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Little Pend Oreille National Wildlife Refuge: Geomorphic Survey of the Little Pend Oreille River

Robes Parrish and Ken Muir

U.S. Fish and Wildlife Service
Mid-Columbia River Fishery Resource Office
Leavenworth Fisheries Complex
Leavenworth, WA 98826

***On the cover**: Little Pend Oreille NWR at sunset, September, 2014. USFWS photograph by Robes Parrish.*

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LITTLE PEND OREILLE NATIONAL WILDLIFE REFUGE: GEOMORPHIC SURVEY OF THE LITTLE PEND OREILLE RIVER

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U.S. Fish and Wildlife Service
Portland, OR.

and authored by

Robes Parrish
Ken Muir

U.S. Fish and Wildlife Service
Mid-Columbia River Fishery Resource Office
Leavenworth Fisheries Complex
7501 Icicle Road
Leavenworth, WA 98826

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Robes Parrish and Ken Muir

U.S. Fish and Wildlife Service
Mid-Columbia River Fishery Resource Office
7501 Icicle Rd.
Leavenworth WA 98826

Abstract

A geomorphic analysis of the Little Pend Oreille River on the Little Pend Oreille National Wildlife Refuge was performed to assess the current status and trajectory of riparian and instream habitat conditions. A continuous longitudinal profile, channel geometry measurements, and floodplain topography were acquired along a 0.5-mile reach using a total station to construct a digital elevation model (DEM). An aerial photo analysis of the broader 2.8-mile reach was performed to quantify changes in channel planform and riparian vegetation since 1950. The results show an increase in length and sinuosity by 20% from 1950 to 2014. Riparian vegetation has also expanded spatially by approximately 37%, though many areas along the streambanks are still devoid of shrubs and trees. The available photo record suggests that increases in channel length have stabilized since approximately 1998, although riparian extents have continued to expand steadily to the present time. Ongoing rapid lateral channel migration, frequent avulsions, and extensive abandoned floodplain surfaces suggest that lateral and vertical instability still persists in this reach. A suite of restoration alternatives is provided to address these issues and the topographic data can be used to inform potential designs. The DEM can also be used as a baseline to compare future changes in channel geometry, sediment flux, and to infer the effects of land management actions on the floodplain corridor.

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Introduction

In 2013, Little Pend Oreille National Wildlife Refuge (hereinafter LPONWR or Refuge) staff sought support from the Mid-Columbia River Fishery Resource Office (MCRFRO) to assist in determining the current status and trajectory of riparian and instream habitat conditions. This was based, in part, on a desire to quantify the effect of land management actions which have occurred over the last decade and the relationship to physical habitat in the Little Pend Oreille River. Funding was provided in Fiscal Year 2014 and staff from the MCRFRO Habitat Restoration and Conservation Division visited the Refuge September 17 – 26, 2014. Other collaborative and long-term monitoring projects are ongoing on the Refuge, including a separate US Fish and Wildlife Service (heretofore Service or USFWS) effort to quantify the effects of a changing climate on fish habitat and fish population structure.

Study Area

The Little Pend Oreille National Wildlife Refuge is located in the Selkirk Mountains of northeast Washington State, approximately 9 miles southeast of the City of Colville. It was established in 1939 as a federally-managed wildlife and migratory bird refuge and now encompasses 42,593 acres. It consists primarily of mixed coniferous forest but also contains many riparian and wetland habitats that are important to a variety of wildlife. Most of the Refuge lies within the Little Pend Oreille River watershed. Bear Creek is the largest tributary to the Little Pend Oreille River and their confluence is directly across the meadow from the Refuge Headquarters. The Washington Department of Fish and Wildlife managed these lands from 1965 to 1994, at which time responsibility was transferred back to the Service.

The survey on the Little Pend Oreille River began at river mile (RM) 10.4 (0.15 miles southeast of the discontinued US Geological Survey gaging station) and ended at RM 10.9 (approximately 0.35 miles northwest of the Refuge Headquarters) (Figure 1). The contributing drainage area is 130.3 square miles, varies in elevation from 1,970 feet to 5,610 feet, and receives a mean annual precipitation of 29 inches (USGS StreamStats, v.3) (http://water.usgs.gov/osw/streamstats/).

The study reach falls within what was formerly called “Pasture 13a” or the “Chimney Pasture” (Figure 2). The pasture derives its name from the remnants of a chimney inside a homestead cabin in the adjacent upland (Figure 8). This feature also serves as a useful long-term control point for any future topographic surveys.

The exact locations of all control points and the longitudinal extent of the survey reach are documented in the Appendix and associated electronic files. These include a topographic point file, photopoint logs with GPS coordinates, as well as spatial GIS information.

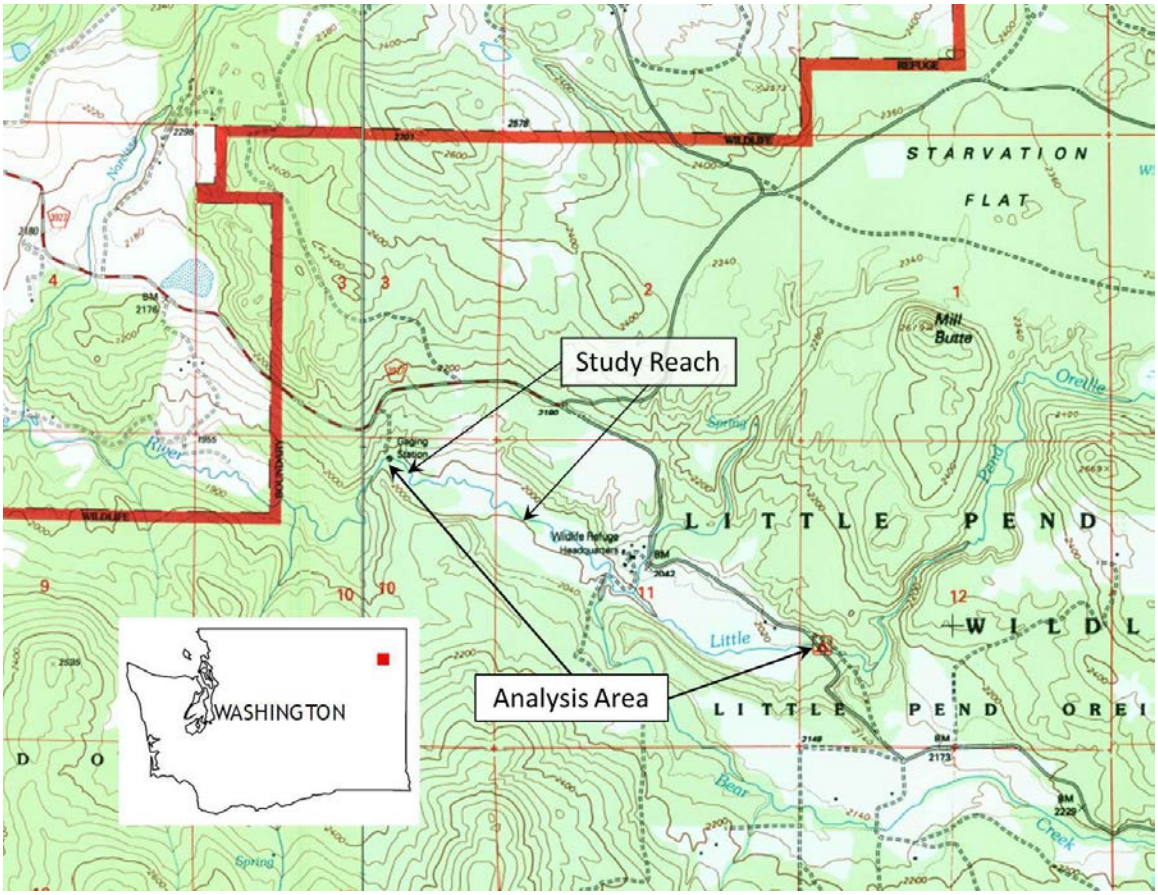

Figure 1. Map showing location of 2014 topographic survey ("Study Reach") and overall analysis area.

Land Use History

An exhaustive land use history study was not completed as part of this effort. However, limited information about the grazing history within the analysis area provides a useful background for understanding and analyzing historical changes in stream morphology.

As with other land uses, grazing has the potential to alter the physical and vegetative components of streams and riparian areas. A wealth of scientific information describes the mechanisms by which cattle may directly or indirectly affect the landscape (e.g., Kauffman & Krueger, 1984; Belsky et al., 1999). These ecosystem responses are not evenly distributed across the landscape and the magnitude of effect varies by stream type, season of use, intensity, and duration. The floodplain which extends from the USGS stream gage to Cottonwood Campground (RM12.8) has desirable forage and was heavily utilized for decades. The low-gradient channel and herbaceous-shrub vegetation respond quickly to adverse livestock impacts. Conversely, the channel and floodplain would also be expected to exhibit relatively rapid improvements once the ecological stressors are removed (Platts & Nelson, 1989; Stevens et al., 1992).

Livestock grazing has occurred since this area was originally settled in the late 1800's and was an officially sanctioned activity when the Refuge was designated in 1939. The USFWS resumed on-site management of the Refuge in 1994, at which time grazing was determined to be incompatible with the goals of native species conservation. This decision was controversial when annual grazing permits were discontinued beginning in the mid-1990's, and still so when it was phased-out completely in 2000 (Table 1). However, some cattle trespass from active allotments on adjacent National Forest land still occurs annually on both pastures (J. Cline, pers. comm.).

The Refuge was divided into many pastures, including unit 13a (Chimney Pasture) and 13b (Log Barn Pasture), which encompassed the meadow from east to west, respectively (Figure 2). The fenced boundary between them was approximately 175 meters west of Refuge Headquarters which places the 2014 survey reach entirely within the former Chimney Pasture.

Table 1. Grazing history of Pasture 13a (Chimney Pasture), 1994 - 2000 (J. Cline, pers. comm. 3/31/15)

Grazing Year	Grazing Season	Animal Units
1994	June 3 – mid-July	48 heifers
1995	July 11 – August 10	19 cow/calf pairs, 1 bull
1996	Rested	n/a
1997	Rested	n/a
1998	Rested	n/a
1999	Jun 29 – mid-July	43 cows, 40 calves, 21 heifers, 3 bulls
2000	Grazing ceased	n/a

The current goals of the Refuge[1] are to:

1. Conserve, enhance, and restore native forest, riparian, in-stream, and wetland habitats and their associated fish, wildlife, and plants, representative of the native biological diversity of northeastern Washington.
2. Monitor, protect, and recover special status plants and animals and species of management interest.
3. Provide opportunities for wildlife-dependent recreation and education to enhance public appreciation, understanding, and enjoyment of Refuge wildlife, fish, habitats, and cultural history.

[1] U.S. Fish and Wildlife Service (2000).

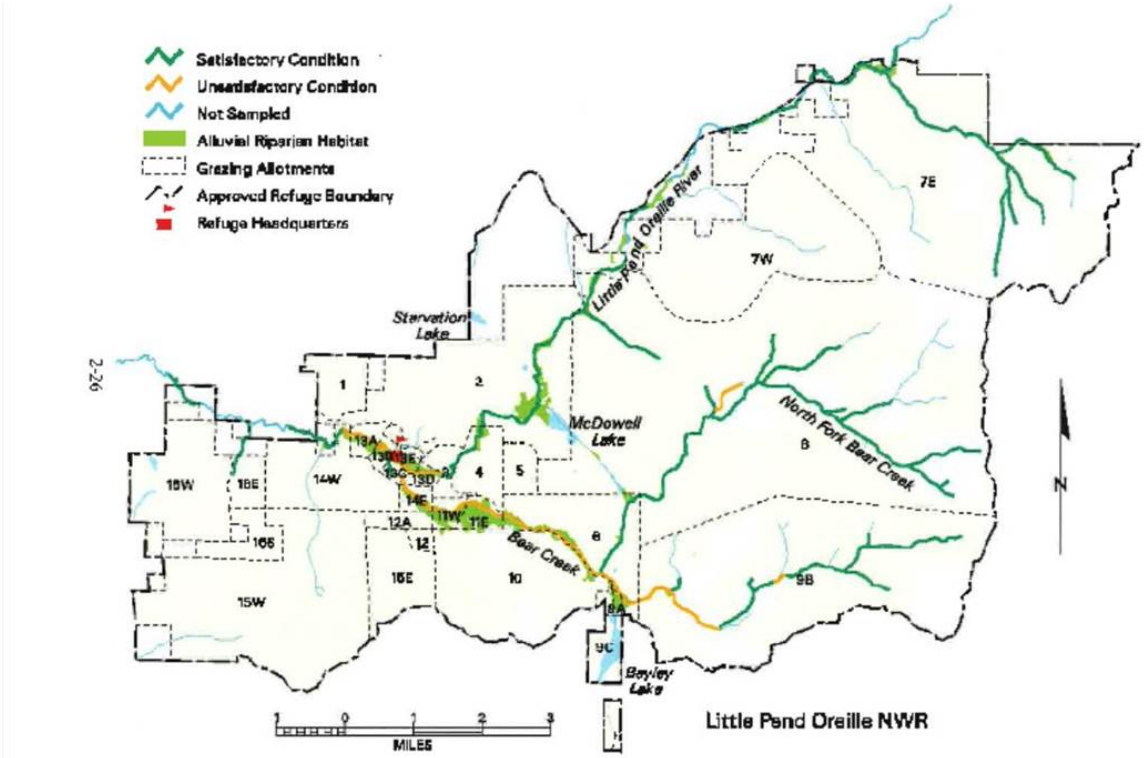

Figure 2. Map of historical grazing allotments and riparian condition on Little Pend Oreille National Wildlife Refuge (USFWS 2000).

Methods

Project goals were defined by the needs of LPONWR staff. Specific, measurable objectives and methods were chosen to: 1) provide scientific support for the 2015/2016 Comprehensive Conservation Plan (CCP) update, and 2) provide a baseline dataset for quantitatively comparing future physical habitat changes.

One initial objective was to quantify the effects of livestock removal on riparian and instream habitats because a previous MCRFRO study had established a baseline dataset (Kelly Ringel, 1998, 1999). This prior work utilized a modified Hankin-Reeves methodology (Hankin & Reeves, 1988) to collect physical and biological information on both the Little Pend Oreille River and Bear Creek. Although this information is useful in providing descriptive and quantitative information about certain instream habitat elements, it has significant limitations when used for quantifying responses due to management actions.

Research has shown that considerable subjectivity and observer bias inherently limits the precision and repeatability of the Hankin-Reeves methodology (Roper & Scarnecchia, 1995; Poole et al., 1997; Archer et al., 2004). This method quantifies the frequency of habitat units (such as pools and riffles) which may not necessarily be altered at the reach scale due to land management activities (Poole et al., 1997). The Hankin-Reeves data is spatially continuous, largely qualitative information which is a good indicator of broad-scale habitat types and quality. The 1998 study is regarded as a useful general inventory of reach-scale conditions but did not

allow enough spatial precision to conduct a statistically-rigorous repeat survey, or serve as a numerical baseline to document physical changes since livestock were removed.

It was determined that a more quantitative and repeatable method of measuring habitat attributes should be employed to meet project goals. The 2014 physical habitat survey will provide useful information for the CCP update, form the baseline for comparing future physical changes on the landscape, and be sufficient to inform restoration project design.

An initial field reconnaissance was performed across the Refuge to determine potential survey reaches on the Little Pend Oreille River and Bear Creek. The primary criterion was to select a reach which might be morphologically integrative of any upstream land-use or management activities. Response reaches are generally low-gradient (<2%) and reactive to anthropogenic activities and natural processes which alter sediment and wood budgets by adjusting their morphological form (Kershner et al., 2004). Shifts in riparian vegetation composition and extents, as well as changing hydrologic patterns, may be observed in the morphology of the response reach over time. The survey reach of the Little Pend Oreille River was also chosen because it is the lowest point in the watershed on the Refuge and has an observable planform history, as seen in aerial photos dating to 1950.

The survey measured morphological attributes by collecting topographic information using a Topcon TDS-223 total station. This included a continuous longitudinal profile in the thalweg, channel geometry, and floodplain topography measurements. Monumented control points (rebar-and-cap or rebar-only) were installed along line-of-sight intervals on the floodplain and occasionally within the active channel. A sufficient number of points over ½-mile of channel were collected to build a digital elevation model (DEM) which yielded almost 2,200 total shots. These data are included in Appendix C.

Geographic location data were collected at each control point using a handheld Trimble datalogger with a general spatial precision of 2 feet or less. The total station data were collected in local, assumed coordinates and later transformed into real-world coordinates for analysis (NAD83 State Plane North US Feet). Topographic data correction was completed using TDS ForeSight software (Trimble Corp.) and exported as ASCII (*.txt) files. Construction of the DEM was performed in AutoCAD Civil 3d (v.2014) where the surface was assigned breaklines and edited.

Aerial photographs were used to measure stream length, sinuosity, and changes to riparian vegetation extents. Aerial photos from the LPONWR files were scanned in high-resolution, imported using a common projection (WGS 1984 UTM Zone 10N), and orthorectified. Orthorectification was done by selecting multiple like points from each photo and correlating them to the 2013 base imagery. The 2013 image was chosen for this purpose because it offered the greatest resolution of the modern imagery and precise spatial correlation was possible. Like points were chosen across an east-west alignment (often using the historical railroad bridge just downstream of the stream gage, the homestead chimney, refuge buildings, and the log barn just west of Cottonwood Campground) to stretch each photo appropriately. These fixed objects also have a latitudinal (north-south) difference which allowed for proper rotation and skew adjustment in each photo. This process of stretching and rotating each point was imperfect and

resulted in minor geographical errors, though these are estimated to be less than 15 feet in any direction.

For each photograph, the centerline of the stream channel was digitized in ArcMap to allow for comparison of morphological differences through time. In some cases, poor photo quality, shadows, and dense riparian vegetation precluded definitive location of the centerline. Where this occurred, assumptions were made based on previous known channel position, presumed lateral trajectory, and observable depositional features (such as point bars). The Google Earth DEM was used to estimate channel elevations at the top and bottom of the measured reach to yield estimates of stream slope (elevation/channel length).

For each year, the stream centerline was digitized and measured (Figure 5). The 2014 channel centerline was chosen as a basis of morphological comparison because it is the year of the MCRFRO topographic survey.

Several sources of potential error were quantified, including re-digitizing the same photo twice and comparison of field-surveyed thalweg distance to digitized distance (Table 3). Generally, the surveyed distance is longer than aerial photo measurements because small-scale movements of the thalweg are not often observable in a photo but do occur within the channel prism (i.e., uni-directional bias). The differences associated with re-digitizing can be expected to increase or decrease channel length randomly (i.e., true error).

Historic peak streamflows were fitted to a statistical distribution to develop flood frequency information. The USGS stream gage (12408300) was operated on the Little Pend Oreille River at the western edge of the meadow near the Refuge boundary from 1958 – 1979 and was recently restored by the Service. The 2009 – 2014 data were added to the original dataset for synthesis and a new rating curve was established (T. Mayer, personal communication, January 15, 2015).

Hydrology information was downloaded from the USGS NWIS website (http://waterdata.usgs.gov/nwis) and coupled with the recent data to produce a cumulative 28-year period-of-record. Peak flow and flood frequency analysis procedures followed standard log-Pearson Type III methods described in USGS Bulletin 17B (Interagency Advisory Committee on Water Data, 1982). For comparative purposes, additional calculations were made using regionally-derived regressions from Sumioka et al. (1998).

Photopoints were taken within the active channel for qualitatively monitoring future morphological and vegetative changes. Photos were taken with a GPS-enabled digital camera, generally looking downstream, and were added to the project geodatabase in ArcMap. The specific location of each photopoint is shown in Figure 7 and included in Appendix A. The accompanying ArcMap file (available upon request) includes all the location metadata and allows the user to select an individual point on the associated raster image.

Limitations of Analysis

Much of the historical analysis relied on the aerial photo record which has limitations in terms of accuracy. Older air photos tend to be grainer and more difficult to determine the exact channel position in some locations. Shadows also make it difficult to precisely determine channel

location, particularly upstream of the Refuge Headquarters where the channel lies along the forested margin of the floodplain. Orthorectification of the 1950, 1957 and 1970 photos was particularly difficult due to inherent image distortion and the ability to align like features precisely. Delineation of riparian shrub/tree extents is somewhat imprecise and did not include native herbaceous vegetation. Sedges can have excellent streambank stability; therefore, not all un-forested areas should be presumed unstable.

Results

Topographic Surface Model

The topographic surface is presented as a TIN (triangulated irregular network) because it is a more spatially precise, vector-based type of DEM. The TIN for the entire reach is shown in Figure 3 to graphically represent the existing channel and floodplain morphology and is also contained within the accompanying ArcMap file (available upon request).

Similar to the Columbia Habitat Monitoring Program (CHaMP) (https://www.champmonitoring.org), geomorphic data were collected because of its utility for examining stream channel attributes at any chosen spatial scale (individual channel unit up to watershed-scale), its temporal repeatability, and the potential to compare to other similar stream types in another area (Wheaton et al., 2010). It also allows quantitative evaluation of lateral and vertical channel stability through time if enough points are collected at the scale of interest.

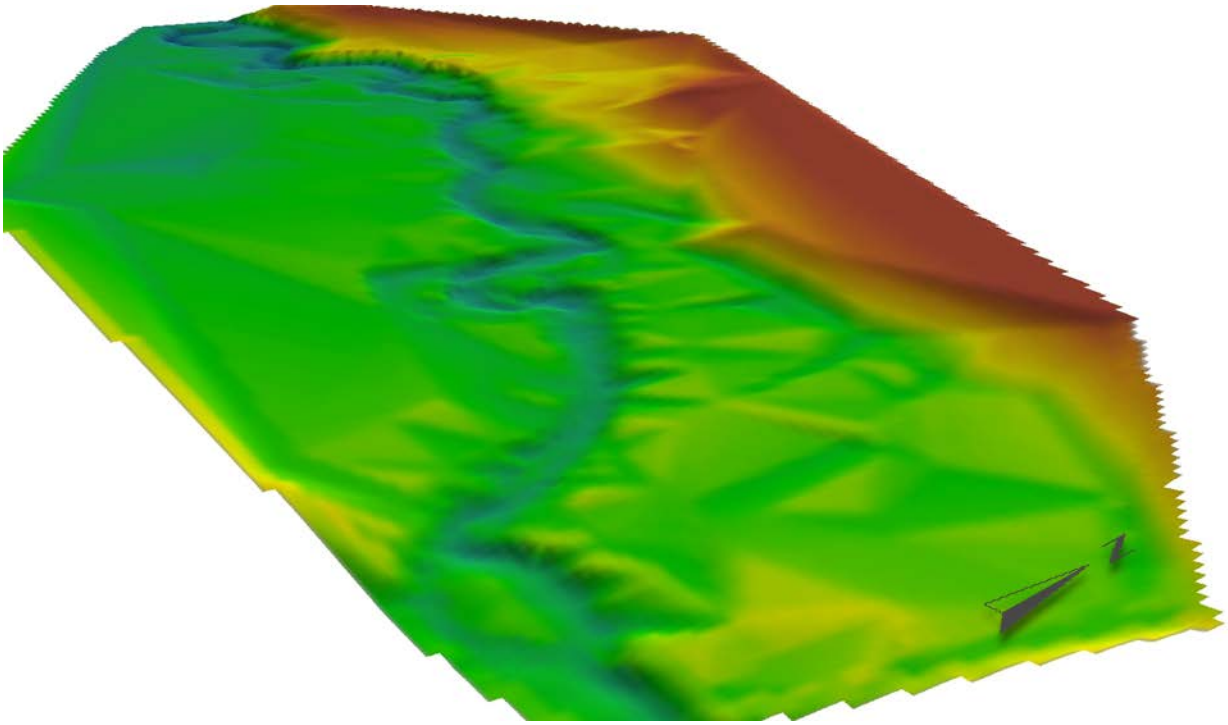

Figure 3. Isometric view of survey reach from the southeast, with flow from bottom of image to top. Note upstream areas where the channel has lower relative floodplain surfaces, but downstream is cutting into higher terrace and hillslope features.

Aerial Photo Analysis

Aerial photos allow for coarse-scale detection of changes in channel position, geometry, and riparian vegetation extents over time. An analysis was completed for several easily identifiable attributes across the available period of record (1950 – 2015). Since 1950, the Little Pend Oreille River has increased in length approximately 20% from RM 10.4 to RM 12.8 (Table 2). This reach appears to have lengthened steadily until 1998, since which time it has plateaued. Annual changes since 1998 appear to be within the digitizing margin of error. Some reach-scale changes in length would be expected to naturally fluctuate within a stable range as the processes of lateral erosion, deposition, and infrequent avulsions occur. Since no aerial photos were available between 1980 and 1998, it is impossible to determine more precisely when the increase in channel length leveled off.

Table 2. Comparison of Little Pend Oreille River channel length from Cottonwood Campground to the USGS stream gage, 1950 - 2015.

Year	Channel Length (ft.)	Difference from 2014 Baseline (ft.)	Change from 2014 Baseline (%)
1950	11,867	-2,964	-19.99%
1957	12,900	-1,931	-13.02%
1970	12,786	-2,045	-13.79%
1980	13,232	-1,599	-10.78%
1998	15,440	609	4.11%
2004	14,641	-190	-1.28%
2006	14,746	-85	-0.57%
2012	14,871	40	0.27%
2013	14,963	132	0.89%
2014	14,831	-	-
2015	14,761	-70	-0.47%

Table 3. Sources of digitizing error.

Year	Measured Length (ft)	Difference
2014 Aerial Photo	2,555	-
2014 Topographic Survey Thalweg Length	2,681	4.7%
1970 Aerial Photo Repeat Digitization, Complete Meadow Reach	12,786 (original value) 12,560 (repeat value)	226 ft. (1.77%)

Under the most conservative estimate, the river has lengthened at least 7% during the 1950 – 2014 period. This value is derived when the potential sources of digitizing error are combined (6.47%) and assumed to be positive for the 1950 photo (i.e., producing an underestimate of actual channel length) and negative for the 2014 photo (overestimating channel length).

Channel Geometry

Evaluating differences in reach-scale sinuosity provides another expression of morphological change over time. Table 4 shows a marked increase in sinuosity from 1950 to 2015, as measured by comparing the channel centerline length to the fall-line valley length. The Little Pend Oreille River was visibly straighter in the 1950s and, since it is intrinsic with length, has remained relatively constant since 1998. The channel segments in the vicinity of the Refuge Headquarters and the upper one-third of the meadow are where sinuosity has increased the most (Figure 5). From this information it is possible to infer that overall stream slope was greater in 1950 since it is inversely proportional to length (Table 4).

Table 4. Changes in channel pattern and profile, Little Pend Oreille River, 1950 - 2015.

Year	Channel Length (ft)	Sinuosity	Estimated Slope (%)*
1950	11,867	1.27	0.62
1957	12,900	1.38	0.57
1970	12,786	1.36	0.57
1980	13,232	1.41	0.55
1998	15,440	1.65	0.47
2004	14,641	1.56	0.50
2006	14,746	1.57	0.50
2012	14,871	1.59	0.50
2013	14,963	1.60	0.49
2014	14,831	1.58	0.49
2015	14,761	1.58	0.49

*Google Earth-derived elevation at Cottonwood Campground = 2,043 ft., historic train trestle = 1,970 ft., valley length for all calculations = 9,371 ft.

Riparian Vegetation

For the 1950, 1998, and 2015 aerial photos, a polygon was drawn around the perimeter of the primary riparian vegetation zone. This captured all trees and shrubs which were clustered and spatially continuous within the river corridor. Individual trees which were isolated on the floodplain were not included. An attempt was also made to differentiate and exclude shadows cast by the vegetation. While this method is somewhat imprecise, it shows a considerable increase in riparian vegetation through the period from 33.2 acres in 1950, to 45.5 acres in 1998, and 52.6 acres today (Figure 4). The largest spatial increases in vegetation appear to be in the middle one-third of the meadow reach, especially from the area due south of the maintenance yard and in the vicinity of the Bear Creek confluence.

Throughout the entire reach, many areas on the right (north) streambank are conspicuously more devoid of riparian shrubs and trees than on the left (south) side. This is because the channel is

cutting into a high terrace or hillslope along much on the meadow reach. Downstream locations show more extensive riparian vegetation wherever an inset floodplain has developed at or below the bankfull elevation. As the meander belt width (amplitude) increases in the middle- and upstream segments, an expansion of riparian vegetation should ensue.

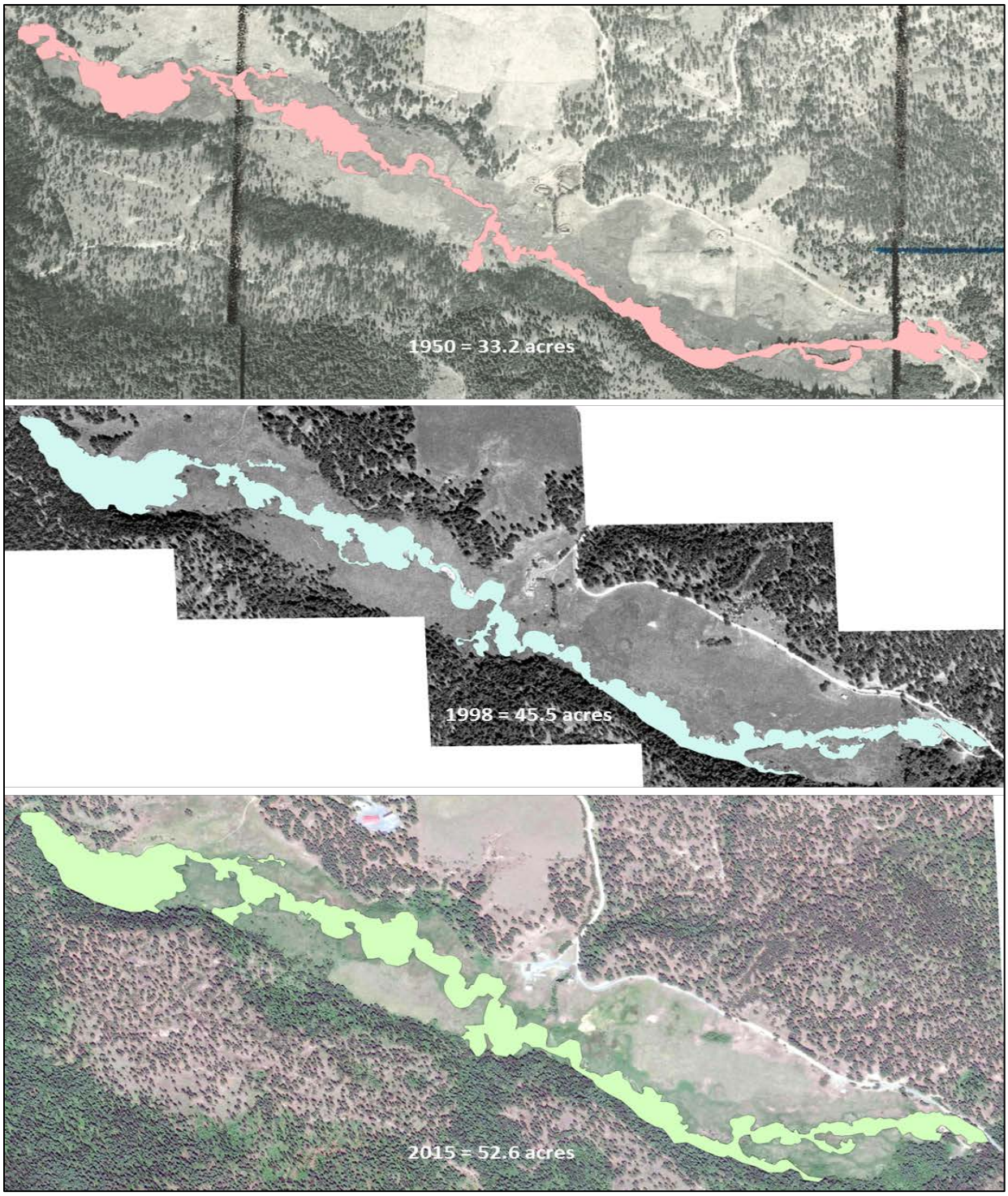

Figure 4. Riparian vegetation extents, Little Pend Oreille River corridor, 1950 - 2015.

Streambank Erosion

Considerable erosion was observed in the study reach but quantitative measurements were not taken. However, quantitative rates of lateral erosion will be possible by comparing future channel position to the 2014 TIN. The 1996 survey (Kelly Ringel 1998) noted that 34% of the reach streambanks were eroding and a considerable amount of this was caused by active hoof shear from livestock grazing. No permitted grazing currently occurs on the Refuge and no observations of concentrated hoof shear by livestock or ungulates were made during the 2014 survey. However, a 2015 USFWS habitat survey noted that cattle had entered the survey reach and some areas of active hoof shear were noted (B. Kelly Ringel, pers. comm.).

As the 1996 survey also noted, the channel is vertically entrenched and does not regularly access its floodplain on either bank in many locations. The upper two-thirds of the meadow reach appear to have the greatest levels of entrenchment (measured as floodprone width/bankfull width), though this variable was not quantified.

Hydrology

Annual peak flow and flood return interval data are shown in Tables 5 and 6. The flood-of-record occurred in 1961 but three of the ten largest floods have been observed since 2011. Statistics developed with the USGS Bulletin 17B method utilized the entire period-of-record (1959 – 1979, 2009 – 2014) while the Sumioka et al. (1998) method only utilized the 1959 – 1979 data. Table 6 shows that peak flow estimates calculated using the two different equations produced very similar values. Since only mean daily values were available for this analysis, it is expected that short-duration, instantaneous flows would produce higher annual peak values and lower magnitude flood return intervals for the same discharge.

Table 5. Ranked list of Little Pend Oreille River annual peak flows (mean daily values), 1959 - 1979, and 2009 - 2014.

Rank	Date	Discharge (cfs)
1	5/10/1961	1,060
2	4/24/1969	834
3	5/16/2011	730
4	4/7/1960	668
5	4/27/2012	609
6	4/26/1974	586
7	4/20/1958	512
8	4/29/1965	466
9	5/3/1975	432
10	4/7/2013	355
11	5/12/1976	353
12	5/3/1959	329
13	5/11/1967	297
14	5/16/1978	279
15	4/18/2014	278
16	5/6/1970	274
17	5/8/1963	263
18	2/2/1979	256
19	5/4/1971	255
20	4/20/1962	224
21	3/19/1972	212
22	5/10/1964	203
23	4/23/2009	202
24	6/12/2010	164
25	4/10/1966	154
26	5/9/1973	119
27	4/23/1968	97
28	3/23/1977	59

Following standard USGS flood frequency procedures 17B (Interagency Advisory Committee on Water Data, 1982), Table 6 shows the results computed by fitting the 28-annual peak flows to a log-Pearson Type III distribution. Development of this distribution involves calculating the logarithms (base 10) of the mean, standard deviation, and skew coefficient which describe the

mid-point, slope, and shape of the curve, respectively, when plotted. The station skew coefficient is used with the weighted regional skew coefficient to determine the frequency factor *K*. The resulting skew coefficient describes the relative symmetry of the distribution around the median value and is thus less influenced by extreme events (outliers).

Table 6. Flood frequency analysis using two predictive equations.**

Return Interval (years)	Probability of Exceedance (%)	Skew Coefficient (K= -0.29)	Peak Discharge (cfs) Predicted by USGS Bulletin 17B	Peak Discharge (cfs) Predicted by Sumioka et al.
1.0101	99	2.544	56	n/a
1.25	80	0.823	174	n/a
2	50	0.05	310	301
5	20	0.852	528	n/a
10	10	1.245	687	688
25	4	1.643	893	906
50	2	1.89	1,052	1,070
100	1	2.104	1,213	1,240

****Data Notes: For USGS Bulletin 17B Method: Data Range = 1959 – 1979, 2009 – 2014, A = -0.0836, B = 0.8672, V(gs) = 0.338, W = 0.472, Weighted generalized skew coefficient = -0.29; For Sumioka Method: Data Range = 1959 – 1979, Area-averaged equation prediction error = 83% – 93%.**

Discussion

Hydrology

Peak flows are often expressed as annual exceedance probabilities which describe the statistical likelihood of a certain magnitude flood occurring in any given year. This can also be described as a return interval which expresses the flood discharge in terms of the average time interval between floods of equal or greater magnitude. For example, an event with an exceedance probability of 0.01 (1%) equates to a return interval of 100 years (Q100). These values are not dependent on previous year's floods, but rather, the probability of a specific magnitude flood event occurring in any particular year. If a 100-year event occurs in subsequent years, it does not imply that the equations are incorrect, but that two very large floods with low statistical probability happened to occur back-to-back. Nor does it imply that a 100-year flood only occurs once every 100 years, or even at regular 100-year intervals.

Since mean daily values were used for statistical analysis and instantaneous values were not available, it is certain that higher peak flows do occur for short periods of time. For the purposes of restoration project design, a more thorough evaluation of Little Pend Oreille River hydrology should be performed. Structural stability can be compromised very rapidly by high flows and the performance of any stream treatment should be based on more conservative estimates of discharge.

Recent analyses have documented a 30% reduction in snow water equivalent (SWE) since 1950 in this region (Mote, 2003). Spring runoff onset has also been found to occur 5-15 days earlier than a mid-20th century reference value (Stewart et al., 2005). Minimum daily and maximum daily air temperatures have increased an average of 0.4°C and 0.6°C per decade, respectively, in the Pend Oreille watershed (Hatcher and Jones, 2013). It is likely that continued hydrologic changes will be driven by a rapidly warming climate.

Channel Morphology

A stable stream channel has morphology which, over time, in the present climate, transports the water and sediment produced by its watershed in such a manner that it maintains its dimension, pattern and profile without aggrading or degrading (Rosgen, 2001). It is useful to understand that while a range of natural variability exists in all morphological values, a stable stream channel maintains its general form by balancing inputs and outputs—water, wood, and sediment—over time. Significant morphological changes occur when one or more of these inputs change substantially and the channel is forced to adjust its form to accommodate the new supply. Habitat unit-scale or even meander-scale changes can occur annually but the reach-scale morphology remains within the same range of values. For example, in a stable channel, point-bar deposition occurs at the same rate as outside meander erosion to maintain a roughly constant channel width. Reach-scale changes in channel form may occur due to natural events such as large fires or landslides, but also when land management activities significantly affect flow, riparian vegetation, or sediment inputs. Both natural and anthropogenic stressors can reduce the channel's ability to dissipate stream energy and may cause undesirable degradation of the channel at multiple spatial scales.

Lateral Channel Stability

Broadly speaking, stream energy is dissipated by internal fluid friction and turbulence along the bed and banks (i.e., the boundary) where it contacts the substrate and roots of vegetation. As energy increases during a flood, it first begins to transport sediment by rolling rocks along the streambed and smaller particles as suspended material in the water column. Very high stream flows eventually erode the boundary if the resistive forces are exceeded. For example, if riparian vegetation is reduced, removed, or its composition changed, resistive forces are lowered and significant streambank erosion will occur during high flow events.

If rapid erosion occurs on tight meanders they may avulse (i.e., chute cut-offs). This is occasionally seen in the photo record of the Little Pend Oreille River, particularly in the reach just west of Refuge Headquarters (Figure 5). A chute cut-off reduces stream length which causes velocity and slope to further increase, often causing excess erosion or bed scour, and a positive feedback loop ensues. This process is only reversed or stabilized when meanders elongate, vegetation is sufficient to resist erosive forces, and the channel dimensions equilibrate to balance the sediment flux. The 2014 survey and current aerial photos show that many raw streambanks still exist throughout the meadow reach and will likely persist until vegetation is sufficient to resist flood events. Except in areas where the channel is migrating into a high terrace or hillslope, the river will eventually re-establish a new floodplain where vegetation can flourish. This process is particularly evident in the middle one-third of the meadow reach (Figure 4).

While it is not possible to directly compare the amount of eroding streambank to historical periods, it is reasonable to conclude that more fine sediment was generated prior to 1998 due to less extensive riparian vegetation and a steeper stream slope. A comparison to similar stream types in other reference reaches suggests that the current sinuosity of 1.58 in the meadow reach may be nearing a stable value. Data from the Chiwawa River shows a value of 1.65 (R. Parrish, unpublished data), although two other stable C4 reference streams in Montana and Colorado show even higher values of 1.93 and 1.8, respectively (D. Rosgen, unpublished data).

The plateau in channel length suggests that pre-1998 livestock management changes, and the subsequent cessation of grazing, has helped reduce browsing pressure and allowed vegetation to expand vigorously. The current improving trajectory is most evident on low floodplains recently formed within the floodprone area. These lower surfaces have generally formed wherever sinuosity has increased to create a low depositional area between either side of the valley (i.e., "inset floodplains").

Avulsions and conspicuous lateral erosion continue to occur throughout the meadow reach. While the expansion of riparian vegetation is indicative of ecological recovery, it may still be many decades before lateral stability is fully achieved and vegetation on both banks makes the boundary resistant to excess erosion during large floods. LPONWR management should promote land management activities which protect the entire floodplain corridor from anthropogenic disturbance to allow the river to naturally stabilize.

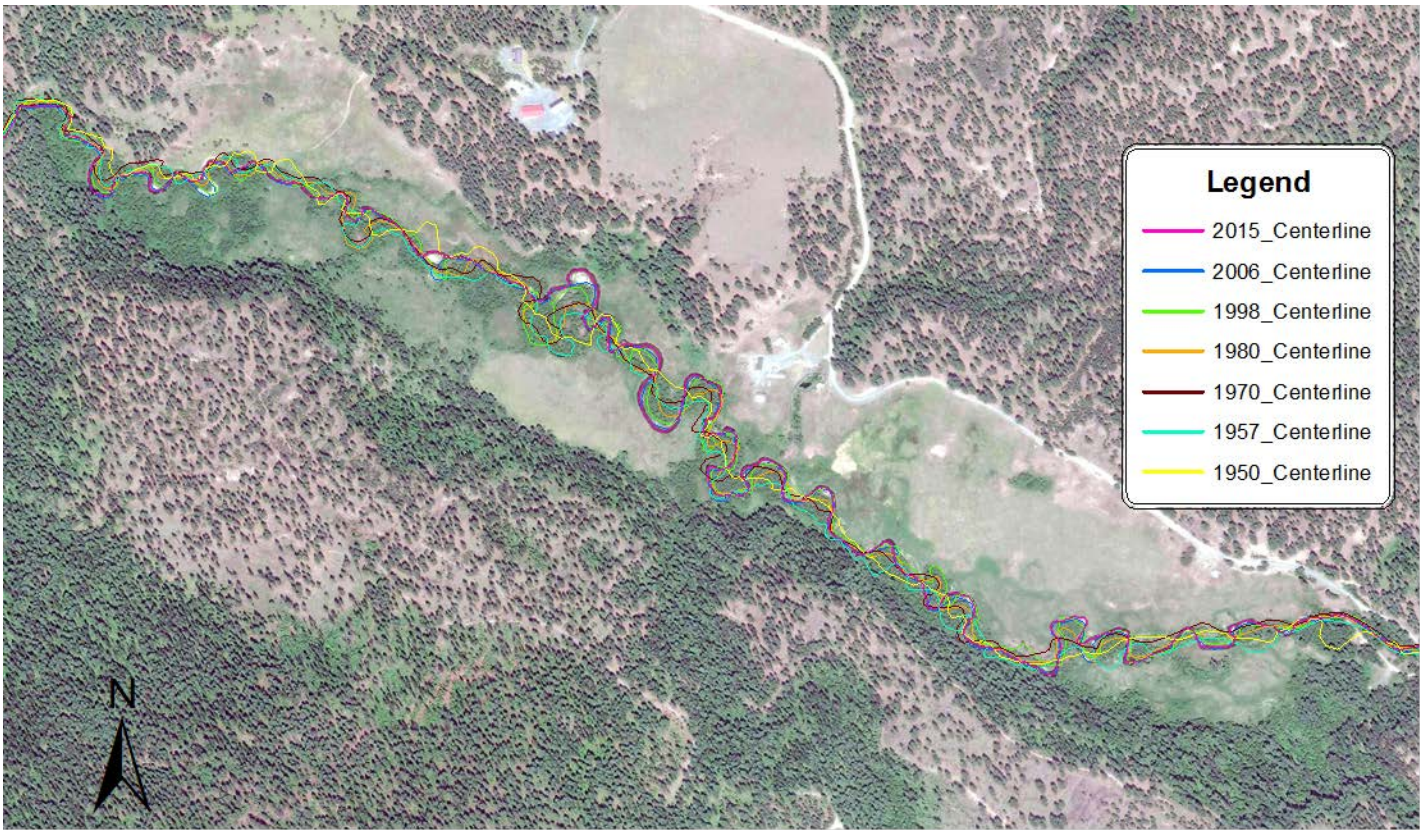

Figure 5. Little Pend Oreille River channel position, 1950 - 2015. 2015 Aerial photo used as base image. Note: Not all years that were digitized are shown for clarity.

Vertical Channel Stability

In cases where excess stream energy causes more sediment transport to occur than is replaced from upstream, vertical incision of the channel ensues. An incised channel results in less sediment storage capacity on the floodplain during flood events and riparian vegetation has a difficult time establishing or maintaining its vigor and extent as groundwater levels drop.

The extent of vertical incision in the study reach is difficult to quantify without comparable geomorphic data from an earlier time period. Completion of a 2-dimensional hydrologic analysis would also indicate the current level of entrenchment in relation to flood return intervals. There are many places in the study reach where a low floodplain has recently developed at or below the bankfull elevation, albeit below the pre-disturbance floodplain elevation. This is indicative of recent improvements in localized vertical stability, although it does not appear to be aggrading back to its historic elevation throughout the entire reach. In certain areas, lateral migration into high terraces or an abandoned floodplain is apparent (e.g., the 13-foot high bank near the bottom of the study reach). These locations are not expected to naturally develop an inset floodplain for many decades unless the channel migrates away from these features.

The current slope value of 0.49% is very close to the 0.5% value of a Colorado reference reach (D. Rosgen, unpublished data). The Little Pend Oreille River and Wolf Creek are both Rosgen C4 stream types and have similar valley slopes (0.86% and 0.9%, respectively). This, in addition to the plateau in channel length, gives some indication that the meadow reach may have stabilized in profile. Knowing the current status and trajectory of vertical channel dynamics are critical for choosing the most appropriate restoration alternative.

Sediment Flux

As a consequence of lateral instability and streambank erosion, sediment generation, routing, and storage will continue to be an issue for the foreseeable future. Without the stabilizing effects of continuous riparian vegetation throughout the reach, eroding streambanks will continue to be a source of fine sediment.

Any sediment generated by the river must be routed through or stored within the channel prism and/or on the floodplain. Most of the meadow reach is underlain by the fine-grained Narcisse silty-sandy loam and mixed alluvium soils (Donaldson et al., 1982). This soil type is easily eroded by the channel when it is not protected by the roots of native vegetation. Many locations in the meadow reach exhibit “slump blocks” where the streambanks have collapsed as a whole unit. This occurs exclusively where shallow-rooted annual grasses have colonized the banks instead of denser-rooted sedges and woody vegetation.

Excess fine sediment poses hazards for aquatic life, primarily through siltation of fish redds, chronic water quality impairment, and changes in the macroinvertebrate community composition. It is difficult to estimate the timeframe when sediment equilibrium will occur, however, active restoration can reduce the time to achieve sediment balance and channel stability.

Potential Future Analysis

Since certain land management activities (such as grazing) would be expected to physically affect both the channel morphology and the local sediment budget, comparison of the 2014 topographic data to future surveys will permit an effects analysis using DEM of Difference (DoD) procedures (Wheaton et al., 2010). A DoD example from Wheaton (2008) is shown in Figure 6. This will help future researchers or managers understand the status, trajectory, and morphological processes at work in the Little Pend Oreille River. By understanding the quantity of sediment routed and stored in the channel and on the floodplain, it is possible to analyze the spatial and temporal effects of land uses and make decisions about how the river corridor can be better managed in the future.

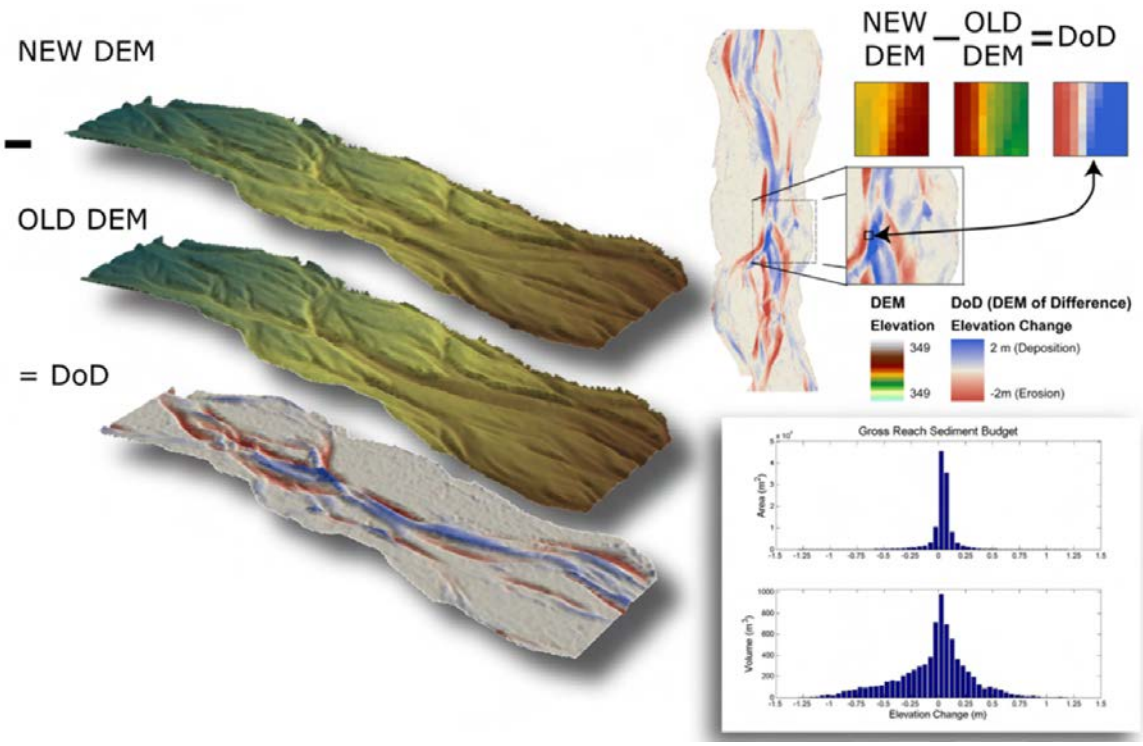

Figure 6. Example output from DEM of Difference (DoD) analysis. By comparing two DEMs, it is possible to see changes in planform (lateral channel position), aggradation (blue) and scour (red). 2014 topographic data can be used as a baseline for future comparisons. Graphic reproduced from Wheaton (2008).

Future Management Considerations

Nielson and Lohman (1999) performed an analysis of riparian vegetation on the Refuge shortly after the cessation of active livestock grazing. They reported only subtle changes in structure and composition were measurable and that distinctions between grazed and ungrazed pastures were statistically insignificant. Our aerial photo analysis documents an increasing vegetative extent since 1999 but cannot discern species-level differences in community structure and composition. It would be valuable to repeat the 1999 transects, species plots, and green-line surveys to better measure vegetation changes now that sufficient time has passed to expect such changes to have manifest.

If it is a goal of LPONWR management, the most definitive way to quantify the effects of livestock removal is to compare the Little Pend Oreille River channel morphology to an actively grazed reach elsewhere. One comparable reach exists downstream below the Refuge boundary on a property which is believed to have been continuously grazed for decades. This reach lies on private land and thus cooperative relationships must be formed with this landowner(s). Coordination with the property owner(s) should demonstrate goodwill and assure them that a purely scientific—and not punitive—analysis could yield insights into better attainment of management goals. This would afford an opportunity for the landowner(s) to examine how season-of-use, stocking rates, and pasture rotation can yield gains in animal productivity, while still protecting ecological values.

Restoration Recommendations

The LPONWR Comprehensive Conservation Plan (USFWS, 2000) established a direction which includes the restoration of habitat components along with a mix of existing uses and priority recreation activities. Our study can support these goals by using geomorphic data to inform a suite of potential aquatic and riparian restoration actions at multiple spatial and temporal scales. Either active or passive restoration activities would be appropriate so the selection of opportunities is only dictated by the recovery timeframe desired by Refuge management.

Our work has shown that local areas of instability still persist within the meadow reach from Cottonwood Campground to the USGS gage. Improved stability and ecological improvement may be accomplished by several potential treatment alternatives. In order of increasing complexity, cost, and effort, these include:

1. Passive Restoration (i.e., No Action). The Little Pend Oreille River would be expected to continue to stabilize over a period of several decades. Ecological recovery would primarily occur through continued expansion of riparian shrubs, trees, and herbaceous vegetation (sedges, rushes, etc.), mainly in those areas which are inundated seasonally by flood flows or supported by near-surface groundwater. Continued protection from further disturbances which removes or retards vegetation growth is necessary to ensure that this trajectory remains upward.

   It is unlikely that the pre-settlement floodplain will be re-occupied in this timeframe, but a stable pattern, dimension, and profile should eventually establish at the current base elevation. Upslope or upstream management activities which substantially alter flow and/or sediment inputs should not occur. Growing ungulate populations may affect streambank stability and vegetation conditions if they exceed the carrying capacity of the landscape or are not subject to adequate predation pressure (Ripple & Beschta, 2012). Solutions to reduce or eliminate trespass livestock would benefit natural recovery of vegetation and soils.

2. Riparian Revegetation. Many areas of eroding streambank still exist, principally due to the lack of established riparian vegetation. Active planting of native trees and shrubs may reduce the rates of erosion and eventually stabilize the channel. Most of the current

erosion occurs on the outside of meanders which are often above the bankfull elevation. Planting in these droughty areas would be challenging since the sandy soils in the meadow experience rapid moisture loss after spring snowmelt. Plant roots often have a difficult time growing fast enough to keep up with a declining water table which is why these areas are currently dominated by annual grasses. This can be overcome by either installing plants at the base flow water table elevation with mechanical means (e.g., Stinger™, waterjet, mechanical or hand augers), or with sufficient irrigation to allow them to persist through the dry season. Mechanical installation is more expensive initially, but plants require minimal maintenance thereafter. Irrigation systems require constant maintenance until roots successfully grow to the baseflow water table and then become self-sustaining.

All plantings should be protected from ungulate browsing with minimum 6-ft fencing that can withstand snow-loading. These may eventually be removed after plants grow above browse height. Individual plant cages are not recommended, except in locations where block exclosures are not feasible.

3. Beaver Dam Analogues (BDAs). These structures are a relatively new technique which emulates the effects of multiple beaver dams at sufficient longitudinal scale to induce aggradation. This technique has the advantage of being cost-effective with a high likelihood of success if sufficient redundancy is a component of the design.

   Multiple small-diameter (<4-inch) posts are driven into the streambed across the active channel to provide the structural support for subsequent wicker materials. Willows, cottonwoods and alders are woven between the posts to span the channel and mimic the full geomorphic effect of beaver dams. These structures are proven to capture sediment from upstream and induce rapid aggradation of the streambed in low-gradient stream-types such as the study reach of the Little Pend Oreille River. Large-scale aggradation of the streambed depends on the amount of bedload and suspended sediment available, and the relative elevation of floodplains. Structures are often flanked as they fill with sediment and the water flows around it. Continued vertical aggradation after flanking will require subsequent treatments.

   Some BDA projects have utilized partial-spanning deflection structures which actively erode targeted streambanks to provide additional sediment for downstream capture and faster aggradation. BDAs are not dependent on colonization by beavers but often function best in those landscapes currently or formerly occupied by these animals. See Pollock et al. (2014) (http://bit.ly/1j89bME) or contact MCRFRO restoration staff for more information.

4. Large Woody Material (LWM) Addition. The strategic placement of whole trees has been well-documented to improve instream habitat and may also yield benefits for improvement of channel stability (e.g., Lassettre and Harris, 2001). Wood functions similarly to beaver dams in that it deflects flow and captures sediment while providing excellent gravel sorting and instream fish cover. LWM is most effective at enhancing

natural processes when it is placed in reaches where the geomorphic attributes are broadly maintained by wood.

The study reach of the Little Pend Oreille River is unlikely to have ever supported large quantities of overstory trees larger than alders, though individual cottonwoods and conifers may once have been more abundant and fallen into the channel. Regardless, even large quantities of small-diameter material can form localized log jams and provide the grade-control necessary to maintain pool-riffle morphology. Some of these jams were observed in the study reach but additional LWM could be strategically placed to further enhance fish habitat and reduce localized instability. This reach has the advantage of no infrastructure or public boating which often limit LWM supplementation and require use of artificial anchoring. This treatment would require very little long-term maintenance, although additional wood could be added if whole structures are lost during flood events or objectives are not met.

5. Bankfull Bench Creation. There are multiple locations where the current channel is aligned tightly against a hillslope or high terrace. These locations will likely persist as sources of fine sediment for the foreseeable future. Throughout much of the meadow reach the channel appears to be incised or entrenched within the former floodplain. Absent the addition of BDAs or LWM to provide material for inducing aggradation, constructing a bankfull bench would help riparian vegetation establish and stabilize the channel. An excavator would be required to cut into higher surfaces to create a lower floodplain where it must then be planted vigorously with appropriate riparian vegetation. The largest expense is hauling excavated material out of the floodplain, although this can be reduced by spoiling in nearby locations.

   This alternative has the advantage of rapid reductions in fine sediment production. It may be implemented at any spatial scale to test its ecological effectiveness, although lower surfaces with less cut would be more cost effective. LWM structures should also be installed along the channel margins to encourage lateral channel migration away from hillslopes. This alternative would be the most expensive initially and may require some long-term maintenance of vegetation and wood structures. Additional treatments may also be needed if erosion rates remain unacceptably high.

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Appendices

A. Photopoints

B. Orthorectified Aerial Photos

C. Topographic Survey Data (included and attachment)

D. Topographic Survey Notes (attachment only)

E. Georeferenced Photopoints in ArcMap (attachment only)

F. DEM, Historic Aerial Photos in ArcMap (attachment only)

Figure 7. The namesake relict homestead chimney in the uplands of the Chimney Pasture.

U. S. Fish and Wildlife Service
Mid-Columbia River Fishery Resource Office
7501 Icicle Road
Leavenworth, WA

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