Memorandum

Rio ASE 2601 W. Woodlawn Ave., Boise, Idaho 83702, Telephone: 208-559-4615

TO:	HANS SMITH, YAKAMA NATION FISHERIES
FROM:	ROB RICHARDSON
DATE:	OCTOBER 10, 2016
FILE:	006-051-001-01
SUBJECT:	WAR CREEK RESTORATION DESIGN: DRAFT CONCEPT REPORT

Rio ASE has prepared a DRAFT concept for the War Creek Project Area on the Twisp River for review by the Yakama Nation Fisheries and its partners. Attached below are the following components of the DRAFT concept:

- Summary of our technical findings to-date (based on background data review, field observations, hydrology, hydraulics, and geomorphic analyses). This includes a summary of observed problem areas where we believe treatment should be focused and observed areas of existing high-quality habitat that we believe should be left untouched.
- Simplistic "cartoon" plan-view of the proposed concept overlaying the 2-yr flood depth output grid from our existing conditions 1-D HEC RAS hydraulic model. A LiDAR hillshade has also been added to provide topographic detail on the floodplain.
- Written summary of the proposed treatments and treatment objectives (individually and grouped into suites based on interdependencies). Rationale is provided for each structure type/suite.
- Not provided with the DRAFT concept: construction drawings, access routes, construction techniques, materials list, cost estimates, water management plans, planting plans. These additional design components will be added during preliminary and final design phases once the concepts have been approved.

BACKGROUND INFORMATION

Previously Reported Results

- Inter-Fluve's 2015 Reach Assessment identifies the War Creek Bridge as one of the primary human impacts within the project reach. Coarse reach-scale hydraulic modeling from the Reach Assessment suggests the bridge and its associated road fill restricts floodplain interaction and floodwater conveyance at flows greater than the 2-year recurrence interval.
- Reach-scale hydraulic modeling from Inter-Fluve's 2007 Reach Assessment suggests floodplain connection is restricted at all discharges (2-year through 100-year recurrence interval) within the majority of the reach, but especially restricted within the straight section between War Creek and Eagle Creek.
- Previous reports (Inter-Fluve's 2015 Reach Assessment and Reclamation's 2007 Geomorphic Assessment) briefly identified the lack of sinuosity within the project reach, but did not provide explanation or discussion regarding historic sinuosity or the channel response resulting from recent reductions in sinuosity.
- Two documented historic avulsions have occurred within the project area. The first occurred near the War Creek Campground probably as a result of the 1972 flood, and the second more recent avulsion occurred immediately downstream of Eagle Creek in 2012. Ongoing avulsion dynamics and instability were recognized in the Inter-Fluve Reach Assessment, but not discussed in any detail.
- Channel restoration potential for the project area (Reach 6) was identified as "Moderate" in Inter-Fluve's 2015 Reach Assessment. The proposed restoration strategy included whole tree placement and addressing impacts associated with the War Creek Bridge, lack of in-stream complexity, and potential off-channel enhancement opportunities.

SUMMARY OF TECHNICAL FINDINGS TO DATE

Conclusions

- Field evidence and hydraulic modeling suggest the channel is further incised than previously realized (as much as 3 feet). Large channel obstruction and/or significant increases in channel length (greater sinuosity) are required to overcome the incision.
- Field observations and survey/LiDAR topography suggest the channel's geomorphic response potential is high. Where present, existing structures were observed to force flow convergence, form pools, and sort sediment. Large suites of structures appear to have a larger influence promoting up-stream deposition and plan-form channel response.
- The existing bridge and bridge approach road fill do not appear to have a significant influence on channel or floodplain hydraulics. We recommend postponing any alteration to the bridge or approach road fill until after such time that the primary channel restoration effort has had several years to observe the response. If, in the future, the project is successful in increasing the floodplain connection, a strategic culvert (or similar treatment) may then be warranted for the bridge approach road fill.
- The proposed concept provides a short-term and long-term approach. Over the short-term, log structures will be used to improve hydraulic and habitat complexity in areas currently lacking such complexity. As observed, small and large log structures were capable of exhibiting a favorable geomorphic response resulting in improved habitat conditions. These structures will also be individually placed and collectively grouped to evoke a long-term response by forcing strategic scour and deposition to encourage increased reach-scale deposition and lateral channel migration to begin to overcome years of incision.

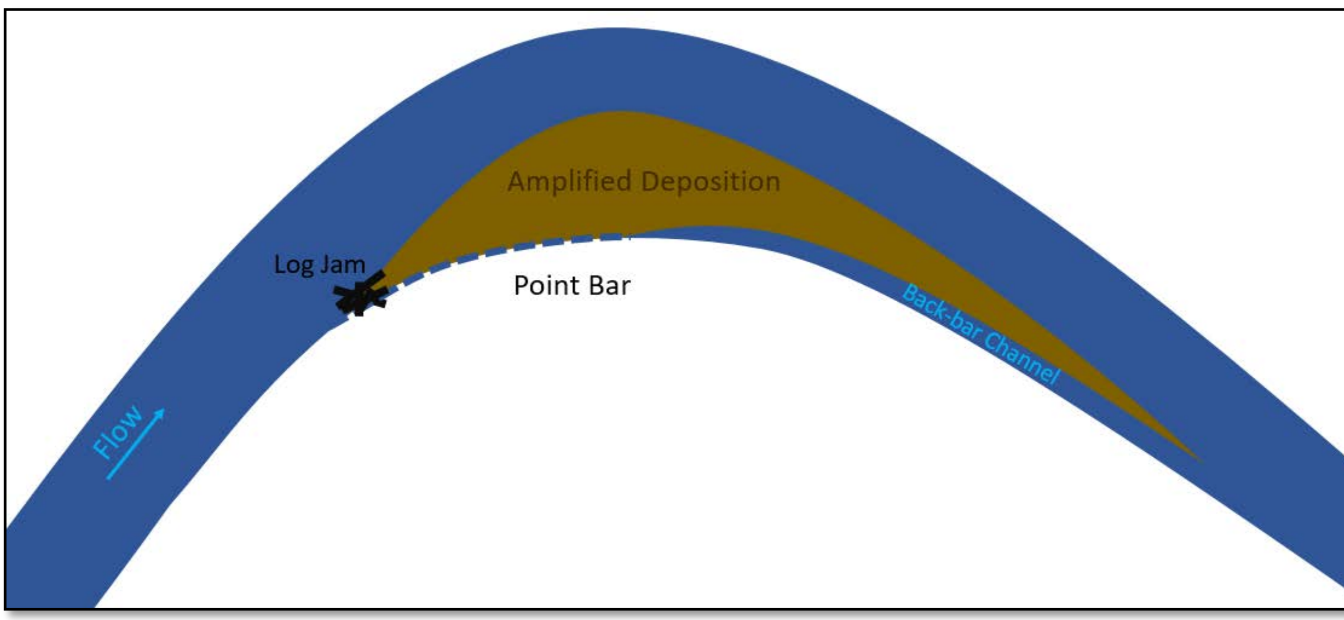
Field observations

- Several existing log structures reveal excellent channel response resulting in localized scour and deposition. Scour is a result of channel constriction and/or pressure flow beneath the log/structure. Deposition generally occurred immediately downstream of and within the hydraulic shadow (lee) of the structure.
- Many point bars exhibit back-bar channels. Sediment appears to deposit primarily on the outside (distal) end of the bar, leaving a lower-elevation along the bank that often expresses small amounts of surface water or hyporheic flow (Figure 1a and 1b). When log jams are located near their upstream end of a point bar, the deposition and back-bar channel formation appears to be amplified (Figure 1b and 1c below).

Figure 1a: Image illustrating a representative back-bar channel (left channel as seen in the photo) at the confluence with War Creek and the main-stem Twisp River. Deposition on the point bar was concentrated toward the outside (distal) end of the bar, resulting in a relative low area near the bank that receives ephemeral surface and perennial hyporheic flow. The photo is taken looking upstream.

Figure 1b: Image illustrating a representative back-bar channel (right channel as seen in the photo) located immediately upstream of the straight subreach. Deposition on the outside edge of the bar has been enhanced by large woody material (some of which can be seen in the photo) resulting in a relatively low area and associated channel near the bank that receives ephemeral surface and perennial hyporheic flow. The photo is taken looking upstream.

Figure 1c: Cartoon illustrating enhanced point bar deposition behind a log jam near the outside (distal) edge of the bar leaving a relatively low-elevation trough occupied by a back-bar channel with ephemeral surface and perennial hyporheic flow.



- Where several log jams were observed in close proximity, the area within and upstream of the log jams appeared to exhibit greater deposition and associated response than areas without a dense volume of large woody debris. It is assumed that the added friction of the multiple log jams decreases sediment transport competency resulting in an enhanced response character.

- Much of the area upstream of the War Creek bridge and a highly sinuous S-curve about 1500-feet downstream of the bridge exhibit relatively dense woody debris loading, highly complex hydraulic conditions, deep pools, significant cover, and actively eroding banks.
- A well-defined, groundwater-fed side channel (alcove) was observed on the left bank immediately upstream of the War Creek bridge. A similar groundwater-fed side channel was observed on the left bank near the upstream end of the "straight" sub-reach. The upper portion of both side channels was dry (July 2016). The lower portion of both side channels was wetted with groundwater observed to be colder than the main-stem Twisp River.
- The high-water mark on the War Creek bridge abutments was observed to be roughly 3-feet higher than the adjacent observed vegetation line (ordinary high water mark or the roughly 1.5-year recurrence interval flood elevation) (Figure 2). The large difference between the high-water mark and the ordinary high water mark suggests the potential for incision.

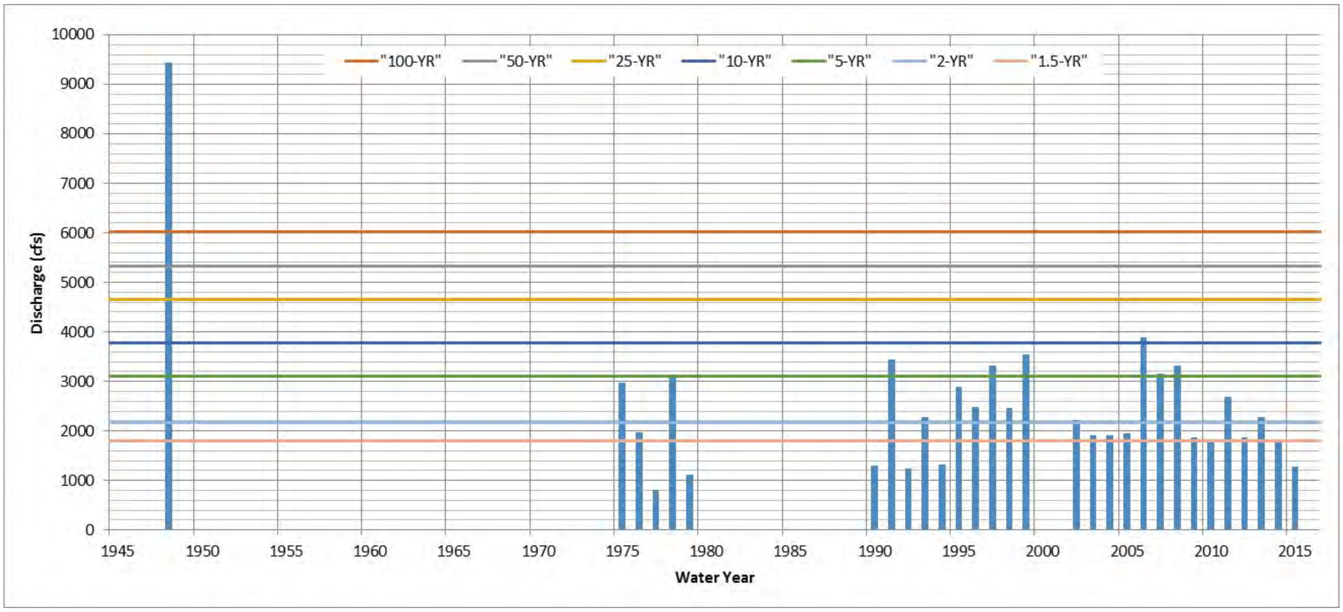
Figure 2: Image illustrating the marked high-flow line on the left bridge abutment and vegetation line marking the ordinary high water mark about 3-feet lower. The large difference between the two elevations suggests the possibility of incision.

- Bed material was measured via Wolman pebble counts at four locations (and many more photo points). Average grain sizes include a roughly 82mm d_{50} and 152mm d_{84} from point bars, and a roughly 108mm d_{50} and 197mm d_{84} from riffles. Significant armoring was observed at the toe of the Eagle Creek alluvial fan (less so at War Creek) consisting of large boulders presumably deposited by ancient debris flows through glacial drift containing well-rounded boulders.
- War Creek flows into a broad back-bar side channel at its confluence with the Twisp River. The temperature was notably colder in the War Creek portion of the back-bar channel versus the main-stem Twisp River (in July). The back-bar channel itself is shallow and broad with minimal cover and hydraulic complexity.
- The "straight sub-reach" originates at the toe of the Eagle Creek alluvial fan and is heavily armored with large boulders (2-4-foot diameter). The banks are vegetated with mature (old-growth) forest consisting of Douglas fir, spruce, and cedar. The channel exhibits no defined thalweg in the upper half of the straight reach, and a clearly defined sinuous thalweg in the lower half.
- The most recent avulsion site near the downstream end of the project area has filled with several feet of gravel and cobble deposition upstream of a large, channel-spanning log jam. The newly formed avulsion channel is rapidly evolving as apparent from observed bank erosion, recently recruited whole-trees in the channel, and areas of relatively narrow channel geometry suggesting minimal response time (i.e.: recent secondary avulsion). The area is highly dynamic and complex, and likely to continue evolving rapidly for several more years.

Hydrology

The War Creek project site on the Twisp River encompasses approximately 124 square miles of the Twisp watershed from 2,360 ft up to 8,770 ft at the headwaters. The average annual precipitation for this basin is approximately 48 inches (USGS, 2016). The closest long term stream gaging stating is maintained by the United States Geological Survey (USGS) and has been in operation on and off from 1974 to the present time (October 2016). This gage (USGS Gage 12448998) has 30 years of annual instantaneous peak flow data and 29 years of continuous daily average discharge data. The peak flows for this site were analyzed using the USGS PeakFQ computer program following methodologies described the USGS Bulletin 17B (USGS, 1981). Figure 3 shows the results of this flood frequency analysis compared to the measured instantaneous annual flows at the USGS gage. As previously described within the Middle Twisp Reach Assessment peak flows typically occur from snowmelt dominated runoff peaking in May and June (IFI, 2008).

Figure 3. Annual Peak Floods of Record Compared to Flood Frequency Recurrence Intervals for USGS Gage 12448998.



These peak flow recurrence interval discharges were then reduced using two regression equations described with the United States Bureau of Reclamation's (USBR) Methow Subbasin Geomorphic Assessment (USBR 2010). The project area was broken down into three sections; the downstream limits, upstream of Eagle Creek, and upstream of War Creek. Table 1 displays the approximate basin area of each of these basins (USGS, 2016). The flood frequency results of these regression equations for each of these watersheds can be seen in Table 2.

Table 1. Basin Areas of Project Watersheds.

Basin Description	Basin Area (mi^2)
Upstream of War Creek	77.7
Upstream of Eagle Creek	105.3
Downstream Limits of Project	120.2

Table 2. Flood Frequency Discharge Estimates at Various Annual Return Intervals.

Recurrence Interval (years)	Annual Exceedance Probability	USGS Gage (cfs)	Downstream Site Limits (cfs)	Upstream of Eagle Creek (cfs)	Upstream of War Creek (cfs)
1.005	0.995	739	321	282	209
1.010	0.990	818	358	315	233
1.05	0.950	1081	483	424	314
1.11	0.900	1257	567	498	369
1.25	0.800	1512	690	606	449
1.5	0.667	1798	845	743	550
2	0.500	2161	1007	885	655
2.33	0.429	2333	1092	959	710
5	0.200	3111	1478	1299	962
10	0.100	3774	1810	1590	1178
25	0.040	4647	2249	1976	1463
50	0.020	5322	2591	2276	1685
100	0.010	6016	2943	2585	1914
200	0.005	6735	3309	2906	2152
500	0.002	7729	3815	3351	2482

Rio ASE developed regression equations to approximate low flow and fish passage discharges at the project location based on historic daily discharge values on multiple historic stream gages on the Twisp river and the upper Methow River. This analysis utilized the 29 years of continuous discharge record at the Twisp gage and reduced the daily annual exceedance discharge values based on basin area relationships. The 5%, 50% and 95% daily annual exceedance discharges for each project site basin is shown in Table 3.

Table 3. Annual Exceedance Fish Passage Design Flows for Project Areas.

Basin Description	5% Exceedance (cfs)	50% Exceedance (cfs)	95% Exceedance (cfs)
Upstream of War Creek	368	36	15
Upstream of Eagle Creek	495	46	18
Downstream Limits of Project	563	51	20

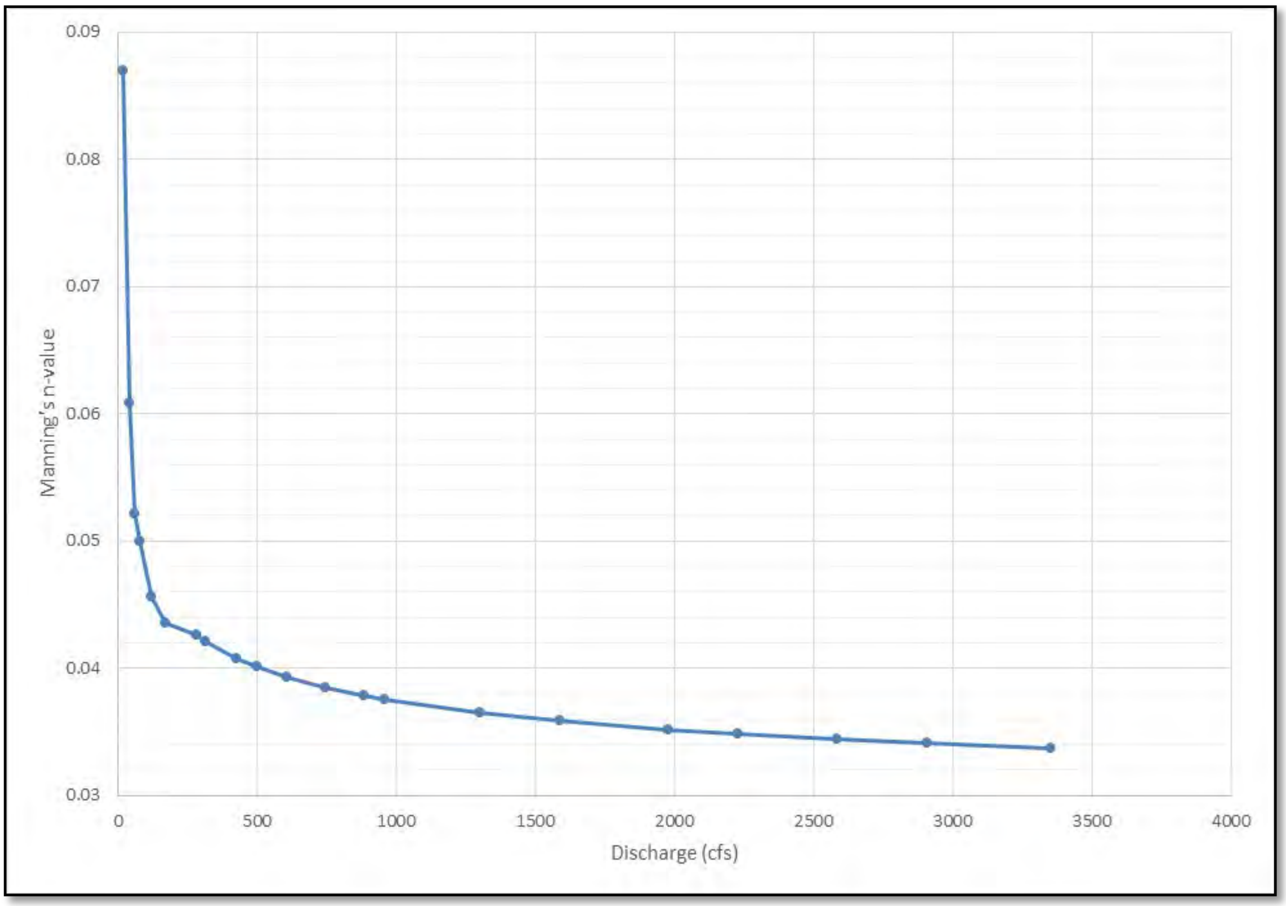
Hydraulics

A digital elevation model (DEM) was developed of the existing project site from approximately rivermile 16.55 upstream to rivermile 18.45. The existing DEM was a combination of LiDAR based elevation data obtained from November 9, 2006 and bathymetric survey data obtained from July 11-15, 2016 by Rio ASE using a combination of GPS RTK and total station survey techniques. It should be noted that there was an approximate 2.5-foot elevation difference between the survey data and the LiDAR data. To merge the data together the survey data was temporarily increased by 2.5 feet to tie into the LiDAR data until an explanation of the difference can be obtained.

A one-dimensional HEC-RAS hydraulic model was developed based on this existing conditions DEM. Cross sections were cut across the DEM at a maximum spacing of 100 feet. Near the downstream limits two additional reaches were included within the model to better represent a complex hydraulic scenario where the main channel has the option to split into three or more channels; the existing main channel, the old (pre-avulsion channel) and a new side channel on valley left. Lateral structures were included between the floodplain interface of these channels to allow the exchange of flow between them at connected flood flows.

Initial Manning's n-values representing the channel roughness were approximated by Rio ASE's engineer based on onsite observations and professional judgment. These values were then calibrated using approximated discharges during the LiDAR flight on November 9, 2006. It was approximated that discharges during the LiDAR flight upstream of War Creek, upstream of Eagle Creek and at the downstream limits of the project were 163 cfs, 220 cfs, and 250 cfs, respectively. Manning's n-values were adjusted until the average difference between LiDAR water surface elevation and estimated water surface elevations using the hydraulic model were approximately 0.0 feet. There are localized differences where water surfaces differ by as much as 1.8 feet (plus or minus). These areas are thought to be hydraulically localized areas influenced by large wood structures or other obstructions to the channel. Based on this initial calibration roughness values were then increased or decreased based on the discharge to represent the increased or decreased relative roughness associated with the bed material (As the water depth increases the relative roughness of the bed decreases and the Manning's n-value decreases). The Limerinos equation was used to estimate this variation in n-value as sediment size stayed constant and hydraulic depth increased or decreased. This final variation in n-value compared to discharge can be seen in Figure 4.

Figure 4. Manning's n-Value Variation with Discharge for the War Creek Project Area.



The hydraulic model was used to estimate hydraulic characteristics for all discharge events described within the hydrology section above. Hydraulic characteristics reviewed were floodplain inundation area, depth, velocity, shear stress, incipient motion of sediment, etc. These results are summarized in the table below.

Table 4. Hydraulic Characteristics Summary for the Twisp River.

Return Interval (years)	Velocity (ft/sec)			Depth (ft)			Shear Stress (lb/ft^2)		
	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.
95% Exceedance	0.2	1.2	3.4	0.3	0.5	1.3	0.0	0.6	4.6
50% Exceedance	0.1	1.8	4.5	0.1	0.7	1.6	0.0	0.7	3.7
5% Exceedance	2.0	4.6	10.3	0.8	1.5	2.7	0.1	1.0	3.3
1.005	1.1	3.8	8.3	0.5	1.2	2.2	0.1	0.8	3.9
1.01	1.3	4.0	8.6	0.5	1.3	2.3	0.1	0.9	3.4
1.05	1.8	4.4	9.8	0.7	1.5	2.5	0.1	0.9	3.0
1.11	1.6	4.3	7.0	0.6	1.4	2.3	0.1	0.9	2.9
1.25	2.2	4.9	11.2	0.9	1.7	3.0	0.1	1.0	3.7
1.5	2.4	5.3	11.8	1.0	1.8	3.2	0.2	1.1	3.9
2	2.7	5.6	12.6	1.0	1.9	3.5	0.2	1.1	3.5
2.33	2.8	5.8	12.0	1.0	2.0	3.5	0.2	1.2	3.7
5	2.7	6.3	12.5	1.1	2.3	3.9	0.3	1.2	2.9
10	2.2	6.8	10.9	1.3	2.5	4.3	0.2	1.3	3.5
25	2.3	7.2	12.4	1.4	2.8	4.6	0.2	1.4	3.5
50	2.4	7.6	12.8	1.5	3.0	4.8	0.2	1.4	3.2
100	2.6	7.8	13.2	1.7	3.2	5.3	0.2	1.5	3.4
200	2.7	8.2	13.6	1.7	3.3	5.7	0.2	1.6	4.0
500	2.1	8.4	16.6	1.5	3.6	7.6	0.1	1.6	4.1

Geomorphology

- Channel sinuosity has reduced through the project reach from 1.20 in 1953 to 1.11 in 2013.
- Minimal bank erosion and channel migration was observed. Where bank erosion and channel migration was observed, rates ranged between less than 1ft/yr to as much as 3.5ft/yr. The greatest bank erosion was observed in two locations: 1) in the vicinity of several log jams within an S-curve located about 1500-feet downstream of the War Creek bridge, and 2) within the recent avulsion area at the downstream end of the reach. Banks appeared to be extremely stable within the upper portion of the long straight subreach as a result of very large bank material (boulders) and dense, mature (old-growth) vegetation.
- Comparing measured grain sizes with calculated reach-scale hydraulic conditions (shear stress and velocity), suggests the bed is armored and does not fully mobilize except in relatively large floods (roughly 25-year floods and greater). Observations of relatively clean, loose bed material with moderate armoring and embeddedness in most riffles suggests localized scour and deposition associated with in-stream obstructions (log jams and bend scour) has a significant influence within the reach resulting in many localized areas of nearly annual sediment transport. From field observations and hydraulic calculations, we estimate that a large obstruction (blocking roughly 30% of the channel) is required in order to mobilize the bed locally (channel-spanning pool). Smaller, localized pools are feasible with much smaller obstructions.
- The largest flood following the 1958 installation of the War Creek Bridge was in 1972. Although the 1972 flood was not captured on the Twisp Gage, regional records suggest it likely measured between a 25- and 50-year event. If the ordinary high water mark is equivalent to the 1.5-year flood, and the difference between the ordinary high and the observed high-water mark was 3-feet, according to the results of our hydraulic modeling (see Table 4), the flood responsible for creating the high-water mark would have had a roughly 200-year recurrence interval (add 3-feet to the 1.5-year water depth). Since the 1972 flood likely did not exceed a 50-year event (approximately 1.5 feet higher than the ordinary high water mark according to the hydraulic model), there may have been as much as

1.5 feet of incision accounting for the difference (i.e.: the difference between the measured high-water mark and the estimated 50-year flood water depth from our hydraulic model).

- Large woody debris was observed throughout the project reach in varying quantities and densities. Based on 2013 aerial photos, the average quantity of large woody debris per mile within the project reach included: 3.8 large log jams (10+ logs), 4.4 small log jams (3-10 logs) and 24.5 individual logs for an approximate total of 76 pieces per mile (assuming the minimum number of logs per jam). The upstream subreach (upstream of the War Creek bridge) had the highest density of woody debris per mile: 5 large log jams, 3 small log jams, and 17 individual pieces for an approximate total of 116 pieces per mile. The S-curve section of the middle subreach had similar density of large wood as the upstream subreach. The long straight subreach had the lowest density per mile: 0 large log jams, 0 small log jams and 8 individual pieces (18 total pieces per mile).

- Many existing individual logs and log jams observed in the field showed evidence of marked channel response (scour pool, leeward deposition, and in the case of large structures, channel planform adjustment) along the lines of the goals for this project. Unfortunately, the frequency of such influence is relatively low, suggesting there is ample room for improvement. Specifically, a handful of large jams were observed redirecting nearly the entire channel creating tight-radius meander bends. These large structures also promoted large scour pools and significant sediment deposition and sorting. Similarly, several small log jams and individual logs were observed enhancing point-bar and mid-channel bar development, back-bar side channel formation, and localized scour pools. See figures 5-7 below for several photo examples from the project reach.

- Physical habitat conditions observed within the project reach were variable and correlated strongly with the volume of wood loading. The greatest physical habitat diversity and complexity was repeatedly observed in the immediate vicinity of large wood where it was present (e.g.: upstream of the War Creek Bridge, within the S-curve section located about 1500 feet downstream of the War Creek Bridge, and in the recent avulsion area). Historic removal of wood from the channel and floodplain has been previously documented (Reclamation Geomorphic Assessment, 2003; Inter-Fluve Reach Assessment, 2015). It is believed that the historic removal of wood from the system has reduced the amount of existing physical habitat. Pre-disturbance wood volumes are unknown, but research (Fox and Bolton, 2007) and observations from reference reaches (Chiwawa River) suggest larger reach-scale volumes of wood and larger diameter wood historically. Although wood volumes and associated physical habitat appear to be favorable in a handful of sub-reaches, large areas within the project reach are relatively lacking both wood and physical habitat. Regardless of existing versus historic wood volumes, observations of the project reach clearly illustrate that wood within the channel is directly responsible for physical habitat complexity believed to be favorable for adult and juvenile salmonids suggesting a relatively high restoration potential for those areas currently lacking wood structure.

Figure 5: Existing log jam in the S-curve section of the project reach about 1500ft downstream of War Creek Bridge. Flow is from right to left. There are several key-member logs in the 24-30-inch DBH range stabilizing the structure and racking additional material. This structure has completely altered the local planform by forcing a nearly 90-degree turn in the river. A significant scour pool and associated hydraulic/habitat variability is visible in the photo.

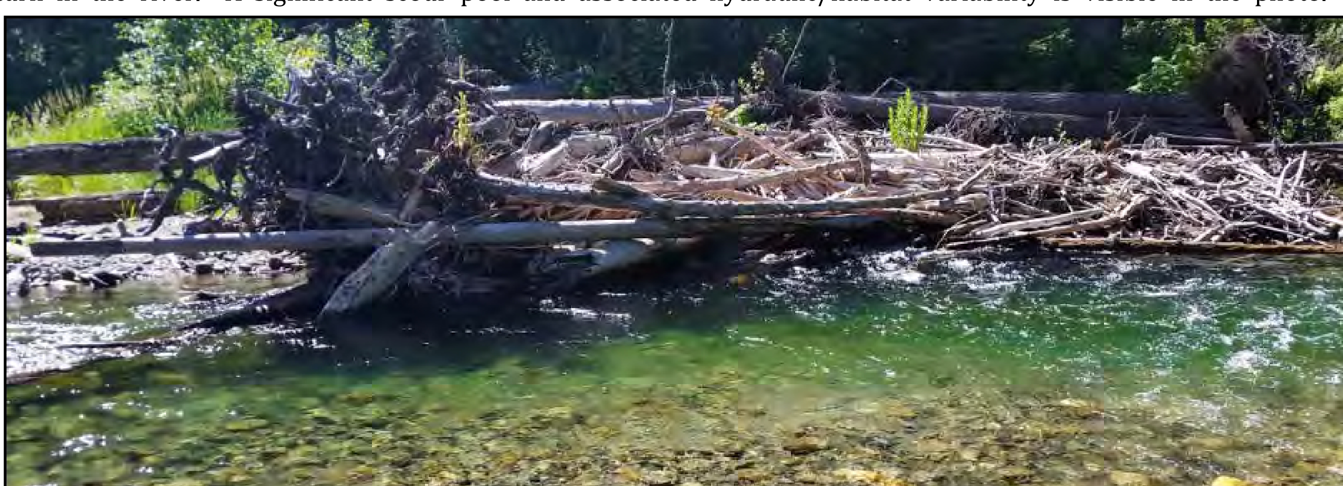


Figure 6: Existing LWD just upstream of the War Creek Bridge. Photo is looking upstream. Greater deposition is observed in the lee of the log structures promoting point bar deposition and a back-bar side channel (see also Figure 1c).

Figure 7: Existing LWD spanning the main stem (pinned against existing vegetation on the right bank and a key piece of wood on a point bar on the left bank). This single spanning structure forces pressure flow under the log at ordinary high water resulting in a large pool. We believe this type of structure can be used between a point bar and a back-bar channel to reduce the width-to-depth ratio on the back-bar channel while creating valuable pool habitat with cover. An example of this application is proposed at the outlet of War Creek. The photo is looking downstream.

DRAFT CONCEPTS

Summarized below are descriptions of the proposed conceptual treatments for the project area. See the attached Conceptual Map Series for accompanying conceptual drawings.

Upstream Area

- Defined as the area upstream of the S-curve section located about 1500 feet downstream of the War Creek Bridge.
- <u>Overall objective:</u> Support or enhance existing in-stream channel and habitat complexity over the short term while enhancing lateral channel migration and channel response character over the long-term.
- <u>Treatment ID #1</u>: Isolated (optional) apex jam intended to split additional flow into an existing high-flow channel to increase connectivity. Limited construction access
- <u>Treatment ID #2</u>: Optional culvert through bridge road approach fill. As discussed above, we recommend delaying this proposed treatment until the frequency of floodplain inundation increases sufficiently to warrant the proposed action.
- <u>Treatment ID #3-9</u>: This suite of treatments is intended to add short-term hydraulic and habitat complexity while enhancing long-term sediment accumulation, channel migration, and stream length improving overall floodplain connection and groundwater recharge. Construction access possible via the 1980s channel path (dry) and campground.

Middle Subreach (includes S-curve section)

- Defined as the area downstream of the S-curve section located about 1500 feet downstream of the War Creek Bridge and upstream of the straight subreach.
- <u>Overall objective</u>: Protect the highly-functional areas within the subreach (i.e.: S-curve section) while enhancing in-stream hydraulic complexity and habitat, side-channel activation, and improved thermal refuge over the short-term while improving channel migration, sediment deposition, and floodplain connection over the long-term.
- <u>Treatment ID #10</u>: Enhance the existing point bar and back-bar side channel that coincides with the outflow of War Creek. Use whole trees along the submergent portion of the point bar to increase roughness and increase deposition, while installing logs spanning the back-bar side channel from the bank to the point bar to create pressure flow under the log(s) and promote scour pool formation during seasonal high flows. Brace logs against existing vegetation on the right bank to reduce potential impact to existing riparian vegetation. Enhancing the point bar will also promote left-lateral channel migration over the long-term. Limited construction access.
- <u>Treatment ID #11</u>: Apex jam installed to split existing flow and (in conjunction with Structure #10), force long-term left bank channel migration to improve channel sinuosity and floodplain connection. Consider excavating a small pilot channel connection between the existing main-stem Twisp River and the currently abandoned side channel. Total excavation is estimated to be less than 10 cubic yards and likely feasible using a hand-crew to reduce the impact from heavy equipment. Limited construction access.
- <u>Treatment ID #12-15</u>: Suite of log jams and individual structures aimed at improving hydraulic and habitat complexity over the short-term while increasing the potential for left-lateral channel migration over the long-term. Structure #12 would be located at the head of an existing point bar that is lacking a log jam currently. Structures #13 and 14 would augment existing wood in the area by providing cover and complexity within existing pools by bracing whole trees against existing vegetation. Structure #15 would create a tight-radius bend and force flow against the valley margin over the short-term and be flanked to the left over the long-term further promoting lateral channel migration. Limited construction access.

Straight Subreach

- Defined as the obviously straight subreach downstream of War Creek and upstream of the recent avulsion area.
- <u>Overall objective</u>: Significantly roughen the channel and promote lateral channel migration. Reduce the potential for future upstream-migrating incision (head cut) associated with the recent avulsion immediately downstream.

- Treatment #16: Install a large bank jam to obstruct flow and force channel migration. The very course bed/bank material and mature (old-growth) riparian vegetation suggest channel migration will take many years to advance appreciably. Increased roughness will be required to reduce the potential for short-term channel incision (head cut). Limited construction access.
- Treatment #17-22: Use whole trees braced against existing riparian vegetation to add in-stream friction, promote localized deposition, hydraulic variability, habitat complexity and floodplain connection. Limited construction access; consider falling existing trees to accomplish.
- Treatment #23: Suite of logs intended to scour a pool at the outlet of the existing groundwater-fed alcove and potential future side channel. Stack logs to create pressure flow and scour during high-flow periods. Limited construction access.
- Treatment #24: Install a large bank jam to obstruct flow and promote up-stream deposition reducing the potential for upstream migrating incision (head cut) and improving floodplain connection. The right bank is situated at the edge of the valley wall; therefore, lateral channel migration is unlikely. Forcing flow against a relatively erosion-resistant bank will increase friction and promote an upstream backwater and depositional character. Construction access via existing access road.
- Treatment #25: Enhance the formation of a point bar and associated back-bar side channel at the outlet of Eagle Creek to enhance thermal refugia at the confluence similar to the War Creek confluence. Limited construction access.
- Treatment #26 and 27: Individual whole trees braced against existing riparian vegetation to add in-stream friction, promote localized deposition, hydraulic variability, habitat complexity and floodplain connection strategically located at the head of existing submergent point bars. Adding structure at the head of submergent point bars will enhance their formation and thereby drive channel migration. Limited construction access; consider falling existing trees to accomplish. Limited construction access.

Avulsion Area

- Defined as the recent avulsion area immediately upstream of the area where the Twisp River runs adjacent the road.
- Overall objective: Obstruct flow within the new avulsion channel to reduce in-stream velocity and scour potential thereby reducing the risk of upstream-migrating incision (head cut) while promoting lateral channel migration within a reach that has undergone significant channel straightening over time. Split flow where possible to increase friction and further promote deposition over time.
- Treatment #28 -30: Split flow into the abandoned main-stem Twisp River within the avulsion site. Splitting flow in this area, increasing friction and promoting deposition will reduce the risk of upstream migrating incision (head cut) from the ongoing response to the recent avulsion. Consider excavating a small pilot channel to expedite side-channel activation. Limited access.
- Treatments #31-34: Obstruct flow with semi-porous channel-spanning structures (bleeder jams) and whole trees to increase friction, promote deposition, and lateral channel migration within the new avulsion channel to reduce the potential for upstream-migrating incision (head cut) and promote increased sinuosity within this otherwise straight reach. Limited construction access.

DRAFT CONCEPTUAL DRAWINGS

The following images illustrate our proposed conceptual plan for the War Creek project area (extending into the Eagle Creek subreach).

DRAFT Concept: War Creek Project - Twisp River
Vicinity Map

Subreach Breaks

0 500 1,000 2,000 Feet

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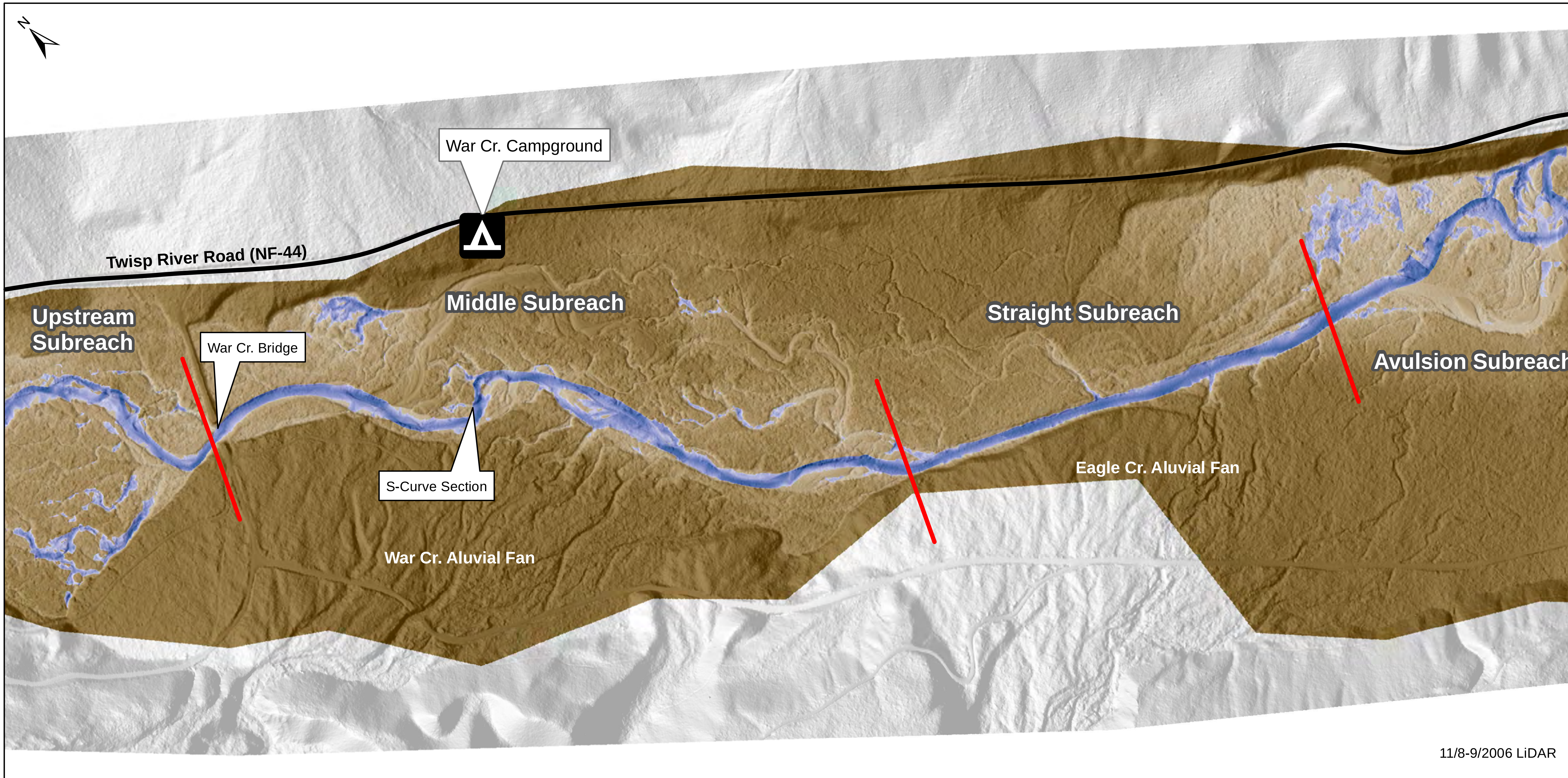

DRAFT Concept: War Creek Project - Twisp River
Vicinity Map

Subreach Breaks

N

0 500 1,000 2,000 Feet

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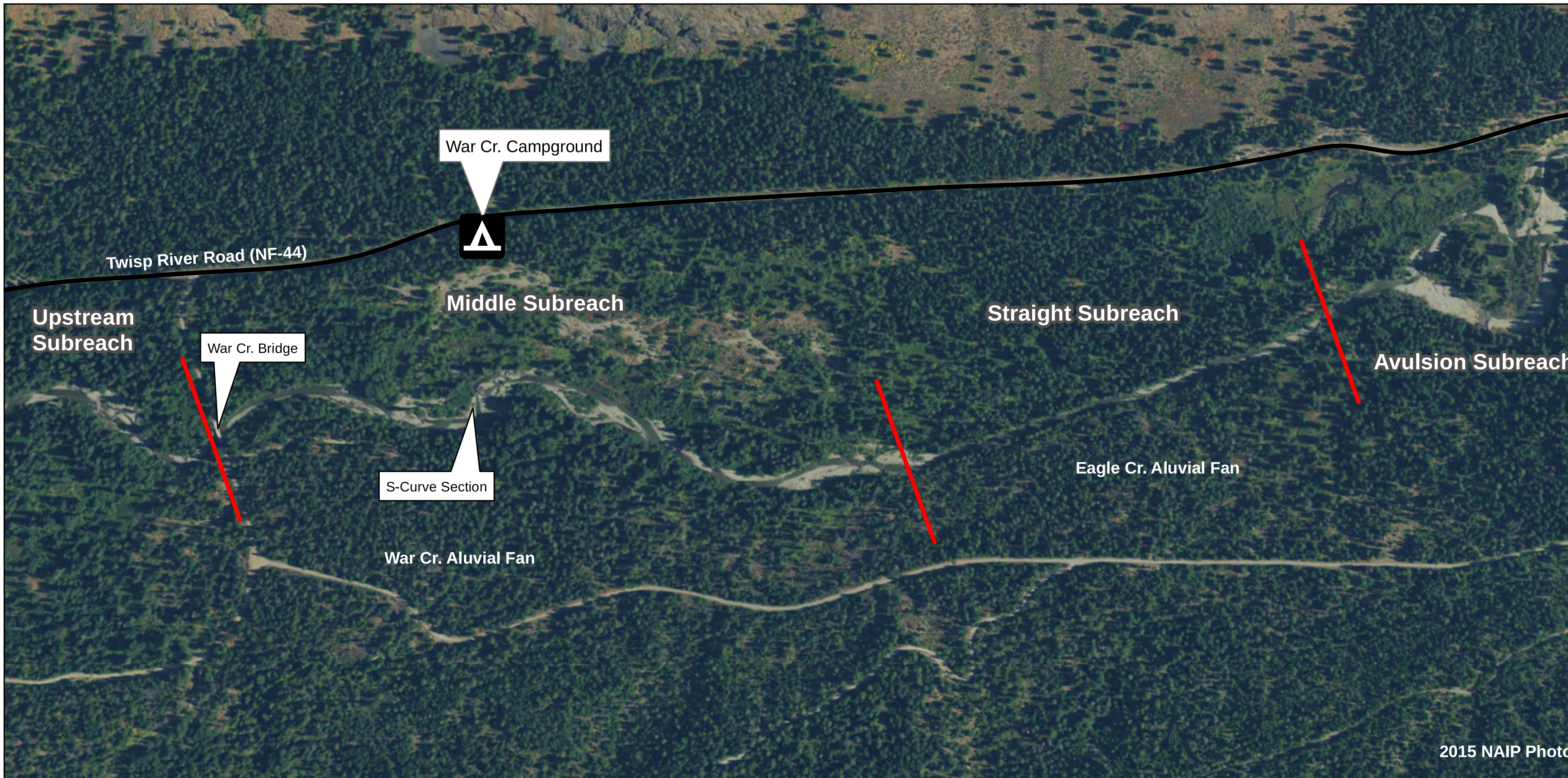


DRAFT Concept: War Creek Project - Twisp River Overview Map

Legend

1.5yr Velocity (ft/s)

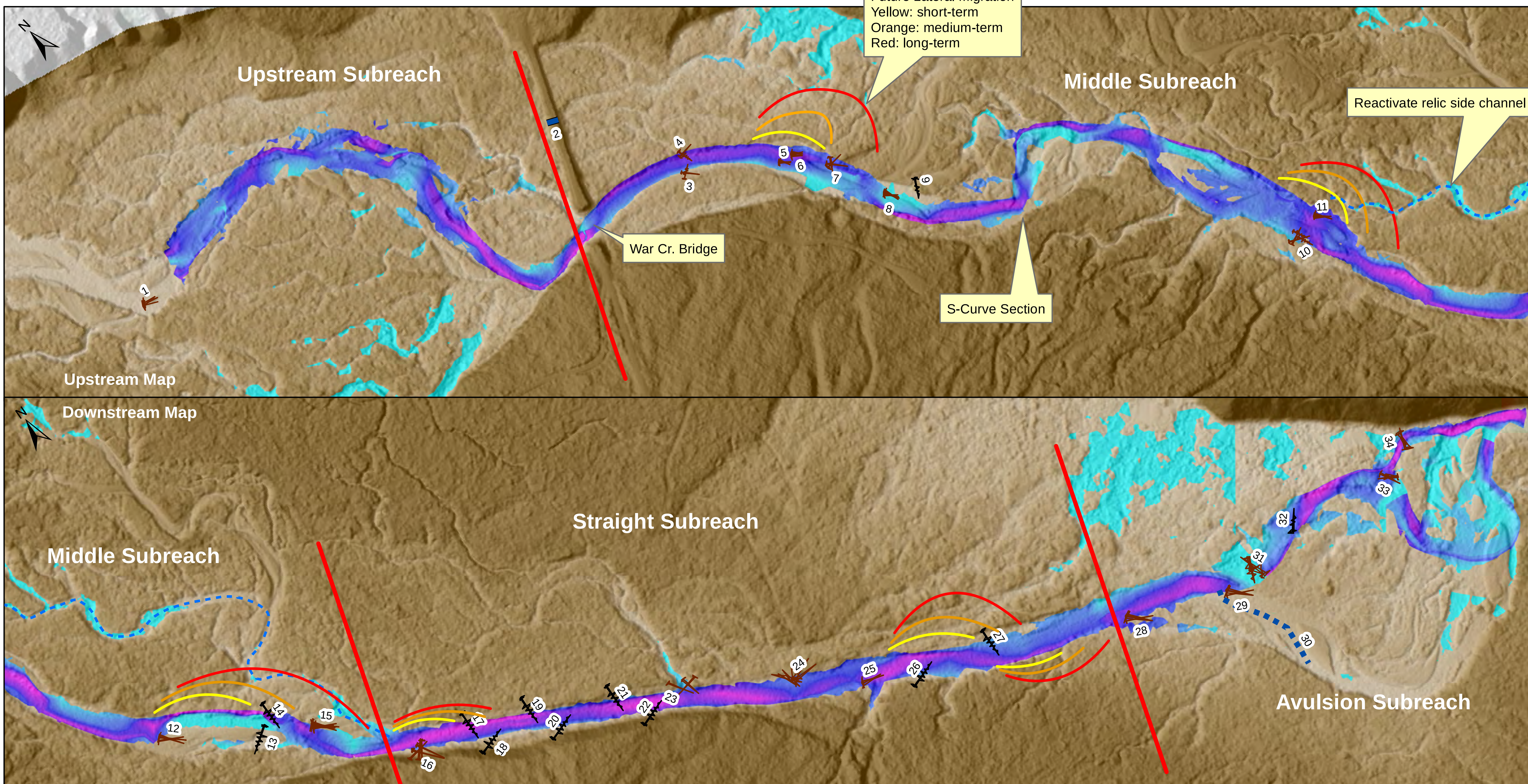
High : 13.2491

Low : 0

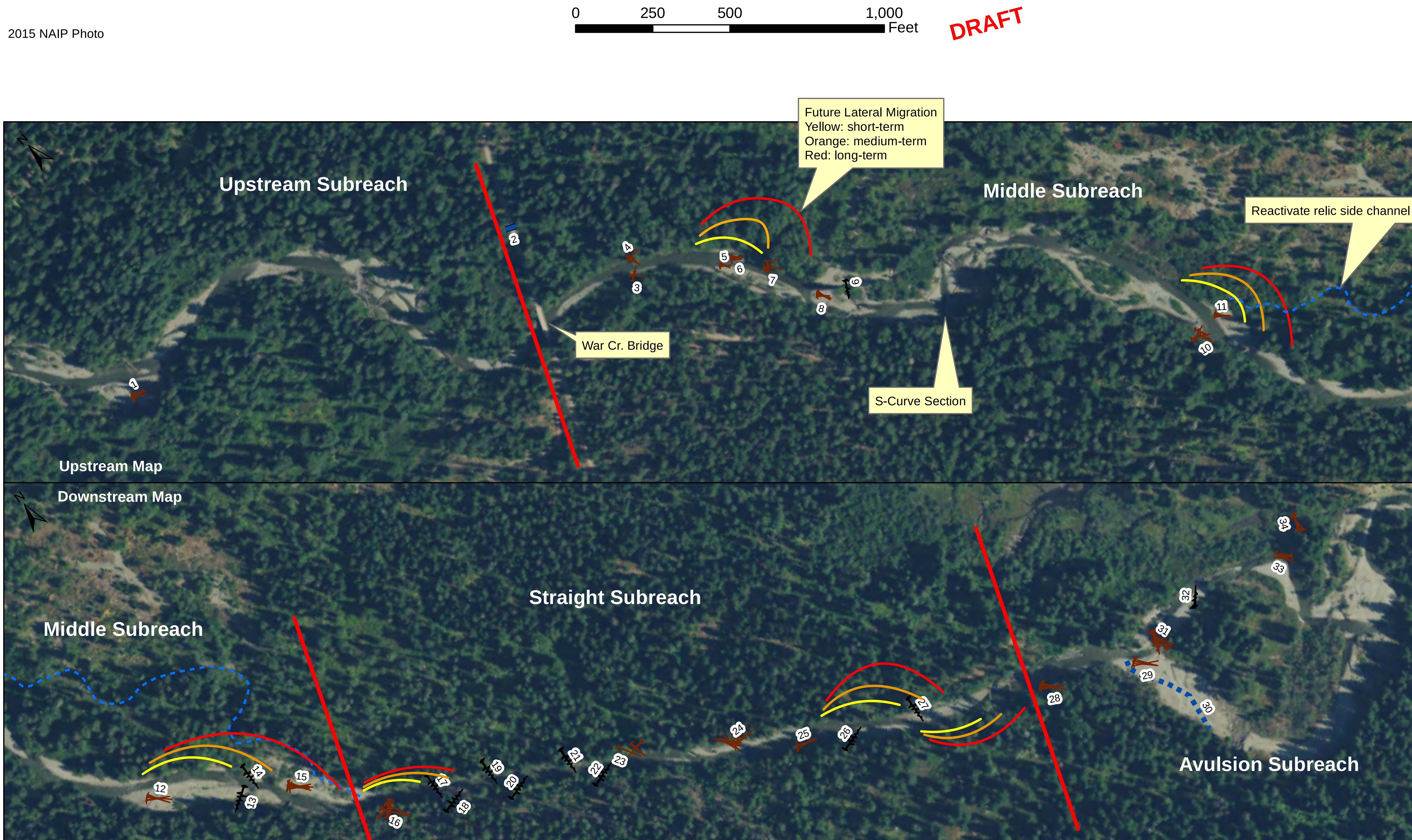
11/8-9/2006 LiDAR

0 250 500 1,000 Feet

DRAFT



DRAFT Concept: War Creek Project - Twisp River
Overview Map



DRAFT Concept: War Creek Project - Twisp River Upstream Map

Legend

1.5yr Velocity (ft/s)

High : 13.2491

Low : 0

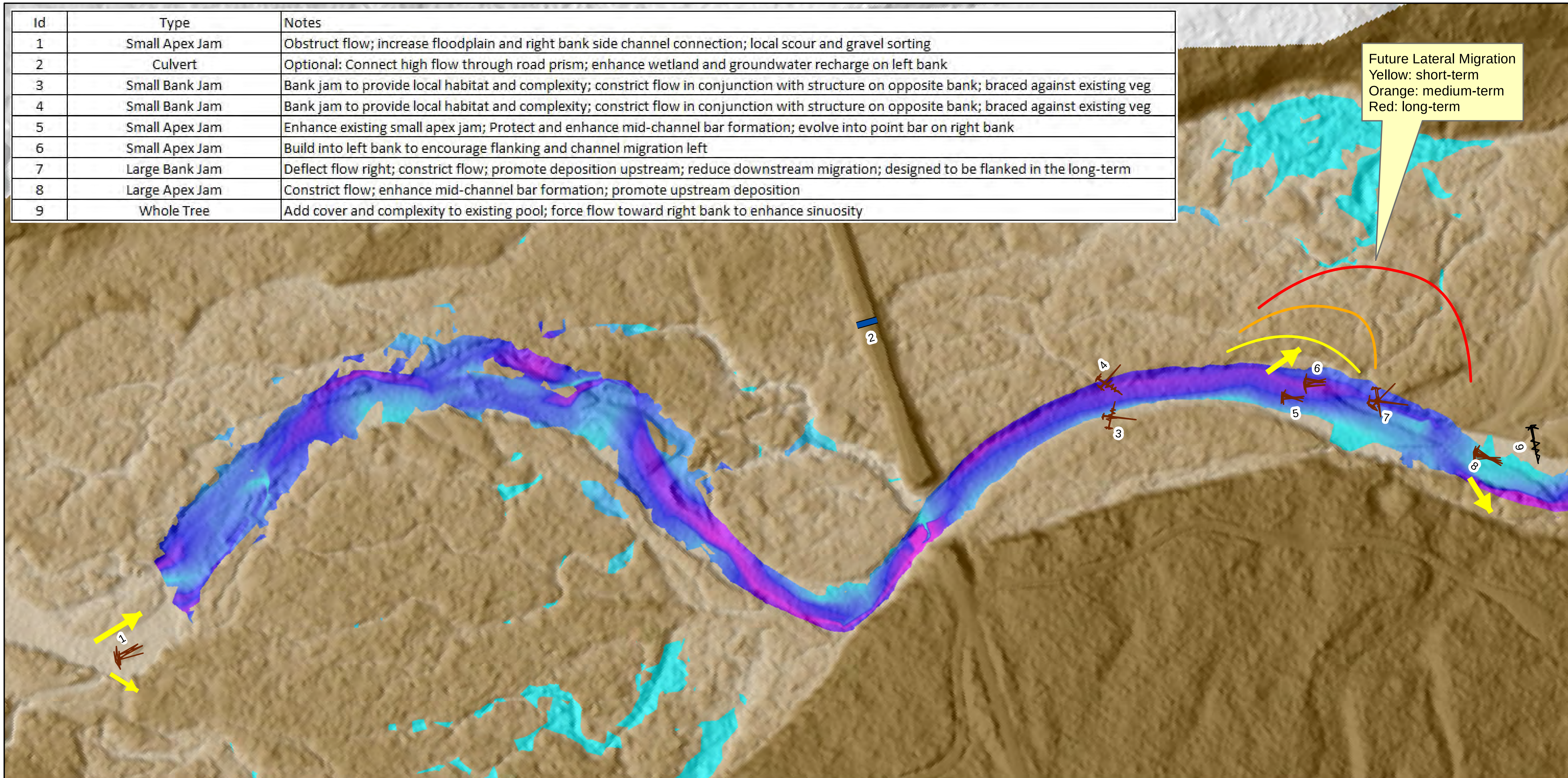
11/8-9/2006 LiDAR

N

0 125 250 500 Feet

DRAFT

Id	Type	Notes
1	Small Apex Jam	Obstruct flow; increase floodplain and right bank side channel connection; local scour and gravel sorting
2	Culvert	Optional: Connect high flow through road prism; enhance wetland and groundwater recharge on left bank
3	Small Bank Jam	Bank jam to provide local habitat and complexity; constrict flow in conjunction with structure on opposite bank; braced against existing veg
4	Small Bank Jam	Bank jam to provide local habitat and complexity; constrict flow in conjunction with structure on opposite bank; braced against existing veg
5	Small Apex Jam	Enhance existing small apex jam; Protect and enhance mid-channel bar formation; evolve into point bar on right bank
6	Small Apex Jam	Build into left bank to encourage flanking and channel migration left
7	Large Bank Jam	Deflect flow right; constrict flow; promote deposition upstream; reduce downstream migration; designed to be flanked in the long-term
8	Large Apex Jam	Constrict flow; enhance mid-channel bar formation; promote upstream deposition
9	Whole Tree	Add cover and complexity to existing pool; force flow toward right bank to enhance sinuosity



DRAFT Concept: War Creek Project - Twisp River
Upstream Map

2015 NAIP Photo

N

0 125 250 500 Feet

DRAFT

Id	Type	Notes
1	Small Apex Jam	Obstruct flow; increase floodplain and right bank side channel connection; local scour and gravel sorting
2	Culvert	Optional: Connect high flow through road prism; enhance wetland and groundwater recharge on left bank
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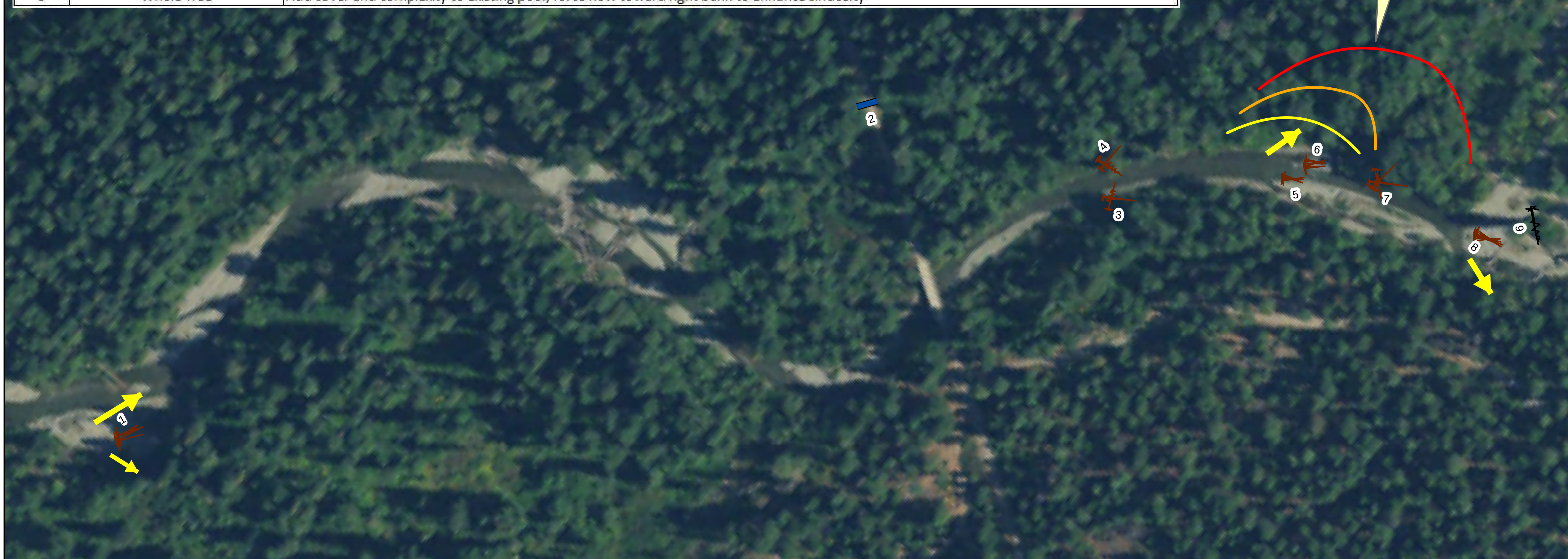
8	Large Apex Jam	Constrict flow; enhance mid-channel bar formation; promote upstream deposition
9	Whole Tree	Add cover and complexity to existing pool; force flow toward right bank to enhance sinuosity



DRAFT Concept: War Creek Project - Twisp River Middle Subreach Map

Legend

1.5yr Velocity (ft/s)

High : 13.2491

Low : 0

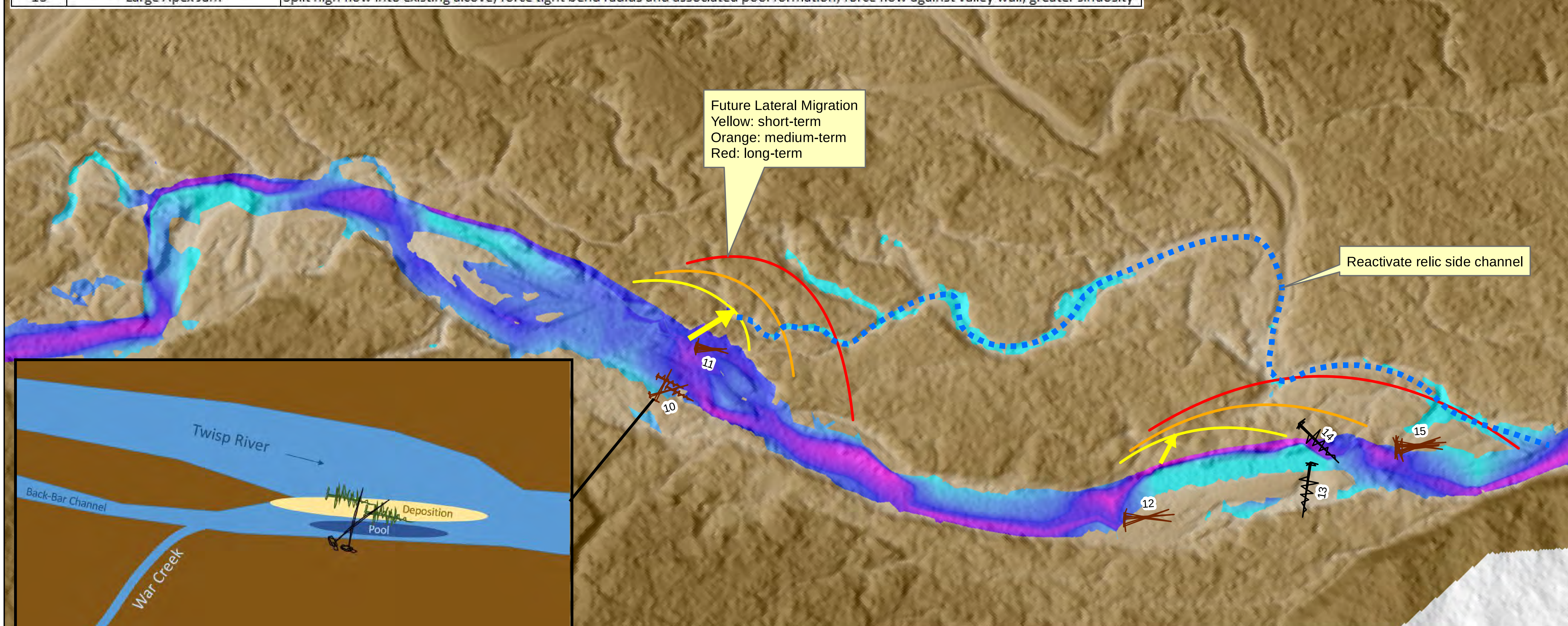
11/8-9/2006 LiDAR

N

0 125 250 500 Feet

DRAFT

Id	Type	Notes
10	Small Bank Jam	Enhance deposition in War Cr. outlet to narrow channel; enhance existing point bar
11	Large Apex Jam	Located at head of point bar to promote back-bar channel formation and left lateral migration
12	Small Apex Jam	Enhance mid-channel bar and right bank back-bar channel; no existing LWD at head of bar
13	Whole Tree	Braced against existing LWD: obstruct flow; enhance overbank flow and back-bar channel formation on both banks
14	Whole Tree	Braced against existing LWD; Obstruct flow; enhance overbank flow and back-bar channel formation on both banks
15	Large Apex Jam	Split high flow into existing alcove; force tight bend radius and associated pool formation; force flow against valley wall; greater sinuosity



DRAFT Concept: War Creek Project - Twisp River
Middle Subreach Map

2015 NAIP Photo

N

0 125 250 500 Feet

DRAFT

Id	Type	Notes
10	Small Bank Jam	Enhance deposition in War Cr. outlet to narrow channel; enhance existing point bar
11	Large Apex Jam	Located at head of point bar to promote back-bar channel formation and left lateral migration
12	Small Apex Jam	Enhance mid-channel bar and right bank back-bar channel; no existing LWD at head of bar
13	Whole Tree	Braced against existing LWD: obstruct flow; enhance overbank flow and back-bar channel formation on both banks
14	Whole Tree	Braced against existing LWD; Obstruct flow; enhance overbank flow and back-bar channel formation on both banks
15	Large Apex Jam	Split high flow into existing alcove; force tight bend radius and associated pool formation; force flow against valley wall; greater sinuosity

DRAFT Concept: War Creek Project - Twisp River Straight Subreach Map

Legend

1.5yr Velocity (ft/s)

High : 13.2491

Low : 0

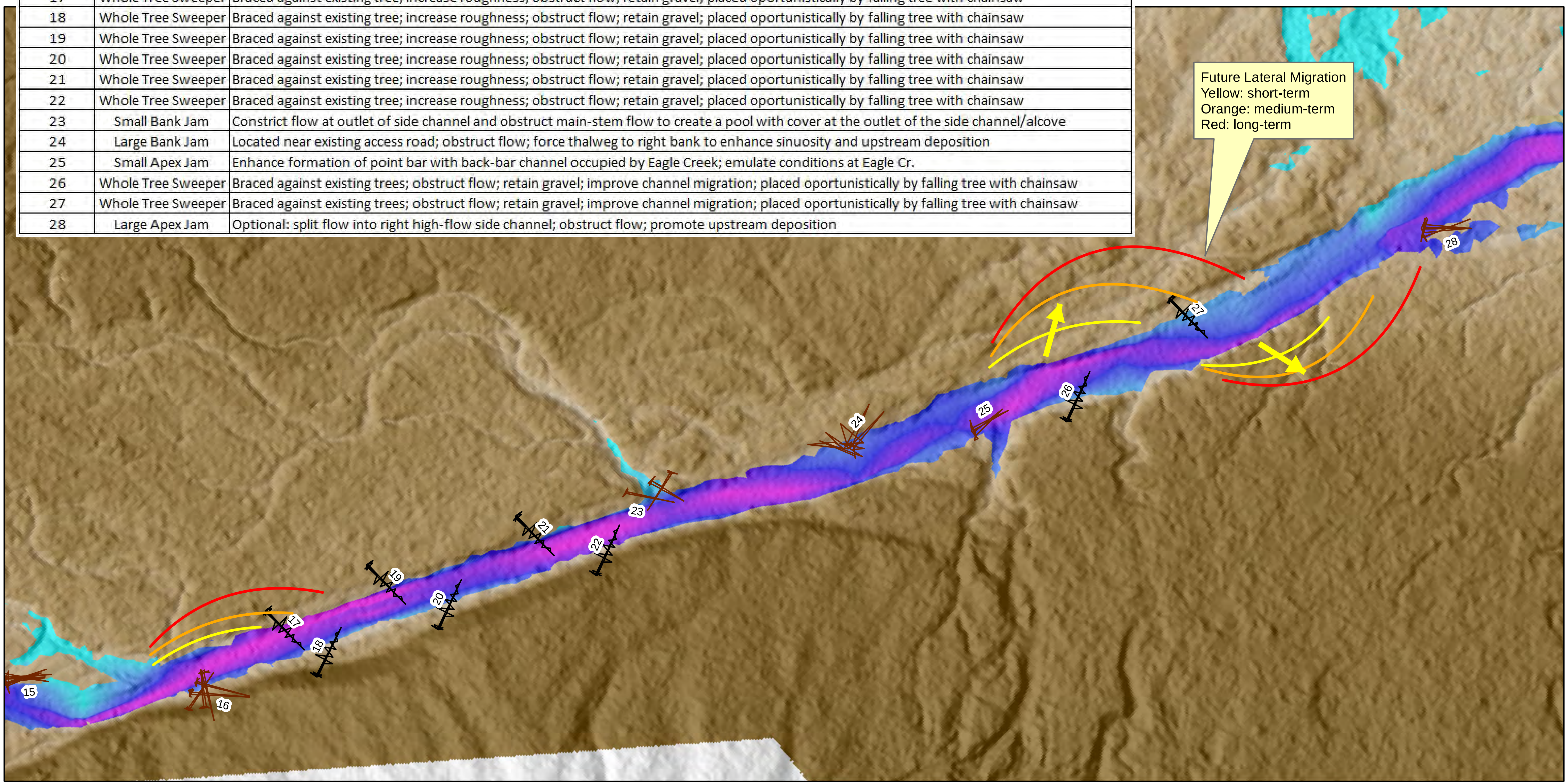
11/8-9/2006 LiDAR

N

0 125 250 500 Feet

DRAFT

Id	Type	Notes
16	Large Bank Jam	Optional: Deflect flow left; brace logs against existing veg; add substantial racking; stack to elevation of 100yr water surface
17	Whole Tree Sweeper	Braced against existing tree; increase roughness; obstruct flow; retain gravel; placed oportunistically by falling tree with chainsaw
18	Whole Tree Sweeper	Braced against existing tree; increase roughness; obstruct flow; retain gravel; placed oportunistically by falling tree with chainsaw
19	Whole Tree Sweeper	Braced against existing tree; increase roughness; obstruct flow; retain gravel; placed oportunistically by falling tree with chainsaw
20	Whole Tree Sweeper	Braced against existing tree; increase roughness; obstruct flow; retain gravel; placed oportunistically by falling tree with chainsaw
21	Whole Tree Sweeper	Braced against existing tree; increase roughness; obstruct flow; retain gravel; placed oportunistically by falling tree with chainsaw
22	Whole Tree Sweeper	Braced against existing tree; increase roughness; obstruct flow; retain gravel; placed oportunistically by falling tree with chainsaw
23	Small Bank Jam	Constrict flow at outlet of side channel and obstruct main-stem flow to create a pool with cover at the outlet of the side channel/alcove
24	Large Bank Jam	Located near existing access road; obstruct flow; force thalweg to right bank to enhance sinuosity and upstream deposition
25	Small Apex Jam	Enhance formation of point bar with back-bar channel occupied by Eagle Creek; emulate conditions at Eagle Cr.
26	Whole Tree Sweeper	Braced against existing trees; obstruct flow; retain gravel; improve channel migration; placed oportunistically by falling tree with chainsaw
27	Whole Tree Sweeper	Braced against existing trees; obstruct flow; retain gravel; improve channel migration; placed oportunistically by falling tree with chainsaw
28	Large Apex Jam	Optional: split flow into right high-flow side channel; obstruct flow; promote upstream deposition



DRAFT Concept: War Creek Project - Twisp River
Straight Subreach Map

N

0 125 250 500 Feet

DRAFT

2015 NAIP Photo

Id	Type	Notes
16	Large Bank Jam	Optional: Deflect flow left; brace logs against existing veg; add substantial racking; stack to elevation of 100yr water surface
17	Whole Tree Sweeper	Braced against existing tree; increase roughness; obstruct flow; retain gravel; placed oportunistically by falling tree with chainsaw
18	Whole Tree Sweeper	Braced against existing tree; increase roughness; obstruct flow; retain gravel; placed oportunistically by falling tree with chainsaw
19	Whole Tree Sweeper	Braced against existing tree; increase roughness; obstruct flow; retain gravel; placed oportunistically by falling tree with chainsaw
20	Whole Tree Sweeper	Braced against existing tree; increase roughness; obstruct flow; retain gravel; placed oportunistically by falling tree with chainsaw
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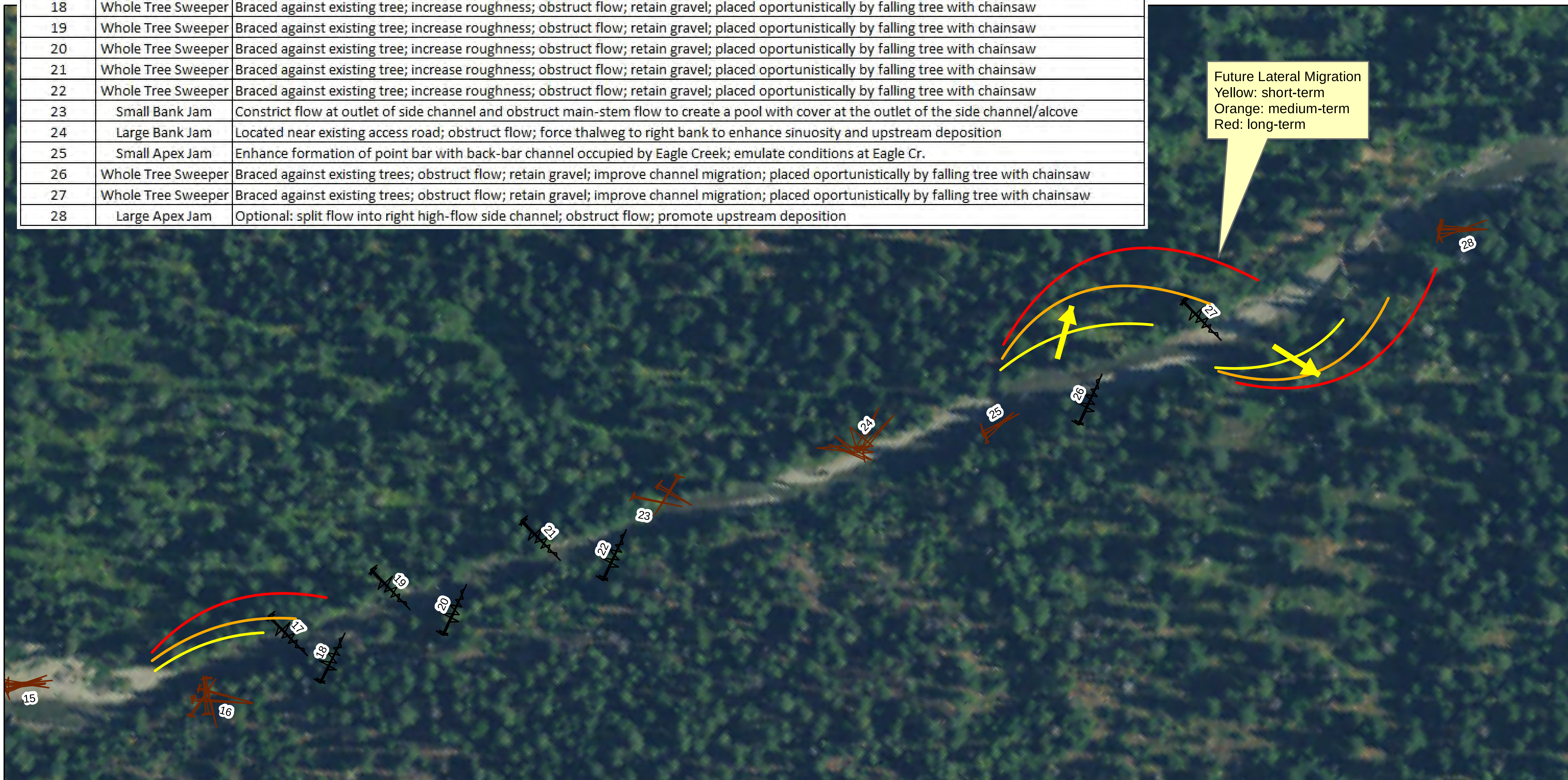
23	Small Bank Jam	Constrict flow at outlet of side channel and obstruct main-stem flow to create a pool with cover at the outlet of the side channel/alcove
24	Large Bank Jam	Located near existing access road; obstruct flow; force thalweg to right bank to enhance sinuosity and upstream deposition
25	Small Apex Jam	Enhance formation of point bar with back-bar channel occupied by Eagle Creek; emulate conditions at Eagle Cr.
26	Whole Tree Sweeper	Braced against existing trees; obstruct flow; retain gravel; improve channel migration; placed oportunistically by falling tree with chainsaw
27	Whole Tree Sweeper	Braced against existing trees; obstruct flow; retain gravel; improve channel migration; placed oportunistically by falling tree with chainsaw
28	Large Apex Jam	Optional: split flow into right high-flow side channel; obstruct flow; promote upstream deposition



DRAFT Concept: War Creek Project - Twisp River Avulsion Subreach Map

Legend

1.5yr Velocity (ft/s)

High : 13.2491

Low : 0

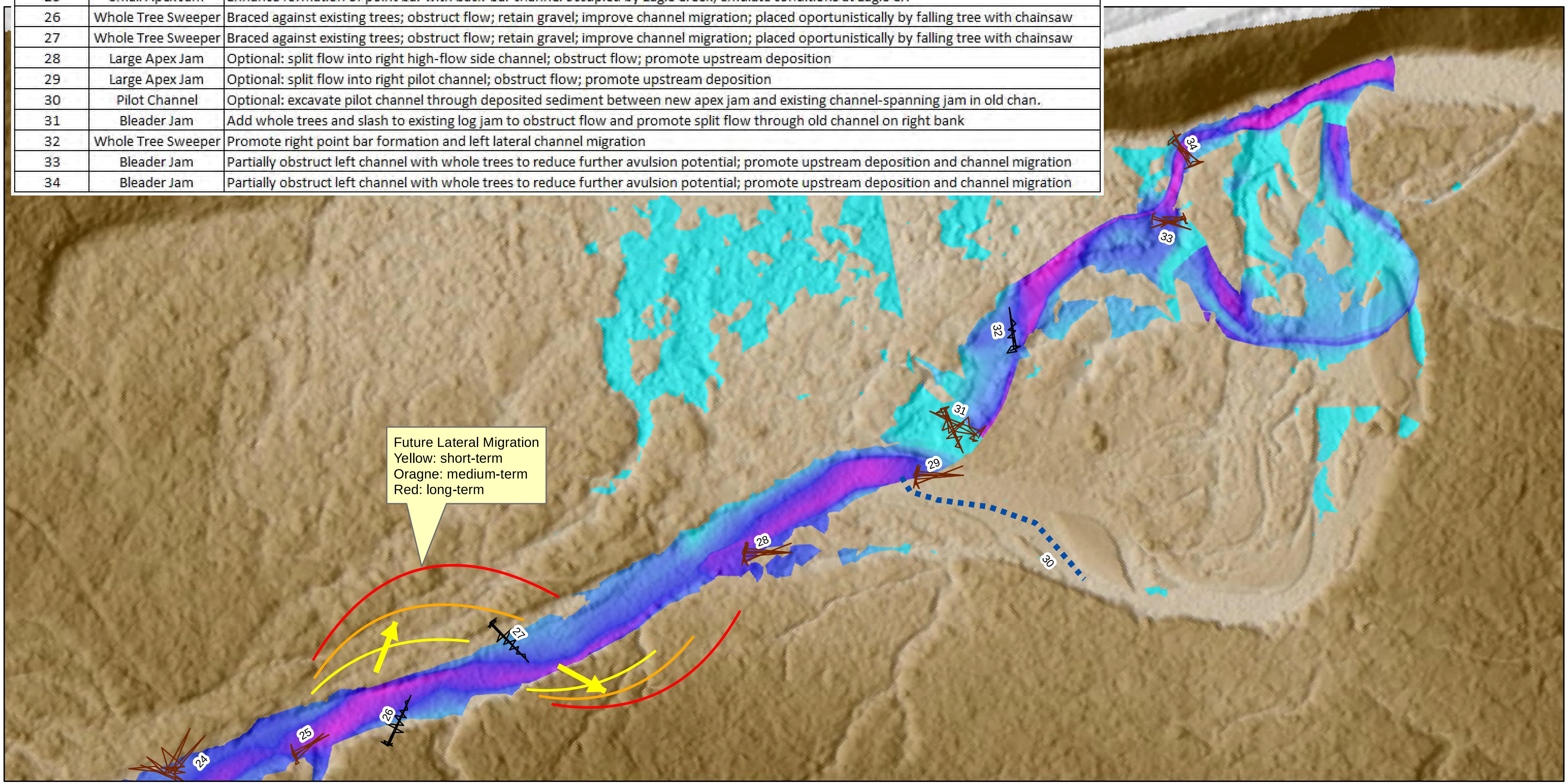
11/8-9/2006 LiDAR

N

0 125 250 500 Feet

DRAFT

Id	Type	Notes
25	Small Apex Jam	Enhance formation of point bar with back-bar channel occupied by Eagle Creek; emulate conditions at Eagle Cr.
26	Whole Tree Sweeper	Braced against existing trees; obstruct flow; retain gravel; improve channel migration; placed oportunistically by falling tree with chainsaw
27	Whole Tree Sweeper	Braced against existing trees; obstruct flow; retain gravel; improve channel migration; placed oportunistically by falling tree with chainsaw
28	Large Apex Jam	Optional: split flow into right high-flow side channel; obstruct flow; promote upstream deposition
29	Large Apex Jam	Optional: split flow into right pilot channel; obstruct flow; promote upstream deposition
30	Pilot Channel	Optional: excavate pilot channel through deposited sediment between new apex jam and existing channel-spanning jam in old chan.
31	Bleader Jam	Add whole trees and slash to existing log jam to obstruct flow and promote split flow through old channel on right bank
32	Whole Tree Sweeper	Promote right point bar formation and left lateral channel migration
33	Bleader Jam	Partially obstruct left channel with whole trees to reduce further avulsion potential; promote upstream deposition and channel migration
34	Bleader Jam	Partially obstruct left channel with whole trees to reduce further avulsion potential; promote upstream deposition and channel migration



DRAFT Concept: War Creek Project - Twisp River Avulsion Subreach Map

N

0 125 250 500 Feet

DRAFT

2015 NAIP Photo

Id	Type	Notes
25	Small Apex Jam	Enhance formation of point bar with back-bar channel occupied by Eagle Creek; emulate conditions at Eagle Cr.
26	Whole Tree Sweeper	Braced against existing trees; obstruct flow; retain gravel; improve channel migration; placed oportunistically by falling tree with chainsaw
27	Whole Tree Sweeper	Braced against existing trees; obstruct flow; retain gravel; improve channel migration; placed oportunistically by falling tree with chainsaw
28	Large Apex Jam	Optional: split flow into right high-flow side channel; obstruct flow; promote upstream deposition
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30	Pilot Channel	Optional: excavate pilot channel through deposited sediment between new apex jam and existing channel-spanning jam in old chan.
31	Bleader Jam	Add whole trees and slash to existing log jam to obstruct flow and promote split flow through old channel on right bank
32	Whole Tree Sweeper	Promote right point bar formation and left lateral channel migration
33	Bleader Jam	Partially obstruct left channel with whole trees to reduce further avulsion potential; promote upstream deposition and channel migration
34	Bleader Jam	Partially obstruct left channel with whole trees to reduce further avulsion potential; promote upstream deposition and channel migration