Upper Salmon River Reference Reach Assessment

For the Idaho Governor's Office of Species Conservation
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Applied Science & Engineering

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LIST OF ACRONYMS

1’ – primary channel
2’ – secondary channel
ANOVA – analysis of variance
Assessment Team – Upper Salmon Assessment Team
BDD – Beaver Dam Distributed
BIS – Bar-island Split
cfs – cubic feet per second
CHaMP – Columbia Habitat Monitoring Program
cm – centimeter
DASH – drone assisted stream habitat
DEM – digital elevation model
DS – downstream
EPA – Environmental Protection Agency
ESA – Endangered Species Act
ft – feet
IA – Inlet Angle
in – inch
IQR – inter-quartile range
ISEMP – Integrated Status and Effectiveness Monitoring Program
km – kilometer
m – meter
MFSR – Middle Fork Salmon River
MHE – Mount Hood Environmental
mi – mile
MR – Meander-Relict
MRA – Multiple Reach Assessment
NOAA – National Oceanic and Atmospheric Administration
OSC – Idaho Governor’s Office of Species Conservation
QRF – quantile random forest
RDP – Residual Pool Depth
Rio ASE – Rio Applied Science & Engineering
RKM – river kilometer
SPR – Spring
sq mi – square miles
TW – Top Width
UAV – uncrewed aerial vehicle
US – upstream
USBR – U.S. Bureau of Reclamation
USFS – U.S. Forest Service
USGS – U.S. Geological Survey
USRB – Upper Salmon River Basin
VFD – Valley-fill Distributed
WRCC – Western Regional Climate Center

1 INTRODUCTION

In 2016, the U.S. Bureau of Reclamation (USBR), Idaho Governor's Office of Species Conservation (OSC), and members of the Project Team, including Rio Applied Science & Engineering (Rio ASE) and Mount Hood Environmental (MHE), assembled the Upper Salmon Assessment Team (Assessment Team) with the intent of completing biologic and geomorphic analyses in support of future salmon and steelhead habitat restoration project identification, prioritization, and design. Recent efforts from the Assessment Team resulted in the development of Multiple Reach Assessments (MRA) within the four priority areas of the Lower Lemhi River (Rio ASE & Biomark, 2021a), Upper Lemhi River (Rio ASE & Biomark, 2021c), Lower Pahsimeroi River (Rio ASE & Biomark, 2021b), and select reaches in the Sawtooth Valley of the Salmon River (Rio ASE & Biomark, 2021d). Each MRA included an integrated biological and geomorphic assessment of existing conditions within the priority area and based on restoration needs, identified objectives to increase fish habitat capacity. These objectives in turn formed the basis for a restoration strategy that integrated resource protection, water management, process restoration, and habitat restoration. The strategy included recommended restoration actions at both the reach- and subreach-scales, as well as a range of targeted conditions for juvenile fish habitat quality, primary and secondary channel geometry, fish habitat geomorphic complexity, instream and floodplain roughness characteristics, and riparian vegetation type and extent.

Habitat restoration project development in the Upper Salmon River Basin (USRB) is implemented in stream reaches across a continuum of spatial and temporal scales, each with a corresponding diversity and ever-changing composition of biological and physical characteristics. The information currently used for project development and design in these stream reaches relies on data from the four project areas encompassed by the MRA reports (Rio ASE & Biomark, 2021a, 2021b, 2021c, and 2021d), as well as from legacy fish habitat data from the Columbia Habitat Monitoring Program that was terminated in 2017 (Integrated Status and Effectiveness Monitoring Program & Columbia Habitat Monitoring Program [ISEMP & CHaMP], 2017). Unfortunately, the four MRA areas primarily contain low- to medium-quality habitat with lower fish densities and only limited patches of multi-thread channels with high-quality habitat. Moreover, the MRA areas occur in only three of the eight watersheds located in the USRB. As a result, there is a need to better identify, prioritize, and design habitat restoration projects in priority project development areas using information on fish habitat and geomorphology from other areas of the USRB and central Idaho with high-quality Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*Oncorhynchus mykiss*) habitat.

Some of the highest quality habitat in the central Idaho is found in tributary streams within the Middle Fork Salmon River (MFSR) watershed (Figure 1-1). In particular, sections of Marsh Creek, Bear Valley Creek, and Elk Creek comprise high-quality habitat and geomorphic complexity, including multi-thread channels. The MFSR watershed contains some of the most important ecological areas for salmon and steelhead in central Idaho and is managed as a designated wild anadromous fish sanctuary, where the production potential of the watershed and the ability of salmon and steelhead to respond to the quality and quantity of available natal habitat have not been altered (Thurow et al., 2020). Although ecological conditions are degraded in small, localized areas outside of wilderness areas in the MFSR, fish habitats throughout most of the MFSR tributaries are in excellent condition (National Oceanic and Atmospheric Administration [NOAA], 2017). Natural physical and ecological processes in the MFSR watershed function relatively unimpeded by humans, resulting in high-quality and diverse natal fish habitats (Thurow et al., 2020). The habitat found in these MFSR tributaries provides valuable insight that can be used to inform restoration strategies and designs within priority project development areas of the USRB.

The overall goal of the information provided in this report is to improve the science and engineering practice of multi-thread channel stream restoration design in the USRB by evaluating reference reaches exhibiting relatively high-quality geomorphic and biological characteristics. Advancing our understanding of multi-thread channel formation and evolution, and the associated fish habitat characteristics, within each reference reach is intended to facilitate future secondary channel project development and restoration design. The geomorphic assessment of the reference reaches was guided by the following objectives:

1) Describe the physical setting within which multi-thread channels develop,
2) Describe the geomorphic processes that create and maintain multi-thread channels, and
3) Quantify geomorphic characteristics that can be used to guide the design, construction, and effectiveness monitoring of self-sustaining multi-thread channels.

The biological assessment addresses habitat characteristics associated with carrying capacity more broadly, with a focused discussion on how secondary channels help facilitate suitable conditions for multiple life stages of Chinook salmon and steelhead. Recommendations on integrating suitable habitat for different life stages into side channel design are also provided. The biological assessment of the reference reaches was guided by the following objectives:

1) Quantify and compare habitat characteristics between watersheds in or adjacent to the USRB,
2) Define reference reach characteristics that result in high-quality fish habitat, and
3) Identify how reference reach information can be incorporated into the design and implementation of secondary channel fish habitat.

This report includes a summary of the environmental setting (Section 2) for the reference reaches within Marsh Creek, Bear Valley Creek, and Elk Creek, including a description of the secondary channel types located in those reference reaches. Desktop and field methods used for the geomorphic assessment are described in Section 3; methods for the biological assessment are described in Section 3 and Appendix B. Summaries of the reference reach geomorphic and biological/habitat characteristics are provided in Section 4, with additional details described in Appendix A, Appendix B, and Appendix C. The findings from the geomorphic and biological assessments are synthesized in Section 5 to provide secondary channel design guidelines.

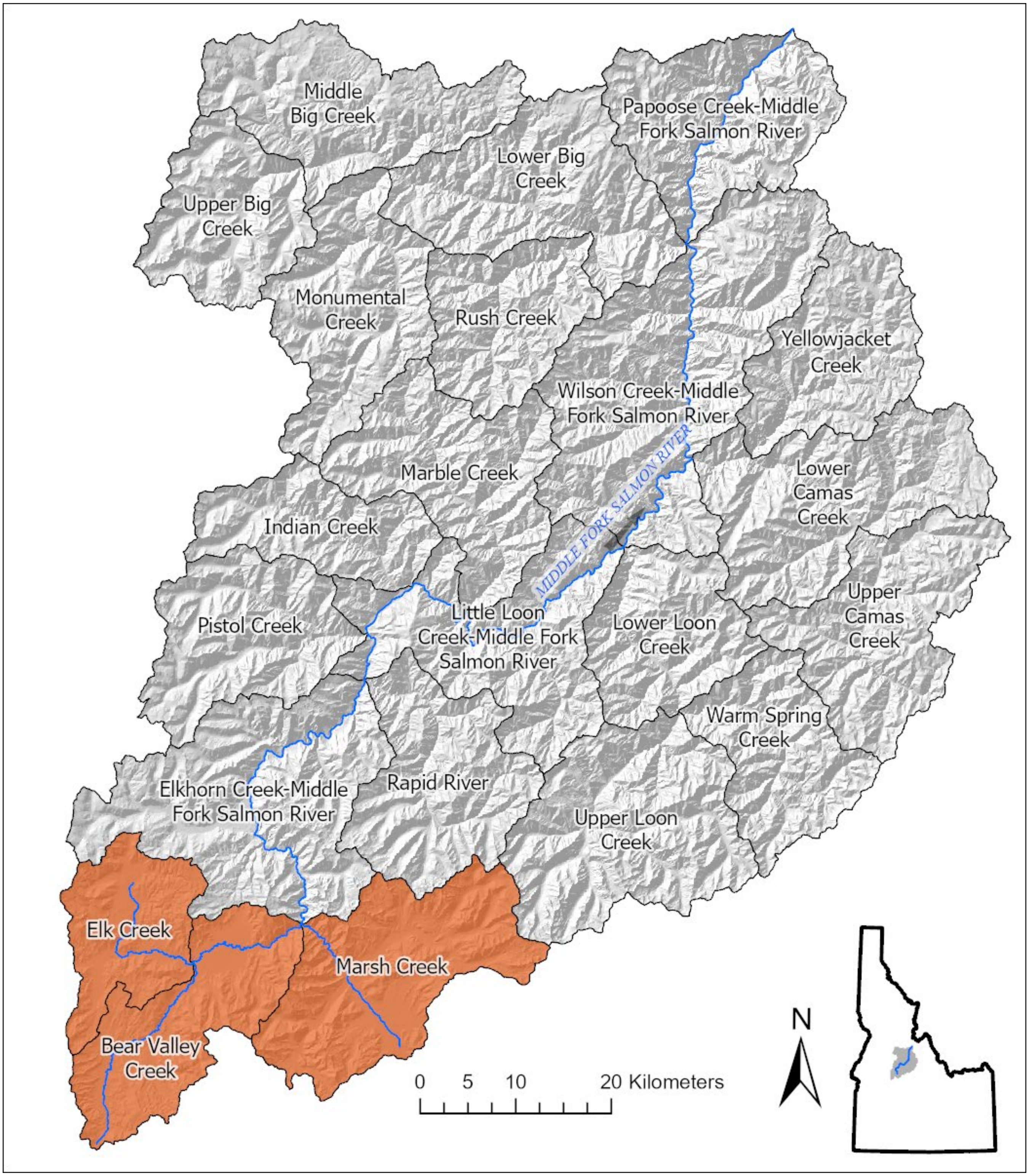


Figure 1-1. Marsh Creek, Bear Valley Creek, and Elk Creek subwatersheds within the Middle Fork Salmon River Watershed.

2 ENVIRONMENTAL SETTING

2.1 Physical Geography

The reference reaches within Marsh Creek, Elk Creek, and Bear Valley Creek are located in very broad, unconfined valleys within the mountainous terrain of west-central Idaho (Figure 2-1). The watersheds of these streams range in size from approximately 51 miles (mi)^2 to 72 mi^2 (Table 2-1). Elevations in these watersheds range from approximately 9,630 feet (ft) along the mountainous peaks of Knapp Creek to approximately 6,380 ft along the valley floor of Bear Valley Creek. Mean watershed elevations range from 7,300 ft to 7,010 ft.

Ecoregions describing physical and biological characteristics of different areas of Idaho are described at various spatial scales by McGrath et al. (2002). On a broad scale, Bear Valley Creek, Elk Creek, and Marsh Creek are all located in the Idaho Batholith Level III Ecoregion known for dry, granitic soils that are susceptible to erosion when vegetation is removed. Vegetation is dominated by fir and pine forest. At a finer resolution, Marsh Creek is located within the High Glacial Drift-Filled Valleys Level IV Ecoregion (16g) containing terraces, outwash plains, moraines, wetlands, and hills. Wetland soils are vegetated with sedges and rushes while upland areas include sagebrush and pine. Winters are cold and precipitation is dominated by snow. The ecoregion provides summer pasture for livestock. The characteristics of this Level IV ecoregion also describe Bear Valley Creek and Elk Creek, despite their location within the Southern Forest Mountains Level IV Ecoregion (16k).

2.2 Geology

The reference reaches within Marsh Creek, Elk Creek, and Bear Valley Creeks exhibit a similar geologic history. The underlying lithology generally consists of roughly 150-million-year-old granitic rocks of the Idaho Batholith (Kiilsgaard et al., 2006). About 45 million years ago, rhyolitic rocks of the Challis Volcanics intruded into and displaced the Idaho Batholith in the eastern portion of the project area (Fisher et al., 1992). In the past 10 million years, north-south trending valleys were formed by block faulting believed to be associated with basin and range crustal extension south of the project area (Schmidt & Mackin, 1970; Fisher et al., 1992). Over thousands of subsequent years, alluvium accumulated in the fault valleys augmented by glacial and periglacial erosion from the last ice age over 10,000 years ago (Schmidt & Mackin, 1970). It has been estimated that cooler/wetter ice age climate conditions in central Idaho resulted in an order of magnitude greater stream discharge compared with modern conditions (Pierce & Scott, 1982). The associated increase in stream power likely contributed significantly to sediment transport and valley fill alluvial aggradation. Large-scale bedrock and glacial moraine grade controls also served to trap sediment and create broad, low-gradient alluvial valley bottoms.

Since the last significant glacial period over 10,000 years ago, the climate has become drier and warmer (Pierce & Scott, 1982). During this time Marsh Creek, Elk Creek, and Bear Valley Creek have incised into the glacial-era alluvium by several feet, creating terraces accompanied by broad, active floodplains within the terrace margins (Kiilsgaard et al., 2006). Geologic grade controls have limited overall incision, as noted above. Also, periods of aggradation have punctuated the overall incisional trend over the past few thousand years, as evident in modern cutbank exposures revealing fine sediment overlying coarse glacial lag and fluvial bedload deposits. Such deposition was likely the result of backwater conditions from beaver damming and/or localized debris flow dams at the mouths of tributaries.

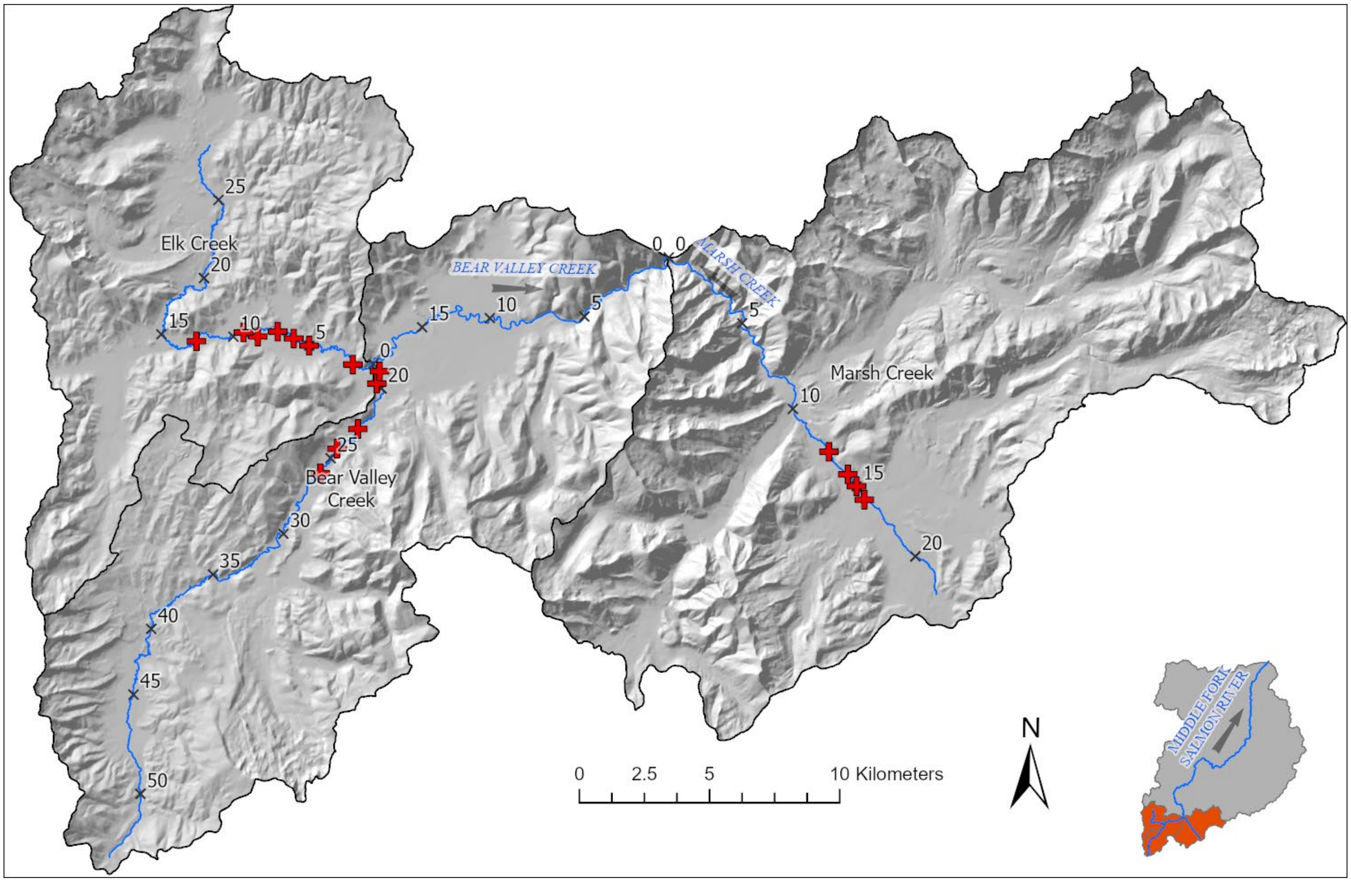


Figure 2-1. Marsh Creek, Bear Valley Creek, and Elk Creek reference reaches (red crosses).

2.3 Climate and Hydrology

The project area watersheds experience a mix of Pacific maritime and continental climate patterns. Portions of the watersheds in generally higher elevations are affected by maritime climate patterns characterized by moist air in prevailing westerly winds. The maritime influence is prominent in winter, with greater average cloud cover, greater frequency of precipitation, and mean air temperatures that are above those at similar latitude and elevation mid-continent. During the summer, and at lower elevations, a continental climate prevails in the watersheds, with characteristically warmer temperatures and less precipitation (Finklin, 1988).

The climate patterns in the watersheds are depicted in long-term weather observations from the National Climate Data Center records at the Stanley station (108676). This station is located near the community of Stanley, Idaho, southeast of the study area at an elevation of approximately 6,250 feet. The station has a period of record from 1963 to 2005. Mean average monthly air temperatures range from 12°F (-11°C) in December to 57°F (14°C) in July, with mean maximum monthly air temperatures ranging from 26°F (-3°C) to 79°F (26°C), respectively. Mean annual precipitation is approximately 13.2 inches (in) (33.5 centimeters [cm]), with a mean winter accumulation of 4.5 in (11.4 cm) and mean summer accumulation of 2.3 in (5.8 cm). Mean annual snowfall accumulation is 72 in (182.9 cm) (Western Regional Climate Center [WRCC], 2006).

The climate of these watersheds results in a snowmelt runoff hydrology pattern, with peak flows occurring in May and June and the lowest flows occurring in late fall and winter. The hydrologic conditions are similar among the three project area streams (U.S. Geological Survey [USGS], 2019). Low flows range from approximately 12 cubic feet per second (cfs) to 15 cfs, while bankfull flows range from approximately 500 cfs to 700 cfs (Table 2-1).

Table 2-1: Peak Flow Statistics for Bear Valley Creek, Elk Creek, and Marsh Creek (data from USGS, 2019)

Stream Name	Drainage Area[a] (sq mi)	Low Flow[b] (cfs)	Bankfull (cfs)	2yr Flood (cfs)	10yr Flood (cfs)	100yr Flood (cfs)
Bear Valley Cr	66.4	12.2	638	957	1580	2420
Elk Cr	72.0	15.4	684	1040	1710	2620
Marsh Cr	51.0	12.8	508	559	941	1460

Notes:
a) Drainage area calculated from the most-downstream point of the most-downstream study reach.
b) Low flow measured as 1 day 10-year low flow.
sq mi = square miles
cfs = cubic feet per second

2.4 Land Use

The reference reaches within Marsh Creek, Elk Creek, and Bear Valley Creek are located on public land managed by the U.S. Forest Service (USFS). The primary uses and activities in this area have included dispersed recreation, livestock grazing, timber management, and limited watershed restoration. All of the streams are listed in the Wild and Scenic River Classification system, with the reference reaches including designations of wild, scenic, and recreational (USFS, 2010).

Although the three project area streams are considered remote and relatively pristine by most standards, they are not without a history of human disturbance. The Alexander Ross party in 1824 and the Hudson's Bay Company brigade in 1832 both reached Bear Valley and Meadow Creeks, where they trapped beaver for the booming fur trade (Rossillon, 1981). Loss of beaver influence in meadow streams has been well documented to simplify channel characteristics, often including incision, floodplain abandonment, concentrated flow, and overall loss of in-stream habitat (Rosell et al., 2005). Additional impacts came from livestock grazing, which has occurred in the project area since the 1880s. A larger impact was the result of more than 200,000 sheep trailed through the project area annually on their way to and from summer range near the Thunder Mountain mining district in the early- to mid-1900s (Rossillon, 1981).

Mining also caused historical impacts, especially within Bear Valley Creek. According to the Environmental Protection Agency (EPA, 2015), dredge mining of rare earth and metallic elements occurred in the upper Bear Valley watershed (Big Meadow) between 1956 and 1959, obliterating 17,000 linear feet of Bear Valley Creek and 10,000 linear feet of tributary channels. Sediment from mining and flood-related mobilization of tailings material and fine sediment resulted in the 1994 EPA 303(d) listing of Bear Valley Creek. Habitat restoration of the dredge mined areas between 1985 and 1989, along with subsequent riparian revegetation and road improvements in the valley, stabilized the channel, reduced excessive sediment production, and ultimately resulted in the removal of Bear Valley Creek from the 303(d) list in 2008 (EPA, 2015).

2.5 Fish Use

Bear Valley Creek and Marsh Creek watersheds support independent populations of natural-origin, spring-run Chinook salmon, listed as “threatened” under the Endangered Species Act (ESA). Chinook salmon use Bear Valley Creek and Marsh Creek watersheds for most of their key freshwater life stages, including adult holding (prior to spawning), spawning, embryo development, fry emergence and rearing, and juvenile rearing prior to emigration. Recent abundance and productivity estimates for Chinook salmon fall short of population viability thresholds for both watersheds and are considered “high risk” of extinction (NOAA, 2017). Current Chinook salmon spawning locations mimic historic distributions, occurring primarily in upper and lower Bear Valley Creek, Elk Creek, and Marsh Creek. In 2021, 153 and 105 Chinook redds were counted in Bear Valley Creek (including Elk Creek) and Marsh Creek, respectively (Poole et al., 2022), well below maximum archival redd counts of 791 in Bear Valley Creek (1957), 388 in Elk Creek (1963) and 709 in Marsh Creek (1964) (Metsker, 1958; Hassemer, 1993, as cited in Thurow et al., 2020). Based on maximum archival redd counts, corresponding harvest reports and contemporary redd census data, a historic estimate for MFSR production potential is 24,000 redds annually for the 1950s-1960s, compared to 362 redds counted in 2021 (Poole et al., 2022; Thurow et al., 2020). However, MFSR population declines are attributed to out-of-basin effects, not to loss or degradation of historic habitat (Thurow et al., 2020; NOAA, 2017). Long-term monitoring on Marsh Creek shows a linear relationship between the number of spawning adults and juvenile out-migrants the following year, indicating natal habitat quality and quantity is likely not a limiting factor for the Marsh Creek population (NOAA, 2017). Sharing similar habitat characteristics as Marsh Creek, rearing habitat conditions are not believed to be limiting for the Bear Valley Creek population.

The summer-run steelhead in the upper MFSR watershed (upstream of Loon Creek) are considered an independent population. Steelhead use the upper MFSR, including Bear Valley Creek, Elk Creek, and Marsh Creek, for all of their key life stages, with some juveniles rearing for up to 4 years prior to emigration. The population includes both A-run and B-run steelhead. Recent steelhead abundance and productivity estimates based on genetic stock composition fall short of viability thresholds established for the upper MFSR population (NOAA, 2017). However, because steelhead distribution is widespread in the upper watershed, the spatial structure and genetic diversity of the population is relatively robust, and the population is at a “moderate risk” of extinction (NOAA, 2017). For spawning year 2020, the adult steelhead escapement estimate at Lower Granite Dam for MFSR steelhead was 453 fish (385-521 90% CI; Baum et al., 2022). Bear Valley Creek and Marsh Creek watersheds are considered two of six major spawning areas for upper MFSR steelhead. Juvenile steelhead have been detected in most tributaries throughout the upper watershed where spawning habitat is available. In the Marsh Creek watershed alone, it was estimated that 3,803 juvenile steelhead >80 mm fork length emigrated in 2021 (Heller et al., 2022).

Bear Valley Creek and Marsh Creek watersheds also support ESA-listed bull trout (*Salvelinus confluentus*) and westslope cutthroat trout (*O. Clarki lewisi*), which was previously petitioned for listing under the ESA. Both species use the upper MFSR for spawning, embryo development, and juvenile rearing. However, less is known about these populations, with some individuals exhibiting resident, fluvial, and adfluvial life histories to varying and unknown degrees.

2.6 Multi-thread Channels

Prior work in multi-threaded river systems has identified five secondary channel types that can be used as a range of analogues for restoration designs in the USRB (Rio ASE & Biomark, 2021a). Multi-thread channels encompass a wide range of channel morphology and physical processes. 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 & 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

This section contains a brief description of secondary channel types to foster interpretation of information provided in subsequent sections of this report. Additional details on secondary channel types are provided in Appendix C.

2.6.1 Secondary Channel Types

The reference reaches within Marsh Creek, Bear Valley Creek, and Elk Creek contain many secondary channels with a range of physical characteristics. Based on prior work in multi-threaded river systems (Rio ASE & Biomark, 2021a), the secondary channel types in Marsh Creek, Bear Valley Creek, and Elk Creek include Beaver Dam Distributed (BDD), Valley-fill Distributed (VFD), Meander-Relict (MR), and Bar-island Split (BIS). In most of the reference reaches, these secondary channel types co-occurred with one another. Secondary channel types and characteristics are depicted in Figure 2-2 and summarized in Table 2-2.

1. Beaver Dam Distributed
Backwater conditions; multiple dam outlet channels; variable width; dense riparian; broad active floodplain

2. Valley-fill Sub-parallel
Stable channels; limited floodplain connection; topographic structural controls

3. Valley-fill Distributed
Small-scale avulsion occupying low-lying floodplain; stabilized by riparian vegetation; often combined with beaver activity

4. Meander-Relict
Channel migration; small scale avulsion on inside of bend stabilized by riparian vegetation and/or LWD; channel migration into relict feature; small-scale avulsion stabilized by riparian vegetation; variable width

5. Bar-Island Split
High bedload; dynamic channel migrates/avulses around multiple island nodes stabilized by mature vegetation and/or LWD

Figure 2-2. Secondary channel types and characteristics.

Table 2-2. 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
Laterally Active	Peak-flow	Moderate coarse material bedload transport	Primarily suspended bed material and wash load; moderate coarse bedload	**Valley-fill Distributed**	• Associated with primary channel 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 2-2. 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 primary channel point-bars and lateral channel migration • Small-scale avulsion into relict channel scar along outside of meander bend • Former primary channel becomes secondary channel • Multiple secondary 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 relict 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 primary channel 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

3 APPROACH

This assessment focused on characterizing the physical processes and conditions of the reference reaches and how the controlling factors at this scale affect the development of river attributes and habitat conditions at the reach- and site-scales. The assessment included a desktop analysis of readily available data, as well as field data collection and analysis.

The focus of this work was to develop information for restoration design purposes. The data summarized in this report and appendices provides information that can be used to guide the design, construction, and effectiveness monitoring of self-sustaining multi-thread channels. Due to the small number and type of reference sites evaluated, conclusions and recommendations are limited, and additional analysis should be considered during the development and design of any restoration project incorporating secondary channels.

3.1 Geomorphic Study Areas

Field observations and data collection were completed from all study areas in August 2021. Initial study planning identified several candidate multi-thread reference reaches in Bear Valley Creek, with the final set of study reaches determined during the field visit of August 9-12, 2021. Reconnaissance efforts during this field visit also resulted in identifying and sampling reference reaches in Elk Creek and identifying reference reaches in Marsh Creek. Field observations and data collected in Marsh Creek were completed during August 23-25, 2021.

Five reference reaches were established in Bear Valley Creek, extending from river kilometer (RKM) 18.8 upstream to RKM 26.4. The five reaches ranged in length from 0.3 RKM to 1.6 RKM (Figure 3-1). Elk Creek is a tributary to Bear Valley Creek, with the confluence near Bear Valley Creek RKM 18.3. Seven reference reaches were established in Elk Creek, extending from RKM 0.6 upstream to RKM 12.6. The seven reaches on Elk Creek range in length from 0.4 RKM to 1.4 RKM (Figure 3-2). Four reference reaches were established in Marsh Creek, with the downstream-most reach located 12.4 RKM upstream of the confluence with Bear Valley Creek. The four Marsh Creek reaches extend from RKM 12.4 upstream to RKM 16.3, with reach lengths ranging from 0.6 RKM to 0.8 RKM (Figure 3-3).

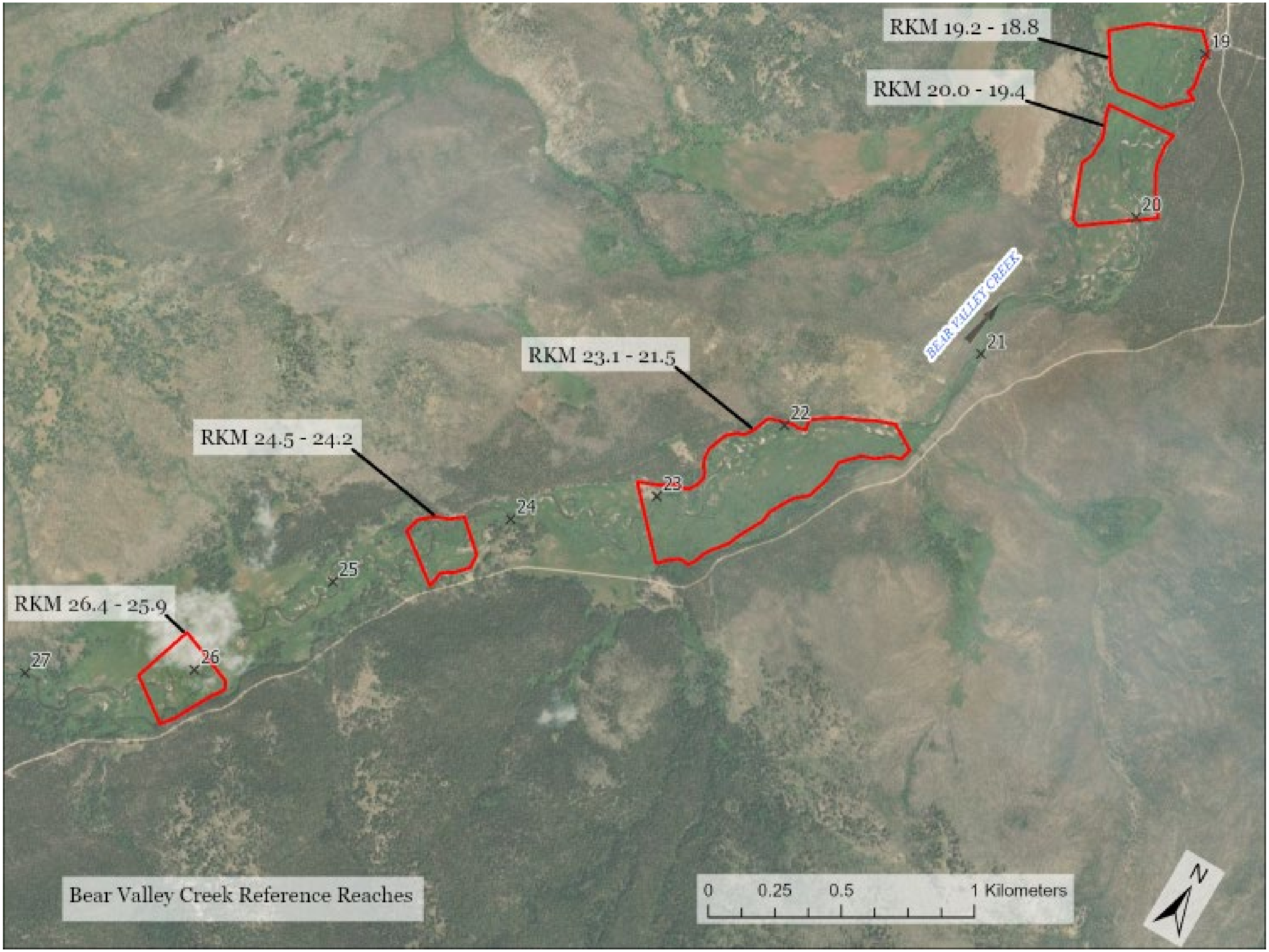


Figure 3-1. Bear Valley Creek reference reaches.

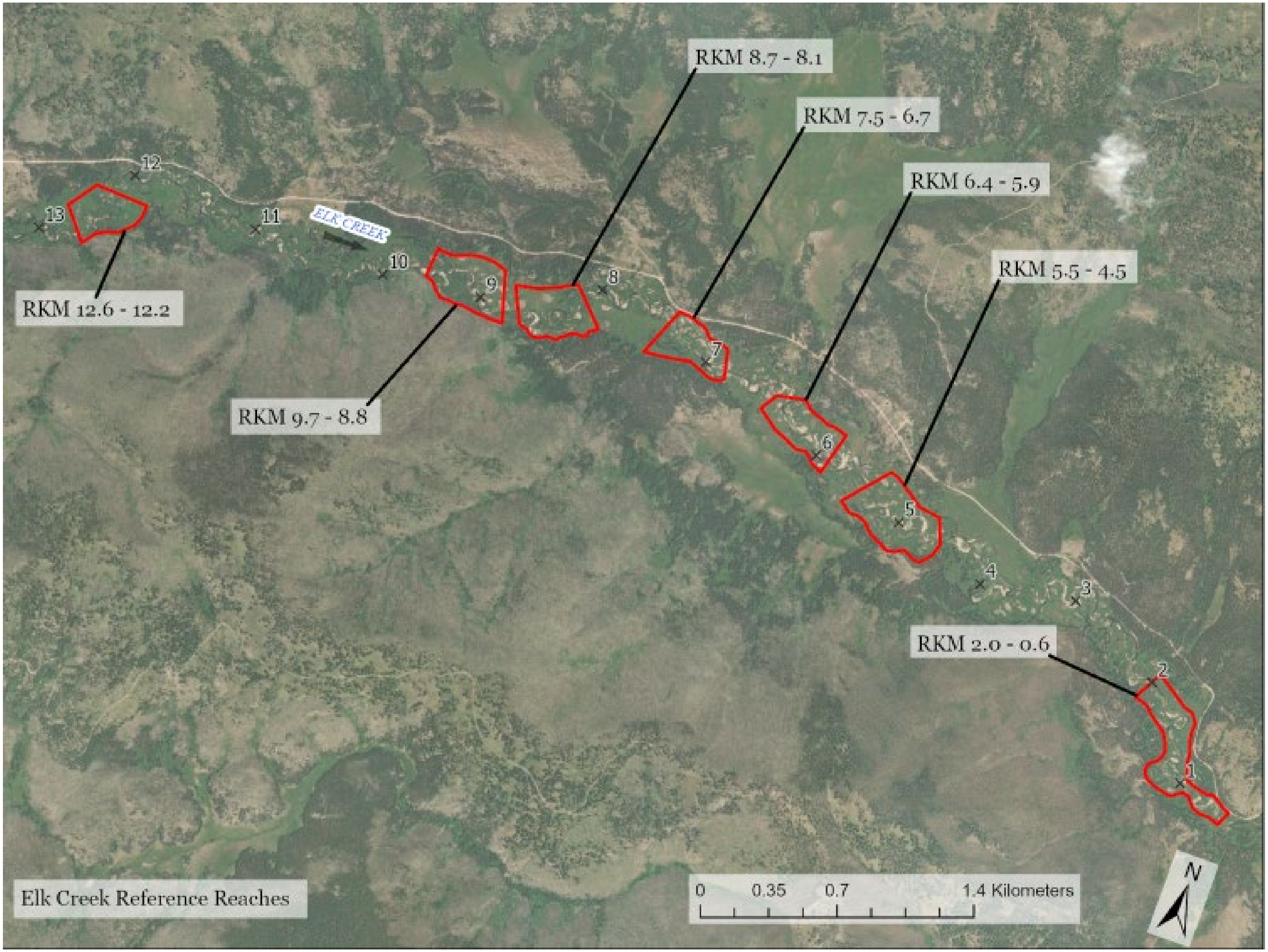


Figure 3-2. Elk Creek reference reaches.

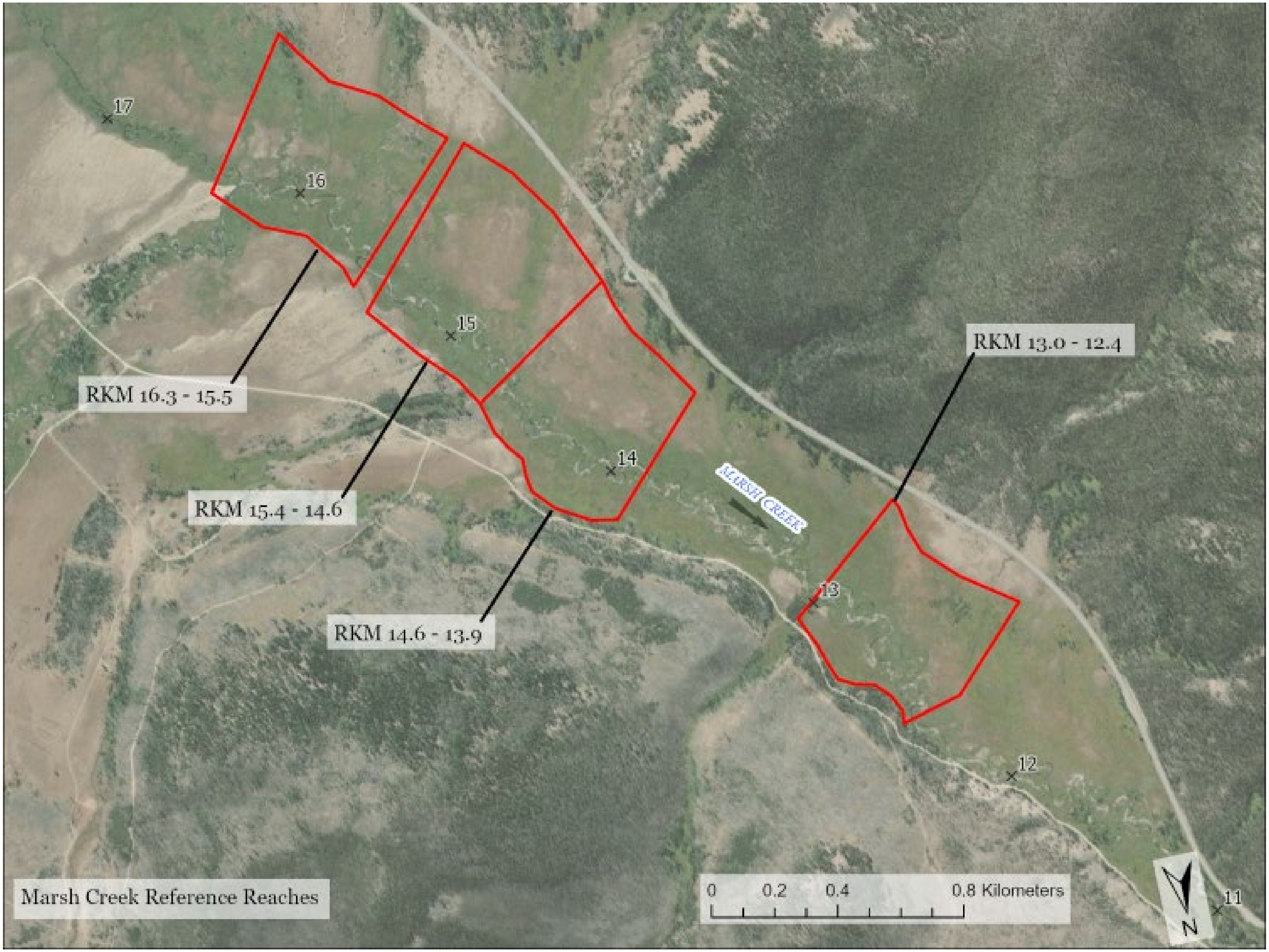


Figure 3-3. Marsh Creek reference reaches.

3.2 Biological Study Areas

To evaluate biological conditions, nine sites from Bear Valley Creek, Elk Creek, Marsh Creek, and Knapp Creek were surveyed from August 5-11 and August 24-25, 2021 (Figure 3-4). Sites ranged from 1.12 km to 4.43 km with diverse, contiguous habitat characterized by multi-thread channels and frequent off-channel areas. Some floodplain habitats were so complex and expansive that surveyors were unable to quantify them entirely (Figure 3-5). As a result, habitat capacity estimates reported in this assessment for biological reference reach sites may underrepresent true carrying capacity.

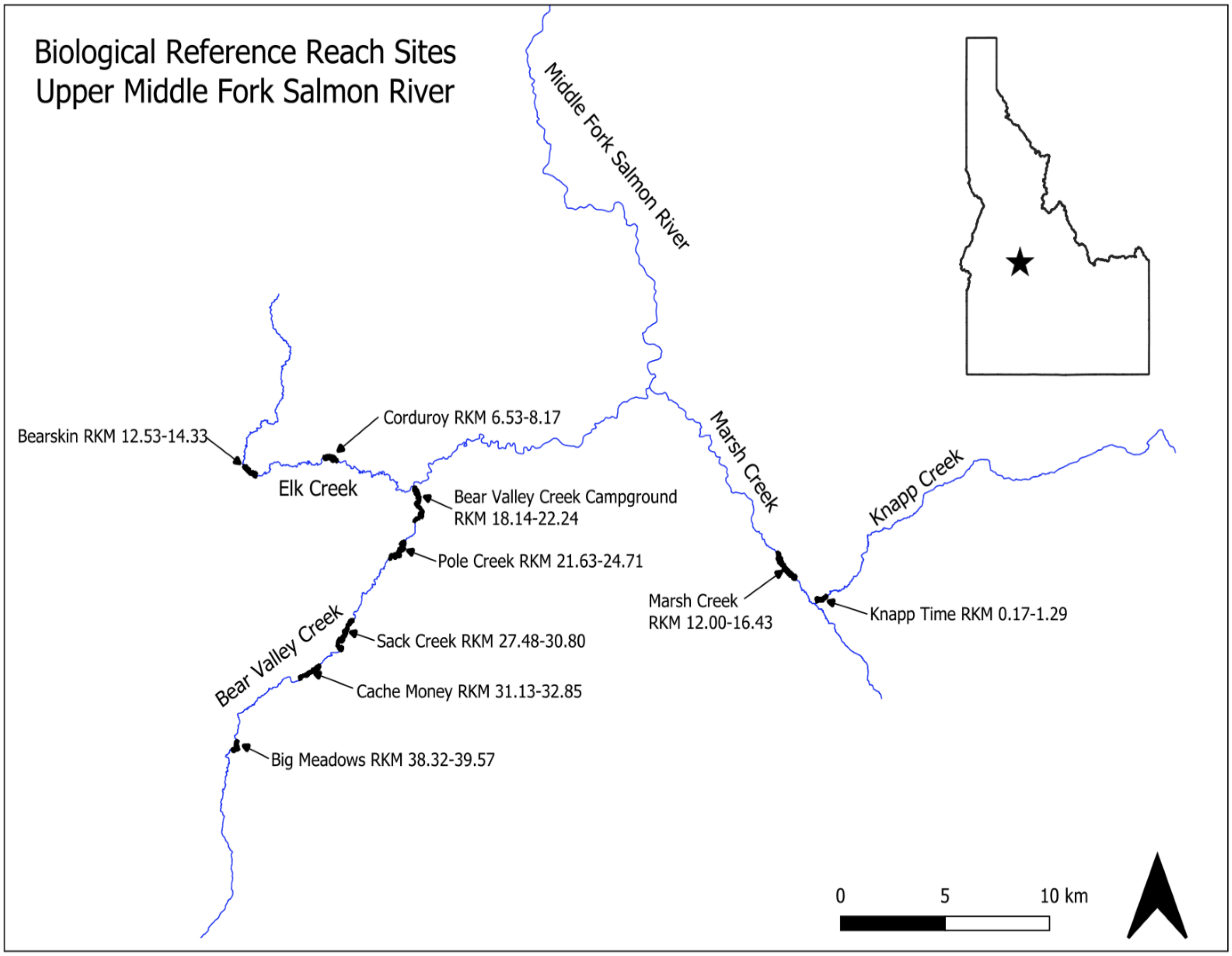


Figure 3-4. Upper MFSR reference reach sites surveyed for biological assessment.

Figure 3-5. Bear Valley Creek campground site exhibiting expansive and complex secondary channels and floodplain habitat.

3.3 Geomorphic Evaluation

Field observations and data were collected throughout each of the reference reaches, with some data collected at fixed locations and other data in a continuous manner. Channel geometry data were collected in each reach with an RTK GPS system referencing locally established benchmarks. The sampling density and spatial extent varied depending on the characteristics specific to each reference reach; the sampling effort focused on proximity to primary-secondary channel connections (i.e., inlets and outlets) and areas within any secondary channels. For example, where a secondary channel inlet occurs within a primary channel pool, the extent of the primary channel sampling included the riffle-pool-riffle geomorphic unit sequence that encompasses the secondary channel inlet, in addition to sampling the secondary channel itself. Sampling was not conducted in subreaches without primary-secondary channel connections.

Channel geometry data collected with the RTK GPS system included longitudinal elevation profiles along the thalweg of primary and secondary channels and cross-section elevation profiles throughout multiple geomorphic units within each reach. Thalweg elevation was surveyed at all significant breaks in elevation and slope (e.g., pool bottom, pool tail-out, riffle crest, etc.), and the resulting data were used to verify geomorphic units and to calculate channel lengths, sinuosity, residual pool depth, and slope of pool-riffle geomorphic units. Multiple slope values were calculated for pool-riffle transitions, including pool inlets (i.e., upstream riffle to pool bottom), pool outlets (i.e., pool bottom to downstream riffle), the upstream side of riffles (“riffle stoss”), downstream side of riffles (“riffle lee”), and intermediate notable changes in slope identified along the pool inlet and outlet transitions. Cross-section geometry was measured with specific focus on the geomorphic units located at, upstream of, and downstream of secondary channel inlets in order to identify the geometry controlling hydraulic behavior at the inlet and outlet. Station elevations were surveyed for top of bank, toe of bank, edge of water, thalweg, and other significant breaks in elevation and slope. When possible, cross sections were surveyed once in each geomorphic unit; for example, occurring in a sequence of riffle crest>pool bottom

>riffle crest>pool bottom. Cross-section elevation data were used to calculate channel top width, bottom width, and to plot cross-section elevation profiles.

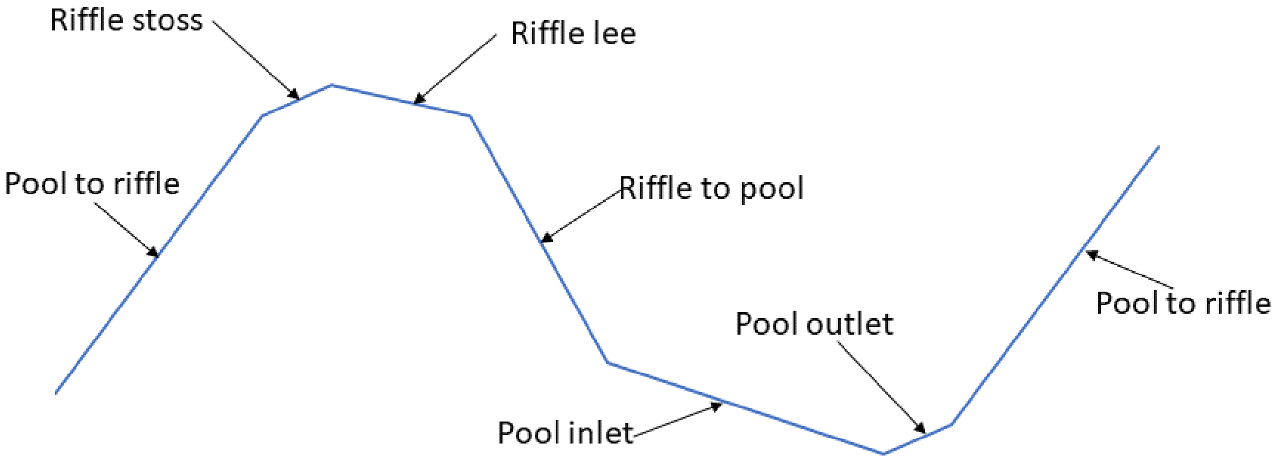


Figure 3-6. Schematic profile of geomorphic unit transitions for slope measurements.

Field data collection from all reaches also included observations of bank characteristics, estimates of woody material abundance, and in-channel grain size distribution of the channel surface. Throughout each reach, continuous observations of bank characteristics were recorded for bank angles (degree from horizontal), plant community type and composition (% abundance of forbs/grasses, shrubs, trees), bank sediment characteristics (grain-size texture and thickness of bank strata), and general bank formation/genesis conditions (Hey & Thorne, 1986; Millar & Eaton, 2011; Eaton & Millar, 2017). Wood material abundance was mapped as point locations of large wood pieces (>1.0 meter [m] length and >0.1 m diameter), log jams (>10 pieces of large wood), small accumulations (>10 pieces of any size), and beaver dams occurring in primary and secondary channels. Qualitative observations were also made of wood material condition, orientation, and functionality (Wohl et al., 2010). Digital photography was used to record the riverbed surface along multiple depositional bar locations distributed throughout the project reaches. Photographs were taken of the dry streambed surface at each sampling location and processed in digital image analysis software (Hydraulic Toolbox v4.4) to produce composite grain-size distributions for each sampled bar (Graham et al., 2005a; Graham et al., 2005b). This sampling approach resulted in very large sample sizes at each bar, ranging from 1,400 to 6,500 individual grains at each sampled bar.

Desktop analysis of imagery was used to supplement the field data at all reference reaches. Low elevation aerial imagery was acquired with an uncrewed aerial vehicle (UAV) during the August 2021 field reconnaissance and additional flights in summer 2022. High elevation imagery from multiple years in the National Agricultural Imagery Program was used through ArcGIS Online services. All of the imagery was used for multiple mapping purposes, including verification of geomorphic unit distinctions, the alignment and type of primary and secondary channels, the junctions/nodes of primary and secondary channels, and the location and type of wood material in primary and secondary channels. Imagery was used to measure channel top widths in non-surveyed subreaches by digitizing the active channel boundary and measuring channel width at cross-sections spaced approximately one channel-width apart. Secondary channel inlet angles were measured from imagery as the angle (degrees) between the primary channel bank line downstream of the inlet and the secondary channel bank line at the inlet (Figure 3-7).

Desktop analysis of additional spatial data was used for all reference reaches. Elevation data throughout the valleys were acquired from the 10-meter digital elevation model (DEM) in the National Elevation Database available from the USGS. The geologic controls in the watersheds were identified by GIS mapping and description of lithology and surficial geology with data compiled from the Idaho Geological Survey (Lewis et al., 2012). The imagery, 10-m DEM, and geology data were used to interpret and map the contemporary valley bottom and valley slope for each reference reach. The valley bottom of each reference reach was mapped as a polygon and valley widths were measured from cross-sections spaced 50 m apart along the valley profile.

Data from the field work and desktop analysis were summarized to compare the physical characteristics within and among reference reaches and streams. The summaries include statistical distributions of individual variables, as well as calculated values per distance of channel length and valley length. Calculated indices of complexity included sinuosity (channel length/valley length), channel braidedness (total channel length/main channel length), and valley braidedness (total channel length/valley length). To foster the development of guidelines for some design engineering elements (e.g., secondary channel inlet angles), single-factor analysis of variance (ANOVA) and two-sample t-tests were used to test for differences in mean values among groups (e.g., reference streams) for the purposes of identifying if and when it may be appropriate to pool data from all or some reference streams to develop a design guide such as the inter-quartile range.

Figure 3-7. Example measurement of secondary channel inlet angle.

3.4 Biologic Evaluation

For the biological assessment, fine resolution habitat data were collected using the Drone Assisted Stream Habitat (DASH; Carmichael et al., 2020) surveys to quantitatively compare habitat characteristics between reference sites. Adapted from the Columbia Habitat Monitoring Program, DASH surveys measure habitat characteristics deemed important for juvenile rearing and adult spawning for Chinook salmon and steelhead across multiple spatial scales. On-the-ground surveys consisted of habitat assessments at the channel unit-scale, quantifying metrics such as channel unit types (i.e., pool, run, riffle, rapid, small side channel, or off-channel area), substrate composition, large wood, fish cover, undercuts, water depth characteristics, and discharge. These metrics were then paired with high resolution imagery captured using UAV to spatially reference habitat characteristics and capacity estimates. DASH surveys allow for the calculations of over 70 habitat covariates, a subset of which are used as input data for a quantile random forest model (QRF; See et al., 2021) used to estimate freshwater carrying capacity for Chinook salmon and steelhead during three critical life stages: juvenile summer rearing (parr), juvenile winter rearing (presmolt), and adult spawning (redds). A detailed description of the DASH surveys and the habitat covariates that are used in QRF carrying capacity models can be found in Appendix B.

4 REFERENCE REACH SUMMARIES

This section summarizes the findings of the geomorphic assessment at the valley- and reach-scales. The valley setting at the spatial extent encompassing the reference reaches within Bear Valley Creek, Elk Creek, and Marsh Creek is first described, followed by subsections describing the geomorphic characteristics of the reference reaches at the reach- and subreach-scales. Collectively, this information is intended to provide design parameters for multi-thread channels in similar physical settings as Bear Valley Creek, Elk Creek, and Marsh Creek.

4.1 Valley Setting

All of the reference reaches are located in low-gradient valleys. Throughout the valley extent of the reference reaches, the valley slope ranged from 0.0017 in Elk Creek to 0.0058 in Marsh Creek (Table 4-2). The wide, low-gradient valleys filled with glacial-era alluvium foster the development of highly sinuous primary stream channels. Throughout the valley extent of the reference reaches, the primary channel sinuosity ranged from 1.65 in Elk Creek to 1.95 in Marsh Creek (Table 4-2). The valleys also provide the physical controls for the development of multi-thread channel geomorphic characteristics at the reach- and subreach-scales.

All of the reference reaches are located in similar valley settings, including the width of the valley bottoms available to floodplain connectivity and channel migration. The mean valley width ranged from 905 ft in Bear Valley Creek to 1,079 ft in Marsh Creek (Table 4-1, Figure 4-1). Among each of these streams, the range in valley width was much larger in Marsh Creek than in Elk Creek and Bear Valley Creek (Table 4-1, Figure 4-1). There was also significant variation in the valley width among the reference reaches of each stream. For example, the mean valley width ranged from 698 ft to 1,421 ft in Bear Valley Creek reference reaches, from 734 ft to 1,217 ft in Elk Creek, and from 790 ft to 1,600 ft in Marsh Creek (Table 4-1, Figure 4-2, Figure 4-3, Figure 4-4). Similarly, there were significant differences in the range of valley width within reference reaches in each of the three study streams. For example, the variability in valley width in Bear Valley Creek ranged from 111 ft to 748 ft (Table 4-1, Figure 4-2). Similar variability in valley width was observed within Elk Creek and Marsh Creek reference reaches, ranging from 157 ft to 475 ft and from 175 ft to 572 ft, respectively (Table 4-1, Figure 4-3, Figure 4-4).

Table 4-1. Valley Width of the Reference Streams and Reaches

Stream and Reach	Valley Width (ft)		
	Minimum	Mean	Maximum
Bear Valley Creek	236	905	1,458
BVC_19.2_18.8	1,050	1,180	1,271
BVC_20.0_19.4	867	1,083	1,275
BVC_23.1_21.5	518	927	1,266
BVC_24.5_24.2	549	698	833
BVC_26.4_25.9	1,347	1,421	1,458
Elk Creek	334	894	1,794
EC_2.0_0.6	424	734	1,040
EC_5.5_4.5	1,093	1,217	1,410
EC_6.4_5.9	853	1,142	1,470
EC_7.5_6.7	696	906	1,171
EC_8.7_8.1	822	939	1,092
EC_9.7_8.8	705	766	862
EC_12.6_12.2	818	957	1,071
Marsh Creek	301	1,079	2,000
MC_13.0_12.4	1,445	1,599	1,772
MC_14.6_13.9	1,140	1,432	1,650
MC_15.4_14.6	812	922	987
MC_16.3_15.5	377	790	949

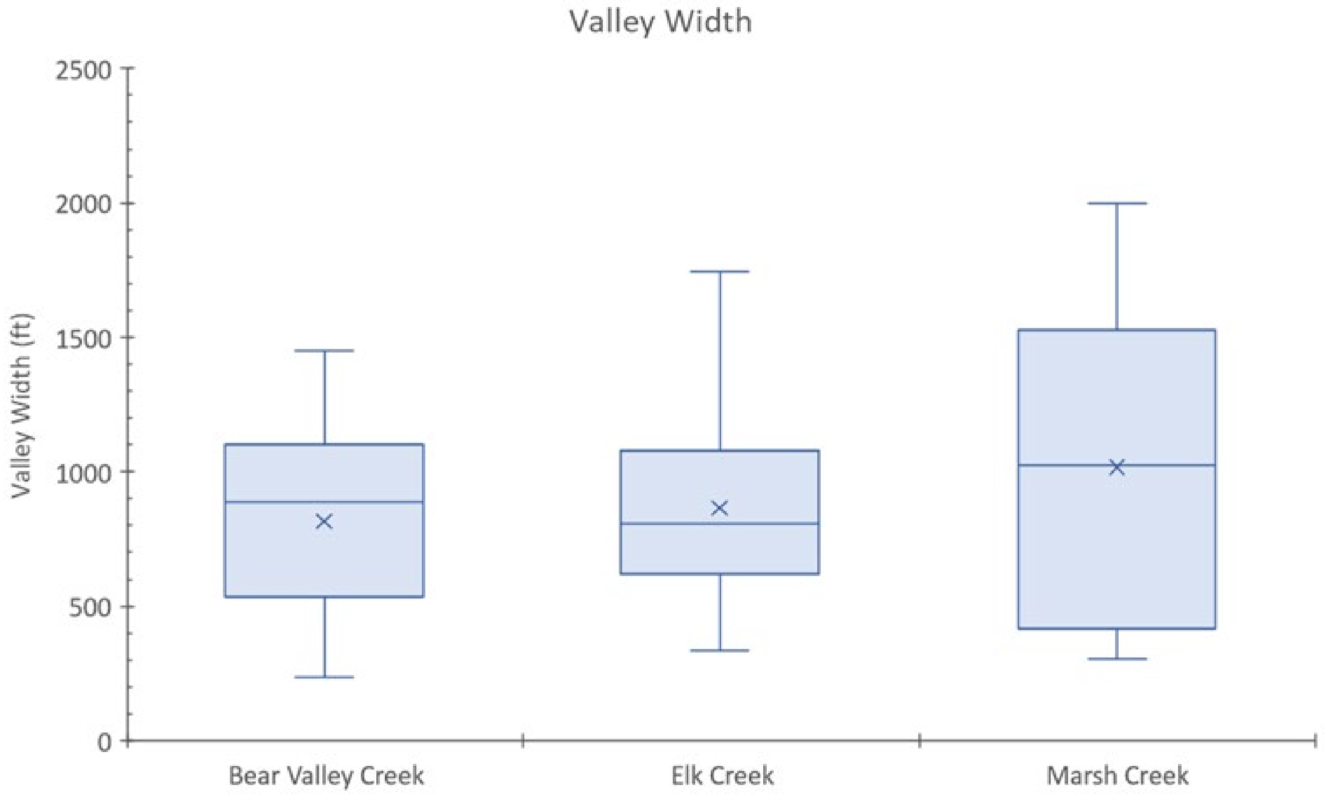


Figure 4-1. Valley width of Bear Valley Creek, Elk Creek, and Marsh Creek.

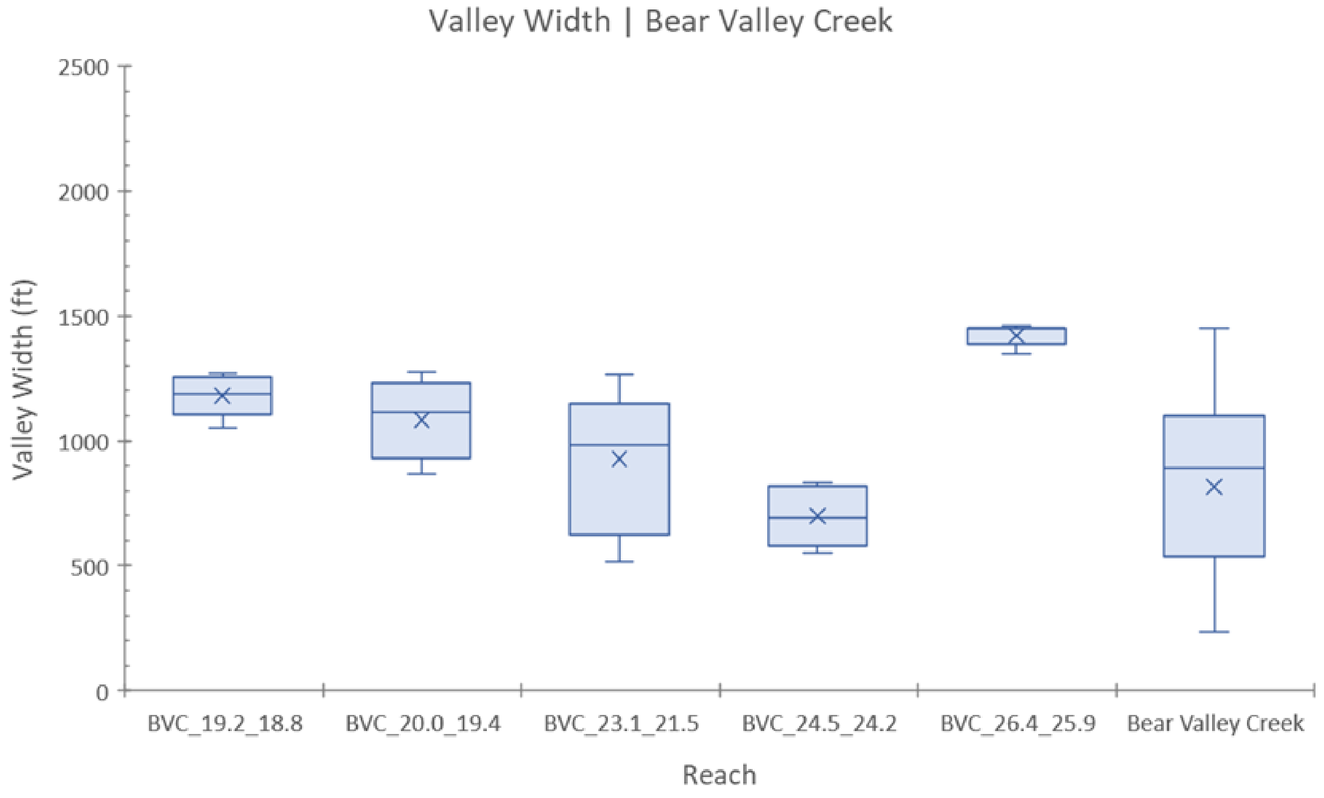


Figure 4-2. Valley width of reference reaches within Bear Valley Creek.

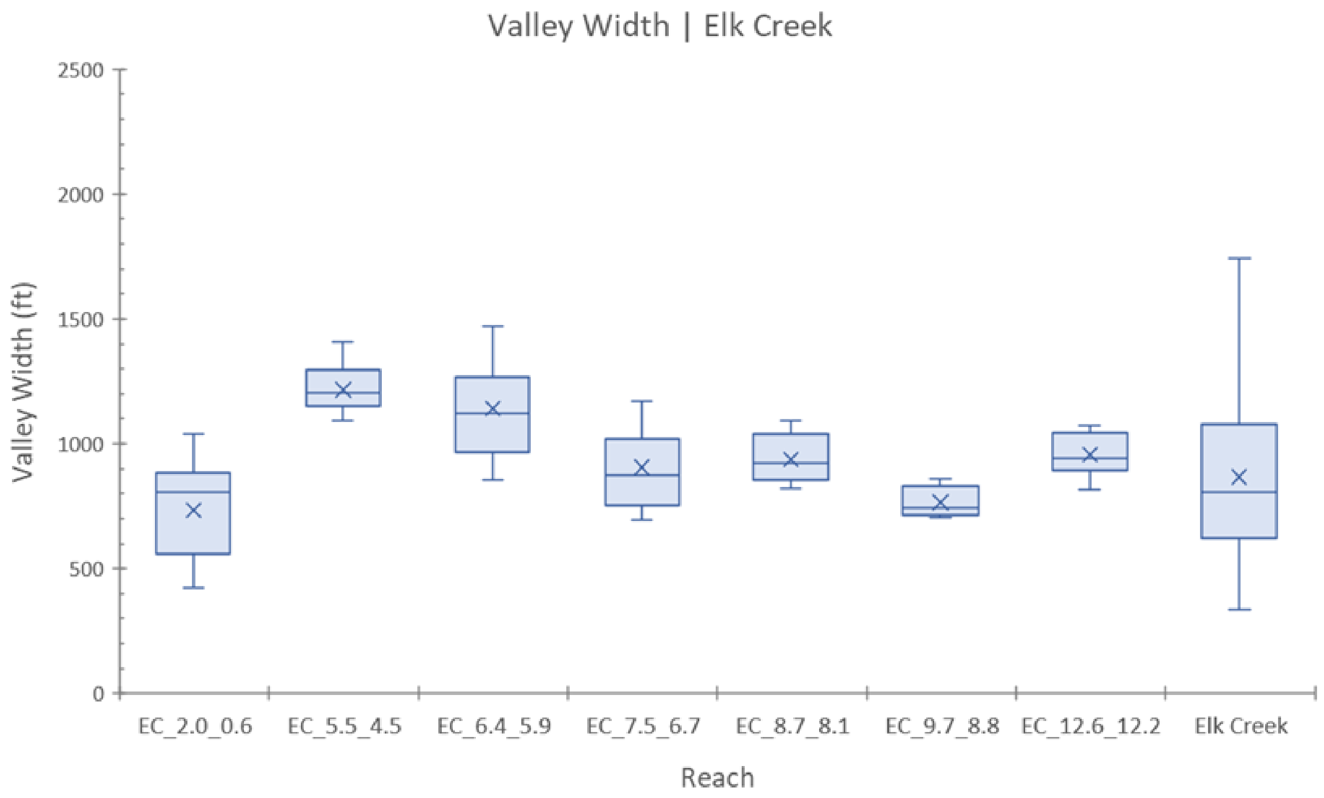


Figure 4-3. Valley width of reference reaches within Elk Creek.

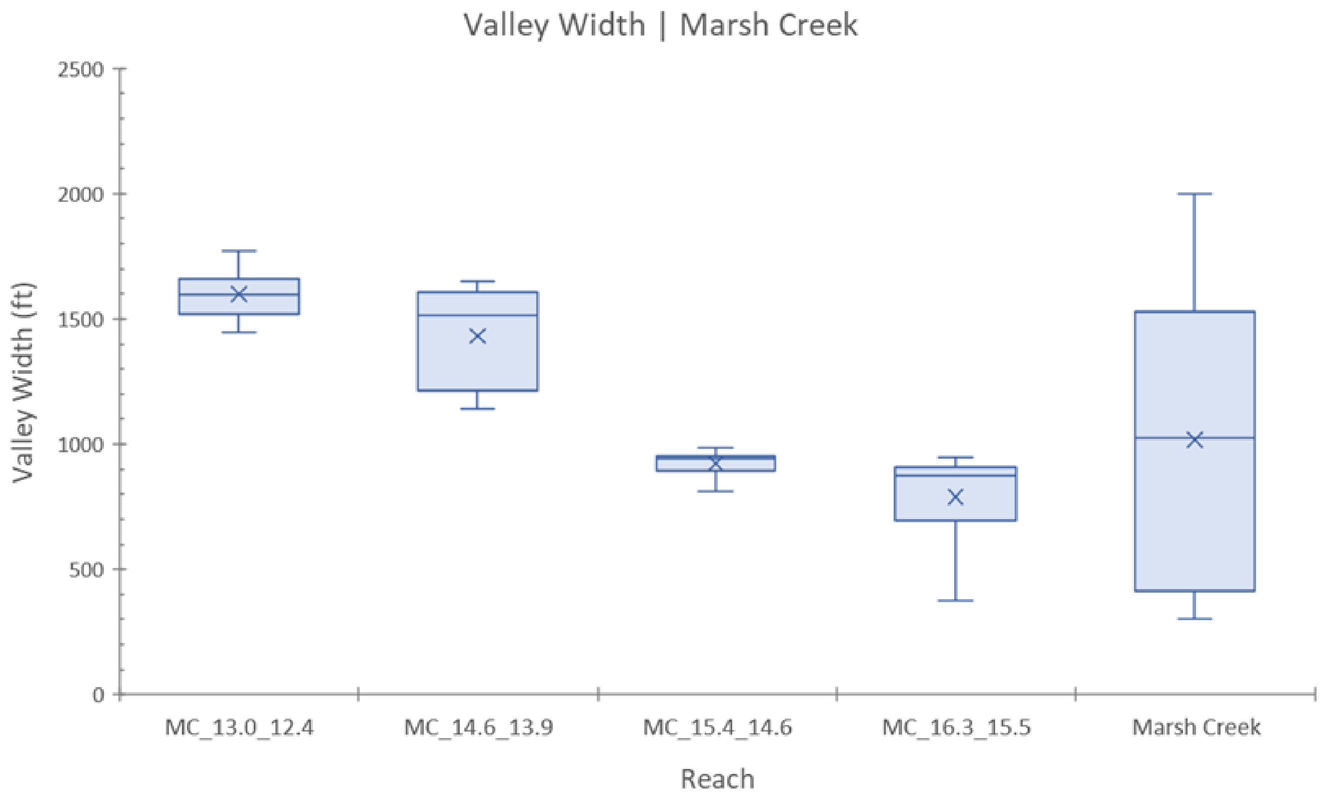


Figure 4-4. Valley width of reference reaches within Marsh Creek.

Table 4-2. Slope, Sinuosity, and Braidedness of the Reference Streams and Reaches

Stream and Reach	Valley Slope	Reach Slope	Sinuosity	Channel Braidedness
Bear Valley Creek	0.0051		1.69	2.87
BVC_19.2_18.8	0.0077	0.0047	1.8	3.3
BVC_20.0_19.4	0.0042	0.0055	1.6	3.5
BVC_23.1_21.5	0.0044	0.0033	1.5	2.4
BVC_24.5_24.2	0.0030	0.0027	1.4	2.9
BVC_26.4_25.9	0.0032	0.0026	2.1	2.3
Elk Creek	0.0017		1.65	2.27
EC_2.0_0.6^	0.0027		1.7	1.7
EC_5.5_4.5	0.0064	0.0007	1.6	2.9
EC_6.4_5.9^	0.0024		1.3	2.6
EC_7.5_6.7*	0.0001	0.0019	1.5	2.0
EC_8.7_8.1*	0.0130		2.0	1.5
EC_9.7_8.8*	0.0005	0.0025	1.5	2.2
EC_12.6_12.2	0.0063	0.0010	1.8	3.0
Marsh Creek	0.0058		1.95	2.28
MC_13.0_12.4	0.0010	0.0045	2.0	2.3
MC_14.6_13.9	0.0112	0.0031	2.0	2.5
MC_15.4_14.6	0.0072	0.0032	1.9	2.2
MC_16.3_15.5	0.0030	0.0036	1.8	2.1

Notes:
Sinuosity and channel braidedness at the stream-scale are average values of the reaches within that stream.
** indicates a reach with questionable source elevation data.*
^ indicates missing field survey data.

4.2 Channel Length and Complexity

The reference reaches exhibit high variability in multi-thread channel length and indicators of channel complexity. Within each reference reach, the sinuosity of the primary channel ranged from 1.4 to 2.1 in Bear Valley Creek, from 1.3 to 2.0 in Elk Creek, and from 1.8 to 2.0 in Marsh Creek (Table 4-2). In all but two of the reference reaches the channel braidedness index (ratio of total channel length to primary channel length) exceeded 2.0, indicating that the total secondary channel lengths within these reaches exceed that of the primary channel length (Table 4-3). Within each reference reach, the channel braidedness index ranged from 2.3 to 3.5 in Bear Valley Creek, from 1.5 to 3.0 in Elk Creek, and from 2.1 to 2.5 in Marsh Creek (Table 4-2, Figure 4-5). There was similar high variability within the reference reaches and among the streams in the valley braidedness index (ratio of total channel length to valley length). Within each reference reach, the valley braidedness index ranged from 3.5 to 5.9 in Bear Valley Creek, from 2.9 to 5.5 in Elk Creek, and from 3.8 to 5.0 in Marsh Creek (Figure 4-5).

All of the reference reaches comprised secondary channel types characterized as Bar-island Split (BIS), Meander-Relict (MR), and Valley-fill Distributed (VFD). Among all the reference reaches, VFD secondary channels were the predominant channel type, followed by MR and BIS secondary channels. When expressed in terms of secondary channel lengths normalized to the valley length and primary channel length, there is high variability among the reference reaches within a stream and among streams. Among all the references reaches and secondary channel types within Bear Valley Creek, the length of secondary channels per 1,000 ft of valley length ranged from 342 ft to 2,881 ft; within Elk Creek and Marsh Creek these values ranged from 40 ft to 2,048 ft and from 141 ft to 2,341 ft, respectively (Table 4-4, Figure 4-6). Similarly, among all the references reaches and secondary channel types within Bear Valley Creek, the length of secondary channels per 1,000 ft of primary channel length ranged from 181 ft to 1,764 ft; within Elk Creek and Marsh Creek these values ranged from 23 ft to 1,125 ft and from 79 ft to 1,161 ft, respectively (Table 4-5, Figure 4-7).

The mean length of secondary channels varied by secondary channel type. Among all the reference reaches in all the reference streams, the mean length of secondary channels was 153 ft for BIS, 243 ft for VFD, and 436 ft for MR (Table 4-6). Results from the ANOVA of mean secondary channel lengths suggest that the BIS mean channel length is different among the reference streams (p=0.02, F=4.2, df=52). The subsequent t-test of means indicates that BIS mean channel lengths are similar in Bear Valley Creek and Elk Creek, while different from Marsh Creek (p=0.16, t=-1.5, df=15). This finding is interpreted to suggest that the length of BIS channels likely scales positively with primary channel size, with Marsh Creek being the smallest of the three reference streams. Results from the ANOVA of mean secondary channel lengths indicate that the MR (p=0.48, F=0.75, df=52) and VFD (p=0.10, F=2.37, df=99) mean channel length is similar among all three reference streams. Collectively, this information suggests that the inter-quartile range (IQR) of MR and VFD channel lengths from all three streams (Table 4-6) could be used as a guide for channel design of streams in similar physical settings and that the IQR of BIS channel lengths from individual reference streams could be used for channel design of streams similar to each reference stream (Figure 4-8).

The complexity of the multi-thread channel network within the reference streams is indicated by the number of junctions (nodes) between the primary channel (1') and secondary channels (2'), as well as between secondary channels. Among all reference reaches, primary channel junctions with VFD secondary channels were most predominant, followed by connections with MR and BIS secondary channels (Figure 4-9). Similarly, junctions between secondary channels (2'-2') were predominantly VFD channels, except in the Bear Valley Creek reference reaches where Beaver Dam Distributed (BDD) secondary channel junctions were most abundant (Figure 4-10). When expressed in terms of the number of channel nodes normalized to the valley length and primary channel length (i.e., node density), there is high variability among the reference reaches within a stream and among streams. The 1'-2' channel node density per 1,000 ft of valley length ranged from 10.3 to 19.5 in Bear Valley Creek, 6.3 to 22.2 in Elk Creek, and 14.1 to 23.0 in Marsh Creek (Table 4-7, Figure 4-11). The 2'-2' channel node density per 1,000 ft of valley length ranged from 11.5 to 36.3 in Bear Valley Creek, 2.2 to 8.8 in Elk Creek, and 1.9 to 8.2 in Marsh Creek (Table 4-7, Figure 4-12). The 1’-2’ channel node density per 1,000 ft of primary channel length ranged from 6.4 to 14.5 in Bear Valley Creek, 4.1 to 12.2 in Elk Creek, and 7.3 to 11.3 in Marsh Creek (Table 4-8, Figure 4-13). The 2’-2’ channel node density per 1,000 ft of primary channel length ranged from 7.0 to 20.1 in Bear Valley Creek, 1.3 to 5.4 in Elk Creek, and 0.9 to 4.1 in Marsh Creek (Table 4-8, Figure 4-14).

Table 4-3. Reference Reach Valley and Channel Lengths

Stream	Reach ID	Valley Length (ft)	Primary Channel Length (ft)	Secondary Channel Length (ft)	Total Channel Length (ft)
Bear Valley Creek	BVC_19.2_18.8	855	1,544	3,510	5,054
Bear Valley Creek	BVC_20.0_19.4	1,114	1,819	4,535	6,354
Bear Valley Creek	BVC_23.1_21.5	3,308	4,934	6,739	11,673
Bear Valley Creek	BVC_24.5_24.2	767	1,036	1,976	3,012
Bear Valley Creek	BVC_26.4_25.9	868	1,861	2,394	4,254
Elk Creek	EC_2.0_0.6	2,722	4,724	3,414	8,138
Elk Creek	EC_5.5_4.5	1,478	2,426	4,556	6,983
Elk Creek	EC_6.4_5.9	1,273	1,699	2,697	4,396
Elk Creek	EC_7.5_6.7	1,733	2,583	2,478	5,061
Elk Creek	EC_8.7_8.1	1,068	2,175	1,054	3,229
Elk Creek	EC_9.7_8.8	1,457	2,165	2,688	4,853
Elk Creek	EC_12.6_12.2	856	1,558	3,181	4,739
Marsh Creek	MC_13.0_12.4	1,608	3,285	4,245	7,530
Marsh Creek	MC_14.6_13.9	1,587	3,200	4,815	8,014
Marsh Creek	MC_15.4_14.6	1,558	3,033	3,572	6,605
Marsh Creek	MC_16.3_15.5	1,828	3,266	3,750	7,016

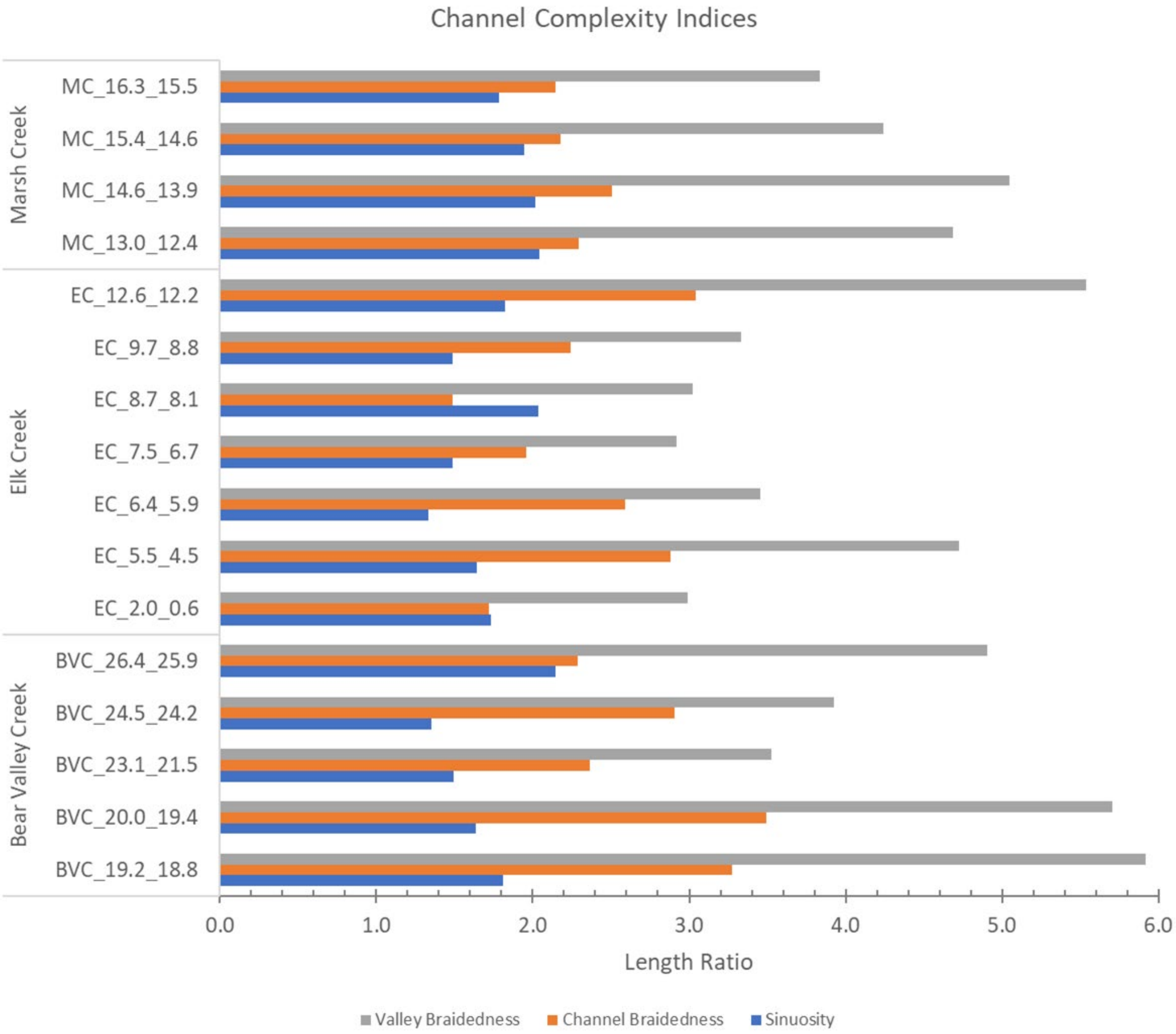


Figure 4-5. Channel complexity indices of reference reaches.

Table 4-4. Secondary Channel Length (by type) per 1,000 ft of Valley Length

Stream	Reach ID	Length (ft)		
		Bar-island Split	Meander-Relict	Valley-fill Distributed
Bear Valley Creek	BVC_19.2_18.8	427	1,424	2,257
Bear Valley Creek	BVC_20.0_19.4	555	635	2,881
Bear Valley Creek	BVC_23.1_21.5	342	1,282	413
Bear Valley Creek	BVC_24.5_24.2	552	1,552	471
Bear Valley Creek	BVC_26.4_25.9	389	1,610	760
Elk Creek	EC_2.0_0.6	40	644	570
Elk Creek	EC_5.5_4.5	1,521	1,449	113
Elk Creek	EC_6.4_5.9	67	1,030	1,022
Elk Creek	EC_7.5_6.7	198	892	339
Elk Creek	EC_8.7_8.1	139	301	547
Elk Creek	EC_9.7_8.8	276	957	612
Elk Creek	EC_12.6_12.2	399	1,270	2,048
Marsh Creek	MC_13.0_12.4	492	951	1,196
Marsh Creek	MC_14.6_13.9	176	517	2,341
Marsh Creek	MC_15.4_14.6	154	430	1,708
Marsh Creek	MC_16.3_15.5	141	971	939

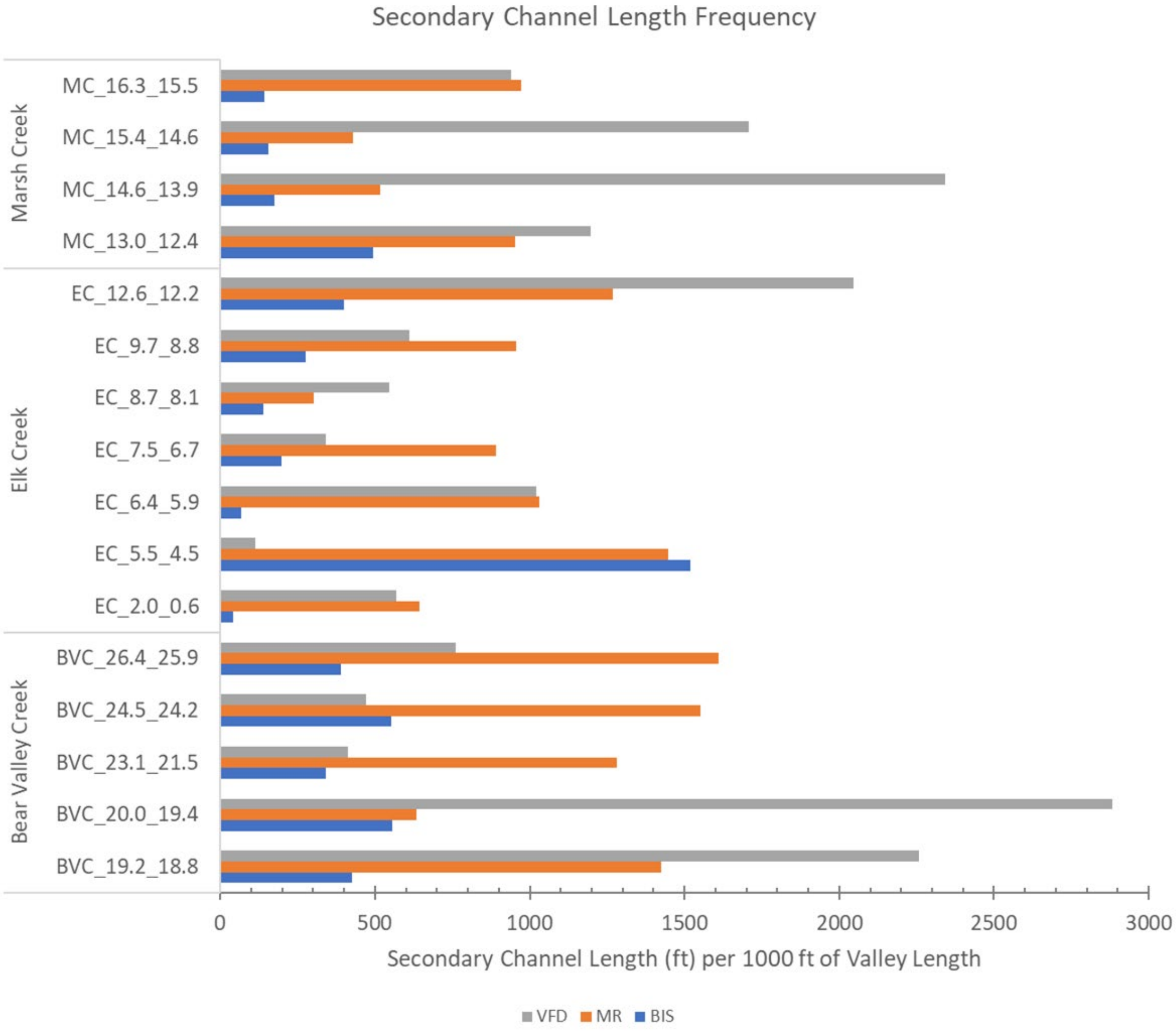


Figure 4-6. Secondary channel length (by type) per 1,000 ft of valley length.

Table 4-5. Secondary Channel Length (by type) per 1,000 ft of Primary Channel Length

Stream	**Reach ID**	**Length (ft)**		
		Bar-island Split	**Meander-Relict**	**Valley-fill Distributed**
Bear Valley Creek	BVC_19.2_18.8	236	788	1,249
Bear Valley Creek	BVC_20.0_19.4	340	389	1,764
Bear Valley Creek	BVC_23.1_21.5	229	860	277
Bear Valley Creek	BVC_24.5_24.2	409	1,150	349
Bear Valley Creek	BVC_26.4_25.9	181	751	354
Elk Creek	EC_2.0_0.6	23	371	328
Elk Creek	EC_5.5_4.5	926	883	69
Elk Creek	EC_6.4_5.9	50	772	766
Elk Creek	EC_7.5_6.7	133	599	228
Elk Creek	EC_8.7_8.1	68	148	269
Elk Creek	EC_9.7_8.8	186	644	412
Elk Creek	EC_12.6_12.2	219	698	1,125
Marsh Creek	MC_13.0_12.4	241	466	585
Marsh Creek	MC_14.6_13.9	87	256	1,161
Marsh Creek	MC_15.4_14.6	79	221	878
Marsh Creek	MC_16.3_15.5	79	544	526

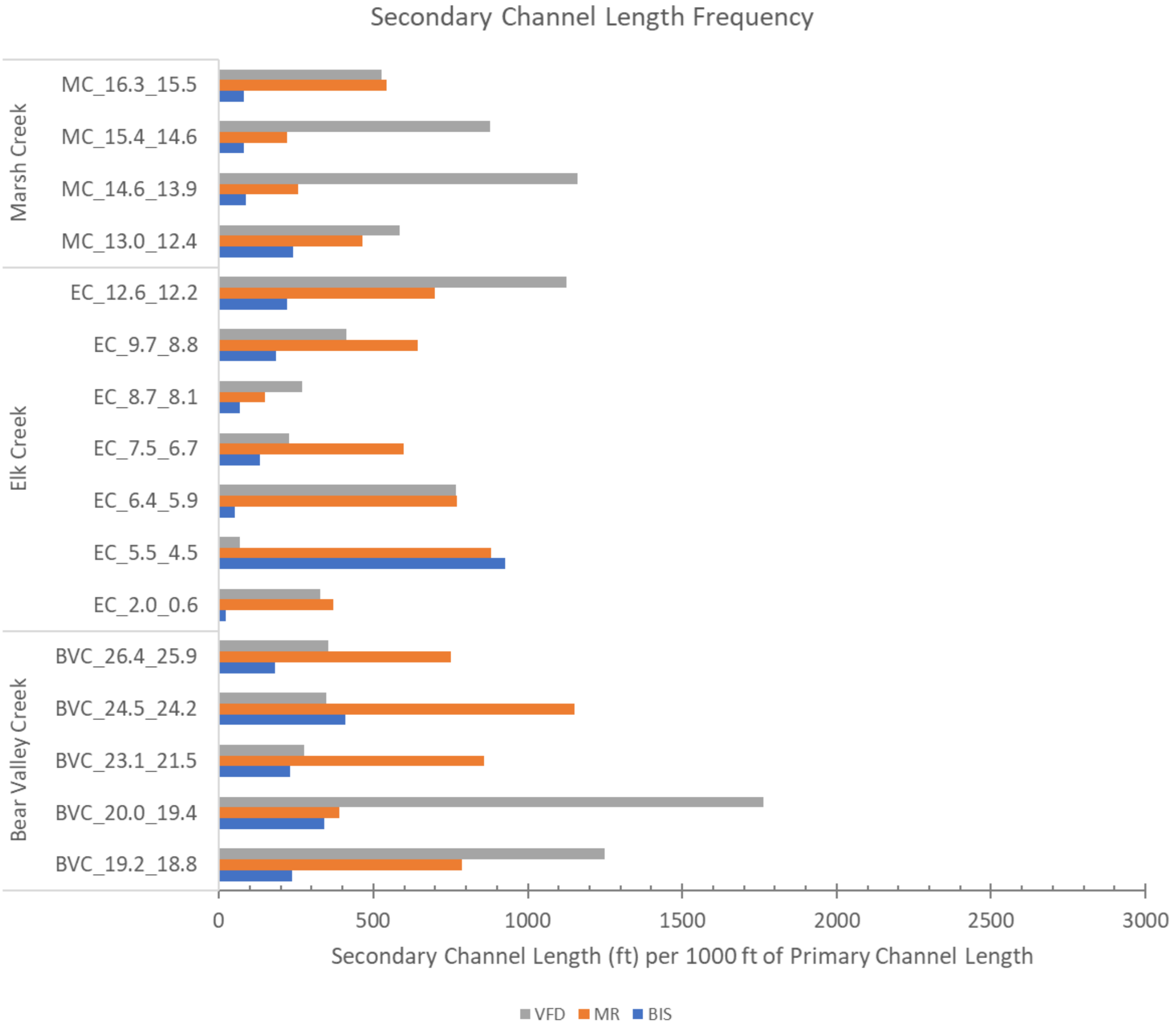


Figure 4-7. Secondary channel length (by type) per 1,000 ft of primary channel length.

Table 4-6. Secondary Channel Length Statistics (by type)

Statistic	Secondary Channel Length (ft)		
	Bar-island Split	Meander-Relict	Valley-fill Distributed
L0.10	68	147	62
L0.25	82	234	98
L0.50	110	377	154
Mean	153	436	243
L0.75	170	543	304
L0.90	257	784	621

Note:
L_x is the percentile value of secondary channel length. Statistics were calculated based on data from all reference reaches.

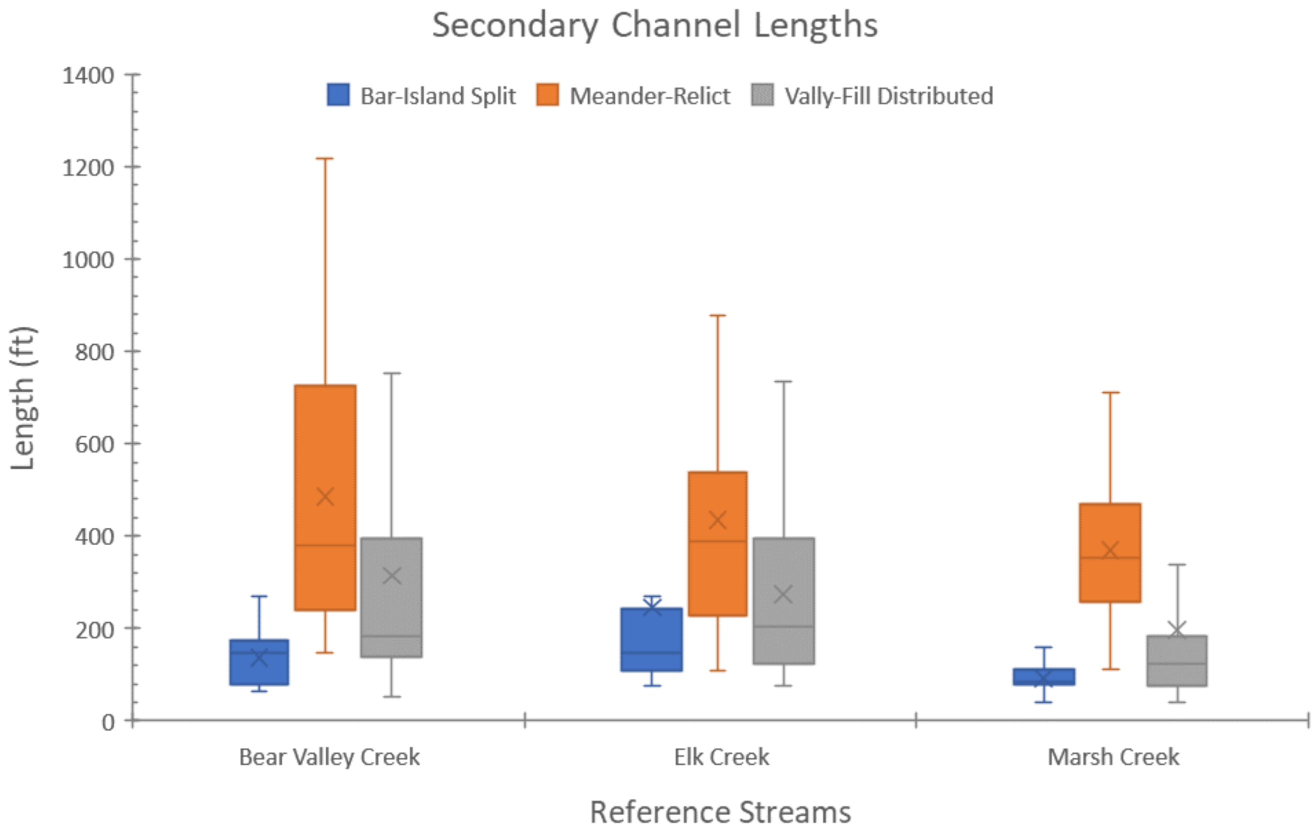


Figure 4-8. Secondary channel lengths (by type) in reference reach streams.

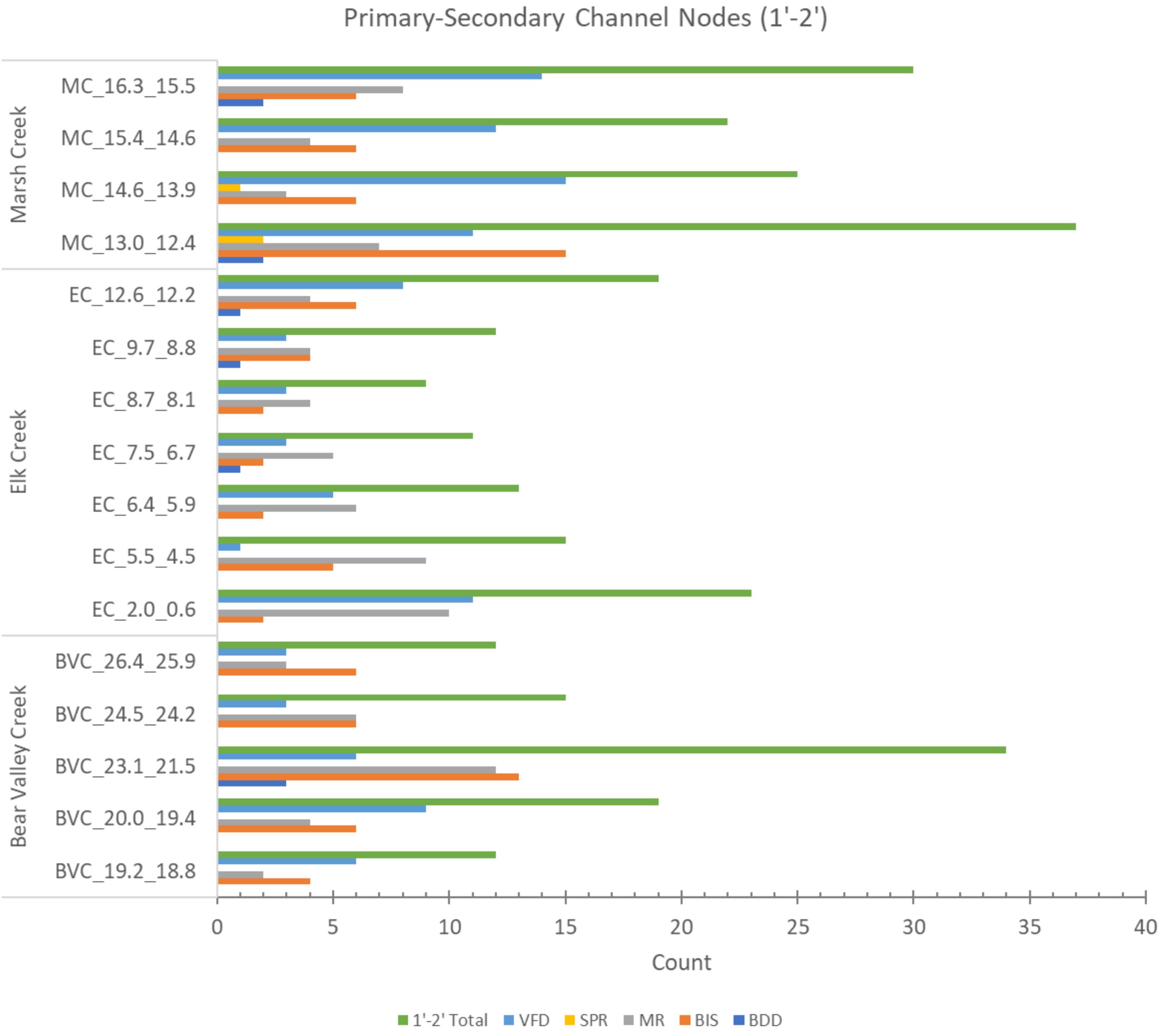


Figure 4-9. Count of junctions/nodes between primary (1') and secondary (2') channels.

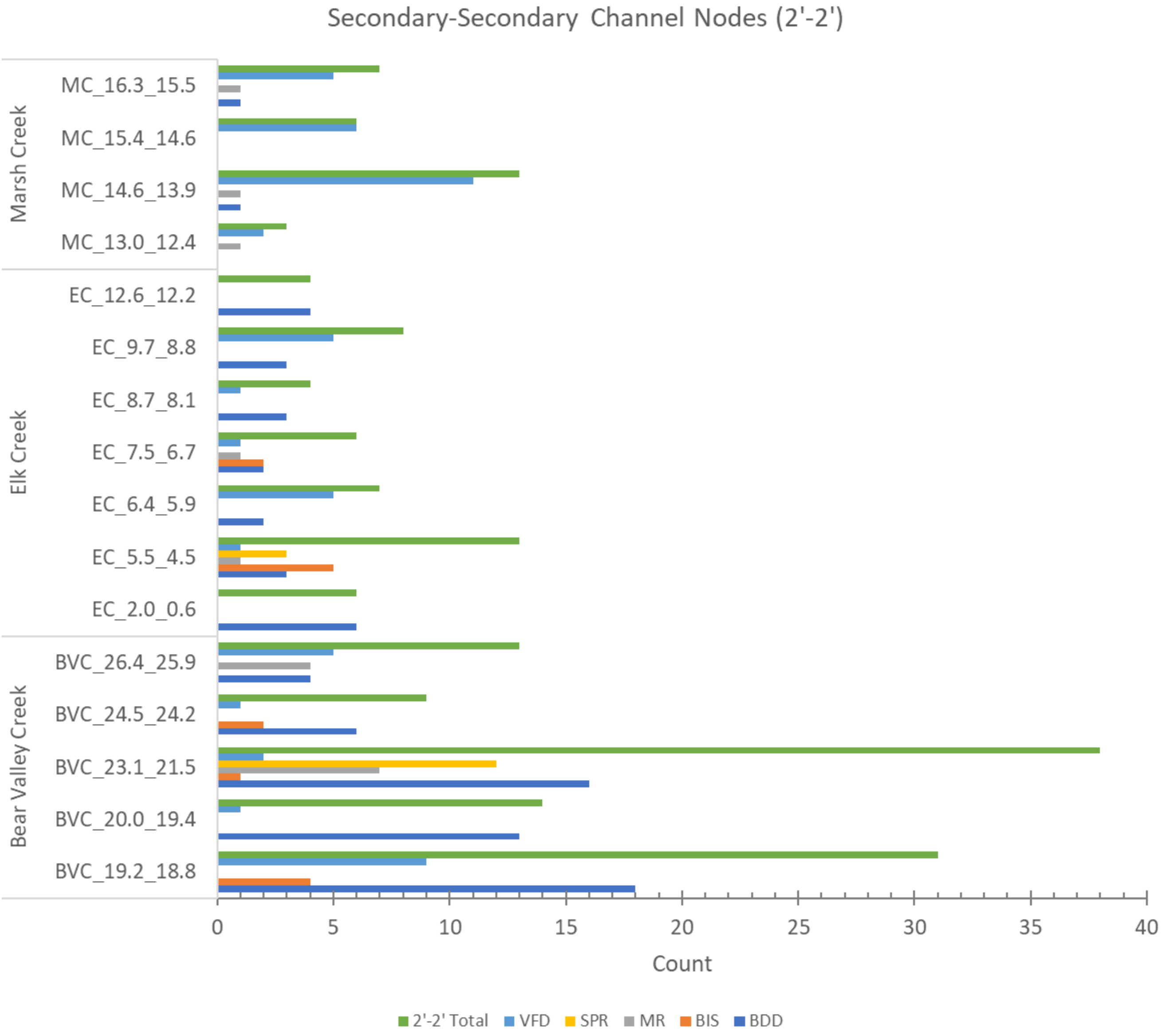


Figure 4-10. Count of junctions/nodes between secondary (2') channels.

Table 4-7. Secondary Channel Nodes (by Type) Per 1,000 ft of Valley Length

Stream and Reach	**Primary-Secondary Nodes (1’-2’)**						**Secondary-Secondary Nodes (2’-2’)**					
	BDD	**BIS**	**MR**	**SPR**	**VFD**	**1’-2’ Total**	**BDD**	**BIS**	**MR**	**SPR**	**VFD**	**2’-2’ Total**
Bear Valley Creek												
BVC_19.2_18.8	0.0	4.7	2.3	0.0	7.0	14.0	21.1	4.7	0.0	0.0	10.5	36.3
BVC_20.0_19.4	0.0	5.4	3.6	0.0	8.1	17.1	11.7	0.0	0.0	0.0	0.9	12.6
BVC_23.1_21.5	0.9	3.9	3.6	0.0	1.8	10.3	4.8	0.3	2.1	3.6	0.6	11.5
BVC_24.5_24.2	0.0	7.8	7.8	0.0	3.9	19.5	7.8	2.6	0.0	0.0	1.3	11.7
BVC_26.4_25.9	0.0	6.9	3.5	0.0	3.5	13.8	4.6	0.0	4.6	0.0	5.8	15.0
Elk Creek												
EC_2.0_0.6	0.0	0.7	3.7	0.0	4.0	8.4	2.2	0.0	0.0	0.0	0.0	2.2
EC_5.5_4.5	0.0	3.4	6.1	0.0	0.7	10.1	2.0	3.4	0.7	2.0	0.7	8.8
EC_6.4_5.9	0.0	1.6	4.7	0.0	3.9	10.2	1.6	0.0	0.0	0.0	3.9	5.5
EC_7.5_6.7	0.6	1.2	2.9	0.0	1.7	6.3	1.2	1.2	0.6	0.0	0.6	3.5
EC_8.7_8.1	0.0	1.9	3.7	0.0	2.8	8.4	2.8	0.0	0.0	0.0	0.9	3.7
EC_9.7_8.8	0.7	2.7	2.7	0.0	2.1	8.2	2.1	0.0	0.0	0.0	3.4	5.5
EC_12.6_12.2	1.2	7.0	4.7	0.0	9.3	22.2	4.7	0.0	0.0	0.0	0.0	4.7
Marsh Creek												
MC_13.0_12.4	1.2	9.3	4.4	1.2	6.8	23.0	0.0	0.0	0.6	0.0	1.2	1.9
MC_14.6_13.9	0.0	3.8	1.9	0.6	9.5	15.8	0.6	0.0	0.6	0.0	6.9	8.2
MC_15.4_14.6	0.0	3.9	2.6	0.0	7.7	14.1	0.0	0.0	0.0	0.0	3.9	3.9
MC_16.3_15.5	1.1	3.3	4.4	0.0	7.7	16.4	0.5	0.0	0.5	0.0	2.7	3.8

Notes:
BDD = Beaver Dam Distributed
BIS = Bar-island Split
MR = Meander-Relict
SPR = Spring
VFD = Valley-fill Distributed

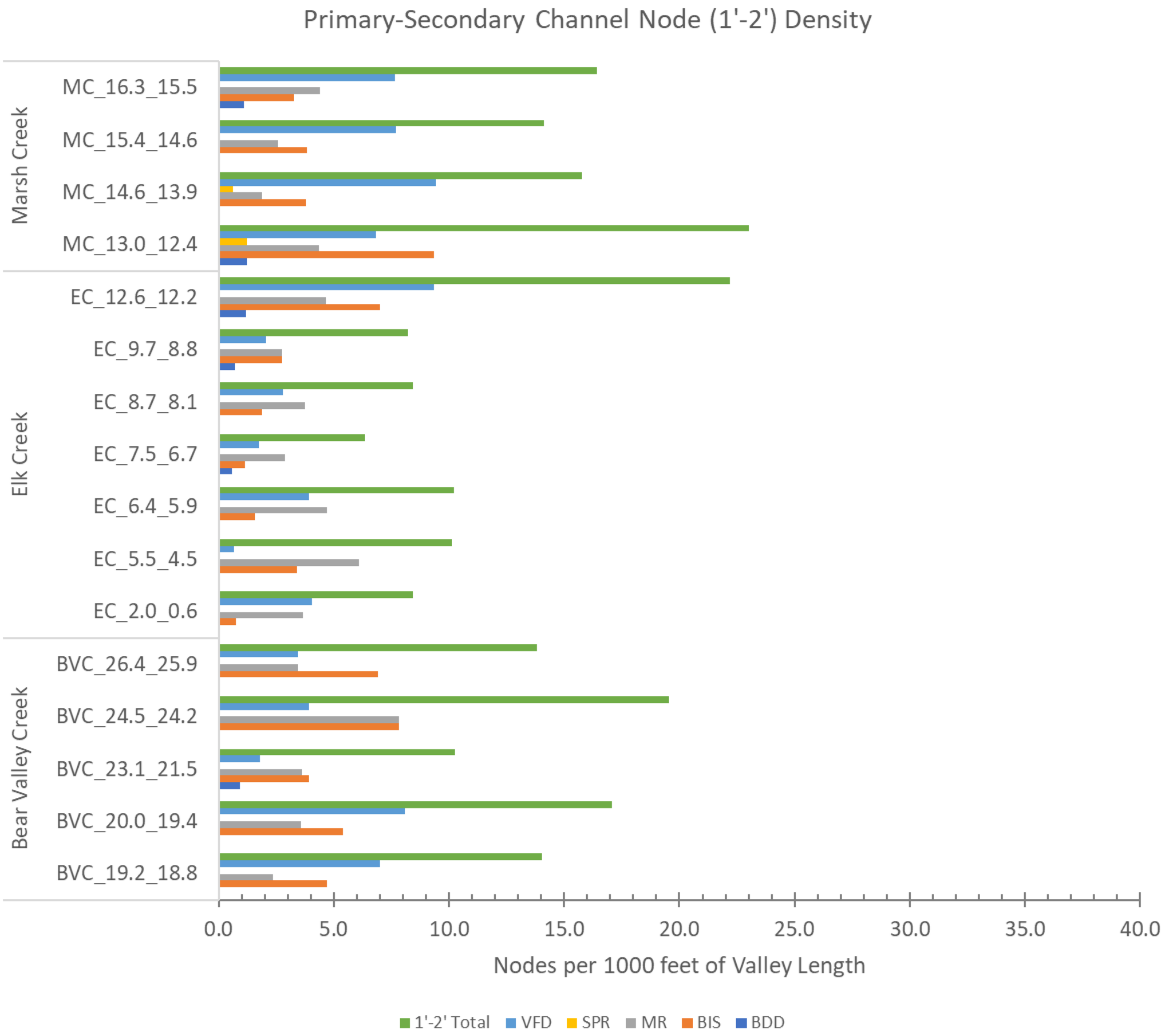


Figure 4-11. Frequency of junctions/nodes between primary (1') and secondary (2') channels per 1,000 ft of valley length.

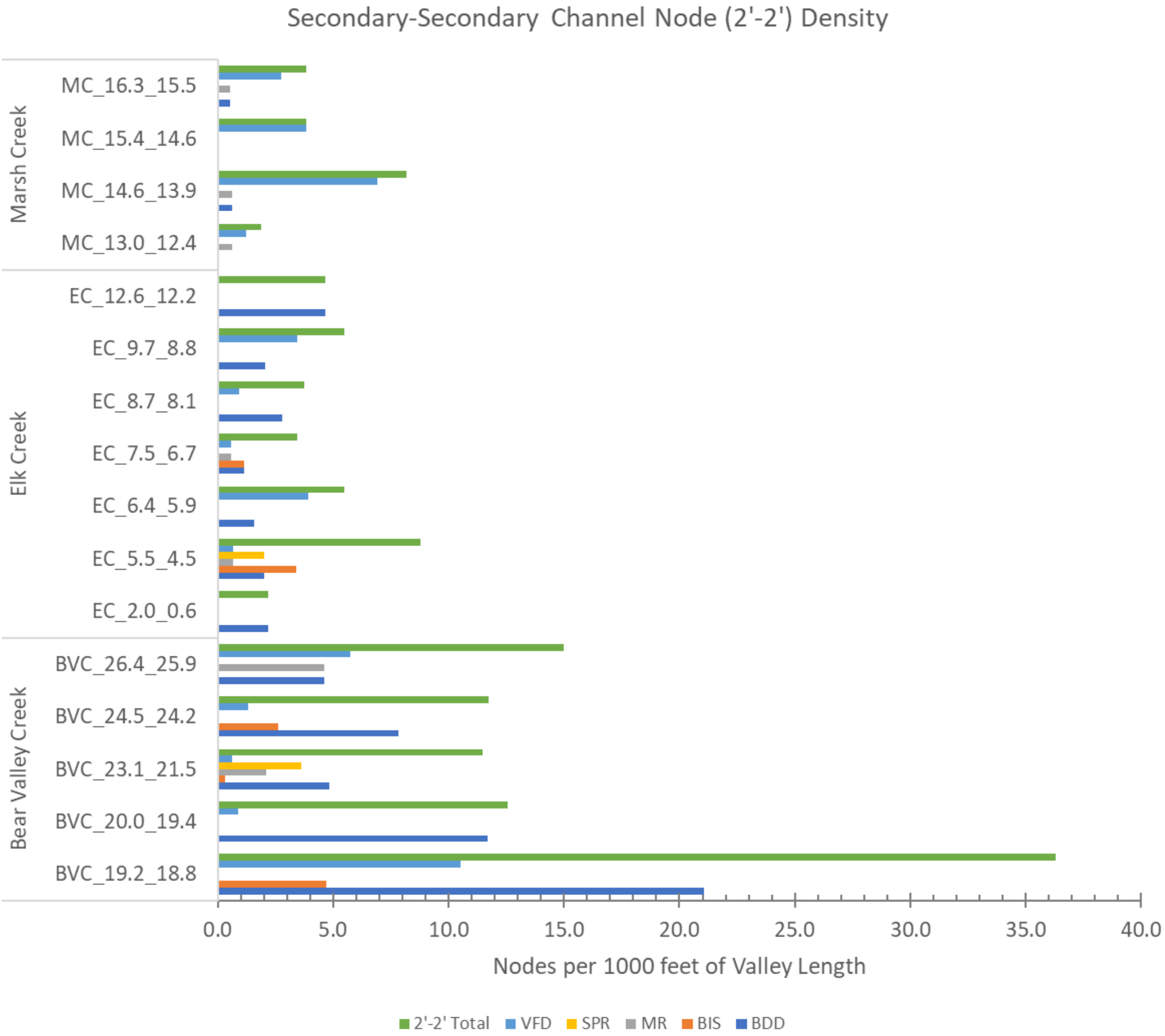


Figure 4-12. Frequency of junctions/nodes between secondary (2') channels per 1,000 ft of valley length.

Table 4-8. Secondary Channel Nodes (by Type) per 1,000 ft of Primary Channel Length

Stream and Reach	**Primary-Secondary Nodes (1’-2’)**						**Secondary-Secondary Nodes (2’-2’)**					
	BDD	**BIS**	**MR**	**SPR**	**VFD**	**1’-2’ Total**	**BDD**	**BIS**	**MR**	**SPR**	**VFD**	**2’-2’ Total**
Bear Valley Creek												
BVC_19.2_18.8	0.0	2.6	1.3	0.0	3.9	7.8	11.7	2.6	0.0	0.0	5.8	20.1
BVC_20.0_19.4	0.0	3.3	2.2	0.0	4.9	10.4	7.1	0.0	0.0	0.0	0.5	7.7
BVC_23.1_21.5	0.6	2.6	2.4	0.0	1.2	6.9	3.2	0.2	1.4	2.4	0.4	7.7
BVC_24.5_24.2	0.0	5.8	5.8	0.0	2.9	14.5	5.8	1.9	0.0	0.0	1.0	8.7
BVC_26.4_25.9	0.0	3.2	1.6	0.0	1.6	6.4	2.1	0.0	2.1	0.0	2.7	7.0
Elk Creek												
EC_2.0_0.6	0.0	0.4	2.1	0.0	2.3	4.9	1.3	0.0	0.0	0.0	0.0	1.3
EC_5.5_4.5	0.0	2.1	3.7	0.0	0.4	6.2	1.2	2.1	0.4	1.2	0.4	5.4
EC_6.4_5.9	0.0	1.2	3.5	0.0	2.9	7.7	1.2	0.0	0.0	0.0	2.9	4.1
EC_7.5_6.7	0.4	0.8	1.9	0.0	1.2	4.3	0.8	0.8	0.4	0.0	0.4	2.3
EC_8.7_8.1	0.0	0.9	1.8	0.0	1.4	4.1	1.4	0.0	0.0	0.0	0.5	1.8
EC_9.7_8.8	0.5	1.8	1.8	0.0	1.4	5.5	1.4	0.0	0.0	0.0	2.3	3.7
EC_12.6_12.2	0.6	3.9	2.6	0.0	5.1	12.2	2.6	0.0	0.0	0.0	0.0	2.6
Marsh Creek												
MC_13.0_12.4	0.6	4.6	2.1	0.6	3.3	11.3	0.0	0.0	0.3	0.0	0.6	0.9
MC_14.6_13.9	0.0	1.9	0.9	0.3	4.7	7.8	0.3	0.0	0.3	0.0	3.4	4.1
MC_15.4_14.6	0.0	2.0	1.3	0.0	4.0	7.3	0.0	0.0	0.0	0.0	2.0	2.0
MC_16.3_15.5	0.6	1.8	2.4	0.0	4.3	9.2	0.3	0.0	0.3	0.0	1.5	2.1

Notes:
BDD = Beaver Dam Distributed
BIS = Bar-island Split
MR = Meander-Relict
SPR = Spring
VFD = Valley-fill Distributed

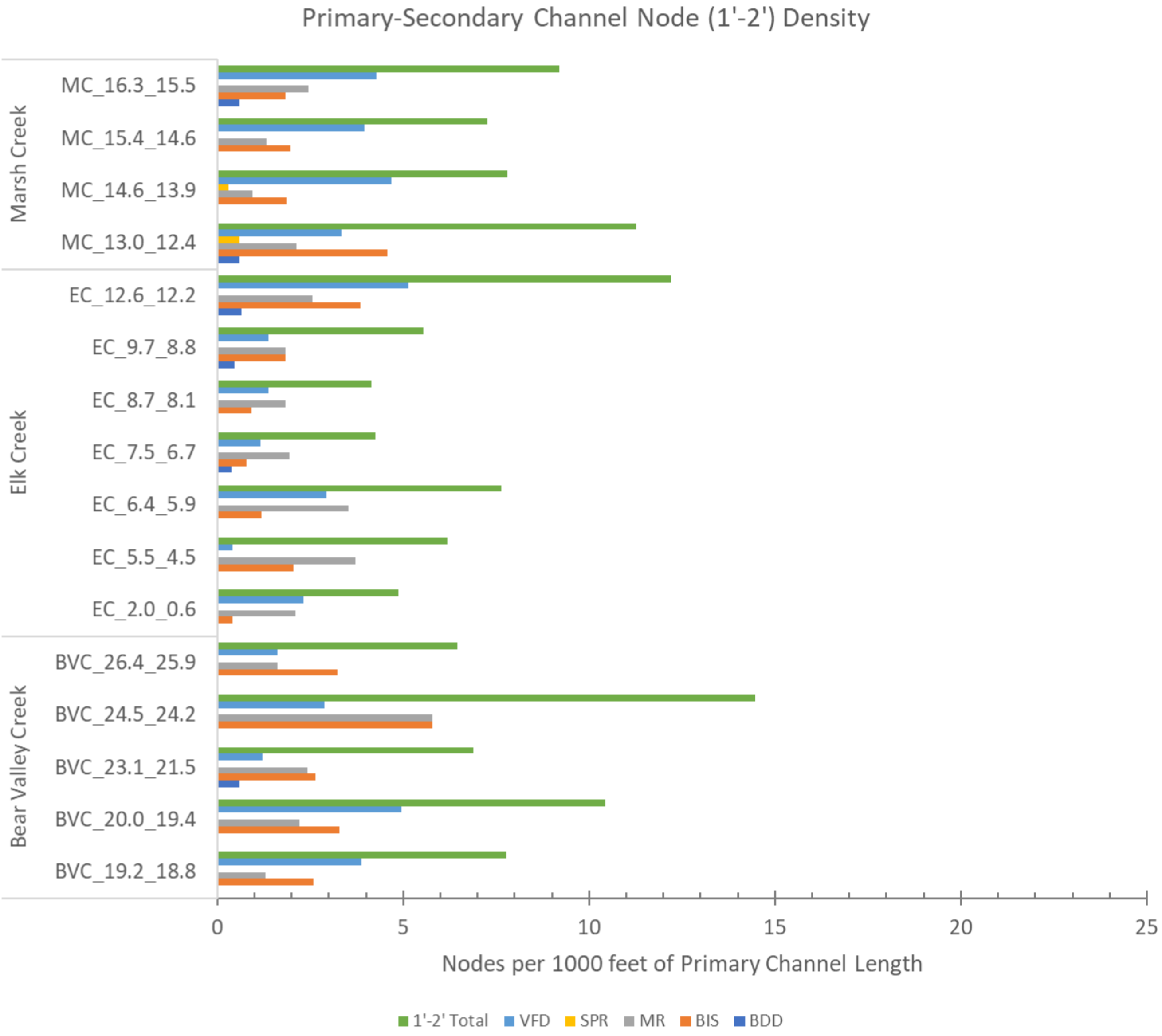


Figure 4-13. Frequency of junctions/nodes between primary (1') and secondary (2') channels per 1,000 ft of channel length.

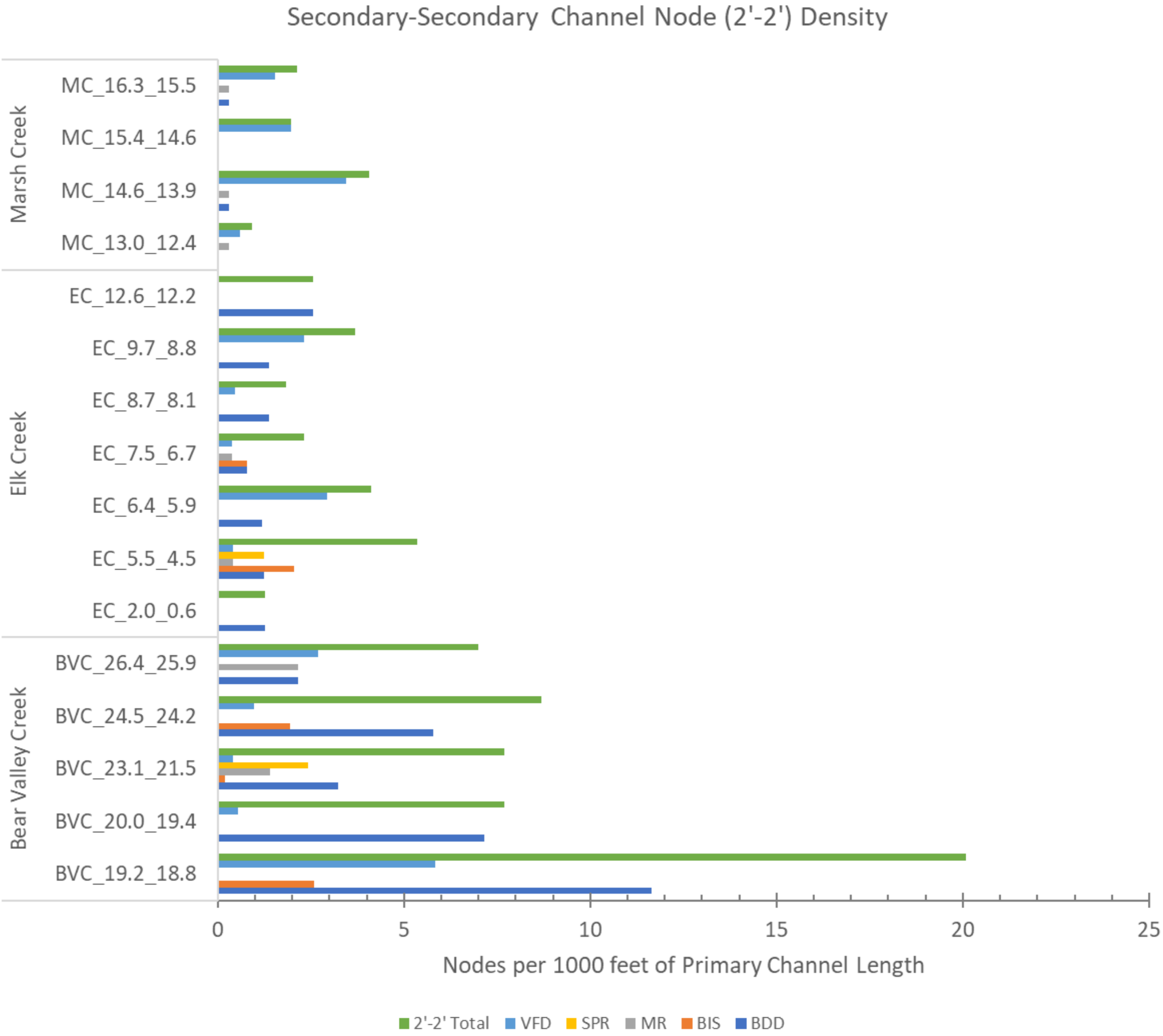


Figure 4-14. Frequency of junctions/nodes between secondary (2') channels per 1,000 ft of channel length.

4.3 Reach-scale Geometry

While all of the reference streams are located in similar valley settings, their differences in the top width of the primary channel reflect their differences in drainage area and discharge. Among the three reference streams, Elk Creek, with the largest drainage area and discharge, had the largest primary channel mean top width of 67.5 ft, followed by Bear Valley Creek and Marsh Creek with mean top widths of 46.7 ft and 33.5 ft, respectively (Table 4-9, Figure 4-15). There was high variability in primary channel top with among the reference reaches within each reference stream. The mean top width among reaches in Bear Valley Creek ranged from 37.6 ft to 53.8 ft (Figure 4-16), while that in Elk Creek and Marsh Creek ranged from 52.4 ft to 82.3 ft (Figure 4-17) and 31.8 ft to 35.4 ft (Figure 4-18), respectively. Results from the ANOVA of mean channel widths indicates that the primary channel top width is different among all of the reference streams ($p<<0.001$). The subsequent t-tests of means suggest that the mean primary channel top widths in each reference stream is different from both other reference streams ($p<<0.001$); i.e., based on primary channel top widths, each reference stream is unique. Collectively, this information suggests that the IQR of primary channel top width from each reference stream (Table 4-9) could be used as a guide for channel design of streams with geomorphic and hydraulic characteristics similar to each reference stream.

The variability of the pool-riffle channel morphology of the reference streams is reflected in the abundance of these geomorphic units in the primary channel. The number of pools per 1,000 ft of primary channel length ranged from 3 to 6 among the reference reaches within Bear Valley Creek, while in Elk Creek and Marsh Creek pool frequency per 1,000 ft of primary channel length ranged from 4 to 6 and from 2 to 7, respectively (Figure 4-19). There was similar variation in the abundance of all geomorphic units per 1,000 ft of primary channel length. The number of geomorphic units per 1,000 ft of primary channel length ranged from 6 to 12 among the reference reaches within Bear Valley Creek, while in Elk Creek and Marsh Creek geomorphic unit frequency per 1,000 ft of primary channel length ranged from 7 to 12 and from 4 to 13, respectively (Figure 4-19).

The longitudinal profiles of the primary channel thalweg in the reference streams exhibit remarkable variability (Figure 4-20). All of the reference reaches within each reference stream had thalweg profiles with marked changes in slope, including relatively steep slopes from riffle into a pool (termed “riffle to pool”), followed by a lower slope into the pool bottom (termed “pool inlet”), and a lower slope from the pool bottom (termed “pool outlet”) to an inflection in the profile resulting in a relatively steep slope from the pool to a riffle (termed “pool to riffle”). The mean slope of riffle to pool transitions ranged from 4.9% to 11.0% in Bear Valley Creek reference reaches, from 10.0% to 11.9% in Elk Creek, and from 4.9% to 11.2% in Marsh Creek (Figure 4-20). The mean slope of pool to riffle transitions ranged from 3.3% to 4.7% in Bear Valley Creek reference reaches, from 5.7% to 8.9% in Elk Creek, and from 5.1% to 11.2% in Marsh Creek (Figure 4-20). Results from the ANOVA of mean transition slopes for all geomorphic units indicate that the pool to riffle slope is different among all of the reference streams ($p=0.002$, $F=6.7$, $df=88$). The subsequent t-test of means indicates that mean pool to riffle slopes are similar in Elk Creek and Marsh Creek, while different from Bear Valley Creek ($p=0.49$, $t=2.0$, $df=58$) (Figure 4-21). For all of the other geomorphic unit transition slopes, ANOVA results indicate no significant difference in the mean slope among the reference streams ($p>>0.01$). Collectively, this information suggests that the IQR of pool to riffle slope in Bear Valley Creek should be considered separately from that in Elk Creek and Marsh Creek when being used as a design guide; however, the IQR of all other geomorphic unit transition slopes from all of the reference streams combined (Table 4-10, Figure 4-22) could be used as a guide for channel design of streams with geomorphic and hydraulic characteristics similar to any of the reference streams.

The variability in longitudinal profiles of the reference reaches is also reflected in the residual pool depth of the primary channel. Among the reference reaches within each reference stream, the IQR of residual pool depth ranged from 0.8 ft to 1.9 ft in Bear Valley Creek, 2.6 ft to 4.3 ft in Elk Creek, and 1.3 ft to 2.5 ft in Marsh Creek (Table 4-11, Figure 4-23). Results from the ANOVA of mean residual pool depths indicates that the primary channel residual pool depth is different among all of the reference streams ($p<<0.001$, $F=42.8$, $df=84$). The subsequent t-tests of means suggest that the mean primary channel residual pool depth is marginally statistically similar in Bear Valley Creek and Marsh Creek (p=0.01, t=2.0, df=58), and significantly different from that in Elk Creek (p<<0.001). Collectively, this information suggests that the IQR of primary channel residual pool depth from each reference stream (Table 4-11, Figure 4-23) could be used as a guide for channel design of streams with geomorphic and hydraulic characteristics similar to each reference stream.

The inlet angles from primary to secondary channels vary widely within the reference reaches and among the secondary channel types. In Bear Valley Creek the mean inlet angle to BIS channels was 73° (IQR 43°–99°), while the mean inlet angle to MR channels was 77° (IQR 62°–93°), and the mean inlet angle to VFD channels was 59° (IQR 42°–80°) (Figure 4-24). In Elk Creek, the mean inlet angle to BIS channels was 73° (IQR 35°–108°), while the mean inlet angle to MR channels was 89° (IQR 70°–109°), and the mean inlet angle to VFD channels was 95° (IQR 66°–125°) (Figure 4-24). In Marsh Creek the mean inlet angle to BIS channels was 59° (IQR 46°–72°), while the mean inlet angle to MR channels was 79° (IQR 57°–108°), and the mean inlet angle to VFD channels was 81° (IQR 63°–98°) (Figure 4-24). Results from the ANOVA indicate that the mean inlet angles to BIS, MR, and VFD channels are not different among the reference streams (p=0.33, F=1.14, df=46; p=0.35, F=1.08, df=43; p=0.04, F=3.55, df=41, respectively). Collectively, this information suggests that for a given secondary channel type (BIS, MR, VFD) the IQR from all reference streams could be used as a guide for design of inlet angles from primary to secondary channels (Table 4-12, Figure 4-25).

Table 4-9. Top Width in Primary Channel Statistics

Statistic	**Top Width (ft)**		
	Bear Valley Creek	**Elk Creek**	**Marsh Creek**
$TW_{0.10}$	31.7	41.9	23.9
$TW_{0.25}$	37.8	51.1	27.4
$TW_{0.50}$	44.4	63.2	31.9
Mean	46.7	67.5	33.5
$TW_{0.75}$	53.0	81.1	38.1
$TW_{0.90}$	65.7	100.1	45.3

Note:
TW_x is the percentile value of top width in the primary channel (TW).

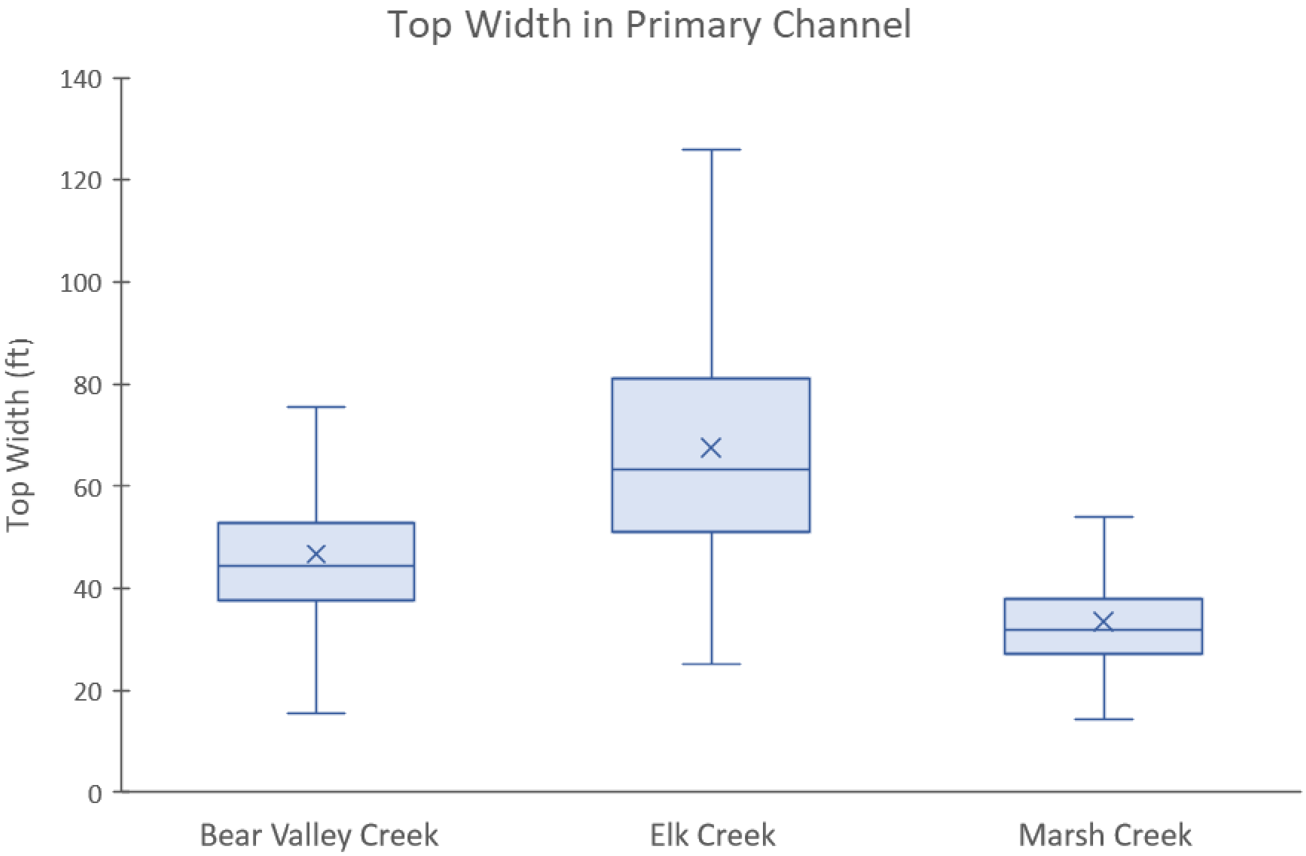


Figure 4-15. Primary channel width of reference reach streams.

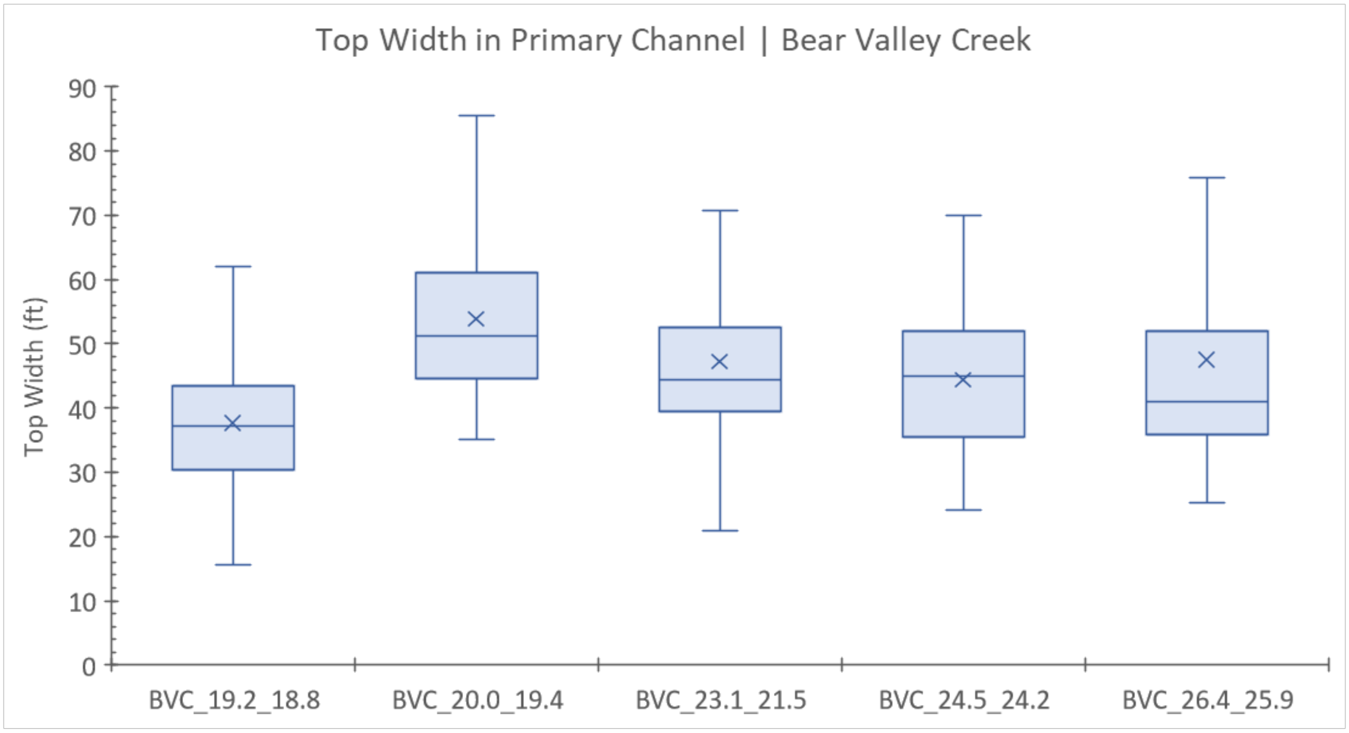


Figure 4-16. Primary channel width of reference reaches in Bear Valley Creek.

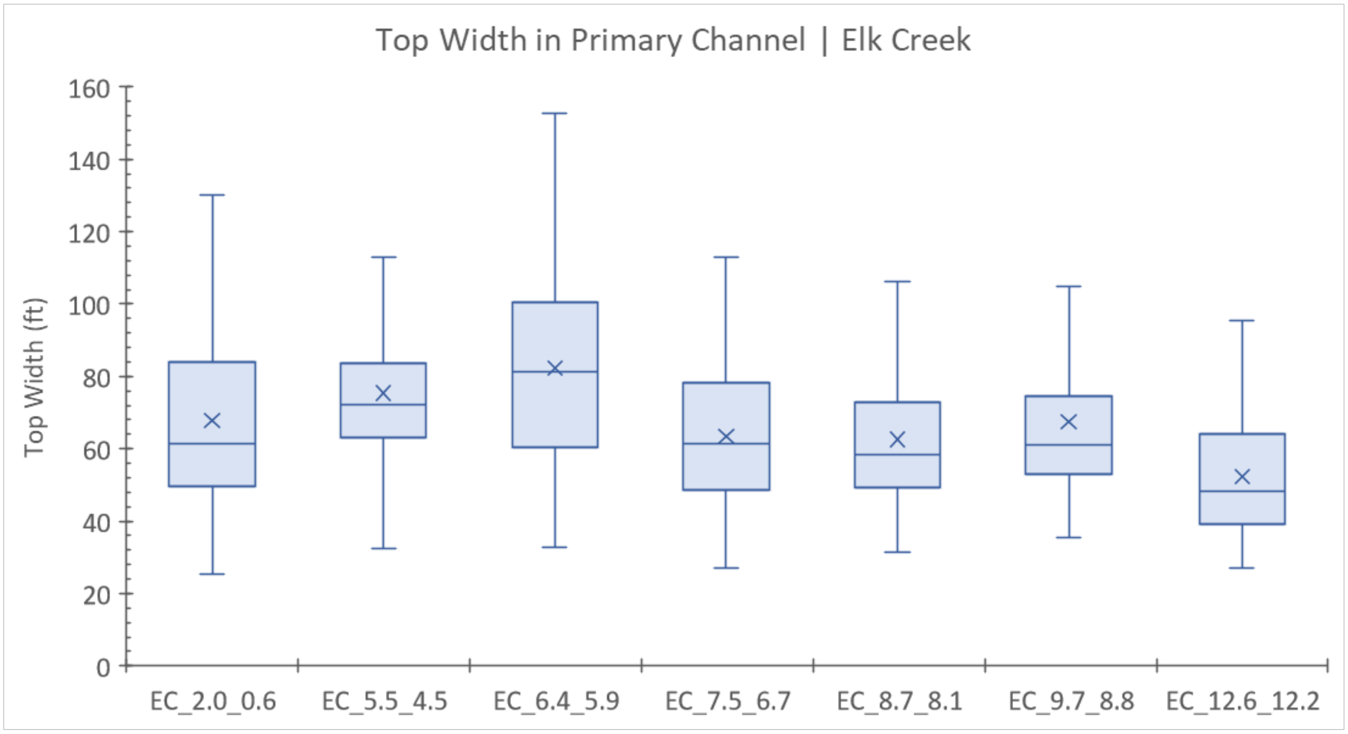


Figure 4-17. Primary channel width of reference reaches in Elk Creek.

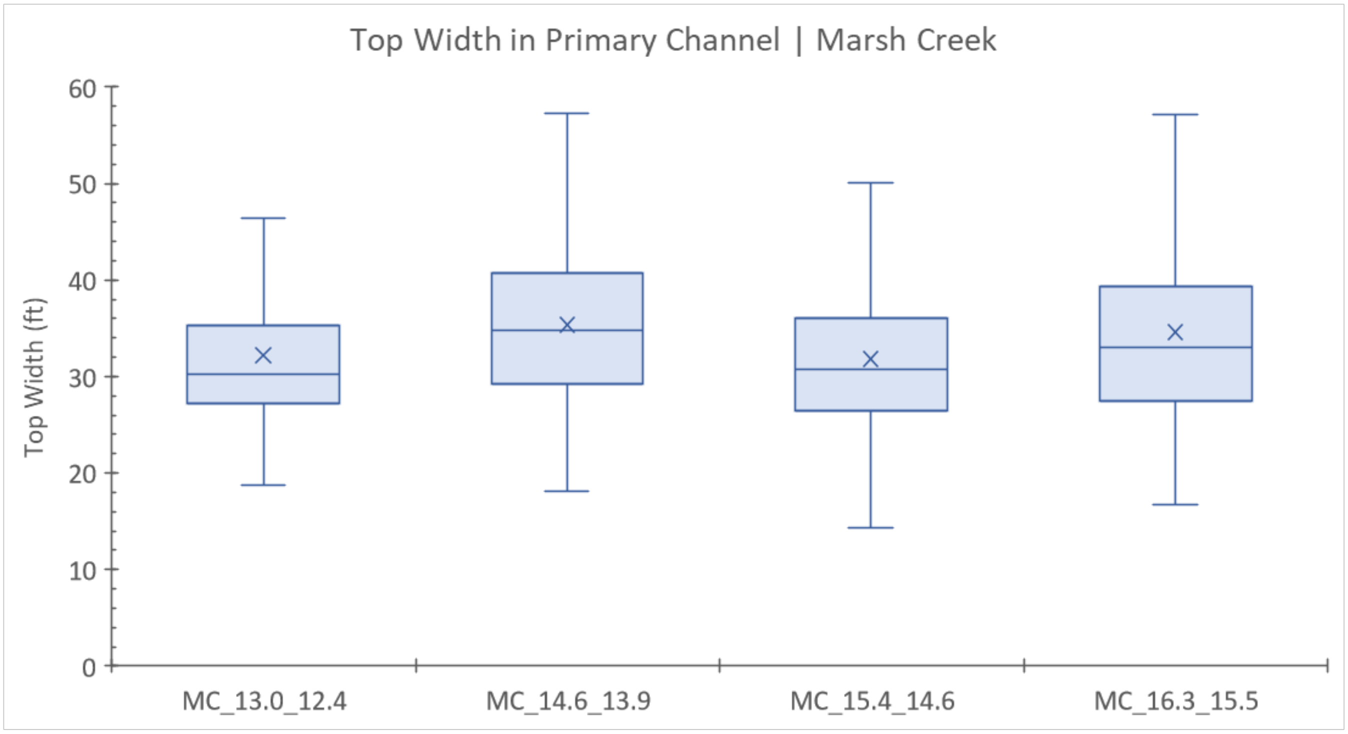


Figure 4-18. Primary channel width of reference reaches in Marsh Creek.

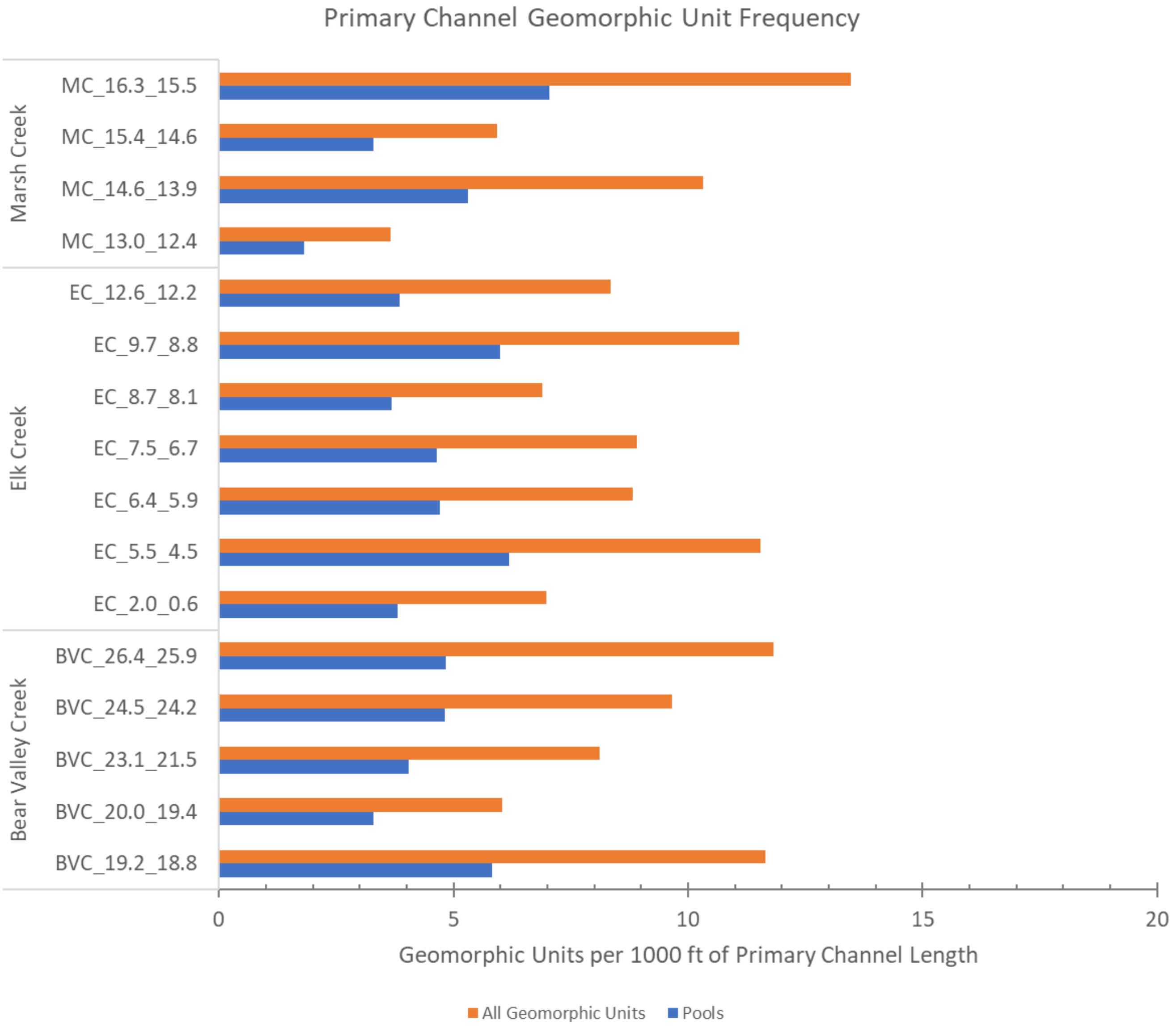


Figure 4-19. Number of geomorphic units per 1,000 ft of primary channel length.

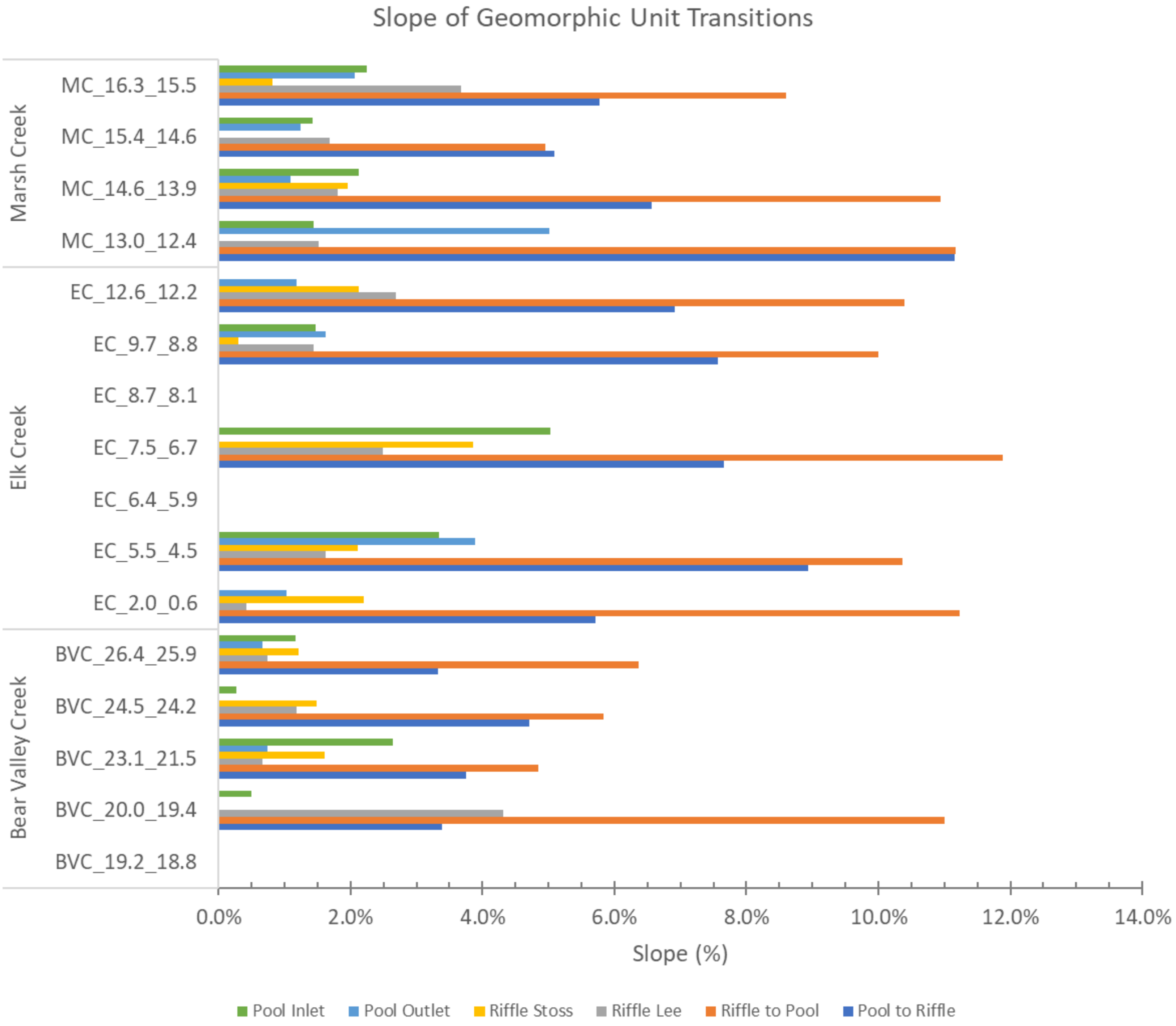


Figure 4-20. Mean slope of geomorphic unit transitions in all reference reaches.

Notes:

Pool to riffle (P2R) is along a steep profile transition from pool bottom to downstream riffle crest; Pool inlet (Pi) is upstream of pool bottom; Pool outlet (Po) is downstream of pool bottom; Riffle to Pool (R2P) is along a steep profile transition from riffle crest to downstream pool bottom; Riffle lee (Rl) is a relatively low slope downstream of the riffle crest; Riffle stoss (Rs) is a relatively low slope upstream of the riffle crest.

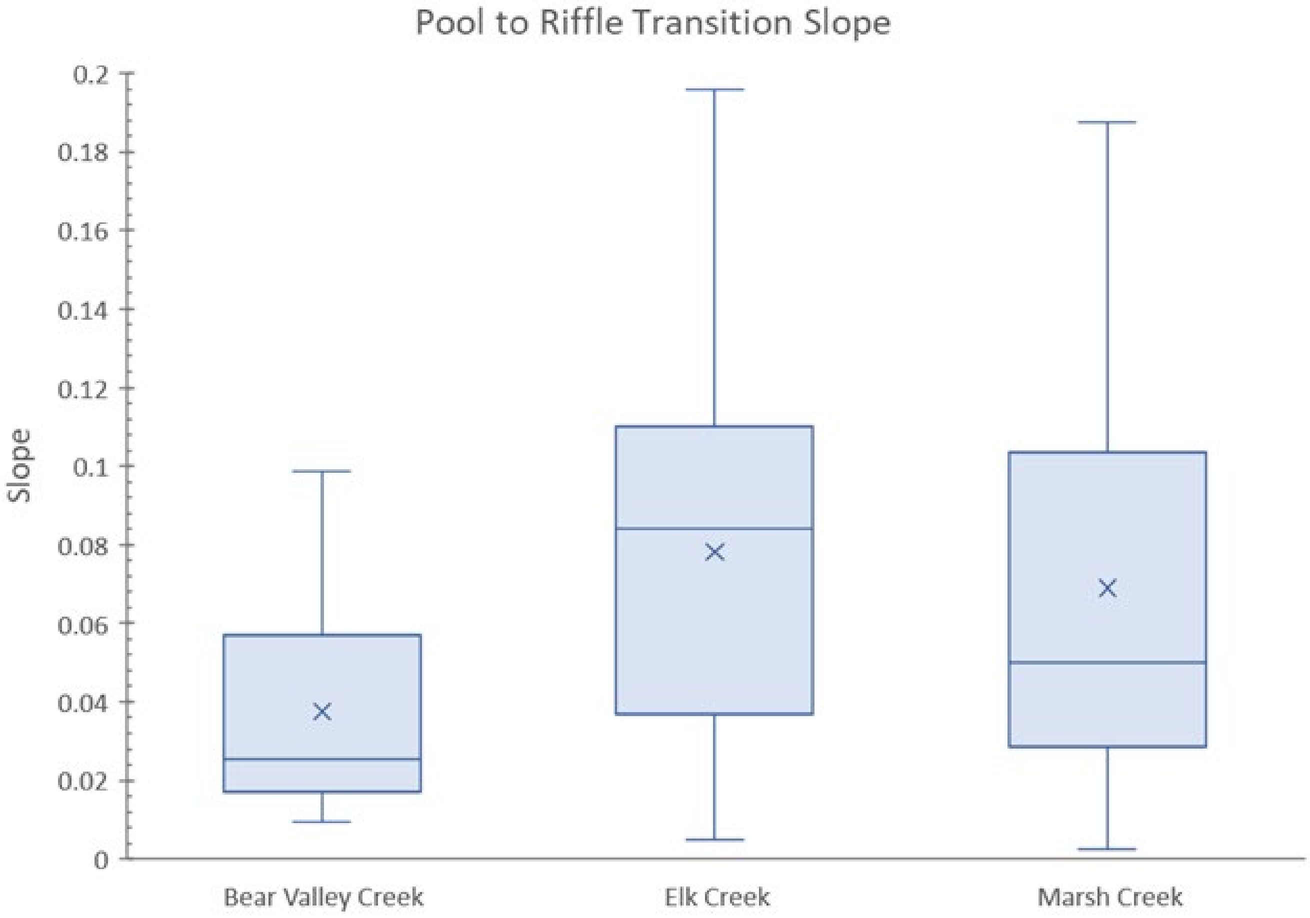


Figure 4-21. Pool to riffle transition slope in reference streams.

Table 4-10. Geomorphic Unit Transition Slope Statistics

Statistic	**Slope of Geomorphic Unit Transitions**					
	Pool to Riffle	**Pool inlet**	**Pool outlet**	**Riffle to Pool**	**Riffle lee**	**Riffle stoss**
$S_{0.10}$	0.015	0.003	0.005	0.020	0.003	0.003
$S_{0.25}$	0.024	0.009	0.009	0.039	0.006	0.008
$S_{0.50}$	0.047	0.013	0.012	0.070	0.014	0.016
Mean	0.062	0.024	0.025	0.090	0.019	0.019
$S_{0.75}$	0.089	0.027	0.036	0.133	0.028	0.029
$S_{0.90}$	0.123	0.074	0.070	0.174	0.040	0.038

Notes:

S_x is the percentile value of geomorphic unit transition slope.

Statistics were calculated based on data from all reference reaches.

Pool to riffle (P2R) is along a steep profile transition from pool bottom to downstream riffle crest; Pool inlet (Pi) is upstream of pool bottom; Pool outlet (Po) is downstream of pool bottom; Riffle to Pool (R2P) is along a steep profile transition from riffle crest to downstream pool bottom; Riffle lee (Rl) is downstream of riffle crest; Riffle stoss (Rs) is upstream of riffle crest.

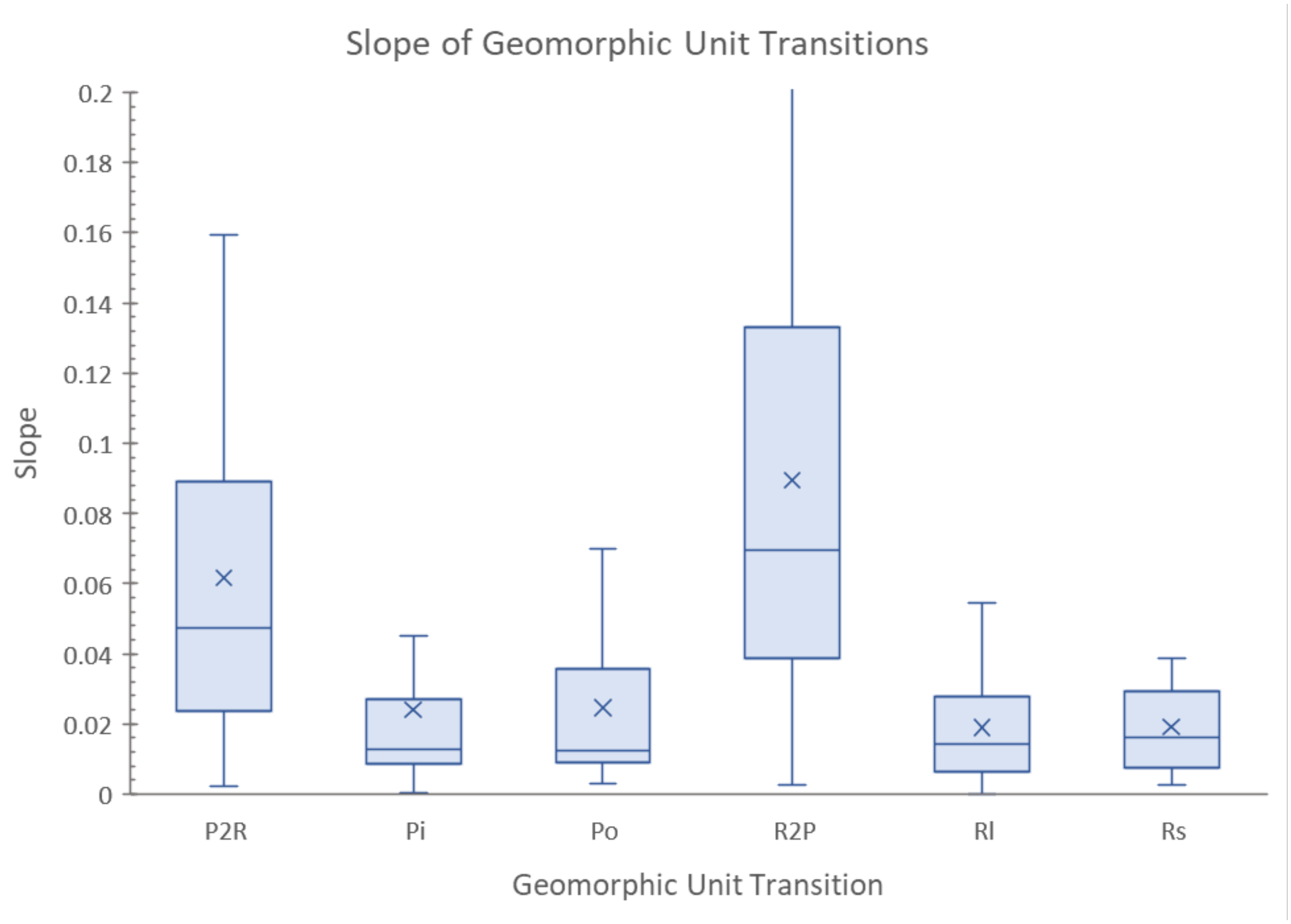


Figure 4-22. Summary of all geomorphic unit transition slopes.

Table 4-11. Residual Pool Depth Statistics

Statistic	Residual Pool Depth (ft)		
	Bear Valley Creek	**Elk Creek**	**Marsh Creek**
$RPD_{0.10}$	0.5	2.1	1.0
$RPD_{0.25}$	0.8	2.6	1.3
$RPD_{0.50}$	1.3	3.5	2.1
Mean	1.5	3.5	2.0
$RPD_{0.75}$	1.9	4.3	2.5
$RPD_{0.90}$	2.5	4.8	2.9

Note:
RPD_x is the percentile value of residual pool depth (RPD).

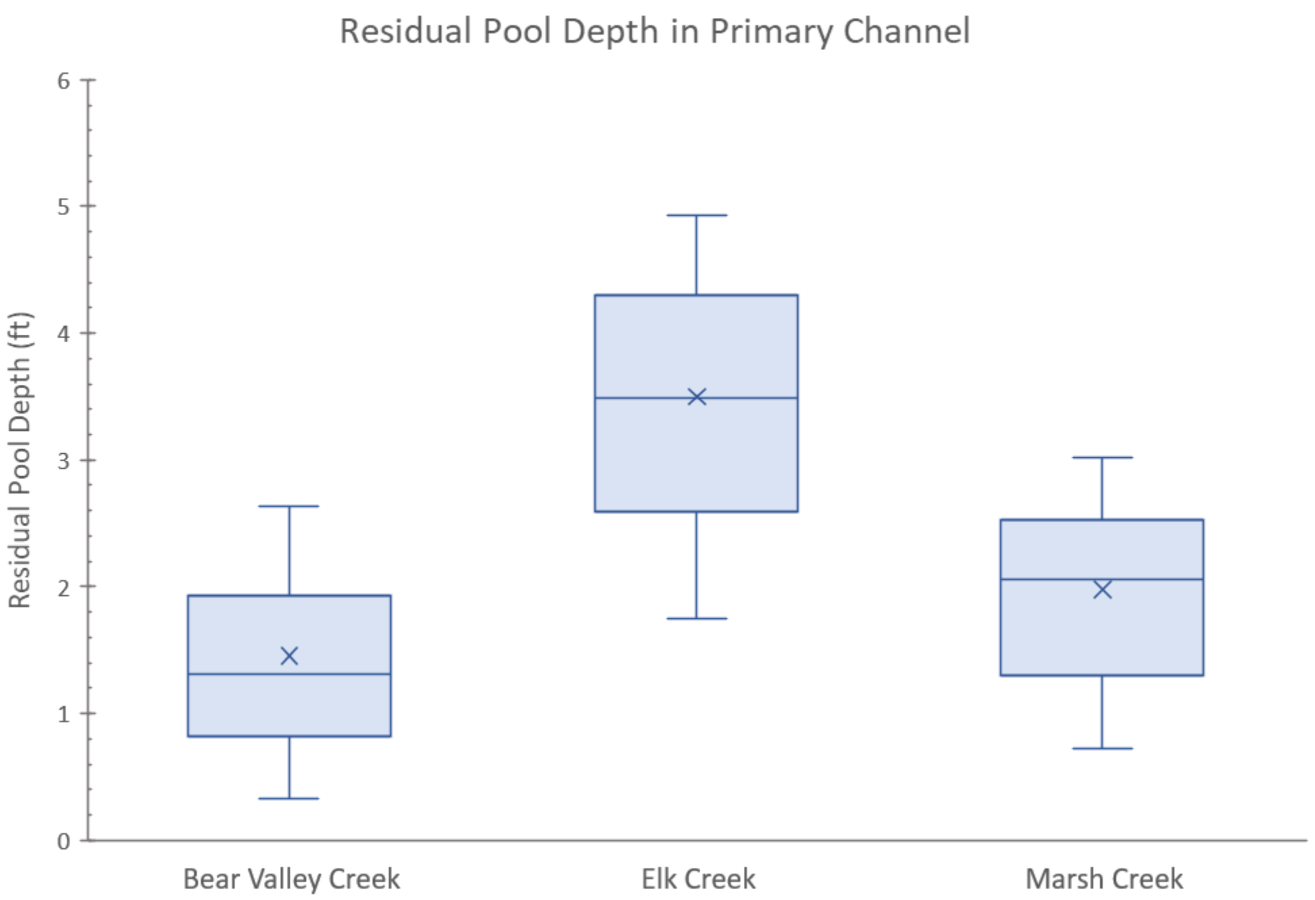


Figure 4-23. Residual pool depth in the primary channel of reference streams.

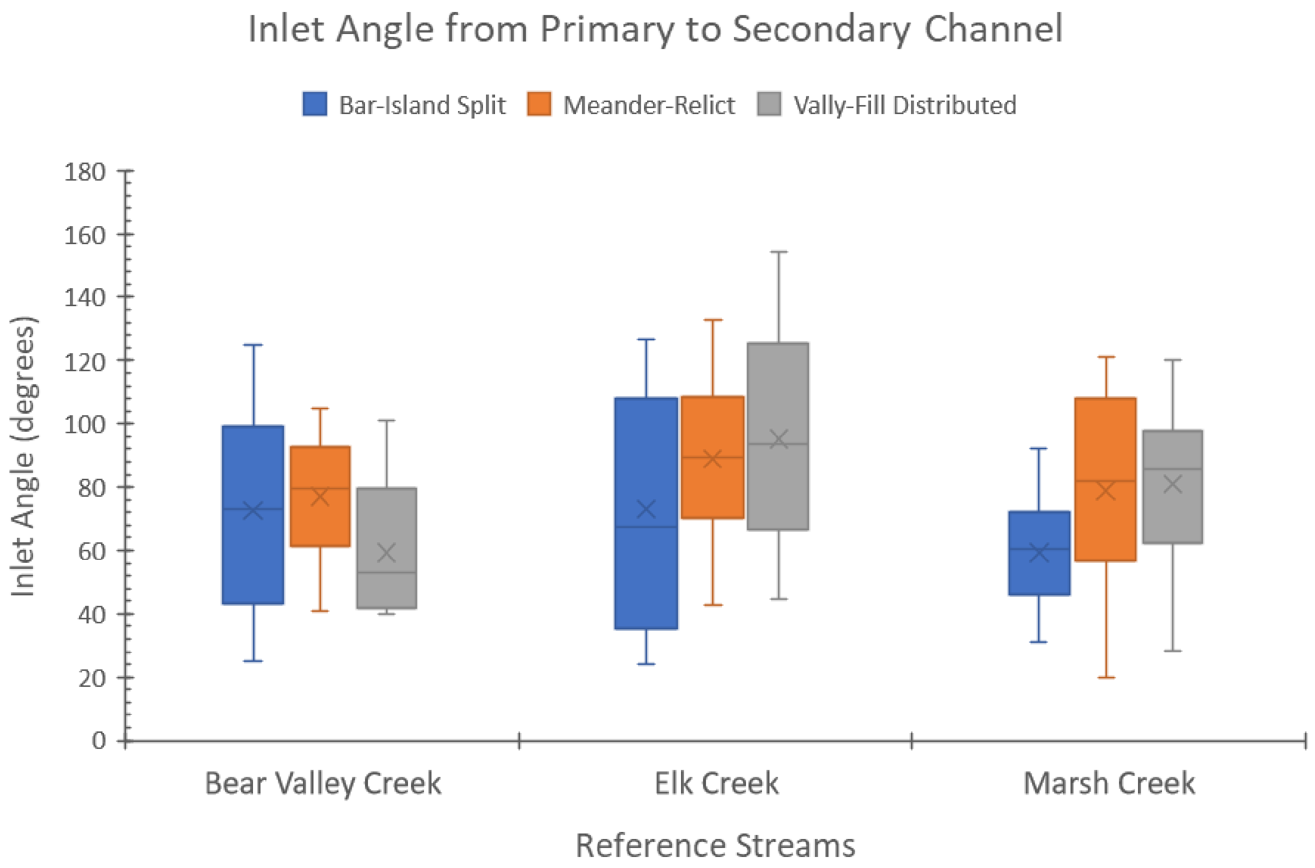


Figure 4-24. Inlet angles from primary to secondary channels, by reference stream and secondary channel type.

Table 4-12. Inlet Angle from Primary to Secondary Channel Statistics

Statistic	Inlet Angle (degrees)		
	Bar-island Split	**Meander-Relict**	**Valley-fill Distributed**
$IA_{0.10}$	30	53	46
$IA_{0.25}$	46	63	58
$IA_{0.50}$	62	85	87
Mean	68	83	84
$IA_{0.75}$	91	102	102
$IA_{0.90}$	113	118	126

Note:
IA_x is the percentile value of inlet angle from the primary channel to secondary channel (IA).

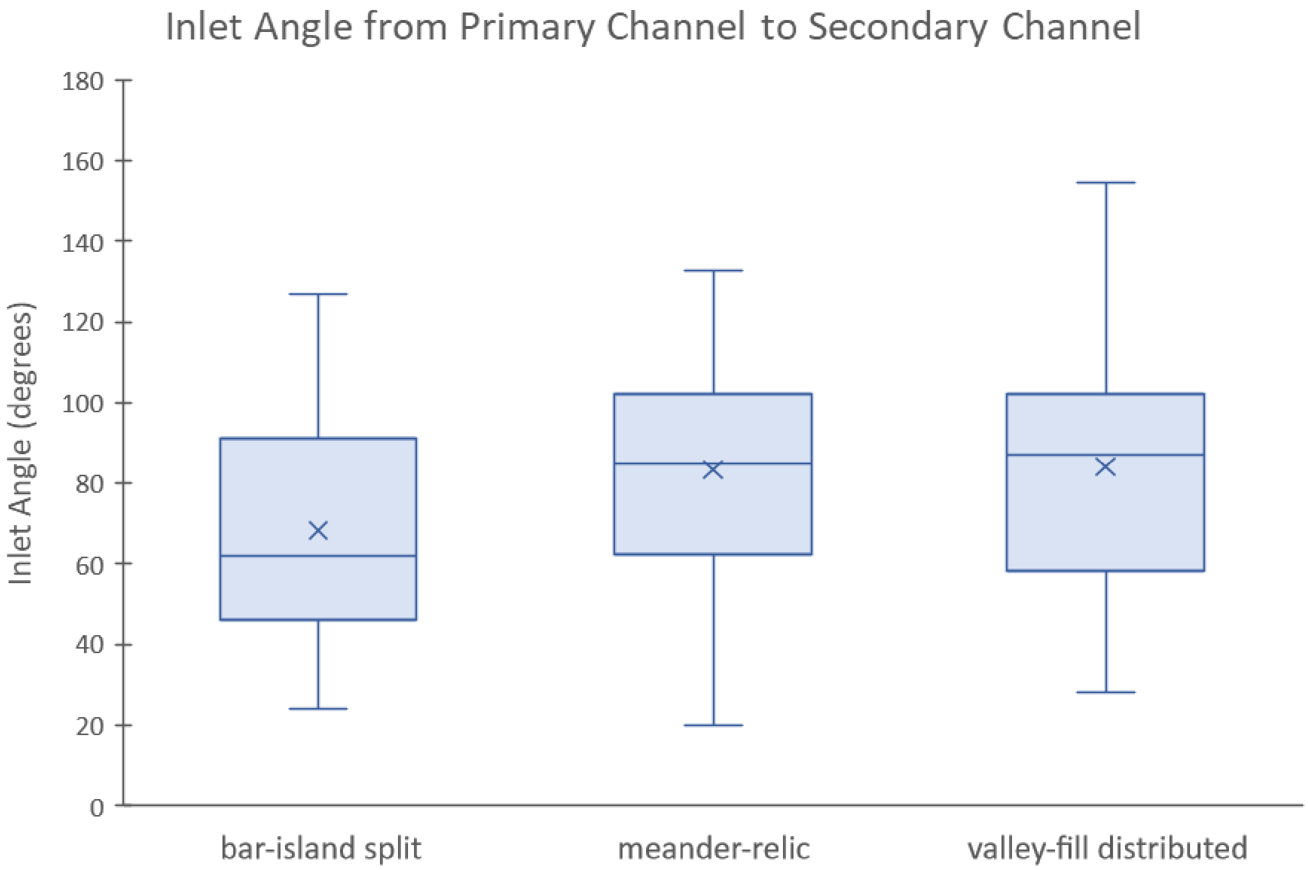


Figure 4-25. Inlet angles from primary to secondary channels.

4.4 In-channel Woody Material

The types and quantity of wood material in the primary and secondary channels of the reference streams is reflective of the streamside plant communities and wood supply to the channel network. In general, all of the reference streams have riparian zones comprising predominantly grasses, forbs, and shrubs. Any large wood material supplied to the channels likely has a very low transport rate downstream, owing to the geomorphic and hydraulic characteristics of the relatively small, low-gradient channels. Wood observed in the channels fell into three categories: Jams, Log-Rootwads, and Beaver Dams. The wood abundance in the primary channel of all the reference reaches was very low (Table 4-13, Figure 4-26). For example, Bear Valley Creek reference reaches had the most Jams, with eight Jams in one reach and only one Jam in each of two other reaches (Table 4-13, Figure 4-26). Most of the Beaver Dams were observed in secondary channels (Table 4-13, Figure 4-27), with the largest abundance of Beaver Dams located in Bear Valley Creek. Beaver dams were identified based on abundance of beaver-chewed wood and dam structure consisting of small beaver-chewed wood along with various amounts of rock and soil.

When expressed in terms of wood abundance normalized to the valley length and channel lengths, there is high variability among the reference reaches within a stream and among streams. For example, there were no Log-Rootwads or Jams observed in Marsh Creek, while there was a maximum of 13 Log-Rootwads per 1,000 ft of valley length and seven Jams per 1,000 ft of valley length observed in the primary channel of Bear Valley Creek (Table 4-14, Figure 4-28). Beaver Dam abundance in secondary channels ranged from zero in several Marsh Creek reaches to 19 per 1,000 ft of valley length in Bear Valley Creek (Table 4-14, Figure 4-29). Similar variability in wood abundance was observed when quantified in terms of primary and secondary channel lengths (Table 4-15, Figure 4-30, Figure 4-31). These findings suggest that wood abundance in primary channels is not a primary control on geomorphic processes within the reference streams; however, beaver dams in secondary channels likely contribute to the formation and maintenance of multi-thread channel networks in these streams.

Table 4-13. Wood Material Abundance (Count) by Channel Type

Stream and Reach	**Primary Channel**			**Secondary Channel**		
	Beaver Dam	**Jam**	**Log-Rootwad**	**Beaver Dam**	**Jam**	**Log-Rootwad**
Bear Valley Creek						
BVC_19.2_18.8	4	1	11	16		4
BVC_20.0_19.4		8	5	13		
BVC_23.1_21.5		1	32	19	1	11
BVC_24.5_24.2	1		1	6		
BVC_26.4_25.9			6	9		
Elk Creek						
EC_2.0_0.6		3	13	6	1	1
EC_5.5_4.5			3	3		
EC_6.4_5.9			2	2		
EC_7.5_6.7		1		3		1
EC_8.7_8.1			3	3		
EC_9.7_8.8			2	4		3
EC_12.6_12.2			1	5		
Marsh Creek						
MC_13.0_12.4						
MC_14.6_13.9						
MC_15.4_14.6						
MC_16.3_15.5	1			2		

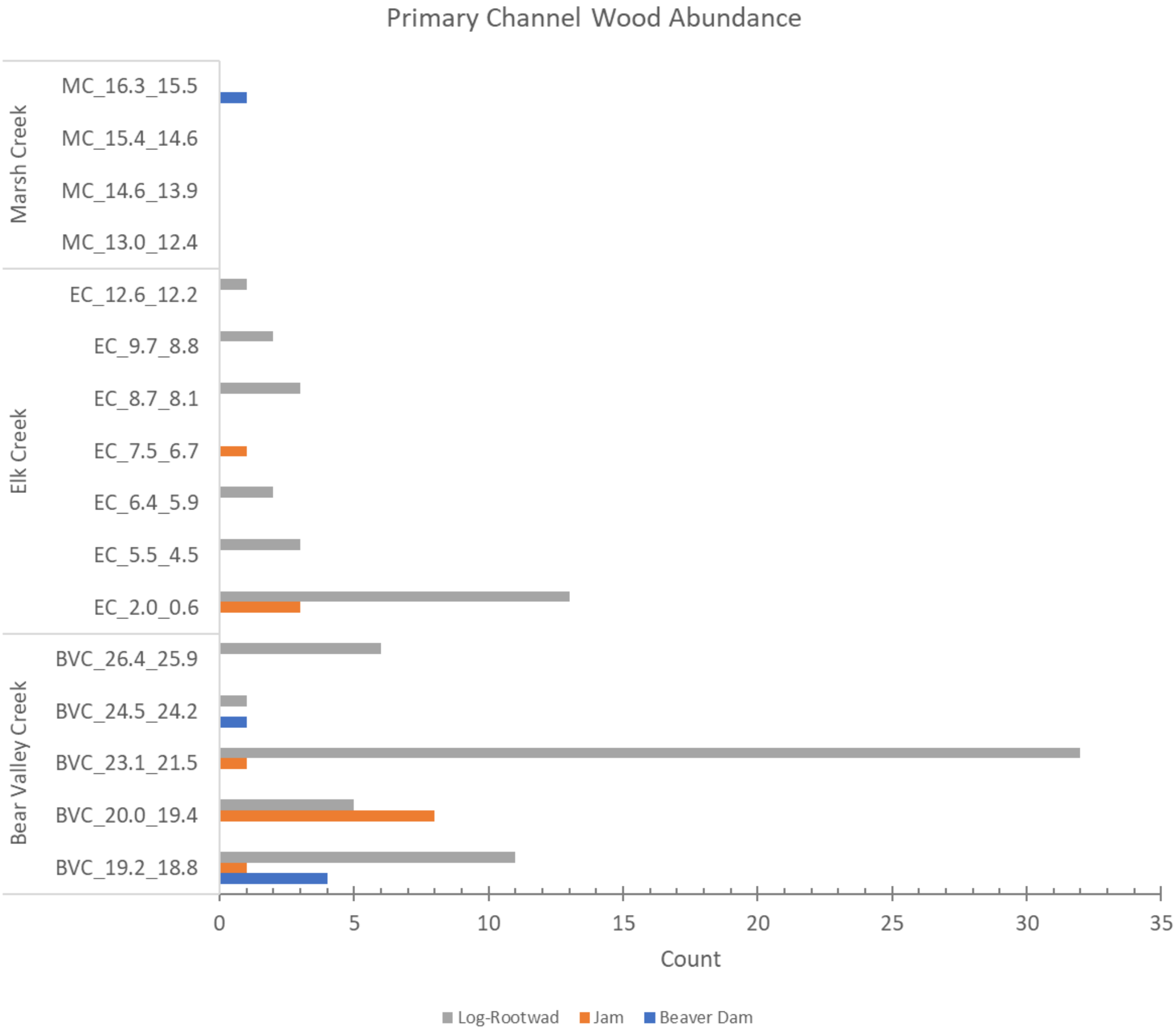


Figure 4-26. Wood material abundance (count) in primary channels.

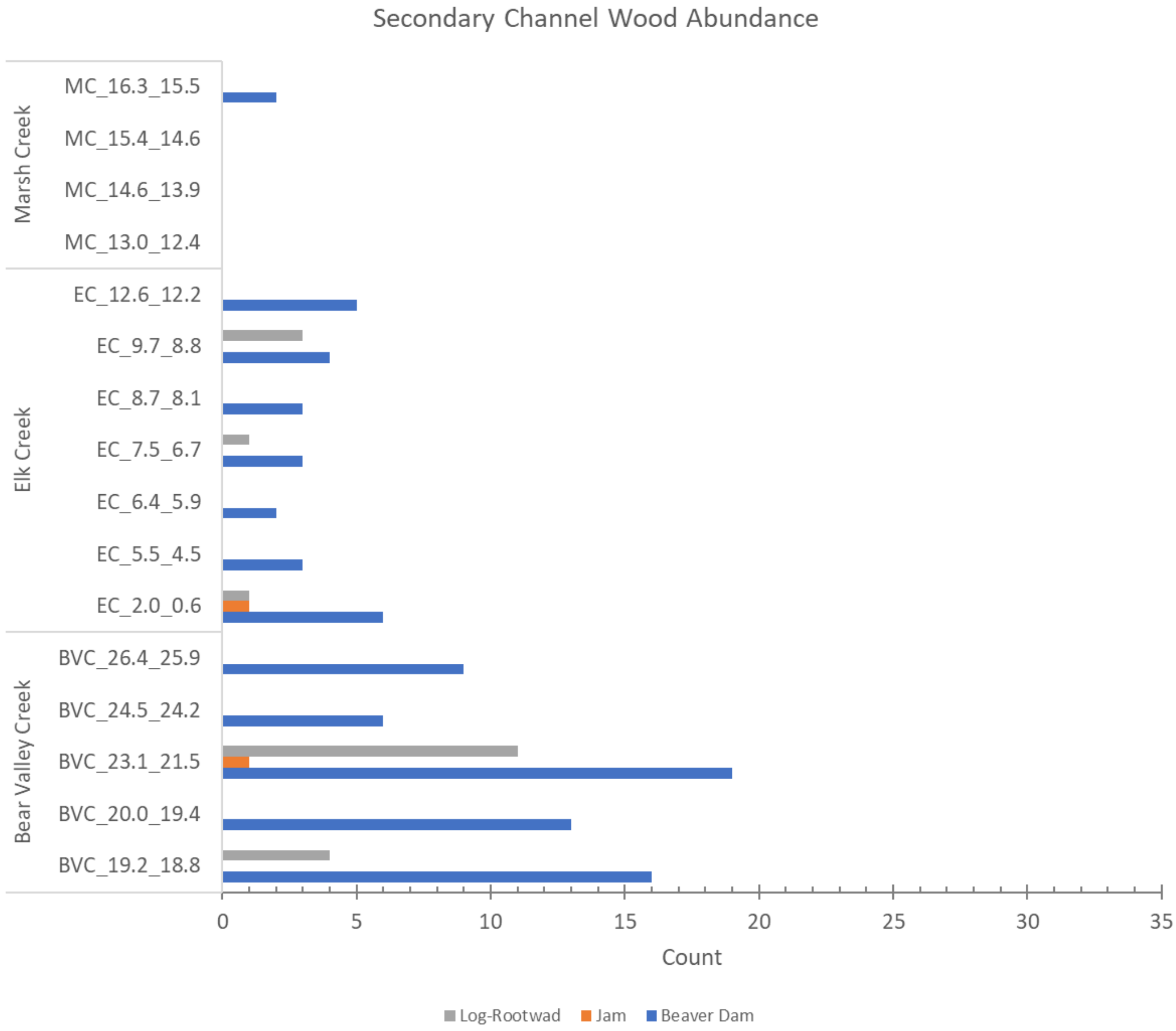


Figure 4-27. Wood material abundance (count) in secondary channels.

Table 4-14. Wood Material Frequency per 1,000 ft of Valley Length

Stream and Reach	Primary Channel			Secondary Channel		
	Beaver Dam	Jam	Log-Rootwad	Beaver Dam	Jam	Log-Rootwad
Bear Valley Creek						
BVC_19.2_18.8	5	1	13	19		5
BVC_20.0_19.4		7	4	12		
BVC_23.1_21.5			1	6		3
BVC_24.5_24.2	1		1	8		
BVC_26.4_25.9			7	1		
Elk Creek						
EC_2.0_0.6		1	5	2		
EC_5.5_4.5			2	2		
EC_6.4_5.9			2	2		
EC_7.5_6.7		1		2		1
EC_8.7_8.1			3	3		
EC_9.7_8.8			1	3		2
EC_12.6_12.2			1	6		
Marsh Creek						
MC_13.0_12.4						
MC_14.6_13.9						
MC_15.4_14.6						
MC_16.3_15.5	1			1		

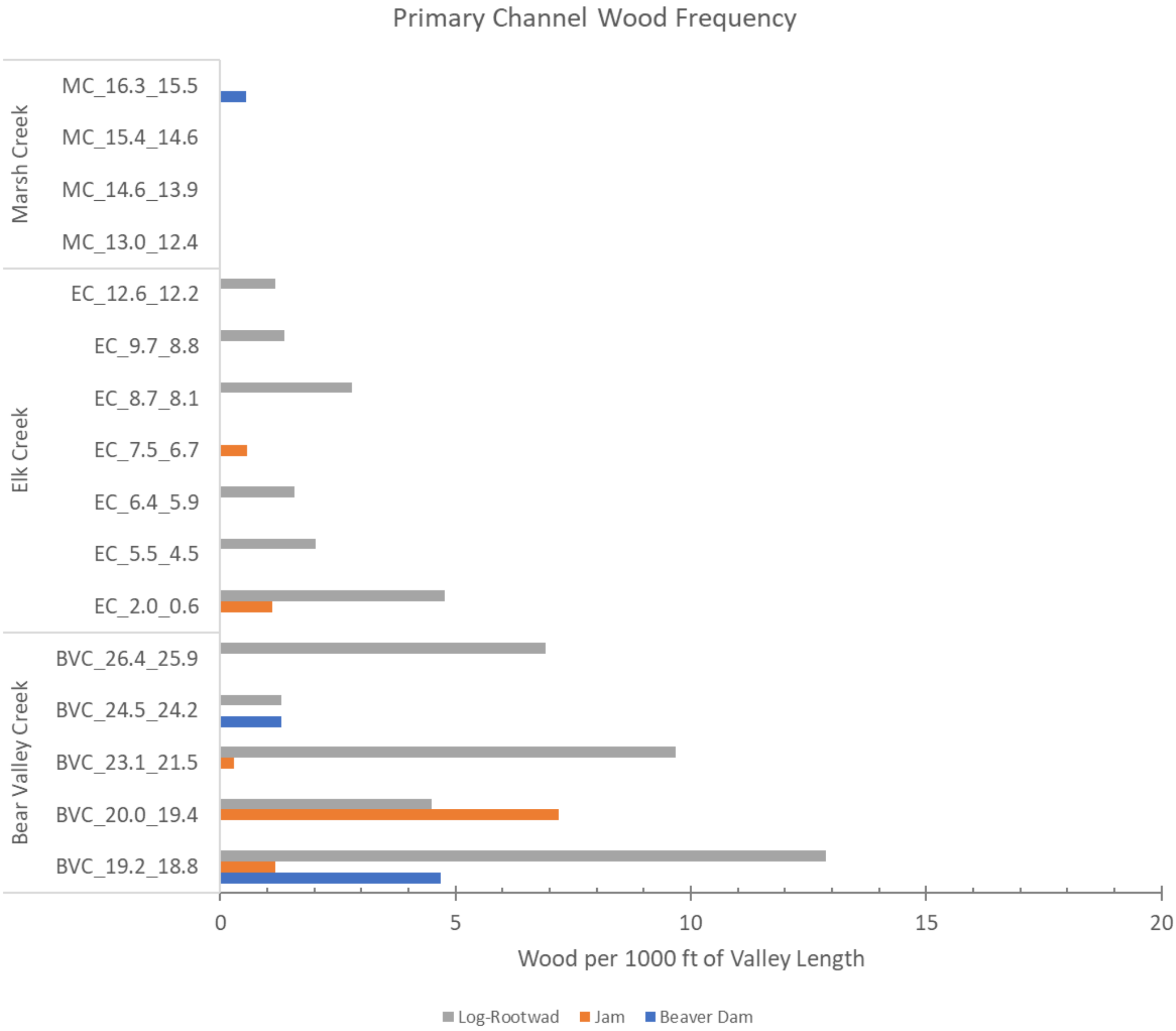


Figure 4-28. Wood abundance in primary channels per 1,000 ft of valley length.

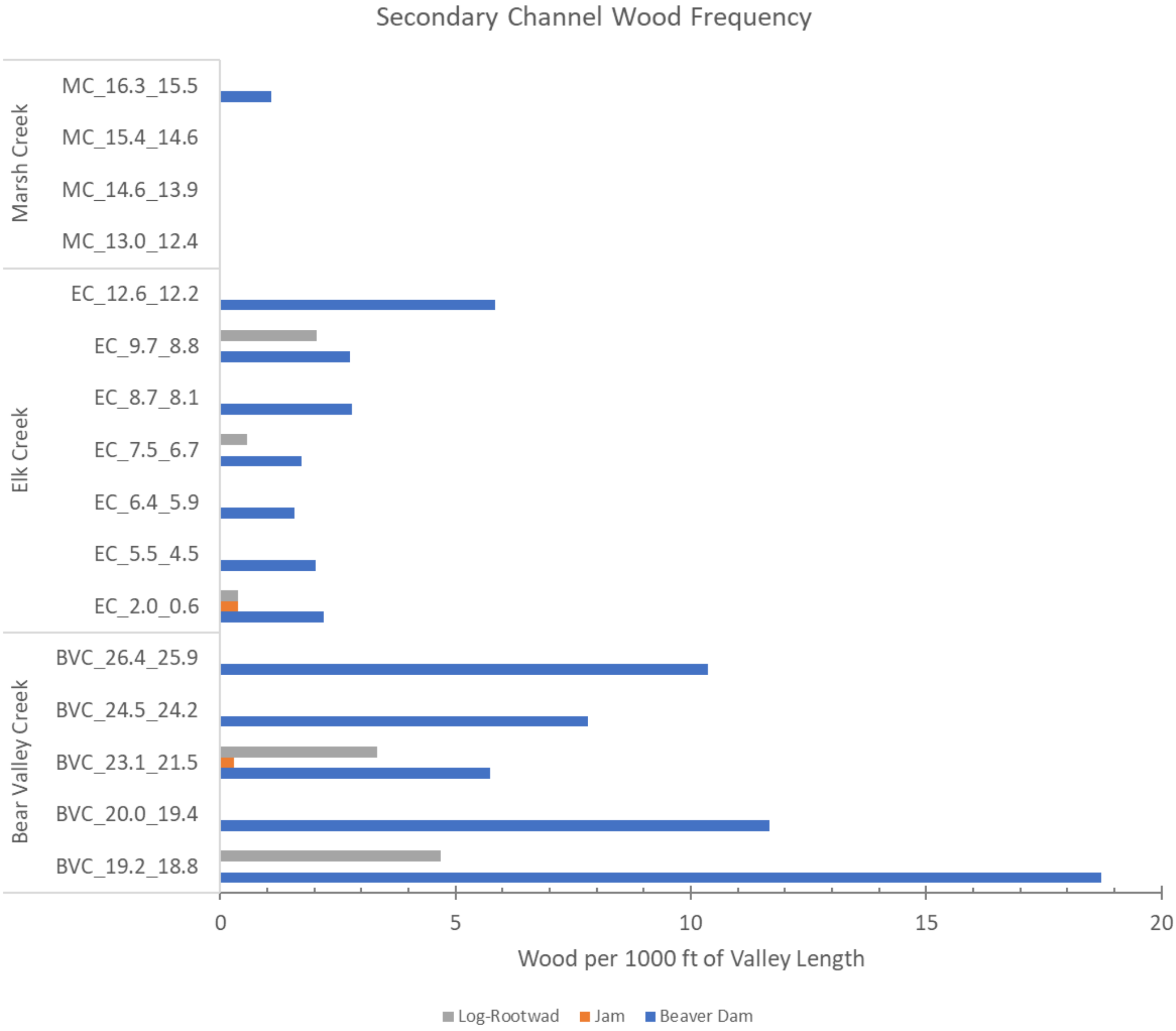


Figure 4-29. Wood abundance in secondary channels per 1,000 ft of valley length.

Table 4-15. Wood Material Frequency per 1,000 ft of Primary and Secondary Channel Lengths

Stream and Reach	Primary Channel			Secondary Channel		
	Beaver Dam	Jam	Log-Rootwad	Beaver Dam	Jam	Log-Rootwad
Bear Valley Creek						
BVC_19.2_18.8	3	1	7	5		1
BVC_20.0_19.4		4	3	3		
BVC_23.1_21.5			6	3		2
BVC_24.5_24.2	1		1	3		
BVC_26.4_25.9			3	4		
Elk Creek						
EC_2.0_0.6		1	3	2		
EC_5.5_4.5			1	1		
EC_6.4_5.9			1	1		
EC_7.5_6.7				1		
EC_8.7_8.1			1	3		
EC_9.7_8.8			1	1		1
EC_12.6_12.2			1	2		
Marsh Creek						
MC_13.0_12.4						
MC_14.6_13.9						
MC_15.4_14.6						
MC_16.3_15.5				1		

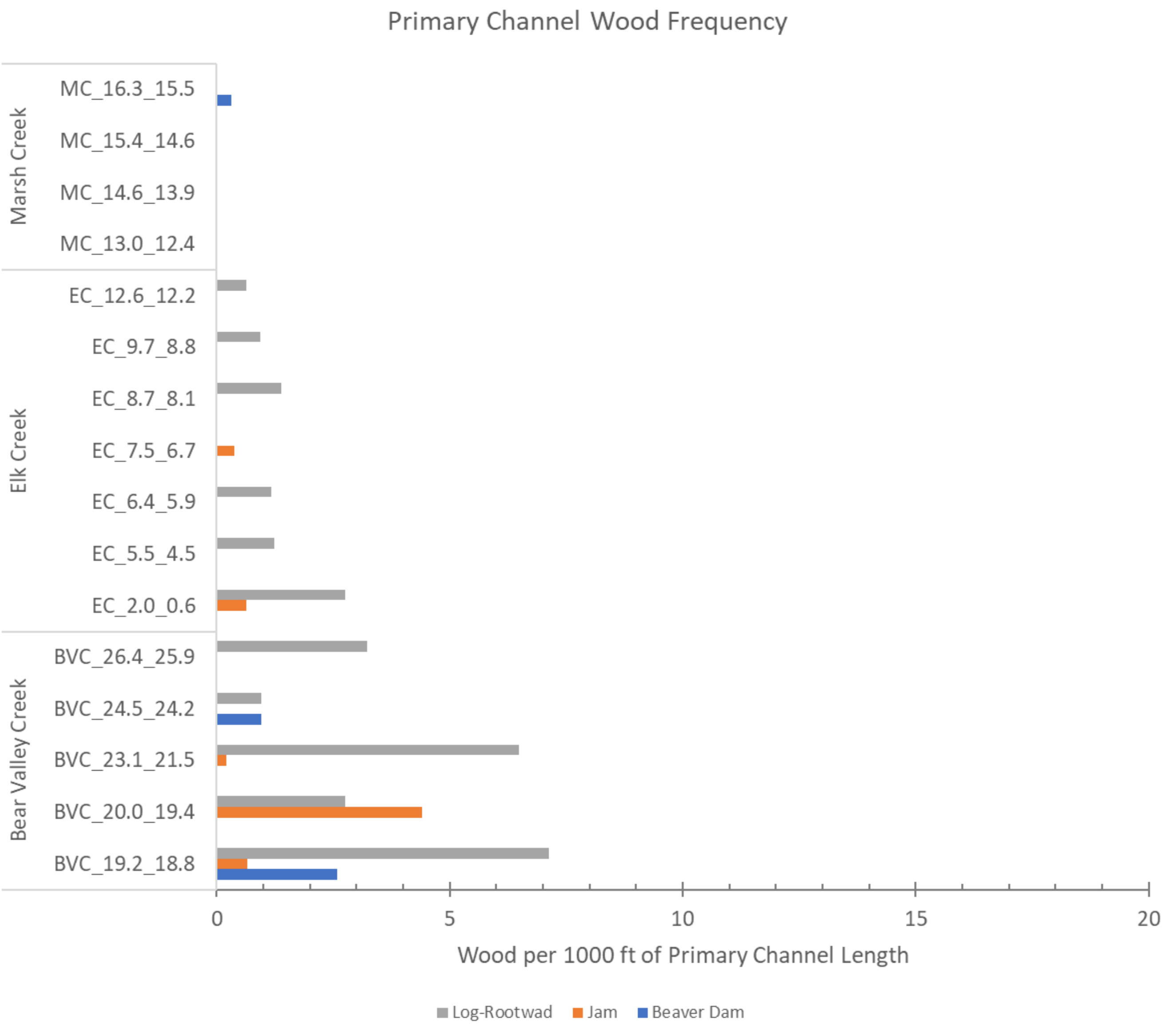


Figure 4-30. Wood abundance in primary channels per 1,000 ft of primary channel length.

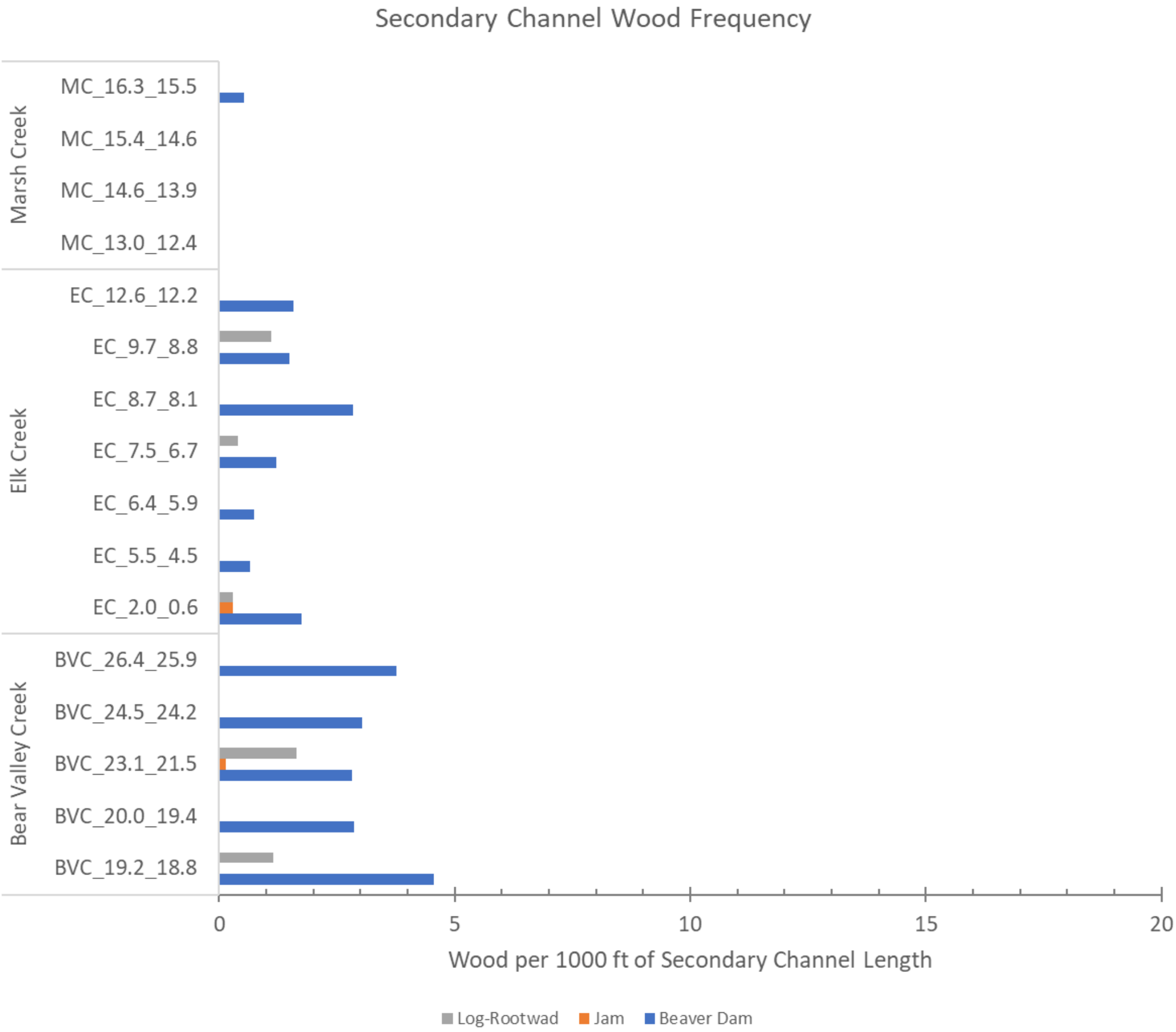


Figure 4-31. Wood abundance in secondary channels per 1,000 ft of secondary channel length.

4.5 Streambed Surface Grain Size

All three of the reference streams are gravel-bed rivers with grain sizes characterized as moderately to moderately well sorted mixtures of medium gravel through small cobble. The median grain size (D_{50}) among reference reaches sampled in Bear Valley Creek ranged from 38 mm (very coarse gravel) to 66 mm (small cobble) (Table 4-16, Figure 4-32), while the D_{16} ranged from 22 mm to 34 mm and the D_{84} ranged from 60 mm to 96 mm. Reference reaches in Elk Creek exhibited the smallest grain size mixtures of the three reference streams, where the D_{50} ranged from 21 mm to 31 mm (coarse gravel), the D_{16} ranged from 12 mm to 16 mm and the D_{84} ranged from 28 mm to 43 mm (Table 4-17, Figure 4-33). The D_{50} among reference reaches sampled in Marsh Creek ranged from 42 mm to 49 mm (very coarse gravel) (Table 4-18, Figure 4-34), while the D_{16} ranged from 22 mm to 24 mm and the D_{84} ranged from 57 mm to 86 mm.

Table 4-16. *Bear Valley Creek Surface Substrate Grain Size Distributions*

Grain Size Statistic	Grain Size (mm)						
	RKM 26.3	**RKM 26.4**	**RKM 24.4**	**RKM 22.6**	**RKM 22.4**	**RKM 19.7**	**RKM 19.6**
D_{95}	99	101	82	89	138	85	99
D_{84}	77	84	62	64	96	60	81
D_{75}	70	74	54	55	87	57	70
D_{50}	57	53	38	40	66	49	49
D_{25}	41	38	26	27	38	30	36
D_{16}	34	32	22	23	34	26	30
D_5	18	17	13	13	22	15	16
S_{Psi}	0.67	0.73	0.77	0.80	0.78	0.68	0.75
Sorting Classification	moderately well	moderate	moderate	moderate	moderate	moderately well	moderate

Note:
S_{Psi} is the Folk and Ward sorting coefficient in Psi units.
RKM = river kilometer

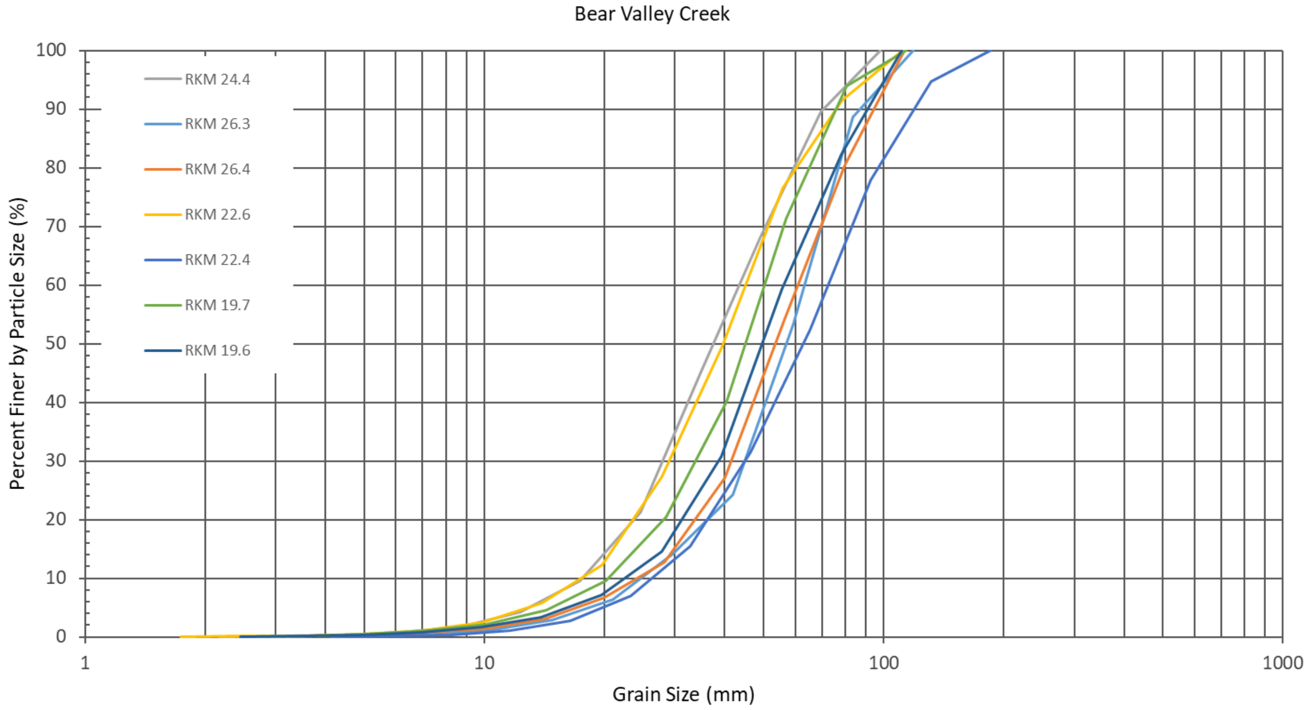


Figure 4-32. Bear Valley Creek surface substrate grain size distributions.

Table 4-17. Elk Creek Surface Substrate Grain Size Distributions

Grain Size Statistic	Grain Size (mm)							
	RKM 12.5	RKM 12.3 US	RKM 12.3 DS	RKM 6.8	RKM 5.4	RKM 4.7	RKM 2.0	RKM 1.7
D_{95}	63	50	65	39	38	50	34	47
D_{84}	43	38	43	31	31	37	28	34
D_{75}	36	33	38	28	29	32	28	30
D_{50}	25	25	31	21	21	24	25	23
D_{25}	17	17	19	15	14	18	15	17
D_{16}	14	14	16	13	12	15	12	15
D_5	8	8	9	8	7	9	7	9
S_{Psi}	0.86	0.74	0.77	0.67	0.72	0.69	0.63	0.67
Sorting Classification	moderate	moderate	moderate	moderately well	moderate	moderately well	moderately well	moderately well

Notes:
S_{Psi} is the Folk and Ward sorting coefficient in Psi units.
Sampling locations in the same river kilometer (RKM) extent.
US = upstream
DS = downstream

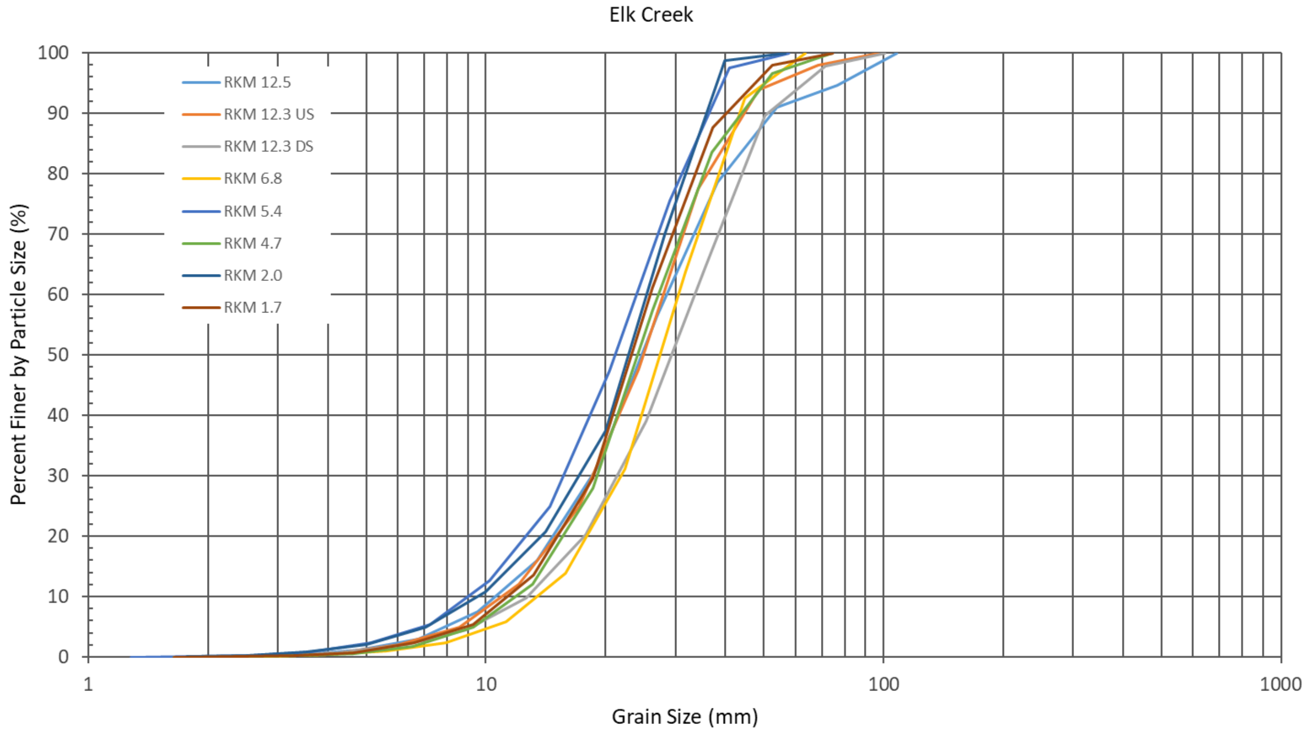


Figure 4-33. Elk Creek surface substrate grain size distributions.

Table 4-18. Marsh Creek Surface Substrate Grain Size Distributions

Grain Size Statistic	Grain Size (mm)		
	RKM 12.9	**RKM 14.5**	**RKM 16.2**
D_{95}	73	132	93
D_{84}	57	86	61
D_{75}	54	70	54
D_{50}	43	49	42
D_{25}	28	29	25
D_{16}	24	24	22
D_5	14	13	14
S_{Psi}	0.66	0.97	0.78
Sorting Classification	moderately well	moderate	Moderate

Note:
S_{Psi} is the Folk and Ward sorting coefficient in Psi units.
RKM = river kilometer.

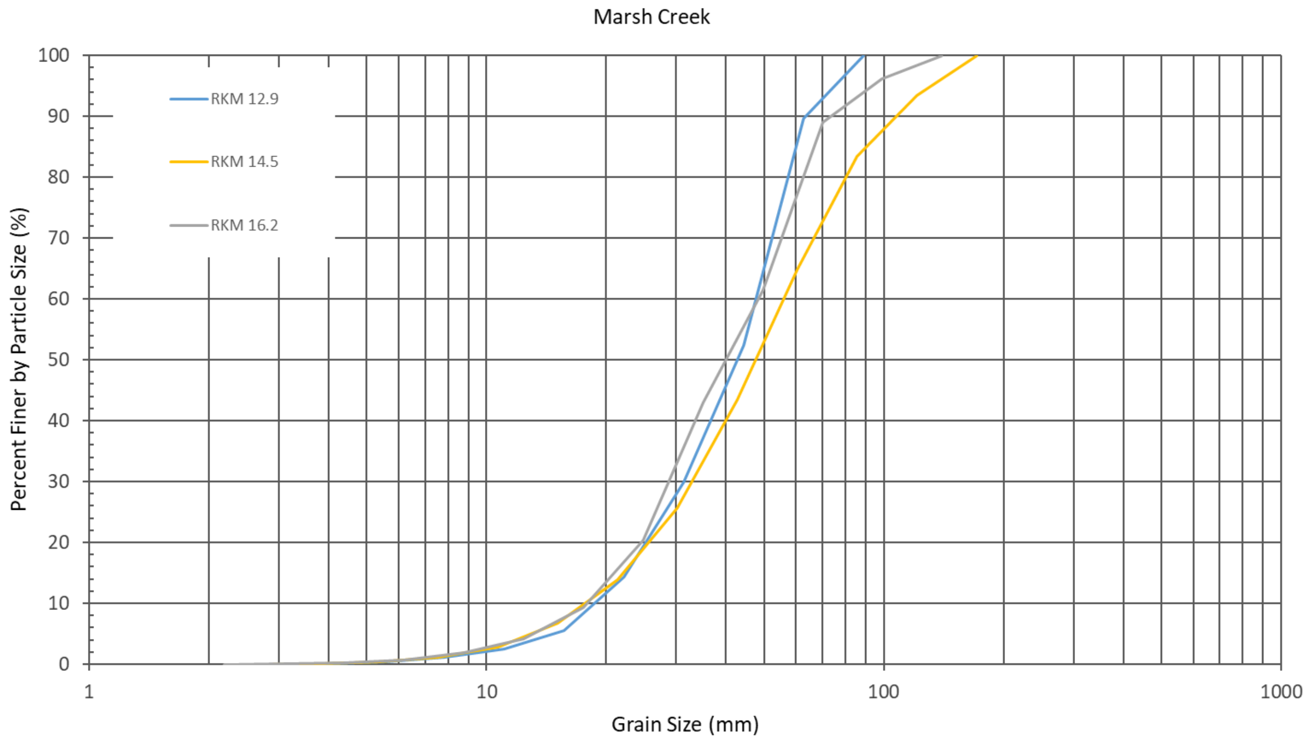


Figure 4-34. Marsh Creek surface substrate grain size distributions.

4.6 Reach-scale Habitat

Methods used to identify habitat characteristics commonly associated with high-capacity Chinook salmon and steelhead juvenile rearing and adult spawning habitat are described in detail in Appendix B. Using the results of the Appendix B analysis, reach-scale summaries of key habitat metrics that transcend salmonid species and life stages are summarized in this section for Bear Valley Creek, Elk Creek, and Marsh Creek (including the Knapp Time reference site located on Knapp Creek) reference reach tributaries. Complete summaries of habitat metrics for each site are available from the authors upon request.

Additionally, it should be noted that habitat metrics are often highly correlated; attempting to draw inference on the effect or impact one habitat metric has on habitat quality without considering the entire suite of habitat characteristics of a site or reach can lead to false conclusions. For example, it was found that high-quality redd habitat was often associated with reaches that had higher frequencies of channel units. Using this information to design or guide restoration efforts while excluding other important habitat metrics often associated with high-quality redd habitat (e.g., appropriate substrate size, available cover, channel unit types, etc.) would likely lead to suboptimal redd habitat. Because of this, the following summaries of key habitat characteristics associated with high-quality habitat should be viewed as general trends and consumed holistically with other habitat characteristics in mind.

Channel unit refers to an individual feature within a channel (i.e., riffle, pool, glide, etc.); thus, channel unit frequency is a measure of how many individual features appear within a given area. In general, higher channel unit frequencies were associated with higher estimates of carrying capacity for juvenile winter presmolt (>2.5 channel units per 100 m) and adult redds (>5 channel units per 100 m) for both species (Appendix B). Lower channel unit frequency (<8 channel units per 100 m) was associated with higher estimates of carrying capacity for summer parr for both species (Appendix B). Reference reach sites averaged approximately three to four channel units per 100 m, with the distributions ranging from 0.46 to 8.41 channel units per 100 m (Figure 4-35). Reference sites in Elk Creek had the most consistent frequency of channel units while Bear Valley Creek exhibited the greatest variation, encompassing both the highest and lowest frequency of channel units of all reference reaches.

Greater frequency of fast-water habitat (>2 riffle and/or rapid channel units per 100 m) was generally associated with higher carrying capacity estimates of adult redds for both species (Appendix B). Conversely, less frequent fast-water habitat (< 4 riffle and/or rapid channel units per 100 m) was generally associated with higher estimates of carrying capacity of juvenile summer parr for both species (Appendix B). All three reference reach tributaries exhibited relatively low frequencies of fast-water habitat (<2.5 riffle and/or rapid channel units per 100 m; Figure 4-36). Marsh Creek exhibited the greatest frequencies and distribution of fast-water habitat while Elk Creek had the least. Sites surveyed on Elk Creek also had some of the highest frequencies (1.5-2.5 channel units per 100 m) of off-channel habitat of all DASH sites surveyed to date.

Deeper average thalweg depth (> 0.3 m) was associated with higher carrying capacity estimates of juvenile summer parr for both species (Appendix B). For redds, shallower average thalweg depth (<0.4 m) was associated with higher carrying capacity estimates for both species (Appendix B). Average thalweg depth distributions for each reference tributary span suitable thresholds for both summer rearing and adult spawning habitat (Figure 4-37).

Deeper residual pool depth (>0.3 m) was associated with higher estimates of carrying capacity for juvenile summer parr for both species. Shallower residual pool depths (<0.5 m) were associated with higher estimates of carrying capacity of adult redds for both species. This falls in line with hydraulic parameters (i.e., depth) suitable for Chinook salmon and steelhead spawning. Residual pool depth distributions for each reference tributary span suitable depths for both summer parr and adult redds, except for Elk Creek, which exhibits depths more suitable for summer parr rearing (Figure 4-38).

Increased fish cover, defined as the percent of wetted area with some form of fish cover, (>25% of the wetted area) was associated with higher estimates of carrying capacity for juvenile winter presmolts and adult redds for both species (Appendix B). Bear Valley Creek and Elk Creek distributions fall above 20% fish cover for middle and upper quantiles, while Marsh Creek distributions are slightly lower (Figure 4-39). One site, Sack Creek on Bear Valley Creek, had a reach with 81% fish cover, primarily from aquatic vegetation.

Higher percentages of sand and fine sediment (0.01-2 mm) within the wetted site area were associated with higher carrying capacity for juvenile winter presmolts and adult redds for both species (Appendix B). While these life stages are likely not using sands and fines specifically, this type of substrate is a surrogate for slow water habitats as fine sediment falls out of suspension as water velocities decline. Elk Creek has the highest proportions of sands and fines, with most of its distribution over 40%. Bear Valley Creek and Marsh Creek have larger distributions of sands and fines, spanning approximately 10%-70% (Figure 4-40).

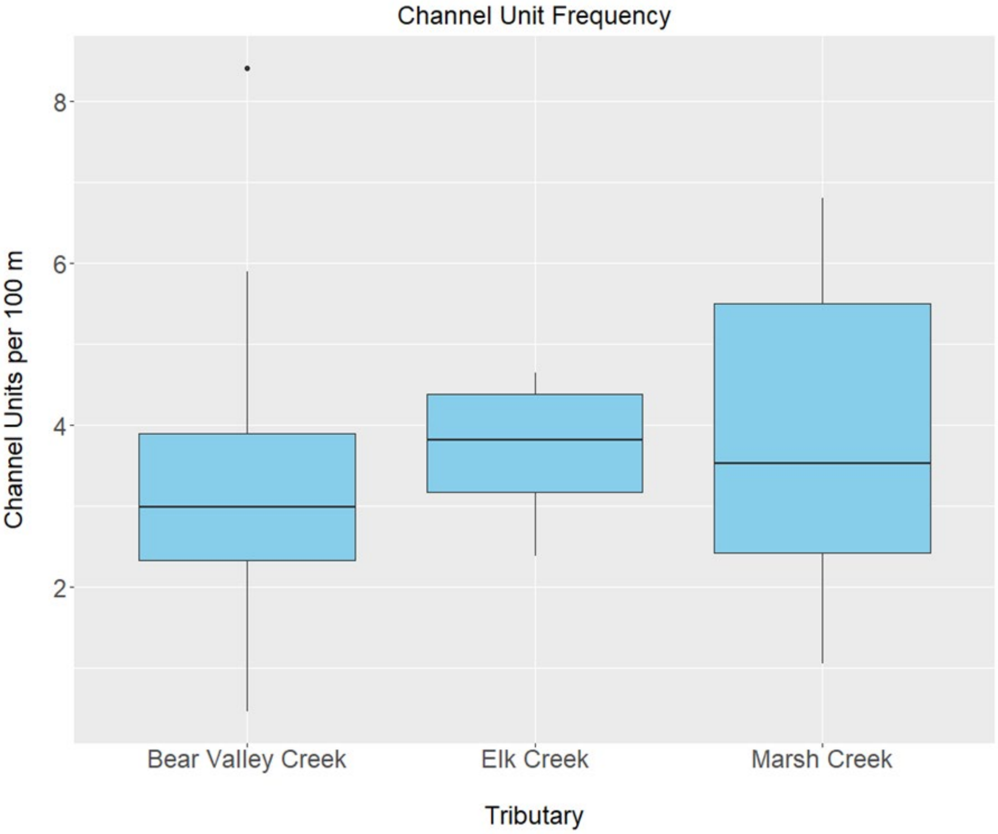


Figure 4-35. Channel unit frequency per 100 meters for each reference reach tributary.

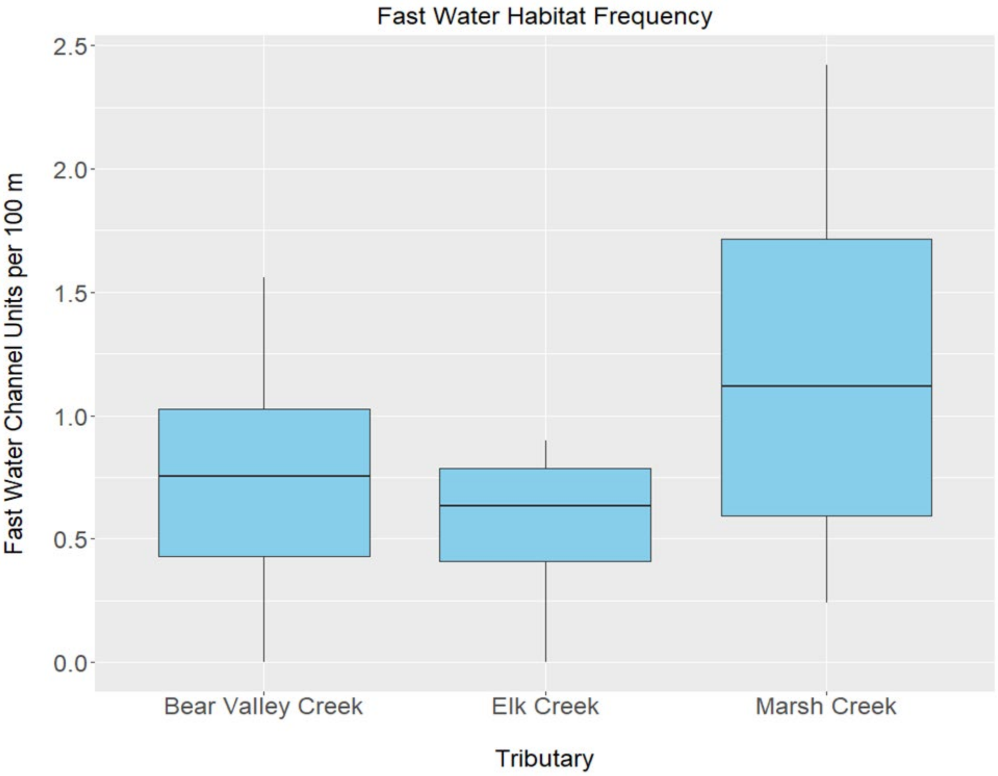


Figure 4-36. Fast water habitat (i.e., riffle and rapids) frequency per 100 meters for each reference reach tributary.

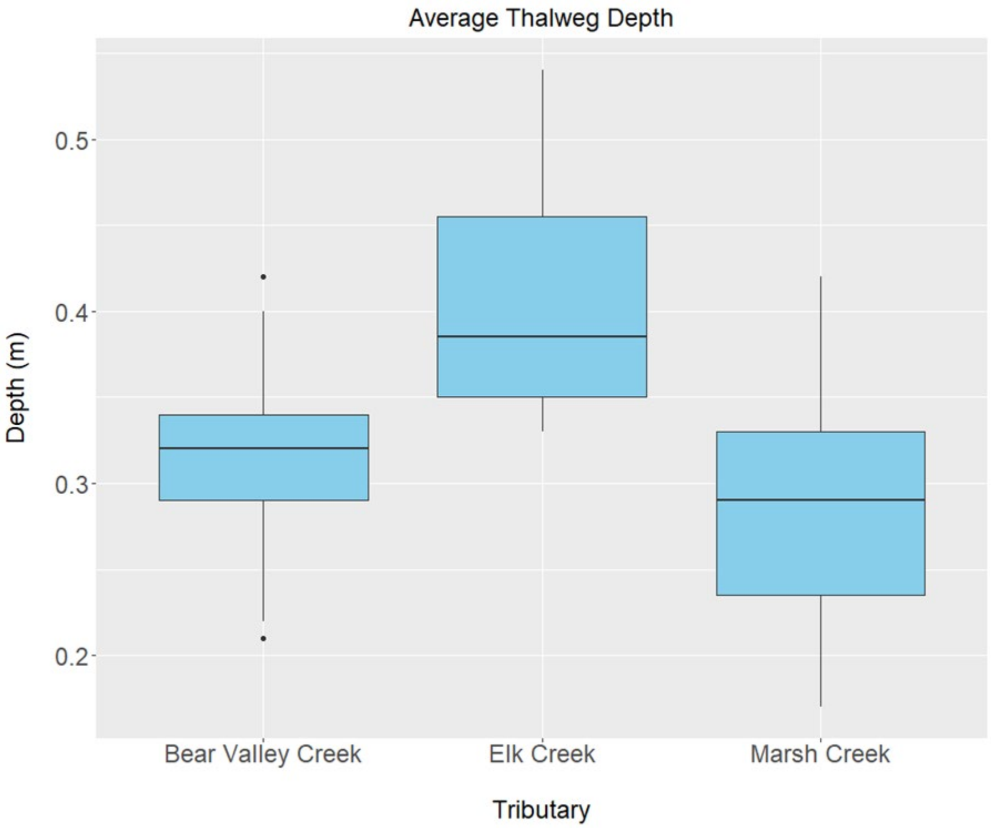


Figure 4-37. Average thalweg depth (m) for each reference reach tributary.

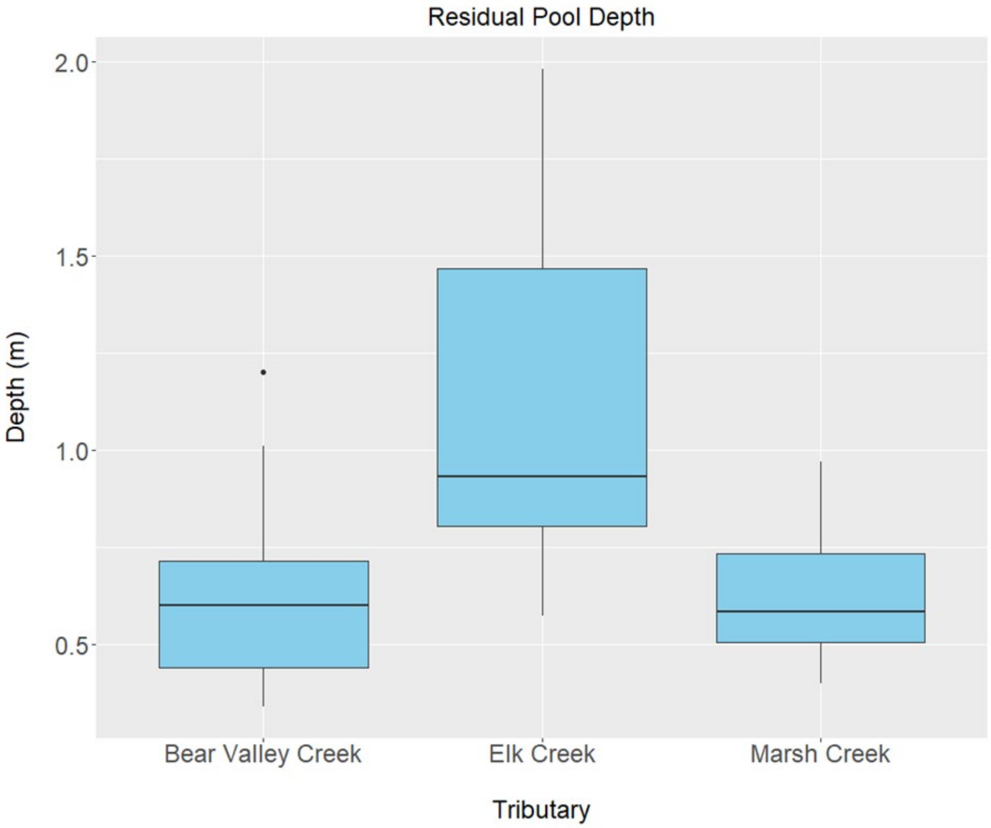


Figure 4-38. Residual pool depth (m) for each reference reach tributary.

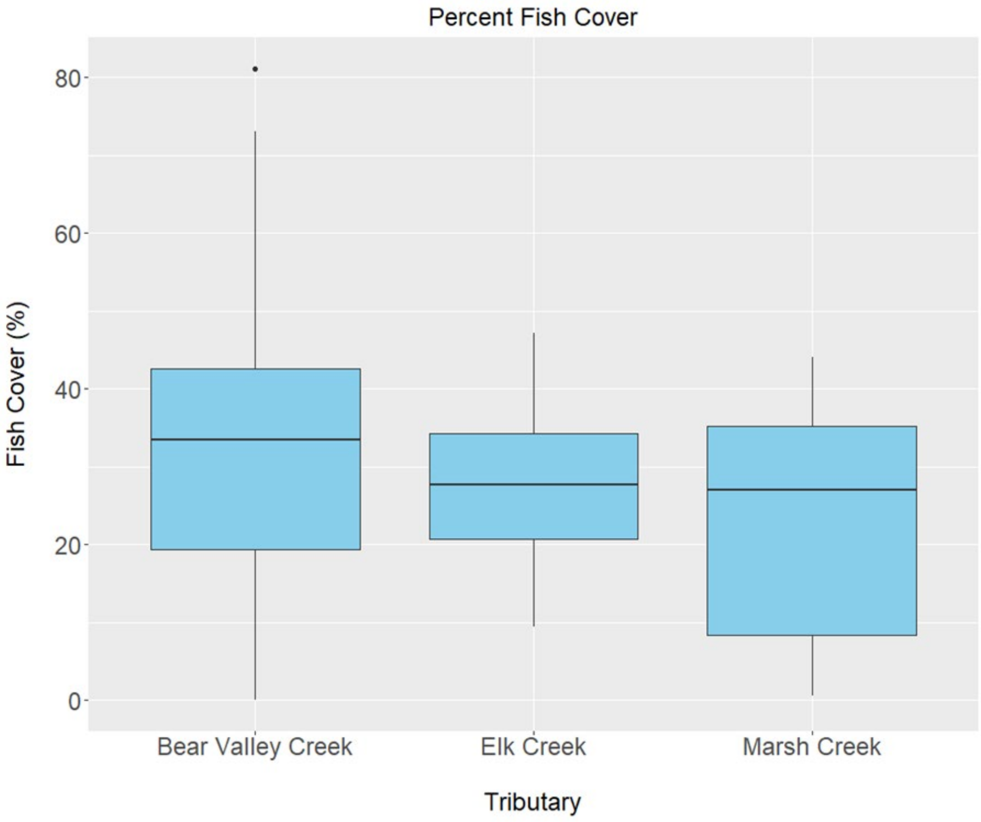


Figure 4-39. Percent fish cover defined as the percent of wetted area with some form of fish cover by channel unit for each reference reach tributary.

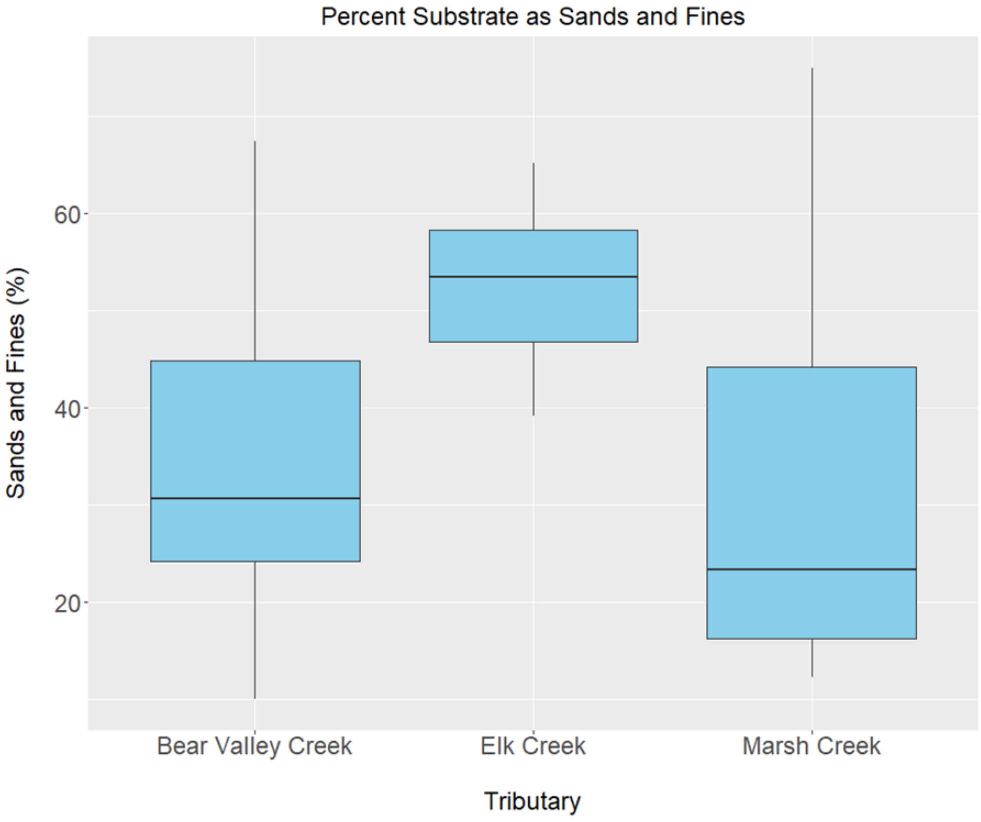


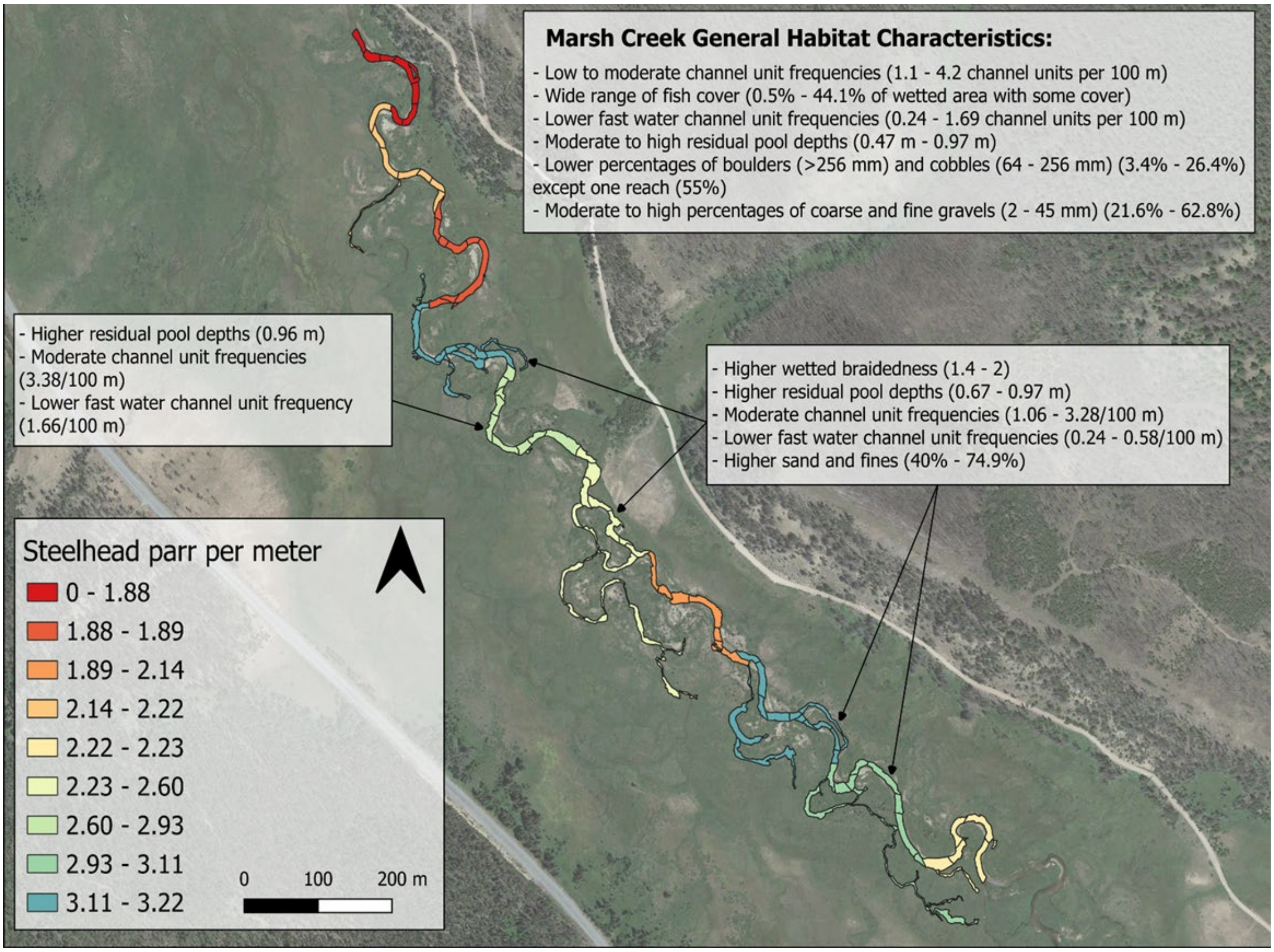
Figure 4-40. Percent of substrate as sand and fine sediment (0.01-2 mm) within the wetted channel for each reference reach tributary.

4.6.1 Example Habitat Characteristics

While discrete habitat characteristics serve as the foundational elements of an individual site or reach, high-quality habitat is created through the intricate interplay and synchronization of multiple habitat characteristics. The ability to quantify these complex, often non-linear relationships is a strength of the QRF model (See et al., 2021); therefore, capacity estimates and high-quality habitat should be considered through the analysis of multiple habitat covariates together. It can be informative to conduct a qualitative assessment of example reference sites (and reaches within each site) that contain high carrying capacity estimates for both species and multiple life stages, along with key habitat characteristics likely resulting in the high-quality habitat.

The Marsh Creek reference site had relatively high estimates of carrying capacity for Chinook salmon and steelhead summer parr. While higher estimates are associated with similar habitat characteristics for both species (i.e., less frequent fast water habitat, greater residual pool depth), nuanced habitat features and spatial structure of habitat characteristics make Marsh Creek an ideal reference site. For example, reaches with multi-thread channels were associated with higher estimates of steelhead parr (Figure 4-41) and interspersed with single thread reaches containing deep pools (Figure 4-41, Figure 4-42), ideal for both species at the parr life stage. Marsh Creek also has relatively high-capacity estimates for Chinook redds (Figure 4-43). Reaches with suitable Chinook spawning habitat overlap those reaches suitable for both Chinook and steelhead parr but are associated with different habitat characteristics including higher amounts of gravel and fish cover. Marsh Creek also exhibits large, complex off-channel habitat, which has been shown to support ideal conditions for fish growth (Limm & Marchetti, 2009).

The Corduroy reference site, located on Elk Creek, has one reach with relatively high carrying capacity estimates for winter presmolts for both species. This reach has a large secondary channel and exhibits higher channel unit frequency, lower average thalweg exit depths, slow water habitat (based on higher frequencies of sands and fines), and lower frequencies of cobble and boulders (Figure 4-44, Figure 4-45). The site also contains multiple reaches with higher carrying capacity estimates for steelhead redds, including the reach with the large secondary channel (Figure 4-46). The reaches associated with higher steelhead redd capacity exhibit higher amounts of fine and coarse gravel, as well as fish cover.



Marsh Creek General Habitat Characteristics:

- Low to moderate channel unit frequencies (1.1 - 4.2 channel units per 100 m)
- Wide range of fish cover (0.5% - 44.1% of wetted area with some cover)
- Lower fast water channel unit frequencies (0.24 - 1.69 channel units per 100 m)
- Moderate to high residual pool depths (0.47 m - 0.97 m)
- Lower percentages of boulders (>256 mm) and cobbles (64 - 256 mm) (3.4% - 26.4%) except one reach (55%)
- Moderate to high percentages of coarse and fine gravels (2 - 45 mm) (21.6% - 62.8%)

- Higher residual pool depths (0.96 m)
- Moderate channel unit frequencies (3.38/100 m)
- Lower fast water channel unit frequency (1.66/100 m)

- Higher wetted braidedness (1.4 - 2)
- Higher residual pool depths (0.67 - 0.97 m)
- Moderate channel unit frequencies (1.06 - 3.28/100 m)
- Lower fast water channel unit frequencies (0.24 - 0.58/100 m)
- Higher sand and fines (40% - 74.9%)

Figure 4-41. Marsh Creek reference reaches with relatively high estimates for steelhead summer parr carrying capacity.

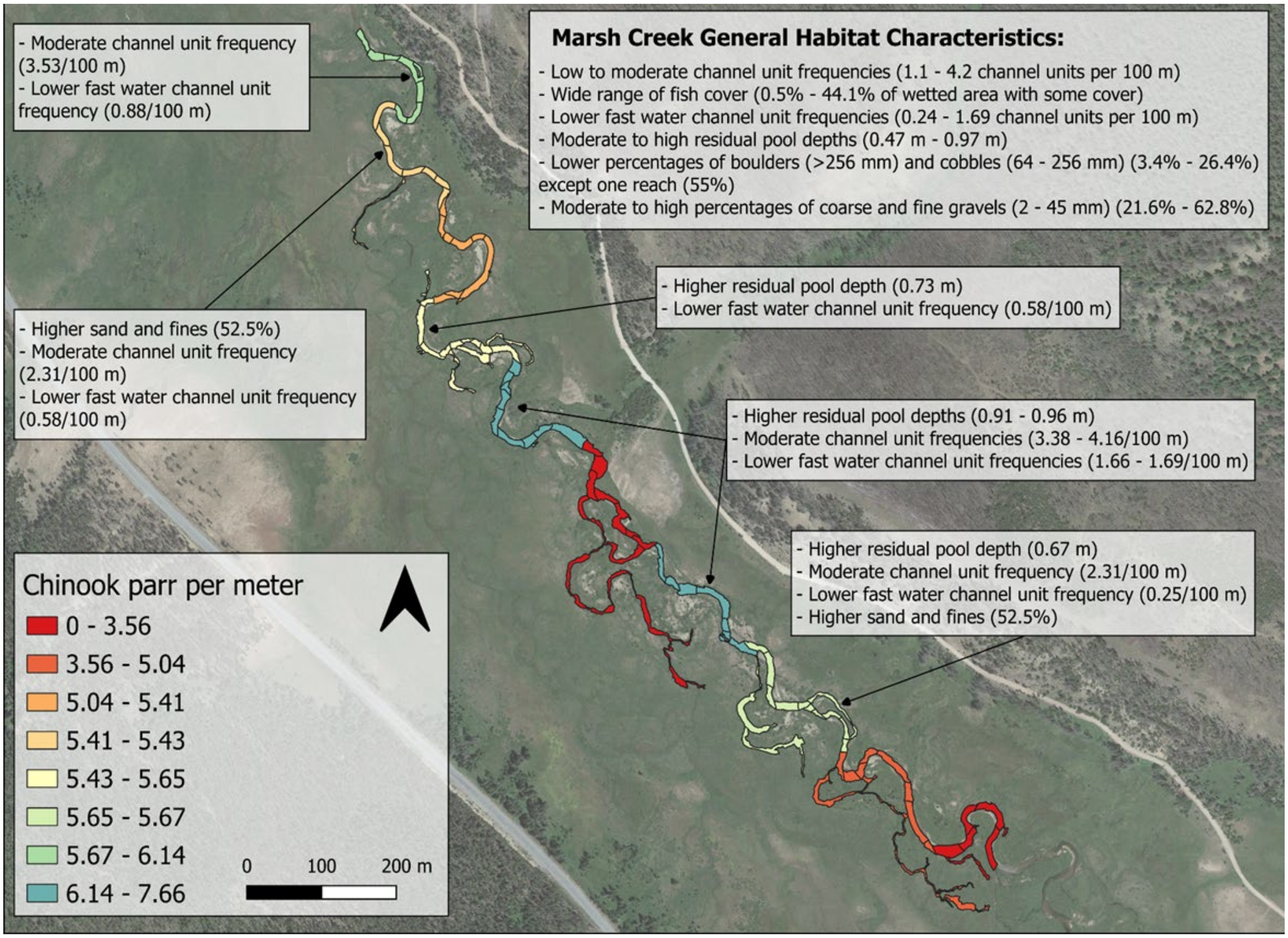


Figure 4-42. Marsh Creek reference reaches with relatively high estimates for Chinook summer parr carrying capacity.

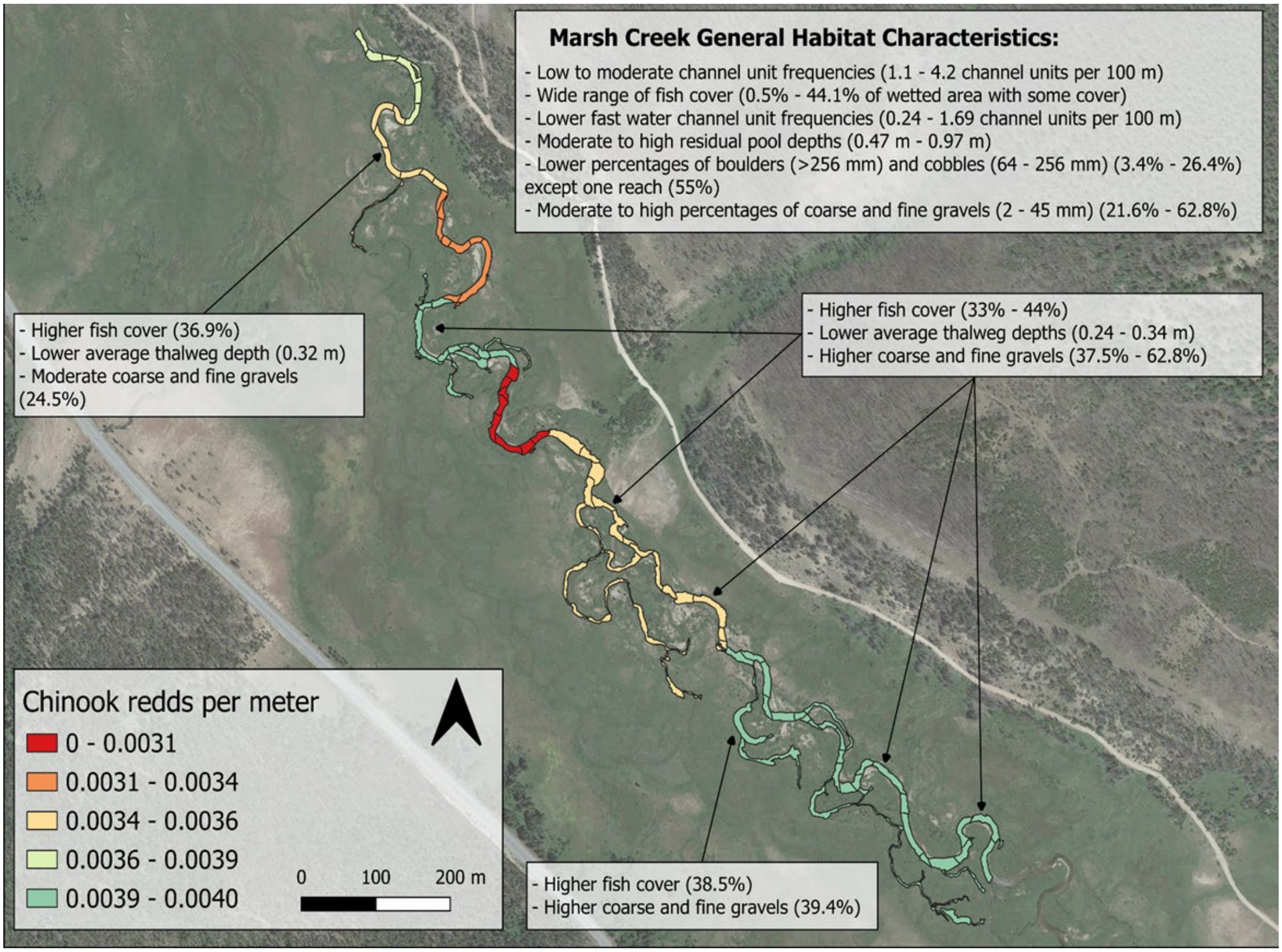


Figure 4-43. Marsh Creek reference reaches with relatively high estimates of Chinook redd carrying capacity.

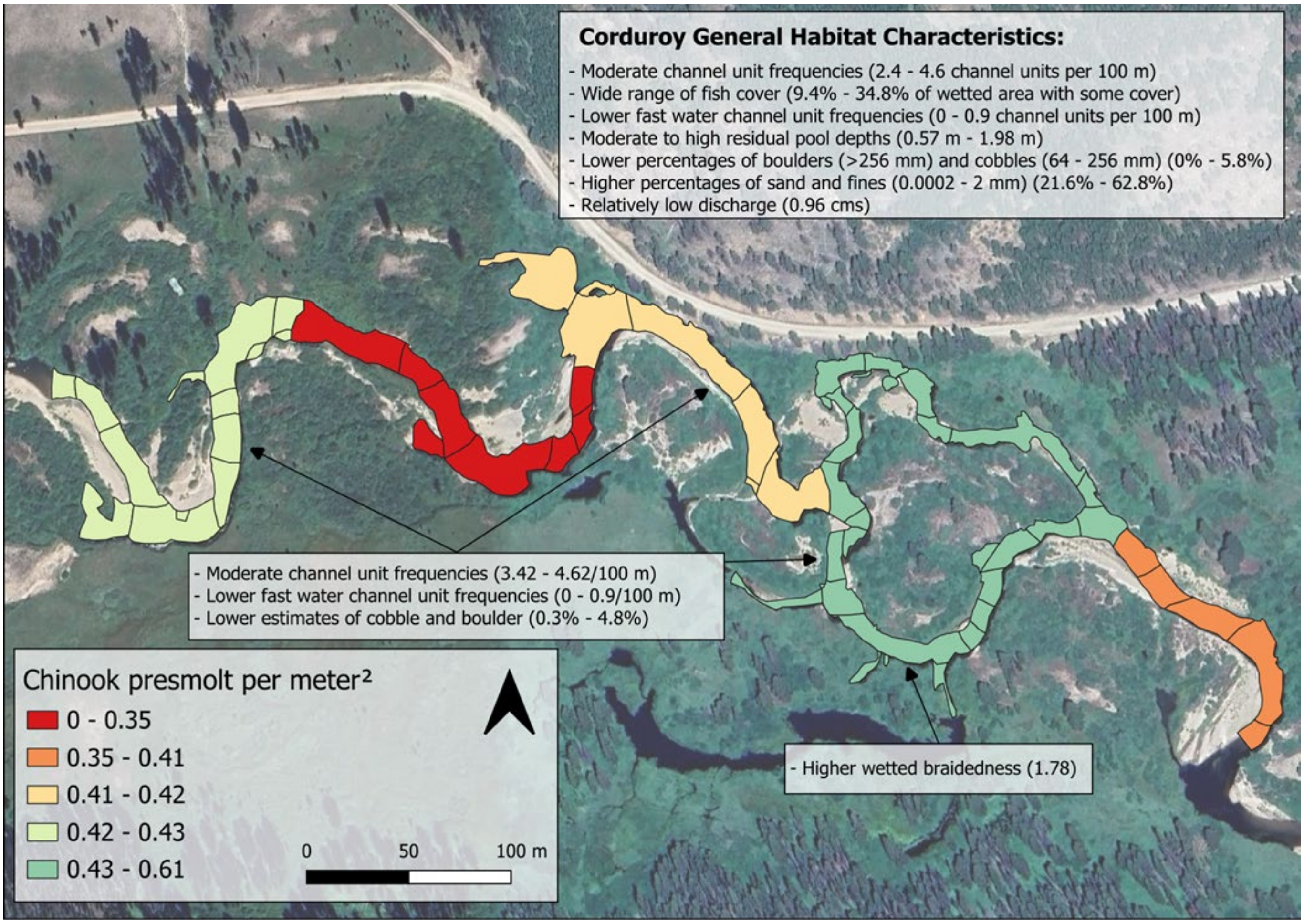
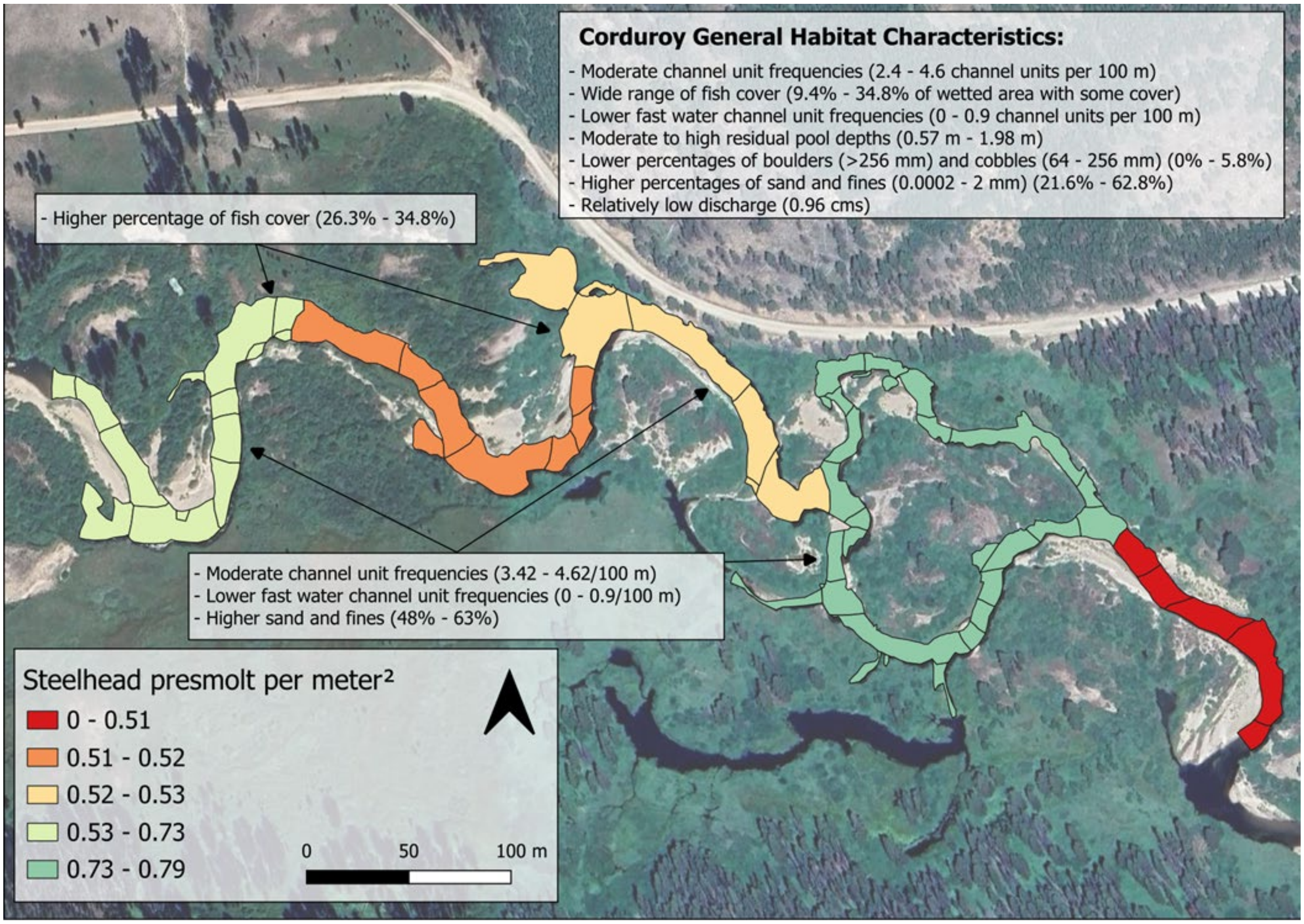


Figure 4-44. Corduroy reference reach (on Elk Creek) with a relatively high carrying capacity for Chinook winter presmolts.


Corduroy General Habitat Characteristics:

- Moderate channel unit frequencies (2.4 - 4.6 channel units per 100 m)
- Wide range of fish cover (9.4% - 34.8% of wetted area with some cover)
- Lower fast water channel unit frequencies (0 - 0.9 channel units per 100 m)
- Moderate to high residual pool depths (0.57 m - 1.98 m)
- Lower percentages of boulders (>256 mm) and cobbles (64 - 256 mm) (0% - 5.8%)
- Higher percentages of sand and fines (0.0002 - 2 mm) (21.6% - 62.8%)
- Relatively low discharge (0.96 cms)

- Higher percentage of fish cover (26.3% - 34.8%)

- Moderate channel unit frequencies (3.42 - 4.62/100 m)
- Lower fast water channel unit frequencies (0 - 0.9/100 m)
- Higher sand and fines (48% - 63%)

Figure 4-45. Corduroy reference site (on Elk Creek) contains a reach with a relatively high carrying capacity estimate for steelhead winter presmolts.

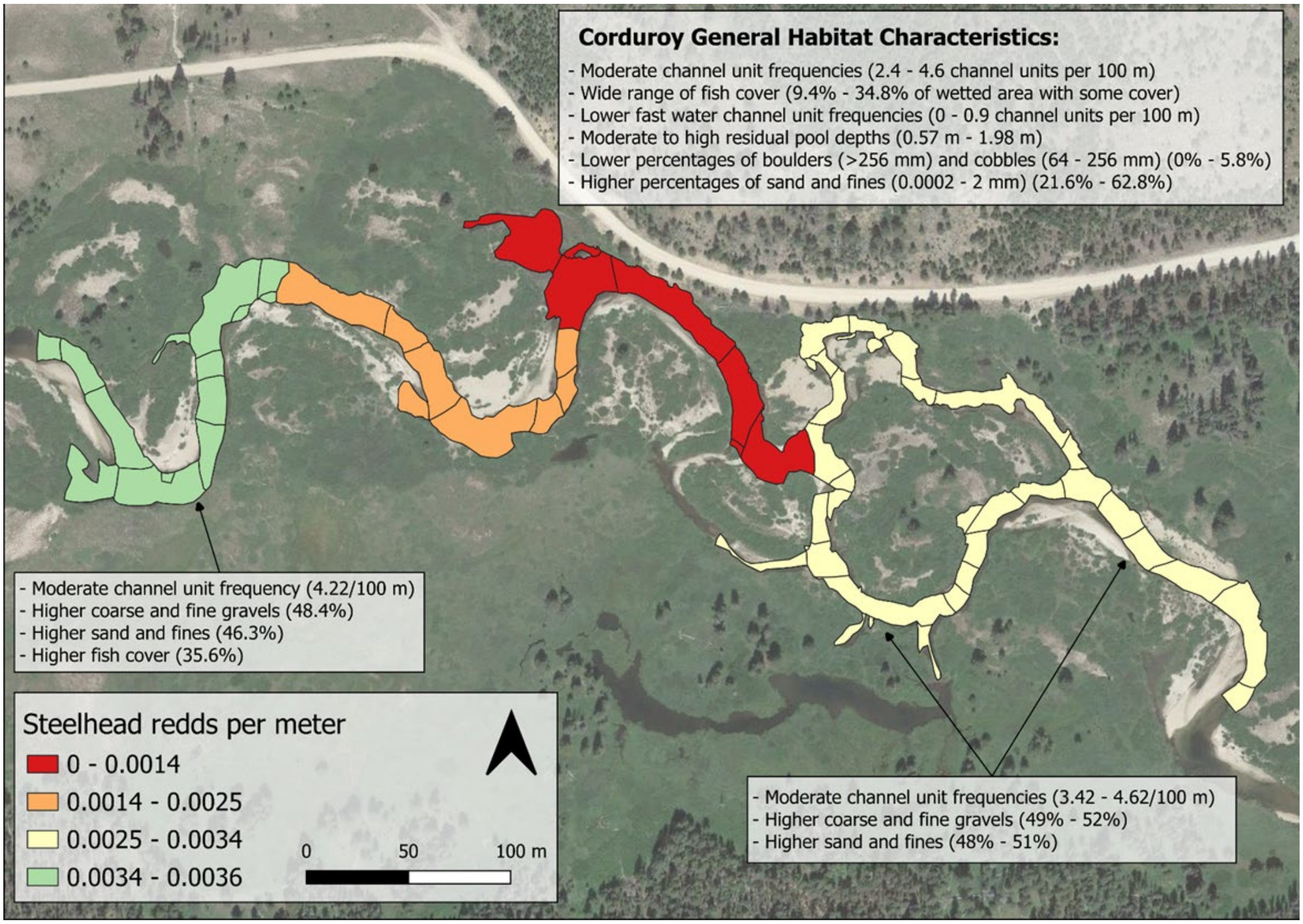


Figure 4-46. Corduroy reference site (on Elk Creek) contains multiple reaches with relatively higher carrying capacity estimates for steelhead redds.

5 SECONDARY CHANNEL DESIGN CONSIDERATIONS & DISCUSSION

The first step in establishing a suitable secondary channel design is understanding if and what type of secondary channels are appropriate for a given project area. Previous assessments from the Upper Salmon subbasin have defined five different secondary channel types (Figure 2-2, Table 2-2, Appendix C). Figure 5-1 and Figure 5-2 summarize the recommendations from these assessments identifying which secondary channel types are generally appropriate for different settings.

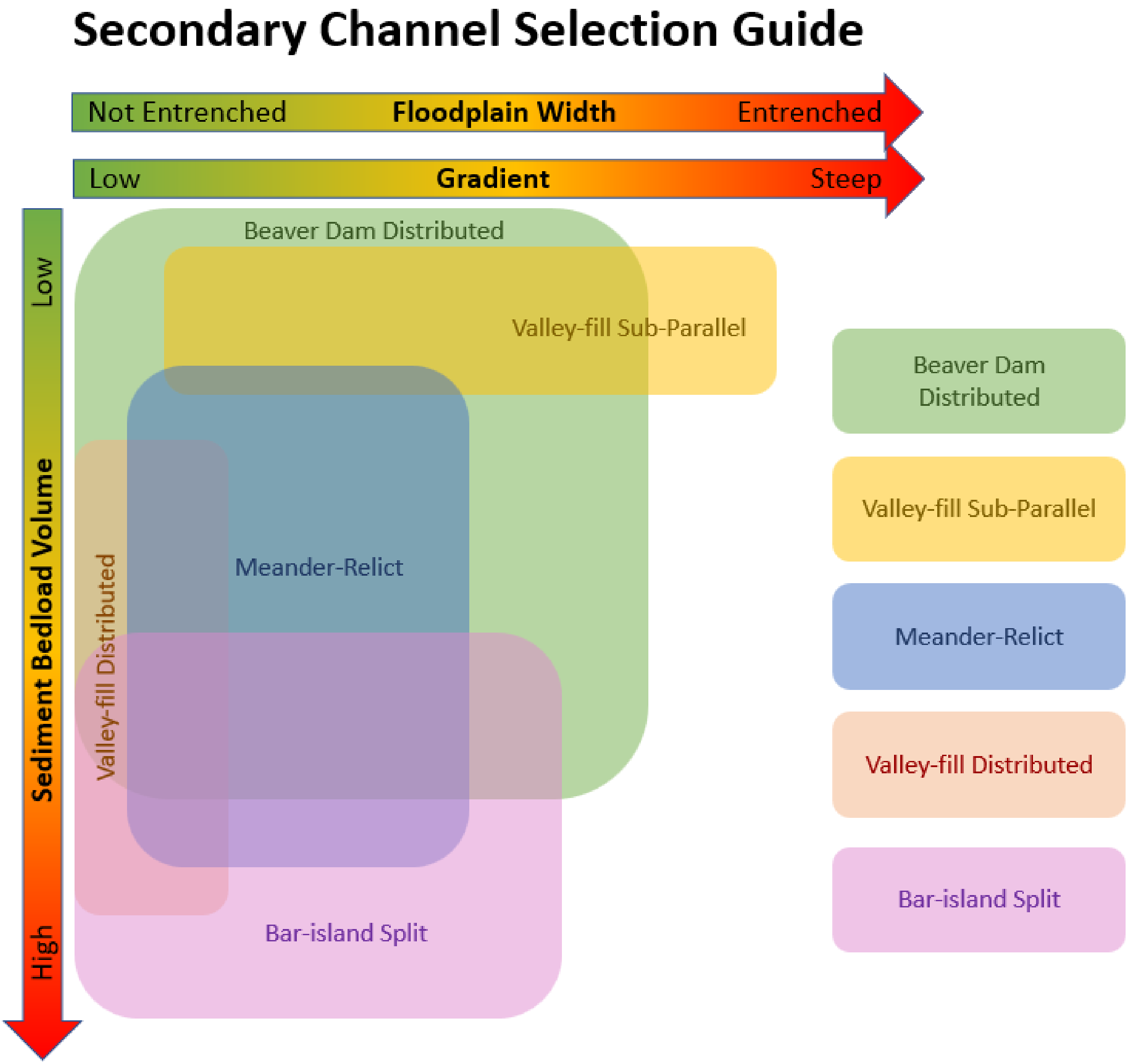


Figure 5-1: Secondary channel selection guide flow chart (Appendix C).

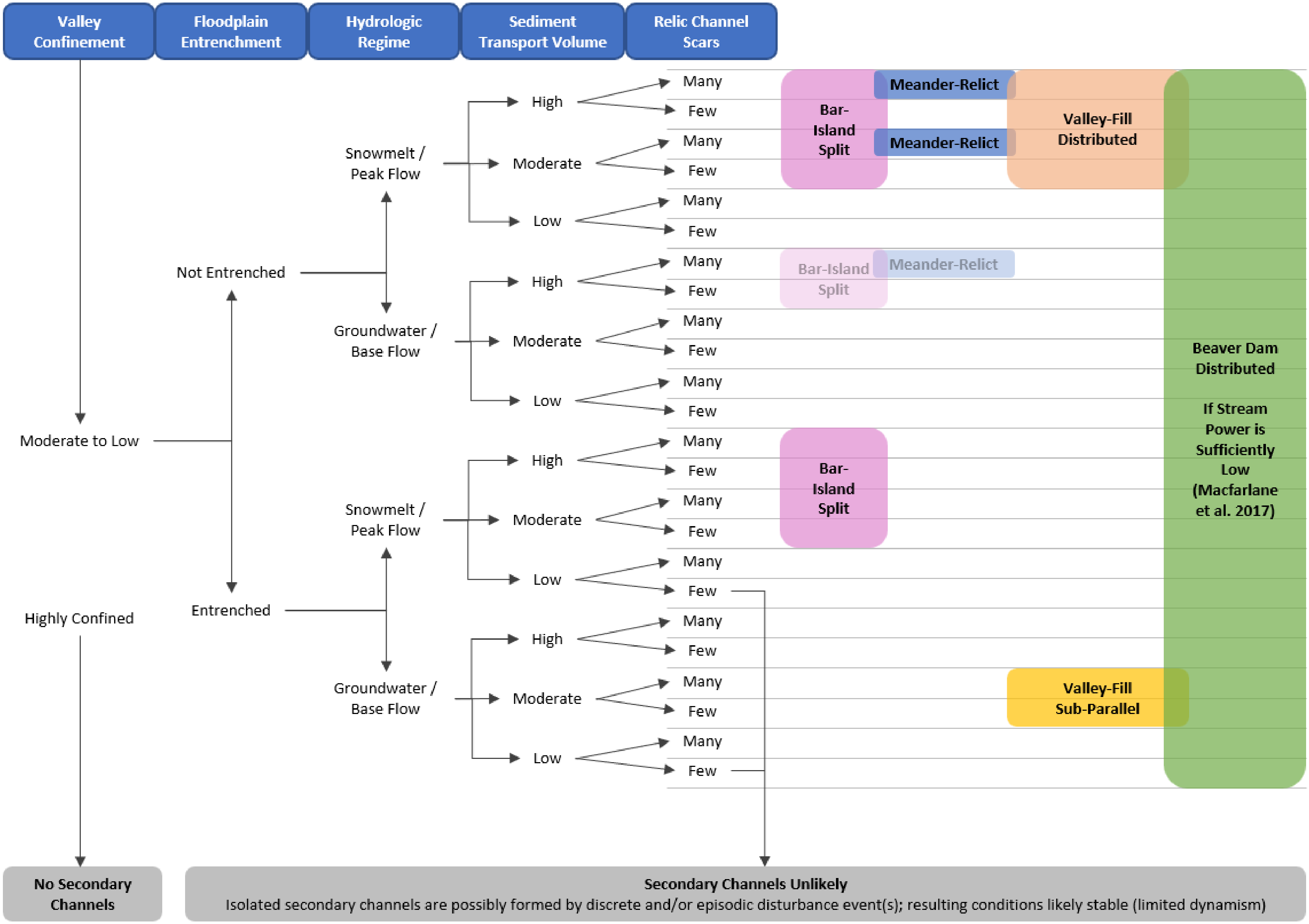


Figure 5-2: Secondary channel selection guide decision tree (Appendix C).

Once a secondary channel design has been identified and determined geomorphically appropriate, physical criteria must be selected to ensure successful implementation and long-term project success. Secondary channels and multi-threaded channel networks can form in a variety of valley settings and under a wide range of physical conditions. Based on available research (Schumm, 1985; Schumm et al., 1996; Knighton, 1998; Brummer et al., 2006; Judd et al., 2007; Sear et al., 2010; Wohl, 2011) and limited site data collected from the few reference reaches in this assessment, several key physical conditions have been identified that support the formation and maintenance of secondary channels that can be used to guide stream restoration design.

Secondary channels are essentially slow-motion avulsions. Rather than a new floodplain channel rapidly expanding to accommodate the entire river, secondary channels maintain a restrictive channel geometry for extended periods of time, able to convey only a portion of the overall river conveyance, thereby maintaining a split flow condition. The restrictive channel geometry is the result of erosion resistance, often in the form of dense riparian vegetation, woody debris, coarse substrate, and/or cohesive soils. The longer a secondary channel has been connected, the longer the forces in the stream have had to erode the banks, expand the channel, and capture more flow. By nature of this evolutionary process, it becomes possible to evaluate relative age among secondary channels within a similar environment, recognizing that there are several types of multi-threaded stream systems (Schumm et al., 1996). In those secondary channels observed within the reference reaches evaluated for this effort, new channels were relatively small and narrow, with freshly eroded banks associated with widening. Similar to the incision-based channel evolution model (Schumm, 1985), older secondary channels were generally larger, wider, and tended to exhibit more stable banks along with depositional features such as point bars. The mainstem channels were increasingly depositional, with more frequent and larger sediment bars and vegetative encroachment inversely proportional to the size and age of the associated secondary channel (Figure 5-3). In a restoration design setting, the earlier within this evolutionary sequence a new side channel can be created, the longer it will theoretically persist.

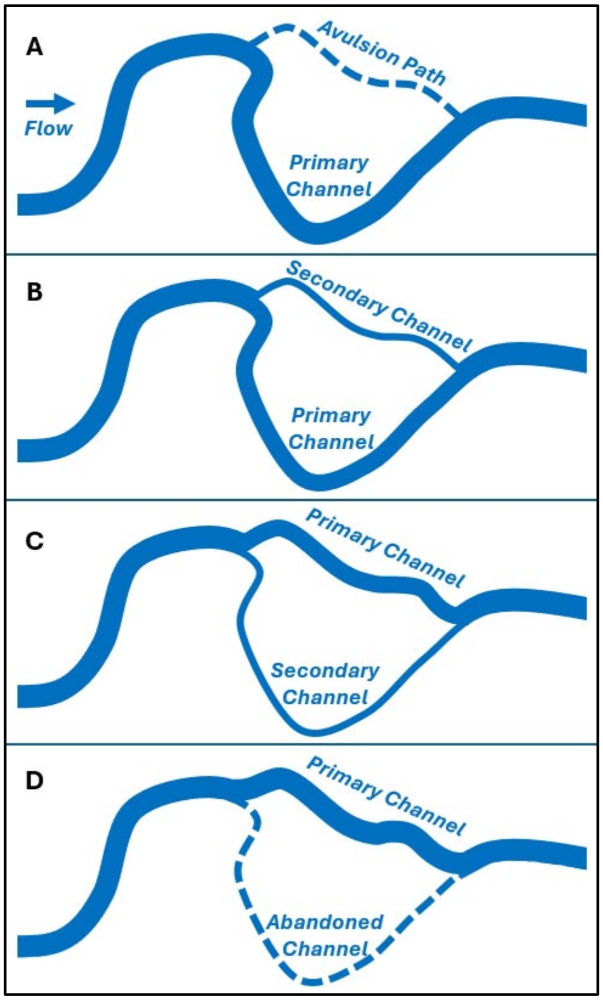


Figure 5-3: Secondary channel evolution model illustrating a slow-motion avulsion whereby an avulsion path (A) initiates the formation of a secondary channel that increases capacity while the primary channel reduces capacity (B) until the secondary channel captures more flow than the primary channel thereby becoming the new primary channel (C), ultimately abandoning the former primary channel (D).

The second thing to understand is that despite the variety of different side channel types, anecdotal field observations from the Upper Salmon subbasin suggest secondary channels typically form one of two ways:

1) Flow split: An obstruction in the middle of the channel splits flow. This could be the result of woody debris accumulation, the channel migrating into an erosion-resistant feature, or channel migration capturing a relict channel scar.
2) Backwater overflow: One or more conditions cause a backwater condition or otherwise raise the water surface elevation, forcing overbank flow into a new flow path. This could be the result of several factors:
    a. Flow is displaced onto the floodplain when there is a reduction in channel width, slope, and/or roughness. (Judd et al., 2007).
    b. Flow resistance (i.e., roughness) reduces conveyance, creating backwater conditions that raise water-surface elevations and force flow overbank, which concentrates into existing or newly scoured topographic depressions creating side channels (Sear et al., 2010)
    c. Flow resistance (i.e., roughness) provided by logjams promotes upstream deposition in streams with sufficient bedload, additionally raising the water-surface elevation until flow is diverted to side channels or the floodplain (Brummer et al., 2006).

d. Rivers with stable banks are more susceptible to flow displacement onto the floodplain and subsequent secondary channel formation because stable channels cannot readily migrate around obstructions (woody debris, dense riparian vegetation, beaver dam, etc.), which reduces channel conveyance and forces overbank flow (Judd et al., 2007). Additionally, as flow is lost to a new side channel, vegetative encroachment in the old channel further reduces its capacity, while existing dense vegetation in the new channel reduces its rate of expansion allowing both the old and new channels to coexist for an extended period (Schumm et al., 1996).

e. The combined effect of flow diverted across the floodplain and into secondary channels reduces flow depth and associated forces that might otherwise remove a spanning feature creating a positive feedback loop (Wohl, 2011).

Once a secondary channel has formed, maintenance of the channel depends on a balance between not capturing all the stream flow (i.e., avulsion) and not filling in with sediment. Field observations suggest that newly formed secondary channels tend to occupy a shorter flow path (i.e., avulsion path) compared with the primary channel. Rapid avulsion into the shorter flow path is prevented by bank stability, robust structure, and roughness within the secondary channel reducing the rate of erosion, thereby preventing channel expansion that would otherwise allow the secondary channel to capture a greater proportion of flow.

Sediment infilling of the secondary channel is prevented by several factors, including the fact that a newly formed secondary channel typically has a shorter (and therefore steeper) gradient than the primary channel and often has a lower width-to-depth ratio than the primary channel, both of which increase sediment transport capacity. Flow efficiency and sediment transport capacity can also be altered by changing the number of secondary channels and the width-to-depth ratio of those channels (Huang & Nanson, 2007). Increasing the number of secondary channels while decreasing their width-to-depth ratio can increase flow and sediment transport capacity, but this is a complex relationship and adding too many secondary channels can reverse the effect, resulting in one or more secondary channels filling over time (Huang & Nanson, 2007). Maintaining a narrow width-to-depth ratio requires bank stability commonly provided by dense, woody riparian vegetation. The optimal number of secondary channels can vary depending on the width-to-depth ratio of each, the channel slope, incoming sediment volume, bedload grainsize distribution, and discharge. Generally, to maintain sediment transport capacity, increasing numbers of side channels needs to be accompanied by decreasing width-to-depth ratios. Too many secondary channels will result in deposition regardless of width-to-depth ratio. Detailed, two-dimensional hydraulic modeling can be used to greatly inform the sediment transport characteristics associated with the number and geometry of proposed secondary channels.

Also affecting sediment transport is the location and angle of the secondary channel inlet. In a sinuous channel segment, meander bends create helical flow whereby bedload is directed away from the outside of the bend in the downstream half of the bend (Thorne et al., 1985). To minimize the volume of bedload sediment entering a secondary channel, the optimal location for a side channel inlet is on the outside of the bend roughly 2/3 down the length of the bend (interpreted from Brink et al., 2006). At this point, helical flow is typically the most pronounced, directing bedload toward the inside of the bend and away from the side channel inlet. The wider the channel, though, the farther downstream helical flow initiates and the farther downstream the optimal side channel location will be (Brink et al., 2006). The most optimal inlet location along a bend to reduce bedload capture can be calculated using the empirical formula shown in Equation 1 (Brink et al., 2006; Basson, 2006):

Equation 1: $$L = \xi w \sqrt{\frac{4r}{w} + 1}$$

Where L = distance to optimum diversion location from the upstream end of a bend

ξ = 1.71 (coefficient)

r = average radius of curvature

w = channel width

The secondary channel inlet angle also affects sediment transport. Research from field and flume experiments suggest that the optimal inlet angle in a straight channel varies with the diversion ratio (diverted discharge divided by the total incoming discharge of the stream channel) such that the optimum diversion angle increases as the diversion ratio decreases (Bulle, 1926). In other words, the greater the percentage of flow within the secondary channel, the smaller the diversion angle. Without calculating the optimal angle, 30-45° is the recommended diversion angle for minimizing sediment trapping on the outside of a curve in the channel (Hufferd et al., 1975), while Jagadale and Patil (2013) suggest 60° is optimal in a straight channel. Significantly higher and lower angles create eddy currents that can scour sediment locally and/or alter helical flow patterns, entraining more sediment within the secondary channel (Mosselman, 2001; Keshavarzi & Habibi, 2005; Obasi et al., 2012). Anecdotal information from field observations suggest that a secondary channel inlet angle formed by a flow-split is typically acute (as noted above), while a secondary channel inlet angle formed by a backwater overflow tends to span a broader range, including much larger, obtuse angles.

5.1 Biological Recommendations

The assessment described in Appendix B provides useful insights into key habitat metrics often associated with high-quality habitat in relation to different life stages of Chinook salmon and steelhead. While useful, the aggregate of various habitat characteristics within a site defines whether the site contains high- or low-quality habitat. The reference reach sites used in this assessment are great examples of high-quality habitat because they support high estimates of carrying capacity across multiple species and life stages. Side channel construction and enhancement can be an effective restoration strategy to integrate habitat characteristics that result in high-quality habitat for multiple species and life stages. Based on assessment results from Appendix B and reference reach site examples, the following provides life-stage-specific recommendations for side channel design while considering potential impacts on adjacent mainstem habitat.

5.1.1 Summer Parr

Previous studies have shown that juvenile Chinook salmon and steelhead typically select for relatively deep, slower velocity habitat in the summer (Hillman et al., 1987; Holecek et al., 2009; Holmes et al., 2014). As juveniles grow during the summer season, they begin to select deeper habitats with higher velocities compared to early summer (Hillman et al., 1987; Holecek et al., 2009; Holmes et al., 2014). Similarly, results in Appendix B show higher-quality juvenile summer rearing habitat was, in general, associated with higher average thalweg depths (> 0.3 m) and thalweg exit depths (> 0.35 m); greater residual depth in pools (> 0.35 m; difference between maximum and thalweg exit depth); lower frequency of channel units (<8 per 100 m); lower frequency of riffles and rapids (< 4 per 100 m); and substrate compositions with well-distributed percentages of boulders, cobbles, gravels, sands, and fines. Providing a range of depths and velocities for summer rearing juveniles is important to accommodate subtle changes in habitat preference as they grow. It is also important to design habitat for optimal foraging conditions (i.e., slower velocity habitat adjacent to higher velocity habitat), particularly in the summer when juvenile growth rate is highest because juvenile size can influence survival during subsequent life stages (Zabel & Achord, 2004).

Secondary channels can help facilitate high-quality summer rearing habitat in several ways. Secondary channels provide the opportunity to create shallower, slower velocity habitat near deeper, faster velocity habitat in main channels for optimal foraging conditions and evolving habitat preferences related to fish size. Secondary channels increase the area of stream bank, providing more bank roughness and slowing water velocities down. An increase in bank area allows for potentially more fish cover, increasing the area for overhanging vegetation, woody debris, and undercuts, which can also provide velocity refuge and shear zones for foraging. Larger, deep pools are primarily associated with higher capacity estimates for summer parr, as fish potentially seek cooler water during summer temperature extremes. As seen in the Marsh Creek site, designing secondary channels that are interspersed between single thread mainstem channels with deep, slow water habitat offers both habitat types, benefiting both species. For summer parr of both species, high channel unit frequency is less important than having ample slow water habitat that is relatively deep.

5.1.2 Winter Presmolt

Winter can be a critical period for juvenile Chinook salmon and steelhead as food availability declines and stream temperatures slow metabolic rates. Maintaining in-stream position for juvenile fish can become bioenergetically expensive if quality habitat is not available during winter periods when foraging opportunities decline. As a result, juvenile salmonids typically search for velocity refuge and cover during winter to reduce energetic costs and maintain body condition. Within the DASH dataset, the highest-capacity juvenile winter reaches were typically associated with increased frequency of channel units (> 4 per 100 m), increased fish cover (both large wood and total [includes overhanging and aquatic vegetation, artificial cover, etc.] cover), deeper average thalweg and thalweg exit depths, and a higher percentage of fines and sands (indicative of slow stream velocities). The increased channel unit frequency likely provides options for juvenile fish to occupy slow velocity microhabitats while maintaining proximity to habitat with higher foraging opportunities when invertebrate activity increases during warmer winter periods. Additionally, the association between fine and sand substrates with higher quality winter rearing habitat is likely a byproduct of geomorphic processes; suspended fines and sands are deposited out of the water column as velocity decreases around pools and structure. Alternatively, sands and fines often support higher abundances of chironomids (midges) than larger-sized substrates. Chironomids are small, benthic macroinvertebrates that hatch throughout the year and are readily consumed by juvenile Chinook salmon and steelhead when available. Regardless of whether the relationship between sands and fines and high-quality juvenile winter habitat is driven by minimizing energetic costs, increasing forage opportunities, or both, the dynamic highlights the importance of interpreting fish habitat holistically.

Design characteristics for high-quality overwintering habitat for both species should include higher channel unit frequency (>4 per 100m), higher fish cover including large wood (>25%), and abundant slow water habitat. Shallower side channels with pools and runs divided by small riffles with abundant fish cover provide suitable rearing conditions for winter presmolts. Off-channel alcove and floodplain habitat can increase channel unit frequency and provide zero-velocity habitat. While cover is typically considered beneficial for all life stages, it is of particular importance for winter rearing, providing concealment from predators, and refuge from higher velocities. In general, side channels add more wetted width, increasing the amount of available lateral habitat with low water velocities. As stated above, secondary channels also increase the area of stream bank, providing more bank roughness and slowing water velocities down. An increase in bank area allows for potentially more fish cover, increasing the area for overhanging vegetation, woody debris and undercuts and providing velocity refuge and concealment from predation.

5.1.3 Adult Redd

High-capacity spawning habitats for DASH sites were generally associated with lower average thalweg and thalweg exit depths, increased frequency of channel units (> 4 per 100 m), higher frequency of riffles, increased available fish cover (including large wood), and substrate compositions dominated by coarse and fine gravels.

Large amounts of wood and cover provide areas for adult Chinook salmon and steelhead to rest and hide during staging, redd construction, and spawning. Higher channel unit frequency is typically associated with hydraulic diversity and increased pool-riffle sequences, which provides access to pool tailouts for spawning with adjacent resting areas, as well as suitable fry and juvenile rearing habitat as fish emerge from the substrate in spring. Lastly, the abundance of gravel and high frequency of riffles allow adults to build redds in locations that minimize the chance that eggs become dislodged from substrate while also allowing sufficient flow and oxygen for egg and alevin development. Combined, these characteristics result in conditions where adults can build redds and spawn in high-quality gravels in pool-riffle interfaces and pool tailouts near adjacent cover and large structure to rest and escape predators.

While side channels have the potential to benefit adults, they are largely designed and constructed with juvenile rearing in mind. For suitable spawning conditions, it is important to consider the impacts of side channel design on main channel habitat that typically supports spawning, as well as spawn timing for the two species. Unlike rearing life stages, spawning occurs at different times of the year for Chinook salmon and steelhead, under different hydrologic conditions. For Chinook salmon in the USRB, spawning occurs in late summer under low flow conditions. Design and construction of side channels should take this into consideration, especially in systems where water is utilized for agriculture production. Suitable hydraulic parameter indices (i.e., depth and velocity) have been developed for Chinook salmon and steelhead spawning in the USRB, with depths >0.25 m and velocities between 0.25-1 m per second being most suitable (Maret et al., 2006). Additionally, fish passage and pre-spawn holding parameters for adult Chinook salmon should also be considered, identified as >0.27 m depth (Bjornn & Reiser, 1991; Cowan et al., 2017) and >0.7 m depth (Torgersen et al., 1999; McIntosh et al., 2000), respectively. Steelhead spawn timing is typically less affected by water allocation, occurring in spring under run-off conditions in the USRB. However, a minimum depth of 0.21 m for adult steelhead passage has been identified in a coastal California system (Holmes et al., 2016; Thompson, 1972).

5.1.4 Fry

Quantifying habitat suitability and carrying capacity for the fry life stage is extremely difficult, largely due to fish size precluding traditional methods for estimating fish abundance and density. Carrying capacity estimation methods used in this analysis do not address this life stage; however, it is critical for population productivity, as fry are highly vulnerable to environmental variables including hydraulic conditions and predation. This life stage could potentially benefit the most from secondary channels; therefore, suitable habitat characteristics for fry should be considered. Shallow (0.2-0.7 m), low velocity (0.1-0.2 m/s) habitat has been shown to be hydraulically suitable for fry (Raleigh et al., 1986) and could likely mitigate predation by larger fish. Fish cover, particularly aquatic vegetation or woody debris that extends through the entire water column, can create preferable hydraulic breaks and micro-cover for fry. Root wads and willow clumps that have many smaller limbs and roots typically provide more complex micro-refugia than large wood.

6 CONCLUSION

Secondary channels have been shown to exhibit characteristics that provide habitat especially suitable for juvenile rearing salmonids, and juvenile rearing habitat capacity has been shown to be limiting in many parts of the USRB. This suggests improved secondary channel development and restoration can be a useful tool to aid salmon and steelhead population recovery, but secondary channels exhibit many different characteristics. Summarized below are key geomorphic and biological conclusions from this report intended to support the selection and development of secondary channel restoration designs in the USRB.

Geomorphic conclusions:

- All of the reference reaches exhibited variable conditions but occupied a generally wide, unconfined valley with a low gradient, high sinuosity primary channel with medium gravel through small cobble substrate. Riparian conditions reflected wet meadow vegetation predominantly comprising grasses, forbs, and shrubs. Large woody debris contributions were minimal and generally associated with stream segments adjacent upland alluvial fans and terraces.
- The length of Bar-island Split channels likely scales positively with primary channel size, potentially due to large channels commonly conveying greater sediment loads driving bar and island formation.
- The length of individual secondary channels can be designed around the inter-quartile range associated with the length of secondary channels measured from reference sites, assuming similar physical settings.
- Side channel length is highly variable, but generally Bar-island Split channels are individually shorter and constitute a shorter total length per 1,000 feet of valley length compared to Valley-fill Distributed and Meander-Relict side channel types.
- The frequency of secondary channel nodes (primary-to-secondary and secondary-to-secondary channel connections) was highly variable and independent of secondary channel type, with the exception of Beaver Dam Distributed secondary channels, which tended to exhibit the highest number of secondary-to-secondary channel connections.
- Larger drainage areas tend to produce primary and secondary channels with greater top width than smaller drainage areas.
- Geomorphic unit frequency is relatively high, ranging from 6-12 per 1,000 ft of primary channel length.
- Longitudinal profiles showed great variability among the reference reaches with a relatively steep slope from riffles leading into pools, shallow slope in the pool bottoms, and again relatively steep slope leading out of the pools to the next riffle.
- Other than pool-to-riffle slope, the inter-quartile range of the other geomorphic unit transition slopes from all of the reference streams could be used as a guide for channel design of streams with geomorphic and hydraulic characteristics similar to any of the reference streams.
- Secondary channel inlet angle varied significantly, but was most commonly acute, generally between 45 and 90 degrees. Bar-island Split side channels had slightly lower inlet angles versus the other secondary channel types. For a given secondary channel type (Bar-island Split, Meander-Relict, Valley-fill Distributed) the inter-quartile range from all reference streams could be used as a guide for design of inlet angles from primary to secondary channels.
  - Backwater influenced secondary channel inlet angles are commonly greater than those of flow split secondary channels.
- Wood abundance in primary channels is likely not a primary control on geomorphic processes within the reference streams observed; however, beaver dams in secondary channels likely do contribute to the formation and maintenance of multi-thread channel networks. Most beaver dams were observed in secondary channels.

- Secondary channels are generally formed by a flow split around an obstruction or from a backwater condition forcing overbank flow.
- Secondary channels typically occupy a shorter flow path than the primary channel.
- Secondary channels are slow-motion avulsions controlled by bank stability and structure preventing the secondary channel from expanding to capture the entire flow of the river.
- In many settings, the preferred location for a secondary channel inlet is along the outside of a bend, roughly 2/3 of the way around the bend where helical flow is most pronounced. This is not always applicable for Bar-island Split, Valley-fill Distributed, or Beaver Dam Distributed side channels.

The design philosophy for a project can be either passive or active. A passive design requires allowing the stream to “do the work,” which is potentially more suitable for a dynamic stream system, or one with ample structure to prevent undesirable channel evolution. An active design incorporates larger amounts of construction and earth moving, often creating conditions that emulate natural features that work with natural processes. Secondary channel design should consider channel evolution and incorporate a greater number of early-evolution channels to maximize the longevity of each (see Figure 5-3, A and B). In stream reaches with high bedload sediment volumes, conditions change frequently, such that secondary channel evolution may occur much more rapidly than in reaches with less sediment load and stable banks. It may be beneficial, therefore, to design a higher frequency of secondary channels in dynamic reaches with high bedload in order to accommodate some secondary channels filling with sediment. Providing adequate space for channel evolution is also important for long-term maintenance of a secondary channel network, ensuring new channels have space to form when current channels are abandoned in the future. Regarding channel form and geometry, many conditions should be considered including flow distribution (especially in flow-limited channel segments), secondary channel location and inlet angle, the number and size of secondary channels, and the available structure maintaining both primary and secondary channels. After developing a design that is geomorphically appropriate for a given valley segment, specific design features can be optimized for biological benefit.

Biological Conclusions

- Higher-quality juvenile summer rearing habitat was generally associated with a range of depths and velocities that accommodates subtle changes in habitat preference over time; high channel unit frequency is less important than having ample slow water habitat that is relatively deep.
- Secondary channels provide high-quality summer juvenile rearing habitat by providing shallower, slower velocity habitat near deeper, faster velocity habitat. Secondary channels also increase total stream bank area, providing more bank roughness, more cover, and slower water.
- Optimal juvenile salmonid foraging conditions were generally associated with slower velocity habitat adjacent to higher velocity habitat.
- Juvenile salmonids typically search for velocity refuge and cover during winter to reduce energetic costs and maintain body condition.
- The highest juvenile winter capacity was associated with increased frequency of channel units, increased fish cover, deeper average thalweg and thalweg exit depths, a higher percentage of fines and sands, and slower water velocity.
- High-capacity adult spawning was generally associated with lower average thalweg and thalweg exit depths, increased frequency of channel units, higher frequency of riffles, increased available fish cover (including large wood), and gravel substrate.
- Splitting flows to create side channels should be carefully evaluated, especially in flow-limited channel segments, recognizing that Chinook migration and spawning occurs in the late summer when water levels are often lowest.

- Juvenile fry could potentially benefit the most from secondary channels, given their need for shallow, low velocity habitat with cover, particularly aquatic vegetation or woody debris that extends through the entire water column.

While several habitat characteristics associated with higher carrying capacity estimates for different life stages of Chinook salmon and steelhead were identified in analyses, reference sites show that reaches exhibiting many complimentary characteristics typically have the greatest benefit to both species. How these characteristics are structured spatially within reaches, tributaries, and watersheds likely influence species production and life-stage survival but may be more specific to individual systems. Secondary channels provide the opportunity to enhance micro-habitat largely associated with juvenile rearing, particularly by increasing bank area, which creates lower velocities and opportunity for more cover.

While not incorporated in quantile random forest models, water temperature at the channel unit-scale and bioenergetics likely play an important role in the value of secondary channel habitat. Short side channels and flow splits may promote greater surface water and groundwater exchange, which has been shown to create pockets of water temperature heterogeneity, important for thermal refugia for fish during periods of water temperature extremes (Weber et al., 2017). Additionally, smaller secondary channels are typically shaded more easily by riparian vegetation because of their smaller widths, reducing solar input and potentially mitigating high water temperatures (Seixas et al., 2018). Secondary channels, specifically the “nodes” created at the intersection of multiple channels, may provide bioenergetically favorable conditions where fish can save energy by occupying slower water habitat while taking advantage of adjacent faster water for foraging opportunities.

Secondary channels are an important part of the riverscape that can provide beneficial habitat for Chinook salmon and steelhead, but are also diverse and often dynamic, requiring specialized design considerations. This document is intended to provide data and conclusions to facilitate secondary channel design but should not be used without appropriate training in river restoration design, site-specific data, hydraulic modeling, and industry-standard best practices in stream and floodplain restoration design. The data provided in this report were derived from a limited number of reference reaches in the USRB and do not represent the full extent of potential secondary channel conditions or metrics suitable or appropriate for a given restoration design. All streams and restoration sites are different. Individual project design teams and engineers should consider the data and conclusions in this report as one tool of many necessary to develop a complete and holistic stream and floodplain restoration design with or without secondary channels.

7 REFERENCES

Basson, G. R. (2006). *Considerations for the Design of River Abstraction Works in South Africa. Report to the Water Research Commission* (WRC Report No. TT 260/06). https://www.wrc.org.za/wp-content/uploads/mdocs/TT%20260-06.pdf

Baum, C. M., Lawry, K. M., Sullivan, C. L., Hargrove, J. S., Delomas, T., Davison, M., Dobos, M. E., Smith, N. R., Schrader, W. C., Copeland, T., & Campbell, M. R. (2022). *Wild Adult Steelhead and Chinook Salmon Abundance and Composition at Lower Granite Dam, Spawn Year 2020: Annual Progress Report* (IDFG Report Number 22-11). Idaho Department of Fish and Game. https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Res22-11Baum2020Wild%20Adult%20Steelhead%20Chinook%20Salmon%20Abundance.pdf

Bjornn, T. C., & Reiser, D. W. (1991). Habitat Requirements of Salmonids in Streams. In W. R. Meehan (Ed.), *Influences of Forest and Rangeland Management on Salmonid Fishes and Their Habitats* (p. 622). American Fisheries Society.

Brink, C. J., Basson, G. R., & Denys, F. (2006). *Sediment Control at River Abstraction Works in South Africa. Volume I. Report to the Water Research Commission* (WRC Report No. TT 259/06). https://www.wrc.org.za/wp-content/uploads/mdocs/TT259-06.pdf

Brummer, C., Abbe, T. B., Sampson, J. R., & Montgomery, D. R. (2006). Influence of Vertical Channel Change Associated With Wood Accumulations on Delineating Channel Migration Zones, Washington, USA. *Geomorphology*, *80*(3–4), 295–309. https://doi.org/10.1016/j.geomorph.2006.03.002

Carmichael, R. A., Tonina, D., Keeley, E. R., Benjankar, R. M., & See, K. E. (2020). Some Like It Slow: A Bioenergetic Evaluation of Habitat Quality for Juvenile Chinook Salmon in the Lemhi River, Idaho. *Canadian Journal of Fisheries and Aquatic Sciences*, *77*(7), 1221-1232. https://doi.org/10.1139/cjfas-2019-0136

Cowan, W. R., Rankin, D. E., & Gard, M. (2017). Evaluation of Central Valley Spring-Run Chinook Salmon Passage Through Lower Butte Creek Using Hydraulic Modelling Techniques. *River Research and Applications*, *33*(3), 328–340. https://doi.org/10.1002/rra.3098

Eaton, B., & Millar, R. (2017). Predicting Gravel Bed River Response to Environmental Change: The Strengths and Limitations of a Regime-Based Approach. *Earth Surface Processes and Landforms*, *42*(6), 994–1008. https://doi.org/10.1002/esp.4058

Finklin, A. I. (1988). *Climate of the Frank Church-River of No Return Wilderness, Central Idaho* (General Technical Report INT-240). U.S. Department of Agriculture Forest Service. https://www.fs.usda.gov/rm/pubs_int/int_gtr240.pdf

Fisher, F. S., McIntyre, D. H., & Johnson, K. M. (1992). *Geologic Map of the Challis 1° x 2° Quadrangle, Idaho* [Map]. U.S. Geological Survey. https://pubs.usgs.gov/publication/i1819

Graham, D. J., Reid, I., & Rice, S. P. (2005a). Automated Sizing of Coarse-Grained Sediments: Image-Processing Procedures. *Mathematical Geology*, *37*, 1–28. https://doi.org/10.1007/s11004-005-8745-x

Graham, D. J., Rice, S. P., & Reid, I. (2005b). A Transferable Method for the Automated Grain Sizing of River Gravels. *Water Resources Research*, *41*(7). https://doi.org/10.1029/2004WR003868

Hassemer, P. F. (1993). *Salmon Spawning Ground Surveys, 1989-92. Project F-73-R-15*. Idaho Department of Fish and Game. https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Res-Hassemer1992%20Salmon%20Spawning%20Ground%20Surveys.pdf

Heller, M., Barnett, B., Felts, E., Davison, M., Smith, N. R., Knoth, B., Poole, J. R., Meyer, S. F., & Wauhkonen, K. (2022). *Idaho Anadromous Emigrant Monitoring: 2021 Annual Report* (IDFG Report Number 22-07). Idaho Department of Fish and Game. https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Res22-07Heller2021%20Idaho%20Anadromous%20Emigrant%20Monitoring.pdf

Hey, R. D., & Thorne, C. R. (1986). Stable Channels with Mobile Gravel Beds. *Journal of Hydraulic Engineering*, *112*(8). https://doi.org/10.1061/(ASCE)0733-9429(1986)112:8(671)

Hillman, T. W., Griffith, J. S., & Platts, W. S. (1987). Summer and Winter Habitat Selections by Juvenile Chinook Salmon in a Highly Sedimented Idaho Stream. *Transactions of the American Fisheries Society*, *116*(2), 185–195. https://doi.org/10.1577/1548-8659(1987)116<185:SAWHSB>2.0.CO;2

Holecek, D. E., Cromwell, K. J., & Kennedy, B. P. (2009). Juvenile Chinook Salmon Summer Microhabitat Availability, Use, and Selection in a Central Idaho Wilderness Stream. *Transactions of the American Fisheries Society*, *138*(3), 633–644. https://doi.org/10.1577/T08-062.1

Holmes, R. W., Allen, M. A., & Bros-Seeman, S. (2014). Seasonal Microhabitat Selectivity by Juvenile Steelhead in a Central California Coastal River. *California Fish and Game*, *100*(4), 590–615.

Holmes, R. W., Rankin, D. E., Ballard, E., & Gard, M. (2016). Evaluation of Steelhead Passage Flows Using Hydraulic Modeling on an Unregulated Coastal California River. *River Research and Applications*, *32*(4), 697–710. https://doi.org/10.1002/rra.2884

Huang, H. Q., & Nanson, G. (2007). Why Some Alluvial Rivers Develop an Anabranching Pattern. *Water Resources Research*, *43*(7). https://doi.org/10.1029/2006WR005223

Hufferd, J. A., Vance, R. L., & J. J. Watkins. (1975). Chapter V. Sediment Control Methods. In V. A. Vanoni (Ed.), *Sedimentation Engineering*. American Society of Engineers.

Integrated Status and Effectiveness Monitoring Program and Columbia Habitat Monitoring Program (ISEMP & CHaMP). (2017). *Integrated Status and Effectiveness Monitoring Program (ISEMP) and Columbia Habitat Monitoring Program (CHaMP) 2016 Annual Combined Technical Report, January-December 2016. BPA Projects 2003-017-00 and 2011-006-00.*

Jagadale, M. M., & Patil, A. P. (2013). Study the Effect of Off-Take Angle on Sediment Trapping at Channel Bifurcation in Krishna Canal. *International Journal of Engineering Research & Technology*, *2*(7), 354–358.

Judd, D. A., Rutherford, I. D., Tilleard, J. W., & Keller, R. J. (2007). A Case Study of the Processes Displacing Flow From the Anabranching Ovens River, Victoria, Australia. *Earth Surface Processes and Landforms*, *32*(14), 2120–2132. https://doi.org/10.1002/esp.1516

Keshavarzi, A., & Habibi, L. (2005). Optimizing Water Intake Angle by Flow Separation Analysis. *Irrigation and Drainage*, *54*(5), 543–552. https://doi.org/10.1002/ird.207

Kiilsgaard, T. H., Stanford, L. R., & Lewis, R. S. (2006). *Geologic Map of the Deadwood River 30 x 60 Minute Quadrangle, Idaho* [Geologic Maps]. Idaho Geological Survey. https://www.idahogeology.org/product/GM-45

Kleinhans, M. G. (2010). Sorting Out River Channel Patterns. *Progress in Physical Geography*, *34*(3), 287–326. https://doi.org/10.1177/0309133310365300

Kleinhans, M. G., & Van den Berg, J. H. (2011). River Channel and Bar Patterns Explained and Predicted by an Empirical and Physics-Based Method. *Earth Surface Processes and Landforms*, *36*(6), 721–738. https://doi.org/10.1002/esp.2090

Knighton, D. (1998). *Fluvial Forms & Processes: A New Perspective*. Routledge.

Lewis, R. S., Link, P. K., Stanford, L. R., & Long, S. P. (2012). *Geologic Map of Idaho* [Map]. Idaho Geological Survey.

Limm, M. P., & Marchetti, M. P. (2009). Juvenile Chinook Salmon (Oncorhynchus tshawytscha) Growth in Off-Channel and Main-Channel Habitats on the Sacramento River, CA Using Otolith Increment Widths. *Environmental Biology of Fishes*, *85*(2), 141–151. https://doi.org/10.1007/s10641-009-9473-8

Macfarlane, W. W., Wheaton, J. M., Bouwes, N., Jensen, M. L., Gilbert, J. T., Hough-Snee, N., & Shivik, J. A. (2017). Modeling the Capacity of Riverscapes to Support Beaver Dams. *Geomorphology*, *277*, 72–99. https://doi.org/10.1016/j.geomorph.2015.11.019

Maret, T. R., Hortness, J. E., & Ott, D. S. (2006). *Instream Flow Characterization of Upper Salmon River Basin Streams, Central Idaho, 2005* (Scientific Investigations Report 2006–5230; pp. 1–110). https://pubs.usgs.gov/sir/2006/5230/pdf/sir20065230.pdf

McGrath, C. L., Woods, A. J., Omernik, J. M., Bryce, S. A., Edmondson, M., Nesser, J. A., Shelden, J., Crawford, R. C., Comstock, J. A., & Plocher, M. D. (2002). *Ecoregions of Idaho* [Map]. U.S. Geological Survey.

McIntosh, B. A., Sedell, J. R., Thurow, R. F., Clarke, S. E., & Chandler, G. L. (2000). Historical Changes in Pool Habitats in the Columbia River Basin. *Ecological Applications*, *10*(5), 1478–1496. https://doi.org/10.1890/1051-0761(2000)010[1478:hciphi]2.0.co;2

Metsker, H. E. (1958). *Aerial Survey of Spring Chinook Salmon Redds in the Salmon and Weiser River Drainages, Idaho 1957*. Idaho Department of Fish and Game. https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Mgt-Metsker1958%20Aerial%20Survey%20of%20Spring%20Chinook%20Salmon%20Redds%20in%20the%20Salmon%20and%20Weiser%20River%20Drainages.pdf

Millar, R. G., & Eaton, B. C. (2011). Bank Vegetation, Bank Strength, and Application of the University of British Columbia Regime Model to Stream Restoration. In A. Simon, S. J. Bennet, & J. M. Castro (Eds.), *Stream Restoration in Dynamic Fluvial Systems: Scientific Approaches, Analyses, and Tools* (Vol. 194). American Geophysical Union. https://doi.org/10.1029/2010GM000989

Mosselman, E. (2001). *Morphological Development of Side Channels* (CFR Project Report 9 IRMA-SPONGE and Delft Cluster). Delft Hydraulics. https://edepot.wur.nl/322868

National Oceanic and Atmospheric Administration (NOAA). (2017). *ESA Recovery Plan for Snake River Spring/Summer Chinook Salmon (Oncorhynchus tshawytscha) & Snake River Basin Steelhead (Oncorhynchus mykiss)*. National Oceanic and Atmospheric Administration National Marine Fisheries Service West Coast Region. https://www.fisheries.noaa.gov/resource/document/recovery-plan-snake-river-spring-summer-chinook-salmon-and-snake-river-basin

Obasi, N. L., Oloke, D. A., & Agunwamba, J. C. (2012). Effect of Off-Take Angles on Spatial Distribution of Silt Materials at Concave Channel Bifurcation. *International Journal of Engineering Research and Applications*, *2*(5), 528–534.

Pierce, K. L., & Scott, W. E. (1982). Pleistocene Episodes of Alluvial-Gravel Deposition, Southeastern Idaho. In B. Bonnichsen & R. M. Breckenridge (Eds.), *Cenozoic Geology of Idaho*. Idaho Geological Survey.

Poole, J. R., Felts, E. A., Barnett, B., Davison, M., Heller, M., Hand, R., & Brown, E. (2022). *Idaho Adult Chinook Salmon Monitoring: 2021 Annual Report* (IDFG Report Number 22-05). Idaho Department of Fish and Game. https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Res22-05Poole2021Idaho%20Adult%20Chinook%20Salmon%20Monitoring.pdf

Raleigh, R. F., Miller, W. J., & Nelson, P. C. (1986). *Habitat Suitability Index Models and Instream Flow Suitability Curves: Chinook Salmon* (Biological Report 82(10.122)). U.S. Fish and Wildlife Service. https://apps.dtic.mil/sti/pdfs/ADA322912.pdf

Rio Applied Science & Engineering & Biomark (Rio ASE & Biomark). (2021a). *Lower Lemhi River Multiple Reach Assessment Report. Prepared with the Idaho Governor's Office of Species Conservation under U.S. Bureau of Reclamation Cooperative Agreement R19AC00078*. https://modelwatershed.idaho.gov/wp-content/uploads/2021/04/LowerLemhiMRA_Final_20210426_Reduced.pdf

Rio Applied Science & Engineering & Biomark (Rio ASE & Biomark). (2021b). *Lower Pahsimeroi River Multiple Reach Assessment Report. Prepared with the Idaho Governor's Office of Species Conservation under the U.S. Bureau of Reclamation Cooperative Agreement R19AC00078* (pp. 1–79).

Rio Applied Science & Engineering & Biomark (Rio ASE & Biomark). (2021c). *Upper Lemhi River Multiple Reach Assessment Report. Prepared with the Idaho Governor's Office of Species Conservation under U.S. Bureau of Reclamation Cooperative Agreement R19AC00078*. https://modelwatershed.idaho.gov/wp-content/uploads/2021/04/UpperLemhiMRA_Final_20210422_Reduced.pdf

Rio Applied Science & Engineering & Biomark (Rio ASE & Biomark). (2021d). *Upper Salmon River Multiple Reach Assessment Report. Prepared with the Idaho Governor's Office of Species Conservation un U.S. Bureau of Reclamation Cooperative Agreement R19AC00078*. https://modelwatershed.idaho.gov/wp-content/uploads/2021/07/UpperSalmonMRA_Final_20210510_Reduced-1.pdf

Rosell, F., Bozsér, O., Collen, P., & Parker, H. (2005). Ecological Impact of Beavers Castor fiber and Castor canadensis and their ability to modify ecosystems. *Mammal Review*, *35*(3–4). https://doi.org/10.1111/j.1365-2907.2005.00067.x

Rossillon, M. P. (1981). *An Overview of History in the Drainage Basin of the Middle Fork of the Salmon River* (Cultural Resource Report No. 6). U.S. Forest Service Intermountain Region. http://npshistory.com/publications/usfs/region/4/salmon/cultres6.pdf

Schmidt, D. L., & Mackin, J. H. (1970). *Quaternary Geology of Long and Bear Valleys, West-Central Idaho* (Geological Survey Bulletin 1311-A; Contributions to General Geology). U.S. Department of the Interior, U.S. Geological Survey. https://pubs.usgs.gov/bul/1311a/report.pdf

Schumm, S. A. (1985). Patterns of Alluvial Rivers. *Annual Review of Earth and Planetary Sciences*, *13*, 5–27. https://doi.org/10.1146/annurev.ea.13.050185.000253

Schumm, S. A., Erskine, W. D., & Tilleard, J. W. (1996). Morphology, Hydrology, and Evolution of the Anastomising Ovens and King Rivers, Victoria, Australia. *Geological Society of America Bulletin*, *108*(10), 1212–1224. https://doi.org/10.1130/0016-7606(1996)108<1212:MHAEOT>2.3.CO;2

Sear, D. A., Millington, C. E., Kitts, D. R., & Jeffries, R. (2010). Logjam Controls on Channel:Floodplain Interactions in Wooded Catchments and their Role in the Formation of Multi-channel Patterns. *Geomorphology*, *116*(3–4), 305–319. https://doi.org/10.1016/j.geomorph.2009.11.022

See, K. E., Ackerman, M. W., Carmichael, R. A., Hoffmann, S. L., & Beasley, C. (2021). Estimating Carrying Capacity for Juvenile Salmon Using Quantile Random Forest Models. Ecosphere, 12(3). https://doi.org/10.1002/ecs2.3404

Seixas, G. B., Beechie, T. J., Fogel, C., & Kiffney, P. M. (2018). Historical and Future Stream Temperature Change Predicted by a LiDAR-Based Assessment of Riparian Condition and Channel Width. *Journal of the American Water Resources Assocation*, *54*(4), 974–991. https://doi.org/10.1111/1752-1688.12655

Thompson, K. (1972, March 15). Determining Stream Flows for Fish Life. *Instream Flow Requirements Workshop*. Pacific Northwest River Basins Commission, Vancouver, Washington. https://digital.osl.state.or.us/islandora/object/osl%3A17982/datastream/OBJ/view

Thorne, C. R., Zevenbergen, L. W., Pitlick, J. C., Rais, S., Bradley, J. B., & Julien, P. Y. (1985). Direct Measurements of Secondary Currents in a Meandering Sand-Bed River. *Nature*, *315*, 746–747. https://doi.org/10.1038/315746a0

Thurow, R. F., Copeland, T., & Oldemeyer, B. N. (2020). Wild Salmon and the Shifting Baseline Syndrome: Application of Archival and Contemporary Redd Counts to Estimate Historical Chinook Salmon (Oncorhynchus tshawytscha) Production Potential in the Central Idaho Wilderness. *Canadian Journal of Fisheries and Aquatic Sciences*, *77*(4), 651–665. https://doi.org/10.1139/cjfas-2019-0111

Torgersen, C. E., Price, D. M., Li, H. W., & McIntosh, B. A. (1999). Multiscale Thermal Refugia and Stream Habitat Associations of Chinook Salmon in Northeastern Oregon. *Ecological Applications*, *9*(1), 301–319. https://doi.org/10.1890/1051-0761(1999)009[0301:MTRASH]2.0.CO;2

U.S. Department of Agriculture (USDA). (2017). *National Agriculture Imagery Program (NAIP) GeoHub*. https://naip-usdaonline.hub.arcgis.com/

U.S. Environmental Protection Agency (EPA). (2015). *Stakeholders Collaborate to Reduce Sediment and Restore Fish Habitat in Bear Valley Creek* (EPA 841-F-15-001MM; Section 319 Nonpoint Source Program Success Story: Idaho). https://19january2017snapshot.epa.gov/sites/production/files/2016-01/documents/id_bear.pdf

U.S. Forest Service (USFS). (2010). *Boise National Forest Land and Resource Management Plan: 2003-2010 Integration*. https://www.fs.usda.gov/detail/boise/landmanagement/planning/?cid=stelprdb5394192

U.S. Geological Survey (USGS). (2019). *StreamStats*. https://streamstats.usgs.gov/ss/

van Denderen, R. P., Schielen, R. M. J., Straatsma, M. W., Kleinhans, M. G., & Hulscher, S. J. M. H. (2019). A Characterization of Side Channel Development. *River Research and Applications*, *35*(9), 1597–1603. https://doi.org/10.1002/rra.3462

van Dijk, W. M., Schuurman, F., van de Lageweg, W. I., & Kleinhans, M. G. (2014). Bifurcation Instability and Chute Cutoff Development in Meandering Gravel-Bed Rivers. *Geomorphology*, *213*, 277–291. https://doi.org/10.1016/j.geomorph.2014.01.018

Weber, N., Bouwes, N., Pollock, M. M., Volk, C., Wheaton, J. M., Wathen, G., Wirtz, J., & Jordan, C. E. (2017). Alteration of Stream Temperature by Natural and Artificial Beaver Dams. *PLoS ONE*, *12*(5). https://doi.org/10.1371/journal.pone.0176313

Western Regional Climate Center (WRCC). (2006). *Stanley, Idaho, Station 108676* [dataset]. Cooperative Climatological Data Summaries. https://wrcc.dri.edu/cgi-bin/cliMAIN.pl?idstan

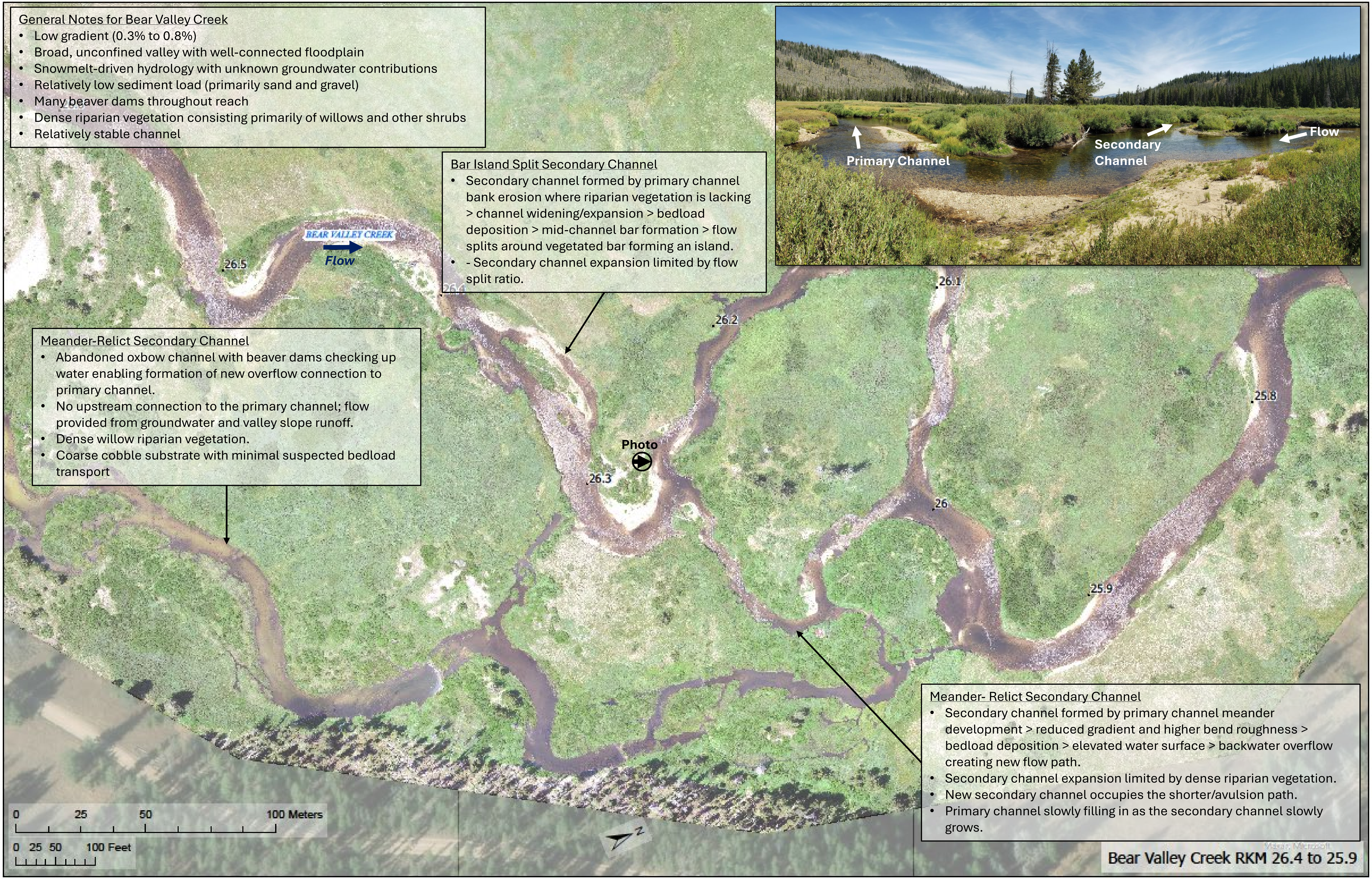
Wohl, E. (2011). Threshold-Induced Complex Behavior of Wood in Mountain Streams. *Geology*, *39*(6), 587–590. https://doi.org/10.1130/G32105.1

Wohl, E., Cenderelli, D. A., Dwire, K. A., Ryan-Burkett, S. E., Young, M. K., & Fausch, K. D. (2010). Large In-Stream Wood Studies: A Call for Common Metrics. *Earth Surface Processes and Landforms*, *35*(5), 618–625. https://doi.org/10.1002/esp.1966

Zabel, R. W., & Achord, S. (2004). Relating Size of Juveniles to Survival Within and Among Populations of Chinook Salmon. *Ecology*, *85*(3), 795–806. https://doi.org/10.1890/02-0719

APPENDIX A REFERENCE REACH GEOMORPHIC CHARACTERISTICS

Bear Valley Creek RKM 26.4 to 25.9



General Notes for Bear Valley Creek

- Low gradient (0.3% to 0.8%)
- Broad, unconfined valley with well-connected floodplain
- Snowmelt-driven hydrology with unknown groundwater contributions
- Relatively low sediment load (primarily sand and gravel)
- Many beaver dams throughout reach
- Dense riparian vegetation consisting primarily of willows and other shrubs
- Relatively stable channel

Bar Island Split Secondary Channel

- Secondary channel formed by primary channel bank erosion where riparian vegetation is lacking > channel widening/expansion > bedload deposition > mid-channel bar formation > flow splits around vegetated bar forming an island.
- - Secondary channel expansion limited by flow split ratio.

Meander-Relict Secondary Channel

- Abandoned oxbow channel with beaver dams checking up water enabling formation of new overflow connection to primary channel.
- No upstream connection to the primary channel; flow provided from groundwater and valley slope runoff.
- Dense willow riparian vegetation.
- Coarse cobble substrate with minimal suspected bedload transport

Meander- Relict Secondary Channel

- Secondary channel formed by primary channel meander development > reduced gradient and higher bend roughness > bedload deposition > elevated water surface > backwater overflow creating new flow path.
- Secondary channel expansion limited by dense riparian vegetation.
- New secondary channel occupies the shorter/avulsion path.
- Primary channel slowly filling in as the secondary channel slowly grows.

Bar-Island Split Secondary Channel

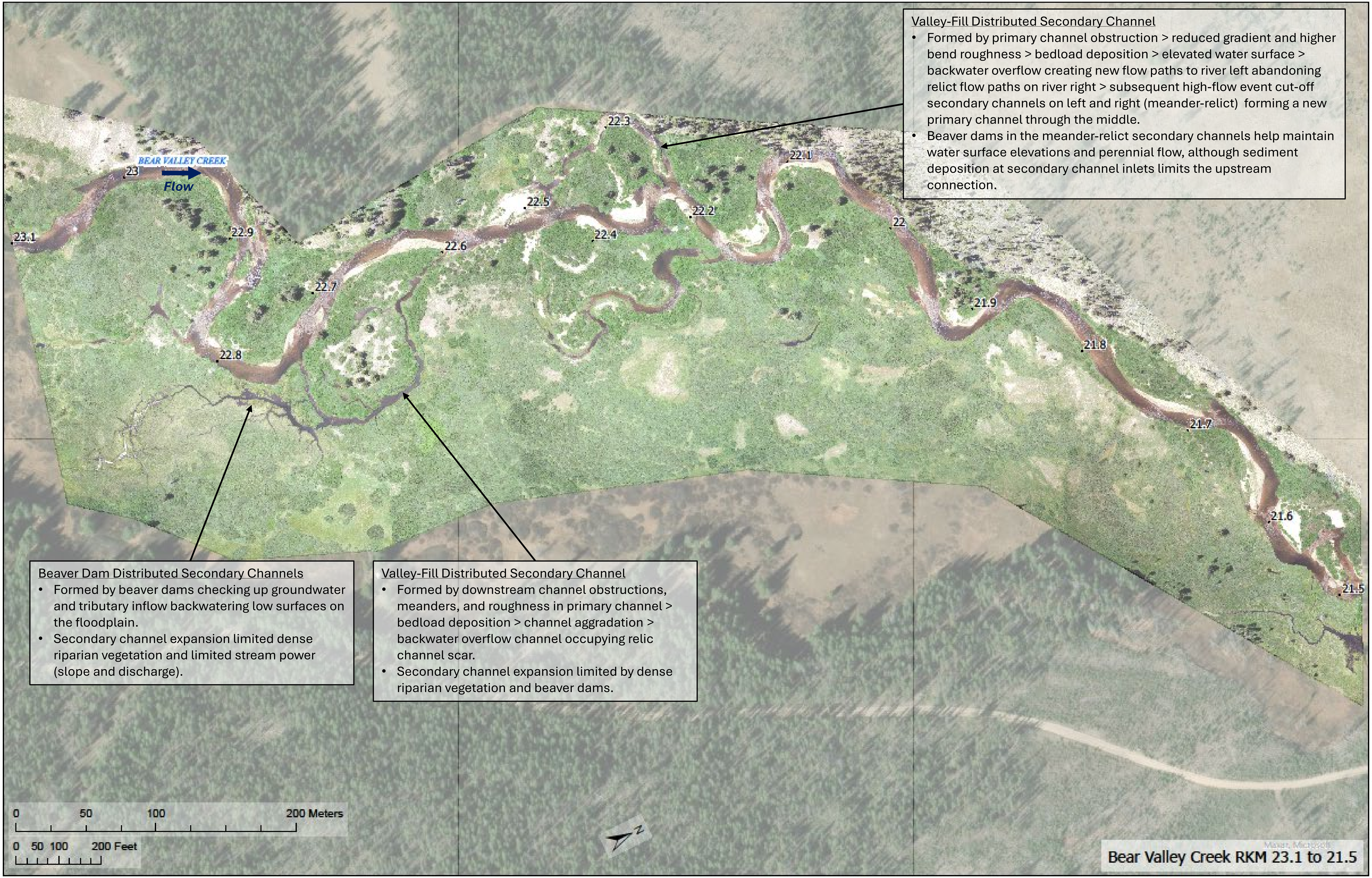
- Formed by primary channel right bank erosion > channel migration > flow splits around dense vegetation forming an island with the new channel on the outside of the bend and the old channel on the inside of the bend.
- Secondary channel expansion limited by dense riparian vegetation.

Valley-Fill Distributed Secondary Channel

- Formed by primary channel meander development > reduced gradient and higher bend roughness > bedload deposition > elevated water surface > backwater overflow creating new flow path (upper segment of channel) then occupying meander-relict flow path (lower segment of channel).
- Secondary channel expansion limited by dense riparian vegetation reducing bank erosion and channel expansion as well as beaver dams checking up flow, reducing gradient and local stream power.

Becomes Meander-Relict secondary channel where flow occupies a relic meander scar.

Bear Valley Creek RKM 24.5 to 24.2



Valley-Fill Distributed Secondary Channel

- Formed by primary channel obstruction > reduced gradient and higher bend roughness > bedload deposition > elevated water surface > backwater overflow creating new flow paths to river left abandoning relict flow paths on river right > subsequent high-flow event cut-off secondary channels on left and right (meander-relict) forming a new primary channel through the middle.
- Beaver dams in the meander-relict secondary channels help maintain water surface elevations and perennial flow, although sediment deposition at secondary channel inlets limits the upstream connection.

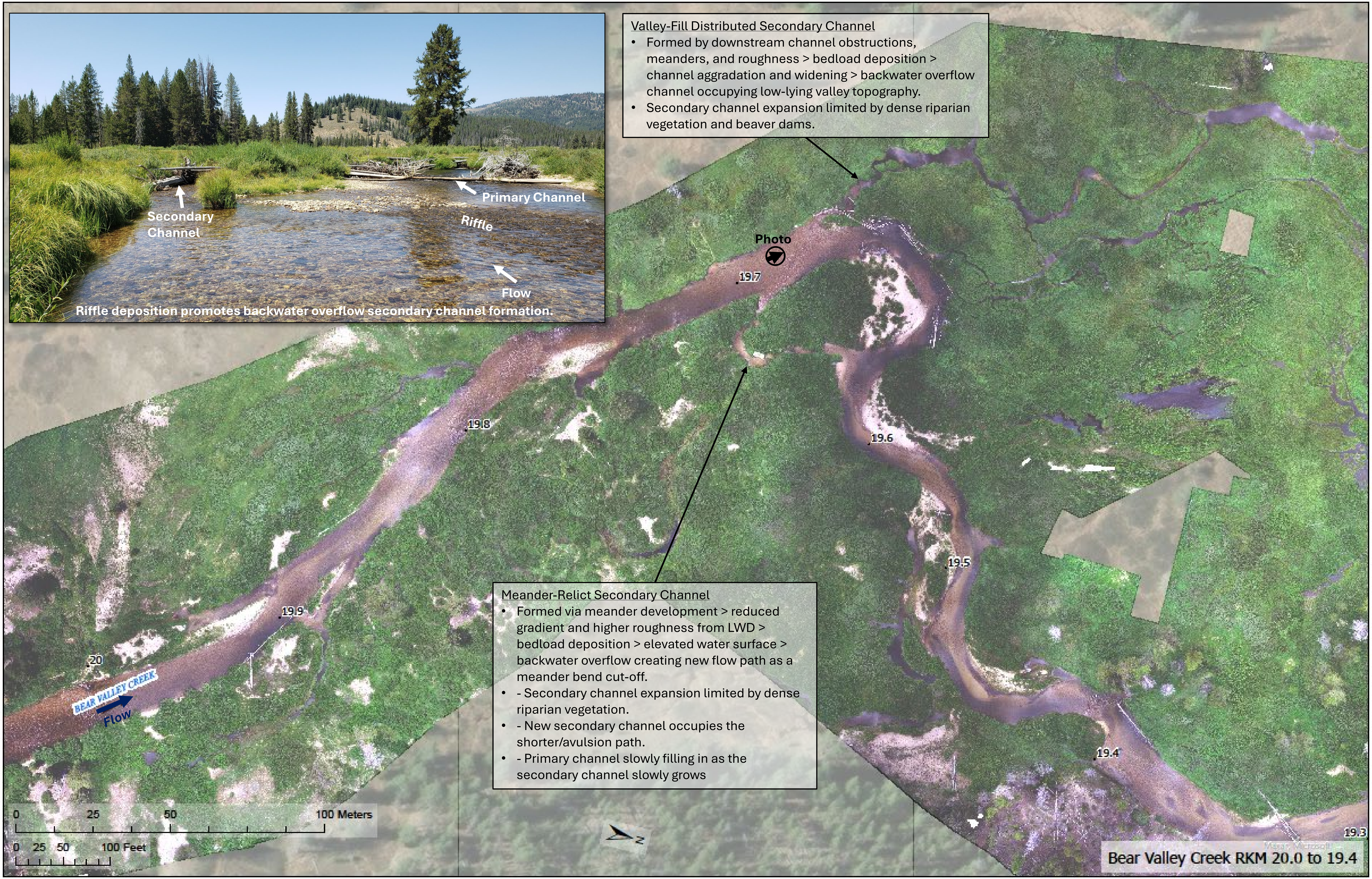
Beaver Dam Distributed Secondary Channels

- Formed by beaver dams checking up groundwater and tributary inflow backwatering low surfaces on the floodplain.
- Secondary channel expansion limited dense riparian vegetation and limited stream power (slope and discharge).

Valley-Fill Distributed Secondary Channel

- Formed by downstream channel obstructions, meanders, and roughness in primary channel > bedload deposition > channel aggradation > backwater overflow channel occupying relic channel scar.
- Secondary channel expansion limited by dense riparian vegetation and beaver dams.

Bear Valley Creek RKM 23.1 to 21.5



Riffle deposition promotes backwater overflow secondary channel formation.

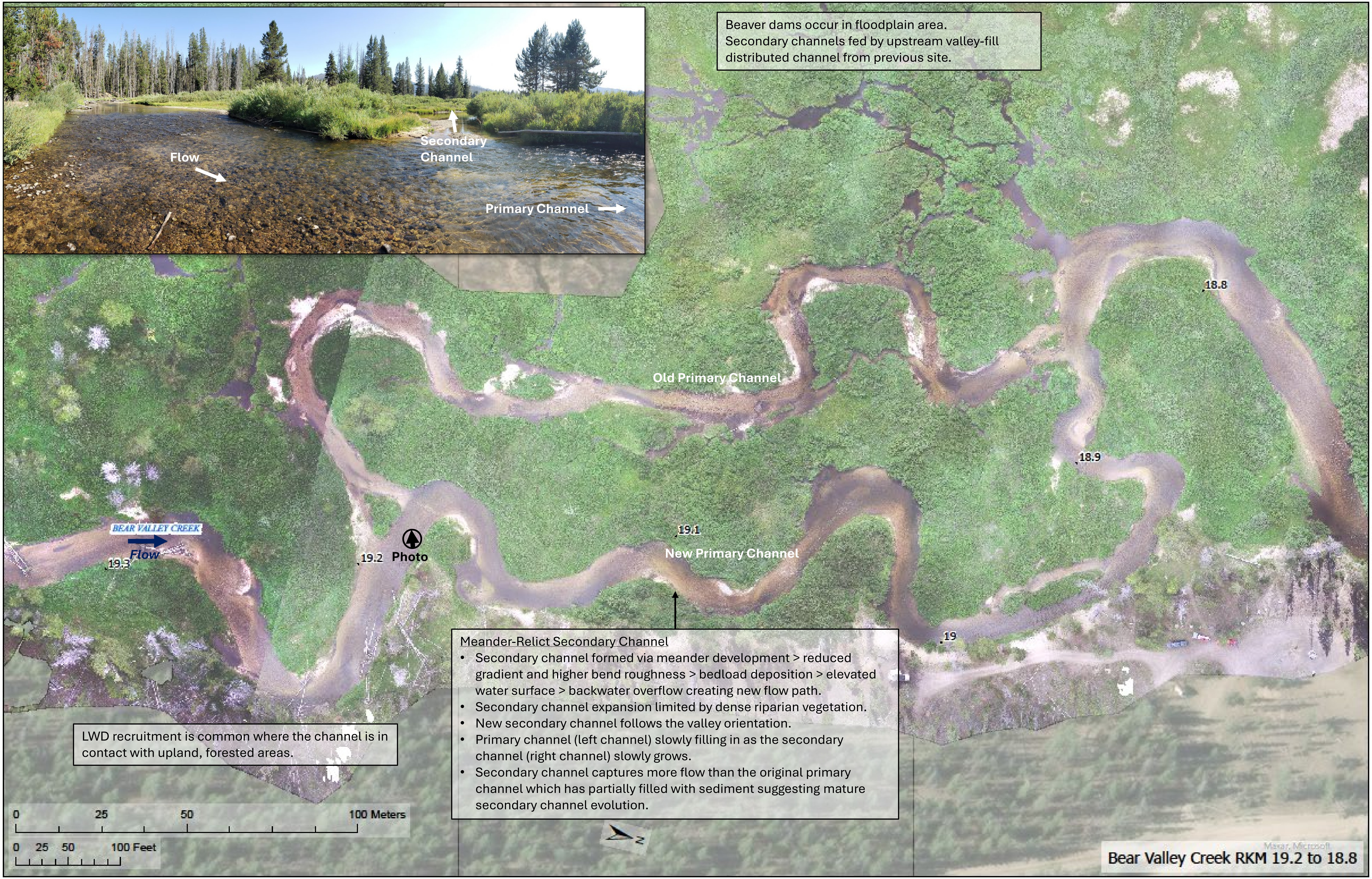
Valley-Fill Distributed Secondary Channel

- Formed by downstream channel obstructions, meanders, and roughness > bedload deposition > channel aggradation and widening > backwater overflow channel occupying low-lying valley topography.
- Secondary channel expansion limited by dense riparian vegetation and beaver dams.

Meander-Relict Secondary Channel

- Formed via meander development > reduced gradient and higher roughness from LWD > bedload deposition > elevated water surface > backwater overflow creating new flow path as a meander bend cut-off.
- - Secondary channel expansion limited by dense riparian vegetation.
- - New secondary channel occupies the shorter/avulsion path.
- - Primary channel slowly filling in as the secondary channel slowly grows

Bear Valley Creek RKM 20.0 to 19.4



Beaver dams occur in floodplain area. Secondary channels fed by upstream valley-fill distributed channel from previous site.

Meander-Relict Secondary Channel

- Secondary channel formed via meander development > reduced gradient and higher bend roughness > bedload deposition > elevated water surface > backwater overflow creating new flow path.
- Secondary channel expansion limited by dense riparian vegetation.
- New secondary channel follows the valley orientation.
- Primary channel (left channel) slowly filling in as the secondary channel (right channel) slowly grows.
- Secondary channel captures more flow than the original primary channel which has partially filled with sediment suggesting mature secondary channel evolution.

LWD recruitment is common where the channel is in contact with upland, forested areas.

Bear Valley Creek RKM 19.2 to 18.8

Elk Creek RKM 12.6 to 12.2

Meander- Relict Secondary Channel

- Secondary channel formed via meander development > reduced gradient and higher bend roughness > bedload deposition > elevated water surface > backwater overflow creating new flow path.
- Secondary channel expanded to capture entire flow (meander cut-off avulsion).
- Relict primary channel largely filled in with sediment; remains partially as a wetland and oxbow pond.

Meander-Relict Secondary Channel

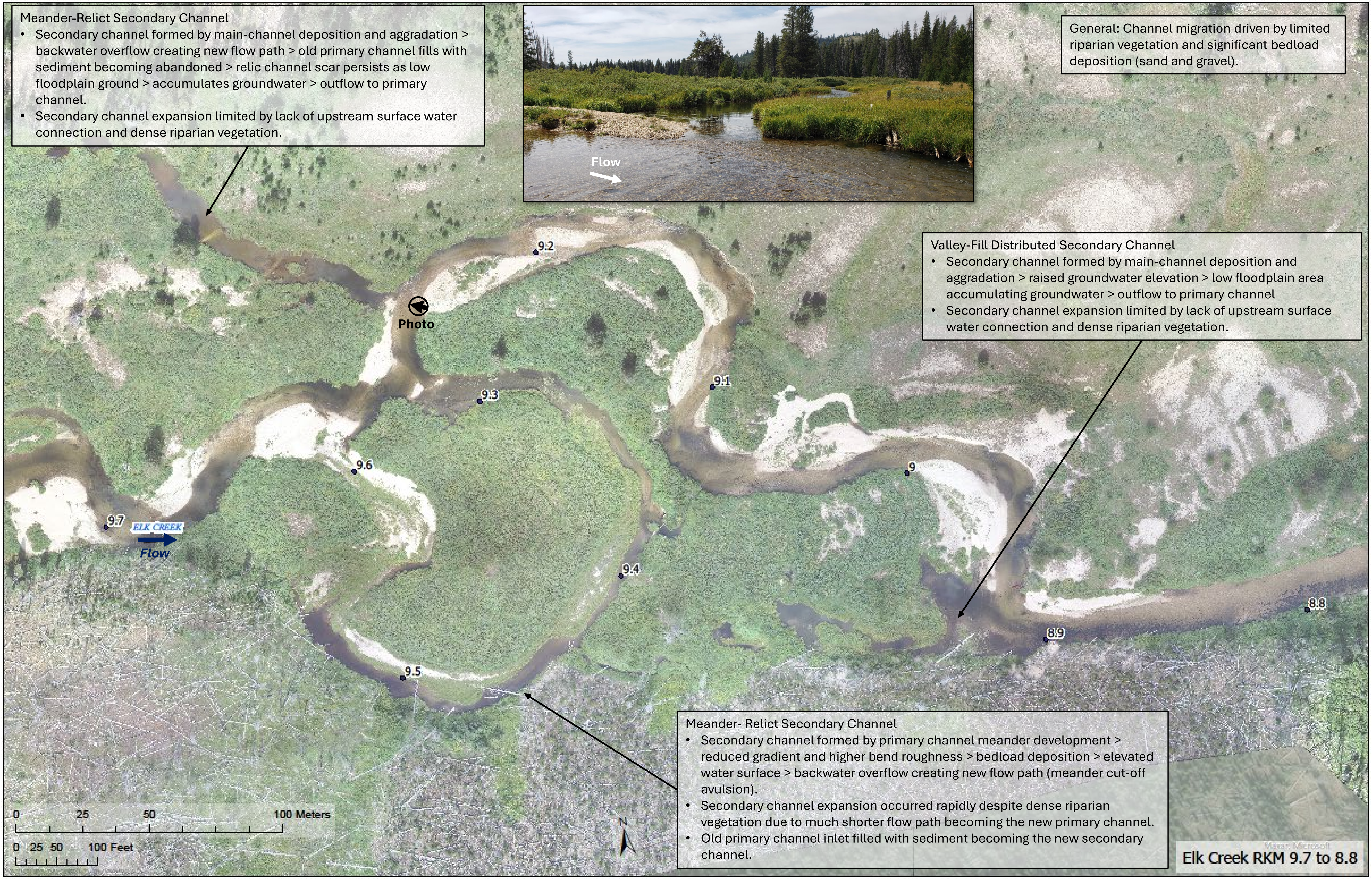
- Secondary channel formed by main-channel deposition and aggradation > backwater overflow creating new flow path > old primary channel fills with sediment becoming abandoned > relic channel scar persists as low floodplain ground > accumulates groundwater > outflow to primary channel.
- Secondary channel expansion limited by lack of upstream surface water connection and dense riparian vegetation.

Bar-Island Split Secondary Channel

- Secondary channel formed via meander development where vegetation was lacking > point bar deposition > increased bank roughness and channel length; elevated water surface > backwater overflow creating new flow path (back-bar channel).
- Secondary channel expansion limited by channel hydraulics affected by a beaver dam in the secondary channel and a lack of recent channel migration.

General Notes for Elk Creek

- Low gradient (0.1% to 0.6%)
- Broad, unconfined valley with well-connected floodplain
- Snowmelt-driven hydrology with unknown groundwater contributions
- Moderate to high sediment load (primarily sand and gravel) driving channel migration and avulsion
- Many beaver dams throughout reach, generally in secondary channels
- Dense riparian vegetation consisting primarily of willows and other shrubs
- Moderate channel stability provided by vegetation



Meander-Relict Secondary Channel

- Secondary channel formed by main-channel deposition and aggradation > backwater overflow creating new flow path > old primary channel fills with sediment becoming abandoned > relic channel scar persists as low floodplain ground > accumulates groundwater > outflow to primary channel.
- Secondary channel expansion limited by lack of upstream surface water connection and dense riparian vegetation.

General: Channel migration driven by limited riparian vegetation and significant bedload deposition (sand and gravel).

Valley-Fill Distributed Secondary Channel

- Secondary channel formed by main-channel deposition and aggradation > raised groundwater elevation > low floodplain area accumulating groundwater > outflow to primary channel
- Secondary channel expansion limited by lack of upstream surface water connection and dense riparian vegetation.

Meander- Relict Secondary Channel

- Secondary channel formed by primary channel meander development > reduced gradient and higher bend roughness > bedload deposition > elevated water surface > backwater overflow creating new flow path (meander cut-off avulsion).
- Secondary channel expansion occurred rapidly despite dense riparian vegetation due to much shorter flow path becoming the new primary channel.
- Old primary channel inlet filled with sediment becoming the new secondary channel.

Elk Creek RKM 9.7 to 8.8

Meander- Relict Secondary Channel

- Both examples below formed following the same process: primary channel meander development > reduced gradient and higher bend roughness > bedload deposition > elevated water surface > backwater overflow creating new flow path (meander cut-off avulsion).
- Secondary channel expansion limited by dense riparian vegetation.
- Primary channel slowly fills in as the secondary channel slowly grows.

- New meander cut off (early secondary channel evolution)

- Old meander cut off (mature secondary channel evolution).
- Secondary channel has become the new primary channel abandoning the old primary channel, which persists as an oxbow pond).

Bar-Island Split Secondary Channel

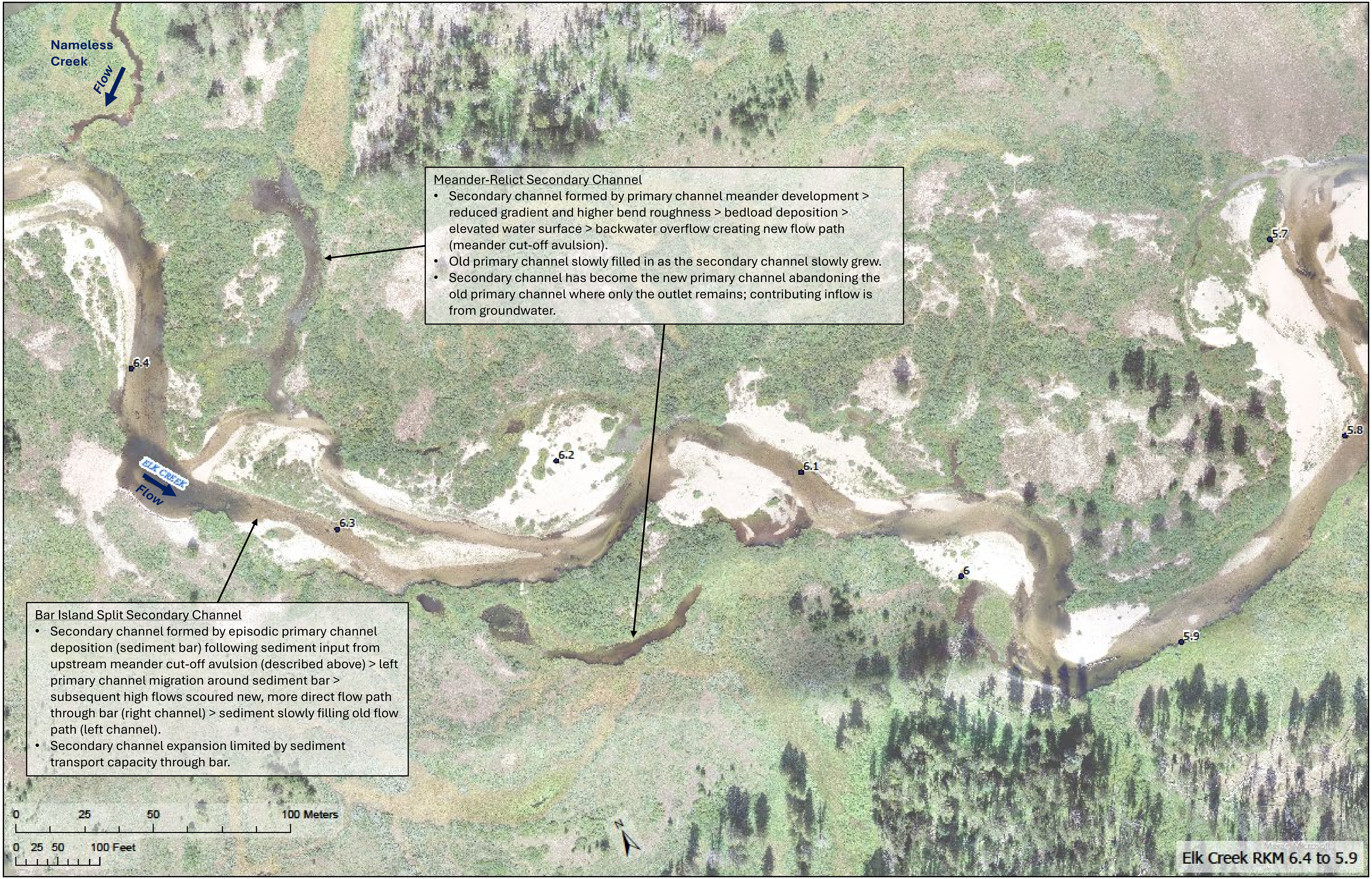
- Formed by primary channel right bank erosion > channel migration > flow splits around dense vegetation forming an island with the new channel on the outside of the bend and the old channel on the inside of the bend.
- Secondary channel expansion limited by dense riparian vegetation.

Elk Creek RKM 8.7 to 8.1

Meander-Relict Secondary Channel

- Secondary channel formed via meander development > reduced gradient and higher bend roughness > bedload deposition > elevated water surface > backwater overflow creating new flow path occupying relic channel scars.
- Secondary channel expansion limited by dense riparian vegetation.
- New secondary channel follows the valley orientation.
- Old primary channel (left channel) slowly filling in as the secondary channel (right channel) slowly grows.
- Secondary channel captures more flow than the original primary channel which has partially filled with sediment suggesting mature secondary channel evolution; becomes new primary channel.

Elk Creek RKM 7.5 to 6.7



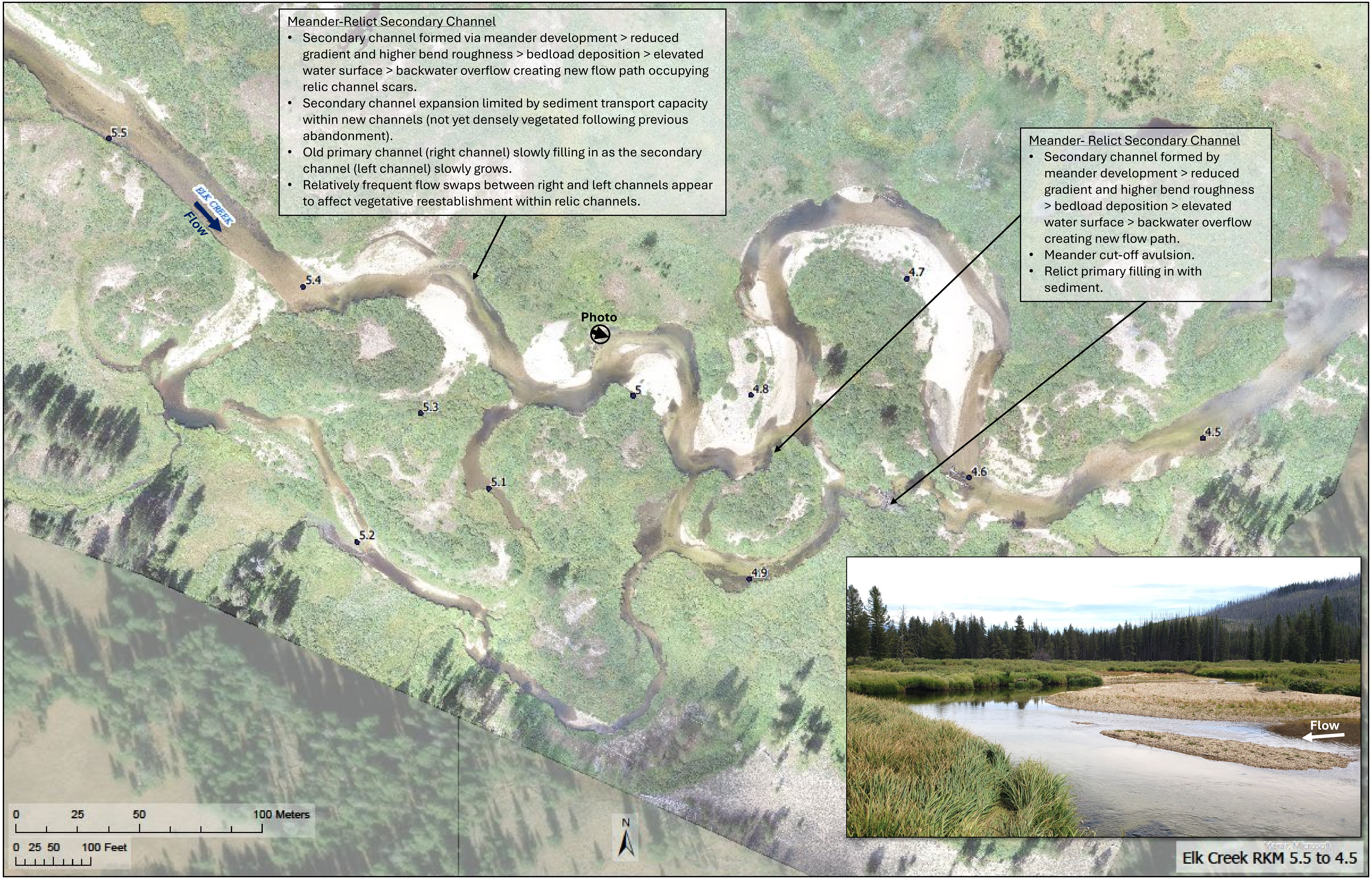
Meander-Relict Secondary Channel

- Secondary channel formed by primary channel meander development > reduced gradient and higher bend roughness > bedload deposition > elevated water surface > backwater overflow creating new flow path (meander cut-off avulsion).
- Old primary channel slowly filled in as the secondary channel slowly grew.
- Secondary channel has become the new primary channel abandoning the old primary channel where only the outlet remains; contributing inflow is from groundwater.

Bar Island Split Secondary Channel

- Secondary channel formed by episodic primary channel deposition (sediment bar) following sediment input from upstream meander cut-off avulsion (described above) > left primary channel migration around sediment bar > subsequent high flows scoured new, more direct flow path through bar (right channel) > sediment slowly filling old flow path (left channel).
- Secondary channel expansion limited by sediment transport capacity through bar.

Elk Creek RKM 6.4 to 5.9



Meander-Relict Secondary Channel

- Secondary channel formed via meander development > reduced gradient and higher bend roughness > bedload deposition > elevated water surface > backwater overflow creating new flow path occupying relic channel scars.
- Secondary channel expansion limited by sediment transport capacity within new channels (not yet densely vegetated following previous abandonment).
- Old primary channel (right channel) slowly filling in as the secondary channel (left channel) slowly grows.
- Relatively frequent flow swaps between right and left channels appear to affect vegetative reestablishment within relic channels.

Meander- Relict Secondary Channel

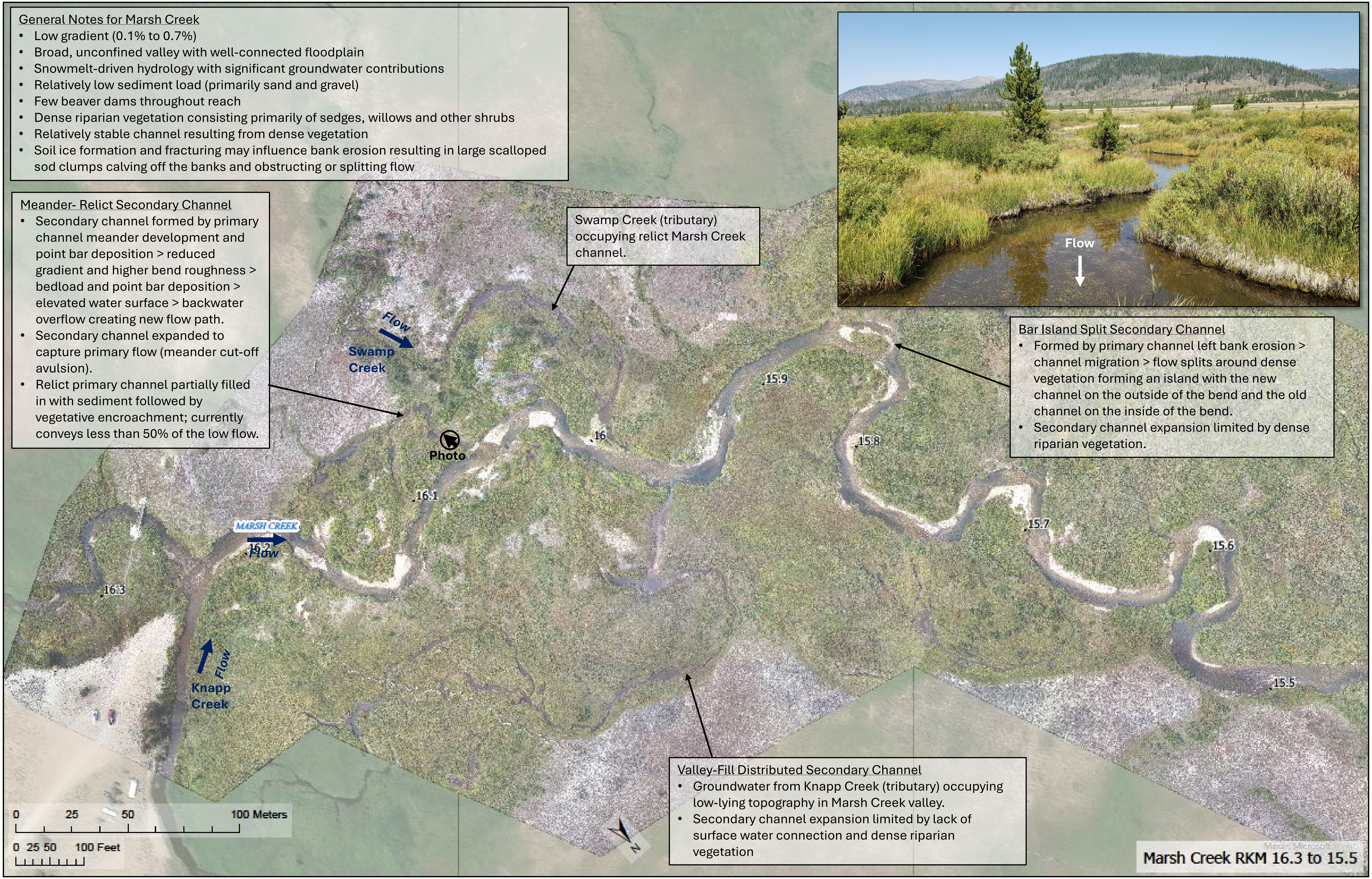
- Secondary channel formed by meander development > reduced gradient and higher bend roughness > bedload deposition > elevated water surface > backwater overflow creating new flow path.
- Meander cut-off avulsion.
- Relict primary filling in with sediment.

Elk Creek RKM 5.5 to 4.5

Meander- Relict Secondary Channel

- Secondary channel formed by primary channel meander development and point bar deposition > reduced gradient and higher bend roughness > bedload and point bar deposition > elevated water surface > backwater overflow creating new flow path.
- Secondary channel expanded to capture primary flow (meander cut-off avulsion).
- Relict primary channel partially filled in with sediment; currently conveys less than 50% of the low flow.
- Rock weir installed in an unsuccessful attempt to prevent avulsion.

Elk Creek RKM 2.0 to 0.6



General Notes for Marsh Creek

- Low gradient (0.1% to 0.7%)
- Broad, unconfined valley with well-connected floodplain
- Snowmelt-driven hydrology with significant groundwater contributions
- Relatively low sediment load (primarily sand and gravel)
- Few beaver dams throughout reach
- Dense riparian vegetation consisting primarily of sedges, willows and other shrubs
- Relatively stable channel resulting from dense vegetation
- Soil ice formation and fracturing may influence bank erosion resulting in large scalloped sod clumps calving off the banks and obstructing or splitting flow

Meander- Relict Secondary Channel

- Secondary channel formed by primary channel meander development and point bar deposition > reduced gradient and higher bend roughness > bedload and point bar deposition > elevated water surface > backwater overflow creating new flow path.
- Secondary channel expanded to capture primary flow (meander cut-off avulsion).
- Relict primary channel partially filled in with sediment followed by vegetative encroachment; currently conveys less than 50% of the low flow.

Swamp Creek (tributary) occupying relict Marsh Creek channel.

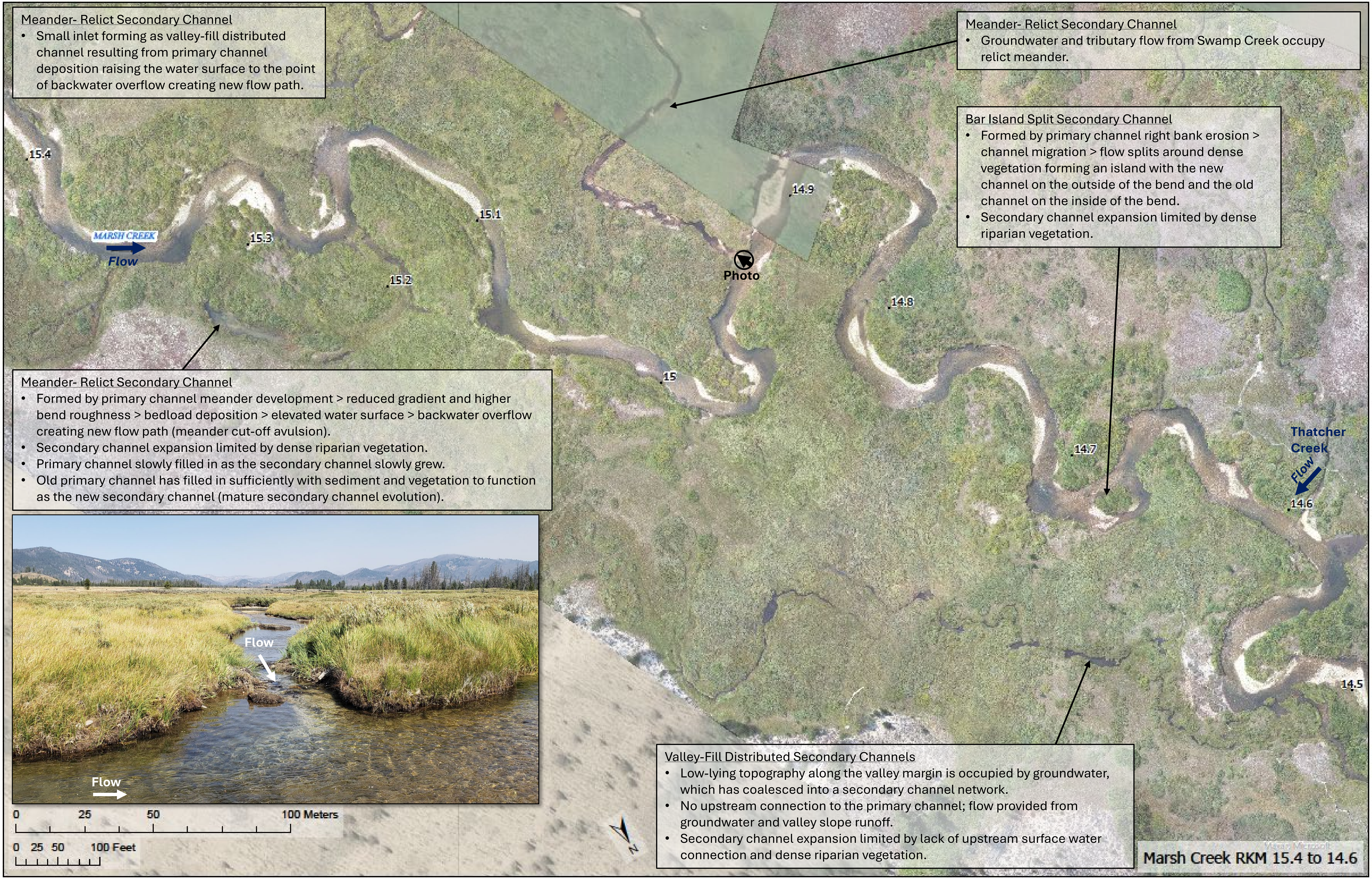
Bar Island Split Secondary Channel

- Formed by primary channel left bank erosion > channel migration > flow splits around dense vegetation forming an island with the new channel on the outside of the bend and the old channel on the inside of the bend.
- Secondary channel expansion limited by dense riparian vegetation.

Valley-Fill Distributed Secondary Channel

- Groundwater from Knapp Creek (tributary) occupying low-lying topography in Marsh Creek valley.
- Secondary channel expansion limited by lack of surface water connection and dense riparian vegetation

Marsh Creek RKM 16.3 to 15.5



Meander- Relict Secondary Channel

- Small inlet forming as valley-fill distributed channel resulting from primary channel deposition raising the water surface to the point of backwater overflow creating new flow path.

Meander- Relict Secondary Channel

- Groundwater and tributary flow from Swamp Creek occupy relict meander.

Bar Island Split Secondary Channel

- Formed by primary channel right bank erosion > channel migration > flow splits around dense vegetation forming an island with the new channel on the outside of the bend and the old channel on the inside of the bend.
- Secondary channel expansion limited by dense riparian vegetation.

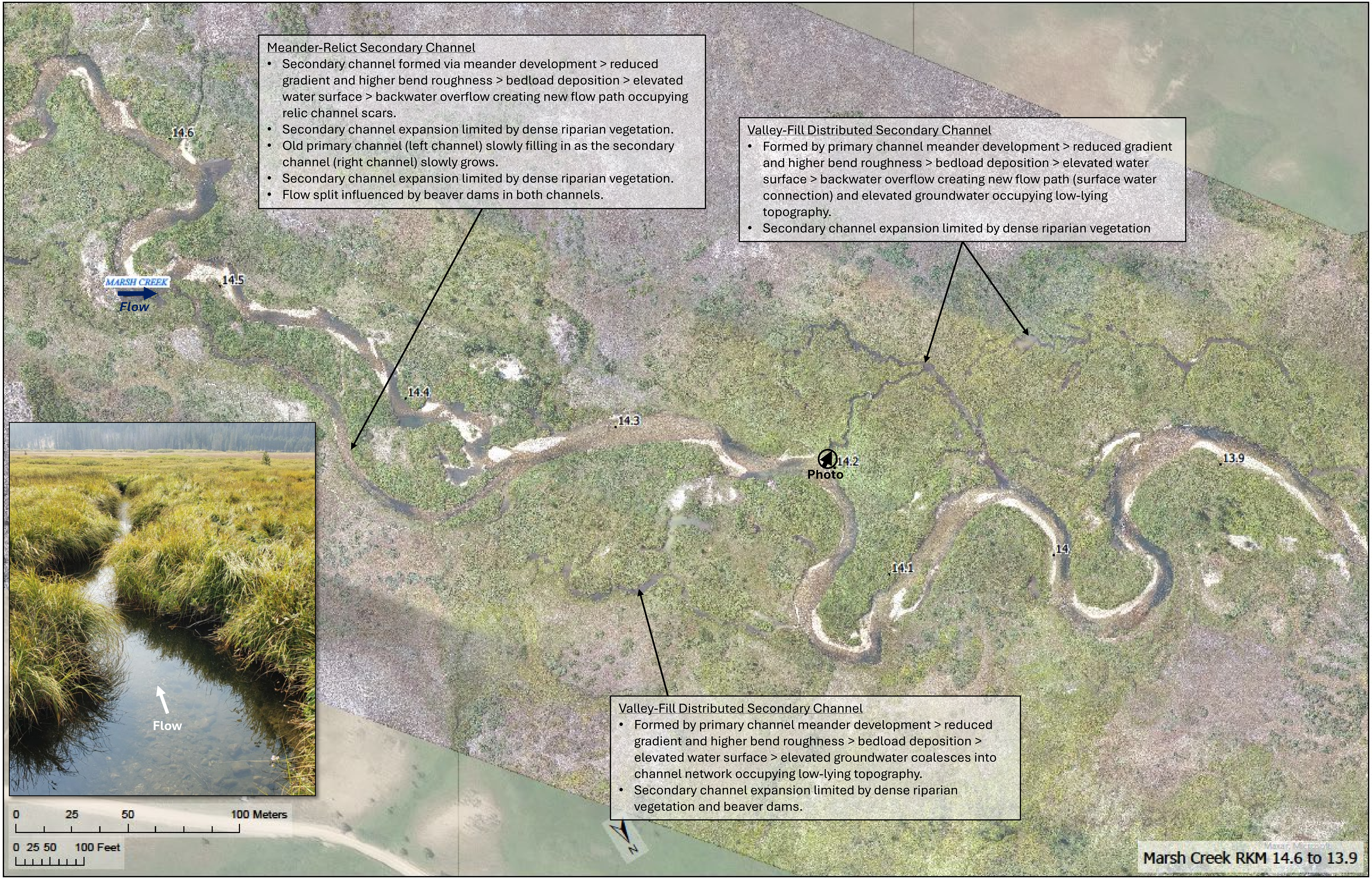
Meander- Relict Secondary Channel

- Formed by primary channel meander development > reduced gradient and higher bend roughness > bedload deposition > elevated water surface > backwater overflow creating new flow path (meander cut-off avulsion).
- Secondary channel expansion limited by dense riparian vegetation.
- Primary channel slowly filled in as the secondary channel slowly grew.
- Old primary channel has filled in sufficiently with sediment and vegetation to function as the new secondary channel (mature secondary channel evolution).

Valley-Fill Distributed Secondary Channels

- Low-lying topography along the valley margin is occupied by groundwater, which has coalesced into a secondary channel network.
- No upstream connection to the primary channel; flow provided from groundwater and valley slope runoff.
- Secondary channel expansion limited by lack of upstream surface water connection and dense riparian vegetation.

Marsh Creek RKM 15.4 to 14.6



Meander-Relict Secondary Channel

- Secondary channel formed via meander development > reduced gradient and higher bend roughness > bedload deposition > elevated water surface > backwater overflow creating new flow path occupying relic channel scars.
- Secondary channel expansion limited by dense riparian vegetation.
- Old primary channel (left channel) slowly filling in as the secondary channel (right channel) slowly grows.
- Secondary channel expansion limited by dense riparian vegetation.
- Flow split influenced by beaver dams in both channels.

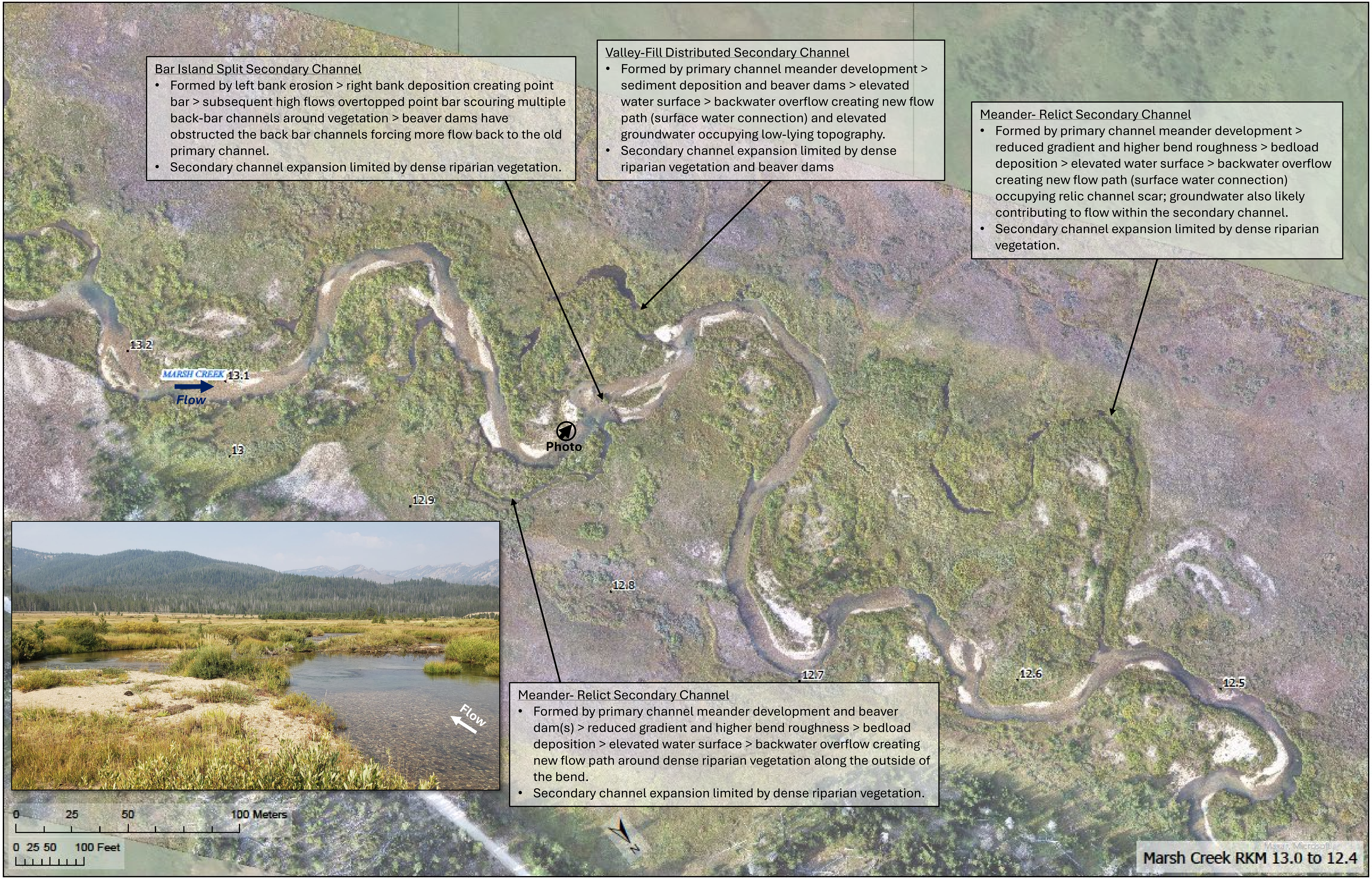
Valley-Fill Distributed Secondary Channel

- Formed by primary channel meander development > reduced gradient and higher bend roughness > bedload deposition > elevated water surface > backwater overflow creating new flow path (surface water connection) and elevated groundwater occupying low-lying topography.
- Secondary channel expansion limited by dense riparian vegetation

Valley-Fill Distributed Secondary Channel

- Formed by primary channel meander development > reduced gradient and higher bend roughness > bedload deposition > elevated water surface > elevated groundwater coalesces into channel network occupying low-lying topography.
- Secondary channel expansion limited by dense riparian vegetation and beaver dams.

Marsh Creek RKM 14.6 to 13.9



Bar Island Split Secondary Channel

- Formed by left bank erosion > right bank deposition creating point bar > subsequent high flows overtopped point bar scouring multiple back-bar channels around vegetation > beaver dams have obstructed the back bar channels forcing more flow back to the old primary channel.
- Secondary channel expansion limited by dense riparian vegetation.

Valley-Fill Distributed Secondary Channel

- Formed by primary channel meander development > sediment deposition and beaver dams > elevated water surface > backwater overflow creating new flow path (surface water connection) and elevated groundwater occupying low-lying topography.
- Secondary channel expansion limited by dense riparian vegetation and beaver dams

Meander- Relict Secondary Channel

- Formed by primary channel meander development > reduced gradient and higher bend roughness > bedload deposition > elevated water surface > backwater overflow creating new flow path (surface water connection) occupying relic channel scar; groundwater also likely contributing to flow within the secondary channel.
- Secondary channel expansion limited by dense riparian vegetation.

Meander- Relict Secondary Channel

- Formed by primary channel meander development and beaver dam(s) > reduced gradient and higher bend roughness > bedload deposition > elevated water surface > backwater overflow creating new flow path around dense riparian vegetation along the outside of the bend.
- Secondary channel expansion limited by dense riparian vegetation.

Marsh Creek RKM 13.0 to 12.4

APPENDIX B REFERENCE REACH HABITAT CHARACTERISTICS

Memorandum

MOUNT HOOD ENVIRONMENTAL
39085 Pioneer Blvd #100, Mezzanine, Sandy, OR 97055

APPENDIX B. REFERENCE REACH HABITAT CHARACTERISTICS

Introduction

Previous assessments have identified watershed-scale habitat capacity limitations for Endangered Species Act listed populations of Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead trout (*Oncorhynchus mykiss*) and offered solutions to address capacity limitations in the Upper Salmon River Basin, Idaho (Rio ASE & Biomark, 2021a – 2021d). However, the assessments lacked contemporary data from perceived high-quality habitats to help describe and quantify the fish habitat necessary to support recovery goals. The lack of data from high-quality habitats has presented challenges for managers, hydrologists, engineers, etc. to design rehabilitation projects that are geomorphically appropriate for watersheds in the Upper Salmon River Basin and optimize the habitat carrying capacity potential based on life stage specific needs for target species.

In this assessment, we compared habitat characteristics and carrying capacity estimates between watersheds in Idaho that were identified *a priori* as exhibiting high-quality habitat relative to watersheds and river reaches in the Upper Salmon River Basin that exhibit impacted and/or low-quality habitat. The two primary watersheds selected as high-quality, reference watersheds were the Upper Secesh and Upper Middle Fork Salmon River (Upper MFSR). These were considered reference watersheds due to their relatively unaltered condition, geomorphic similarity to the Upper Salmon River Basin, active floodplains, historically high adult Chinook salmon and steelhead escapement and juvenile abundances, and relatively high contemporary adult escapement and juvenile abundances. A total of 26.7 kilometers on Elk Creek, Bear Valley Creek, and Marsh Creek in the Upper MFSR watershed, and Summit Creek, Lake Creek, and Grouse Creek in the Upper Secesh River watershed were surveyed using Drone Assisted Stream Habitat (DASH) protocols and used as high-quality habitat reference reaches. The Lemhi River, Pahsimeroi River, and Upper Salmon River (Sawtooth Valley above Redfish Lake Creek) watersheds were chosen as impacted and/or low-quality habitat. These watersheds have been significantly altered by anthropogenic activities (mining, ranching, farming, direct river and floodplain alterations, and urban development) and support a fraction of their historic abundances of Chinook salmon and steelhead spawning and juvenile rearing. Approximately 110.5 kilometers of habitat within these impacted watersheds were surveyed using DASH protocols and used in comparison to the Upper MFSR and Upper Secesh reaches.

GOALS AND OBJECTIVES

The goal of this appendix was to identify habitat characteristics commonly associated with high-capacity Chinook salmon and steelhead spawning and juvenile rearing habitat in central Idaho. More specifically, we aimed to:

1) Compare estimates of habitat capacity for sites and reaches by watershed to explore the *a priori* designation of high-quality and impaired/impacted watersheds.

2) Compare habitat characteristics between the highest (upper 10% quantile) and lowest (lower 10% quantile) capacity reaches for all DASH surveyed sites, irrespective of watershed, and identify key habitat characteristics and relationships associated with high-capacity Chinook salmon and steelhead spawning and juvenile rearing habitat.

WATERSHED DESCRIPTION

Bear Valley Creek (Upper Middle Fork Salmon River)

See *Section 2.5 Fish Use* in the main document for thorough descriptions for Bear Valley Creek, tributary in the Upper Middle Fork Salmon River watershed.

Marsh Creek (Upper Middle Fork Salmon River)

See *Section 2.5 Fish Use* in the main document for thorough descriptions for Marsh Creek, tributary in the Upper Middle Fork Salmon River watershed.

Upper Secesh River

The Secesh River watershed encompasses approximately 170,000 acres, of which more than 98% is public land. In general, much of the watershed remains relatively unaltered from historic conditions and supports Chinook salmon and steelhead spawning and juvenile rearing, primarily in the upper Secesh River, Lake Creek, and Lick Creek (NOAA, 2017). Chinook salmon adult escapement objectives for a sustainable population in the Upper Secesh River is 750 spawners, compared to the recent ten-year geometric mean of 472 spawners (2005-2014), putting the population at high risk for extinction (NOAA, 2017). In 2022, 243 Chinook salmon redds were counted in the watershed (Ruthven et al., 2023), compared to only 66 in 2021 (Poole et al., 2022). The summer run steelhead population in the Secesh River consists of both A- and B-run fish and is considered at moderate risk for extinction (NOAA, 2017). The ten-year geometric mean for adult steelhead escapement abundance is estimated at 1,028 for the South Fork Salmon River population, which contains the Secesh River population (NOAA, 2017). For juvenile Chinook salmon and steelhead rearing, Summit Creek and Lake Creek both exhibit reaches with perceived high-quality habitat, characterized by abundant multi-threaded channels and off-channel habitat. Rearing habitat for steelhead in the watershed is considered good to excellent quality (NOAA, 2017). Small, localized impacts from mining, livestock grazing, timber management, road construction, and dispersed recreation have resulted in areas with elevated sedimentation and reduced riparian vegetation (NOAA, 2017). Additionally, a small development of private inholdings in Secesh Meadows likely reduced historic secondary channels and off-channel habitat and constricted lateral channel migration in the meadow complex. It is estimated that the South Fork Salmon River watershed, which includes the Secesh River and its tributaries, has lost only 5.3% of historic side channel habitat (Bond et al., 2019). Despite historic anthropogenic impacts, the Secesh River watershed remains relatively unaltered and is generally considered high-quality Chinook salmon and steelhead habitat.

Lemhi River

The Lemhi River watershed encompasses more than 800,000 acres, of which over 80% is public land (NOAA, 2017). Historically, the Lemhi River watershed supported a “very large” population of spring/summer-run Chinook salmon and an “intermediate” size population of steelhead (Interior Columbia Technical Recovery Team, 2003; NWFSC, 2015; NOAA, 2017). Land use practices, particularly agricultural development and roadway infrastructure, have greatly reduced spawning and rearing habitat for both Chinook salmon and steelhead throughout the watershed. Prior to 2000, all but two tributaries (Hayden Creek and Big Springs Creek) would become seasonally disconnected from the Lemhi River due to irrigation withdrawals. A major flood in 1957 resulted in reconfiguration of Highway 28 along the Lemhi River, altering 20.9% of all Chinook salmon spawning habitat in the watershed, and removal of 11.9% of spawning habitat used by 90% of the population (Gebhards, 1959; NOAA, 2017). In addition to loss of habitat, unscreened diversions entrained large amounts of juvenile fish annually (Gebhards, 1959). Though not well studied, it is assumed that habitat degradation in the Lemhi had comparable impacts on its historic steelhead population. Efforts began in the late 1990s and early 2000s to restore watershed function and fish habitat by reconnecting tributaries, removing passage barriers, and restoring riparian areas. Today, large scale restoration projects aim to restore natural fluvial processes with a focus on increasing floodplain and secondary channel habitat, primarily in the Lemhi River. While restoration efforts have increased fish passage and floodplain connectivity throughout the watershed, Chinook salmon and steelhead production continues to be limited to a fraction of their historic area and large amounts of the watershed remain degraded.

Pahsimeroi River

The Pahsimeroi River watershed drains approximately 537,600 acres and is characterized by semiarid conditions, with most precipitation falling as snow at higher elevations (NOAA, 2017). The watershed exhibits large amounts of surface water and groundwater connectivity, which creates sections of disconnected surface water, thought to be natural historically, in several tributaries and the upper Pahsimeroi River. The lower Pahsimeroi River is largely spring-fed, and stays connected year-round, with significant amounts of sinuous, pool habitat. Agricultural practices, primarily irrigation withdrawals, have constrained historic Chinook salmon and steelhead distributions in the Pahsimeroi watershed. All but one tributary becomes seasonally disconnected from the Pashimeroi River, and approximately 5.7 river kilometers of the main Pahsimeroi River becomes disconnected, precluding fish migration between the lower and upper systems. Degraded riparian areas, channel form, and water quality are also limiting factors for salmonid rearing and spawning in the watershed (IDEQ, 2013; NOAA, 2017). Restoration in the Pahsimeroi watershed has followed a similar trajectory to the Lemhi watershed, where efforts over the last 40 years have focused on removing passage barriers, improving instream flow, and screening irrigation diversions. These efforts have led to increased available habitat, expanded Chinook spawning and rearing distributions, and increased juvenile production but much of the Pahsimeroi watershed remains degraded or disconnected (Copeland et al., 2021).

Upper Salmon River

The Upper Salmon River watershed is defined as the mainstem Salmon River and all its tributaries upstream from Redfish Lake Creek (including Redfish Lake Creek). Much of the watershed is within the Sawtooth National Recreation Area, resulting in more regulated land use practices relative to adjacent watersheds. However, historic Chinook salmon and steelhead distributions have been reduced primarily through hydraulic barriers resulting from irrigation withdrawals for agriculture. Additionally, the Sawtooth Fish Hatchery, operated by the Idaho Department of Fish and Game upstream of Redfish Lake Creek, collect brood-stock from natural-origin Chinook salmon, further reducing adults returning to natal spawning grounds (NOAA, 2017). Chinook spawning is limited to the mainstem Salmon River and Alturas Lake Creek with primary spawning grounds in the mainstem below Alturas Lake Creek (Interior Columbia Technical Recovery Team, 2003). Limited spawning occurs in the mainstem Salmon River above Alturas Lake Creek and in Pole Creek (NOAA, 2017). Historic steelhead distributions in the Upper Salmon watershed are not well understood but were likely more extensive than current distributions. Steelhead are known to use Mays Creek and Fisher Creek, and to a greater extent, Fishhook Creek, Gold Creek, Beaver Creek, Smiley Creek and Pole Creek (Figure 1). Outside of the mainstem Salmon River, steelhead spawning is thought to occur in Alturas Lake Creek, Pole Creek, Champion Creek, Fourth of July Creek, and Fisher Creek (NOAA, 2017).

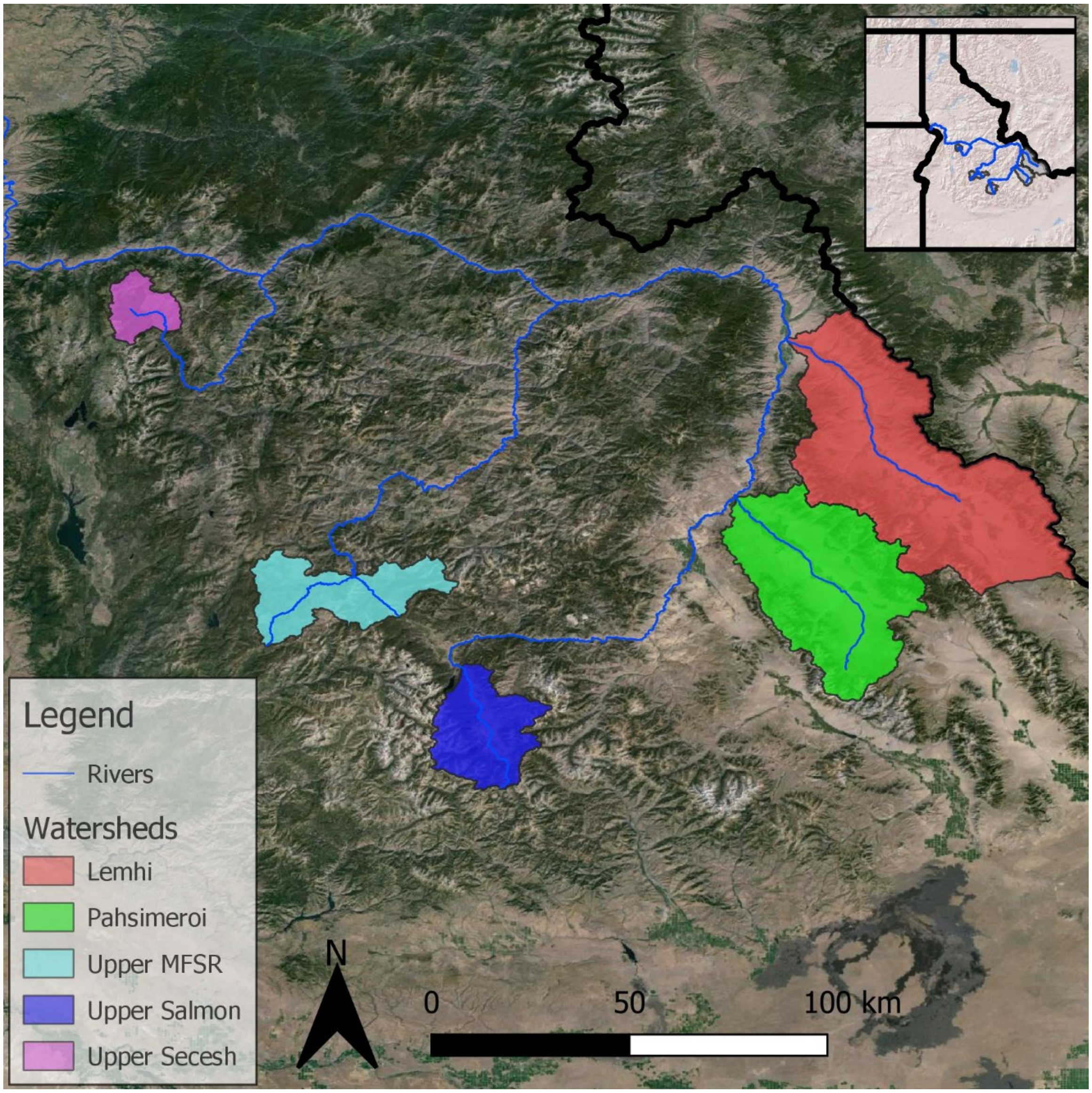


Figure 1. Lemhi River, Pahsimeroi River, Upper Middle Fork Salmon River (Upper MFSR), Upper Salmon River (Sawtooth Valley above Redfish Lake Creek), and Upper Secesh River watersheds located in central Idaho.

METHODS

Fine resolution habitat data were collected using Drone Assisted Stream Habitat protocols (DASH; Carmichael et al., 2019) to quantitatively compare habitat characteristics between watersheds and habitat reaches (collection of channel units roughly 150-600 meters long). Adapted from the Columbia Habitat Monitoring Program (CHaMP; ISEMP and CHaMP, 2017), DASH surveys measure habitat characteristics deemed important for Chinook salmon and steelhead juvenile rearing and adult spawning across multiple spatial scales. On-the-ground surveys consisted of habitat assessments at the channel unit-scale, quantifying metrics such as channel unit types (i.e., pool, run, riffle, rapid, small side channel, or off-channel area), substrate composition, large wood, fish cover, undercuts, and water depth characteristics. These metrics were then paired with high resolution imagery captured using an unmanned aerial vehicle to spatially reference habitat characteristics. DASH surveys allow for the calculations of over 70 habitat covariates, a subset of which can then be used as input data for quantile random forest models to estimate habitat carrying capacity.

Quantile random forest (QRF) models fit with fish-habitat data from state, federal, and tribal fish monitoring programs and CHaMP have been recently developed to estimate habitat carrying capacity for Chinook salmon and steelhead during juvenile summer parr, juvenile winter presmolt, and adult spawning (redds) life stages (Appendix B of Idaho OSC Team, 2019). The QRF models provide a novel approach to estimate habitat carrying capacity of wadable streams that address issues commonly associated with noisy data, correlated variables, and non-linear relationships. Covariates included in the six models, along with their ranking of relative importance, are described below for each species (Table 1). A full description of the covariate selection process and model performance for models used in this assessment can be found in Oldemeyer et al., in prep.

Table 1. Habitat covariates by species and life stage for the quantile random forest models used for habitat carrying capacity estimation. Numbers indicate where each metric ranked in relative importance for each species. Dashes indicate the metric was not used for a given model.

Name	Juvenile Chinook (Summer)	Juvenile Steelhead (Summer)	Juvenile Chinook (Winter)	Juvenile Steelhead (Winter)	Chinook Spawning (Redd)	Steelhead Spawning (Redd)	Description
Channel Unit Frequency	5	11	3	2	1	1	Number of channel units per 100 meters.
Fast Non-Turbulent Frequency	9	13	–	–	13	6	Number of fast water non-turbulent channel units per 100 meters.
Fast Turbulent Frequency	3	6	–	–	4	2	Number of fast water turbulent channel units per 100 meters.
Sinuosity	13	7	6	5	10	11	Ratio of the thalweg length to the straight-line distance

Name	Juvenile Chinook (Summer)	Juvenile Steelhead (Summer)	Juvenile Chinook (Winter)	Juvenile Steelhead (Winter)	Chinook Spawning (Redd)	Steelhead Spawning (Redd)	Description
							between the start and end points of the thalweg.
Wetted Channel Braidedness	14	14	10	11	–	–	Ratio of the total length of the wetted mainstem channel plus side channels and the length of the mainstem channel.
Fish Cover: LW	–	–	4	6	–	–	Percent of wetted area that has large woody debris as fish cover.
Fish Cover: Some Cover	7	3	11	8	9	4	Percent of wetted area with some form of fish cover
Residual Depth	–	–	2	3	–	–	Residual depth (m) of the channel unit.
Average Thalweg Depth	1	2	–	–	2	3	Average thalweg depth (m).
Thalweg Exit Depth	–	–	5	4	–	–	Depth (m) of the thalweg at the downstream edge of the channel unit.
Residual Pool Depth	12	10	–	–	11	5	The average difference between the maximum depth and downstream end depth (m) of all slow water, including pool, channel units.
Discharge	–	–	1	1	–	–	Discharge in cubic meters per second.
Substrate Est: Boulders	8	9	–	–	6	12	Percent of boulders (256-4000 mm) within the wetted site area.
Substrate Est: Cobble and Boulder	–	–	7	10	–	–	Percent of cobbles and boulders within the wetted area.
Substrate Est: Cobbles	11	5	–	–	8	8	Percent of cobbles (64-256 mm) within the wetted site area.
Substrate Est: Coarse and Fine Gravel	6	8	8	9	5	13	Percent of coarse and fine gravel (2-64 mm) within the wetted area.
Substrate Est: Sand and Fines	10	4	9	7	7	7	Percent of sand and fine sediment (0.01-2 mm) within the wetted area.
Avg. August Temperature	2	1	–	–	3	10	Average predicted daily August temperature (°C) from NorWeST (Northwest Stream

Name	Juvenile Chinook (Summer)	Juvenile Steelhead (Summer)	Juvenile Chinook (Winter)	Juvenile Steelhead (Winter)	Chinook Spawning (Redd)	Steelhead Spawning (Redd)	Description
							Temperature), averaged across years 2002-2011.
Large Wood Frequency: Wetted	4	12	–	–	12	9	Number of large wood pieces per 100 meters within the wetted channel.

Juvenile summer rearing and redd surveys included in the paired fish-habitat data used to fit the QRF models were collected at the habitat reach scale and summarized in linear densities (fish per meter). The juvenile winter rearing fish surveys were conducted at the channel unit level and fish densities were summarized in fish per meter squared. Winter rearing capacities were estimated at the channel unit level and summarized at the reach scale using the mean weighted density of channel units by length within the reach. If the wetted areas of all channel units and habitat reaches were known—and assuming reach lengths and wetted areas were similar between the habitat data used to fit the model and the habitat data being used for prediction —fish density units could be standardized between the species and life stages. Because several sites in the DASH dataset lacked channel unit areas, and the objective of the assessment was to understand key habitat metrics driving habitat capacity within species and life stages, densities were reported in their original units (fish per meter for juvenile summer rearing and redds; fish per meter squared for juvenile winter rearing) at the habitat reach scale.

Estimates of habitat capacity for Chinook salmon and steelhead during summer parr, winter presmolt, and adult spawning (redds) life stages where compared for DASH surveyed sites from the Lemhi (561 reaches; 100.3 rkms), Pahsimeroi (13 reaches; 3.6 rkms), Upper MFSR (65 reaches; 22.1 rkms), Upper Salmon (7 reaches; 6.7 rkms), and Upper Secesh (14 reaches; 4.6 rkms) watersheds to explore the *a priori* designation of watersheds that exhibit high-quality and impaired habitats. Following, habitat characteristics for the highest capacity reaches (upper 10% quantile) and lowest capacity reaches (lower 10% quantile) for all DASH surveyed reaches, irrespective of watershed, were quantitively compared. A Welch two-sided t-test implemented in the Program R “stats” package (R Core Team, 2024) was used to identify habitat metrics with statistically significant differences ($p < 0.05$) between the highest and lowest capacity reaches by species and life stage.

It is important to note there were a variety of motivations for surveying habitat sites within each of the watersheds (e.g., pre- and post-project monitoring, fish-habitat relationship assessment, surveys for watershed assessments, etc.). There was no attempt to randomize or stratify these surveys; as such, results may not be wholly representative of habitat for an entire watershed, rather an overview of the relative habitat quality surveyed using the DASH protocol within each watershed. Regardless, it was expected that the large sample size of surveyed habitat (660 reaches totaling 137.2 kms over the five watersheds) would help illuminate general trends within each watershed related to their relative habitat quality.

RESULTS

Watershed Comparison

In general, the Upper MFSR, Upper Secesh, and Lemhi watersheds had the highest median habitat capacities of the five watersheds (Figure 2, Figure 3). The Upper Secesh had the highest median habitat capacities for juvenile Chinook salmon summer rearing and juvenile steelhead winter rearing. The Upper MFSR had the highest median juvenile Chinook salmon winter rearing habitat capacity, and the second or third highest median habitat capacities for most other species and life stages. The Lemhi watershed generally had low to medium habitat capacity estimates except for one or two habitat reaches that would often exhibit high, or the highest, capacity estimate of all DASH surveyed sites. The Upper Salmon watershed had the lowest or second lowest median habitat capacities for all species and life stages. The Pahsimeroi watershed generally had the most consistent habitat capacities for each species and life stages, and median habitat capacities were near the average of all the watersheds. Estimated habitat capacities were highly variable within the Lemhi, Upper MFSR, and Upper Secesh watersheds. The Lemhi watershed exhibited the highest and lowest capacity reaches for nearly every species and life stages. For juvenile Chinook summer rearing, the highest capacity reaches in the Lemhi watershed were estimated to have more than double the capacity of next highest capacity site (surveyed in the Upper Secesh).

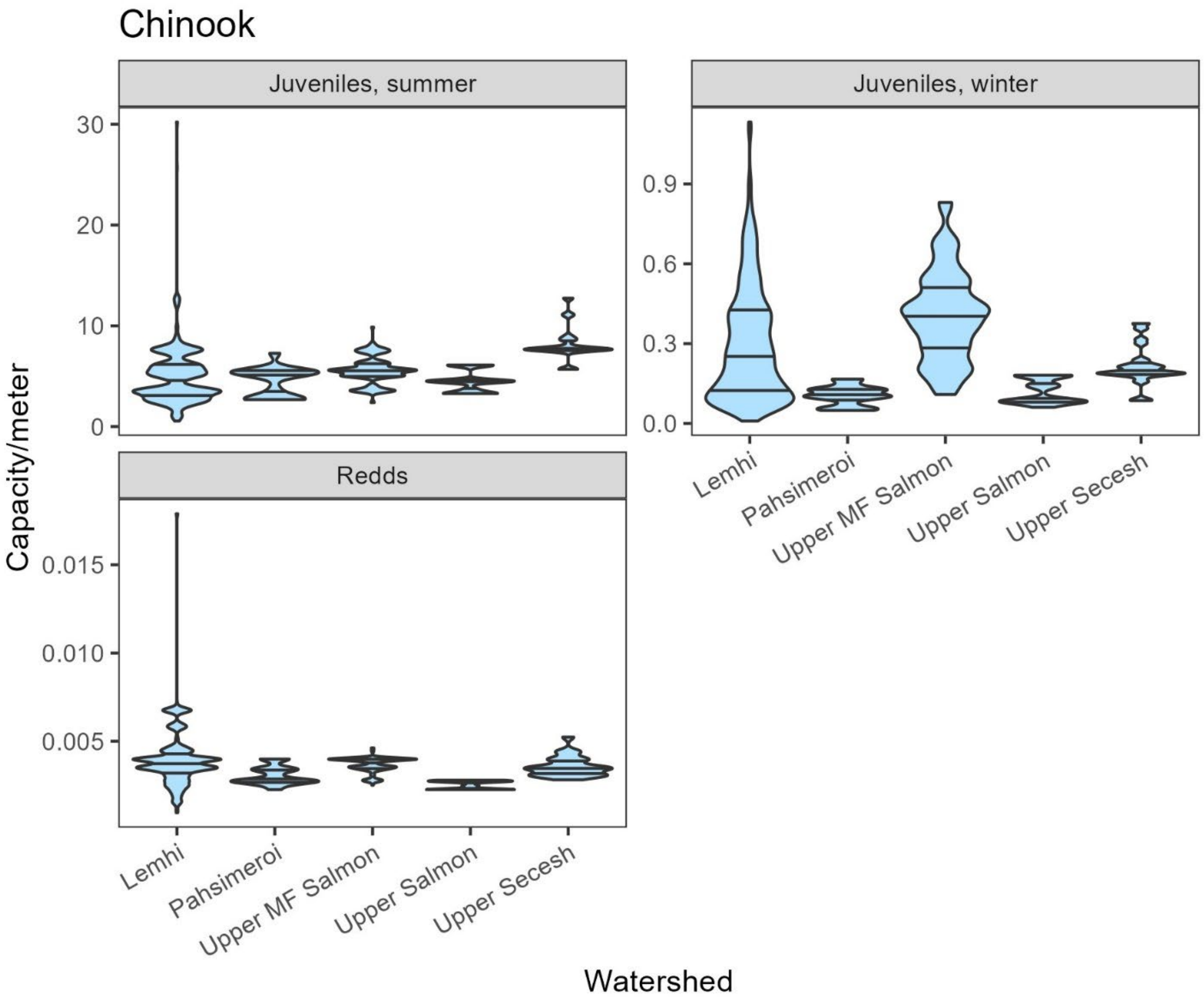


Figure 2. Distribution of Chinook salmon habitat carrying capacities by watershed for sites surveyed using DASH protocols, 2018 – 2021. Note, juvenile winter rearing capacity is capacity/meter^2.

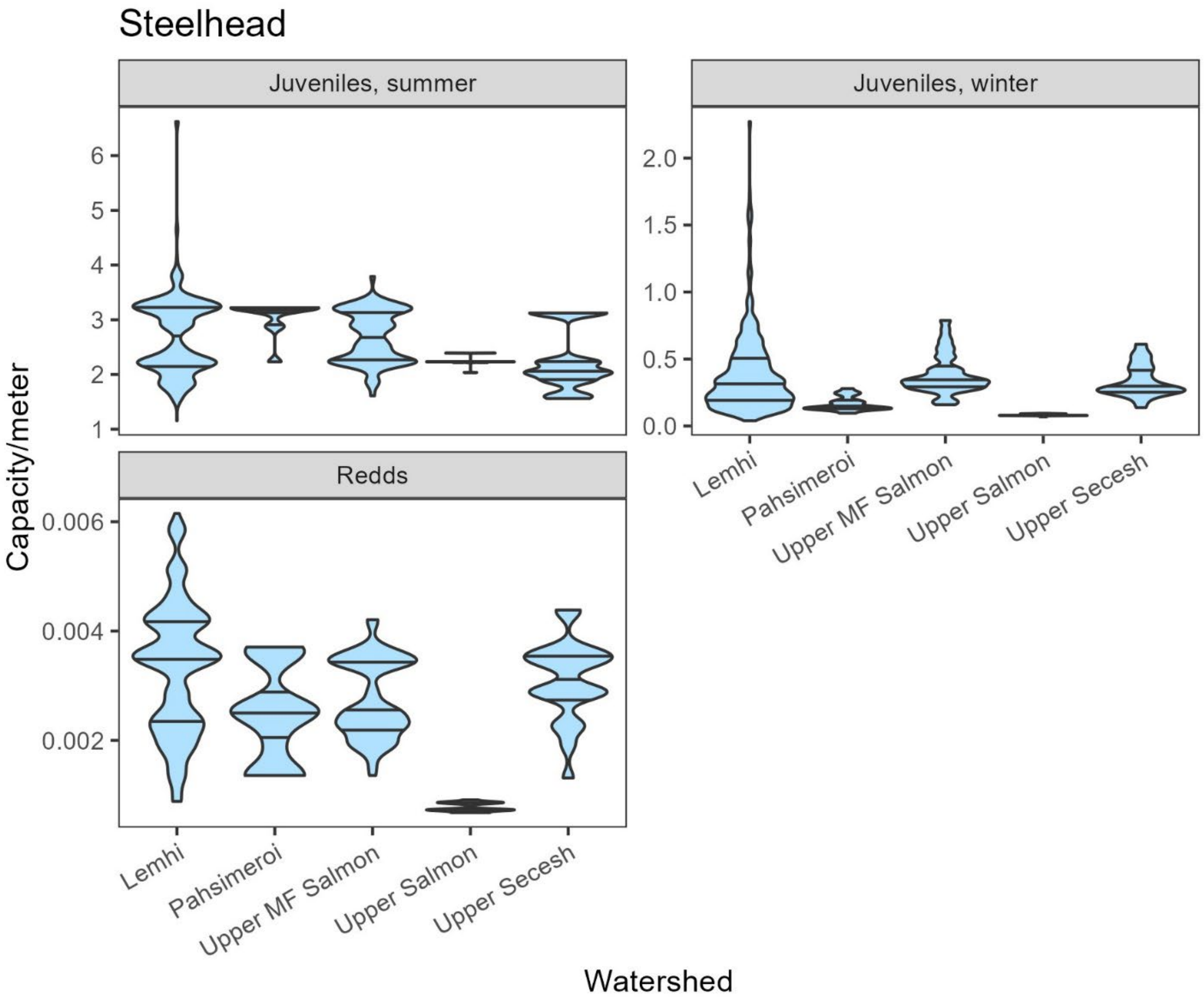


Figure 3. Distribution of steelhead habitat carrying capacities by watershed for sites surveyed using DASH protocols 2018 - 2021. Note, juvenile winter rearing capacity is in capacity/meter^2.

High-Capacity and Low-Capacity Habitat Comparison

Juvenile summer rearing

Comparison of habitat metrics for reaches that were estimated to support the highest and lowest 10% of summer rearing capacities revealed eight metrics for juvenile Chinook salmon and 12 metrics for juvenile steelhead with significant difference ($p < 0.05$; Figure 4, Figure 5). In general, the highest capacity juvenile summer rearing habitat was associated with deeper average thalweg depths (> 0.35 m), lower frequencies of fast turbulent channel unit types (< 4 riffles or rapids per 100 m), deeper residual pool depths (>0.35 m), lower frequencies of channel units (< 8 channel units per 100 m), and lower sinuosity (< 1.09). To a lesser extent, high-capacity juvenile summer rearing habitat was loosely associated with larger substrate (cobbles and boulders), although substrate habitat metric distributions were variable between species.

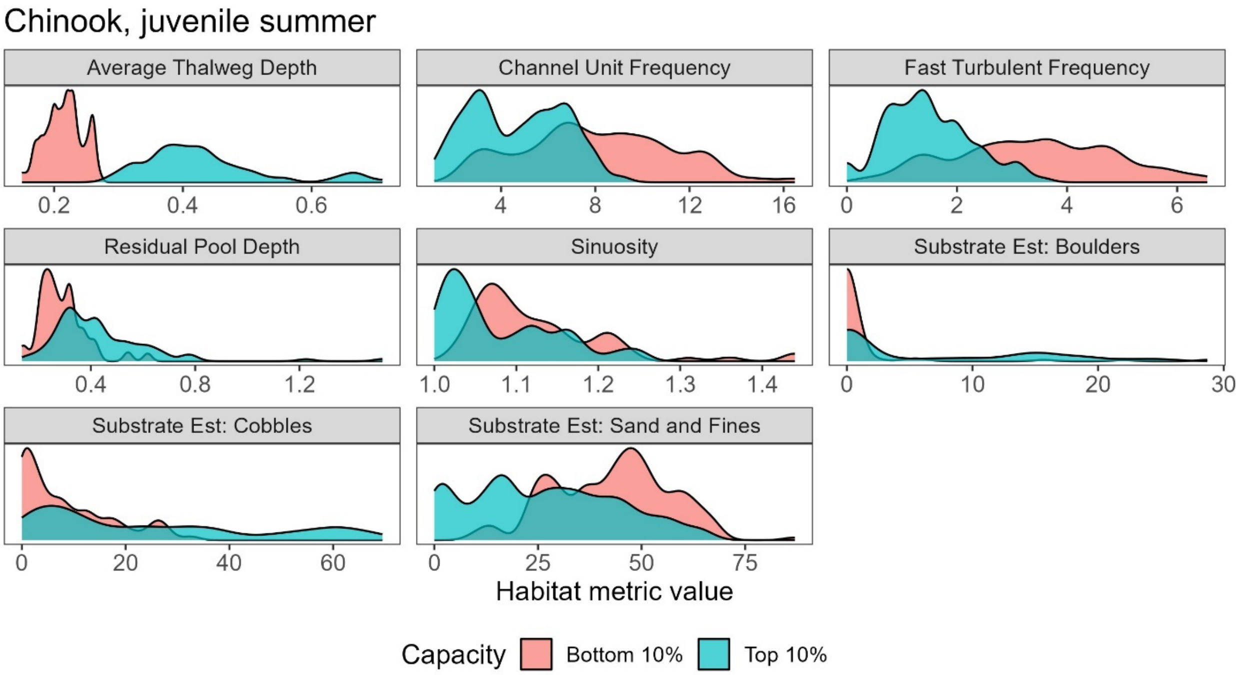


Figure 4: Density plots for habitat metrics with statistically significant ($p < 0.05$) differences between the highest capacity Chinook salmon summer parr habitat (top 10%) and the lowest capacity Chinook salmon summer parr habitat (bottom 10%) for reaches surveyed using DASH protocols, 2018-2021.

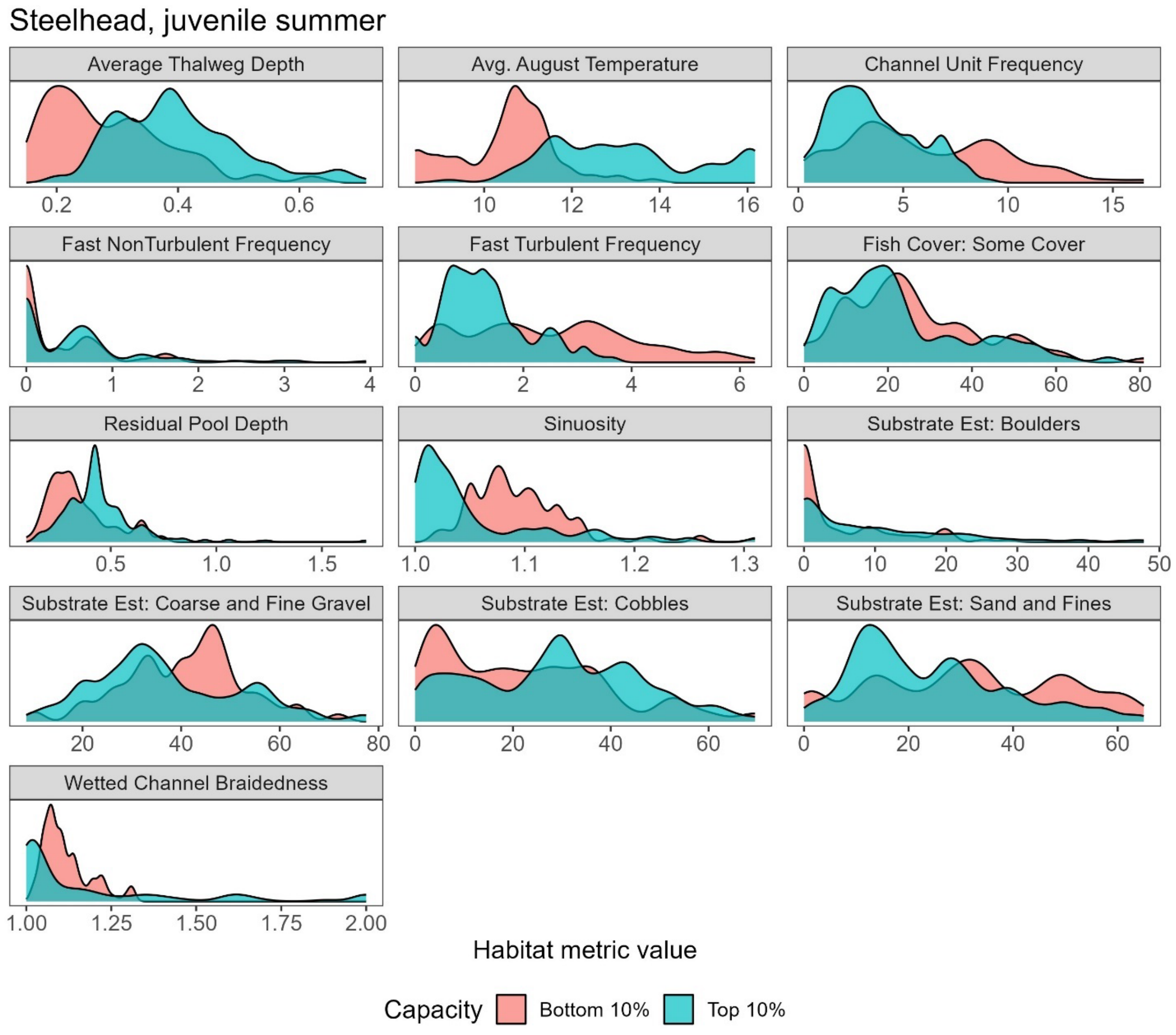


Figure 5: Density plots for habitat metrics with statistically significant ($p < 0.05$) differences between the highest capacity steelhead summer parr habitat (top 10%) and the lowest capacity Steelhead summer parr habitat (bottom 10%) for reaches surveyed using DASH protocols, 2018-2021.

Juvenile Winter Rearing

Comparison of habitat metrics for reaches that were estimated to support the highest and lowest 10% of winter rearing capacities revealed eight metrics for juvenile Chinook salmon and juvenile steelhead with significant difference ($p < 0.05$; Figure 6, Figure 7). The highest capacity juvenile winter rearing reaches generally exhibited habitat metrics associated with greater habitat complexity and slower water velocities. High-capacity juvenile winter rearing reaches had higher channel unit frequency (> 4 channel units per 100 meters), lower discharge (<1.5 cms), increased fish cover (both large wood and total [includes overhanging and aquatic vegetation, artificial cover, etc.] cover), higher percentage of sands and fines (> 40%), and lower percentage of cobbles and boulders (< 25%). Reaches with lower capacities were associated with deeper average thalweg exit depths (> 0.5 meters) and, to a lesser extent, average residual channel unit depths (for steelhead). This is likely a product of how these two metrics were averaged over the habitat reach-scale for the upper and lower quantile capacity comparison.

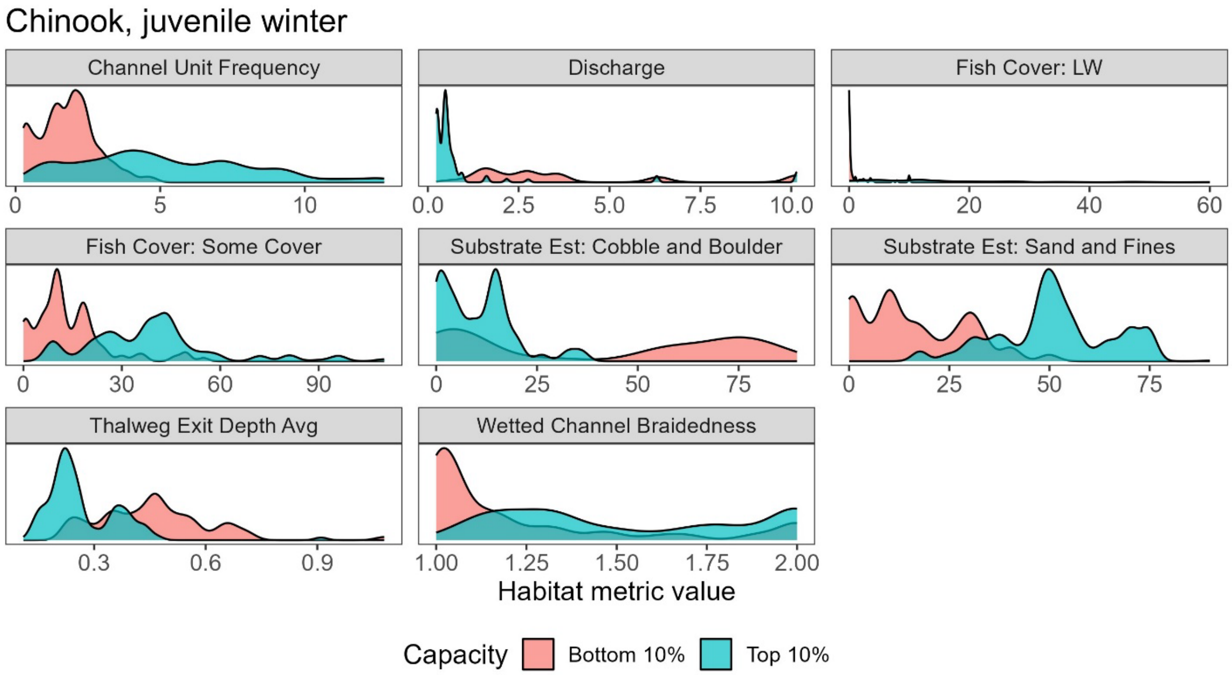


Figure 6: Density plots for habitat metrics with statistically significant ($p < 0.05$) differences between the highest capacity Chinook salmon winter presmolt habitat (top 10%) and the lowest capacity Chinook salmon winter presmolt habitat (bottom 10%) for reaches surveyed using DASH protocols, 2018-2021.

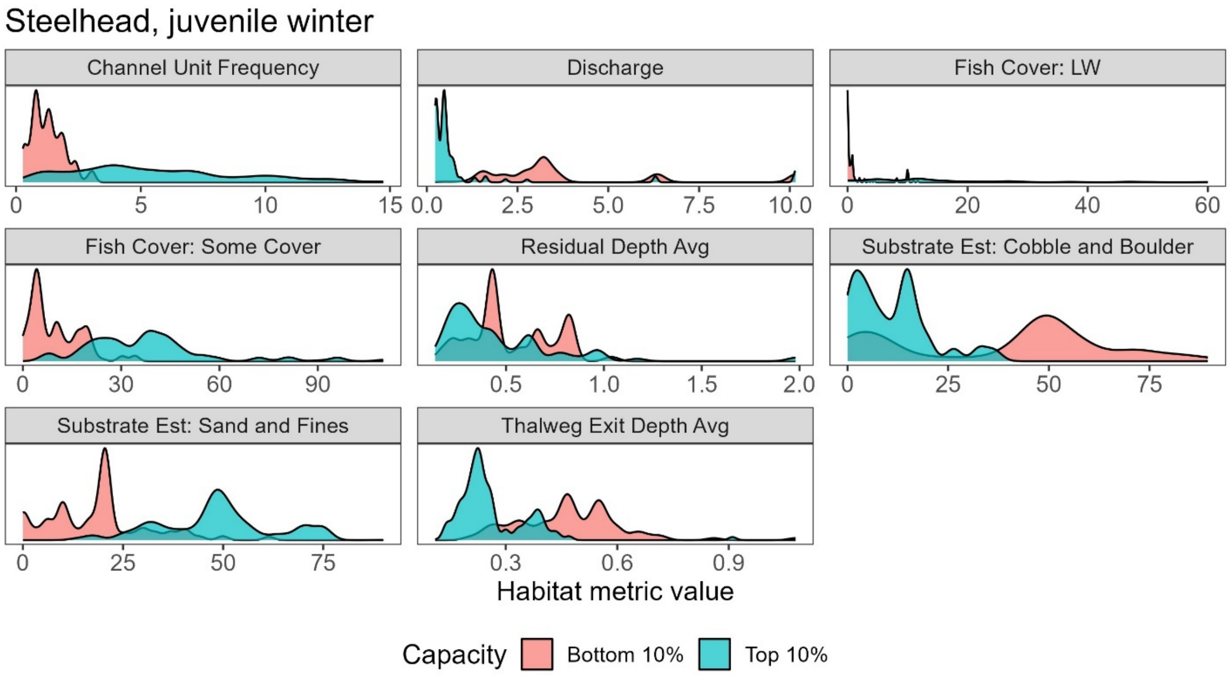


Figure 7: Density plots for habitat metrics with statistically significant ($p < 0.05$) differences between the highest capacity steelhead winter presmolt habitat (top 10%) and the lowest capacity steelhead winter presmolt habitat (bottom 10%) for reaches surveyed using DASH protocols, 2018-2021.

Redds

High-capacity spawning reaches for Chinook salmon and steelhead were generally associated with lower average thalweg exit depths (< 0.3 m), increased frequency of channel units (> 4 channel units per 100 meters), higher frequency of fast turbulent channel units (> 2 riffles or rapid channel units per 100 meters), increased available fish cover (including large wood), and substrate compositions dominated by coarse and fine gravels (> 35%; Figure 8, Figure 9). Additionally, high-capacity spawning reaches were generally associated with lower average august stream temperatures, though the bimodal distribution for high-capacity reaches had significant overlap with the distributions of lowest capacity reaches for the metric.

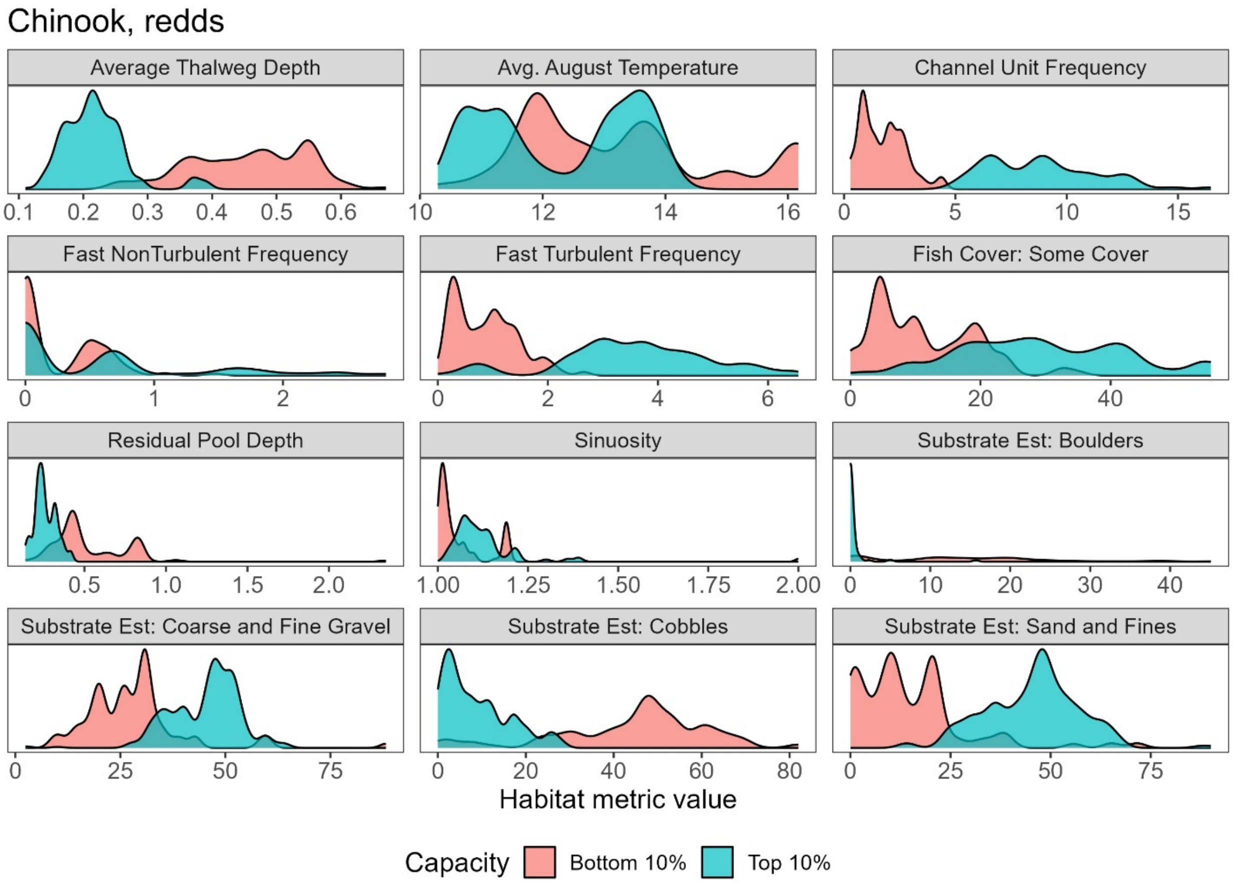


Figure 8: Density plots for habitat metrics with statistically significant ($p < 0.05$) differences between the highest capacity Chinook salmon spawning (redds) habitat (top 10%) and the lowest capacity Chinook salmon spawning (redds) habitat (bottom 10%) for reaches surveyed using DASH protocols, 2018-2021.

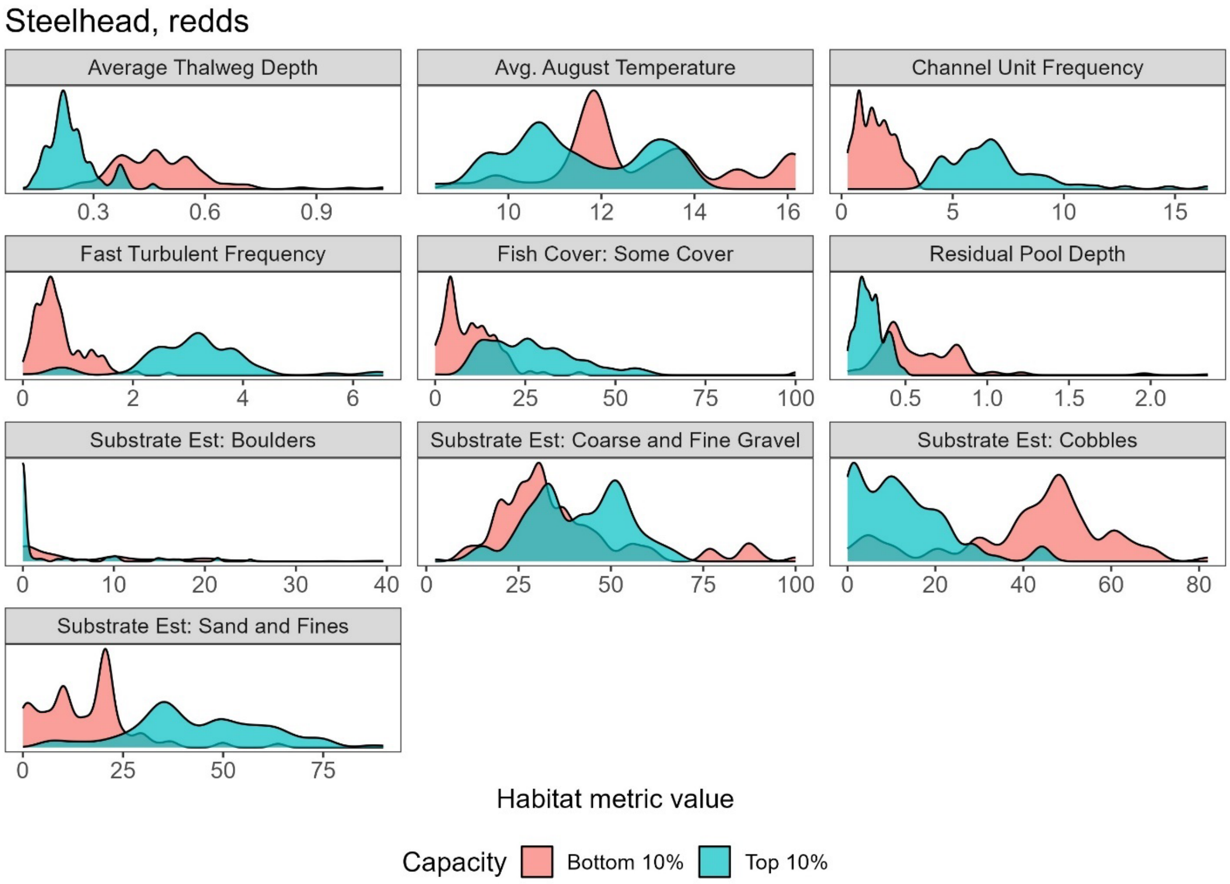


Figure 9: Density plots for habitat metrics with statistically significant ($p < 0.05$) differences between the highest capacity steelhead spawning (redds) habitat (top 10%) and the lowest capacity steelhead spawning (redds) habitat (bottom 10%) for reaches surveyed using DASH protocols, 2018-2021.

DISCUSSION

Sites in designated high-quality reference watersheds (Upper Secesh and Upper MFSR) were estimated to support higher capacities than those surveyed in impaired/impacted watersheds (Lemhi, Pahsimeroi, and Upper Salmon River). There was significant overlap in distributions of habitat capacities between watersheds, as well as significant variability within several watersheds. The Lemhi watershed exhibited substantial variation in capacity, including some of the highest and lowest density reaches of all DASH surveyed sites. This within-watershed variability can partially be attributed to the natural variation present within complex habitat. Even within an unimpacted watershed with high-quality and complex habitat, we expect that some reaches would be more amenable to supporting certain species and life stages. Another potential source for the large within-watershed variation in capacity is that the selection of survey sites may not provide a representative sample. The motivations behind site selection were variable, including pre- and post-project monitoring, habitat assessments, watershed assessments, and others. This resulted in a non-random survey design that may or may not accurately represent the range of habitat within each watershed. We attempted to account for this potential issue with the large sample size, along with the variety of study designs that were applied. It appears that the surveyed sites represented the range of habitat present in the five watersheds, however, the high variability and non-normal distribution of capacity estimates provide some evidence that the composition of sites may not be a representative sample. A formal study design that included randomized, stratified, and balanced site selection within and between watersheds would result in a dataset where assumption regarding randomization and watershed representation could be met. This would allow for statistically robust methods to measure habitat capacities and habitat quality between watersheds. Despite the lack of formal sample design, analyzing the current DASH dataset still offered insights into the general habitat capacities and habitat quality between the five watersheds.

The comparison of habitat characteristics between the highest quality reaches (reaches in the upper 10% quantile of habitat capacities) and lowest quality reaches (reaches in the lowest 10% quantile of habitat capacities) provided useful insight into the habitat characteristics most often associated with high-capacity habitat. High-capacity summer rearing habitat was generally associated with relatively deep and slower velocity water, consistent with prior studies (Hillman et al., 1987; Holecek et al., 2009; Holmes et al., 2014). High-capacity juvenile summer rearing habitats had deeper average thalweg, thalweg exit, and residual pool depths, a range of substrate types, and lower frequencies of fast turbulent channel units (riffles and rapids). Habitat characteristics often associated with higher geomorphic complexity (increased channel unit frequency, sinuosity, and wetted channel braidedness) were not represented in the high-capacity habitats for juvenile summer rearing, as deeper water depths and slower velocities generally result in increased channel unit lengths. Larger channel units with slower velocities and deeper conditions (e.g. runs or pools) generally provide juvenile Chinook salmon and steelhead more opportunity to occupy habitat that minimizes energetic expenses to maintaining in-stream position. If adequate instream cover that provides forage and protection from predators is also present, relatively large and deep channel units would make for bioenergetically advantageous habitat for summer rearing.

The highest capacity winter rearing habitat exhibited similar habitat features as the highest capacity juvenile summer rearing habitats. In general, high-capacity juvenile winter rearing habitat was associated with slow velocity, reduced discharge, increased fish cover, higher channel unit frequencies, and higher wetted channel braidedness. Unlike high-capacity juvenile summer rearing, the highest capacity winter rearing habitats were associated with sands, fines, and coarse gravels. These types of substrates often support greater abundances of chironomids (small, benthic macroinvertebrates that hatch throughout the year) that are readily consumed by juvenile salmonids (Limm and Marchetti, 2009). Additionally, the association between fine and sand substrates with higher quality winter rearing habitat is likely a byproduct of geomorphic processes; suspended fines and sands are deposited out of the water column as velocity decreases around pools and structure. While we cannot directly infer if the relationship between sands and fines and winter rearing capacity is more strongly related to forage opportunity or an association with reduced water velocity, this result underlines the importance of interpreting fish habitat on a holistic scale. Another difference from the summer rearing model is that high-capacity winter habitat was not associated with increases in average thalweg exit and residual channel unit depth. We infer that this result is due to differences in spatial scale between the models.

When constructing the QRF models, fish observations and habitat data that informed the summer model were collected at the reach scale, while the winter model utilized channel unit scale observations and a combination of channel unit and reach scale habitat data. Results were summarized to the reach scale, so some resolution may be lost for metrics that exhibit substantial variation by channel unit (i.e., thalweg exit and residual pool depths). At a channel unit scale, winter rearing capacity was predicted to increase with thalweg exit depth and residual channel unit depth, which are common features of pool and run channel units. However, the influence of increased thalweg and residual depth is less clear at the reach scale, and capacity increases are instead credited to increased channel unit frequency. We expect that increased channel unit frequency is correlated with the presence of pools and runs with adequate depths.

High-capacity spawning habitats were generally associated with increased channel unit frequency, riffle frequency, sinuosity, percent gravel substrate, and fish cover (including large wood), and reduced thalweg and thalweg exit depths. Large amounts of wood and cover provide areas for adult Chinook salmon and steelhead to rest and hide during staging, redd construction, and spawning. Higher channel unit frequency is typically associated with hydraulic diversity and increased pool-riffle sequences, providing access to pool tailouts for spawning with adjacent resting areas as well as suitable fry and juvenile rearing habitat as fish emerge from the substrate in spring. Lastly, the abundance of gravel and high frequency of riffles allow adults to build redds in locations that minimize the chance that eggs become dislodged from substrate while also allowing sufficient flow and oxygen for egg and alevin development (Hamann et al. 2014). Combined, these characteristics result in conditions where adults can build redds and spawn in high-quality gravels typically associated with pool-riffle interfaces and pool tailouts while being near cover and large structures to rest and escape predators.

It is broadly recognized that high-capacity fish habitat is not the product of one or two individual habitat characteristics within a reach. Rather, it is the result of the dynamic interplay of the entire suite of habitat characteristics at the channel unit- and reach-scale working in synchrony. Due to the complexity and highly correlated nature of habitat data, modeling and quantifying the interaction between habitat and Chinook salmon and steelhead carrying capacities has been an on-going challenge in the Pacific Northwest. This assessment was able to leverage advanced statistical models to address issues commonly associated with correlated and non-linear fish-habitat data to begin to identify and quantify habitat metrics most often associated with high-capacity habitat for sites surveyed in central Idaho. When viewed holistically, the results from this appendix and subsequent examples from the main document can help inform and guide habitat restoration and rehabilitation efforts that optimize the habitat carrying capacity potential based on life stage specific needs for target species in the Upper Salmon River Basin.

REFERENCES

Bond, M.H., T.G. Nodine, T.J. Beechie, and R.W. Zabel. 2019. Estimating the benefits of widespread floodplain reconnection for Columbia River Chinook salmon. Canadian Journal of Fisheries and Aquatic Sciences 76:1212–1226.

Carmichael, R.A., M.W. Ackerman, K. See, B. Lott, T. Mackay, and C. Beasley. 2019. Drone assisted stream habitat (DASH) protocol, DRAFT. Boise, Idaho.

Copeland, T., D. Blythe, W. Schoby, E. Felts, and P. Murphy. 2021. Population effect of a large-scale stream restoration effort on Chinook salmon in the Pahsimeroi River, Idaho. River Research and Applications, 37(1), 100-110.

Gebhards, S. V. 1959. The effects of irrigation on the natural reproduction of Chinook salmon in the Lemhi River, Idaho. M.S. Thesis, Utah State University, Logan, Utah. pp. 60

Hamann, E.J., B.P. Kennedy, , D.C. Whited and J.A. Stanford. 2014. Spatial variability in spawning habitat selection by Chinook salmon (Oncorhynchus tshawytscha) in a wilderness river. River research and applications, 30(9), pp. 1099-1109.

Hillman, T. W., J. S. Griffith, and W.S. Platts. 1987. Summer and winter habitat selection by juvenile chinook salmon in a highly sedimented Idaho stream. Transactions of the American Fisheries Society, 116(2), 185-195.

Holecek, D. E., K. J. Cromwell, and B.P. Kennedy. 2009. Juvenile Chinook salmon summer microhabitat availability, use, and selection in a central Idaho wilderness stream. Transactions of the American Fisheries Society, 138(3), 633-644.

Holmes, R.W., M.A. Allen, and S. Bros-Seeman. 2014. Seasonal microhabitat selectivity by juvenile steelhead in a central California coastal river. California Fish and Game, 100(4): 590-615.

Idaho Department of Environmental Quality (IDEQ). 2013. Pahsimeroi River subbasin assessment and total maximum daily load, 2013 addendum and five-year review. Boise, Idaho.

Idaho Governor's Office of Species Conservation Team (OSC). 2019. Upper Salmon Subbasin Habitat Integrated Rehabilitation Assessment. Assessment Prepared for and with the U.S. Department of the Interior, Bureau of Reclamation. pp. 625.

Integrated Status and Effectiveness Monitoring Program and Columbia Habitat Monitoring Program (ISEMP and CHaMP). 2017. ISEMP and CHaMP Annual Combined Technical Report. January-December 2016. Bonneville Power Administration (BPA) Projects 2003-017-00 and 2011-006-00.

Interior Columbia Technical Recovery Team. 2003. Independent populations of Chinook, steelhead, and sockeye for listed evolutionarily significant units within the Interior Columbia River domain. NOAA Fisheries, Portland, Oregon.

Limm, M.P., and M.P. Marchetti. 2009. Juvenile Chinook salmon (Oncorhynchus tshawytscha) growth in off-channel and main-channel habitats on the Sacramento River, CA using otolith increment widths. Environ Biol Fish 85, 141–151. https://doi.org/10.1007/s10641-009-9473-8

National Oceanic and Atmospheric Administration (NOAA). 2017. ESA Recovery Plan for Snake River Spring/Summer Chinook Salmon (Oncorhynchus tshawytscha) and Snake River Steelhead (Oncorhynchus mykiss). NOAA National Marine Fisheries Service, Portland, Oregon.

Northwest Fisheries Science Center (NWFSC). 2015. Status review update for Pacific salmon and steelhead listed under the Endangered Species Act: Pacific Northwest.

Oldemeyer, B.O., M. Ackerman, and M. Roes. *In prep*. Chinook salmon and steelhead quantile random forest model updates, 2024: Increased utility for restoration monitoring and improved watershed predictions. Prepared for the Idaho Governor’s Office of Species Conservation under Bureau of Reclamation Cooperative Agreement R19AC00078.

Poole, J. R., E. A. Felts, B. Barnett, M.Davison, M. Heller, R. Hand, and E. Brown. 2022. Idaho adult Chinook Salmon monitoring. Annual report 2021. Idaho Department of Fish and Game Report 22-05.

R Core Team. (2024). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Rio Applied Science and Engineering (Rio ASE) and Biomark, Inc. (Biomark). 2021a. 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.

Rio Applied Science and Engineering (Rio ASE) and Biomark, Inc. (Biomark). 2021b. Lower Pahsimeroi River Multiple Reach Assessment Report. Prepared with the Idaho Governor’s Office of Species Conservation under Bureau of Reclamation Cooperative Agreement R19AC00078. May.

Rio Applied Science and Engineering (Rio ASE) and Biomark, Inc. (Biomark). 2021c. Upper Lemhi River Multiple Reach Assessment Report. Prepared with the Idaho Governor’s Office of Species Conservation under Bureau of Reclamation Cooperative Agreement R19AC00078. April.

Rio Applied Science and Engineering (Rio ASE) and Biomark, Inc. (Biomark). 2021d. Upper Salmon River Multiple Reach Assessment Report. Prepared with the Idaho Governor’s Office of Species Conservation under Bureau of Reclamation Cooperative Agreement R19AC00078. May.

Ruthven, J. S., B. Barnett, M. Davison, M. Heller, A. Young, and J. Thiessen. 2023. Idaho Adult Chinook Salmon Monitoring. Annual report 2022. Idaho Department of Fish and Game Report 23-08.

APPENDIX C MULTI-THREAD CHANNEL TYPES

Appendix C - Multi-Thread Channel Types

For The Idaho Governor's Office of Species Conservation
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1 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 1-1. 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 (Figure 2-1 and Table 2).

Table 1-1. 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

2 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.

1. Beaver Dam Distributed
Backwater conditions; multiple dam outlet channels; variable width; dense riparian; broad active floodplain

2. Valley-fill Sub-parallel
Stable channels; limited floodplain connection; topographic structural controls

3. Valley-fill Distributed
Small-scale avulsion occupying low-lying floodplain; stabilized by riparian vegetation; often combined with beaver activity

4. Meander-Relict
Channel migration; small scale avulsion on inside of bend stabilized by riparian vegetation and/or LWD; channel migration into relict feature; small-scale avulsion stabilized by riparian vegetation; variable width

5. Bar-Island Split
High bedload; dynamic channel migrates/avulses around multiple island nodes stabilized by mature vegetation and/or LWD

Figure 2-1. Secondary Channel Types and Characteristics

Table 2-1. 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
Laterally Active	Peak-flow	Moderate coarse material bedload transport	Primarily suspended bed material and wash load; moderate coarse bedload	**Valley-fill Distributed**	• Associated with primary channel 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 2-1. 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 primary channel point-bars and lateral channel migration • Small-scale avulsion into relict channel scar along outside of meander bend • Former primary channel becomes secondary channel • Multiple secondary 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 2-1. 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 primary channel 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 2-1 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 2-1 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.

3 REFERENCES

Kleinhans, M. G. 2010. Sorting out river channel patterns. Progress in Physical Geography 34(3): 287-326.

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.