Technical Memorandum

Date: February 14, 2012

To: Jennifer Goodridge and Mike Kaputa
Chelan County Natural Resources Department

cc: John Soden
ICF International

From: Tim Abbe, PhD, PEG, PHG, Shawn Higgins, and Steve Ralph

RE: **Geomorphic Assessment of Lower Nason Creek from RM 3.3 to 4.6**

Introduction

The purpose of the N1 Floodplain Reconnection Project is to restore floodplain connectivity and increase off-channel habitat for a segment of Lower Nason Creek in the Wenatchee River basin. The Chelan County Natural Resources Department (CCNRD) evaluated six alternatives to reconnect floodplain habitat at the N1 site (CCNRD, 2011). ICF International (ICF) is assisting CCNRD with an assessment of biological benefits for the proposed alternative to relocate a section of State Route (SR) 207 out of the floodplain. Cardno ENTRIX was contracted by ICF to support the biological assessment with an evaluation of geomorphic conditions for the project site.

The objectives of this geomorphic assessment are to:

1. Present a description of geomorphic processes affecting physical conditions of Lower Nason Creek within the N1 Floodplain Reconnection Project area;
2. Interpret the anticipated future conditions for both the no action and SR 207 relocation alternatives; and
3. Generate a quantitative estimate of the extent and relative distribution for different habitat types (e.g., pools, riffles, and runs) under the two alternative scenarios.

This assessment covers the segment of Nason Creek between river miles (RM) 3.3 and 4.6 (Figure 1). Reach scale geomorphic processes are evaluated with an approach that includes review of existing information, field reconnaissance, terrain analysis of a LIDAR-based digital elevation model (DEM), and evaluation of historic channel changes from a time series of aerial imagery. Previous studies consulted in the review of existing information include assessments by Jones and Stokes (2004), the Bureau of Reclamation (2008, 2011), and CCNRD (2011). Observations from the field reconnaissance are combined with evidence from the DEM and aerial imagery from the period 1966-2011 to support an interpretation of anticipated future conditions.

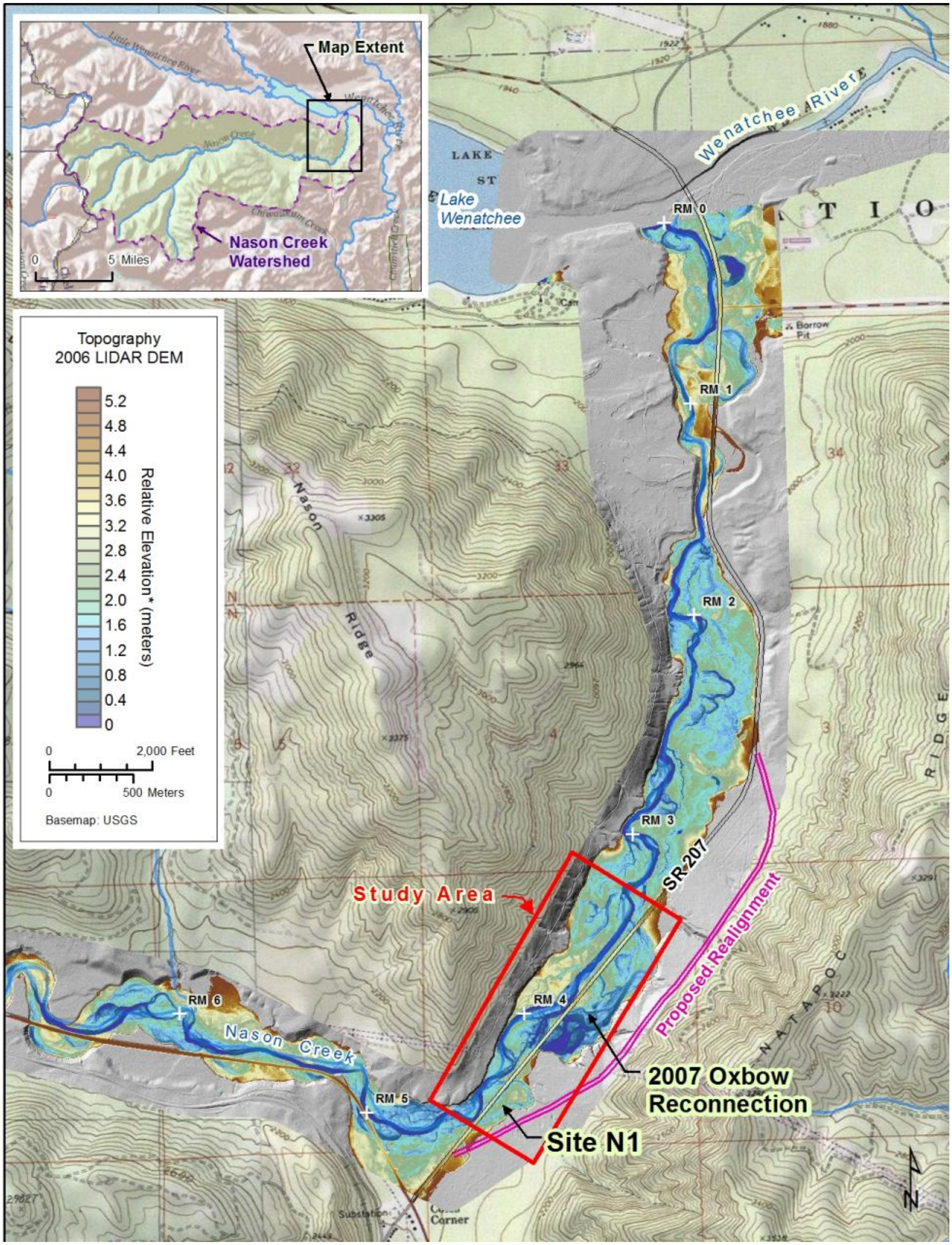

Figure 1. Project location and valley bottom topography.

The anticipated future changes are utilized to modify a dataset of the areal extent and distribution of aquatic habitat types which was prepared for existing conditions by ICF. The assessment yields an estimate of the anticipated future extent and distribution of habitat types which will provide input to the Ecosystem Diagnosis and Treatment (EDT) model in preparation by ICF to evaluate the biological benefits of the SR 207 relocation alternative. Interpretations of future geomorphic conditions in the study area focus on the near future and use a time period of 20 years to be consistent with the methodology of the EDT analysis.

Reach Description

Nason Creek is a perennial stream draining approximately 109 square miles from the eastern slopes of the Cascade Range and joining the Wenatchee River just downstream of Lake Wenatchee (Figure 1). The basin hydrology has a snowmelt-dominated flow regime; however, high flows also occur in response to rainfall and rain-on-snow events. The watershed is primarily forested and 78 percent of the land area is federally owned. The upper basin is underlain by relatively hard, metamorphic rocks of the Nason Terrane and the lower basin is underlain by less resistant, sedimentary rocks of the Chumstick formation.

The study reach has a gravel- and cobble-bedded alluvial channel characterized by pool-riffle morphology (Figure 2). Stream gradient transitions from an average slope of 0.010 ft/ft (1%) upstream of RM 4.6 to a slope of 0.003 ft/ft (0.3%) at the downstream end of the study area (Figure 3). The change in gradient occurs at the narrowest segment of the valley where there is also a bedrock exposure in the channel bed between RM 4.1 and 4.2 (Figure 2). The valley bottom is forested and ranges in width between 700 and 1,700 feet. The widest sections of the valley are downstream of the change in channel gradient near RM 4.1 and include alluvial terraces in addition to floodplain areas.

SR 207 crosses portions of the floodplain between RM 3.5 and 4.6 and impacts geomorphic and ecologic processes in the stream corridor. The 1940's road construction project relocated the stream channel out of the historic alignment between RM 3.5 and 4.0 to a new alignment which parallels the west side of the roadway (Figure 4). The active floodplain trended easterly across the valley near RM 4.0 prior to the forced relocation. Construction of SR 207 across this section essentially dammed the historic stream corridor which was confined between the east valley margin and an alluvial terrace at RM 3.9. The road stays on the terrace surface until it reaches RM 3.6 and again crosses the historic floodplain. The new channel created as part of the 1940's road construction project excavated material from the terrace surface between RM 3.6 and 4.0 (Figure 2). Note that the terrace on the west side of the valley naturally constrained the stream's active floodplain width (600 feet) to less than half of the valley bottom width (1600 feet) in this area and that the road is positioned on the terrace surface between RM 3.6 and 3.9 (Figure 5).

The 2007 Oxbow Reconnection Project installed culverts across the roadway at RM 3.5 and 3.9 to create additional off-channel habitat. The excavated channel west of SR 207 remains the primary channel and approximately 10% of the total flow upstream is directed into the historic alignment via the culverts (CCNRD, 2007). The 2007 project generated dramatic improvement to secondary channel habitat within the reach by reconnecting floodplain areas. There is actually a greater area of perennial channel habitat in the reach now than existed before the SR 207

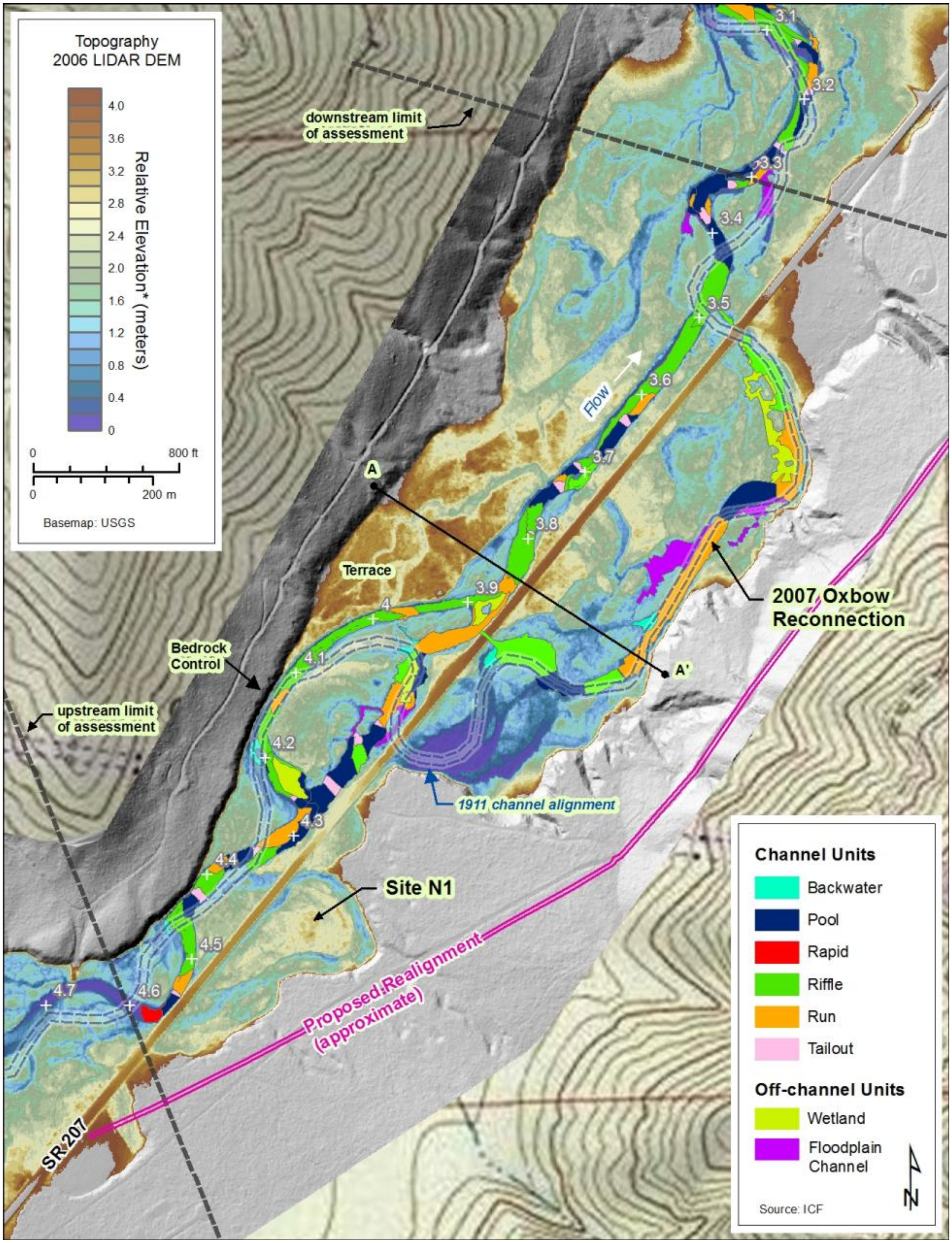

Figure 2. Existing conditions of the assessment reach between RM 3.3 and 4.6.

construction project because of the additional channel created by excavation. Existing conditions still impact geomorphic and ecologic processes in the reach; however, natural bank erosion and wood recruitment are improving habitat.

The segment between RM 3.9 and 4.3 has a multi-channel (anabranching) pattern with split flow around a forested island (Figure 6). The main channel flows along the west side of the valley and a 1,500 foot long side channel cuts across the bend. The entrance to the side channel is partially blocked by a log jam which deflects flow laterally in both directions. A second log jam spans the side channel approximately 400 feet downstream of the entrance.

The segment between RM 4.3 and 4.6 has a single-thread, meandering pattern. The upstream meander bend at RM 4.6 abuts the road embankment and was stabilized by rock revetment for 240 linear feet. The revetment was constructed prior to 1992 and has been augmented by additional rock in 2011. Action site N1 encompasses approximately 13 acres of disconnected floodplain east of SR 207 between RM 4.3 and 4.6 (Figure 7).

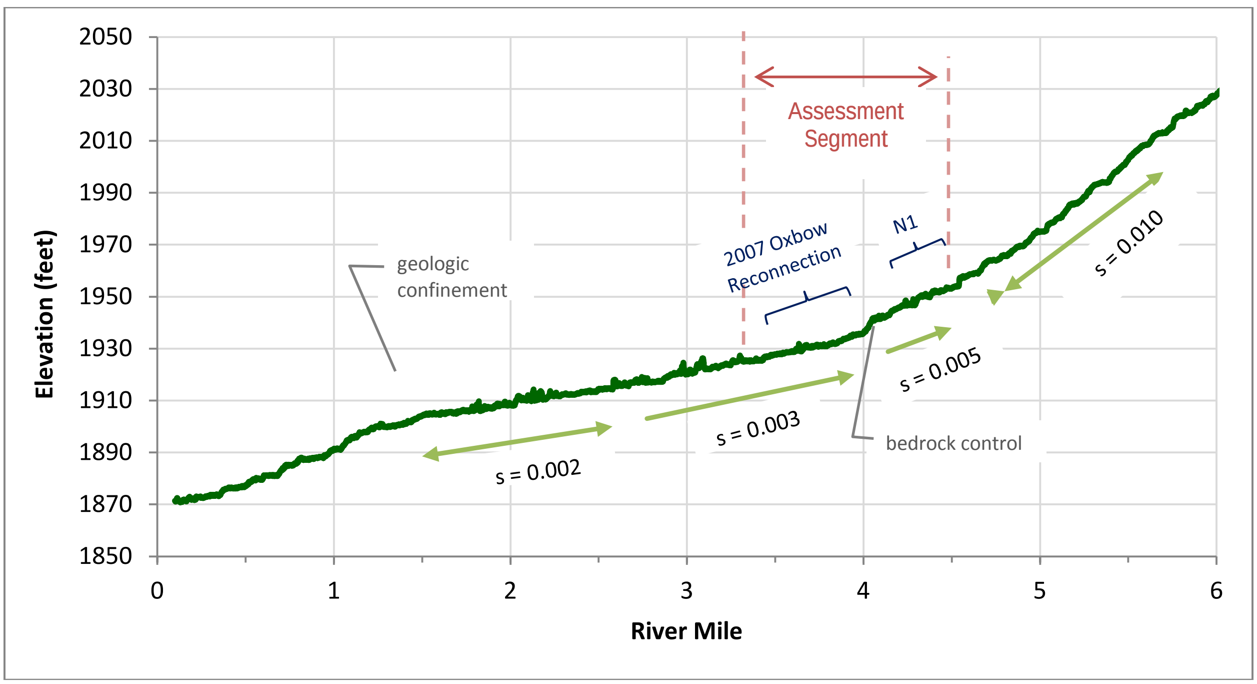

Figure 3. Longitudinal profile of Lower Nason Creek. Elevation data is the 2006 LIDAR DEM and reflects the water surface elevation (not the channel bottom). Channel slope (s) estimation is based on channel length from the 2006 channel alignment.

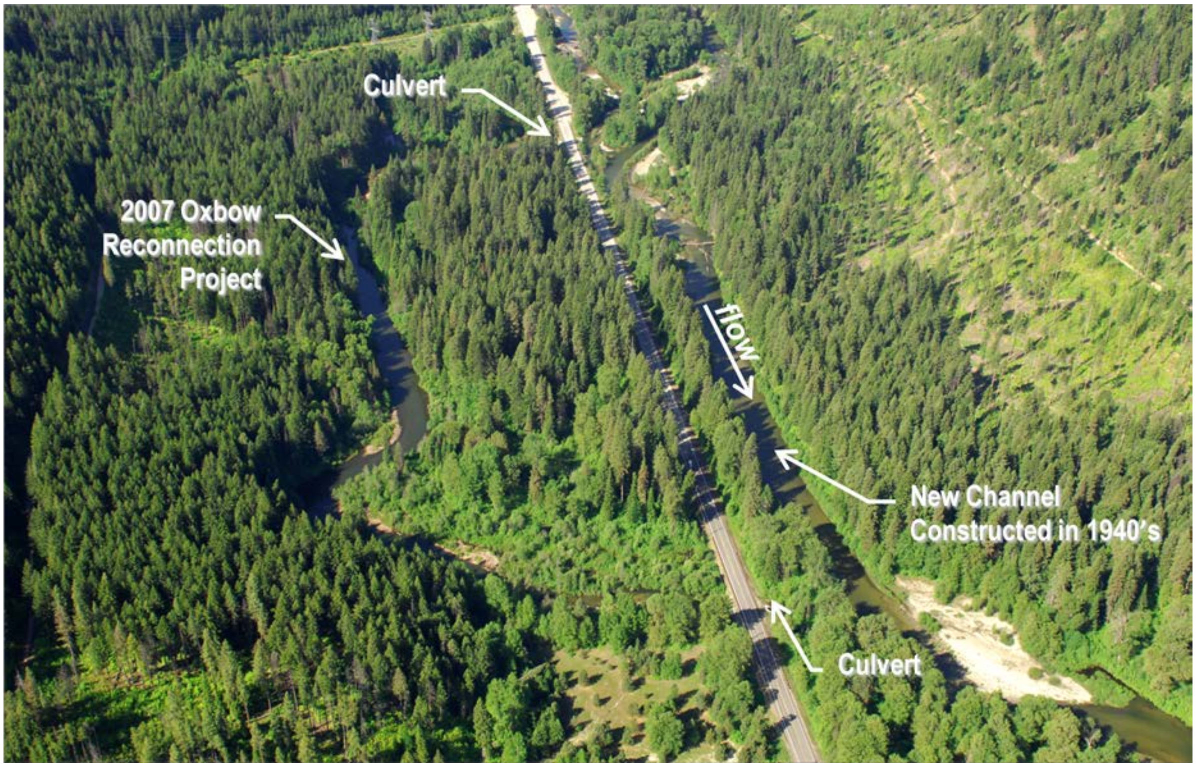

Figure 4. Nason Creek segment between RM 3.5 and 4. The historic alignment of the channel is to the left of the image. A new channel was constructed in the 1940's to the west of SR 207. Image acquired 6/10/2011 (source: Bureau of Reclamation).

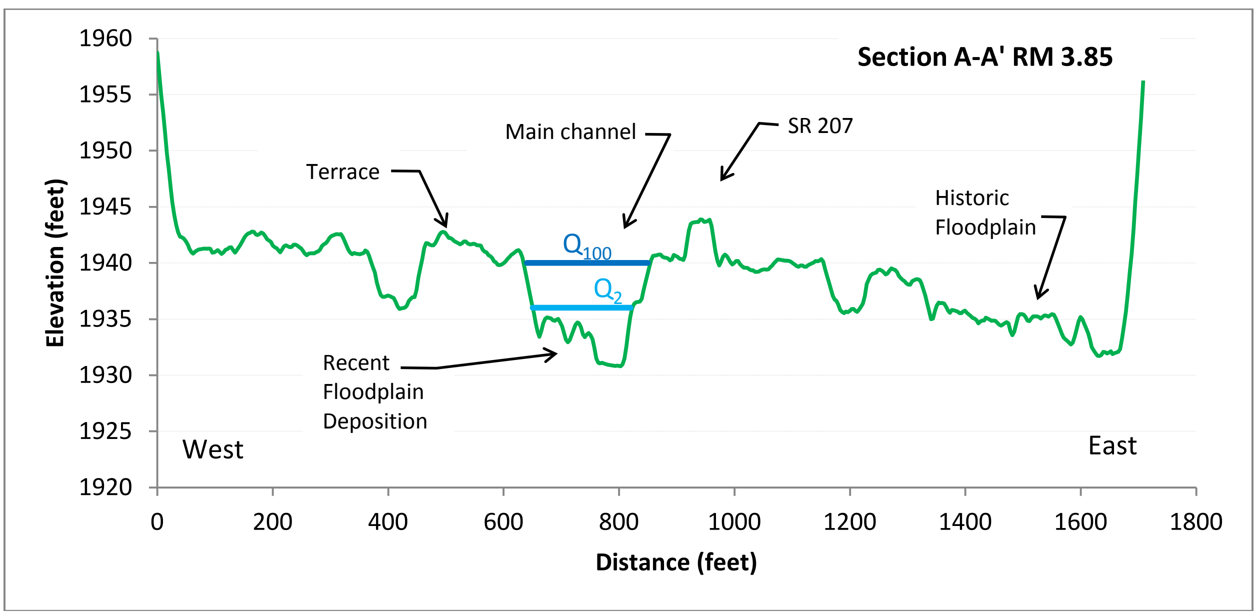

Figure 5. Cross-section profile from west (left) to east (right) near RM 3.85. Topography from 2006 LIDAR DEM. Predicted water surface for 2-year (Q_2) and 100-year (Q_{100}) flood from hydraulic model (ICF, 2011). Cross-section alignment A-A' is indicated on the map in Figure 2.

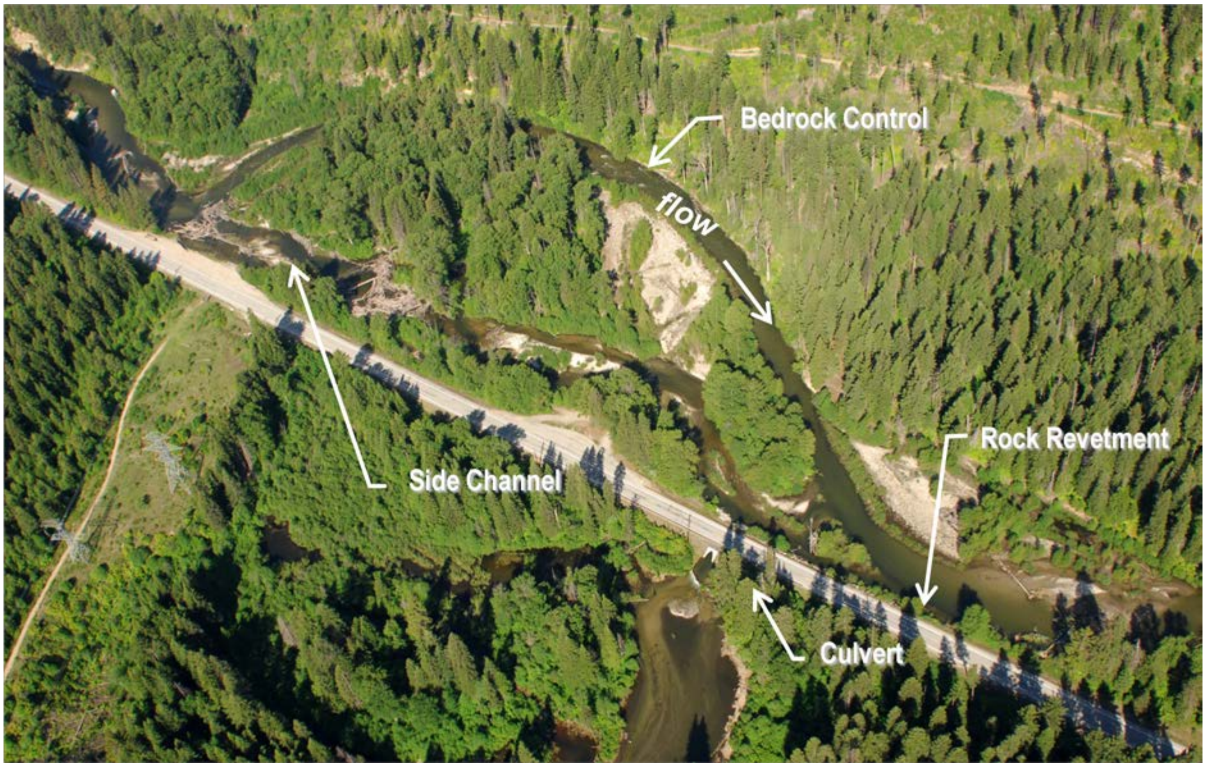

Figure 6. Multi-channel segment from RM 3.8 to 4.4. The culvert at the downstream end of the side channel is the inlet to the 2007 Oxbow Reconnection Project. Image acquired June 10, 2011 (source: Bureau of Reclamation).

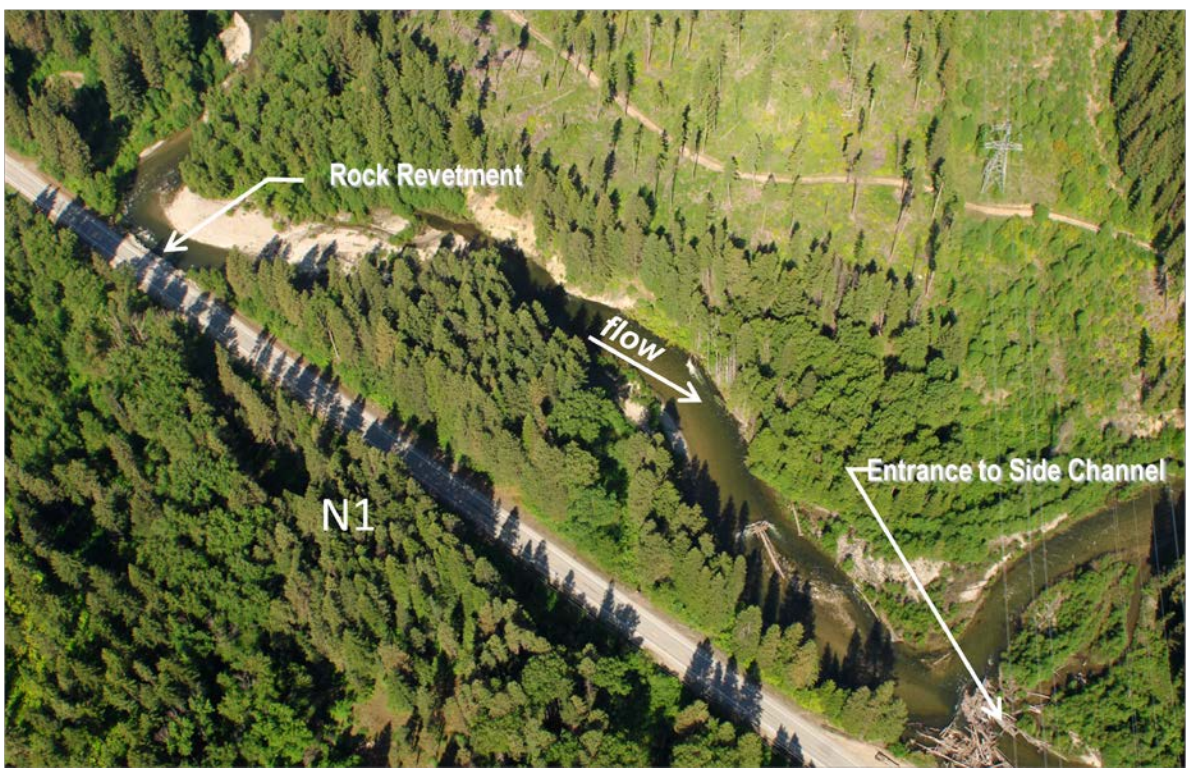

Figure 7. Upstream segment between RM 4.3 and 4.6. The N1 floodplain site is on the east side of SR 207. Image acquired June 10, 2011 (source: Bureau of Reclamation).

Historic Impacts to Geomorphic Processes

As described in the previous section, construction of SR 207 in the 1940's blocked off the historic flowpath near RM 4.0 (see 1911 channel alignment on Figure 2) and a new channel was excavated within a terrace surface on the west side of the valley. The elevation of the valley bottom to west side of SR 207 between RM 3.6 and 4.1 is generally higher than the ground on the east side of the valley. The historic floodplain did not extend across the entire valley bottom. The surface extending from the left side of the new channel between RM 3.6 and 4.1 is a terrace approximately 6 feet above the historic floodplain. Note that the terrace is not inundated by model simulations of the 100-year flood (Figure 5). The historic floodplain was approximately 400-800 feet wide and approximately 1 to 2 times the average meander amplitude as drawn on the 1911 survey and as interpreted from the relict topography. The new channel has a floodplain width of 125 feet at RM 3.6 (the channel is entrenched) and 240 feet between RM 3.8 and 3.9 where the channel has migrated laterally since the 1940's channel disturbance.

The imposed change decreased channel length and increased channel gradient by 50% creating an imbalance between sediment supply and transport capacity (capacity > supply). The stream responded by incising the upstream end of the new channel by approximately 3 feet (estimated by comparison between the existing channel profile and the design profile in the 1941 plan sheet). A vertical offset between the main channel and side channel at the downstream junction suggests that the incision observed in the main channel did not progress upstream through the side channel. Rather, the main channel shifted laterally to the north between RM 3.9 and 4.0 and the downstream 550 feet of the side channel now occupies the alignment abandoned by the main channel. Incision of the mainstem progressed upstream to a bedrock control observed in the channel near RM 4.1 (Figure 3). This bedrock control inhibits further incision and limits upstream progression of a headcut.

Wood recruited to the channel from bank erosion processes is a critical geomorphic process for creating salmonid habitat in the Nason Creek stream corridor. Historic impacts to the stream corridor have reduced wood recruitment to the channel in localized areas. Wood alters flow hydraulics, creates distinctive patterns of alluvial bed forms (Abbe and Montgomery, 1996), and affects the frequency of pools within a reach (Montgomery et al., 1995). An example of wood-induced channel complexity is shown in the side channel between RM 3.9 and 4.3 (Figure 6). Flow displacement around wood accumulations is an important trigger in development of anabranching channels (Abbe and Montgomery, 1996; Nanson and Knighton, 1996). Functional woody debris creates multiple channel anabranches (side channels) within Nason Creek. Similar complexity in the mainstem channel would benefit ecological conditions in the stream corridor. The forced relocation of the channel between RM 3.5 and 4.0 reduced the abundance of wood, relative to the historic corridor, and resulted in a channel that lacked geomorphic complexity. Incipient changes are evident in the new channel and an increase in wood recruitment has been initiated at RM 3.8. The presence of large trees on eroding terraces has been a critical factor in the formation of functional wood accumulations.

Ongoing bank erosion in response to natural wood accumulations and sediment deposits, which redirect flows, illustrate problems with the road's current configuration and underlie the chronic maintenance issues along this segment of SR 207. For example, channel migration at RM 3.9

and 4.6 eroded the floodplain buffers west of the road and the Washington State Department of Transportation responded with bank stabilization projects that protected the road with rock revetment (riprap). Channel migration is a natural process that is essential to the formation and maintenance of aquatic and riparian habitats. Riprap bank protection halts channel migration and therefore prevents potential wood recruitment from the stabilized bank and impedes habitat forming processes from occurring. Channel migration will continue to create conflicts between stream channel processes and the need to protect the road. Large wood accumulations forming within the creek will also raise water surface elevations and increase potential of flooding the road which has not been a problem historically. Maintaining SR 207 in its current alignment in a manner that does not further impact habitat recovery will require protection measures other than riprap to sustain channel complexity associated with natural wood accumulation. Further study is needed to determine if flooding could become an issue if wood is allowed to continue accumulating in the stream.

Anticipated Future Conditions for the No Action Alternative

Predictions of future conditions under the no action alternative are based on an assumption that recent trends and rates of geomorphic processes will be representative of the upcoming 20 year period. Twenty years is a relatively short period of time to assess geomorphic changes in a river; however, several flood flows with sufficient discharge to mobilize sediment and wood in the channel can be expected in this time. As such, deformation of the channel boundary and localized areas of channel migration can be anticipated (Figure 8).

The future alignment and channel pattern is expected to maintain similar geometry to existing conditions. Anticipated changes differ for the upper, middle, and lower segments of the study area and include the following channel adjustments:

- Continued downstream migration of meander bends in the upstream segment between RM 4.3 and 4.5 (adjacent to the N1 site) at a rate of about 2 feet/year, on average;
- Accelerated bank erosion at the entrance to the side channel near RM 4.3 which will threaten to damage the road; and
- Lateral migration and increases in channel complexity triggered by recent wood recruitment between RM 3.7 and 3.9 (Figure 9).

Anticipated changes to the no action alternative are expected to have little influence on the distribution and overall area of aquatic habitats in the study area. The largest changes, in terms of affected area, are expected to be downstream migration of meander bends. Such movement has no net impact on channel length, sinuosity, or the distribution of aquatic habitats but this process will eventually create a meandering and anabranching channel where the stream is currently confined in the excavated segment. As meanders move downstream, bar development on the inside bend generally matches the area of new channel created along the eroding bank. The predicted average rate of 2 feet/year is based on observations of down valley meander migration over the period 1973-2011 for the unprotected (no riprap) banks in the upstream channel segment between RM 4.3 and 4.5. The estimated migration rate approximates an average condition for the period reviewed. Actual bank erosion and channel migration rates can exceed this average in localized areas or over shorter timescales (e.g., episodic bank erosion).

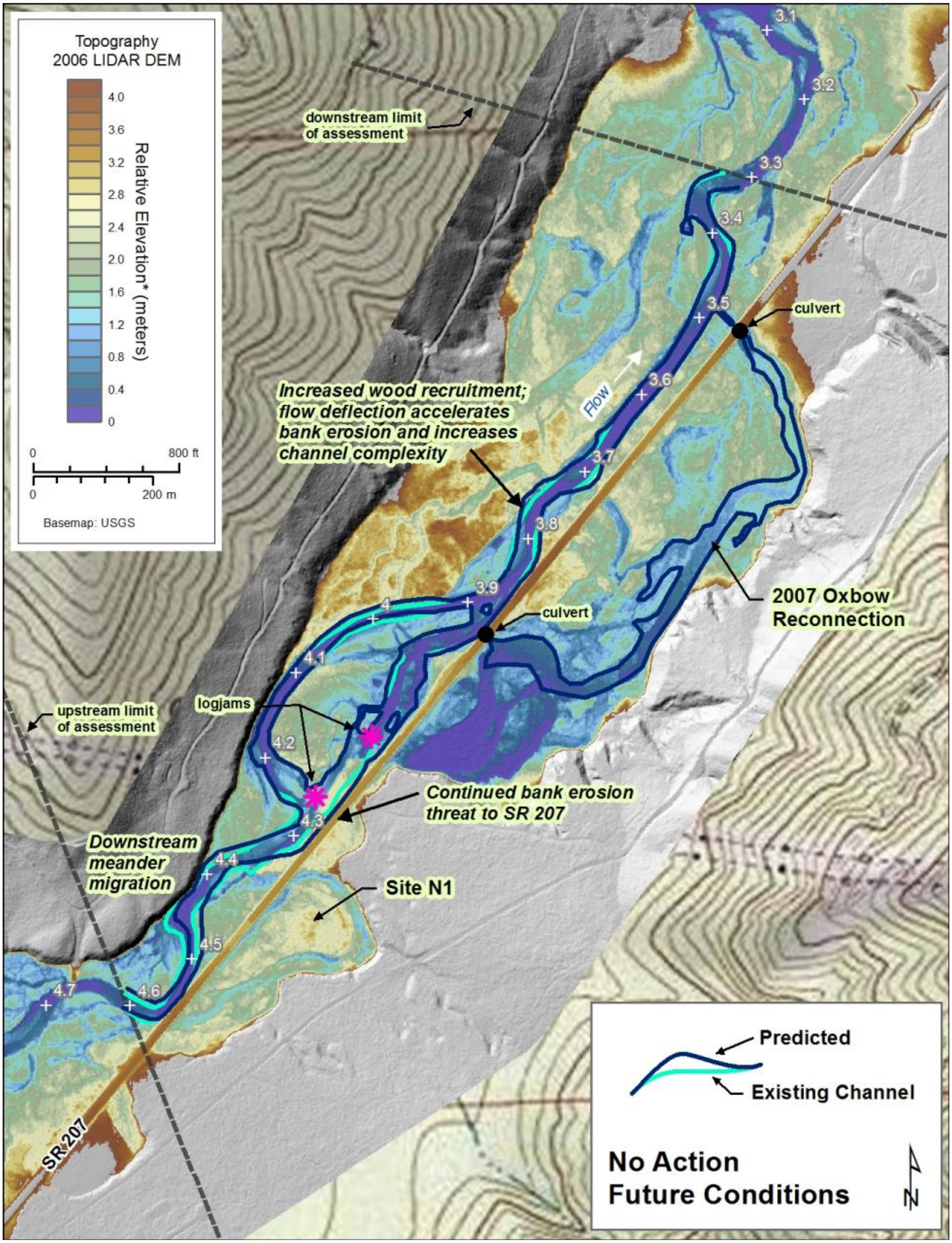

Figure 8. Anticipated channel changes in the next 20 years under the No Action alternative.

Previous discussions raised a question of whether the riprap revetment at RM 4.6 will accelerate erosion downstream along the right bank and result in a straight alignment parallel to the road. Such a result is not likely in the near future; rather, the channel is expected to maintain a geometry that approximates the existing sinuosity and pattern for the 20 year period focused on in this assessment. Evidence supporting this assertion can be seen in the meander bend downstream on the opposite (left) side of the valley where the meander was previously truncated by bedrock on the outer bend near RM 4.45. The channel has since moved along the bedrock as the meander bend migrated downstream, maintaining a sinuous path and depositing new floodplain sediments in the abandoned channel alignment. The meander geometry adjacent to the N1 site has not changed extensively from its configuration observed in an image from 1981. Additional erosion along the outer bend can be expected in the next 20 years but this should not produce a large change in the channel geometry for this segment. Beyond this 20 year period of assessment, however, the river will continue to erode the right bank downstream of the riprap revetment and the floodplain area in this confined segment will become part of the active channel over longer timescales of consideration (>100 years). There is a large element of uncertainty in the specific channel response over such time periods. Additional factors affecting the specific response over the long term include the effect of wood recruitment to the channel from bank erosion processes and the concurrent channel migration processes upstream of the meander in question. Continued erosion of the left bank upstream of the riprap revetment will eventually lead to a cutoff of the meander and reset the planform geometry of the reach.

The area of most concern for future bank erosion threats to infrastructure in the stream corridor is the right bank near the powerline crossing at RM 4.3 (Figure 10). The log jam spanning the entrance to the channel deflects flow in both directions. Flow that is directed eastward is eroding the right bank and threatens the integrity of the road. The upstream section of the bank has no vegetation or roughness elements to resist erosive forces exerted by the flow. The anticipated rate of bank erosion for this site is greater than the average presented for the segment upstream. It is anticipated that lateral migration toward the road will continue in the next 20 years and require action to prevent failure of the road embankment. It is assumed that continued movement will trigger stabilization of the right bank to protect the road. Bank stabilization of this section should be designed with elements that minimize impacts to natural river processes by incorporating roughness elements that deflect flow away from the road. It is important that the log jam downstream of the channel entrance remains intact to maintain stability of the reach. The log jam functions as grade control for the reach and contributes to the formation and maintenance of aquatic habitats.

The most important factor affecting the anticipated future conditions for the no action alternative is the role of large wood accumulations in the stream corridor. Recent accumulations of wood near RM 3.8 give an example of developing channel complexity within the entrenched segment (Figures 9 and 10). The channel segment between RM 3.5 and 4.0 was constructed in the 1940's and has been adjusting over time to the imposed condition. Lateral changes happened rapidly between RM 3.9 and 4.0 (in concert with vertical channel change); however, much of the altered segment has remained fixed in an entrenched channel with little geomorphic or aquatic habitat complexity. A relatively recent (< 10 years) accumulation of two logs oriented parallel to the stream alignment (with rootwads facing upstream) deflect flow laterally towards the channel boundary. Accelerated erosion undercut the left bank and caused two trees to fall across the channel between the years 2006 and 2011. The channel has responded with a localized increase in channel complexity and formation of pool habitat which was not likely to be present in this segment previously (Figure 9). The existing wood pieces are expected to trap additional woody materials and increase the size of the log jam similar to what has occurred near RM 4.3 (Figure 10). The log jam will continue to deflect flow and deform the channel boundary. As such, the recent wood recruitment will generate positive feedback leading to further bank erosion and therefore additional wood recruitment to the channel. Ultimately, channel migration processes will lead to development of new floodplain in areas that are presently upland habitats (terrace). Wood accumulations over time will increase water surface elevation and influence vertical fluctuations of the streambed which increase potential for the channel to avulse and/or migrate laterally across the floodplain (Brummer et al., 2006).

Anticipated changes will lead to increased channel complexity in the straight, channelized segment from RM 3.5 to 3.8. Review of historical trends, however, show that such change is occurring relatively slowly. A slight increase in channel complexity is anticipated in the 20 year period covered by this prediction. Bank erosion around the area of anticipated wood recruitment will produce small increases in channel sinuosity, length, and area (similar to recent changes observed at RM 3.8). However, the river will require a much longer time period to develop extensive increases in channel complexity within the affected area.

Figure 9. Recent wood recruitment and developing channel complexity near RM 3.8. Image acquired June 10, 2011 (source: Bureau of Reclamation).

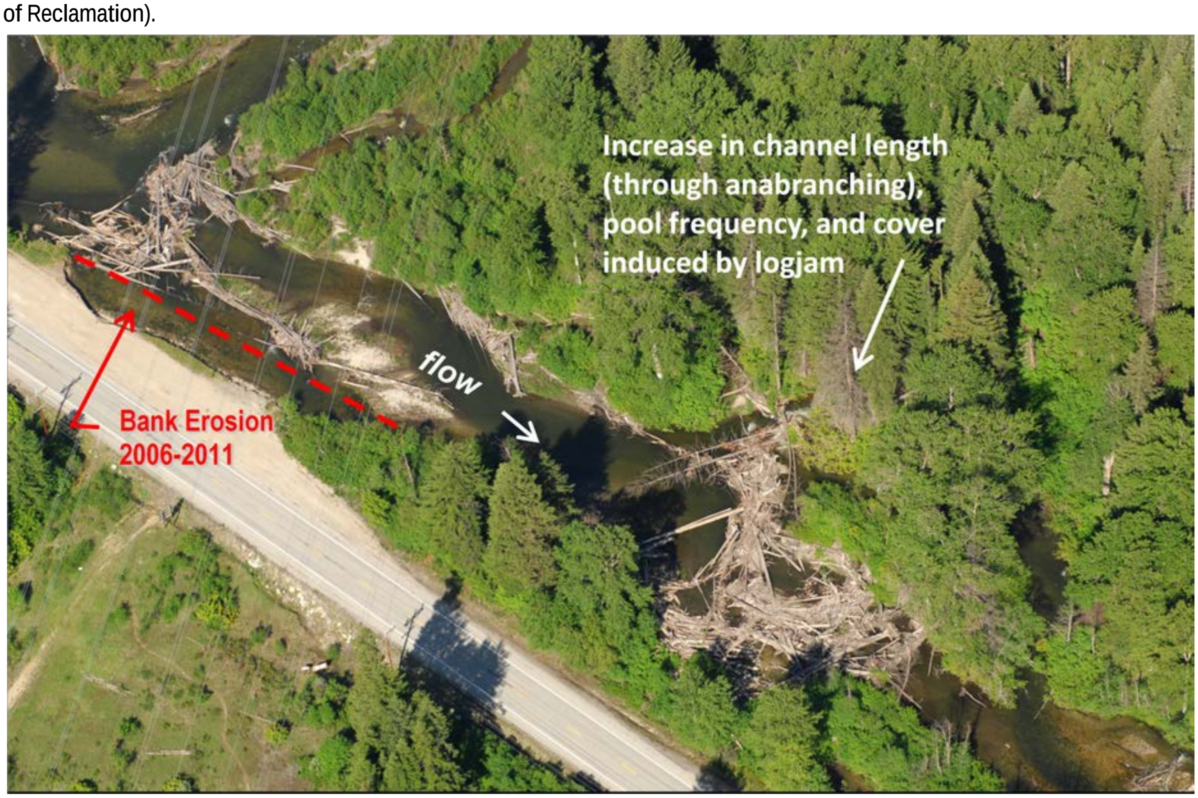

Figure 10. Channel migration at the upstream end of the side channel (near RM 4.3) has eroded the right bank and poses a threat to the adjacent road. Wood accumulations deflect flow laterally but are an important grade control and a key component to formation of channel complexity and maintenance of aquatic habitat. Image acquired June 10, 2011 (source: Bureau of Reclamation).

Anticipated Future Conditions for the SR 207 Relocation Alternative

The SR 207 relocation alternative proposes to remove the entire road out of the valley bottom and construct a new road on higher ground to the east. At the upstream end of the assessment segment, this will have an immediate effect on the channel as the stream is currently flowing against a rock revetment along the road. Given the river's impingement along SR 207 at RM 4.5 to 4.6, disturbance associated with road removal (lack of vegetation, disturbed soils), and the added shear created by the steep angle of the meander bend, removal of the road and revetment will induce rapid bank erosion. The rate of channel migration will decrease as the meander establishes a geometry that aligns more closely with the segment upstream (Figure 11). The meander apex is predicted to move approximately 160 feet laterally towards site N1. The floodplain channel at N1 will be only engaged at high flow for a few days per year. During these flows the depth will be shallow and velocity low. Hydraulic model simulations by ICF (2011) show predicted depths of 1 to 2 feet in the channel for a flood with a recurrence interval of 2 years. As such, the floodplain channel will continue to trap more sediment and gradually fill in over time.

The predicted channel morphology downstream of the N1 site to approximately RM 3.9 is not substantially different from that expected under the no action alternative. Some lateral channel migration is expected at meander bends with a predicted average rate of about 2 feet/year. In general, accumulation of gravel on point bar surfaces matches the area eroded on cut-bank surfaces resulting in no net gain of aquatic habitat. Some increase in the extent of aquatic habitat is expected in locations where functional wood enters the channel.

Flow deflected by the log jam at RM 4.3 is expected to produce additional bank erosion and lateral migration toward the right bank. Previous discussion of the no action alternative described the likely necessity to arrest bank erosion at this location as part of future highway protection measures. The SR 207 relocation alternative eliminates this need. Given the flow deflection generated by a developing log jam at the side channel entrance, anticipated channel migration is estimated at 4 ft/year, on average (the highest average rate observed in historic record). The expected response is that the channel will migrate easterly at RM 4.3 and increase the sinuosity and length of the side channel. Such migration will increase aquatic habitat as the wood accumulating in the side channel is expected to trap additional wood and maintain an anabranching channel pattern.

Removal of SR 207 in the vicinity of the side channel downstream of the powerline crossing at RM 4.3 will reestablish connectivity to the area of low ground on the east side of the valley. The proposed change will create an opportunity for this side channel to avulse into the former channel east of SR 207 upstream of the existing culvert near RM 3.9 (Figure 11). This channel change is anticipated in the future; however, the timing of such an event is uncertain and will be affected by the project design and resulting configuration of the SR 207 removal project. The anticipated alignment presented in Figure 11 does not place the channel into this avulsion pathway for this 20 year prediction; however, such an event is possible. The assumption in Figure 11 is that erosion of the right bank adjacent to the upstream log jam (RM 4.3) will initiate flow towards the lower log jam such that a larger proportion of flow is deflected towards the left bank of the existing side channel. This assumption could change due to additional wood accumulation or different bank erosion scenarios upstream. There is uncertainty as to the final configuration of the side channel associated with what design elements are included as part of the road removal effort.

Increasing flow through the historic stream corridor by an order of magnitude (from 10% to 100%) is expected to restore dynamic fluvial processes and accelerate development of channel complexity. Increased coarse sediment supply from upstream will enhance bar development and channel migration. Increased stream power and sediment transport capacity will flush fine-grained sediments, enhancing spawning habitat, and redistribute bedload material to form new alluvial bars. The existing floodplain has multiple secondary channels that will become engaged more frequently under the restored flow regime (increased discharge). The predicted channel evolution in the reconnected channel segment includes development of an anabranching channel pattern and results in an increase in the habitat complexity and suitability for juvenile and adult salmon.

Anticipated channel changes downstream of RM 4.0 are highly dependent on the design of the connection between the existing channel and the historic alignment to be reconnected. The historic alignment presently receives approximately 10% of the total flow via the culvert installed as part of the 2007 Oxbow Reconnection Project. Detailed design of the proposed connection has not begun; however, it is assumed that the objectives of the SR 207 relocation alternative will include restoration of dynamic fluvial processes within the historic stream corridor. Such changes will require that additional flow be directed into the historic corridor and necessitate channel modifications at the junction near RM 3.9. Maintaining open connections to both channels presents a design challenge in that the existing alignment has a steeper gradient and could recapture the flow. The avulsion risk (towards the excavated channel path) could be reduced by loading the existing channel with large wood to roughen the channel boundary, reduce velocity, and increase the proportion of the total flow entering the historic stream corridor on the east side of the valley. Using wood to plug the existing channel with a permeable structure would have an added advantage of converting the existing primary channel into secondary channel habitat. Alternatively, the existing channel could be completely plugged at the upstream end to deflect all flows into the historic stream corridor. Coordination with ICF for the biological assessment developed an assumption that the SR 207 relocation alternative will be assessed with the assumption that all flow is deflected into the historic flowpath. As such, anticipated channel changes shown in Figure 11 assume that the existing channel is completely plugged at RM 3.9. Note that this assumption has an important effect of reducing the spatial extent of channel habitats by not utilizing the excavated channel path (existing main channel) as secondary channel.

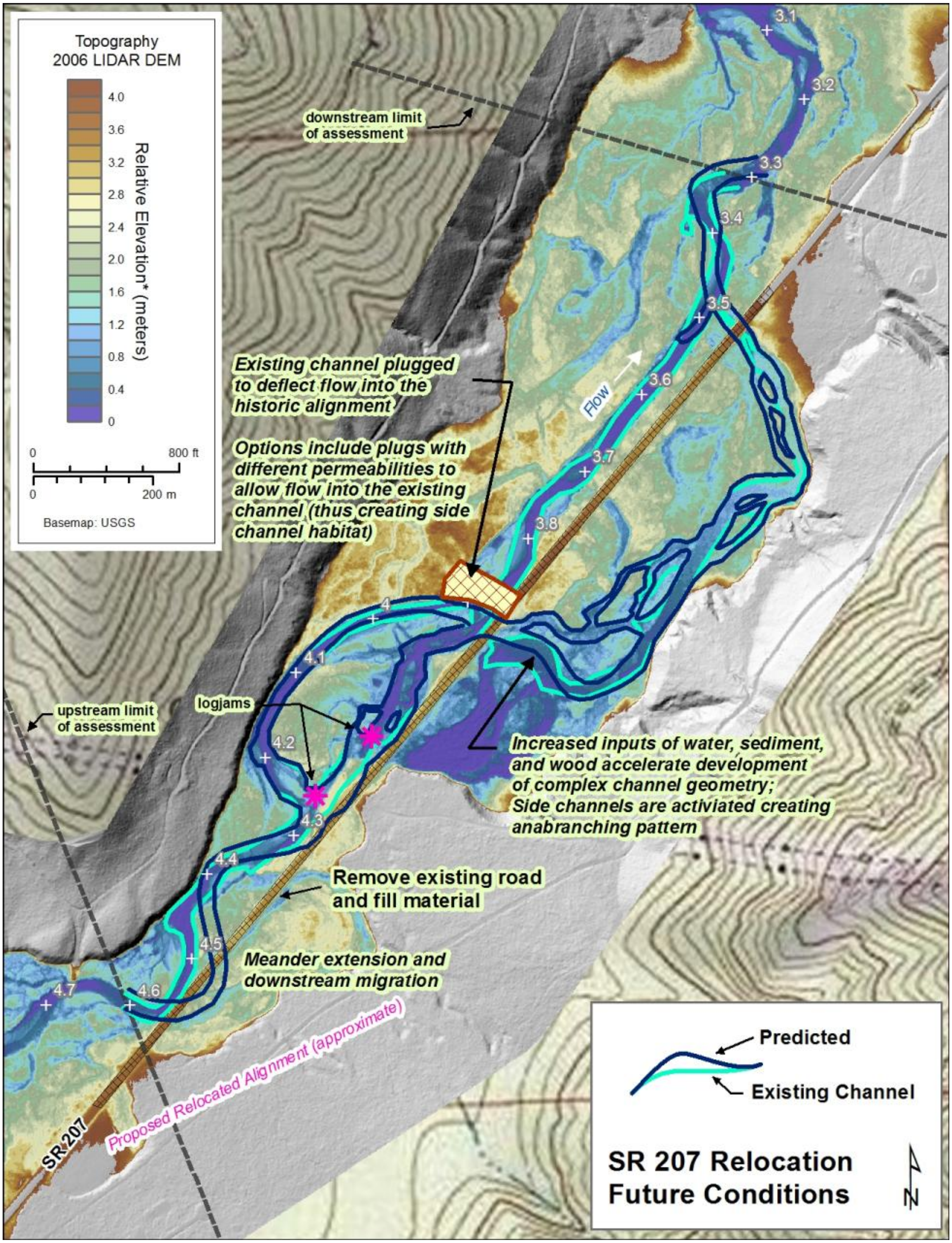

Figure 11. Anticipated channel changes in the next 20 years under the proposed SR 207 relocation alternative.

Predicted Change in Channel Length, Wetted Area, and Habitat Distribution

Estimates of the anticipated change in channel characteristics are assessed for the study area based on the assessment of existing geomorphic conditions and historical channel changes. Predictions focus on the future condition 20 years from the present. Note that the future is uncertain and that predictions of channel change presented here are intended to forecast anticipated conditions based on the best information available. Anticipated changes in channel length are presented in Table 1. The anticipated channel conditions were further evaluated to assess predicted changes in wetted channel area and habitat. Wetted areas of the river channel for three flow conditions (69 cfs, 250 cfs, and 1000 cfs) were tabulated by ICF. Adjustments to these values accounting for anticipated changes are summarized in Tables 2 and 3 for the summer baseflow (69 cfs) and typical spring runoff (1000 cfs) conditions, respectively.

Little change is anticipated in the next 20 years under the no action alternative. The changes that are expected include some additional bank erosion in the channelized segment which will increase sinuosity slightly (Table 1). Additional wood recruitment can be expected to increase pool frequency in the study area; however, the total pool area may not change relative to the existing distribution. The spatial extent of primary and secondary habitat in the study area is expected to stay relatively constant (predicted to increase by approximately 1%) for the no action alternative (Tables 2 and 3). The anticipated changes for the no action alternative have little impact on the overall distribution of habitat units within the reach. Note that options to add stable wood or excavate new flow paths into existing terrace areas (particularly near RM 3.4 to 3.8) could have a large impact on the area and distribution of habitat types without moving SR 207.

The SR 207 relocation alternative has a larger impact on channel length and wetted area. The primary channel length is predicted to increase by 25% for the study area (Table 1). Locally, the difference is greater as redirecting the primary channel into the historic alignment will lengthen the channel by 65% between RM 3.4 and 3.9 (Figure 11). The area of primary channel habitat in the study area is predicted to increase by 35% relative to existing conditions due to the additional length and sinuosity of the historic flowpath into which flow will be directed. Predictions of the anticipated change in habitat distributions account for expected morphologic changes in response to the reactivation of the historic channel. The estimates in Tables 2 and 3 assume that the relative proportion of riffle habitat for the primary channel will decrease and that other habitat types (i.e., run, pool, and tailout) will increase slightly in relative proportion. Both scenarios considered for the SR 207 relocation alternative are expected to increase the total wetted area of aquatic habitat. It is important to note that the east side of the valley is generally characterized by lower elevations than the terrain bordering the channelized segment on the west side. As such, increasing flow into the historic alignment can be expected to increase connectivity to secondary channels and off-channel wetlands.

Conversion of existing habitat in the 2007 Oxbow Reconnection project area from secondary channel to primary channel habitat has a large impact on results presented in Tables 2 and 3. It is assumed that new side channels formed adjacent to the historic channel alignment will cover a smaller wetted area compared to the existing side channel. New side channels created by increasing the flow along the east side of the valley will likely be narrower than the wide, shallow channel which presently exists. The additional side channels are expected to have greater interaction with large wood accumulations and a higher pool frequency as a result. The increased frequency will provide a more complex spatial distribution; however, the overall area is expected to maintain a similar proportion of the total shown in ICF's data for existing conditions (Figure 2). As such, the distribution of habitat types is not adjusted for secondary channels under the SR 207 relocation alternative.

The SR 207 removal alternative that assumes a complete plug in the existing channel at RM 3.9 results in a 1% increase for the combined wetted area of primary and secondary channel habitats. This result implies an approximate balance between the additional area of primary channel habitat gained by lengthening the reach and the net reduction of side channel habitat that results by eliminating the split flow situation. The scenario which removes SR 207 but maintains a split flow at RM 3.9 will partially offset some of the loss to secondary channel habitat and could also increase the wetted area of the combined primary and secondary channel habitats when accounting for increases to the channel area of upstream segments. There is potential for additional side channel habitat under the SR 207 relocation alternative if the project is designed to maintain flow through the existing alignment or engage additional floodplain channels. Such design components could utilize installations of large woody material to roughen the channel boundary and increase water surface elevations; thus engaging the channels at higher elevations on the floodplain.

Table 1. Predicted changes in channel length for a future condition forecasted in 20 years.

	Existing Conditions	No Action	SR 207 Removal	
			Plug Existing Channel	Maintain Partial Flow to Existing Channel
Primary Channel	6,828	7,028	8,502	8,502
Secondary Channel	7,159	7,209	6,244	8.493
Total	13,987	14,237	14,746	16,995

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Table 2. Anticipated changes to the area of aquatic habitat for high flow estimated for typical spring runoff (1000 cfs). Existing habitat area and distribution provided by ICF. Anticipated changes are based on predictions of anticipated channel change over a 20 year period.

	Existing Condition	Predicted Future Condition in 20 years					
		No Action		SR 207 Removal			
				Plug Existing Channel		Maintain Partial Flow to Existing Channel	
	Area (m^2)	Area (m^2)	Net Change	Area (m^2)	Net Change	Area (m^2)	Net Change
Primary Channel Units							
Rapid	789	789	0%	789	0%	789	0%
Riffle	27,194	27,679	2%	34,790	28%	34,790	28%
Run	6,101	6,209	2%	9,353	53%	9,353	53%
Pool	8,958	9,117	2%	13,733	53%	13,733	53%
Tailout	1,851	1,884	2%	2,838	53%	2,838	53%
Backwater	716	728	2%	985	38%	985	38%
Total Primary Channel	45,608	46,408	2%	61,508	35%	61,508	35%
Secondary Channel Units							
Riffle	12,520	12,637	1%	8,128	-35%	11,198	-11%
Run	15,870	16,018	1%	10,302	-35%	14,194	-11%
Pool	10,856	10,957	1%	7,047	-35%	9,710	-11%
Tailout	857	865	1%	557	-35%	767	-11%
Backwater	1,768	1,785	1%	1,148	-35%	1,581	-11%
Total Secondary Channels	41,872	42,262	1%	**27,182**	**-35%**	**37,451**	**-11%**
Total Combined Primary and Secondary Channels	87,479	88,669	1%	**88,689**	**1%**	**98,958**	**13%**
Off-Channel Units							
Floodplain Channel	7,115	7,115	0%	11,165	57%	11,165	57%
Wetland	8,374	8,374	0%	28,374	239%	28,374	239%
Total Off-Channel	15,489	15,489	0%	39,539	155%	39,539	155%
Total Aquatic Habitat	102,969	104,159	1%	**128,229**	**25%**	**138,498**	**35%**

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Table 3. Anticipated changes to the area of aquatic habitat for low flow conditions estimated for summer baseflow (69 cfs). Existing habitat area and distribution provided by ICF. Anticipated changes are based on predictions of anticipated channel change over a 20 year period.

	Existing Condition	Predicted Future Condition in 20 years					
		No Action		SR 207 Removal			
				Plug Existing Channel		Maintain Partial Flow to Existing Channel	
	Area (m^2)	Area (m^2)	Net Change	Area (m^2)	Net Change	Area (m^2)	Net Change
Primary Channel Units							
Rapid	513	513	0%	513	0%	513	0%
Riffle	14,367	14,623	2%	18,380	28%	18,380	28%
Run	5,576	5,676	2%	8,549	53%	8,549	53%
Pool	7,418	7,550	2%	11,373	53%	11,373	53%
Tailout	1,572	1,601	2%	2,411	53%	2,411	53%
Backwater	189	193	2%	261	38%	261	38%
Total Primary Channel	29,636	30,156	2%	41,486	40%	41,486	40%
Secondary Channel Units							
Riffle	7543.68	7,614	1%	4,897	-35%	6,747	-11%
Run	11600.09	11,708	1%	7,530	-35%	10,375	-11%
Pool	7599.52	7,670	1%	4,933	-35%	6,797	-11%
Tailout	334.84	338	1%	217	-35%	299	-11%
Backwater	0	0	0%	0	0%	0	0%
Total Secondary Channels	27,078	27,330	1%	17,578	-35%	24,219	-11%
Total Combined Primary and Secondary Channels	56,714	57,486	1%	59,064	4%	65,705	16%
Off-Channel Units							
Floodplain Channel	0	0	0%	0	0%	0	0
Wetland	0	0	0%	0	0%	0	0
Total Off-Channel	0	0	0%	0	0%	0	0
Total Aquatic Habitat	56,714	57,486	1%	59,064	4%	65,705	16%

Conclusion

This geomorphic assessment interprets the anticipated future conditions for the no action and SR 207 relocation alternatives associated with the N1 Floodplain Reconnection Project. While it is clear that relocating SR 207 out of the floodplain is most beneficial to the long term ecological condition of Nason Creek, the relative changes in channel morphology and habitat area need to be quantified in order to evaluate the project benefits relative to the costs. The 2007 Oxbow Reconnection Project had a significant positive effect on the project reach by increasing the extent of secondary channel habitat. Combining this reconnected area with the new channel excavated as part of the 1940's road construction project yields a greater length and area of channel (combined primary and secondary) than existed before the 1940's modifications.

The scope of this investigation focused on predicting the near term geomorphic response within a 20 year time period. Within this period, the expected changes under the no action alternative produce a small increase in aquatic habitat associated with accelerated bank erosion and channel expansion around recent wood recruitment and developing log jams. Note that predicted channel migration under the no action alternative is expected to necessitate additional bank protection along the road where the bank is failing near the entrance to the side channel at RM 4.3 (Figure 10). Bank protection methods could either improve or degrade habitat conditions depending on the approach. Additional rock revetments along the road would negatively impact habitat. Bank protection utilizing complex wood structures can improve conditions by supporting natural fluvial processes which increase channel complexity and habitat diversity.

The expected response to both alternatives involves a relatively modest adjustment of geomorphic characteristics. The channel has the capacity to adjust its alignment and pattern by sediment transport, erosion, and deposition; however, general rates of channel change have not been extreme in the recent period reviewed (1966-present). Channel incision, estimated as approximately 3 feet, generated a relatively rapid response near RM 3.9 following forced relocation of the stream into a straightened channelized alignment parallel to the road. Observed changes in the historic record appear to be episodic in nature and generally attributed to either: (1) flow deflections around large wood accumulations in the channel; or (2) bank erosion where the meander bend creates a relatively steep angle and increases shear along the bank toe on the outer bend. Continued channel migration is expected but predicted to continue at a relatively modest rate. Wood accumulation will continue and the net result will be improvement to habitat conditions by aggrading the channel, raising water surface elevations, triggering bank erosion in localized areas, and increasing connectivity to side channel habitats.

A key finding of the present study is that there are multiple opportunities to improve both habitat conditions and road protection by strategic placement of wood structures. Large wood accumulations add roughness to the channel boundary, reduce velocity, increase water surface elevation and create distinctive patterns of alluvial bedforms which generally increase the complexity of the channel. Adding wood to select locations can increase water surface elevations by 0.5-1.0 meter and dramatically influence the spatial extent of side channel habitats under both alternatives. General reconnaissance of the study area and review of LIDAR based topographic data suggests that the extent of side channel habitat could be increased by as much as 50% compared to existing conditions by adding wood in strategic placements and limited grading of floodplain surfaces. The increase could be greater than the amount of side channel habitat expected under the SR 207 relocation alternative given that the majority of existing side channel habitat will be converted to primary channel.

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