APPENDIX B

Supporting Documentation

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Hydrology

The Hoko, Clallam, and Pysht River watersheds are low in elevation and drain to the Strait of Juan de Fuca. Due to the low elevation, the dominant form of precipitation is rainfall. Average annual precipitation within the Hoko River watershed is approximately 83 inches based on a weighted average from select sub-basins. Peak flows in the rivers therefore generally occur during the winter, when the highest precipitation occurs, and low river flows occur during the summer. All watersheds have been subject to forestry land use practices, and the change in age and type of forest cover is believed to be associated with increased frequency and severity of peak flows. In addition, flow velocities have increased due to reduced large woody debris loading, channelization, and incision. Water withdrawals for municipal drinking water use in the Hoko River watershed have led to reduced low-flow discharge rates during the summer (Smith 1999).

Detailed and comprehensive hydrologic analyses of the Hoko, Clallam, and Pysht River watersheds were not conducted for this study due to a lack of available and documented hydrologic data. Existing studies and data sources were identified and reviewed to determine hydrologic conditions of the rivers and peak discharge rates were estimated. The following sections discuss the available data, methods of analysis, and results of the peak flood discharge estimates.

Available Data

Existing hydrologic studies and data sources reviewed for the Hoko, Clallam, and Pysht Rivers include:

- Hoko River Watershed Analysis – Appendix C Hydrology Assessment (Pentec 1994).
- Magnitude and Frequency of Floods in Washington (Sumioka et al. 1997)
- Salmon and Steelhead Habitat Limiting Factors in the Western Straight of San Juan de Fuca (Smith 1999).
- Flood Insurance Rate Study: Clallam County, Washington Unincorporated Areas (FEMA 2001).
- USGS Stream Gauge #12043300 – Hoko River near Sekiu (River Mile [RM] 5.3)

- Ecology Stream Gauge #19H080 – RM 1.3 Clallam River near Clallam Bay (Ecology 2005a)
- Ecology Stream Gauge #19A070 – RM 4.9 Pysht River near Pysht (Ecology 2005b)

General hydrologic conditions of the Hoko, Clallam, and Pysht River basins are summarized by Smith (1999). U.S. Geological Survey (USGS) documents a complete record of flow data for the Hoko River at RM 5.3 for July 1962 to September 1974 and October 1995 to present. Additionally, annual maxima are available for water years 1976 to 1978 and seasonal data are available for the period of June 1983 to September 1995. The Hoko River USGS data are analyzed and summarized by Pentec (1994) and Sumioka et al. (1997). FEMA (2001) estimates peak discharge rates at four locations on the Clallam River, including a cross-section within the Clallam study reach. Stream gauges established by Ecology on the Clallam River in April 2005 and Pysht River in March provide data records within their respective study reaches (Ecology 2005a; 2005b).

Methods

USGS Regression Equations

Peak discharge estimates for 2, 10, 25, 50, and 100-year recurrence intervals were developed using regression equations developed by Sumioka et al. (1997). These equations are intended for use in ungauged rivers and in gauged rivers where the contributing drainage area at the site is less than 50 percent or greater than 150 percent of the drainage area at the gauge. The following regression equation was used:

$$Q=aA^bP^c$$

Where:

Q = peak discharge in cubic feet per second (cfs),
A = contributing drainage area in square miles (mi^2),
P = average annual precipitation in inches (in)
a = regression constant (varies by climatic region)
b, c = regression exponents (vary by climatic region).

Regression constants and exponents (a, b, c) have been developed for different climatic regions in Washington. Table B-1 presents these values for Region 2 (Puget Sound Basin), where the Hoko, Clallam, and Pysht River watersheds are located. Average annual precipitation in the three watersheds was estimated to be 83 inches based on Hoko River basin data reported by Pentec (1994).

Table B-1. USGS regression equation constants and exponents for Region 2 – Puget Sound Basin (Sumioka et al. 1997).

Exceedance Probability	Recurrence Interval (year)	Regression Constant [a]	Regression Constant [b]	Regression Coefficient [c]
0.5	2	0.090	0.877	1.51
0.1	10	0.129	0.868	1.57
0.04	25	0.148	0.864	1.59
0.02	50	0.161	0.862	1.61
0.01	100	0.174	0.861	1.62

[a] Sumioka et al. (1997).
[b] Pentec (1994).

Flood Frequency Analysis

Peak discharge estimates for 2, 10, 25, 50, and 100-year recurrence intervals in the Hoko River were developed by analyzing the complete peak flow record at the existing USGS gauge. Peak flows for this gauge have been published, but do not include the last nine years of discharge data. These discharge estimates were developed by applying a Log Pearson Type III distribution to the available data with a weighted skew coefficient value calculated from both the available data and published regional values. The detailed method used to calculate the discharge estimates is described by OSU (2005 online). A regional skew coefficient of 0.2 was selected based on a chart published by the Interagency Advisory Committee on Water Data (1982).

Watershed Scaling Analysis

Peak discharge estimates for 2, 10, 25, 50, and 100-year recurrence intervals in the Hoko River were developed using available gauge data and a drainage area scaling method developed by Sumioka et al. (1997). This method is intended for use on gauged rivers where the contributing drainage area at the site is greater than 50 percent and less than 150 percent of the drainage area at the gauge. The watershed scaling equation is in the form of:

$$Q_u=Q_g \times (A_u/A_g)^x$$

Where:

Q_u = peak discharge at ungauged site in cfs,
Q_g = peak discharge at gauged site in cfs,
A_u = contributing drainage area at ungauged site in mi2,
A_g = contributing drainage area at gauged site in mi2,
x = regression exponent (varies by climatic region).

Different regression exponents (x) have been developed for the Washington's climatic regions. The value developed for Region 2, the Puget Sound Basin, is 0.98 (Sumioka et al. 1997).

Because gauges on the Pysht and Clallam River are newly established and do not have historic data records, the watershed scaling method was also applied as a check on the results of the USGS regression equations. To apply the basin scaling method to these systems, discharge values were transposed from the Hoko River basin and then scaled based on basin area. Due to the similar climatic, topographic, and land use characteristics of these watersheds, this application of the basin scaling method provides a reasonable approximation of peak discharge values.

Results

Hoko River

The Hoko River stream gauge is located at RM 5.3, approximately 1.9 miles upstream of the upper extent of the study reach. The Little Hoko River, a major tributary, enters the river between these locations at RM 3.7. Sumioka et al. (1997) analyzed a period of data from the Hoko River gauge that includes 17 peak flow values and estimated peak flows for 2, 10, 25, 50, and 100-year recurrence intervals. Additional analysis was conducted on 16 years of the same gauge data by Pentec (1994), but the only comparable peak discharge value reported was for the 10-year recurrence interval. The 10-year peak discharge value estimated by Pentec (7,060 cfs) was 40 percent lower than the equivalent estimate by Sumioka et al. (1997) of 11,700 cfs. Because additional data were available since these published values were developed, an analysis was performed on the complete 25-year flow record at the gauge using the Log Pearson Type III analysis method described in the previous section above. Regression equations were used to estimate peak discharge at the gauge site to determine if this method provides reasonable values for these specific watersheds. Table B-2 summarizes the discharge values published for the gauge using the different methods.

Table B-2. Peak discharge estimates in cubic feet per second for the Hoko River stream gauge (USGS Gauge #12093300).

		Analysis Method			
Exceedance Probability	Recurrence Interval (year)	Published Values [a]	Published Values [b]	Log Pearson Type III Analysis	Regression Equation
0.5	2	7,050	na	7,448	2,244
0.1	10	11,700	7,060	13,106	4,048
0.04	25	14,300	na	16,373	4,994
0.02	50	16,300	na	18,990	5,888
0.01	100	18,300	na	21,764	6,624

na = data not available.
[a] Sumioka et al. (1997).
[b] Pentec (1994).

The USGS regression equations produced estimates 70 percent below the analyzed values at the existing stream gauge, suggesting that these equations are not appropriate for use in these watersheds. The Log Pearson Type III analysis is considered the best estimate of discharge at the gauge because it incorporates additional data collected since the published values were developed. Peak discharge estimates in the Pysht River at the project site are presented in Table B-3 and Figure B-1.

Table B-3. Peak discharge estimates in cubic feet per second for the Hoko River study reach.

		Analysis Method			
Exceedance Probability	Recurrence Interval (year)	Watershed Scaling (Sumioka et al.1997)	Watershed Scaling (Log Pearson Type III Analysis)	Regression Equation	Best Estimate
0.5	2	9,847	10,403	3,032	10,403
0.1	10	16,341	18,305	5,451	18,305
0.04	25	19,973	22,868	6,717	22,868
0.02	50	22,766	26,523	7,914	26,523
0.01	100	25,560	30,398	8,901	30,398

The basin scaling method (using the new Log Pearson Type III peak flow estimates) was selected as the best estimate of peak discharge values at the project site.

Clallam River

Peak discharge estimates at the Clallam River study reach were taken from FEMA (2001) published values and estimated using USGS regression equations and the basin scaling method (discharge values transposed from the Hoko River). The published values include discharge estimates for the 10, 50, and 100-year recurrence intervals developed using regional regression equations published by USGS (1978). The basin scaling method was determined to be valid because the contributing basin area at the Clallam River project site is 61 percent of the area at the Hoko River stream gauge, greater than the 50 percent lower limit. Due to the large difference between the published data and regression equation results at the Hoko River stream gauge (see Table B-2), the regression equation results were not deemed reliable estimates of peak discharge values in the Clallam River.

Because the published data (FEMA 2001) were developed from regression equations that are nearly 30 years old, the basin scaling method was selected as the best estimate in this system. Peak discharge estimates in the Clallam River at the project site are presented in Table B-4 and Figure B-2.

Pysht River

The USGS regression equations and basin scaling (using discharge values transposed from the Hoko River) methods were used to estimate peak discharge values in the Pysht River. The basin scaling method was determined to be valid because the contributing basin area at the Pysht River project site is 84 percent of the area at the Hoko River stream gauge, greater than the 50 percent lower limit. Due to the large difference between the published data and regression equation results at the Hoko River stream gauge (see Table B-2), the basin scaling method results (using the new Log Pearson Type III peak flow estimates) were selected as the best estimate in this system. Peak discharge estimates in the Pysht River at the project site are presented in Table B-5 and Figure B-3.

Table B-4. Peak discharge estimates in cubic feet per second for the Clallam River study reach.

		Analysis Method				
Exceedance Probability	Recurrence Interval (yr)	Published Values [a]	Regression Equation	Watershed Scaling (Sumioka et al.1997) [b]	Watershed Scaling (Log Pearson Type III Analysis)[b]	Best Estimate
0.5	2	–	1,448	4,312	4,555	4,555
0.1	10	4,350	2,623	7,155	8,015	8,015
0.04	25	–	3,243	8,746	10,013	10,013
0.02	50	6,280	3,828	9,969	11,614	11,614
0.01	100	7,200	4,309	11,192	13,310	13,310

[a] FEMA (2001).
[b] Flows transposed from Hoko River USGS gauge in nearby watershed.

Table B-5. Peak discharge estimates in cubic feet per second for the Pysht River study reach.

		Analysis Method			
Exceedance Probability	Recurrence Interval (yr)	Regression Equation	Watershed Scaling (Sumioka et al.1997)[a]	Watershed Scaling (Log Pearson Type III Analysis)[a]	Best Estimate
0.5	2	1,929	5,942	6,277	6,277
0.1	10	3,485	9,861	11,045	11,045
0.04	25	4,303	12,052	13,799	13,799
0.02	50	5,075	13,737	16,004	16,004
0.01	100	5,711	15,423	18,342	18,342

[a] Flows transposed from Hoko River gauge in nearby watershed.

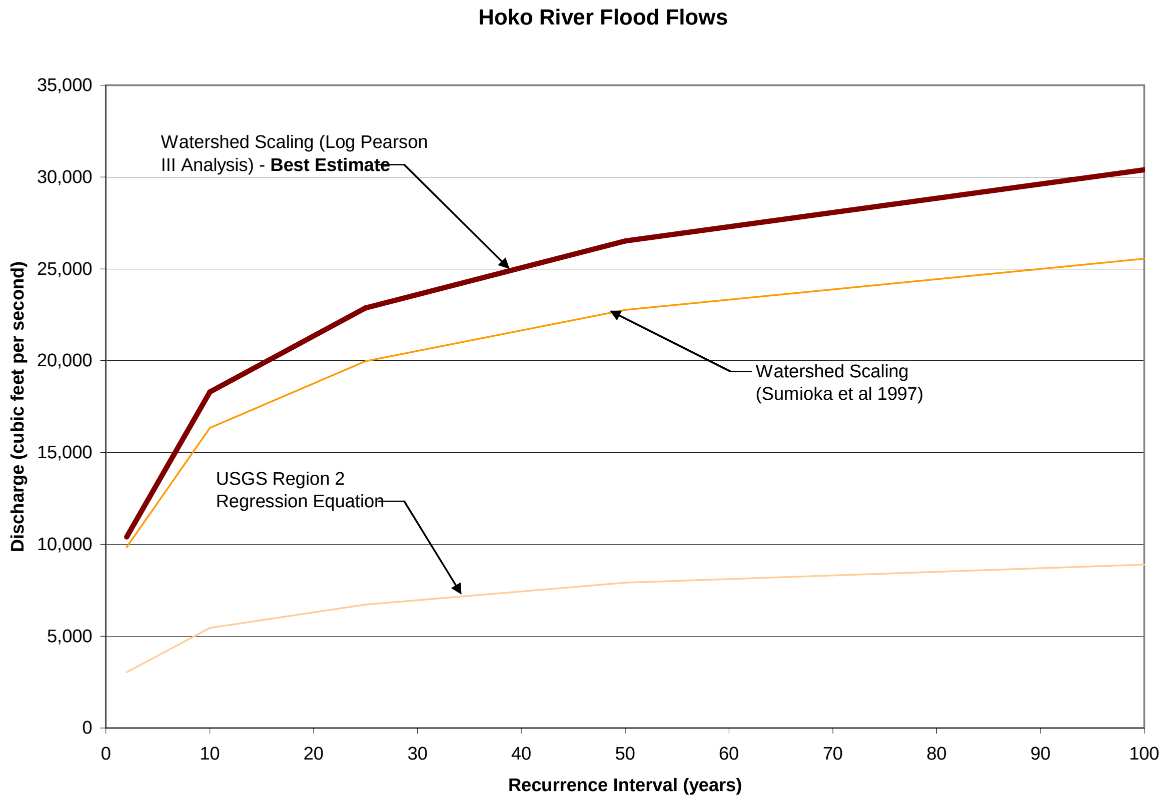

Figure B-1. Peak flood discharge estimates for the upper extent of the Hoko River study reach (RM 3.4).

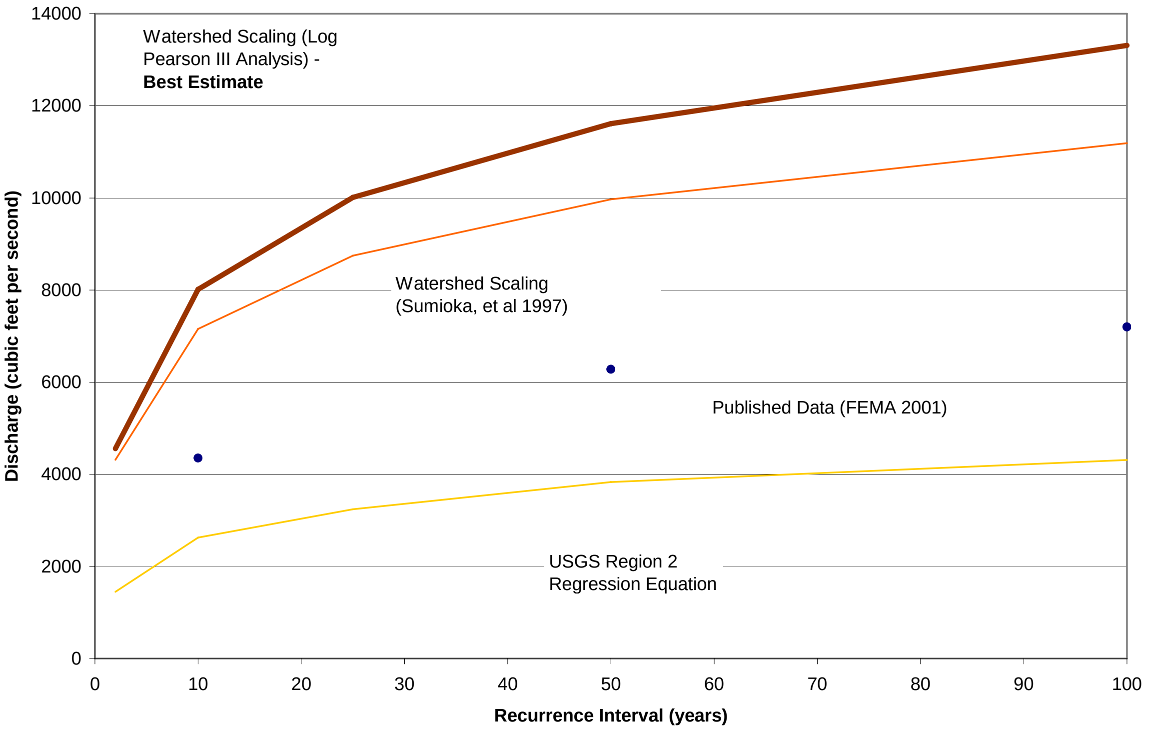

Figure B-2. Peak flood discharge estimates for the Clallam River study reach.

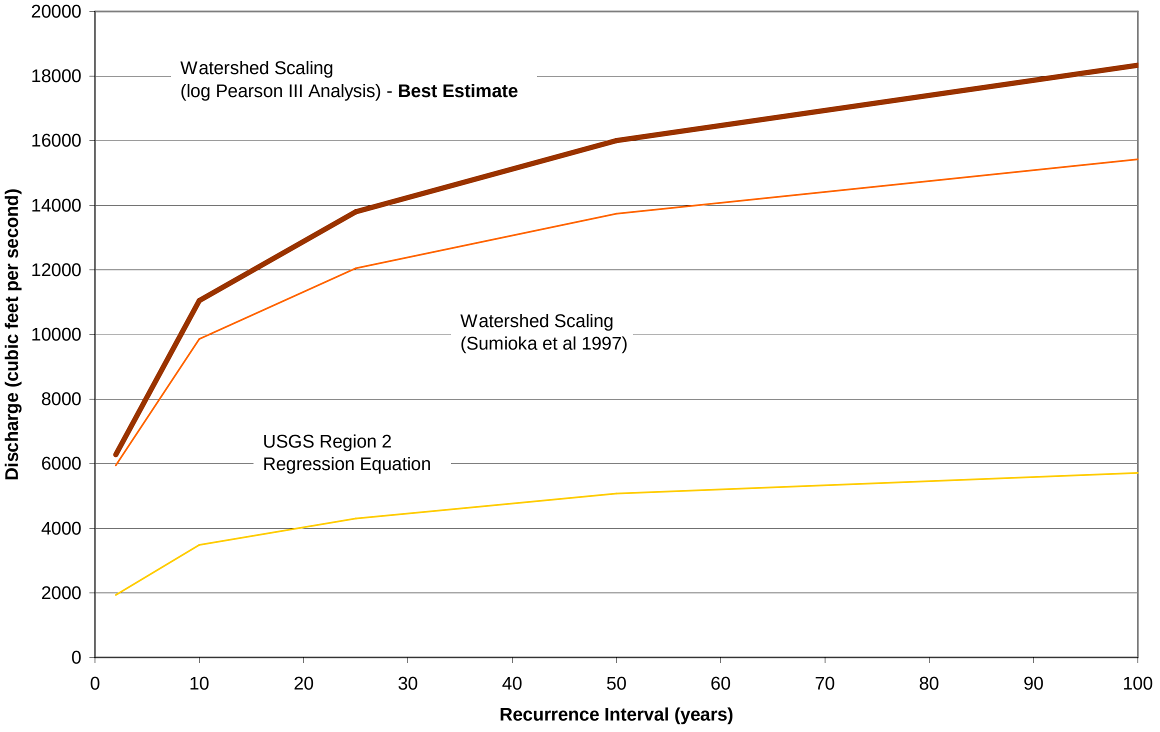

Figure B-3. Peak flood discharge estimates for the Pysht River study reach.

Geomorphology

Lateral channel migration and floodplain inundation are natural processes in low to moderate gradient alluvial rivers. Highway 112 is located in valley bottoms of the Hoko, Clallam, and Pysht Rivers and is subject to chronic maintenance problems due to natural geomorphic processes. A characterization of the geomorphic conditions of the study reaches of the Hoko, Clallam, and Pysht Rivers was completed in order to better understand the context surrounding erosion and flooding issues along Highway 112. Knowledge of the geomorphic processes that have led to the current erosion and flooding issues can also aid in predicting future channel changes and problem sites. This information is key in developing conceptual design measures that will alleviate flooding and erosion issues along Highway 112.

The characterization of the geomorphic conditions of the Hoko, Clallam, and Pysht study reaches combined analyses of archival and current aerial photographs, the results of a topographic survey conducted in 2005 by means of light detection and ranging (lidar), a review of available literature, and an evaluation of current field conditions to assess channel form and complexity that was completed concurrently with the identification of problem sites. The literature review included the Watershed Analysis of the Hoko Watershed (Martin et al. 1995) and the Habitat Limiting Factors Analysis of the Western Strait of Juan de Fuca that assessed conditions related to salmonid habitat in the contributing watersheds of the three study reaches (Smith 1999).

Channel alignments within each of the study reaches were delineated from aerial photographs (Table B-6). Digitized aerial photographs from 2003, 1982 and 1966 that cover the entire study reaches were provided by WSDOT. Additionally, 1951 digitized aerial photographs that cover the Physt River study reach were also provided by WSDOT. Orthorectified quarter-quadrangle aerial photographs (DOQs) from 1990 and 1994 were acquired from the USGS. The 1994 DOQs cover the entire Hoko and Pysht study reaches. Coverage of the Clallam River study reach, however, is split between the 1990 and 1994 DOQs. The 2003, 1982, 1966, and 1951 aerial photographs were georeferenced to the USGS DOQs.

Table B-6. Aerial photographs used for Hoko, Clallam, and Pysht River reach analyses.

Photograph Date	Scale	Area Covered	Type	Source
1951	1:12,000	Pysht study reach	Black-and-white	Merrill and Ring
1966	1:24,000	Hoko, Clallam, and Pysht study reaches	Black-and-white	WSDOT
1982	1:24,000	Hoko, Clallam, and Pysht study reaches	Black-and-white	WSDOT
1990	Unknown	Clallam study reach	Black-and-white	USGS
1994	Unknown	Hoko, Clallam, and Pysht study reaches	Black-and-white	USGS
2003	1:10,000	Hoko, Clallam, and Pysht study reaches	Color	WSDOT

Channel profiles were delineated using both USGS 7.5 minute topographic maps and a lidar digital elevation map (DEM) and were used to calculate channel gradient. The 6-foot pixel lidar DEM is accurate to 15 cm of elevation on open surfaces and coverage includes the entire Pysht River study reach and RM 3.7 to RM 8.2 of the Clallam River study reach. Due to the limited resolution of the USGS 7.5 minute topographic map elevation data, local variability in channel gradient could not be determined for the Hoko River.

The relatively narrow channel widths of the study reaches and the conditions of encroaching riparian vegetation make it generally difficult to delineate stream banks within the aerial photographs. As such, the centerline of the channel alignment was delineated as accurately as possible for each of the study reaches in each of the available aerial photographs. Clear movement of this centerline between years indicates the magnitude of lateral migration. Where stream banks could be clearly delineated, these were tracked in order to develop quantitative rates of average annual lateral migration. The sinuosity of each study reach, calculated as the ratio of the channel alignment length to the valley length, was completed using the delineated centerlines. Channel confinement was described by the ratio of the floodplain valley width to the active channel width: where this ratio is less than 2 the channel is considered confined, where it is between 2 and 4 the channel is moderately confined, and where it is greater than 4 the channel is unconfined. Active channel widths were measured during field surveys and floodplain valley widths were estimated from USGS 7.5 minute topographic maps and existing lidar data.

Although the lidar DEM is available for only one time period, the resolution of the elevation data provides considerable detail on current conditions of channel complexity and the alignments of historical channels. Using the lidar DEM, a hillshade image was created by shining an artificial light source onto the lidar DEM using ArcView 9.0 Spatial Analyst. The hillshade representation facilitates the interpretation of the lidar DEM. Identification of side channels and historical channel alignments was completed through a review of the lidar hillshade.

Local geomorphic conditions were detailed during the field reconnaissance survey conducted from May 10 through May 12, 2005. Conditions that were recorded during the field surveys include descriptions of bank stability and composition, depositional features and substrate conditions, LWD loading, side channels, and mid-channel islands in addition to measurement of channel geometry and bank height. Photographs taken during the field survey that illustrate local geomorphic conditions are included with problem site photos in Appendix A.

Factors Affecting Bank Stability

Lateral channel migration is a natural process in the Hoko, Clallam, and Pysht River study reaches and bank erosion related to channel migration poses considerable threat to the Highway 112. Stream bank erosion occurs through a combination of bank-toe erosion due to river flow and subsequent bank mass failure. The magnitude of hydraulic shear forces at the bank toe depends on the magnitude of flow velocities and the velocity gradient near the bank. Depending on bank characteristics, mechanisms of bank mass failure following toe erosion and bank oversteepening can include shallow and rotational-slip, as well as slab and cantilever failures. A number of factors affect the stability of stream banks and their resistance to erosion. The principal influences on bank stability include:

- Flow properties
- Channel and bank geometry
- Composition and cohesion of bank material
- Riparian vegetation
- Subsurface conditions (saturation)

The conditions of flow acting against a stream bank are important because little bank erosion is likely to take place in the absence of high discharges. The near-bank velocity conditions determine the erosion forces acting upon stream banks and high flows both entrain material directly from a bank face and remove material from the bank toe. Particularly high shear forces can result with turbulence that can be generated within large scale-horizontal eddies that can scour both the stream bed and the bank, enlarging existing embayments. Such bank erosion is occurring at problem site H-1 on the Hoko River where a large eddy has formed at the outside of a meander bend and scour at the bank toe is oversteepening the bank. Bank erosion, however, is not solely a function of discharge and so a threshold for bank erosion is not easily defined. Depending on antecedent bank conditions, similar discharges can result in varying degrees of erosion.

Channel alignment and bank geometry strongly influence how flows will interact with stream banks. Significantly different, and higher, shear forces will be imparted to a bank that is located at the outside of a tight meander as opposed to one within a generally straight alignment and the forces resulting from the alignment of a thalweg of a single channel against a stream bank will be higher than those imparted by a channel of a multiple-threaded system that contains only a portion of the total flow. This is illustrated by the high proportion of Highway 112 erosion problem sites that are located at the outside of meander bends. In addition to the channel geometry, the geometry of the bank plays a large role in its stability. As material is removed from the bank toe the bank may become oversteepened (Photo A-73 in Appendix A). Oversteepened banks are susceptible to rotational and slump failures and both the height and steepness of the bank influence the magnitude of failures. Generally, as banks become steeper and higher there is greater probability of significant bank retreat. The Hoko River study reach, as well as the lower portion of the Pysht River study reach, and much of the Clallam River study reach, have high banks located in close proximity to the highway alignment. Stabilizing the toe of such banks without providing adequate setback may not sufficiently protect the highway as larger mass failures can occur that can easily extend back from the edge of the bank a distance equivalent to the bank height. Cracks in the highway surfacing are one indication of potential failure surfaces (Photos A-1, A-59 in Appendix A).

The composition of stream banks will largely influence their general resistance to erosion in addition to the type of mass failures that are likely to occur and the angles at which they are likely to stabilize. Oversteepened banks of cohesive soils with high silt and clay content typically fail by deep-seated rotational slips or by slab failure where blocks of soil topple forward or slump into the channel (Photo A-5 in Appendix A). Alternatively, the retreat of banks composed of coarse grained soils such as alluvial sands and gravels occurs primarily through shallow slips. Alluvial banks often contain layers of different soil types that result from the complex depositional environments that occur within dynamic fluvial systems. When cohesive sediments overlie non-cohesive alluvial sands and gravels, undercutting of the lower bank by hydraulic action can create an overhang, or cantilever, in the upper cohesive layer which fails when the weight of the overhanging blocks exceeds the cohesive strength of the soil. A similar overhanging condition is occurring at problem site C-1 on the Clallam River. At this site, a large maple tree is reinforcing the bank, but once it topples the sandy banks will be subject to continued erosion. Collapsed material from mass failure may protect the bank toe from further erosion until it is removed by subsequent hydraulic action. This cycle of toe erosion, bank failure, accumulation of failed material at the bank toe, and removal of this material plays an important role in the form and stability of stream banks.

The character of riparian vegetation, as noted above, can influence the stability of stream banks in a number of ways by both increasing and decreasing bank stability through mechanical and hydrological processes as well as deflecting flow into or away from stream banks once introduced into the active channel. The root systems of riparian vegetation can reinforce soil banks and provide resistance to erosion. The hydrologic effects of riparian vegetation, however, can reduce bank stability and the mass of the vegetation itself can add surcharge to the bank, increasing the gravitational forces acting upon it. The hydrologic effects from riparian vegetation that reduce bank stability are typically offset by the increases that result from mechanical stabilization but need to be considered when riparian vegetation is being implemented for the purposes of bank stabilization (Simon and Collinson 2002). The character of riparian vegetation that enters the channel also influences rates of bank erosion. Large diameter trees that are recruited through bank erosion can deflect flow into or away from stream banks although research indicates that mature trees within riparian forests limit rates of bank erosion and lateral migration (Micheli et al. 2003).

Subsurface conditions of bank soils, primarily soil moisture levels and porewater pressures, also influence the stability of stream banks. Banks may become saturated through subsurface flow and during flood events or high tides. When water in the channel recedes, or once it has become saturated through subsurface flow the porewater pressures that result in stream bank soils decreases the soil strength and it becomes more susceptible to erosion and mass failure. Additionally, the wetting and drying of soils can lead to fissures between soil layers and tension cracks which can reduce the strength of the soil.

Bank erosion threatens Highway 112 in numerous locations where the highway alignment is adjacent to the Hoko, Clallam, and Pysht River study reaches. Where stream banks have become oversteepened and the EOP is not further from the top of the bank than the height of the bank this threat is immediate. Where riparian buffers between the highway and the rivers are limited ongoing erosion is likely to threaten the highway in the future.

Geomorphic Characterization of Study Reaches

Hoko River

The channel network of the Hoko River watershed consists primarily of steep headwater channels and lower-gradient, relatively unconfined gravel-bedded streams. Many headwater reaches flow within step mountainous terrain and are susceptible to direct sedimentation from mass wasting and prone to debris-flows. As a result of the high sediment supply from steep headwater tributaries, the lower-gradient reaches in the Hoko River have extensive gravel deposits within their meandering alignments. The lower-gradient channel network generally flows within wide floodplain valleys that serve as large storage reservoirs for the sediment produced in the upper watershed. The channel migration zone for the low-gradient channel network can be estimated by the extent of the floodplain valley.

Within the study reach from RM 1.0 to RM 3.4 the Hoko River is a sand and gravel bedded pool-riffle channel. The gradient of the Hoko River is very low within the study reach; the first 40 foot contour on the USGS 7.5 minute topographic map of the area is at RM 7.2 (USGS 1984). Therefore the gradient of the lower Hoko River is estimated at approximately 0.1 percent or 5.7 feet per mile. The study reach is sinuous, with a channel length of 1.3 miles for every mile of river valley. Typical channel widths of 70 to 100 feet were documented during the field survey and the width of floodplain valley in the study reach ranges from 1,800 to 2,300 feet. Although the Hoko River floodplain valley is extensive through the study reach, entrenchment of the mainstem alignment may have resulted in a limited contemporary floodplain. The lower portion of the Hoko River is tidally influenced and backwater affects were observed to extend at least 1.6 miles upstream. Management of upland watershed resources has impacted the conditions of sediment supply and LWD loading to the Hoko River which has in turn influenced its current geomorphic character.

The Hoko River study reach has been subjected to considerable impacts as a result of channel modifications and land uses practices. Instream LWD loading, channel complexity, and channel stability have been affected by log drives made in the 1920s to 1940s, the removal of LWD associated with early agriculture and grazing, and the removal of LWD from the channel from 1930 to 1970 for “fisheries enhancement” (Martin et al. 1995). Levels of wood loading in the lower mainstem Hoko River (RM 0.0 to RM 15.7) have recently been estimated at 0.17 pieces per channel width, far below the 2 to 4 pieces per channel width that is considered functional (Martin et al. 1995). The widespread reduction in LWD resulting from channel modifications is likely responsible in part for channel incision and abandonment of portions of the formerly active floodplain (Martin et al. 1995). Further impacts to channel conditions have resulted from historical and modern-day forest practices.

The mainstem Hoko River has been characterized as unstable, and coupled with a lack of LWD, this is largely attributed to increased sediment production resulting from mass wasting associated with forest practices (Smith 1999, Martin et al. 1995). Documented within the Hoko River Watershed Analysis, 330 landslides were identified within the watershed in aerial photographs from 1953, 1964, 1971, 1981, and 1993 (Martin et al. 1995). A strong relationship was observed between landslides and forest harvest activities; 40 percent of landslides were associated with logging roads and 55 percent were associated with clearcuts (Martin et al. 1995). Of the total number of landslides documented, 141 occurred between 1981 and 1993 (Martin et al. 1995). Channel response to increased sediment supply depends on the ratio of transport capacity to sediment supply (Montgomery and Buffington 1997). Aggradation, widening, pool filling and braiding can occur when sediment supply locally overwhelms transport capacity. In addition to changes in channel form, increases in sediment supply can result in fining of bed material. This response has been documented in the Hoko River where levels of fine sediment (<0.85mm) in the lower main stem channel substrate exceeds 17.5 percent (McHenry et al. 1994). Westward migration at the mouth of the Hoko River between 1994 and 2003 has also been attributed to high levels of sediment supply (Smith 1999).

Although lateral migration and bank erosion were observed in a handful of locations within the aerial photographs and during the field reconnaissance, widespread channel instability or rapid translation of the channel alignment was not observed (Figure B-4). During the review of aerial photographs, lateral migration could be quantified in two locations. Just downstream of the study reach, at RM 0.9, 40 m of lateral migration of the left bank was observed between 1994 and 2003. Further downstream, at RM 0.2, 30 m of right bank erosion occurred between 1982 and 1994. Although observations of lateral migration were limited, the natural channel migration zone of the Hoko River includes the entire valley bottom and the current channel migration zone is limited only where banks have been armored or revetted. Problem Site H-1 at approximately RM 1.6 to RM 1.7, and along Highway 112 from MP 11.42 to MP 11.56, is an example of where the channel migration zone has been limited. Widespread erosion of the high left bank at this location threatens the highway alignment as erosion has undercut and oversteepened the bank.

The stream bank at Problem Site H-1 is composed primarily of silt and sand and the bank is eroding at the toe and other locations where it is unprotected. The vertical condition of banks at this location is one indication of channel incision. Channel complexity at this site was limited. The complexity that was observed at this location resulted from instream LWD that had been recruited from local bank erosion. The substrate was predominantly sand with some gravel and a point-bar deposit of gravel and sand occurred on the inside of the meander, opposite the eroding bank. Evidence of tidal influence was observed at this location and the magnitude of this influence during high flow events impacts the extent of flooding that occurs at the site.

High sediment loads, low channel gradients, and tidal backwater influences which limit sediment transport capacity may together result in continued aggradation with the study reach. Aggradation is particularly likely at the upstream extent of the tidal influence where sediment transport capacity decreases. Depending on the location of this transition and other factors controlling the location and magnitude of deposition, the tortuous meander that occurs from RM 1.2 to RM 2.6 is at risk of a future meander-neck avulsion. Excessive sinuosity increases the path length between two locations on a rivers alignment, decreases the channel gradient, and in turn decreases transport capacity. Neck avulsions may develop when a bend continues to increase in amplitude and tightness, and a threshold sinuosity is reached that the river can no longer maintain (Knighton 1998). Neck avulsions occur at such meanders when the river accesses a shorter path that has a higher local slope and higher sediment transport capacity. Flow across the meander neck at RM 2.6 (and RM 1.2) has been observed during high flow events and an avulsion of this meander would redirect the flow alignment where the Hoko River approaches the Highway 112 bridge at MP 11.85 (Shellberg 2005 personal communication). Channel conditions and elevations at RM 2.6 should be monitored in order to forecast any rapid channel realignment.

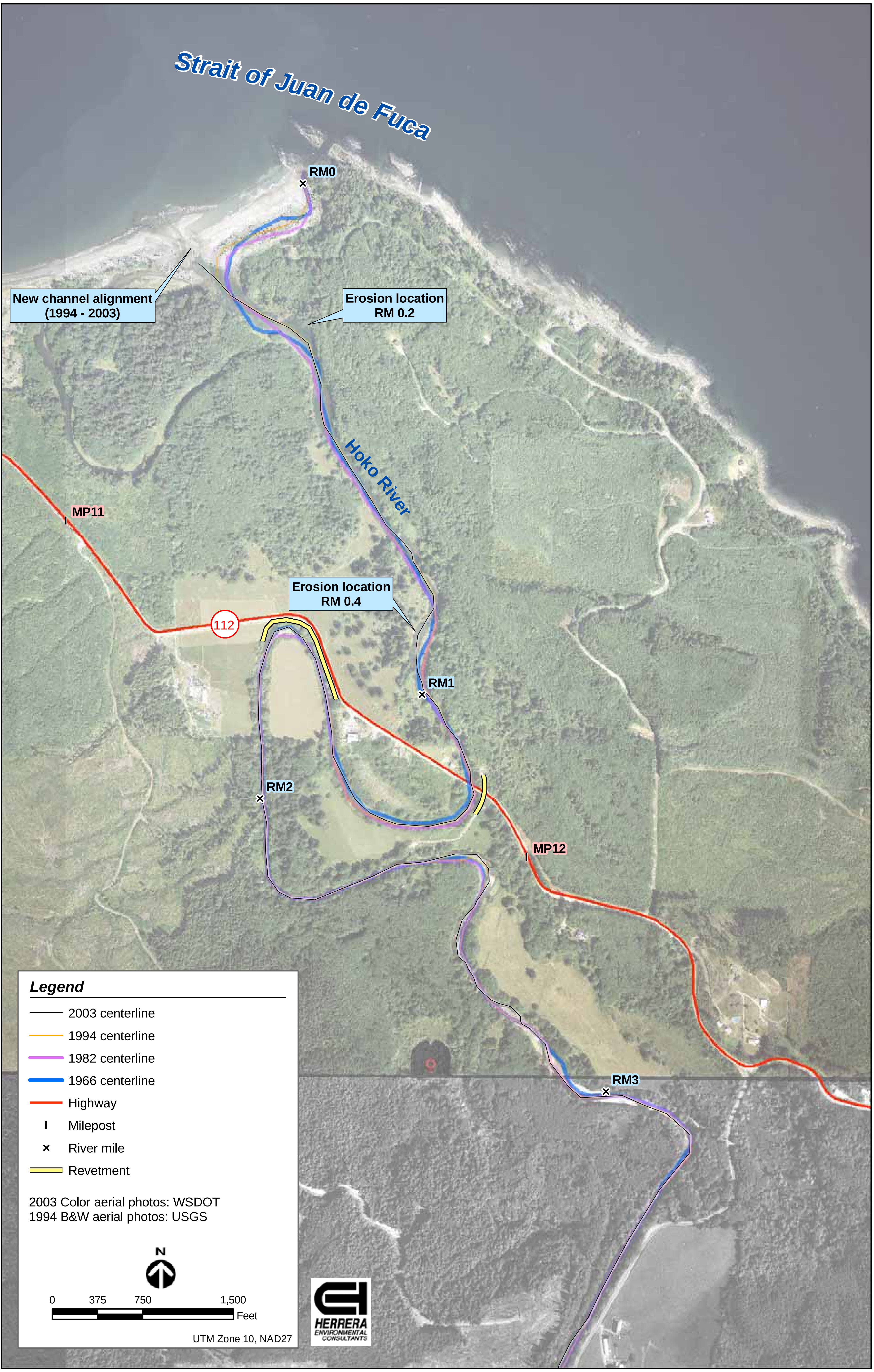

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Figure B-4. Hoko River channel centerlines (RM 0.0 to RM 3.4) and select lateral bank erosion locations along Highway 112.

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Clallam River

Similar to that of the Hoko River watershed the Clallam River channel network is made up of steep and confined headwater channels and lower-gradient and relatively unconfined meandering gravel bedded streams. The study reach of the Clallam River (RM 0.0 to RM 6.8) ranges from a sand-bedded single-thread channel to a complex multiple-thread gravel- and cobble-bedded pool-riffle channel network. The Clallam River is a pool-riffle channel that ranges from a plain single-thread channel to a complex multiple-thread system within the study reach. Based on topographic data from the 1984 USGS 7.5 minute topographic map and lidar data from 2005 the gradient of the Clallam River study reach varies between 0.3 percent and 1.6 percent and at least the lower 2.3 miles of the river are tidally influenced (Figure B-5). The highway profile is projected along with the river profile in Figure CG1 and illustrates the vertical distance between the highway elevation and the channel bed. The channel alignment is characterized by a sinuous path of irregular meanders and the sinuosity of the study reach is 1.6 (channel length/river valley length). The Clallam River is generally unconfined within the study reach downstream of RM 5.0. Between RM 5.0 and RM 6.0, the reach is moderately confined, and upstream of RM 6.0 the reach is increasingly confined by bedrock. The channel is also locally confined downstream of RM 6.0 at bridge crossings at RM 2.3, 3.5, 4.4, and 5.2 and also at RM 5.5 where a historical landslide deposit decreases the floodplain width. Channel widths of 30 to 100 feet were documented during the field survey. Channel widths generally increase further upstream until the river is confined by bedrock near RM 6.0 and widths decrease. The width of the floodplain valley in the study reach ranges from over 1000 feet downstream of RM 3.0, to 600 feet between RM 3.0 and RM 5.0, to 300 to 400 feet upstream of RM 5.0. Charley Creek is the most significant tributary within the study reach and joins the Clallam River at RM 3.8.

Conditions of sediment supply to the Clallam River channel network are not well documented. Whereas the lower Clallam is influenced by the community of Clallam Bay and associated land use activities, the upper Clallam River watershed, much as in the Hoko River watershed, has been heavily logged and mass wasting and road surface erosion related to forest harvest practices are major contributors of fine sediment to the channel (WDNR 1994 in Smith 1999). The average percent of fine sediment (<0.85mm) within samples taken between RM 2.8 and RM 4.5 was 21.5 percent, (McHenry et al. 1994). Samples taken from Hoko River tributaries all had greater percentages of fine sediment than samples from unharvested reference basins (Peterson et al. 1992 in Smith 1999). The substrate conditions in the Clallam River study reach ranged from sand- to cobble-sized particles and the mean particle size of bed sediments typically decreased further downstream. High sediment loads within the Clallam River may cause local channel instability, widening, or aggradation. In contrast to the Hoko River, moderate lateral migration was observed through the aerial photograph analysis of the Clallam River.

Lateral migration of the Clallam River alignment was observed in four locations (Figure B-6). Average migration rates range up to approximately 10 feet annually, though lateral migration at a given location could be much greater in a single year (Table B-7). Although the majority of the channel alignment was observed to be generally stable over the aerial photo record, the identified locations of channel migration suggest the degree of bank erosion that can occur. Further evidence of ongoing erosion and migration of the Clallam River is indicated by successive highway realignments. A significant length of the Highway 112 between MP 17.1 and MP 19.0 was relocated in 1971 and select portions of the highway between MP 19.7 and MP 20.4 were set further from the river between 1994 and 2003 (Figure CG2). Where the channel was not confined by the current or historical Highway 112 highway prism, stream banks were observed to be composed primarily of alluvial cobble, gravel, sand, and silt. In multiple locations, stream banks contained alternating layers of sand and gravel, evidence of dynamic lateral movement and deposition typical of pool-riffle channels. Such banks of alluvial sediment or road fill are not particularly resistant to erosion and where mature vegetation does not buffer the channel, or banks are not revetted, there is little to prohibit bank erosion and lateral migration (Photo A-73 in Appendix A). The natural channel migration zone for the low-gradient channel network can be estimated by the extent of the floodplain valleys.

Table B-7. Extent of Clallam River lateral erosion identified through analysis of aerial photographs.

Erosion Location	Time Span	Bank	Length (feet)
RM 3.4	1966 - 1982	Right	150
RM 4.0	1966 - 1982	Left	175
RM 4.6	1966 - 1982	Left	50
RM 5.5	1966 - 1982	Left	85
	1982 - 1994	Left	75

There was considerable local variation in channel complexity within the Clallam River study reach. Within the lower part of the surveyed study reach where the river is influenced by development and land use associated with Clallam Bay, the channel is incised into the wide floodplain (Photo A-76 in Appendix A). Where observed in this condition at RM 2.3, the channel substrate and vertical stream banks consist primarily of silt and sand with some gravel. Riparian vegetation in many places is limited to a narrow buffer of deciduous trees and shrubs between the channel alignment and adjacent agricultural fields. Mean substrate particle size increases upstream with gradient, and where the channel was observed at RM 3.5 (Highway 112 MP 18) the pool-riffle morphology of the gravel bedded channel was typical of the other upstream portions of the study reach.

The level of channel complexity observed within the study reaches was frequently associated with the level of LWD loading. LWD formed logjams at multiple sites and deflection scour at logjams was a common pool forming mechanism at these locations. At RM 5.9, the Clallam River was observed to contain numerous side channels and these too were typically associated with LWD. A complex series of side channels were observed in the Clallam River near RM 5.9. This survey reach contained considerable LWD and the initiation point of these channels occurred where logjams deflected and split the main stem flow path (Photo A-74 in Appendix A). Finer sediment was observed within these side-channels indicating that their presence increases sediment storage and particle residence time. In addition to locally recruited LWD, buried relic LWD, wood that was recruited to the channel network prior to the harvest of

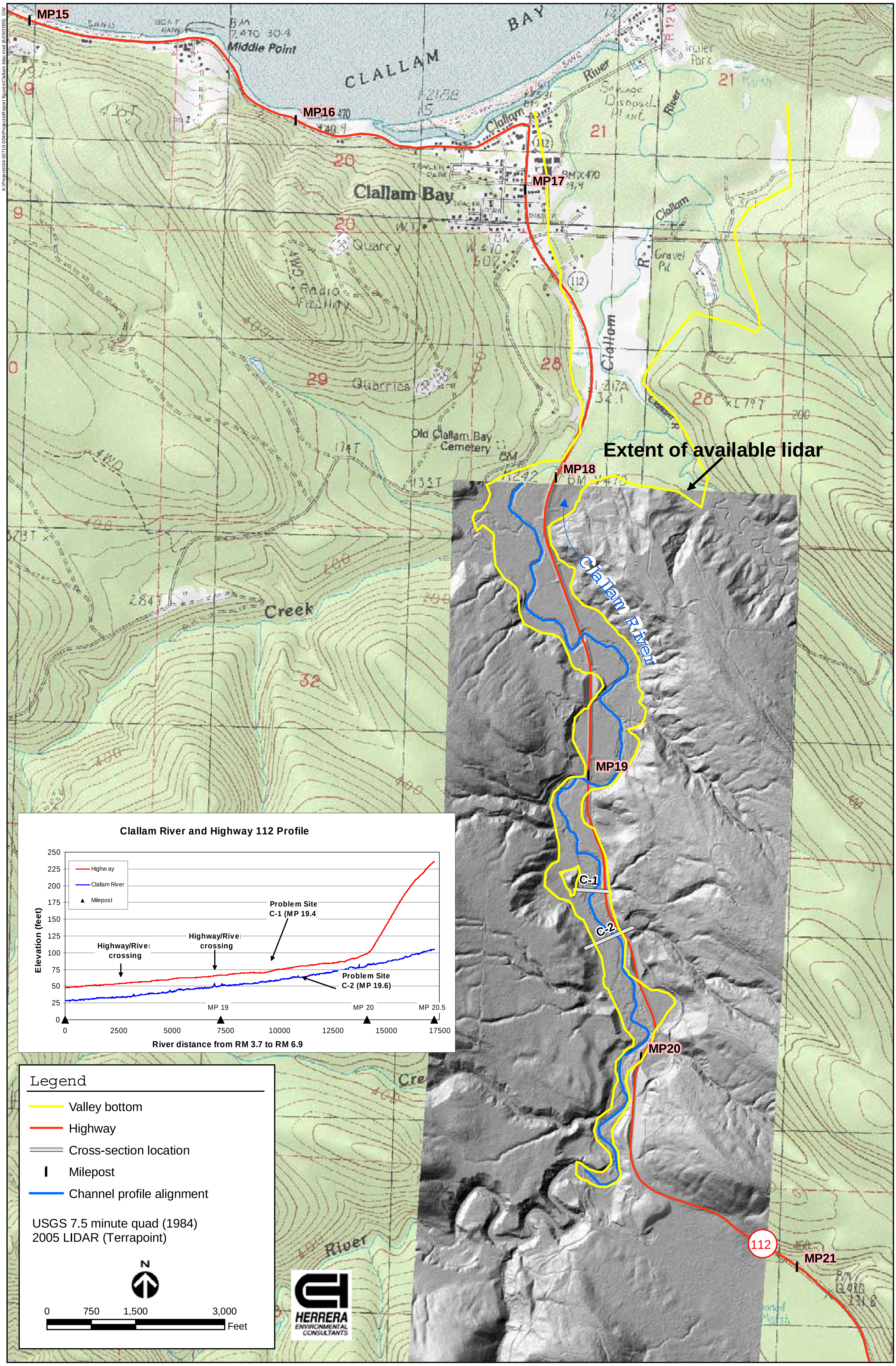

Figure B-5. Clallm River 2005 lidar hillshade, river and Highway 112 alignments and profiles, and cross-section locations

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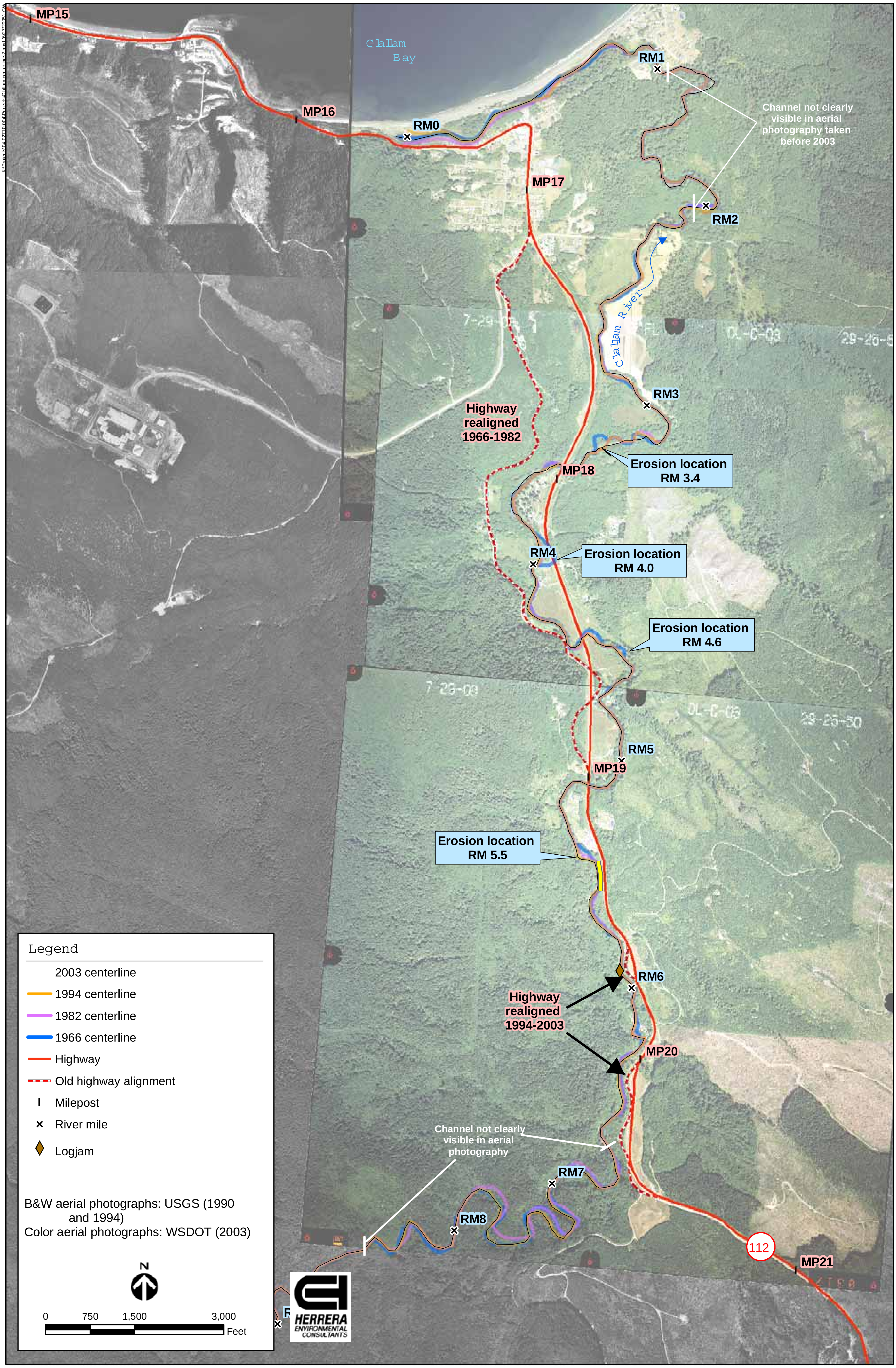

Figure B-6. Clallam River channel centerlines (RM 0.0 to 6.8), select lateral bank erosion locations, and highway realignments along along Highway 112.

the adjacent riparian community, was also observed at RM 5.9. Relic wood is identified its stem diameter that is greater than those of trees within the existing community of riparian vegetation. This relic LWD spanned a significant portion of the active channel width and served to store sediment and provide grade control limiting any potential downcutting (Photo A-75 in Appendix A).

Pysht River

On a watershed scale, the distribution of channel types and influences on channel geomorphology are similar to the nearby Hoko and Clallam Rivers, where confined channels drain steep headwater regions and flow into low-gradient channels occupying broad alluvial valleys. At the study-reach scale, the morphology of the Pysht River study reach (RM 2.0 to RM 9.0) is much like that of the Clallam River, and ranges considerably over its length. In the lower portion of the study reach (RM 2.0 to approximately RM 4.0) the Pysht River is an incised channel with cohesive fine-grained banks, whereas upstream it exhibits the characteristics of an unconfined alluvial system (RM 4.0 to RM 9.0). The Pysht River exhibits pool-riffle morphology throughout the study reach and the grain-size of substrate sediment is finest in the tidally influenced portion of the reach and becomes considerably coarser further upstream. The study reach is characterized by a sinuous path of irregular meanders with a sinuosity of 1.6 and a channel gradients ranging from 0.1 percent to 0.4 percent (Figure B-7). The highway profile is projected along with the river profile in Figure PG1 and illustrates the vertical distance between the highway elevation and the channel bed. The South Fork of the Pysht River is the most significant tributary to the Pysht River within the study reach and joins the main stem from the south-east at RM 8.5. Channel widths observed during the field survey ranged from 60 feet to 120 feet and widths generally increased further upstream. The width of the floodplain valley is approximately 2000 feet downstream of RM 7 and 1000 feet above RM 7. The river is generally unconfined within the wide floodplain valley of the study reach except where it is restricted by the Highway 112 alignment, most notably from RM 3.0 to RM 3.8, RM 6.7 to RM 7.0, and RM 8.0 to RM 9.0 as well as at RM 6.1 the location of a bridge crossing.

In addition to the similarities in watershed channel networks, the principal land use in the Pysht River watershed, like those of the Hoko and Clallam Rivers, is managed forestland and the primary sources of sediment to the channel network come from forest roads and mass wasting associated with forest harvest activities (McHenry et al. 1994). Significant sediment production from forest harvest activities has been documented in tributaries to the Pysht River and the condition of sediment supply to the study reach likely influences current channel conditions. In Green Creek, a tributary to the Pysht River at RM 9.8, Benda (1993) identified highly unstable banks, frequent lateral channel migration, and significant aggradation. Further, Benda (1993) noted that 90 percent of the landslide-derived sediments from the last-four decades are stored in the valley floor, indicating sediment supply that greatly exceeds transport capacity and a long-term source of sediment to the Pysht River study reach.

Channel response to increased sediment inputs depends on the ratio of transport capacity to sediment supply. Typical channel responses to excess sediment include aggradation, widening, pool filling, local braiding, and/or increased levels of fines in channel substrate. Such responses have been documented in studies of the Pysht River since at least 1989-1991 when large shifts in channel form and bed elevation, including aggradation at 15 out of 27 sites monitored, were observed (Steve Ralph, EPA, unpublished in Smith 1999). High levels of fine sediment (<0.85mm) in substrate sediment have also been documented. Within samples collected between RM 3.5 and RM 5.2 fine sediment accounted for 20.3 percent of the total, and in samples from RM 7.2 and RM 7.4 this value was 16.9 percent (McHenry et al. 1994).

Analysis of historical aerial photos indicates that there has been relatively limited channel migration over the last half-century (Figure B-8). One area where meander migration was observed lies just downstream of the confluence of the South Fork and main stem Pysht Rivers. At this location, just upstream of problem site P-2, downstream translation of meanders has occurred at an average rate of approximately 20-25 feet per year over the last two decades. Further downstream, abandoned channel meanders are clearly visible in the lidar imagery and provide evidence of widespread historical lateral migration (Figure B-7). As does the current channel alignment, these historical channel planforms extend to the floodplain margin in multiple locations and suggest that the channel migration zone stretches from valley wall to valley wall. A cross-section through the abandoned meanders indicates the elevation of the current channel bed is lower than those of the abandoned meanders (Figure B-9). This suggests either deposition within the historical alignments or incision of the current alignment. Significantly, all erosion-related problem sites along Highway 112 identified on the Pysht River study reach, save one, are located at the outside on meanders, indicating persistent, if gradual, channel meander lateral extension or downstream translation. The exception, problem site P-2, occurs where the highway confines the channel migration zone to approximately 300 feet, approximately one-fifth the valley width.

Although recent rates of channel migration within the Pysht River study reach have been low, local adjustments in channel alignment were documented in recent aerial photographs and during Herrera's field survey. These adjustments are strongly correlated to the occurrence of logjams within the study reach and logjams appear to play a significant role in the current morphological conditions. Logjams can impart significant morphological control on channels of all types. Where logjams deflect flow through existing floodplain forests, islands may form when channels avulse through floodplain surfaces (Figure 6). Alternatively, logjams can ultimately create forested islands when they form hardpoints in the active channel. Deposition occurs in the lee of such structures (bar-apex logjams) which subsequent become vegetated (Photo A-77 in Appendix A). Such islands can endure for centuries and are one of the fundamental features controlling the morphology of forested river systems (Abbe 2000).

Logjams significantly influencing channel form were observed throughout the study reach (Figure B-8). The majority of logjams within the study reach are flow-deflection jams consisting of locally recruited key members and racked material transported during high flows (Table B-8). Within the study reach, these jams deflect flow through the interior portion of meanders. Such channel adjustments function similar to neck-cutoff avulsions and decrease the length of the river while increasing the local slope. As the highway alignment is generally located at the outside of river meanders, such realignments, and the related potential for bank erosion, do not pose the principal threat from such jams, and in fact bank erosion is typically decreased when flow is split

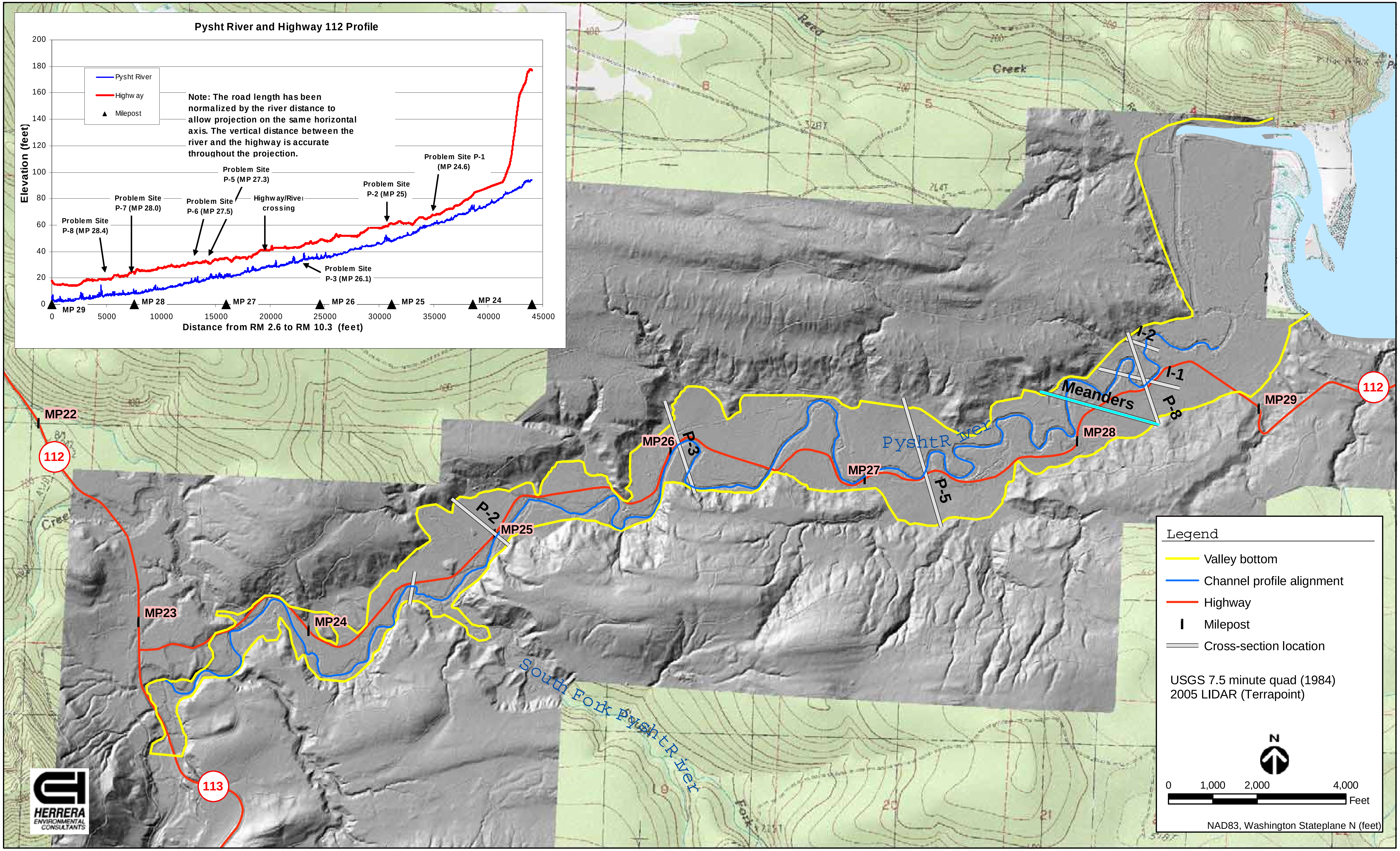

Figure B-7. Pysht River 2005 lidar DEM hillshade, river and Highway 112 alignments and profiles, and cross-section locations.

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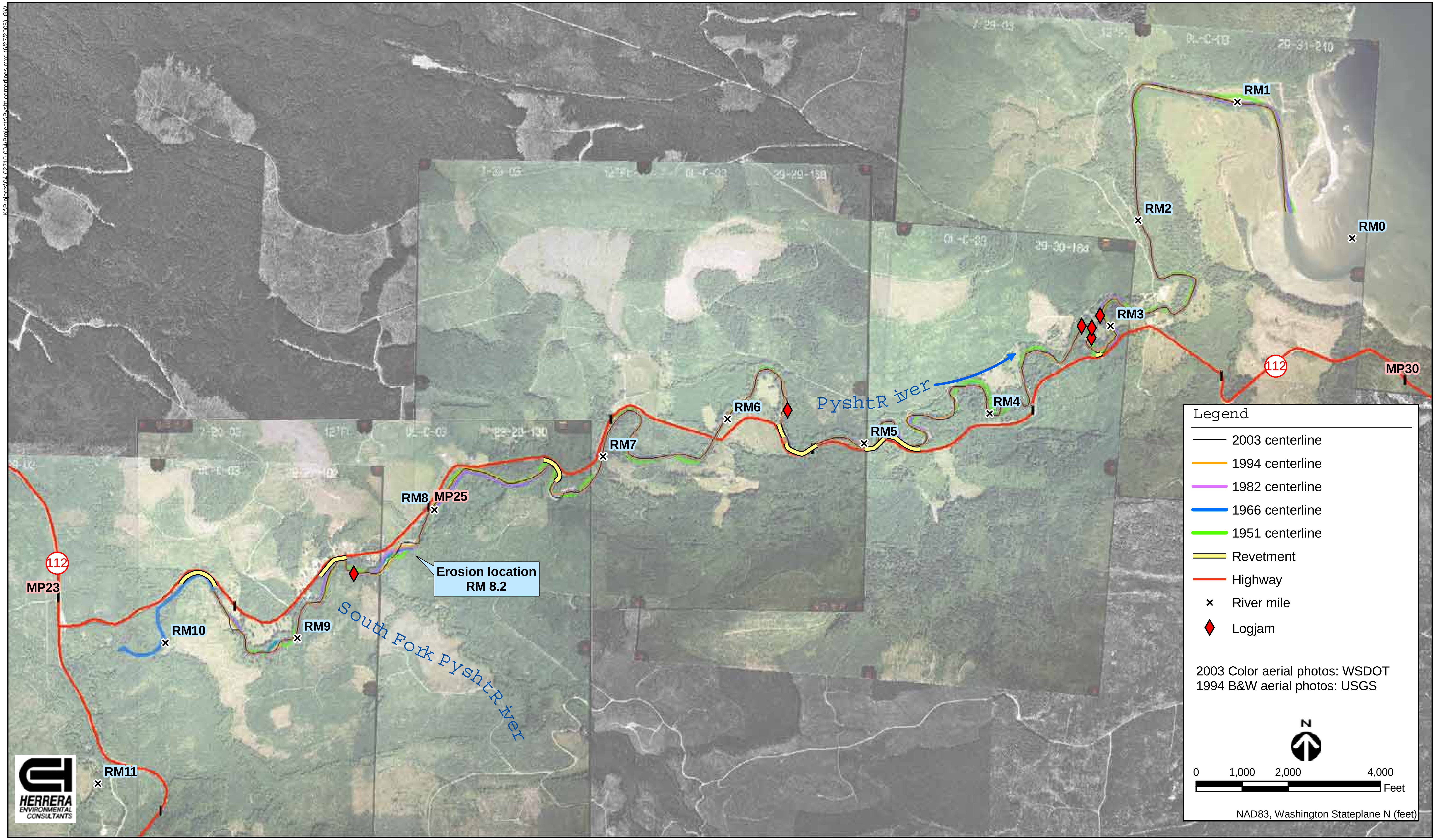

2003 Color aerial photos: WSDOT
1994 B&W aerial photos: USGS

NAD83, Washington Stateplane N (feet)

Figure B-8. Pysht River channel centerlines (RM 0.5 to RM 9.5) and select lateral bank erosion locations along Highway 112.

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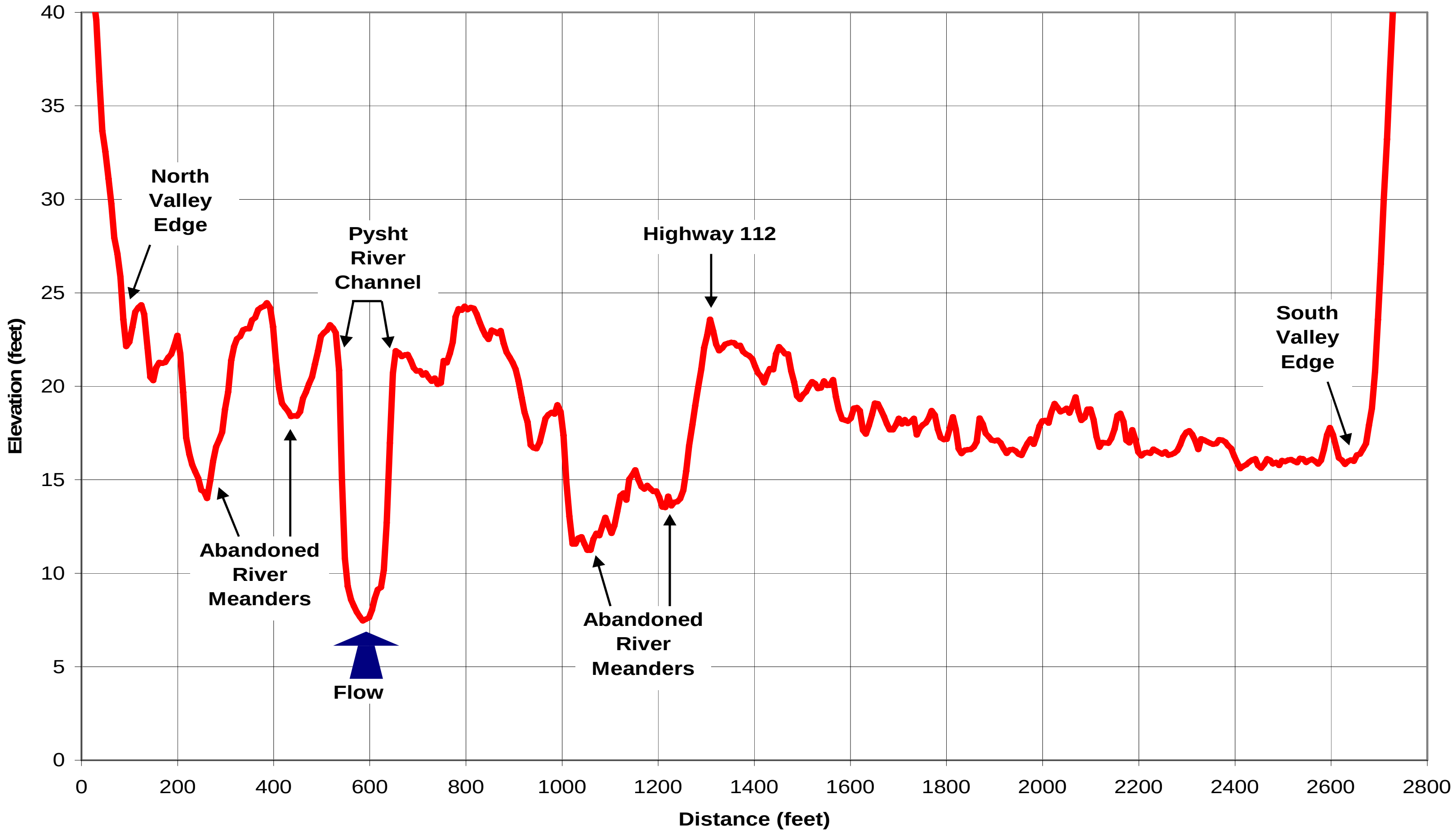

Figure B-9. **Cross-section M-1 of the Pysht River valley at RM 3.6 and Highway 112 MP 28.2 based on the 2005 lidar DEM. The cross-section illustrates abandoned river meanders indicating the magnitude of historical lateral migration and suggesting that the channel migration zone occupies the entire river valley.**

between multiple channels. Flow deflection jams, however, can develop into valley jams if their expansion impounds the channel. It is increases in flood stage that are associated with aggradation upstream of such channel-spanning jams that could potentially threaten the highway in its current alignment (Abbe and Montgomery 2003). Such aggradation has occurred upstream of the valley jam at RM 8.2, which is now responsible for problem site P-1 where flooding of the highway and private residences has resulted.

Table B-8. Location and character of significant logjams identified within the Pysht River study reach (RM 2.0 to RM 10.0).

River Mile	Related to Identified Threat to Highway 112?		Logjam Form	Principal Geomorphic Influence
	Yes/No	Problem Site		
2.9	No	–	Flow deflection	Created side channel and forested island following flow deflection through forested floodplain
2.9	No	–	Bar apex	Causing deposition in lee of logjam and forming of mid-channel island
3.2	No	–	Flow deflection	Created side channel and forested island following flow deflection through forested floodplain
3.9	No	–	Flow deflection	Created side channel and forested island following flow deflection through forested floodplain
5.5	No	–	Flow deflection	Created side channel and forested island following flow deflection through forested floodplain
8.2	Yes	P-1	Valley (channel spanning)	Creating backwater and causing upstream deposition and aggradation

Vegetation

Hoko, Clallam, and Pysht River Valley Forest Current Conditions

The historically forested Hoko, Clallam, and Pysht River valleys are currently a mosaic of various vegetation types resulting from commercial forestry operations, pasture conversion, highway construction, and land development (Table B-9; Figures B-10, B-11, and B-12). The riparian forest immediately adjacent to the river channels, and within the channel migration zone, is often discontinuous with areas of pasture and limited tree cover. Riparian forests located between the river channels and Highway 112 stabilizes stream banks and reduces the potential for channel migration into the highway road embankments. The loss of riparian forest at sites throughout all three reaches has resulted in areas of Highway 112 at risk from channel erosion, see Section Exiting Problem Sites and Potential Problem Sites.

Table B-9. Hoko, Clallam, and Pysht Valley vegetation cover types within the reach analysis study areas.

	Hoko River	Clallam River	Pysht River
Vegetation Cover Type [a]	Percentage of Valley Bottom	Percentage of Valley Bottom	Percentage of Valley Bottom
Deciduous forest	11	21	17
Early seral forest	Na	6	16
Immature mixed forest	38	19	29
Mature mixed forest	10	23	10
Immature conifer forest	Na	1	8
Mature conifer forest	Na	1	6
Pasture	31	19	4
Wetland	2	1	7
Developed	8	9	3

[a] Vegetation cover types. Deciduous forest: areas dominated by red alder. Early seral forest: recently harvested or cleared areas. Immature mixed forest: even aged mixed conifer deciduous forest with minimal canopy stratification. Mature mixed forest: mixed conifer deciduous forest with canopy stratification evident on aerial photography. Immature conifer forest: young, even aged, non-stratified conifer stands (e.g., conifer plantations). Mature conifer forest: conifer forest with identifiable canopy stratification. Pasture: agricultural pasture lands. Wetland: scrub-shrub and emergent wetlands. Developed: land associated with buildings.

Riparian Forest Influences on Large River Channels and Floodplains ─ Aspects Relevant to River Valley Road Corridors

Riparian forests:

- Decrease channel width and restrict channel migration
- Stabilize river banks through vegetation root cohesion
- Dissipate flood erosive energy by increasing floodplain roughness
- Are sources of large wood that form stable wood jams
- Add physical complexity to channels and floodplains resulting in a diversity of fish and wildlife habitat
- Are the “engine” that forms the food base for healthy riverine aquatic ecosystems
- Act as filters of pollutants associated with road surface run-off.

Riparian forests are an integral part of the river valley landscape in forested river basins (Naiman et al. 1998). They include both valley bottom floodplain forests and forests of the adjacent valley hillslope margins. These forests influence both channel and floodplain processes and

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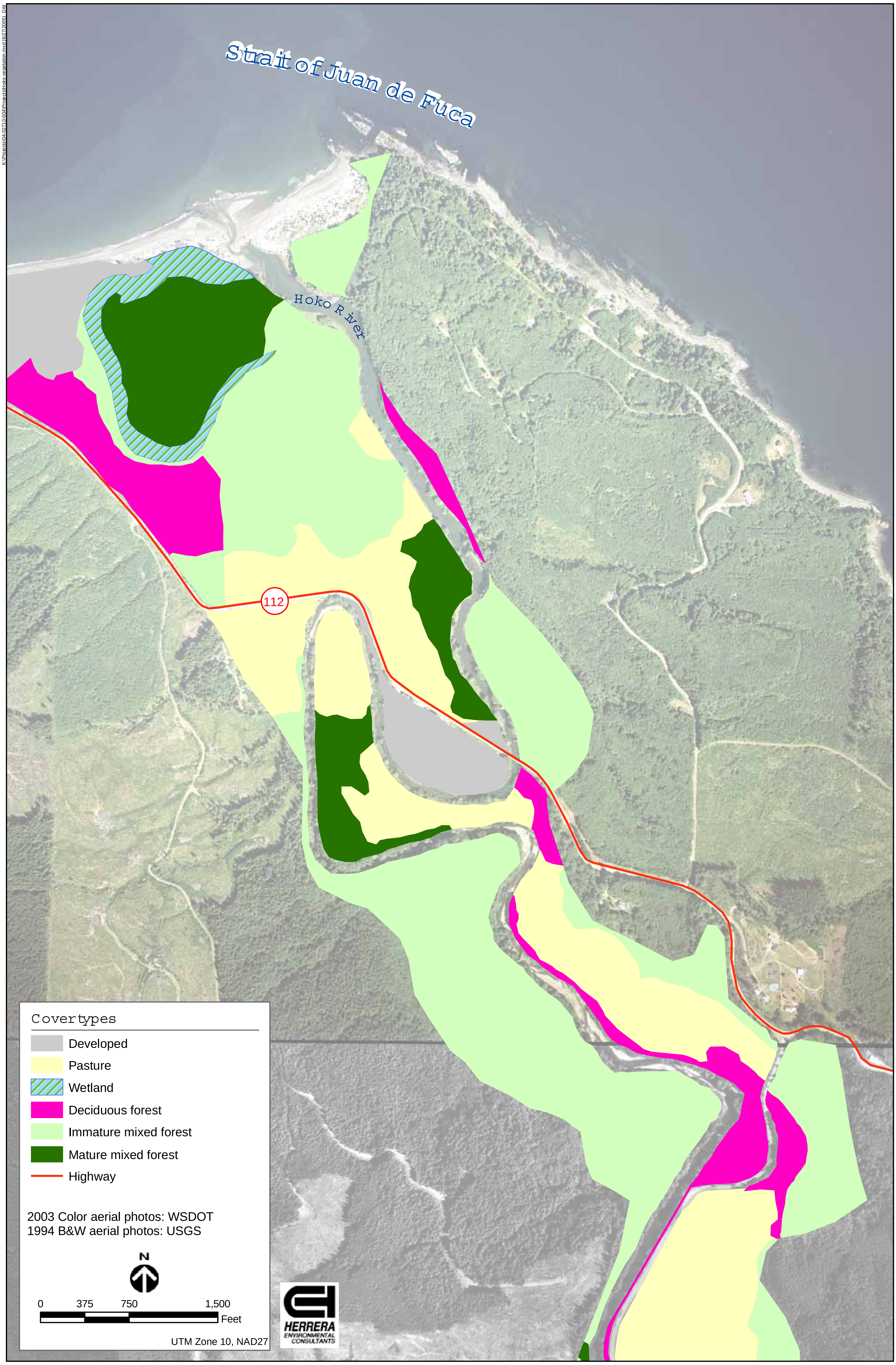

Figure B-10. **Hoko River valley vegetation types.**

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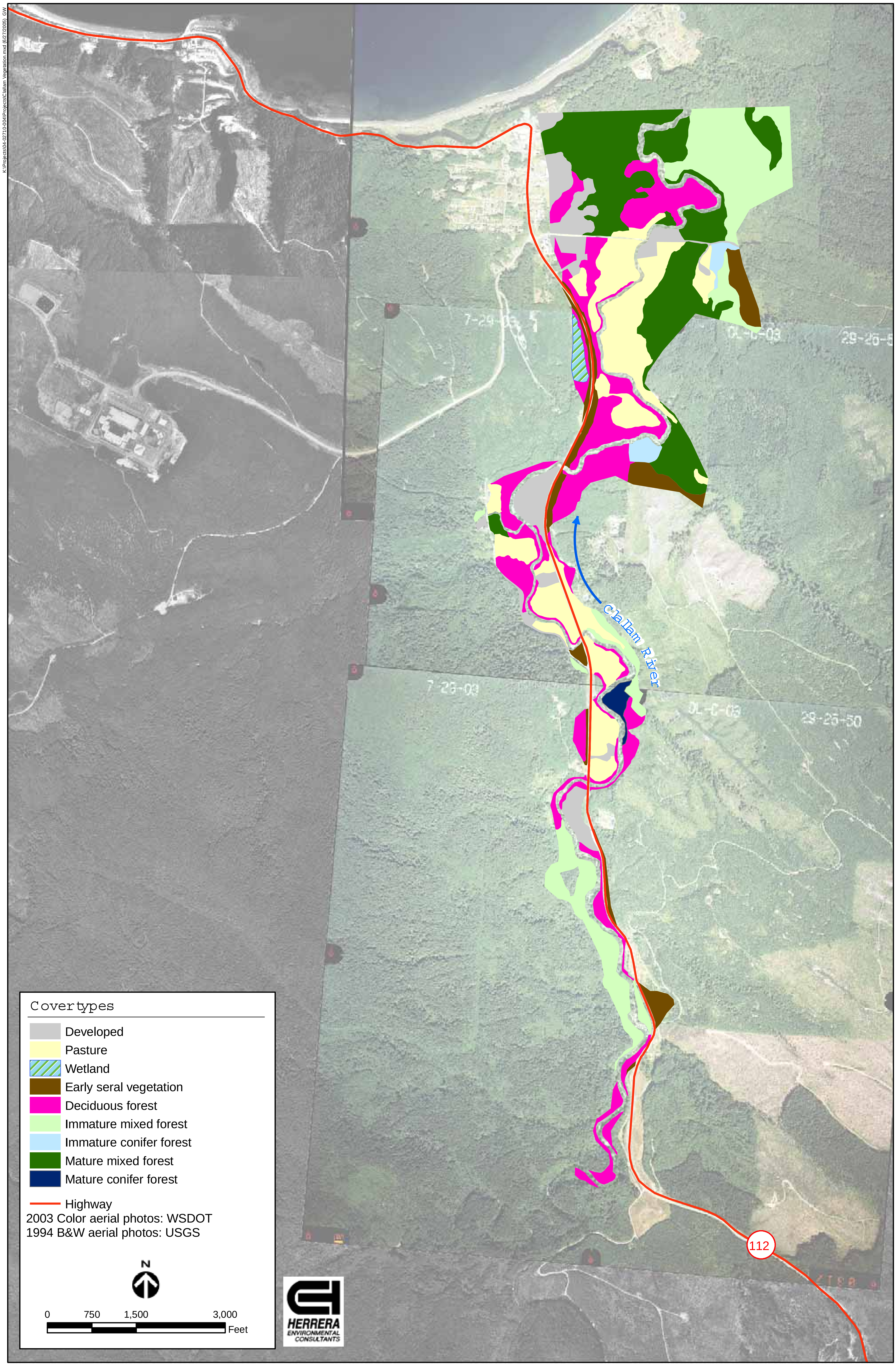

Figure B-11. **Clallam River valley vegetation types.**

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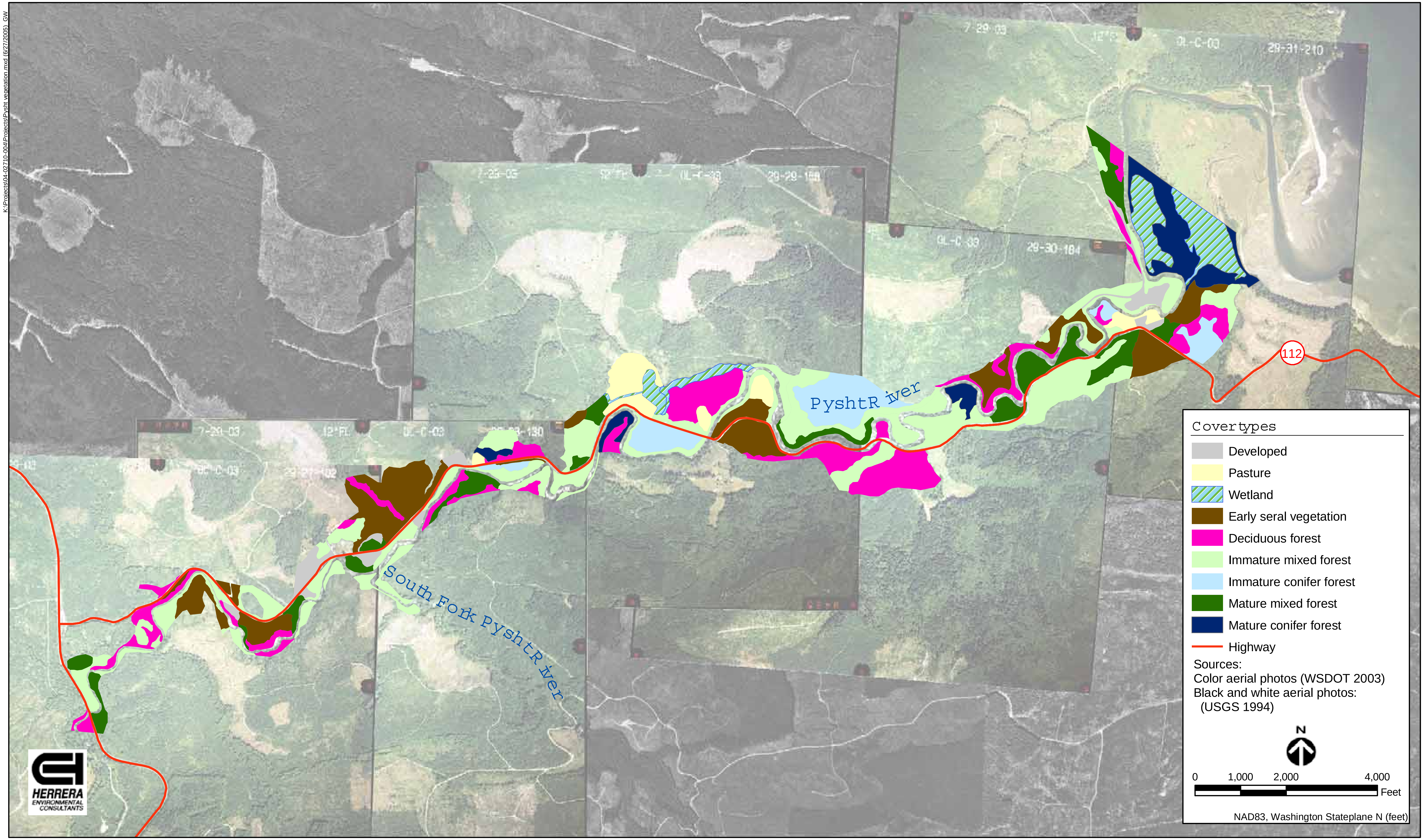

Sources:
Color aerial photos (WSDOT 2003)
Black and white aerial photos: (USGS 1994)

NAD83, Washington Stateplane N (feet)

Figure B-12. Pysht River valley vegetation types.

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structure while providing a diversity of habitat features that maintain biological diversity and the ecological integrity of the entire forested riverine landscape. Riparian forests have a number of ecological functions in healthy riverine landscapes including: hydrogeomorphological, biogeochemical, and plant and animal habitat (Gregory et al. 1991; Naiman et al. 1998). Riparian forest functions immediately relevant to Washington DOT river valley road issues include their role in maintaining channel stability and plant and animal habitat.

Riparian forests play a significant role in constraining river channel movements, river banks, and floodplains (Simon and Collison 2002; Abbe 2004). River bank erosion results from both hydraulic-induced river bank-toe erosion and subsequent bank mass failure (Simon and Collison 2002). Riparian vegetation root reinforcement has been demonstrated to be a primary mechanism stabilizing river embankments (Abernathy and Rutherford 2001; Simon and Collison 2002). Numerous studies of hillslope and river bank vegetation root reinforcement (root cohesion) have shown that vegetation roots provide a significant increase in soil shear strength as compared with unvegetated substrates (Schmidt et al. 2001; Abernethy and Rutherford 2001). Concerning road embankment stability, not all riparian vegetation types are created equal. Mature conifer forests have been shown to provide greater root reinforcement then either non-forest (pasture or shrubs resulting form land clearing) or red alder floodplain forests (Figures B-13 and B-14) (Simon and Collison 2002). Along the Hoh River, Olympic Peninsula Washington, riparian forests with average diameters > 21 inches were found to erode at a slower rate than floodplain forests with smaller diameter trees or no trees (Figure B-14) (Abbe 2004).

Historic clearing of valley and hillslope riparian forests in the Hoko, Clallam, and Pysht River valleys has lead to a widening of the erosion hazard area. Most of the Hoko, Clallam, and Pysht River riparian areas are characterized by young conifers and red alder small diameter trees interspersed with patches of pasture and developed land. These areas do not provide a significant degree of river bank stability. Therefore, active riparian conifer restoration is recommended to be a primary component of valley road stabilization projects in addition to road engineering designs.

Fisheries Habitat

The Hoko River, Clallam River, and Pysht River drain into the Strait of Juan de Fuca and are located within WRIA 19. No federally listed or proposed listed endangered or threatened fish species occur within the Hoko, Clallam, or Pysht watersheds. These rivers provide habitat for runs of chinook salmon, coho salmon, chum salmon and winter steelhead trout. Factors limiting salmon abundance in the Hoko, Clallam, and Pysht River watersheds include channel instability, sedimentation, reduced LWD, increased peak flows, riparian vegetation, and high stream temperatures (Smith 1999). Restoring riparian conditions and floodplain connectivity within the study reaches has the potential to improve fish habitat condition and fish abundance. A summary of existing fish habitat within the study reaches for these rivers is presented below. The existing habitat assessment includes the examination of habitat limiting factors and fish habitat utilization.

Hoko River

Fish Utilization of the Existing Habitat

Historical surveys indicate the Hoko River watershed has supported four species of anadromous fish between RM 1.0 and RM 3.4: winter steelhead trout (*Oncorhynchus mykiss*), coho salmon (*O. kisutch*), chinook salmon (*O. tshawytscha*), and chum salmon (*O. keta*) (StreamNet 2005). Of these fish species, chinook and coho salmon spawn and rear in the study reach (Table B-10). Chum salmon and winter steelhead trout use habitat in the study reach for migration only. The chinook stock is considered depressed within the Hoko River system. The chum, coho, and steelhead stocks are identified healthy by the WDFW (WDFW 2002).

Table B-10. Salmon and steelhead habitat utilization between RM 1.0 and RM 3.4 of the Hoko River.

Species	Use Type (River Mile Points)	
Chinook Salmon	Spawning and Rearing	(RM 1.0 – RM 3.4)
Coho Salmon	Rearing and migration	(RM 1.0 – RM 2.9) (RM 2.9 – RM 3.4)
Chum Salmon	Migration	(RM 1.0 – RM 3.4)
Winter Steelhead	Migration	(RM 1.0 – RM 2.0)

Source: StreamNet (2005).

Habitat Limiting Factors

Unless otherwise stated, information from the entire lower Hoko River mainstem was used to describe the limiting factors for the study reach.

For the entire Hoko River watershed, Smith (1999) lists excess sedimentation coupled with a lack of LWD as primary limiting factors, which affects channel instability and impacts incubating salmon eggs. LWD conditions in segments of the Hoko River where chinook and chum spawn are below target levels and likely impacts adult migration, incubation stability, and juvenile rearing (Martin et al. 1995). According to McHenry spawning habitat in the lower Hoko River is degraded due to high level of fines in spawning gravels (McHenry et al. 1994). LWD in streams provide streambank support against high flows and floods by holding soils into the bank, which in turn reduces downstream sediment inputs to spawning gravel and redds. Additionally, LWD diversifies flows, in turn helping protect redds from souring effects of high flows (Naiman et al. 1992). Low summer water flows are a documented habitat problem in the lower Hoko River for returning adult fall chinook and coho salmon runs (Currence 1999).

Clallam River

Fish Utilization of the Existing Habitat

Historically salmon utilization in the Clallam River watershed between RM 0.0 and RM 5.7 includes four species of anadromous fish: winter steelhead trout (*Oncorhynchus mykiss*), coho

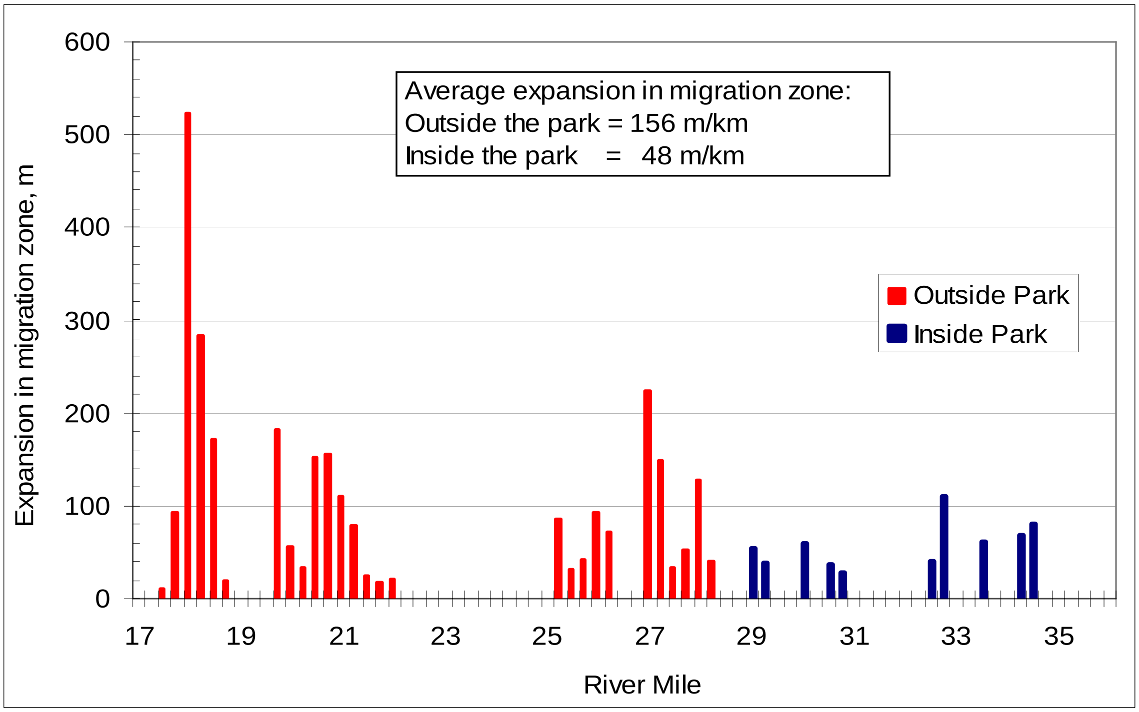

Figure B-13. Expansion of the Hoh River channel migration zone within Olympic National Park old-growth forest and second growth forest outside the Park (Abbe 2004).

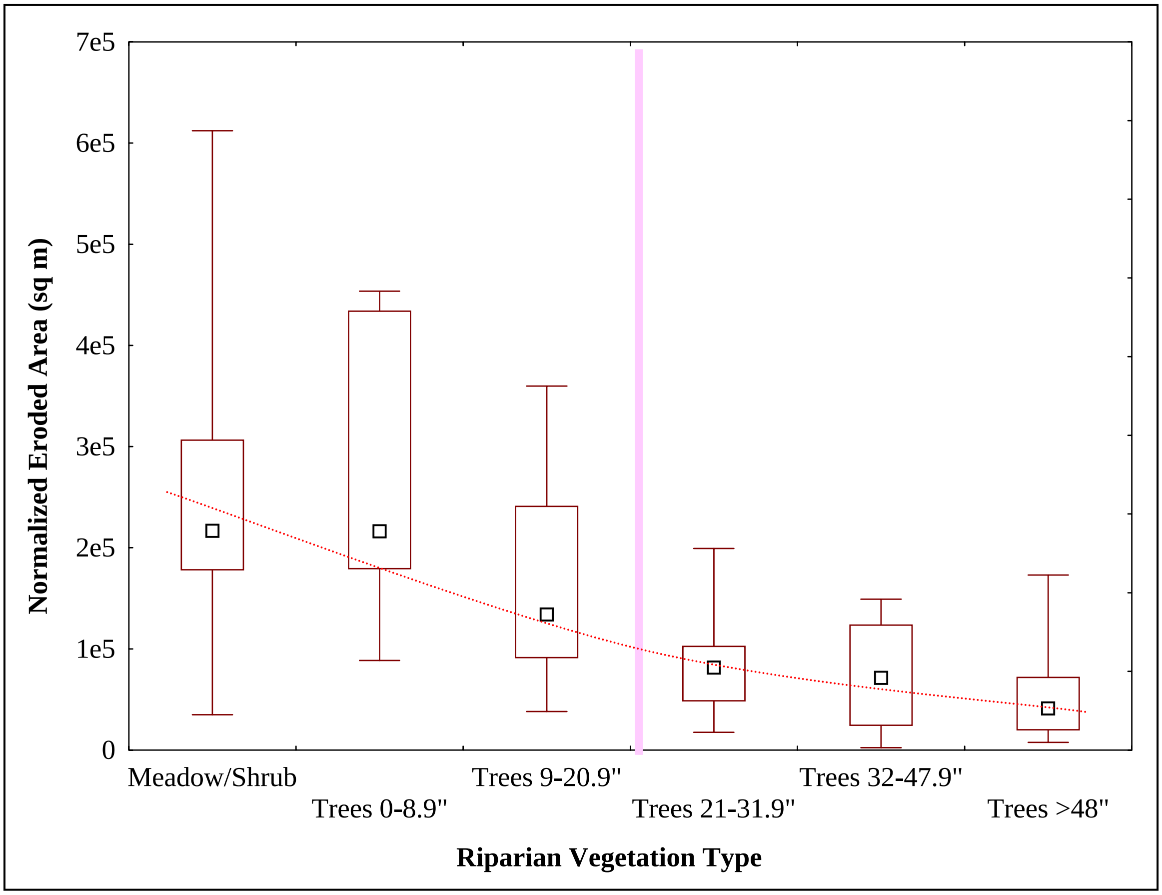

Figure B-14. Hoh River floodplain erosion rates by vegetation type and tree diameter (Abbe 2004).

salmon (*O. kisutch*), chinook salmon (*O. tshawytscha*), and chum salmon (*O. keta*) (StreamNet 2005). Of these fish species, coho salmon and winter steelhead are reported to spawn and rear in this segment of stream (Table B-11). The StreamNet database lists chinook salmon as historically spawning through RM 4.4 of the Clallam River however sighting of chinook salmon have not been observed in recent years (Smith 1999). Chum salmon use habitat in the Clallam River for migration only through RM 5.5 (StreamNet 2005). The chinook stock is considered depressed within the Clallam River system. The chum, coho, and steelhead stocks are identified healthy by the WDFW (WDFW 2002).

Table B-11. Salmon and steelhead habitat utilization between RM 0.0 and RM 5.7 of the Clallam River.

Species	Use Type (River Mile Points)	
Chinook Salmon	Spawning and rearing	(RM 0.0 – RM 4.4)
Coho Salmon	Migration	(RM 0.0 – RM 0.2)
	Rearing and migration	(RM 0.2 – RM 3.0)
	Spawning and rearing	(RM 3.0 – RM 5.7)
Chum Salmon	Migration	(RM 0.0 – RM 5.5)
Winter Steelhead	Migration	(RM 0.0 – RM 0.7)
	Spawning and rearing	(RM 0.7 – RM 5.7)

Source: StreamNet (2005).

Habitat Limiting Factors

Specific data regarding habitat conditions are lacking for the lower Clallam River within the study reach (Smith 1999). Therefore, information from the entire Clallam watershed is used to describe the limiting factors for the study reach.

For the entire Clallam River watershed, Smith (1999) lists excessive sedimentation, lack of LWD, open or hardwood riparian areas, floodplain impacts, and severe peak flows as major factors limiting salmon habitat. Poor riparian vegetation and LWD conditions are a problem in lower reaches of the Clallam River, where high flow velocities and gravel scour are thought to affect coho and steelhead productivity (Noble 2004). Warm water temperatures are a documented habitat problem in the lower Clallam River and likely impact spawning and rearing habitat. The lower river is included in the Washington State Section 303(d) list for water temperature violations (Ecology 2000).

Pysht River

Fish Utilization of the Existing Habitat

Historical surveys indicate the Pysht River has supported four species of anadromous fish between RM 3.0 and RM 9.0: steelhead trout (*Oncorhynchus mykiss*), coho salmon (*O. kisutch*), chinook salmon (*O. tshawytscha*), and chum salmon (*O. keta*) (StreamNet 2005). Of these fish species, coho salmon and winter steelhead trout spawn and rear in this segment of the river (Table B-12). Chinook salmon utilize the Pysht River study reach from RM 2.4 to RM 9.0 for spawning and rearing habitat. Chum utilize habitat in the study reach for migration only. The chum salmon, coho salmon, and steelhead trout stocks are considered healthy within the Pysht River system. The chinook stock status is unknown for the river system (WDFW 2002).

Table B-12. Salmon and steelhead habitat utilization between RM 2.0 and RM 9.0 of the Pysht River.

Species	Use Type (River Mile Points)	
Chinook Salmon	Rearing and migration Spawning and rearing	(RM 2.0 – RM 2.4) (RM 2.4 – RM 9.0)
Coho Salmon	Spawning and rearing	(RM 2.0 – RM 9.0)
Chum Salmon	Migration	(RM 2.0 – RM 9.0)
Winter Steelhead	Spawning and Rearing	(RM 2.0 – RM 9.0)

Source: StreamNet (2005).

Habitat Limiting Factors

Unless otherwise stated, information from the entire lower Pysht River mainstem area were used to describe the limiting factors for the study reach. When appropriate, information from the entire Pysht River watershed were also used in determining habitat limiting factors in the study reach.

According to Smith (1999), current major factors limiting salmon habitat are thought to include poor riparian conditions, lack of LWD, excessive sedimentation, severe peak flows, and floodplain impacts. Specific data regarding habitat conditions are lacking for the lower Pysht River however, migration barriers to spawning and rearing habitat are documented for tributary to the mainstem Pysht River (McHenry 2005). The removal of trees along riparian roads have likely reduced the potential LWD recruitment and riparian vegetation cover for salmon habitat. The lack of LWD in the channel is thought to have decreased pool habitat formation and spawning gravel storage. The loss of floodplain complexity and connectivity in the vicinity of Highway 112 potentially contributes to sediment problems and increased channel instability in the lower Pysht watershed. Warm water temperatures are a documented habitat problem in the lower Pysht River.

Habitat Elements

Background

In river systems such as the Hoko, Clallam, and Pysht Rivers, the interplay between water, soil, plants, and animals occurs in cycles of intensity driven by climatic and geological processes. Stochastic processes and natural disturbances place stresses on the river and associated riparian areas (river corridor; Figure B-15) and have the potential to reshape, rejuvenate, or impair its ability to perform ecological functions. Natural disturbances in the Hoko, Clallam, and Pysht Rivers can occur anywhere within the river corridor and can vary in terms of frequency, duration, and intensity. In river systems in general, a single disturbance event may trigger a variety of disturbances that differ in frequency, duration, intensity, and location (NRC 1997). Ecologists (Holling 1973; White and Picket 1985) have long recognized the dynamic nature of aquatic and terrestrial ecosystems and how the associated biota and physical characteristics change through time due to stochastic processes and natural disturbances. Floods, fire, lightning, earthquakes, insects and disease, landslides, temperature extremes, and drought are among the many natural disturbances affecting structure and functions in the river corridor (NRC 1997).

As in other river systems, in the Hoko, Clallam, and Pysht Rivers, natural processes create and maintain habitat for aquatic species, including habitat for salmonid fish species. In addition these processes create and maintain habitat for terrestrial species, including bold eagle (*Haliaeetus leucocephalus*), which are protected under the Endangered Species Act (ESA). Osprey (*Pandion haliaetus*) also occurs in the area. Natural disturbances can: (1) increase biological diversity; (2) be crucial for the persistence of some organisms and the habitat that supports them; and (3) express and maintain key ecological processes (Turner et al. 1994). frequency and magnitude of disturbance events over time define the disturbance regime for an area. The disturbance regime largely defines the conditions in which native species adapt. Indeed, plants and animals have evolved to cope with environmental perturbation (Reeves et al. 1995).

The successful management of the Hoko, Clallam, and Pysht Rivers and their floodplain encompasses the protection of fish and aquatic, riparian, and river migration zone habitat, and requires a detailed understanding of the physical characteristics of the river, its historical channel movements, and its propensity to migrate.

Channel Migration: Maintenance of Side-channel and Floodplain Wetlands

Channel migration is a natural fluvial process, particularly in rivers such as the Hoko, Clallam, and Pysht Rivers with substantial sediment supply. Channel migration creates aquatic and riparian habitat that sustains fluvial ecosystems. Some of these habitats include side-channels and floodplain wetlands. In general, river areas of active channel migration provide a diversity of complex riverine habitat that is absent in constricted river reaches where the channel cannot move laterally. Complex river channels provide a diverse array of salmonid habitats, including deep pools; cover provided by boulders, large wood, and undercut banks, riffle areas for food production; and areas of gravel for spawning. The diversity and abundance of fish within habitat units is directly related to their complexity (Mouw 2005; Ruediger and Ruediger 1999).

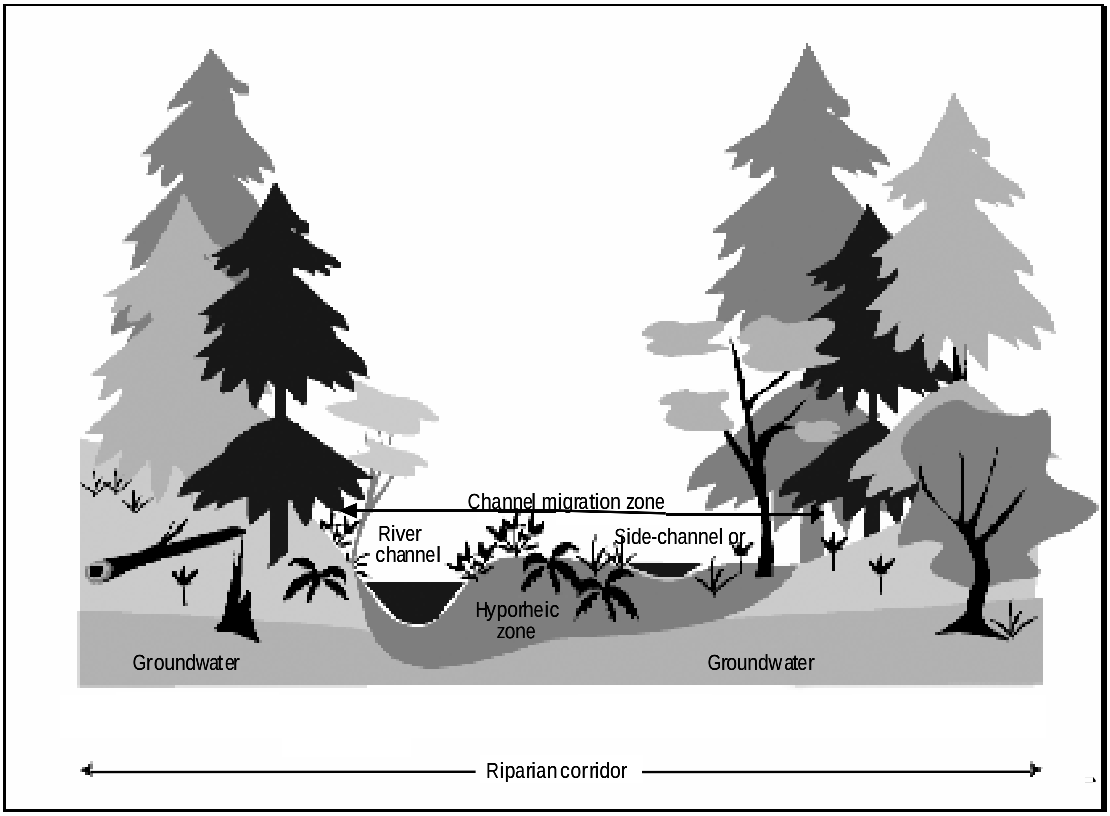

Figure B-15. **Typical river riparian corridor in the Pacific Northwest (Adopted from May 2003).**

While restricting channel migration is often necessary for protection of roads, it hinders the beneficial effects of channel migration and often damages the habitat in the river and limits or eliminates opportunities for natural habitat creation and maintenance. Floodplain areas within the channel migration zone provide unique rearing, foraging, holding, overwintering, and spawning habitat as well as refugia for salmonid fish species and other aquatic species that inhabit the Hoko, Clallam, and Pysht Rivers. If flood walls or road embankment structures are constructed to prevent the channel migration, there would likely be a loss of this highly complex physical habitat. A loss of habitat, or the constriction or elimination of the processes that create and maintain such habitat areas, could affect the density of aquatic organisms that use the reach by limiting the amount of available physical habitat (density-dependent limiting factor), depending on the magnitude of the adverse effects.

Complex Structures

Most alluvial reaches of rivers such as the Hoko, Clallam, and Pysht Rivers are characterized by flow and sediment regimes and stochastic processes, which interacting with woody debris lead to floodplains with a mosaic of hydrologically connected and embedded aquatic habitats. This hydrologic connectivity between the river and its floodplain, either through surface connection or hyporheic exchange flow, is critical to maintaining floodplain function and biodiversity (Bornette el al. 1998; Ward et al. 1999; Sheldon et al. 2002).

Channel planform and flow obstructions can result in significant changes in water surface topography, locally raising water elevations enough to inundate secondary channels and portions of the floodplain during flows that otherwise would not engage the floodplain (Miller 1995). In river systems, logjams create the same effect as they can obstruct flow and control channel planform (Gallinatti 1984, Lisle 1987 and 1986), thus serving as one of the principal mechanisms of connecting secondary channels and wetlands within floodplains to the mainstem channel. These fluvial processes are driven by bank erosion and lateral and point bar accretion (Mouw 2005).

Large woody debris, particularly logjams, also have a strong influence on creating multiple channel networks and initiating important floodplain habitat processes that influence fish and wildlife habitat (Smith and Pearce 2002; Prowse and Conly 2002). In the Hoko, Clallam, and Pysht Rivers, woody debris likely provides for habitat partitioning, complexity, and maintenance of aquatic habitat, particularly for salmonid fish species. Habitat partitioning and complexity increase the habitat functionality and availability, allowing a greater number of species and individuals to coexist. Therefore, in those activities affecting woody debris and/or woody debris recruitment potential, are likely to induce habitat simplification over time, resulting in density-dependent mortality of rearing salmonid fishes and some wildlife species that depend upon these habitats.

Buffers

The terms “buffer” is often loosely used as synonyms for riparian areas. However, the term buffer is typically applied in a specific management context to denote an area set aside and managed to protect a natural area from the effects of surrounding land-use or human activities (May 2003; Knutson and Naef 1997). Depending on the context, buffers may be designed to perform a specific function or set of functions, such as filtering pollutants or providing shade (May 2003). The use of the term “buffer” in this report and the recommendations therein are directed to protect the floodplain and riparian area needed for the ecological functions of the river.

Buffer widths associated with a river are intended to protect an area of sufficient size to provide functions considered important for protecting aquatic processes, riparian species, and to buffer against road and development impacts. If properly functioning, riparian vegetation within river buffers provides great benefits for bank stabilization, floodplain habitat, woody debris recruitment, and overbank channel roughness as well as lateral space for the channel migration and hyporheic zones. Riparian vegetation also provides nutrients that help to sustain the system food web.

Tables B-13 and B-14 are summaries of buffer width requirements to protect stream and riparian system functions, based on literature reviews of best available science. There is no consensus in the literature recommending a single buffer width for a particular function or to accommodate all functions.

Table B-13. Riparian buffer functions and appropriate widths identified by May (2003).

Riparian Function	Range of Effective Buffer Widths (feet)	Minimum Recommended Widths (feet)	Notes on Function
Sediment Removal/Erosion Control	26 – 600	98	For 80% sediment removal
Pollutant Removal	13 – 860	98	For 80% nutrient removal
LWD Recruitment	33 – 328	164	1 SPTH based on long-term natural levels
Water Temperature	36 – 141	98	Based on adequate shade
Wildlife Habitat	36 – 141	328	Coverage not inclusive
Microclimate	148 – 656	328	Optimum long-term support

As can be seen, the greater the buffer the greater the ecological function and benefits it provides. Given that Highway 112 occurs within floodplain areas that are utilized by many fish and wildlife species, any road work should give consideration to the protection of buffer areas that are greater than those required to ensure maximum ecological functions (i.e., 860-foot wide) based on best available science.

Table B-14. Riparian functions and appropriate widths identified by Knutson and Naef (1997).

Function	Range of Effective Buffer Widths (feet)	Average of Reported Widths (feet)
Sediment filtration	26 – 300	138
Erosion Control	100 – 125	112
Pollutant Removal	13 – 600	78
LWD Recruitment	100 – 200	147
Water Temperature Protection	35 – 151	90
Wildlife Habitat	25 – 984	287
Microclimate	200 – 525	412

Impacts

Effect of Forest Removal on Heat

Given that in some areas, Highway 112 occurs within the floodplain of the Hoko, Clallam, and Pysht Rivers, in widening this road, consideration should be given to the potential effect of forest removal on heat. The replacement of forests with roads or other impervious surfaces and structures changes the relationship between incoming solar radiation and outgoing terrestrial radiation within watershed areas (Towson University 2005).

Heat energy not utilized in evapotranspiration is released to the atmosphere as sensible heat (i.e., heat energy which is felt and can be measured with a thermometer). The more energy that enters the atmosphere as sensible heat, the higher the relative air temperatures over watershed surfaces. Latent Heat (i.e., the heat energy stored in water vapor and that cannot be felt or measured with a thermometer) enters the atmosphere when water is evaporated from the surface. Since evaporation removes heat, it is a cooling process. The relationship between sensible heat and latent heat is described by the Bowen ratio and the sensible heat index. For example, the summer sensible heat indices for impervious urban surfaces and deciduous forests are 80 percent and 25 percent respectively. Here, the sensible heat index is the sensible heating divided by total heating (sensible + latent) and multiplied by 100, which is the total heat energy at the surface used to raise the temperature of air above it (Towson University 2005).

Stormwater runoff originated from impervious surfaces also likely contribute to increased water temperature, particularly in slow flowing habitats like those typically associated with floodplain side-channels and wetlands. Therefore, replacement of forests with impervious surface areas associated with the widening of SR 112 may affect the ambient as well as water temperature. Other factors potentially contributing to increased water temperatures include a reduction in channel sinuosity and in hyporheic flows.

General Road and Road Construction Impacts

Past general road and road construction impacts have been categorized and summarized as indicated in this quote (adapted) from Ruediger and Ruediger (1999):

> ***Highway effects on channels*** *– Roads have been constructed in valley bottoms in mountainous regions in order to take advantage of the flatter valley topography and gentler valley gradient. In order to reduce the amount and severity of curves in the road and to reduce the amount of cuts and fills it was standard practice to occupy, realign or encroach on stream channels and to cross and recross the channel. Relocated channels are generally shorter than the original stream resulting in a loss of channel sinuosity and an increase in local stream gradient. Extensive riprap revetments are built to protect the road right-of-way from erosion during high streamflow events. As a result of these highway construction practices many stream reaches have become straighter and more constricted, have greater velocities, and channel roughness has been reduced from natural conditions.*
>
> ***Highway effects on floodplains*** *– Stream channels can be separated from all or portions of their floodplain if the highway occupies or bars access to the floodplain. During flood events, flows in unconstrained channels will inundate the floodplains where much of the flows energy is dissipated by the riparian vegetation. Floodplains provide temporary storage areas for floodwater, reducing the amount of water which must be conveyed in the channel during the event. Without access to floodplains, floodwaters must be contained within the stream channel or within a constricted floodplain, generating higher in-channel velocities and intensifying stream power. In keeping with the equilibrium equation the stream will respond by increasing its sediment load by eroding its bed and banks. Fish habitat can be impacted by increased sedimentation; loss of riparian vegetation; higher velocities in incised channel reaches; loss of low velocity refugia such as side channel and backwater habitats; and channel widening and pool filling in downstream deposition areas.*
>
> ***Highway effects on riparian vegetation*** *– Riparian vegetation is a critical component to the proper functioning of aquatic ecosystems. Critical functions of riparian vegetation which can be impacted by highways include shade, cycling of nutrients, contribution of large wood, and refugia for fish during floods. Streamside shading is one of the most important elements in temperate climates for maintaining cold water temperature for salmon and trout. Streamside vegetation takes up nutrients from the stream and banks and returns it in the form of litter fall which provides food and habitat for aquatic insects. Terrestrial insects dropping from the overhanging vegetation are an important source of food for salmonids.*

Riparian vegetation and habitat permanently lost when highways occupy or encroach on stream channels. These loses maybe extensive both longitudinally along the channel and horizontally away from the channel depending on the valley constraint and highway location. The roadway may occupy the historic riparian zone and road fills protected with boulder revetments may extend into the channel. Removal of riparian vegetation can allow sun light to reach the stream channel causing heat transfer to the water; sometimes the revetments can act as a reflector and direct sun light at the channel.

Most large wood enters channels from adjacent riparian areas through windfall, landslides and when trees on streambanks are undercut during high flows. Riparian source areas maybe permanently lost when highways occupy near stream areas, or when roads disconnect the stream from adjacent hillslopes. Large wood is susceptible to decay, abrasion by bedload, and to transport downstream so local and upstream sources of new wood are necessary to maintain adequate amounts of wood in the channel.

***Highway effects on fish passage** –Stream crossing passage barriers affect spawning and rearing of both anadromous and resident salmonids. Complete barriers prevent access to all life history stages while partial barriers may prevent passage at particular flows, to particular sizes of fish (juveniles vs. adults, small adults vs. larger adults, etc), or to some species. Improperly designed culverts can stop adult spawning migrations because outfall barriers, excessive water velocity, lack of jump or resting pools, insufficient flow, or a combination of these factors. When adults are unable to access upstream spawning areas there maybe increased egg mortality due to competition for available downstream spawning habitat, increased adult mortality by predators as adults congregate below a barrier, and increased density dependent mortality among juveniles forced to use limited rearing habitat. Because dispersal of juvenile fish occurs both upstream and downstream, substantial rearing habitat can be lost because of impassable culverts on smaller streams. The effect of a passage barrier on anadromous fish is typically a decrease in production due to lost spawning and rearing habitat. With habitat loss, these populations may decline in size, or be restricted to marginal habitats and become more vulnerable to stochastic events.*

Highway barriers can also affect dynamics of resident salmonid populations by isolating that portion of the population above the barrier from fish of the same species below the barrier. A population is defined as a group of animals that has a high probability of mating among its members relative to mating with members of other populations of the same species.

***Highway effects on sediment** – Highway construction and maintenance activities are potential sources of sediment to streams. Potential sources of sediment during construction include surface erosion from fill slopes and exposed soils in work* *areas, storage areas and temporary access roads; mass wasting of fill slopes; blasting; and construction sites near streams for bridges, culverts, and bank revetments.*

Highway construction contractors are required to apply erosion control measures during construction, however the risk of sediment reaching streams is high because construction activities can last for several years and often require construction of stream crossings. Failures of older highways can impact nearby streams. Causes for these failures include saturation of fill material, road locations on unstable soils, erosion of the road right-of-way by flooding, debris plugged stream crossings, and indirectly when upslope debris torrents come in contact with, and destroy, stream crossings. These failures are frequently corrected quickly to ensure public safety, to maintain public access and to reduce additional resource damage from occurring. However, this often means construction activities must take place on wet soils when soil erosion risks are high. These failures can be particularly impacting to fall-spawning salmon and trout, some of which are listed under the ESA, because the failures generally happen in mid-winter after the fish have spawned and the eggs are still in the gravel. Emergency repairs are often exempt from the usual environmental requirements, even if the construction takes place months or years after the event.

A significant, chronic source of sediment to streams is winter sanding to provide vehicle traction on snow and ice covered roads. Sand and cinders are often the most cost-effective tool for providing vehicle safety but can cause significant impacts to streams adjacent to highways. Sanding materials can enter streams indirectly when the snowmelt water transports it off the road surface into drainage systems discharging into streams, and directly when snowplows push or blow sand packed snow to nearby streambanks or streams. Sanding materials can often be found in deep layers on streambanks, filling pools, and coating riffle and shoreline areas.

***Highway effects on stream pollution** – The use and maintenance of highways can lead to the introduction of various chemicals, many of which are toxic to aquatic organisms, into streams and rivers. Highway runoff and hazardous materials spills are the most common pathways for chemicals to enter streams. Contaminants are deposited on roadway surfaces and rights-of-ways from lubrication system losses (drips of oil, grease, hydraulic fluids, antifreeze, etc), tire and brake wear, atmospheric fallout, fuel combustion processes, herbicides, deicing agents, paving oils, leadbased paint from bridges and transportation load losses. Highway run off can be highly polluted and negatively affect water quality and aquatic organisms. The impacts of highway runoff are highly site specific and vary with the frequency, intensity and duration of precipitation and with the amount of vehicular use.*