Appendix C

Reach-Based Ecosystem Indicators (REI)

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1 INTRODUCTION

The REI provides a consistent means of evaluating biological and physical conditions of a watershed in relation to regional standards and known habitat requirements for aquatic biota. These indicators, along with other scientific evaluations, describe the current quality of stream biophysical conditions and can help inform restoration targets and actions. The REI indicators used in this assessment are adaptations from previous efforts including the NMFS matrix of pathways and indicators (NMFS 1996) and the USFWS (1998). With a few exceptions that are noted, the REI are based on the USBR's latest adaptations and use of these indicators (USBR 2011).

The REI evaluation for the Upper Wenatchee River was conducted using field data, observations, previous studies, and available data for the study area. In particular, the rankings were developed based on: 1) quantitative inventory information from the Habitat Assessment performed as part of the Reach Assessment, 2) assessment of geomorphic patterns and processes and how they have deviated, if at all, from historical conditions, and 3) analysis of existing watershed assessments and data (e.g. available ArcMap layers).

2 PATHWAY: WATERSHED CONDITION

2.1 GENERAL INDICATOR: WATERSHED ROAD DENSITY AND EFFECTIVE DRAINAGE NETWORK

2.1.1 Metric Overview

Watersheds with high road density can alter drainage networks and increase fine sediment loads to the river (USFS 2006). Soil erosion and mass wasting have been demonstrated to be higher in areas where there are high road networks than in undisturbed areas (Amaranthus et al 1985). Road networks can increase the frequency and quantity of sediment pulses to streams. Increased fine sediment can adversely affect aquatic habitat in numerous ways (Waters 1995, Wilber and Clarke 2001), including suffocation of salmonid eggs or larvae, reduced forage success due to impaired water clarity, limiting the growth of aquatic plants, channel instability from altered sediment budgets, and adverse physiological effects on invertebrates.

Criteria: From USFWS (1998), modified by USBR (2012).

Pathway	General Indicators	Specific Indicators	Adequate	At Risk	Unacceptable
Watershed Condition	Effective Drainage network and Watershed Road Density	Increase in Drainage Network/Road Density	Zero or minimum increase in active channel length correlated with human-caused disturbance **And** Road density <1 *miles/mile^2*	Low to moderate increase in active channel length correlated with human-caused disturbance **And** Road density 1 to 2.4 *miles/mile^2*	Greater than moderate increase in active channel length correlated with human-caused disturbance **And** Road density >2.4 *miles/mile^2*

2.1.2 Assessment Results

Road density was calculated using Chelan County's roads ArcMap layer. Road density was calculated for the watershed area contributing to the study area (combining the HUC-12 layer (170200110701) and HUC-10 layers (1702001101, 1702001102, 1702001103). Road density for the entire contributing watershed area was 0.83 miles per square mile.

Historical channel planform and length were evaluated by georeferencing historical survey maps of the Upper Wenatchee. Evaluation of historical channel planform from 1887 and 1911 survey maps indicated that little to no increase in active channel length has occurred that is associated with human disturbance.

2.1.3 REI Rating

Watershed Rating: **Adequate**

2.2 INDICATOR: DISTURBANCE REGIME (NATURAL & HUMAN-CAUSED)

2.2.1 Metric Overview

Environmental disturbance is a natural ecosystem process that is important for creating and maintaining habitats over time. Natural disturbance events include wildland fire, flooding, landslides, and windstorms. In some cases, human alterations to the landscape can impair natural disturbance processes and create large catastrophic disturbance events or long-term ‘press’ disturbances that impair natural processes for extended periods. Artificial, human-caused disturbances include timber harvest and road-induced landslides. Human-caused ‘press’ disturbances include construction of roads, creation of impervious surfaces, and infrastructure that disconnects floodplains.

Criteria: From USFWS (1998).

Pathway	General Indicators	Specific Indicators	Adequate	At Risk	Unacceptable
Watershed Condition	Disturbance Regime	Natural/Human Caused	Environmental disturbance is short lived; predictable hydrograph; high quality habitat and watershed complexity providing refuge and rearing space for all life stages or multiple life-history forms. Natural processes are stable.	Scour events, debris torrents, or catastrophic fires are localized events that occur in several minor parts of the watershed. Resiliency of habitat to recover from environmental disturbances is moderate.	Frequent flood or drought producing highly variable and unpredictable flows, scour events, debris torrents, or high probability of catastrophic fire exists throughout a major part of the watershed. The channel is simplified, providing little hydraulic complexity in the form of pools or side channels. Natural processes are unstable.

2.2.2 Assessment Results

The disturbance history in the upper Wenatchee subbasin is deemed functioning at an **At Risk** condition. The rating reflects historical accounts of riparian timber harvest, splash damming, log drives, and development in and around the floodplain. Furthermore, fire suppression within the basin has elevated the risk of catastrophic wildland fires (USFS 1999). These alterations include past human disturbance to which the system is still recovering from or on-going 'press' disturbances that have a persistent and long-lasting impact. There is also risk for potential future catastrophic disturbance (e.g. stand-replacing fire) to the basin.

2.2.3 REI Rating

Watershed Rating: **At Risk**

2.3 INDICATOR: STREAMFLOW (CHANGE IN PEAK/BASE FLOW)

2.3.1 Metric Overview

Stream discharge and channel morphology are directly linked to the magnitude, timing, duration, and frequency of hydrologic inputs to the system. Hydrology is predominantly controlled by climate, vegetation, geology, and human alterations and impacts. Potential human impacts to hydrologic systems include flow regulation (e.g. dams), water withdrawals (e.g. for irrigation), widespread timber harvest, increased impervious surfaces, or intensive road building.

Criteria: From USFWS (1998), modified by USBR (2012).

Pathway	General Indicators	Specific Indicators	Adequate	At Risk	Unacceptable
Watershed Condition	Streamflow	Change in Peak/Base flows	Magnitude, timing, duration and frequency of peak flows within a watershed are not altered relative to natural conditions of an undisturbed watershed of similar size, geology, and geography.	Some evidence of altered magnitude, timing, duration and frequency of peak flows relative to natural conditions of an undisturbed watershed of similar size, geology, and geography	Pronounced evidence of altered magnitude, timing, duration and frequency of peak flows relative to natural conditions of an undisturbed watershed of similar size, geology, and geography

2.3.2 Assessment Results

The hydrology of the Wenatchee Basin is driven by a combination of precipitation and snowmelt. Precipitation, in the form of snow and rain, varies with elevation and distance from the Cascade crest. The higher elevations of the Wenatchee Basin receive 50 to 140 inches of precipitation a year, whereas lower areas receive less than 8.5 inches (WDOE 1983, Andonegui 2001, CCG et al. 2003). These low areas are also further east, and more affected by the rain shadow of the Cascades.

Spring snowmelt dominates the seasonal streamflow pattern in the basin (Figure 2). Snowmelt primarily occurs during the spring and early summer, and is driven by changes in ambient air temperature, snowpack mass, and the elevation distribution of the season’s snowpack (WDOE 1983). Peak runoff usually occurs from April through July, with the highest rates typically in late June (USFS 1999). The Wenatchee typically returns to baseflows in September (MWG 2003).

The 1-, 2-, 5-, 20-, 50-, 100-, 200-, and 500-year recurrence intervals were calculated for the Wenatchee River using the USGS gage at Plain for the period 1911- present. Hydrologic data was then compared by time period. This comparison shows that floods have remained relatively constant, with the exception of 1991 to 2011 (Figure 1). These higher flows coincide with the three top water events on record (Table 4). These likely correlate with events that had coincidental occurrences of high precipitation and snowmelt, such as in the flood of 1948 (WDOE 1983). Precipitation records indicate that rainfall rates increased during the late 1940s and early 1950s, decreased in the 1960s, and have risen steadily since then. This analysis suggests that there could be potential changes in the watershed hydrologic regime (i.e. increased peak flows); however, the data and analysis are not sufficient enough to document changes or causation with certainty.

Climate change modeling indicates that rainfall is expected to increase one to two percent by 2040, and four percent by 2080 (e.g. Mote and Salanthe 2009). Climate change models (synthesized by CIG 2009) also indicate that changes will likely result in an increase in winter stream flows, earlier and lower peak runoff, and lower summer baseflows (Figure 3). These analyses suggest that human-induced climate change is likely to have an effect on the magnitude, timing, duration, and frequency of streamflows.

Based on the potential effects of climate change on watershed hydrology, this metric is rated **At Risk**.

2.3.3 REI Rating

Watershed Rating: **At Risk**

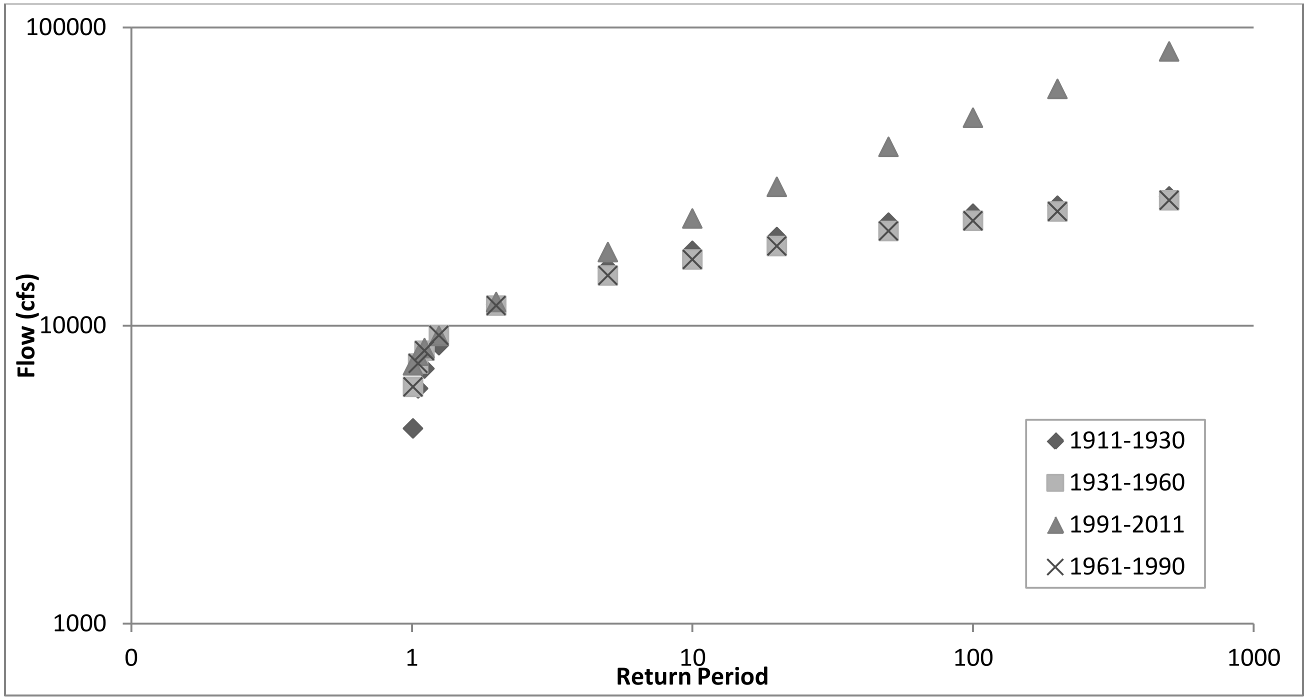

Figure 1. Changes in Hydrologic Regime Over time, beginning in 1911. Discharge was measured at the USGS gage at Plain, WA (Gage 12457000, 1911 to present).

Table 1. Top 20 water events (floods) since 1911.

Event Rank	Water Year	CFS
1	1996	36,100.0
2	1991	33,200.0
3	2007	23,600.00
4	1948	22,700.00
5	1922	21,100.00
6	1918	18,700.00
7	1974	18,500.00
8	1976	18,000.00
9	1972	17,900.00
10	1956	17,100.00
11	1955	17,000.00
12	1916	16,700.00
13	1950	16,300.00
14	1999	16,200.00
15	2006	16,100.00
16	1949	16,000.00
17	1997	15,800.00
18	2008	15,400.00
19	1951	15,300.00
20	1961	15,100.00

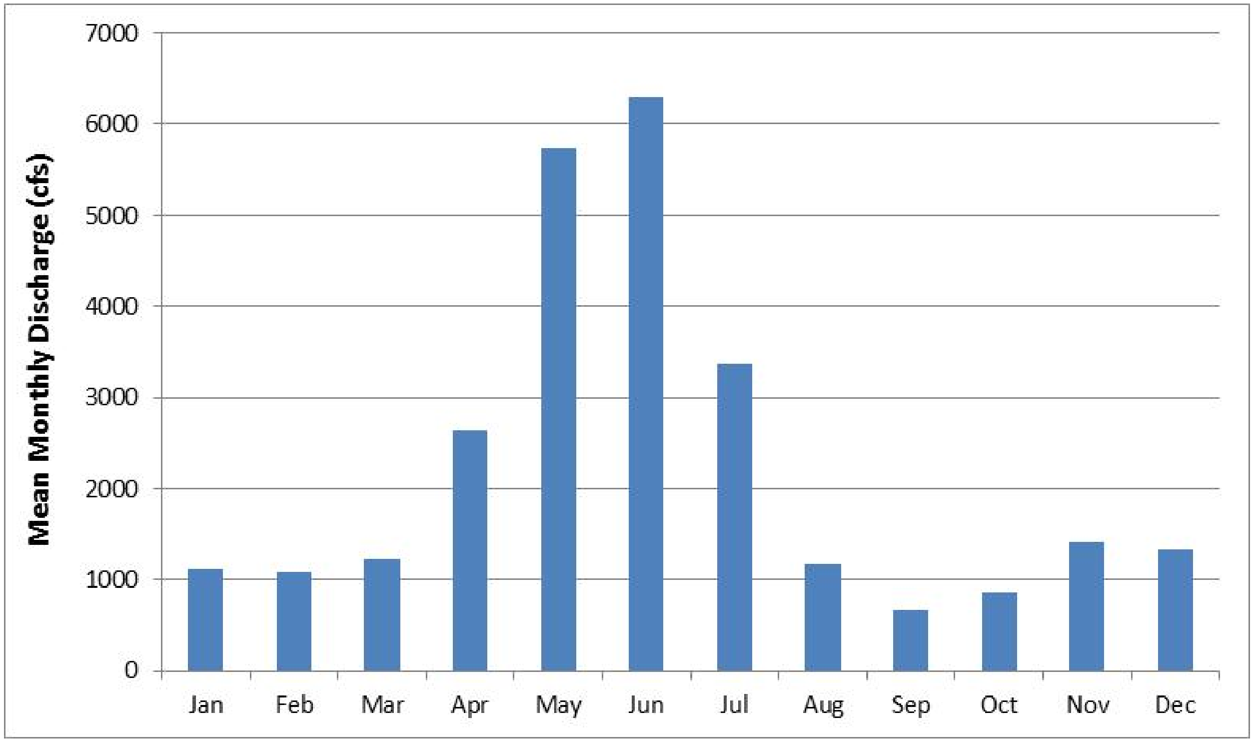

Figure 2. Mean monthly discharge for the period of record at the USGS gage at Plain, WA (Gage 12457000, 1911 to present).

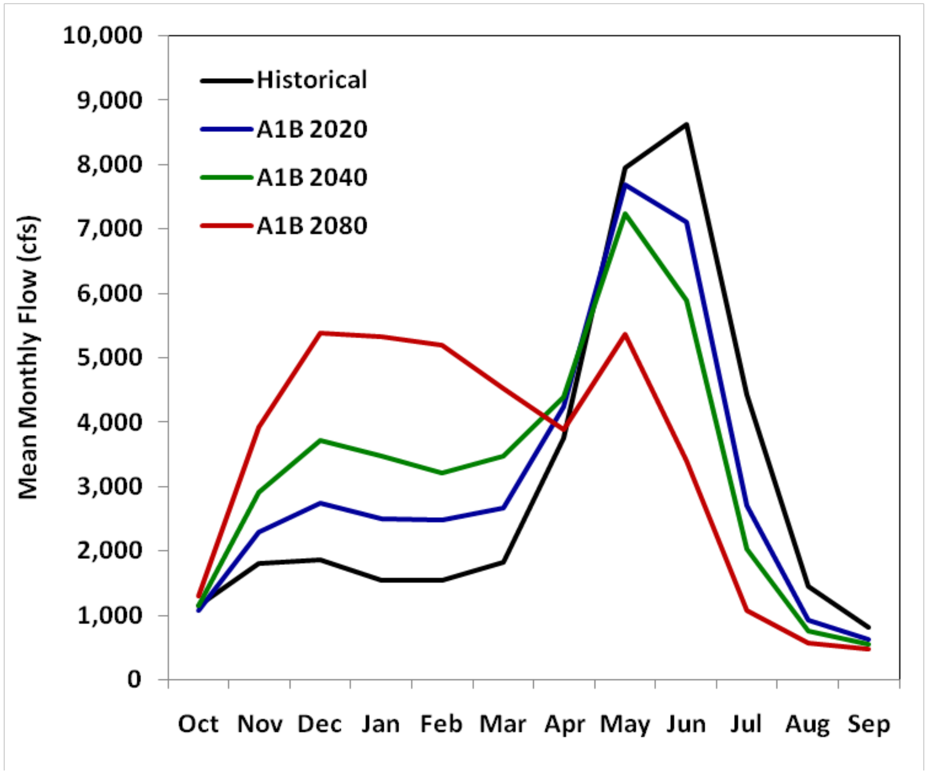

Figure 3. Projected impacts of climate change on the magnitude, timing, and frequency of the Wenatchee River at Peshastin (CIG 2009, Elsner 2011).

3 PATHWAY: REACH-SCALE HABITAT ACCESS

3.1 Physical Barriers – Main Channel Barriers

3.1.1 Metric Overview

This metric evaluates the presence or absence of fish passage barriers that affect upstream or downstream passage of fish in the Wenatchee River.

Criteria: From USFWS (1998), modified by USBR (2012).

Pathway	General Indicators	Specific Indicators	Adequate	At Risk	Unacceptable
Habitat Access	Physical Barriers	Main Channel Barriers	No manmade barriers present in the mainstem that limit upstream or downstream fish passage at any flows	Manmade barriers present in the mainstem that prevent upstream or downstream migration at some flows that are biologically significant	Manmade barriers present in the mainstem that prevent upstream or downstream migration at multiple or all flows

3.1.2 Assessment Results

No fish passage barriers were present on the mainstem Wenatchee River in the study area. Furthermore, the majority of tributaries were accessible to fish. The only barrier to fish passage observed was a perched culvert on Deadhorse Creek at RM 38.62 This tributary becomes naturally impassible within 200 feet, so this passage barrier is not limiting access to a significant amount of habitat.

3.1.3 REI Rating

General Indicators	Specific Indicators	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	Reach 10	Reach 11
Physical Barriers	Main Channel Barriers	adequate	adequate	adequate	adequate	adequate	adequate	adequate	adequate	adequate	adequate	adequate

4 PATHWAY: REACH-SCALE HABITAT QUALITY

4.1 Substrate – Dominant Substrate Fine Sediment

4.1.1 Metric Overview

Substrate conditions affect salmonid uses including spawning, egg incubation, and early rearing. Salmonids require adequately sized substrate that is free of excessive fines.

Criteria: Modified from USFWS (1998) and USBR (2012).

Pathway	General Indicators	Specific Indicators	Adequate	At Risk	Unacceptable
Habitat Quality	Substrate	Main Channel Barriers	Dominant Substrate is gravel or cobble (interstitial spaces clear), or embeddedness < 20%, <12% fines (<0.85mm) in spawning gravel or <12% surface fines of <6mm	Gravel and Cobble is subdominant, or if dominant, embeddedness is 20-30%; 12-17% fines (<0.85mm) in spawning gravel or 12-20% surface fines of <6mm	Bedrock, sand, silt, or small gravel dominant, or if gravel and cobble dominant, embededeness > 30%; >17% fines (<0.85mm) in spawning gravel or >20% surface fines of <6mm

4.1.2 Assessment Results

Bed substrate was based on pebble counts and the ocular estimates that were collected at each habitat unit. For most reaches, 1-2 pebble counts were collected per reach, except for reaches 4, 6, and 7 where high flows prevented pebble counts. The ocular estimate for each reach is the average of all the individual ocular estimates in the reach. The pebble count data are believed to be more reliable than ocular estimates; however, there were a greater number of ocular estimates and the ocular estimates have greater spatial coverage. For these reasons, the pebble count and ocular data were combined (and weighted evenly) for use in this analysis. They were first averaged within each reach to derive a pebble count and ocular count for each reach. These two values were then averaged together for each reach to obtain the substrate value used for the REI analysis (Table 8). In general, bed substrate in the Upper Wenatchee River was gravel and cobble, with smaller amounts of boulder, bedrock, and sand. Most reaches are considered **Adequate** with respect to substrate, except for reaches 4, 8, and 9, which are considered **At Risk** due to a higher incidence of fines.

Table 2. The values for this analysis used the average of the averaged pebble counts and the averaged ocular estimates. Reaches 4, 6, and 7 did not have pebble count data and so the values are the averaged ocular estimates only.

Total	**Reach 1**	**Reach 2**	**Reach 3**	**Reach 4**	**Reach 5**	**Reach 6**	**Reach 7**	**Reach 8**	**Reach 9**	**Reach 10**	**Reach 11**
% Sand	12%	8%	13%	19%	8%	8%	12%	19%	16%	8%	12%
% Gravel	43%	27%	34%	29%	30%	17%	20%	40%	67%	59%	17%
% Cobble	42%	57%	44%	42%	50%	45%	33%	41%	15%	28%	61%
% Boulder	4%	8%	7%	8%	13%	30%	35%	2%	3%	3%	11%
% Bedrock	1%	1%	2%	2%	0%	0%	0%	0%	0%	0%	0%

4.1.3 REI Ratings

General Indicators	**Specific Indicators**	**Reach 1**	**Reach 2**	**Reach 3**	**Reach 4**	**Reach 5**	**Reach 6**	**Reach 7**	**Reach 8**	**Reach 9**	**Reach 10**	**Reach 11**
Substrate	Dominant Substrate/Fine Sediment	adequate	adequate	adequate	at risk	adequate	adequate	adequate	at risk	at risk	adequate	adequate

4.1.4 INDICATOR: Large Woody Debris (LWD)

4.1.5 Metric Overview

For the purposes of this analysis, a variation was made to the LWD metric. We chose to use the western cascades 80 pc/mi target from NMFS (1996) as opposed to the eastern cascades 20 pc/mi target for the following reasons. First, based on measurements of wood in unmanaged streams in eastern Washington, Fox and Bolton (2007) determined that the NMFS (1996) standard is low for larger eastern Washington streams (5m-50m bankfull width), which had greater than 40 pc/mi on average. Because the bankfull widths on the upper Wenatchee are even larger than the streams included in the Fox and Bolton study (i.e. average of 90m), historical wood numbers would be expected to be even greater, primarily due to large log jams that are assumed to have been present in this reach historically (see discussion in the Reach Assessment in the Geomorphology section). Second, Reach 1, which serves as a reference reach due to its relatively undisturbed condition, has 142 pc/mi currently; and there is no reason to believe that wood numbers here would be higher now than under historical conditions. Lastly, the upper Wenatchee study area as a whole averages 64 pc/mi under existing conditions; consequently, achieving >80/pieces per mile is believed to be an appropriate and attainable restoration goal.

A second evaluation metric, log jam frequency, was added to the large wood indicator in order to better reflect the wood distribution types that would be expected under natural conditions (i.e. free of human influence). The **Adequate** condition was set at 4 jams per mile based on conditions found in Reach 1.

Criteria: See above description of criteria development.

Pathway	General Indicators	Specific Indicators	Adequate	At Risk	Unacceptable
Habitat Quality	Substrate	Pieces per mile at bankfull	>80 pieces/mile >12'' dbh > 35' length; and adequate sources of woody material available for long and short term recruitment. And, At least 4 jams/mi (10 qualifying pieces per jam)	Currently meets piece frequency standards for **Adequate**, but lacks potential sources from riparian areas of wood debris recruitment to maintain that standard. And, 1-4 jams/mi	Does not meet standards for **Adequate** and lacks potential large woody material recruitment.

4.1.6 Assessment Results

Wood counts from the habitat surveys were queried to obtain counts of wood of the size classes used for this indicator (>12" diam; >35' long). Log jam counts were also derived from the habitat survey data. Only reaches 1, 3, and 11 met the piece frequency standard for **Adequate**, and only Reach 1 met the log jam standard (used rounded value) for **Adequate**.

Table 3. Large wood piece and jam frequency from the habitat survey (August 2011).

	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	Reach 10	Reach 11
Pieces/mi (>12" diam; >35' long)	142	26	133	35	17	38	2	29	48	50	115
Log jams/mi	3.8	1	1.2	0.8	0	0.7	0	0.8	0.5	1.5	0

4.1.7 REI Ratings

General Indicators	Specific Indicators	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	Reach 10	Reach 11
LWD	Pieces per mile at bankfull	adequate	unacceptable	at risk	unacceptable	unacceptable	unacceptable	unacceptable	unacceptable	unacceptable	unacceptable	unacceptable

4.2 INDICATOR: Pools – Pool Frequency & Quality

4.2.1 Metric Overview

The pool frequency and quality metric was adapted for the Upper Wenatchee River. The largest bankfull channel width provided in the NMFS matrix is 65 to 100 feet, and 4 pools per mile is the standard for this width. Because Upper Wenatchee bankfull widths far exceed the criteria (ranging from 270 feet to 360 feet), reaches were primarily evaluated based on the pool quality metrics provided by NMFS (1996) (e.g. depth, substrate, cover, refugia), rather than number of pools.

Criteria: Adapted from NMFS (1996).

Pathway	General Indicators	Specific Indicators	Adequate	At Risk	Unacceptable
Habitat Quality	Pools	Pool frequency and quality	Pools have good cover and cool water and only minor reduction of pool volume by fine sediment; each reach has many large pools > 1m deep with good cover	Meets pool quality standards, but does not meet LW standards, so unable to maintain pools over time; reaches have few large pools (>1m) present with good fish cover	Lacking pools, pool quality is inadequate and there has been a major reduction of pool volume by fine sediment; reaches have no deep pools (> 1m) with good fish cover

4.2.2 Assessment Results

Pool frequency ranged from 0.0 to 2.7 pools/mile, with a mean pool spacing of 8.0 to 28.3 channel widths per pool. Reach 6 and 7 had no pool habitat. Reaches 10 and 11 had the greatest proportion of pool habitat (57% and 77%, respectively), although Reach 1 had the greatest number of pools/mile (2.7). Reaches 1 and 11 had the shortest pool spacing (9.4 and 8.0 channel widths per pool, respectively). Reaches 1 and 3 had the greatest number of deep pools with residual depths exceeding 3 ft (n=6 in both reaches). The majority of the pools throughout the study area were relatively deep, with shallow residual depths (<3 ft) comprising less than 7% of total pools. Most reaches were rated **At Risk** due to not meeting LW standards.

Table 4. Pools per mile based on the habitat assessment (August 2011).

Pools	**Total**	**Reach 1**	**Reach 2**	**Reach 3**	**Reach 4**	**Reach 5**	**Reach 6**	**Reach 7**	**Reach 8**	**Reach 9**	**Reach 10**	**Reach 11**
Pools per mile	1.6	2.7	0.9	1.9	2.2	1	0	0	1.8	1.4	2.3	2
Residual Depth (% of pools)												
Pools < 3 ft	7%	0%	0%	0%	33%	0%	0%	0%	0%	0%	20%	0%
Pools 3-6 ft	20%	33%	100%	50%	0%	0%	0%	0%	0%	0%	0%	0%
Pools 6-9 ft	43%	17%	0%	33%	34%	67%	0%	0%	100%	0%	80%	100%
Pools 9-12 ft	27%	33%	0%	17%	33%	33%	0%	0%	0%	100%	0%	0%
Pools > 12 ft	3%	17%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

4.2.3 REI Ratings

General Indicators	**Specific Indicators**	**Reach 1**	**Reach 2**	**Reach 3**	**Reach 4**	**Reach 5**	**Reach 6**	**Reach 7**	**Reach 8**	**Reach 9**	**Reach 10**	**Reach 11**
Pools	Pool frequency and quality	adequate	at risk	at risk	at risk	at risk	unacceptable	unacceptable	at risk	at risk	at risk	at risk

4.3 INDICATOR: Off-Channel Habitat

4.3.1 Metric Overview

Off-channel habitats include backwaters, abandoned oxbows, floodplain channels, and flow-through side-channels. Off-channel habitats that are accessible by fish from the mainstem provide important rearing habitats. Off-channel areas can provide various benefits to rearing fish including flood refuge, temperature refuge, and productive feeding areas.

Criteria: Modified from USFWS (1998).

Pathway	General Indicators	Specific Indicators	Adequate	At Risk	Unacceptable
Habitat Quality	Off-Channel Habitat	Connectivity with main channel	Reach has ponds, oxbows, backwaters, and other low-energy off-channel areas with cover; similar to conditions that would be expected in the absence of human disturbance	Reach has some ponds, oxbows, backwaters, and other low-energy off-channel areas with cover; but availability or access is less than what would be expected in the absence of human disturbance	Reach has few or no ponds, oxbows, backwaters, or other off-channel areas relative to what would be expected in the absence of human disturbance.

4.3.2 Assessment Results

A total of 33 wetted side-channel habitat units were measured in the study area during the habitat survey. Reach 1 had the greatest area of side-channel habitat and Reach 3 had the greatest number of side-channel units. Reaches 5 and 7 had no side-channel habitat. Side-channel riffles (n=21) accounted for 64% of all side-channel units. Side-channel pools (n=8) accounted for 24%, all occurring in Reaches 1 and 3. Average and maximum side-channel depths were 1.7 feet (stdev 0.9) and 3.7 feet (stdev 1.8) respectively, with the deepest side-channels observed in Reach 8.

In addition to side-channels, the Upper Wenatchee study area had nine marshes ranging from small backwaters to large open water ponds. Off-channel marshes were identified in Reaches 1, 8, 9, and 10. Reach 9 had the greatest number of marsh units (n=3) and Reach 10 had the largest marsh habitat within the study area.

Natural and artificial confinement limits off-channel habitat throughout some portions of the study area. In some areas, human development of riparian areas and floodplains also impairs floodplain and channel migration processes that are necessary to create and maintain off-channel habitats. The primary impairments to off-channel habitat occur along the reaches that flow through the community of Plain, from Reach 4 through Reach 7. Roads, bank armoring, berms, and channel/floodplain filling have reduced the abundance and connectivity of off-channel habitat and have impaired the floodplain and channel migration dynamics necessary to create and maintain off-channel habitats over time.

4.3.3 REI Ratings

General Indicators	Specific Indicators	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	Reach 10	Reach 11
Off-Channel Habitat	Connectivity with main channel	adequate	adequate	at risk	unacceptable	unacceptable	at risk	unacceptable	at risk	at risk	at risk	at risk

5 PATHWAY: CHANNEL FORMS & PROCESSES

5.1 Channel Dynamics - Floodplain Connectivity

5.1.1 Metric Overview

Floodplains serve a number of significant geomorphic and ecological functions including conveyance of flood waters, sediment source and storage, supply of large wood, and development of diverse habitat for aquatic and terrestrial species (e.g. Allen 1970, Zwolinski 1992, Nanson and Croke 1992). Floodplain connectivity was evaluated through geomorphic and hydraulic analysis. As part of the geomorphic assessment, floodplain areas were mapped and were given a designation of ***connected*** or ***disconnected*** based on the degree to which human influence has altered floodplain processes including floodplain inundation frequency, inundation extent, flood energy and scour, and channel migration. The hydraulic analysis was used to confirm the floodplain mapping and to further evaluate the effects of human development on floodplain inundation patterns.

Provided here is a brief summary of the floodplain mapping; more information can be found in Appendix B. Floodplains were initially delineated using LiDAR imagery, and then verified using hydraulics analysis and field surveys. A floodplain was determined to be ***disconnected*** if processes such as flood inundation and channel migration had been significantly altered due to anthropogenic modifications. A designation of ***disconnected*** does not mean the floodplain has been completely isolated from the main river, but it does indicate that significant human alterations have impaired floodplain and channel migration processes compared to historical conditions. These alterations can be direct contemporary (or remaining) alterations including straightening, ditching, filling, riprap, levees, road embankments, or bridges; or they can be historical alterations, such as splash damming and log drives, that have caused channel incision that persists today.

Criteria: Modified from USFWS (1998).

Pathway	General Indicators	Specific Indicators	Adequate	At Risk	Unacceptable
Channel	Dynamics	Floodplain connectivity	Floodplain areas are frequently hydrologically linked to main channel; overbank flows occur and maintain wetland functions, riparian vegetation and succession	Reduced linkage of wetlands, floodplains, and riparian areas to main channel; overbank flows are reduced relative to historic frequency, as evidenced by moderate degradation of wetland function, riparian vegetation/succession	Severe reduction in hydrologic connectivity between off-channel wetland, floodplain, and riparian areas; wetland extent drastically reduced and riparian vegetation/succession altered significantly

5.1.2 Assessment Results

Table 13 includes the percentage of mapped floodplain areas that were identified as "disconnected" as part of the geomorphic analysis. See Appendix B [##] for additional information. REI ratings were determined based on the degree of disconnection of floodplains. A ***disconnection*** amount of <20% is considered **Adequate**; 20-80% is **At Risk**; and greater than 80% is **Unacceptable**.

Table 5. Percent of "disconnected" floodplain (see Appendix B for more information).

	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	Reach 10	Reach 11
Proportion of floodplains that are "disconnected"	0%	14%	55%	85%	81%	90%	80%	61%	64%	62.8%	0%

5.1.3 REI Ratings

General Indicators	Specific Indicators	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	Reach 10	Reach 11
Channel Dynamics	Floodplain connectivity	adequate	adequate	at risk	unacceptable	unacceptable	unacceptable	unacceptable	at risk	at risk	at risk	adequate

5.2 INDICATOR: Bank stability/Channel migration

5.2.1 Metric Overview

Low gradient alluvial channels adjust laterally via bank erosion and channel avulsions (rapid shifting of channel location). These processes play important roles in maintenance of long-term aquatic habitat via large wood recruitment, gravel recruitment, and creation of new instream habitats. The rate and frequency of channel migration are a function of numerous physical and biological processes including hydrologic regime, underlying geology, sediment supply, streambank vegetation, and floodplain hydraulic roughness. Human alterations that affect these processes will affect the rate and frequency of channel migration. Common human alterations that affect rates of channel migration include bank armoring, removal of streambank vegetation, channelization, levee building, and development within the floodplain.

Criteria: From USBR (2011).

Pathway	General Indicators	Specific Indicators	Adequate	At Risk	Unacceptable
Channel	Dynamics	Bank Stability/Channel Migration	Channel is migrating at or near natural rates.	Limited amount of channel migration is occurring at a faster/slower rate relative to natural rates, but significant change in channel width or planform is not detectable; large woody debris is still being recruited.	Little or no channel migration is occurring because of human actions preventing reworking of the floodplain and large woody debris recruitment; or channel migration is occurring at an accelerated rate such that channel width has at least doubled, possibly resulting in a channel planform change, and sediment supply has noticeably increased from bank erosion.

5.2.2 Assessment Results

There has been significant human alteration and artificial armoring of streambanks that has reduced the ability of the stream to migrate laterally. Incidences of bank armoring are more prevalent than human-induced erosion, suggesting that impairments to channel migration are primarily related to a reduction in migration rates as opposed to acceleration of migration rates. Legacy incision (e.g. from log drives) and floodplain alterations (e.g. bridges and floodplain fill) have also likely reduced channel migration rates compared to historical conditions. An analysis of historical planform changes was performed and indicated relatively little change since 1911, which is the date of the earliest reliable map. However, log drives took place prior to this and likely resulted in channel bed degradation (incision) that served to limit channel migration, which was subsequently further limited by residential development in the mid-1900s.

Bank armoring in the form of riprap, concrete walls, concrete stairways, bridge abutments, and levees were mapped as part of the geomorphic assessment. The total length of bank armoring was calculated as a percentage of reach length (Table 6). This does not include areas of channel upstream and downstream of bridges where channel migration might be affected by the bridge. Reaches with greater degrees of bank armoring were considered more impaired than those with less armoring. For this analysis, reaches with <5% armoring were assumed **adequate**, 5-10% **at risk**, and >10% **unacceptable**.

Table 6. Percent bank armoring by reach.

Reach	Percent bank armoring by length[1]
1	2%
2	0%
3	17%
4	10%
5	13%
6	5%
7	3%
8	2%
9	0%
10	14%
11	2%

[1]*Total length of armoring divided by length of both banks*

5.2.3 REI Ratings

General Indicator	Specific Indicator	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	Reach 10	Reach 11
Channel Dynamics	Bank stability/ Channel migration	adequate	adequate	un-acceptable	un-acceptable	un-acceptable	at risk	adequate	adequate	adequate	un-acceptable	adequate

5.3 INDICATOR: Vertical Channel Stability

5.3.1 Metric Overview

Alterations to stream energy, sediment transport, and bed stability can lead to aggradation or degradation (incision) of the streambed. Aggradation is the raising of the streambed elevation and incision is the lowering of the streambed elevation. Alterations that could affect vertical channel stability include bank armoring, log drives / splash damming, levee building, channel straightening, and channelization.

Criteria: From USBR (2011).

Pathway	General Indicators	Specific Indicators	Adequate	At Risk	Unacceptable
Channel	Dynamics	Vertical channel stability	No measurable trend of aggradation or incision and no visible change in channel planform.	Measureable trend of aggradation or incision that has the potential to but not yet caused disconnection of the floodplain or a visible change in channel planform (e.g., single thread to braided).	Enough incision that the floodplain and off-channel habitat areas have been disconnected; or, enough aggradation that a visible change in channel planform has occurred (e.g., single thread to braided).

5.3.2 Assessment Results

Since the period of last glaciation, the Wenatchee River has been naturally downcutting through glacial till and outwash, leaving behind abandoned alluvial terraces and establishing new floodplains. This metric evaluates vertical channel stability on a much more recent geologic timescale, evaluating shorter-term sediment storage and examining if aggradation or incision has become accelerated due to human alterations. The degree of alteration to vertical channel stability was assessed using results of the hydraulic and geomorphic analyses. The extent of floodplain inundation, width-to-depth ratios, and the presence of human alterations known to affect vertical stability were used to help determine the REI ratings. In general, most of the observed incision is believed to be related to natural incision into glacial terraces. In some reaches, additional incision is believed to have occurred due to past log-drives and more recent floodplain constrictions (i.e. bridges), bank armoring, and floodplain fill.

Reaches determined to be **unacceptable** include reaches 4 and 9. Inundation mapping conducted as part of the hydraulics analysis shows that considerable floodplain constriction is created by the Burlington Northern Railroad Bridge crossing at the downstream end of Reach 4, which has likely caused base lowering that has progressed upstream. This is supported by inundation extents within the meander bends in Reach 4 that show limited inundation only at the largest flood events (e.g. 50 to 100-yr events) despite scroll scars evident from LiDAR that indicate these surfaces were laid down in relatively recent history and would therefore be expected to have greater floodplain connectivity. Reach 9 has similar inundation patterns in overbank areas and also has a steep “hanging” tributary on the downstream left-bank alluvial surface, which suggests recent incision of the mainstem (i.e. tributary channel has not yet adjusted to mainstem incision). **At risk** ratings were given to reaches 3, 5-8, and 10-11 due to anthropogenic floodplain constrictions (e.g. bridges) and bank armoring, which are factors known to induce streambed lowering.

5.3.3 REI Ratings

General Indicators	Specific Indicators	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	Reach 10	Reach 11
Channel Dynamics	Vertical channel stability	adequate	adequate	at risk	unacceptable	at risk	at risk	at risk	at risk	unacceptable	at risk	at risk

6 PATHWAY: RIPARIAN CONDITION

6.1 INDICATOR: STRUCTURE

6.1.1 Metric Overview

Riparian areas serve a number of important geomorphic and ecological functions including streambank stability, current and future sources of large wood material, water filtration, habitat, hydraulic regulation, and temperature fluctuation modification (Gregory et al. 1991). Here, the structure of riparian areas is evaluated based on how well the seral stage, species composition, and complexity approximate natural conditions that would be expected in the absence of human alterations.

Criteria: From USBR (2011).

Pathway	General Indicators	Specific Indicators	Adequate	At Risk	Unacceptable
Riparian Vegetation	Condition	Structure	>80% species composition, seral stage, and structural complexity are consistent with potential native community.	50-80% species composition, seral stage, and structural complexity are consistent with potential native community.	<50% species composition, seral stage, and structural complexity are consistent with potential native community.

6.1.2 Assessment Results

Results of the habitat assessment were used to help determine the riparian structure REI ratings. General seral stage information was recorded as part of the habitat assessment and is presented in Table 17. Dominant overstory and understory species were also recorded as part of the habitat survey, and general notes and observations of riparian conditions were also taken. In general, riparian areas in the absence of human disturbance would be expected to be dominated by mature trees but to also have a diversity of other size classes. Riparian areas along the Upper Wenatchee River have been harvested in the past and many of the riparian areas lack the large sized trees that would be expected under natural conditions. Furthermore, many of the riparian areas affected by residential development lack the smaller size classes due to clearing of the understory for houses and yards. These developed areas also tend to have less species diversity than unaltered areas where flooding and erosion processes are still intact. Reaches 1 and 2 were given an **adequate** rating due to the lack of recent (last 50 years) riparian clearing, dominance by large trees, and representation by other size classes. Reach 3-11 were given **at risk** ratings due to either lack of dominance by large trees, lack of representation by other size classes, or by observed riparian clearing related to residential development (Reaches 3-8, & 10).

Table 7. Results of riparian size classes recorded during the stream habitat survey (August 2011).

Vegetation (% of sampled units)	Total	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	Reach 10	Reach 11
Riparian Zone (100-ft wide zone averaged between both banks)												
Sapling/Pole	7%	9%	11%	16%	0%	0%	0%	0%	0%	0%	6%	0%
Small Trees	41%	36%	33%	44%	22%	39%	87%	0%	63%	38%	19%	100%
Large Trees	52%	55%	56%	40%	78%	61%	13%	100%	37%	62%	75%	0%

6.1.3 REI Ratings

General Indicators	Specific Indicators	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	Reach 10	Reach 11
Riparian	Structure	adequate	adequate	at risk	at risk	at risk	at risk	at risk	at risk	at risk	at risk	at risk

6.2 INDICATOR: Disturbance (human)

6.2.1 Metric Overview

Human disturbance to the floodplain affects riparian processes including bank stability, wood recruitment, shade, and water quality. Riparian disturbance was assessed using information from the habitat assessment (Appendix A) and an analysis of road densities within riparian areas.

Criteria: From USBR (2012).

Pathway	General Indicators	Specific Indicators	Adequate	At Risk	Unacceptable
Riparian Vegetation	Condition	Disturbance (human)	>80% mature trees (medium-large) in the riparian buffer zone (defined as a 30 m belt along each bank) that are available for recruitment by the river via channel migration; <20% disturbance in the floodplain (e.g., agriculture, residential, roads, etc.); <2 mi/mi^2 road density in the floodplain.	50-80% mature trees (medium-large) in the riparian buffer zone (defined as a 30 m belt along each bank) that are available for recruitment by the river via channel migration; 20-50% disturbance in the floodplain (e.g., agriculture, residential, roads, etc.); 2-3 mi/mi^2 road density in the floodplain.	<50% mature trees (medium-large) in the riparian buffer zone (defined as a 30 m belt along each bank) that are available for recruitment by the river via channel migration; >50% disturbance in the floodplain (e.g., agriculture, residential, roads, etc.); >3 mi/mi^2 road density in the floodplain.

6.2.2 Assessment Results

Riparian size class information was obtained from the habitat assessment (Table 7). Road density in the floodplain was calculated using the Chelan County roads layer and floodplain areas delineated as part of the geomorphic assessment subunit mapping (see Appendix B). Road densities by reach are displayed in Table 8. For the purposes of this assessment, historical riparian timber harvest (> 50 yrs ago) was not considered a disturbance, as long as new riparian forests have become established.

Table 8. Results of floodplain road density per square mile.

Reach	**Reach 1**	**Reach 2**	**Reach 3**	**Reach 4**	**Reach 5**	**Reach 6**	**Reach 7**	**Reach 8**	**Reach 9**	**Reach 10**	**Reach 11**
Road Density (miles/mi²)	0	0	4.5	0	4.5	1.8	0.5	0	2.6	3.2	0

6.2.3 REI Ratings

General Indicators	**Specific Indicators**	**Reach 1**	**Reach 2**	**Reach 3**	**Reach 4**	**Reach 5**	**Reach 6**	**Reach 7**	**Reach 8**	**Reach 9**	**Reach 10**	**Reach 11**
Riparian	Disturbance (human)	adequate	adequate	unacceptable	at risk	unacceptable	unacceptable	at risk	at risk	at risk	at risk	at risk

6.3 INDICATOR: Canopy Cover

6.3.1 Metric Overview

Riparian canopies serve a number of important instream functions including moderating water temperature fluctuations and governing light quantity and quality. Water temperature is a main driver of the health, productivity, and life cycles of many aquatic organisms, including salmonids.

Criteria: From USBR (2011).

Pathway	General Indicators	Specific Indicators	Adequate	At Risk	Unacceptable
Riparian	Condition	Canopy Cover	Trees and shrubs within one site potential tree height distance have >80% canopy cover that provides thermal shading to the river.	Trees and shrubs within one site potential tree height distance have 50-80% canopy cover that provides thermal shading to the river.	Trees and shrubs within one site potential tree height distance have >50% canopy cover that provides thermal shading to the river.

6.3.2 Assessment Results

REI canopy cover ratings were determined using recent aerial photography. The percentage canopy cover is based on the extent of canopy closure within riparian areas (100 ft buffer), not the percentage of stream that is covered.

6.3.3 REI Ratings

General Indicators	Specific Indicators	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	Reach 10	Reach 11
Riparian	Canopy Cover	adequate	adequate	at risk	at risk	unacceptable	at risk	at risk	at risk	adequate	at risk	at risk

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