Lower Lemhi River

Multiple Reach Assessment Report

April 2021

Acronyms and Abbreviations

Biomark ABS	Biomark Applied Biological Services
CEM	channel evolution model
cfs	cubic feet per second
CHaMP	Columbia Habitat Monitoring Program
DASH	Drone-Assisted Stream Habitat
DSR	downstream reach rearing
ESA	Endangered Species Act
FTP	file transfer protocol
GR	geomorphic reach
HHS	hydraulic habitat suitability
HUC	hydrologic unit code
IRA	Upper Salmon Subbasin Habitat Integrated Rehabilitation Assessment
ISEMP	Integrated Status and Effectiveness Monitoring Program
LWD	large woody debris
MAT	minimum abundance threshold
MRA	multiple reach assessment
NRR	natal reach rearing
OSC	Idaho Governor's Office of Species Conservation
OSC Team	Biomark ABS fish biologists, Rio Applied Science and Engineering geomorphologists and engineers, Trout Unlimited biologists and project planners, The Nature Conservancy stakeholder outreach specialist, U.S. Bureau of Reclamation planners and technical QC, and OSC planners/managers
PBF	physical and biological feature
QRF	quantile random forest
RM	river mile
SEM	Stream Evolution Model
WUA	weighted usable area

Suggested report citation:

- Rio Applied Science and Engineering and Biomark, Inc. 2021. Lower Lemhi River Multiple Reach Assessment Report. Prepared with the Idaho Governor's Office of Species Conservation under Bureau of Reclamation Cooperative Agreement R19AC00078. April.

Executive Summary

The Idaho Governor's Office of Species Conservation (OSC) and an interdisciplinary team of partners created the Upper Salmon Subbasin Habitat Integrated Rehabilitation Assessment (IRA) (OSC Team 2019), which is a biologically based assessment of habitat conditions for spring/summer run Chinook salmon and summer run steelhead in the upper Salmon River subbasin in central Idaho. The IRA is a watershed-scale assessment that included detailed habitat capacity modeling and geomorphic response potential evaluations to identify key limiting physical and biological features affecting salmon and steelhead recovery. This lower Lemhi River Multiple Reach Assessment (MRA) is a companion to the IRA with a focus on reach-scale assessments in high-priority areas identified in the IRA. This MRA builds upon analyses from the IRA by incorporating finer-resolution data, observations from fieldwork, and reach-specific river and floodplain characteristic targets, which will inform future habitat rehabilitation actions.

This lower Lemhi River MRA includes the lower Lemhi River mainstem valley segment between Hayden Creek (River Mile [RM] 33) and its confluence with the Salmon River in Salmon, Idaho (RM 0). While the lower Lemhi River currently supports populations of Chinook salmon and steelhead, the stream ecosystem conditions need improvement. Findings from the biological assessment indicate that there appears to be sufficient adult spawning (redd) habitat capacity within the Lemhi River watershed to support recovery goals for Chinook salmon and steelhead. However, habitat capacity deficits were identified for Chinook salmon juvenile rearing during both summer (parr) and winter (pre-smolts) months. Given current data and results, findings suggest that available rearing capacity may need to be approximately tripled in both cases to provide sufficient habitat for recovery.

The primary biological objective in the lower Lemhi River valley segment is to increase rearing habitat capacity for both Chinook salmon summer parr and winter pre-smolts. By focusing on increasing capacity for juvenile Chinook salmon, our assumption is that capacity for juvenile steelhead rearing, during summer and winter months, will also be increased. Lower Lemhi River MRA biological objectives include the following:

- Increase the overall wetted braidedness throughout the lower Lemhi valley segment. This can be accomplished by increasing the overall frequency and diversity of flow splits in the main channel (i.e., many short, but some long side channels creating an island braided morphology), and/or increasing the sinuosity of the main channel.
- Increase the frequency of channel units (i.e., more pools with shorter riffles and glides, more pool-riffle interfaces), thus increasing the density of channel units within habitat reaches.
- Improve and increase base- and winter-flow fish cover quantity and quality including interstitial spaces of comparable size to juvenile fish (10s to 100s of millimeters) for concealment cover.
- Increase the structural and hydraulic diversity of available foraging locations. Similar to increased overall braidedness, this can be accomplished via increases in available off-channel and/or side-channel habitat with proximal access to the mainstem (i.e., a preference towards more, short side channels versus fewer, long side channels where appropriate).
- Increase availability of reduced water velocity (and increase diversity or standard deviation of available velocities) across a broad range of flows to decrease bioenergetic demands.

- Maintain or improve tributary connection and maintain or increase baseflow of the mainstem Lemhi River, most notably near and below current areas of adult spawning.
- Mediate temperatures through actions to increase hyporheic flow or riparian cover or both.

The lower Lemhi geomorphic objectives are focused on improving the physical processes that will result in habitat conditions necessary to improve salmonid production, growth, and survival. The restoration actions recommended for the lower Lemhi River geomorphic reaches are intended to encourage natural channel and habitat forming processes. While providing near-term functional and habitat benefits, the vision for the restoration actions is an evolution of geomorphic and habitat characteristics over annual and decadal time scales that will improve the factors limiting salmon recovery in the lower Lemhi River. Restoration treatments are intended to provide the following functional processes:

- Distribution of stream flow and energy among multiple channels and onto the floodplain, thereby reducing the available stream power concentrated into one primary channel
- Improved primary and secondary channel geometry (i.e., generally narrow and sinuous with a diversity of widths, depths, and structure)
- Increased floodplain connectivity and activation of secondary channels at multiple discharges (i.e., some activation during average peak flows and significant activation above the 2-year recurrence interval flood)
- Increased secondary channel abundance and diversity
- Increased hydraulic and structural diversity and complexity (i.e., greater diversity of depth and velocity with ample structure and cover)
- Increased density of native riparian plant communities (especially willow and cottonwood)

This lower Lemhi River MRA culminates in a restoration strategy that integrates resource protection, water management, process restoration, and habitat restoration. Identifying and describing this well-documented and scientifically accepted strategy in the context of the lower Lemhi is intended to facilitate its understanding and incorporation into future project development, prioritization, and implementation. For the lower Lemhi River, rehabilitation projects utilizing this strategy are generally intended to improve habitat complexity by restoring reaches that are currently unstable, straightened and over-widened, and contain artificially stabilized streambanks. Reaches with these characteristics should be restored into sinuous, multi-threaded channel systems with reduced width-to-depth ratios, while incorporating increased riparian tree- and shrub-dominated habitat to provide long-term structure and cover. This lower Lemhi River MRA includes reach-specific recommended actions as part of the restoration strategy.

The lower Lemhi River restoration strategy was developed by the OSC Team and regional partners with a vision to conserve and restore watershed and stream functions for the long-term benefit of native salmonids, especially Chinook salmon and steelhead. This vision includes advancing fish population recovery, in balance with the needs of agricultural producers and the local community. The restoration strategy will be implemented throughout the lower Lemhi River over the next several decades. The timeframe for implementing individual restoration actions will vary due to available financial and technical resources, available data and information, restoration prioritization needs, and restoration action opportunities. Within this restoration strategy, each action is viewed as a local building block that results in incremental improvements for achieving recovery and sustainability of fish populations. If desired, project development and/or coordination regarding these recommendations can be initiated by contacting the OSC Team and partners (see Contacts in the Lower Lemhi River).

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Section 1: Introduction

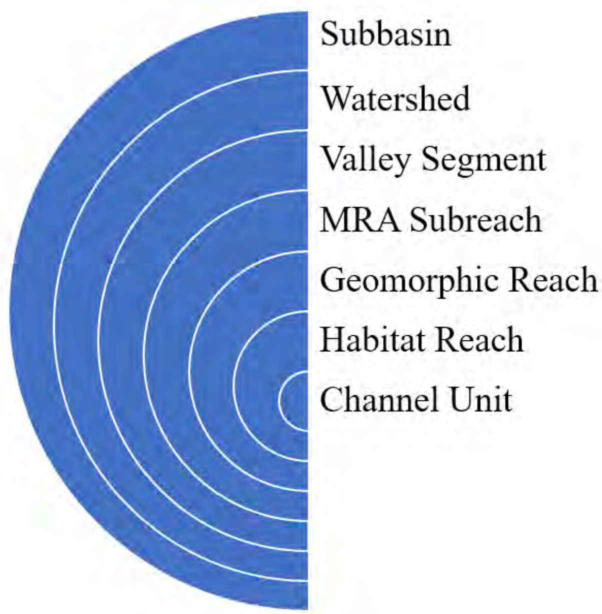
The Idaho Governor's Office of Species Conservation (OSC) and an interdisciplinary team of partners[1] created the Upper Salmon Subbasin Habitat Integrated Rehabilitation Assessment (IRA) (OSC Team 2019), which is a biologically based assessment of habitat conditions in the upper Salmon River subbasin in central Idaho for spring/summer run Chinook salmon (*Oncorhynchus tshawytscha*; hereafter Chinook salmon) and summer run steelhead (*O. mykiss*; hereafter steelhead) listed under the Endangered Species Act (ESA). The IRA is a watershed-scale assessment intended to identify key habitat issues causing life-stage-specific capacity limitations for ESA fish in the upper Salmon River subbasin. The IRA included habitat capacity modeling and geomorphic response potential that was used to identify key limiting physical and biological features affecting Chinook salmon and steelhead recovery. The IRA also provided an evaluation of potential impacts associated with climate-change-projected water temperatures. The next step is to perform reach-scale assessments (e.g., Multiple Reach Assessment [MRAs]) in high-priority areas identified by the IRA. These MRAs are intended to refine analyses from the IRA by incorporating finer-resolution data, fieldwork, and reach-specific rehabilitation targets, which will inform future habitat actions. This lower Lemhi MRA builds upon the IRA to develop more detailed biological and geomorphic characterization at the reach, subreach, and channel unit scale and directly support upcoming project work (Figure 1). The goal of this MRA is to help identify biologically based and geomorphically appropriate target conditions and solutions to capacity limitations identified in the IRA.

Like the IRA, this MRA focuses primarily on Chinook salmon and steelhead. The assessments and recommended actions primarily encompass the mainstem Lemhi River, while recognizing the importance of tributaries. Given the similarities in habitat needs for Chinook salmon and steelhead, the IRA framework assumes any habitat rehabilitation actions that occur to improve conditions for Chinook salmon will also improve steelhead habitat. The lower Lemhi River (Figure 2) was selected for analysis because its populations are critical to Chinook salmon recovery (NOAA 2017), and it is identified as a designated stronghold in the Nez Perce Fishery Management Plan 2013–2028 (Nez Perce Tribe 2013). The Lemhi River is roughly split in half, with the upper Lemhi (upstream of Hayden Creek) heavily influenced by the traits associated with groundwater hydrology and the lower Lemhi (below Hayden Creek) more heavily influenced by traits associated with predominantly snowmelt-influenced hydrology; the focus of this MRA is the lower Lemhi valley segment (which encompasses what the IRA refers to as the middle Lemhi and lower Lemhi valley segments). Due to limited available data, ESA-listed bull trout (*Salvelinus confluentus*) are outside of the scope of this MRA. Habitat rehabilitation actions to benefit Chinook salmon (and steelhead) would likely benefit (or do no harm to) existing bull trout populations, including both fluvial and resident populations.

Summarized below are the definitions used to characterize waterbodies in subsequent chapters listed from largest scale to smallest scale. These definitions are listed one time here to provide context for the remainder of the report and to reduce potential redundancy within each of the chapters that follow.

[1] The OSC Team consists of Biomark Applied Biological Services fish biologists, Rio Applied Science and Engineering geomorphologists and engineers, Trout Unlimited biologists and project planners, The Nature Conservancy stakeholder outreach specialist, U.S. Bureau of Reclamation planners and technical QC, and OSC planners/managers.

- **Subbasin**: Spatial unit delineated by 8th field Hydrologic Unit Codes (HUC-8) (i.e., medium-sized river basins) (e.g., upper Salmon upstream of Panther Creek)
- **Watershed**: Spatial unit delineated by HUC-10s (Lemhi, Pahsimeroi, and upper Salmon [upstream of Redfish Lake Creek])
- **Valley Segment**: Spatial unit delineated by HUC-10 confluences, identified based on where the HUC-10 watersheds interact with or are identified along a river (upper and lower Lemhi, upper and lower Pahsimeroi, and upper Salmon) (delineated in the IRA)
- **MRA Subreach**: Approximately 3–4 river kilometer reaches within each valley segment where finer-scale fish and habitat data were collected during summer 2018 to inform future prioritization and target conditions in the upper Salmon River subbasin. The spatial units were defined by the OSC Team and habitat data were collected using the Drone-Assisted Stream Habitat (DASH) protocol (Carmichael et al. 2019). The MRA subreaches generally fall within one geomorphic reach within each valley segment.
- **Geomorphic Reach**: Spatial unit delineated based on changes in measured valley confinement (entrenchment ratio), significant grade controls, and observed channel response characteristics (delineated in the IRA).
- **Habitat Reach**: An approximately 200-meter stretch of habitat made up of a set of consecutive stream segments (designated such that channel units were not interrupted) within the MRA subreaches. Fish and habitat data collected using the DASH protocol were paired at the habitat reach scale to estimate fish-habitat relationships; estimates of (QRF) capacity are made for a finer-scale assessment of habitat quality.
- **Channel Unit**: Specific physical features defining a habitat use area commonly delineated as pools, runs, riffles, and rapids, as well as small side channels and off-channel areas (Carmichael et al. 2019).



This MRA is intended to be a companion document to the IRA. Therefore, material previously reported in the IRA is incorporated by reference or briefly summarized, as needed.

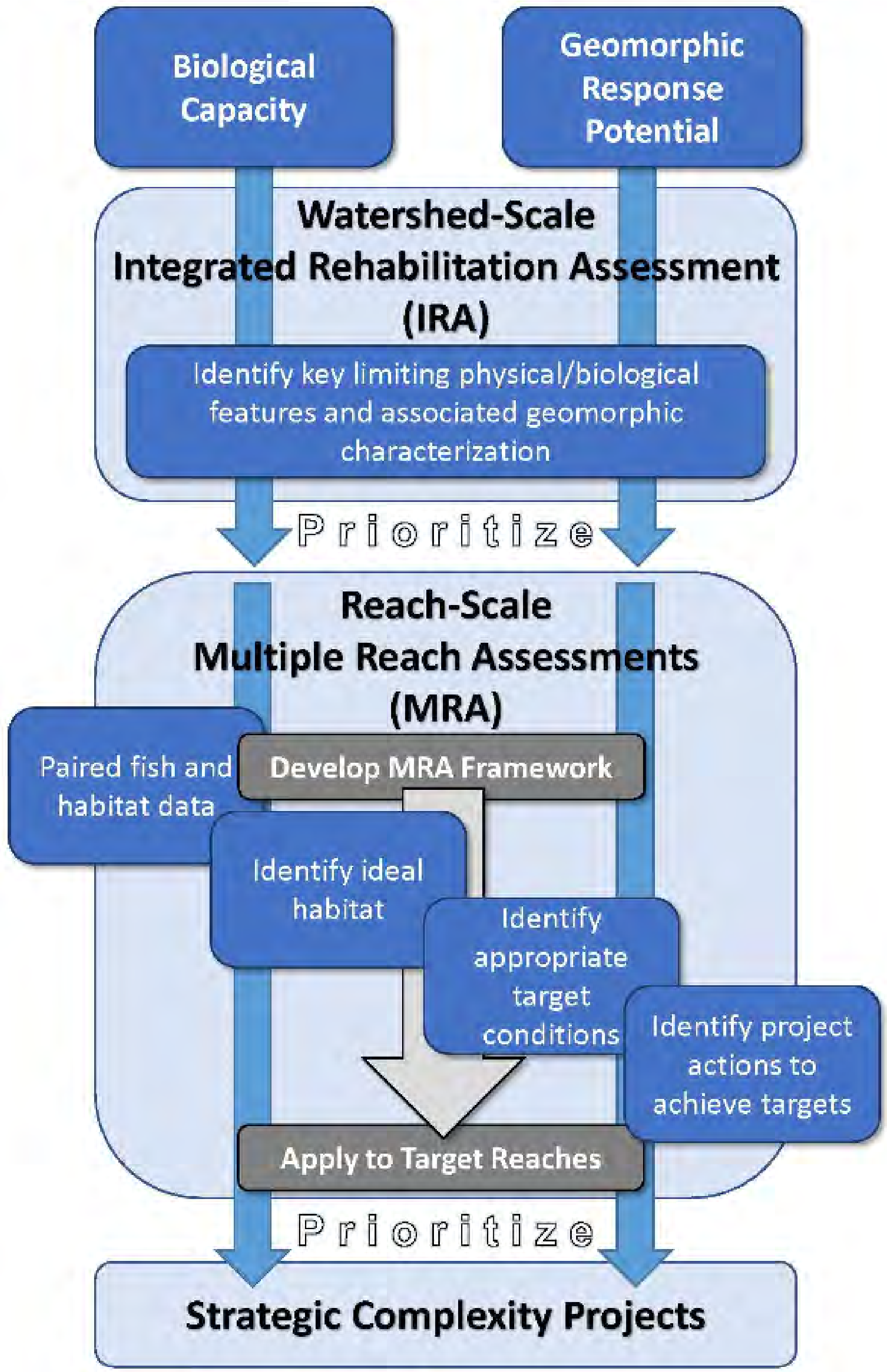


Figure 1. Flow chart illustrating the relationship of the Integrated Rehabilitation Assessment (IRA) and Multiple Reach Assessments (MRAs), including inputs and goals for the overall assessment framework.

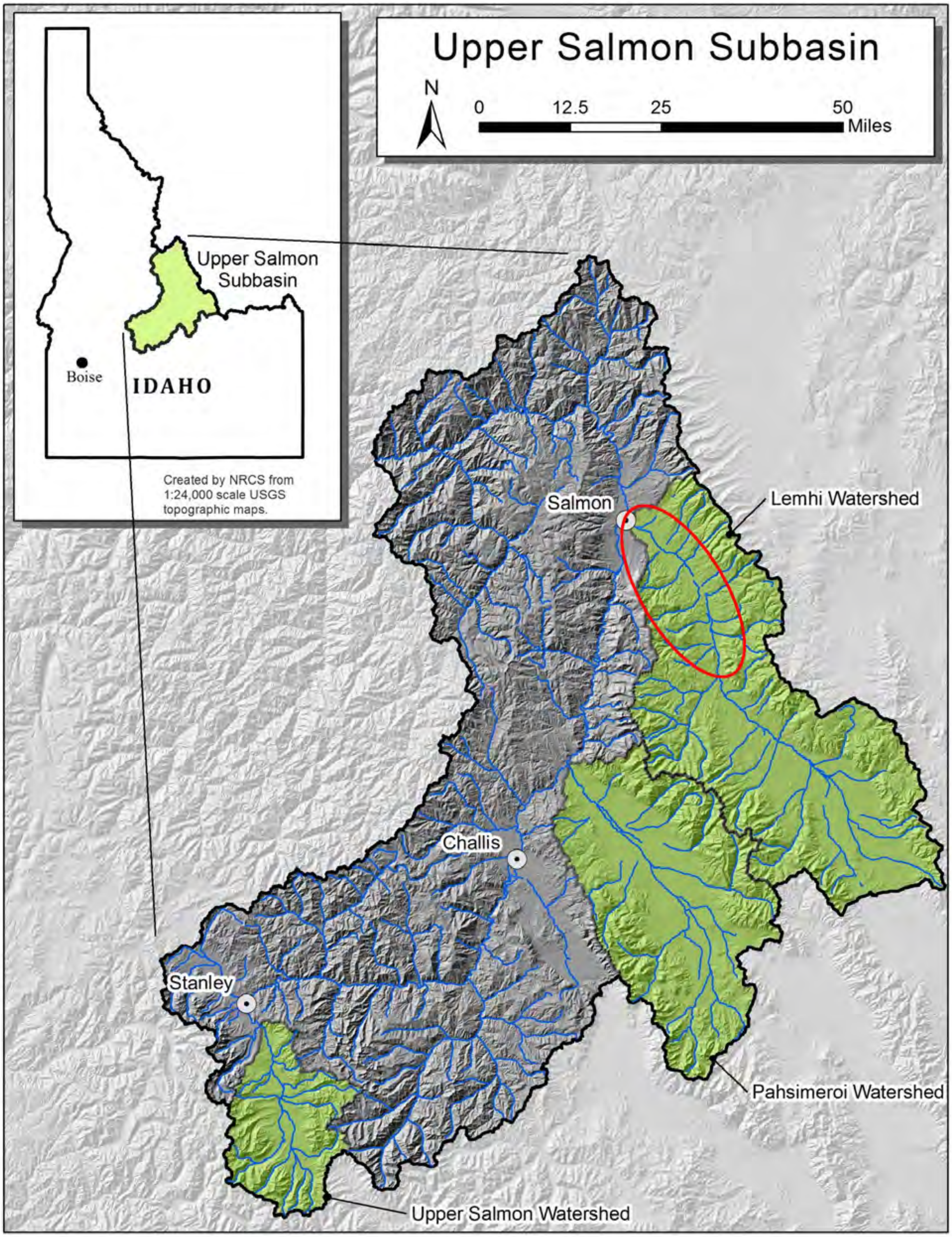


Figure 2. Location of the Lower Lemhi (red oval) within the upper Salmon River subbasin. (Source: OSC Team 2019)

Audience

This MRA is a reach-scale refinement of the IRA, developed through a combination of fieldwork and desktop analyses. The primary audience is Chinook salmon and steelhead habitat rehabilitation project sponsors and their design teams. Associated funders, regulators, partners, and stakeholders may also find information in this MRA useful for planning and resource management.

Goals and Objectives

The goal of this MRA is to provide concise, data-driven, quantifiable, and science-based guidance to inform prioritization and facilitate the development, implementation, and evaluation of Chinook salmon and steelhead habitat rehabilitation projects.

The objectives of this MRA are as follows:

- Briefly summarize species and life-stage capacity limitations for the valley segments (middle and lower Lemhi, jointly referred to as lower Lemhi in this MRA).
- Define species and life-stage habitat preferences.
- Assign/describe associated reach-specific habitat conditions.
- Identify and quantify reach-specific geomorphically appropriate target conditions (i.e., physical metrics).
- Identify and quantify reach-specific species and life-stage capacity limitations.
- Identify reach-specific habitat rehabilitation actions that are geomorphically appropriate, address capacity limitations, and meet habitat preferences.
- Describe data-driven "tools" available to inform prioritization and habitat preferences.
- Describe the design application, intent, and considerations for each identified habitat rehabilitation action.

Limitations

This MRA is a companion document to the IRA, which included a desktop-level assessment of the upper Salmon River subbasin. Fish mark-recapture and DASH (Carmichael et al. 2019) habitat surveys were completed at subreaches (approximately 3–4 river kilometers in length) within four IRA valley segments in summer 2018 to help inform subsequent MRAs (Biomark ABS 2019). All data sources and methods related to prioritization and target conditions, from a fish perspective, are described in supplementary documents with locations and hyperlinks provided herein (see Table 1). This MRA was not prepared for purposes of project construction bid development. See the Implementation Path section for next steps in the IRA and MRA process.

Section 2: Environmental Setting

The lower Lemhi valley begins at the confluence of the Lemhi River and Hayden Creek (the watershed's largest surface water tributary) and continues downstream to the Salmon River, including discharge from Kenney Creek and 10 other named tributaries (river mile [RM] 32.7 to RM 0.0). The upper boundary of the lower Lemhi valley segment includes the area of bedrock confinement from RM 25 to RM 34 that separates the upper and lower valley segments based on groundwater influence.

Compared to the upper Lemhi River, the lower Lemhi River below Hayden Creek has a steeper gradient, a more snowmelt/surface-flow-dominated hydrology, and greater coarse sediment availability from large tributaries. Historically, these characteristics promoted a more dynamic channel response enabling significant portions of the lower Lemhi River to migrate on a year-to-year basis, punctuated by episodic avulsions evident by meander scrolls and abandoned channels visible in aerial imagery and LiDAR. The regular natural disturbance supported the establishment of a cottonwood riparian forest and associated large woody debris recruitment, which collectively formed hard points throughout the floodplain, forcing and maintaining flow splits and lateral distribution of flow. The lower Lemhi River was therefore likely dominated by a primary mainstem channel with a seasonally active floodplain and large areas of island braiding where the floodplain was unconfined with a dense cottonwood riparian area obstructing and distributing flow laterally.

Lower Lemhi River rehabilitation actions to date have focused on improving instream flow during the irrigation season, as well as irrigation diversion consolidation screening, barrier removal for habitat access and tributary flow reconnection, and increasing floodplain and habitat complexity (Photograph 1).

Photograph 1. Example from a completed side-channel, floodplain connection, and bank/riparian improvement project from the lower Lemhi River (Eagle Valley Ranch Phase 3, completed in 2018).

The current environmental setting of the lower Lemhi River is provided in the sections below. Additional watershed and reach-scale data are provided in the IRA. The lower Lemhi River valley and geomorphic reaches are depicted on Figure 3.

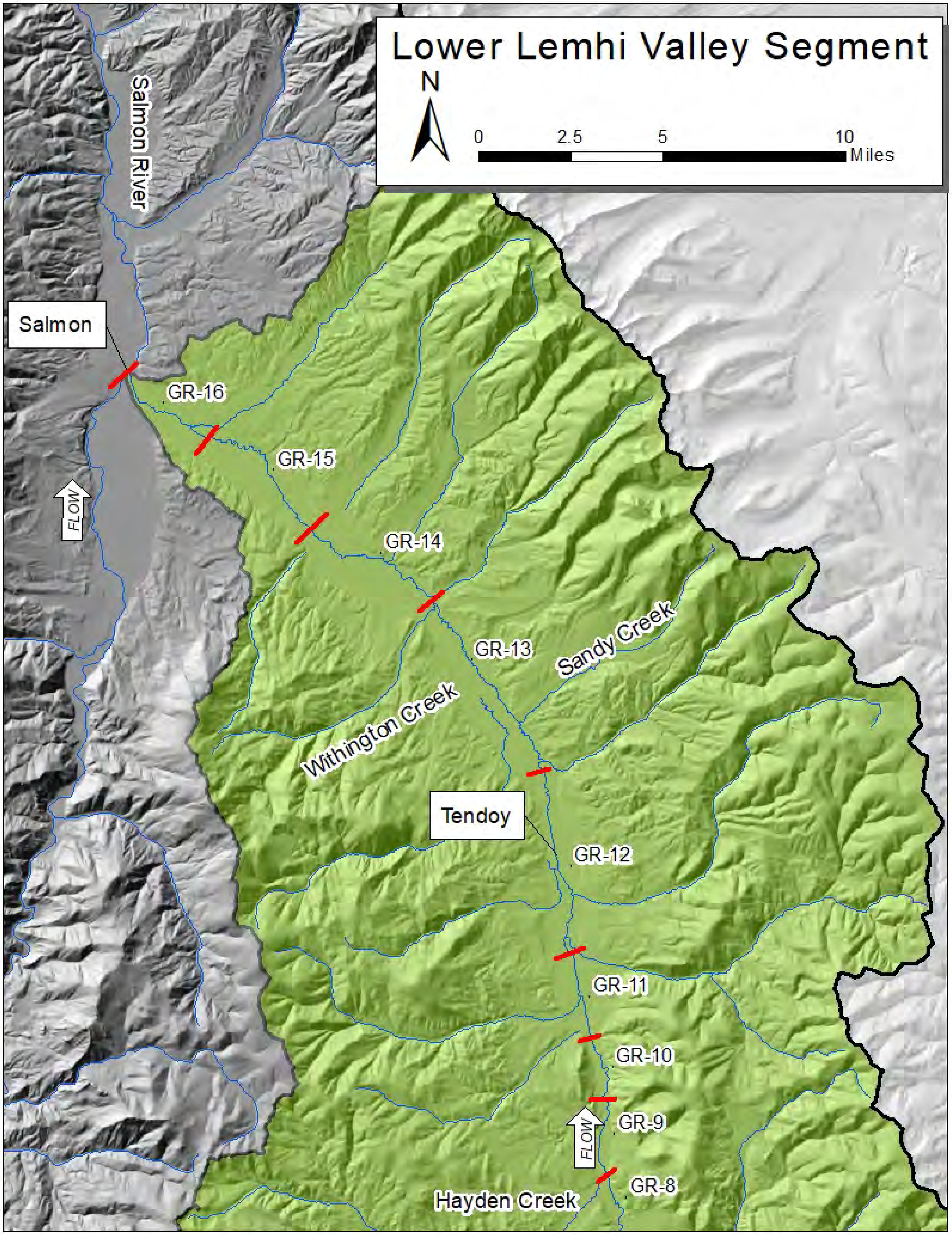


Figure 3. Lower Lemhi River valley segment and geomorphic reach locations.

Hydrology

The Lemhi River hydrologic regime is a complex interaction of snowmelt surface water flows, groundwater gains and losses, and an extensive network of irrigation diversions and returns. Most of the peak discharge events on the Lemhi River occur during the snowmelt runoff period of approximately May through June, while minimum base flows typically occur in August and September (USBR 2017). Groundwater recharge and discharge are significant components of the year-round water budget in the upper Lemhi River, while the Lower Lemhi (below Hayden Creek) is predominantly snowmelt-influenced hydrology. Groundwater levels are highest from May to September due to snowmelt and irrigation recharge (IDWR 2017, OSC Team 2019).

The magnitude and timing of lower Lemhi River flow is influenced by the management of water for irrigation purposes. Numerous irrigation diversions and returns exist along the lower Lemhi River and in its tributaries, with corresponding permitted water rights for a wide range of water volumes. There are 54 irrigation diversions with actively managed fish screens in the lower Lemhi River and tributaries, with legal water rights totaling approximately 525 cubic feet per second (cfs) (Idaho Department of Fish and Game fish screen database). The volume of streamflow diverted to irrigation varies throughout the irrigation season, ranging from approximately 517 cfs to 919 cfs. These irrigation diversions in the lower Lemhi River are in addition to the 47 irrigation diversions with actively managed fish screens in the upper Lemhi River and tributaries, with legal water rights totaling approximately 261 cfs (Idaho Department of Fish and Game fish screen database). Irrigation withdrawals generally occur between late April and early October, reducing peak flow discharge during the snowmelt runoff period and base flow discharge during the late-summer period. Irrigation withdrawal effects on reduced instream flows are most noticeable during the late-summer period when flows in the downstream reaches of the lower Lemhi River are less than flows in the upper reaches (USBR 2017).

These effects of irrigation withdrawals on Lemhi River flow are evident from analyses of annual hydrographs like that of 2014, a low-snowpack water-year (Figure 4). In this example, the estimated daily magnitude of irrigation withdrawals can be added to gaged stream flow to estimate an approximate natural hydrograph (Figure 5). The natural hydrograph of the Lemhi River is less affected during heavy-snowpack water-years like 2010 (Figure 6). It is also assumed that changes to channel form have affected the natural channel hydrograph not illustrated in these figures. For example, the modern channel has less floodplain activation resulting in less lag time and therefore potentially greater peaks in the hydrograph than historically when the channel was presumed to be multithreaded and connected to its floodplain providing greater flood attenuation.

Improvements to water management in the lower Lemhi River have been ongoing for several decades. Examples of these improvements include restoring surface water connections of Kenney Creek, Pratt Creek, and Bohannon Creek to the Lemhi River, and negotiated water rights agreements that result in more instream flow. Another example of these agreements is at the L-6 irrigation diversion near RM 7 on the Lemhi River, which makes it possible to maintain a 25 cfs minimum flow to improve fish habitat quality and provide late-season fish passage. Despite these and other improvements to irrigation water management, there remains the need for a more normative hydrologic regime in the lower Lemhi River to promote habitat formation and access, especially with consideration of expected climate change effects on water supply over the next several decades.

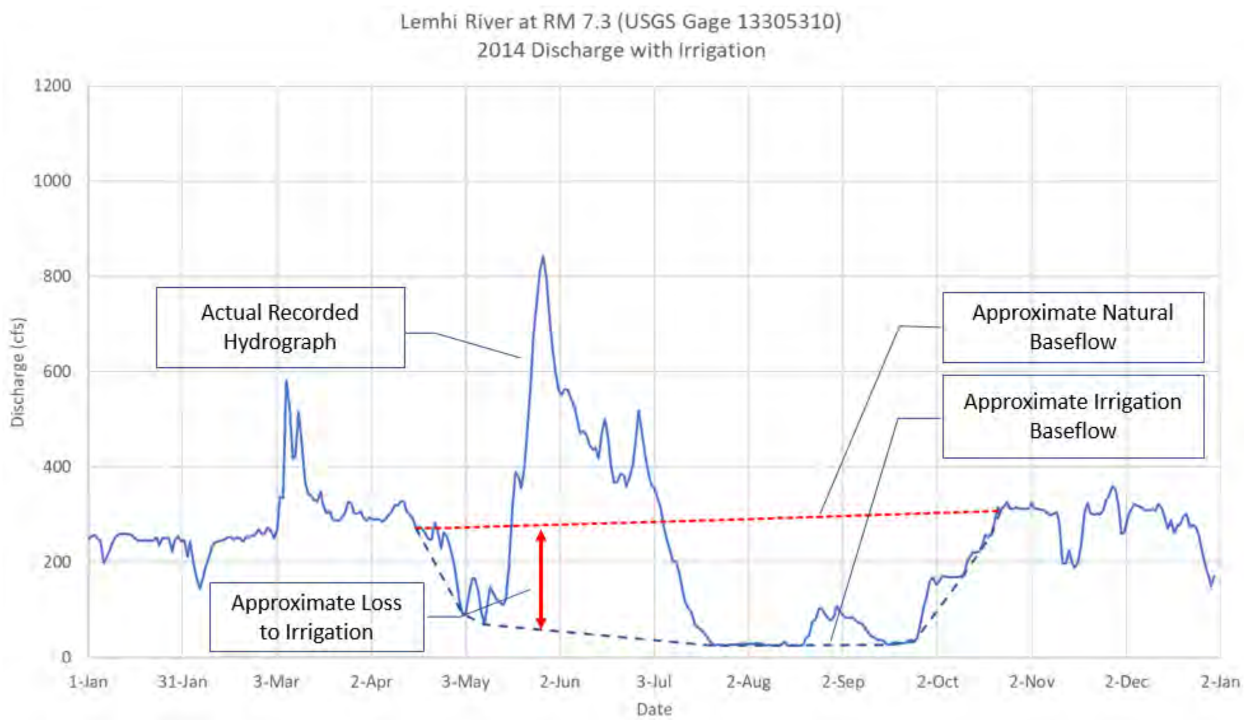


Figure 4. Annual hydrograph of the Lemhi River at RM 7.3 and estimated irrigation diversion magnitude.

Figure 5. Comparison of a low-snowpack water-year actual and estimated natural hydrograph for the Lemhi River at RM 7.3.

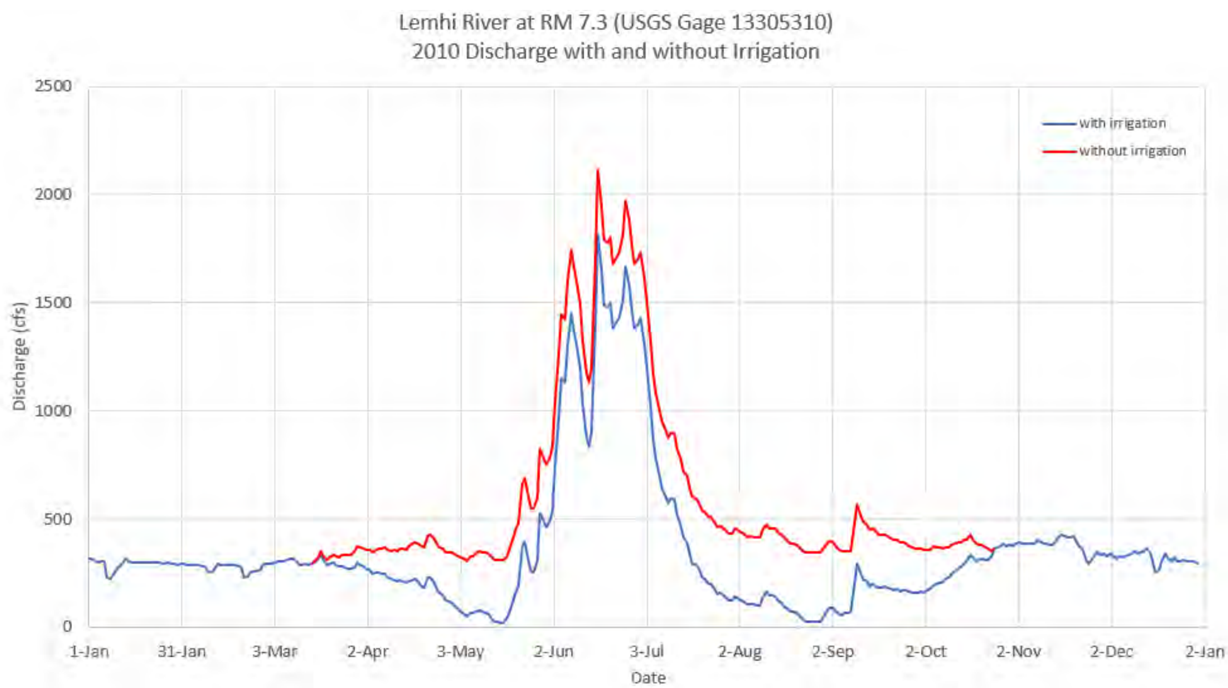


Figure 6. Comparison of a heavy-snowpack water-year actual and estimated natural hydrograph for the Lemhi River at RM 7.3.

Physiography and Geomorphology

The headwater streams of the Lemhi River basin are generally classified as sediment supply zones, dominated by weathering and erosion of steep slopes, where tributaries collect and transport sediment downslope to the alluvial fan zone. The alluvial fan zone is where coarse sediment has accumulated across broad alluvial fans and hillslopes, creating terraces along the valley margins. Here, the basin-fill sediments are porous, and the river commonly loses surface water to the aquifer. Unlike most streams, the Lemhi River exhibits a pronounced deposition zone (upper Lemhi) below the alluvial fan zone before entering a sediment transfer zone (lower Lemhi). Soils that have formed on these features range from floodplains, outwash fans, and fan terraces to loams, clays, and silts in the alluvial fans and stream terraces.

Historically, the upper Lemhi River banks were likely somewhat more stable than the lower Lemhi River due to the fairly flat, groundwater-influenced hydrograph and lack of coarse sediment input. However, both the upper and lower Lemhi were characterized by relatively stable banks and a low width-to-depth ratio enabled by dense riparian vegetation (willow shrubs and/or cottonwood) and a low gradient. Mature riparian vegetation provided bank structure along the outside of bends, forcing flow convergence that created pools with associated tail-out riffles. The flashier hydrology and increased coarse sediment load in the lower valley likely created a disturbance regime more suitable for the establishment and propagation of cottonwood and aspen trees, in addition to willows and other shrubs. It is likely that large woody material has been recruited to the lower Lemhi River via local windfall for thousands of years. Large floods and debris torrents from tributaries may have transported large wood from the uplands episodically, but research suggests that wood is unlikely to transport through such small streams with low channel width and meander radius of curvature (Braudrick and Grant 2001). Hayden Creek is likely the only tributary large enough to have consistently transported large woody material to the Lemhi River.

As reported in the IRA, it is believed that prior to beaver trapping and riparian clearing associated with Euro-American settlement, the vast majority of the Lemhi River riparian area and floodplain consisted of dense woody vegetation. Beginning in the 1800s through present day, riparian corridors have been converted to grassland and irrigated agricultural production areas, with discontinuous woody riparian vegetation resulting in bank instability, sedimentation, and high water temperatures (Trapani 2002). About 60% of the streambanks have woody riparian vegetation along the stream corridors, and about 40% of the streambanks have grassland along the stream corridors (Trapani 2002). Land clearing and livestock grazing have altered the riparian vegetation through consumption and soil compaction, resulting in the replacement of native sedge, willow, and cottonwood species with grass and other species that do not have the bank-stabilizing effects that natural woody riparian vegetation provides.

The width of the Lemhi River floodplain, as defined by the location of confining terraces and/or valley margin, is generally wide, ranging from approximately 1,400 to 2,800 feet (OSC Team 2019). However, the available floodplain width has been reduced by highway infrastructure and bank protection along the channel margins. Channelization and straightening in multiple locations have resulted in channel simplification and incision; however, ancient coarse-grained sediment underlying fine-grained floodplain soils across most of the valley bottom limits the magnitude and potential for widespread channel incision. The inability of the system to dissipate energy by mobilizing this ancient sediment on the bed has resulted in excess energy being forced downstream and onto the riverbanks. In the absence of dense, riparian vegetation (or riprap) that prevents erosion, bank recession has occurred, resulting in channel widening. Channel widening was observed via aerial photographs throughout the Lemhi River but was less pronounced in the lower compared to the upper Lemhi River. The channel confinement and straightening allow greater conveyance between the banks resulting in less over-bank conveyance during floods (i.e., less frequent floodplain inundation), less bedload sediment deposition and bar formation, and less scour potential for forming pools (i.e., more frequent plane-bed morphology).

Historically, the lower Lemhi River exhibited lateral channel movement via regular channel migration and abrupt channel relocation (called avulsion). It is believed that channel avulsion resulting from log jams and other instream obstructions historically created complex, multi-threaded channel forms. The presence or absence of dense, woody riparian vegetation influenced the direction and shape of avulsion channel formation in the Lemhi. The existing straightened and armored channel along with a lack of dense riparian vegetation and associated large woody debris flow obstruction has increased the hydraulic efficiency of the stream within the banks, reducing the frequency and magnitude of floodplain connection and associated off-channel habitat formation. Furthermore, without floodplain roughness in the form of dense vegetation, if new avulsion channels do form, they are more likely to be straighter and less complex than desired. This trend in channel evolution suggests an ongoing simplification of habitat if actions are not taken to reintroduce greater channel sinuosity, side channels, structure, instream obstructions, and riparian vegetation.

Channel planform on the Lemhi River is generally sinuous, with several channel segments that have been straightened adjacent to roads or other human features. Channelization, levees, the removal of riparian vegetation, and other human impacts on the Lemhi River have all but eliminated areas of island braiding and have significantly reduced sinuosity while increasing entrenchment of the channel. The reduction of riparian vegetation in many areas has led to areas of increased bank erosion, channel widening, and even more pronounced entrenchment.

Land Use and Human Impacts

The Lemhi River watershed covers about 1,260 square miles, and about 80% of the land is managed by the federal government and administered by the U.S. Forest Service and Bureau of Land Management.

Private lands are located predominantly along the more-fertile valley bottom. The primary land uses in the watershed include livestock grazing, irrigated pasturelands and hayfields, developed and dispersed recreation, and timber harvests. Livestock grazing occurs on both public and private lands across much of the middle and lower elevations in the watershed. Livestock typically graze on public lands from May to October and then return to private lands for the remainder of the year.

Land development and increased population density resulted in land clearing and manipulation for agriculture, livestock grazing, and infrastructure throughout the broad valley bottom. Most notably, a railroad was constructed down the valley bisecting much of the floodplain. The railroad grade was later converted to a road which ultimately became Highway 28. The road prism blocks floodplain access, cuts off many side channels and off-channel habitat, and many segments of the active river channel (and several tributaries) have been modified, straightened, and/or armored to accommodate the road prism (Figure 7). The Lemhi River passes beneath the road in many locations via individual bridges, which further confines the system by forcing any potential side channel, off-channel, and/or floodplain flow back into a single channel rather than allowing a broader distribution via multiple channels and bridges where appropriate.

Figure 7. Google Earth aerial image of the lower Lemhi illustrating significant channel straightening and confinement adjacent Highway 28.

Forested, higher-elevation areas along the Beaverhead Mountains and Lemhi Range have been relatively minimally impacted by human activities. Road density, timber harvests, and dispersed recreation have had minor impacts on the watershed as a whole. However, at middle and lower elevations, there are significant, localized human impacts that have negatively affected riverine processes. These impacts include, but are not limited to, flow alteration from irrigation diversions, loss of riparian vegetation, channel and floodplain alteration from roads, and increased fine-sediment deposition.

Excessive bank erosion and runoff from agricultural land use and grazing along the valley bottom have increased fine sediment inputs to the channel, as have roads and mining operations in the tributaries. Dense riparian vegetation had historically stabilized banks composed of fine sand and silt, which are now eroding and contributing sediment to the river on an annual basis. Cattle grazing has disturbed the surface of the floodplain and compacted the soils, both of which lead to more fine sediment runoff. Roads have been located adjacent to many of the tributaries where they have altered the riparian vegetation composition, compacted soils, and provide conduits for concentrated sheet flows during snowmelt and thunderstorms. Mining operations have included placer mining and exploratory trenches, especially in the foothills and headwater areas along the Beaverhead Mountains from Gilmore to Salmon. The cumulative effects of these impacts have likely increased fine-sediment inputs entering the Lemhi River system, resulting in elevated fine sediment levels and siltation.

Additionally, the existing influence from beavers has been severely limited as a result of legacy fur trapping. Limited evidence of beaver activity on the Lemhi River was observed during 2016–2018 fieldwork, suggesting population numbers remain extremely low, which is a marked difference from historical conditions. Beaver activity likely played a significant role in modifying and developing the historical Lemhi River morphology.

Fish Use

The Lemhi River maintains populations of three fish species listed under the ESA: Chinook salmon (*Oncorhynchus tschawytscha)*, steelhead (*O. Mykiss*), and bull trout (*Salvelinus confluentus)*. The watershed additionally supports native westslope cutthroat trout (*O. clarki lewisi*), which has been petitioned for listing under the ESA, a listing that was subsequently determined to be unwarranted. Data-driven prioritization “tools” and target conditions described in this report are focused toward Chinook salmon and steelhead, but the presence of bull and cutthroat trout should be acknowledged during implementation efforts. Further, it is assumed that actions to improve conditions for Chinook salmon and steelhead will improve (or do no harm to) conditions for bull and cutthroat trout.

Early reports of tribal fishing (Walker 1994) estimated Chinook salmon and steelhead harvest at 60,000 pounds per year in the Lemhi River and its tributaries. Historical harvest and abundance estimates, contrasted against contemporary adult fish returns, led the latest Snake River recovery plan (NOAA 2017) to identify a high-risk finding for Lemhi River Chinook salmon (population classified as “Very Large”). Whereas the Lemhi River steelhead were identified as being maintained (population classified as “Intermediate”), but insufficient data have that listing as “tentative.” NOAA (2017) delisting requirements include a minimum annual escapement (i.e., minimum abundance threshold or MAT) of 2,000 Chinook salmon adults and 1,000 steelhead adults to support recovery. The OSC Team (2019) added an additional 25% to that recovery goal to account for uncertainty and provide an additional buffer, resulting in adult escapement goals of 2,500 and 1,250 for Chinook salmon and steelhead, respectively.

Confounding the monitoring and recovery of the steelhead population in the Lemhi River is the presence of a sympatric, non-native coastal rainbow trout population in the watershed (Ackerman et al. 2012). Native steelhead in Idaho (and east of the Cascade Range) are the anadromous form of redband trout (*O. mykiss gairdneri*) whereas coastal rainbow trout (*O. mykiss irideus*) are native to the west side of the Cascade Range. Presumably, fertile coastal rainbow trout were stocked or transported into the area in past decades and a fluvial population has since become established in the Lemhi River. Introgression (i.e., genetic transfer) between native redband steelhead and coastal rainbow trout confounds status and trend monitoring in the watershed and has the potential to reduce fitness and productivity in the native steelhead population.

Identified Capacity Limitations

In the IRA, available habitat capacity estimated using the quantile random forest (QRF) approach (See et al. 2021) was compared to capacity requirements for recovery to identify potential capacity deficits for Chinook salmon and steelhead (Figure 8 and Figure 9).[2] These capacity deficits were flagged as "problems" to be addressed during the MRA phase. To summarize, there appears to be more than sufficient adult spawning (redd) capacity in the entire Lemhi River watershed (predominantly upstream of Hayden Creek and in tributaries) to support recovery goals for Chinook salmon and steelhead. However, capacity deficits were identified for Chinook salmon juvenile rearing during both summer (parr) and winter (pre-smolts) months, and that available capacity may need to be at least tripled in both cases to provide sufficient rearing habitat for recovery. Comparisons of available and required habitat for steelhead did not identify capacity deficits for juvenile rearing; however, capacity estimates were considered preliminary and may be greater because the modeled domain is larger than what is currently utilized by juvenile steelhead in the Lemhi River. Additionally, capacity assessments for steelhead did not account for non-native fluvial coastal rainbow trout that also occupy available habitat in the Lemhi River. Accounting for the non-native fluvial coastal rainbow trout would effectively reduce the available capacity estimated for steelhead. Further research is needed and ongoing; tentatively, juvenile steelhead rearing should be considered a potential limitation in the lower Lemhi River valley segment. Improving habitat for Chinook salmon juvenile rearing is hypothesized to also improve habitat for steelhead given the following:

- Sites with greater quantities of fish cover (large wood and other), including pools, supported higher observed densities of steelhead pre-smolts during winter months, which parallels Chinook salmon pre-smolts results.
- Sites with higher channel unit frequencies, including pools within sites with higher channel unit frequencies, tend to support higher juvenile pre-smolt densities for both Chinook salmon and steelhead (Product C in Table 1).

Finally, tributary habitat access should be considered (maintained or improved) for steelhead given their preference for tributary habitat over mainstem reaches and current tributary access for Chinook should be protected and maintained, or potentially expanded.

[2] QRF capacity estimates differ from extrapolation estimates in that they are not reliant on remotely sampled globally available attributes. Thus, QRF estimates provide a better understanding of how measured QRF metrics (e.g., cover, woody debris, discharge, etc.) relate to capacity.

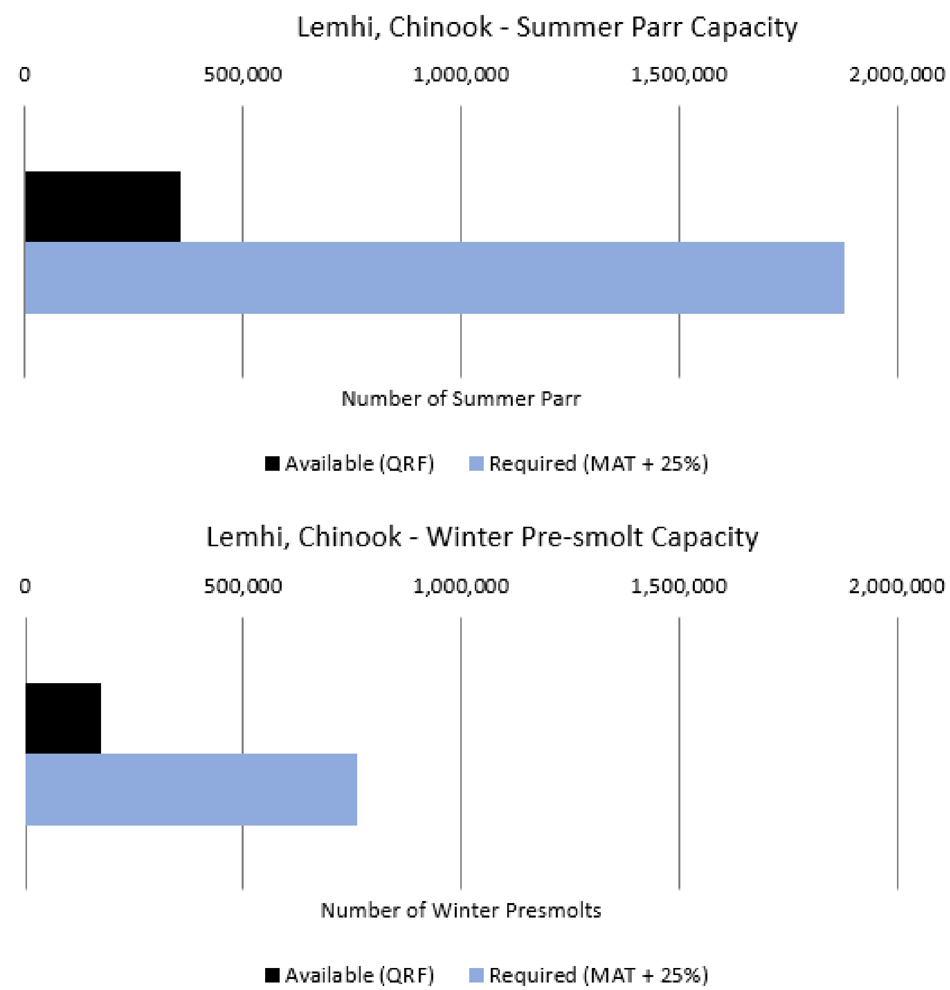
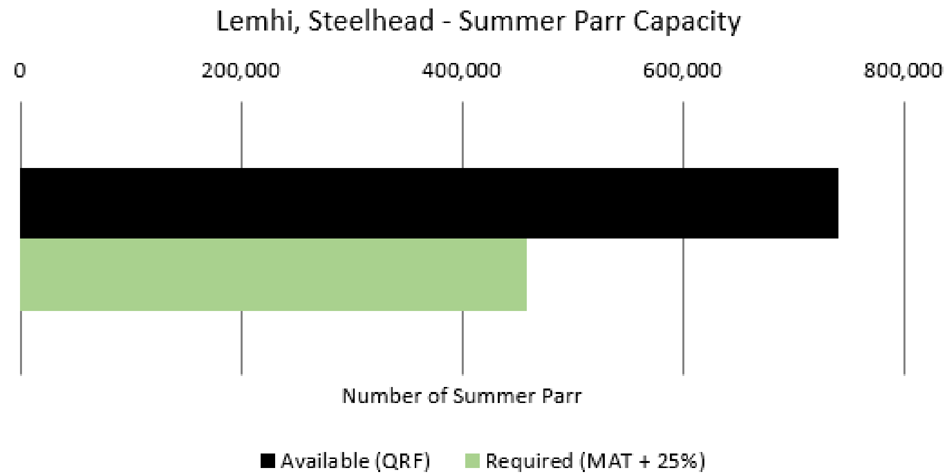


Figure 8. Estimated parr and pre-smolt capacity requirements (blue bars) to accommodate a minimum abundance threshold (MAT) plus 25% buffer to achieve recovery goals set forth by the IRA against estimated available capacities (QRF) (black bars) for Chinook salmon in the Lemhi River. The differences between the blue and black bars represent a capacity deficit.



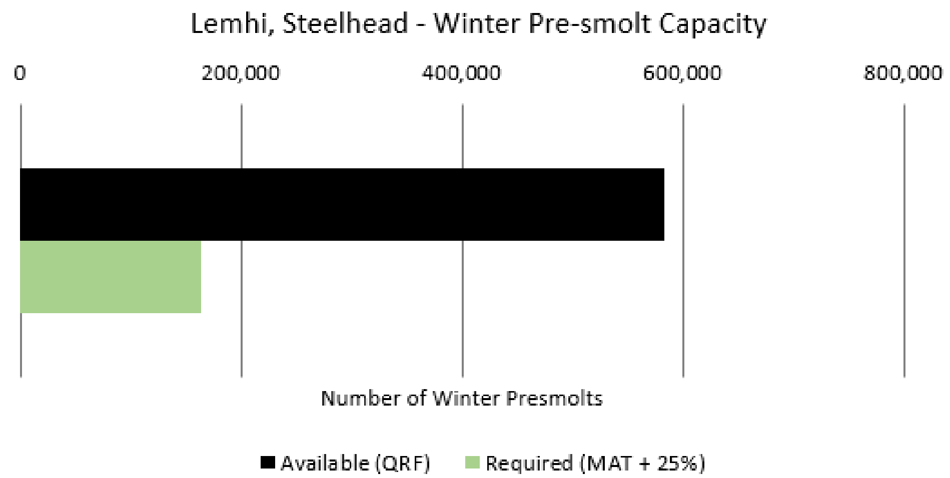


Figure 9. Estimated parr and pre-smolt capacity requirements (green bars) to accommodate a minimum abundance threshold (MAT) plus 25% buffer to achieve recovery goals set forth by the IRA against estimated available capacities (QRF) (black bars) for steelhead in the Lemhi River. The differences between the green and black bars represent a capacity deficit.

Ultimately, the key limiting feature for population productivity in the Lemhi River was identified as summer and winter juvenile Chinook salmon rearing downstream of current spawning habitat. Given current information, we suggest an initial goal to increase Chinook salmon parr and pre-smolt rearing habitat capacity approximately three-fold, relative to current conditions, to move toward population recovery (OSC Team 2019). Both parr and pre-smolt juvenile rearing capacity are considered as high-priority biological features limiting Chinook salmon production in the Lemhi River. Juvenile rearing habitat quality and capacity is especially important throughout the lower Lemhi River as offspring from all upstream spawning activities (upper Lemhi and Hayden Creek where the majority of spawning is observed) must spend at least some portion of their freshwater rearing life stage, including winter, in the lower Lemhi River prior to emigration to the ocean.

Section 3: Restoration Approach

The upper Salmon River restoration strategy is to protect and restore the health of upper Salmon River watersheds and river corridors for the benefit of salmon, trout, and other fish species of concern, as well as general ecosystem function. This document and restoration approach is focused specifically on salmon and steelhead, recognizing these are keystone species whose health is indicative of the larger ecosystem they inhabit (Hyatt and Godbout 2000; Cederholm et al. 2000). It is believed that improvements to keystone species will benefit the larger ecosystem as a whole (Paine 1966; Mills et al. 1993; Cederholm et al. 2000). Central to the restoration approach outlined in this document is the fundamental principle of determining what actions need to be done and in what locations to protect good salmon and steelhead habitat and restore poor habitat to a more productive condition. The complexity of the biological, physical, social, and economic systems within the upper Salmon River basin requires an approach that is integrative among these systems and adaptive as new information is developed.

The restoration strategy is based on the scientific principle of a hierarchy of ecological processes, whereby processes operating at the watershed scale (and over long time periods) create the form and function of the river corridor at smaller scales (and shorter time periods). In this hierarchical concept, the watershed scale geology, climate, and land cover control the form and function of the river corridor at the valley scale, which includes such elements as stream flow, floodplain inundation, channel migration, sediment transport, and water temperature. Both the watershed- and valley-scale controlling factors are responsible for shaping the river corridor characteristics at the smaller scale of the geomorphic reach and individual channel unit. The geomorphic reach and channel unit elements include such characteristics as channel size and shape, morphological units, substrate composition, large wood material, bank stability, and riparian vegetation.

Disruption of ecological processes at all of these spatial scales is responsible for the reduced functioning of river corridors, impairment of fish habitat, and loss of overall fish productivity. Disruption of ecological processes at the larger scales can affect the connectivity of rivers upstream and downstream, as well as the connectivity between rivers and their floodplains. These disruptions can also alter the delivery of water, sediment, wood, and nutrients from upper regions to lower regions of the watershed affecting the aquatic ecosystem and beneficial uses therein, including agriculture. Larger scale ecological process alterations are manifested as reduced habitat quantity and quality at the reach and channel unit scale, wherein spawning, rearing, and migration are compromised.

The lower Lemhi River restoration strategy is based on ecological processes across the range of spatial and temporal scales, as well as the disruptions affecting those processes. The strategy seeks to identify restoration opportunities that protect, restore, and enhance natural processes resulting in productive salmon habitat. This includes identifying opportunities to address disturbances of ecological processes ranging from the watershed scale to the individual channel unit scale. At the larger scales, this may include efforts to restore flow and sediment balances in an entire sub-watershed; while at smaller scales, it may include adding habitat complexity elements to individual channel units. A holistic approach of implementing restoration actions at a range of spatial scales and processes is viewed as a fundamental principle to restoring salmon productivity in the lower Lemhi River and upper Salmon subbasin. Implementation of these actions should be done in parallel, based on both prioritization and opportunity.

While many factors are considered in prioritizing and sequencing the implementation of restoration actions, the watershed restoration strategy generally follows the principles of process-based restoration (Roni et al. 2002; Roni et al. 2008; Beechie et al. 2008; Beechie et al. 2010). The ecological processes across spatial and temporal scales are evaluated, and the causes of disturbance that reduce salmon habitat quantity and quality are addressed. This framework includes four elements prioritized based on their effectiveness at addressing the fundamental ecological processes responsible for creating and maintaining highly functional habitat. When considering new projects, restoration planners must also consider how effectively each element can address the type(s) and magnitude of impacts within their specific project area(s) and the level to which each element has already been addressed based on past rehabilitation efforts. For this reason, we refer to the following elements as a "strategy for sequencing stream rehabilitation techniques" (Roni et al. 2008):

- **Protection –** Protect the things that are already working and/or prevent further degradation.
    - Often the first step in a habitat restoration strategy is protecting areas where the ecological processes are highly functioning across the range of spatial and temporal scales. Areas of particularly important biological productivity, such as spawning and rearing areas, are also candidates for protection. Protection and conservation could also be afforded to those areas with the greatest potential for restoring ecological processes, regardless of their present condition**.**
- **Water –** Ensure sufficient water for habitat- and channel-forming processes.
    - Protecting, enhancing, and restoring stream flows and water quality in tributaries and the Lemhi River is important in maintaining and improving ecological processes across the range of spatial and temporal scales. Minimum low flows are required for fish passage, habitat, and water quality, while appropriate high flows (both frequency and magnitude) provide appropriate erosion and deposition required to create and maintain habitat within the riverine environment.
- **Restore Process –** Enable the river to create and maintain complex habitat.
    - Connectivity of both biological and physical processes is an important component for restoring salmon productivity in the Lemhi River and tributaries. Biological process connectivity includes habitat continuity creating links among habitat types within stream reaches (connectivity among diverse habitat types such as main channel, side channel, and floodplain) and among migration routes by removing passage barriers. Physical process connectivity targets the restoration of natural flow regimes, sediment, wood, and nutrients upstream to downstream, and among the primary river channel and side channels, by removing barriers to these exchange processes.
- **Restore Habitat –** Create complex habitat forms appropriate for the specific area.
    - Often referred to as "habitat creation," when it is not feasible for the river to restore itself in a timely manner, it may be necessary to create appropriate target conditions that the river can then maintain. Improving instream habitat therefore generally focuses on increasing local habitat quantity or quality through treatments that are focused on the symptoms of degradation rather than fundamental ecological processes. Adding instream structure in conjunction with or independent of the rehabilitation approaches prioritized above, is an effective means of increasing habitat complexity and overall habitat capacity but may not represent a long-term solution if the underlying cause of degradation is not also addressed.

Application of the Restoration Strategy

The restoration strategy is applied in practice around the following key questions:

- What is the existing vs. potential salmonid distribution and abundance during different life stages?
- What habitat conditions are currently limiting salmonid production, growth, and survival?
- What impacts to ecological processes are causing degraded habitat conditions?
- What opportunities exist to protect, enhance, and restore ecological processes and habitat conditions to improve salmonid production, growth, and survival?

For each reach in this lower Lemhi River MRA, these key questions are addressed in a four-step process:

1. Evaluation of fish life history needs/preferences (biological evaluation)
2. Identification of habitat limiting factors (biological evaluation)
3. Identification of restoration needs to improve habitat conditions and ecological processes (biological and geomorphic evaluation)
4. Identification of resource management practices and actions to address the restoration needs (restoration actions)

Reach Assessments

The restoration strategy for the lower Lemhi River is primarily a biologically focused effort to identify actions that will foster Chinook salmon and steelhead recovery. This focus was applied through a biological evaluation of fish habitat preferences and conditions for targeted life stages (adult spawning, juvenile summer and winter rearing) in the lower Lemhi River. Recognizing that physical habitat conditions are largely the result of geomorphic processes, a geomorphic evaluation was completed to help identify the restoration actions necessary to improve habitat conditions and ecological processes.

Biological Evaluation

Our biological evaluation is founded on watershed-level results from the IRA, years of experience with legacy fish-habitat datasets in the Pacific Northwest (i.e., the Columbia Habitat Monitoring Program [CHaMP] and the Integrated Status and Effectiveness Monitoring Program [ISEMP]), a literature review of target or preferred habitat conditions for Chinook salmon and steelhead at multiple life stages, a legacy dataset of redd site selection collected over recent decades, a stream temperature dataset available from NorWeST (Isaak et al. 2017), and information on species-specific temperature preferences and thresholds (Carter 2005). We built on those foundations using newly available data for the upper Salmon subbasin, including paired fish and habitat data collected during summer 2018 (DASH, mark-recapture abundance estimates) and bathymetric LiDAR-supported 2-dimensional (2D) hydraulic modeling and resulting multivariate habitat suitability analysis.

Table 1 summarizes the fish and habitat data sources and products used to either support prioritization efforts or describe target habitat conditions. The table includes species, life stage, watershed that each applies to, and the resolution or spatial coverage of application. Each product can be accessed via hyperlink to a live version that users can download for further information. Those products may be updated in the future as additional data become available or further information or inference is required and time allows. In addition, timestamped and stable versions of those products have been saved to the

OSC file transfer protocol (FTP) site at the time of writing of this document and are available for download. Those products contain more detailed and thorough methods, results, and contact information for the authors if questions arise. Within this MRA document, we provide a concise summary of tools currently available to inform prioritization efforts and provide our data-driven and science-based biological recommendations based on the primary lessons learned from those products.

Table 1. Fish and habitat products table summarizing data sources and evaluations available for prioritization and description of target habitat conditions for Chinook salmon and steelhead in the MRA watersheds.

ID	Product	Species	Life Stage	Watershed	Application	Location	Resolution/Spatial Coverage	Description
A	Literature Review	Chinook, steelhead	spawning, incubation, parr, pre-smolt, emigration	Lemhi, Pahsimeroi, upper Salmon	Target Conditions	MRA litreview GitHub Repo	Watershed	A literature review summarizing target conditions for Chinook salmon and steelhead. References are included within and are largely from the Pacific Northwest.
B	QRF Capacity	Chinook, steelhead	parr, pre-smolt, spawning	Lemhi, Pahsimeroi, upper Salmon	Prioritization, Target Conditions	MRA QRF GitHub Repo	Global model = 1km Habitat reaches = ~200m	A summary of findings from quantile random forest (QRF) habitat capacity models applied at MRA subreaches and watersheds.
C	CHaMP Q4	Chinook, steelhead	parr, pre-smolt, spawning	Lemhi, Pahsimeroi, upper Salmon	Target Conditions	champ Q4s GitHub Repo	Watershed	Exploring sites in the CHaMP habitat dataset with fish densities in the highest quartile (Q4). Do certain habitat characteristics stand out as associated with higher densities?
D	Depth & Velocity HSI	Chinook, steelhead	parr, pre-smolt, spawning	Lemhi, Pahsimeroi, upper Salmon	Prioritization, Target Conditions	mra hsi GitHub Repo	1m to watershed	Depth, velocity, and composite suitability for spawning and juvenile rearing based on LiDAR 2D supported numerical model results.
E	2018 MRA Observed Fish-Habitat Data	Chinook, steelhead	parr	Lemhi, Pahsimeroi, upper Salmon	Prioritization, Target Conditions	MRA QRF GitHub Repo	200-300m reaches to watershed	Lessons learned from fish and habitat data collection at the MRA subreaches in summer 2018.
F	Lemhi Hydrograph Evaluation	Chinook	incubation, fry, pre-smolt	Lemhi	Prioritization, Target Conditions	mra fish n hydro GitHub Repo	Watershed	A closer look at available hydrograph data in the Lemhi River and how changes in the hydrograph correspond to fry emergence or pre-smolts emigration timing.
G	Observations from Lemhi Fish Crews	Chinook, steelhead	parr, pre-smolt	Lemhi	Target Conditions	mra_lemhi_juv_obs GitHub Repo	Watershed	Lessons learned from fish crews sampling in the Lemhi River over the past decade.
H	Redd & Temperature Evaluation	Chinook, steelhead	all	Lemhi, Pahsimeroi, upper Salmon	Prioritization, Target Conditions	mra redds norwest GitHub Repo	1km	A spatially and temporally explicit assessment of stream temperature data and species-specific temperature thresholds; includes redd geolocation information.
I	Deadwater Predation Assessment	Chinook	pre-smolt	Lemhi, Pahsimeroi, upper Salmon	Prioritization	deadwateR GitHub Repo	N/A	Assessment of predator abundance in the Deadwater Reach on the mainstem Salmon River and potential impacts to local Chinook salmon populations.
J	*O. mykiss* Intogression	steelhead	all	Lemhi, Pahsimeroi	Prioritization	Ackerman et al. (2012) Appendix C	Watershed	Potential impacts of coastal rainbow trout *O. mykiss irideus* introgression in native redband *O. mykiss gairdneri* steelhead trout populations.

Geomorphic Evaluation

In keeping with the principles of a process-based restoration strategy, a functional approach to identifying the fundamental causes of habitat limiting factors was applied through reach-scale assessments. Stream function assessments are commonly used to determine aquatic habitat conditions and restoration opportunities (Somerville 2010; Palmer et al. 2014). The functional approach used for the lower Lemhi restoration strategy was based on an adaptation of the concepts developed for a range of physical settings (Fischenich 2006; Sear et al. 2009; Somerville 2010; Cluer and Thorne 2014; Fryirs 2015) and generally followed the framework proposed by Harman et al. (2012).

The lower Lemhi River restoration strategy focuses on process-based restoration which is assessed by evaluating functions in four primary categories: hydrology, hydraulics, geomorphology, and vegetation (Table 2). These functional categories represent the primary watershed- and reach-scale processes responsible for determining the health of stream ecosystems. Each category is comprised of one or more functional parameters that are used to quantify or describe the status of each functional category. The functional parameters are evaluated using functional metrics that are measured or calculated from available data and modeled at the reach scale. The metrics are quantifiable attributes associated with one or more functional parameter and can be used to directly or indirectly evaluate the status and trend of stream function.

The data available for this assessment was limited to readily available geospatial data, hydraulic model results, and information available from existing reports, including biological and geomorphic information from the IRA (OSC Team 2019). There were no new data collected from field-based habitat surveys or geomorphic measurements. The hydraulic model results were based on a 2D modeling domain that was limited in extent to an area just outside the primary channel throughout much of the lower Lemhi River. The model results may not be suitable for estimating secondary channel activation and floodplain connectivity within all reaches. However, the model results are appropriate to use for planning-level and reach-scale analyses. Additional topographic and bathymetric surveying, along with additional 2D hydraulic modeling, is recommended for evaluating hydraulic characteristics of restoration projects at the subreach and project site scales.

The functional metrics were scored on a scale of 1 (absent/dysfunctional) to 3 (abundant/fully functional) and in the context of the geomorphic setting and corresponding expected conditions within a given reach. Each functional parameter value was calculated as the sum of functional metric scores normalized to the total possible score for the parameter, resulting in a functional parameter score on a scale from 0.0 (absent/non-functional) to 1.0 (abundant/fully functional). Functional category values were calculated as the average functional parameter scores, and overall reach functionality was estimated as the average of functional category scores. This approach helps identify the fundamental drivers of overall reach functionality and fosters comparability of functionality among reaches (Langhans et al. 2013).

Table 2. Functional metric evaluation guidelines. Functional metrics were evaluated and scored based on available data and professional judgment. The metrics were scored on a scale of 1 (absent/dysfunctional) to 3 (abundant/fully functional), and in the context of the geomorphic setting and corresponding expected conditions within a given reach. The metrics were summarized at the reach scale for all reaches.

Functional Category	Functional Parameter	Functional Metric	Evaluation Guidelines
Hydrology	Hydrologic connectivity	Alterations to tributary connectivity	Fully functional tributaries should have unimpeded connectivity with the mainstem channel and/or secondary channels for fish migration and the supply of water, sediment, and wood. Anthropogenic impacts such as land use, stream diversions, and road crossings can limit connectivity.
		Alterations to floodplain hydrology	Fully functional floodplains typically have wetlands, wet meadows, and other low-elevation areas to store and transfer surface water and groundwater to and from primary and secondary channels on the floodplain. Land use impacts that result in disconnection from channels, filling and/or conversion to agricultural lands can limit the functionality of these areas.
		Alterations to instream flow	Increases in the number of stream diversions and the volume of water diverted results in reduced hydrologic functionality.
Hydraulic	Floodplain connectivity	Inundated area	Fully functional floodplains typically become initially inundated at discharges approximating the 50% annual chance peak discharge (2-year peak flow), with the area of inundation increasing as discharge increases. The proportion of available floodplain area inundated by a range of flood discharges is a good indicator of functionality.
		Secondary channels	The functionality of secondary channels increases as the number, length, and number of connection junctions of secondary channels increases.
	Hydraulic diversity	Depth variability	A large range in depth variability increases the hydraulic functionality. Depth variability can be indicated by roughness characteristics and diversity in longitudinal, cross-sectional, and planform dimensions.
		Velocity variability	A large range in velocity variability increases the hydraulic functionality. Velocity variability can be indicated by roughness characteristics and diversity in longitudinal, cross-sectional, and planform dimensions.

Table 2. Functional metric evaluation guidelines. Functional metrics were evaluated and scored based on available data and professional judgment. The metrics were scored on a scale of 1 (absent/dysfunctional) to 3 (abundant/fully functional), and in the context of the geomorphic setting and corresponding expected conditions within a given reach. The metrics were summarized at the reach scale for all reaches.

Functional Category	Functional Parameter	Functional Metric	Evaluation Guidelines
Geomorphology	Large woody material transport and storage	Wood accumulation abundance	The functionality of wood loading increases as the abundance of wood accumulations (e.g., jams, beaver dams) comprised of all sizes of woody material increases.
		Wood piece abundance	The functionality of wood loading increases as the abundance of individual wood pieces increases. Individual pieces can be indicated by streamside recruitment or supply from upstream.
	Channel migration	Lateral stability	Fully functional channels have bank erosion rates and locations that are consistent with the geomorphic setting. These conditions are generally indicated without signs of channel expansion or artificial bank armoring.
		Floodplain alterations	An increase in anthropogenic alterations of the floodplain generally corresponds to decreased floodplain function.
	Channel planform	Sinuosity of channels	Fully functional channel sinuosity is in the range expected for the geomorphic setting, including the bedload texture and sediment transport regime.
		Bed form diversity	Fully functional channels have a diverse assemblage, pattern, and condition of geomorphic units (e.g., pool, riffle, run, step, cascade, depositional bars).
	Bed character	Sediment transport regime	Fully functional channels have a sediment transport regime (storage, transport, supply limited, capacity limited) consistent with the geomorphic setting, without indications of excessive aggradation or degradation.
		Grain-size distribution	Full functionality is indicated by grain-sizes, sorting, and spatial distribution among geomorphic units that is consistent with the geomorphic setting, including the sediment transport regime.
Vegetation	Riparian plant community	Riparian abundance	Fully functional riparian zones have plant community composition comprised of natural expected vegetation, and in abundance/density consistent with the geomorphic setting.

Channel Evolution Conceptual Model

The channel evolution model (CEM) concept has been used for more than 40 years to help understand the morphological responses of rivers to a range of disturbances (Schumm 1977; Schumm et al. 1984; Doyle and Shields 2000; Simon and Rinaldi 2006; Van Dyke 2013; Cluer and Thorne 2014), including river restoration treatments. These models foster a conceptual understanding of how channels may evolve through a sequence of phases based on characteristics common to rivers in similar physiographic settings.

The application of classic CEMs focuses on qualitative state transitions at large spatial and temporal scales such as systemic channel incision, not short-lived or localized process changes such as individual pool scour. These qualitative changes refer to the channel planform and geometry undergoing significant reach-scale modifications. The development of CEMs helps identify the processes driving morphological changes such as aggradation, degradation, and fluctuations in available stream power. The classic CEMs partition channel evolution into a discrete set of five or six stages along a linear trajectory, with each state being defined by characteristic processes and forms (Schumm et al. 1984; Simon and Rinaldi 2006).

The classic CEM concept has been adapted into a Stream Evolution Model (SEM) by Cluer and Thorne (2014). The SEM approach adds three channel evolution stages to the original CEMs and represents channel evolution as cyclical rather than a linear trajectory (Figure 10). The concept of cyclical channel evolution explicitly recognizes that a reach may experience repeated episodes of degradation, widening, and aggradation without crossing a geomorphic threshold toward another stage of evolution. The SEM approach also provides a framework for linking the evolutionary stages of stream adjustment to indicators of habitat and ecosystem benefits (Cluer and Thorne 2014).

The CEM and SEM stages were developed based on decades of quantitative data and qualitative observations regarding river process-form linkages. The CEM and SEM propose that channels respond in a predictable, sequential manner, depending on the physiographic setting, disturbance regime, and subsequent stage of channel evolution. This framework has been applied to the lower Lemhi River geomorphic reaches by interpreting the available data on channel morphology, hydraulics, sediment transport, previous restoration treatments, and recommended actions. The potential channel evolution of the lower Lemhi River geomorphic reaches is described in Sections 4 and 5.

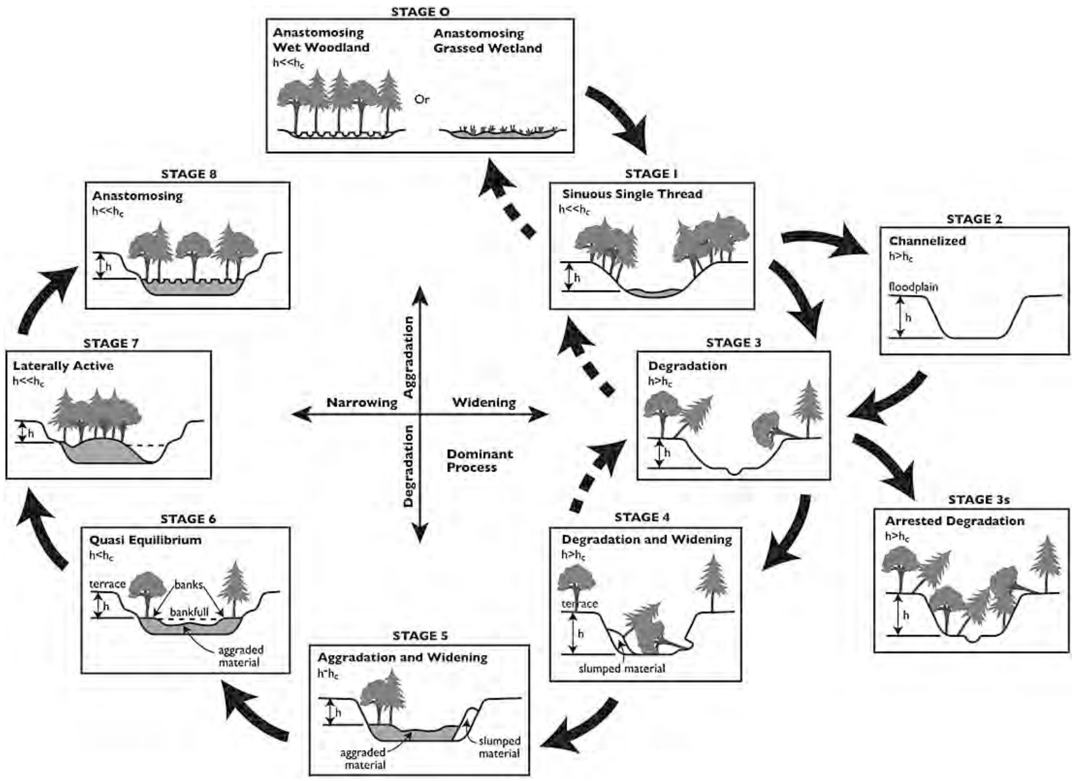


Figure 10. Cyclical Stream Evolution Model presented by Cluer and Thorne (2014).

Section 4: Assessment Summary

This section summarizes findings from the biological and geomorphic assessments used to inform the following recommendations for target conditions and restoration actions. The biological summary provides a summary of key findings from the fish-centric products in Table 1. The geomorphic summary helps identify the fundamental drivers of fish habitat conditions and overall reach functionality in the four primary categories of hydrology, hydraulic, geomorphology, and vegetation.

Biological Summary

The lower Lemhi River currently functions primarily as a juvenile rearing catchment from the upstream spawning areas in the upper Lemhi (Rio ASE and Biomark, Inc., 2021), Hayden Creek, and their tributaries. Chinook salmon in the Lemhi River have two life history strategies: (1) natal reach rearing (NRR) in which juveniles overwinter in the Lemhi before emigrating to the mainstem Salmon River the following spring, and (2) downstream reach rearing (DSR) in which juveniles leaves the Lemhi River during fall of their first year and overwinter in the mainstem Salmon River before emigrating to the ocean (e.g., Copeland et al. 2014). It is hypothesized that poor overwinter habitat in the lower Lemhi, along with an increase in discharge when summer diversions are closed, may signal emigration, and potentially drive artificial selection for DSR. Yet, maintaining both life history strategies may be evolutionarily important in case one of the strategies is more susceptible to environmental or anthropogenic events, increasing resilience of the population.

Regardless of emigration timing, maximizing body condition along with parr and pre-smolt survival in the lower Lemhi should be a focus for restorative actions. The goal in the lower Lemhi River valley segment should be to provide optimal rearing conditions for juveniles emigrating from the upper watershed as fry, pre-smolts, or smolts; increase survival for all juvenile life stages; and provide opportunities of individuals to maximize body condition prior to the decision to migrate downstream either as pre-smolts (during fall) or smolts (the following spring).

Summer stream temperatures in the Lemhi River, especially in the lower valley segment, can exceed optimal and even approach maximum thresholds for spawning and juvenile rearing especially during low flows (Figure 11, product H in Table 1). Similarly, stream temperatures during winter are often below optimal for juvenile rearing, which is exacerbated by stream velocities above suitable for Chinook salmon and steelhead through much of the lower Lemhi (product D in Table 1). Stream temperature moderation during extreme months (via increased shade and hyporheic flow resulting from restored sinuosity and braidedness) would increase odds of survival and improve individual body condition, improving juvenile rearing conditions for the entire Lemhi population, most notably in the lower valley segment. Additional stream temperature summaries by species, life stage, and river kilometer are available in product H in Table 1. Habitat suitability maps are provided in Appendix A.

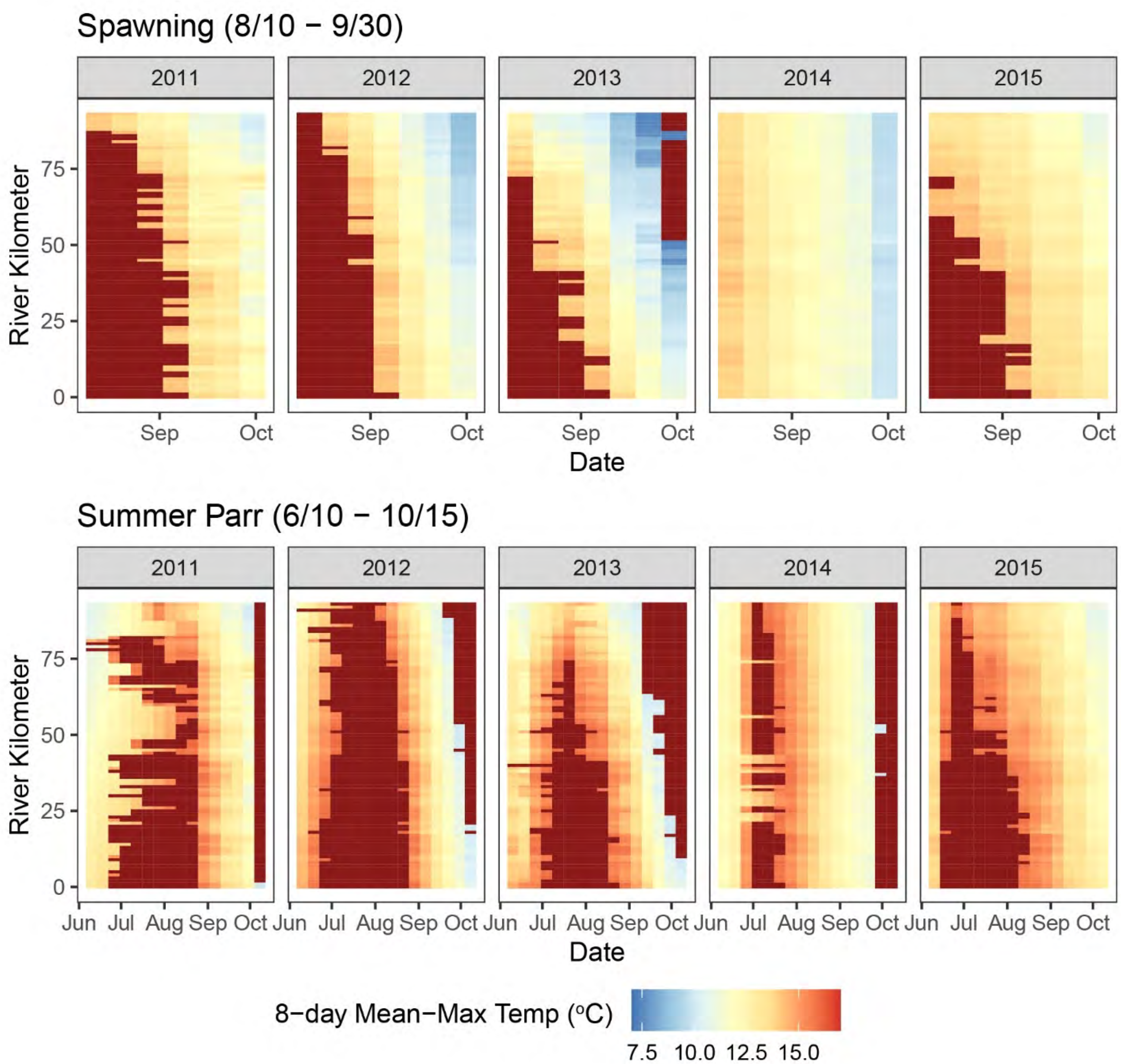


Figure 11. Modeled temperatures available from McNyset et al. (2015) for spawning and summer parr displayed across space (y-axis) and relevant time for the life stage (x-axis). Temperatures within the suitable range are displayed according to the legend, while temperatures above optimal ranges are displayed as the darkest red. River kilometer 0 is the downstream extent at the confluence with the Salmon River. Note that the 8-day mean of predicted daily maximum temperatures in the lower Lemhi valley segment (approximately river kilometers 0–53) and during the summer parr life stage are frequently above the optimal range (Carter 2005) and can exceed acute temperatures.

The spatial distribution of hydraulic habitat suitability (HHS) and suitability curves from Maret et al. (2006) for Chinook salmon and steelhead corroborate results from the IRA (OSC Team 2019). Habitat (in this case, hydraulic conditions) in the lower Lemhi River is unsuitable for juvenile Chinook salmon, though less limiting for juvenile steelhead. Hydraulic habitat suitability is least for juvenile summer and winter rearing for Chinook salmon (Figure 12), which is previously identified as the first priority limiting factor for population productivity (OSC Team 2019). In addition, geomorphic reaches with a greater proportion of channel categorized as “complex” (GR-15) tended to have greater suitability, whereas simpler reaches (GR-09 to GR-11) are less suitable for juvenile Chinook rearing. Unlike juvenile rearing, there are suitable depths and velocities present for spawning conditions of both species throughout the entirety of the lower Lemhi valley segment (Figure 12). Product D in Table 1 provides additional summaries of depth, velocity, and composite suitability and the resulting raster .tiff format files have been posted to the OSC FTP for users to examine further. The results are useful for prioritization efforts and areas of high depth and velocity suitability may be useful for describing target geomorphic conditions.

Within the geomorphic reaches encompassed in this study, areas exhibiting a simplified morphology (which is the case with much of the lower Lemhi River) characterized as single thread, straightened, confined, and oftentimes over-widened, typically have lesser suitable habitat for juvenile Chinook salmon rearing, while areas with greater morphological complexities are more suitable. It has also been shown that river segments with simplified morphology tend to have a greater reduction in growth potential with increased flow and reduced temperatures, when diversions are closed in the fall, compared to areas of the upper Lemhi River with greater complexity (Carmichael et al. 2020). Morphological complexities such as side channels, backwaters, and off-channel areas limit the reduction in growth potential during the critical period when flows artificially transition from extreme low flows in the summer to relatively large, high flows in the fall. Overall, this results in much greater growth potential and larger areas of suitable habitat when compared to morphologically simplified reaches. Observed reductions in growth potential are also a function of decreased temperatures and likely a diminishing drift macroinvertebrate supply in the fall, highlighting the importance of channel complexities as fish prepare to conserve energy during cold, artificial high flow periods within the Lemhi River.

The lower Lemhi valley segment also has few areas of dense riparian and instream cover, which are critical for juvenile concealment (OSC Team 2019). More suitable juvenile rearing conditions include increased variation in stream velocities, including access to low-velocity areas, increased channel unit (including pool) frequency, temperature moderation during summer and winter months, and a more complex stream channel including increased sinuosity, braidedness, and depth and velocity variation. Efforts to add cover, increase channel unit frequency and diversity, increase sinuosity of the single thread channel, and return to multi-threaded channels would increase juvenile habitat capacity in the lower Lemhi.

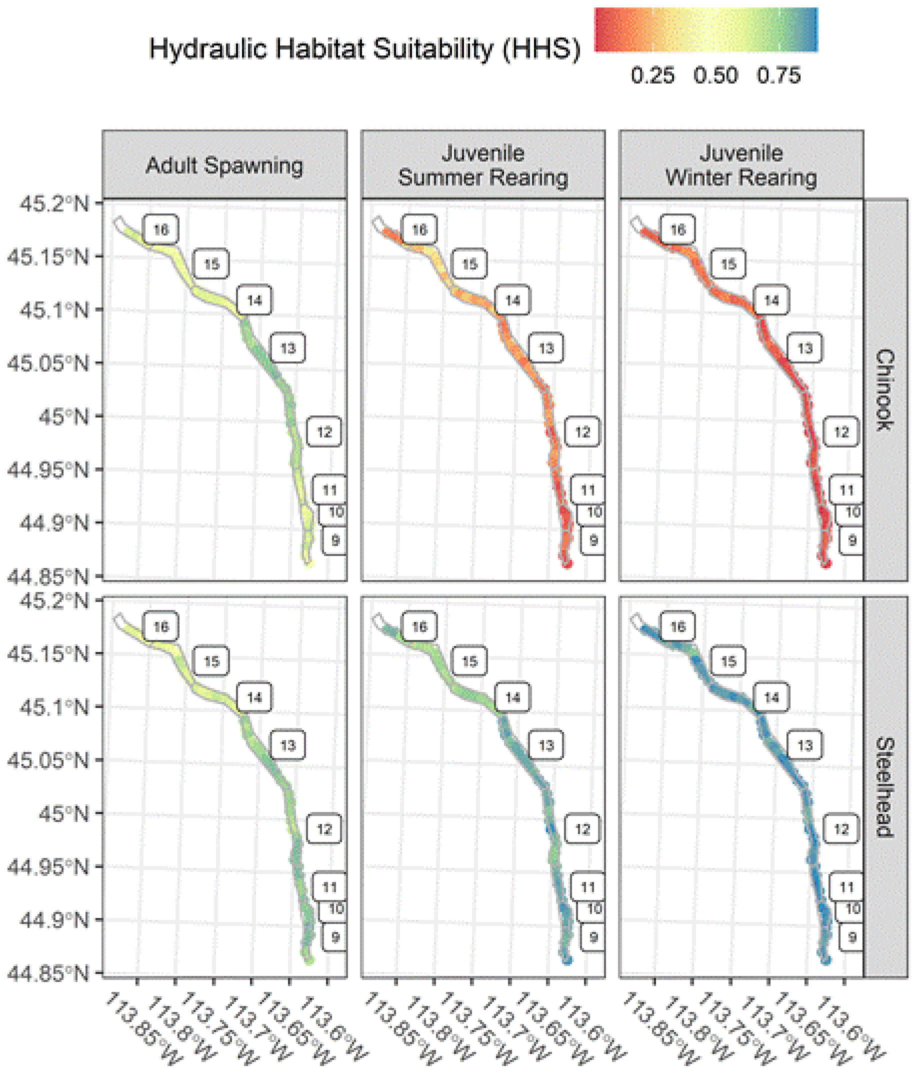


Figure 12. Hydraulic habitat suitability by life stage across geomorphic reaches for Chinook salmon and steelhead in the lower Lemhi valley segment (Table 1 product D).

To evaluate fish-habitat relationships at a finer scale, a DASH subreach was sampled within GR-14. Habitat capacity using the QRF approach (See et al. 2021; products B and E from Table 1) and resulting fish-habitat relationships for the lower Lemhi demonstrate that reaches with greater capacity are generally characterized by a multi-threaded, island braided morphology, greater variation in depth, and/or the presence of side channel or off-channel areas (Figure 13). Notably, the reach with poorest capacity in those sampled with DASH is an approximately 0.5-kilometer-long riffle along a significantly straightened section where the river is confined by the old Lemhi Road (Figure 13). The surrounding reaches also demonstrate poor capacity, which is likely a result of minimal instream complexity and morphological variation as well as a lack of fish cover of any type.

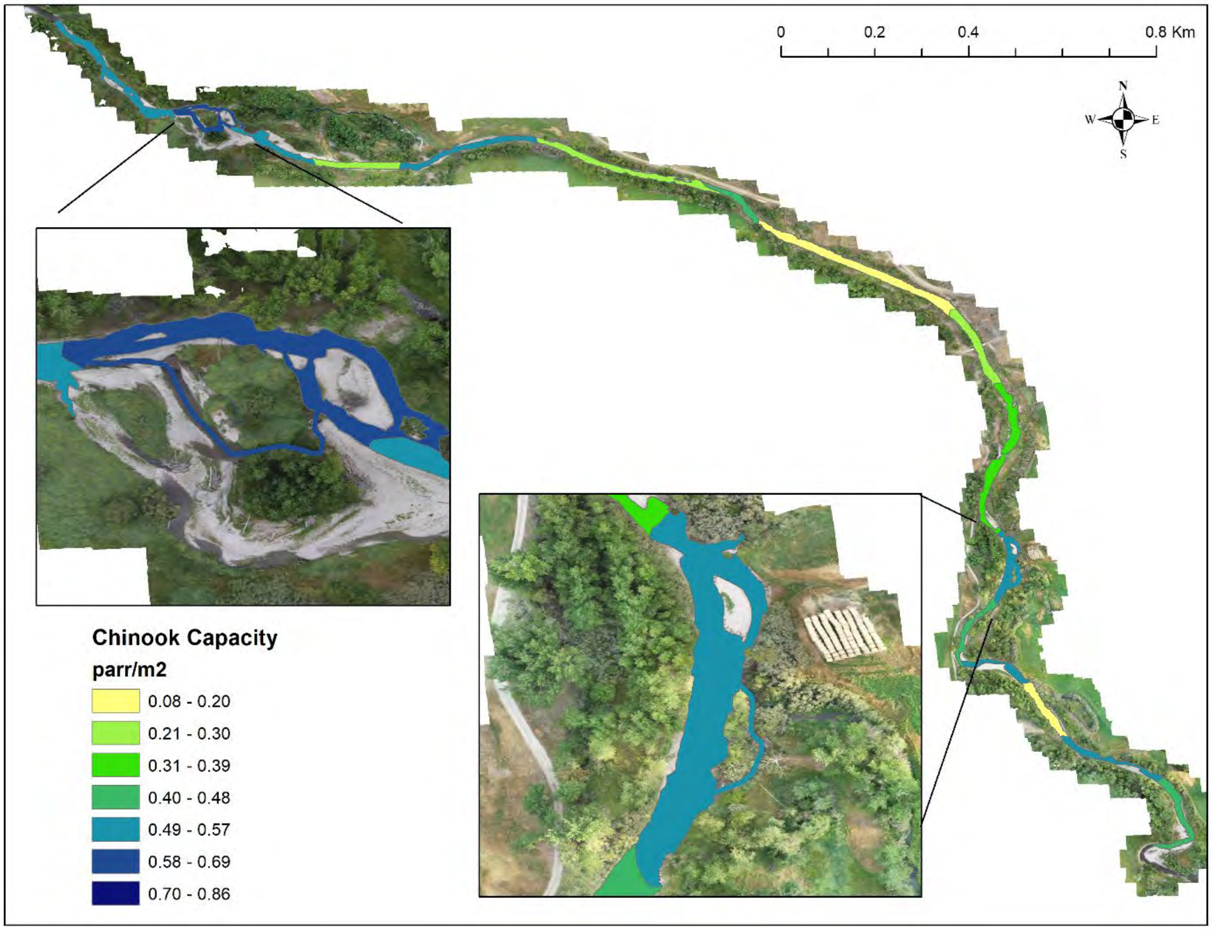


Figure 13. Predictions of capacity (parr/m^2) for habitat reaches within the lower Lemhi River MRA.

Among the DASH sampled habitat reaches, there is minimal variation in average August temperature and discharge, the two predictors of capacity with the greatest relative importance. Greater carrying capacity for juvenile Chinook salmon was identified within those mainstem reaches that had smaller wetted widths combined with an increase in coarse and fine gravel, channel unit frequency, side channel percentage, slow water percentage, fish cover (including large wood frequency and volume) and undercuts, and channel braidedness (Figure 14). We do not mean to suggest that smaller wetted widths cause increased predicted densities; it may instead be that those reaches have a greater proportion of edge habitat along the margins.

Habitat reaches with increased sinuosity and braidedness (or side channel frequency) and off-channel habitat with large amounts of fish cover tended to have the greatest predicted capacities for Chinook salmon parr, while straightened single-threaded channels had the least estimated capacities (Figure 13, Figure 14). Additionally, areas with greater channel unit frequencies and slow water percent (and a combination of both) tended to have greater estimated carrying capacity.

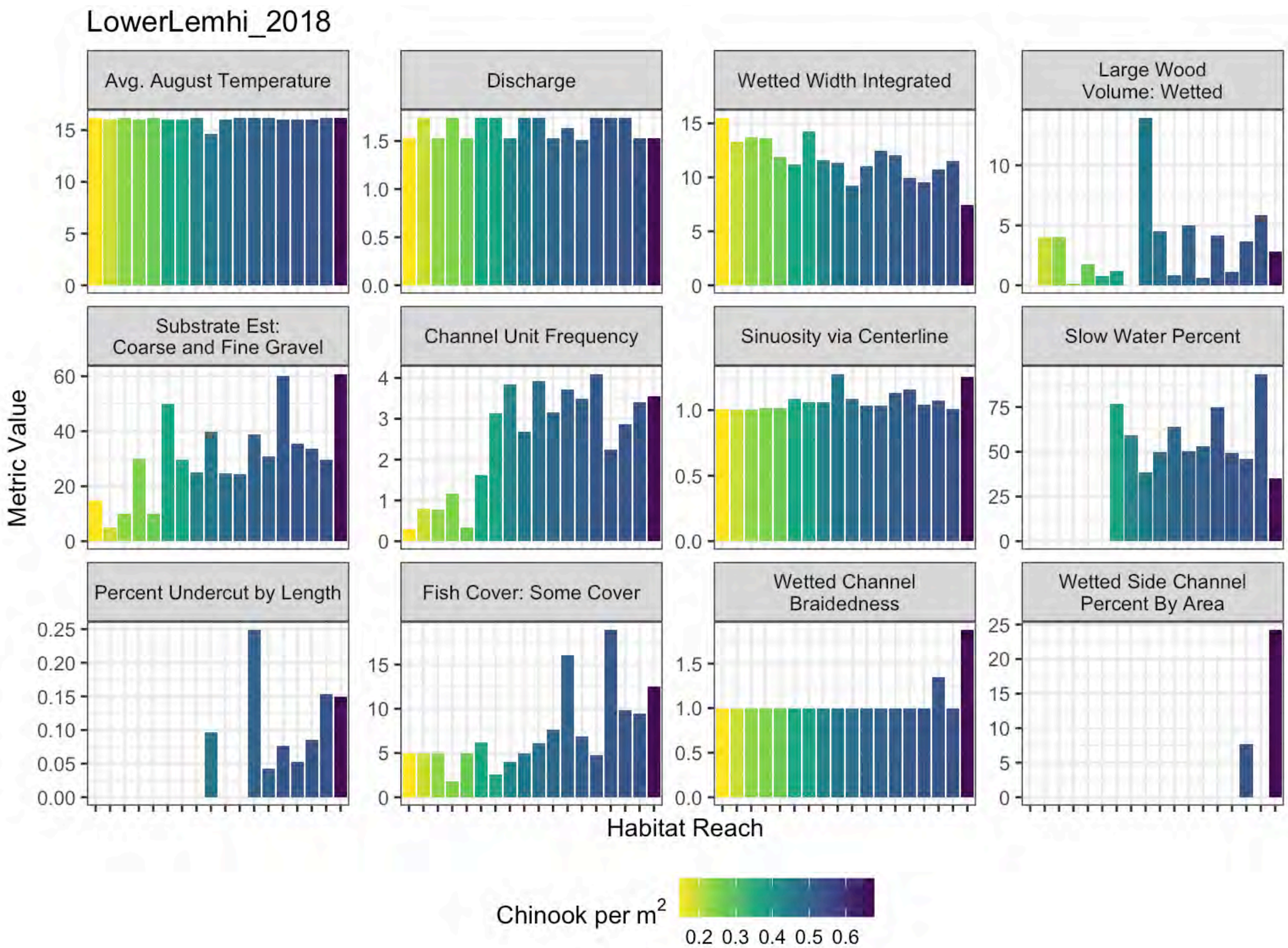
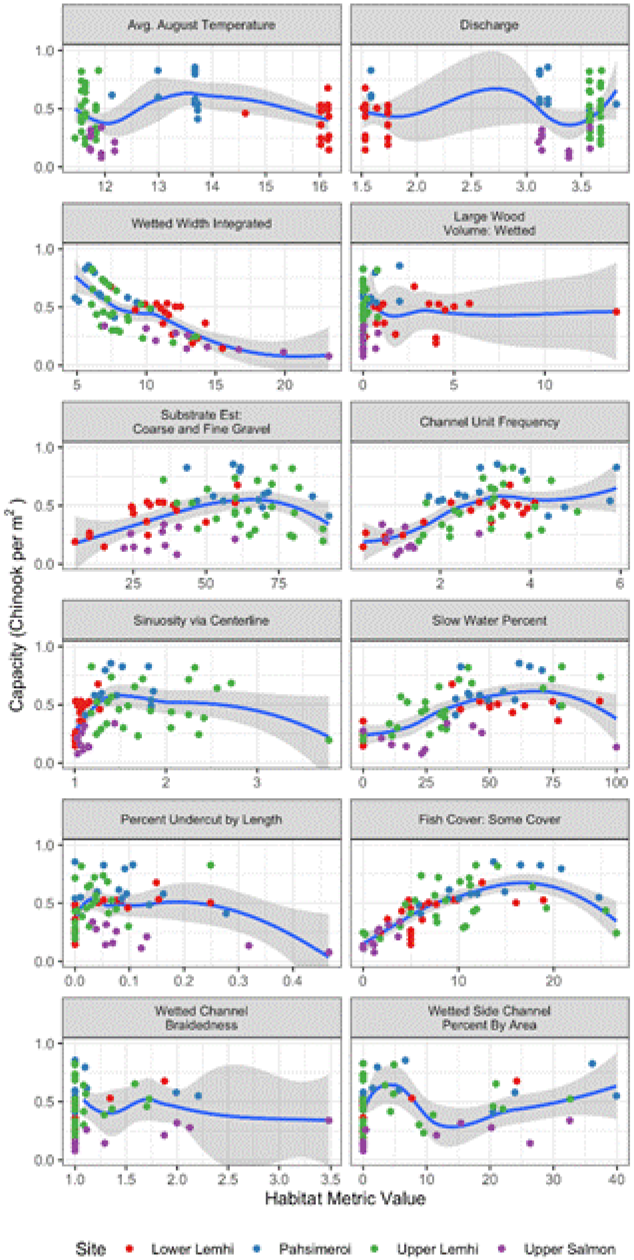


Figure 14. Bar plots by habitat reach within the lower Lemhi MRA subreach, which falls entirely within GR-14. All of the habitat reaches represented in this figure are continuous within the DASH sampled subreach (for definitions of morphological scale units see Section 1: Introduction). The habitat reaches are ordered from lowest capacity to highest, and the bars are also colored that way. The height of each bar shows the value of that habitat covariate.

Figure 15 demonstrates relationships between measurements of habitat metrics and predictions of QRF habitat capacity for Chinook salmon parr (summer) for habitat reaches surveyed in the four MRA subreaches during summer 2018. Habitat reaches within the lower Lemhi MRA subreach are shown in red. As an example, the ‘Fish Cover: Some Cover’ facet shows that the percentage of fish cover (of any type) tends to be lower than observed in the upper Lemhi and lower Pahsimeroi MRA subreaches and, correspondingly, has lower predictions of habitat capacity (y-axis). However, when interpreting Figure 15, it should be noted that the predictions of capacity are also partially driven by all other covariates.

The relationships between habitat covariates and capacity demonstrated in the lower Lemhi (Figure 14) are similar to those throughout the four valley segments captured in this study (Figure 15). Comparatively, the lower Lemhi had the most extreme average August temperature predictions: one of the two most important predictors of capacity (Figure 15). Additionally, the lower Lemhi has limited fine and coarse gravel, sinuosity, and side channel percent relative to other valley segments (Figure 15). Finally, of the habitat covariates used for QRF capacity predictions, and metrics that can be altered by restoration actions, temperature, channel unit frequency, wetted width, large wood volume, and fish cover appear to be the most important relative to other metrics evaluated (Figure 15).



Name	Metric Category	Description
Avg. August Temperature	Temperature	Average predicted daily August temperature, degrees Celsius, from NorWeST, averaged across years 2002–2011.
Discharge	Size	The sum of station discharge across all stations. Station discharge is calculated as depth x velocity x station increment for all stations except first and last. Station discharge for the first and last station is 0.5 x station width x depth x velocity.
Wetted Width Integrated	Size	Average width of the wetted polygon for a site in meters.
Large Wood Volume: Wetted	Wood	Total volume of large wood pieces within the wetted channel, scaled by site length.
Substrate Est: Coarse and Fine Gravel	Substrate	Percent of coarse and fine gravel (2–64 mm) within the wetted site area.
Channel Unit Frequency	Channel Unit	Number of channel units per 100 meters.
Sinuosity Via Centerline	Complexity	Ratio of the wetted centerline length and the straight line distance between the start and end points of the wetted centerline.
Slow Water Percent	Channel Unit	Percent of wetted area identified as Slow Water/Pool channel units.
Percent Undercut by Length	Cover	The percent of the wetted streambank length that is undercut.
Fish Cover: Some Cover	Cover	Percent of wetted area with some form of fish cover.
Wetted Channel Braidedness	Complexity	Ratio of the total length of the wetted mainstem channel plus side channels and the length of the mainstem channel.
Wetted Side Channel Percent by Area	Complexity	Ratio of the total area of side channel unit areas (both small and large) divided by the total area of channel unit polygons.

Figure 15. Scatterplots showing all habitat reaches (typically ~120–200 meters in length) within the four MRA subreaches (colored by subreach) with carrying capacity for Chinook parr (y-axis) and the given metric value (x-axis) (Table 1, Products B and E). Scatter plots (left) show the relationship between predicted habitat capacity and habitat metrics (right) at MRA subreaches where juvenile fish and DASH habitat data were collected during summer 2018. A description of the x-axis for each facet is provided in the table above. Metrics are listed in order of importance to capacity predictions.

In addition to the habitat reach scale (consecutive channel units approximately 200 meters in length) analysis performed to evaluate in-depth habitat metrics, a geomorphic reach scale analysis of capacity was conducted for the lower Lemhi river (Figure 16) to compare with classifications of simplified, mixed, or complex made for those geomorphic reaches. This geomorphic scale approach could be of use to practitioners for prioritization efforts to evaluate relative deficits (or lack thereof) among geomorphic reaches within and across valley segments. In this instance, the upper Lemhi has on average more capacity for juvenile Chinook rearing than does the lower Lemhi (Figure 16). Since the lower Lemhi functions primarily as a catchment for juveniles moving downstream, the argument could be made that efforts to uplift capacity in the lower portions of the river should be prioritized in this valley segment. If necessary, the approximately 200-meter capacity predictions could be summarized at other, additional spatial scales that might be of use to stakeholders or practitioners.

Figure 16. Geomorphic reaches in the Lemhi River colored by relative juvenile rearing capacity. Relative capacity of each geomorphic reach was calculated for each species by subtracting the minimum average capacity from all geomorphic reaches within the valley segment and dividing by the range of average capacities.

Geomorphic Function

Results of the reach assessments indicate a large range of hydrogeomorphic functionality exists among the lower Lemhi River reaches (Figure 17 to Figure 19). It should be noted that the following analyses and results were conducted for geomorphic function exclusively without regard to fish habitat or species abundance. Conclusions and recommendations provided later in this report were derived by integrating biological and geomorphic results.

The riparian plant community is a low functioning parameter (0.33) in four geomorphic reaches and a moderately functioning parameter (0.67) in four geomorphic reaches, owing to the lack of riparian vegetation. In stream systems like the lower Lemhi River, woody riparian vegetation is typically a primary control on bank strength and secondary channel development, while also recruiting to the stream channel and persisting in small to large accumulations. The low abundance of woody riparian vegetation is reflected in the large woody material transport and storage functionality score of 0.33 in all reaches.

When coupled with poor riparian vegetation conditions, impacts from grazing and other land uses along the streambanks and floodplain result in bank instability in some subreaches. In other subreaches, artificial channel confinement has restricted typical rates of bank erosion. Collectively, these impacts are reflected in the channel migration functionality scores ranging from 0.33 to 0.5 in all reaches.

In those subreaches with excessive bank instability, field observations indicate channel over-widening and increased fine sediment accumulation. In those subreaches with appreciable channel confinement, field observations indicate an armoring of the riverbed with very coarse grain sizes. While these conditions are present in all the lower Lemhi geomorphic reaches, there are very limited data available to evaluate channel bed characteristics at the subreach scale within each geomorphic reach. Therefore, the bed character functionality score is indicated as moderately functional (0.67) in all reaches.

Limited floodplain connectivity is indicated in all lower Lemhi River reaches. This limited functionality is a result of lower than expected inundated area at discharges approximating the 20% annual chance peak flow (5-year recurrence interval). In addition, the number of secondary channels present in most reaches is far less than would be expected in the lower Lemhi River.

Hydraulic diversity is another low-functioning parameter (0.33–0.50) in most reaches. This low functionality is due to the lack of variability in depth and velocity, owing to reduced channel complexity, lack of woody debris and structure, and altered flow regimes. The limited hydraulic diversity is in part controlled by the lack of bed form diversity and reduced channel sinuosity in many subreaches, as indicated by lower channel planform functionality scores in most reaches.

The overall functionality in the lower Lemhi River valley segment ranges from 35% of fully functional (Geomorphic Reach [GR]-13) to 60% of fully functional (GR-10) (Figure 18 and Figure 19). The lowest performing functional categories are vegetation and hydraulics, due to degraded riparian vegetation conditions and limited floodplain connectivity and hydraulic diversity.

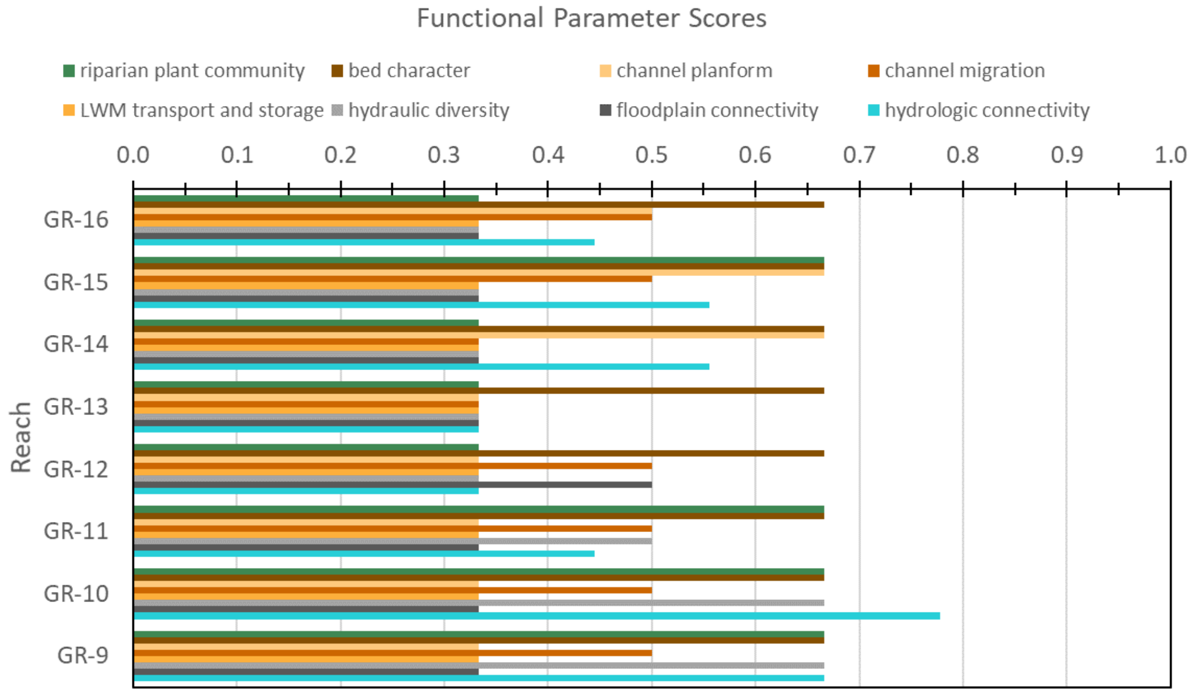


Figure 17. Hydrogeomorphic functional parameter scores in the lower Lemhi River geomorphic reaches.

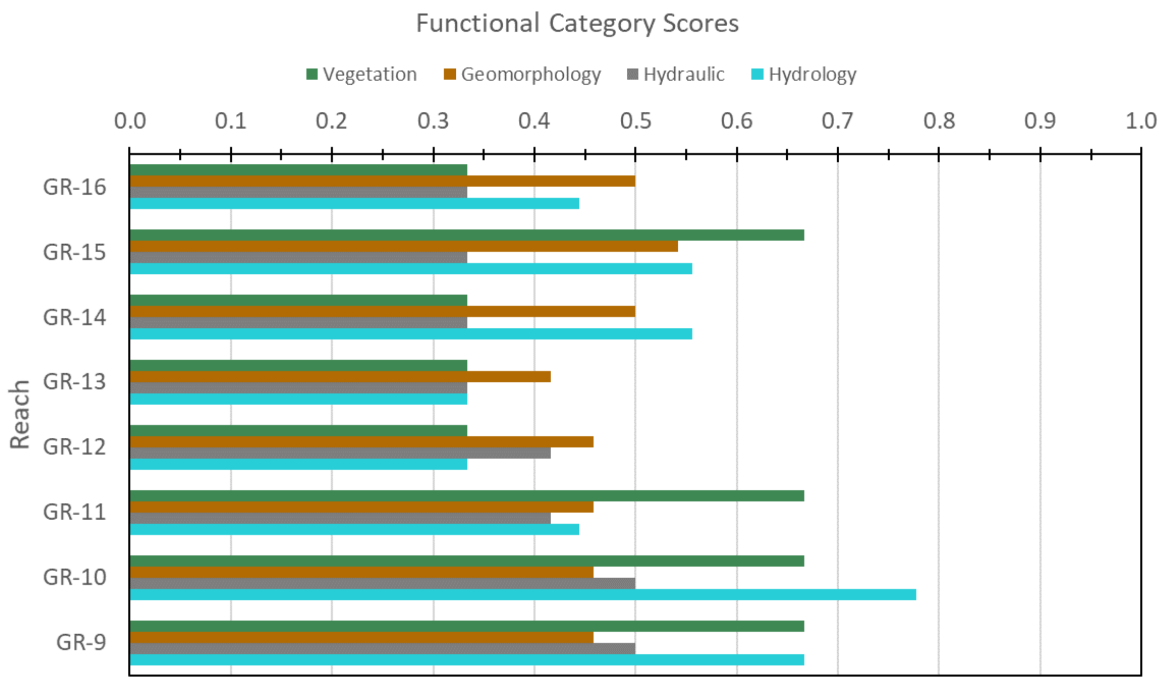


Figure 18. Hydrogeomorphic functional category scores in the lower Lemhi River geomorphic reaches.

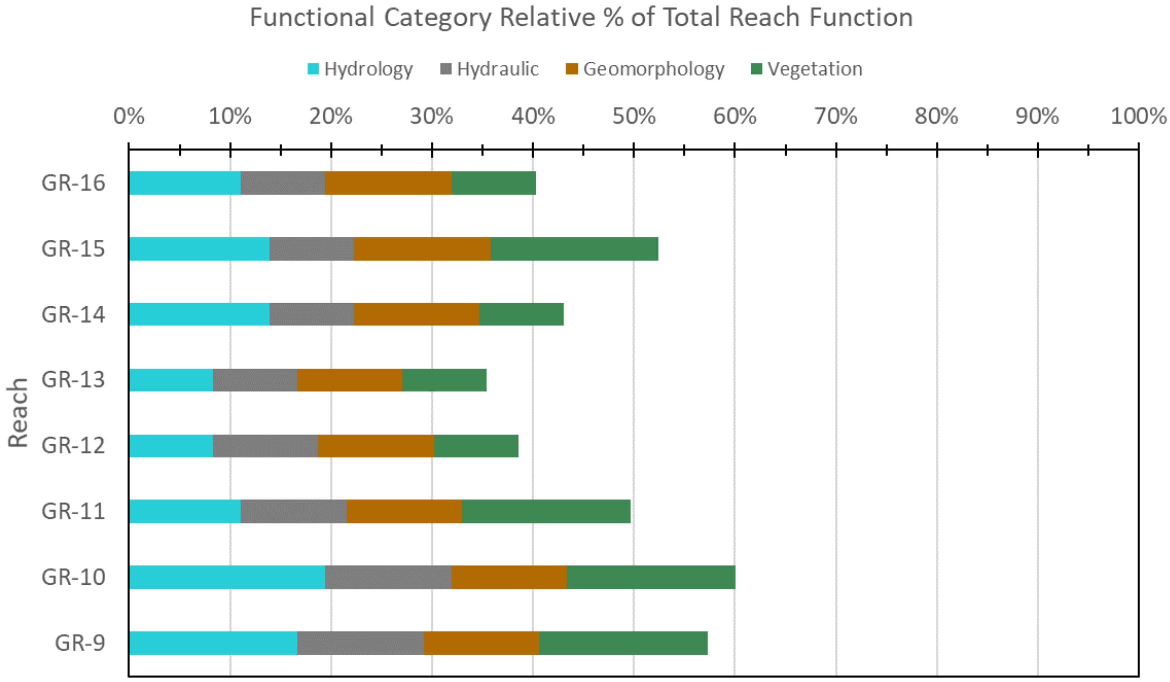


Figure 19. Hydrogeomorphic reach functionality scores in the lower Lemhi River geomorphic reaches.

Conceptual Model of Functionality

Existing Conditions

The existing geomorphic characteristics and habitat conditions in the lower Lemhi River are the result of multi-decadal changes throughout the Lemhi River system. After several decades of decreased abundance of native riparian plant communities, changes in the hydrologic regime, removal of woody debris, and modifications to stream channel and floodplain characteristics, the lower Lemhi River has become predominantly a single-thread, simplified, plane-bed channel that lacks geomorphic complexity and has limited interaction with its floodplain. The existing condition throughout much of the lower Lemhi River is interpreted to be cycling primarily among the SEM stages (Cluer and Thorne 2014) of 2 (Channelized), 3 (Degrading), and 3a (Arrested Degradation), with some subreaches transitioning through SEM stages 4 (Degradation and Widening) and 5 (Aggrading and Widening).

The channel, bank, and floodplain alterations that have occurred in the lower Lemhi River are likely the primary controlling factors of the observed channel and habitat conditions. In stream systems like the lower Lemhi River, woody riparian vegetation is typically a primary control on bank strength and secondary channel development. When coupled with poor riparian vegetation conditions, impacts from channel straightening, bank stabilization, and channel confinement result in increased stream power, channel widening and/or incision, and disconnection between the stream channel and adjacent floodplain. The reduced stream sinuosity and increased sediment transport capacity results in a reduction of bar development and sediment sorting, which in turn causes the channel morphology to become further simplified. As the stream channel widens and/or incises and remains disconnected from the floodplain, secondary channels become abandoned and bank and floodplain conditions become unsuitable for native riparian plant community succession. This geomorphic cycle (Figure 20) of channel, bank, and floodplain transitions creates simplified, low-quality habitats available to salmonids, reduces habitat diversity and complexity, and reduces access to secondary channels.

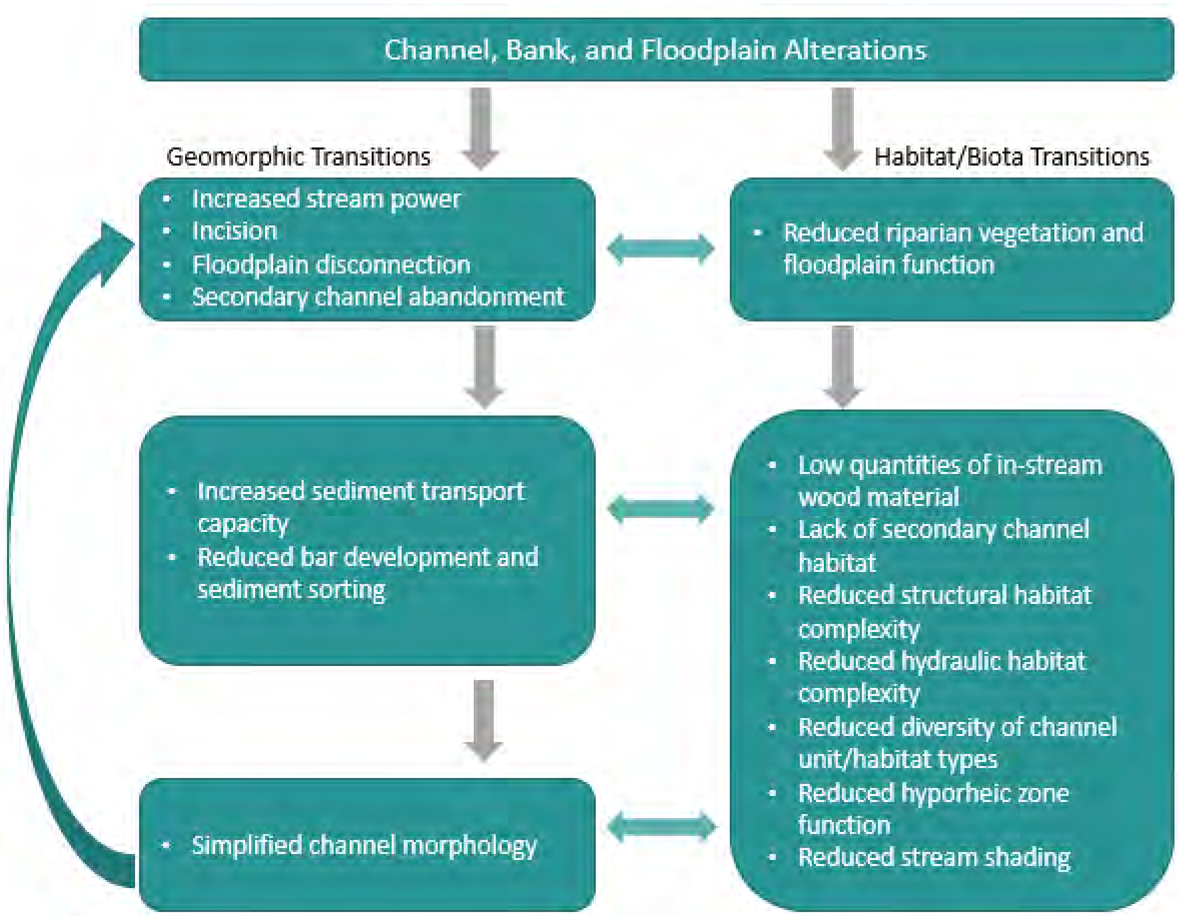


Figure 20. Lower Lemhi River conceptual model of existing geomorphic function and related fish habitat characteristics.

Section 5: Restoration Actions

The lower Lemhi River reach assessments identified the habitat conditions limiting salmonid production, growth, and survival. This section describes resource management practices and actions that should improve fish habitat conditions. The section begins with a summary of the limiting habitat characteristics and issues, followed by specific restoration objectives for the lower Lemhi River, and culminating in recommended actions that encompass a range of spatial scales.

Limiting Habitat Characteristics and Issues

Juvenile rearing habitat quantity and quality is insufficient to support recovery of the Lemhi River Chinook salmon population (OSC Team 2019 and product B in Table 1) and, although not identified in our QRF assessment, is likely limiting for steelhead as well (see Identified Capacity Limitation section for further discussion there). The vast majority of Chinook salmon spawning occurs above the lower Lemhi valley segment (product H, Table 1), and steelhead spawning occurs primarily in the upper Lemhi valley segment and tributaries of the Lemhi River, all of which flow to the lower Lemhi valley segment. The lack of sufficient quantity and quality of rearing habitat in the lower Lemhi valley segment is of particular concern because nearly all juvenile Chinook salmon and steelhead in this population group must spend at least some portion of their freshwater rearing life cycle in the lower Lemhi River, and in some cases a large portion of it including summer, fall, and winter months prior to emigration. The goal of rehabilitation activities in the lower Lemhi River valley segment should be to provide the highest quality habitat to (1) increase survival of juvenile Chinook salmon through summer, fall, and winter months and (2) maximize body condition of surviving individuals for successful emigration downriver and to the ocean. Given their similarities in habitat preference (OSC Team 2019), improving conditions for juvenile Chinook salmon will also improve conditions for steelhead and likely other species of concern.

Greater summer temperatures and reduced flows during summer limit habitat for summer juvenile rearing. Additionally, an artificial peak in flow occurs when diversions are closed in the fall. These alterations to the hydrology are particularly concerning when considering effects on the two life history strategies present in the Lemhi. For fish that overwinter in the lower Lemhi (NRR), lack of concealment necessary for predator avoidance combined with reduced temperatures and excessive stream velocities create conditions that negatively impact survival and body condition. Thus, individuals that survive the winter face an energy shortage during emigration. Similarly, fish that emigrate in the fall (DSR) may spend insufficient time in the lower Lemhi to obtain adequate body condition for overwinter survival in the mainstem Salmon. Furthermore, the peak in fall stream discharge and velocity as a result of diversion closures may trigger emigration, thus artificially selecting for DSR and disrupting the evolutionary strategy of the two counterbalanced life history strategies.

Low sinuosity, channel braidedness, and channel unit frequency (e.g., too many long riffles and too few pool-riffle interfaces, products B, C in Table 1), lack of fish cover (including large woody debris, undercut banks, etc.; products B, C in Table 3), and suboptimal to poor temperatures during extreme months (products A, B, H in Table 3) are all identified as limiting factors in the lower Lemhi. The low sinuosity and lack of channel braidedness in the lower Lemhi valley segment are largely attributed to the main channel being confined by the highway (old railroad grade) and valley walls in many places, and also to the reduction to a single main channel through most of the valley segment. The low sinuosity and braidedness exacerbate issues with high stream velocities (especially a lack of variation in velocity) and low channel unit frequencies, and further, results in reduced hyporheic flow and reduced stream temperature mediation. Increasing the sinuosity of the main channel and, perhaps more importantly, increasing the number of side channels and overall channel braidedness would help remedy many of the limiting characteristics identified above, both directly and indirectly. Restoration efforts should keep the following items in mind:

- Many shorter side channels would be preferential over few long side channels, increasing the number of channel junctions, though any side channels are beneficial. Increasing channel unit frequencies, including slow channel units (especially with cover), the number of pool-riffle interfaces, and the standard deviation (variation) in depths in the lower Lemhi River valley segment would also benefit the quality of juvenile rearing habitat in the lower Lemhi valley segment, as would increasing total cover in the forms of large woody debris, undercuts, riparian vegetation Figure 21.
- Rehabilitation efforts in the lower Lemhi River valley segment should aim for temperature moderation, especially during the extreme summer and winter months, through actions such as increasing hyporheic flow or exchange (through increased channel complexity described above) or increasing riparian (fish) cover, or both. Upstream actions that improve temperature mediation may also positively affect suitability in the lower Lemhi. Any actions that improve complexity may not net benefits to capacity until temperatures are also improved.

Figure 21. Google Earth aerial image from the Big Lost River, Idaho, illustrating a multi-threaded channel network with a diversity of side channels, a high frequency of habitat units, large woody debris, and dense woody riparian vegetation. Flow is from left to right.

Table 3. Recommendations and proposed actions to improve habitat quantity, quality, and/or capacity in the lower Lemhi River valley segment in an attempt to restore tributary habitat towards conditions that would allow for population recovery. Habitat characteristics are limited to those that are used in current QRF capacity models, can be measured using the DASH protocol (Carmichael et al. 2019), or are available from NorWeST.

Habitat Characteristic or Issue	Definition	Recommendation	Geomorphic Reaches	Target	Product ID / References
Channel Unit Frequency	Number of channel units per 100m	In general, we find that higher channel unit frequency, a surrogate for habitat complexity, is associated with higher juvenile densities (Figure 15), especially during winter months.	All	Increase from existing; >2 or 3 (Figure 15)	B, C, G
Wetted Channel Braidedness	Ratio of the total area of side channel unit areas (both small and large) divided by the total area of site.	Increase wetted channel braidedness by adding side channels and converging/diverging channels. More shorter channels are preferential over few long channels, increasing the number of "junctions", but a combination of both should be considered.	All	>1.5	B, E, G
Sinuosity	Ratio of the wetted centerline length and the straight-line distance between the start and end points of the wetted centerline	Increase channel sinuosity, especially in areas with a high percentage of morphological simplification and/or confinement.	All	>1.2 (Figure 15)	B, D
Wetted Side Channel Percent	Ratio of the total area of side channel unit areas (both small and large) divided by the total area of site.	Increase the overall percent of wetted area and stream length that is made up of side channels	All	>20 %	B, E, G
Depth and Velocity	2D modeled depth and velocity supported by bathymetric LiDAR	In general, decrease stream velocity in the lower Lemhi valley segment, during winter months. But more importantly, increase the standard deviation and broaden the distribution of both depths and stream velocities throughout the valley segment.	All	N/A	A, B, C, D
Slow Water Percent	The percent of wetted area characterized as a slow water channel unit (run or pool)	Increase slow water percentage with self-maintaining pools. Consider pool-riffle sequences and cover (riparian, wood, complex substrate).	All	40–70 %	A, B, D, E, G
Fish Cover: Some Cover	Percent of wetted area with some form of fish cover	Increase the percentage of fish cover, in any form, to greater than 5% where appropriate. Fish cover could be provided in many forms, including, but not limited to, woody debris, undercut banks, boulders, or overhanging vegetation.	All	Increase from existing; >5% (Figure 15)	A, B, C, E, G
Fish Cover – Large Wood (wetted)	Area of the wetted channel covered by woody debris	Increase small and large woody debris to maximize local scour and reduce local velocities while increasing fish cover.	All	>2.5% of wetted area	A, B, C, E, D
Large Wood Frequency	Number of qualifying pieces of large wood per 100m	Increase large wood frequency spread throughout target rehabilitation sites to increase deviation of depths and velocities and provide opportunity for predator avoidance.	All	>15	A, B, C, E, D
Percent Undercut by Length	The percent of the bank that is undercut	Maintain or restore processes that develop undercut banks.	All	~20%	A, E, G

Restoration Objectives

Biological and geomorphic assessments were conducted independently with the goal of integrating both approaches into the MRA process. The initial biological assessments provided recommendations and guidance from a data-driven fish-centric point of view on physical habitat preferences of multiple life stages for Chinook salmon and steelhead. The morphological assessments were made to determine (within the range of biological recommendations) what actions would be morphologically appropriate, while maximizing biological benefit of target species and life stages identified in the IRA process. The intersection of the biological and morphological assessments is laid out within the following objectives and ensuing reach recommendations.

Biological Objectives

The primary biological objective in the lower Lemhi River valley segment is to increase rearing habitat capacity for both Chinook salmon summer parr and winter pre-smolts. By focusing on increasing capacity for juvenile Chinook salmon, our assumption is that capacity for juvenile steelhead rearing, during summer and winter months, will also be increased. Additionally, actions will either do no harm to or improve conditions for other species of concern including bull trout and cutthroat trout. In particular, habitat capacity for Chinook salmon rearing can be improved through increased habitat complexity (see Table 3) especially considering the valley segment occurs below core spawning areas. Actions performed in the lower Lemhi should also aim to mediate extreme summer and winters temperatures. Actions should also be taken to maintain current flow criteria within the mainstem Lemhi River and its tributaries. Due to the capacity limitations of rearing habitat identified in the IRA (OSC Team 2019), ensuring tributary connection to the mainstem is an integral part in increasing rearing capacity and overall access to habitat areas. Further, maintenance of base flows is also a required piece in improving rearing habitat capacity to meet delisting criteria of salmonid species. The biological objectives are as follows:

- Increase the overall wetted braidedness (i.e., side channel density) throughout the lower Lemhi valley segment. This can be accomplished by increasing the overall frequency and diversity of flow splits in the main channel (i.e., many short, but some long side channels creating an island braided morphology), and/or increasing the sinuosity of the main channel.
- Increase the frequency of channel units (i.e., more pools with shorter riffles and glides, more pool-riffle interfaces), thus increasing the density of channel units within habitat reaches.
- Improve and increase base- and winter-flow fish cover quantity and quality including interstitial spaces of comparable size to juvenile fish (10s to 100s of millimeters) for concealment cover.
- Increase the structural and hydraulic diversity of available foraging locations. Similar to increased overall braidedness, this can be accomplished via increases in available off-channel and/or side-channel habitat with proximal access to the mainstem (i.e., a preference towards more, short side channels versus fewer, long side channels where appropriate).
- Increase availability of reduced water velocity (and increase diversity or standard deviation of available velocities) across a broad range of flows to decrease bioenergetic demands.
- Maintain or improve tributary connection and maintain or increase baseflow of the mainstem Lemhi River, most notably near and below current and historic areas of adult spawning.
- Mediate temperatures through actions to increase hyporheic flow or riparian cover or both.

Geomorphic Objectives

The lower Lemhi geomorphic objectives are focused on improving the physical processes that will result in habitat conditions necessary to improve salmonid production, growth, and survival. The restoration actions recommended for the lower Lemhi River geomorphic reaches are intended to encourage natural channel and habitat forming processes. While providing near-term functional and habitat benefits, the vision for the restoration actions is an evolution of geomorphic and habitat characteristics over annual and decadal time scales that will improve the factors limiting salmon recovery in the lower Lemhi River.

Restoration treatments are intended to provide the following functional processes:

- Distribution of stream flow and energy among multiple channels and onto the floodplain, thereby reducing the available stream power concentrated into one primary channel
- Improved primary and secondary channel geometry (i.e., generally narrow and sinuous with a diversity of widths, depths, and structure)
- Increased floodplain connectivity and activation of secondary channels at multiple discharges (i.e., some activation during average peak flows and significant activation above the 2-year recurrence interval flood)
- Increased secondary channel abundance and diversity
- Increased hydraulic and structural diversity and complexity (i.e., greater diversity of depth and velocity with ample structure and cover)
- Increased density of native riparian plant communities (especially willow and cottonwood)

The existing conditions of the lower Lemhi River suggest the channel is primarily in the evolutionary stages of 2 (Channelized), 3 (Degrading), 3a (Arrested Degradation), with some localized subreaches in stages 4 (Degradation and Widening), and 5 (Aggrading and Widening). The recommended restoration treatments are intended to initiate a transition of future project reaches to SEM stages 6 (Quasi-equilibrium) and stage 7 (Laterally active) within 1 to 5 years following construction. Future channel evolution into SEM stage 7 and stage 8 (Anastomosing) may occur over the next several decades following project completion.

The channel evolution stages described in the CEM and SEM frameworks are idealized, general depictions of complex channel conditions. Rarely do these conceptual frameworks adequately represent the diverse river responses and diverse channel states that are often observed (Fryirs and Brierley 2013). One reason for this shortcoming is that most rivers adjust not just in response to a discrete event isolated in time (e.g., river restoration treatment); rather, fluvial landscapes evolve as a result of multiple disturbances that occur over multiple spatial and temporal scales (Van Dyke 2013). Channel response depends on the landscape context, environmental history, anthropogenic constraints, and sequence of disturbance events to which a river is subjected throughout time (Fryirs and Brierley 2013).

Recommended Actions

While the lower Lemhi River currently supports local populations of Chinook salmon and steelhead, the stream ecosystem conditions need improvement. Changes in land use and resource management practices have occurred for over a century, resulting in ecological, geomorphic, and hydrologic conditions that have contributed to fish population declines. Some improvements to these conditions have occurred over the past several decades. Recognizing that improvements to these conditions and fish populations cannot be realized immediately, the lower Lemhi River restoration strategy provides a framework of project types that broadly address the restoration needs. As introduced earlier in this document, elements of the restoration framework include protection, water, restore processes, and restore habitat. As described below, these restoration elements can be used individually or collaboratively to address habitat limitations in the lower Lemhi River.

Protection

None of the mainstem lower Lemhi is of pristine condition suitable for standalone protective status given systemic disruptions to natural process and human impacts on the landscape (historical and present) as summarized in the IRA (OSC Team 2019). On the other hand, there are isolated features and elements of the lower Lemhi that should be protected to prevent further decline in habitat quality or quantity—among these is the use of the valley segment as a migratory corridor for adult Chinook salmon and steelhead spawning in the upper Lemhi valley segment and tributaries of the Lemhi River. Adequate flows should be maintained in the mainstem Lemhi River through the entirety of the valley segment to allow adults to access suitable spawning habitats. In particular, the vast majority of Chinook salmon spawning occurs in the upper Lemhi (above Hayden Creek), so Chinook salmon adults must be able to navigate through the lower Lemhi to access their preferred spawning habitat. Steelhead spawning is distributed throughout tributaries of the Lemhi River and also must use the lower Lemhi valley segment to access suitable habitat. Any actions conducted in the lower Lemhi valley segment should ensure no harm is done to the existing migratory corridor or enhance migration through increased flow refugia and cover.

The protection of high-quality fish habitat is dependent on protecting the physical and ecological processes that create and sustain those habitats. Priority protection areas in the lower Lemhi River are reaches, or portions of reaches, that exhibit complex morphology in the primary channel and secondary channels, floodplains that are well connected to these channels, and highly functional riparian vegetation. Additional priority protection areas are those with the greatest potential for restoring physical and ecological processes, regardless of their current condition. These areas include currently undeveloped, or minimally developed, land within the expected channel migration corridor and targeted meander amplitude (summarized by geomorphic reach on the following pages) that could be protected from future land use impacts.

Conservation measures are effective management tools to protect existing high-quality habitat and/or to prevent further degradation in areas with high habitat restoration potential. Efforts in the lower Lemhi have recently established and should continue to establish land use guidelines, restrictions, and/or incentives to reduce human-related impacts on the ecosystem. Ongoing conservation practices have been applied by landowners and resource managers throughout the Lemhi River watershed over the past several decades (IDEQ 2012). These practices include improving livestock grazing practices, riparian fencing, and improved agricultural best management practices. In several instances, landowners have been incentivized and improvements enshrined in legally binding conservation easements to ensure such measures are maintained over the long-term.

Water

Much has been accomplished in the Lemhi River over the past few decades to improve instream flows, particularly low flows, enabling adequate fish passage and spawning conditions in the summer by way of irrigation improvements and tributary reconnections. As discussed in the IRA (OSC Team 2019) and earlier in this report, human impacts to the landscape (i.e., channel straightening, bank armoring, beaver eradication, riparian vegetation removal, etc.) have altered the lower Lemhi channel morphology into a primarily confined, straightened, single-threaded, relatively simplified condition. Compounding this issue has been the reduction in flood frequency and magnitude by early season irrigation withdrawals, which has reduced one of the principal drivers (i.e., flood hydrology) capable of scouring pools, accessing the floodplain, creating side channels, and forming new complex habitat.

While many projects over the past few decades have worked to improve instream flows, recent analysis suggests that further flow increases in morphologically simplified channels may not result in improved habitat quality in the mainstem Lemhi until or unless improvements to the channel morphology can also be addressed. Within areas of significantly altered morphology (i.e., straightened and confined), greater discharge results in higher velocities rather than more off-channel habitat connectivity (Appendix C). The resulting instream velocities are less suitable for juvenile salmonids (Carmichael et al. 2020) because flows are confined within channel banks and insufficient structure is available to provide localized velocity refuge within simplified reaches. However, areas of morphological complexity provide adequate growth opportunity and suitability both in the summer and transitioning into the fall when channel flows are increased, and temperatures decrease. With current and potential future increases in flow, proper morphological adjustments to the river channel and floodplain connectivity are needed to maximize the benefit of additional water, notably when irrigation diversions are shut off and river temperatures begin to decrease. Evidence also suggests that current base flows during summer months should be maintained to protect any and all suitable habitat provided.

Maintenance of tributary connections to the Lemhi River is essential in addressing the current capacity deficit estimated in the IRA assessment (OSC Team 2019). Tributary flow has also been shown to be a good predictor of production in the Lemhi River (smolt to adult return rates [Arthaud et al. 2010]) and is another piece of evidence supporting the necessity for mainstem and tributary flow maintenance and protection. In addition to water quantity, water quality has been historically impacted, and reductions in fine sediment from bank erosion and upland runoff along with improvements to instream temperature from greater riparian vegetation and shade are needed to enhance existing conditions and to complement potential future improvements to channel morphology.

In general, flow is not believed to be limiting salmon production because of the recent work in enhancing base flows and improving tributary flow and connection in the lower Lemhi (OSC Team 2019). However, as outlined in the IRA (OSC Team 2019), fine sediment, temperature, and reduced high-flow frequency and magnitude (channel-forming flows) continue to negatively affect habitat capacity within the watershed as a whole. Strategic water quality- and quantity-related rehabilitation addressing fine sediment, temperature, and high flows (i.e., floodplain connectivity) remains a priority.

Restore Process

Impacts to physical process connectivity and habitat simplification/isolation represent many of the underlying causes of habitat impairment. These types of root-cause impacts are pervasive throughout much of the lower Lemhi River valley segment. Restoring and/or reconnecting these broken linkages will enable the long-term restoration of natural river process supporting habitat and ecosystem function into the future.

Restoring process refers to enabling the stream to create and/or maintain suitable habitat conditions on its own through natural river processes including improved flow as discussed above, appropriate sediment input, nutrient cycling, erosion and deposition, woody recruitment, beaver activity, and riparian vegetation. Restoring processes can generally be accomplished by removing barriers to habitat creation and/or facilitating natural channel response appropriate for a given area. Removing barriers such as levees, bank armor, and bridge constrictions can reconnect previously isolated historical forms such as oxbows, wetlands, side channels, alcoves, and low floodplain areas allowing for the reestablishment and/or expansion of natural river processes into those areas. Likewise, encouraging more frequent and appropriate flood inundation, channel migration, pool scour, and wood recruitment, enables the channel to form and maintain complex habitat.

Removing barriers to process often involves complex analysis and modeling to evaluate risk and potential channel response, but the concept is relatively straight forward (i.e., remove a levee and the channel and/or floodwater will reoccupy some portion of the area behind the levee). Encouraging a greater frequency and/or magnitude of channel-forming processes on the other hand can be conceptually more complicated and nuanced. For example, adding strategically placed structure to a stream channel can be used to reduce inappropriate rates of erosion in unfavorable areas, while increasing rates of channel migration into favorable areas. The same approach can be applied to affect pool formation, flood inundation, and avulsion potential. Allowing and/or enabling the river to more frequently overtop its banks in strategic locations will simultaneously provide high-flow refuge for juvenile fish, promote fine sediment deposition, increase nutrient cycling, recharge the local groundwater table, create off-channel habitat, and potentially create a new side channel.

Given this nuance, process restoration treatment types exist along a continuum from very limited interventions (i.e., passive) to very extensive and comprehensive channel and floodplain reconstruction (i.e., active). All of the potential treatments along this continuum are intended to initiate and expedite the natural evolution of the stream channel(s) toward a more desired condition, thereby improving fish habitat conditions essential for production, growth, and survival.

Restore Habitat

While restoring and reconnecting natural processes is the most effective means of addressing root problems and therefore enabling long-term habitat benefit, many constraints (physical, socioeconomical, financial, etc.) can diminish the potential for true process restoration. Meanwhile, Chinook salmon and steelhead remain listed under ESA, and habitat conditions continue to decline in many areas. Directly restoring instream habitat (i.e., habitat creation) with or without more comprehensive process restoration, remains a viable means of providing immediate habitat benefits for imperiled species.

Restoring river forms via direct habitat creation should include appropriate analysis and geomorphic considerations to ensure those created features provide habitat benefit while working with (not against) the natural processes in the system. For example, adding large woody debris to an existing channel for habitat cover can be done to create instream hydraulic variability, localized pool scour, and low-velocity flow areas along the banks. While the wood structures may not be fundamentally restoring river process, they are working with existing processes to maintain the habitat being created. Similarly, new mainstem and/or side channels can be excavated to mimic high-quality, mature channel forms following appropriate geomorphic target conditions (outlined per reach later in this report). In a best-case scenario, existing high-quality habitat and habitat-forming processes are largely protected within a watershed; water quantity and quality are not significantly limiting fish production; and process restoration is ongoing on a large scale. Added to these beneficial treatments (often rapidly increasing the rate by which habitat becomes most beneficial) are individual instream structures and habitat elements meant to complement larger scale process restoration by emulating mature reference conditions that may otherwise take years or decades to form naturally (Figure 22).

Figure 22. Drone image of lower Lemhi project immediately after construction illustrating constructed side channels, mainstem riffles, and engineered log jams designed to create immediate habitat while working with the natural processes within this reach to maintain a multi-threaded channel planform over the long-term.

Summary

Protection, water, process restoration, and habitat restoration while described individually above are not necessarily standalone treatments. The most effective restoration strategies incorporate all these treatments within a watershed and often several within a single project. Identifying and describing this well-documented and scientifically accepted strategy in the context of the lower Lemhi is intended to facilitate its understanding and incorporation into future project development, prioritization, and implementation.

For the lower Lemhi River, restoration projects that utilize the strategy summarized above are generally intended to improve habitat complexity while preferably restoring a sinuous, multi-threaded channel system with reduced width-to-depth ratios where currently straightened and simplified, stabilized streambanks where currently unstable, and increased riparian tree- and shrub-dominated habitat to provide long-term structure and cover. The following specific actions should be considered to achieve these goals in all reaches of the lower Lemhi River:

- Restore process and habitat by distributing flow and energy laterally by enabling channel migration and avulsion and/or reconstructing appropriate primary and secondary channel planforms within the range of recommended target conditions (see reach summaries below). Preferably, relocate and/or create new channels directly adjacent to existing, mature, woody riparian vegetation to immediately take advantage of their root structure, large woody debris recruitment potential, overhead cover, and shade.

- Restore process and reconnect habitat by increasing side channel abundance and diversity with proximal access to the primary channel (i.e., more short side channels versus fewer long side channels) (Figure 23). Side channels and other similar off-channel habitat can be created passively by forcing overbank flow into areas with dense riparian vegetation or other similar roughness/structure, by removing a structure blocking an existing side channel (e.g., levee removal), or by raising the water surface to access the overbank area. Suitable forcing mechanisms to raise the water surface may include an elevated grade control (e.g., constructed riffle) or adding one or more instream obstructions to sufficiently back up flow (e.g., log jams in the primary channel and beaver dam analogues in secondary channels). Alternatively, secondary channels and associated floodplain benches can be excavated to mimic a natural and diverse morphology incorporating structure and variability as appropriate (i.e., high frequency of habitat reaches).
- Restore hydraulic processes, floodplain reconnection, and habitat by providing a greater diversity of channel forms (i.e., channel geometry and planform) incorporating variability within the range of recommended target conditions and seeking to maximize habitat unit frequency (see reach summarizes below). Channel geometry and planform restoration should focus on reducing channel confinement, increasing sinuosity, and increasing geomorphic complexity. Secondary channels should be incorporated where possible.
- Protect existing areas of dense, woody, riparian vegetation where hydraulic complexity and habitat conditions are already favorable.
- Restore riparian processes by planting woody vegetation (especially cottonwood) with greater plant density along the outside of bends and in floodplain areas susceptible to channel migration and/or avulsion to ensure future channel evolution results in favorable conditions. Streamside trees and shrubs provide local erosion resistance on the channel boundary enabling lateral distribution of flow and energy within the stream and floodplain, thereby fostering pool scour and lateral migration (as opposed to downstream migration and/or widening).
- Restore process and habitat by increasing the abundance of instream structure creating hydraulic diversity and habitat complexity while promoting more floodplain inundation and side channel development. Historically, instream structure in the lower Lemhi was provided by log jams and areas of dense/mature riparian vegetation (OSC Team 2019). Beaver dams are likely unsustainable within the single-thread mainstem of the lower Lemhi given its size, but beaver dams are appropriate within secondary channels and other off-channel habitat where instream forces are lower. Reach-specific suitability for beaver dam restoration can be evaluated on a case-by-case basis (Macfarlane et al. 2017). Use of woody debris and other bioengineering techniques are highly recommended for instream structure and short-term bank stabilization. Quantified bioengineering stability thresholds are well established and can be used to appropriately size and select treatment types (Fischenich 2001). Habitat features should include interstitial spaces comparable to the size of juvenile fish (10s to 100s of mm) for concealment cover.
- Restore localized hydraulic processes and habitat by modifying primary channels to result in a diversity of habitat units, including pool-riffle sequences with a range of geometry and spatial distribution. This can be accomplished by adding instream structure, increasing channel sinuosity, improving bank structure with riparian vegetation, creating side channels, and/or introducing new grade controls with constructed riffles and beaver dam analogues.

Stream reaches comprised of multiple channels with high habitat and geomorphic complexity represent some of the most important ecological areas for salmon and steelhead. These reach types are a primary focus of this restoration strategy. Multi-threaded streams can develop in a range of physical settings, while exhibiting common characteristics and processes within unique types of secondary channels (Table 4; Figure 24; Appendix B). Multi-threaded stream systems typically have one primary channel and multiple secondary channels, oftentimes with a flow distribution similar among all the channels. Some of these stream systems may have one obvious primary channel with one or several much smaller secondary (or "side") channels. The terms secondary and side channel are used interchangeably, typically depending on the channel planform characteristics and the number of channels in the reach of interest. As restoration treatments, secondary channels are most effective at directly addressing degraded stream conditions such as the following:

- Incised single-thread channels
- Limited lateral distribution of flow
- Lack of instream hydraulic and structural habitat diversity

The development of secondary channels can also indirectly address degraded stream conditions such as the following:

- Over-widened channels—by creating fewer, narrow channels with less energy, thereby enabling sediment deposition and vegetative encroachment (i.e., narrowing)
- High summer stream temperatures—by fostering cooler groundwater inflow to side channels, creating deeper channels with microscale thermal stratification, and creating narrower channels with greater shading potential

When developing new and additional secondary channels to improve juvenile salmonid rearing conditions in the lower Lemhi (Figure 25), the following approach is recommended:

- Use Table 4 and Appendix B to facilitate conceptual side channel designs for a given reach. Detailed analysis and hydraulic modeling will be required to advance and ultimately finalize the side channel design if a high degree of certainty is required of the outcome.
- Building side channels with appropriate geomorphic and habitat conditions that will work with the stream's natural processes is recommended where existing bank and floodplain structure (i.e., especially dense riparian vegetation) is lacking. Forcing the stream to create a new side channel or channel network on its own (i.e., commonly termed "Stage-0" restoration in reference to Cluer and Thorne's 2014 Stream Evolution Model) is only advised where significant floodplain roughness is available or can be placed/embedded prior to construction.
- Within a project reach, an abundance of shorter side channels is better than fewer, long side channels, thereby maximizing the number of points of channel convergence and divergence while also minimizing the distance between side channel habitat and mainstem habitat types (i.e., greater diversity and frequency of habitat reaches) (Figure 23).
- A variety of appropriate side channel types and sizes (i.e., widths) provides greater habitat diversity and is considered more favorable than fewer side channel types and sizes.
- Perennial, seasonal, high-flow, and groundwater side channels are possible within any of the side channel types identified in Table 4 and each provide different habitat benefits.

- Side channels with greater slopes and shorter lengths than the primary channel may present an avulsion risk that should be thoroughly evaluated during assessment and design.
- Large woody debris (especially log jams) and microtopography should be used to facilitate flow splits within the existing and potential future channel alignments enabling a dynamic channel response while ensuring future lateral flow distribution (i.e., preventing an undesirable, straight, incised, avulsion).
- Instream structures should be scaled appropriately for the size of the side channel and potential future evolution of the side channel. If the side channel may accumulate more flow and/or become the primary channel in the future it may be warranted to size large wood structures accordingly.

Figure 23. Google Earth aerial image from the upper Big Lost River, Idaho, illustrating a side channel complex with many small and diverse side channel types. Flow is from right to left.

Table 4. Secondary channel types and characteristics.

Lateral Adjustment	Hydrologic Regime	Sediment Transport Regime		Secondary Channel Type	Characteristics
		Primary Channel Transport	**Secondary Channel Supply**		
Laterally Inactive	Peak and Base Flows	Low to moderate fine and coarse material bedload transport	Suspended bed material and wash load	Beaver Dam Distributed	• Flow distributed laterally by beaver dam(s) • Multi-thread backwater channels of variable width • More than one outlet channel at various elevations • Dense riparian vegetation and abundant instream woody material
	Base Flow	Low to moderate coarse material bedload transport	Suspended bed material and wash load	Valley-fill Sub-parallel	• Multiple individual stable channels that persist over time in the same location • Channels separated by vegetated floodplain, upland terraces, or stable islands • Dense riparian vegetation and abundant instream woody material
Laterally Active	Peak Flow	Moderate coarse material bedload transport	Primarily suspended bed material and wash load; moderate coarse bedload	Valley-fill Distributed	• Associated with bedload deposition and channel aggradation • Multiple small-scale avulsion channels along outside of meander bend carving new channels • Dense riparian vegetation limits side channel expansion • Beaver dam development following side channel formation

Table 4. Secondary channel types and characteristics.

Lateral Adjustment	Hydrologic Regime	Sediment Transport Regime: Primary Channel Transport	Sediment Transport Regime: Secondary Channel Supply	Secondary Channel Type	Characteristics
Laterally Active (cont.)	Peak Flow (cont.)	Moderate to high coarse material bedload transport	Bedload, suspended bed material, and wash load	Meander-Relict	• Associated with point-bars and lateral channel migration • Small-scale avulsion into relict channel scar along outside of meander bend • Former main channel becomes secondary channel • Multiple side channels develop adjacent to the avulsion path, often from beaver occupation • Dense riparian vegetation and/or large wood material limits capture of entire primary channel • Avulsion channel (secondary channel) expansion to size of relic main channel • Dense riparian vegetation develops throughout multi-thread channels stabilizing isolated hard points throughout the floodplain
		High coarse material bedload transport	Bedload, suspended bed material, and wash load	Bar-Island Split	• Located in unconfined and partially-confined valleys • Associated with aggradation of bedload and multiple bar formation • Development of mature riparian forests in between active channels • Recruitment of large wood material to the stream channel • Mature riparian vegetation and large wood material stabilize islands and bars creating multiple channels

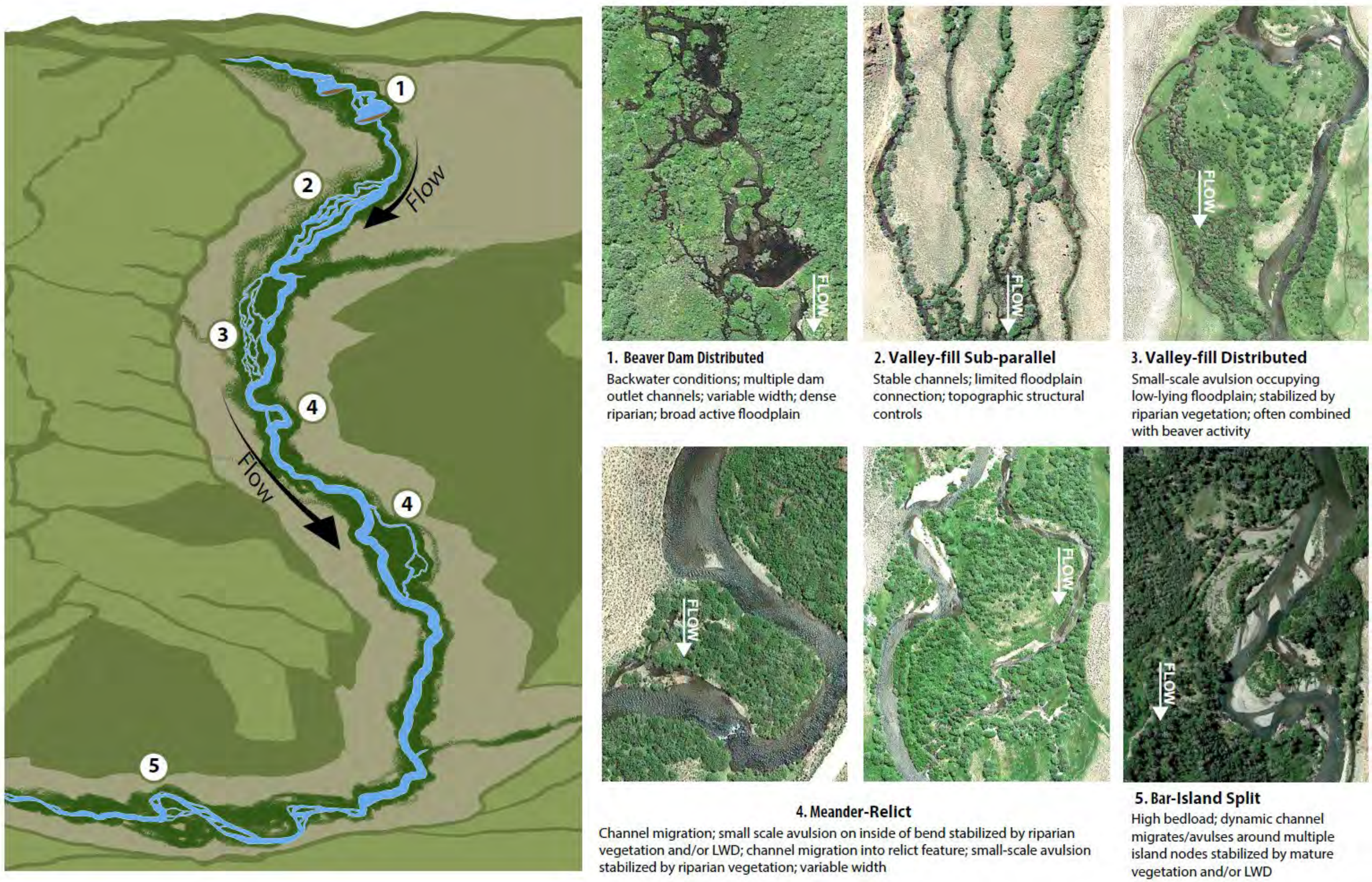


Figure 24. Types of secondary channels.

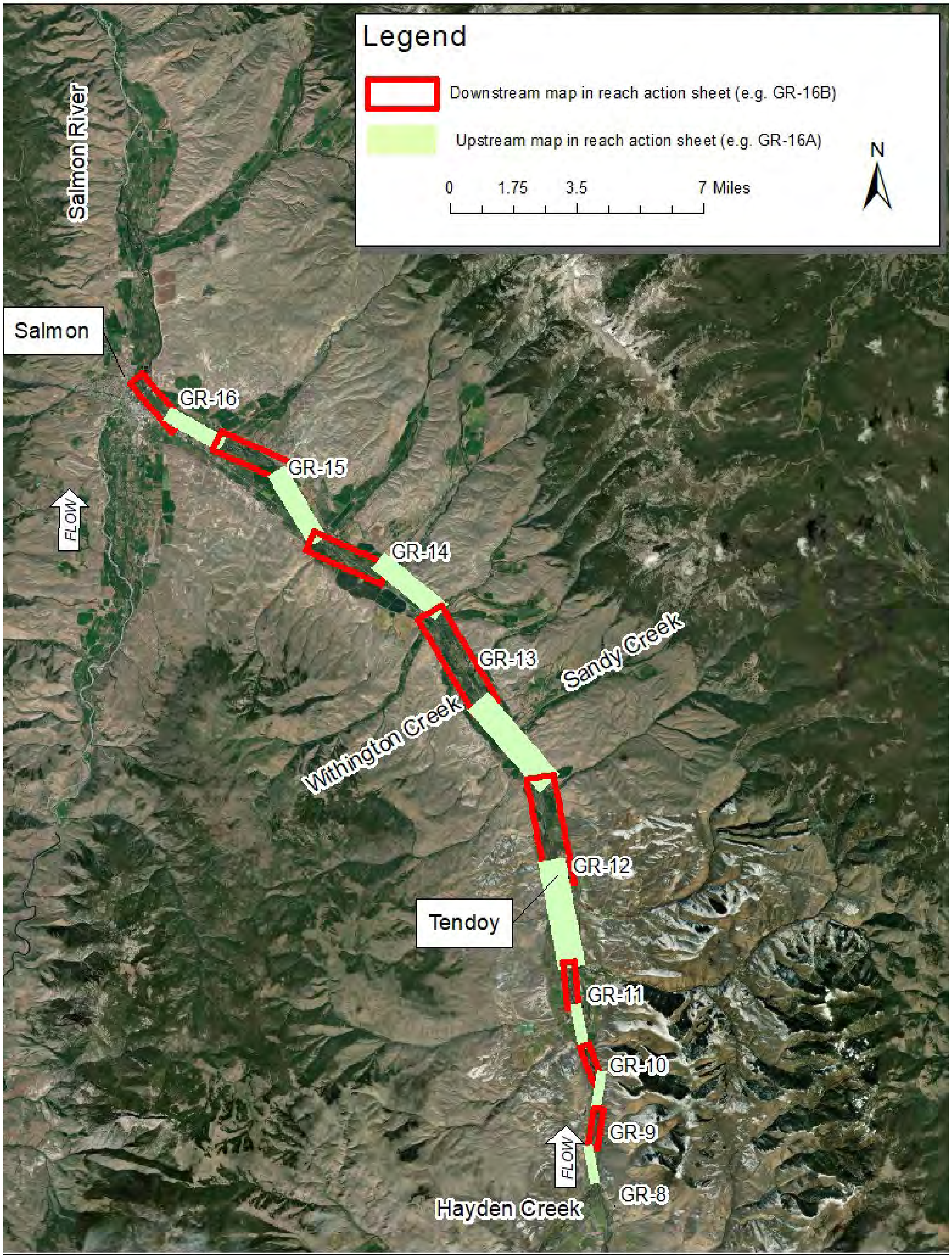


Figure 25. Index map for Geomorphic Reach (GR) maps containing descriptions of existing conditions and example restoration actions.

Interpretation of Reach Action Sheets

The following information is provided on the reach action sheets in the sections below.

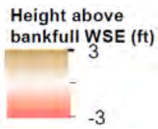
Reach Descriptions

Summary of existing conditions, target conditions, and recommended restoration actions for each reach

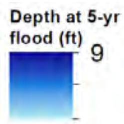
Existing Conditions Map

The existing conditions (EC) map is the first map for each reach and includes the following layers:

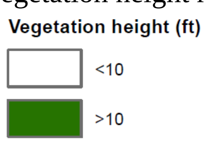
- LiDAR hillshade baselayer illustrating topography
- Relative surface model derived from LiDAR illustrating the relative height of floodplain features above or below the bankfull water surface elevation (brown is higher and red is lower)



- Hydraulic modeling depth outputs from modeling of the 5-year flood (darker blue is deeper)



- Vegetation height model from LiDAR output illustrating vegetation over 10-feet tall (dark green)

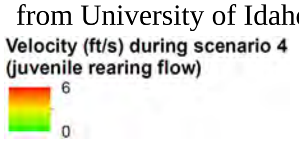


- Landownership parcel lines
- River miles upstream from the confluence with the Salmon River
- Geomorphic Reach (GR) boundaries

Potential Actions Map

The potential actions (PA) map is the second map for each reach and includes the following layers

- Recent aerial image baselayer
- Hydraulic modeling velocity outputs from modeling juvenile rearing habitat flow (Scenario 4 from University of Idaho modeling output) (darker red is faster)



- Landownership parcel lines

Notes and Photos from Map Callouts

Callouts on EC# maps identify and describe existing conditions of note. Included in these results are examples of especially low-quality habitat and high-quality habitat to use as a reference.

Callouts on PA# maps identify potential restoration actions and considerations, as described in greater detail in Table with potential restoration actions. These callouts are intended to provide representative examples and are not intended to be all inclusive or represent the best/only actions.

Methods for Geomorphic Targets

The following methods apply to elements described per geomorphic reach discussed below.

- **Bankfull Discharge**: According to Castro and Jackson (2001), the bankfull discharge in this area tends have a similar magnitude to the 1.5 -year flood. The Lemhi River Hydraulics and Hydrologic Assessment (USBR 2017) provided 1.5-year flood magnitudes for each georeach. Where hydrology changed within a georeach (e.g., if a tributary entered the Lemhi midway through a georeach), the 1.5-year flood was averaged for the reach.
- **Sinuosity**: Where the channel did not appear straightened, mainstem sinuosity was assumed to be appropriate. In areas where there was evidence of channel straightening, an appropriate mainstem sinuosity was assessed from local reference sites.
- **Meander Amplitude**: Target meander amplitude was determined by measuring the meander amplitudes observed in reference sites from each georeach. The maximum observed meander amplitude was then used to provide an upper constraint on design.
- **Meander Wavelength**: Target meander wavelength was determined using reference sites within each georeach. The average meander wavelength in those reference sites is reported.
- **Radius of Curvature**: Target radius of curvature was determined using reference sites within each georeach. The average radius of curvature in those reference sites is reported. Standard deviation is determined by measuring the ratio of standard deviation to average radius of curvature in all reaches and applying that value to the average for a given reach to provide a range.
- **Bankfull Width**: A range of average bankfull widths were measured empirically at representative locations within local reference sites. Additional estimates for restored bankfull widths were derived from channel geometry regime equations with empirical data from the Lemhi River (Millar and Eaton 2011; Eaton and Millar 2017). Widths are expected to vary depending on local riparian vegetation, hydraulics, bend geometry, etc. (e.g., point bars along bends, island areas, channel constrictions, side channels). The target bankfull represents the average for the reach, not the full range of potential widths.
- **Bankfull W:D**: Bankfull width-to-depth was determined based on target calculated bankfull widths and depths from regime equations (Millar and Eaton 2011; Eaton and Millar 2017).
- **Bedload**: The sediment bedload is a qualitative measurement, based on professional judgement.
- **Side Channel Type**: qualitative determination based on observations of reference conditions and SEM (Cluer and Thorn 2014)
- **Side Channel Density**: High quality reference sites outside of the Lemhi were observed remotely using aerial photos to determine side channel density targets. The dominant side channel formation process was determined by professional judgement. Side channel density in those sites were measured remotely in GIS, and the average side channel density by side channel type was then calculated to determine target side channel density. Synonymous with "braidedness."
- **Structure Type**: Based on reference condition observations and interpretation of local conditions.
- **Structure Spacing**: Qualitative value based on lower Lemhi reference sites observed and professional judgement.

GR-9 Actions

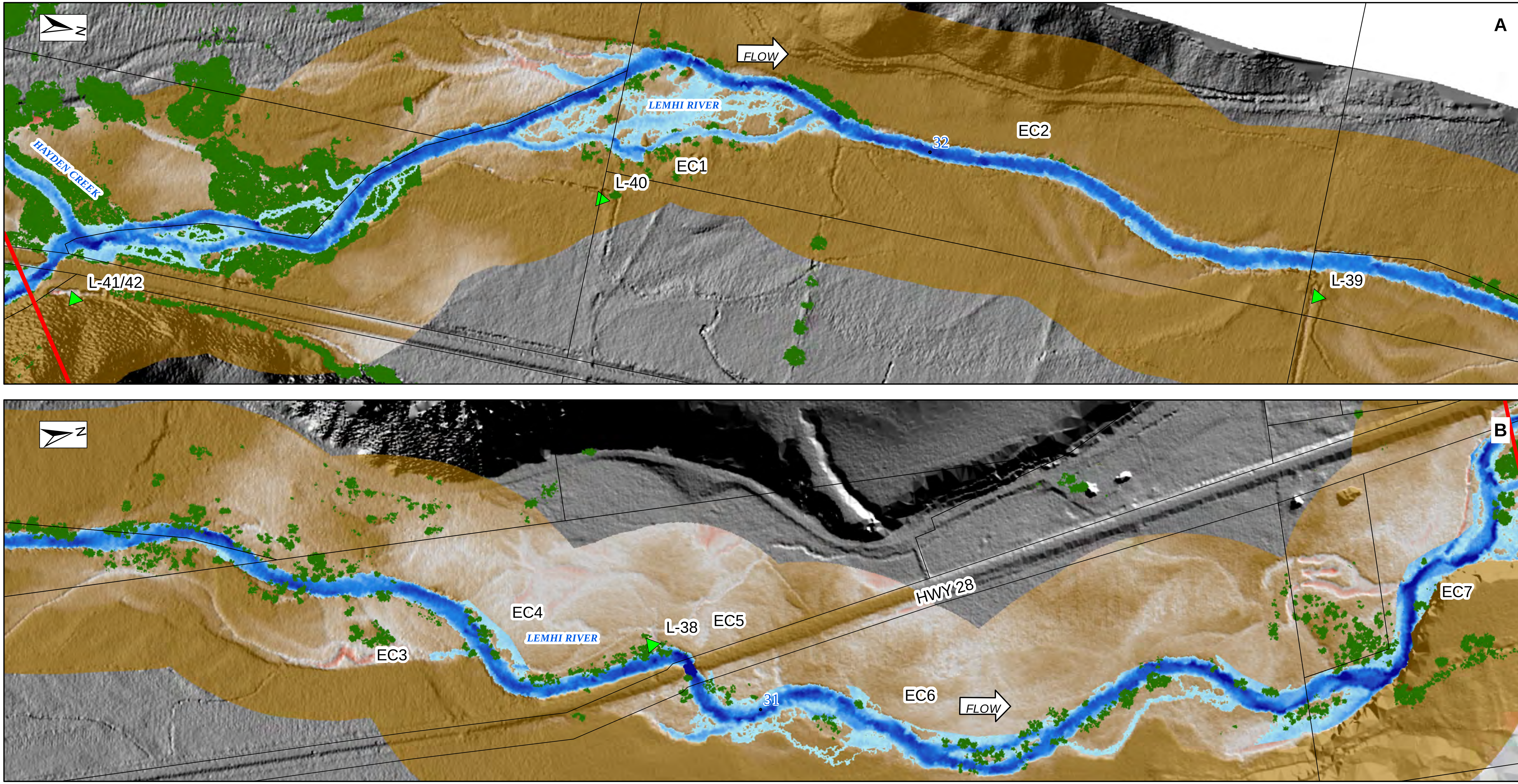
Geomorphic Reach 9 (GR-9) is located along the Lemhi River between RM 32.7 and RM 30.3, in an unconfined valley with moderate valley bottom constraints resulting in the narrowing of the accessible valley bottom by about 25 percent. The reach is located immediately below the confluence with Hayden Creek and is significantly influenced by the peak-flow hydrology and coarse sediment inputs from Hayden Creek. Throughout much of this reach, the river has been mechanically straightened, with increased artificial bank protection and corresponding removal of complex channel morphology. These channel alterations have resulted in limited hydraulic connectivity between the river and floodplain, and a limited extent of functional riparian vegetation communities. The highway bridge and road prism near the downstream end of the reach concentrate in-channel and overbank flows into one primary channel, maintaining a single-thread river system.

Table 5. Lower Lemhi River – Geomorphic Reach 9 Targets.

Element	Target	Notes
Channel Morphology	Pool-Riffle	Based on Montgomery and Buffington (1998)
Bankfull Discharge (cfs)	637	1.5 yr flood (Castro and Jackson 2001); at downstream end of reach
Sinuosity	1.7	Much of channel has been mechanically altered and straightened
Meander Amplitude (ft)	568	Max amplitude equivalent to minimum floodplain width; based on meander scars in Lower Lemhi
Meander Wavelength (ft)	915	Equivalent to 2 full meanders; based on reference site in GR-15
Radius of Curvature (ft)	288	Average based on meander scars; Radius encompass a large range
Bankfull Width (ft)	27–34	Range for single-thread channel
Bankfull W:D (ft/ft)	8–12	Average width / average depth
Bedload	Gravel	Bedload; areas with cobble armor persist
Side Channel Type	Meander-Relict and Beaver Dam Distributed	Diversity of short and long side channels with similar geometry to main stem; maintained by dense riparian vegetation; beaver dams in smaller, low energy channels
Side Channel Density	>3.75	Total channel length / valley length
Structure Type	LWD, Willow clumps & vegetation	Instream structure material
Structure Spacing	Multiple per bend	To replicate dense riparian vegetation and beaver dams

Recommended treatments are focused on addressing the primary functional limitations in this reach that have resulted from channel straightening and artificial confinement. These treatments include remeandering of the primary channel to increase sinuosity, which would result in a corresponding decrease in stream power and increase in gravel bar formation with subsequent improvement in complex channel morphology. Remeandering of the primary channel can be accompanied by developing secondary channels in low-lying areas of the floodplain, including full secondary channel construction and minor excavation to initiate self-forming secondary channels. In some locations, a more passive approach can be used to activate legacy side channels over a larger range of flows. Improvements to primary and secondary channel morphology should be accompanied by increasing roughness in all channels with large woody debris (LWD), willow clumps, and replanting of woody riparian vegetation. All of the recommended treatments are intended to improve floodplain connectivity and foster more extensive and functional riparian vegetation communities.

Existing conditions and proposed actions maps of this reach are provided on the next pages.



River Mile

Lemhi County Parcels

Reach Boundary

Depth at 5-yr flood (ft): 9 – 0

Height above bankfull WSE (ft): 3 – -3

Vegetation height (ft): <10; >10

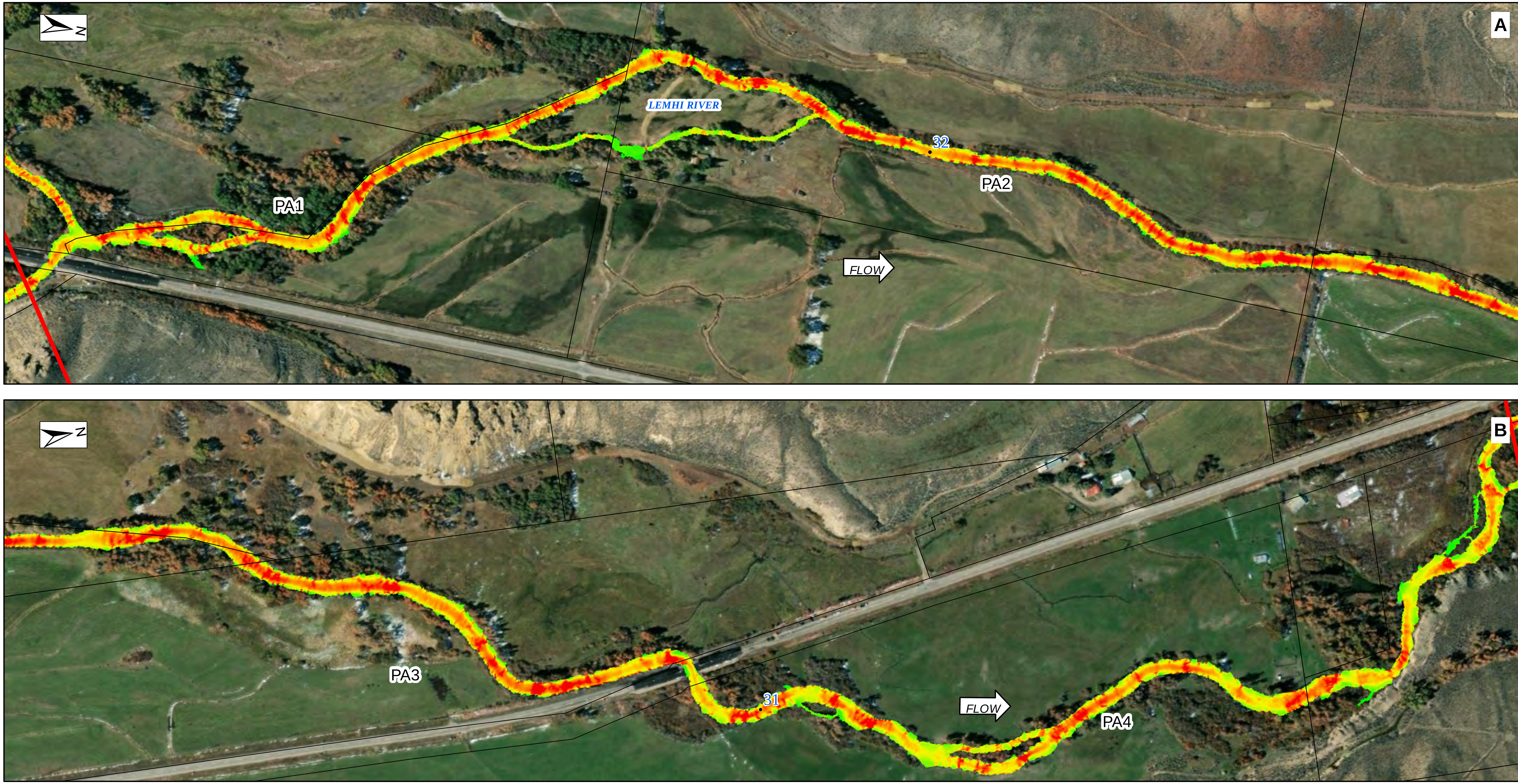
Irrigation Fish Screens

Notes:
-Hydraulic model extent may not depict the total inundated area for this discharge.

0 250 500 1,000 Feet

Data Sources: Hillshade, vegetation, and relative surface model (2014 and 2011 LiDAR), Depth raster (University of Idaho hydraulic modeling)

Figure 26
Existing Conditions Map
Lower Lemhi Georeach 9



River Mile

Lemhi County Parcels

Reach Boundary

Velocity (ft/s) during scenario 4
(juvenile rearing flow)

6

0

Notes:
-Hydraulic model extent may not depict the total inundated area for this discharge.
-Scenario 4 corresponds to a discharge of 441 cfs.

0 250 500 1,000 Feet

Figure 27
Proposed Actions Map
Lower Lemhi Georeach 9

Data Sources: Aerial imagery (ESRI streaming), Velocity raster (University of Idaho hydraulic modeling)

Georeach 9

Existing Condition Notes:

EC1: Connected floodplain with active side channel.

EC2: Confined, straightened (low sinuosity), incised channel with relatively homogenous bedform, limited floodplain connectivity, and little to no riparian vegetation.

EC3: Low-lying topography (relic channel scar) in valley is near channel grade; currently functioning as an irrigation return.

EC4: Relic channel scars on river left illustrate historical multi-threaded channel planform.

EC5: Road and bridge confine channel forcing a single-thread planform morphology.

EC6: Increasing floodplain connectivity in this subreach; areas of improved riparian vegetation correspond with areas of increased bedform complexity (i.e., frequency of pools).

EC7: Location of recent floodplain reconnection and side-channel creation project not illustrated in the LiDAR.

Potential Actions Notes:

PA1: Opportunities at this location (and similar areas with existing dense riparian vegetation and low lying topography) to benefit from a light-handed approach of activating legacy side channels at greater range of flows or constructing side channels in the floodplain.

PA2: Increase sinuosity, floodplain connectivity, and secondary channel development in this straightened subreach. Add large wood material for instream and floodplain roughness.

PA3: Potential site for improving floodplain connectivity and sinuosity by activating side channel and remeandering. Could be done in conjunction with downstream channel relocation, moving channel away from the road.

PA4: Tie into recently completed downstream project by increasing sinuosity, side channels, floodplain connectivity, and riparian vegetation.

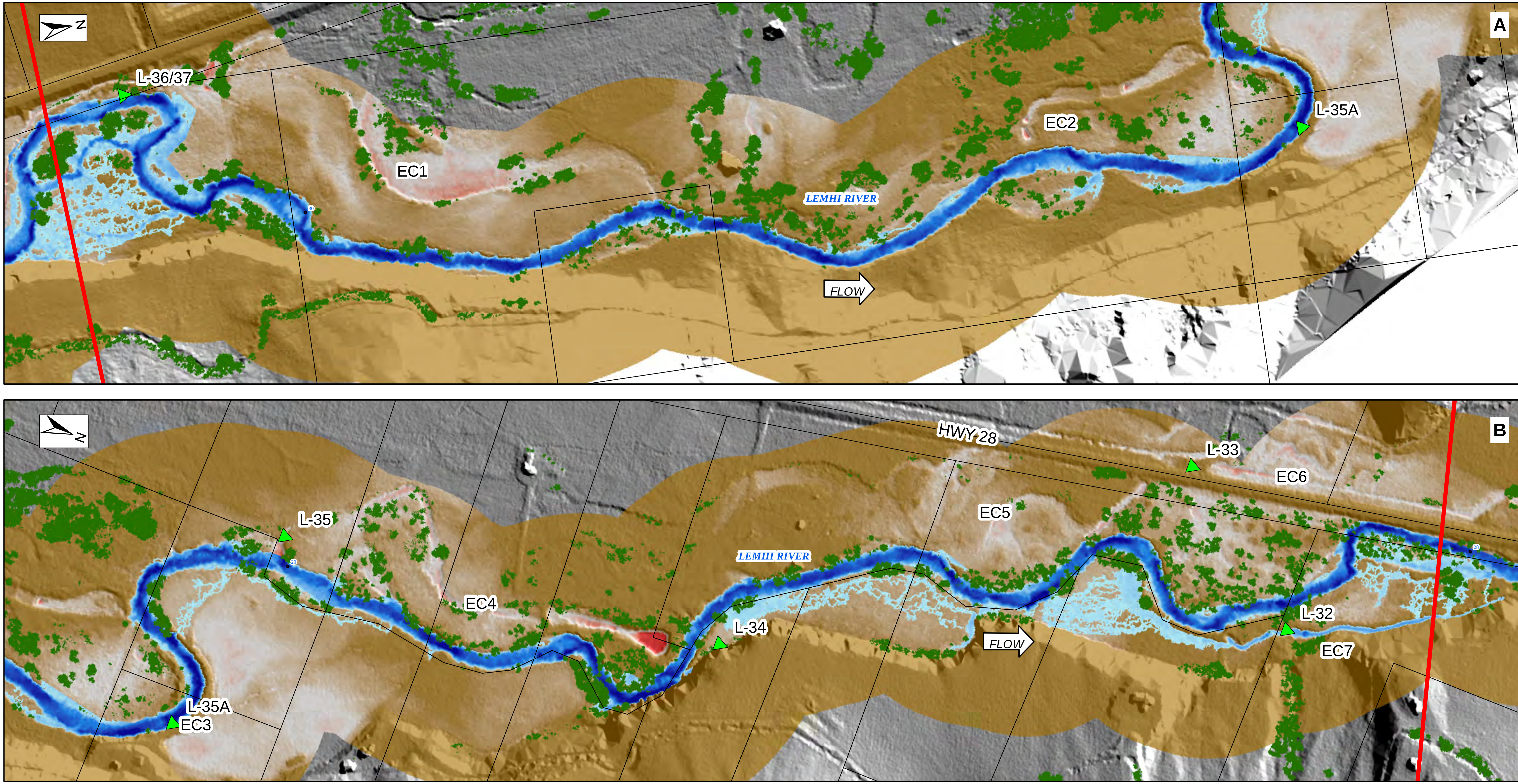
GR-10 Actions

Geomorphic Reach 10 (GR-10) is located along the Lemhi River between RM 30.3 and RM 28.0, in an unconfined valley with moderate valley bottom constraints, resulting in the narrowing of the valley bottom by about 35 percent. Throughout much of this reach, the river has been mechanically straightened. These channel alterations are most significant in the upper half of the reach where the primary channel has been relocated to the base of the valley wall and maintained there with bank protection. While the reach exhibits some meandering characteristics, this alignment is largely artificially maintained by bank protection treatments. The channel straightening and confinement, along with a lack of LWD, has fostered hydraulic characteristics that limit gravel bar formation and development of complex channel morphology. The existing conditions have reduced the hydraulic connectivity between the river and floodplain, and have reduced lateral channel migration, which are important processes for creating and sustaining a complex network of side channels and the corresponding high-quality fish habitat. Some areas within the reach contain mature riparian vegetation, which present an opportunity for future restoration efforts in these areas.

Table 6. Lower Lemhi River – Geomorphic Reach 10 Targets.

Element	Target	Notes
Channel Morphology	Pool-Riffle	Based on Montgomery and Buffington (1998)
Bankfull Discharge (cfs)	664	1.5 yr flood (Castro and Jackson 2001); at downstream end of reach
Sinuosity	1.7	Some straightening has occurred
Meander Amplitude (ft)	155	Max amplitude equivalent to minimum floodplain width
Meander Wavelength (ft)	915	Equivalent to 2 full meanders; based on reference site in GR-15
Radius of Curvature (ft)	215	Average based on meander scars; Radius encompass a large range
Bankfull Width (ft)	30–32	Range of average for single-thread channel
Bankfull W:D (ft/ft)	8–12	Average width / average depth
Bedload	Gravel	Bedload
Side Channel Type	Meander-Relict and Beaver Dam Distributed	Diversity of short and long side channels with similar geometry to main stem; maintained by dense riparian vegetation; beaver dams in smaller, low energy channels
Side Channel Density	>3.75	Total channel length / valley length
Structure Type	LWD, willow clumps & vegetation	Instream structure material
Structure Spacing	Multiple per bend	To replicate dense riparian vegetation and beaver dams

Recommended treatments are focused on addressing the primary functional limitations in this reach that have resulted from channel straightening and artificial confinement. These treatments include removal of bank protection to encourage channel migration and floodplain connectivity, accompanied with additions of LWD to the primary channel. These actions would result in a corresponding decrease in stream power and increase in gravel bar formation with subsequent improvement in complex channel morphology. Treatments in the primary channel can be accompanied by developing secondary channels in low-lying areas of the floodplain, including full secondary channel construction and minor excavation to initiate self-forming secondary channels. These actions could be more passively oriented in areas with existing mature riparian vegetation. Existing conditions and proposed actions maps of this reach are provided on the next pages.



River Mile

Lemhi County Parcels

Reach Boundary

Depth at 5-yr flood (ft)
9

Height above bankfull WSE (ft)
3
-3

Vegetation height (ft)
<10
>10

Irrigation Fish Screens

Notes:
-Hydraulic model extent may not depict the total inundated area for this discharge.

0 250 500 1,000 Feet

Data Sources: Hillshade, vegetation, and relative surface model (2014 and 2011 LiDAR), Depth raster (University of Idaho hydraulic modeling)

Figure 28
Existing Conditions Map
Lower Lemhi Georeach 10

River Mile

Lemhi County Parcels

Reach Boundary

Velocity (ft/s) during scenario 4 (juvenile rearing flow)

6

0

Notes:
-Hydraulic model extent may not depict the total inundated area for this discharge.
-Scenario 4 corresponds to a discharge of 441 cfs.

0 250 500 1,000 Feet

Data Sources: Aerial imagery (ESRI streaming), Velocity raster (University of Idaho hydraulic modeling)

Figure 29
Proposed Actions Map
Lower Lemhi Georeach 10

Georeach 10

Existing Conditions Notes:

EC1: Relic channel meander with areas of existing, mature riparian vegetation potentially utilized as irrigation ditch (upper meander near L-36/37).

EC2: Relic channel meanders and side channel augmented by excavated ponds with artificial grade control and poor riparian vegetation. Mainstem Lemhi has been straightened and confined by cutting off relic meanders causing modest incision and bed armoring.

EC3: Levee blocking floodplain connection. Irrigation diversion.

EC4: Relic channel meander with suspected levees and elevated roads preventing activation at high flow. Excavated pond at downstream end of relic meander scar.

EC5: Relic channel meander on the left bank with active floodplain on the right bank. Poor to moderate riparian vegetation improving toward the downstream reach break.

EC6: Highway 28 constricts available area for channel migration, side channels, off-channel habitat and flooding.

EC7: Irrigation ditch.

Potential Actions Notes:

PA1: Continuation of restoration project immediately upstream. Potential setback of levees and/or removal of bank protection and placement of large wood material instream. Consider evaluating split flow potential utilizing relic channel on western (left) floodplain (may require modifications to the irrigation ditch).

PA2: Potential to reactivate relic channel meander(s), preferably connected to the main channel with additional small side-channels.

PA3 Potential site to add several small side channels between the meander bend.

PA4: Site has potential for channel remeandering, side channel development, and improved floodplain connection within area of relatively accessible floodplain with existing moderate- to high-quality riparian vegetation. Utilize existing riparian vegetation for channel and bank structure.

GR-11 Actions

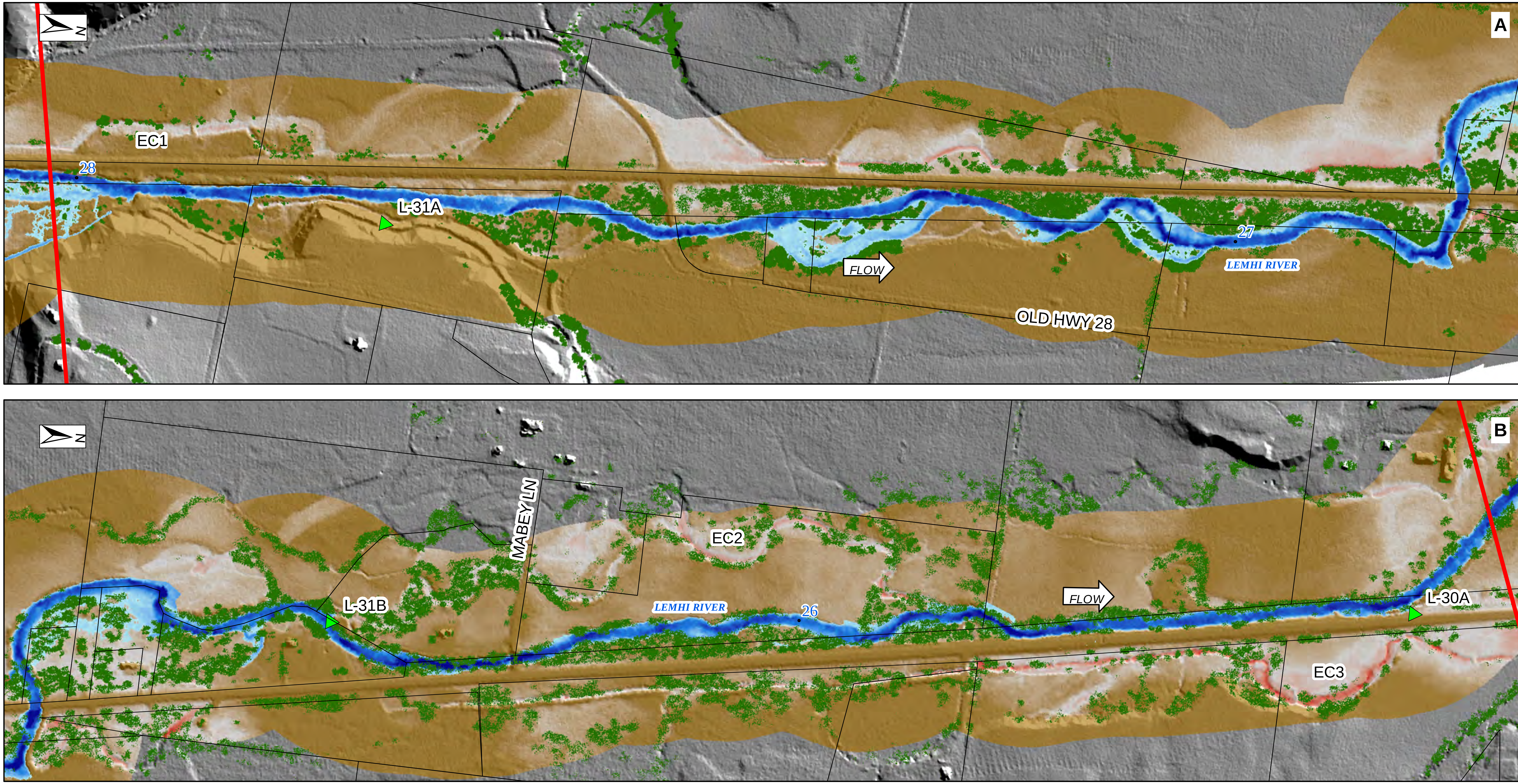
Geomorphic Reach 11 (GR-11) is located along the Lemhi River between RM 28.0 and RM 25.4 in a naturally unconfined valley with significant valley bottom constraints resulting from narrowing of the valley bottom by about 55 percent due to Highway 28. The channel straightening and artificial confinement has limited the hydraulic connectivity between the river and floodplain and concentrated high energy flow within the Lemhi River. These conditions have produced a simplified channel morphology and low-quality fish habitat, owing to limited hydraulic habitat diversity and instream cover. The existing conditions have removed connections with relic side channels and reduced lateral channel migration, which are important processes for creating and sustaining a complex network of side channels and the corresponding high-quality fish habitat. Some areas within the reach contain mature riparian vegetation, which present an opportunity for future restoration efforts in these areas.

Table 7. Lower Lemhi River – Geomorphic Reach 11 Targets.

Element	Target	Notes
Channel Morphology	Pool-riffle	Based on Montgomery and Buffington (1998)
Bankfull Discharge (cfs)	715	1.5 yr flood (Castro and Jackson 2001); at downstream end of reach
Sinuosity	1.7	Many straightened segments
Meander Amplitude (ft)	568	Max amplitude equivalent to minimum floodplain width; based on meander scars in Lower Lemhi
Meander Wavelength (ft)	915	Equivalent to 2 full meanders; based on reference site in GR-15
Radius of Curvature (ft)	233	Average based on meander scars; Radius encompass a large range
Bankfull Width (ft)	31-35	Range of average for single-thread channel
Bankfull W:D (ft/ft)	8-12	Average width / average depth
Bedload	Gravel	Bedload
Side Channel Type	Meander-Relict and Beaver Dam Distributed	Diversity of short and long side channels with similar geometry to main stem; maintained by dense riparian vegetation; beaver dams in smaller, low energy channels
Side Channel Density	>3.75	Total channel length / valley length
Structure Type	LWD, willow clumps & vegetation	Instream structure material
Structure Spacing	Multiple per bend	To replicate dense riparian vegetation and beaver dams

Recommended treatments are focused on addressing the primary functional limitations in this reach that have resulted from channel straightening and artificial confinement. These treatments include remeandering of the primary channel to increase sinuosity, which would result in a corresponding decrease in stream power and increase in gravel bar formation with subsequent improvement in complex channel morphology. Treatments in the primary channel can be accompanied by developing secondary channels in low-lying areas of the floodplain, including full secondary channel construction and minor excavation to initiate self-forming secondary channels. These actions could be more passively oriented in areas with existing mature riparian vegetation. Improvements to primary and secondary channel morphology should be accompanied by increasing roughness in all channels with LWD, willow clumps, and replanting of woody riparian vegetation. All of these treatments will result in increased quantity, quality, and diversity of juvenile fish rearing habitat.

Existing conditions and proposed actions maps of this reach are provided on the next pages.



River Mile

Lemhi County Parcels

Reach Boundary

Depth at 5-yr flood (ft)
9

Height above bankfull WSE (ft)
3
-3

Vegetation height (ft)
<10
>10

Irrigation Fish Screens

Notes:
-Hydraulic model extent may not depict the total inundated area for this discharge.

0 250 500 1,000 Feet

Data Sources: Hillshade, vegetation, and relative surface model (2014 and 2011 LiDAR), Depth raster (University of Idaho hydraulic modeling)

Figure 30
Existing Conditions Map
Lower Lemhi Georeach 11

River Mile

Lemhi County Parcels

Reach Boundary

Velocity (ft/s) during scenario 4
(juvenile rearing flow)

6

0

Notes:
-Hydraulic model extent may not depict the total inundated area for this discharge.
-Scenario 4 corresponds to a discharge of 441 cfs.

0 250 500 1,000 Feet

Data Sources: Aerial imagery (ESRI streaming), Velocity raster (University of Idaho hydraulic modeling)

Figure 31
Proposed Actions Map
Lower Lemhi Georeach 11

Georeach 11

Existing Conditions Notes:

EC1: The reach is straightened and cut off from many relic meanders and from much of the floodplain by the highway. Channel straightening and simplification has led to a lack of complexity and poor habitat conditions for salmonids including excessive instream velocity, plain-bed morphology, armored substrate, and a lack of structure. The reach provides no refugia, and high velocities require energy expenditure and fewer feeding opportunities reducing growth potential for juvenile salmonids.

EC2: Relic side channel that activates infrequently; moderate amounts of existing riparian vegetation providing shade, cover, and structure. Abundance of relic/abandoned channel scars suggests this reach was historically multi-threaded prior to channelization and simplification.

EC3: Floodplain and relic channel scars on river right side of the highway appears to be lower than on river left (where the river is currently located).

Potential Actions Notes:

PA1: In targeted locations throughout the reach, restore floodplain and secondary channel connectivity through forested riparian zone utilizing existing low-lying topography and relic/abandoned channel scars where appropriate. Consider modifications to the road prism and floodplain enabling greater connectivity between main-stem, off-channel, and floodplain areas on both sides of the highway. Where secondary channel and floodplain connectivity are not feasible due to constraints, additions of instream structure and roughness (especially LWD) are recommended to disrupt flow, form/maintain pools, and provide cover for multiple life stages using this reach as a migration corridor.

PA2: Side channel enhancement opportunity in low-lying area.

PA3 Side channel enhancement opportunity in low-lying area with existing mature riparian vegetation.

PA4: Potential site to improve floodplain connectivity, side channels, and sinuosity. Consider options for split flow, and islands with LWD. Split flow would effectively provide two channels with main-stem habitat character doubling the opportunity from which multiple, smaller side channels could be created and/or formed.

PA5: Add sinuosity. Potential meander reconnection.

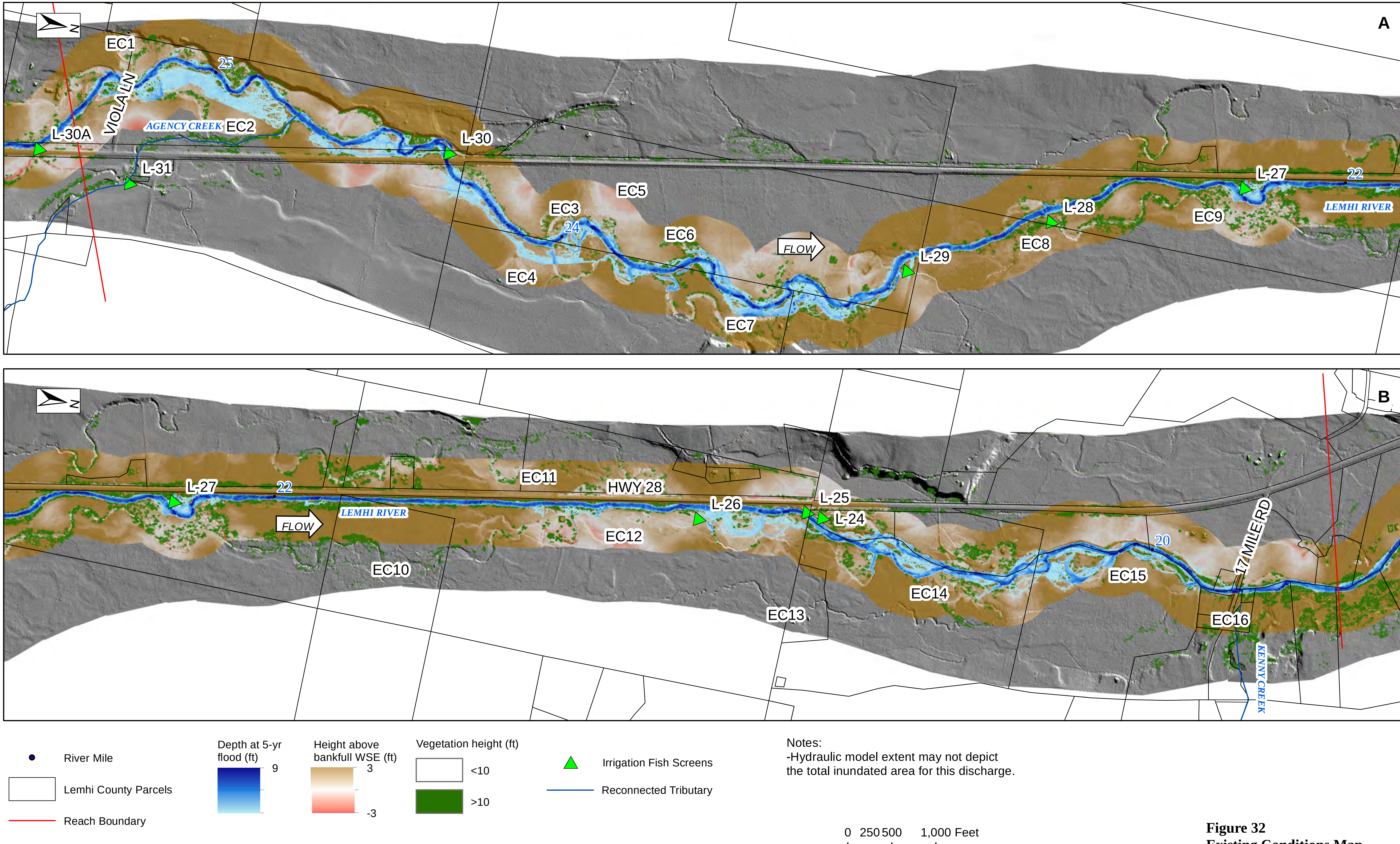
GR-12 Actions

Geomorphic Reach 12 (GR-12) is located along the Lemhi River between RM 25.4 and RM 19.6 in a naturally unconfined valley with significant valley bottom constraints associated with Highway 28, resulting in the narrowing of the valley bottom by about 30 percent. Channel straightening and artificial confinement has maintained a single-thread channel throughout the reach, with very limited floodplain connectivity and secondary channel activation. These channel alterations are most pronounced in the lower half of the reach, in an area where relic channel scars exist across the floodplain. These conditions have produced a simplified channel morphology and low-quality fish habitat, owing to limited hydraulic habitat diversity and instream cover in the mainstem river, and limited availability of side channel habitat. The channel straightening and confinement, along with a lack of LWD, has fostered hydraulic characteristics that limit gravel bar formation and development of complex channel morphology. This reach also has a limited extent of functional riparian vegetation communities.

Table 8. Lower Lemhi River – Geomorphic Reach 12 Targets.

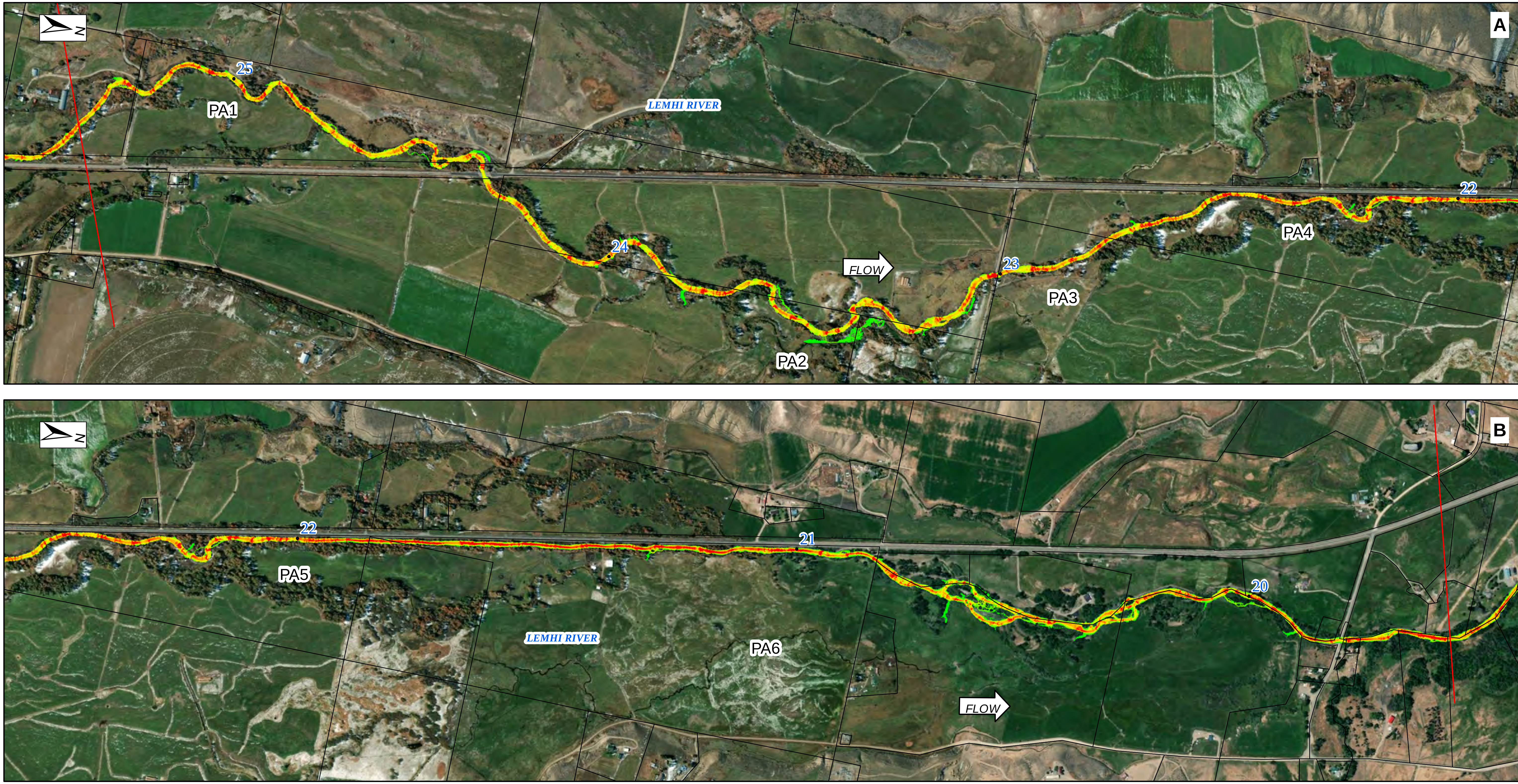
Element	Target	Notes
Channel Morphology	Pool-riffle	Based on Montgomery and Buffington (1998)
Bankfull Discharge (cfs)	789	1.5 yr flood (Castro and Jackson 2001); at downstream end of reach
Sinuosity	1.7	Address areas of historical channel straightening
Meander Amplitude (ft)	568	Max amplitude equivalent to minimum floodplain width; based on meander scars in Lower Lemhi
Meander Wavelength (ft)	915	Equivalent to 2 full meanders; based on reference site in GR-15
Radius of Curvature (ft)	232	Average based on meander scars; Radius encompass a large range
Bankfull Width (ft)	33-35	Range of average for single-thread channel
Bankfull W:D (ft/ft)	8-12	Average width / average depth
Bedload	Gravel	Bedload
Side Channel Type	Meander-Relict and Beaver Dam Distributed	Diversity of short and long side channels with similar geometry to main stem; maintained by dense riparian vegetation; beaver dams in smaller, low energy channels
Side Channel Density	>3.75	Total channel length / valley length
Structure Type	LWD, willow clumps & vegetation	Instream structure material
Structure Spacing	Multiple per bend	To replicate dense riparian vegetation and beaver dams

Recommended treatments are focused on addressing the primary functional limitations in this reach that have resulted from channel straightening and artificial confinement. These treatments include remeandering of the primary channel to increase sinuosity, which would result in a corresponding decrease in stream power and increase in gravel bar formation with subsequent improvement in complex channel morphology. Remeandering of the primary channel can be accompanied by developing secondary channels in low-lying areas of the floodplain, including full secondary channel construction and minor excavation to initiate self-forming secondary channels. In some locations, a more passive approach can be used to activate legacy side channels over a larger range of flows. Improvements to primary and secondary channel morphology should be accompanied by increasing roughness in all channels with LWD, willow clumps, and replanting of woody riparian vegetation. All of the recommended treatments are intended to improve floodplain connectivity and foster more extensive and functional riparian vegetation communities. Existing conditions and proposed actions maps of this reach are provided on the next pages.



Data Sources: Hillshade, vegetation, and relative surface model (2014 and 2011 LiDAR), Depth raster (University of Idaho hydraulic modeling)

Figure 32
Existing Conditions Map
Lower Lemhi Georeach 12



River Mile

Lemhi County Parcels

Reach Boundary

Velocity (ft/s) during scenario 4
(juvenile rearing flow)

6

0

Notes:
-Hydraulic model extent may not depict the total inundated area for this discharge.
-Scenario 4 corresponds to a discharge of 441 cfs.

0 250 500 1,000 Feet

Data Sources: Aerial imagery (ESRI streaming), Velocity raster (University of Idaho hydraulic modeling)

Figure 33
Proposed Actions Map
Lower Lemhi Georeach 12

Georeach 12

Existing Condition Notes:

EC1: Within the lower Lemhi valley segment, georeach 12 had the lowest median capacity for juvenile Chinook salmon, resulting from long, confined channels with long riffles, very low channel unit frequency and little variation in depth and velocity. High energy demand for juveniles. Low refugia and feeding opportunities.

EC2: Active floodplain lacking riparian vegetation. Hydraulic model extents clipped in this area – likely extend farther into the floodplain.

EC3: Areas with greater sinuosity/braidedness, velocity variation, more channel unit frequency, and floodplain connectivity generally have greater habitat function and capacity. These subreaches commonly also have greater potential for rehabilitation (e.g., ability to use old channels; less excavation to reactivate floodplain; lighter touch is more feasible).

EC4: Flood model has been clipped here, and likely extends farther into the floodplain.

EC5: Apparent low-lying topography is most likely an artifact of relative surface model methodology.

EC6: Narrow ribbon of riparian vegetation. Channel scars in floodplain lack riparian vegetation.

EC7: Relic meander scar. Hydraulic model clipped in this area, which likely receives high flows not illustrated in model results.

EC8: Overly straightened. Juvenile fish prefer greater depth and velocity variation, and increased channel unit frequencies (including pool-riffle interfaces), to increase feeding opportunities.

EC9: Relic/abandoned side channels on floodplain.

EC10: Greater width of available low elevation floodplain and relic channel scars in this reach than in others (extending beyond the LiDAR-based relative surface model and hillshade surface extents).

EC11: Most of this subreach is straightened and cut off from many relic meanders and from much of the floodplain by the highway. Evidence of historical multi-threaded channel planform that has been simplified and straightened into a single channel.

EC12: Low-lying floodplain partially disconnected from the main channel by levees.

EC13: Existing groundwater channel with no riparian vegetation.

EC14: Existing floodplain connectivity and secondary channel activation is better in this subreach than in others. Flow obstructions associated with breached levee enable persistence of split flows and hydraulic diversity/complexity.

EC15: Discontinuous series of levees. Example of stream channel that has widened enabling mid-channel gravel bar deposition creating side channels and diversity/complexity.

EC16: Constriction at bridge forces single-thread channel morphology.

Reconnected tributaries include the following:

- Agency Creek was reconnected to the Lemhi River (date unknown)
- Kenny Creek was reconnected to the Lemhi River (date unknown)

Potential Actions Notes:

PA1: Potential for light-touch restoration. Consider adding LWD other channel obstructions to split flows, create multiple small side-channel, and reconnect the floodplain within areas of existing riparian vegetation. One option may be to split-flow and then create numerous small side-channels connecting the two primary channels. Varying amounts of excavation may be required depending on the restoration approach and desired outcomes.

PA2: Consider riparian exclusion fencing enabling the river to restore naturally.

PA3: Consider reactivating relic channel scars to increase sinuosity and/or multi-threaded channel pattern.

PA4: Consider potential for splitting flow onto opposite side of the highway reoccupying relic channel features with improved riparian vegetation and improved cattle management possibly including exclusion fencing.

PA5: Realign primary channel away from highway and increase secondary channel activation, reduce instream velocity, and promote more dynamic/complex channel form.

PA6: Add exclusion fencing and riparian vegetation to existing groundwater channel to improve water quality (i.e., temperature and fine sediment) for downstream habitat.

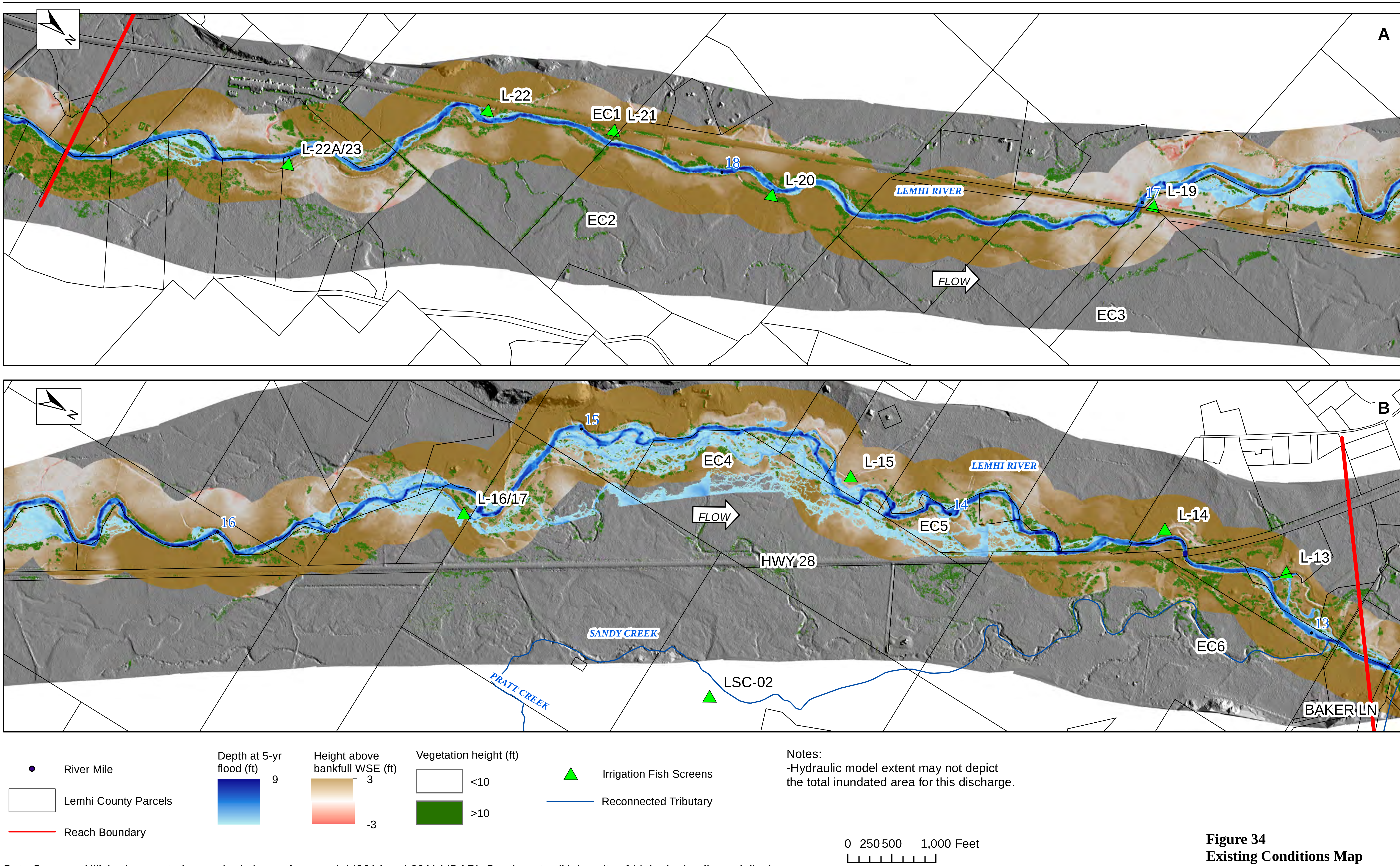
GR-13 Actions

Geomorphic Reach 13 (GR-13) is located along the Lemhi River between RM 19.6 and RM 12.9 in an unconfined valley with significant valley bottom constraints, resulting in the narrowing of the valley bottom by about 65 percent. Throughout much of this reach the river has been mechanically straightened, with increased artificial bank protection and corresponding removal of complex channel morphology. These channel alterations have resulted in limited hydraulic connectivity between the river and floodplain, and a limited extent of functional riparian vegetation communities. The existing conditions have removed connections with relic side channels and reduced lateral channel migration, which are important processes for creating and sustaining a complex network of side channels and the corresponding high-quality fish habitat.

Table 9. Lower Lemhi River – Geomorphic Reach 13 Targets.

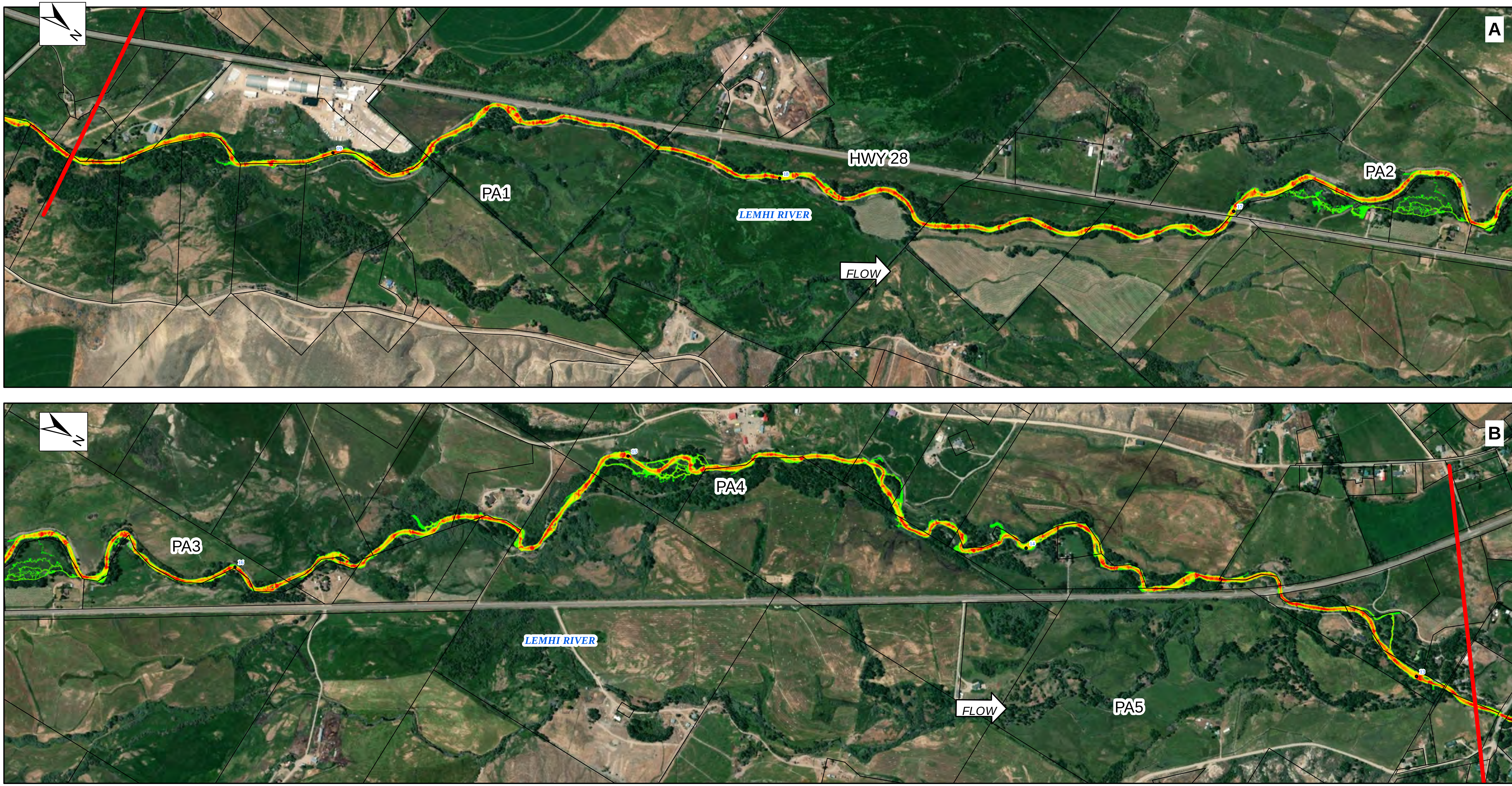
Element	Target	Notes
Channel Morphology	Pool-riffle	Based on Montgomery and Buffington (1998)
Bankfull Discharge (cfs)	849	1.5 yr flood (Castro and Jackson 2001); at downstream end of reach
Sinuosity	1.7	Address areas of historical channel straightening
Meander Amplitude (ft)	568	Max amplitude equivalent to minimum floodplain width; based on meander scars in Lower Lemhi
Meander Wavelength (ft)	915	Equivalent to 2 full meanders; based on reference site in GR-15
Radius of Curvature (ft)	328	Average based on reference site; Radius encompass a large range
Bankfull Width (ft)	35-37	Range of average for single-thread channel
Bankfull W:D (ft/ft)	8-12	Average width / average depth
Bedload	Gravel	Bedload
Side Channel Type	Meander-Relict and Beaver Dam Distributed	Diversity of short and long side channels with similar geometry to main stem; maintained by dense riparian vegetation; beaver dams in smaller, low energy channels
Side Channel Density	>3.75	Total channel length / valley length
Structure Type	LWD, willow clumps & vegetation	Instream structure material
Structure Spacing	Multiple per bend	To replicate dense riparian vegetation and beaver dams

Recommended treatments are focused on addressing the primary functional limitations in this reach that have resulted from channel straightening and artificial confinement. These treatments include remeandering of the primary channel to increase sinuosity, which would result in a corresponding decrease in stream power and increase in gravel bar formation with subsequent improvement in complex channel morphology. Remeandering of the primary channel can be accompanied by developing secondary channels in low-lying areas of the floodplain, including full secondary channel construction and minor excavation to initiate self-forming secondary channels. In some locations, a more passive approach can be used to activate legacy side channels over a larger range of flows. Improvements to primary and secondary channel morphology should be accompanied by increasing roughness in all channels with LWD, willow clumps, and replanting of woody riparian vegetation. All of the recommended treatments are intended to improve floodplain connectivity and foster more extensive and functional riparian vegetation communities. Existing conditions and proposed actions maps of this reach are provided on the next pages.



Data Sources: Hillshade, vegetation, and relative surface model (2014 and 2011 LiDAR), Depth raster (University of Idaho hydraulic modeling)

Figure 34
Existing Conditions Map
Lower Lemhi Georeach 13



River Mile

Lemhi County Parcels

Reach Boundary

Velocity (ft/s) during scenario 4
(juvenile rearing flow)

6

0

Notes:
-Hydraulic model extent may not depict the total inundated area for this discharge.
-Scenario 4 corresponds to a discharge of 441 cfs.

0 250 500 1,000 Feet

Data Sources: Aerial imagery (ESRI streaming), Velocity raster (University of Idaho hydraulic modeling)

Figure 35
Proposed Actions Map
Lower Lemhi Georeach 13

Georeach 13

Existing Conditions Notes:

EC1: Straightened, confined, lacking riparian vegetation, off-channel habitat, and floodplain connection.

EC2: Multiple relic channel meanders and relic side channels disconnected hydrologically from the Lemhi River and lacking riparian vegetation (relic side channels only possess a ribbon of riparian vegetation along banks). Relic channels suggest historical multi-threaded channel planform in this reach.

EC3: Greater width of available low elevation floodplain in this reach than in others (not shown on this hillshade surface).

EC4: Floodplain connectivity and riparian vegetation is better here than in most areas of the Lower Lemhi. Hydraulic model extent clipped; likely extends farther east.

EC5: Greater bedform and habitat diversity within this subreach associated with greater sinuosity and riparian vegetation. LWD accumulations also present.

EC6: Groundwater (and possibly irrigation return) side channel to Sandy Creek, with narrow ribbon of riparian vegetation.

Reconnected tributaries include the following:

- In 2017, Pratt Creek was reconnected to Sandy Creek, which flows into the Lemhi River near RM 13.

Potential Actions Notes:

PA1: From here to downstream bridge, increase sinuosity, floodplain connectivity, and secondary channel development. Add large wood material for instream and floodplain roughness. Downstream of the bridge are potential opportunities to reconnect isolated, relic channel scars on the opposite side of the highway.

PA2: Restore banks and riparian vegetation community function.

PA3: Add large wood material for instream and floodplain roughness.

PA4: Opportunity for side channel development in low-lying floodplain with dense riparian vegetation.

PA5: Evaluate functionality of existing, long groundwater channels and relic channel scars near Sandy Creek. Consider improving riparian vegetation, cattle exclusions, and instream habitat complexity. May have sediment and temperature problems. Consider opportunities to reconnect surface flow on the right (eastern) side of the highway upstream of this location.

GR-14 Actions

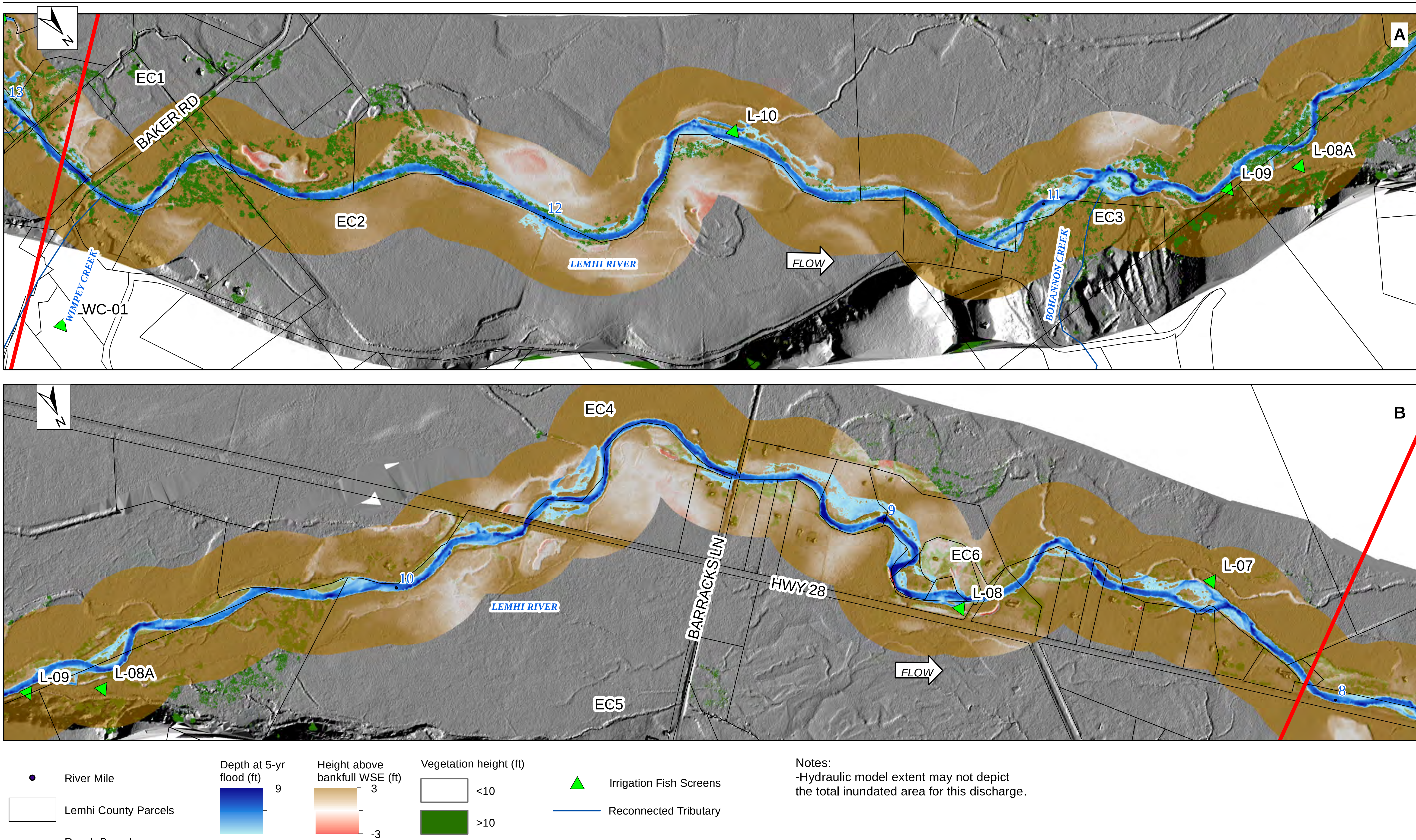
Geomorphic Reach 14 (GR-14) is located between RM 43.2 and 41.1 largely between the two bridges on Highway 28, immediately upstream of the intersection of HWY 28 and Meyers Lane. While the reach exhibits some meandering characteristics, this alignment is largely artificially maintained by bank protection treatments. The channel confinement and limited abundance of instream LWD has fostered hydraulic characteristics that limit gravel bar formation and development of complex channel morphology. These channel alterations have resulted in limited hydraulic connectivity between the river and floodplain, and a limited extent of functional riparian vegetation communities. Collectively, the existing conditions have produced a simplified channel morphology and low-quality fish habitat, owing to limited hydraulic habitat diversity and instream cover in both the primary channel and secondary channels.

Table 10. Upper Lemhi River – Geomorphic Reach 14 Targets.

Element	Target	Notes
Channel Morphology	Pool-riffle	Based on Montgomery and Buffington (1998)
Bankfull Discharge (cfs)	889	1.5 yr flood (Castro and Jackson 2001); at downstream end of reach
Sinuosity	1.7	Address areas of historical channel straightening
Meander Amplitude (ft)	568	Max amplitude equivalent to minimum floodplain width; based on meander scars in Lower Lemhi
Meander Wavelength (ft)	915	Equivalent to 2 full meanders; based on reference site in GR-15
Radius of Curvature (ft)	328	Average based on reference site; Radius encompass a large range
Bankfull Width (ft)	34-36	Range of average for single-thread channel
Bankfull W:D (ft/ft)	8-12	Average width / average depth
Bedload	Gravel	Bedload
Side Channel Type	Meander-Relict and Beaver Dam Distributed	Diversity of short and long side channels with similar geometry to main stem; maintained by dense riparian vegetation; beaver dams in smaller, low energy channels
Side Channel Density	>3.75	Total channel length / valley length
Structure Type	LWD, willow clumps & vegetation	Instream structure material
Structure Spacing	Multiple per bend	To replicate dense riparian vegetation and beaver dams

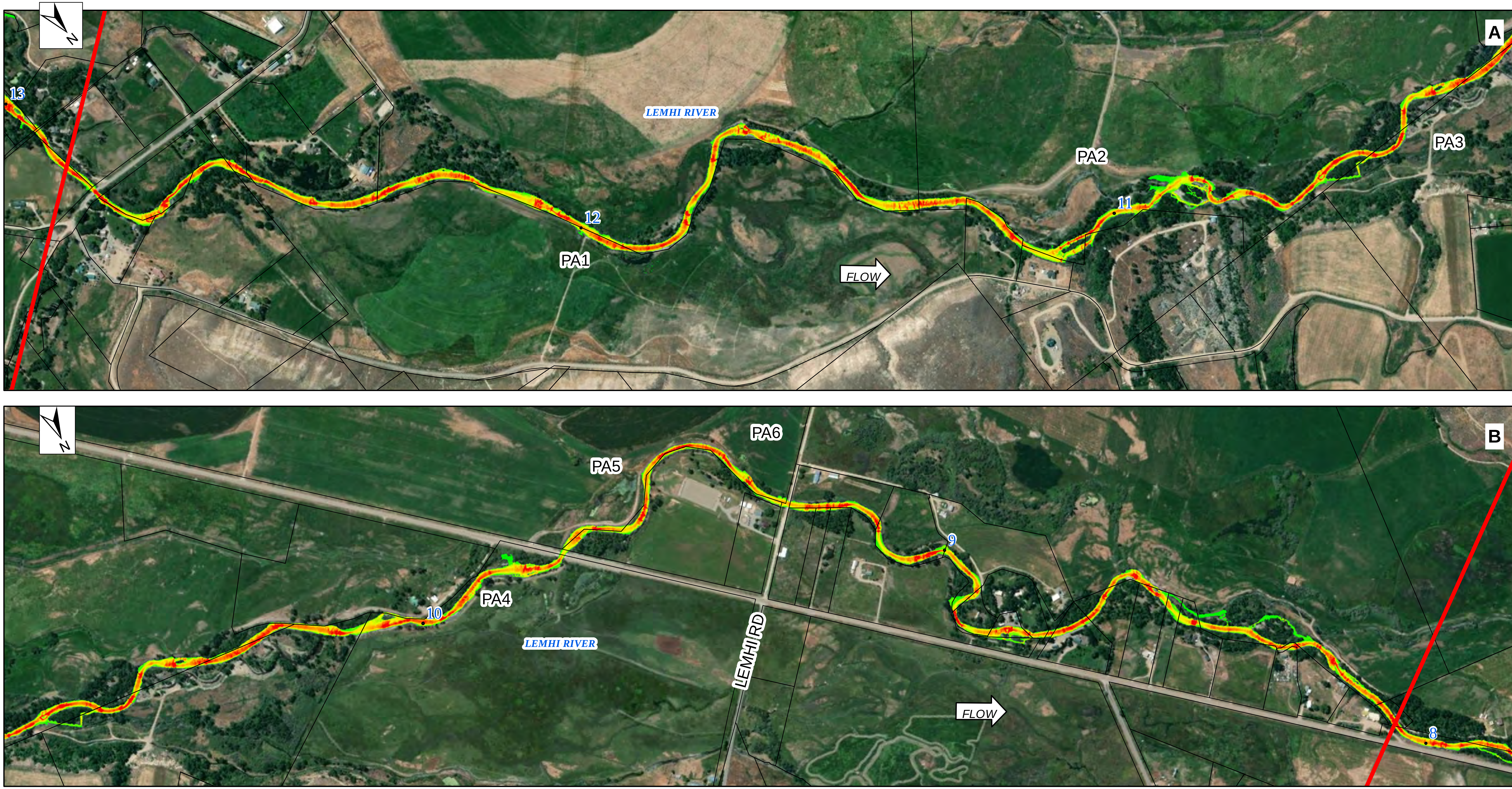
Recommended treatments are focused on addressing the primary functional limitations in this reach that have resulted from artificial confinement and disconnected secondary channels. Actions in this reach can build on the strategy of an ongoing multi-phased restoration project whose goals include creating a multi-threaded channel planform, increasing habitat unit frequency, increasing floodplain connectivity, and restoring riparian vegetation communities. Improvements to primary and secondary channel morphology should be accompanied by increasing roughness in all channels with LWD, willow clumps, and replanting of woody riparian vegetation. All of these treatments will result in increased quantity, quality, and diversity of juvenile fish rearing habitat.

Existing conditions and proposed actions maps of this reach are provided on the next pages.



Data Sources: Hillshade, vegetation, and relative surface model (2014 and 2011 LiDAR), Depth raster (University of Idaho hydraulic modeling)

Figure 36
Existing Conditions Map
Lower Lemhi Georeach 14



River Mile

Lemhi County Parcels

Reach Boundary

Velocity (ft/s) during scenario 4
(juvenile rearing flow)

6

0

Notes:
-Hydraulic model extent may not depict the total inundated area for this discharge.
-Scenario 4 corresponds to a discharge of 441 cfs.

0 250 500 1,000 Feet

Data Sources: Aerial imagery (ESRI streaming), Velocity raster (University of Idaho hydraulic modeling)

Figure 37
Proposed Actions Map
Lower Lemhi Georeach 14

Georeach 14

Existing Conditions Notes:

EC1: Among all Lemhi valley segments (including lower and upper), GR-14 had the second lowest relative juvenile Chinook salmon capacity during summer.

EC2: Site of completed and ongoing multi-phased restoration project not illustrated in LiDAR (from approximately RM 10 to RM 12.5). Project goals include creating a multi-threaded channel planform, increasing habitat unit frequency, increasing floodplain connectivity, and restoring riparian vegetation communities.

EC3: Example of area with modest habitat, but high potential. This subreach has since been restored, expanding the frequency and extent of side channels and floodplain connection.

EC4: Indicators of artificial channel confinement and bank protection (i.e., levees, riprap, and channel confinement) throughout this subreach.

EC5: Low-lying floodplain not illustrated in relative surface model.

EC6: Channel maintains appropriate planform, but lacks instream structure, habitat complexity, side channels, off-channel habitat and floodplain connection. Riparian vegetation is discontinuous.

Reconnected tributaries include the following:

- Wimpey Creek was reconnected to the Lemhi River (date unknown).
- Bohannon Creek was reconnected to the Lemhi River in 2016.

Potential Actions Notes:

PA1: Ongoing, multi-phased restoration project with goals to create a multi-threaded channel planform, increase habitat unit frequency, increase floodplain connectivity, and restore riparian vegetation communities.

PA2: Existing project completed (see goals listed above). Lessons learned include incorporating greater floodplain connection, more split flows, and more tortuous meanders.

PA3: Existing project completed (see goals listed above). Lessons learned being evaluated at the time of this report.

PA4: Project concept developed incorporating a multi-threaded channel planform while considering flood risks to low-lying topography and historical flood risk to the north.

PA5: Restore banks and riparian vegetation community function. Existing concept has been prepared for Idaho Department of Fish and Game.

PA6: Distribute flow and energy laterally where the channel has been confined and straightened. Add large wood material for instream and floodplain roughness. Add split flows and off-channel habitat.

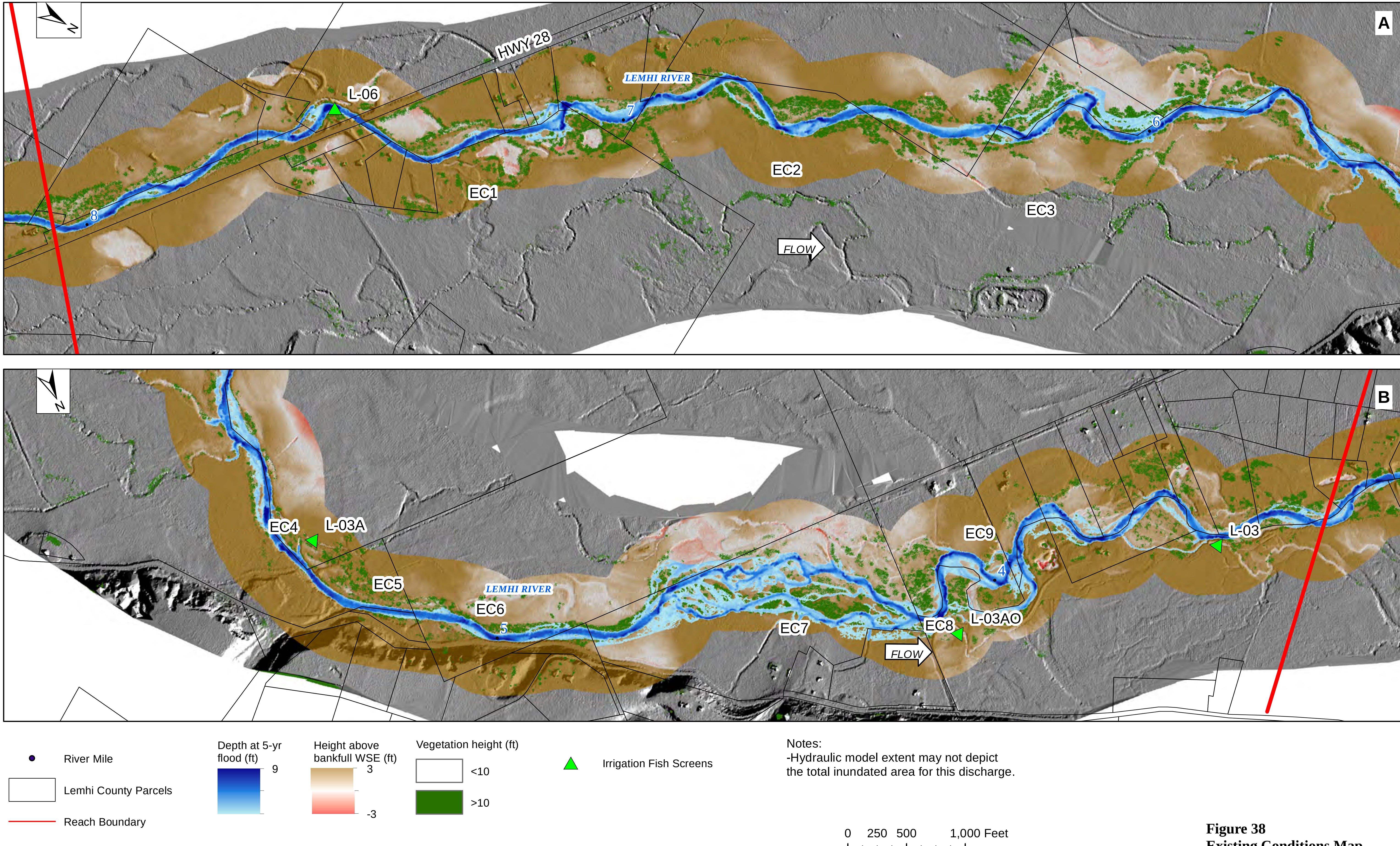
GR-15 Actions

Geomorphic Reach 15 (GR-15) is located along the Lemhi River between RM 8.1 and RM 3.3 in an unconfined valley with significant valley bottom constraints, resulting in the narrowing of the valley bottom by about 50 percent. While the reach exhibits some meandering characteristics, this alignment is largely artificially maintained by bank protection treatments. The channel straightening and confinement, along with a lack of LWD, has fostered hydraulic characteristics that limit gravel bar formation and development of complex channel morphology. The existing conditions have reduced the hydraulic connectivity between the river and floodplain, and have reduced lateral channel migration, which are important processes for creating and sustaining a complex network of side channels and the corresponding high-quality fish habitat. This reach also has a limited extent of functional riparian vegetation communities.

Table 11. Upper Lemhi River – Geomorphic Reach 7 Targets.

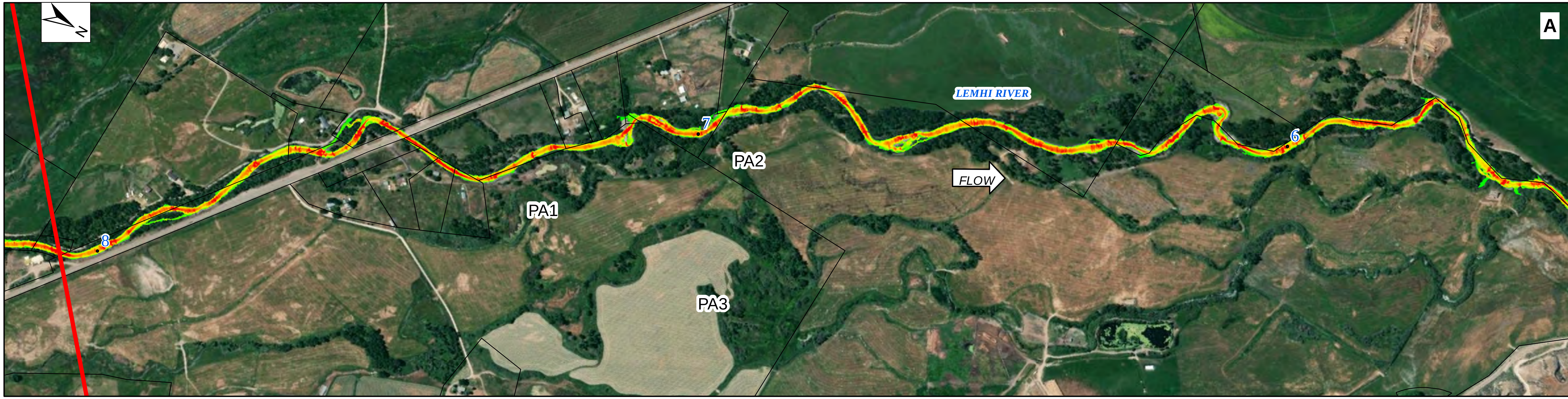
Element	Target	Notes
Channel Morphology	Pool-riffle	Based on Montgomery and Buffington (1998)
Bankfull Discharge (cfs)	895	1.5 yr flood (Castro and Jackson 2001); at downstream end of reach
Sinuosity	1.7	Address areas of historical channel straightening
Meander Amplitude (ft)	568	Max amplitude equivalent to minimum floodplain width; based on meander scars in Lower Lemhi
Meander Wavelength (ft)	915	Equivalent to 2 full meanders; based on reference site in GR-15
Radius of Curvature (ft)	328	Average based on reference site; Radius encompass a large range
Bankfull Width (ft)	34-36	Range of average for single-thread channel
Bankfull W:D (ft/ft)	8-12	Average width / average depth
Bedload	Gravel	Bedload
Side Channel Type	Meander-Relict and Beaver Dam Distributed	Diversity of short and long side channels with similar geometry to main stem; maintained by dense riparian vegetation; beaver dams in smaller, low energy channels
Side Channel Density	>3.75	Total channel length / valley length
Structure Type	LWD, willow clumps & vegetation	Instream structure material
Structure Spacing	Multiple per bend	To replicate dense riparian vegetation and beaver dams

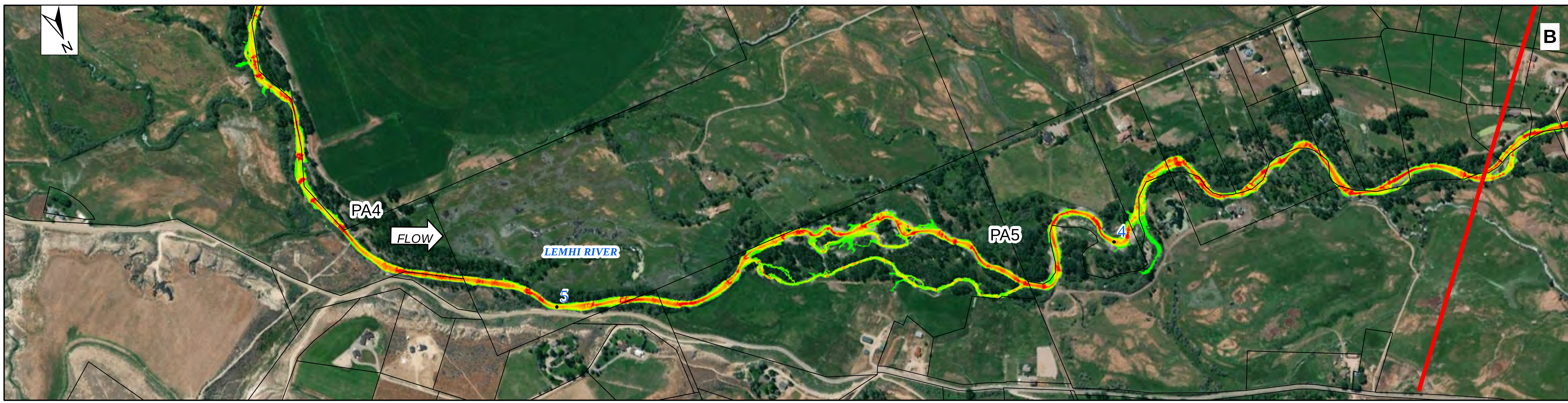
Recommended treatments are focused on addressing the primary functional limitations in this reach that have resulted from channel straightening and artificial confinement. These treatments include remeandering of the primary channel to increase sinuosity, which would result in a corresponding decrease in stream power and increase in gravel bar formation with subsequent improvement in complex channel morphology. Remeandering of the primary channel can be accompanied by developing secondary channels in low-lying areas of the floodplain, including full secondary channel construction and minor excavation to initiate self-forming secondary channels. In some locations, a more passive approach can be used to activate legacy side channels over a larger range of flows. Improvements to primary and secondary channel morphology should be accompanied by increasing roughness in all channels with LWD, willow clumps, and replanting of woody riparian vegetation. All of the recommended treatments are intended to improve floodplain connectivity and foster more extensive and functional riparian vegetation communities. Existing conditions and proposed actions maps of this reach are provided on the next pages.



Data Sources: Hillshade, vegetation, and relative surface model (2014 and 2011 LiDAR), Depth raster (University of Idaho hydraulic modeling)

Figure 38
Existing Conditions Map
Lower Lemhi Georeach 15





- River Mile
- Lemhi County Parcels
- Reach Boundary

Velocity (ft/s) during scenario 4 (juvenile rearing flow)
6
0

Notes:
-Hydraulic model extent may not depict the total inundated area for this discharge.
-Scenario 4 corresponds to a discharge of 441 cfs.

0 250 500 1,000 Feet

Data Sources: Aerial imagery (ESRI streaming), Velocity raster (University of Idaho hydraulic modeling)

Figure 39
Proposed Actions Map
Lower Lemhi Georeach 15

Georeach 15

Existing Conditions Notes:

EC1: Indicators of artificial channel confinement and bank protection throughout this subreach. Disconnected floodplain and side channels.

EC2: Greater width of available low elevation floodplain in this reach than in others, particularly in the lower areas of this reach.

EC3: Minimal floodplain development/infrastructure in this subreach with relic channel scars.

EC4: Previously placed instream structure (LWD and rock).

EC5: Approximately 0.5-kilometer-long riffle along a significantly straightened section where the river is confined by the old Lemhi Road. This was the stretch of lowest estimated capacity in our MRA subreach.

EC6: MRA subreach (includes area of confined poor habitat upstream and sinuous, flow splits with good habitat downstream). Greater field data collection occurred within this area for the entire valley segment.

EC7: Within the lower Lemhi valley segment, GR-15 had the highest median capacity for juvenile Chinook salmon, and nearly, for steelhead as well. Likely due to this subreach being comprised of the best example of relatively good juvenile fish habitat in the lower Lemhi River. The channel has an appropriate sinuosity/braidedness, modest amounts of LWD, better variety of depths and velocities, and modest amounts of instream cover. This subreach has been used as a reference for the development of target conditions and restoration projects in this valley segment. It is a good example, but not ideal or pristine. High summer temperatures may limit fish use despite relatively good habitat conditions.

EC8: Location of screw trap.

EC9: Reference site for channel planform. Significant gravel deposition where channel migration and width allows – suggests large volume of gravel bedload within system in upstream reaches but confined, high-velocity character precludes deposition in upstream reaches.

Potential Actions Notes:

PA1: Potential setback of levees and/or removal of bank protection, coupled with placement of large wood material instream to obstruct flow, distribute flow laterally, and improve floodplain connection.

PA2: Increase sinuosity, floodplain connectivity, and secondary channel development in this straightened subreach. Add large wood material for instream and floodplain roughness. Increased sinuosity, secondary, and off-channel connectivity can improve hyporheic groundwater flow which may provide localized areas of temperature refugia and/or buffer instream temperatures.

PA3: Existing groundwater channels. Consider evaluating the potential of improving habitat and main-stem connectivity for off-channel fish rearing. Add cattle exclusions and riparian planting.

PA4: Augment existing structure placement with improved floodplain connectivity and potential side channel and/or off-channel habitat where feasible.

PA5: Augment existing reference area with additional woody debris for structure and cover. Protect and/or expand riparian corridor.

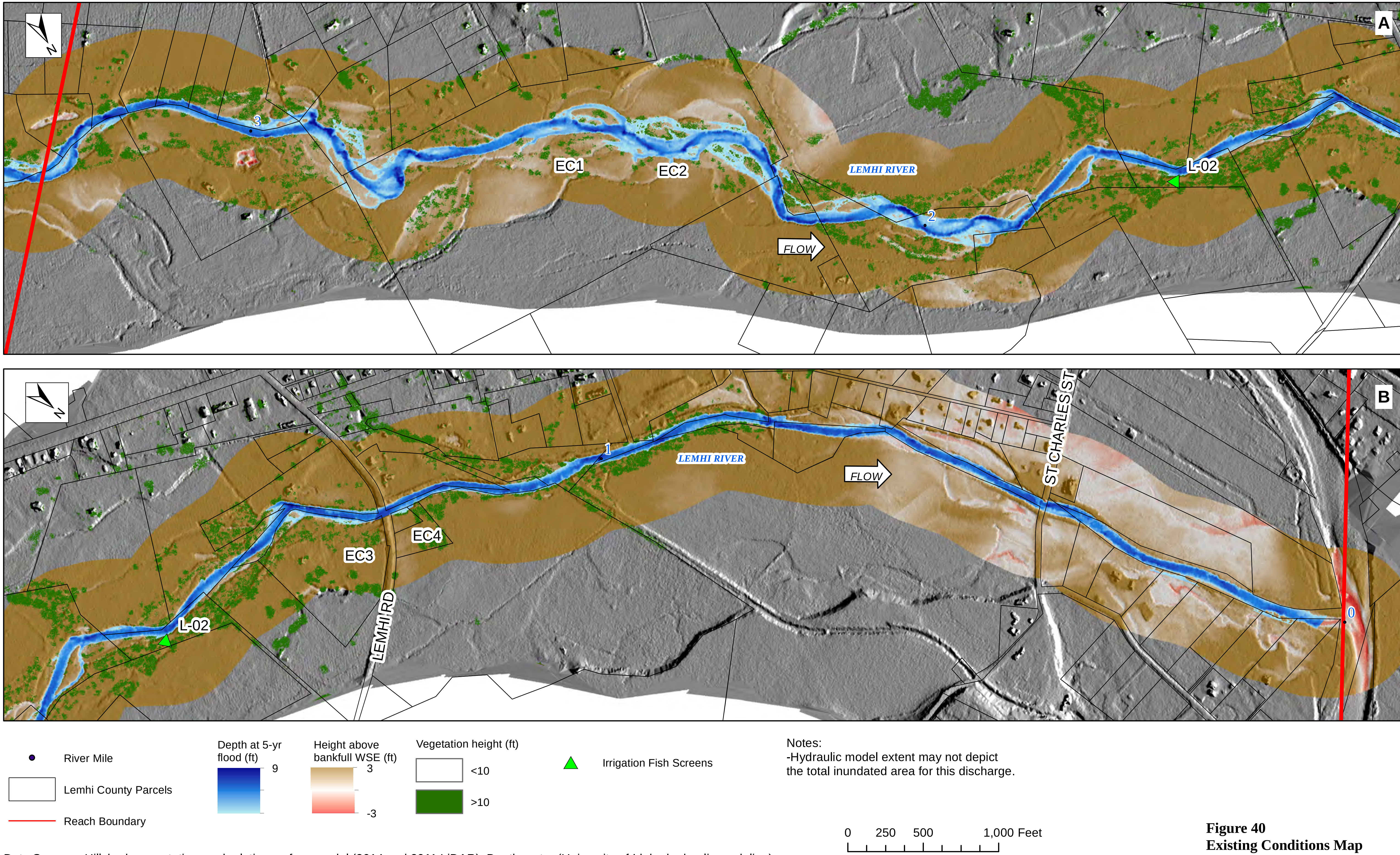
GR-16 Actions

Geomorphic Reach 16 (GR-16) is located along the Lemhi River between RM 3.3 and RM 0 in an unconfined valley with significant valley bottom constraints associated with roads and levees, resulting in the narrowing of the valley bottom by about 65 percent. Throughout much of this reach the river has been mechanically straightened, with accompanying artificial bank protection, and resulting in a removal of complex channel morphology. These channel alterations have resulted in limited hydraulic connectivity between the river and floodplain, and a limited extent of functional riparian vegetation communities. The existing conditions have removed connections with relic side channels and reduced lateral channel migration, which are important processes for creating and sustaining a complex network of side channels and the corresponding high-quality fish habitat. Collectively, the existing conditions have produced a simplified channel morphology and low-quality fish habitat, owing to limited hydraulic habitat diversity and instream cover.

Table 12. Lower Lemhi River – Geomorphic Reach 16 Targets.

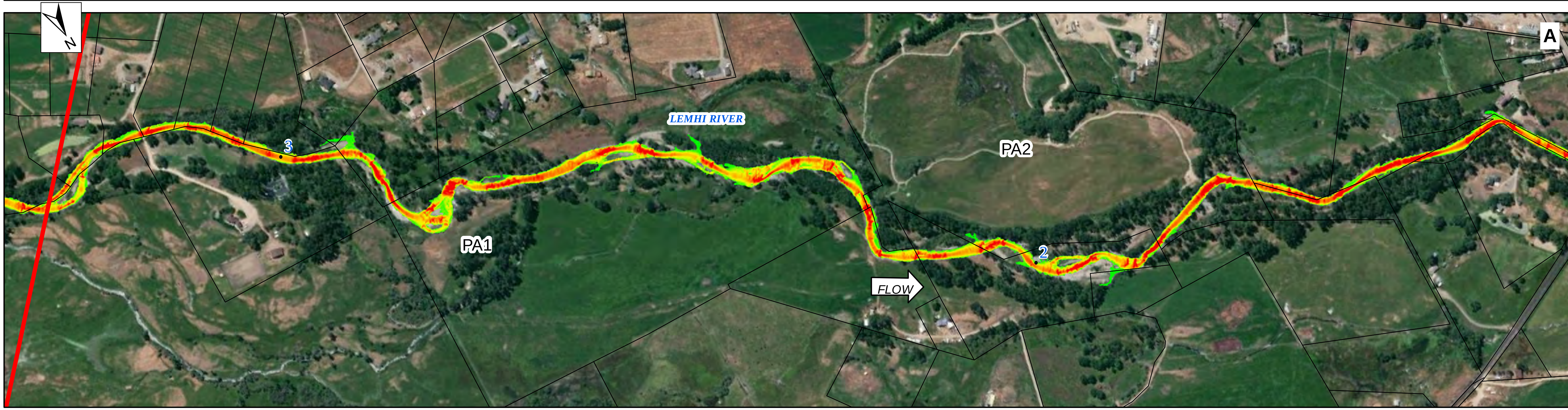
Element	Target	Notes
Channel Morphology	Pool-riffle	Based on Montgomery and Buffington (1998)
Bankfull Discharge (cfs)	912	1.5 yr flood (Castro and Jackson 2001); at downstream end of reach
Sinuosity	1.7	Address areas of historical channel straightening
Meander Amplitude (ft)	568	Max amplitude equivalent to minimum floodplain width; based on meander scars in Lower Lemhi
Meander Wavelength (ft)	915	Equivalent to 2 full meanders; based on reference site in GR-15
Radius of Curvature (ft)	328	Average based on GR-15 reference site; Radius encompass a large range
Bankfull Width (ft)	36-41	Range of average for single-thread channel
Bankfull W:D (ft/ft)	8-12	Average width / average depth
Bedload	Gravel	Bedload
Side Channel Type	Meander-Relict and Beaver Dam Distributed	Diversity of short and long side channels with similar geometry to main stem; maintained by dense riparian vegetation; beaver dams in smaller, low energy channels
Side Channel Density	>3.75	Total channel length / valley length
Structure Type	LWD, willow clumps & vegetation	Instream structure material
Structure Spacing	Multiple per bend	To replicate dense riparian vegetation and beaver dams

Potential restoration treatments in this reach are likely limited by existing infrastructure and floodplain development. Nevertheless, there are opportunities to address the primary functional limitations in this reach that have resulted from channel straightening and artificial confinement. These treatments include remeandering of the primary channel to increase sinuosity, which would result in a corresponding decrease in stream power and increase in gravel bar formation with subsequent improvement in complex channel morphology. Remeandering of the primary channel can be accompanied by developing secondary channels in low-lying areas of the floodplain, including full secondary channel construction and minor excavation to initiate self-forming secondary channels. Improvements to primary and secondary channel morphology should be accompanied by increasing roughness in all channels with LWD, willow clumps, and replanting of woody riparian vegetation. All of these treatments will result in increased quantity, quality, and diversity of juvenile fish rearing habitat. Existing conditions and proposed actions maps of this reach are provided on the next pages.



Data Sources: Hillshade, vegetation, and relative surface model (2014 and 2011 LiDAR), Depth raster (University of Idaho hydraulic modeling)

Figure 40
Existing Conditions Map
Lower Lemhi Georeach 16



River Mile

Lemhi County Parcels

Reach Boundary

Velocity (ft/s) during scenario 4 (juvenile rearing flow)

6

0

Notes:
-Hydraulic model extent may not depict the total inundated area for this discharge.
-Scenario 4 corresponds to a discharge of 441 cfs.

0 250 500 1,000 Feet

Data Sources: Aerial imagery (ESRI streaming), Velocity raster (University of Idaho hydraulic modeling)

Figure 41
Proposed Actions Map
Lower Lemhi Georeach 16

Georeach 16

Existing Conditions Notes:

General note: Restoration opportunity may be limited by infrastructure and development within this reach.

EC1: Bedload deposition and bar development in this subreach increases geomorphic complexity.

EC2: Within the lower Lemhi valley segment, GR-16 had the highest relative capacity for juvenile steelhead and the second highest relative capacity for juvenile Chinook salmon, potentially due to locations like this subreach that has greater channel unit frequency, some braidedness via split flows, side channels, and cover (LWD). Summer temperatures may limit fish use despite habitat potential. Significant flow gains from groundwater in this reach.

EC3: Indicators of artificial channel confinement and bank protection throughout this subreach.

EC4: From just upstream of the Lemhi Road bridge in Salmon and downstream to the mouth of the Lemhi River, habitat conditions are very poor. The channel is confined, straightened, largely riffle habitat, with little depth and velocity refugia for fish. This area is of particular concern, because it makes for a difficult transition to the mainstem Salmon River for out-migrating juvenile fish.

Potential Actions Notes:

PA1: Add large wood material for instream and floodplain roughness.

PA2: There may be an opportunity to implement a light-handed restoration project (or series of projects) at the Sacajawea Center, perhaps just a few short side channels using the mature riparian vegetation that is already there. Potential to demonstrate benefits of stream rehabilitation to the public with informational signs and/or other interpretative outreach.

PA3: Restore banks and riparian vegetation community function.

PA4: Increase sinuosity, floodplain connectivity, and secondary channel development in this straightened subreach. Add large wood material for instream and floodplain roughness. Potential opportunities associated with large parcels and potential single ownership; however, it is also the area with the highest density of homes along the stream corridor.

Section 6: Implementation Path

The lower Lemhi River restoration strategy was developed by the OSC Team and regional partners with a vision to conserve and restore watershed and stream functions for the long-term benefit of native salmonids, especially Chinook salmon and steelhead. This vision includes advancing fish population recovery in balance with the needs of agricultural producers and the local community.

Historical land use and resource management practices in the lower Lemhi River have resulted in ecological, geomorphic, and hydrologic conditions that have contributed to fish population declines. Recognizing that improvements to these conditions and fish populations cannot be realized immediately, this strategy provides a collection of project types that address the restoration needs in both the near term and long term, as well as across a range of spatial scales. This strategy is intended to facilitate project identification and development, but determining the timing, place, and appropriate action(s) requires additional planning and collaboration.

Climate Change and Restoration Planning

Like many watersheds within the Columbia River Basin, predictions of climate change over the next 20 to 60 years suggest that the upper Salmon River Basin watersheds will be drier and warmer than recent history (Kliskey et al. 2019). Among many of the projected impacts of climate change, these watersheds are likely to experience an earlier snowmelt runoff that will result in reduced stream flows during the summer and early fall time periods. When coupled with predicted increases in air temperature and existing riparian shade limitations, summer stream temperature conditions are projected to be worse than the already deleterious conditions that exist for much of the summer and fall periods (OSC Team 2019).

The lower Lemhi River restoration strategy is designed to accommodate the predicted climate change impacts on stream flow and temperature. The process-based restoration strategy is intended to result in implementing restoration actions that address fundamental causes of habitat degradation while also providing resiliency to future climate variability (Rieman et al. 2015; Wohl et al. 2015).

Typical restoration actions differ in the extent to which climate change effects are moderated. Those actions that are most effective at addressing increased stream temperature, reduced stream flows, and increased fish population resilience include the following (Beechie et al. 2013):

- Improved native riparian plant community
- Floodplain reconnection laterally and vertically
- Tributary hydrology and fish passage connectivity
- Improved near-surface groundwater hydrology (hyporheic exchange)
- Improved streamflow management
- Improved channel geometry form and diversity
- Improved channel planform and profile structure and complexity

All of these restoration actions are central to the lower Lemhi River restoration strategy.

Future Restoration Planning

The restoration strategy will be implemented throughout the lower Lemhi River over the next several decades. The timeframe for implementing individual restoration actions will vary due to available financial and technical resources; available data and information; restoration prioritization needs; and restoration action opportunities. Within this restoration strategy, each action is considered a building block resulting in incremental improvements for achieving recovery and sustainability of fish populations.

Planning restoration projects will include identifying the types of actions needed (Section 5) and the locations where actions are needed. While implementing projects based on prioritized reaches or actions is an ideal scenario, funding, access restrictions, and organizational constraints will play a significant role in the implementation sequence. Given the rearing capacity deficit in the lower Lemhi, project location prioritization is potentially less important than project type prioritization. Focusing on those project types that provide short- and long-term juvenile habitat are the most important. Juvenile habitat requirements suggest projects creating side channels, floodplain connection, hydraulic diversity, and general habitat complexity are the highest priority within the lower Lemhi, which was identified in the IRA as the highest priority valley segment within the Lemhi River for targeted restoration.

The assessment results presented in this report will provide guidance to the OSC Team and project partners in the region when identifying projects that will provide the greatest benefit over the life of this strategy. Recognizing the implementation sequence challenges, a more general multi-path approach to implementation can be used to guide future restoration (Table 13). These paths can be pursued in parallel over varying time periods.

Table 13. Lower Lemhi River restoration implementation paths.

Path Number	Description
1	Collaboration with willing landowners on restoration and resource management
2	Restoration in locations that are spatially linked to existing high habitat capacity and high hydrogeomorphic functioning locations
3	Restoration in reaches that are spatially linked to effective past restoration locations
4	Protection and conservation of locations with existing high habitat capacity and high hydrogeomorphic functioning

Partnerships are a key component for implementing restoration projects in the lower Lemhi River. The OSC Team, partners, and community stakeholders work collaboratively on a regular basis to ensure coordination and effective project development throughout the watershed. As partners work through the multi-path approach to implementation, they are encouraged to use the recommended actions identified for each reach (Section 5) as a starting point to develop project concepts. The types of restoration actions and geomorphic targets should be refined based on site-specific conditions and biological objectives established at the beginning of each project. Project partners are encouraged to work with an interdisciplinary team of scientists and engineers to advance restoration ideas from concept through final design and implementation. OSC Team members have been allocated funding to work with local sponsors throughout the life of a project from identifying a new project, to evaluating an existing concept, to coordinating with the project design team, reviewing designs, and evaluating post-construction results, all with the aim of integrating the results of this assessment into ongoing and future projects.

Project development and/or coordination regarding these recommendations can be initiated by contacting the OSC Team and partners.

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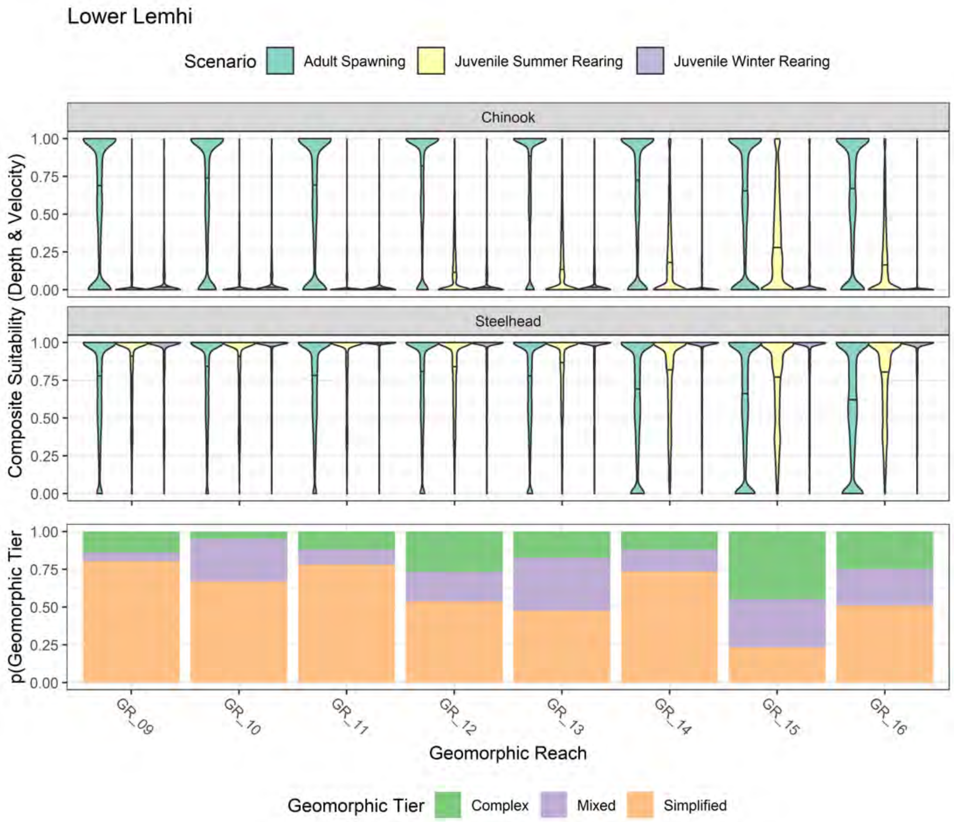
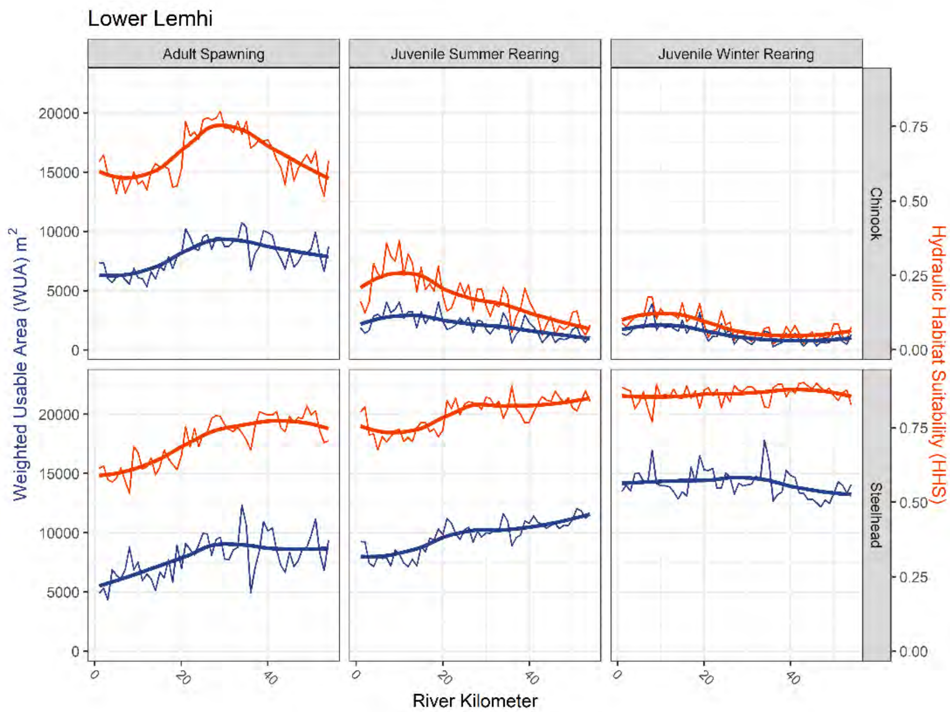
Appendices

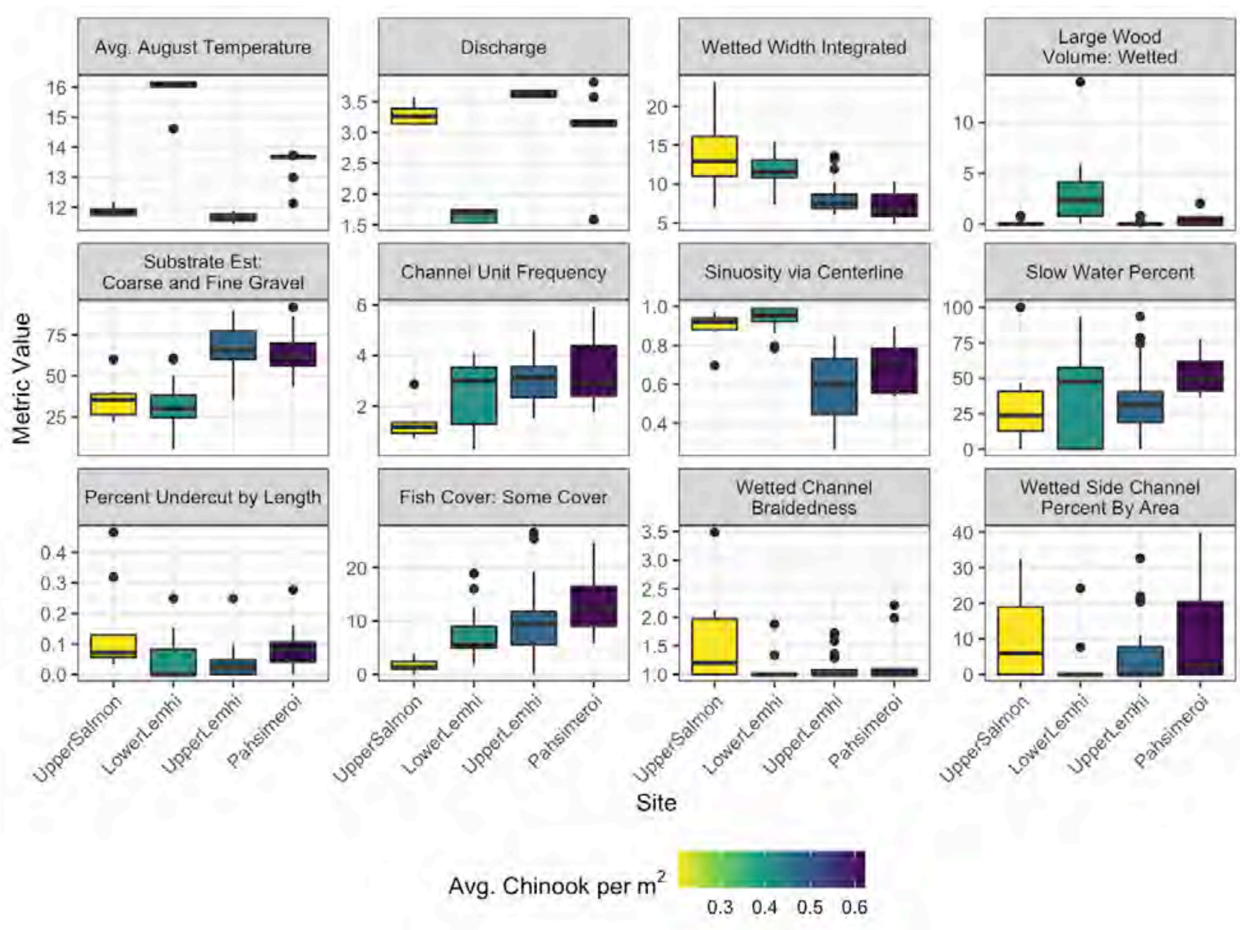
Appendix A. Reach-Specific Hydraulic Summary and Habitat Suitability



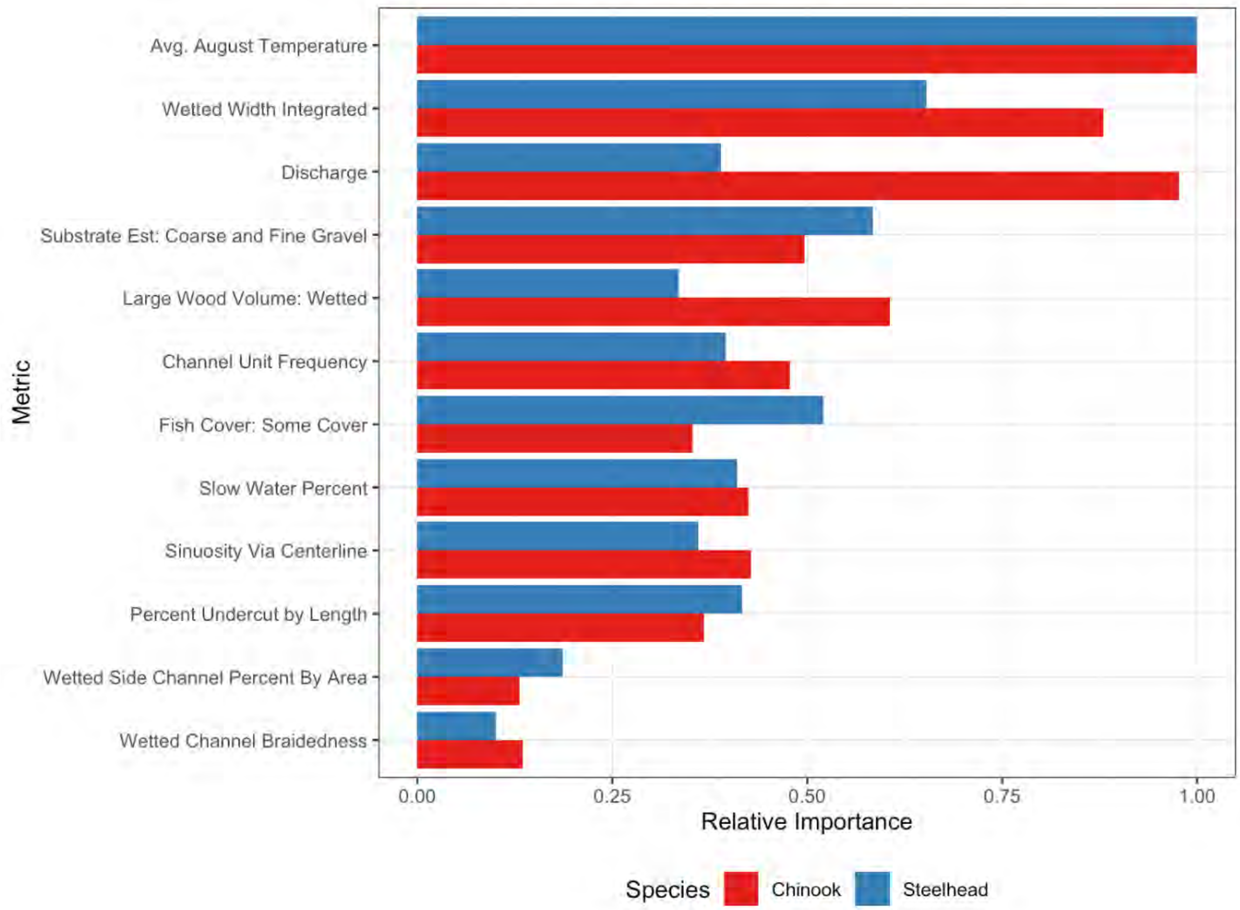
Distribution of composite suitability values (geometric mean of depth and velocity suitability) across geomorphic reaches in the lower Lemhi valley segment. Results for both Chinook salmon and steelhead and for three life stages (adult spawning, juvenile summer rearing, juvenile winter rearing) are shown. The bottom panel shows the proportion of each geometric reach classified as simple, mixed, or complex.



Weighted usable area (WUA; blue) and hydraulic habitat suitability (HHS; orange). The WUA is normalized by species, life stage, and river kilometer for the lower Lemhi River valley segment. The HHS is normalized by dividing the WUA for each reach by the total area of that reach. Estimates by river kilometer are shown on the finer lines; a smoothed line is in bold.



Boxplots showing distribution of covariates in each MRA site, colored by their average Chinook parr capacity. The facet order of covariates corresponds to their relative importance.



Relative importance of metrics driving Chinook salmon (red) and steelhead (blue) summer parr capacity predictions across the entire model domain (Products B and E). The relative importance is a measure of the respective influence that each habitat covariate has on predictions of habitat capacity and is quantified by the average decrease in residual sum of squares for splits on that variable amidst the trees in the random forest.

Table 1: Hydraulic summary for juvenile rearing flows

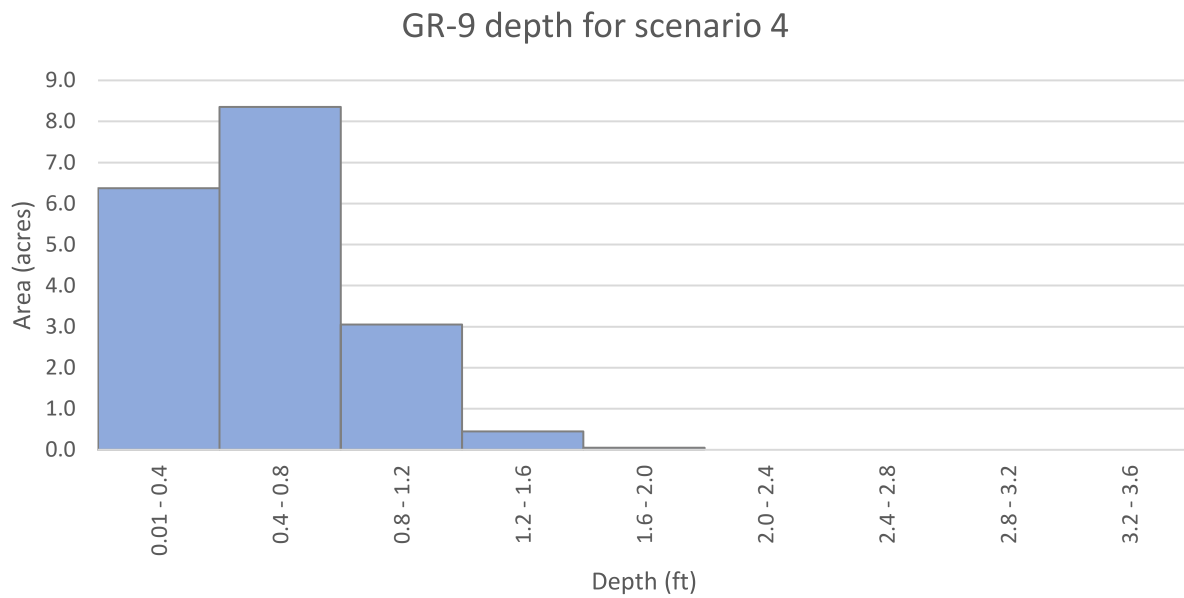
		Scenario 4 (Juvenile rearing flow) [A]							
		GR-9	GR-10	GR-11	GR-12	GR-13	GR-14	GR-15	GR-16
Depth (ft)	Mean	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.5
	Maximum	1.9	2.1	2.1	2.5	2.1	2.7	2.3	2.0
	Standard deviation	0.3	0.3	0.3	0.3	0.4	0.3	0.4	0.3
Velocity (fps)	Mean	1.2	1.2	1.3	1.1	1.0	1.1	1.0	1.2
	Maximum	4.7	4.9	5.6	4.3	4.5	4.1	3.8	3.6
	Standard deviation	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.6

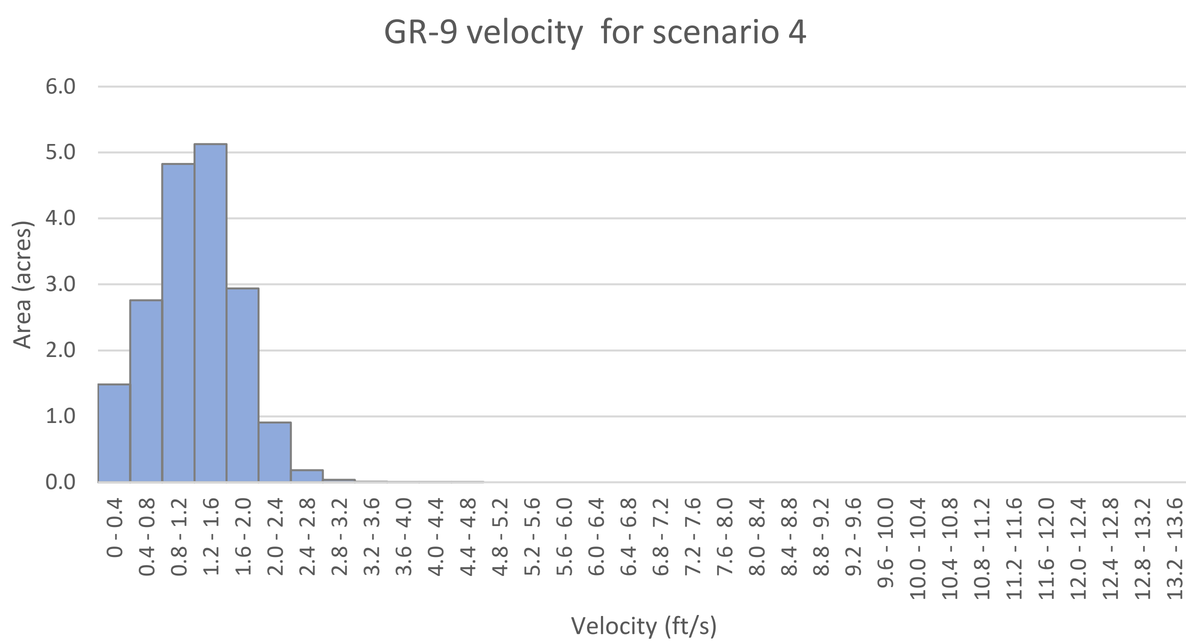
[A] This scenario corresponds to a total discharge of 441 cfs.

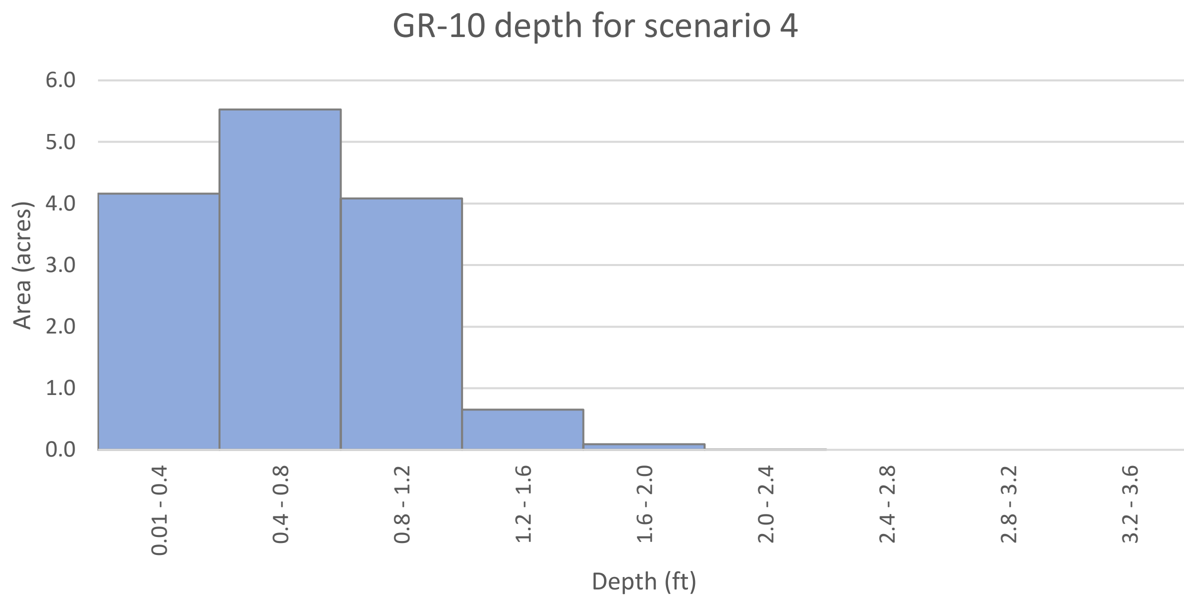
Table 2: Hydraulic summary for 1.5-year flow

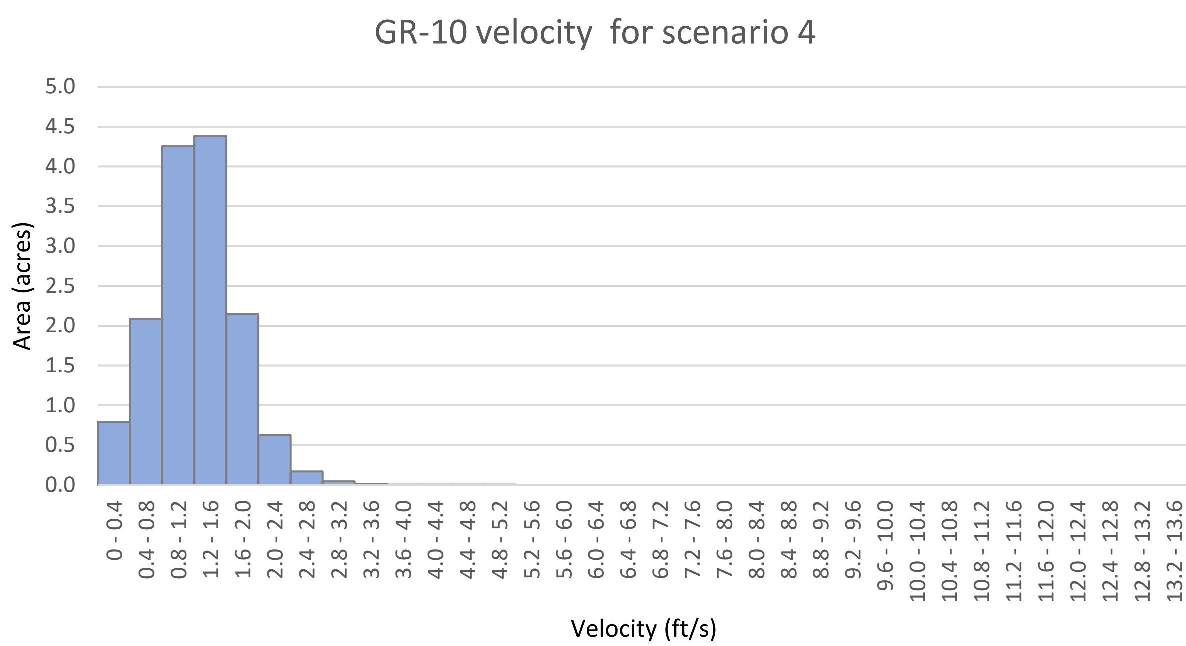
		Scenario 6 (approximately 1.5-yr flow) [A]							
		GR-9	GR-10	GR-11	GR-12	GR-13	GR-14	GR-15	GR-16
Depth (ft)	Mean	0.6	0.8	0.7	0.6	0.6	0.7	0.7	0.7
	Maximum	2.1	2.3	2.3	2.6	2.4	3.1	2.6	2.2
	Standard deviation	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Velocity (fps)	Mean	1.4	1.4	1.5	1.2	1.1	1.3	1.2	1.4
	Maximum	5.3	4.0	6.0	4.9	13.5	4.5	4.7	4.0
	Standard deviation	0.8	0.8	0.8	0.8	0.7	0.8	0.8	0.7

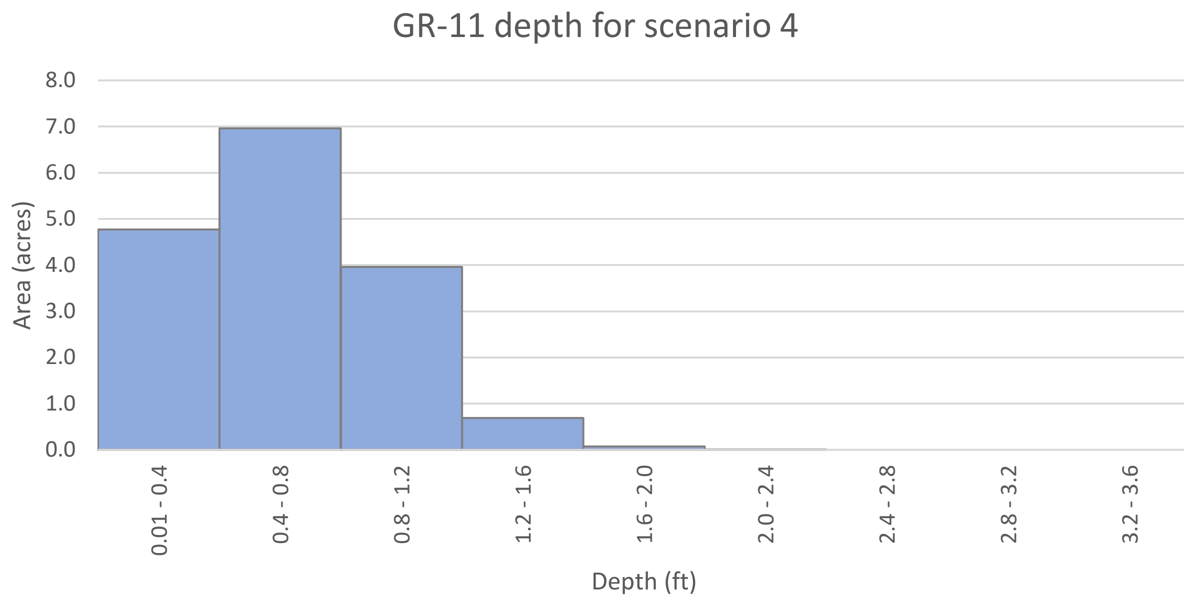
[A] This scenario corresponds to a total discharge of 777 cfs.


GR-9 depth for scenario 4
Area (acres)
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0.01 - 0.4
0.4 - 0.8
0.8 - 1.2
1.2 - 1.6
1.6 - 2.0
2.0 - 2.4
2.4 - 2.8
2.8 - 3.2
3.2 - 3.6
Depth (ft)

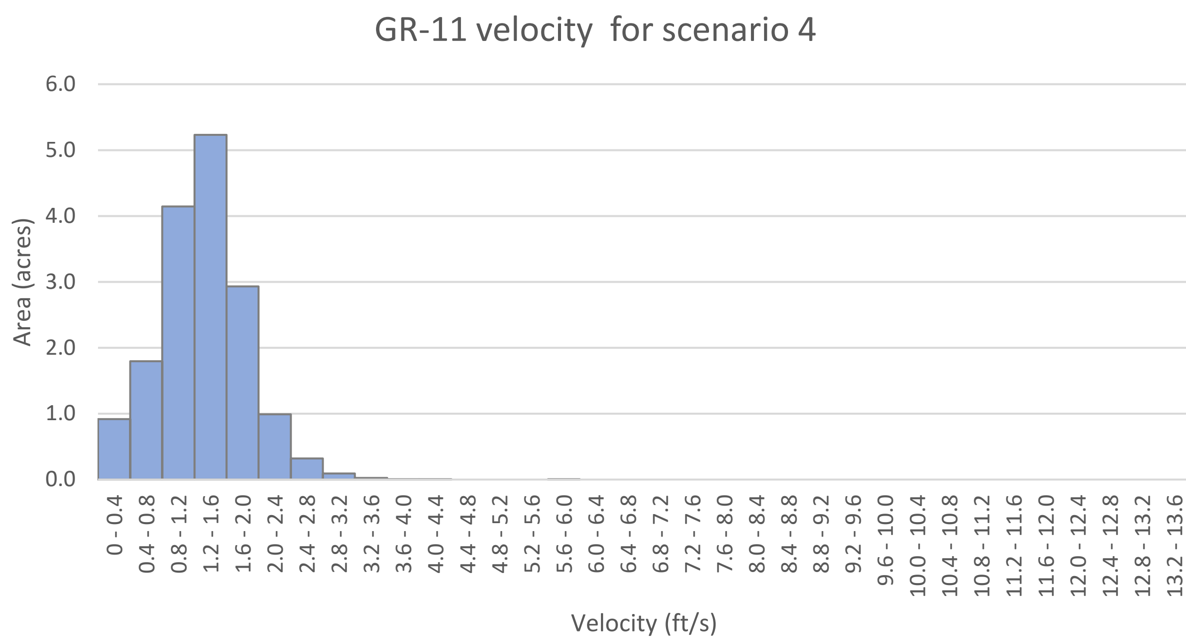

GR-9 velocity for scenario 4
Area (acres)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0 - 0.4
0.4 - 0.8
0.8 - 1.2
1.2 - 1.6
1.6 - 2.0
2.0 - 2.4
2.4 - 2.8
2.8 - 3.2
3.2 - 3.6
3.6 - 4.0
4.0 - 4.4
4.4 - 4.8
4.8 - 5.2
5.2 - 5.6
5.6 - 6.0
6.0 - 6.4
6.4 - 6.8
6.8 - 7.2
7.2 - 7.6
7.6 - 8.0
8.0 - 8.4
8.4 - 8.8
8.8 - 9.2
9.2 - 9.6
9.6 - 10.0
10.0 - 10.4
10.4 - 10.8
10.8 - 11.2
11.2 - 11.6
11.6 - 12.0
12.0 - 12.4
12.4 - 12.8
12.8 - 13.2
13.2 - 13.6
Velocity (ft/s)


GR-10 depth for scenario 4
Area (acres)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0.01 - 0.4
0.4 - 0.8
0.8 - 1.2
1.2 - 1.6
1.6 - 2.0
2.0 - 2.4
2.4 - 2.8
2.8 - 3.2
3.2 - 3.6
Depth (ft)

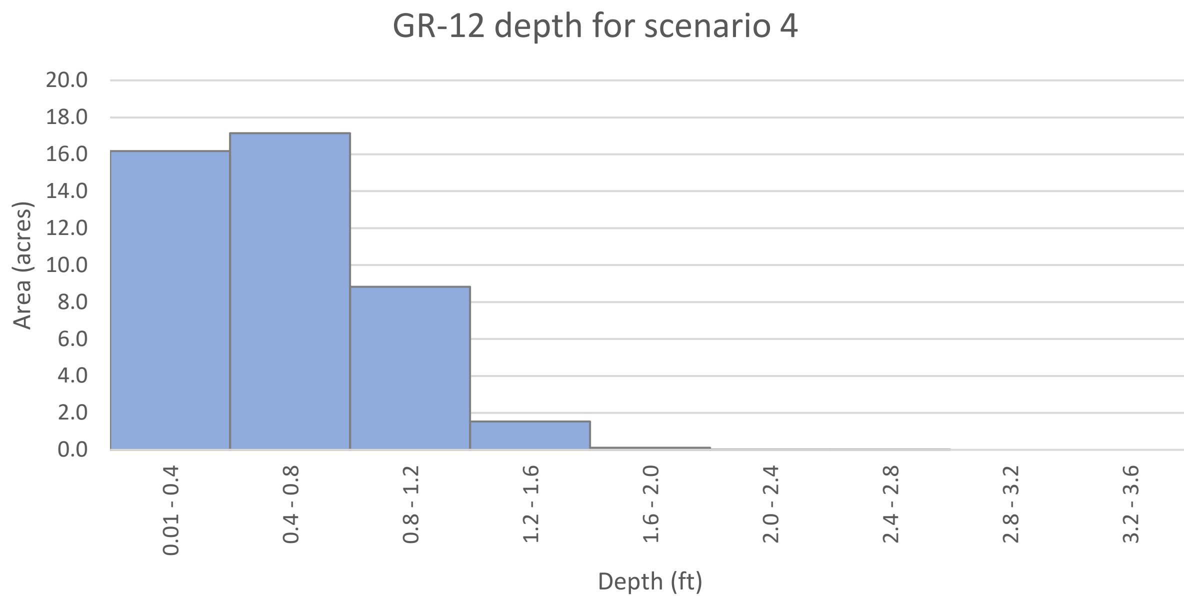

GR-10 velocity for scenario 4
Area (acres)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0 - 0.4
0.4 - 0.8
0.8 - 1.2
1.2 - 1.6
1.6 - 2.0
2.0 - 2.4
2.4 - 2.8
2.8 - 3.2
3.2 - 3.6
3.6 - 4.0
4.0 - 4.4
4.4 - 4.8
4.8 - 5.2
5.2 - 5.6
5.6 - 6.0
6.0 - 6.4
6.4 - 6.8
6.8 - 7.2
7.2 - 7.6
7.6 - 8.0
8.0 - 8.4
8.4 - 8.8
8.8 - 9.2
9.2 - 9.6
9.6 - 10.0
10.0 - 10.4
10.4 - 10.8
10.8 - 11.2
11.2 - 11.6
11.6 - 12.0
12.0 - 12.4
12.4 - 12.8
12.8 - 13.2
13.2 - 13.6
Velocity (ft/s)

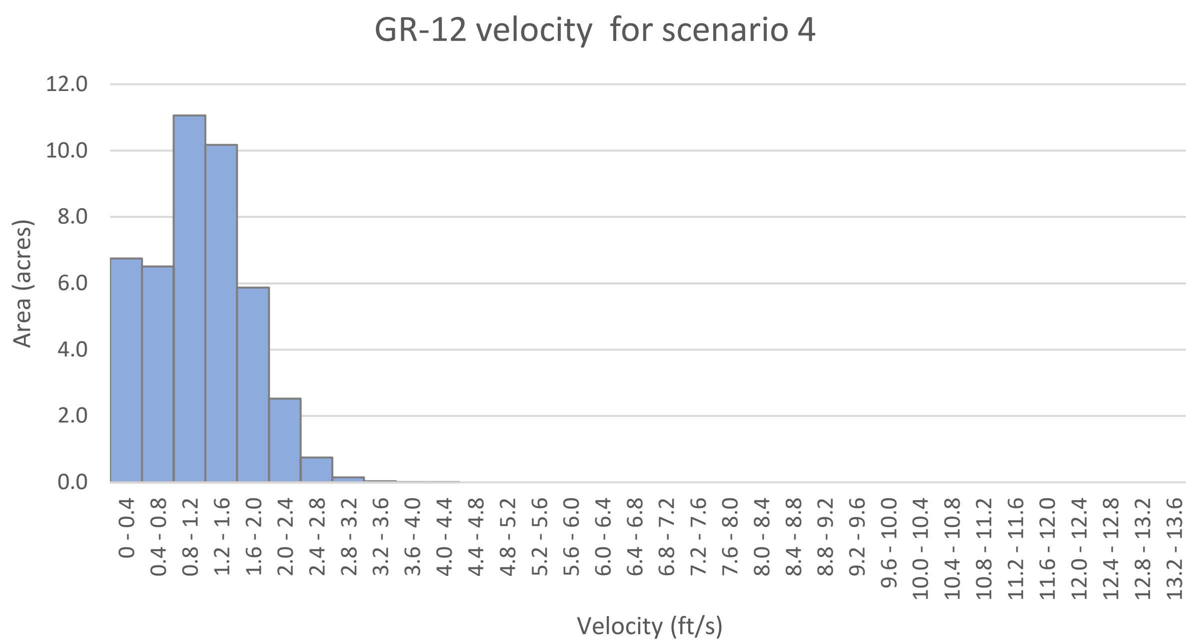


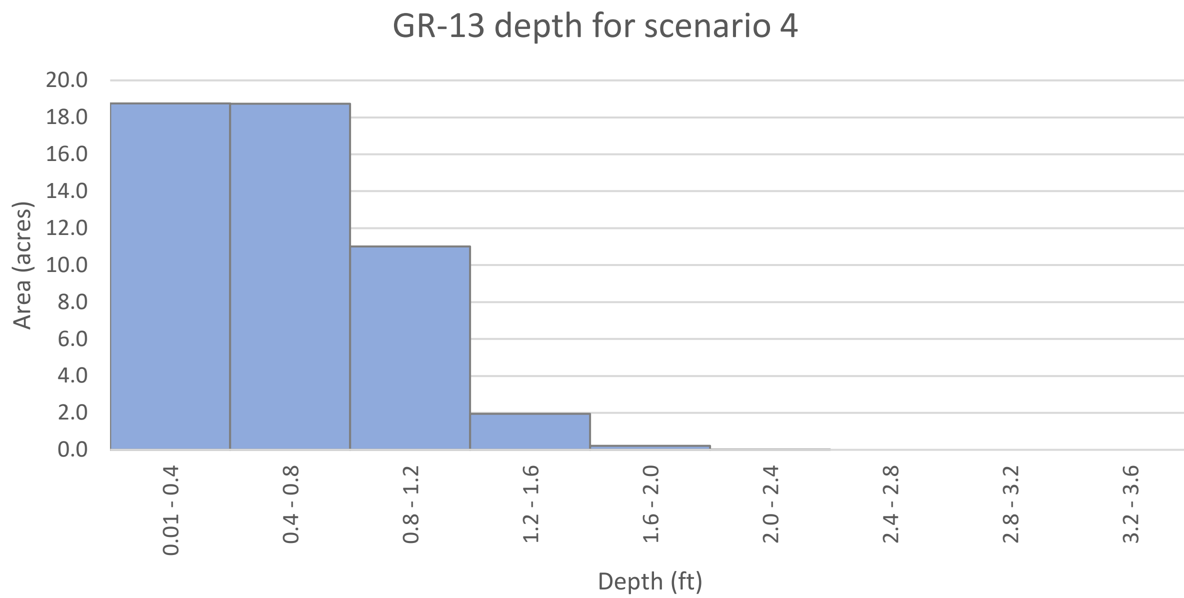
GR-11 depth for scenario 4
Area (acres)
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0.01 - 0.4
0.4 - 0.8
0.8 - 1.2
1.2 - 1.6
1.6 - 2.0
2.0 - 2.4
2.4 - 2.8
2.8 - 3.2
3.2 - 3.6
Depth (ft)

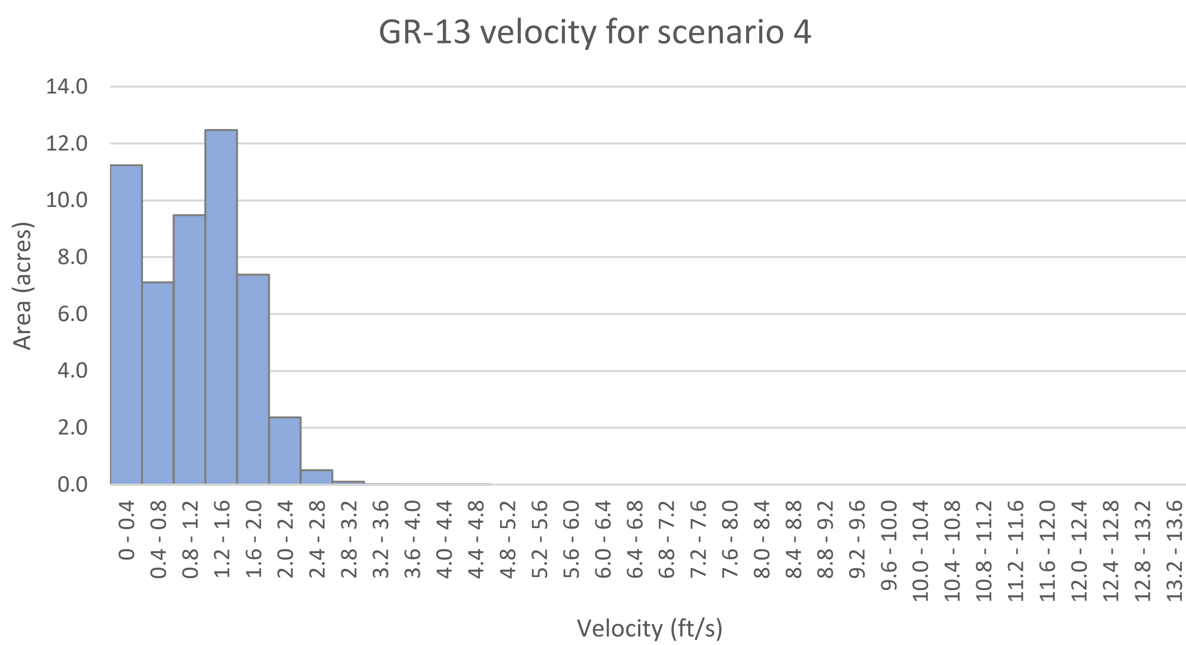


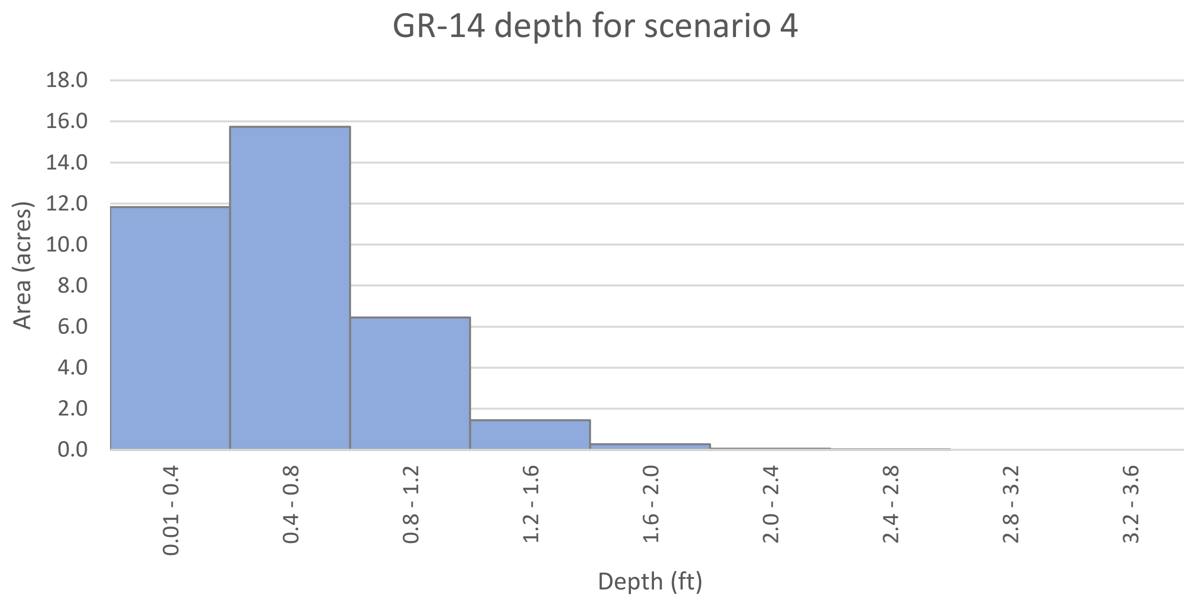
GR-11 velocity for scenario 4
Area (acres)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0 - 0.4
0.4 - 0.8
0.8 - 1.2
1.2 - 1.6
1.6 - 2.0
2.0 - 2.4
2.4 - 2.8
2.8 - 3.2
3.2 - 3.6
3.6 - 4.0
4.0 - 4.4
4.4 - 4.8
4.8 - 5.2
5.2 - 5.6
5.6 - 6.0
6.0 - 6.4
6.4 - 6.8
6.8 - 7.2
7.2 - 7.6
7.6 - 8.0
8.0 - 8.4
8.4 - 8.8
8.8 - 9.2
9.2 - 9.6
9.6 - 10.0
10.0 - 10.4
10.4 - 10.8
10.8 - 11.2
11.2 - 11.6
11.6 - 12.0
12.0 - 12.4
12.4 - 12.8
12.8 - 13.2
13.2 - 13.6
Velocity (ft/s)

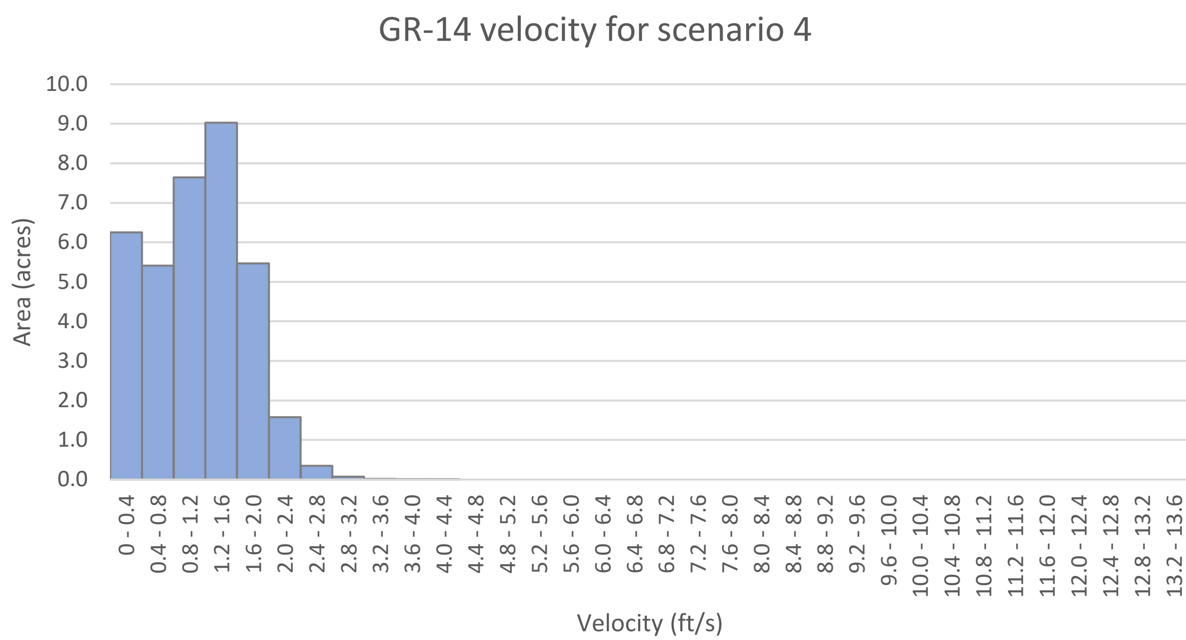

GR-12 depth for scenario 4
Area (acres)
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0.01 - 0.4
0.4 - 0.8
0.8 - 1.2
1.2 - 1.6
1.6 - 2.0
2.0 - 2.4
2.4 - 2.8
2.8 - 3.2
3.2 - 3.6
Depth (ft)

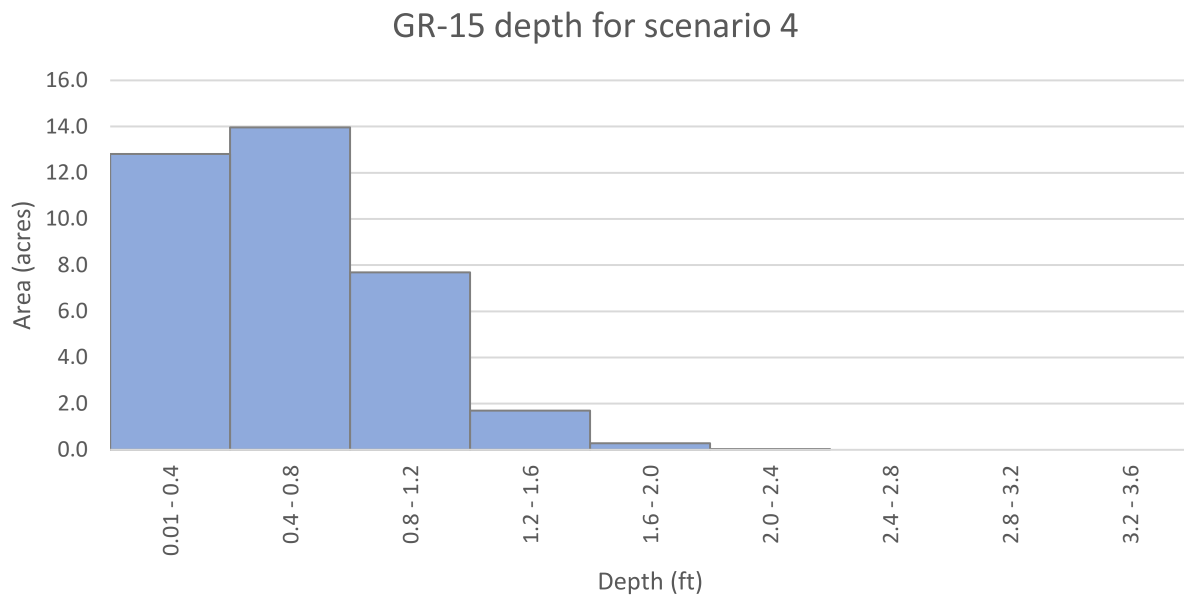

GR-12 velocity for scenario 4
Area (acres)
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0 - 0.4
0.4 - 0.8
0.8 - 1.2
1.2 - 1.6
1.6 - 2.0
2.0 - 2.4
2.4 - 2.8
2.8 - 3.2
3.2 - 3.6
3.6 - 4.0
4.0 - 4.4
4.4 - 4.8
4.8 - 5.2
5.2 - 5.6
5.6 - 6.0
6.0 - 6.4
6.4 - 6.8
6.8 - 7.2
7.2 - 7.6
7.6 - 8.0
8.0 - 8.4
8.4 - 8.8
8.8 - 9.2
9.2 - 9.6
9.6 - 10.0
10.0 - 10.4
10.4 - 10.8
10.8 - 11.2
11.2 - 11.6
11.6 - 12.0
12.0 - 12.4
12.4 - 12.8
12.8 - 13.2
13.2 - 13.6
Velocity (ft/s)

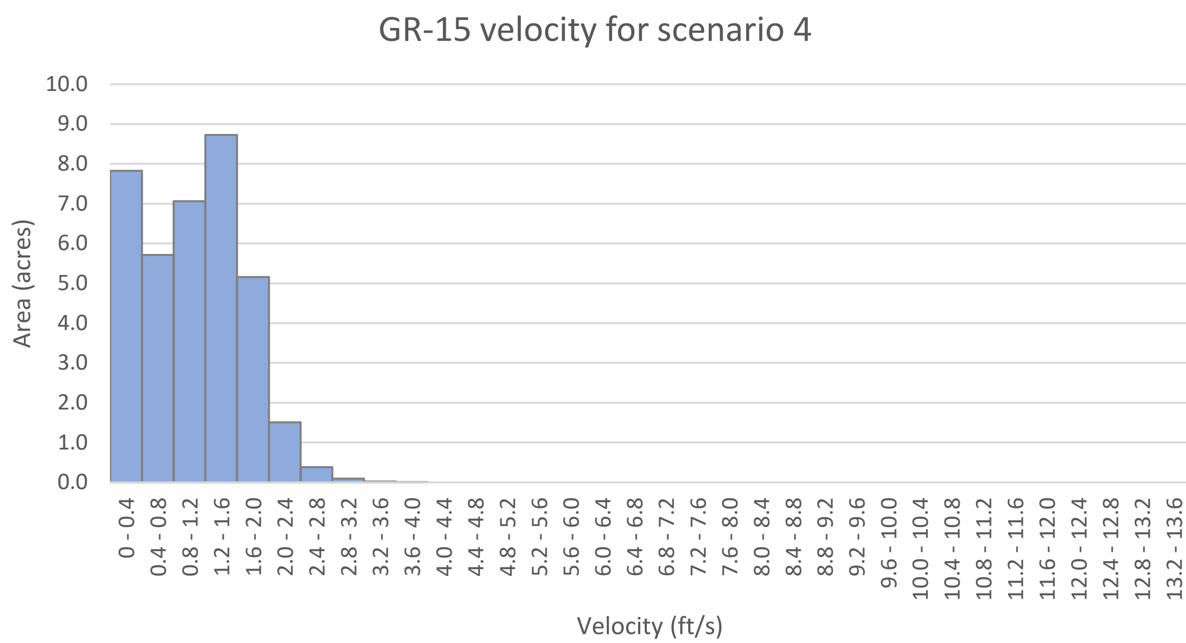

GR-13 depth for scenario 4
Area (acres)
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0.01 - 0.4
0.4 - 0.8
0.8 - 1.2
1.2 - 1.6
1.6 - 2.0
2.0 - 2.4
2.4 - 2.8
2.8 - 3.2
3.2 - 3.6
Depth (ft)

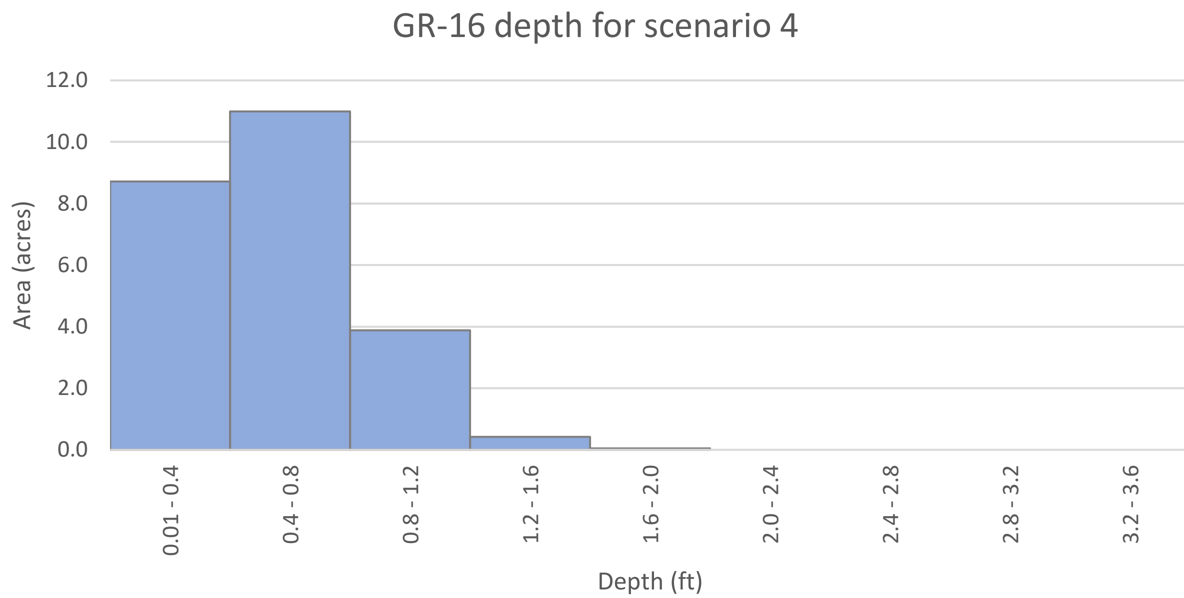

GR-13 velocity for scenario 4
Area (acres)
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0 - 0.4
0.4 - 0.8
0.8 - 1.2
1.2 - 1.6
1.6 - 2.0
2.0 - 2.4
2.4 - 2.8
2.8 - 3.2
3.2 - 3.6
3.6 - 4.0
4.0 - 4.4
4.4 - 4.8
4.8 - 5.2
5.2 - 5.6
5.6 - 6.0
6.0 - 6.4
6.4 - 6.8
6.8 - 7.2
7.2 - 7.6
7.6 - 8.0
8.0 - 8.4
8.4 - 8.8
8.8 - 9.2
9.2 - 9.6
9.6 - 10.0
10.0 - 10.4
10.4 - 10.8
10.8 - 11.2
11.2 - 11.6
11.6 - 12.0
12.0 - 12.4
12.4 - 12.8
12.8 - 13.2
13.2 - 13.6
Velocity (ft/s)

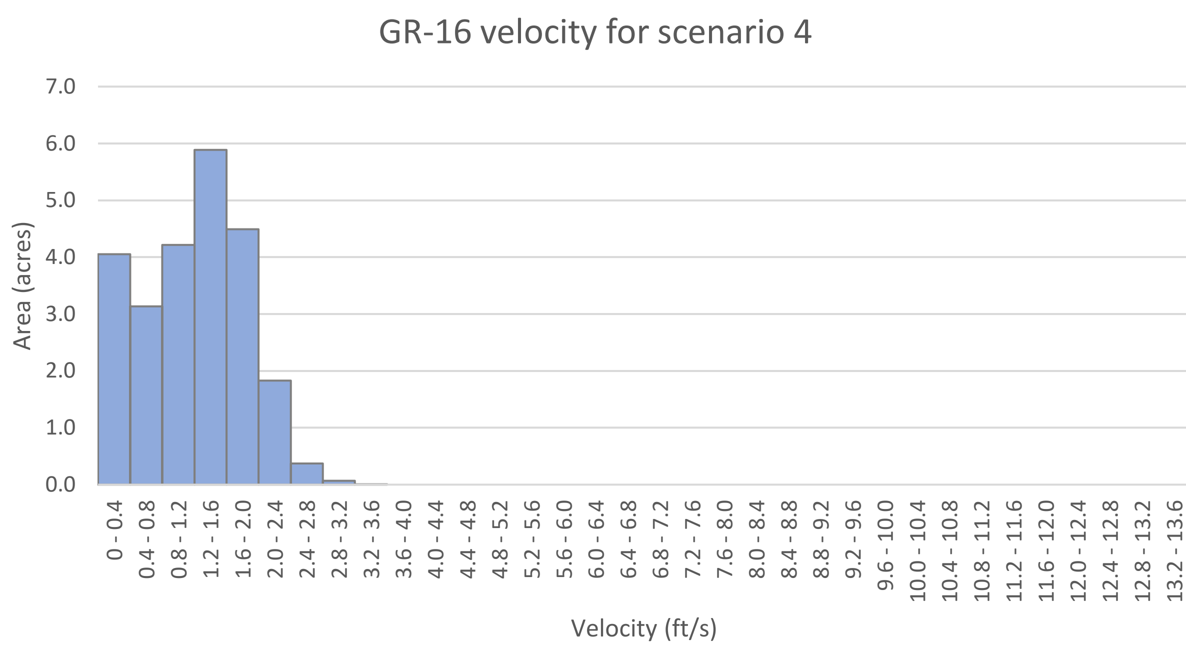

GR-14 depth for scenario 4
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Area (acres)
0.01 - 0.4
0.4 - 0.8
0.8 - 1.2
1.2 - 1.6
1.6 - 2.0
2.0 - 2.4
2.4 - 2.8
2.8 - 3.2
3.2 - 3.6
Depth (ft)

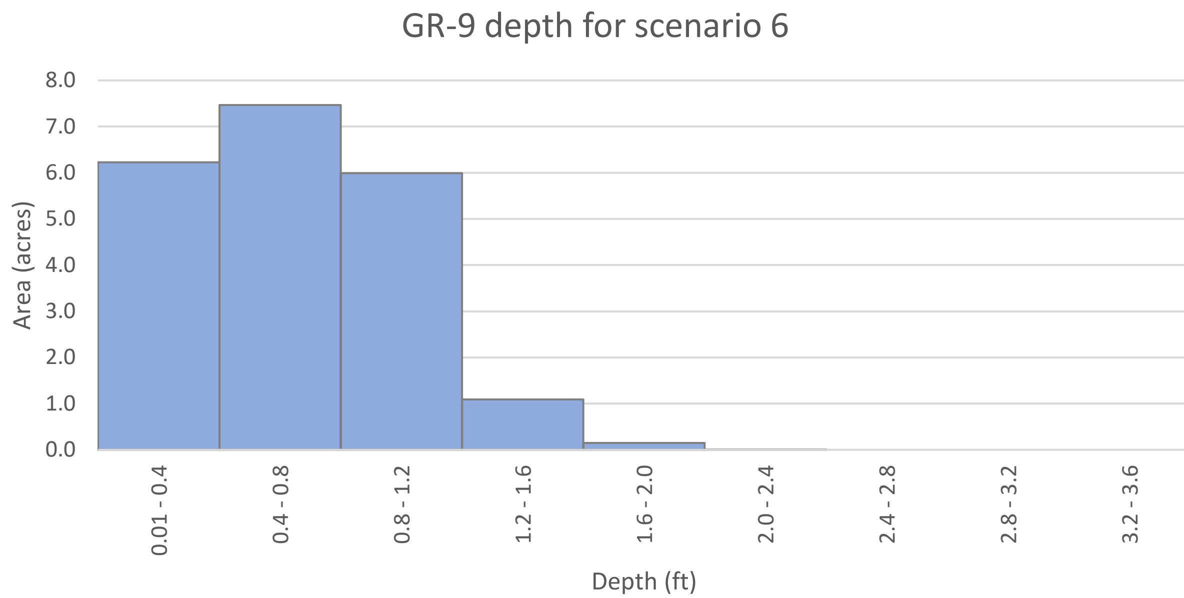

GR-14 velocity for scenario 4
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Area (acres)
0 - 0.4
0.4 - 0.8
0.8 - 1.2
1.2 - 1.6
1.6 - 2.0
2.0 - 2.4
2.4 - 2.8
2.8 - 3.2
3.2 - 3.6
3.6 - 4.0
4.0 - 4.4
4.4 - 4.8
4.8 - 5.2
5.2 - 5.6
5.6 - 6.0
6.0 - 6.4
6.4 - 6.8
6.8 - 7.2
7.2 - 7.6
7.6 - 8.0
8.0 - 8.4
8.4 - 8.8
8.8 - 9.2
9.2 - 9.6
9.6 - 10.0
10.0 - 10.4
10.4 - 10.8
10.8 - 11.2
11.2 - 11.6
11.6 - 12.0
12.0 - 12.4
12.4 - 12.8
12.8 - 13.2
13.2 - 13.6
Velocity (ft/s)

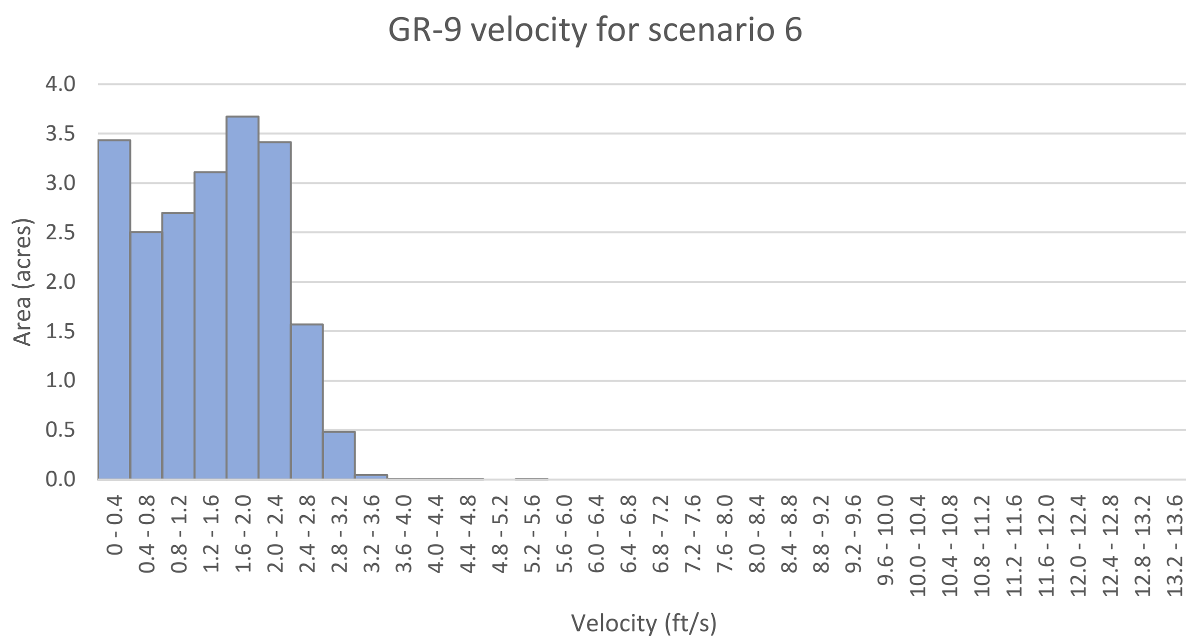

GR-15 depth for scenario 4
Area (acres)
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0.01 - 0.4
0.4 - 0.8
0.8 - 1.2
1.2 - 1.6
1.6 - 2.0
2.0 - 2.4
2.4 - 2.8
2.8 - 3.2
3.2 - 3.6
Depth (ft)

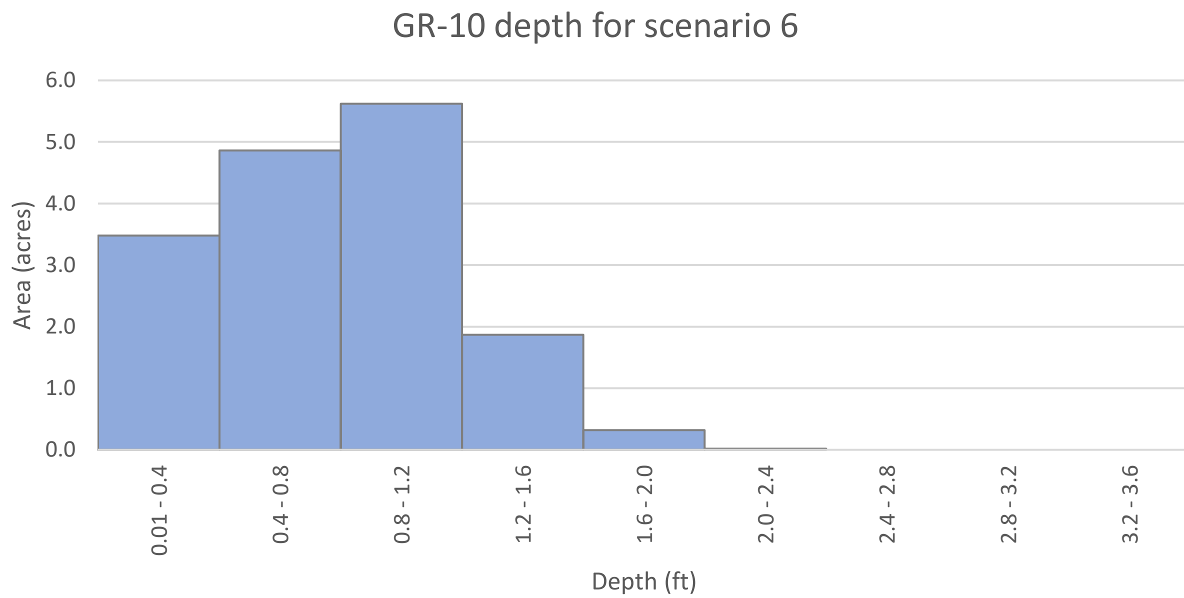

GR-15 velocity for scenario 4
Area (acres)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0 - 0.4
0.4 - 0.8
0.8 - 1.2
1.2 - 1.6
1.6 - 2.0
2.0 - 2.4
2.4 - 2.8
2.8 - 3.2
3.2 - 3.6
3.6 - 4.0
4.0 - 4.4
4.4 - 4.8
4.8 - 5.2
5.2 - 5.6
5.6 - 6.0
6.0 - 6.4
6.4 - 6.8
6.8 - 7.2
7.2 - 7.6
7.6 - 8.0
8.0 - 8.4
8.4 - 8.8
8.8 - 9.2
9.2 - 9.6
9.6 - 10.0
10.0 - 10.4
10.4 - 10.8
10.8 - 11.2
11.2 - 11.6
11.6 - 12.0
12.0 - 12.4
12.4 - 12.8
12.8 - 13.2
13.2 - 13.6
Velocity (ft/s)


GR-16 depth for scenario 4
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Area (acres)
0.01 - 0.4
0.4 - 0.8
0.8 - 1.2
1.2 - 1.6
1.6 - 2.0
2.0 - 2.4
2.4 - 2.8
2.8 - 3.2
3.2 - 3.6
Depth (ft)

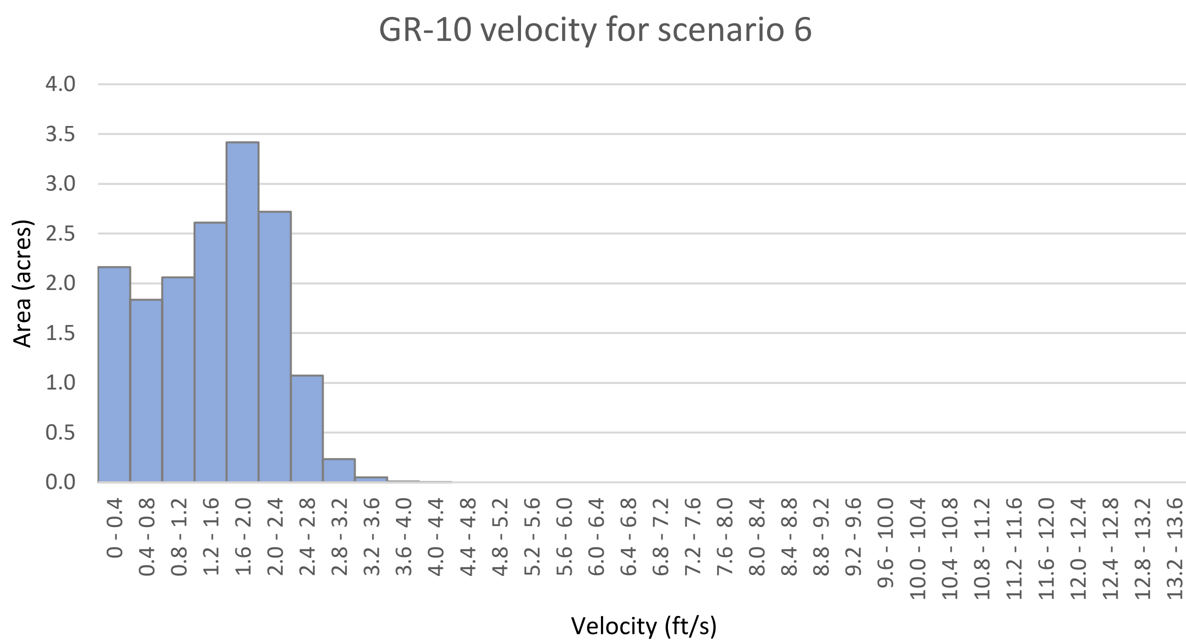

GR-16 velocity for scenario 4
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Area (acres)
0 - 0.4
0.4 - 0.8
0.8 - 1.2
1.2 - 1.6
1.6 - 2.0
2.0 - 2.4
2.4 - 2.8
2.8 - 3.2
3.2 - 3.6
3.6 - 4.0
4.0 - 4.4
4.4 - 4.8
4.8 - 5.2
5.2 - 5.6
5.6 - 6.0
6.0 - 6.4
6.4 - 6.8
6.8 - 7.2
7.2 - 7.6
7.6 - 8.0
8.0 - 8.4
8.4 - 8.8
8.8 - 9.2
9.2 - 9.6
9.6 - 10.0
10.0 - 10.4
10.4 - 10.8
10.8 - 11.2
11.2 - 11.6
11.6 - 12.0
12.0 - 12.4
12.4 - 12.8
12.8 - 13.2
13.2 - 13.6
Velocity (ft/s)


GR-9 depth for scenario 6
Area (acres)
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0.01 - 0.4
0.4 - 0.8
0.8 - 1.2
1.2 - 1.6
1.6 - 2.0
2.0 - 2.4
2.4 - 2.8
2.8 - 3.2
3.2 - 3.6
Depth (ft)

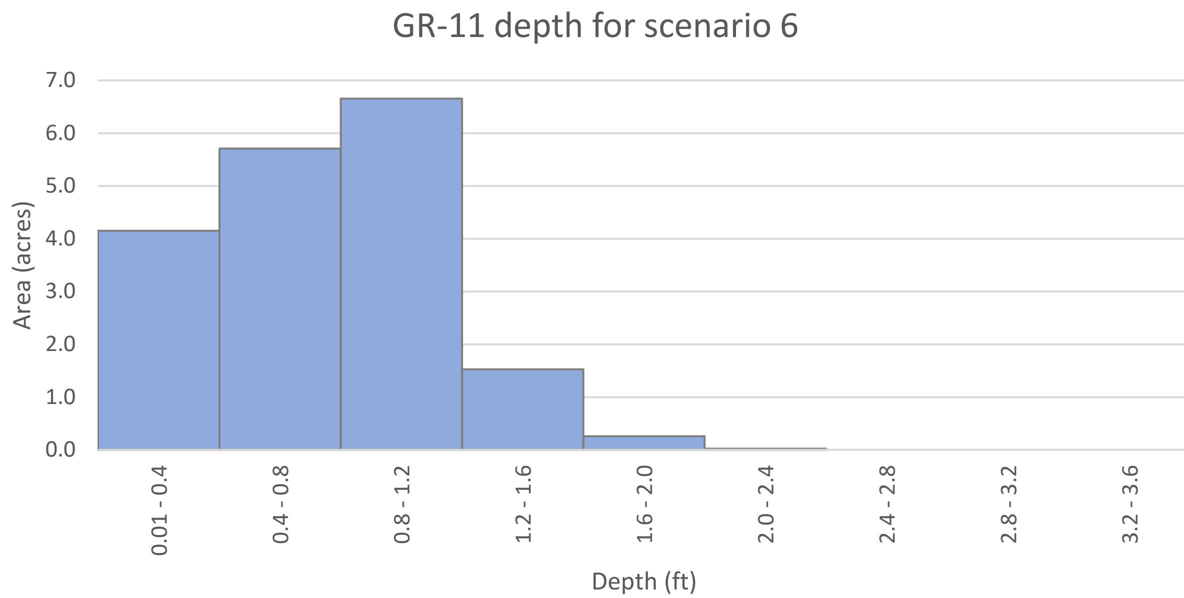

GR-9 velocity for scenario 6
Area (acres)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0 - 0.4
0.4 - 0.8
0.8 - 1.2
1.2 - 1.6
1.6 - 2.0
2.0 - 2.4
2.4 - 2.8
2.8 - 3.2
3.2 - 3.6
3.6 - 4.0
4.0 - 4.4
4.4 - 4.8
4.8 - 5.2
5.2 - 5.6
5.6 - 6.0
6.0 - 6.4
6.4 - 6.8
6.8 - 7.2
7.2 - 7.6
7.6 - 8.0
8.0 - 8.4
8.4 - 8.8
8.8 - 9.2
9.2 - 9.6
9.6 - 10.0
10.0 - 10.4
10.4 - 10.8
10.8 - 11.2
11.2 - 11.6
11.6 - 12.0
12.0 - 12.4
12.4 - 12.8
12.8 - 13.2
13.2 - 13.6
Velocity (ft/s)

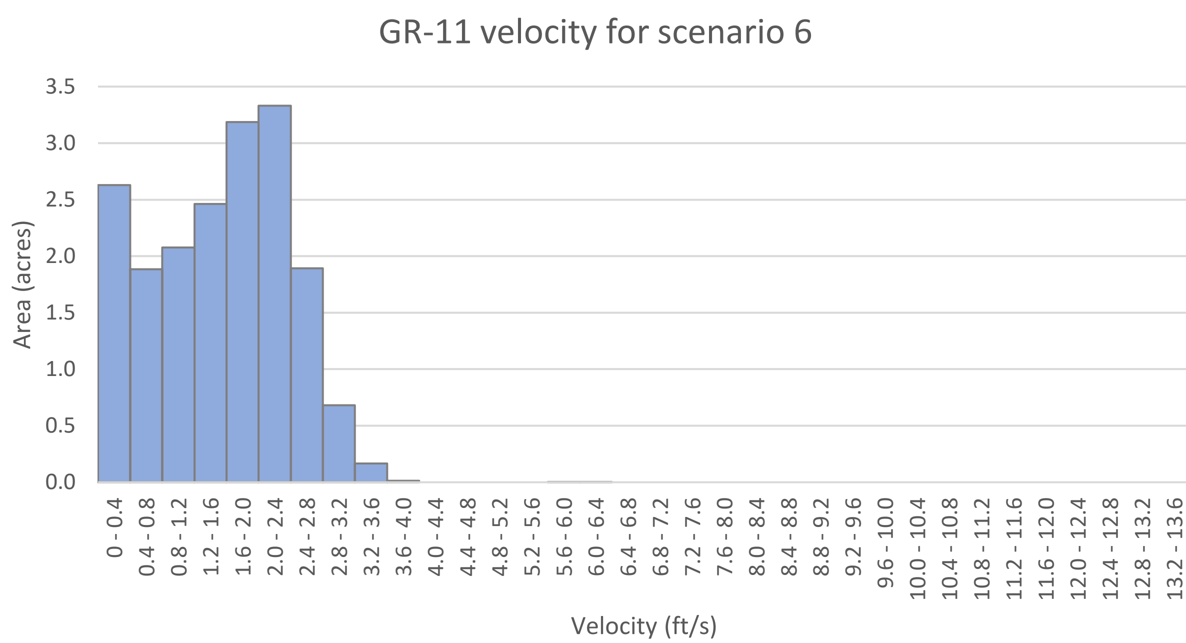


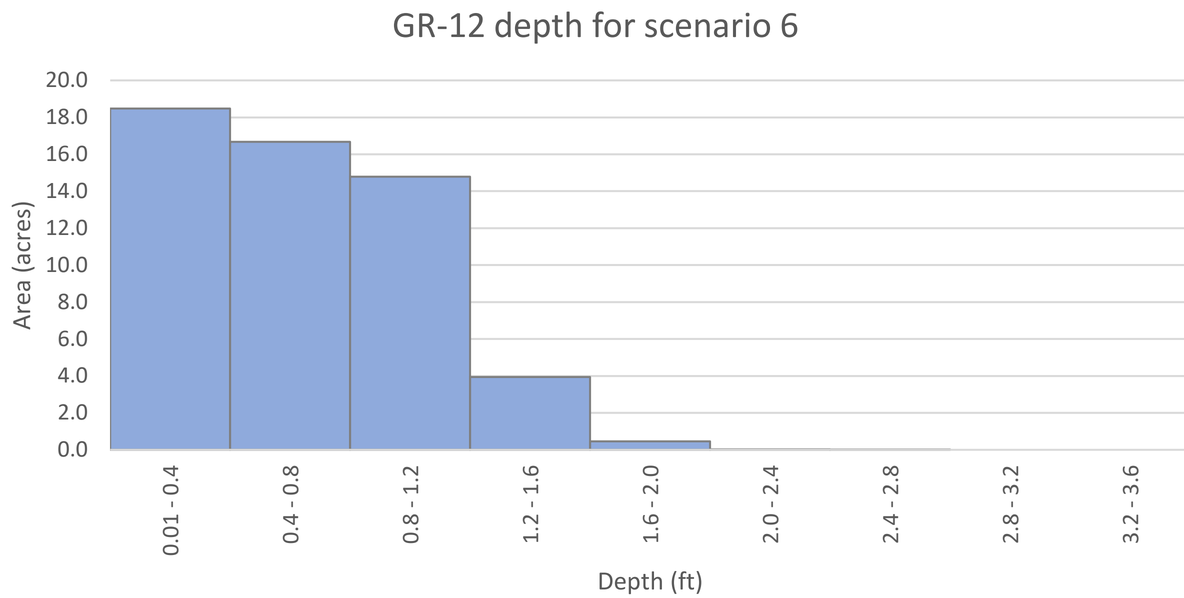
GR-10 depth for scenario 6
Area (acres)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0.01 - 0.4
0.4 - 0.8
0.8 - 1.2
1.2 - 1.6
1.6 - 2.0
2.0 - 2.4
2.4 - 2.8
2.8 - 3.2
3.2 - 3.6
Depth (ft)



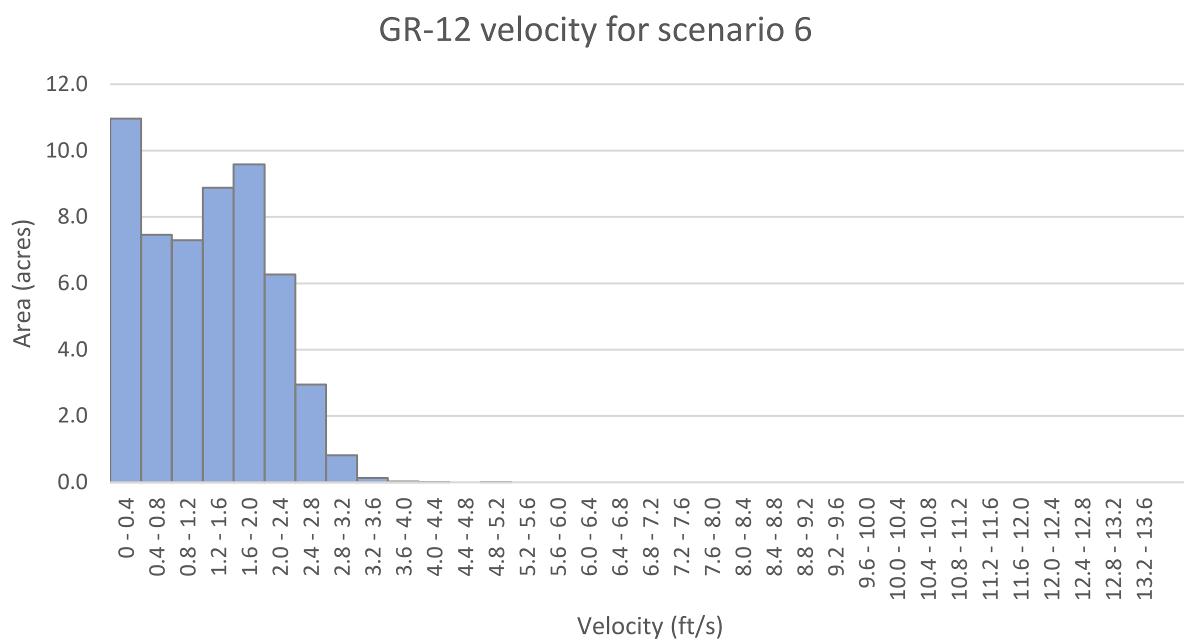
GR-10 velocity for scenario 6
Area (acres)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0 - 0.4
0.4 - 0.8
0.8 - 1.2
1.2 - 1.6
1.6 - 2.0
2.0 - 2.4
2.4 - 2.8
2.8 - 3.2
3.2 - 3.6
3.6 - 4.0
4.0 - 4.4
4.4 - 4.8
4.8 - 5.2
5.2 - 5.6
5.6 - 6.0
6.0 - 6.4
6.4 - 6.8
6.8 - 7.2
7.2 - 7.6
7.6 - 8.0
8.0 - 8.4
8.4 - 8.8
8.8 - 9.2
9.2 - 9.6
9.6 - 10.0
10.0 - 10.4
10.4 - 10.8
10.8 - 11.2
11.2 - 11.6
11.6 - 12.0
12.0 - 12.4
12.4 - 12.8
12.8 - 13.2
13.2 - 13.6
Velocity (ft/s)


GR-11 depth for scenario 6
Area (acres)
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0.01 - 0.4
0.4 - 0.8
0.8 - 1.2
1.2 - 1.6
1.6 - 2.0
2.0 - 2.4
2.4 - 2.8
2.8 - 3.2
3.2 - 3.6
Depth (ft)

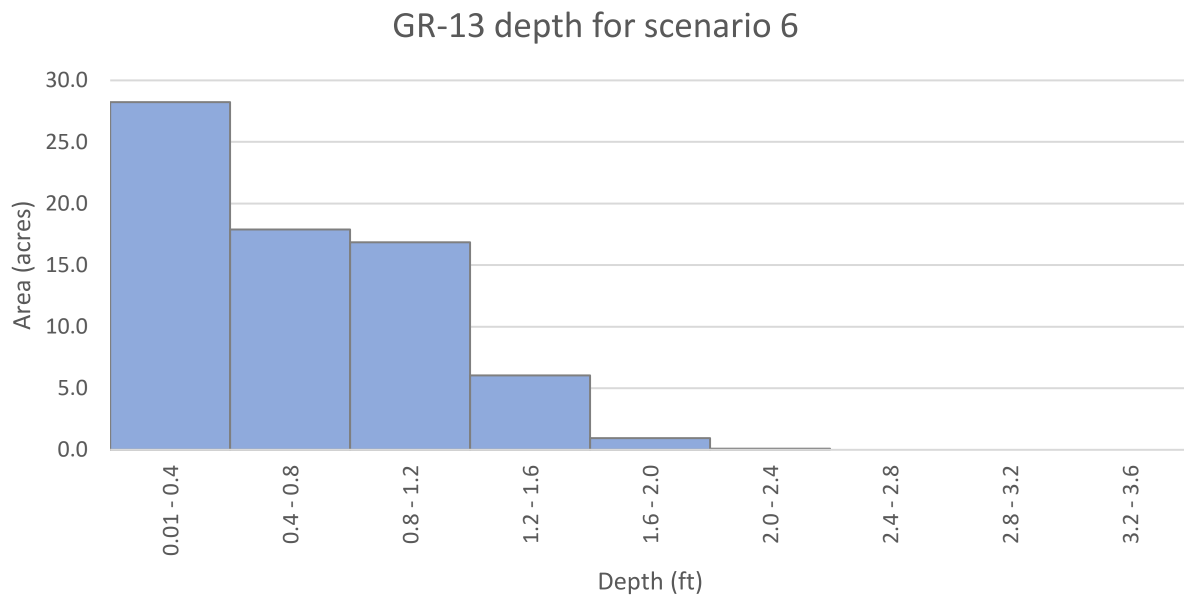

GR-11 velocity for scenario 6
Area (acres)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0 - 0.4
0.4 - 0.8
0.8 - 1.2
1.2 - 1.6
1.6 - 2.0
2.0 - 2.4
2.4 - 2.8
2.8 - 3.2
3.2 - 3.6
3.6 - 4.0
4.0 - 4.4
4.4 - 4.8
4.8 - 5.2
5.2 - 5.6
5.6 - 6.0
6.0 - 6.4
6.4 - 6.8
6.8 - 7.2
7.2 - 7.6
7.6 - 8.0
8.0 - 8.4
8.4 - 8.8
8.8 - 9.2
9.2 - 9.6
9.6 - 10.0
10.0 - 10.4
10.4 - 10.8
10.8 - 11.2
11.2 - 11.6
11.6 - 12.0
12.0 - 12.4
12.4 - 12.8
12.8 - 13.2
13.2 - 13.6
Velocity (ft/s)

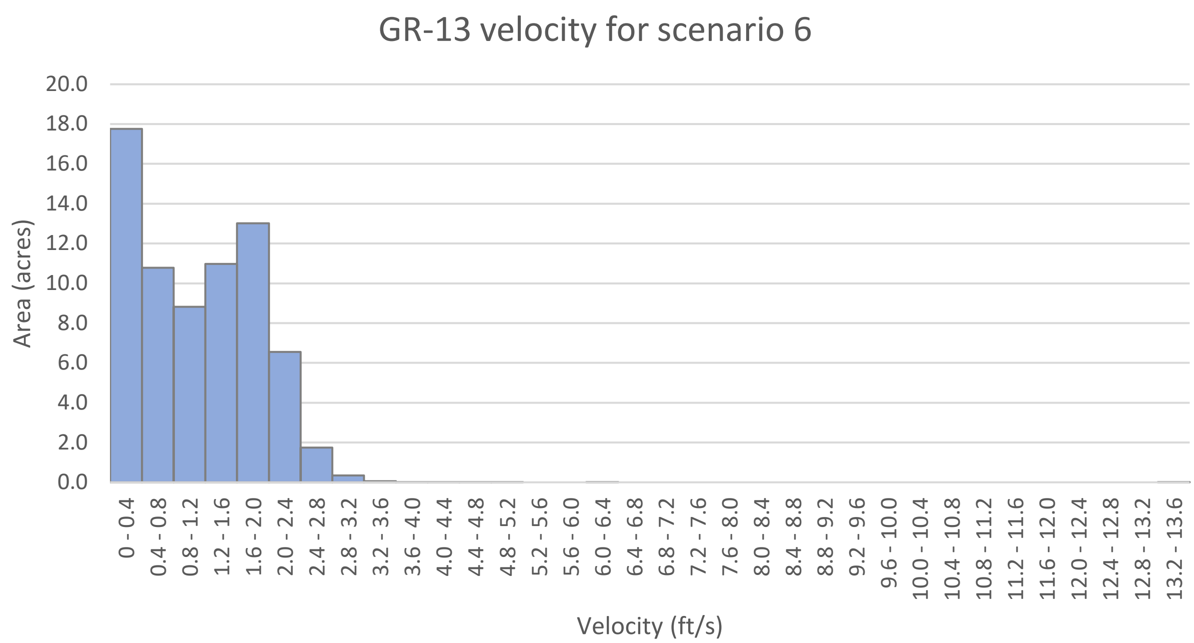


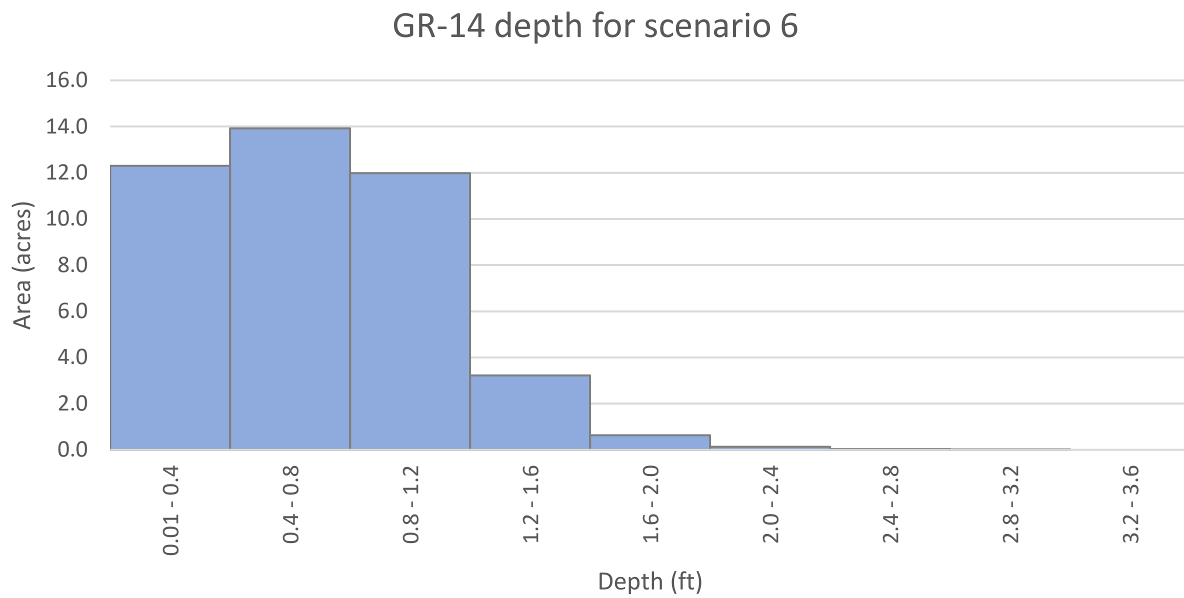
GR-12 depth for scenario 6
Area (acres)
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0.01 - 0.4
0.4 - 0.8
0.8 - 1.2
1.2 - 1.6
1.6 - 2.0
2.0 - 2.4
2.4 - 2.8
2.8 - 3.2
3.2 - 3.6
Depth (ft)

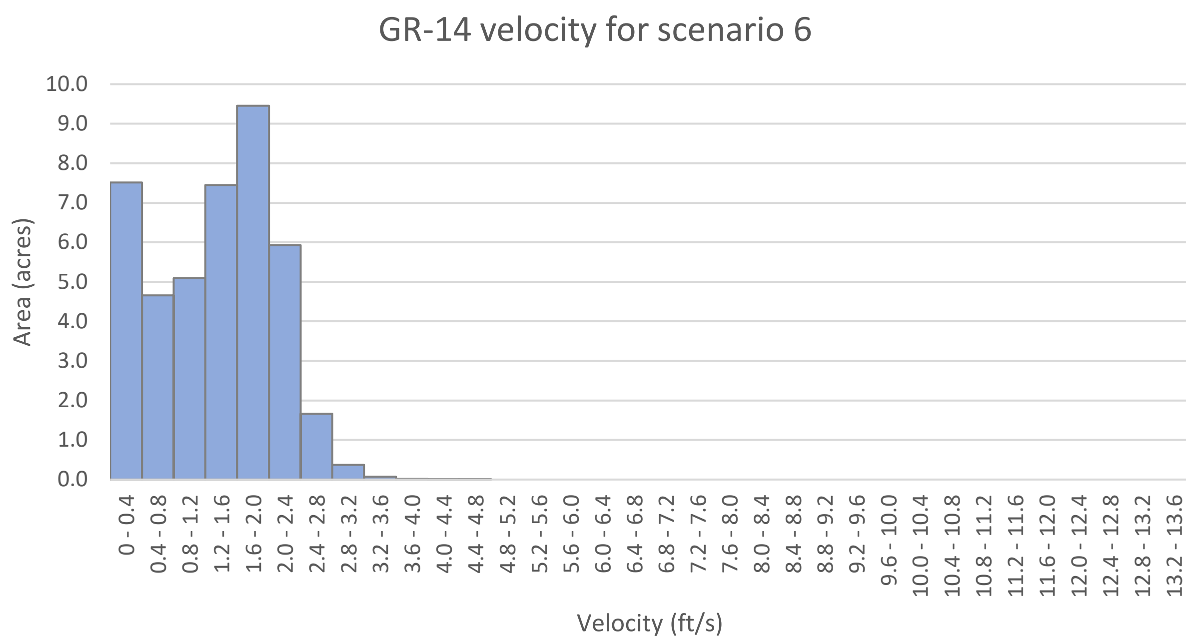


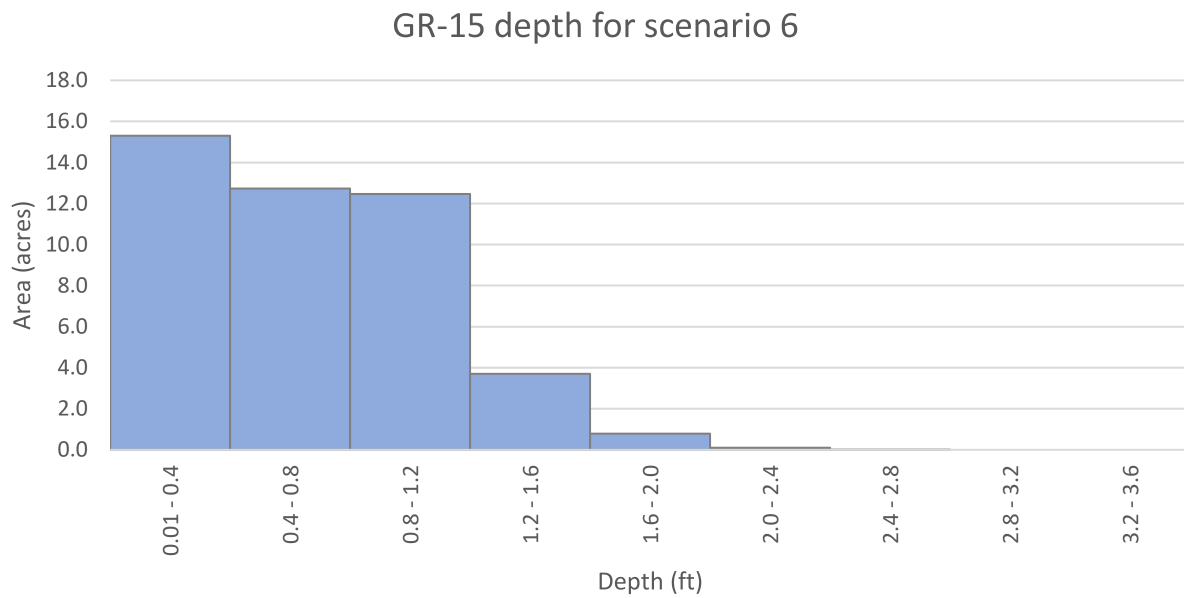
GR-12 velocity for scenario 6
Area (acres)
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0 - 0.4
0.4 - 0.8
0.8 - 1.2
1.2 - 1.6
1.6 - 2.0
2.0 - 2.4
2.4 - 2.8
2.8 - 3.2
3.2 - 3.6
3.6 - 4.0
4.0 - 4.4
4.4 - 4.8
4.8 - 5.2
5.2 - 5.6
5.6 - 6.0
6.0 - 6.4
6.4 - 6.8
6.8 - 7.2
7.2 - 7.6
7.6 - 8.0
8.0 - 8.4
8.4 - 8.8
8.8 - 9.2
9.2 - 9.6
9.6 - 10.0
10.0 - 10.4
10.4 - 10.8
10.8 - 11.2
11.2 - 11.6
11.6 - 12.0
12.0 - 12.4
12.4 - 12.8
12.8 - 13.2
13.2 - 13.6
Velocity (ft/s)

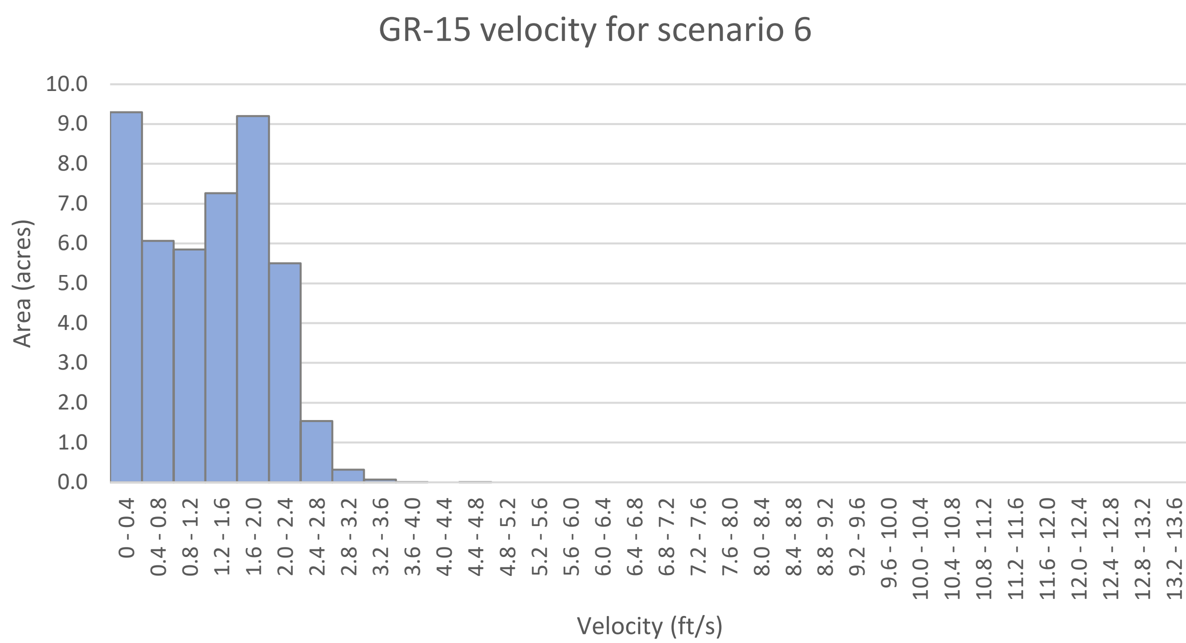

GR-13 depth for scenario 6
Area (acres)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
0.01 - 0.4
0.4 - 0.8
0.8 - 1.2
1.2 - 1.6
1.6 - 2.0
2.0 - 2.4
2.4 - 2.8
2.8 - 3.2
3.2 - 3.6
Depth (ft)

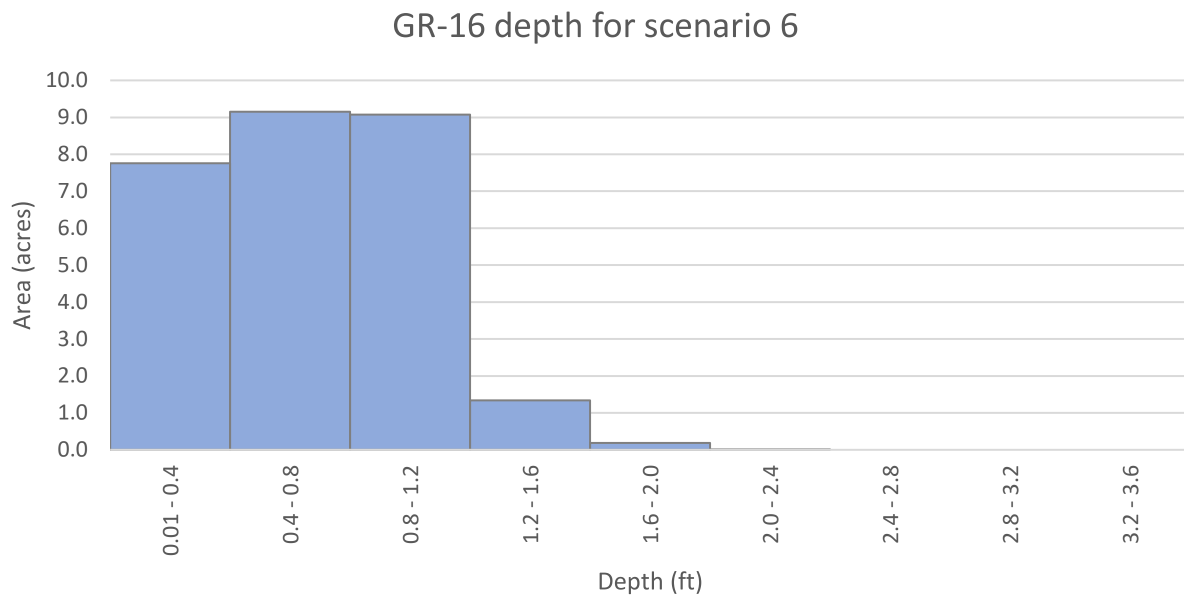

GR-13 velocity for scenario 6
Area (acres)
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0 - 0.4
0.4 - 0.8
0.8 - 1.2
1.2 - 1.6
1.6 - 2.0
2.0 - 2.4
2.4 - 2.8
2.8 - 3.2
3.2 - 3.6
3.6 - 4.0
4.0 - 4.4
4.4 - 4.8
4.8 - 5.2
5.2 - 5.6
5.6 - 6.0
6.0 - 6.4
6.4 - 6.8
6.8 - 7.2
7.2 - 7.6
7.6 - 8.0
8.0 - 8.4
8.4 - 8.8
8.8 - 9.2
9.2 - 9.6
9.6 - 10.0
10.0 - 10.4
10.4 - 10.8
10.8 - 11.2
11.2 - 11.6
11.6 - 12.0
12.0 - 12.4
12.4 - 12.8
12.8 - 13.2
13.2 - 13.6
Velocity (ft/s)

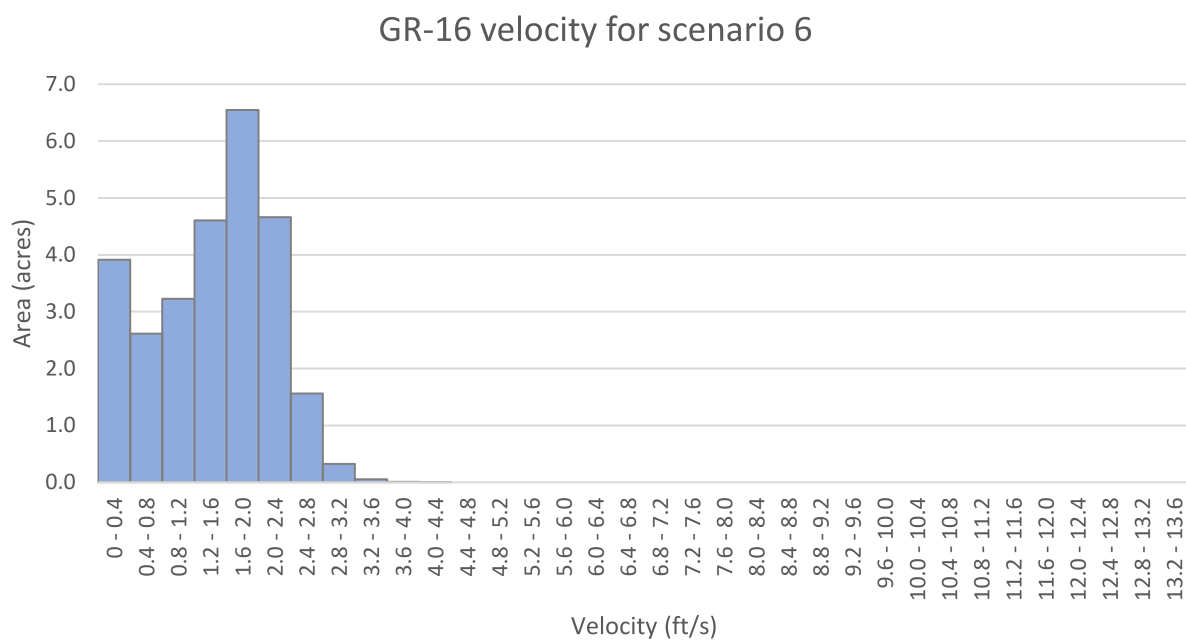

GR-14 depth for scenario 6
Area (acres)
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0.01 - 0.4
0.4 - 0.8
0.8 - 1.2
1.2 - 1.6
1.6 - 2.0
2.0 - 2.4
2.4 - 2.8
2.8 - 3.2
3.2 - 3.6
Depth (ft)

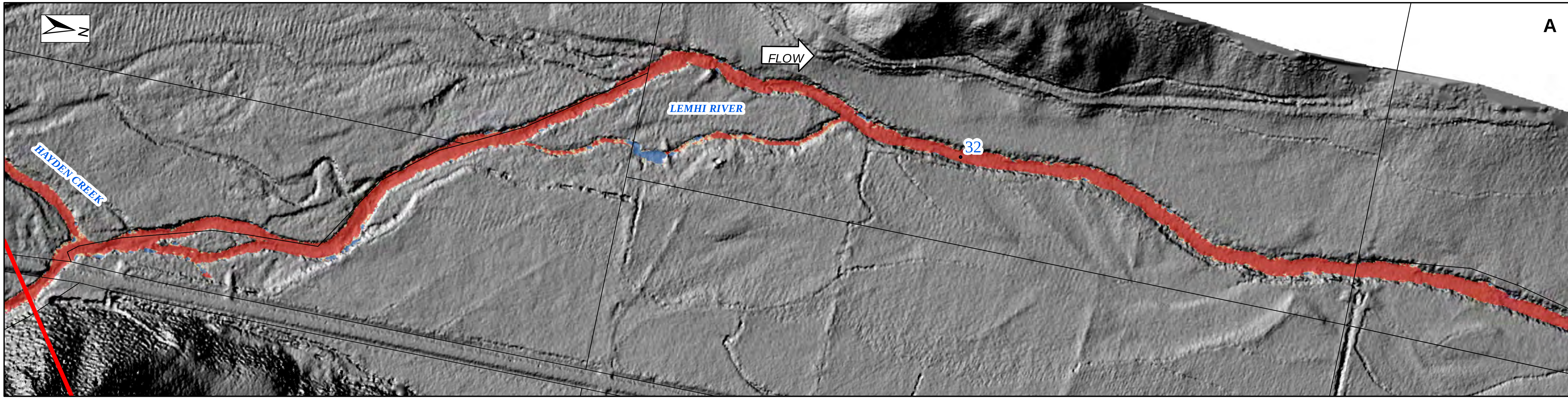

GR-14 velocity for scenario 6
Area (acres)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0 - 0.4
0.4 - 0.8
0.8 - 1.2
1.2 - 1.6
1.6 - 2.0
2.0 - 2.4
2.4 - 2.8
2.8 - 3.2
3.2 - 3.6
3.6 - 4.0
4.0 - 4.4
4.4 - 4.8
4.8 - 5.2
5.2 - 5.6
5.6 - 6.0
6.0 - 6.4
6.4 - 6.8
6.8 - 7.2
7.2 - 7.6
7.6 - 8.0
8.0 - 8.4
8.4 - 8.8
8.8 - 9.2
9.2 - 9.6
9.6 - 10.0
10.0 - 10.4
10.4 - 10.8
10.8 - 11.2
11.2 - 11.6
11.6 - 12.0
12.0 - 12.4
12.4 - 12.8
12.8 - 13.2
13.2 - 13.6
Velocity (ft/s)

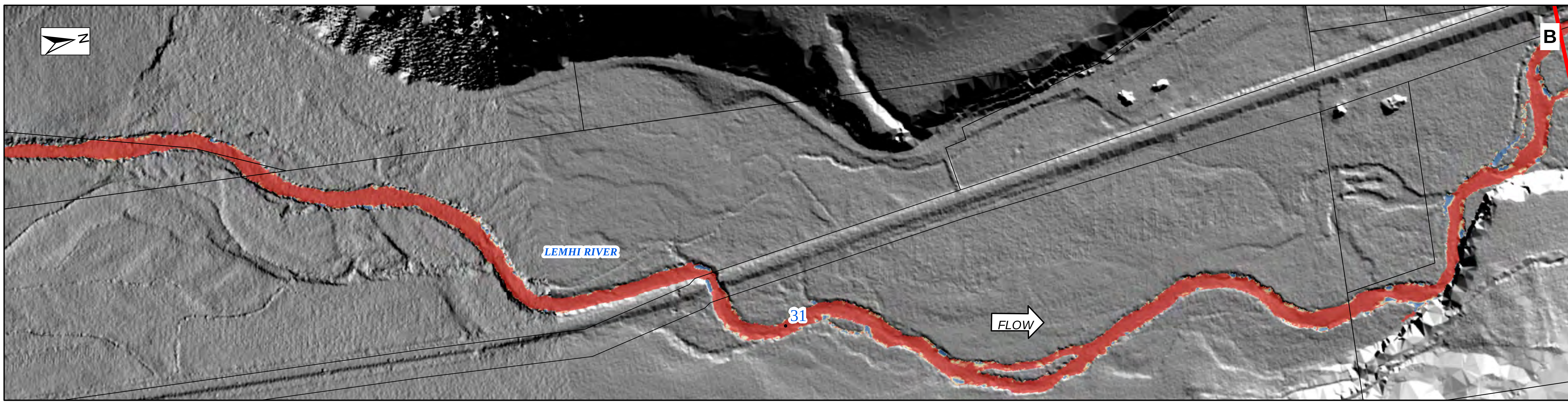

GR-15 depth for scenario 6
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Area (acres)
0.01 - 0.4
0.4 - 0.8
0.8 - 1.2
1.2 - 1.6
1.6 - 2.0
2.0 - 2.4
2.4 - 2.8
2.8 - 3.2
3.2 - 3.6
Depth (ft)


GR-15 velocity for scenario 6
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Area (acres)
0 - 0.4
0.4 - 0.8
0.8 - 1.2
1.2 - 1.6
1.6 - 2.0
2.0 - 2.4
2.4 - 2.8
2.8 - 3.2
3.2 - 3.6
3.6 - 4.0
4.0 - 4.4
4.4 - 4.8
4.8 - 5.2
5.2 - 5.6
5.6 - 6.0
6.0 - 6.4
6.4 - 6.8
6.8 - 7.2
7.2 - 7.6
7.6 - 8.0
8.0 - 8.4
8.4 - 8.8
8.8 - 9.2
9.2 - 9.6
9.6 - 10.0
10.0 - 10.4
10.4 - 10.8
10.8 - 11.2
11.2 - 11.6
11.6 - 12.0
12.0 - 12.4
12.4 - 12.8
12.8 - 13.2
13.2 - 13.6
Velocity (ft/s)


GR-16 depth for scenario 6
Area (acres)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0.01 - 0.4
0.4 - 0.8
0.8 - 1.2
1.2 - 1.6
1.6 - 2.0
2.0 - 2.4
2.4 - 2.8
2.8 - 3.2
3.2 - 3.6
Depth (ft)


GR-16 velocity for scenario 6
Area (acres)
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0 - 0.4
0.4 - 0.8
0.8 - 1.2
1.2 - 1.6
1.6 - 2.0
2.0 - 2.4
2.4 - 2.8
2.8 - 3.2
3.2 - 3.6
3.6 - 4.0
4.0 - 4.4
4.4 - 4.8
4.8 - 5.2
5.2 - 5.6
5.6 - 6.0
6.0 - 6.4
6.4 - 6.8
6.8 - 7.2
7.2 - 7.6
7.6 - 8.0
8.0 - 8.4
8.4 - 8.8
8.8 - 9.2
9.2 - 9.6
9.6 - 10.0
10.0 - 10.4
10.4 - 10.8
10.8 - 11.2
11.2 - 11.6
11.6 - 12.0
12.0 - 12.4
12.4 - 12.8
12.8 - 13.2
13.2 - 13.6
Velocity (ft/s)





River Mile

Lemhi County Parcels

Reach Boundary

Composite Suitability Index

High : 1

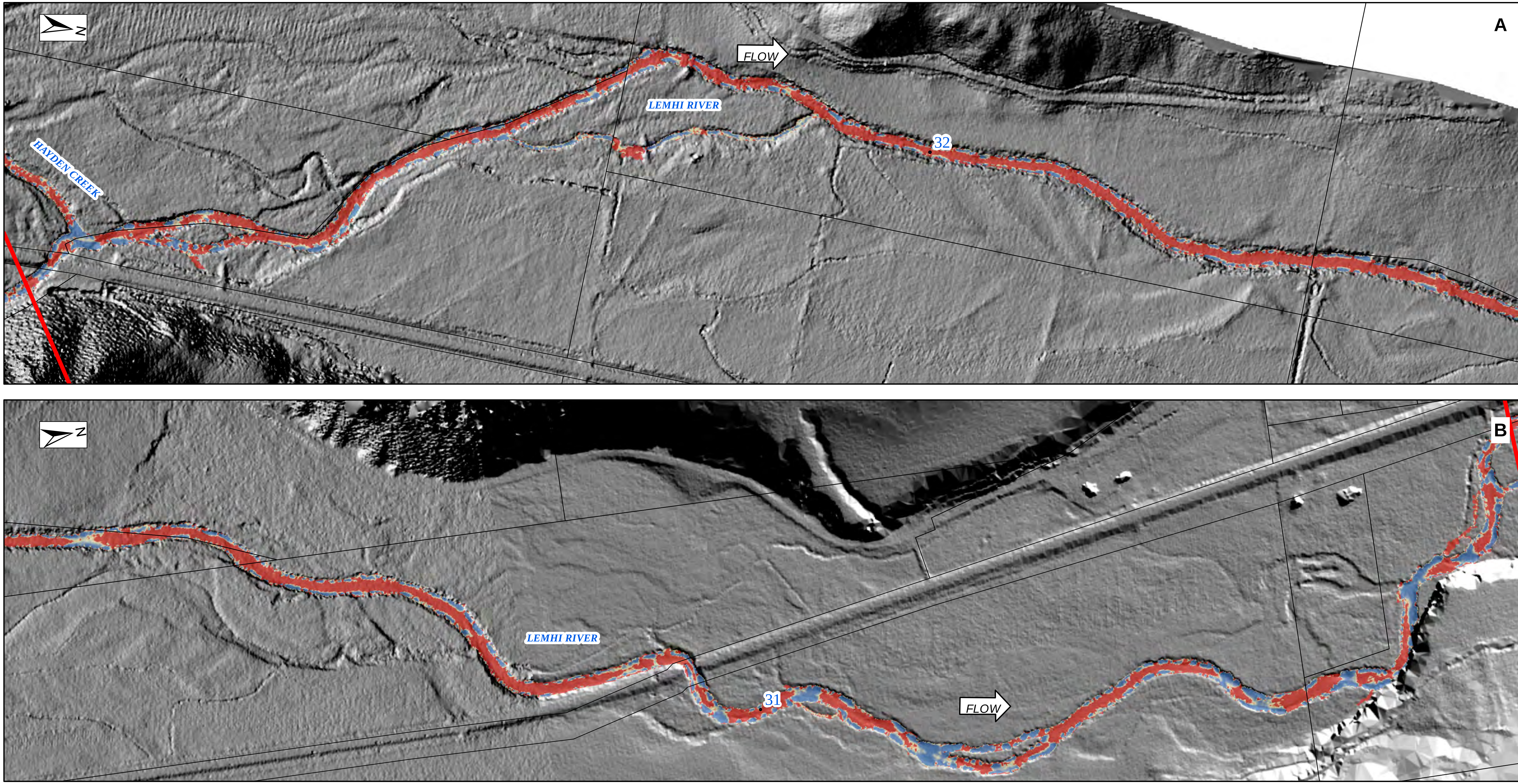
Low : 0

Notes:
-Hydraulic model extent may not depict the total inundated area for this discharge.
-Scenario 4 corresponds to a discharge of 441 cfs

0 250 500 1,000 Feet

Habitat Suitability Map
Rearing Habitat
for Juvenile Chinook Salmon
at Scenario 4 (juvenile rearing flow)
Upper Lemhi Georeach 9

Data Sources: Hillshade (2008 LiDAR), HSI composite suitability index (University of Idaho hydraulic modeling)



River Mile
Lemhi County Parcels
Reach Boundary

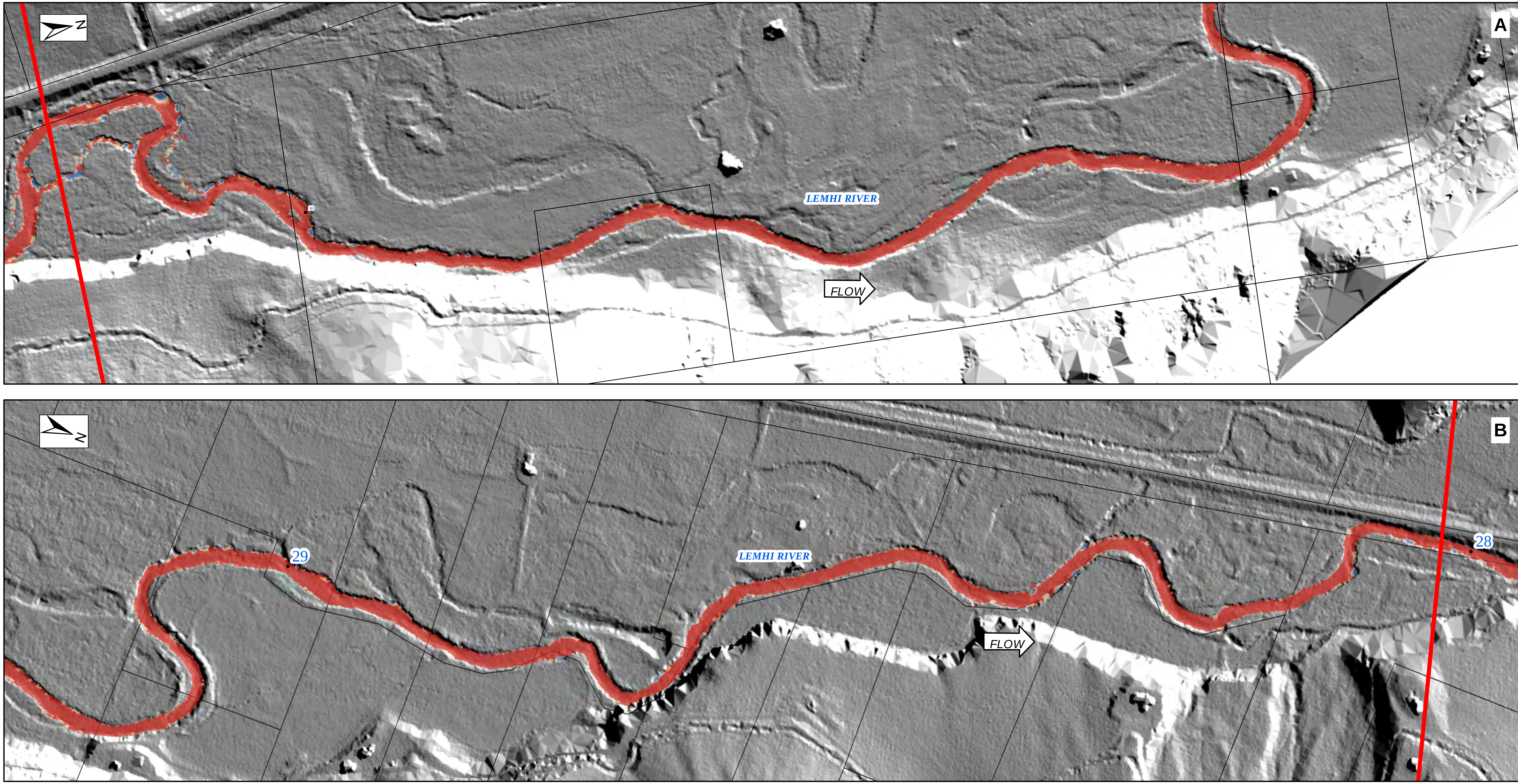
Composite Suitability Index
High : 1
Low : 0

Notes:
-Hydraulic model extent may not depict the total inundated area for this discharge.
-Scenario 4 corresponds to a discharge of 441 cfs

0 250 500 1,000 Feet

Habitat Suitability Map
Spawning Habitat
for Chinook Salmon
at Scenario 4 (juvenile rearing flow)
Upper Lemhi Georeach 9

Data Sources: Hillshade (2008 LiDAR), HSI composite suitability index (University of Idaho hydraulic modeling)



River Mile

Lemhi County Parcels

Reach Boundary

Composite Suitability Index

High : 1

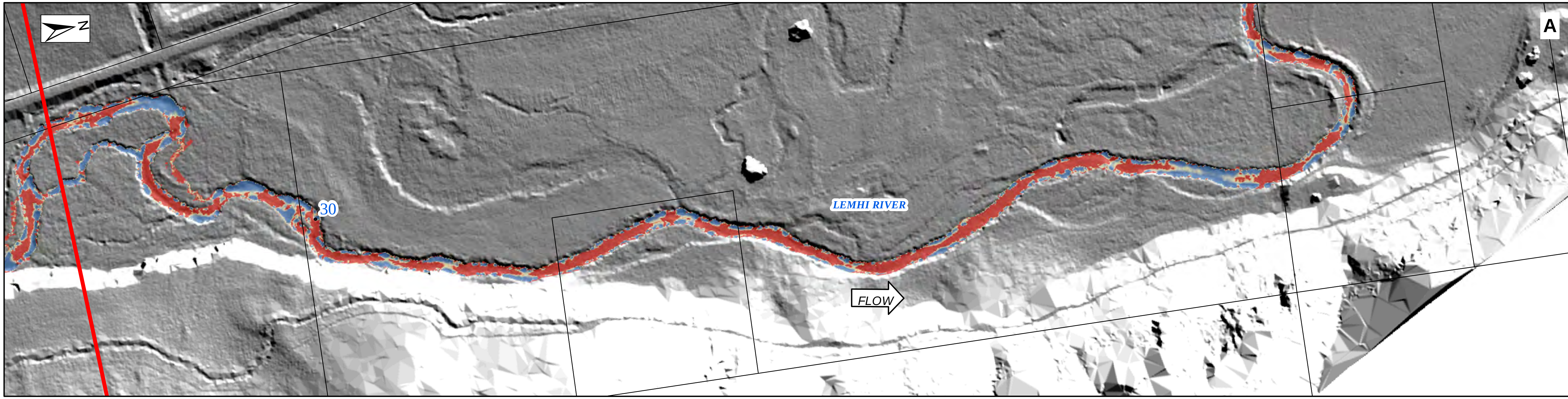
Low : 0

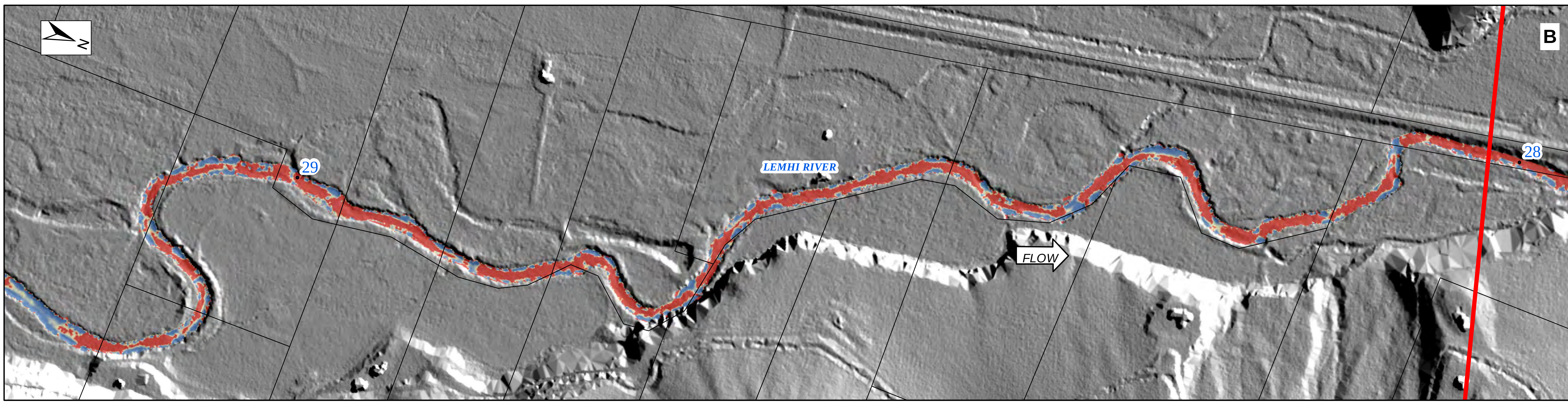
Notes:
-Hydraulic model extent may not depict the total inundated area for this discharge.
-Scenario 4 corresponds to a discharge of 441 cfs

0 250 500 1,000 Feet

Habitat Suitability Map
Rearing Habitat
for Juvenile Chinook Salmon
at Scenario 4 (juvenile rearing flow)
Upper Lemhi Georeach 10

Data Sources: Hillshade (2008 LiDAR), HSI composite suitability index (University of Idaho hydraulic modeling)





River Mile
Lemhi County Parcels
Reach Boundary

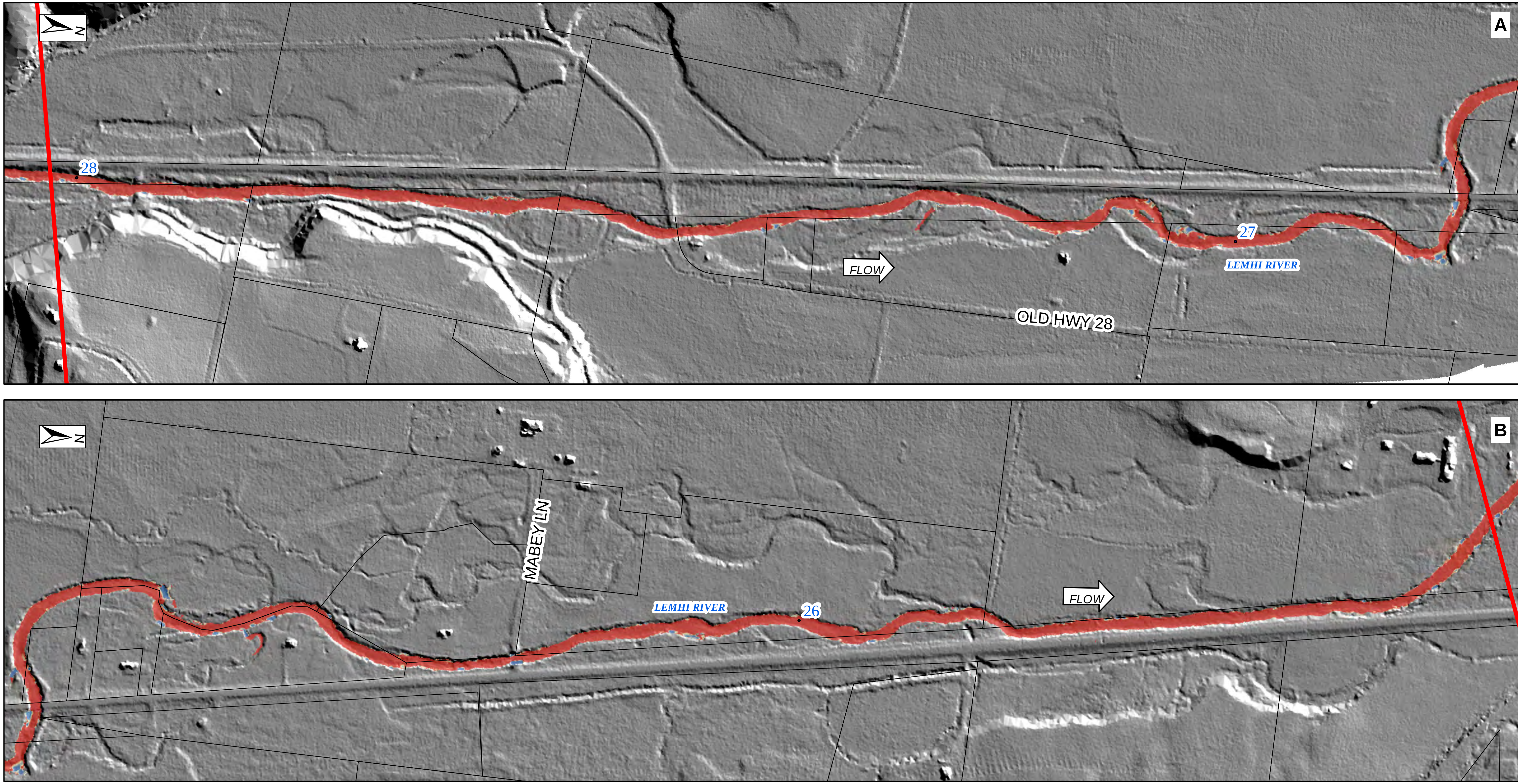
Composite Suitability Index
High : 1
Low : 0

Notes:
-Hydraulic model extent may not depict the total inundated area for this discharge.
-Scenario 4 corresponds to a discharge of 441 cfs

0 250 500 1,000 Feet

Habitat Suitability Map
Spawning Habitat
for Chinook Salmon
at Scenario 4 (juvenile rearing flow)
Upper Lemhi Georeach 10

Data Sources: Hillshade (2008 LiDAR), HSI composite suitability index (University of Idaho hydraulic modeling)



River Mile

Lemhi County Parcels

Reach Boundary

Composite Suitability Index

High : 1

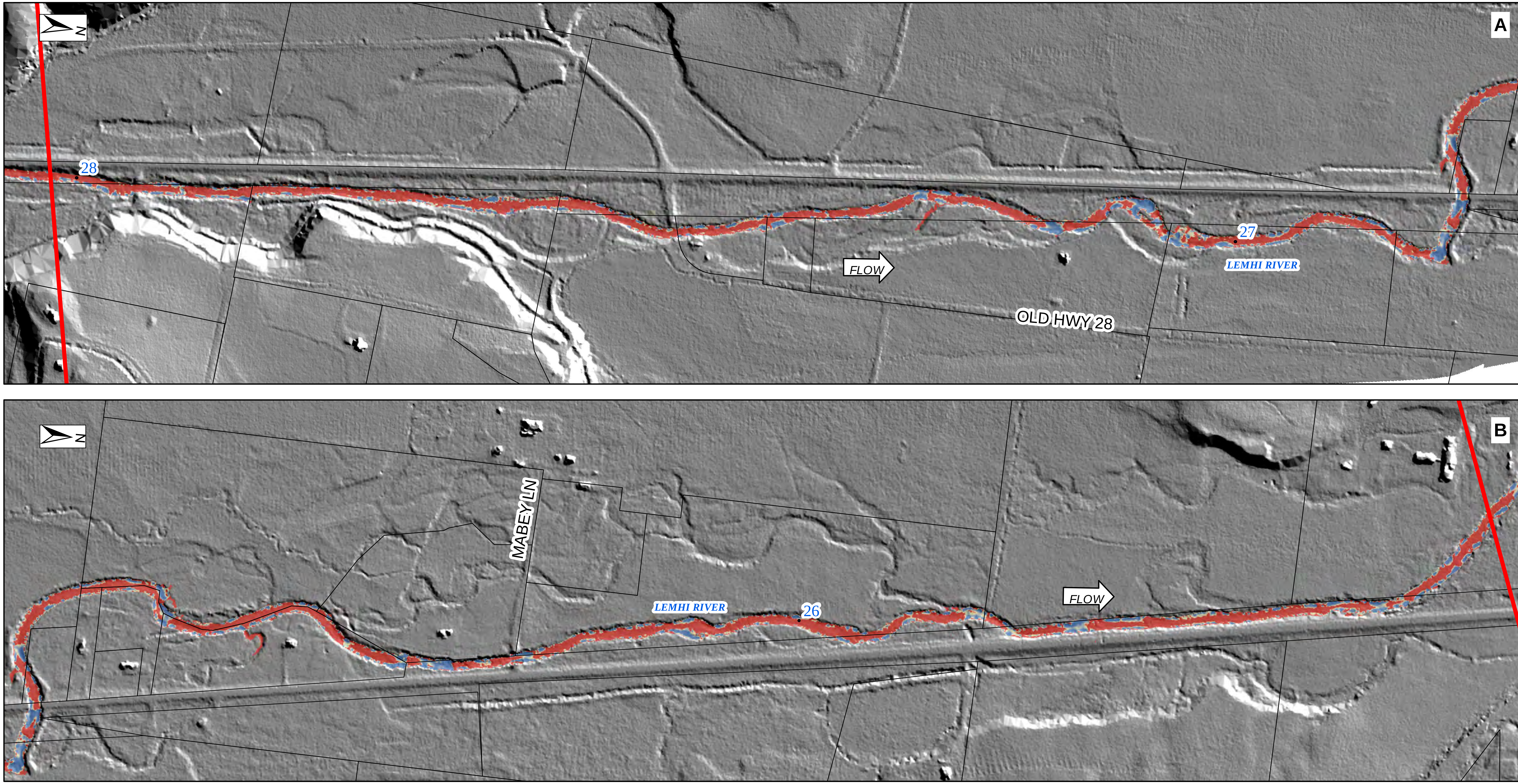
Low : 0

Notes:
-Hydraulic model extent may not depict the total inundated area for this discharge.
-Scenario 4 corresponds to a discharge of 441 cfs

0 250 500 1,000 Feet

Habitat Suitability Map
Rearing Habitat
for Juvenile Chinook Salmon
at Scenario 4 (juvenile rearing flow)
Upper Lemhi Georeach 11

Data Sources: Hillshade (2008 LiDAR), HSI composite suitability index (University of Idaho hydraulic modeling)



River Mile

Lemhi County Parcels

Reach Boundary

Composite Suitability Index

High : 1

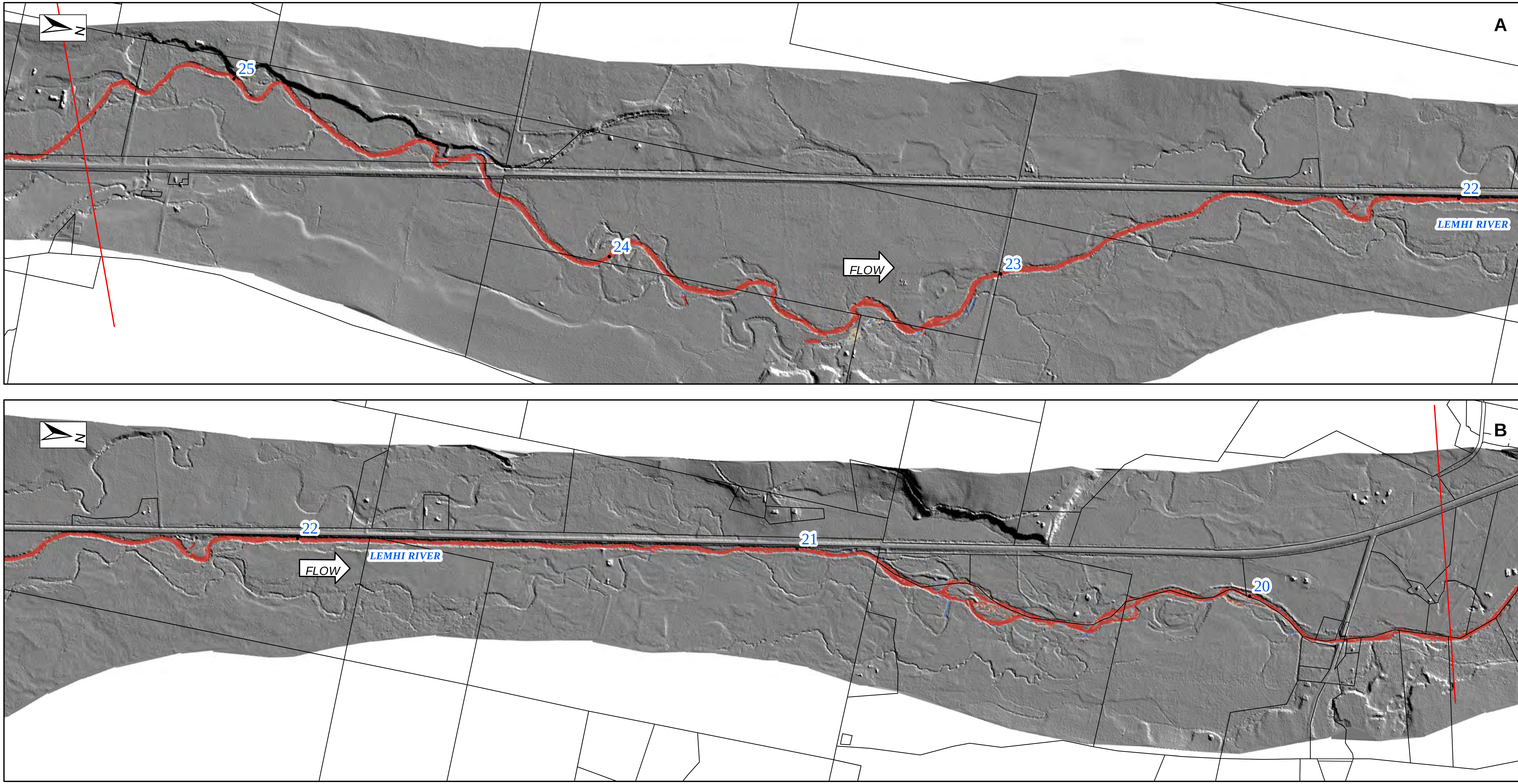
Low : 0

Notes:
-Hydraulic model extent may not depict the total inundated area for this discharge.
-Scenario 4 corresponds to a total discharge of 300 cfs at the downstream end of GR-8.

0 250 500 1,000 Feet

Habitat Suitability Map
Spawning Habitat
for Chinook Salmon
at Scenario 4 (juvenile rearing flow)
Upper Lemhi Georeach 11

Data Sources: Hillshade (2008 LiDAR), HSI composite suitability index (University of Idaho hydraulic modeling)



River Mile

Lemhi County Parcels

Reach Boundary

Composite Suitability Index

High : 1

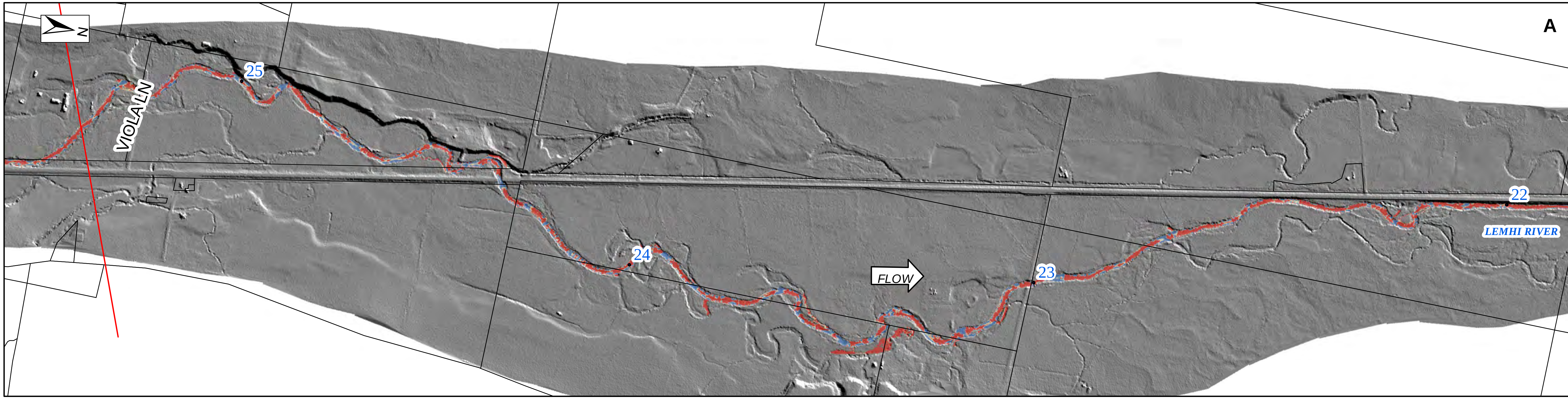
Low : 0

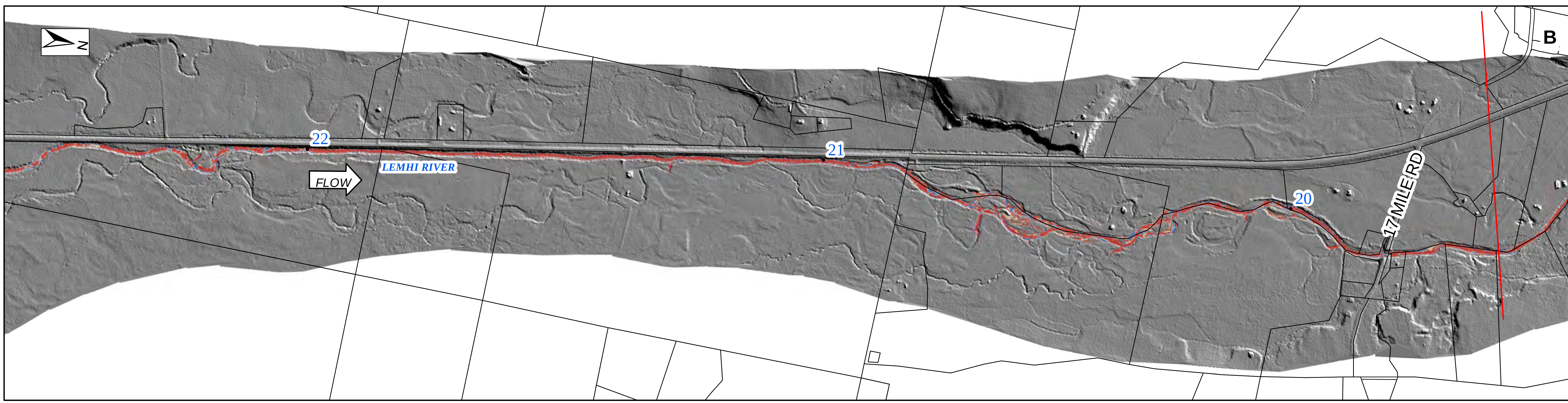
Notes:
-Hydraulic model extent may not depict the total inundated area for this discharge.
-Scenario 4 corresponds to a discharge of 441 cfs

0 250 500 1,000 Feet

Habitat Suitability Map
Rearing Habitat
for Juvenile Chinook Salmon
at Scenario 4 (juvenile rearing flow)
Upper Lemhi Georeach 12

Data Sources: Hillshade (2008 LiDAR), HSI composite suitability index (University of Idaho hydraulic modeling)





River Mile

Lemhi County Parcels

Reach Boundary

Composite Suitability Index

High : 1

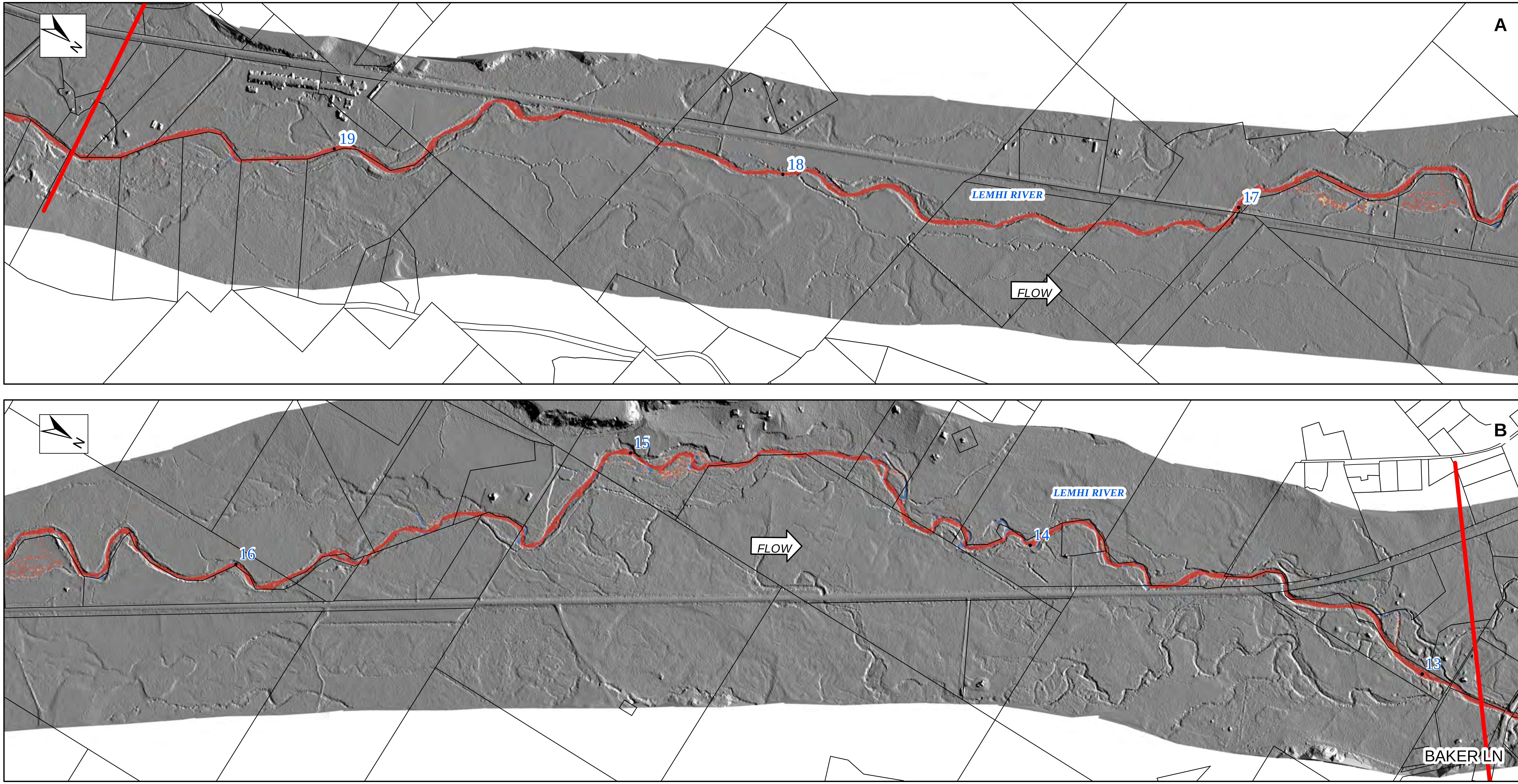
Low : 0

Notes:
-Hydraulic model extent may not depict the total inundated area for this discharge.
-Scenario 4 corresponds to a discharge of 441 cfs

0 250 500 1,000 Feet

Habitat Suitability Map
Spawning Habitat
for Chinook Salmon
at Scenario 4 (juvenile rearing flow)
Upper Lemhi Georeach 12

Data Sources: Hillshade (2008 LiDAR), HSI composite suitability index (University of Idaho hydraulic modeling)



River Mile

Lemhi County Parcels

Reach Boundary

Composite Suitability Index

High : 1

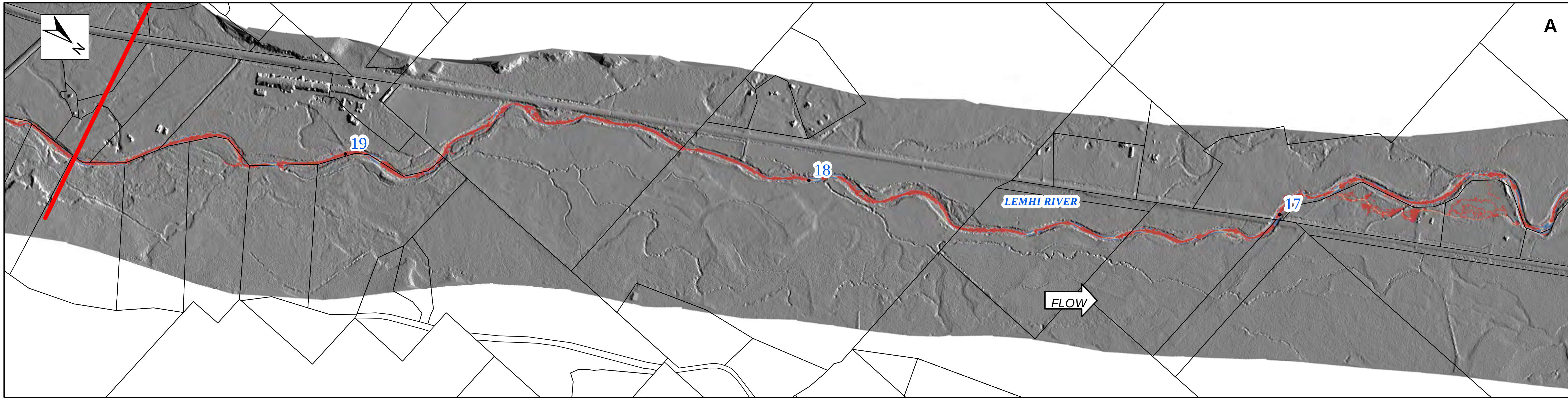
Low : 0

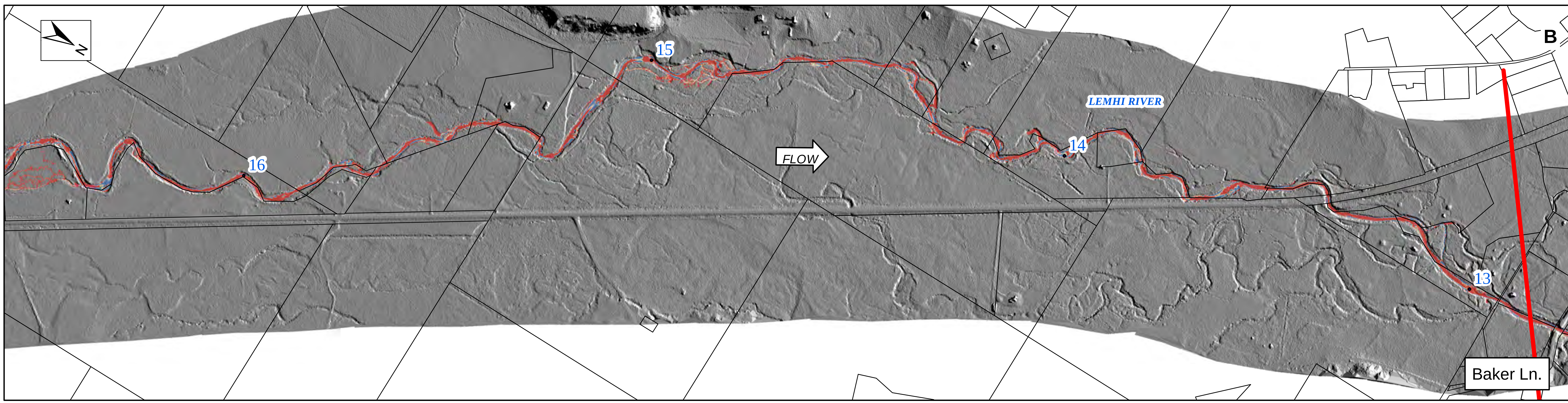
Notes:
-Hydraulic model extent may not depict the total inundated area for this discharge.
-Scenario 4 corresponds to a discharge of 441 cfs

0 250 500 1,000 Feet

Habitat Suitability Map
Rearing Habitat
for Juvenile Chinook Salmon
at Scenario 4 (juvenile rearing flow)
Upper Lemhi Georeach 13

Data Sources: Hillshade (2008 LiDAR), HSI composite suitability index (University of Idaho hydraulic modeling)





River Mile

Lemhi County Parcels

Reach Boundary

Composite Suitability Index

High : 1

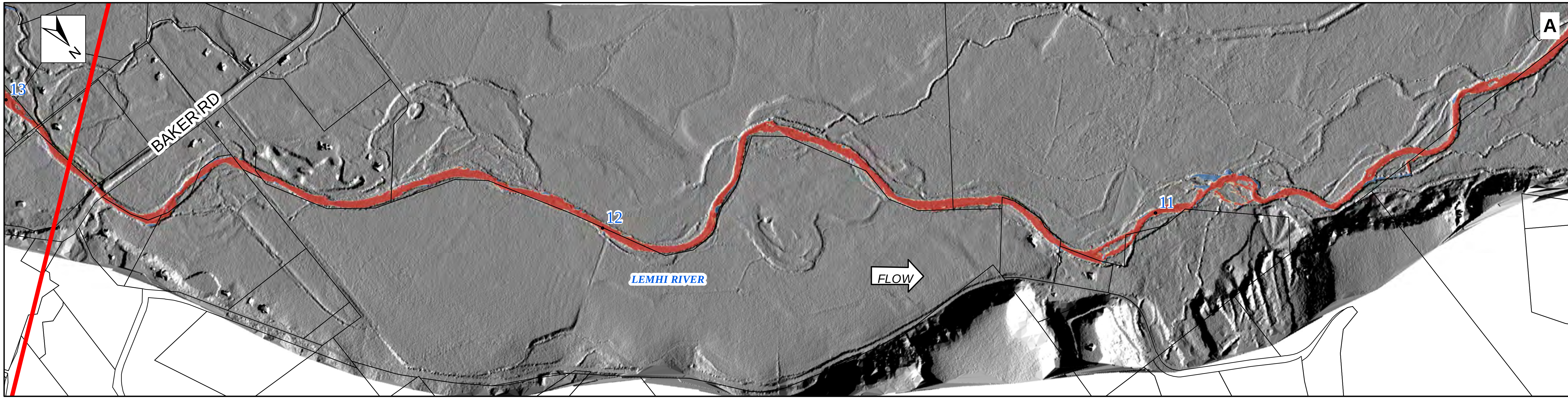
Low : 0

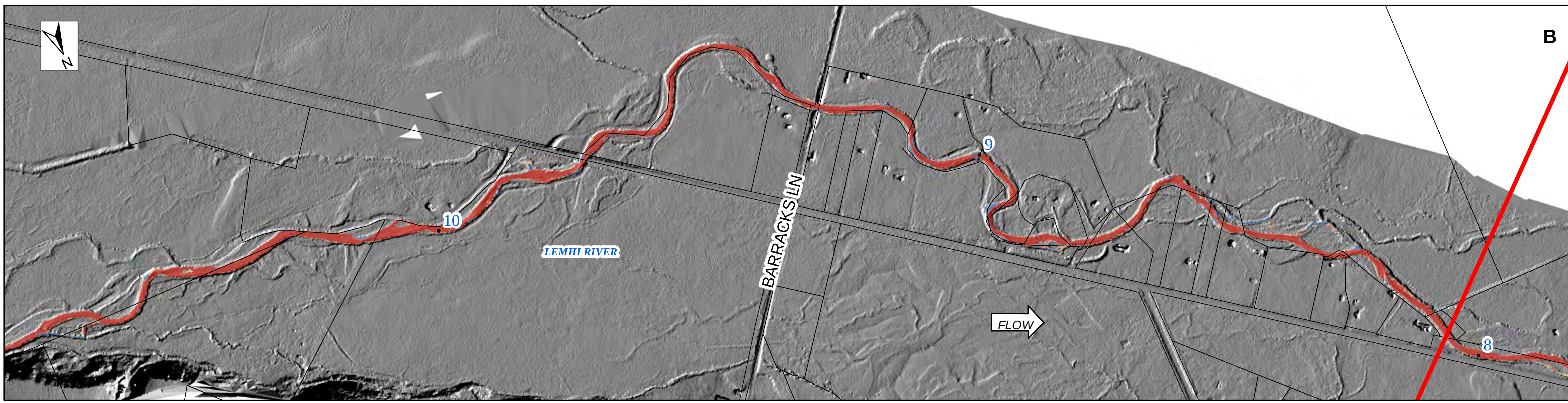
Notes:
-Hydraulic model extent may not depict the total inundated area for this discharge.
-Scenario 4 corresponds to a discharge of 441 cfs

0 250 500 1,000 Feet

Habitat Suitability Map
Spawning Habitat
for Chinook Salmon
at Scenario 4 (juvenile rearing flow)
Upper Lemhi Georeach 13

Data Sources: Hillshade (2008 LiDAR), HSI composite suitability index (University of Idaho hydraulic modeling)





River Mile
Lemhi County Parcels
Reach Boundary

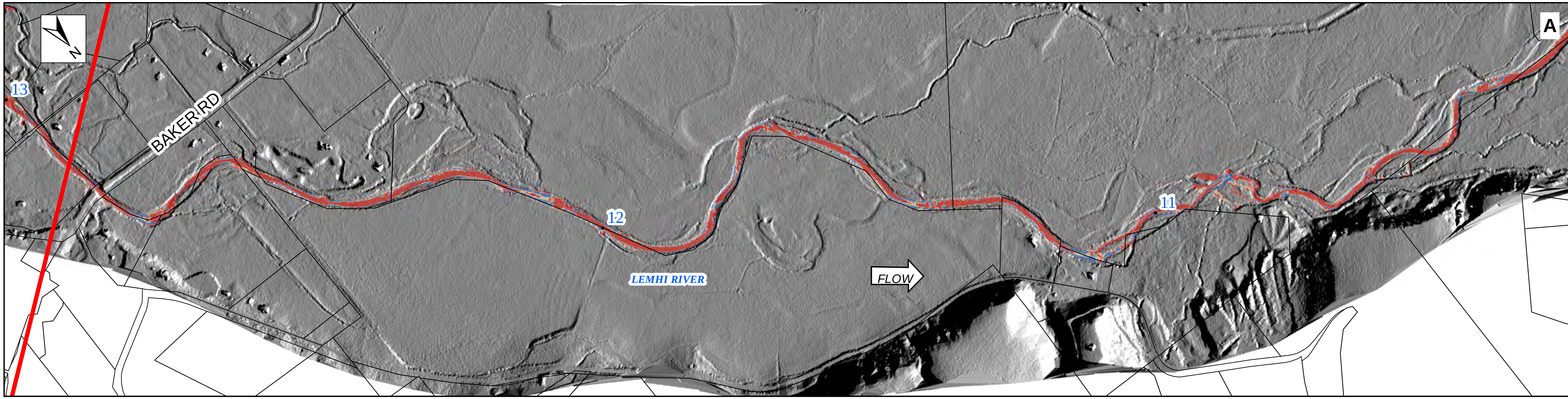
Composite Suitability Index
High : 1
Low : 0

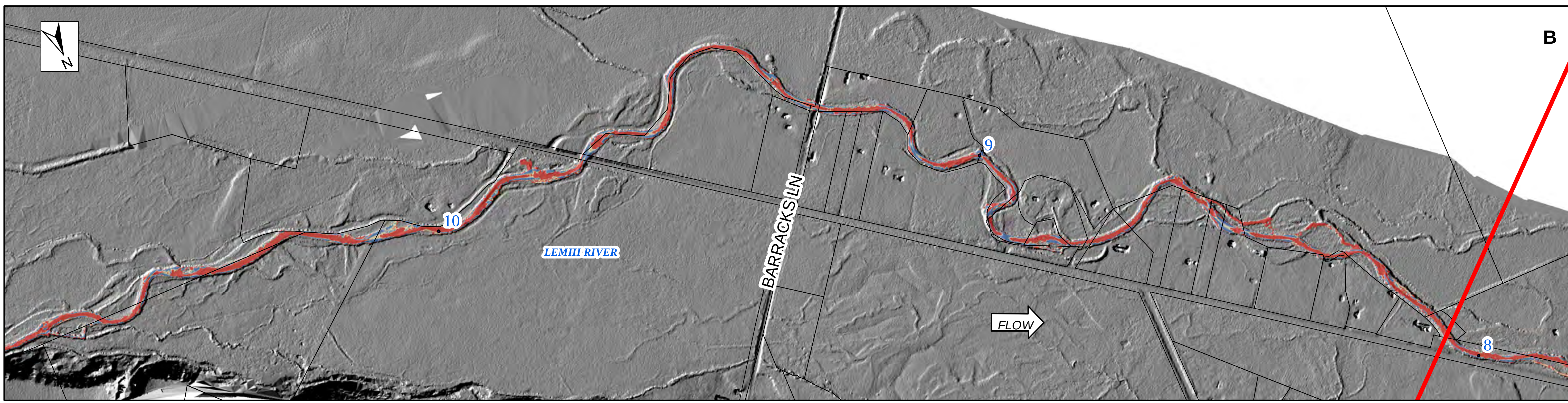
Notes:
-Hydraulic model extent may not depict the total inundated area for this discharge.
-Scenario 4 corresponds to a discharge of 441 cfs

0 250 500 1,000 Feet

Habitat Suitability Map
Rearing Habitat
for Juvenile Chinook Salmon
at Scenario 4 (juvenile rearing flow)
Upper Lemhi Georeach 14

Data Sources: Hillshade (2008 LiDAR), HSI composite suitability index (University of Idaho hydraulic modeling)





River Mile

Lemhi County Parcels

Reach Boundary

Composite Suitability Index

High : 1

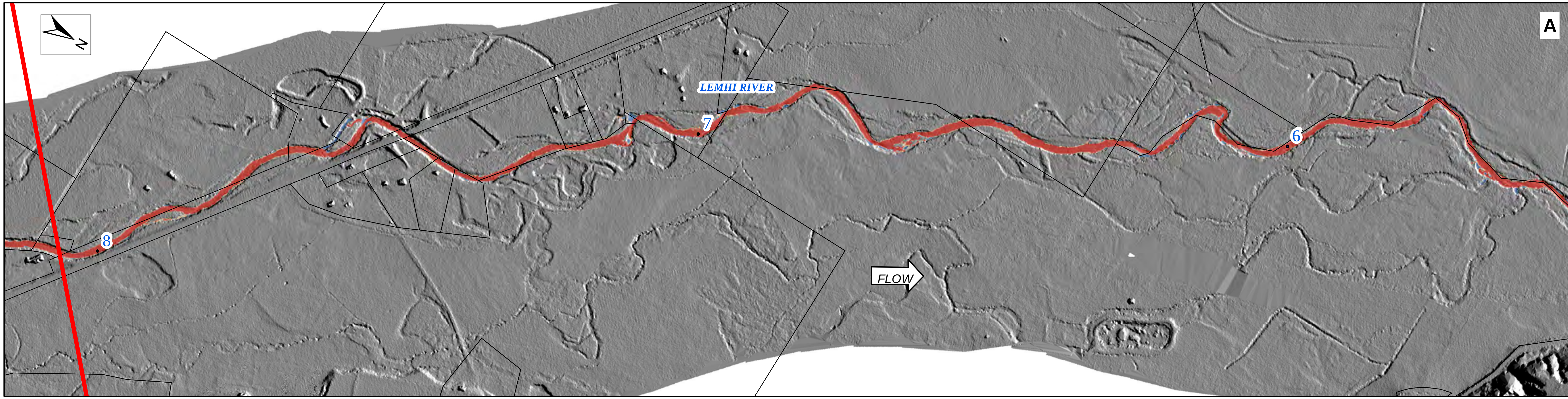
Low : 0

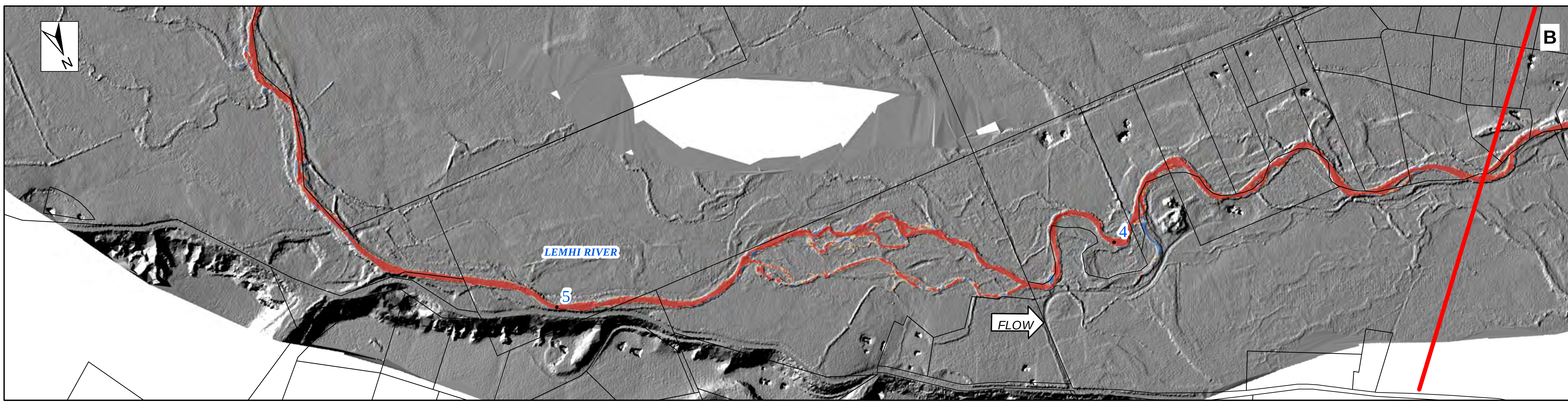
Notes:
-Hydraulic model extent may not depict the total inundated area for this discharge.
-Scenario 4 corresponds to a discharge of 441 cfs

0 250 500 1,000 Feet

Habitat Suitability Map
Spawning Habitat
for Chinook Salmon
at Scenario 4 (juvenile rearing flow)
Upper Lemhi Georeach 14

Data Sources: Hillshade (2008 LiDAR), HSI composite suitability index (University of Idaho hydraulic modeling)





River Mile

Lemhi County Parcels

Reach Boundary

Composite Suitability Index

High : 1

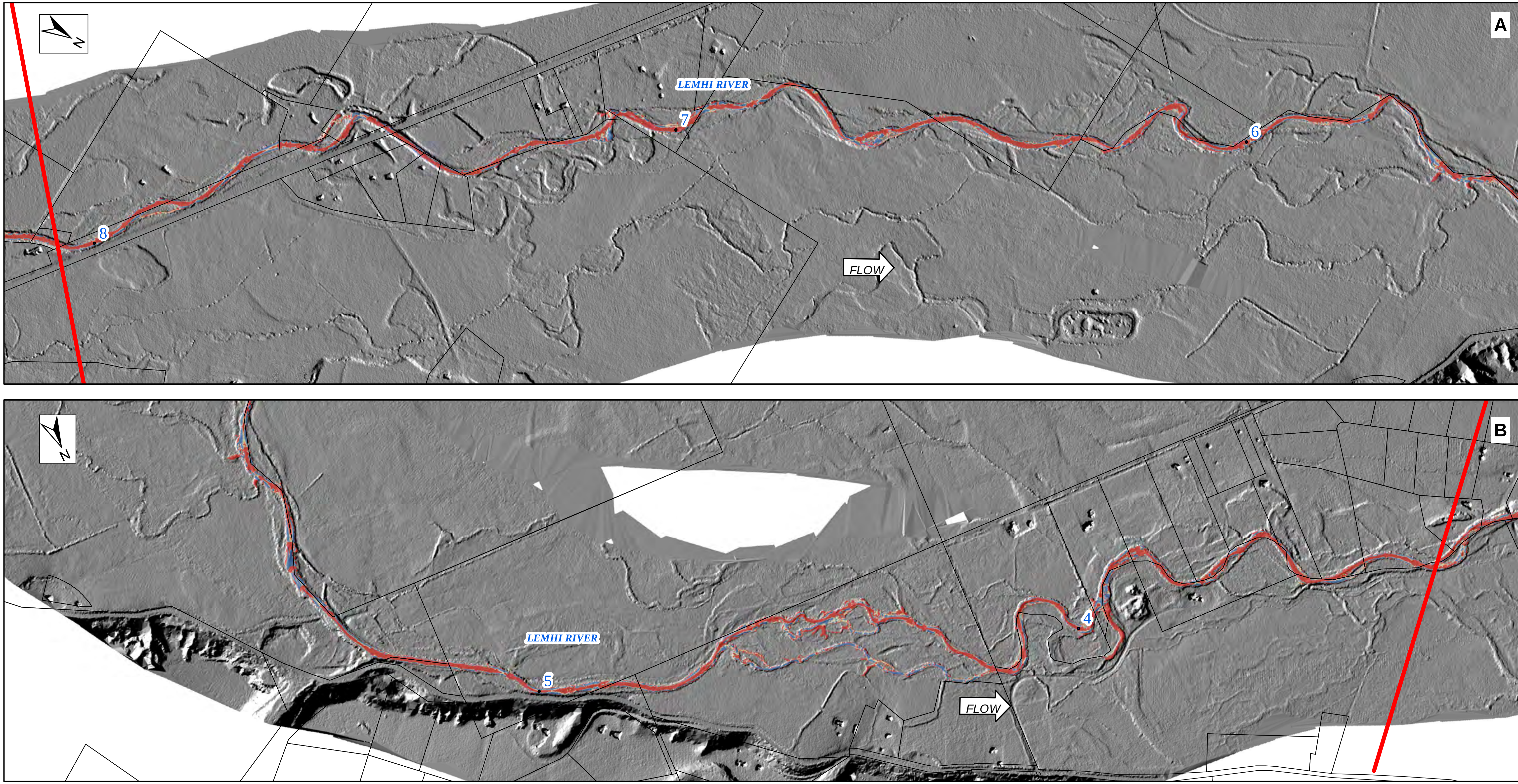
Low : 0

Notes:
-Hydraulic model extent may not depict the total inundated area for this discharge.
-Scenario 4 corresponds to a discharge of 441 cfs

0 250 500 1,000 Feet

Habitat Suitability Map
Rearing Habitat
for Juvenile Chinook Salmon
at Scenario 4 (juvenile rearing flow)
Upper Lemhi Georeach 15

Data Sources: Hillshade (2008 LiDAR), HSI composite suitability index (University of Idaho hydraulic modeling)



River Mile

Lemhi County Parcels

Reach Boundary

Composite Suitability Index

High : 1

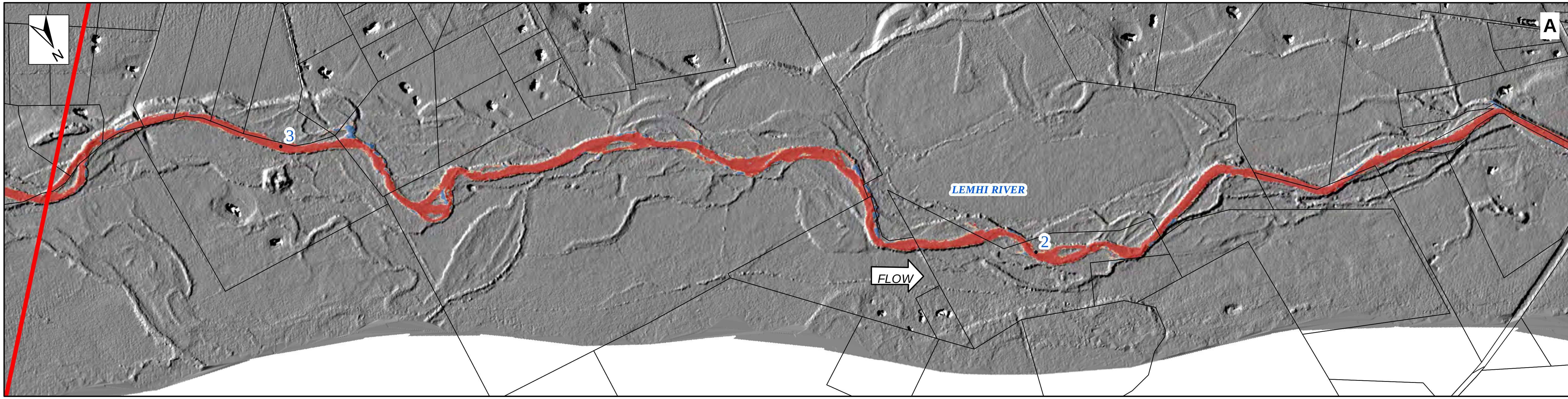
Low : 0

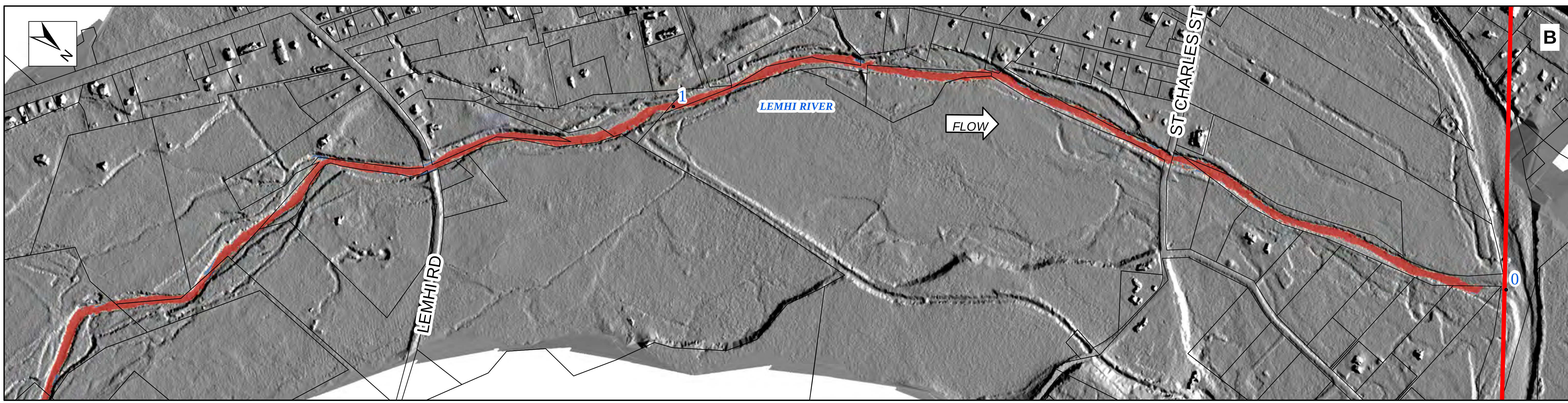
Notes:
-Hydraulic model extent may not depict the total inundated area for this discharge.
-Scenario 4 corresponds to a discharge of 441 cfs

0 250 500 1,000 Feet

Habitat Suitability Map
Spawning Habitat
for Chinook Salmon
at Scenario 4 (juvenile rearing flow)
Upper Lemhi Georeach 15

Data Sources: Hillshade (2008 LiDAR), HSI composite suitability index (University of Idaho hydraulic modeling)





River Mile

Lemhi County Parcels

Reach Boundary

Composite Suitability Index

High : 1

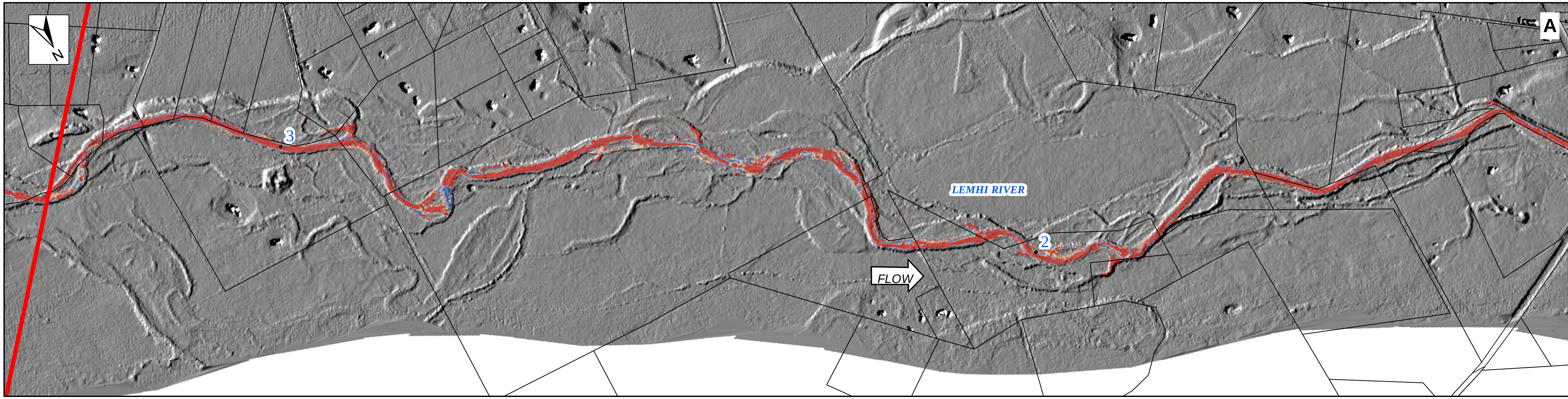
Low : 0

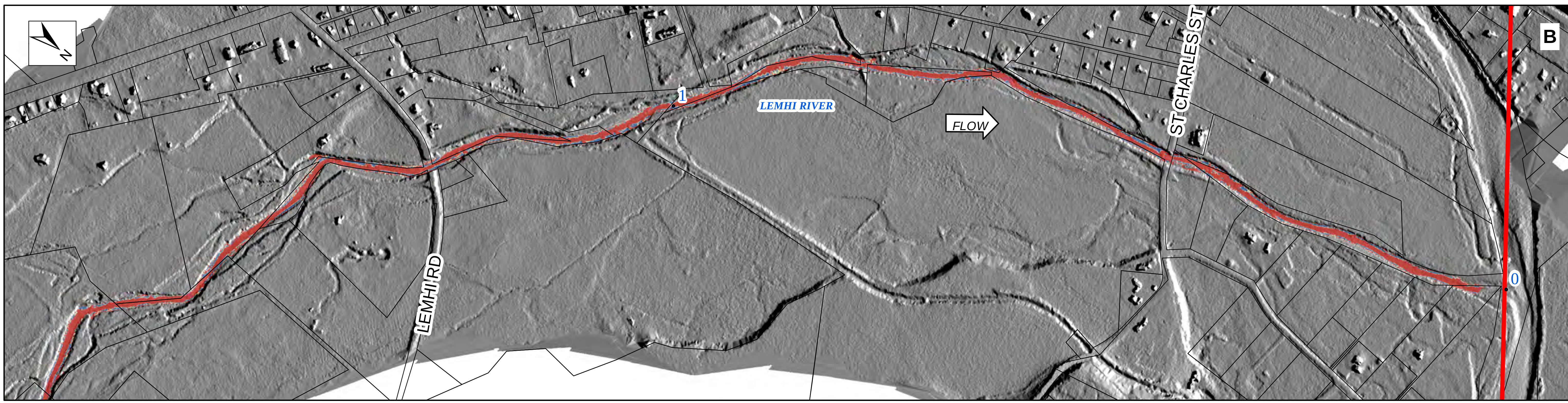
Notes:
-Hydraulic model extent may not depict the total inundated area for this discharge.
-Scenario 4 corresponds to a discharge of 441 cfs

0 250 500 1,000 Feet

Habitat Suitability Map
Rearing Habitat
for Juvenile Chinook Salmon
at Scenario 4 (juvenile rearing flow)
Upper Lemhi Georeach 16

Data Sources: Hillshade (2008 LiDAR), HSI composite suitability index (University of Idaho hydraulic modeling)





River Mile

Lemhi County Parcels

Reach Boundary

Composite Suitability Index

High : 1

Low : 0

Notes:
-Hydraulic model extent may not depict the total inundated area for this discharge.
-Scenario 4 corresponds to a discharge of 441 cfs

0 250 500 1,000 Feet

Habitat Suitability Map
Spawning Habitat
for Chinook Salmon
at Scenario 4 (juvenile rearing flow)
Upper Lemhi Georeach 16

Data Sources: Hillshade (2008 LiDAR), HSI composite suitability index (University of Idaho hydraulic modeling)

Appendix B. Secondary Channels and Characteristics

Technical Memorandum

3380 Americana Terrace, Ste 390, Boise, ID 83706

Prepared by: Rio ASE
Date: January 8, 2021
Subject: Multi-Thread Channel Types

Introduction

Stream reaches comprised of multiple channels with high habitat and geomorphic complexity represent some of the most important ecological areas for salmon and steelhead. These reach types are a primary focus of many salmon and steelhead restoration strategies in the Pacific Northwest, including those in the Upper Salmon River Basin. Multi-threaded streams can develop in a range of physical settings, while exhibiting common characteristics and processes within unique types of secondary channels. While the science and engineering practice of stream restoration in general has advanced significantly in the last several decades, there remains a lack of practical guidelines that can be used for the design and construction of multi-thread channels.

Multi-thread channels encompass a wide range of channel morphology and physical processes. The channels described in this document are focused on the multi-thread channels observed in the Upper Salmon River Basin, including those that have been identified as providing the most important habitats for salmon and steelhead recovery. These channel types can be categorized based on process-based interactions of the sediment transport regime, bar formation, channel and floodplain development, and vegetation dynamics (Kleinhans, 2010; Kleinhans and van den Berg, 2010; van Dijk et al., 2014; van Denderen et al., 2019), including:

- Laterally inactive multi-thread channels separated by well-vegetated islands, ridges, and terraces
- Laterally active meandering rivers with secondary channels associated with bar formation and meander bend dynamics

Secondary channels separate a portion of the surface water flow from the primary channel over a range of discharges. There are many names used to describe various types of secondary channels. We consider side channels to be a sub-type of secondary channel. Side channels have one inlet from the primary channel and one outlet to the primary channel without any flow divergence to or convergence from other secondary channels. Side channels are perennial and generally convey less than 20% of the total stream flow. Channels that convey more than 20% of the total stream flow are considered a split-flow channel. Multiple secondary channel inlets that converge into a single channel are considered as comprising a secondary channel network. For clarification and to ensure a common understanding, the secondary channel nomenclature used in this report is summarized in Table 1. In addition to nomenclature, there are multiple secondary channel types common throughout the Upper Salmon river basin that form under a variety of conditions and provide different habitat characteristics. Using empirical observations from the Upper Salmon River Basin, five secondary channel types have been identified as the focus of this document (Table 2).

Table 1. Secondary Channel Nomenclature

Nomenclature	Description
Secondary Channel	Any channel that separates a portion of the surface water flow from the primary channel over a range of discharge; perennial or non-perennial
Side Channel	Sub-type of secondary channel that has one inlet from the primary channel and one outlet to the primary channel without any flow divergence to or convergence from other secondary channels; perennial; convey less than roughly 20% of the total stream flow
Split-Flow Channel	Secondary channel that conveys more than roughly 20% of the total stream flow
Secondary Channel Network	Multiple side channels and/or secondary channel inlets that converge into a single channel

Secondary Channel Types

Multi-thread channel systems in the Upper Salmon River Basin are observed to occur along a continuum from low energy to high energy. Within this continuum, some secondary channel types can co-occur with each other. For example, beaver dam distributed channels often occur within small channels that exist in all of the other secondary channel types. While all the secondary channel types occur along a continuum, there are some distinguishing attributes that facilitate identifying different types of channels and determining which secondary channel types are most appropriate for different restoration settings. These attributes include:

- **Lateral Adjustment**: channel types are identified as laterally inactive or active depending on indications of the rate of change in lateral channel adjustment (bank erosion and migration) and vertical channel adjustment (degradation, aggradation, bar formation). While some secondary channels may be very extensive laterally (occurring across much of a floodplain) they may naturally lack sufficient stream power for significant morphodynamic adjustments over annual timescales (i.e., channel migration).
- **Hydrologic Regime**: this attribute indicates the primary hydrologic regime within the reach of interest that results in the formation of the secondary channel type. In all of these multi-thread channel systems, secondary channels are often supplied by groundwater in addition to surface water. Observations from the Upper Salmon watershed suggest streams dominated by a snowmelt surface water hydrologic regime are commonly more dynamic than those with a primarily groundwater hydrologic regime.
- **Sediment Transport Regime**: this attribute indicates the relative bedload transport magnitude in the primary channel and the sediment supply to the secondary channels (van Denderen 2019). The development of secondary channels results from an imbalance of sediment supply and transport capacity in both the primary channel and secondary channels. The bedload transport magnitude, channel morphology, and hydraulic characteristics near

secondary channel inlets will control the type of sediment supplied to the secondary channels: bedload consisting of gravel and sand, suspended bed material load consisting primarily of sand, or wash load consisting of silt and clay.

Table 2. Secondary Channel Types and Characteristics

Lateral Adjustment	**Hydrologic Regime**	**Sediment Transport Regime**		**Secondary Channel Type**	**Characteristics**
		Primary Channel Transport	**Secondary Channel Supply**		
Laterally Inactive	Peak-flow and/or Base-flow	Low to moderate fine and coarse material bedload transport	Suspended bed material and wash load	**Beaver Dam Distributed**	• Flow distributed laterally by beaver dam(s) • Multi-thread backwater channels of variable width • More than one outlet channel at various elevations • Dense riparian vegetation and abundant instream woody material
	Base-flow	Low to moderate coarse material bedload transport	Suspended bed material and wash load	**Valley-fill Sub-parallel**	• Multiple individual stable channels that persist over time in the same location • Channels separated by vegetated floodplain, upland terraces, or stable islands • Dense riparian vegetation and abundant instream woody material

Table 2. Secondary Channel Types and Characteristics

Lateral Adjustment	Hydrologic Regime	Sediment Transport Regime		Secondary Channel Type	Characteristics
		Primary Channel Transport	Secondary Channel Supply		
Laterally Active	Peak-flow	Moderate coarse material bedload transport	Primarily suspended bed material and wash load; moderate coarse bedload	**Valley-fill Distributed**	• Associated with bedload deposition and channel aggradation • Multiple small-scale avulsion channels along outside of meander bend carving new channels • Dense riparian vegetation limits side channel expansion • Beaver dam development following side channel formation

Table 2. Secondary Channel Types and Characteristics

Lateral Adjustment	Hydrologic Regime	Sediment Transport Regime		Secondary Channel Type	Characteristics
		Primary Channel Transport	Secondary Channel Supply		
Laterally Active (cont.)	Peak-flow (cont.)	Moderate to high coarse material bedload transport	Bedload, suspended bed material, and wash load	**Meander-Relict**	• Associated with point-bars and lateral channel migration • Small-scale avulsion into relict channel scar along outside of meander bend • Former main channel becomes secondary channel • Multiple side channels develop adjacent to the avulsion path, often from beaver occupation • Dense riparian vegetation and/or large wood material limits capture of entire primary channel • Avulsion channel (secondary channel) expansion to size of relic main channel • Dense riparian vegetation develops throughout multi-thread channels stabilizing isolated hard points throughout the floodplain

Table 2. Secondary Channel Types and Characteristics

Lateral Adjustment	Hydrologic Regime	Sediment Transport Regime		Secondary Channel Type	Characteristics
		Primary Channel Transport	Secondary Channel Supply		
Laterally Active (cont.)	Peak-flow (cont.)	High coarse material bedload transport	Bedload, suspended bed material, and wash load	**Bar-Island Split**	• Located in unconfined and partially-confined valleys • Associated with aggradation of bedload and multiple bar formation • Development of mature riparian forests in between active channels • Recruitment of large wood material to the stream channel • Mature riparian vegetation and large wood material stabilize islands and bars creating multiple channels

Table 2 can be used as a decision tree tool to facilitate identification of existing side channel types and the development of new side channels as part of a proposed restoration project. Using geomorphic target conditions and expected morphodynamic project outcomes developed for a particular restoration project area, the design team can use Table 2 to identify the most geomorphically appropriate side channel type(s) for the project. Care should be taken in using this tool for secondary channel restoration, as interpretation of predicted conditions may not be a straightforward exercise and unanticipated outcomes may result. Technical experts including fluvial geomorphologists and/or engineers with specialized training in open channel hydraulics should be consulted during this process.

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Kleinhans, M. G., and J. H. van den Berg. 2010. River channel and bar patterns explained and predicted by an empirical and a physics-based method. Earth Surface Processes and Landforms, DOI: 10.1002/esp.2090.

van Dijk, W. M., F. Schuurman, W. I. van de Lageweg, and M. G. Kleinhans. 2014. Bifurcation instability and chute cutoff development in meandering gravel-bed rivers. Geomorphology 213: 277-291.

van Denderen, R. P., R. M. J. Schielen, M. W. Straatsma, M. G. Kleinhans, and S. J. M. H. Hulscher. 2019. A characterization of side channel development. River Research and Applications 35: 1597-1603.

Secondary Channel Type: Beaver Dam Distributed

Key Attributes:

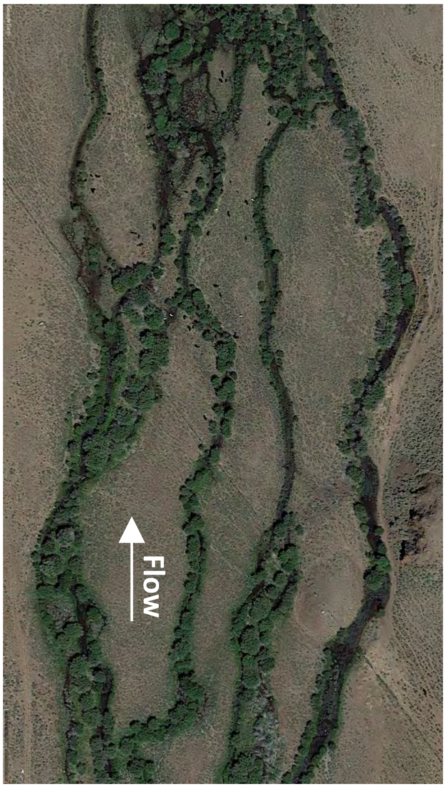
Lateral Adjustment	Hydrologic Regime	Sediment Transport Regime	
		Primary Channel Transport	Secondary Channel Supply
Laterally Inactive	Peak-flow and Base-flow	Fine and coarse material bedload transport	Suspended bed material and wash load

Formation and Processes:

Beaver dams generally occur in partially-confined and unconfined valley settings. Beaver dam distributed channels are formed by the backwater effects from beaver dams. Increased water surface elevations upstream of the dams result in water flowing into preferential flow paths over and around the dams, resulting in a complex network of secondary channels. The distributed channels are typically laterally inactive, owing to the very low available stream power and dense riparian vegetation. Woody riparian vegetation such as willow species provide a primary control for the initial points of flow divergence into multiple channels, as well as a primary control on bank strength along the channel margins that results in vertical bank structure.

Beaver dams are observed in a diversity of locations, from the primary channel of small streams to secondary channels of large rivers. As such, beaver dam distributed channels are often observed to co-occur with other secondary channel types where the physical and vegetation characteristics are conducive to their formation. The primary channel bedload transport can be comprised of fine (e.g., sand) through coarse (e.g., gravel-cobble) material, while the sediment supplied to the distributed channels is typically suspended bed material (e.g., sand) and wash load (e.g., silt-clay) that eventually deposits in the channel over the antecedent channel boundary material.

Secondary Channel Type: Valley-fill Sub-parallel



Key Attributes:

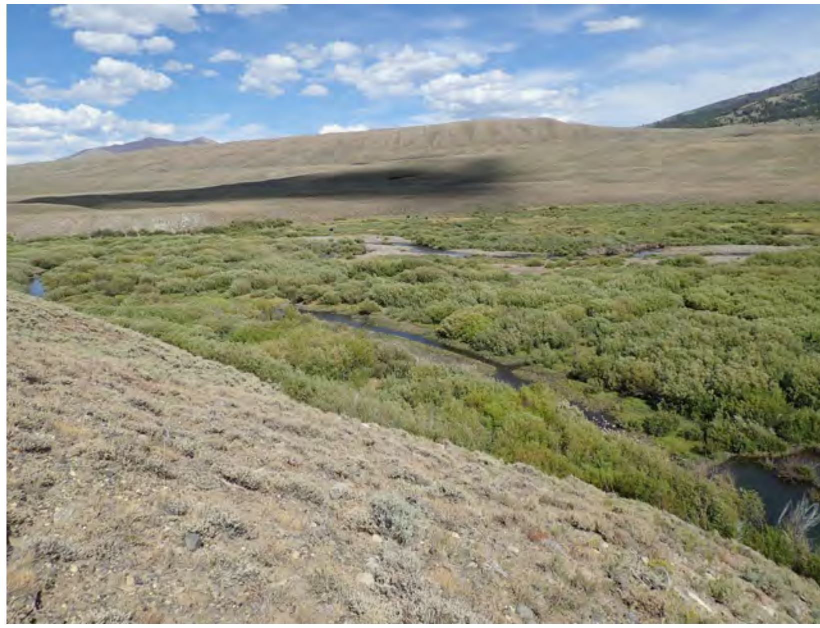
Lateral Adjustment	Hydrologic Regime	Sediment Transport Regime	
		Primary Channel Transport	Secondary Channel Supply
Laterally Inactive	Base-flow	Low to moderate coarse material bedload transport	Suspended bed material and wash load

Formation and Processes:

Valley-fill sub-parallel channels generally occur in low-gradient partially-confined valley settings that have filled with sediment over long periods of time in response to valley-scale geologic controls such as lithology, debris flow dams, and alluvial fan deposition. These channel types typically occur in watersheds with predominantly a base-flow hydrologic regime. The distributed channels are typically laterally inactive, owing to the very low available stream power and dense riparian vegetation. These processes and characteristics result in multiple individual stable channels that persist over time in the same location, with minimal connectivity to the adjacent floodplain and among the sub-parallel channels. The individual channels can be separated by higher elevation upland terraces or by relatively low-elevation floodplains that are rarely inundated because of the base-flow dominant hydrologic regime. If and where the channels become laterally confined, individual channels will converge with a corresponding increase in stream power and accompanying vertical and lateral adjustment.

Beaver dams are observed to co-occur with these channels, resulting in the formation of additional secondary channels among the established sub-parallel channels. Bedload transport in the primary channel is generally low to moderate owing to the limited transport competency of existing coarse lag deposits. The sediment supplied to the sub-parallel channels is typically limited to a coarse bed-material deposit near the inlet, with suspended bed material (e.g., sand) and wash load (e.g., silt-clay) that eventually deposits in the channel over the antecedent channel boundary material.

Secondary Channel Type: Valley-fill Distributed



Key Attributes:

Lateral Adjustment	Hydrologic Regime	Sediment Transport Regime	
		Primary Channel Transport	Secondary Channel Supply
Laterally Active	Peak-flow	Moderate coarse material bedload transport	Primarily suspended bed material, and wash load; moderate bedload

Formation and Processes:

Valley-fill distributed channels generally occur in low to moderate gradient unconfined valley settings that have filled with sediment over long periods of time in response to valley-scale geologic controls such as lithology and glacial deposits. These channel types typically occur in watersheds with predominantly a peak-flow hydrologic regime. Moderate bedload transport of coarse material in the primary channel results in deposition and bar formation, initiating vertical and lateral channel adjustments. Low elevation floodplains are regularly inundated, with some flow concentrated into low elevation preferential flow paths by abundant woody riparian vegetation, resulting in secondary channel formation. Depending on the subsequent timing and magnitude of peak flow events, the size of these channels can range from much smaller than the primary channel to more significant small-scale avulsion channels similar in size to the primary channel. Beaver dams are observed to co-occur within these secondary channels, resulting in the formation of additional secondary channels among the established valley-fill distributed channels. The secondary channels often diverge and converge into a complex network of relatively small channels as a function of flow resistance from woody riparian vegetation, woody debris, and the location of low elevation preferential flow paths. Significant secondary channel convergence can lead to localized increased stream power and knickpoint migration upstream to a primary channel connection.

Because of elevation differences between the lower primary channel and higher floodplain and initial secondary channel inlets, the sediment supplied to the valley-fill distributed channels is typically limited to suspended bed material (e.g., sand) and wash load (e.g., silt-clay) that eventually deposits in the channel over the antecedent channel boundary material. As the secondary channels increase in available stream power, coarse bedload transport into and within the secondary channels can be significant. As primary and secondary channels evolve over time, elevation differences among the channels can become very complex, with secondary channels much lower in elevation that the primary channel.

Secondary Channel Type: Meander-Relict

Key Attributes:

Lateral Adjustment	Hydrologic Regime	Sediment Transport Regime	
		Primary Channel Transport	Secondary Channel Supply
Laterally Active	Peak-flow	Moderate to high coarse material bedload transport	Bedload, suspended bed material, and wash load

Formation and Processes:

Meander-relict channels generally occur in moderate gradient partially-confined to unconfined valley settings. These channel types typically occur in watersheds with predominantly a peak-flow hydrologic regime. Moderate to high bedload transport of coarse material in the primary channel results in deposition and bar formation, resulting in bank erosion and channel migration as a primary morphodynamic response. Owing to the sediment transport dynamics and hydraulic characteristics, small-scale avulsions initiate along the outside of meander bends resulting in secondary channel formation. Bedload deposition and bar formation often initiate additional secondary channel inlets along the primary channel. Depending on the subsequent timing and magnitude of peak flow events, the size of these channels can range from much smaller than the primary channel to more significant avulsion channels similar in size to the primary channel. Beaver dams are observed to co-occur within the secondary channels, resulting in the formation of additional secondary channels among the established meander-relict channels. The secondary channels often diverge and converge into a complex network of relatively small channels as a function of flow resistance from woody riparian vegetation and the location of low elevation preferential flow paths. Significant secondary channel convergence can lead to localized increased stream power and knickpoint migration upstream to a primary channel connection. Bar-island split channels are also observed to co-occur in meander-relict channel systems.

Because of elevation differences between the lower primary channel and higher floodplain and initial secondary channel inlets, the sediment supplied to the meander-relict channels includes coarse bed material, suspended bed material (e.g., sand) and wash load (e.g., silt-clay) that eventually deposits in the channel over the antecedent channel boundary material. As the secondary channels increase in available stream power, coarse bedload transport into and within the secondary channels can be significant. Eventually, full primary channel avulsion can occur wherein a former secondary channel becomes the primary channel and vice versa.

Secondary Channel Type: Bar-Island Split

Key Attributes:

Lateral Adjustment	Hydrologic Regime	Sediment Transport Regime	
		Primary Channel Transport	**Secondary Channel Supply**
Laterally Active	Peak-flow	High coarse material bedload transport	Bedload, suspended bed material, and wash load

Formation and Processes:

Bar-island split channels generally occur in moderate gradient partially-confined to unconfined valley settings. These channel types typically occur in watersheds with predominantly a peak-flow hydrologic regime. High bedload transport of coarse material in the primary channel results in deposition and extensive multiple bar formations. The morphodynamic response to these processes includes hydraulically-driven chutes and split flows through and around bar deposits, bank erosion and channel migration. Bedload deposition and bar formation often initiate additional secondary channel inlets along the well-vegetated primary channel. Depending on the subsequent timing and magnitude of peak flow events, the size of these channels can range from much smaller than the primary channel to more significant avulsion channels similar in size to the primary channel. As riparian forest succession progresses, mature trees and shrubs provide resistance to flow and become local sources of large wood recruitment to the active channels. As secondary channels evolve and expand the mature riparian forests often become vegetated islands that persist over decadal time scales. Beaver dams are observed to co-occur in the small channels, resulting in the formation of additional secondary channels among the established bar-island split channels.

Because of the primary channel sediment transport regime and the formation processes of bar-island split flows, these channels are comprised primarily of coarse bedload and suspended bed material. Where large elevation differences exist between the lower primary channel and higher floodplain and initial secondary channel inlets along well-vegetated banks, the sediment supplied to these channels is primarily suspended bed material (e.g., sand) and wash load (e.g., silt-clay) that eventually deposits in the channel over the antecedent channel boundary material. As the secondary channels increase in available stream power, coarse bedload transport into and within the secondary channels can be significant. As primary and secondary channels evolve over time, elevation differences among the channels can become very complex, with secondary channels much lower in elevation that the primary channel.

Appendix C. Restoration Treatments and Characteristics

Treatment: Side Channels
Type: Reconnection and Restoration

Lemhi River, Big Springs Confluence Restoration Design: Proposed design hydraulic model velocity output overlying pre-construction aerial photo

Application

- Reconnect existing low-lying topography
- Excavate/create side channels where geomorphically appropriate
- Create diverse off-channel habitat with cover and access to the main channel

Biological Considerations

- Frequent, short/narrow side channels (less than 35% flow split, up to 800 ft long) preferred to less frequent, long/wide side channels
- Habitat units should be proportionally smaller and more frequent compared to the larger main stem
- Winter/summer rearing for Chinook and steelhead

Geomorphic Considerations

- Spring-fed hydrology and/or limited bedload systems tend toward lower width-to-depth, sinuous, side channels with few/no exposed bars maintained by dense riparian vegetation
- Snowmelt hydrology and/or high bedload systems tend toward less sinuous, island-braided systems maintained by instream structure (esp. log jams)

Design Considerations

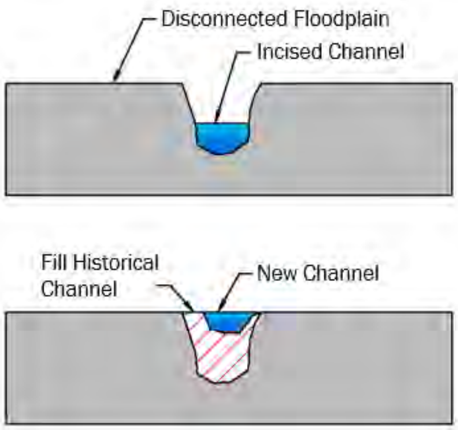
- Channel inlet/outlet located in pools or glides, generally upstream of riffles
- High (close to 90°) angle inlets may limit bedload entering the side channel
- Use natural scour/deposition to form side channels with limited earthwork where geomorphic processes and risk allow

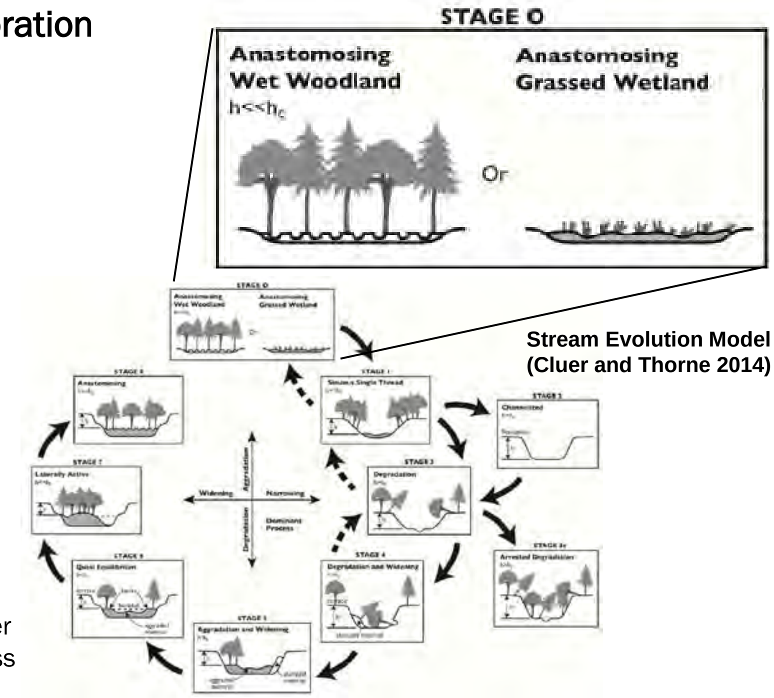
Lemhi River, ID; Over-widened, single-thread channel; average channel width over 100 ft.

Lemhi River, 1.5 years after construction of multi-threaded channel network using various bank treatments and instream structure to split flow into many, short, narrow side channels; average width less than 20 ft.

Lemhi River, during construction; including FESL, brush bank, and LWD with sod mats and potted plants.

Treatment: Floodplain Reconnection – Fill or Raise the Channel
Type: Reconnection and Restoration





Stream Evolution Model (Cluer and Thorne 2014)

Application

- Raise the water surface with channel fill, constructed riffles, increased sinuosity (i.e., lower gradient), narrower channel, increased roughness and/or other means to inundate the floodplain more frequently

Biological Considerations

- Provides high-flow refuge for juvenile salmonids

Geomorphic Considerations

- Dissipates flood energy
- Deposits fine sediment in the floodplain
- Improves hydrologic connectivity for riparian areas and wetlands

Design Considerations

- Promote over-bank flow in densely vegetated areas
- Significant roughness is often required in frequently inundated floodplain areas to prevent avulsion and undesired channel response resulting in low sinuosity and/or channel incision
- Complete channel commonly referred to as “stage-zero restoration” after Cluer and Thorn (2014) stream evolution model

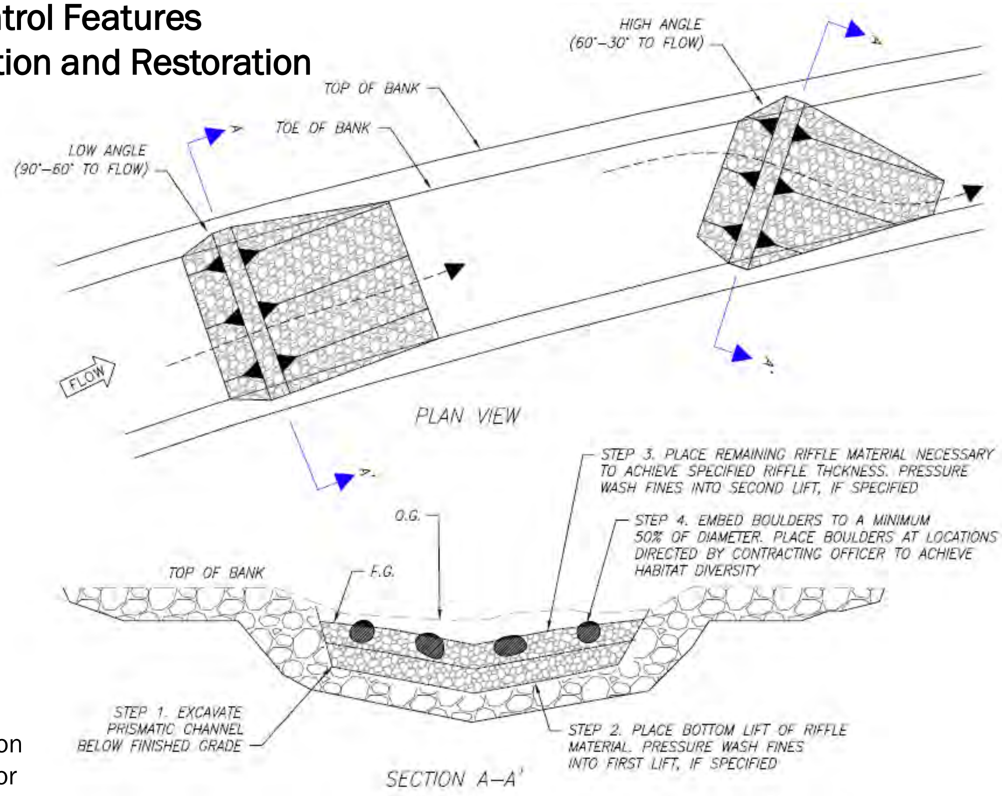
Lost Creek, OR, before channel fill

5-yr Flood Model of Lemhi River and Big Springs Creek Confluence, ID

Narrower channel, increased sinuosity, grade control and hydraulic roughness increased floodplain connection in restored channel

Jackson Creek, OR, immediately after channel fill

Treatment: Grade Control Features
Type: Reconnection and Restoration



Application

- Raise the streambed elevation
- Abate channel incision and/or knickpoint

Biological Considerations

- Adult and juvenile fish often feed in riffles due to macroinvertebrate abundance
- Proximity to cover and pool refuge is an important consideration

Geomorphic Considerations

- Can be used to backwater floodplain and/or side channel areas, activating off-channel habitat
- Flow passes over the riffle crest perpendicular to the crest angle; a high-angle riffle crest can be used to direct flow toward the bank
- Temporary storage of transient bedload

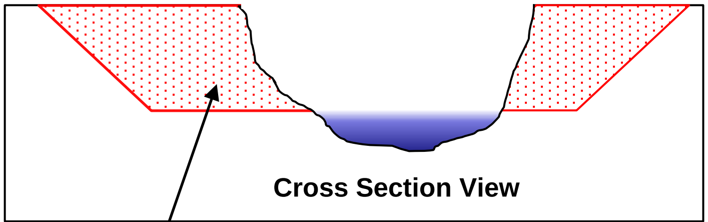
Design Considerations

- Must understand channel migration trends to ensure channel does not migrate off the riffle before the system has stabilized
- Material sizes should be comparable to the native substrate and should be keyed into the bank to prevent short-term flanking
- Constructed riffles are elongated features that can range in slope from 0.1–5%, while drop structures (step pools) are singular features that control vertical grade and can be used to develop pool habitat
- Roughened chutes are a combination of step pools incorporated into longer reinforced riffles and are typically placed in channels with steeper slopes (>5%)
- Selection of material is important to stability
- A concave cross section may be necessary to focus low-flow water sufficiently to provide adequate depth for seasonal fish passage
- Downstream pool formation and upstream backwater conditions often occur

Constructed riffle during construction; LWM bank structure installed on left bank (right side of photo) to reduce over-widened channel width; Lemhi River, ID

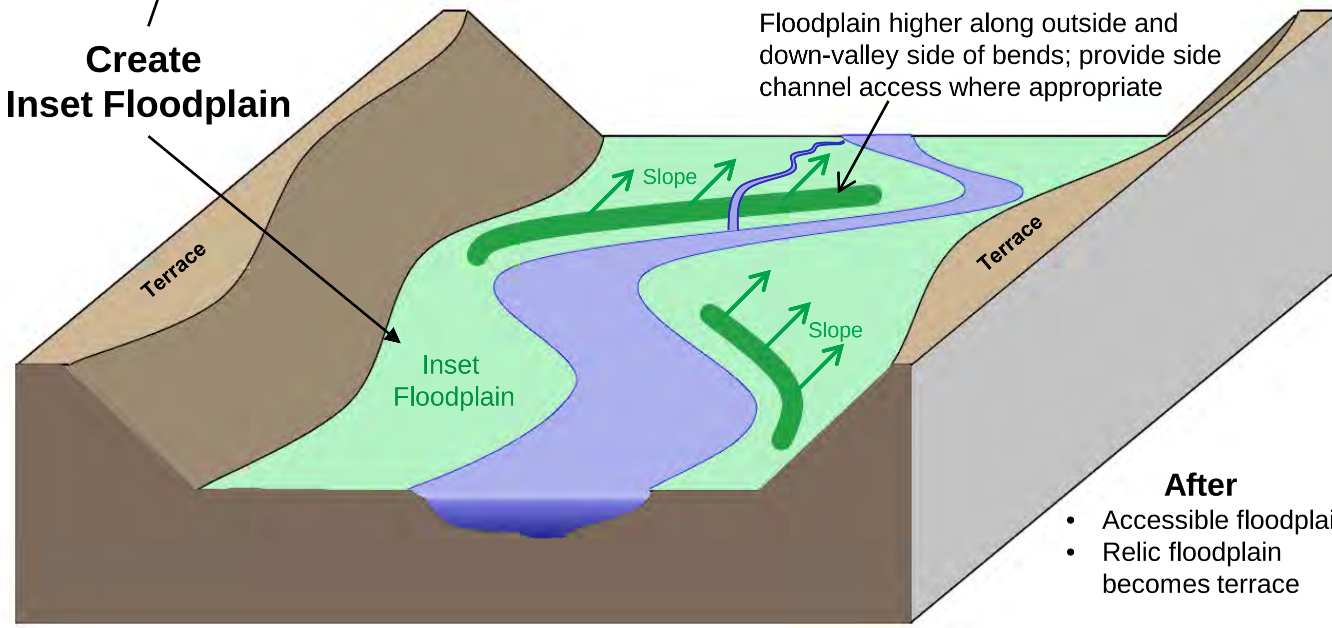
Constructed riffle immediately after construction; Lemhi River, ID

Treatment: Floodplain Reconnection – Create Inset Floodplain
Type: Reconnection and Restoration



Before

- Incised channel
- Poor floodplain connection
- Concentrated flow
- No high-flow refugia



After

- Accessible floodplain
- Relic floodplain becomes terrace

Application

- Selective earthwork to create a new, lower, inset floodplain to enable more frequent inundation

Biological Considerations

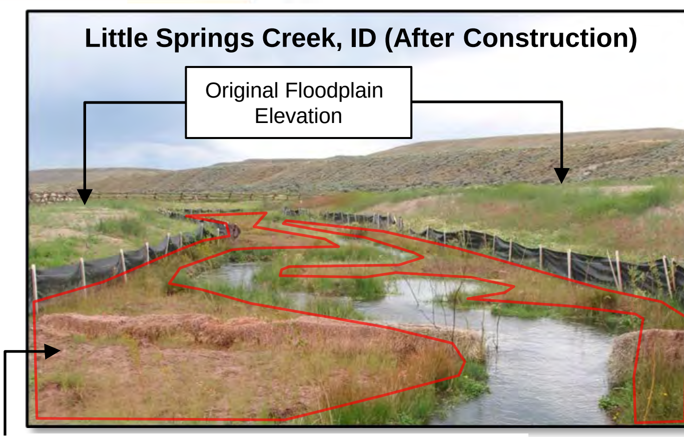
- Provides high-flow refuge for juvenile salmonids
- Creates a floodplain surface near the groundwater table to enable/enhance riparian vegetation

Geomorphic Considerations

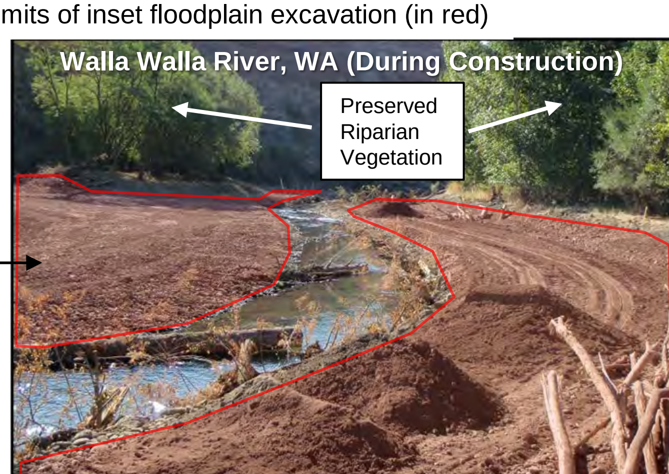
- Dissipates flood energy
- Deposits fine sediment in the floodplain
- Improves hydrologic connectivity for riparian areas
- Reduces flooding elevations by increasing capacity within the inset floodplain
- Does not address the cause of incision
- Results in "Arrested Degradation" stage of channel evolution (Stage 3s – Cluer and Thorne 2014)

Design Considerations

- Consider constructing new banks and floodplain surfaces slightly higher on the outside and down-valley side of bends and islands, sloping slightly down-valley to limit avulsion risk while still providing large areas of flood backwater inundation
- Floodplain width (i.e., meander belt width) should be at least as wide as the maximum calculated meander amplitude
- Can often require disposal site for excavated floodplain material



Limits of inset floodplain excavation (in red)



Treatment: Reduce Channel Width
Type: Restoration

Big Springs Creek, ID; Before construction; Over-widened channel with plane-bed and poor habitat diversity

Big Springs Creek, ID; 1 year after construction; Reduced channel width, increased sinuosity, improved shade, and hydraulic diversity using a variety of bank fill treatments (FESL, brush mat, willow clumps, post-line willow-weave, gravel placement

Application

- Reduce channel width where over-widened to meet geomorphic targets
- Excavate new channel(s) and/or fill portions of the existing channel

Biological Considerations

- Install habitat structures and cover; plant riparian vegetation to maintain habitat diversity and shade

Geomorphic Considerations

- Relocate the channel against existing, mature vegetation where possible to provide immediate structure, cover, and shade

Design Considerations

- Add sinuosity, side channels, and/or floodplain connection to compensate for increased velocity associated with narrower channel width to achieve desired instream conditions across a variety of flows
- Detailed hydraulic modeling required; compare existing vs. proposed hydraulic diversity using histogram outputs of velocity and depth area distributions to confirm increased hydraulic variability and habitat suitability
- Provide variability in width by providing areas of contraction and expansion
- Use a variety of bank treatments; provide topographic variability in floodplain areas

Treatment: Channel Realignment
Type: Restoration


Channel realignment and side channel creation during construction, Catherine Creek, OR

Application

- Create a new, more geomorphically appropriate channel network with improved habitat
- Used to relocate a new channel away from negative response areas and/or toward positive response areas

Biological Considerations

- Redirect channel to areas with improved floodplain connection, mature riparian vegetation, and/or greater habitat potential
- Optimize channel form and structure to meet habitat objectives, including habitat unit frequency and diversity

Geomorphic Considerations

- Create channel through cut and fill earthwork where geomorphic processes will not naturally restore conditions within a reasonable period of time
- Integrate process-based restoration where feasible by identifying dominant processes and enabling a response around them (e.g., where deposition is a likely response, add strategic structure to capture sediment forming new bars, islands, and floodplain areas; where erosion is a likely response, excavate a narrow "pilot channel" with strategic structure enabling the river to cut new channels where directed).

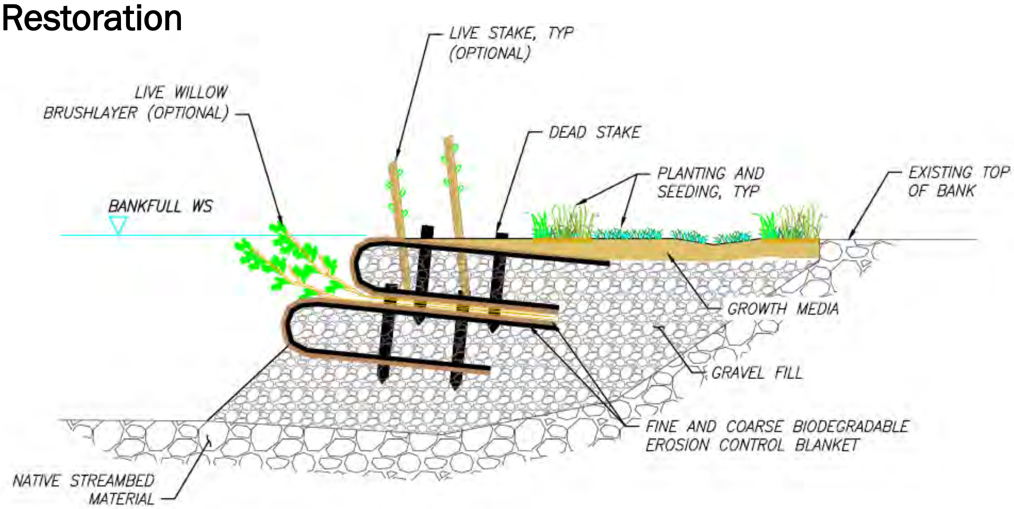
Design Considerations

- Determine target planform, side-channel character, and channel geometry conceptually based on reach geomorphic and biological targets/objectives
- Multiple iterations of design and 2-dimensional hydraulic modeling recommended to evaluate likely response and make appropriate adjustments
- Use bank treatments and instream structure appropriately based on potential stream energy and habitat needs
- Incorporate cross sectional and plan form geometry variability, especially compound radius bends
- May increase floodwater and groundwater elevations


Newly constructed channel with LWM bank structure 1 year after construction; Catherine Creek, OR


New channels with FESL bank treatments and increased floodplain activation 6 months after construction during spring runoff; Lemhi River, ID

Treatment: Bank Fill – Fabric Encapsulated Soil Lift (FESL)
Type: Restoration



Application

- Temporarily stabilize banks (typically outside bends) until riparian vegetation is established
- Used to retain soil to fill over-widened channel

Biological Considerations

- Integrate brush, willow clumps, and/or LWM to increase cover and interstitial spaces for juvenile salmonids
- Integrate live vegetation to improve riparian conditions and enhance root mat development

Geomorphic Considerations

- Can create stable, near vertical banks

Design Considerations

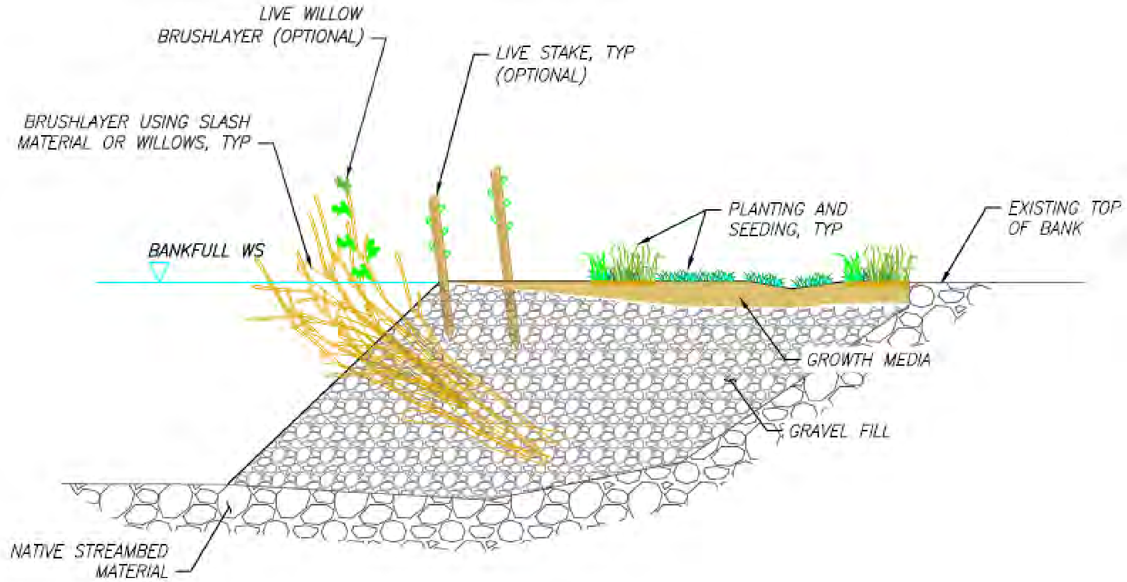
- Select appropriate geotextile fabric to withstand anticipated hydraulic forces
- Useful with otherwise unstable fill material (silt/sand)
- Use narrow sheets of fabric to reduce the overall width of the FESL treatment
- Install top lift several inches below final design elevation to allow space for sod mat if proposed
- Consider planting container plants directly into FESL
- Install with an irregular final surface elevation to provide topographic complexity
- Do not fill fabric with soil or leave gaps where LWM will be placed to provide space for the LWM

Over-widened channel; Big Springs Creek, ID

Big Springs Creek 1 year after construction; Width-to-depth ratio reduced by over 50% using FESL on both banks

Big Springs Creek during construction; Fill placed behind the FESL with potted plants; Sod mat and potted plants within FESL not yet installed

Treatment: Bank Fill – Brush Layer
Type: Restoration



Application

- Temporarily stabilize banks (typically outside bends) until riparian vegetation is established
- Used to dissipate energy in high-energy areas
- Can be used with or without other treatments to retain soil to fill over-widened channels

Biological Considerations

- Provides increased cover and interstitial spaces for juvenile salmonids
- Integrate live vegetation to improve riparian establishment and enhance root mat development

Geomorphic Considerations

- Creates significant bank roughness that can accumulate fine sediment in low-energy areas

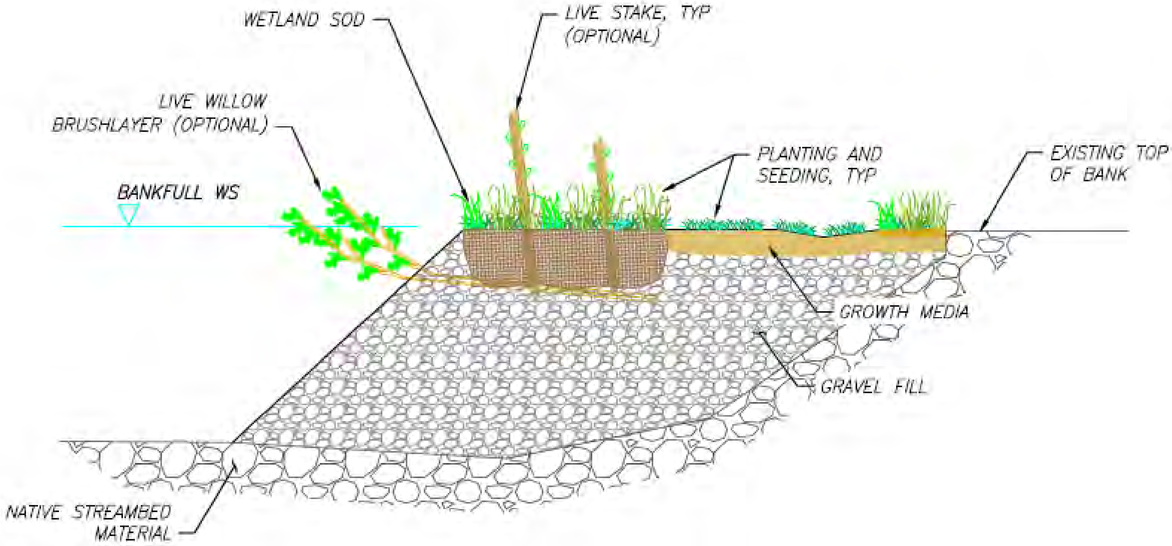
Design Considerations

- Specify min/max protrusion to match roughness conditions from hydraulic model

Willow brush layer during construction (Above) and immediately after construction (Below); Lemhi River, ID

Slash brush layer 1 year after construction; Catherine Creek, OR

Treatment: Bank Fill – Wetland Sod
Type: Restoration



Application

- Used with or without other treatments to retain soil to fill over-widened channels
- Used for short- and long-term bank stabilization

Biological Considerations

- Increases rates of vegetative establishment
- Integrate woody vegetation (potted plants and/or live stakes) to increase riparian diversity, structure, cover, and shade
- Provides high flow cover and refuge for juvenile fish

Geomorphic Considerations

- Creates bank roughness and promotes the formation of a root mat providing long-term bank structure

Design Considerations

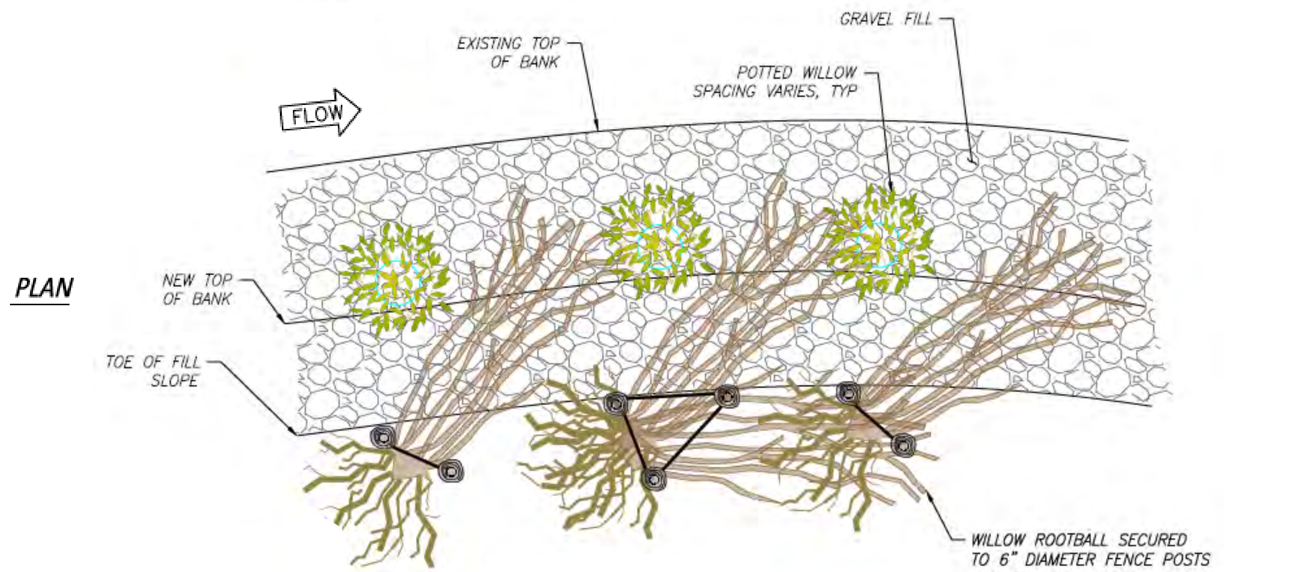
- Can use nursery stock or harvest sod mats on-site
- Specify thickness and ensure final grade elevations are sufficiently low to accommodate the sod mats
- Prioritize directly adjacent the bank, but consider strips of sod with woody plantings in between

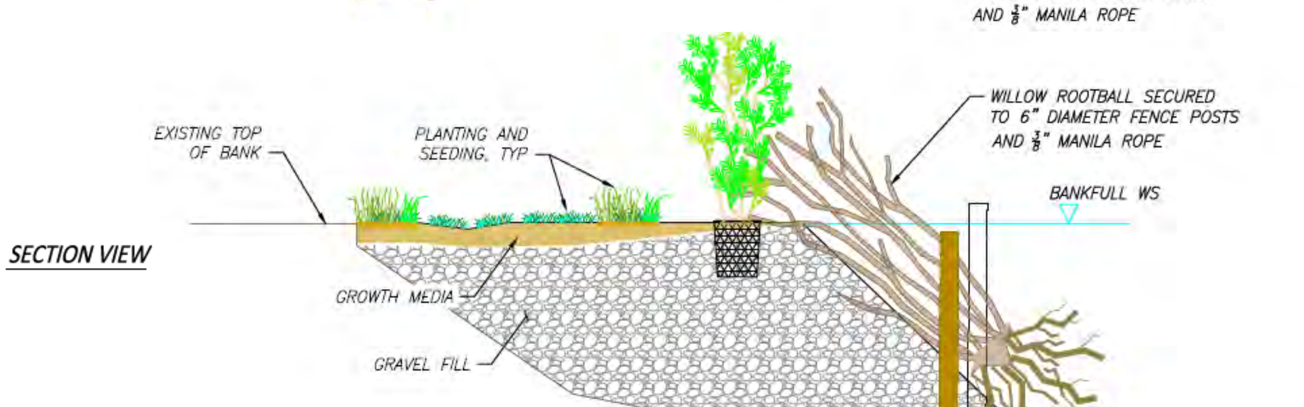
Thick strips of wetland sod harvested on-site used to retain unstable sandy bank fill immediately after construction; Big Springs Creek, ID

Bank fill stabilized with on-site harvested wetland sod immediately after construction; Big Springs Creek, ID

Strips of nursery-grown wetland sod placed over FESL bank treatment with potted willows between strips 1 year after construction; Big Springs Creek, ID

Treatment: Bank Fill – Willow Clumps
Type: Restoration





Application

- Used to reduce effective channel width and create instream structure
- Used with or without other treatments to retain and stabilize soil to fill over-widened channels
- Used for short- and long-term bank stabilization

Biological Considerations

- Provides cover, structure, and interstitial spaces for juvenile salmonids
- Creates instream velocity and habitat complexity across a range of flows

Geomorphic Considerations

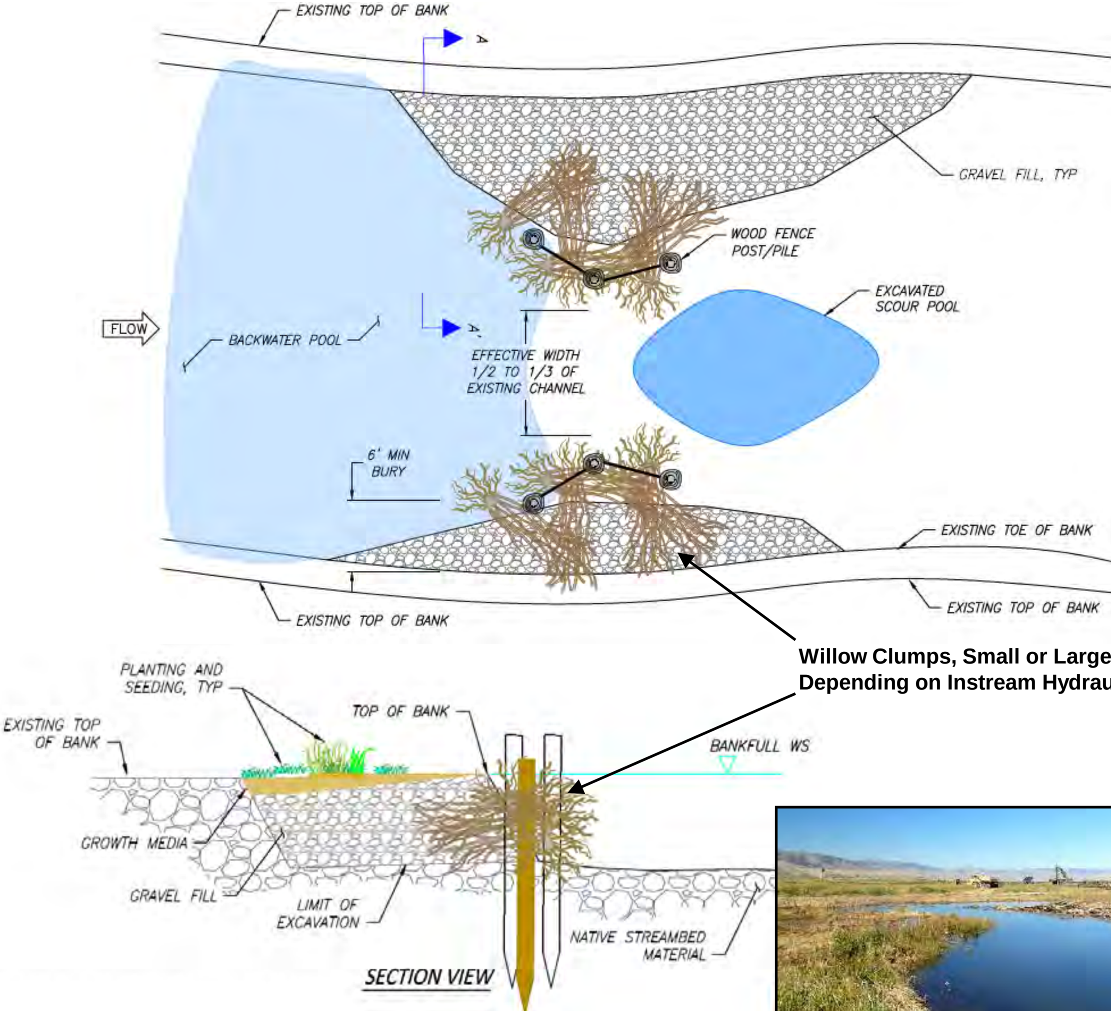
- Creates bank roughness and structure until riparian vegetation can be established
- Can be used to obstruct flow and provide sharp hydraulic gradients sorting bedload and directing flow

Design Considerations

- Place rootwad into channel for greater rigidity (i.e., outside of bend) and consider placing willow branches into channel where hydraulic forces are less severe (i.e., inside of bend)
- Consider use of live willow clumps to increase vegetative establishment

Series of willow clumps placed along the outside of a newly constructed meander bend to provide bank stability, instream structure, and cover immediately after construction; Big Springs Creek, ID

Treatment: Channel Constriction
Type: Reconnection, Restoration



Application

- Create channel constriction to force upstream backwater and/or downstream scour pool
- Reduce effective channel width locally

Biological Considerations

- Increases habitat unit frequency near suitable areas for spawning and rearing salmonids
- Can create backwater and scour pools
- Provides in-channel complexity, velocity and depth variability
- Incorporating LWM or similar structure may increase structural diversity and habitat value

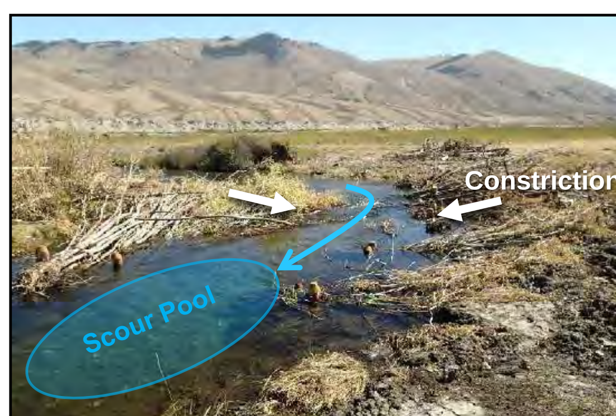
Geomorphic Considerations

- Hydraulic contraction and expansion creates velocity gradients that can sort sediment and create geomorphic complexity
- The greater the contraction the greater the hydraulic effect

Design Considerations

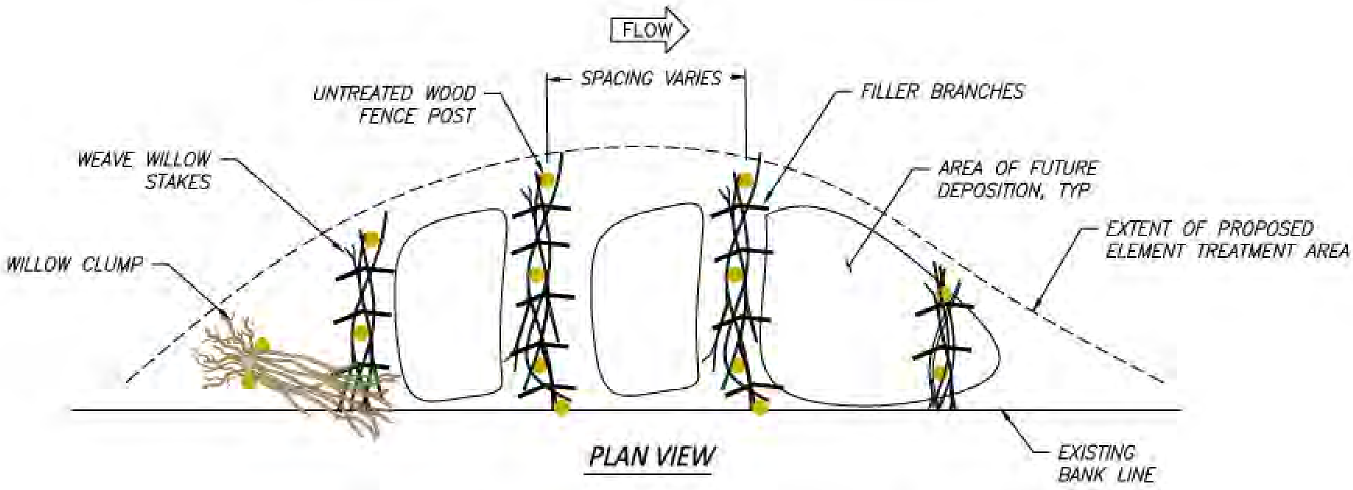
- Allow an appropriate width within the conservation easement (minimum of one channel width from existing banks).

Backwater pool above flow constriction; Big Springs Creek, ID



Flow acceleration and scour pool downstream of flow constriction; Big Springs Creek, ID

Treatment: **Post-Line Willow-Weave**
Type: **Reconnection and Restoration**



Application

- Used to reduce effective channel width and capture sediment forming point bars
- Primarily used to form or enhance the inside of bends
- Can be used with or without other treatments to capture sediment to fill over-widened channel areas

Biological Considerations

- Provides short-term cover and low-velocity refuge for juvenile salmonids
- Creates long-term vegetated point bar increasing habitat diversity, cover, and shade

Geomorphic Considerations

- Narrows effective channel width forming areas of contraction and expansion creating hydraulic diversity
- Captures fine sediment forming point bars increasing sinuosity and reducing overall width-to-depth ratio
- To be used in streams with moderate to high sediment supply

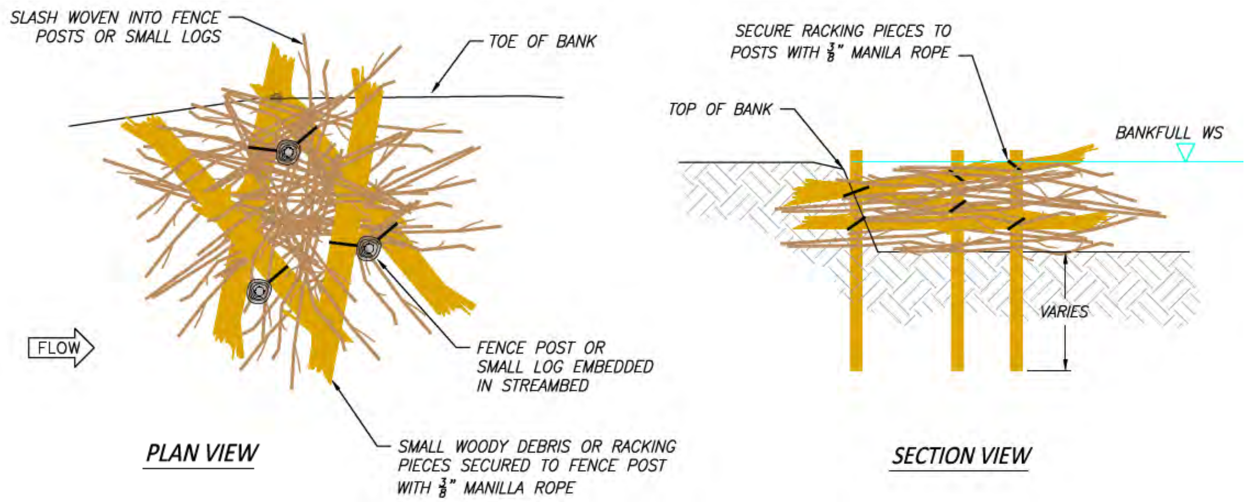
Design Considerations

- Consider adding willow clumps, LWM, or other structure to the upstream and/or outer ends of the willow-weave to dissipate energy
- Using live willows in the weave may increase the rate of point bar vegetation establishment

Over-widened channel before construction; Big Springs Creek, ID

6 months after construction; fine sediment deposition observed between willow weaves; effective channel width reduced by approximately 50%

Treatment: Small Wood Material Structure
Type: Reconnection and Restoration



Application

- Used to create in-channel complexity, velocity, and depth variability
- Can be used to create channel constrictions promoting scour and gravel sorting
- Create cover for improved habitat

Biological Considerations

- Promotes velocity gradients and habitat diversity suitable for juvenile and adult salmonids
- Provides instream cover and interstitial spaces for juvenile salmonids

Geomorphic Considerations

- Increasing frequency and size of structures has a proportional affect on channel roughness
- Encourages sorting of bedload sediment

Design Considerations

- Incorporate LWD for increased stability and habitat diversity
- Consider excavating a scour pool to increase rate of channel response
- Anticipate channel response to determine size and frequency of structures

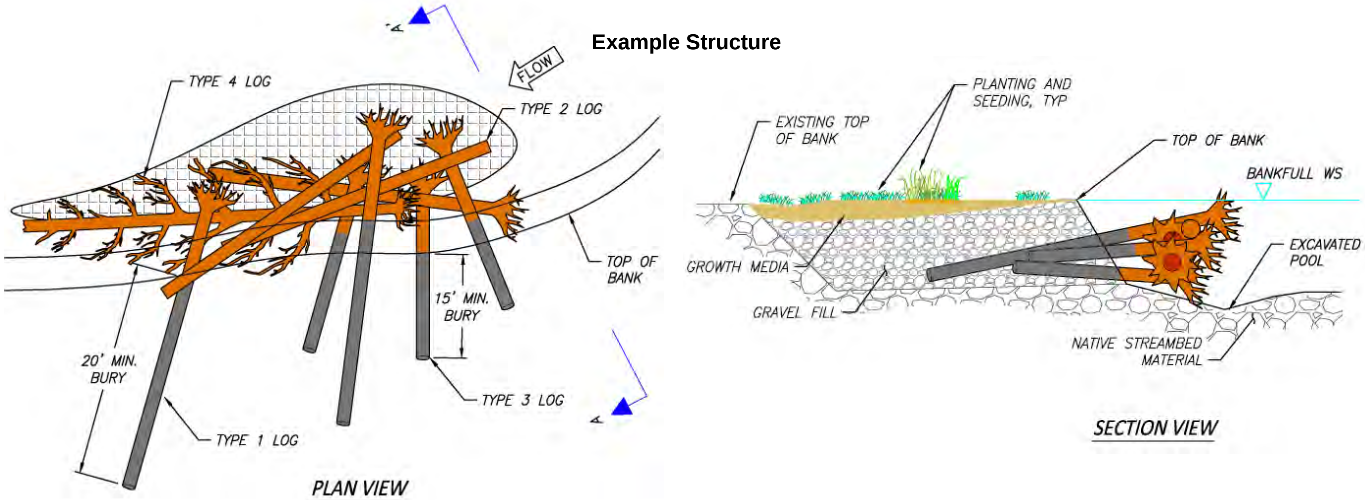
Small wood material structures 1 year after construction; Big Springs Creek, ID

Small and large wood material bank structures immediately after construction; Big Springs Creek, ID

Small wood material bank structures with excavated scour pool immediately after construction; Big Springs Creek, ID

Treatment: Large Wood Material (LWM) Habitat Structure
Type: Reconnection and Restoration

Example Structure



Application

- Used to create in-channel complexity and velocity and depth variability
- Can be used in series for bank stabilization to buffer bank soils from erosive stream forces
- Can be used individually or on opposite banks to create channel constrictions
- Can be used to obstruct and/or block flows

Biological Considerations

- Create habitat diversity including scour pools with instream cover suitable for adult and juvenile salmonids

Geomorphic Considerations

- Can be used to obstruct flow to create backwater areas, sort gravel, and improve floodplain connection

Design Considerations

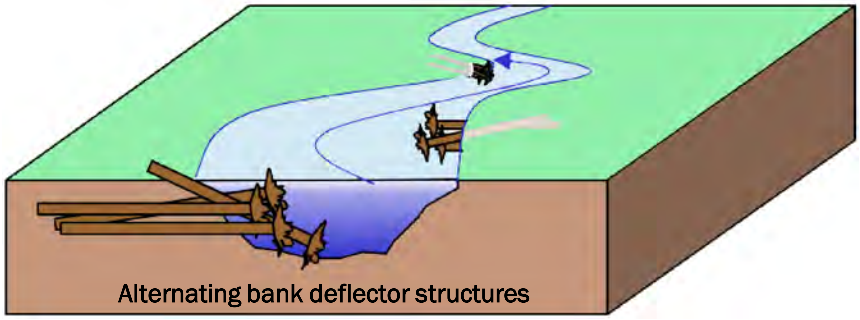
- Hydraulic modeling should be used to calculate the appropriate size and frequency of structure(s) to evaluate likely hydraulic response and change to habitat
- Incorporate small woody material and slash between key LWM members to provide interstitial cover
- Greater protrusion into stream can improve habitat and hydraulic response

LWM habitat structure immediately after restoration; Lemhi River, ID

Series of LWM habitat structures 1 year after construction; Lemhi River, ID

1 year after construction; Nason Creek, WA

Treatment: Bank Deflector Structures (Barbs)
Type: Reconnection and Restoration



Application

- Structures that protrude from either streambank but do not span the channel
- Deflect flows away from the bank, form scour pools by creating channel constriction, and define channel thalweg

Biological Considerations

- Create velocity gradients and habitat complexity along the channel margin

Geomorphic Considerations

- Alternating bank deflector structures can be used to define and/or shape the thalweg

Design Considerations

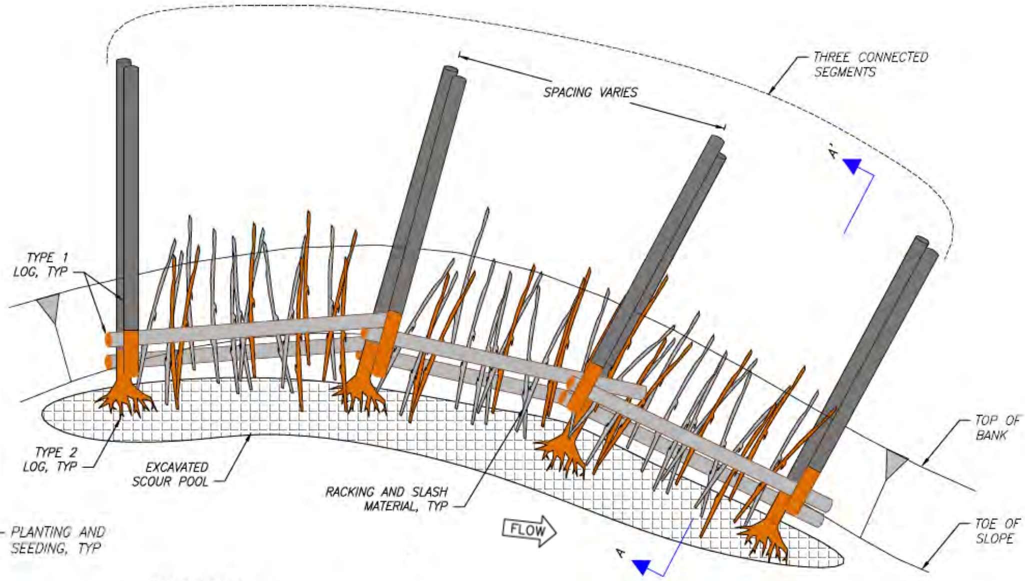
- Bank deflector structures can be constructed of LWM, small wood material, willow clumps, slash, post-line willow-weave, rock, or other suitable structure depending on local hydraulics and site conditions
- Material type, structure size, and spacing should be based on anticipated scour, stream energy, and anticipated hydraulic response
- Can be installed in series to redirect the thalweg away from an existing eroding bank (i.e., bank stabilization)
- Can be installed along alternating streambanks to encourage lateral migration, channel widening, and inset floodplain development and produce a meandering thalweg and associated structural diversity.
- Flow overtopping structures will be directed perpendicular to the axis of the structure; upstream angled structures will direct overtopping flows toward the middle of the stream while downstream angled structures will direct overtopping flows toward the adjacent bank
- Can stabilize one bank and destabilize the opposite bank if structure extends into the channel a significant distance

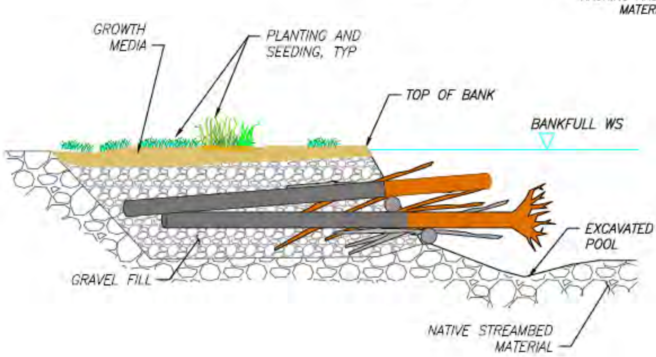
Log bank deflector structure during installation; Lemhi River, ID

Series of low-profile wood and rock bank deflectors used to narrow the effective channel width and define the thalweg; Methow River, WA

Series of post-line willow-weave bank deflectors creating a point bar; Lemhi River, ID

Treatment: **Bank Roughening Structure**
Type: **Reconnection and Restoration**





Bank roughening structure during construction; Lemhi River, ID

Bank roughening structure on newly created side channel 1 year after construction; Lemhi River, ID

Application

- Used to create in-channel habitat complexity with velocity and depth variability
- Can be used for habitat and/or bank stabilization

Biological Considerations

- Creates contraction scour pools and provides cover with many interstitial spaces for rearing salmonids

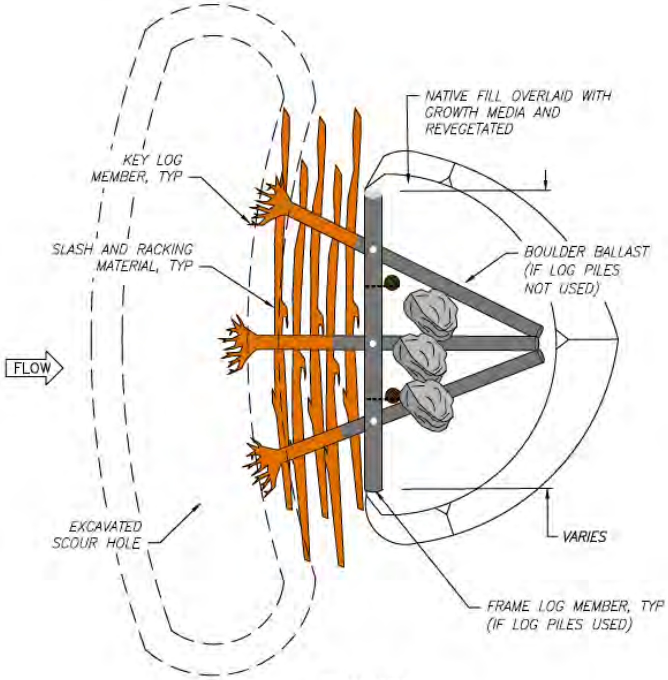
Geomorphic Considerations

- Can reduce local hydraulic energy and/or obstruct stream flow
- Creates instream roughness

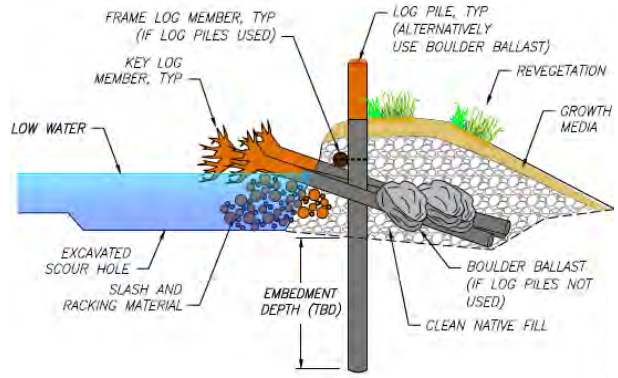
Design Considerations

- For bank stabilization – overlap wood material structure and/or place in series along an eroding bank to buffer the bank soils from erosive stream forces; obstruct flow with the wood material creating the appropriate overall width-to-depth ratio; create an inset floodplain (if necessary) along the bank to establish riparian vegetation for long-term stability and shade
- For in-channel habitat – place an individual structure or structures on opposite banks to interact with and obstruct flow creating areas of contraction (scour) and expansion (sediment deposition and gravel sorting) with cover
- Incorporate slash and retain appropriate interstitial space for habitat cover
- Consider incorporating an excavated scour pool to expedite habitat response

Treatment: Apex Log Jam
Type: Reconnection and Restoration



PLAN VIEW



SECTION VIEW

Application

- Used to split flow, obstruct flow and create in-channel complexity with velocity and depth variability

Biological Considerations

- Split flow into multiple channels, doubling margin habitat
- Incorporate excavated scour pool and cover
- Creates diverse habitat suitable for adult and juvenile salmonids

Geomorphic Considerations

- Evaluate bed and banks to determine if a large mid-channel obstruction is likely to erode the banks or scour the bed; design accordingly
- Use obstruction to activate new or relic side channels
- Evaluate reach-scale sediment transport and deposition to inform bar formation expectations

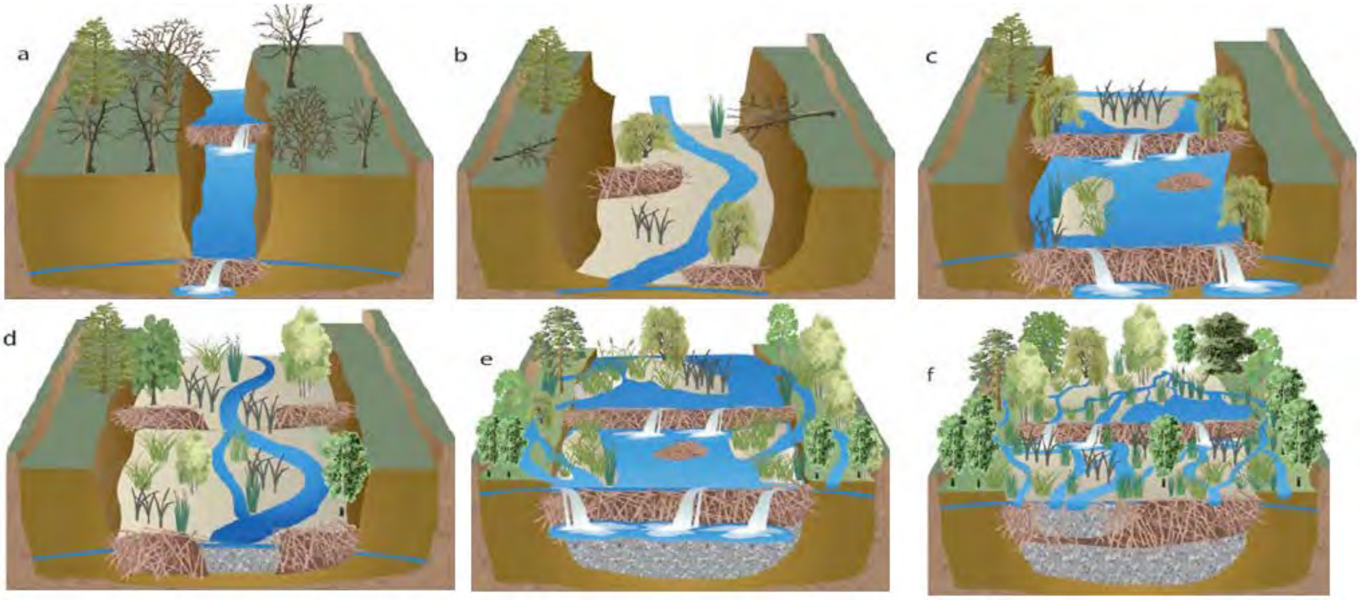
Design Considerations

- Consider use of piles where depth of alluvium is sufficient to enable adequate embedment
- Use ballast where piles are not feasible
- Design key structures assuming additional racking material will be retained over time
- Provide adequate protrusion of logs into the channel for cover
- Willow clumps may be a suitable replacement for LWD in certain environments where stream size and power allow

Apex log jam 1 year after construction; Yankee Fork of the Salmon River, ID

Apex jam constructed of willow clumps; Lemhi River, ID

Treatment: Beaver Dam Analogues (BDAs)
Type: Reconnection and Restoration



Conceptual model of how beaver dams help a stream to progress from an incised trench to an aggraded channel. Beaver attempting to build dams within narrow incision trenches resulting in blowouts (a), which help to widen the incised channel allowing an inset floodplain to form, as illustrated in (b). The widened channel more readily dissipates energy, enabling beaver to build wider, more stable dams (c). Beaver ponds fill with sediment, facilitating the growth of riparian vegetation (d). The process repeats itself until the beaver dams raise the water table sufficiently to reconnect the stream to its former floodplain (e). Eventually the stream ecosystem develops a high level of complexity (f). Figure from Pollock et al. 2015.

Application

- Intended to mimic beaver dams obstructing flow, capturing sediment, raising the water table, more frequently inundating the floodplain, attenuating high flows, and creating habitat diversity

Biological Considerations

- Backwater pools and interstitial spaces within the beaver dam provide juvenile salmonid rearing habitat
- May create partial passage barriers to certain species and life stages of fish depending on conditions

Geomorphic Considerations

- Channel-spanning structures capture sediment and raise the water elevation
- Partial spanning structures capture sediment forming point bars enhancing sinuosity (see post-line willow-weave treatment)

Design Considerations

- Construction requires minimal machinery and disturbance
- Can be used to initiate complex stage-0 habitat conditions (Cluer and Thorne 2014)
- Typically requires annual monitoring, maintenance, and additional structures to achieve goals, especially if there are no live beavers supporting the structures over time
- Generally only suitable in smaller streams and/or side channels of large rivers

BDA series capturing sediment and raising the water surface immediately after construction; Hawley Creek, ID

Recently installed BDA; Hulls Gulch, ID

Treatment: Conservation Easements
Type: Reconnection and Restoration

Application

- Management tool used to protect, preserve, and/or enable the enhancement of river, floodplain, and upland habitat in critical locations
- Can be used in conjunction with more active restoration strategies where rates of natural habitat recovery are slow or trending negatively

Biological Considerations

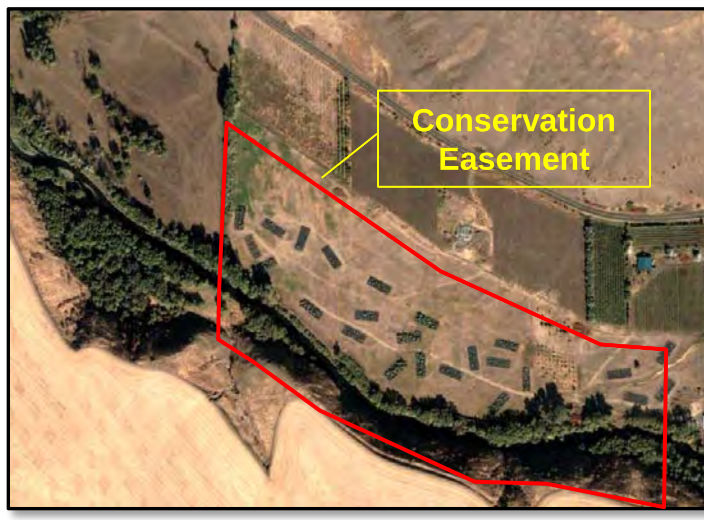
- Broad range of biological applications and benefits ranging from conservation of pristine habitat, to habitat protection enabling natural recovery, to habitat management allowing active restoration to expedite recovery

Geomorphic Considerations

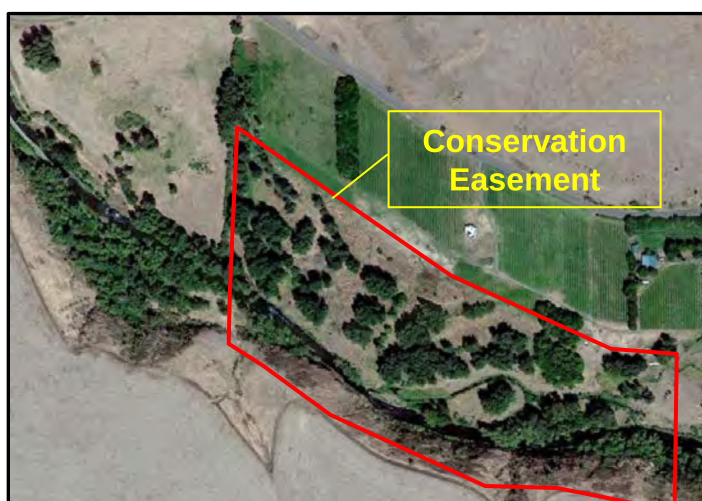
- Management strategy is dependent on trend and rate of natural recovery
- May require active restoration to reverse impact trends and offset unmitigated watershed impacts

Design Considerations

- Fencing is needed to protect, maintain, or improve riparian flora and fauna and water quality
- Applicable on stable areas adjacent to permanent or intermittent streams, wetlands, and areas with groundwater recharge
- Supplemental planting may be desired based on overall goals of conservation easement
- Tolerant plant species and supplemental watering may be needed in some areas
- Can reduce grazing and human impacts to allow riparian vegetation to respond naturally or with assisted planting efforts



Conservation easement recently established illustrating multiple planting strips (dark rectangles); Walla Walla River, OR



Conservation easement 12 years after establishment and riparian planting; Walla Walla River, OR

Treatment: Riparian Planting
Type: Reconnection and Restoration


Riparian vegetation 5 years after restoration (left photo) and 14 years after restoration (right photo); Meadow Creek, ID

Application

- Create appropriate, long-term streambank conditions, bank stability, and shade through root structure and overhead canopy
- Increase rate of colonization of native species and reduce non-native species

Biological Considerations

- Provides instream structure and cover for multiple life stages of salmonids
- Channel erosion into dense riparian vegetation provides undercut banks, instream structure, and cover

Geomorphic Considerations

- Promotes woody debris recruitment
- Enables appropriate rates of channel migration
- Dense riparian vegetation provides floodplain structure promoting side-channel formation and maintenance versus channel avulsion during periods of floodplain activation

Design Considerations

- Requires many years to achieve desired outcomes
- May require temporary short-term bank stabilization to facilitate vegetative establishment
- Can be used to promote long-term bank stabilization
- Surface and groundwater elevations must be appropriately near the bank and floodplain surface to promote riparian establishment
- Species selection, spacing, and density depend on site conditions, riparian management strategy, and land use; temporary irrigation may improve establishment

Prior to riparian revegetation; Big Springs Creek, ID

1 year after riparian revegetation; Big Springs Creek, ID