
Mad River, near Ardenvoir, WA - October, 2017.

Lower Mad River Reach Assessment & Restoration Strategy Report

SUBMITTED TO
Yakama Nation Fisheries - Wenatchee

DECEMBER 2018

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PREPARED BY
Inter-Fluve
501 Portway Ave, Suite 101
Hood River, OR 97031
(541) 386-9003

Table of Contents

1. Introduction

1.1 PROJECT OVERVIEW

The Mad River Reach Assessment and Restoration Strategy evaluates existing aquatic habitat and watershed process conditions along the lower 4.3-miles of the Mad River. The Mad River is a primary tributary within the Entiat River watershed. The watershed is located within the eastern foothills of the Cascade Mountains in central Washington along the western border of the Columbia Plateau (Figure 1). The Mad River flows southeast through the foothills and joins the Entiat River approximately 11 river miles (RM) upstream of where the Entiat meets the Columbia River near the community of Entiat. The assessment area extends from the mouth of the Mad River at its confluence with the Entiat River 4.3 river miles to its confluence with an unnamed tributary (river right) near Pine Flats campground.

This reach assessment provides a technical foundation for understanding existing conditions and for identifying restoration strategies for the lower Mad River. Conditions are assessed at both the project area scale and reach scale. The aim is to identify restoration actions that address factors limiting the productivity of native salmonids, and to ensure that these actions fit within the appropriate geomorphic context of the river system. An emphasis is placed on understanding the underlying biological and physical processes at work and how human impacts have affected these processes and the habitat they support. Restoration measures focus on recovering, to the extent possible, these impaired processes. Although the proposed restoration measures are expected to benefit a large suite of native aquatic and terrestrial species, there is a particular emphasis on recovery of Endangered Species Act (ESA) listed Upper-Columbia Summer Steelhead (*Oncorhynchus mykiss*), Upper-Columbia Spring Chinook (*Oncorhynchus tshawytscha*), and Columbia River bull trout (*Salvelinus confluentus*).

The report includes the following components:

- Study area characterization – Evaluation of valley- and basin-scale factors influencing aquatic habitat and stream geomorphic processes.
- Reach-scale characterization – Inventory and analysis of habitat and geomorphic conditions at the reach and sub-reach scales.
- Restoration strategy – A comparison of “existing” conditions to “target” conditions at the reach-scale and identification of recommended restoration treatments that address habitat and ecological process limitations within the geomorphic context of the reach.
- Stream habitat assessment – Aquatic habitat inventory at the reach-scale.
- Reach-Based Ecosystem Indicators (REI) analysis – Comparison of habitat conditions to established functional thresholds.
- Specific project opportunities – A list and maps of specific potential project opportunities that would help to achieve the reach-scale restoration strategies.

This framework allows for the identification of restoration activities at discrete locations while considering broader scale physical and ecological factors that influence the assessment study area.

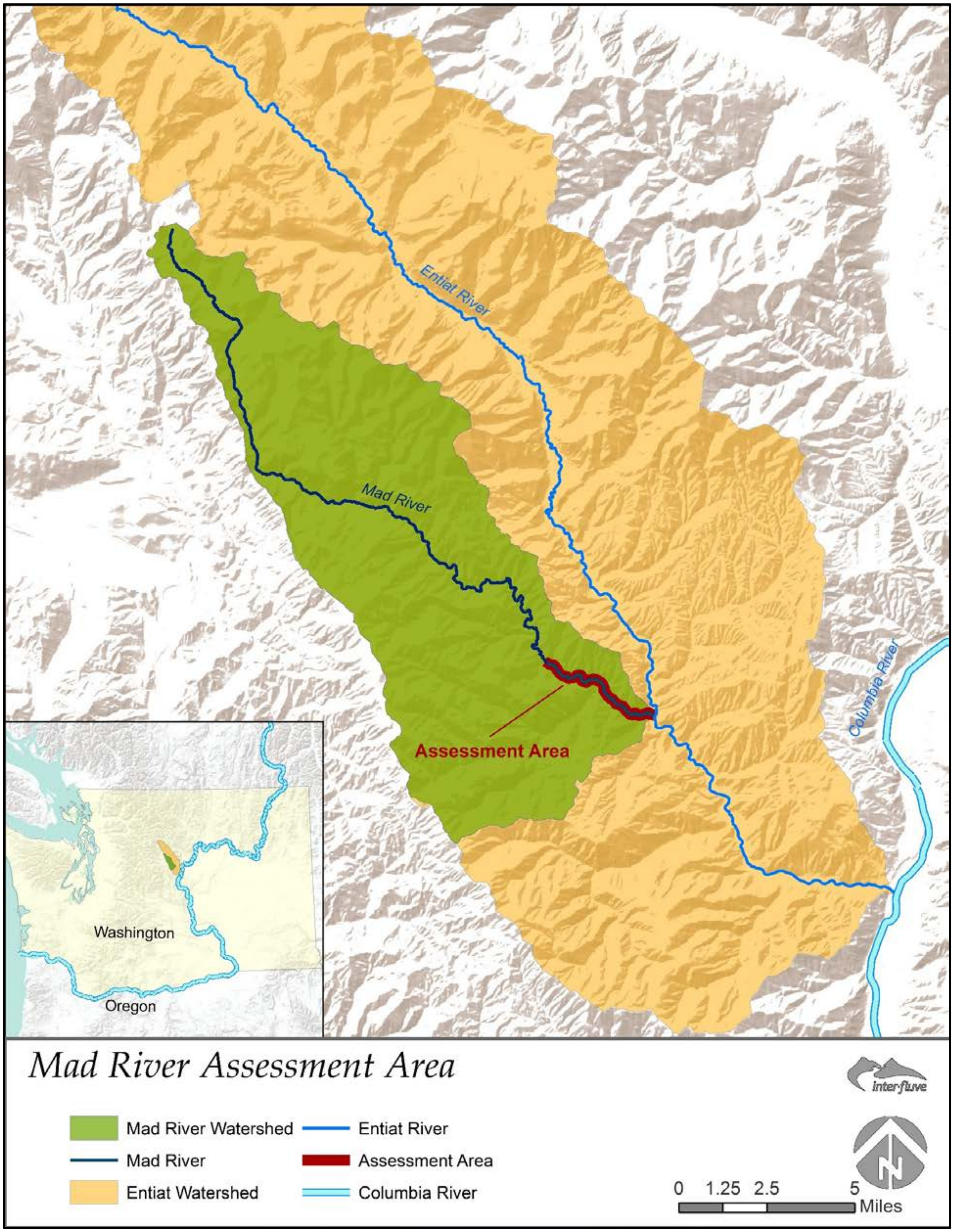

Figure 1. Lower Mad River Assessment area locator maps. Basemaps: ESRI world terrain maps and Bing imagery.

1.2 BACKGROUND

This project was completed on behalf of the Yakama Nation as part of their efforts to improve native aquatic fisheries within the Columbia River Basin through their Upper Columbia Habitat Restoration Project (UCHRP). UCHRP projects work to achieve the objectives of the Upper Columbia Spring Chinook Salmon and Steelhead Recovery Plan (USFWS 2007) and the associated updated Biological Strategy (Arterburn et al. 2017).

Conducting the assessment involved collecting field data of the area and combining it with existing available information on the Mad River and the Entiat watershed. Existing available information utilized in this assessment includes, but is not limited to the Entiat Water Resource Inventory Area (WRIA 46) Management Plan (CCCD (Chelan County Conservation District) 2005), Biological Overview for the Entiat River Tributary Assessment (Phil Archibald 2009), Entiat Subbasin Plan (Peven et al., 2004), available digital and paper geologic maps, past habitat assessment results, and Inter-Fluve's Tillicum Creek Habitat Restoration Project Report (2018). This report does not attempt to re-create the work accomplished in existing documents, but summarizes that material and adds detail where appropriate. New data collection and analysis performed as part of this effort include a geomorphic assessment of the mainstem channel, side channels, and floodplain surfaces, as well as an aquatic habitat inventory, characterization of landforms and human impacts, and identification of habitat restoration opportunities.

1.3 PURPOSE

The purpose of this assessment is to document and evaluate hydrologic processes, geomorphic processes, and aquatic habitat conditions in the Lower Mad River (RM 0 - 4.3) and to present a comprehensive reach-based restoration strategy to address limiting factors to aquatic habitat. Evaluations used in this assessment include historical characterization, geomorphic assessment, hydraulic assessment, and an aquatic habitat inventory.

Specific goals of this assessment include:

- Provide a comprehensive inventory and assessment of geomorphic and aquatic habitat conditions and trends to provide the technical foundation for development of an effective stream habitat restoration strategy.
- Develop a restoration strategy that identifies and prioritizes restoration actions that protect and improve aquatic habitat and supports ecological processes, with an emphasis on culturally significant riverine species.
- Coordinate efforts with local landowners, resource managers, and other stakeholders in order to establish collaborative efforts that contribute to the success of restoration strategies.

1.4 SALMONID USE AND STATUS

The Entiat River sub-basin currently supports anadromous runs of native spring Chinook and steelhead trout, and resident and fluvial bull trout (Arterburn et al. 2017; Andonaegui et al. 2002; U.S. Bureau of Reclamation 2009). According to reported surveys (UCSRB , 2018), the Lower Mad River supports spawning and rearing habitat for endangered Upper Columbia spring Chinook salmon and Upper Columbia steelhead. The Mad River is considered a stronghold for resident bull trout, which are listed under the ESA as threatened (see Figure 2 for species distribution map), as well as fluvial bull trout. Coho were once present in the watershed but wild populations have since been extirpated (Nehlsen, Williams, and Lichatowich 1991). Other resident species in the sub-basin include salmonids such as westslope cutthroat trout, redband trout, and rainbow trout, as well as Pacific lamprey, mountain whitefish, and eastern brook trout. Pacific lamprey are present in the Entiat River and therefore may be present in the Mad River. However, there are limited data to confirm the use of the Mad River by adult or juvenile lamprey. In the lower Mad River, the primary focal species for restoration efforts include spring Chinook salmon, steelhead trout, bull trout and Pacific lamprey. A diagram that provides the life stage and usage timing for these species is provided in Figure 3.

The 2017 Revised Biological Strategy for the Upper Columbia Region (Arterburn et al. 2017) describes habitat conditions and primary ecological concerns within the Upper Columbia Basin, including the Mad River. Of primary concern, according to the 2017 revised strategy for the Mad River is channel structure and form (bed and channel form). Habitat complexity in the channel is limited, in part due to the historical logging efforts in the riparian zone, flood control measures that straightened and simplified the channel, and removal of large woody material from the river. Increased amounts of sediment, poor riparian condition or lack of recruitable wood in the riparian zone, limited prey availability, and anthropogenic barriers to habitat are other key ecological concerns for salmonids in the Mad River (Arterburn et al. 2017).

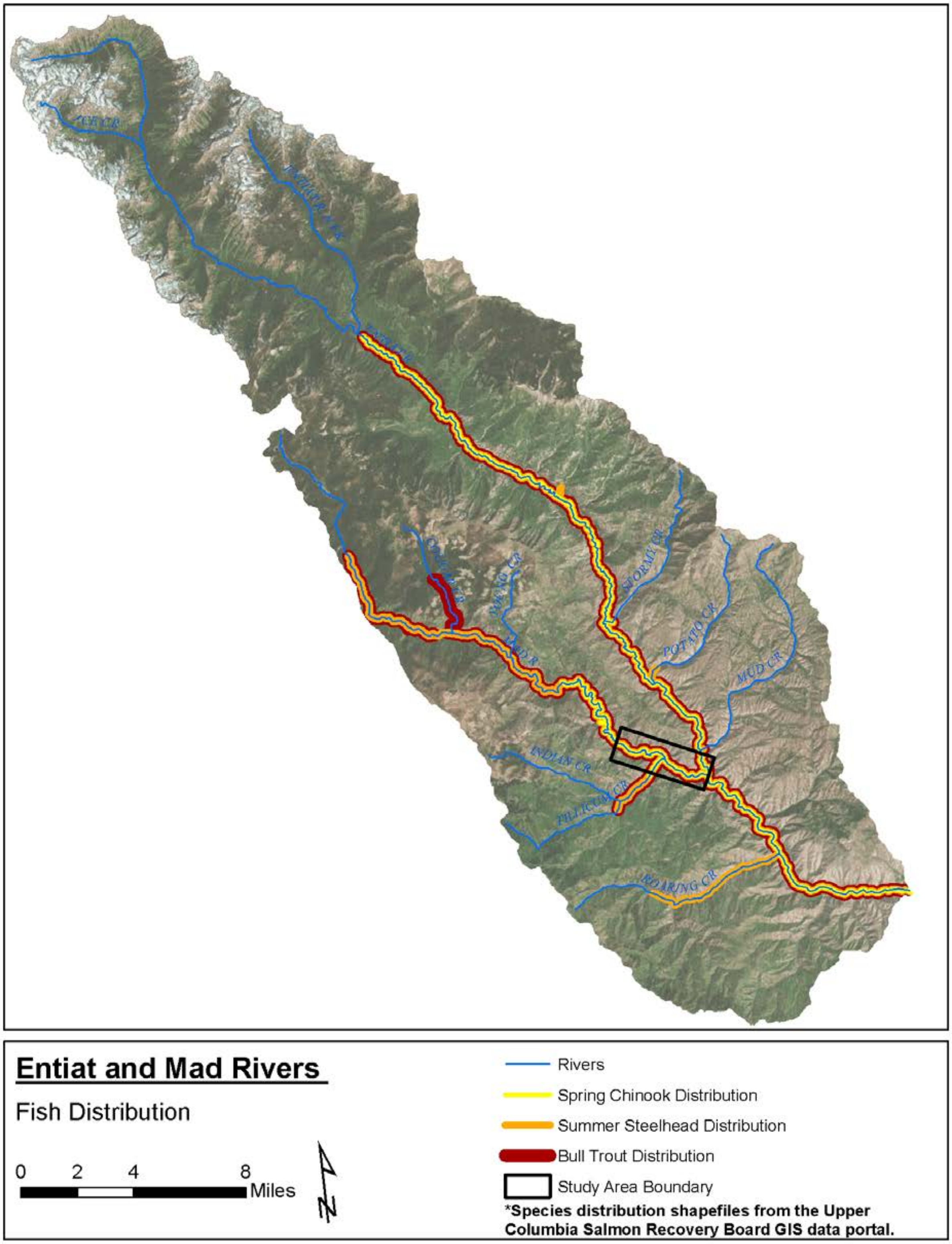

Figure 2. Reported distribution of Spring Chinook, Summer steelhead, and bull trout in the Entiat and Mad River Sub-basins (Upper Columbia Salmon Recovery Board (UCSRB, 2018) – GIS data portal, accessed 9/2018)

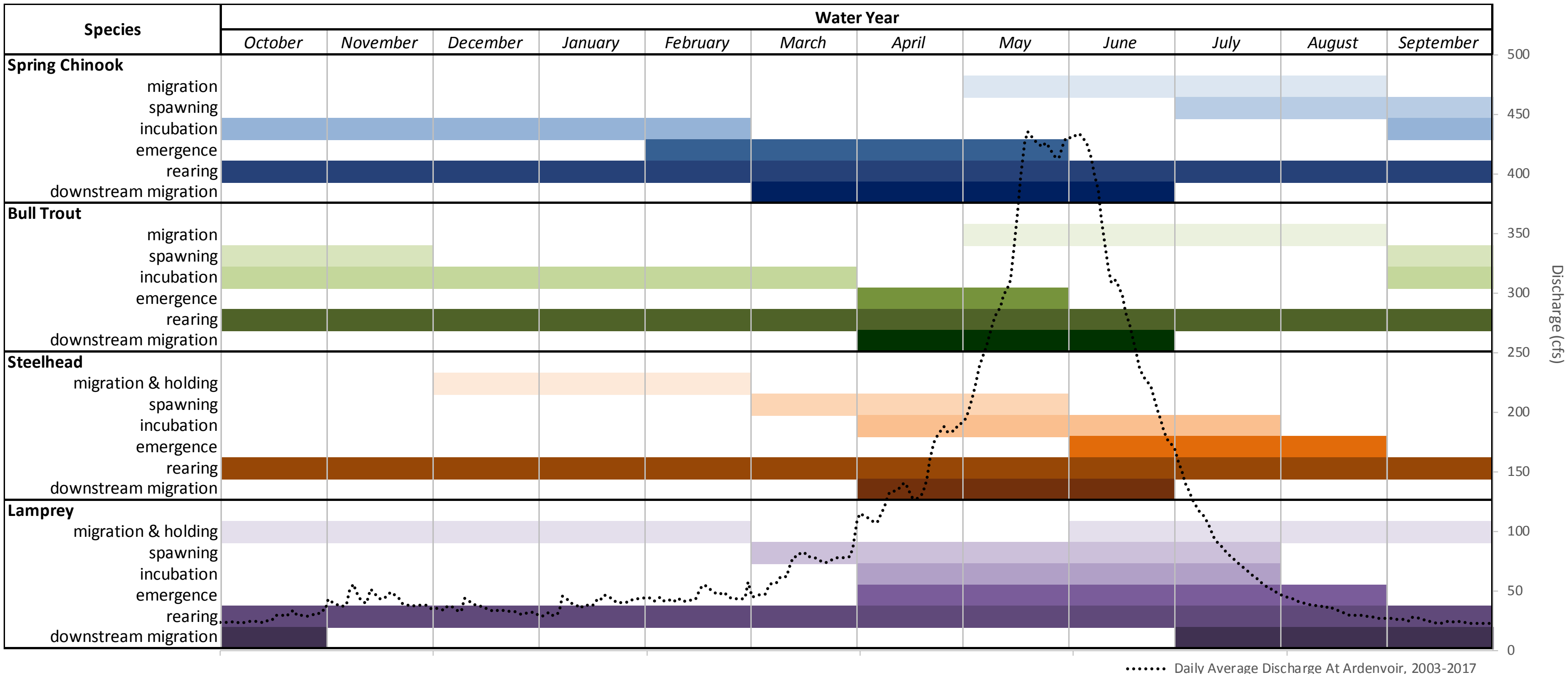

Figure 3. Summary of life history timing of steelhead and bull trout and Chinook Salmon in the Entiat River basin, overlaid on an annual hydrograph depicting mean daily discharge from the period 2003 - 2017. (USGS Mad River near Ardenvoir gage (12452890); life history reference cited in species description sections 1.41, 1.42, and 1.43)

1.4.1 Steelhead

Steelhead (*Oncorhynchus mykiss*) enter and ascend the Columbia River in June and July, arriving near their spawning grounds nine to eleven months prior to spawning. Adult steelhead overwinter in the mainstem Columbia, returning to the Entiat in the late winter prior to spawning. Spawning survey data from the Mad River during the 2000–2008 spawning seasons showed that spawning occurred between late March and early May with a peak observed in late April (Archibald 2009). Egg survival is highly sensitive to intra-gravel flow and temperature (Peven et al. 2004) and is particularly sensitive to siltation earlier in the incubation period. Fry emerge from the redds six to ten weeks after spawning (Peven et al. 2004).

Age-0 juveniles spend their first year primarily in shallow riffle habitats, feeding on invertebrates and utilizing overhanging riparian vegetation and undercut banks for cover (Moyle 2002). Age-0 steelhead use slower, shallower water than Chinook Salmon, preferring small boulder and large cobble substrate (Hillman and Miller 1989). Older juveniles prefer faster moving water including deep pools and runs over cobble and boulder substrate. Juveniles out-migrate between ages one and three, though some hold over and display a resident life history form. Smolts begin migrating downstream from natal areas in March (Peven et al. 2004).

Summer steelhead use, including spawning and rearing, has been documented throughout much of the Entiat River and in the lower Mad River (Arterburn et al. 2017; P. Archibald, Johnson, and Baldwin 2008; Washington Department of Fish and Wildlife (WDFW) 2018) (Figure 2). Redd surveys conducted in the Mad River by the USFS indicate steelhead spawning occurs from the confluence with the Entiat up to approximately RM 7. Specific locations of these redds were not available and thus are not included in the steelhead redd map provided in Figure 4. The steelhead red map only depicts steelhead redd locations within the mainstem Entiat River due to the lack of GPS's data for the Mad River redds (UCSRB , 2018).

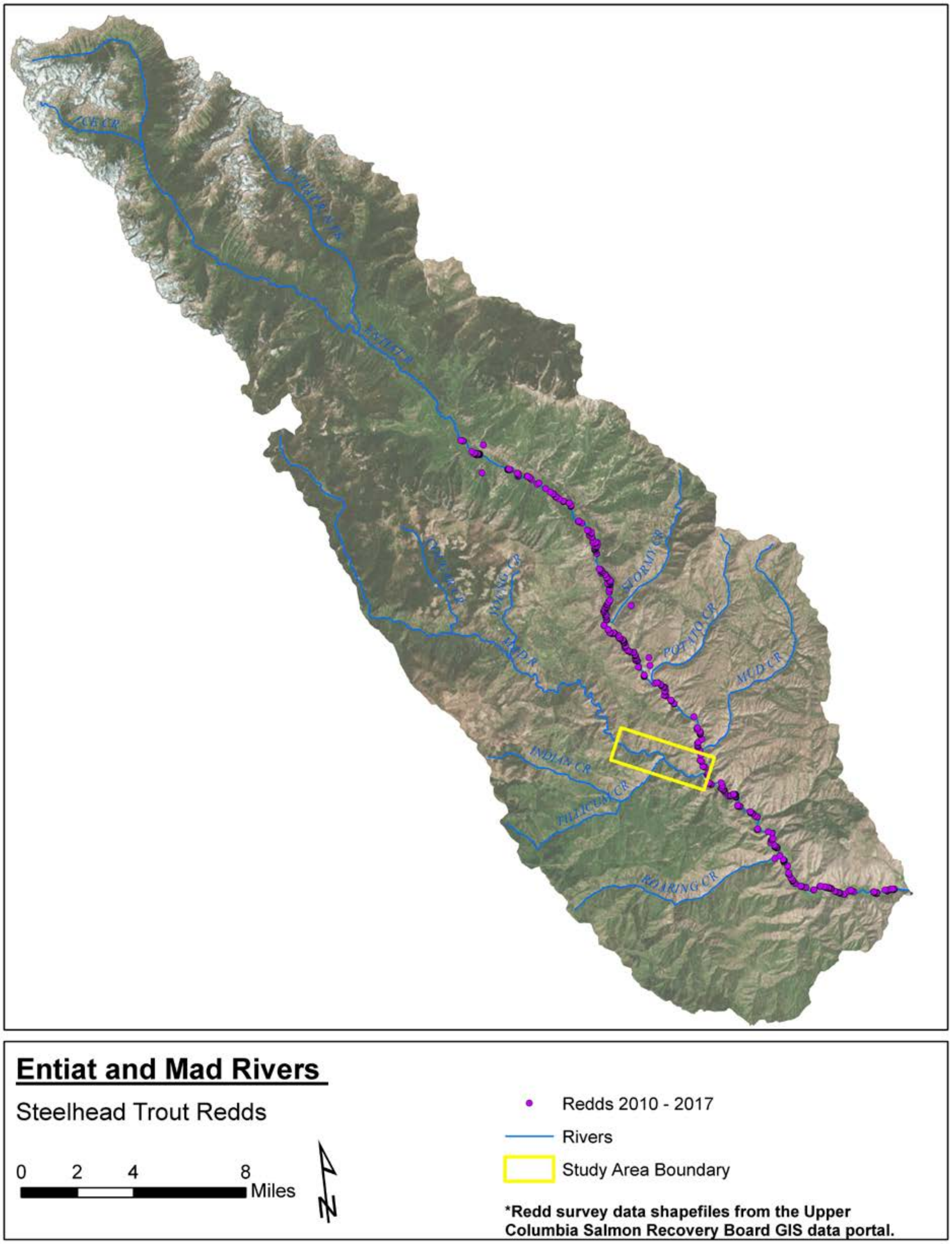

Figure 4. Steelhead trout redd locations collected in the Entiat River between 2010 – 2017 (UCSRB, 2018). Note: the dataset does not include USFS surveys conducted on the Mad River which reported steelhead spawning in the Lower Mad River (RM 0-7).

1.4.2 Spring Chinook

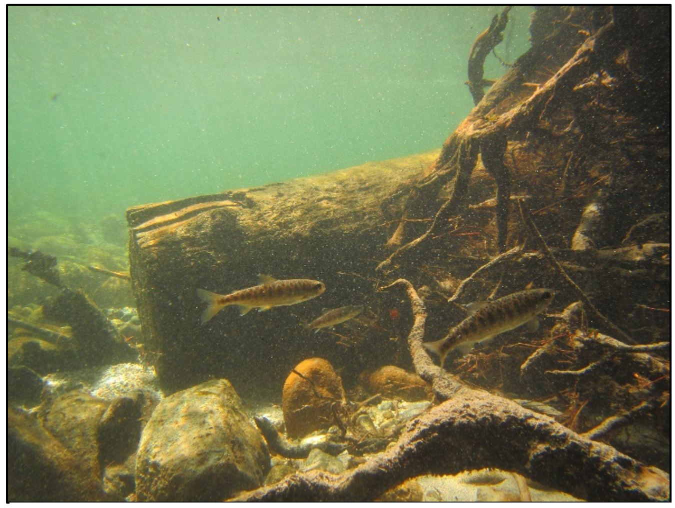

Figure 5. Chinook Salmon parr resting behind a constructed log jam in the Entiat River mainstem between feeding forays. (Inter-Fluve, 2017)

Spring Chinook (*O. tshawytscha*) are reported to use the lower Mad River for spawning. Adult spring Chinook enter the Entiat basin in May, holding in deep pools under overhead cover in the Entiat or Mad Rivers. Spawning occurs from very late July through September with a peak in mid to late August. Spawning typically begins when temperatures drop below 16°C (Healy 1991; Peven et al. 2004). Eggs are very sensitive to changes in oxygen levels and percolation, both of which are affected by sediment deposition and siltation in the redd (Peven et al. 2004). Fry emerge in the spring, which coincides with the rising hydrograph. High water forces juveniles to seek out backwater or margin areas with lower velocities, dense cover, and abundant food (Quinn 2005). Fry are extremely vulnerable in these systems when they emerge, because their swimming ability is poor and flows are high. Near-shore areas with eddies, large woody debris, undercut tree roots, and other cover are very important for post-emergent fry (Hillman and Miller 1989; Healy 1991). Age-1 parr utilize deeper pools with resting cover in mainstem habitats more than post-emergent individuals (Figure 5). Spring Chinook typically express a stream-type life history where they rear for 1 year in freshwater before out-migrating as yearlings. Out-migration typically begins in March (Peven et al. 2004; Healy 1991).

Spring Chinook spawning has been documented within the study area of the Mad River (WDFW, 2018) (Figure 2). Redd surveys by the US Fish and Wildlife Service (USFWS) over the past 20 years have identified an approximately two-mile stretch of the upper portion of the study area as the primary spawning area within the Mad River for spring Chinook salmon, though only a few redds each year is common (Greg Fraser 2018) (Figure 6).

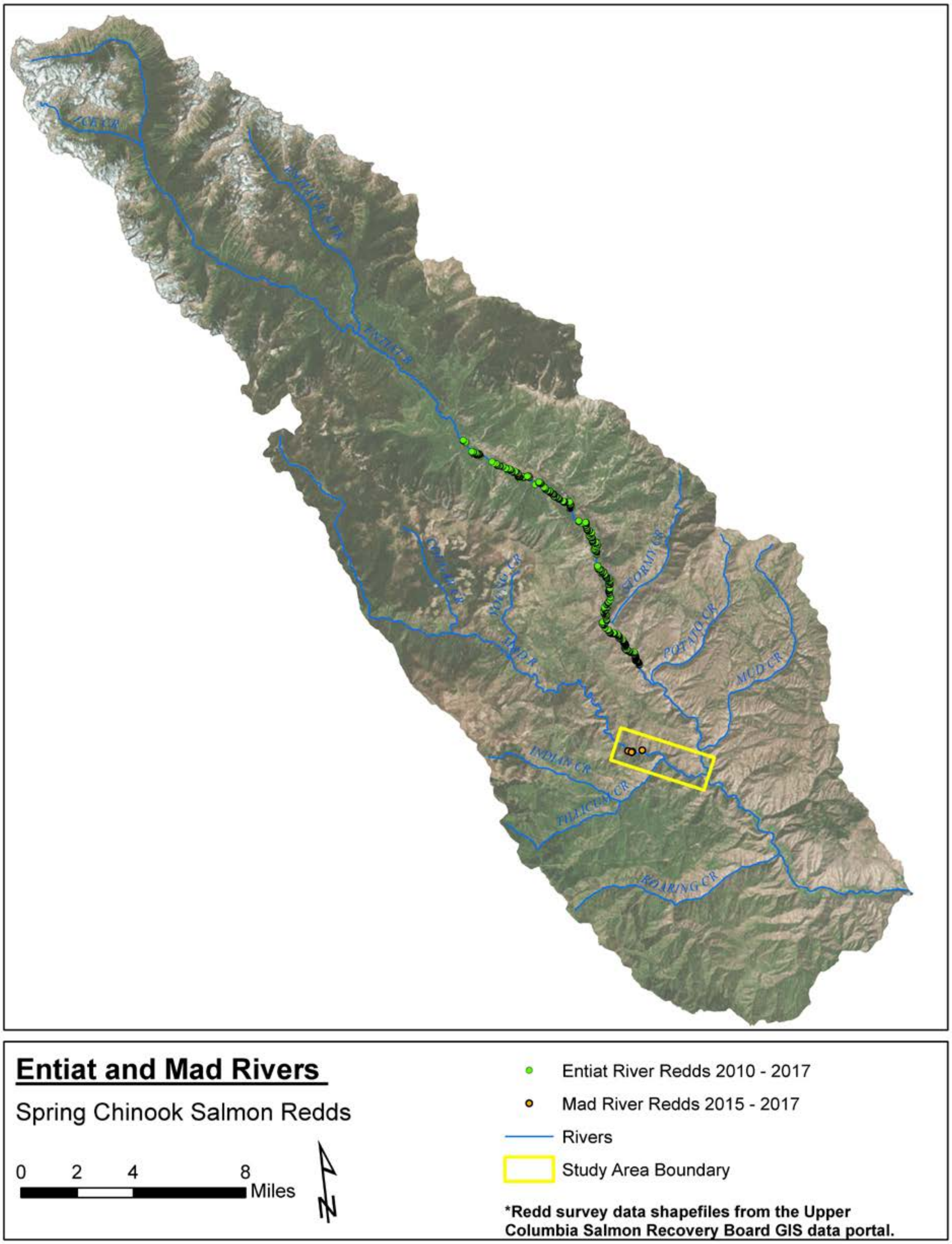

Figure 6. Spring Chinook salmon redd locations collected in the Entiat River 2010 - 2017 and in the Mad River 2015 - 2017. Entiat River redd point file data from UCSRB, 2018 and Mad River redd data points from Greg Fraser, USFWS 2018.

1.4.3 Bull Trout

Bull trout (*Salvelinus confluentus*) spawn and rear in the middle and upper Mad River, upstream of the study site. The Mad River supports the largest populations of bull trout in the Entiat Basin. Bull trout from both areas were listed as threatened under the ESA in 1999 (U.S. Fish and Wildlife Service 1999).

Bull trout may exhibit both resident and migratory life-history strategies (Rieman and Mclntyre 1993). Resident bull trout complete their life cycles in the tributary streams, such as the Mad River, in which they spawn and rear. Compared to other salmonids, bull trout have more specific habitat requirements that appear to influence their distribution and abundance. Critical parameters include water temperature, cover, channel form and stability, valley form, spawning and rearing substrates, and migratory corridors (U.S. Fish and Wildlife Service 1999).

Bull trout normally reach sexual maturity in 4 to 7 years and can live 12 or more years. Bull trout in the Columbia River basin typically spawn from August to November during periods of decreasing water temperatures. Redd surveys in the Entiat and Mad Rivers indicate a majority of bull trout spawning occurs here in September and October (Nelson et al. 2008; U.S. Fish and Wildlife Service 1999). Preferred spawning habitats are generally low gradient stream reaches, or in areas of loose, clean gravel in higher gradient streams (Fraley and Shepard 1989), and where water temperatures are between 5 to 9° C (41 to 48° F) in late summer to early fall (Goetz 1989). Spawning areas are often associated with cold-water springs, groundwater infiltration, and are typically the coldest systems in a given watershed (U.S. Fish and Wildlife Service 1999).

Depending on water temperature, egg incubation can last between 100–200 days, and juveniles remain in the substrate after hatching. Fry normally emerge from early April through May, depending upon water temperatures and increasing stream flows (U.S. Fish and Wildlife Service 1999).

In the Mad River, considered a stronghold for bull trout, spawning occurs primarily upstream of the study area. Within the lower Mad River and the study area, juvenile rearing, adult migration, and over wintering have been documented (Arterburn et al., 2017; WDFW, 2018) (Figure 2). Surveys have found bull trout redds in the upper Entiat River and Mad River, though the number of documented redds in the Mad River is very low (UCSRB, 2018)(Figure 7).

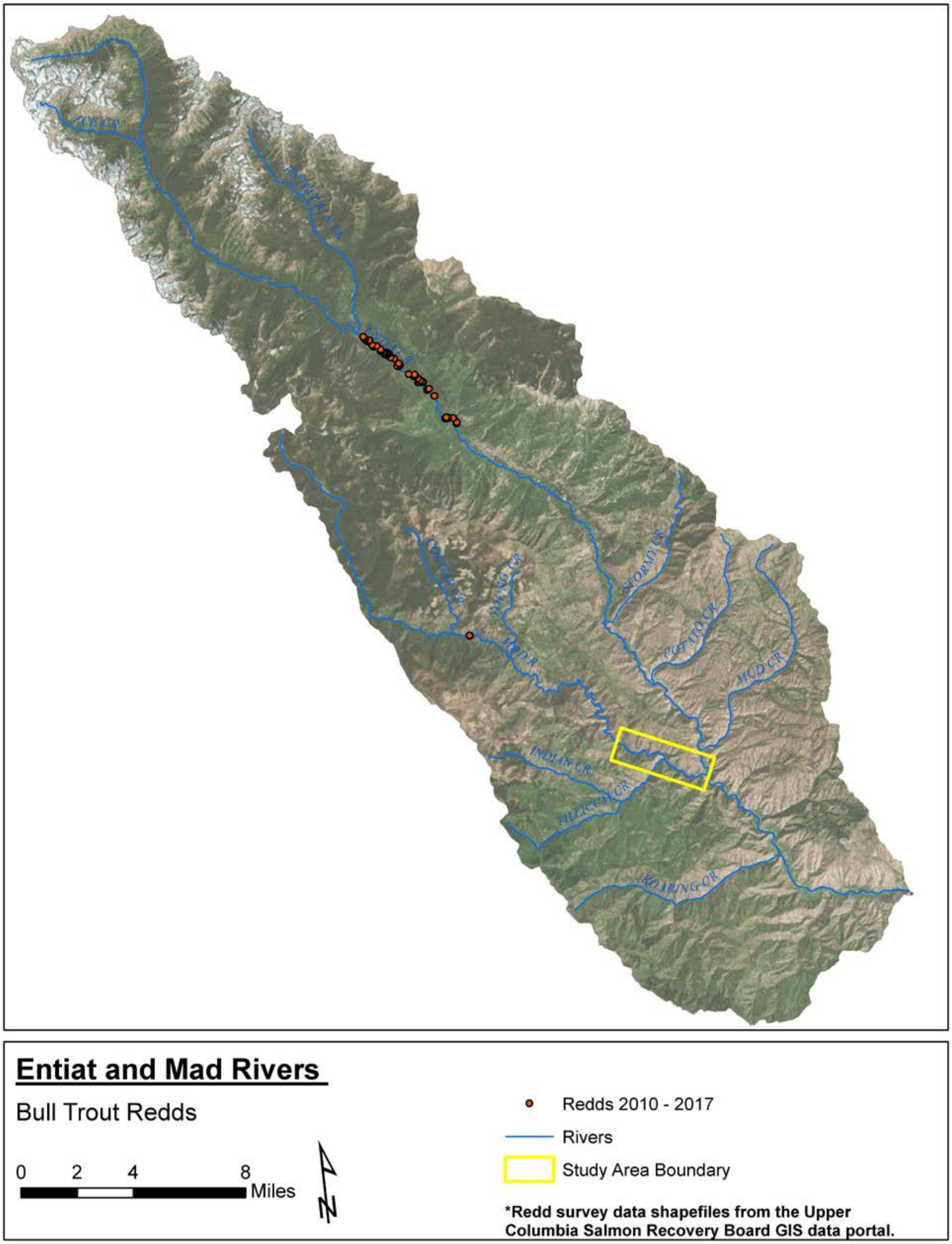

Figure 7. Bull trout redd locations in the Entiat and Mad Rivers, 2010 - 2017. Redd point file data from UCSRB, 2018.

1.4.4 Pacific Lamprey

Adult upstream migration of Pacific lamprey occurs from the late spring through fall in the Columbia River Basin, with peak passage occurring in the Upper Columbia at Rock Island Dam in late August (McIlraith et al. 2017). In the Entiat basin, spawning generally occurs from March through July at temperatures between 10-15°C (50-59°F) (USBR 2017). Preferred spawning habitat is in low gradient runs and pool tail-outs. Hatching date varies according to water temperature and is typically around 15 days after spawning. Ammocetes, the larval stage of the lamprey, spend a short period of time (~15 days) in the redd after hatching before drifting downstream to suitable rearing habitats. Rearing habitat typically consists of low gradient areas with low water velocity, soft substrate, and organic material. Ammocetes can rear in freshwater for up to 7 years as they grow, during which time they filter feed on diatoms and suspended organic material. Juvenile downstream migration occurs between July and October and includes metamorphosis into macropthalmia (adult stage), similar to smoltification in salmonids. Macropthalmia then migrate to the ocean during high flows in late winter or early spring (USBR 2017).

Surveys for adult and juvenile Pacific lamprey in the Mad River indicate there is currently limited suitable habitat available for lamprey rearing or spawning. Despite the appearance of quality lamprey habitat in the lower Mad River (Lampman 2018), juvenile lamprey presence has not been confirmed. Randomized surveys in 2015 in the Mad River from Maverick Saddle to the confluence with the Entiat found no evidence of juvenile lamprey (Grote 2018). Despite a very large lamprey run in the Upper Columbia and Entiat Rivers in 2018, redd and adult surveys in the Mad River did not confirm lamprey were on redds and actively spawning, though there was anecdotal evidence to indicate at least a few lamprey were spawning in the downstream portion of the Mad River (Grote 2018).

2. Assessment Area Characterization

2.1 SETTING

The Mad River is a primary tributary to the Entiat River, which is a contributing river within the greater Columbia River Basin. It flows southeast through the foothills of the eastern Cascade Mountains of Central Washington and is approximately 23 river miles long from its headwaters to its confluence with the Entiat River. The Yakama Nation has identified the lower 4.3 river miles of the Mad River for assessment and potential restoration efforts for native salmonid populations. Several tributaries contribute to the Mad River within the assessment area. Tillicum Creek is the largest contributing tributary with its confluence at approximately RM 2.0. The other tributaries in the assessment area are relatively small and mostly ephemeral.

The assessment area was divided into four distinct geomorphic reaches to facilitate description and discussion of local channel characteristics and restoration needs. Reaches were delineated at major physical transitions in channel form, gradient, degree of sinuosity, confinement, bedload and floodplain connectivity. Reaches are numbered from downstream to upstream within the assessment area. Figure 8 is a map of the assessment area with reach breaks and river miles depicted.

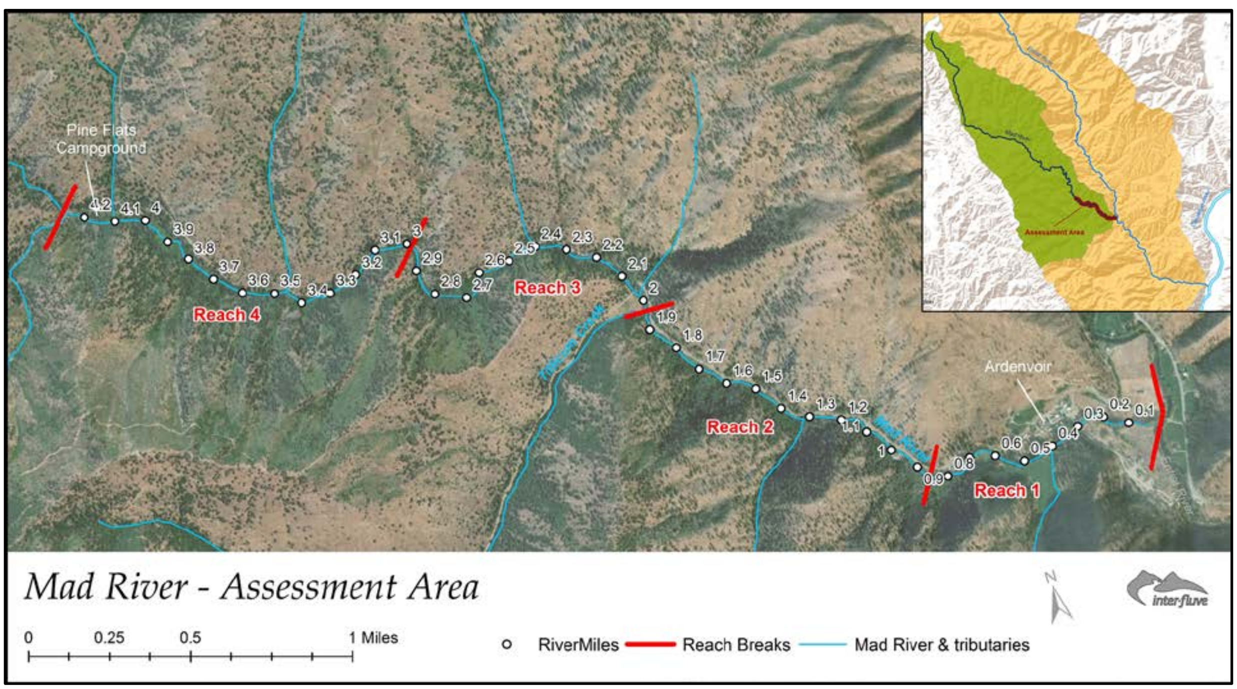

Figure 8. Lower Mad River assessment area with reach breaks and river miles.

2.2 GEOLOGY

The geology and landscape history of the assessment area and its surroundings are important components of ongoing local geomorphic processes. The Mad River watershed is located within the eastern portion of the North Cascades Geologic Province – a complex assemblage of lithologic types shaped by millions of years of tectonic activity. The formation of the province was and is powered by subduction along the western margin of the North American Plate resulting in volcanic processes along the Cascades. The geology in the vicinity of the assessment area has been shaped by strike-slip and thrust faulting, bedrock metamorphism, and plutonic emplacements. The Entiat River Watershed, in which the Mad River resides, contains fault-bound geologic terranes characterized by unique stratigraphic and structural histories. The assessment area is located within the Chelan Block, composed primarily of crystalline metamorphic and igneous bedrock. Specifically, the study area is located within intrusive, Cretaceous-aged tonalite and migmatite of the Chelan Mountains Terrance (Tabor etal., 1987).

Bedrock within the Mad River watershed is dominated by (1) late Cretaceous metamorphic rocks, and (2) Late Cretaceous to Early Tertiary granitic rocks. The bedrock character of the Mad River watershed is crystalline and erosion-resistant. Protoliths (original lithology types) of today's bedrock are marine/near-shore sediments and emplaced volcanic rocks. Through metamorphic processes, the original marine sediments and volcanic rocks were transformed into the gneiss and schist that are present in the watershed today. During the Late Cretaceous and early Tertiary periods, multiple granitic plutons occurred within the watershed, that are now visible via processes of erosion along the Mad River. A few locations within the Mad River watershed have accumulations of unconsolidated sediments (alluvium and colluvium) – in particular, the small valleys in the uppermost section of the watershed, at Tillicum Creek's small alluvial fan where it joins the Mad River at RM 2.0, and in the lowermost section of the Mad River where its valley widens and it meets the Entiat River Valley. Otherwise, sediment accumulations are found as small narrow pocket floodplains and terraces, where valley confinement allows.

Tectonic compression, which resulted in folding of underlying bedrock, is manifested in northwest-southeast trending synclines and anticlines in the Mad River Watershed. A series of roughly northwest-southeast trending thrust faults are present in the bedrock schist and gneiss of the Mad River Terrane (Figure 9). This is evidence of northeast-southwest compression after the rocks were metamorphosed (Tabor et al. 1987). The Mad River itself follows a northwest-southeast directional trend, likely stemming from the tectonic history of the area.

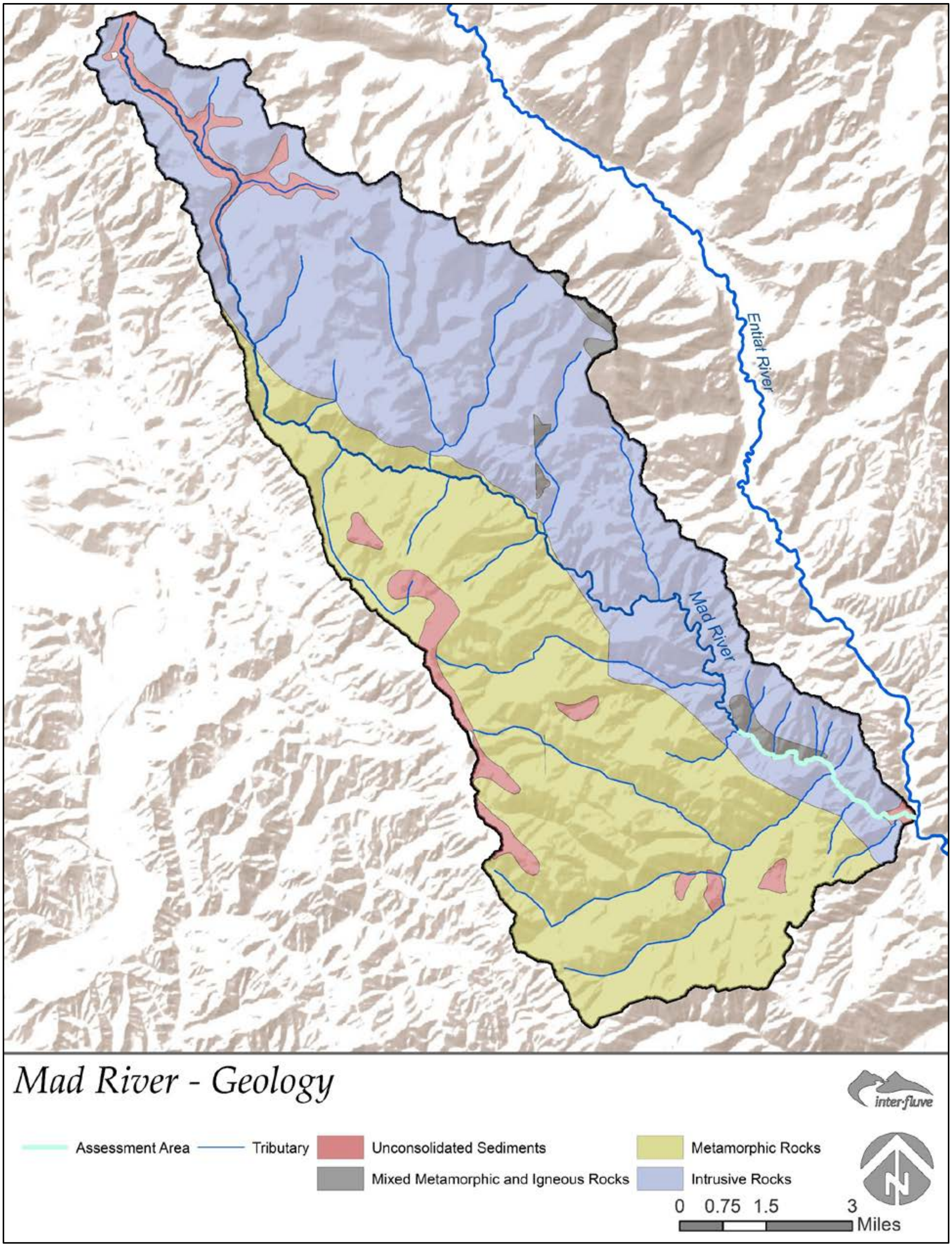

Figure 9. Surficial geology of the Mad River watershed (Geology unit map source: WDNR, 2010).

2.2.1 Pleistocene Glaciation

Early Quaternary glacial processes contributed to the surficial deposits and topography of the Mad River watershed. Although the Cordilleran ice sheet did not extend into the Mad River, and alpine glaciation did not advance down valley to the location of the assessment area (RM 0–4.3), the uppermost section of the watershed shows evidence of small-scale alpine glaciation. Cirques located below Klone Peak and Kelly Mountain are examples of early Quaternary alpine glaciation in the headwaters of the Mad River. Ultimately, however, the impact of glaciation on the Mad River watershed was relatively minimal compared to nearby drainages such as the Entiat River. Instead, the topography of the Mad River has been shaped by underlying geology, mass wasting (landslides) and fluvial processes. As a result, the river valley is generally v-shaped with varied depths of sediment accumulations on the floor. Hillslope coupling to channel processes is evident throughout, except in the downstream-most one mile where the valley widens and meets the Entiat River Valley.

2.2.2 Soils

Soils on the adjacent hillslopes and valley floor of the assessment area are derived from the underlying bedrock and some aerial inputs of volcanic material. A map of the soils in the assessment area is provided in Figure 10. The hillslopes on the north (river left) side of the Lower Mad River are dominated by granitic rock outcroppings and talus covered slopes. The south (river right) side is a mix of soils that are predominantly either a stony or gravelly sandy loam. Except for the low gradient alluvial deposits at the mouth of the Mad River, the Tillicum Creek fan, and a section near Pine Flats, the soils are relatively shallow. All the soil types present are considered well-drained.

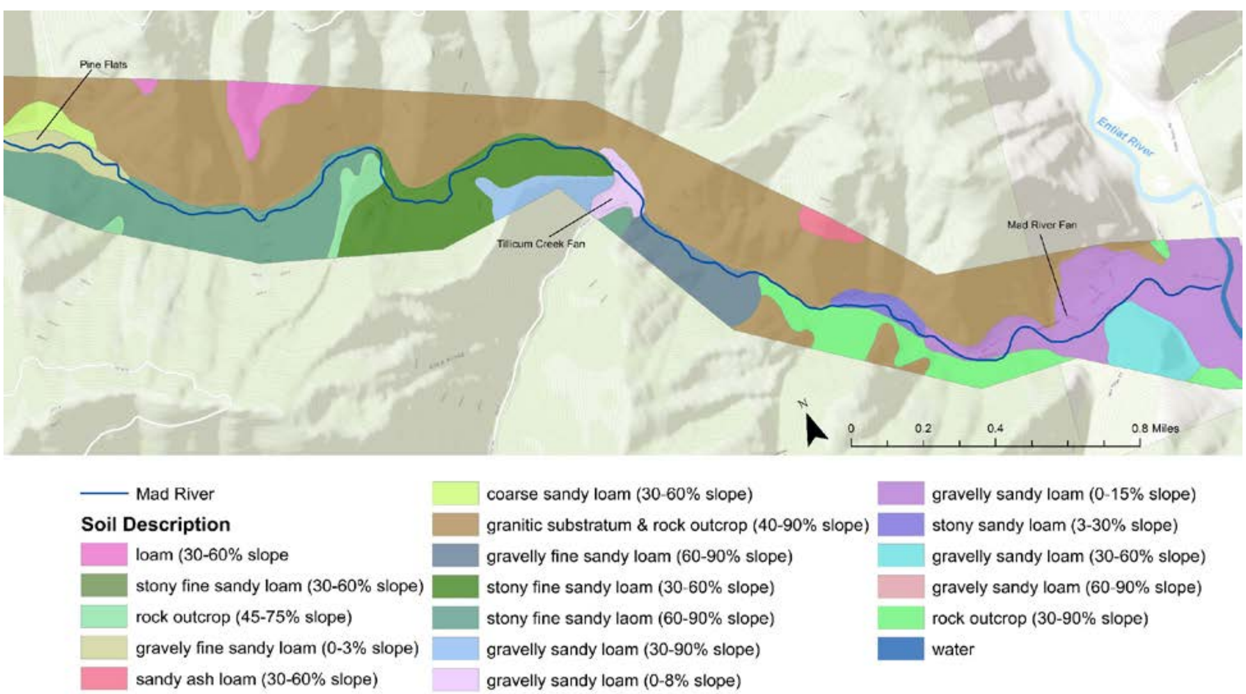

Figure 10. Soil types along the assessment area. (Source: USDA/NRCS, 2017)

2.3 HISTORICAL FORMS AND PROCESSES

Within this Reach Assessment, historical conditions are considered as those that would have existed previous to Euro-American settlement (i.e. prior to large-scale human alteration). Historical conditions represent the conditions to which native species such as salmonids were presumably best adapted, prior to the population crashes that ensued as human disturbances increased on the landscape in the last two hundred years. In many cases, restoration to historical conditions will be impossible or inappropriate; however, historical conditions nevertheless provide a reference point for helping to determine how habitats and processes have changed and can help inform the identification of restoration objectives. This section provides a brief summary of presumed historical conditions of the Lower Mad River.

Although there is little direct evidence about conditions of the Mad River before the early twentieth century, field observations, USGS records and related surveys, as well as underlying geology and glaciation cycles can provide some theories on historical channel process of the Mad River. Overall, the watershed and riparian forests were relatively undisturbed and the valley bottom was vegetated with mature forests composed of very large trees prior to Euro-settlement in the 1800's. These forest conditions would have allowed the river channel to incorporate large wood into the system via floods, lateral erosion, hillslope contributions, and channel avulsions. The lower one mile of the Mad River traverses its alluvial fan as it enters the Entiat River Valley. Here, the Mad River likely had several historical pathways across the fan over time and was once connected to the surface as a functioning floodplain. Today, this section of the river has been incised and confined within a single-thread, levee bound pathway with bridge crossings that shows no to minimal channel form changes since the 1940's. Road confinement along much of the upstream sections of the river have also restricted channel pathway evolution and lateral processes. Near Pine Flats Campground, in the upstream section of the assessment area, some valley restrictions associated with the campground exist but the channel had less lateral confinement here overall compared to up and downstream. Hillslope and upstream inputs of sediment and wood support more channel complexity today in the upstream-most section of the assessment area. However, the available aquatic habitat throughout the Lower Mad River was likely more complex than is expressed today– with backwater and side channel features, active channel migration, connected floodplains, and large wood jams.

2.4 HISTORICAL HUMAN DISTURBANCE

White settlers began establishing homesteads in the Entiat and Mad River Valleys in the late 1880s and sheep-grazing and trapping were common practice in Chelan County at that time (CCCD, 2005). According to early agricultural records (Plummer 1902), between 13,000 and 16,000 sheep grazed in the Entiat Valley in the late 1800s and early 1900s, with more than 60,000 sheep at the headwaters of the Mad River. Although specific numbers and bands are not reported within the assessment area, it is assumed that some portion of the grazing herds in the Entiat utilized the lower Mad River valley near Ardenvoir and other forage areas between the river's mouth and its grazed headwaters. Grazing was regulated in the 1940s in the Entiat on federal land which resulted in reductions from two to three bands to only one band annually (Peven et al., 2004).

In 1932, the Harris Mill was constructed on the Entiat River at river mile (RM) 10.5 at the confluence with the Mad River near present day Cooper's General Store. At this time, logging was a major resource extraction industry in the Entiat and Mad Rivers. The mill was originally constructed on the west side of the valley floor between the Mad and Entiat Rivers. The 13.5-feet high Harris Mill Dam and related reservoir were built in conjunction with a bridge across the Entiat River to access the mill. The dam was constructed with what was reported as an "ineffective" fish ladder (USBOF, 1936) -- which is assumed to mean that the dam did not allow fish passage. The reservoir extended upstream 1,300 feet, very close to the mouth of the Mad River. The Harris Mill dam washed out in the 1948 flood and was not rebuilt, but the Harris mill and a mill pond was re-built shortly thereafter (Peven et al. 2004). The Harris Mill (also referred to as the Ardenvoir Mill) was the last mill to close in the Entiat Valley in 1979 (CCCD, 2005; Bountry, 2009). Figure 11 is a 1957 historical aerial photo of the Harris/Ardenvoir Mill site near the confluence of the Mad and Entiat Rivers.

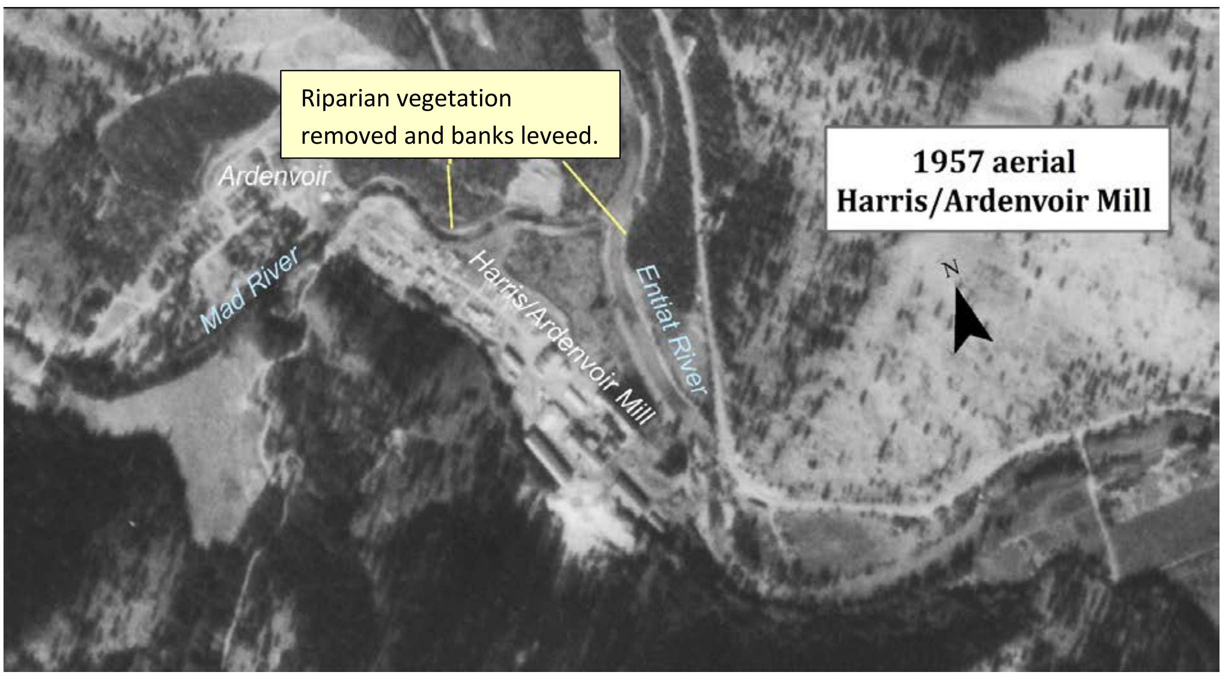

Figure 11. Harris/Ardenvoir Mill site – 1957 aerial image.

Logging in the Entiat basin was a major industry through the 1900's. Several mills and dams were constructed in the basin to support these efforts. An historical photo (1914) from the Kellogg Mill reservoir near river mile 3.6, downstream of the Harris Mill and Mad River confluence, depicts the scale of logging efforts that occurred in the basin, starting in the early 1900's (Figure 12). Logging and its associated road building are suspected to have resulted in increased sediment delivery to the channel as a result of destabilized hillslopes, reduced connectivity of contributing flow-paths due to roads, removal of large wood from the system, and general reduction in geomorphic complexity.

Figure 12. Kellog Mill reservoir, 1914. Published in Bountry, 2009: Courtesy of WA State Historical Society, Asahel Curis Collection, #300119)

On the Mad River at the old homestead site located on the toe of the Tillicum Fan at RM 2, a dam was constructed. The purpose (logging, hydro-electricity, passage) and specific date of construction and deconstruction of this dam are unknown. A local resident described it as "about 10 feet high and not good for fish wanting to get upstream" (conversation with unnamed Tillicum Road resident at the site on 11/09/2017). The dam is visible in historical aerial imagery from 1967 (Figure 13), but no longer appears in photos after 1990. It is likely that this dam was a fish barrier for the duration of its existence.

Figure 13. Tillicum Fan - 1967 aerial photo. On the Mad River at RM 2. Historical dam and homestead identified.

Along most of the Lower Mad River assessment area, from its mouth to Pine Flats Campground (RM 0-4.3) road building, logging, residential, and agriculture development have resulted in a loss of riparian connectivity and function. The modern effects of these activities at the watershed scale are considered relatively minor but are important at the reach and local scales. Based on USFS surveys, the lower 4.3 river miles of the Mad River are expected to provide habitat for chinook and steelhead spawning. However, the poorest ecological conditions within the watershed exist within the assessment area. For example, the lower one mile of the Mad River has been impacted by levee construction and channel entrenchment, home, road, and bridge development associated with the town of Ardenvoir, and historical mill site impacts.

2.5 EXISTING BUILT FEATURES

Human-built features have the potential to influence or inhibit geomorphic and ecologic processes depending on their proximity to a channel and its floodplain. Human-built features include constructed components on the modern landscape such as levees, roads, bridges, culverts, irrigation structures or piping, buildings, riprap and other bank protection, and utility crossings. Figure 14 displays the mapped built features within the assessment area that are in close enough proximity to the channel to potentially impose direct influence on it or adjacent floodplain processes.

Although the Mad River is considered a rural watershed with relatively low population density at its mouth and no permanent residences upstream of river mile 1.0, human-built features have and do influence natural channel processes and thus impact modern aquatic habitat conditions. A majority of the built features visible on the landscape today occur in the lower one mile of the river. However, the Mad River Road that runs along the channel through much of the assessment area occupies a notable portion of the available valley floor in confined sections. The road prism is constructed with large boulder riprap where it borders the channel. The road and multiple bridge crossings visibly control the channel's pathway and define channel form. Culverts built under the road convey surface flow (tributaries and hillslope surface flow) from the other side of the road into the channel at a single location instead of dispersing it naturally.

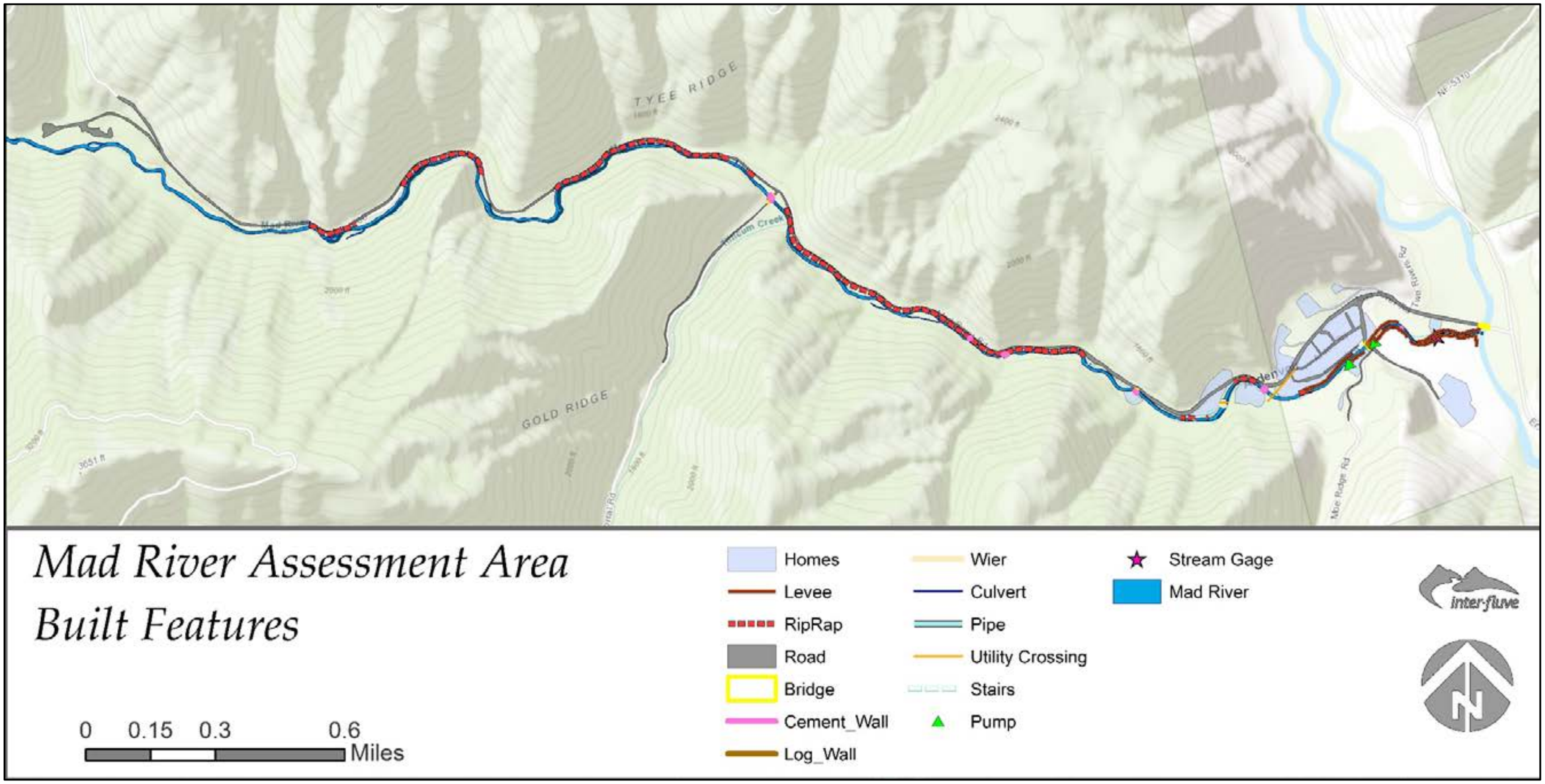

Figure 14. Human-built features on the Lower Mad River (RM 0-4.3).

2.6 CLIMATE

The climate of the Mad River basin generally consists of dry, warm summers and cold, relatively wet winters. The majority of the precipitation throughout the basin falls as rain and snow in the winter and spring. However, the annual precipitation received varies across the basin from headwater to river outlet (Figure 15). The headwaters to the west receive over 46 inches of precipitation on average annually, while the eastern portion of the basin, near the confluence with the Entiat River, receive only about 15 inches annually (PRISM Climate Group, Oregon State University, 2017).

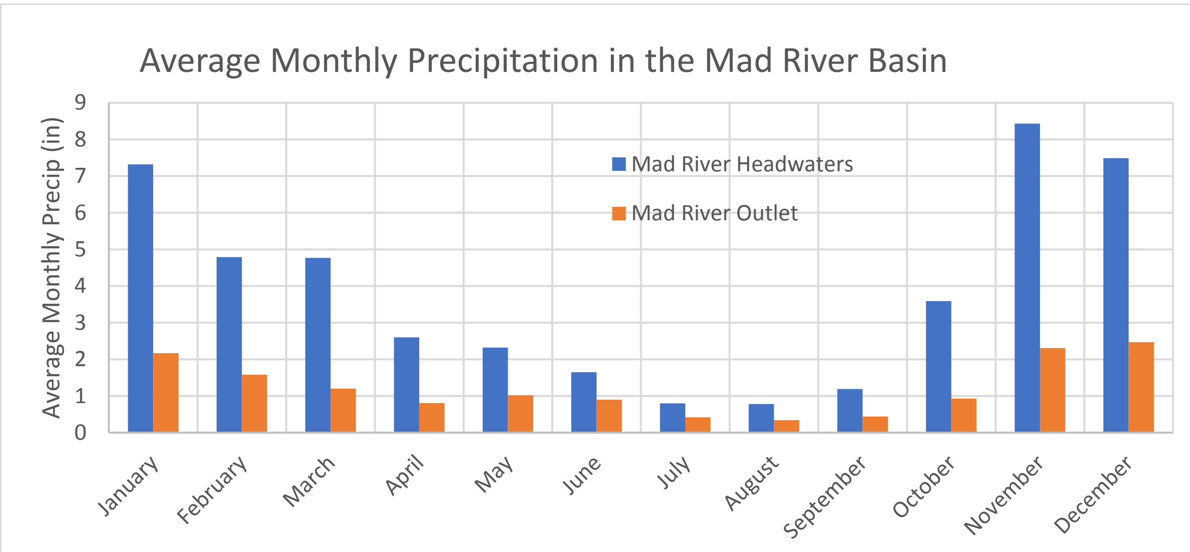

Figure 15. Monthly average precipitation in the Mad River basin at the headwaters (west side of watershed) and near the confluence with the Entiat River (east side of watershed).

Near the mouth of the Mad River, monthly air temperatures reveal moderately cold winters and moderately warm summers (Figure 16). Average daily air temperatures throughout the winter are 32°F, although they occasionally drop as low as 10°F or rise up to as much as 50°F. As a result, snow accumulations within the assessment area vary from year to year. Average daily air temperatures in the summer months (June–August) typically fluctuate between 60-85°F (PRSIM Climate Group, Oregon State University, 2017). Average air temperatures in the winter months decrease upstream as elevation increases. As a result, the headwater areas that receive notably more precipitation in the winter receive more of it as snow. The snow accumulations in the upper watershed supply water to the channel throughout the spring and summer months.

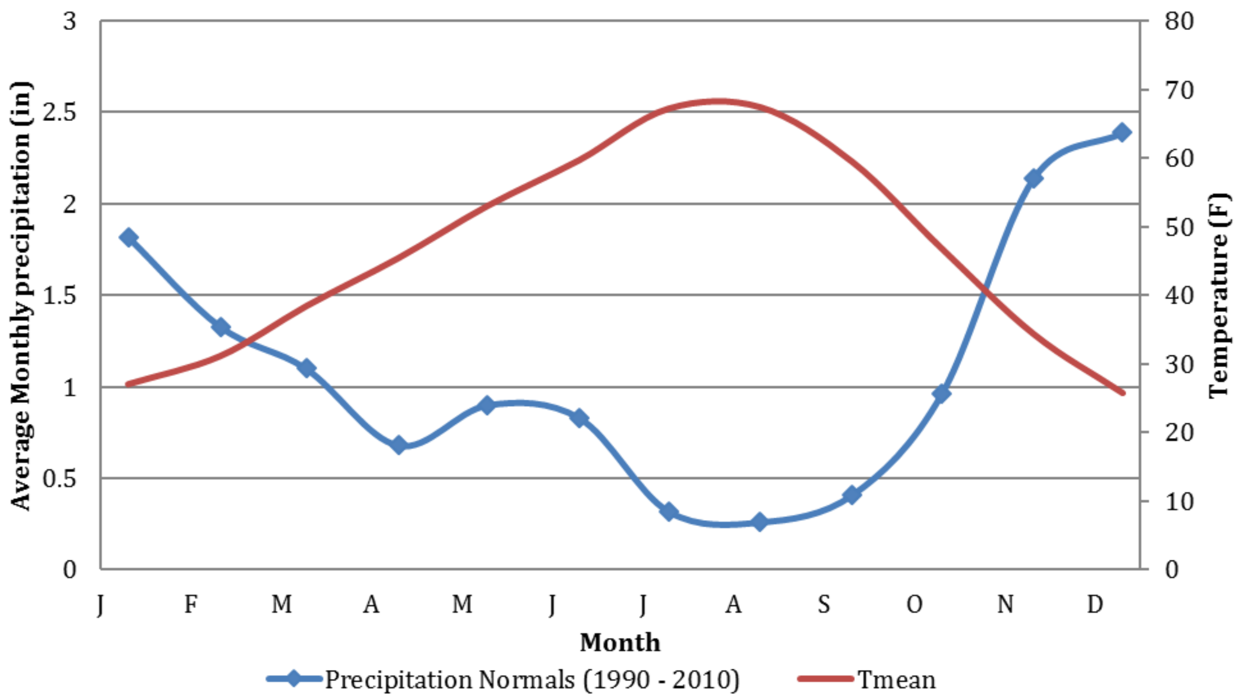

Figure 16. Average monthly (30 yr. normal) and mean daily temperatures (Tmean) near mouth of the Mad River at Ardenvoir, WA (PRISM 2017).

2.6.1 Potential Effects of Climate Change

Global climate models used to accurately capture the 1.4°F warming measured in the Pacific Northwest over the 20th century have been applied to predict future climate trends (Srinivasan et al. 2007). These models predict an average increase in annual temperature in the region of 2.0° F by the 2020s, 3.2° F by the 2040s, and 5.3°F by 2080 (Mote and Salathé 2010). Climate simulations indicate precipitation and streamflow in the Pacific Northwest will respond to a changing climate through increased intensity of winter storm events resulting in higher streamflow, and decreased summer precipitation resulting in longer periods of, and decreased, low streamflow (Mantua et al, 2009). These changes are predicted to have the most substantial implications for *transient* (watersheds influenced by both autumn rains and spring snowmelt) as well as snowmelt driven watersheds.

The Entiat watershed, a transient watershed that includes the Mad River, is predicted to see an increase in summer streamflow temperatures. These increases are predicted to shift temperatures into the stressful-to-salmon range (64-70°F) by 2020 and fatal-to-salmon range (70-75°F) by 2080. In addition to stressors associated with temperature, the extended low streamflow period during the summer season is expected to have implications for stream-type lifecycle salmon habitat, while the enhanced winter flooding will likely result in reduced egg-to-fry survival (Mantua et al. 2009).

2.7 HYDROLOGY

2.7.1 Basin Characteristics

The Mad River flows approximately 23 river miles southeasterly from its headwaters at Mad Meadow (5,900 feet above sea level), to its confluence with the Entiat River near the community of Ardenvoir (1,250 feet above sea level). The drainage area of the Mad River watershed is approximately 91 square miles, with a mean basin elevation of 4,370 feet above sea level (USGS Streamstats, 2018). The Mad River initiates in mid-montane meadows then flows through a series of steep confined and partially confined valleys until it eventually reaches its terminus, where its river valley gradually opens near the community of Ardenvoir onto the Ential River Valley. Immediately upstream of the assessment area, the Mad River flows through a confined v-shaped valley with steep hillslopes composed of the metamorphosed schists and gneisses of the Mad River Terrane.

2.7.2 Assessment Area Hydrology

The assessment area (RM 0–4.3) receives upstream hydrologic watershed inputs as well as direct inputs from within the assessment area. Figure 17 provides a map of the Mad River watershed and its contributing tributaries. The largest contributing tributary in the Mad River watershed is Tillicum Creek. This creek meets the Mad River at approximately RM 2.0, in the middle of the assessment area. Otherwise, contributing tributaries within the assessment area have relatively small contributing upstream drainage areas.

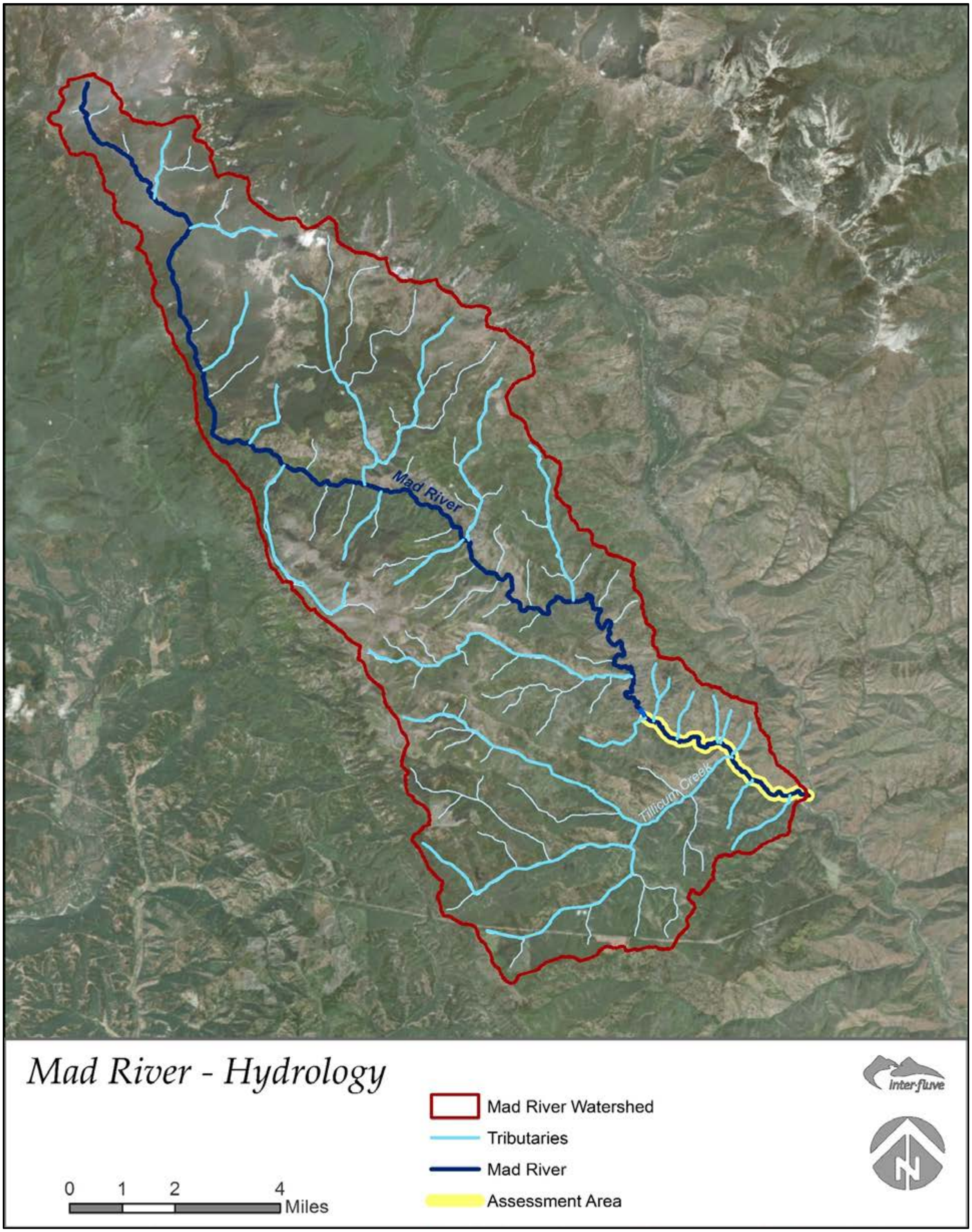

Figure 17. Mad River watershed and tributaries.

2.7.3 Surface Water

The average annual discharge of the Mad River watershed follows a snowmelt runoff pattern typical of east-slope Cascade Mountain streams. A USGS gage located near the mouth of the Mad River, at Ardenvoir, WA (USGS 12452890) provides surface water discharge data from 2002–2017 (Figure 18). The hydrograph depicts elevated spring flows most likely generated by snow melt further influenced by rain events. Base flow is relatively constant from August through October. Autumn and winter rain events usually produce only small peaks from November through February, prior to the snow-pack melting in spring.

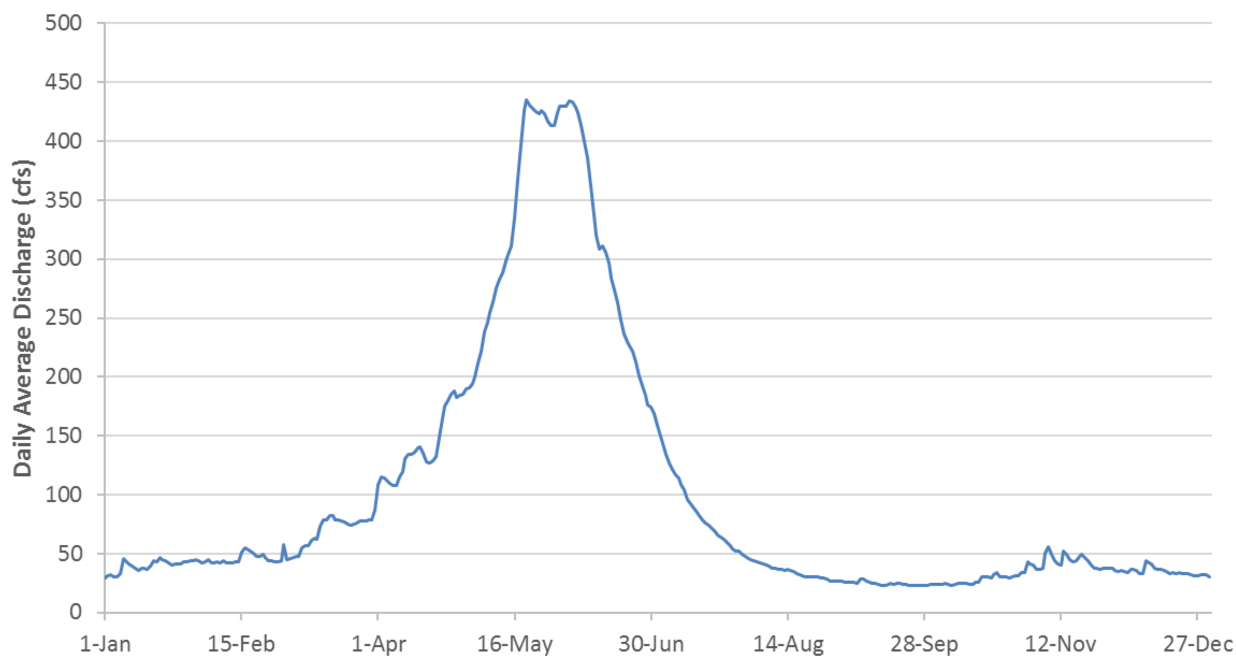

Figure 18. Daily average mean discharge at Ardenvoir 2003-2017 (USGS gage 12452890 Mad River).

2.7.4 Peak Flows

Recorded peak flow data on the Mad River at the USGS gage near Ardenvoir is limited to 2002–2017 and range from 269 cfs in 2015 to 965 cfs in 2006. Although the data is limited to 16 years of record, a Log-Pearson Type III statistical distribution analysis was performed using annual peak flood events to estimate flood frequency discharges (2, 5, 10, 25, 50, and 100-year flood events). Flood frequency discharges were also estimated in StreamStats (USGS 2017), which uses regional regression equations developed by the USGS (Mastin et al., 2016). The standard error reported for these estimates range between 96% for the 2-year return period event to 52% for the 100-year return period event. Given the large standard error of the peak flow estimates and the ephemeral nature of contributing streams, these results should be considered with caution. Both estimated peak discharge event results are provided in Table 1. The peak flood events for the period of record at the Ardenvoir gage (2002-2017) are plotted in Figure 19 with the StreamStats flood estimates.

Table 1. Mad River Estimated discharge for selected recurrence flood events at Ardenvoir.

Flood Return Period	Estimated Peak Discharge (cfs) Log-Pearson Type III	Estimated Peak Discharge (cfs) USGS StreamStats
2- year	650	658
5-year	843	809
10-year	952	896
25- year	1,075	995
50-year	1,151	1,060
100-year	1,226	1,120

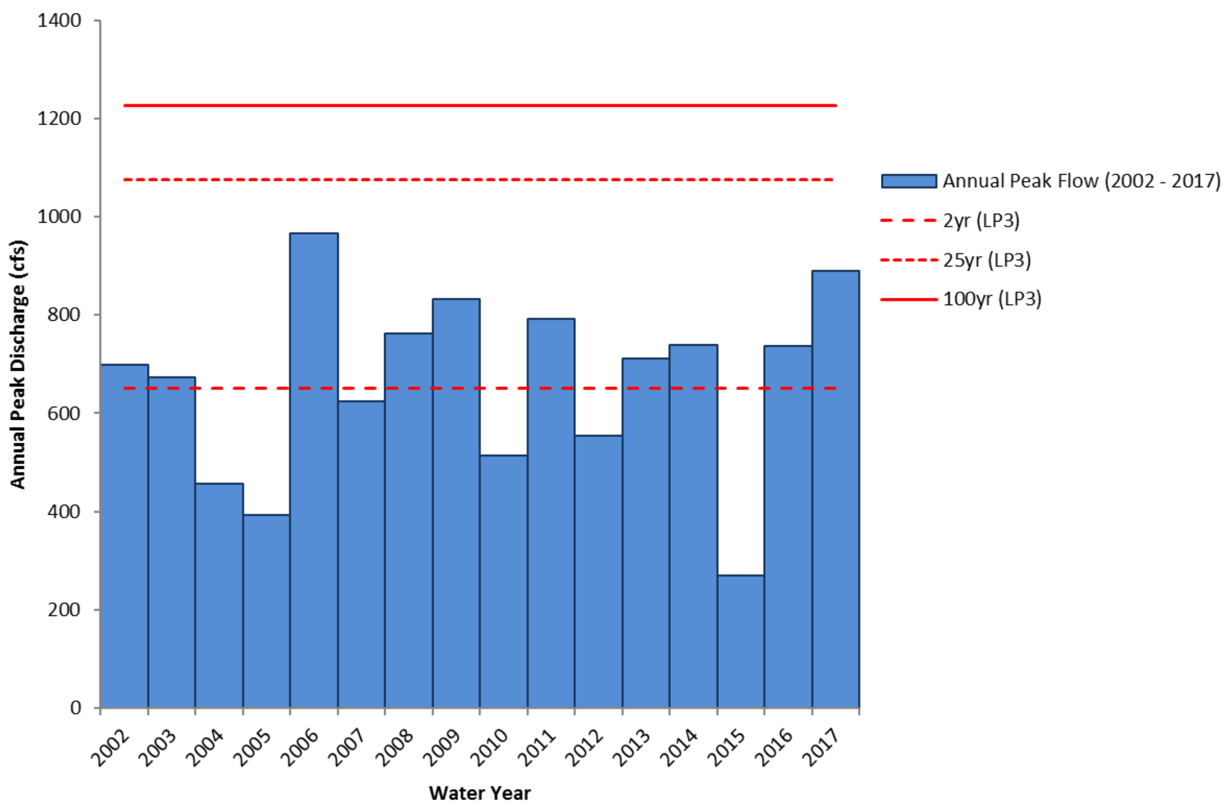

Figure 19: Annual peak flows at Ardenvoir, WA, from 2002–2017 (blue bars) and Log-Pearson Type III estimated flood events (red lines).

2.8 HYDRAULIC ANALYSIS – STREAM POWER

The hydraulic analysis for this assessment is a reach-based stream power analysis. Stream power is the amount or rate of energy exerted on the banks and bed of a channel from the water flowing over it. This widely-used hydraulic analysis technique (Fonstad 2003; Knighton 1999; Burke et al. 2009; Julian et al. 2012; Bureau of Reclamation 2006; Bizzi and Lerner 2015) was selected because it is appropriate for analysis where the channel is primarily single-thread, reach-scale assessment is being performed, and detailed topographic data and cross sections of the channel and floodplain are not available for the entire study area. As a measure of the hydraulic energy produced by a river, stream power is commonly used to estimate hydraulic forces acting on the channel bed and banks and to quantify a river's capacity to perform geomorphic work (i.e. erosion, deposition, sediment transport). This analysis examines the total cross sectional stream power (Watts/m (Ω)) and unit stream power (Watts/m^2 (ω)) (as defined by (Rhoads 1987) for a set of selected discharges at the downstream boundary of each reach within the study area.

2.8.1 Stream Power

Controlled by slope and discharge, stream power quantifies the kinetic energy of water that a flow event has to perform work (sediment transport or erosion) on the channel bed it moves over (Knighton 1998). Stream power, a function of discharge, slope, and channel geometry, was calculated for the reach-averaged slope and channel width to aid in characterizing the dominant hydraulic and/or geomorphic variables responsible for downstream patterns of sediment transport.

Total cross-sectional stream power was calculated for a set of estimated discharges (Q). The set of peak flood events (2, 5, 10, 25, 50, and 100-year) were estimated at the downstream boundary of each reach by scaling the Log-Pearson Type III regression peak flow results to the upstream drainage area for each reach (see Table 2). Reach slope was determined by taking total elevation gain within the reach divided by channel length.

Table 2. Peak flood discharge estimates– derived by scaled Log-Pearson Type III regression done for the downstream boundary of each reach (see Table 1).

Flood Event	Estimated Discharge (cfs) Reach 1	Estimated Discharge (cfs) Reach 2	Estimated Discharge (cfs) Reach 3	Estimated Discharge (cfs) Reach 4
2-year	650	632	463	441
5-year	843	820	600	572
10-year	952	926	677	645
25-year	1075	1045	765	729
50-year	1155	1123	822	783
100-year	1226	1192	872	831

Stream power was calculated using: $\mathbf{\Omega = \mathit{pg}QS}$

where p is the density of water, g is acceleration due to gravity, Q is discharge, and S is reach slope. Table 3 provides the results.

Table 3. Stream power (Watts/m) for each estimated flood event discharge. Discharge estimates in Table 2 converted from cfs to si units for stream power calculations.

Stream Power (Watts/m)

Flood Event	Reach 1	Reach 2	Reach 3	Reach 4
2-year	2778	3122	3016	2018
5-year	3603	4049	3912	2617
10-year	4068	4572	4418	2955
25-year	4595	5163	4989	3337
50-year	4936	5547	5360	3585
100-year	5239	5888	5689	3806

As assumed, stream power increases with increasing discharge. However, higher channel slopes in Reaches 2 and 3 result in higher stream powers in the middle-section of the assessment area, even though Reach 1 has a greater upstream drainage area and thus a greater estimated discharge for each flood event.

2.8.2 Specific Stream Power

Estimations of specific stream power is used to quantify a river's capacity to transport sediment, investigate hydraulic thresholds of flood-related geomorphic response (Costa and O'Connor 2013; Magilligan 1992; Fonstad 2003), and to classify and define channel-floodplain types and floodplain genesis (Nanson and Croke 1992). Specific stream power takes the values calculated above for total stream power and normalizes them based on channel width. In this case, we use bankfull widths as measured in the field for the Habitat Survey (see Appendix A and Table 5) as approximations of representative channel width for each reach.

Specific stream power was calculated using: $\omega = \Omega/w$
where w is average bankfull width in the reach.

Specific Stream Power (Watts/m²)

Flood Event	Reach 1	Reach 2	Reach 3	Reach 4
2-year	222	199	206	126
5-year	288	259	267	163
10-year	325	292	302	185

Based on Nanson and Croke's (1992) classification, all reaches in the assessment area are considered medium-energy systems at reach-average bankfull width for the 2-year estimated flood discharge (shaded green). Medium-energy systems (ω = 10-300 W/m^2) are described by Nanson and Croke as having non-cohesive floodplains, meandering to braided form, and point bar or braid/multi-channel accretion processes that form floodplains. Note that Reaches 1, 2, and 3 have specific stream powers within the upper-range of what is considered medium energy. Since estimated average bankfull width is used in this analysis, it is understood that stations within each reach that have a narrower bankfull width would have higher specific stream power for the same discharge (Q), and wider areas would have lower specific stream power.

In the Nanson & Croke classification, high-energy systems ($\omega > 300$ W/m^2) have non-cohesive floodplains, confinement where lateral processes are inhibited, and vertical accumulations of coarse gravels and sands to form floodplains. It is plausible that bankfull width remains relatively constant as discharge increases in the fully confined sections, including the leveed portions of Reach 1. In this scenario using the same estimated bankfull width, specific stream energy for the 5 and 10-year estimated flood events approach and then become high-energy (shaded purple) for Reaches 1 - 3.

Within the study area the floodplains are composed primarily of non-cohesive sands, gravels, and cobbles. Channel form is primarily confined meandering with limited potential for braiding in Reach 4. Point bar and floodplain pocket development of non-cohesive materials occurs only where reduced confinement allows. Confinement is exaggerated throughout most of the project area (Reaches 1, 2, 3, and part of 4) by anthropogenic infrastructure (roads, bridges, levees, etc.).

Based on this analysis, Reaches 1 and 3 are expected to be capable of transporting larger sized bedload material than Reaches 2 and 4 for any given flood event in their current conditions. The channel and floodplain characteristics observed and surveyed as part of this assessment (see Reach-Scale Conditions in Section 3) confer that modern geomorphology in Reach 2 is likely medium-high energy formed, Reach 1 and 3 are high-energy formed, and Reach 4 is medium energy formed. This suggests that Reaches 2 and 4 have more capacity to store sediment, comparatively, than Reaches 1 and 3 – within current conditions.

2.9 GEOMORPHOLOGY

Developing a successful habitat restoration strategy requires an understanding of the geomorphic processes and trends of the modern channel, floodplain, and contributing hillslopes. This section provides an overview of the geomorphology of the watershed as well as a summary discussion on the primary geomorphic features within the Lower Mad River (RM 0–4.3). The information presented here is based on field-based survey observations (Oct 24-26 and Nov 9-10, 2017 and April 25, 2018) combined with available digital and printed data and reports (as referenced). Detailed discussions of geomorphic conditions and trends at the reach-scale are provided in Section 4.

The Mad River watershed is a relatively steep montane system that initiates off the ridges and high meadows of the Entiat Mountains located in the eastern foothills of the Cascades. Except for a handful of small headwater meadows, almost all of the upper 19 miles (RM 4.3-23) of the channel are hillslope or bedrock confined. The channel is single-thread with a planform defined by the pathway the river has cut into the underlying geology over millennia and the resulting hillslope and tributary contributions. Debris flows and/or landslide colluvium have, in places, appeared to have periodically blocked or temporarily confined the channel. These contributions also supply sediment to and create sediment sources for the system, including floodplain development and bedload.

Immediately upstream of the assessment area (upstream of RM 4.3), channel gradient steepens and confinement increases. Here, bed load material smaller than gravels are readily flushed downstream or stored temporarily in small pools or pocket eddies found near large boulders or large wood jams. Bedload is a mix of cobble-boulder alluvium and colluvium contributed from the hillslopes and bedrock contacts (Figure 20).

Figure 20. Confined section immediately upstream of assessment area (RM 4.31). Photo: 11/10/2017

Within the assessment area, downstream of RM 4.3, the channel flows through alternating sections of partially and completely confined sections until it exits the mountains onto the Entiat River Valley. The Mad River Road occupies a portion of the valley floor throughout much of the reach, increasing natural confinement and impeding, to some degree, riparian vegetation and hillslope contributions from the river-left (north) side of the valley. When the Mad River exits the mountains, it passes through its historical alluvial fan before it meets the Entiat River Valley. A brief discussion on the primary geomorphic features (see Figure 21) in the assessment area are provided below (hillslopes, valley, floodplains, terraces, fans, tributaries, and channel).

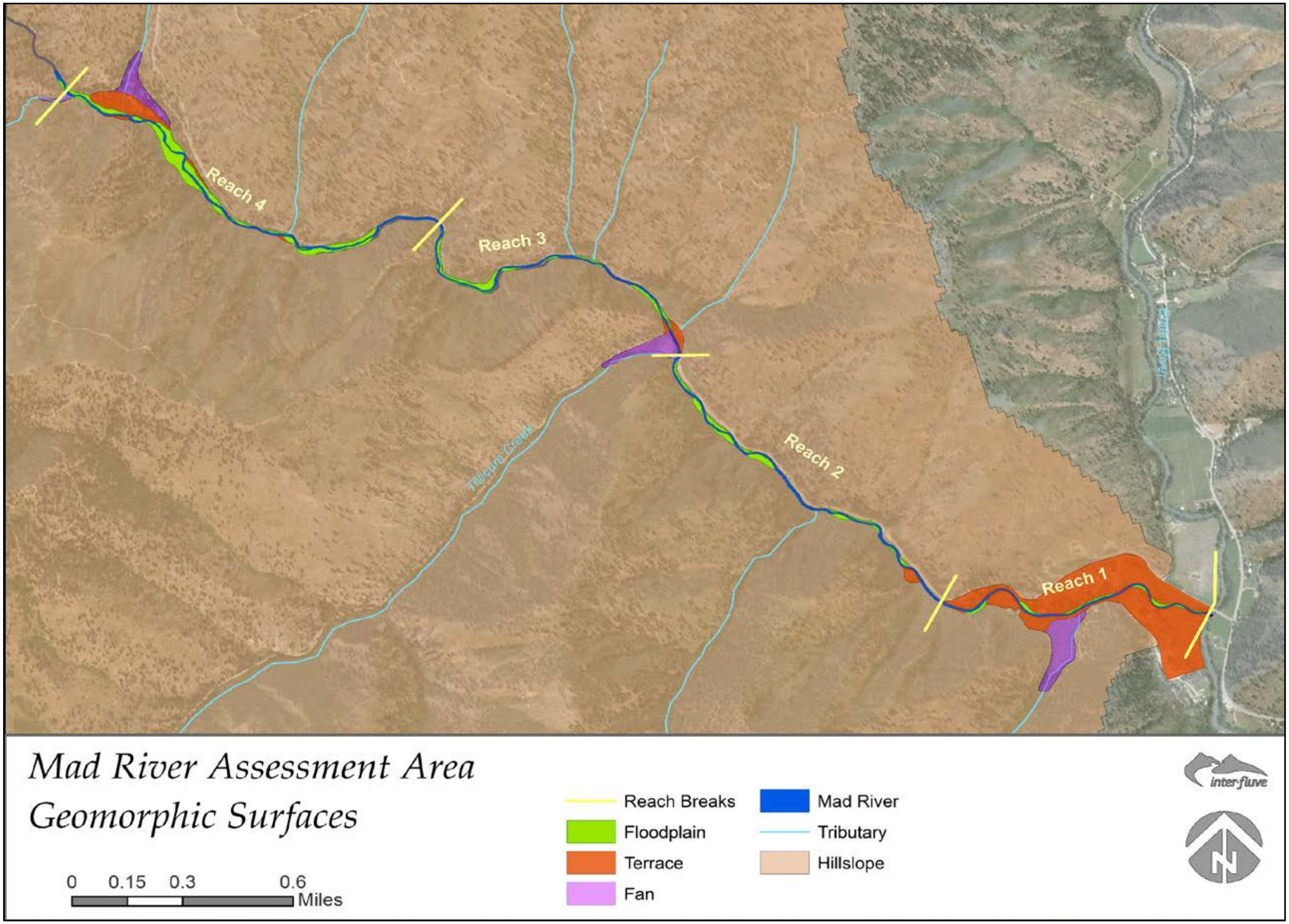

Figure 21. Geomorphic surfaces of the Lower Mad River assessment area (RM 0-4.3)

2.9.1 Hillslopes and Valley

The hillslopes that contribute sediment to and host tributaries of the Lower Mad River assessment area are relatively steep and vegetated with sparse conifer forests. Their geologic composition is mostly granitic as well as gneiss and schists from metamorphosed sedimentary and volcanic parent material (see Geology, Section 2.2). These bedrocks are generally erosion resistant and thus often form high, steep hillslopes and walls. The hillslopes and valley of the Mad River were created by the gradual process of downcutting over millennia via fluvial erosion, mass wasting, and subtle faulting. Glaciers did not extend into the assessment area during the last glacial period. As a result, hillslope-valley form is basically "V" shaped instead of "U" shaped. As a result, there is a high degree of natural hillslope-channel coupling that controls channel form, shape, confinement, and sediment supply. Hillslope and tributary contributions in the form of landslides, rock-fall, debris flows, and bedload have and will continue to influence river morphology through sediment and wood routing into the channel. Land use (i.e. logging and road building), as well as wildfires (natural and human caused), are known to trigger increased temporary sediment and wood inputs into steep montane systems similar to the Mad River (Beschta et al., 2004; Silins et al., 2009).

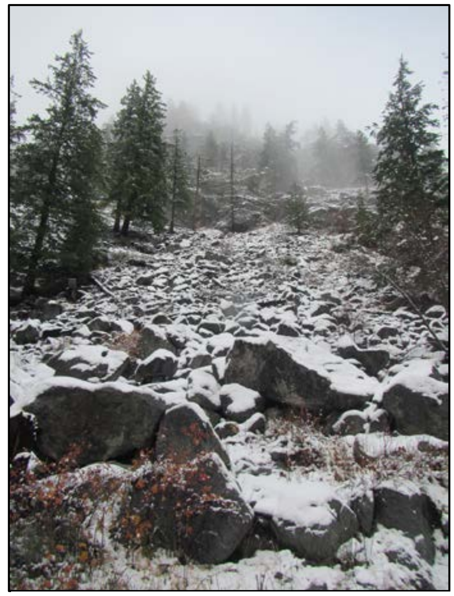

Figure 22. Hillslope along the Mad River, (Photo: 11/9/2017)

The valley floor of the Lower Mad River upstream of RM 1 is confined between hillslopes. The width of the modern valley floor ranges from approximately 280-ft to 25-ft within the assessment area. The downstream-most 0.86 river miles flow through the Mad River's historical alluvial fan and into the relatively wide Entiat River Valley. The floor of the Mad River valley is composed of both alluvial (river deposited) and colluvial (hillslope contributed) materials. Valley width and localized gradient is influenced by the presence of substantial sediment contributions, most extensively at alluvial and debris fans located at the mouths of tributaries. Floodplains and terraces exist in the wider, less-confined, valley sections.

2.9.2 Terraces, Floodplains, and Fans

Terraces are alluvially created or re-worked surfaces that are currently not connected to the channel via flood flow inundation. Terraces, if adjacent to the channel, can continue to contribute sediment from their banks if lateral channel processes continue and nutrients from the established riparian vegetation on its surface. The naturally-formed terraces in the upstream section of the assessment area are the result of substantial sediment contributions from tributaries and/or upstream inputs that infilled the valley. The river has been gradually working its way through the available sediment and, in its contemporary form, has incised to the point where historical channel and floodplain surfaces have been abandoned (e.g., up-slope part of Pine Flats Campground). The small terraces near the Tillicum Creek alluvial fan would have likely undergone similar processes. However, the construction of a dam, road, bridge, homesite, and related bank armoring at the fan toe exaggerated entrenchment at this site making it difficult to discern without more research the difference between natural vs anthropogenic terrace development. Similarly, the terrace surfaces at the tributary on river right in Reach 1 may have resulted from mainstem incision along its toe where it contacted the Mad River as flow regimes and sediment supply decreased through the Holocene (last 12 thousand years). However, levees, roads, bridges, and bank armoring along most of the mainstem channel in the downstream portion has exaggerated channel entrenchment and magnified floodplain abandonment. The exaggerated channel entrenchment has resulted in the historical floodplain and alluvial fan currently functioning as a terrace feature.

The active floodplain surfaces of the Mad River upstream of RM 1 are generally discontinuous and occupy the remaining portion of the valley floor not occupied by the channel or the Mad River Road. Almost all of these floodplain surfaces are well vegetated but the maturity and composition of that vegetation varies depending on land-use history. Vegetation, elevation, observed high-water indicators, and channel form suggest that the floodplain surfaces are partially inundated during high flow events at least every 1-5 years. The surfaces are composed primarily of alluvial deposits, but it is not uncommon for colluvium to be present. Floodplain materials generally include a boulder and cobble base strata that is topped with gravels, sands, and sometimes fines. The composition of the floodplain and active bar material indicates that hyporheic flow exchange is expected.

Alluvial fans or debris fans form where the slope of a contributing flow-path is reduced and available lateral area increases – allowing for sediment to accumulate. Often, fans are developed over time from a sequence of depositional events that shift the location of the primary flow-path(s) across the apron of the fan. In montane environments, fans usually form at the edge of a valley along the toe of hillslopes or at the mouth of a tributary which has a greater slope than the channel and valley it is contributing to. Unlike a floodplain surface that generally has a down-valley slope to its surface, an alluvial fan often has a subtle convex apron shape with an axis that slopes towards the valley it is developing in. Fans can be reworked into floodplain features or truncated by the channel in which it is contributing. For example, the downstream end of what was the Mad River alluvial fan where it enters the Entiat Valley has been reworked such that the surface there has a down-valley slope to the Entiat River. Incision and anthropogenic infrastructure exaggerated abandonment of the Mad River's historical alluvial fan and floodplain surface such that it now functions primarily as a disconnected terrace surface. At the mouth of Tillicum Creek, the toe of its alluvial fan has been truncated by the Mad River and construction of the road and bridge, leaving a disconnected terrace remnant on the opposite side of the road.

2.9.3 Tributaries and Channel

The mainstem channel of the Lower Mad River is a montane river system that alternates between confined and partially confined. Channel form is straight to sinuous with an average profile slope of

0.0165 (1.65%) through the assessment area. Substrate is primarily gravel-cobble-boulder alluvium and size distribution varies depending on proximity to active sediment sources, gradient, and geomorphic complexity. For example, an extended riffle in a low gradient, entrenched section may have a cobble-boulder substrate composition (i.e., lack finer sediments and gravels), while a boulder or log-step in a higher gradient section that creates a localized reduction in stream energy at it may have related accumulations of gravels. This reflects a mixed-size bedload transport capacity (i.e., coarse sand to small boulder) throughout that is driven both by stream power and local sediment supply and/or lack thereof. Bedrock contacts on adjacent hillslopes next to the channel occur periodically in Reaches 2-4 but no channel-spanning bedrock grade-control was observed in the bed of the channel within the assessment area. Large boulder colluvium in the channel do act as grade control in a few locations as well as add geomorphic complexity where they occur.

There are both ephemeral and perennial tributaries within the Lower Mad River assessment area, depending on upstream drainage area. The several unnamed ephemeral streams that contribute seasonal inputs are steep and relatively small in acreage. These ephemeral tributaries provide minimal relative annual discharge to the channel. However, it is likely that they have been routes of delivery for hillslope contributions (debris flows or landslides) to the valley floor and may serve this purpose again in the future. The larger perennial tributaries, most notably Tillicum Creek, contribute discharge year-round and input some quantity of sediment into the mainstem Mad River. A small unnamed tributary near the upstream boundary of the assessment area has produced debris flow contributions into the mainstem channel from river-right that are continuing to influence contemporary local geomorphic processes.

2.10 LARGE WOOD MATERIAL (LWM)

Pieces of large wood (≥ 6 inches diameter) in a channel contribute nutrients, shade, cover, and promote habitat complexity suitable for many riverine species (Langford et al., 2012). Quality large woody material (LWM) (≥12-in dbh and at least 35 feet long) in a channel can influence local geomorphic processes and increase channel complexity by promoting scour and erosion relative to induced flow hydraulics around them and by redirecting or splitting flow pathways (Langford, Langford, and Hawkins 2012; Montgomery and Piégay 2003; Grabowski and Gurnell 2016). The quantity of LWM within a riverine system depends on the presence of mature or maturing forests upstream and locally, as well as the processes of recruitment (infall from banks, debris flows or landslides off hillslopes, in-channel transport, etc.) occurring within the watershed. Tree size (length and diameter) compared to active channel width, channel form, and flow regimes control retention and accumulation patterns of LWM.

Within the Lower Mad River, LWM currently plays a moderate to minor role in the modern geomorphology and habitat complexity of the channel, depending on the reach. A total of 286 pieces of channel-influencing LWM were counted during field surveys (Oct 24-26, 2017) within the 4.3 river miles included in the assessment area (see Section 3.4 in Appendix A). Of the LWM identified in the 2017 survey, Reach 4 (RM 3.14-4.3) contained 48% (137 pieces), Reach 3 (RM 1.93-3.14) contained 31% (89 pieces), Reach 2 (RM 0.86-1.93) contained 17% (49 pieces), and Reach 1 (RM 0-0.86) had only

4% (11 pieces). Only four large wood jams (>10 pieces of LWM) were surveyed in 2017. Of the four, three of the jams were located in Reach 4 while one was in Reach 2. Prior to the construction of Mad River Road, most of the area that the road now occupies along the channel would have been forested with mature conifers. Home building and vegetation clearing further reduced available mature forest contributions in the downstream reaches of the assessment area. In addition, maintenance and safety requirements associated with human-built infrastructure such as irrigation outtakes, bridges, utility crossings, etc. have likely resulted in periodic "cleaning" of wood from the channel, further reducing natural retention of LWM contributions from the existing riparian areas and hillslopes.

Land use practices along the Lower Mad River result in impacts to both channel and floodplain processes. For example, surface grading and vegetation clearing near homes and agricultural areas have altered floodplain contributions (large wood and nutrients) and thus further reduced habitat complexity. Levee construction and channel dredging along the downstream portion of the channel impede floodplain connectivity and natural lateral channel processes. Upslope logging and associated road building likely made the steep slopes of the watershed more prone to erosion, increasing sediment inputs and perhaps landslide frequency. A common historical practice in the region was/is to remove large wood and wood jams from the channel to reduce flood potential and minimize infrastructure damage. This activity has further simplified aquatic habitat in sections of the assessment area.

2.11 VEGETATION

Riparian vegetation in the Lower Mad River generally consists of a mid-seral stage coniferous overstory with a frequently dense shrub/sapling understory. The primary overstory species included Douglas fir (*Pseudotsuga menziesii*), ponderosa pine (*Pinus ponderosa*) and some large cottonwoods (*Populus trichocarpa*) scattered throughout the riparian area of the Lower Mad River. Generally, tree age and size increase upstream through the project area with the largest size class of overstory tree canopy, "mature tree", recorded in Reach 4. Understory species increase in diversity and density upstream as a reflection of human land use impacts. In Reach 4, western red cedar (*Thuja plicata*) was recorded both as an overstory and understory species. Understory canopy in Reach 1 was primarily grasses and small shrubs as a result of the increased density of human land use and vegetation clearing within the riparian area. Understory canopy in Reaches 2, 3, and 4 primarily consisted of small deciduous trees, saplings, and shrubs dominated by willow (*Salix* spp.), alder (*Alnus* spp.), redosier dogwood (*Cornus sericea*), and bigleaf maple (*Acer macrophyllum*).

2.12 AQUATIC HABITAT CONDITIONS

Habitat conditions in the Lower Mad River include limited deep pools and a large proportion of higher velocity riffles. Based on field observations, spawning areas and refugia are limited as a result of channel simplification. The presence of large wood is minimal, particularly in the lower reaches of the study area. The few channel-spanning log jams occurring on the Mad River locally reduce channel gradient, thus facilitating sediment storage and the potential for accumulating better spawning gravel areas. However, these tend to be transitory influences in the higher energy, confined sections of channel. Micro-pools located behind large boulders in the channel may provide some velocity refuge for salmonids migrating upstream or holding in the system, depending on the flows. Temperatures do not seem to be a contemporary issue in the Mad River but that may shift with climate change impacts if more precipitation is delivered as rain instead of snow to the upper watershed. For more information on habitat conditions, please see Appendix A.

2.13 REACH-BASED ECOSYSTEM INDICATORS

This section presents an overview and summary of the Reach-based Ecosystem Indicators (REI) analysis, which is presented in more detail in the REI Report (Appendix B). A summary table of the REI analysis results is provided below in Table 4. The REI applies habitat survey data and other analysis results to a suite of REI indicators in order to develop reach-scale ratings of functionality with respect to each indicator. Functional ratings include adequate, at risk, or unacceptable. The REI analysis helps to summarize habitat impairments and to distill the impairments down to a consistent value that can be compared among reaches. This analysis is also used to help derive restoration targets as part of the restoration strategy presented later in this document. The rating definitions, and explanations of how the ratings were made, can be found in Appendix B.

At the watershed-scale, the Mad River was rated **At Risk** for the Drainage Network and Hydrologically Impaired Surfaces indicator and the Disturbance Regime indicator, due to the number of roads and residential/agricultural clearing, particularly in the lower basin. The Streamflow indicator was also rated **At Risk** for the Mad River, while Water Quality – including water temperature and contaminants – was rated as **Adequate**.

At the reach-scale, Reaches 1 and 2 of the Lower Mad River were generally the most impacted reaches, having the highest number of **Unacceptable** ratings. Reach 3, though it had fewer **Unacceptable** ratings, still had a high number of **At Risk** ratings due to historic impacts from human disturbances such as timber harvests, channel confinement by a road, and instream large wood removal. Reach 4 was the least impacted, with seven **Adequate** ratings and only two **At Risk** and two **Unacceptable** ratings.

The ratings relating to salmonid habitat ranged from Adequate to Unacceptable across the study area. Reaches 3 and 4 were given **Adequate** ratings for the Habitat Access Pathway- Main Channel Barriers indicator since there were no barriers within the main channel that completely excluded fish passage. Reaches 1 and 2 were given **At Risk** ratings due to the presence of man-made irrigation and boulder weirs in Reach 1 and cement debris in the channel in Reach 2 that may limit access at certain flows.

Reaches 1 – 3 were given **At Risk** ratings for the Dominant Substrate/Fine Sediment indicator due to the relatively large grain size and limited retention of smaller gravels in the system. Reach 4, with more large wood in the channel, had higher amounts of smaller gravels and cobbles appropriate for spawning and was therefore given an **Adequate** rating.

Large Woody Material (LWM) ratings increased from **Unacceptable** in Reaches 1 and 2 to **Adequate** in Reach 4. The lower reaches had low numbers of large wood pieces and lacked potential large wood recruitment. Pool frequency was rated **Unacceptable** in all reaches due to the very low pool frequency and low quality of the pools (low residual depths and minimal/no large wood cover or habitat). The Off-channel Habitat indicator was rated as **Unacceptable** for Reaches 1 – 3 and **At Risk** for Reach 4 due to either the complete lack or very infrequent occurrence of connected alcoves and side channels.

Riparian vegetation condition indicators – Structure and Canopy Cover – were both rated **Unacceptable** for Reaches 1 and 2. Reach 3 received an **Unacceptable** structure rating due to the relatively young seral stage of the overstory and a rating of **At Risk** for canopy cover. Reach 4 riparian vegetation structure was rated as **At Risk** and canopy cover was classified as **Unacceptable**, owing to some areas with little riparian vegetation despite a mature tree overstory**.** Human disturbance was rated as **Adequate** in Reaches 2 – 4 due to minimal roads and development located within the riparian zone of these reaches. Reach 1, however, was rated as **At Risk** due to the number of residences and developed areas within the riparian zone of the lower Mad River near the town of Ardenvoir.

Channel dynamics for Reaches 1 and 2 are unsatisfactory. Reach 1 received **Unacceptable** ratings and Reach 2 received **At Risk** ratings in all three categories. Floodplain connectivity and Bank Stability/Channel Migration were rated **At Risk** in Reach 3, though Vertical Channel Stability was categorized as **Adequate**. Reach 4 was the only reach to receive an **Adequate** rating for all three Channel Dynamics indicators.

For the study area as a whole, **Unacceptable** was the most common reach-scale rating (18), followed by **At Risk** (15), then **Adequate** (11).

Table 4. Summary table of the Lower Mad River Reach-based Ecosystem Indicators (REI) analysis results. (See Appendix B for details)

Pathway	General Indicators	Specific Indicators	Reach 1	Reach 2	Reach 3	Reach 4
Habitat Access	Physical Barriers	Main Channel Barriers	At Risk	At Risk	Adequate	Adequate
Habitat Quality	Substrate	Dominant Substrate / Fine Sediment	At Risk	At Risk	At Risk	Adequate
	LWM	Pieces per Mile at Bankfull	Unacceptable	Unacceptable	At Risk	Adequate
	Pools	Pool Frequency and Quality; Presence of Large Pools	Unacceptable	Unacceptable	Unacceptable	Unacceptable
	Off-Channel Habitat	Connecivity with Main Channel	Unacceptable	Unacceptable	Unacceptable	At Risk
Riparian Vegetation	Condition	Structure	Unacceptable	Unacceptable	Unacceptable	At Risk
		Disturbance (Human)	At Risk	Adequate	Adequate	Adequate
		Canopy Cover	Unacceptable	Unacceptable	At Risk	Unacceptable
Channel	Dynamics	Floodplain Connecivity	Unacceptable	At Risk	At Risk	Adequate
		Bank Stability / Channel Migration	Unacceptable	At Risk	At Risk	Adequate
		Vertical Channel Stability	Unacceptable	At Risk	Adequate	Adequate

3. Reach-Scale Conditions

The Lower Mad River assessment area was divided into four distinct geomorphic reaches to facilitate description and discussion of local channel characteristics and restoration needs (Figure 23). Reaches were delineated at major tributary confluences and by identifying physical transitions in channel form, gradient, degree of sinuosity, bedload and floodplain connectivity. Reaches are numbered from downstream to upstream within the assessment area. Geomorphologists walked each reach in the assessment area to characterize physical conditions and channel processes. Specifically, we focused on: 1) channel incision and channel evolution trends, 2) substrate type, distribution, and sediment availability, 3) surface and subsurface flow interactions, 4) channel bank composition and migration patterns, 5) floodplain and habitat connectivity, 6) occurrence and influence of large woody material, and 7) influence of past and current human structures and activities. Information from the reach-scale geomorphic assessment is used to inform the REI analysis. Table 5 includes a set of metrics used to help characterize each reach. In addition to a discussion of the metrics provided in Table 5, vegetation condition, and the location of human-built features that influence channel processes are provided below for each reach.

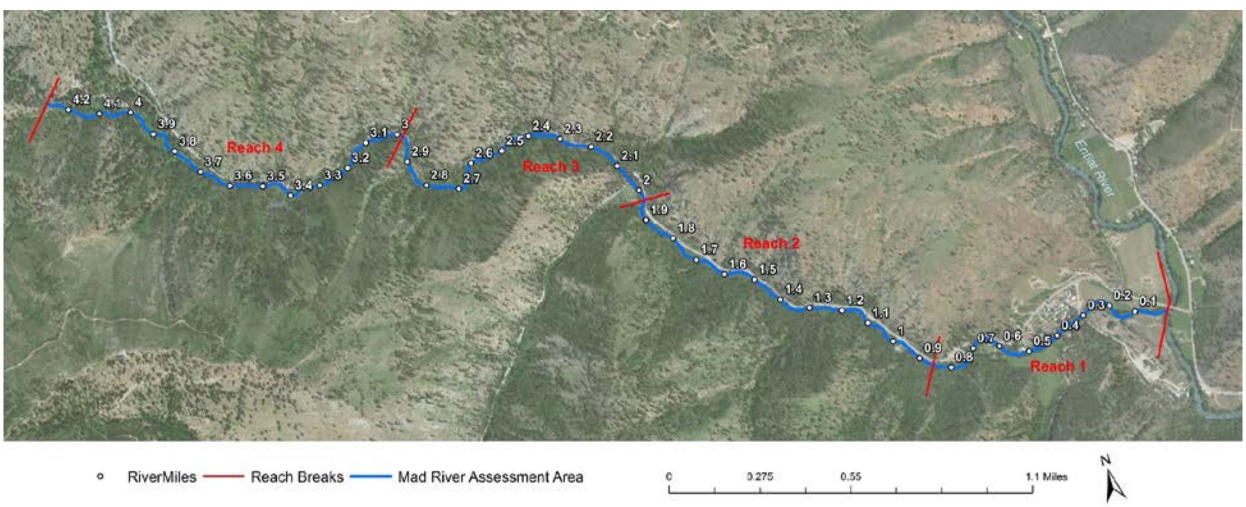

Figure 23. Lower Mad River reach assessment area with reach boundaries and river miles. Basemap: ESRI

Table 5. Reach-scale metrics for Lower Mad River – RM 0 to 4.3.

	METRIC	Reach 1	Reach 2	Reach 3	Reach 4
Channel and Floodplain	Length (miles)	0.86	1.07	1.05	1.32
	River Mile	0 - 0.86	0.86 - 1.93	1.93 - 2.98	2.98 - 4.3
	Stream Gradient (%)	1.54%	1.79%	2.35%	1.65%
	Sinuosity	1.18	1.07	1.33	1.20
	Dominant Channel Habitat Unit Type	Riffle	Riffle	Riffle	Riffle
	Average Bankful Width (ft)	41.0	51.3	48.0	52.5
	Dominant Substrate	cobble	cobble	cobble	cobble
Channel Habitat Area (%)	Pool	7%	8%	1%	7%
	Riffle	84%	79%	82%	87%
	Glide	9%	13%	17%	5%
	Side Channel	0%	0%	1%	1%

NOTES:

Average Bankfull Width and Channel Habitat Unit Types surveyed in the field per USFS Stream Inventory Guidelines (2015). See Habitat Assessment for analysis and results (Appendix A).

Dominant Substrate characterized by ocular field observations.

3.1 REACH 1 (RM 0 – 0.86)

3.1.1 Overview

Reach 1 is 0.86 river miles long and extends from the mouth of the Mad River at its confluence with the Entiat River to the top of the Mad River's historical alluvial fan, where the channel exits the mountains to meet the Entiat Valley. Throughout Reach 1, the river is a single-thread channel with a sinuosity of 1.14 and a reach gradient of 1.54%. Average bank-full width measured during the Habitat Assessment (Appendix A) of the channel is 41.0 feet. The channel is entrenched and leveed through most of Reach 1. Even though this reach is located in a downstream-widening valley, the active floodplain surfaces (inundated ~1-5 years) exist as discontinuous narrow strips and pockets that support riparian vegetation (Figure 24). The Mad River's historical-alluvial fan is an abandoned surface that is rarely or no longer inundated during flood events. The modern terrace surface that occupies most of the valley floor has been graded and cleared for building and road construction or agriculture. Direct hillslope coupling with the channel occurs on river right in the upstream-most section for approximately 200 feet. Vegetation clearing for homes, roads, and the historical Ardenvoir/Harris Mill site has altered the native vegetation of the valley floor from what historically likely mature old growth forest to grasses and sparse shrubs, orchard trees, and a few conifers. Today, the channel in this reach is lacking in large wood recruitment potential and retention.

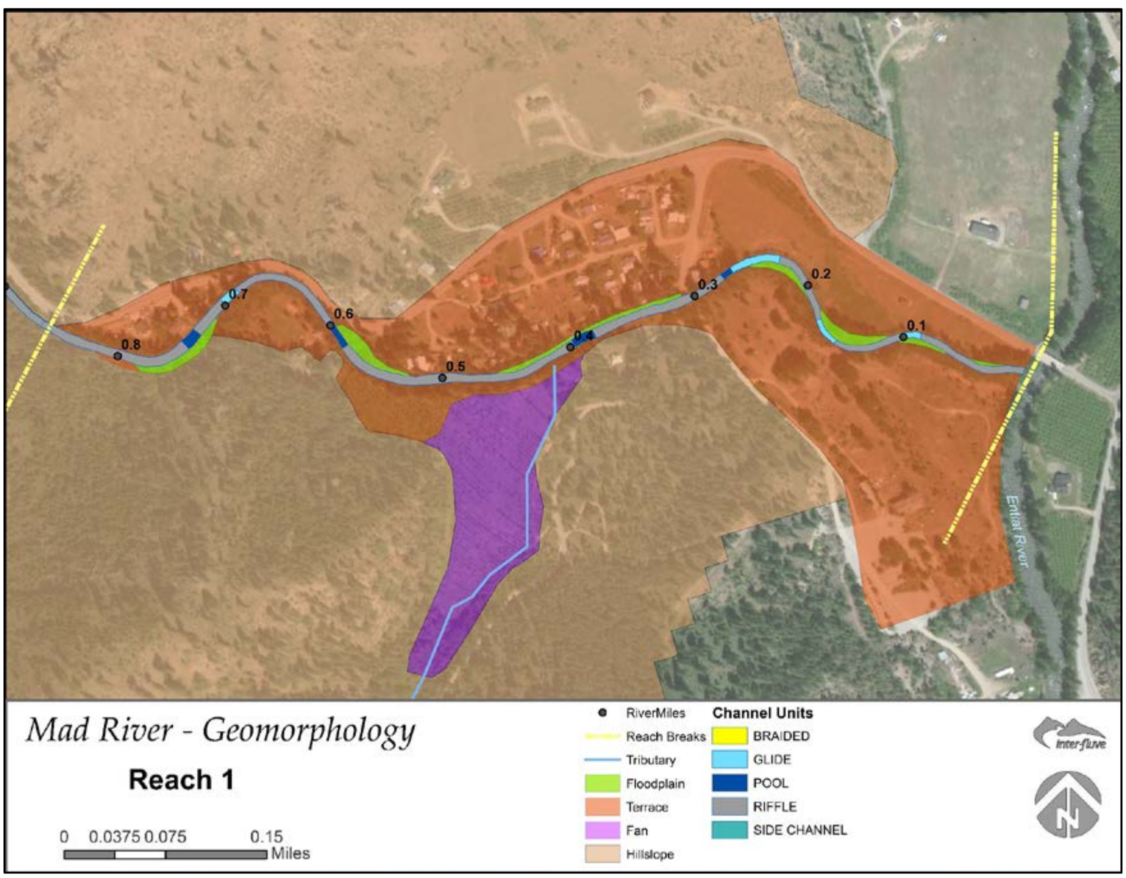

Figure 24. Reach 1: Geomorphic surfaces and channel units. Basemap: ESRI World Imagery

3.1.2 Channel and Floodplain Geomorphology

The Mad River in Reach 1 has a moderate gradient (1.54%) with a planform that alternates between straight and sinuous (Figure 24). The channel is entrenched below its historical floodplain throughout the reach. The levees along the channel from RM 0-0.55 appear to be constructed of material excavated from the bed of the channel, exaggerating entrenchment in this portion of the reach. Banks are composed of coarse alluvium (gravel to boulder) that is mixed and topped with sands and fines. Valley soils are gravelly sandy loam (USDA and NRCS 2017). Inset floodplain surfaces range from 1 to approximately 4-5 feet above the elevation of the channel bed. Terrace surface banks are generally steeper than the floodplain banks and range from 5-12 feet above the elevation of the channel bed. Active lateral channel processes are minimal and historical aerial photos from 1957 confirm that the channel has been in basically the same position for over 60 years. A lack of lateral processes equates to minimal local sediment sources for bar or spawning habitat development. The lack of lateral channel processes through the wide river valley is due to channel entrenchment, leveeing, bridge confinement, and bank hardening with cement slabs, wood, and riprap. Where established, tree roots and riparian vegetation contribute additional stability to the banks (Figure 25).

Figure 25. Looking downstream at RM 0.15. River right: outside meander, partially vegetated stabilized cobble-boulder bank topped with a levee; River left: vegetated floodplain pocket with small gravel-cobble point bar (partially inundated during spring flows). (Photo: 4/25/2017).

Channel complexity in Reach 1 is impaired. The 2017 Habitat Assessment (see Appendix A) measured 84% of the channel as extended riffles, while only 7% is pool habitat, and the remaining 9% is glides. The glides and several of the riffles are plane-bed. The four pools occur where large boulders and/or built features such as a collapsed bridge footing or an irrigation out-take weir create a stable grade control that produces scour on the downstream side. The bed of the channel is dominated by coarse alluvium (cobble and small boulders). Narrow gravel-cobble bars form at the inside bends of the subtle meanders at RM 0.15 and 0.22, as well as at the mouth of the channel. Otherwise, the only other gravel accumulations observed occur at the grade control and eddies associated with the four small pools – confirming that gravels are mobilized through Reach 1 but that retention is limited and local generation of sediment is likely minimal. Based on bed and bank material, hyporheic flow is expected to occur between the channel bed, bars, and floodplain surfaces.

Figure 26. Two of the four pools in Reach 1: A) Small pool downstream of Irrigation out-take weir and related boulder spur at RM. 0.27 (10/24/2017); B) Pool downstream of hillslope contributed boulders at RM 0.39 (11/9/2017).

3.1.3 Vegetation and Large Woody Material

Riparian vegetation in Reach 1 is a discontinuous narrow strip of trees and shrubs with open patches composed of grasses and forbes. The riparian strip is primarily a sparse overstory of cottonwood and Ponderosa pine with an understory of alder, dogwood, and willow (Figure 27). The native vegetation beyond the existing riparian strip has been cleared or partially cleared for homesite development, roads, and agriculture. The cleared areas are now vegetated primarily with grasses and forbes. Where they occur, the overstory trees are mostly classified as large (21 to 32-inch dbh) but are relatively sparse. Alder is the dominant riparian shrub/small tree and, in places, add stability to the banks. The understory vegetation is dense, where it exists, and is expected to provide a partial shade canopy for the channel during the summer. From RM 0.7-0.86, a pine-dominated forest grows on the adjacent steep hillslope along river right. It is probable that all riparian vegetation in Reach 1 was removed at some point in the last 100 years, including when levees were being constructed. The riparian strip that exists today is in the process of recovering and maturing.

Figure 27. Riparian vegetation strip at RM 0.3. (Photo: 4/25/2018)

The lack of mature or large trees (21-32-inch dbh), narrowness of the vegetated riparian zone, and lack of lateral channel process limits local source and recruitment potential of large woody materials (LWM) into the channel. A total of only 11 pieces of wood and no log jams were observed in the channel during the survey (10/24/2017). All 11 pieces were in the small size class (9 to 12-inch dbh). No quality large woody material (>12-inch dbh and at least 35-feet long) were observed in the channel (Figure 28). Due to the small size and scarcity of large wood material (LWM), it plays only a minor temporary role in aquatic habitat and geomorphic complexity in Reach 1. The lack of LWM in Reach 1 is the result of past riparian vegetation removal, lack of mature trees in the riparian corridor, lack of channel migration capacity, and probably continued periodic "cleaning" of wood from the channel. Clearing large wood from the channel has been a common practice in places were infrastructure such as bridges or culverts exist.

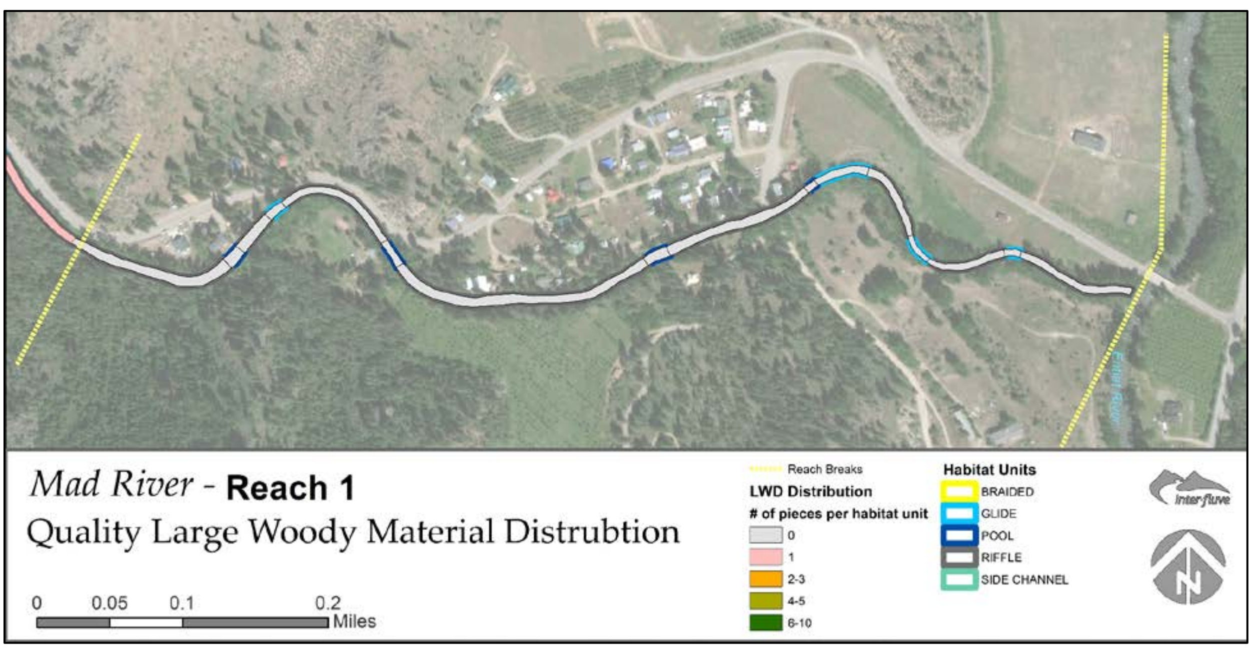

Figure 28. Reach 1 – Quality Large Woody Material (>12-inch dbh and at least 35 feet long) distribution by number of pieces per mapped habitat unit per the 2017 survey.

3.1.4 Human Alterations

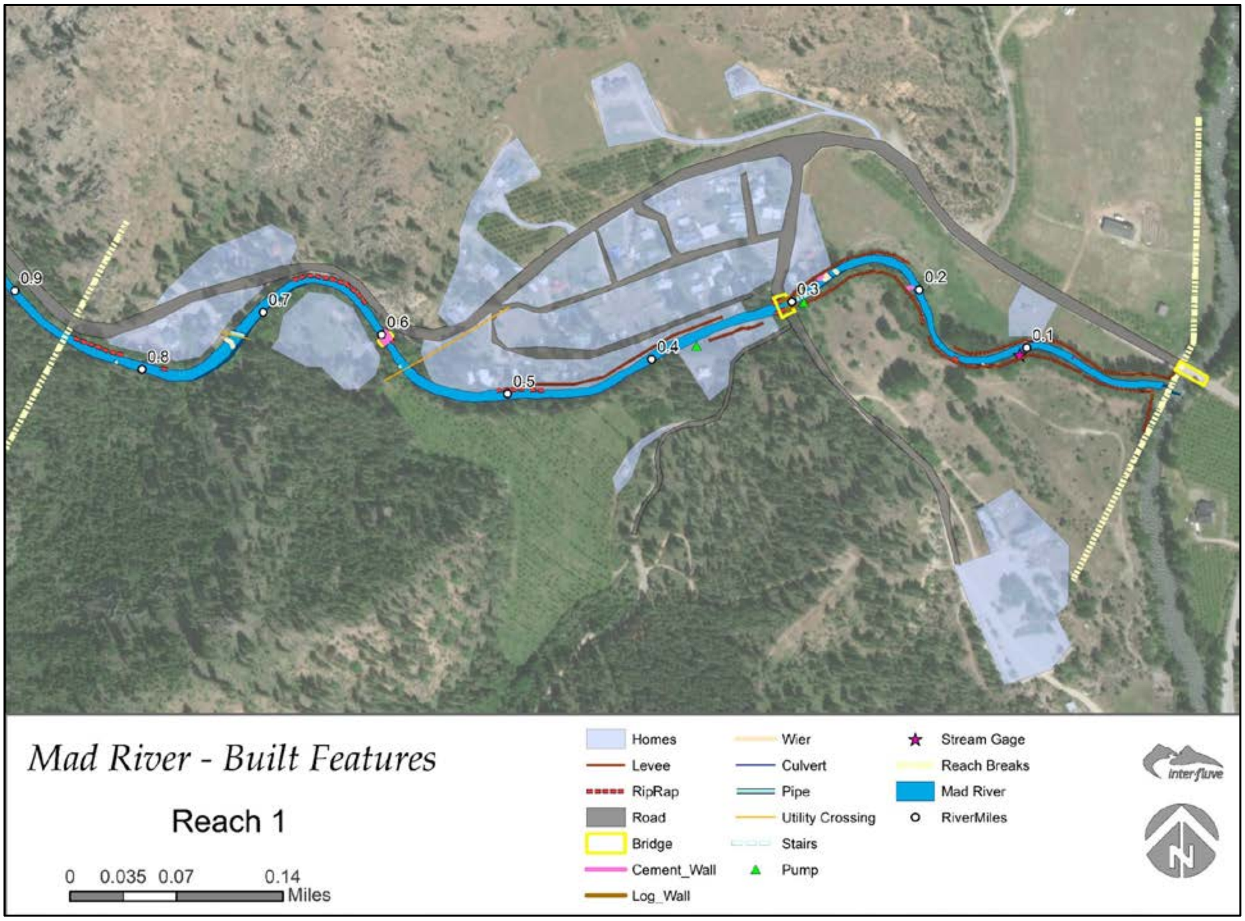

Figure 29. Reach 1: anthropogenic built features. Basemap: ESRI World Imagery.

Reach 1 contains the most anthropogenic built-feature impediments compared to the other reaches in the assessment area. In addition to clearing and altering the valley floor and riparian vegetation, anthropogenic features in Reach 1 include buildings, roads, bridges, levees, bank protection, weirs, irrigation, and utility crossings (Figure 29). Levees of up to 3.5 feet high, and constructed of material that looks to be excavated from the channel, line both sides of the river bank from RM 0.0-0.3. Additional similarly-constructed levees exist on river right from RM 0.34-0.36 and on river left from RM 0.35-0.49. Two railroad-car bridges have footings of cement, wood, and/or rock that protect the bank and confine the channel near RM 0.3 and RM 0.6 (Figure 30). At the bridge near RM 0.6, an old cement footing collapsed into the channel and remains in place under the bridge, armoring over half of the channel bed.

Figure 30. Railroad-car bridge crossings: A) near RM 0.3 with log, cement, and riprap footings and bank protection. Logs are old footings from historical bridge crossing, and B) near RM 0.6 with cement footings and large boulder riprap. (Photos: 11/9/2017).

Bank armoring and protection treatments occur throughout Reach 1. Large boulder riprap has been placed along the banks at RM 0.28 in correlation with a cement-walled irrigation out-take and weir. Riprap is also present at RM 0.48-0.51 on river left in front of homes built on relative low surfaces, at RM 0.63-0.67 and RM 0.82-0.85 on river left to protect the Mad River Road and homes (Figure 31), and at RM 0.15. On river left at RM 0.78, pieces of steal and cabling are buried into and protecting the bank. Cement blocks on river right at RM 0.2 also add bank protection to an already anthropogenically-confined reach.

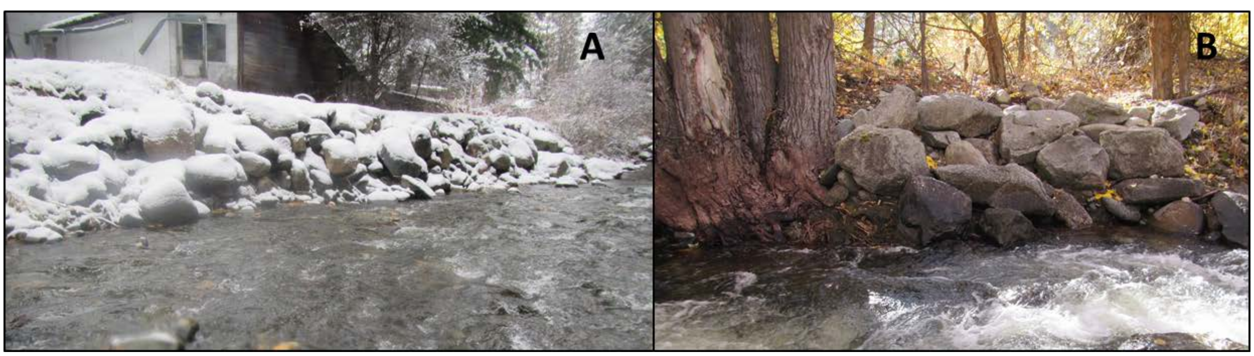

Figure 31. Riprapped banks: A) river left at RM 0.51 (11/9/2017), and B) river left at RM 0.28 (10/24/2017).

Other features that interact with the channel and its banks include built stairs, a hand-built rock weir, old steal piping that extends across the channel bed, and a modern utility line crossing, all located between RM 0.73-0.74. The USGS discharge gage on river right at RM 0.1, a groundwater pump next to the channel on river right at RM 0.37, and the fish-tag piping, pump, and data collection box at RM 0.29 impose minimal impacts to modern channel processes.

3.1.5 Recommended Actions

Recommended actions for Reach 1 are focused on increasing channel complexity and floodplain connectivity to improve available habitat and channel function. These actions include riparian restoration, removal of unnecessary anthropogenic materials, enhancing channel complexity, and improving available aquatic habitat. There is a lot of potential for actions to notably improve habitat quantity and quality in the downstream portion of Reach 1 (RM 0.0-0.3) that would benefit aquatic species that utilize the Mad and/or Entiat Rivers. These recommendations consider private land ownership and density of development on both sides of the channel through Reach 1. Several of the recommended actions in Reach 1 will likely require landowner engagement and approval. Although bordered by private land, the lower section of the reach has minimal developed and no occupied structures. In this area, recommended actions include levee, riprap, and weir removal, as well as excavation to create a wider inset floodplain, installation of large log jams, and native riparian vegetation restoration. The weir and associated irrigation out-take structure at RM 0.29 should be evaluated and improved or removed for fish passage. Additional recommended actions in the upstream section of reach 1 include the removal a short weir and cement slab from the channel and adding a large wood jam in an existing pool to increase and maintain habitat quality. Improving the two existing bridge crossings by removing associated bank armoring and then widening the span between footings is recommended to reduce channel confinement and further entrenchment at these crossings. The additional bank armoring and surface water out-take infrastructure at RM

Maps and more detailed descriptions of recommended treatments are provided in Section 4 of this report.

3.2 REACH 2 (RM 0.86 – 1.93)

3.2.1 Overview

Reach 2 is 1.07 river miles long and occupies a confined river valley from the confluence with Tillicum Creek downstream to where the valley floor begins to widen and stream gradient decreases at the border with Reach 1. Through Reach 2, the river is a single thread channel with a reduced sinuosity (1.09) and increased reach gradient (1.79%) compared to Reach 1. However, average bank-full width of the channel is 51.3 feet – slightly wider than Reach 1. Floodplain surfaces (inundated ~1-5 years) exist as alternating pockets in the upstream portion between RM 1.5-1.92 and as discontinuous narrow pockets between RM 1.0-1.3. Elsewhere, the channel is confined between hillslopes and the Mad River Road with basically no floodplain. The existing floodplain surfaces are well-vegetated with riparian trees and shrubs. A small terrace surface at RM 0.95-1.1 on river right is occupied with a home. The construction of the Mad River Road along the valley floor has further confined and altered the native vegetation of the valley floor from what was likely mature old-growth forests. This reach is lacking in large wood recruitment and retention.

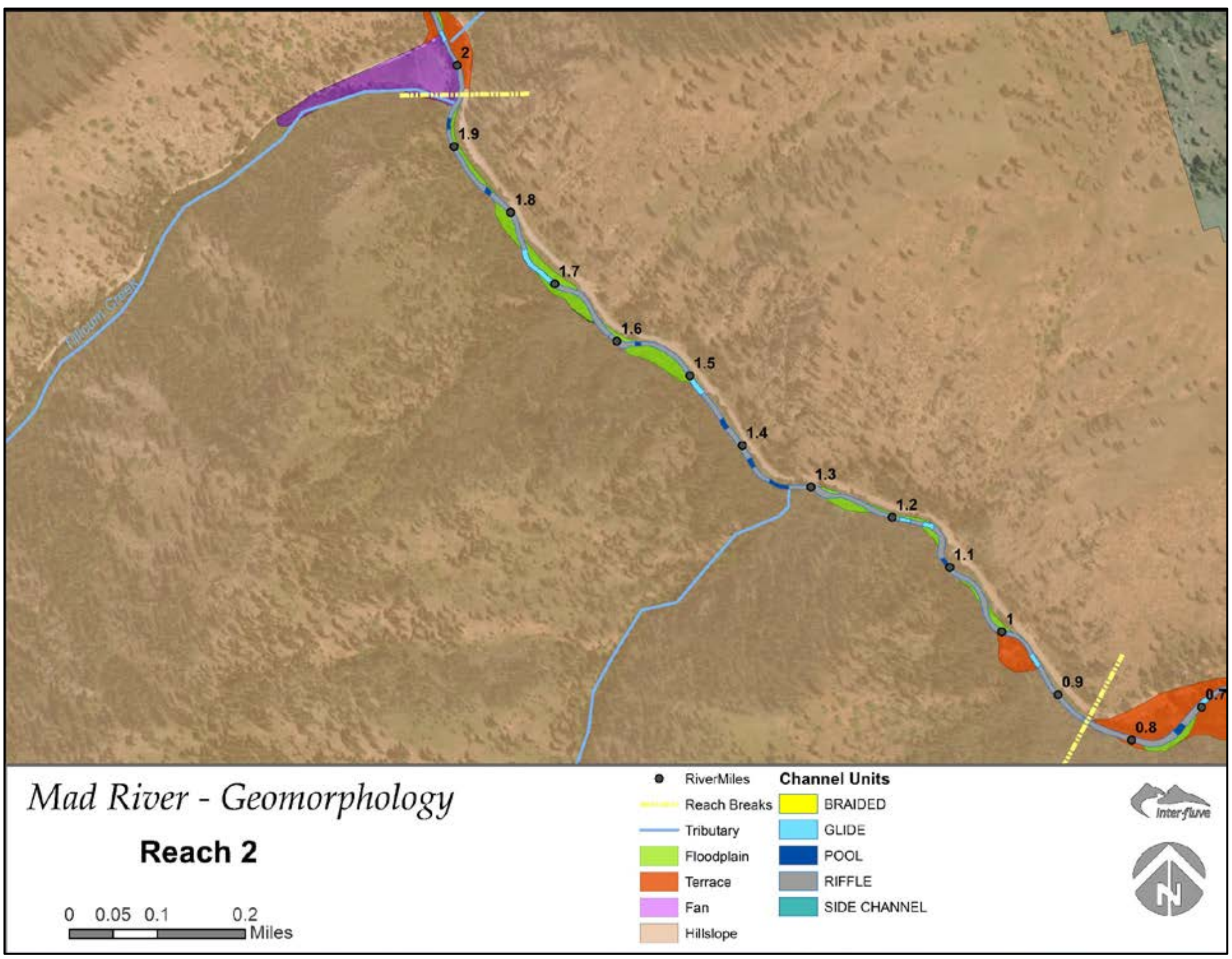

Figure 32. Reach 2: Geomorphic surfaces and channel units. Basemap: ESRI World Imagery

3.2.2 Channel and Floodplain Geomorphology

The Mad River in Reach 2 has a moderate gradient (1.79%) with a generally straight planform (Figure 32). Planform is straightest where the channel is confined between hillslope and the Mad River Road (RM 0.86-0.95, 1.04-1.2, 1.3-1.49, and 1.82-1.93). In these sections, hillslope contributions of boulders add some complexity (scour pools and back eddies) to channel geomorphology. Channel substrate is composed of cobble and boulders with sparse gravels. Gravels were observed in back water eddies and pool-tailouts – indicating mobilization of spawning-sized material through Reach 2, but limited retention. Based on bed and bank material, hyporheic flow is expected to occur between the channel bed, bars, and floodplain surfaces.

Figure 33. Reach 2 at RM 1.48, a hillslope and road confined section - looking downstream. (Photo: 4/25/2018)

In the less confined sections (RM 0.95-1.04, 1.2-1.3, and 1.5-1.82), the floodplain pockets alternate with hillslope or Mad River Road confinement on the outside bend of meanders. The floodplain pockets are well vegetated with a mix of riparian vegetation. Based on exposed banks, the floodplains are composed of a cobble-boulder base topped with gravels that fine-upward to coarse sands. Soils in Reach 2 are described as gravely sandy loam in the downstream portion and a gravely fine sandy loam in the upstream portion (USDA and NRCS 2017). Where floodplains exist, channel banks range from 1 to approximately 4 feet above the bed of the channel.

Figure 34. Reach 2 at RM 1.68, vegetated floodplain – looking upstream. (Photo: 11/9/2017)

Channel complexity in Reach 2 is impaired. The 2017 Habitat Assessment (see Appendix A) measured 79% of the channel as extended riffles while only 8% is pool habitat and the remaining 13% is glides. The glides and several of the riffles are plane-bed. The pools occur where large boulders create a grade control that produces scour on the downstream side. The bed of the channel is dominated by coarse alluvium (cobble and small boulders). A few small gravel accumulations were observed in eddies or pools behind boulders or upstream of large wood (Figure 35).

Figure 35. Spawning gravel accumulation behind boulders (with spawning salmoind) at RM 1.45. (Photo: 11/9/2017)

3.2.3 Vegetation and Large Woody Material

Riparian vegetation in Reach 2 is well established except where the channel is bordered by the Mad River Road. The riparian vegetation is primarily an overstory of fir trees, Ponderosa pine, and a few cottonwoods with a thick understory of alder and dogwood (Figure 36). The adjoining hillslope vegetation is dominated with conifers (fir and pine). Floodplain surfaces are densely vegetated with alder and dogwood with a sparse overstory of conifer or cottonwood. Only 33% of the overstory trees are considered large (21 to 32-inch dbh). However, the understory and small trees are thick enough that the existing vegetation provides a shade canopy for the channel during summer months, except in the less vegetated areas adjacent to the Mad River Road. It is probable that most of the riparian vegetation on river left in Reach 2 was removed in the past during the construction of the Mad River Road.

Figure 36. Riparian vegetation example in Reach 2, at RM 1.6. (Photo: 11/24/2017)

Although adjoining hillslopes along river right are vegetated with conifers, the lack of large trees (>32-inch dbh) within the riparian corridor limits local recruitment potential of large woody materials (LWM) into the channel. In addition, the exaggerated confinement of the channel in Reach 2 by the construction of the Mad River Road restricts lateral channel process that would promote natural wood recruitment and floodplain development.

A total of 49 pieces of woody material and only one log jam was observed in the channel during the survey (10/24/2017). Of the 49 pieces, only three classified as large size class (≥20-inches dbh and >35-feet long), 19 were classified as medium size class (12 to 20-inch dbh and at least 35-feet long), and the rest were all small size classified (9 to 12-inch dbh). See Figure 37 for distribution of quality large woody material (>12-in dbh and at least 35-feet long) per mapped habitat unit throughout the reach.

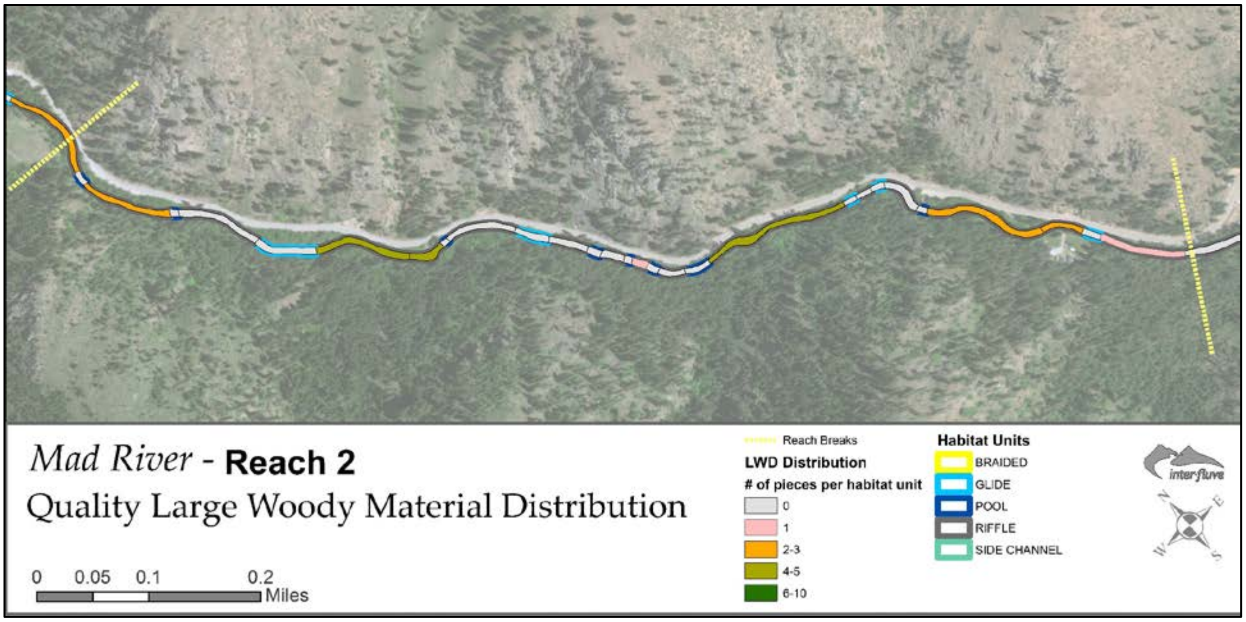

Figure 37. Reach 2: Quality Large Woody Material (>12-inch dbh and at least 35 feet long) distribution by number of pieces per mapped habitat unit per the 2017 survey.

The log jam observed in Reach 2 contained only one large piece of wood and 9 small pieces (Figure 38). This is an example of the lack of quality in-stream Large Woody Material (LWM) and riparian recruitment potential in the reach. As a result, LWM currently plays only a minor role in localized aquatic habitat and geomorphic complexity. Where it does exist, channel complexity is improved. The lack of LWM and jams in Reach 2 today is likely the result of past riparian vegetation removal for the construction of the Mad River Road and periodic "cleaning" of wood from the channel. Cleaning LWM from the channel has been a common practice where infrastructure such as roads and bridges exist.

Figure 38. Large wood jam at RM 1.19 in Reach 2. (Photo: 4/25/2018)

3.2.4 Human Alterations

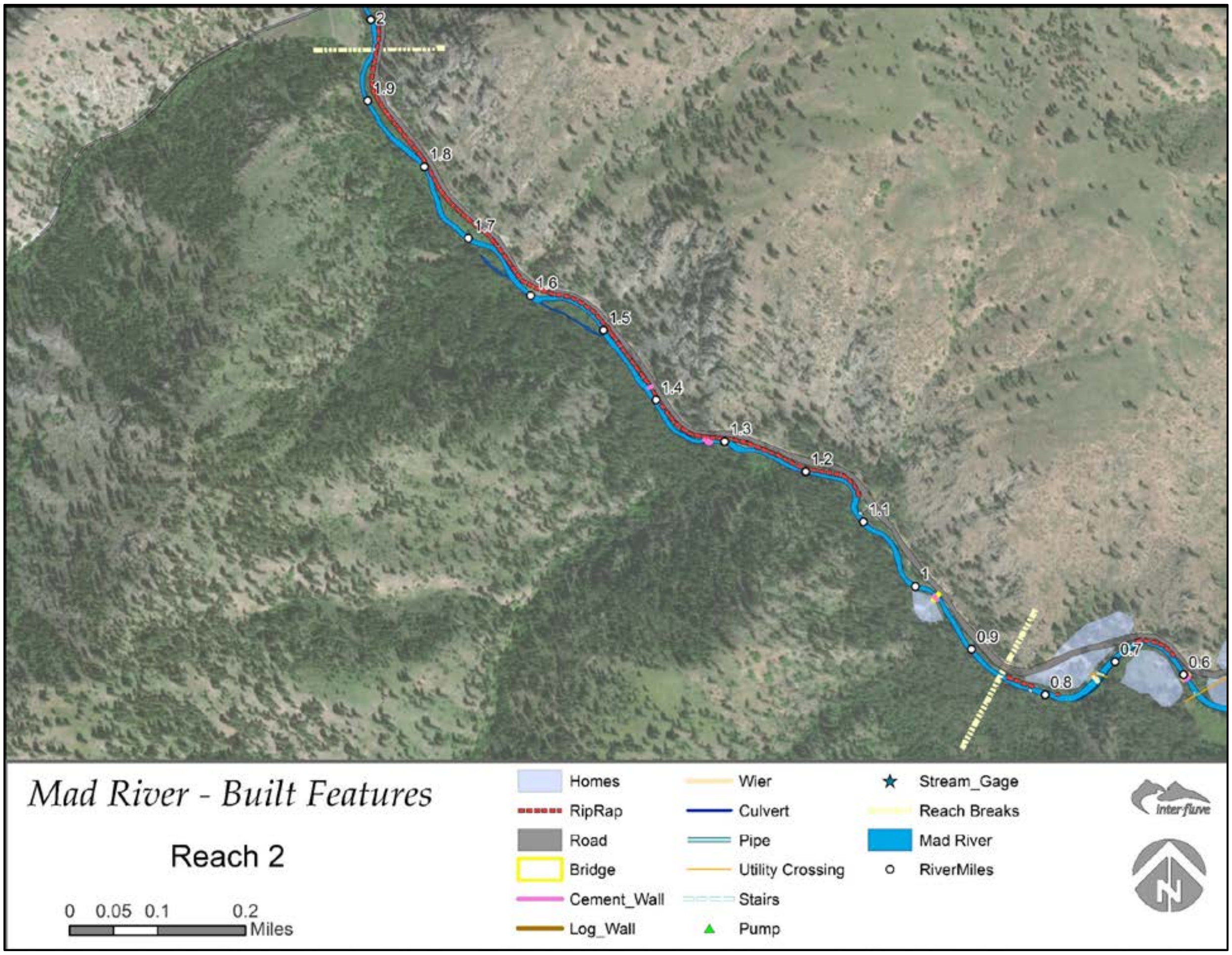

Figure 39. Reach 2: Anthropogenic built features. Basemap: ESRI World Imagery

Anthropogenic features in Reach 2 include the Mad River Road, bank riprap, a bridge crossing, an existing homesite, related vegetation clearing, and cement wall bank and bed armoring. The Mad River Road occupies approximately half of the available valley floor from RM 0.86-1.65 and from RM 1.65-1.93 it occupies approximately a third of it (Figure 40A). From RM 1.13-1.93, the road bank is armored with large-boulder riprap. The bridge crossing at RM 0.98 includes cement, steel beam, log, and large boulder riprap footings and bank protection (Figure 40B). A homesite located on a low terrace on river right at the bridge crossing (RM 0.98) includes riparian vegetation clearing. A remnant cement wall extends from the road perpendicular to flow on the river left bank at RM 1.42 but it does not contact the channel at normal or low flows (Figure 41A). Another cement slab was observed on the channel bed with steel pipe embedded into it at RM 1.33. The slab is creating a grade control with a step pool on the downstream side and accumulated gravels and cobbles on the upstream side (Figure 41B).

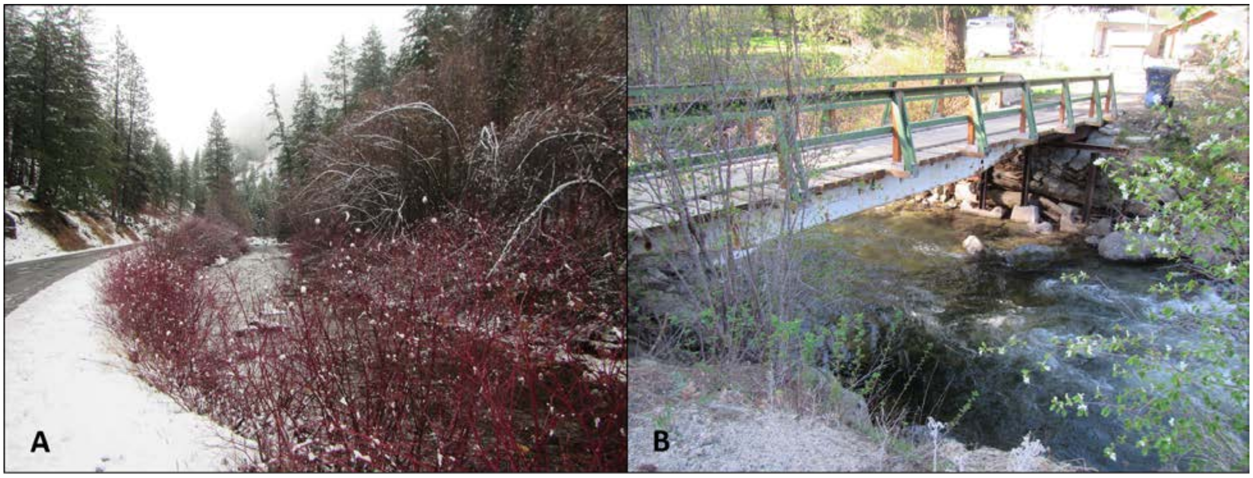

Figure 40. A) Mad River Road along Reach 2 occupying ½ of valley floor at RM 1.55 (Photo: 11/9/2017); B) bridge crossing at RM 0.98. (Photos: 4/25/2018)

Figure 41. A) cement wall on bank at RM 1.42; B) cement slab on channel bed at RM 1.33. (Photos: 11/9/2017)

3.2.5 Recommended Actions

Recommended actions for Reach 2 are focused on increasing channel complexity and improving available aquatic habitat. These actions include riparian restoration, enhancing channel complexity, removing unnecessary materials, creating side/off-channel habitat, and improving available aquatic habitat in the mainstem. All recommended actions downstream of RM 1.25 are on private and everything upstream of that in Reach 2 is on public lands managed by the US Forest Service. Sustainability of the action treatment and protection of the Mad River Road was considered in selecting recommendations for this reach. Primary actions are installing small, medium and large-sized log jams, some with placed large boulders, in appropriate locations that take advantage of existing features or instigate geomorphic function to increase channel complexity and habitat quality. Constructing side channels through existing functioning floodplains has the potential to notably increase available high-quality habitat in the reach.

Maps and more detailed descriptions of recommended treatments is provided in Section 4 of this report.

3.3 REACH 3 (RM 1.93 – 2.98)

3.3.1 Overview

Reach 3 is 1.05 river miles long and occupies a river valley that has confined and partially confined sections. The Reach extends from the confluence of Tillicum Creek (RM 1.93) upstream to RM 2.98, at a bedrock contact on river right. The channel is primarily single thread throughout Reach 3, with the exception of two short side channels in the upper portion. Reach average sinuosity (1.33) and gradient (2.35%) are both higher than the other reaches in the assessment area. Average bankfull width of the channel in Reach 3 is 48 feet, which is slightly narrower than Reach 2 downstream and Reach 4 upstream. Floodplain surfaces (inundated ~1-5 years) exist as discontinuous narrow strips within the confined channel section and as extended but narrow surfaces in the partially confined section (RM 2.6-2.85). The existing floodplain surfaces are well-vegetated with riparian trees and shrubs. The toe of the Tillicum Creek alluvial fan occupies the downstream section of the reach. The construction of Mad River Road further confined the channel and limited vegetation establishment along the river left side of the valley throughout the reach. Retention of large woody material appears to be temporary in most locations in the reach, but where it does occur, geomorphic complexity is increased.

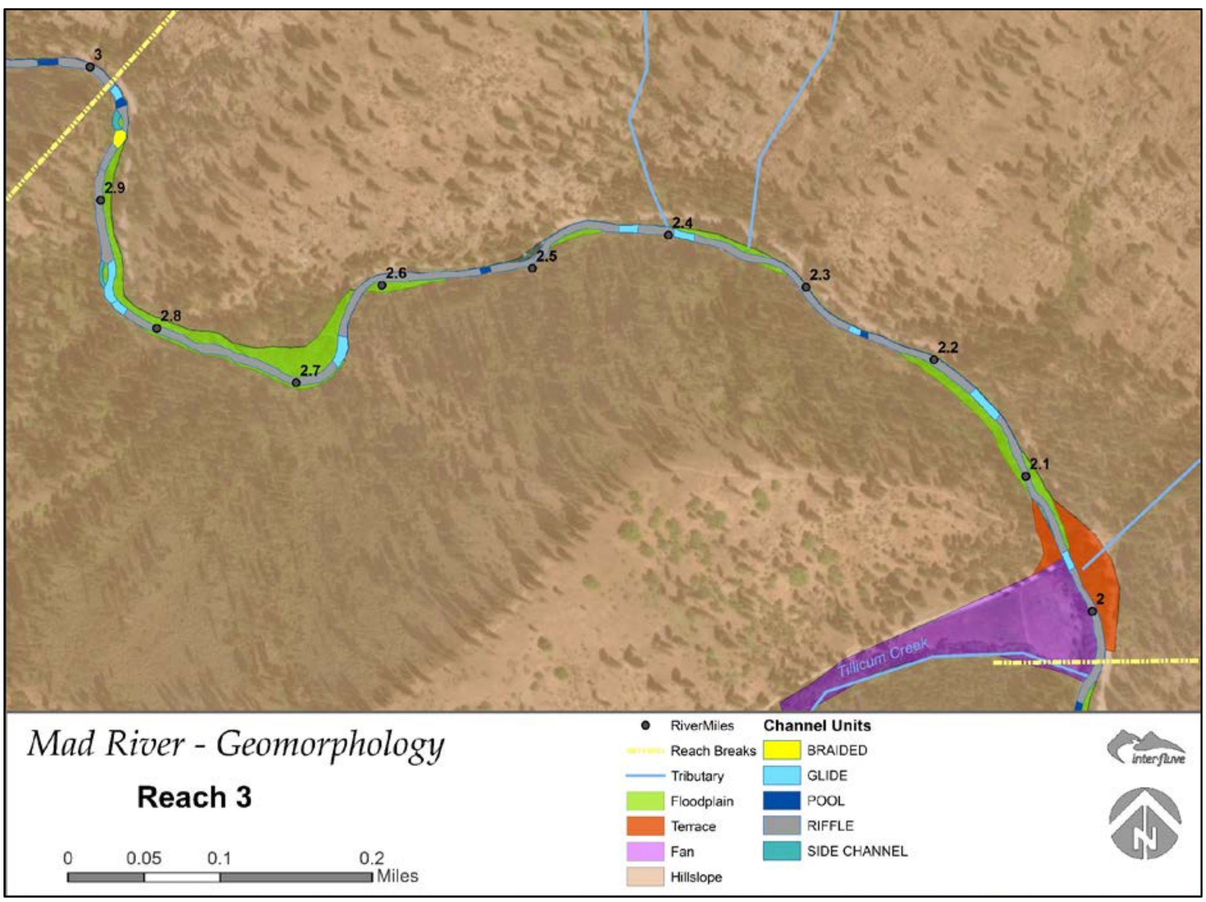

Figure 42. Reach 3: Geomorphic surfaces and channel units. Basemap: ESRI World Imagery

3.3.2 Channel and Floodplain Geomorphology

The Mad River in Reach 3 has a moderate gradient (2.35%) with a planform that alternates between straight and moderately sinuous (Figure 32). The relatively straight sections occur where the channel is completely confined between hillslopes and the Mad River Road (RM 2.23-2.32, 2.4-2.55, and 2.97-3.14). In the confined areas, local hillslope contributions of boulders add some complexity to channel geomorphology (steps, scour pools, and some wood accumulation). Hillslopes on river right include vegetated slopes, periodic bedrock bank contacts, and large boulder colluvium. River left is occupied by the Mad River Road. Bedrock contacts (25-100 feet long) occur along the right bank of the channel at RM 2.65 and 2.91. Boulder colluvium occurs along the river right side of the channel along the toe of most other confining hillslope contacts. Channel substrate in Reach 3 is composed of cobble and boulders with sparse gravels. Gravels and coarse sands were observed in depositional areas such as small eddies, pools tail-outs, and bars – indicating the presence of salmonid spawning material moving through the reach. Based on bed and bank material, hyporheic flow is expected to occur through the channel bed, and bars.

Figure 43. Mad River confined by hillslope and road at RM 2.45. (Photo: 11/9/2017)

Split-flow conditions (side channels) occur near RM 2.85 and RM 2.95. In these locations, woody material accumulations and/or boulders support mid-channel bar development and island maintenance. Geomorphic complexity of the channel is higher where split-flow conditions occur (Figure 44).

Figure 44. Mad River at RM 2.95: Split-flow at wood accumulation. (Photo: 4/24/2018)

Discontinuous floodplain strips alternate with hillslope or Mad River Road confining banks. The floodplain strips are generally composed of alluvium and colluvium that range in size from fines to boulders. Floodplain surfaces are approximately 1 to 4 feet above the bed of the channel and are well-vegetated with riparian shrubs and sparse trees. The contributing hillslopes in Reach 3 have soils described as stony fine sandy loam (30%-60% grade) on river right and granitic substratum and bedrock outcrops (40%-90% grade) on river left (USDA and NRCS 2017).

Figure 45. Mad River at RM 2.7 looking upstream: Hillslope on river right and vegetated floodplain strip on river left. (Photo: 11/25/2017)

At the downstream end of the reach (RM 1.93-2.09), the channel is relatively straight as it flows entrenched through terraced surfaces of the Tillicum Creek alluvial fan and under the Tillicum Road Bridge. This is the site where a small dam (resident estimated as ~10-feet high) was located for an unknown period of time until it was removed between 1970-1990 (unknown deconstruction date). Downstream of the bridge, the Tillicum Creek alluvial fan continues to border the channel. The terraces and alluvial fan are described as gravely sandy loam. These surfaces would be a good sediment source for the Mad River but historical damming, and modern road, bridge, and related bank armoring have constrained lateral movement and control channel location here. The Tillicum Creek Habitat Restoration Project Report (Inter-Fluve 2018) provides a more detailed assessment of the geomorphic conditions and habitat restoration recommendation for the Mad River along the distal end of the Tillicum Fan.

Figure 46. Extended riffle (~800 feet long), photo looking upstream at RM 2.75. (Photo: 11/9/2017)

Channel complexity in Reach 3 is impaired. The 2017 Habitat Assessment (see Appendix A) measured 82% of the channel as extended riffles while only 1% is pool habitat, 17% is glides, and 1% is side channels. The glides and some of the riffles are generally plane-bed. The pools occur where boulders create a grade control or scour. The bed of the channel is dominated by coarse alluvium (cobble and small boulders). Only small pockets of coarse sand and gravel were observed in eddies and pools behind boulders and/or wood accumulations.

3.3.3 Vegetation and Large Woody Material

The riparian vegetation in Reach 3 is dominated by dense shrubs and sparse trees. The sparse overstory of trees is composed of ponderosa pine and fir while the understory is primarily alder, dogwood, and maple. Where the channel is bordered by the Mad River Road, riparian vegetation is marginalized and lacking in overstory trees. All of the overstory trees are considered small trees (9 to 21-inch dbh). However, the understory is mature and thick enough that the existing riparian vegetation does provide a partial shade canopy for the channel during summer months, except in the confined areas adjacent to the Mad River Road. It is probable that most of the riparian vegetation in Reach 3 was removed during the construction of the Mad River Road. In addition, the exaggerated confinement of the channel by the road and related bank protecting riprap limits lateral channel process that would promote large wood recruitment and floodplain development.

Figure 47. Riparian understory vegetation on floodplain at RM 2.84. (Photo: 11/25/2017)

A total of 89 pieces of wood were observed in the channel during the survey (10/25/2017). Of the 89 pieces, fourteen pieces classified as large size class (≥20-inches dbh and >35 feet long), 30 were classified as medium (12 to 20-inch dbh and at least 35 feet long), and 45 were all small size classified (9 to 12-inch dbh). No wood accumulations that constitute a log jam were observed. See Figure 48 for distribution of quality large woody material (>12-in dbh and at least 35 feet long) per mapped habitat unit throughout the reach. Where LWM exists, it plays an important role in aquatic habitat and geomorphic channel complexity. The lack of LWM is due to past riparian vegetation removal, lack of mature forests within the riparian corridor, increased confinement of lateral process by the Mad River Road, and potentially periodic "cleaning" of wood from the channel. Cleaning of LW from the channel is a common practice where infrastructure such as roads and bridges exist.

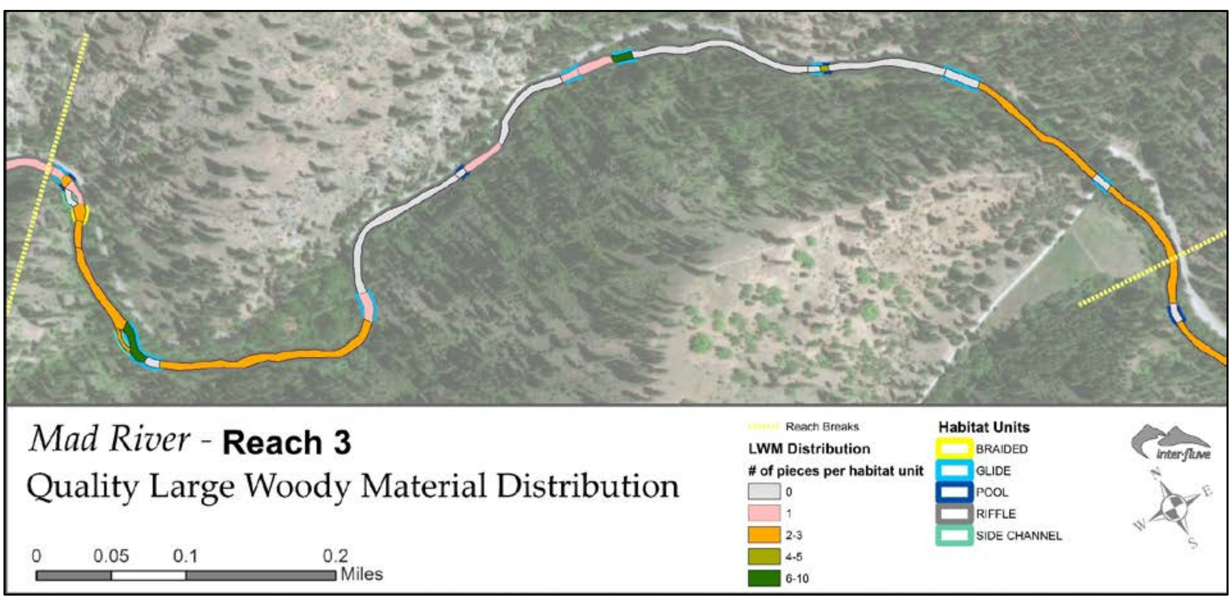

Figure 48. Reach 3: Quality Large Woody Material (>12-inch dbh and at least 35 feet long) distribution by number of pieces per mapped habitat unit per the 2017 survey.

3.3.4 Human Alterations

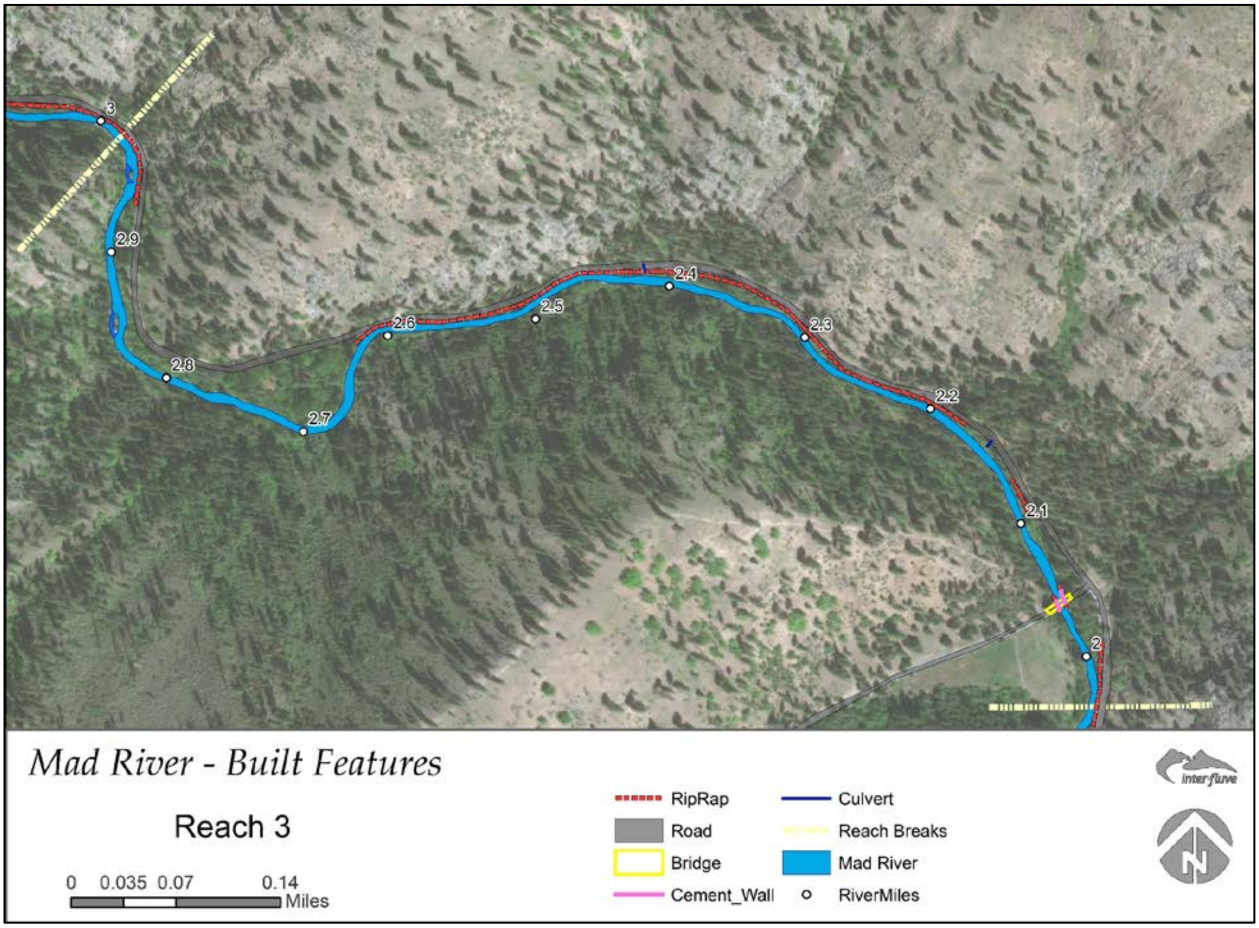

Figure 49. Reach 3: Anthropogenic built features. Basemap: ESRI World Imagery

Anthropogenic features in Reach 3 include the Mad River Road, bank riprap, a bridge crossing, an abandoned homesite, and related vegetation clearing. The Mad River Road occupies up to half of the available valley floor in the most confined sections of Reach 3. From RM 2.1-2.13, RM 2.17-2.63, and RM 2.93-3.14 the road bank is armored with large-boulder riprap which restricts the bank from contributing sediment or supporting riparian vegetation. Culverts under the Mad River Road at RM 2.15 and 2.42 control surface water contribution points from the hillslopes into the Mad River. The Tillicum Road bridge crossing at RM 2.04 includes cement footings and large-boulder riprap bank protection that locally confine the channel and control its pathway. This, in conjunction with a dam that was located immediately upstream of the bridge until the 1970's, has resulted in channel entrenchment and simplification in this area. A public day-use area on river right, immediately upstream of the bridge, is the site of an historical homestead. The home has been removed but the area remains mostly cleared of vegetation. A public parking and day-use area on river left immediately downstream of the bridge is also cleared of surface vegetation.

Figure 50. Tillicum Road bridge crossing at RM 2.04, looking upstream. (Photo: 10/25/2017)

Figure 51. Mad River Road occupying valley floor and the associated impaired riprapped channel bank. (Photo: 11/9/2017)

3.3.5 Recommended Actions

Recommended actions for Reach 3 are focused on increasing channel complexity and improving available aquatic habitat. These actions include riparian restoration, enhancing channel complexity, creating off-channel habitat, and improving available aquatic habitat in the mainstem. All recommended actions are on public lands managed by the US Forest Service. Sustainability of the treatment actions and protection of the Mad River Road was considered in selecting recommendations for this reach. Primary actions are installing small, medium and/or large-sized log jams, some with placed large boulders, in appropriate locations that take advantage of existing features or instigate geomorphic function to increase channel complexity and habitat quality. Enhancing the downstream end of an existing overflow channel and converting it into an alcove habitat feature would provide off channel refugia in the mid-section of this relatively high-gradient reach.

Maps and more detailed descriptions of recommended treatments is provided in Section 4 of this report.

3.4 REACH 4 (2.98 – 4.3)

3.4.1 Overview

Reach 4 is 1.32 river miles long and occupies a river valley that is partially confined. The Reach extends from the border with Reach 3 to a confined higher gradient section upstream of Pine Flats campground. The channel is primarily single thread throughout Reach 4, with the exception of two side channels near RM 3.3 and RM 4.05. Reach-average sinuosity (1.20) and gradient (1.65%) are lower than in Reach 3 but higher than both Reach 1 and 2. Average bankfull width of the channel in Reach 4 is 52.5 feet, which is wider than all of the downstream reaches – the result of a less confined floodplain. The channel has sections of continuous and alternating floodplain surfaces along most of its banks except in the confined downstream portion from RM 2.98-3.17. The floodplain surfaces are well vegetated with riparian shrubs and trees. Alluvial and debris-flow fans from tributaries located near the upstream boundary of the reach historically contributed sediment directly into the channel and these deposits continue to be active sources of bank-derived sediment. The construction of the Mad River Road on the valley floor from RM 3.08-3.6 increases channel confinement and limits riparian vegetation in this downstream section of the reach. Reach 4 has an overall adequate quantity of woody material in the channel which includes three large wood jams. Where wood occurs, geomorphic complexity is increased.

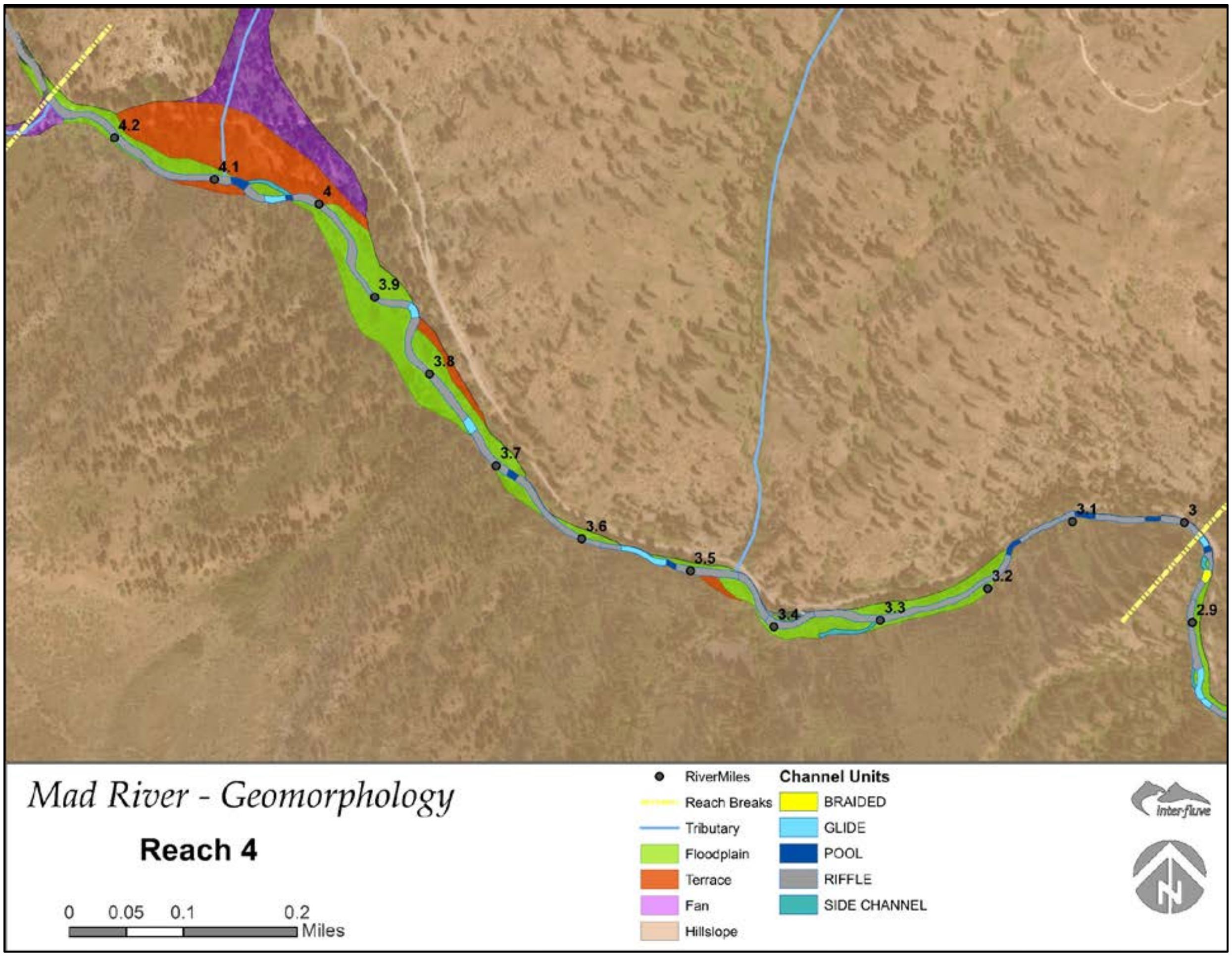

Figure 52. Reach 4: Geomorphic surfaces and channel units. Basemap: ESRI World Imagery

3.4.2 Channel and Floodplain Geomorphology

The Mad River in Reach 4 has a moderate gradient (1.65%) with a subtle sinuous planform (Figure 52). The channel is partially confined upstream of RM 3.17 and completely confined at the downstream end between the Mad River Road and hillslopes (RM 2.98 and 3.17). Channel habitat complexity in Reach 4 is impaired. The 2017 Habitat Assessment (see Appendix A) measured 87% of the channel as extended riffles while only 7% is pool habitat, 5% is glides, and just 1% is side channels. The glides and some of the riffles are generally plane-bed. The pools occur where boulders and/or large wood accumulations create a grade control or scour (see Figure 53). Based on ocular survey, channel substrate in Reach 4 is composed of gravels, cobbles, and small boulders. Plentiful gravels were observed in the upstream portion of the reach. Throughout, gravels and coarse sands were observed in depositional areas such as bars and upstream of large wood log jams. Local hillslope contributions of boulders add localized complexity (steps, scour pools, and wood retention) to channel geomorphology. Split-flow conditions occur near RM 4.05 and a hillslope and/or groundwater-generated side channel join the mainstem Mad River on river right at RM 3.3.

Figure 53. Boulder colluvium creating cascade step into small pool at RM 4.08. (Photo: 10/26/2017)

The hillslopes in Reach 4 are relatively sparsely vegetated. The hillslopes on river right contain bedrock exposures and/or large boulder colluvium toes that periodically contact the channel. Bedrock contacts (25-100 feet long) occur along the right bank of the channel at RM 3.0, 3.09, 3.4 and 4.3. Boulder colluvium occurs along the river right side of the channel along the toe of most other confining hillslope contacts. Hillslope-channel contacts on river right alternate with extended pockets of floodplain. Based on exposed banks, the floodplains are composed of a cobble-boulder base topped with gravels that fine-upward to coarse sands. Based on bed and bank material, hyporheic flow is expected to occur throughout the channel bed, bars, and floodplain surfaces. Soils in Reach 4 are described as gravely fine sandy loam (USDA and NRCS 2017). Floodplain surfaces range from 1 to approximately 4 feet above the bed of the channel. The floodplain surfaces are well-vegetated with a mix of riparian shrubs and trees.

Figure 54. At RM 3.86: Hillslope contact on river right, boulder colluvium, large wood piece with gravel bar accumulation in front of active floodplain on river left. (Photo: 4/24/2018)

Contributing drainages and their fans are important sediment sources to the Mad River at the upstream end of Reach 4. Two steep drainages with unnamed tributaries have produced debris flows or sets of debris flows (unsorted rock and soil that flows downslope due to gravity and water content) that created fans on both sides of the channel between RM 3.96 and 4.21. The elevation and fan toe extents suggest that, at points in the past, debris flow deposits from one or both of these drainages have temporarily blocked the mainstem channel. Today, Pine Flats Campground occupies part of a terrace feature on river left which is the result of the channel working through debris flow fan deposits. The debris fan on river left is older than the debris fan deposits on river right. More research would be needed to determine the age, sequence, and influence on the mainstem channel of debris flow deposits from the two drainages. Modern debris flow deposits occurred on river right between 2010 and 2012 (according to Google Earth aerial photos). The channel is actively eroding laterally and vertically into the deposits at RM 4.27. At RM 4.07 the channel is actively eroding the river left bank of terrace and debris fan deposits (Figure 55). These are sediment source to the Mad River that are generating bedload that includes gravels as well as materials for local and downstream floodplain development.

Figure 55. Sediment sources: A) debris fan on river right at RM 4.27, B) terrace & fan bank on river left at RM 4.07. (Photos: 11/10/2017)

3.4.3 Vegetation and Large Wood Material

The riparian vegetation in Reach 4 is dominated by mature trees with an understory of dense shrubs. The overstory trees are composed of fir, cedar, ponderosa pine, and cottonwood. The understory is a mix of small trees and shrubs made up mostly of dogwood, alder, cedar, and maple. Where the channel is bordered by the Mad River Road in the downstream portion, riparian vegetation is marginalized and lacking in overstory trees (river left, RM 2.98-3.16). The existing overstory of large mature trees and the established understory provide a shade canopy for the channel during summer months, except in patches adjacent to the Mad River Road. It is assumed that the riparian forest along the Mad River Road was removed during its construction. The well-vegetated floodplains and hillslopes upstream of the area confined by the Mad River Road offer large wood for recruitment potential to the mainstem channel.

Figure 56. Example of riparian forests in Reach 4 – at ~RM 4.0 looking downstream. (Photo: 10/26/2017)

Figure 57. Channel-spanning LWM jam at RM 3.18. (Photo: 11/9/2017)

A total of 137 pieces of wood were observed in the channel during the habitat survey (10/26/2017). Of those pieces, 31 classified as large size class (>20-inches dbh and >35 feet long), 43 as medium (12 to 20-inch dbh and at least 35 feet long), and 63 as small (9 to 12-inch dbh). Three large wood jams were counted and additional small wood accumulations were observed along the channel margins. A channel spanning large wood jam at RM 3.18 created a grade control pool and upstream gravel accumulations (Figure 57). See Figure 58 for distribution of quality large woody material (>12-in dbh and at least 35 feet long) per mapped habitat unit throughout the reach. Note that LWM distribution is correlated to less confined sections with vegetated floodplains. The availability of mature forests combined with lateral bank processes increases large wood recruitment potential in Reach 4 compared to downstream reaches.

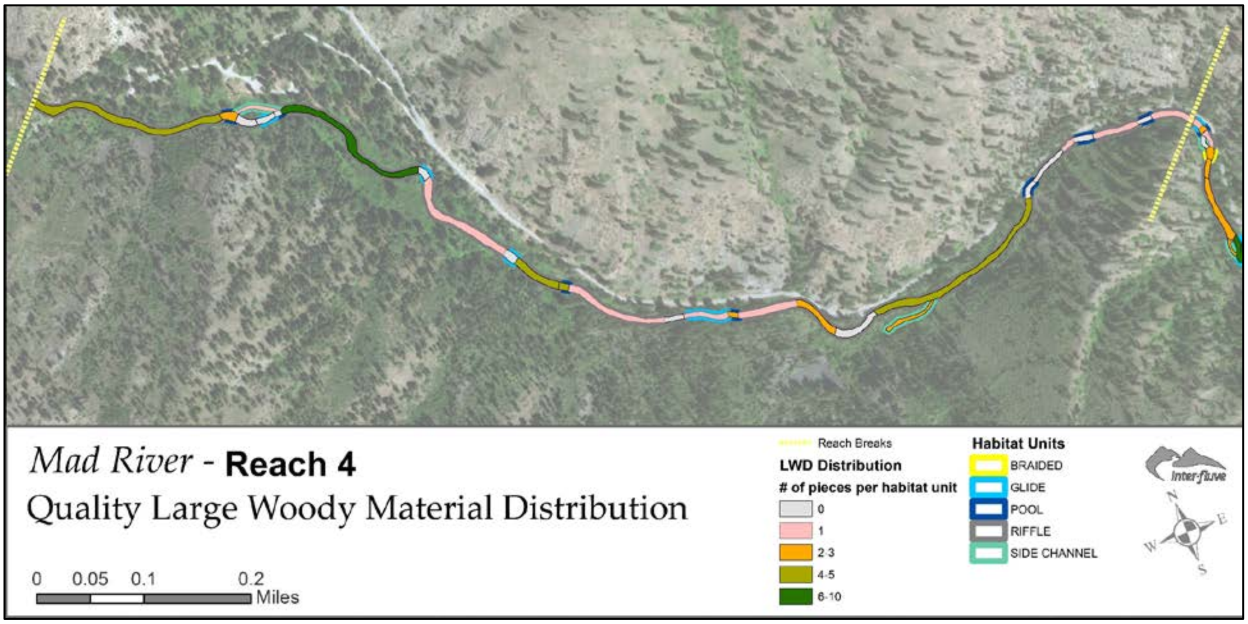

Figure 58. Reach 4 - Quality Large Woody Material (>12-inch dbh and at least 35 feet long) distribution by number of pieces per mapped habitat unit per the 2017 survey.

3.4.4 Human Alterations

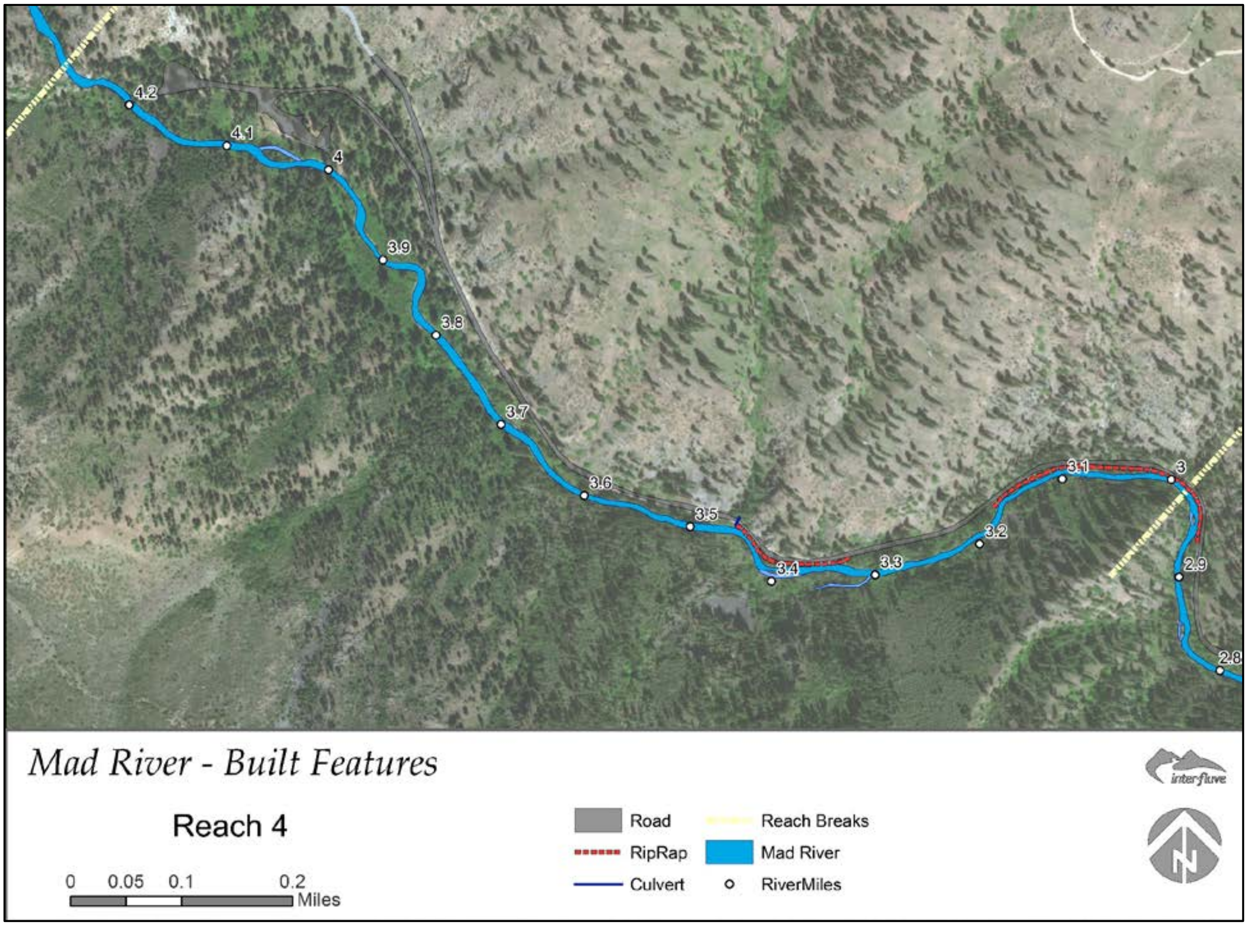

Figure 59. Reach 4: anthropogenic built features. Basemap: ESRI World Imagery

Anthropogenic features in Reach 4 include the Mad River Road, bank riprap, a culvert, Pine Flats Campground, and related vegetation management. The Mad River Road occupies up to half of the available valley floor from RM 2.98-3.16, exaggerating channel confinement. Between RM 3.34-3.46 the Mad River Road and its related bank rip rap border the channel in this less-confined section before it leaves the floor of the valley and continues upslope. A culvert passes hillslope surface water contributions under the Mad River Road at RM 3.16. Pine Flats Campground occupies the terrace and part of the floodplain on river left between RM 4.0 to 4.2. The campground includes cleared dirt and gravel roads, campsites, trails parking areas and a vaulted outhouse. It is unknown if water quality issues exist(ed) related to the campground and outhouse, which was converted from a pit house to vaulted in 2013, but the porosity of the floodplain material suggests that periodic testing may be warranted.

3.4.5 Recommended Actions

Recommended actions for Reach 4 are focused on increasing channel complexity and improving available aquatic habitat. These actions include riparian restoration, enhancing channel complexity, creating side/off channel habitat, and improving available aquatic habitat in the mainstem. All recommended actions are on public lands managed by the US Forest Service. Sustainability of the action treatment and protection of the Mad River Road was considered in selecting recommendations for this reach. Primary actions are installing small, medium and large-sized log jams, some with placed large boulders, in appropriate locations that take advantage of existing features or instigate geomorphic function to increase channel complexity and habitat quality. Constructing a new side channel, enhancing an existing side channel, and creating an alcove in existing functioning floodplains has the potential to notably increase available high-quality habitat within the reach.

Maps and more detailed descriptions of recommended treatments is provided in Section 4 of this report.

4. Restoration Strategy Framework

4.1 INTRODUCTION

The Restoration Strategy uses the field surveys, inventories, and analyses performed in the Reach Assessment (Sections 1-4) as the technical basis for identifying and prioritizing restoration actions. The intent is to provide a direct linkage between the technical analyses, identified limiting factors, and the actions that are moved forward towards implementation. At the core of the Restoration Strategy is the 'Gap Analysis', which compares existing and target conditions in order to identify and evaluate project opportunities. The existing and target conditions are obtained from the findings of the Reach Assessment and rely heavily on the REI ratings, although other factors are also considered. For each project area, existing and target conditions are compared, which helps to identify the types of actions that need to be performed and is also used as a factor in project ranking – i.e. the larger the 'gap' between existing and target conditions that can be addressed through restoration, the higher the project is ranked. Other factors are also considered, including the potential for the site to support the focal species and whether or not it is possible to address the root causes of impairments.

The Restoration Strategy describes the restoration opportunities identified in nine distinct project areas to address the identified limiting factors. Planform concept maps are included for each project area below the descriptions. The project area ranking and prioritization is included after the concept maps.

4.2 RESTORATION STRATEGY FRAMEWORK

An overview of the restoration strategy for the Lower Mad River is presented in Section 4.3. Following this, in Section 4.4, are the individual reach-scale restoration strategies. The information included in the reach-scale strategies is described in the subsections below.

4.2.1 Summaries of Reach Assessment Findings

For each reach, the summary of reach assessment findings distills the large amount of information contained in the Reach Assessment (Sections 1 – 3) into a snapshot summary for each reach. It includes a designation of good, moderate, or high for overall ecological function. The rationale for the designation is provided in the table. The summary also includes a description of the trajectory of the system if no action is taken. This is based primarily on the geomorphic analysis including current trends and the effects of land use. A rating of high, medium, or low is also provided for the recovery potential of the reach. This designation is based on the likelihood of being able to effectively address degraded processes and habitat based on the realities of current and anticipated land use, infrastructure, and ownership.

4.2.2 Restoration Objectives

Restoration objectives were developed for multiple ecological attributes, including habitat, geomorphic, and riparian. These objectives are presented as restoration targets. They are made to be as quantifiable as possible at this stage of analysis. These target conditions are compared to existing conditions from the Reach Assessment. This highlights habitat deficiencies and the "gap" that needs to be filled to recover habitat.

Target conditions were developed using the Reach-based Ecosystem Indicators (REI) targets (Appendix B) as well as reference to site conditions and inference from regional studies. The REI analysis is based on previous REI analyses conducted by the USBR and Yakama Nation in other Upper Columbia tributaries, with some modifications. See Section 2.6 of this report and Appendix B for more information on the REI analysis.

4.2.3 Restoration Action Types

Five restoration action types appropriate for the aquatic species and geomorphic processes of the Lower Mad River were developed for application in individual project areas within each reach. Action types are developed at a broad scale and are often achieved through the use of numerous project elements. For example, the action type "enhance channel complexity" might be achieved via numerous methods ranging from adding large wood to the channel to excavating inset floodplains. The specific project opportunities, on the other hand, are more site-specific and have unique characteristics (i.e. size of large wood jam), depending on the particular habitat conditions, land uses, geomorphic context of the site and existing infrastructure limitations.

We use the term 'restoration' as a broad catch-all when we refer to recommended actions; however, we acknowledge that many of the actions are not restoration in the true sense of the word, and would be more appropriately labeled as "enhancement" or "creation." We consider true restoration actions to be those that address root causes of impairments and that aim to return the system close to its naturally functioning state. This is often not achievable due to past changes to the underlying processes or to process impairments that are unlikely to change due to infrastructure. An example of a true restoration project would be a project that fully removes a levee, returns the channel to its historical form, and replants the valley floor to restore natural floodplain inundation patterns. Enhancement measures are those that improve or rehabilitate habitat to the extent possible given existing impaired processes and anthropogenic constraints. Placement of large wood in an existing pool to provide cover is an example of habitat enhancement. Installation of a large wood apex jam to encourage split flow conditions is an example of complexity enhancement. Creation projects are those that create new habitat that is currently lacking or that will not be created on its own in a reasonable timeframe given existing trends and process impairments. Excavating a backwater alcove into the floodplain is an example of a creation project.

The five action types recommended for the Lower Mad River assessment area are described below.

1. Riparian Restoration

Riparian restoration projects are located in areas where native riparian vegetation communities have been impacted by anthropogenic activities such that riparian function and connection with the stream are compromised. In the Lower Mad River assessment area riparian vegetation has been cleared for homes, campgrounds, agricultural purposes, bridges, levees, roads, and resource extraction. Restoration actions are focused on restoring native riparian vegetation communities in order to reestablish natural stream stability, stream shading, nutrient exchange, and large wood recruitment. Even though it is not always explicitly stated, riparian restoration is a recommended component of most restoration projects, particularly within the project's disturbance limits.

Examples:

- Replanting a riparian buffer area with native vegetation.
- Fencing out grazing animals along a riparian area that is being restored to minimize impacts on naturally regenerated and/or planted vegetation.

2. Remove Anthropogenic Materials

Removal of materials includes identifying and removing human-placed items currently impeding natural channel processes and/or habitat complexity. In the Lower Mad River, large sections of the channel bank and localized areas on the channel bed have been armored such that geomorphic processes are limited and habitat in marginalized. The removal of anthropogenic materials is aimed at reducing unnecessary bed and bank armoring from the active channel and/or its migration zone. Removing unnecessary materials is done with design to improve physical and biological conditions at the site. Selection and removal of such elements will need to consider potential bank or bed disturbance and remediation, resultant changes to channel stability, and flow hydraulics.

Examples:

- Remove collapsed cement bridge wall to eliminate unnatural bed armoring.
- Remove bank riprap (boulders, logs, metal, etc.) to promote potential lateral processes and riparian vegetation establishment.
- Remove levees to allow for more frequent lateral channel processes.

3. Enhance Channel Complexity

Channel complexity enhancement actions are aimed at increasing or improving existing channel geomorphology. This type of action will be designed to improve the geomorphic function of the system. These types of projects can span a broad range of actions but are installed in areas where they will naturally be maintained by the existing stream hydrology and geomorphology. Within the study area, these actions are focused where channel unit type is dominated by extended glides and riffles or where the channel is intrenched and/or leveed. Channel complexity enhancement actions are designed to also result in improved aquatic habitat.

Project examples:

- Strategically add an apex jam constructed of large wood and/or boulders to create mid-channel or side channel bars that promote split-flow features, sediment accumulations, and eventually reduce local channel width - thus maximizing channel-margin habitat and complexity.

- Installation of large wood jam to promote pool and bar development and/or lateral migration processes.
- Excavate inset floodplain along incised channel and plant with appropriate vegetation to improve floodplain connectivity and future wood/nutrient recruitment.

4. Improve Aquatic Habitat

This strategy includes placement of habitat structures such as large wood, log jams, and/or boulders in order to improve existing habitat features. The Lower Mad River is lacking in quality mainstem pool and spawning habitat. Aquatic habitat improvement projects can span a broad range of actions. For instance, a single log placement might be used in an existing pool to simply provide salmonid hiding cover. In contrast, a large constructed log jam might be used as a more function-based element that is intended to maintain pool scour while also providing habitat cover. The structural elements included in these actions, are placed in areas where they would naturally accumulate and be maintained by the existing stream hydrology and geomorphology. These projects are generally considered enhancement measures, as they do not fully restore the root cause of the problem (e.g. valley confinement due to road construction or lack of mature riparian vegetation due to floodplain clearing and home construction).

Examples:

- Installation of a large wood log jam to maintain pool scour, provide cover, and to increase quantity of available high velocity refugia for rearing.
- Installation of large wood jam and/or boulders to existing pool to improve and then maintain habitat conditions.
- Installation of large wood (channel spanning or jam) in an extended glide or riffle section of the channel to increase habitat complexity by adding step-pools, pools, or sediment accumulation features.

5. Side and Off Channel Habitat Creation or Enhancement

Off channel habitat creation or enhancement projects are located in areas where there is the potential to increase the quantity and quality of off channel aquatic habitat. The Lower Mad River is lacking in off-channel habitat. Off channel habitat provides rearing and refugia areas, especially during high-velocity flow periods. These projects may include the activation of existing habitat areas that have been disconnected via channel incision or floodplain alterations. In other cases, off channel areas can be created via excavation and construction of features such as alcoves and side channels. These actions generally include the enhancement or creation of habitat, rather than the full restoration of root causes of the lack of off-channel habitat.

Examples:

- Construct or enhance an alcove that is connected to the main channel.
- Construct or enhance a side channel that is connected to the main channel.
- Construct apex jam at mouth of existing high-flow side channel to maintain continued connectivity and increase available habitat.

4.2.4 Projects and Prioritization

Projects were identified through field surveys and analysis performed in the Reach Assessment. Project elements were identified that are believed to best achieve target conditions and to address key factors limiting ESA listed steelhead populations and improve their habitat conditions in the Lower Mad River. These projects represent an initial first step in this process; it is expected that projects will be modified as appropriate once project-specific surveys, analysis, and stakeholder coordination are performed as part of design. Project descriptions and maps are provided below.

Project prioritization was performed to rank the projects into three priority tiers. Prioritization occurred by subjecting the projects to a set of scoring criteria. These criteria are based on several factors, including how well projects address the “gap” between existing and target conditions, species use/potential use of the area, and whether or not projects address root causes of impairments. Projects are also given a cost score and feasibility designation in order to provide a relative cost perspective in project selection and planning.

4.3 RESTORATION STRATEGY OVERVIEW

An overview of the reach-scale conditions, recovery potential, identified projects within each reach, and recommended restoration action types are provided in Table 6. The ecological function (Low, Moderate, or High) of each reach is characterized by the ratings that resulted from the REI (see Appendix B). The trajectory (decline, same, improve) is determined by evaluation of the modern geomorphic trends, related existing habitat conditions, and continued limitations such as infrastructure and land-use (see Reach Assessments in Section 3). The recovery potential (Low, Moderate, and High) is based on the potential for the site to recover functioning habitat and processes with restoration actions. To do so, the potential for the REI indicator ratings to improve via restoration actions is considered. The recovery potential rating considers known limitations to recovery that are unlikely to be eliminated as part of implementation of this restoration strategy, such as the presence of transportation and residential infrastructure. Below, the project prioritization and recommended restoration action types for each project area are presented.

Table 6. Overview of restoration strategy for the Lower Mad River (Reaches 1-4).

Reach	Ecological Function	Trajectory	Recovery Potential	Prioritization (Tier 1-3)	Project Area	Restoration Action Type
1	Low	Decline	Moderate-High	1	Lower Ardenvoir	1,2,3,4
				1	Upper Ardenvoir	1,2,3,4
				1	Ardenvoir Bridge	1,2,3
2	Low	Decline	Moderate - High	2	Moe	1, 4
				1	Rothrock	1,3,4,5
				3	French Corral	1,3,4
3	Low	Same	Moderate	3	Mad Tyee 1	1,3,4
				2	Mad Tyee 2	1,3,4,5
4	Moderate	Same or Improve	High	2	Gold	1,3,4,5
				2	Pine Flats	1,3,4,5

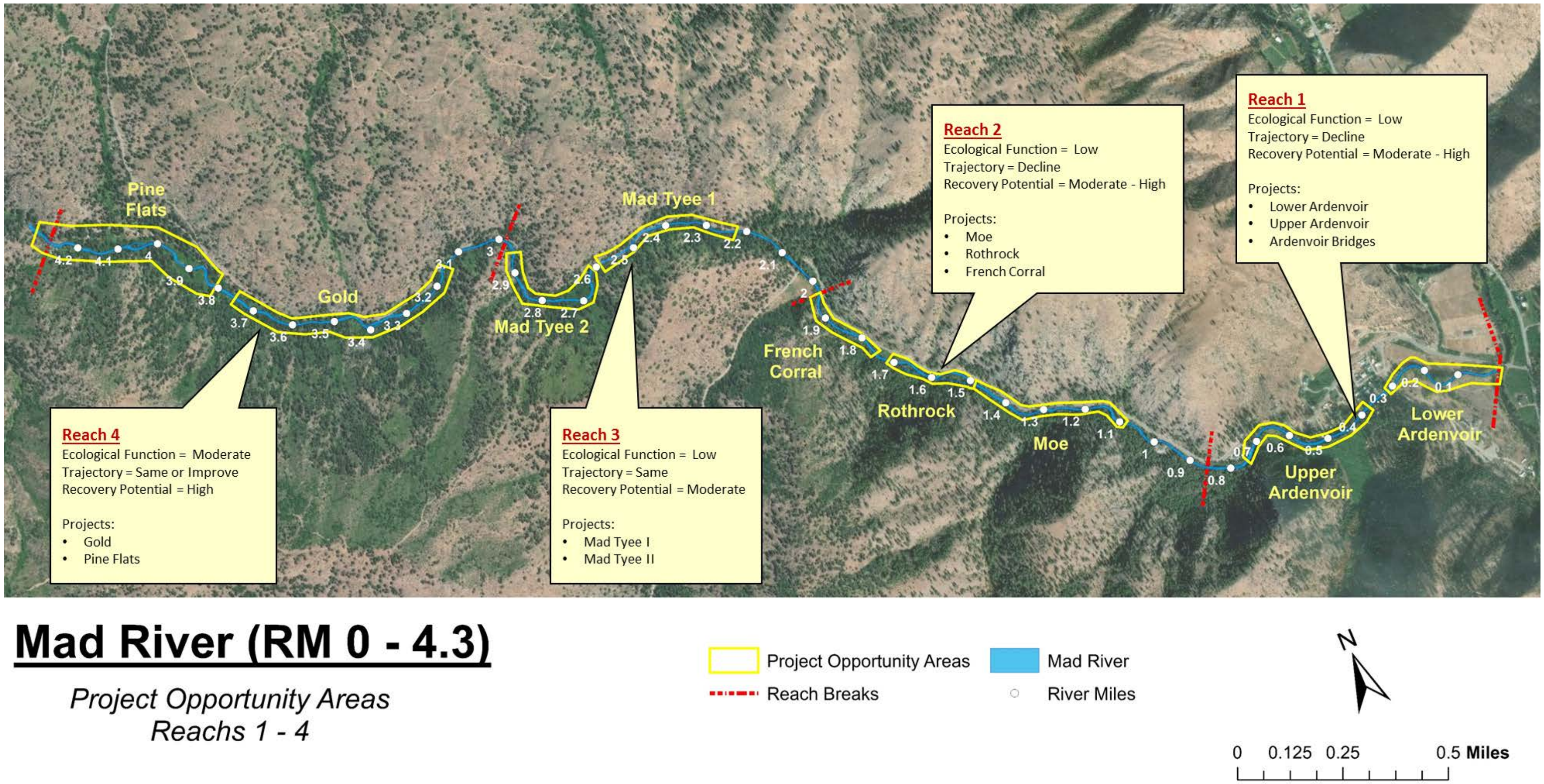

Figure 60. Lower Mad River reach-based restoration strategy overview. Basemap: ESRI

4.4 REACH-SCALE STRATEGIES

4.4.1 Reach 1 Restoration Strategy

Overall ecological function	Low
	Rating is based on the Reach Assessment evaluations of habitat, geomorphology, hydrology, hydraulics, and vegetation. 11 of 11 REI metrics are at risk or unacceptable. Significant impairment of channel and floodplain function due to channel entrenchment and constructed levee, riparian vegetation clearing, potential fish passage barrier, few pools and none ≥ 3-ft deep, minimal habitat complexity, limited desirable substrate, lack of large wood in the channel, and no off-channel habitat.
Trajectory if no action taken	**Decline**
	Continued degradation due to persistent anthropogenic impacts to floodplain, channel migration and entrenchment, riparian, and large wood processes. Some minimal passive recovery of riparian shade function due to vegetation establishment at channel margins. The 2018 Cougar Creek Fire burned the Mad River basin upstream of Reach 2. This has the potential to increase wood and sediment loading to the system.
Recovery potential	**Moderate to High**
	Available floodplain area if reactivation treatments are installed in downstream section. Increased habitat complexity potential via increased scour pools and added large wood. Available habitat for Mad and Entiat River fishes.
Restoration objectives	**Target conditions in Table 7**
	Bring existing conditions to target conditions (multiple habitat and geomorphic attributes), where possible, for the metrics identified in Table 7 below. To the extent possible at this stage of planning, the targets are presented as measurable quantities.
Action Types	**Riparian Restoration** **Remove Anthropogenic Materials** **Enhance Channel Complexity** **Improve Aquatic Habitat**
	Actions include enhancement/improvement of channel complexity and aquatic habitat as well as removing materials from the channel and floodplain to restore function. Full restoration is limited by existing private land ownership and homesites.
Project Areas & Prioritization	**Lower Ardenvoir (Tier 1)** **Upper Ardenvoir (Tier 1)** **Ardenvoir Bridges (Tier 1)**
	The potential to improve the quantity and quality of available habitat in Reach 1 is moderate to high. The Lower Ardenvoir project area has high potential due to minimal occupancy on the floodplain--which may allow for levee removal, large wood installations, and floodplain set-back potential. Homes and infrastructure limit recovery potential in Upper Ardenvoir to moderate. All Reach 1 project areas are complimentary to each other but would provide habitat and function benefits if completed independently.

Table 7. Reach 1 Restoration Objectives, Action Types, and Projects.

Attribute	Existing Condition (from assessment)	Target Condition [REI – Adequate Rating]	Action Type	Project
Habitat Access	The irrigation out-take weir at RM 0.27 and man-made boulder weir at 0.75 may pose a velocity or passage barrier at high or very low flows.	No man-made barriers present in the mainstem that limit upstream or downstream migration at any flow.	Remove Anthropogenic Materials	Lower Ardenvoir Upper Ardenvoir
Habitat Quality	Cobble dominated substrate; gravels/sands on bars only. 0 pieces of LW per mile. 4.6 pools per mile with 0 pools > 1m (3ft) and low pool shade/cover. No side-channel or off-channel refugia	Gravels or small cobbles make up >50% of the bed materials in spawning areas and ≤12%fines/sand (<2 mm) in spawning gravel. At least 32 pieces/mile of large wood and sources for LW recruitment. Pool frequency of 23/mile with ≥50% of pools ≥1m (3ft) deep and good fish cover and cool water. Contains side or off-channel refugia.	Remove Anthropogenic Materials Enhance Channel Complexity Improve Aquatic Habitat	Lower Ardenvoir Upper Ardenvoir
Riparian Condition	Forested riparian buffer is only 20-75ft: 50% large trees; 30.7% disturbed; 42% canopy cover for thermal shading; and 10.7 mile/miles^2 road density within 200-ft riparian buffer	At least a 200-ft riparian buffer with: > 80% mature trees, or consistent with potential native community < 20% riparian disturbance (human) > 80% canopy thermal coverage; and <1 mile/miles^2 road density	Riparian Restoration Remove Anthropogenic Materials Enhance Channel Complexity	Lower Ardenvoir Upper Ardenvoir
Channel Dynamics	Channel entrenchment & floodplain disconnection throughout exaggerated by levees, roads, riprap, and bridges. No to minimal lateral migration occurring due to human built features and probable bed excavation to build levees. Continued incision is possible but will not be rapid.	Floodplain areas are hydrologically linked to main channel within the context of the local process domain. Channel is migrating at or near natural rates within the geomorphic construct of the reach. No measurable trend of aggradation or incision beyond the natural geomorphic processes of the reach	Riparian Restoration Remove Anthropogenic Materials Enhance Channel Complexity Improve Aquatic Habitat	Ardenvoir Bridges Lower Ardenvoir Upper Ardenvoir

4.4.2 Reach 2 Restoration Strategy

Overall ecological function	Low
	Rating is based on the Reach Assessment evaluations of habitat, geomorphology, hydrology, hydraulics, and vegetation. 10 of 11 REI metrics are at risk or unacceptable. Significant impairments due to limited desirable substrate, channel confinement, riparian vegetation age and cover, few pools and only one ≥ 3-ft deep, minimal habitat complexity, lack of large wood in the channel potential fish passage barrier, and no off-channel habitat.
Trajectory if no action taken	**Decline**
	Continued degradation due to anthropogenic impacts that impeded channel migration and large wood processes. Some passive recovery of riparian function due to maturing vegetation on floodplain pockets. Channel incision and lack of complexity expected to continue due to valley and channel confinement (Mad River Rd and bridge crossings), and lack of large wood in the channel. The 2018 Cougar Creek Fire burned the Mad River basin upstream of Reach 2. This has the potential to increase wood and sediment loading to the system.
Recovery potential	**Moderate - High**
	If complexity added (side channels and large wood) and riparian vegetation permitted to mature, then high potential for improved quantity and quality of habitat. Connected floodplains are developing. Mad River Rd. confinement limits full recovery potential (moderate).
Restoration objectives	**Target conditions in Table 8**
	Bring existing conditions to target conditions for the habitat and geomorphic metrics identified in Table 8 below. These targets apply to multiple habitat and geomorphic attributes. To the extent possible at this stage of planning, the targets are presented as measurable quantities.
Action Types	**Riparian Restoration** **Remove Anthropogenic Materials** **Enhance Channel Complexity** **Improve Aquatic Habitat** **Side and Off-Channel Habitat Creation or Enhancement**
	Actions include enhancement/improvement of channel complexity and aquatic habitat as well as create side-channel habitat. Full restoration is limited by existing infrastructure (Mad River Rd and bridge crossings).
Projects & Prioritization	**Moe (Tier 2)** **Rothrock (Tier 1)** **French Corral (Tier 3)**
	Reach 2 has mixed (high-low) restoration potential. The greatest potential is associated with creating side channels within existing floodplains (Rothrock). Increasing channel complexity and available habitat (LW jams and boulders) at hydraulically and geomorphically appropriate locations results in a moderate (Moe) and low (French Coral) restoration potential within existing infrastructure constraints.

Table 8. Reach 2 Restoration Objectives, Action Types, and Projects.

Reach 2 Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Habitat Access	Cement slab on bed of channel at RM 1.32 may pose passage barrier at certain flows.	No man-made barriers present in the mainstem that limit upstream or downstream migration at any flow.	Remove Anthropogenic Materials	Moe
Habitat Quality	Cobble dominated substrate with boulders; gravels and sand in eddies and on boulder tailouts only. 20.5 pieces of LW per mile. 7.5 pools per mile with 1 pool (13%) > 1m (3ft) and low pool shade/cover. No side-channel or off-channel refugia	At least 32 pieces/mile of large wood and sources for LW recruitment. Pool frequency of 23/mile with ≥50% of pools ≥1m (3ft) deep and good fish cover and cool water. Contains side or off-channel refugia.	Enhance Channel Complexity Improve Aquatic Habitat Side and Off-Channel Habitat Creation	Moe Rothrock French Corral
Riparian Condition	Riparian buffer composition: 33% large trees; 87% disturbed; 42% canopy cover for thermal shading; and 12.6 mile/miles^2 road density within 200-ft riparian buffer	At least a 200-ft riparian buffer where road does not exist with: > 80% mature trees, or consistent with potential native community < 20% riparian disturbance (human) > 80% canopy thermal coverage; and <1 mile/miles^2 road density	Riparian Restoration	Moe Rothrock French Corral
Channel Dynamics	Road with riprap bank and bridge reduce width of valley floor and confine lateral channel processes. Inset small floodplain pockets are connected to the channel. Incision at bridge (RM 0.98) expected to continue. Lack of LW and increased confinement reduces sediment retention and promotes incision.	Floodplain areas are hydrologically linked to main channel within the context of the local process domain. Channel is migrating at or near natural rates within the geomorphic construct of the reach. No measurable trend of aggradation or incision beyond the natural geomorphic processes of the reach	Enhance Channel Complexity Improve Aquatic Habitat	Moe Rothrock French Corral

4.4.3 Reach 3 Restoration Strategy

Overall ecological function	**Low**
	Rating is based on the Reach Assessment evaluations of habitat, geomorphology, hydrology, hydraulics, and vegetation. 8 of 11 REI metrics are at risk or unacceptable. Significant impairments due to limited desirable substrate retention, channel and valley confinement (Mad River Rd), riparian vegetation age and cover, few pools and none ≥ 3-ft deep, minimal habitat complexity, lack of large wood in the channel and minimal off-channel habitat.
Trajectory if no action taken	**Same**
	Ecologic function is expected to remain the same under existing conditions. The 2018 Cougar Creek Fire burned the Mad River basin in Reach 3. This has the potential to increase wood and sediment loading. Restoration actions should take advantage of these inputs by designing features that capture and utilize them.
Recovery potential	**Moderate**
	Roadway and related riprap impacts are likely to remain. Bridge at downstream end of reach will likely remain (Tillicum Rd Bridte). Potential to add complexity to existing channel with large wood placement and creation of off-channel habitat.
Restoration objectives	**Target conditions in Table 9**
	Bring existing conditions to target conditions for the habitat and geomorphic metrics identified in Table 9 below. These targets apply to multiple habitat and geomorphic attributes. To the extent possible at this stage of planning, the targets are presented as measurable quantities.
Action Types	**Riparian Restoration** **Enhance Channel Complexity** **Improve Aquatic Habitat** **Side and Off-Channel Habitat Creation or Enhancement**
	Actions include enhancement/improvement of channel complexity and aquatic habitat as well as creation of off-channel habitat. Full restoration is limited by existing infrastructure (Mad River Rd and Tillicum Rd Bridge).
Projects & Prioritization	**Mad Tyee I (Tier 3)** **Mad Tyee II (Tier 2)**
	There is moderate restoration opportunities and recovery potential in this reach. The reach is easily accessible and located on public lands with infrastructure limited to the Mad River Rd and downstream Tillicum Rd Bridge. Adding off-channel alcove habitat (Mad TyeeI 2) and large wood/boulders in appropriate locations will increase channel and habitat complexity. Large wood jams and boulders can take advantage of sediment and wood loading that may occur as a result of the 2018 Cougar Creek Fire.

Table 9. Reach 3 Restoration Objectives, Action Types, and Projects.

Reach 3 Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Habitat Access	There are no anthropogenic barriers in the main channel.	No man-made barriers present in the mainstem that limit upstream or downstream migration at any flow.	No action needed	
Habitat Quality	Cobble dominated substrate with boulders; gravels and sand in eddies and on boulder tailouts only. 41.9 pieces of LW per mile. 2.9 pools per mile with 0 pools > 1m (3ft) and low pool shade/cover. Two existing side-channel with moderate cover.	Gravels or small cobbles make up >50% of the bed materials in spawning areas and ≤12%fines/sand (<2 mm) in spawning gravel. At least 32 pieces/mile of large wood and sources for LW recruitment. Pool frequency of 23/mile with ≥50% of pools ≥1m (3ft) deep and good fish cover and cool water. Contains side or off-channel refugia.	Enhance Channel Complexity Improve Aquatic Habitat Side/Off-channel Habitat Creation or Enhancement	Mad Tyee 1 Mad Tyee 2
Riparian condition	Riparian buffer composition: 100% small trees; 5.1% disturbed; 54% canopy cover for thermal shading; and 13 mile/miles^2 road density within 200-ft riparian buffer	At least a 200-ft riparian buffer where road does not exist with: > 80% mature trees, or consistent with potential native community < 20% riparian disturbance (human) > 80% canopy thermal coverage; and <1 mile/miles^2 road density	Riparian Restoration	Mad Tyee I Mad Tyee II
Channel Dynamics	Bridge and walls for an historical dam at downstream end confine channel and disconnect local Tillicum fan surface. Small floodplain pockets are connected. Road with riprap bank reduces available valley floor and confines lateral processes. Past incision from bridge, dam, and road occurred but presence of large boulders limits continued incision.	Floodplain areas are hydrologically linked to main channel within the context of the local process domain. Channel is migrating at or near natural rates within the geomorphic construct of the reach. No measurable trend of aggradation or incision beyond the natural geomorphic processes of the reach	Enhance Channel Complexity	Mad Tyee I Mad Tyee II

4.4.4 Reach 4 Restoration Strategy

Overall ecological function	**Moderate**
	Rating is based on the Reach Assessment evaluations of habitat, geomorphology, hydrology, hydraulics, and vegetation. 4 of 11 REI metrics are at risk or unacceptable. Impairments of channel include lack of desirable sediment retention, lack of large wood, few pools and only one ≥ 3ft deep, limited off-channel habitat, and poor riparian structure and cover.
Trajectory if no action taken	**Same or Improve**
	Ecologic function is expected to remain the same under existing conditions. The 2018 Cougar Creek Fire burned the Mad River basin in Reach 4. This has the potential to increase wood and sediment loading. Restoration actions should take advantage of these inputs by designing features that capture and utilize them. Riparian and floodplain vegetation impacts of the fire may take an extended period of time to recover from.
Recovery potential	**High**
	Only the downstream section of Reach 4 is constricted by the Mad River Rd. Pine Flats campground may limit some actions in upstream-most section. Riparian vegetation includes mature trees in upstream section. Sediment inputs and large wood sources available. Functioning and available floodplains to create/enhance side-channel and off-channel habitat features.
Restoration objectives	**Target conditions in Table 10**
	Bring existing conditions to target conditions for the habitat and geomorphic metrics identified in Table 10 below. These targets apply to multiple habitat and geomorphic attributes. To the extent possible at this stage of planning, the targets are presented as measurable quantities.
Action Types	**Riparian Restoration** **Enhance Channel Complexity** **Improve Aquatic Habitat** **Side and Off-Channel Habitat Creation or Enhancement**
	Actions include enhancement/improvement of channel complexity and aquatic habitat as well as creation and enhancement of side and off-channel habitat.
Projects & Prioritization	**Gold (Tier 2)** **Pine Flats (Tier 1)**
	There is good restoration opportunities and high recovery potential in this reach. Portions of the reach are accessible via Mad River Rd (downstream) and Pine Flats campground (upstream) and located on public lands. Adding off-channel alcove habitat (Gold), side-channels (Pine Flats) and large wood/boulders in appropriate locations will increase channel and habitat complexity. Large wood jams and boulders can take advantage of sediment and wood loading that may occur as a result of the 2018 Cougar Creek Fire.

Table 10. Reach 4 Restoration Objectives, Action Types, and Projects.

Reach 4 Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Habitat Access	There are no anthropogenic barriers in the main channel.	No man-made barriers present in the mainstem that limit upstream or downstream migration at any flow.	No action needed	
Habitat Quality	Cobble, gravel, boulder substrate with plentiful gravels and small boulders on bars, tail-outs, and behind LW jams. 56.1 pieces of LW per mile. 5.3 pools per mile with 1 (14%) pools > 1m (3ft) and low pool shade/cover. Two existing side-channel with moderate cover.	Gravels or small cobbles make up >50% of the bed materials in spawning areas and ≤12%fines/sand (<2 mm) in spawning gravel. At least 32 pieces/mile of large wood and sources for LW recruitment. Pool frequency of 23/mile with ≥50% of pools ≥1m (3ft) deep and good fish cover and cool water. Contains side or off-channel refugia.	Enhance Channel Complexity Improve Aquatic Habitat Side/Off channel Habitat Creation or Enhancement	Gold Pine Flats
Riparian condition	Riparian buffer composition: 57% mature trees and 14% large trees; 4.7% disturbed; 43% canopy cover for thermal shading; and 9.5 mile/miles^2 road density within 200-ft riparian buffer	At least a 200-ft riparian buffer with: > 80% mature trees, or consistent with potential native community < 20% riparian disturbance (human) > 80% canopy thermal coverage; and <1 mile/miles^2 road density	Riparian Restoration	Gold Pine Flats
Channel Dynamics	Connected floodplains occur where valley width occurs. Road with riprap bank limits valley width and lateral processes at downstream end. Evidence of sediment delivery from tributaries and hillslopes.	Floodplain areas are hydrologically linked to main channel within the context of the local process domain. Channel is migrating at or near natural rates within the geomorphic construct of the reach. No measurable trend of aggradation or incision beyond the natural geomorphic processes of the reach	Enhance Channel Complexity Side/Off channel Habitat Creation or Enhancement	Gold Pine Flats

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Appendix A

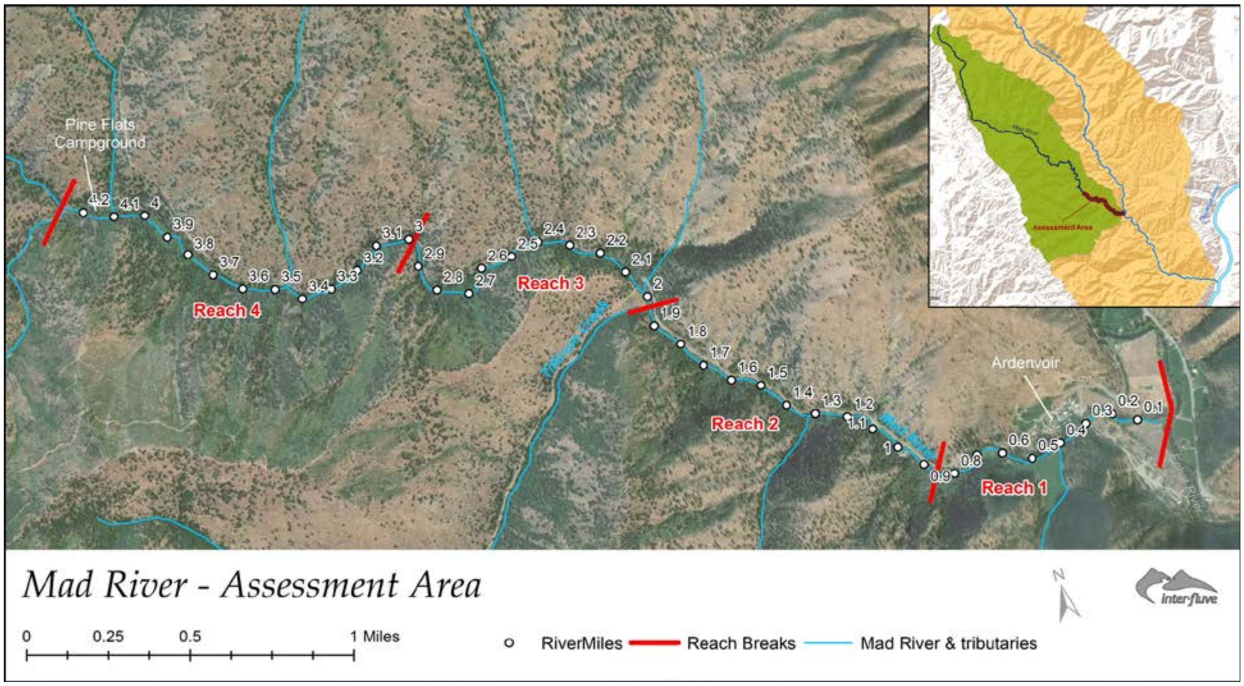
Stream Habitat Assessment

Lower Mad River Reach Assessment (RM 0-4.3)

December 2018

Habitat Inventory *Survey: October 24 – October 26, 2017*

Table of Contents



1 Introduction & Background

The Mad River is located within the eastern foothills of the Cascade Mountains in central Washington along the western border of the Columbia Plateau. The Mad River is approximately 23 river miles long from its headwaters to its confluence with the Entiat River. Flowing southeast through the foothills, it joins the Entiat River approximately 11 river miles (RM) upstream of where the Entiat meets the Columbia River. The Lower Mad River Reach Assessment and Restoration Strategy evaluates existing aquatic habitat and watershed process conditions along the lower 4.3 miles of the Mad River and was completed on behalf of the Yakama Nation as part of their efforts to improve native aquatic fisheries within the Columbia River Basin. As part of the assessment process, Inter-Fluve conducted a salmon habitat survey of the Lower Mad River from October 24 to 26, 2017 from RM 0 (confluence with the Entiat River near Ardenvoir, WA) to RM 4.3 (near Pine Flats Campground). A flow rate of 38.3 cfs was measured in the field on October 24th at the downstream boundary. A flow rate of 27.9 cfs was measured in the field on October 25th in Reach 3 above the Tillicum Creek confluence with Mad River. Insignificant precipitation was received over the survey period and visual estimates of flow did not vary with the exception of contributions from tributary sources. Stream flow was not otherwise measured as part of this survey.

The objective of the Habitat Assessment is to characterize the habitat quantity and quality for salmonid species native to the Mad River by quantifying specific in-channel morphologic feature types, characterizing riparian conditions, and identifying anthropogenic features influencing aquatic habitat. This information is used to inform potential restoration and conservation actions and will provide a baseline for evaluating future habitat trends and/or measuring the effectiveness of restoration efforts to improve the quantity and quality of available habitat within the study area.

1.1 COMPARISON TO PREVIOUS SALMON HABITAT ASSESSMENTS

The earliest known record of a fisheries and habitat assessment on the Mad River is from a 1934 Bureau of Fisheries stream survey. Stream surveys by the Wenatchee National Forest (WNF) have occurred on various portions of the Mad River in 1972, 1990, 1995, and 1997.

A modified Hankin-Reeves approach (Region 6 USFS standard stream survey protocol) was used for the stream surveys since the 1990s, facilitating the capacity for a relatively direct comparison of recent historical data to the present stream habitat survey. The 1990 survey was from the mouth of the Mad River to Blue Creek (approximately RM 23), the 1995 survey was from the mouth to Young Creek (approximately RM 12.5), and the 1997 survey was done from Young Creek to Blue Creek.

Additional analyses in the greater Entiat basin include the Entiat Tributary Assessment (U.S. Bureau of Reclamation 2009), Entiat Subbasin Plan (Peven et. al, 2004), Lower Entiat Reach Assessment (USBR 2012), Columbia Habitat Monitoring Program (CHaMP) surveys of four small segments within the study area (2011-2016), and the Geomorphic Assessment of the Entiat Subbasin (Terraqua 2017). Further information on the Mad River can be found in the Mad Lake Survey (Rich and Jayson 1995), Wenatchee National Forest bull trout monitoring reports (Nelson, Kelly-Ringel, and Nelle 2008; Nelson 2013), WSFWS Chinook salmon spawning ground surveys (Hamstreet 2012; Hamstreet 2010), and in recent Intensively Monitored Watershed (IMW) reports for the Entiat and Mad Rivers (Johnsen et al. 2013; Potter et al. 2015; Potter et al. 2013). Some discussion of historic surveys and other aquatic data for the Mad River is included throughout this report, and a brief summary of the 1995 stream assessment results will be provided here, but for more information on the historical conditions in the Mad River the reader is encouraged to see the original aforementioned documents.

1.1.1 1995 Wenatchee National Forest Stream Inventory – Results Summary

In the 1995 stream survey by WNF (Rich and Jayson 1995), the river segment between the mouth of the Mad River (RM 0) and Pine Flats Campground (approximately RM 4.3) is referred to as Reach I. This is equivalent to the spatial extent of the current 2017 stream survey (described here) that recognizes four geomorphic reaches. The 1995 data is compared to the project area summary results of the 2017 data presented here.

In the 1995 survey, discharge of the Mad River on August 31 was measured at 45.3 cfs at Mill Camp Bridge in Ardenvoir (at RM 0.3). The average stream wetted width was 33 feet, with 7 pools per mile and an average residual pool depth of 1.6 feet. The number of large woody material was low; of 18 recorded pieces, 17% fell in the "large" category and 33% was classified as "small." A majority (93%) of the habitat (presented as stream surface area in the 1995 report) was categorized as riffle habitat with only 5% pool habitat and a low amount (2%) of side channels and other types of habitat, such as “falls.”

In 1995, riparian vegetation consisted of sparse overstory trees dominated by alder with an occasional willow, redosier dogwood, cottonwood, and cedar. Upslope vegetation was described as Douglas fir-Ponderosa pine stand interspersed with open areas. Orchards and lawns were the primary floodplain vegetation in the section closest to the confluence near Ardenvoir. It was estimated that the upper 20% of the riparian and surrounding vegetation in this reach were burned in the 1994 Tyee Fire.

In 1995, the dominant streambed substrate was reported as cobble, with gravel as a subdominant. The side slopes were noted as steep (65-70%) and the channel gradient ranged between one and four percent slope. One chinook redd was observed (along with a chinook carcass). Potential spawning gravels for rainbow and bull trout were reported as scattered from RM 0 to RM 4.3. Fish hiding cover was low and was predominantly provided by substrate, with a small amount provided by turbulence. Rainbow trout were also observed.

In the 1995 survey, stream shade throughout the reach (RM 0-4.3) was relatively low (< 30%) and human disturbances rated as high. The greatest impacts noted in the survey include water diversions, garbage dumping, heavy fishing pressures, and channel confinement due to roads and residential uses.

2 Methods

In this habitat assessment, the study area (Lower Mad River RM 0--4.3) was subdivided into four geomorphic reaches. The same reach delineations were used for both this habitat assessment as well as the geomorphic reach assessment and restoration strategy (see main report).

This survey employed the methods outlined in the US Forest Service Region 6 Level I & II Stream Inventory Handbook, Version 2.15 (USFS, 2015) and the "Eastside" protocol was used. All protocols were followed when safe, and most of the suggested forest inventory options were applied in the survey. However, due to the late-season timing and the arrival of inclement weather conditions, the survey had to be completed at discharge values slightly above summer base-flow and within a short time-frame. As a result, some of the USFS (USFS, 2015) protocols were adapted for safety purposes.

The survey protocol adaptations made in the field specifically for this survey are as follows: All reach and habitat unit lengths were measured in GIS from field recorded GPS data collected with a high-accuracy Trimble GeoExplorer GPS unit instead of measuring the distance between unit breaks with a tape in the field; Water temperature was only recorded once per day as ambient air temperature was in the 40s °F and therefore negated capturing water temperature at baseflow and the potential exceedances of seasonal water quality standards. Stream discharge was measured at the downstream border of the study area at the beginning of the survey and again upstream of the Tillicum Creek confluence.

The n^{th} channel unit (riffle, pool, glide) measurement frequency applied in the field for data collection initially was 100% for pools (due to the very low frequency of pool habitat units) and approximately 30%, or 1 unit measured in every 3, for fast-water units (riffles and glides). Following USFS protocol, once adequate nth channel units had been measured, the measurement frequency dropped to every 2^{nd} unit for pools and every 5^{th} unit (or one in five) for fast-water units. This choice was made to ensure that the n^{th} unit measurements were representative of the field area. In total, 30 n^{th} units were measured in Reaches 1-4.

At n^{th} units, the surveyors performed an ocular estimate of the wetted channel width and flood-prone width, and also measured the wetted channel width with a 100-foot tape. At every channel unit measured, the length of unstable bank was estimated for both the left and right channel banks. Depth of pools, riffles, and glides was measured using a graduated stadia rod carried by the observer. Where water velocity or depth was unsafe for surveying (e.g. excessively deep pools), the observer either estimated depth and/or measured as close to the thalweg as possible.

For the riparian vegetation measurements, it is a "Forest Option" to designate a riparian corridor as either a single 100-ft wide zone or two adjacent riparian zones (inner and outer zones) totaling 100 feet in width (USFS, 2015). For this assessment, one single 100-ft wide riparian zone was designated for the Lower Mad River study area. Survey methods dictate defining a dominant size class of vegetation type within the riparian corridor (e.g. small trees, shrubs), then defining the dominate species observed in the overstory and understory. Survey protocol differed from USFS protocol by collecting a dominant overstory and understory size class within the 100-foot wide riparian zone in addition to species. Six additional riparian vegetation survey measurements were recorded in a few non-n^{th} units throughout the study area where dominant vegetation type changes were noted to support the riparian vegetation assessment.

For each of the four reaches, two gravel counts were completed by the habitat team to characterize the size distribution of sediment. In total, eight gravel counts were completed. Criteria for gravel count locations state that they must be representative of the general character of the individual reach and completed at a representative glide to riffle transition point. Due to safety reasons associated with extremely cold water and air temperatures as well as depth of water at the time of the survey, gravel counts were conducted on exposed point bars. This protocol modification provides data that represents the bedload wash at hydraulically-reduced accumulation zones within the mainstem channel. Mainstem channel substrate composition was characterized with ocular observations provided in Section 4 of the Reach Assessment.

For this habitat survey, we use the USFS protocols (USFS, 2015) to define habitat unit types. Pools are “slow water” units that include dam, scour, or plunge pools. Riffles are “fast water – turbulent” features that are most commonly relatively shallow and glides are “fast water -nonturbulent” units. We considered “side-channels” as naturally wetted flow paths connected to the mainstem channel at their upstream and downstream ends at average annual flow. Side channel units were identified when the main channel split to form a stable island with soil or fine sediment accumulations and with establishing vegetation older than 2 to 3 years. Each side channel was determined to be fast or slow, and its average width and length measured. Both total and wetted lengths were recorded using GPS and a 100-ft tape. Wetted lengths are used in this report unless otherwise noted.

A “braided” channel unit is defined as a series of three or more roughly parallel channels separated from each other by active bars during lower flows but relatively connected during bankfull flows. Within the assessment area for this survey only one “braided” unit was observed -- in Reach 3. All other channel unit designations (riffle, pool, glide, side-channel) were considered single-threaded.

Large woody material (LWM) was counted in the mainstem and side channels following the size class characterizations for “Eastside” forests. The forest option to count large wood pieces in the small size category was used. Tallies of Small (> 6 in. diameter, >20 ft long), Medium (>12 in. diameter, > 35 ft long) and Large (>20 in. diameter, >35 ft long) pieces of Large Wood were completed for each reach. For this report, Medium and Large pieces of LWM will be collectively referred to as “Quality Large Wood.” Only four log jams were identified within the study area, one in Reach 2 and the remainder in Reach 4. Open-water wetlands on floodplains were not observed, measured, or recorded.

3 Summary of Results

This section summarizes the results of the four channel reaches surveyed from October 24 to 26, 2017 between RM 0 to 4.3 on the Mad River. Detailed descriptions of the survey results from the individual reaches are included in Section 4 of this report.

3.1 CHANNEL MORPHOLOGY

The surveyed reaches in the Lower Mad River are dominated by extended riffle-cascade morphology with infrequent step pools. In general, channel form is single thread with a sinuosity ≤ 1.2 (straight to sinuous). Much of Reach 1 (RM 0-0.86) is entrenched and leveed while most of Reaches 2, 3, and the downstream half of Reach 4 (RM 0.68-3.6) experience exaggerated valley confinement as a result of the Mad River Road. Overall, sediment surveyed at point bars consisted primarily of gravels (29-75%) and cobbles (22-57%) with 0-9% sand, 0-6% boulder, and 0% bedrock. Observed mainstem channel substrate was dominated by cobbles with minor gravels and boulders. Bedrock contacts (25-100 feet long) occur along the right bank of the channel at RM 2.65, 2.91, 3.0, 3.09, 3.4 and 4.3. Boulder colluvium occurs along the river right side of the channel at the toe of most other confining hillslope contacts.

Channel geometry varied within the study area. Mean bankfull depths ranged from 2.6 feet in Reach 1 to 3.7 feet in Reach 3 (Table 2) and widths ranged from 41 feet in Reach 1 to 52.5 feet in Reach 4 (Table 1). The typical downstream increasing trend in bankfull width/depth is not clearly observed in the data as a result of protocol measurement distribution and statistical averaging. A narrower bankfull width in Reach 1 compared to upstream reaches is the result of anthropogenic confinement. Floodprone widths reflect both geomorphic surface changes within the study area and human influenced incision (Table 3). Average floodprone width is greatest in Reaches 1 and 3 and the smallest average floodprone width was recorded in Reach 2.

Table 1. Lower Mad River bankfull width results from habitat assessment.

Bankfull Widths (feet)				
	Reach 1	**Reach 2**	**Reach 3**	**Reach 4**
Max	46	55	60	53
Min	38	46	40	52
Mean	41.0	51.3	48.0	52.5
St Dev	3.5	3.6	7.9	0.7

Table 2. Lower Mad River bankfull depth results from habitat assessment.

Bankfull Depths (feet)				
	Reach 1	**Reach 2**	**Reach 3**	**Reach 4**
Max	3.7	4.7	5.5	5
Min	0.9	0.6	1.8	1.4
Mean	2.6	2.7	3.7	3.2
St Dev	0.7	1.0	0.9	0.9

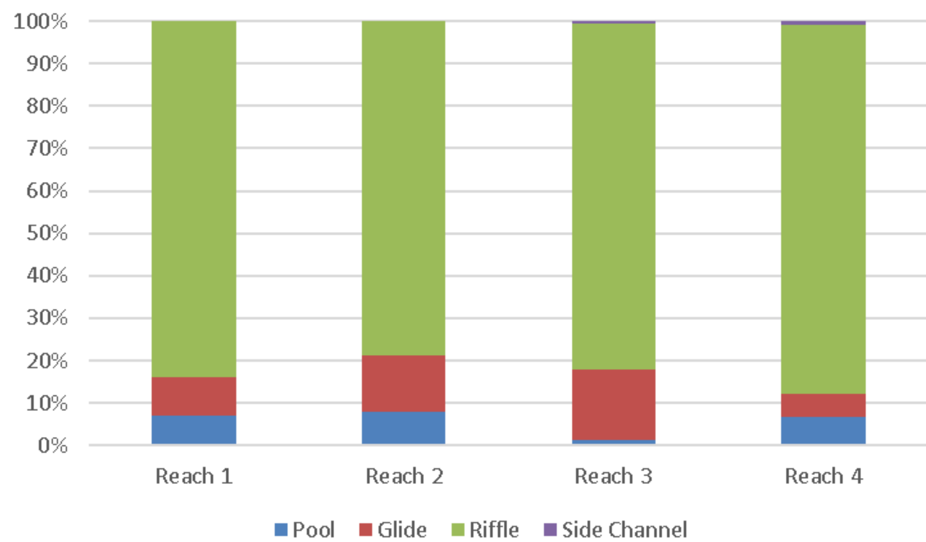
Table 3. Lower Mad River floodprone width results from habitat assessment.

Floodprone Widths				
	Reach 1	**Reach 2**	**Reach 3**	**Reach 4**
Max	250	115	155	100
Min	65	70	100	70
Mean	137.5	82.5	125	85
St Dev	83.32	16.66	22.73	21.21

3.2 HABITAT UNIT COMPOSITION

Within the surveyed area, riffles are the dominant habitat type, comprising 83% of the total area of the channel. Glides comprise 11% of the area, and pools only 5%. Side channels comprise less than 1% of the channel area (Figure 1). Reach 2 maintains the highest percentage of pool habitat at nearly 8%, while Reach 3 is the lowest at 1.2%. Side channel habitat area was low overall across the study area but Reaches 3 and 4 maintain the most side channel habitat area at just 0.7 and 0.8%, respectively.

The mean residual pool depth for the entire study area was 1.9 feet, while the residual pool depth ranged from a minimum of 0.7 feet in Reach 4, to a maximum of 3.7 feet, also in Reach 4 (Figure 2). Pool frequency was uniformly low throughout the study area ranging from a minimum of 2.5 pools per mile (Reach 3), to 7.5 pools per mile (Reach 2), with an average pool frequency throughout the project of 4.9 pools per mile. On average, pools were < 3 feet deep at the time of the survey. Of the 22 pools identified, 91% were less than 3 feet deep. Reaches 1 and 3 both had no pools with residual depths greater than 3 feet, while Reaches 2 and 4 had one pool each with a residual depth greater than 3 feet (13% and 14%, respectively). Average pool spacing throughout the study area was 20.3 channel widths per pool, though there was high variability among the reaches. Reach 2 maintained the lowest average pool spacing with 14.2 channel widths per pool and Reach 3 maintained the highest pool spacing with an average of 43.4 channel widths per pool. The mean estimated wetted width of the main channel was 29 feet with a standard deviation of 8.4 feet. Mean riffle depths were also fairly uniform throughout the study area ranging from 1.1 feet in Reach 4 to 1.3 feet in Reach 2. In total, 71 fast water units (riffles and glides) were measured. A summary of all data recorded is provided in Table 14 in Section 4.6 Summary Data.



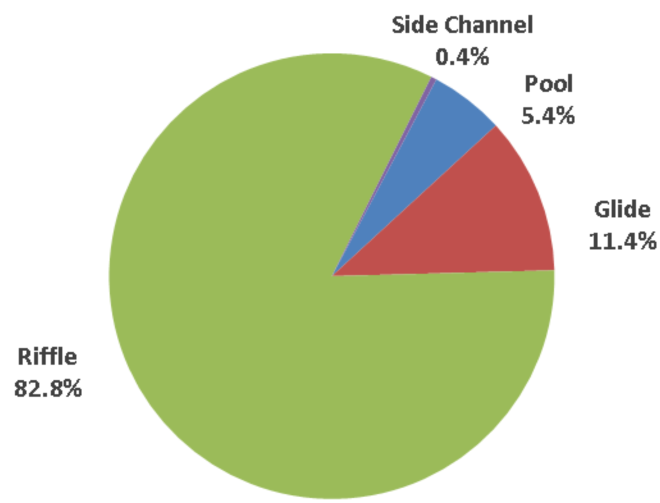


Figure 1. The top figure illustrates distribution of habitat unit composition of Reaches 1-4; riffle habitat composed a majority of the habitat area. The bottom figure displays habitat unit composition in the study area as a whole.

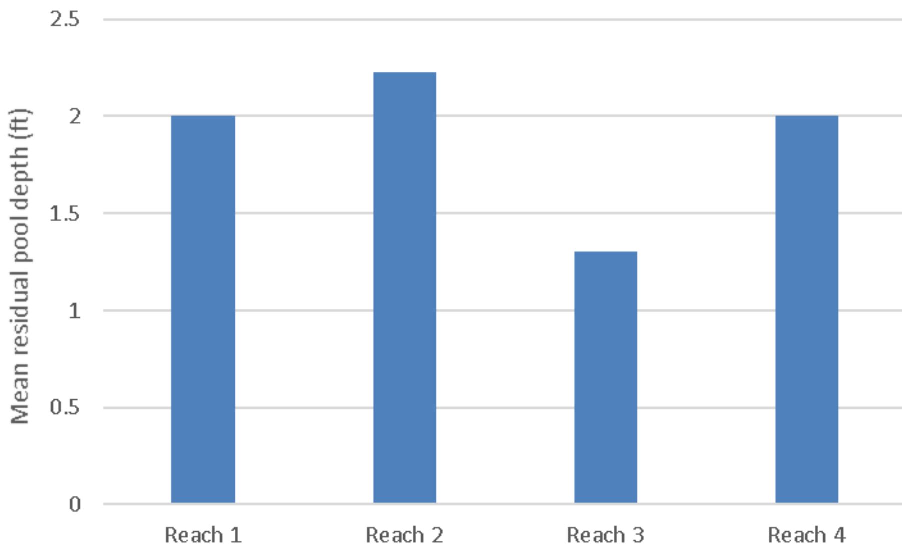


Figure 2. Mean residual pool depth by reach.

3.3 SIDE CHANNEL HABITAT

Side channel habitat area overall throughout the surveyed area was relatively low, accounting for less than 1% of the surface habitat area. In total, four side channel units were observed, averaging 1.1 side channels per mile of stream. The wetted side channels averaged 147 feet in length and 6 feet in width (wetted). Figure 3 is a photo of a slow-water side channel in Reach 4. The side channels maintained similar counts of LWM as the mainstem channel. In total, 12 pieces of LWM were counted in the 4 side channels, with approximately 45 pieces of medium and large wood per mile.

Figure 3. 300-foot long side channel in Reach 4 with low flows during the time of survey. (Photo: 10/26/2017)

3.4 LARGE WOODY MATERIAL

On average, 67 pieces of LWM per mile were counted in the project area; 51% were "small" pieces with diameters between 6 and 12 inches and lengths greater than 20 feet, 32% were "medium" pieces with diameters between 12 and 20 inches and lengths over 35 feet, and were 17% "large" pieces with diameters over 20 inches and lengths over 35 feet (Figure 4). Reach 4 maintained the most LWM in both number of pieces per mile (56.1 pieces of quality large wood per mile) and number of total pieces (137). Reach 1 maintained the least LWM with only 11 pieces identified, all in the small size class. Four log jams were identified during the survey in the study area.

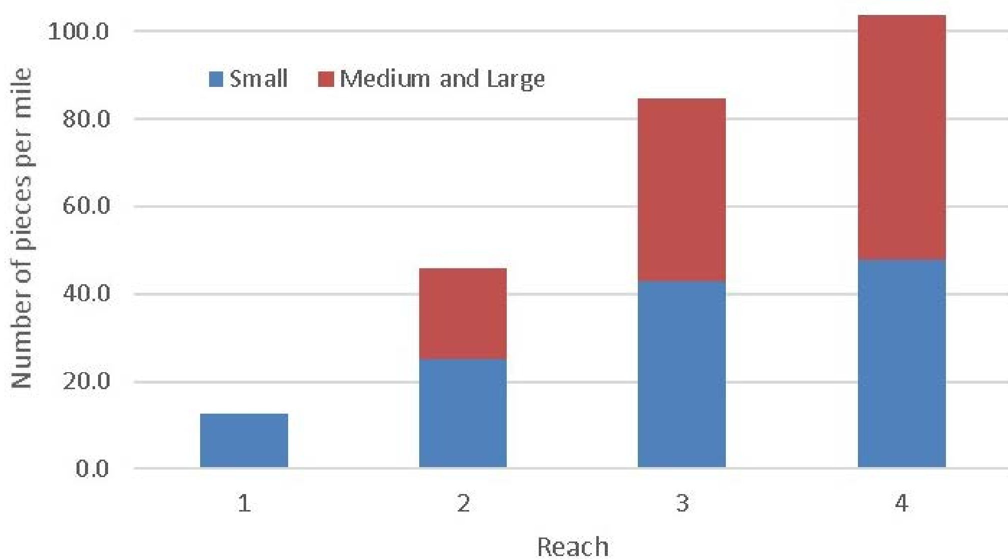


Figure 4. Pieces of large wood per river mile for Lower Mad River Reaches 1 – 4.

Based on thresholds established by Fox and Bolton (2007) for Eastside forests, the "adequate" threshold for LWM is >32 pieces per mile of quality – medium and large size class – wood, with additional woody debris available for short and long-term recruitment. There were 29.6 pieces of quality large wood per mile averaged across the whole study area. However, Reaches 1 and 2 are at "unacceptable risk" for LWM present and LWM recruitment, while Reaches 3 and 4 meet the criteria for "adequate" for LWM present (with 41.9 and 56.1 quality large wood per mile, respectively). Both Reaches 3 and 4 generally have good LWM recruitment potential.

Figure 5. Large in-channel woody material in Reach 4; (Photo: 10/26/2017)

3.5 SUBSTRATE & FINE SEDIMENT

Bedload characterization is based on eight gravel counts that were completed between Reaches 1 and 4. All gravel counts were completed at exposed bars because water temperatures and depths made riffle-crest counts unsafe. Overall, the gravel count sample results are quite similar between all reaches, with predominately gravel and cobble present (Figure 6 and Figure 7). Reach 4 had the largest proportion of gravels (60%, averaged between two counts), while Reaches 1 and 2 had approximately equal amounts gravel and cobble and 5% or less of sand. This indicates that fine sediment (<2mm), which can be harmful to salmonid survival in high concentrations at spawning grounds, is likely readily transported out of the system and thus not expected to pose consistent risk to aquatic habitat quality in the surveyed area. Sand was observed accumulating in elongate pools or behind large boulders where reduced flow hydraulics allowed. Sediment type is classified by the B-axis diameter of the clasts sampled (sand = < 2mm, gravel = 2.1-64 mm, cobble = 64.1-256 mm, boulder = >256.1mm). A low proportion of boulders were recorded on the bars (between 2 – 4%). Ocular observations reveal that channel bed substrate is dominated by cobbles throughout the study area, but in higher gradient reaches more boulders are present.

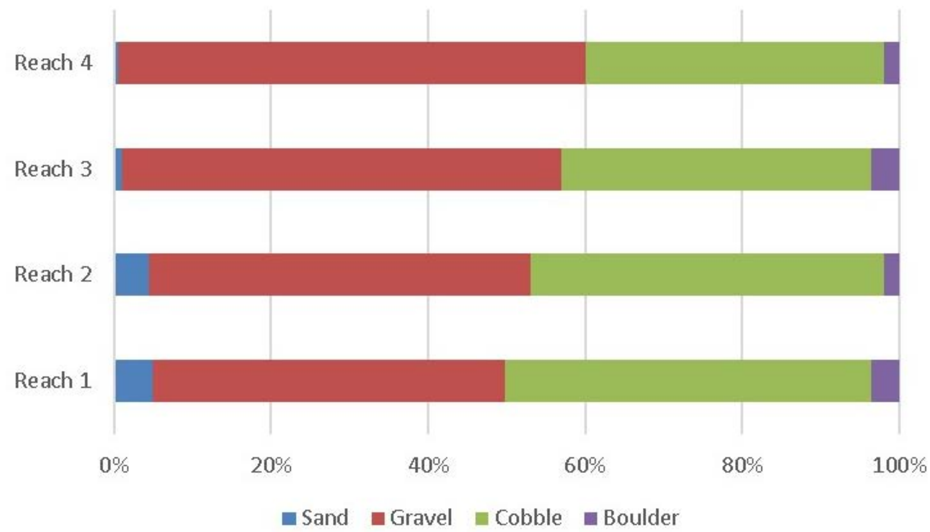


Figure 6. Gravel count classification of bar deposits by reach for Reaches 1-4. For each reach, two gravel counts were performed and then averaged.

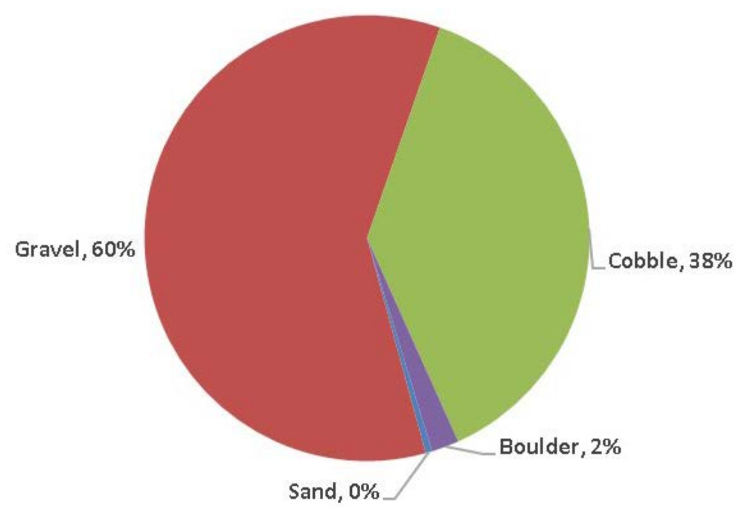


Figure 7. Gravel count of bar deposits clast size classification averaged for Reaches 1 – 4. Gravel is the dominant classification that was observed.

Figure 8. Gravel Count 4.1 (in Reach 4) location on an exposed bar. (Photo: 10/26/2017)

3.6 BANK INSTABILITY

Reach 1 had the most human imposed impacts including levees, irrigation out-takes, home development, bridges, and weirs which have resulted in channel entrenchment and geomorphic simplification. Reaches 2 and 3 are confined on river left by the Mad River Road. In Reach 3 much of the road bank is lined with large-boulder riprap. Reach 2 also has bridge crossings and riparian vegetation clearing. Reach 4 has the least modern human impacts imposed on it. None-the-less, the lower portion of Reach 4 is also confined by the Mad River Road with segments of rip rap embankment. At the upstream end of Reach 4 minor floodplain riparian vegetation clearing and grading has occurred in conjunction with Pine Flats campgrounds. See section 4 of the Assessment Report for detailed description of anthropogenic disturbances.

The habitat team estimated the extent of bank erosion (instability) on both the left and right banks at each channel unit. The length of the unstable (eroding) left and right banks was then divided by the total length (left and right bank) of each reach to determine the percentage of each reach that had eroding banks. Overall, bank instability is low, averaging only 3.5% throughout the study area (Figure 9). The highest percentage of erosion was in Reach 3 on the river left bank (9.4%), while Reach 2 had no unstable banks on river right. Although large portions of it are protected with Mad River Rad riprap, river left generally had a higher proportion of unstable banks throughout the project area.

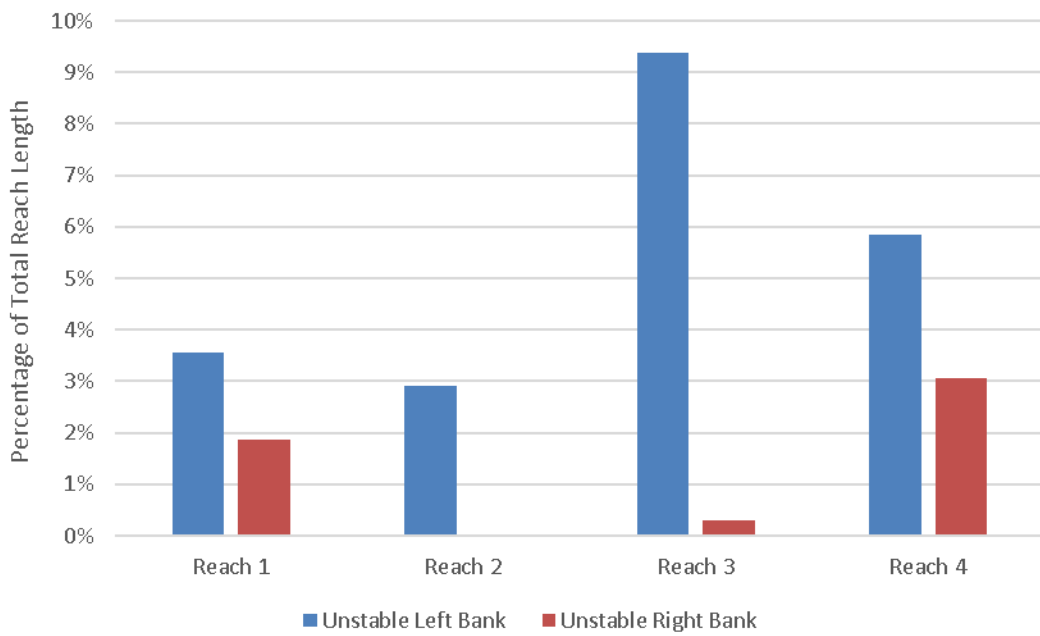


Figure 9. Total percentage of right and left-bank erosion for each reach. Percentages are based on left and right bank ocular estimates measured at each habitat unit throughout the project area.

Unstable banks indicate lateral and sometimes vertical processes and serve as sediment sources to the channel. Bank erosion is currently expressed as "low" throughout the project area. Confining hillslopes on river right in Reaches 2, 3, and 4 often have colluvium at their toe that protects from bank erosion. Riprap along the Mad River Road also protects large portions of the bank on river left in these same reaches. It is assumed that where bank erosion was present historically in Reaches 1, 2, and 3, riprap, cement slabs, pieces of metal, and logs were used to minimize it. The discontinuous pockets of floodplain provide areas for bank erosion to occur. Terrace banks and debris fan also provide good bank sediment sources in Reach 4.

3.7 FISH PASSAGE BARRIERS

No natural or anthropogenic fish passage barriers were observed in the mainstem channel during the habitat assessment. However, there may be velocity or passage impediments for some species and/or life stages at weirs and cement blocks in Reaches 1 and 2. In addition, the channel-spanning log jams may also act as a migratory impediment for certain species or life stages during certain times of the year (Figure 10).

Figure 10. Looking downstream at a channel-spanning log jam that may act as a migratory impediment for certain species or life stages at some flows. (Photo: 10/26/2017)

3.8 RIPARIAN CORRIDOR

Of the 30 n^{th} units measured in Reaches 1-4, the dominant (58%) riparian vegetation size class was designated as small tree (9.0 – 20.9-inch diameter at breast height (dbh)). Large tree (21 – 31.9-inch dbh) was the second most dominant class (28%). All recorded units in Reach 4 had mature tree (> 32-inch dbh) as the dominant class of overstory within the riparian corridor, while shrub/seedling (1.0 – 4.9-inch dbh) overstory was observed in Reach 1 (Figure 11). The overall dominant overstory species was Douglas fir (42%), followed by 33% of units composed primarily of ponderosa pine. Cottonwood-dominant overstory followed at 14% -- found mostly in Reach 1. Additional species in the overstory in a handful of habitat units included cedar (6%), willow (3%) or alder (3%) (Figure 12).

The dominant understory size classes were sapling/pole (5 – 8.9-inch dbh) (58%), shrub/seedling (25%), small tree (8%) and grassland/forb (8%) (Figure 13). Alder was the most dominant riparian understory observed, accounting for 61% of the understory. Additional dominant riparian understory species included redosier dogwood (19%); grassland forbes (8%); bigleaf maple (6%); willow (3%); and cedar (3%) (Figure 14).

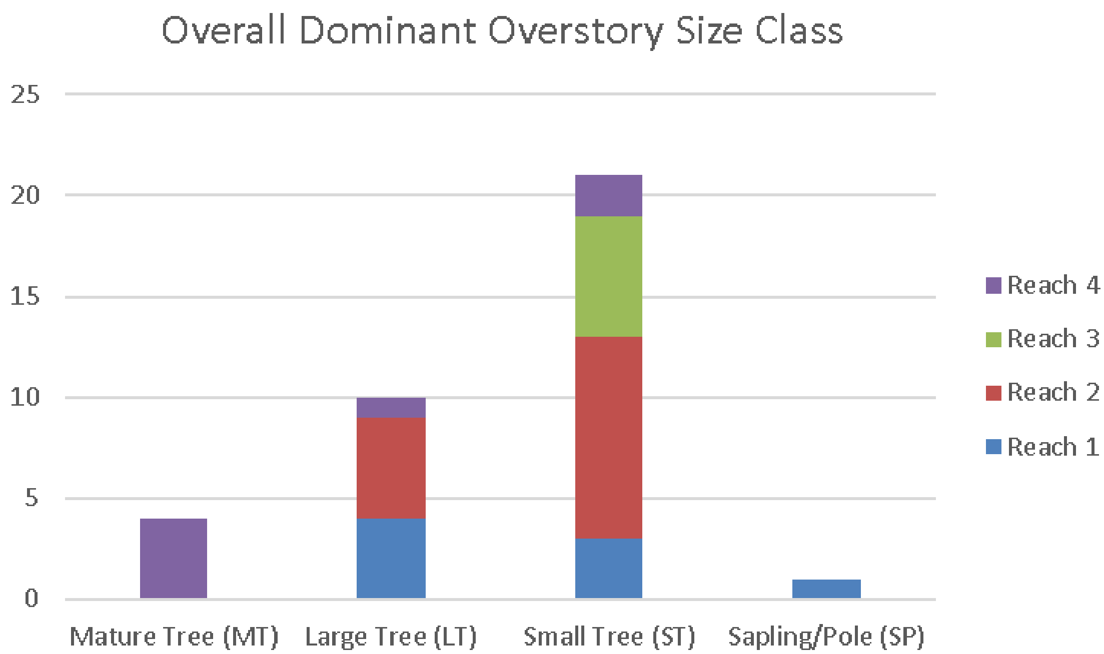


Figure 11. Distribution of dominant overstory size class category for the riparian zone, all reaches combined. Based on n^{th} unit measurements from Reaches 1 – 4.

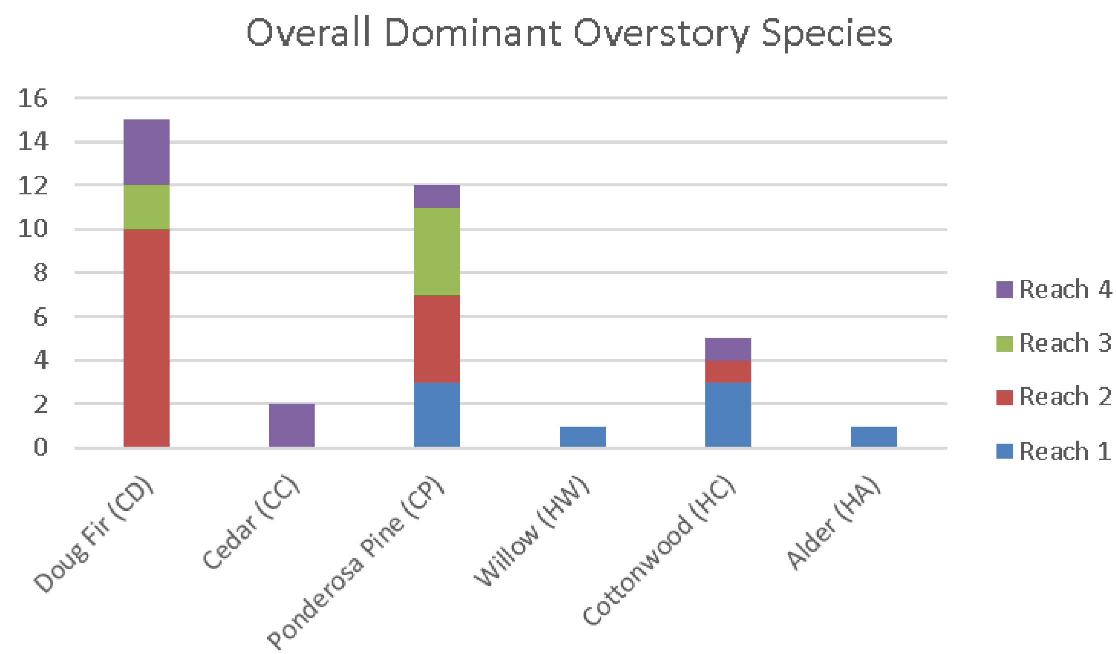


Figure 12. Dominant overstory species in the riparian zone, by reach. Based on n^{th} unit measurements from Reaches 1 – 4.

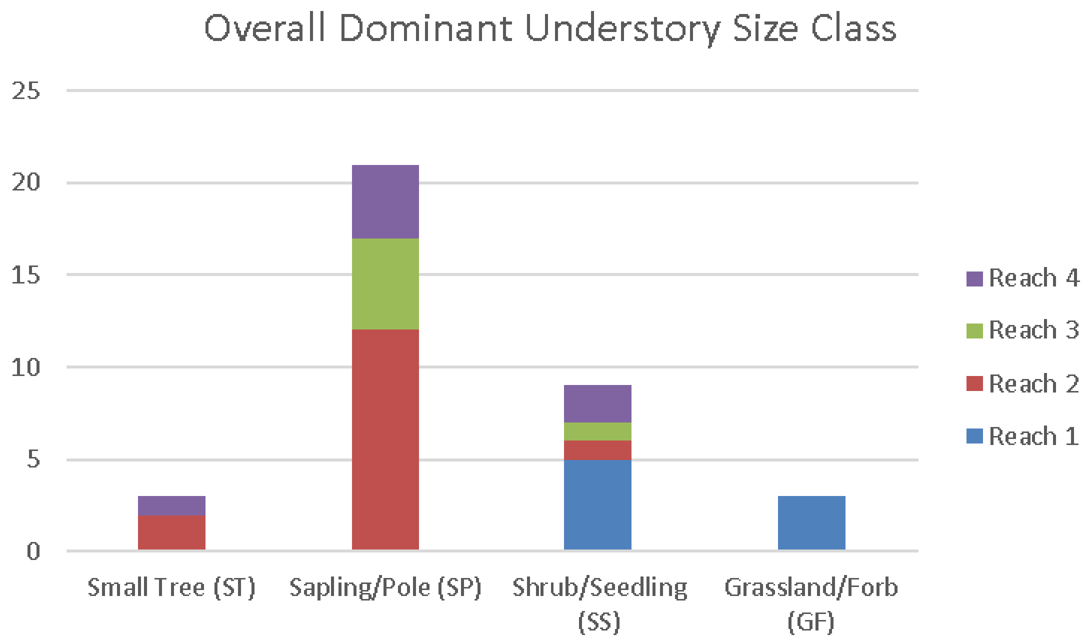


Figure 13. Distribution of dominant understory size class category for the riparian zone, all reaches combined. Based on nth unit measurements from Reaches 1 – 4.

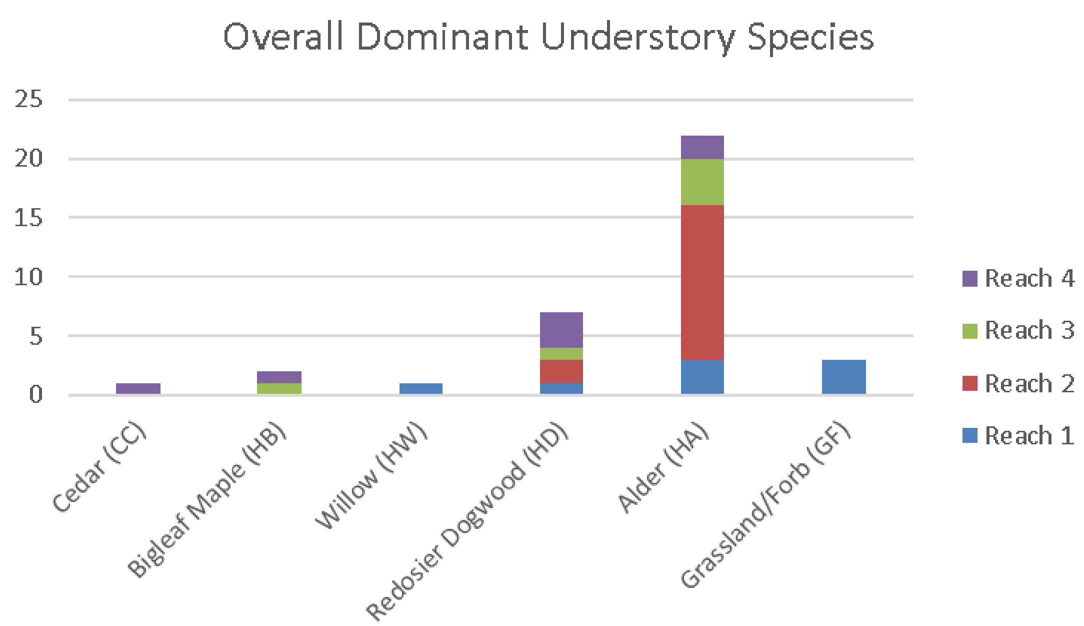


Figure 14. Dominant understory species in the riparian zone, by reach. Based on nth unit measurements from Reaches 1 – 4.

4 Stream Habitat Reach Reports

4.1 REACH 1

Location: River mile 0 – 0.86
Total length: 0.86 miles
Survey date: October 24, 2017

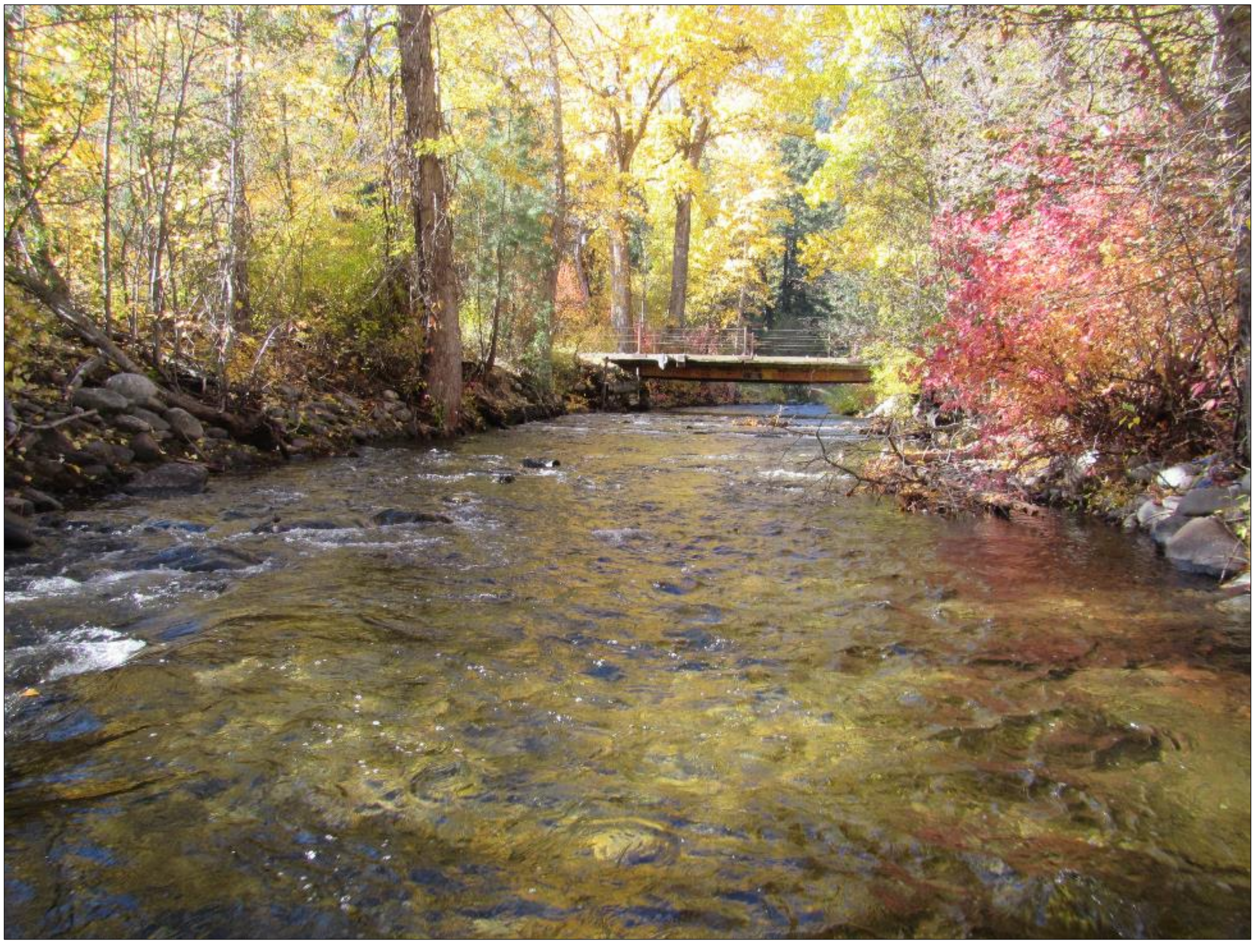


Figure 15. Representative view of Reach 1. Human disturbance within the channel and riparian area are most frequent in this reach. (Photo: 10/24/2017)

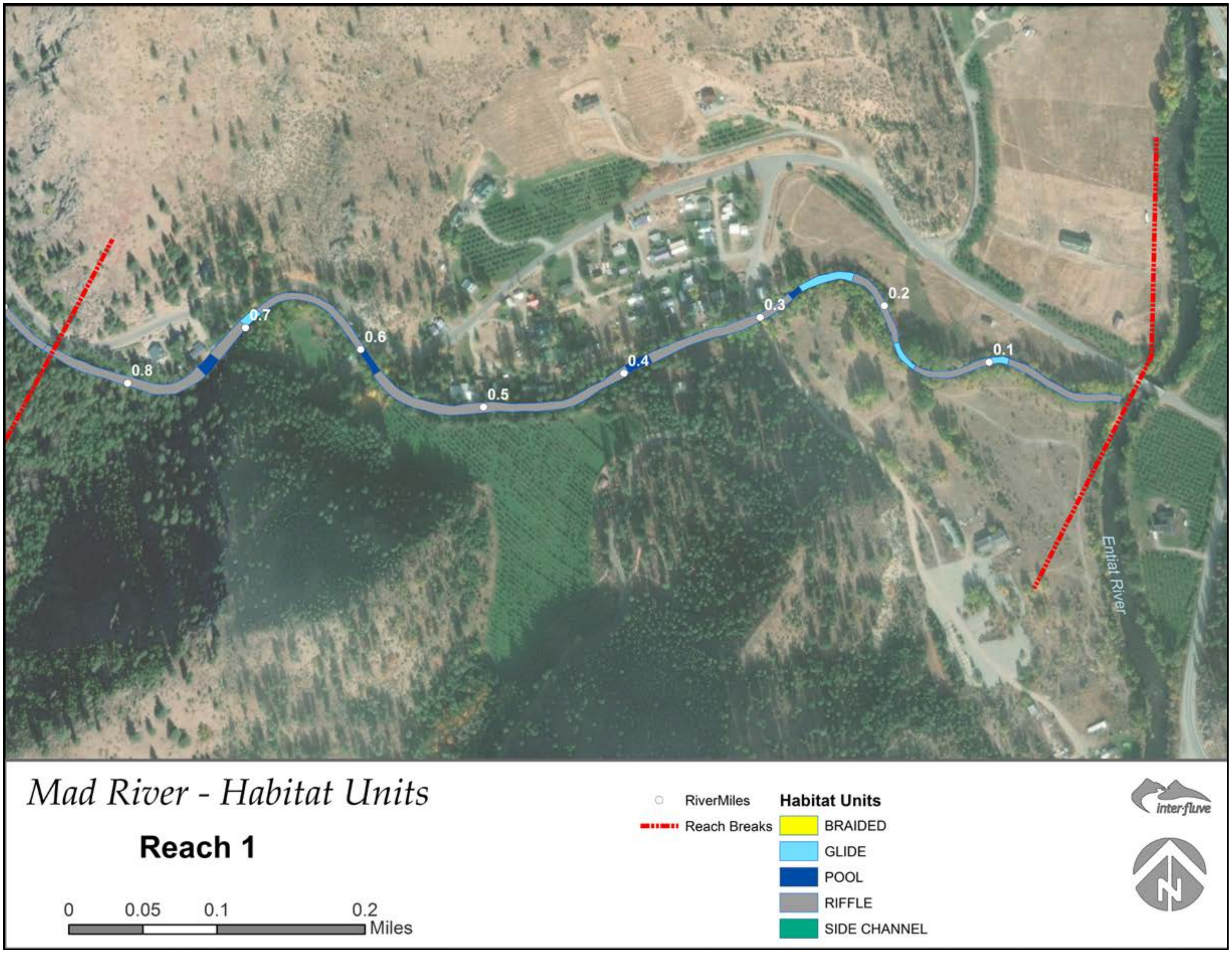


Figure 16. Lower Mad River, Reach 1 -- channel unit distribution (RM 0 – RM 0.86). Basemap: ESRI Bing imagery

4.1.1 Habitat Unit Composition

Reach 1 is the shortest reach delineated in the study area at 0.86 miles. It maintains 84% of habitat area as riffle and the remaining habitat area is glide (9%) and pool (7%) (Figure 16). Reach 1 has the lowest stream gradient (1.54%) among all four reaches. No side channel habitat was observed in Reach 1. The channel is confined by residential land use, levees, bridges, and, at the upstram end, the Mad River Road.

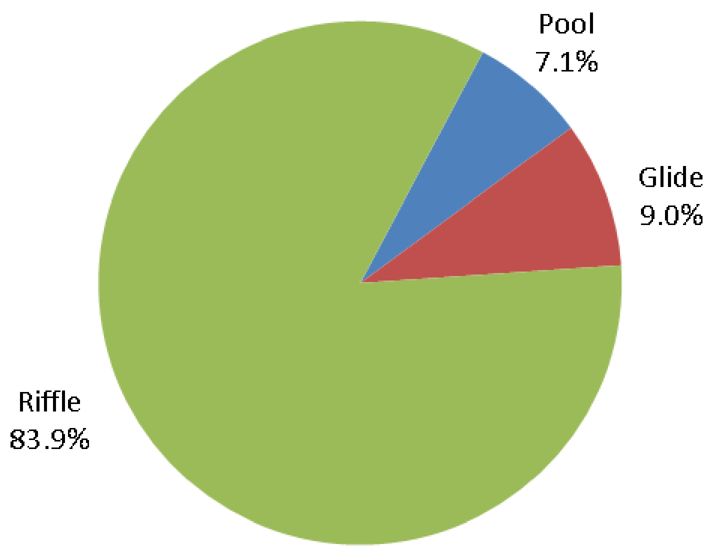


Figure 17. Stream habitat unit area composition of Reach 1.

4.1.2 Pools

Pool was the least common habitat type recorded in Reach 1 with only 7.1% of the habitat unit surface area identified as pools (Figure 17). A total of 4 pools were counted, averaging 4.6 pools per mile. The average pool depth was 3.2 feet with a max of 3.7 feet and minimum of 2.8 feet. Mean pool spacing in Reach 1 was 22 channel widths per pool, compared to an average of 20.3 channel widths per pool for the entire study area. Residual pool depth averaged 2.0 feet. Of the 4 pools identified, all maintained a residual depth of less than 3 feet and none of the pools had a residual depth of more than three feet.

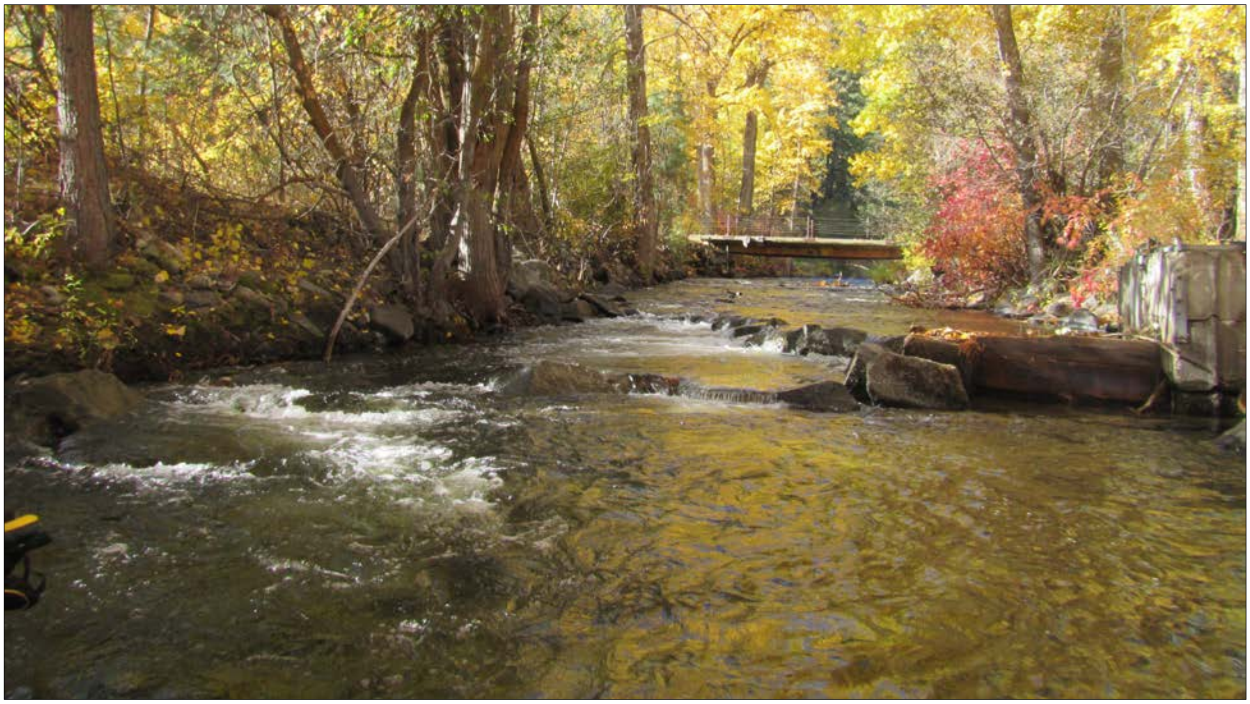


Figure 18. Pools occur in Reach 1 where large boulders or cement added to the channel result in downstream scour. (Photo: 10/24/2017)

4.1.3 Side Channel Habitat

No side channels were identified in Reach 1.

4.1.4 Large Woody Material

LWM quantities in Reach 1 were the lowest of all four reaches with a total of only 11 pieces of LWM identified, equating to 12.8 pieces of wood per mile. All LWM pieces observed were in the "small" size class. No quality large wood (medium or large size class) was observed in Reach 1. No log jams were observed in Reach 1 (Table 4).

Table 4. Large woody material quantities in Reach 1.

	Small (6 in x 20 ft)	Medium (12 in x 35 ft)	Large (20 in x 35 ft)	Total
Number of pieces	11	-	-	11
Number of pieces per mile	12.8	-		12.8
Number of jams	-			0
Number of jams per mile	-			0

4.1.5 Substrate & Fine Sediment

A total of two gravel counts were conducted in Reach 1 on exposed depositional bars. The composition of material from the gravel counts combined was primarily gravel (80%) with 18% cobble and 2% sand. This distribution is comparable to the project area average of 78% gravel, 21%

cobble, and 1% sand. The cumulative distribution and grain size composition of the gravel counts completed in Reach 1 are provided below in Figure 19, Figure 20, and Table 5. Both the D16 and D50 are slightly smaller than the study area average, but the D84 for Reach 1 is approximately the same as the study area average.

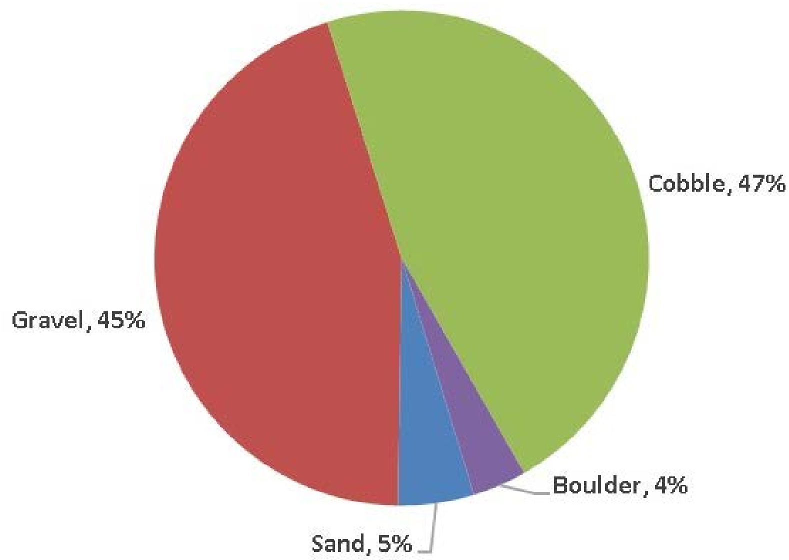
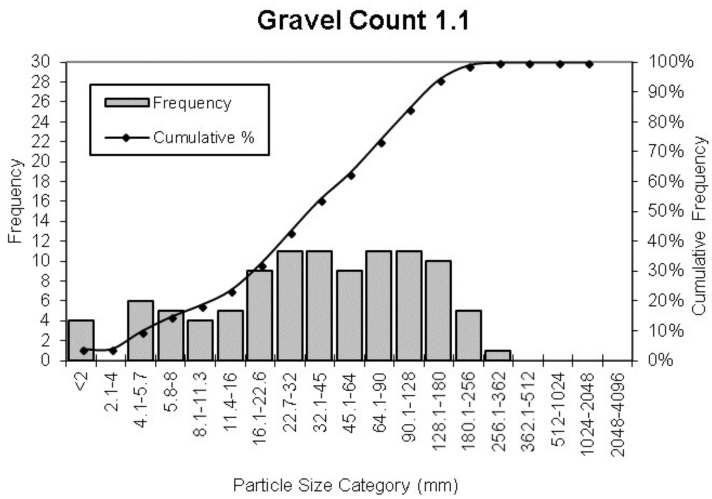


Figure 19. Combined percent composition sediment size type from two gravel counts on exposed bars in Reach 1.



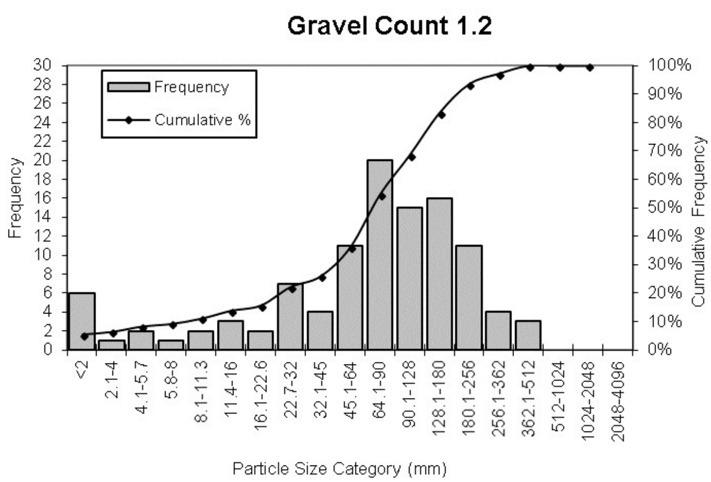


Figure 20. Cumulative grain size distribution for Gravel Count 1.1 and 1.2 (Reach 1).

Table 5. Grain size class for gravel counts 1.1 and 1.2

Size Class	REACH 1	
	GC # 1.1 Size % finer than (mm)	**GC # 1.2** Size % finer than (mm)
D16	21	22
D50	64	50
D84	154	90

4.1.6 Riparian Corridor

Reach 1 included eight riparian vegetation unit evaluations. Overall, the dominant riparian vegetation class observed was large tree (50%), with the small tree category following at 37% and 13% (only a single unit) with sapling/pole as the dominant overstory vegetation class. Overstory species were a mix of cottonwood (38%), Ponderosa pine (37%), alder (13%) and willow (12%) (Figure 21). In 62% of the measured units, the understory was dominated by shrub/seedling-sized alder (38%), redosier dogwood (12%), and willow (12%). The remainder of the units were classified as a grassland/forb (38%) understory (Figure 22).

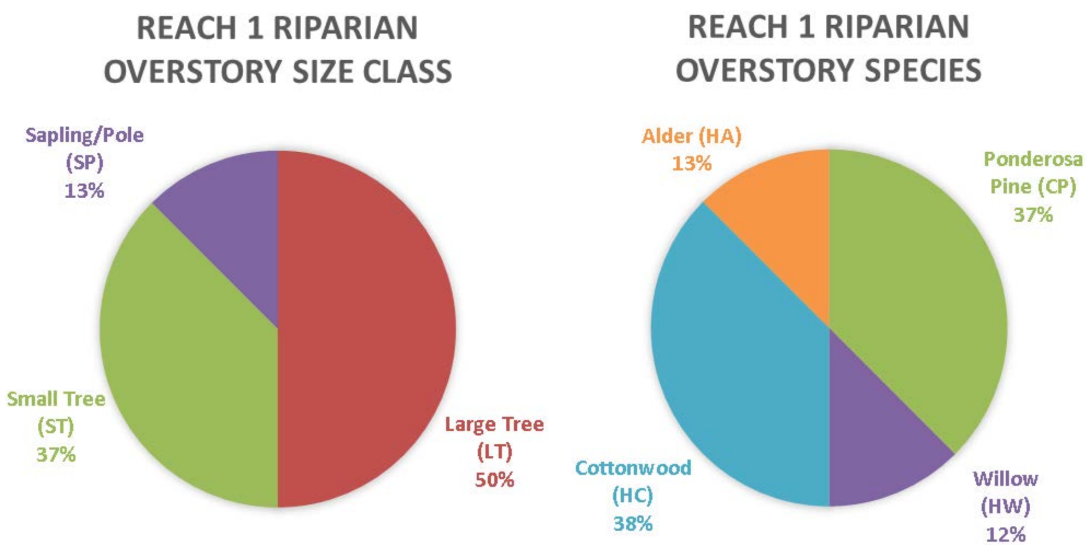


Figure 21. Dominant overstory riparian vegetation class and species identified within 100 feet of the Mad River by ocular estimate.

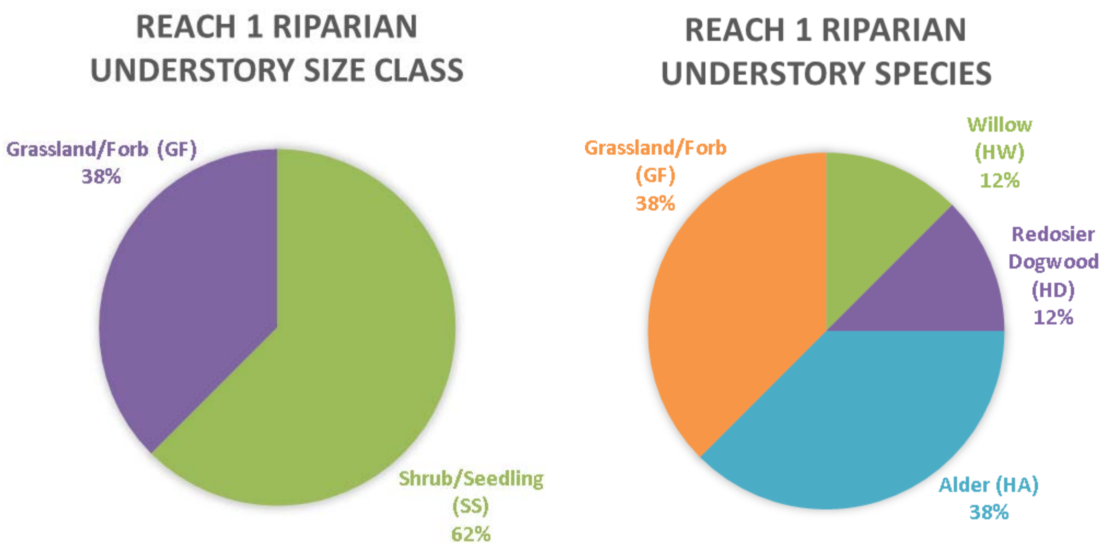


Figure 22. Dominant understory riparian vegetation class and species identified within 100 feet of Mad River by ocular estimate.

4.2 REACH 2

Location: River mile 0.86 – 1.93
Total length: 1.07 miles
Survey Date: October 24, 2017

Figure 23. Representative view of Reach 2. The reach has long riffle/cascades with large boulders present in the channel. (Photo: 10/25/2017)

4.2.1 Habitat Unit Composition

Reach 2 had the greatest proportion of pool habitat of all the reaches, with 8% pool habitat and 79% riffle habitat. The remainder of the habitat area was comprised of glide units (13%) (Figure 24 and Figure 25). Reach 2 had the second highest stream gradient at 1.79%, compared to the average gradient across the entire study area 1.83%.

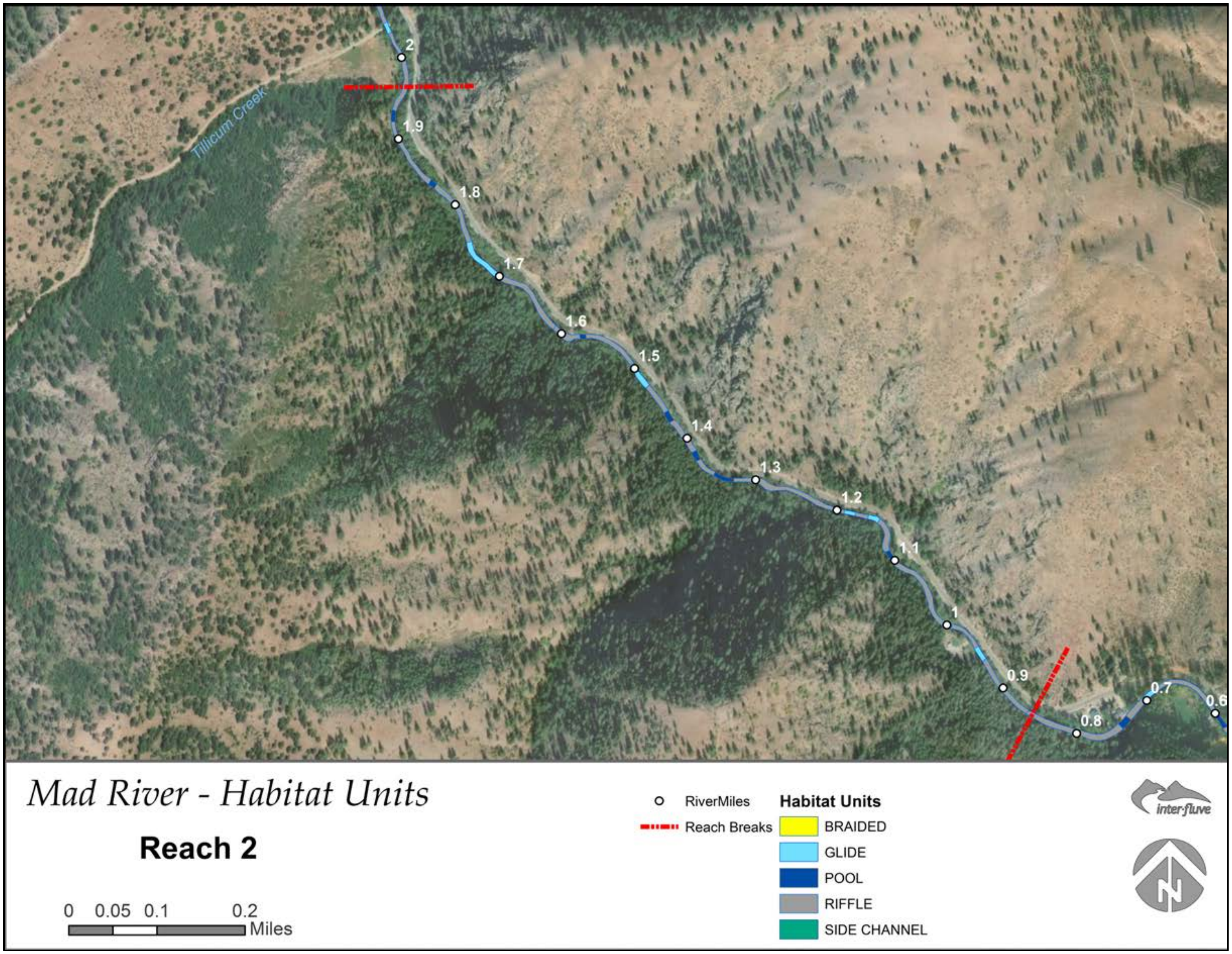


Figure 24. Lower Mad River, Reach 2 - channel unit distribution: RM 0.86 – 1.93. Basemap: ESRI Bing imagery

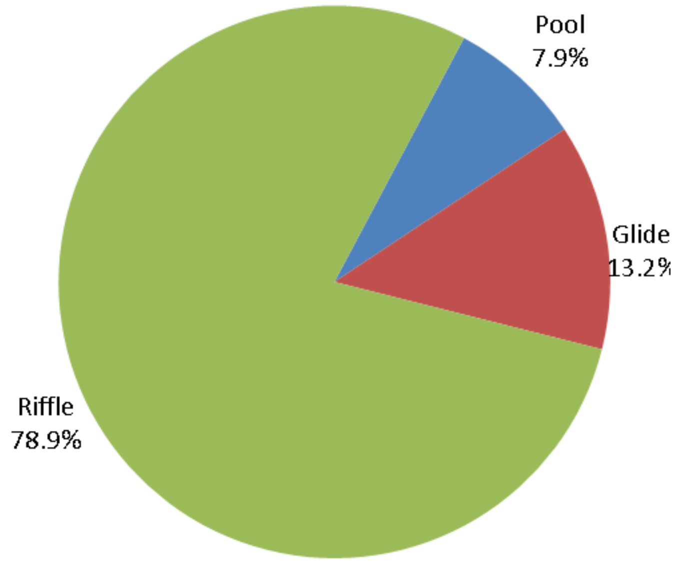


Figure 25. Stream habitat unit composition for Reach 2.

4.2.2 Pools

A total of 8 pools were identified in Reach 2, averaging 7.5 pools per mile. Residual depth of pools ranged from 1.5 feet to 3.5 feet. Of the 8 pools counted, seven (88%) had residual depths less than 3 feet and only one pool (12%) had residual depths greater than 3 feet. Mean pool spacing was 14.2 channel widths per pool, the lowest of all the reaches.

4.2.3 Side Channel Habitat

No side channels were identified in Reach 2.

4.2.4 Large Woody Material

LWM quantities in Reach 2 were the second lowest of all four reaches with a total of 49 pieces of LWM identified, equating to 45.7 pieces of wood per mile (Table 6). Of these 49 pieces, 19 were classified as medium (measuring more than 12 inches diameter and 35 feet in length) and only three pieces were in the large woody material category (greater than 20 inches diameter and at least 35 feet long). This equates to an average of 20.5 pieces of quality LWM per mile. One log jam was observed, consisting of a majority of small pieces (9) and a single large piece of wood.

Table 6. Large woody material quantities in Reach 2.

	Small (6 in x 20 ft)	**Medium (12 in x 35 ft)**	**Large (20 in x 35 ft)**	**Total**
Number of pieces	27	19	3	49
Number of pieces per mile	25.2	20.5		45.7
Number of jams	1			1
Number of jams per mile	1			1

4.2.5 Substrate & Fine Sediment

Two gravel counts were conducted in Reach 2 on exposed bars. The composition of material from the combined gravel counts was nearly equal parts gravel and cobble (49% and 45%, respectively; Figure 26). A greater proportion of sand was present in this reach (similarly to Reach 1) compared to the upstream reaches. The cumulative distribution and grain size composition of the gravel counts completed in Reach 2 are provided below in Figure 26, Figure 27, and Table 7. Both the D16 and D50 are approximately the same as the rest of the study area, but the D84 for Reach 2 was the smallest size of all reaches at 108 mm.

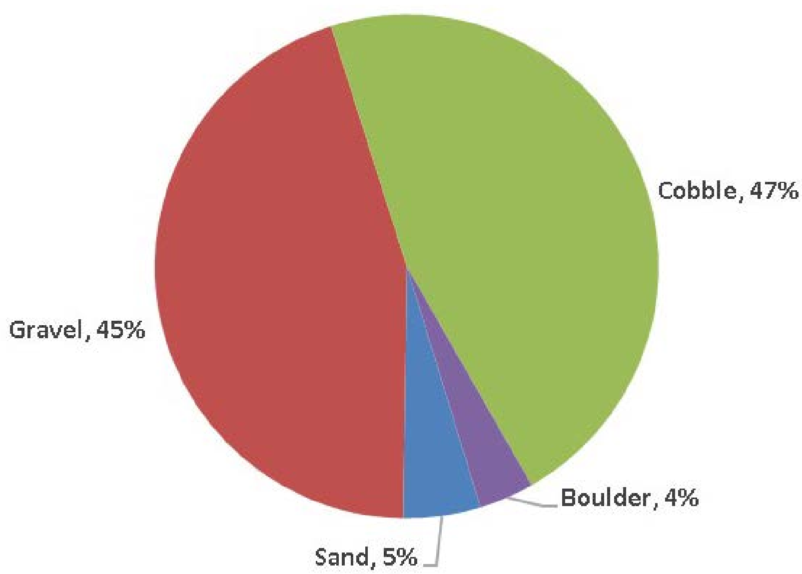
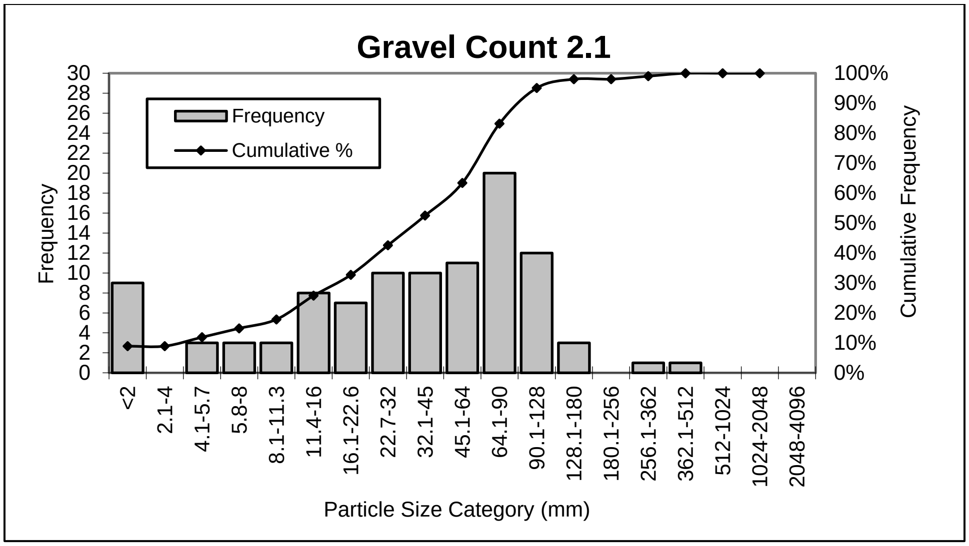


Figure 26. Combined percent composition sediment size type from two gravel counts on exposed bars in Reach 2.



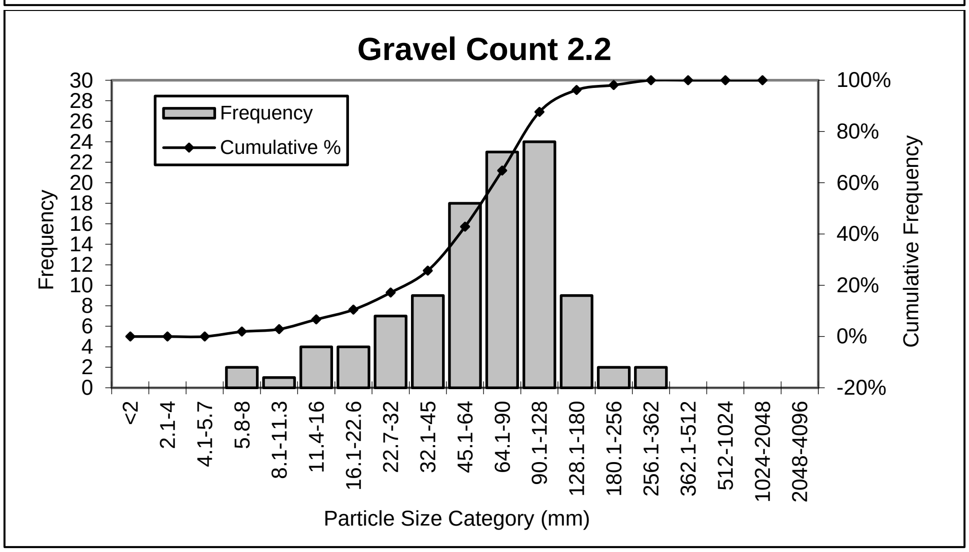


Figure 27. Cumulative grain size distribution for Gravel Count 2.1 and Gravel Count 2.2.

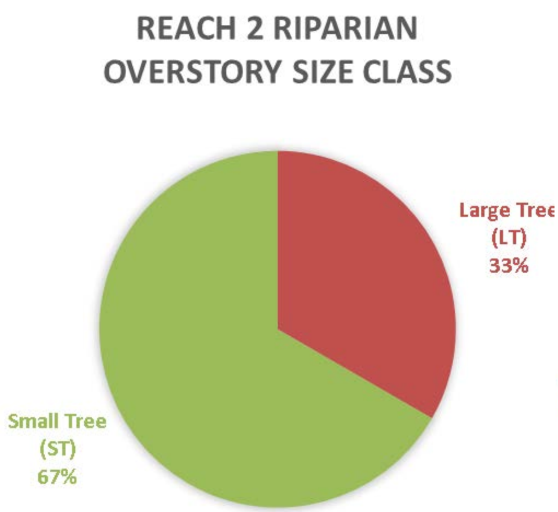
Table 7. Grain size class for Gravel Count 2.1 and 2.2.

Size Class	REACH 2	
	GC # 2.1 Size % finer than (mm)	**GC # 2.2** Size % finer than (mm)
D16	9	30
D50	42	72
D84	93	122

4.2.6 Riparian Corridor

A total of 15 n^{th} unit measurements were performed in Reach 2. A majority of the riparian vegetation within 100 feet of the river was identified as small trees (67%). The remaining 33% of vegetation was identified as large trees. The overstory species were primarily Douglas fir (67%) followed by 27%

ponderosa pine and 6% cottonwood (Figure 28). The understory was composed primarily of alder (87%) with some redosier dogwood (13%), predominantly within the sapling/pole size class (80%) with some small trees (13%) and shrub/seedlings (7%) (Figure 29).



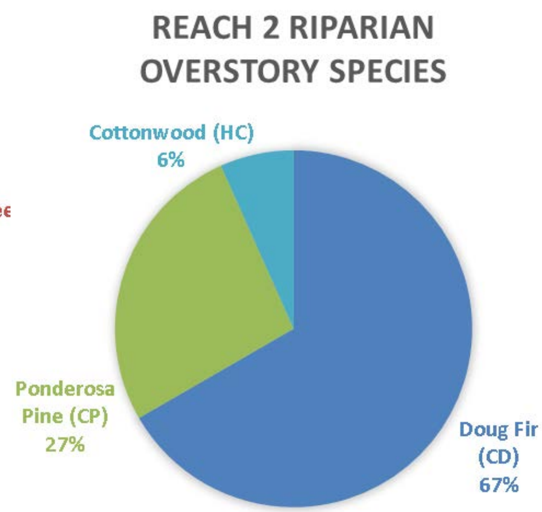
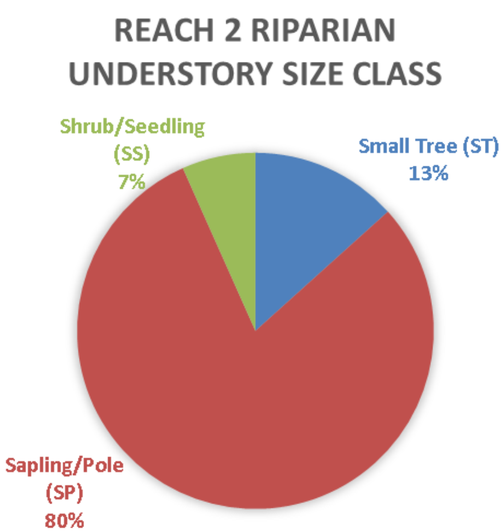


Figure 28. Dominant overstory riparian vegetation size and species identified within 100 feet of Mad River based on n^{th} unit ocular estimates.



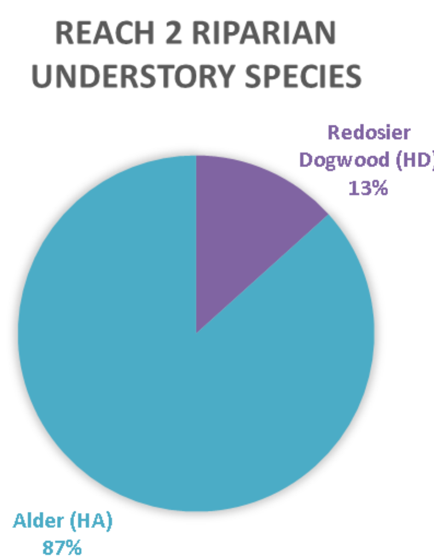


Figure 29. Dominant understory riparian vegetation size and species identified within 100 feet of the Mad River based on n^{th} unit ocular estimates.

4.3 REACH 3

Location: River mile 1.93 – 2.98
Total length: 1.05 miles
Survey Date: October 24, 2017

Figure 30. Representative view of Reach 3. (Photo: 10/26/17)

4.3.1 Habitat Unit Composition

Reach 3 is the third longest reach delineated in the study at 1.05 miles long. Nearly all of the Reach 3 habitat area was identified as fast water, either riffles (82%) or glides (17%). Only 1% of the habitat area was identified as pools, the lowest of all reaches (Figure 31). The stream gradient of 2.35% in Reach 3 is the highest within the study area.

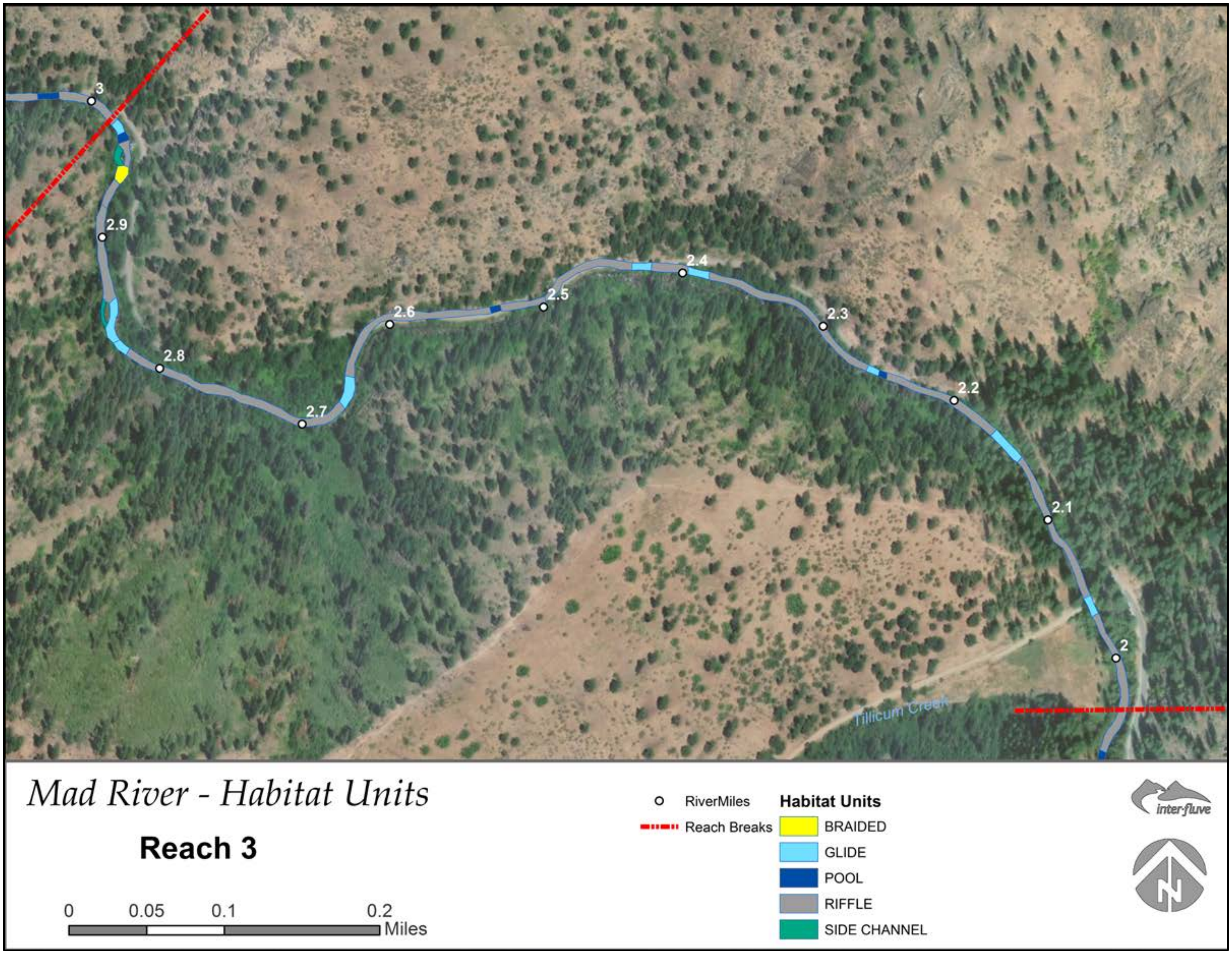


Figure 31. Lower Mad River, Reach 3 -- channel unit distribution: RM 1.93 – 2.98. Basemap: ESRI Bing imagery

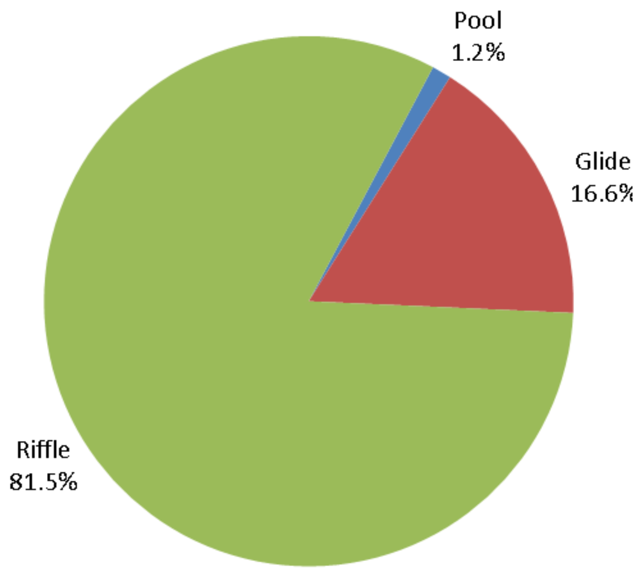


Figure 32. Stream habitat unit composition for Reach 3.

4.3.2 Pools

Reach 3 had a total of 3 pools and a pool frequency of 2.9 pools per mile, compared to an average of 4.9 pools per mile throughout the study area. Mean pool spacing for the reach is 43.4 channel widths per pool with the highest in the project area. Project area average pool spacing is 20.3 channel widths per pool. No pools in this reach maintained residual depths of greater than three feet.

4.3.3 Side Channel Habitat

Side channel habitat in Reach 3 accounted for 1% of the habitat area. Only two side channels were recorded, totaling 164 feet in length (Table 8). One side channel was identified as a slow water unit, while the other was identified as a predominantly fast water unit. Two pieces of medium LWM were observed in the slow side channel and one piece of small LWM in the fast side channel.

Table 8. Secondary channel habitat in Reach 3.

Location	Length (ft)	Dominant unit type	Wood count
SIDES1	83	Slow water	2
SIDEF2	81	Fast water	1
Total	164		3

4.3.4 Large Woody Material

LWM quantities in Reach 3 were the second highest of all four reaches with a total of 89 pieces of LWM identified, equating to 84.8 total pieces of wood per mile (Table 9). Of these 89 pieces, 30 were classified as medium (measuring more than 12 inches diameter and 35 feet in length) and 14 pieces were in the large woody material category (greater than 20 inches diameter and at least 35 feet long). This equates to an average of 36.3 pieces of quality large woody material per mile. No log jams were observed in Reach 3.

Table 9. Large woody material quantities in Reach 2.

	Small (6 in x 20 ft)	Medium (12 in x 35 ft)	Large (20 in x 35 ft)	Total
Number of pieces	45	30	14	89
Number of pieces per mile	42.9	41.9		84.8
Number of jams	0			0
Number of jams per mile	0			0

4.3.5 Substrate & Fine Sediment

Two gravel counts were performed in Reach 3 on exposed bars. When the gravel counts are combined, gravel was the dominant substrate (56%) with 40% cobble, 4% boulder, and 1% sand in Reach 3 (Figure 33). The cumulative distribution and grain size composition of the gravel counts completed in Reach 3 are provided below in Figure 34 and Table 10.

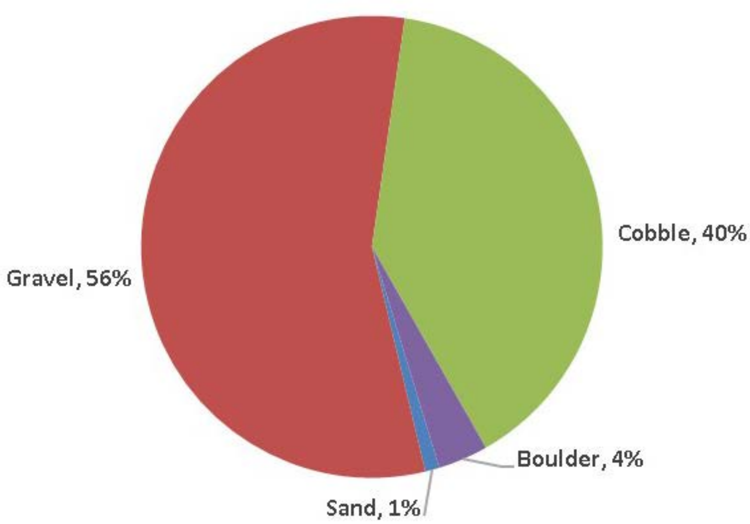
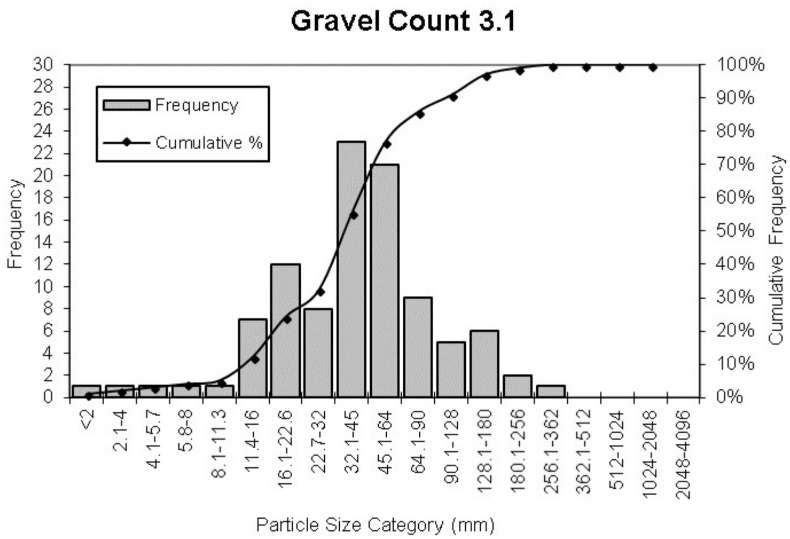


Figure 33. Percent composition of bed substrate based on two gravel counts at exposed bars in Reach 3.



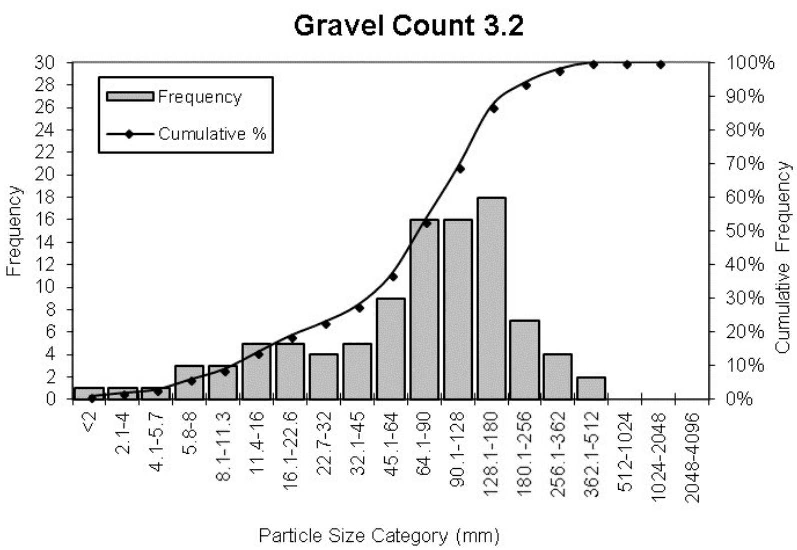


Figure 34. Cumulative grain size distribution for Gravel Count 3.1 and Gravel Count 3.2.

Table 10. Grain size class for Gravel Count 3.1 and 3.2.

Size Class	**REACH 3**	
	GC # 3.1 Size % finer than (mm)	**GC # 3.2** Size % finer than (mm)
D16	18	19
D50	42	85
D84	87	171

4.3.6 Riparian Corridor

Based on six n^{th} unit measurements, 100% of the riparian vegetation identified within 100 feet of the creek throughout Reach 3 was small tree (9.0 – 20.9 inch diameter). Ponderosa pine was the primary overstory species (67%), with the remaining 33% Douglas fir (Figure 35). The understory was mostly sapling/pole (83%; 5.0 – 8.9 in. diameter), with 17% shrub/seedling (1.0 – 4.9 in. diameter). The understory was dominated by alder (67%). Other species observed included dogwood (17%), and bigleaf maple (16%) (Figure 36).

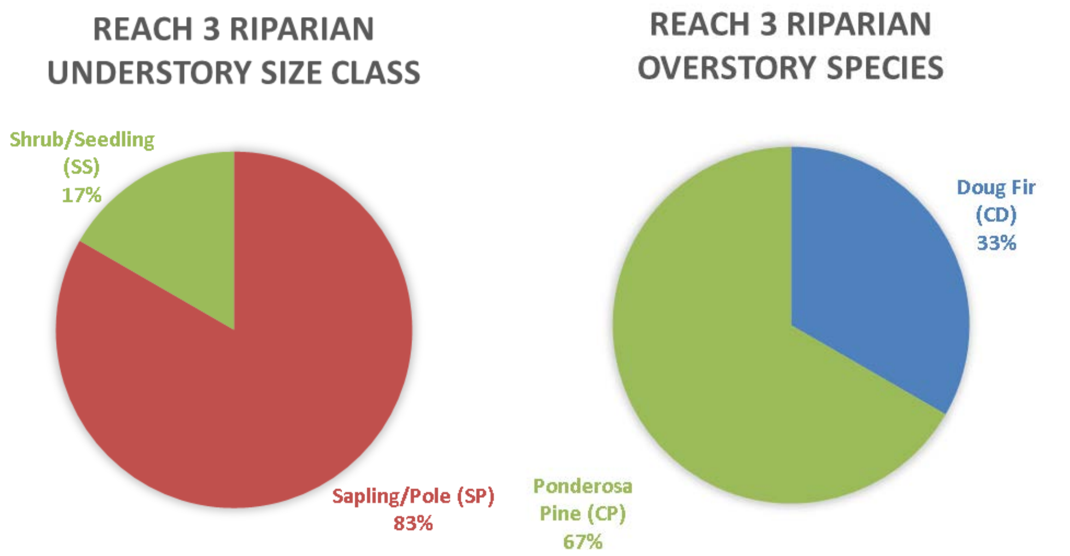


Figure 35. Dominant overstory riparian vegetation size and species identified within 100 feet of Mad River based on nth unit ocular estimates.

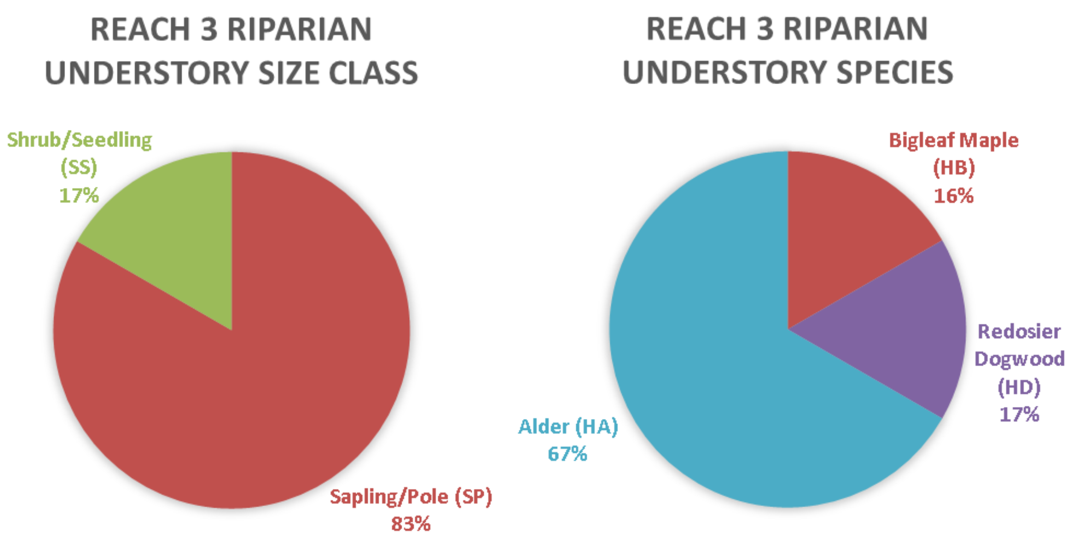


Figure 36. Dominant understory riparian vegetation size and species identified within 100 feet of Mad River based on nth unit ocular estimates.

4.4 REACH 4

Location: River mile 2.98 – 4.3
Total length: 1.32 miles
Survey date: October 25, 2017

Figure 37. Representative view of Reach 4. (Photo: 10/26/2017)

4.4.1 Habitat Unit Composition

Reach 4, the longest reach in the study area, is 1.32 miles long. This reach was riffle-dominated: composed of 87% riffle, 7% pool, 5% glide, and 1% side channel (Figure 38 and Figure 39). Reach 4 has the third steepest gradient in the project area at 1.65%.

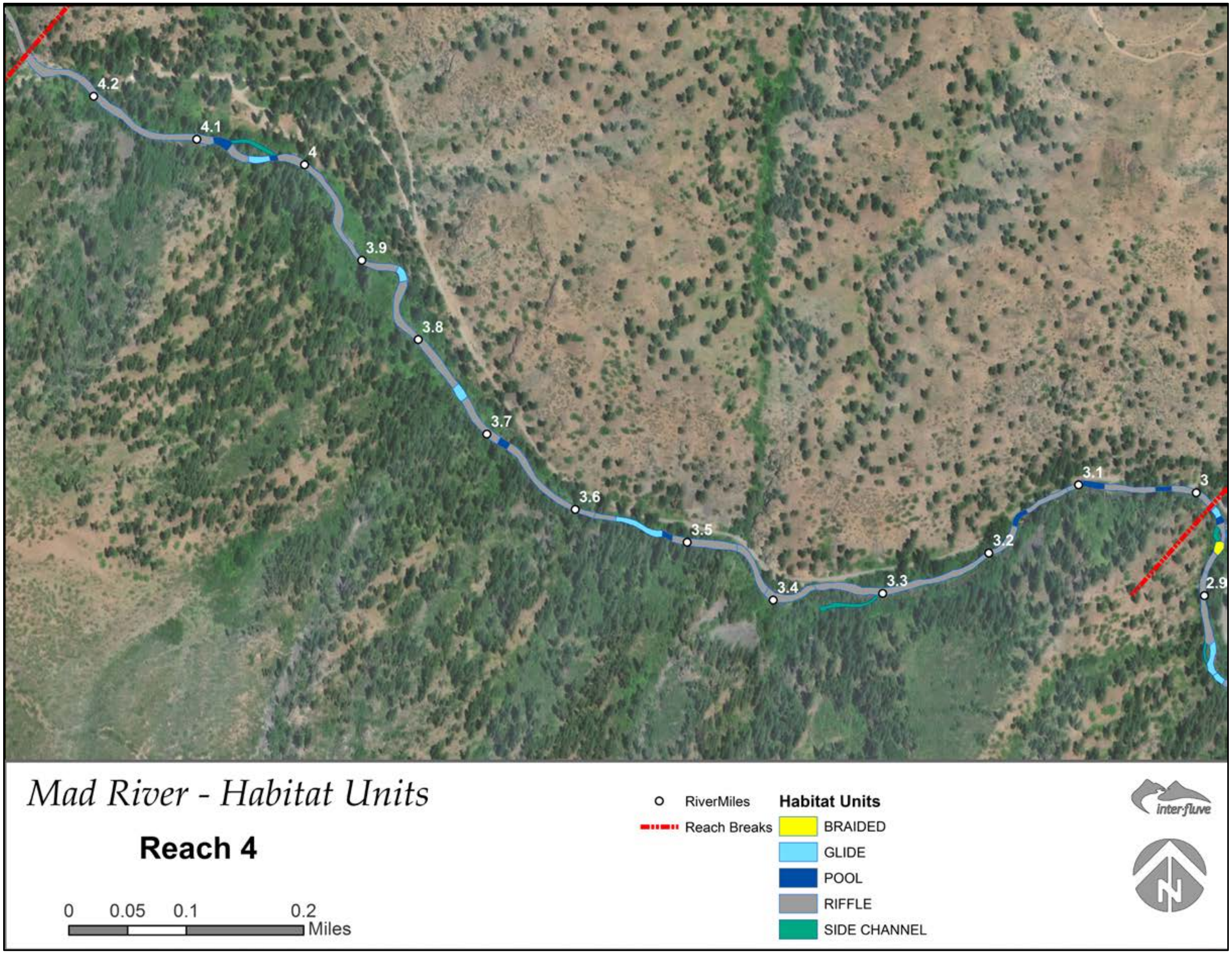


Figure 38. Lower Mad River, Reach 4 -- channel unit distribution: RM 2.98 – 4.3. Basemap: ESRI Bing imagery

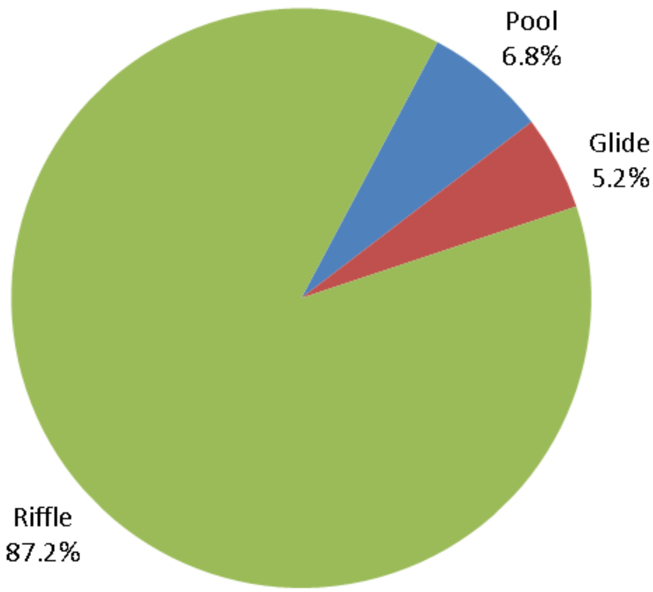


Figure 39. Stream habitat unit composition for Reach 4.

4.4.2 Pools

A total of 7 pools were identified in Reach 4, averaging 5.3 pools per mile. The average residual pool depth was 2.0 feet and mean pool spacing was 16 channel widths per pool, the second lowest mean pool spacing in the project area. Only one of the pools maintained a residual depth of greater than three feet deep.

4.4.3 Side Channel Habitat

Two side channels were identified in Reach 4 (Table 11), comprising less than 1% of the habitat area in the reach. Both of the side channels were identified as slow water units and had a total of 9 pieces of wood: one large piece, two medium pieces, and a majority small pieces.

Table 11. Secondary channel habitat in Reach 4.

Location	Length (ft)	Dominant unit type	Wood count
SIDES3	300	Slow water	7
SIDES4	125	Slow water	2
Total	425		9

4.4.4 Large Woody Material

A total of 137 pieces of LWM were identified in Reach 4, averaging 103.8 pieces per mile. Over half of those 137 pieces were classified as medium (43 pieces measuring more than 12 inches diameter and 35 feet in length) and large (31 pieces greater than 20 inches diameter and at least 35 feet long), two were small pieces and one was medium (Table 12). This equates to an average of 56.1 pieces of quality large woody material per mile. This was the highest wood count of the four reaches in the study area. Three log jams were observed in Reach 4, consisting of approximately one-third each of small (11), medium (15) and large (13) pieces of wood.

Table 12. Large woody material in Reach 4.

	Small (6 in x 20 ft)	Medium (12 in x 35 ft)	Large (20 in x 35 ft)	Total
Number of pieces	63	43	31	137
Number of pieces per mile	47.7	56.1		103.8
Number of jams	3			3
Number of jams per mile	3			3

4.4.5 Substrate & Fine Sediment

Two gravel counts were performed within Reach 4 at exposed bars. The dominant substrate type observed was gravel (60%) with additional 38% cobble, and 2% boulder (Figure 40). No bedrock or sand were identified in either gravel count. The cumulative distribution and grain size composition of the gravel counts completed in Reach 4 are provided below in Figure 41 and Table 13.

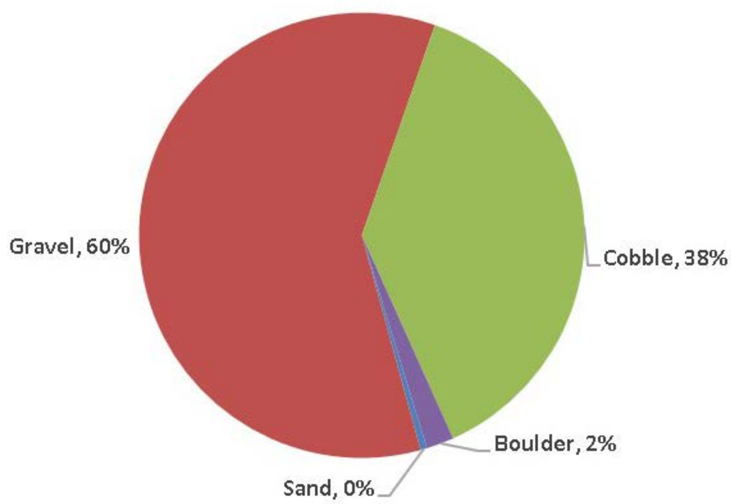
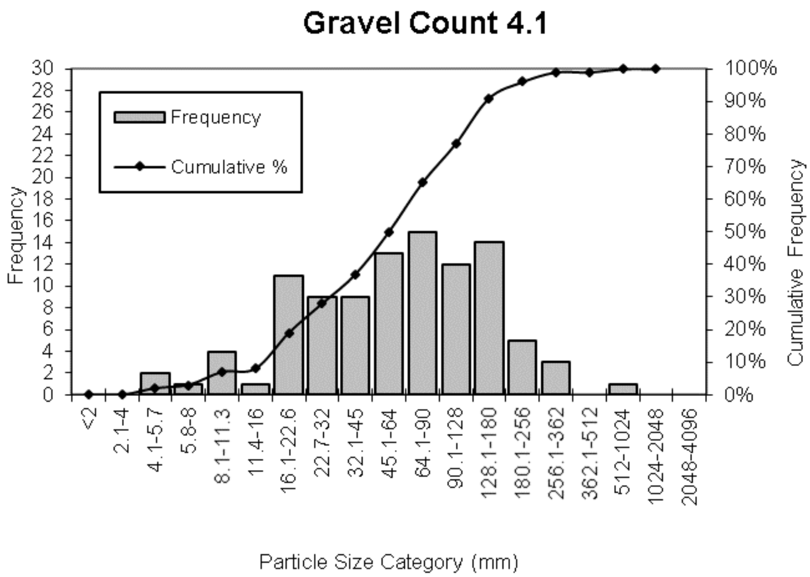


Figure 40. Percent composition of bed substrate based on two gravel counts at exposed bars in Reach 4.



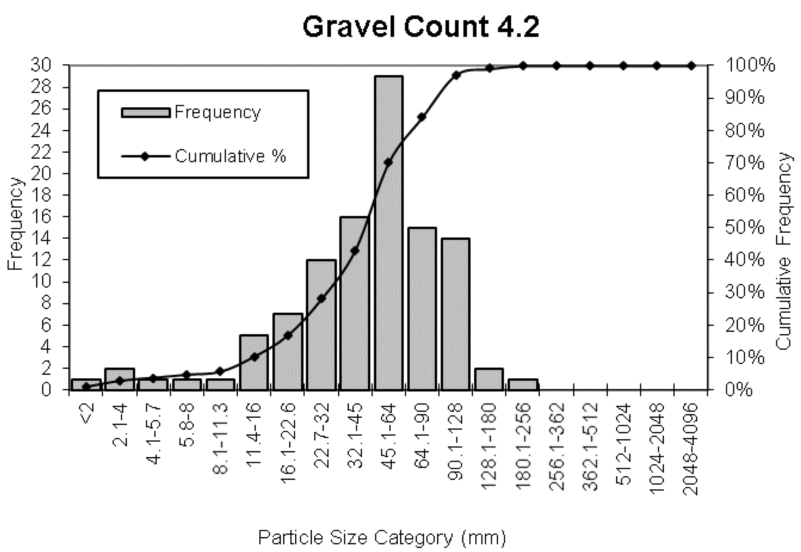


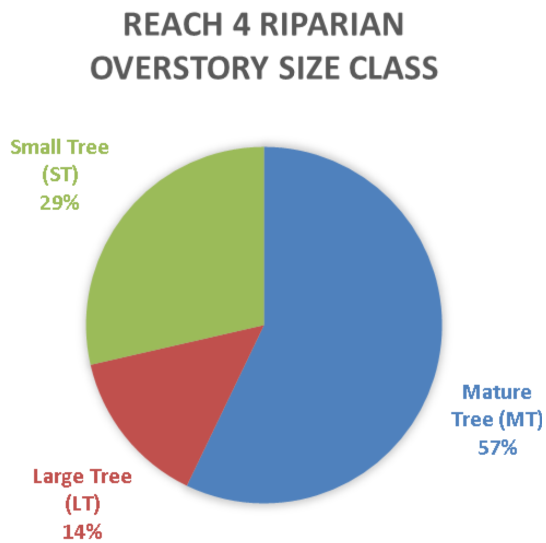
Figure 41. Cumulative grain size distribution for Gravel count 4.1 and Gravel Count 4.2.

Table 13. Grain size class for Gravel Count 4.1 and 4.2.

Size Class	REACH 4	
	GC # 4.1 Size % finer than (mm)	**GC # 4.2** Size % finer than (mm)
D16	21	22
D50	64	50
D84	154	90

4.4.6 Riparian Corridor

Based on seven n^{th} unit measurements, 54% of the riparian vegetation identified within 100 feet of the river in Reach 4 was mature trees (> 32-inch dbh). The remaining vegetation observed was 14% large tree (21 – 31.9-inch dbh), and 29% small tree (5.0 – 8.9 in. diameter). The understory was dominated by sapling/poles (57%) with 43% dogwood, 29% alder, 14% cedar, and 14% bigleaf maple. Observed overstory species included Douglas fir (43%), cedar (29%), Ponderosa pine (14%), and cottonwood (14%).



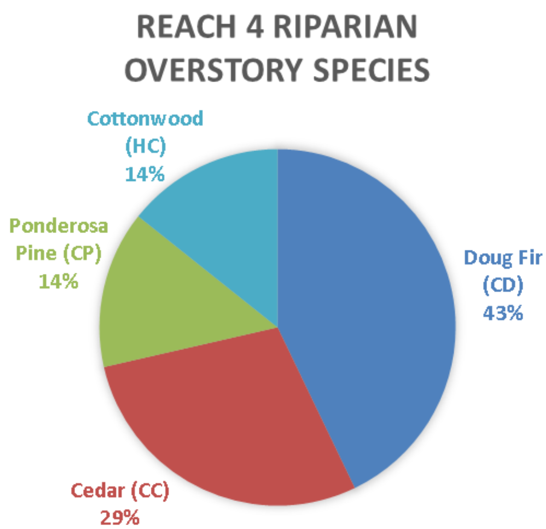
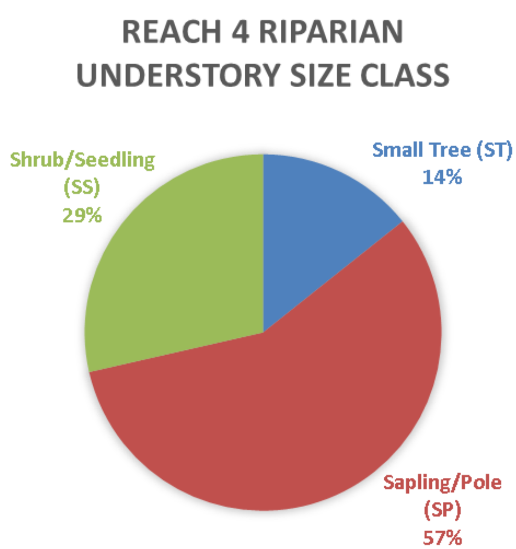


Figure 42. Dominant overstory riparian vegetation size and species identified within 100 feet of Mad River based on n^{th} unit ocular estimates.



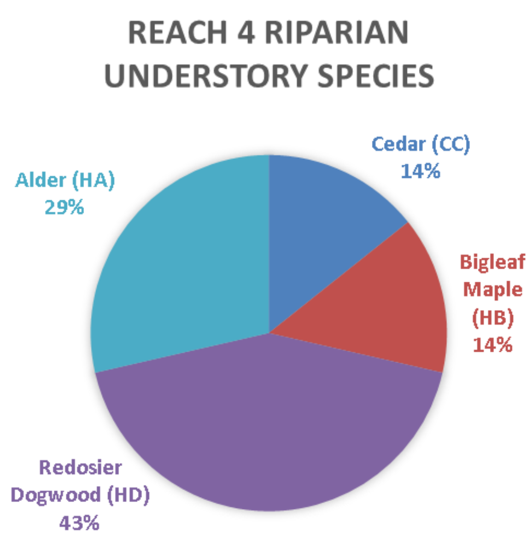


Figure 43. Dominant understory riparian vegetation size and species identified within 100 feet of Mad River based on n^{th} unit ocular estimates.

4.5 SUMMARY DATA

Table 14 provides a list of the data and metrics presented in this habitat assessment for the Lower Mad River (RM 0 – 4.3).

Table 14. Summary of all data collected for Reaches 1-4 of the Lower Mad River Habitat Assessment.

Reach	***1***	***2***	***3***	***4***	***All Reaches***
Reach Mileage boundaries	0 – 0.86	0.86 – 1.93	1.93 – 2.98	2.98 – 4.3	0 – 4.3
Wetted Width (ft)					
Pool					Averages
Mean	30	28.13	25.33	29.43	28.22
Median	30	28.5	26	26	27.63
StDev	7.53	6.03	5.03	10.26	7.21
Glide					
Mean	29.1	30.20	28.22	21.50	27.26
Median	27.75	29	28	21.5	26.56
StDev	4.0	6.61	5.45	5.45	5.38
Riffle					
Mean	29.6	30.20	34.50	28.07	30.60
Median	31	30	34.5	28	30.88
StDev	4.2	7.01	8.04	7.58	6.71
Side Channel					
Mean			9.00	3.50	6.25
Median			9	3.5	6.25
StDev			4.24	0.71	2.47
Water Depth (ft)					
Pool Maximum Depth					Averages
Mean	3.2	3.4	2.7	3.17	3.11
Median	3.15	3.2	2.6	3.00	2.99
StDev	0.5	0.6	0.3	0.8	0.55

Reach	***1***	***2***	***3***	***4***	***All Reaches***
Pool Residual Depth					
Mean	2	2.2	1.3	2.00	1.88
Median	2	2.2	1.3	2.00	1.86
StDev	0.7	0.6	0.2	1.0	0.63
Riffle/Glide Average Depth					
Mean	1.2	1.3	1.2	1.1	1.2
Median	1.2	1.3	1.3	1.1	1.2
StDev	0.3	0.4	0.3	0.3	0.3
Side Channel Average Depth					
Mean			0.65	0.3	0.48
Median			0.65	0.3	0.48
StDev			0.21	0	0.11
Bankfull Characteristics					
Width (ft)					Averages
Mean	41.00	51.33	48.00	52.50	48.2
StDev	3.46	3.56	7.87	0.71	3.9
Average Depth (ft)					
Mean	2.6	2.7	3.7	3.2	3.1
StDev	0.7	1.0	0.9	0.9	0.9
Maximum Depth (ft)					
Mean	0.50	0.76	0.63	1.13	0.8
StDev	0.50	0.76	0.63	1.13	0.8
Width: Depth Ratio					
Mean	15.52	18.79	12.88	16.41	15.90
Floodprone Width					
Mean	137.50	82.50	125.00	85.00	107.50
StDev	83.32	16.66	22.73	21.21	35.98

Reach	***1***	***2***	***3***	***4***	***All Reaches***
Habitat area %					
Pool	7%	8%	1%	7%	6%
Glide	9%	13%	17%	5%	11%
Riffle	84%	79%	82%	87%	83%
Side Channel	0%	0%	1%	1%	0.4%
Pools					
Pools per mile	4.6	7.5	2.9	5.3	4.9
Residual Depth (% of pools)					Average
Pools < 3 ft	100%	88%	100%	86%	93%
Pools 3-6 ft	0%	13%	0%	14%	7%
Riffle:Pool ratio	2	1.9	4	2.1	2.3
Mean Pool Spacing (bankfull channel widths per pool)	21.9	14.2	43.4	16.0	20.3
Large Woody Material					
Total Number Pieces					Total
Total	11	49	89	137	286
Large	0	3	14	31	48
Medium	0	19	30	43	92
Large and Medium	0	22	44	74	140
Small	11	27	45	63	146
Number of Pieces/Mile					Average
Total	12.8	45.7	84.8	103.8	61.8
Large (20 in by 35 ft)	0.0	2.8	13.3	23.5	9.9
Medium (12 in by 35 ft)	0.0	17.7	28.6	32.6	19.7
Large and Medium (Quality LW)	0.0	20.5	41.9	56.1	29.6
Small (6 in x 20 ft)	12.8	25.2	42.9	47.7	32.1

Reach	***1***	***2***	***3***	***4***	***All Reaches***
Jams					
Total jams per reach		1		3	4
Unstable Banks					
Total Unstable Banks (% of total bank)	2.7%	1.5%	4.8%	4.5%	3.4%
Substrate: at 2 exposed bar gravel counts					
Total					Average
% Sand	5%	4%	1%	0%	3%
% Gravel	45%	49%	56%	60%	52%
% Cobble	47%	45%	40%	38%	42%
% Boulder	4%	2%	4%	2%	3%
% Bedrock	0%	0%	0%	0%	0%
Vegetation (% of sampled units in 100-foot-wide zone averaged between both banks)					
Dominant Overstory Size Class					Average
Mature Tree	0%	0%	0%	57%	14%
Large Tree	50%	33%	0%	14%	24%
Small Tree	38%	67%	100%	29%	58%
Sapling/Pole	13%	0%	0%	0%	3%
Overstory Species Composition					
Doug Fir (CD)	0%	67%	33%	43%	36%
Cedar (CC)	0%	0%	0%	29%	7%
Ponderosa Pine (CP)	38%	27%	67%	14%	36%
Willow (HW)	13%	0%	0%	0%	3%
Cottonwood (HC)	38%	7%	0%	14%	15%
Alder (HA)	13%	0%	0%	0%	3%

Reach	***1***	***2***	***3***	***4***	***All Reaches***
Dominant Understory Size Class					
Small Tree (ST)	0%	13%	0%	14%	7%
Sapling/Pole (SP)	0%	80%	83%	57%	55%
Shrub/Seedling (SS)	63%	7%	17%	29%	29%
Grassland/Forb (GF)	38%	0%	0%	0%	9%
Dominant Understory Species					
Cedar (CC)	0%	0%	0%	14%	4%
Bigleaf Maple (HB)	0%	0%	17%	14%	8%
Willow (HW)	13%	0%	0%	0%	3%
Redosier Dogwood (HD)	13%	13%	17%	43%	21%
Alder (HA)	38%	87%	67%	29%	55%
Grassland/Forb (GF)	38%	0%	0%	0%	9%

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Appendix B

Reach-Based Ecosystem Indicators (REI)

Lower Mad River Reach Assessment (RM 0 – 4.3)

December 2018

Contents

1 Introduction

1.1 BACKGROUND

The Reach-based Ecosystem Indicators (REI) provides a consistent means of evaluating biological and physical conditions of a watershed in relation to regional standards and known habitat requirements for aquatic biota. These indicators, along with other scientific evaluations, are used to describe the current quality of stream biophysical conditions and to help inform restoration targets and actions. The REI indicators used in this assessment are adaptations from previous efforts including the National Marine Fisheries Service (NMFS) matrix of pathways and indicators (NMFS 1996) and the United States Fish and Wildlife (USFWS) (1998). With a few exceptions, the REI are based on the United States Bureau of Reclamation's (USBR) latest adaptations and use of these indicators (USBR 2012).

The REI evaluation for the Lower Mad River was conducted using field data, observations, previous studies, and available data for the study area. In particular, the rankings were developed based on quantitative inventory information from: 1) Habitat Assessment (Appendix A) performed as part of the Reach Assessment using United States Forest Service (USFS) (2015) protocols, 2) assessment of geomorphic patterns and processes and how they have deviated, if at all, from historical conditions, and 3) analysis of existing watershed assessments and data (e.g. available ArcMap layers and shapefiles etc.). Functional ratings include **Adequate**, **At Risk**, or **Unacceptable**. The REI analysis helps to summarize habitat impairments and to distill the impairments down to a consistent value that can be compared among reaches.

1.2 SUMMARY OF RESULTS

At the watershed-scale, the Mad River was rated **At Risk** for the Drainage Network and Hydrologically Impaired Surfaces indicator and the Disturbance Regime indicator, due to the number of roads and residential/agricultural clearing, particularly in the lower basin. The Streamflow indicator was also rated **At Risk** for the Mad River, while Water Quality – including water temperature and contaminants – was rated as **Adequate**.

At the reach-scale, Reaches 1 and 2 of the Lower Mad River were generally the most impacted reaches, having the highest number of **Unacceptable** ratings. Reach 3, though it had fewer **Unacceptable** ratings, still had a high number of **At Risk** ratings due to historic impacts from human disturbances such as timber harvests, channel confinement by a road, and instream large wood removal. Reach 4 was the least impacted, with seven **Adequate** ratings and only two **At Risk** and two **Unacceptable** ratings.

The ratings relating to salmonid habitat ranged from Adequate to Unacceptable across the study area. Reaches 3 and 4 were given **Adequate** ratings for the Habitat Access Pathway- Main Channel Barriers indicator since there were no barriers within the main channel that completely excluded fish passage. Reaches 1 and 2 were given **At Risk** ratings due to the presence of man-made irrigation and boulder weirs in Reach 1 and cement debris in the channel in Reach 2 that may limit access at certain flows.

Reaches 1 – 3 were given **At Risk** ratings for the Dominant Substrate/Fine Sediment indicator due to the relatively large grain size and limited retention of smaller gravels in the system. Reach 4, with more large wood in the channel, had higher amounts of smaller gravels and cobbles appropriate for spawning and was therefore given an **Adequate** rating.

Large Woody Material (LWM) ratings increased from **Unacceptable** in Reaches 1 and 2 to **Adequate** in Reach 4. The lower reaches had low numbers of large wood pieces and lacked potential large wood recruitment. Pool frequency was rated **Unacceptable** in all reaches due to the very low pool frequency and low quality of the pools (low residual depths and minimal/no large wood cover or habitat). The Off-channel Habitat indicator was rated as **Unacceptable** for Reaches 1 – 3 and **At Risk** for Reach 4 due to either the complete lack or very infrequent occurrence of connected alcoves and side channels.

Riparian vegetation condition indicators – Structure and Canopy Cover – were both rated **Unacceptable** for Reaches 1 and 2. Reach 3 received an **Unacceptable** structure rating due to the relatively young seral stage of the overstory and a rating of **At Risk** for canopy cover. Reach 4 riparian vegetation structure was rated as **At Risk** and canopy cover was classified as **Unacceptable**, owing to some areas with little riparian vegetation despite a mature tree overstory**.** Human disturbance was rated as **Adequate** in Reaches 2 – 4 due to minimal roads and development located within the riparian zone of these reaches. Reach 1, however, was rated as **At Risk** due to the number of residences and developed areas within the riparian zone of the lower Mad River near the town of Ardenvoir.

Channel dynamics for Reaches 1 and 2 are unsatisfactory. Reach 1 received **Unacceptable** ratings and Reach 2 received **At Risk** ratings in all three categories. Floodplain connectivity and Bank Stability/Channel Migration were rated **At Risk** in Reach 3, though Vertical Channel Stability was categorized as **Adequate**. Reach 4 was the only reach to receive an **Adequate** rating for all three Channel Dynamics indicators.

For the study area as a whole, **Unacceptable** was the most common reach-scale rating (18), followed by **At Risk** (15), then **Adequate** (11).

2 Metrics & Indicators

2.1 WATERSHED-SCALE METRICS

Pathway	General Indicators	Specific Indicators	Adequate Condition	At Risk Condition	Unacceptable Risk Condition
Watershed Scale					
Watershed Condition	Drainage Network and Hydrologically Impaired Surfaces	Increase in Drainage Network/ Hydrologically Impaired Surfaces	Zero or minimal increases in the drainage network that is correlated with human caused disturbances. Hydrologically impaired surfaces in watershed total < 8%. Road density <1 mile/miles^2.	Low to moderate increase in the drainage network correlated with human caused disturbances. Hydrologically impaired surfaces in watershed total between 8 and 14.9%. Road density 1-2.4 miles/miles^2.	Substantial increase in the drainage network correlated with human caused disturbances. Hydrologically impaired surfaces in watershed total > 15%. Road density >2.4 miles/miles^2.
	Disturbance Regime	Natural/Human Caused	Environmental disturbance is short-lived; predictable hydrograph, high quality habitat and watershed complexity providing refuge and rearing space for all life stages or multiple life-history forms. Natural processes are stable.	Localized events of hillslope contributions, avulsion, lateral migrations, minor bed incision, or wildfires. Resiliency of habitat to recover from environmental disturbances is moderate.	Frequent flood or drought producing highly variable and unpredictable flows, hillslope contributions, avulsion, lateral migrations, minor to major bed incision (head cuts), or wildfires throughout a majority of the watershed. The channel is simplified, providing little hydraulic complexity in the form of pools or side channels. Natural processes are unstable.
Flow/Hydrology	Streamflow	Alterations to Peak/Base Flows	Magnitude, timing, duration, and frequency of peak flows within a watershed are not altered relative to natural conditions of an undisturbed watershed of similar size, geology, and geography.	Some evidence of altered magnitude, timing, duration and/or frequency of peak flows relative to natural conditions of an undisturbed watershed of similar size, geology, and geography.	Pronounced changes in magnitude, timing, duration and/or frequency of peak flows relative to natural conditions of an undisturbed watershed of similar size, geology, and geography.
Water Quality	Temperature	(1) Maximum Weekly Temperature or (2) 7-day average daily maximum temperatures	(1) Bull Trout: incubation 2 - 5°C, rearing 4 - 10°C, spawning 1 - 9°C; Other salmonids: Spawning (June-Sept) <15°C and (Sept-May) <12°C, rearing <15°C, holding and migration <15°C; Lamprey: rearing 10 – 18 °C, migration <18°C (2) Salmonids: spawning <13°C, rearing and migration <17.5°C	(1) Incubation <2°C or ≥6°C, rearing <4°C or ≥13-15°C, spawning <4°C to ≥10°C; temperatures in areas used by adults during the local spawning migration sometimes exceed 15°C. Lamprey: rearing 18 – 22 °C, migration 18 - 22°C (2) 7-day average daily maximum temperature standards are exceeded by ≤15%	(1) Incubation <1°C or >6°C; rearing >15°C; spawning <4°C or >10°C; temperatures in areas used by adults during the local spawning migration regularly exceed 15°C. Lamprey: rearing >22 °C, migration >22°C (2) 7-day average daily maximum temperature standards are exceeded by ≥15%

2.2 REACH-SCALE METRICS

Pathway	General Indicators	Specific Indicators	Adequate Condition	At Risk Condition	Unacceptable Risk Condition
Reach Scale					
Habitat Access	Physical Barriers	Main Channel Barriers	No man-made barriers present in the mainstem that limit upstream or downstream migration at any flow.	Man-made barriers are present in the mainstem that have the potential to prevent or inhibit upstream or downstream migration at a subset of flows.	Man-made barriers present in the mainstem that prevent upstream or downstream migration at multiple or all flows.
Habitat Quality	Substrate	Dominant Substrate/Fine Sediment	Gravels or small cobbles make up >50% of the bed materials in spawning areas. ≤12%fines/sand (<2 mm) in spawning gravel.	Gravels or small cobbles make up 30-50% of the bed materials in spawning areas. 12-17% fines (<2 mm) in spawning gravel.	Gravels or small cobbles make up <30% of the bed materials in spawning areas. >17% fines (<2 mm) in spawning gravel.
	LWM	Pieces per Mile at Bankfull	Based on Fox and Bolton (2007) metrics for Eastern Washington, at least 32 pieces/mile of large wood. Qualifying pieces are those classified as Medium or Large in the USFS Stream Inventory protocol (2015), under the Eastside Forests criteria: Medium = diameter > 12 in, length > 35 ft; and Large = diameter > 20 in, length > 35 ft In addition to a minimum of 32 pieces of large wood/mile, an adequate rating also indicates there are sources of woody debris available for both long- and short-term recruitment within the reach.	Current levels are able to maintain the minimum requirements for an "adequate" rating, but potential sources for long-term woody debris recruitment, as determined by the Riparian Structure reach metrics, are lacking in order to maintain these current levels.	Current levels are not meeting the minimum requirements for an "adequate" rating, and potential source of woody debris for short- and/or long-term recruitment are lacking as well.
	Pools	Pool Frequency and Quality; presence of large pools.	Pool frequency: Number of pools/mile for a given channel width. Channel widths were variable throughout the study area, therefore the following channel width metrics for minimum pool frequencies will be used to determine adequate conditions based on average bankfull widths for each reach: Reaches 1, 2 and 4: 20-30 feet = 23 pools/mile Reach 3: 30-35 feet = 18 pools/mile To be considered adequate, at least 50% of the total pools are large pools >1 m (3 ft) deep. Pools must also have good fish cover (as determined by riparian vegetation and canopy cover metrics) and cool water with only a minor reduction in pool volume from fine sediment.	Pool frequency meets the values for the "adequate" rating, but pools have inadequate cover/temperature and/or there has been a moderate reduction of pool volume by fine sediment. Reaches have between 20 – 50% large pools (>1 m deep) present with good fish cover.	Pool frequency does not meet the pools/mile metric given in the "adequate" rating. Pools also have inadequate cover/temperature and/or there has been a major reduction of pool volume by fine sediment. Reaches have <20% large pools (>1 m deep).
	Off-Channel Habitat and Refugia	Connectivity with Main Channel	Reach has side channels and/or groundwater fed tributaries. Aquatic refugia such as backwaters, alcoves, large boulder eddies exist within the channel. Well-vegetated floodplains with healthy riparian community are inundated on a 1--2-year recurrence frequency. No man-made barriers along the mainstem that prevent access to off-channel areas.	Reach provides some aquatic off-channel and refugia features but access varies or is at risk of disconnection due to human impacts or man-made barriers. Floodplains along the off-channel habitat are well-vegetated with inundation recurrence of 2—5-years.	Reach provides no or only minimal off-channel or in-channel refugia. Floodplains are disconnected by processes of incision and/or human structures (levee, bridges, etc.) and riparian vegetation has been altered.

Pathway	General Indicators	Specific Indicators	Adequate Condition	At Risk Condition	Unacceptable Risk Condition
Riparian Vegetation	Condition	Structure	>80% large trees (>21” DBH; USFS 2013) in the riparian buffer zone (defined as a 200ft buffer along each bank) based on habitat assessment data.	50-80% large trees (>21” DBH; USFS 2013) in the riparian buffer zone (defined as a 200ft buffer along each bank) based on habitat assessment data.	<50% large trees (>21” DBH; USFS 2013) in the riparian buffer zone (defined as a 200ft buffer along each bank) based on habitat assessment data.
		Disturbance (Human)	<20% disturbance in the 200-foot riparian buffer zone (e.g. agriculture and grazing, residential, roads, etc.) and <1 mile/miles^2 road density in the 200-foot riparian buffer zone.	20-50% disturbance in the 200-foot riparian buffer zone (e.g. agriculture and grazing, residential, roads, etc.) and 1-2.4 miles/miles^2 road density in the 200-foot riparian buffer zone.	>50% disturbance in the 200-foot riparian buffer zone (e.g. agriculture and grazing, residential, roads, etc.) and >2.4 miles/miles^2 road density in the 200-foot riparian buffer zone.
		Canopy Cover	Trees and shrubs within one site potential tree height distance (~100 feet) have >80% canopy cover that provides thermal shading to the river.	Trees and shrubs within one site potential tree height distance have 50-80% canopy cover that provides thermal shading to the river.	Trees and shrubs within one site potential tree height distance have <50% canopy cover that provides thermal shading to the river.
Channel	Dynamics	Floodplain Connectivity	Floodplain areas are hydrologically linked to main channel within the context of the local process domain; overbank flows occur and maintain wetland functions, and riparian vegetation. Naturally confined channels are considered adequate.	Reduced linkage of floodplains and riparian areas to main channel in reaches with historically strong connectivity; overbank flows are reduced relative to historic frequency, as evidenced by moderate degradation of floodplain soil accumulations and riparian vegetation/succession.	Severe reduction in hydrologic connectivity between off-channel, floodplain, and riparian areas relative to historical connectivity; riparian vegetation/succession is altered significantly.
		Bank Stability/Channel Migration	Channel is migrating at or near natural rates within the geomorphic construct of the reach.	Channel migration is occurring at a faster or slower rate relative to natural rates, but significant change in channel width or planform is not detectable; large woody debris is still being recruited.	Little or no channel migration is occurring because of human actions preventing reworking of the floodplain and large woody debris recruitment; or channel migration is occurring at an accelerated rate such that channel width has at least doubled, possibly resulting in a channel planform change, and sediment supply has noticeably increased from bank erosion.
		Vertical Channel Stability	No measurable trend of aggradation or incision beyond the natural geomorphic processes of the reach.	Measurable trend of aggradation or incision that has the potential to, but has not yet caused, disconnection of the floodplain or a visible change in channel planform (e.g. single thread to braided.)	Enough incision or human infrastructure has occurred that the floodplain and off-channel habitat areas have been disconnected from the main channel; or enough aggradation has occurred to create a visible change in channel planform (e.g. single thread to braided.)

3 REI Ratings

This section discusses the results for each indicator, rated at either the reach-scale or watershed-scale for all four reaches.

3.1 WATERSHED-SCALE RATINGS

General Characteristics	General Indicators	Specific Indicators	Rating	Discussion
Watershed Scale				
Watershed Condition	Drainage Network and Hydrologically Impaired Surfaces	Increase in Drainage Network/ Hydrologically Impaired Surfaces	At Risk Condition	Watershed hydrologically impaired surfaces (roads, parking lots, and buildings) were calculated based on data from Washington State Department of Ecology. A GIS shapefile of land use data based on 2010 tax parcels from the Washington Department of Revenue was used to classify parcels as "hydrologically impaired" or "Not hydrologically impaired" for the watershed. Hydrologically impaired parcel polygon areas were summed and compared to the total watershed area, as determined using the Streamstats online mapper application (USGS 2017). The average percentage of hydrologically impaired surfaces for the entire contributing watershed was 0.5%. Road density was calculated using state roads GIS data from Washington Department of Natural Resources. Length of roads in the Mad River watershed were summed and compared to the total watershed area, giving an overall watershed road density of 3.64 miles of road per square mile of watershed. The upper Mad River watershed has little to no roads or buildings, while the lower portions of the watershed have higher densities of roads, both public and private roads. Though the percentage of hydrologically impaired surfaces for the entire contributing watershed is low, the road density and proximity of the roads to the active channel of Mad River places this indicator in the At Risk category.
	Disturbance Regime	Natural/Human Caused	At Risk Condition	This disturbance history rating reflects historical accounts of riparian and hillslope timber harvest, mining, grazing, agriculture and roads, and residential development. These activities have been shown to create channel instability and decrease the ability of the system to respond to natural disturbance regimes such as fire or flood. The watershed had a naturally frequent regime of low intensity fires that rejuvenated vegetation (USBR 2009). It has annual spring flooding and frequent rain-on-snow floods. As a result of largely human-caused modifications, the channel has reduced complexity and floodplain/alluvial fan connection and is incised in the lower sections. Historical timber harvest and severe wildfires have likely had significant direct and indirect effects on riparian vegetation, such as burning or extreme flooding. Channel-clearing activities were undertaken as a result of these large floods and debris-flow events (USBR 2009) have further negatively impacted watershed and aquatic habitat conditions. Currently a large portion of the lower watershed is within private ownership and used primarily for residential housing. A majority of the watershed is within public (federal/state) ownership, including campground and trails. It is likely that some timber harvest will continue in the upper reaches, but any additional disturbance potential other than from natural causes is low in the upland reaches. However, alterations from past human disturbance are still influencing the Mad River (such as the lag between riparian timber harvest/clearing and in-stream LWD removal that takes many years for new trees to mature and fall into the river). The system is still recovering from these disturbances that have a persistent and long-lasting impact. Based on this information, the Mad River receives a rating of At Risk.
Flow/Hydrology	Streamflow	Alternations to Peak/Base Flows	At Risk Condition	The hydrology of the watershed contributing to the Mad River is driven by a combination of precipitation and snowmelt. Annual snowmelt flooding in the spring with infrequent rain-on-snow floods dominate the seasonal streamflow pattern in the basin. Snowmelt runoff is primarily driven by changes in ambient air temperature, snowpack mass, and the elevation of the season's snowpack. Peak runoff usually occurs in May and June, typically returning to baseflow by late summer. Many of the land-use activities and channel alterations affecting the Mad River have been shown to change one or all of the above-mentioned attributes of peak flows in other basins. Climate change models indicate that winter precipitation is expected to increasingly fall as rain in the Cascade Mountains (Mote and Salanthe 2009) and likely result in an increase in winter stream flows, earlier and lower peak runoff, and lower summer baseflows. Drier and warmer conditions in the lower, Eastern portion of the basin may exacerbate the low summer flows. These analyses suggest that human-induced climate change is likely to have an effect on the magnitude, timing, duration, and frequency of stream flows in the Mad River. Based on the effects of past watershed management, and the potential effects of climate change, this indicator is rated At Risk.
Water Quality	Temperature	Daily maximum and 7-day mean daily maximum temperatures	Adequate Condition	Water temperatures in Mad River can exceed Washington State water quality standards for salmonids and Class AA streams and criteria set by the Wenatchee Forest Plan (<60.8 and 61°F, respectively) during the summer. Harsh winter conditions, such as icing, may be equally problematic for juvenile salmonids overwintering in the Mad River (Archibald and Johnson 2003). Mad Lake, the source of the Mad River, contributes warmer water that is successively cooled by tributaries and warmed by solar radiation as it moves downstream. As a result of these contrasting influences, thermal spatial variability in Mad River is very high, and may be representative of relatively natural conditions (Archibald and Johnson 2003). The Mad River is generally cooler than the Entiat River at their confluence during the summer. Therefore, this indicator is rated Adequate for the Mad River.

3.2 REACH-SCALE RATINGS

Pathway	General Indicators	Specific Indicators	Reach 1	Reach 2	Reach 3	Reach 4
Habitat Access	Physical Barriers	Main Channel Barriers	At Risk The irrigation out-take weir at RM 0.27 and man-made boulder weir at 0.75 may pose a velocity or passage barrier at high or very low flows.	At Risk Cement slab on bed of channel at RM 1.32 may pose passage barrier at certain flows.	Adequate There are no anthropogenic barriers in the main channel.	Adequate There are no anthropogenic barriers in the main channel.
Habitat Quality	Substrate	Dominant Substrate/ Fine Sediment	At Risk Cobbles dominate the channel substrate. Gravels were observed on the few depositional bars and pool tail-outs. Adequate material is moving through the reach but not being retained due to human impacts.	At Risk Cobbles dominate with boulders and sparse gravels. Gravels and coarse sand present in boulder eddies and pool tail-outs. Adequate material is moving through the reach but not being retained, partially due to human impacts.	At Risk Cobbles and boulders dominate with sparse gravels. Gravels and coarse sand present in boulder eddies, pool tail-outs, and small bars Adequate material is moving through the reach but not being retained, partially due to human impacts.	Adequate Cobble, gravel, boulder substrate. Plentiful gravels and small cobbles on bars, pool tail-outs, and behind log jams and boulder steps.
	LWM	Pieces per Mile at Bankfull	Unacceptable M+L pieces/mi = 0 Does not meet minimum criteria of 32 M+L pieces/mile, and limited availability of large wood for future recruitment.	Unacceptable M+L pieces/mi = 20.5 Does not meet minimum criteria of 32 M+L pieces/mile. Moderate availability of large wood for future recruitment.	At Risk M+L pieces/mi = 41.9 Meets minimum criteria of 32 M+L pieces/mile, with moderate availability of large wood for future recruitment.	Adequate M+L pieces/mi = 56.1 Meets minimum criteria of 32 M+L pieces/mile, with moderately acceptable availability of large wood for future recruitment.
	Pools	Pool Frequency and Quality; presence of large pools.	Unacceptable Total Pools = 4 Pools/mi = 4.6 Pools > 3 ft = 0 (0%) Average residual pool depth: 2 ft Low pool shading and cover from riparian vegetation.	Unacceptable Total Pools = 8 Pools/mi = 7.5 Pools > 3 ft = 1 (13%) Average residual pool depth: 2.2 ft Low pool shading and cover from riparian vegetation.	Unacceptable Total Pools = 3 Pools/mi = 2.9 Pools > 3 ft = 0 (0%) Average residual pool depth: 1.3 ft Low pool shading and cover from riparian vegetation.	Unacceptable Total Pools = 7 Pools/mi = 5.3 Pools > 3 ft = 1 (14%) Average residual pool depth: 2.0 ft Low pool shading and cover from riparian vegetation.
	Off-Channel Habitat and Refugia	Connectivity with Main Channel	Unacceptable Total SC = 0 Lacking off-channel habitats that are connected at a higher range of flows.	Unacceptable Total SC = 0 Lacking off-channel habitats that are connected at a higher range of flows.	Unacceptable Total SC = 2 Fast water = 1 Slow water = 1 Cover = moderate Minimal off-channel habitats that are connected at a higher range of flows. Boulders provide some refugia.	At Risk Total SC = 2 Fast water = 0 Slow water =2 Cover = moderate Minimal off-channel habitats that are connected at a higher range of flows. Boulders provide some refugia

Pathway	General Indicators	Specific Indicators	Reach 1	Reach 2	Reach 3	Reach 4
Riparian Vegetation	Condition	Structure	Unacceptable The riparian canopy overstory composition within the 200-foot riparian buffer was recorded as 50% large tree, 37% small tree, and 13% shrubs/seedlings. However, human disturbance in this reach has reduced the riparian canopy buffer to substantially less than 200 feet wide in many areas of this reach.	Unacceptable The riparian canopy overstory composition within the 200-foot riparian buffer was recorded as 33% large tree and 67% small tree. Human disturbance in this reach has impacted stand age and structural complexity, as historically more patches of mature trees would have been present.	Unacceptable The riparian canopy overstory composition within the 200-foot riparian buffer was recorded as 100% small tree. Human disturbance in this reach has impacted stand age and structural complexity, as historically more patches of mature trees would have been present.	At Risk The riparian canopy overstory composition within the 200-foot riparian buffer was recorded as 57% mature tree, 14% large tree and 29% small tree. Human disturbance in this reach has moderately impacted stand age and structural complexity, as historically more patches of mature trees would have been present.
		Disturbance (Human)	At Risk 30.7% disturbance in the 200-foot buffer zone (e.g. residential, roads, etc.) and 10.7 miles/miles^2 road density in the 200-foot riparian buffer zone.	Adequate 8.0% disturbance in the 200-foot buffer zone (e.g. residential, roads, etc.) and 12.6 miles/miles^2 road density in the 200-foot riparian buffer zone.	Adequate 5.1% disturbance in the 200-foot buffer zone (e.g. residential, roads, etc.) and 13.0 miles/miles^2 road density in the 200-foot riparian buffer zone.	Adequate 4.7% disturbance in the 200-foot buffer zone (e.g. residential, roads, etc.) and 9.5 miles/miles^2 road density in the 200-foot riparian buffer zone.
		Canopy Cover	Unacceptable Canopy Cover = 42%, Stream and banks highly visible at several portions of the reach, particularly river left bank adjacent to the road. Other residential or agricultural clearing throughout the reach and the relatively young seral stage of riparian vegetation results in moderate thermal shading. Several locations are present in this reach where roads and bridges intersect the channel resulting in lower canopy cover.	Unacceptable Canopy Cover = 42%, Stream and banks highly visible at several portions of the reach, particularly river left bank adjacent to the road. Other residential or agricultural clearing throughout the reach and the relatively young seral stage of riparian vegetation results in moderate thermal shading.	At Risk Canopy Cover = 54%, Stream and banks highly visible at several portions of the reach, particularly river left bank adjacent to the road. Locations with riparian vegetation that is primarily shrubs and seedlings provide minimal shading of the active channel.	Unacceptable Canopy Cover = 43%, Stream and banks highly visible at several portions of the reach, particularly river left bank adjacent to the campground and in the lower Reach 4 where Mad River Road runs adjacent to the channel.

Pathway	General Indicators	Specific Indicators	Reach 1	Reach 2	Reach 3	Reach 4
Channel	Dynamics	Floodplain Connectivity	Unacceptable The channel is entrenched in this reach. Levees along a large portion of the channel exaggerate floodplain disconnection	At Risk Bridge and road confinement have reduced available valley floor. Existing floodplain pockets are regularly connected	At Risk Bridge and an historical dam at the downstream end of the reach continues to locally disconnect available floodplain. Road confinement reduces available valley floor. Existing floodplain pockets are regularly connected.	Adequate Where valley width allows floodplains occur. Connectivity is adequate overall.
		Bank Stability/ Channel Migration	Unacceptable No channel migration is occurring due to human-imposed channel confinement. Discontinuous strips of narrow inset floodplain pockets are gradually developing.	At Risk Although a naturally partially confined reach, the Mad River Rd and a bridge further limit potential lateral processes.	At Risk Although a naturally confined reach, the Mad River Road and a bridge further limit potential lateral processes.	Adequate Where valley-width and channel complexity allow, lateral processes are occurring.
		Vertical Channel Stability	Unacceptable The channel is entrenchment due, in large part, to human impacts. Continued incision is possible but not expected to be rapid.	At Risk Road confinement and removal/lack of large wood in the channel likely prompted incision and loss of stored sediment in the past. Localized incision at bridge confinement (RM 0.98) is expected to continue. The presence of boulders and existing substrate size reduces incision rates elsewhere.	Adequate Road confinement and removal/lack of large wood in the channel likely prompted incision and loss of stored sediment in the past. Localized incision at the bridge and historical dam site (RM 2.04) impaired natural vertical channel stability processes. Large boulders and existing substrate limits continued incision throughout the reach.	Adequate Inputs from hillslopes and tributaries provide sediment pulses that periodically force changes in channel form. At the upstream end of this reach the channel is continuing to process debris-flow inputs. No measurable trend in incision or aggradation beyond natural geomorphic processes was observed. Exaggerated confinement by Mad River Rd and removal of LW in the lower portion of the reach may have instigated incision in the past.

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Appendix C

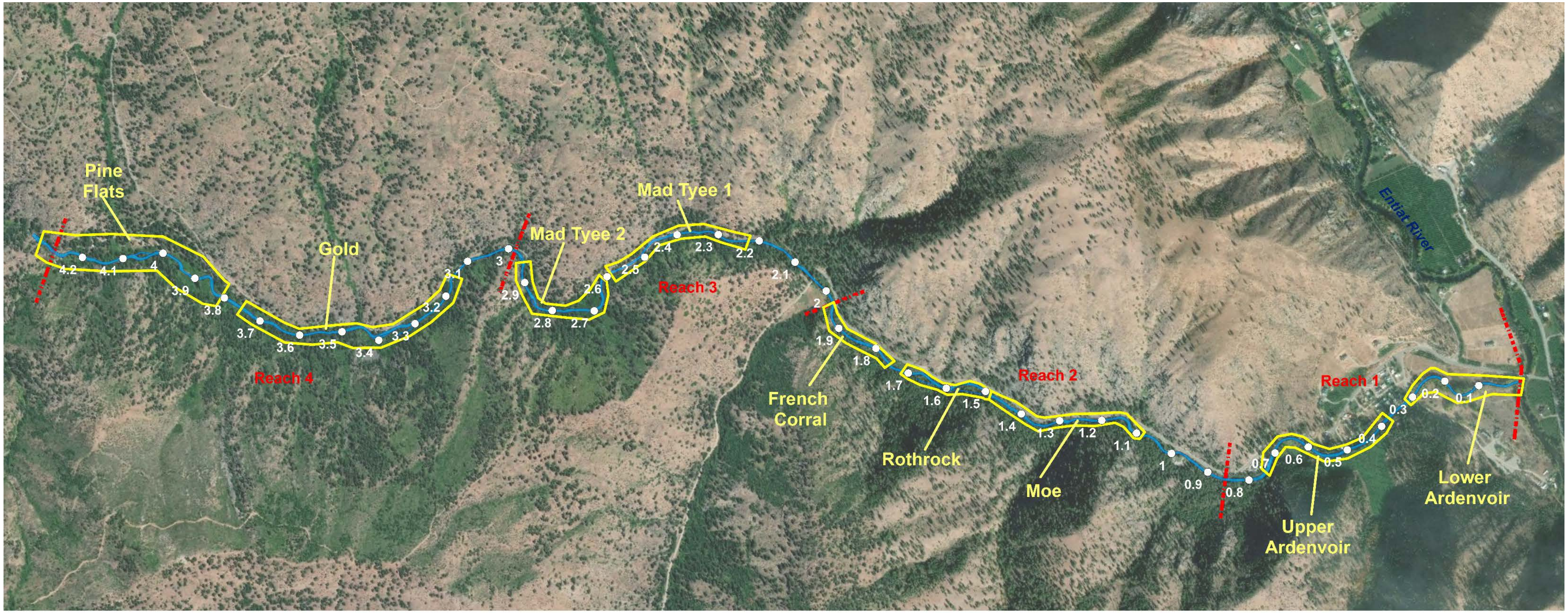
Project Opportunities and Prioritization

Lower Mad River Reach Assessment (RM 0 – 4.3)

December 2018

TABLE OF CONTENTS

1 Project Opportunity Areas Map



<u>Mad River (RM 0 - 4.3)</u>

Project Opportunity Areas

Project Opportunity Areas
Reach Breaks
Mad River
River Miles

N

0 0.125 0.25 0.5 **Miles**

These drawings should be viewed only as very preliminary concepts intended to describe the type of potential restoration work that could be performed. Additional site investigations and analysis will be necessary to determine specific treatment types and locations

2 Project-Based Restoration Recommendations

This table describes project opportunities by project area within the Lower Mad River Assessment area. Concept maps of the project opportunities are included below the table.

Reach	River Miles	Project Area Name	Project Description	Considerations
1	0 – 0.29	Lower Ardenvoir	**Narrative:** The Lower Ardenvoir Project area includes a combination of in-channel and floodplain treatments. Mainstem in-channel treatments include removing cement, riprap, and historical bridge supports made of logs that currently confine the channel by unnecessarily hardening the banks in specific locations. Constructed large wood jams (>10 pieces) and related scour hole development is recommended to greatly improve the quality and quantity of aquatic habitat and increase geomorphic complexity in Reach 1, where no large wood and limited complexity currently exists. Subtle lateral migration is encouraged through large wood jam construction design and placement to increase activation of local sediment supply and future riparian/floodplain wood recruitment. Floodplain treatments include removing existing levees, excavating sections of abandoned floodplains along the existing mainstem channel to elevations that will result in regular (2-5 year) inundation while also supporting healthy riparian vegetation. Riparian restoration is focused on planting appropriate riparian trees and shrubs to create wider vegetated riparian buffer and to remediate areas disturbed by levee removal and jam construction. There is potential for the excavated materials to be used in the mainstem to augment spawning gravels on bars but this will need to be modeled and designed in detail. Temporary fencing that excludes cattle and other grazing undulates is strongly recommended to promote establishment of and protect riparian vegetation. These treatments are intended to reduce channel entrenchment and create an active functioning riparian floodplain while improving the quantity and quality of available mainstem habitat. Restoration treatments here will also improve and increase available habitat for fish utilizing the Entiat River. **Project Elements:** ***Riparian Restoration*** • Plant and maintain appropriate riparian and floodplain vegetation in all areas disturbed as a result of restoration actions. • Utilize exclusion fencing to protect riparian and floodplain plantings from grazing ungulates until established. ***Remove Unnecessary Materials*** • Remove anthropogenic features (riprap, cement slabs, historical log bridge supports) from the mainstem channel that limit natural processes and/or promote channel entrenchment. • Remove from the floodplain selected levee selection that limit natural processes and/or continue to promote channel entrenchment. ***Enhance Channel Complexity*** • Floodplain excavation: excavate selected sections of the modern terrace and leveed bank on river right to create inset connected floodplain benches capable of supporting desired riparian vegetation. Plant inset surface with appropriate native riparian vegetation. ***Improve Aquatic Habitat*** • Installation of large (≥10 root wad logs) LW side log jams into the banks at identified locations. LW log jams will extend into the channel to approximately half or more of the channel width. Scour pools will be dug during installation but jams and pools will be designed to maintain pool scour, promote lateral processes, and increase gravel retention downstream of jams. This will notably increase channel complexity and improve aquatic habitat. • Installation of large (≥ 10 l root wad ogs) LW apex log jam at the mouth of the Mad River on river right to maintain scour pool at confluence, provide cover, and notably enhance available aquatic habitat for the lower Mad River and adjoining Entiat River. • Evaluate and improve or remove weir and associated irrigation outtake structure at RM 0.29. *Note: Improve Bridge Crossing at RM 0.3 is described below.*	Accessible, but permission will need to be granted by property owners. Modelling will be necessary to predict potential changes to flood event inundation patterns. Examination of potential changes to flow hydraulics at the Mad River Road bridge crossing over the Entiat River is recommended. In-water work will require permit acquisition. Removal of bank-hardening material is expected to improve geomorphic process, including lateral migration. Land-owner communication is highly recommended. Installation of log jams prior to potential future development at Two Rivers Ranch is recommended.

Reach	River Miles	Project Name	Project Description	Considerations
1	0.39 and 0.73	Upper Ardenvoir	**Narrative:** The Upper Ardenvoir Project Area includes two separate project sites. These projects could be installed separately. Mainstem in-channel treatments include removing cement slab and a hand-built weir and constructing LW jams to maintain pool scour and greatly improve the quality of available aquatic habitat it provides. These features will increase geomorphic complexity in Reach 1, where no large wood and limited complexity currently occurs. Riparian restoration is focused on planting appropriate riparian trees to remediate areas disturbed by jam construction. Temporary fencing that excludes cattle and other grazing undulates is strongly recommended to promote establishment of and protect riparian vegetation. **Project Elements:** ***Riparian Restoration*** • Plant and maintain appropriate riparian and floodplain vegetation in all areas disturbed as a result of restoration actions. Utilize fencing if necessary to reduce or eliminate grazing impacts to establishing vegetation treatments above the ordinary high-water elevation. ***Remove Unnecessary Materials*** • Remove cement slab (RM 0.6) and human-built boulder weir (RM 0.73) from the mainstem channel. These features currently armor the channel bed and potentially inhibit fish passage at certain flows. ***Improve Aquatic Habitat*** • Installation of large ($\geq$10 root wad logs) LW side log jam at RM 0.39 on river left at existing pool. It is recommended that the LW log jams will extend into the channel to approximately half or more of the channel width. Should improve aquatic habitat and increase gravel retention. • Installation of small (1-3 root wad logs) LW jam and excavate pool. Design jam to maintain existing pool with scour and improve aquatic habitat quality. Ballast wood to existing large boulders on river right. *Note: Improve Bridge Crossing at RM 0.6 is described below.*	Accessible, but permission will need to be granted by property owners. In-water work will require permit acquisition. Early land-owner communication is highly recommended. Proximity of homes to the channel limits treatment recommendations.
1	0.3 and 0.6	Ardenvoir Bridge Crossings	**Narrative:** Improvements to the bridge crossings at RM 0.3 and 0.6 include removing the existing bridge and bridge supports that currently confine the channel and then installing a wider bridge. New bridge footings would be constructed on the terrace/floodplain at a designed width and height. This treatment would improve floodplain inundation, reduce unnatural channel constriction and allow for future lateral processes – all of which enhance channel complexity at, up, and downstream of the bridge locations. **Project Elements:** ***Riparian Restoration*** • Plant and maintain appropriate riparian and floodplain vegetation in all areas disturbed as a result of restoration actions ***Remove Unnecessary Materials*** • Remove existing bridge supports that currently confine the channel. ***Enhance Channel Complexity*** • After removal of the existing bridge, set channel banks back to increase flow conveyance capacity and riparian vegetation establishment. Install new bridge footings outside the estimated inundation zone at a designed width and height for new bridge.	Accessible, but construction will need to be coordinated with bridge users and owners. In-water work will require permit acquisition. Right-of-way agreements and permitting may be necessary. Removal of bank-hardening material is expected to improve geomorphic process. Bridge crossings are located on straight river sections but the potential for lateral processes should be modeled and necessary bank protection added if needed.

Reach	River Miles	Project Name	Project Description	Considerations
2	1.1-1.47	Moe	**Narrative:** The Moe Project Area includes removal of a cement wall from the channel bank and multiple options for installation of large wood jams to improve aquatic habitat. The cement wall remnant at RM 1.42 on river right does not currently interact with low and moderate flows but it has the potential to influence local hydraulics and bank processes at high flows. Five locations were identified as potentially suitable for the installation of small (2-3 root wad logs) large wood jams. Three of those small LW jams include adding large boulders to the channel for ballasting and increasing channel complexity and habitat quality at the site. The other two small LW jams would be placed at sites with existing large boulders that would be employed for ballasting. Two locations were identified as potentially suitable for the installation of medium (4-9 root wad logs) large wood jams. Both locations utilize existing boulders for ballasting. All proposed LW jams (small and medium) include burial of trunks into the bank and ballasting of root wads. Additional slash and small wood is expected to be added to the jams. These projects could be installed together or separately. The LW jams are all expected to improve available aquatic habitat by increasing pool frequency and adding cover. **Project Elements:** ***Riparian Restoration*** • Plant and maintain appropriate riparian and floodplain vegetation in all areas disturbed as a result of restoration actions. • If tree trimming or removal is necessary along the Mad River Road for road safety, fell the trees into the channel to increase wood quantities. Otherwise, restrict any resource extraction from the river corridor. ***Remove Unnecessary Materials*** • Remove cement wall from bank at RM 1.42. • Remove cement slab on bed of channel at RM 1.32 that may pose fish passage barrier at certain flows. ***Improve Aquatic Habitat and Enhance Channel Complexity*** • Installation of small LW jams (2-3 root wad logs) at RM 1.1, 1.18, 1.19, 1.23, and 1.37 on river left. Install large boulders in conjunction with LW jams at RM 1.1, 1.19, and 1.23. These LW jams will improve the quantity and quality of available aquatic habitat by adding channel complexity that includes scour pools that have good fish cover. Trunks should be partially buried in the bank and logs will be ballasted to existing or added boulders. • Installation of medium LW jams (4-9 root wad logs) at RM 1.44 and 1.46. These LW jams will improve the quantity and quality of available aquatic habitat by adding channel complexity that includes scour pools that have good fish cover. Trunks will be partially buried in the bank and logs will be ballasted to existing or added boulders	Cement wall is above ordinary high water and thus would not likely require a permit for removal. All actions accessible from Mad River Road or adjacent floodplain. Source for large boulders on hillslope north of Mad River Rd at RM 1.45. In-water permits will be required. Existing infrastructure (bridge) downstream so ballasting of LW is recommended. Burial of trunks should take advantage of existing road riprap boulders and maintain road stability.

Reach	River Miles	Project Name	Project Description	Considerations
2	1.49 – 1.7	Rothrock	**Narrative:** The Rothrock Project Area includes installation of large wood jams and the creation of side-channels to improve aquatic habitat and enhance channel complexity. Three locations were identified as potentially suitable for the installation of small (2-3 root wad logs) large wood jams with large boulders for ballasting. One location was identified as potentially suitable for the installation of a mid-channel LW jam that is medium in size (4-9 root wad logs) to promote split flow and bar development. The creation of two side channels is recommended on available floodplains on river right. Both side-channels include a large (>10 root wad logs) apex jam at the upstream inlet end and a medium (4-9 root wad logs) LW jam at the downstream outlet end to maintain side-channel connectivity to the mainstem, increase channel complexity, and provide habitat at varied flows. These projects could be installed together or separately. All treatments are expected to improve available aquatic habitat in the mainstem by increasing pool frequency and adding cover. The side-channels are expected to increase the quantity and quality of habitat, including providing refugia at high and low flows. Treatments in this project area should be integrated with the recently installed (2018) Tillicum Fan side-channel treatments. **Project Elements:** ***Riparian Restoration*** • Plant and maintain appropriate riparian and floodplain vegetation in all areas disturbed as a result of restoration actions. • Utilize exclusion fencing to protect riparian and floodplain plantings from grazing ungulates until established where needed. ***Enhance Channel Complexity and Improve Aquatic Habitat*** • Install mid-channel apex LW jams at RM 1.59 (med size) and RM 1.54 (small size) to instigate split-flow processes, narrow channel surface width, and promote bar development. • Installation of small LW jams (2-3 root wad logs) at RM 1.5 and 1.63 on river left and 1.54 at mid-channel. Install large boulders in conjunction with LW jams for ballasting and increased channel complexity. These LW jams will improve the quality of available aquatic habitat by adding channel complexity that includes scour pools. promoting split flow at low-discharge and adding cover. The trunks of the side-jams will be buried in the bank. • Installation of medium LW jams (4-9 root wad logs with slash) at RM 1.44 and 1.46. These LW jams will improve the quantity and quality of available aquatic habitat by adding channel complexity that includes scour pools that have good fish cover. Partially burial of trunks in the bank and ballast logs to existing or added boulders. • Installation of large LW jams (>10 root wad logs) at RM 1.58 and 1.7. Ideally, these will be installed as inlet jams in conjunction with the construction of side channels but they would provide high-quality mainstem habitat improvements if installed without the side channels. • Installation of medium LW jams (4-9 root wad logs) at RM 1.49 and 1.64. Include large ballast boulders at the RM 1.64 jam. Ideally, these will be installed as outlet jams in conjunction with the construction of side channels but, they would provide high-quality mainstem habitat improvements if installed without the side channels. ***Side/Off-Channel Habitat Enhancement*** • Construct side channels on available well-vegetated existing floodplain surfaces between RM 1.49 to 1.58 and RM 1.64 and 1.7. Take advantage of existing well-vegetated surface. Construct in conjunction with inlet and outlet LW jams (see above). Side channels will increase the quantity of available habitat and provide refugia at high and low flows.	Access to mid-channel and river left treatments is from Mad River Rd and adjacent floodplain. Access to side-channels and river-right treatments will require crossing (temp bridge?) the Mad River mainstem. Burial of LW trunks should take advantage of existing riprap boulders and maintain road stability. Source for large boulders on hillslope north of Mad River Rd at RM 1.45. In-water permits will be required.

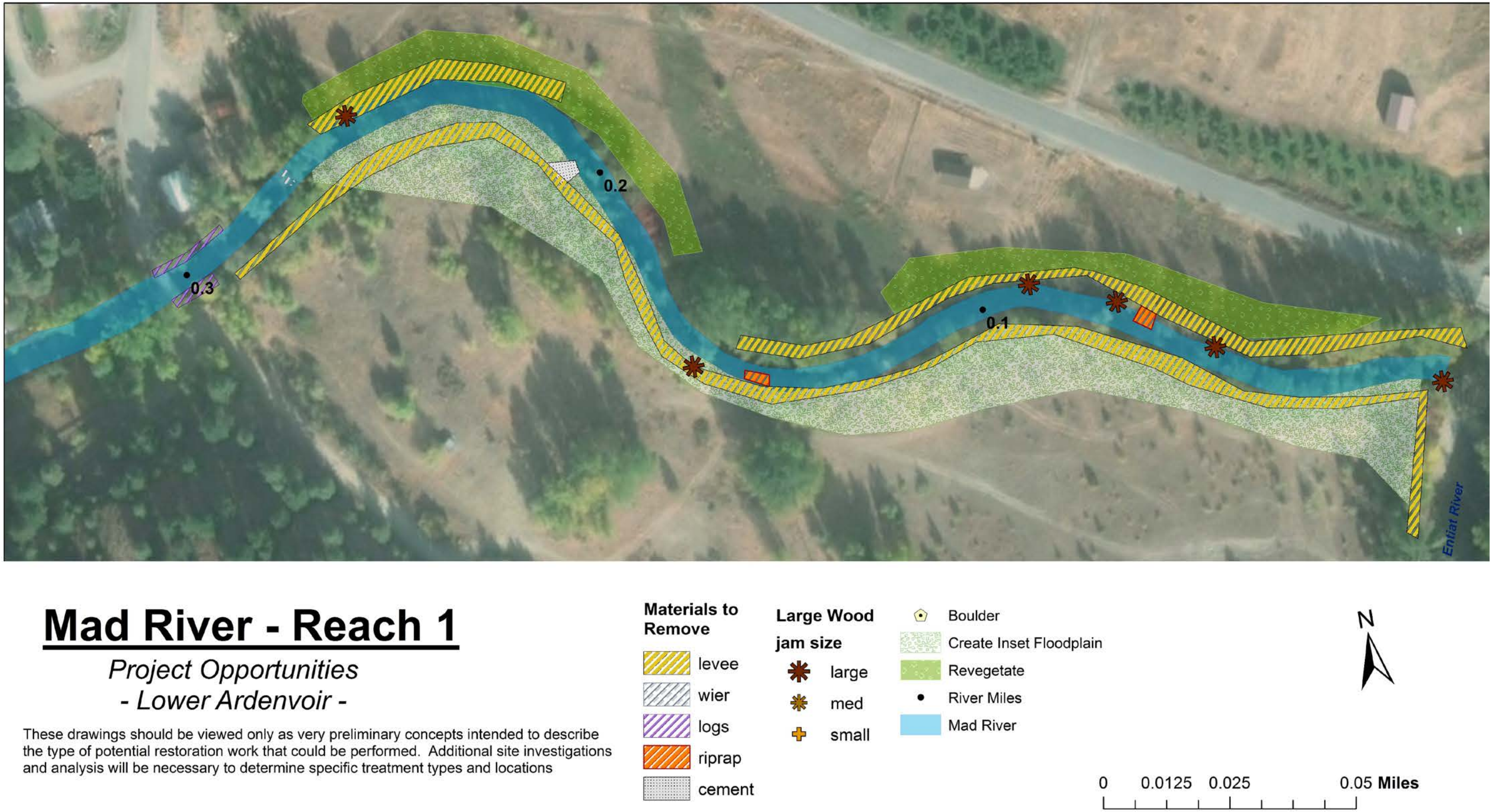
Reach	River Miles	Project Name	Project Description	Considerations
2	1.75 and 1.95	French Corral	**Narrative:** The French Corral Project Area includes two LW jam project sites. These projects could be installed separately. At RM 1.95 a medium (4-10 root wad logs) LW jam is recommended that would be ballasted to existing large boulders in the middle of the channel. At RM 1.75, large boulders would be added to a small (1-3 root wad logs) LW side-channel jam for ballasting and edge-of-channel complexity. Burial of a portion of the side-channel jam into the floodplain for structural stability will likely be recommended. A scour pool would be dug in conjunction with the installation of the LW jams. Both LW jams would improve aquatic habitat (currently dominated by extended riffles) by enhancing localized channel complexity via pool scour, altered high-flow hydraulics, potential sediment accumulations, and pool cover. Riparian restoration is focused on planting appropriate riparian trees to remediate areas disturbed by jam construction. **Project Elements:** ***Riparian Restoration*** • Plant and maintain appropriate riparian and floodplain vegetation in all areas disturbed as a result of restoration actions. Utilize fencing if necessary to reduce or eliminate grazing impacts to establishing vegetation treatments above the ordinary high-water elevation. ***Enhance Channel Complexity*** • Install LW jams: increase presence of LW in the channel with engineered log jams designed to maintain pool scour at the root wads, catch additional small and large woody debris moving through the channel, and promote localized sediment accumulation downstream. ***Improve Aquatic Habitat*** • Installation of a large (>10 root wad logs) LW log jam at RM 1.95, ballasted to existing large boulders in the channel. The LW jam will improve aquatic habitat by increasing and maintaining pool frequency as well as adding cover and complexity to site. • Installation of small (1-3 root wad logs) LW side-channel jam with added large boulders and excavate pool. Design jam to maintain pool scour and improve aquatic habitat quality. Ballast wood to existing large boulders and partially burry on river right.	Access is from Mad River Rd and adjacent floodplain. Burial of LW trunks (RM 1.75) should consider maintenance of road stability. Source for large boulders on hillslope north of Mad River Rd at RM 1.45. In-water permits will be required Potential to pull LW from RR hillslope Limited available project areas in this river section
3	2.25-2.58	Mad Tyee 1	**Narrative:** The Mad Tyee I Project Area includes four potential LW jam project sites. These projects could be installed separately. All jams are small (1-3 root wad logs) and would be designed as features along the side of the mainstem channel. Two of the recommended LW jams include adding large boulders for ballasting and two include utilizing existing boulders for ballasting. A scour pool would be dug in conjunction with the installation of the LW jams. LW design would facilitate pool scour maintenance, habitat cover, racking/catching additional LW mobilized in the channel and, where appropriate, sediment accumulations immediately downstream. Burial or partial burial of log tops will likely be recommended for structural stability. Riparian restoration is focused on planting appropriate riparian vegetation to remediate areas disturbed by jam construction. **Project Elements:** ***Riparian Restoration*** • Plant and maintain appropriate riparian and floodplain vegetation in all areas disturbed as a result of restoration actions. Utilize fencing if necessary to reduce or eliminate grazing impacts to establishing vegetation treatments above the ordinary high-water elevation. ***Enhance Channel Complexity*** • Install LW jams: increase presence of LW in the channel with engineered log jams designed to maintain pool scour at the root wads, catch additional small and large woody debris moving through the channel, and promote localized sediment accumulation downstream. ***Improve Aquatic Habitat*** • Installation of two small (1-3 root wad logs) side-channel LW log jam at RM 2.25 RR and 2.51 RL that are ballasted to imported large boulders. The LW jam will improve aquatic habitat by increasing and maintaining pool frequency as well as adding cover and complexity to habitat. • Installation of two small (1-3 root wad logs) side-channel LW log jam at RM 2.48 RR and 2.58 RL that are ballasted to existing large boulders. The LW jam will improve aquatic habitat by increasing and maintaining pool frequency as well as adding cover and complexity to habitat.	Access is from Mad River Rd and adjacent floodplain. May be necessary to construct temporary crossing (bridge) for installation of jams on RR. May utilize helicopter for log and boulder placement. Burial of logs should consider maintenance of road stability. May utilize road riprap in burial. Source for large boulders on hillslope north of Mad River Rd at RM 1.45. In-water permits will be required. Investigate potential to source LW from RR hillslope.

Reach	River Miles	Project Name	Project Description	Considerations
3	2.63-2.94	Mad Tyee II	**Narrative:** The Mad Tyee II Project Area includes creation of a backwater alcove habitat and installation of four potential LW jams. These projects could be installed separately. However, it is recommended that the alcove be constructed in conjunction with an outlet LW jam at RM 2.63. The alcove would be excavated into the floodplain surface and utilize existing large boulders for maintenance. A large (>10 root wad logs) LW structure would be constructed at its mouth to maintain connectivity with the mainstem channel and provide high-quality covered pool habitat. It is recommended that a large (>10 root wad logs) LW mid-channel apex jam at RM 2.7 be designed to split flow, catch/rack additional LW, instigate bar development and enhance channel and floodplain complexity. The medium (4-10 root wad logs) LW side-channel jam at RM 2.73 on RL would be designed to maintain pool scour, provide cover, and potentially promote high-flow onto the floodplain. If appropriate (modeling and survey required) this could be done to instigate development of a side-channel that connects to the downstream constructed alcove. The small (1-3 root wad logs) LW side jam at RM 2.94 on RL would be designed to maintain pool scour, provide cover, and promote gravel and floodplain accumulations downstream. All jams include adding imported large boulders for ballasting and increased channel complexity. A small scour pool would be dug in conjunction with the installation of the LW jams. Jams would be designed to facilitate pool scour maintenance, habitat cover, racking/catching additional LW mobilized in the channel and, where appropriate, sediment accumulations immediately downstream. Burial or partial burial of log tops will likely be recommended for structural stability. Riparian restoration is focused on planting appropriate riparian vegetation to remediate areas disturbed by jam construction. **Project Elements:** ***Riparian Restoration*** • Plant and maintain appropriate riparian and floodplain vegetation in all areas disturbed as a result of restoration actions. Utilize fencing if necessary, to reduce or eliminate grazing impacts to establishing vegetation treatments above the ordinary high water elevation. ***Enhance Channel Complexity*** • Installation of LW apex jam at RM 2.7 that is ballasted to imported large boulders to promote split-flow, notably increase channel complexity, and promote bar and floodplain development. • Installation of sidel LW jams (RM 2.73 and 2.94) ballasted to imported large boulders to increase inundation of the floodplain. ***Improve Aquatic Habitat*** • Installation of LW apex jam at RM 2.7 with imported large boulders to promote split-flow, notably increase channel complexity, and promote gravel accumulations • Installation of medium LW side jam RL at RM 2.73 that is ballasted to imported large boulders to create and maintain pool habitat with cover. • Installation of small (1-3 root wad logs) side-channel LW log jam at RM 2.94 that is ballasted to imported large boulders to create and maintain pool habitat with cover. ***Side/Off-Channel Habitat Enhancement/Development*** • Construct off-channel alcove feature with LW habitat enhancement feature at its mouth at RM 2.63 to provide off-channel habitat and high-flow refugia.	Access is from Mad River Rd and adjacent floodplain. May utilize helicopter for log and boulder placement. Road maintenance and stability should be considered when designing alcove. Source for large boulders on hillslope north of Mad River Rd at RM 1.45. In-water permits will be required. Investigate potential to source LW from RR hillslope. Hyporheic flow captured by alcove for water quality.

Reach	River Miles	Project Name	Project Description	Considerations
4	3.08-3.73	Gold	**Narrative:** The Gold Project Area includes eight potential LW jam project sites. These projects could be installed separately but it is recommended that they be lumped by RM 3.08-3.25, RM 3.3 to 3.41 (priority), and RM 3.55 to 3.73. Five of these jams are recommended to be large (>10 root wad logs). Four of the large LW jams are recommended as mid-channel jams -- three of which include adding large boulders for ballasting and added habitat complexity. The other three LW jams are medium (4-10 root wad logs) and all of these include adding large boulders for ballasting and added habitat complexity. The medium jam at RM 3.25 could be channel spanning. There is potential for adding large boulder(s) to increase complexity. Jam design would facilitate all or some of the following features: split-flow, pool scour maintenance, habitat cover, racking/catching additional LW and, where appropriate, sediment accumulations. Burial or partial burial of log tops will likely be recommended for structural stability. Riparian restoration is focused on planting appropriate riparian vegetation to remediate areas disturbed by jam construction. **Project Elements:** ***Riparian Restoration*** • Plant and maintain appropriate riparian and floodplain vegetation in all areas disturbed as a result of restoration actions. Utilize fencing if necessary to reduce or eliminate grazing impacts to establishing vegetation treatments above the ordinary high-water elevation. ***Enhance Channel Complexity*** • Installation of large LW apex lag jam at RM 3.55, 3.68, and 3.74 that are ballasted to imported large boulders to promote split-flow, notably increase channel complexity, and promote bar and floodplain development. • Installation of medium LW side jam at RM 3.39 (RR) to improve channel complexity and promote extension of and connection to side channel/alcove development downstream. • Installation of medium LW channel-spanning jam at RM 3.25 to increase complexity (step at designed flows) and promote gravel accumulations. • Add large boulders at RM 3.08 to increase channel complexity (pools with downstream sediment accumulations and steps) ***Improve Aquatic Habitat*** • Installation of large LW apex jam at RM 3.55, 3.68, and 3.73 that are ballasted to large boulders to create and maintain pool habitat with cover and promote spawning gravel recruitment. Large boulder will likely need to be imported. • Installation of medium side-channel LW log jams at RM 3.17 (RL) and RM 3.39 (RR) that are ballasted to large boulders to create and maintain pool habitat with cover. Large boulder will likely need to be imported for RM 3.39 and a very large boulder will be moved downstream ~20ft to build jam at RM 3.17. ***Side/Off-Channel Habitat Enhancement*** • Installation of large LW apex jam at existing split-flow feature (RM 3.41) to promote continued and more complex split flow processes and support mid-channel bar and floodplain development. This should be done in conjunction with downstream side-channel at RM 3.39. • Develop alcove at RM 3.3 at existing side-channel outlet with hyporheic and/or spring-fed surface water contributions. Construct large LW jam at outlet of alcove to provide cover, maintain scour pool, and support mainstem connectivity at low-flows.	Access is from Mad River Rd and adjacent floodplain. May utilize helicopter for log and boulder drop. Access to construct alcove and RR features may require temporary creek crossing or bridge. Source for large boulders on hillslope north of Mad River Rd at RM 1.45. In-water permits will be required. Potential to source LW from RR hillslope. Hyporheic flow captured by alcove for water quality.

Reach	River Miles	Project Name	Project Description	Considerations
4	3.82-4.3	Pine Flats	**Narrative:** The Pine Flats Project Area includes ten potential LW jam project sites in the mainstem as well as three LW jam projects in side channel features. These projects could be installed separately but it is recommended that they be lumped by RM 3.82-3.95, RM 4.03-4.07, and RM 4.29-4.3 and in that relative priority. Eight of the total recommended jams are large (>10 root wad logs) – three of which are apex jams while the other five are large side-channel jams. Five of the total recommended LW jams are medium (4-10 root wad logs) – three of which are side jams in enhanced side-channel project areas. Two large and one medium LW jam includes adding large boulders for ballasting and improving habitat complexity. This project area includes enhancing a side-channel feature on RL (RM 4.03-4.07) and developing a side channel on RR (RM 3.82-3.93). Both side channel features include inlet and outlet LW jams (large) and side-channel (medium) LW habitat jams. Side channel habitat development and enhancement increases the quantity of available habitat in the project area. LW jam design would facilitate all or some of the following features: split-flow, pool scour maintenance, habitat cover, racking/catching additional LW, off-channel habitat connectivity and, where appropriate, sediment accumulations. Burial or partial burial of log tops will likely be recommended for structural stability. Riparian restoration is focused on planting appropriate riparian vegetation to remediate areas disturbed by jam construction. **Project Elements:** ***Riparian Restoration*** • Plant and maintain appropriate riparian and floodplain vegetation in all areas disturbed as a result of restoration actions. Utilize fencing if necessary to reduce or eliminate grazing impacts to establishing vegetation treatments above the ordinary high-water elevation. ***Enhance Channel Complexity*** • Installation of large (RM 3.86) and medium (RM 3.88 and 3.95) LW side-channel jams are designed to promote side-channel development at high-flows on adjacent floodplain surfaces. • Installation of large LW apex jam near RM 3.94 that is ballasted to imported large boulders is designed to promote split-flow, notably increase channel complexity, promote local bar and floodplain development, and support development of RR side-channel downstream. ***Improve Aquatic Habitat (mainstem)*** • Installation of large LW side-channel jams in the mainstem channel at RM 3.82 (RR & side-channel outlet), RM 3.86 (RL), RM 3.93 (RR & side-channel inlet), RM 4.03 (RL & side-channel outlet), 4.07 (RL & side-channel inlet), RM 4.29 (RR), and 4.3 (RR with imported boulders) will be designed to create and/or maintain pool habitat, provide habitat cover, and promote spawning gravel recruitment. • Installation of medium LW side-channel log jams in the mainstem at RM 3.88 (RR) and RM 3.95 (RL) to create and maintain pool habitat with cover and promote spawning gravel recruitment. Large boulder will likely need to be imported for jam at RM 3.95. ***Side/Off-Channel Habitat Enhancement/Development*** • Enhance side-channel on RL (RM 4.03-4.07): construct inlet and outlet jams to provide cover, maintain pools, and support mainstem connectivity; potentially excavate bed to capture hyporheic or GW inputs at low flow periods; add medium LW side-channel jam (RL) to improve habitat • Develop side-channel on RR (RM3.82-3.93): construct inlet and outlet jams to provide cover, maintain pools, and support mainstem connectivity; excavate channel to design specifications that ideally include capturing hyporheic or GW inputs; add medium LW side-channels and/or mid-channel jams to enhance habitat and geomorphic complexity. Construct this feature from within the side-channel path to minimize riparian vegetation disturbance.	Access is from Pine Flats campground and adjacent floodplain. Routes from campground will need to be developed. May utilize helicopter for log and boulder delivery/placement. Access to construct side-channel on RR floodplain may require temporary creek crossing or bridge. Source for large boulders on hillslope north of Mad River Rd at RM 1.45. In-water permits will be required. Investigate potential to source LW from RR hillslope. Potential for hyporheic or groundwater flow capture by side-channel.

3 Project Opportunity Reach Maps



Mad River - Reach 1

Project Opportunities
- Upper Ardenvoir -

These drawings should be viewed only as very preliminary concepts intended to describe the type of potential restoration work that could be performed. Additional site investigations and analysis will be necessary to determine specific treatment types and locations

Materials to Remove
- wier
- cement

Large Wood jam size
- large
- med
- small

- Revegetate
- Improve Bridge
- Mad River
- River Miles

N

0 0.0125 0.025 0.05 **Miles**

Mad River - Reach 2

Project Opportunities

- Moe -

These drawings should be viewed only as very preliminary concepts intended to describe the type of potential restoration work that could be performed. Additional site investigations and analysis will be necessary to determine specific treatment types and locations

Materials to Remove

cement

Large Wood jam size

- large
- med
- small

Boulder

Mad River

River Miles

0 0.0225 0.045 0.09 **Miles**

N

Mad River - Reach 2

Project Opportunities
- Rothrock -

These drawings should be viewed only as very preliminary concepts intended to describe the type of potential restoration work that could be performed. Additional site investigations and analysis will be necessary to determine specific treatment types and locations

Large Wood jam size
- large
- med
- small

Boulder
Construct Side Channel
Mad River
River Miles

N

0 0.0125 0.025 0.05 **Miles**

Mad River - Reach 2

Project Opportunities
- French Corral -

These drawings should be viewed only as very preliminary concepts intended to describe the type of potential restoration work that could be performed. Additional site investigations and analysis will be necessary to determine specific treatment types and locations

Large Wood jam size
- large
- med
- small

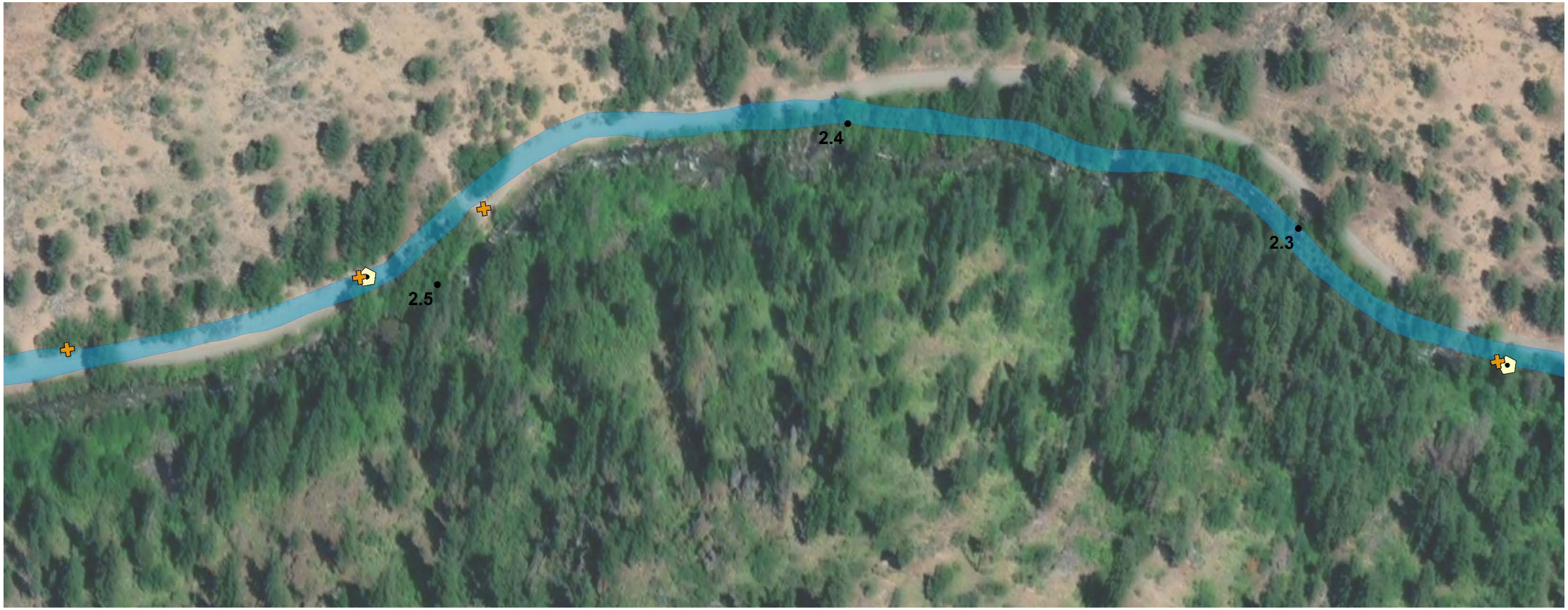
Boulder

Mad River

River Miles

N

0 0.0125 0.025 0.05 **Miles**



Mad River - Reach 3

Project Opportunities
- Mad Tyee 1 -

These drawings should be viewed only as very preliminary concepts intended to describe the type of potential restoration work that could be performed. Additional site investigations and analysis will be necessary to determine specific treatment types and locations

Large Wood jam size
- large
- med
- small

Boulder
Mad River
River Miles

N

0 0.0125 0.025 0.05 **Miles**

Mad River - Reach 3

Project Opportunities

- Mad Tyee 2 -

These drawings should be viewed only as very preliminary concepts intended to describe the type of potential restoration work that could be performed. Additional site investigations and analysis will be necessary to determine specific treatment types and locations

Large Wood jam size
- large
- med
- small

Boulder

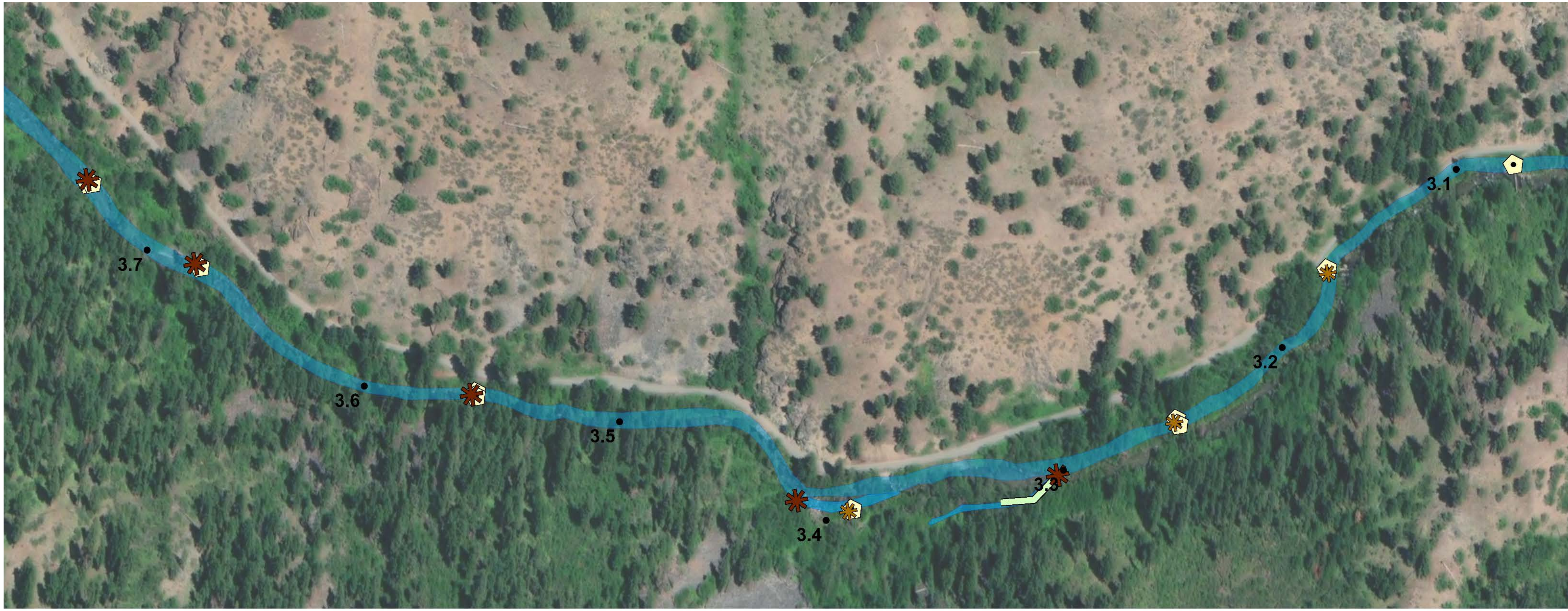
Create Alcove

Mad River

River Miles

N

0 0.0125 0.025 0.05 **Miles**



Mad River - Reach 4

Project Opportunities

- Gold -

These drawings should be viewed only as very preliminary concepts intended to describe the type of potential restoration work that could be performed. Additional site investigations and analysis will be necessary to determine specific treatment types and locations

Large Wood jam size
- large
- med
- small

Boulder

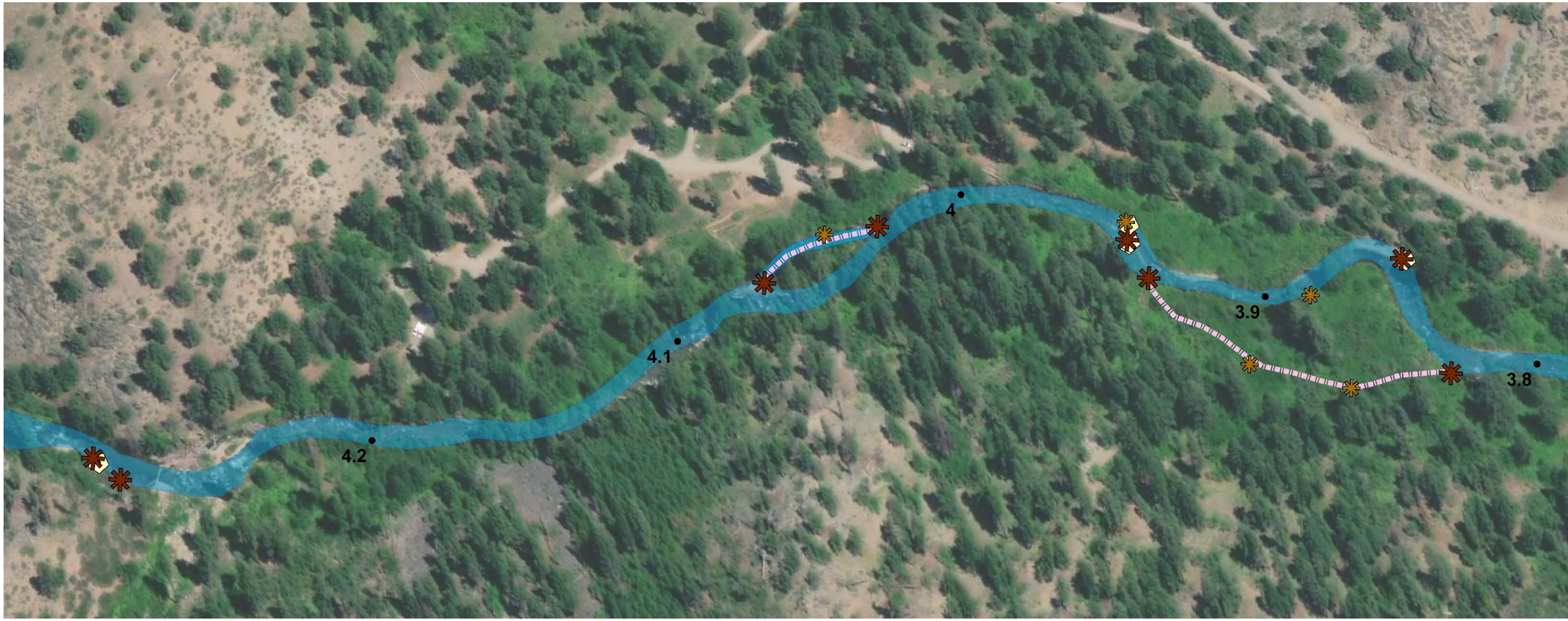
Create Alcove

Mad River

River Miles

N

0 0.025 0.05 0.1 **Miles**

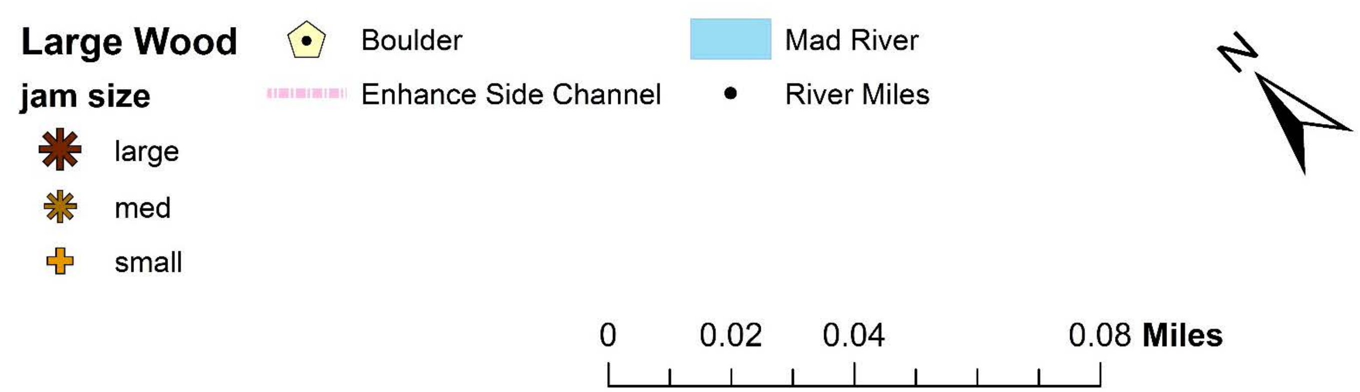


Mad River - Reach 4

Project Opportunities

- Pine Flats -

These drawings should be viewed only as very preliminary concepts intended to describe the type of potential restoration work that could be performed. Additional site investigations and analysis will be necessary to determine specific treatment types and locations



4 Project Ranking Summary

Project InfB10+A5:O12						Benefit Score									Cost Score		Cost Benefit	Feasibility Designation	
						Restoration Gap Analysis				Existing and Potential Fish Use		Root Causes							
Tiers	Project Name	Reach	Down-stream RM	Up-stream RM	Total Length (mi)	Existing Condition (1-7)	Achievable Target (1-7)	Final Gap Score (Target - Existing) (0-6)	Rationale/ assumption	Score (1-3)	Rationale/ assumption	Score (1-3)	Rationale/ assumption	Total Benefit Score	Cost Score	Rationale/ assumption	Benefit-to-Cost Score	Feasibility Designation	Rationale/ assumption
1	Lower Ardenvenoir	1	0.00	0.29	0.29	1	5	4	Low existing functionn (leveed, periodic bank armor, incised). lModerate-high potential assuming undeveloped floodplain, available for treatment. Direct connectivity to Entiat, minimal/no infrascture immediately downstream	1	Mnimal redds surveyed. Available gravels but they are currently being transported through the system instead of retained.	2	Increases channel and floodplain proceses but does not activate historical floodplain or raise bed elevations to pre-incision/entrenment elevation due to probable limitation from private property owners.	7	3	Levee and bank-protection material removal, floodplain excavation and large wood strucuires. Assume access to site along floodplain.	2.3	Moderate	Landowner willingness is unknown. Floodplain not currently formally developed.
	Upper Ardenvenoir	1	0.39	0.73	0.34	1.5	4.5	3	Low existing function. High potential assuming access to channel via private lands.	1	Mnimal to no redds surveyed. Available gravels but they are currently being transported through the system instead of retained.	2	Improves localized habitat conditions and processes. Does not elimnate impacts from human features (private property, road, utilities, bridges) .	1	1.5	Remove impeding features. Construct habitat LW. Assumes access to the site via private property is granted.	0.7	Moderate	Landlower willingness is unknown. LW structures and materials removal is manageable.
	Ardenvenoir Bridge Crossings	1	0.3 and 0.6		na	1	2	1	Low existing localized function (confinement, armoring, entrenchment). Good potential to improve at, up, and downstream processes	2	Redd and salmon observed at RM 0.6 bridge crossing. Available gravels but they are currently being transported through the system instead of retained.	1	Improves floodplain and channel function. Does not eliminate human -caused confinement.	4	3	Removal of exsitng bridge and support features. Reconstruct bridge crossing. Temporary access across river likely required.	1.3	Moderate	Right-of-way exists. Landower willingness unknown; permit requirements unknown;
	Rothrock	2	1.49	1.70	0.21	2.5	5.5	3	Low-moderate existing function. High potential to increase quantity and quality of habitatt, including side-channel development.	2	Available substrate for mainstem spawning if captured by iincreased complexity. Available floodplain to reconnect and construct side-channel; Potential to notably increase quantity and quality of rearing habitat.	2	Improves habitat and geomorphic function. Does not eliminate confinement by Mad River Rd.	7	3	Construction of side channels and LW jams. Accessed by Mad River Rd. Log jam construction may uitilize locally generated LW	2.3	High	Minimal downstream instrastructure of concern; Easy access Limited land-owner restrictions.
	Pine Flats	4	10.94	11.32	0.38	3.5	6.5	3	Moderate existing function. High potential to increase quantity and quality of habitatt and geomorphic compleixty, ncluding side-channel development.	1	Some observed available salmonid habitat; upstream sediment source (debris flow cut-bank). Increase quantity and quality of off-channel habitat	1	Improves habitat and geomorphic function.	5	3	Ground access via campground. Requires construction of temporary mainstem crossing. Could use helicopter for rock and log placement;.	1.7	High	Minimal downstream instrastructure. USFS land managers.
2	Moe	2	1.10	1.47	0.37	2	5	3	Low existing function (simplified channel complexity). High potential to improve localized habitat conditions in a geomorphically sustainable manner. Limited by Mad River Rd.	2	Mnimal to no redds observed.. Available gravels but they are currently being transported through the system instead of retained.	1	Improves habitat and geomorphic function. Does not eliminate confinement by Mad River Rd.	6	2	Removal of materials is minimal. Relatively easy access by Mad River Rd;	3.0	High	Minimal downstream infrastructure of concern. Easy access. Assume minimal land-owner restrictions.
	Mad Tyee II	3	13.29	13.94	0.65	3.5	5	1.5	Low-moderate existing function (simplified channel complexity). High potential to improve localized habitat conditions in a geomorphically sustainable manner. Limited by Mad River Rd.	2	Minimal spawning or rearing habitat. Potential off-channel habitat creation on available floodplain. Improve geomorphic complexity and habitat	2	Improves habitat and geomorphic function. Does not eliminate confinement by Mad River Rd.	5.5	2	LW jam construction and alcove construction. Access via Mad River Rd.	2.8	High	Minimal downstream infrastructure of concern. Easy access from Mad River R. Bridge exists downstream.
	Gold	4	10.66	10.93	0.27	3	5.5	2.5	Low-moderate existing function. High potential to increase quantity and quality of habitatt and geomorphic compleixty, ncluding off-channel development.	2	Minimal spawning or rearing habitat. Potential off-channel habitat creation on available floodplain. Improve geomorphic complexity and habitat	2	Improves habitat and geomorphic function. Does not eliminate confinement by Mad River Rd.	6.5	2.5	LW jam construction and alcove construction. Access via Mad River Rd. Will include costs for temporary mainstem crossing (i.e. culvert or bridge)	2.6	High	Minimal downstream infrastructure of concern. Easy access. Assume minimal land-owner restrictions.
3	French Corral	2	1.75	1.95	0.20	3	5	2	Low existing function (simplified channel complexity). High potential to improve localized habitat conditions in a geomorphically sustainable manner. Limited by Mad River Rd.	2	Mnimal evidence of spawning habitat. Available gravels but they are currently being transported through the system instead of retained.	2	Improves habitat and geomorphic function. Does not eliminate confinement by Mad River Rd.	6	1	LW jam construction. Access via mad River Rd.	6.0	High	Minimal downstream infrastructure of concern. Easy access. Assume minimal land-owner restrictions.
	Mad Tyee I	3	12.06	12.49	0.43	2.5	4	1.5	Low existing function (simplified channel complexity). High potential to improve localized habitat conditions in a geomorphically sustainable manner. Limited by Mad River Rd.	2	Spawning gravels and habitat where LW features occur.Currently minimal spawning and rearing habitat otherwise. Available gravels but they are currently being transported through the system instead of retained.	2	Improves habitat and geomorphic function. Does not eliminate confinement by Mad River Rd.	5.5	1	LW jam construction. Access via Mad River Rd.	5.5	HIgh	Minimal downstream infrastructure of concern. Easy access. Assume minimal land-owner restrictions.

4.1 PROJECT RANKING METHODS (JULY 2018)

Step 1: **Benefit Score**: Projects are scored according to 3 benefit categories, which include a "recovery gap" category and 2 additional categories. Scores for each category are summed to obtain the ***Benefit Score***.

Step 2: **Cost Score**: Projects are given a ***Cost Score***, which reflects the overall *relative cost* for the project based on techniques, access, and construction feasibility issues.

Step 3: **Benefit-to-Cost Score**: Total benefit score (sum of all 4 benefit scores) is divided by the cost score to obtain the ***Benefit-to-Cost Score***.

Step 4: **Feasibility Designation:** Projects are given a ***Feasibility Designation*** based on the overall likely feasibility of being able to implement the project within a 10-year timeframe.

Benefit Score

The Benefit Score includes the summation of scores from 3 categories. These include the Recovery Gap score (0-6 points), the Fish Use score (1-3 points), and the Root Causes score (1-3 points). The guidelines for scoring are provided below.

Recovery Gap

Existing Condition Rating (1-7)

1 – Very low ecosystem function and habitat quality. Highly altered systems.
2 – Low ecosystem function and habitat quality.
3 – Low-to-moderate ecosystem function and habitat quality.
4 – Moderate ecosystem function and habitat quality.
5 – Moderate-to-high ecosystem function and habitat quality.
6 – High ecosystem function and habitat quality.
7 – Very high level of natural ecosystem function and habitat quality. Pristine, unaltered systems.

Achievable Condition Rating (1-7)

These ratings use the same categories as above but reflect the future potential recovery trajectory. This is a rating of what can realistically be achieved given past and on-going impacts and constraints of land use, infrastructure, social acceptance, and ownership. Ratings should reflect an "optimistic potential scenario" in order to not discount large potential changes.

Final Gap Score (0-6)

This is simply the achievable condition rating minus the existing condition rating. This represents the gap that can be filled between existing and target conditions through restoration measures.

Fish Use

3 – High existing or potential productivity area for spawning or rearing for multiple species
2 – Moderate existing or potential productivity area for one or more species
1 – Low existing or potential productivity area for one or two species

Root Causes

3 – Restoration of root causes and key physical processes that create and maintain habitat over time
2 – Partial restoration of root causes
1 – Primarily a structurally-focused restoration strategy that doesn't significantly address underlying causes

Cost Score

The cost score reflects the relative cost for the project based on techniques, access, and feasibility issues. This is a relative cost, not an absolute cost, so the scale of the project is NOT factored into this score. The cost score ranges from 1 to 3, with 1 reflecting relatively lower cost projects. The following guidelines/examples can help to determine the cost score.

3 – High relative cost

- Uses high cost techniques (e.g. constructed banks, highly engineered log jams, extensive channel shaping, water crossings or bridges)
- Deep excavation or long-distance hauling of spoils
- Entails construction of additional new flood control or bank erosion features (e.g. set-back levees or buried rip-rap)
- Extensive planting or invasive weed control
- Limited, difficult, or remote access
- Intensive de-watering requirements

2 – Moderate relative cost

- Uses moderate cost techniques (e.g. typical log jam structures)
- Moderate excavation and hauling distance of spoils
- Typical planting or invasive weed control
- Moderate access conditions
- Standard or no de-watering requirements

1 – Low relative cost

- Uses low cost techniques (e.g. non-ballasted log placements)
- Minimal excavation and hauling distance of spoils
- Little to no planting or weed control
- Easy access conditions
- No de-watering required
- Availability of free materials or volunteer labor

Benefit-to-Cost Score

The benefit-to-cost score is simply the benefit score divided by the cost score. This is a relative value used to compare project benefits.

Feasibility Designation

The feasibility designation is the overall likely feasibility of being able to implement the project within a 10-year timeframe. This is based on landownership, as well as economic, regulatory, political, social, permitting, or other considerations that are known to impact the feasibility of conducting projects within a reasonable timeframe. The feasibility designation is not used as part of the project scoring because feasibility issues may change over time and it is desirable to evaluate project benefits independent of feasibility. The designations include the following:

High feasibility

- No known feasibility issues.
- One or two landowners; or landowner(s) has already indicated willingness

Moderate feasibility

- There are potential feasibility constraints that could affect the likelihood of project implementation within a 10-year timeframe
- Three to five landowners; or there is reason to believe landowner(s) would grant permission

Unlikely feasibility

- There are known feasibility constraints that would be expected to limit the ability to implement the project within a 10-year timeframe
- More than five landowners: or there is reason to believe landowner(s) would not grant permission