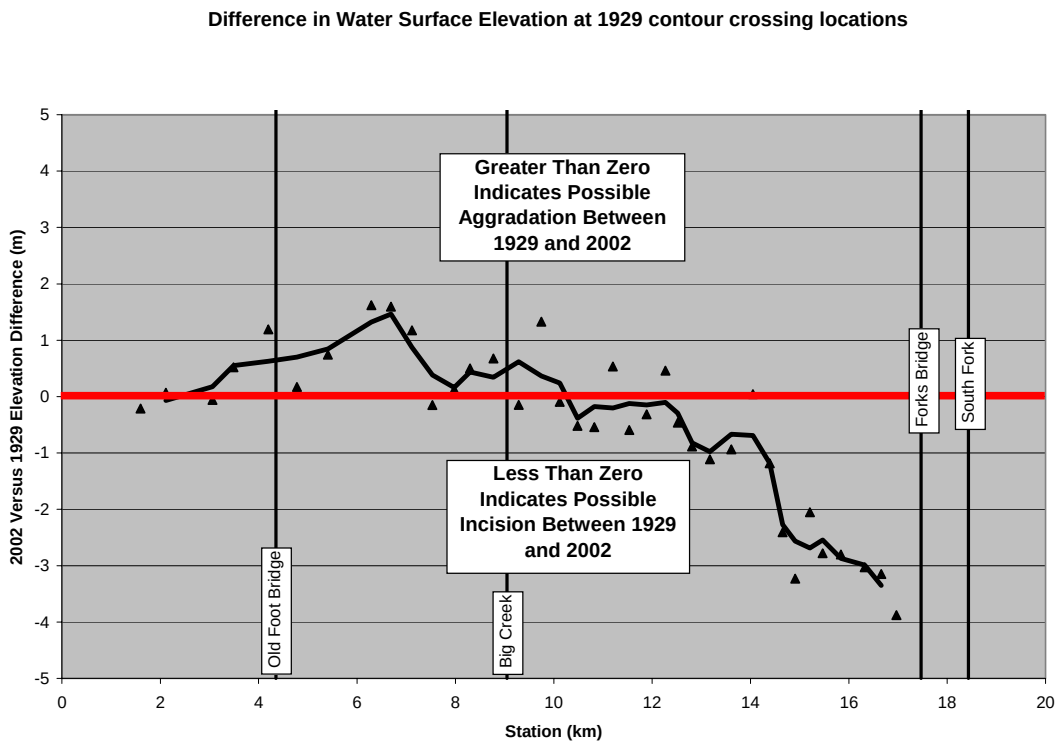

Figure 10. Difference in water surface elevation of 1929 versus 2002 channel. Black line represents a 3-point moving average.

Delta Processes

The lower section of our study reach (RK 0 to 2) is part of a delta that forms as the Quinault River flows into Lake Quinault. The highest lake stage recorded (QIN, 1999) backs water up to almost river kilometer 3, near the downstream end of the Finley Creek alluvial fan. As the slope of the channel flattens at the inlet to Lake Quinault, the river responds by depositing sediment that creates a delta. Over time the delta extends further into the lake (progrades) until the river channel has lengthened so much that the slope is too flat to continue to transport sediment. At this point the channel shifts laterally to a new location and begins to prograde the delta at the new channel position. The channel has to occupy all lateral positions across the delta before the leading (downstream-most) edge of the delta can continue to advance downstream. For a constant lake level, the channel upstream from the lakeshore would be expected to aggrade once the delta has deposited across the width of the lake. Aggradation of the upstream river channel within the influence of the delta would increase flood levels on adjacent land surfaces.

Between 1939 and 2002, the aerial photograph sets indicate the Quinault River has occupied the majority of possible locations at the inlet to Lake Quinault (Figure 11). Additional progradation is expected to occur along the 2002 location before the channel shifts to a new location. The amount of time until the leading edge of the delta begins to move farther downstream is expected to occur over a period of several decades to a century.

Determination if flood stage immediately upstream from the lake shoreline is increasing or decreasing over time could not be quantified in this study. The quantity of additional sediment contributed from measured bank erosion between 1939 and 2002 tends to increase the rate of delta deposition. However, some of the sediment contributed from bank erosion is stored (at least temporarily) in the expanded HCMZ between 1939 and 2002 (see Appendix G). At the downstream end of Lake Quinault, the moraine which controls the lake elevation is incising at an estimated amount of 0.5 m per hundred years (see Appendix C). A lowering of the lake level would cause incision of the river channel in the delta area and tend to reduce flood stage in the upstream river channel influenced by the delta.

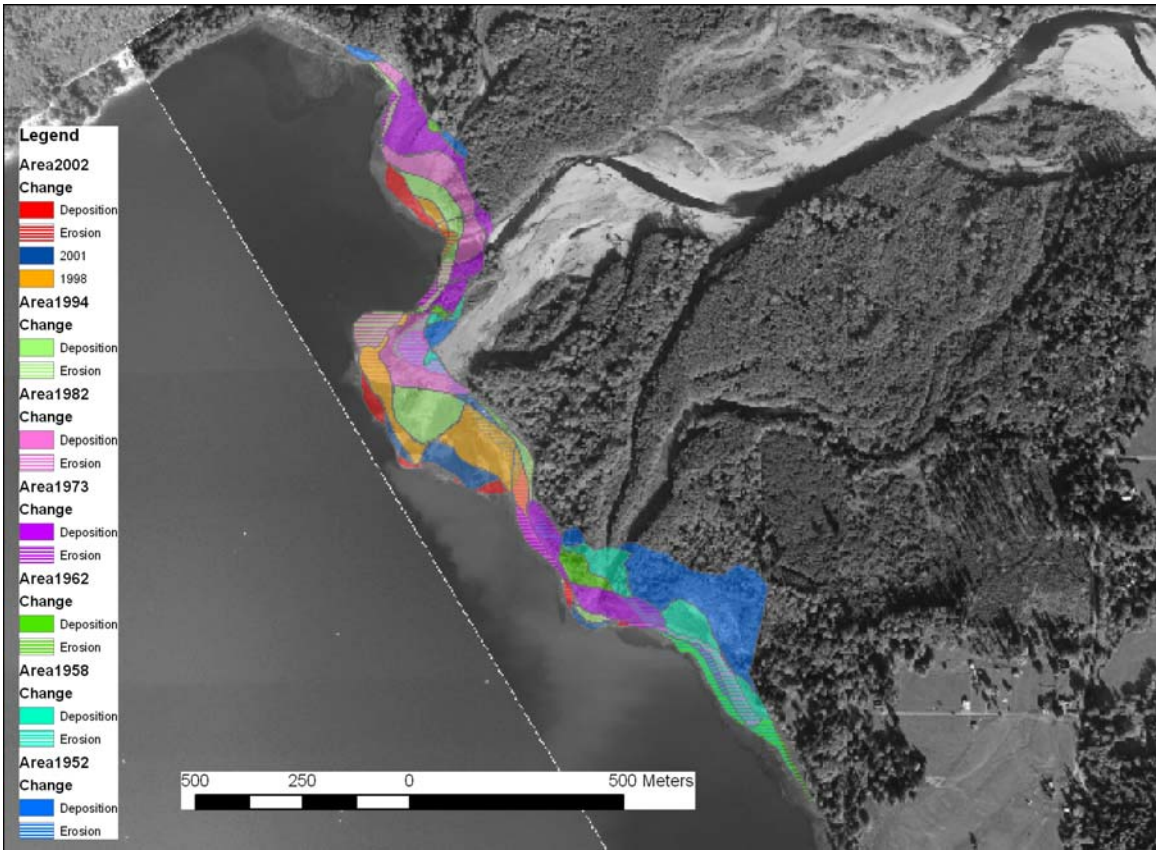

Figure 11. Delta changes at Lake Quinault between 1939 and 2002.

Sediment Budget

A sediment budget is a way of tracking how much sediment is available for transport in the study reach versus how much is transported out of the reach (Gaeuman et al, 2003). If the input sediment volume is larger than the amount of sediment making it out of the study reach, this indicates aggradation may be occurring within the reach. For the Quinault River, the delta of the Upper Quinault River formed as it enters Lake Quinault provides a unique opportunity to measure the amount of sediment being transported out of the study reach. The amount of sediment stored in the study reach can also be measured using topographic data and aerial photography. The volumes of sediment being input to the study reach can be evaluated for bank erosion, but had to be estimated for upstream sediment supply which includes sediment from the upstream drainage basin and incoming tributaries. Changes in fine sediment (silts and clay) loads affect river turbidity and water quality, but do not typically change river morphology in Pacific Northwest Rivers such as the Quinault. Coarse sediment (sand, gravel, cobbles, and boulders), however, can markedly change river morphology. For our study, the sediment budget equation is meant to provide a qualitative method for looking at how the different categories of sediment compare to each other and see if there is any evidence to support aggradation in the river between 1939 and 2002. The sediment budget evaluated cumulative changes in the coarse-sized sediment supply, storage, and transport for the Upper Quinault River between 1939 and 2002 to help answer the following questions:

1) How does the amount of sediment supplied from bank erosion compare to the amount of sediment supplied from the upstream basin (natural load) and amount of sediment in storage between 1939 and 2002?
2) Could bank erosion since 1939, which is believed to have been occurring at an accelerated rate, provide enough coarse sediment to cause aggradation in the river?
3) What amount of aggradation in the study reach is plausible given the available sediment sources and amount of sediment known to exit the study reach (deposit in the delta).

Sediment Budget Equation

The sediment budget for the Quinault River can be represented by the following equation:

[Sediment Inputs to Reach] = [Sediment Stored In Reach] + [Sediment Exiting Reach]

This equation can be re-written in terms of the following variables:

[Upstream Supply + Tributary Sediment (Bed Load and Debris Flows) Within Study Reach + HCMZ Bank Erosion] = [Floodplain storage] + [delta deposition]

In this relationship the upstream supply, tributary sediment loads, and historical channel migration zone (HCMZ) bank erosion are the sediment being contributed to the system. Once the sediment is supplied to the Quinault River it can be stored in the floodplain in new storage areas (created where bank erosion occurs or where channel shifts to a new location), it can aggrade the existing floodplain, or it can be transported out of the reach into Lake Quinault. Each of the variables in the above equation requires a volume of sediment to be measured, estimated, or computed. Because there can be a large amount of variation in sediment transport from year to year and between aerial photographs we had available for interpretation, we used our sediment budget equation to evaluate the cumulative changes in sediment volume for each variable between 1939 and 2002, rather than trying to only look at values between aerial photography. We developed a spreadsheet to work with the sediment budget using the following steps:

- Step 1: Measure Historic Channel Migration Zone (HCMZ) area on aerial photography (area bound by terraces, bedrock, or alluvial fan where channel has been since 1939)
- Step 2: Measure Side Channel Area: Area of wetted side channels within HCMZ
- Step 3: Measure Active Channel Area: Area of primary unvegetated, active channel within HCMZ
- Step 4: Compute Sediment in Storage = [(HCMZ area - side channels - active channels) X (estimated surface height above active channel)]

- Step 5: Measure delta growth between aerial photographs, and determine volume by multiplying by height of delta as measured in 2002 survey
- Step 6: Measure area of terrace bank erosion & compute volume of coarse sediment supplied to Quinault River
- Step 7: Compute upstream supply based on sediment budget equation (balance between other components of sediment budget)
- Step 8: Sediment transport capacity within the active channel was computed to check capacity versus computed incoming supply from sediment budget
- Step 9: Factor in potential aggradation and evaluate sensitivity of upstream supply to see if reasonable assumption
- Step 10: Use input values (yellow squares in spreadsheet) to look at sensitivity to budget of adjusting values assumed as input data and possible error in measurements

The following variables were measured using aerial photography:

1) Bank Erosion Area
2) Floodplain Storage Area
3) Delta Deposition Area

The area measurements have a fairly high degree of confidence, although there is some error incorporated due to error in aerial photo rectification and human error in mapping. How these areas were mapped based on interpretations on aerial photographs spaced roughly a decade apart is discussed in detail in GIS Appendix I. For these three variables of area, the height of the area eroded or deposited had to be estimated to get a sediment volume. Heights were determined using field observations, 2002 LiDAR data, and 2002 cross-sections generated from the LiDAR and river channel survey data. Because the heights can be variable throughout the study reach, a high and a low estimate of the potential range of heights were made (see Tables 4 and 5).

The upstream supply of sediment and tributary sediment loads within the study reach are not known. These variables were lumped together as one term and computed by rearranging the sediment budget equation to solve for “supply”. An attempt was made to determine the incoming sediment supply based on sediment transport capacity using a sediment transport equation and the hydraulic model output data. However, due to the large amount of sediment in storage available to the channel and the rapid shifting of the channel during high flows, this approach was believed to under-estimate the amount of sediment being brought in from the upstream drainage basin and was not used.

The amount of aggradation in the system was considered an input variable. The sediment budget was formulated in such a way that the aggradation could be adjusted between a low and high range to see its effect on other variables. The percentage of the study reach with aggradation was also an input variable that could be adjusted from 0 to 100%. Because the only unknown variable in the equation is the upstream supply, any amount of aggradation applied must be made up for by increasing the upstream sediment volume

supplied to the study reach system. How much aggradation is plausible can be estimated by comparing how much aggradation could occur in the study reach and still provide reasonable estimates of the upstream supply. The definition of reasonable was determined from our experience on other gravel-bed rivers with known measurements, and a comparison to the nearby Elwha River drainage with a measured upstream supply of coarse sediments.

Sediment Supply between 1939 and 2002

Sediment sources for the Upper Quinault River include sediment transported in from the upper drainage basin, sediment supplied from tributaries as bed load or debris flows, sediment stored in the active floodplain in the form of bars and islands that can be re-mobilized during high flows, and sediment supplied as the river erodes the surfaces binding the historic channel migration zone (terraces, lake deposits, and alluvial fans). The first step of the sediment budget was to evaluate if there was any evidence to support a change in sediment supply from any of these sources between 1939 and 2002.

The watershed analysis (QIN, 1999) concluded that there have been no significant changes in large-scale sediment sources associated with landslides in the upper basin above the Forks. The watershed analysis (QIN, 1999) also concluded that there is no evidence from gage data at the outlet of Lake Quinault for a change in flood peaks or recurrence interval since 1939 that would result in more sediment transport. This implies that the upstream sediment supply entering the Quinault River at the Forks should not have significantly changed between 1939 and 2002.

Below the Forks, both Finley Creek and Big Creek drain from the north and have natural debris fans that contribute sediment to the Quinault River. At least one small drainage on the south side, Fletcher Creek, was also observed by our study team to have debris flows that reach the Quinault River. Although there are no measurements of the volume of sediment contributed from these drainages, our visual observations in the field indicate that the amount of sediment contributed is presently small relative to the total load of the Upper Quinault River. The two largest tributaries to the Quinault in the study reach are Finley creek and Big Creek. Historically, the Finley Creek alluvial fan periodically provided sediment to the Quinault River during debris flows. In recent decades the upstream Finley Creek channel has been dredged and now little Finley Creek sediment likely reaches the Quinault River. This hypothesis is supported by the fact that the Quinault River has eroded a significant portion of the toe of the fan in recent years. The other major tributary in this reach is Big Creek. Although Big Creek does contribute sediment to the Quinault, no large fan is visible in the Quinault River. Thus Big Creek's sediment contribution is small relative to the sediment load and transport capacity on the Upper Quinault. Smaller drainages do periodically have debris flows, some of which reach the Quinault River, but the coarse sediment that they contribute was estimated to be a small portion of the total coarse sediment load in the system.

A fisheries report from 1936 mentions three large landslides that occurred in the early 1930s in our study reach. The 1939 aerial photographs were evaluated to look for evidence of these slides. Large slides on the hill slopes could be seen in the Finley Creek drainage and along the south side of the river near Fletcher Creek, however, the landslides appeared to be contained on the hill slopes and did not reach the river. Although fine sediment could have easily traveled quickly to the river from the slide areas, there was no evidence of an increase in tributary channel size or alluvial fans at the confluence with the Quinault River that might indicate sediment contributions were larger in 1939 than today. There is no obvious evidence that the magnitude of coarse sediment contributed from tributaries has changed between 1939 and 2002 in a significant amount that would alter the sediment supplied during debris flow events. There has been significant logging on the hill slopes of the Upper Quinault valley during this time period which could accelerate the rate and volume of sediment delivered to the Quinault River, particularly fine sediment that is easily transported. Evaluation of this potential impact was beyond the scope of our study.

Bank Erosion

Bank erosion along terraces, lake deposits, and alluvial fan material were measured between 1939 and 2002 along the boundary of the historic channel migration zone in GIS (see GIS Appendix I). The volume of bank erosion was then computed by multiplying a height to the area of erosion. The height of the bank being eroded can vary depending on the height of the surface being eroded relative to the river bed. The higher the surface above the bed, the greater the height. Additionally, not all of the bank material being eroded contains coarse sediment. A low and high height range was estimated based on 2002 LiDAR data, field estimates, and cross-section developed from the 2002 LiDAR and channel survey data. A low and high percent of bank containing coarse sediment was estimated based on field observations of exposed banks. Results were used to assess how much additional sediment has been added to the upstream supply, and how that volume compares with the amount now stored in the floodplain or transported to Lake Quinault.

Delta Sediment

The cumulative volume of delta deposition since 1939 was measured to evaluate the volume and rate of coarse sediment that has been transported out of the Upper Quinault River study reach into Lake Quinault (see Figure 11). Based on aerial photography between 1939 and 2002, it was assumed that the delta has been building primarily longitudinally and laterally into the lake rather than vertically. This allowed us to measure the area of delta growth by looking at the exposed portion of the delta on aerial photographs of the lake inlet. Under this scenario, the height of the delta would be relatively consistent since 1939 as the channel continues to shift to new positions. A low and high estimate of delta height was determined from a 2002 longitudinal profile survey of the delta (Figure 12).

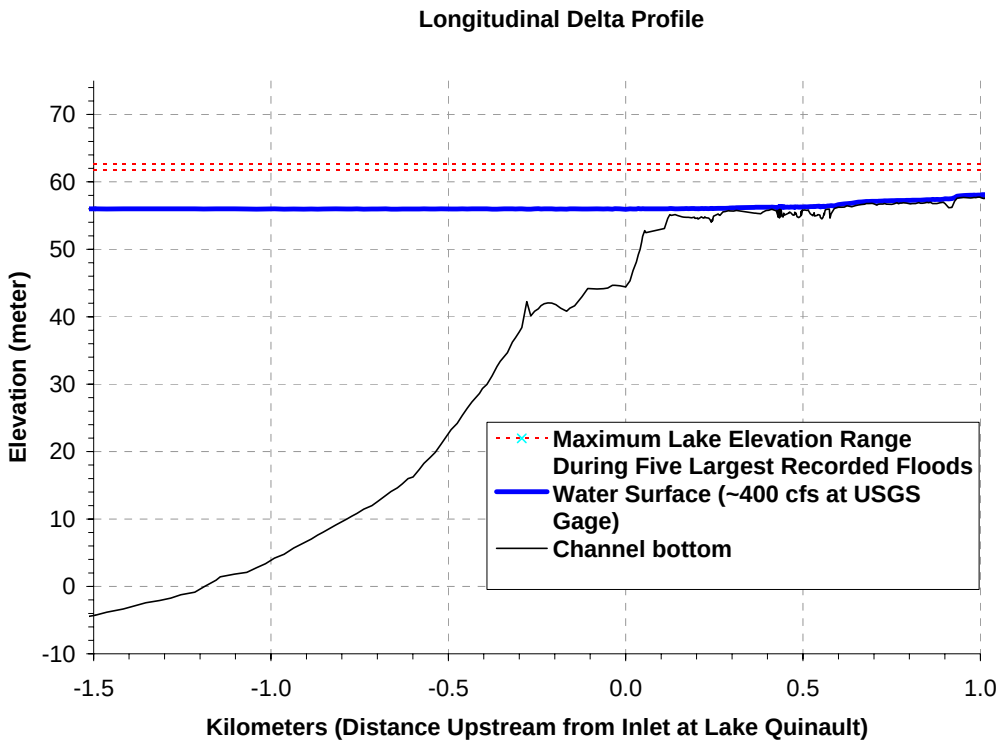

Figure 12. Profile from 2002 survey data of delta at inlet to Lake Quinault.

Floodplain Storage

Floodplain storage was measured by delineating the area of HCMZ containing sediment bars, either unvegetated or vegetated. Floodplain storage areas did not include the area occupied by the active Quinault River channel or significant (normally wetted) side channels. These channels are typically inundated during all flows. A low and high range of heights of the sediment being stored in the floodplain was determined by measuring the height of bars above the average channel bed on cross sections generated from the 2002 channel and LiDAR data surveys.

Sediment Budget Spreadsheet and Results

Because part of the objective in using the sediment budget was to be able to adjust the variables in the equation, a spreadsheet was developed that allows the computations to be interactive based on user input. The spreadsheet follows the methodology explained in the sediment budget equation section of this appendix, and can be used to test how a specified level of aggradation over a specified percentage of the floodplain affects the balance of sediment variables in the sediment budget. In reality, certain areas of the Quinault River would be in an aggradational mode while others are in equilibrium. The aggradation input value is meant to provide a generalized average of the study reach to look at implications on aggradation to the sediment balance in the system. Two checks

were also made on the sediment budget input variables to see if the input values are reasonable:

1. Difference between height of terrace and floodplain storage thickness should be greater than 0
2. Quinault sediment supply should be greater than the Elwha sediment supply by a reasonable amount based on the following criteria:
    a. Elwha upstream coarse sediment supply is 6,000,000 yds^3/yr as measured at Lake Mills between 1927 and 1994
    b. Drainage areas of two rivers similar; and
    c. Quinault 2-yr flood is greater than twice the Elwha 2-yr flood at the points where the drainage areas are similar.

An example of using the baseline set of values in the equation is shown in Attachment 3. These values represent our best estimates on the possible range of input values based on our measurements and interpretation of sediment processes in the system. In this example, permanent aggradation is assumed to have occurred between 1939 and 2002 between 0.3 to 0.5 meters across 50% of the entire HCMZ within the study reach (Table 4). This aggradation amount combined with other baseline input values indicate that the upstream supply of the Quinault River is 3 to 4 times that of the Elwha River (measured at inlet to Lake Mills). This differential seems reasonable given that, at the points compared, the Elwha River's drainage area is nearly equivalent to that of the Upper Quinault River, but its 2-year discharge is less than half. Aggradation of 3 meters (about 10 feet) over the entire study reach was also assumed with the some baseline input variables as a test of the order of magnitude of possible deposition of sediment between 1939 and 2002. This assumption increased the Quinault River's upstream sediment supply by a factor of 3, which seems unreasonably high for this drainage basin. This interpretation along with the additional information provided in this appendix suggests that some aggradation is possible on the Upper Quinault, but on the order of a few feet rather than several feet, and only in localized areas and not across the entire floodplain in the eighteen kilometers of study reach.

Using the same baseline variables as shown in Table 4 and measurements of additional variables (delta area, bank erosion area, and floodplain storage area) as shown in Attachment 3, the total sediment input and output contributions were determined (Table 5). These results indicate that bank erosion contributes 6 to 15% of the total incoming sediment supply. The volume of bank erosion exceeds the amount of sediment in floodplain storage, so some aggradation of the floodplain from bank erosion is possible.

Table 4. Input variables and computation "checks" for sediment budget. See Attachment 3 for guidelines on low and high range of variables with yellow cells.

User Input Variables & Checks	Low Range	High Range
Floodplain Storage Thickness Above Act Ch Bottom (m)	0.5	1
Delta Storage Thickness (m)	44	50
Height of eroded terrace bank (m)	1	2
% of terrace bank containing coarse sediment	50%	70%
Aggradation of HCMZ since 1939 (m)	0.3	0.5
% of HCMZ aggraded	50%	50%
Check difference between terrace height and floodplain storage (m)	0.5	1.0
Check ratio between Elwha & Quinault Sediment Supply	3.6	4.1

Table 5. Sediment budget input and output summary for low and high range of baseline variables shown in Table 3.

		LOWER RANGE VALUES			
		Volume (m^3)	Total Input or Output (m^3)	% Input or Output	Annualized Values 1939 to 2002 (m^3/year)
Sediment Inputs:	Bank Erosion	1,067,719		6%	16,948
	Upstream Supply	15,675,260	16,742,978	94%	248,814
Sediment Outputs:	Floodplain Storage	963,445		6%	15,293
	Aggradation	1,426,540		9%	22,643
	Delta Storage	14,352,993	16,742,978	86%	227,825
		UPPER RANGE VALUES			
		Volume (m^3)	Total Input or Output (m^3)	% Input or Output	Annualized Values 1939 to 2002 (m^3/year)
Sediment Inputs:	Bank Erosion	2,989,613		15%	47,454
	Upstream Supply	17,625,064	20,614,677	85%	279,763
Sediment Outputs:	Floodplain Storage	1,926,890		9%	30,586
	Aggradation	2,377,567		12%	37,739
	Delta Storage	16,310,219	20,614,677	79%	258,892

Conclusions

We used a suite of sediment transport analysis indicators to look for evidence of river aggradation or incision within the study reach between the early part of the twentieth century and 2002. Conclusions from this analysis are presented below.

Upper Reach (RK 14 to 17)

Since the early part of the twentieth century the Quinault River between RK 14 and 17 has incised (eroded) on the order of a few meters or less. The HCMZ in this reach is naturally more constricted than downstream sections of the study reach suggesting it has always had higher sediment transport capacity than downstream sections, but the channel was more meandering from 1939 to 1973. The south side of the HCMZ is lined by a road and bedrock. The north side of the HCMZ boundary is terrace and has had some measurable expansion, but since 1973 the channel has remained mostly on the south side. This resulted from a constriction (beyond natural influences) imposed by the Forks Bridge and a levee constructed just downstream. This narrowing of the channel and floodplain area would likely increase sediment transport capacity and could result in incision. Evidence of incision was found in our analysis from the comparison of the 1929 to 2002 profile showing the main channel lower today than in 1929; cross section comparisons showing the present main channel about 1 m lower than adjacent side channels (which is not typical in braided, aggrading channels); unit stream power computations that show a higher transport capacity in this section than all other areas of the study reach; and pebble count data that indicate the coarsest size particles in this section.

Middle Reach (RK 2 to 14.7)

Aggradation would be expected in areas where the HCMZ is widest, the channel migrates rapidly, sediment transport capacity decreases relative to upstream sections, and there is accelerated delivery of sediment relative to natural conditions. This is what we observed between RK 2 to 14.7 in the Middle Reach. Sequential aerial photography shows the rapid migration of the river between 1939 and 2002, which is supported by regime equations that note the river is dominantly braided (with meandering tendencies), and channel cross-sections which show the channel is equal in elevation across the floodplain indicating depositional tendencies. A longitudinal profile comparison between 1929 and 2002 shows a higher channel bed today than in 1929; and stream power and pebble count results which shows a lower transport capacity in this reach relative to the upstream reach even with an increase in discharge.

Above natural sediment loads has been supplied to the Middle Reach over the last century which also supports potential for aggradation, at least temporarily. Sediment supplied above natural levels is thought to have occurred during early disturbance in the twentieth century when stable islands were cleared and released large, localized sediment sources; from the channel bed in the upstream reach following incision in latter part of

twentieth century; and from high rates of bank erosion occurring in the Middle Reach along the HCMZ boundary since at least 1939. On the other hand, the HCMZ has expanded between 1939 and 2002 and the active channel has remained a consistent width. This indicates the additional HCMZ area provides more floodplain storage as it expands. The amount of sediment contributed to the Middle Reach from upstream incision and early twentieth century island disturbance could not be quantified and compared to the increase in storage area. Changes in floodplain storage and bank erosion were quantified as part of the sediment budget exercise, but the increase in storage does not account for all of the terrace bank sediment that has been contributed. This indicates there is a potential for aggradation in the Middle Reach just from bank erosion without even considering other sediment sources that may have added to natural levels.

The amount of aggradation that has occurred over the last century is thought to be on the order of a few feet over the entire Middle Reach, but may be higher or even near zero in localized areas. The 1929 versus 2002 profile suggest it is on the order of zero to two meters between RK 2 to 10, but has been relatively minimal between 10 to 14. This is also supported by the unit stream power plots which show between RK 10 to 14 sediment transport capacity gradually decreases, and then levels off between 10 to 2. Further, the sediment budget indicates the upstream sediment load to the study area is large relative to the amount contributed from bank erosion or other smaller localized sources. A significant change in the balance between sediment load and river flow can change the river's sediment transport capacity and produce a change in the width of the active channel. We compared average active channel widths from 1939 to 2002 but did not find any significant trends that would indicate a change in sediment transport capacity. This provides some evidence that the aggradation rates have not increased dramatically since 1939, such that channel width increased. The regime equations indicate the present study reach is more prone to a braided channel which is a sign of aggradation, but that there are some meandering tendencies which also indicates it may not be aggrading at a rapid rate.

Results from the woody debris transport analysis also indicate that there are high and low transport reaches within the Middle Reach (see Woody Debris Appendix E). The majority of wood present and being mobilized in the system is small, and is thought to be qualitatively comparable to coarse sediment transport processes. Large woody debris jams may locally cause scour and aggradation, but because they are limited in number and do not persist for long periods of time, their overall influence on sediment transport in the system since 1939 is thought to be limited.

The Middle Reach may naturally have been prone to deposition to some degree even before disturbance since the HCMZ was wider with a flatter slope than upstream sections, but it is difficult to know without more topographic information of the reference channel conditions. Presently, channels in the middle reach aggrade as they fill with sediment and result in channel shifting. We conclude, however, that when the river later re-occupies this former channel area, the deposited sediment is reworked and transported downstream, and the average floodplain elevation does not increase a significant amount. Our interpretation suggests that future aggradation can occur in the widest sections of the middle reach as long as the channel remains wide and shallow and bank erosion volumes

continue to outweigh increase in floodplain storage areas. However, the amount of aggradation would be expected to continue to be small on the order of a few feet over several decades due to the large area of available storage.

Lower Reach (RK 0 to 2)

The lower section of our study reach (RK 0 to 2) is part of a delta that forms as the Quinault River flows into Lake Quinault. The highest lake stage recorded (QIN, 1999) backs water up to almost river kilometer 3, near the downstream end of the Finley Creek alluvial fan. Between 1939 and 2002, the aerial photograph sets indicate the Quinault River has occupied the majority of possible locations at the inlet to Lake Quinault (see Figure 12). Additional progradation is expected to occur along the 2002 location before the channel shifts to a new location. The amount of time until the leading edge of the delta begins to move farther downstream is expected to occur over a period of several decades to a century. Determination if flood stage immediately upstream from the lake shoreline is increasing or decreasing over time could not be quantified in this study from available data.

Additional Study

There was sufficient evidence to qualitatively describe incision and aggradation processes in the study reach over the last century, but there is less evidence and more uncertainty in our ability to quantify these conclusions. Comparing future LiDAR and channel surveys to 2002 topographic data would help monitor and refine our interpretations. Another technique that could be tried is a new GIS analysis that recreates topographic elevations on historical aerial photography. Although beyond the scope of our study, this technique may allow generation of elevation data on exposed bars in older aerial photography, such as the 1939 or 1952 photographs. These floodplain elevations could be compared to present floodplain elevations from the 2002 LiDAR data over the study reach to look for changes and trends that would better quantify our conclusions.

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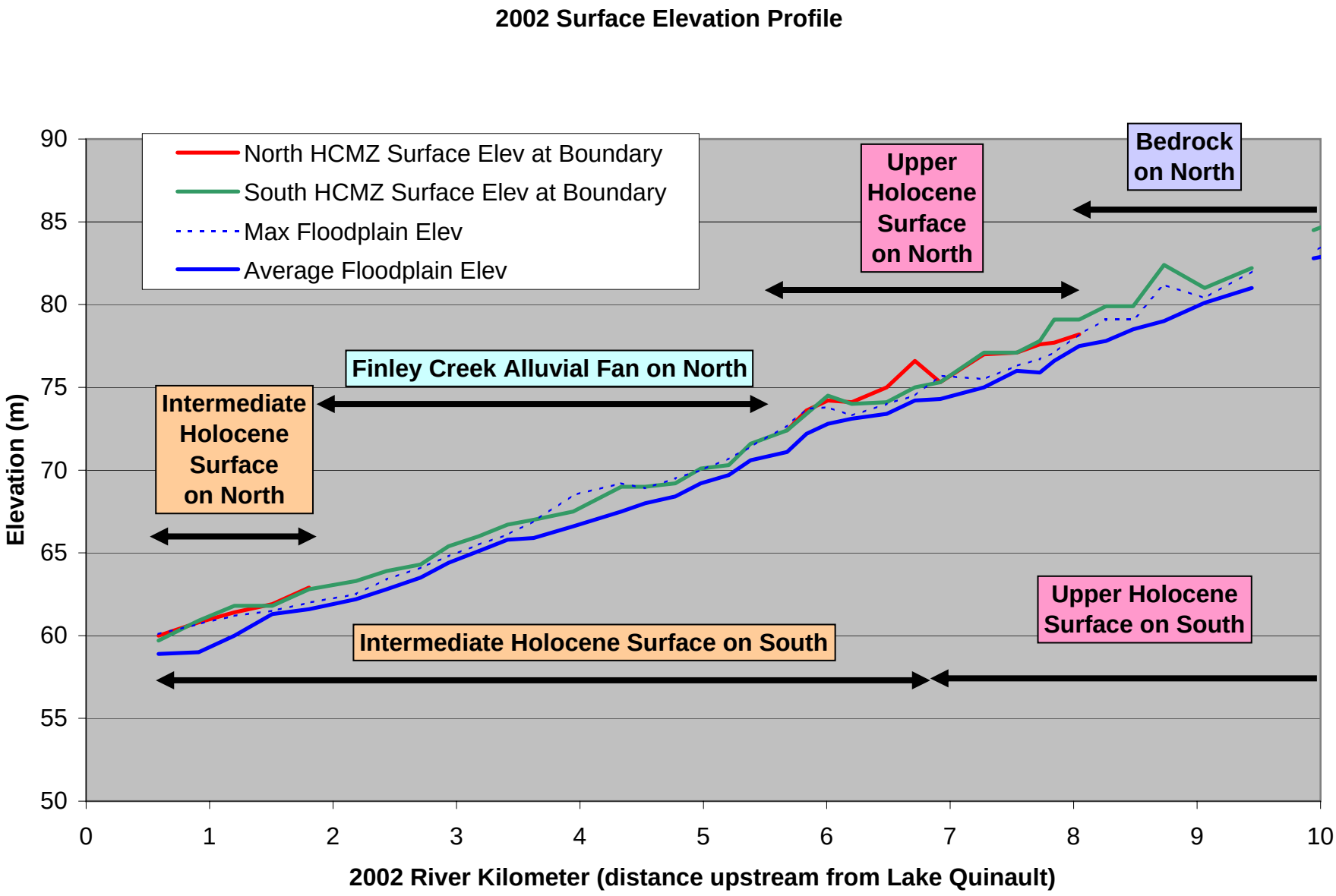
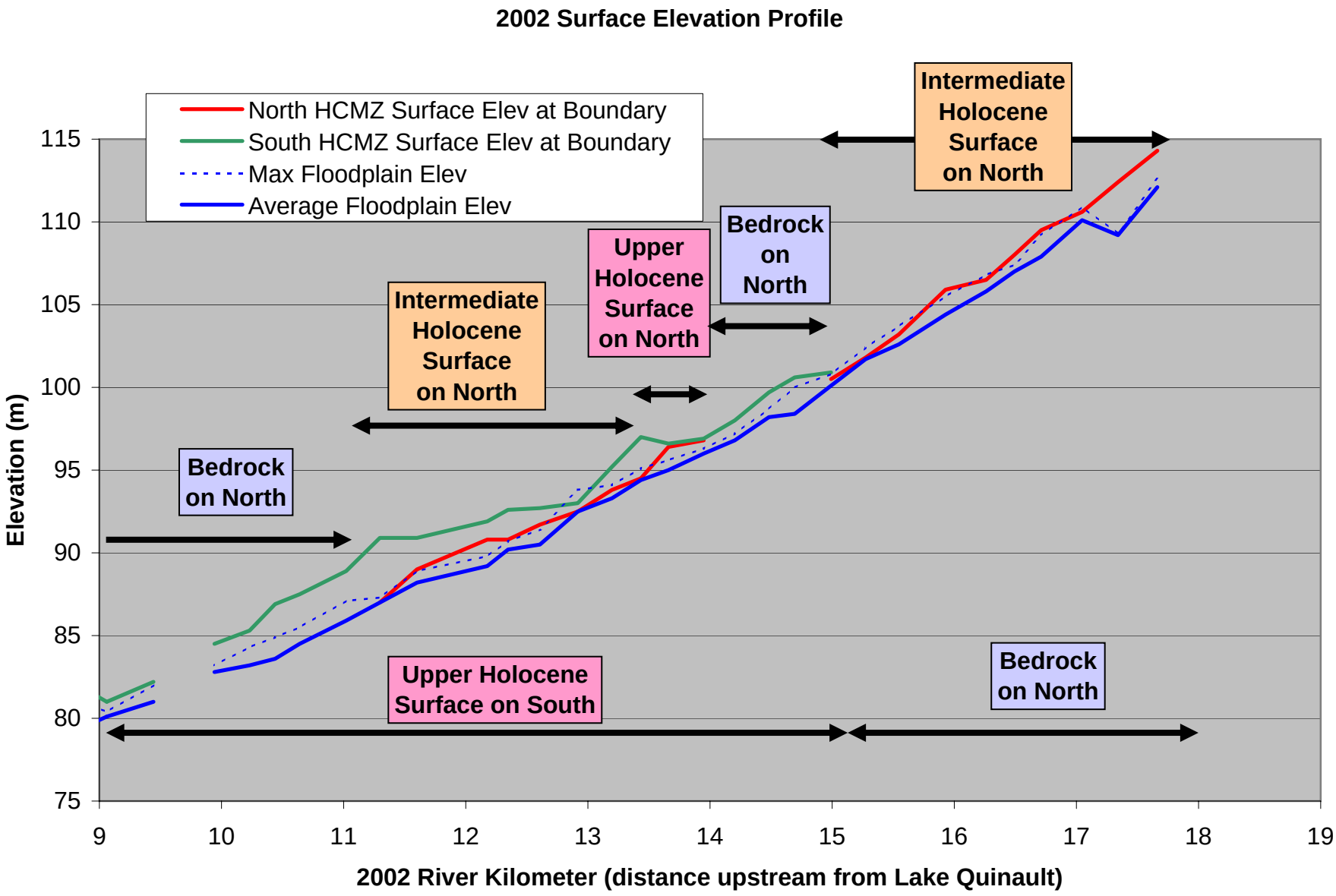
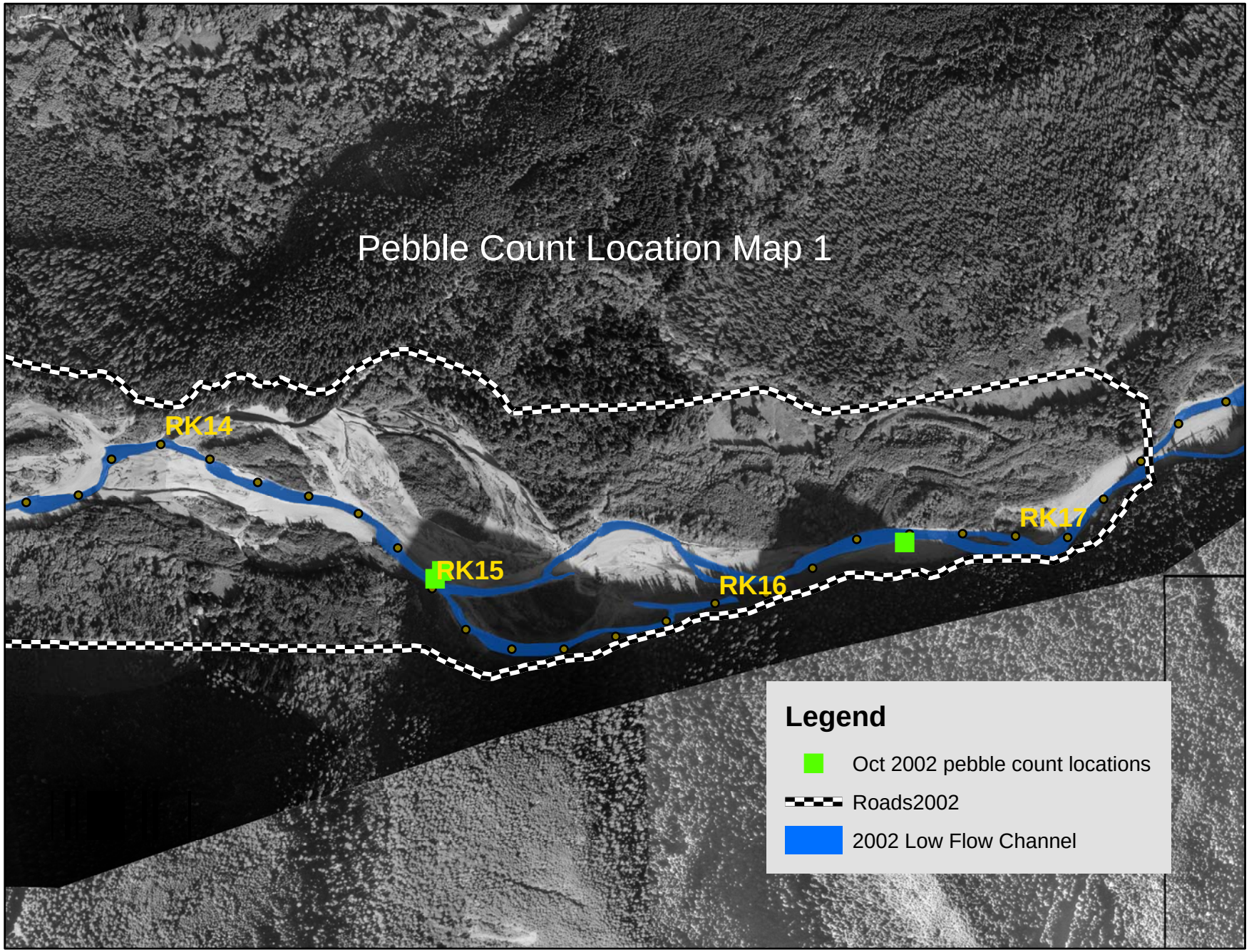
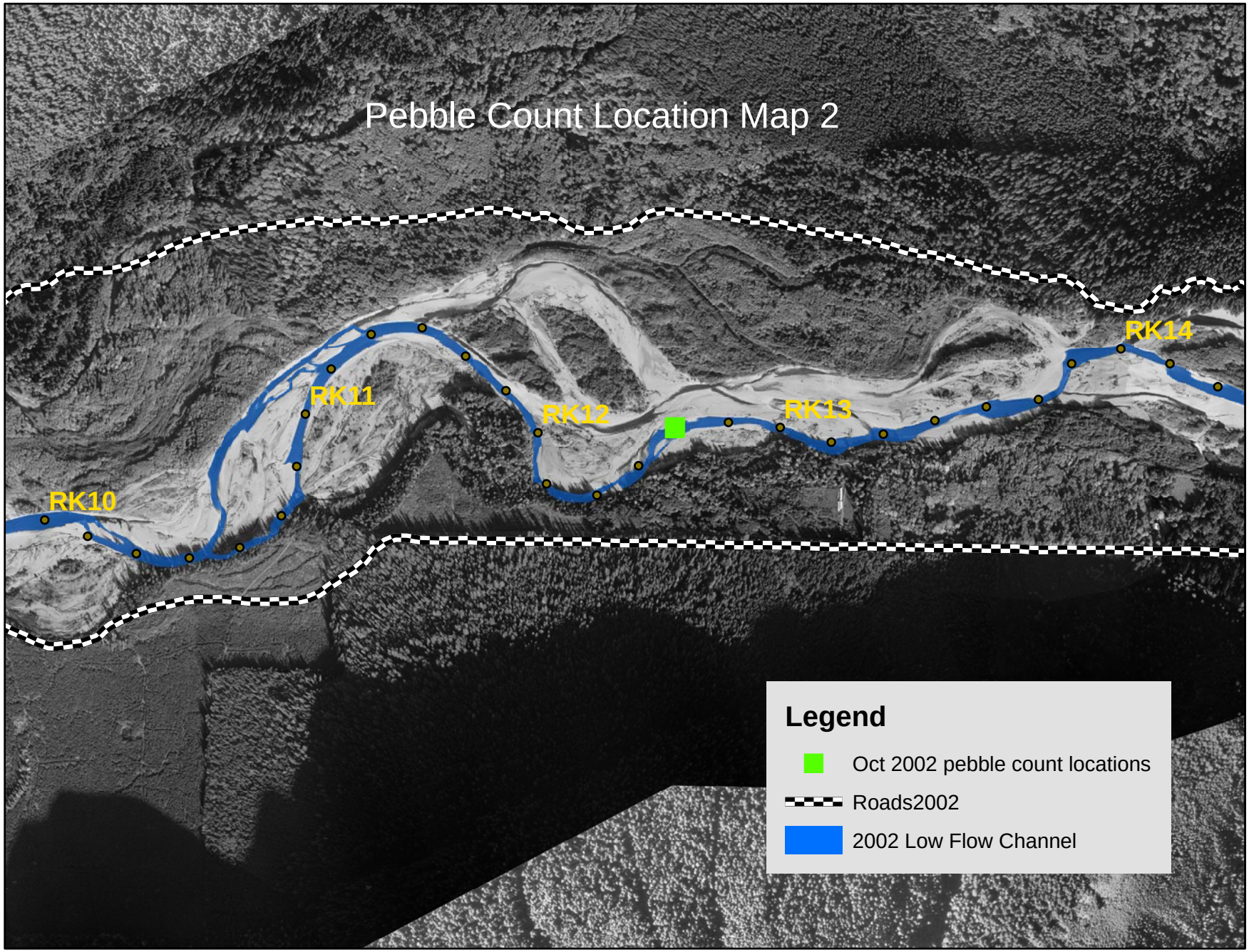
ATTACHMENT 1:
Surface elevation profiles of terraces and floodplain bars within the study reach.

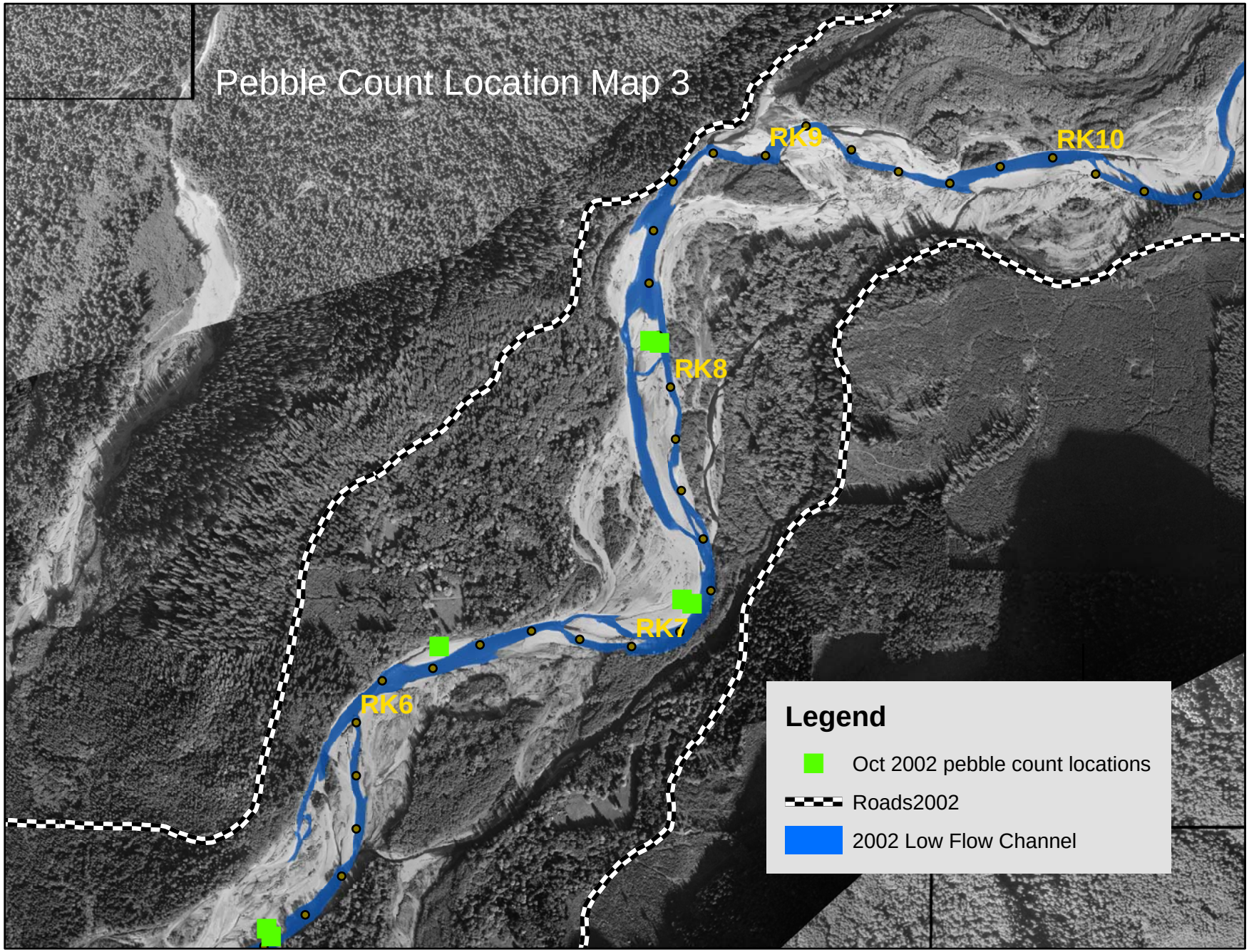

2002 Surface Elevation Profile
North HCMZ Surface Elev at Boundary
South HCMZ Surface Elev at Boundary
Max Floodplain Elev
Average Floodplain Elev
Bedrock on North
Upper Holocene Surface on North
Finley Creek Alluvial Fan on North
Intermediate Holocene Surface on North
Upper Holocene Surface on South
Intermediate Holocene Surface on South
Elevation (m)
90
85
80
75
70
65
60
55
50
0
1
2
3
4
5
6
7
8
9
10
2002 River Kilometer (distance upstream from Lake Quinault)

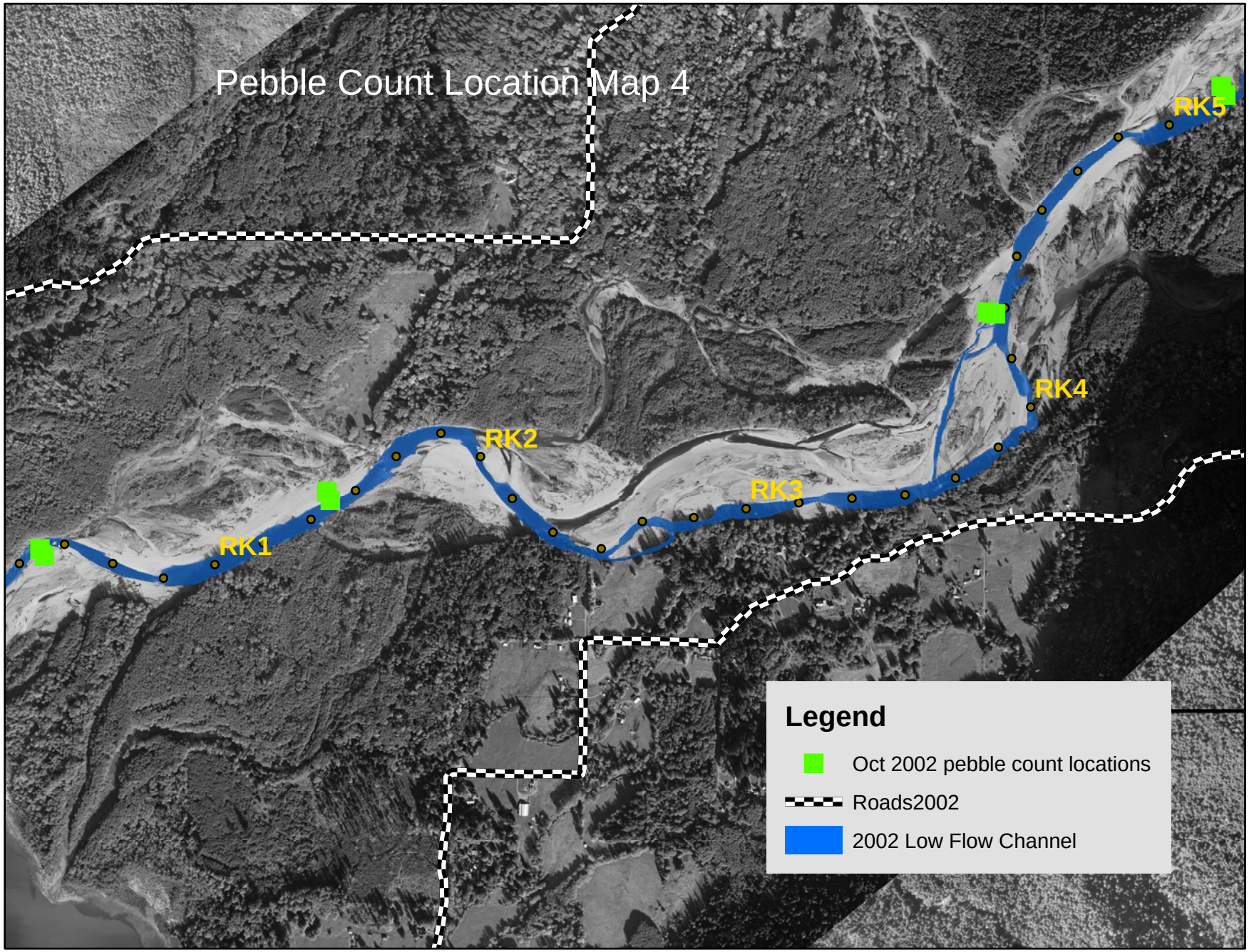

2002 Surface Elevation Profile
North HCMZ Surface Elev at Boundary
South HCMZ Surface Elev at Boundary
Max Floodplain Elev
Average Floodplain Elev
Intermediate Holocene Surface on North
Bedrock on North
Upper Holocene Surface on North
Intermediate Holocene Surface on North
Bedrock on North
Upper Holocene Surface on South
Bedrock on North
Elevation (m)
115
110
105
100
95
90
85
80
75
9
10
11
12
13
14
15
16
17
18
19
2002 River Kilometer (distance upstream from Lake Quinault)

ATTACHMENT 2:
Pebble Count Locations from October 2002. Yellow circles and text in figures document river kilometer distance from Lake Quinault along 2002 low flow channel.


Pebble Count Location Map 1
RK14
RK15
RK16
RK17
Legend
Oct 2002 pebble count locations
Roads2002
2002 Low Flow Channel


Pebble Count Location Map 2
RK10
RK11
RK12
RK13
RK14
Legend
Oct 2002 pebble count locations
Roads2002
2002 Low Flow Channel


Pebble Count Location Map 3
RK9
RK10
RK8
RK7
RK6
Legend
Oct 2002 pebble count locations
Roads2002
2002 Low Flow Channel


Pebble Count Location Map 4
RK1
RK2
RK3
RK4
RK5
Legend
Oct 2002 pebble count locations
Roads2002
2002 Low Flow Channel

ATTACHMENT 3:
Sediment budget worksheet example

ATTACHMENT 3: SEDIMENT BUDGET WORKSHEET

Purpose: To look at sensitivity and relative contribution of sediment budget components
Data Extent: RK 0 (Inlet at Lake Quinault) upstream to RK 15.8 (extent of shortest aerial photo coverage: 1998)

How to use: Follow steps listed below.
Yellow cells indicate numbers that can be changed to adjust budget
Green squares show numbers used in budget

Sediment Budget Equation: Upstream supply + terrace bank erosion - delta deposition = change in floodplain storage

User Input Variables & Checks	Low Range	High Range	Guidelines
Floodplain Storage Thickness Above Act Ch Bottom (m)	0.5	1	*Cross section measurements (Oct 2002) indicate this value ranges between 0.5 m to 1 m*
Delta Storage Thickness (m)	44	50	*Measurements from Oct 2002 survey show delta thickness of 44 to 50 m*
Height of eroded terrace bank (m)	1	2	*Majority of historical terrace bank erosion estimated to occur on intermediate Holocene surface, which is 1 to 2 m above normal water surface elevation based on Lidar data and field observations*
% of terrace bank containing coarse sediment	50%	70%	*Visual observations of exposed terrace banks indicate about 50% to 70% of bank is composed of coarse sized sediment*
Aggradation of HCMZ since 1939 (m)	0.3	0.5	*Aggradation estimated to be less than 1m since 1939 based on terrace heights, cross sections, and historical channel paths (0.3 to 0.5 m is default range)*
% of HCMZ aggraded	50%	50%	*Sediment analysis indicates that since 1939: 1) downstream most 20% HCMZ is aggrading due to delta, 2) middle 70% HCMZ is transititional, and 3) active channel in upstream-most 10% HCMZ is incisional since 1939 (default is to assume 50% of HCMZ has aggraded)*
Check difference between terrace height and floodplain storage (m)	0.5	1.0	*Difference between height of terrace and floodplain storage thickness should be greater than 0*
Check ratio between Elwha & Quinault Sediment Supply	3.6	4.1	*Elwha Upstream Coarse Sediment Supply (6,000,000 yds^3/yr measured at Lake Mills between 1927 and 1994); drainage areas of two rivers similar; Quinault 2-yr flood greater than twice the Elwha 2-yr flood;*

		LOWER RANGE VALUES				UPPER RANGE VALUES			
		Volume (m^3)	Total Input or Output (m^3)	% Input or Output	Annualized Values (m^3/year)	Volume (m^3)	Total Input or Output (m^3)	% Input or Output	Annualized Values (m^3/year)
Sediment Inputs:	**Bank Erosion**	1,067,719		6%	16,948	2,989,613		15%	47,454
	Upstream Supply	15,675,260	16,742,978	94%	248,814	17,625,064	20,614,677	85%	279,763
Sediment Outputs:	**Floodplain Storage**	963,445		6%	15,293	1,926,890		9%	30,586
	Aggradation	1,426,540		9%	22,643	2,377,567		12%	37,739
	Delta Storage	14,352,993	16,742,978	86%	227,825	16,310,219	20,614,677	79%	258,892

Note: Measurements accomplished in GIS on rubber-sheeted or ortho-rectified aerial photographs. Some error exists in these measurements.

Sediment Storage

Step 1: Measure Historic Channel Migration Zone (HCMZ) Area on aerial photography (area bound by terraces, bedrock, or alluival fan where channel has been since 1939)

Reach:	1939 (m^2)	1952 (m^2)	1962 (m^2)	1973 (m^2)	1982 (m^2)	1994 (m^2)	2002 (m^2)	% total HCMZ
Upper (RK 14 to 15.8)	796,198	831,872	892,783	882,962	888,854	901,238	906,894	9.5%
Middle (RK 2 to 14)	5,416,003	5,593,108	5,944,426	6,053,405	6,381,233	6,689,202	6,898,660	72.5%
Lower (RK 0 to 2)	1,129,149	1,177,392	1,272,357	1,438,126	1,494,879	1,621,848	1,704,715	17.9%
Sum of HCMZ Areas	7,341,350	7,602,372	8,109,566	8,374,493	8,764,966	9,212,288	9,510,269	

Step 2: Measure Side Channel Area: Area of wetted side channels within HCMZ

	1939 (m^2)	1952 (m^2)	1962 (m^2)	1973 (m^2)	1982 (m^2)	1994 (m^2)	2002 (m^2)
RK 0 to 15.8	113,725	180,297	95,630	134,043	282,324	368,556	668,480

Step 3: Measure Active Channel Area: Area of primary unvegetated, active channel within HCMZ

	1939	1952	1962	1973	1982	1994	2002
	(m^2)	(m^2)	(m^2)	(m^2)	(m^2)	(m^2)	(m^2)
RK 0 to 15.8	1,894,725	1,627,821	2,223,055	1,747,652	1,318,664	1,852,395	1,581,997

Step 4: Compute Sediment in Storage = (HCMZ area - side channels - active channels) * Estimated surface height above active channel

		1939	1952	1962	1973	1982	1994	2002
	Area (m^2)	5,332,901	5,794,254	5,790,882	6,492,798	7,163,978	6,991,336	7,259,791
	Lower Volume (m^3)	2,666,450	2,897,127	2,895,441	3,246,399	3,581,989	3,495,668	3,629,895
	Upper Volume (m^3)	5,332,901	5,794,254	5,790,882	6,492,798	7,163,978	6,991,336	7,259,791
Lower Value:	Change Relative to 1939 (m^3)		230,677	228,990	579,949	915,539	829,218	963,445
Upper Value:	Change Relative to 1939 (m^3)		461,353	457,981	1,159,897	1,831,078	1,658,436	1,926,890

Delta Deposition

Step 5: Measure delta growth between aerial photographs, and determine volume by multiplying by height of delta as measured in 2002 survey

		1939 to 1952	1952 to 1962	1962 to 1973	1973 to 1982	1982 to 1994	1994 to 2002
	Area (m^2)	58,922	59,399	58,770	52,807	35,570	60,737
	Lower Volume (m^3)	2,592,556	2,613,539	2,585,893	2,323,504	1,565,093	2,672,409
	Upper Volume (m^3)	2,946,087	2,969,930	2,938,514	2,640,345	1,778,515	3,036,828
Lower Value:	Cumulative Delta Deposition (m^3)	2,592,556	5,206,095	7,791,988	10,115,491	11,680,584	14,352,993
Upper Value:	Cumulative Delta Deposition (m^3)	2,946,087	5,916,017	8,854,531	11,494,877	13,273,391	16,310,219

Terrace Bank Erosion

Step 6: Measure area of terrace bank erosion & compute volume of coarse sediment supplied to Quinault River

		1939 to 52	1952 to 62	1962 to 73	1973 to 82	1982 to 94	1994 to 2002
	Area (m^2)	417,964	481,999	297,302	336,303	383,190	218,680
	Lower Volume (m^3)	208,982	240,999	148,651	168,151	191,595	109,340
	Upper Volume (m^3)	585,150	674,798	416,222	470,824	536,466	306,153
Lower Value:	Cumulative Bank Erosion (m^3)	208,982	449,981	598,632	766,784	958,379	1,067,719
Upper Value:	Cumulative Bank Erosion (m^3)	585,150	1,259,948	1,676,170	2,146,994	2,683,460	2,989,613

Upstream Supply

Step 7: Compute upstream supply based on sediment budget equation (balance between other components of sediment budget)

Sediment Transport Capacity C

Step 8: Sediment transport capacity within the active channel was computed to check capacity versus computed incoming supply from sediment budget

Aggradation

Step 9: Factor in potential aggradation and evaluate sensitivity of upstream supply to see if reasonable assumption

Lower Value:	Aggradation since 1939 (m^3)	1,426,540
Upper Value:	Aggradation since 1939 (m^3)	2,377,567

Sensitivity

Step 10: Use input values (yellow squares) to look at sensitivity to budget of adjusting values assumed as input data and possible error in measurements

APPENDIX H: QUINAULT RIVER HISTORICAL AERIAL PHOTO & MAP GEOGRAPHIC TRANSFORMATION

Part 1: Aerial Photo Documentation

This section was written by Kurt Wille, Geographic Information Systems, Bureau of Reclamation, Technical Service Center, Denver, Colorado.

This data set is a compilation of historic World BIL image files, covering a portion of the Quinault River in northern Grays Harbor and southern Jefferson County, Washington from Quinault Lake to the river's confluence with the North Fork of the Quinault River. These images were created by the United States Bureau of Reclamation, Denver Technical Service Center, Remote Sensing and Geographic Information Group.

Scanned historic aerial photo sets were acquired for the study area. Image dates for the historic photos include 1939, 1952, 1958, 1962, 1973, 1982, and 1998. Each aerial photograph was plotted out and attached to this appendix for reference.
The historic scanned images were geo-referenced and rectified to horizontal control points that were derived from an 18'' pixel resolution Digital Ortho Photo (DOQ) mosaic which was developed and provided by the Quinault Indian Nation. The DOQ aerial photography was flown on July 8, 2001 and processed by the Washington State Department of Natural Resources (WDNR). It should be noted that the WDNR lists the source date as year 2000 because it was part of a large state wide project that was started in year 2000 but took two years to complete so some basins were not flown until 2001.

The input historic photo scans were geo-referenced using ESRI software. Control point values were transferred from an image point on the DOQ (example: road intersection, tree) to the same image point on the scanned photograph. Two processing techniques were used to satisfy two separate image output goals.

A first-order transformation used only points from within the floodplain. This technique was utilized to rectify the scanned photos for the purpose of delineating stream channel and floodplain features. Points from outside the floodplain were avoided to reduce error. As such, the first-order output images are not suitable for delineation of any features outside of the floodplain. The first-order output images were used in this study for mapping all channel and floodplain features compared between each photo set.

A third-order transformation using points from throughout the photo was used to rectify the entire image. The third-order output images are suitable for delineating features throughout the photo, but will not be as precise as the first-order output for areas within the floodplain. Mosaic images of the third-order images were done (ArcINFO SID files).

Root mean square (RMS) errors were documented for all of the transformations (Table 1). Relative spatial accuracy of the output images is a function of a variety of factors and varies from one image to another. One of the main factors influencing spatial accuracy is

the amount of vertical terrain variation that occurs within the bounds of each image. Images that represent earth features in more undulating terrain (mountains, canyons, etc.) will generally be less accurate. Another major factor specific to this study area is the overall lack of visible control points, especially in the upper reaches of the study area. Budget concerns did not allow vertical control to be considered in this effort. However, a vertical control component would most likely improve the overall output accuracy of transformation process.

The DOQs meet National Map Accuracy Standards; however the resulting images may not meet NMAS

Table 1. Average RMS errors by photo set and transformation technique.

First Order Transformations

Photo Set	X (meters)	Y (meters)	Range X (meters)	Range Y (meters)
1939	16.0	23.3	6.9 to 25.4	21.1 to 26.4
1952	22.5	23.1	0.3 to 84.3	0.0 to 74.5
1958	17.6	22.9	8.4 to 29.3	4.3 to 34.7
1962	12.8	10.7	9.0 to 20.7	6.4 to 14.5
1973	16.7	12.1	3.7 to 32.5	3.1 to 23.2
1982	12.3	8.7	2.5 to 37.1	1.5 to 18.4
1998	3.0	2.8	1.3 to 4.3	1.3 to 6.5

Average RMS errors by photo set and transformation technique

Third Order Transformations

Photo Set	X (meters)	Y (meters)	Range X (meters)	Range Y (meters)
1939	23.8	20.2	9.7 to 44.3	12.9 to 32.4
1958	18.6	21.6	13.4 to 31.0	10.6 to 33.9
1962	3.2	3.4	0.1 to 10.7	0.1 to 10.8
1973	16.7	13.5	5.7 to 42.6	6.3 to 36.3
1982	7.3	6.6	2.7 to 15.1	2.2 to 15.5
1998	2.1	2.0	0.3 to 3.3	1.1 to 4.3

Part 2: Methods Used in the Preparation of and Mapping on 1897, 1902, 1906, and 1913 Cadastral Surveys for Our Study Reach on the Quinault River

Introduction

As part of our assessment of part of the Quinault River, we used historical and recent aerial photographs and maps that were readily available in order to identify past and present channels.

Map Information

The 1897, 1902, 1906, and 1913 maps are cadastral surveys for the three townships and ranges in our study reach (T.23N., R.9W., T.24N., R.8W., and T.24N, R.9W.). Two surveys were done for both T.23N., R.9W. and T.24N., R.8W., and one was done for T.24N, R.9W. No survey is available for T.23N., R.8W., which is adjacent to our area.

The first survey of T.23N., R.9W. was conducted between September 9 and October 2, 1895, for the meanders of the Quinault River. The meanders were resurveyed between June 14 and June 21, 1897. The map was approved April 15, 1898, and accepted March 21, 1900. The map covers the upper end of Quinault Lake, and the river about 5900 meters upstream of the lake. The 1897 survey shows the Quinault River (spelled Quinaielt on all of the surveys) channel, sloughs (especially south of the river channel), tributaries, buildings, roads, and ownship names. It includes notes about areas that have been cleared or that are planted as orchards, but it does not show the boundaries of the modified areas. Mountainous areas were not surveyed.

The second survey of T.23N., R.9W. was conducted by G.R. Campbell between June 30 and July 2, 1902. The map was approved June 29, 1904, and accepted September 28, 1904. This map shows the Quinault River channel, section boundaries, and general areas of public, private, and mountainous (unsurveyed) land. The Quinault River channel is in the same position as it was in 1895-1897, so this map was not used in our study.

The survey for two adjacent townships and ranges, T.24N., R.8W., and T.24N, R.9W., was conducted by John R. Fenland between July 4 and July 7, 1906, for the meanders of the Quinault River in T.24N, R.9W., and between July 26 and July 27, 1906, for the meanders in T.24N., R.8W. Both maps were approved February 17, 1908, and accepted June 20, 1908. These maps show the Quinault River channel, tributaries, swamps, lakes, buildings, and some land ownship. The maps note cleared areas, but do not show boundaries of these. Mountainous areas were not surveyed.

A second map for township and range T.24N., R.8W. is dated as approved January 3, 1913. Dates when any surveying was done are not noted. The map shows the Quinault

River channel and section boundaries. The Quinault River channel is shown in the same position as it was on the 1906 map, and so this map was not used in our study.

The cadastral surveys were downloaded in jpg format from the Land Records section of the Bureau of Land Management (BLM) web site (http://www.or.blm.gov/lo/). The maps were converted to Imagine format (.img) or ESRI grids, which were used throughout the georeferencing and subsequent construction of a mosaic of the 1906 georeferenced maps.

Methods Used to Georeference and Mosaic the Maps

Each map was georeferenced to electronic versions of 1:24,000-scale topographic maps of the U.S. Geological Survey (Lake Quinault East, Finley Creek, and Bunch Lake quadrangles). The topographic maps had an original or native projection of UTM, Zone 10, NAD 27, meters, but had been reprojected into UTM, Zone 10, NAD 83, meters. The maps were georeferenced to the reprojected topographic maps using ARC. The georeferencing was done by using the corners of the 36 sections within each township and range. These points were common to both the maps and the USGS topographic quadrangles.

The following number of data points were used in georeferencing each of the surveys. For the 1897 survey of T.23N., R.9W., 22 data points were used. For the 1902 survey of T.23N., R.9W., 24 data points were used. For the 1906 survey of T.24N., R.8W., 31 points were used. For the 1913 survey of T.24N., R.8W., 33 points were used. For the 1906 survey of T.24N., R.9W., 28 points were used.

Georeferencing was done using 3rd-order polynomial equations. For the 1897 survey of T.23N., R.9W., the total RMS error is 13.21 meters, and the range in residuals is 0.25 to 25.96 meters. For the 1902 survey of T.23N., R.9W., the total RMS error is 14.55 meters, and the range in residuals is 0.87 to 24.60 meters. For the 1906 survey of T.24N., R.8W., the total RMS error is 8.21 meters, and the range in residuals is 1.38 to 13.88 meters. For the 1913 survey of T.24N., R.8W., the total RMS error is 5.75 meters, and the range in residuals is 1.47 to 12.61 meters. For the 1906 survey of T.24N., R.9W., the total RMS error is 13.13 meters, and the range in residuals is 1.06 to 36.24 meters.

The 1897, 1902, and 1913 georeferenced surveys were converted from .jpg format to ESRI grids, so that the projection of UTM, Zone 10, NAD 83, meters could be applied. The two 1906 georeferenced surveys were combined into a mosaic using ERDAS Imagine and saved in Imagine format (.img) with the projection of UTM, Zone 10, NAD 83, meters. The georeferenced individual surveys and mosaic were overlain onto the USGS topographic quadrangles, and the locations of relatively stable features, such as roads, were noted on the georeferenced surveys. In general, there is good agreement between the georeferenced surveys and the USGS quadrangles.

Channel Mapping and Assessment

The channel of the Quinault River on the 1897 and 1906 georefernced surveys was digitized using Arc. The Quinault River channel is shown in the same position on the 1902 and 1913 surveys as it is on the 1897 and 1906 surveys. Consequently, the 1902 and 1913 surveys were not used in our study. The main channel of the Quinault River and tributaries are shown on both the 1897 and 1906 surveys. Sloughs also are shown on the 1897 survey. The tributaries and sloughs were digitized using Arc.

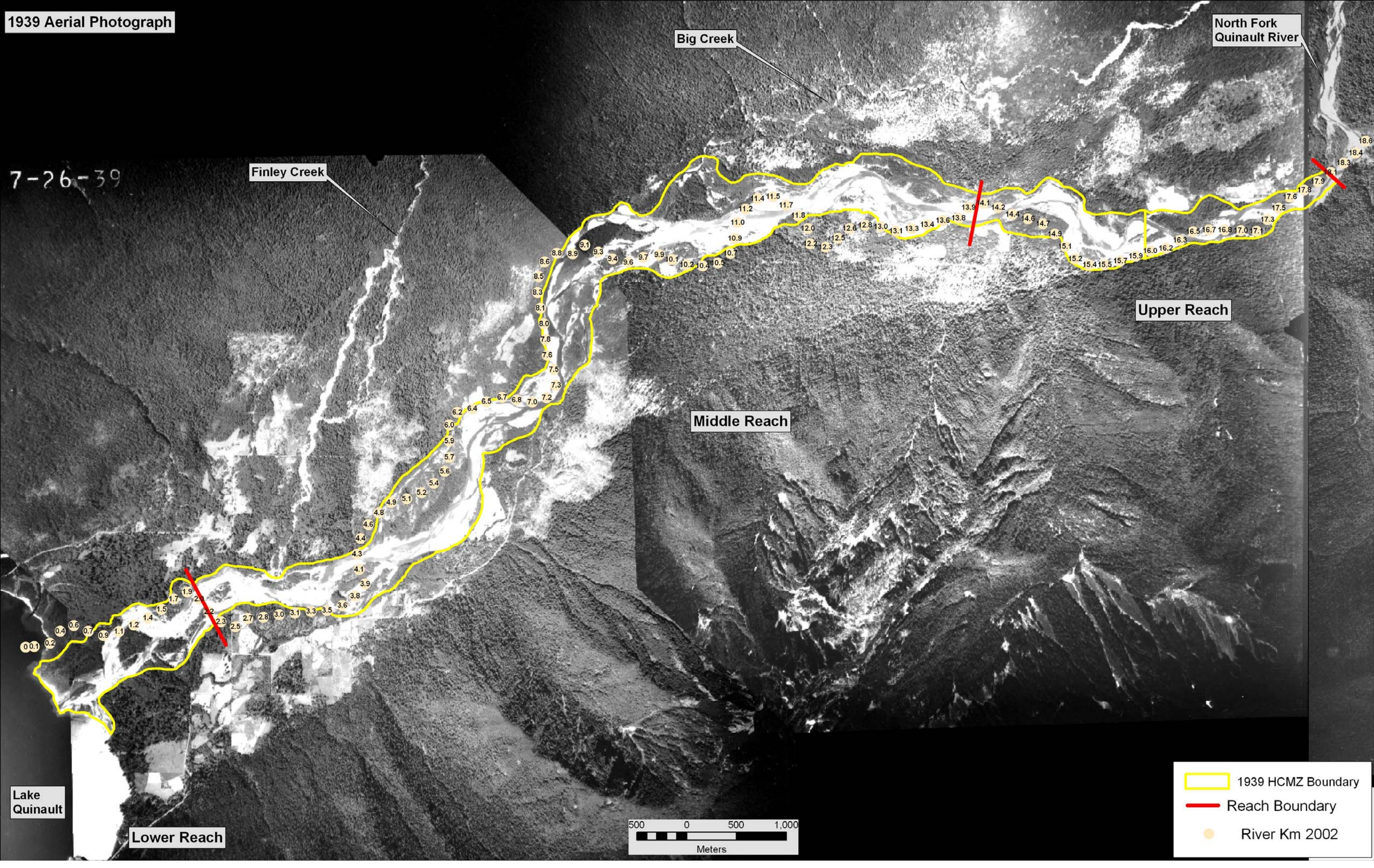
The Quainault River channels shown on the 1897 and 1906 surveys broadly match the configuration of the low-flow and unvegetated channels present on the 1939 aerial photographs and on the USGS topographic quadrangles. The channels on the older maps are almost entirely within the channel zone that is visible on a hillshade constructed from LIDAR data collected in 2002.

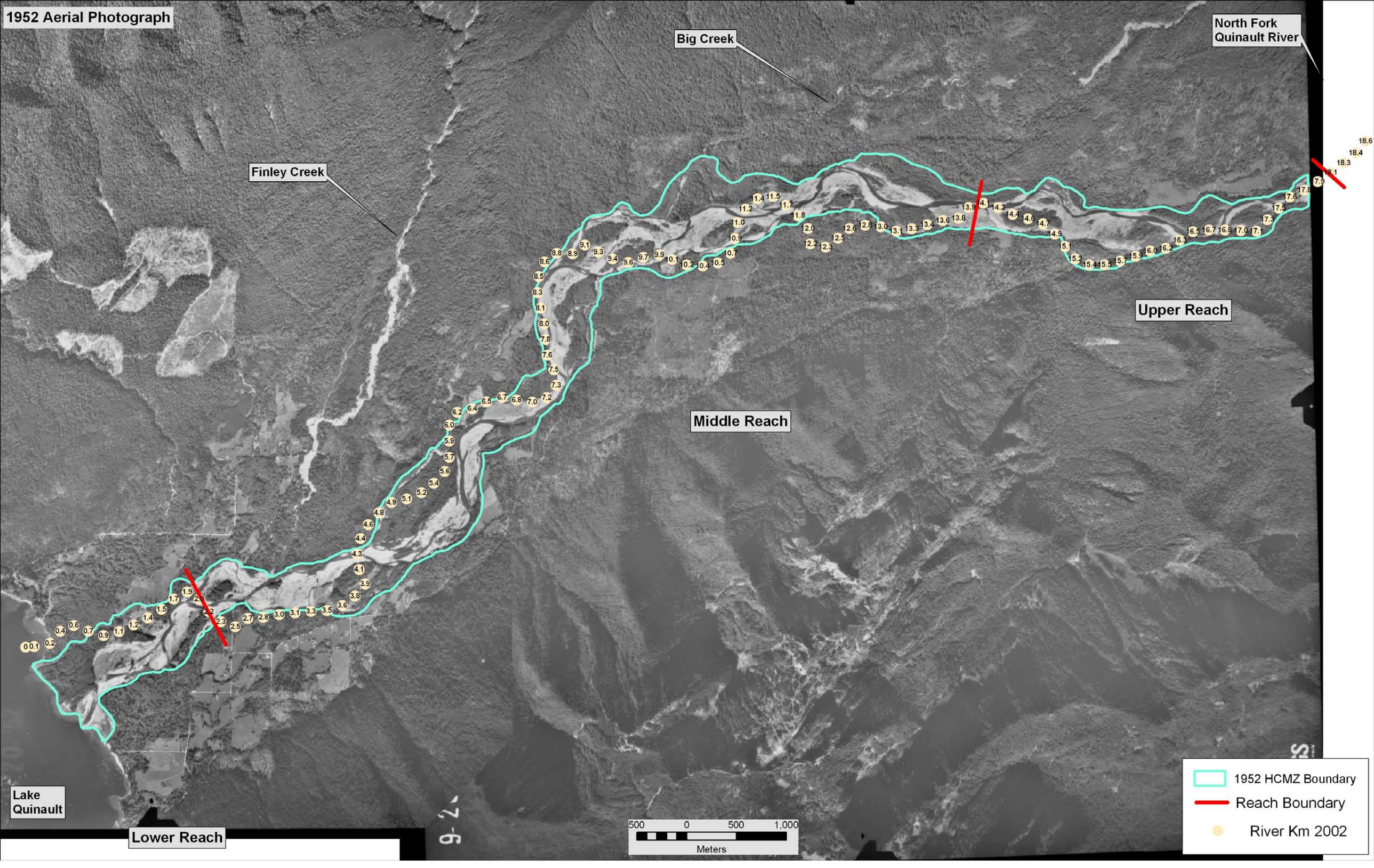
In two places, the 1906 channel between the junction with the North Fork and about 2000 meters downstream extends 80 or 100 meters into the steep (rock) slope along the south side of the valley. Along the North Fork, the 1906 channel extends up to 1500 meters into relatively steep topography. The tributaries on both the 1897 and 1906 maps are generally in good agreement with drainages shown on the USGS topographic quadrangles and with channels that are visible on the hillshade (2002). A few tributaries on the south side of the main valley appear to be incorrectly placed (relative to their location on the USGS quadrangles) by about 100 m or less.

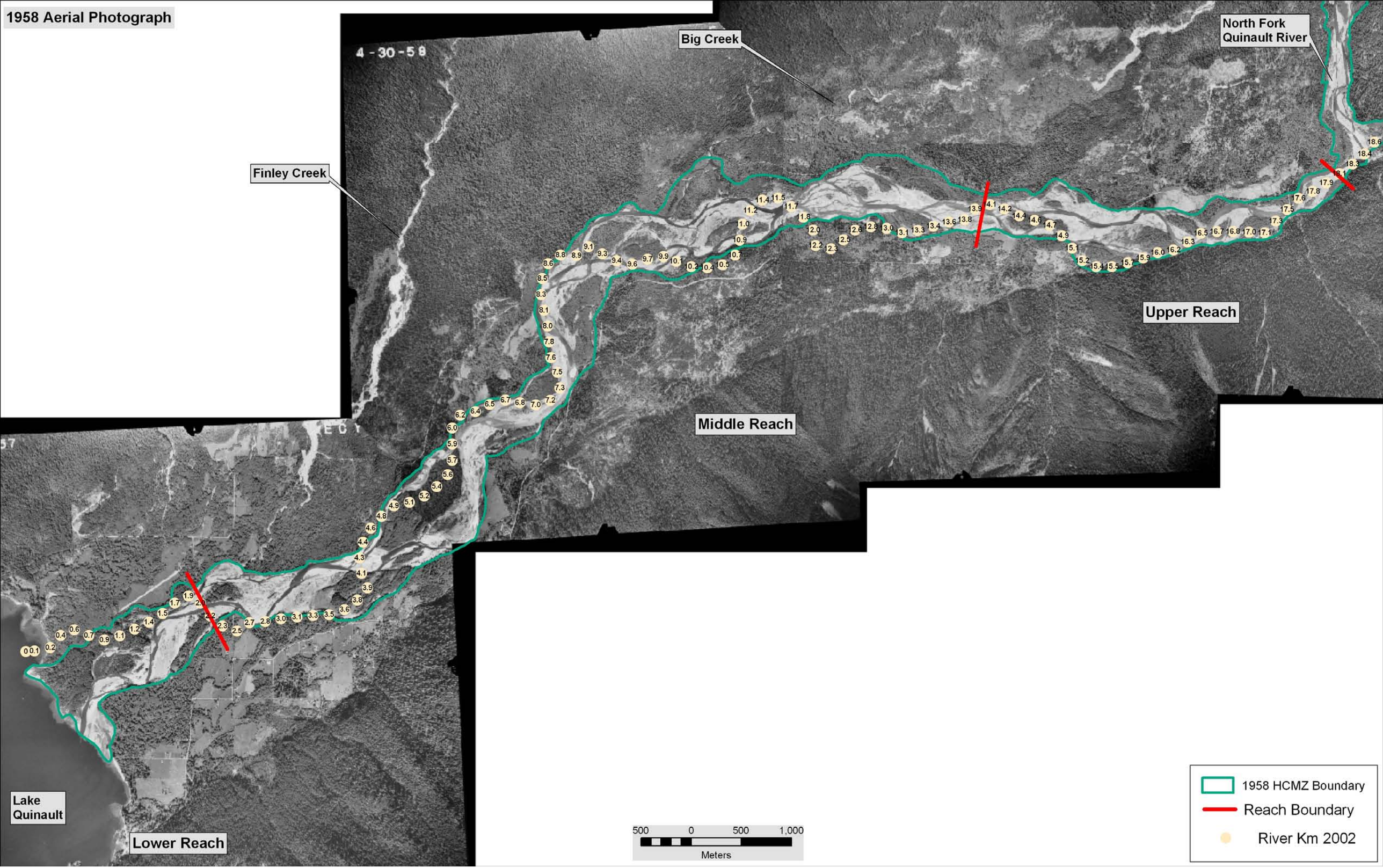
The incorrect locations of both the main channel of the Quinault River and some of the tributaries on the south side of the valley on the 1906 map probable occurred because no surveying was done in the steep areas. The south valley wall is a very steep bedrock slope. Locations in the valley appear to be accurate.

Comparison of the 1897 and 1906 channels with the 1939 aerial photograph reveals that the 1897 and 1906 channels, which are probably unvegetated (not low-flow) channels because of their widths, roughly correspond with the channel area in 1939. In the downstream about 5700 meters of our study reach, the 1897 channel is straighter than the unvegetated channel in 1939, but the older channel coincides with the zone created by the unvegetated channel in 1939. Upstream of this area, the 1906 channel is near the 1939 unvegetated channel or in areas where less active (overflow) channels are visible on the 1939 aerial photographs.

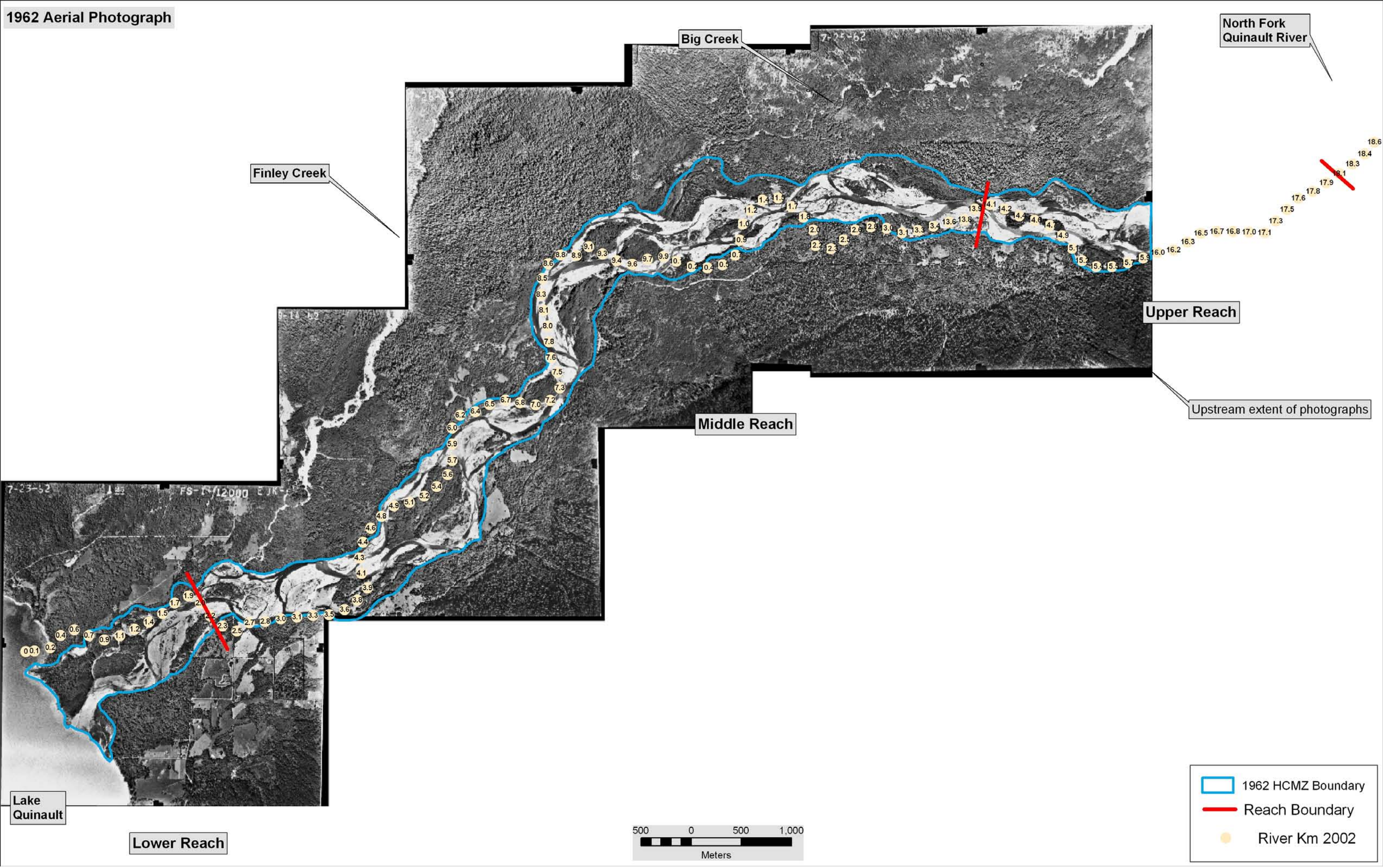
Because of the seemingly accurate locations of the 1897 and 1906 channels, we use them in our identification of historical channel paths. The portrayal of the Quinault River channel on the older maps provides verification of the general channel position, as well as human development within the study reach approximately 100 years ago (106 years for the about 5700 meters upstream of Lake Quainault and 97 years for the portion upstream of this to the Forks Bridge). On the 1897 and 1906 surveys, buildings with names, roads, and notes showing cleared areas or orchards indicate the locations of homesteads in the valley at the times of the surveys.

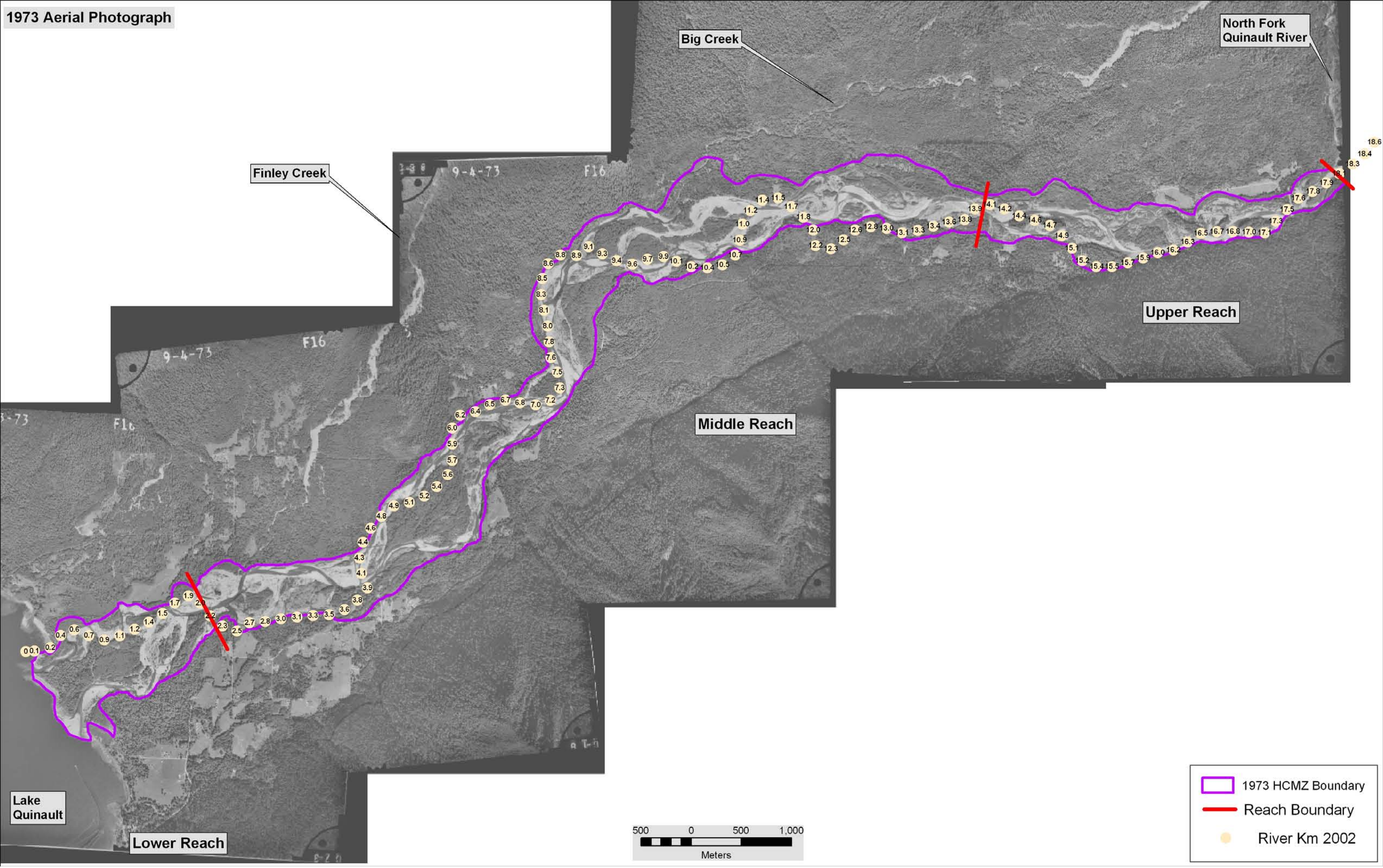

1939 Aerial Photograph
7-26-39
Big Creek
North Fork Quinault River
Finley Creek
Upper Reach
Middle Reach
Lower Reach
Lake Quinault
500 0 500 1,000
Meters
1939 HCMZ Boundary
Reach Boundary
River Km 2002


1952 Aerial Photograph
Big Creek
North Fork Quinault River
Finley Creek
Upper Reach
Middle Reach
Lower Reach
Lake Quinault
1952 HCMZ Boundary
Reach Boundary
River Km 2002
500 0 500 1,000
Meters

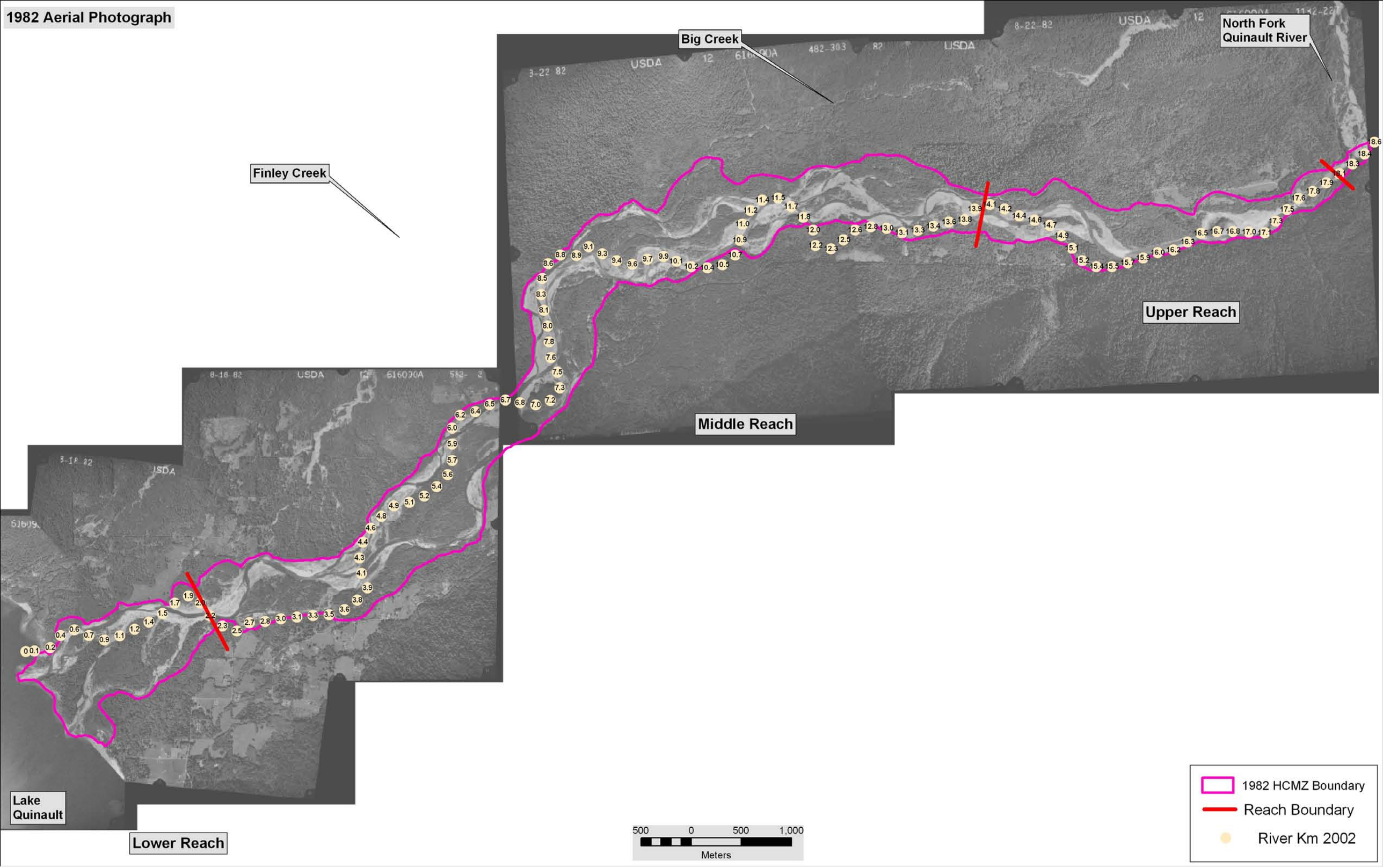

1958 Aerial Photograph
4-30-58
Big Creek
North Fork Quinault River
Finley Creek
Upper Reach
Middle Reach
Lower Reach
Lake Quinault
1958 HCMZ Boundary
Reach Boundary
River Km 2002
500 0 500 1,000
Meters

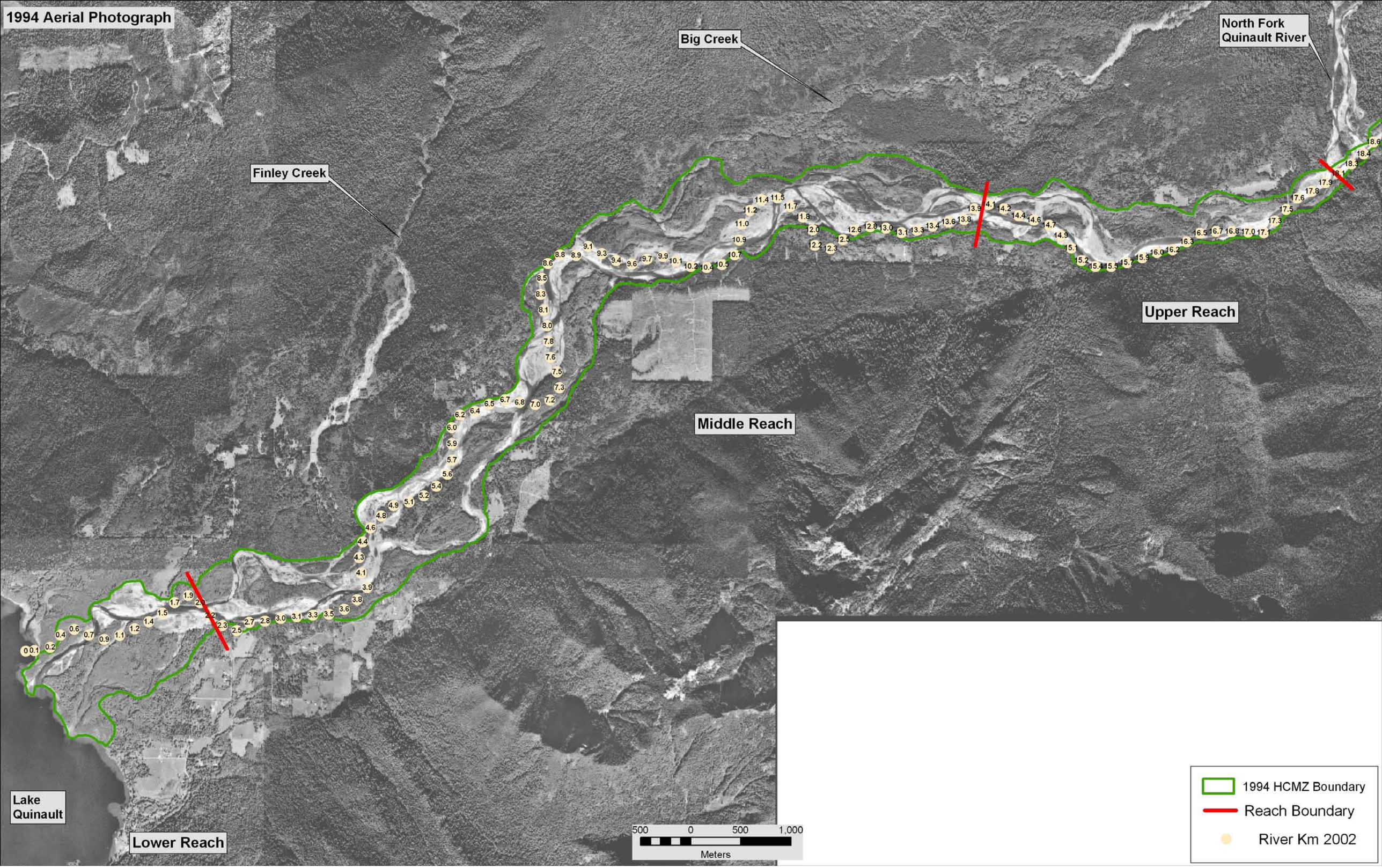
1962 Aerial Photograph



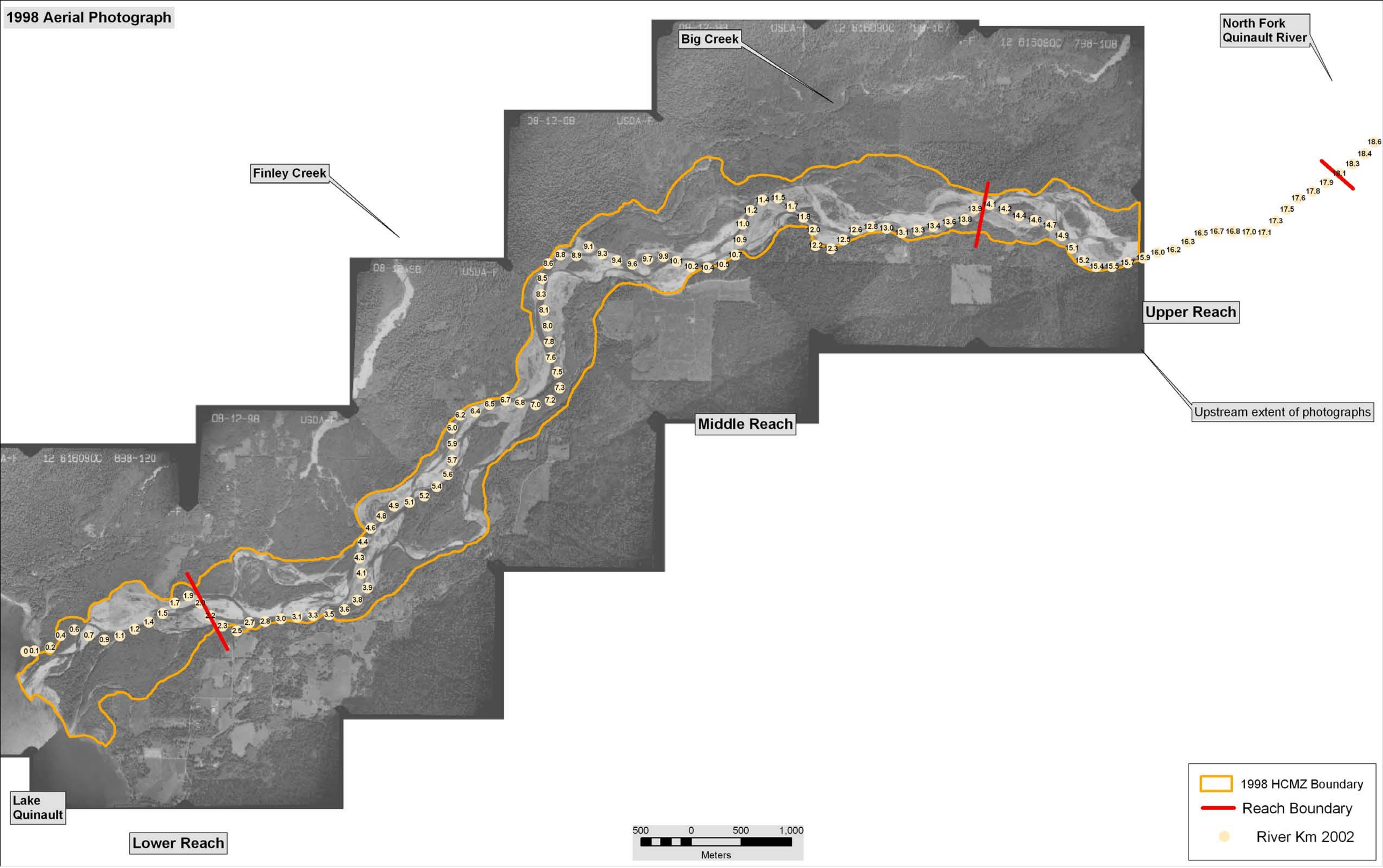

1973 Aerial Photograph
Big Creek
North Fork Quinault River
Finley Creek
Upper Reach
Middle Reach
Lower Reach
Lake Quinault
9-4-73
F16
500 0 500 1,000
Meters
1973 HCMZ Boundary
Reach Boundary
River Km 2002

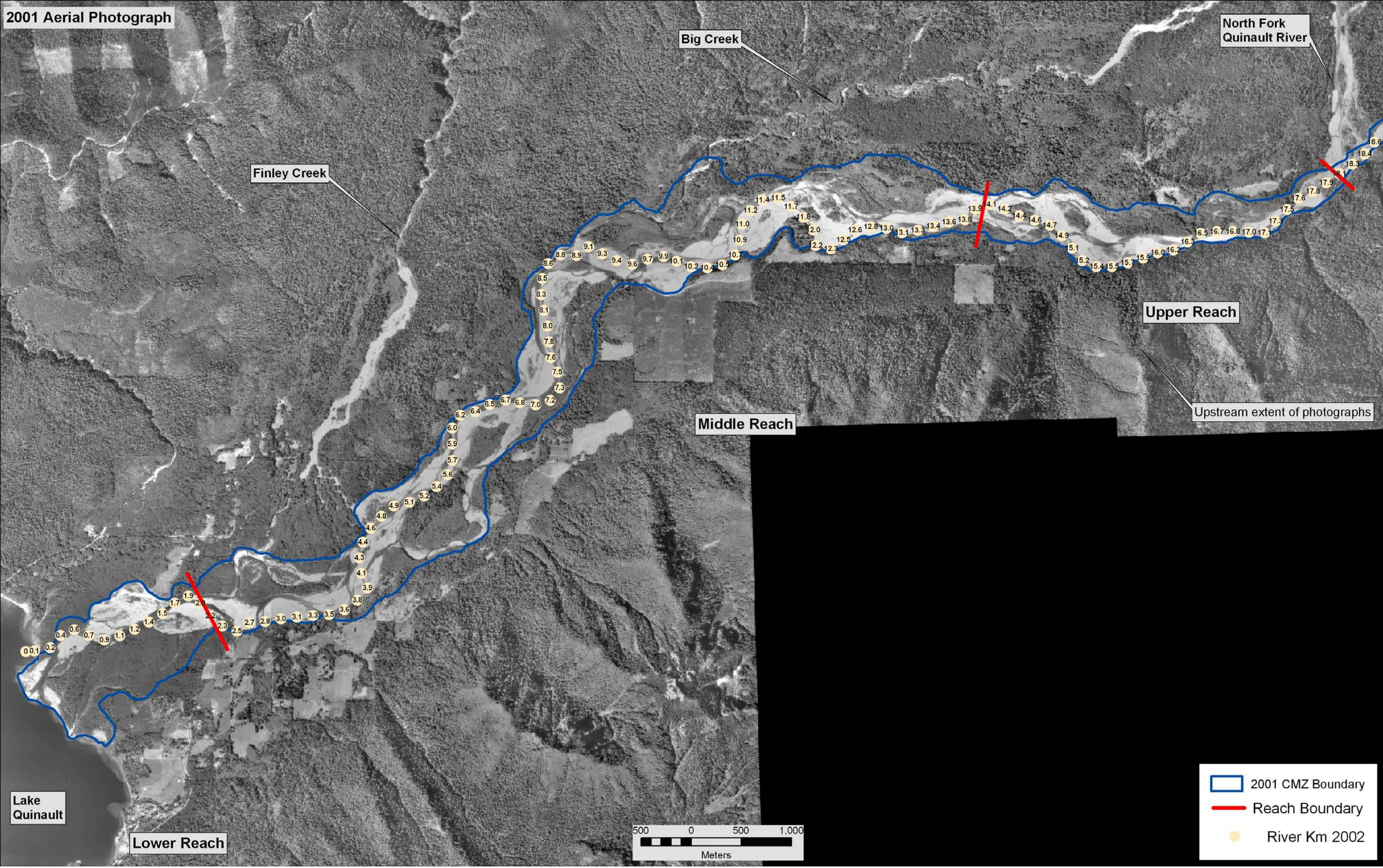
1982 Aerial Photograph

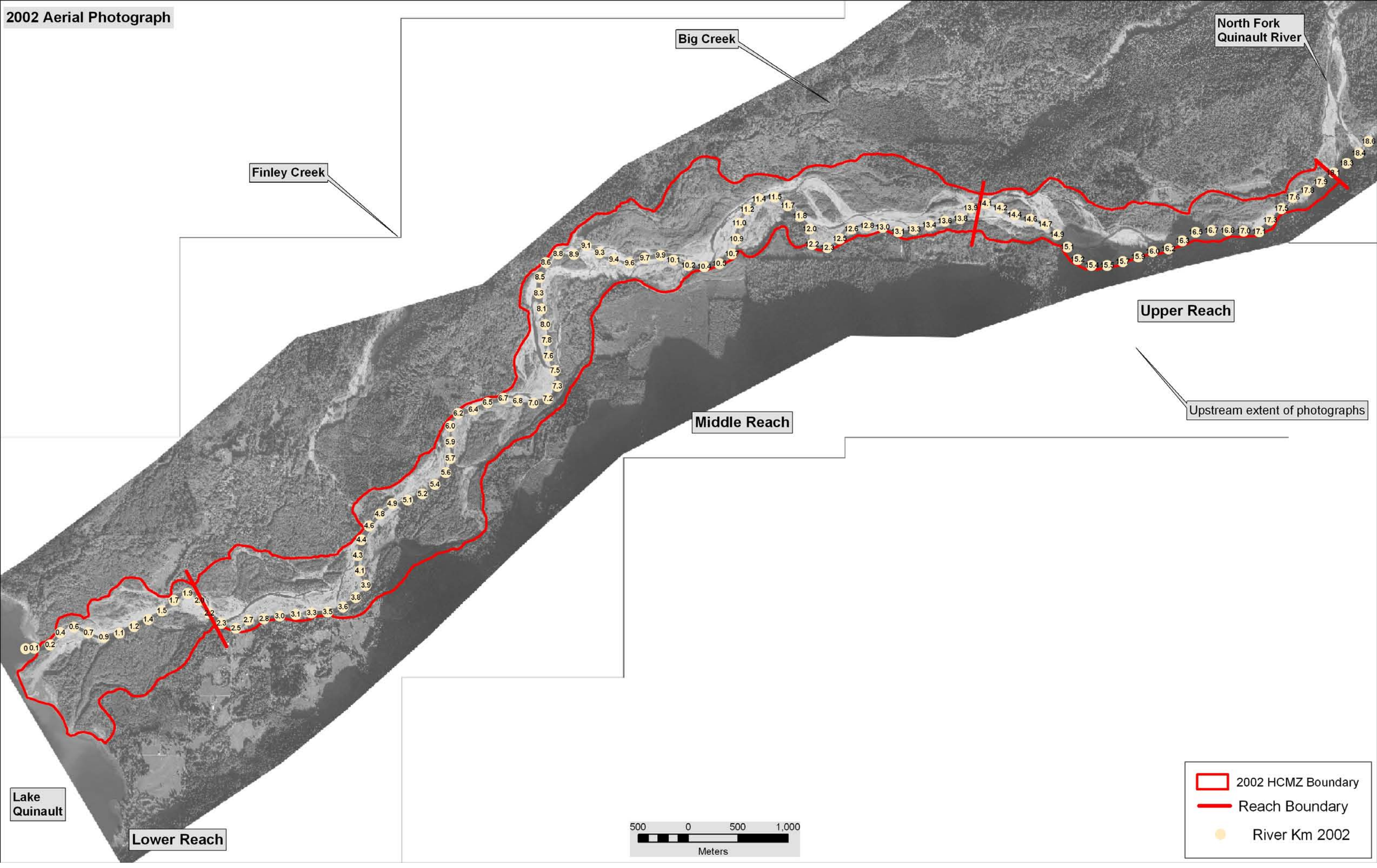



1994 Aerial Photograph
Big Creek
North Fork
Quinault River
Finley Creek
Upper Reach
Middle Reach
Lower Reach
Lake
Quinault
500 0 500 1,000
Meters
1994 HCMZ Boundary
Reach Boundary
River Km 2002

1998 Aerial Photograph




2001 Aerial Photograph
Big Creek
North Fork
Quinault River
Finley Creek
Upper Reach
Middle Reach
Lower Reach
Upstream extent of photographs
Lake
Quinault
500 0 500 1,000
Meters
2001 CMZ Boundary
Reach Boundary
River Km 2002


2002 Aerial Photograph
Big Creek
North Fork Quinault River
Finley Creek
Upper Reach
Upstream extent of photographs
Middle Reach
Lower Reach
Lake Quinault
500 0 500 1,000
Meters
2002 HCMZ Boundary
Reach Boundary
River Km 2002

Appendix I: Mapping and Analyses of Geomorphic Units Using ArcGIS

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1.0 Overview of Geomorphic Mapping

Geomorphic mapping in ArcGIS was used to evaluate channel position, sediment bars, vegetation, and general characteristics of the channel to investigate the possibility of trends that could indicate morphological response to changes in woody debris, vegetation, sediment supply and transport capacity. This appendix provides a description of geomorphic map units delineated within the study reach using rectified aerial photographs taken in 1939, 1952, 1958, 1962, 1973, 1982, 1994, 1998, 2001, and 2002 and rectified cadastral survey maps from 1897, 1906, and 1929 (see Appendix H for information on rectification). This appendix also describes the geologic units discussed in the geology appendix.

For most geomorphic map units, the study reach was broken into three sections (upper, middle, and lower) based on geomorphic differences (Table I.1). The boundary between the upper and middle sections occurs at the location of a large bedrock feature on the north side of the Quinault River (RK14). The boundary between the middle and lower sections occurs at a location thought to be near the upstream end of present delta processes occurring as a result of Lake Quinault (RK 2). The boundary between the lower and middle section is also unique in that it has the downstream end of a large, historical alluvial fan from the Finley Creek drainage. Mapping was done on all of the photographs and maps, except as indicated.

Table I.1. Reach boundaries for study area between Lake Quinault (RK 0) and the Forks (RK 18.1).

Lower Reach	Middle Reach	Upper Reach - Downstream Section (DS)	Upper Reach - Upstream Section (US)
RK 0 to 2	RK 2 to 14	RK 14 to 16	RK 16 to 18.1

All of the aerial photographs cover the entire study reach except for the 1962 and 1998 aerial photographs, which only cover the area from Lake Quinault upstream to about RK 16. Some of the geomorphic mapping was compared on a decadal time scale, so results from 1962 and 1998 were not needed. Other comparisons required results from all aerial photographs. To allow comparison between mapping units, the Upstream Reach was subdivided at RK 16 into two sections, with only the downstream section containing 1962 and 1998 photography. The 1929 map covers the entire study reach. The 1906 map covers the Quinault River upstream of about RK 7.5 to RK 18.1, and the 1897 map cover the channel downstream of RK 7.5 to Lake Quinault.

The Quinault River is very dynamic and it is not uncommon for the river to change positions and geomorphic features one or more times during a winter flood season. Because the mapping used aerial photographs spaced about every ten years apart, the results are meant to look at average characteristics and trends of the river over decadal time scales rather than characterizing the exact frequency of changes. For example, the rate at which the channel re-occupies the floodplain represents a minimum rate because

there could be more frequent changes between photographs. However, major channel changes were fairly obvious even on decadal time scales and could be reasonably tracked by looking at growth and removal of vegetated surfaces. Additionally, many mapping parameters looked at total change between photographs, such as terrace bank erosion or delta growth, which can be more easily measured on a decadal time scale when using aerial photography.

The historical maps have the most uncertainty associated with them. This is because geomorphic features distinguishable on the aerial photographs had to be interpreted from the maps and because these maps contained errors associated with reproduction. The majority of aerial photographs had reasonable clarity to distinguish geomorphic mapping units. The 1939 photographs were the most challenging due to more areas of distortion that were difficult to interpret. In cases of uncertainty, the areas were tracked through time to try and establish if the interpretation on a particular photograph or map was reasonable. For more recent photographs from 2001 and 2002, field checking was utilized along with Lidar data from October 2000.

2.0 Channel Units within HCMZ

The historical channel migration zone is composed of a series of channel and vegetated areas. Several types of channels were delineated on the aerial photographs (Figure I.1; Table I.2). The ability to distinguish the units depends on the quality of the photographs and relies on the interpretation and consistency of the individual doing the mapping. The newer photographs have better resolution and contrast. Each unit, except the active channel, includes areas of variable relative age, which could be distinguished if larger-scale mapping was done.

The low-flow and active channels (where shown by the presence of unvegetated bars) were traced on the older maps to supplement the mapping done on the aerial photographs. The quality of the historical mapping is unknown, but, in general, the channels fall within the 1939 HCMZ providing a cursory-level check that the channel locations are reasonable. Evidence of some of the channels delineated on the older maps is still present on the 1939 aerial photographs, even if they are vegetated by that time.

Table I.2. Characteristics of channel map units

Map Unit	Appearance on Aerial Photographs	Geomorphic Interpretation	Relative Age
Low-flow Channel	Wetted channel at the time the photographs were taken, which was typically during low-flow conditions	Deepest part of the active channel that is wetted even at the lowest flows	Active; conveys water throughout the year
Active Channel	Area that is unvegetated adjacent to the low-flow channel	Channel that conveys the majority of the river's bed load	Active; conveys most of the flow
Unvegetated Channel	Area that is primarily unvegetated adjacent to the active channel (bars); includes the active channel	Unvegetated bars adjacent to the active channel; area coveys flow at higher discharges; lack of vegetation suggests area receives flows at least once, and probably several times, per year	Active; conveys higher flows, probably at least once, and probably several times, per year
Slightly Vegetated Channel	Area that has scattered vegetation and is adjacent to the unvegetated channel at some point;	Slightly vegetated bars and channels related to the unvegetated channel; overflow channels; convey flow at the highest discharges; the presence of some vegetation suggests that the area receives flow less often than the unvegetated channel so that the area has begun to revegetate	Active or recently active; carries highest flows at most a few times per year; may not have conveyed flow for a few months
Old Channel (partially vegetated)	Area that has continuous areas of vegetation but also open areas	Old channels (mostly unvegetated channels at one time) that have not conveyed enough flow to disrupt vegetation, so that the area is beginning to revegetate; unvegetated areas are still present	No longer active; probably has not conveyed significant flow for at least a year, possibly several years
Side Channel – Wide	Wide channels through vegetated areas; channels wide enough or area is open enough so that water is visible in the channels; channels may include adjacent unvegetated bars	Side channels of the Quinault River; connected both upstream and downstream to the main channel; may have once been an unvegetated channel; location through a vegetated area suggests that only a small portion of the Quinault River flow is conveyed by these channels; water may also have a ground water source	Active, often a former location of the main channel
Side Channel – Narrow	Narrow channels through vegetated areas; channels usually too narrow or through vegetation too dense to determine if water is present in the channel; channels visible as sinuous breaks in vegetation (usually shrubby or mixed units)	Side channels of the Quinault River; usually, but not always, connected both upstream and downstream to the main channel; channel may convey surface flow, or groundwater, or both	Active
Tributary Channel	Unvegetated channel of major tributaries to the Quinault River; includes the active channel and adjacent unvegetated bars (if present); only that portion within the HCMZ is shown	Tributary channel that conveys most of the flow from that tributary to the Quinault River	Active; conveys flow at all discharges

2.1 Active Channel Results

The area within the HCMZ occupied by the active channel was computed for each year (Table I.3). Average widths of the active channels of the Quinault River were also computed by dividing the total area of the unvegetated channel for each reach by the length of the center line (Figure I.2; Table I.4). Center lines were mapped along the approximate center of the unvegetated channels.

Table I.3. Area of active channels as a percent of HCMZ area for each reach by year (Note that only RK 14 to 16 is included for Upper Reach in 1962 and 1998)

	Active Channel Area as Percent of HCMZ		
Year	**Upper Reach**	**Middle Reach**	**Lower Reach**
1939	28	28	19
1952	19	22	24
1958	32	29	20
1962	30	28	23
1973	23	20	23
1982	22	18	14
1994	22	22	13
1998	16	19	12
2001	26	25	21
2002	26	17	13

Table I.4. Average widths of active channels for each reach

	Average Active Channel Width (m)		
Year	**Upper Reach**	**Middle Reach**	**Lower Reach**
1897		181	88
1906			
1929	102	116	188
1939	100	142	112
1952	80	114	157
1958	134	160	134
1962	162	159	145
1973	98	118	160
1982	93	109	107
1994	96	137	105
1998	82	124	98
2001	117	160	167
2002	113	109	123

2.2 Unvegetated Channel Results

The area within the HCMZ occupied by the unvegetated channel was computed for each year (Table I.5). Average widths of the unvegetated channels of the Quinault River were also computed by dividing the total area of the unvegetated channel for each reach by the length of the center line (Figure I.2; Table I.6). Center lines were mapped along the approximate center of the unvegetated channels.

Table I.5. Area of unvegetated channels as a percent of HCMZ area for each reach by year
(Note that only RK 14 to 16 is included for Upper Reach in 1962 and 1998)

	Unvegetated Channel as Percent of HCMZ		
Year	**Upper Reach**	**Middle Reach**	**Lower Reach**
1939	52	50	42
1952	34	34	35
1958	56	55	41
1962	48	49	38
1973	33	38	35
1982	41	38	30
1994	47	44	29
1998	61	45	32
2001	47	44	33
2002	44	42	30

Table I.6. Average widths of unvegetated channels for each reach

	Average Unvegetated Channel Width (includes Active Channel) (m)		
Year	**Upper Reach**	**Middle Reach**	**Lower Reach**
1897	No Data		
1906	237	350	
1929	252	319	204
1939	190	260	251
1952	141	178	229
1958	231	299	273
1962	258	279	240
1973	139	225	246
1982	177	235	220
1994	205	273	232
1998	312	298	257
2001	210	288	266
2002	197	271	286

The temporal and spatial relationships of the mapped unvegetated channels were compared to determine the rate at which the floodplain is reworked (Tables 7 and 8). Shapefiles for the unvegetated channels for each year were converted to a raster using spatial analyst in ARC. A value of 1 was assigned to each pixel that was part of the unvegetated channel and a value of 0 was assigned to areas outside of the unvegetated channel but within the 2002 HCMZ. Rasters were summed using the raster calculator in spatial analyst in ARC to determine how many times a pixel (an area) had been part of the unvegetated channel for the 10 years for which we have aerial photographs. The areas where the channel has been most often are the ones that are shown as most active (Figure 17 in main report).

Table I.7. Areas reworked by the unvegetated channel of the Quinault River for each reach and the entire study reach by year

Year	Total Area Reworked (m^2)			
	Upper Reach	Middle Reach	Lower Reach	Total for Study Reach
2002	744,686	2,893,006	504,630	4,142,322
2001	861,429	3,299,732	614,447	4,775,608
1998	919,133	3,582,131	681,377	5,182,641
1994	984,801	3,962,980	725,228	5,673,009
1982	1,115,839	4,422,008	846,092	6,383,939
1973	1,151,116	4,841,374	998,122	6,990,612
1962	1,260,427	5,197,089	1,144,173	7,601,688
1958	1,422,451	5,479,025	1,261,637	8,163,113
1952	1,451,282	5,508,172	1,295,716	8,255,169
1939	1,509,714	5,704,403	1,376,170	8,590,287
1929	1,629,583	6,304,371	1,387,030	9,320,984
1906	1,660,306	6,533,372		8,193,678

Table I.8. Areas reworked by the unvegetated channel of the Quinault River as a percent of the total 2002 HCMZ area for each reach and the entire study area by year and time before present

Year	Percent of 2002 HCMZ			Cumulative Total Area Reworked for Study Reach	Time: Years Before 2002
	Upper Reach	Middle Reach	Lower Reach		
2002	44	42	30	40	0
2001	51	48	36	46	1
1998	55	52	40	50	4
1994	59	57	43	55	8
1982	66	64	50	62	20
1973	68	70	59	68	29
1962	75	75	67	74	40
1958	85	79	74	79	44
1952	86	80	76	80	50
1939	90	83	81	84	63
1929	97	91	81	91	73
1906	99	95	No data	96	96

2.3 Unvegetated and Slightly Vegetated Channel Results

Because the distinction between unvegetated and slightly vegetated channels is often hard to determine, the total area of both channels was also computed to look for trends in channel properties within the HCMZ (Table I.9).

Table I.9. Area of unvegetated and slightly vegetated channels as a percent of HCMZ area for each reach by year
(Note that only RK 14 to 16 is included for Upper Reach in 1962 and 1998)

	Unvegetated and Slightly Vegetated Channels as Percent of HCMZ		
Year	**Upper Reach**	**Middle Reach**	**Lower Reach**
1939	64	59	53
1952	50	50	46
1958	60	59	46
1962	66	59	45
1973	39	44	42
1982	43	41	33
1994	50	46	34
1998	64	49	35
2001	53	47	35
2002	48	43	31

2.4 Side Channel Results

Side channels were generally consistent in their formation process over time except for the side channels at the base of the Finley Creek alluvial fan and from the Big Creek tributary channel. The total side channel length for a given reach including the Finley Creek and Big Creek areas are included in Table I.10 and these are excluded in Table I.11 for comparative analysis. The narrow side channel lengths were also computed and are listed in Table I.12.

Table I.10. Lengths of wide (prominent) side channels for each reach by year
(Note that only RK 14 to 16 is included for Upper Reach in 1962 and 1998)

	Prominent Side Channel Length (Big Creek & Finley Creek not included)									
Reach	**1939**	**1952**	**1958**	**1962**	**1973**	**1982**	**1994**	**1998**	**2001**	**2002**
Lower Reach	1142	0	2382	758	1763	0	1141	2770	2364	2859
Middle Reach	2605	5971	5997	4086	5245	5520	7697	6701	8860	12323
Upper Reach DS	0	0	204	0	2101	1307	1468	415	515	0
Upper Reach US	586	662	660	-	1447	1692	600	-	589	612

Table I.11. Lengths of wide (prominent) side channels and tributaries Big Creek and Finley Creek for each reach by year
(Note that only RK 14 to 16 is included for Upper Reach in 1962 and 1998)

	Prominent Side Channel Length (Includes Big Creek & Finley Creek Channels)									
Reach	**1939**	**1952**	**1958**	**1962**	**1973**	**1982**	**1994**	**1998**	**2001**	**2002**
Lower Reach	1142	0	2382	758	1763	0	1141	2770	2364	2859
Middle Reach	3494	8301	6912	4981	7474	9165	9731	8739	10898	14366
Upper Reach DS	0	0	204	0	2101	1307	1468	415	515	0
Upper Reach US	586	662	660	-	1447	1692	600	-	589	612

Table I.12. Lengths of narrower side channels for each reach by year
(Note that only RK 14 to 16 is included for Upper Reach in 1962 and 1998)

	Narrower Side Channel Length (Includes Big Creek & Finley Creek Channels)									
Reach	**1939**	**1952**	**1958**	**1962**	**1973**	**1982**	**1994**	**1998**	**2001**	**2002**
Lower Reach	341	2906	1987	192	1739	2274	3630	3481	1193	4774
Middle Reach	2141	4032	2302	3775	7740	8077	7864	10311	8713	14760
Upper Reach DS	907	536	969	246	966	1841	759	888	923	2812
Upper Reach US	982	1230	1330	-	1383	1503	1748	-	985	2391

3.0 Vegetation Map Units within HCMZ

It was of interest to evaluate the stability of vegetated surfaces over time. Several types of vegetated surfaces that are outside of the channel units but within the HCMZ were delineated on the aerial photographs (Figure I.1; Table I.13). Vegetation categories were based on general characteristics rather than specific species because of the difficulty in discerning species in historical photographs solely based on planview appearance. The vegetation map units are more subjective in their delineation than the channel map units. The ability to distinguish the units depends on the quality of the photographs. The newer photographs have better resolution and contrast. Vegetation types are more easily distinguished on some photographs than on others. In addition, the units are often gradational over area and time, so that the contact between units may be difficult to discern on a single photograph and between adjacent years. Each vegetation unit includes areas of several relative ages. This is partly because of the scale and simplicity of our mapping and partly because the units are often intertwined. Additional units would likely be delineated if larger-scale mapping was done.

Table I.13. Characteristics of vegetation map units

Map Unit	Appearance on Aerial Photographs	Geomorphic Interpretation	Relative Age
Shrubby Vegetation	Low vegetation; individual plants are not distinguishable; usually dense enough to cover surface continuously; often appear to follow old channels (e.g., have sinuous paths)	Once-active channels or bars that have become stable enough to have revegetated to the point of continuous, but low, vegetative cover; may include side channels (often in the deepest parts of the old channels)	Minimum age estimated to be a few years
Mixed Vegetation	Includes shrubby vegetation and scattered trees; shrubby vegetation often appears to be larger and more continuous than in the shrubby vegetation map unit; includes individual or small areas of trees (appear to be deciduous primarily)	Once-active channels or bars that have become stable enough to have revegetated to the point that shrubby vegetation has matured and trees are becoming large enough to be visible; may include side channels	Minimum age estimated to be about 10 years
Trees	Areas of nearly continuous trees, either deciduous, or conifer, or both; little other vegetation is visible	Surfaces that have not been part of the unvegetated channel in the recent past; the surfaces have been stable enough that trees have become established to the point that other vegetation types are subsidiary; surfaces may still receive some overbank flood flows, but not enough to disrupt tree growth; may include side channels	Minimum age estimated to be tens of years
Cleared	Areas are covered with grasses, primarily; areas appear to have been cleared by human activities; areas are generally outside of the unvegetated and slightly vegetated channels, and old channel map units	Areas cleared by human activity	Vegetation does not reflect surface age
Partially Cleared and (or) Regrowth on Previously Cleared Area	Areas that have several types of vegetation (e.g. open trees with grass, tree-covered areas and shrubby vegetation areas) in artificially appearing patterns (e.g., linear patterns that appear to roads)	Areas partially cleared by human activity, or areas that have been allowed to revegetate after clearing by human activities	Vegetation does not reflect surface age

3.1 Presence of trees

Presence of trees on vegetated surfaces within the HCMZ was interpreted to be indicative that the area had not been recently reworked by the river. These areas were important to our analysis to determine the stability of surfaces within the HCMZ, and their ability to impact channel processes. Vegetation map units containing trees were compared over time to look for trends (Figure I.1; Tables 14 and 15).

Table I.14. Area for mixed vegetation and trees within the HCMZ by reach for each year

Trees and mixed vegetation within HCMZ (Area, m^2)				
	Lower Reach	Middle Reach	Upper Reach DS	Upper Reach US
1939	362,218	562,631	35,030	127,820
1952	116,576	1,022,583	217,786	259,896
1962	220,543	714,726	75,947	-
1973	197,132	940,421	102,758	142,720
1982	129,658	655,871	64,664	79,595
1994	414,176	1,370,635	133,822	114,901
2002	726,583	2,164,847	256,468	284,247

Table I.15. Area of mixed vegetation and trees as percent of HCMZ area by reach for each year

Trees and mixed vegetation within HCMZ Percent of HCMZ)				
	Lower Reach	Middle Reach	Upper Reach DS	Upper Reach US
1939	32	10	4	20
1952	10	18	24	42
1962	17	12	8	-
1973	14	16	11	20
1982	9	10	7	11
1994	26	20	14	16
2002	43	31	26	40

3.2 Location of Persistently Vegetated Areas within the HCMZ From 1939 to 2002

A raster analysis was used to evaluate the number of times an area was mapped as containing trees between 1939 and 2002. Aerial photographs representing decadal times scales were used including 1939, 1952, 1962, 1973, 1982, 1994, and 2002. Areas stored in GIS files for the mixed and tree vegetation units for each year were converted to a raster using spatial analyst in ARC. A value of 1 was assigned to each pixel that was part of the either the mixed or tree map units and a value of 0 was assigned to areas outside of these two vegetation map units, but within the 2002 HCMZ. Rasters were summed using the raster calculator in spatial analyst in ARC to determine how many times a pixel (an area) had been part of a mixed or tree map unit (relatively stable vegetation) for the 10

years for which we have aerial photographs. Results of this analysis are shown in the main report (see Figure 23).

3.3 Ages of Vegetation Within the 2002 HCMZ

To determine the minimum age of vegetated areas containing trees, For example, if an area was within the mixed or tree map units in 2002 and 1994, then the age of that surface is assumed to be at least 8 years. Because of the number of years that are missing between the photographs that we used, it is possible that the vegetation had been destroyed and reestablished between photos. However, consistency among the years and evidence of channel occupation areas suggests that the vegetation was probably present between the years of the photographs. From this raster analysis, minimum ages for the surfaces within the HCMZ were estimated, and the area of each map unit was calculated in ARC (Tables 16 and 17). Results of this analysis are shown in graphical format in the main report (see Figure 25).

Table I.16. Areas for surfaces within each age map unit for each reach by year

	Area (m^2) for each age			
Minimum Age	**Lower Reach**	**Middle Reach**	**Upper Reach DS**	**Upper Reach US**
8	290706	641557	59683	33133
20	2735	126974	7762	8059
30	19505	21377	876	21230
40	33970	39161	0	0
50	0	73371	120	10477
63	17696	104774	5213	8627

Table I.17. Areas for surfaces within each age map unit as a percent of the total 2002 HCMZ area for each reach by year

	Percent of 2002 HCMZ			
Minimum Age	**Lower Reach**	**Middle Reach**	**Upper Reach DS**	**Upper Reach US**
8	17.05	9.30	6.16	4.66
20	0.16	1.84	0.80	1.13
30	1.14	0.31	0.09	2.98
40	1.99	0.57	0	0
50	0.00	1.06	0.01	1.47
63	1.04	1.52	0.54	1.21

3.4 Lengths of Vegetated Surfaces That Separate Active and Unvegetated Channels

Longitudinal lengths of vegetated surfaces were measured and computed to determine if a trend existed in the length of vegetated surfaces that separate either the active channel or unvegetated channel over time (Figure I.3; Tables I.18 and I.19). Center lines were

mapped along the approximate center of vegetated surfaces that split the unvegetated channel on each year of photographs.

Table I.18. Lengths of vegetated areas that separate active channel paths.

	Length of Vegetated Areas that Separate the Active Channel (m)		
	Upper Reach	**Middle Reach**	**Lower Reach**
1939	0	1362	270
1952	0	993	0
1958	945	3444	0
1962	804	3218	1043
1973	551	1439	1265
1982	0	1800	280
1994	0	3490	0
1998	0	277	0
2001	110	518	0
2002	0	0	0

Table I.19. Lengths of vegetated areas that separate unvegetated channel paths (includes active channel path areas).

	Length of Vegetated Areas that Separate the Unvegetated Channel (m)		
	Upper Reach	**Middle Reach**	**Lower Reach**
1939	576	2740	0
1952	823	2788	0
1958	1237	1268	68
1962	0	2545	203
1973	908	2869	178
1982	905	2909	2020
1994	1418	4670	0
1998	810	3543	0
2001	603	2386	0
2002	641	3445	672

4.0 Vegetation Map Units Outside of the HCMZ

Almost all of the surfaces that bound the HCMZ have been thinned or cleared at least once since 1939. The types of vegetation that have been persistent or newly established since disturbance of each area affect the rate at which the channel can erode the surface, as well as the recruitment potential of large woody debris. An interpretation was made of the age and general characteristics of the vegetation on surfaces that bound the HCMZ. The vegetative cover classifications mapped are intended to qualitatively compare the types of vegetation and the potential for large woody debris recruitment along the Upper Quinault River (Figure I.4; Table I.20). The reader is referred to Chapter 2.8 of the Quinault River Watershed Analysis (1999) for a thorough discussion on the vegetation found within the Quinault River drainage. These mapping units were delineated on the 1939 and 2002 aerial photographs.

Table I.20. Interpretation of Vegetative Cover on Surfaces that Bound the HCMZ

Map Unit	Description
Mature	Canopy is generally heterogeneous in appearance, multi-storied, and of high-relief (tall) consisting predominantly of conifers. These areas are interpreted to represent late-successional forest stages. These areas are labeled as mature rather than old growth because timber harvesting was predominantly done through selective tree thinning leaving a substantial population of old growth (180 + years) but also disrupting the natural diversity and succession of forest. Although small remnants remain on the lower Holocene surface, the most expansive populations are found on bedrock and Pleistocene surfaces above the Holocene valley floor.
Mixed	Canopy is mottled in appearance, single- and multi-storied, and of moderate-relief consisting predominantly of deciduous trees. These areas are interpreted to represent middle- and late-successional forest stages. In many areas conifers were removed by extensive timber harvest (clear cutting) or by channel migration. The conifers were subsequently replaced by the deciduous trees. Most of the populations range in age between 35 and 50 years, but there are also populations of less than 30 years and greater than 60 years. Nearly all of the populations are on the Holocene surfaces with the more expansive populations being predominantly on the intermediate and upper surfaces.
Immature	Canopy is homogeneous in appearance, single-storied, and of low- to moderate-relief consisting of either conifers or deciduous trees. These areas are interpreted to represent early- and middle-successional forest stages which include both managed and unmanaged stands. Most of these populations are replacement stands that have grown within the last 35 years following timber harvesting and/or channel migration. The stands occur on all surfaces including Pleistocene terraces and bedrock.
Scattered	Canopy is heterogeneous in appearance, partially open, and of low- to moderate-relief. These areas are generally composed of deciduous trees, but also contain numerous conifers. No successional stages are interpreted because these areas appear to be actively managed. The tree populations contain an array of ages (from less than 20 years to greater than 65 years) depending on the stands origin (ie. homesteading, timber harvest, or channel migration). These stands are predominantly found on the Holocene surfaces.
Scrub	Canopy can be heterogeneous or homogeneous in appearance, predominantly open, and of low-relief. No successional stages are interpreted because these areas appear to be actively managed. Areas are comprised of brush that has grown-in following timber harvesting or channel migration. These areas can be found throughout the valley where clear cuts have been conducted and are common on the Holocene surfaces.
Grass	Canopy is homogeneous in appearance, open, and of very low-relief. No successional stages are interpreted because these areas appear to be actively managed. Areas are comprised of grasslands, pastures, and other openings that have been cleared by human disturbance or by channel migration. These areas are predominantly found on the Holocene surfaces.

5.0 Historical Bank Erosion along HCMZ

Expansion of the HCMZ between 1939 and 2002 was mapped to determine if a trend was present in the amount and location of erosion between 1939 and 2002 (Tables I.21 and I.22). The total area of bank erosion was also used as an input variable to the sediment budget (see Sediment Appendix). The HCMZ was delineated for each photograph year by observing changes in channel position and newly eroded areas, and then overlaid on the previous year HCMZ to identify areas that eroded between the photograph years (Figure I.5). A figure documenting locations and timing of erosion is presented in the main report (see Figure 17).

Table I.21 Lengths of the left (south) and right (north) HCMZ boundaries that were eroded between 1939 and 2002, and the percent of these lengths of the total 2002 HCMZ boundaries

Reach	Bank	Bank Length (m)	Length of Bank Eroded 1939-2002 (m)	Percent of Bank Eroded 1939-2002
Lower	Left	1900	736	39
	Right	1991	1660	83
Middle	Left	10,399	6989	67
	Right	11,069	7249	65
Upper	Left	4223	1224	29
	Right	3998	2576	64

Table I.22. Area of the left (south) and right (north) HCMZ boundaries that were eroded between 1939 and 2002 by year. (Note that only RK 14 to 16 is included for Upper Reach in 1962 and 1998)

	Total Area (m^2) By Reach By Boundary (Left and Right)							
	Lower Reach		Middle Reach		Upper Reach (Downstream Section)		Upper Reach (Upstream Section)	
	Left	Right	Left	Right	Left	Right	Left	Right
2001-2002	100	19068	25485	4916	0	0	0	0
1998-2001	0	4152	84296	4650	0	0	0	0
1994-1998	2297	3583	86388	7755	3847	0	0	0
1982-1994		119665	139161	164872	0	0	8474	0
1973-1982	445	17308	84950	238909	8426	0	0	0
1939-1973	--	--	--	--	--	--	--	33076
1962-1973	17297	161081	69318	43376	0	0	0	0
1958-1973	--	--	--	--	--	--	--	19952
1958-1962, Possible	--	--	--	--	--	--	--	8418
1958-1962	11830	8616	107754	84873	6969	10260	0	0
1952-1958	26616	5306	78012	105047	6933	13365	0	14399
1939-1952	15717	0	61590	114959	16679	24263	0	38910

Table I.23. Area of the left (south) and right (north) HCMZ boundaries that were eroded between 1939 and 2002. (Note that only RK 14 to 16 is included for Upper Reach in 1962 and 1998)

Reach	Bank	Bank Area (m^2)
Lower	Left	74,303
	Right	338,779
Middle	Left	736,954
	Right	769,357
Upper (Downstream Section)	Left	42,855
	Right	47,887
Upper (Upstream Section)	Left	8,474
	Right	114,755

As the HCMZ expands, it is possible that the channel has more area to occupy so it runs along the HCMZ boundary less, which results in less erosion. To test this hypothesis, the lengths of sections of the HCMZ that have coincided with the active channel and unvegetated channel of the Quinault River were compared between 1939 and 2002 (Figure I.6). Sections where the HCMZ boundary coincides with the active channel or unvegetated channel in that year were delineated for each reach in each year. Lengths were summed for each boundary (left and right) for the entire reach. The percentages of the total HCMZ boundary of these lengths for each year were computed in Excel. Results for the right and left HCMZ boundaries in the Lower Reach are presented in Tables 23 and 24, in Tables 25 and 26 for the Middle Reach, and in Tables 27 and 28 for the Upper Reach. Results for the active channel and unvegetated channel are presented separately. The active channel would be expected to have the deepest depths and highest velocities along the HCMZ boundary, but anywhere the unvegetated channel runs against the HCMZ could also result in significant erosion. Note that for the Lower Reach, the channel shifts to the north after 1973, such that it no longer runs along the left HCMZ boundary and vice versa for the right side. In the Upper Reach, a levee placed by 1973 has remained in place and prevented the channel from running along the left HCMZ boundary for most of the reach.

Table I.24. Lengths of active and unvegetated channel that coincide with the left HCMZ boundary for the Lower Reach

Lower Reach, Left Boundary				
	Active Channel Along Boundary		Unvegetated Channel Along Boundary	
Year	Lengths Total (m)	Percent of Total Bank	Lengths Total (m)	Percent of Total Bank
1939	294	18	717	44
1952	824	41	1074	53
1958	497	23	1015	48
1962	681	32	770	36
1973	407	21	512	26
1982	0	0	0	0
1994	0	0	0	0
1998	0	0	0	0
2001	0	0	0	0
2002	0	0	0	0

Table I.25. Lengths of active and unvegetated channel that coincide with the right HCMZ boundary for the Lower Reach

Lower Reach, Right Boundary				
	Active Channel Along Boundary		Unvegetated Channel Along Boundary	
Year	Lengths Total (m)	Percent of Total Bank	Lengths Total (m)	Percent of Total Bank
1939	310	16	310	16
1952	0	0	0	0
1958	0	0	0	0
1962	369	18	369	18
1973	256	12	727	34
1982	663	30	663	30
1994	213	9	1104	47
1998	39	2	1125	49
2001	223	9	983	41
2002	184	9	974	46

Table I.26. Lengths of active and unvegetated channel that coincide with the left HCMZ boundary for the Middle Reach

Middle Reach, Left Boundary				
	Active Channel Along Boundary		Unvegetated Channel Along Boundary	
Year	Lengths Total (m)	Percent of Total Bank	Lengths Total (m)	Percent of Total Bank
1939	4862	46	6630	63
1952	860	8	1909	18
1958	1951	19	3354	32
1962	2710	26	3668	35
1973	2362	23	3440	33
1982	1073	10	2256	22
1994	2510	24	3814	37
1998	1459	14	2663	26
2001	1671	16	3280	32
2002	2498	24	3563	34

Table I.27. Lengths of active and unvegetated channel that coincide with the right HCMZ boundary for the Middle Reach

Middle Reach, Right Boundary				
	Active Channel Along Boundary		Unvegetated Channel Along Boundary	
Year	Lengths Total (m)	Percent of Total Bank	Lengths Total (m)	Percent of Total Bank
1939	761	7	2569	23
1952	1689	15	2041	18
1958	2513	22	3502	31
1962	2471	22	4807	43
1973	1225	11	2287	20
1982	1701	15	4744	43
1994	2126	19	3630	32
1998	266	2	2540	23
2001	617	5	1951	17
2002	722	6	1768	16

Table I.I.28. Lengths of active and unvegetated channel that coincide with the left HCMZ boundary for the Upper Reach

Upper Reach, Left Boundary				
	Active Channel Along Boundary		Unvegetated Channel Along Boundary	
Year	Lengths Total (m)	Percent of Total Boundary	Lengths Total (m)	Percent of Total Boundary
1939	1559	37	2484	59
1952	0	0	279	7
1958	950	23	2010	48
1962	706	36	706	36
1973	1231	29	2364	57
1982	1398	33	1941	46
1994	1739	42	2305	55
1998	0	0	1363	32
2001	1770	43	1770	43
2002	1662	42	1662	40

Table I.I.29. Lengths of active and unvegetated channel that coincide with the right HCMZ boundary for the Upper Reach

Upper Reach, Right Boundary				
	Active Channel Along Boundary		Unvegetated Channel Along Boundary	
Year	Lengths Total (m)	Percent of Total Bank	Lengths Total (m)	Percent of Total Bank
1939	578	14	968	23
1952	151	4	151	4
1958	806	21	1380	36
1962	268	14	459	25
1973	0	0	0	0
1982	0	0	0	0
1994	0	0	324	8
1998	410	10	550	14
2001	0	0	527	13
2002	0	0	59	2

6.0 Delta Mapping

Mapping of the aerial extent of the Quinault River delta formed at the inlet to Lake Quinault was undertaken to estimate the amount of sediment being deposited in the delta for input into the sediment budget analysis (see Sediment Appendix). The sequential change of both erosion (reduction in delta size) and deposition (increase in delta size) were mapped for all historical maps and aerial photographs (Figure I.7), but only the deposition from 1939 to 2002 was used for the sediment budget. Delta areas below the water are visible on the aerial photographs and were mapped for each year. The Quinault River has occupied several different paths to Lake Quinault between RK 2 and the lake. Delta area was subdivided into four areas based on the different source channels that entered the lake at each of the four paths observed. A summary of the planform growth of each delta area is provided (Table I.29), along with computed areas (Tables I.30 to I.33).

Table I.30. Characteristics of the areas used in the mapping of the delta deposits

Year	Location of Low-flow Channel Relative to Deposition Areas (or Alluvial Fans)	Location of Low-Flow Channel Relative to Location in Previous Years
1897	Area 2, south side for main low-flow channel	South of the 1982 and 1994 low-flow channels
	Area 1, north side for a smaller low-flow channel	About the same location as the 1939 low-flow channel
1939	Area 1, north side	
1952	Area 1, near center	South of the location of the 1939 low-flow channel
1958	Area 1, near center	About the same location as the 1952 low-flow channel
1962	Split flow--one channel in Area 1, near center	About the same location as the 1952 and 1958 low-flow channels
	One channel in Area 2, near center	New location for the unvegetated channel
1973	Split flow--one channel in Area 1, near center	About the same location as the 1952, 1958, and 1962 (south branch) low-flow channels
	One channel in Area 2, near center	About the same location as the north branch of the 1962 low-flow channel
1982	Area 2, near center	About the same location as the north branches of the 1962 and 1973 low-flow channels
1994	Area 2, near center	About the same location as the 1982 low-flow channel
1998	Area 2, near center	About the same location as the 1982 and 1994 low-flow channels
2001	Area 2, near center and north part	About the same location as the 1982, 1994, 1998 low-flow channels and to the north of these channels
	Meander in the low-flow channel intersects the upper part of Area 3	Appears to be a narrow channel through the vegetation that leads to Area 3; a new location
2002	Area 3, near center	A new channel location; in about the same location as the narrow channel (not part of the unvegetated channel) in 2001

Table I.31. Changes in the delta in Area 1 between 1939 and 2002

Year	Type	Area (m^2)	Year	Type	Area (m^2)
1939	Deposition	82,769	1939	Erosion	0
1952	Deposition	51,840	1952	Erosion	3705
1958	Deposition	42,189	1958	Erosion	1825
1962	Deposition	5783	1962	Erosion	11,531
1962			1962	Erosion	5434
1973	Deposition	27,083	1973	Erosion	2250
1982	Deposition	1263	1982	Erosion	8648
			1982	Erosion	9753
1994	Deposition	1468	1994	Erosion	1028
1994	Deposition	2936			
1998	Deposition	4185			
2001	Deposition	1957			
2002	Deposition	920			
2002	Deposition	456			
Total	Deposition	222,849	Total	Erosion	44,174
Total	(Dep-Ero)	178,675			

Table I.32. Changes in the delta in Area 2 between 1939 and 2002

Year	Type	Area (m^2)	Year	Type	Area (m^2)
1939	Deposition	66,300			
1952	Deposition	3518			
1952	Deposition	1629			
1958	Deposition	10,073			
1962	Deposition	749	1962	Erosion	1690
			1962	Erosion	1960
1973	Deposition	5826	1973	Erosion	4513
1982	Deposition	31,894	1982	Erosion	1698
1994	Deposition	15,904	1994	Erosion	12,354
1994	Deposition	1246			
1998	Deposition	679			
1998	Deposition	28,906			
2001	Deposition	1545			
2001	Deposition	8268			
2002	Deposition	3118			
2002	Deposition	316			
2002	Deposition	1556			
2002	Deposition	935			
Total	Deposition	182,463	Total	Erosion	22,215
Total	(Dep-Ero)	160,248			

Table I.33. Changes in the delta in Area 3 between 1939 and 2002

Year	Type	Area (m^2)	Year	Type	Area (m^2)
1939	Deposition	20,843	1939	Erosion	0
1973	Deposition	7021	1973	Erosion	0
1982	Deposition	5048	1982	Erosion	1763
1994	Deposition	4905	1994	Erosion	0
1998	Deposition	661	1998	Erosion	0
2002	Deposition	0	2002	Erosion	1484
Total	Deposition	38,478	Total	Erosion	3247
Net Change		35,232			

Table I.34. Changes in the delta in Area 4 between 1939 and 2002 (Note that no erosion was observed in this area)

Year	Type	Area (m^2)
1939	Deposition	12,772
1952	Deposition	1935
1962	Deposition	605
1973	Deposition	18,839
1982	Deposition	12,687
1982	Deposition	1915
1994	Deposition	2406
1994	Deposition	6705
1998	Deposition	1774
2002	Deposition	5460
Total	Deposition	65,098
Net Change		65,098

7.0 Human Disturbances

A cursory evaluation of areas that were interpreted to be thinned or cleared on each aerial photograph available was done to determine the general extent and timing of disturbance to the vegetation within the Upper Quinault River Valley (FigureI.8). This mapping is not intended to be a thorough documentation of logging and would need to be further refined for computation purposes. However, it provided an adequate qualitative interpretation of the extent and timing of logging activities over the last century.

Additional mapping of roads, bank protection, engineered log jams, levees, bridges, culverts, and other unique human placed features were also mapped. In many cases these features were observed in the field or on a particular aerial photograph, but the exact construction date is not known. A map of these features known to exist in 2002 is provided in the main report (see Figure 32).

An additional mapping unit was delineated on the 2002 aerial photograph that estimates the minimum time period for which surfaces binding the HCMZ were last disturbed in some way. For example, if a surface was relatively undisturbed in 1939, logged in 1952, and has remained cleared since 1952, the 2002 map unit would show the area as last disturbed 50 years ago. If a surface was cleared by the 1939 aerial photograph and has remained cleared, it would show the last disturbance as 65 + years ago. The disturbance mapping was combined with vegetation mapping of terrace surfaces to estimate minimum ages of trees present in 2002 on surfaces binding the HCMZ.

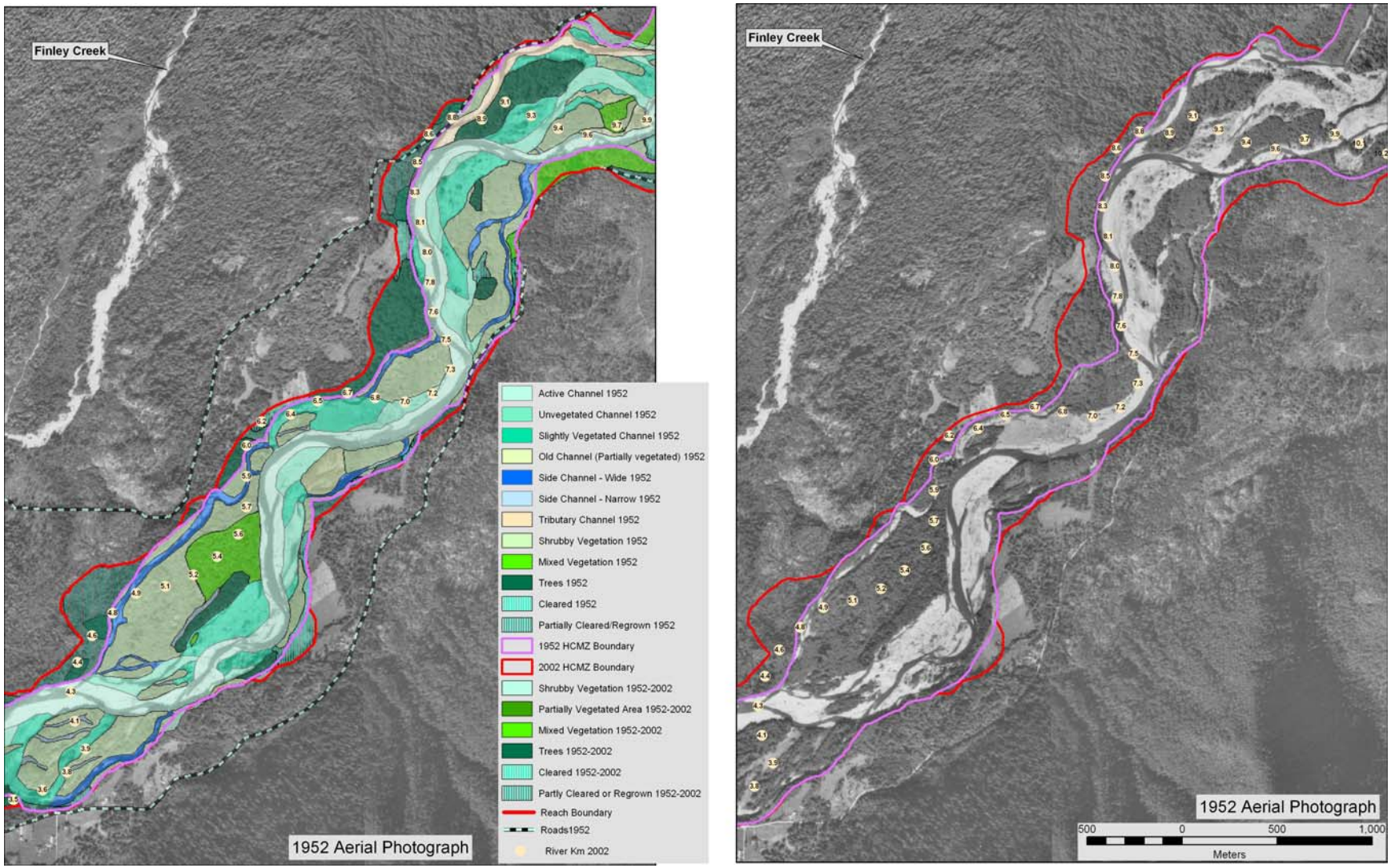
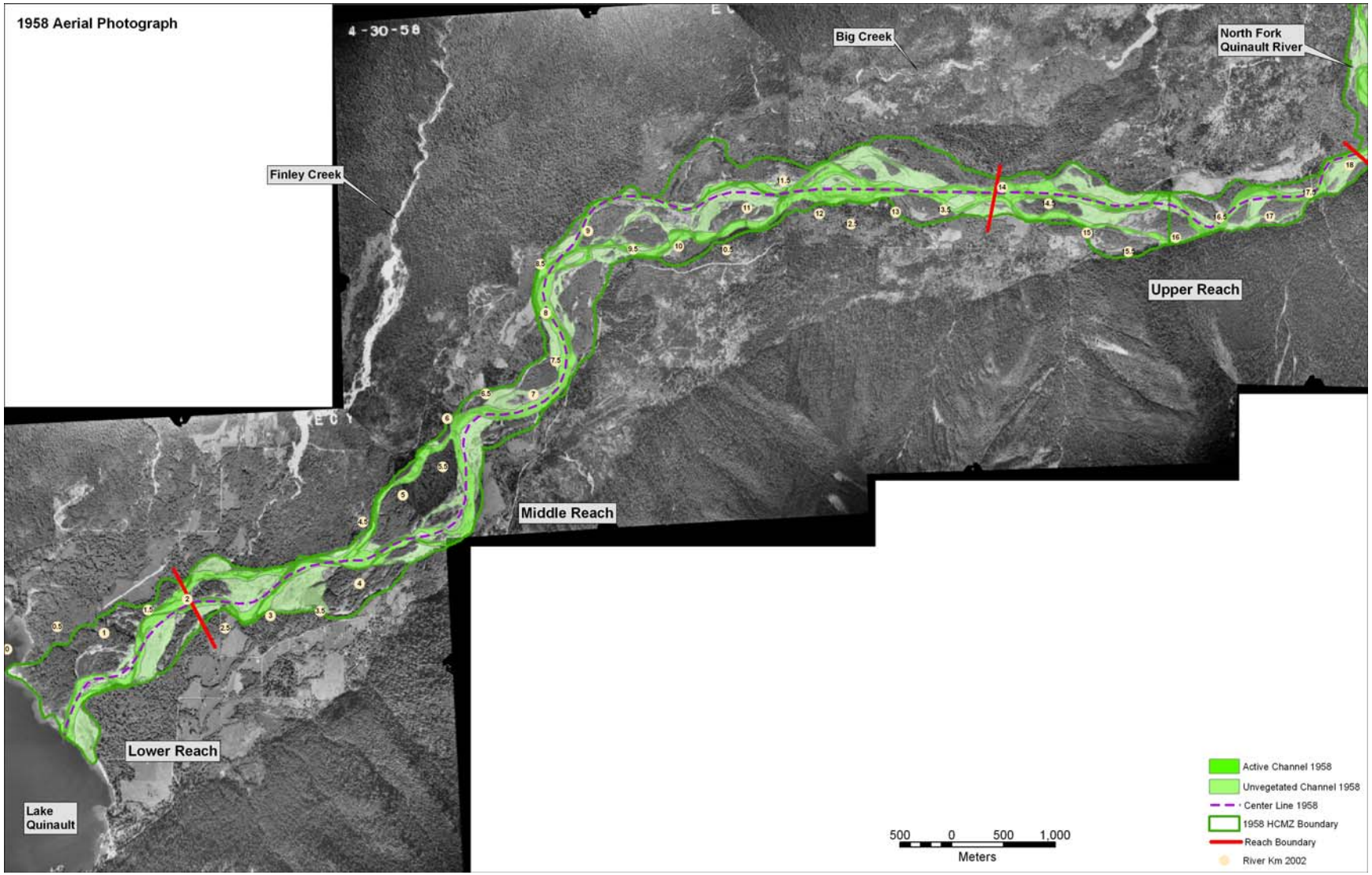


Figure I.1. An example of the channel and vegetation map units delineated within the HCMZ on a portion of the 1958 aerial photograph.



FigureI.2. Average widths were calculated for the active channel and unvegetated channel (includes the active channel) for each year of photographs. The average widths were calculated by dividing the area of each channel type by the length of a line drawn

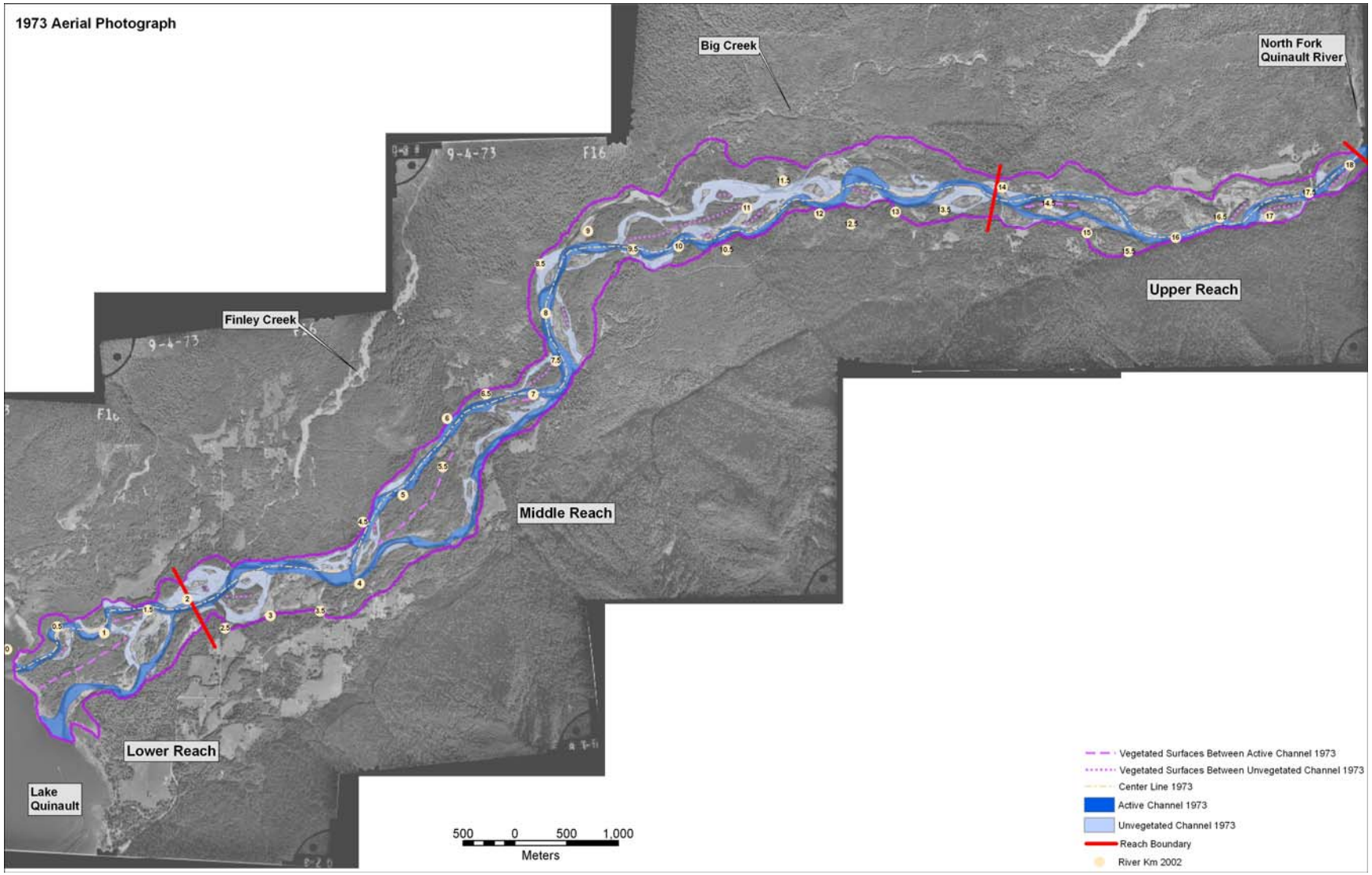


Figure I.3. Lengths of vegetated surfaces that separated the active and unvegetated channels were mapped for each year of photographs. The lengths of the separating vegetated surfaces were compared to the entire length of the reach as represented by the center line of the channels, as discussed in Section 2.1. This figure shows the 1973 channel units and center line as an example of these calculations.

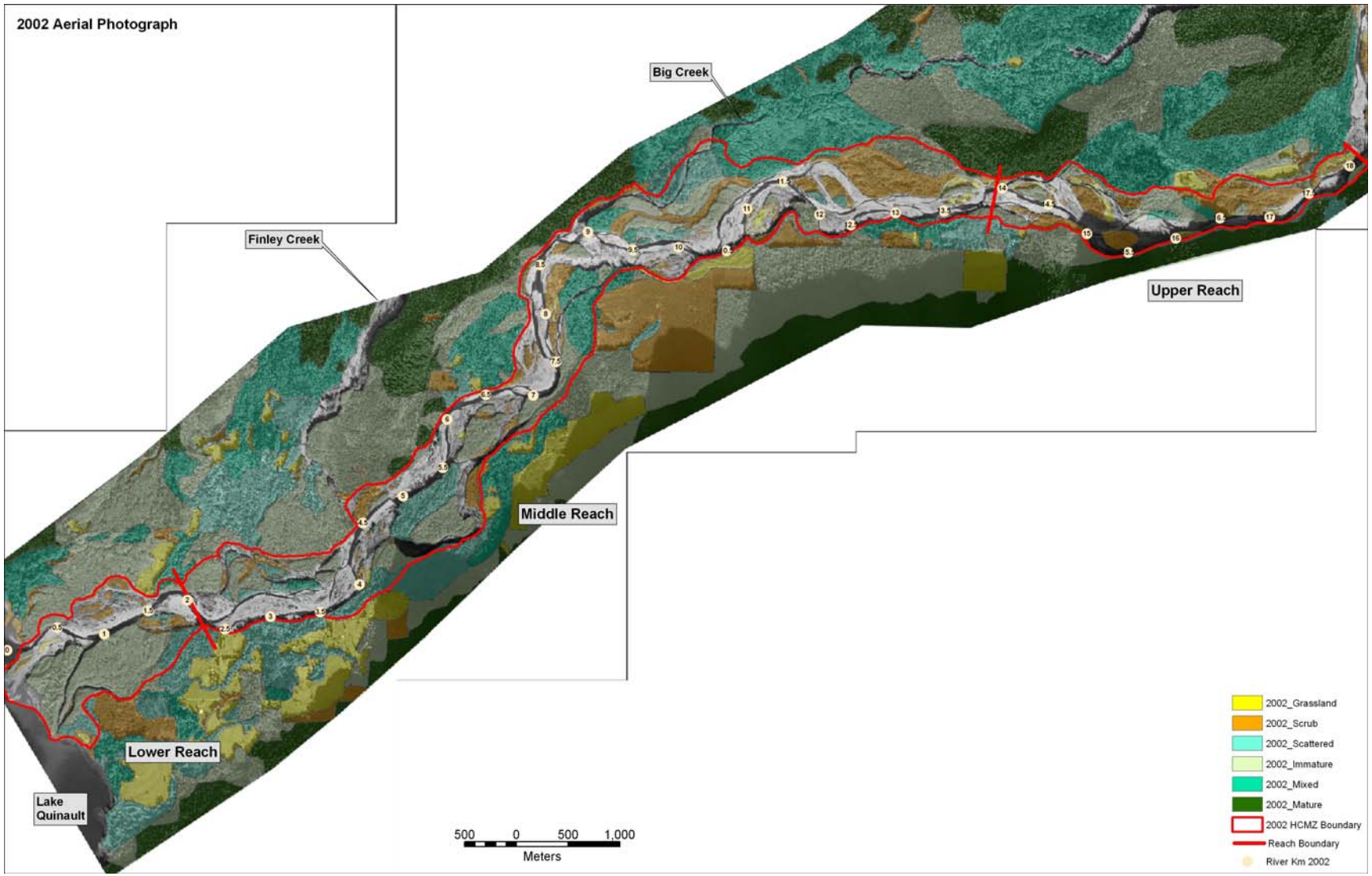


Figure I.4. Vegetation units that were mapped primarily outside of the HCMZ using the 2002 aerial photographs.

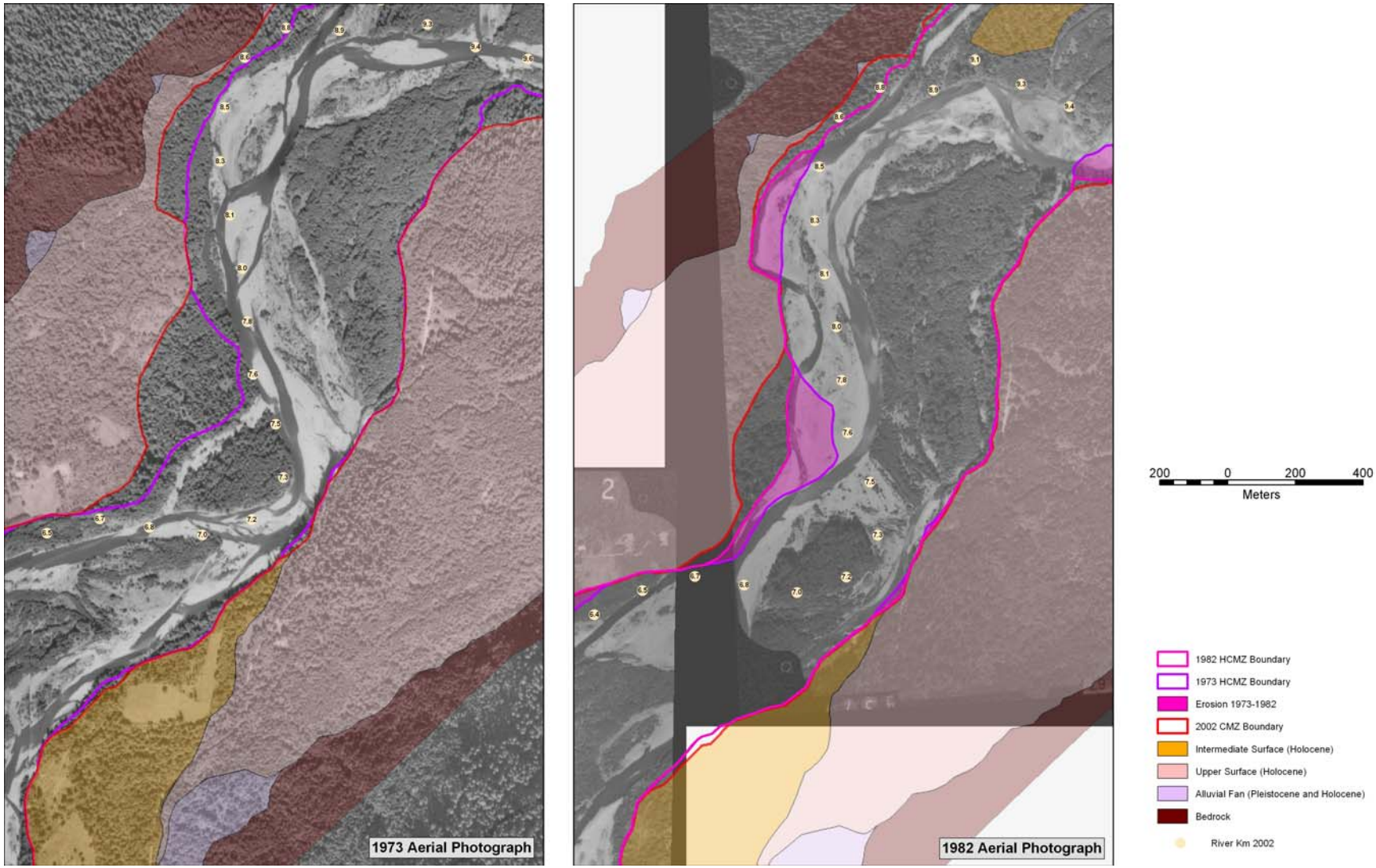


Figure I.5. Areas that were incorporated into the HCMZ between years of photographs were delineated and their areas were calculated in Arc. In this way, expansion of the HCMZ between 1939 and 2002 was documented. This figure shows an example of HCMZ e

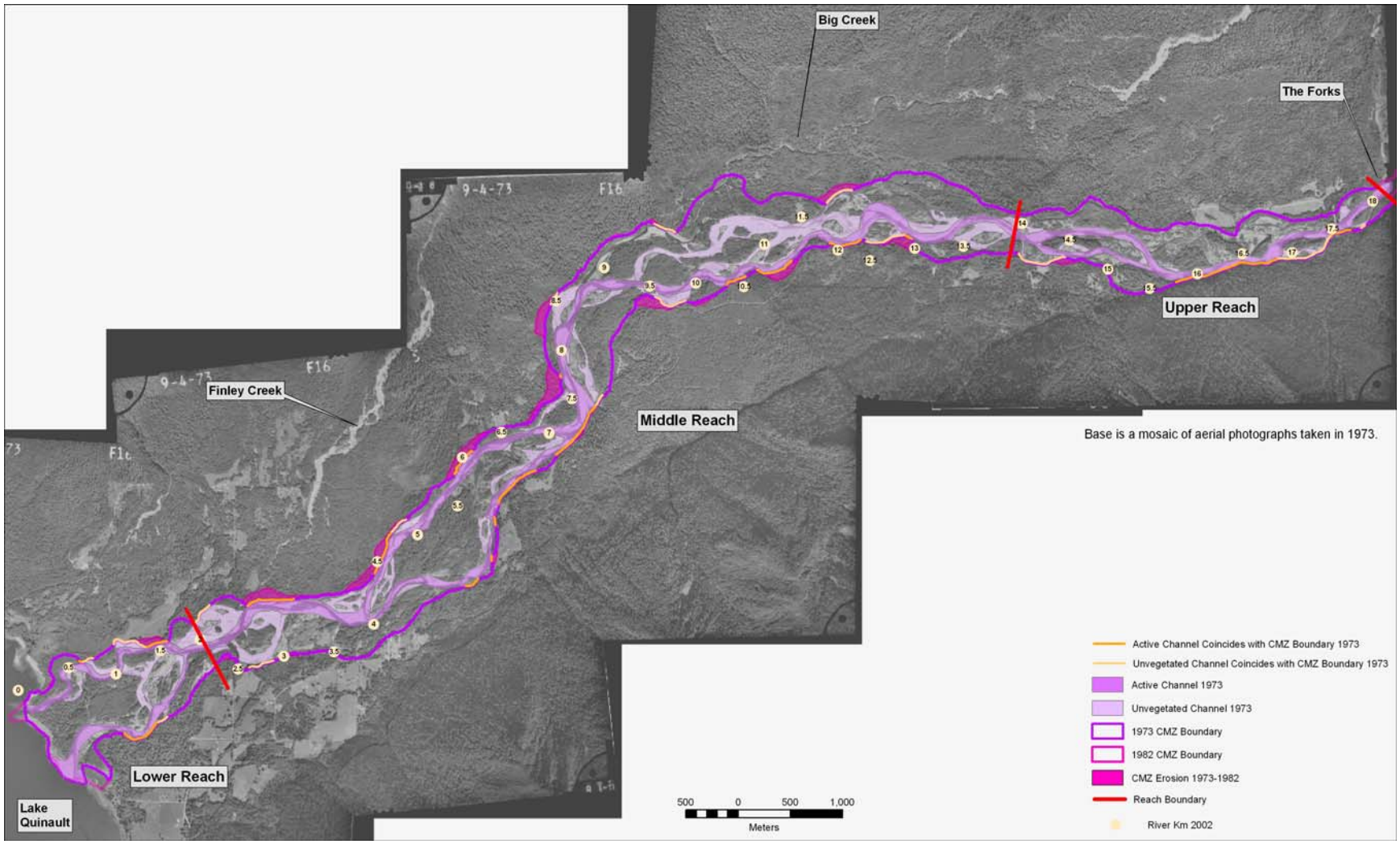


Figure I.6. Lengths of the left and right HCMZ boundaries that coincide with the active and unvegetated channels were mapped for each year of photographs. The lengths were summed for each boundary in each reach by year, and the percent of the total HCMZ

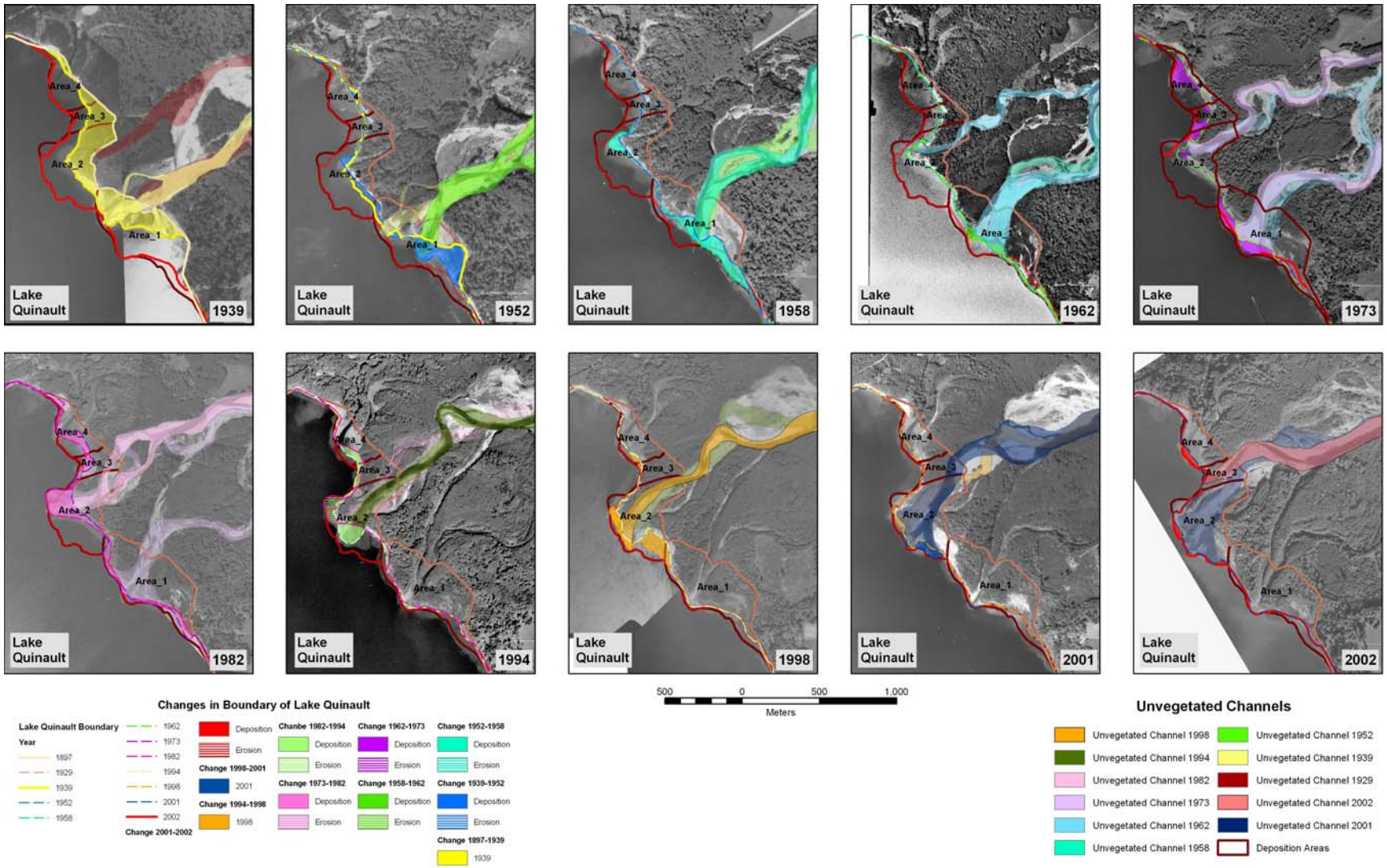


Figure I.7. Mapping of changes in the delta area between 1939 and 2002. The delta area was subdivided into 4 areas based on the source of the sediment entering Lake Quinault.

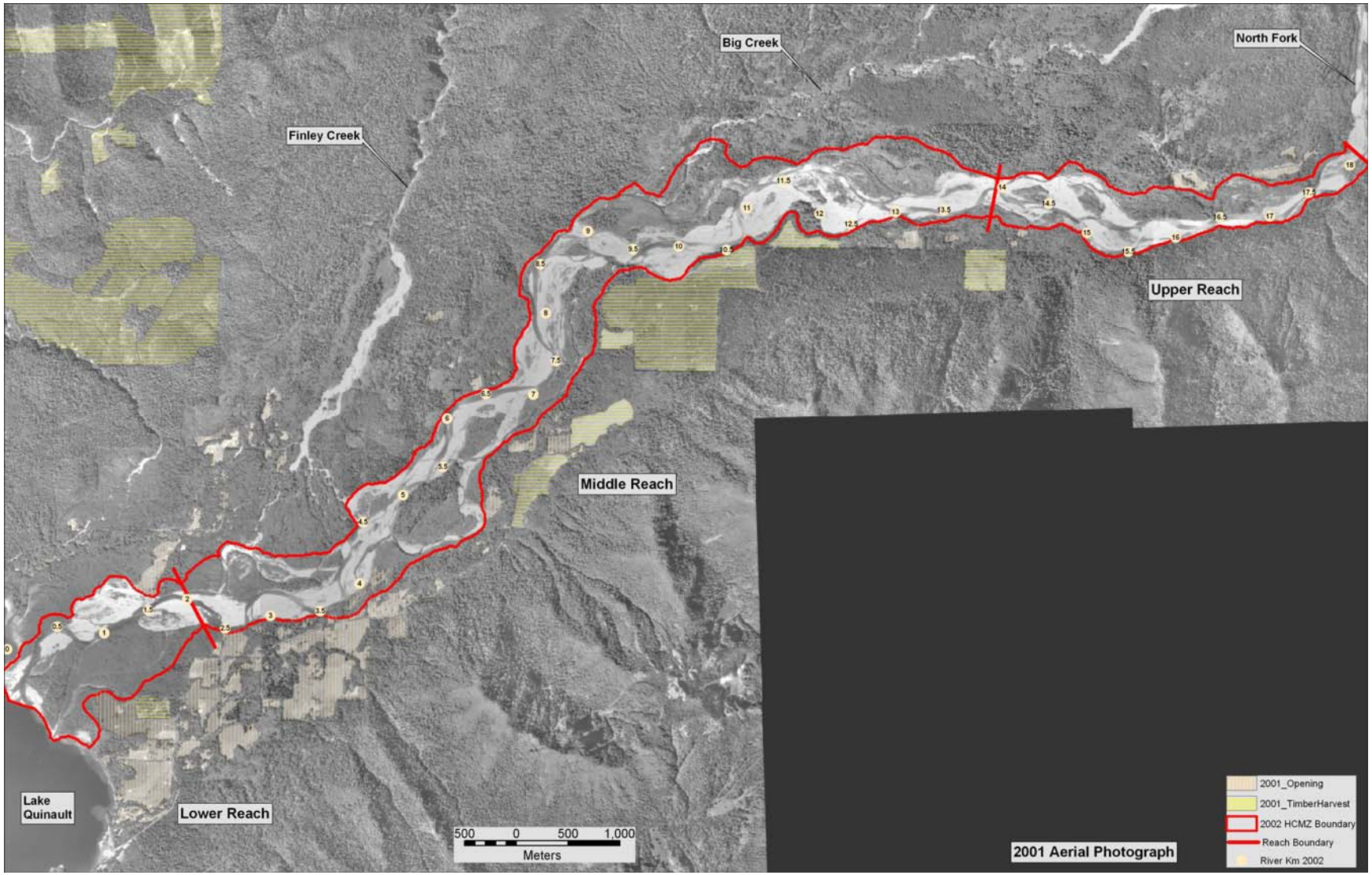


Figure I.8. An example of cleared and harvested areas that were mapped outside of the HCMZ using the 2001 aerial photographs. Mapping of this type was done for the following years: 1939, 1958, 1962, 1973, 1982, 1998, and 2001.

APPENDIX J: IDENTIFICATION OF HISTORICAL CHANNEL MIGRATION ZONE

We define the historical channel migration zone as a boundary encompassing areas of historical channel occupation over a particular timeframe. This appendix explains how we delineated the historical channel migration zone (HCMZ) for the Quinault River study area, and what timeframe each boundary represents.

1.1 Definitions and Terminology

A historical channel migration zone represents an area where the main river channel occupies and transports sediment and woody debris within an established timeframe in history. The area within the HCMZ is dynamic and continually changing form during floods. It represents the area where the majority of coarse sediment (sand, gravel, and cobbles) and woody debris has been transported during at least the last century. The active channel represents the low flow river channel and gravel bars that are frequently reworked during floods and over which bedload is transported. The active channel is free of mature woody vegetation. The active floodplain was built by lateral migration of the active channel. It includes side channels, secondary or flood-flow channels, and low-elevation vegetated surfaces that are frequently inundated by floods. The area outside of the HCMZ boundary can still be inundated, but it takes larger floods to overtop the surfaces that form the HCMZ boundary.

For our study of the Upper Quinault River, we were most interested in river occupation over the last century. We delineated the 2002 HCMZ boundary, which is believed to represent a time period of at least a hundred years based on documentation of channel position between 1906 and 2002. It has been documented that surfaces binding the HCMZ boundary in the Quinault River valley range in age between a few hundred to several thousand years old (see radiocarbon dating appendix). These ages represent the minimum age during which these surfaces were last occupied by the Quinault River or inundated by the historic, larger Lake Quinault (see geology appendix). Because these surfaces are greater than a hundred years old, the "HCMZ" boundary likely encompasses a longer time interval than a hundred years of active channel and floodplain occupation, but the exact time interval is unknown.

The HCMZ is not a fixed boundary, and can expand and contract during different periods in the river's history. Thousands of years ago the river occupied much of the Upper Quinault River valley between the Forks and the present location of Lake Quinault. This boundary gradually narrowed as the river incised into the valley. Many of the present terraces have smaller channels cut through them that provide evidence for times in history when the river occupied a larger portion of the valley bottom. Historic channel migration zones associated with geologic time scales were not done for this study, but we did map geologic surfaces. These surfaces can be used to get a feel for the portion of the valley the river occupied during Holocene and Pleistocene time periods. The geology appendix of our report provides more information about these surfaces and how they are linked to the recession history of Lake Quinault.

Since at least 1939, the HCMZ boundary has continually expanded due to river erosion. The 2002 HCMZ can be bounded by terraces composed of glacial material (till, outwash, or lacustrine sediments) or alluvium, alluvial fans, bedrock, older lake deposits, or engineered bank protection (riprap, engineered log jam, bridge abutment, levees, road embankment). The 2002 HCMZ will continually expand in the future where the river runs against erodible material, particularly in areas that have been cleared of native riparian vegetation that help slow the rates of erosion. It was of interest to track how much and when the HCMZ boundary has eroded since 1939. For this reason, an interpretation was made using sequential aerial photography of where the 1939 and subsequent aerial photography year HCMZ boundaries were. The differences between the 1939 HCMZ and more 2002 HCMZ boundaries represent areas of bank erosion along the boundary since 1939.

The rate and extent of potential expansion of the 2002 HCMZ boundary can be interpreted by looking at historical rates measured between 1939 and 2002, by evaluating which surfaces are most susceptible for river erosion based on geologic controls and sediment transport capacity in the system, and by looking at where channels are currently dissected through the binding surfaces. Areas where the channels dissected through these surfaces have an upstream connection with the Quinault River pose the greatest risk for future channel avulsion. Erosion of the intermediate Holocene surface is thought to be at a greater risk for higher lateral rates of erosion than the higher elevation upper Holocene surface. Further evaluation of bank material properties in each geologic surface would need to be accomplished to refine predictions of future historic channel migration zone boundary erosion rates. Methodology that could be used as a guideline to estimate the risk of future erosion distances and rates of the historic channel migration zone is described in a report by the Bureau of Reclamation on the Hoh River in Washington State (Piety, et al, 2004), and in literature developed by the Washington State Department of Ecology (Abbe and Raff, 2003).

1.2 Methodology for Determination of Historical Channel Migration Zone

We developed a HCMZ boundary using the following steps:

1. Document active floodplain and river channel paths as observed in aerial photography between 1939 and 2002
2. Document geologic surfaces that bind the active floodplain
3. Delineate the 2002 historic channel migration zone boundary at the edge of geologic surfaces encompassing the 1939 to 2002 channel paths. Surfaces on the Quinault River were composed of Holocene and Pleistocene terraces, lake deposits, bedrock, and alluvial fans.
4. Document channel paths on historical maps from 1897, 1906, and 1929.
5. Expand the 2002 historic channel migration zone boundary to include these areas where there is evidence of a historical channel based on Lidar data collected in 2002 or from field work.
6. Field check results.

Analysis of historical aerial photographs and maps to document historical main channel paths and active floodplain areas. Historical channel paths show areas where the active channels have been in the recent past, which defined the 2002 HCMZ. Older channel paths are often still visible in the existing active floodplain as side and overflow channels. In other cases, development or logging activities have disturbed or filled in the older channel paths and floodplain making them undetectable from aerial photography. For the Quinault River, historical aerial photographs ranging from 1939 to 2002 were used, along with historical maps documenting channel position in 1897, 1906, and 1929.

Lidar Data from 2002 to verify the boundary of the HCMZ. This data was used to identify the boundaries of older surfaces, mapped as Holocene or Pleistocene in age, and low surfaces that show topographic evidence of old channels, such as narrow zones of lower or sparse vegetation on an otherwise densely vegetated surface. These low surfaces would be included in the HCMZ. On the other hand, high terrace surfaces that appear to be uncut by large channels would be excluded from the HCMZ. In some areas of the Upper Quinault, Lidar data revealed small channels dissected through the surfaces that bind the HCMZ. These channels can be frequently inundated even when the binding surface is not, but were not considered part of the HCMZ unless there was evidence of the main channel occupying these areas between 1906 and 2002. These areas would likely be considered part of a channel migration zone associated with a longer historical timeframe, such as several hundred to thousands of years.

Field inspections to verify delineated terrace banks and confirm the location of the HCMZ boundary as defined from the Lidar data. Terrace banks were identified in the field to verify mapping done from aerial photography and maps. Where the location of the HCMZ boundary was questionable, low surfaces were investigated to determine if they contained evidence of frequent flooding and active channels. Frequent flooding would mean the surface was part of the active floodplain in the HCMZ as opposed to being a higher terrace that forms the HCMZ boundary. Characteristics looked for were overflow paths that were fairly unvegetated, debris backed up against woody vegetation, and fine sediment deposition.

1.3 Methodology for Defining the 1939 Historical Channel Migration Zone

It was desired to identify the HCMZ as far back in time as possible to quantify the amount and rate of terrace bank erosion that has occurred over time. The 1939 aerial photography was the oldest possible date to determine a HCMZ boundary. Unlike the determination of the 2002 historical channel migration zone, which integrates extensive field work and could incorporate field observations, the 1939 HCMZ was estimated solely on the basis of aerial photography and historical maps. An interpretation was made of the 1939 HCMZ based on the distinction between vegetation in the active floodplain (1939 HCMZ) and on terraces that bound the 1939 HCMZ. In general, the vegetation within the 1939 HCMZ is dense, appears of the same age or height, and is often discontinuous because of recently active side channels that have removed vegetation or have kept it from growing. The vegetation on the terraces that bound the

HCMZ is less dense and appears irregular, because individual trees are large enough to be visible and the trees are of differing species and heights. The original land survey maps from 1897 and 1906, and a USGS 1929 map document channel position prior to 1939. These maps have been found to be very accurate in many different watersheds studied and were used as a check on the 1939 HCMZ to ensure the boundaries identified as terraces were reasonable. In many cases the 1952 aerial photography was also used to check the 1939 HCMZ boundaries because the 1952 aerial photographs were flown at a lower elevation and had a higher level of clarity regarding vegetation and channel paths.

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Appendix K: Hydrology

This section documents information on the hydrology of the Quinault River above Lake Quinault specifically related to study questions. A more detailed description of overall hydrology of Quinault watershed and determination of flood frequency numbers used in this appendix can be found in the Watershed Analysis, Chapter 2 (QIN, 1999). Because this study evaluates river channel changes over the last century, it is important to determine when the majority of floods that can result in river channel changes occur. The question has also been raised as to whether flood magnitudes have been impacted by natural and human induced changes in the river valley over the last century. Given the possibility that in-channel restoration projects may be implemented as part of future studies, it is also important to know the probability and magnitude of flood flows. Because it is expected that Lake Quinault dampens the flood peak during storms, the flows measured at the gage at the lake outlet are likely smaller than those experienced in the Upper Quinault. A cursory hydrologic analysis was performed to predict the equivalent river flows for standard flood frequency intervals in the Upper Quinault watershed, using several methods for comparison. Discharge values presented in this section are provided in English units because of the familiarity and provision of data in this format from U.S. Geological Survey (USGS).

Discharge and Precipitation Measurements

The Quinault River drains from the glaciated Olympic Mountains in northwest Washington State, with a total drainage area above the outlet of Lake Quinault of 684 km^2 (264 mi^2), and 606 km^2 (234 mi^2) above the inlet of Lake Quinault. About 18 km upstream from the inlet to Lake Quinault, two stems of the Quinault River join together informally referred to as the Forks. Above the Forks, the North Fork Quinault has a drainage area of 208 km^2 (80.3 mi^2), and the East Fork has a drainage area of 234 km^2 (90.3 mi^2). River flows have been measured at the outlet of Lake Quinault from October 1, 1911 to the present time by the USGS (Gage 12039500) with the exception of water years 1923 to 1925 where no data is available. Discharge data was also recorded at a location on the North Fork Quinault (above the Forks Bridge) from November 1, 1964 to September 30, 1986 (USGS Gage 12039300, drainage area on North Fork of 74.1 square miles). The average annual flow is 2,876 ft^3/s (81.4 m^3/s). Precipitation was measured at the Quinault Ranger Station from 1961 to 1990, and shows average monthly precipitation varied between 3 to 24 inches during this time period (QIN, 1999). The average annual precipitation is 146 inches. A representation of how precipitation varies throughout the watershed is shown in Figure 3 of Attachment 1 of this appendix.

Flow patterns

The majority of floods occur in the Upper Quinault between November to February as a result of winter storm events (Figure 1). Flows gradually decline until late April, and then increase again to mid-June due to melting of winter snowpack (QIN, 1999). Low

flow periods during drier summer and fall months are sustained from Anderson Glacier and numerous snowfields in the upper watershed (QIN, 1999).

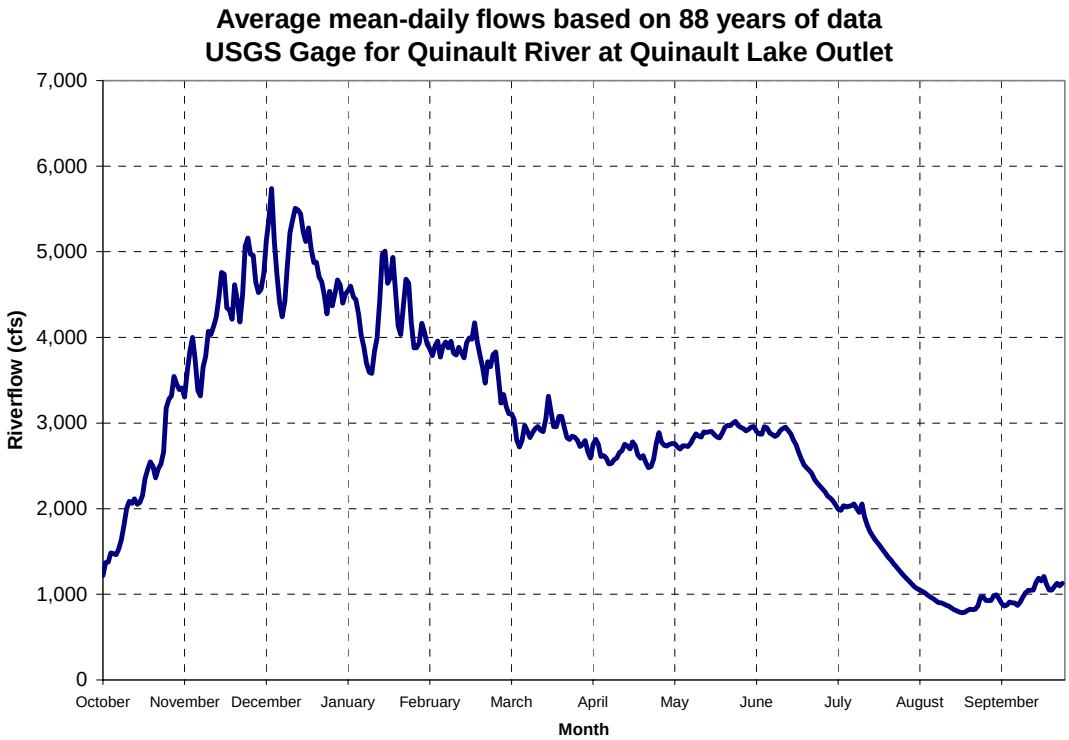

Figure 1. Average mean daily flows for a typical water year based on historical gaging station data at USGS Gage 12039500 (Data downloaded from USGS Web Site).

Flood Events

Major known floods occurred in 1909, 1949, 1955, 1961, and 1997 (Figure 2). The 1909 flood was estimated by USGS after the gage was installed in 1911. The discharge was inferred from observed high-water marks and the relation between stream gage height and discharge that was established after operation of the streamflow station near the outlet of Lake Quinault (QIN, 1999). The flood of November 1949 reportedly brought an 18-foot rise in the level of Lake Quinault, and completely inundated the Falls Creek Campground on Lake Quinault (Aberdeen Daily World, 1949 as reported in QIN, 1999). The 1949 flood was between a 10- and 25-year flood (instantaneous peak 42,300 ft^3/s). Local landowners have observed that high lake levels do not necessarily occur at the same time the river is at its highest flood stages, although occasionally the two do coincide to create a "worst case" flooding scenario such as in 1949. Table 1 and Figure 2 shows the amount and relative frequency of floods occurring between aerial photographs and maps evaluated which is important to consider when evaluating rates and magnitudes of channel change. Almost all time periods had at least one flood greater than the 5-year flood except for 1962 to 1973, and 1998 to 2001.

Table 1. Number and relative frequency of floods between aerial photographs and maps.

Time Period (years)	Number Years Spanned	Return Period Range				
		50- to 100-Year Flood	25- to 50-Year Flood	10- to 25-Year Flood	5- to 10-Year Flood	2- to 5-Year Flood
1909 to 1929	20	1			4	5
1929 to 1939	10				2	3
1939 to 1952	13			1	1	3
1952 to 1958	6		1		1	2
1958 to 1962	4			1		5
1962 to 1973	11					3
1973 to 1982	9			1	5	4
1982 to 1994	12			2	3	7
1994 to 1998	4		1		2	5
1998 to 2001	3					2
2001 to 2002	1			1		1

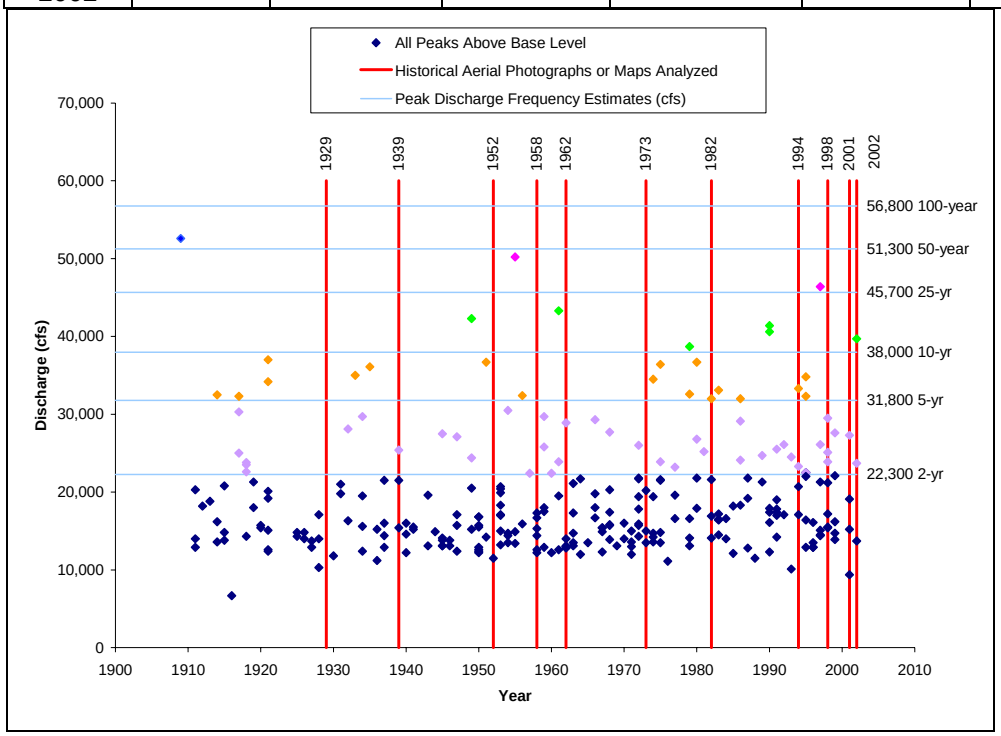

Figure 2. Instantaneous peak discharges above base level measured at USGS gaging station at outlet of Lake Quinault are shown. Peaks are color coded to show how they relate to flood frequency estimates labeled on right vertical axis. Date of historical aerial photographs and maps acquired are shown in red lines for reference.

Hydrologic Trends

Analysis of sockeye by the Quinault Department of Fisheries indicates that numbers started to substantially decline between 1950s (see Figures 2 and 3 in main report), yet the majority of disturbance to the watershed occurred in the early part of the twentieth century. Therefore, it is of interest to evaluate the hydrologic trends over the last 100 years. The majority of sediment transport and significant channel shifting typically occurs during the 2-year and greater floods. One school of thought is that over a long period of time the majority of channel changes occur during the 2-year floods because it is the flood that occurs the most frequently. However, larger floods can result in more extensive channel changes because they inundate more areas of the floodplain. If floods are occurred at a greater frequency or magnitude during certain parts of the last century, it could help explain the timing of channel response to human disturbance.

The Watershed Analysis (QIN, 1999) noted that a relatively dry climate period ended in the late 1940's in the Pacific Northwest, and was followed by a relatively wet period that ended in 1977. From 1977 to 1998, another dry period was occurring (QIN, 1999). However, it is noted in the Watershed Analysis that these are multi-year trends based on long-term precipitation records. A particular year within the dry or wet designated periods could actually be fairly wetter or drier than overall trend during that time period.

The Watershed Analysis (QIN, 1999) evaluated historical gage data between 1911 and 1998 to look for any changes in hydrology that could have occurred as a result of natural or man-made changes that have taken place in the basin upstream of the USGS gage at the outlet of Lake Quinault. The study evaluated mean monthly flows, low flows, and peak discharges. No visually detectable trends were observed in low or peak flows (QIN, 1999). Some additional analysis of peak flows by Reclamation does indicate a trend of common floods occurring more frequently in the latter part of the twentieth century.

The Quinault Department of Fisheries showed a sockeye decline starting in the 1950s (see Figure 2 and 3 in main report). The USGS gaging station data at the outlet of Lake Quinault was evaluated to determine if there was any evidence of floods occurring at a more frequent or higher magnitude since the 1950s that may have had an impact on sockeye habitat. The peak flow data shown in Figure 2 indicates the first and largest documented flood occurred in 1909, probably when human disturbance in the river channel area was still fairly localized. The second two largest flood peaks that occurred in 1955 and 1997 are of similar order of magnitude and do not indicate that the largest flood peaks have changed over the last century.

The USGS gaging station record is available for annual peak flows and for all peak flows above 15,000 ft^3/s. Both sets of gaging station data were broken out into time periods between 1911 to 1950 and 1951 to 2002. For all flows above 15,000 ft^3/s, the occurrence of more common floods (2-, 5-, and 10-yr) floods were compared between the two time periods (Table 2). The USGS gage record is only available for 35 water years in the first set of data and 51 years in the second set so it is difficult to directly compare the number of floods between each time period. However, when averaged out per year the frequency

of floods greater than the 2- and 5-year floods appear to be occurring about twice as often between 1951 to 2002 than in 1911 to 1951 (Table 2). Therefore, from 1911 to 1950 the 2-year flood occurred about once every two years, and between 1951 and 2002 occurs almost annually. There was only 1 flood greater than a 10-year flood between 1911 and 1950, yet there were 7 floods greater than the 10-year flood between 1951 and 2002.

Table 2. Occurrence of common floods between 1911 and 1951 and 1952 and 2002.

Flood Frequency	Total Number of Floods Greater than Flood Frequency Value		Flood Occurrence Per Year for Floods Greater than Flood Frequency Value	
	1911 to 1950	1951 to 2002	1911 to 1950	1951 to 2002
2-yr flood	18	49	0.51	0.96
5-yr flood	7	19	0.20	0.37
10-yr flood	1	7	0.03	0.14

Another way to compare the two time periods is to compute the 2-year flood for each time period using a Log Pearson III computation. Data for the USGS gaging station between 1911 and 2004 was utilized (one additional year than other computations). Using this method, the 2-year flood between 1911 and 1950 was 19,989 ft^3/s and between 1951 and 2004 was 24,504 ft^3/s, indicating it has increased about 23%.

Mean monthly flow analysis (QIN, 1999) did indicate that certain periods of time since 1911 have been higher or lower than the average (Figure 3). The Watershed Analysis (QIN, 1999) concluded that the trends in monthly flows were closely tied to fluctuations in precipitation: “With few exceptions, the cumulative departures for precipitation agree closely with those for streamflow. This close agreement indicates that most of the variation in streamflow trends is probably a result of precipitation trends, with little or no influence from any natural or man-made changes that may have taken place in the basin.” The Watershed Analysis did recognize that forest harvesting and road construction in the watershed may have an effect of increasing annual water yield, decreasing low flows, and increasing magnitude of high flows but it was noted that additional analysis would be needed to determine the magnitude of impact on the Quinault River.

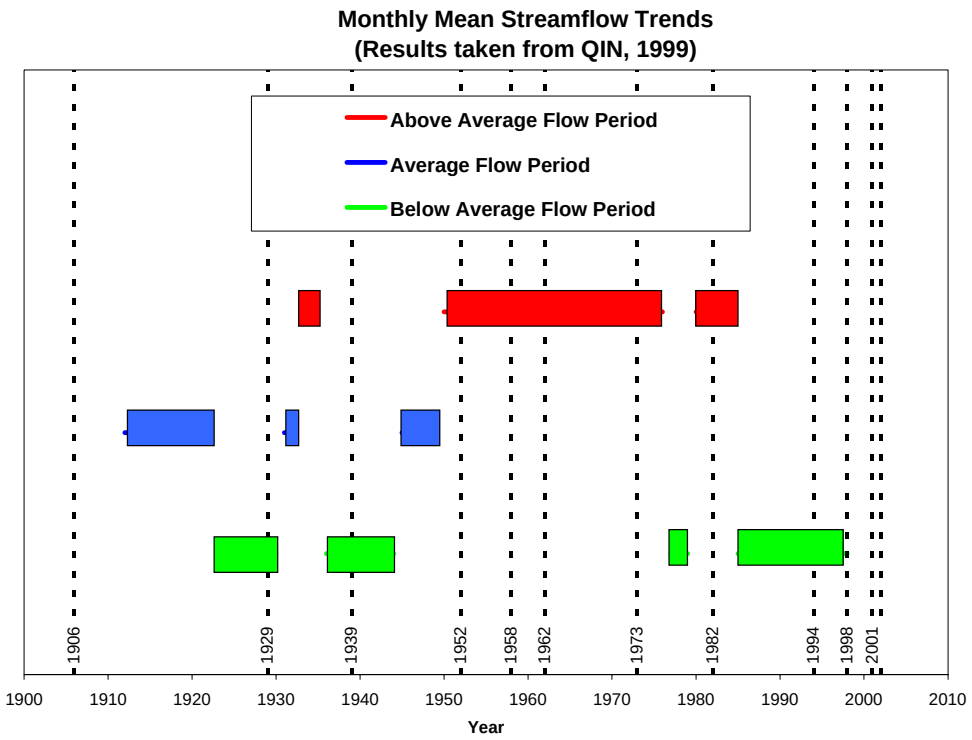

Figure 3. Periods of monthly mean streamflow that were average, above average, or below average based on monthly streamflow data from USGS gaging station at Lake Quinault (12039500). Results taken from Watershed Analysis (QIN, 1999).

Change in Flood Peak Magnitude throughout Study Reach

The largest sub-basins between the Forks and Lake Quinault that contribute water and sediment to the Quinault River are Big Creek and Finley Creek (see Figure 2, Attachment 1). Many other small sub-basins drain onto terrace surfaces in the study reach. Attachment 1 provides estimates for the ungaged portion of the upper Quinault watershed to compare the relative difference in flood peaks in the downstream direction as drainage area increases. A USGS approach incorporating drainage basin area and average precipitation estimates were used to develop the flood frequency estimates for the ungaged basin (methodology described in Attachment 1). Additional flood frequency estimates were needed for input data to computing the change in total stream power (discharge times slope) within the study reach (Attachment 2). Sub-basins were chosen for total stream power calculations based on major tributary inputs to the study reach: at Forks which is just below confluence of the North and East branches of Quinault River at RK 18 (sub-basin 1), just below the confluence with Big Creek at RK 8 (sub-basin 2), at the inlet to Lake Quinault (sub-basin 3). The USGS approach indicates the 2- to 100-year floods at the Forks are increased by roughly 20% by RK 8 (Big Creek confluence), and by a total of 30% at RK 0 at the lake inlet.

Dampening Effect of Lake Quinault

Lake Quinault is a natural unregulated reservoir with a surface area of approximately 15.1 km^2 (3,729 acres). A 1995 survey documented a maximum depth of 73 m (240 ft) (Gubala, 1995). The lake dampens both peak and low flows between the inlet and the outlet where the gaging station is located (QIN, 1999). Two methods of analysis document this potential dampening effect: 1) comparing normalized discharges for a series of floods on the Queets and Quinault Rivers which showed 31 to 38% decrease (QIN, 1999); and 2) computing a reverse reservoir routing and comparing average inflow to average outflow of the lake which showed a 5 to 26% decrease for mean daily values and about a 41% decrease for hourly values (peaks above 15,000 ft^3/s).

To determine the potential dampening effect of the lake during flood flows, the Watershed Analysis (QIN, 1999) normalized discharges to drainage area size for the Quinault River gage at the lake, a gage on the nearby Queets River, and a gage on the Humptulips River near Humptulips. The top five normalized peak flow events between 1933 to 1960 at each site were then averaged and compared. In that analysis it was shown that the average normalized peak flow value for the Quinault River below Lake Quinault was about 31 to 38 percent below the average normalized values for the two other sites. It is interesting to note that the drainage area of the Quinault River (264 square miles) and the Elwha River at the McDonald Bridge gage (269 square miles) are roughly equivalent, but the 2-year flood on the Quinault at the lake outlet (22,300 ft^3/s) is 1.7 times that of the nearby Elwha River (13,300 ft^3/s). Although both rivers drain from the same mountain range in Olympic National Park, the Elwha drains north into the Strait of Juan de Fuca and may likely result in different storm events controlling winter floods.

Reservoir routing is a commonly used approach to look at the impacts of the lake's storage capacity on incoming discharge versus releases from the reservoir. However, reverse reservoir routing (going from outgoing to incoming flow) is much more complex. Reverse reservoir routing can be used to compare average inflows to average outflows for purposes of this discussion. A reverse reservoir routing model was developed in a spreadsheet to evaluate the potential dampening effect of the lake by looking at the change in storage. The gage at the lake outlet has a relationship between river stage and lake elevation that was used to determine the change in lake storage (QIN, 1999). Changes in storage volume were based on change in lake elevation as incoming discharge varies. Daily stage values were available from USGS for the gaging station at the lake outlet from 1998 to 2002. Hourly stage was downloaded from the USGS web site for the October 2003 flood, which had two peaks between a 5- and 10-year flood frequency. Mean-daily discharges greater than 15,000 ft^3/s were attenuated 5 to 26% by Quinault Lake. Hourly discharge values for two peaks above 15,000 ft^3/s during the October 2003 flood greater than 15,000 ft^3/s were attenuated 41 and 42% by Quinault Lake (Figure 4). This indicates that values recorded at the USGS gage at the outlet of Lake Quinault may be about 30 to 40% lower than the river flow in the upstream river near the inlet to Lake Quinault. Flows would reduce in magnitude in the upstream direction from the inlet to the Forks as the drainage basin area reduces.

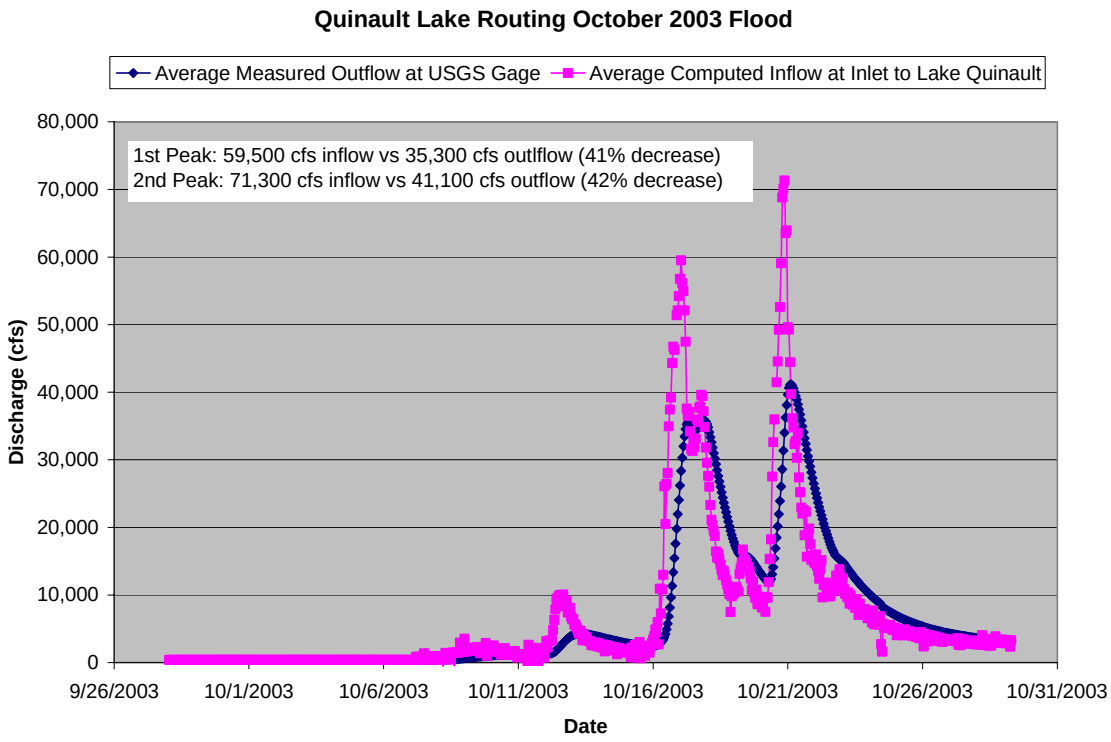

Figure 4. Reverse reservoir routing results for October 2003 flood.

Recommendations for Monitoring Future Hydrologic Change

The Watershed Analysis (QIN, 1999) suggested the following studies to improve the understanding of hydrology in the Upper Quinault River:

- Maintaining and expanding existing network of streamflow stations within the watershed.
- Establishing at least one paired-basin investigation of effects of forest practices on streamflow.
- Improving and expanding collection and archiving of meteorological data.
- Assessing and, if necessary, revising the preliminary map of current wetlands, and monitoring impacts on wetlands from timber harvesting, road construction, and recreation.

Additional suggestions from landowners during our study presentation were to develop a hydrologic model of the watershed and develop a better flood prediction and monitoring tool.

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Attachment 1: Peak Flow Frequency Estimation

Prepared by Ken Bullard

Authorization: The River and Sedimentation Group requested assistance with ongoing Quinault River studies. Available stream gage information below Lake Quinault shows the effect of regulation and is not suitable for determining peak flows at various stream locations above Lake Quinault. This study uses the regional regression equations prepared by the USGS for peak flow frequency estimation and does not rely on the stream gage record for the Quinault River below Lake Quinault.

Regional Peak Flow Regression Analysis: The USGS prepared a report in 1997 that provided a means to calculate peak flows for ungaged, unregulated stream locations throughout Washington State (Sumioka, S. S. and others, 1998). This report relied on available unregulated peak flow stream gage data from several hundred sites. The entire state of Washington was further divided into nine regions representing similar hydrologic and meteorologic conditions.

Using recommended Bulletin 17B (Interagency Advisory committee on Water Data, 1982) calculation techniques for peak flow frequency analysis at each of these sites, the peak flows for several return periods were calculated. The calculated peak flows for the various return periods were used as the dependent variable in a multiple regression analysis. The independent variables were various measured hydrologic and meteorologic variables such as drainage area, basin slopes, vegetation measurements, and mean annual precipitation amounts averaged over the basin. The results of the multiple regression analysis, within each of the previously established regions, indicated which of the independent variables played the most important roles in predicting the calculated peak flows for each return period. For each region the most important of the tested independent variables were used to establish regression equations that could then be used to calculate the peak flow for a specified return period.

The Quinault River lies in what was defined as region 1 by the USGS for Washington State. This region includes all of the Pacific Ocean drainages in Western Washington State, and specifically the Pacific Ocean drainages of the Olympic Peninsula. Figure 1 displays a general location map for the Upper Quinault River basin. Sixty-one independent unregulated peak flow stream gages were used in the regression analysis for USGS region 1. For this region the most significant variables in the regression analysis were the drainage area and the mean annual precipitation amount calculated for the basin.

The drainage areas used were the entire contributing, non-regulated drainage area established by the USGS for each of the 61 gage stations. Mean annual precipitation amounts for the USGS study were taken from maps prepared by the National Weather Service in 1965 (U. S. Weather Bureau, 1965). The mean annual precipitation amount was averaged over the entire drainage basin. The Weather Service mean annual precipitation map from 1965 is no longer readily available, but more recent mean annual

precipitation maps, in GIS form and based on data from 1951 to 1990, are available from the NRCS (Natural Resources Conservation Service, 1998) and can be used for this study.

The standard error of the estimated peak flows for this region was between 32 and 37 percent for return periods between 2- and 100-years. The ability of a regression equation to reliably estimate the peak streamflow having selected recurrence intervals at ungaged sites is measured by the error of prediction. The error of prediction is the measure of confidence in the estimated peak streamflow and describes the range within which an estimate would occur two-thirds of the time. The range of drainage areas applicable for using the regression equations is between 0.15 and 1,294 square miles, and for mean annual precipitation amounts ranging from 45 to 201 inches. The actual regression equations developed by the USGS are given in the published report (Sumioka, S. S. and others, 1998) and are not repeated here.

Peak Flood Flow Analysis for the Quinault River Basin: To apply the published USGS regression equations to the Quinault River basin measures of the drainage area at various locations in the basin and the associated basin average mean annual precipitation with in the drainage area were derived. Figure 2 displays the basin and sub area boundary map used in this study.

The drainage basins for six locations above Quinault Lake were determined by use of available 7 ½ minute DEMs (digital elevation models) and the WMS (Watershed Management Program, version 7.0) (Brigham Young University, 2003). For each of these locations a drainage basin boundary was established and the contributing area measured. In addition a shape file was created with an appropriate projection that could be used with the mean annual precipitation maps.

The mean annual precipitation amounts for each of the six locations in the Quinault River basin were determined by overlaying the basin areas defined by shape files created in the basin area calculation process onto the available NRCS mean annual precipitation maps, (NRCS, 2001). The mean annual precipitation maps display contours with ranges of values representing the mean annual precipitation. The average value in each precipitation band was determined, and the amount of area of each elevation band contained in each sub area above the desired flow point on the Quinault River was calculated in ArcView. A weighted area average value of the MAP (mean annual precipitation) for the total area above each flow point was then calculated. This MAP was used in the regression equations to determine the desired peak flows for each return period at each flow point. In the original USGS regression equation determination, MAP values were determined from a now outdated map. The use of the more recent MAP values may provide some minor inconsistency in the theoretical application of the regression equations. This difference in the source of the MAP values is assumed to be minor. Figure 3 displays the six sub areas along with the MAP contours used in this study.

Table 1 presents a summary of the results of the peak flow calculations by the method described above. The location of the flow points would be at the most downstream end of the sub area given in the table. Table 2 provides the basic drainage area and MAP data used with the USGS equations to produce the peak flow values in Table 1.

Table 1
Upper Quinault River, Washington
Summary of Peak Flow Computations
(Values computed by USGS Regression Equations (Sumioka, S. S. and others 1998))
(ft^3/s)

Flow Point at the Downstream End of Sub Area

Return Period (years)	Sub Areas 7	6	5	4	3	2
2	25,250	20,740	10,150	10,620	7,960	9,610
10	39,570	32,520	15,930	16,710	12,480	15,130
25	46,500	38,220	18,720	19,640	14,670	17,780
50	52,490	43,140	21,140	22,170	16,560	20,070
100	59,040	48,510	23,750	24,910	18,600	22,550

Table 2
Upper Quinault River, Washington
Data for USGS Regional Peak Flow Regression Equations

Flow Point at the Downstream End of Sub Area

Sub Area Flow Point	Total Area (sq. mi.)	Mean Annual Precipitation (inches)	Major Drainage Basin Included
7	233.2	143.1	Upper Quinault R, Big Crk, Raley Crk
6	184.9	145.1	Upper Quinault R blw Howe Crk
5	90.3	139.0	S F Quinault R, Howe Crk
4	80.3	157.3	N F Quinault R
3	71.6	135.7	S F Quinault R, Graves & O'Neil Crk
2	69.2	162.2	N F Quinault R, Rustler Crk, Kimta Crk

Comparison with other results: An analysis of the peak flow data for the USGS Gage below Lake Quinault (USGS Gage 12039500) was performed. The peak flows were analyzed using a standard log-Pearson III analysis and the results are summarized in table 3. The results were in general were a few percent below the results given in table 1 above for the various return periods at flow point 7. Reasons for this difference include a

difference in drainage area, the fact that the Lake Quinault provides some attenuation effect on peak flows, rain falling on the lake appears in the single station statistics but not the regional analysis, and the differences that are expected to occur between a regional analysis and a single station peak flow analysis. Given these differences in data sources and calculation techniques the results computed specifically for the Upper Quinault River are actually quite close.

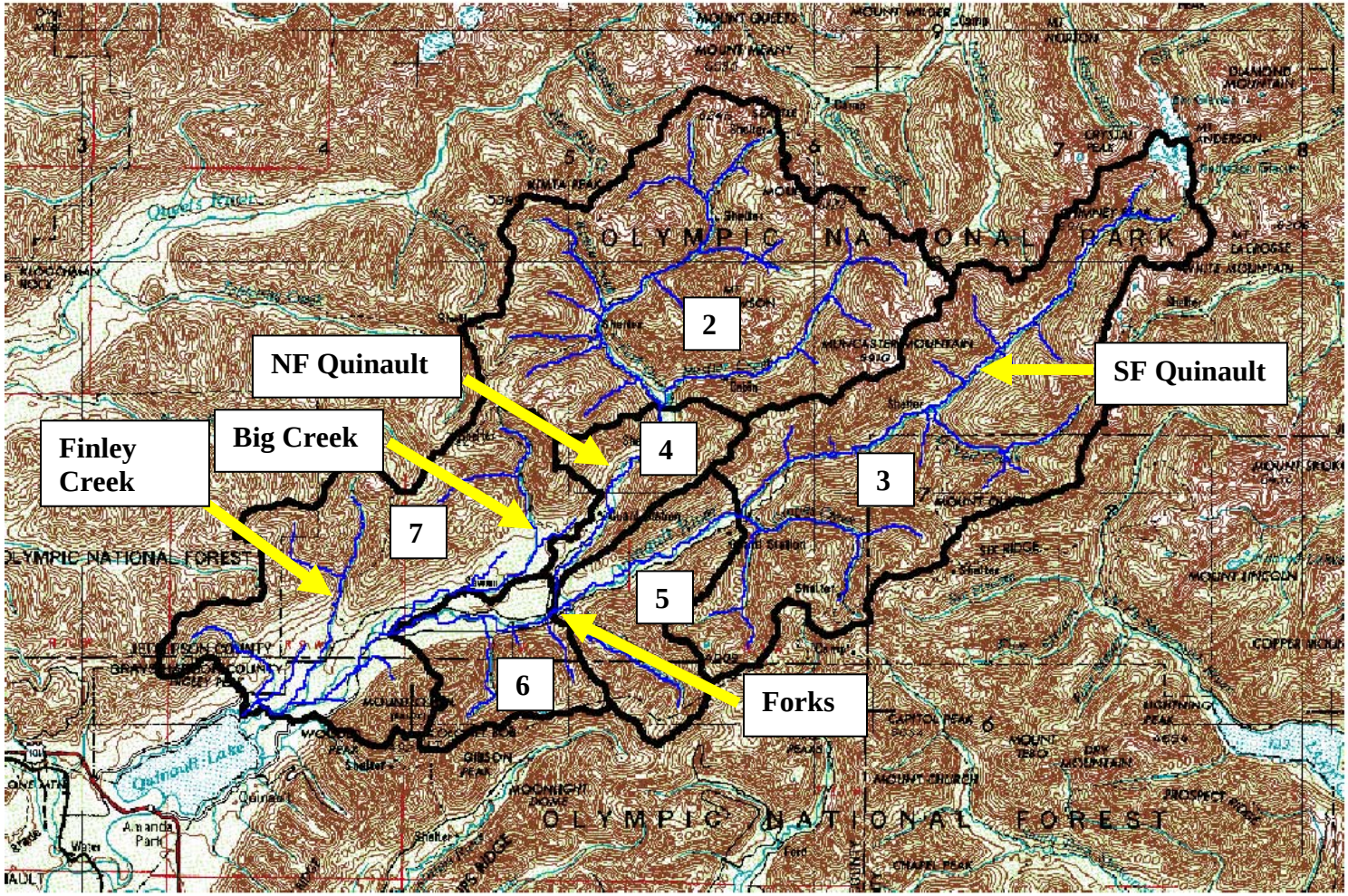
Table 3
Upper Quinault River, Washington
Summary of Peak Flow Computations
(Values computed by USGS Regression Equations (Sumioka, S. S. and others 1998) and log-Pearson III analysis of USGS Gage 12039500)

Return Period	USGS Regional Regression (Flow Point 7)	Single Gage (12039500) LPIII Analysis	Differences	
(years)	(ft^3/s)	(ft^3/s)	(ft^3/s)	(percent)
2	25,250	22,262	2,988	11.8
10	39,570	37,977	1,593	4.0
25	46,500	45,657	843	1.8
50	52,490	51,263	1,227	2.3
100	59,040	56,772	2,268	3.8

In the Quinault River Watershed Analysis (1999) an analysis of selected peak flows, for a common period of record, for two nearby gage sites was provided. The top five events at the two different gage sites were analyzed by normalizing the peak flow data and representing the selected peaks as a unit discharges ($ft^3/s/sq.$ mi.). The top five normalized peak flow events at each site were then averaged. In that analysis it was shown that the average normalized peak flow value for the Quinault River below Lake Quinault was about 31 to 38 percent below the average normalized values for the two other sites. The Watershed Analysis study did not document the return periods on any of the peak flows studied.

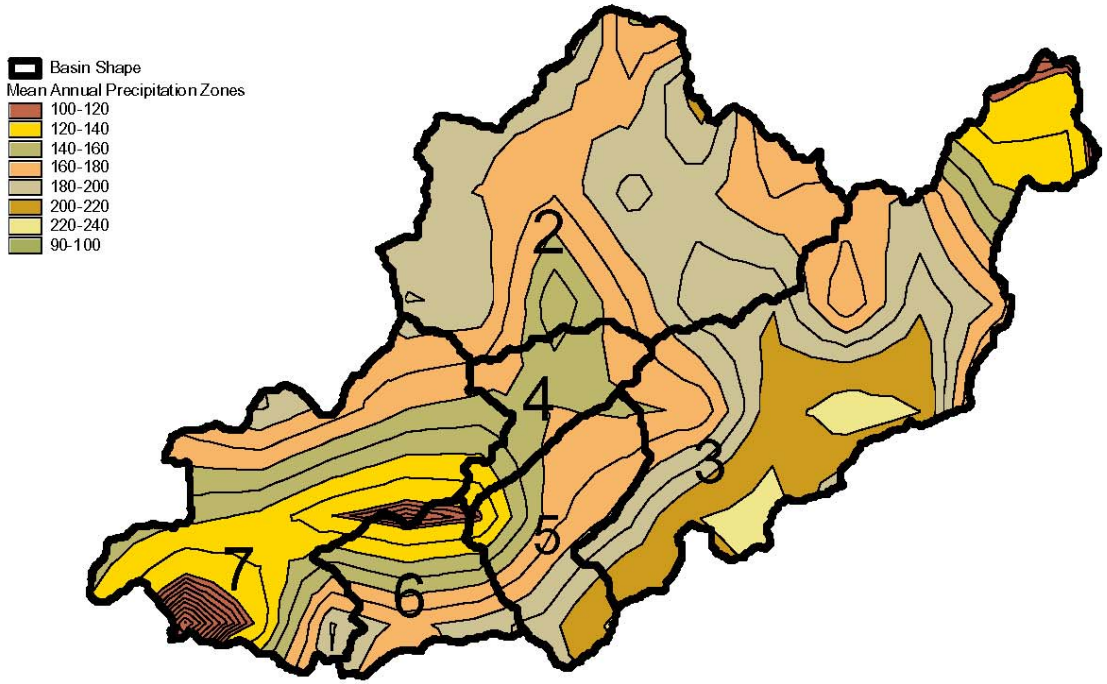
Upper Quinault River Basin Drainage Basin Location

Figure 1



Quinault River Basin above Quinault Lake, WA
Basin and sub area delineations

Figure 2



Quinault River Basin
Above Quinault Lake
Mean Annual Precipitation Contours

Figure 3

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Attachment 2: Additional Locations of Peak Flow Frequency Estimates

Additional estimates of peak flood frequency were needed at different locations than described in Attachment 1. These new locations were needed for input data to computing the change in total stream power (discharge times slope) within the study reach. Sub-basins were chosen for total stream power calculations based on major tributary inputs to the study reach: just below Forks of the North and East branches of Quinault River at RK 18 (sub-basin 1), just below the confluence with Big Creek at RK 8 (sub-basin 2), at the inlet to Lake Quinault (sub-basin 3). The absolute values computed by the method described in Attachment 1 have a certain level of unknown error that cannot be resolved without measured gage data to compare to. However, the method is based on known gaging station data and the relative differences between sub-basin outlet locations 2, 3, and 4 provide a reasonable comparison of change in flood frequency magnitude between the upstream end of the study reach at the Forks, and the downstream end at the inlet to Lake Quinault.

The USGS approach based on drainage basin size and precipitation indicates the discharge at the Forks is increased by roughly 20% by RK 8 (Big Creek confluence), and by a total of 30% at RK 0 at the lake inlet.

Table 1. Quinault River Basin - Total Drainage Areas and MAP for USGS Regression Equation Input

Location Description	WMS Sub basin Number Flow point location	Sub basin Area (square miles)	Total Area above flow point (square miles)	Mean Annual; Precipitation for total area (inches)
RK 18 at Forks	1	170.8	170.8	141.0
RK 8 at Big Creek	2	33.1	203.9	143.0
RK 0 at inlet to lake	3	29.5	233.4	140.0

Table 2. USGS regression equation constants.

Return Period (years)	Equation Constant	Area Exponent	Precipitation Exponent
2	0.350	0.923	1.24
10	0.502	0.921	1.26
25	0.590	0.921	1.26
50	0.666	0.921	1.26
100	0.745	0.922	1.26

Table 3. Quinault River estimated flood peaks using USGS equations. Flow point located at downstream-most point of each sub-basin as shown in Figure 1.

Return Period (years)	Location 1 (RK 18) (peak ft^3/s)	Location 2 (RK 8) (peak ft^3/s)	Location 3 (RK 0) (peak ft^3/s)
2	18,610	22,300	24,600
10	29,170	34,950	38,530
25	34,280	41,070	45,280
50	38,700	46,360	51,120
100	43,510	52,140	57,490

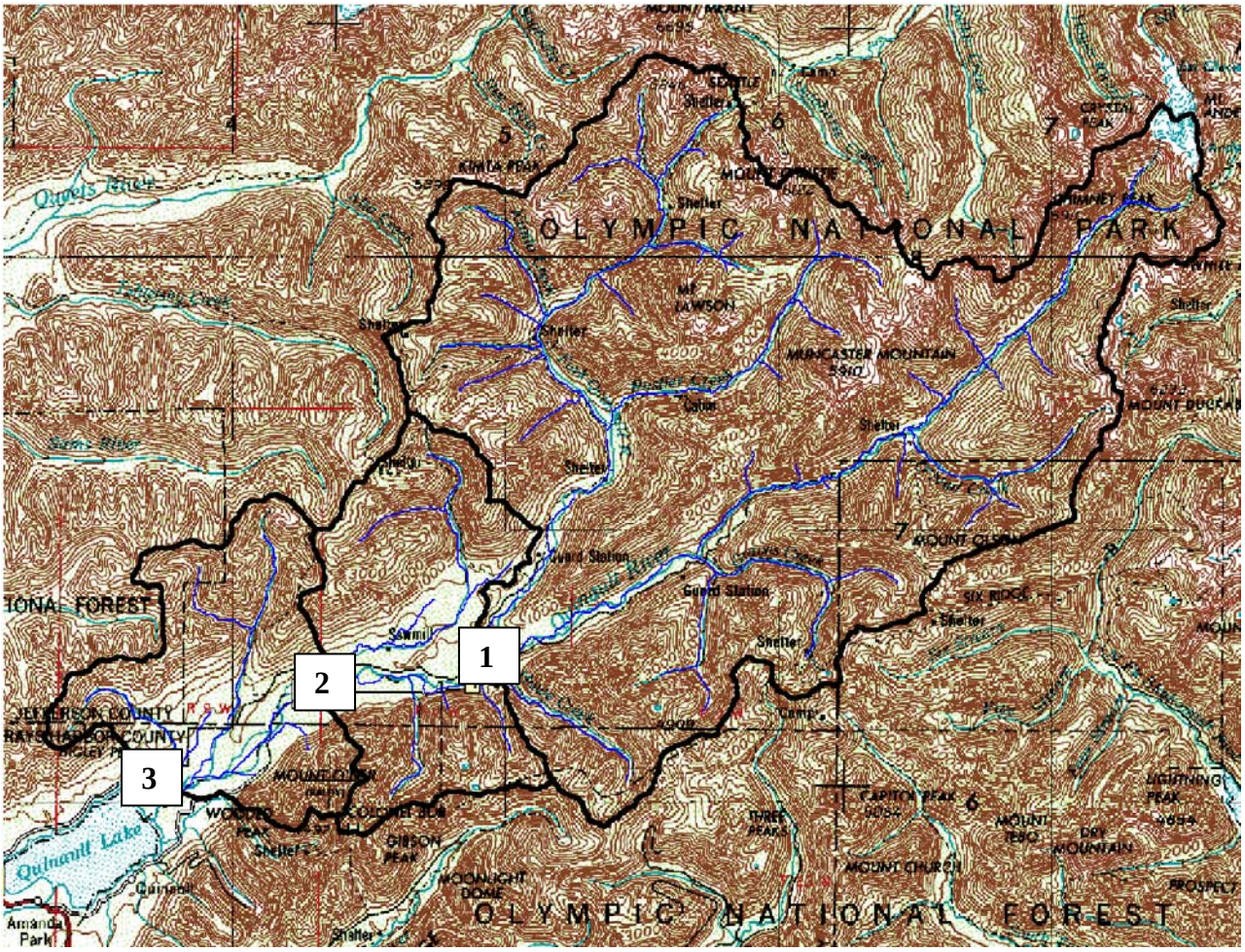

Figure 5. Location and extent of sub-basins delineated in study reach.

Appendix L
Finley Creek Area

1. Methods

Photographs from ten years are shown in the accompanying figures, along with a hillshade that was made using Lidar data that were collected in 2002. For each year, the channels of Finley Creek were mapped. These are primarily unvegetated channels (water, if any, and unvegetated bars). Other narrow channels are likely present in the trees. In some places, a curving path in the trees is suggestive of a channel path. These were not mapped. Consequently, the actual number of paths is much higher than shown in these figures.

For the Quinault River, the active channel, unvegetated channel, and overflow channels through vegetated areas have been mapped. The active channel includes the low-flow channel and adjacent unvegetated areas that appear to carry the majority of flow and sediment. The unvegetated channel includes unvegetated areas that appear to carry water and sediment only at higher flows. Partially vegetated channels are shown also. These channels have some vegetation, but appear to carry flow water only at the highest flows. The flows must still have enough energy to disrupt vegetation. The overflow channels through vegetated areas may carry enough flow to disrupt vegetation, but are within vegetated areas, not in the area of the active channel. The overflow channels shown in the brighter blue in each figure are those that are narrower; the ones shown in the light blue are wider and often have unvegetated channels along with the low-flow path.

In 2002, we walked up Finley Creek and noted the remains of an engineered log jam (ELJ). The locations of these remains are shown by the green circles on each figure. We also noted the extent of a high eroding bank of glacial deposits along the east side of Finley Creek. The extent of these eroding banks is shown by the orange squares in each figure. Primary and secondary roads have been mapped from the aerial photographs. The white lines in each figure show the valley edge or bedrock. The section shown of the Quinault River is between about RK (river kilometer) 2.2 and 6.2. The labels in the pink squares are localities that are the same in each figure, so that they can be used to compare similarities and differences in the channel locations.

The conditions of the area of the ELJ and eroding bank were examined again in 2004. These observations are summarized in Attachment 1.

2. Summary

The following is a summary of the changes to Finley Creek and the adjacent section of the Quinault River between 1939 and 2002.

2.1. Upper Finley Creek

In 1939, upper Finley Creek flowed in two channels with the western channel being wider and probably carrying more flow than the eastern one. The western of these two channels and the channel in lower Finley Creek form a nearly straight path to the Quinault River. Development has already occurred on the east side of the Finley Creek

alluvial-fan complex. At some point an engineered log jam (ELJ) was placed at the head of the western path of the upper Finley Creek. We don't know when this occurred, but by 1952, the western path appears to carry only a small amount of water. The upstream half of the western path is mostly vegetated by 1952. In 1952, flow in upper Finley Creek is contained in the eastern path, which makes a sharp meander to the west and joins the 1939 path in lower Finley Creek. In 1958, this west meander is even more marked. However, in 1962, the meander appears to have been modified to direct flow back into the 1939 path in lower Finley Creek. By 1994, the main path of upper Finely Creek has migrated eastward and may have started incising the high exposure in glacial deposits along the east side.

2.2. Lower Finley Creek

Between 1939 and 1973, the path of lower Finley Creek is approximately in its 1939 path. On the 2002 hillshade, this channel appears to be incised into the alluvial-fan surface. The path becomes slightly more meandering over time and the position of its lower end, where it joins the Quinault River, changes position. Beginning by 1973, several unvegetated paths appear on the east side of the alluvial fan. These paths become wider and more continuous between 1982 and 2002. At some time, perhaps between 1973 and 1982 (although it could be earlier), the channel of Finley Creek near the bridge begins to be excavated, and levees are constructed on both sides of the channel. These levees direct the flow eastward into the multiple and branching east paths to the Quinault River. Some flow still reaches the river by the western path. Except in 1982, the paths of Finley Creek join the Quinault River in overflow channels of the Quinault River. The overflow channels carry water and sediment only in higher flows. Small unvegetated alluvial-fan deposits are visible at the mouths of the Finley Creek flow paths in several years.

2.3. Quinault River Between RK 2.2 and 6.2

Between 1939 and 2002, the Quinault River changes form and position many times along this section by Finley Creek. Two main overall changes occur. First, the active channel in 1939 cuts off to the north into a narrow overflow channel along the toe of the Finley Creek alluvial-fan complex. In 1952 and 1958, the active channel remains approximately along this same path. The downstream end of this path is mostly abandoned by 1962. By 1973, the north channel path is reoccupied by the active channel in which a meander forms and moves progressively downstream between 1973 and 1994. By 1998, this channel is abandoned, and becomes an unvegetated overflow channel that appears to decrease in width and continuity between 1998 and 2002. This abandoned channel becomes Taiber Slough, an area of sockeye spawning (B. Armstrong of Quinault Indian Nation, 2002, written commun.).

The second main change between 1939 and 2002 is that the channel of the Quinault River moves, through meander migration or cut offs, to the north. This is true not only in the Taiber Slough area, but also upstream. In the upstream section, an unvegetated overflow channel in 1939 and 1952 becomes part of the active channel by 1958, when the Quinault River has split flow paths. The north path widens and progressively carries more flow between 1958 and 1994. It also becomes more sinuous, so that part of this channel

migrates northward into the alluvial fan. By 1998, the north path is the only active channel path, which has straightened. An abrupt menader to the north has been cut off.

3. Changes Between Individual Years

The following sections discuss features of Finley Creek and the Quinault River that are present in each year shown, and changes from the previous and subsequent years.

3.1. 1939

3.1.1. Finley Creek

Finley Creek has two channels upstream of FC7 in upper Finley Creek (figure 1). The widest channel (carrying the most flow?) is the west path. Both paths are slightly meandering. The two paths join at FC7. The east path makes a fairly sharp west bend at FC6 to join the west path. The reason for the sharp turn is not known. An older channel is present west of the west active path. The older channel is indicated by low riparian vegetation between the trees on the higher slope to the west and the higher vegetation between the older channel and the west active channel.

Downstream of FC7 in lower Finley Creek, the creek flows in one primary channel. At FC8, the channel is braided. The Finley Creek channel joins the Quinault River between FC9 and C1. The Finley Creek channel at this point has several flow paths. All the Finley Creek paths flow into a narrow unvegetated overflow path of the Quinault River.

Note the amount of area that has been cleared or logged by 1939. Several residences are present on the west side of the creek. It doesn't appear that a bridge is present across Finley Creek in 1939. It may be that a bridge is present but just not visible on the aerial photographs (e.g., because of the photograph quality). In the photographs taken in the other years, the bridge is visible because of the shadow that it casts in the "white" channel bed. However, it appears in 1939 that the road from the west turns north just before reaching Finley Creek, and then the channel was driven across to the east and south to meet the road on the east side of the creek.

3.1.2. Quinault River

The active channel is slightly meandering in the Finley Creek area. One fairly abrupt meander in the active channel occurs at B1. A narrow unvegetated overflow channel extends between near B1 and D1, which is the one that the paths that Finley Creek joins. Note the relatively wide unvegetated overflow channel (shown in blue) that is present between V and Y, north of the unvegetated main channel.

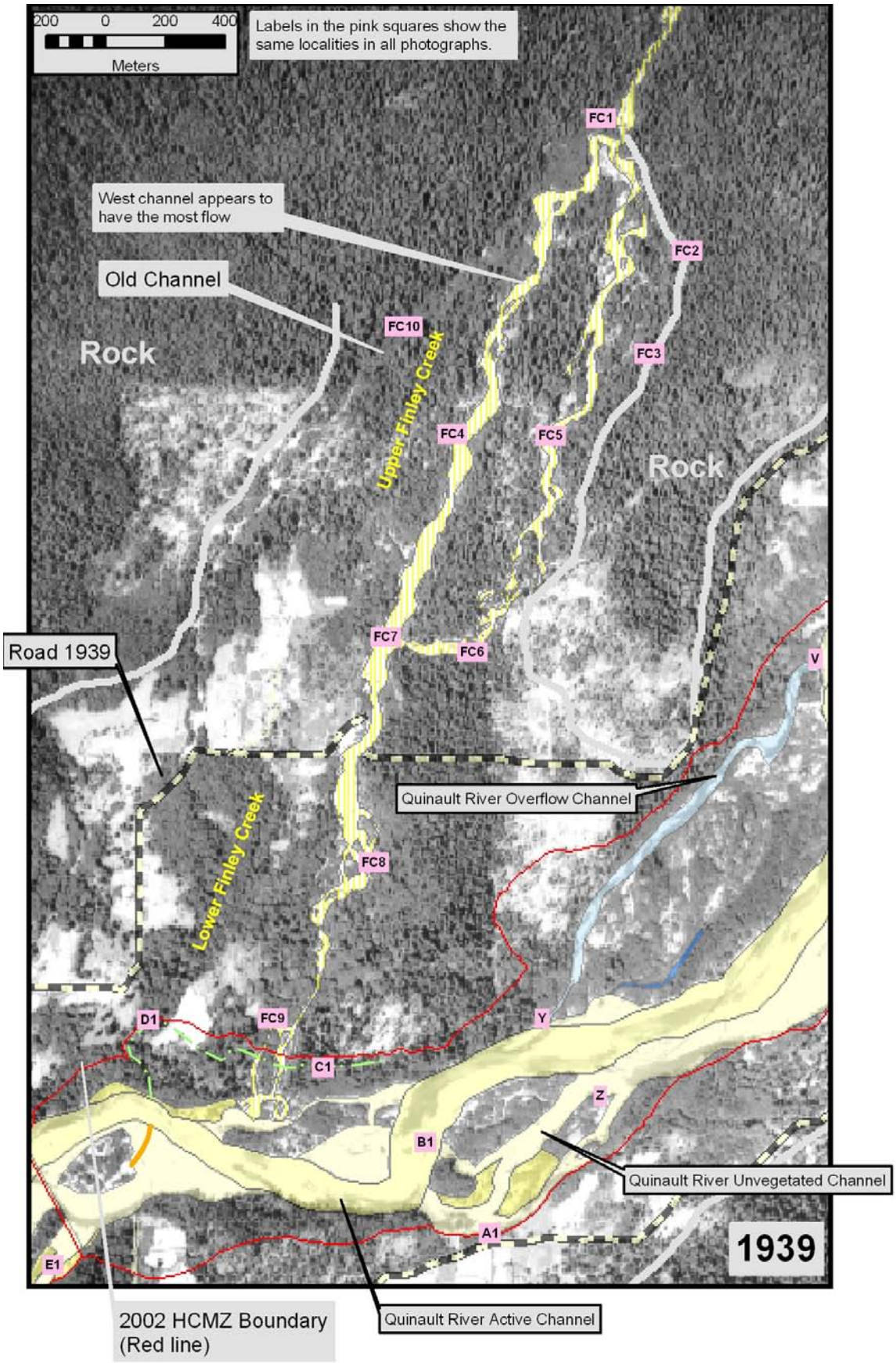

Figure 1. Finley Creek area in 1939. Note the amount of area that had been cleared by 1939.

3.2. 1952

3.2.1. Finley Creek

By 1952, the west path of upper Finley Creek that was present in 1939 appears to carry very little water and has nearly become vegetated (figure 2). We do not know when the ELJ was placed along Finley Creek, but it may have been what caused flow to cease in the west channel. Although the west path appeared to carry more water in 1939, all the Finley Creek flow is in the east path by 1952. The east path is wider, but has nearly the same alignment as it did in 1939. A new narrow path has developed to the east of the main 1952 path near FC2. This channel is along the bedrock along the east side of Finley Creek.

The abrupt bend is still present in the path of Finley Creek at FC6. This bend is now a meander bend in the now-single path of Finley Creek. The channel makes another abrupt bend in the opposite direction at FC7. The meander at FC7 has migrated outward (to the west) since 1939. In 1952, this meander makes a 90° bend.

The braided paths in lower Finley Creek that were present at FC8 in 1939 appear to be nearly a single path in 1952 and immediately east of the 1939 braided area, although at least one braid is visible. An unvegetated path is now visible in places through the vegetation between FC8 and D1.

Finley Creek appears to join the Quinault River in a single narrow channel between FC9 and C1, in the position of one of the multiple braids that was present in 1939. Finley Creek joins an unvegated overflow channel of the Quinault River.

The older channel path that was present in 1939 is still visible in the vegetation to the west of Finley Creek.

A bridge across Finley Creek is visible in 1952.

No levees are visible downstream of the bridge. Not much human activity in the channel near the bridge is visible either.

The amount of clearing on the west side of Finley Creek appears to be about the same as it was in 1939. The logged area on the east seems to be revegating.

3.2.2. Quinault River

The meander at B1 in the 1939 active channel has cut off and now flows in what was in 1939 a narrow unvegetated overflow channel along C1. The 1952 active channel in this section is straighter than it was in 1939. The 1939 active channel with the meander bend is now an unvegetated overflow channel. The 1952 active channel divides into two paths just upstream of D1. The 1952 active channel between V and Z is more meandering than this section of the 1939 active channel. The 1939 unvegetated overflow channels between Z and A1 have become narrow channels through vegetation except for one channel, which remains an unvegetated overflow channel. The relatively wide overflow channel between V and Y that was visible in 1939 is still present in 1952.

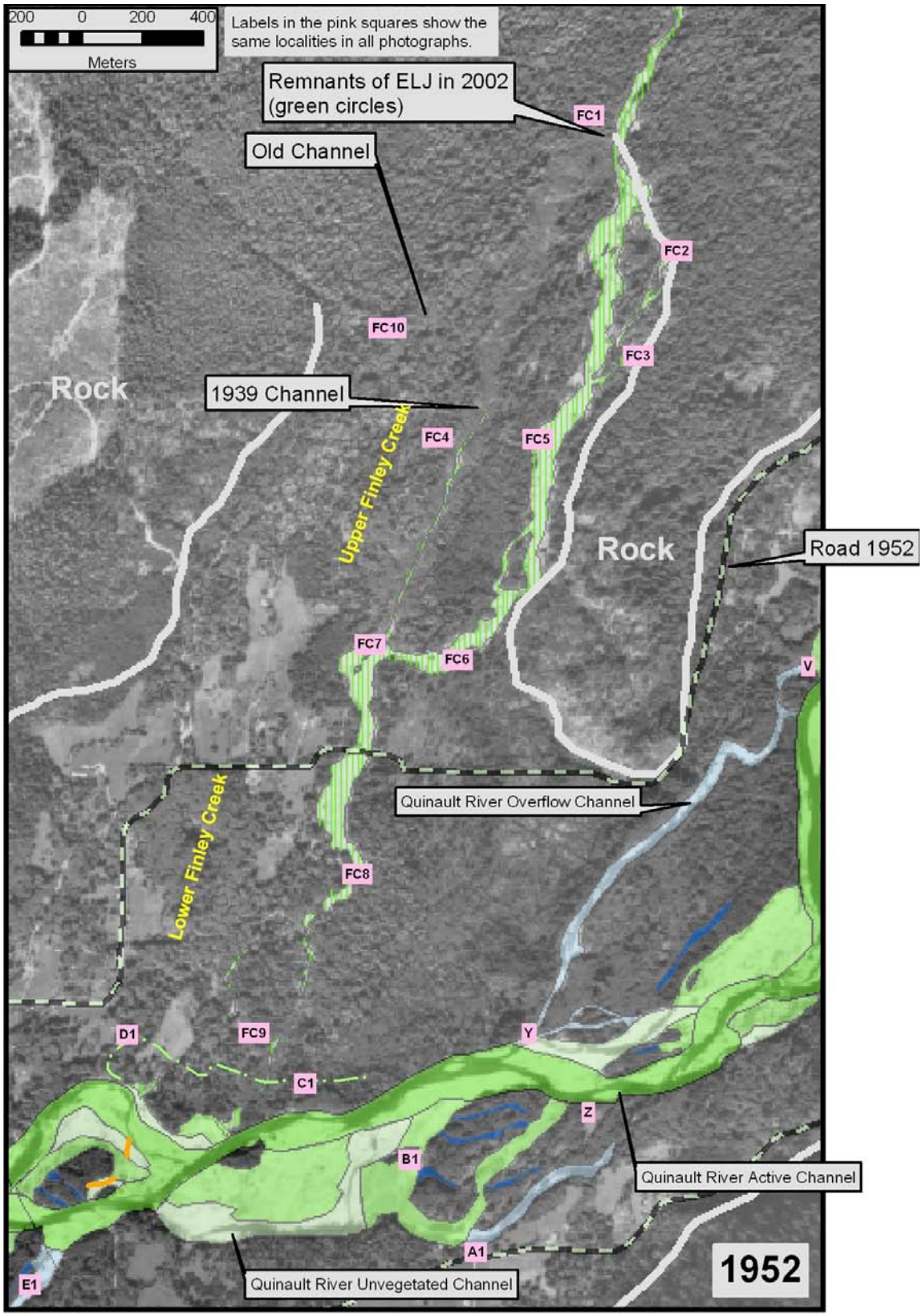

Figure 2. Finley Creek area in 1952.

3.3. 1958

3.3.1. Finley Creek

Flow in upper Finley Creek is in the same path as it was in 1952. Although photograph coverage is not continuous, it appears that the 1939 west path is now abandoned and is vegetated (figure 3). The 1958 path upstream of FC6 appears to be wider than it was in 1952. The narrow east path in 1952 at FC2 is in 1958 nearly continuous with the main path of Finley Creek.

The abrupt (nearly 90°) meander at FC7 has migrated farther outward (to the west).

In lower Finley Creek, the channel at FC8 has several braids, although the east path still seems to be the main one, as it was in 1952. The path downstream of FC7 is mostly in one channel, and this channel meanders to the west and enters the Quinault River near D1. This was a noncontinuous narrow path in 1952. The 1952 path appears to be abandoned or does not carry enough water to move sediment, so it is no longer visible through the vegetation. Finley Creek joins the Quinault River in an unvegetated channel path that was a meander in one of the split paths in the unvegetated channel in 1962.

Cleared areas on the west side of Finley Creek appear to be about the same as they were in 1952. The logged areas on the east side continue to revegetate.

Levees are not visible downstream of the Finley Creek bridge. However, the channel has been altered near the bridge.

3.3.2. Quinault River

The wide unvegetated overflow channel between V and Y that was present in both 1939 and 1952 is part of the active channel by 1958 and appears to carry near half the flow and sediment of the Quinault River. The 1958 active channel just upstream of Z is in a path that was an unvegetated overflow channel in 1952. The 1939 meander path near B1 still receives some flow. The split path that in 1952 began just upstream of D1 now splits farther upstream at C1. The meander in the 1952 unvegetated channel at D1 is now an overflow channel.

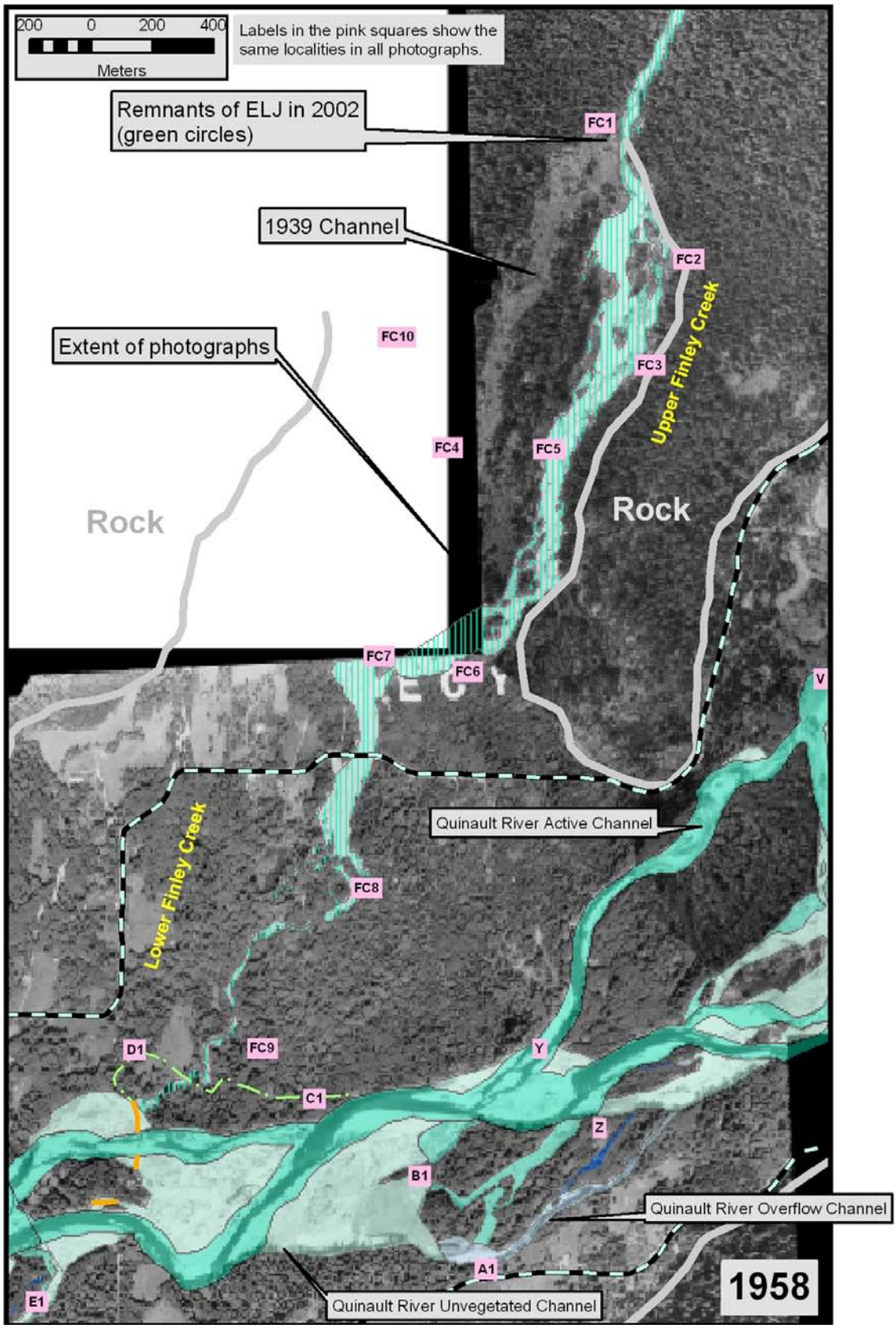

Figure 3. Finley Creek area in 1958.

3.4. 1962

3.4.1. Finley Creek

Our photograph coverage is not continuous for upper Finley Creek in 1962 (figure 4). The channel upstream of FC6 is still along the same general path as it was in 1958. The path meanders slightly more westward at FC2 than it did in 1958. The path appears to be about the same width. The meander at FC7 is not as pronounced as it was in 1952. This could be from human intervention (to keep the channel from the development downstream on the west), but nothing is obvious on the 1962 photographs.

In lower Finley Creek, the channel at FC8 is now in two distinct paths separated by a treed area. The path downstream of FC8 is mainly in a single, meandering path that is in a location about the same as it was in 1958. Finley Creek joins the Quinault River at the same location as it did in 1958. However, the unvegetated overflow channel of the Quinault River (near D1) is now partially vegetated, suggesting that this channel has received less flow than it did earlier.

Clearing on the west side looks about the same. Vegetation on the east side looks nearly the same, also.

Levees are not visible downstream of the Finley Creek bridge. However, the channel has been altered near the bridge.

3.4.2. Quinault River

The unvegetated channel path between V and Y has widened and become slightly more meandering. The path between Z and V may be slightly more meandering than it was in 1958, but it has not changed much. A narrow overflow channel between the two paths of the 1962 active channel has become more pronounced. (The narrow channel was first visible in the vegetation on the 1952 photograph.) The paths between Z and A1 continue to revegetate and are reduced to a couple of overflow paths within the vegetation. The 1939 meander bend near B1 has started to become vegetated. The meanders in the 1962 active channel between C1 and E1 have become more pronounced. It appears that more flow has been in the south path of this split in the 1962 active channel.

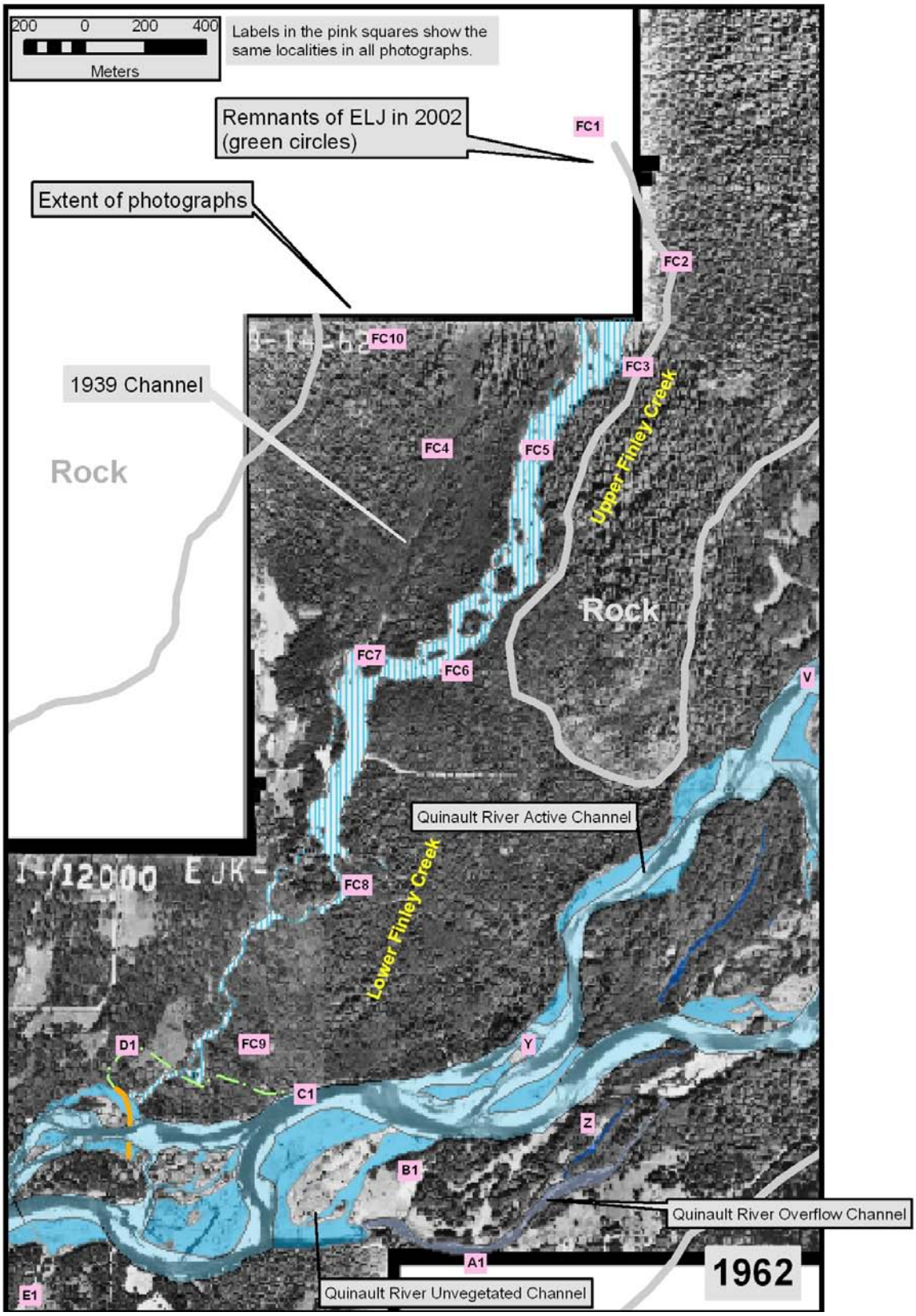

Figure 4. Finley Creek area in 1962.

3.5. 1973

3.5.1. Finley Creek

In upper Finley Creek, the creek in 1973 is in a single path approximately where it was in 1962 (figure 5). The meander at FC7 is broader in 1973 than it was in 1962.

In lower Finley Creek, the split flow at FC8 that was present in 1962 is in a main single channel by 1973. Multiple, unvegetated paths are visible for the first time to the east of FC8 and begin between FC7 and FC8.

Downstream of FC8, Finley Creek in 1973 is in a single path that is about in the same location as it was in 1962. The path to the Quinault River has lengthened a bit. Finley Creek enters an unvegetated overflow path of Quinault River, but this channel is south of the one where Finley Creek joined the Quinault River in 1962.

Some of the cleared areas on the west side of Finley Creek appear to be slightly less extensive than earlier. Not much change is apparent in the vegetation on east of Finley Creek.

Levees do not appear to be present downstream of the Finley Creek bridge, but work has occurred in the channel near the bridge.

3.5.2. Quinault River

The active channel between V and Y has straightened since 1962. It looks as if the meander upstream of Y cut off to the northwest into a channel that was not apparent in 1962. The south path that was between Z and V now begins farther upstream (out of the area shown), so that the 1973 active channel does not connect these two points. The narrow overflow channel through the vegetation between the two paths of the active channel that has been present in previous years now includes two additional channels that were wider overflow paths in 1962.

Between Y and E1, the active channel now meanders more tightly. The south path of the split 1962 active channel has been abandoned. This was the main path in 1962 and had a relatively tight meander. The tight meander is now an overflow channel. The active channel appears to have cut off into a path slightly north of the north path in the 1962. The north path then meanders into what was the south path near D1. Finley Creek joins the Quinault River near D1 and curves around the new meander in the active channel of the Quinault River before entering the river.

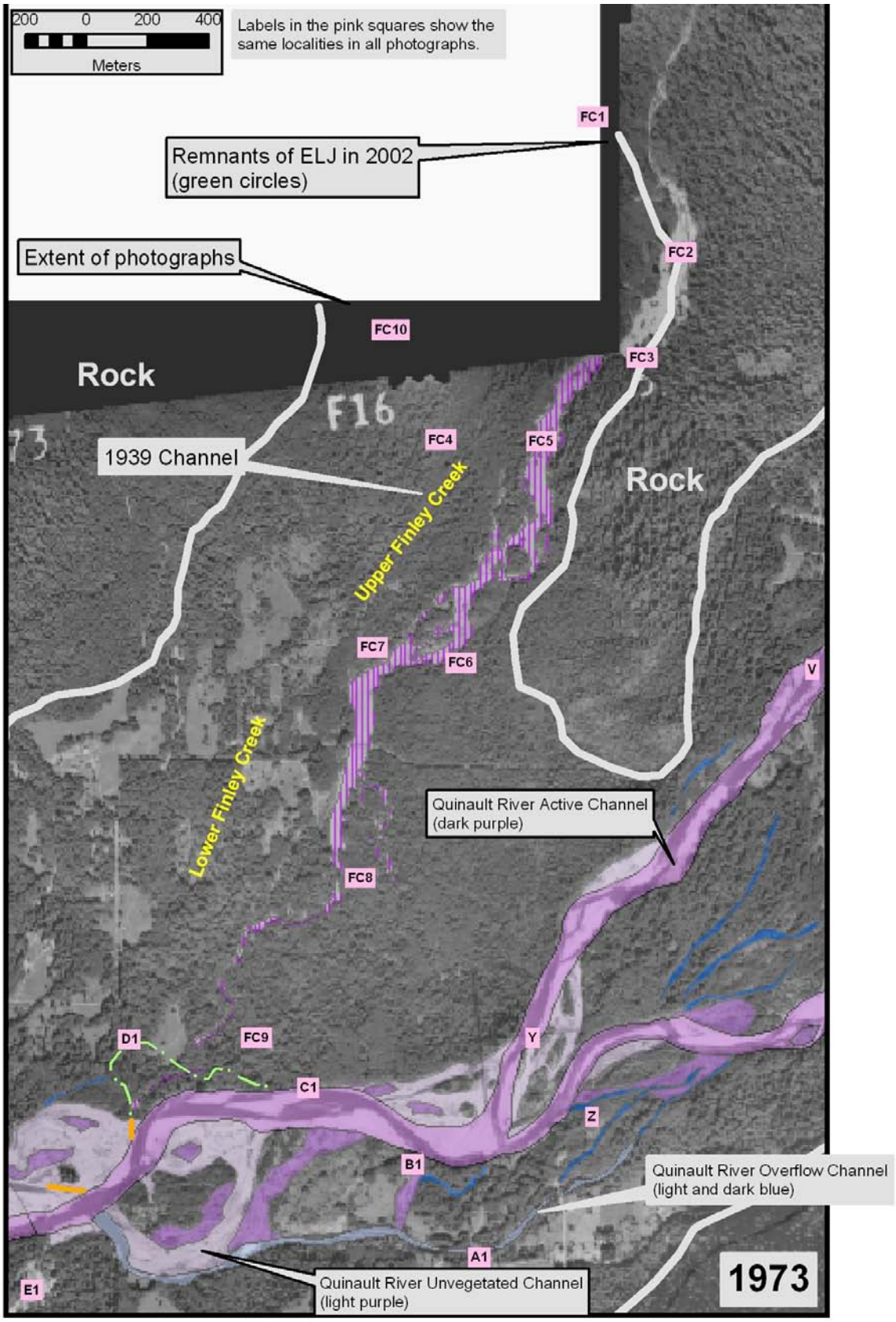

Figure 5. Finley Creek area in 1973.

3.6. 1982

3.6.1. Finley Creek

Photograph coverage in 1982 is limited to lower Finley Creek and the downstream portion of upper Finley Creek (figure 6).

Upper Finley Creek, upstream of FC6, is a braided channel. The meander at FC7 is much straighter than it has been in earlier years.

In lower Finley Creek, the east paths between FC7 and FC8 that were first visible in 1973 are more continuous and pronounced by 1982. One path extends to the Quinault River and joins its active channel downstream of Y. The path downstream of FC8 that was the single unvegetated path to the Quinault River in 1973 is not quite a continuous unvegetated path in 1982. This path joins the active channel of the Quinault River near FC9, upstream of where it joined the Quinault River in 1973.

The cleared areas on the west side of Finley Creek are more extensive than they were in 1973 in some areas, such as near D1 and along the valley edge. The area east of Finley Creek is vegetated by 1982.

It looks as if some work has begun in the area of the levees, but this is not clear on the photographs.

3.6.2. Quinault River

The unvegetated channel between V and Y is wider than it was in 1973. The unvegetated channel upstream of Z is narrower. The narrow overflow channels between these two unvegetated channel paths appear to be more extensive. A meander to the north has developed between C1 and FC9, so that the downstream portion of the Finley Creek fan has been eroded in this area. The meander between FC9 and D1 has moved outward and downstream since 1973. A wide overflow channel through vegetation is present downstream of B1 (shown in light blue). The upstream part of this overflow channel was the 1939 active channel. The downstream part was the active channel in 1962. Narrow overflow channels have developed through the vegetated area between C1 and the wide overflow channel downstream of B1.

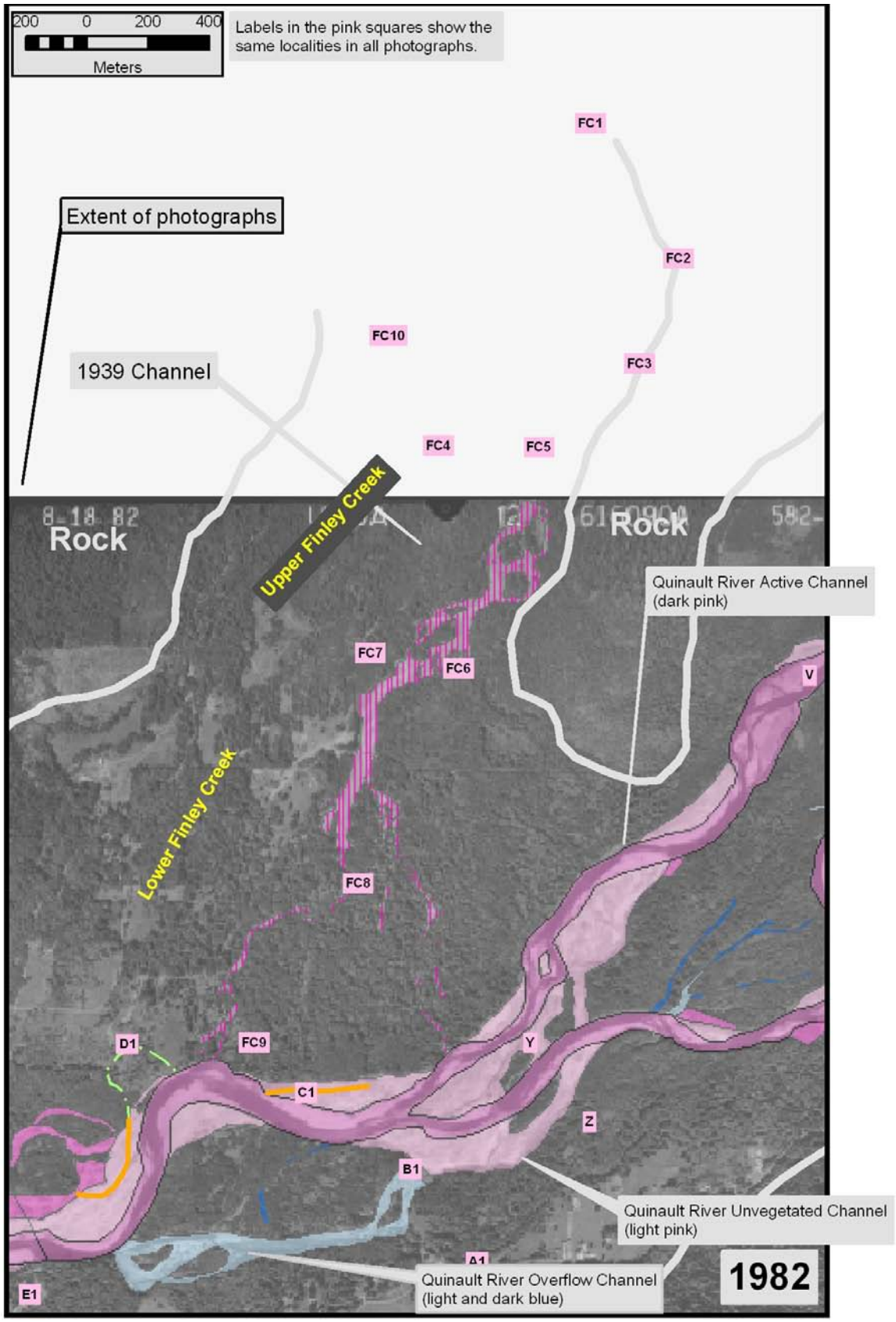

Figure 6. Finley Creek area in 1982.

3.7. 1994

3.7.1. Finley Creek

In upper Finley Creek, Finley Creek between FC1 and FC3 is now along bedrock in the narrow east path that was present in 1952 (figure 7). The 1952 and 1958 main paths can be seen in the vegetation as an abandoned path. The 1994 main path has a narrow branch near FC3. The path downstream of FC3 is a single fairly wide path. Just upstream of FC6 and FC7, the path splits. The west path is wider and probably carries more flow. The channel curves to the east in the area of the bridge. In this area, activity on the levees is visible. The position of the levees is not quite the same alignment as it will be in 2002.

In lower Finley Creek, the paths east of FC8 appear to be more in number and more continuous. The west path between FC8 and about D1 is no longer present as an unvegetated channel. A new west path has developed upstream of FC8. The now-active braided paths east of FC8 join the Quinault River in a narrow unvegetated overflow channel. A small alluvial-fan deposit is visible from Finley Creek in this overflow channel of the Quinault River.

The area west of Finley Creek appears to be more vegetated than it was in earlier years.

3.7.2. Quinault River

The north branch of the active channel between V and Y carries nearly all of the flow. This was an unvegetated overflow path in 1939. The south active channel path upstream of Y is very narrow. The main overflow path between these two active channel paths has widened. The north active channel path upstream of Y is now split into two main channels with a circular configuration. The north of these two flow paths has eroded the lower end of Finley Creek alluvial fan in this area.

Near Y, the active channel splits. The south active channel now flows between Z and B1 and downstream to E1 in what was a wide overflow path through vegetation in 1982. The north path of the active channel flows partially in what was the 1982 active channel. The meander between FC9 and D1 has moved farther downstream, now to D1. The 1973 active channel at D1 has revegetated.

The narrow unvegetated overflow channel, where Finley Creek joins the Quinault River, is in part a new path and was in part the 1982 unvegetated channel.

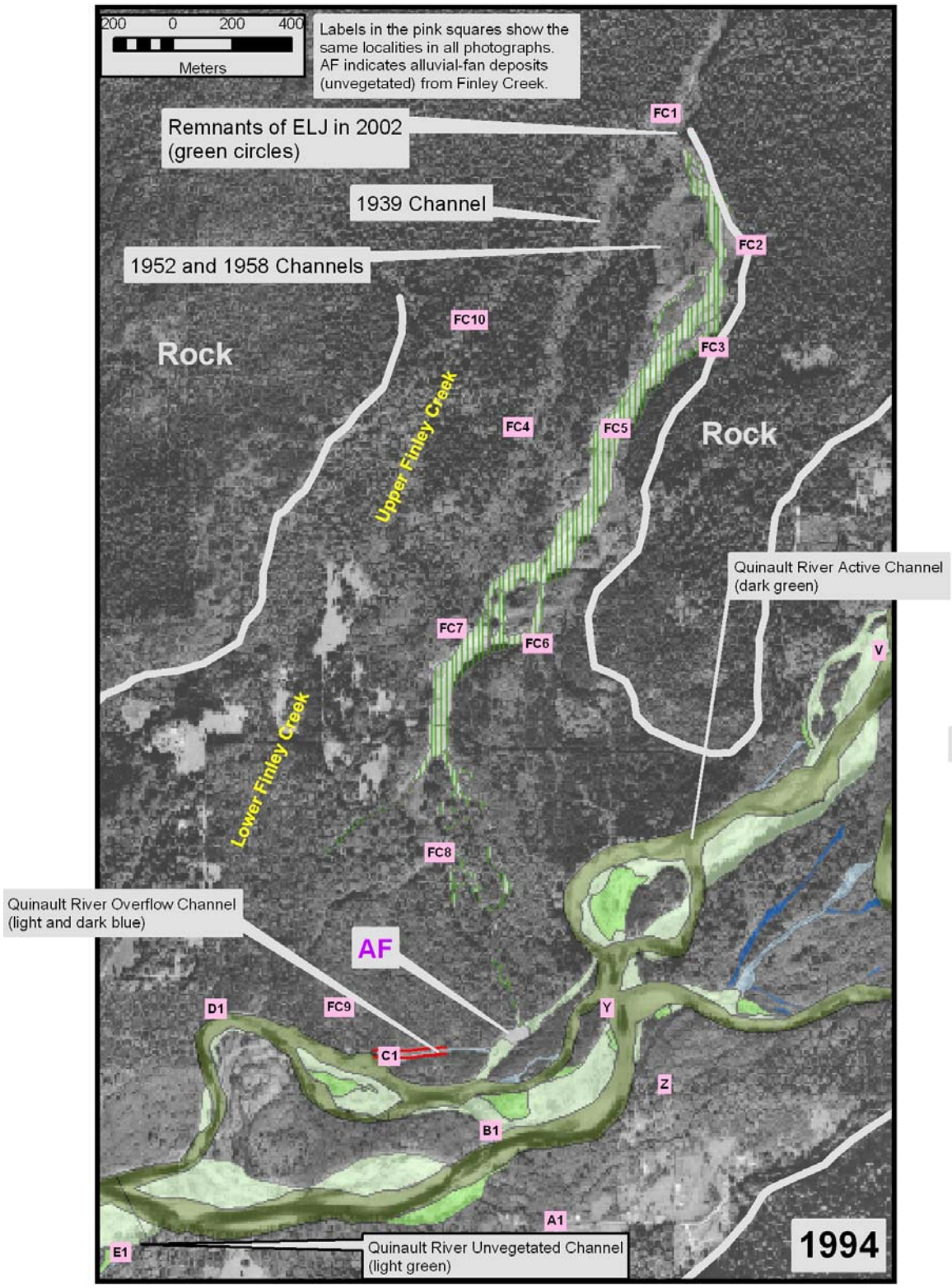

Figure 7. Finley Creek area in 1994.

3.8. 1998

3.8.1. Finley Creek

In upper Finley Creek, the creek in 1998 is entirely along what was the east path in previous years (figure 8). The east channel edge corresponds with the eroding bank that will be visible in 2002 (shown by the orange squares). The levees downstream of FC6 and FC7 are present along approximately the same alignment as they will be in 2002.

In lower Finley Creek, the multiple channel paths east of FC8 are wider and more continuous. The levees end at the upstream end of these channel paths, and appear to direct flow to the east into these channels. These channels join the Quinault River in at least two localities: one upstream of Y and one downstream of Y. A scar visible along the upstream path suggests bank erosion.

An additional unvegetated path is now present on the west in about the same location as channels have been in previous years. This channel joins the Quinault River west of FC9 into an unvegetated overflow channel. A small alluvial-fan deposit from the Finley Creek channel is present in the overflow channel (shown as AF on figure 8).

Cleared areas appear to be approximately the same as they were in 1994.

3.8.2. Quinault River

The active channel between V and Y has straightened. Only the north path of the split flow paths is now part of the active channel. The south path is now an unvegetated overflow path. The sharp meander and split path in the north path upstream of Y has been abandoned. This is the unvegetated overflow path that upstream east branches of Finley Creek enter. At Y, the active channel is partly within the narrow unvegetated overflow channel that was present in 1994.

Between B1 and E1, the active channel is solely within the south path of what was split flow in 1994. The active channel has branching flow paths. The former north path is now an unvegetated overflow channel. This the channel that the west branch of Finley Creek joins near FC9. Several narrow overflow channels have developed through the vegetation between these two former active channel paths of the Quinault River.

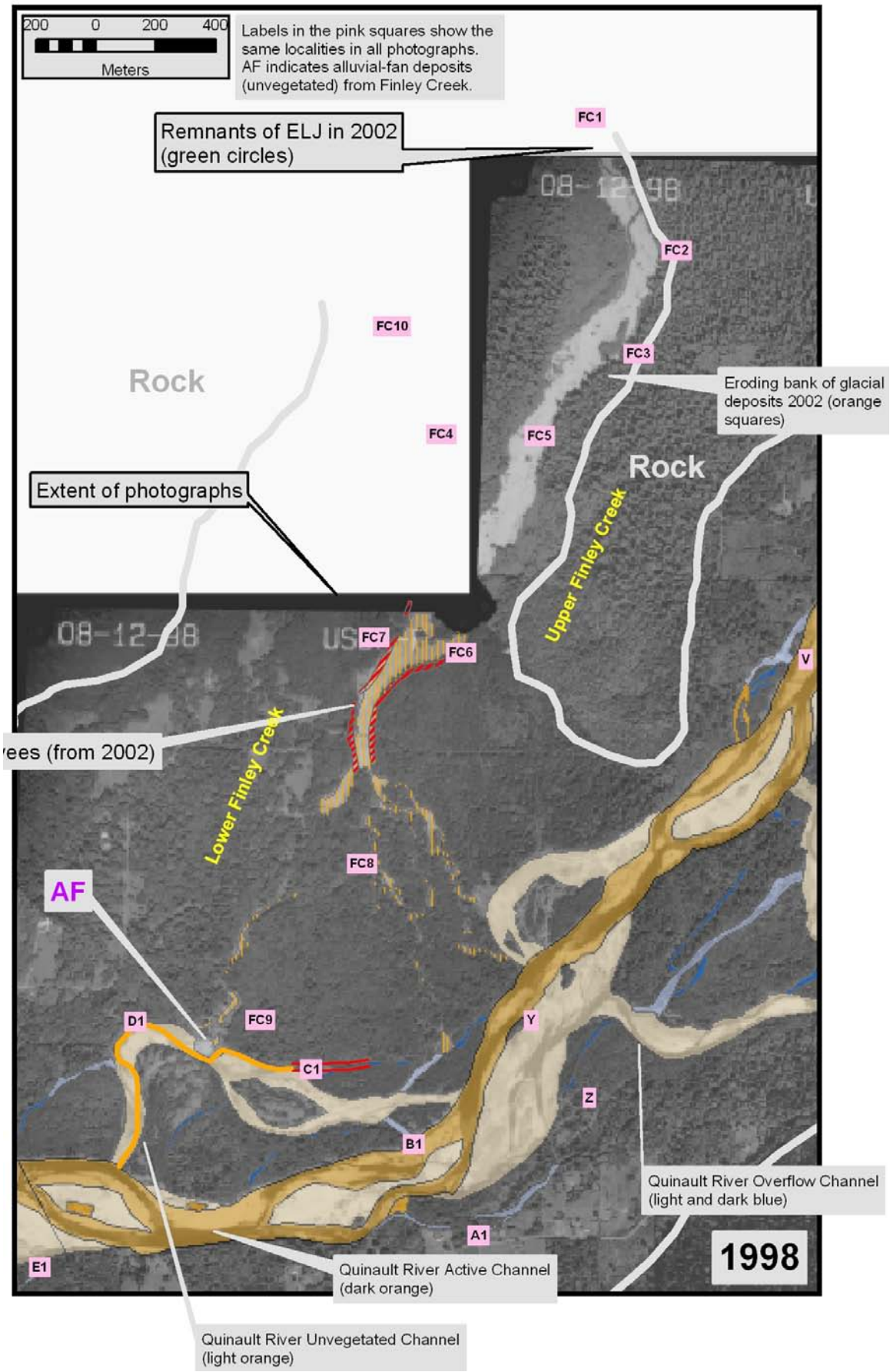

Figure 8. Finley Creek area in 1998.

3.9. 2001

3.9.1. Finley Creek

In upper Finley Creek, the creek is along bedrock and glacial deposits, where the eroding bank is likely present in 2002. This bank is visible on the 2002 hillshade. The older channel, 1939 channel, and main 1952 and 1958 channels are all still visible as differences in vegetation (figure 9).

The levees are readily visible near FC6 and FC7, and follow the alignment that they have in 2002. Flow splits into several narrow unvegetated channels downstream of the levees. The east flow path is in the same position as it was in 1998. A larger alluvial-fan deposit is present where it enters the overflow channel of the Quinault River (shown as AF on figure 9). The upstream and downstream ends of this overflow channel are now partially vegetated, suggesting less and (or) less frequent flows. The west unvegetated path of Finley Creek follows approximately the west path that was present in 1998. It enters an unvegetated overflow channel of the Quinault River, and also has an alluvial-fan deposit at its mouth.

Only a small portion of the Finely Creek alluvial fan is now cleared of vegetation.

3.9.2. Quinault River

The active channel is about the same as it was in 1998, except that the split flow paths are now a single path within which the low-flow channel meanders. The abandoned path upstream of Y (the old meander) was unvegetated in 1998, but now its upstream and downstream ends have some vegetation. This is the channel that one path of Finley Creek enters.

The abandoned path between Y and D1 appears about the same as it did in 1998, perhaps slightly narrower. This has become Taiber Slough, an area of sockeye spawning, by at least 2002 (B. Armstrong (Quinault Indian Nation), 2002, written commun.).

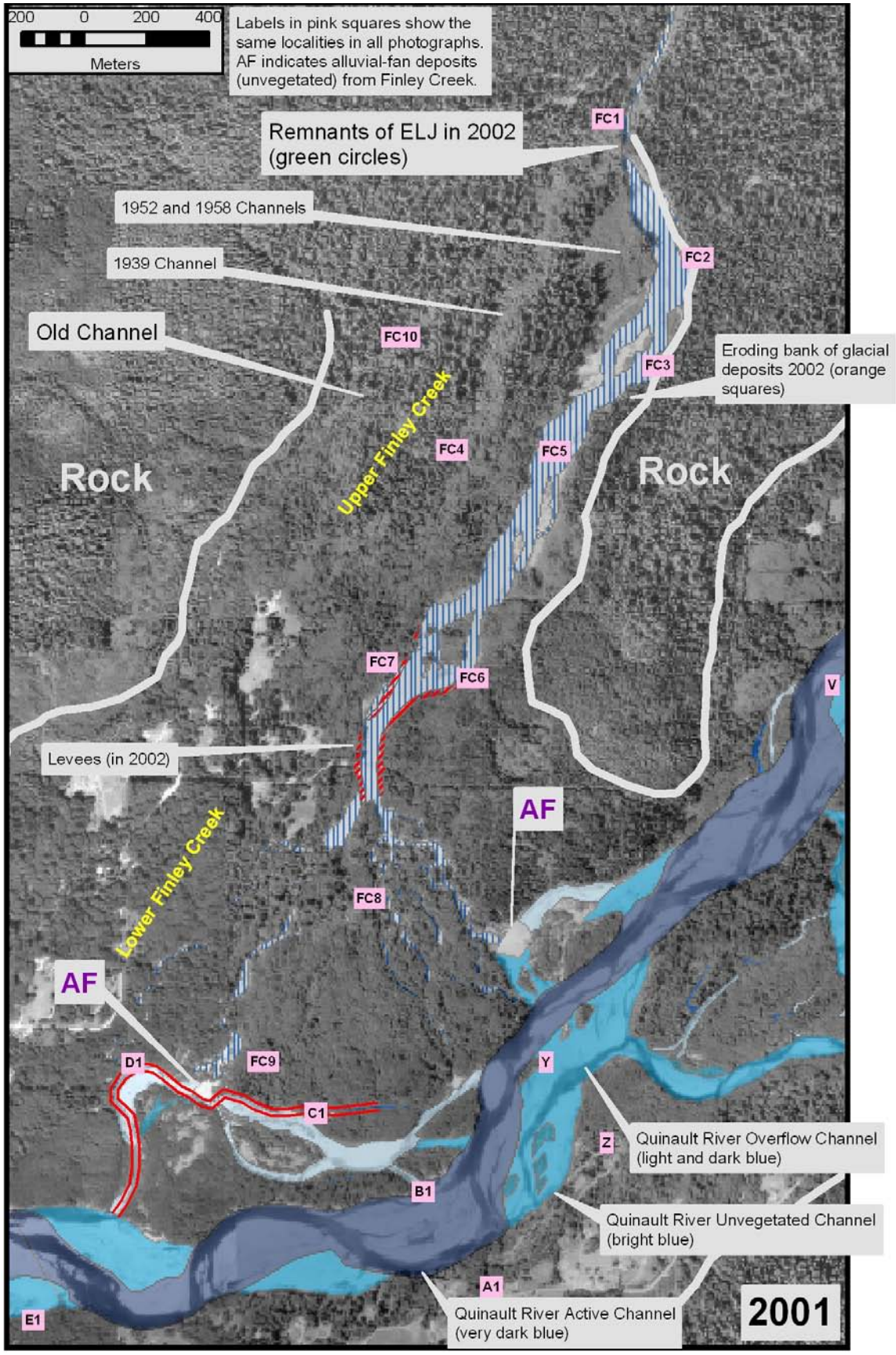

Figure 9. Finley Creek area in 2001.

3.10. 2002

3.10.1. Finley Creek

In upper Finley Creek, the channel path is not much different from what it was in 2001 (figure 10).

In lower Finley Creek, the easternmost channel path downstream of the levees may be slightly more pronounced than it was in 2001. An alluvial-fan deposits (unvegetated) still is present where this channel enters the overflow channel of the Quinault River (shown as AF). The upstream end of the Quinault River overflow channel appears to be unvegetated, whereas it had some vegetation in 2001. The west channel at the downstream end of Finley Creek is about the same as it was in 2001. It still enters the overflow channel of Quinault River, now called Taiber Slough. The west channel can be seen on the hillshade as an incised channel between FC8 and FC9. In contrast, the eastern channel paths are only barely visible on the 2002 hillshade.

The levees near FC6 and FC7 are prominent. They are readily visible on the 2002 hillshade. These levees direct flow to the east. The west levee cuts off flow to the west path of lower Finley Creek.

3.10.2. Quinault River

The active channel path is similar to what it was in 2001. However, the low-flow channel is straighter, especially downstream of Y, where the path has moved to the south. Several narrow overflow channels are visible through the vegetated surface upstream of Y.

The unvegetated overflow channel downstream of Y (Taiber Slough) appears narrower and more braided than it did in 2001, suggesting that the channel receives less flow. This may be because the low-flow main channel has moved to the south downstream of Y. This remains the active channel path of the Quinault River to 2002. Because of the cut offs and changes in the location of the active channel, the toe of the Finley Creek alluvial-fan complex has progressively eroded between 1939 and 2002.

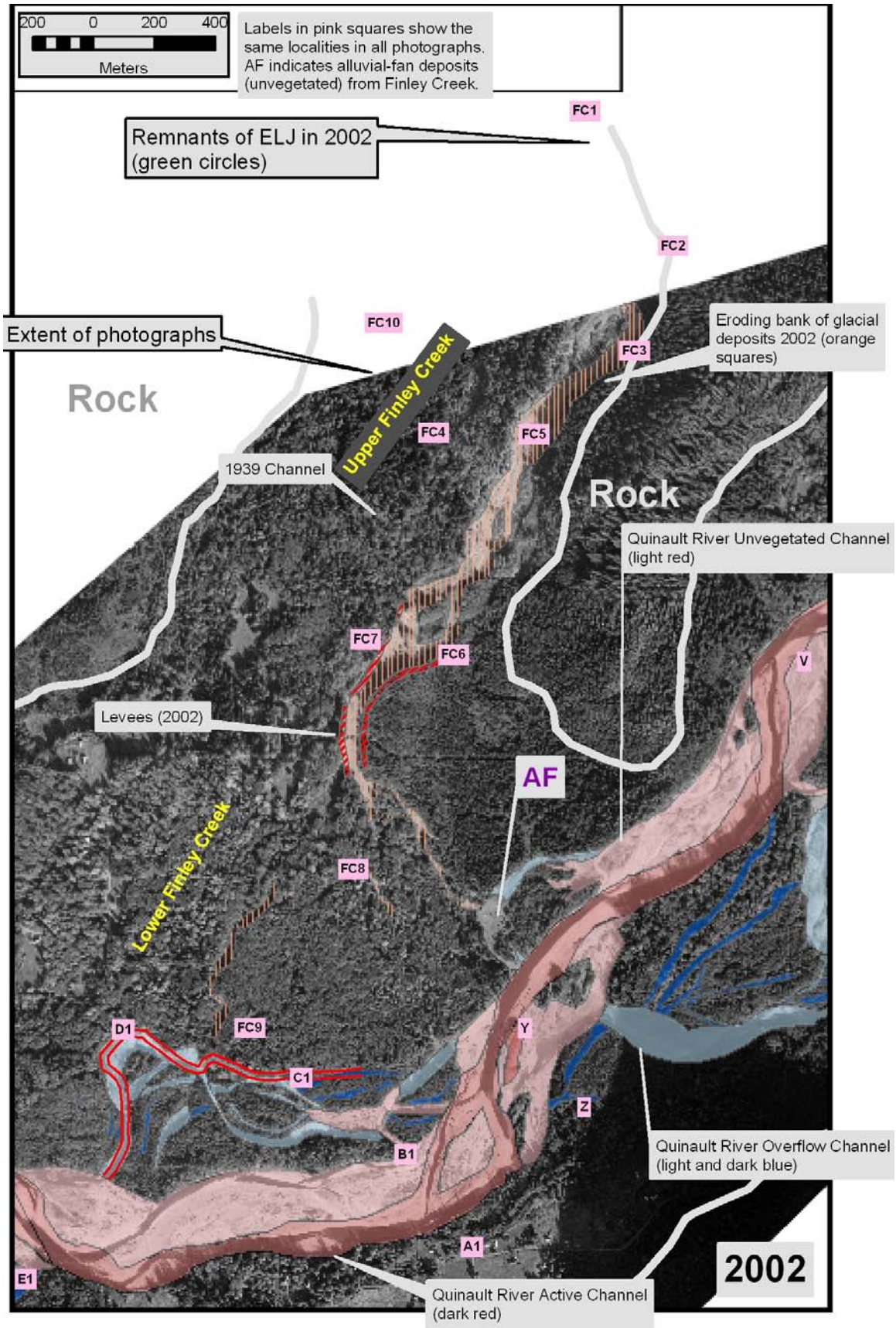

Figure 10. Finley Creek area in 2002.

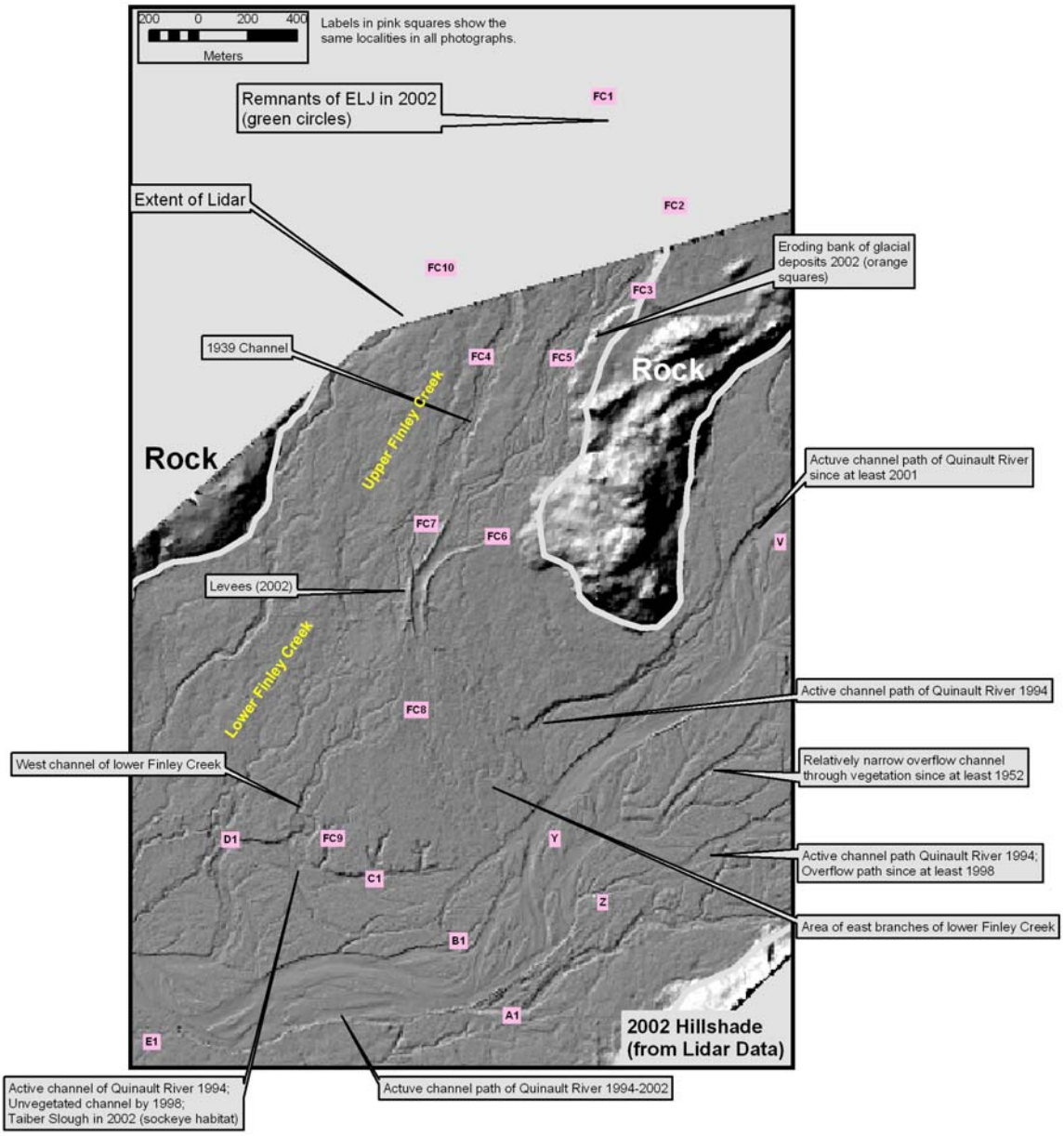

Figure 11. Finley Creek area shown on the hillshade calculated from the Lidar data collected in 2002. Evidence of former channels of both Finley Creek and the Quinault River are still visible in the landscape in 2002 as shown by the notes.

Finley Creek, Upper Quinault River Valley, Washington
Summary of Observations

E. Lyon and L. Piety, USBR Geologists

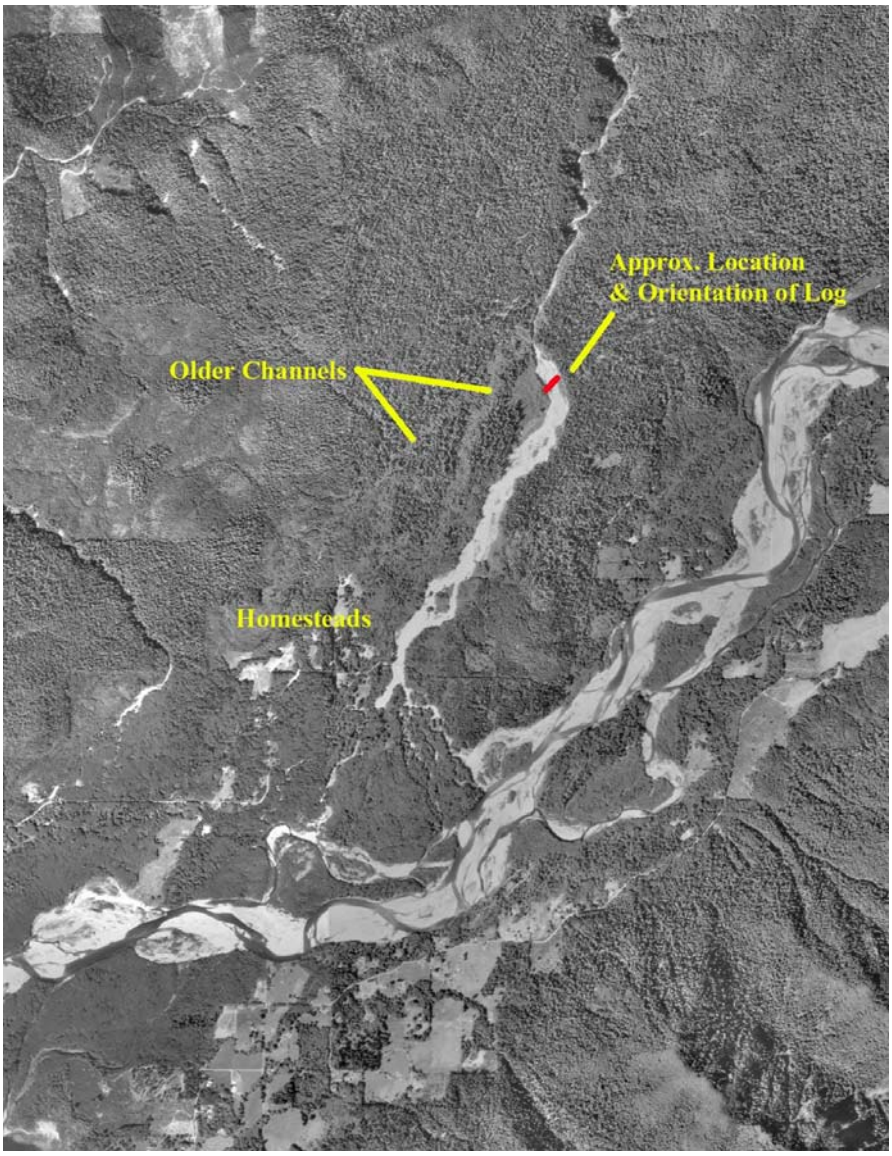

Figure 1. 2001 Aerial photograph of Finley Creek drainage showing the location of a recently fallen Sitka Spruce which is partially elevated above the active Finley Creek channel, but as the west bank erodes the tree will enter the active channel and adversely direct flows toward older channels (unfortunately a photo is unavailable). These older channels are directed towards the homesteads downstream.

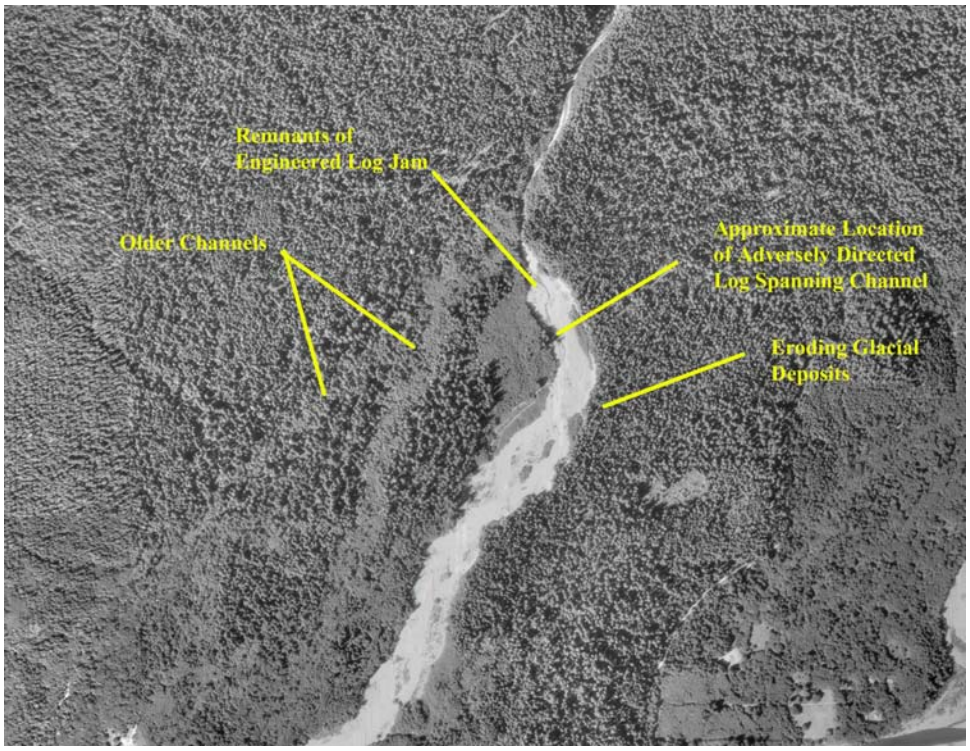

Figure 2. 2001 Aerial photograph showing location of old engineered log jam (ELJ) which was put in-place between 1939 and 1952. The ELJ directs flow away from the older western channels and eastward into the glacial bluff. Erosion of the bluff has introduced copious amounts of coarse sediment into the system.

Figure 3. Glacial bluff along the eastern bank of Finley Creek. These glacial deposits are composed of delta foresets indicating the Late Pleistocene highstand of Lake Quinault.

Figure 4. Remnants of the ELJ that directed the Finley Creek flows towards the eastbank between 1939 and 1952, note the eroding glacial bluff in the background. Most of the logs are now separated with cables still attached.

Figure 5. Log and cable protruding from right streambank (left side in photo) is a remnant of the ELJ that directed the channel to the east.

APPENDIX M: Journal Accounts from Expeditions from 1878 to 1890

The following accounts are directly taken from the reference: Lien, Carsten. *Exploring the Olympic Mountains: Accounts of the Earliest Expeditions 1878-1890*. Seattle, Washington: The Mountaineers Books, 2001.

Watkinson Expedition (1878)

This expedition involved five young men from logging camps of Hood Canal. They traveled from Hood Canal up the Skokomish River to Lake Cushman, and then up to the top of the Olympic Mountains. At that point they went down the east fork of the Quinault River to the forks, and down the remainder of the Quinault River to the Pacific Ocean. They then went south and then east to Aberdeen.

September 8 and 9, 1878, headed down the mainstem of the Quinault River between the Forks and Lake Quinault (p.15).

"The river was becoming too deep to ford."

"There were many indications of very heavy freshets here. In some places, the bars are one quarter of a mile wide, with great drift piles on top of them."

September 11, 2004, Traveling by canoe down the lower Quinault below the lake (p.16).

"Its (the river) banks are much more regular below the lake than above it."
"At this time, the water was very low, and there were many dangerous riffles to shoot."

Press Expedition (1889 to 1890), Described by Captain Barnes Journal unless otherwise noted

May 16, 1890, headed downstream on the North Fork Quinault (p.100):

"One hundred yards below camp we forded a slough and traveled for a short distance on a bar. Recrossing to the mainland we came to a large island, over a mile long and about a mile wide. We crossed a deep stream separating it from the mainland, and traveled the length of the island through a dense jungle of underbrush. It is heavily timbered and possesses a fertile soil. At the west end of the island we dropped a tree across and took to the sidehill. The task now became very heavy, as for the remainder of the day we climbed up and down."

"At one point descending to the river we found a small sandbar covered with driftwood. The land on the other side of the river was flat and we were desirous of getting there to avoid continuous climbing of these sidehills. The river was unfavorable, however, for fording, and the driftwood was too rotten and heavy for a raft, so that we had to give up the idea and take again to the sidehill. Toward evening, descending again to the river, we made two more attempts to cross. The first attempt was made with a rope

lashed from man to man, but our united strength could not resist the strength of the current. At a short distance above we made another attempt, in water to our armpits, and succeeded in reaching an island in the middle of the river. We arrived there wet and tired and made camp on the sand of the island."

May 17, 1890, Traveled down North Fork Quinault to Forks, and continued downstream on mainstem Quinault to Bunch Creek (p.100).

"We felled a large tree from the island to the north bank and crossed. We continued all day down the river, through dense underbrush consisting of a tangled thicket of salmon berry bushes, vine maple and all other usual small growth that can be imagined. About noon we came to a big bend of the river with a fork from the eastward. This fork at the point of junction is about equal in size and in its possibilities for navigation with the main river….Below the fork we suddenly emerged upon a little clearing, in the middle of which was a log cabin[1], our first sign of civilized man for many months…The river was now large and broad. As we went onward we found frequent signs of man. We presently came upon the cold embers of an Indian fire surrounded by a frame work of drying fish. The bank of the river becoming now so dense with underbrush as to be almost impenetrable, we struck backward from the river and found dry sloughs, which we followed. They led us again to the river about one mile below and there we made camp on a sand bar[2]..."

May 18, 1890, Started across from Bunch Creek, and built raft between Bunch and Fletcher Creek (p.102).

"We had a spur to climb and follow, half a mile long, to reach the sand bars again. But the spur was so matted and jungled that we could penetrate only with difficulty, so we descended to the water's edge and scrambled along the rock, clinging to the overhanging foliage. Passing this we struck inland and followed a dry slough for a mile, which brought us out on the bank again."

"For several miles back the river had been smooth and quiet, and the banks and channel free of drift timber…So as we looked down the smoothly gliding stream, which would carry us in an hour a distance which it would take us two or three days to make along the bank, Mr. Christie was persuaded to build a raft."

"White still cutting and rolling down logs, which lay upon the bank, we were suddenly surprised to catch sight of a man as he emerged from bushes on the opposite bank…His name was F.S. Antrim of Aberdeen….He said the lake was eight miles down. We asked him if a raft would go down. He said he was ignorant of rafting, and turning to one of his Indian guides, asked him what he thought of it. The Indian nodded toward the hills on the north of the valley and said: "Good trail over there." "Yes, but can these gentlemen

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[1] This location is estimated to be on the north bank of the Quinault River just below the Forks near where Bunchfield Slough is now present. This clearing can still be seen today on the present aerial photographs.
[2] This sand bar was located across from Bunch Creek drainage.

go down on a raft?" The Indian looked thoughtful for a moment and then said: "Yes, raft go down." But still he looked at the hills as he repeated: "Trail over there."

"Seven good sized sticks rolled into the water and lashed to good solid cross pieces with rope lashings, made a comfortable raft of about eight by fifteen feet."

"Pushing out into the stream we were soon gliding quietly and swiftly down. The steering oar in Mr. Christie's experienced hands, assisted by an occasional check with the poles, served to keep us in mid channel. The river for over a mile continued as gentle as could be desired, and we congratulated ourselves on an early termination of our journey."

"As we rounded a sharp bend in the river we were suddenly horrified to see the whole current sweep in toward the right bank and pass under a great pile of drift timber which lay upon the bank and projected half way across the stream. We were then traveling at 10 to 12 miles an hour, and the poles were powerless. Mr. Christie, however with his oar was able to swing the raft so that it struck the drift pile broadside, thereby preserving it from instant destruction. The instant we struck, Crumback and Sims sprang from the raft to the driftpile and were safe. At the same moment a huge volume of water poured over the raft, sweeping from it Hayes, myself and all the baggage. When I came to the surface a few seconds later I had passed under the outer corner of the driftpile and was grasping the pack which contained the records, the loss of which we would have felt most. I managed to grasp a spar, which projected some distance out from the lower end of the driftpile. Mr. Christie meanwhile had succeeded in extricating young Hayes, who had been swept off the raft and was being borne directly under the timber. Mr. Christie grasped him by the arm just in time. It was a narrow shave for Hayes, for even if he had not met with an obstruction beneath, which would have terminated his career like a cat in a bag, the chances are a hundred to one that he would have bumped his head in the passage."

"Hayes then being safe ashore, Mr. Christie, not knowing but that I had gone on down the river, determined to follow with the raft. The raft had by this time swung out to near the point of the driftpile, and a strong effort on his part was sufficient to clear it entirely. I was , however, but 50 to 60 yards below, and fearing the raft might crush me, I let go the snag to which I was clinging. I was carried down the stream several hundred yards before I succeeded in getting out of the boiling waters which formed the current, and felt under my feel the gravel of terra firma on the opposite or left bank. Mr. Christie and the raft went on down a couple of hundred yards further, and then he succeeded in getting to the same side on which I was."

"The boys had the best of the road, their side (north side) being for a large part along sandy bars. Our side was covered with thick woods, dense with underbrush, and cut with sloughs. The salmon berry brushes and bramble held us so that we did not make more

than a mile in three hours of hard work…Finally we reached a sandbar and camped there wit the boys opposite us." [3]

May 18, 1890 (Christie's Journal, p.133)

On reaching a gravel beach some six miles below the east fork (location was actually a shorter distance from forks according to map of party), dry wood being handy, I determined to collect timber and launch a raft at the point."

May 19, 1890 (Barnes Journal, p.104-105)

"The boys, on seeing us, came down the river bank, and we were able to communicate by shouting…."From the information furnished by Mr. Antrim, we estimated that we were about five miles from a settler's cabin at the head of the lake. The boys having permission to go on started at once, and it was as good as a joke to see the speed with which they disappeared into the woods….He (Mr. Christie) had not been gone five minutes when who should come around the bend from above but our benefactor of yesterday, Mr. Antrim, in his canoe…Mr. Antrim camped at the forks last evening. This morning he had left his camp at 4 o'clock, coming down the river (by canoe with the Indian guides), and thus we met him….Once in the canoe we thoroughly enjoyed the day…The river was a surprise to us. Piles of driftwood were frequent. In fact, it soon became evident to us that it would have been impossible for us to have descended the river on a raft. If we had not been wrecked where we were it would have been impossible to escape it half a mile below. As we neared the lake drift piles became still more numerous, and it required most skillful handling to clear them with the canoe. But in the hands of the Indians, who had been brought up from boyhood on the river, and had frequently traveled as high as the forks, the voyage was made in perfect safety. Their knowledge of the current is wonderful. They know every submerged sandbar, rock, and snag on the river, and just the right stroke of the paddle at the right time sends the canoe past dangers which to us were invisible until we were by them."

"About a mile down the river we picked up the boys who were stoutly trudging down the bank…Eight men and three dogs made a large passenger list for the little canoe, but it arrived safely at last at the mouth of the river. Here we found a house, and an actual, bona fide, settler. Antrim's stores were cached here…"

May 20, camping on the Lower Quinault below the lake (p.107)

"From this point to the mouth of the river the channel is free of obstruction. A bar is said to obstruct the mouth of the river, but from that point to the forks, 10 or 12 miles above the lake, the river channel is navigable for streamboats. The current is nowhere swift, and plenty of depth obtains. The only present obstacle is the occasional jam of logs or

[3] "Camp 45 of the Press Party, 'Split Camp', for May 18, 1890, were two separate campsites, located on opposite sides of the Upper Quinault River, in the north half of section 36. Christie and Barnes were encamped on the south side of the river, while Hayes, Crumback, and Sims camped on the north side."

pile of drift timber, but these are small and easily cleared with a small quantity of dynamite."

Geology of the Olympics, Charles A. Barnes, Seattle Press, July 16, 1890 (p.137)

"The mountains, as a whole, are well timbered. Hemlock, fir, spruce, cedar and pine are the chief varieties. On the Quinault River the timber is equally good as far up as Alexander river[4]. About the lake the timber is unsurpassed. Above Alexander the timber is poor. It grows to a large size, but is rotten, conchy, and crooked. The river could be cleared at a slight expense, and logs driven with ease from as high as the head of Chester valley at all seasons of the year."

"There is no grass in these mountains, except some little on the lower Elwha upon old burnt mountain sides." "Beaver and fisher are numerous on the Quinault."

Gilman Explorations, 1889 to 1890, October 20, 1890 started at Quinault River and traversed in up the river to its headwaters. They were two men on this expedition who hired and Indian guide to take them up the Quinault to the forks by canoe. Descriptions below were printed in Seattle Post-Intelligencer, June 5, 1890

October 20, 1889 (p. 172 – 73)
"The tributary country was at the time almost unsettled, though a number of settlers have gone in since and established an embryo city of the banks of the lake."

"At the lake they found three hunters and trappers occupying a house that had been built and abandoned by a squatter the spring before. The three men received them well, but were very dubious when told of the mission of the Gilmans (the men had a hard time finding a guide because of the high waters and deep snow that were predicted to be encountered at this time of year)."

"The adventurers found the river very swift and were constrained to walk most of the time, while the Indians pulled the canoe. Occasionally they would strike an obstruction on the bank and then the Indians would ferry them to the other side where they pursued their course until they were compelled to cross over again. They continued up the river until the afternoon of the next day, October 25, when they reached the forks about 4:30 pm."

"On October 28, they took the canoe and started on up the east fork, which came down from the direction of Mount Constance, in a course a little south of west; but they had hardly gone three miles before they encountered an immense log jam and had to abandon the canoe."

"On the second morning after reaching the east fork of the Quinault (coming back down the mountain), they started downstream, in search of an old canoe they had noticed on their way up. They soon found it and spent some time in patching it up. Next morning,

[4] This stream today is known as Rustler Creek.

making an early start, they continued down to the forks, reaching them at noon; and at night they came to the lake."

DeFord Party Expedition, 1890 (p. 206-207)

"Above the lake they found the canoeing difficult, it being necessary in many places to drag their canoes over the shoals and jams. They traveled for an entire day above the lake by canoe. After leaving their boats they continued on foot for three days to the hills of the Olympic, and had the experience of a snow storm on the 25th of August."

O'Neil Expedition, August 1890 (p.273)

"After a very heavy tramp of five days we reached Lake Quinault….After the junction of the North and East Forks, about 10 miles from the lake, the river becomes a large-sized stream, in spring very rapid…The North Fork is a stream nearly as large as the East Fork, rising just south of Mount Olympus."

"We then turned eastward to strike a stream on the other side of the divide which we knew to be the North Fork of the Quinault, or one of its tributaries. We reached it, but were unable to travel either on the ridge or hillside, and again forced into the bed of the stream….This stream increased in size very rapidly, fed by its numerous tributaries, and I was puzzled to know where it joined the North Fork of the Quinaiult. But what puzzled me more a little later was where the stream we had been following, a rushing, foaming body of water, fully 30 feet wide and from 6 inches to 5 feet in depth, disappeared and as completely as if it had never existed; and for three hours we tramped along in its bed, which was as dry as if water had never touched it. We dug several feet but found no water. At last we had about resolved to make a dry camp, when just in front of us flowed the stream, much larger than where it disappeared. We afterwards noticed a great many of these freaks, the water sinking and again rising some 8 or 10 miles distant. We had mistaken the location of this stream, for instead of flowing on to the North Fork it makes a curve and joins the main Quinault River about 5 miles above the lake."[5]

[5] This stream is believed to be what is presently referred to as Big Creek.

Appendix N. Chronology of Events in Upper Quinault River Valley

12000 BP	First evidence of natives on the Peninsula; hunters and gathers (McNulty, 1996); Natives' first use of mountainous areas of Olympic National Park (QIN, 1999)
	Quinault Indian Nation occupation – upper valley utilized primarily for hunting and fishing (Olson, 1936; Lien, 2001); riverine oriented (QIN, 1999); upper reaches were sites of seasonal base camps for fishing (principally Sockeye), hunting and gathering (QIN, 1999)
1855	Quinault River treaty (QIN, 1999)
1878	Watkinson Expedition (Lien, 2001)
1888	Alfred Noyes first documented white settler (Armstrong, 2002, written communication)
1889-1890	Press Expedition (Lien, 2001)
	Gillman Expedition and first Euro American settlers, subsistence farming and grazing (Wood, 1994; Lien, 2001)
1890	DeFord Party Expedition (Lien, 2001)
	O'Neil Expedition (Lien, 2001)
	Quinault Township Company formed; promote area for development (Evans, 1983)
1891	Alfred Higley begins building hotels and to provide services to early settlers and travelers (Jones, 1997)
1891-1900	More than 30 new settlers arrive in upper Quinault valley (Evans, 1983)
1897	Homesteaders occupy bottomlands between lake and confluence (Evans, 1983)
	Olympic Forest Reserve declared by President Cleveland, unsettled lands north and east of lake (QIN, 1999)
1900s	Homesteaders use selective harvesting, timber with highest value; typical timber harvest activities a) clearcut, broadcast burn for plantable sites, and reforesting (QIN, 1999)

	Drastic decline in salmon runs (QIN, 1999)
1905	US Forest Service formed and manages reserve as Olympic National Forest (QIN, 1999)
1910	First road connecting Quinault valley to Hoquiam (Armstrong, 2002, written communication)
1910-1911	Theodore Rixon surveys in summer home lots (QIN, 1999)
1914-1918	World War I
1914	State Highway between Quinault Lake, Neilton and Humptulips (QIN, 1999)
1916	First logging, cedar salvage from “Neilton Burn” (QIN, 1999)
1918	Quinault National Fish Hatchery constructed on Falls Creek at Quinault Lake (QIN, 1999)
1920s	Several campgrounds constructed or improved, some in upper valley (Buck, 1924)
Post 1920s	Logging has reduced species, diversity, abundance, and size of riparian areas (QIN, 1999)
1921	Suspension bridge constructed across Quinault River near river kilometer 2.5
1922	Quinault Recreation Area designated (QIN, 1999)
1923	Suspension bridge washed-out (Workman, 1997)
1924	Railroad logging, large-scale commercial logging downstream of lake (QIN, 1999)
1926	Road finished between Lower Quinault Valley and North Shore Area (Armstrong, 2002)
1926-1944	Logging driven by war materials need, lower valley and North Shore road area (Armstrong, 2002)
1926	Lake Quinault Lodge constructed (QIN, 1999)
1927	Low Divide Chalet constructed (Evans, 1983)

1930	Pontoon bridge constructed across Quinault River below the confluence of North and East Forks at river kilometer 18 (Workman, 1997)
1931	Enchanted Valley Chalet constructed (Evans, 1983)
1932	Quinault Research Natural Area designated (QIN, 1999)
1938	Olympic National Park designated and 4,538 acres of private land included (QIN, 1999)
1939-1945	World War II
1940-1950s	NPS land acquisitions terminate harvesting operations along the North Fork (Wagner, 2003, written communication)
1960	Multiple Use-Sustained Yield Act; national forests must be managed for many uses; must provide 1) flood and erosion control, 2) grazing land, 3) wildlife habitat, 4) biomass fuel, 5) scientific, educational, wilderness, and recreational uses (Owen and Chiras, 1995)
1961	ONP begins land acquisition program and about 1,000 acres were acquired (Gallison, 1962)
	Bank protection of South Shore Road and quarrying of Meriman Creek Quarry on August 22, 1961; Quarry is most likely cement plant near Pruce Boys Road (Grays Harbor County memo)
1964	Bank protection along Quinault River Road washed-out during flood on February 7 (Jefferson County memo)
	Wilderness Act; identify candidates and include in the National Wilderness Preservation System (Owen and Chiras, 1995)
1965	Channel excavation on October 4 (State of Washington, Hydraulics Project Approval memo)
1950s	Quinault River Bridge constructed downstream of confluence (QIN, 1999)
1950s-1980s	Extensive road construction and logging (QIN, 1999)
1950s-1990s	Logging on NFS lands, broadcast burning leading to removal of both SWD and LWD (QIN, 1999)
1970s-1980s	Last lower valley timber harvest, eastside of Finley Creek down to the river (Armstrong, 2002, written communication)

1972	Federal Water Pollution Control Act (Owen and Chiras, 1995)
1973	Endangered Species Act (Owen and Chiras, 1995)
1974	Safe Drinking Water Act (Owen and Chiras, 1995)
1974 & 1976	Forest Reserves Management Acts (Owen and Chiras, 1995)
1976	Federal Land Policy Management Act (Owen and Chiras, 1995)
	National Forest Management Act (Owen and Chiras, 1995)
1977	Clean Water Act (FWPCA of 1972 amended 1977, 1981 & 1987); key requirements 1) minimal water quality standards, and 2) water should be fishable and swimmable (Owen and Chiras, 1995)
1978	Endangered American Wilderness Act (Owen and Chiras, 1995)
1984	Colonel Bob Wilderness included in Washington Wilderness Act (QIN, 1999)
1987	Bank protection and culvert installations along South Shore Road on May 1(Jefferson County memo)
1987	Cottonwood Campground protection with anchored logs September 30 (Olympic National Forest memo)
Post 1990s	NFS lands focused on removal of SWD (QIN, 1999)
1996	South Shore Road protection, riprap, anchored logs and culverts August 1 (Jefferson County Contract Plans)
1999	ONP, about 246 private acres remain (QIN, 1999)

APPENDIX O: GEOMORPHIC HISTORY AT HABITAT SIDE CHANNEL SITES

List of Discussions Included in Appendix O by Locality:

1. Bunchfield Slough
2. Fletcher Slough
3. North Slough
4. Big Creek Side Channel
5. Alder Side Channel
6. Taiber Slough

History and Geomorphology of Bunch Field Slough, 1906 through 2002

Bunch Field Slough is located on the north side of the Quinault River valley between RK 15.5 and RK 17.0 (Figure 1). It is between a bedrock knob that extends into the valley (downstream end) between RK 14 and RK 14.5 and the NPS Bridge near RK 17.5. The following discussion does not include 1962 or 1998, because aerial photographs taken in these years do not extend upstream to this area.

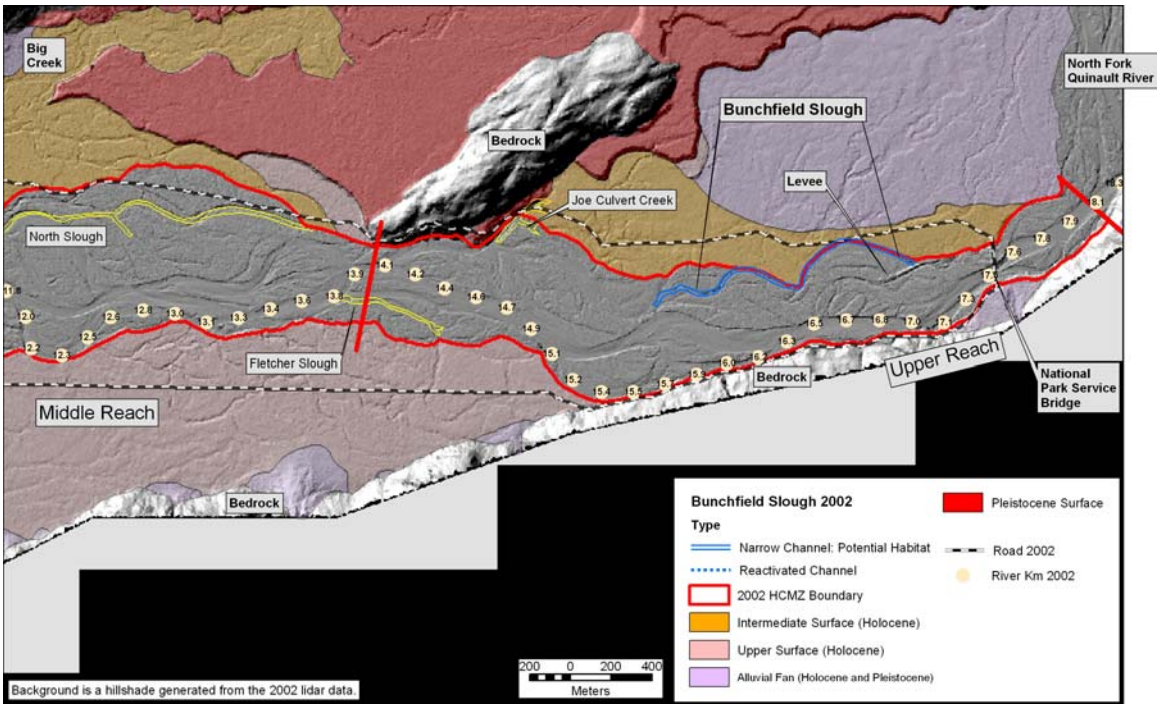

Figure 1. Bunch Field Slough is located between RK 15.5 and RK 17.0 along the north side of the historical channel migration zone (HCMZ). Background is a hillshade created from 2002 LiDAR data. River kilometers are from the low-flow channel at the time of a river survey in 2002.

Changes in Bunch Field Slough by Year

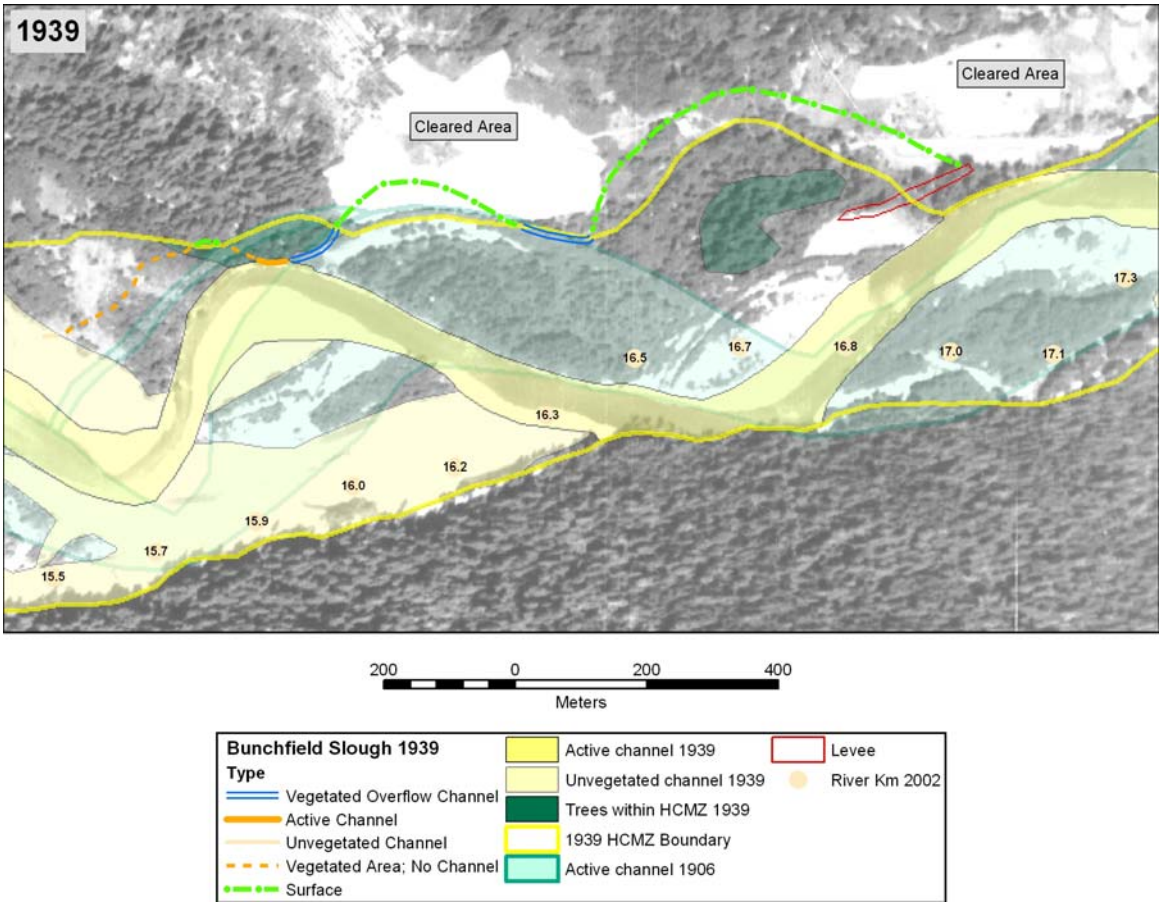

Figure 2. In 1906 (light green channel) and in 1939, none of Bunch Field Slough was present. A couple of short (100 to 200 m long) sections were present as part of the main Quinault River channel. However, most of the future Bunch Field Slough was outside of the channel zone in these years. The levee that is present by 1972 at the upstream end of the slough is shown as a reference point. The NPS Bridge near RK 17.5 had not yet been built in 1939. The cleared areas on the north side of the river are persistent through 2002, and may have influenced the migration of the Quinault River to the north and the resulting formation of Bunch Field Slough.

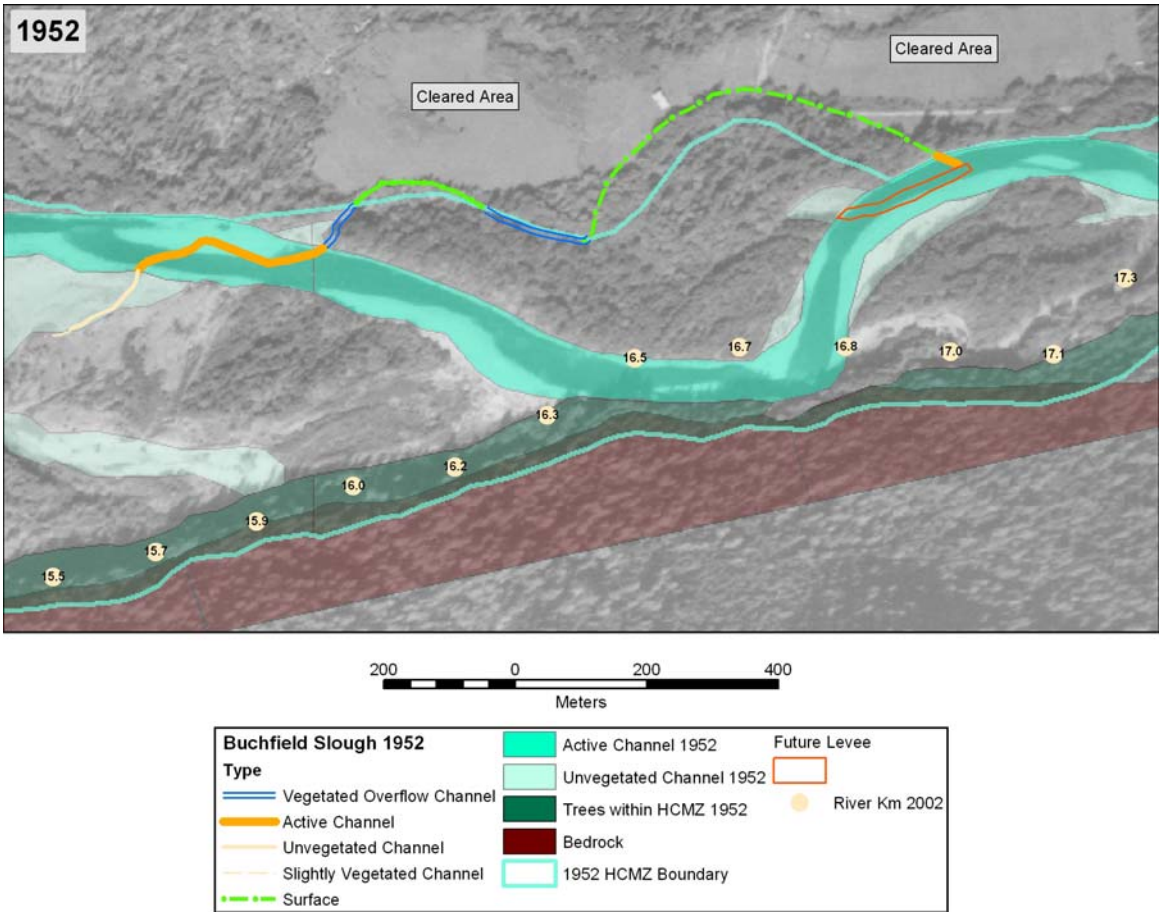

Figure 3. By 1952, the meander in the Quinault River channel between RK16.7 and RK 17.3 had moved outward by eroding into the bounding surface that was present in 1939. The recently excavated channel will become part of Bunch Field Slough. Similarly, the Quinault River between RK 15.5 and RK 16.0 had cutoff a meander and flowed in a north path that had eroded the 1939 bounding surface. This path becomes the downstream about 500 m of Bunch Field Slough. The NPS Bridge near RK 17.5 had not yet been built in 1952.

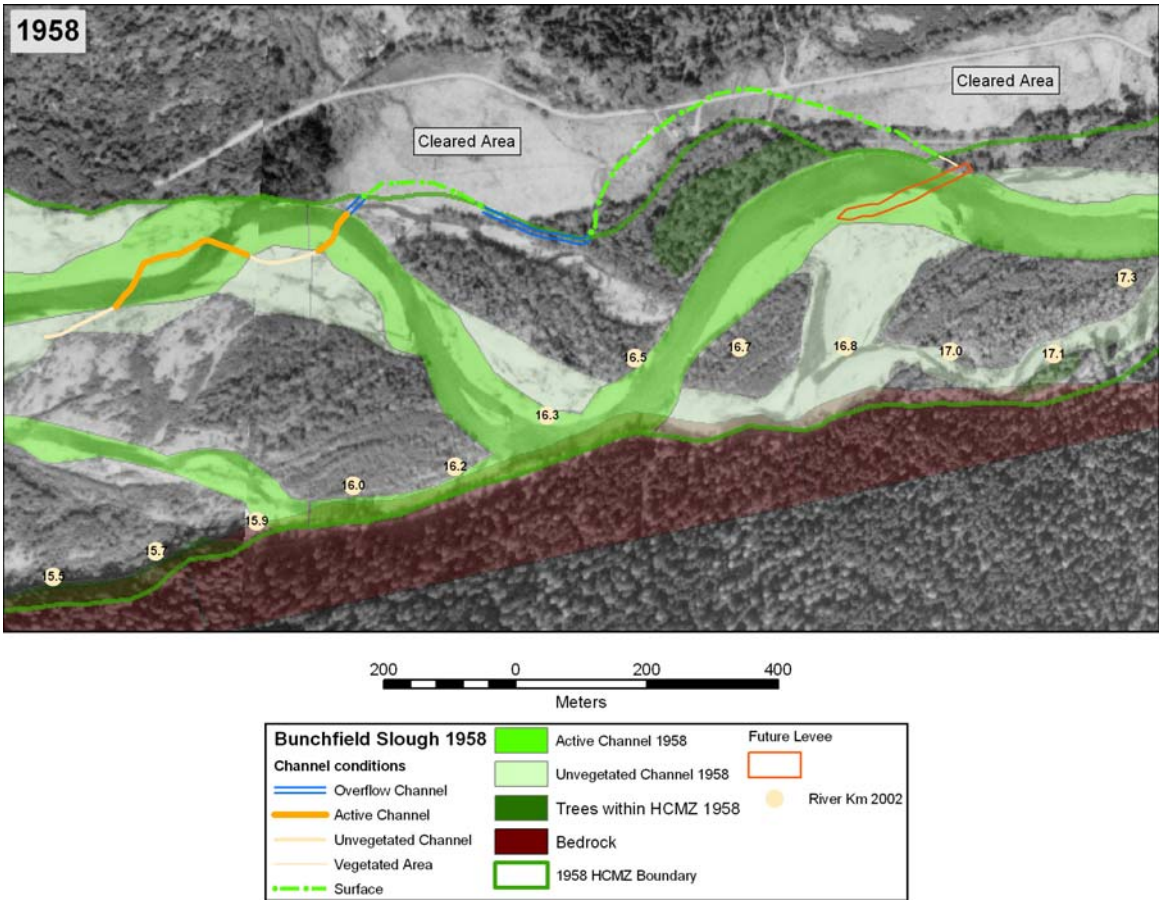

Figure 4. By 1958, the upstream meander in this section of the river had moved outward and downstream to near RK 16.5. The surface at the upstream end of Bunch Field Slough had eroded laterally, but not to the position of the future slough. At least half of the Bunch Field Slough still crossed the surface bounding the channel zone in 1958. A new overflow or side channel was present between RK 16.0 and RK 16.5. Part of this channel will become a section of Bunch Field Slough. The downstream about 600 m of the future Bunch Field Slough was part of the active and unvegetated channels of the Quinault River. This was the first year that the road and bridge near RK 17.5 are visible on the aerial photographs.

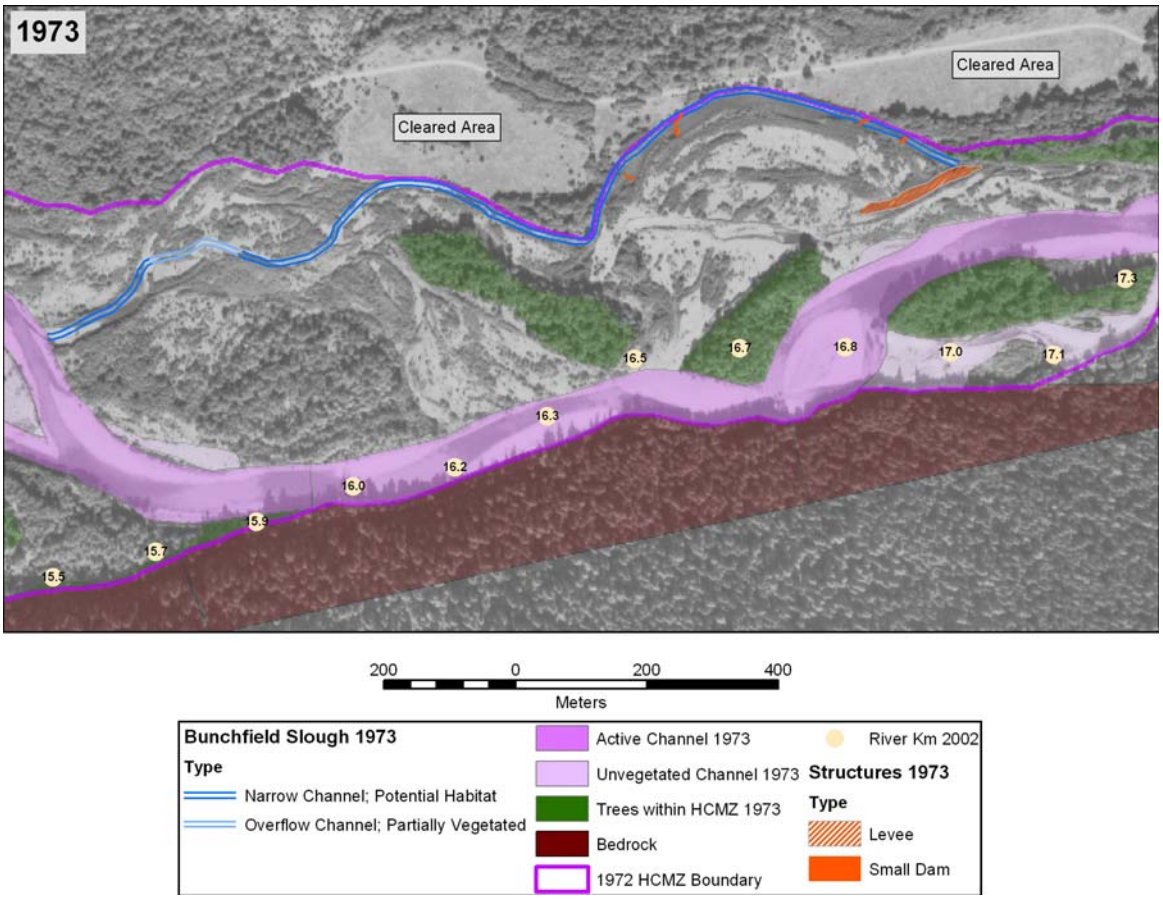

Figure 5. By 1973, most of Bunch Field Slough had been excavated, presumably by the active channel of the Quinault River. The slough had been abandoned as a main flow path and was a partially vegetated side channel. In addition, an earth levee had been built at the upstream end of the slough. The levee was likely at least partly responsible for the shift in the position of the main Quinault River channel to the south between RK 17.0 and RK 17.2. There were also four structures across Bunch Field Slough downstream of the levee. These appear to have been retention structures, although B. Armstrong (QIN, written commun., 2003) reported beaver dams that coincide with the location of two of these structures. The Quinault River channel flowed along the south side of the valley. Its migration to the south was restricted by bedrock.

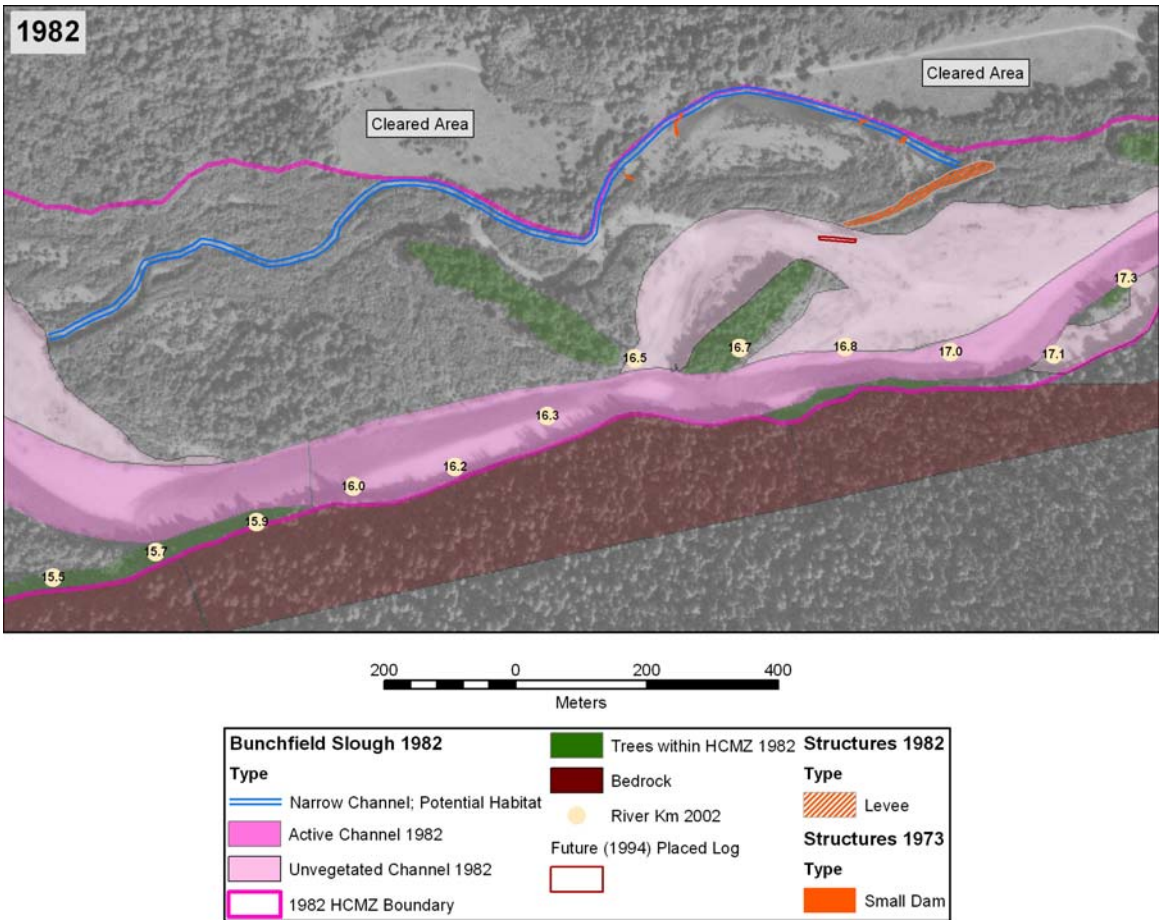

Figure 6. By 1982, the active channel of the Quinault River had straightened between RK 15.7 and RK 17.1 along the south edge of the valley. However, an unvegetated overflow channel had developed between RK 16.5 and RK 17.4, and removed some of the vegetation that was present in this area in 1973. Bunch Field Slough remained intact because of the levee at its upstream end. The configuration of the unvegetated overflow channel suggests that flow would have gone into Bunch Field Slough had the levee not been present. The position of a placed log at the downstream end of the levee that is visible in 1994 is shown for reference. The retention structures or beaver dams were still visible in 1982.

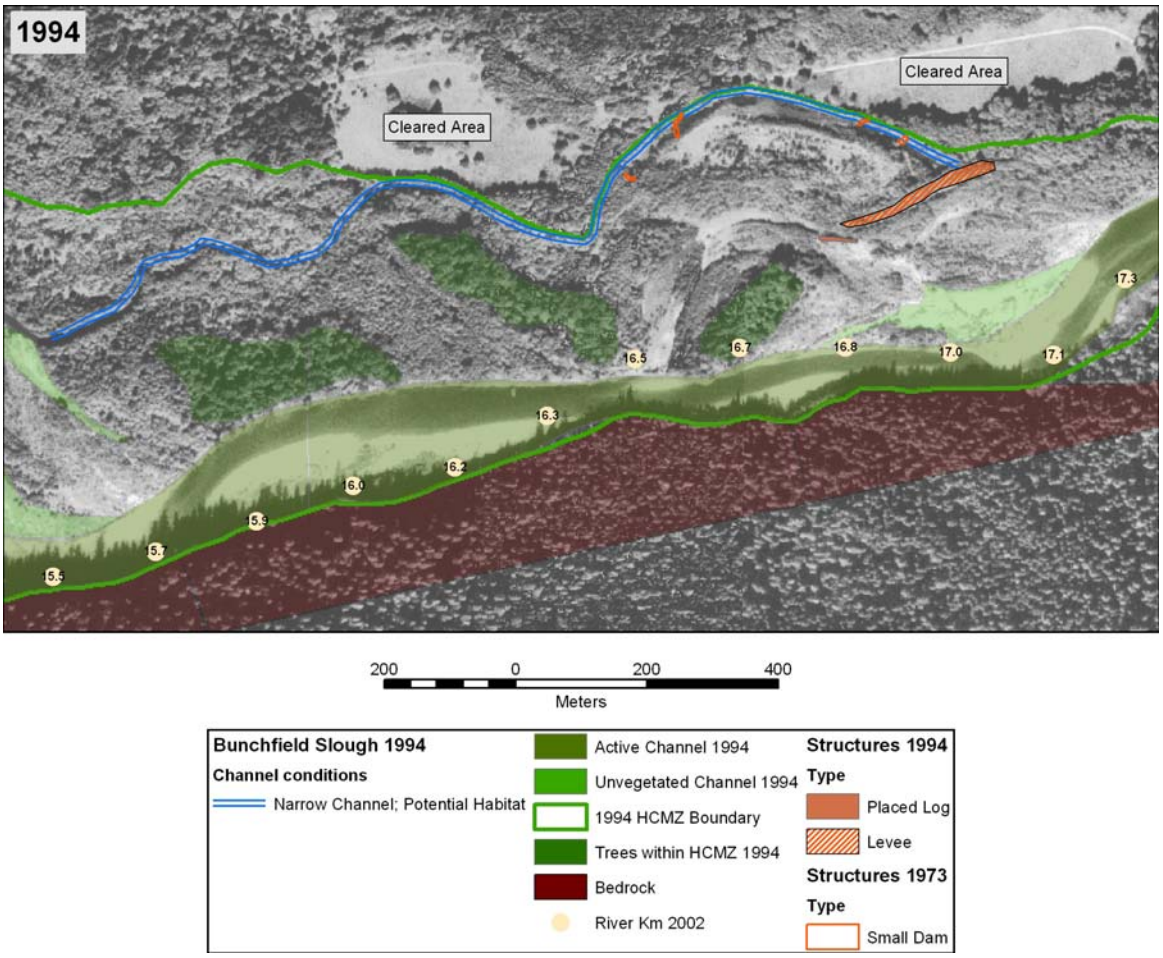

Figure 7. By 1994, the Quinault River channel still flowed along the south edge of the valley. Bunch Field Slough appears to be as it was in 1973. A log has been placed at the downstream end of the earthen levee, and was likely used to direct flow into the channel that it aligned with. The downstream end of the levee appears to have been lengthened and widened. The retention structures or beaver dams are difficult to distinguish on the photographs without knowing that they were present. However, the characteristics of Bunch Field Slough (e.g., vegetation, channel width, presence or absence of water) changed at these points. Vegetation was beginning to fill in the downstream cleared area between RK 16.0 and RK 16.5 outside of the historical channel migration zone.

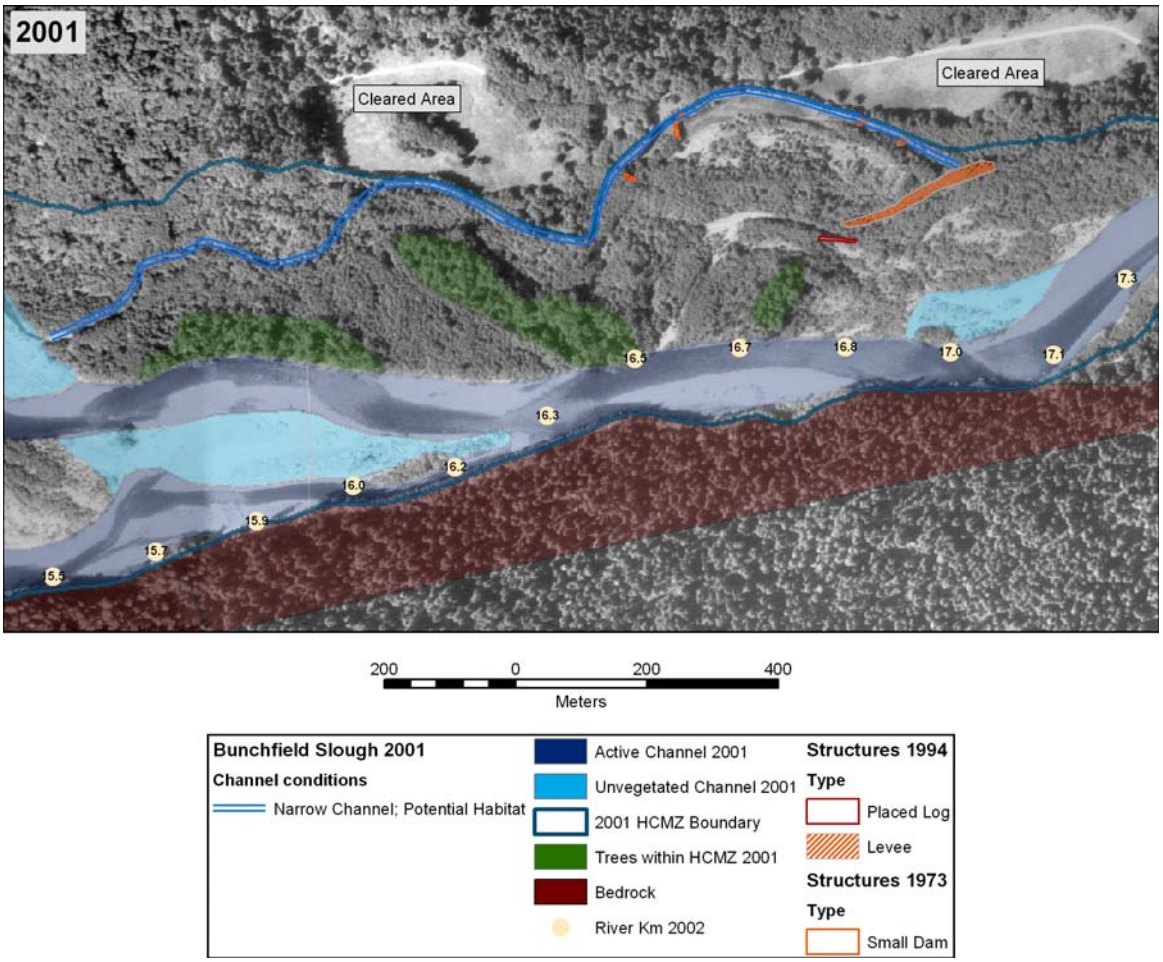

Figure 8. By 2001, the Quinault River channel and Bunch Field Slough appear to be much as they were in 1998. The area within the channel migration zone and north of the Quinault River had denser and larger vegetation. The earthen levee was still visible. Linear vegetation surrounded the placed log, which is no longer recognizable as a log. Similarly, the retention structures or beaver dams can only be recognized by changes in the characteristics of Bunch Field Slough.

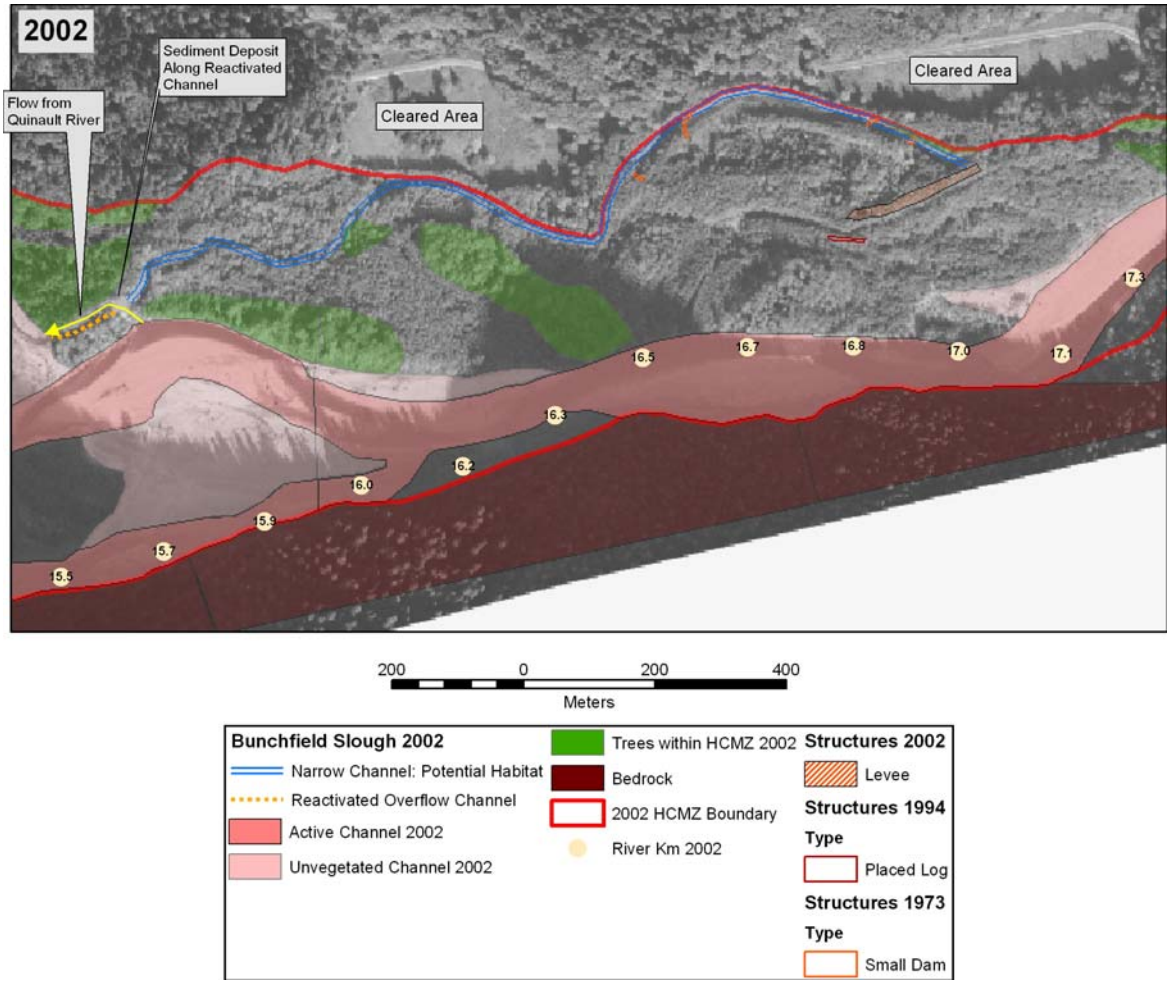

Figure 9. By 2002, the main difference in the Quinault River channel and Bunch Field Slough was between RK 15.5 and RK 16.2. The Quinault River had split into two flow paths. The north path had meandered close to the downstream end of the slough, and during a large flow, a flow path of the Quinault River went to the northwest and occupied the downstream about 130 m of the slough (shown by the yellow arrow). At a near-perpendicular bend in the flow path, where the Quinault River high flow encountered Bunch Field Slough, a sediment deposit is visible on the aerial photographs.

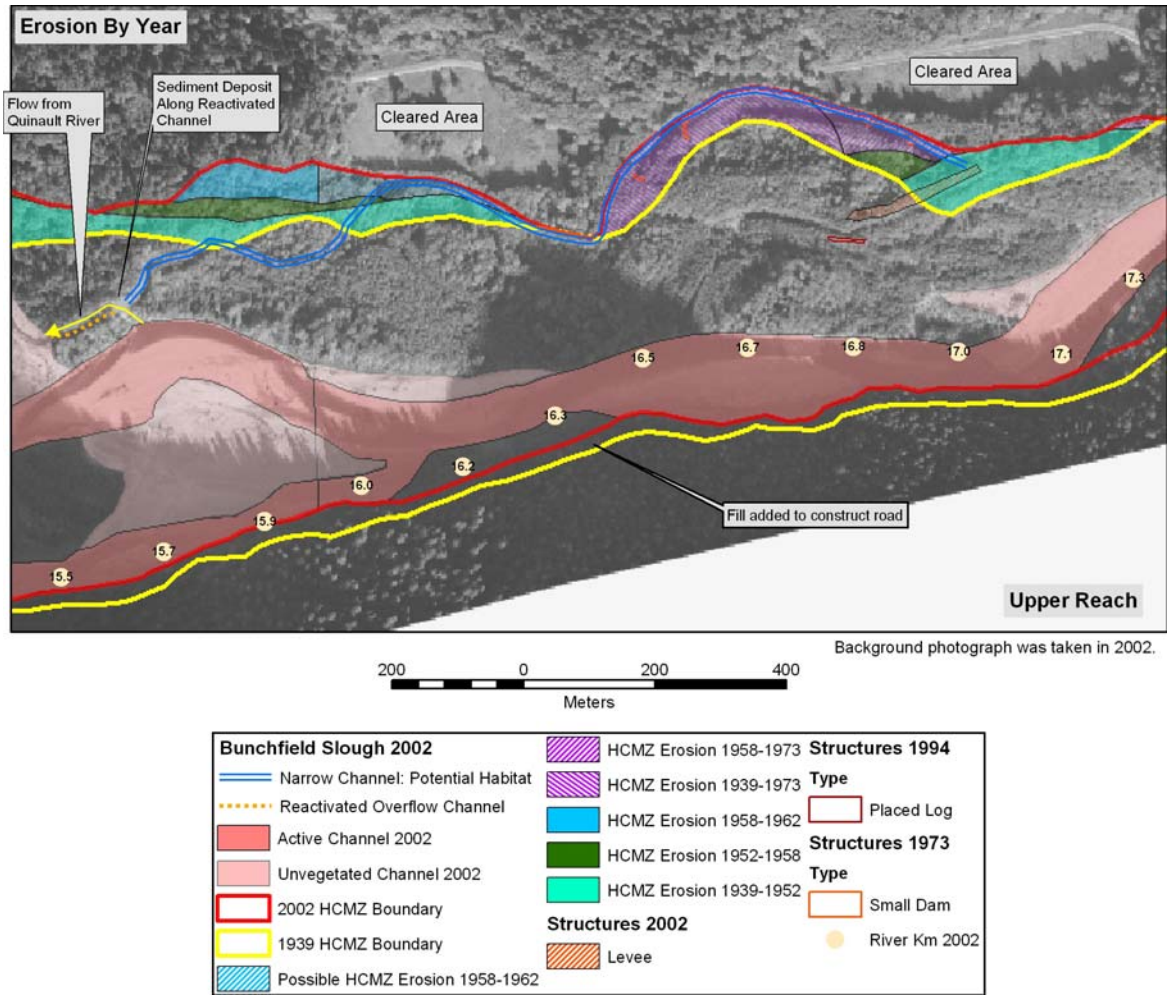

Figure 10. Bank erosion between 1939 and 1973 formed the channel that became Bunch Field Slough. Several areas are labeled as possible erosion because the time interval is unclear. The 1962 and 1998 aerial photographs do not extend upstream to Bunch Field Slough.

History and Geomorphology of Fletcher Slough and Lower Joe Culvert Creek, 1906 through 2002

Fletcher Slough, a side channel in the Quinault River system, is located on the south side of the Quinault River valley between RK 13.8 and RK 14.4 (Figure 1). It is opposite from a bedrock knob on the north side of the valley. Joe Culvert Creek is a tributary that enters the Quinault River near RK 14.5 on the north side of the valley (Figure 1). North Slough is on the north side of the valley just downstream from Joe Culvert Creek, and Bunchfield Slough is just upstream of Joe Culvert Creek between RK 15.7 and 17 (Figure 1).

Lower Joe Culvert Creek is a habitat area that includes the downstream about 200 m of the Joe Culvert Creek tributary channel and about 200 m of an old Quinault River channel, where the tributary enters the Quinault River system. Joe Culvert Creek tributary flows along a remnant of a Pleistocene surface that is preserved along the east side of the bedrock knob north of the Quinault River (Figure 1). Lower Joe Culvert Creek habitat area crosses the HCMZ boundary. The upstream half of the habitat area is outside of the HCMZ; the downstream half is within the HCMZ and has been affected by channel processes related to the Quinault River.

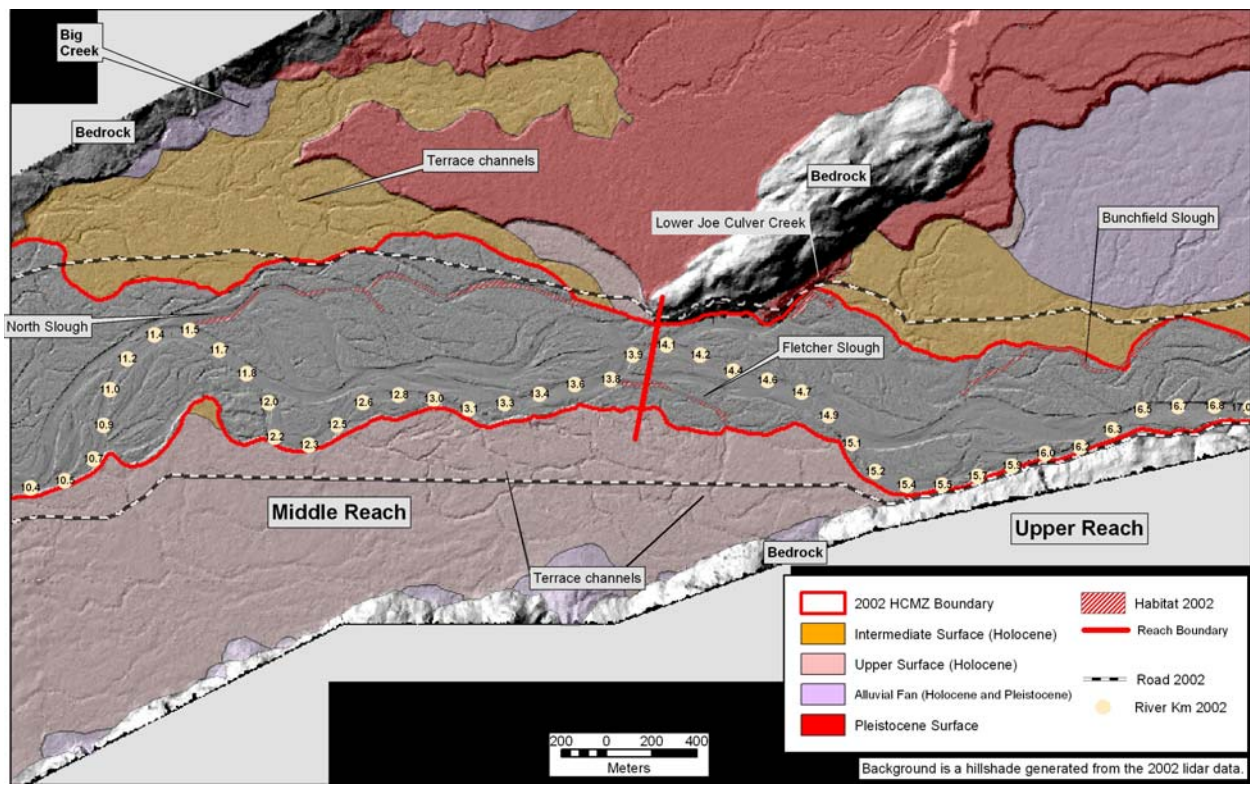

Figure 1. Fletcher Slough is located between RK 13.8 and RK 14.4 along the south side of the historical channel migration zone (HCMZ). Lower Joe Culvert Creek habitat includes the downstream part of a tributary that enters the Quinault River near RK 14.5 and the part of an old Quinault River channel where the tributary enters the Quinault

River system. Consequently, Lower Joe Culvert Creek habitat is both within and outside of the CMZ. River kilometers are from the low-flow channel at the time of a river survey in 2002.

Terrace Channels on the Upper Surface South of the Quinault River

Terrace channels are present on the Upper Surface south of the Quinault River from upstream of Fletcher Slough (near RK 15.4) and to downstream of North Slough (near RK 10.5) (Figure 1). The terrace channels form a complex network, which is connected to the Quinault River at both upstream and downstream ends. However, not all of the channels are connected directly to the Quinault River. The terrace channels are deeply dissected (up to about 5 m) to about the elevation of the present main Quinault River channel (Figure 2). Alternating gravelly alluvium (channel deposits) and fine-grained silt and sand beds (floodplain deposits) are exposed in the banks of the terrace channels (Figure 2). Wood is common in the terrace channels. Root wads have created scour pools in the channel beds. Large single logs or jams form hydraulic controls. At times of low flow in the Quinault River, water is still present in the scour pools. Flow in the terrace channels is fed from both the surface connections to the river and groundwater. The Upper Surface adjacent to the terrace channels has vegetation of various ages, including areas of mature forest. The terrace channels provide sockeye habitat as indicated by observed redds (B. Armstrong, QIN, 2004, oral commun.). Some of the terrace channels have been impacted by human activities. For example, a bridge with a culvert is present across a terrace channel near Fletcher Creek.

Figure 2. Bank exposure along one of the terrace channels on the south side of the Quinault River between RK 10.5 and RK 15.4. Note the depth of the incision and the alternating gravelly channel deposits and fine-grained floodplain deposits exposed in the bank. Photograph taken by J.Bountry (Bureau of Reclamation, Denver, 2004).

Changes in Fletcher Slough and Lower Joe Culvert Creek by Year

The following maps (Figures 3 through 12) show the history of formation and destruction of potential habitat in the area of Fletcher Slough and the downstream part of Lower Joe Culvert Creek between 1906 and 2002. Figure 13 shows the relationship between erosion of the HCMZ boundary and habitat formation and destruction for this time interval. Figure 14 shows the upstream part of Lower Joe Culvert Creek and discusses possible changes in habitat characteristics during the last few years.

1939 and Earlier

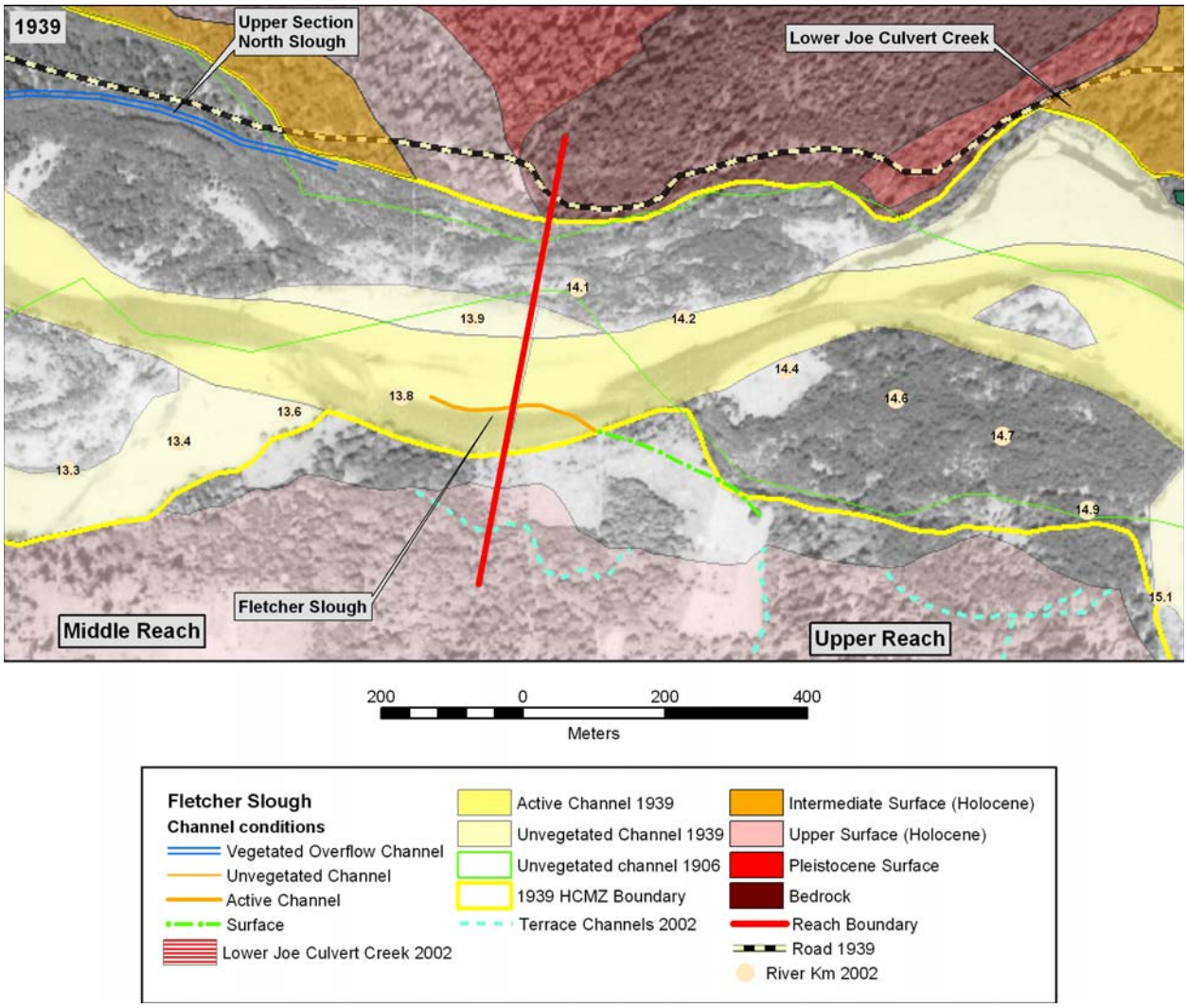

Figure 3. The area between RK 13.3 and RK 15.0 as it looked in 1939. The 1906 (green outline) unvegetated channel was north of Fletcher Slough, which did not appear to have been present in these years. In 1906 and 1929, the area of the slough was part of the bank that included buildings, which indicates that the area was likely outside of the historical channel migration zone.

By 1939, the downstream about 250 m of Fletcher Slough had been excavated and was part of the active channel of the Quinault River. The upstream half of Fletcher Slough had not yet been excavated and was still part of a surface outside of the historical channel migration zone. The surface in the area of the future Fletcher Slough had been cleared of vegetation by 1939. The presence of buildings on this surface in 1906 and 1929 suggests that the surface was cleared much earlier.

The downstream part of Lower Joe Culvert Creek (within the HCMZ) was part of the unvegetated channel in 1939, so the future habitat channel had already been excavated by that time. The active channel between about RK 14.5 and RK 15.0 was near the center of the 1939 CMZ. The downstream part of Lower Joe Culvert Creek did not appear to be part of the unvegetated channel in 1906, but may have been part of the unvegetated channel of the Quinault River by 1929.

1952

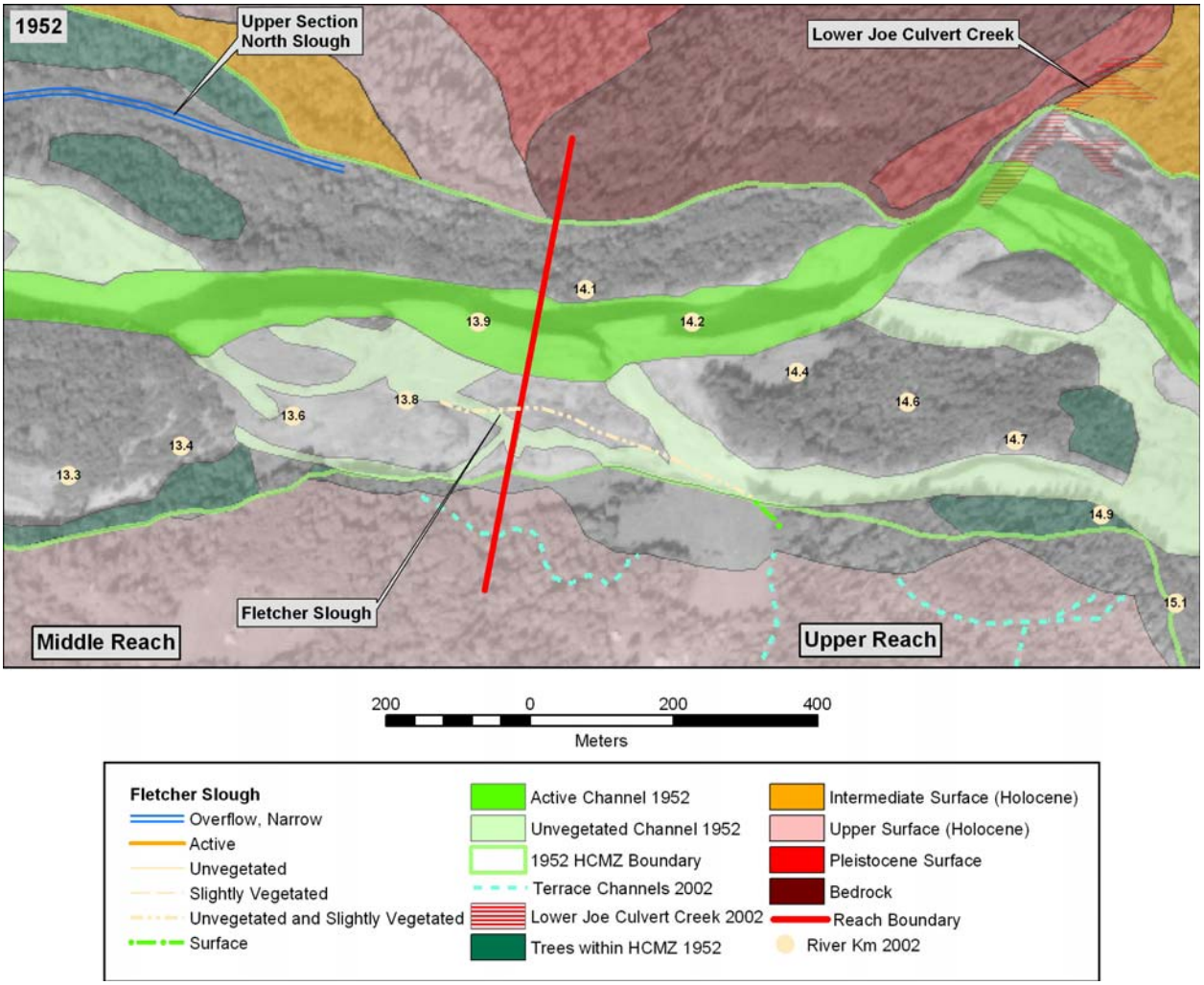

Figure 4. By 1952, most of Fletcher Slough had been excavated by the Quinault River. Only about 50 m at the upstream end did not yet exist and was in an area of the still-cleared surface. Most of Fletcher Slough was in either an unvegetated channel or a slightly vegetated channel of the Quinault River. No potential habitat appeared to exist in 1952.

In 1952, the downstream about 100 m of the downstream part of Lower Joe Culvert Creek was part of the active channel of the Quinault River, because the active channel between RK 14.5 and RK 15.0 had meandered to the north between 1939 and 1952. The upstream about 100 km of the downstream part of Lower Joe Culvert Creek is a sparsely vegetated channel of the Quinault River. This channel was part of the unvegetated channel in 1939, but appears to carry little flow by 1952.

The active and unvegetated channels of the Quinault River between about RK 14.5 and at least RK 15.0 had three paths in 1939. These paths are separated by vegetated islands.

1958

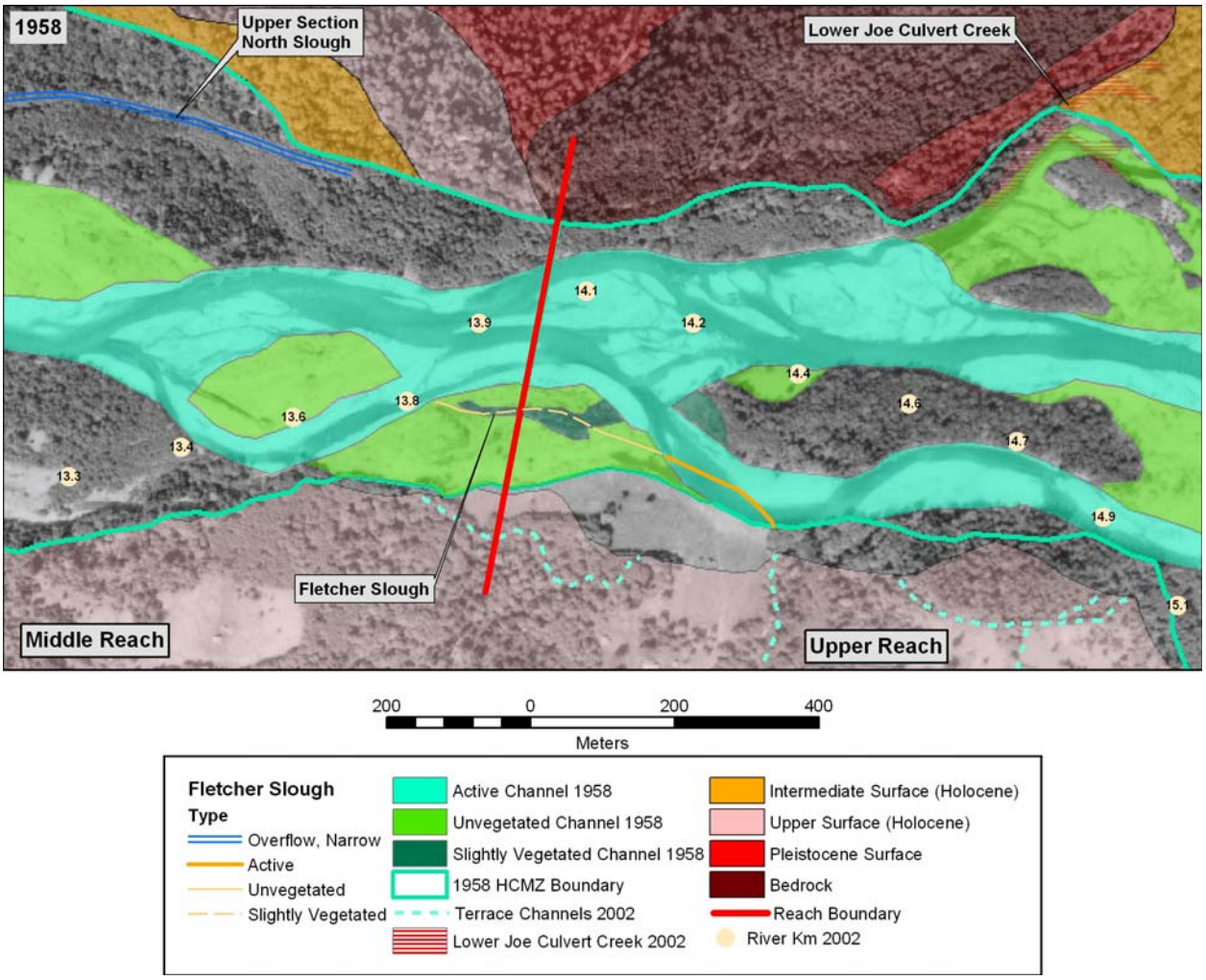

Figure 5. By 1958, the CMZ boundary had expanded or eroded to include all of Fletcher Slough. The upstream about 250 m was part of the active channel of the Quinault River. The downstream half of Fletcher Slough was either within an unvegetated channel or a slightly vegetated channel of the Quinault River.

By 1958, the entire downstream part of Lower Joe Culvert Creek was part of the unvegetated channel of the Quinault River, as it was in 1939. The active channel of the Quinault River in 1958 occupied the middle and left paths of the three channel paths that were present in 1952.

1962

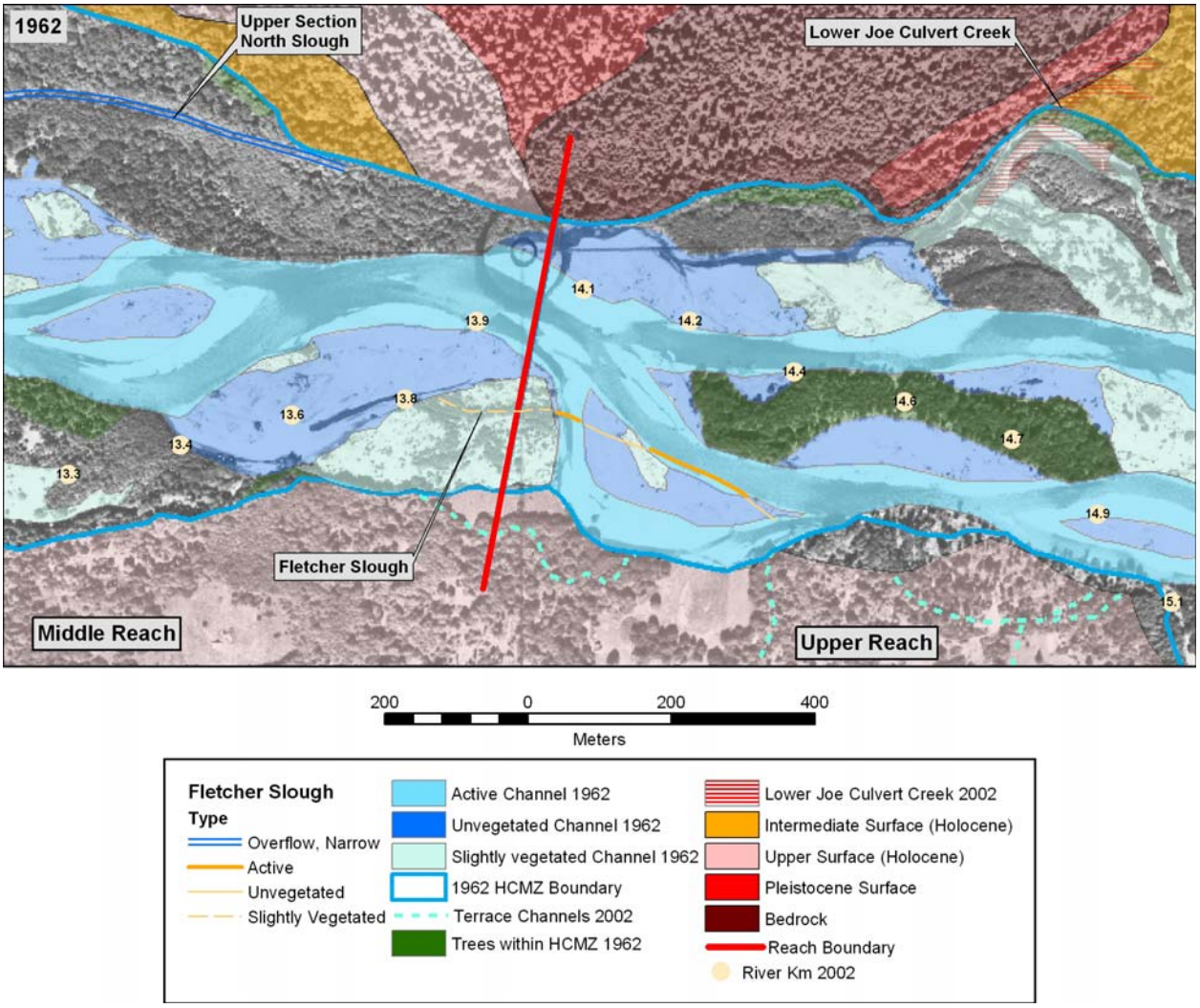

Figure 6. By 1962, the downstream about 150 m of Fletcher Slough was across a slightly vegetated channel of the Quinault River. A small channel appeared to have coincided with this section of the slough and may have provided initial conditions for habitat. The rest of Fletcher Slough was part of either the active channel or unvegetated channel of the Quinault River and did not appear to be potential habitat because of the high flows in these channels.

By 1962, the downstream part of Lower Joe Culvert Creek was part of a sparsely vegetated channel of the Quinault River, suggesting that this channel has less or less frequent flows than it did in 1958. The right (north) path of the active channel of the Quinault River was straighter and closer to the center of the CMZ than it was in 1958 (and, consequently, farther away from the downstream part of Lower Joe Culvert Creek).

1973

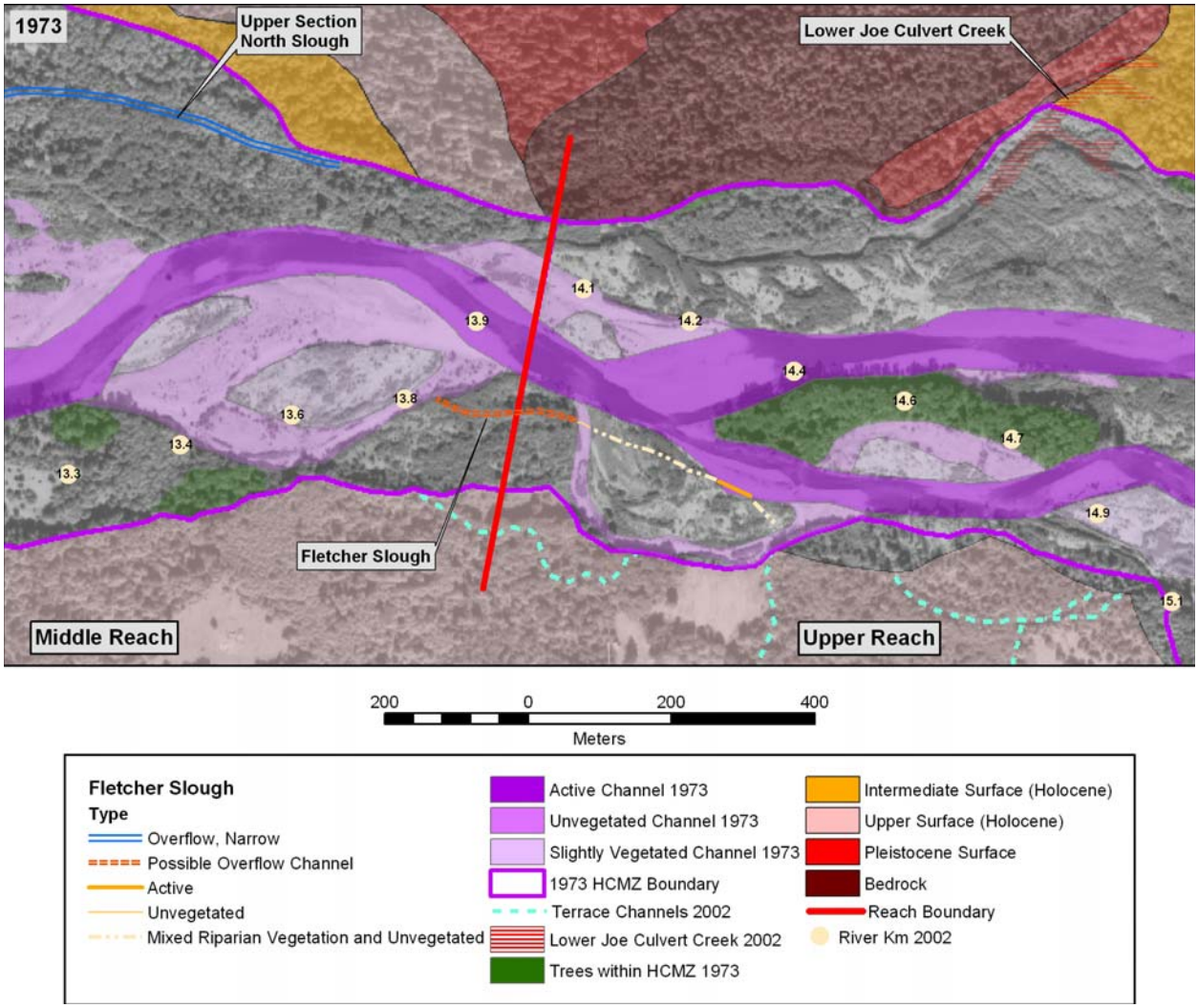

Figure 7. By 1973, the downstream about 150 m of Fletcher Slough flowed across a surface that had thicker and larger riparian vegetation than it did in 1962. This section of the slough may have been potential habitat. Most of the upstream section was across a surface with only scattered vegetation. The exceptions were two short sections: one near the upstream end that was within the active channel of the Quinault River and one near the middle of the slough that was crossed by an unvegetated channel of the Quinault River. By 1973, the downstream part of Lower Joe Culvert Creek appeared as a narrow channel through a vegetated surface. This channel does not appear to have had a direct upstream connection to the Quinault River. The creek appears to have continued downstream of its mapped extent in 2002 as a narrow channel that joined the Quinault River near RK 14.0. The narrow channel may have been connected to the Quinault River at higher flows, because a partially vegetated area was present between the two channels. The entire narrow channel had a length of about 700 m. The narrow channel downstream of the downstream part of Lower Joe Culvert Creek section was part of the unvegetated channel in 1962, and so was excavated by that time.

1982

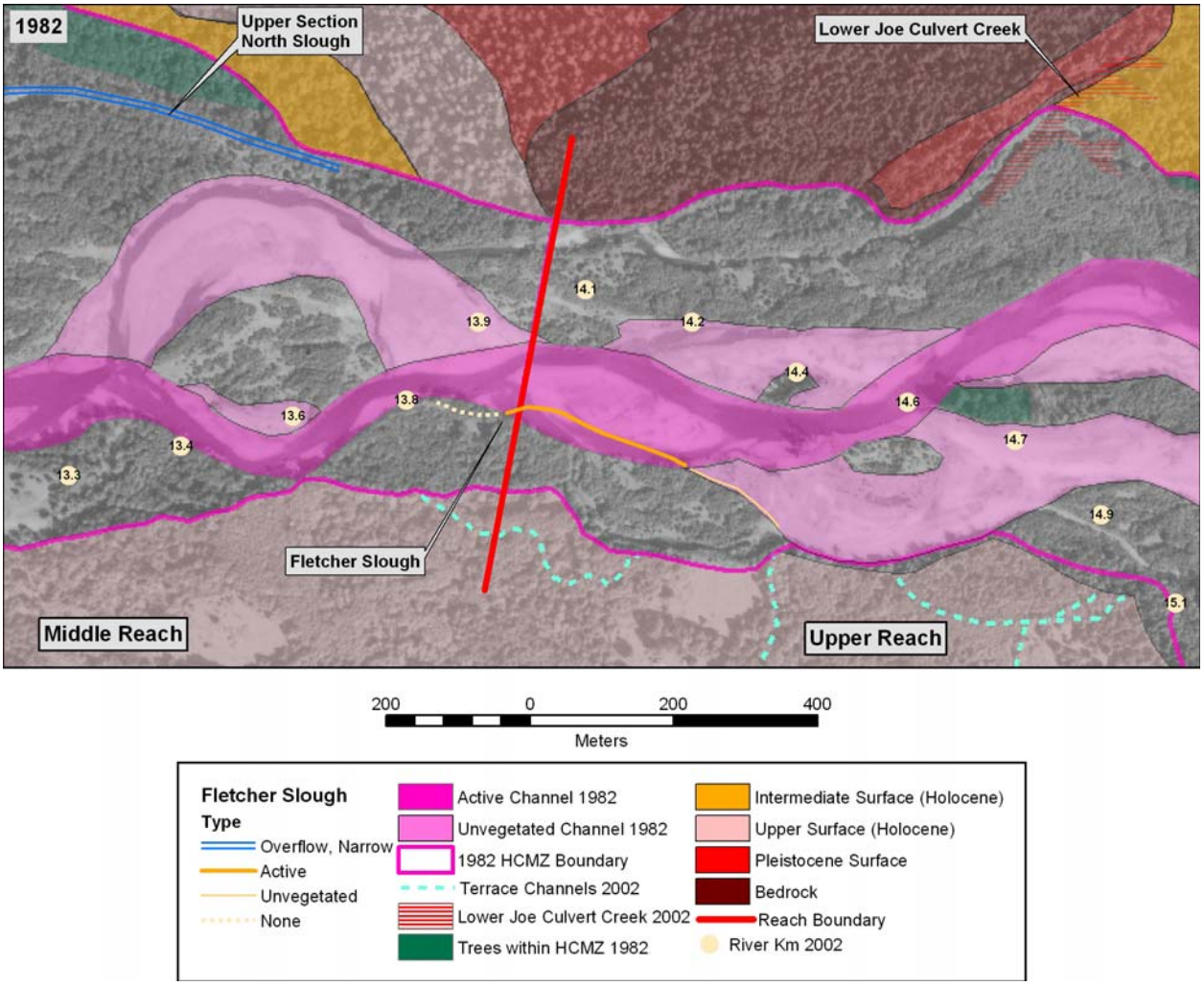

Figure 8. By 1982, the downstream section that was possible habitat at Fletcher Slough in 1973 had shortened to a little more than 100 m. The rest of the Fletcher Slough was part of the active channel or the unvegetated channel of the Quinault River and did not appear to provide potential habitat.

The configuration of the downstream part of Lower Joe Culvert Creek was nearly the same in 1982 as it was in 1973. The narrow channel that extends downstream of the 2002 extent of Lower Joe Culvert Creek has extended downstream about 100 m, for a total length of about 800 m. The partially vegetated area between the narrow channel and the Quinault River has become mostly filled with vegetation since 1973.

By 1982, the active channel of the Quinault River had moved to the south between RK 14.5 and RK 15.0, and had eroded part of the vegetated island that had formed between the central and south paths before 1952. The smaller island to the north, closer to Lower Joe Culvert Creek, has become part of the vegetated area within the HCMZ.

1994

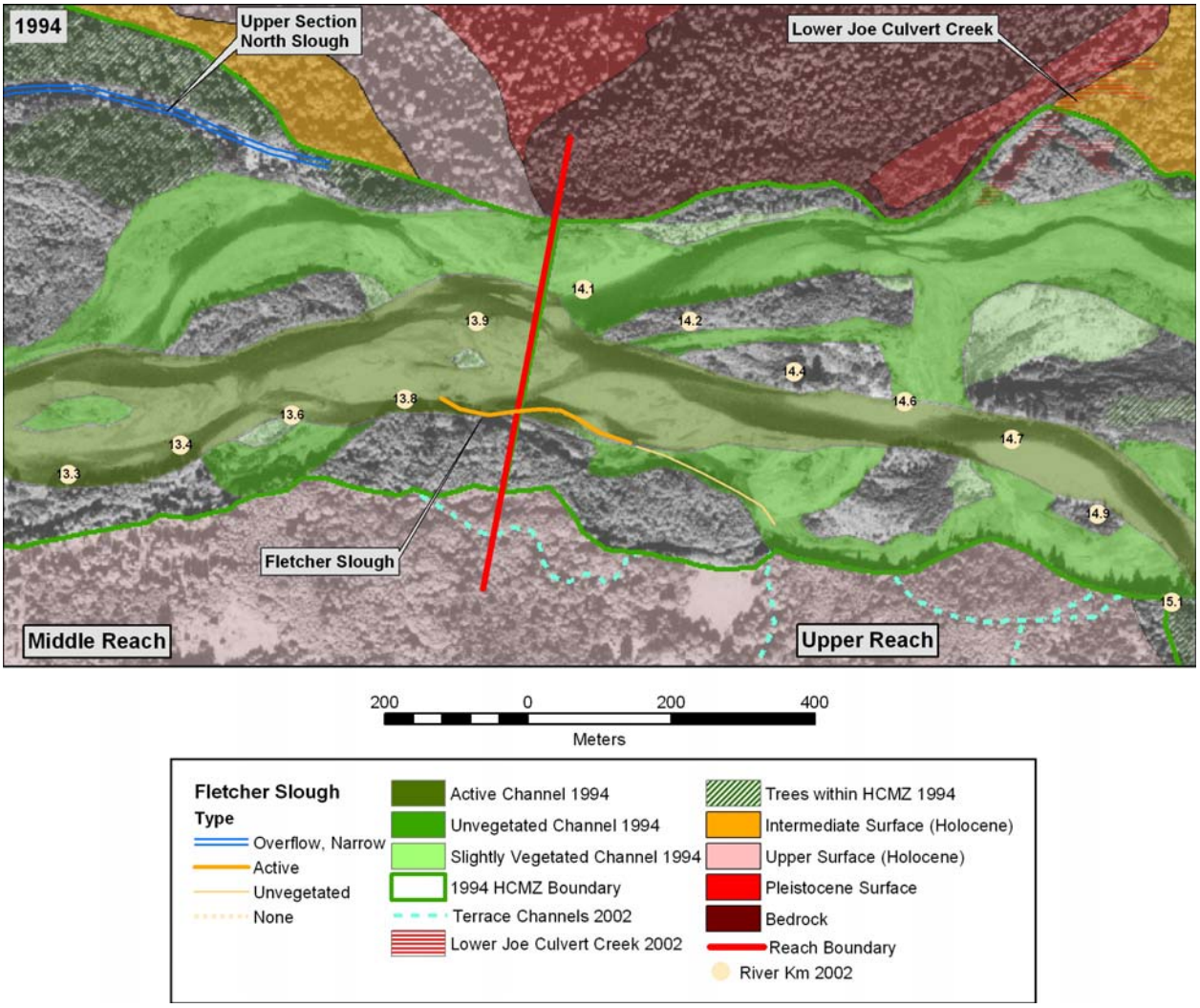

Figure 9. By 1994, the entire Fletcher Slough was within either the active channel or the unvegetated channel of the Quinault River. No potential habitat appears to be present at this time.

By 1994, the unvegetated channel of the Quinault River between about RK 14.5 and RK 15.0 has split flow. The north path extended into the downstream about 35 m of the downstream part of Lower Joe Culvert Creek. Upstream of this 35-m-long section, the downstream part of Lower Joe Culvert Creek was still a narrow channel through a vegetated surface. This part of Lower Joe Culvert Creek in 1994 was a secondary or side channel that was connected to the Quinault River at both its upstream and downstream ends.

1998

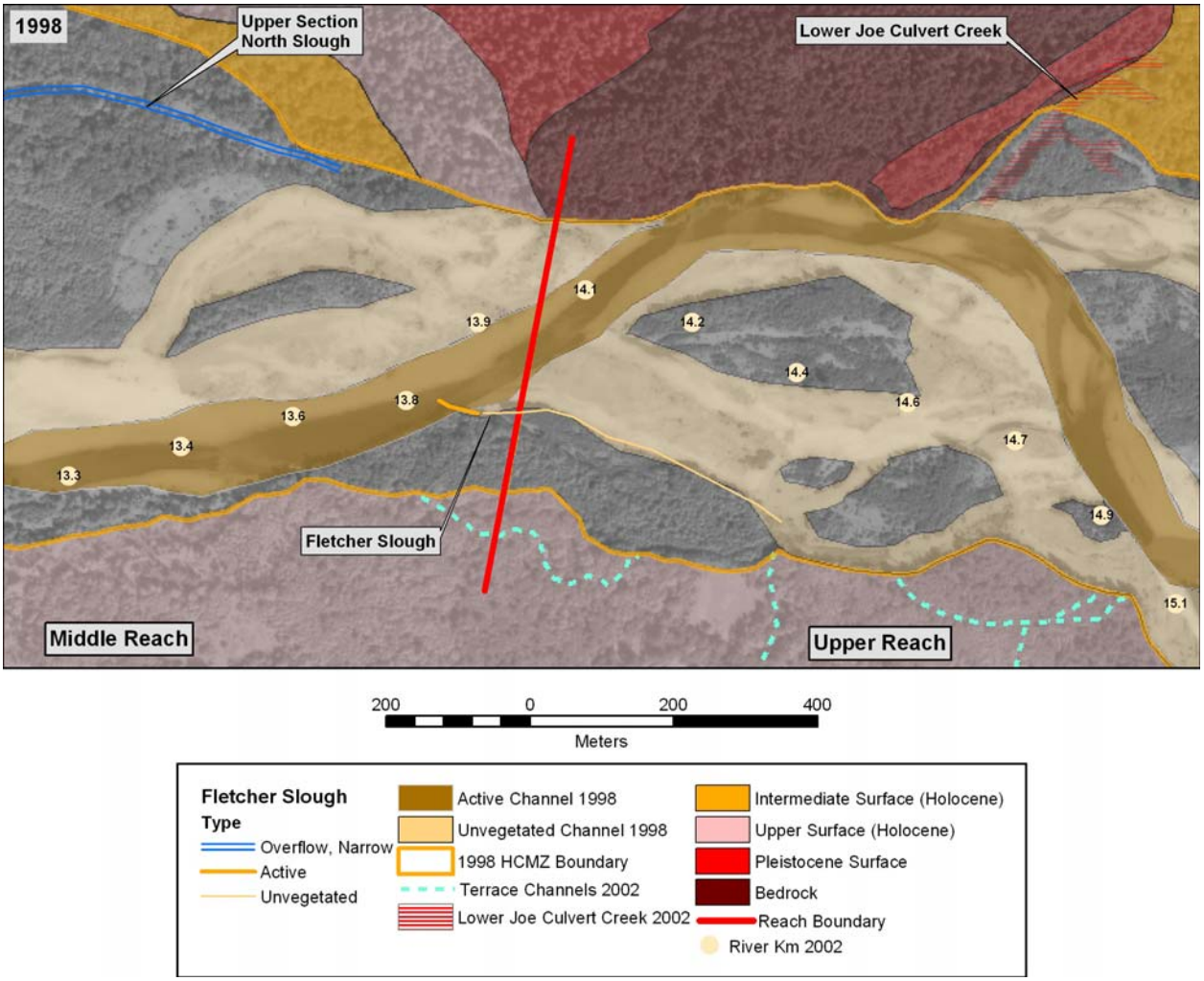

Figure 10. The section of active channel that coincided with Fletcher Slough in 1994 was mostly unvegetated channel by 1998. However, the entire length of the slough was still within either the unvegetated channel or active channel of the Quinault River. Consequently, no potential habitat appeared to be present at this time.

By 1998, the active channel of the Quinault River had meandered to the north in the area of the downstream part of Lower Joe Culvert Creek. This part of Lower Joe Culvert Creek was a narrow channel through a vegetated surface. The channel may have been slightly wider than it was in 1994. This part of Lower Joe Culvert Creek in 1998 was a secondary or side channel that was connected to the Quinault River at both its upstream and downstream ends.

2001

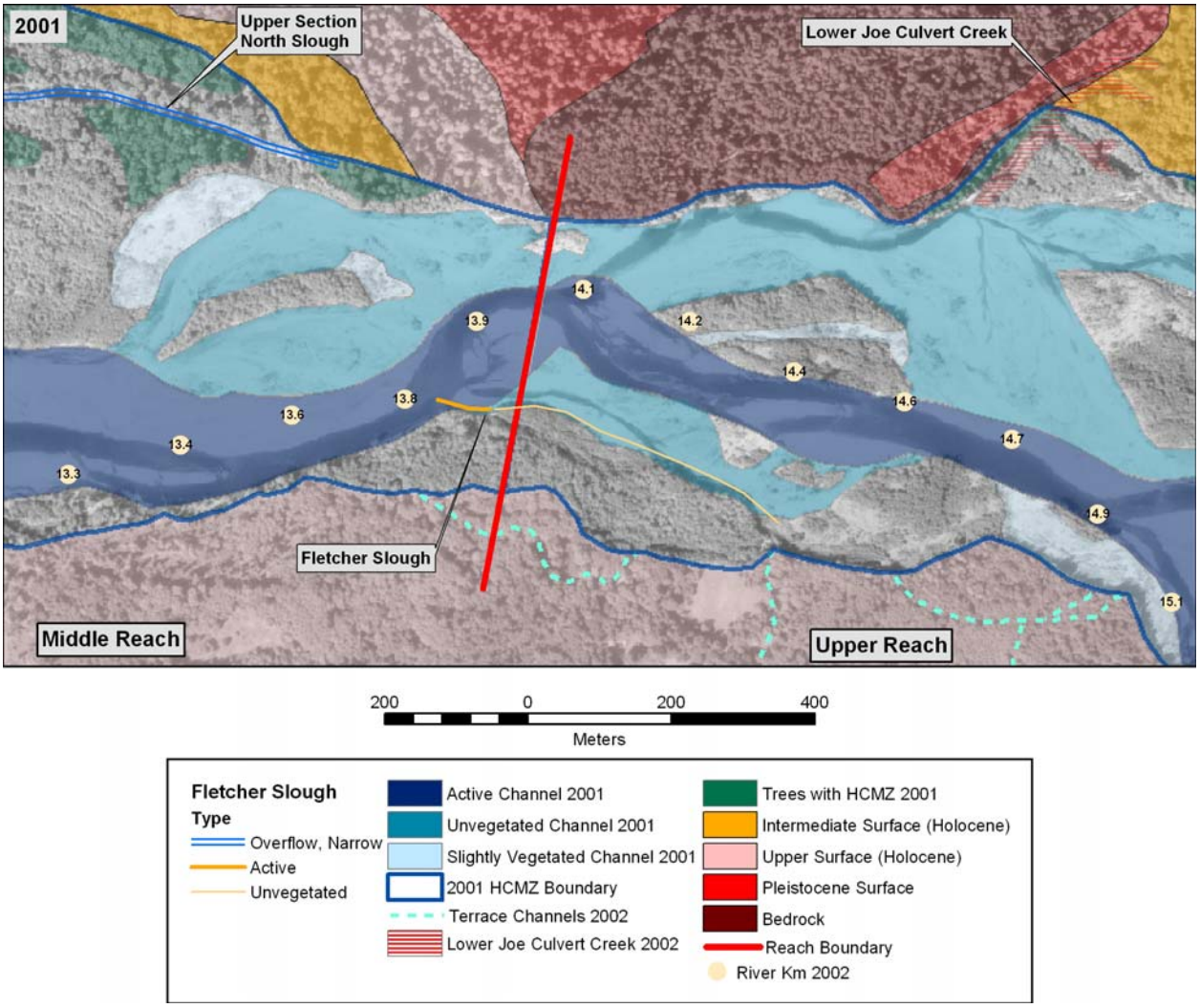

Figure 11. Although the unvegetated channel that coincided with Fletcher Slough appeared to have less flow in 2001 than it did in 1998, the slough was still within either the active or unvegetated channel in 2001. No potential habitat appeared to be present.

In 2001, the downstream part of Lower Joe Culvert Creek remained a narrow channel through a vegetated area. The active channel of the Quinault River had moved to the south, and was no longer at the downstream end of the creek. The downstream part of Lower Joe Culvert Creek in 2001 was a secondary or side channel of the Quinault River and was connected to the river at both its upstream and downstream ends.

2002

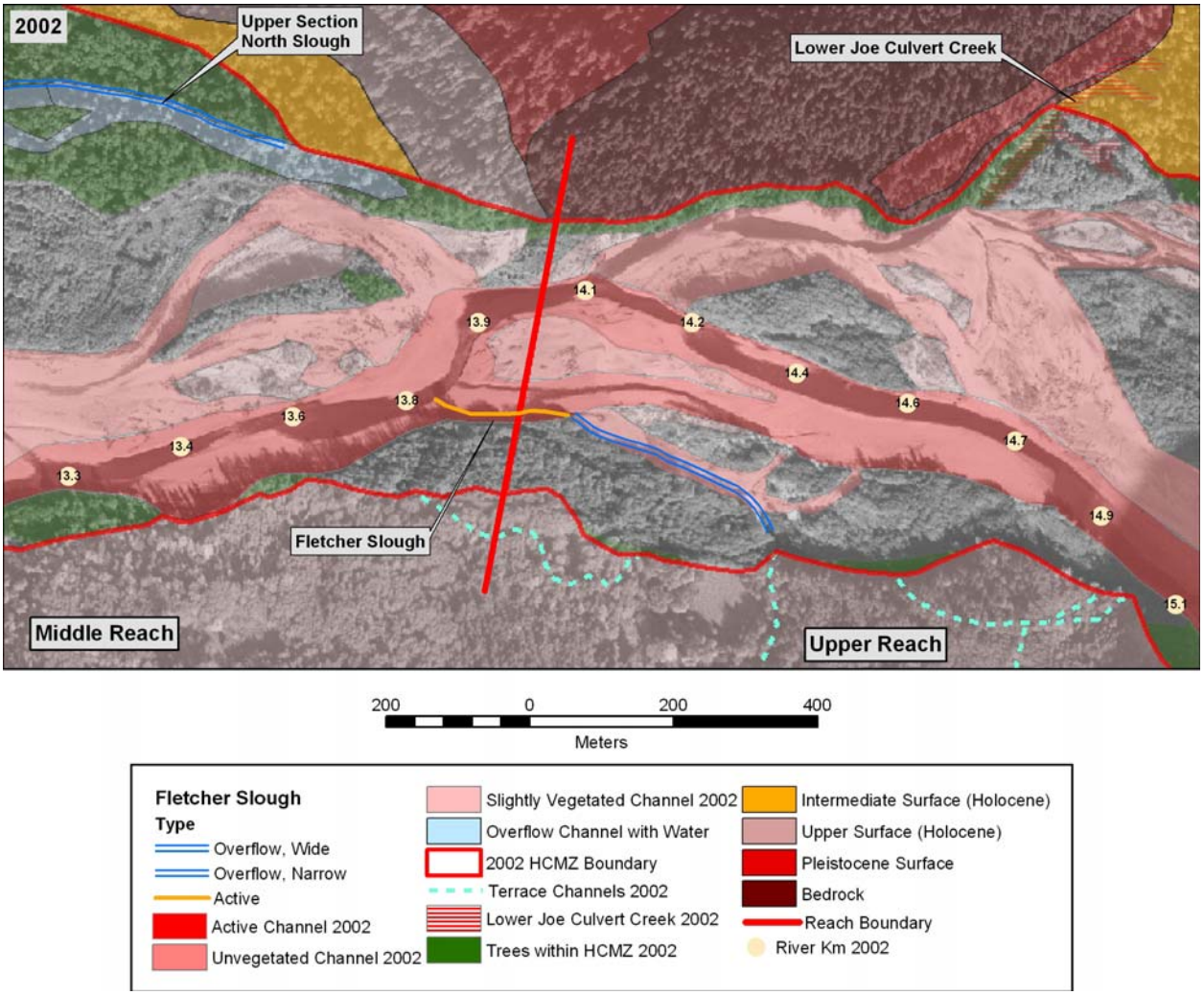

Figure 12. By 2002, the upstream about 500 m of Fletcher Slough appeared to be within a relatively wide overflow channel through riparian vegetation. (The active channel had abandoned this path.) This section of the slough appeared to be potential habitat. Water is visible in the channel in 2002. The downstream about 100 m of Fletcher Slough was still part of the active channel of the Quinault River in 2002, and did not appear to have been potential habitat.

The downstream part of Lower Joe Culvert Creek in 2002 had a configuration similar to its configuration in 2001. This part of Lower Joe Culvert Creek in 2002 was a secondary or side channel of the Quinault River and was connected to the river at both its upstream and downstream ends.

Erosion by Year

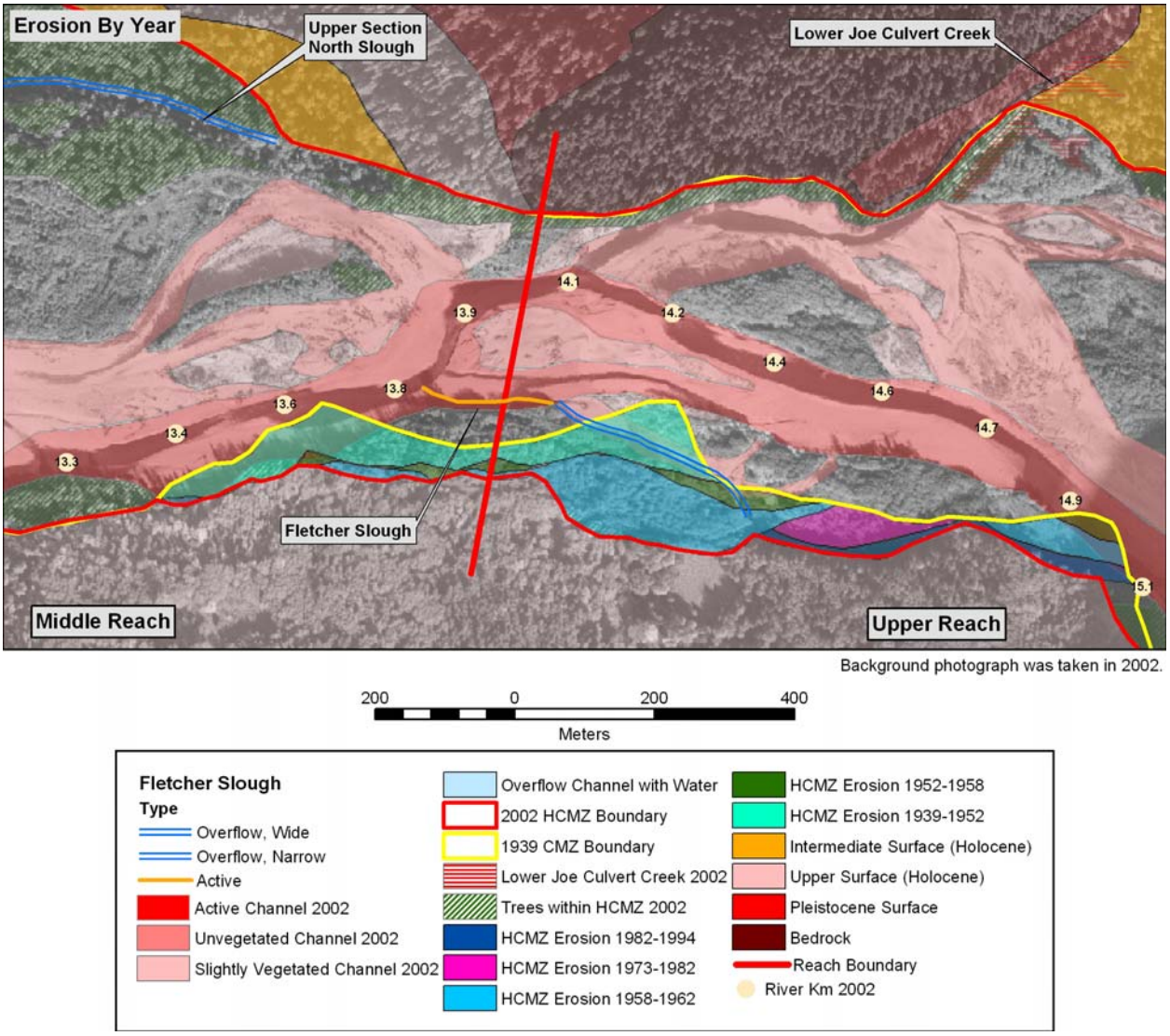

Figure 13. Erosion of the left (south) boundary of the HMCZ between 1939 and 1962 allowed the upstream about 500 m of Fletcher Slough to form. Most of this erosion occurred between 1939 and 1952. Erosion of the bank immediately upstream of Fletcher Slough continued between 1973 and 1994. The downstream about 200 m of Fletcher Slough has been part of the historical channel migration zone since some time between 1929 and 1939.

The right or north boundary of the HCMZ along this section of the valley has not eroded since 1939. This may be because of the bedrock that composes about half of the boundary in this section. Thus, erosion of the HCMZ boundary has not been a factor in the configuration of and changes in Lower Joe Culvert Creek between 1939 and 2002.

Changes in the Upstream Part of Lower Joe Culvert Creek (outside of the HCMZ)

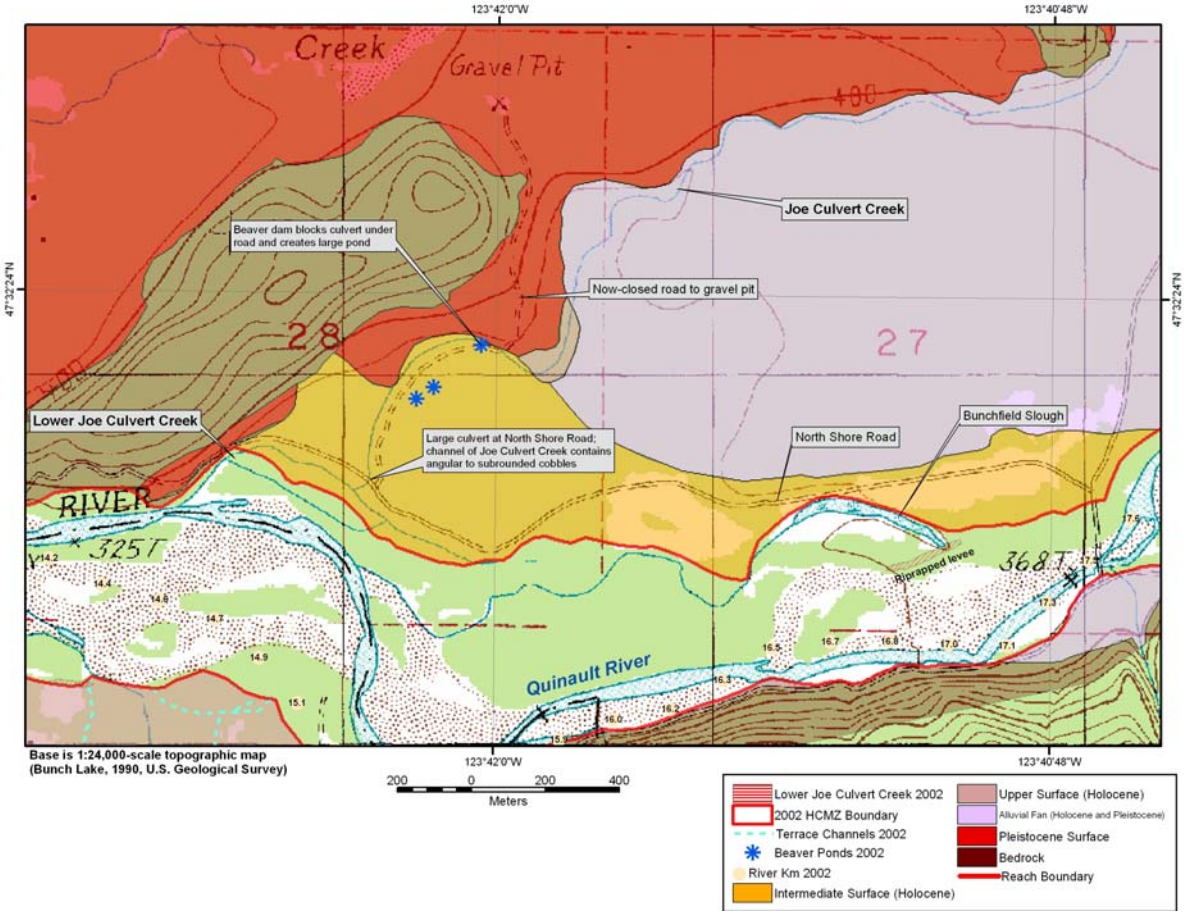

Figure 14. The upstream part of Lower Joe Culvert Creek (outside of the HMCZ) is the downstream end of a tributary that heads along a bedrock ridge north of section 27. Because this part of Lower Joe Culvert Creek is outside of the HCMZ, it has not been affected by processes in the Quinault River channel. The approximate location of beaver dams in 2002 are shown by the blue stars. One dam blocks a road culvert, which creates a large pond. Before the culvert was blocked and the pond formed, sockeye and coho probably had access to spawning areas upstream to the upper end of the bedrock knob.

An old dirt road, which led to a gravel quarry, crosses the creek. Beaver activity also has affected the channel during the last about 10 years. The approximate location of beaver dams in 2002 are shown by the blue stars. One dam blocks a road culvert, which creates a large pond. Before the pond was present, spawning took place in the creek upstream to the upper end of the bedrock knob. Until the middle 1990s, sockeye used the tributary channel up to the culvert-blocking beaver dam. The dam caused headward channel cutting along the road, which started during the winter of 2000-2001 and accelerated during the winter of 2001-2002. The incision has improved the sockeye's access to the beaver pond. The pond may have increased the amount of rearing habitat in the tributary. Additional changes in habitat are likely because of the interaction of the beaver activity, the old road, and channel incision.

History and Geomorphology of North Slough, 1906 through 2002

North Slough, a side channel in the Quinault River system, is located on the north side of the Quinault River valley between RK 11.5 and RK 13.6 (Figure 1). It is between Big Creek (downstream) and a bedrock knob that extends into the valley (upstream) near RK 14.

Terrace channels are present on the terraces both north and south of the Quinault River. The ones on the south side extend from upstream of Fletcher Slough to the North Slough area (Figure 1). The ones on the north side extend from the North Slough area to Big Creek (Figure 1). The characteristics of these terrace channels area discussed in the sections on Fletcher Slough and Big Creek.

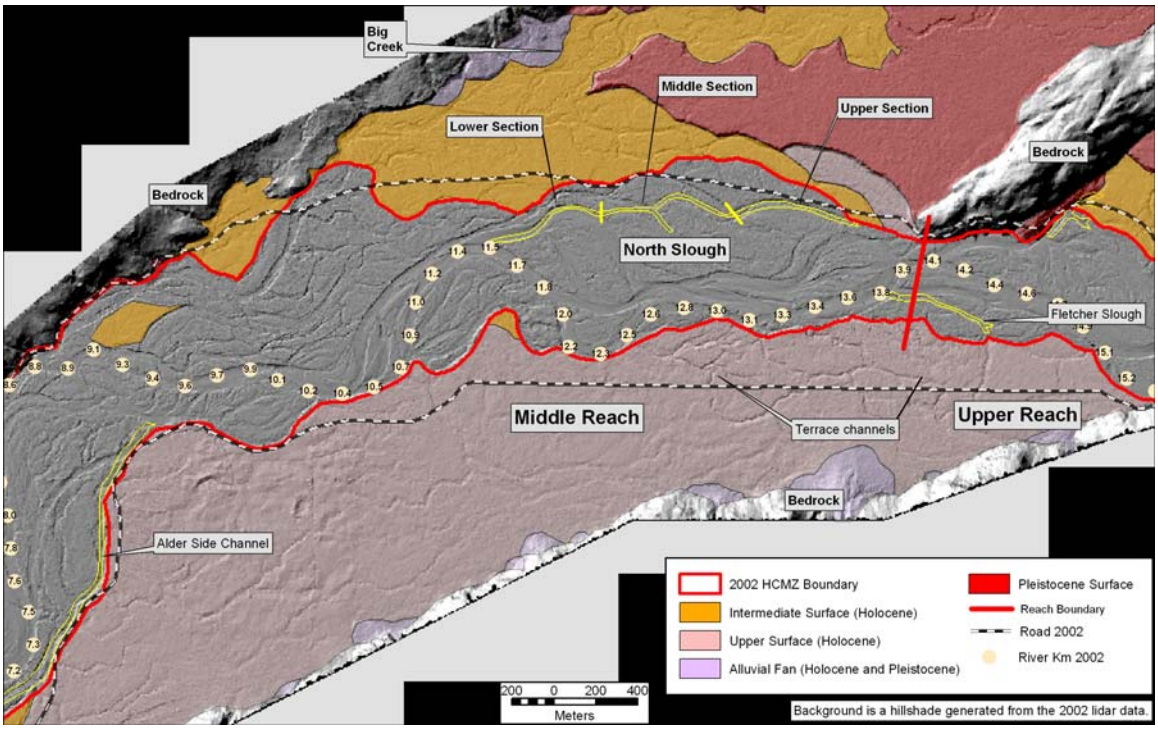

Figure 1. North Slough is located between RK 11.5 and RK 13.6 along the north side of the historical channel migration zone (HCMZ). Background is a hillshade created from 2002 LiDAR data. River kilometers are from the low-flow channel at the time of a river survey in 2002.

The following maps (Figures 2 through 11) show the history of formation and destruction of potential habitat in the area of North Slough between 1906 and 2002.

North Slough has been subdivided into three sections for discussion, primarily on the basis of the history of formation of different parts of the slough (Figures 2 through 11). The Upper section is about 630 m long beginning at the upstream end of the slough. The Middle section extends between 630 m and about 1330 m downstream.

Changes in North Slough by Year

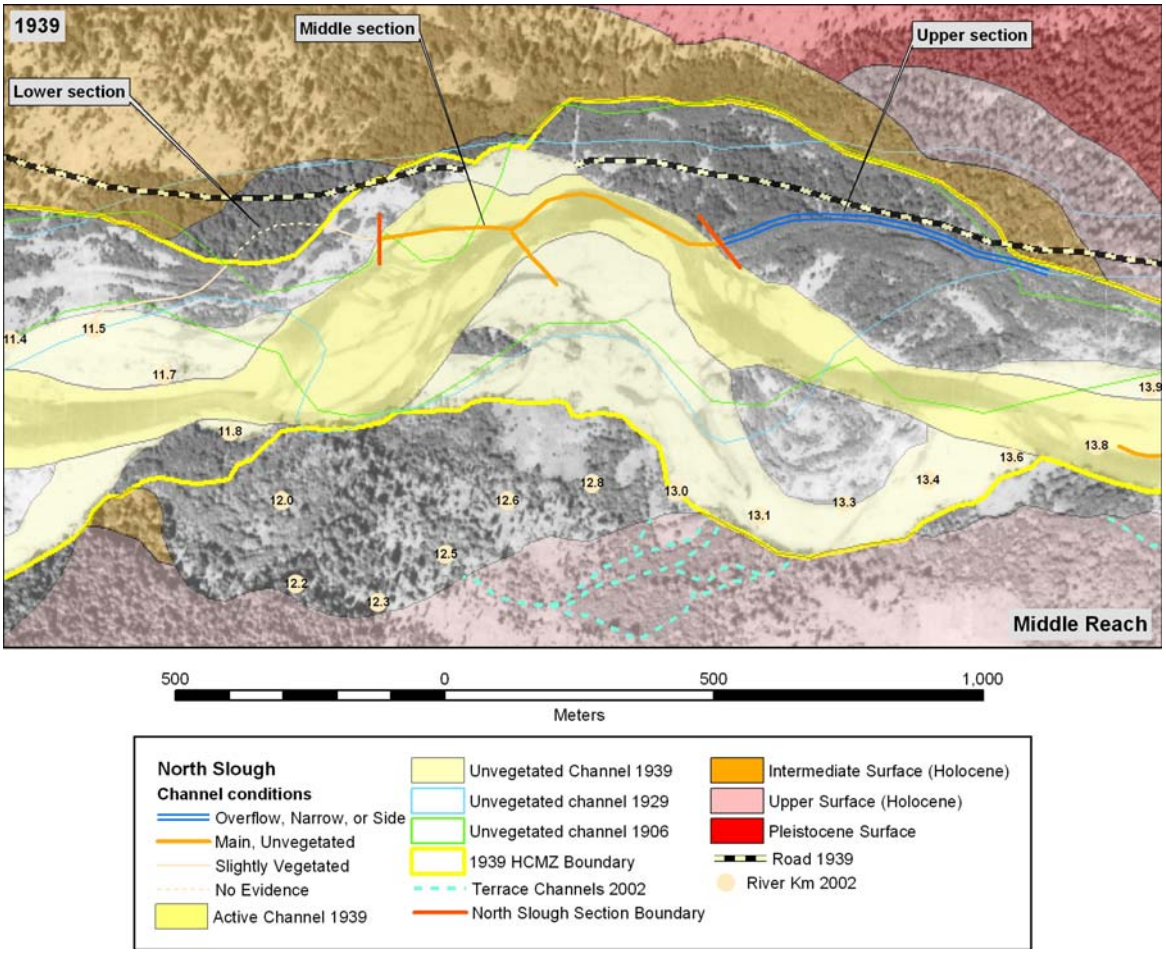

Figure 2. In 1906 (green outline) and 1929 (blue outline), North Slough was part of the unvegetated channel of the Quinault River. The slough, which is now a side channel, was probably a remnant of the Quinault River channel during these years. In 1939, the Upper section appears to have been habitat, but the Middle and Lower sections were still part of or close to the unvegetated channel complex of the Quinault River.

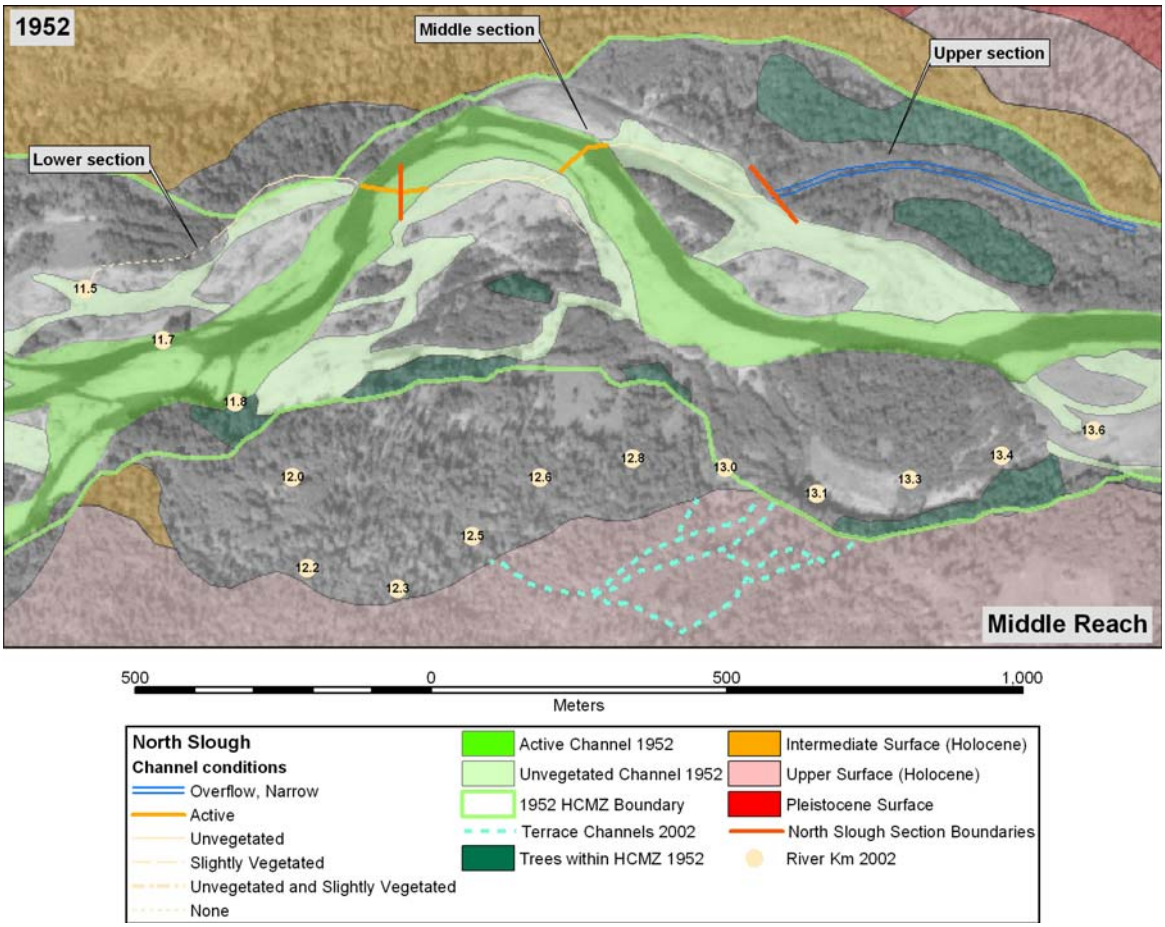

Figure 3. In 1952, the Upper section was still potential habitat, and the Middle and Lower sections were still part of or close to the unvegetated channel complex of the Quinault River, much as they were in 1939. A section of possible habitat at the downstream end of the Lower section had shortened since 1939, from about 200 m to about 50 m. This occurred because the unvegetated channel of the Quinault River moved into this area between 1939 and 1952.

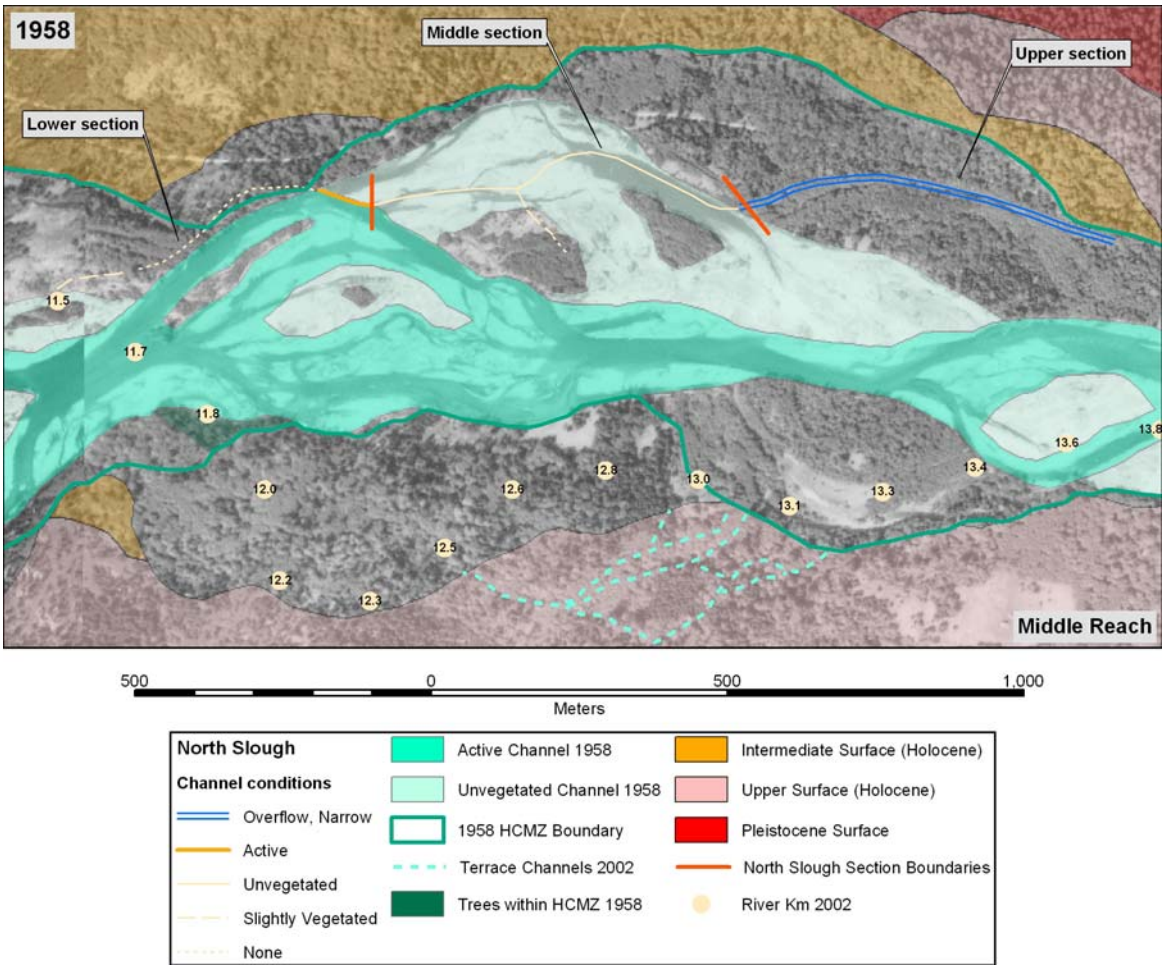

Figure 4. In 1958, the Upper section was still potential habitat, and the Middle and Lower sections were still part of or close to the unvegetated channel complex of the Quinault River, much as they were in 1939 and 1952. The active channel had moved to the south and the meander that was between RK 12.3 and RK 13.0 in 1939 and 1952 had moved downstream to between RK 12 and RK 12.8. The Middle section of the future North Slough was still part of the unvegetated channel and was not likely potential habitat. The section of possible habitat at the downstream end of the Lower section had lengthened to about 350 m as the area had become more vegetated since 1952.

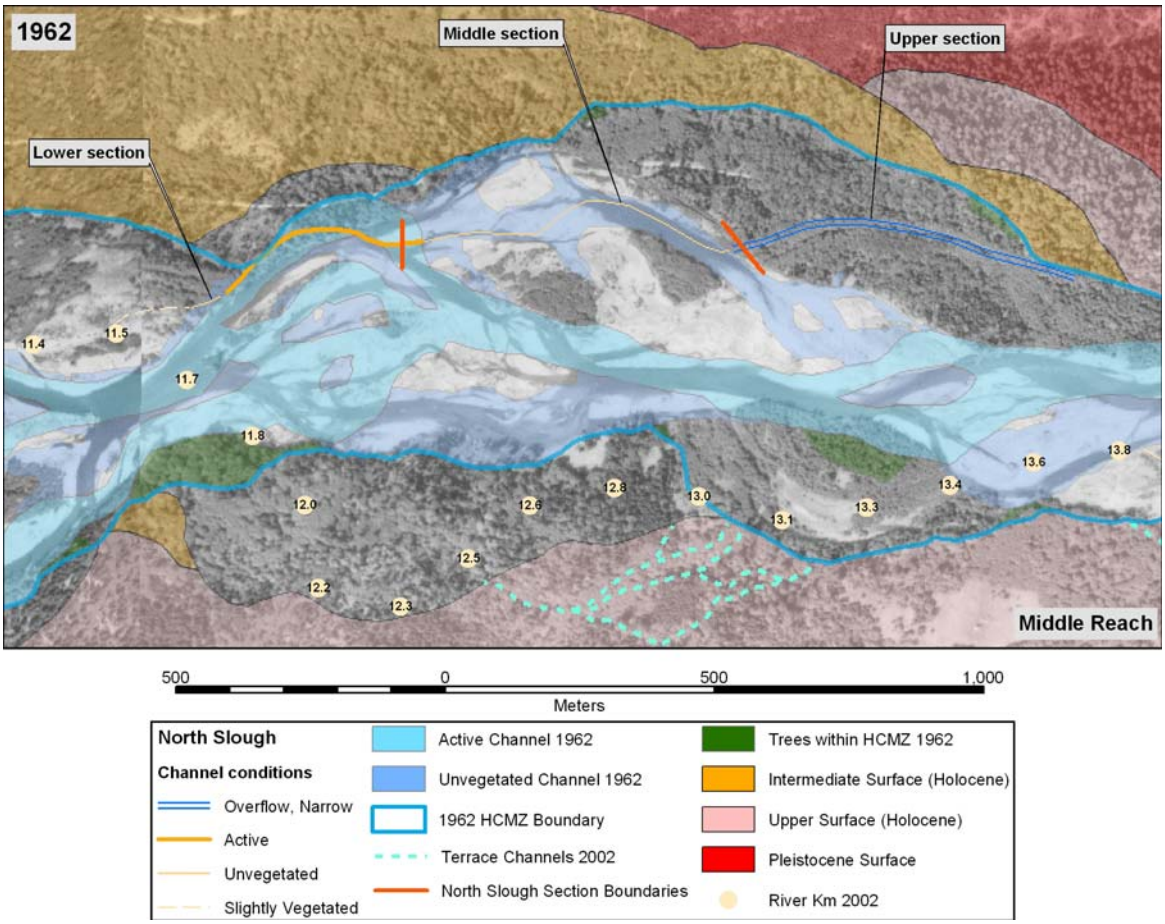

Figure 5. In 1962, the Upper section was still potential habitat, and the Middle and Lower sections were still part of or close to the unvegetated channel complex of the Quinault River, similar to their configuration since 1939. One path of the active channel had moved to the north and was north of North Slough between RK 11.8 and RK 12.3. This was part of the meander that moved progressively downstream and outward since 1939. In 1962, the Middle section of the future North Slough was still part of the unvegetated channel and was not likely potential habitat. The section of possible habitat at the downstream end of the Lower section was limited to the very downstream 150 m of the section, because the downstream migration of the active channel of the Quinault River had eliminated part of the area of riparian vegetation that was present in 1958.

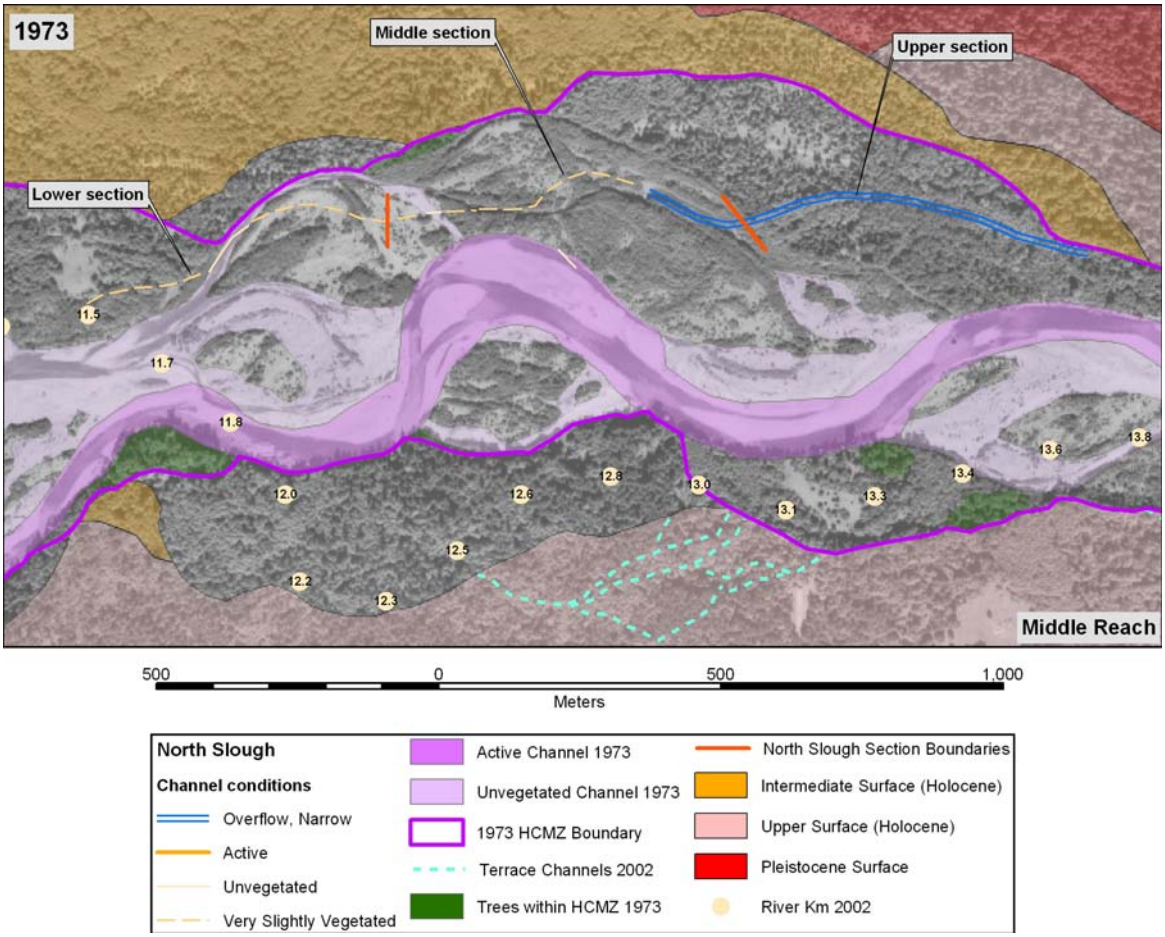

Figure 6. In 1973, the Upper section was still potential habitat. The meander in the active channel of the Quinault River that migrated downstream between 1939 and 1962 was an unvegetated overflow channel in 1973. The active channel was to the south of North Slough, and had moved away from the area of the slough. In addition, the upstream about 200 m of the Middle section flowed through riparian vegetation in 1973 and was likely potential habitat. Much of the Middle section was no longer within the unvegetated channel of the Quinault River, and riparian vegetation had started to encroach into the area. About 300 m of the Lower section was still within an unvegetated overflow channel of the Quinault River. However, the downstream about 200 m of the Lower section was within an area that was starting to become vegetated and was becoming more favorable as potential habitat.

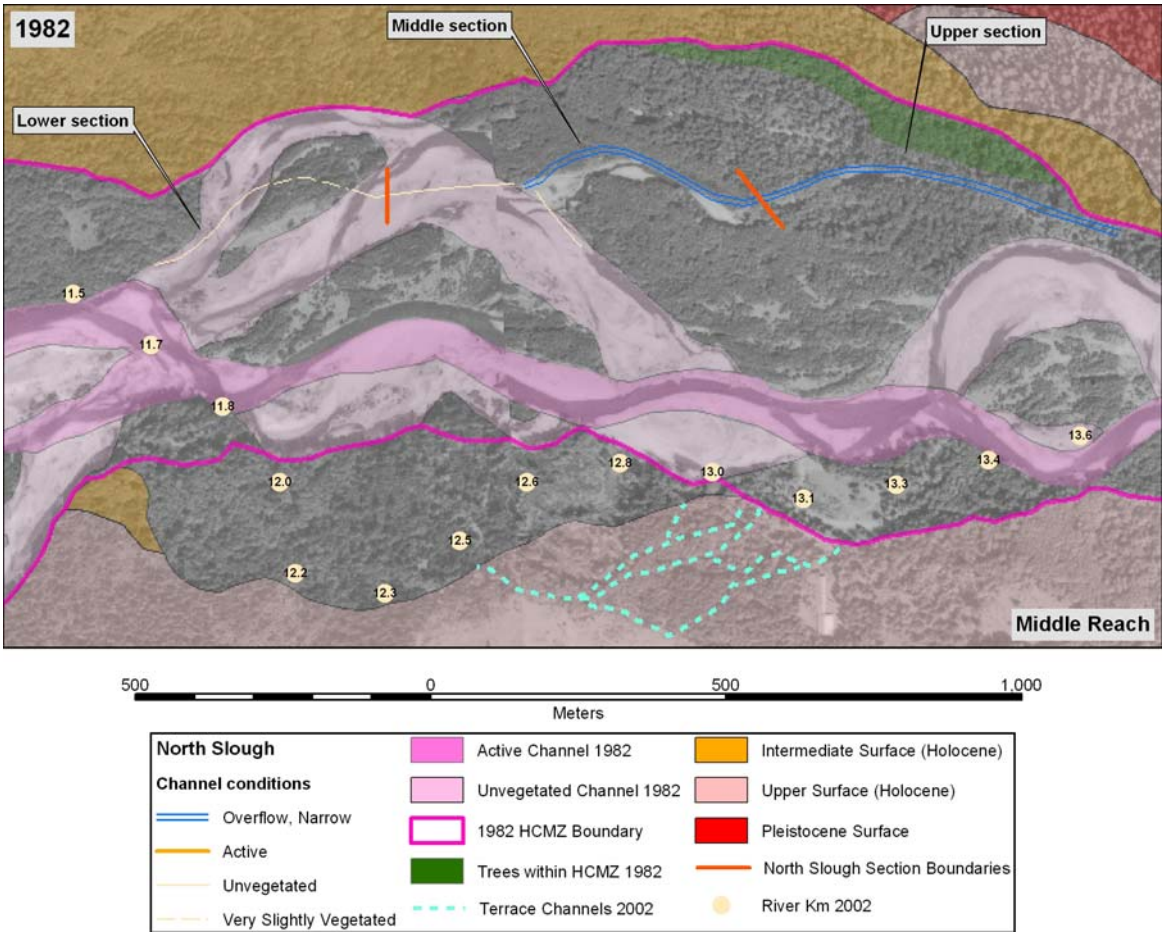

Figure 7. In 1982, the Upper section and the upstream half of the Middle section were potential habitat. The section of potential habitat was about 1800 m long. A north path of the Quinault River between RK 11.5 and RK 13.0 looks as if it had been reactivated since 1973. It was partially vegetated in 1973, but was unvegetated in 1982. Consequently, the downstream half of the Middle section and most of the Lower section were once again part of the unvegetated channel of the Quinault River. Any habitat that was present earlier had been eliminated from these sections by 1982. Since the north channel path was abandoned, the active channel became straighter, and was located south of North Slough. A couple of short (200 to 300 m) areas of possible habitat were present through vegetated areas in the Lower section.

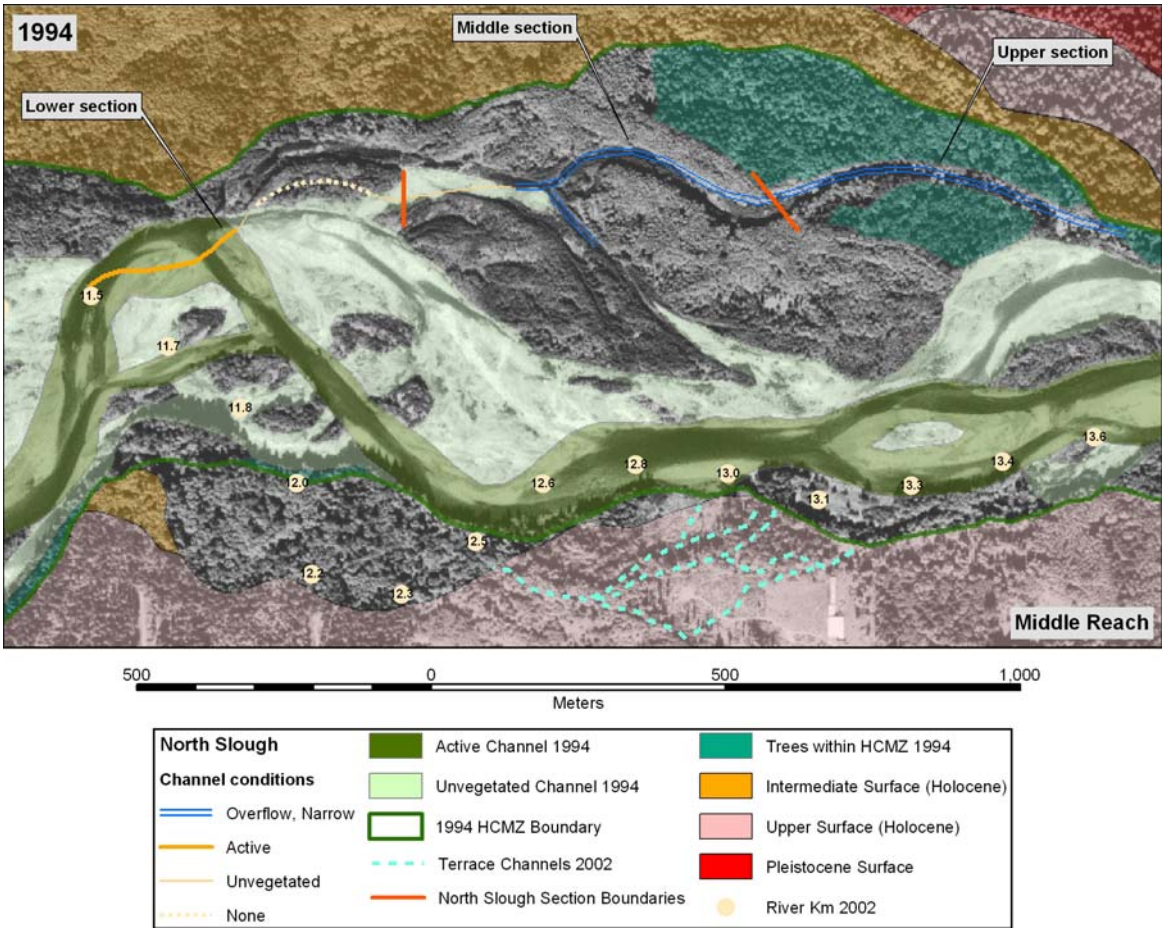

Figure 8. In 1994, the Upper section and the upstream half of the Middle section were potential habitat. This section of potential habitat was about 1800 m long. This was approximately the same length of potential habitat that was present in 1982. The north path of the Quinault River between RK 11.5 and RK 13.0 looks as if it had been abandoned again, although the downstream half of the Middle section of North Slough flowed within an unvegetated overflow channel of the Quinault River. Since 1982, a meander had formed in the active channel of the Quinault River between RK 11.5 and RK 12.3. The channel had eroded into an area that had riparian vegetation in 1982. Most of the Lower section of North Slough was within this new active channel. Consequently, the potential habitat that had formed or was forming in 1982 was gone by 1994, except for the upstream 300 to 400 m of the Lower section, which still flowed through riparian vegetation.

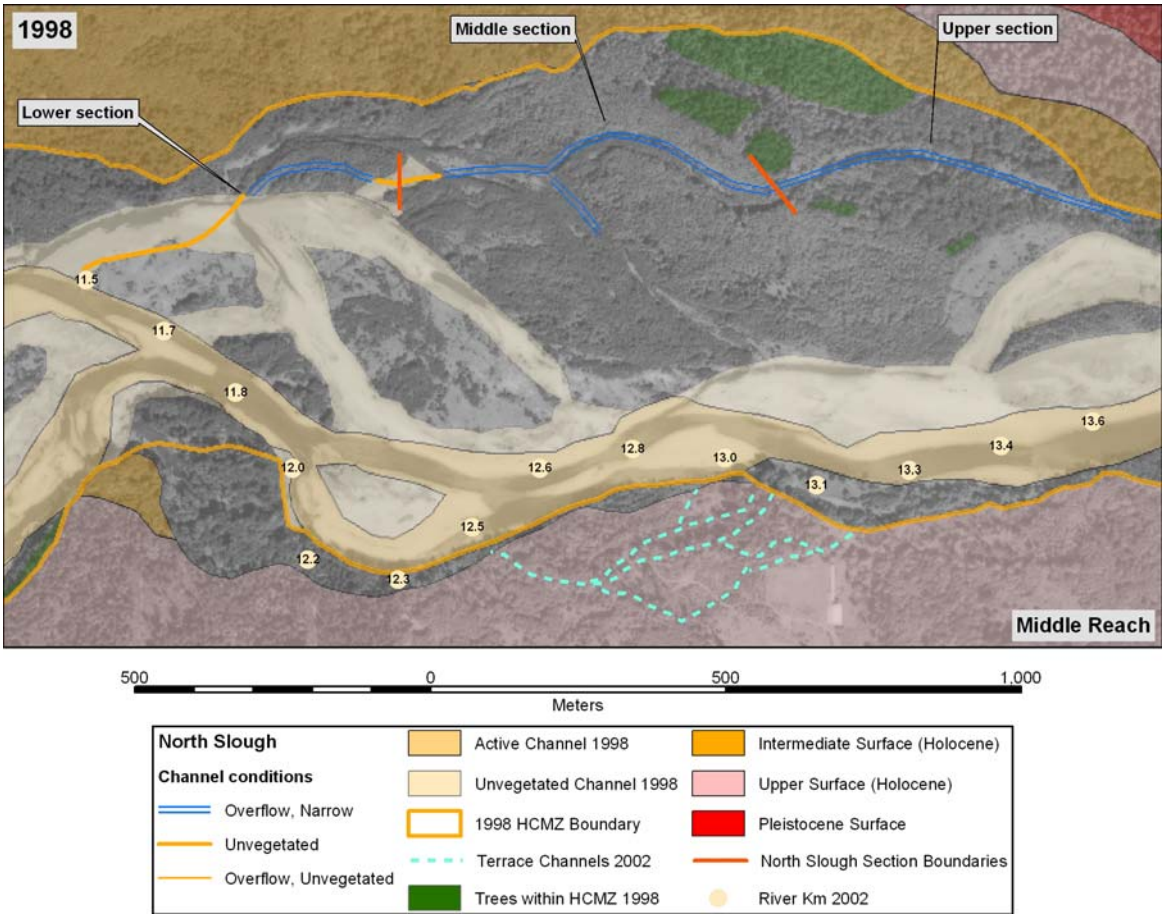

Figure 9. By 1998, the active channel of the Quinault River had moved south of North Slough. The meander that was between RK 11.5 and RK 12.3 in 1994 had moved downstream of the North Slough area. Much of the area around North Slough was covered with riparian vegetation by 1998, and most of the slough appears to have been potential habitat. The Upper and Middle sections of habitat were nearly entirely present, which resulted in nearly 1350 m of continuous potential habitat. The Upper section appears to have flowed through mixed (low shrubs and trees) vegetation, or through trees. Since the Upper section had been potential habitat through vegetation since some time between 1929 and 1939, this is about 60 to 65 years for the area to change from riparian vegetation to recognizable tree cover. The upstream about 230 m of the Lower section also was possible habitat as a narrow channel flows through riparian vegetation. A short section of about 100 m long flowed that through a remnant of an unvegetated channel of the Quinault River separated this habitat from that in the Middle and Upper sections. The downstream about 400 m of the Lower section was still part of an unvegetated overflow channel of the Quinault River and was not potential habitat.

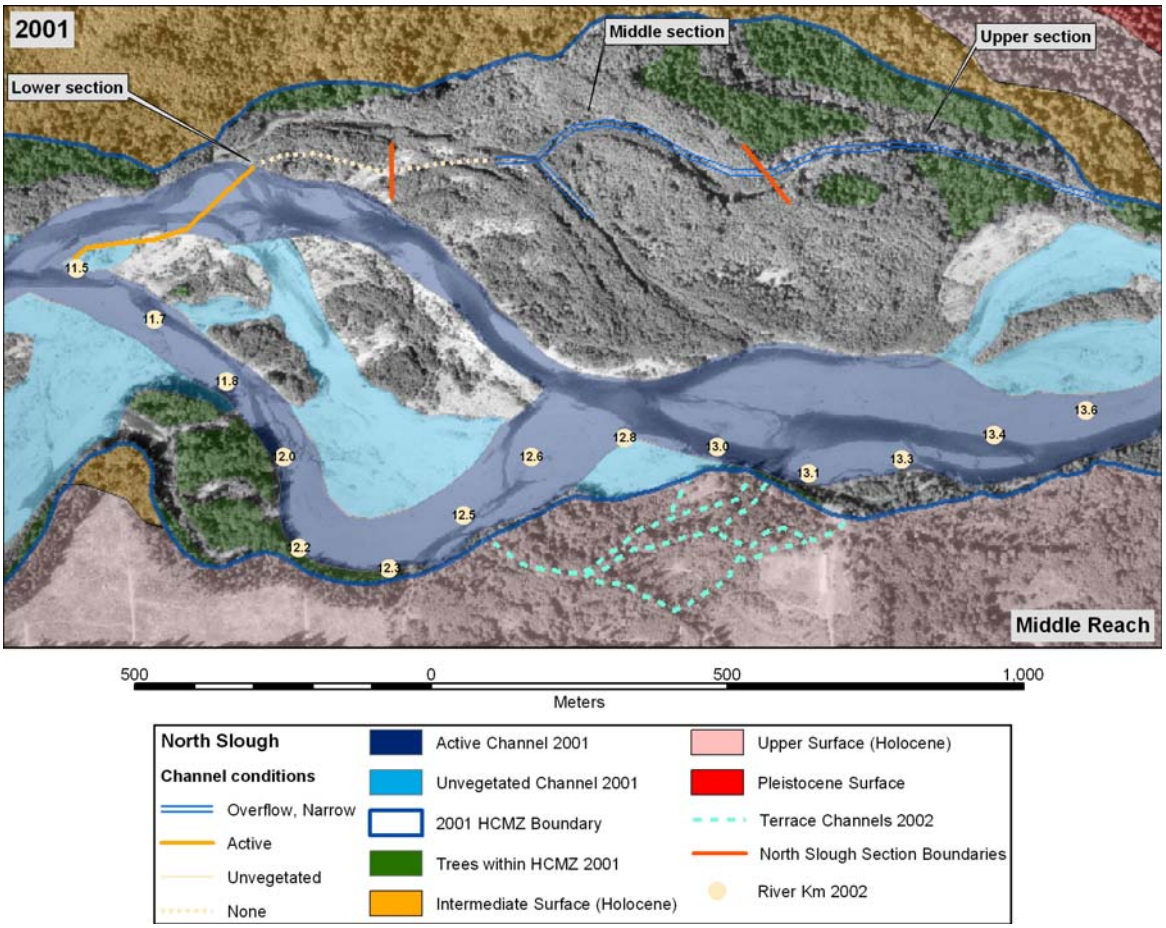

Figure 10. By 2001, the vegetation surrounding the Upper section and the upstream half of the Middle section seems to have been thicker and larger. Trees are visible along both sides of the Upper section by 2001. The active channel of the Quinault River had reoccupied a north path between RK 11.5 and RK 12.7, so that the downstream about 400 m of the Lower section was within the active channel. (This 400-m-long section was part of the unvegetated channel of the Quinault River in 1998.) The upstream about 200 m of the Lower section and the downstream about 200 m of the Middle section were within an area that was beginning to be covered with vegetation and may have been possible habitat.

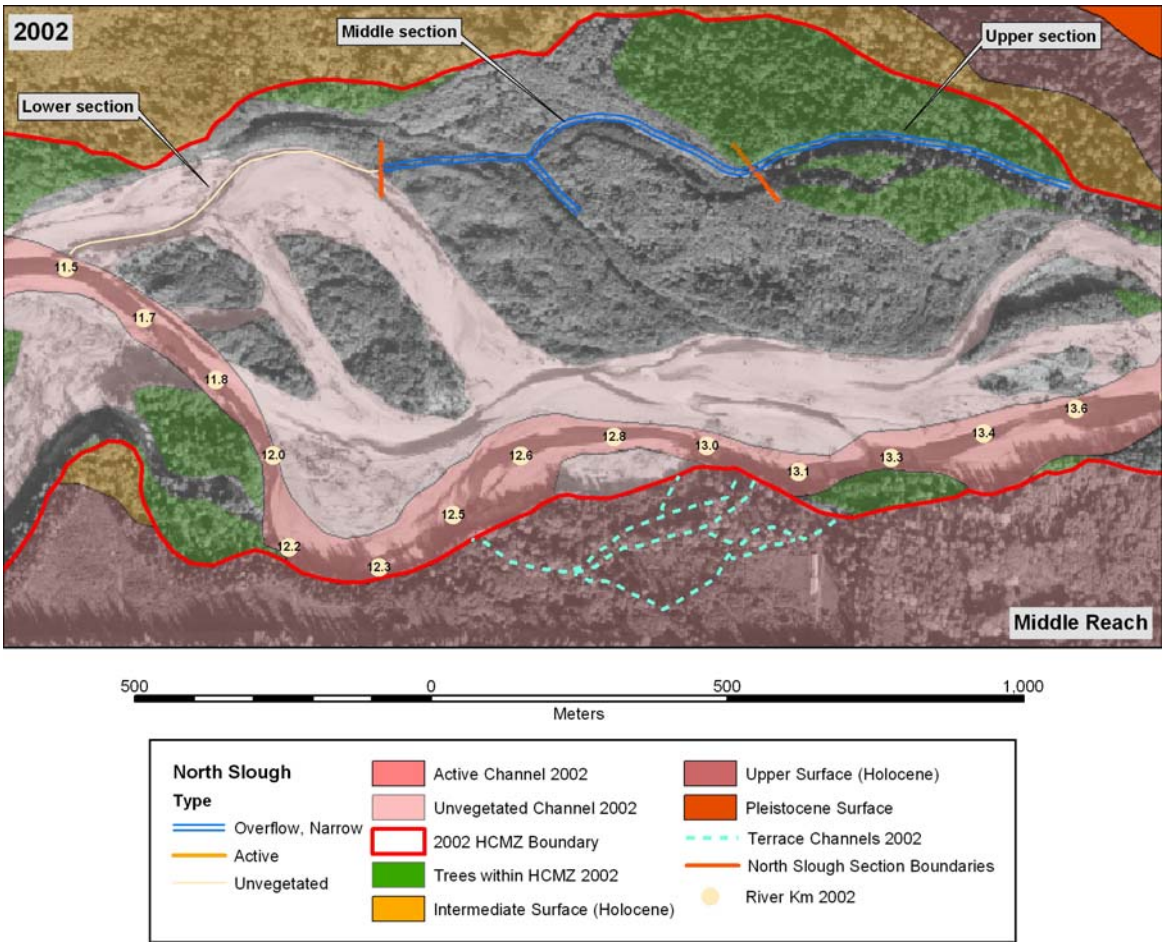

Figure 11. By 2002, the vegetation surrounding the Upper and Middle sections seems to have been more continuous, thicker, and larger than it was in 2001. Trees were present on both sides of the Upper section in 2002. The active channel of the Quinault River between RK 11.5 and RK 12.6 had move once again to the south. However, the Lower section was still within an unvegetated overflow channel of the Quinault River and probably had little habitat. Although the Middle and Upper sections have become increasingly stable potential habitat, the Lower section was still vulnerable to reoccupation by the active channel of the Quinault River.

In the summer, North Slough received underground flow. However, in winter, surface (flood) flows dominated in the slough (B. Armstrong, QIN, written commun., 2003).

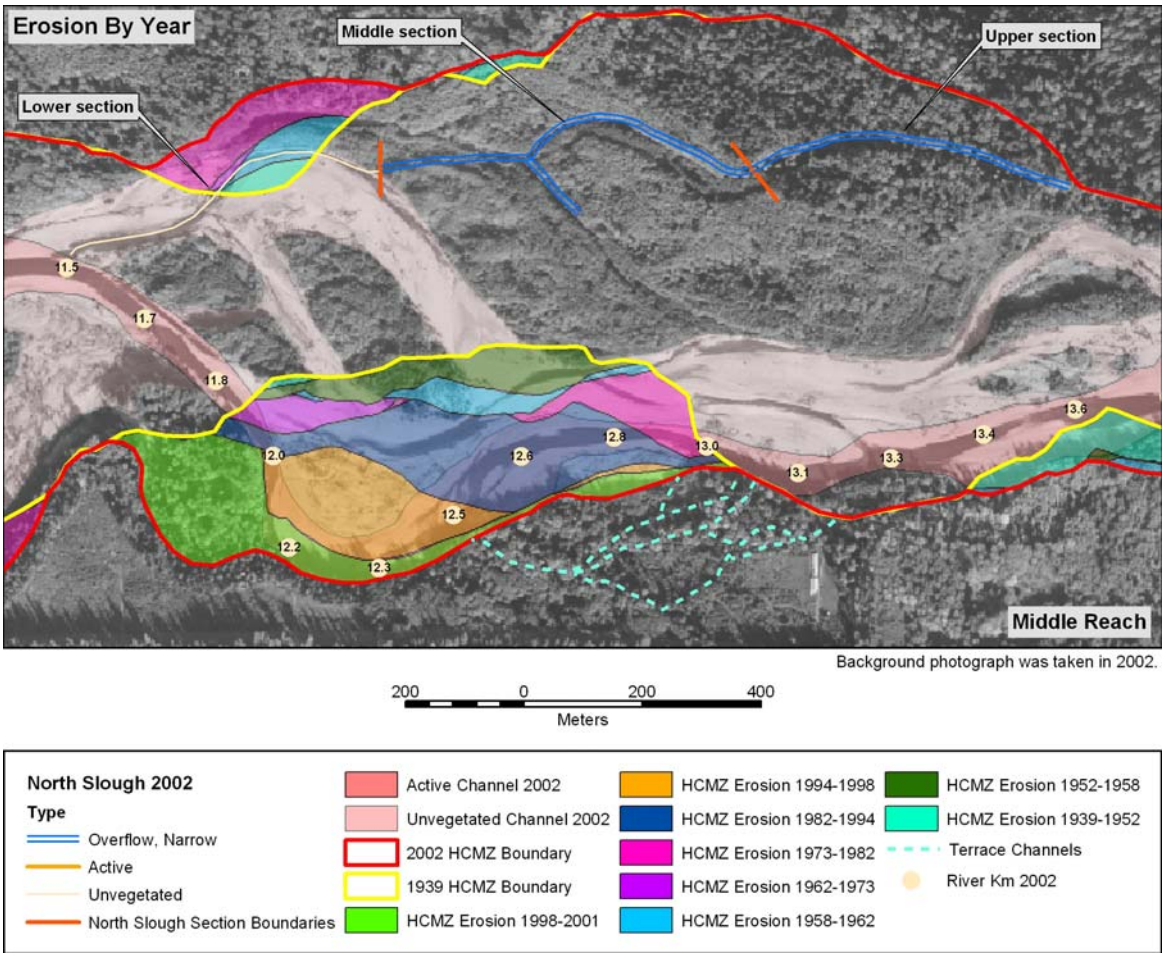

Figure 12. Bank erosion between 1939 and 2001 along the south boundary of the HCMZ allowed the Upper and Middle sections of North Slough to form as a side channel and to progressively become more stable. Erosion of the bank adjacent to the Lower section of North Slough occurred because the active channel of the Quinault River was repeated in this location. Consequently, the Lower section has not been a stable habitat area.

History and Geomorphology of Big Creek, 1906 through 2002

Big Creek, a major tributary of Quinault River system, is located on the north side of the Quinault River valley. It enters the Quinault River between RK 7.5 and about RK 10 (Figure 1). Bedrock limits the west migration of lower Big Creek; the upstream section of Big Creek is incised into Pleistocene and Holocene surfaces (Figure 1). A section of Big Creek about 5 km upstream of the Quinault River is dry for much of the year as flow goes into the subsurface.

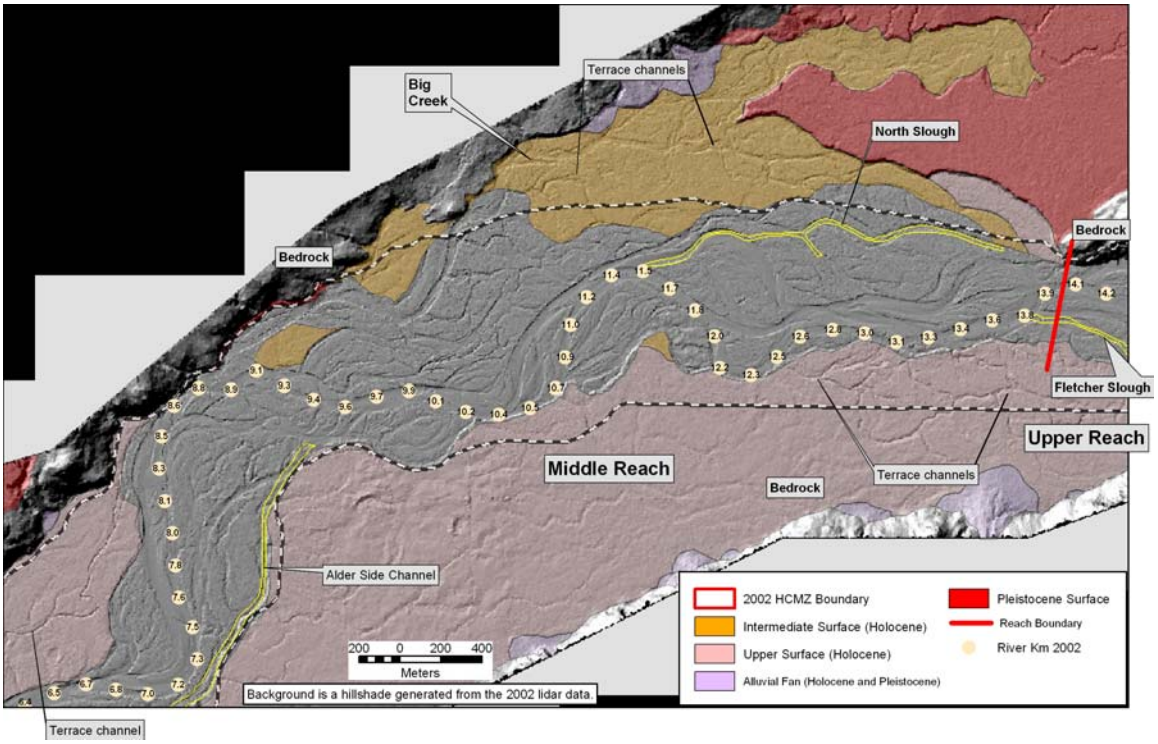

Figure 1. Big Creek is located on the north side of the Quinault River valley and enters the Quinault River between RK 7.5 and RK 10.

Lower Big Creek

The length of the section of lower Big Creek that could provide habitat has varied since 1906 (Figure 2). The active channel was at the upstream end of lower Big Creek in 1906 (at our HCMZ boundary), and the amount of potential habitat was probably limited at that time.

The length of potential habitat along lower Big Creek was estimated using the positions where Big Creek intersects 1) the active channel of the Quinault River and 2) the unvegetated channel of the Quinault River. An assumption was made that the more flow that lower Big Creek gets from the Quinault River, the poorer the conditions for sockeye habitat. Thus, the section of lower Big Creek upstream of the upstream-most intersection with the Quinault River is considered the best potential habitat in lower Big Creek. The upstream-most intersection of Big Creek with the Quinault River is usually the

unvegetated channel of the Quinault River, which likely carries flow only at higher discharges and may have minimal impact on habitat conditions in lower Big Creek. However, depending upon the amount of time and the size of the flows carried by the unvegetated channel, the potential habitat downstream of this intersection may be marginal.

Once Big Creek intersects the active channel of the Quinault River, it is assumed that habitat conditions degrade, even if Big Creek is still visible downstream of this point as a separate channel. Thus, the section of Big Creek between the HCMZ boundary and its intersection with the unvegetated channel of the Quinault River is considered the minimum length of potential habitat in lower Big Creek. Similarly, the section of Big Creek between the HCMZ boundary and its intersection with the active channel of the Quinault River is considered the maximum length of potential habitat in lower Big Creek. In some years, Big Creek intersects the active and unvegetated channels of the Quinault River at about the same location. In these years, the minimum and maximum lengths of potential habitat in lower Big Creek are the same.

The maximum length of potential habitat in lower Big Creek has varied between about 675 m in 1929 to about 3475 m in 1982 (fig. 3). The minimum length of potential habitat in lower Big Creek has varied between 675 m in 1939 to nearly 1900 m in 2002 (fig. 3). The minimum length might better reflect the lengths of relatively stable potential habitat, because it includes only the section of Big Creek upstream of its intersection with channels of the Quinault River. Although the maximum lengths of potential habitat in lower Big Creek have been highly variable, the minimum lengths of potential habitat in lower Big Creek as measured to the unvegetated channel of the Quinault River have been relatively consistent (between 675 and 868 m) until 1998. In 1998, 2001, and 2002, the minimum length of potential habitat in lower Big Creek increased to between 1770 and nearly 1900 m (fig. 3). This occurred because the Quinault River channel moved to the south, preceding a dramatic change in the position of the channel in the winter of 2002 and 2003.

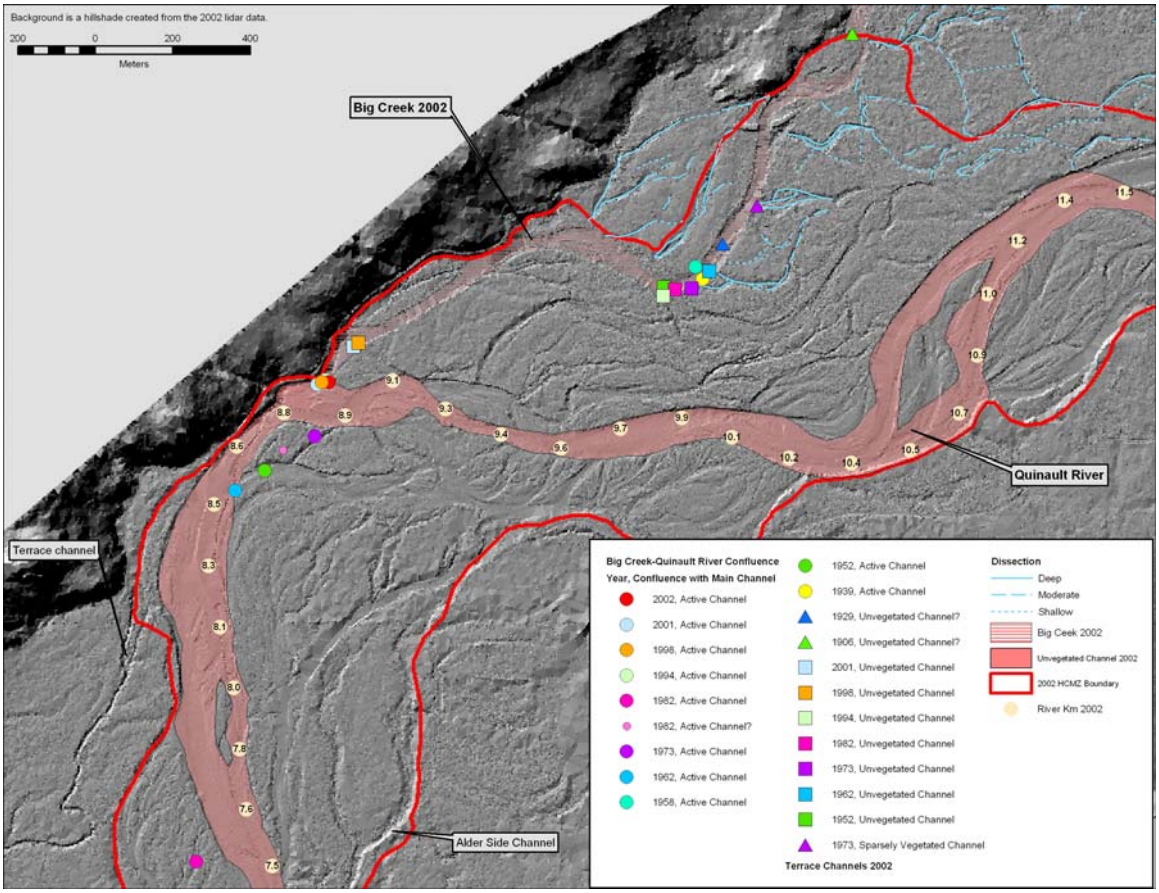

Figure 2. The positions of the intersections of Big Creek with the active and unvegetated channels of the Quinault River have varied between 1906 and 2002. However, the minimum lengths of potential habitat in lower Big Creek were relatively constant between 1906 and 1994, but markedly increased by 1998 (fig. 3). The maximum length of potential habitat was greatest in 1982.

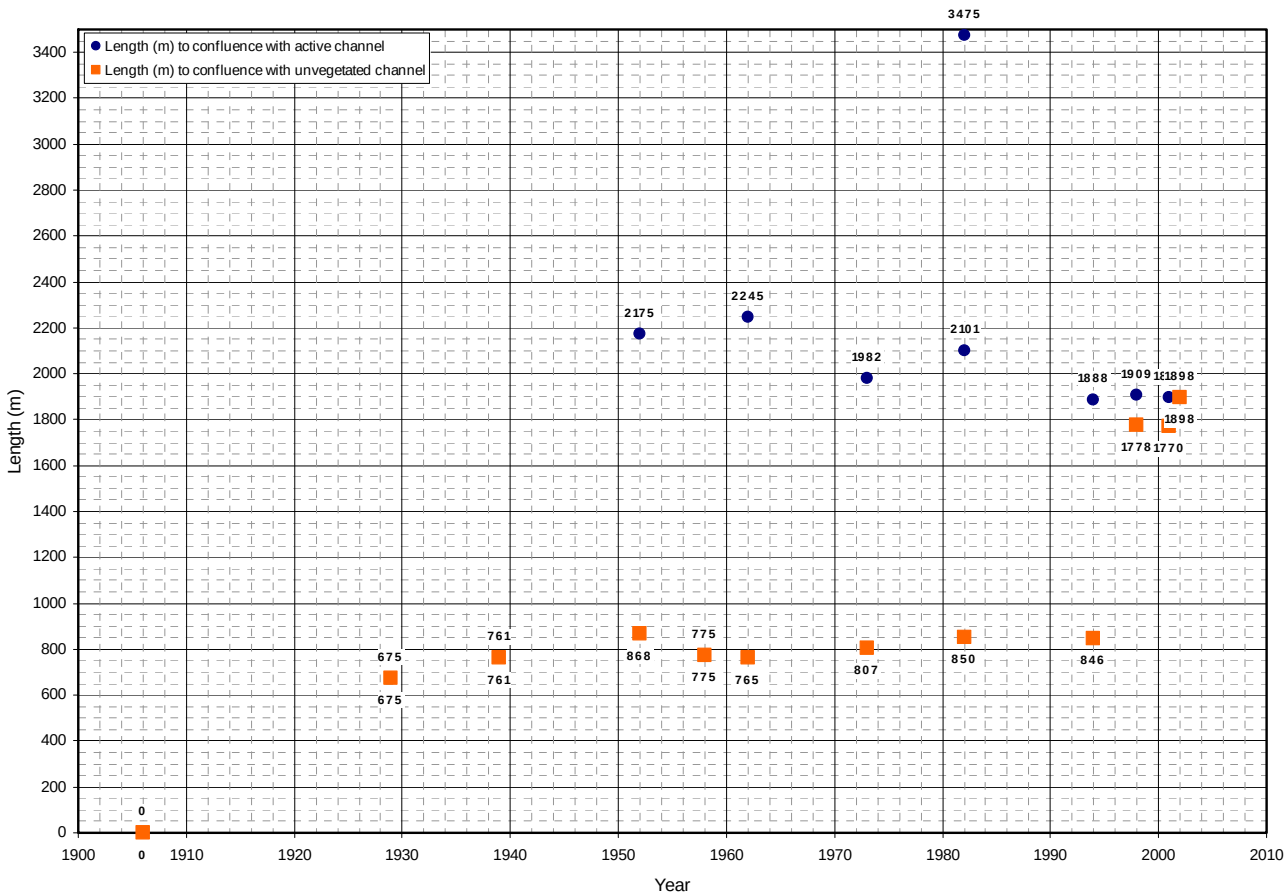

Figure 3. The minimum lengths (orange squares) and maximum lengths (blue circles) of potential habitat in lower Big Creek have varied since 1906.

The minimum lengths of potential habitat in lower Big Creek have been between 40 and 45 percent of the longest minimum length of potential habitat in lower Big Creek, which occurred in 2002.

Between 1929 and 1994, the minimum length of potential habitat in lower Big Creek was between 35 and 45 percent of the minimum length in 2002 (fig. 4). However, by 1998, the minimum length of potential habitat in lower Big Creek had increased to 94 percent of its 2002 value. This history suggests that a relatively long period of stability was followed by a relatively rapid increase in the length of potential habitat in lower Big Creek. The reason for this change is unclear, but appears to be related to the abandonment of an unvegetated channel path of the Quinault River. The change preceded a shift in the winter of 2002-2003 of the Quinault River channel to the south, away from lower Big Creek.

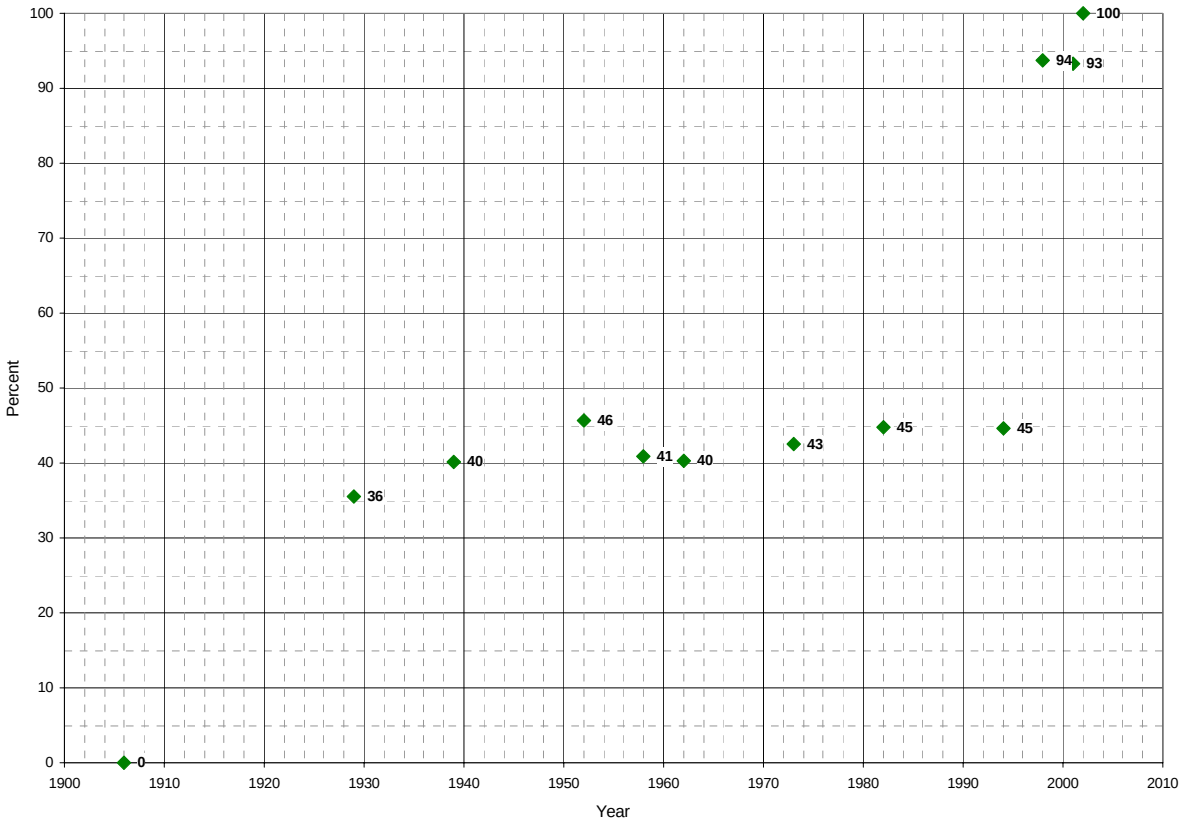

Figure 4. Minimum lengths of potential habitat in lower Big Creek over time as a percent of the minimum length of lower Big Creek in 2002 were relatively stable between 1929 and 1994, but markedly increased by 1998, after an unvegetated channel path was abandoned by the Quinault River and started to fill with vegetation.

Terrace Channels

Terrace channels are common on the Intermediate Surface between the Quinault River near RK 13.0 and lower Big Creek (fig. 5). The channels are often located along the boundary between terrace levels within our map units.

The upstream ends of the terrace channels (near the Quinault River) are not visible along the edge of the Intermediate Surface, which is 1 to 2 m above the active channel of the Quinault River, and the channels are barely visible on the surface itself. At their upstream ends, the channels are broad, poorly defined, and only a few centimeters deep. The depth and width of the terrace channels progressively increase downstream (toward Big Creek). The channels become well defined. Maximum depths of the channels closer to Big Creek are up to 2.5 m, but are commonly 1.5 to 2 m. Maximum widths are up to about 80 m, but are mostly $\leq$10 m. The channels are incised into silt and sand (floodplain deposits). The downstream portions of the terrace channels are often incised into the underlying gravel (channel deposits) (fig. 6). The gravel deposits include boulders, some with maximum diameters of 35 cm or larger. The gravel in some scour holes has been

moved as bed load at higher flows. At low flows, the terrace channels are mostly dry or have standing water only. Some channels have continuous flow, which is provided by a surface connection to the Quinault River or by groundwater.

The terrace channels appear to form by flow over the Intermediate Surface. The flow is spread out over the surface initially. But, within a few tens of meters of the terrace edge, the flow consolidates enough to incise into the fine-grained floodplain deposits that underlie the surface. Incision and lateral erosion increase downstream as flow continues to consolidate, and well-defined channels are formed. Terraces within the channels suggest intermittent periods of channel incision and widening. Incision seems to continue to the top of the underlying gravel deposits, and at this point the rate of incision probably slows. At times, the flows are enough to transport some of the gravel short distances as bed load. However, the flows in the terrace channels appear to transport mainly sand and silt. Once the channels have formed, they continue to be conduits of transport, and may move upstream by headward erosion.

Side or Overflow Channels Within the HCMZ

Channels that have only limited flow are present within the HCMZ in the Big Creek area between about RK 11.4 and RK 10.0. In some cases, these channels were once active or unvegetated channels of the Quinault River that have been abandoned, but still receive some surface flow or groundwater flow. The characteristics of these channels are similar to those of the terrace channels, although their location and origin are different. These channels also are areas of sockeye habitat.

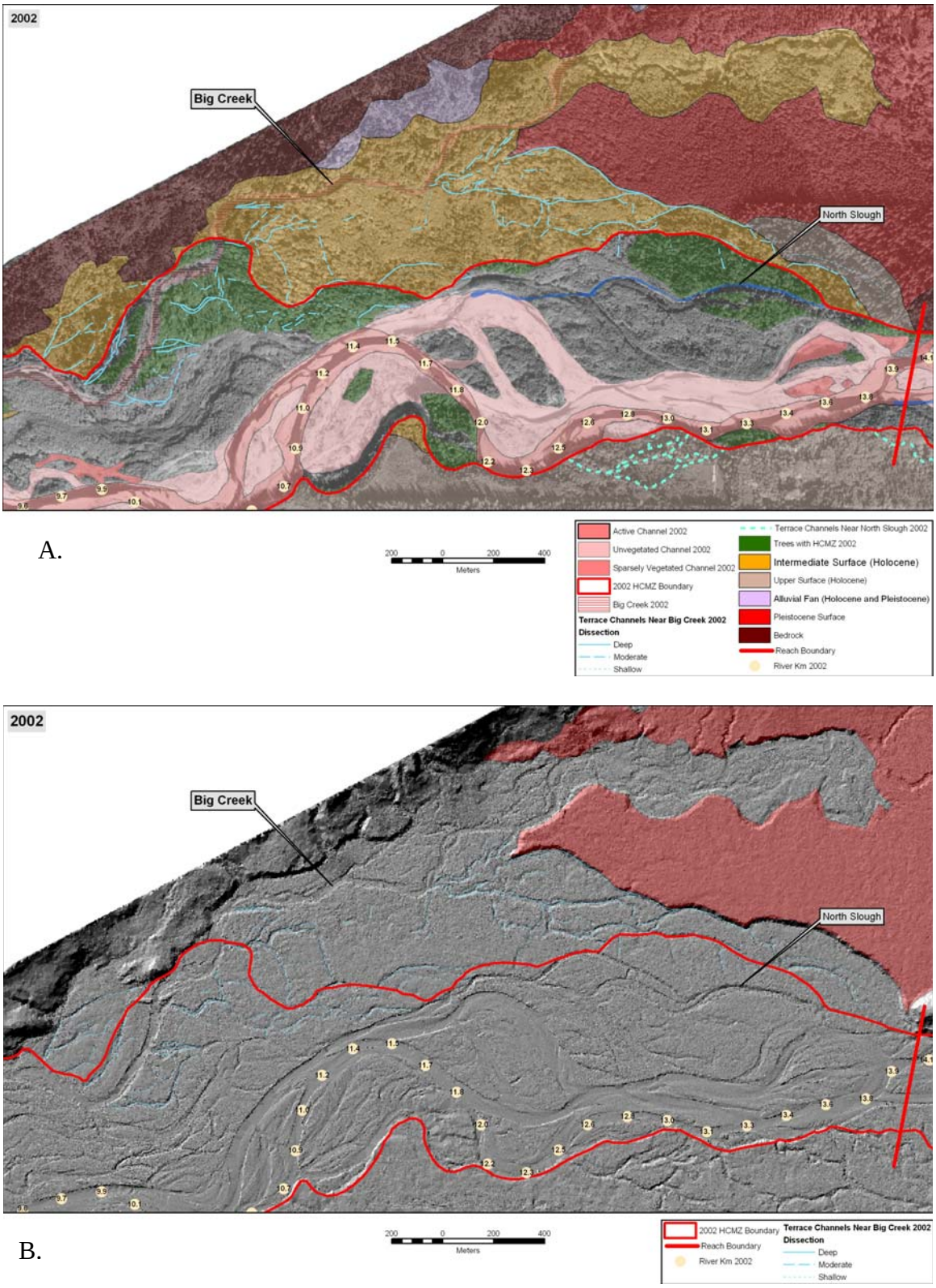

Figure 5. Terrace channels between Big Creek and the Quinault River shown on the 2002 aerial photograph (A) and a hillshade created from the 2002 LiDAR data (B).

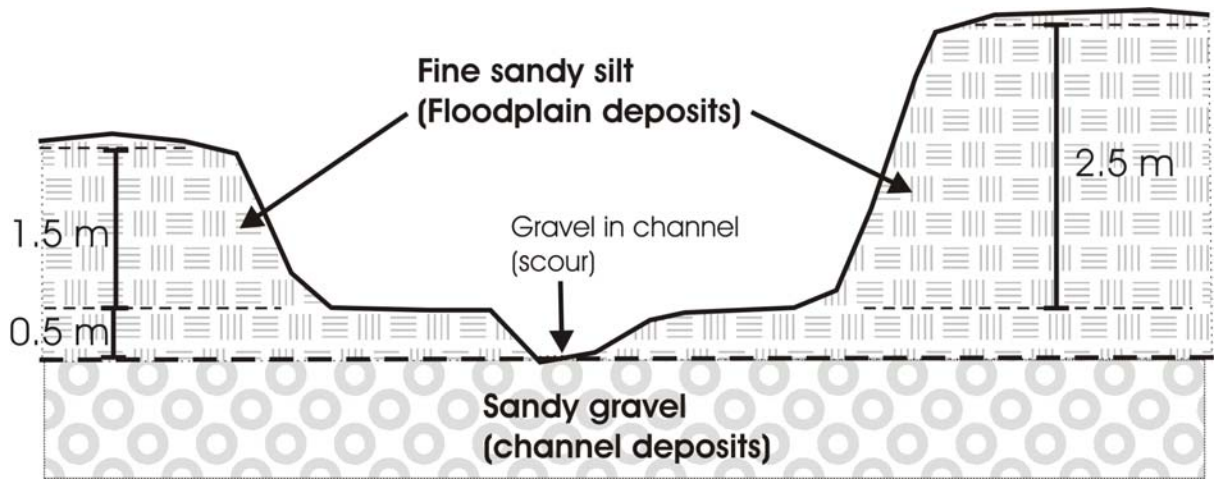

Figure 6. Schematic cross section across a well-defined terrace channel between the Quinault River and Big Creek in the Big Creek area. Dense alder with some larger cottonwood or sitka spruce occur on some of the surfaces adjacent to the terrace channels. Other surfaces are covered by ferns, sitka spruce, and big-leaf maple. The terrace channels, if vegetated, have small alder and grasses (mostly).

The following maps (Figures 7 through 16) show the history of formation and destruction of potential habitat in the area of Big Creek between 1906 and 2002. Both the lower section of Big Creek and the terrace channels between Big Creek and the Quinault River are primary sockeye habitat in the Big Creek area. Figure 17 shows the erosion of the CMZ boundary since 1939 in the Big Creek area.

Changes in the Big Creek Area by Year

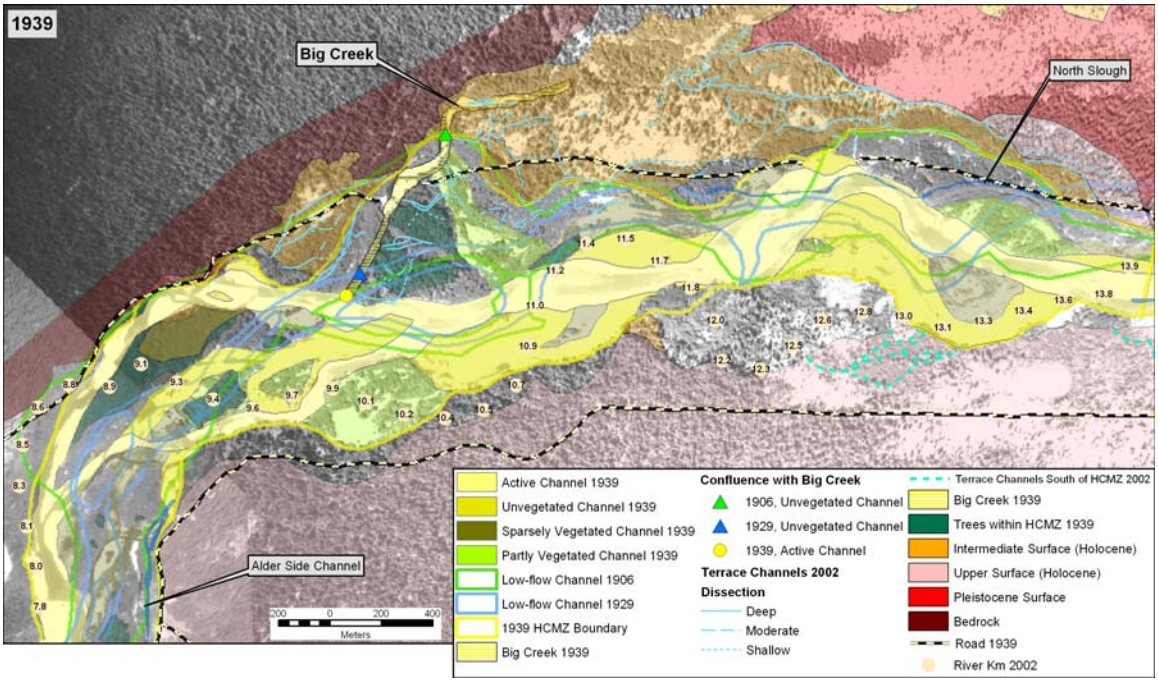

Figure 7. In 1906 (green outline), the Quinault River channel meandered to the north and included what became lower Big Creek. The intersection of Big Creek and the estimated unvegetated channel of the Quinault River occurred near the HCMZ boundary (shown by the green triangle). The 1906 channel was still visible on the 1939 aerial photographs as a band of low vegetation. The 1906 channel becomes progressively more vegetated through 2002.

By 1929 (blue outline), the Quinault River channel had moved to the south, closer to the center of the 1939 CMZ. The 1906 channel in the Big Creek area has been abandoned for at least most flows. The intersection of lower Big Creek and the estimated unvegetated channel of the Quinault River had moved downstream, increasing the minimum length of potential habitat in lower Big Creek by about 675 m.

In 1939, the confluence of Big Creek with the active channel of the Quinault River was near RK 9.9 (yellow circle), about 100 m downstream of the 1929 confluence and about 700 m downstream of the 1906 confluence. The minimum length of potential habitat in lower Big Creek in 1939 (760 m) was slightly greater than it was in 1929 (675 m). In 1939, the Intermediate Surface has been logged in the area where the terrace channels are present in 2002.

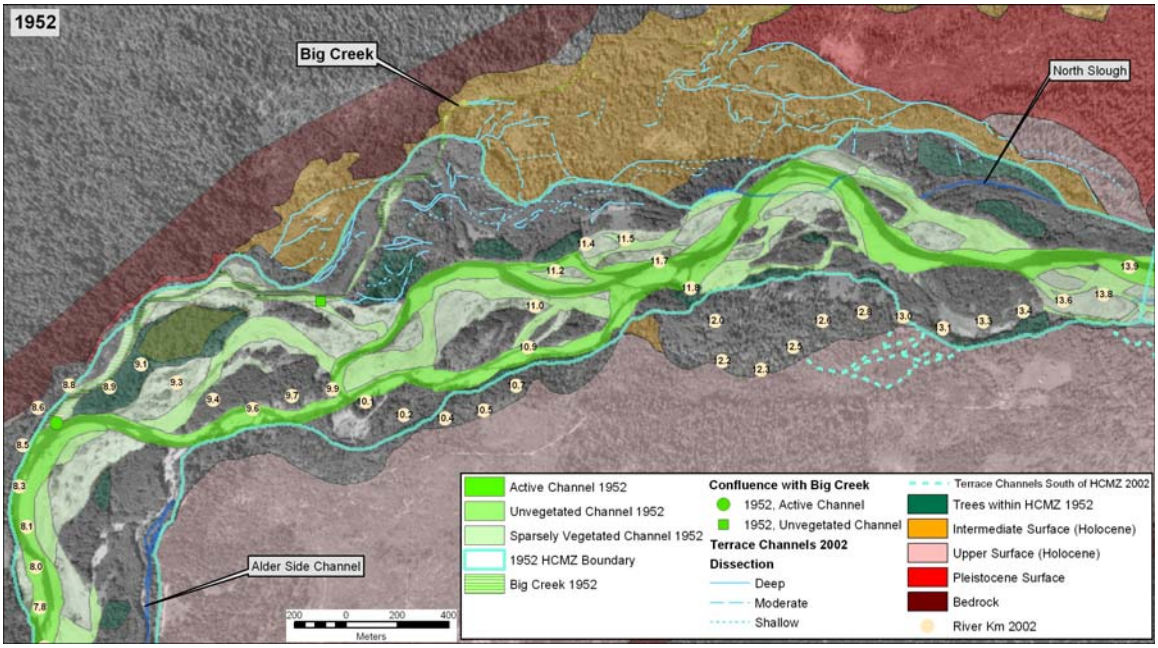

Figure 8. In 1952, the confluence of Big Creek and the active channel of the Quinault River was near RK 8.5 (green circle), and was about 1400 m downstream of its location in 1939 (fig. 2). Consequently, the maximum length of potential habitat in lower Big Creek (2175 m) was markedly longer than it was in the previous years of available record (1906, 1929, 1939). The influence of the higher flows on the potential habitat is not known. However, the minimum length of potential habitat in lower Big Creek was, at about 870 m, about the same as it was in 1939, when it was about 760 m long (figs. 2 and 3).

The Quinault River channel between RK 8.5 and RK 13.5 was braided in 1952, even at lower flows. The lower section of lower Big Creek coincided with one of at least three high-flow channels of the Quinault River in this area.

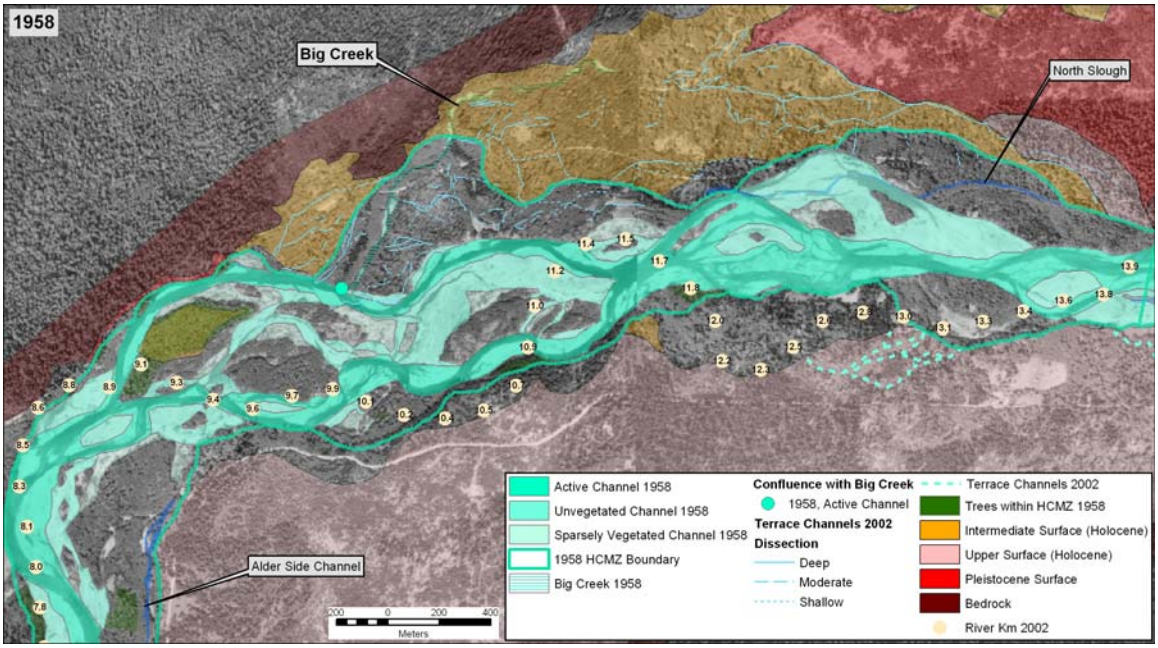

Figure 9. By 1958, the confluence between Big Creek and the active channel of the Quinault River had move upstream about 1400 m of its location in 1952. In 1958, the active channel of the Quinault River was in the 1952 lower Big Creek channel. Thus, the maximum length of potential habitat in lower Big Creek decreased to about 775 m in 1958 from 2175 m in 1952. However because lower Big Creek intersected the active and unvegetated channels near the same location, the minimum length of potential habitat in lower Big Creek in 1958 (775 m) was about the same as it was in previous years (870 m in 1952, 760 m in 1939, 675 m in 1929).

The Quinault River channel was braided, even at lower flows.

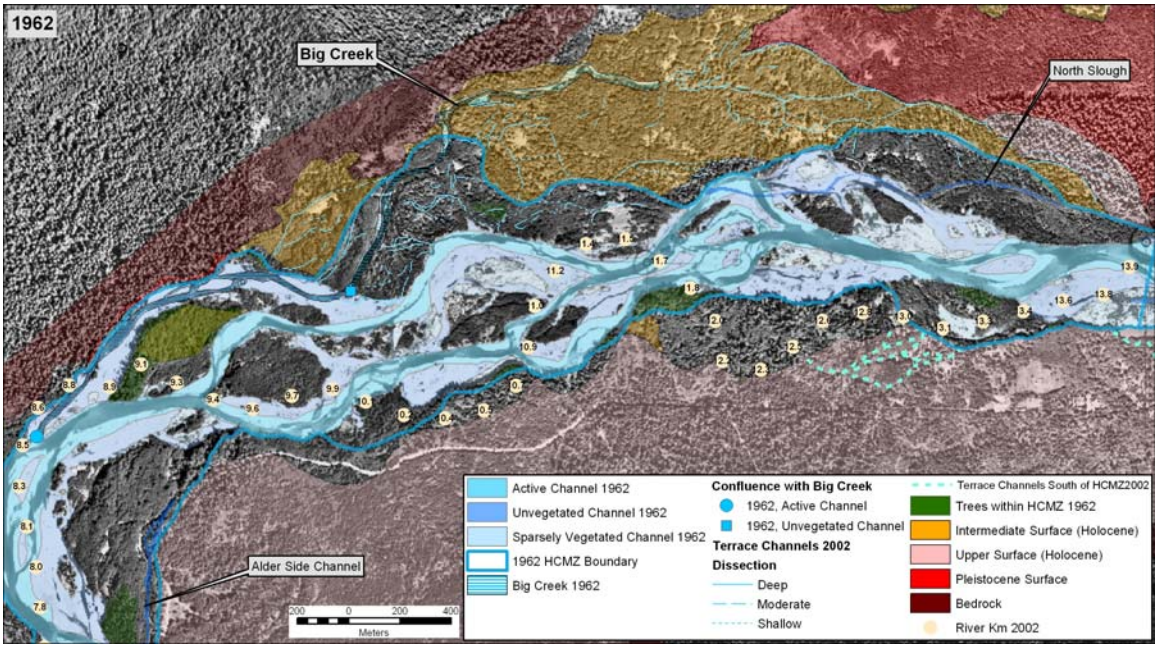

Figure 10. By 1962, the confluence between Big Creek and the active channel of the Quinault River was near RK 8.5, nearly in the same location as it was in 1952. Thus, the maximum length of potential habitat in lower Big Creek increased to about 2245 m from its maximum length of about 775 m in 1958. The minimum length of potential habitat in lower Big Creek was about 807 m, about the same as it had been in previous years (figs. 2 and 3).

The Quinault River channel was braided, and had two or more flow paths, especially at higher flows, along most of the section between RK 8.5 and RK 13.3.

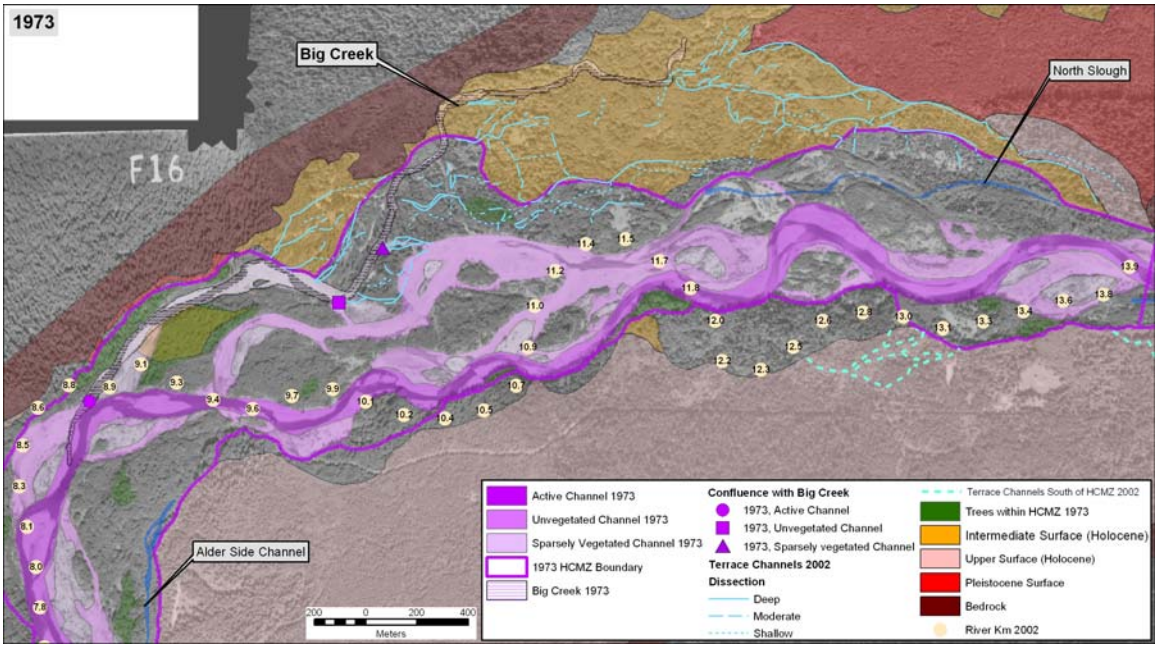

Figure 11. In 1973, the confluence of Big Creek and the active channel of the Quinault River channel was near RK 8.8, only slightly upstream of where it was in 1962. Thus, the maximum length of potential habitat in lower Big Creek was slightly less in 1973 (about 1980 m) than it was in 1962 (2245 m). The path of the active channel to the Quinault River that coincided with lower Big Creek in 1962 had become sparsely vegetated, which suggests that flows in this channel were less frequent or shallower that they were in 1962. The minimum length of potential habitat in lower Big Creek was nearly the same (807 m) as it had been in previous years (figs. 2 and 3).

The active channel of the Quinault River was primarily a single path in 1973, although the channel was braided at higher flows along this section of the river. The channel path that was active in 1906 had a small area of trees in it by 1973.

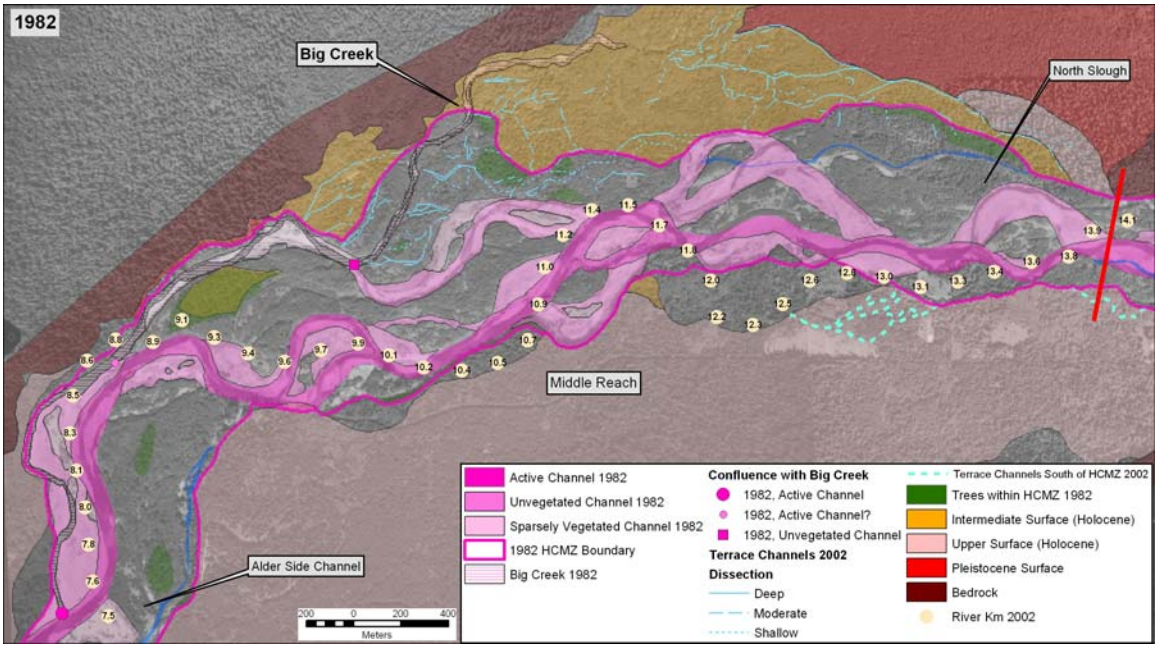

Figure 12. In 1982, the confluence of Big Creek and the active channel of the Quinault River was near RK 7.5, its farthest downstream location observable between 1906 and 2002. This made the maximum length of potential habitat in lower Big Creek about 3475 m. Lower Big Creek and the active channel of the Quinault River nearly joined near RK 8.8; however, distinct channels are observable downstream of this point. If the confluence of lower Big Creek and the Quinault River is taken to be this point, then the maximum length of potential habitat in lower Big Creek in 1982 was only about 2100 m, approximately what it was in 1952, 1962, 1973, and 1982. At higher flows a connection between lower Big Creek and the unvegetated channel of the Quinault River occurred downstream of RK 9.8. The minimum length of potential habitat in lower Big Creek was about 850 m, about the same as it had been in previous years.

The active channel of the Quinault River was mostly a single strand, although two short sections of split flow were present between RK 9.6 and RK 10 and between RK 11.2 and RK 11.7. The unvegetated channel was braided in one location only, between RK 11.7 and RK 12.8. The channel path near Big Creek that was active in 1906 had a slightly larger area of trees in 1982 than it did in 1973.

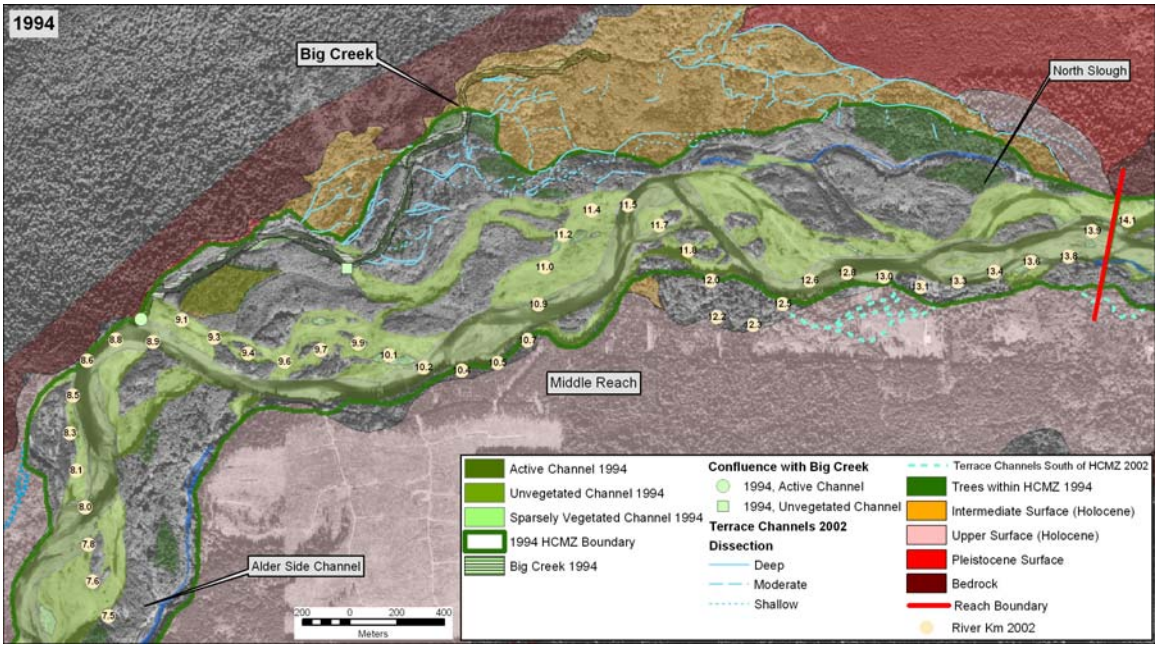

Figure 13. In 1994, the confluence between Big Creek and the active channel of the Quinault River was near RK 8.8, about where it was in 1952, 1962, and 1973. Thus, the maximum length of potential habitat in lower Big Creek was about 1890 m in 1994, about the same length that it was in the previous years listed above. Lower Big Creek coincided with the unvegetated channel of the Quinault River near RK 9.9. The minimum length of potential habitat in lower Big Creek was about 845 m, about what it had been since 1929.

The active channel of the Quinault River had a single path along this section of the valley in 1994. The unvegetated was wide and slightly braided. The channel path that was active in 1906 in the lower Big Creek area had a larger area of trees in 1994 than it did in 1982.

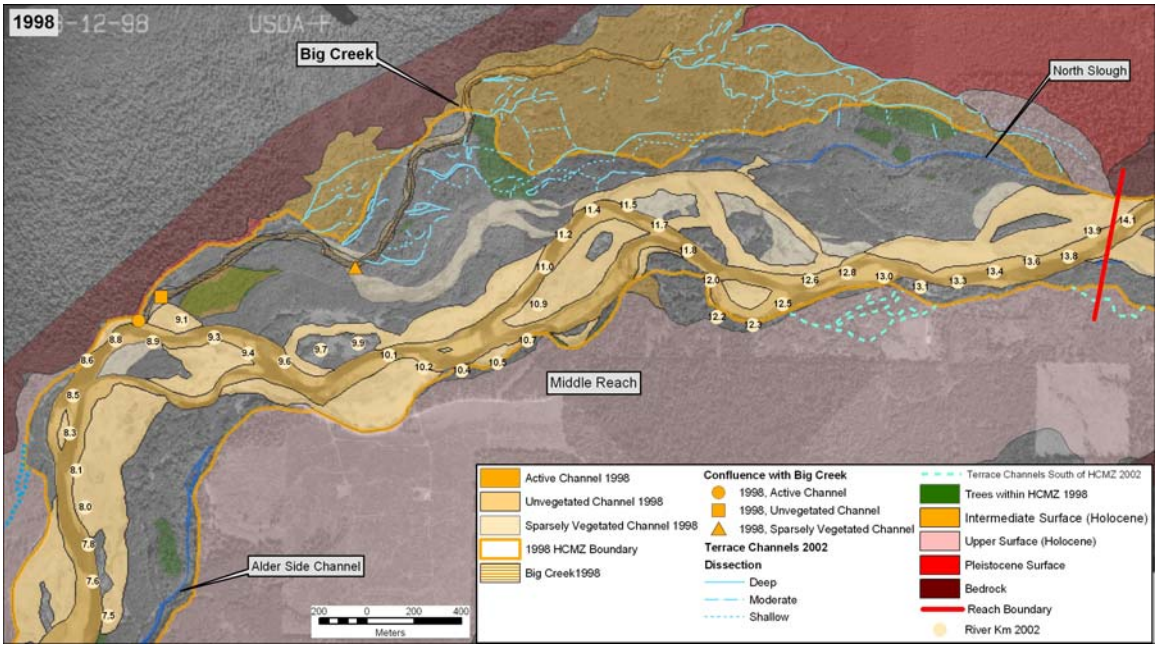

Figure 14. In 1998, the confluence between lower Big Creek and the active channel of the Quinault River was in about the same location as it was in 1994, so that the maximum length of potential habitat in lower Big Creek was about 1910 m. However, the confluence between lower Big Creek and the unvegetated channel of the Quinault River had moved downstream since 1994. Thus, the minimum length of potential habitat in lower Big Creek upstream of this confluence had increased to about 1780 m. (It was only about 845 m long in 1994.) The unvegetated channel that coincided with lower Big Creek in 1994 was sparsely vegetated by 1998, and may or may not have carried flow from the Quinault River in 1998.

The active channel of the Quinault River was primarily a single path along this section of the valley. The unvegetated channel had multiple paths mainly between RK 11.5 and RK 12.8.

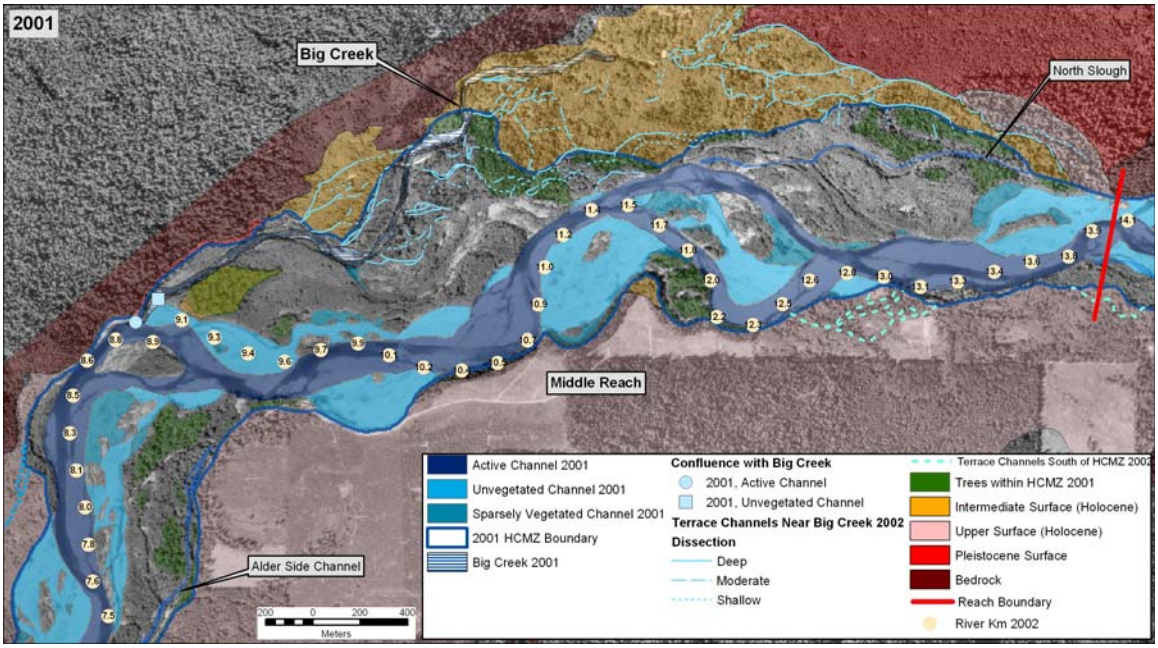

Figure 15. In 2001, the confluences between Big Creek and both the active channel and unvegetated channel of the Quinault River were near their locations in 1998. Consequently, the maximum and minimum lengths of potential habitat in lower Big Creek were about the same as they were in 1998 (figs. 2, 3, and 4). The path of the unvegetated channel of the Quinault River that had connected to lower Big Creek between 1962 and 1994 contained more vegetation than it did in 1998.

The active channel of the Quinault River was a single path, except between RK 11.5 and RK 12.7, where the channel had two paths of similar size. The unvegetated channel was wide, and had multiple paths primarily in this area.

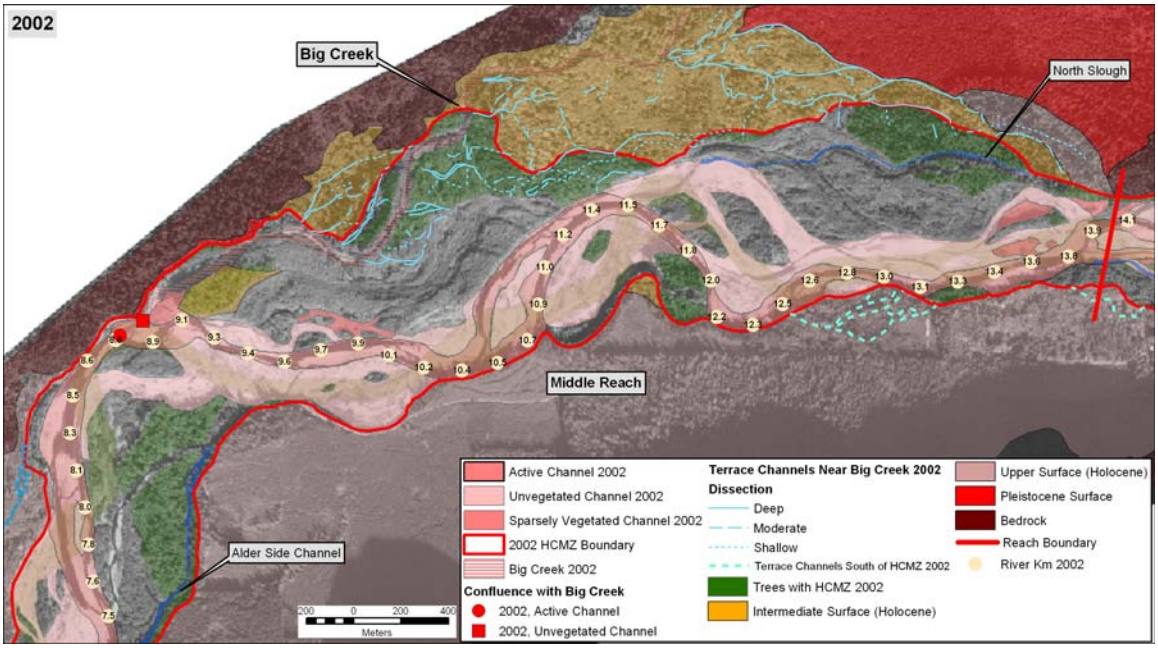

Figure 16. By 2002, the confluence of Big Creek with the active channel of the Quinault River was near RK 8.9, in about the same location as it had been since 1994. In 2002, lower Big Creek intersected the active channel and unvegetated channel in the same location, making the minimum length of potential habitat in lower Big Creek the longest it had been since 1929 (figs. 2, 3, and 4). The unvegetated channel path that was present between 1962 and 1994 had more vegetation than it did in 2001, although flow path was still visible.

The active channel of the Quinault River was a single path, except between RK 10.5 and RK 11.2, downstream of the section with multiple paths in 2001. The unvegetated channel was wide, and had multiple paths between RK 11.5 and RK 12.6. The channel path that was active in 1906 in the lower Big Creek area and that had become progressively more vegetated since 1973, included a large area of trees by 2002.

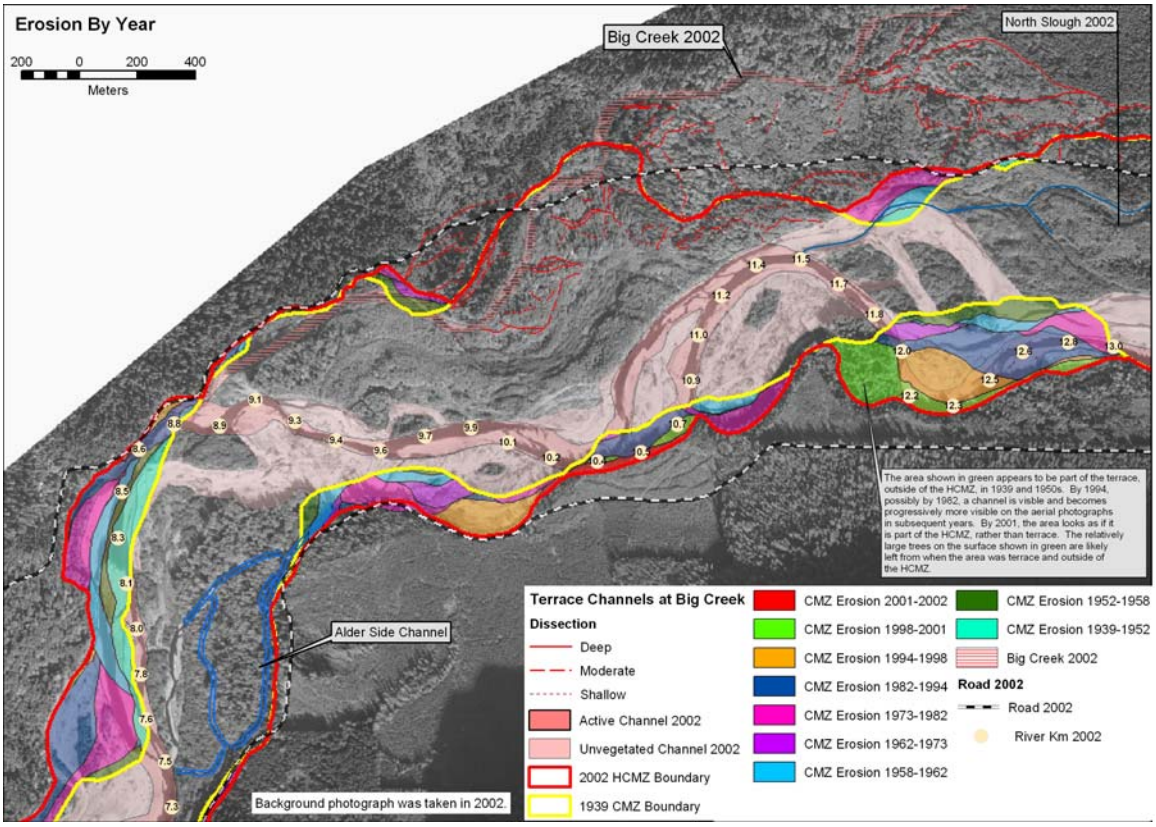

Figure 17. Bank erosion between 1939 and 2002 along the south boundary of the HCMZ allowed the north boundary to be relatively stable in the Big Creek area. The north boundary has remained relatively unchanged since 1939, except near RK 12. Consequently, vegetation has become progressively denser and larger on the north side of the HCMZ in the Big Creek area. The stability on the north side allowed the terrace channels to form, and resulted in a relatively constant minimum length for lower Big Creek, the section of lower Big Creek upstream of its intersection with the unvegetated channel of the Quinault River. The maximum length of lower Big Creek has been highly variable since 1929, in part because erosion of the west (or north) HCMZ boundary downstream of RK 8.8 allowed the maximum length of lower Big Creek to increase between 1929 and 1982. After that time, a shift in the position of the Quinault River channel resulted in a decrease in the maximum length of lower Big Creek, to a value less than the maximum length between 1952 and 1973.

History and Geomorphology of Alder Side Channel and Straughn Slough, 1939 through 2002

Alder Side Channel and Straughn Slough are side channels on the south side of the Quinault River valley (Figure 1). Alder Side Channel extends between about RK 5.7 and RK 9.5. Straughn Slough extends between about RK 4.7 and RK 5.1. Inner Creek Slough is a terrace channel located on the south side of the valley between Alder Side Channel and Straughn Slough, between about RK 5.3 and RK 7.2 (Figure 1). Because of its location through a terrace, Inner Creek Slough has been relatively stable since 1939 and will not be included in this discussion.

Figures 2 through 11 show the history of formation of potential habitat in the area of Alder Side Channel and Straughn Slough between 1939 and 2002. (The 1897, 1906, and 1929 channels all extended outside of the HCMZ in this section of the Quinault River and their locations are suspect and so were not used in this discussion.) Bank erosion that has occurred since 1939 is shown in Figure 12.

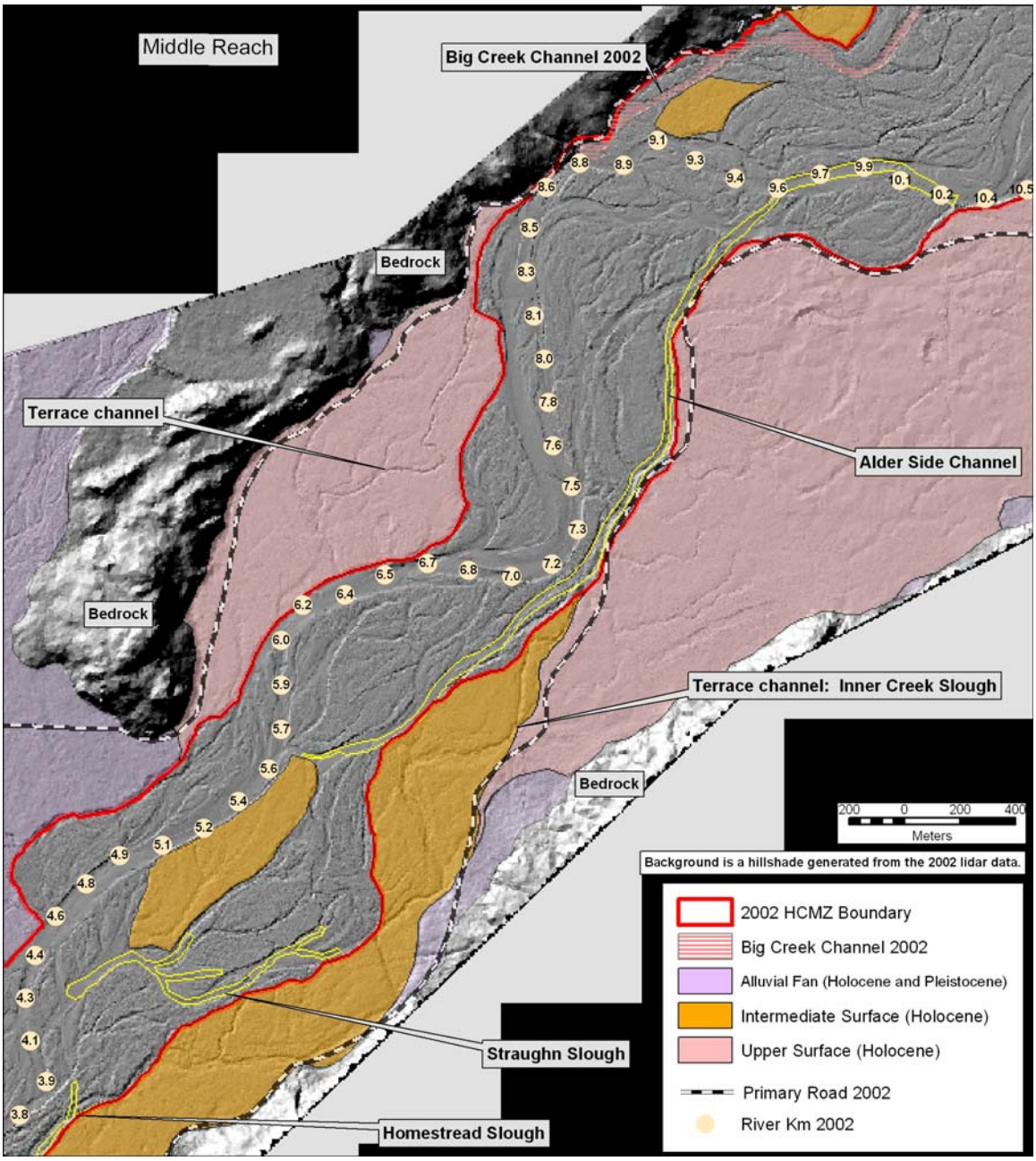

Figure 1. Alder Side Channel and Straughn Slough are located along the south boundary of the historical channel migration zone (HCMZ) between RK 4.7 and RK 9.5 on the south side of the Quinault River valley. Portions of Alder Creek flow along an older Holocene surface. A terrace channel, Inner Creek Slough, flows through the Holocene terrace between Alder Side Channel and Straughn Slough. Big Creek , a major tributary from the north, enters the Quinault River just upstream of Alder Side Channel. Background is a hillshade created from 2002 LiDAR data. River kilometers are from the low-flow channel at the time of a river survey in 2002.

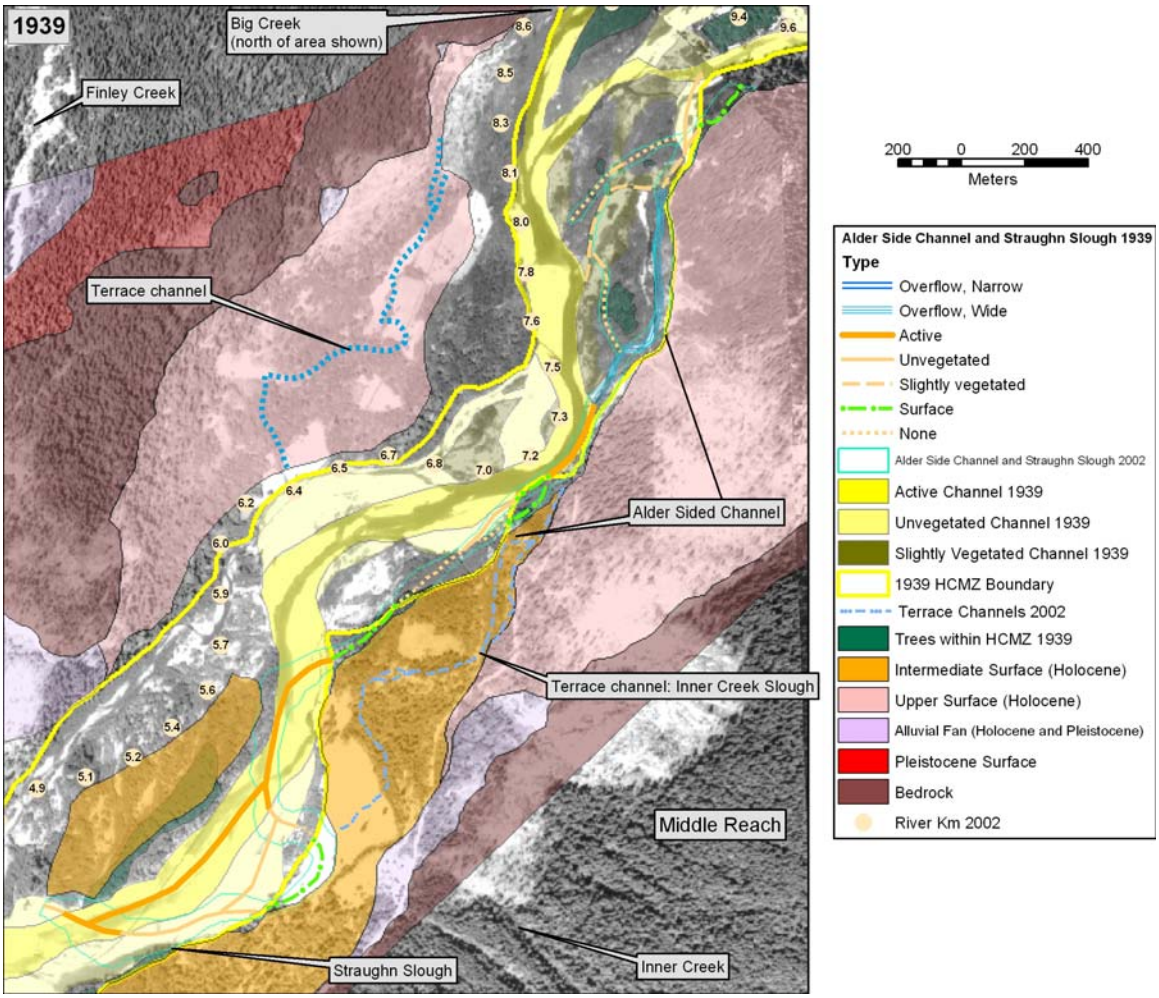

Figure 2. Only section of Alder Side Channel that existed as side channel and potential habitat was a 300-m-long section near the upstream end between RK 7.3 and RK 8.1. The section downstream of Alder Side Channel and Straughn Slough were part of the active or unvegetated channel of the Quinault River or had not yet been cut. (The Alder Side Channel and Straughn Slough were not entirely present until 1994.)

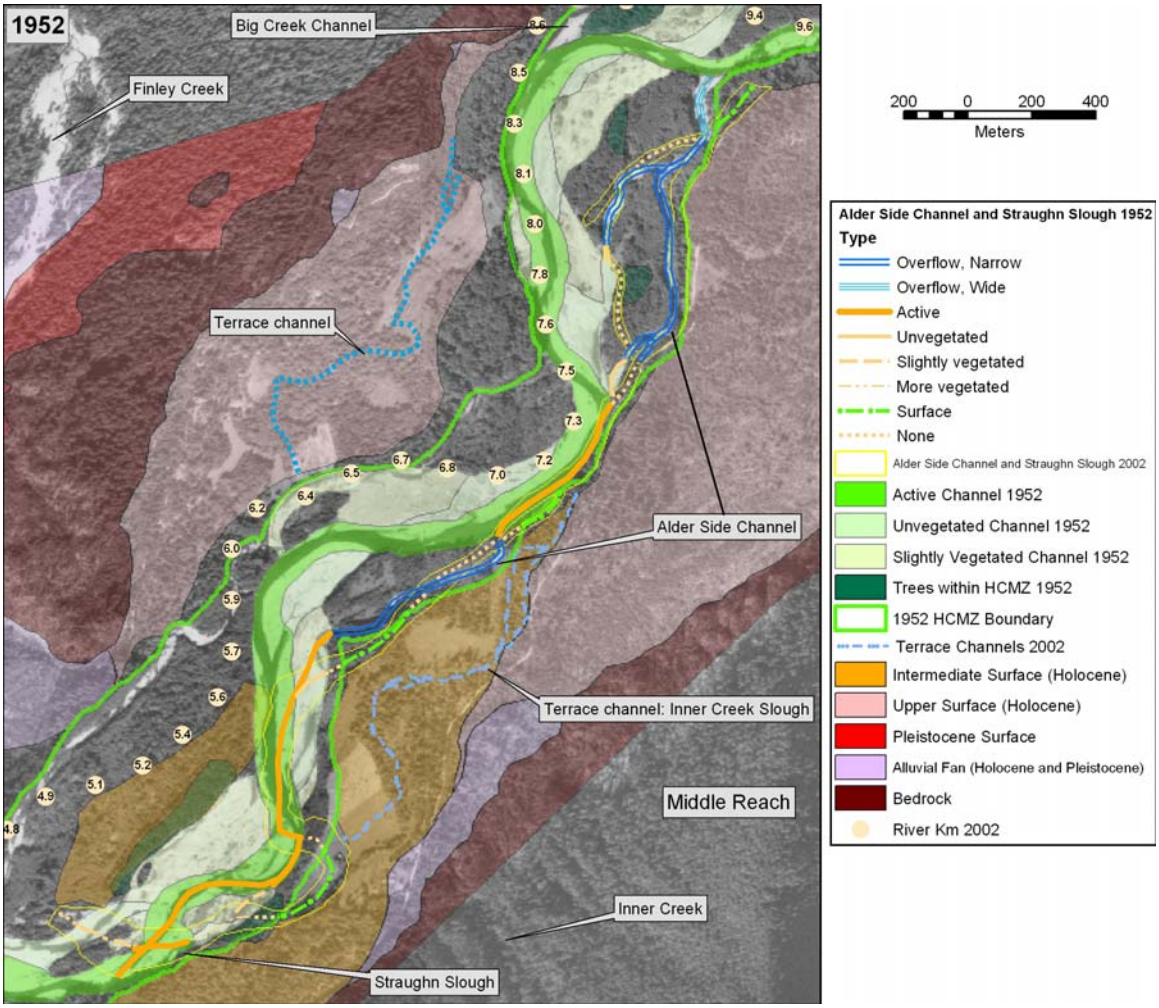

Figure 3. In 1952, the upstream section of Alder Side Channel that was potential habitat increased in length to about 850 m. A downstream section of potential habitat about 650 m long was present in 1952 between about RK 5.9 and RK 6.8. Straughn Slough was still part of the active channel or had not yet been excavated.

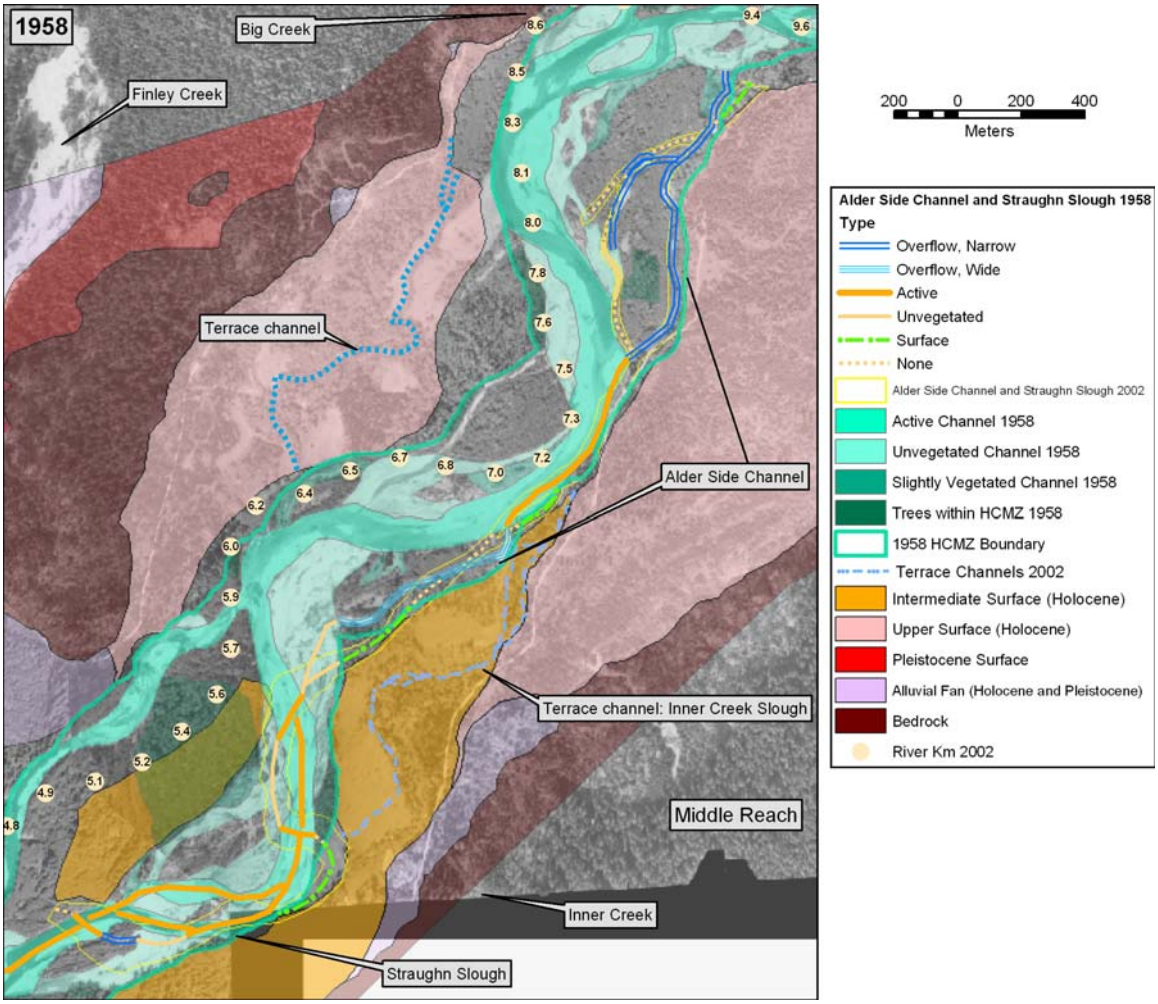

Figure 4. By 1958, the length of the upstream section of Alder Side Channel that was potential habitat had increased to about 900 m. The downstream section of potential habitat was about as it was in 1952. Straughn Slough was still part of the active channel, unvegetated channel, or had not yet been excavated.

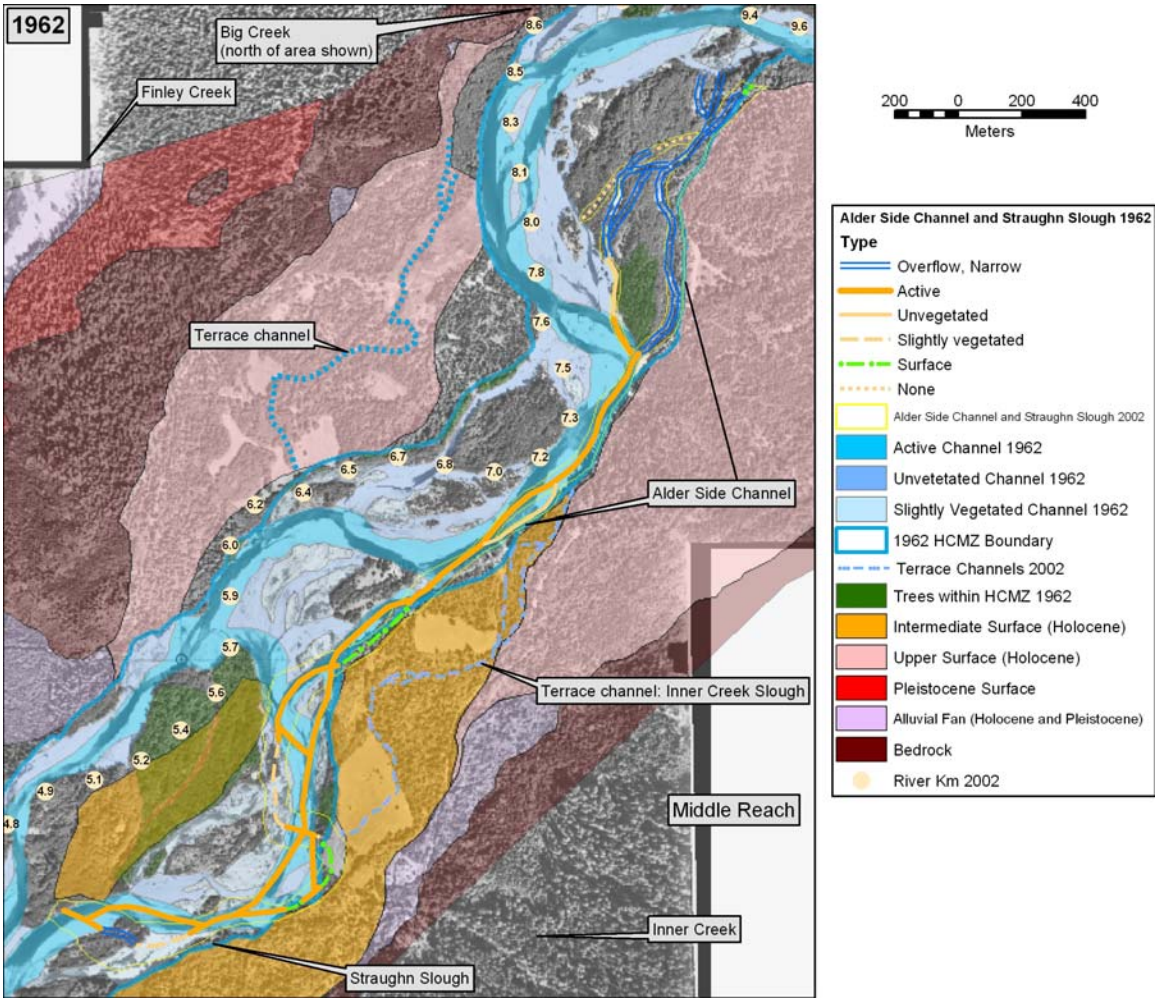

Figure 5. By 1962, the upstream section of Alder Side Channel that was potential habitat increased in length to about 1000 m. A meander in the active channel of the Quinault River had lengthened in a downstream direction since 1958, so that the active channel occupied the downstream section of potential habitat that existed in 1952 and 1958. The part that was active channel in 1962 continued to cut laterally to the south, creating sections that will become part of Alder Side Channel and Straughn Slough in later years. Part of Straughn Slough had not yet been excavated.

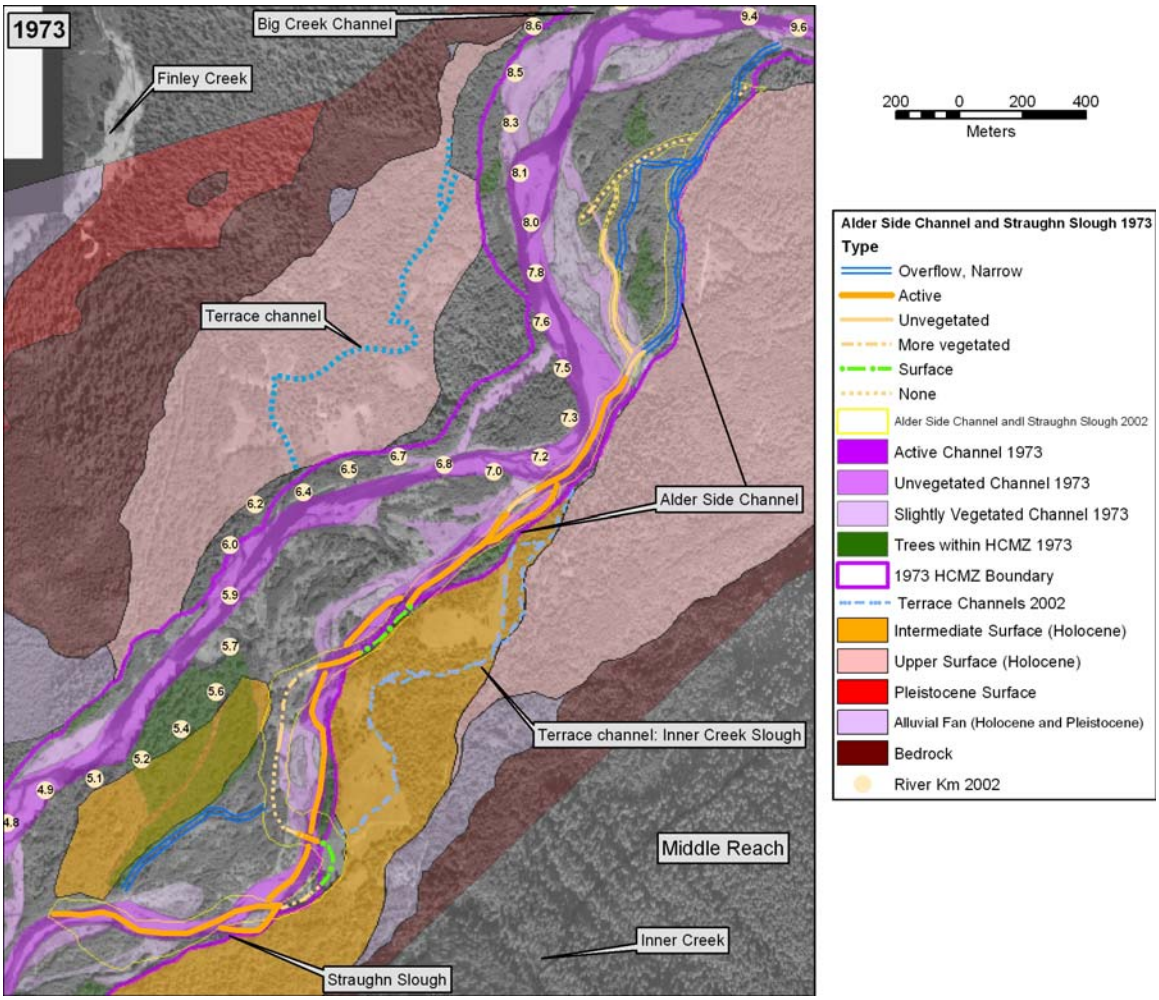

Figure 6. In 1973, the upstream section of Alder Side Channel that was potential habitat was still about 1000 m long, as it was in 1962. One path of the active channel of the Quinault River still flowed along the south (left) HCMZ boundary near the position of the future south portion of Alder Side Channel and Straughn Slough. Part of Straughn Slough had not yet been excavated.

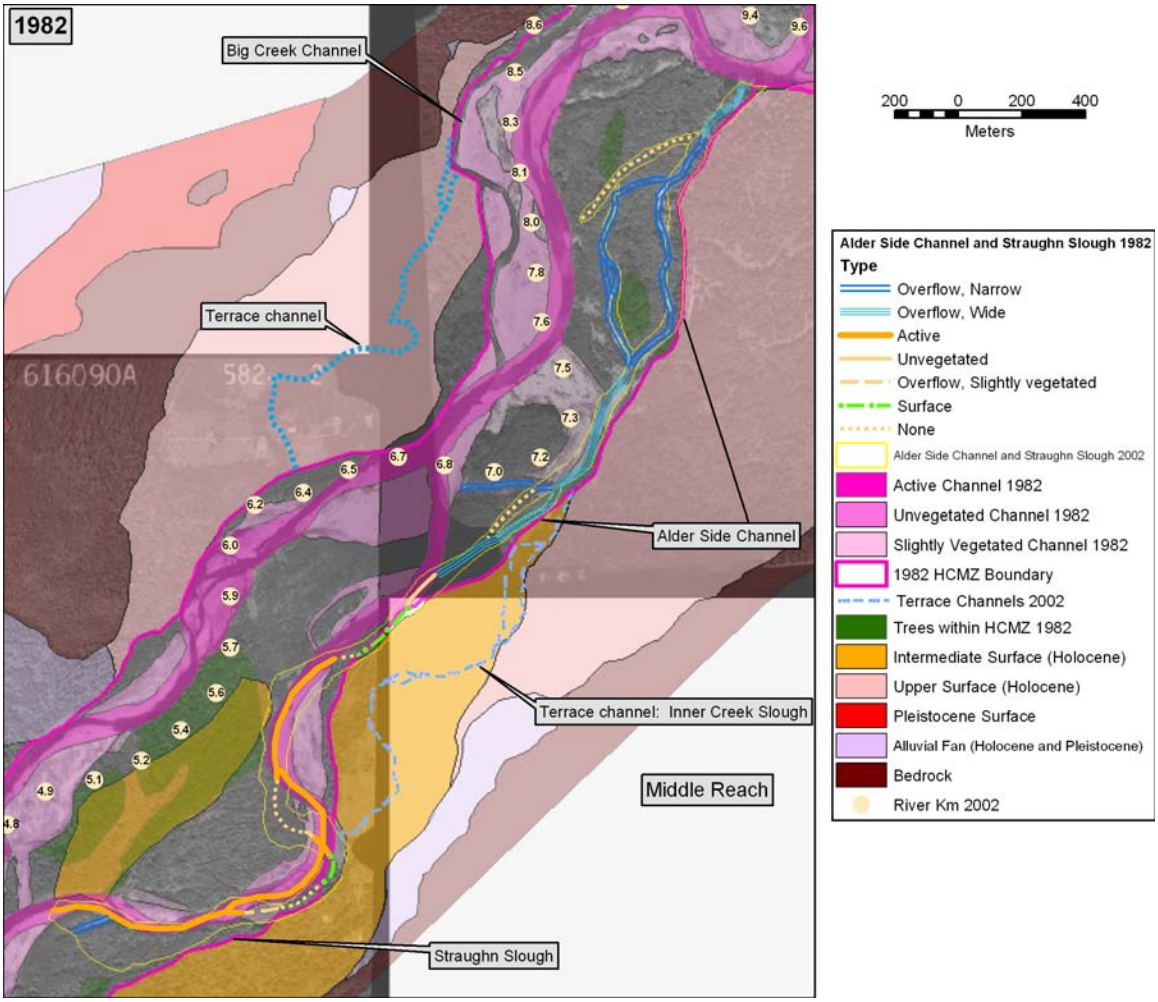

Figure 7. By 1982, the upstream section of potential habitat in Alder Side Channel has extended to a length of about 2000 m. The south (left) path of the active channel of the Quinault River flowed along the downstream about 2000 m of Alder Side Channel and Straughn Slough. In 1982, it appears that more flow was in the north path of the active channel of the river. The channel that becomes Straughn Slough had been nearly entirely excavated by 1982.

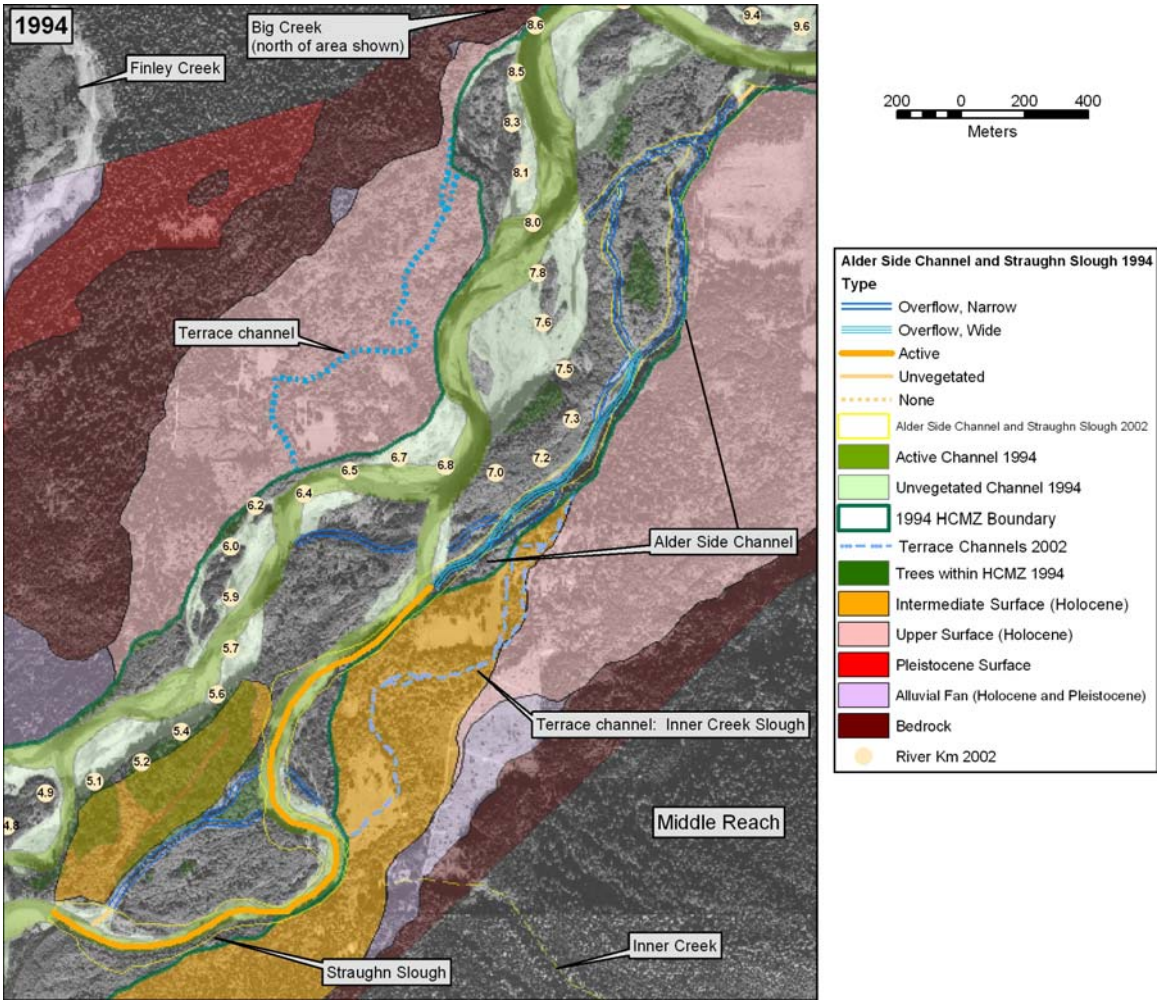

Figure 8. In 1994, the length of the upstream section of Alder Side Channel that was potential habitat was still about 2000 m long. The south (left) path of the active channel of the Quinault River flows in the downstream section of Alder Side Channel and Straughn Slough. Alder Side Channel and Straughn Slough have the configuration that they do in 2002.

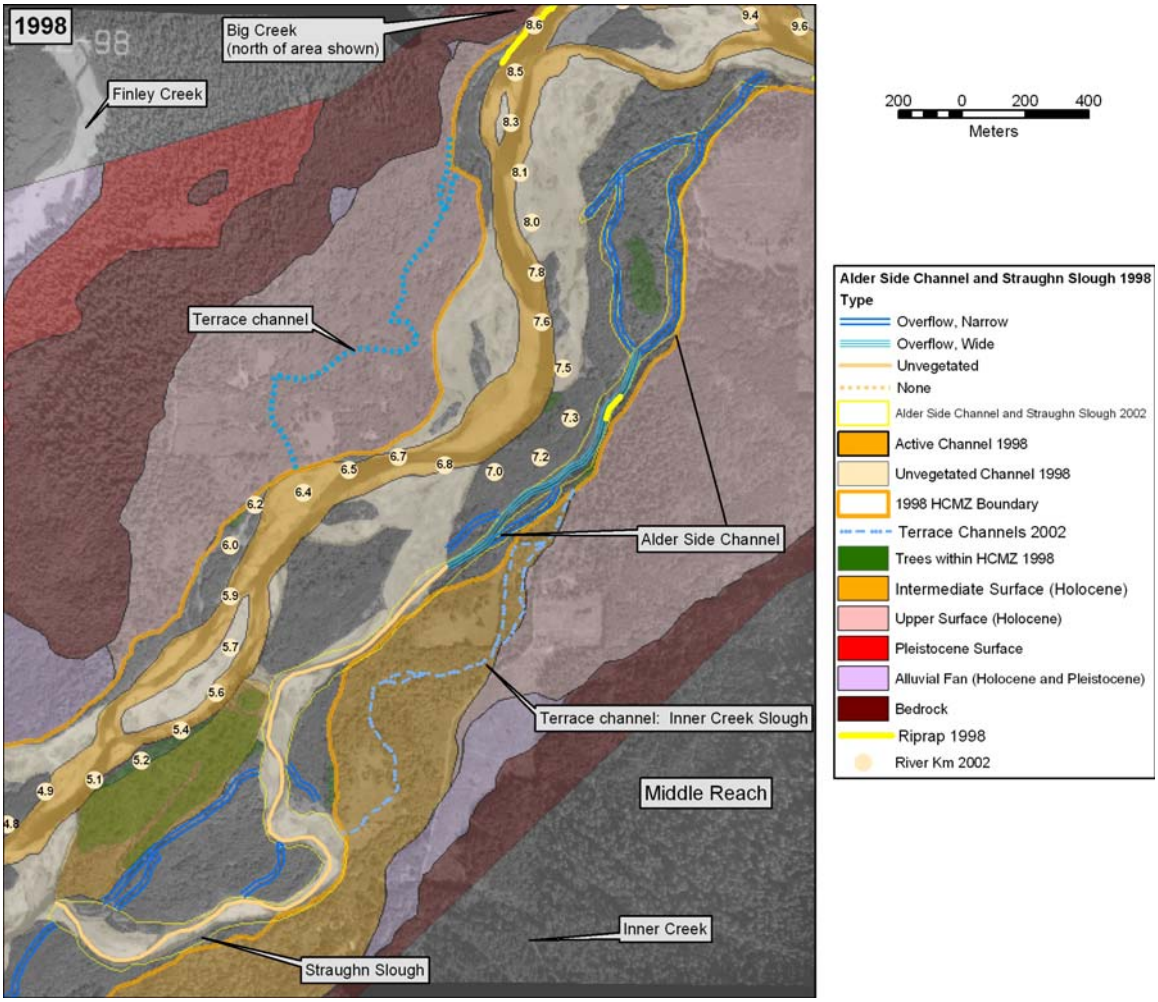

Figure 9. In 1998, the upstream section of Alder Side Channel that was potential habitat was about the same as it was in 1994. However, the downstream section of Alder Side Channel (between about RK 5.7 and RK 6.7) and Straughn Slough had been abandoned by the active channel of the Quinault River, and were now an unvegetated overflow channel only. Note the formation of additional narrow channels through riparian vegetation in several localities adjacent to Alder Side Channel.

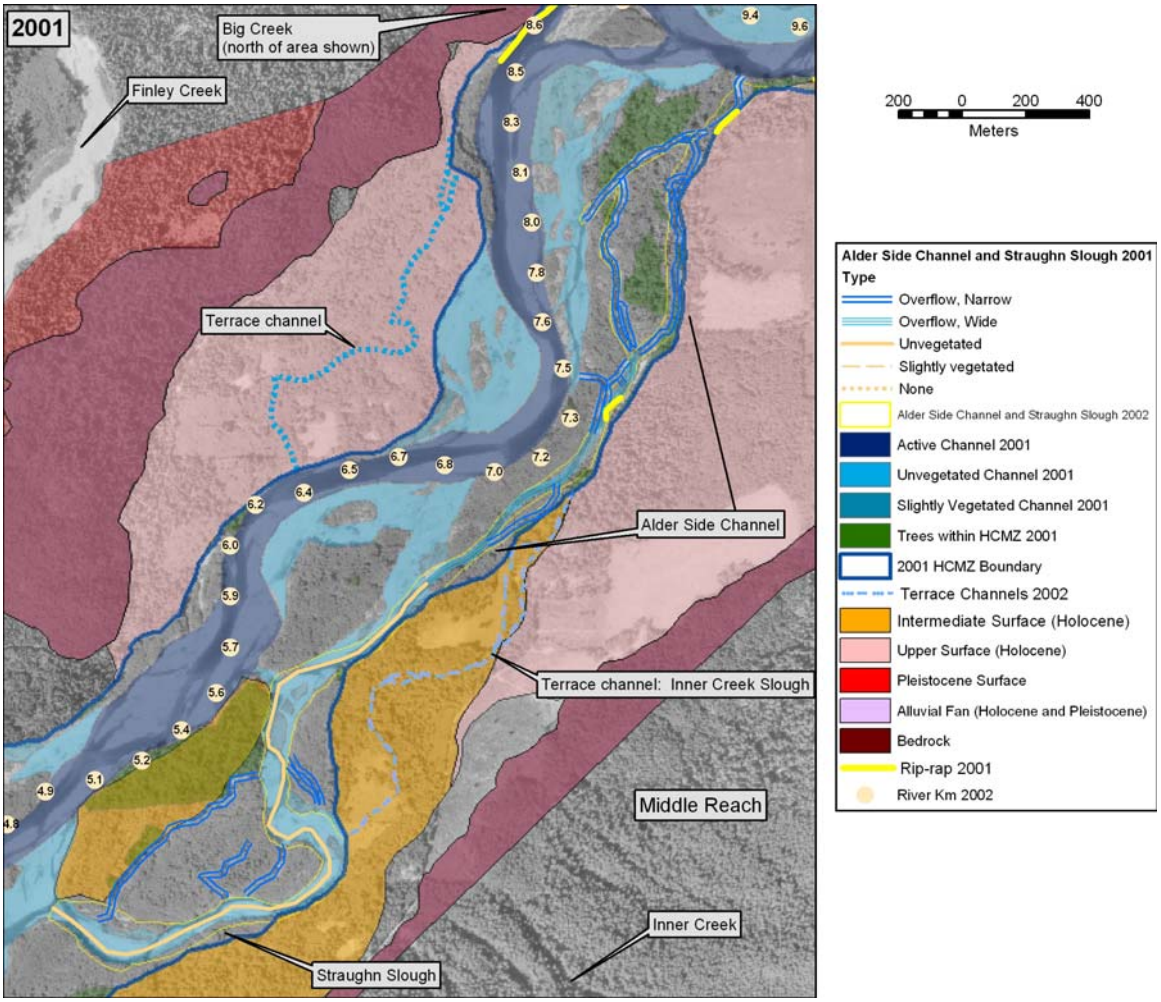

Figure 10. In 2001, the configurations of Alder Side Channel and Straughn Slough were much as they were in 1998. The upstream section of Alder Side Channel that was potential habitat was still about 2000 m long. The downstream portion of Alder Side Channel and Straughn Slough (about 2000 m long) were still part of the unvegetated channel of the Quinault River.

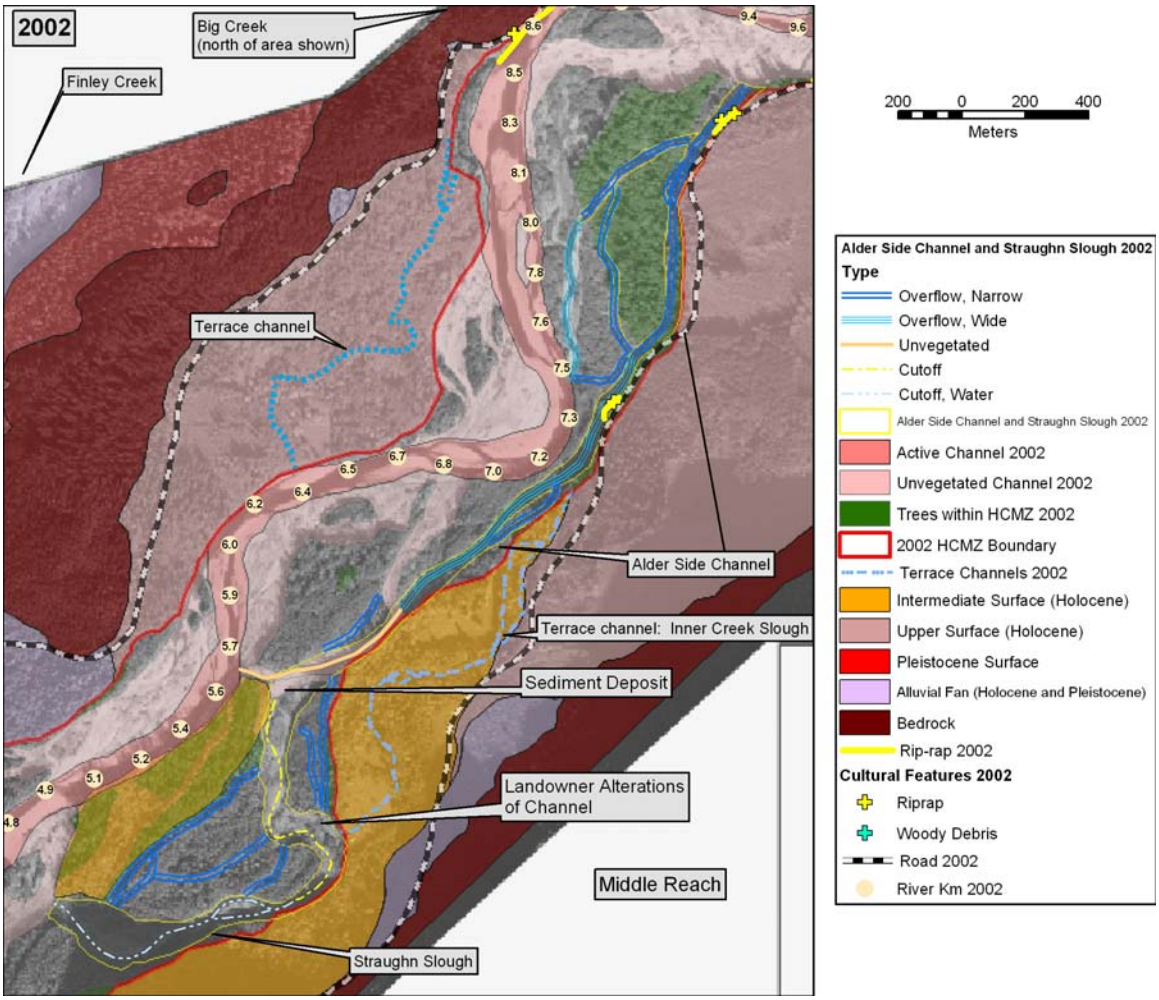

Figure 11. By 2002, the upstream section of Alder Side Channel that was potential habitat was similar to its configuration and length in 2001. A high flow caused the Quinault River to reoccupy the unvegetated channel between RK 5.7 and RK 6.8, the downstream end of Alder Side Channel. A sediment deposit was present near the mouth of Alder Side Channel near RK 5.6, where the unvegetated channel turns to join the active channel of the Quinault River. An overflow channel downstream of this point did not appear to receive surface flow from the river. Straughn Slough, which is the downstream about 900 m of this dry overflow channel, still had water visible in it in 2002. This flow may be from Inner Creek, a tributary, or groundwater.

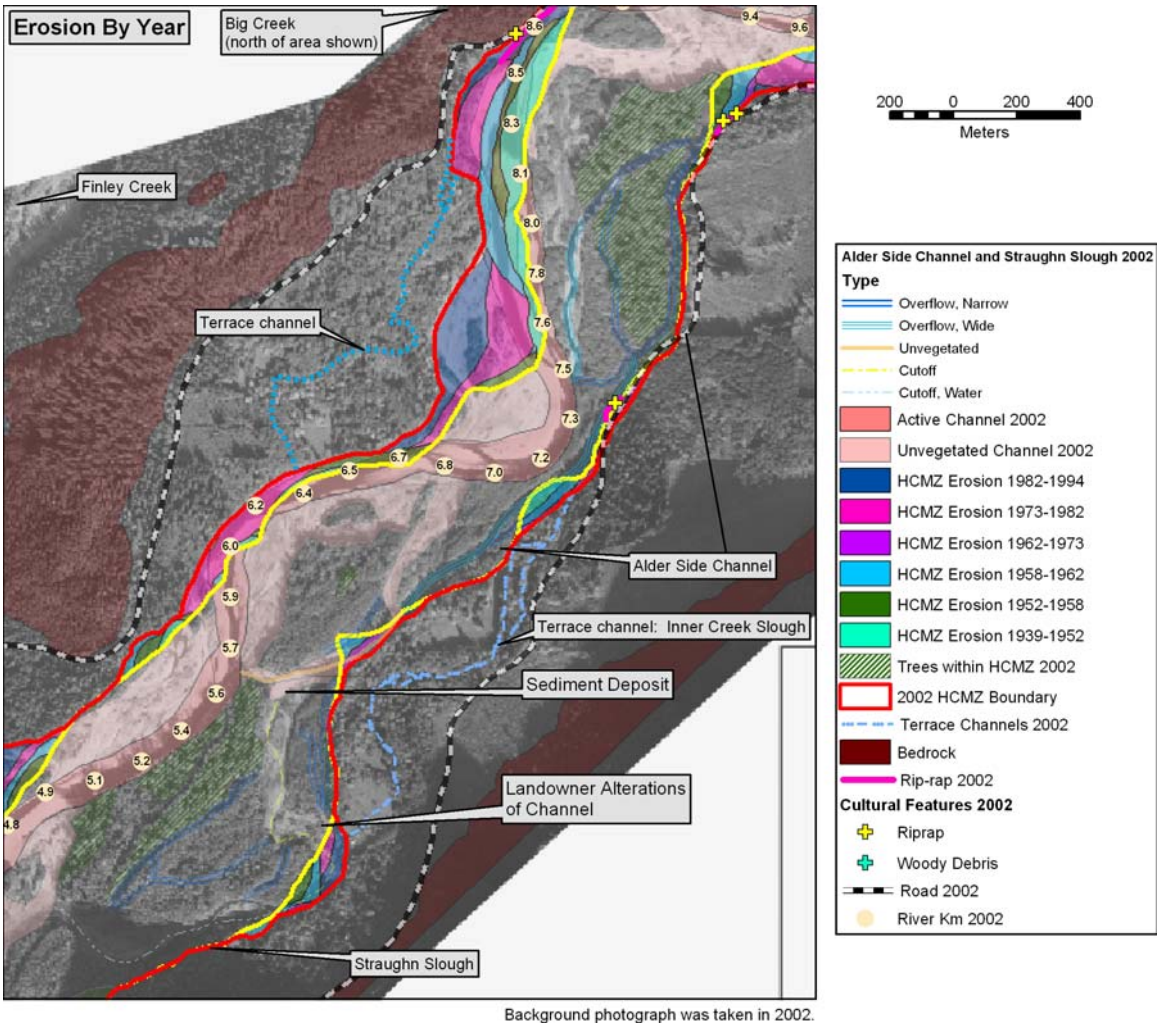

Figure 12. Bank erosion between 1939 and 2002 occurred mostly on the northwest side of the Quinault Valley opposite Alder Side Channel. The erosion occurred between 1939 and 1994. The erosion between RK 7.5 and RK 8.6 allowed the upstream end of Alder Side Channel to become stable habitat between 1939 and 2002. Erosion also has occurred upstream of Alder Side Channel on the south side of the valley.

History and Geomorphology of Taiber Slough, 1897 through 2002

Taiber Slough, a side channel in the Quinault River system, is located on the north side of the Quinault River valley between RK 2.5 and RK 3.5 (Figure 1). It flows along a large alluvial-fan deposit (purple area in Figure 1) from Finley Creek, mainly, and Kestner Creek. Taiber Slough is downstream of a bedrock knob that extends into the valley (upstream) from the north near RK 5.2.

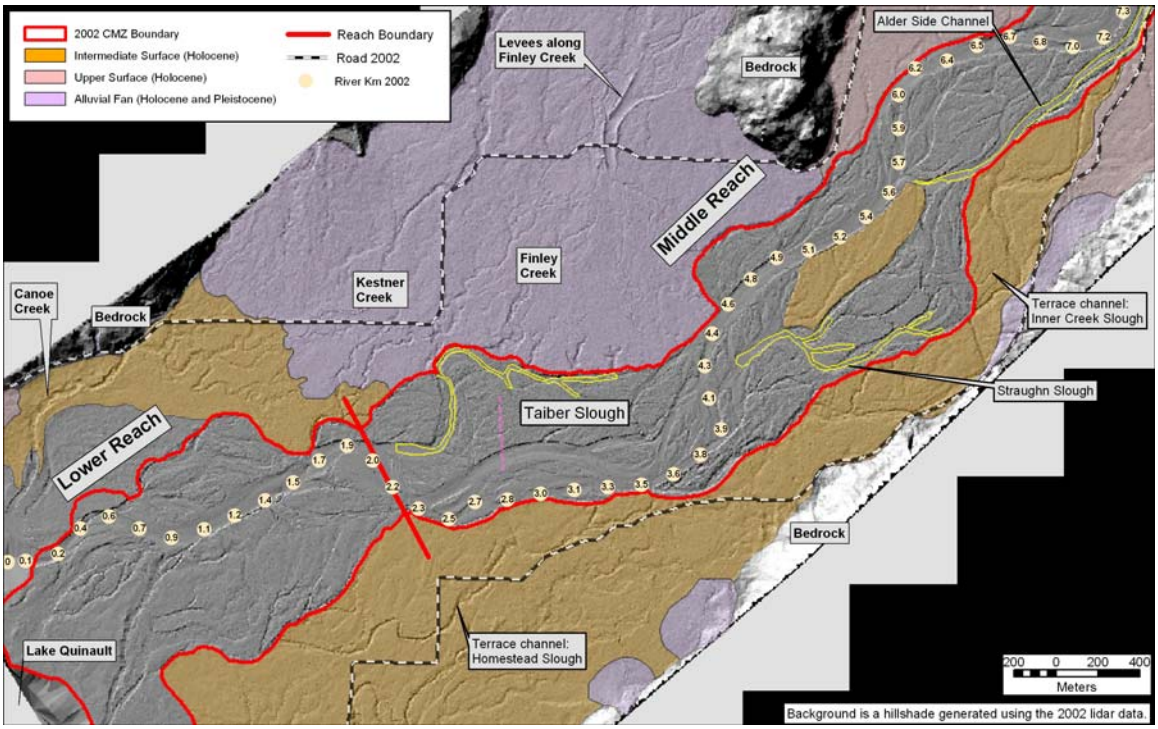

Figure 1. Taiber Slough is located along the north boundary of the historical channel migration zone (HCMZ) between RK 2.5 and RK 3.5 on the north side of the Quinault River valley. It flows along the large alluvial-fan deposit from Finley Creek, mainly, and Kestner Creek. Background is a hillshade created from 2002 LiDAR data. River kilometers are from the low-flow channel at the time of a river survey in 2002.

The following maps (Figures 2 through 11) show the history of formation of potential habitat in the area of Taiber Slough between 1897 and 2002.

Changes in Taiber Slough Area by Year

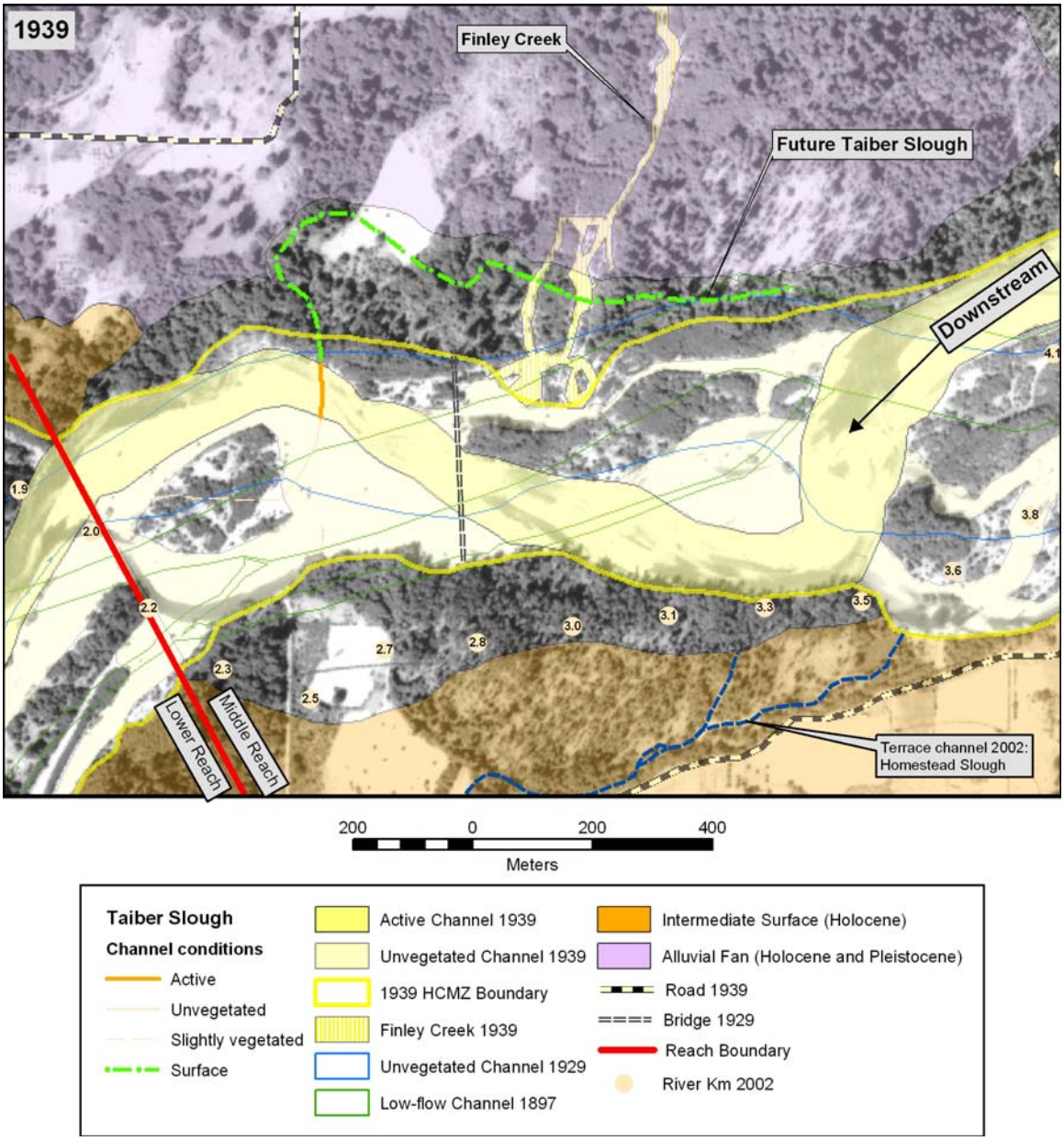

Figure 2. In 1897 (green outline) and 1929 (blue outline), the path of the future Taiber Slough was north of the low-flow and active channels, and the channel that became Taiber Slough is presumed to be not present at these times. The area was likely the surface of the alluvial-fan deposit from Finley Creek. In 1939, most of the path of the future Taibor Slough (dashed green line) is through the vegetated surface of the large alluvial-fan deposit from Finley Creek. Taiber Slough would have crossed perpendicularly channels of Finley Creek. The downstream about 450 m of Taiber Slough flows in the unvegetated channel of the Quinault River, and probably was not potential habitat.

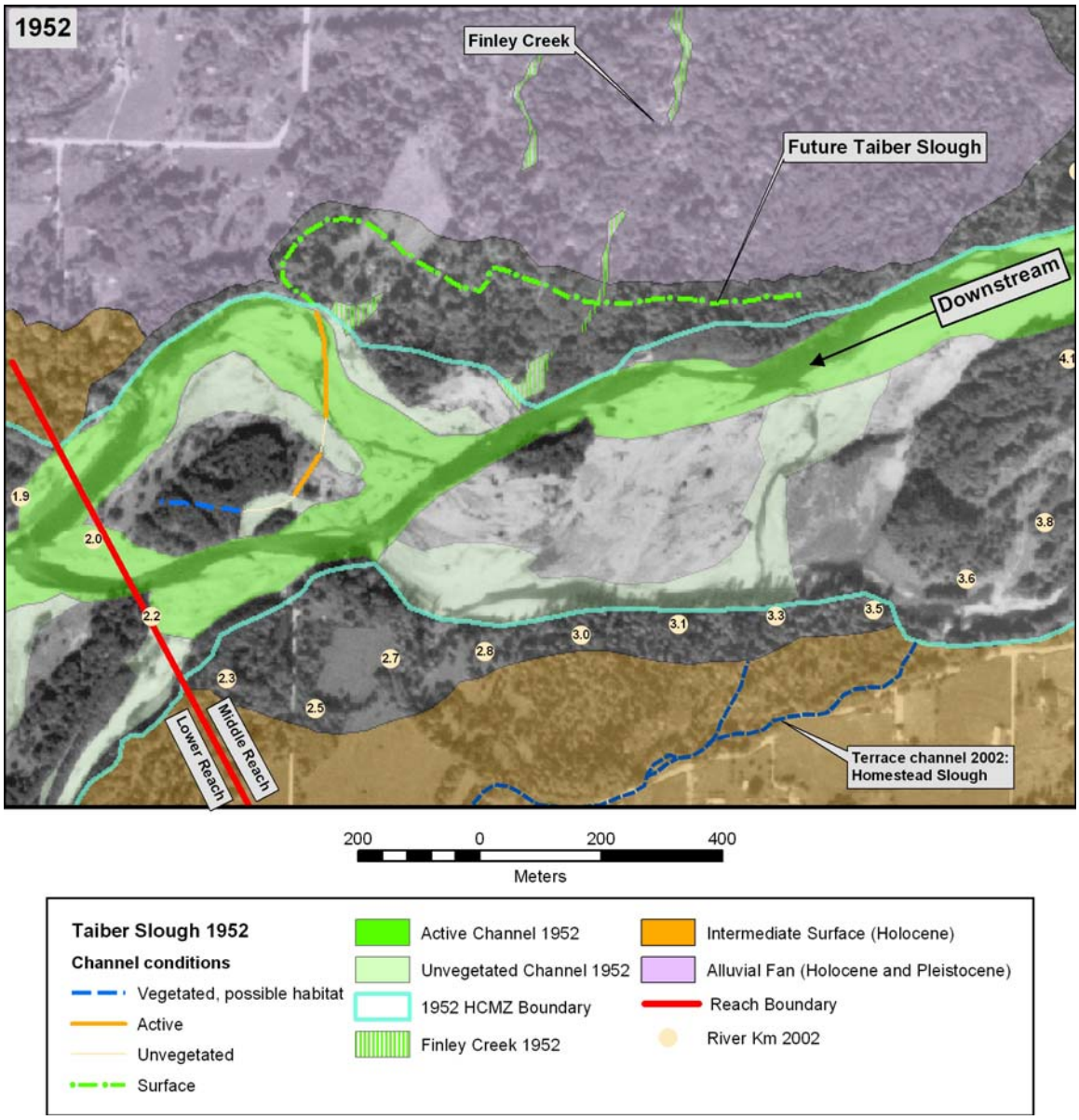

Figure 3. In 1952, the configuration of Taiber Slough was similar to its configuration in 1939. The downstream portion that was within the unvegetatetd channel of the Quinault River (about 560 m long) was slightly longer than it was in 1939 (about 450 m long).

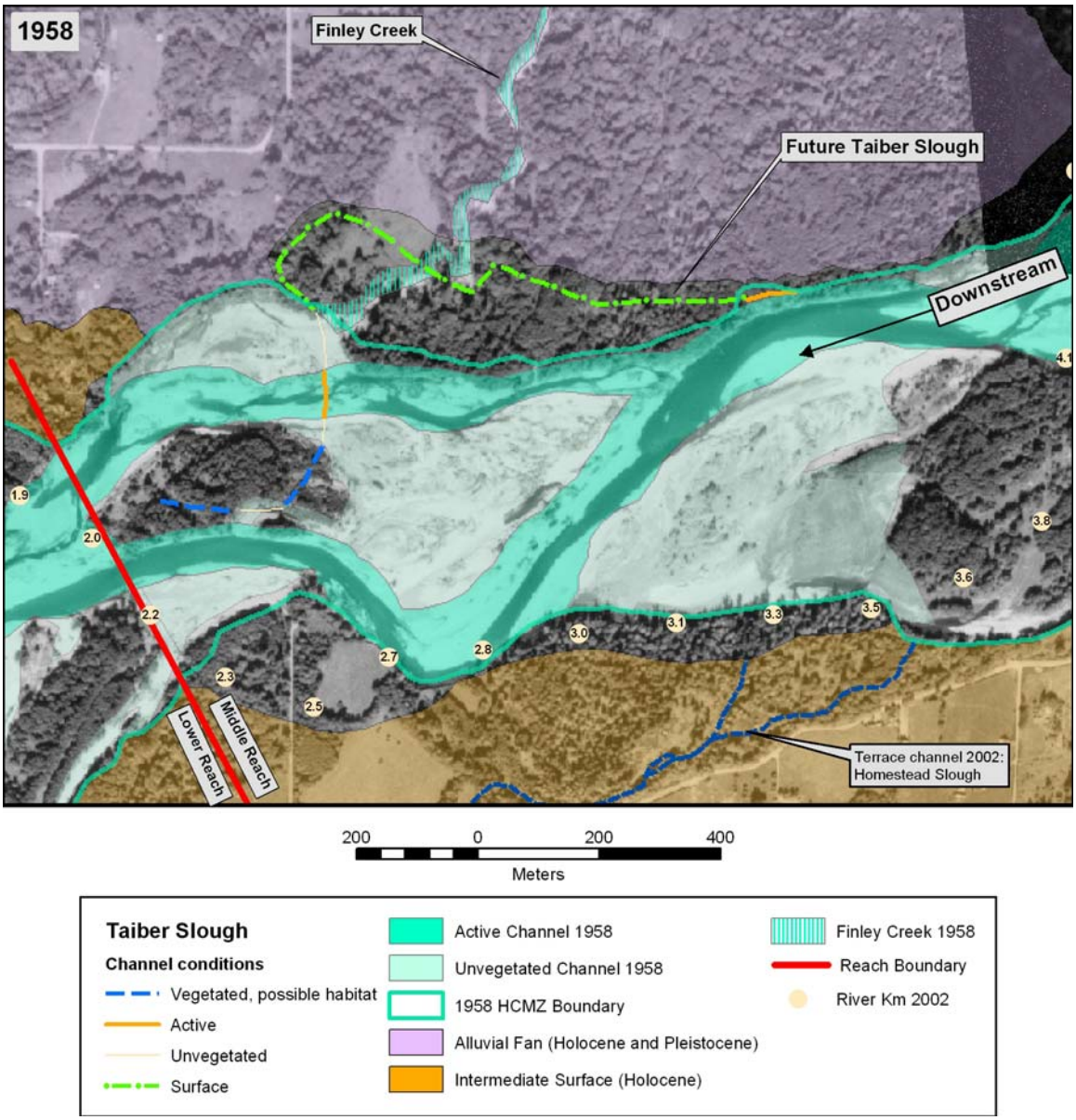

Figure 4. The configuration of Taiber Slough in 1958 was similar to what it was in 1952. One change was that the active channel of the Quinault River had moved northward (laterally) into the alluvial-fan surface of Finley Creek near RK 3.3, so that about 85 m of the future Taiber Slough had been excavated. This slight bend in the active channel of the Quinault River will become progressively more pronounced and will migrate downstream by eroding into the alluvial-fan deposit and eventually result in cutting of the channel that will become Taiber Slough. The split flow path in the active channel of the Quinault River between RK 2.0 and RK 3.1 had lengthened since 1952, and the north flow path of the Quinault River had straightened and eroded laterally into the large alluvial-fan deposit from Finley Creek.

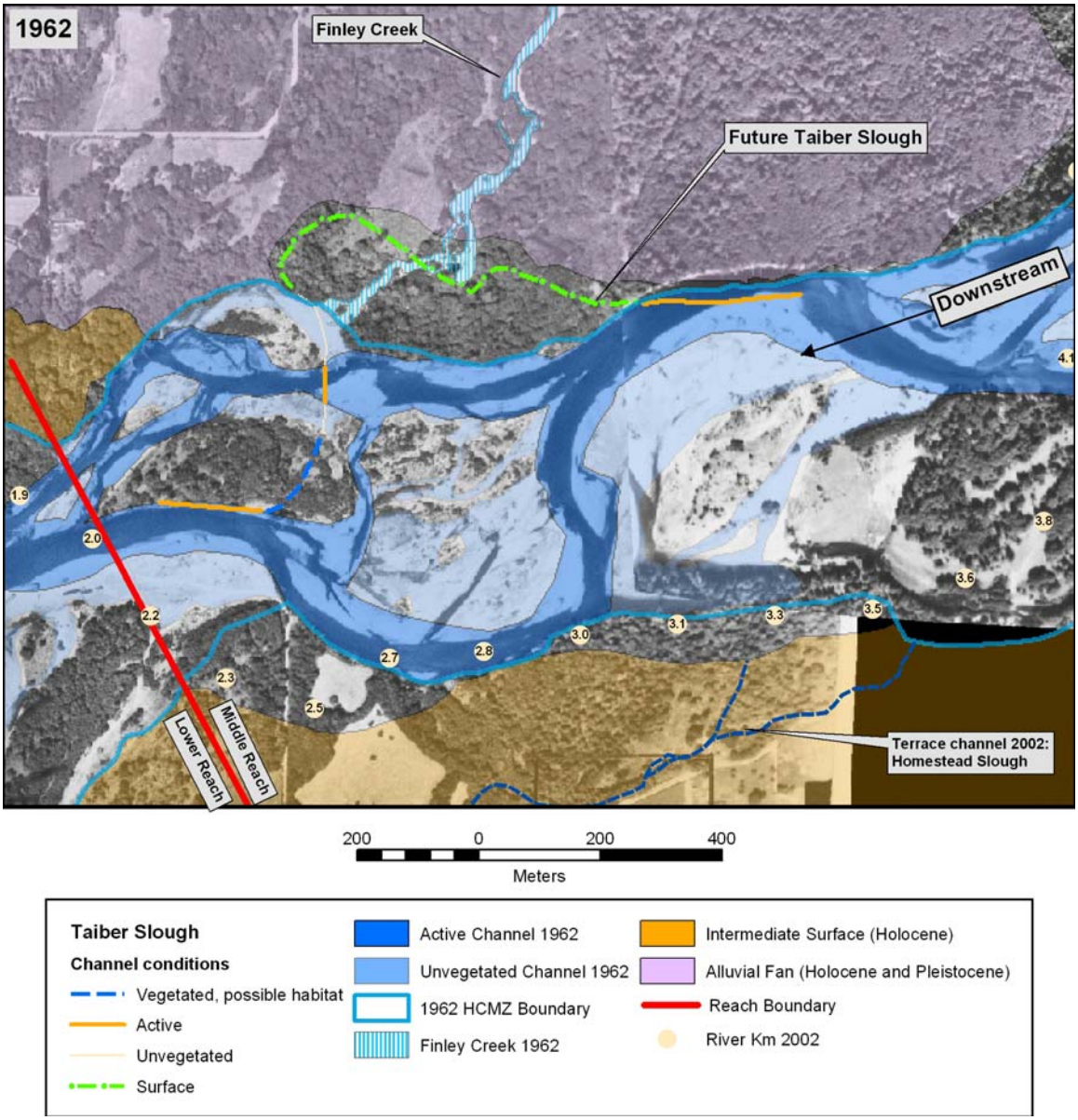

Figure 5. The upstream end of the future Taiber Slough that formed as part of the active channel of the Quinault River had lengthened to about 250 m in 1962. (In 1958, it was about 85 m long.) This was because the meander between RK 3.1 and RK 3.5 moved outward (to the north) and downstream by eroding the alluvial-fan deposit. The downstream portion of the future Taiber Slough that was within or near the unvegetated channel of the Quinault River also had lengthened to nearly 600 m. Consequently, the section of Taiber Slough that traversed the vegetated surface of the alluvial-fan deposit was shorter than it had been in previous years. The active and unvegetated channels of the Quinault River were more branching between RK 1.9 and RK 3.1 than they were in previous years, when only two flow paths were present.

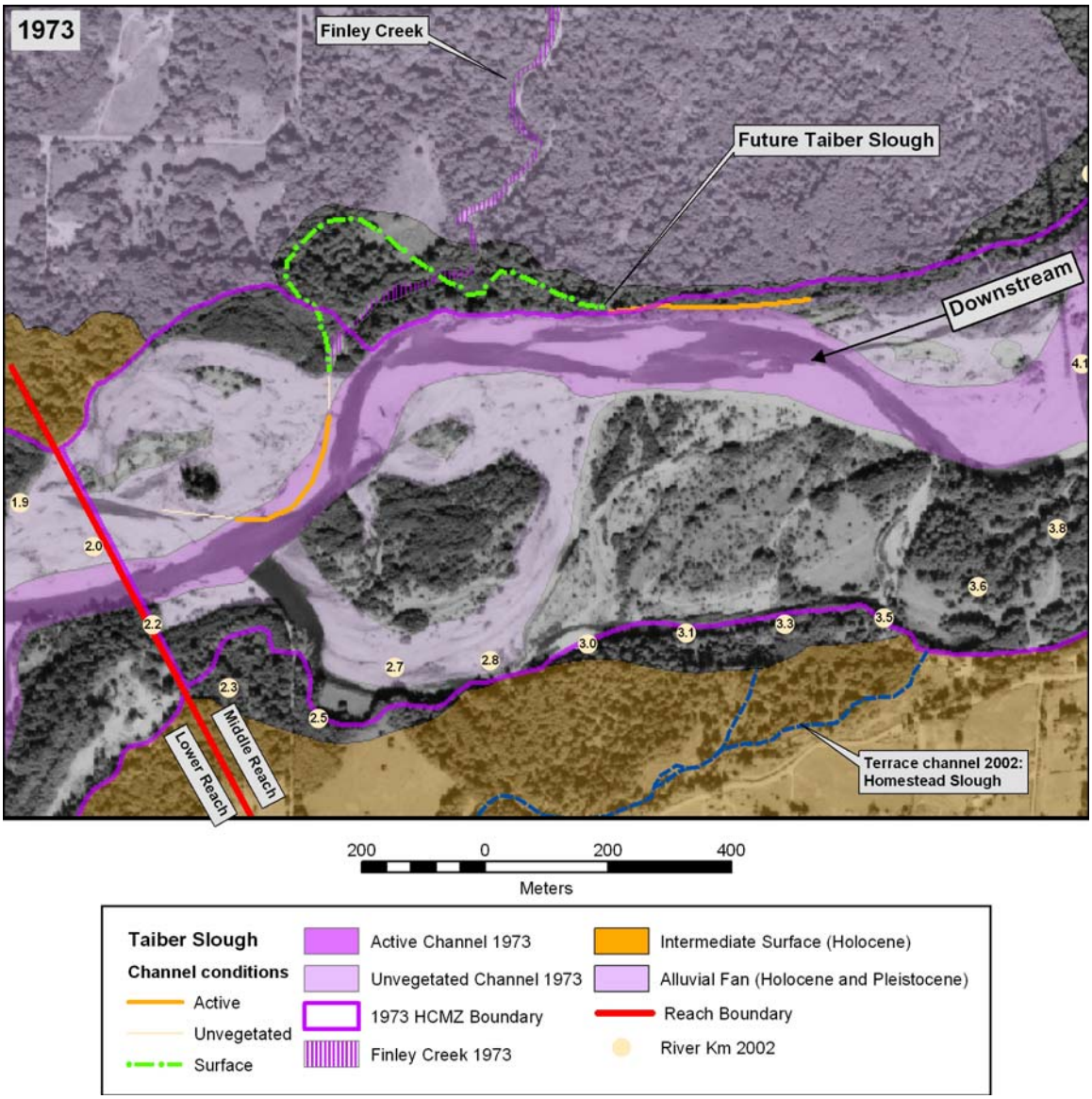

Figure 6. The upstream end of the future Taiber Slough that was part of the active channel of the Quinault River had lengthened to about 330 m by 1973. (It was about 250 m long in 1962.). This was because the meander had again moved downstream, to about RK 2.7 by 1973, by eroding more of the large alluvial-fan deposit from Finley Creek. The downstream portion of the future Taiber Slough that was within or near the unvegetated channel of the Quinault River was about the same length (600 m) as it was in 1962. Consequently, the section that traversed the vegetated surface was about the same as it was in 1962. The active channel of the Quinault River was a single flow path in 1973, which was along the north edge of the alluvial-fan deposit in this section of the river.

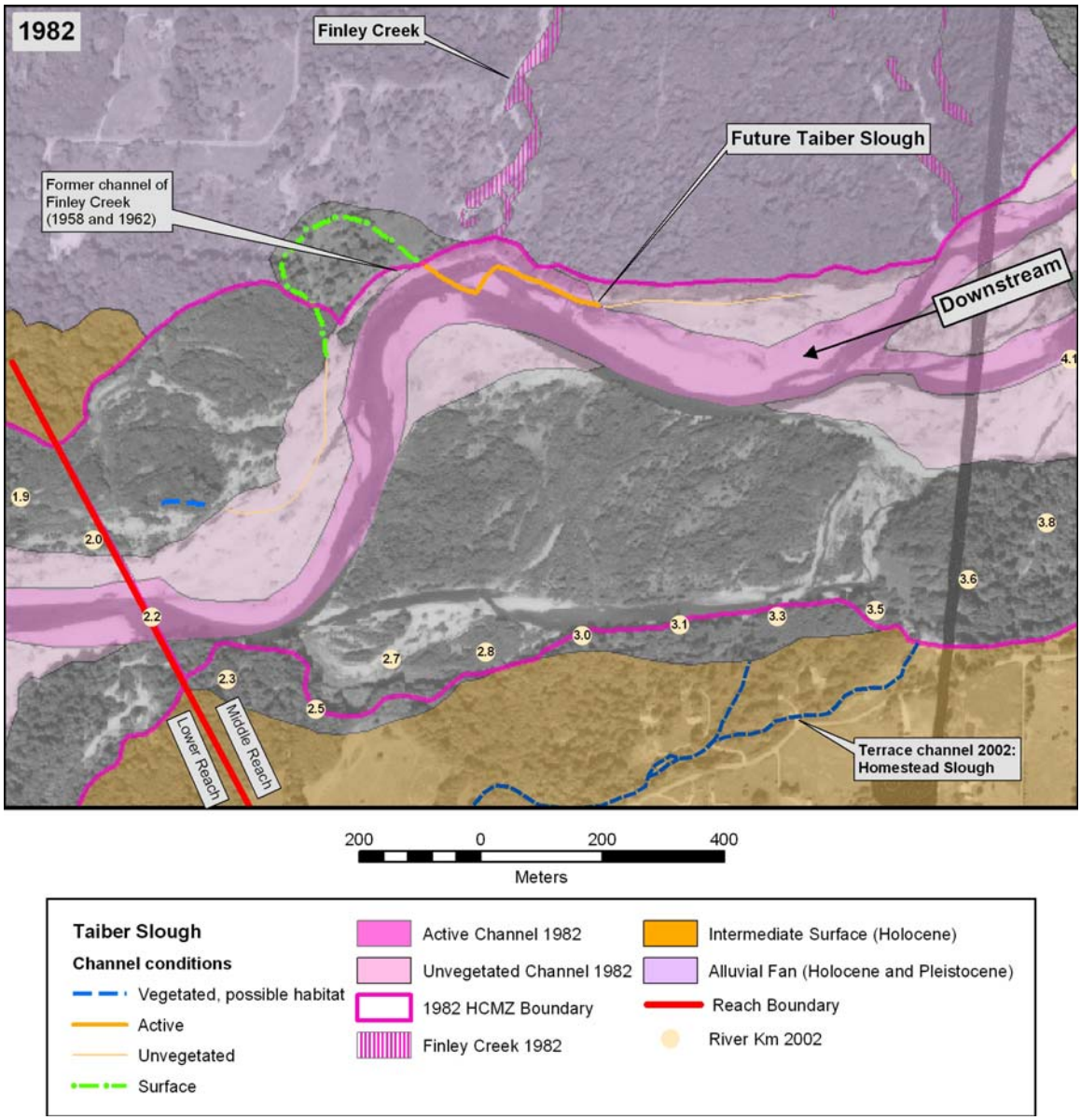

Figure 7. By 1982, the upstream section of the future Taiber Slough that had formed as part of the active and unvegetated channels of the Quinault River had lengthened to about 670 m. (It was about 330 m long in 1973.) As a result, the section of the future slough that had not yet formed was still part of the vegetated surface of the large alluvial-fan deposit from Finley Creek was only about 400 m long. The meander in the active channel of the Quinault River between RK 2.7 and RK 3.1 had become more sinuous and had migrated outward and downstream since 1973 by eroding farther into the alluvial-fan deposit. The active channel had overtaken an old path of Finley Creek that had been present since at least 1958 (fig. 4). The downstream portion of Taiber Slough that was within an unvegetated channel of the Quinault River was about as long as it was in 1962 and 1973 (about 600 m).

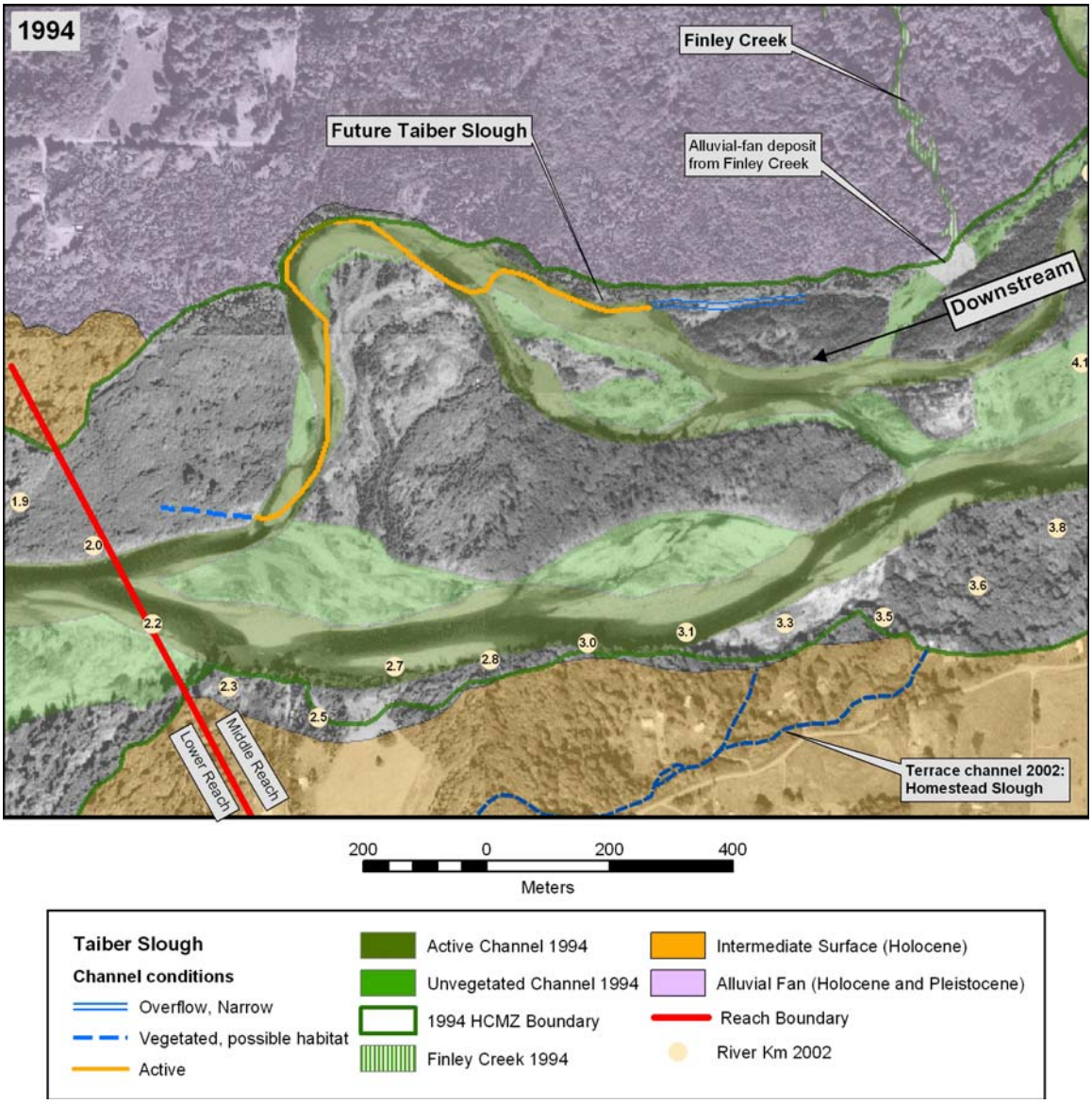

Figure 8. By 1994, the entire path of the future Taiber Slough had been cut by outward and downstream migration of the meander in the active channel of the Quinault to about RK 2.5. Nearly all of the future Taiber Slough was part of the active channel of the Quinault River in 1994. The exceptions were the very upstream end (about 250 m) and very downstream end (about 200 m), which were narrow channels through vegetation and may already have been potential habitat. The active channel of the Quinault River had split flow between RK 2.5 and RK 3.6. Finley Creek in 1994 entered the Quinault River channel upstream of Taiber Slough. This may have been at least in part to redirection of the flow paths of Finley Creek by levees constructed and maintained about 600 m upstream of Taiber Slough (fig. 1).

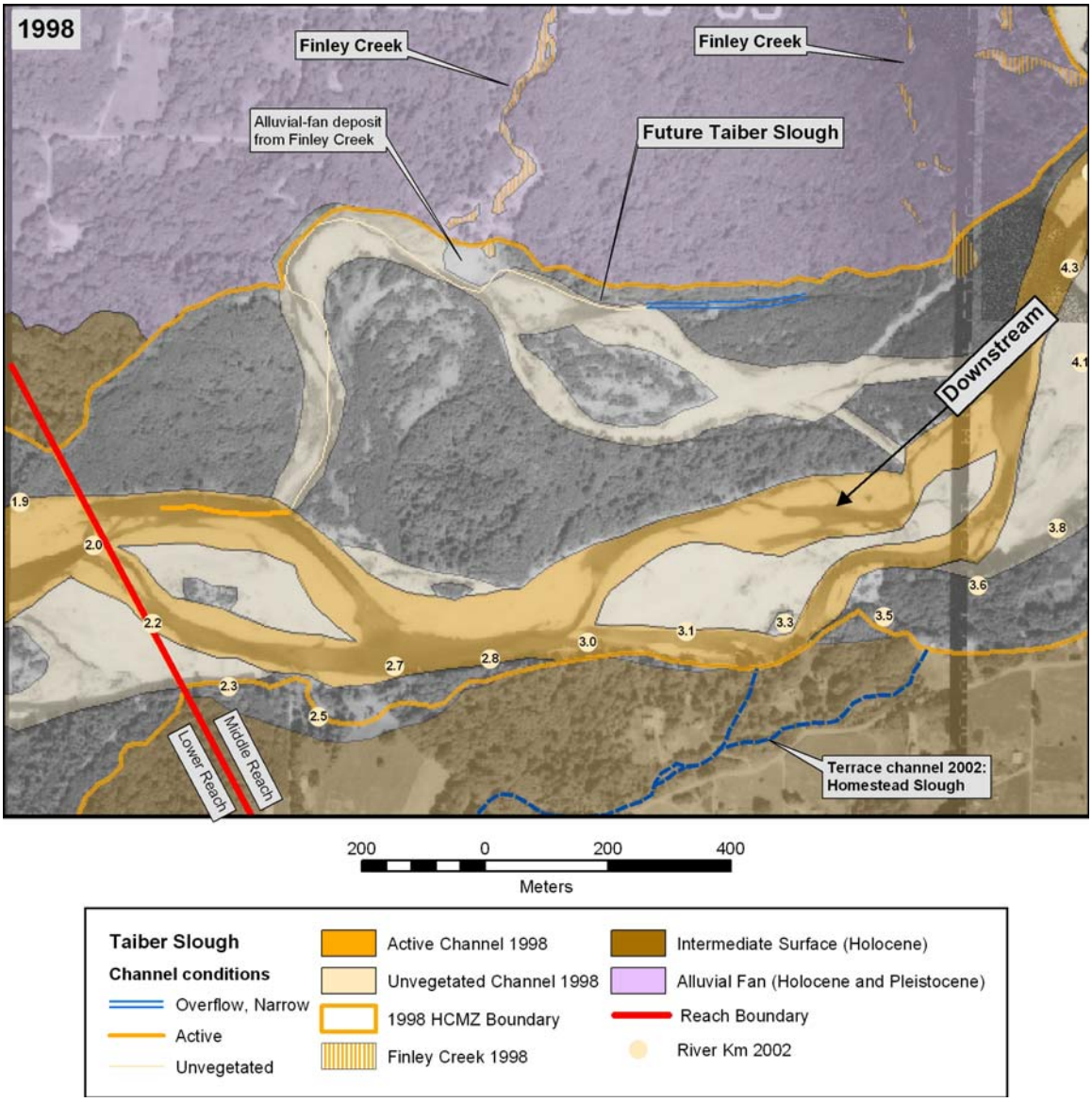

Figure 9. By 1998, the north path of the active channel of the Quinault River (future Taiber Slough) had been abandoned except during highest flows. It was now an unvegetated overflow channel, which will eventually become Taiber Slough (a side channel). The active channel was limited to the south path, and had straightened since 1994. Most of the future Taiber Slough was within the unvegetated overflow channel of the Quinault River. The exceptions were the upstream end (about 250 m), which was a narrow channel through riparian vegetation and may have been potential habitat, and the downstream end (about 250 m), which was within the active channel of the Quinault River.

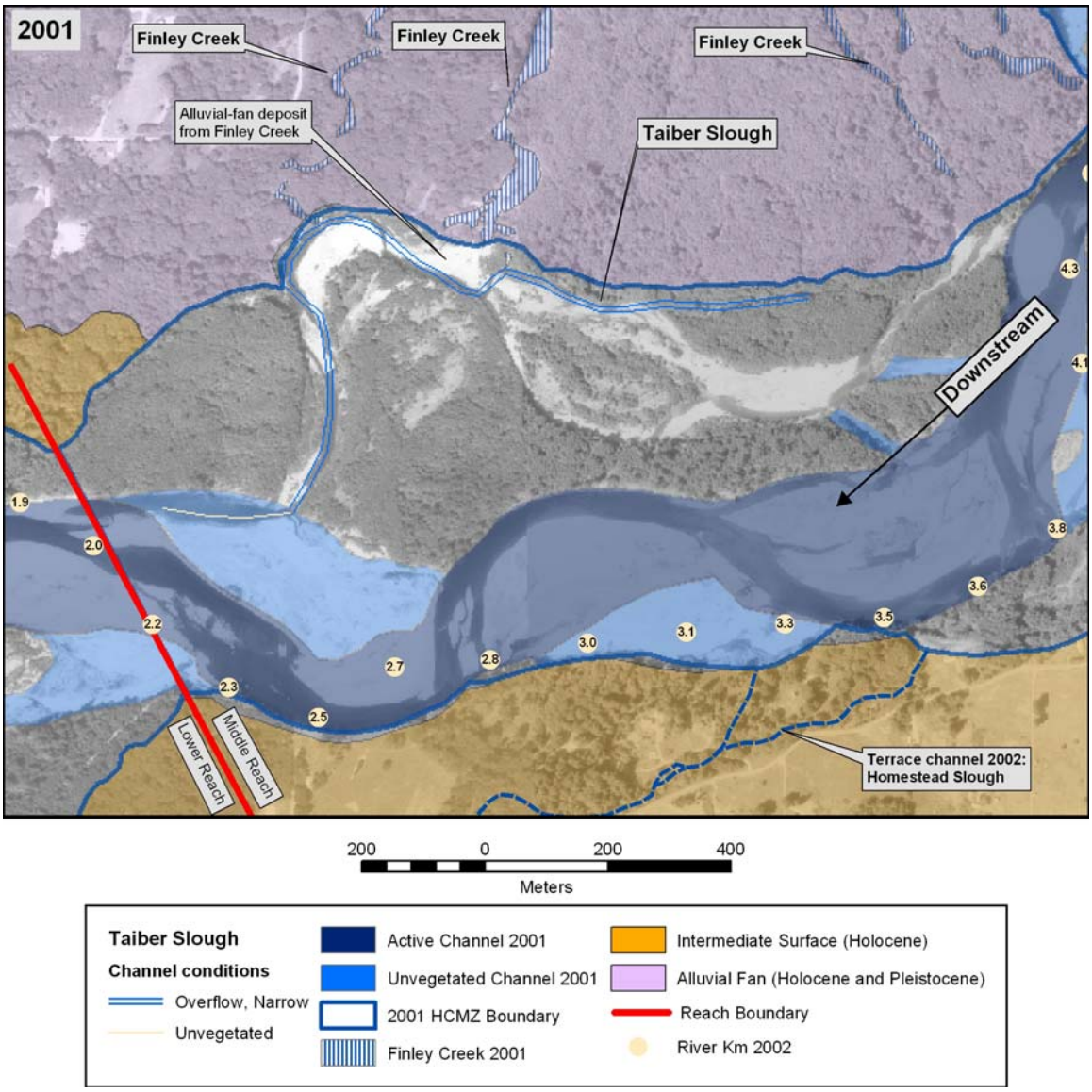

Figure 10. By 2001, most of Taibor Slough was present as potential habitat, a relatively narrow channel through areas with dense to sparse vegetation. B. Armstrong of QIN (written commun., 2003) suggested that this newly formed habitat replaced some of the habitat that was lost at Merriman Creek on the opposite side of the valley. Flows strong enough to disrupt vegetation apparently did not reach this channel or reached it infrequently. Deposition at the head of the channel, near RK 3.5, may have been responsible. The active channel of the Quinault River maintained a path to the south. Finley Creek had established several paths to the Quinault River, two of which entered Taiber Slough.

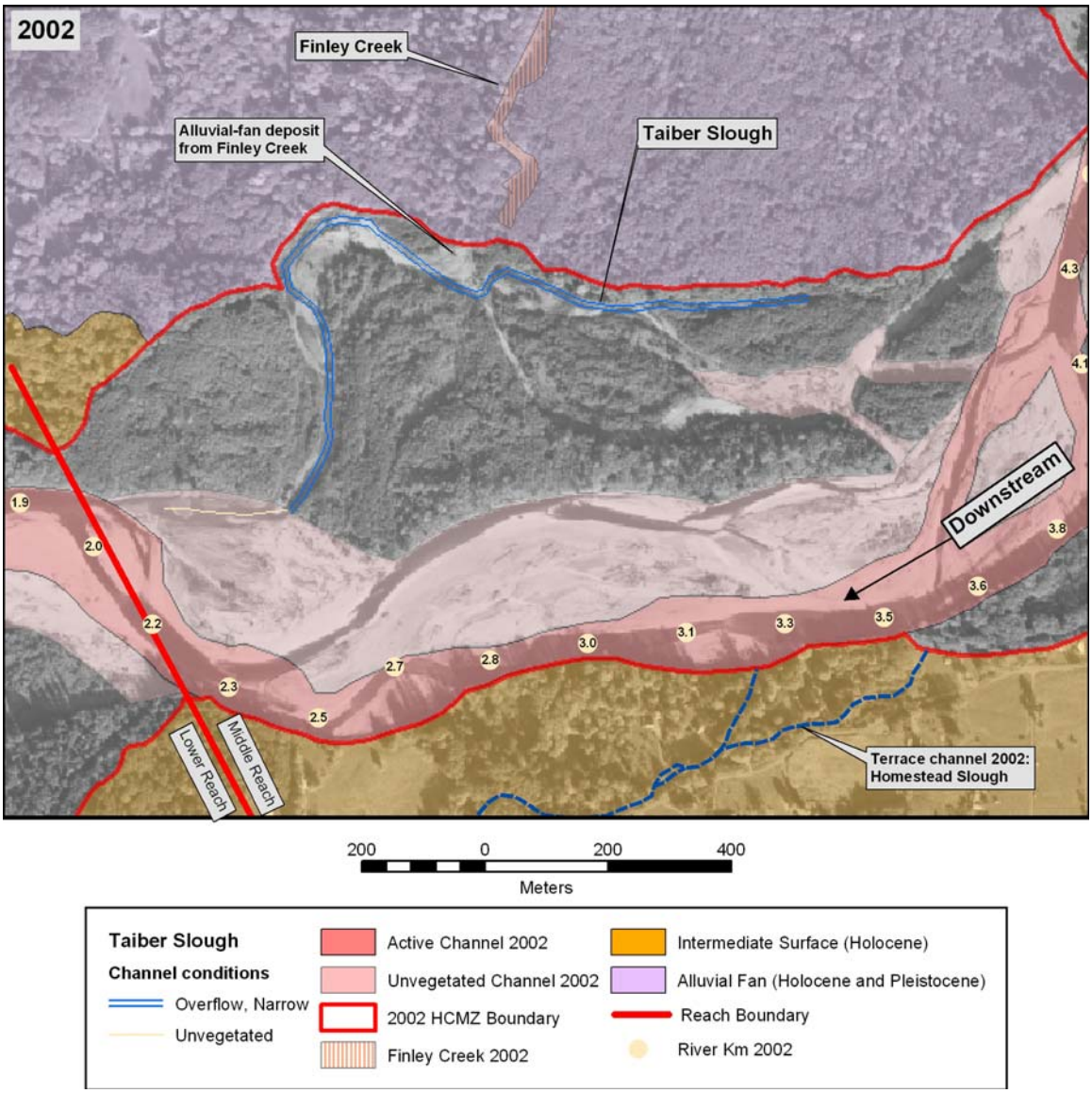

Figure 11. In 2002, the area around Taiber Slough had not changed much since 2001. The active channel of the Quinault River had become straighter, and had moved to the south, farther away from Taiber Slough. Some flow still may have reached Taiber Slough, but the vegetation appears to have increased in density along most of the slough. B. Armstrong (QIN, written commun., 2003) suggested that Taiber Slough was gradually becoming more isolated from the Quinault River, so that sockege habitat was improving in the slough. The downstream section (about 200 m) was still part of the unvegetated channel of the Quinault River and was not likely to be potential habitat.

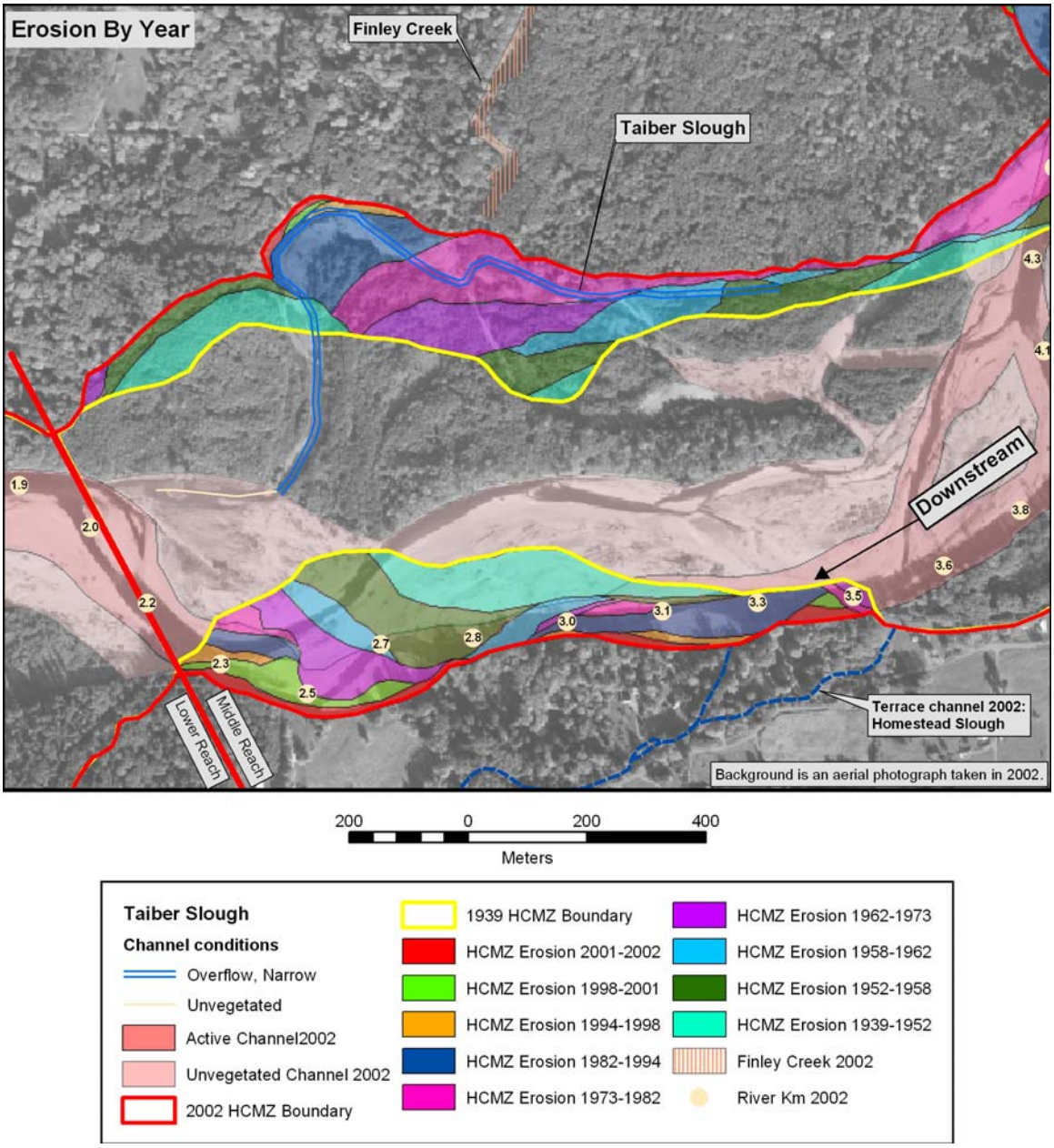

Figure 12. Bank erosion between 1939 and 1994 allowed Taiber Slough to form. A small amount of bank erosion continued until 2002. Erosion also occurred between 1939 and 2002 on the left bank opposite from Taiber Slough.