Multi-thread Channel Types

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. In addition to nomenclature, there are multiple secondary channel types common throughout the Upper Salmon river basin that form under a variety of conditions and provide different habitat characteristics. Using empirical observations from the Upper Salmon River Basin, five secondary channel types have been identified as the focus of this document (Table 2).

Table 1. Secondary Channel Nomenclature

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

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.

Table 2. Secondary channel types and characteristics.

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

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

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

3 References

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

Secondary Channel Type: Beaver Dam Distributed

Key Attributes:

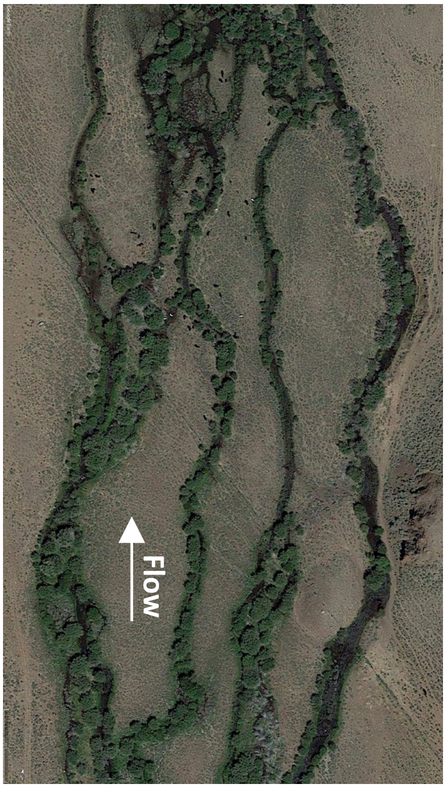
Lateral Adjustment	Hydrologic Regime	Sediment Transport Regime	
		Primary Channel Transport	Secondary Channel Supply
Laterally Inactive	Peak-flow and Base-flow	Fine and coarse material bedload transport	Suspended bed material and wash load

Formation and Processes:

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

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

Secondary Channel Type: Valley-fill Sub-parallel



Key Attributes:

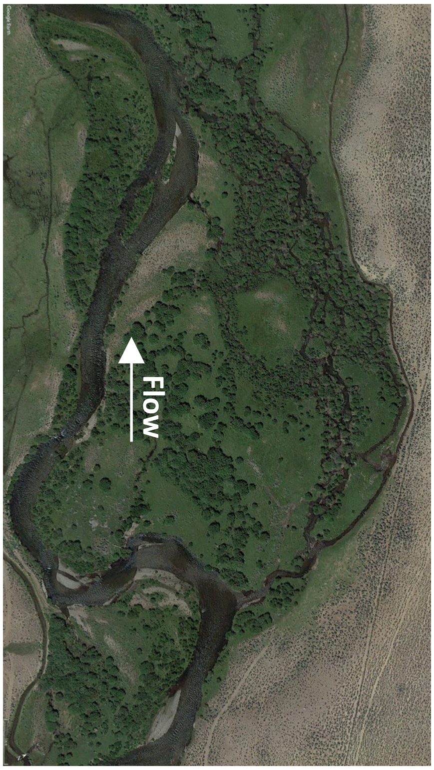
Lateral Adjustment	Hydrologic Regime	Sediment Transport Regime	
		Primary Channel Transport	Secondary Channel Supply
Laterally Inactive	Base-flow	Low to moderate coarse material bedload transport	Suspended bed material and wash load

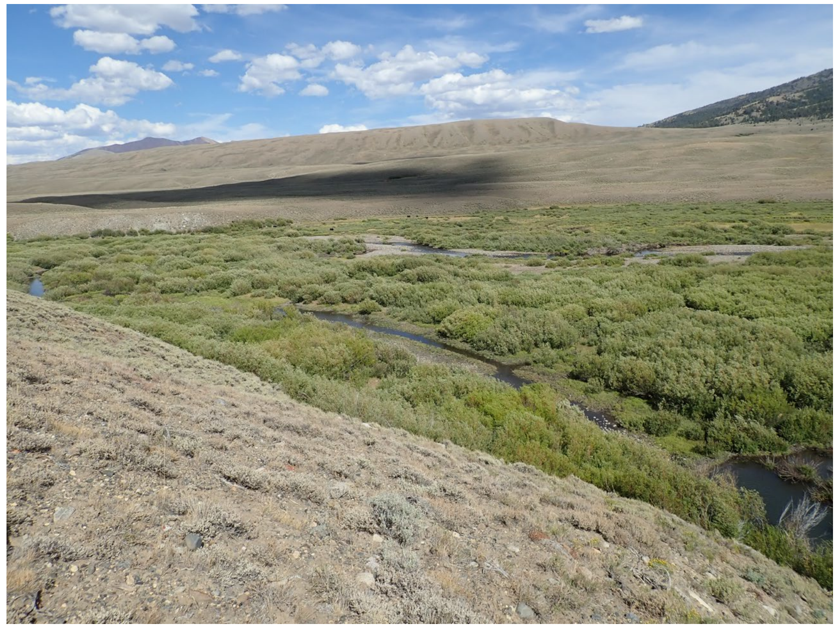
Formation and Processes:

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

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

Secondary Channel Type: Valley-fill Distributed





Key Attributes:

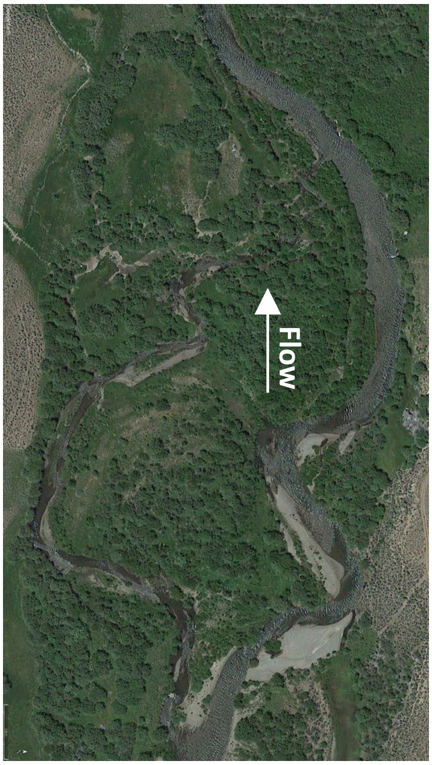
Lateral Adjustment	Hydrologic Regime	Sediment Transport Regime	
		Primary Channel Transport	Secondary Channel Supply
Laterally Active	Peak-flow	Moderate coarse material bedload transport	Primarily suspended bed material, and wash load; moderate bedload

Formation and Processes:

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

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

Secondary Channel Type: Meander-Relict



Key Attributes:

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

Formation and Processes:

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

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

Secondary Channel Type: Bar-Island Split

Key Attributes:

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

Formation and Processes:

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

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