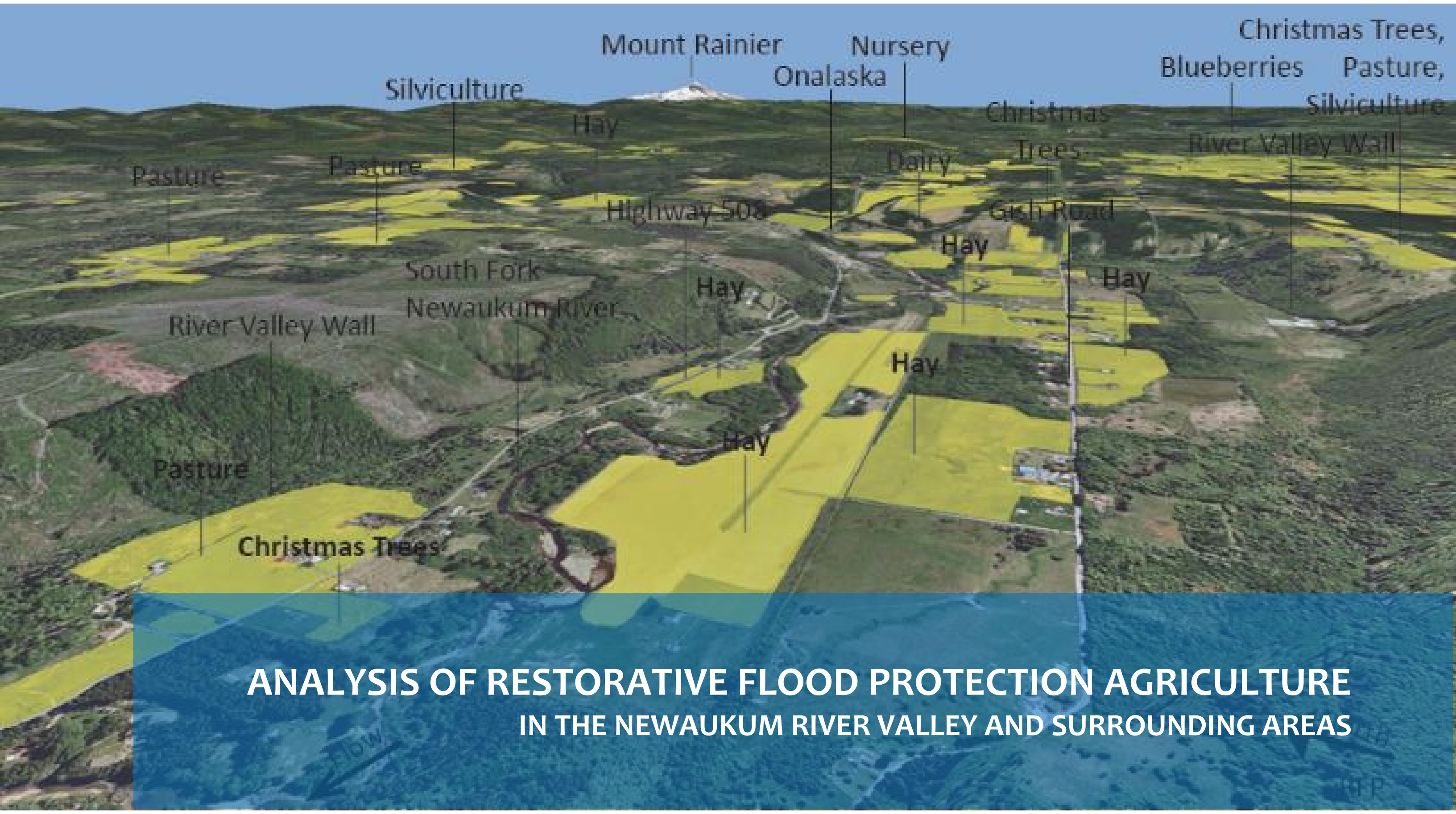
Appendix 4

Analysis Of Restorative Flood Protection Agriculture In The Newaukum River Valley And Surrounding Areas

Natural Systems Design

THIS PAGE INTENTIONALLY LEFT BLANK



ANALYSIS OF RESTORATIVE FLOOD PROTECTION AGRICULTURE

IN THE NEWAUKUM RIVER VALLEY AND SURROUNDING AREAS

DEPARTMENT OF ECOLOGY
State of Washington

Andrea McNamara Doyle
Director, Office of the Chehalis Basin
Department of Ecology
andrea.doyle@ecy.wa.gov

Natural Systems Design

1900 N. Northlake Way, Suite 211
Seattle, WA 98103

THIS PAGE INTENTIONALLY LEFT BLANK

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

This study was conducted in support of the Chehalis Basin Strategy Restorative Flood Protection Analysis. The focus of this study was on agriculture within the Newaukum River Valley, and the surrounding areas. The primary goal of the Restorative Flood Protection (RFP) approach is to create flood resilient communities and economies that also enhance native ecosystems that support fish and wildlife and contribute to a high quality of life. The Restorative Flood Protection approach is based on a voluntary program with three basic elements: 1) move people and businesses out of harm's way to areas safe from flooding and erosion, 2) provide floodproofing assistance to protect residences and support agricultural operations well suited to occasional flooding and 3) reduce downstream flood peaks by restoring natural floodplain functions that slow and store flood waters. With regards to 1) above, landowners who wish to participate can either choose a buyout, a conservation easement, or relocation. Since one of the goals of the RFP is enhancing local community and economy, it was assumed relocation alternatives would remain within the local area of Lewis County. To evaluate the feasibility of such alternatives, this study focused on southern Lewis County in close proximity to the Newaukum River watershed, where a pilot RFP feasibility assessment was recently completed (NSD, June 2019). The analysis presented here focuses on two questions linked to the first two elements above:

1) Are there upland areas that are equal or better than floodplain areas?
2) Are there farming alternatives for flood prone land?

Broad, flat river valleys have provided fertile soil for farming since the origin of agriculture. But the natural processes that created these valleys pose significant risks to people, property and infrastructure. Floodplain farms are periodically subjected to damages by flooding or erosion. Suitable physical conditions for productive agriculture operations can also be found in many areas not subjected to flood hazards. For example, there are large areas of relatively level, high, flat terraces in southern Lewis County which have diverse and productive farms that are not subjected to the same flood and erosion hazards that farms in river floodplains, such as the South Fork Newaukum River, experience (Figure 1).

This analysis includes a geomorphic description of the landscape, differentiating landforms such as river valleys, hillslopes and upland terraces. It also includes an examination of factors that influence both geomorphic processes and agricultural operations such as slope of the land, soil conditions, vegetative cover and drainage. The analysis also examines the types of agriculture currently found on different landforms. We were particularly interested in understanding the limitations of farming associated with the dominant landforms of the study area. The analysis also investigates agricultural operations that are best able to accommodate periodic flooding.

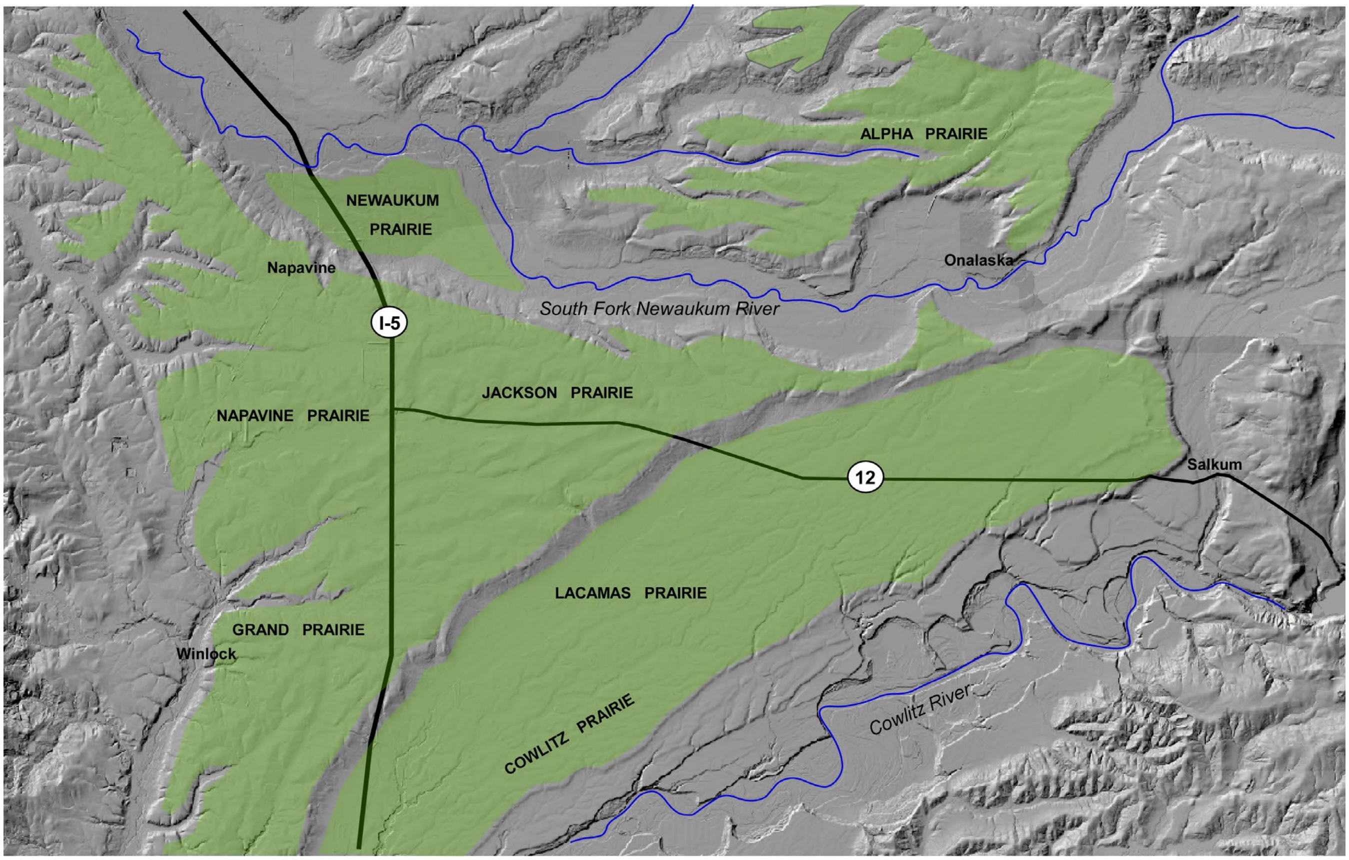


Figure 1. Example of large areas of relatively level, high, flat terraces in southern Lewis County, shown in green, illustrating that much of this area is comprised of low-relief plateaus or terraces associated with local "prairies". Terraces have relatively level ground and are productive agricultural areas, which are not subjected to flood or erosion hazards.

The analysis is organized into four sections. First, the project study approach is presented (Section 1). Second, specific agricultural operations that make use of upland terraces are presented and characterized (Section 2). Third, farming practices and risks in floodplains are compared with upland agricultural practices (Section 3). Fourth, resilient agricultural systems with potential applications both within and outside of the floodplain are described (Section 4).

While conditions in this study area are in some ways specific to this region of Lewis County, the overall findings are applicable to other flood-prone areas of the Chehalis Basin and Western Washington and can be of use to farmers, ranchers, land managers, and planners throughout the west side region.

Within the study area, the floodplain domain was defined as the Federal Emergency Management Agency's (FEMA) 100-year floodplain. The non-floodplain domain consists of all lands within the study area outside of this floodplain. Detailed maps for analysis domains are included in the relevant narrative sections.

1.1 Approach

The analysis focused on physical landscape data, flood studies, landuse data, visual observations from ground reconnaissance and aerial images. We compiled available literature, data on soils, topography, flooding, erosion and known agricultural operations for the study area and whether they were located in flood prone or upland areas. Specifically, public datasets pertaining to soil type, drainage capacity, and soil depth; current crop production, land slope and topography, along with the Washington State Department of Agriculture (WSDA) database of agricultural acreage and crop production. Data analysis was conducted using ESRI's ArcGIS and R statistical analysis software. The analysis examined the relationship between agriculture and the landscape, particularly differences in agriculture within floodplains and uplands along with principal challenges associated with the different landforms.

To assess challenges and risks farmers face in flood-prone areas, interviews were conducted with fourteen agriculture experts and floodplain farmers regarding the specific risks and costs associated with farming in flood-prone areas. These interviews were supplemented with a literature review focused on floodplain agriculture in Western Washington. The following questions guided the interview and literature review process:

What are the risks associated with farming in flood-prone areas?

What are farmers doing to deal with periodic high water?

What opportunities exist in nearby locations outside of the flood risk zone?

How do soil and terrain conditions compare between floodplain and non-floodplain areas?

What does current agricultural production, in terms of crop type and its location, tell us about flood risk and opportunity?

What systems might growers use to cope with high water?

The following local experts were interviewed:

- Bill Blake - Skagit Conservation District
- Ryan Williams – Snohomish Conservation District
- Michael Kirshenbaum – Skagit Land Trust
- Don McMoran – Ex Dir. Skagit County WSU Ag. Ext.
- Kate Ryan – Snohomish County Conservation District
- Jordan Jobe – WSU, Farming in the Floodplain
- Cynthia Grass – SnoValley Preservation Alliance
- Cindy Dittbrenner – Snohomish Conservation District
- Bobbi Lindemulder – Snohomish Conservation District
- Bob Aldrich – Formerly with Snohomish Conservation District
- Linda Nuenzig, Snohomish County Agricultural Coord. Forterra N. Sound Reg. Leadership Council
- Stephen Bramwell, Ex. Dir. Thurston Co. WSU Agricultural Extension
- Patrick Shults, South West Washington WSU Agricultural Extension Agro-forester
- Dr. Bob Norton, Ret. WSU Ag. Extension, Mount Vernon

1.2 Summary

Our results clearly show that upland areas outside of floodplains provide significant opportunities for agricultural use with substantially reduced risk to flooding and erosion. Geographic features such as upland terrace prairies sustain soil with comparable depth to nearby floodplains and, on-average, better drainage. Interviews with local experts describe a demonstrated agricultural base in upland areas with land availability for additional agriculture. These uplands do not have the risks and uncertainties inherent with production in flood-prone valleys. Agriculture expansion in Lewis County would entail either conversion of managed forests or agricultural conversions to more intensive crops such as converting hay to vegetables or fruit orchards. Interviews and literature also document a number of resilient agricultural strategies available to farming constrained to flood prone areas.

2. CASE STUDIES: AGRICULTURE OPERATING OUTSIDE OF FLOOD-PRONE AREAS

Much of the agriculture in the Chehalis – Newaukum River floodplains centers on pasture or hay farming. Land gradient, soil type, drainage capacity and water supply strongly dictate where agriculture is feasible throughout the Chehalis – Newaukum area of southern Lewis County. Accessibility and proximity to infrastructure and other farmers also factor into land use patterns. While pasture and hay dominate agriculture in floodplain areas, there is a diverse range of agricultural operations outside of river valleys. The relatively level ground and deep soils found on high terrace "prairie" areas is conducive to a wide range of agriculture including dairies, chickens, hay, vegetables, grains, fruits, flowers, and livestock. Even hillslopes support livestock (cattle, goats, sheep and horses) pasturing and fruit/nut tree orchards.

The purpose of this section is to highlight existing agricultural operations in SW Washington State that are located in representative landscapes of the Chehalis and Newaukum River basins above flood prone elevations. The examples cited in this analysis span a range of agricultural activity types, as well as landscape terrain positions.

Existing agricultural operations in areas surrounding the Newaukum basin were identified using aerial imagery. These sites were then screened against available LiDAR (WA-DNR) to prioritize locations that are above their respective floodplain. Elevations of each location were recorded along with the relative elevation above the neighboring floodplain.

Sites that met these criteria (outside of floodplain) were identified in the Washington State Department of Revenue database of active businesses to verify that the operation was active. Where possible, the type of business was noted. Finally, soil data was gathered for each operation using the USDA-NRCS Web Soil Survey tool.

Topographic features recorded included GPS position, elevation, relative elevation above neighboring floodplain, and ground slope (average). Soil characteristics used include dominant soil type, drainage capacity, farmland classification, and whether or not predominant soils were hydric.

2.1 Map and Table of Upland Agriculture Examples and Case Studies

Four examples of successful upland agriculture are presented in the following sections. However, there are other agricultural operations in the area that are situated out of river valleys, including vegetable farms, fruit and nut tree nurseries, a tulip producer, blueberry farms, tree farms, and pasture land (Figure 2). Collectively, these upland operations represent a diverse suite of land use practices that illustrate agricultural development in varied landscapes outside of floodplains. This case study is not intended to assert that several farms located on hillslopes and uplands conclusively demonstrate the primacy of upland agriculture. Rather, it demonstrates that a diverse array of upland agricultural projects exists and are successfully operating in the Newaukum and Chehalis Basins.

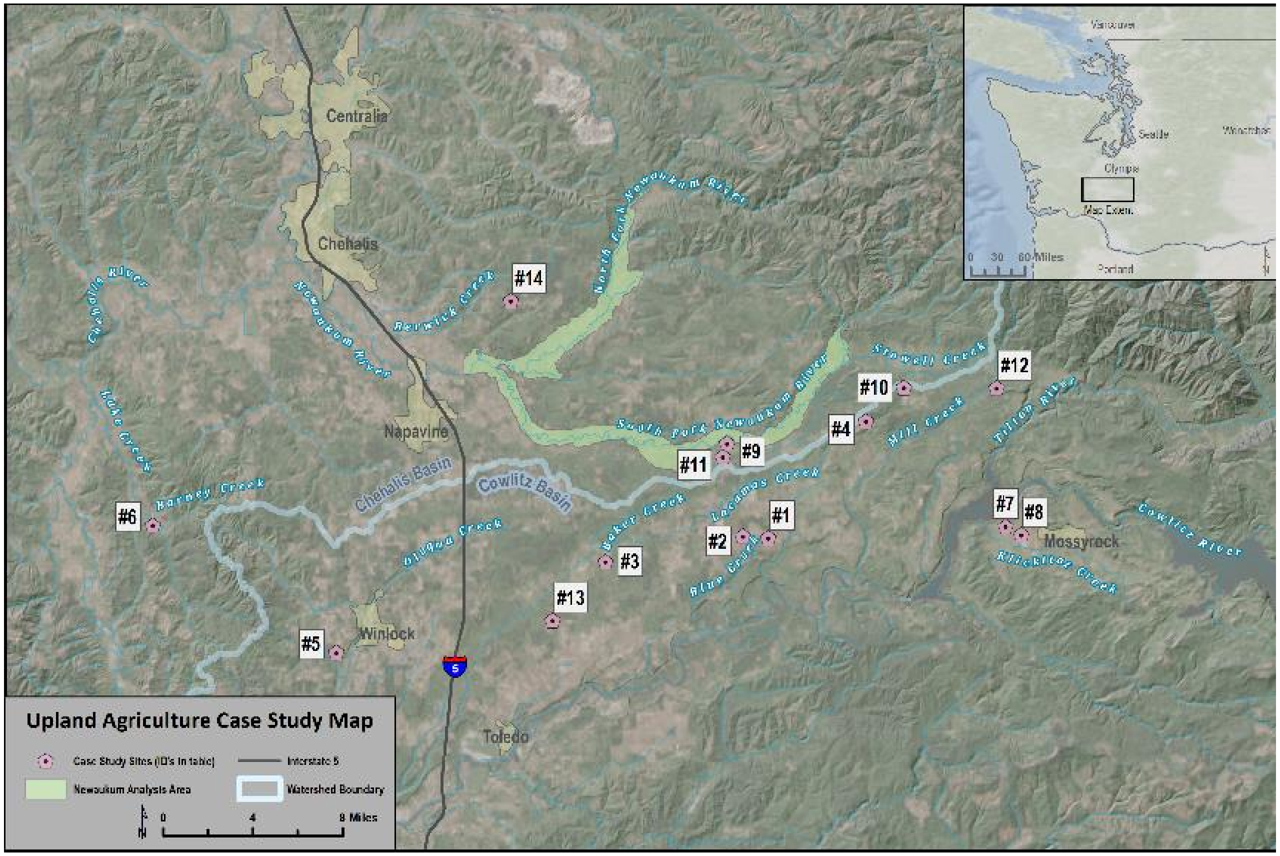


Figure 2. Examples of agricultural operations outside of the river valley floodplains in and around the Upper Chehalis Basin, see Error! Reference source not found. **for detailed descriptions of each farm.**

Table 1. Select examples of upland agriculture in the vicinity of the Newaukum River valley, in the Chehalis River and Cowlitz River watersheds.

MAP # (CASE STUDY #)	WSDA FARM TYPE & NOTES	LATITUDE, LONGITUDE	ELEVATION (FT)	RELATIVE ELEVATION* (FT)	GROUND SLOPE (%)	USDA NRCS SOIL TYPE	USDA NRCS FARMLAND SOIL CLASSIFI-CATION	USDA NRCS DRAINAGE CLASSIFI-CATION	USDA NRCS SOIL DRAINAGE RATE	USDA NRCA SOIL HYDRIC (YES OR NO)
1	Vegetable Farm	46.535°, -122.679°	583	391	1.6%	Salkum silty clay loam	Prime farmland	well drained	Moderately high (0.20 to 0.57 in/hr.)	No
2	Vegetable Farm	46.531°, -122.695°	554	362	1.125%	Salkum silty clay loam	Prime farmland	well drained	Moderately high (0.20 to 0.57 in/hr.)	No
3	Vegetable Farm	46.521°, -122.786°	393	261	0-3%	Lacamas silt loam	Prime farmland if drained	poorly drained	Very low (0.00 in/hr.)	Yes
4 **(Case Study #3)**	Burnt Ridge Nursery and Orchards. Since 1980. Fruit, nut, natives, ornamentals.	46.582°, -122.617°	960	200	8-15%	Cinebar silt loam	Farmland of statewide importance	well drained	Moderately high to high (0.57 to 1.98 in/hr.)	No
5	Vegetable Farm	46.479°, -122.960	440	176	0-5%	Salkum silty clay loam	Prime farmland	well drained	Moderately high (0.20 to 0.57 in/hr.)	No

MAP # (CASE STUDY #)	WSDA FARM TYPE & NOTES	LATITUDE, LONGITUDE	ELEVATION (FT)	RELATIVE ELEVATION* (FT)	GROUND SLOPE (%)	USDA NRCS SOIL TYPE	USDA NRCS FARMLAND SOIL CLASSIFI-CATION	USDA NRCS DRAINAGE CLASSIFI-CATION	USDA NRCS SOIL DRAINAGE RATE	USDA NRCA SOIL HYDRIC (YES OR NO)
6 **(Case Study #1)**	Pasture. 1990-2005	46.539°, -123.079 °	368	83	8-15%, 30-65%	(1,2) Melbourne loam, (1) Mal clay loam, (3) Reed silty clay loam	Farmland of statewide importance	(1,2) well drained	Moderately high (0.20 to 0.57 in/hr.)	Partially
7	Blueberry Farm. Pan American Berry Growers	46.535°, -122.528°	586	159	0.52%	Mossyrock silt loam	Prime farmland	well drained	Moderately high to high (0.57 to 1.98 in/hr.)	No
8	Tulip Farm. Degoede Bulb Farm & Gardens	46.531°, -122.516	592	165	0.75%	Mossyrock silt loam	Prime farmland	well drained	Moderately high to high (0.57 to 1.98 in/hr.)	No
9	Dairy Farm and Pasture. Terrace south of SF Newaukum, pasture on	46.571°, -122.705°	555	55	0-5%	Lacamas silt loam, Salkum silty clay loam	Prime farmland if drained, prime farmland	poorly drained, well drained	Very low (0.00 in/hr.), Moderately high (0.20 to 0.57 in/hr.)	Partially

MAP # (CASE STUDY #)	WSDA FARM TYPE & NOTES	LATITUDE, LONGITUDE	ELEVATION (FT)	RELATIVE ELEVATION* (FT)	GROUND SLOPE (%)	USDA NRCS SOIL TYPE	USDA NRCS FARMLAND SOIL CLASSIFI-CATION	USDA NRCS DRAINAGE CLASSIFI-CATION	USDA NRCS SOIL DRAINAGE RATE	USDA NRCA SOIL HYDRIC (YES OR NO)
	ground as high as 597'									
10 **(Case Study #2)**	Dairy Farm. Fire Mountain Farm, Burnt Ridge, Cattle, hay, grain, timber, biosolids recycling	46.596°, -122.593°	1111	371	0-8%	Cinebar silt loam	Prime farmland	well drained	Moderately high to high (0.57 to 1.98 in/hr.)	No
11	Tree Farm.	46.566°, -122.709°	657	182	0-15%	Salkum silty clay loam, Lacamas-Scamman complex	Prime farmland	well drained	Moderately high (0.20 to 0.57 in/hr.)	No
12	Shoestring Valley Nursery	46.596°, -122.533°	846	16	0-8%	Cinebar silt loam	Prime farmland	well drained	Moderately high to high (0.57 to 1.98 in/hr.)	No

MAP # (CASE STUDY #)	WSDA FARM TYPE & NOTES	LATITUDE, LONGITUDE	ELEVATION (FT)	RELATIVE ELEVATION* (FT)	GROUND SLOPE (%)	USDA NRCS SOIL TYPE	USDA NRCS FARMLAND SOIL CLASSIFI-CATION	USDA NRCS DRAINAGE CLASSIFI-CATION	USDA NRCS SOIL DRAINAGE RATE	USDA NRCA SOIL HYDRIC (YES OR NO)
13 **(Case Study #4)**	Mill Creek Farms, 1990-2005, Finished beef, hay	46.493°, -122.820°	350	237	0-3%	Lacamas silt loam	Prime farmland if drained	poorly drained	Very low (0.00 in/hr.)	Yes
14	Logan Hill Tree Farm	46.635°, -122.846°	556	151	0-5%	Prather silty clay loam	Prime farmland	Moderately well drained	Moderately low to moderately high (0.06 to 0.20 in/hr.)	No

*Relative elevation is defined as height above the nearest creek bed or river valley.

2.2 Case Study #1: Lake Creek Farm

Lake Creek Farm is a cattle operation where calves are brought in during the Spring and fattened on pastures for sale in the Fall. The farm is located along Lake Creek which flows into the South Fork Chehalis River. It is located about 10 miles directly west of the intersection of State Route 12 and Interstate 5. The farm is located in a topographically heterogeneous area with diverse soil conditions. Ranch operations include both valley bottom and hillslope areas. Soil types include: Melbourne loam, Mal clay loam, and Reed silty clay loam which range from well drained to hydric, respectively. The farm spans a valley bottom and rises up both valley walls encompassing mostly open land with some forested riparian areas. Much of its open land was recently forested. Conversion from forest to pasture began in the mid 1990's and continued up until about 2005. Elevations range from approximately 280 feet to 515 feet above sea level. Areas 1 and 2 in Figure 2 are over 50 feet above the valley bottom and have slopes up to 65%. This landscape is significantly different than the flat valley bottom, Area 3, but is still viable for cattle grazing. See **Error! Reference source not found.**, location #6, for farm context and relative location.

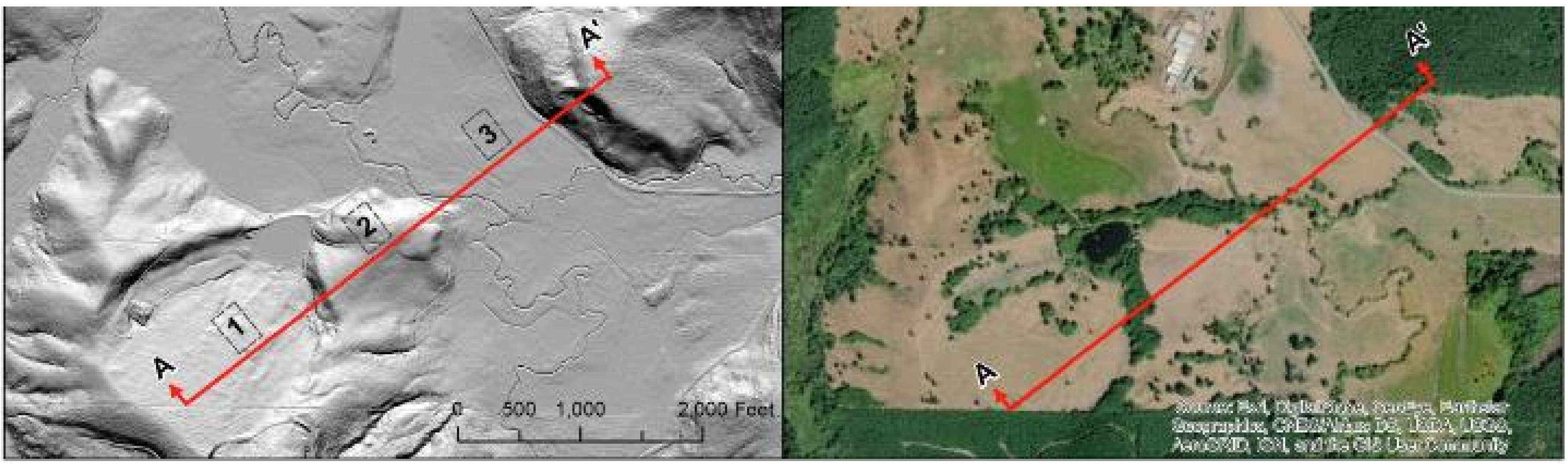


Figure 3. Lake Creek beef fattening pasture operation: topographic hillshade (left) and aerial image (right). The southwest portion of the images (Areas 1 & 2) are hillslopes where forest clearing in the 1990s was done to expand pasture. Pasture on hillslopes north of A on westside of valley were also cleared for pasture in the 1990s. Hillslope pastures offer improved drainage. Valley bottoms have large wetland areas difficult to graze livestock. Shaded relief from 2006 LiDAR. Photo on right is July 2018.

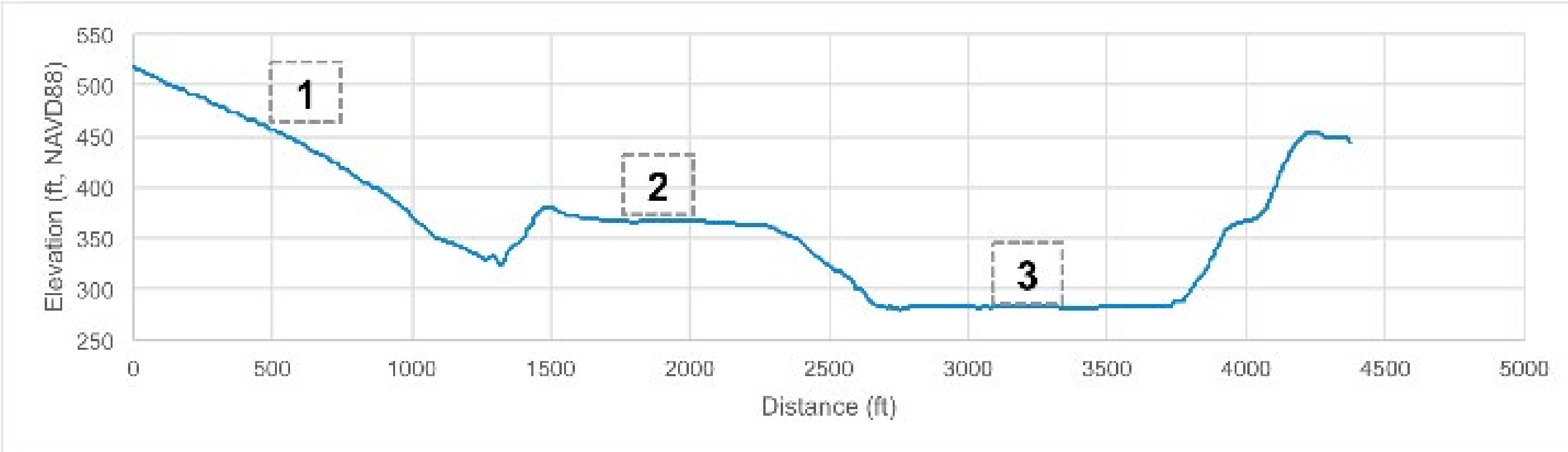


Figure 4. Cross-section A-A' across Lake Creek pasture, showing Areas 1, 2, 3 in Figure 3. Areas 1 and 2 are hillslope pasture and Area 3 is valley bottom pasture.

2.3 Case Study #2: Fire Mountain Farm

Fire Mountain Farm, located on upland areas of Burnt Ridge, raises cattle, produces hay, grain, and timber, and serves as a regional bio-solids recycling facility. The farm sits in a cleared parcel on flat land 300 feet above and adjacent to the floodplain of Stowell Creek to the north (Figures 4 and 5). The practice of upland forest conversion to productive farmland is typical within the Chehalis and Newaukum basins. Clearing land out of the floodplain allows for agricultural development without the risk of property loss and damage through flooding. This property has an average slope of 4%. In the same area, east of B' at northeast quadrant of images is a chicken farm that developed in the 1990s. See **Error! Reference source not found.**, location #10, for farm context and relative location.

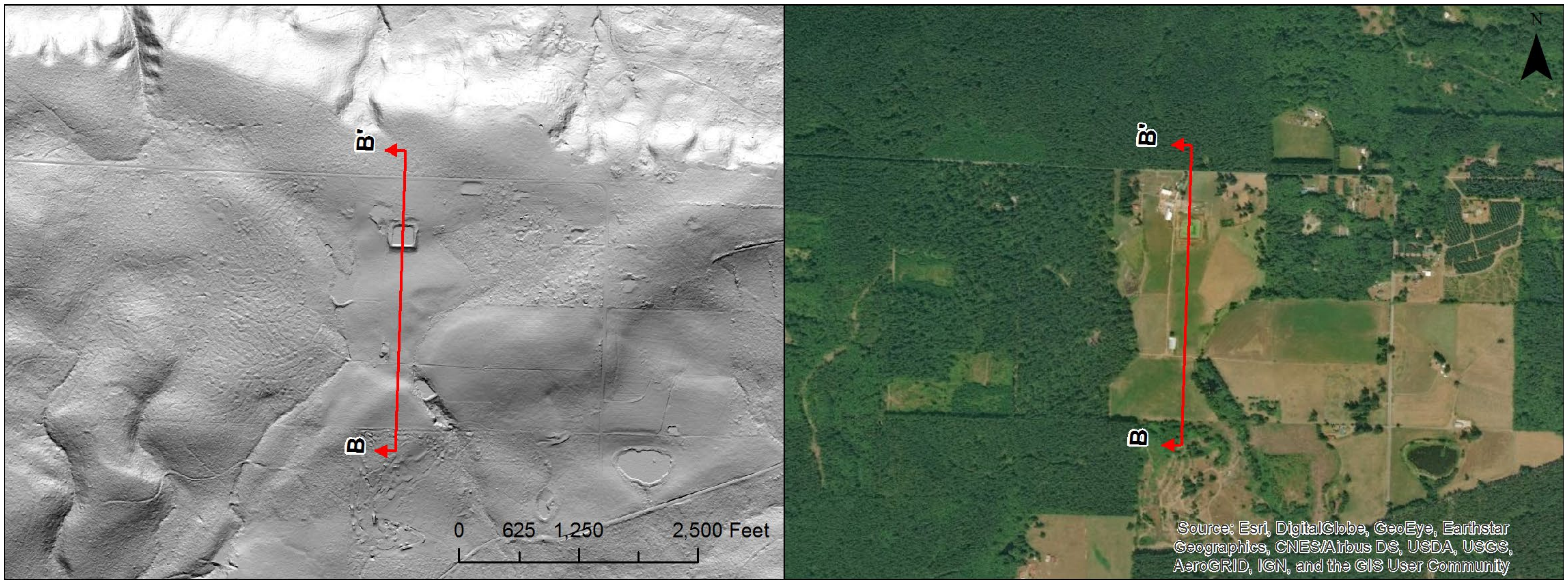


Figure 5. Fire Mountain Farm; topographic hillshade (left) and aerial image (right).

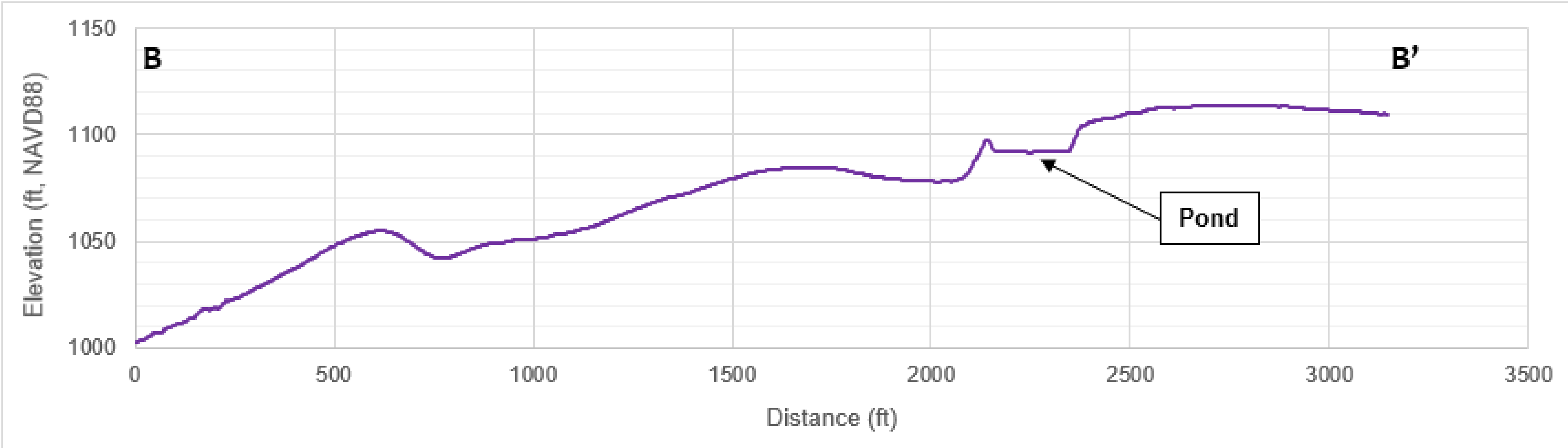


Figure 6. Cross-section B-B' across Fire Mountain Farm.

2.4 Case Study #3: Burnt Ridge Nursery

Burnt Ridge Nursery is located near Fire Mountain Farm on sloping ground atop the Burnt Ridge plateau (shown in Figure 7 and Figure 8). The property is located about 4.8 miles due east of Onalaska and 3.5 miles north of Salkum. The soil is well-drained Cinebar silt loam, with a steeper ground slope (7.9%) than Fire Mountain Farm (4%). Burnt Ridge Nursery supports a completely different suite of agricultural practices from nearby Fire Mountain Farm. This upland nursery grows exclusively trees, including orchards of fruit and nut trees, as well as native and ornamental trees. See **Error! Reference source not found.**, location #4, for farm context and relative location.

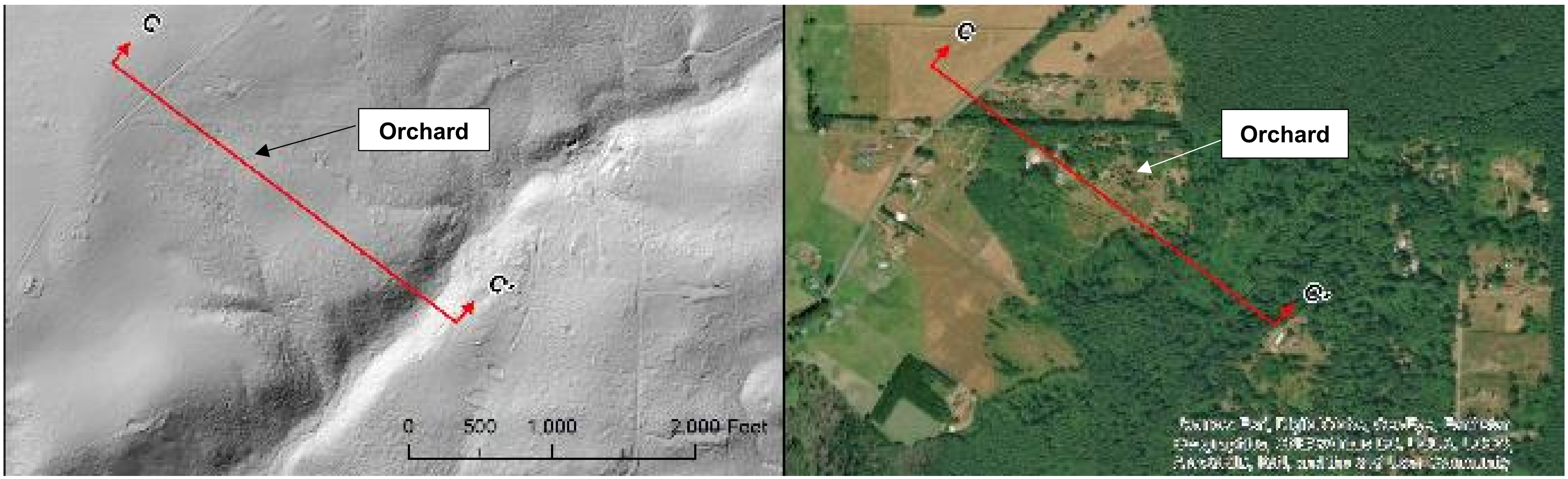


Figure 7. Burnt Ridge Nursery; topographic hillshade (left) and aerial image (right). In the 1990s, additional forest was converted to a tree orchard immediately north of the orchard depicted above.

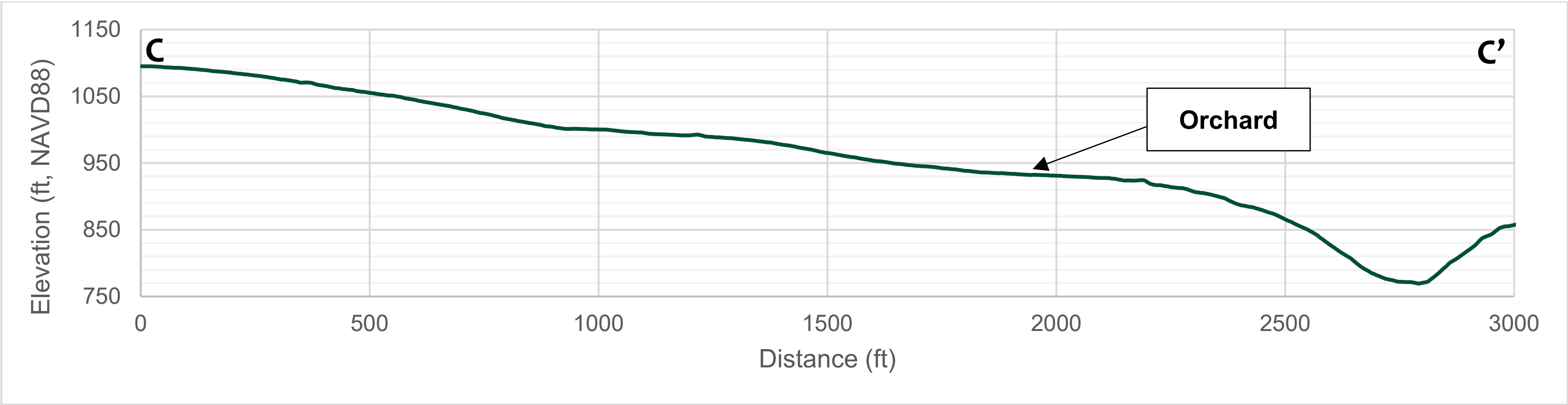


Figure 8. Cross-section C-C' across Burnt Ridge Nursery.

2.5 Case Study #4: Mill Creek Farms

Mill Creek Farms is located in southern Lewis County off the Jackson Highway. The farm lies on a relatively level terrace 240 ft above the Cowlitz River floodplain with Lacamas silt loam soils, classified as hydric and poorly draining. The farm appears to be a chicken farm with a large hay operation. This is an example of property that would be considered prime farmland if drained. Between 1990 and 2005, Mill Creek Farms was cleared of its forest for agricultural production. Figure 8 shows a progression of land conversion. From 1990 to 2005, approximately 60 acres of forest land was cleared on parcel 1. From 2005 to 2011, approximately 25 acres were cleared on parcel 2, followed by an additional 15 acres between 2011 and present. This effective forest to agricultural land cover conversion illustrates conversion of managed forest land to agricultural use. Within a radius of 1.7 miles of Mill Creek Farms, there are three other chicken farms and many more in southern Lewis County, most of which developed since 1990. See **Error! Reference source not found.**, location #13, for farm context and relative location.

Figure 9. Aerial photographs of Mill Creek Farms parcels 1 and 2 (1990, 2005, 2011, 2018), Google.

3. THE AVAILABILITY OF ARABLE LAND OUTSIDE OF THE FLOODPLAIN

This analysis was conducted to characterize the availability of farmland outside of the floodplain. The study area for this analysis was much larger than the Newaukum River Restorative Flood Protection feasibility analysis area, which was the main focus of this project. The larger study area helped to determine whether the local landscape outside of the floodplain could provide capacity to accommodate new farms for owners who may elect to be relocated outside of the floodplain as a potential element of the Chehalis Basin Strategy.

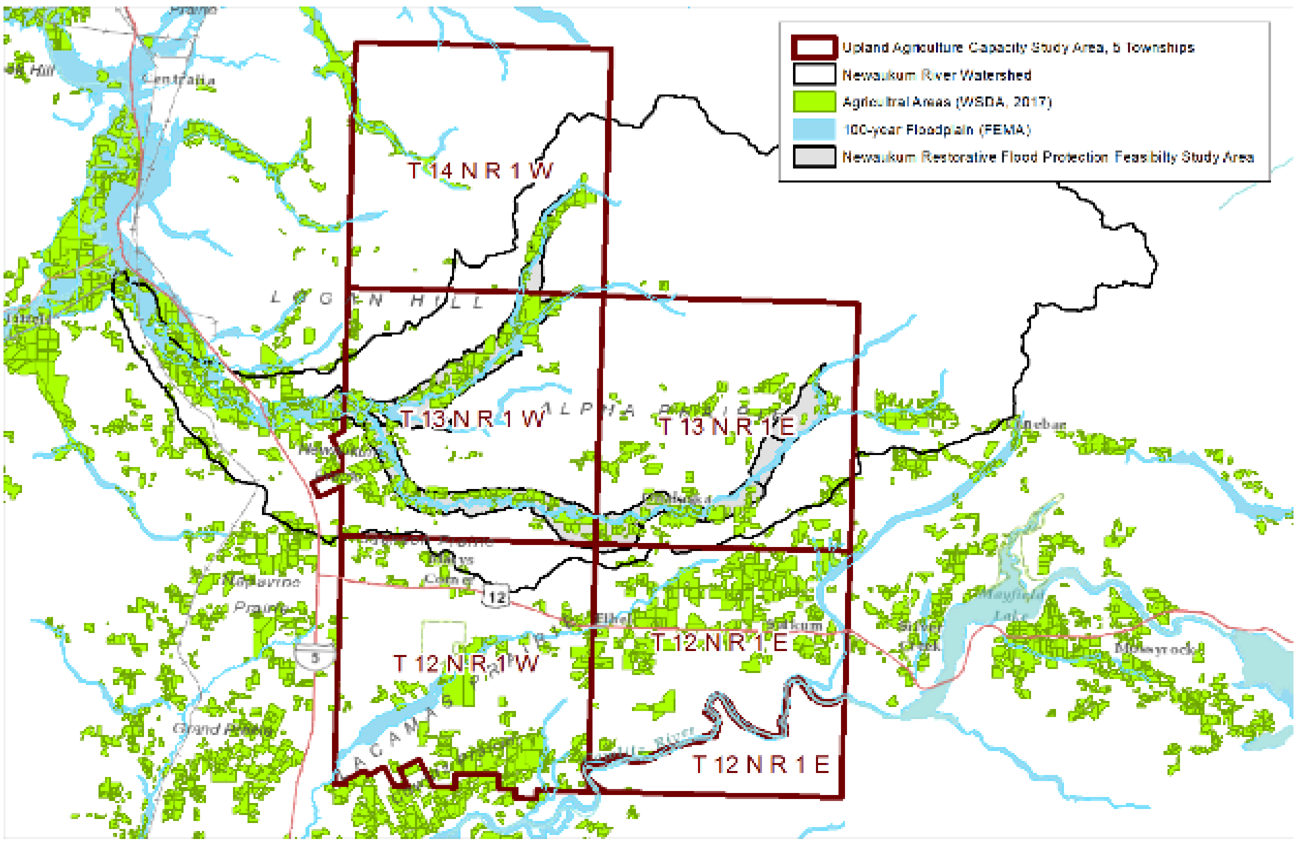


Figure 10. Floodplain and upland agricultural land use study area comprised of five townships. Three townships cover the Newaukum River Restorative Flood Protection analysis area and two townships cover areas to the south, creating a large analysis area, covering a total of 180 square miles of land.

Specifically, the broader study area was made up of five land survey townships that encompass the Newaukum River Valley from I-5 in the west, up and into the foothills in the east, southward to the agricultural districts of the Jackson Prairie (centered around SR 12 just east of I-5) and the areas surrounding Ethel, Salkum, and Mossyrock, and northward up to and including the North Fork of the Newaukum River. There are high concentrations of dairy, chicken, equestrian and grain farms near Salkum. There is also very productive blueberry, tulip and chicken production in the Mossyrock area.

3.1 Agricultural Lands Analysis

To assemble a picture of agriculture in the study area, data was collected from: the Washington State Department of Agriculture (WSDA), the Federal Emergency Management Agency (FEMA), and the National Resource Conservation Service (NRCS) along with contemporary and historical aerial imagery. The entire study area was then categorized as within or not within a floodplain (FEMA). Within each category, acreage farmed and crop composition was evaluated (WSDA), along with soil type, depth, drainage characteristics and slope angle (USDA NRCS Soil Survey Staff, Accessed May 2016). The data categorizations and analysis allow for a comprehensive comparison of floodplain and upland farmland in the study area.

To validate the assumption that the WSDA database represents the entire extent of agricultural production in the study area, aerial imagery was evaluated for potential blind spots in the dataset. While it appears that some active pastureland is not represented, this land is an inconsequential fraction of total farmland, validating the WSDA as a source for comprehensive agricultural data. The WSDA dataset does not, however, include timber lands in the Designated Forest Lands program. Given the systematic differences in management between timber lands and other categories of agricultural land – especially rotation frequency – timberland was not considered in this analysis.

3.2 Current Agricultural Use of Flat, Well-Drained Lands–Inside and Outside of the Floodplain

The entire study area covered 180 square miles - 114,397 acres. Within this area, about 13,880 acres, or 12% percent of the land was in agricultural production. The FEMA 100-year floodplain occupies 4,899 acres, 4%, of the total study area. As of 2017, 17%, or 833 acres of this floodplain acreage were in agricultural production. Areas outside of the FEMA 100-year floodplain occupy 95.7% of the study area or 109,499 acres. Within this area, 12% of the land, 13,059 acres, is currently in agricultural production. This represented a slightly reduced percent utilization relative to floodplain agriculture but a vastly greater total area.

3.2.1 *Flat, Well-Drained Land*

Low gradient land is widely preferred for farming because it is easier to work and erosion is less of a concern. A threshold slope of 3% or less was used to identify flat lands inside and outside of the floodplain. Within the study area, 58% of the land has a surface slope of 3% or less (see Figure 11). Within the floodplain, 88% of land has a slope less than 3%. Outside of the floodplain, 57% of land has a slope of 3% or less. However, due to the vastly larger total area outside of the floodplain, 96% of all low gradient land in the study area is outside of the floodplain. Currently, 17% of the low-gradient acreage within the floodplain is farmed. This percentage is nearly the same (18%) outside of the floodplain. In both zones, the majority of low gradient land is not farmed.

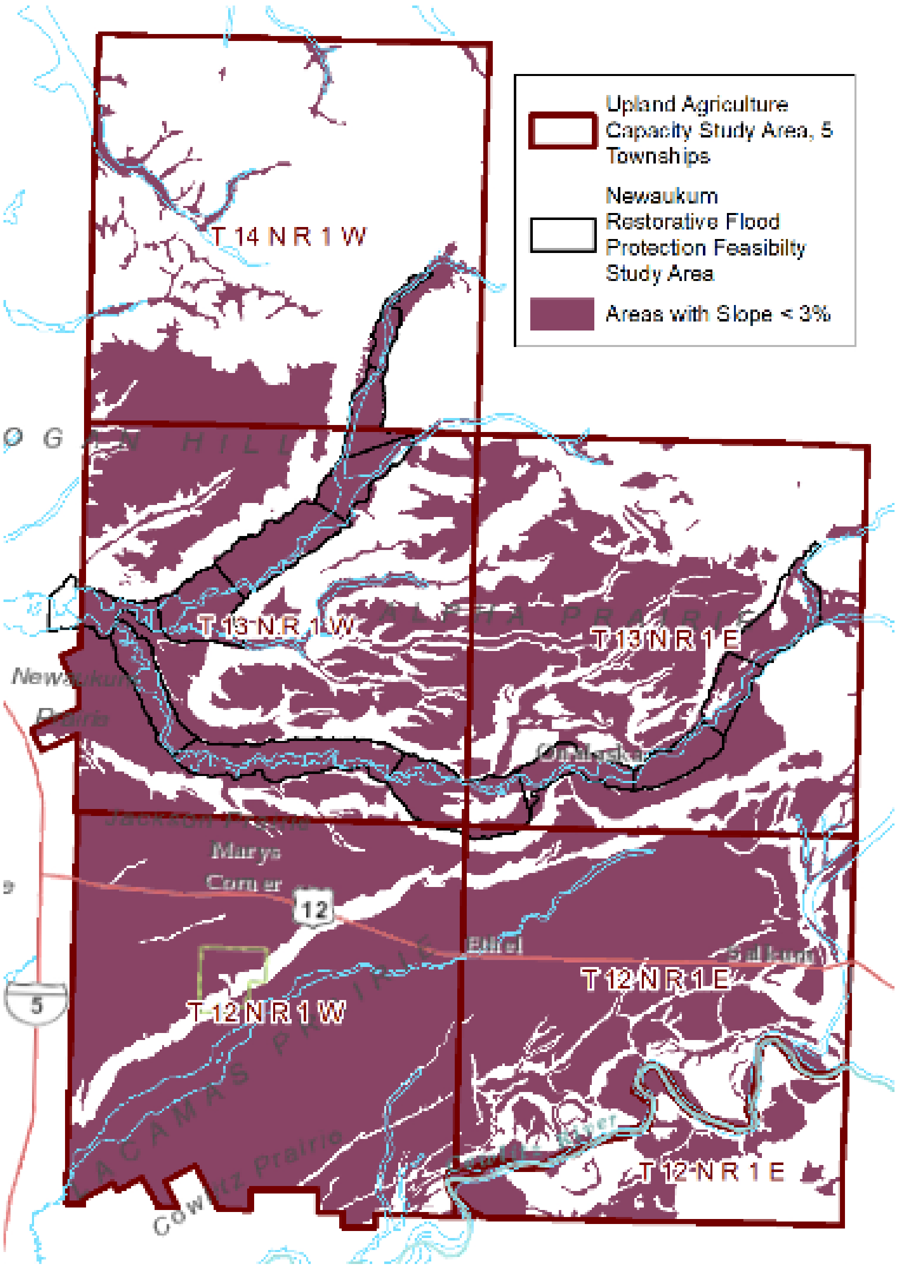


Figure 11. Flatland, or areas with slopes less than 3%, in and around the Newaukum Restorative Flood Protection feasibility analysis area.

Across the entire study area, 65% of agriculture occurs on soils that are moderately well- or well-drained. Within the floodplain, 41% of low gradient soils are well- or moderately well-drained. Outside of the floodplain, 65% of low gradient soils are well- or moderately well-drained. Considering only land that is in agricultural production, 67% of land outside of the floodplain occurs on soil that is well- to moderately well-drained, while 39% of farm land within the floodplain is well- to moderately well-drained. Soil depth does not appear to significantly diverge between floodplain and upland areas, almost all soils within the study area are classified as very deep, or more than 60 inches.

3.2.2 *Crop Composition*

Within the floodplain, crop production is primarily comprised of hay/silage or "other". Silviculture, likely Christmas tree production, occupies 8 acres or just over 1%, according to WSDA data. The diversity of crops grown outside of the floodplain is significantly greater (see table).

Table 2. Results from analysis of agricultural land use on shallowly sloped terrain (areas with <3% slope) inside and outside of the 100-year FEMA floodplain boundary for a 5 square mile study area in and around the Newaukum River valley. In this area, 66,787 acres had a slope gradient less than 3%.

AGRICULTURE TYPE (WSDA 2017)	FLOODPLAIN ACRES	NON-FLOODPLAIN ACRES
Other	398	4,712
Hay/Silage	325	4,664
Commercial Tree	8	1,200
Cereal Grain	4	818
Vegetable	--	105
Berry	--	31
Nursery	--	13
Orchard	--	3
Vineyard	--	3
Not-farmed	3,562	50,942
Total area	**4,297**	**62,491**

Upland opportunities in the region far exceed those in flood prone areas. Currently, farming occupies 735 acres (17%) of the 4,297 acres of floodplain land in the study area. Farming occupies 11,549 acres (18%) of the 62,491 acres of upland areas. These numbers indicate there is more than enough capacity to relocate flood prone farmers to more productive and safer areas within Lewis County.

3.3 Summary of the Availability of Arable Land Outside of the Floodplain

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 in general flatter than uplands. Upland soil is generally better drained than floodplains. The greatest difference between the two land categories is in abundance. There is simply much more land in upland settings than in floodplains. As a function of this, there is more low-angle land, more well drained land, and more diversely planted land in uplands than there is 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 are likely 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. The table below summarizes some of the characteristics of agriculture within and outside of the floodplain.

Table 3. Summary of risks and benefits of farming within and outside of the Newaukum River floodplain.

PARAMETER	NEWAUKUM FLOODPLAIN AGRICULTURE	NEARBY AGRICULTURE OUTSIDE OF THE FLOODPLAIN (UPLANDS)
Soil Drainage	Poor	Moderate to Good
Soil Depth	Good	Good
Land Slope	Level to gentle sloping	Level to moderately sloping
Land Base Size	Small	Large
Regulatory complexity	Challenging	Easy to moderate
Risk of flooding	High	None
Market insecurity	Concerns due to flood damages	Minor

3.3.1 *Consistency with National & Local Flood Protection Strategies, Science and Economics*

Moving people out of harm's way provides permanent protection from flooding. Research examining catastrophic flooding in 16 countries shows that flood fatalities and economic losses correlate with human proximity to rivers, noting that in societies which chose resettlement out of flood hazard areas there were reduced flood impacts (Mård et al., 2018). It is important to note that relocation of agriculture to appropriate safe upland areas is consistent with larger national and state policy goals:

- The National Flood Insurance Program (NFIP) goals to reduce flood damages and claims. Buyouts and relocation are core parts of floodplain management in the United States (National Academies of Sciences, 2019). The NFIP funds 75% of buyouts and relocation out of floodplains for chronically impacted areas. In Washington State, a Comprehensive Flood Hazard Management Plan (CFHMP) must be completed and adopted by local authority to receive Flood Control Assistance Account Program (FCAAP) flood damage reduction project funds.
- The USDA Natural Resources Conservation Service funds floodplain easements through their Emergency Watershed Protection Program.
- At the state level, the Chehalis Strategy has dual goals to both:

- To restore fluvial processes and to restore fish and wildlife habitat within floodplain corridor, which requires large areas of floodplain be reforested and accommodation of natural river processes such as channel migration, in an Aquatic Species Restoration Plan (ASRP)
- To provide communities with improved flood protection, which may include a variety of land acquisition and flood protection actions. This is the focus of this study and the Restorative Flood Protection analysis, presented in a separate report to be published by Natural Systems Design in June 2019.

At the national scale, "Following the Mississippi Floods of 1993, federal policies encouraged flood-damaged property acquisition and demolition (so-called 'buy-out' policies) (Godschalk et al., 1998). Buyouts and relocations usually pay for themselves in 10 years and permanently reduce future disaster recovery costs and taxpayer liability ("Moving out of Harm's Way", Center for American Progress, https://www.americanprogress.org/issues/green/reports/2013/12/12/81046/moving-out-of-harms-way/).

There are major efforts supporting voluntary buyout and relocation programs for communities across the country. Major relocations have been implemented in Rapid City South Dakota, Prairie du Chen and Soliders Grove Wisconsin, Austin Texas, Portland Oregon and many other areas. The Charlotte-Mecklenburg Buyout Program in North Carolina has spent a total of $67 million over an 18-year period of 1999 to 2017. The Program has acquired 400 properties, restored 185 acres of floodplain, and is projected to save $300 million in future losses avoided (KINUR (Kinder Institute for Urban Research), 2018). Under current National Flood Insurance Program, FEMA typically funds 75% of property acquisition with local municipality or state contributing 25%. Since 1993, FEMA has funded acquisition of over 37,000 properties to prevent future disaster damages, mostly from flooding (James-Kavanaugh et al., 2017) . FEMA predicts that the nation's flood-prone area is likely to increase by 40-45% over the next 90 years (Baker Jr, 2013). Between 2001 and 2003 (two-year biennium) in Washington State, there were five acquisition projects of flood-prone structures: Quilcene River in Jefferson County, Cedar River in King County, Clear Creek in Pierce County, and Methow and Similkameen Rivers in Okanogan County (Washington Department of Ecology (WDOE), 2004) .

Scientific and economic studies also support consideration of relocation efforts along with development outside of hazard areas. Green (2010) presents example of economic benefits associated with developing in floodplains versus elsewhere (Figure 12).

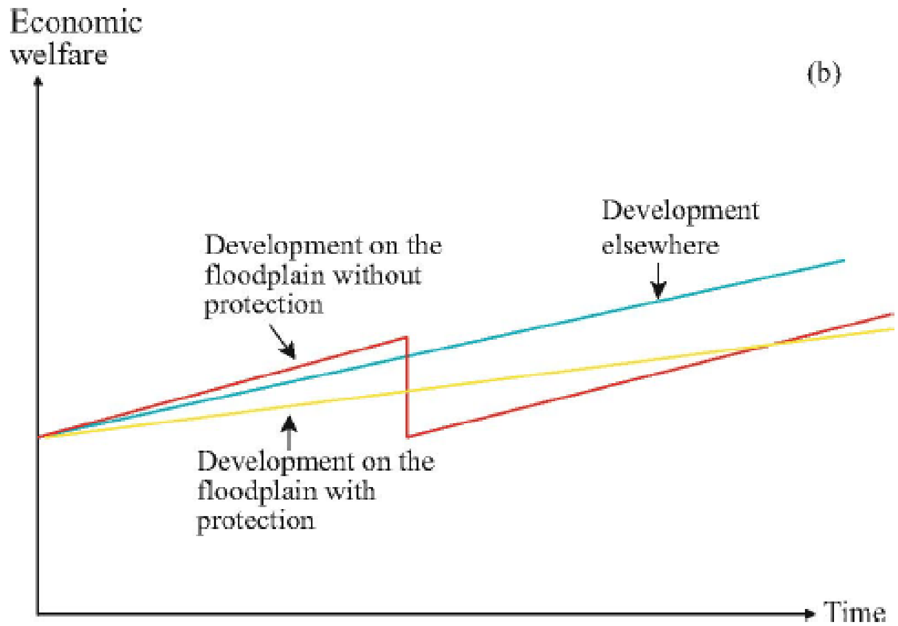


Figure 12. Illustration of economic benefits of developing in floodplains opposed to other areas. Example assumes in the short-term there is greater economic benefit developing in the floodplain as evident in the steeper slope of red line, but that benefit is erased when that development is impacted by flooding (steep drop in red line). Development outside floodplain (yellow line) has a more gradual slope, but attains the greatest economic welfare. Development in floodplain with protection is depicted by yellow line. It has most gradual rise because of costs of building and maintaining flood defenses not needed when developing outside the floodplain (Green, 2010).

The cumulative benefits of restoring floodplains for flood conveyance and ecosystem functions are a major economic driver. Floodplain restoration can significantly improve water supply, water quality, quality of life, recreation, fisheries, hunting, and climate change resilience. It provides a permanent solution to flood damages by moving people out of harm's way. Hawley et al. (2012) compared the benefit-cost ratios of various flood protection actions, showing that restoration of floodplains far exceeds traditional measures such as dams, dikes and levees (Figure 13).

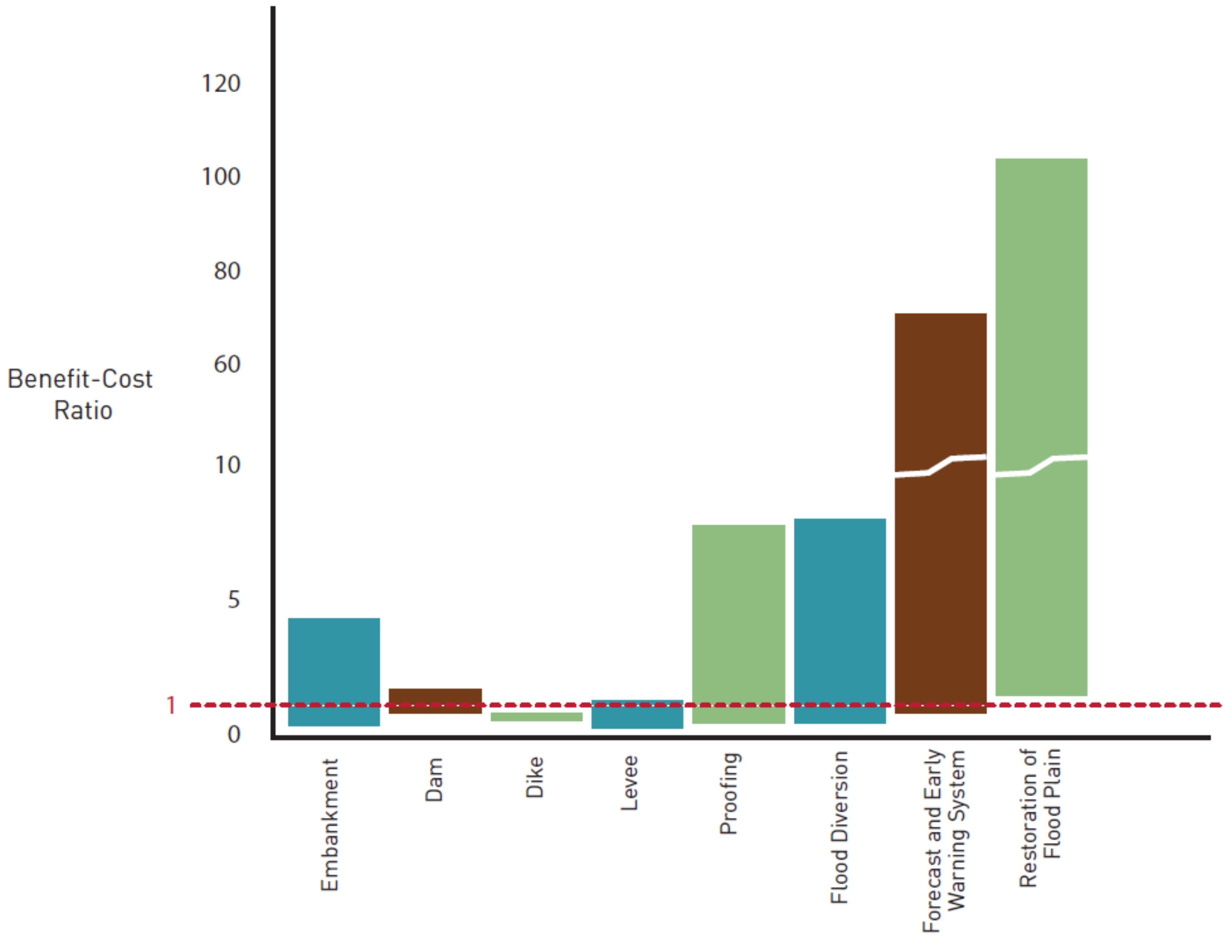


Figure 13. Benefit-cost ratio of different flood protection actions. Floodplain restoration offers the greatest benefits, particularly when time is considered. Floodplain restoration is a permanent solution. All other options require significant costs for construction and continual maintenance as long as they are utilized (Hawley et al., 2012) .

Strong floodplain management programs guiding appropriate development have proven to be effective in reducing flood problems (Burby et al., 2013). Flood damages have been shown to increase in areas not complying with floodplain regulations (Burby, 1998; Godschalk et al., 1998). These facts underscore the importance of a strong floodplain management program in the Chehalis Basin focusing on helping residents and native ecosystems. Recent actions in Harris County Texas came about after Hurricane Harvey and provide an example of a voluntary buyout program by a local municipality (HCCSD (Harris County Community Services Department), 2018).

Harris County voluntary buyout program objectives (HCCSD (Harris County Community Services Department), 2018) :

1. Acquire properties that have been subject to multiple floods (including those damaged in 2015, 2016 and Hurricane Harvey) and use for public space, green space, and/or flood control measures.
2. Assist homeowners to move to an area with reduced risk of flooding.
3. Return properties in the floodplain to natural and beneficial function, aiding in the storage of floodwaters.
4. Eliminate future flood damages and health and safety risks for owners and rescuers.
5. Reduce repetitive subsidized flood insurance payments and federal disaster assistance.

This analysis has demonstrated that a floodplain management program to help farmers relocate out of flood prone areas to higher ground in Lewis County, as proposed in the Restorative Flood Protection approach, is not only feasible, but would offer benefits to individual farmers, as well as strengthening local agricultural communities and economies. These actions would also significantly contribute to achieving the goals of the Chehalis ASRP. The findings show key elements of the Restorative Flood Protection approach could strengthen, not weaken Lewis County agriculture, as well as stimulate economic growth associated with the development associated with relocations.

The next section describes farming practices that could be possible within active floodplains and also, be consistent with the Restorative Flood Protection alternative.

4. FLOOD RESILIENT AND PROTECTIVE FARMING SYSTEMS

Farming is an inherently risky endeavor. Shifting market prices, soil-borne and invertebrate pests, diseases, temperature, rainfall, and unanticipated personal health issues can ruin a season (Dittbrenner et al., 2015). In addition to these general risks and challenges, farming in the floodplain presents another set of obstacles:

- added cost of flood protection devices and their management,
- interruption of operations (field preparation, production, harvest) due to flooding and the subsequent period of soil saturation,
- loss of productive land to flood erosion,
- deposition of sands, gravels, and large wood on productive lands,
- loss of annual crops to physical or pollutant damage,
- loss of stored crops (cut and bailed hay) to rot or mold,
- loss of perennial crops due to lethal damage or dislocation from the site,
- difficulty and cost of obtaining regulatory approval for facility expansion near environmentally critical areas,
- loss of, or difficulty in securing contracts due to a concern about crop unpredictability in flood-prone fields.

Each of these issues raises the risks and costs of farming. Money and time must be spent cleaning up debris and unwanted larger sediments. Land lost to erosion is permanently lost earning potential and likely will lower the value of the property. Damage to crops from inundation usually leads to the total loss of that crop. Where perennial crops are concerned, the cost can include replacement of crops that have been dislodged or damaged and lack of income during re-establishment and maturation period.

In addition to the physical consequences of actual flooding, concerns about potential flooding from buyers, regulators, and insurers has real consequences that are borne by all farmers in flood-prone areas. Buyers of fresh produce may be reluctant to enter into contracts with producers in flood-prone areas because of the concern that orders may go unfilled or be delayed if floods or untimely soil saturations occurs. Regulations or enforcement may change in unexpected ways, complicating business and development planning. Insurers may change rates or reassess risk, confounding accounting and short- or long-term financial viability.

Flood waters flowing over existing crops is not ideal. Soil erosion, damaging sediment deposition, and pollution can result from inundation and flood flows from offsite. Agricultural practices that can withstand some level of inundation and surface flood flows should be considered for landowners who wish to grow crops in flood-prone areas. Crop type, timing of maturity, structure, and layout are key considerations in choosing an agricultural system that is resilient enough to withstand active flood regimes. Interviews with farmers, farm-support professionals, and a review of relevant publications, offer a depth of information on flood resistant agriculture and form the basis of this summary.

In their publication "The Working Buffer Opportunity: A Proposal for Ecologically Sound and Economically Viable Riparian Buffers on Agricultural Lands," experts from the Snohomish Conservation District, NOAA, and Penn State University lay out practical considerations and design criteria for landowners farming on and in riparian buffers. Included in the publication are descriptions of the benefits to the landowner and to the ecosystem (Dittbrenner et al., 2015).

A resilient agricultural system in flood prone areas:

1. Produces mature crops during periods of low-flow so that crop damage does not occur and harvest is not impacted by wet conditions.
2. Has structural components that are durable enough to withstand overland flooding.
3. Protects itself and the surrounding soil on which it depends, and
4. Consists of plant types adapted to periodic inundation and saturated soils, as well as relatively dry conditions, as would be expected during the summer months in the Chehalis Basin.

Local, regional, national and international examples illustrate that agriculture systems may be designed to function and excel in riparian, flood-prone areas. These systems tend to incorporate perennial crops (i.e. tree fruits and nuts, berries), emphasize a vertical structural component absent from most annual cropping systems, and incorporate more than one crop type and sometimes numerous crops, growing in conjunction with one another. Agroforestry as a crop system has been in use for centuries and adaptations of its principles should be considered in areas that must contend with periodic flooding. Agroforestry–type systems have the benefit of:

1. Durability: perennial plants with well-developed root systems persist for decades and can withstand flood flows and summer drought.
2. Protective of soils and assets: perennial plants with well-developed root systems increase soil cohesion (anchor the soil) and can direct flows away from more sensitive crops or domestic or agricultural structures.
3. Diversity: mixed crop systems support a wider range of invertebrate species which ultimately decreases pest pressure on crops.
4. Versatility: systems can be designed to 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.

Agroforestry as an agricultural system is not explicitly focused on riparian or frequently flooded areas. Its benefits are more typically focused around economic and ecological diversity. Regionally, however, work has been done to show that agroforestry principals, specifically its structural and layout elements can have a positive impact where flooding is an issue – namely as buffering and protective structures that also produce cash crops (Table 4).

Table 4. Forecasted Durability of Saleable Crops in an Agroforestry System during a Flood Year.

SALEABLE PORTION OF PLANT	HARVEST TIMING	LIKELIHOOD OF HARVEST TIME IN CONFLICT WITH FLOOD	ABILITY OF PLANT PART TO WITHSTAND FLOOD DAMAGE (*FACTORING IN FLOOD AND HARVEST TIME*)	INDUSTRY
Whole plant	Winter dormancy	High	Medium	Horticultural, Restoration Planting
Stems/branches, bare or with buds	Winter dormancy, early spring	Medium	Medium	Floral, Restoration Planting
Stems/branches with leaves	Spring	Low	High	Floral
Stems/branches with flowers	Spring	Low	High	Floral
Fruit	Summer, early Fall	Low	High	Culinary
Nuts	Summer, early fall	Low	High	Culinary

4.1 Hedgerows: Flood Shelter Belts

Often referred to as 'living fences,' hedgerows are versatile. They can be purposed to buffer flood flows, redirect flows, produce crops, or protect main crops. These structures can be planted densely with berry, dwarf fruit crops, nuts, crops for the floral or environmental restoration industries, or species whose primary purpose is protection. Hedgerows can be designed as single crop or multi-crop structure and can be designed to any length and shape (Figure 15). Hedgerows also can provide privacy, habitat for beneficial insects, (pollinators and predators), and heat traps. Hedgerow crops typically ripen May (some floral crops) through September so harvest timing does not overlap with typical flood inundation or soil saturation in the Chehalis Basin. Harvest challenges can be partially met by designing hedgerows so that single crop varieties are planted in discernable segments, so that harvest efforts can be focused rather than scattered. Locally, farmers and farm-support agencies have taken steps to design, seek funding for, and install protective crop hedgerows along riparian buffers (Bramwell, 2018).

Figure 14. Example of a hedgerow, or "living fence". A hedgerow system can be multifunctional, combining flood sheltering functions with crop production.

Site specific design of hedgerow flood protection must be configured to fit a specific landscape; taking into account topography, known flow patterns, anticipated flood elevations, available acreage, resources to be protected, and durability of crop type. Crop type durability depends on both the strength and depth of the root system, its ability to withstand surface flows, and the crop's above ground characteristics: durability of stems, branches and buds, exposure of any saleable plant parts during flood, and durability of that saleable part (e.g. stems, branches, fruits). Potential field layouts should share the following characteristics:

- A deep-rooted protective crop at the flow-path's primary contact edge (upstream edge). Possible installations in these rows could be a durable deep rooted, multi-stemmed edible crop (e.g. nuts), a durable multi-stemmed floral-industry crop (e.g. ornamental willow, dogwood twigs, flowering branches) or a thick hedge of energy-dissipating spirea (*Spiraea douglasii*). Depending on location, historic flows, additional downstream crops or infrastructure, and other risk assessment factors, landowners could add protection by increasing the number and/or width of these buffering rows.
- As a shelter design, rows are arranged to shed flows away from valuable resources, such as crops or infrastructure. Alley ways through which flood waters could flow unrestricted are blocked. Rows are arranged as a series of baffles in order to dissipate flow energy.
- Downstream of the primary contact, protective rows, installations can transition to higher value, and perhaps less-durable crops. Crops would still need to be carefully chosen to avoid conflicts between harvest timing and flood timing, as well avoiding flood damage to crops. As with all farming in flood-prone areas, a crop's annual harvest would ideally occur before the onset of the rainy season. Many local floral industry crops, however can be harvested from early-spring through fall.

Crops to consider for hedgerow structures include: currants, gooseberries, raspberries, tall blueberries, blackberries, wild or domesticated elderberries and serviceberries, dwarf plums including cherry plums, raspberries, figs, ornamental crops for the floral industry, and dozens of others. Non-crop hedgerows can be installed whose primary purpose is to protect nearby crops. These structures would consist of species that are well rooted, adapted for periodic saturated soil conditions, and short or tall in stature. Depending on the farm's needs and the hedgerow's purpose, it can be designed to any length.

Hedgerow maintenance primarily involves mowing alongside the structure during the growing season to maintain its footprint and limit its spread via suckers. Periodic thinning or additional installations can occur depending on ability of hedgerow to meet specific landowner goals (i.e. production, protection, pollinator habitat, etc.). As the landowner gets to know her or his hedgerows, additional adaptations can be made to improve performance.

4.2 Silvo-pasture

Silvo-pasture is, "the deliberate integration of trees and livestock operations on the same ground". Well-managed silvo-pastures… typically include introduced or native pasture grasses, nitrogen-fixing legumes, and managed intensive grazing (MIG) systems applying short grazing periods which maximize vegetative plant growth and harvest, see Figure 16 (Brantly, 2013; Garrett, 2004; Hamilton, 2008). The tree canopy is managed for timber, fruit/nut production, or any combination of forest products." (Dittbrenner et al., 2015)

Figure 15. Silvo-pasture is the integration of trees into a pasture system. Image: USDA's National Agroforestry Center

In a silvo-pasture system, grazing recommendations follow standards issued by NRCS and conservation districts (i.e. short duration and low intensity grazing periods) in order to maximize forage re-growth and nutrient uptake, thereby providing a more productive crop during the dry season (Dittbrenner et al., 2015). The presence of trees, especially those varieties with deep roots, increases nutrient uptake potential of the soil (Hooper and Vitousek, 1997), and slows the speed and erosional force of flood waters, thereby increasing infiltration and reducing migration of nutrients off site (Jose et al., 2009; Michel et al., 2007). Shade created by trees increases soil moisture retention into the summer months and can lengthen the productive period (Dittbrenner et al., 2015). Shade production also provides livestock with shelter from summer heat and can increase nutritive quality of the forage crop (Angima, 2009; Garrett, 2004).

In silvo-pasture, the landowner has the potential to produce three products from the land: tree crop, livestock, and forage. Numerous models exist and there are seemingly limitless potential design-types when one considers potential tree varieties, arrangement/layout patterns, forage crops varieties, and management. Additional management options include taking advantage of the opportunities presented during the initial tree establishment period and the different scenarios possible during a young canopy, mid-sized canopy, and then mature tree cover. Tree crops can be fruit or nut, or non-food crops, such as timber. Trees can also be grown for non-crop uses such as on-farm mulch, nitrogen-fixing for pasture renovation, sawdust for mushroom spawn, or wood for commercial mushroom cultivation.

4.3 Alley Cropping

Alley cropping is "the planting of trees in rows with agronomic, horticultural, or forage crops cultivated in the alleys between the rows… [It] is a production model where a tree crop is grown in rows that are wide enough to simultaneously allow for cultivation of ground level plants. Rows of tree or shrub species can be managed for fruit, nut, medicinal, timber, and/or ornamental production while allowing for continued production of cultivated crops, such as small grains, vegetables, ground cover fruits, or forage such as hay and silage, see Figure 17." (Dittbrenner et al., 2015). Ornamental crops for use in the floral industry can also be grown in the alleys.

Selection of the right combination of tree and alley crops should take into account local markets, soil conditions, available machinery, expertise, and species' compatibility. Critical to the success of an alley cropping system is the long-term goal of the tree species. This will influence and possibly determine the height of the tree crop (e.g. timber, standard fruit size, dwarf, or semi-dwarf) and duration that it is in place (e.g. expected tree life or potential harvest of the tree). Annual cropping or forage production can be maintained permanently within the alleys, or phased out as the trees mature. Alley crops can start or transition into perennial crops of a shorter stature than the mature trees (e.g. figs, trellised kiwis).

Figure 16. Example of an alley cropping system with perennial crops growing in the "alley." The tree crops can provide shelter from flood flows. Image: National Farmers Union.

By growing two or more crops simultaneously, the grower can add some economic security from market fluctuations or individual crop failures (Schoeneberger et al., 2012). Depending on the system and the crops, harvest and maintenance labor can be spread throughout the year to provide for year-round, or nearly year-round income and labor (Dittbrenner et al., 2015). Year-round farm labor may be important for some farmers in their effort to find and retain skilled laborers.

During flood events, trees within or adjacent to cultivated fields provide physical obstructions slowing surface flood waters reducing soil erosion and nutrient and chemical runoff. (Michel, et al., 2007; Jose 2009). Most crops are harvested before late fall or winter storm events, but where perennial crops are used as the alley crop, the reduction in surface water velocity caused by the structural tree barrier can protect the crop from damage or dislocation from the site. The ability of trees to protect soils and crops is highly dependent on location and arrangement – designing tree rows in positions to spread, deflect, or block concentrated flows is key. In flood-prone areas, two or three rows of trees could be planted, or alternate rows of trees and woody shrubs, along the upstream edge to better protect the alley crop. Potential crops and production models are further described in (Dittbrenner et al., 2015) and by the USDA's National Agroforestry Center.

4.4 Agroforestry Obstacles

Agroforestry systems, such as silvo-pasture, and alley cropping, are not without their drawbacks. Crop material in the form of perennial shrub or tree stock is relatively expensive. 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).

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.

More importantly for most though, is the shift in management style. 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 challenges to successful management. To mitigate these challenges of management, local and regional advisors, and potentially other growers, are available for guidance and consultation. Examples of support services include the SW Washington Agroforestry advisor at Washington State University, USDA/NRCS publications, and several not-for-profit organizations (Association for Temperate Agroforestry https://www.aftaweb.org/).

4.5 Agroforestry in the uplands

While agroforestry provides solutions to challenges posed by farming in the floodplain, Agroforestry practices are applicable regardless of the land's flood-potential. The benefits of shade on livestock health, forage crop nutrition, soil moisture retention, and season extension; the economic security inherent in multi-crop systems; and the ecological benefits in terms of biodiversity exist regardless of location.

5. CONCLUSIONS

Farming in a flood zone comes with certain unique risks. Costs associated with property and business flood insurance, loss of crops, debris removal, building repair, erosional loss of productive land, personal economic uncertainty coupled with the possible uncertainty and hesitation of buyers, and increasingly complex regulatory climate, bring to question whether or not farming in flood-prone areas is worth the risk to growers.

Surrounding the Newaukum floodplain, opportunities for agricultural growth exist in upland areas outside of the flood risk zone. Soil conditions are in many ways similar, and in some cases superior, to floodplains and there is a large land base, of mostly low gradient, mostly undeveloped land that could be converted to agriculture.

The intent of this document is not to advocate land-use policy changes or compel landowners to change their business or lifestyle. Rather, it seeks to describe the approach and conditions of successful upland farms, provide a quantitative and qualitative comparison of agricultural lands and usage in floodplains and uplands, and provide guidance on flood resistant agricultural approaches. By providing contextualized information and analysis, this document is offered to empower landowners and farmers to make informed decisions regarding their livelihood.

REFERENCES:

Angima, S.D., 2009. Silvopasture: An Agroforestry Practice, Oregon State University Extension

Baker Jr, M., 2013. The impact of climate change and population growth on the National Flood Insurance Program through 2100.

Bramwell, S., 2018. Hegerow Grant Budget. In: B. Keller (Ed.), Seattle, WA.

Brantly, S., 2013. What is Silvopasture. Working Trees Info Sheet. USDA National Agroforestry Center.

Burby, R., Dixon, J., Ericksen, N., Handmer, J., May, P., Michaels, S., Smith, D.I., 2013. Environmental management and governance: Intergovernmental approaches to hazards and sustainability. Routledge.

Burby, R.J., 1998. Cooperating with nature: confronting natural hazards with land-use planning for sustainable communities. Joseph Henry Press.

Burnt Ridge Nursery, 2018. https://www.burntridgenursery.com/, Onalaska, WA.

Dittbrenner, C., Cereghino, P., Hagan, E., 2015. The Working Buffer Opportunity: A proposal for ecologically sound and economical viable riparian buffers on agricultural lands, Snohomish Conservation District.

Garrett, H.E., M.S. Kerley, K.P. Ladyman, W.D. Walter, L.D. Godsey, J.W. Van Sambeek, D.K. Brauer, 2004. Hardwood silvopasture management in North America., Springer Netherlands.

Godschalk, D., Beatley, T., Berke, P., Brower, D., Kaiser, E.J., 1998. Natural hazard mitigation: Recasting disaster policy and planning. Island Press.

Green, C., 2010. Towards sustainable flood risk management. International Journal of Disaster Risk Science, 1(1), 33-43.

Hamilton, J., 2008. Silvopasture: Establishment & management principles for pine forests in the Southeastern United States, USDA National Agroforestry Center.

Hawley, K., Moench, M., Sabbag, L., 2012. Understanding the economics of flood risk reduction: A prelminary analysis, Institute for Social and Environmental Transition-International, Boulder, CO.

HCCSD (Harris County Community Services Department), 2018. Disaster Recovery Voluntary Buyout Program Guidelines. Project Recovery Harvey. Harris County, Texas, Harris County, Texas, pp. 52 p.

Hooper, D.U., Vitousek, P.M., 1997. The effects of plant composition and diversity on ecosystem processes. Science (New York, NY), 5330(277), 1302-1305.

James-Kavanaugh, K., Foster, C., Chandler, T., Anagnost, J., Salvesen, D., Lerner, M., Moraga-Lewy, N., Streitwieser, A., Liu, S., Kihslinger, R., 2017. Floodplain buyouts: An action guide for local governments on how to maximize community benefits, habitat connectivity, and resilience. Environmental Law Institute (ELI).

Jose, S., Holzmueller, E.J., Gillespie, A.R., 2009. Tree-crop interactions in temperate agroforestry. In: H.E. Garrett (Ed.), North American AgroForestry: An Integrated Science and Practice. American Society of Agronomy, Inc, Madison, WI, pp. 57-73.

KINUR (Kinder Institute for Urban Research), 2018. Case studies in floodplain buyouts. Looking to best practices to drive the conversation in the Houston Region. Rice University, Houston, TX, pp. 28 p.

Mård, J., Di Baldassarre, G., Mazzoleni, M., 2018. Nighttime light data reveal how flood protection shapes human proximity to rivers. Science advances, 4(8), eaar5779.

Michel, G.A., Nair, V.D., Nair, P.K.R., 2007. Silvopasture for reducing phosphorus loss from subtropical sandy soil. Plant Soil, 297, 267-276.

National Academies of Sciences, E., Medicine (NASEM), , 2019. Framing the Challenge of Urban Flooding in the United States. National Academies Press.

Raintree Nursery, 2018. https://raintreenursery.com.

Schoeneberger, M., Bentrup, G., de Gooijer, H., Soolanayakanahally, R., Sauer, T., Brandle, J., Zhou, X., Current, D., 2012. Branching out: agroforestry as a climate change mitigation and adaptation tool for agriculture. Journal of Soil and Water Conservation, 67(5).

USDA NRCS Soil Survey Staff, Accessed May 2016. Soil Survey Geographic (SSURGO) Database. In: U.S.D.o.A. Natural Resources Conservation Service (Ed.), Available online at http://sdmdataaccess.nrcs.usda.gov/.

Washington Department of Ecology (WDOE), 2004. Floodplain Management in the State of Washington. A Status Report as of February 2004. WA Depart. of Ecology Olympia, WA, pp. 16 p.

THIS PAGE INTENTIONALLY LEFT BLANK