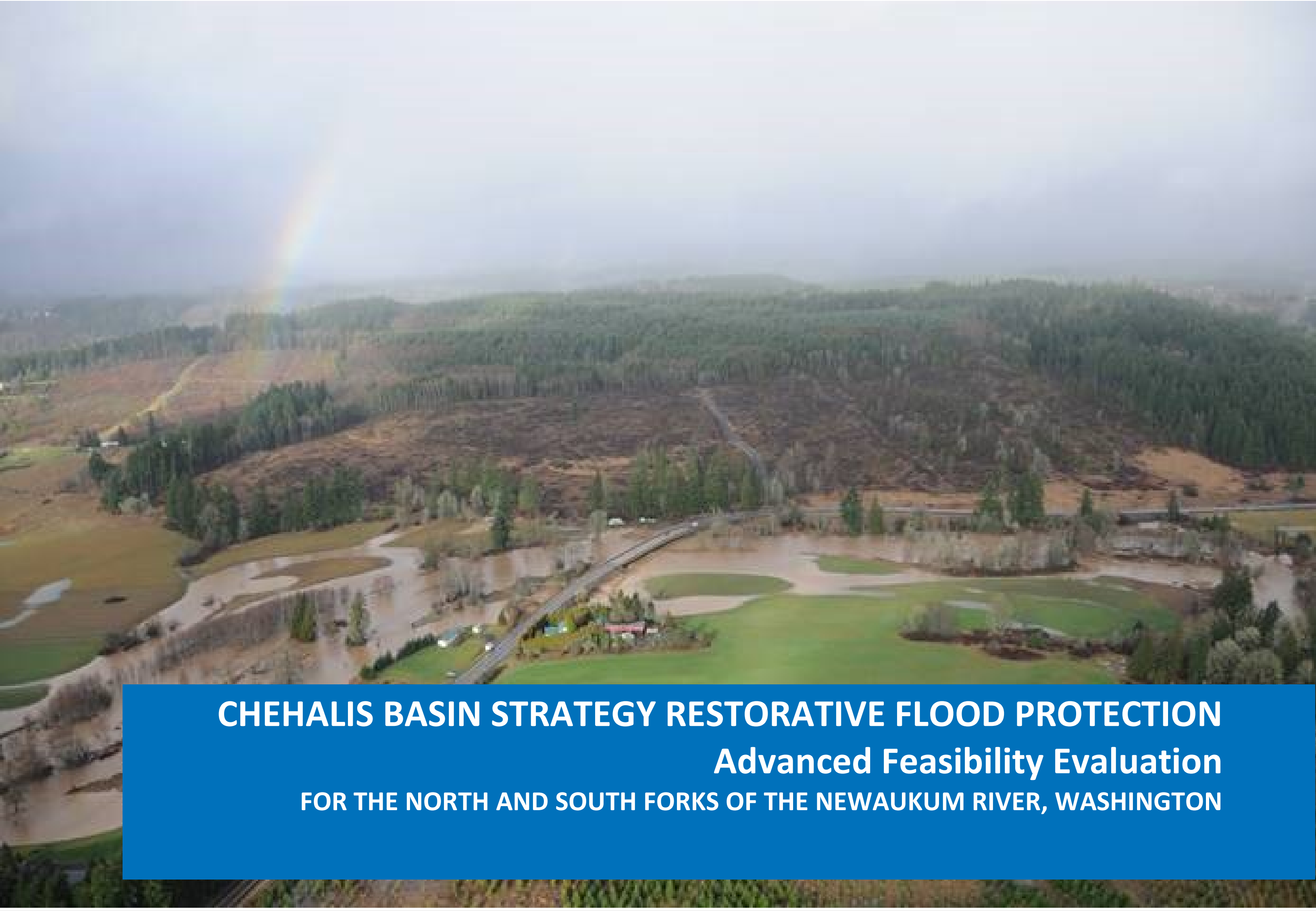

CHEHALIS BASIN STRATEGY RESTORATIVE FLOOD PROTECTION

Advanced Feasibility Evaluation

FOR THE NORTH AND SOUTH FORKS OF THE NEWAUKUM RIVER, WASHINGTON

Photo: North Fork Newaukum River at the North Fork Road Bridge Crossing during January 2009 Flood
Photo Credit: WSDOT

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Washington State Department of Ecology

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Acknowledgement

This assessment was made possible by funding from the State of Washington to best ensure that a restorative alternative to improving flood protection was provided to the people and resources of the Chehalis River Watershed

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RESTORATIVE FLOOD PROTECTION EXECUTIVE SUMMARY

The Chehalis Basin Strategy has evaluated a broad range of flood damage reduction measures including a proposed flood retention structure and levees. It has also implemented many small-scale actions such as floodproofing of homes and farm pads for farm animal and equipment safety. An alternative *approach that was also evaluated is called **Restorative Flood Protection**.*

What is Restorative Flood Protection?

A Restorative Flood Protection (RFP) approach has the goals of reducing flood damage losses while restoring critical habitat and water resources. The approach consists of three goals:

RFP Goal #1:

Permanently eliminate future flood damages and liabilities for areas addressed.

RFP Goal #2:

Decrease and delay downstream flood peaks in Chehalis and Centralia.

RFP Goal #3:

Restoration of aquatic and riparian habitat within treatment areas.

These goals will be attained through two fundamental RFP actions:

RFP Action #1:

Help people move out of harm's way through voluntary buyouts or relocation to higher ground.

RFP Action #2:

Restore the natural hydraulic roughness and flood storage within the river valley that attenuates (lowers) and slows flood peaks moving through the valley.

There are locations where the basic components of restorative flood protection have been successfully applied in the United States and Europe, including but not limited to areas in Texas, North Carolina, Vermont, Oregon, France and the United Kingdom.

The RFP concept works by reconnecting as much of the river as possible to the full extent of its natural floodplain. Natural elements that acted to slow, disperse and temporarily store floodwaters are restored. The natural elements can include in-stream wood and floodplain forests and wetlands. The treated, or restored, alluvial valleys reduces the speed of flood waters and quantity of flood water moving to downstream communities, with increased benefits to salmon and many other important aquatic species as well. It also raises water tables that can store large volumes of alluvial groundwater.

In the Chehalis Basin, the mainstem Chehalis River near the cities of Chehalis (Newaukum confluence) and Centralia (Skookumchuck River confluence) poses elevated flood risks. Homesteaders accounts describe extensive and frequent flooding across the valley and thus, homesteaders settled on high ground on the valley margins. The RFP analysis revealed that rivers with low gradients less than 0.003 have the most pronounced influence on attenuating flood peaks. The Chehalis-Centralia reach has a gradient of 0.00014, indicating that the area once acted as a capacitor to reduce downstream flood peaks. This is consistent with documented historical observations by homesteaders. Historic channel clearing, splash damming and riparian deforestation throughout the Chehalis Basin led to channel incision that reduced the frequency of flooding in the Chehalis-Centralia area.

Results of the Restorative Flood Protection Evaluation

Early results from the Restorative Flood Protection evaluation suggested that flood flows could be reduced by approximately 10 percent during a 100-year flood. These results were described in the 2017 Programmatic Environmental Impact Statement (PEIS). The Chehalis Basin Board chose to pursue a more detailed analysis focused on the North and South Fork Newaukum River basins, leading to an exhaustive and holistic evaluation of the RFP approach. Some of the products of the work included:

- Compilation of applicable published research and examples related to the science, economics, engineering and programs advancing components of the RFP approach.
- Evidence demonstrating that four to six feet of channel incision occurred following historic channel clearing which disconnected the river from its original floodplain
- Evidence showing the development of “inset” floodplains much smaller than their original extent prior to European settlement (late 1800s) and that these inset floodplains continue to expand, posing on-going erosion risks.
- Mapping of future channel migration and associated erosion hazards.
- A feasibility assessment examining options for relocation in close proximity to the Newaukum River in Lewis County, with detailed focus on agriculture within and outside flood prone areas.
- Landowner interviews in which the RFP approach was explained and landowner interest was noted, particularly with regards to buyouts or relocation.
- Documentation of existing riparian and floodplain vegetation and land use.
- A topographic reconstruction of historic floodplains and floodplain vegetation prior to European settlement which was used in two-dimensional hydraulic modeling
- Detailed descriptions of restorative structural elements and vegetation plans. Restoration scenarios included:
  - Restoration of the historic floodplain
  - A theoretical exercise in which landscape engineering was implemented to increase floodplain storage areas to test downstream influence
- Detailed two-dimensional hydraulic modeling with updated hydrologic inputs to predict flood inundation extents, flow velocities and depths, water storage and downstream hydrographs. This was performed for existing conditions, the historic floodplain reconstruction and several different restorative treatments.

- An additional analysis was also conducted to examine the influence of alluvial groundwater recharge during flooding on increasing water storage and reducing downstream peaks.
- Modeling was also completed to predict the effect of increased peak flows associated with the warming climate.

The RFP work completed, including the initial PEIS work for the Upper Chehalis and more detailed work in the Newaukum basin provide valuable new information on the region. It also represents the most exhaustive and large-scale assessment that the authors are aware of anywhere in the world and will help to advance the understanding of floodplain functions and holistic approaches to flood protection. Analysis from other regions, such as Vermont, have shown that natural floodplains can reduce downstream flood peaks by over 50% (Watson et al. 2016). Key findings of the Newaukum work with regards to the goals of the RFP approach include:

- Results applicable throughout the region and world:
  - The flood attenuation benefits of the RFP are most sensitive to valley gradients and secondarily to floodplain area and roughness.
  - Flood infiltration into alluvial sediment can have a significant influence on reducing flood peaks that occur early in the wet season or during the dry season (summer thunderstorms)
  - Historic land use, particularly clearing of in-stream wood and floodplain forests contributes to channel incision that exacerbates downstream flooding and reduces alluvial water storage and availability.
- *Results specific to the Newaukum and Upper Chehalis Basins*
  - The RFP resulted in a three-fold increase in flood storage but only a modest reductions (<10%) of downstream flood peaks, below those predicted by one-dimensional modeling in the Programmatic EIS. There is a notable exception that, when floodplain infiltration was integrated into modeling, shows a potential of a 24% reduction in the 100 yr flood peak. RFP flood peak reductions are below those predicted for the proposed dam in the Upper Chehalis. The valleys are simply too steep, but the work does indicate that for valleys with low gradients less than 0.003%, there can be substantial reductions as seen on Otter Creek, Vermont during hurricane Irene (Watson et al. 2016).
  - Based on the RFP work, we can identify low gradient areas that once had a more significant role on attenuating downstream flood peaks. One example is the main stem Chehalis River between the Newaukum and Skookumchuck confluences which has a slope of 0.00014 indicating that this reach would have had been subject to regular flooding and had a significant attenuation influence on flood peaks further downstream. This is supported by homesteader accounts that noted this area was extensively flooded every winter (Smith 1945). This same area has become heavily developed and not viable for an RFP approach, but highlights the

area's susceptibility to flooding. Since many other low gradient areas within the Chehalis Basin have not yet been analyzed in a meaningful way, it is recommended that the RFP analysis be expanded to assess these areas throughout the basin.

- Relocating people out of harm's way, a prerequisite for river and floodplain restoration, was found to be entirely plausible given the large areas of relatively level uplands with no flood or erosion risks adjacent to the Newaukum Valley. These high terraces, historically referred to as "prairies," have good alluvial soils and support diverse agriculture, and they offer lots of potential for expanding agriculture and community development outside hazard areas. Relocating people and businesses currently at risk will provide permanent flood protection and stimulate the local economy with new upland development and large-scale aquatic habitat restoration of lowland floodplain areas. Based on resident interviews, a voluntary buyout and relocation program would be receptive to affected communities. This would reduce future flood damage liabilities of participating landowners and lower taxpayer burdens associated with flood damage relief.
- Since the RFP approach was not able to meet the Chehalis Basin Board's objective to demonstrate a significant reduction in flood stage in the Centralia Chehalis area, the authors recommended not moving forward with engineering design of the RFP in the North and South Fork Newaukum Rivers. The authors also recommended redirecting the budget to delineate erosion hazards throughout the Chehalis Basin and assess the flood attenuation benefits of the RFP approach in lower gradient valleys of the basin, such as the South Fork Chehalis. Erosion hazards from channel migration was identified through landowner interviews in the Newaukum to be the biggest river-related problem, and these hazards have not yet been delineated and evaluated in the Chehalis Basin. The authors strongly recommended doing much more to map erosion and flood hazards. This would be essential to prioritize voluntary buyouts and relocations which should be a core component of the Community Flood Assistance and Resilience (CFAR) program. The Chehalis Basin Board chose to discontinue RFP design and further advancement and analysis of restorative flood protection actions.
- The North and South Fork Newaukum currently have significant flood and erosion risks which will worsen in the future due to the effects of the warming climate.

- *Key elements of the RFP are a viable food protection alternative for the Chehalis Basin.*
    - The RFP provides a sustainable approach to the future in which communities will not be dependent on flood defenses that are expensive to build and maintain, and leave a residual risk of failure. Traditional flood defenses, such as levees and dams, encourage further development in hazard areas which puts more people at risk. This of course increases dependence on flood protection measures. Since flood peaks will continue to increase as a result of the

  warming climate, maintaining flood protection will become increasingly expensive in addition to putting more people at risk that currently aren't.
  - Traditional flood defenses directly impact salmon and many other native species in several ways:
    - Disconnecting habitat from the streams and rivers that formed and sustained them
    - Habitat loss through land development
    - Alteration of fluvial processes essential in forming and sustaining aquatic habitat such as changing flow regimes, sediment and wood supply, channel migration, and riparian vegetation.
- Detailed hydraulic modeling that included floodplain infiltration showed much higher flood attenuation affects and the potential of increasing alluvial water storage within any areas where a restorative flood protection approach is possible.
- Advancing the component of the RFP which identifies landowners with the greatest flood and erosion risk and provides assistance for moving people out of harm's way, offers permanent flood protection and economic and habitat restoration benefits. A voluntary program would provide an incremental long-term flood protection strategy.
- These benefits are especially important to residents who will not benefit from flood level reductions in the mainstem Chehalis from a dam, such as the North and South Fork Newaukum. This action will also reduce the economic liabilities that flood damages impose on local, state and federal governments. A buy-out and relocation program can be done without the costly restoration actions of the RFP, that accounted for more than half the estimated cost, which results in a much higher benefit/cost ratio if it were to be implemented. This effort would also directly benefit the Aquatic Species Restoration Plan (ASRP). The authors are therefore supportive of development and implementation of the 2019 Community Flood Assistance and Resilience (CFAR) Program, which is being led by the Chehalis Basin Board to aid basin residents with a focus on river erosion and local flood protection assistance.

The Restorative Flood Protection Evaluation benefited the Chehalis Basin by exploring an important alternative to traditional flood protection, adding valuable data and information on the basin, and demonstrating that some elements of the RFP can be integrated into comprehensive floodplain management, reducing risks and improving environmental conditions. Communities around the country are increasingly turning to combinations of measures that include helping people move away from chronically flooded areas and are more environmentally sensitive. It was important that the Chehalis Basin Strategy consider such an approach and integrate the lessons learned into ongoing planning.

1. INTRODUCTION

1.1 Project Background

This advanced restorative flood protection (RFP) feasibility evaluation arose from the P*reliminary Scientific Assessment Of A Restorative Flood Protection Approach For The Upper Chehalis River Watershed* (Abbe et al., 2016), which was developed during the 2017 Chehalis Basin Strategy Programmatic Environmental Impact Statement (PEIS) (Ecology, 2017).

This study developed as a part of the greater Chehalis Basin Strategy, http://chehalisbasinstrategy.com, is defined as

> "an ambitious collection of potential actions to address the challenges of extreme flooding and degraded river habitat. The State of Washington and local leaders are working to develop the Strategy to both improve river habitat and reduce flood damage. It will be a basin-wide strategy that includes near-term and long-term actions, as well as small- and large-scale projects. The long-term goal of the Strategy is to make the basin a safer place for families and communities impacted by flooding, and to improve and restore aquatic species habitat now and for future generations."

A key element of RFP approach that assists at-risk landowners with relocation or buyouts is consistent with a "basin-wide strategy". Traditional flood protection measures only address specific areas within the basin, providing no benefits to other areas. The RFP also provides the most viable alternative to large-scale habitat restoration and protecting water resources. The approach consists of three fundamental components:

1) Permanently eliminate future flood damages by helping people move out of harm's way. This can be voluntary buyouts or relocation to higher ground which can be implemented as a basin-wide strategy benefiting people and natural resources throughout the Chehalis Basin.
2) River and floodplain restoration that restores the natural storage and hydraulic roughness that slows flood peaks moving through the valley. Floodplain landowners who don't have assets at risk of flooding but are interested in restoration could also be compensated through conservation and flood easements for the land affected. This will help prevent future development and contribute to downstream flood protection benefits.
3) Improve downstream flood protection by attenuating (reducing and slowing) flood peaks.

The basic tenet of the RFP approach is establishing a landscape corridor or greenway ("space" for the river) that accommodates fluvial processes both of an active river channel and its floodplain (e.g., flooding, erosion, sedimentation, groundwater flow, wood recruitment). Establishing river corridors not only has direct ecological benefits, e.g., (Baptist et al., 2004; Kline and Cahoon, 2010; Ward et al., 2002), but flood protection and economic benefits as well, e.g., (Allen et al., 2003; Biron et al., 2014; Buffin-Bélanger et al., 2015; Mears and McKearnan, 2012; Ollero, 2010; Watson et al., 2016; Wenger and Fowler, 2000). Recognition of these benefits, as well as the hazards of living within a fluvial corridor, have led several states to establish guidelines for delineating corridor areas. Examples include:

Channel Migration Zones (CMZs)

- Washington — Rapp and Abbe 2003; Legg and Olson 2014
  https://fortress.wa.gov/ecy/publications/documents/0306027.pdf
  https://ecology.wa.gov/Water-Shorelines/Shoreline-coastal-management/Hazards/Stream-channel-migration-zones
- Montana — http://geoinfo.msl.mt.gov/Home/data/montana_channel_migration_zones
- Oregon — https://www.oregongeology.org/flood/channelmigration.htm

Erosion Hazard Areas

- FEMA — 1999:
  https://www.fema.gov/media-library-data/20130726-1545-20490-8123/ft_rivex.pdf
  2000:
  https://www.fema.gov/pdf/library/erosion.pdf
- Washington — https://www.codepublishing.com/WA/Edgewood/html/Edgewood14/Edgewood14110.html
- Austin, Texas — 2013:
  http://austintexas.gov/sites/default/files/files/Watershed/erosion/erosion_hazardguidline.pdf

Fluvial Hazard Zones (FHZs)

- Colorado — Jagt et al. 2016
  http://coloradohazardmapping.com/hazardMapping/fluvialMapping

River Corridors

- Vermont — https://floodready.vermont.gov/flood_protection/river_corridors_floodplains/river_corridors
  https://floodready.vermont.gov/sites/floodready/files/documents/2014-10-06%20%20Final%20Draft%20Flood%20Hazard%20Area%20and%20River%20Corridor%20Protection%20Procedures.pdf

In 2016, a preliminary study was released, which used best available science to answer the following question at a very coarse-scale: "Can large scale watershed restoration reduce flooding and flood impacts to residents and communities in the Chehalis Watershed? Is this a viable flood damage reduction strategy?" (Abbe et al., 2016). The answer to this question was, "Yes, large scale watershed restoration will reduce flooding and flood impacts." (Abbe et al., 2016), however, due to the coarse-scale of this analysis, questions remained about how various data gaps and one-dimensional hydraulic modeling may have affected the results, whether these results would be the same with more detailed information and two-dimensional modeling that more accurately represents the landscape in addressing flood attenuation (RFP goal 3). The additional work also included a more detailed assessment of the potential of upland areas to accommodate relocation of agriculture and residents currently located in flood prone areas (RFP goals 1 and 2) and landowner interviews to better understand their interest in the RFP.

Four major rivers and streams were studied in the preliminary assessment, including the South Fork (SF) Chehalis River, Newaukum River, Bunker Creek, and Elk Creek (Figure 1). The North and South Forks of the Newaukum River were chosen for the more advanced study presented in this report because:

1) The Newaukum River basin upstream of the North and South Fork confluence is generally outside of previous flood protection strategy analyses. There are no dams or levees currently proposed for the Newaukum River, except for select locations along Interstate 5 (I-5) and near the confluence with the Chehalis River.
2) The proposed flood control dam on the Upper Chehalis is not predicted to reduce flood hazards in the North and South Forks of the Newaukum, thus supporting the case for considering the RFP approach.
3) Restorative flood protection analyses benefit the basin by providing geomorphic, ecological, and hydraulic information for future planning.
4) The Newaukum had previously been identified as a focus area for habitat restoration by the Chehalis Basin Lead Entity (http://www.chehalisleadentity.org/our-work/), which is in alignment with the restorative flood protection approach.

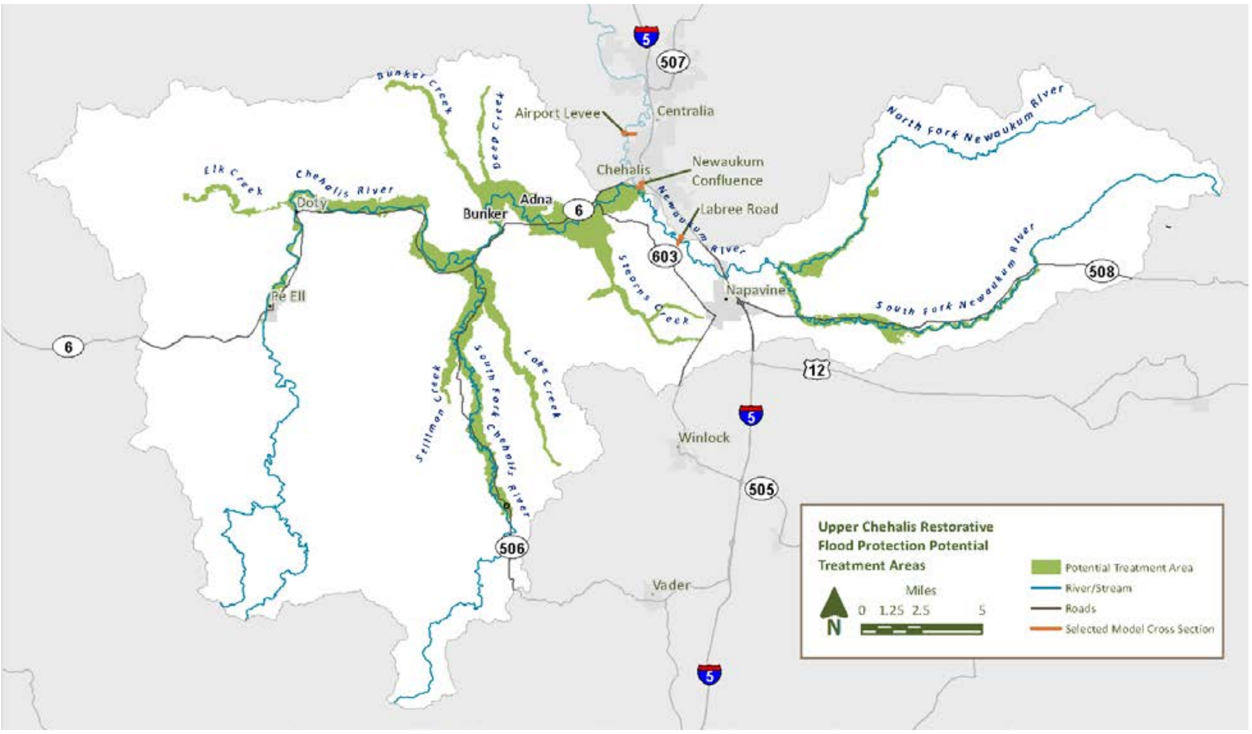


Figure 1. Preliminary assessment study area shown in green, including Bunker Creek, Elk Creek, South Fork (SF) Chehalis River, and the North Fork and South Forks of the Newaukum River (Eastern drainage above). The Newaukum River was chosen for the more advanced study presented in this report.

1.2 Purpose and Scope

The purpose of this report is to present the methods and findings from an advanced restorative flood protection study, which was conducted in the Newaukum River basin. This evaluation was conducted to both gauge the feasibility of using the Restorative Flood Protection approach for slowing and storing large floods (100-year or greater) by simulating the effects of river and floodplain restoration on flood flows using a hydraulic computer model, and to determine the feasibility of moving people from harm's way and develop a framework for identifying those with the greatest need.

The modeled study area included 30 miles of the North Fork and South Fork Newaukum Rivers, as well as hundreds of acres of adjacent floodplain and side channels.

In addition to the flood simulations, the scope of the study included:

1) Data-driven spatial assessment of existing floodplain conditions, including topography and landforms, land use, vegetation, soils, hydrology, flood inundation and erosion hazards.
2) Analysis of the anticipated effects of Restorative Flood Protection actions on floodplain processes, such as geomorphic changes, shifts in vegetation, changes in flood inundation and flow velocities, floodplain storage and groundwater recharge during a large flood, and flood peak flow attenuation.
3) A landscape assessment of current agriculture within flood prone areas and in nearby uplands of Southern Lewis County, focusing on:
    a. Capacity of upland areas to accommodate expansion of agricultural and residential development with regards to moving people currently in flood prone areas out of harm's way.
    b. A summary of options for flood resilient agriculture that could be integrated into an RFP approach.
4) A summary of local landowner perspectives on current conditions with respect to flooding, erosion, environmental quality, and of the concept of restorative flood protection, including interest in relocation or buyouts.
5) A discussion about the applicability of these study results to other areas.
6) Conclusions and recommendations.

1.3 Overall Approach

At its core, an RFP approach is a holistic sustainable approach to floodplain management that incorporates a wide range of issues so that human communities and ecosystems thrive. This is unique from traditional flood protection that simply focuses on protecting development within naturally flood prone areas that have negative ecosystem effects, e.g., (Biron et al., 2014; Buffin-Bélanger et al., 2015; Ollero, 2010; Ward et al., 2002). This feasibility study was conducted using a combination of geomorphic reconnaissance field work, geomorphic analysis of high resolution topography, hydraulic modeling of existing and proposed conditions, surface water and groundwater storage, GIS analysis of existing landscape conditions and land use, spatial statistics of restorative flood protection effects on current conditions, in-person interviews with local landowners, phone interviews with a wide range of regional floodplain farmers, and literature-based estimates of natural plant community composition.

There are not many studies which combine large-scale shift in flood-friendly land use practices with estimates of local and downstream flood effects and local landowner perspective on these hypothetical changes. The methods and many of the findings are applicable to other areas, and this analysis may be useful for other regions struggling with increasing and more frequent flood damages.

2. DATA AND METHODS

Numerous analyses were performed as part of the feasibility study to assess the existing conditions of the Newaukum River Valley and evaluate the effectiveness of restorative flood protection treatments and how they would influence the current conditions. These analyses relied on field assessments, remotely sensed data such as LiDAR and aerial imagery, historical accounts, hydrological data, and 2-dimensional hydraulic modeling. The following section outlines the data sources and methods used in the feasibility assessment.

2.1 Data Sources and Baseline Mapping

Analysis performed using topographic data were based on topo-bathymetric LiDAR data that were collected by Quantum Spatial between April 15th and May 26th 2017. These data were provided in WA State Plane South, NAD 83 (2011) and NAVD 88 as a bare earth digital elevation model (DEM) and a highest hit DEM. LAS files of RAW LIDAR point clouds were also provided from this collection effort. LAS is a standardized binary format for storing 3-dimensional point cloud data and point attributes along with header information and variable length records specific to the data. Upon receipt, data were classified into the following categories: default, ground, water column, bathymetric bottom, and water surface.

Aerial Imagery of the North and South Forks of the Newaukum study areas was gathered for the following years and from the associated sources: 1938, WA DNR; 1940, DOE Shoreline Atlas; 1951, USGS Earth Explorer; 1952, USGS Earth Explorer; 1975, USGS Earth Explorer; 1980, USGS Earth Explorer; 1990, USGS Earth Explorer; 2006, USDA NAIP; 2009, USDA NAIP; 2014, Google Earth; 2015, USDA NAIP; 2017, USDA NAIP.

The Lewis County GIS database was used to categorize and map roads, parcels and structures in the area of interest. Several structures were added on a case by case basis due to observed absences in the public database.

United States Department of Agriculture Natural Resources Conservation Service (USDA-NRCS) Soil Survey Geographic Database (SSURGO) data were used to create maps of soil type, with an overlay identifying hydric soils.

FEMA flood mapping was used to identify currently delineated flood zones. The following flood map zones overlay the area of interest: 5301020100B effective 12/15/1981, 5301020300B effective 12/15/1981, 5301020270B effective 12/15/1981, 5301020265C effective 7/17/2006, 5301020275B effective 12/15/1981, 5301020075B effective 12/15/1981, 53010221801C effective 7/17/2006 (www.fema.gov).

DATA	SOURCE	COLLECTION DATE
LiDAR	Quantum Spatial	4/15/17 – 5/26/17
Current Aerial Imagery	USDA NAIP	7/17 – 8/17
Historical Aerial Imagery	WA DNR	1938
Historical Aerial Imagery	DOE Shoreline Atlas	1940
Historical Aerial Imagery	USGS Earth Explorer	1951, 1952, 1975, 1980, 1990

DATA	SOURCE	COLLECTION DATE
Historical Aerial Imagery	USDA NAIP	2006, 2009, 2015
Historical Aerial Imagery	Google Earth	2014
Parcels	Lewis County	2017
Roads	Lewis County	2017
Structures	Lewis County	2017
Additional Structures	NSD observation	2017
Flood Model	FEMA	1981, 2006
Soils	USDA-NRCS	*Refer to source*
Soils	SSURGO	*Refer to source*

2.2 Field Methods

Natural Systems Design (NSD) conducted field reconnaissance surveys on the North and South Fork Newaukum Rivers between 9/25/17-9/29/17 and again from 10/9/17-10/11/17. The South Fork of the Newaukum was surveyed from the confluence with the North Fork upstream to the Gheer Creek confluence, directly downstream from Onalaska (RM 12-22.5). The North Fork was surveyed from the confluence to River Mile (RM) 2.

The following field data were collected during the surveys:

- identification of stable large wood jams,
- observations of channel bed material, including photographic and quantitative documentation through pebble counts,
- identification and mapping of bank armoring features,
- description and photographic documentation of bank material,
- classification and mapping of riparian vegetation,
- identification of recent erosion,
- identification of existing infrastructure, such as culverts and bridge crossing data including low chord and deck elevations,
- characterization of geomorphic and geologic features,
- identification of high-water marks from recent flood events.

2.3 Relative Elevation Model

A relative elevation model (REM) is a tool that depicts elevations of floodplain features relative to the water surface elevation of the river channel at the time when the LiDAR was collected. A topographic plane of the water's surface at the time of LiDAR collection was developed from the classified LAS point clouds using ArcGIS software. This surface was then mosaiced on top of the topo-bathymetric bare-earth DEM to effectively "fill the channel" with water and establish a reference plane with a slope consistent with the local channel gradient. The water surface plane was extended across the entire valley and subtracted from the bare earth DEM using raster calculator in ArcGIS to establish a relative elevation for each pixel of the bare earth DEM (Jones, 2006).

The REM provides a rapid means of identifying low lying areas prone to flooding, floodplain and terrace areas, and historic channel paths. One-meter resolution REMs developed for the Newaukum study area were used to interpret current geomorphic conditions present at the site. Images showing the REM are used throughout this report; an example is provided below (Figure 2).

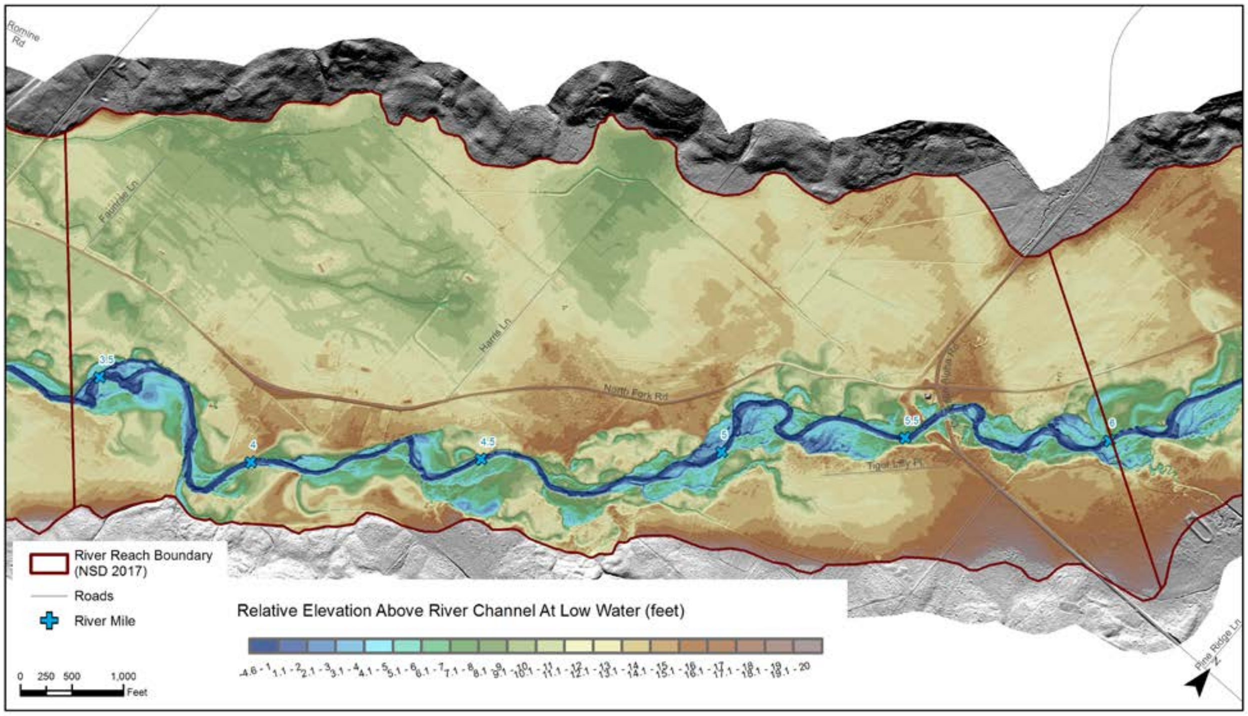


Figure 2. Example relative elevation model map, depicting elevations of South Fork Newaukum River floodplain features relative to the water surface elevation of the river at the time the bathymetric - topographic LiDAR data was collected April 15 – June 24, 2017. Image shows river mile 3.5 to 6, river flow is from right to left.

2.4 Geomorphic Landform Mapping

The complete range of geomorphic processes that have acted formatively on the Newaukum Valley have produced a discrete set of geomorphic landforms in the valley bottom. By assessing the morphology and orientation of topographical features in the valley bottom, as rendered through the REM, the area within the valley was partitioned into categories based on these geomorphic landforms. This analysis was conducted in ArcGIS 10.1 and based loosely on work done by the USGS in the Willamette Valley (J. Rose Wallick, 2013). A geomorphic map was created by digitizing terrain features such as active channel, floodplain, terrace and valley margins. Alluvial terraces are relic floodplains located above flood elevations. Terraces form as rivers cut down or incise through a landscape. Terraces can range in age from recent times to hundreds of thousands of years old. Terrace formation can be triggered by climatic driven increases in flow and a stream's erosive power, a lowering in downstream base-level, land uplift or human driven changes, such as removal of in-stream wood, splash damming, increases in flow peaks due to land development or channel straightening. Phenomena and actions that can trigger channel incision include, but not limited to:

- increased peak flows, such as heavily deforested and urbanized basins, see (Abbe et al., 2016; Booth, 1990; Hardison et al., 2009; Perry et al., 2016a; Perry et al., 2016b; Simon and Rinaldi, 2006) and others.
- reduction of sediment supply, such as downstream of dams and gravel mining, e.g., (Grams et al., 2007; James, 1997; Kondolf, 1997; Phillips et al., 2005; Power et al., 1996; Rollet et al., 2014; Schmidt and Wilcock, 2008).
- channelization, such as straightening and levees, e.g. (Kroes and Hupp, 2010; Shields et al., 1994; Wyżga, 2001).
- splashing damming and wood clearing, e.g. (Abbe et al., 2016; Abbe, 2000; Brummer et al., 2006; Montgomery and Abbe, 2006; Schanz et al., 2019).

Valleys of the Newaukum watershed are surrounded by several very high terraces. The focus in the Newaukum was to identify the lower terraces within 20 feet of the current floodplain. These terraces were then carefully examined for evidence of relic channel features that would further support historic abandonment. Landscape descriptions by homesteaders and early land surveyors were also used to help identify the historic floodplain that was regularly flooded every winter prior to European settlement.

Smith (1941) documented homesteader accounts of regular winter valley wide flooding of the Centralia and Chehalis area, some of which include:

> *"The flooded land (Chehalis valley) about a mile south of the Skookumchuck mentioned by Patterson Laurk was the section from the outlet of what is now Salzer Valley on towards the outskirts of the present city of Chehalis. Frequently, in winter, this whole area was like one large lake about four miles across. It is within the memory of many older residents that canoes often plied over this flooded section."* (p.24)

> *"One immigrant party, it is said, camped one night at McElroy's, now the site of the Southwest Washington Fair Grounds just south of Centralia. In the morning, when they awoke, they found themselves on a tiny island in the center of a sea of water – a mile to dry land in all directions. McElroy (Salzer) Creek had flooded the area during the night."* (p.25)

> *"This long, winding creek (Lincoln or "Natcheles" Creek) cuts through the valley for many miles until it reaches what is now Galvin. Here it joins the Chehalis River. Early settlers remember that in the summer time it was just an ordinary stream, but in the winter its valley presented a different view. Log jams in the Chehalis River backed the water up the creek**, making the valley a sea from hill to hill**."* (p.292)

> *"To be out of reach of the flood waters, the early homesteaders built on the hillslopes."* (p.292)

These accounts are consistent with interpretations of wide spread incision in the Chehalis Basin. This Newaukum analysis provides additional evidence of actions driving incision, as well as geomorphic, stratigraphic and carbon dating. Based on this information, terrace areas, that are believed to correspond to historic floodplain surfaces that would have been inundated every 1 to 2 years at the time of European settlement circa 1880s, were mapped. Because of incision, these surfaces now may only be inundated every 20 years or more. Higher terraces are interpreted as older landforms linked to geologic and climatic changes that occurred thousands to hundreds of thousands of years ago. The alluvial composition (fluvially deposited sand, gravel and cobble) and stratigraphy (layering of coarse bedload and fine over-bank deposits) of current and historical floodplain, abandoned because of channel incision, are usually similar but located at different elevations. Older geologic terrace features can have different composition and surface topography reflecting the different geomorphic processes occurring at the time they were formed. Terrace surfaces that still retain relic channel scars indicate they may be a historic floodplain. Strong evidence of incision is provided when channels on historic maps or aerial photos spatially correspond with channel scars situated above the current floodplain. These interpretations are important in determining how much the river has down-cut, or incised, into its valley over the last two centuries. Mapping geomorphic features helps reconstruct pre-disturbance conditions and quantify how the landscape has evolved into present day conditions.

The geomorphic landform map, along with other lines of evidence, such as bank stratigraphy and historical accounts, were used to delineate the extents of the modern and historical floodplain. The modern inset floodplain extent represents the current geomorphic surface within which moderate floods are contained and was mapped as the “active floodplain” surface.

It is also important to note that alluvial rivers in forested regions with abundant in-stream wood have complex floodplains that vary in elevation because of spatial variations of wood loading and its effect on water levels through time (Abbe, 2000; Abbe and Montgomery, 2003; Brummer et al., 2006; Bureau of Reclamation and U.S. Army Engineer Research and Development Center (USBR and ERDC), 2016; Collins et al., 2012; Montgomery and Abbe, 2006). Periods of high wood loading raised water levels and sediment deposits. In periods where channels found paths around the wood, the channel would temporarily incise, but the associated erosion triggered new wood recruitment bringing the channel back up. The cumulative results are a valley bottom mosaic of alluvial surfaces at different elevations, something quite unique from systems lacking wood and logjams (Abbe, 2000; Abbe and Montgomery, 2003; Brummer et al., 2006; Bureau of Reclamation and U.S. Army Engineer Research and Development Center (USBR and ERDC), 2016; Collins et al., 2012; Montgomery and Abbe, 2006). Human driven incision permanently lowers rivers well below the lowest range that occurred when the system had wood. For incised rivers lacking stable in-stream wood and mature riparian forests, the incision is irreversible without costly human intervention to restore in-stream wood and riparian forests with mature trees. Older geologic terraces are typically located well above these surfaces. Historical floodplain surfaces in the Newaukum Valleys correspond to terraces ranging from 4-15 ft above the current floodplain. The cumulative area of these surfaces represents the range of frequent flood inundation extents prior to European colonization.

2.5 Channel Incision Estimates

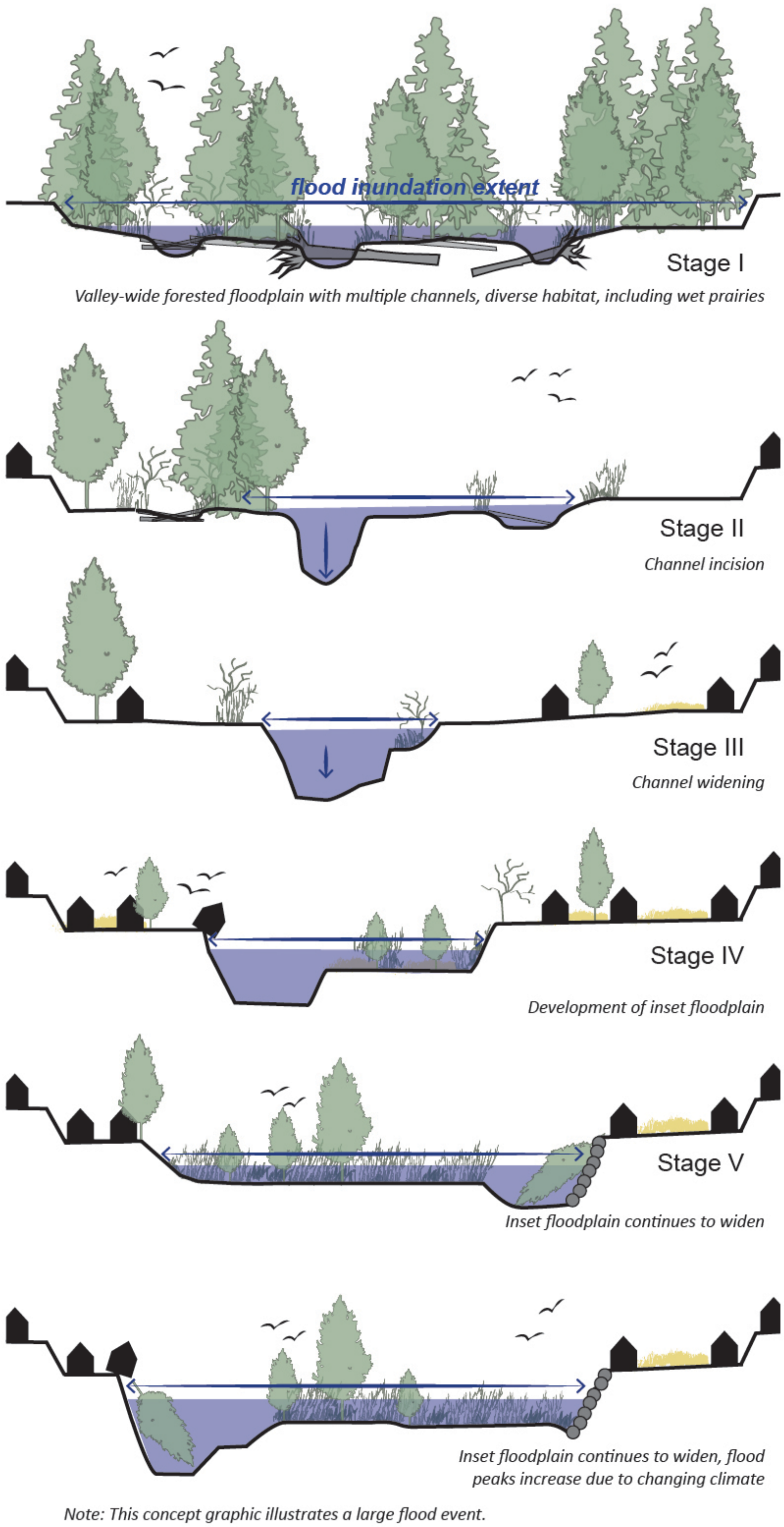
Under stable tectonic and climatic conditions, the profile of an alluvial channel can attain a quasi-equilibrium in which the elevation of the channel bed remains relatively constant. This is important because channel elevations influence flood elevations. Reductions in channel length (such as occurs when channels are straightened) and in-stream wood loading (such as historic wood removal) will result in a lowering of channel bed elevation. Conversely, increases would increase bed elevations. An equilibrium channel also depends on a balance of sediment supply and the river's sediment transport capacity. If transport capacity exceeds supply, the channel will cut down. If supply exceeds the river's capacity to move it, the channel will raise up (aggrade). Channel incision refers to a river undergoing a lowering of its bed elevation. This goes on to trigger incision in its tributaries. Unlike local bed scour (e.g., pool formation), channel incision effects an entire channel, gradually working its way upstream. Incision results in a reduction in the flood inundation frequency of its floodplain, thereby converting the surface to a terrace.

Channel incision starts a sequence of unique stages of morphological channel evolution. The rate of change depends on characteristics of bedrock, alluvial sediment, flows and riparian vegetation. Initial downcutting tends to occur quickly over years or decades. This is followed by bank erosion that gradually forms a new inset floodplain associated with the lower channel elevation. This widening tends to take several hundred years to re-establish a new floodplain similar in size to the historic floodplain. For example, it has taken over 100 years for the South Fork Newaukum to form an inset floodplain about 25% of its historic extent. The widening stage represents a period of elevated bank erosion risks to local residents and infrastructure. The stages of channel evolution are described below, and illustrated in Figure 3:

- Stage 0 or I (depending on classification) is the pre-modified condition representing a stable channel morphology defined by the condition where the stream's abilities to convey flow and transport sediment are in balance with the volume of runoff and sediment delivered from upstream. Schumm et al. (1984) present Stage I as a single-thread channel; however, the prevailing channel pattern in forested valley bottoms of the Pacific Northwest was more typically an anabranching (multi-channel) network with vegetated islands formed by stable 'hard points' that develop behind accumulations of large wood (Collins et al., 2012). The bankfull discharge is a relatively moderate flow that is exceeded on a nearly annual basis. Larger floods inundate broad areas of the valley bottom.
- Stage II represents the initial period of incision, whereby the channel begins downcutting due to an increase in stream power and/or loss of erosional resistance. The flow that previously overtopped banks on a regular basis is now contained within the channel, well below the bank height. The discharge needed to overtop the banks equates to a relatively extreme flood magnitude that previously inundated broad areas of the valley.
- Stage III is characterized by channel widening and expansion of an inset stream corridor entrenched below the valley bottom. Stage III follows the period of incision, as the over-steepened banks are prone to slumping. Episodic bank failures deposit sediment at channel margins where it is scoured away in subsequent high flows leading to a further steepening of the bank angle.

- Stage IV defines the condition, whereby sediment begins accumulating and aggrading the channel within the inset stream corridor. Slumping bank material builds berms that begin to stabilize the outer toe and new floodplain deposits accumulate.
- Stage V represents a period of renewed stability, as berms are stabilized by vegetation and a new inset floodplain develops by channel migration within the inset corridor, created by widening, during Stages III and IV. The inset floodplain is regularly inundated by floods, but the initial floodplain abandoned by incision in Stage II is left perched above and remains a terrace. Extreme floods may rarely inundate the terrace surface, depending on the magnitude of incision at a given location.

Terraces vary in their height above a river but are generally accepted to be abandoned floodplains that rarely or never flood. Hoyt and Langbein (1955) define terraces as surfaces lying above the 100-year flood elevation. One technique to estimate the magnitude of channel incision is to measure the vertical distance between the inset floodplain and historical floodplain. This distance is defined by the extent of downcutting in Stage II and is thereby a reliable characterization of the extent of channel incision. Elevations of the inset and historical floodplain were determined on a cross-section, and the difference between the floodplain elevations was then used as the incision estimate for that particular location. Four to ten cross-sections were analyzed per reach to calculate average reach estimates.



EARLY 1800s [Stage I]
A diverse old growth forest exists throughout the river valley. Large wood in the channel and the roots of nearby trees and shrubs contribute to the stability of multiple river channels, and help to minimize bank erosion. The broad floodplain is seasonally inundated and large flood events cover the entire valley bottom. Native communities thrive on abundant fish and wildlife.

MID 1800s to EARLY 1900s [Stage II]
Settlers begin to clear the forest and build homes on high ground, along valley margins. Natural log jams were cleared from river channels. Splash dams were used to flush timber downstream in artificial flood bursts. These actions caused rapid down-cutting, or incision, of the river channel. The dramatic reduction in habitat and destabilized channel severely impacts salmon and other wildlife.

EARLY 1900s [Stage III-IV]
Channel incision slows and channel width expands (Stage III). Increased size of channel lowers flood stage and sediment transport capacity and some deposition begins, starting formation of "inset floodplain" (Stage IV). Development expands into the valley bottom since flood extents are diminished. Sedimentation begins in oversized channel, forming a new "inset" floodplain four to eight feet below the elevation of the historical floodplain.

MID to LATE 1900s [Stage IV]
Incision ceases and channel migration expands width of inset floodplain. Development into valley continues. Expansion of inset floodplain is coincident with bank erosion that threatens property and infrastructure. Bank protection is constructed to limit channel migration. Width of flood inundation increases with width of inset floodplain. Small trees begin to grow in inset floodplain while some areas are kept clear for pasture.

NEAR FUTURE [Stage IV-V, II*]
Inset floodplain continues to expand to about 30% the width of the historic floodplain. Bank erosion will continue to threaten development on the historic floodplain. Bank protection becomes more extensive, triggering local incision and loss of habitat in some reaches (*return to Stage II). Bank erosion recruits trees from maturing floodplain forests which form logjams, which in turn raise local water levels. Areas without riparian forests have severely degraded habitat and higher erosion rates. Peak flows increase due to changing climate which elevate flood and erosion hazards. Low flows diminish further impacting salmon habitat. Without aggressive restoration the pattern of disturbance will continue into the future. Establishing a river corridor of sufficient size and restoring natural features would provide ecological and flood resilience.

Figure 3 Illustration of the typical stages of, channel incision reflected in the Newaukum system.

2.6 Identifying Plant Communities and Landcover

The first task in this category was to classify the plant communities of the riparian corridor and the adjacent floodplain into five (5) main types, as defined by the US Fish and Wildlife Service (USFWS). Using a canopy height raster, which is the difference between the bare earth LiDAR returns and the highest hit return, types were applied to the tallest plants that comprise 30% or more of the canopy cover:

1) Scrub-shrub ≥ 30% woody vegetation < 18 ft. (6 m) high
2) Deciduous Forest ≥ 30% deciduous woody vegetation > 18 ft. (6 m) high
3) Mixed Forest ≥ 30% deciduous and ≥ 30% coniferous woody vegetation > 18 ft. (6 m) high
4) Coniferous Forest ≥ 30% woody vegetation > 18 ft. (6 m) high
5) Emergent ≥ 30% herbaceous vegetation

Once vegetation types were identified, paved roads (digitized in GIS), buildings (Source: Lewis County GIS, 2013), and water courses (LiDAR 2017) were overlaid on top of the mapped vegetation height, superseding the vegetation data in overlapping locations. The resultant data set displays the Newaukum Valley bottom as a map of different vegetation types, aquatic features, roads, and buildings. This landcover dataset was used to delineate roughness areas for the 2-dimensional hydraulic model described in detail below.

The second task within this category of data development was to use the United States National Vegetation Classification System (USNVCS) to create a list of likely plant communities. Since species composition of the five plant community types listed above varies from place to place, depending on local geology, hydrology, and climate; and plants self-assemble into groups that adapt to particular landscape conditions, ranging from dry and rocky, to wet and mucky, and with different levels of flood tolerance; it is therefore necessary to use the most robust and local dataset to derive a detailed list of plant communities for the Newaukum River basin.

Decades of research has gone into the USNVCS, 2016), which provides detailed regional information on groundcover, shrub, and tree species typically found together under various ranges of landscape and climatic conditions. Plant species and their associations were selected from the USNVCS database for their current or likely presence on the Newaukum River floodplain and river banks under existing and proposed restored conditions.

2.7 Hydraulic Model Set-up

A 2-dimensional (2D) hydraulic model of the Newaukum River was developed using Hydronia's RiverFlow-2D Plus GPU and Aquaveo SMS v12.2 computer software and used as a primary tool in evaluating restorative flood protection effects. The upstream extents of the model domain are at RM 11.5 of the North Fork Newaukum River and RM 33 of the South Fork Newaukum River. The model domain contains the confluence of the Middle, North and South Forks, and ends at RM 10.5 on the mainstem Newaukum River just past the Jackson Highway Bridge. The model geometry utilizes topographic data obtained from topo-bathymetric LiDAR collected in 2017 along with bridge deck information from the 2017 survey. See Appendix 3 for detailed hydrology, peak inflow discharge rates, river reach breaks, and statistical analysis of flood hydraulics and peak flow attenuation, Appendix 3.

2.8 Assessment of Groundwater Recharge Potential

When a floodplain is inundated, there is infiltration into the underlying alluvial soil that can store substantial water volumes that won't return to the river within the timeframe of the flood hydrograph, thereby potentially decreasing downstream flood peaks. Since this can influence flood peak attenuation and raising groundwater tables, it directly bears on important aspects of the RFP approach. To investigate these effects, Riverflow 2D has a module to represent the rate of infiltration into the subsurface based on the Green-and-Ampt model, which approximates soil infiltration as a function of soil saturated conductivity and antecedent moisture. The original Green and Ampt equation (Green and Ampt, 1911) for a single ponding (i.e., floodplain inundation in context of this work) is:

$$f_p = K_s\,(((H_c\,\Delta\theta)/F) + 1)$$

where f_p = potential infiltration rate; K_s = soil saturated hydraulic conductivity; H_c = Green and Ampt wetting-front capillary pressure parameter; $\Delta\theta$ = soil water deficit defined by $\theta_e - \theta_i$, where θ_e = water content of soil at natural saturation; θ_i = initial soil water content; and F = cumulative infiltrated depth. The equation shows that the lower the initial soil water content, the greater the infiltration rate and thus, more water stored. As the difference between the soil's water content and its capacity at saturation approaches zero, so does the infiltration rate. Thus, antecedent conditions are important. Water storage potential will tend to be greatest when there hasn't been recent flooding or prolonged rainfall.

The Riverflow 2D model assumes unlimited subsurface volume for storage, and therefore, is likely to overestimate groundwater storage in cases where the groundwater table is relatively close to the surface. Thus, we used an analytical approach established by Doble et al. (2012) to estimate total groundwater storage volume based on both the infiltration rate and the available storage volume. In order to translate the estimated groundwater storage volumes to a hydrograph, we then calibrated the Green-and-Ampt model parameters in Riverflow 2D such that the modeled volume of infiltrated water matched the empirical estimates of groundwater storage volume. See Appendix 3 for detailed information on the estimation of groundwater infiltration volume, and translation of groundwater infiltration volume to peak flow attenuation values.

2.9.1 2.9 Channel Migration and Erosion Hazard Assessment

To understand expansion of the modern inset floodplain, an analysis of channel migration was conducted using historical aerial imagery in order to calculate rates, patterns and trends.

Historic Channel Traces

Using historical aerial images in ArcGIS 10.1, the active, unvegetated channel was delineated for the following years: 1940, 1951, 1980, 1990, 2006, 2009, 2011 and 2015. The active unvegetated channel was determined to be the point in the image where the gravel channel bed transitioned to vegetated ground cover. The channel polygon was interpolated in areas where the channel was obscured by vegetation. By comparing channel locations across a period of time, it is possible to assess differential rates of channel migration in different substrates and land use areas.

2.9.2 Channel Migration and Erosion Rates

Bank erosion is the mechanism by which channels migrate across a valley. It is important to recognize that bank erosion can occur into high terraces and hillslopes well above any flooding, so erosion is not limited to floodplains or historic migration zones (Rapp and Abbe 2003). Residents living above regulated floodplains but in erosion hazard areas are wise to purchase flood insurance at reduced rates since erosion losses are typically covered by FEMA when the erosion resulted from high flows. Erosion rates were calculated using the record of historical aerial imagery. Migration rates were determined by measuring the linear distance between the outside edge of a single meander bend at two different points in time. The distance migrated was divided by the elapsed time to generate a rate of migration (i.e. distance/time). The predominant land-use of the eroded area was classified and used to compare channel migration rates between pastured and forested land. Because land-use changed during some of the time periods, only land-cover types that persisted throughout the analysis time were used. This analysis was also conducted for the full period of record (1951-2017) in locations, irrespective of land-cover type, in order to calculate average historical migration rates.

2.9.3 Erosion Hazard Analysis

100-year Erosion Hazards

Potential erosion hazards within the study area for a 100-year planning timeline were delineated using methods presented in Rapp and Abbe (2003). For the North and South Forks of the Newaukum, historical migration rates were calculated by measuring the distance between bank lines at the apex of meander bends identified in the 1951 and 2017 aerial images. Historical migration rates and trends along with information about the landform erodibility and vegetative cover provide a means to predict areas likely to erode within the designated future time period. It is important to note that rivers can erode into areas they have never been, in fact this is how valleys are formed. A historic migration zone (HMZ) is where a river has been, a channel migration zone (CMZ) represents where a channel can go in the future, so by definition, a CMZ will be larger than the HMZ. The following erosion hazard areas were then delineated for a 100-year planning timeframe as follows:

- Historical Migration Zone (HMZ) – Locations occupied by the river between 1951-2017
- Avulsion Hazard Zone (AHZ) – Areas not included in the HMZ that are at risk for an avulsion to occur. These areas include low lying areas adjacent to the modern channel.
- Erosion Hazard Area High (EHA [H]) – Areas located within a set-back assuming that future migration rates will continue at the same rate as historical rates for the 100-year planning timeframe (4.5 ft/yr x 100 yrs = 450 ft)
- Erosion Hazard Area Moderate (EHA [M]) – Areas located with a set-back assuming that future migration rates will continue at double the rate of historical rates (9.0 ft/yr) for

the 100-year planning timeframe (9.0 ft/yr x 100yrs = 900ft). This rate is approximately equal to the maximum of the historical rates measured.

- Erosion Hazard Area Low (EHA [L]) – Areas located within the alluvial valley bottom, but outside of the High and Moderate erosion set-backs.
- Disconnected Erosion Hazard Areas – Areas located on the non-river side of major roads (State Route 508 and North Fork Rd.). This designation assumes that maintenance of the road network will continue throughout the planning timeframe.

20-year Erosion Hazards

Hazard areas were further refined to delineate areas likely to experience erosion within the next 20-years in order to guide local flood protection planning efforts within the basin. These areas were identified based on their geomorphic setting and focused on places on the outside of actively migrating meander bends which are the primary driver of channel migration within the study area. Meander bends tend to move outward and down valley and thus, can destabilize channel segments that have appeared stable. When meander bends get too tortuous, the river often finds a shorter path (of least resistance) and cuts off the meander bend, causing an avulsion. Meander bends that have actively migrated over the past 20 years were first identified and digitized in GIS. The bend was then projected outwards to simulate channel migration using a buffer distance equal to the 95th percentile historical erosion rate over a 20-year timescale. The buffer line was then edited using the judgement of a professional geologist specializing in geomorphology to locations in the path of the expected meander migration.

3. EXISTING FLOODPLAIN CONDITIONS

3.1 Topography and Landforms

3.1.1 Watershed Setting

The Newaukum River Watershed encompasses an area of 173 square miles with headwater tributaries that originate in the foothills of the Cascade Range at about 3000 feet above sea level. The watershed has three major sub-basin areas that drain the South Fork (SF) Newaukum River, North Fork (NF) Newaukum River, and Middle Fork (MF) Newaukum River, respectively. The three forks converge to form the mainstem Newaukum River that flows westerly approximately 11 miles to the confluence with the Chehalis River.

The SF Newaukum River drains a watershed area covering 66 square miles and has a mean annual precipitation of 65.5 inches. Headwater areas in the upper watershed receive higher precipitation with a mean annual total over 100 inches. The unvegetated width of the river varies from 50 to 100 feet. Upstream of Kearny Creek near RM 30[1], the SF Newaukum River has a relatively steep channel and confined valley. Downstream of Kearny Creek, the valley is unconfined and ranges between 2,000 and 3,000 feet in width and channel gradient, or slope, ranges from 0.003 to 0.005 ft/ft. The community of Onalaska is located in the SF Newaukum River Valley near RM 24. Lost Creek drains hillslope areas to the south and flows into the SF Newaukum River just upstream of Onalaska. Gheer Creek drains hillslope areas from the north side of the valley and flows into the SF Newaukum River downstream of Onalaska. The channel and active floodplain are incised below the valley bottom creating an alluvial terrace that has been cleared for agriculture and residential land use. State Route 508 runs parallel to the SF Newaukum River channel for much of the project area (Figure 4).

[1] River Mile (RM) markers in the South Fork Newaukum River reference the distance upstream from the Chehalis River confluence. RM markers in the NF Newaukum River are measured upstream from the confluence with the SF Newaukum River.

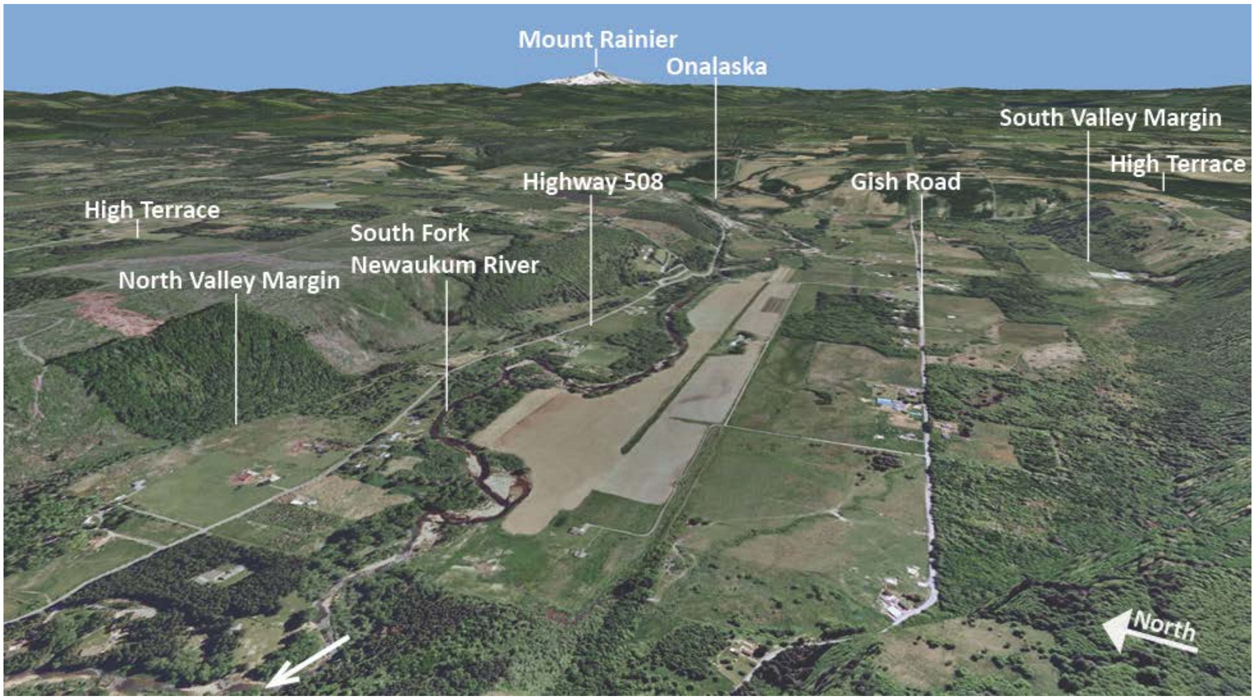


Figure 4. Birds eye view example of current watershed and river conditions in the Newaukum River basin, looking upstream (East) at the South Fork Newaukum River, just downstream from the community of Onalaska, Washington. Clearings are associated with farming and tree farms, 2017 image.

The NF Newaukum River drains a watershed area of 71 square miles and has a mean annual precipitation of 60.1 inches. Precipitation totals in the upper watershed increase to a mean annual total of 85 inches. The channel flows through a relatively steep, confined valley upstream of Mitchell Creek and emerges into an unconfined and broad valley near RM 9. Valley width in the unconfined segment ranges between 1,000 and 3,000 feet. The channel gradient averages between 0.003 and 0.006 ft/ft. Lucas Creek drains a tributary subbasin area and flows into the NF Newaukum River near RM 6.5. The MF Newaukum River drains a subbasin encompassing 18 square miles and joins with the NF Newaukum River at RM 1.5. Similar to the SF Newaukum River, the NF Newaukum River channel is incised below the historic floodplain which now forms an alluvial terrace where land use is predominantly agriculture.

3.1.2 Historical Impacts to Floodplain Processes

As described in ***Section 2.5 Channel Incision Estimates***, the NF and SF Newaukum River channels present today differ greatly from what they resembled prior to Euro-American settlement in the late 1800s (Abbe et al., 2016). Historical impacts affecting geomorphic processes and river channel conditions in the Newaukum River Valley include: (1) clearing of the large trees that grew in the valley; (2) removal of logjams and wood from the river corridors; (3) straightening of the river channels; (4) gravel mining from the active channel; and (5) armoring the banks with large rock, or riprap, to prevent channel migration. The collective effects of these impacts were a net reduction in channel complexity and energy dissipation associated with natural logjams, consolidation of flow into a single channel, and an increase in the stream power available to move sediment and erode banks.

These anthropogenic impacts to the NF and SF Newaukum Rivers caused a condition where the channels had an excess of stream power relative to the incoming sediment supply and cut down, or incised, below the former floodplain. Historical incision has created a narrower stream corridor inset below the historic valley bottom and floodplain. Incision likely began during the early 1900s, after industrial logging began bringing practices, such as splash damming and log drives that cleared river channels. Smith (1941), p.261, documented a homesteader's account of seeing trout disappear from the Skookumchuck River about five miles northeast of Centralia:

> *"The river was full of brush and drift …. But this was before the sawmills… Or before the splash dams .... For the dams lowered the river to a few feet, then flooded it with a rush of water, mud, and logs, and repeated it again a week or so later."*

The downcutting phase of incision (Stage II) occurs relatively rapidly and was complete prior to the period when aerial imagery became available in the 1940s. The widening of the inset floodplain (Stages III-IV) takes much longer. Ultimately, it can take centuries for a river to adjust to major incisional events.

In forested valley bottoms of the Pacific Northwest, such as the Newaukum River Watershed, the prevailing channel pattern was more typically an anabranching channel network with vegetated islands formed by stable 'hard points' that develop behind accumulations of large wood (Collins et al., 2012; Montgomery and Abbe, 2006). As such, it is reasonable to presume that a more complex, anabranching (multi-channel) pattern would replace the relatively simple, single thread channel in Stage I. Cluer and Thorne (2013) applied this concept to the Channel Evolution Model from Schumm et al. (1984) and referred to the anabranching channel condition that prevailed prior as "Stage 0". Figure 5 illustrates the contrast between the stable, anabranching channel with well-connected floodplain (Stage 0) that prevailed in the Newaukum River Watershed prior to historical impacts and a more current view of the incised channel and inset floodplain (Stage V).

Geomorphic Mapping of the Historical Floodplain

Evidence from the geomorphic landform mapping analysis, historical records and bank stratigraphy analysis allowed for the historical landscape (prior to clearing and development that followed Euro-American settlement in the late-1800s) to be re-constructed, visualized and mapped. Results from the historical reconstruction reveal that the floodplain surface, once spanned the entirety of the valley bottom. A complex network of multiple channels flowed throughout the valley bottom floodplain between the valley margins instead of the single channel that exists today. Much like other rivers of the Pacific Northwest, the valley was heavily forested with large old-growth trees that included Western Red Cedar, Douglas Fir, Western Hemlock, Sitka Spruce, Bigleaf Maple and Black Cottonwood. This mature forest provided stability to the river channel banks through extensive tree root systems. The forest was also a source of large wood that would fall into the river and form logjams that limited bank erosion, created deep pools, split flow to form new channels and forested islands. The floodplain forest and in-channel logjams acted together to slow the speed of flood waters, reduce erosion, and increase the extent of ponded areas and floodplain inundation during the wet season. The reconstructed landscape is supported by observations from early settlers who described valley wide inundation and large logjams.

Field observations and geomorphic landform mapping revealed an active floodplain surface that is inset at a lower elevation than the adjacent valley bottom (Figure 7). The active floodplain surface surrounded the main low flow channel and contained side channels, gravel bars, logjams, and other features found within river systems.

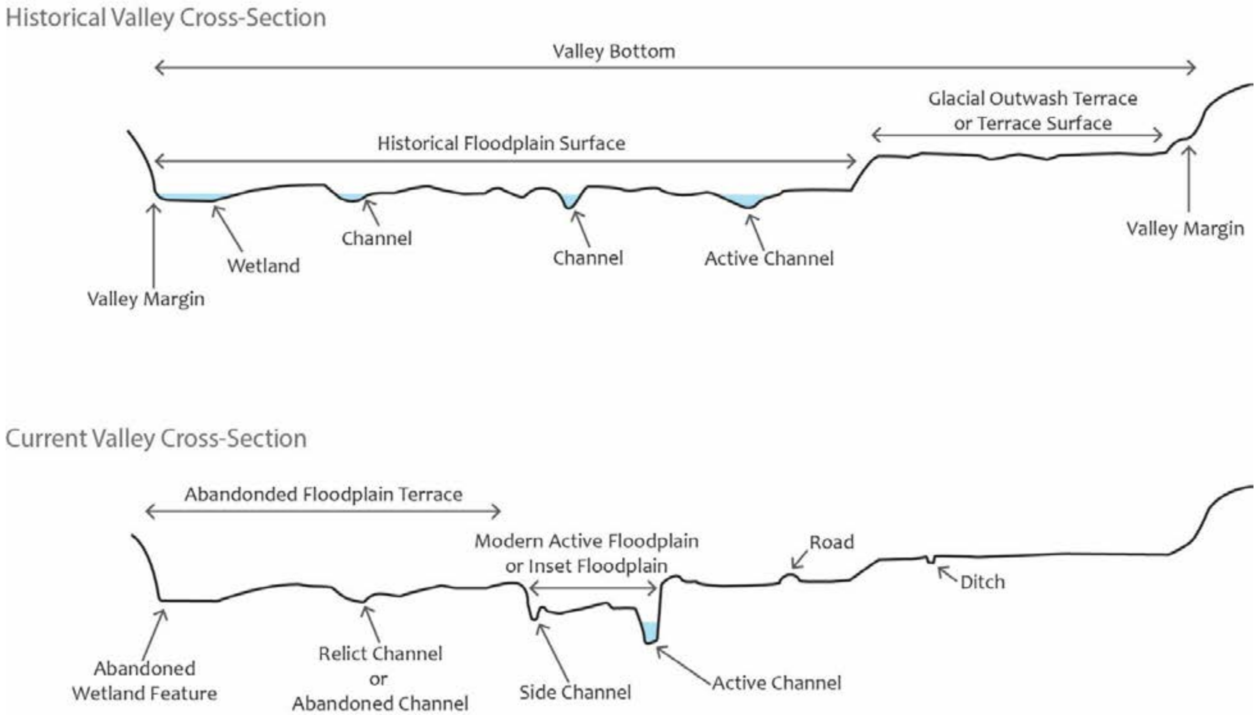


Figure 5. **Typical cross-section views of the project reaches showing: (1) the historical, or pre-developed, condition characterized by multiple shallow channels and a hydrologically connected floodplain surface; and (2) the current condition with an incised active channel and narrow floodplain that is inset below the abandoned floodplain terrace.**

Alluvial terraces were arranged in three different elevation bands that ranged in relative elevation of 4-6 ft, 6-10 ft, and 10-15 ft above the low flow water surface and contained connected depressions of fluvial origin (sinuous bends, channel geometry) that were determined to be abandoned channel features (Figure 6).

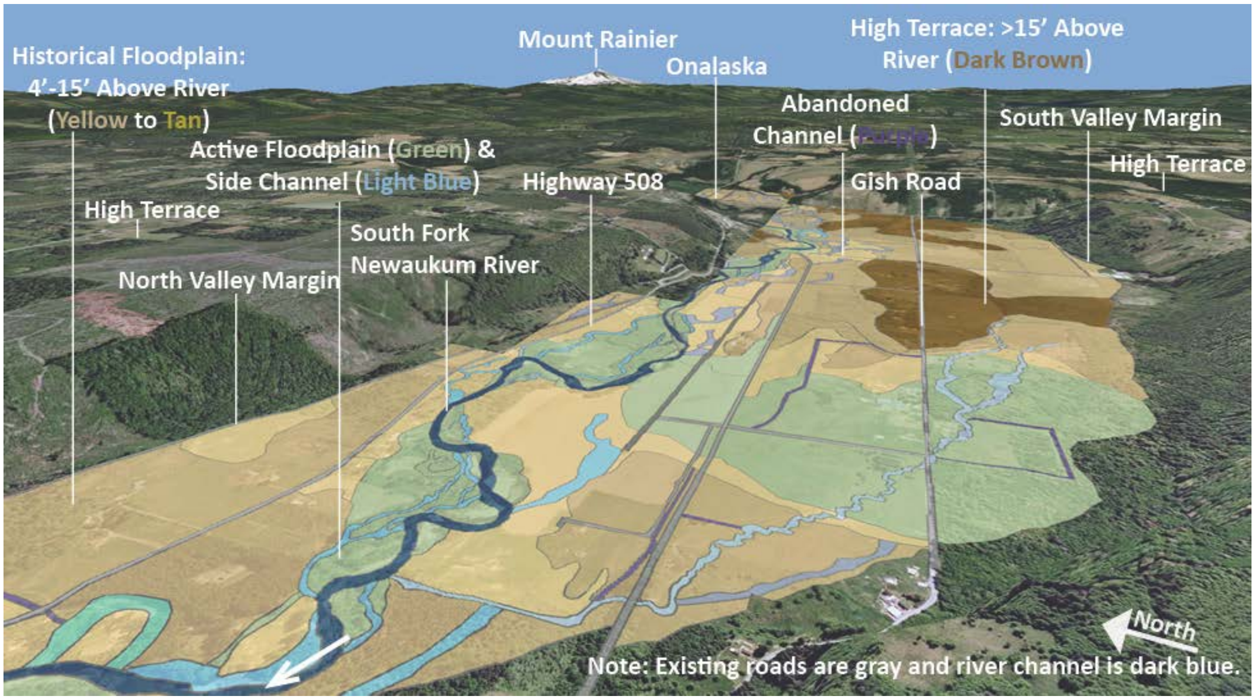


Figure 6. **Example birds eye view of the South Fork Newaukum River (reach 3) showing the current river channel (dark blue) and active floodplain (green), the historical floodplain (yellow/tan) and abandoned channels (purple), and the higher terraces (dark brown) and current roads (gray).**

Multiple alluvial surfaces at different elevations are a characteristic of wood dominated old-growth forest rivers (Abbe, 2000) (Brummer et al., 2006) (Montgomery and Abbe, 2006). Historic channels were typically about half of the width of current bankfull channels, which makes sense given there were two or more historic channels to convey similar quantities of water as the current channel. The origin of these channels was evaluated by comparing the existing topography with notes from land surveys performed in the 1850's by the General Land Office (United States Bureau of Land Management, 2016). Most of the terrace surfaces are currently pastured or developed into residential properties. Our analysis indicated that the relict channel features and terraces are remnants of the historical floodplain surface within the Newaukum River Valley (Figure 7).

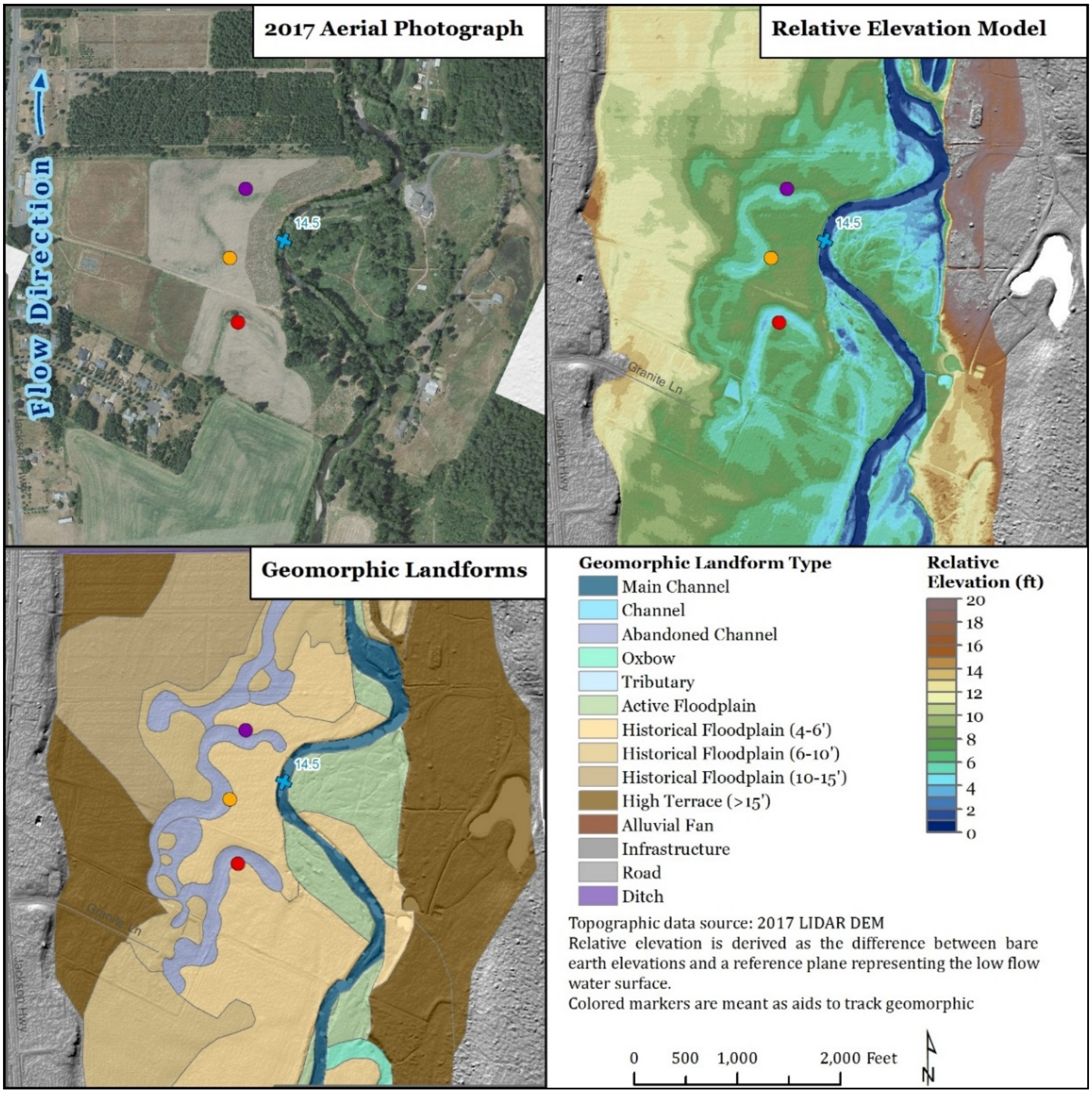


Figure 7. Relict channel network still present on the landscape; colored circles represent the same spot on the landscape in both images. The fluvial landscape when the first Europeans arrived would have been dominated by large trees with river channels commonly plugged with logjams.

A relict channel feature is evident in the terrain on the South Fork Newaukum River just upstream of the SR 508 bridge (Figure 8). Land surveyors from the General Land Office traversed the valley in the 1850s following the section line boundary that SR 508 follows today. Near RM 15.8, the surveyors noted the channel crossed the section line boundary in a meander pattern that is preserved in the topography on the landscape today. That feature however, has been disconnected by SR 508 and is 5 ft above the existing channel network. Combining this historical survey information with analysis of other abandoned channel features of similar elevation evident on the landscape provided a line of evidence to define the mapped terraces as the historical floodplain. The origin of the terraces was further investigated using results from the bank material and stratigraphy analysis.

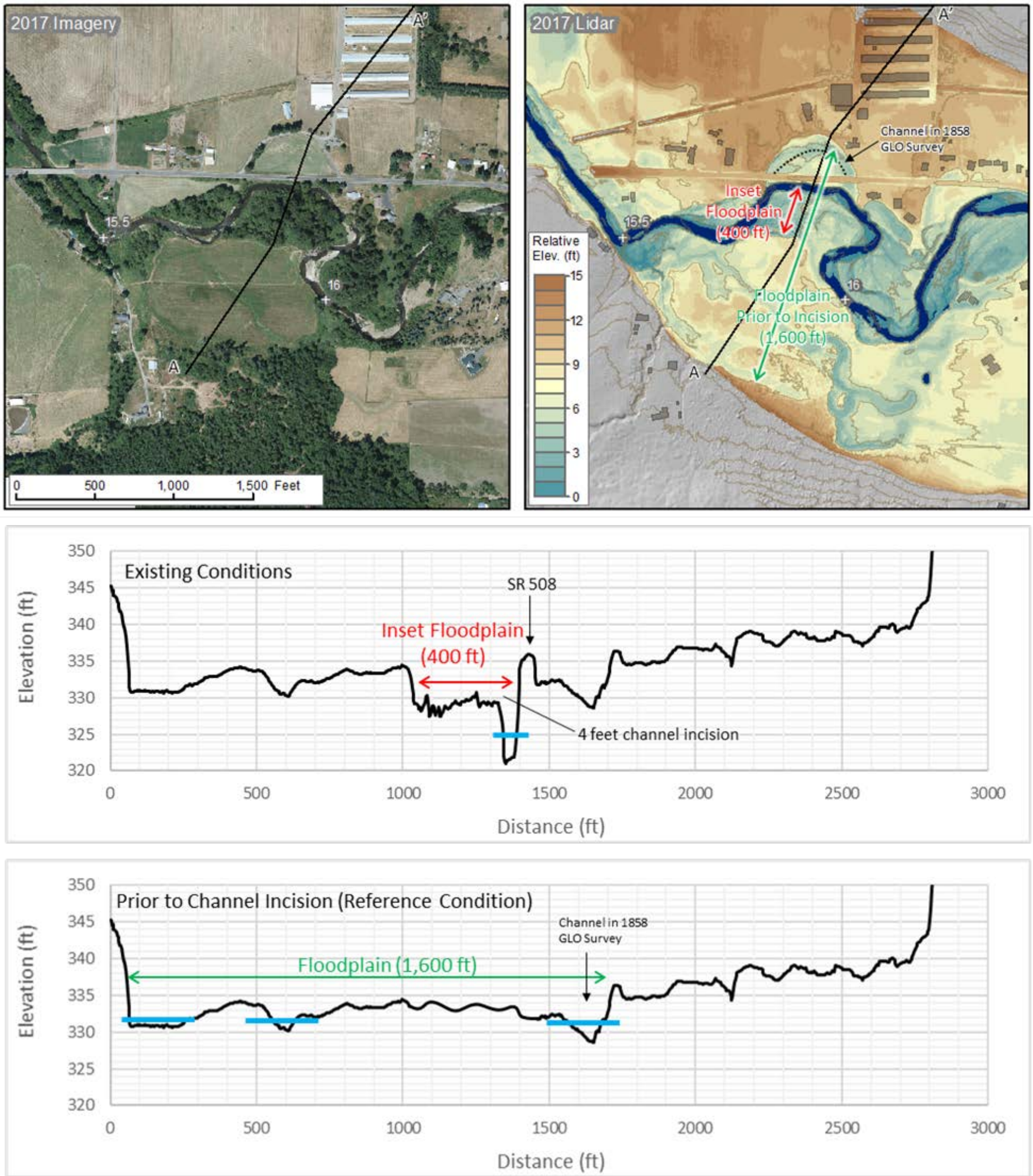


Figure 8. Cross-checking geomorphic landforms against historical data. Comparison between 1858 General Land Office survey of the study area and the Relative Elevation Model based on 2017 topography. Note that the channel identified in the 1858 survey is at a similar relative elevation to abandoned channels on the mapped historical floodplain. This example is from the South Fork Newaukum River; river flow is from right to left.

The bank stratigraphy analysis added additional evidence to define the historical floodplain across the entirety of the valley. Field surveys of river bank material indicate that mapped 4-15' terrace surfaces are comprised of silts, gravels, and cobbles - which show evidence (i.e. rounded edges) of being fluvial in nature (Figure 9). In some cases, large logs were observed to be embedded in the alluvial deposits exposed in eroding banks, offering direct evidence of logjams in historic channels. Radiocarbon dating indicates that these historical wood pieces ranged in age from 180-1220 years which is prior to European Settlement (and the subsequent incision) in the valley. Surfaces of similar elevation to the river-derived material were connected across the valley bottom as additional evidence supporting the historical floodplain delineation.

Figure 9. Right bank of South Fork Newaukum River near RM 15 (between Middle Fork Road and SR 508). The bank height is approximately 8 ft high in this location. The channel has incised approximately 3 feet reducing connectivity with the abandoned floodplain surface. Flow is from right to left. September 2017. In the photo inset (lower right) the modern floodplain can be seen in the lower right corner, sitting well below the historic floodplain on the left.

Combining evidence from the geomorphic landform mapping, historical records, and bank material stratigraphy allowed us to reconstruct the extent of the historical floodplain. Throughout the Newaukum River Valley, the historical floodplain is on average 1,500 feet wide and 9 times wider than the modern floodplain (Figure 10).

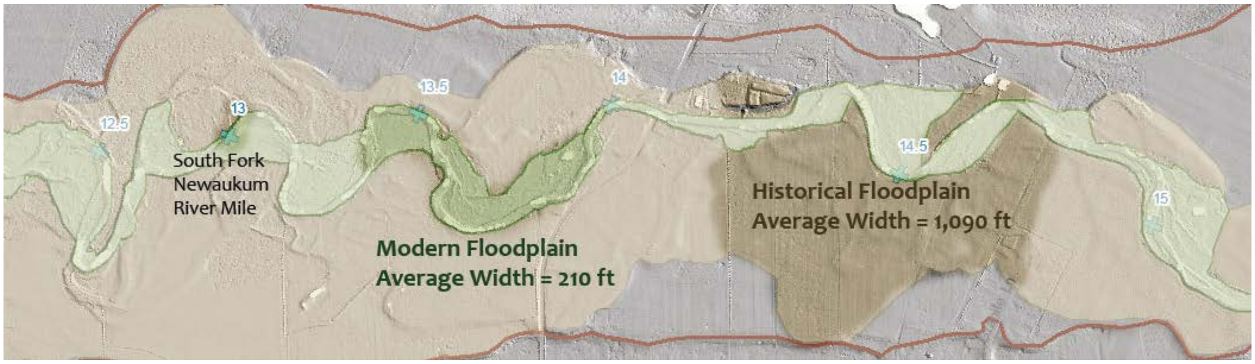


Figure 10. Example of difference between modern and historical floodplains in Reach 1 of the South Fork Newaukum River.

Channel incision depths range between 3-10 ft with an average of 5.6 ft. As a result, flood waters are contained within the active floodplain corridor and do not spread out across the valley as they likely would have under historical conditions. This significant reduction in floodplain width has implications for aquatic habitat (reduction in habitat area and quality), downstream flooding (higher peak flows), and channel processes (increased erosion) within the valley.

The project area covering the NF and SF Newaukum River Valleys was delineated into a series of channel segments, or reaches, separated by tributary inflows, changes in confinement, or gradient (Figure 11). Results including maps of floodplain topography and geomorphic features, including the active floodplain and terrace surfaces, are presented at the reach scale in Appendix 1.

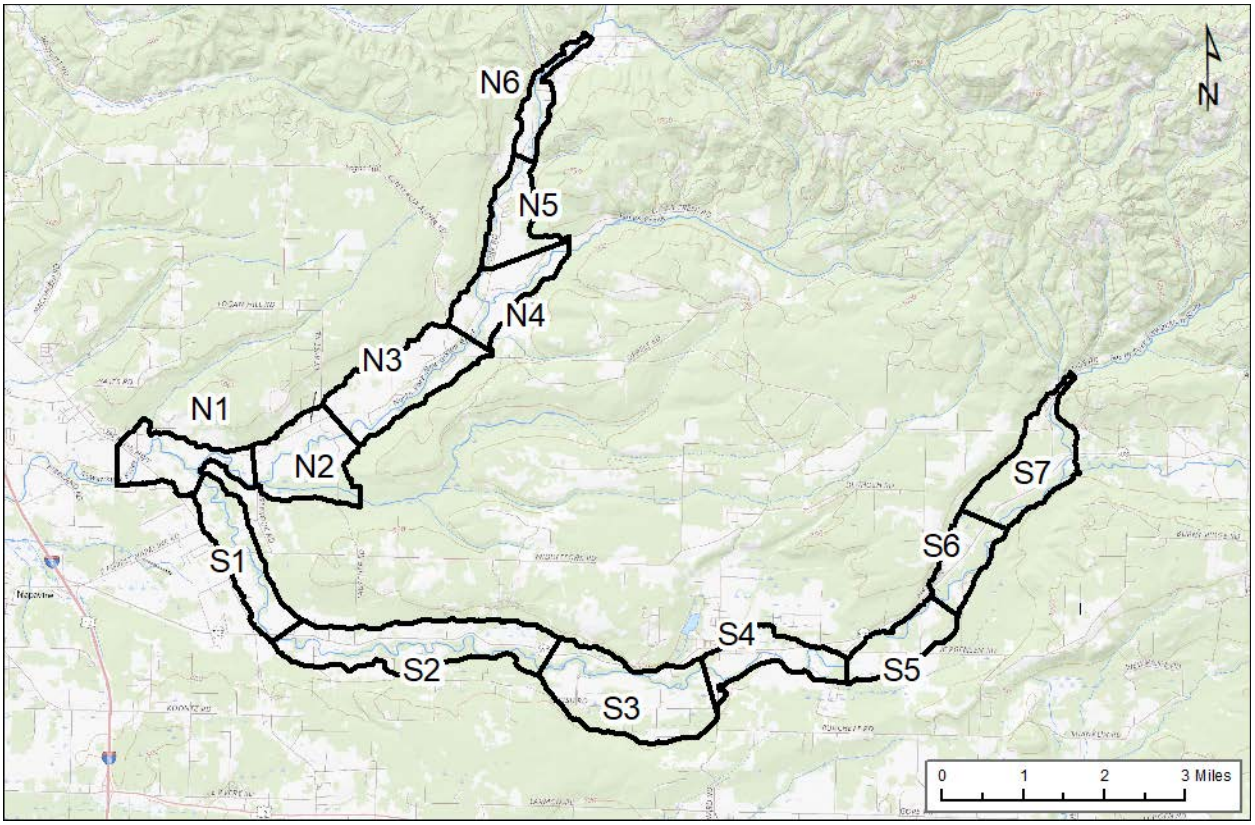


Figure 11. Reference map of geomorphic reaches delineated in the NF and SF Newaukum Rivers. Detailed reach maps of existing conditions are presented in Appendix 1.

3.2 Land Use, Vegetation and Soils

3.2.1 Historical Landscape

US General Land Office (GLO) boundary surveys of the NF and SF Newaukum River Valleys were conducted as early as 1851/53, with more detailed surveys in 1857/58. The GLO survey found large prairies in the area, separated by large areas of coniferous forest, primarily Douglas-fir and Western red cedar, with some deciduous forest, comprised of big-leaf maple, red alder, Oregon ash, black cottonwood, Garry oak (Figure 12). Much of the valley bottom was also seasonally flooded. According to GLO survey notes from 1858, the bottomland around the NF and SF Newaukum River confluence used to flood from 1-foot to 6-feet deep every year. In these historical surveys, "Bottomland" was generally considered to extend from valley wall to valley wall.

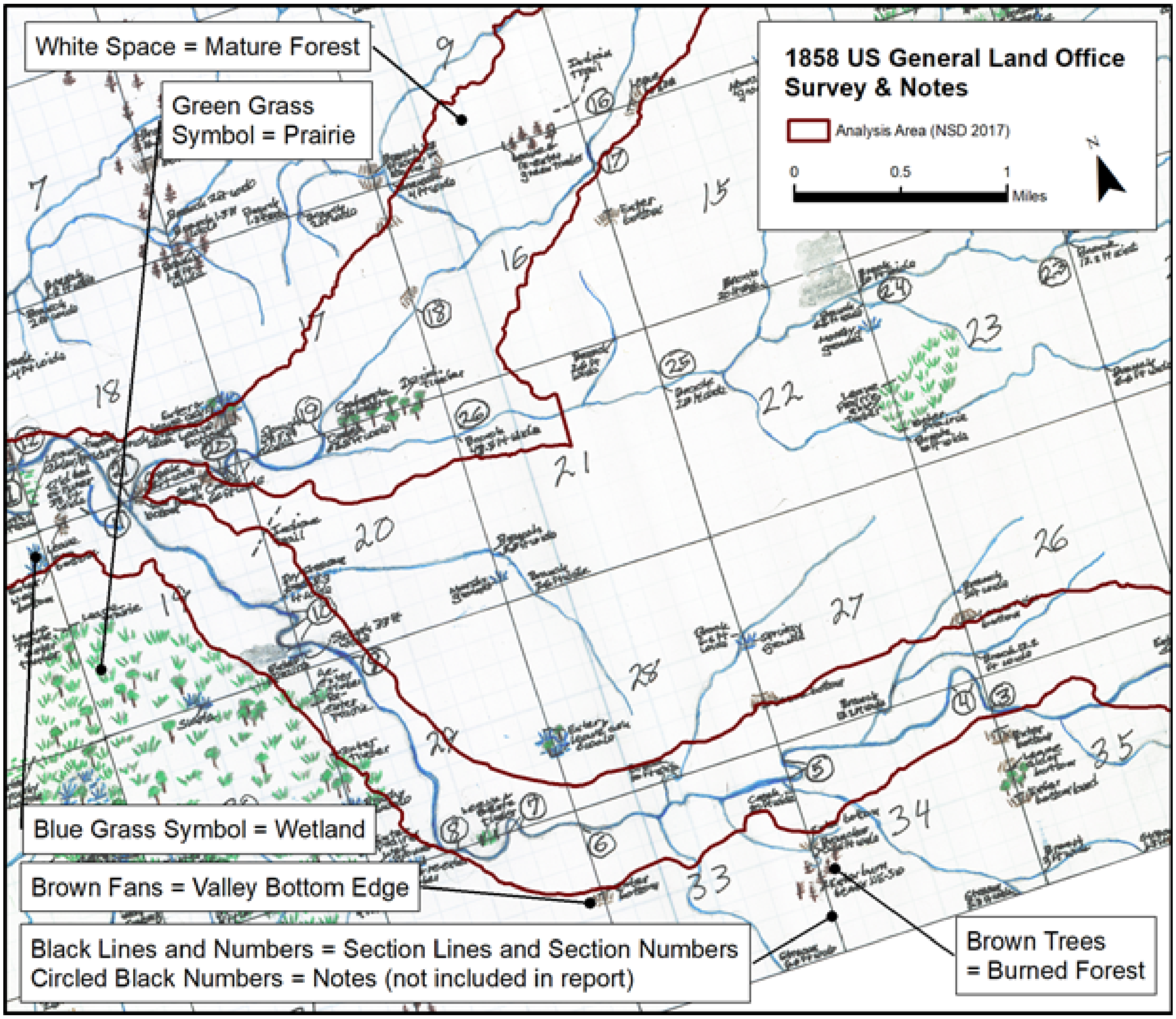


Figure 12. Sketch-map of combined historical surveys and survey notes from General Land Office (GLO) surveys in 1873 (T13N R1E) and 1858 (T13N R1W) of the Newaukum River area. Note that prairies are almost all on uplands outside the valley bottoms.

The name "Newaukum" originates from the Upper Chehalis language word náwaqwəm, meaning "big prairie" (Bright, 2004). The Chehalis and Cowlitz Tribes once used fire to maintain the prairies occupying well drained high terraces near the Newaukum River and Chehalis River valleys, which were once a significant source of food, fiber, and medicine (Storm, 2004). It is likely that the large prairies mentioned in the GLO surveys were maintained by indigenous people and that these landscapes have been cultivated for a long time. These prairies are reflected in the names European settlers gave to local communities (Figure 13), including:

- Newaukum Prairie lies on a relatively low terrace, 20-40 ft above the river, south of the mainstem Newaukum and east of the South Fork Newaukum and bisected by I-5 near its western margin. Jackson Highway runs along the east margin of the terrace.
- Alpha Prairie lies on a high terrace, about 200 ft above the river, between the North and South Fork Newaukum Rivers and bisected by the Middle Fork.

- Jackson Prairie lies on a high terrace, about 200 ft above the river, south of the south Fork, atop the high terrace bisected by State Route 12.
- Napavine Prairie lies on the same terrace as Jackson Prairie to the west of I-5.
- Grand Prairie lies on the same terrace as Napavine Prairie to the south near Winlock, also west of I-5.
- Lacamas Prairie lies on a terrace about 100 feet below and to the south of the Jackson Prairie and 100 ft above and north of the Cowlitz River.
- Cowlitz Prairie is located southwest of the Lacama Prairie on the same terrace.

All of these prairies lie on terraces well above even the most extreme floods and have negligible erosion risks, but they do have relatively level land with well-drained alluvial soils. They are some of the best agricultural areas in Lewis County (Appendix 4). Hoyt and Langbein (1955), both distinguished hydrologists with the United States Geological Survey, describe alluvial terraces as the following:

> *"Terrace lands have many of the advantages of the more modern flood plain (with regards to alluvial soils), combined with the advantage of relative freedom from flooding."*

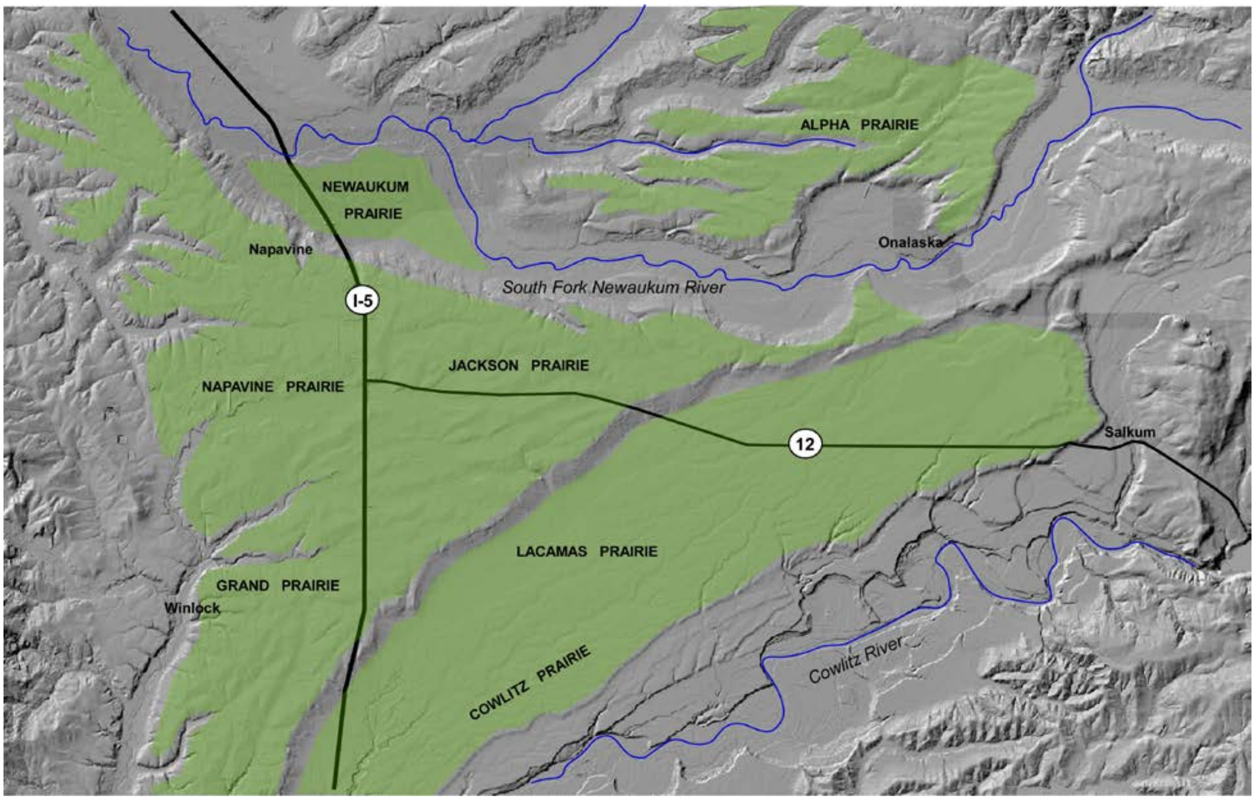


Figure 13. Shaded relief map showing the high terrace prairies of southern Lewis County in close proximity to the Newaukum that offer abundant opportunity to relocate residents and business out of flood prone areas. The terraces offer level land with good soils and drainage and already have some of the most productive agricultural operations in the region. Expansion of agricultural, residential and industrial development onto these terraces would provide long-term sustainable flood protection.

Today's Newaukum River Valley Landscape

The South Fork Newaukum River Valley study area is approximately 4,900 acres in size. Where there was once, historically, a mix of old-growth coniferous forest, oak prairie, wetlands, alder bottom-lands, swales, ash-swamps (United States Bureau of Land Management, 2016), the South Fork Newaukum River Valley bottom landscape is now co-dominated by low-growing pasture and mixed-forest of various ages (see Table 1). These valley bottom areas include areas up to twenty feet above the current river (such as illustrated in Figure 2) and are not all susceptible to flooding, but could experience erosion depending on proximity to the river. The North Fork Newaukum River Valley study area is almost 3,300 acres in area. While this valley was once a mix of old growth coniferous forest, crabapple thickets, sloughs, and wetland complexes, it is now predominantly an equal mix of pasture and shrubs, with some immature forest. This landscape composition is different from the South Fork Newaukum River Valley in that it is co-dominated by shrubs, rather than forest. However, both valleys are similarly covered in over 30% of pasture acreage (see Table 1, Figure 14). The NF Newaukum River Valley landscape composition is slightly different from the South Fork Newaukum River valley in that it is co-dominated by shrubs, rather than forest. However, both valleys are similarly covered in over 30% of pasture acreage.

Table 1. Summary of current valley bottom land cover for South and North Fork Newaukum Rivers (2017).

	SOUTH FORK NEWAUKUM RIVER		NORTH FORK NEWAUKUM RIVER	
Land Cover (2017)	Area (acres)	Percent Total Area (%)	Area (acres)	Percent Total Area (%)
Pasture or grass groundcover	1,811	37%	1,074	34%
Forest	1,647	34%	672	20%
Shrubs	727	15%	1,018	32%
Small Trees, Large Shrubs	323	7%	196	6%
Everything Else (Water, Roads, Gravel Bars, Buildings, Log Jams)	350	7%	207	8%
Grand Total	**4,858**	**100%**	**3,167***	**100%**

* The data used to generate this statistic did not cover the entire valley bottom

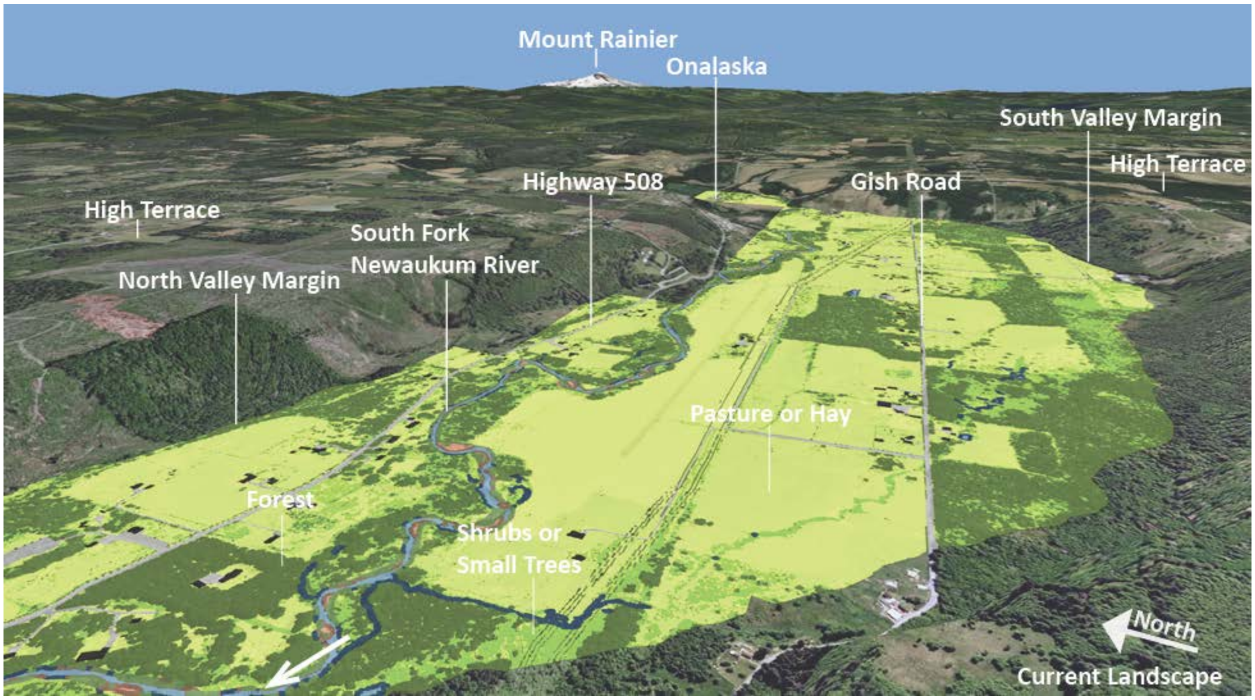


Figure 14. Example of existing land cover from the South Fork Newaukum River. Perspective is looking upstream to the east.

Figure 15 and Figure 16 show typical images of the Newaukum River landscape, including a mowed pasture, and a range of coniferous and deciduous tree species. These trees are all second or third growth. The understory of the forested areas is often covered in a dense mat of reed canary grass, however in some locations there are native forest understory species present.

Figure 15. Image of typical South Fork Newaukum River Valley bottom landscape, with mowed pasture in the foreground, and a young mixed forest in the middle ground.

Figure 16. Image of typical South Fork Newaukum River floodplain forest and understory. The forest is dominated by immature deciduous trees and the understory is dominated by invasive reed canary grass and blackberry, with few native shrubs.

One of the key differences between the North Fork and South Fork Newaukum Rivers, observed in the field, was the presence of Western red cedars along the river bank in the North Fork (Figure 17). The banks of the South Fork Newaukum River tend to be dominated by deciduous species such as Oregon ash, black cottonwood, and red alder.

Figure 17. Remnant Red Cedar trees and old stumps along the North Fork Newaukum River. While these Cedars are the largest observed in the study area, they are still a fraction of size and age they can achieve (15 ft in diameter and a 1000 years). The stumps offer a glimpse of the larger trees cut in the early 1900s which were common in floodplain forests of the area.

Soils

The soils of the South Fork Newaukum River Valley bottom generally indicate alluvial parent material and are comprised of Newberg fine sandy loam in the active channel area-- perfect conditions for cottonwood bottomland-- and Chehalis silty clay on the higher floodplain and terraces, which lends itself to dry upland forest species such as Douglas fir, Garry oak, big leaf maple, Sitka spruce, Nootka rose, snowberry, and thimbleberry (Figure 18). See Appendix 1 for detailed soils and plant information. As the valley topography increases in elevation from the river channel to the valley wall, hydric silty clay loam soils appear on the landscape. These hydric soils are an indicator of wetland soil formation processes.

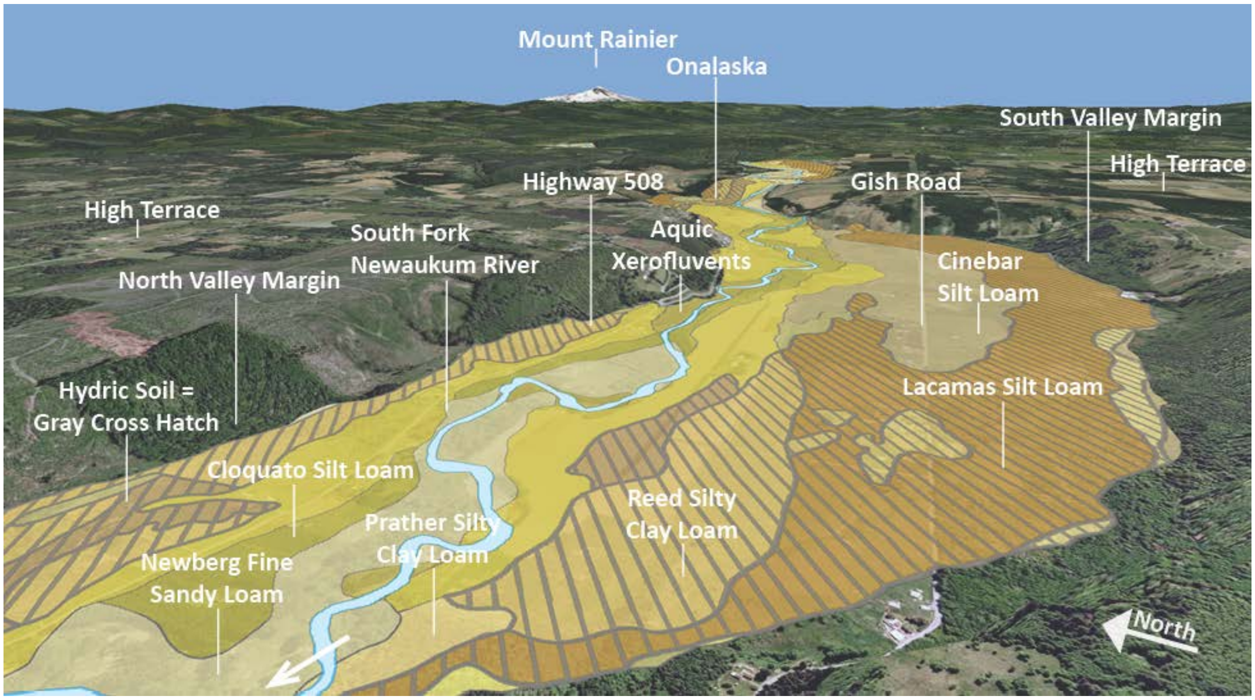


Figure 18. Example of USDA soils mapping for South Fork Newaukum River Valley.

Modern Land Use

As previously mentioned in the geomorphic mapping section, current riparian and floodplain landscape conditions within the North and South Fork Newaukum River Valleys are very different than those reported in the General Land Survey records from the 1850-90's. In general, floodplain vegetation and forests have been cleared and replaced by homes, pasture and some small farms (Figure 19).

Farming and residential development is also occurring outside of the valley bottom and is similar to valley bottom land use, with the exception that much more-diverse and productive farming is found on upland areas outside floodplains, including dairy farms, poultry, beef, row crops (grains, vegetables, berries) and others. Based on spatial data from the Washington State Department of Agriculture (WSDA), the proportion of agricultural land within and outside the 100 year floodplain is about the same, 17-18% of the total areas with slopes less than three percent totaling about 23,000 acres . Most of the agricultural land inside the floodplain is limited to lower value crops such as grass, hay and seasonal pasture.

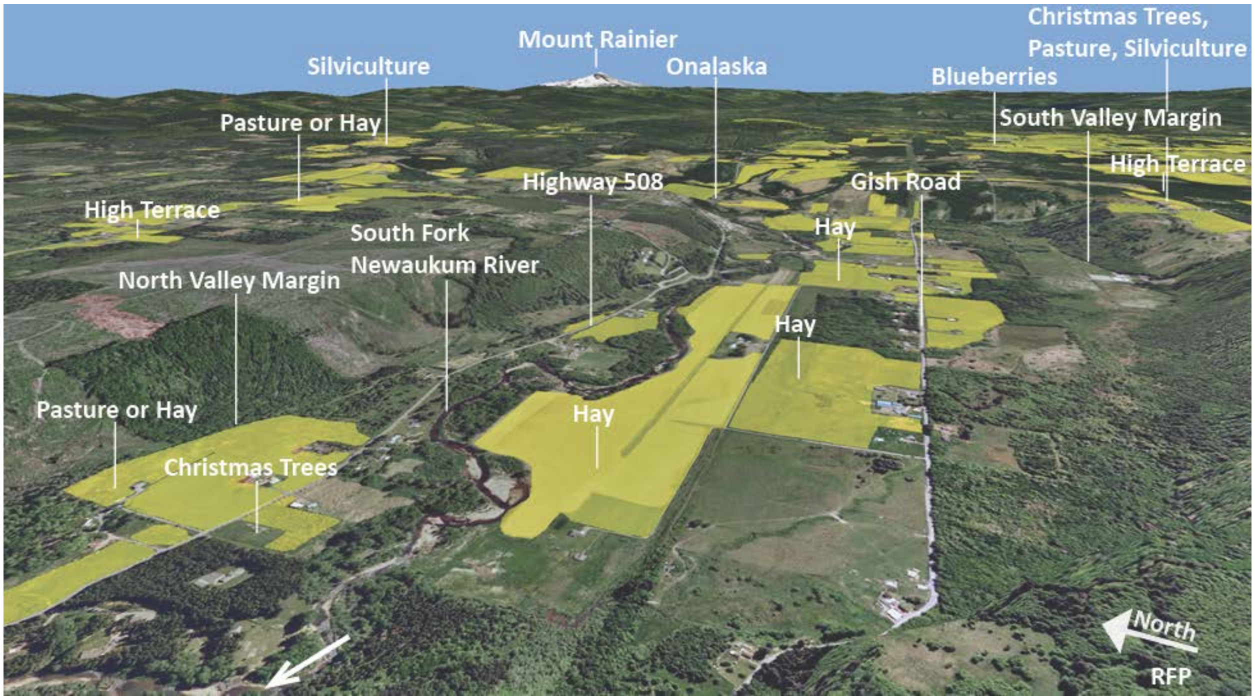


Figure 19. Example of modern agricultural land use in the South Fork Newaukum River Valley, which includes agriculture that is both inside and outside of the regulated 100-year floodplain (data source: WSDA 2017).

Floodplain development and land use in the South Fork and North Fork Newaukum River Valleys is typical for Lewis County. According to a recent Washington Department of Fish and Wildlife (WDFW) study of floodplain land use change along the mainstem Chehalis River (Pierce Jr. et al., 2017), development, such as rural residential and single family residential, has been increasing at an average rate of about 9 acres per year from 1938 through 2013. This increase in development is displacing important habitat along with forest and agriculture.

Development within erosion hazard areas of the South and North Fork Newaukum Valleys has led to significant bank hardening to protect roads and property (Figure 20). The most common method uses large rock piled up from the river bed to the top of bank which is commonly referred to as rip rap. Bank hardening can result in increased erosion in non-hardened portions of the river, such as the bed or the downstream banks (Reid and Church, 2015). It also degrades aquatic and riparian habitat. A more detailed analysis of erosion hazards is presented later in this chapter.

Figure 20. Examples of South and North Fork Newaukum River bank armoring that results in loss of cover and shade, as well as limiting floodplain formation and wood recruitment which is essential to sustaining salmon habitat.

Roads, Bridges, Buildings: In the South Fork Newaukum River Valley study area, there is currently an equal amount of river and road length, 21 miles and 20 miles, respectively. There are also at least 970 buildings in this valley, some of which are near the river, others which are located on higher terraces. Using the simulated 2009 flood event inundated area, there were 141 buildings in the flooded area. However, many of the valuable residential or commercial buildings were elevated above the flood water surface. Simulated 2009 flood water surface inundated 4 of these valuable structures. Valuable structures were identified by the improvements field in the assessor's data, which indicates the presence and assessed value of residential buildings.

In the North Fork Newaukum River Valley study area, there are also an equal amount of river and road length, 12 miles and 14 miles, respectively. However, there are proportionally fewer buildings, approximately 425 structures, both near the river and on higher terraces. Using the simulated 2009 flood event inundated area, there were about 58 buildings in the flooded area. However, the approximate finished floor elevations of many of the valuable residential or commercial buildings (or assessed parcels with improvements) were elevated above the flood water surface. Nevertheless, simulated 2009 flood water surface went above the finished floor elevation of about 8 of these valuable structures.

This analysis of the simulated effects of the 2009 flood on homes and businesses in the South Fork and North Fork Newaukum Rivers indicates that flooding is not a serious problem for the residents of these basins. However, the large amount of riprap observed on the lower portions of both rivers, with about 2 or 3 miles of total riprap in each river, indicates that river bank erosion, and the resulting loss of land has been a problem that will continue into the future.

3.3 Flood Hydrology and Inundation Mapping

Peak flows in the Newaukum River Watershed occur during late fall or winter in response to frontal storms that bring periods of intense precipitation. Large floods are typically associated with atmospheric river events in which moisture-rich air from the tropics is directed in a relatively narrow plume that produces extreme precipitation. Most large floods (greater than a 5-year recurrence interval) are produced by atmospheric river events, however, there can be localized effects related to watershed characteristics and the direction of approach for individual storms (Neiman et al., 2011).

The U.S. Geological Survey (USGS) maintains three active streamflow gaging stations in the Newaukum River Watershed (Figure 21). The gage on the lower Newaukum River near Chehalis (#12025000) has the longest period of record with 77 years of peak flows. Flood frequency statistics calculated with a Log-Pearson Type III distribution, as described in the USGS Bulletin 17B, are presented below in Table 2. The annual maximum flood series shows an increase in both peak flow magnitude and variability for the period since 1970 (Figure 22). Eight of the ten largest peak flows have all occurred since 1990 (Table 3). Floods from February 1996, January 2007, and December 2007 stand out as having similar flow magnitudes in the mainstem Newaukum with a recurrence interval of approximately 50-years (annual chance of exceedance = 2%).

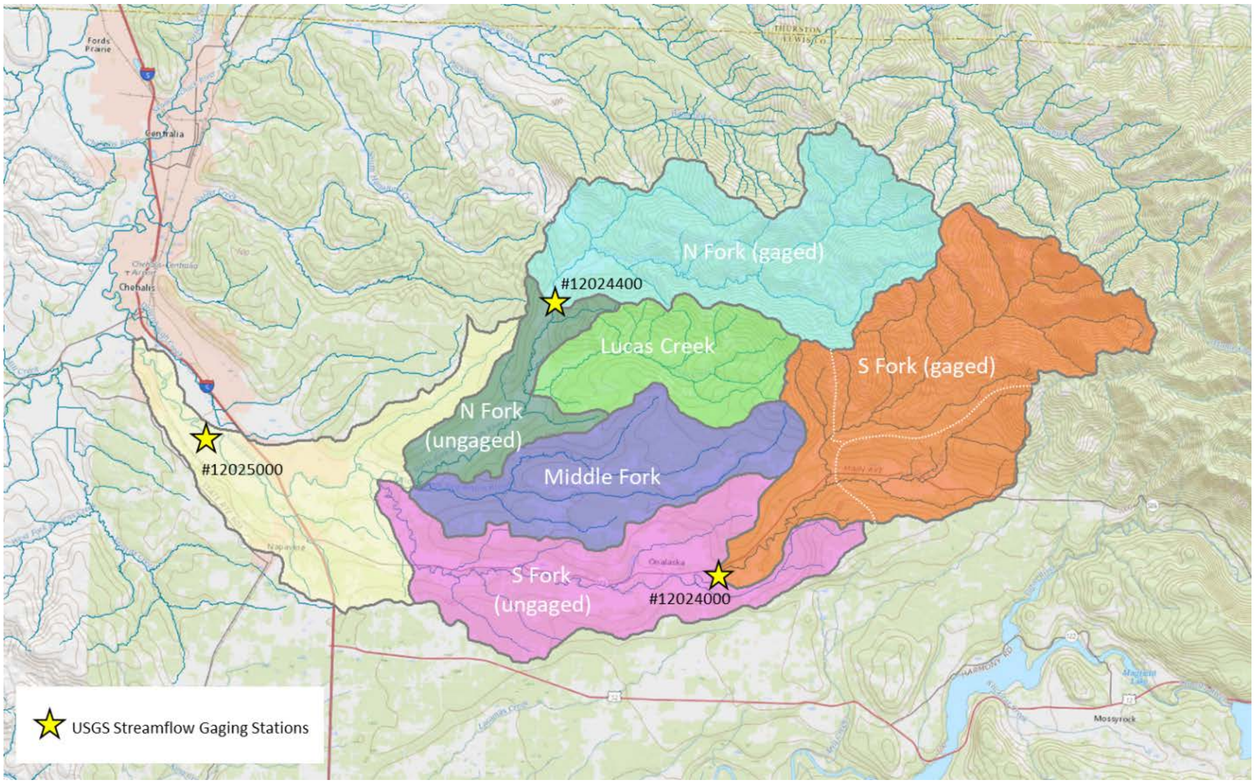


Figure 21. Map of the Newaukum River Watershed showing sub-basin areas and location of USGS streamflow gaging stations.

Table 2. Flood frequency statistics for the Newaukum River near Chehalis (USGS gage #12025000) for the period water year (WY) 1929-2017.

RECURRENCE INTERVAL (YRS)	% ANNUAL CHANCE OF EXCEEDANCE	PEAK DISCHARGE (CFS)	95% CONFIDENCE LIMITS	
			UPPER (CFS)	LOWER (CFS)
100	1	14,100	16,400	12,500
50	2	13,000	15,000	11,700
25	4	11,900	13,500	10,700
10	10	10,200	11,400	9,340
5	20	8,810	9,700	8,110
2	50	6,420	6,930	5,960
1.25	80	4,510	4,890	4,100
1.05	95	3,090	3,450	2,700

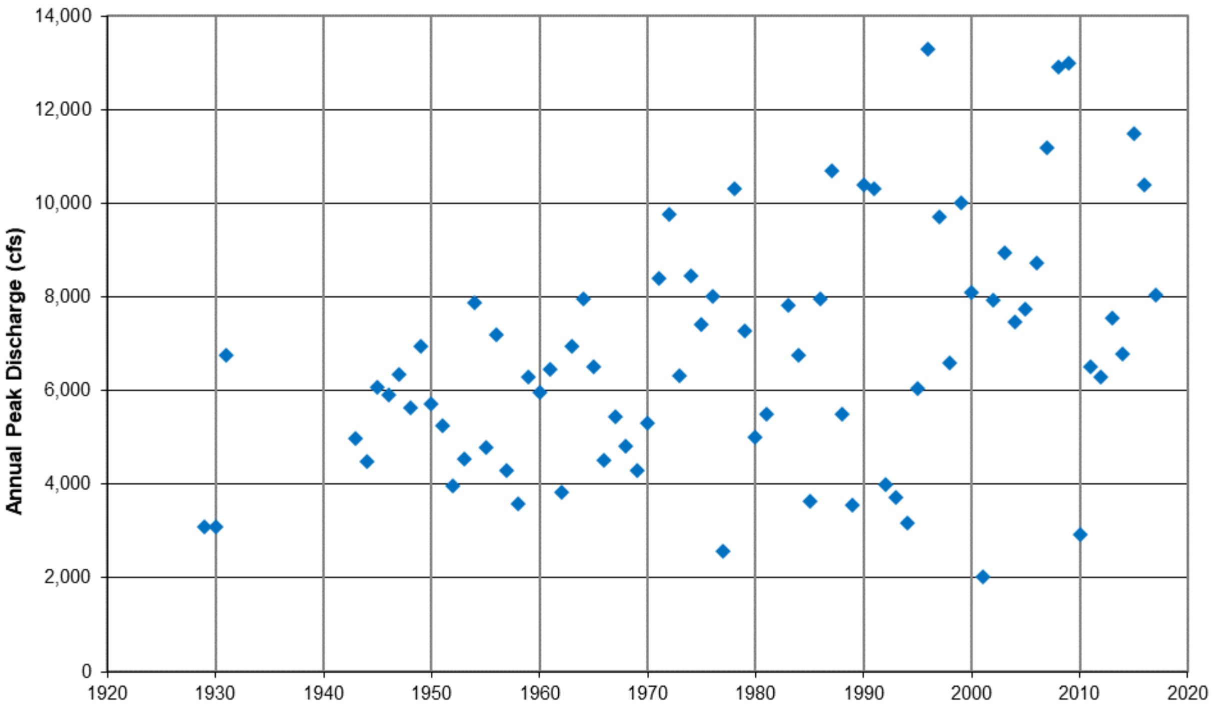


Figure 22. Annual Maximum Discharge (peak flow) for the Newaukum River near Chehalis (USGS gage #12025000). The data clearly show a trend of increasing flood peak discharge over the last 100 years. Based on a linear regression of historic data, the annual peak will increase 30% from 2020 to 2080, and 40% by 2100.

Table 3. Summary of the 10 largest recorded floods in the annual maximum flood series for the Newaukum River near Chehalis (USGS gage #12025000).

RANK	DATE	PEAK FLOW (CFS)
1	Feb. 08, 1996	13,300
2	Jan. 07, 2009	13,000
3	Dec. 03, 2007	12,900
4	Jan. 05, 2015	11,500
5	Nov. 07, 2006	11,200
6	Nov. 24, 1986	10,700
7	Jan. 09, 1990	10,400
8	Nov. 18, 2015	10,400
9	Dec. 02, 1977	10,300
10	Nov. 24, 1990	10,300

Flood Inundation

To gain a better understanding of the extent to which the Newaukum River Valley floods during large events, a the 2-dimensional hydraulic model described in Chapter 2 was used. The January 2009 flood event was simulated in the model using inflow hydrographs scaled from the streamflow data from the USGS gage on the mainstem Newaukum near Chehalis, WA. More information on the modeling process can be found in the Hydraulic Modeling Report in Appendix 3.

Results from the model estimated that the January 2009 flood was largely contained within the inset floodplain. The average width of the simulated inundation at its peak is 753 ft (calculated by dividing the area of inundation by the length of the model), while the average valley width is more than three times larger at 2,745 ft. This prediction was consistent with landowner observations and indicates that even during the flood of record the majority of the valley bottom was not engaged (Figure 23). Given homesteader accounts of frequent valley bottom inundation (Smith 1941), hydraulic model results provide additional evidence of historic channel incision.

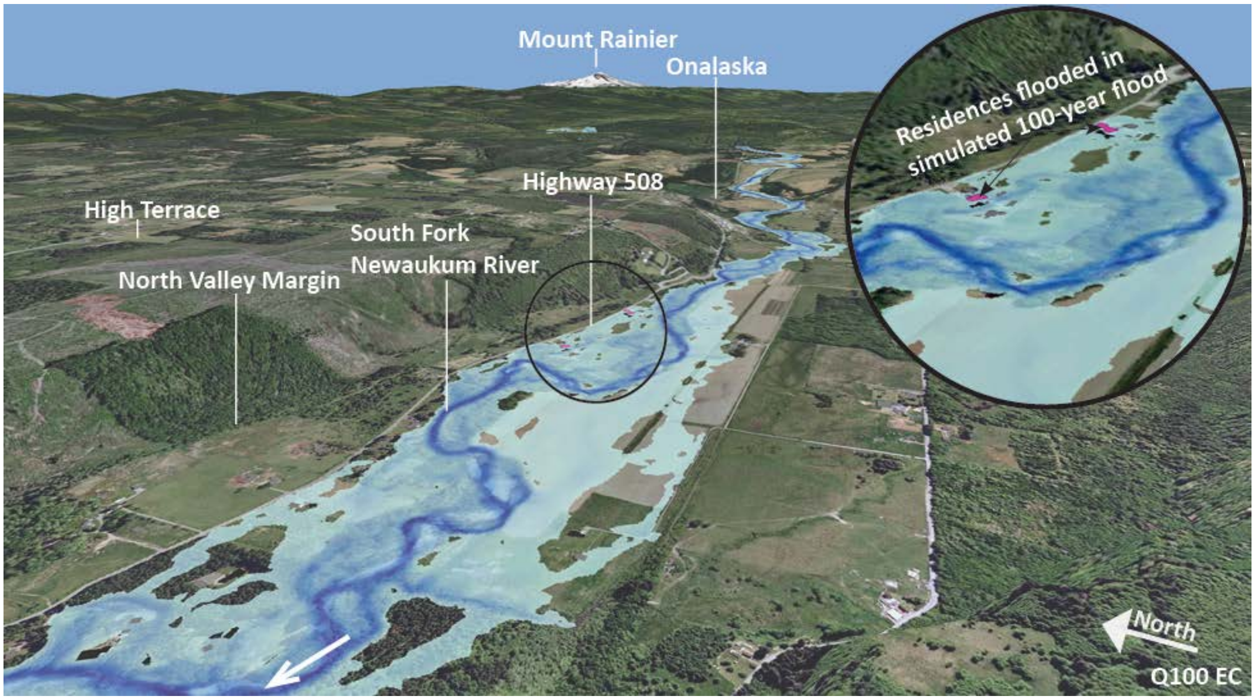


Figure 23. Example birds eye view of a simulated 100-year flood under current landscape conditions along the South Fork Newaukum River, just downstream from the community of Onalaska, Washington. Notice that flood inundation occupies just a fraction of the valley bottom depicted in previous images, consistent with historic incision.

The restriction of waters to the inset floodplain is likely a modern phenomenon due to the effects of land use and incision as discussed above. Historically, floods would typically crest the banks of alluvial rivers in Western Washington about once a year (Castro and Jackson, 2001; Parker, 1978). The speed at which floods move downstream (flood celerity) depends on the roughness or frictional resistance flow encounters on the floodplain. Flows across the original forested floodplains (prior to European colonization) moved much slower than cleared pastures common in the present valley. As floodwaters spread over the forested floodplain, they would also be captured by floodplain wetlands, beaver dam ponds and marshes, and slowly infiltrate into the ground. Larger floods, such as the January 2009 flood which roughly corresponds to a 100-yr return interval flow, would have covered the majority of the valley bottom. Similar to smaller annual floods, these larger floods interacted with the vast forest and floodplain wetlands, slowing the water as it moved downstream, but to a lesser degree than the smaller floods because of the sheer volume of water. In the NF and SF Newaukum Rivers, this valley bottom engagement would likely have delayed and reduced downstream flood elevations in the modern-day locations of the cities of Chehalis and Centralia.

A spatial analysis was performed on the results of the January 2009 flood simulation to determine the flood risk of buildings in the North and South Fork Newaukum Valleys. By overlaying the Lewis County database of structure locations with the inundation extents of the modeled January 2009 event, it was possible to determine which structures would likely be flooded during an event of similar magnitude. Results of this analysis showed that about two hundred buildings, including residences and outbuildings, were affected by this flood. Under current conditions, about 40% of these buildings (approximately 83 buildings) are within the mapped Federal Emergency Management Agency (FEMA) 100-year floodplain and about 118 buildings, or 60%, are not within this FEMA floodplain area. The 2006 FEMA estimate for the 100 yr flood is 11,500 cfs. Karpack (2014) estimated the Newaukum 100-year recurrence discharge to be 14,400 cfs.

Despite being primarily confined within the undeveloped inset-floodplain corridor within the Newaukum River Valley, there are some locations where flooding in the valley does occur. However, many of these locations are not mapped as floodway by the FEMA and thus, can be subject to development. In general, the FEMA 100-year flood boundary, shown in darker blue in Figure 24, is smaller than hydraulic simulation results of the January 2009 flood event.. The un-regulated areas that do experience flooding extend as much as 2,000 ft away from the river. The difference between the 2009 flood and the FEMA 100-year floodplain may be associated with different hydraulic models and topographic data. A detailed analysis into the difference was not done but our analysis of the January 2009 flood indicates more analysis is warranted and current FEMA mapping may under-estimate flood risks.

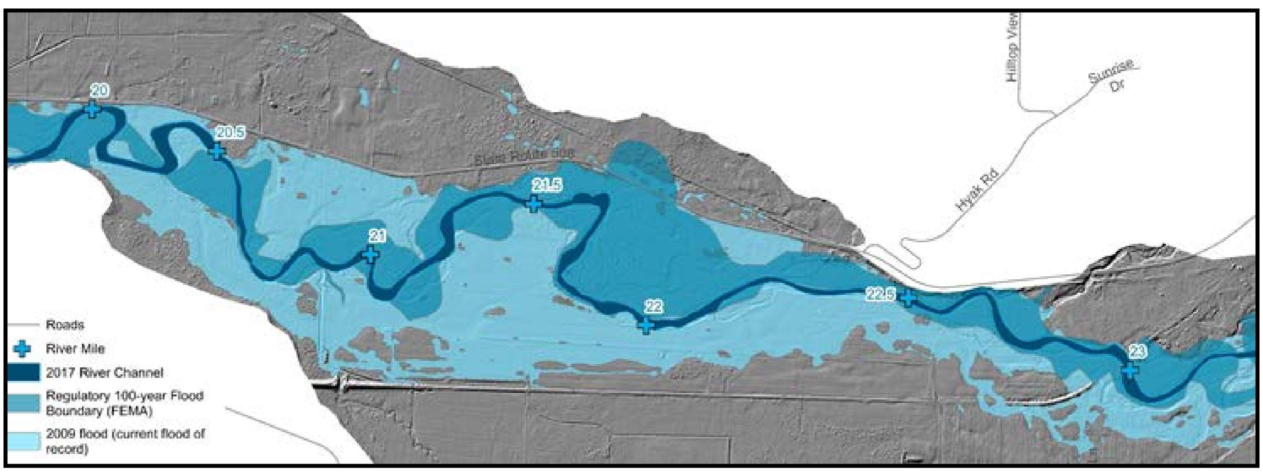


Figure 24. Difference between preliminary simulation results of the January 2009 flood, the current flood of record (lighter blue) and the FEMA 100-year floodplain (darker blue).

3.4 Erosion Hazards

3.4.1 Mechanisms of River Erosion

The current story of the Newaukum River Valley (as of 2018) is one of increasing degrees of erosional losses of land. These conditions have been brought about by the evolution of the river due to channel incision and the development of an inset-floodplain. Analysis of the river channel in aerial photography, dating back to 1940, demonstrates that the channel is actively widening the inset-floodplain corridor through channel migration and bank erosion processes which is putting local landowners and important infrastructure, such as state route 508, at risk (Figure 25). The main processes driving channel migration throughout the valley include lateral migration of meander bends and channel avulsions, or cutoffs.

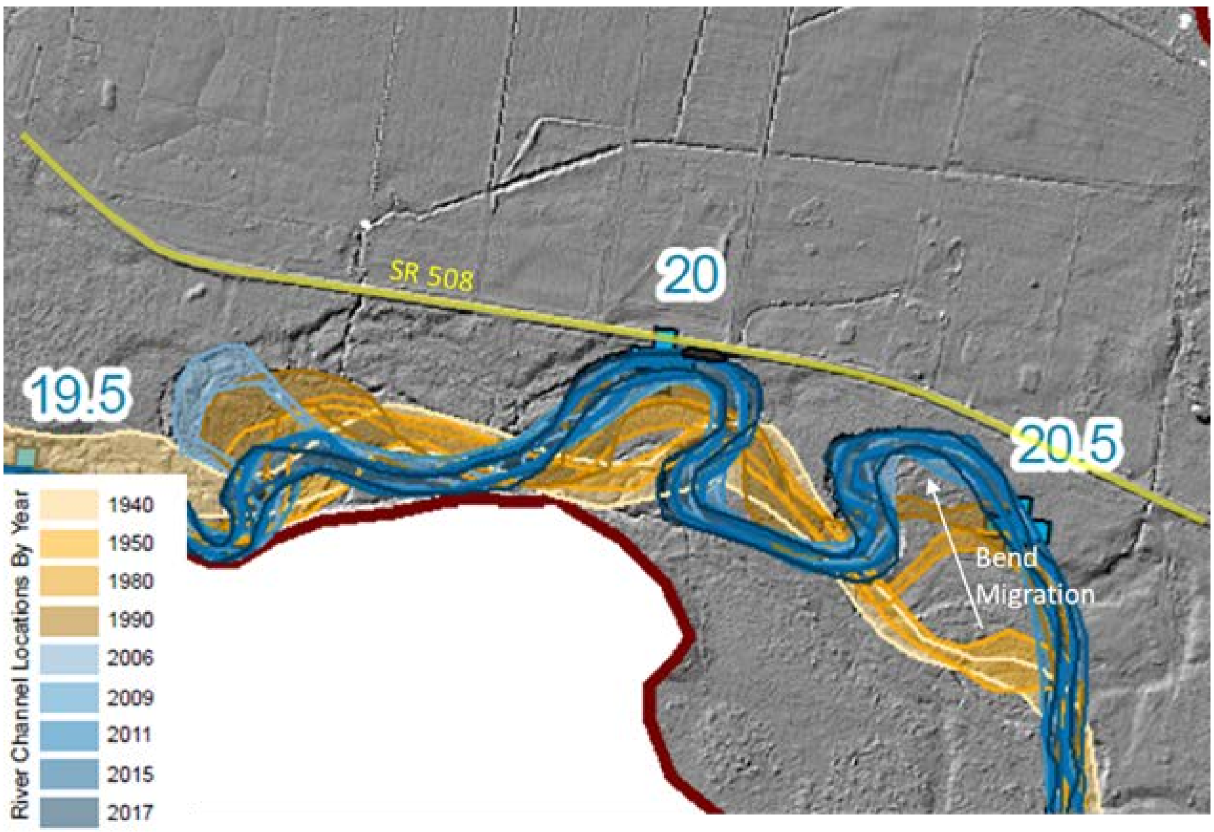


Figure 25. Widening of the inset-floodplain corridor since 1940 along the South Fork Newaukum River. Note that the channel is migrating into State Route 508. Flow is from right to left.

Lateral migration occurs when a river erodes into its bank and moves its position in the valley (Knighton, 2014). It occurs on the outside of meander bends because the curvature accelerates and deepens flow (and thus stream energy) on the outside of the bend versus the inside. This results in a general pattern of meander bends migrating outward and down valley. Lateral migration of meander bends continues to occur until the river avulses, or cuts off the bend. While this process is somewhat predictable, bank materials, vegetation, topography and in-stream wood material result in local variations of channel migration.

Avulsions occur when a river abandons its existing location for a completely new or relict channel pathway (Knighton, 2014). This causes a rapid shift in river location, sometimes to an area where it has not been in many years. One type of avulsion, meander cut-offs, occur when meander bends become too tortuous and the extended channel length reduces the slope to a point where the river cannot carry its sediment load. At that point, the river will often cut a new pathway along the straight-line distance between the meander bend, thus reducing channel length and increasing slope and sediment transport capacity. The river often begins to laterally migrate and form another meander bend from this location. Another type of avulsion occurs when a blockage, such as a log jam or large plug of sediment, physically blocks the river and directs it into a new path with less resistance. Figure 26 shows an example of both lateral migration and avulsion processes along a short reach of the South Fork Newaukum River.

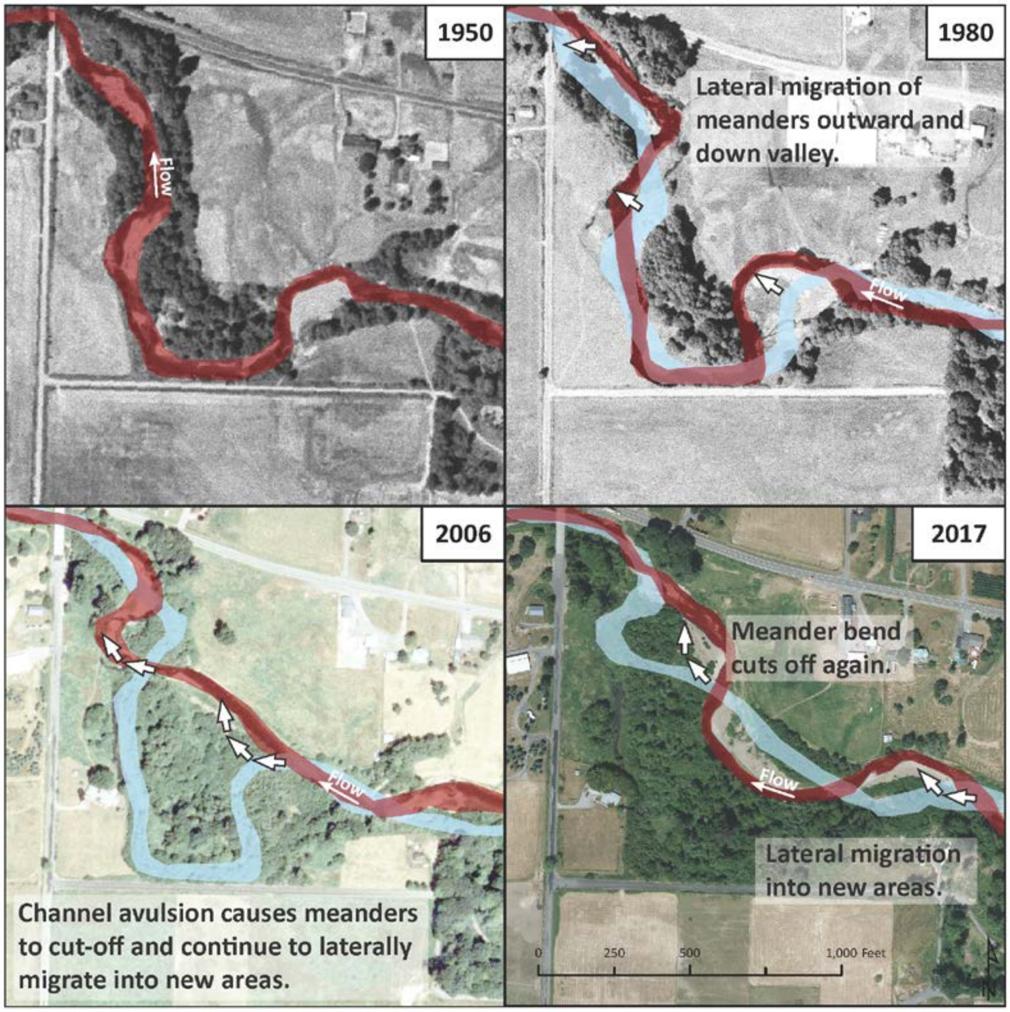


Figure 26. Channel migration process within a reach of the South Fork Newaukum River near RM 16.5 and Guerrier Rd. Between 1950 and 1980, meander bends caused lateral migration of the river both outward and down valley. Sometime between 1980 and 2006, avulsions occurred as two of the bends were cut-off and the river shortened the channel length. The river subsequently began lateral migration processes in the new locations. Between 2006-2017, the downstream meander bend cut-off a second time and the upstream bend migrated into areas that did not interact with the river in the aerial photo record (since 1940).

The speed at which both lateral migration and avulsion processes occur is dependent on the erodibility of the bank material, the strength of vegetation on the bank to withstand erosion, and resistance provided by obstructions, such as logjams on and near the bank, that can absorb stream energy (Abbe and Montgomery, 2003; Czarnomski et al., 2012; Rapp and Abbe, 2003; Thorne, 1982). In the Newaukum, most of the banks are composed of historical floodplain material and have similar degrees of erodibility. Thus, the speed of bank erosion is generally dependent on the type of bank vegetation and amount of obstructions, such as logjams.

Due in large part to the differences between what forested-root systems provide compared to pasture grasses, the Newaukum River Valley pasture land erodes almost twice as fast on average as forest lands (Figure 27). Measurement of erosion rates in the Newaukum River since 1940 reveal that there is a statistically significant difference ($p<0.005$) between the speed of erosion into pastured land as compared to forested land. A small p-value, typically less than 0.05, indicates that there is strong evidence that the null hypothesis of pasture vs forest having no effect on erosional rates is incorrect. This difference in erosion is caused by differences in bank roughness. Along forested banks, fallen trees form in-stream roughness that partitions shear stress and lowers erosion rates. The lack of wood material along banks with pasture or small trees leads to higher shear stresses and higher erosion rates (Bureau of Reclamation and U.S. Army Engineer Research and Development Center (USBR and ERDC), 2016). The roots and trunks of the forest and the shrub understory also slow water down and resist erosional forces better than that of grass species (Thorne 1982, Rapp and Abbe 2003, Czarnomski et al. 2012). In some instances, pasture erodes roughly four times faster than adjacent land that is forested. For example, pasture land on the North Fork Newaukum near RM 2.5 eroded 220 ft from 1980-2006 (8.4 ft/year) while adjacent forest land eroded 65 ft (2.5 ft/year) (Figure 28). This is despite there only being a 250 ft forested buffer between the river and nearby pasture to provide root cohesion and stability.

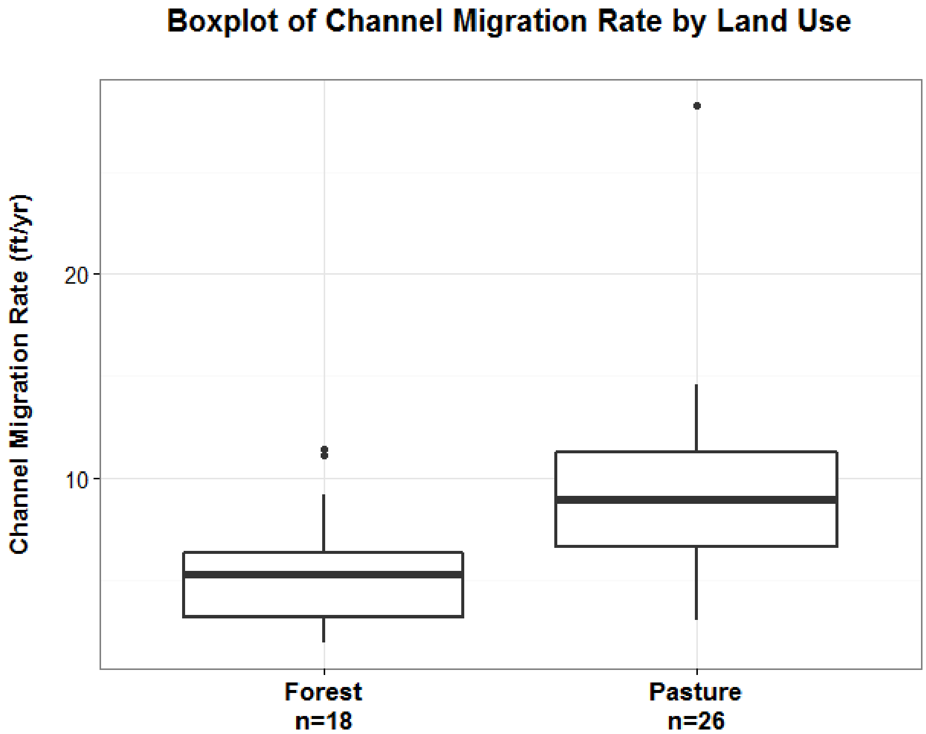


Figure 27. Boxplot of combined South Fork and North Fork Newaukum Rivers bank migration rates, for forest and pasture. The thick horizontal line is the median, the box shows the 25th to 75th percentile (interquartile) range, the vertical lines are the smallest and largest values within 1.5 times the interquartile range, and the dots are values >1.5 and <3 times the interquartile range. The analysis shows that pasture erosion experiences a much wider range of erosion rates well above those of forest areas. Mean erosion rates into pasture are almost twice those of forest areas, a similar observation as found along the Sacramento River (Micheli et al., 2004). Mapped areas of historical lateral channel migration, which is caused by bank erosion, were compared to mapped geomorphic landforms and landcover types to estimate channel migration rates based on soil composition, relative elevation above the river, and vegetative cover of the riverbank.

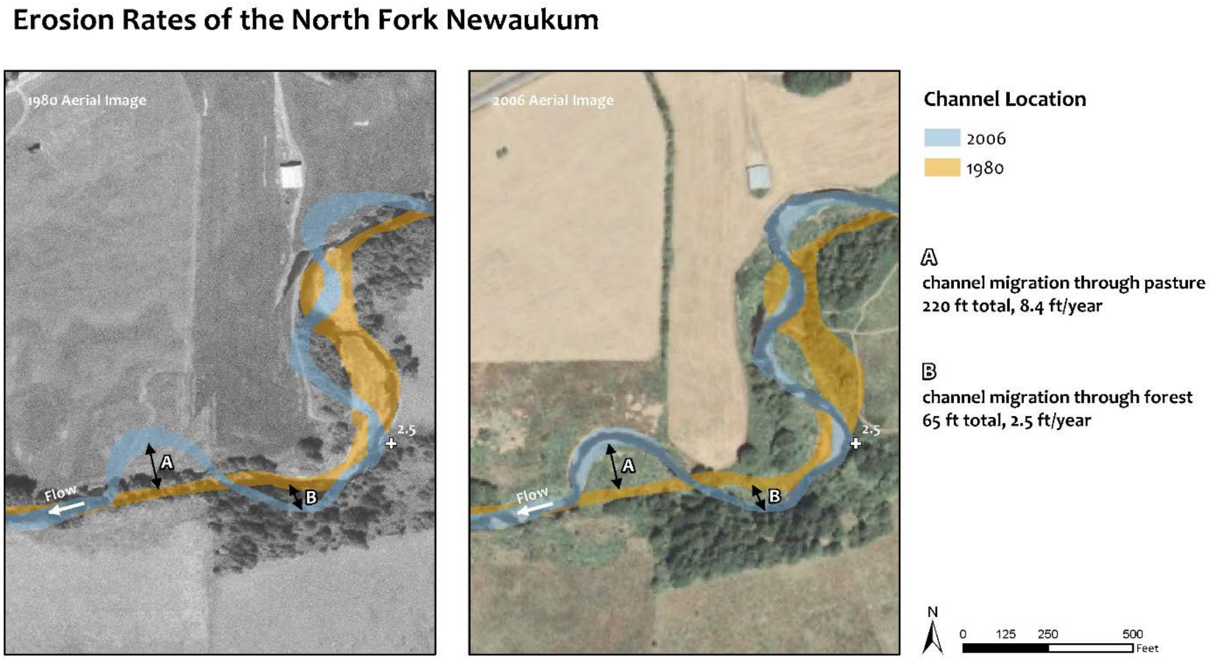


Figure 28. Differences in erosion rates of pastured versus forested land along the North Fork Newaukum River at RM 2.5 between 1980 and 2006. A shows rapid erosion into a pasture. B shows slower erosion into forest area. Rapid erosion into pastures is evident in the upper right.

The increased erosion rates of floodplain grass land over the past 100 years has resulted in the loss of agricultural and residential land within the Newaukum River Valley. About 1,000 acres of pasture (34% of valley bottom lands) within the study area are located in the historical floodplain directly adjacent to the river without a protective buffer of mature forest. These erosion risks underscore the influence that continued channel evolution, through local channel widening, is having on Newaukum Valley riverscape. Although valley wide flooding is no longer occurring due to the historical channel incision, channel widening continues due to erosional land loss within the inset-floodplain corridor. The inset floodplain will continue to expand in width well into the future. The rate of this expansion will depend in part on whether riparian areas are reforested or cleared, along with implementation of bank protection measures.

As such, erosion hazard areas in both the North Fork and South Fork Newaukum River Valleys extend laterally away from the river and into the adjacent upland surface (terrace). Rates of historical channel migration and expansion of the inset-floodplain were quantified from comparison of aerial images over the period 1951-2017 to calculate an average annual erosion rate of 4.5 feet per year. Variability between erosion rates at individual sites reflects localized differences in river hydraulics, presence or absence of bank protection such as riprap, and differences in riparian vegetation, as noted in comparison of forested and non-forested erosion rates (Figure 27). Erosion hazard areas along the valley bottom have been delineated using an erosion setback that is calculated as the product of historical erosion rates and a projected timeframe of 100 years and based on methods presented in Rapp and Abbe 2003 (Reach Scale Map Appendix 1). Erosion hazard areas (EHA) are designated into relative degree of risk, based on the following criteria:

- Areas of highest risk to erosion hazards, EHA (H), are delineated with a 450-foot erosion setback, defined as the product of the average historic erosion rate (4.5 ft/yr.) and a 100-year planning timeframe;
- A moderate risk erosion hazard area, EHA (M), extends laterally from the landward edge of the highest risk area and is delineated at its outer boundary by a 900-foot erosion setback, defined as the product of two times the average historic erosion rate and a 100-year planning timeframe (note that two times the average historic rate is approximately equal to the maximum observed erosion rate over the historic period);
- A lower risk erosion hazard area, EHA (L), extending laterally from the landward edge of the moderate risk zone to the toe of the hillslope marking the edge of the alluvial valley.
- Disconnected erosion hazard areas, Disconnected EHAs, are defined as the area which is protected by State Route 508.

These zones are defined for planning purposes as areas potentially susceptible to future erosion hazards based on the observed historical channel changes in the Newaukum River Watershed. The zones encompass the entirety of the valley (Figure 29).

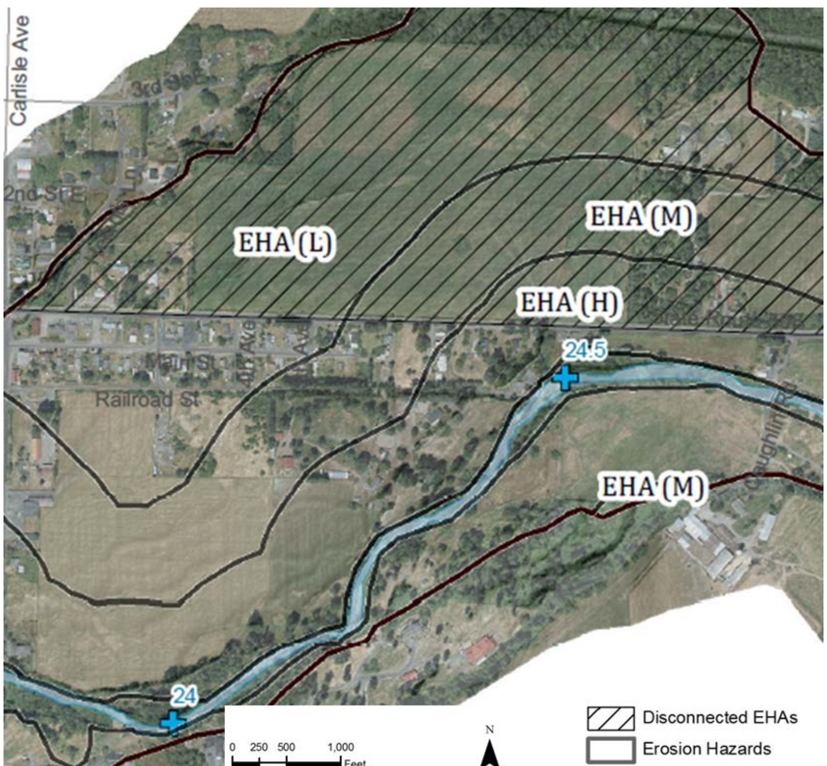


Figure 29. Residences, land, and key infrastructure are predicted to be at risk to future erosional processes. For example, a portion of the town of Onalaska, WA, is mapped within High, EHA(H), and Moderate Erosion Hazard Areas, EHA(M), and will not be protected through maintenance of SR 508. The area protected by SR 508 is shown as a hatched area. EHA(L) indicates areas with low erosion hazard risk.

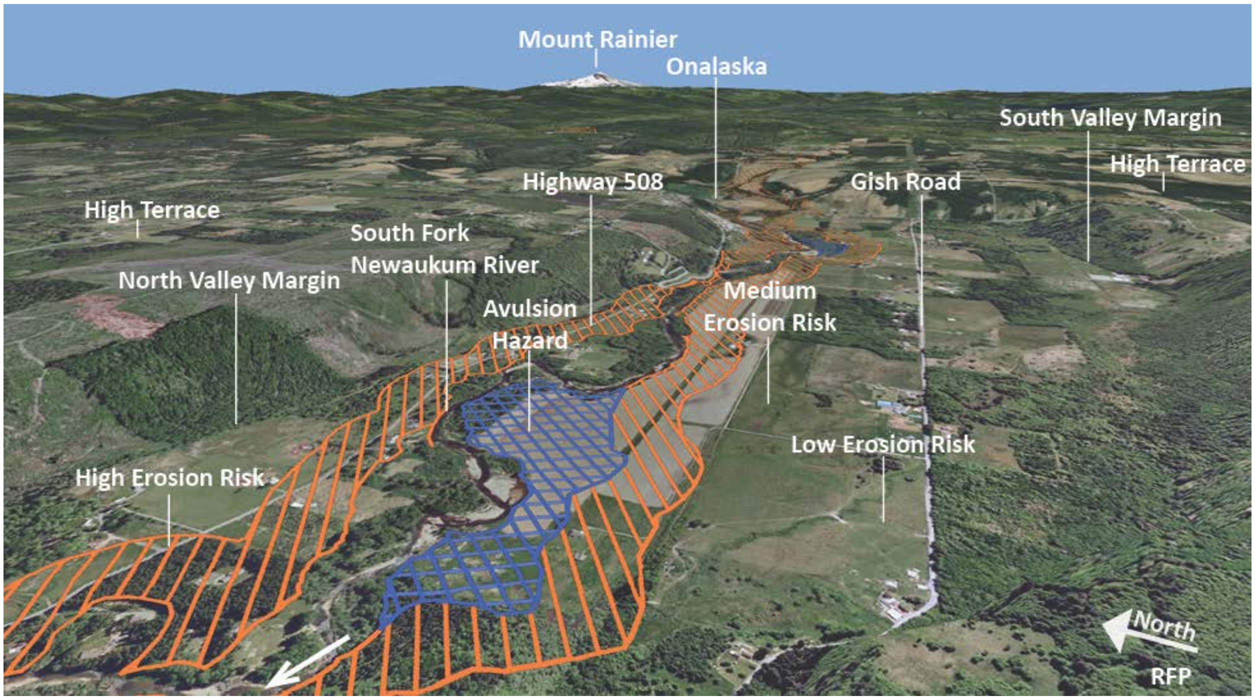


Figure 30. Erosion hazard mapping example of high-risk areas along the South Fork Newaukum River, just downstream from the community of Onalaska, Washington. Areas of high risk are shown with the orange crosshatch and areas with avulsion risk are shown with the blue crosshatch. The remainder of the visible valley bottom has a medium to low erosion hazard risk.

Areas likely to experience erosion within the next 20 years were also identified in order to highlight immediate risk areas for land use planning. The 20-year hazard analysis identified areas outward and down valley from actively migrating meander bends and used a conservative estimate of the historical migration rate (95th percentile of geomorphic subreach). The migration rate was then extended for a 20-year period (Figure 31). These areas are shown as an overlay on the Erosion Hazard Maps (Figure 30).

Figure 31. Example of 20-year erosion hazard area delineation within the South Fork Newaukum River near RM 17.5. Areas on the outside of actively migrating meander bends are in the current path of the river and are likely to experience erosion within a 20-year timeframe.

Most of the infrastructure and residences at risk are those in close proximity to the river (Table 4). The road network has 14.9 miles within the high-risk erosion hazard area – with the majority of those roads comprising SR 508 and North Fork Rd. areas which bisect both the South and North Fork Valleys respectively. About 1.1 miles of the road (7.4%) lies within the 20-year erosion hazard. These roads are major transportation arteries for the communities within the valley and will require significant maintenance to prevent washouts. There are also 619 structures that are within high erosion risk areas that will not be protected by maintenance of the road network with 61 of those structures predicted to experience erosion within 20 years.

Table 4. Roads and structures at risk of being affected by erosion within the North and South Fork Newaukum Rivers. Erosion Hazard analysis conducted using methods presented in Rapp and Abbe 2003. Road and structures data provided by Lewis County. Disconnected EHAs are on the non-river side of state roads (SR 508).

EROSION HAZARD AREA	LENGTH OF ROAD (MILES)	NUMBER OF STRUCTURES
20 Year Erosion Hazards	1.1	61
Historical Migration Zone, HMZ	0.4	11
Avulsion Hazard Zone, AHZ	0.0	21
Erosion Hazard Area, EHA (H)	14.9	619
Erosion Hazard Area, EHA (M)	7.4	279
Low Erosion Hazard Area, EHA (L)	8.4	254

Future expansion of the inset-floodplain will continue to create erosion hazards within the Newaukum River Valley as the river attempts to re-create its historical floodplain dimensions. Residences, land, and vital infrastructure are all predicted to be affected by future erosion, especially if erosion rates continue at their historical levels. These risks will be further exacerbated by the high degree of pastured land within the valley which will cause erosion rates to increase as the river interacts with them. Furthermore, the predicted increase in the magnitude and frequency of peak flows due to climate change will likely also speed up erosion rates.

3.5 Climate Change Implications

The warming climate is changing the hydrology of rivers across the country. In the Chehalis, the future will bring larger flood events along with drier summers. Numerous studies around the world have concluded climate change will result in significant changes in river discharge and create water stress for both rivers with and without dams (Palmer et al., 2008). Mauger et al. (2016) investigated climate driven changes in precipitation and streamflow in the Chehalis Basin. Their analysis indicates that changes in precipitation are mostly a function of the increased water-holding capacity of warmer air, not changes in the intensity or position of storm systems (Mauger et al., 2016). They projected substantial changes in streamflow through the Chehalis Basin under different global climate models and carbon emission scenarios. They present the percent change of future estimates relative to flows from 1970 to 1999. By the 2050s, they predict substantial increases in the 100 year flood discharge in the Newaukum mainstem near Chehalis with average increases ranging from 46 to 91% and maximum increases ranging from 184 to 244%, dependent on the model and carbon emission scenario (Mauger et al., 2016), p.45. By the 2080s, the average increases will range from 36 to 111% and maximum increases ranging from 106 to 228% (Mauger et al., 2016), p.45. Their models also predict widespread decreases in low flows throughout the Chehalis Basin, including the Newaukum (Mauger et al., 2016), p.46. Additional evaluation incorporating new dynamically-downscaled projections from UW Climate Impacts Group reported by Hill and Karpack (2019) show a more moderate increase in peak flows (11-26% increase by the late 21st Century averaged for the Chehalis River Basin), however these results are based on output from only two climate models, whereas Mauger et al. utilize an ensemble of ten global climate models. Given the climate is warming more rapidly than most predictions and human carbon emissions reached an all-time high in 2019, caution is warranted with regards to new development within or close to flood and erosion hazard areas.

The hydraulic model developed for the North Fork and South Fork Newaukum River (See Appendix 3) was run for the 100-year flood simulation with a multiplier of 26% on all inflows to simulate a future condition with climate change. Other than inflows, no changes were made to the model inputs for the climate change simulation. The resulting output shows a 14% increase in inundation area under the modeled climate change scenario including inundation of buildings that are currently elevated on the terrace just above the flood hazard area, but are predicted to be flooded by the same recurrence-interval flow based on the predicted increase in peak flow magnitudes (Appendix 3).

An increase in the frequency of bed mobilizing peak flows will increase unvegetated channel width. Combined with lower summer flows, water depths during critical times will diminish and could impede fish passage. Water temperatures will increase in response to higher air temperatures and lack of shade in wider channels. As previously discussed, increases in peak flows may drive additional channel incision. Cumulatively, these impacts will further diminish alluvial groundwater levels of the affected valleys. The increase in flood peaks will cause more extensive and frequent flooding and increase rates of bank erosion and channel avulsions.

Restoration actions, as proposed in the RFP approach, will help to significantly mitigate or offset negative impacts of the warming climate. In-stream structures, such as engineered logjams (ELJs) will constrict flow and maintain cooler water pools year-round. When enough in-stream structure is restored it sustain higher water tables. The ELJs, together with riparian reforestation, will contribute to narrower channels which allow for riparian to more effectively cool the water. This is particularly important in the Chehalis Basin where high water temperatures in the summer and fall can be lethal to salmonids. Riparian ecosystems are naturally resilient and their restoration will be an essential component to climate change adaptation to preserve functional ecosystems (Seavy et al., 2009). Based on this Savey et al. (2009) recommend that restoration practice should become an integral part of land management, including the restoration of private lands. Similar arguments have been presented on the values of wetlands in mitigating climate change (Erwin 2009, p.74):

> *"There is an urgent need to preserve existing, intact floodplain rivers as strategic global resources and begin to restore hydrologic dynamics, sediment transport and riparian vegetation to those rivers that retain some level of ecological integrity. Otherwise, dramatic extinctions of aquatic and riparian species and of ecosystem services are faced within the next few decades (Tockner and Stanford, 2002)."*

In their comprehensive assessment of river response to the warming climate, Palmer et al. (2008) presented the following conclusions:

- *"Healthy, free-flowing rivers respond to changes in land use and climate through dynamic movements and flow adjustments that buffer against impacts."*
- *"However, many river basins are sufficiently impacted that their ability to absorb disturbances, such as changes in discharge and water stress, is severely limited."*

- *"A global analysis of the potential effect of climate change on river basins indicates that rivers impacted by dams or extensive development will require more management interventions to protect ecosystems and people than basins with free-flowing rivers."*
- *"Specific, proactive restoration, rehabilitation and management actions are recommended to enhance the resilience of riverine ecosystems and minimize impacts."*

Some of the specific recommendations to address limited water availability include floodplain restoration that allows for overbank flows which may require land acquisition or easements, and that these overbank flows are needed to enhance groundwater recharge (Palmer et al., 2008). They also point out that adding habitat features can not only prevent further simplification and degradation of channels, but they can help to retain water. Their final message underscores the urgency at hand (Palmer et al., 2008), p.88):

> *"Delays in implementation of proactive forms of restoration, rehabilitation and river management will inevitably exacerbate the effects of global climate change on efforts to balance the needs of humans and rivers."*

Based on the analyses in this report, these recommendations are directly applicable to the Newaukum Basin and broader Chehalis Basin. The urgency of the situation is particularly relevant in the Newaukum given the precarious state of Spring Chinook, a critical salmon population particularly sensitive to low flows and high temperatures given their life history of returning to the river in the spring and holding through the summer.

River Corridors

All of the scientific literature underscores that ecosystem resilience relies on space for rivers to move, space for side channels, space for wetlands and forests, and space to spread out floodwater and recharge groundwater. Small scale restoration will not be sufficient to save Spring Chinook or provide long-term safety for people and the ecosystem. The RFP approach clearly demonstrates that valley scale restoration will dramatically improve habitat and resilience. This assessment also shows that many landowners are receptive to buyouts, easements and relocation (actions supported by other numerous studies), one of the core elements of the RFP approach.

In an exhaustive treatise on the causes of flooding and flood policy in the United States, Hoyt and Langbein (1955) put forth recommendations they believe are of national interest, including limiting development that impairs the natural function of floodplains to convey floodwaters :

> *A) that States, river communities and conservation districts should foster wise use of valley lands and discourage obstruction of rivers and their floodplains, and*
>
> *B) loans, grants or other forms of relief should only be awarded to actions that will not encourage imprudent occupancy of flood plains*.

Policy limiting development that reduces flood storage and conveyance is intended to prevent downstream increases in flood stage. Since channel incision reduces the river's floodplain area, it is analogous to obstructing the floodplain. The loss of floodplain capacity sends water more rapidly downstream worsening flooding. The RFP restores floodplain function, thus improving downstream flooding and addresses “imprudent occupancy” by helping people move out of harm’s way, actions consistent with best floodplain management practice.

In the Newaukum Basin, restoration of the entire floodplain would attenuate downstream peak flows by 3-10% using a standard 2-D hydraulic model approach (see Section 5.1) and 7%-20% by adding alluvial groundwater infiltration into the same model (see Section 5.3). This work demonstrates that voluntary programs can incrementally provide long-term flood protection by assisting people in moving to safe ground and that these actions will provide ecosystem benefits that contribute to achieving the goals of the Chehalis Aquatic Species Restoration Plan (ASRP).[2] Some of the basic principles of the RFP have helped in educating landowners about flood and erosion hazards, work that has helped advance Early Action Sites on the Wynoochee and Satsop Rivers. These Early Action projects are also showing that voluntary programs can incrementally establish ecological river corridors that accommodate fluvial processes essential to restoration. The State Department of Fish and Wildlife has made significant progress in talking with landowners. The state has retained specialized contractors to develop a template about options for compensation or acquisition with willing landowners.

Many restoration projects around the Pacific Northwest demonstrate that successful restoration occurs when projects adhere to scientifically founded restoration guidelines and focus work on areas set aside for conservation where landowners are receptive to accommodating a sufficient area for restoration actions and natural processes to create and sustain habitat and accommodate flooding and channel change (river “restoration corridors”). For large scale restoration, such as needed in the Chehalis Basin, it is crucial that projects demonstrate the scale and intensity needed to eventually achieve the desired goals. There are areas where large acquisition can be done or landowners are agreeable, and it is those areas to focus on. Outreach and education about hazards, ecosystem degradation and climate change are essential throughout the basin, including disseminating the results of floodplain scale restoration projects. As people better understand the goals of sustainable river corridors to create more resilient communities, restore ecosystems and fisheries, improve water quality and quantity, and enhance the quality of life, support will grow and lead to more projects making more of a positive difference. The RFP assessment shows that its core elements are the most likely to build climate resilience and can be integral parts of Chehalis Community Flood Assistance and Resilience Program (CFAR) and a means of achieving the goals of the Chehalis Basin Strategy.

[2] Full scale Restorative Flood Protection will take a long time to achieve given nature of private landownership, however the magnitude and scale of flood protection benefits will continue to increase over time, assuming a program is established for implementation and adaptive management.

4. CONCEPTUAL DESIGN OF RESTORATIVE FLOOD PROTECTION ACTIONS

Within the context of the existing conditions characterization described in Chapter 2, this chapter describes the conceptual project design and the changes to the landscape that would enable restorative flood protection to be implemented.

4.1 Opportunities for Flood Attenuation and Storage

River restoration actions can be applied that restore flood storage capacity by reconnecting the river to current terrace areas that were historic floodplain. The primary way this is done is to reverse channel incision by raising up the river channel. This is something that logjams naturally did throughout the Pacific Northwest and many other regions, e.g. (Abbe, 2000; Abbe and Montgomery, 2003; Brummer et al., 2006; Bureau of Reclamation and U.S. Army Engineer Research and Development Center (USBR and ERDC), 2016; Collins et al., 2012; Montgomery and Abbe, 2006). Engineered log structures applied on the South Fork Nooksack in 2014 were successful in raising the river channel 4 ft and reconnecting previously disconnected floodplain (Abbe et al., 2015). The project resulted in approximately 30 acre-ft of increased groundwater storage or 102 acre-ft/mile (Abbe, 2019). Strategic placement of engineered logjams is an effective means of immediately restoring instream complexity and habitat, raising water and dispersing it across floodplains, slowing water flow and increasing storage. All of these actions contribute to attenuating downstream flood peaks. Floodplain scale restoration such as this provides the greatest possible enhancement to improving habitat, sustaining habitat forming processes and improving water quality. Large scale restoration can only be done through acquisitions, easements and relocations, so as to ensure no adverse impacts to landowners. The work may also require moving or floodproofing infrastructure within the treatment reach. The extent to which existing landowners and infrastructure could be impacted is predicted through hydraulic modeling of proposed conditions. The more aggressive the restoration actions, the greater the affected area.

Since historic channel incision has effectively reduced the extent of historic flooding, development has encroached closer to the river. This trend increases the number of landowners potentially impacted and the cost of restoration. Since the goal is ultimately to re-engage historic floodplain surfaces that now only rarely flood, restoration work is likely to impact more landowners within areas of more frequent flooding. Increasing flooding within treatment areas is not fundamentally different from a flood retention reservoir. Both intentionally flood areas to better protect areas downstream. The difference is that water depths in a restorative approach are much shallower and spread out, opposed to the extremely deep water that occurs behind a flood control dam.

Landowners are currently losing land to river bank erosion. As the modern inset floodplain continues to expand, erosion will impact more and more landowners. Increased flood peaks resulting from the warming climate will impact more landowners. Erosion and flooding negatively impacts land value. Moving people out of harm’s way not only helps them, but it benefits the larger community by reducing flood liabilities paid for by the public through local, state and federal governments. By creating river corridors that accommodate flooding and erosion, flood liabilities are permanently eliminated and more vibrant and resilient fluvial ecosystems can form.

Restoring these areas would work to:

- Re-connect incised rivers to the adjacent floodplain
- Restore floodplain plant communities
- Enhance flood peak attenuation and storage

4.2 Design Constraints

The goal of the Restorative Flood Protection Alternative is to evaluate the feasibility of moving people from harm's way and evaluate whether restored rivers and floodplains attenuate downstream flooding during the current 100-year flood event.[3] There would be an increased duration and depth of floodwaters within the treated (restored) area and a larger inundated area. In comparison with the existing conditions, the RFP would affect additional structures and thus, entail acquisition or relocation of more structures than currently impacted by flooding. The RFP treatment increases flooding within the project area in order to reduce the effects of flooding downstream. Existing infrastructure, such as bridges and roads, impacted by increased flood levels would be raised or relocated as part of the RFP. When people and infrastructure are out of harm's way, floods have no impacts and many benefits. For example, the longer floodwaters remain, the greater the environmental benefits, including increasing base flows downstream.

There are numerous existing bridges and roads in the Newaukum River Basin that are within the floodplain and are impacted during flood events. Highway 508 runs parallel to the South Fork Newaukum River, protecting structures that would otherwise be inundated by floods. In doing so, the road itself is subjected to impacts from flooding and has been armored with rip-rap in multiple places to prevent erosion. The North Fork Road is similar to Highway 508, providing a barrier to the North Fork Newaukum and reducing the available floodplain. There are multiple bridge crossings and bridges that become overtopped and are at risk of failure.

The roads and bridges in the Newaukum Basin were analyzed for potential impacts using the results from the 100-year flood event as run through the hydraulic model. All infrastructure analysis was performed on the 2016 hydraulic models and hydrology, as presented in the Chehalis Basin PEIS. The proposed water surface elevation was used to determine which roads and bridges could potentially need to be elevated and/or rebuilt, or decommissioned if restorative flood protection was constructed.

This analysis determined that on the South Fork Newaukum, out of a total of 30 roads/bridges, 11 would be impacted under the current 100-year flood event, and 27 would be impacted

[3] The cumulative effect of Restorative Flood Protection treatment of upper Chehalis watershed on Chehalis/Centralia was never estimated in a 2D hydraulic model because the authors do not have access to the basin-wide model.

under the proposed conditions if the Restorative Flood Protection measures were to be installed. In the North Fork Newaukum, out of a total of 13 roads/bridges, 6 would be impacted under the current 100-year flood event, and 10 would be impacted under the proposed conditions if the Restorative Flood Protection measures were to be installed. Varying degrees of action for each of these road/bridge sections could be pursued, including raising, replacing, or abandoning. See Appendix 3 for a detailed table of water surface elevations under existing and RFP conditions, bridge and road elevations and inundation time.

Buildings in the Newaukum Basin are positioned mainly outside of the floodplain; during the 100-year flood, only six residential structures are flooded. In the South Fork Newaukum alone, there are 232 parcels that are primarily in the floodplain.

Within the study area, these roads, bridges and impacted residential areas could be protected by certain actions, including raising roadways, replacing bridges, moving and creating new roadways, adding scour protection to existing structures, or abandoning the structure. Additionally, restorative flood protection designs could be tailored to reduce local scale flood and erosion impacts by using strategically-located levees or berms to protect valuable infrastructure, elevating homes and buildings, constructing farm pads and sensible placement of engineered log jams away from bridges or low-lying roads.

Design constraints within the RFP area do exist, but on a localized scale, the impacts can be reduced and/or mitigated.

4.3 Creating Space for Restorative Flood Protection: Conservation Easements, Buyout and Relocation Actions

Shifts in land use are a key component of the restorative flood protection concept. It is well established that development in flood prone areas poses significant safety, economic and environmental risks. Hoyt and Langbein (1955), pg. 100), stressed that home-building "*is an example of the most unwise use of flood land.*" Given climate projections of increasing flood risk, assistance to help landowners move to safe ground is prudent.

Helping people get out of harm's way is a fundamental component of the RFP, not only to address current and future risks, but because restoration actions would intentionally increase flooding within treatment areas. A side-benefit of RFP conservation easement, buyout and relocation actions is to strengthen local communities and economies through the effort of restoring floodplain and river sites, acquisition of timber and other materials, planning, design, construction, plant procurement (large scale nursery operations), long-term monitoring and maintenance. Similar to large scale restoration and infrastructure projects around the state, work is likely to be staged over decades, providing long-term opportunities to local communities. To evaluate the feasibility of relocation efforts is dependent on whether there are adequate upland areas both in terms of land area and ability to support the livelihoods of those affected, particularly with respect to agriculture. This study focused on southern Lewis County in close proximity to the Newaukum Watershed. The analysis presented here focuses on two questions linked to the first two elements above:

1) Are there upland agricultural areas that are equal or better than floodplain areas?

2) Are there farming alternatives for flood prone land?

Areas required for dedicated flood storage/transmission purposes could be assembled through a mixture of conservation easements, purchasing property from willing sellers (aka buy-out), establishing binding agreements to restore floodplain (aka compensation for conservation and flood easements) and relocating homes, farms and businesses from the floodplain to high ground safe from flooding (aka relocation).

While this feasibility study did not develop detailed conservation easement, relocation, or buy-out estimates for the Newaukum River Basin, estimates were developed previously for the South Fork Newaukum portion of the study area (Carlstad et al., 2017) and are provided in

Table 5. These cost estimates were developed in 2017 dollars ($) for conservation easements, the fair market purchase price of willingly-sold residential properties, the fair market cost of the willing-relocation of agricultural properties for 21 river miles of the lower South Fork Newaukum River. No commercial or public buildings (e.g., schools) were identified within this study area.

Since a conceptual design will not be developed for the RFP study area, the 2017 analysis was not updated with the 2019 detailed modeling results. The assumptions reported in

Table 5, estimating costs for a shift in floodplain land use, are based on coarse hydraulic modeling results, from the initial 2016 study (Abbe et al., 2016). A conservative planning-level cost assessment for easements and land acquisition was estimated at $49 million, or about $26,000 per acre of floodplain (see Table 4). More detail on the cost approach, variables, and uncertainties is provided in Carlstad et al. (2017).

Table 5. Coarse scale cost assessment range for South Fork Newaukum River restorative flood protection conservation easement, relocation and buy-out ($2017).

ESTIMATED RELOCATION/BUY-OUT COST CATEGORY	ACRES	$2017 APPROXIMATE COST
Conservation Easements	815 acres	$14 million
Agricultural Property Relocation	525 acres	$12 million
Residential Property Buyout	560 acres	$23 million
Total	**1900 acres**	**$49 million**
Average cost per floodplain acre		**$26,000**

Note: Costs presented here represent the higher cost from the 2017 memo. See memo for a detailed approach and list of assumptions.

4.3.1 Conservation Easement Example:

As mentioned in the 2016 *Preliminary Scientific and Technical Assessment of a Restorative Flood Protection Approach for the Upper Chehalis River Watershed (Abbe et al., 2016)*, conservation easements are a well-established mechanism to compensate landowners for use of land for wildlife habitat or other beneficial ecological purposes. Conservation easements are being increasingly employed at a large scale in the United States. For example, in a 2011 article by Ann Robinson of the Iowa Natural Heritage Foundation, 196 farmers in Iowa received federal and state funding to permanently retire farming rights to approximately 21,000 acres of cultivated fields. This easement program was inspired by a major flood in 2008 that resulted in statewide losses of $8-10 billion (Robinson, 2011). There was so much interest in the program, that only 20% of the interested farmers could be funded. Additionally, if landowners were more interested in selling than owning property with a conservation easement on it, the Iowa Natural Heritage Foundation purchased the land outright (Robinson, 2011).

4.3.2 Property Buy-Out Example:

In another example from the 2016 *Preliminary Scientific and Technical Assessment of a Restorative Flood Protection Approach for the Upper Chehalis River Watershed (Abbe et al., 2016),* the national non-profit group, The Nature Conservancy, assisted the US Fish and Wildlife Service with the acquisition of a large farm, called Mollicy Farms, adjacent to the Upper Ouachita National Wildlife Refuge in Louisiana. Together, these two areas provide and restore more than 25 sq. mi. of former floodplain forest back to the Oachita River. As a part of this project, more than three million bald cypress, oak and other local floodplain forest tree species were planted on almost 11,000 acres of the refuge to restore the floodplain forest. As the floodplain forest begins to regrow and flood again, the US Fish and Wildlife Service has observed bird use, especially waterfowl and wading birds, have come back to Mollicy Farms in great numbers (The Nature Conservancy, 2016).

4.3.3 Relocation Examples:

Self-funded example: After flooding three out of four consecutive years, combined with heavy rains in the lush Winooski Intervale Valley, near Burlington, Vermont, two young farmers utilized kick-starter to leverage $25,000 to help them move to higher ground in the high meadows of Plainfield, Vermont. Determined to farm “through hell and high water, through the economic recession and through personal crisis”, this couple has pulled it off. As of August

2016, they are half-way through their second season on the new farm, that has held up to 4 inches of rain in one day (Tamarack Hollow Farm, 2013).

FEMA and state funded example: At a larger scale, FEMA and the state of Kentucky invested $1.3 million in property buy-outs in Shepardsville, Kentucky. Since the area was purchased, there have been four major floods, three 100-year floods and one 500-year flood from 1999 – 2011, and the project has more than paid for itself in emergency services and rebuilding costs. A similar pattern has been seen in Baker County, Georgia, where nearly $2 million in property damages were saved with a $745,000 buy-out by FEMA and the state (Polefka, 2013).

In summary (see Appendix 4), floodplain and non-floodplain lands within the study area share some similarities and several important differences. Both environments support extensive agricultural operations with long and successful legacies. Floodplain lands are dominated by level ground and good soils, but southern Lewis County has extensive high terrace ("prairie") areas with considerably more acreage of level land and similar alluvial soils. Upland soils also tend to be better drained than floodplain soils. The greatest difference between floodplain and upland land categories (besides flood risk) is in abundance. There is simply much more land on upland terraces and gently sloping areas than in floodplains. This is reflected in the fact that these upland areas have a more diverse range of agricultural operations than found in floodplains. Additionally, the capacity to expand agricultural operations to adjacent or nearby parcels is greater outside of the floodplain because potential impediments to expansion such as topographic variations (rivers and valley walls) are less prevalent. Outside of the floodplain, environmentally critical areas limiting development and agricultural operations tend to be smaller and less common across the landscape, thus regulatory hurdles are fewer and less burdensome. Lastly, agriculture outside of the floodplain does not have to contend with the risks of flooding discussed above.

4.4 Restorative Flood Protection Engineered Treatment Elements

The Restorative Flood Protection (RFP) Alternative includes four main design elements as a comparison with the existing conditions; an increased surface roughness, construction of engineered log jams, installation of periodic incision treatment measures, and restoration of the riparian forest. These design elements work together to slow down floodwater and increase flood depths with the goal of reducing peak inundation areas downstream of the treatment area.

4.4.1 Engineered Log Jams

To jumpstart the large wood cycle and restore the river to an anabranching morphology, engineered log jams (ELJs) would be strategically placed in the channel and floodplain. These log jams serve to slow the velocity of water in the channel, create habitat refugia for fish and other aquatic life, and redirect flow into side channels and sloughs. In the RFP model, ELJs were placed at a rate of approximately 21 structures per mile for a total of 656 ELJs within the modeling extents. In wider reaches, closer to the confluence of the North and South Forks of the Newaukum, there was a greater density of the structures. Conversely, fewer structures were positioned in the upper reaches due to a more confined valley bottom. The ELJs were represented as simplified boxes in hydraulic modeling, sized at 120 feet wide by 60 feet deep by 12 feet high, and were positioned perpendicular to flow. The log jams would be planted with scrub-shrub and therefore, they would have an increased manning's roughness coefficient (Appendix 3).

4.4.2 Incision Treatment

Incision treatments or grade control structures were included in the RFP as a way to reconnect the channel to its historic floodplain and encourage floodwaters to overtop the banks. The grade control structures raise the existing channel bed and inset floodplain by 6 feet (Figure 32). In the RFP, an average of 5 grade control structures were positioned per mile for a total of 65 grade control structures within the modeling extents. The structures span the full width of the inset floodplain, and their length extends parallel to flow for approximately 40 to 60 feet. Where in-stream structures cross the floodplain, they would be planted and thus, have a corresponding increase in Manning's roughness in the hydraulic model (Figure 33). These types of structures have been successfully applied in the South Fork Nooksack River (Abbe et al. 2015).

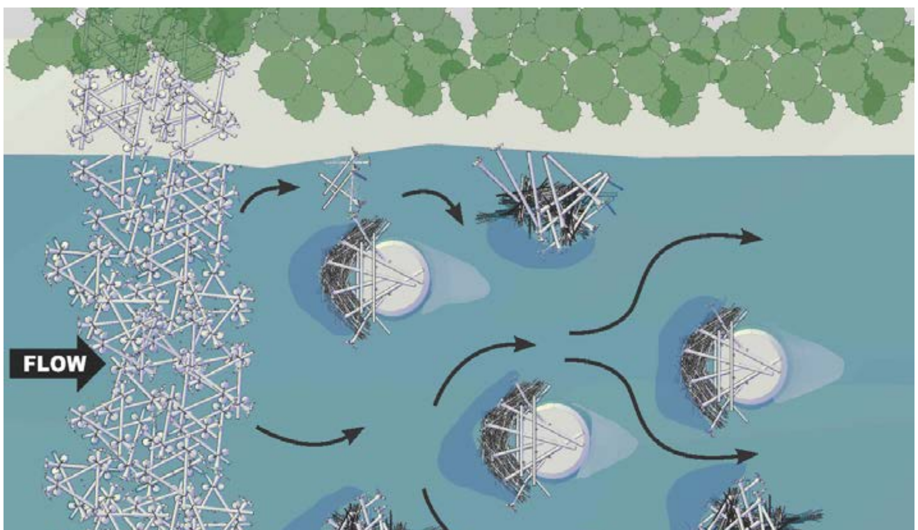


Figure 32. Conceptual example of in-stream restorative flood protection elements (from Abbe et al. (2016) . On left is an example of channel spanning grade control raising the river bed and water levels to reverse impacts of historic channel incision. To the right are examples of individual engineered logjam structures that create pools, cover and forest islands. Cumulatively, these structures also act to raise water levels and restore a multi-thread or anabranching river that better engages its floodplain, improves hyporheic flow by creating lateral hydraulic gradients and increases total channel length which is a critical metric for restoring salmon habitat.

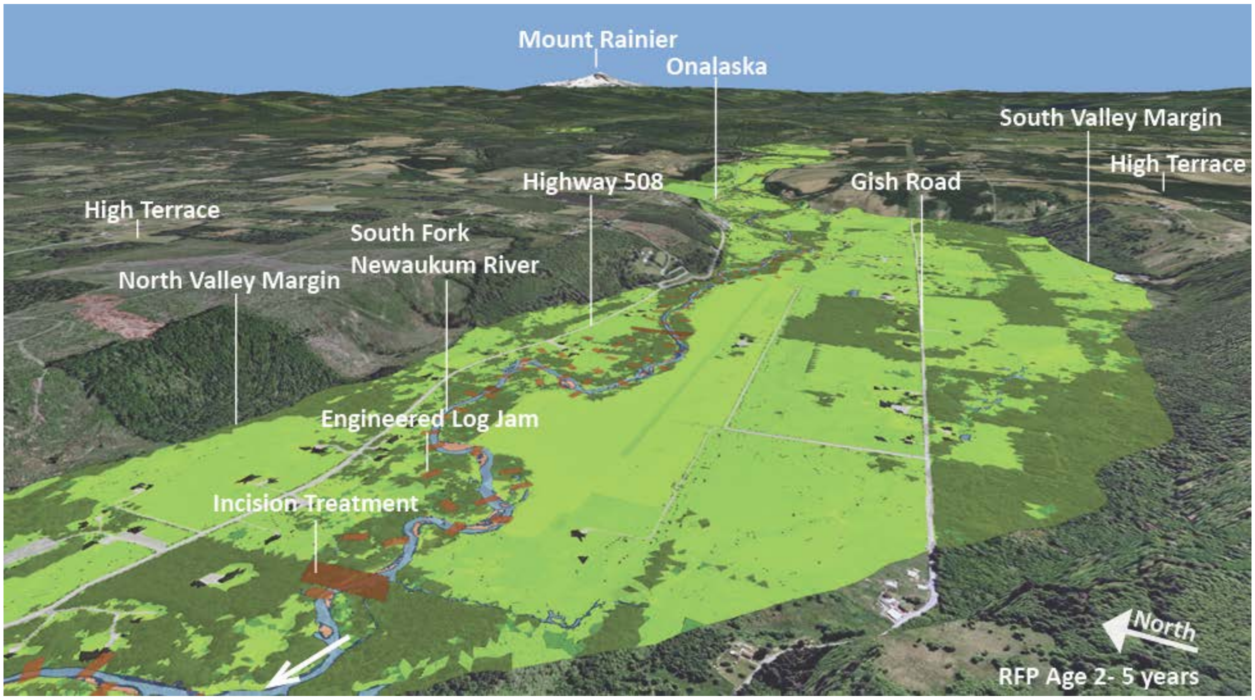


Figure 33. Birds eye view example in the South Fork Newaukum River of simulated locations for engineered log jams in the river and floodplain (brown) and areas where the river bed was elevated to historical levels, called "incision treatment", shown as brown bands across the river. Incision treatments are intended to span the entire channel migration zone of the river. Simulated shifts in floodplain vegetation are also shown in green.

4.5 Restorative Flood Protection Floodplain Landscape

In order for the RFP to work, the floodplain landscape needs to be as complex and rough as possible. This 'roughness' may be achieved by restoring riparian and floodplain forest, which then becomes in-channel roughness as woody debris, or by managing the land to establish mature forest with a dense understory of shrubs. Some of these concepts are presented below and detailed agricultural options are provided in Appendix 4.

4.5.1 Floodplain Forest and Shrubland Restoration

Vegetation Changes

The RFP includes changes to the landscape and vegetation that would increase the hydraulic roughness of the basin, increasing the ability of the landscape to slow floodwaters. For example, open fields may become areas of dense vegetation, either willows or other native mature shrub and tree species, or a dense agro-forestry operation. In order to design the most ecologically diverse and robust restorative flood protection landscape, local and regional literature and databases were consulted to generate a list of plant communities, which either currently exist, or may have existed at one time, in the Newaukum River Basin (see methods in Chapter 2). A similar study was conducted for flood resilient and protective agricultural practices in western Washington. For the purposes of testing the restorative flood protection hypothesis, agro-forestry installations were hydraulically modeled as dense scrub-shrub plant communities (Figure 34Error! Reference source not found.**)**.

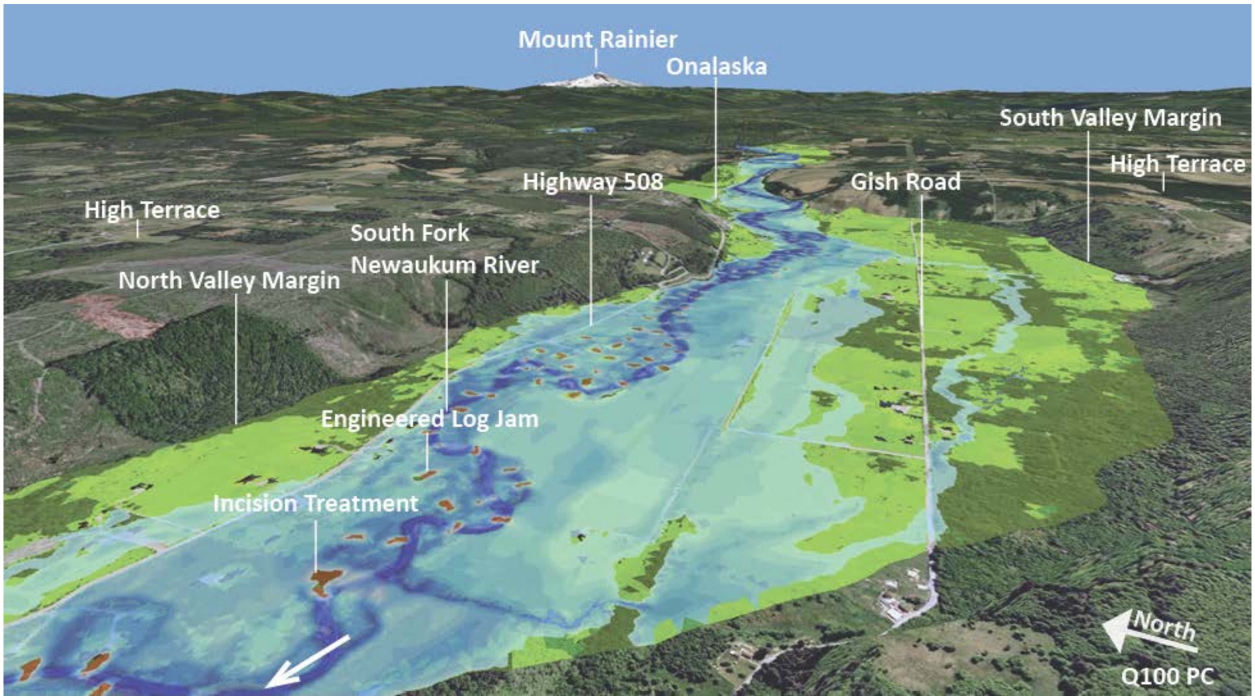


Figure 34. Birds eye view example of simulated shifts in South Fork Newaukum River plant community composition from pasture dominated to forest-dominated (green) plant communities, including a mix of native and agricultural species. All of these adjusted designs work to slow floodwaters and survive or thrive with periodic inundation.

The native plant community research was compiled into plant community fact sheets (see appendix 6). These fact sheets were graphically-designed to provide local landowners, conservation districts, counties, municipalities, tribes, as well as engineers and landscape architects with a more-technical understanding of what types of plant communities may be restored on the floodplains and river-edges to slow floodwaters and river velocities. The floodplain agricultural research has been provided as a stand-alone report (see appendix 4), and written so that it is as useful to farmers as it is to policy and planning decision-makers.

Plant Communities of the Newaukum River Basin

A list of likely dominant species and their relationship to soil moisture conditions is provided in (Figure 35). The soil moisture gradient is shown as a conceptual topographic cross section view, from the lower elevations along the river/creek channel, to the annually flooded area, and up to the 10 or 100-year floodplain. This figure illustrates which species are more tolerant of wet conditions and which are more tolerant of dry conditions, evolving under diverse geomorphic and hydrologic conditions.

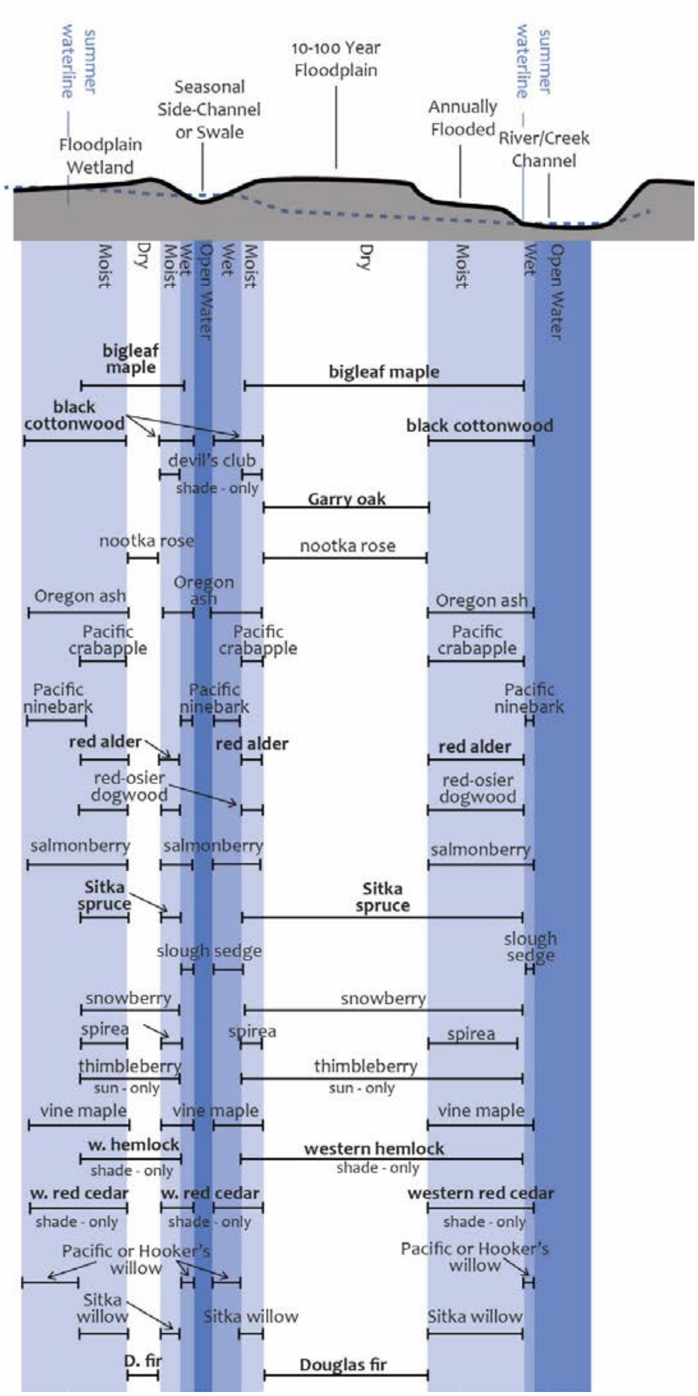


Figure 35. Preferred soil-moisture conditions for dominant native plant species of the Newaukum River Basin.

Growing conditions may be organized into areas which annually flood and areas which rarely flood, such as the 100-year floodplain. Some detailed examples of the different woody plant communities which thrive under these two different geomorphic/hydrologic settings, annually flooded and periodically flooded are provided below.

<u>Forest Communities for Seasonally Flooded (~every year) Areas:</u>

For slowing floodwaters, there are numerous dominant shrub species, and small trees, which would do most of the work of slowing floodwaters including, Pacific ninebark, red osier dogwood, salmonberry, spirea, vine maple, Pacific or Hooker's willow, and Sika willow. Tree species such as black cottonwood, Oregon ash, Pacific crabapple, red alder, Sitka spruce, bigleaf maple, western hemlock and western red cedar would also eventually become woody debris in the river channel, slowing the river down significantly. Examples of annually flooded plant communities with rough woody understory include:

- Pacific ninebark thicket with slough sedge understory
- Red osier dogwood thicket with willow and spirea understory
- Willow thicket, including various combinations of slough sedge, skunk cabbage, horsetail, stinging nettle, Pacific crabapple, and other species
- Black cottonwood and red alder forest with snowberry or salmonberry dominated understory
- Western red cedar forest w/ salmonberry and oxalis
- Western hemlock forest with devil's club and sword fern
- Bigleaf maple forest with salmonberry dominated understory
- Oregon ash and black cottonwood forest with either red osier dogwood and stinging nettle understory; or vine maple, Pacific hazelnut, pacific ninebark, salmonberry, snowberry understory
- Sitka spruce, western red cedar and western hemlock forest with devil's club, sword fern, and salmonberry understory (**Figure 36**)

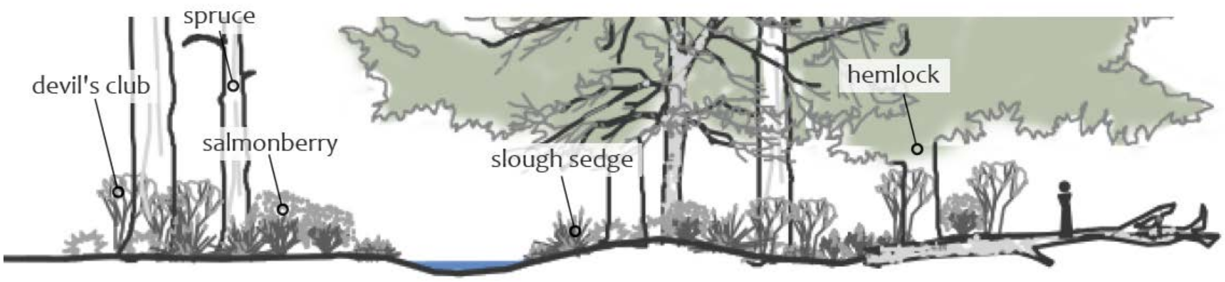


Figure 36. Sitka spruce and western hemlock forest with devil's club, sword fern, and salmonberry understory.

<u>Forest Communities for Periodically Flooded [~10 yr flood recurrence or greater] Areas:</u>

During large floods, water engages the annually flooded areas first and then reaches the higher terraces, which flood less frequently. The dominant shrub species in these higher Newaukum River areas include nootka rose, snowberry, and thimbleberry. Big leaf maple, Garry oak, Sitka spruce, western hemlock are the dominant tree species. Examples of periodically flooded plant communities with rough woody understory:

- Nootka rose thicket with tufted hairgrass dominated understory
- Garry oak forest with snowberry dominated understory

- Black cottonwood and bigleaf maple forest with snowberry dominated understory

These examples use only the most dominant species in the plant community descriptions. Dozens of additional species are also a part of these plant communities. A detailed species list is provided in Appendix 6, along with the plant communities with emergent or non-woody understories.

Soil moisture availability drives plant community composition. This woody diversity affords numerous flood protection benefits, which were hydraulically modeled, as described in earlier sections of this report. For the purposes of testing the restorative flood protection hypothesis, plant communities with herbaceous or emergent understories were not included in the modeled scenario, however, a detailed list of all existing and potential plant communities existing in the Newaukum River Basin are provided in Appendix 6.

4.5.2 Flood Resilient and Protective Farming

Flood waters flowing over existing crops results in soil erosion and deposition, and sometimes pollution imported from offsite. There are agricultural practices that can withstand some level of inundation and surface flood flows. These flood resilient farming practices should be considered for landowners who wish to grow crops in flood-prone areas. Crop type, timing of maturity, plant physiology and structure, and planting layout are key considerations in choosing an agricultural system that is resilient enough to withstand periodic flood regimes. A detailed analysis of the risks and benefits of current farming practices, both in the floodplain and outside of it, as well as diverse sustainable flood friendly farming practices are described in the attached Appendix 4 and are briefly described below.

Resilient agricultural systems in flood prone areas are designed and managed such that:

- The farm produces mature crops during periods of low-flow so that crop damages from flooding do not occur and harvest is not impacted by wet conditions.
- The plants have structural components that are durable enough to withstand sheet flows, such as woody stems.
- The planting design protects itself *and* the surrounding soil on which it depends, and
- The crops consist of plant types, or root stocks, adapted to periodic inundation and saturated soils, as well as relatively dry conditions, as would be expected during the summer months (Figure 37).
- Engineered logjams, riparian buffers and flood fences intercept floating debris that would otherwise cause flood damages to farms

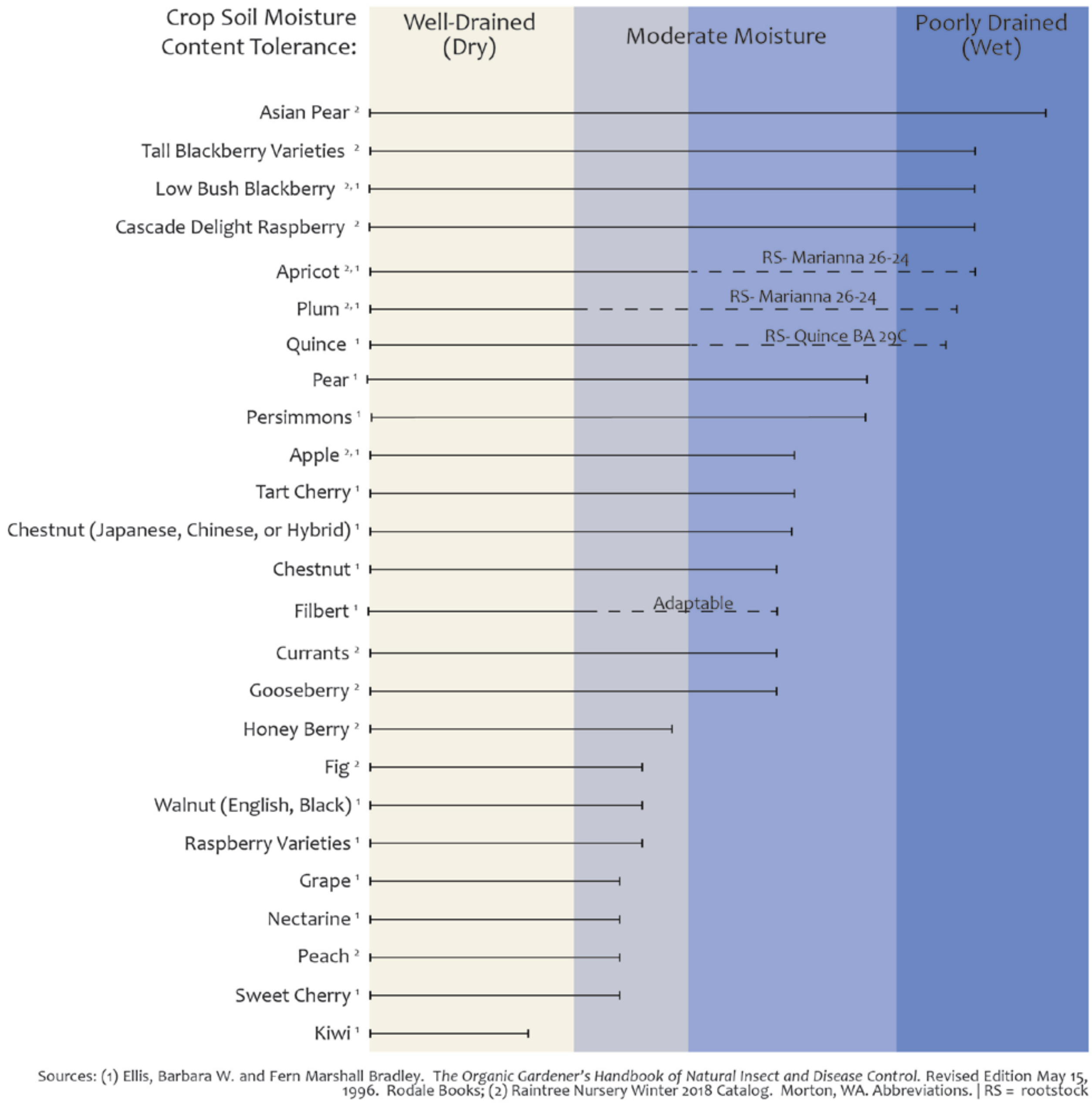


Figure 37. Illustration of locally available crop varieties and their tolerance of wet soils. Root structure development, and thus root strength, is not equal among the varieties. Hedgerow versatility allows for mixing crops and root structure types, or arrangement/layout versatility so that a desirable crop with a weaker root system can be located where it will be protected by a stronger crop. Note: while blueberries are not shown in the table however, they are good candidate species for water-tolerant crop and they are currently being planted in the SF Chehalis River valley.

Work has been done locally, regionally, nationally and internationally to design agriculture systems that function well in flood-prone areas. These systems tend to have three main characteristics, they (1) incorporate perennial crops (i.e. tree fruits and nuts, berries), (2) emphasize a vertical structural component absent from most annual cropping systems, (3) and incorporate more than one crop type and sometimes numerous crops, growing in conjunction with one another. These robust, vertical, and diverse farms are often called “agroforests”. This diverse and adaptive farming practice is called “agroforestry”.

Agroforestry

Agroforestry as a crop science has been in use for decades and adaptations of its principles can and should be considered and employed in areas that must contend with periodic flooding. Agroforestry–type systems have the benefit of:

- **Durability:** perennial plants with well-developed root systems persist for decades and can withstand flood flows and summer drought.
- **Protective of soils and assets:** the same perennial plants which provide durability also increase soil cohesion (anchor the soil) and can direct flows away from more sensitive crops or domestic or agricultural structures.
- **Diversity:** mixed crop systems support a wider range of invertebrate species which typically produce a more balanced invertebrate ecology and ultimately decrease pest pressure on crops.
- **Versatility:** Systems can be designed that make use of the advantages that exist on any specific plot of land and can be adapted to make the most of less than optimal conditions. Location, layout, spacing, crop-types, and timing of activities can all be designed to fit the specific location and functions desired by the landowner.

It should be noted that agroforestry as an agronomic system is not limited to riparian, frequently flooded areas. It is used ubiquitously in all arable landscapes. The benefits are more typically focused around economic and ecological diversity, rather than flood resilience. However, in the Western Washington region, specialized work has been done by conservation districts and counties to show that agro-forestry principals, specifically structural and layout principles, can have a positive impact where flooding is an issue – namely as buffering and protective structures that also produce cash crops (Dittbrenner et al., 2015).

Agroforestry is divided into three main design typologies, which can be used together and a variety of configurations. Hedgerows, silvo-pasture, and alley cropping are all agro-foresty designs and include particular farming practices and benefits. Details for each of these different typologies are provided in the Floodplain and Upland Agriculture Report (Appendix 4).

Agroforestry Cons

Like most farming practices, agroforestry systems are not without their drawbacks.

Cost: Crop material in the form of perennial shrub or tree stock is more expensive than annual crops. Fruit and nut tree stock from local nurseries can retail for as much as $30 per tree depending on stock size, timber tree stock is usually less expensive (Raintree Nursery, 2018). Fruiting shrubs can cost up to $18, less for cane fruit (Burnt Ridge Nursery, 2018). Agricultural support services often have access to less expensive stock, especially stock for timber crops.

Time: Establishment of mature productive trees takes several years during which tree crops will not produce a saleable crop. This lag in production and revenue can be partially offset by the production potential in the understory/ground layer, usually an annual crop with rapid maturation.

Complex Management: More importantly is the shift in management. Agroforestry systems are more complex than single crop rotational farming. They require an increased level of monitoring and management to make these systems successful. Seasonal plant development monitoring and pruning, pest monitoring and management, differing irrigation needs and system installations, especially during establishment, and differing harvest periods and methods are examples of the added effort required to successful management.

Resources: Local and regional advisors, and potentially other growers, are available for guidance and consultation. Washington State University has a SW Washington Agroforestry advisor. USDA/NRCS publishes information about agroforestry systems, and several not-for-profit organizations exist to provide expertise.

5. RESULTS OF FEASIBILITY EVALUATION

This study revealed a range of potential rates for downstream flood attenuation using a restorative flood protection approach, provided further insight into flood and erosion risk in the basin, and identified channel slope criteria to identify reaches where restorative flood protection actions are best suited. This chapter describes the results of an advanced feasibility evaluation undertaken in the North Fork and South Fork Newaukum Rivers.

5.1 Hydraulic Results

To evaluate the RFP concept, a hydraulic model of the North and South Fork Newaukum Rivers was developed using Riverflow-2D to represent existing conditions, and then modified to represent installation of the conceptual RFP treatment. The RFP treatment was modeled by adding grade control structures and engineered log jams (ELJs) to the modeling surface and changing roughness values to represent a more natural landscape. Five flow scenarios were run: one representing the flood of record in January 2009, and four synthetic flow scenarios constructed based on peak flow analysis of the USGS gage on the Newaukum River mainstem near Chehalis, WA. Three of the synthetic flow scenarios represent a 100-yr return interval flood, a 10-yr return interval flood, and a 2-yr return interval flood. In addition, the 100-year flood as effected by climate change was modeled for existing conditions by increasing the magnitude of the 100-yr flood hydrograph by 26%, the increase in peak flow predicted as a result of climate change (Hill and Karpack (2019).[4]

The RFP treatment slowed river velocity and raised water surface elevations within the treatment area, allowing water to overtop the stream banks and re-engage parts of the floodplain that have been abandoned. Results from modeled scenarios are shown below in Table 6. In all flow scenarios, the RFP treatment slowed water in the channel by about 3 feet per second (fps), and cut the overall average water velocity in half. RFP treatment also raised water surface elevation throughout the study area by an average of 2-3 ft, including the downstream end of the model, resulting in double the inundation area and more than double the transient floodplain storage in comparison with existing conditions. It is important to note that the cumulative effect of RFP treatment of Upper Chehalis Watershed on Chehalis/Centralia was never estimated in a 2D hydraulic model because the authors did not have access to the completed basin-wide model. A visualization of the 100-yr flood under existing and RFP conditions is shown in Figure 38. These dramatic metrics translated to only modest flood wave attenuation, with peak discharge at the downstream end of the RFP model reduced by 3-10% in comparison to the peak discharge under existing conditions at the same downstream location. More detailed information on the methods, results, and analysis of the hydraulic model is presented in Appendix 3.

[4] Climate change scenarios were not considered in the PEIS Restorative Flood Protection Assessment, see page 160 of Abbe, T., Anderson, B., Carlstad, C., Devier, D.L., Fetherston, K., Dickerson-Lange, S., Embertson, L., Higgins, S., Katz, S., Lestelle, L., Machata, K.K., Nelson, M., O'Neal, J., Patrick, K., Reinhart, M.A., Riordan, C., Stepp, M., Trotter, P., Ventres-Pake, R., 2016. Preliminary Scientific and Technical Assessment of a Restorative Flood Protection Approach for the Upper Chehalis River Watershed. Report by Natural Systems Design. .

Table 6. Comparison of RFP vs. Existing Conditions Modeling Results.

FLOW SCENARIO	PEAK OUTFLOW EC (CFS)	PEAK OUTFLOW RFP (CFS)	REDUCTION IN PEAK OUTFLOW (%)	MEAN VELOCITY CHANGE IN CHANNEL (FPS)*	MEAN VELOCITY CHANGE OVERALL (%) **	MEAN WSE CHANGE OVERALL (FT)*	INCREASE IN INUNDATED SURFACE AREA (%)	INCREASE IN TRANSIENT FLOODPLAIN STORAGE (%)
Jan2009	14,137	13,732	3%	-3.5	-55%	2.8	111%	123%
100-yr	14,639	13,754	6%	-3.4	-54%	2.8	114%	124%
10-yr	9,483	8,826	7%	-3.5	-56%	2.5	94%	153%
2-yr	7,082	6,407	10%	-3.2	-59%	3.2	156%	182%

*Average of the difference between EC and RFP values at each cell that is wetted in both conditions.

** Difference between the average of the peak velocity values in the RFP model results to the same in the EC model results.

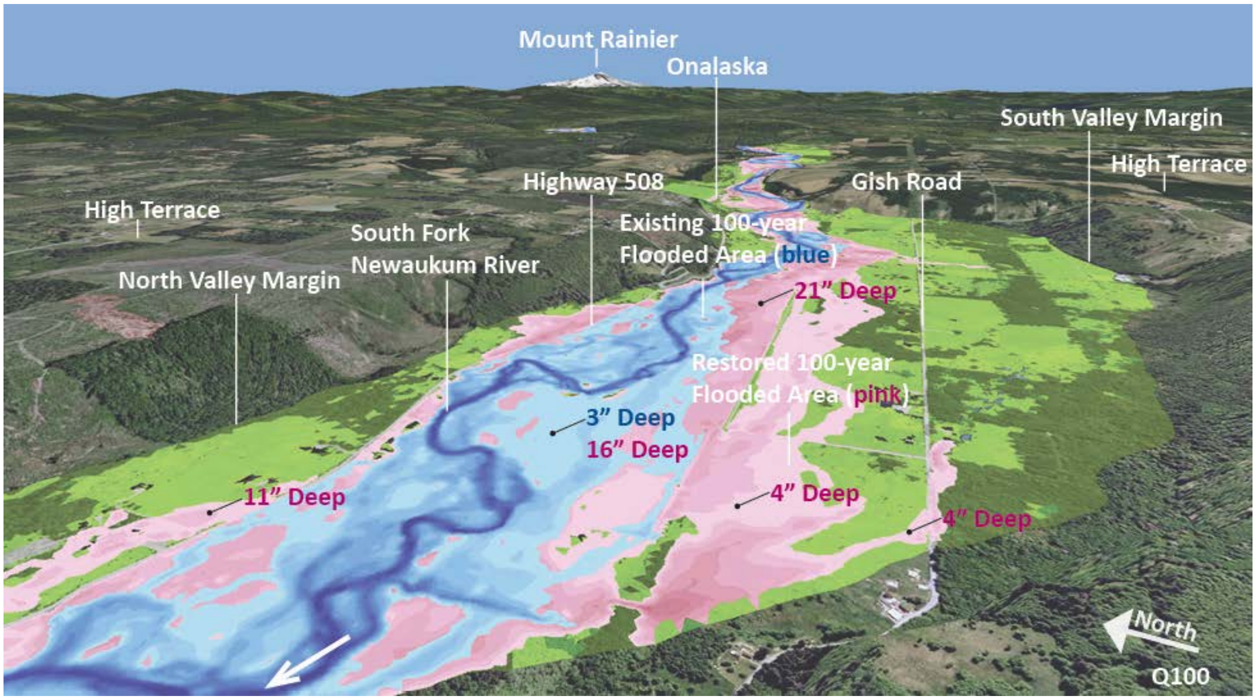


Figure 38. Example of simulated 100-year flood (Q100) along the South Fork Newaukum River under existing (blue) and RFP (pink) conditions. The shades of green represent a shift in valley bottom vegetation from pasture to shrubs and forest.

5.2 Valley Slope: Key to RFP's Ability to Attenuate Floods

Hydraulic results showed that RFP treatment achieved the intended effects of slowing river flow and spreading floodwater across the floodplain to increase transient floodplain storage; however, these dramatic changes within the modeled upland areas did not result in equally dramatic flood wave attenuation/peak flow reduction downstream. A review of the existing literature and of the physics of streamflow indicates that channel slope may be a crucial factor behind this disconnect (Henderson, 1966; Ponce, 1989; Sholtes and Doyle, 2011; Sturm, 2010). The Newaukum Subbasin has predominantly steep channel slopes (0.002 to 0.007 ft/ft), which means flood waves through this basin are overwhelmed by gravitational forces and therefore, resist attenuation. Identifying an effectiveness threshold between steep slopes (over which flood waves tend to resist attenuation) and shallow slopes (over which flood waves tend to attenuate more readily) could point the way to maximizing the effectiveness of RFP treatment.

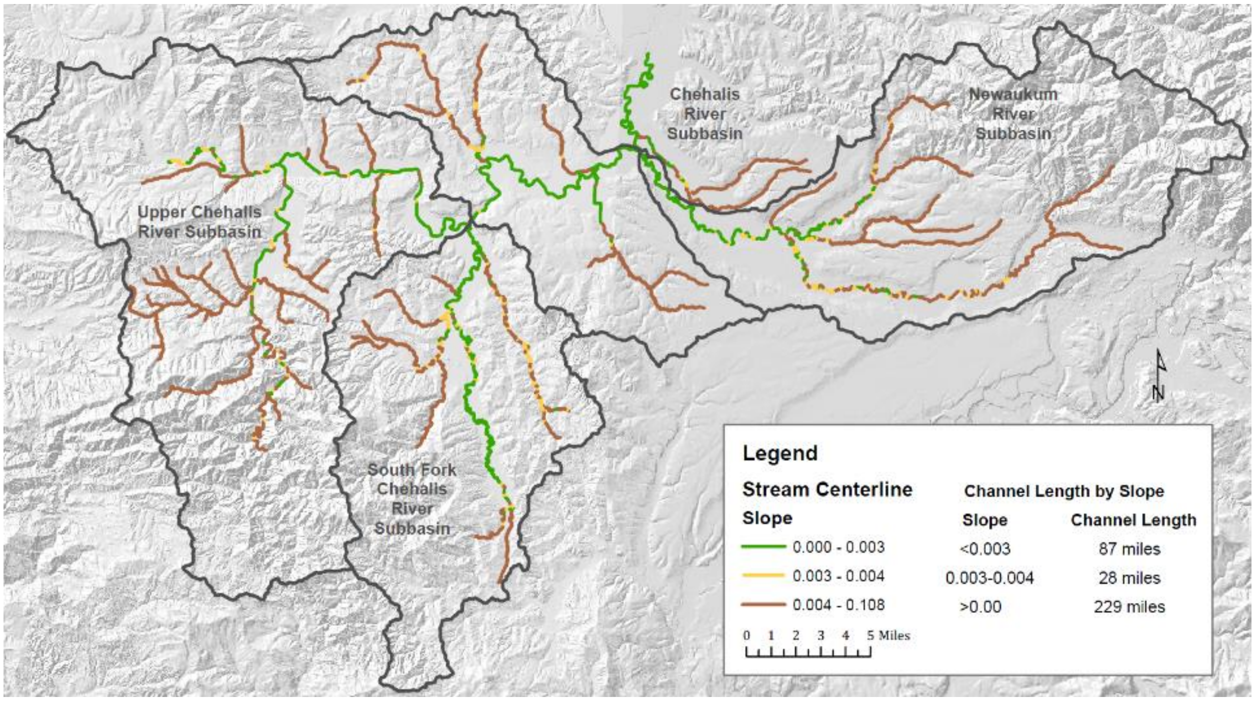


Figure 39. Spatial Distribution of Channel Slope Breakdown in the full Upper Chehalis River Basin.

To determine such a threshold, NSD performed an in-depth analysis of the Newaukum 2D model results and undertook an idealized 2D modeling experiment in which the discharge reduction effect of simplified RFP treatments at a range of channel slopes was recorded. Based on these analyses, the slope threshold separating attenuating from non-attenuating reaches was estimated to be 0.003 ft/ft, and as slopes reduce below this threshold, the peak discharge reduction effect of RFP treatment appears to grow exponentially. To put this in context, there are 87 river miles within the Upper Chehalis Basin with channel slopes below 0.003 ft/ft. Maximizing the effect of RFP treatment would likely mean strategically treating these low-slope reaches, which make up 25% of the channels within the Upper Chehalis River Basin (Figure 39 above).

5.3 A Missing Component: Alluvial Groundwater

Almost every flood mapping project assumes an impermeable floodplain surface, but numerous studies have demonstrated that floodplains can absorb large quantities of water due to their permeable alluvial soils. Some hydraulic models such as Riverflow 2D offer an option to integrate floodplain infiltration and assess its effect on flood routing. While increased infiltration is an expected effect of increased floodplain engagement, conventional hydraulic models do not account for groundwater infiltration. What is more, evidence from USGS streamflow gages in the Newaukum Basin indicates that infiltration is an important process in this region even during large storms. Gages on the North and South Fork of the Newaukum River recorded larger peak discharges (when summed) than the discharge at the (downstream) mainstem Newaukum gage. Therefore, a supplemental analysis was conducted to estimate the effects of RFP with infiltration as a factor.

Combining empirical groundwater storage estimations with the groundwater modeling component of Riverflow-2D, NSD simulated the January 2009 storm event with a low, medium, and high estimate of groundwater storage. As shown in Figure 40 and Figure 41, when infiltration was considered, RFP treatment reduced downstream peak flow by 10% (the conservative estimate within a realistic range of 7-26%). In contrast, hydraulic modeling that neglects infiltration shows a 3% reduction (Table 6). Thus, representing groundwater storage more than triples the peak flow attenuation effect represented by modeling surface water alone. Increased groundwater storage due to greater overbank flow may represent an important mechanism for peak flow attenuation under RFP conditions, and we recommend that this effect be included in future studies of peak flow attenuation.

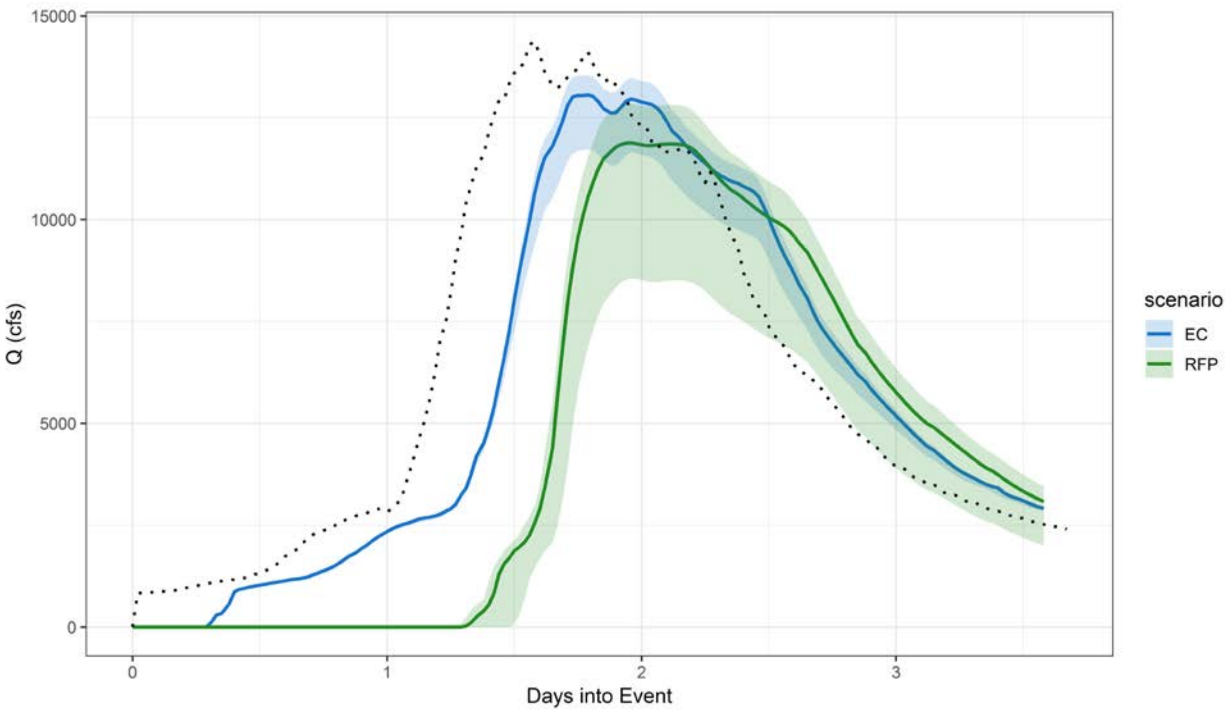


Figure 40. January 2009 inflow hydrograph (black dotted line) and resulting outflow hydrographs for EC (blue) and RFP (green) based on hydraulic modeling to match empirically estimated groundwater storage volumes due to infiltration. The lines represent the middle scenario whereas the envelope around each line represents the range between the low to high bounding scenarios.

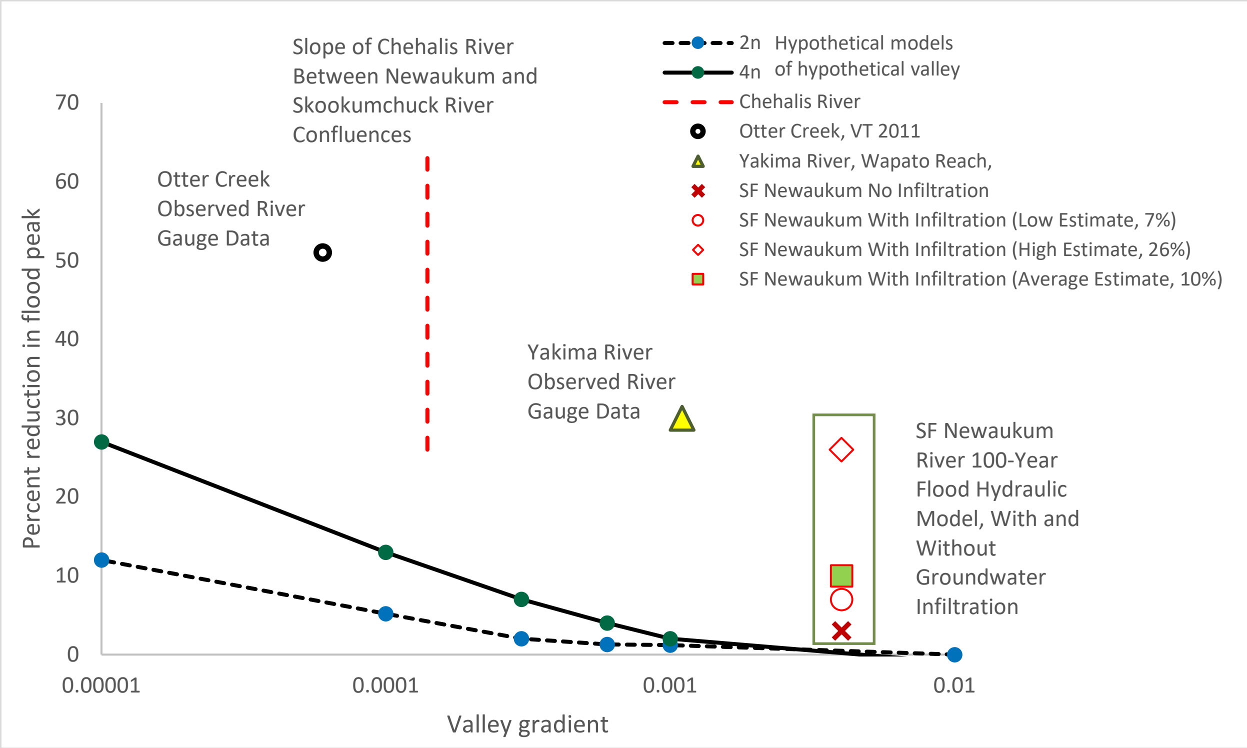


Figure 41: The effect on peak flow attenuation of roughness changes at different slopes in an idealized (hypothetical) 2D model compared to model results from the restorative flood protection hydraulic modeling study of the SF Newaukum River, with and without groundwater infiltration, and two observed floods of record in Otter Creek, Vermont and Yakima River, Washington.

5.4 Effects of Changes in the 100-Year Flood Inundation Area on Existing Homes

In the RFP study area, about a dozen homes are flooded during a 100-year flood event under current river and landscape conditions (see Section 2). Under these same current river and landscape conditions, climate change effects to the 100-year storm increases the number of flooded homes in the study area to about 26. Restorative actions to the river and floodplain also increase the number of flooded homes in the study area to about 26, using the current 100-year event.

Under the climate change scenario, restorative actions increase flooding from a 100-year event. Thus, the number of flooded homes is estimated to increase by more than six times, from 26 homes under the current 100-year flood to 153 affected homes with the climate change amplified 100-year event (Table 7).

However, in all of these cases, additional homes and out buildings may be temporarily surrounded by shallow water.

Table 7. Estimate of the number of flooded homes, under current and climate change scenarios, with and without restorative actions.

RIVER AND FLOODPLAIN SCENARIO	BUILDING TYPE	CURRENT 100-YEAR FLOOD (2019)	CLIMATE CHANGE 100-YEAR FLOOD (2100)
Current River and Floodplain Conditions	Number Buildings within Flooded Area (Note 1)	159	215
	Number Residential Buildings Flooded (Note 2)	**12**	**26**
Restored River and Floodplain	Number Buildings within Flooded Area (Note 1)	766	921
	Number Residential Buildings Flooded (Note 2)	**26**	**153**

Note 1: Measurement of all buildings, including residential and outbuildings, which are within the flooded area, regardless of whether the finished floor elevation of the first story is above or below the simulated water surface elevation.
Note 2: Residential buildings with finished floor elevations below the simulated water surface elevation.

Scenarios for adaptively managing river valley land use to accommodate shifting river and floodplain processes will be discussed in the following chapter. These scenarios may include, but are not limited to:

1) Prioritized buy-out or relocation of homes and farms which are currently flooding or experiencing significant erosion effects, and a shift to restored floodplain forest or flood-friendly crops in these same areas;
2) A more-gradual floodproofing or purchase of homes which may be affected by future flooding and erosion, and extension of floodplain forest restoration and flood friendly farming practices to these areas.

5.5 Geomorphology

From a geomorphic perspective, the best river reaches for attenuation and storage of rare large flood events (greater than 100-year), are ones with a river-channel slope, or the channel gradient from upriver to downriver, of less than 0.01%. In the NF and SF Newaukum River study area, this slope is only found within 5 or 6 miles from the confluence of these two rivers. Both rivers increase in slope upstream from these confluence reaches.

For ecological and river-health reasons, restoration actions are warranted in these steeper areas. While restoration of those areas is not anticipated to provide significant 100-yer flood peak attenuation due to their steep channel slope, restorative actions will store more groundwater during periods of high flow and release this water during summer low flow.

Table 8. Comparison of change in inundated active and historical floodplain between Restorative Flood Protection conditions and existing conditions for simulated 2009 flood event.

	EXISTING LANDSCAPE SIMULATION	RESTORATIVE FLOOD PROTECTION SIMULATION	RELATIVE CHANGE

Inundated Surface Area (Acres)	2,246	4,743	111%
Average Velocity Outside of Active Floodplain at Peak Flow (fps)*	2	1	-48%
Peak Volume Outside of Inset Floodplain (acre-feet)	2,357	9,319	118%
Water Surface Elevation Outside of Inset Floodplain (ft)*	-	-	2.8

* Average Velocity and WSE change are calculated by averaging the difference between EC and RFP values at each cell that is wetted in both conditions.

5.6 Vegetation

Riparian conditions of the Newaukum Valleys are dominated by pasture, immature forests and invasive plants that are nothing like the original old-growth forests. Restoring the mature coniferous forest plant communities that historically grew along the banks and floodplains of the Newaukum River will provide a permanent and naturally sustainable source of the large in-channel wood which the river needs to maintain a diverse channel network, engage the adjacent floodplain, and moderate erosion. The restoration target forest is composed of long-lived large trees, such as:

- western red cedar (200 feet tall, up to 18 feet in diameter, 1000-year lifespan)
- Sitka spruce (170 feet tall, 12 to 17 feet in diameter, 600+year lifespan)
- western hemlock (200 feet tall, 6-8 feet in diameter, 300+ year lifespan)
- black cottonwood (150+ feet tall, 4-6 feet in diameter, 100+ year lifespan)
- bigleaf maple (125 feet tall, 6 feet in diameter, 250+ year life span)
- Oregon ash (60 to 80 feet tall, ~2' in diameter, 150+ year life span)
- *see Newaukum plant community fact sheets in Appendix 6 for more information*

The connection between forest health and river health is described by a geomorphic principle called the "large wood cycle".

5.6.1 Changes to Large Wood Cycle

Since modern human settlement, many floodplain water bodies and wetlands have been drained, filled in, and hydraulically disconnected from regular flood events; and mature floodplain forests have been removed from much of the basin. This reduction in adjacent forests significantly reduces both the source and presence of in-channel wood in the Newaukum River. As mentioned earlier, this lack of in-channel wood has had consequences for river and floodplain connectivity, side-channel formation, and other natural riverine processes, see (Abbe, 2000; Abbe and Montgomery, 2003; Bureau of Reclamation and U.S. Army Engineer Research and Development Center (USBR and ERDC), 2016; Collins et al., 2012). The cumulative effect of this broken large wood cycle are simplified channel and floodplain surfaces, lowered primary channel beds that disconnect flood events from historic floodplains, and separated secondary, floodplain channel networks from primary channels. Reversing these effects will slow river flow, reduce bank erosion, and engage a larger flood network.

6. DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

6.1 Technical Findings

6.1.1 Geomorphology

The RFP approach was found to have the following geomorphic effects.

- Reversing incision increases downstream flood peak attenuation and increases aquatic habitat.
    - The approach will dramatically increase the extent and quality of aquatic and riparian habitat by increasing the hydraulic connectivity across large areas of the valleys where treatment is applied. This will also raise the groundwater table several feet, thereby creating considerable water storage and improving low flows.
    - Reversing incision will also increase floodplain engagement, resulting in slower water velocities which will lead to aggradation, increasing floodplain connectivity even further over time. Using a 2-D hydraulic model with infiltration, modeling predictions show a two to three fold increase in floodplain water storage under RFP scenario in the NF and SF Newaukum study area. In this modeled scenario, attenuation of downstream flood peaks depends largely on infiltration into alluvial aquifer.
- Result in significant reduction in shear stresses driving bank erosion will reduce erosion rates. Most bank erosion will be contained within restoration corridor though localized erosion at margins of the corridor could occur.
- Climate change
    - Will increase peak flood flows and thus, contribute to increased incision and bank erosion assuming no changes in land use. It will also lower summer flows and increase water temperatures.
    - Implementation of RFP scenario of valley bottom restoration will largely offset impacts of climate change by creating more shade (restoring multiple narrower channels with forested banks), raise water table (supplementing low flows), and by moving people out of flood prone areas will create larger floodplain areas able to accommodate large peak flows.

6.1.2 Relationship Between Sustainable Floodplain (Riparian) Forest, Floods and Rivers

While engineered log jams may be used to restore river processes in the short-term (Abbe and Montgomery, 2003), restoring a supply of large (e.g. big and old) floodplain trees is critical for enhancing and sustaining rich riverine biogeomorphic complexity (Collins et al., 2012; Van Pelt et al., 2006), which in-turn supports aquatic habitat, flood protection and other ecological and economic services. For example, Collins et al. (2012) analyzed the change in active channel width from the late 1800s or early 1900s to the late 21st century for the North Fork Nooksack

River and the Cowlitz River and found that as forested land areas decrease, active river channel area increases. In other words, timber removal and the active removal of in-stream wood have resulted in wider, deeper, rivers with fewer pools, coarser bed material, and less floodplain connectivity (Abbe, 2000; Abbe and Montgomery, 1996; Collins et al., 2012; Sedell and Frogatt, 1984).

Floodplain (riparian) forest growth and regeneration is dependent upon the availability of appropriate sediment substrate and hydrological conditions, which are in turn created by both high and low river flow patterns and geomorphic processes (Mahoney and Rood, 1998; Richter and Richter, 2000; Rood et al., 2003; Rood et al., 2005). For example, cottonwood trees are ubiquitous to western North American riparian forests. Cottonwood seed dispersal occurs after annual peak river flows, transporting the seeds onto the floodplain where the seedlings germinate quickly and abundantly. Widespread seedling mortality occurs due to drought stress, in locations where cottonwood roots cannot grow quickly enough to maintain adequate contact with the receding soil moisture zone. Cottonwood seedling roots grow about 0.5 to 1 cm a day, or 0.2 to 0.5 inches per day; and the critical rate of stream stage decline is about 2.5 cm per day, or less (Mahoney and Rood, 1998). Mahoney and Rood found that flood events with recurrences of 5 to 10 years provide this gradual stream stage decline. The relationship between cottonwood recruitment and hydro-geomorphic processes is called the “recruitment box model” (Mahoney and Rood, 1998). In addition to this example from Mahoney and Rood, there are several other studies which investigate how floodplain (riparian) plant communities develop on heterogeneous floodplain topography, and the influence of river flow and disturbance regimes on these plant communities over time, including (Greco and Plant, 2003; Ward, 1998).

6.1.3 Ecologically Functional Floodplains

Healthy Pacific Northwest rivers need healthy forests to provide a supply of in-channel wood, as well as shade, erosion protection, and other ecological benefits

While floodplains are some of the most biologically productive and diverse ecosystems on Earth, they are also among the most modified and threatened ecosystems. Restoration of these heavily utilized and valuable landscapes requires management of both land and water; as well as overcoming technical and socioeconomic challenges. Opperman et al. (2010) proposes a scientific conceptual model, supported by three case studies, to support restoration and re-creation of ecologically functional floodplains. The conceptual model integrates short-term processes that occur during flood events with long-term processes, such as riparian forest growth and regeneration, which then generate the multiple co-benefits that floodplains afford, such as groundwater recharge, highly productive fisheries, recreation, and wood. These types of ecosystem services have been estimated from an economic perspective, for monetary value, to support market development for restoration.

An ecologically functional quantity of connectivity, flow, and space will vary from river to river and reach to reach. Geomorphic assessments, hydrologic modeling, and plant community analyses, such as those presented in this Newaukum River Restorative Flood Protection

Feasibility Study are typical of those conducted to determine an ideal amount of each of these parameters to generate an ecologically functional floodplain.

6.1.4 Landowner Return on Investment for Restoring Agricultural Land to Ecologically Functional Floodplain

Carbon sequestration, nutrient removal, water quality, recreation (e.g. duck hunting and fishing), and flood attenuation are five services for which The Nature Conservancy is currently conducting a long-term monitoring program at Mollicy Farms on the Ouachita River in Louisiana, a large river and floodplain restoration project in the Lower Mississippi River Alluvial Valley (formerly one of Earth's great floodplain forests). A study by Jenkins et al. (2010) found that ecosystem service values exceed the net income from agriculture, making this shift in land use economically viable for many landowners. For example, in the analysis conducted by Jenkins et al., the private market value for the agricultural land use was about $400 per hectare per year, including agricultural net income, farm subsidies, and existing ecosystem services. This value increased to $1,035 per hectare per year for a restored, ecologically functional floodplain, in this region, with potential ecosystem service market creation, including greenhouse gas mitigation, nitrogen mitigation, and wildlife recreation. In this study, this income was from mitigation banking, recreational fees, and increased land value.

Social welfare value, or the economic value of avoided climate change risk damages, adds another $1400 per hectare per year to the potential ecological service value (Jenkins et al., 2010; Murray et al., 2009). The authors of these two papers write that, from the taxpayer perspective, the social benefits easily outstrip the social costs of restoring wetlands via the USDA NRCS Wetlands Reserve Program (WRP), because, according to their calculations, the public investment is covered by the economic value of enhanced ecosystem services in two years. This is a conservative estimate because their economic analysis only included services with a clear monetary value, today. A Congressional Task Force also found that functional floodplains not only reduce flood damages but, they also contribute to a community's social and economic well-being (The Task Force on the Natural and Beneficial Functions of the Floodplain, 2002). Several of the case studies came from Oregon and Washington.

6.1.5 Landowner Perspective and Implications for Restorative Flood Protection-Type Projects (I.E. Ecologically Functional Floodplains)

Recent floodplain management research, such as the studies described above, has found that reduction of unsustainable uses while maximizing functional floodplain area benefits both society and private landowners (Opperman et al., 2009). For example, projects like the Yolo Bypass outside of Sacramento, California, which conveys 80% of the Sacramento River through 24,000 ha, almost 60,000 acres, of floodplain during large flood events, demonstrate that floodplains can remain in private ownership. Two-thirds of the Yolo Bypass floodplain is privately owned and used to grow crops which survive periodic inundation (Opperman et al., 2009). A limited survey of landowners in the Newaukum River Valleys was conducted as a part of this study indicated that there most were open to restoration on their land as long as their quality of life and chosen lifestyle was retained and they were made whole financially. A summary of this survey is provided in Appendix 5.

Landowner perspectives on voluntary conservation incentive programs have been gathered for several Western Washington watersheds. A 2014 survey, conducted by the Snohomish Conservation District, revealed that landowners in the Snohomish and Stillaguamish River Valleys were interested and willing to participate in voluntary conservation incentive programs, and that these programs should be tailored to meet landowner needs (Carr et al., 2014). For example, riparian buffers could vary in width and plant community composition, such as a 'working buffer', which generates income while providing ecological function. Direct financial benefit is a big incentive for landowners (Carr et al., 2014).

The science-based design framework utilized in the Newaukum River Valley RFP Feasibility Study allows for ecologically functional floodplains to remain in private ownership, as long as adequate floodplain function is maintained. In the hypothetical example shown in Figure 421, the area currently flooded by the 100-year flood has been converted from pasture to floodplain forest or agro-forestry zones and the newly inundated areas have been planted with flood-friendly perennial agricultural crops, with hedgerow and forested buffers.

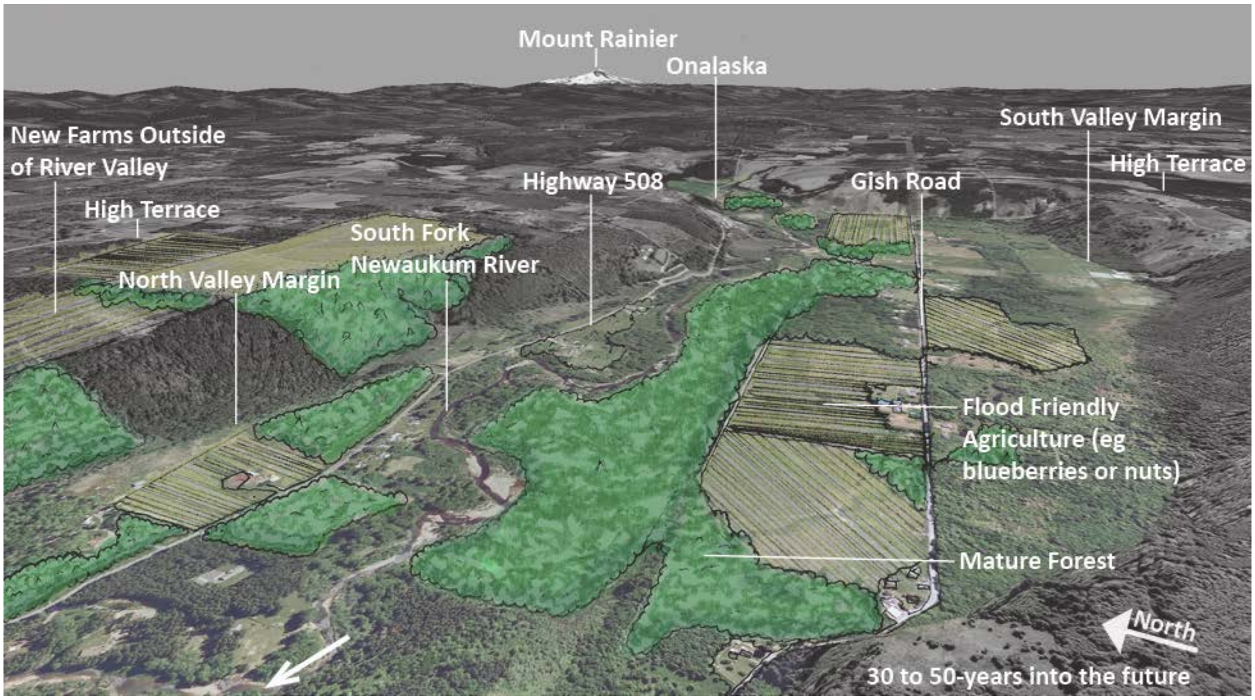


Figure 42. Illustration of site-specific floodplain uses, which address the particular needs of the landowner and the unique dynamics of each river and floodplain reach, to maximize floodplain function, landowner benefits and needs, and other ecological, social, and economic services.

Similar to the conservation incentive program survey recommendations, described by Carr et al. (2014), were the RFP design implemented, site-specific designs would be created, which would address the particular needs of the landowner and the unique dynamics of each river and floodplain reach. These custom-fit river and landscape designs would also maximize floodplain function, and other ecological, social, and economic services. In the fall of 2019, further development of the RFP alternative was suspended by the Chehalis Basin Board. The authors' of the RFP assessment recommended that instead of moving forward with engineering design in the Newaukum Valleys, that the RFP scope be amended to focus on identifying erosion hazards, a prioritization plan for land acquisition and relocation, and delineating low gradient valleys where the RFP approach would provide the greatest flood attenuation benefit.   None of these recommended actions have been done throughout the basin.

The RFP analysis found substantial evidence of landowner interest and good upland conditions supporting relocation and new development on terraces situated well outside flood hazard areas. A major program supporting relocation would not only help landowners and remove flood damage liabilities to the locals, state and federal government, but it would stimulate local economies which would benefit agriculture, construction and services.

Modeling Floods

Limitations to Modeling Approach

6.1.6 While hydraulic modeling is an excellent way to get an idea of the effects of certain actions, there are limitations to any model, especially at such a large scale. Therefore, modeling results must always be considered in the context of reality and the assumptions on which the model is based. For instance, groundwater infiltration is by design an important aspect of restorative flood protection, as the idea is to spread water out over the floodplain and slow it down partially to encourage infiltration. In Riverflow2D, however, the basic model does not allow for infiltration. Even when infiltration was “turned on”, as discussed below, the simulation is still imperfect because groundwater and surface water flows are decoupled – meaning once water infiltrates into the ground, it is essentially treated as lost. In reality, in a system saturated by a large storm, surface and subsurface flow would interact and influence one another. Another aspect of this is the difference between the topographic complexity of a ground in reality as compared to the simplified surface that is necessary for hydraulic modeling. The Newaukum model is based on a mesh that smooths over things like divots and bumps that are smaller than 3 ft across. On the large scale of the Newaukum model, there is a certain amount of transient storage provided by small surface abnormalities that may be overlooked by the model. These missing degrees of complexity may mean that the effects of RFP treatment would be greater in reality than in the model.

Another assumption is the distribution, magnitude, and shape of inflow hydrographs throughout the model. For the Newaukum model, inflows were based on the USGS gage on the mainstem Newaukum River near Centralia and distributed to 9 different inflow locations. In reality, during large storms, there would be nearly infinite flow inputs distributed throughout the entire length of the rivers, consisting of overland flow, subsurface flow, rainfall, and tributaries of varying sizes. The importance of hydrology to the effectiveness of the RFP is demonstrated by the difference between the results under the January 2009 flow scenario vs. those under the 100-yr flow scenario. These two floods had similar peak inflow magnitudes, but different shaped hydrographs and the spatial distribution of inflows was dissimilar – the January 2009 flood had a greater portion of flow concentrated at the upstream ends of the North and South Fork Newaukum Rivers than the 100-yr. The outcome was that RFP treatment was twice as effective at attenuating peak flow under the 100-yr than under the January 2009 flood. The development of both hydrologies is described in the Hydraulic Modeling Report (Appendix 3). The difference between the two flows emphasizes how important assumptions about inflow are to the conclusions that a hydraulic model draws, and how different the effects of RFP treatment might be in reality.

Validation of Groundwater Infiltration Approach

The modeling approach that accounted for the volume of water that infiltrates into the subsurface and is stored as groundwater resulted in a substantially larger peak attenuation effect than in the modeling approach that neglects groundwater storage. These results are likely a more realistic representation of the local water budget during a flood event, based on two lines of evidence: (1) incongruence between local stream gage data and the calibration of the existing conditions hydraulic model, and (2) published literature values.

When the January 2009 existing conditions hydraulic model was set-up and calibrated, the model inflows for ungaged areas had to be substantially adjusted to achieve a better fit between the modeled hydrograph and the observed gage data on the mainstem Newaukum, due to the inherent limitations of surface water modeling (Northwest Hydraulic Consultants, 2018). Because the model was over-predicting flow at the mainstem gage, the estimated inflows from ungaged tributaries (based on the commonly used drainage area ratio method) were reduced from 4,900 to 93 cfs in the South Fork Newaukum, and from 7,900 to 124 cfs in the North and Middle Forks of the Newaukum. Thus, in total, over 12,000 cfs of streamflow were removed from the model to achieve stage calibration to the downstream gage. Some of this discrepancy may be explained by the exclusion of groundwater recharge processes from the hydraulic model. The difference in the standard EC model and the EC model with infiltration is approximately 729 cfs (range of 269-2332), which is much smaller than the inflow discharge that was excluded from the model.

The body of scientific literature on groundwater recharge from overbank flooding is limited, but a few observational and modeling studies exist that provide published points of reference for comparison with the values estimated for the Newaukum. In one observational study in the Tarin River floodplain in China, lysimeters were used to quantify approximately 1.4 feet of groundwater recharge through a silt loam as a result of 0.3 feet of overlying water depth (Zhang et al., 2017). In a modeling study, validated by groundwater elevation observations, Workman and Serrano (1999) estimated almost 5 feet of cumulative groundwater recharge resulting from two large overbank floods that occurred in 1994. These previously reported values for groundwater recharge in a floodplain support the estimated values for the Newaukum, 0.5 to 3.0 feet in EC and 0.7 to 4.0 feet for the RFP are within a plausible range. Antecedent conditions may have a big effect on the groundwater storage capacity or volume, for example, more groundwater storage may be available for early season floods and less for late winter or early spring floods. Lastly, data presented in the USGS hydrogeologic framework for a groundwater well located close to the confluence of the Skookumchuck River with the Chehalis River demonstrates that groundwater elevation rapidly responds to stream stage (Gendaszek, 2011; see their Figure 10A).

6.1.7 Implications for Peak Flow Attenuation in the Chehalis Basin

When the groundwater component is ignored, the RFP failed to significantly attenuate peak flow in the Newaukum pilot, achieving only a 6% reduction in peak flow during the Q100 flow scenario and only 3% during the January 2009 flow scenario. However, as discussed above, infiltration and groundwater flow are significant processes in the Newaukum and taking them into account likely gives us a more realistic idea of how the system functions. When these processes are included in the model, we estimate that peak flow reduction, as a result of the RFP treatment, would be somewhere within the range of 7-24% for the January 2009 flow.

If this range of flow attenuation is translated directly to the Chehalis River at the USGS gage near Grand Mound, it is possible to get a rough estimate of how much RFP treatment across the entire Chehalis Basin might impact the stage of the Chehalis River.

Figure 432 shows the USGS rating curve at the Grand Mound gage, which relates stage to discharge. <u>According to this rating curve, if discharge in the Chehalis River had been reduced by 24% during the January 2009 storm, **the stage would have been 1.2 ft lower**</u>. During such a low frequency flood, when water has overtopped the channel banks, a 1.2 ft reduction in stage likely corresponds to a considerable reduction in flooded area since the floodplain is so flat. This level of reduction is comparable to the proposed dam, but conditional on the stated assumptions regarding infiltration. The results certainly demonstrate that the RFP is worth further development as part of a comprehensive flood and erosion hazard planning in the Chehalis Basin, particularly as a core element of the Community Flood Assistance and Resiliency (CFAR) program.

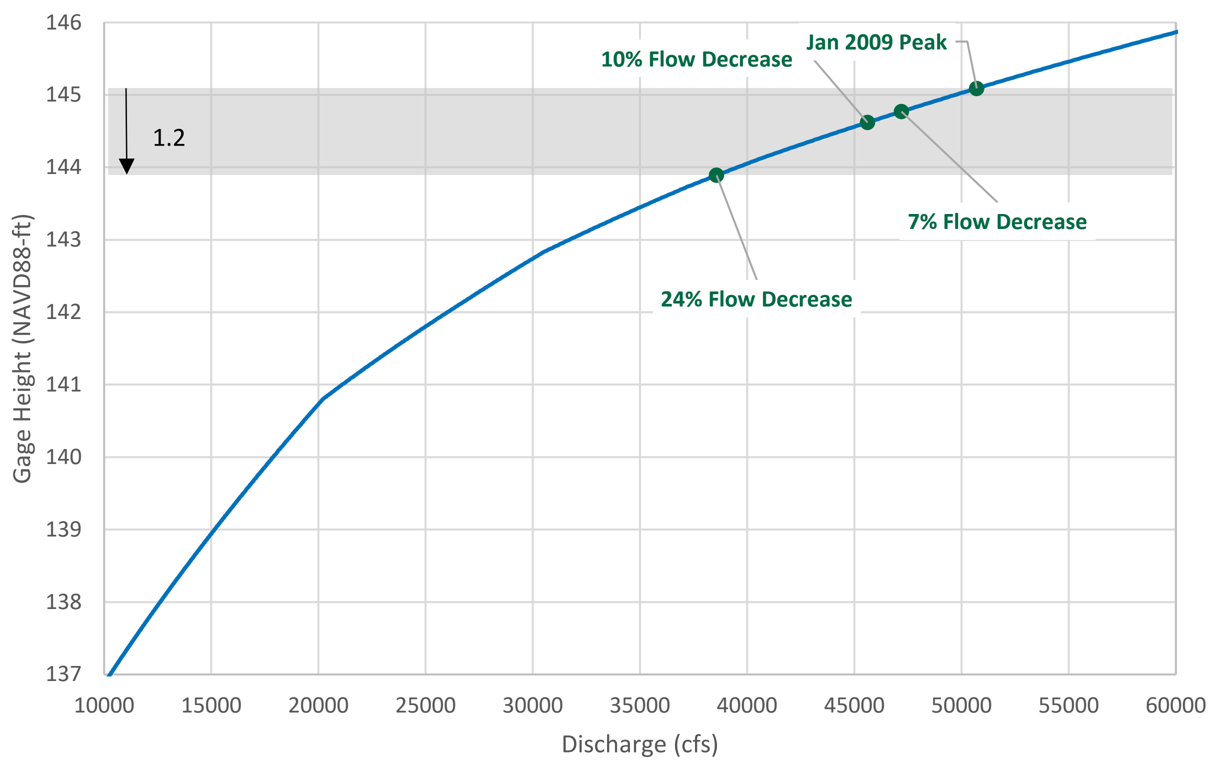


Figure 43. The rating curve for the USGS Gage on the Chehalis River near Grand Mound allows a rough way to translate flow reduction on the mainstem Chehalis River to stage change. Peak streamflow during the January 2009 storm is shown on the rating curve, alongside estimated flow reduction from RFP treatment when infiltration is considered.

One of the goals of RFP treatment is to decrease peak flood flows in downstream areas by re-engaging the natural flood cycles in upland areas. The above gage analysis is a simple translation of the results of the Newaukum Pilot Study to the mainstem Chehalis, but in reality, a strategic combination of RFP treatment in multiple sub-basins could result in much higher peak reduction. There are several sub-basins similar in size to the Newaukum that contribute to mainstem Chehalis flow upstream of the Grand Mound gage and the airport levy. Since RFP treatment in the Newaukum was shown to delay the flood peak, it may be possible to manipulate the celerity of the flood waves in these basins by strategically treating some and not others such that the peaks do not all arrive in the Chehalis mainstem at once. Desynchronizing the sub-basin flood peaks would mean the peaks are not all stacked on top of one another in the mainstem and could reduce mainstem Chehalis flood flows beyond the simple estimation shown in Figure 43.

The Newaukum pilot project modeling effort has produced a maximum slope threshold of 0.003 ft/ft which can help predict where RFP treatment will be most effective. As noted previously in this report, the bed slope in the Newaukum Basin ranges from 0.002 to 0.007 ft/ft. Knowing from the idealized modeling experiment that the attenuation effect of roughness increases exponentially as bed slope decreases below 0.001 ft/ft, it is clear that RFP treatment is not at its peak effectiveness in the Newaukum Sub-basin. Identifying the sub-basins and reaches with flatter slopes and selectively treating those areas with the RFP approach would likely yield greater peak flow attenuation. Figure 43 shows an analysis of the reach slopes within the Chehalis Basin, with slopes below 0.003 ft/ft highlighted in yellow. This figure shows that 87 miles of river in the Upper Chehalis Basin are at low enough slopes that gravity forces will not overwhelm the effects of the RFP treatment. Peak flow attenuation, even greater than 24%, may be possible in lower gradient valleys such as the South Fork Chehalis.

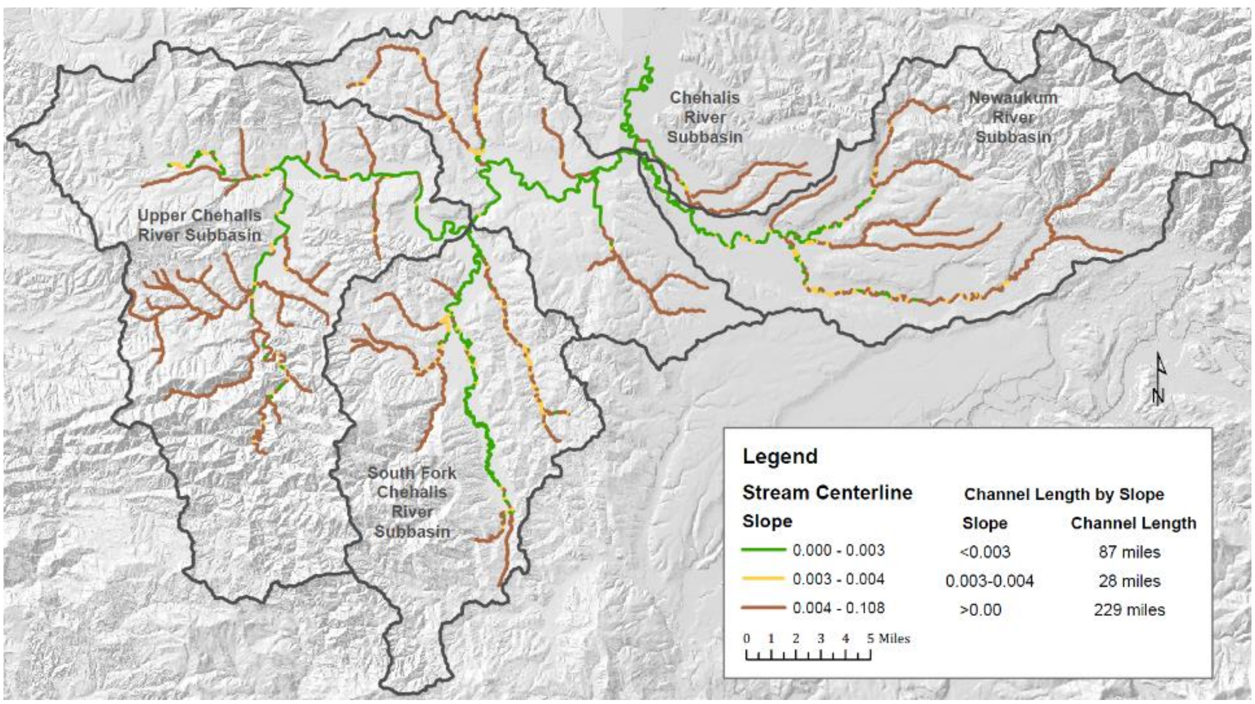


Figure 44. Map of the Chehalis Basin showing river reaches categorized by slope.

6.1.8 Implications for Aquatic and Terrestrial Habitat

The idea behind Restorative Flood Protection is that it not only attenuates peak floods downstream of the treatment area, but also restores the natural geomorphic processes within the treatment area and, by so doing, improves and increases habitat area. The results of hydraulic modeling and geomorphic analysis support this concept.

The conceptual grade control structures and ELJs were included in the RFP treatment in order to help reverse the process of incision and reconnect the river with its floodplain. The hydraulic modeling results show that the RFP treatment reduces velocity in the channel by over 3 fps on average – this may be enough of a reduction in stream power to encourage the stream to aggrade over time. Under historical conditions, before the river incised, there is evidence that the Newaukum Valley was frequently inundated. The hydraulic model shows that the RFP treatment successfully lowers velocities, raises the water surface elevation, and increases the inundation area during small and large flows, re-engaging the floodplain in a way reminiscent of historical conditions. Re-engaging the full extent of the historic floodplain will create a greater variety of available aquatic habitat that had previously been disconnected from the river system by incision. In combination with slower velocities, this will also create more slow water refugia for fish and other aquatic life.

- Large wood cycle would be jumpstarted, Riparian and floodplain forest health would increase with restorative actions (see vegetation technical findings section).
- The RFP increases lateral connectivity between the stream and its floodplain, which is critical to the transfer of water, sediment, organic matter, and nutrients (Tockner et al., 1999).
- With regards to carbon sequestration, Wohl et al. (2017) concluded that “reduction of lateral connectivity between the channel and riparian zone constitutes the most substantial change of carbon dynamics in river corridors” and that natural lateral connectivity supports the function of a river corridor as a carbon sink.

Overbank flows can be a major contributor to groundwater recharge, illustrated by the recharge estimated in Chapter 4. By increasing lateral connectivity and the frequency of overbank inundation, some portion of surface water is stored as groundwater, which has a much longer residence time in the floodplain. Stored groundwater, in turn, becomes a source for baseflow during the dry season. Several observational and modeling studies in California have demonstrated increases in baseflow ranging from 2 to >50% in reaches where restoration actions to raise the incised channel bed resulted in increased frequency of overbank inundation (Hammersmark et al., 2008; Hunt et al., 2018; Ohara et al., 2014; Tague et al., 2008). One study documented a decrease of baseflow locally, but an increase in baseflow downstream of the frequently inundated reach (Essaid and Hill, 2014). Increased groundwater recharge may have additional benefits to water quality. For example, Loheide and Gorelick (2006) quantified up to a 3°C depression in stream temperature from the increased subsurface residence time.

6.2 Conclusions

Assessment of the RFP approach to the North and South Fork Newaukum Rivers, along with the initial assessment of the approach throughout the Upper Chehalis Basin (Abbe et al. 2016) have provided information for better understanding the impacts of historic land development on river channel and floodplain changes, flooding and aquatic habitat. The work has also contributed valuable information specifically related to floodplain management and actions that can reduce flood hazard liabilities and dramatically improve aquatic and riparian habitat.

The three key elements and goals of the RFP are:

1) Help to move people and businesses located in flood and erosion hazard areas out of harm's way through buyouts and relocation to high ground. This permanently removes flood damage liabilities for everyone that is helped.
2) Reduce downstream flood stage by restoring natural floodplain functions which temporarily store and slow flood waters.
3) Restore critical aquatic and riparian habitat essential for salmonids and many other native species.

RFP Element #1

- The RFP assessment demonstrates there is abundant opportunity in southern Lewis County to relocate residents, agriculture and industry to high ground out of flood and erosion hazard areas. The high ground identified is situated on ancient terraces with level ground, good soils, and good drainage. Landowner interviews in the Newaukum Basin found interest and receptivity to the RFP.
- Erosion hazards are a major concern of local landowners in many parts of the Chehalis Basin. Delineation of erosion hazards in the South and North Fork Newaukum Valleys, as part of the RFP, are the only erosion assessments that have been done in the entire Chehalis Basin.
- The RFP approach relies on floodplain availability for flooding. It is important to ensure that it is feasible to use private property for restorative flood protection. This study found that there is abundant space and opportunity for helping people relocate out of the floodplain, if desired, which provides a permanent solution for flood damage reduction and protection and space for water to go. For example, this relocation analysis demonstrated that there are abundant opportunities to expand agriculture on the extensive high terraces of southern Lewis County adjoining the Newaukum River Valleys as well as creating flood friendly farms.
- Flood and erosion risk evaluations are either not accurate or non-existent in the Chehalis Basin. For example, our study found that there are areas flooding during a 100-year flood which are not mapped in the FEMA floodzone. Accurate hydrology inputs were also difficult to come by but, they are critical for developing accurate hydraulic models. Lastly, geomorphic assessments and channel migration zones have not been completed for a majority of the basin.

- The RFP approach has highlighted how historic landscape changes have resulted in habitat degradation and altered flood and erosion processes. Regional channel incision has reduced the extents and frequencies of flooding and triggered development of new "inset" floodplains that are actively widening. The rates of inset floodplain expansion are linked to the rates of bank erosion which are nearly twice as high in non-forested, pasture areas than forested areas.
- Widespread channel incision set in motion landscape changes that lead to development of lands that are not at elevated risk of erosion. Over the twentieth century, inset floodplains have developed below the original floodplain (circa 1850). Active channel migration continues to widen these inset floodplains which correspond to much of the historic channel migration zone (HMZ). Expansion of the inset floodplain/HMZ is a long-term process impacting the entire valley bottom and underscoring future erosion hazards.
- Larger flood events are predicted as our climate continues to warm. This will put residents at greater risk and underscore the need for helping them get out of harm's way.

RFP Element #2

- Using a standard 2D hydraulic model, the RFP approach in the South and North Fork River Valleys was not shown to be effective in attenuating large flood flows (100-year flood) downstream of treatment areas. This is primarily attributed to the prevalence of steeper valley slopes (>0.003 ft/ft). A more significant effect on downstream flood peak attenuation was observed in model runs of more frequent floods with flows less than the 10-year flood recurrence interval.
- The RFP approach does show significant attenuation benefits when implementing alluvial floodplain infiltration as a model variable and also when implemented in low gradient valleys (<0.003 ft/ft) and thus, has potential application elsewhere in the Chehalis Basin and Washington State.
- Using slope thresholds as guidance, an RFP approach at a smaller scale is likely to be an effective element of a flood attenuation strategy, that also contributes habitat, water quality, carbon sequestration and instream flow co-benefits.

RFP Element #3

- Aquatic species restoration is first and foremost dependent on available floodplain lands. Flood and erosion hazard areas are not suitable for human development but are ideal for aquatic species and fluvial ecosystems that directly benefit species throughout a watershed. For example, many large upland species, such as elk and deer, depend on floodplain resources and for moving around in basin. Buyouts and relocations open up critical areas for restoration and greatly reduce the cost of restoration that would otherwise have to implement flood and erosion protections to proceed.

- Incremental implementation of the RFP would be the most effective means of achieving the large scale goals of the Chehalis Aquatic Species Restoration Plan (ASRP).

Lessons learned from the RFP assessment offer valuable information on floodplain science and management that are applicable to many regions around Washington State, the United States and the world. Integrating elements of the RFP to local and regional planning, such as the Aquatic Species Restoration Plan (ASRP) and Community Flood Assistance and Resilience Program (CFAR) of the Chehalis Basin Strategy, can provide long-term benefits to human communities, river ecosystems and the larger state and national population by reducing flood hazard liabilities, improving water quality and quantity and restoring habitat for important aquatic species such as salmon.

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