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Lower Nooksack River Geomorphic Assessment

APPENDIX C
Geomorphic Characterization to Support Future Habitat Analysis

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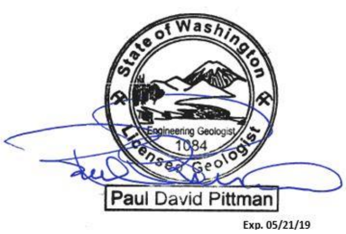


Appendix C: Geomorphic Characterization to Support Future Habitat Analysis

Purpose

The purpose of this geomorphic study is to identify and characterize selected fluvial geomorphic landforms and processes of the Lower (mainstem) Nooksack River that can influence salmonid habitat availability, quantity, and quality (Figure C-1). This assessment is intended to supplement the Lower Nooksack River geomorphic assessment provided in Appendix B and provide background support to a habitat study that is currently proposed; however, there has been no integration of these investigations at this time. Specifically, this analysis characterizes the physical conditions of the low flow floodplain areas, riparian areas, large woody debris occurrences, and high flow/low flow instream conditions that may relate to salmonid habitat conditions.

For this analysis, we defined the boundaries of this characterization as the geomorphic landscape that exists under current conditions (2013-2017) within the mainstem of the Nooksack River and target the geomorphic processes that influence the movement of water and sediment during relatively “frequent” flow conditions (low instream flow, high instream flow, 2-year flow, and 10-year flow). While salmonid species have evolved to be resilient and adapt to dynamic fluvial systems, it is commonly understood that the geomorphic responses related to some land use and river management activities results in degraded habitat quality and reduced habitat quantity. The intent of this analysis is to characterize the major physical processes that are impaired and explain why this may matter to potential habitat conditions.

The next steps following this analysis are to collaborate with the habitat study team to determine where current physical conditions and processes that support salmonid habitat occur, or do not occur, to provide the basis for a discussion focused on what actions can be taken to improve salmonid habitat quantity and quality.

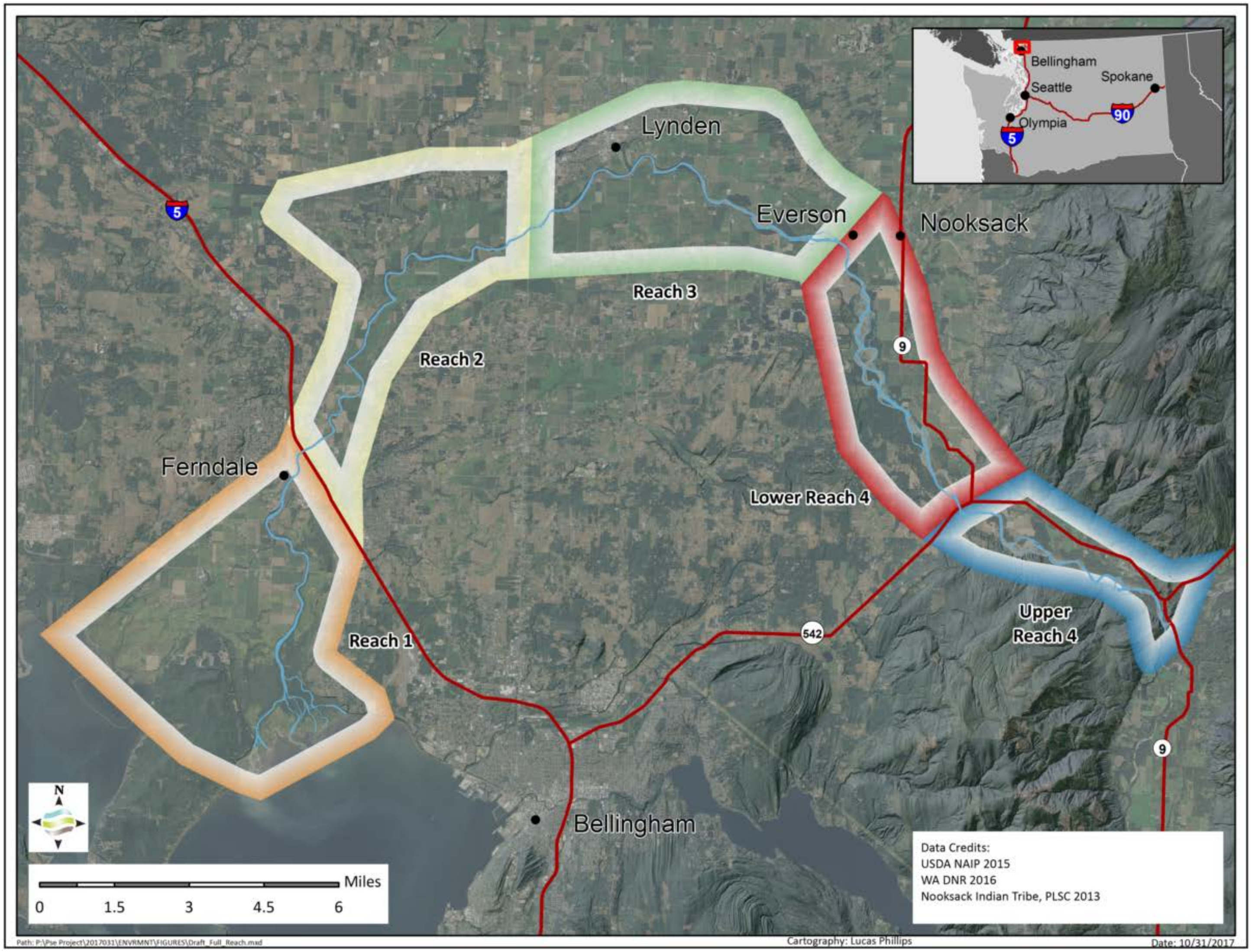


Figure C-1: Reaches of the Lower Nooksack River Mainstem Study Area.

The characterization of geomorphic conditions for this analysis is organized into the following categories:

- Low flow floodplain characterization;
- Riparian floodplain vegetation;
- Instream conditions - forested Islands, backwater features, and active channel areas;
- Large woody debris and logjam occurrence.

The analysis, by design, does not describe, quantify, or qualify the habitat conditions. Rather, this analysis describes the geomorphic processes, specifically as they related to the movement of sediment and water that create environments that support a range of habitat conditions. In addition, this analysis focuses on characterizing the modern conditions. It is understood and well documented that historic habitat was significantly greater in quantity and quality and that the past century and a half of river management have altered those conditions. The modern Nooksack is a managed watercourse and the intent of this analysis is to try to identify limiting conditions and opportunities to improve habitat conditions within this reality by restoring processes that can support habitat well into the future.

Methodologies

The fluvial geomorphic landforms considered in this analysis were characterized in their "current" (2013 through 2017) conditions using GIS spatial datasets (2013, 2016) and a field reconnaissance (July-August 2017). Some uses of historic datasets occurred to define areas of assessment, such as the historic migration zone (HMZ) or modeled floodplains. In summary, the following datasets were used to derive the analyses in this assessment:

- 2013 LiDAR DEM;
- 2013 Digital Ortho-rectified Air Photo (DOQ);
- 2016 Digital Ortho-rectified Air Photo (DOQ);
- Previously mapped spatial datasets, including:
  - Government Land Office survey;
  - Collins and Sheikh (2004) historic channel locations;
  - Historic air photos;
  - Older topographic information (2006 LiDAR DEMS, historic USGS and other historic mapping); and
  - 2004 LWD mapping (Whatcom County).

Floodplain Characterization

Natural system floodplains interact frequently with the river. Partial to full inundations of a natural system floodplain can occur relatively frequently, often annually. The floodplains enable storage of water and sediment and return overbank waters back to the river following flooding. Natural system floodplains often contain tributaries, oxbows or sloughs, side-channels, wetland complexes and other physical features that connect primary channels to floodplains or store water after floods recede. In summary, natural system floodplains provide extensive and diverse salmonid habitats including spawning habitat, rearing habitat, and refugia during high flows and are important systems for maintaining water quality. In addition, the physical process function of a floodplain drives many of the instream geomorphic conditions that directly and indirectly affect instream habitat conditions.

Today's anthropogenically-modified Nooksack River floodplain is no longer a natural system floodplain, and modern floodplain conditions are vastly different than historic floodplain conditions (Collins and Sheikh, 2004). During the past century land use, development and management actions have:

- Altered floodplain accessibility and frequency of inundation through the installation of levees, removal of wood, and gravel bar mining;
- Reduced riparian and floodplain vegetation cover, age composition and species type through land clearing;
- Modified floodplain drainage patterns and disconnected floodplain and floodplain flow paths through the installation of drainage infrastructure and levees; and
- Hardened banks with armored revetments.

As a result, the sum of all these changes have led to conditions in the modern Nooksack River that are identified as limiting factors in salmon recovery; one of which is floodplain habitat (WRIA I SRB, 2005).

To characterize the floodplain physical conditions as they may relate to habitat, we evaluated:

1. Floodplain inundation area and
2. Relative connectivity of the floodplain to the channel.

These physical conditions can influence available habitat type, quantity, quality, and functionality. We did not perform a detailed drainage network analysis which could determine which flow paths provide or limit access to and from floodplain areas during and after flooding. It is our understanding that this will be done in the habitat assessment.

Floodplain Inundation Areas

The floodplain area analysis characterized the 2-year and 10-year floodplain areas as determined by hydraulic modeling. These flows and the corresponding inundation areas were considered because they have a relatively high frequency of occurrence and significant influence on floodplain habitat conditions. For the floodplain area characterization, we:

- Quantified areas that were inundated in the 2-year and 10-year modeled floods;

- Measured areas that were isolated by levee and road systems in the 2-year modeled floods;
- Provided a qualitative discussion of general floodplain connectivity during the low flow floods.

Below are the results from the floodplain area characterization.

The 2 and 10-year floodplain areas were calculated by taking the total modeled inundation areas for each modeled flow and subtracting the total active channel area. The active channel area is defined in this analysis as the low flow wetted channel plus high flow channel areas characterized as exposed gravel bar or wetted areas observed in air photos. The result is defined in this analysis as the **total floodplain area**.

Total Inundation Area – Total Active Channel Area = Total Floodplain Area

The results for the entire Lower Nooksack River study area are:

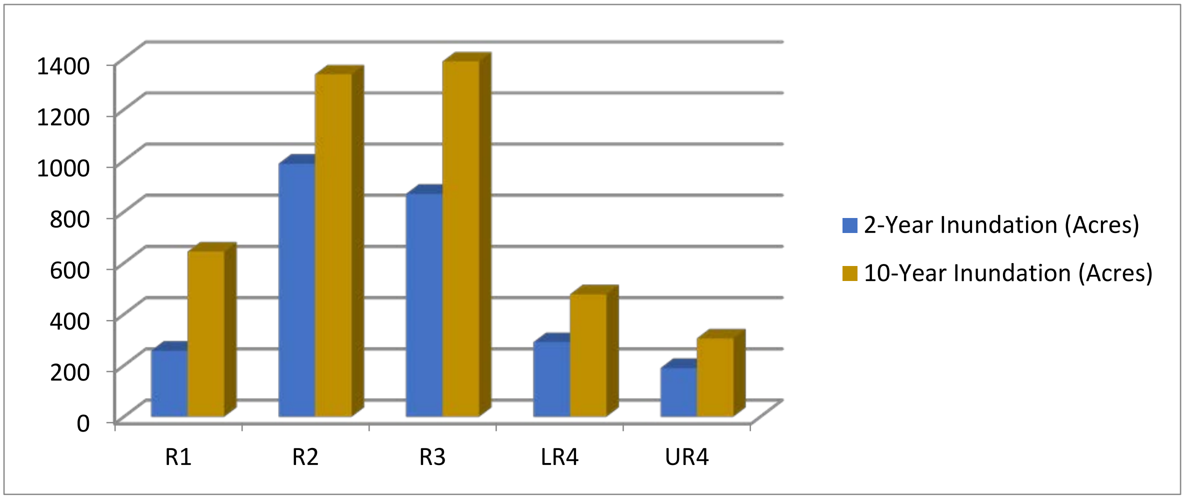
2-Year Flow Event = Total Floodplain Area of 2,596 acres.

10-Year Flow Event = Total Floodplain Area of 4,151 acres.

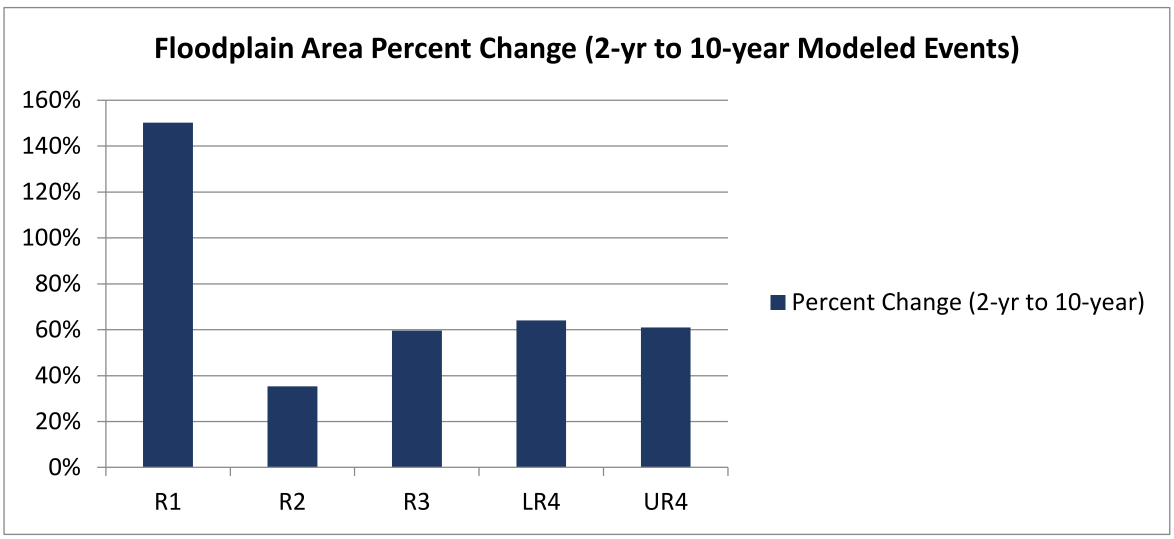
The 10-year floodplain is approximately 60% larger than the 2-year floodplain. The different floodplain areas by reach are presented in Table 1 and graphically represented in Table 1, Graphs 1 and 2, and Figures C-2 through C-6.

Reach	*2-Year Inundated Floodplain Area (acre)*	*10-Year Inundated Floodplain Area (acre)*	*Change in Inundation Area (2-yr to 10-yr)*
Reach 1	258	644	150% increase
Reach 2	988	1337	35% increase
Reach 3	869	1387	60% increase
Lower Reach 4	290	477	64% increase
Upper Reach 4	189	305	61% increase

Table 1: Total Floodplain Areas for 2-Year and 10-Year Modeled Flow Events by Reach and percent change.



Graph 1: Total Inundation Areas in Acres By Reach for 2-Year and 10-Year Modeled Flow Events.



Graph 2: Percent Change in Floodplain Area Between 2-Year Flow and 10-Year Flow.

This data reveals that Reaches 2 and 3 have the largest 2-year and 10-year floodplain areas. Reach 1 has the greatest change in area between the 2 year and 10 year event. Upper and Lower Reach 4 has the least floodplain area.

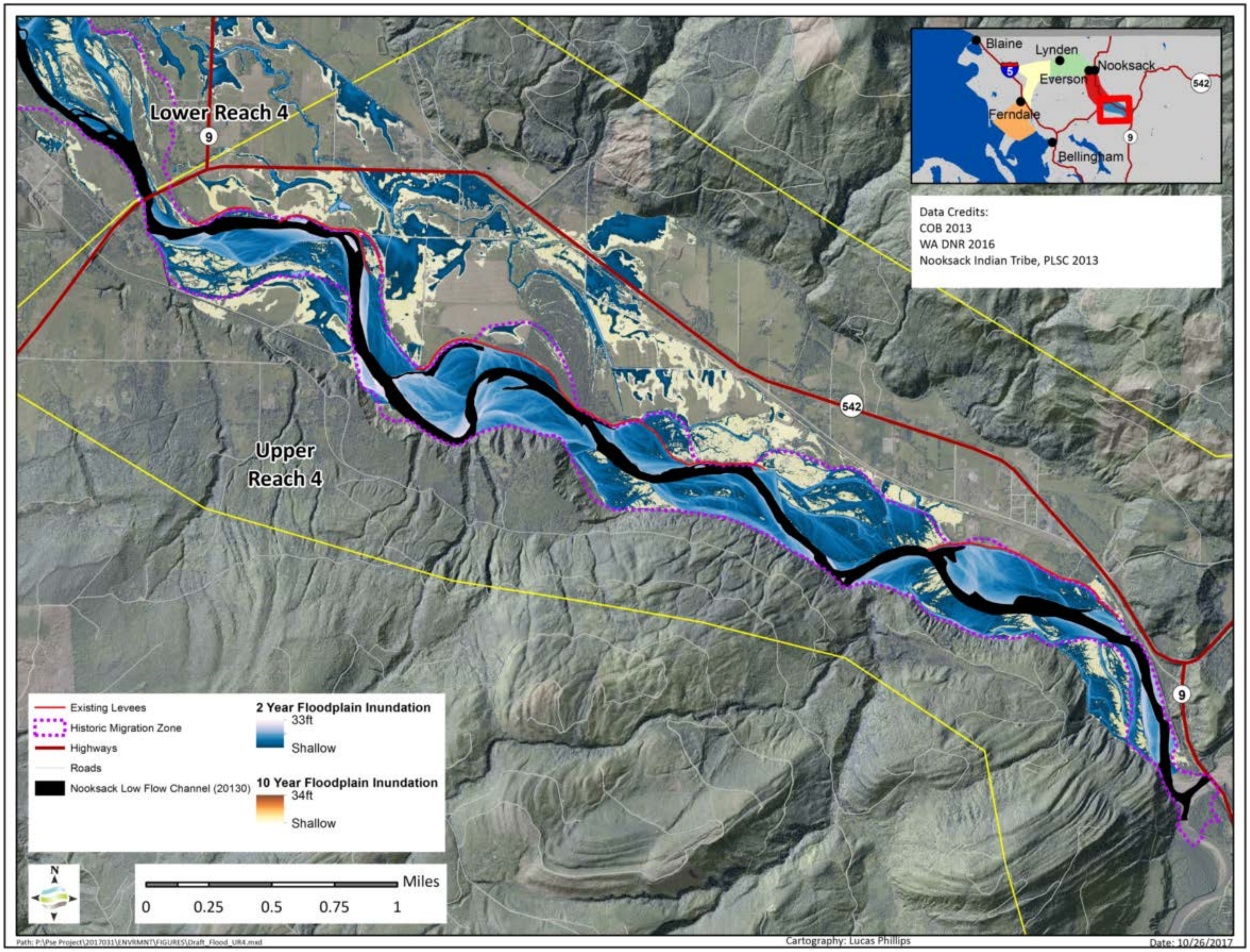


Figure C-2: Upper Reach 4 2-year and 10-year Modeled Flood Inundation Areas.

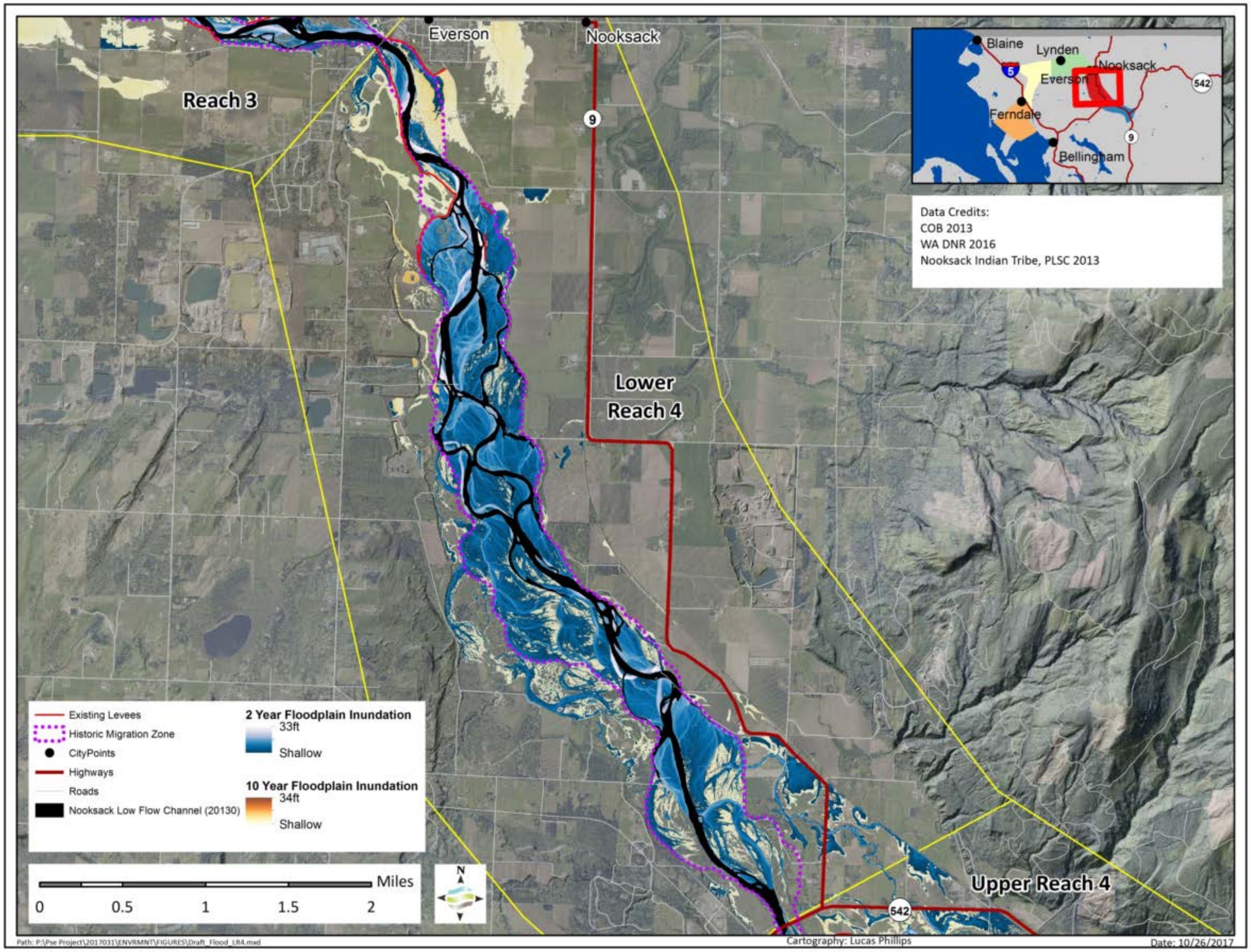


Figure C-3: Lower Reach 4 2-year and 10-year Modeled Flood Inundation Areas.

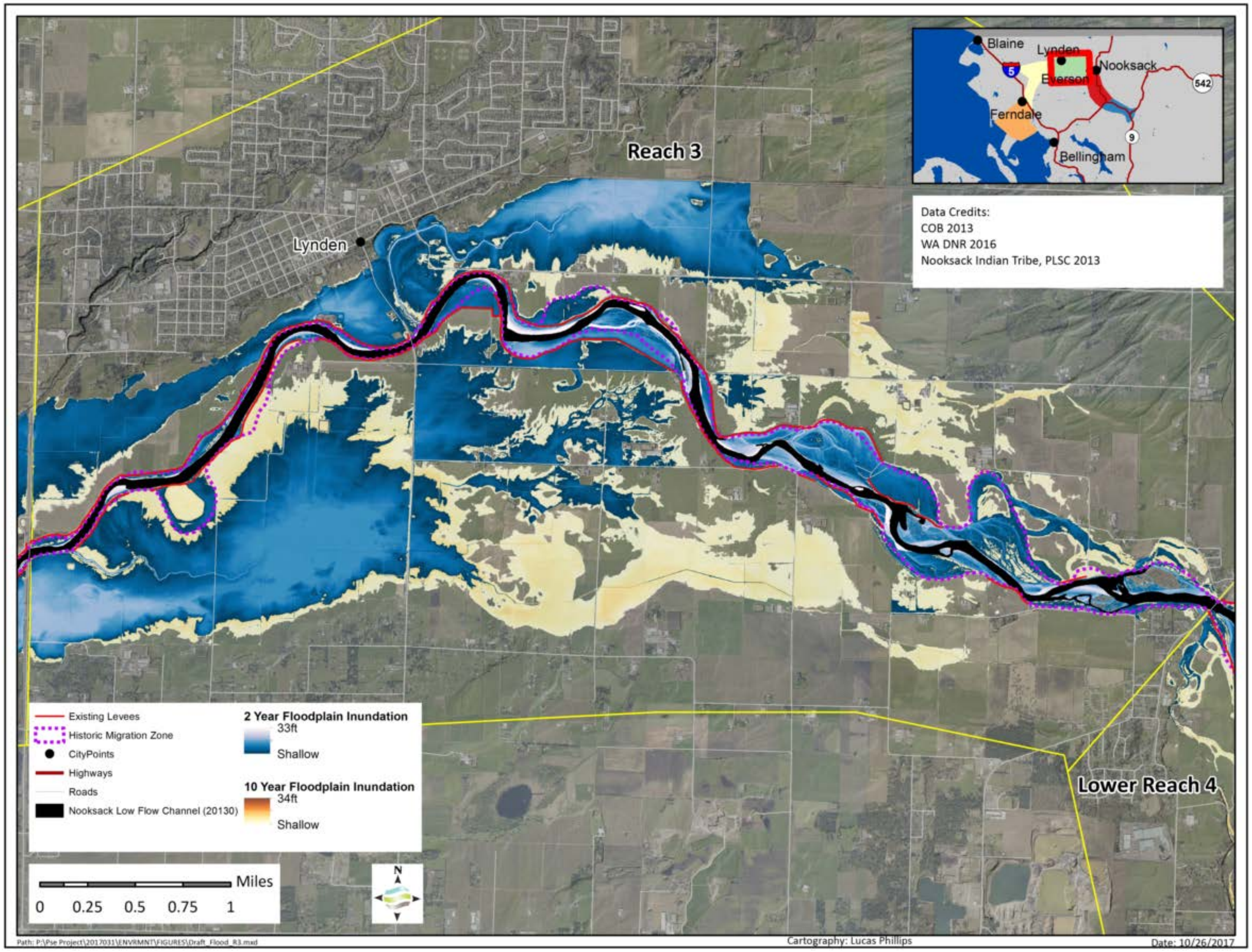


Figure C-4: Reach 3 2-year and 10-year Modeled Flood Inundation Areas.

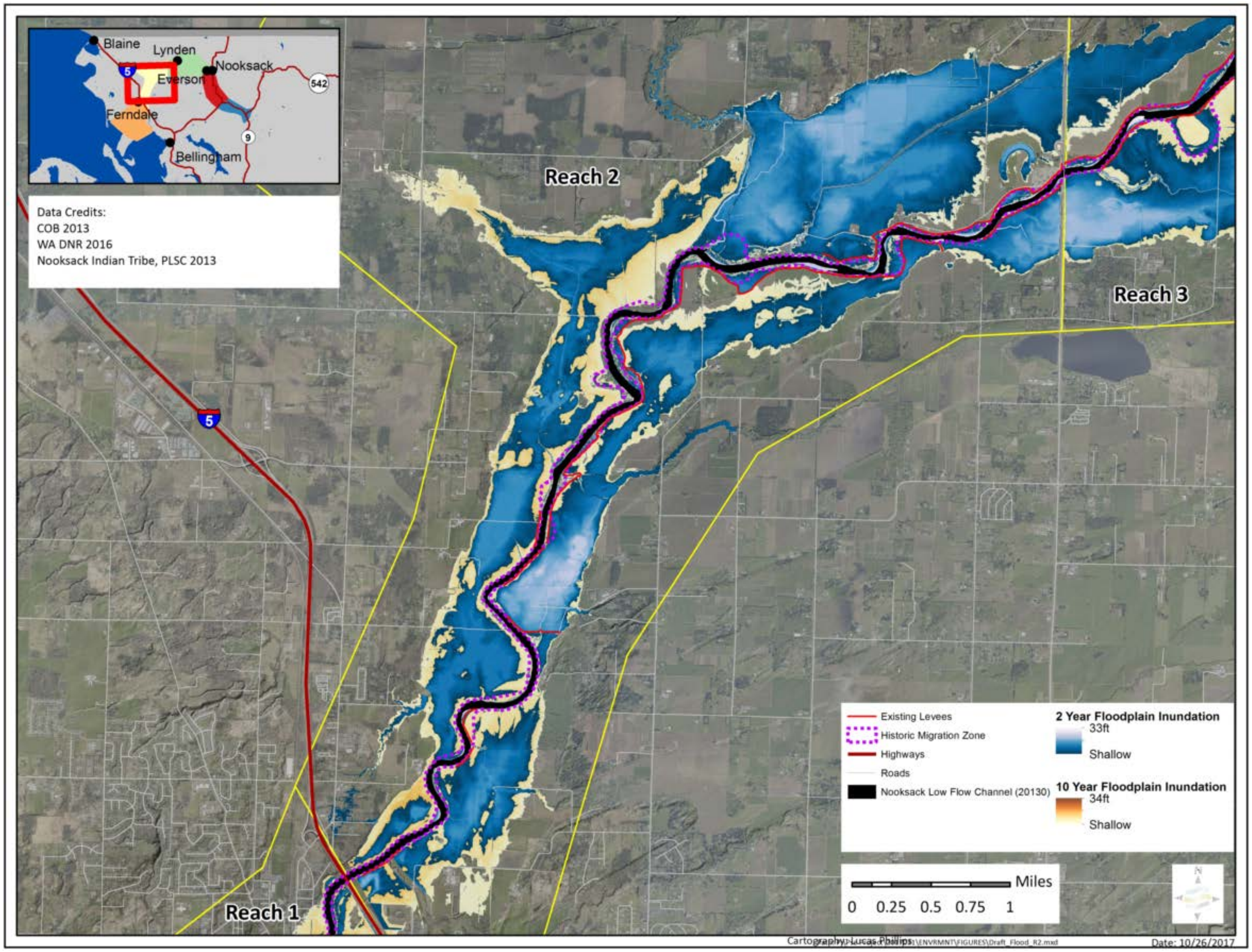


Figure C-5: Reach 2 2-year and 10-year Modeled Flood Inundation Areas.

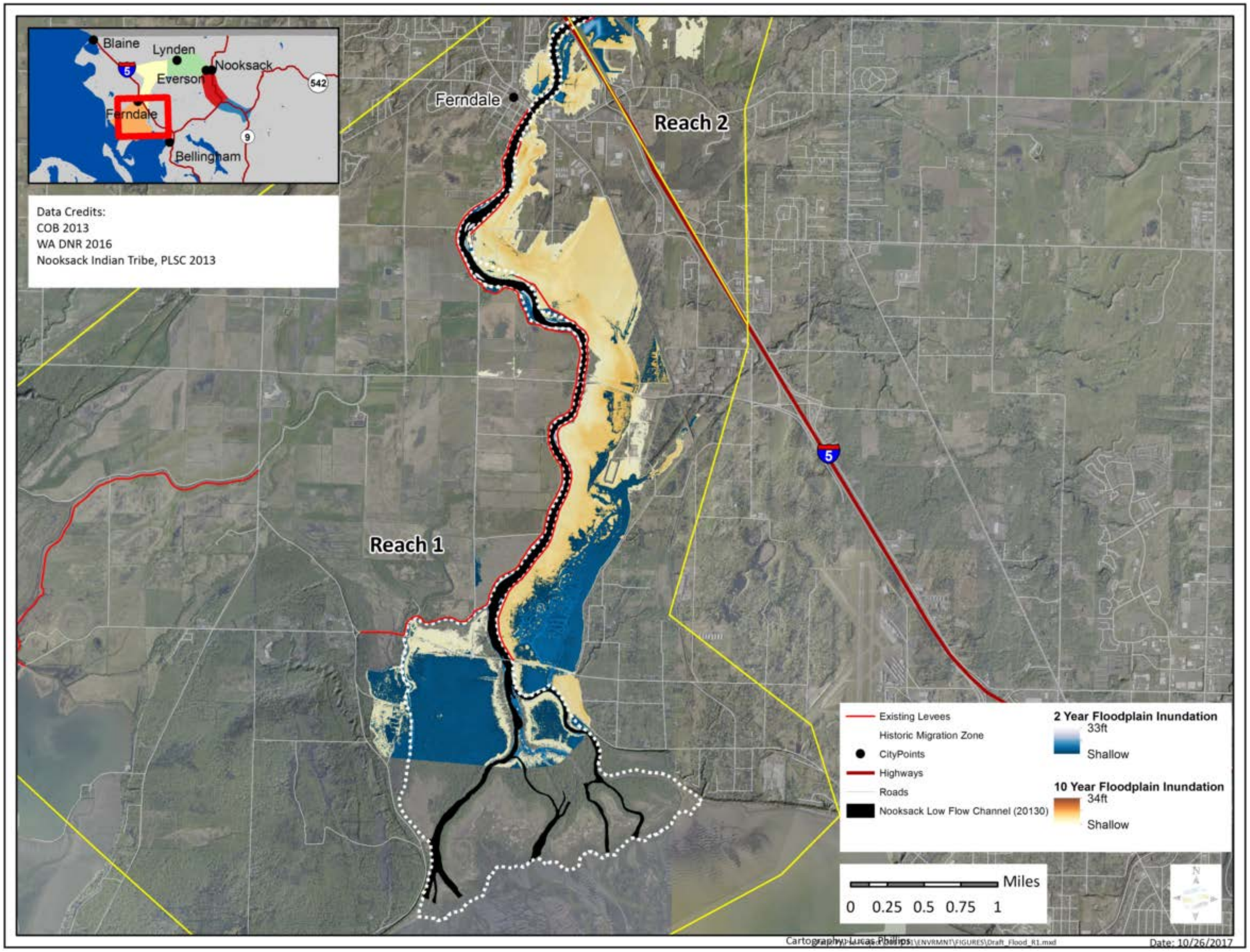


Figure C-6: Reach 1 2-year and 10-year Modeled Flood Inundation Areas (graphic does not show flooding in the Lummi River).

Floodplain connectivity

For this analysis, floodplain connectivity focused on return flow pathways, because this condition was interpreted to have the most significant potential impact to habitat. Specific to the Nooksack River, floodplain tributaries, side channels, and drainage ditches are the primary return flow pathways for overbank flooding. The predominant floodplain tributaries and ditch networks in the study reach are: Smith (RM 29.3), Anderson (RM 28.2), Kamm (RM 18.1), Fishtrap (RM 13.2), Bertrand (RM 12.6), and Silver (RM 0.7) Creeks and Scott Ditch (RM 15.5). Reach 1 below Marine Drive has numerous distributary networks which function similarly to side channels and tributaries and provide potential return access to the main channel following a flood. While many of the larger floodplain tributaries have direct outlet connection with the mainstem Nooksack River, their banks are often leveed and connection between the floodplain and tributary may be impacted. Floodplain drainage systems often have outlet connections that are managed, typically with a flap gate system. The ditch networks may also have conveyance barriers that restrict or limit movement of water. Table 2 characterizes the approximate areas of disconnected 2-year floodplain by reach as interpreted from LiDAR. Note that while the habitat assessment that is currently underway will be mapping the detailed connectivity of these floodplain and drainage networks, our preliminary analysis considers only the predominant connectivity pathways evident in topographic mapping.

Reach	*2-Year Isolated Floodplain Area (acre)*	*Percent Loss From Full 2-Year Floodplain*
Reach 1	63	24%
Reach 2	912	92%
Reach 3	667	77%
Lower Reach 4	58	20%
Upper Reach 4	91	48%

Table 2: Interpreted Isolated Floodplain Areas for 2-Year Flow Events by Reach.

Floodplain Conditions Observation Summary and Discussion

The following summarizes the observations made for the floodplain characterization:

- The largest low flow floodplain area exists in Reaches 2 and 3.
- The average percent increase in potential floodplain inundated area between a 2-year flood and a 10-year flood is approximately 60%.
- Reaches 1, 2 and 3 overbank flows inundate broad depressional areas that run parallel to the channel and return flows organize into ditch and drainage networks that are routed back to the channel at the downstream ends of the depressional areas or infiltrate within the floodplain;

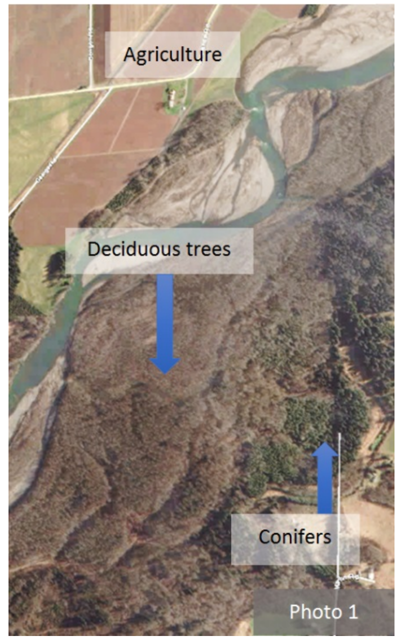
habitat isolation results if the drainage networks or levees create passage barriers when floods recede.

- On average, we estimated that levee and drainage systems isolate about 50% of the average 2-year floodplain; the isolation of floodplain area by levee and drainage infrastructure is most pronounced in Reaches 2 and 4.
- The reach with the greatest change in floodplain area between the 2-year and 10-year flow events is Reach 1; the lower Reach 1 delta also has the greatest floodplain connectivity.
- Reach 4 floodplain is generally confined within the HMZ during the 2-year and 10-year flows. But at flow events larger than approximately a 10-year flow, the floodplain extends beyond the HMZ and leaves the Nooksack River watershed near Everson and enters the Fraser River watershed.
- Upper Reach 4 overbank flows seek numerous relict channel scars on the floodplain. Flow is distributed through these networks and either returns to the main channel or if levee overtopping occurs, becomes locally isolated behind floodplain infrastructure, particularly where that floodplain infrastructure occurs within the HMZ area.

We observed that while the natural levee floodplain morphology in Reaches 2 and 3 results in significant inundated area during 2 and 10 year floods which offer valuable refuge habitat, the connectivity appears impaired by the levee and drainage infrastructure and many isolated basins likely result as flood waters recede. Reach 1 has had connectivity loss to Lummi Bay and the northern delta through the isolation of a primary distributary channel. While this was not evaluated in detail, considerable floodplain, delta, distributary, and estuary habitats are not accessible or functioning. While Reach 4 has the smallest floodplain inundation area, the connectivity of this habitat during receding flows is generally greater than in Reaches 2 and 3. The exceptions are where relict channels and side channels have been leveed, particularly in Upper Reach 4. The lower Reach 1 delta area has the greatest connectivity of floodplain habitat. Connectivity improvement opportunities may include overflow routing, improving downstream connections, improving drainage network conditions by providing vegetative cover and managing water quality impairments.

Riparian and Floodplain Vegetation

Floodplain Vegetation Conditions – Riparian Vegetation Heights



The physical functions provided by floodplain and riparian vegetation support salmonid habitat in several ways, including: water quality functions such as nutrient uptake and shading for water temperature; providing floodplain roughness to slow flows and store water and sediments, and providing a source of LWD for recruitment into the channel environments. The WRIA 1 limiting factors analysis identified the riparian and floodplain conditions in the Lower Nooksack River as limiting conditions for salmon recovery in the Nooksack River (WRIA I SRB, 2005).

The composition of today's Nooksack River floodplain vegetation is very different than the historical forest conditions that occupied this area over a century ago. Historically, the Lower Nooksack River mainstem riparian corridor basal areas were dominated by Sitka spruce (*Picea sitchensis*), black cottonwood (*Populus tricocarpa*), and western red cedar (*Thuja plicata*) (Collins and Sheikh, 2004). These trees likely grew to significant heights; when recruited by channel migration, they likely had the ability to anchor and initiate stable logjams. Extensive logjams were reported within the mainstem of the Nooksack River (Collins and Sheikh, 2004). Contemporary air photos reveal that the forested areas within the HMZ appear to be predominantly young deciduous pioneering tree species, but that some areas of maturing and conifers do exist within the HMZ (Photo 1 above). When the young, immature trees of shorter lengths and reduced basal area are recruited to the channel, their physical properties typically do not enable anchoring to create stable logjams, particularly in larger single-thread channel systems such as the Nooksack River (Latterell and Naiman, 2005; Naiman et. al., 2005).

To determine the potential for functional LWD that could be recruited and create stable logjams in the Lower Nooksack River mainstem, we considered the physical properties of tree height. The assumption is that taller trees have greater potential for initiating logjam formation than shorter trees. We assumed that the most probable source area for LWD recruitment within the study reach was the HMZ plus 200 feet, and therefore utilized this as the area of assessment. Within the area of assessment, we determined tree height from the 2013 LiDAR dataset. We then designated tree height classes for comparative purposes.

The tree height class designations integrated both the physical height parameter obtained by the LiDAR data and our field and desktop observations regarding canopy conditions. We discuss canopy conditions in more detail in the following section and introduce the hypothesis that tree size alone is not the only determining factor for whether or not a stable logjam forms; canopy composition also has some influence on the potential LWD to form stable logjams.

The height classes designated for this analysis are:

- **Agriculture (includes pasture, developed areas, unvegetated areas)** (0 – 2 feet in height)
- **Shrubs** (3 – 5 feet in height)
- **Pioneering Tree Species – Emerging Type 1 Canopy** (6 – 15 feet in height)
- **Establishing Canopy – Type 2** (16 – 80 feet in height)
- **Maturing Canopy – Type 3** (81 – 150 feet in height)
- **Old Growth Forest – Conifer Stand** (greater than 150 feet in height).

Note that the assignment of these heights integrates the following assumptions:

- Black cottonwood are the dominant riparian vegetation in Type 1, 2 and 3 vegetation classes;
- Trees that exceed 150 feet are conifers;
- Vegetated areas with vegetation height less than 2 feet are likely agriculture;
- Shrub canopy height classes may or may not be agricultural.

Below are representative photo examples of the size classes designated for this assessment. The spatial distribution of tree height classes within the study area are presented in Figures C-7 through C-11. The quantitative results are presented in Graphs 3 through 9 that show the total area of tree height classes within the assessment area.

Agriculture – Pasture Size Class Example

Shrub- Size Class Example

Type 1 Pioneering Tree Species – Emerging Canopy Size Class Example (deciduous dominant)

Type 2 – Establishing Canopy Size Class Example (deciduous dominant)

Type 3 – **Maturing Canopy** Size Class Example (mixed conifer and deciduous stand)

Old Growth - Size Class Example (conifer dominant)

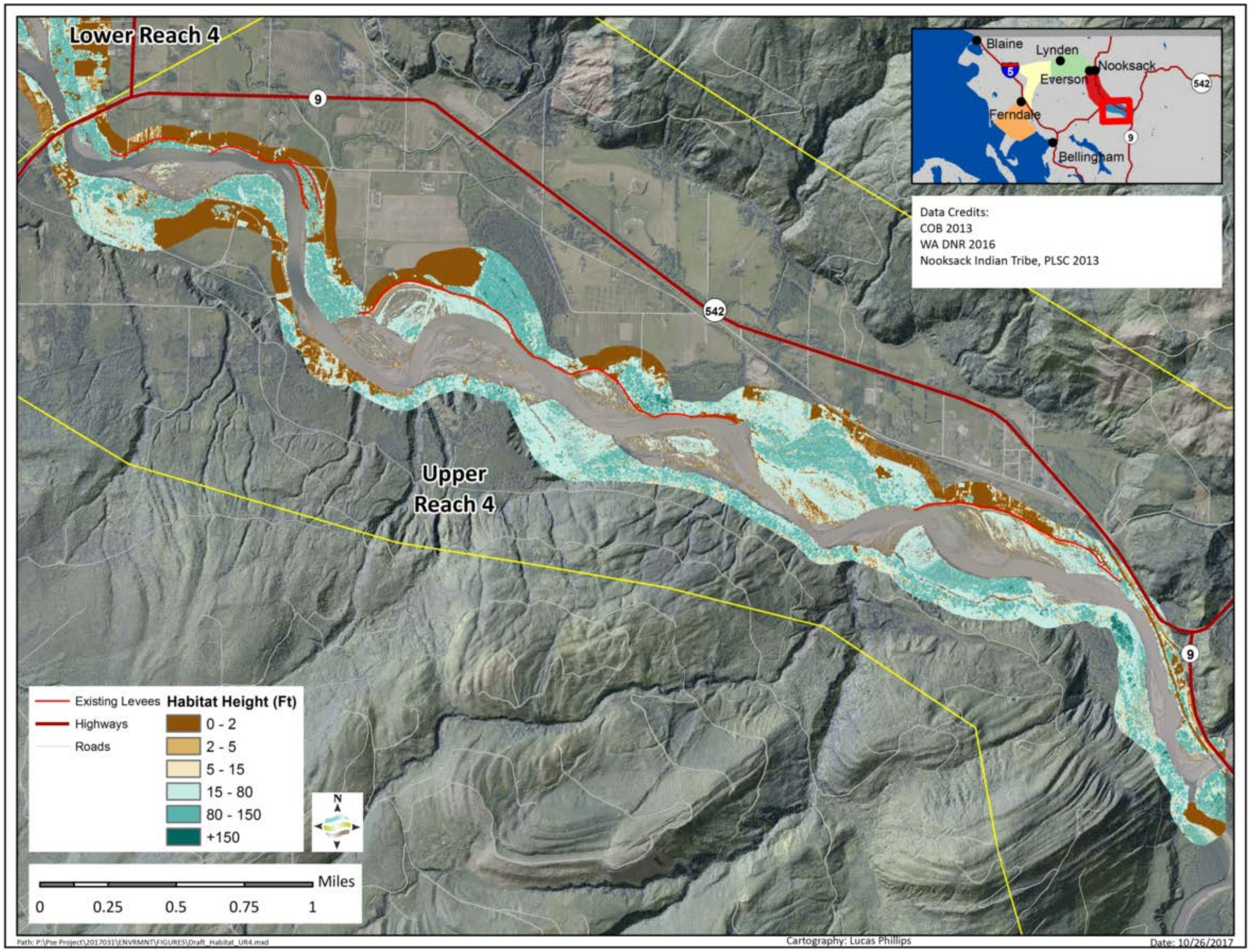


Figure C – 7: 2013 Tree Height Class Spatial Distribution in Upper Reach 4

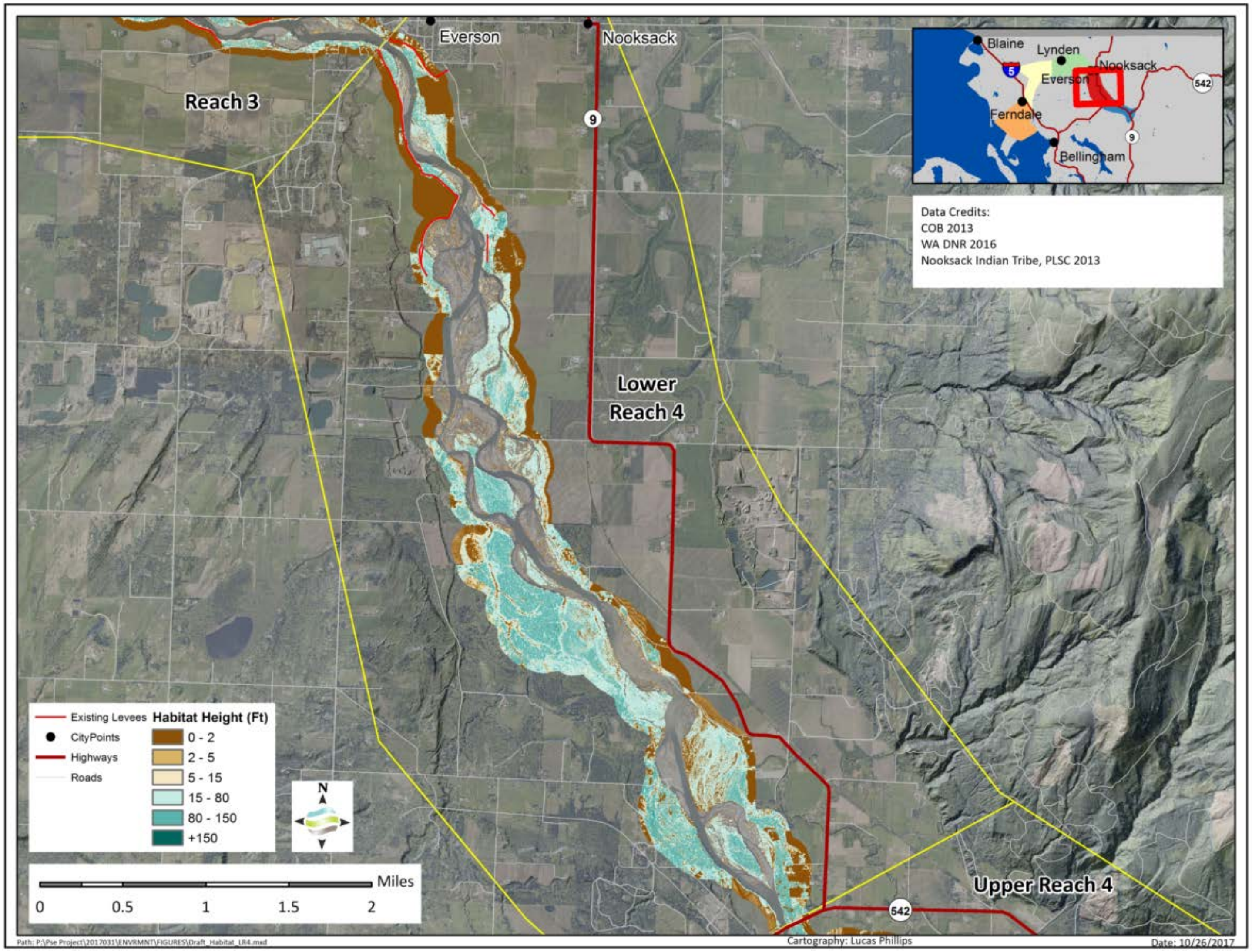


Figure C – 8: 2013 Tree Height Class Spatial Distribution in Lower Reach 4

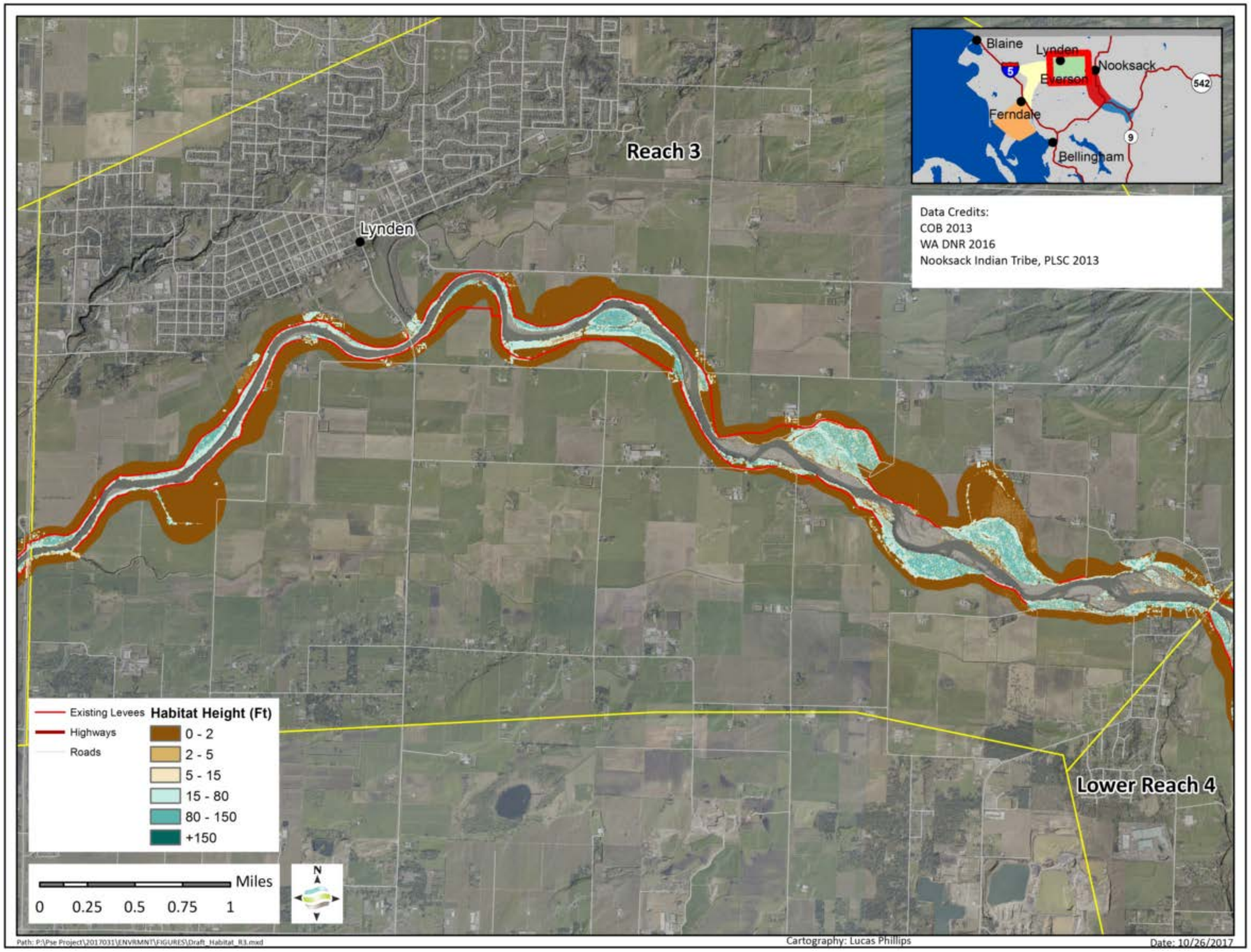


Figure C – 9: 2013 Tree Height Class Spatial Distribution in Reach 3

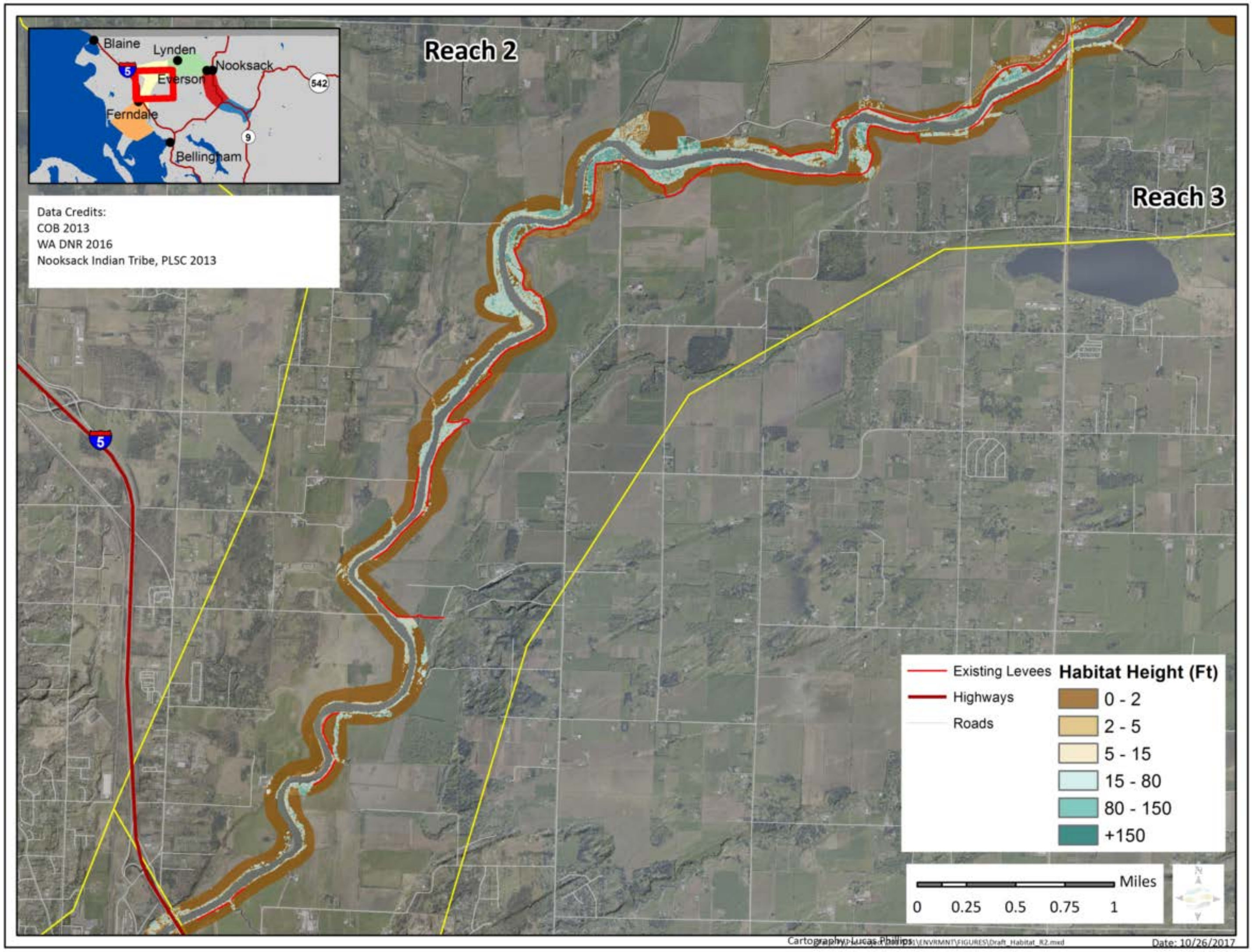


Figure C – 10: 2013 Tree Height Class Spatial Distribution in Reach 2

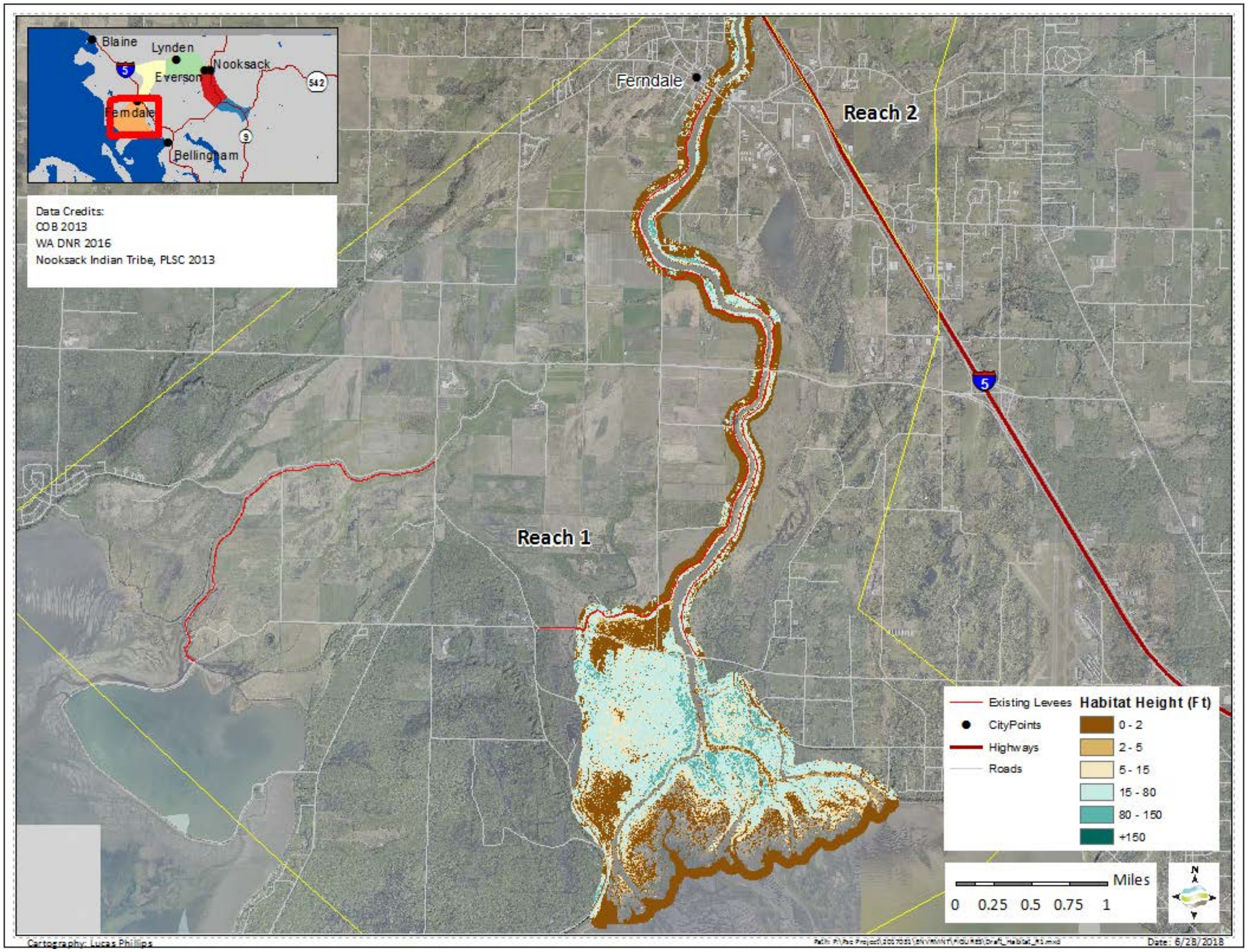
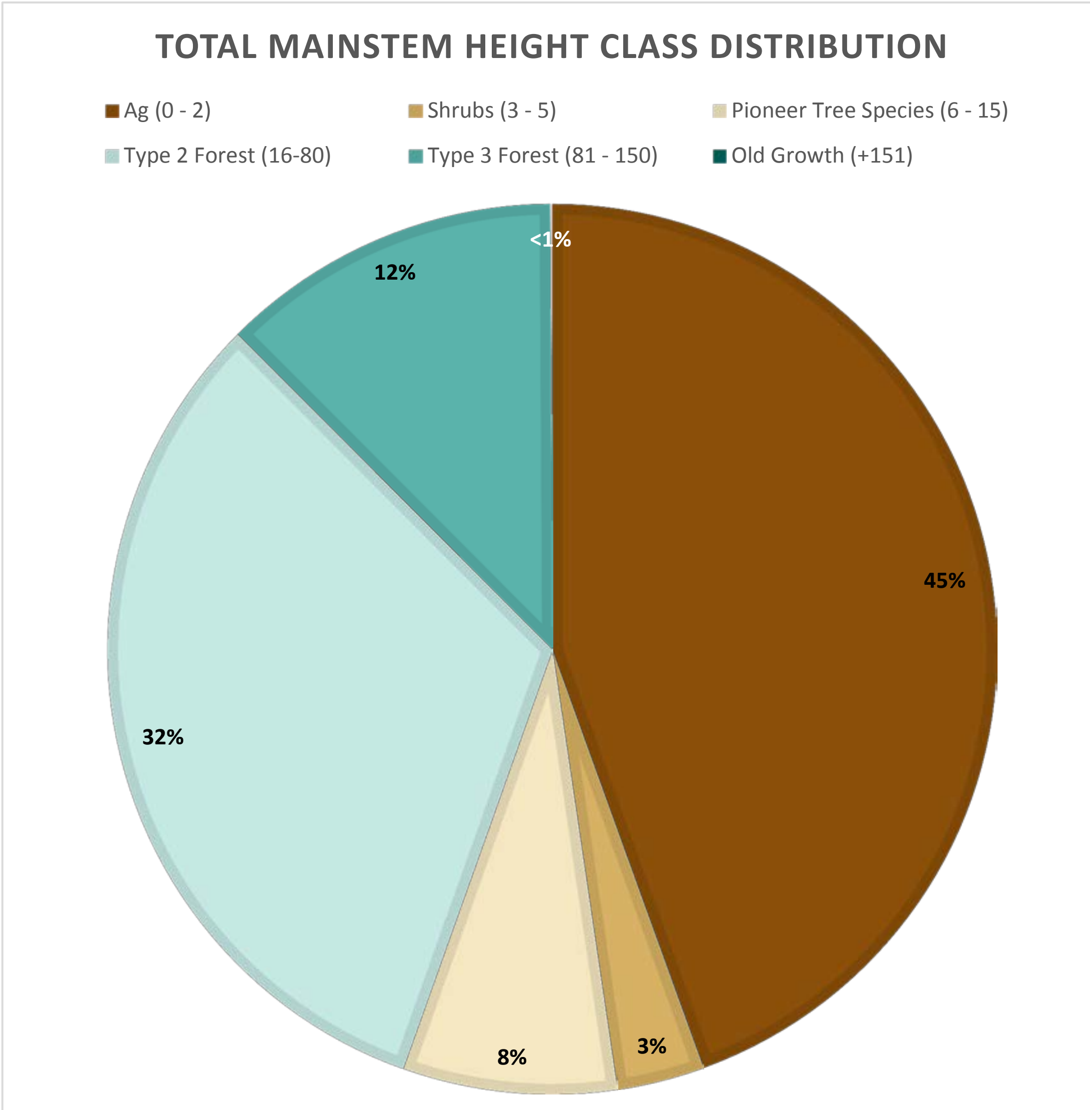


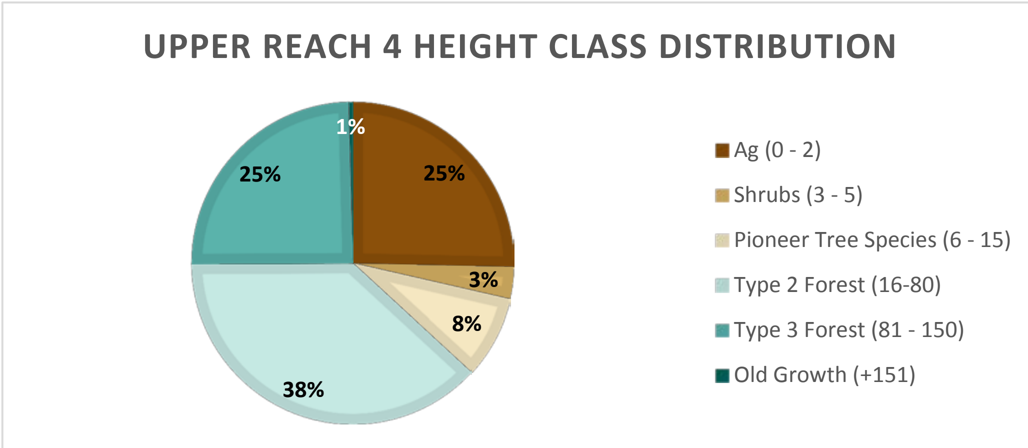
Figure C – 11: 2013 Tree Height Class Spatial Distribution in Reach 1

Graph 3: Total Lower Nooksack River Mainstem Tree Height (Ft) Distributions by Class



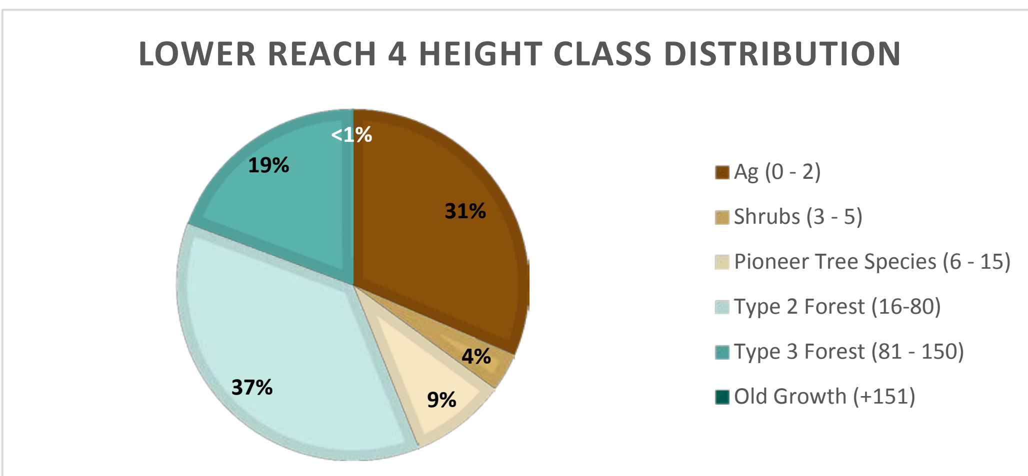
This graph demonstrates that the agricultural vegetation class dominates the HMZ of the Lower Nooksack River mainstem area. A significant proportion of the forested areas of the HMZ is comprised of Pioneering (Emerging)and Type 2 (Establishing) vegetation classes, which likely have low probability for contributing LWD that can function as stable key pieces for logjam formation. The occurrence of Type 3 (Maturing) and Old Growth vegetation currently comprise very little of the HMZ. It is anticipated that pre-disturbance conditions would have predominantly been comprised of Type 3 and Old Growth forests as characterized in Collins and Sheikh (2002).

Graph 4: Upper Reach 4 Nooksack Tree Height (Ft) Distributions by Class



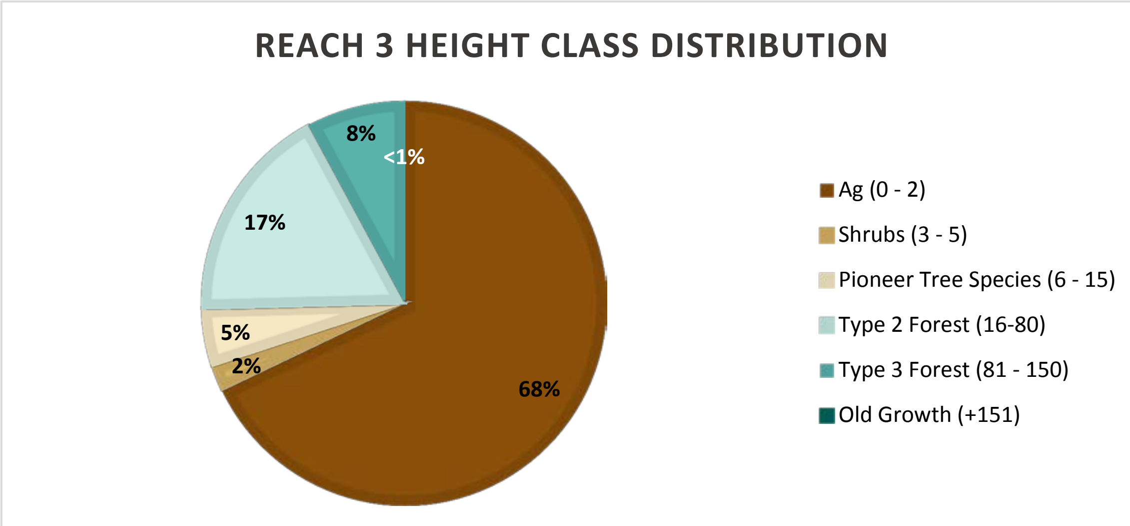
This graph shows the total vegetation height distribution in the Upper Reach 4 area of the Lower Nooksack River HMZ. A sizable percentage of the assessment area is forested and dominated by Type 2 and 3 height class vegetation. Upper Reach 4 has the largest Old Growth size class and the least agricultural vegetation size class compared to the other reaches. Upper Reach 4 has the greatest potential for providing near-term functional LWD to the system. LWD recruitment potential, however, is limited; the left bank where the canopy size is the greatest is located on the valley margin beyond the HMZ and the right bank areas where the canopy size is the greatest is located in areas of the HMZ that are isolated by bank armoring.

Graph 5: Lower Reach 4 Nooksack Tree Height (Ft) Distributions by Class



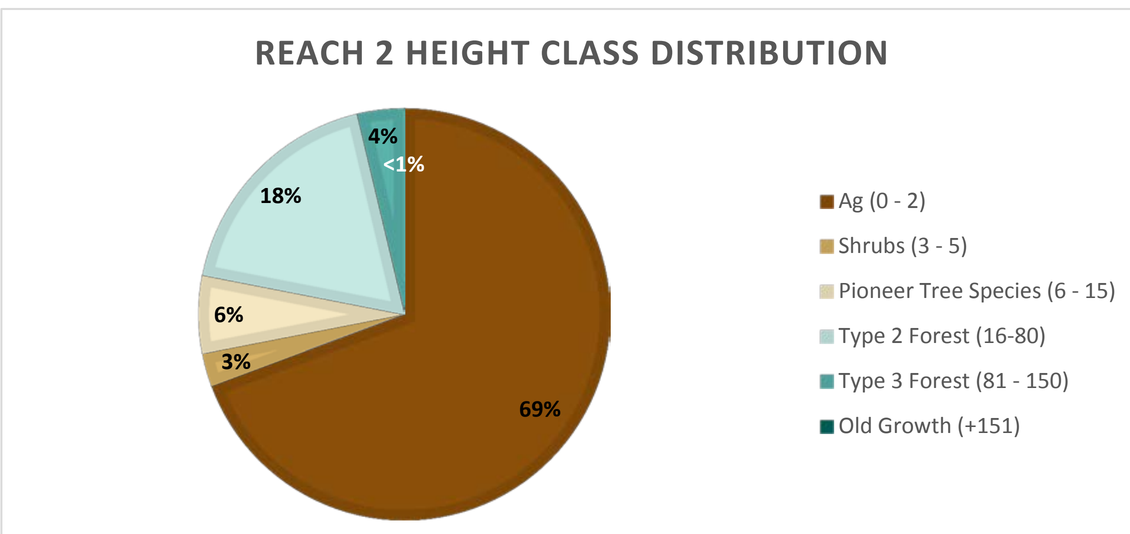
Agricultural land use within the HMZ area is higher in LR4 than UR4. The Pioneering and Type 2 canopy distribution percentages within the HMZ are similar to UR4; however, there is a reduction of Mature Forest and Old Growth size class distributions. Channel migration patterns in LR4 have influenced the quantity and spatial distribution of potential LWD; in general the greatest recruitment potential of higher functioning LWD occurs in LR4, particularly along the left bank.

Graph 6: Reach 3 Nooksack Tree Height (Ft) Distributions by Class



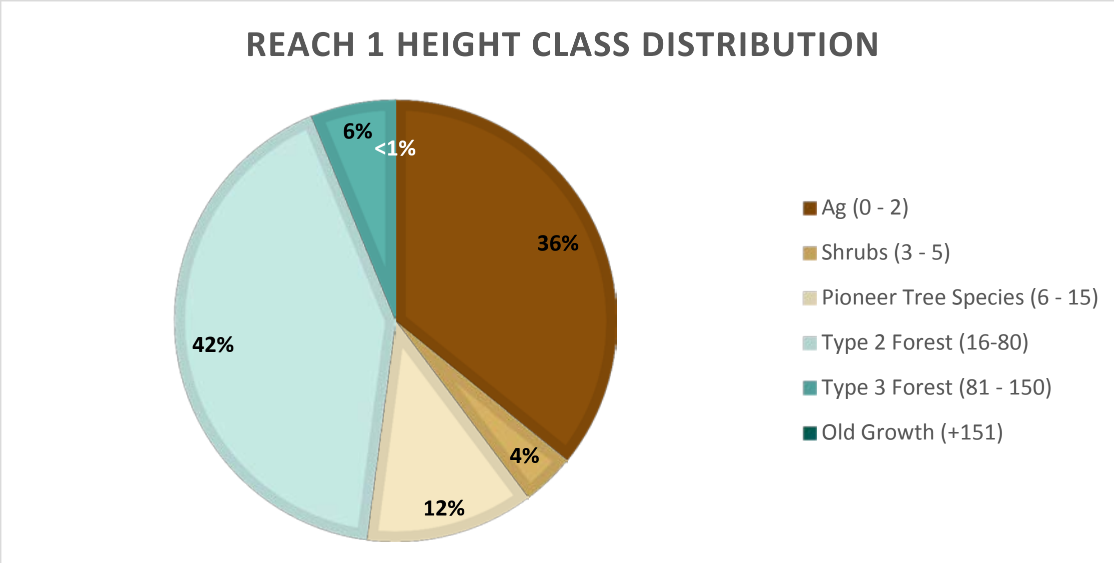
The Reach 3 Nooksack vegetation height distribution varies significantly from Reach 4. 70% of Reach 3 HMZ assessment area is dominated by agricultural and shrub vegetative classes and there is a considerable reduction in Pioneering, Type 2 and 3 height classes. Most of the vegetation with significant height occurs directly in or adjacent to the Nooksack River channel.

Graph 7: Reach 2 Nooksack Tree Height (Ft) Distributions by Class



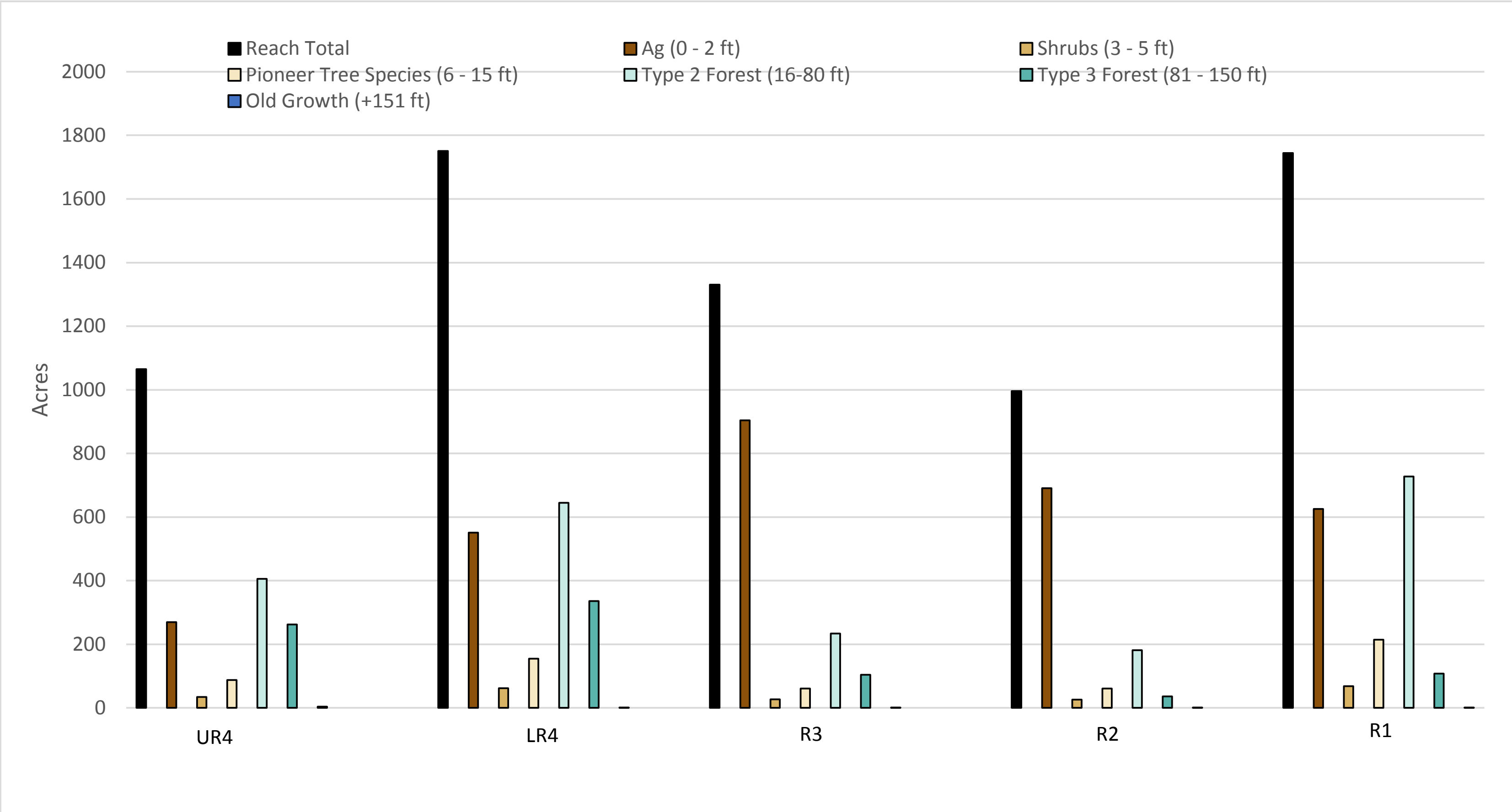
Reach 2 has vegetation height distributions similar to Reach 3, but with an overall reduction in Type 3 Forest class distribution.

Graph 8: Reach 1 Nooksack Tree Height Distributions by Class



Reach 1 has a large distribution of Type 2 height classes. There is a reduction of Agricultural vegetation class distribution when compared to those of Reaches 2 and 3. There is a distinct lack of Type 3 - Maturing vegetation size class despite the large percentage of Type 2 - Establishing size class. We hypothesize that given time, the Type 3 size class, and potentially the Old Growth size class, will increase as Type 2 forests mature. Therefore, the greatest potential for mid-term functional LWD size is in Reach 1.

Graph 9: Distribution of Vegetation Height Class Areas by Reach



The greatest quantity of potentially functional LWD (Type 3 and Old Growth) within the assessment area occurs in Reach 4. Reaches 1, 2 and 3 have the lowest quantity of larger-sized vegetation. Throughout the assessment area, the Type 2 (Establishing) vegetation condition is the most prevalent vegetation size class.

Floodplain Vegetation Conditions – Tree Canopy Composition

While the length of LWD relative to channel width and depth is a factor influencing the potential for LWD to anchor and form logjams, we hypothesize that the complexity of the LWD shape is also an important variable for determining whether LWD has the potential to anchor and form stable logjams. For example, mature big leaf maple (*Acer macrophyllum*) trees are typically less than 50 feet tall, but often form multi-stemmed trunks that may have a greater potential for anchoring than single-stemmed trees of a significantly greater height. Therefore, the floodplain forest composition could influence recruited LWD anchoring potential and habitat functions within the stream channel.

The composition of the riparian forests within the HMZ areas of the Nooksack River appears to be dominated by black cottonwood, and to a lesser extent red alder. These species are pioneering tree species and capable of establishing on mineral soils and can tolerate inundation as well as seasonal drought (photo 2). They grow rapidly and can reach maximum heights in just a few decades; however, at young ages these trees have small basal areas, narrow crowns, spindly branches, tend to be brittle, and have low rot resistance. As a result, pioneering species may have a low likelihood of forming stable logjams, even if they could result in LWD pieces that are comprised of long lengths.

Conifers such as western red cedar, Sitka spruce, and Douglas fir grow much slower and take closer to a century or longer to reach maximum heights. Big leaf maple and other non-pioneering deciduous and conifer species take close to half a century to reach full size, particularly if growing in an understory being shaded by pioneering species. The exhibits shown below are LiDAR point return profiles of several representative forest canopy areas in the study reach. These illustrations demonstrate various successional characteristics and compositions of the riparian canopies.

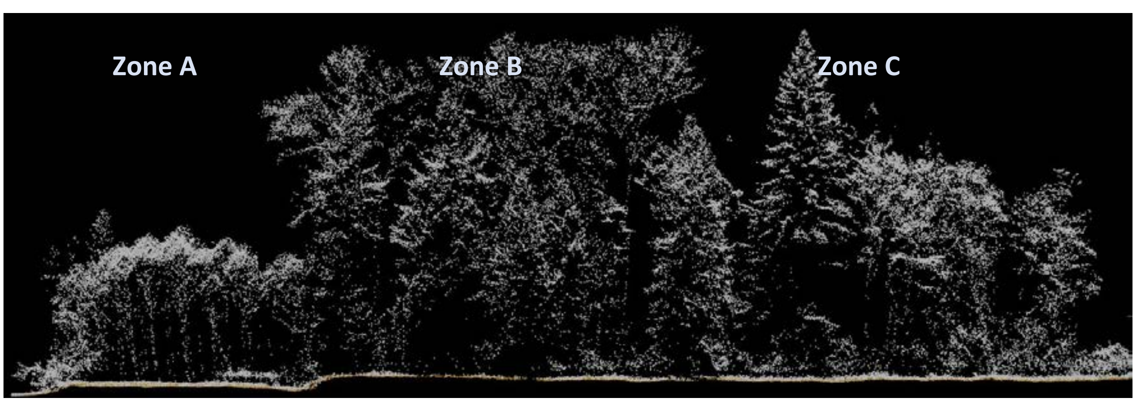


Exhibit 1 (above): This LiDAR LAS point profile from Reach 4 shows emerging, establishing, and mature canopies based on height classes, but also shows the evolution of forest succession. The canopy in Zone A on the lower terrace is homogenous in tree type (black cottonwood), age class (approximately 10 years in age), and height (approximately 30 feet in height). The canopy in Zone B is more diverse and includes mature black cottonwood at their maximum height (approximately 150 feet) and crown width (approximately 75 feet). Conifers emerging from the understory in Zone B are visible and are roughly 50 – 75% of the height of the cottonwoods. The age class represented in Zone B is approximately 50 years. Zone C shows a forest that has evolved beyond the pioneering canopy stage and includes mature conifers, big leaf maples, and a more robust shrub understory; however it has a lower overall vegetation height and tree count density as observed in photo 3.


Photo 3

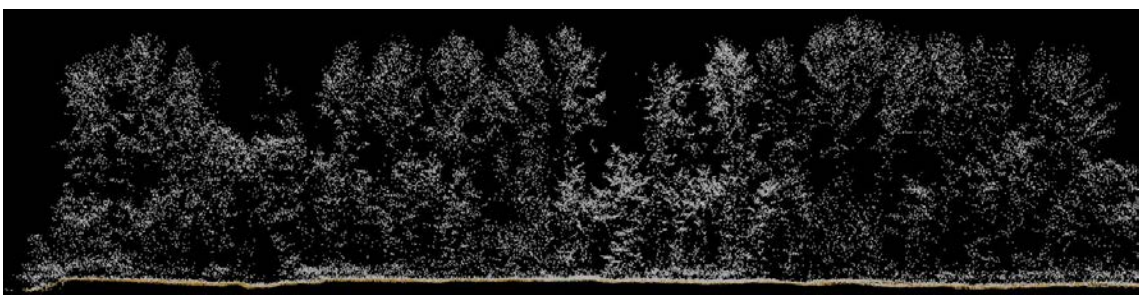


Exhibit 2 (above): This LiDAR profile shows the relatively homogenous nature of much of the riparian conditions prevalent in Reach 4: a uniform age and stand height of a black cottonwood tree canopy. This type of riparian forest exists where floodplain turnover rates are high. Over time, this homogeneous forest could evolve into the Zone B and Zone C type conditions shown in Exhibit 1.

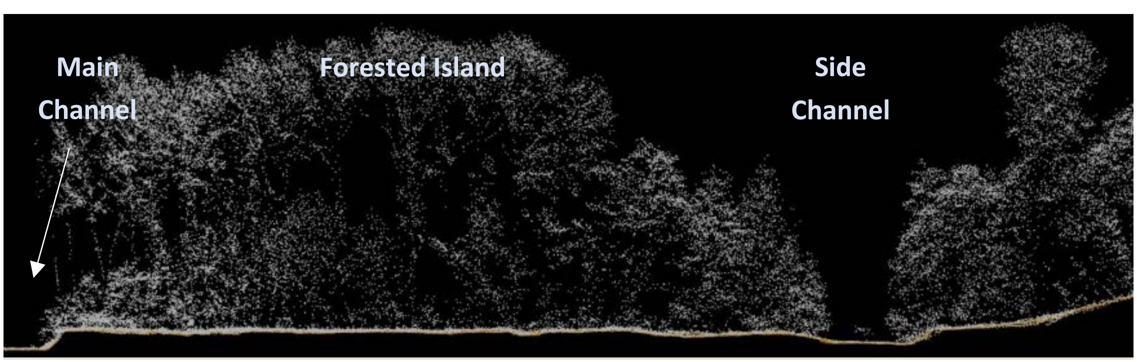
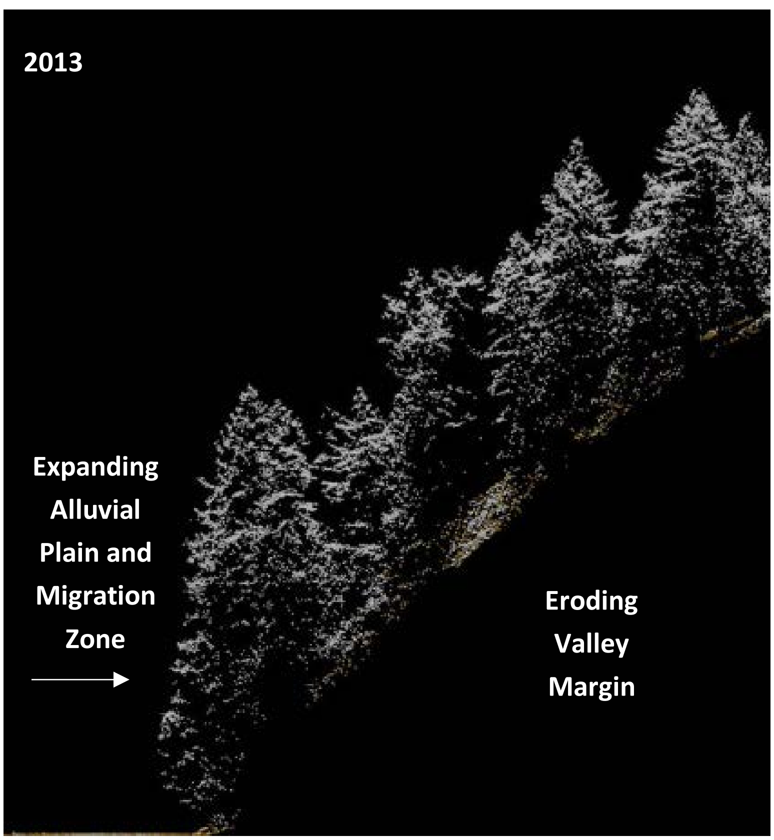


Exhibit 3 (above): This LiDAR profile shows a maturing forested island and side channel that is likely activated at moderate flows, but dry at low flows. The composition of this forest is black cottonwood dominated with an emerging conifer understory. The cottonwoods in the center of the forested island are beginning to develop more robust, wider crowns which likely have a better chance of anchoring than the younger cottonwoods along the main channel, even though both stands or of similar height. The shade function provided by tall canopies adjacent to side channels would be expected to have greater influence on regulating water temperature. Side channels have lower flow volumes and shallower depths than larger main channels, and therefore are more susceptible to being warmed by the sun. Due to the narrow widths of side channels, the probability of LWD anchoring is greater than in the mainstem channels; therefore, forests adjacent to side channels may have greater potential for improving habitat value. The roughness of forested floodplains is more effective than unforested floodplains at creating flow velocity refuge for salmonids during times of higher flows. Roughness along the floodplain floor visually appears to be greater in maturing forest canopies and in areas adjacent to channel edges than in dense emerging forests.



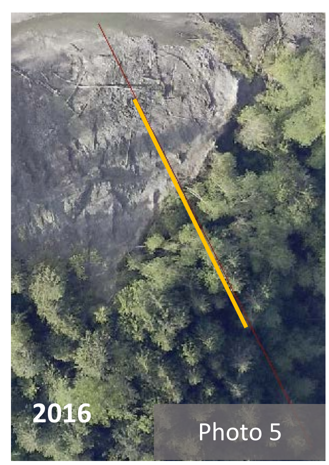


Exhibit 4: This LiDAR profile is of a maturing conifer stand. This exhibit also demonstrates the potential for LWD recruitment from areas outside of the floodplain and HMZ. In this example, the channel migration processes are widening the valley by eroding into the valley margin. Channel migration between 2013 and 2016 eroded into the valley margin at this location and caused slope instability and mass wasting. Photo 4 shows transect shown in the LAS profile and the conditions in 2013 prior to the mass wasting event. Photo 5 shows the loss of vegetation from a mass wasting event. These trees were recruited into the Nooksack River, but did not appear to form logjams adjacent to where they were recruited from. At this location, the valley margin is comprised of sediment deposited during the Pleistocene glacial period and is commonly referred to as the "clay bank". The clay bank provides a significant quantity of fine-grained sediment from mass wasting associated with valley expansion and channel migration processes; it also is a source for LWD recruitment.

Floodplain Vegetation Conditions Summary and Discussion

- Agricultural and Pioneering vegetation size class categories dominate the HMZ areas of the Lower Nooksack River.
- Reach 4 has the greatest quantity of Maturing and Old Growth canopy heights that potentially could be recruited to the channel as LWD and potentially form stable instream logjams; however, given current riparian forest heights, composition, and bank armoring, this potential is likely very low.
- Tree composition may influence recruited LWD's ability to anchor. Trees with multiple stems or with large, robust branch networks and basal areas appear to have a greater ability to anchor in the mainstem than long, single stem LWD pieces. This could make big leaf maple and mature branched cottonwoods potentially more suitable for logjam formation.
- The influence of riparian forests (size, composition, recruited LWD function, and shade benefit) likely has a greater influence on salmonid habitat in side channels than it does in the mainstem channel because of narrow channel widths.

In our analysis of vegetation heights, we determined that tree height did not necessary correlate as well as anticipated with tree age, particularly at the mid-to-tall tree heights. We hypothesize that this is a result of the different tree species occurring within the area of assessment. For the assessment area, we identified that black cottonwood trees appear to be the dominant tree species in the Lower Nooksack River riparian zone. We discovered that black cottonwoods, as pioneering species, grow incredibly fast in their early stages of life and within the study area. We identified that some stands of black cottonwoods were 80 feet tall at only 30 years in age, whereas some stands of mixed conifer-deciduous trees were 80 feet tall at closer to 75 years in age.

Riparian composition and recruited LWD characteristics changed from Reach 4 to the lower reaches. In the lower reaches, where channel migration rates are very low, riparian vegetation adjacent to the channel was fairly mature (large cottonwoods, willow species, and red alder); however conifer understories were generally lacking in these maturing forests. In Reach 4, the vegetative communities adjacent to the river were comparatively younger and smaller, but conifer understories were typically developing beneath maturing pioneer forests.

Single, large trees recruited into the river in Reaches 1 through 3 were observed to occasionally anchor near to where they were recruited, but logjams did not seem to form on these key pieces. It is likely that where narrow bankfull channel conditions exist, more vertical changes in water surface occur and LWD that does rack on key pieces is floated off during higher flow stages.

In Reach 4 where channel migration is more active, the floodplain and valley margins are a frequent source area for LWD recruitment. For relatively stable reaches, such as the reaches downstream of Everson, it is only the immediate riparian zone adjacent to the channel banks that serve as a potential source of LWD recruitment.

Instream Conditions - Forested Islands, Backwater Channel Forms, and Active Channel Area

Forested Islands

Forested islands and channel forms influence the movement of water and sediment and control a number of parameters important to salmonid habitat conditions. The physical form of a channel and formation of mid-channel islands is a response to numerous variables, including slope, bedload, and bank composition. For the mainstem of the Lower Nooksack River system, the occurrence of forested island forms vary by reach and time as characterized in Appendix B and demonstrated in the Lower Reach 4 analysis. The natural system channel forms observed in the GLO mapping of the Nooksack River were, in general, more complex than modern channel forms and the historic mapping reveals anabranching channel forms were dominant in Reach 4 and lacking below Reach 3 (excluding the Reach 1 delta area).

The channel forms present within the modern Lower Nooksack River described in the 2013-2016 characterization reflect the cumulative impacts of river management and the stasis of the variables that influence channel form, including forested islands. The 2013-2016 conditions represent only a snap-shot in time, but Appendix B shows the trends over the past century as the modern Nooksack River channel adapts and responds to the new paradigm.

For this analysis we evaluated:

- The quantity of forested islands by reach, and
- The quantity of low flow backwater channel features ("blind channels" or "alcoves") by reach (Photo 6 above).

The characterization utilized the channel conditions as captured in the 2013 digital orthorectified aerial imagery and LiDAR DEM. The metrics of this characterization are presented in Tables 3 and 4 and summarized below.

Table 3: 2016 Forested Island Occurrence and Metrics by Reach

Reach	*Forested Island Quantity*	*Forested Island Area (acres)*
Upper Reach 4	2	56
Lower Reach 4	7	189
Reach 3	2	17
Reach 2	0	0
Reach 1	6	300

Forested Island Characterization Summary and Discussion

- Lower Reach 4 has the greatest occurrence of forested islands.
- Lower Reach 4 has nearly 4 times the quantity of forested island occurrence and total forested island area than Upper Reach 4; floodplain management is likely the greatest influence on the reduced occurrence of forested islands in Upper Reach 4.
- Reach 1 has the greatest total forested island area.

While forested island quantity and area change over time as demonstrated in Appendix B, there are trends as to where the forested islands occur. Throughout the modern era, Lower Reach 4 has consistently been the reach with the greatest quantity and spatial area of forested islands. However, Reach 4 of the Nooksack River has shown a net decline of forested island area over the past century and considerably less than in the pre-disturbed conditions as inferred from GLO mapping and LiDAR topography. In particular, Upper Reach 4 is an area where forested islands would be predicted based on geomorphic conditions; however, they are distinctly lacking. It appears that the subtle differences between Upper Reach 4 and Lower Reach 4 mean the difference between having forested islands and not having forested islands. The overall channel morphology in Reaches 2 and 3 would not typically support large quantities of forested islands; however, forested islands in upper Reach 3 are possible.

The occurrences of forested islands may correlate to changes in bankfull channel area, reduction of the HMZ, loss of LWD and logjams, and confinement. We hypothesize that it is likely sediment transport conditions that are the primary driver in the smaller time-scale variability in forested island area; however, it bank armoring conditions and confinement that are the primary driver in determining whether or not forested islands can persist in Reach 4.

Backwater Features

Backwater features add to hydraulic complexity and can provide low velocity refuge areas for salmonids. We utilized 2013 air photo and LiDAR to locate and quantify where backwater features could be observed in the photo. Table 4 summarizes our tabulation.

Table 4: Low flow Backwater Feature (Blind Channel and Alcove) Occurrence by Reach

Reach	*Backwater Feature Quantity*
Upper Reach 4	8
Lower Reach 4	17
Reach 3	3
Reach 2	0
Reach 1	2

Backwater Feature Characterization Summary and Discussion

Lower Reach 4 has the highest occurrence of backwater features (blind channels-alcove) by reach and per river mile. Photo 7 is an example of a backwater feature common in Lower Reach 4. This physical condition provides for backwater habitat. Often these features are recharged with hyporheic flow and provide not only low flow refuge, but can be zones of higher water quality (temperature and turbidity). There was distinct contrast in backwater

Photo 7

feature quantity between Upper and Lower Reach 4. Below Reach 4, there were few backwater features observed in the air photo record.

Instream Habitat Area


Photo 8

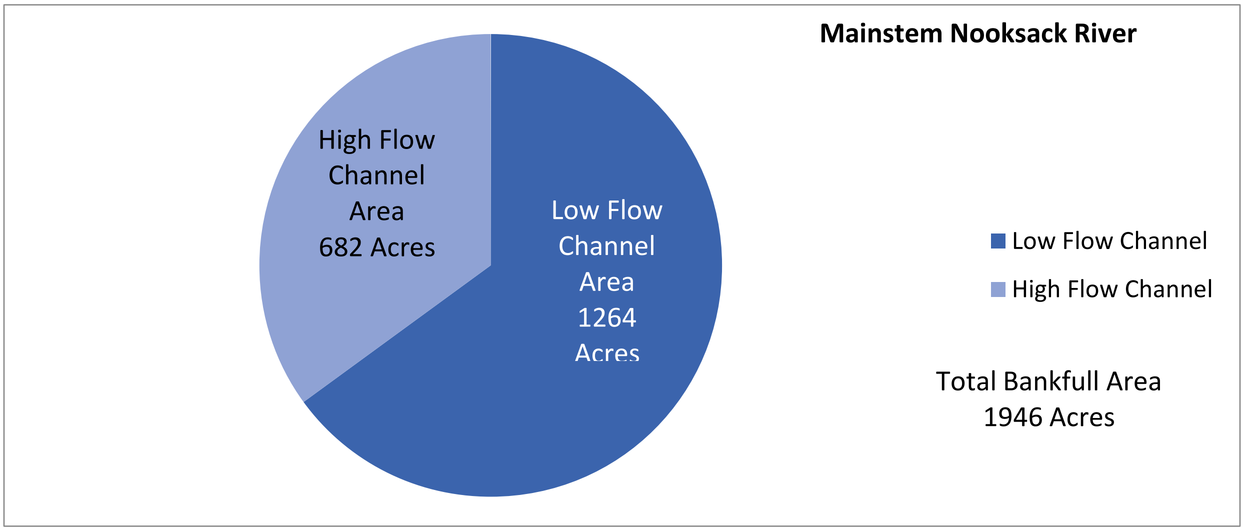
Bankfull flows are important both in fluvial morphology processes, but also enabling in habitat utilization. Bankfull area is often a parameter in defining the physical characteristics of a river (Leopold, et. al. 1964). Bankfull flows are those flows that are contained within the channel banks at the verge of accessing the floodplain. Bankfull flows have the least flow resistance and are therefore efficient at moving water and sediment (Petts and Foster, 1985). Because of the frequent recurrence of bankfull flows (approximately 1 to 2 year event) and the degree of water and sediment movement, these flows are considered vital at creating and maintaining habitat (Leopold, et. al. 1964; Mosley, 1981). For this analysis, we did not delineate bankfull areas. Instead, we estimated a "bankfull area" by mapping the "active channel" area as inferred from the open or unvegetated gravel bars observed in an air photo. It is likely that this slightly underestimates a true bankfull area. It is also possible that the bankfull area correlations typically made for analysis may not apply to the Nooksack River because of the degree of channel, bank, and floodplain modifications. Photo 8 above shows an example in cross section view of a low flow channel and open bar in Reach 4.

Bankfull Area Estimates

The inferred bankfull area for this analysis was estimated from 2016 aerial imagery by digitizing open bar areas which we termed the high flow channel area consistent with Collins and Sheikh (2004) historic mapping effort. We also digitized the wetted channel areas we termed the low flow channel occupied areas visible on the air photo. While this approach may not produce the most accurate estimation of bankfull area, it enabled a rapid characterization and provides for a screening-level tool for targeting areas in which more detailed width to depth ratios or wetted perimeter metrics would be valuable in further characterizing or quantifying important habitat areas. The findings from this assessment are provided in Graphs 10 through 12.

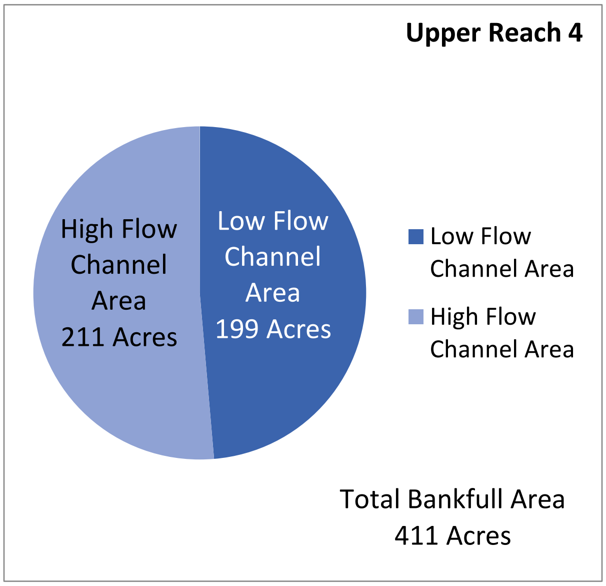
Graph 10: Total Bankfull Area of the Nooksack River Study Area (2016)

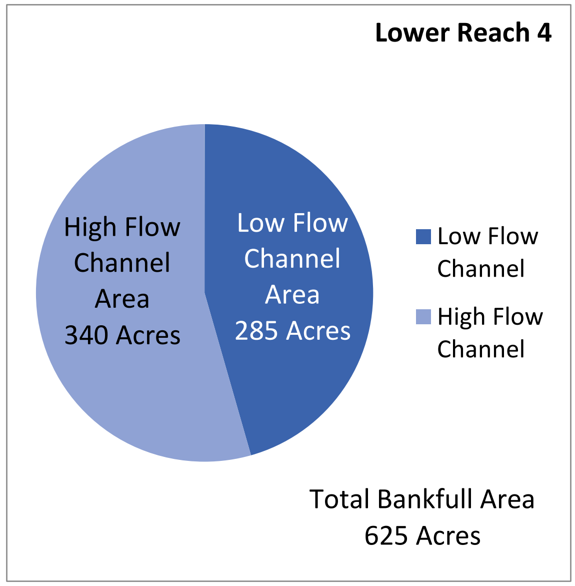
Using the high flow and low flow areas mapped for the study reach, we estimated a total bankfull channel area of 1946 acres, with the low flow occupying 1264 acres and the high flow channel occupying approximately 682 acres. The high flow channel area is approximately 54% greater than the low flow channel area, indicating a relatively narrow bankfull channel area relative to the low flow channel area.



Graph 11: Bankfull Area of Upper and Lower Reach 4 (2016)

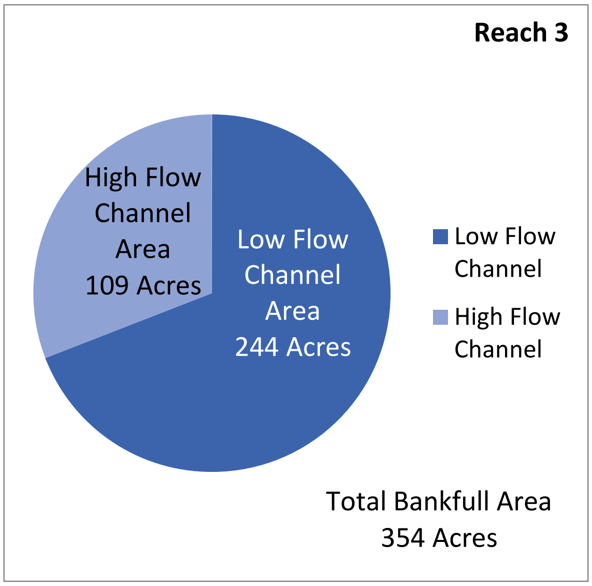
The bankfull area of Reach 4 is relatively broad. The bankfull channel areas are roughly twice as large as the low flow areas. This suggests that as flows increase from low flow conditions toward bankfull conditions, the increasing flows would tend to spread laterally rather than increase vertically. This likely increases the useable habitat area along the channel margin and wetted perimeter. The bankfull characteristics of Reach 4 reflect the channel form, rate of channel migration, sediment load, and degree of confinement. Without confinement, the conditions of Upper Reach 4 may be more likely to resemble the bankfull conditions of Lower Reach 4.

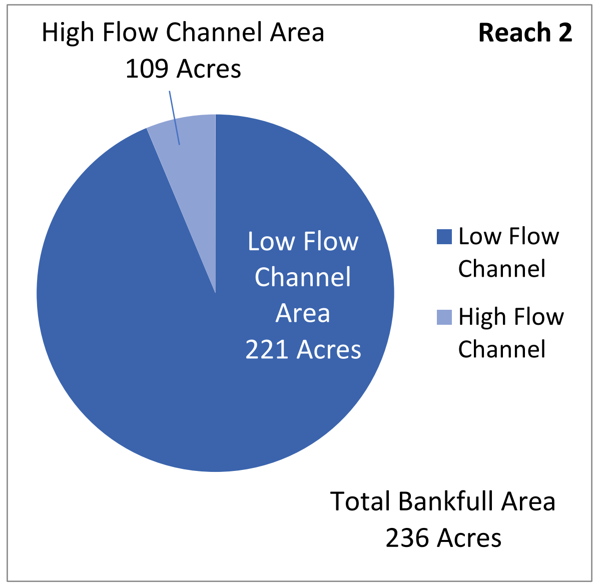




Graph 12: Bankfull Area of Reach 3, Reach 2

We observed a steady decrease in bankfull channel area downstream of Reach 4. As flows increase from low flow conditions toward bankfull conditions, the water in these reaches is more likely to increase vertically as opposed to spread out laterally. As a result, there may not as signficant an increase in habitat area, but there may be more signicant influence of channel bank edge habitat in these reaches.



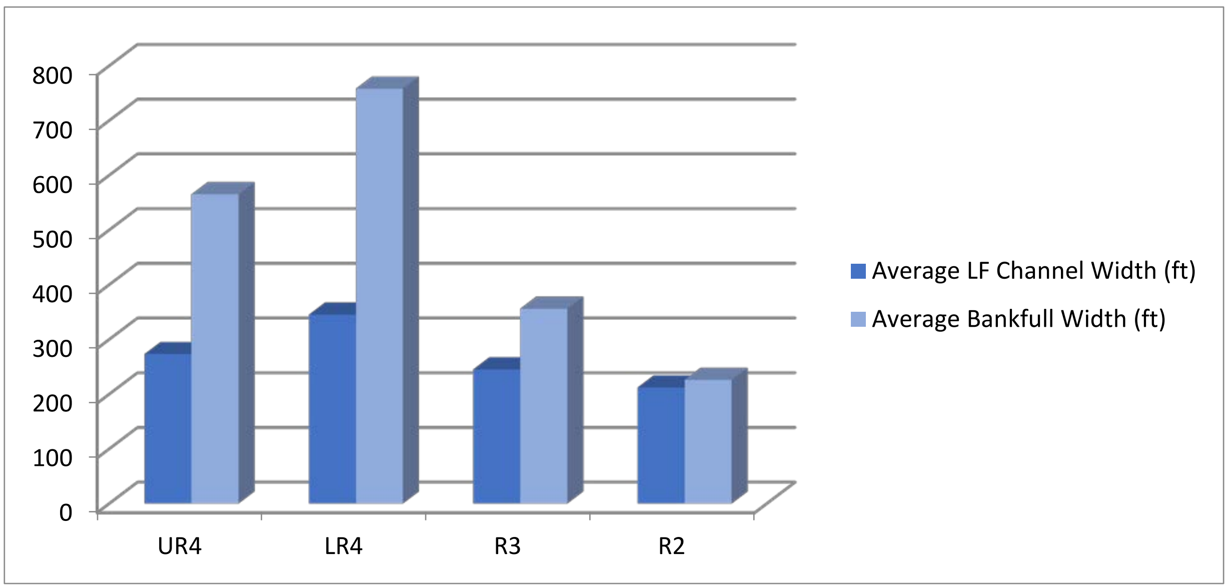


Note: Reach 1 was excluded from this analysis as the low flow and high flow channels are not able to be delineated from air photo analysis since there are no open bars.

Table 5: 2016 Reach 2 through 4 Bankfull Metrics Summary

Reach	*Reach Length (ft) (based on main channel length)*	*Average Low flow Channel Width (feet)*	*Average Bankfull Width (feet)*
Upper Reach 4	31,680	273	565
Lower Reach 4	35,904	345	758
Reach 3	43,296	245	356
Reach 2	45,408	212	226

Note: Reach 1 was excluded from Table 5 and Graphic 13 as the low flow and high flow channels are not able to be delineated from air photo analysis since there are no open bars.



Graph 13: Bankfull (High Flow - HF) and Low Flow (LF) Average Widths (Reaches 2 – 4)

Bankfull Channel Characterization Summary

- Lower Reach 4 has the widest average bankfull width and average low flow channel width.
- Lower Reach 4 has the greatest increase from low flow channel area to bankfull channel area (54% increase).
- Reach 4 average bankfull channel widths are 50% larger than the low flow channel widths.
- Reaches 1 and 2 have the least change from low flow channel to bankfull channel area (less than 6% increase).

- In general, bankfull widths tend to decrease in the downstream direction.

Large Woody Debris and Logjam Occurrence

Large Woody Debris Accumulations in the Bankfull Channel Area

The presence of LWD accumulations and formations of logjams in the bankfull channel area can influence the movement of water and sediment, including wood, in a fluvial system which can provide salmonid habitat. LWD that anchors and creates logjams can influence localized hydraulic conditions that result in scour pools, deposition, abrupt velocity gradients, cover, flow deflection, and surface water mounding; conditions identified as beneficial for salmonid habitat. With larger logjams or more numerous logjams, the increase in channel roughness may influence system-wide processes such as bankfull channel area, channel form, lateral migration, avulsion processes, hyporheic and groundwater surcharge, and floodplain inundation area.

For this assessment, we characterized LWD accumulations that formed “logjams” within the bankfull channel (low flow channel plus open bar areas) observable in the 2016 DOQ. We defined logjams as organized accumulations of LWD that met the following criteria:

- LWD accumulations of 10 or more pieces;
- Occurs within the bankfull area, and;
- Has an observable geomorphic signature.

Logjams meeting these criteria were mapped in GIS. An example of this mapping is shown in Exhibit 5 below.

Exhibit 5: 2016 DOQ with example of LWD accumulations that met the “logjam” criteria and were mapped as indicated by pink markers.

An inventory of LWD occurrence was previously mapped using the 2004 aerial imagery (Whatcom County). While the criteria used to map these LWD appear to be different than those used for the 2016 logjam mapping, we referenced this data for comparative purposes only to determine if there were potential spatial and temporal trends in LWD accumulation areas or patterns in logjam quantities. An example of the 2004 mapping with the 2004 aerial imagery is shown in Exhibit 6.

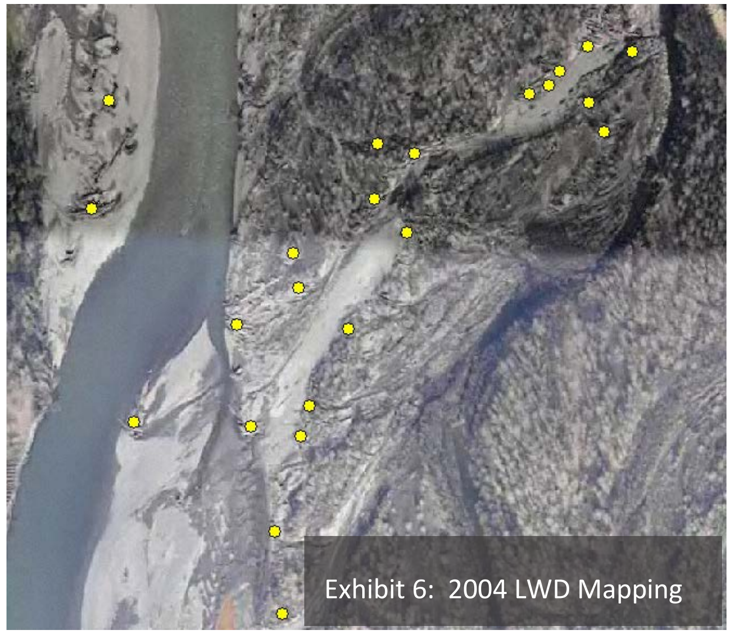


Exhibit 6: 2004 LWD Mapping

The 2004 LWD distribution and 2016 logjam distribution are presented in Figures C-12 through C-16 and quantified in Graph 14.

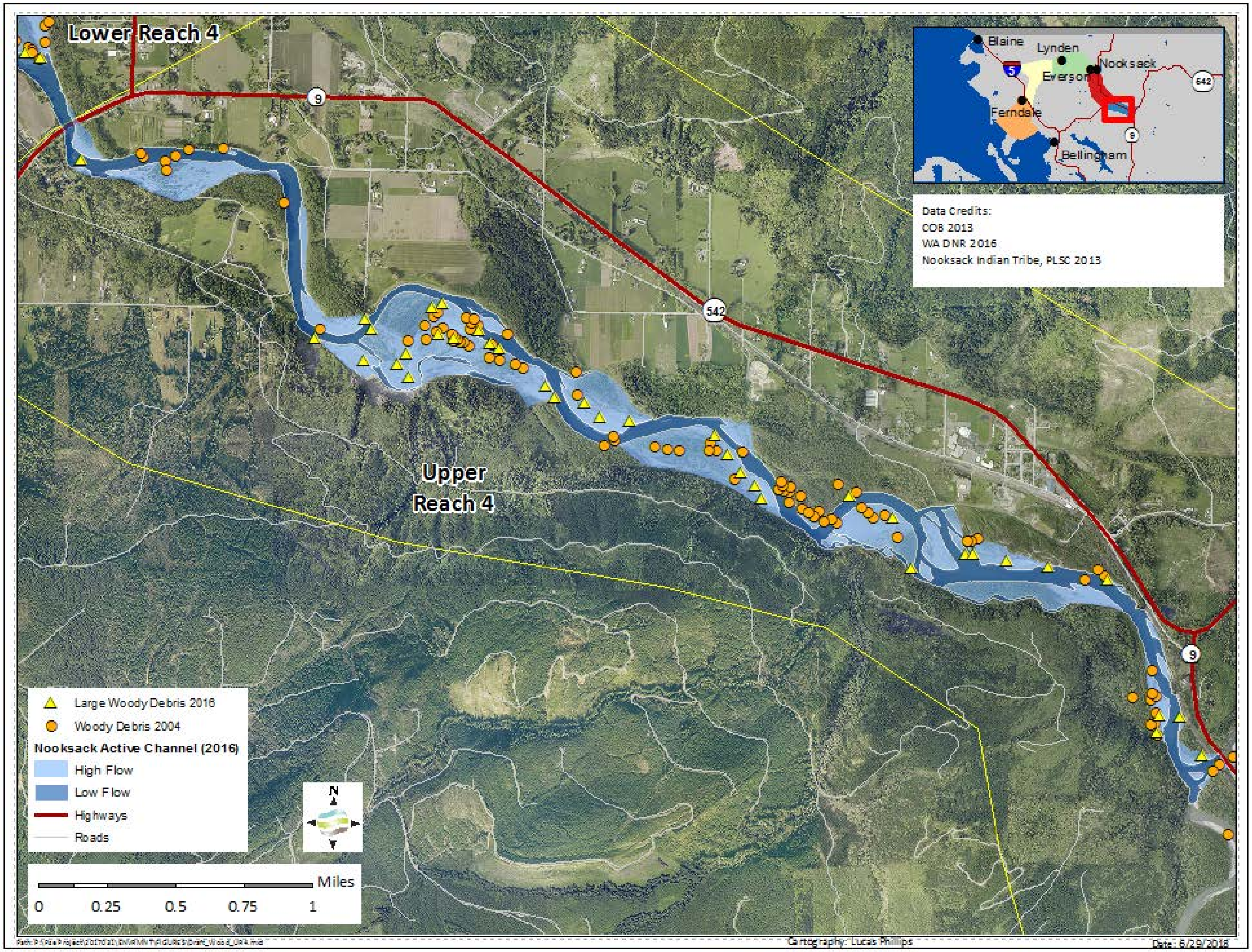


Figure C – 12: 2004 LWD and 2016 Logjam Distribution in Upper Reach 4

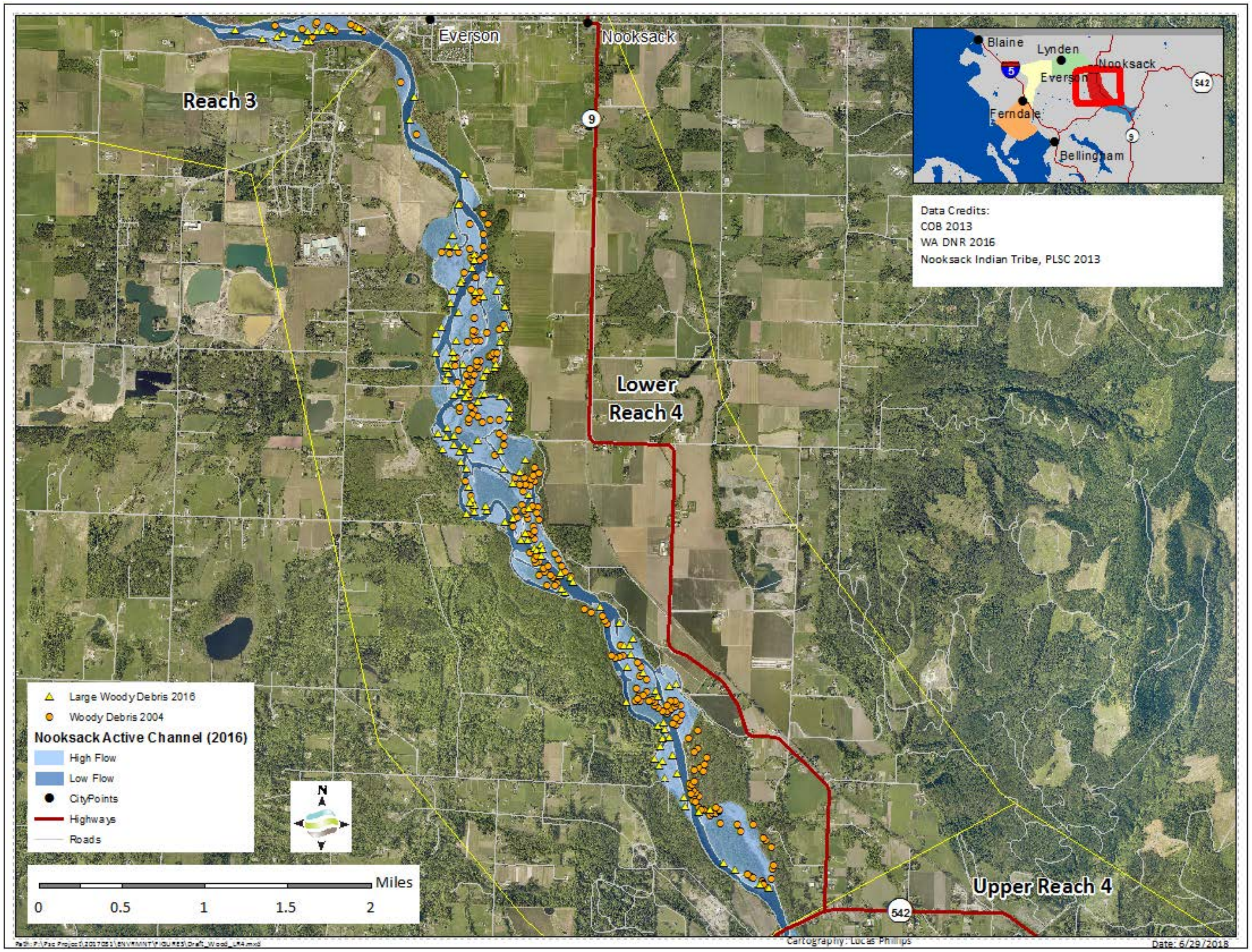


Figure C – 13: 2004 LWD and 2016 Logjam Distribution in Lower Reach 4

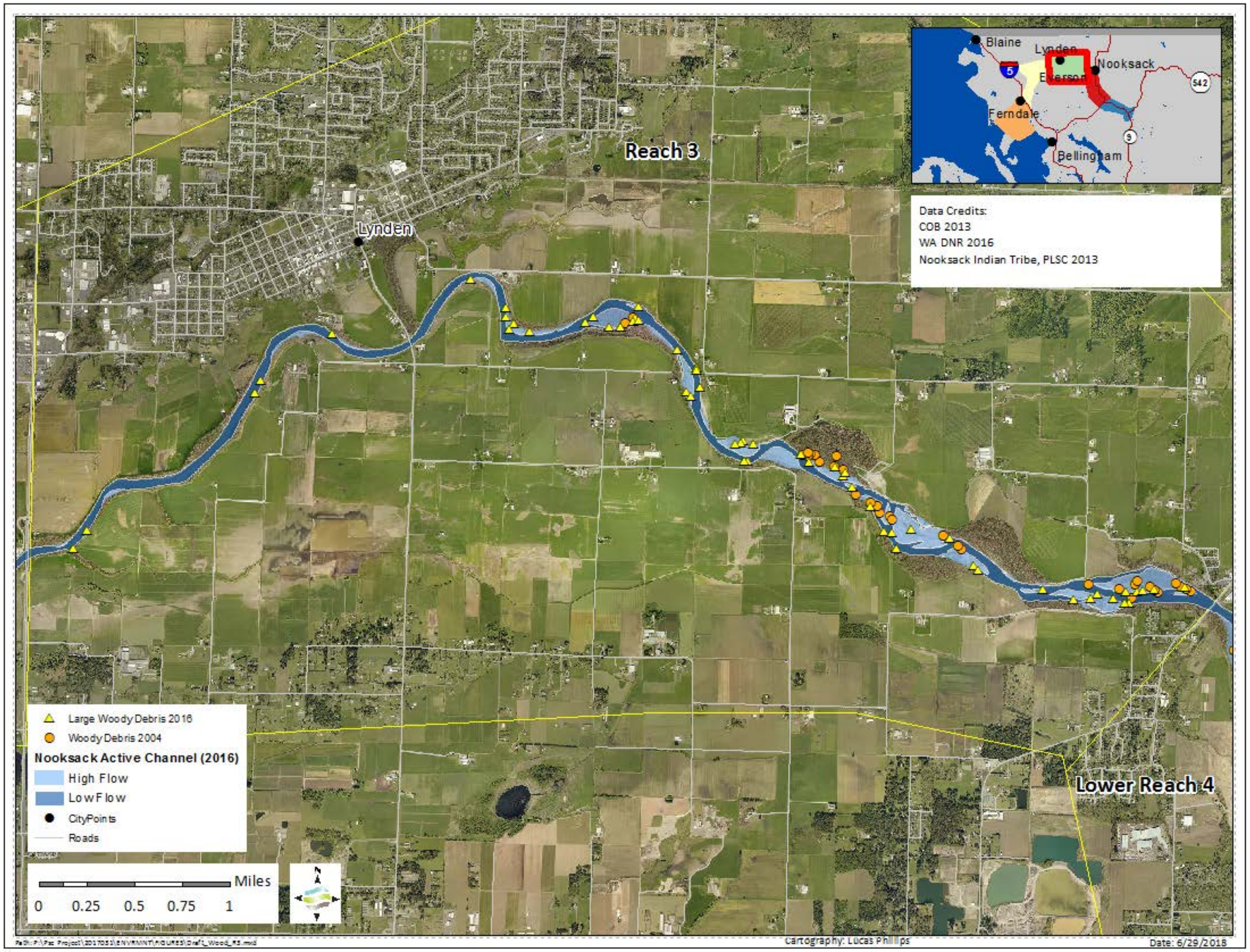


Figure C – 14: 2004 LWD and 2016 Logjam Distribution in Reach 3

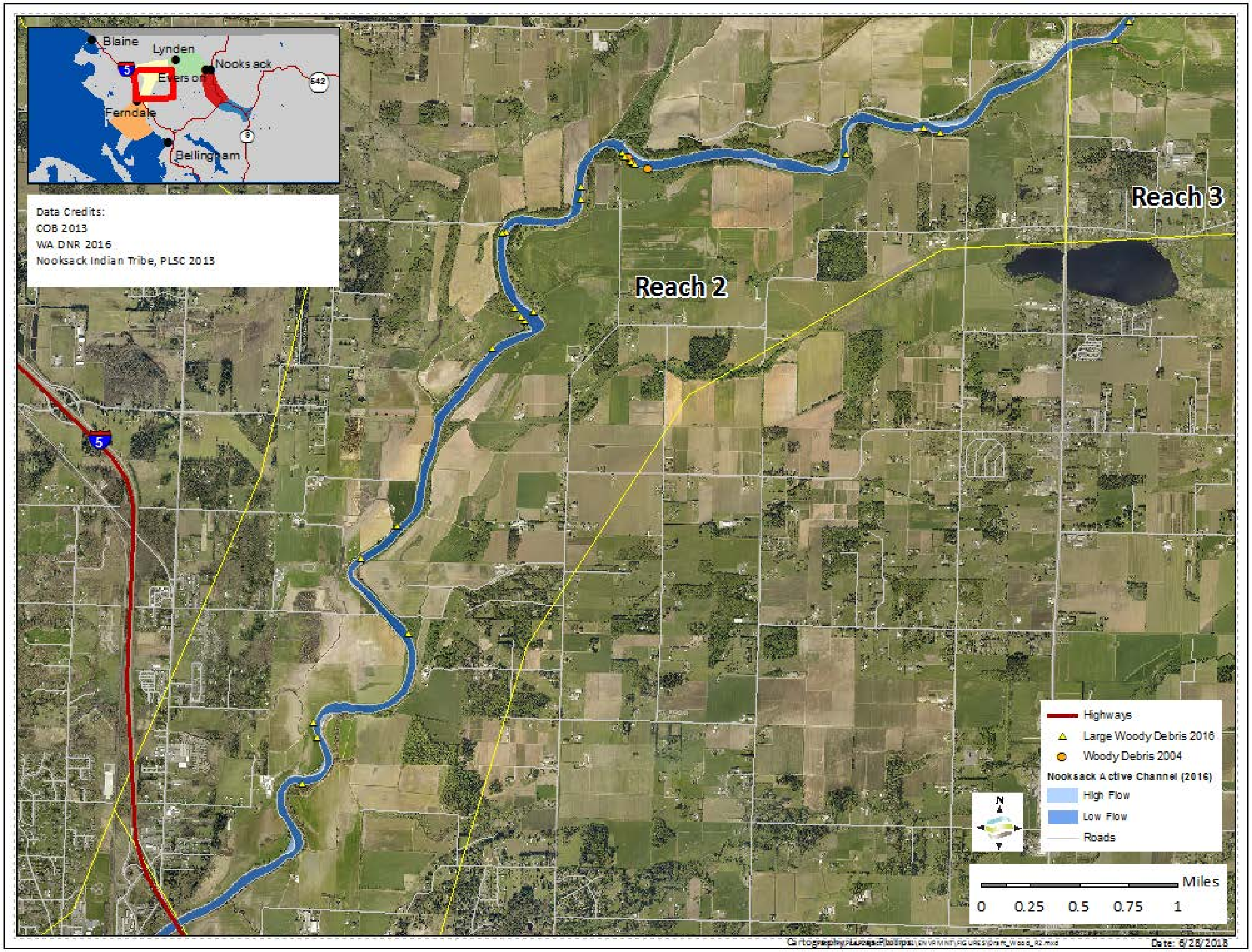


Figure C – 15: 2004 LWD and 2016 Logjam Distribution in Reach 2

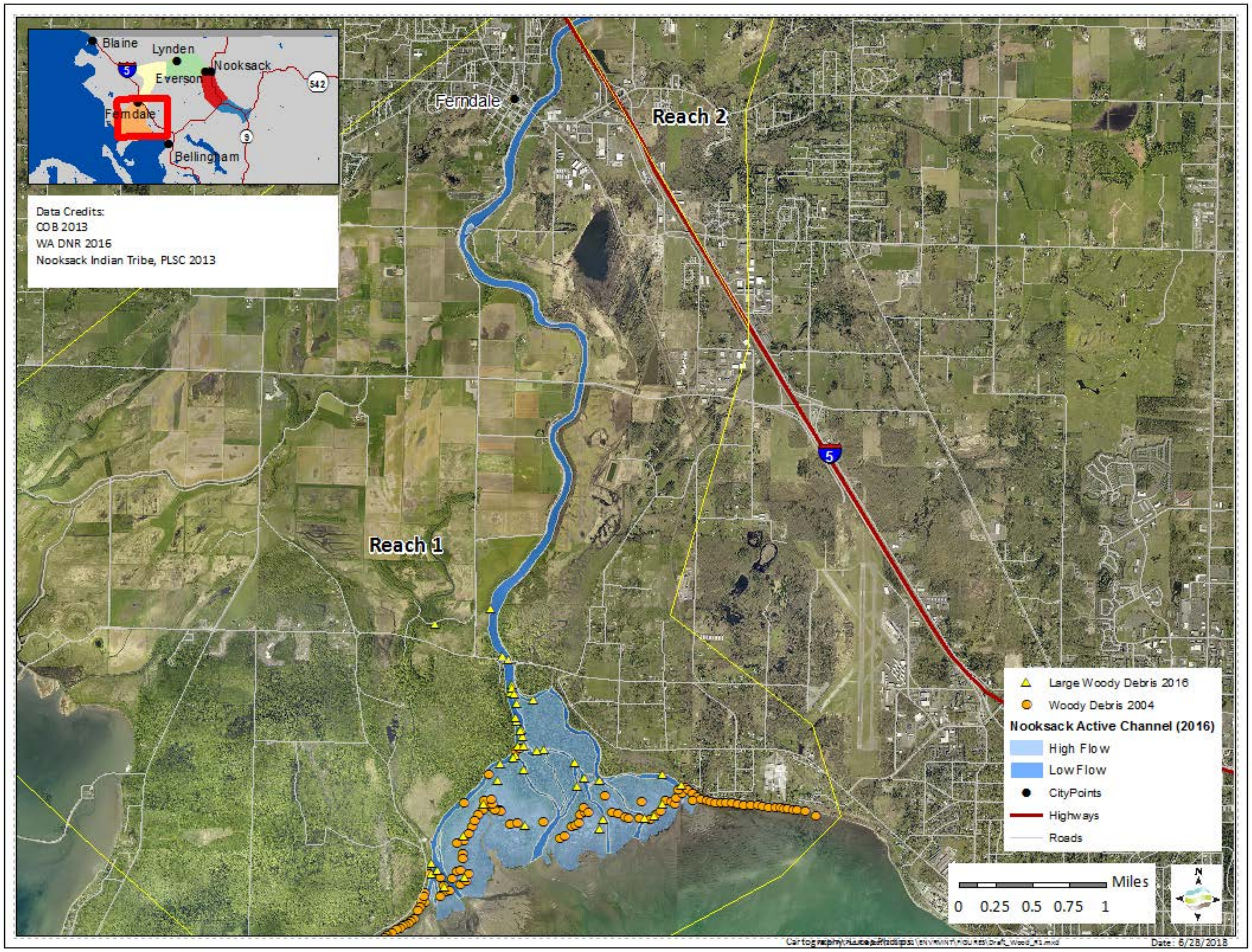
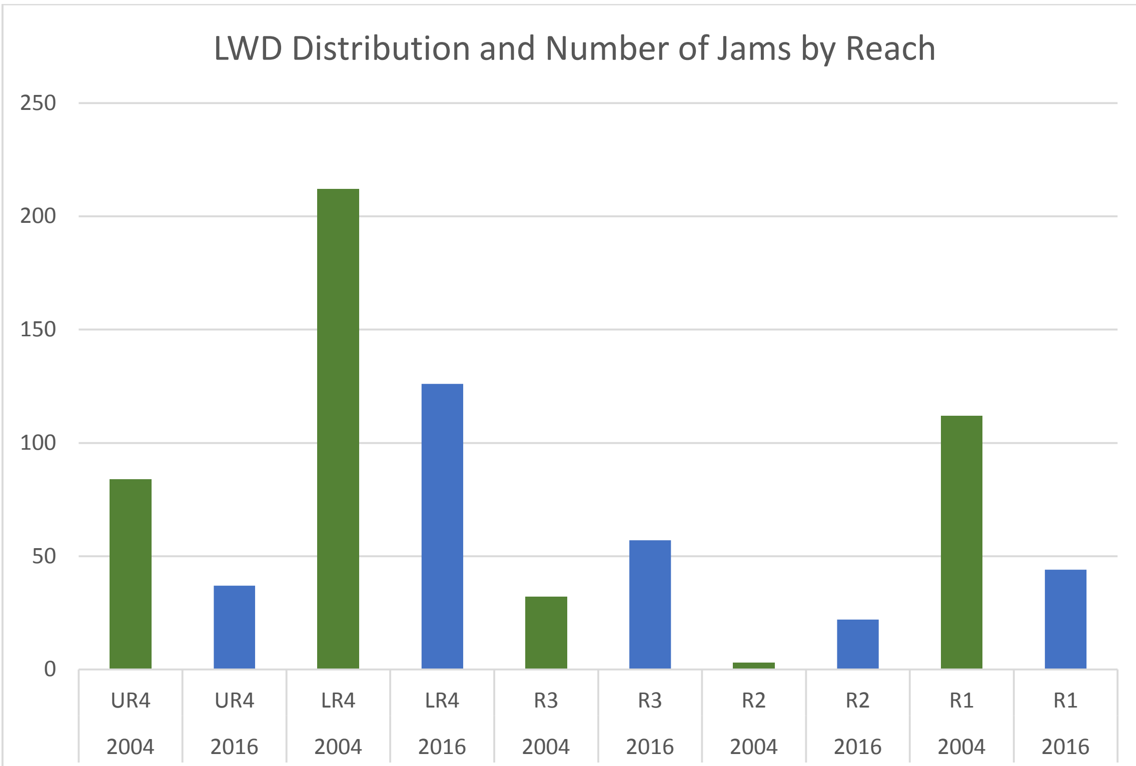


Figure C – 16: 2004 LWD and 2016 Logjam Distribution in Reach 1

Graph 14: LWD Occurrence in 2004 and Logjam Occurrence and Distribution by Reach in 2016. The findings indicate that Lower Reach 4 dominates both in the occurrence of LWD pieces (2004) and logjam formation (2016). The Reach 1 net logjam area is greater than the area of all other reaches. LWD and logjams are likely underrepresented in this dataset because of difficulty interpreting distinct logjam and LWD in the air photo. Logjams in Reach 1 likely have the greatest influence on morphological processes because of their density and channel spanning characteristics.



LWD and Logjam Summary and Discussion

We compared the locations of LWD from 2004 with the mapped logjams in 2016 and determined that most LWD accumulations and logjams were either transient over the decadal time frame of the photos or the channel had migrated and the LWD was no longer present within the bankfull channel area. In general, the mapping assessment in may have 2004 counted more LWD features than the logjam assessment methods used in this analysis; the exception is with Reaches 2 and 3. It is unknown if this is a result of more actual accumulations of LWD in these reaches or may be because of air photo resolution, lower flows, or other method related inventory. Without further quantitative analysis, we hypothesize that the logjam occurrence was higher in 2016 based on field reconnaissance observations. Exhibit 7 below shows an example of the transient LWD observation. Six (6) stable logjams over the 2004 to 2016 air photo period were identified and mapped. Four (4) of these stable logjams occurred in Reach 4. Of the six recurring LWD accumulation, the following patterns were observed:

- One stable logjam was at an apex bar on a stable forested island downstream of a bridge;
- Two recurring LWD accumulation may have just been coincidence, as no physical features could be identified from the air photo record to explain why logjams persisted at these locations;
- One stable logjam was present at the head of a side channel that remained stable for the period included in the photo record comparison;
- Two stable logjam appears to be accumulations of wood that are captured on some stable anchor (the anchoring feature is undetermined).

In Lower Reach 4, we compared logjam stability between 2013 and 2016. During this time period, we observed that 27 logjams persisted and 24 of these were wetted at low flow conditions. A vast majority of these stable logjams were located along the channel margin in sections of the river that experienced very low lateral migration rates. These logjams may have been present in 2004, but air photo quality and vegetation cover did not allow for correlation.

Exhibit 7: 2004 LWD Mapping (yellow markers) Compared to 2016 Logjam Mapping (pink markers)

The predominant area of LWD recruitment within the study reach is Reach 4. Lower Reach 4 in particular has both the greatest localized recruitment areas and LWD accumulation and logjam formation. An example of LWD recruitment is shown in Exhibit 8 which depicts an area with over 5 acres of maturing and emerging stand height trees recruitment between 2013 (green outline) and 2016 (DOQ background). This recruitment was through recapture and lateral expansion of a side channel. Observations from the 2017 field reconnaissance identified that the more sizable LWD pieces from this recruitment area were accumulated a short distance downstream and are contributing to the formation of logjams (Photo 9).

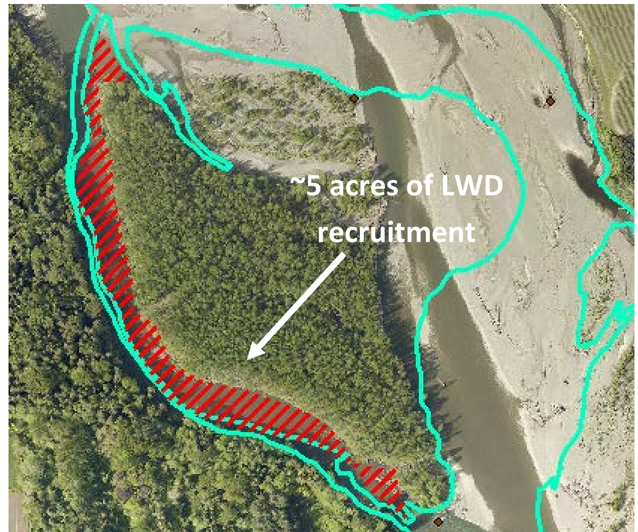


Exhibit 8: LWD Recruitment from bank erosion


Photo 9

Formation of a stable logjam in large channels requires large key pieces to anchor to initiate the accumulation of LWD. Stable key pieces and continual LWD nourishment, supportive flow regimes, and slow channel migration rates are required for the logjam to form and persist from year to year. The general lack of sufficiently-sized LWD is a limiting condition for the formation of stable logjams in the Nooksack River. In single-thread channels, the channel depths and velocities are too great for instream anchoring of the size of LWD available. Therefore, LWD is invariably transported downstream or stranded on bar crests or other elevated floodplain features during peak flow events. Once stranded above the low to moderate flow water surface elevation, LWD can remain isolated with very limited capacity to contribute to low flow in-stream habitat and channel processes. Channel armoring and historic floodplain clearing are the primary drivers for the reduced potential for LWD recruitment and stabilization. Once the riparian forest is cleared, it can take centuries to create LWD suitable to function as logjam key pieces. Very few potential key pieces were identified in the desktop tree-stand height analysis or observed in the field reconnaissance.

Some LWD, however, is generally accumulating in Reaches 4 and 1, but is generally sparse in Reaches 2 and 3 except along the margin of the channel. In general, single-thread channels were virtually devoid of logjam accumulations; small accumulations of LWD were observed in Reaches 2 and 3 (Photo 10). Logjams are more likely to accumulate in unconfined anabranching channel forms such as observed in Lower Reach 4 as compared to Upper Reach 4. Anabranch or side channels are more able to accumulate persistent LWD because of the reduced channel width and flows. These LWD pieces tend to accumulate at the inlet to side channels or overflow channels and can regulate flows. In summary, LWD accumulations and logjams are affected by the following conditions and/or processes:

1) *Armoring and channel confinement* limit the number of opportunities for LWD recruitment and engagement by increasing channel depth and flow velocities while decreasing channel migration.

2) *Historic log jam removal and natural LWD depletion* have eliminated old growth and reduced other large LWD sources throughout the watershed. Removal or rotting of the largest and most stable natural instream structures that would have historically facilitated LWD anchoring and racking has undoubtedly contributed to a likely trend of smaller and less persistent logjams. As a result, the process of key piece loss that has outpaced key piece creation and recruitment.

3) *Predominance of Immature tree stands of LWD within the recruitment zone supply* may be attributed in part to both natural processes (channel migration, hydrologic changes, and sedimentation) and anthropogenic impacts (bank armoring and levee building, logging within the floodplain, and land use), but the net result of their combined influence is diminished quantity and quality of LWD and reduced stable logjam occurrence. The dominance of immature early-successional tree species, primarily black cottonwood, throughout the riparian corridor contributes greatly to the transitory nature of logjams in the study reach. The same mechanical properties that makes these trees undesirable for construction applications such, as framing, makes them poorly suited for long-term log jam development.

4) *Changes in channel form from anabranching to single thread morphology* which affects the width to depth ratios and flow velocity.

LWD Characterization Summary

- Lower Reach 4 had the greatest occurrence of LWD in 2004 and logjams in 2016.

- Lower Reach 4 had the greatest net occurrence of logjams and logjams that occurred within the low flow channel.
- Frequency of logjam occurrence was greatest in anabranching channels.
- The quantities of LWD accumulations were higher in anabranching channels.
- Logjam and LWD accumulations decreased in occurrence as you moved downstream below Reach 4 until Reach 1.
- Logjam occurrence in Reach 1 was directly correlated to the occurrence of distributary channels.

Geomorphic Characterization Conclusions

A summary of the key findings of this analysis are:

- Reaches 2 and 3 have the largest low flow (2-year and 10-year) floodplain inundated areas; however, these two reaches appear to have impaired floodplain connectivity resulting from levees and drainage systems which may affect habitat conditions.
- Reach 4 low flow inundated areas are less extensive and generally contained within the historic channel migration zone (HMZ), and low flow floodplain connectivity appears less impaired than Reaches 2 and 3.
- The predominant vegetation type established in the HMZ is agricultural (~45%) and immature deciduous forests (43%); large, mature and old growth trees are lacking within the HMZ area and comprise less than 12% of the HMZ area.
- The presence of levees and bank armoring significantly decreases the availability of LWD recruitment potential from forested areas within the HMZ.
- The greatest quantity of maturing and old growth tree size classes occurs in Reach 4; therefore the greatest large woody debris (LWD) recruitment potential exists in Reach 4.
- The greatest quantity of logjam occurrence was observed in Lower Reach 4; however, while Upper and Lower Reach 4 have similar channel metrics, the quantity of logjam occurrence in Lower Reach 4 is significantly higher than in Upper Reach 4.
- Observed logjams were found to be transient in nature throughout the entire study area, persisting for only short periods (less than 10 years).
- The probable factors limiting the occurrence of stable logjams are:
    - Lack of suitably sized and shaped LWD sources within recruitment areas;
    - Decreased LWD quantity;
    - Impaired channel migration processes (high turnover rates, confined channels, and armoring)
    - Isolation of potential LWD recruitment areas behind revetments and levees;
    - Confined channels that increase flow depths and velocities.
- Lower Reach 4 has the greatest occurrence of forested channel islands, backwater channel forms, and side channel features; quantities are significantly higher than the other reaches.

- Reach 4 has the greatest change in area between low flow and high flow channel area.

The conclusions of this analysis are that while many restoration alternatives are possible, restoring the following conditions and processes could have considerable habitat improvement potential, but would take a reach scale approach as opposed to small project-by-project approach. It is our opinion that:

- Improving floodplain-mainstem connectivity in Reaches 2, 3, and Upper Reach 4 could considerably improve floodplain salmonid habitat function.
- Reducing confinement, particularly in Upper Reach 4, may enable an increase in forested islands, LWD recruitment, side channels, backwater alcoves, and logjam occurrence which could improve instream habitat function.
- Preserving and restoring the HMZ to the greatest extent possible would allow for channel processes to sustain habitat conditions.
- Introducing engineered logjams into the active channel area to emulate natural logjam function is needed given the state of the riparian conditions and LWD recruitment potential.