Lower Icicle Creek Reach Assessment

River Mile 0.0 – 4.3

February 2017

Chelan County Natural Resources Department
411 Washington St. Suite 201
Wenatchee, WA 98801

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Natural Systems Design
1900 N. Northlake Way, Suite 211
Seattle, WA 98103

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1. INTRODUCTION

This assessment was completed at the request of the Icicle Creek Work Group and funded by the WA Department of Ecology with the purpose of providing the scientific basis for identification and development of stream restoration and protection actions for lower Icicle Creek (RM 0.0 – 4.3). Efforts have been underway for years throughout the Wenatchee River Basin to implement actions that benefit Endangered Species Act (ESA)-listed salmonids including Upper Columbia River spring-run chinook salmon (*Oncorhynchus tshawytsha*), Upper Columbia River steelhead (*Onchorhynchus mykiss*), and bull trout (*Salvelinus confluentus*).The lower 3 miles of Icicle Creek is a Minor Spawning Area for spring Chinook, and a Major Spawning Area for steelhead, and includes spawning and rearing habitat for spring Chinook salmon, coho salmon (*Oncorhynchus kisutch)*, steelhead and bull trout.

This project is one of several potential projects currently being evaluated as part of the Icicle Strategy. This Strategy is being developed by the multi stakeholder Icicle Work Group (IWG), comprised of federal, state, and local agencies; tribes; irrigation districts; the City of Leavenworth; the Leavenworth National Fish Hatchery; environmental groups and others. The Strategy is a comprehensive water resource management plan that identifies a set of projects that collectively are intended to meet the following guiding principles: improved stream flow; a sustainable fish hatchery; provides water to meet domestic and municipal demand; improves agricultural reliability; and improves ecosystem health through restoration and protection actions all while protecting tribal treaty and federally protected fishing rights, protecting non-treaty harvest, and complying with all state and federal laws and wilderness acts.

The lower Icicle Creek project reach spans 4.3 miles starting from the confluence with the Wenatchee River near Leavenworth, WA, and extending up-valley through the Historical Channel associated with the Leavenworth National Fish Hatchery (LNFH) (Figure 1). Above the Leavenworth National Fish Hatchery (LNFH) the channel steepens out of the lower valley and a boulder field at river mile (RM) 5.6 is currently considered a barrier to upstream migration of Chinook salmon (RTT 2014). The primary focus of the assessment is the three-mile long segment of Icicle Creek downstream from the fish hatchery to the confluence with the Wenatchee River. The Historic Channel upstream of the spillway dam at LNFH (RM 3.0) was also assessed as part of rapid field reconnaissance but not included in field data collection or hydraulic analysis. Previous studies completed by U.S. Fish and Wildlife Service (Anglin et. al, 2013; Skalicky et. al, 2013) and U.S. Bureau of Reclamation (2014) assessed conditions of the Historic Channel affected by floodplain modifications at LNFH and were consulted as part of this study.

At the initiation of this assessment local stakeholders were asked: What key questions do we need to address in order to improve our current understanding of the lower Icicle and to support future restoration and protection actions?

From these conversations came the following key questions:

- Is the channel incised? And if so, to what degree?
- What is the historical legacy of the impoundment effects of the Lamb Davis Mill Dam?
- What are the effects of the LNFH on sediment supply and transport in lower Icicle Creek?
- What is the current role of wood in the lower Icicle?
- What is the habitat quality for juvenile and adult salmonids in the lower Icicle?

Chapters within this assessment directly address these questions. The findings from the assessment of geomorphic and hydraulic processes were used to support the identification of restoration and protection opportunities presented in this report. These recommendations are intended to help guide community members and resource managers in developing a strategic approach to holistically improving habitat conditions in lower Icicle Creek. A summary of key metrics developed during the baseline assessment is compiled below in Table 1.

This report is organized into the following chapters:

- Chapter 1: Introduction – Describes the purpose and background of the assessment.
- Chapter 2: Methods – Provides a brief overview of the assessment methods.
- Chapter 3: Geomorphic Setting – Includes a discussion of the key geomorphic factors affecting the project reach.
- Chapter 4: Existing Conditions – Describes the results of the evaluation of physical and biological factors and processes within the project reach.
- Chapter 5: Hydrologic and Hydraulic Analysis – Describes the results of the 2-dimensional hydraulic modeling along with an assessment of floodplain connectivity and sediment mobility.
- Chapter 6: Key Findings – Provides an overview of the key findings of the assessment in relation to the key questions outlined above.
- Chapter 7: Restoration Strategy – Describes the identification and prioritization of protection and restoration opportunities.

Figure 1. Map showing the location of the Icicle Creek Watershed in the Wenatchee River Basin and the project area location in the Lower Icicle Creek Valley. Base map from USGS.

Table 1. Baseline reach characteristics of Icicle Creek from RM 0.0 to 3.0

METRIC	VALUE	DATA SOURCE AND NOTES
Watershed Characteristics		
Drainage Area	214 mi^2	USGS Topographic Maps
Mean Annual Precipitation	64 in	PRISM Climate Group, OSU
Mean Annual Streamflow	690 cfs	ECY gage 45F070
2-yr Peak Flow (Q_2)	4,450 cfs	Flood Frequency Analysis on USGS gage # 12458000
100-yr Peak Flow (Q_{100})	15,230 cfs	Flood Frequency Analysis on USGS gage # 12458000
Channel and Floodplain Geometry		
Channel Length	15,840 ft.	2015 LiDAR DEM;
Sinuosity	2	Channel length / valley length.
Channel Gradient	0.0007 ft./ft.	Reach average
Bankfull Width	200 ft.	Average of 4 cross-sections; ranges between 130-266 ft.
Mean Depth	6.4 ft.	Average of 4 cross-sections; ranges between 5-8.6 ft.
Width/Depth Ratio	31	
Valley Width	640-3,720 ft.	Moderately confined by hatchery near RM 3.0
Confinement Ratio	3-18 ft.	Valley width / channel width (< 4 is confined).
Q100 Wetted Width	1,550 ft.	Average from hydraulic model simulations.
Entrenchment Ratio	7.7	Floodprone (Q100) width/channel width (<1.4 is entrenched).
Bed Material		
Median Grain Size (D_{50})	37 mm	Very Coarse Gravel
10^{th} Percentile Grain Size (D_{10})	6.5 mm	Fine Gravel
90^{th} Percentile Grain Size (D_{90})	67 mm	Fine Cobble
Wood		
Key pieces	0	No stable wood observed in 2016 field reconnaissance
Hydraulic Parameters		
Q_2 Cross-Sectional Area	1230 $ft.^2$	Average of 4 cross-sections; Ranges between 1121-1332 $ft.^2$
Q_2 Avg Velocity	4.1 ft./s	Range between 0 and 6.9 ft./sec.
Q_2 Mean Shear Stress (τ)	0.4 $lb/ft.^2$	Average of active channel 2-D modeling results; Ranges between 0.16-1.05 $lb/ft.^2$ along thalweg
Critical Shear Stress (τ_c) for D_{50}	0.5 $lb/ft.^2$	Mobility of bed material when $\tau > \tau_c$
Q_{100} Avg Velocity	4.5 ft./s	Range between 0 and 15.2 ft./sec.
Q_{100} Total Shear Stress (τ_0)	0.5 $lb/ ft.^2$	Average of active channel 2-D modeling results

2. METHODS

The assessment employed the review of background materials (as cited throughout the text), field surveys, and computer modeling to characterize existing conditions and to support the identification and prioritization of protection and restoration actions. A primary tool in the assessment is the evaluation of floodplain topography and landforms using 2015 LiDAR data. To evaluate reach hydraulics and floodplain connectivity, NSD developed a hydraulic model of Icicle Creek using Hydronia's RiverFlow-2D Plus GPU and Aquaveo SMS v12.1 computer software. The model geometry incorporates bathymetric survey data collected by NSD in September 2016 to represent the low flow channel and topographic data from the 2015 LiDAR DEM to represent channel and floodplain areas outside of the bathymetric survey. Additional detail on model setup and methods are provided in Appendix D.

NSD, in conjunction with CCNRD, conducted a field reconnaissance and survey of Icicle Creek in September 2016 to characterize baseline conditions of the project reach. Field reconnaissance of the Historical Channel at LNFH was limited to visual observations collected during a float beginning downstream from the headgate dam. Field surveys of the project reach downstream of the hatchery, covering the 3-mile long channel segment to the Wenatchee River confluence included:

- Survey of channel bathymetry and water surface elevations;
- Bed material sampling (pebble counts);
- Visual estimates of substrate size;
- Inventory of wood pieces;
- Inventory of streambank protection such as rip-rap bank armoring and rock barbs;
- Riparian community characterization;
- Habitat surveys generally following the USFS Level II protocol.

Analysis methodologies are described in detail below for the following:

- Sediment (Chapter 4.2);
- Large Wood Recruitment (Chapter 4.3);
- Riparian Vegetation (Chapter 4.4);
- Channel Migration (Chapter 4.5);
- Habitat Suitability Index Modeling (Chapter 4.6);
- Hydrologic and Hydraulic Analysis (Chapter 5);
- Identification and Prioritization of Protection and Restoration Opportunities (Chapter 6).

3. GEOMORPHIC SETTING

3.1 Longitudinal Profile

Icicle Creek exits a relatively steep, bedrock confined valley segment and emerges into the broad, unconfined Lower Icicle Creek Valley near the vicinity of the Leavenworth National Fish Hatchery. Upstream of the hatchery, Icicle Creek runs through a series of boulder cascades that range in gradient between 3 and 10 percent (0.03 to 0.10 ft./ft.). The channel gradient transitions to a slope of nearly 1 percent near River Mile (RM) 4.5, then abruptly flattens to a slope of 0.2 percent (0.002 ft./ft.) in the channel segment passing through the hatchery. Downstream of the hatchery, the channel profile continues at a relatively uniform slope of 0.07 percent (0.0007 ft./ft.) over the lower 3 miles to the junction with the Wenatchee River (Figure 2).

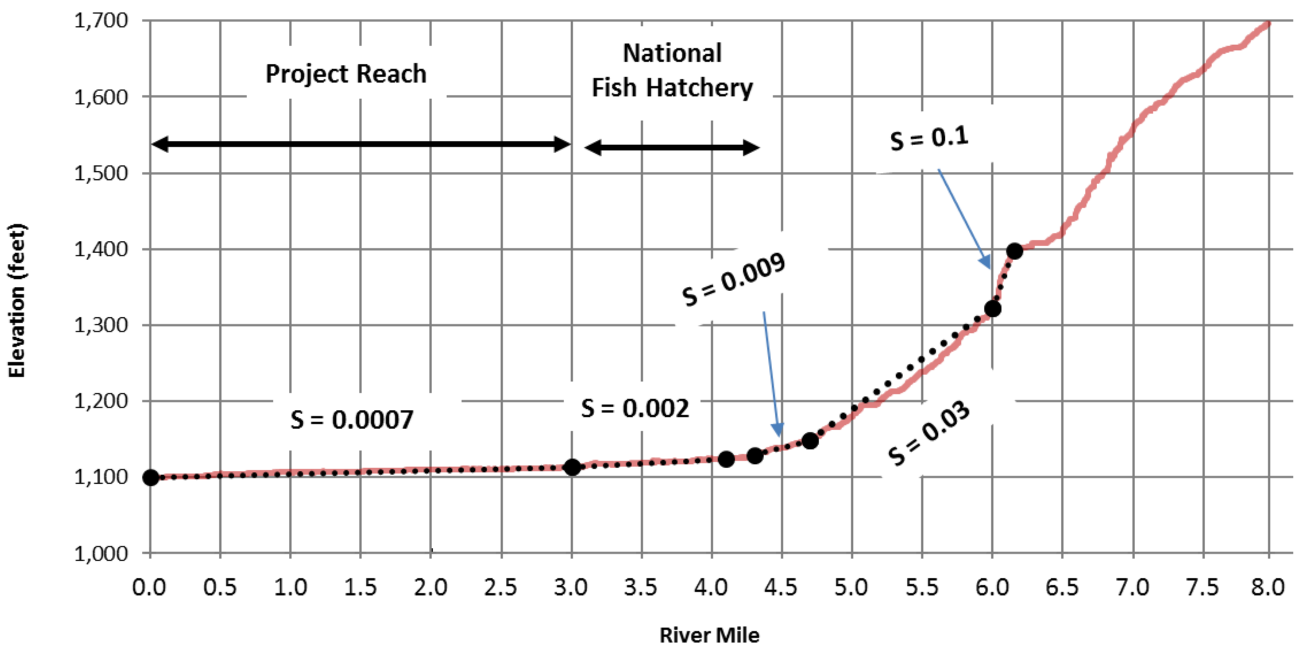


Figure 2. Longitudinal profile showing the transition in channel gradient over the lower reaches of Icicle Creek. Elevations extracted from 2015 LiDAR DEM.

3.2 Valley Topography and Landforms

Alpine glaciers from the eastern Cascades advanced into the Icicle Creek Valley during the last glacial period and continued down valley to a terminus near Leavenworth (Porter and Swanson, 2008). As the glacier receded toward the end of the last glacial period (approximately 13,000 years ago), meltwater channels delivered large amounts of sand and gravel that deposited in the Icicle Creek Valley to form a broad outwash fan. Icicle Creek has since reworked much of the outwash material over the Holocene period though lateral channel migration.

Floodplain topography and landforms using 2015 LiDAR data were processed to de-trend the channel gradient and express the ground surface elevation of the valley bottom topography relative to the adjacent river channel. The Relative Elevation Model (REM) mapped in Figure 3-Figure 5 provides additional topographic resolution to highlight local variations in the floodplain surface and support identification of relict channel features and distinguish between frequently inundated floodplain areas and terrace surfaces that are not frequently engaged with the channel (Jones, 2006; Dilts et al., 2010). A generalized map of geomorphic surfaces identified from the LiDAR mapping is presented in Figure 7.

The Icicle Creek Valley is approximately 3,000 to 4,000 feet in width. An extensive complex of alluvial fans built up along the toe of Icicle Ridge flank the west side of the valley. Hillslopes to the east are underlain by glacial sediment. The active stream corridor formed by Icicle Creek is inset within the broader valley and is approximately 1,000 to 1,500 feet in width. The stream corridor is flanked by terrace surfaces composed of older alluvium and outwash deposits. The highest, approximately 30 to 35 feet above the active channel, is presumed to be glacial outwash and is most prevalent upstream of LNFH and along the west side of the valley (this surface underlies Icicle Road for much of its length). A lower terrace surface, approximately 12 to 16 feet above the active channel, flanks the west side of the stream corridor down the center of the valley and also crops out along the east side of Icicle Creek near RM 0.4 and RM 1.5.

3.3 Historical Impacts of the Lamb-Davis Dam

The Lamb-Davis Lumber Company previously constructed a dam across the Wenatchee River at Leavenworth to create a mill pond near RM 24.3. The 1915 USGS map includes the dam and mill pond extending upstream to the Icicle Creek confluence (Appendix A). The mill closed in 1927 and the dam was subsequently removed (remnants of the dam fill remain on the edge of the floodplain). Much of the sediment accumulated in the pond remains in the valley bottom today forming a terrace surface that flanks the channel. For example, Blackbird Island is underlain by the historical deposition that accumulated in the mill pond. Elevation of these deposits is approximately 1,108 to 1,110 ft. (NAVD88) at Blackbird Island. Topographic analysis of the 2015 LiDAR DEM was used to estimate the spatial extent of floodplain deposition affected by the dam. Results suggest that the terrace surface composed of the historical sediment extending up the Wenatchee River and into the Lower Icicle Creek Valley to about RM 0.5 (Figure 7). The mill pond raised the base level of Icicle Creek such that water surface elevations were elevated further upstream and the extent of the dam influence was seen in bank materials upstream to at least RM 1.0. Subsequent removal of the Lamb-Davis Dam lowered the base level for Icicle Creek and resulted in a period of down-cutting or incision has left high banks approximately 12 to 14 feet above the river (Figure 8). The high banks of the terrace deposits are rarely overtopped and hydraulic model simulations suggest it takes about a 10-year recurrence interval flow to inundate the terrace.

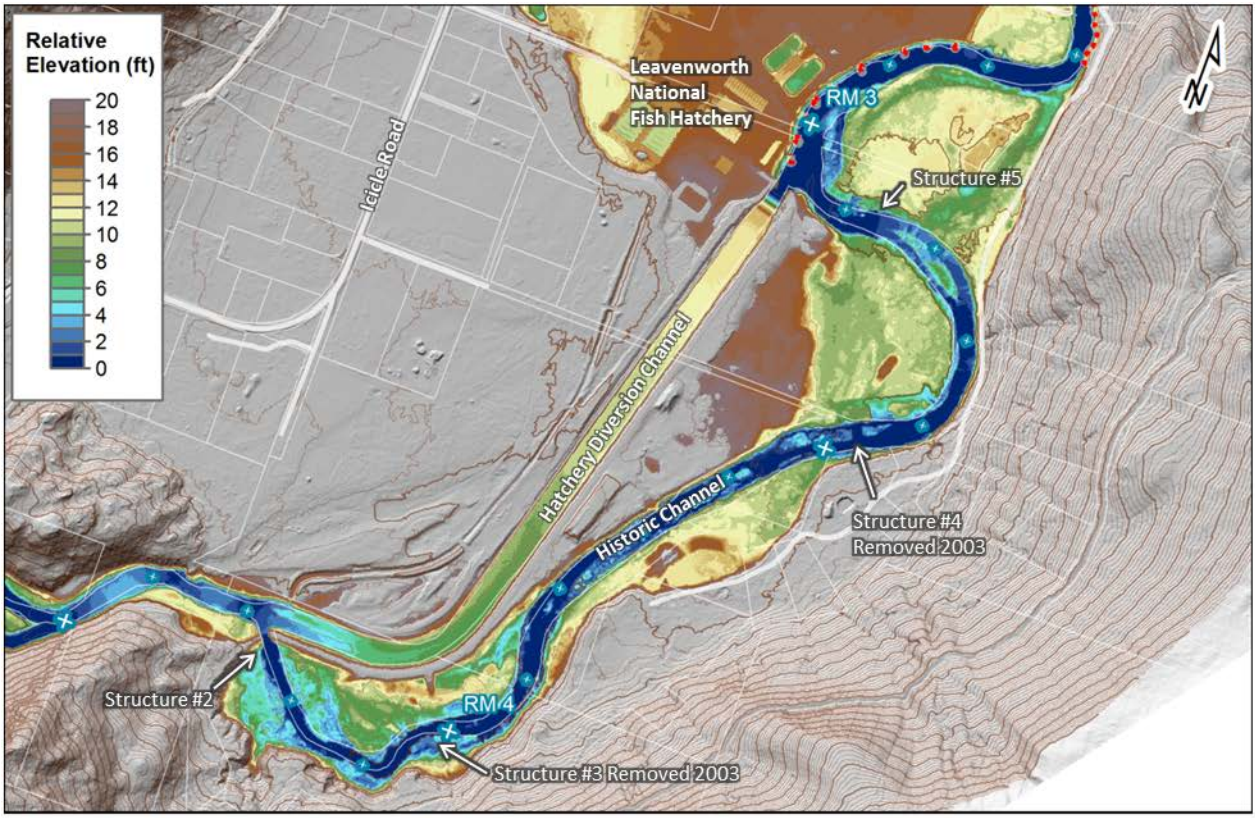
3.4 Channel and Floodplain Modifications at Leavenworth National Fish Hatchery

The historical channel segment is located at the transitional area between the more confined, steeper segment upstream of the LNFH and the unconfined, low gradient alluvial valley of Lower Icicle Creek (Figure 2). Such rapid changes in gradient and valley confinement are common locations for development of alluvial fans. Mapping of pre-modified floodplain conditions showed a dynamic, anabranching channel pattern in this transitional area (see 1910 USGS map in Appendix A). In this geomorphic setting, channel migration tends to occur more episodically with sudden changes in channel planform in response to flood flows. Alluvial fans are very dynamic and would typically provide multiple relict side channel or off-channel habitats along with a complex main channel environment. Much of this dynamism and complexity would have depended on the presence of large woody material to drive hydraulic variability, sorting of sediment, creation of pools, and drive channel avulsion.

Construction of the Leavenworth National Fish Hatchery between 1939 and 1941 split Icicle Creek into two distinct channel segments with creation of a 4,000 -foot long artificial canal (Hatchery Bypass Channel) that runs parallel to the original (Historical) channel between RM markers 3.1 and 4.3 (Figure 3). A diversion structure upstream of the hatchery (Structure #1) directs water to a gravity-fed intake that supplies water for hatchery operations. A headgate dam (Structure #2) was constructed at RM 4.3 to control inflows to the Historical Channel.

A series of dams and weirs (Structures #3, #4, and #5) were installed to create holding ponds within the Historic Channel for hatchery operations. Use of the instream ponds in the Historical Channel has ceased and the hatchery has since constructed a conventional fish ladder and holding ponds in the upland area adjacent to the spillway dam at the downstream end of the Hatchery Bypass Channel. Structures #3 and #4 were removed from the Historical Channel in 2003.

The headgate structure controlling inflow at the upstream end of the Historical Channel (Structure #2) and the weir blocking the Historical Channel at the downstream end (Structure #5) remain in operation and are managed by U.S. Fish and Wildlife Service. The headgate has a maximum capacity of approximately 2,600 cfs during flood stage which is between a 1 and 2-year flood event (Bureau of Reclamation, 2014). During low flows, most of the discharge conveyed from upstream passes through structure #2 and flows along the Historic Channel alignment. During flood stage, the majority of flow bypasses the Historic Channel, flows along the Hatchery Channel, and over the spillway dam.



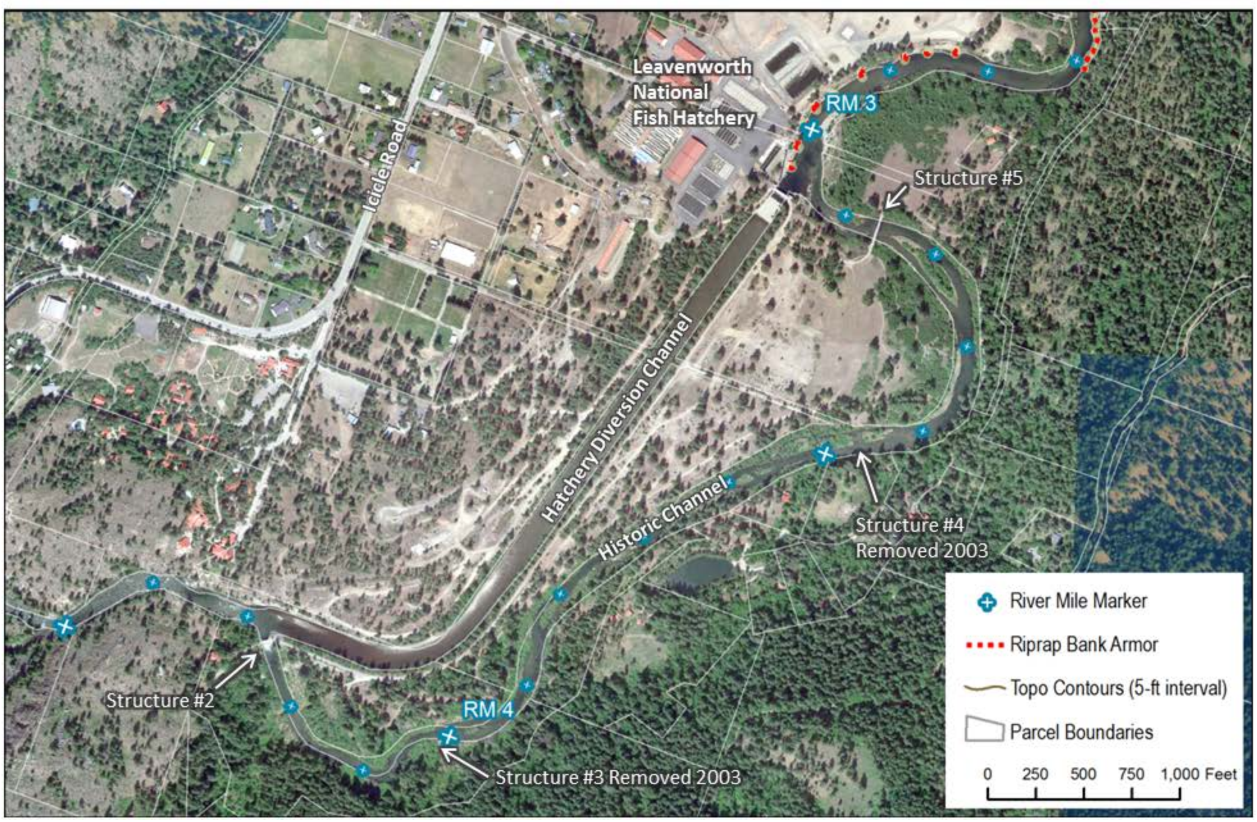


Figure 3. Maps showing floodplain topography near the LNFH (RM 3.0-4,3) as relative elevations in the 2015 LiDAR DEM and landscape features in 2015 aerial imagery.

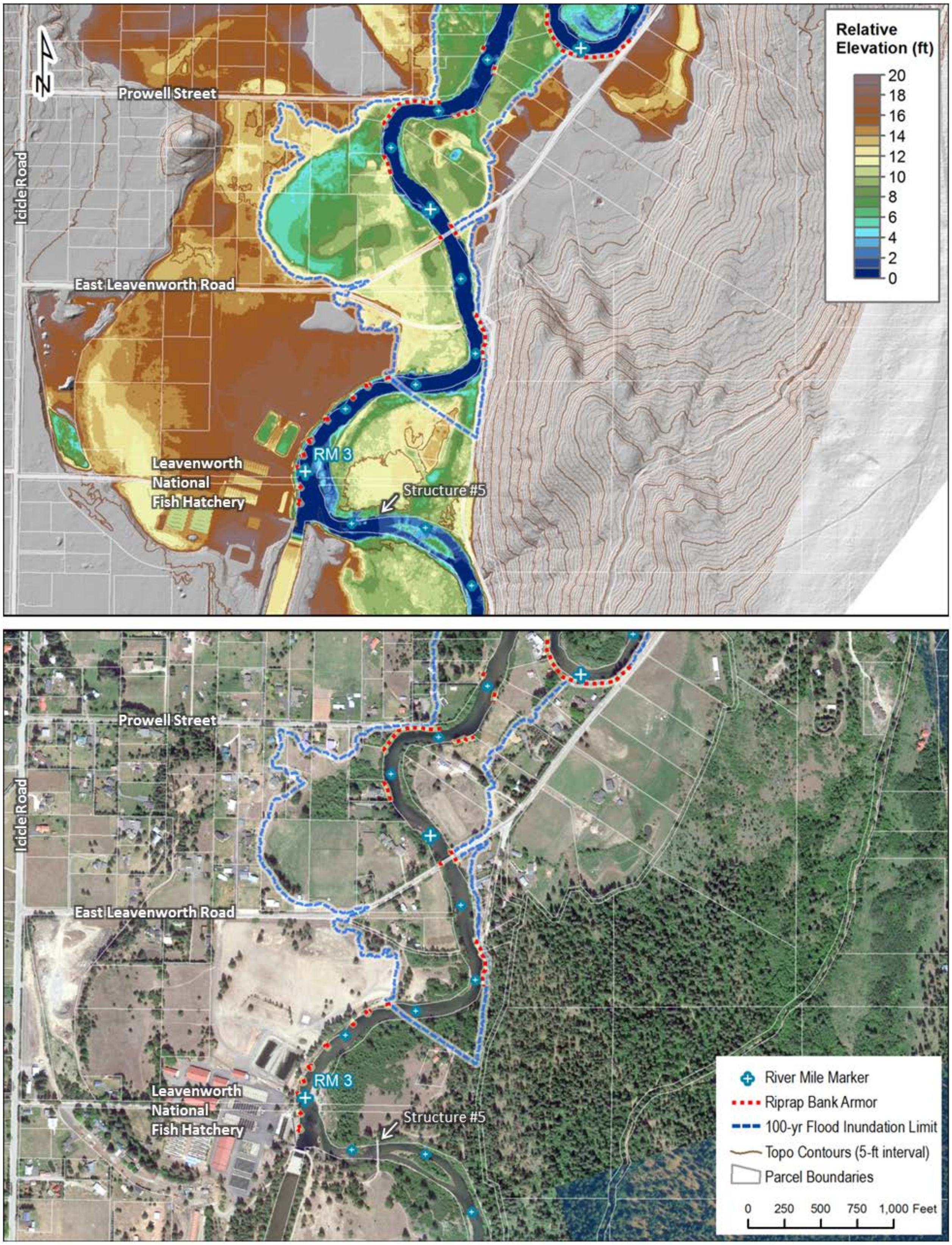
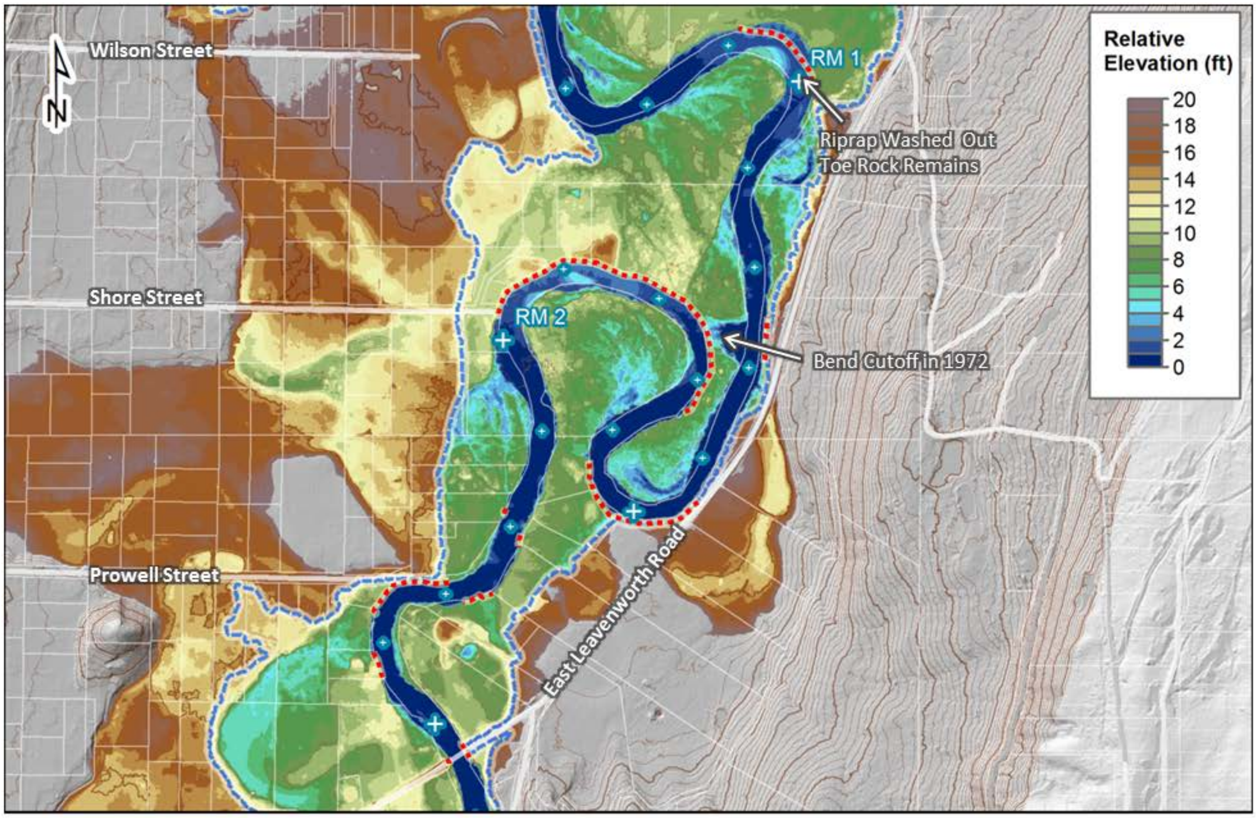


Figure 4. Maps showing floodplain topography downstream of the LNFH (RM 2.2-3.0) as relative elevations in the 2015 LiDAR DEM and landscape features in 2015 aerial imagery.



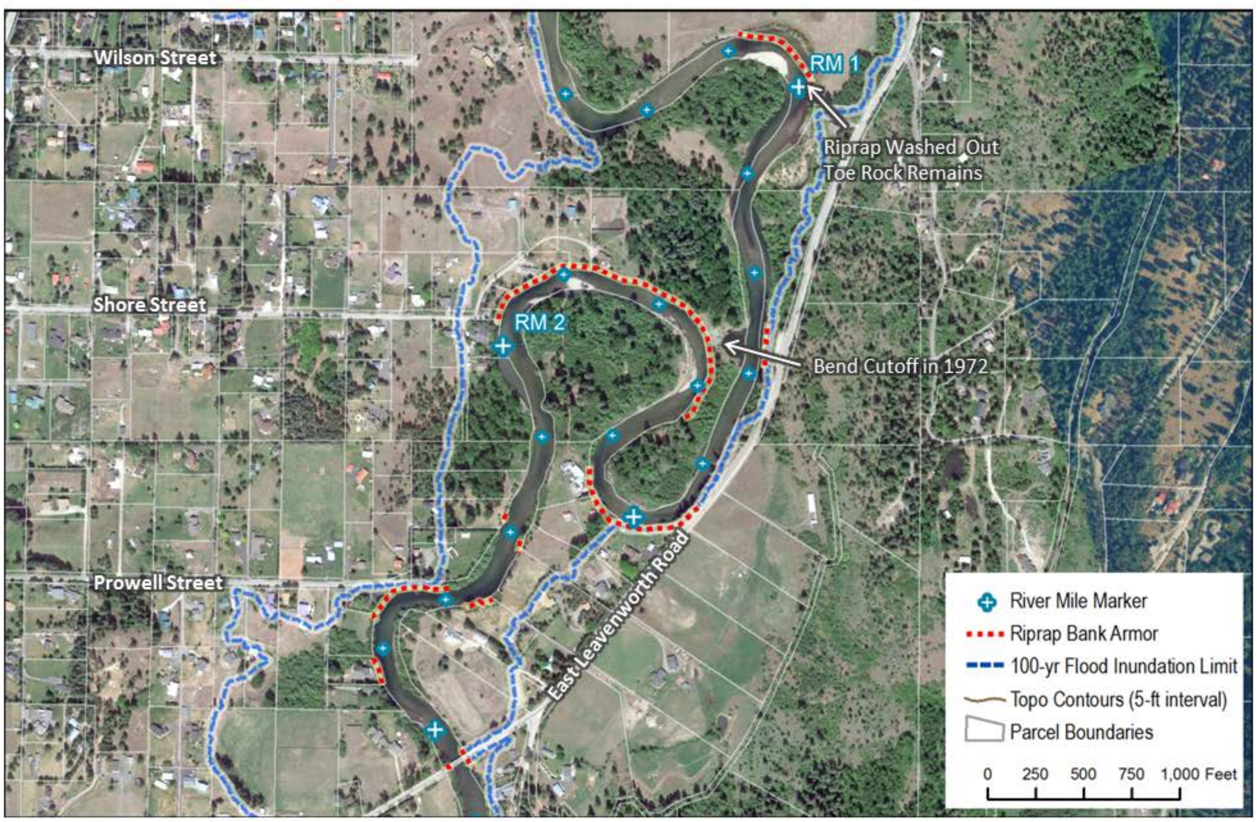


Figure 5. Maps showing floodplain topography from RM 1.0-2.5 as relative elevations in the 2015 LiDAR DEM and landscape features in 2015 aerial imagery.

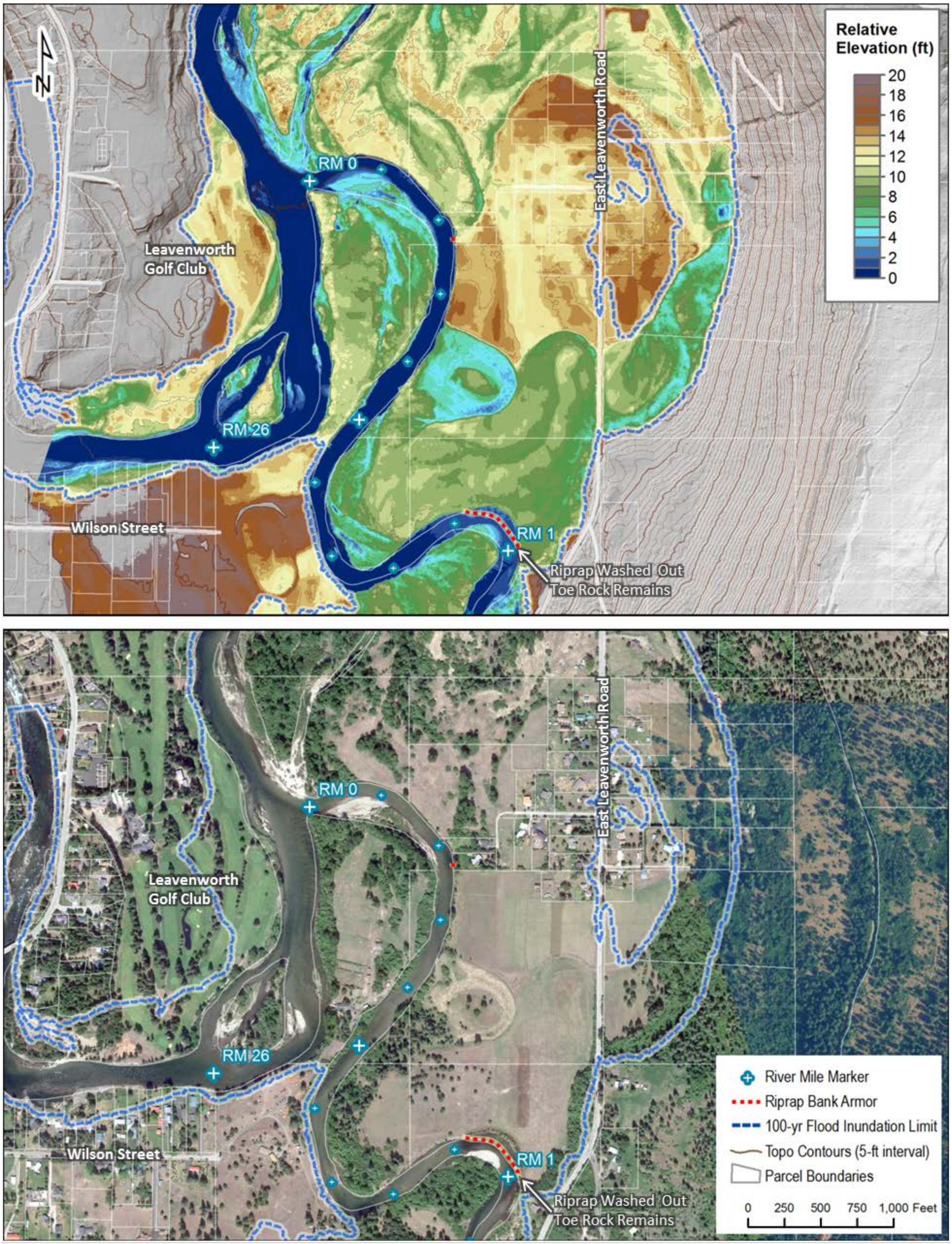


Figure 6. Maps showing floodplain topography near the confluence of Icicle Creek and the Wenatchee River as relative elevations in the 2015 LiDAR DEM and landscape features in 2015 aerial imagery.

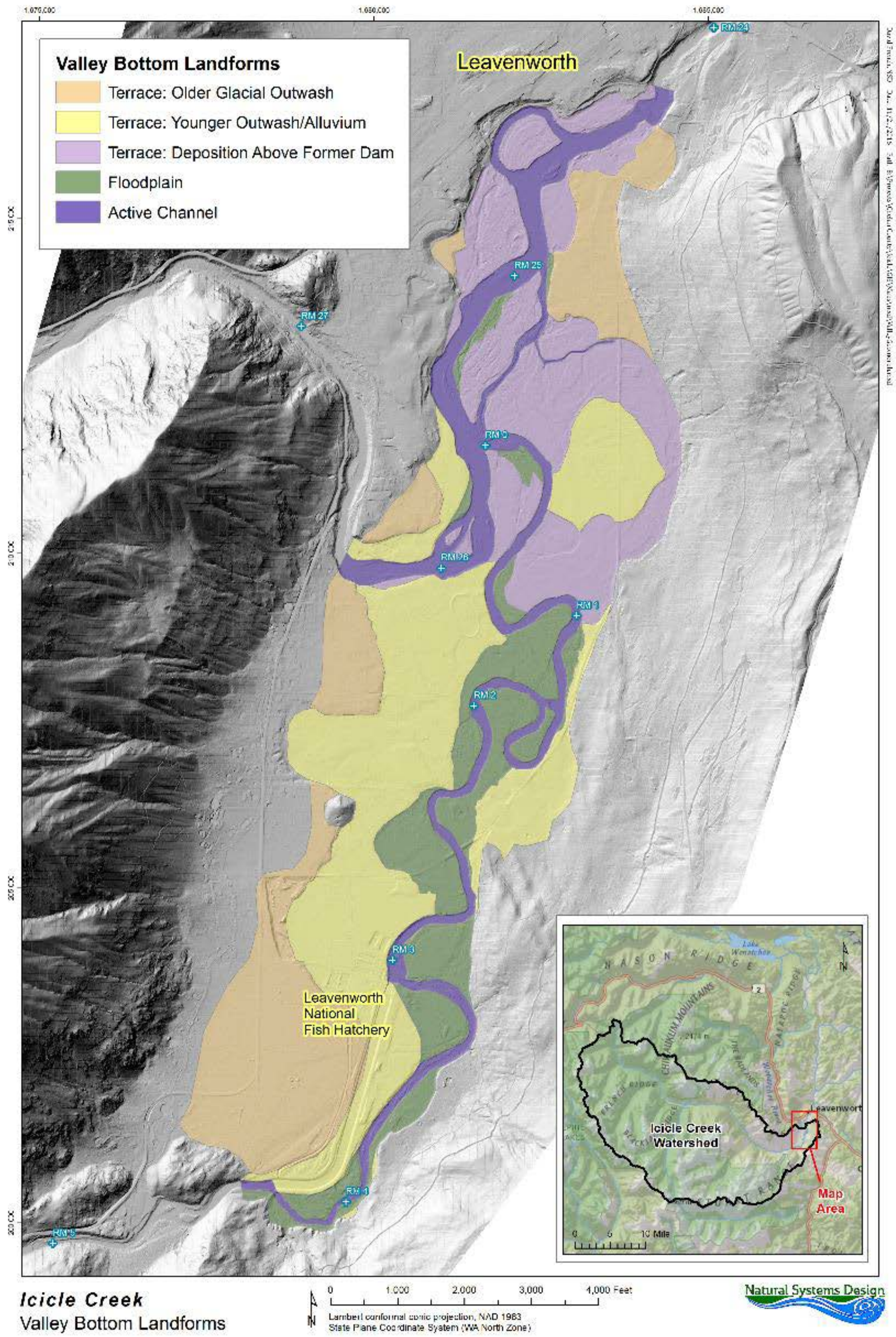


Figure 7. Geomorphic map of the Lower Icicle Creek Valley.

Figure 8. Photo looking upstream along the left bank upstream of the Wenatchee River confluence. The upper bank is composed of fine sediment accumulated in the early 1900s when the Wenatchee River was dammed near Leavenworth. The bank is approximately 12-14 feet high and is just barely overtopped at a 10-year recurrence interval flood.

4. EXISTING CONDITIONS

4.1 Channel Profile, Pattern, and Cross-Sectional Geometry

The Icicle Creek field survey downstream of RM 3 included 41 cross-sections, 140 points along the channel thalweg, and additional points at grade changes for a total of 741 total survey points. A longitudinal profile of the project area was extended upstream through the Historical Channel above the hatchery using the 2015 LiDAR DEM upstream of the survey limit at RM 3 (Figure 9). Channel gradient decreases from an average channel slope of 0.9% (0.009 ft./ft.) in the approaching segment upstream of the hydraulic control at Structure #2 to approximately 0.2% (0.002 ft./ft.) in the Historical Channel downstream of Structure #2. The channel slope flattens to 0.07% (0.0007 ft./ft.) downstream from the hatchery then steepens slightly to 0.1% (0.001 ft./ft.) over the lower 1 mile to the Wenatchee River confluence (Figure 9).

The Historical Channel upstream of LNFH has adjusted to reductions in flow and sediment transport capacity since the 1930s with sediment deposition, channel narrowing, and formation of vegetated alluvial bars that are inset within the pre-modified channel corridor (Figure 10). The active channel width averages around 60 feet. The channel pattern includes many smaller secondary channels that split around the vegetated bar features and form an anabranching channel pattern. Removal of Structures #3 and #4 in 2003, combined with increases in the flow allowed through Structure #2 has resulted in localized erosion of vegetated islands in select locations; most notably over the 2,000 feet downstream of Structure #2.

The lower reaches of Icicle Creek downstream of the Hatchery Bypass Channel are characterized by a single thread, meandering pattern with relatively uniform pool-riffle morphology. The planform channel alignment has remained nearly static over the historical period due to artificial constraints such as riprap bank protection that limits natural channel migration. A bend cutoff occurred between RM 1.3 and 1.8 in 1972; however the bank was subsequently reconstructed and the channel returned to its previous alignment. The unvegetated channel is approximately 140 feet wide (ranging between 120 and 160 feet) and 5 feet deep in typical riffle sections at bankfull stage. Example cross-sectional profiles are shown below for channel segments near RM 2.5 (Figure 11), and RM 1.2 (Figure 12) and RM 0.5 (Figure 13).

The field survey identified a total of 22 pools ranging in depth from 4 to 12.5 feet with average pool spacing of 750 ft. (7 pools per mile). The primary mechanism driving pool formation is bend scour and most pools were located in areas with substantial bank armoring and along meander bends. A few pools are maintained by local scour such as beneath East Leavenworth Road Bridge. No wood-forced pools were observed in the reach. The pools are separated by riffle-run sequences with exposed sediment deposits present in some locations during the baseflow conditions of the channel survey. The pool-riffle morphology and presence of deep pools is highlighted by the longitudinal profile where lower elevation pools are separated by higher elevation riffles (Figure 9).

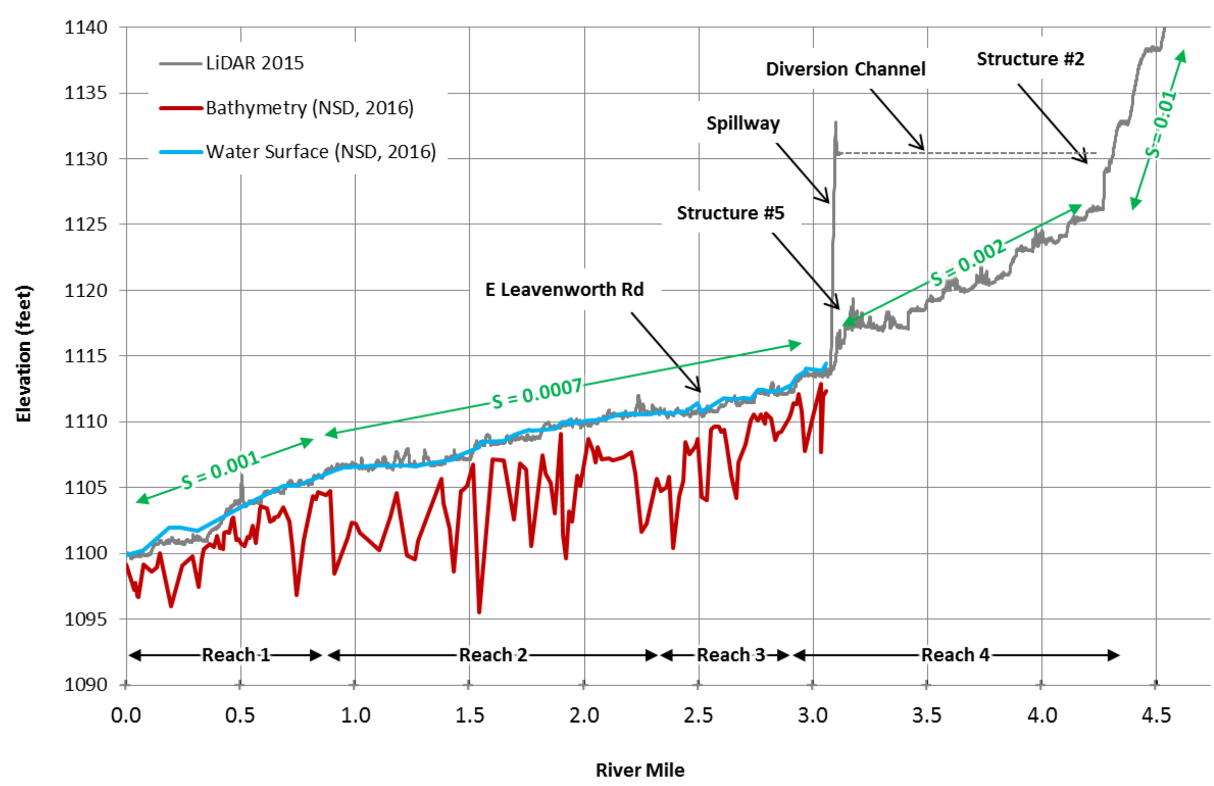


Figure 9. Longitudinal profile of the channel thalweg and water surface of the project reach in Icicle Creek. Channel thalweg and water surface elevation measurements were taken on 9/7/16-9/8/16. The slope of the historic channel directly upstream of the project reach was calculated using LiDAR measurements of the water surface in 2015.

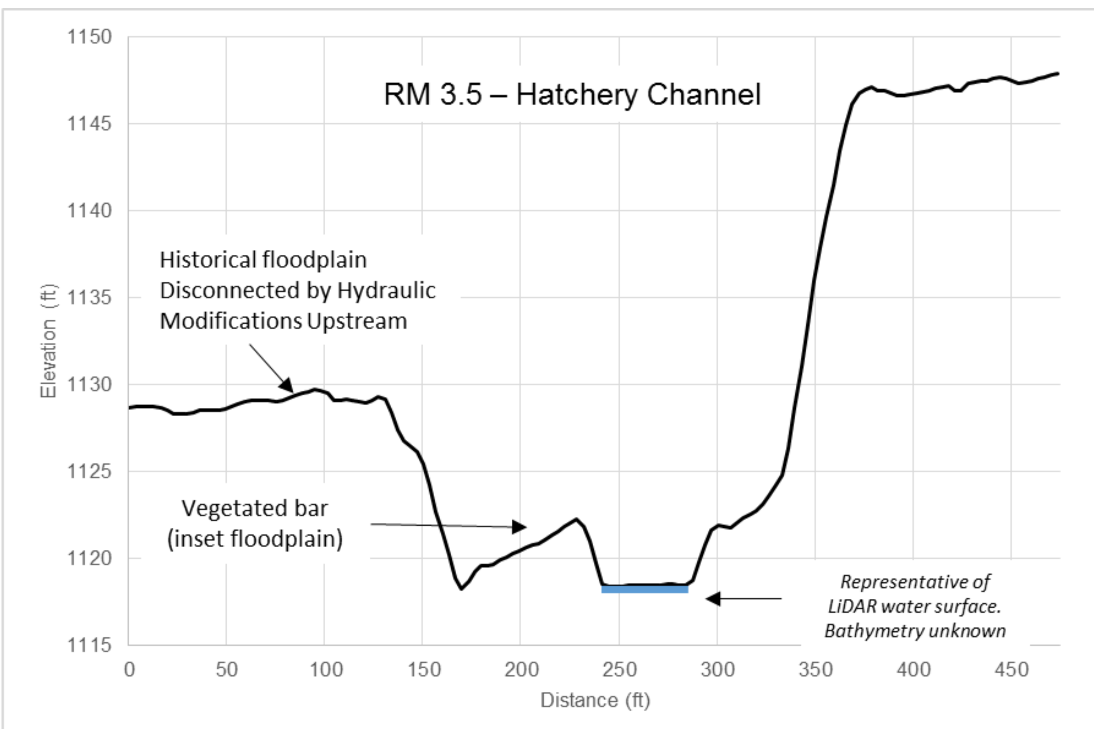


Figure 10. Photograph and cross-sectional profile of at RM 3.5. The left bank in photograph is the vegetated bar composed of historical deposition

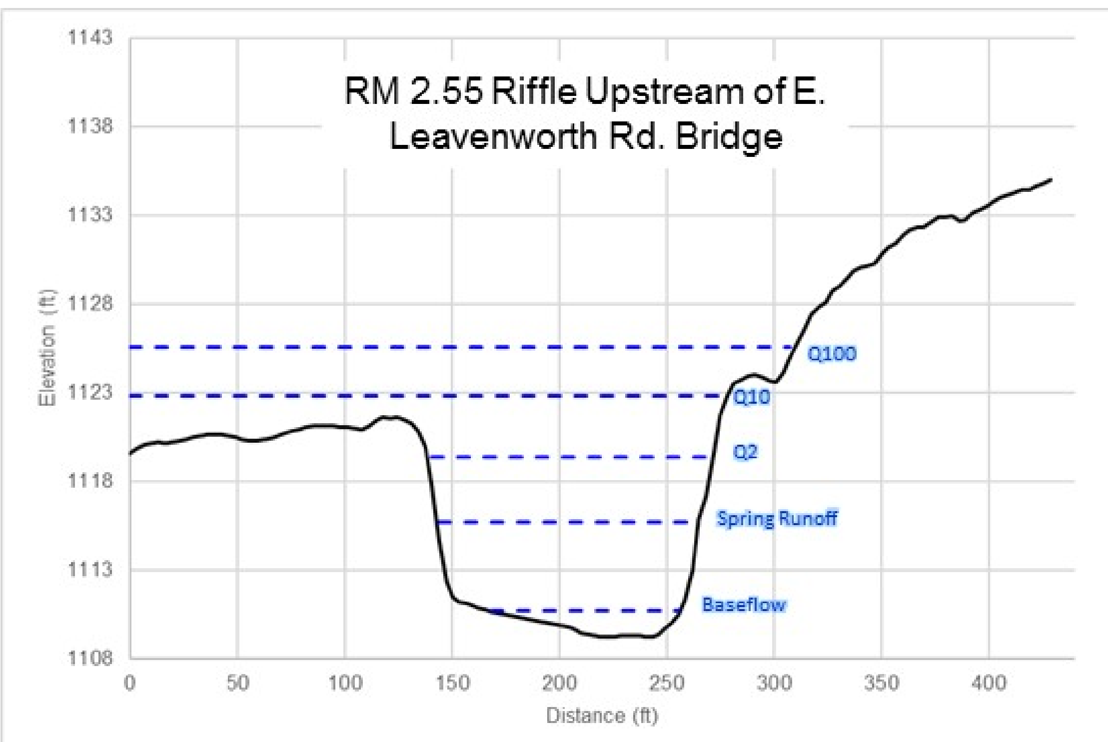


Figure 11. Photograph and cross-sectional profile of a riffle of Icicle Creek located at RM 2.55 directly upstream of the E. Leavenworth Rd. Bridge. The Q2 water surface elevation was calculated using the 2-D hydraulic model described below in section 5.

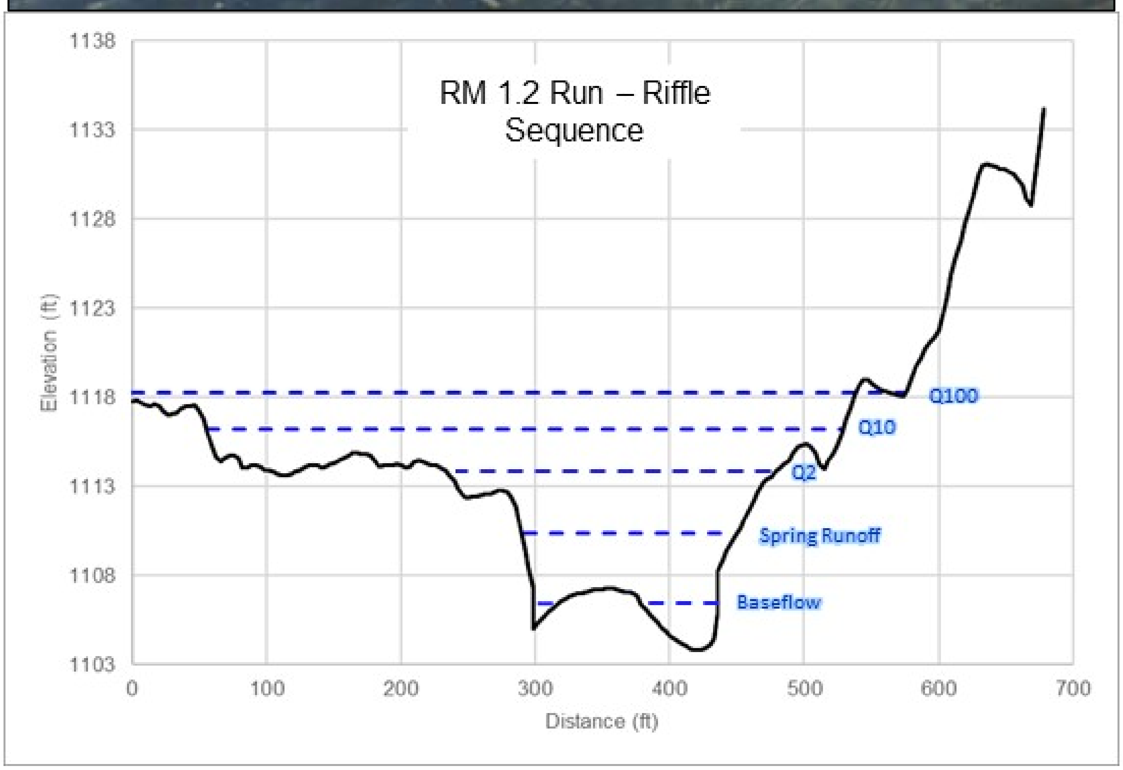


Figure 12. **Photograph and cross-sectional profile of a riffle-run sequence of Icicle Creek located at RM 1.2. The Q2 water surface elevation was calculated using the 2-D hydraulic model described below in section 5.**

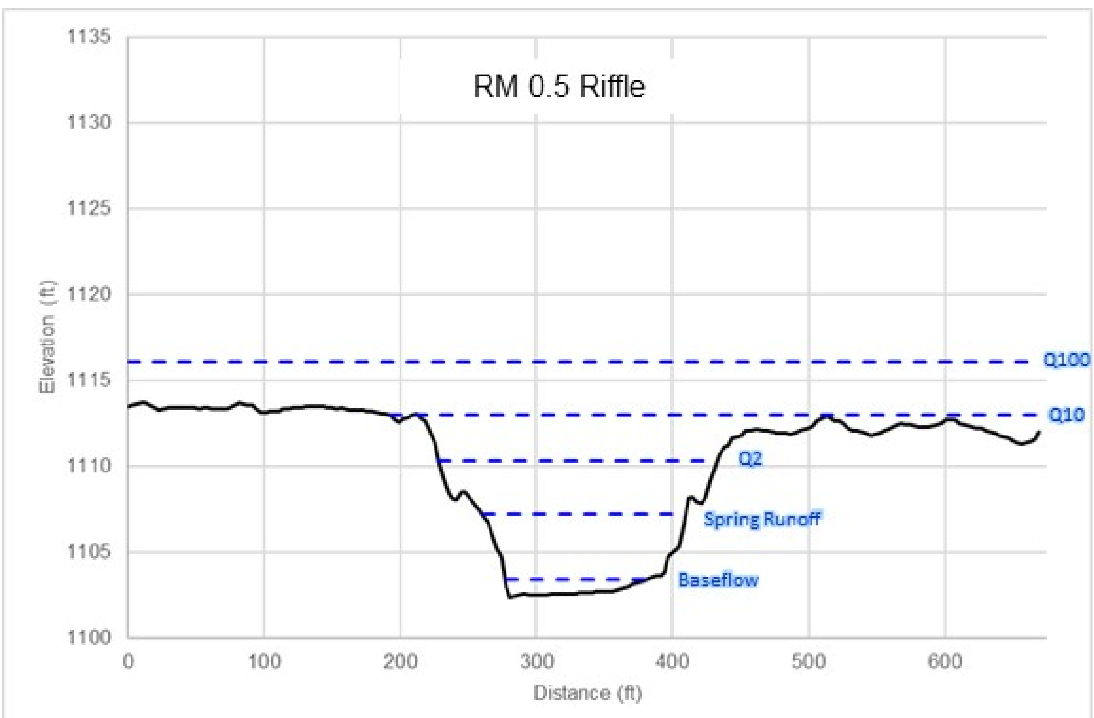


Figure 13. Photograph and cross-sectional profile of a riffle of Icicle Creek located at RM 0.5. The Q2 water surface elevation was calculated using the 2-D hydraulic model described below in section 5.

4.2 Sediment

Sediment sources to the project reach include sediment transported through the steeper and confined channel reach above LNFH, tributary inflows from Mountain Home Creek and remobilization of bedload materials within the project reach. The headgate dam and internal weir structures limit the sediment transport capacity within the Historical Channel upstream of RM 3 and Lorang and Aggett (2005) estimated 36,000 cubic meters (47,000 cubic yards) of historical sediment deposition trapped within the Historical Channel. Structures #3 and #4 within the Historic Channel were removed in 2003. Management of the headgate dam (Structure #2) assessment has also changed since the mid-2000s, remaining open year-round and enabling additional flow through the Historical Channel relative to previous conditions; however, flow is still regulated by Structure #2 with a maximum capacity of approximately 2,600 cfs or just over half of the 2-year peak flow. The combination of removing structures #3 and #4 with leaving the headgate open at Structure #2 has led to additional scour of fine sediments in the Historic Channel and an unknown portion of the historical trapped sediment within the Historical Channel has since remobilized and been transported out of the reach in recent years. Visual reconnaissance of the Historical Channel revealed a bed dominated by gravel and small cobble in the active channel area with vegetated islands composed of sand.

The Hatchery Bypass Channel has filled in with sand and gravel over recent decades. There is no active management to remove sediment from the Hatchery Bypass Channel (email Communication with Jim Craig, USFWS). Presumably, the channel has obtained an equilibrium slope and sediment is conveyed through the Hatchery Bypass Channel passing over the spillway dam during flood events. The adjusted slope of the Hatchery Channel is less steep than that of the Historic Channel due to hydraulic control at the spillway. The reduction in gradient likely results in preferential storage of coarser sediment such as cobbles while smaller sized bedload such as sand and gravel pass through the spillway and into the downstream reach.

The reaches downstream of the Hatchery Bypass Channel to the Wenatchee River confluence include active gravel bar deposits that show signs of recent deposition (void of vegetation, imbricated planform pattern). These bars are found both within the apex of meander bends and upstream from riffle crests within the middle of the channel. Anecdotal evidence from a landowner encountered during the field survey suggests that an area of active deposition near RM 1.8 was previously dredged to remove sediment and that the bar reformed from subsequent deposition soon after the sediment removal. Both lines of evidence indicate that there is an active bedload transport regime within the project reach.

The streambed in the project area is composed of sediment that is a mixture of gravel- and cobble-sized particles with the occasional boulder sized piece of rip-rap residing in the active channel (Figure 14). Bed material was sampled at two riffle locations within the project area as part of the field survey in September 2016. Sampling was conducted using the Wolman Pebble Count method with a sample size of greater than 100 particles at each location (Wolman 1954). The resulting grain size distributions of the sediment samples are presented in Figure 14. Median grain size (D_{50}) values range between 21 and 53 mm (coarse to very coarse gravel). The coarse fraction of the bed material, represented by the value for which 90 percent of the sampled particles are finer than (D_{90}), ranges between 53 and 86 mm (cobbles). There is a broad distribution of sediment size classes in both of the samples with sizes ranging from very fine gravels to fine cobbles. The D_{50}'s of the RM 1.4 and RM 2.9 samples are within the range of sizes preferred by spawning coho and Chinook salmon respectively (Kondolf and Wolman 1993); however, salmonids often prefer well sorted gravels with narrow, uni-modal distributions which are not common within the project reach (Kondolf and Wolman 1993).

The sediment load of Icicle Creek includes a relatively large supply of sand-sized particles that are not common in riffle segments but do drape over the bed surface in parts of the active channel with select channel units characterized by over 20% sand on the bed. The sand component is much more mobile than the coarse fraction of the bed and often settles out in pools and slower moving areas of the active channel on the falling limb of flood hydrographs.

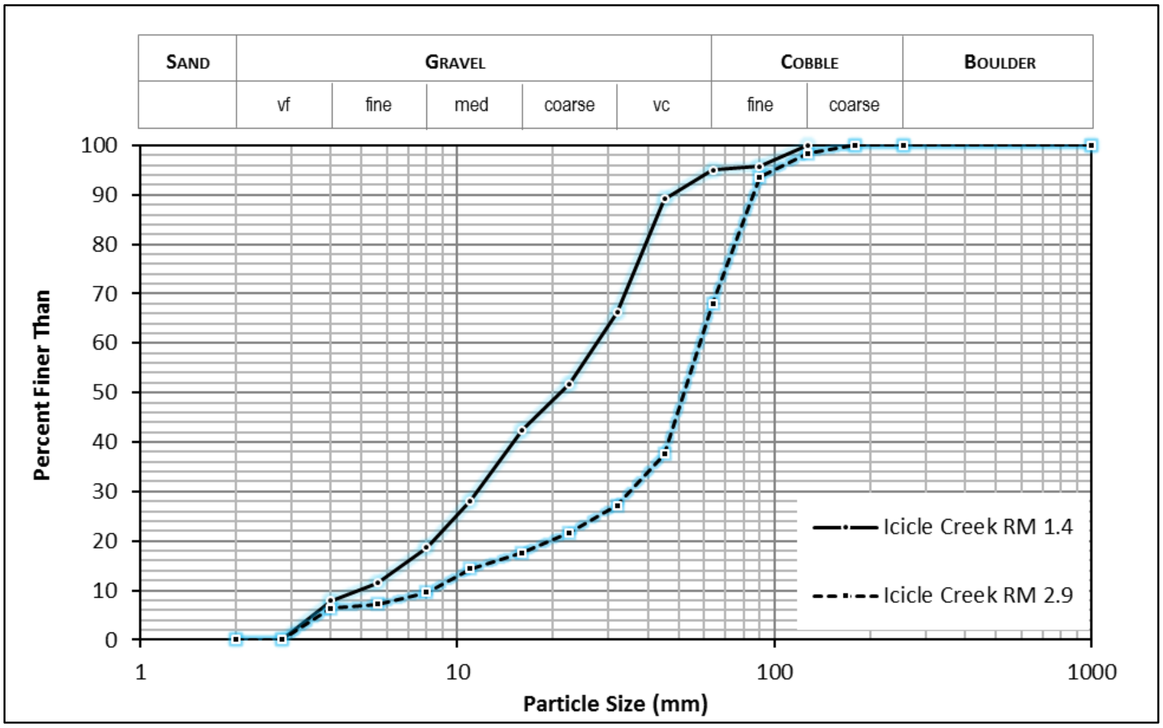


Figure 14. Grain size distribution plots of sediment samples collected from Icicle Creek on 9/7/16 and 9/8/16.

Figure 15. Photo illustrating bed material near RM 2.8.

4.3 Large Wood Recruitment

The natural processes driving the recruitment, transport, and accumulation of wood in the stream corridor are critically important in the formation and maintenance of salmonid habitats. Historical reconstruction of habitat distributions in alluvial valleys in Pacific Northwest rivers shows dramatic transformation from a wood-dominated landscape with abundant off channel habitat (e.g., side channels and floodplain wetlands) to a simplified landscape with widespread human alteration of the stream corridor (Collins et al., 2003). Flow interacts with wood to create distinctive hydraulic patterns that drive processes of scour and deposition to form complex arrangements of channel features including pools and bar areas (Abbe and Montgomery, 1996). Wood pieces interact to develop stable structures within the channel that can be grouped into specific types based on the configuration of logs and resulting geomorphic function (Abbe and Montgomery, 2003). Large wood also plays an important role in the partitioning of shear stress across the channel bed (Manga and Kirchner, 2000) and increases sediment storage capacity by trapping material within depositional features in the alluvial channel and floodplain (May and Gresswell, 2003).

The abundance of instream wood has important effects on the distribution of aquatic habitats. For example, mean pool spacing decreases and pool frequency increases with increasing levels of wood loading (Montgomery et al., 1995). In the Queets River system of Washington's Olympic Peninsula, a relatively intact forest river protected within Olympic National Park, 70% of all surveyed pools were formed by wood accumulations in the channel (Abbe and Montgomery, 1996). Instream wood is an important driver of channel complexity and contributed to increased tendency for multi-thread (anabranching) channel patterns in Puget Lowland streams prior to widespread disturbance and wood removal simplified stream corridors (Collins et al., 2002; Abbe and Montgomery, 2003). Wood also increases hyporheic exchange between surface water and the alluvial aquifer, thus moderating temperature fluctuations and affecting other water quality parameters (Hester and Doyle, 2008).

Within the lower Icicle Creek project reach large wood pieces were tallied to characterize the abundance and size of wood within the active channel. Criteria for sampling large wood followed the procedure outlined in the Washington Salmon Recovery Funding Board (2011) protocol for monitoring effectiveness of in-stream habitat projects (Washington Salmon Recovery Funding Board 2011). Qualifying wood pieces were tallied for the entire project reach. Qualifying criteria included:

- Length > 5 feet (1.33 m),
- Diameter > 4 inches (10 cm), and
- If wood is embedded in the streambed or extends outside of the bankfull channel area, the exposed portion of the piece within the bankfull channel cross-section must meet the minimum length and diameter criteria to be counted.

The wood tally noted length and diameter of 119 total pieces in the 3-mile long project reach. Large wood data were normalized for channel length and compared to reference values for quantities of instream wood in unmanaged basins of Washington State compiled by Fox and Bolton (2007) in Table 2. A similar comparison was developed for the volume of instream wood based on an estimate derived using the standard formula for a cylinder to quantify the volume of each piece tallied (Table 2).

The project reach is characterized by a general lack of wood due to past impacts of land management practices that impaired natural wood recruitment and physically removed large wood from the stream channel. The removal of old growth forest from the riparian area has effectively eliminated the recruitment of trees that are large enough to resist hydraulic forces generated during peak flow events and be considered stable. Such "key pieces" are essential for the formation and maintenance of aquatic habitats in channels such as Icicle Creek. Most of the wood pieces surveyed range between 10-30 feet in length and are less than 20 inches in diameter (Figure 16). Abbe and Montgomery (2003) surveyed large wood in the Queets River basin and found that ratios of log diameter/bankfull depth > 0.5 and log length/bankfull width > 0.5 yield an approximate guideline defining key pieces. As such, pieces roughly 36 inches diameter and greater than 100 feet in length are a minimum value required to develop stable wood accumulations that will affect channel morphology and maintain diversity of bedforms important to salmonid habitat in the project reach (Abbe and Montgomery, 2003). No large wood pieces meeting these minimum criteria were observed in the September 2016 survey. Existing guidelines from the National Marine Fisheries Service and United States Forest Service recommend >20 pieces/mile (1.25 pieces/100 m) meeting minimum criteria of 50 foot length and 24 inch diameter (National Marine Fisheries Service 1998). These guidelines are reasonably similar to the target values of >2 key pieces/100 m (>16 key pieces/mile) recommended by Fox and Bolton (2007) for the Douglas Fir – Ponderosa Pine transition zone.

The wood that does exist in the channel is sparse and consists primarily of single pieces held stable by rip-rap or cabled to the bank (Figure 17). There are a few larger accumulations of rafted and recruited woody material such as one occurring on the left bank at RM 2.16 (Figure 18). This accumulation consists of roughly 14 logs between 12-18" in diameter and 10-40' in length. It is also supplemented by what looks like yard waste from an adjacent property owner.

Table 2. Quantities of wood observed in the project during baseline monitoring investigation and target values based on reference data for western Washington streams of similar bankfull width class Fox and Bolton (2007). Data values are normalized per 100 meters of channel length.

LOWER ICICLE CREEK		REFERENCE CONDITIONS (FOX AND BOLTON (2007))		
Large Wood Classes	Baseline Conditions (#/100m)	75th Percentile (#/100m)	Median (#/100m)	25th Percentile (#/100m)
# Pieces	2.5	> 35	17	< 5
# Key Pieces	0	> 2	0.4	< 0.5

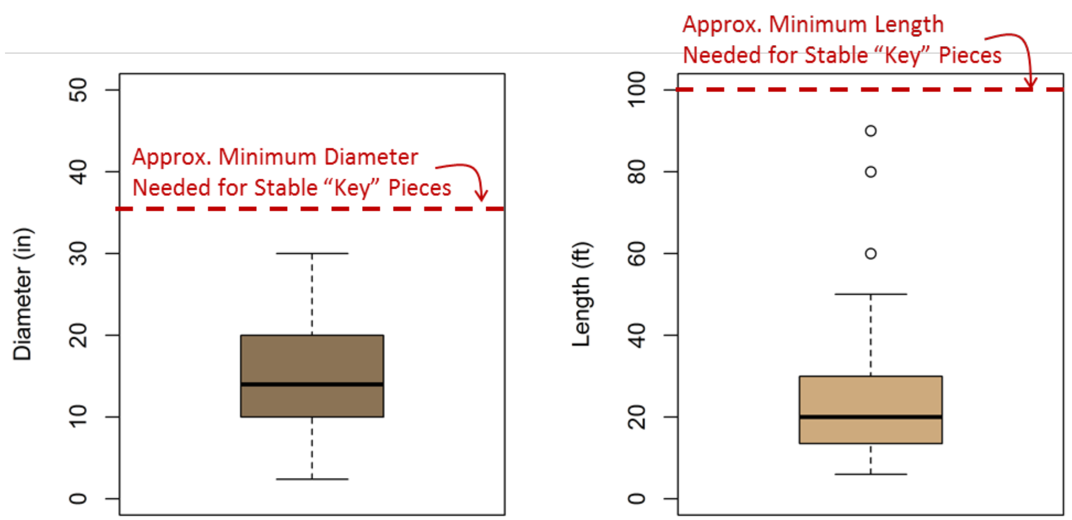


Figure 16. Box and whisker diagrams illustrating the range and variability of wood characteristics in the project reach. Boxes bracket the interquartile range (25th to 75th percentile) and whiskers extend to min/max values observed excluding statistical outliers. Points represent values of statistical outliers. Total sample = 119 pieces. There were no pieces in the inventory that have sufficient diameter or length to provide functions of stable "key" pieces that affect geomorphic processes in the reach.

Figure 17. View downstream of single piece of wood with a diameter of 15" and a length of 24' cabled to rip rap along right bank at RM 2.27.

Figure 18. Photo looking cross stream at existing wood accumulation located on the left bank at RM 2.16.

4.4 Riparian Vegetation

Riparian cover was delineated from 2015 aerial imagery and 2007 LiDAR-derived canopy heights (Figure 19). Areas with canopy height greater than 25 ft. were classified as mature trees. Areas with canopy height less than or equal to 20 ft. were classified as small trees/shrubs, grass/pasture, or having no vegetation (bare soils, roads, buildings). Riparian cover was delineated for the area within a 30-m buffer of the active channel extending to the extent of the 2-year floodplain where applicable (Figure 20). The distribution of riparian cover within the lower Icicle Creek study reach is presented below in Table 3.

Much of the 2-year floodplain has been disturbed by land clearing activities associated with dwellings and agriculture, as evidenced by a general lack of mature forest. The mature forest that remains within the 2-year floodplain is dominated by black cottonwood (*Populus trichocarpa*) with an understory of tall shrubs in the lower floodplain areas. Within the upper floodplain areas (above the 2-year flood extents) the mature forest consists of Douglas fir (*Pseudotsuga menziesii*), ponderosa pine (*Pinus ponderosa*), and an understory of sparse to dense shrubs.

Clearing associated with residential areas are common between RM 2.0 and upstream to the East Leavenworth Road Bridge. These areas typically have narrow bands of small riparian shrub vegetation along the lower river banks with cleared lawn dominating the upper floodplain terrace. These areas provide little benefit associated with stream shading or large wood recruitment potential.

Areas of the 2-year floodplain beyond the 30-m buffer are typically vegetated with riparian shrubs and mature forest communities. Some of these areas have been converted to wet pasture and are good candidates for riparian restoration efforts. This includes the right floodplain at RM 0.4 that directly abuts the stream channel, and a portion of the left floodplain at RM 2.4.

Active bank erosion is occurring in most channel segments where cleared areas coincide with the outside of meander bends, such as the right bank near RM 1.0. Clearings extending to the edge of the active channel occur along the right bank along several areas within the lower 1 mile. This clearing has resulted in unstable vertical banks with little root/soil cohesion.

Riparian and habitat conditions are improving in vegetated and forested areas, however cleared areas are not expected to become forested in the future without restoration actions. Areas of riparian replanting along eroding banks should be accompanied by temporary bank protection measures such as large wood structures or barbs to ensure the establishment of floodplain forest.

Table 3. Riparian cover – 2-year floodplain of the lower Icicle River.

COVER TYPE	PERCENT OF AREA
No Vegetation	1%
Grass/Pasture	38%
Small Tree/Shrub	33%
Tree (25-100')	27%
Tree (>100')	1%

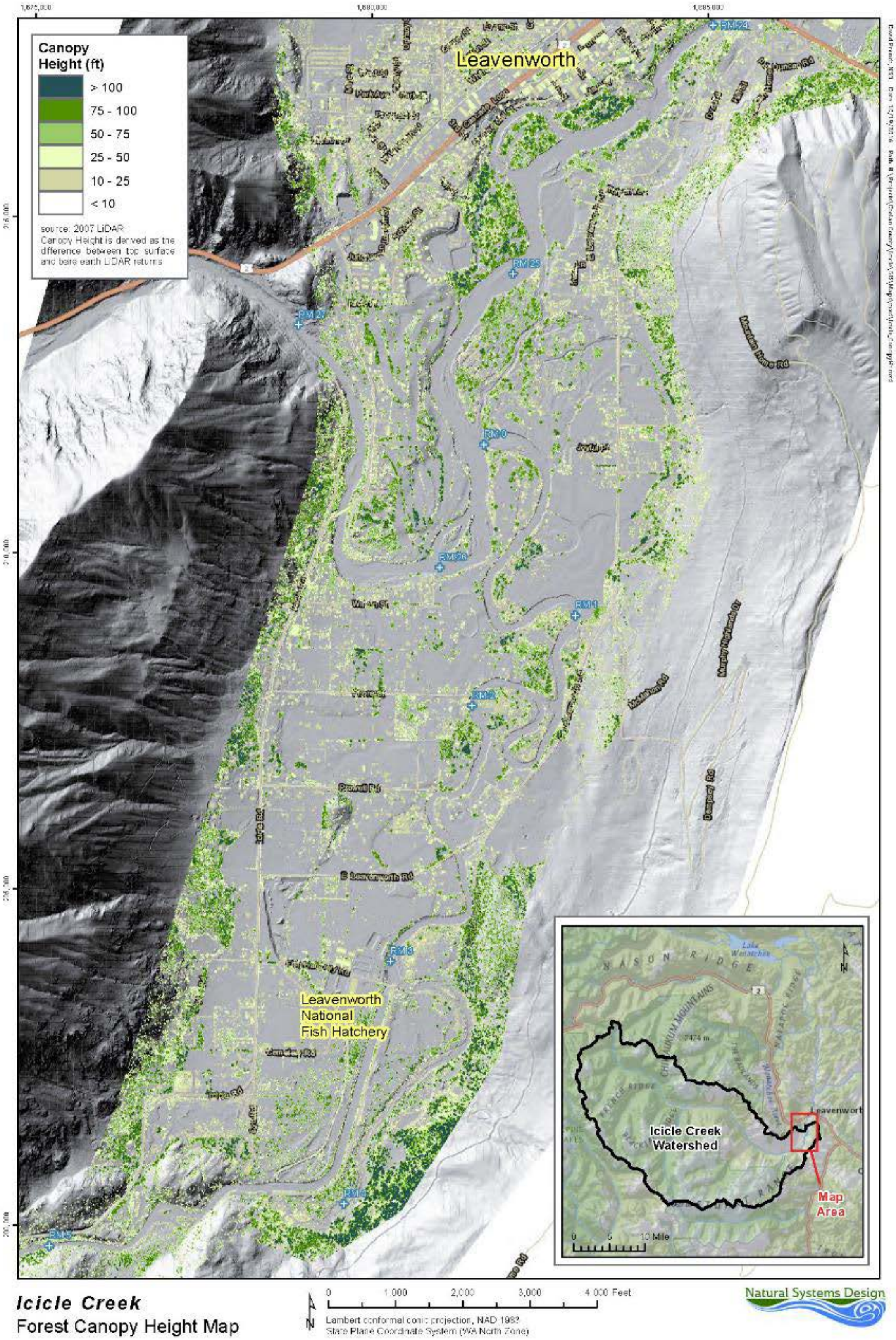


Figure 19. Forest canopy height map.

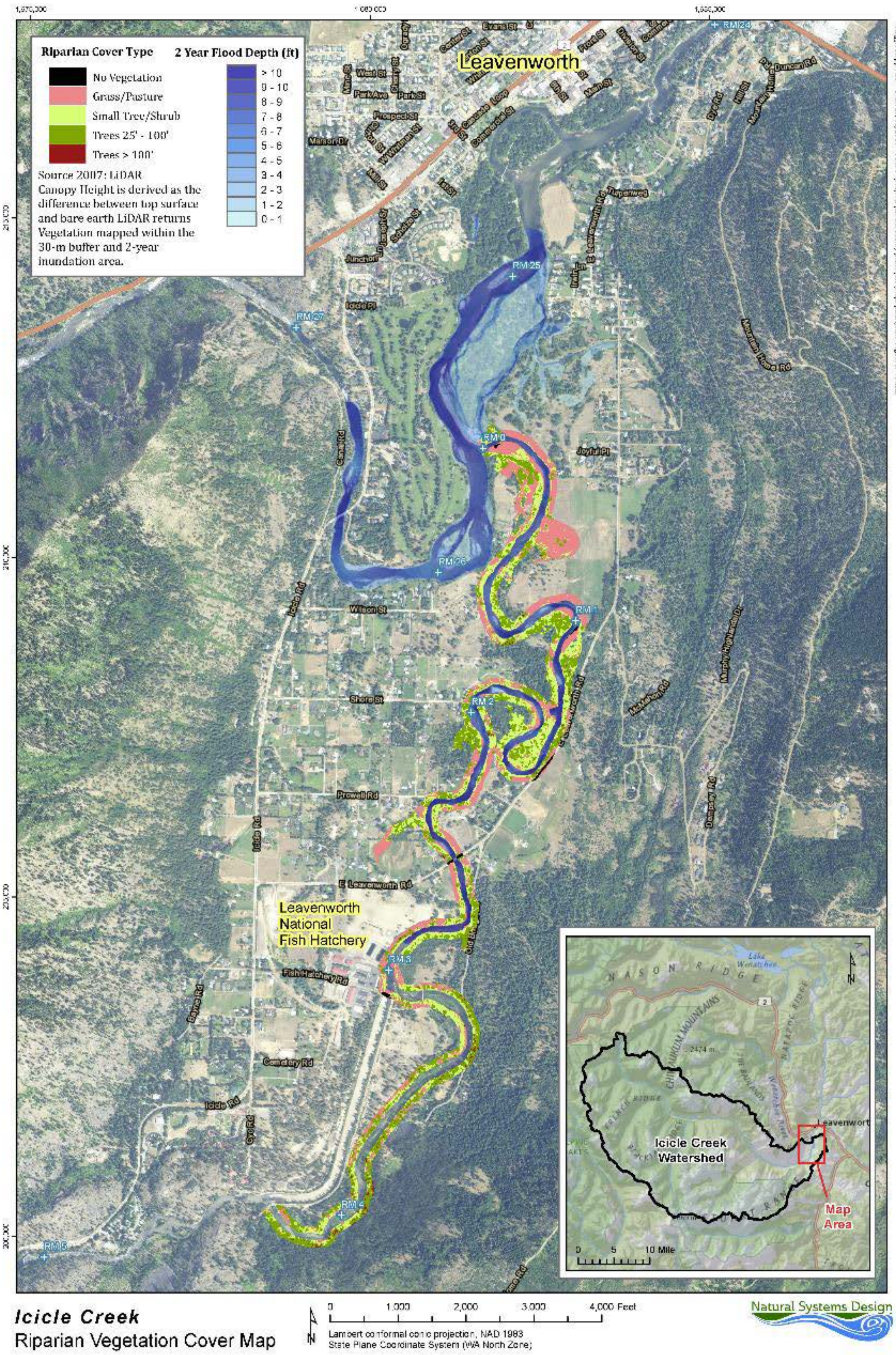


Figure 20. **Riparian vegetation cover map.**

4.5 Lateral Channel Migration

Channel migration processes such as bank erosion and bar development are desirable components of natural river systems that create and maintain aquatic habitats and promote riparian vegetation succession (Florsheim et al., 2008). The ability of the Icicle Creek channel to migrate laterally within the valley has been substantially impaired over the historical period by artificial constraints such as rock revetments (riprap) and barbs. The intent of these structures is to stabilize streambanks that may otherwise erode and thereby protect private property within the stream corridor (Figure 21). As a result, however, natural processes such as wood recruitment and formation of side channels are impaired with the channel locked in place by armored bank protection.

NSD mapped rock rip-rap and rock barb bank hardening structures during the September 2016 field survey and estimated a total of 6,000 linear ft. of rock structures within the upper 2 miles of the project reach (Areas of armored bank protection are overlaid on the reach maps in Figure 3-Figure 6). The lower mile does not have substantial armoring structures. These structures are primarily concentrated along meander bends, however there are additional structures in place throughout the remainder of the project reach that are associated with individual property bank protection. Many of the deep pools described above in section 4.1 are located adjacent to bank hardening structures.

Bank hardening structures of interest include:

- A series of 9 stream barbs along the left bank directly downstream from the hatchery.
- Rip rap along both banks associated with the E. Leavenworth Rd. bridge structure.
- A 500 ft. rip rap structure along left bank between RM 2.5-2.3 associated with the community along Prowell St.
- A 1800 ft. rip rap structure along the left bank between RM 2-1.65 associated with the community along Shore St.
- A 800 ft. rip rap structure along the right bank between RM 1.55-1.45 which protects the surroundings private properties and E. Leavenworth Rd.
- A 500 ft. rip rap structure along the right bank between RM 1-0.9.

Three areas affected by lateral channel migration over the historical period include the following:

- Bank erosion in the 1972 flood produced a bend cutoff in the segment between RM 1.3-1.8. The bank was subsequently reconstructed, armored with riprap, and the channel returned to the pre-cutoff alignment. The bank at RM 1.7 is overtopped during flood events and remains a potential avulsion pathway.
- The right bank near RM 1.1 has migrated laterally to the northeast and erosion of a previously armored bank at RM 1.0 failed in 1995. Toe rock along the previous bank alignment remains in the channel; however. The outer bank has migrated about 70 feet to the north (Figure 22).
- The confluence of Icicle Creek formerly split with a portion of its flow connecting with a side channel running parallel to the Wenatchee River. Over time, the right bank of Icicle Creek has migrated northward at RM 0.1, altering the angle of the confluence and resulting in sediment deposition near the mouth of the side channel. Flows form Icicle Creek (combined with flows from the Wenatchee River) still access the side channel during flood stage but not during normal flow conditions.

Figure 21. Photo with an example of typical streambank protection using riprap to armor the erodible bank materials.

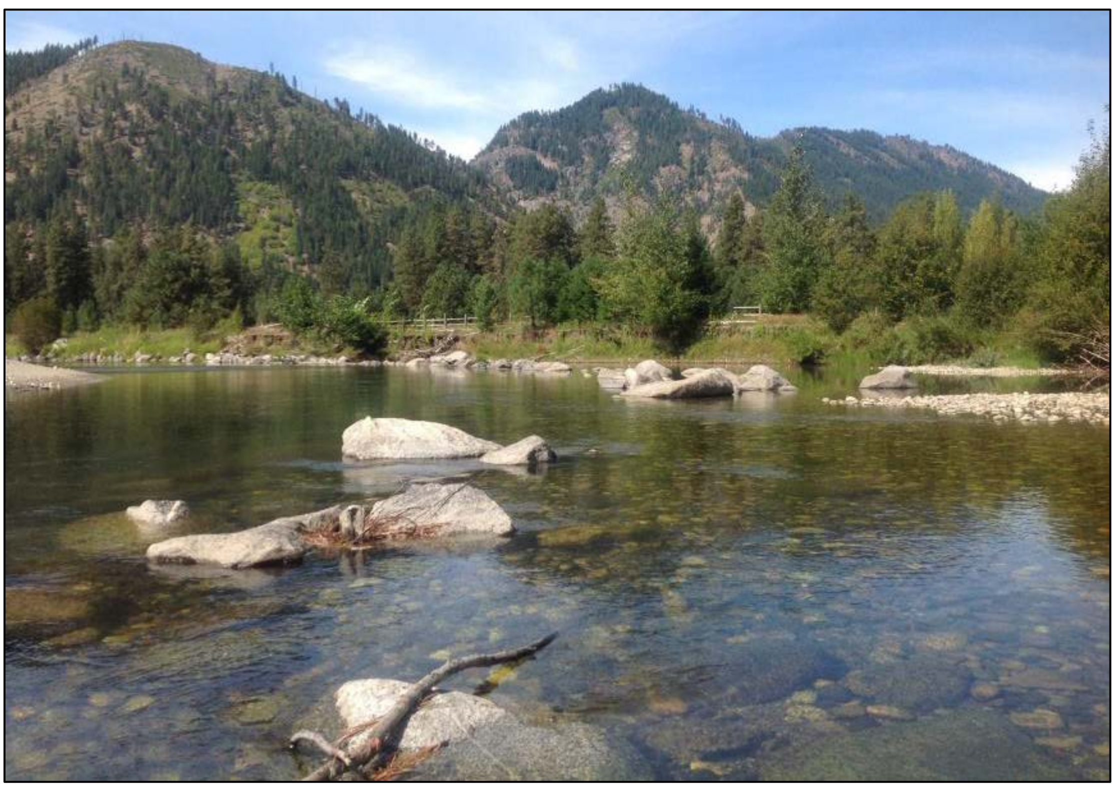


Figure 22. Breached rip-rap structure along right bank between RM 1.0-0.9 looking downstream. The channel has migrated ~70 feet past the structure.

4.6 Habitat Assessment

Habitat within the lower Icicle Creek project reach was assessed to quantify existing habitat availability and quality, and to identify opportunity areas with potential for restoration treatments. Establishing base habitat conditions also enables quantitative comparison with proposed condition analyses to be completed in future project phases. This assessment utilized a habitat survey in the late summer of 2016 and generally follows the USFS Level II Survey protocols. Channel units (e.g. pools, riffles, glides) are referred to as habitat units.

The lower Icicle Creek reach is characterized by a single thread, meandering channel pattern with relatively uniform pool-riffle morphology. The unvegetated channel is approximately 140 feet wide (ranging between 120 and 160 feet) and 5 feet deep in typical riffle sections at bankfull stage. Figure 23 presents the habitat units as identified during the field survey. In total, we identified a total of 18 pools ranging in depth from 4 to 12.5 feet with average pool spacing of 750 ft. The primary mechanism driving pool formation is bend scour and most pools were located in areas with substantial bank armoring and along meander bends. No wood-forced pools were observed in the reach. The pools are separated by riffle-run sequences with exposed sediment deposits present in some locations during the baseflow conditions of the channel survey.

Table 4 provides the percentage of pool, riffle, and glide habitat within the study reach. Habitat Suitability Modeling (Appendix B) examined the value of existing habitats related to juvenile Chinook and steelhead, and adult steelhead spawning (NSD 2017).

Table 4. Percentage of pool, riffle, and glide habitat within the lower Icicle Creek study reach.

HABITAT UNIT	% TOTAL
Pool	46%
Riffle	44%
Glide	10%

Habitat Suitability Index (HSI) modeling for juvenile Chinook (*Oncorhynchus tshawytscha*) and steelhead (*Oncorhynchus mykiss*) was performed and the results are detailed in Appendix B. Habitat suitability modeling is becoming a standard process for restoration planning and design in the Upper Columbia, and is strongly encouraged and supported by BPA, the Upper Columbia Salmon Recovery Board (UCSRB), and CCNRD.

The key findings for the HSI analysis were:

- Index values for juvenile Chinook and steelhead rearing habitats are poor throughout the study area;
- Index values for depth and velocity are generally good for rearing habitat conditions; however, the combined HSI results are strongly affected by a general lack of cover elements due to historical impacts leading to the widespread loss of large wood in the system.
- Lack of connectivity to off-channel habitat areas during high flows further limits the rearing habitat in the reach;
- Index values for steelhead spawning habitats are generally good; however, additional study of egg pocket scour depth during floods should be done to evaluate potential for adverse effects due to loss of wood.

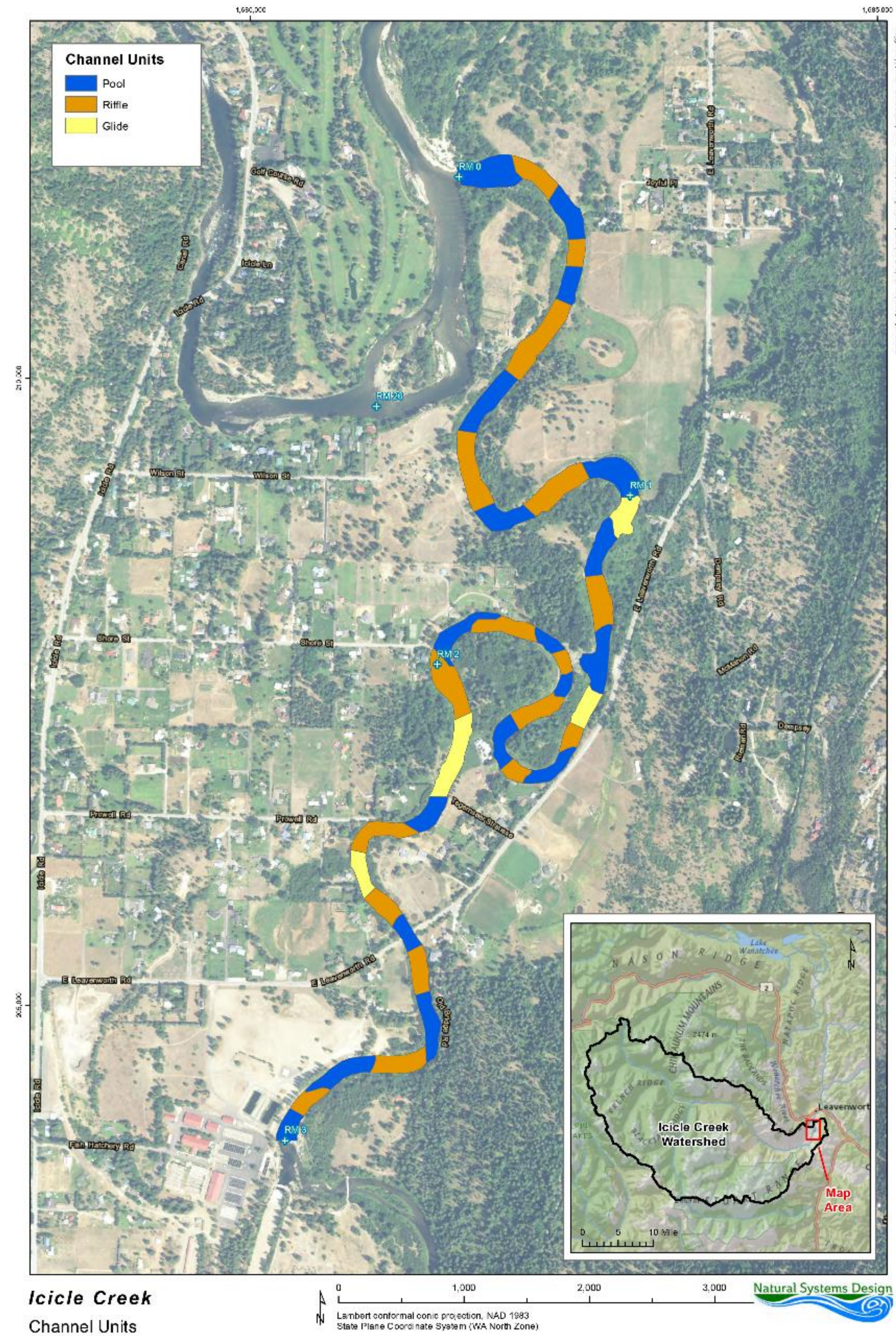


Figure 23. Pool, Riffle, and Glide channel unit mapping within Lower Icicle Creek (RM 0. 0 – 3.0).

5. HYDROLOGIC AND HYDRAULIC ANALYSIS

5.1 Streamflow Data and Hydrologic Regime

Icicle Creek drains a 214-square mile drainage basin on the eastern slope of the Cascade Mountain Range, and is a tributary to the Wenatchee River (Figure 1). Icicle Creek originates from the outlet of Josephine Lake (elevation 4,680 ft.) and receives inflow from tributaries including French Creek, Jack Creek, Eightmile Creek, and Snow Creek. Precipitation over the Icicle Creek watershed exhibits a strong gradient that varies with elevation and distance from the Cascade Crest such that annual precipitation averages over 110 inches per year in headwater areas and decreases in an easterly direction to less than 20 inches per year in the lower valley near Leavenworth. Distributed over the entire drainage basin, annual precipitation in the Icicle Creek Watershed averages 64 inches per year (PRISM Climate Group 2015). Average winter temperature is 28° F (PRISM Climate Group 2015) and much of the precipitation received during winter months falls as snow and is temporarily stored in the watershed until temperature warms and snowmelt runoff flows off the landscape.

Streamflow is measured at the USGS gaging station above Snow Creek (RM 6.8) with a period of record from September 1936 to September 1971, and October 1993 to present (no data recorded 1972-1992). The drainage area above the USGS gage is 193 square miles and accounts for 90% of the total watershed area for Icicle Creek. There are no diversions above the USGS gage and only minor regulation in headwater lakes. Surface flow is diverted from Icicle Creek downstream of the USGS gage.

The Washington Department of Ecology (Ecology) established a gaging station at East Leavenworth Road (RM 2.2) in May 2007 with continuous streamflow measurements starting in Water Year (WY) 2011. The Ecology gage at East Leavenworth Road is better suited to evaluation of base flow conditions given its location downstream of the water diversions; however, the period of record is insufficient for evaluation of peak flow statistics.

The prevailing hydrologic regime is snowmelt dominated and peak runoff typically occurs during spring and early summer (Figure 24) with annual peak flows occurring in May or June for more than 80% of the years in the hydrologic record (1937-2015). Streamflow can be highly variable during the fall/winter period with episodic flood pulses occurring in response to rainfall-driven and rain-on-snow events (Figure 25). These rainfall-driven floods are associated with advection of warm, moist air over the watershed that raises the freezing level elevation and delivers heavy rainfall as opposed to snow. The rainfall-driven flood pulses are flashier than snowmelt-driven floods and tend to account for more of the extreme floods affecting the watershed. Six of the top 10 flows in the annual maximum flood series occurred during the months of November or December including the flood of record on November 29, 1995 (Table 5).

Peak flow statistics were derived from statistical analysis of the USGS gaging station on Icicle Creek above Snow Creek (#12458000) following guidelines for flood frequency analysis is Bulletin 17B (Figure 26). Resulting estimates of peak flow magnitudes are summarized in Table 6. Note that the headgate structure at LNFH limits inflow to the Historic Channel segment (maximum capacity of 2,600 cfs) with the majority of flow during flood stage bypassing the Historic Channel.

Streamflow in Icicle Creek recedes following the summer snowmelt period and typically reaches minimum values during September and early October. Minimum flows are affected by water diversions upstream of the project area. The major diversions are used for irrigation of downstream orchards, the Leavenworth National Fish Hatchery, and municipal water supply. Diversion totals based on existing water rights can account for of a substantial portion of the water supply during summer months in which irrigation demands are high and streamflow is low. Watershed stakeholders utilize low profile dams on several mountain lakes to release supplement streamflow during summer months in effort to mitigate impacts of flow diversions on low flow conditions in Icicle Creek. The IWG (2015) established a set of Guiding Principles that includes a minimum flow of 100 cfs in the historical channel during non-drought years (60 cfs target). It is estimated that a supplemental flow of 40 cfs is needed to maintain this target. The IWG is developing a set of projects that, when implemented, are intended to meet the minimum flow target.

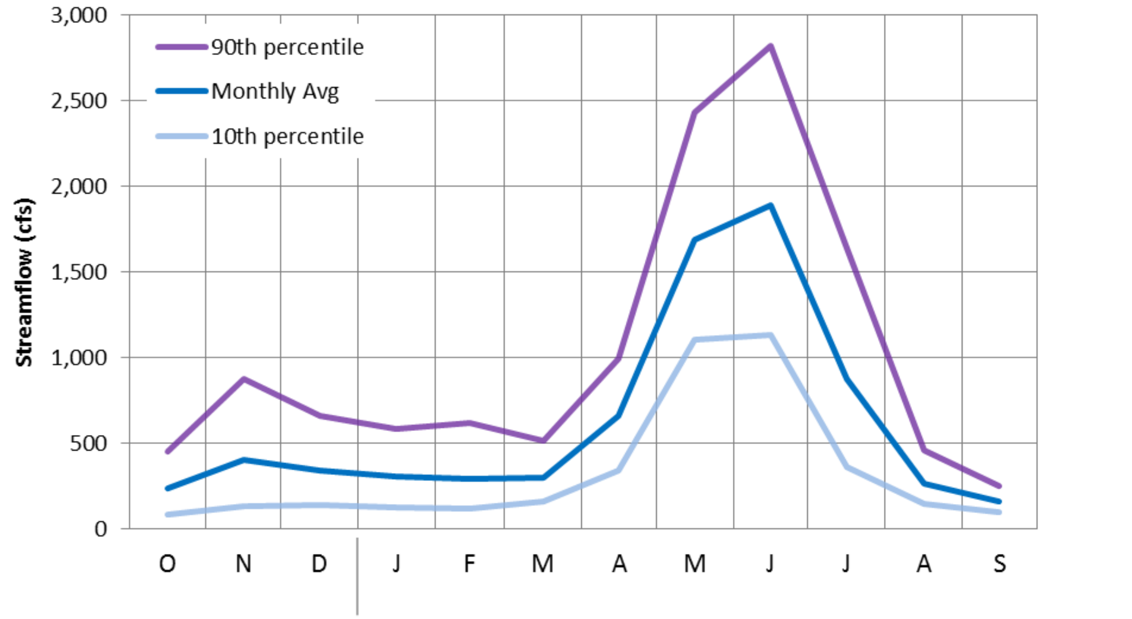


Figure 24. Monthly streamflow statistics for the Icicle Creek at USGS gaging station #12458000 (RM 6.8).

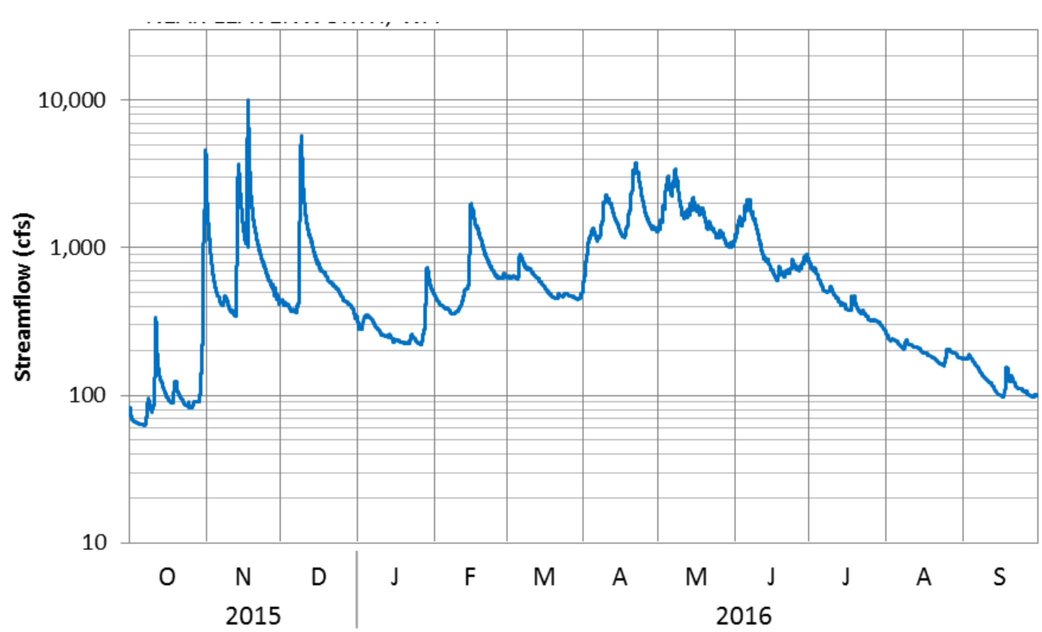


Figure 25. Hydrograph for Water Year 2016 at USGS gaging station #12458000 (RM 6.8).

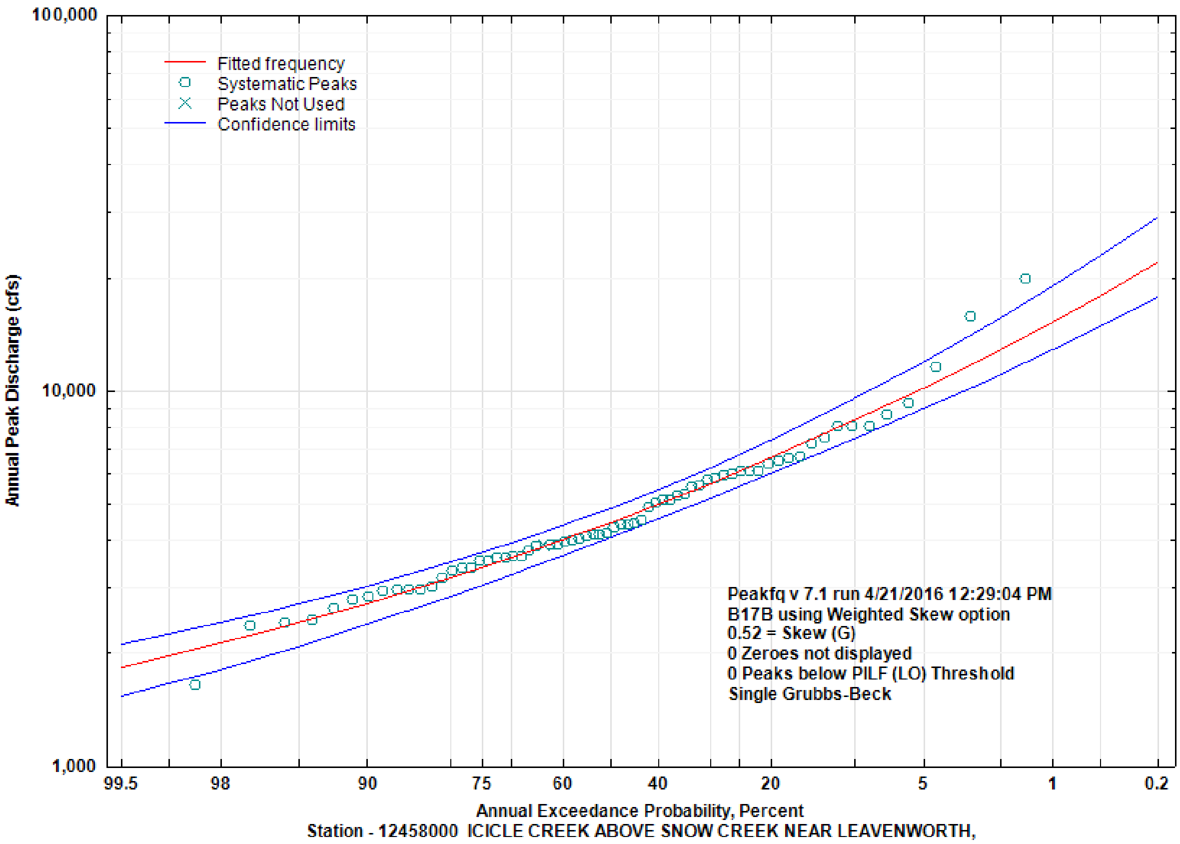


Figure 26. Flood frequency curve based on the historical record at USGS gage #12458000.

Table 5. Summary of peak flows recorded at the USGS gaging station in Icicle Creek (#12458000) over the period 1937-2015.

RANK	DATE	PEAK FLOW (CFS)
1	11/29/1995	19,800
2	11/6/2006	15,700
3	5/28/1948	11,600
4	12/4/1975	9,250
5	11/23/1959	8,620
6	6/10/1972	8,040
7	11/27/1949	8,020
8	6/17/1974	8,000
9	11/12/2008	7,510
10	6/16/1999	7,230

Table 6. Flood frequency statistics calculated for at USGS gage #12458000.

ANNUAL EXCEEDANCE PROBABLITY	RECURRENCE INTERVAL (YEARS)	PEAK FLOW (CFS)
0.99	1.01	1,960
0.8	1.25	3,160
0.5	2	4,450
0.2	5	6,600
0.1	10	8,290
0.04	25	10,770
0.02	50	12,880
0.01	100	15,230

5.2 Projected Impacts of Climate Change

Subtle changes in temperatures have potential to affect the relative distribution of winter precipitation that falls as rain as opposed to snow. Model simulations of future climate changes project an average 5°F increase in temperature over the 21st century relative to historical conditions (Mote and Salathé, 2010). Reductions in winter snowfall with warming temperatures will result in decreasing snowpack, earlier snowmelt, and decreasing summer base flows (Elsner et al., 2010). Future climate simulations by UW Climate Impacts Group show an 11% reduction in the amount of water contained in the snowpack (Snow Water Equivalent) by the 2040s (Mauger, 2010). As rainfall-driven floods in fall and winter account for a larger proportion of the annual runoff volume the seasonal timing of streamflow will shift. Hydrologic projections by UW Climate Impacts Group indicate that peak flows in the Wenatchee River watershed could increase 50-90% by the 2040s with concurrent decreases to summer low flows of more than 20% over the same period (Hamlet et al., 2010; Tohver et al., 2014). Extended projections over the latter half of the 21st century show even greater changes relative to historical conditions.

5.3 Hydraulic Model Development

NSD analyzed hydraulic parameters of the project reach (RM 0.0 – 3.0) such as flow depth, velocity, and shear stress to characterize existing conditions and establish a baseline for use in evaluating conceptual design alternatives as part of future tasks. Resulting maps from the baseline model simulations are attached as Appendix C. This section presents an overview of the hydraulic model simulations and summary of the baseline results. Detailed descriptions of the analysis methods and hydraulic model development are attached in Appendix D. The hydraulic analysis evaluated the reach downstream of the Leavenworth National Fish Hatchery and excluded areas within the historical channel segment adjacent to, and upstream from the hatchery facility.

A hydraulic model of Icicle Creek was developed using the Hydronia's RiverFlow-2D Plus GPU and Aquaveo SMS v12.1 computer software. RiverFlow-2D is a two-dimensional finite element computer model that provides depth averaged hydraulic parameters at nodes within a triangular mesh model domain. The model geometry incorporates bathymetric survey data collected by NSD in September 2016 to represent the low flow channel and topographic data from the 2015 LiDAR DEM to represent channel and floodplain areas outside of the bathymetric survey. Hydraulic resistance is characterized by polygons representing differing surface types such as channel, vegetated bar, forest, or pasture. The surface type polygons were classified with Manning's roughness coefficients listed below in Table 7. The model was calibrated through adjustment of the roughness coefficient to best match the water surface profile surveyed in the field September 7 and 8, 2016 (130 cfs). The root mean square error of the calibrated measured vs. modeled WSE for the final channel roughness value was 0.25 ft. and the average residual was -0.13 ft.

Five representative flow scenarios were selected for evaluation of hydraulic parameters in Icicle Creek ranging between a summer base flow condition and the 100-year recurrence interval peak flow (Table 8). For reference, the representative flow scenarios utilized in the hydraulic analysis are plotted over the annual hydrograph for WY 2016 in Figure 27.

The representative summer base flow utilized for Lower Icicle Creek was selected to match the observed flow upstream of the E. Leavenworth Road Bridge during the field survey completed September 7, 2016 (130 cfs). For reference, 130 cfs is exceeded approximately 90% of the time over the period of record at the Ecology gage site.

The typical snowmelt runoff scenario simulated a flow of 1,830 cfs. The snowmelt runoff flow was selected to match streamflow on June 5, 2016 for which a water surface elevation was marked by landowners upstream of the E. Leavenworth Road Bridge to support model validation. The selected flow approximates a peak flow with a 1-year recurrence interval or a minimum flood peak value expected to be exceeded in any given year. The flow representing a typical snowmelt runoff scenario (1,830 cfs) corresponds to a discharge that was exceeded approximately 7% of the time, or an average of 25 days per year, over the period of record at the USGS gaging station above Snow Creek.

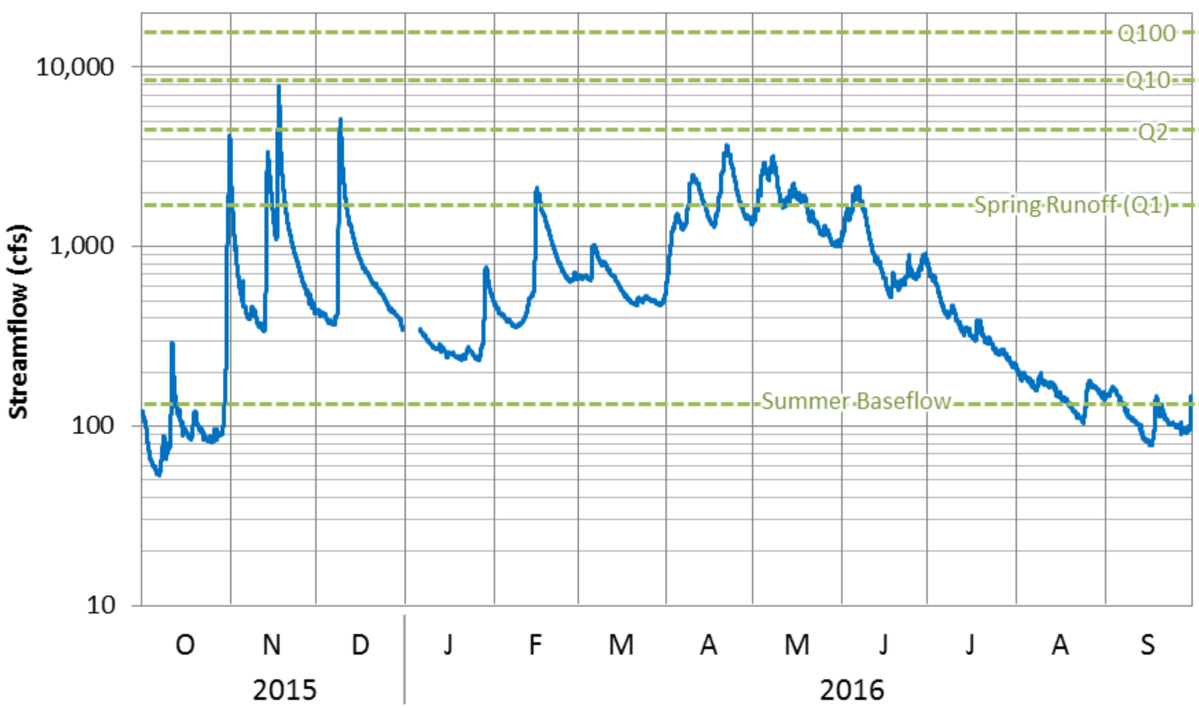


Figure 27. Annual hydrograph for WY 2016 (Icicle Creek near E Leavenworth Road Bridge) with representative flows utilized in hydraulic analysis highlighted in green horizontal lines.

Table 7. Model roughness values.

SURFACE TYPE	MANNNG'S N VALUE
Channel, main	0.035
Channel, upper/side	0.045
Gravel bar	0.035
Gravel bar vegetated	0.07
Forest	0.12
Pasture/clearing	0.05
Road, Paved	0.01
Riprap	0.078

Table 8. Streamflow statistics utilized in representative flow scenarios.

	STREAMFLOW (CFS)
Summer Base Flow	130
Typical Snowmelt Runoff	1,830
2-Year Peak Flow (Q2)	4,450
10-year Peak Flow (Q10)	8,300
100-Year Peak Flow (Q100)	15,200

5.4 Summary of Hydraulic Parameters

Summary statistics compiled for the five representative flow scenarios are presented below in Table 9. Map outputs of flow depth and velocity for all flow scenarios are attached in Appendix C. Figure 28-Figure 30 present hydraulic model results for simulated depth and velocity of the 2-year recurrence interval flow (4,450 cfs). Also shown in maps on Figure 28 - Figure 30 are the outer limits of flood inundation of the 100-year recurrence interval flow for reference.

Table 9. Summary statistics of 2-dimensional hydraulic model results for the baseflow, spring runoff, Q2, Q10, and Q100 modeling scenarios

FLOW	DEPTH (FT)				VELOCITY (FT/S)				SHEAR STRESS (LB/SQFT)		FLOODPLAIN AREA (ACRES)
	MIN	MAX	MEAN	SD	MIN	MAX	MEAN	SD	MEAN	SD	
Baseflow	0.1	11.5	2.0	1.5	0.0	8.4	0.9	0.6	0.0	0.1	0.0
Spring Runoff	0.1	15.3	5.9	1.7	0.0	5.5	2.9	0.9	0.2	0.1	16.2
Q2	2.1	18.5	9.1	1.8	0.0	6.9	4.1	1.2	0.4	0.2	60.9
Q10	4.3	20.9	11.7	2.0	0.0	9.6	4.9	1.8	0.5	0.3	203.6
Q100	6.9	23.4	14.2	2.2	0.0	15.2	4.5	3.0	0.5	0.6	327.0

5.5 Flood Inundation and Off-Channel Hydraulic Connectivity

In stable river channels with forested alluvial valley in the Pacific Northwest, flood flows typically reach bankfull stage and inundate adjacent floodplain areas on a nearly annual basis. Castro and Jackson (2001) evaluated survey data of hydraulic geometry to relate bankfull stage with corresponding flow records from USGS gage sites and found that typical recurrence intervals for bankfull stage in the Pacific Northwest ranges between 1.2 and 1.5 years in the annual maximum flood series. In a valley such as Icicle Creek, we would expect relatively widespread inundation of floodplain surfaces during the 2-year flood with some side channels and off-channel areas hydrologically connected during much more frequent events.

Simulated results show a general lack of floodplain connectivity and few areas of connected off-channel habitats during the normal range of flows. The representative spring snowmelt runoff scenario (1,830 cfs) shows flow that is mostly contained within the unvegetated channel and with only a few small areas of floodplain inundation along the channel margin. As flow ramps up to the 2-year recurrence interval peak (Q2; 4,450 cfs), there are about 61 acres of inundated floodplain outside of the active channel. These locations include very low lying areas of the floodplain such as backwater flooding in abandoned channel features downstream of East Leavenworth Road (RM 2.4) and near RM 0.5. Other areas engaged during the 2-year flood are vegetated bars in areas of relatively recent (past few decades) lateral channel migration such as RM 1.1, RM 0.9, and near the confluence of the Wenatchee River at RM 0.1.

As flow increases to the 10-year recurrence interval peak flow (Q10), alluvial floodplain surfaces identified with a relative elevation between 6 and 10 feet above the active channel become more broadly connected with surface water flows from the active channel. Collectively, these results suggest that Icicle Creek is generally incised, throughout the study area, and that where the channel has been allowed to migrate laterally, new inset floodplain deposits form at a lower elevation than the older floodplain surfaces that likely formed prior to widespread human impacts when the channel had a natural riparian zone and adequate wood loading.

Simulation of the 100-year recurrence interval flood (Q100) show widespread flooding over an approximately 1,500-foot wide corridor. There are 327 acres of inundated floodplain outside of the active channel during the Q100 flow scenario. The entirety of the alluvial valley experiences floodplain engagement during this flow level as evidenced by flow encompassing a high elevation relic meander bend on the east side of East Leavenworth Road near RM 0.5. Flow depths reach 6 ft. in places along the floodplain and flow overtops East Leavenworth Road near the bridge and along the east side of the valley. There is also a strong hydraulic connection between Icicle Creek and the Wenatchee River across both the left bank (of Icicle Creek) floodplain terrace and within the side channel network near the Icicle Creek Confluence.

The floodplain inundation results of the Q100 modeling scenario closely correspond to images recorded during the 11/30/1995 flood (Figure 31). Video taken from a helicopter during the flood indicate a strong hydraulic connection between Icicle Creek and the Wenatchee River as well as full inundation of the large relic meander bend towards the east side of the valley. The images also demonstrate a high terrace and lack of connection between Icicle Creek and the Wenatchee along Wilson Street near RM 0.6 – results that closely agree with our Q100 model. These agreements provide greater confidence in the high flow modeling results.

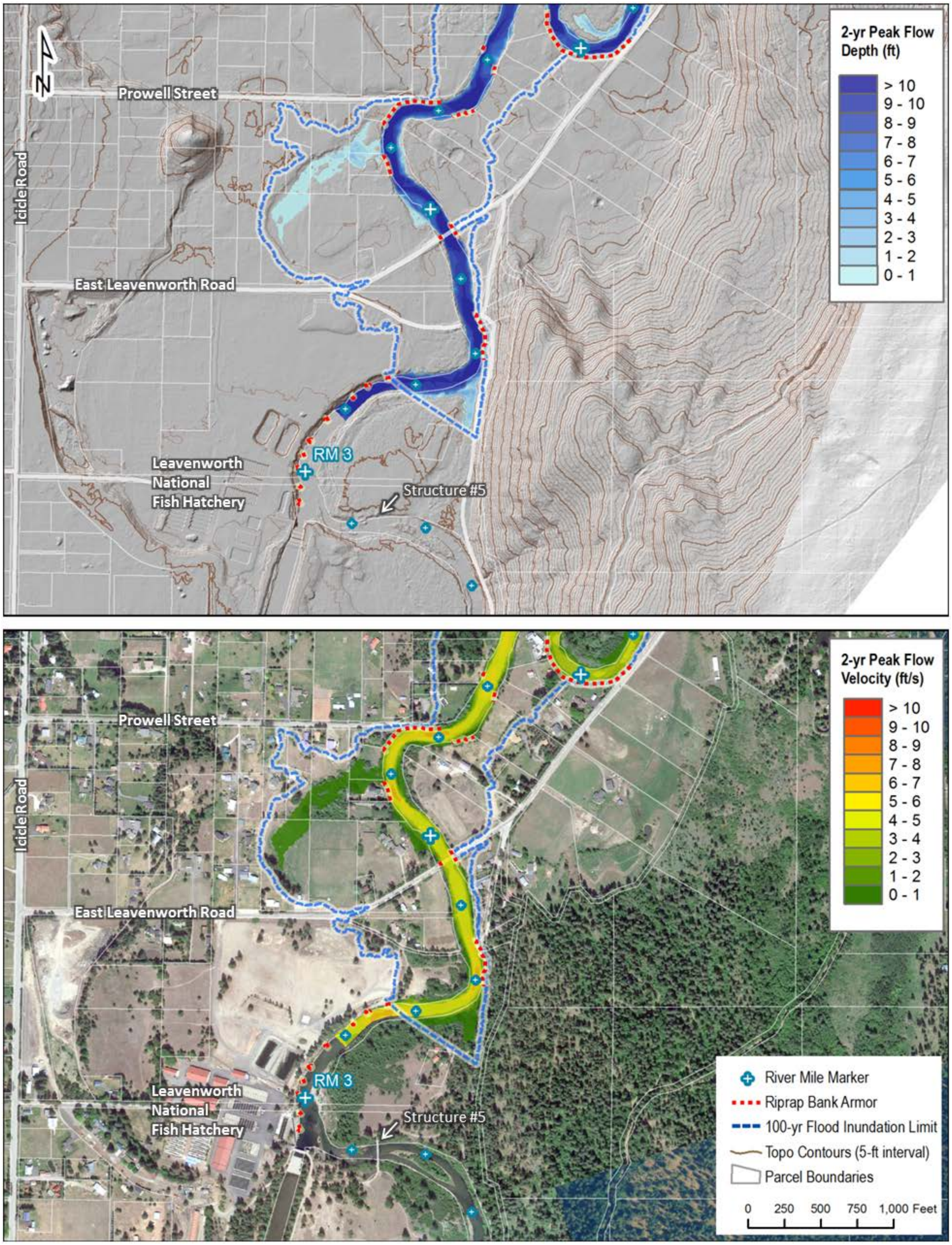


Figure 28. Maps showing the simulated flow depth and velocity of the 2-year recurrence interval flood.

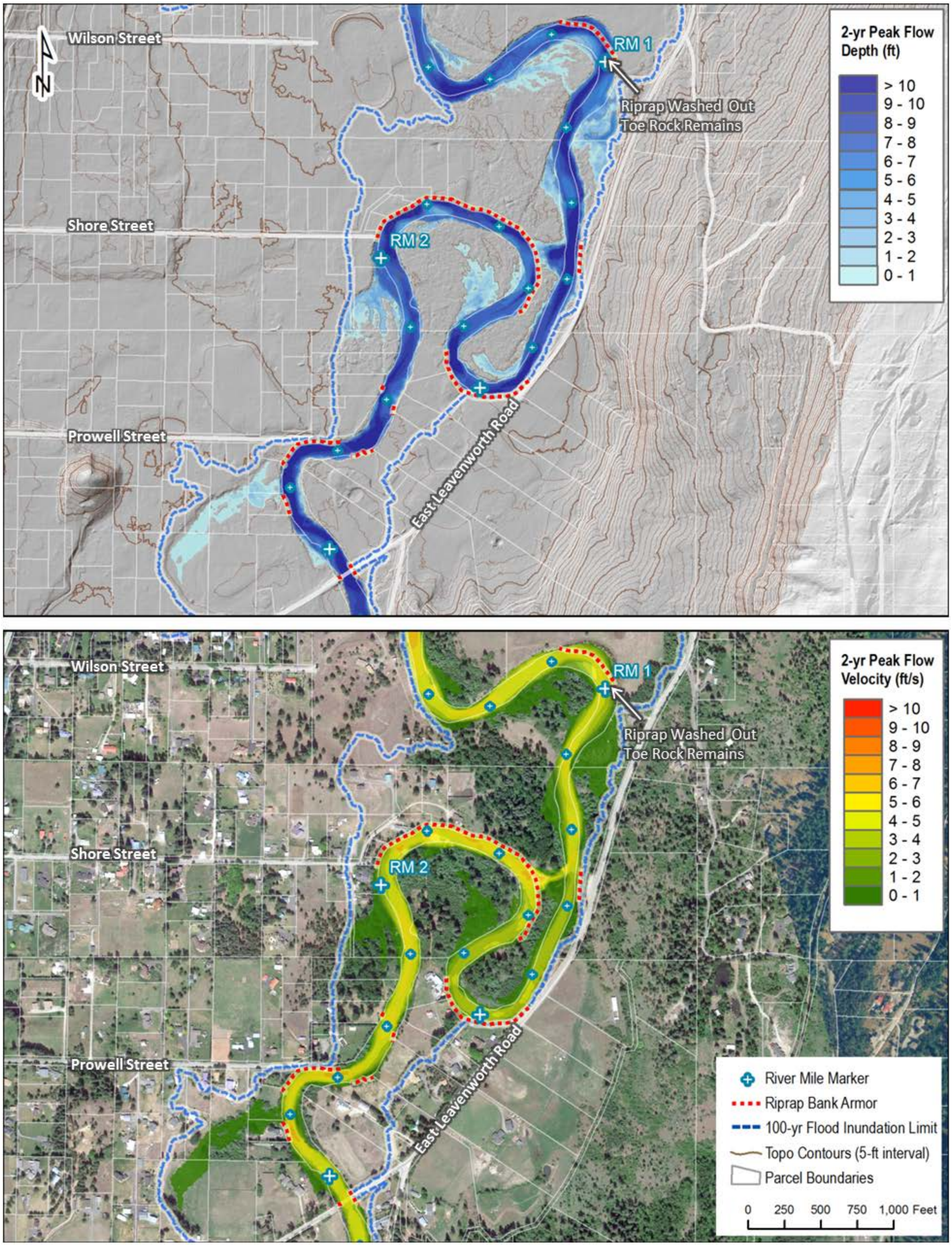


Figure 29. Maps showing the simulated flow depth and velocity of the 2-year recurrence interval flood.

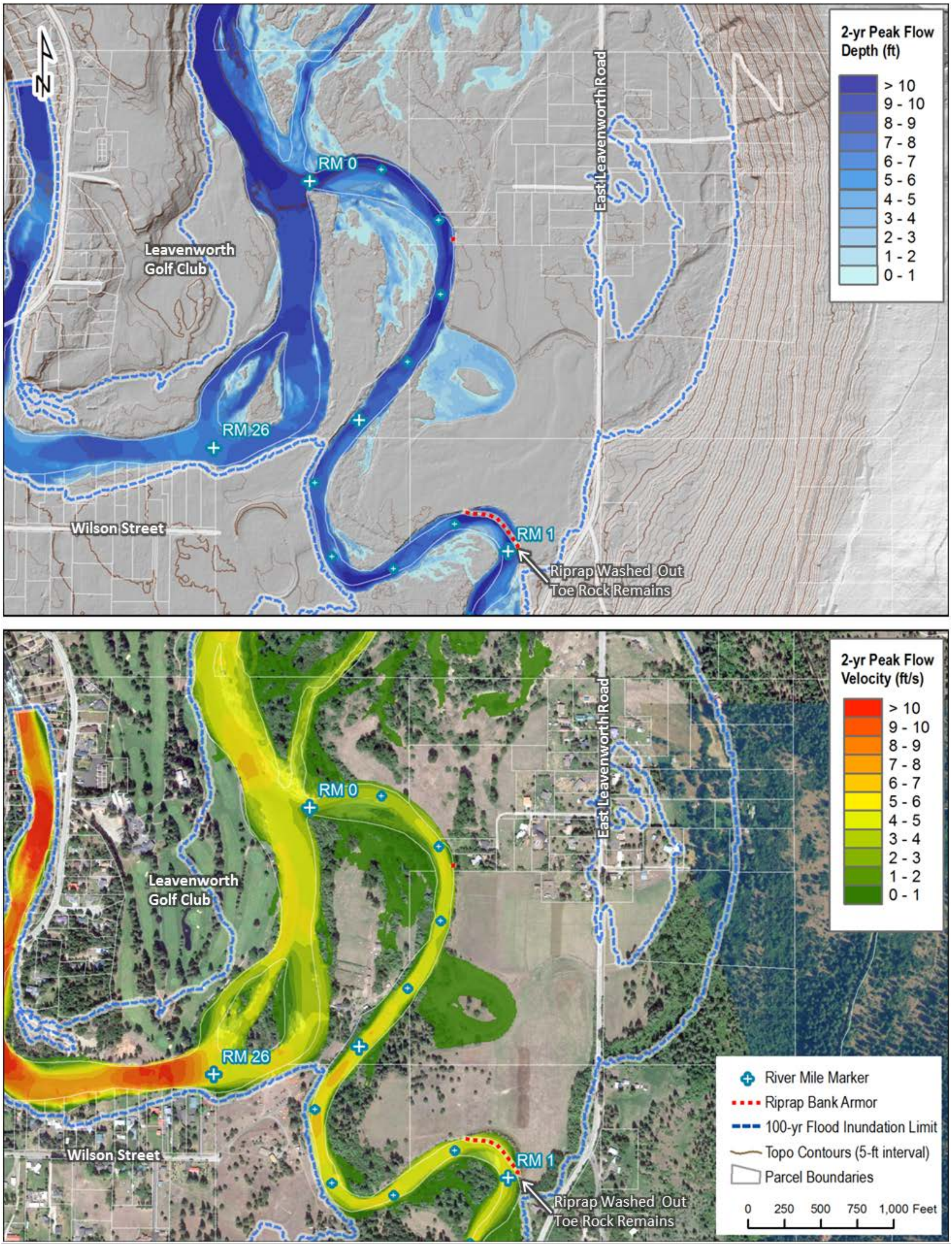


Figure 30. Maps showing the simulated flow depth and velocity of the 2-year recurrence interval flood.

Figure 31. Confluence of Icicle Creek and the Wenatchee River on 11/30/1995. Daily mean discharge was measured as 8,540 cfs in the USGS gage along Icicle Creek and 38,900 cfs in the USGS gage along the Wenatchee River at Peshastin which corresponds closely to the Q100 modeling scenario.

5.6 Sediment Mobility

Erodible sediment grains on the channel bed are entrained by flow when the applied stress on the sediment bed, or grain stress (τ_{gs}), exceeds the critical shear stress for grain motion ($\tau_{gs} > \tau_c$). The total applied shear stress at a given flow is the force exerted by the flowing water per unit area of the bed and, assuming the condition of steady, uniform flow, is calculated as:

$$\tau_0 = \gamma RS$$

where:

τ_0 = total shear stress (lb/ft^2)

γ = specific weight of water (lb/ft^3)

R = hydraulic radius (ft.)

S = energy slope (ft./ft.)

An approach by Wilcock et al. (2009) approximating the original Shields curve to was followed to estimate the Shields parameter by the function:

$$\tau_c^* = 0.105S^{*-0.3} + 0.045e^{-35S^{*-0.59}}$$

where:

S* = dimensionless viscosity

Reference values of critical shear stress for a range of grain size classifications using Wilcock et al.'s (2009) approximation of the Shields curve are summarized below in Table 10.

Table 10. Grain size classes, shield's parameters, and critical shear stress values used to determine sediment mobility.

SEDIMENT CLASSIFICATION	D (mm) (UPPER LIMIT)	τ_χ^*	τ_χ (lb/ft²)
boulder	512	0.046	8
large cobble	256	0.046	4
small cobble	128	0.047	2
very coarse gravel	64	0.047	1
coarse gravel	32	0.046	0.5
medium gravel	16	0.045	0.24
fine gravel	8	0.042	0.11
very fine gravel	4	0.038	0.05
very coarse sand	2	0.033	0.02
coarse sand	1	0.031	0.01
medium sand	0.5	0.035	0.006
fine sand	0.25	0.046	0.004
very fine sand	0.125	0.063	0.003

Downstream variability of shear stress along the thalweg derived from the Q2 modeling scenario are plotted below in Figure 32. Areas of highest shear correlate closely with the areas of highest velocity as mapped in Figure 28-Figure 31. The Q2 modeling scenario was chosen for further sediment transport analysis because it represents the most geomorphically efficient, or bankfull flow.

There is a wide degree of local and longitudinal variability in sediment transport throughout the project reach. The highest degree of flow competence (i.e. the size of sediment that is able to be transported) is exhibited in the upper portion of the project reach between RM 3-2.4. Shear stress values decline downstream of the E. Leavenworth bridge and are minimized directly upstream of the armored potential meander cutoff near RM 1.5. Within this section of the tortuous meander bend, velocity and shear stress decrease and flow is only capable of transporting very fine sized gravels.

Shear stress values rise following the torturous meander bend segment of the project reach and reach another peak in the riffle-run sequence at RM 0.55 where the flow is competent enough to move medium sized gravels. Following this location, shear stress values steadily decline until the mouth with the Wenatchee River.

Results of the evaluation verify assumptions that existing hydraulic conditions are generally highly capable of eroding bed material at the channel toe and driving lateral channel migration. In the absence of such extensive riprap in the reach, we would expect sediment entrainment along channel bends at a nearly annual basis.

After bed material becomes mobilized, sediment transport capacity generally increases with additional flow and increased flow depth. Two additional factors in Lower Icicle Creek influence the change in sediment transport with increasing flood magnitude. First, as flood stage in the mainstem Wenatchee River increases, a backwater effect from the confluence to RM 0.8 decreases the energy gradient of Lower Icicle Creek resulting in lower shear stress values during extreme floods such as the 100-year event in comparison to shear stress resulting from more typical 1- to 2-year recurrence interval floods. Second, the channel pattern with high sinuosity between RM 1.3 and 1.8 affects the relation between sediment transport capacity and flood discharge. During typical flood events, flows are confined to the main channel and the energy gradient follows a relatively uniform slope in the downstream direction. As flood discharge increases to about the 10-year recurrence interval flood, flow spills overbank and bypasses the meander bend between RM 1.3 and 1.8. As a result, the meander bend above RM 1.3 becomes ponded and shear stress drops in this segment during extreme floods (Figure 33).

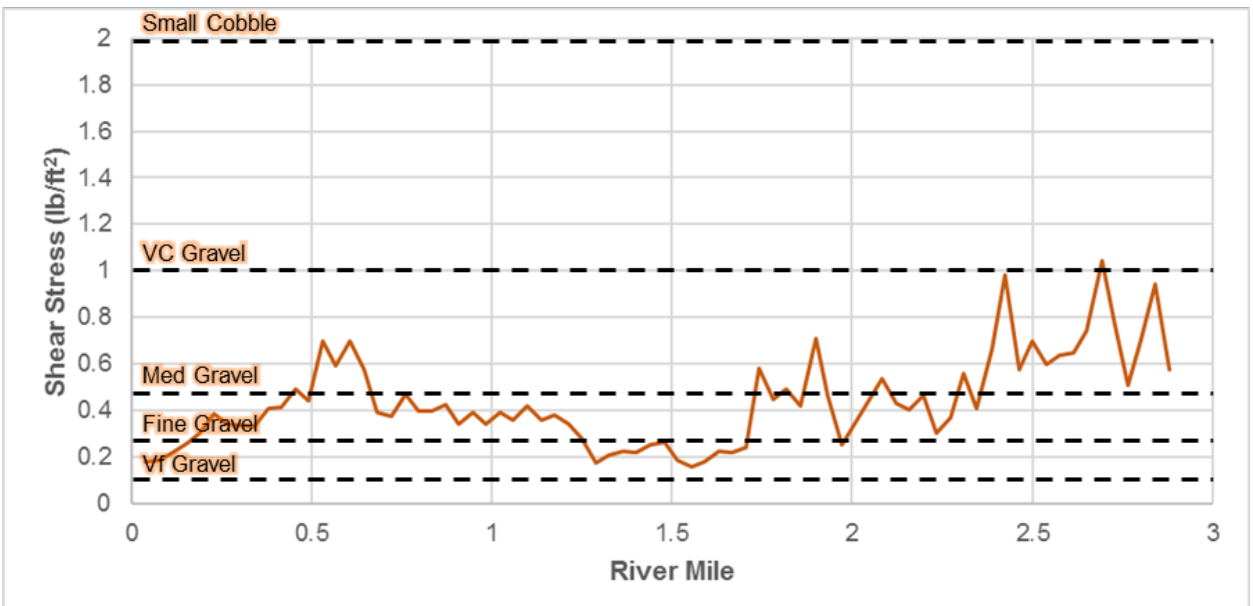


Figure 32. Simulated values of total basal shear stress estimated for the 2-year recurrence interval flow (4450 cfs). Approximate boundaries for the threshold of entrainment of grain size classes based on data from Table 8.

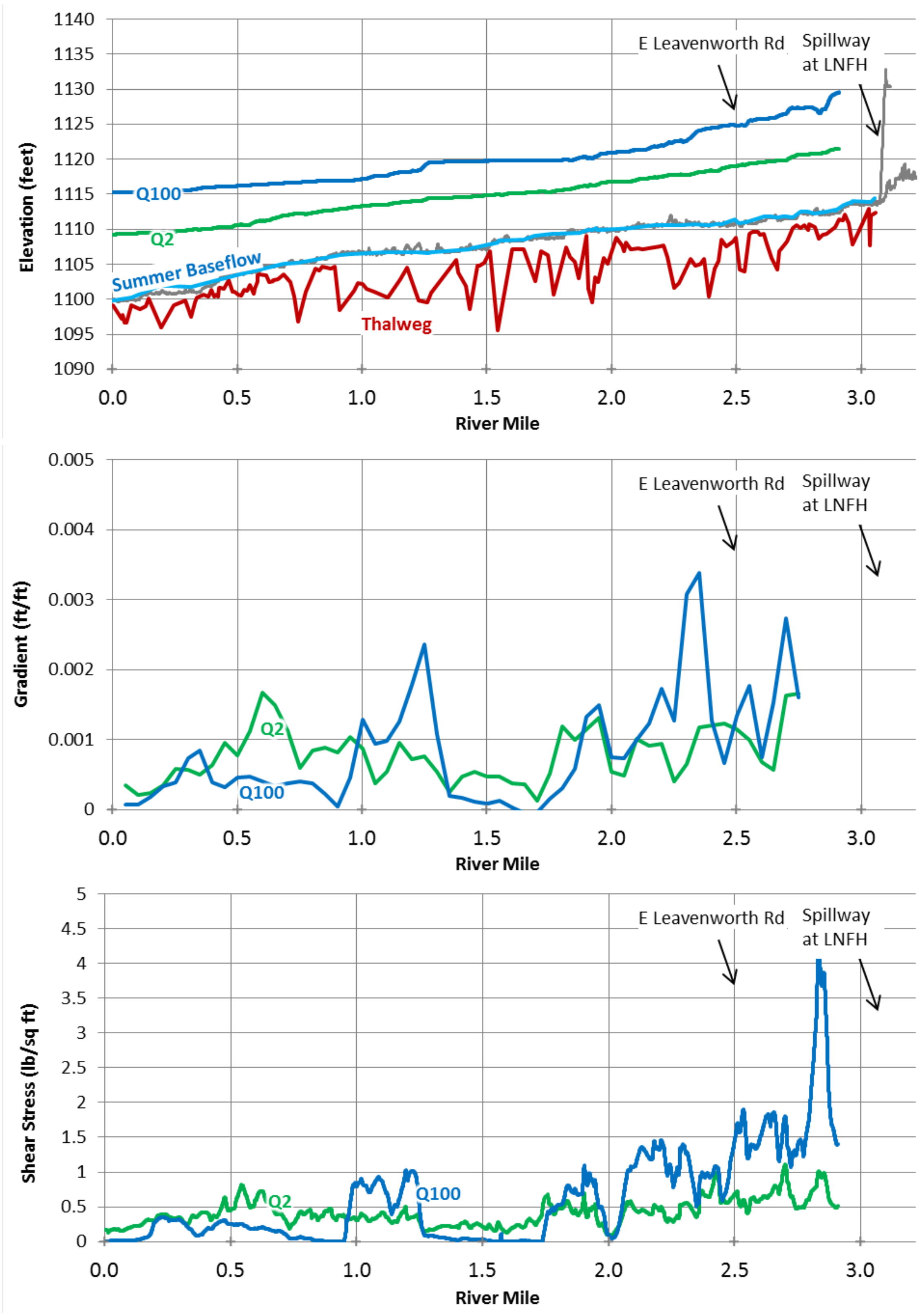


Figure 33. Longitudinal profiles of simulated water surface elevation (top), water surface gradient (middle), and shear stress (bottom) for the 2- and 100-year recurrence interval floods.

6. KEY FINDINGS

Project stakeholders provided a list of questions that guided the direction of this assessment. Those questions are repeated here along with a brief answer.

- Is the channel incised? And if so, to what degree?
  - The channel within the lower three miles is moderately incised with flows generally confined within the channel during the 2-year flood. This has led to a disconnection of floodplain and off-channel habitats during typical spring floods.
  - The average amount of incision in Lower Icicle Creek is on the scale of 3 to 6 feet and within the range of vertical channel adjustments driven changes in large wood recruitment (Brummer et al. 2006).
- What is the historical legacy of the Lamb Davis Mill Dam?
  - The Mill Dam created an impoundment up to approximately RM 1.0. This resulted in a period of initial sediment deposition during the period of impoundment followed by subsequent channel incision following dam removal. The present bank heights are unnaturally high in this area due to the legacy of the historical deposition.
- What are the sediment transport effects of the LNFH on lower Icicle Creek?
  - Current sediment transport processes are likely at equilibrium with gravels and finer materials passing through the LNFH bypass and Historical Channels. There may be some preferential trapping of coarse sediment (cobble sized material) in the Hatchery Bypass Channel.
  - There is little evidence of bed armoring downstream of the LNFH. Hydraulic analysis shows the coarse fraction in riffle segments is mobilized throughout the reach at the 2-year recurrence interval flow.
  - Recent increases in flow through the Historic Channel have increased supply of sediment to downstream reaches. There may be some episodic accumulation of this sediment filling pools in the downstream reaches, however, we do not see evidence of ongoing channel aggradation due to this sediment being exported from the Historical Channel.
- What is the current role of wood in lower Icicle Creek?
  - Large woody material is an important driver of geomorphic processes in lower Icicle Creek and the recruitment, transport, and retention of woody material has been drastically impaired by human impacts in the stream corridor;
  - The quantity of wood present in the channel is an order of magnitude less than that observed in similarly sized rivers with functioning riparian conditions.
  - The size of wood that is present is limited to only small pieces that provide little geomorphic function.
  - The loss of functional wood from the system has led to a corresponding reduction of channel complexity and has resulted in very poor cover conditions for juvenile salmonids.

  - Loss of hydraulic resistance due to lack of wood in the channel contributes to excessive bed scour, long-term channel incision, and disconnection of floodplain areas and off-channel habitats.
  - Restoration of a more natural wood loading regime and the removal of constraints to lateral channel migration where feasible would greatly increase channel complexity and variability thereby providing additional resilience to future disturbance.
  - The implementation of increased wood loading in the lower Icicle Creek will require active outreach with adjacent property owners and recreational entities to ensure that potential conflict is mitigated.

- What are the effects of bank hardening on channel migration?
  - Bank erosion is a natural process that is necessary for the creation and maintenance of critical aquatic habitats.
  - Use of artificial treatments such as riprap bank protection to arrest bank erosion limits opportunities for wood recruitment, contributes to loss of channel complexity, and impairs natural habitat forming processes.
  - 6,000 linear feet of armoring from RM 1.2 to 3.2 greatly limits channel migration, increased channel incision, and reduces wood recruitment. Bank erosion and migration increases below RM 1.2 through sandy, unvegetated banks.
  - The proximity of homes and road infrastructure limits the potential for the restoration of channel migration processes and improved floodplain connectivity within the lower three miles of Icicle Creek.
- What is the habitat quality in lower Icicle Creek?
  - The channel substrate contains many areas of gravel that appear suitable for spawning but may experience excessive bed scour during peak flows given lack of large roughness elements such as wood in the channel.
  - The channel downstream of the Hatchery Bypass Channel contains many pool habitats that are primarily forced by bend scour; however, the quantity and size of wood within the channel is severely limited resulting in lack of cover within existing pools.
  - Historical channel incision and extensive bank armoring with riprap have decreased the frequency and duration of floodplain connectivity resulting in loss of off-channel habitats during periods of high flow.
  - Much of the 2-year floodplain has been disturbed by land clearing activities associated with dwellings and agriculture, as evidenced by a general lack of mature forest.
- How will current predictions of climate change impact the lower Icicle?
  - Projections of climate change over future decades indicate increases in peak flow and a concurrent decrease in low flows associated with an increased proportion of winter precipitation falling as rain as opposed to snow.

6.1 Historical Channel at the LNFH (RM 3.0 – 4.3)

- Prior to historical floodplain modifications at LNFH, this reach included a dynamic alluvial fan at the transition between the more confined, steeper reach upstream and the unconfined, lower gradient valley below. The construction of the Bypass Channel and the associated restrictions to flows within the Historical Channel currently prevent dynamic channel processes related to flood flows, sediment transport, and channel migration.

- Flow regulation at the headgate dam above LNFH and the Hatchery Bypass Channel between RM 3.1 and 4.3 impairs natural functions by interrupting sediment conveyance and limiting flows capable of driving channel migration within the Historical Channel.
- Flow regulation has led to sediment deposition, channel narrowing (from 160' to ~ 80'), and the formation of vegetated alluvial bars that are inset within the pre-modified channel. This has narrowed the active channel width to approximately half of the historical size.
- The artificially-induced anabranching channel form has led to several secondary channel networks and off-channel areas, however, the lack of channel migration has resulted in little recruitment of large wood.
- In the short-term, the installation of large wood within this reach would improve cover, complexity, and gravel sorting in the Historical Channel.
- If full channel realignment into the historical channel is not feasible, then modifications to Structure 2 to increase the quantity and duration of flood flows will is recommended. This includes targeting flows between the 2 and 10-year event to induce channel erosion and migration processes in the historical channel. This should be combined with the installation of large wood in the historical channel.
- The long-term restoration of full unimpeded flows of Icicle Creek to the Historical Channel segment should be considered as allowed given the operations and water supply needs of the LNFH. Existing conditions provide some habitat benefit that functions similar to a relatively stable side channel feature; however, the level of channel complexity will likely decline with time as fine-grained sediment deposits within the channel if inflows remain restricted at the headgate structure. Restoring a natural flow regime with flood discharges capable of driving sediment transport and channel migration is necessary for the creation and maintenance of new habitat features in the Historic Channel over time.

6.2 Downstream of Structure 5 Spillway to East Leavenworth Rd. Bridge (RM 3.0 – 2.55)

- Downstream of the LNFH, existing conditions are most strongly impaired by lateral constraints to channel migration (bank armoring), riparian clearing, and the resultant lack of stable wood recruitment to the channel.
- The channel downstream of the LNFH is heavily armored with stream barbs and rip-rap, and is confined within the active channel during the 2-year flood. It has a high sediment transport capacity and is likely downcutting due to a lack of floodplain connectivity and a high amount of excess shear stress.
- There is also very minimal hydraulic complexity due to the simplified, incised channel void of in-channel roughness elements such as wood structures.
- The overall channel confinement and high adjacent terraces result in little opportunity for the reconnection of flood flows to floodplain and off-channel habitats.
- An important Tribal fishery is supported by the pool formed at the bottom of the Bypass Channel spillway and along the pool tailout which is used primarily during spring high flows (May – July).
- The improvement of instream habitat cover and complexity could be achieved through the placement of large wood in existing pools to provide cover.

6.3 East Leavenworth Rd. Bridge to Bend Cutoff (RM 2.55 – 1.3)

- This portion of the study area is the most developed with residential parcels along many of the banks. Because of this, the banks are heavily armored with rip rap along the outer banks of each meander bend. These rock structures appear to have been placed over 100 years ago as the channel was mapped in the same location as the present in a 1914 map. Since their construction, channel migration has effectively ceased in this location. The channel however, appears to want to avulse and cut-off both meander bends in the hydraulic modeling scenarios presented above.
- The restriction of channel migration has altered channel processes within this reach such as reducing the sediment transport capacity by forcing the channel to flow along a less efficient path through the meander bends.
- Furthermore, the lack of channel migration has cut-off the available floodplain habitat between each meander bend during more frequent flows (such as the 2-year flood).
- During these floods however, velocities within the meander bend between RM 1.7-1.3 are lowered due to the attempted avulsion, and this location may act as slow-water refuge even if it is still effectively the "main channel" of Icicle Creek.
- Due to the adjacent homes opportunities for restoring channel migration through this reach would require the voluntary removal of the residences.
- The improvement of instream habitat cover and complexity could be achieved through the placement of large wood in existing pools to provide cover.
- Low and vegetated floodplain areas at RM 2.1 and 1.7 offer opportunities to improve off-channel habitat through the excavation and creation of side channels.
- Existing vegetated low floodplain also present opportunities for the protection of existing forested floodplain from future development.
- Clearing of vegetation associated with landscaping has reduced the presence of woody vegetation along long sections of floodplain terrace immediately adjacent to the creek. These areas offer the opportunity for riparian plantings on a voluntary basis with private landowners.

6.4 Bend Cutoff to Confluence with Wenatchee River (RM 1.3 – 0)

- This portion of the reach has the least residential development, however there are large portions of agricultural development along the right bank of the creek.
- There is active channel migration within this sub-reach – with an example being the meander development at RM 1 where the stream has eroded past the rip-rap stream armor. This may be due however, to a lack of bank stabilization from tree roots in the location as it is primarily agricultural pasture.
- There is also the most connected floodplain surfaces in the project reach. A large relic oxbow along the right bank at RM 0.5, a low vegetated wetland area at RM 1.1, and the left bank surface near the Wenatchee confluence interact with the stream during the 2-year flood. All areas offer opportunities for improved off-channel high flow rearing habitat.
- Large areas of floodplain on river right provide excellent opportunities for the protection of forested riparian floodplain and the restoration of cleared floodplain lands.
- The improvement of instream habitat cover and complexity could be achieved through the placement of large wood in existing pools to provide cover.

- Extensive riparian revegetation would be an effective measure to reduce bank erosion and restore stream shading and wood recruitment over time. Any riparian restoration within the effective 2-year flow should be combined with wood features to reduce velocities and protect the plantings until root strength is established.
- The historical Icicle Creek channel downstream of the confluence with the Wenatchee River is now a high-flow side channel. This channel offers opportunities for improving flow connectivity along with complexity and cover within the channel itself.

7. RESTORATION STRATEGY

This chapter outlines opportunities for restoration and protection actions within lower Icicle Creek that will directly and indirectly improve habitat conditions for these ESA-listed salmonids. These restoration and protection opportunities have been identified and prioritized relative to channel forming processes, hydrology, aquatic habitat degradation, and stakeholder concerns related to existing infrastructure, property, and uses.

7.1 Summary of Lower Icicle Creek Biological Strategy Recommendations

The lower Icicle Creek is a Minor Spawning Area for spring Chinook salmon and a Major Spawning area for UCR steelhead. The Biological Strategy (RTT 2014) currently ranks Icicle Creek third in the Wenatchee Basin (behind Nason Creek and the Upper Wenatchee respectively) for priority restoration and protection actions.

The Biological Strategy subsequently lists each of the ecological concerns for Icicle Creek in priority order. Each of the Ecological Concerns were given a "weight" through the Federal Columbia River Power System (FCRPS) BiOp Expert Panel process (2012). The percentage weight of each ecological concern is presented in parenthesis for steelhead.

1) Habitat Quantity (Anthropogenic Barriers) (35%)
    a. If the barrier near Snow Creek on the Icicle is determined to be anthropogenic, then develop alternatives and provide passage.
2) Water Quantity (Increase Water Quantity) (25%)
    a. Improved hatchery intake, provide 20 cfs pump back
    b. Water right purchase and lease
    c. Water banking
    d. Conversion of small pumps to wells
    e. Improve irrigation efficiencies
3) Channel Structure and Form (Instream Structural Complexity) (15%)
    a. Reconnect the original (Historic) channel to Icicle Creek between the headgate and Dam 5 at LNFH.
    b. Restore instream habitat diversity by enhancing large wood recruitment, retention, and complexity where feasible.
4) Injury or Mortality (Mechanical Injury) (5%)
5) Riparian Condition (Riparian Condition) (10%)
    a. Riparian plantings where appropriate from hatchery to the confluence with the Wenatchee River (assuming these are areas that are not producing the large sediment inputs where major stream bank restoration is needed).
6) Sediment Conditions (Increased Sediment Quantity) (10%)

a. Restore riparian function and channel migration processes from the LNFH to the confluence with the Wenatchee River.

b. Remove USFS road at Trout Creek.

The first two priority Ecological Concerns address conditions in the upper watershed outside of the study area. For the purposes of identifying restoration and protection actions within the lower three miles of Icicle Creek, we focused on addressing Ecological Concerns 3 -6.

7.2 Goals and Objectives

Specific goals and objectives for restoration and protection actions within lower Icicle Creek were developed based on the recommendations within the Biological Strategy, findings geomorphic and hydraulic assessment, and HSI analysis (NSD 2017), and input from project stakeholders (CCNRD, Icicle Work Group). They are as follows:

1) Goal: Increase geomorphic and ecologic resilience to future disturbance and watershed changes.

   a. Objective: Delineate an erodible stream corridor or Channel Migration Zone (CMZ) needed to protect habitat forming processes and ecosystem functions while lowering potential conflict with human structures and properties.

   b. Objective: Remove or set back infrastructure located within areas at risk to flood and/or erosion hazards and remove constraints to lateral channel migration where feasible.

   c. Objective: Increase wood loading to increase channel complexity and hydraulic resistance.

2) Goal: Increase and improve rearing habitat for juvenile salmonids (spring Chinook and steelhead).

   a. Objective: Increase large wood cover in existing pool habitats.

   b. Objective: Increase area of low velocity refugia with addition of large roughness elements.

   c. Objective: Improve flow connectivity to existing side channel and off-channel habitats.

3) Goal: Decrease summer water temperatures.

   a. Objective: Restore forested riparian vegetation adjacent to the stream channel.

   b. Objective: Increase hyporheic exchange with alluvial aquifer through restoration of large wood in the active channel.

4) Goal: Increase and improve spawning habitat for adult steelhead.

   a. Objective: Reduce negative effects on redds (and embryo mortality) from excessive bed scour through restoration of a natural wood regime that increases stress partitioning (dissipation of energy by wood).

Restoration and protection efforts within the lower Icicle will need to recognize important human uses and be consistent with the IWG's guiding principles. These include:

1) LNFH operations and infrastructure.

   a. The restoration of flows and habitats within the historical channel adjacent to the LNFH must balance the continued operational needs of the hatchery.

2) Tribal Treaty and federally-protected fishing/harvest rights are met at all times.
    a. Any actions at the historical channel at the LNFH or near the LNFH spillway must evaluate potential impacts to the Tribal fish harvest.
3) Close proximity of private property, human structures, and habitation throughout the reach.
    a. Actions must evaluate potential risks to adjacent properties.
4) Recreational uses including drift boat fishing, rafting, and tubing.

The implementation of certain restoration strategies such as increased wood loading, a critical driver of geomorphic processes and ecosystem functions, may conflict with existing land uses within the stream corridor. For example, actions to increase channel complexity and improve rearing habitat for juvenile salmonids may raise water surface elevations and lead to more frequent floodplain connectivity. While this result is desirable for restoration of habitat forming processes, increased flood inundation may adversely affect private property in developed areas within the stream corridor. As such, existing land uses constrain opportunities for restoration actions in the channel and planning will require active outreach and coordination with adjacent property owners and recreational entities to ensure that potential conflicts are mitigated.

7.3 Recommended Restoration Actions

Based on the goals, objectives, and constraints given existing human uses detailed above, actions for the lower Icicle were then generated through a collaborative process with the CCNRD and stakeholders to specifically address the impaired conditions.

Maps below provide an overview of recommended actions within the lower Icicle study area (Figure 34-Figure 37). Table 11 presents each of the proposed recommendations in detail. The actions are presented in order beginning at the confluence with the Wenatchee River and upstream to the LNFH. A suggested prioritization of these actions is present in the chapter below (Table 12).

7.3.1 Protect Floodplain Habitats/Establish a Stream Corridor

Protection actions include the purchase of lands or conservation easements to protect existing functioning habitat and floodplain and help to establish a stream corridor to promote active channel processes including migration and floodplain engagement. Protection actions should prioritize those areas that susceptible to future human development, currently contain functioning habitats, and are located within the active 100-year floodplain. For the purposes of this assessment we have identified specific areas within a stream corridor that includes the active channel, floodplain, and low terraces that are inundated by flooding (Figure 34) but have not delineated area boundaries by landowner. Protection actions can be combined with direct restoration (i.e. riparian planting) or indirect management to remove negative impacts related to human use (i.e. grazing).

This identification of protection opportunities does not include a prioritization of the separate parcels. Future efforts to prioritize the protection of these areas should include a tiered ranking process that ranks parcels on their susceptibility to future development (Land Use Zoning Designation, Private vs. Public Ownership), amount (acres) of active floodplain, and amount (acres) forested riparian habitat.

7.3.2 Reconnect Floodplain and Off-Channel Habitat

The purpose of this action is to improve hydraulic connectivity between the main channel flows and those floodplain areas that include side-channels, off-channel habitat, and riparian wetlands. Prior to alteration of reach scale processes by removal of wood, bank armoring, and clearing of riparian forests, the channel was more frequently connected with these floodplain habitats that provide important ecological functions. The proposed actions increase floodplain capacity and provide access for aquatic organisms to move between floodplain and channel features. Site specific actions include the installation of large wood structures to deflect flows and targeted grading to increase connectivity with off channel areas. Within lower Icicle Creek this also includes the reconnection of flows to the historical Icicle Creek channel at the LNFH.

7.3.3 Remove Lateral Constraints

A total of 6,000 linear ft. of rock structures/riprap lines the channel banks within the lower three miles of Icicle Creek. The lower mile does not have substantial armoring structures. These structures are primarily concentrated along meander bends, however there are additional structures in place throughout the remainder of the project reach that are associated with individual property bank protection (NSD 2016). Riprap stabilizes eroding streambanks which is beneficial to local landowners concerned with protecting private property from erosion hazards; however, artificial bank stabilization measures such as riprap prevent natural channel migration processes, eliminate large wood recruitment, and reduce opportunities for robust streambank plant growth. Due to the close proximity to homes, private property, and infrastructure (i.e. East Leavenworth Road), this riprap typically plays an important role in preventing channel migration and potential impacts.

The opportunity to completely remove existing bank protection without removal of the human structures or private property owners that are willing to allow channel migration within their property is very low. Locations where bank armoring is relict or no longer needed should be addressed first as these opportunities can likely be implemented in the short term. The removal of riprap or the replacement of riprap with “softer” bank stabilization treatments such as large wood should be explored in strategic locations where adjacent landowners will allow for bank deformation. Longer term efforts should focus on removing or setting back human structures from the stream banks in order to allow the complete removal of bank armoring to establish a more dynamic stream corridor.

7.3.4 Increase Instream Wood Loading

Large woody material (LWM) in streams and the benefits associated with pool formation, channel processes, fish habitat, and the routing of sediment and water has been well documented (Abbe and Montgomery 1996, Abbe and Montgomery 2003, Collins et al. 2012, Montgomery et al. 1995). Stable accumulations or “key” pieces of large woody material act as hard points in the floodplain that create backwater, promote sediment deposition and pool formation, decrease potential for channel incision, and provide essential cover habitat.

Wood loading targets typically use reference reaches of “natural and unmanaged” forests in comparison to existing reach conditions. Fox and Bolton (2007) recommend a restoration target of >35 pieces per 100 m (>560 per mile) for channels similar in size to Icicle Creek based on surveys of unmanaged forested valleys in the Douglas Fir- Ponderosa Pine ecoregion. Current wood loading in lower Icicle Creek is less than 2.5 pieces per 100 m (40 pieces per mile). Formation of stable wood jams in the channel relies upon recruitment or placement of key pieces that are large enough to resist hydraulic forces of flood flows. These key pieces are essential to the restoration of habitat-forming processes in lower Icicle Creek. Without key pieces, any wood recruited to the channel is likely to be quickly transported through the system and provide little, if any, geomorphic function.

This assessment reviewed the results of the Habitat Index Suitability (HSI) modeling (NSD 2017) to determine the areas of the greatest potential to increase pool cover. We also used the relative elevation mapping (REM) that compared in-channel water surface elevation relative to the adjacent floodplain height, and 2-dimensional hydraulic modeling to examine areas of floodplain that are most susceptible to increased flood inundation in response to the placement of wood structures (NSD 2016).

Increasing large wood loading in lower Icicle Creek should be accomplished through the construction of engineered log jams with the intention to maximize pool cover, and as desired, to increase location water surface elevations. Large wood can also be placed with the intent to sort and retain bed materials to increase bed elevations thereby reducing channel incision and improving bed stability in relation to redd scour. We recommend the use of the Bureau of Reclamation's Large Woody Material - Risk Based Design Guidelines (Reclamation 2014) to implement a risk-based design approach for the placement of individual and groups of wood structures. The approach applies information from the watershed, reach, and site-scales to determine the level of risk for public safety and property damage. The risk level determination then defines the minimal design criteria that should be used for ensuring stability of the proposed LWM structures. This is a transparent step-wise analysis approach that includes public survey and incorporation of landowner and stakeholder input to ensure a final design that is supported by local stakeholders while meeting project goals and objectives.

7.3.5 Restore Riparian Habitat

Much of the floodplain has been disturbed by land clearing activities associated with dwellings and agriculture, as evidenced by a general lack of mature forest (NSD 2016). Clearing associated with residential areas are common between RM 2.0 and upstream to the East Leavenworth Road Bridge. These areas typically have narrow bands of small riparian shrub vegetation along the lower river banks with cleared lawn dominating the upper floodplain terrace. These areas provide little benefit associated with stream shading or large wood recruitment potential.

Active bank erosion is occurring in most channel segments where cleared areas coincide with the outside of meander bends, such as the right bank near RM 1.0. Clearings extending to the edge of the active channel occur along the right bank along several areas within the lower 1 mile. This clearing has resulted in unstable vertical banks with little root/soil cohesion.

Riparian and habitat conditions are improving in vegetated and forested areas, however cleared areas are not expected to become forested in the future without restoration actions. Riparian restoration is proposed in locations adjacent to the stream bank and/or within the 100-year floodplain that have been impacted by human uses (i.e. grazing, agriculture). The objective is to improve woody vegetation within the stream corridor to increase stream shading, improve bank stability, increase plant diversity for terrestrial species, and provide a source of future wood recruitment that will sustain in-channel habitats over the long term. Areas of riparian replanting along eroding banks should be accompanied by temporary bank protection measures such as large wood structures or barbs that deflect the areas of greatest shear stress away from the bank to ensure the establishment of floodplain forest.

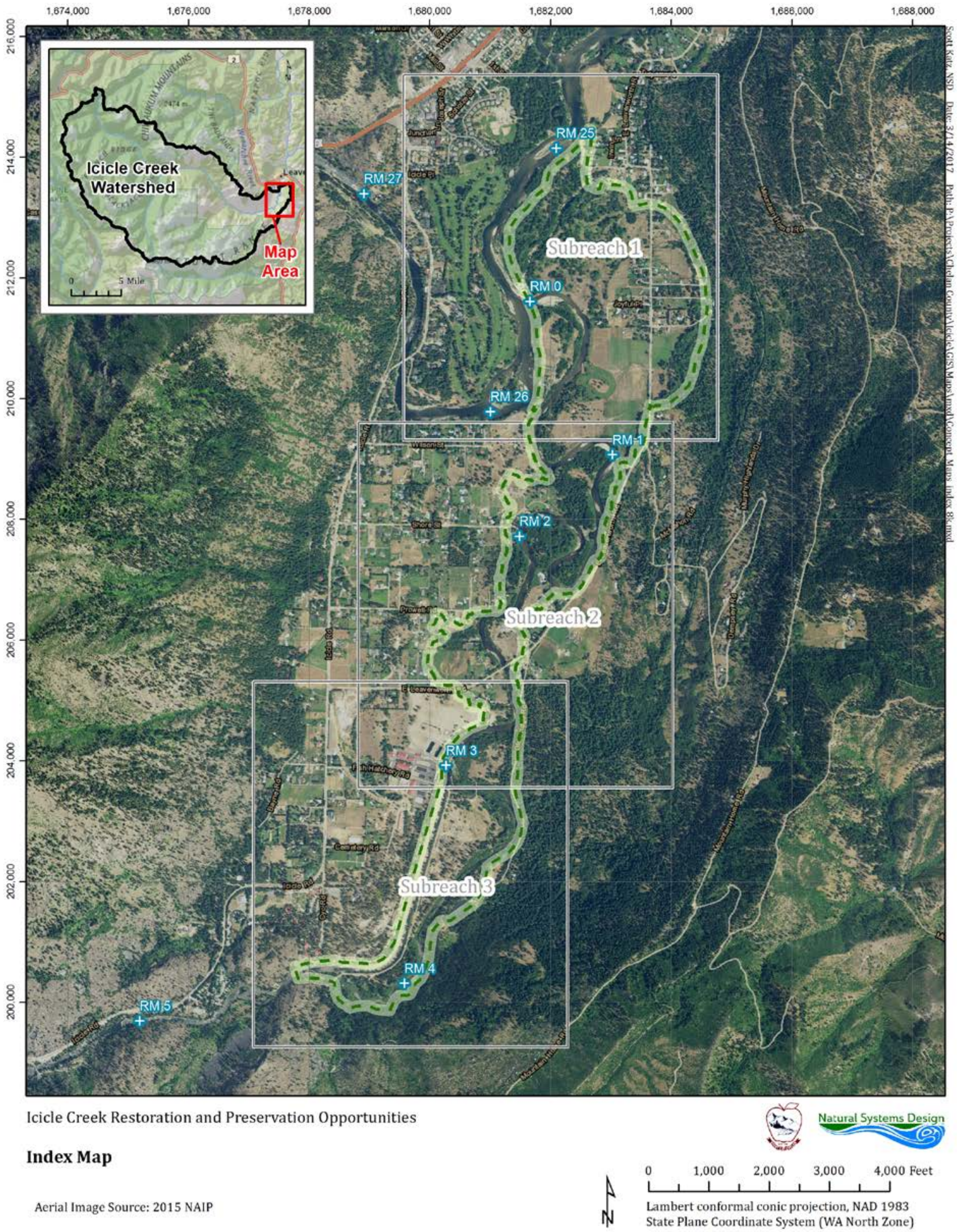


Figure 34. Index sheet to maps showing recommended protection and restoration actions in lower Icicle Creek.

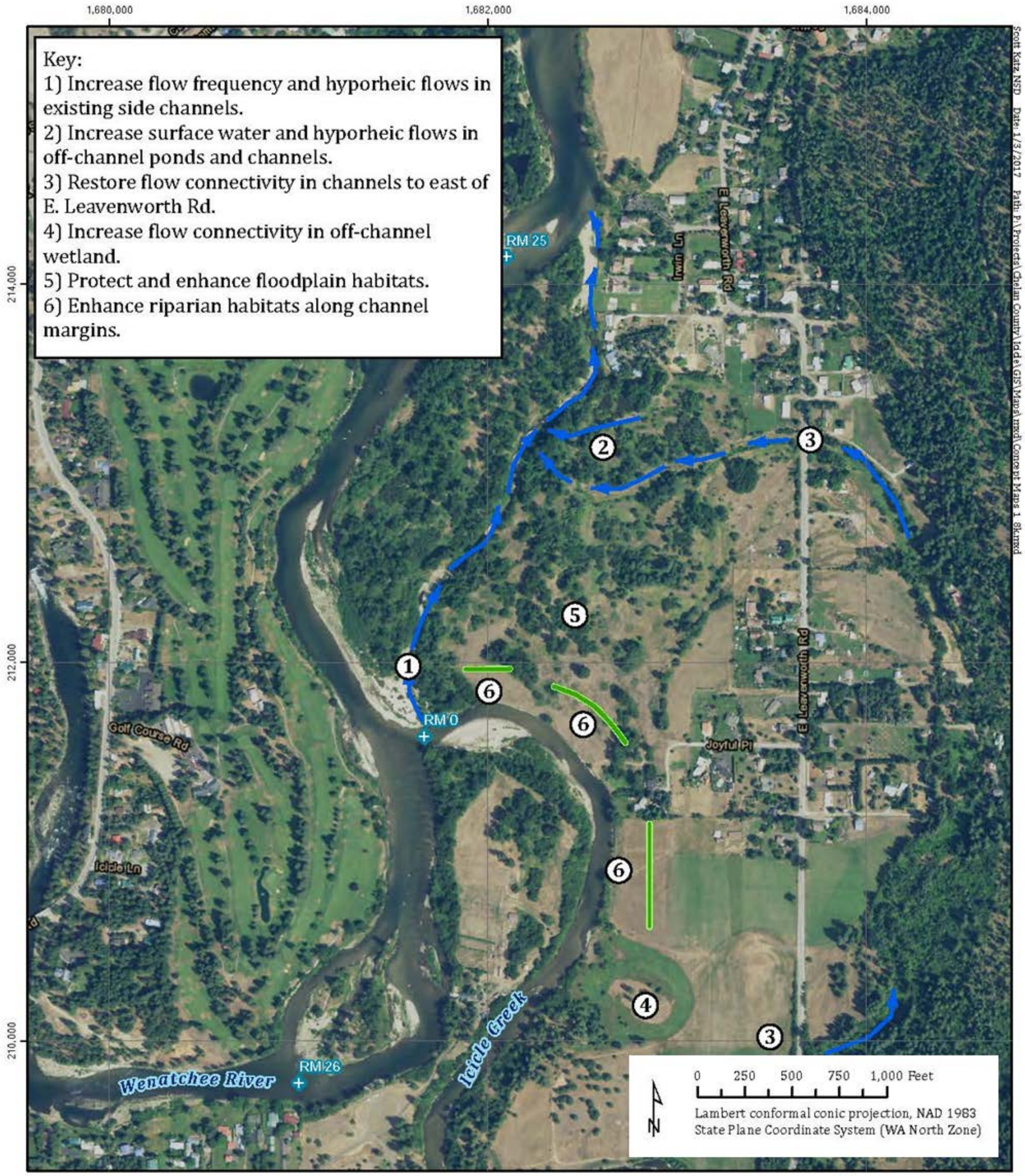


Figure 35. Recommended protection and restoration actions in subreach 1 near the confluence of Icicle Creek and the Wenatchee River.

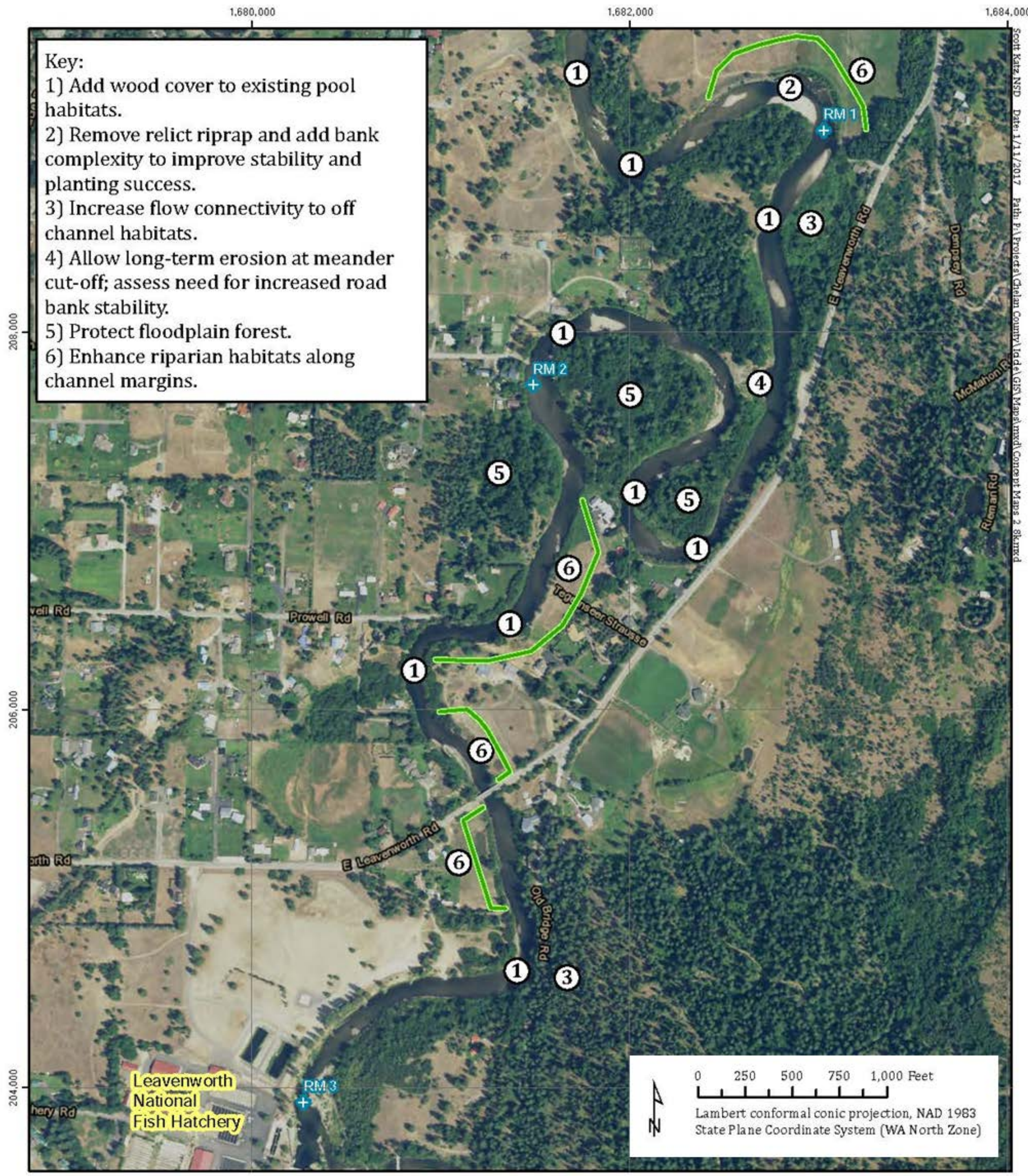


Figure 36. Recommended protection and restoration actions in subreach 2.

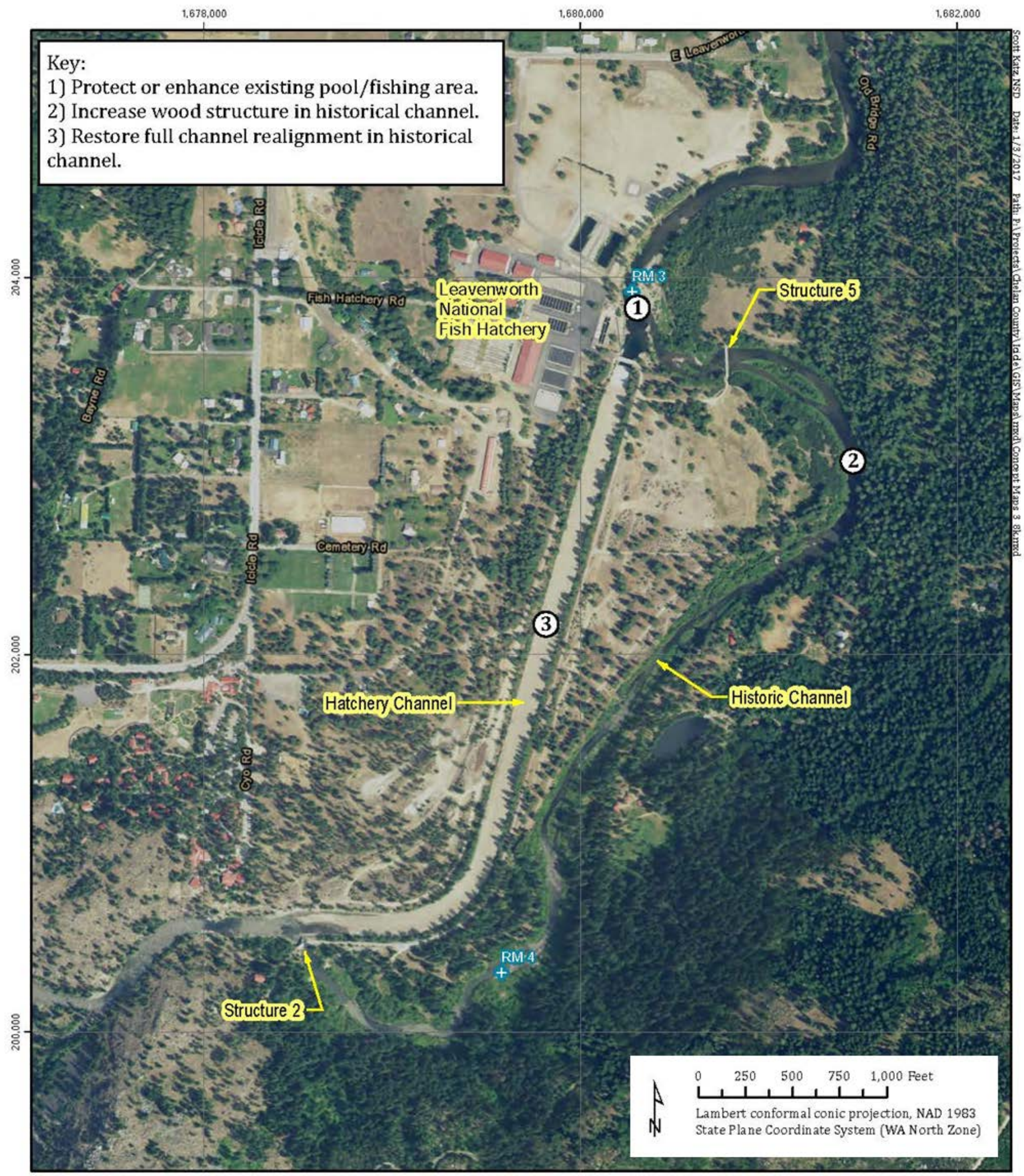


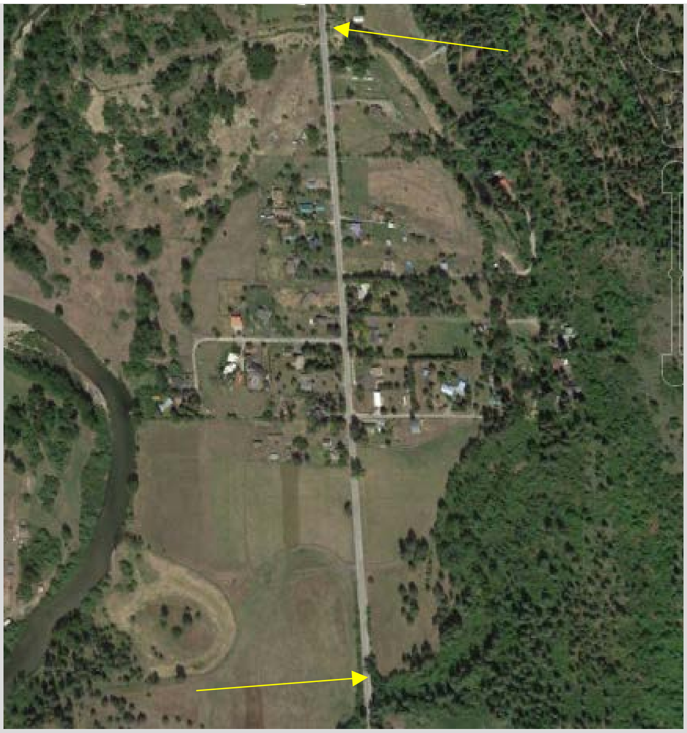
Figure 37. Recommended protection and restoration actions in subreach 3 near the LNFH.

Table 11. Lower Icicle Creek, Restoration and Protection Opportunities.

PROJECT LOCATION (RIVER MILE/BANK)	ACTION/STRATEGY /*ECOLOGICAL CONCERN*	DESCRIPTION	CONCEPT
RM 0.0/Confluence	Reconnect Floodplain and Off-Channel Habitat Large Woody Material Placement *Peripheral and Transitional Habitat*	The existing 2,800 linear foot side channel is disconnected from surface flows during summer and winter months. Increasing surface flow duration to the historical channel would increase juvenile fish access to critical off-channel habitats, improve low-flow season hyporheic inputs, and decrease stranding duration. The placement of multiple large wood structures at the existing inlet of the channel would redirect and raise surface water in the direction of the inlet. This could be combined with the excavation of gravels that have built up at the inlet to allow more frequent connectivity. Additional inlet channels could also be constructed at strategic spots to also improve connectivity. Additional large wood should be placed within the channel to promote scour of sands and improve cover in pools. Blue dashed line shows channel flow path. This action is also described in Lower Wenatchee River Assessment (Tetra Tech, 2016).	

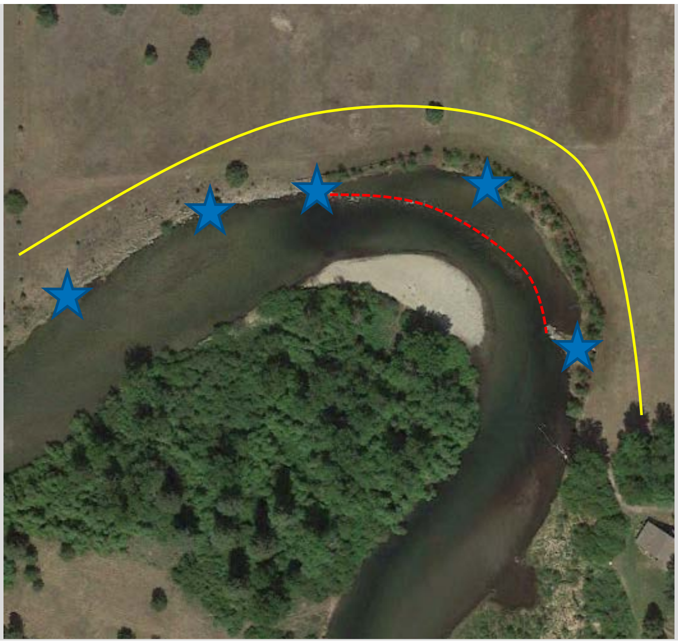
PROJECT LOCATION (RIVER MILE/BANK)	ACTION/STRATEGY /*ECOLOGICAL CONCERN*	DESCRIPTION	CONCEPT
RM 0.1 – 0.2; 0.3 Right Bank	Riparian Restoration *Riparian Condition*	As discussed in the Geomorphic Assessment, much of the floodplain has been disturbed by land clearing activities and generally lacks mature forest. Large areas of the floodplain in lower Icicle Creek is dominated by pasture grasses which provides no stream shading, wood input, or bank stability. The priority areas for riparian restoration are those cleared areas within the 2-year floodplain and/or immediately adjacent to the stream bank. These areas are characterized by the high floodplain banks that are well above seasonal inundation and are located at the top of vertical cut-banks. Revegetation efforts should consider the installation of woody material at the bank toe to slow bank erosion rates, along with irrigation watering to ensure plant establishment.	

PROJECT LOCATION (RIVER MILE/BANK)	ACTION/STRATEGY /*ECOLOGICAL CONCERN*	DESCRIPTION	CONCEPT
RM 0.4	Reconnect Floodplain and Off-Channel Habitat *Peripheral and Transitional Habitat*	A historical channel scar at RM 0.4 is currently an 8.5-acre pasture wetland swale. This area is flooded during a 2-year event, but is disconnected during the normal range of flows and unavailable for fish use. The feature is located on private property and is contiguous with adjacent floodplain (blue polygon) The goal at this location is to increase surface flow interaction with the low floodplain swale to allow greater periods of use by juvenile salmonids. This could be achieved through the construction of instream wood elements to increase surface water elevations, and could be combined with minor excavation within the wetland itself to lower relative elevations. Either action should be combined with the protection of the site from grazing and/or haying operations. Riparian planting along with protection should allow this site to return to a native riparian forest community. Efforts to increase connectivity and duration of flow into this floodplain area requires either substantial increase in channel roughness to back up water and raise bed elevations or an extensive excavation of floodplain deposits to create an open flowpath. Feasibility of this action is constrained by adjacent land use, recreation al activities, and potential issues with permitting.	

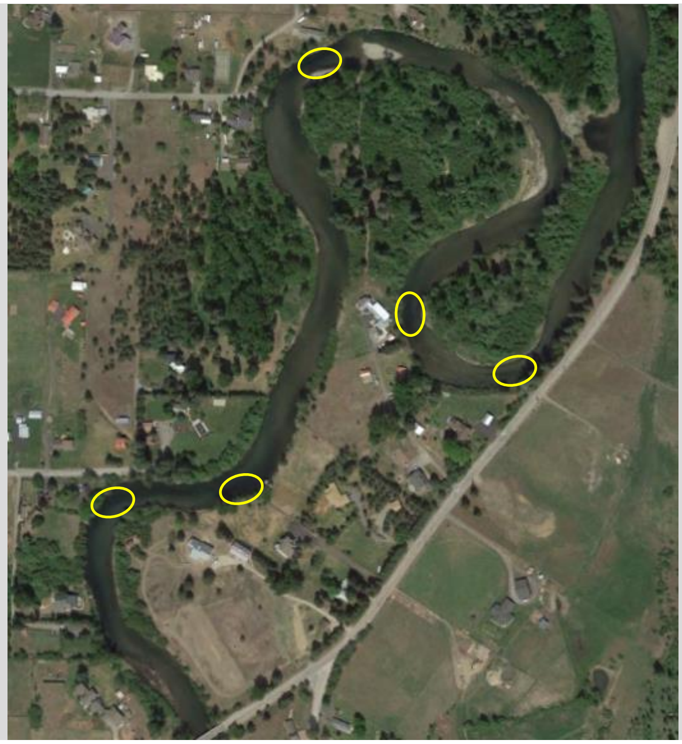
PROJECT LOCATION (RIVER MILE/BANK)	ACTION/STRATEGY /*ECOLOGICAL CONCERN*	DESCRIPTION	CONCEPT
RM 1.0 – 0.0	Reconnect Floodplain and Off-Channel Habitat Install Culverts Within East Leavenworth Road *Peripheral and Transitional Habitat*	East Leavenworth Road bisects the eastern Icicle Creek floodplain. Hydraulic modeling shows that the road effectively restricts large flood flows (i.e. 10-year flow) from inundating floodplain areas to the east of the road. This blocks flood flows from entering existing wetland swale habitats located along the east floodplain valley wall. This swale does carry groundwater-fed surface flows during spring months which feed a surface water channel connected via a 2-foot concrete pipe under East Leavenworth Road back to the historical Icicle Creek channel described above The construction of culverts within E. Leavenworth Road would improve flow connectivity between not only flood flows and the wetland swale, but also from the wetland swale to the paleo-channel on the east side of the road. This action must be paired with additional actions that substantially increase roughness in the channel (e.g. placement of large wood) in order to achieve more frequent overbank flow and floodplain connectivity. The effects of increased flood waters to the east of the road would need to be quantified in relation to existing homes and private property.	

PROJECT LOCATION (RIVER MILE/BANK)	ACTION/STRATEGY *ECOLOGICAL CONCERN*	DESCRIPTION	CONCEPT
RM 1.0 – 0.0	Floodplain Protection Establish a Stream Corridor Acquisition *Peripheral and Transitional Habitat*	The primary constraint to the restoration of channel migration and floodplain inundation processes on Icicle Creek is the close proximity of the channel to human structures. The lower Icicle Creek floodplain provides an opportunity to protect existing functional floodplain from future human development which will allow greater ability to restore impaired riverine processes. The lower Icicle river right floodplain includes over 150 acres of active floodplain that does not currently have human dwellings or structures. Approximately half of this area has been cleared of woody vegetation and now consists of pasture. The other half supports native riparian shrub and forest communities. An additional 15 acres of native floodplain lies on river left at the confluence of the Icicle Creek and the Wenatchee River. These areas are comprised of multiple private landowners and a large area of public landownership. Priority areas are shown in the yellow polygons. Future efforts to prioritize the protection of these areas should include a tiered ranking process that ranks parcels on their susceptibility to future development (Land Use Zoning Designation, Private vs. Public Ownership), amount (acres) of active floodplain, and amount (acres) forested riparian habitat.	

PROJECT LOCATION (RIVER MILE/BANK)	ACTION/STRATEGY /*ECOLOGICAL CONCERN*	DESCRIPTION	CONCEPT
RM 0.5 and 0.7/LB	Large Woody Material Placement *Channel Structure and Form*	Existing pool features at RM 0.5 and 0.7 currently lack cover elements. The installation of large wood within the pools would improve cover for juvenile salmonids during all flow events. Structures do not need to have a significant hydraulic effect; rather they should focus on providing localized cover. Structure design should consider recreational safety and constructability. Note that wood placement opportunities are limited by recreational uses and adjacent land uses. Wood placement locations and intensity are dependent upon stakeholder positions on balancing recreational uses with habitat restoration objectives. Shown is a very minimal approach to add wood given the existing constraints that can yield some additional cover for juvenile salmonids with little impact on recreation or adjacent land uses. Restoration of a functioning wood regime requires much more extensive placement of wood in the channel.	

PROJECT LOCATION (RIVER MILE/BANK)	ACTION/STRATEGY */ECOLOGICAL CONCERN*	DESCRIPTION	CONCEPT
RM 1.0/RB	Protection Reconnect Floodplain and Off-Channel Habitat Large Woody Material Placement Riparian Restoration *Peripheral and Transitional Habitat* *Channel Structure and Form* *Riparian Condition*	The meander at RM 1.0 exhibits active bank erosion on river right, private property pasture floodplain, and relict bank stabilization and riparian restoration efforts. This meander presents the following opportunities: • Protection of floodplain combined with riparian restoration (yellow buffer). • Installation of large wood structure to prevent rapid bank erosion to ensure the success or riparian planting efforts (blue stars – approximate location only) • Removal of relict riprap (red dash).	

PROJECT LOCATION (RIVER MILE/BANK)	ACTION/STRATEGY */ECOLOGICAL CONCERN*	DESCRIPTION	CONCEPT
RM 1.1	Reconnect Floodplain and Off-Channel Habitat Large Woody Material Placement *Channel Structure and Form* *Peripheral and Transitional Habitat*	Low-lying wetland swale occupies a 3-acre area of floodplain that includes an area of seasonal inundation in an abandoned channel feature (likely maintained by groundwater inflow) and is connected to the channel via surface flows during a 2-year event. The feature is located on private property (blue polygon). The goal at this location is to increase surface flow interaction with existing pond and wet swale habitats to allow greater periods of use by juvenile salmonids. An additional goal is to increase habitat cover quality within the existing habitats. This could be achieved through the construction of instream wood elements to increase surface water elevations, and could be combined with minor excavation within the wetland itself to lower relative elevations. In addition to the off-channel actions, an existing pool features at RM 1.1 currently lacks cover elements. The installation of large wood within the pools would improve cover for juvenile salmonids during all flow.events (yellow circle).	

PROJECT LOCATION (RIVER MILE/BANK)	ACTION/STRATEGY /*ECOLOGICAL CONCERN*	DESCRIPTION	CONCEPT
RM 1.5, 1.9, 2.3, 2.4	Reconnect Floodplain and Off-Channel Habitat Large Woody Material Placement *Channel Structure and Form*	Existing pool features between RM 1.1 and 2.5 (East Leavenworth Road) currently lack cover elements. The installation of large wood within the pools would improve cover for juvenile salmonids during all flow events (yellow circles). Wood placement opportunities are limited by recreational uses and adjacent land uses. Wood placement locations and intensity are dependent upon stakeholder positions on balancing recreational uses with habitat restoration objectives. Shown is a very minimal approach to add wood given the existing constraints that can yield some additional cover for juvenile salmonids with little impact on recreation or adjacent land uses. Restoration of a functioning wood regime requires much more extensive placement of wood in the channel.	

PROJECT LOCATION (RIVER MILE/BANK)	ACTION/STRATEGY /*ECOLOGICAL CONCERN*	DESCRIPTION	CONCEPT
RM 1.3 – 2.0	Floodplain Protection Establish a Stream Corridor Remove Bank Armoring Acquisition *Peripheral and Transitional Habitat*	Several forested floodplain parcels near RM 2.0 provide an opportunity to protect existing functional floodplain from future human development which will allow greater ability to restore impaired riverine processes. Area 1 includes 7.5 acres of forested floodplain located within the interior of a tortuous meander. No homes or human structures are located within this area. This also includes an avulsion pathway with riprap reinforcing historical bank protection (red dashed line). Protection actions should allow for continued avulsion across the interior of the property which would include removal of riprap within the immediate vicinity of the avulsion area. This would also require an assessment of erosion risk downstream of the avulsion area and potential protection actions along East Leavenworth Road. Area 2 is a 10-acre parcel of forested floodplain that does not contain human dwellings or structures. A portion of the site floods during the 2-year flow, with the majority of the site flooding at a 10-year event. Area 3 is a 4.5-acre site of low-lying forested floodplain Approximately half of the site is flooding during a 2-year event and it currently supports wetland habitats. The entire site floods during a 10-year event. The site is surrounded by private residences.	

PROJECT LOCATION (RIVER MILE/BANK)	ACTION/STRATEGY /*ECOLOGICAL CONCERN*	DESCRIPTION	CONCEPT
RM 2.1 – 2.6	Riparian Restoration *Riparian Condition*	Residential development between RM 2.1 and 2.6 has resulted in cleared vegetation up to the edge of the stream banks. The re-establishment of mature forested vegetation would improve stream shading and natural bank stability through this reach. Revegetation efforts should consider the installation of woody material at the bank toe to ensure bank stability. Wood structures may replace riprap protection in several locations. Install irrigation watering to ensure plant establishment.	

PROJECT LOCATION (RIVER MILE/BANK)	ACTION/STRATEGY */ECOLOGICAL CONCERN*	DESCRIPTION	CONCEPT
RM 2.7/RB	Reconnect Floodplain and Off-Channel Habitat Large Woody Material Placement *Channel Structure and Form* *Peripheral and Transitional Habitat*	Low-lying wetland swale occupies a 3-acre area of floodplain that is flooded during a 2-year event. The feature is located on private property and is contiguous with adjacent floodplain (blue polygon). The goal at this location is to increase surface flow interaction with existing pond and wet swale habitats to allow greater periods of use by juvenile salmonids. An additional goal is to increase habitat cover quality within the existing habitats. This could be achieved through the construction of instream wood elements to increase surface water elevations, and could be combined with minor excavation within the wetland itself to lower relative elevations. There is concern with creating such habitat through excavation, however, and additional analysis is needed to evaluate whether a deeper off-channel feature could be self-maintaining in this location without excessive sedimentation. In addition to the off-channel actions, an existing pool features at RM 1.1 currently lacks cover elements. The installation of large wood within the pools would improve cover for juvenile salmonids during all flow events (yellow circle).	

PROJECT LOCATION (RIVER MILE/BANK)	ACTION/STRATEGY /*ECOLOGICAL CONCERN*	DESCRIPTION	CONCEPT
RM 3 - 4.3 LNFH	Large Woody Material Placement *Peripheral and Transitional Habitat* *Channel Structure and Form*	The historical Icicle Creek channel runs 6,400 linear feet to the east of the Leavenworth National Fish Hatchery bypass channel (3,950 linear feet). This action will Increase wood loading within the historical channel. Wood installation will provide immediate improvements for cover, complexity, and pool formation. This action is appropriate with either the existing managed flow regime or in combination with potential actions to increase flow and/or for full channel realignment. Wood placement locations and design are dependent on management decisions regarding the existing hydraulic structures.	

PROJECT LOCATION (RIVER MILE/BANK)	ACTION/STRATEGY /*ECOLOGICAL CONCERN*	DESCRIPTION	CONCEPT
RM 3 - 4.3 LNFH	Reconnect Floodplain and Off-Channel Habitat Large Woody Material Placement Full Channel Reconnection *Peripheral and Transitional Habitat* *Channel Structure and Form*	Flows into the Historic Channel are controlled by Structure 2 at the inlet which limits flows larger than 2,600 cfs from entering the channel. This has resulted in deposition of sands, a narrowing of the channel, and it now functions similar to a side channel rather than a dynamic main channel. Multiple recommendations for flow and channel restoration are appropriate at this site. The ultimate action will depend on input from the LNFH, Tribal interests, adjacent landowners, and the local community. Increasing flood flows into the channel will promote dynamic channel process that would be expected within this alluvial fan feature. This would require a modification of Structure 2 to allow flows between a 2-10-yr event to enter the channel system. This would increase pool formation (with the addition of large wood), improve the creation and connection to side channel habitats, and scour/mobilize sands to increase channel-bed coarse grained materials. Full channel realignment option: The existing historical channel retains a planform that over time will accommodate full channel flows. This would require modification of the channel inlet and an equilibrium period during which accumulated sediments in the historical channel mobilize. This would restore dynamic channel process to the main channel. An assessment of the future use/flows within the bypass channel would be required, along with flood effects to adjacent landowners, and retention of Tribal fishing areas.	

7.5 Prioritization Framework

Project prioritization is important to ensure that restoration actions are implemented in the right sequence and location. This prioritization framework was developed by applying the priorities from the Biological Strategy (2014), the FCRPS BiOp Expert Panel process (2012), and the hierarchical strategy adapted from Roni et al. (2002) and Beechie et al. (2008), which results in the logical sequencing of restoration actions based on their probability of "success, response time, and longevity." The logical approach is a very flexible ranking method that has been implemented throughout the Columbia River basin with success. This approach applies the restoration and protection actions defined above and as follows:

1. Protect Floodplain Habitats/Establish a Stream Corridor.
2. Reconnect Floodplain and Off-Channel Habitat
3. Remove Bank Armoring
4. Increase Wood Loading
5. Restore Riparian Habitats.

Using this framework, actions were prioritized and sequenced based on the extent and durability of anticipated biological benefits, feasibility (social, construction, permitting, overall complexity), ability to meet project goals and objectives, and their short-term (1-3 years), intermediate (4-10 years), or long term (10+ years) timeline for implementation and resulting benefits. Biological Benefit was scored as follows:

- High – Restores floodplain or off-channel habitat for juvenile salmonids; protects existing high quality floodplain habitat; establishes stream corridor to allow associated restoration actions.
- Medium – Improves in-channel cover; establishes riparian habitat immediately adjacent to the active channel; protects existing low-quality floodplain.
- Low – Action results in in-frequent flow connectivity and fish use.

Preference in priority was given to actions that exhibited a high feasibility, provided immediate improvement of a targeted impaired process, and/or protected high-quality floodplain habitat. Table 12 provides the "score sheet" for each of the actions along with their ranking and sequencing.

Within Table 12 the Action Ranking denotes the ranked order of the proposed action. The Prioritization and Sequencing rationale describes the reasoning behind the action ranking as well as opportunities for actions to be combined with one another to maximize benefits and gain cost efficiencies. By combining projects and sequencing complimentary actions, impacts to public uses can be reduced, permitting and funding can be streamlined, and disruption to the aquatic and terrestrial environments minimized.

Table 12. Prioritization of Restoration and Protection Opportunities within Lower Icicle Creek.

ACTION RANK	LOCATION	ACTION	TIME SCALE TO ACHIEVE BENEFITS	FEASIBILITY	BIOLOGICAL BENEFIT	PRIORITIZATION & SEQUENCING RATIONALE
1	RM 0.0 – 1.0	Floodplain Protection Establish a Stream Corridor Acquisition	Long-Term	High	High	Provides long-term benefits associated with preventing human disturbance to floodplain habitats over a combined 150 acres of active floodplain; allows for increasing floodplain flooding and channel migration without risk to human structures and property; increases ability to implement instream actions adjacent to the properties with less risk to private property.
2	RM 1.3 – 2.0	Floodplain Protection Establish a Stream Corridor Remove Bank Armoring Acquisition	Long-Term	Moderate	Medium	Provides long-term benefits associated with preventing human disturbance to a combined 22 acres of floodplain habitats; allows for increasing floodplain flooding and channel migration without risk to human structures and property; increases ability to implement instream actions adjacent to the properties with less risk to private property.
3	RM 0.0/ Confluence	Reconnect Floodplain and Off-Channel Habitat Large Woody Material Placement	Short Term	Moderate	High	Provides immediate benefits addressing key off-channel habitat needs within 2,800 linear feet of existing channel. Can be implemented in conjunction with adjacent Protection and Riparian Actions.

ACTION RANK	LOCATION	ACTION	TIME SCALE TO ACHIEVE BENEFITS	FEASIBILITY	BIOLOGICAL BENEFIT	PRIORITIZATION & SEQUENCING RATIONALE
4	RM 3.0 – 4.3/LNFH Channel	Reconnect Floodplain and Off-Channel Habitat Large Woody Material Placement	Short Term	Moderate	High	Install large wood structure within the historical channel. Wood installation will provide immediate improvements for cover, complexity, pool formation. This action is appropriate given potential actions to increase flow and/or for full channel realignment.
5	RM 0.0 – 3.0	Large Woody Material Placement	Short-Term	Moderate	Medium	Provides immediate instream habitat, and floodplain benefits. Implement in association with riparian restoration efforts and with efforts to reduce channel confinement.
6	RM 1.1	Reconnect Floodplain and Off-Channel Habitat Large Woody Material Placement	Short-Term	Moderate	High	Small off-channel area (3 acres) with existing pond and channel features. Restoration can be paired with in-channel wood loading to improve site hydraulics and increase cover.
7	RM 1.0	Large Woody Material Placement Riparian Restoration Remove Bank Armoring	Short Term	Moderate	Medium	Repair of degraded meander can be completed in conjunction with Protection actions. Install large wood structure, remove relict bank protection, establish floodplain riparian community.
8	RM 3.0 – 4.3 LNFH	Reconnect Floodplain and Off-Channel Habitat Flow Improvement	Long-Term	Low	High	Actions to improve flow into the historical channel include modifications to Structure 2 and/or full channel reconnection. This will require direct coordination with LNFH operations, Tribal fishery interests, and adjacent private landowners. This is likely a long-term and low feasibility action with high benefits.

ACTION RANK	LOCATION	ACTION	TIME SCALE TO ACHIEVE BENEFITS	FEASIBILITY	BIOLOGICAL BENEFIT	PRIORITIZATION & SEQUENCING RATIONALE
9	RM 0.4	Reconnect Floodplain and Off-Channel Habitat	Short-Term	Moderate	Medium	Off-channel area (8.5 acres) will required either floodplain excavation or in-channel wood placement to improve inundation regime. Restoration can be paired with Protection and Riparian Restoration actions.
10	RM 0.1 – 0.3	Riparian Restoration	Long-Term	High	Medium	Actions can be paired with lower Icicle Protection actions. Action should be implemented with instream LWM loading to protect plantings, and with irrigation to improve planting performance.
11	RM 2.1 – 2.6	Riparian Restoration	Long-Term	High	Medium	Actions will require willing private landowners. Action should be implemented with instream LWM loading and irrigation to improve planting performance.
12	RM 2.7	Reconnect Floodplain and Off-Channel Habitat Large Woody Material Placement	Short-Term	Moderate	Medium	Small off-channel area (3 acres) will required either floodplain excavation or in-channel wood placement to improve inundation regime. No existing pond or off-channel features.
13	RM 0.0 – 1.0	Reconnect Floodplain and Off-Channel Habitat Install Culverts Within East Leavenworth Road	Long-Term	Low	Low	Requires additional analysis of effects to adjacent landowners; likely difficult to greatly increase inundation regime due to elevated floodplain even with new culverts in E Leavenworth Road. Need to combine with Protection Actions.

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Appendix A

Maps and Aerial Imagery

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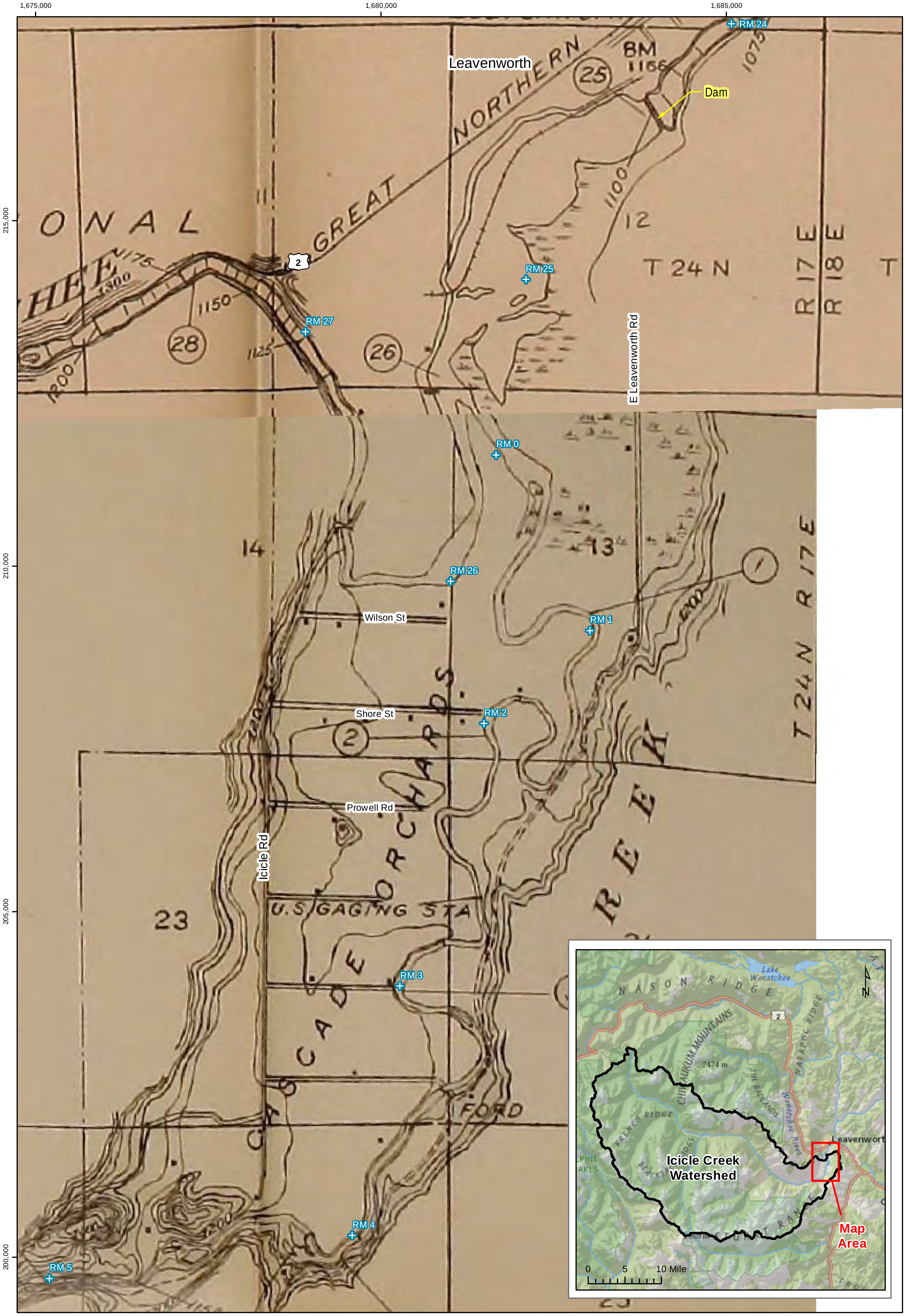

Icicle Creek

1914 USGS Map

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (WA North Zone)

Natural Systems Design

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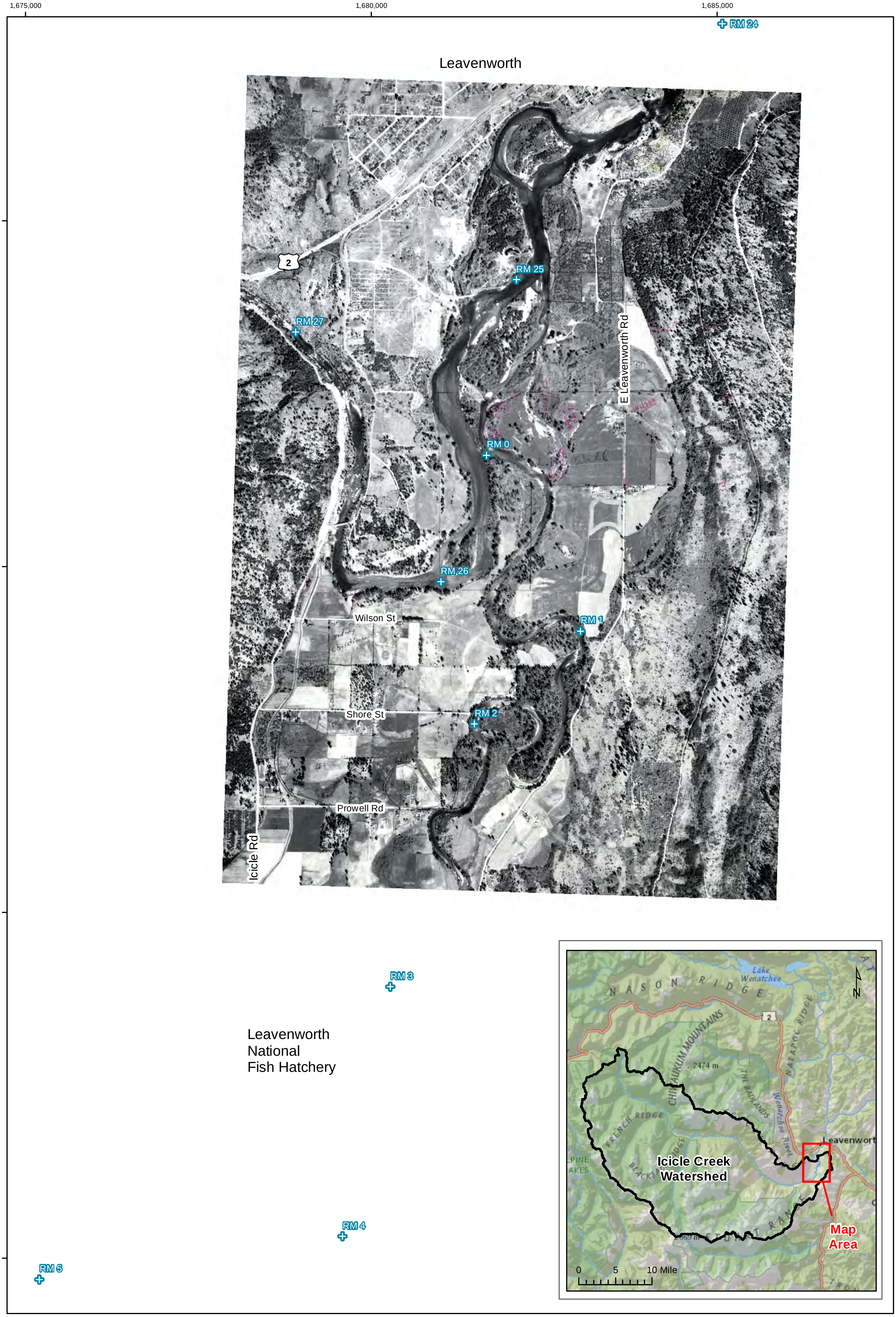

Icicle Creek

1946 Aerial Image

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (WA North Zone)

Natural Systems Design

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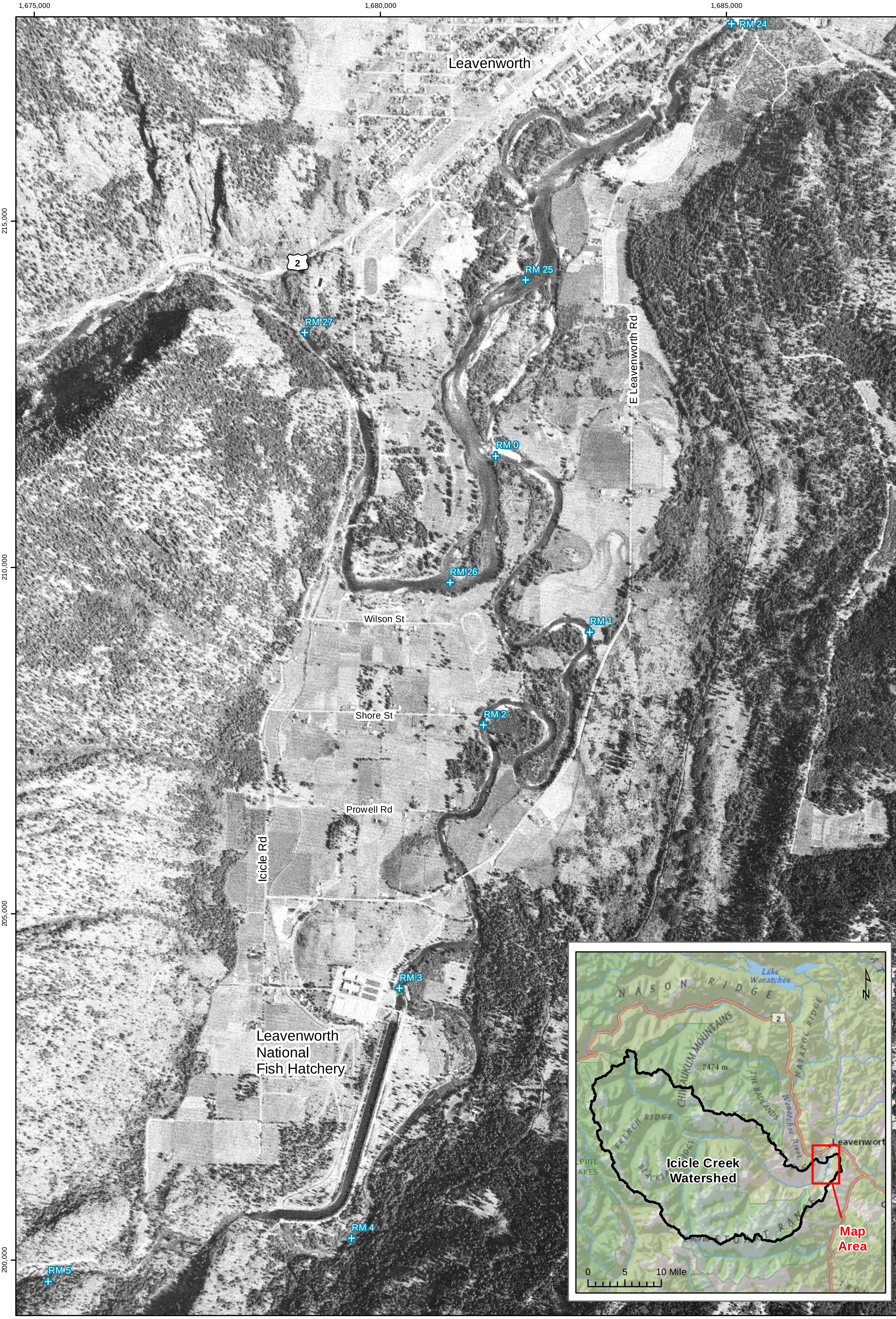

Icicle Creek

1963 Aerial Image

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (WA North Zone)

Natural Systems Design

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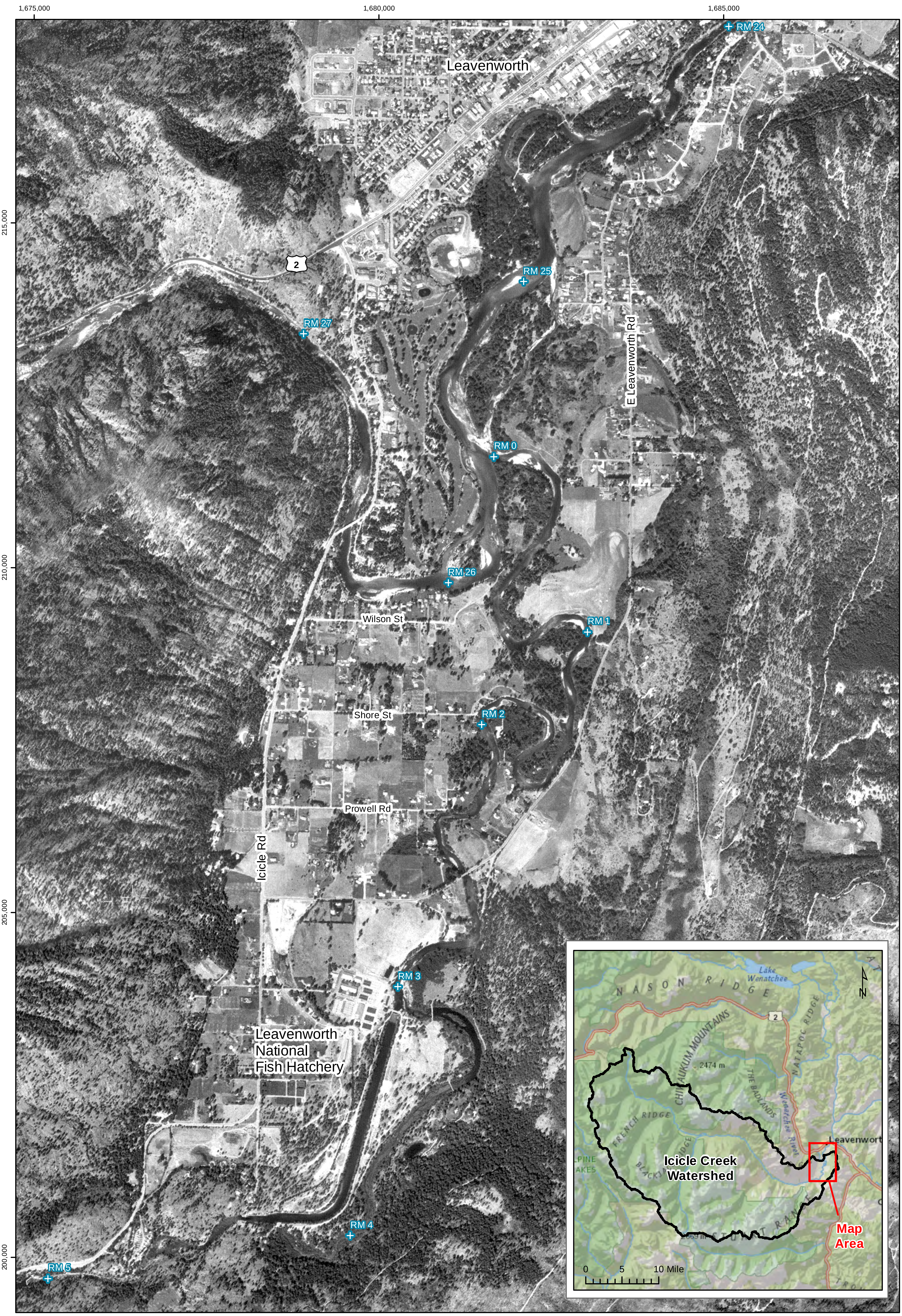

Icicle Creek
1998 Aerial Image

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (WA North Zone)

Natural Systems Design

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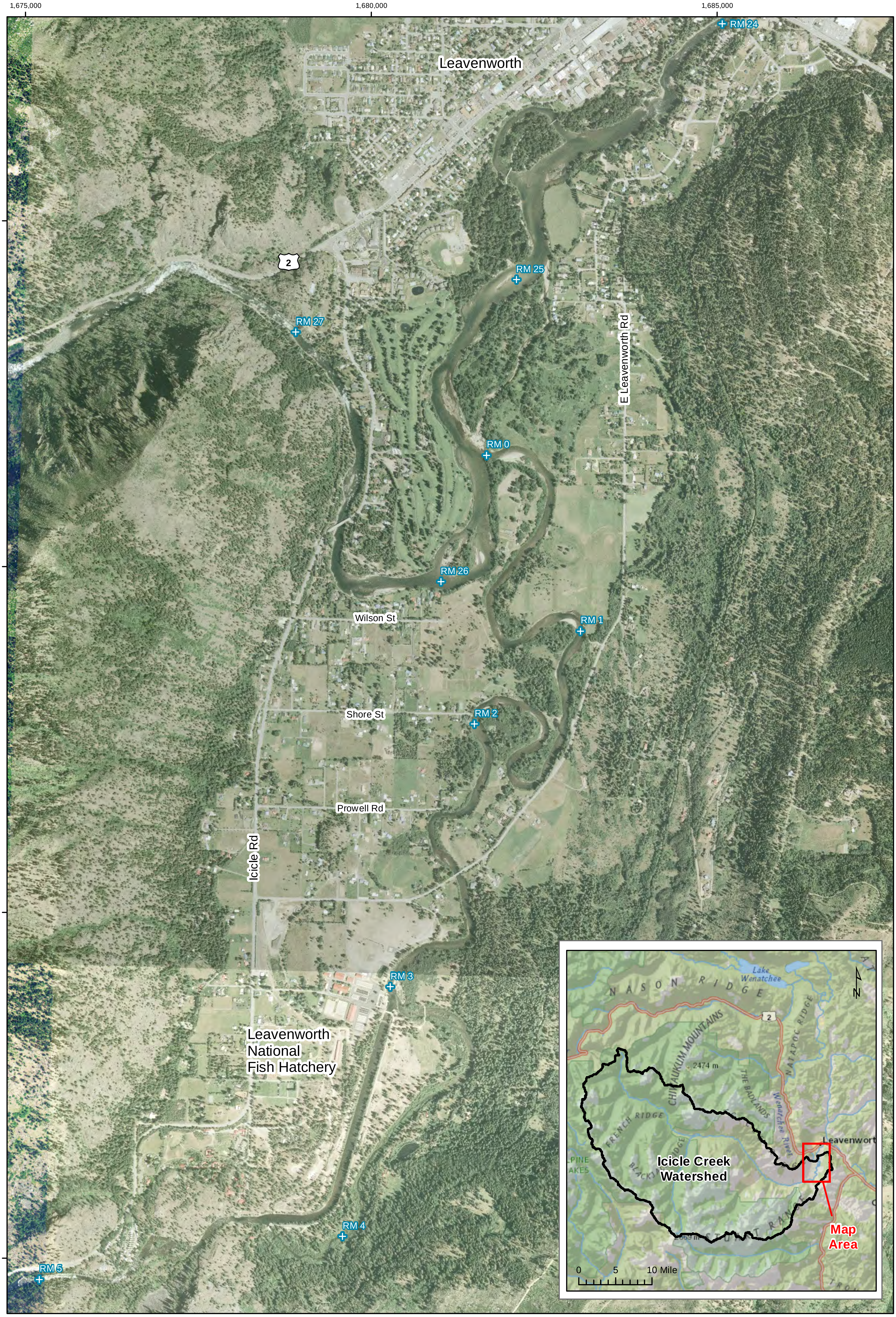

Icicle Creek

2006 Aerial Image

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Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (WA North Zone)

Natural Systems Design

David French, NSD Date: 10/28/2016 Path: B:\Projects\Chelan County\Icicle\GIS\Maps\mxd\Historic_Aerials\Icicle_15k_2006.mxd

Icicle Creek

2015 Aerial Image

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Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (WA North Zone)

Natural Systems Design

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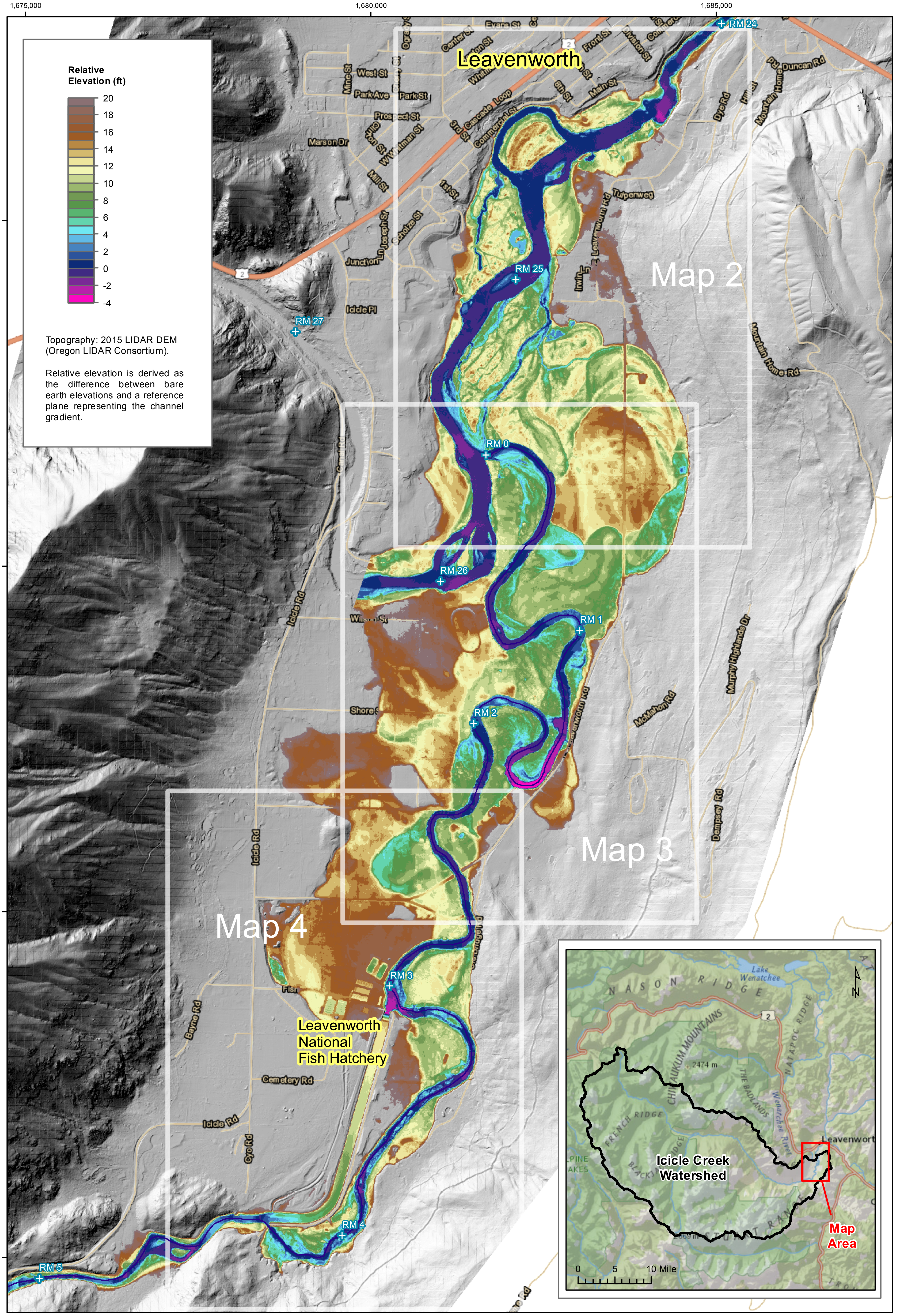


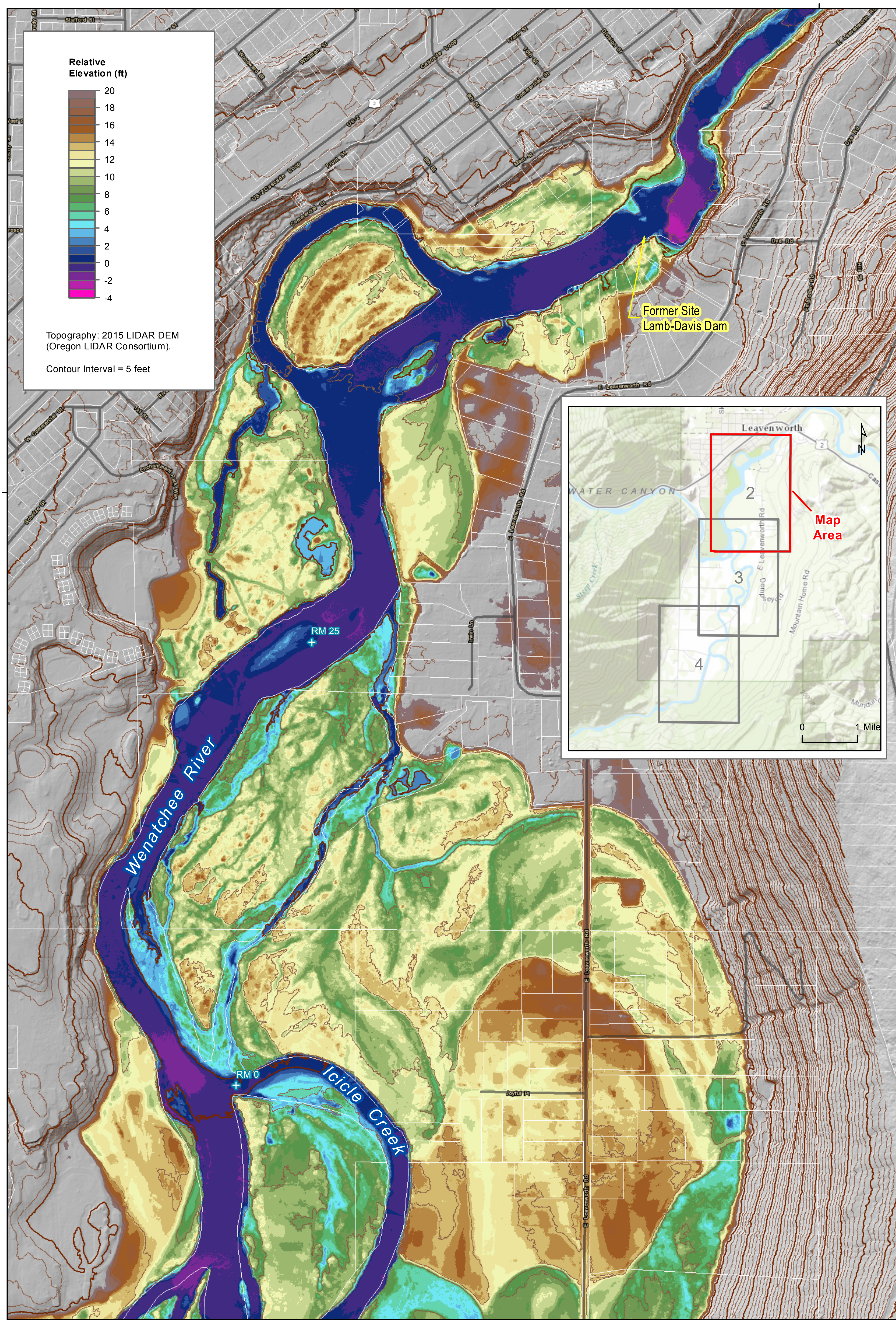
Icicle Creek

Relative Elevation Map 1 (Index)

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (WA North Zone)

Natural Systems Design



Icicle Creek

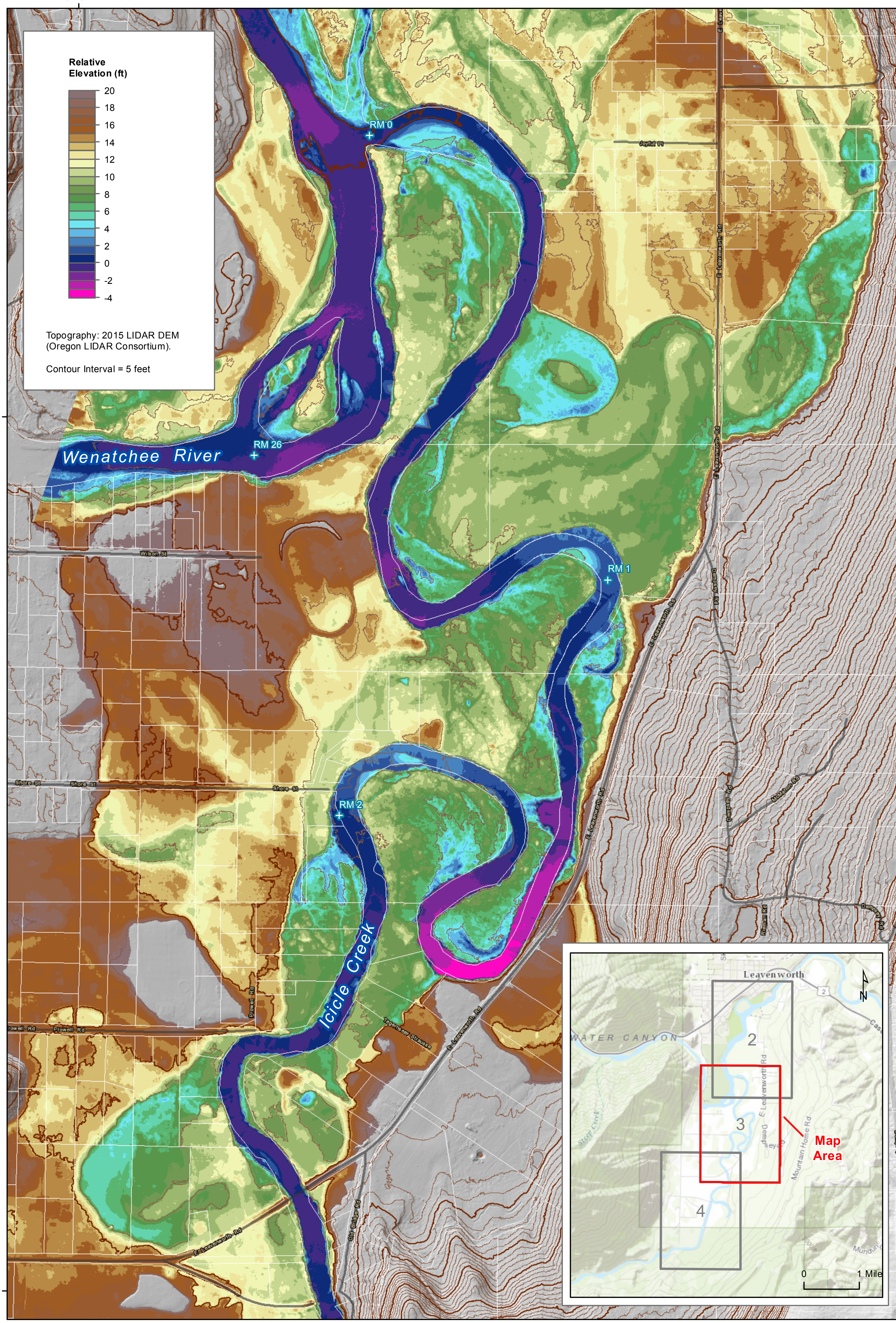
Relative Elevation Map 2

0 500 1,000 1,500 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (WA North Zone)

Natural Systems Design

David French, NSD Date: 8/8/2016 Path: B:\Projects\Chelan County\Icicle\GIS\Maps\mxd\2A_Icicle_REM.mxd



1,680,000

210,000

205,000

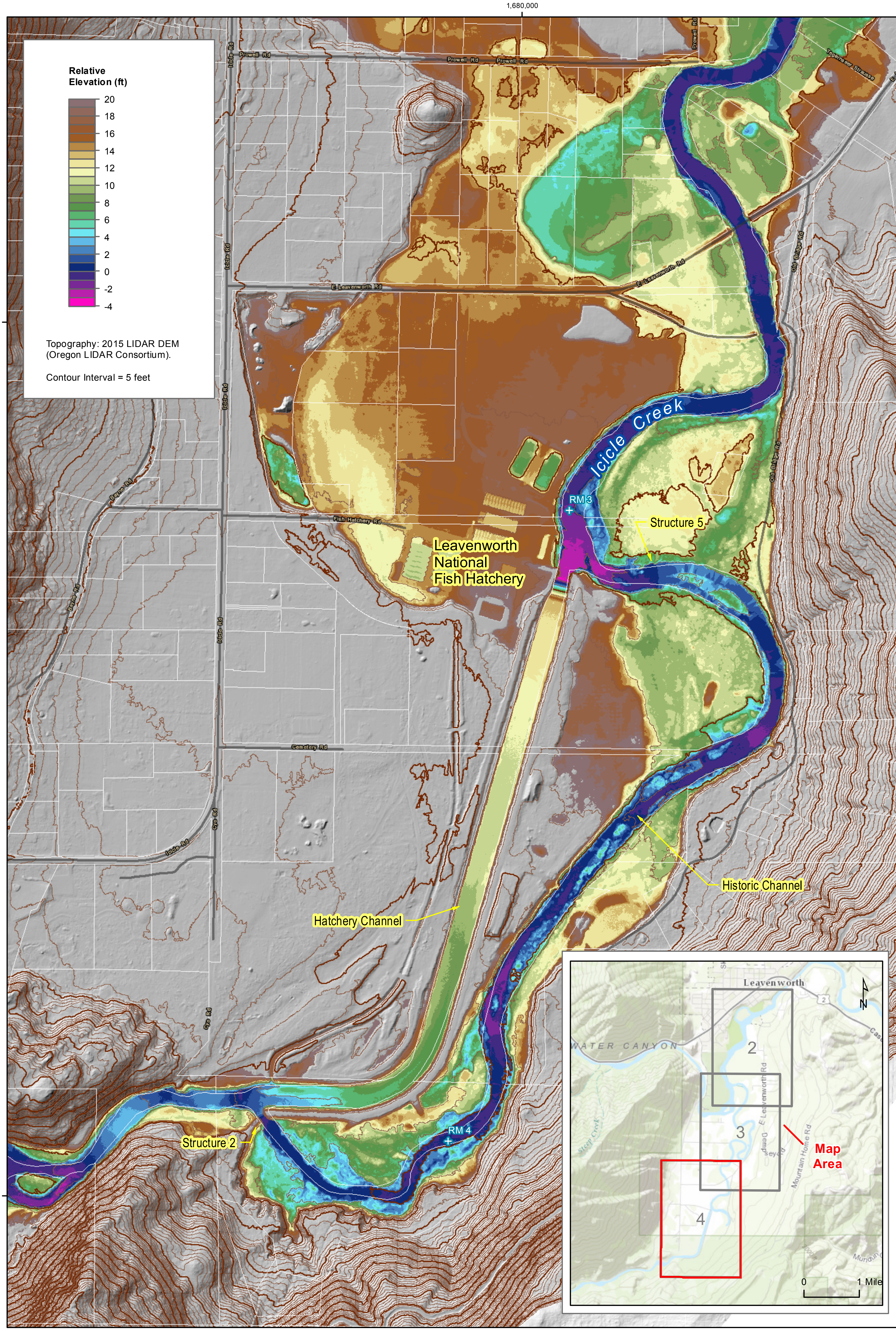
0 500 1,000 1,500 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (WA North Zone)

Icicle Creek
Relative Elevation Map 3

Natural Systems Design

David French, NSD Date: 8/8/2016 Path: B:\Projects\Chelan County\Icicle\GIS\Maps\mxd\3A_Icicle_REM.mxd



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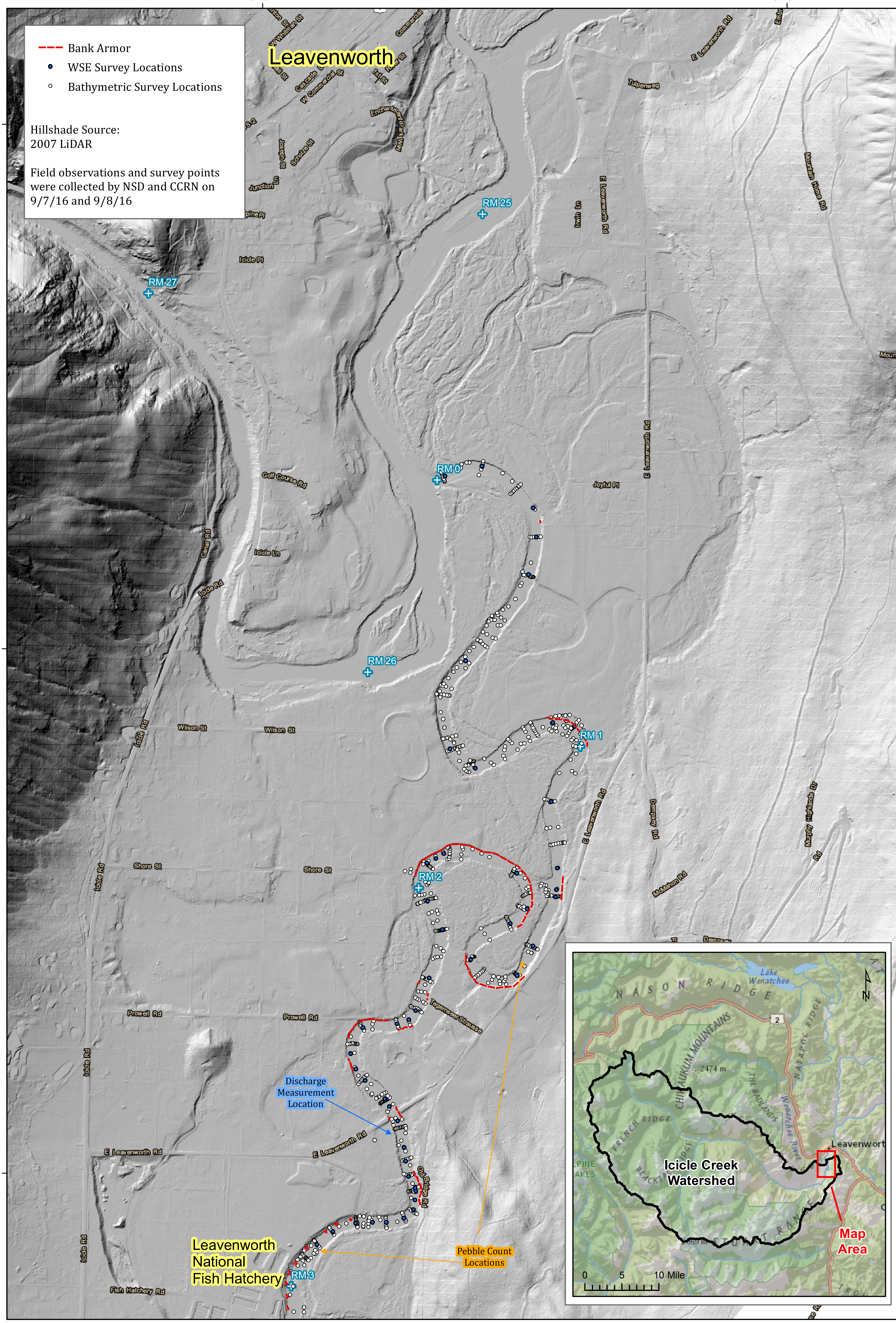
Icicle Creek

Relative Elevation Map 4

0 500 1,000 1,500 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (WA North Zone)

Natural Systems Design



0 1,000 2,000 3,000 4,000

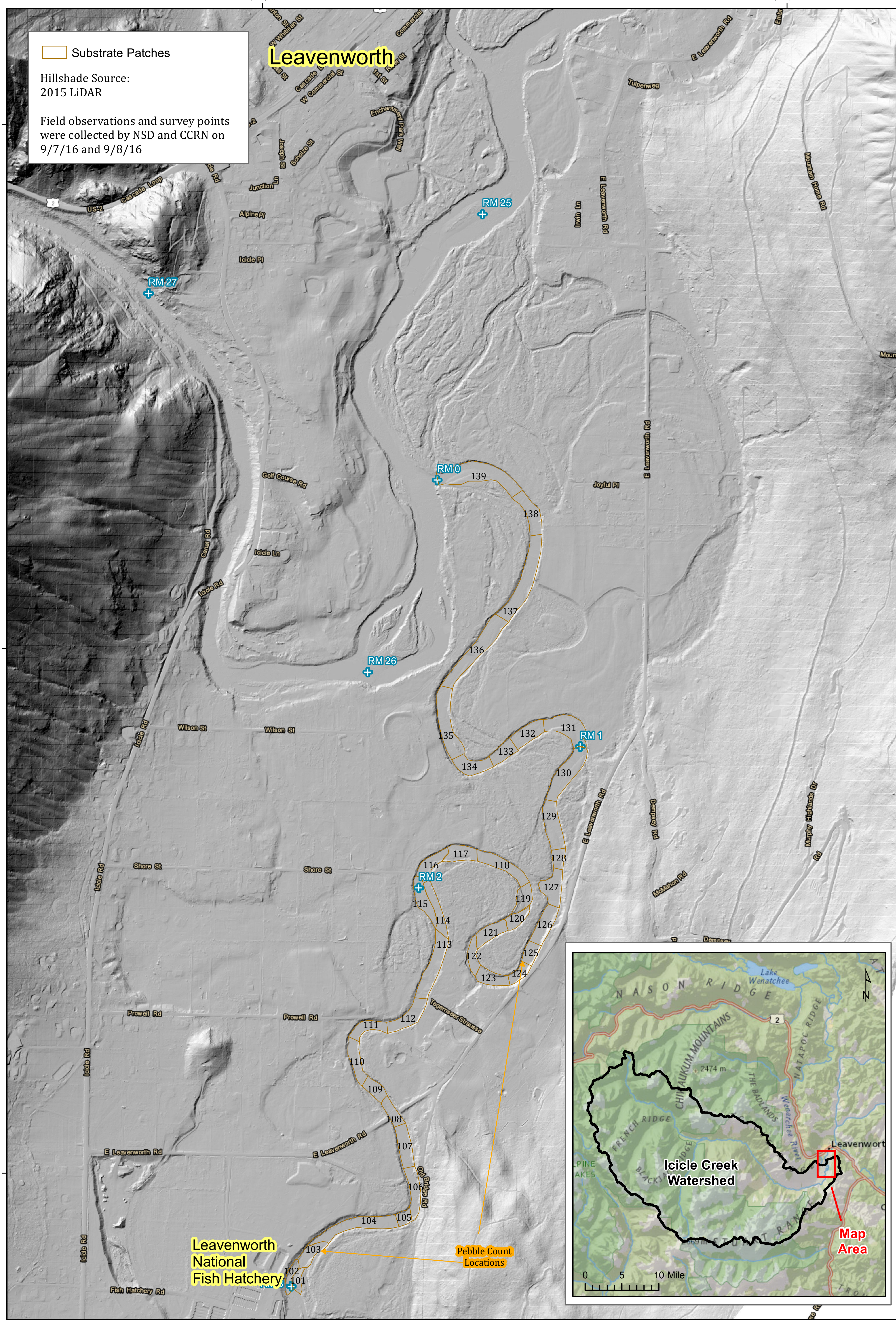
Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (WA North Zone)

Natural Systems Design

Scott Katz, NSD Date: 11/3/2016 Path: P:\Projects\Chelan County\Icicle\GIS\Maps\mxd\Icicle_field_data.mxd

Icicle Creek

Field Data Location Map



Icicle Creek

Substrate Classification Patch Locations

0 1,000 2,000 3,000 4,000

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (WA North Zone)

Natural Systems Design

Scott Katz, NSD Date: 11/9/2016 Path: P:\Projects\Chelan County\Icicle\GIS\Maps\mxd\Icicle_substrate_locations.mxd

Appendix B

Habitat Suitability Index Modeling

Natural Systems Design

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To: Chelan County Natural Resources Department

From: Natural Systems Design

Date: January 7, 2017

Re: Lower Icicle Creek - Habitat Suitability Index Modeling, RM 0.0 – 3.0.

BACKGROUND

Introduction

The Chelan Country Natural Resource Department (CCNRD) is exploring opportunities to implement actions that benefit Endangered Species Act (ESA)-listed salmonids in lower Icicle Creek. This report summarizes results from Habitat Suitability Index (HSI) modeling of the lower Icicle Creek from below the Leavenworth National Fish Hatchery (LNFH) at River Mile (RM) 3.0 to the confluence at the Wenatchee River at RM 0.0 (Figure 1). The Historical Channel upstream of the spillway dam at LNFH (RM 3.0) was assessed as part of a previous study completed to assess conditions of the Historic Channel affected by floodplain modifications at LNFH (Skalicky et at 2013).

In November 2016, the CCFNRD completed a geomorphic and hydraulic assessment of the lower Icicle Creek study reach (NSD 2016). In addition to the quantification of geomorphic and hydraulic conditions, fish habitat use information is desired to aid in restoration planning and design. Information on which salmonid species are present in the reach and what types of habitat they are utilizing will help ensure that restoration actions improve habitat for that target species, and enhance and increase the types of habitat they are actually using.

Habitat Suitability Index (HSI) modeling for juvenile Chinook (*Oncorhynchus tshawytscha*) and steelhead (*Oncorhynchus mykiss*) was performed. Habitat suitability modeling is becoming a standard process for restoration planning and design in the Upper Columbia, and is strongly encouraged and supported by BPA, the Upper Columbia Salmon Recovery Board (UCSRB), and CCNRD. Integration of salmonid species presence, distribution, and habitat utilization will help inform and improve habitat suitability modeling by comparing modeled habitat suitability and distribution to in situ observations of fish distribution and habitat use.

Key Findings

Results developed for the 3 -mile-long channel segment of Lower Icicle Creek include:

- Index values for juvenile Chinook and steelhead rearing habitats are poor throughout the study area;
- Index values for depth and velocity are generally good for rearing habitat conditions; however, the combined HSI results are strongly affected by a general lack of cover elements due to historical impacts leading to the widespread loss of large wood in the system.
- Lack of connectivity to off-channel habitat areas during high flows further limits the rearing habitat in the reach;
- Index values for steelhead spawning habitats are generally good; however, additional study of egg pocket scour depth during floods should be done to evaluate potential for adverse effects due to loss of wood.

Figure 1. Map showing the location of the Icicle Creek Watershed in the Wenatchee River Basin and the project area location in the Lower Icicle Creek Valley. Base map from USGS.

METHODS

The Habitat Model Software is an open, flexible ecological simulation modeling environment. It calculates the area of usable habitat for a particular organism based on a set of physical relationships. Originally developed for modeling anadromous fish habitat, the software is entirely generic and can be used for any species and life stage.

The software takes either tabular or spatially explicit inputs that represent physical conditions (e.g. depth, velocity, cover, and substrate) and combines them using user-defined habitat suitability curves. Typically, these curves are obtained from empirical studies published in the literature and take the form of continuous or categorical utilization curves. A rich user interface allows users to create and manage the curves, link the curves to their data and then batch run simulations.

The following sections describe the methods used to identify and select the targeted species and life history stages, along with the data and assumptions associated with the model inputs.

Targeted Fish Species and Life History Stages

The lower Icicle Creek provides habitat for ESA-listed Upper Columbia River spring-run chinook salmon (*Oncorhynchus tshawytsha*), Upper Columbia River steelhead (*Onchorhynchus mykiss*), and bull trout (*Salvelinus confluentus*). The CCNRD worked with project stakeholders to determine the priority fish species and life history stages within the lower Icicle Creek. For the purposes of this study the group attempted to simplify the modeling effort by limiting the number of modeling runs and resulting data output to focus on the top priority species and life history stages.

The lower 3 miles of Icicle Creek is considered a Minor Spawning Area for spring Chinook, and a Major Spawning Area for steelhead, and includes spawning and rearing habitat for steelhead, spring Chinook salmon, coho salmon (*Oncorhynchus kisutch*), steelhead and bull trout. Above the Leavenworth National Fish Hatchery (LNFH) the channel steepens out of the lower valley and a boulder field at river mile (RM) 5.6 is currently considered a barrier to upstream migration of Chinook salmon (RTT 2014). Figure 2 provides a periodicity chart showing the timing of life history stage utilization within the project reach.

Based on the input from stakeholders, the priority species and life history stages as examined in this study include:

- Steelhead
    - Spawning habitat
    - Rearing habitat
- Spring Chinook
    - Rearing habitat

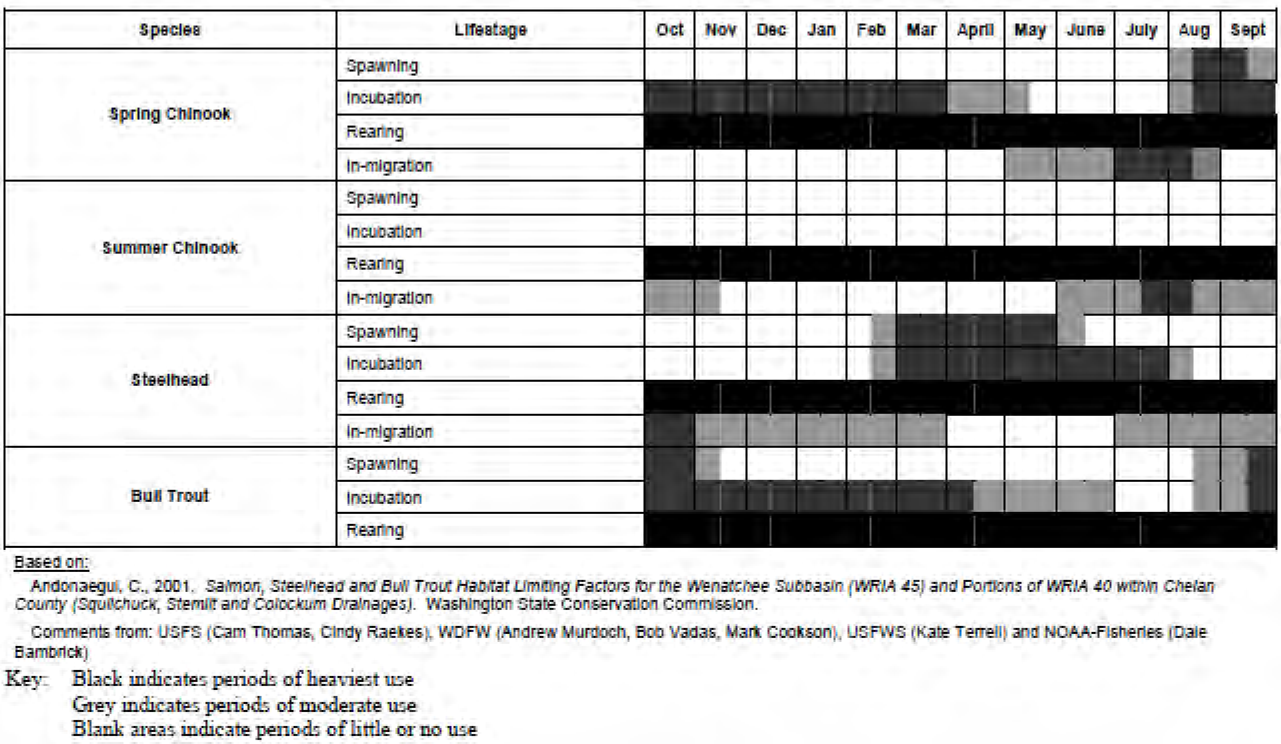

Figure 2. Icicle Creek periodicity chart for spring chinook, summer chinook, steelhead, and bull trout (Reclamation 2005).

Habitat Suitability Index (HSI)

A habitat suitability index provides a framework examining hydraulic, cover, and substrate conditions preferable to a given species, thereby providing an indication of lower Icicle Creek's capacity to support steelhead and spring Chinook, which are the target species of this assessment. The following sections provide information on the methods and results for habitat suitability modeling.

The concept of a HSI was initially developed by the U.S. Fish and Wildlife Service as part of their Habitat Evaluation Procedures in 1974. The intent was to provide an objective and consistent approach for assessing fish and wildlife habitat quality within and between various sample sites. This approach has since been developed for numerous species across many different habitat types.

HSI values were processed in Habitat Model Software version 1.2.8.0. The HSI software takes inputs of spatially explicit habitat conditions (e.g. flow, depth, cover, temperature, etc.) and compares them to a set of user-selected habitat suitability curves to report on habitat suitability across a given geography. The model software includes a library of suitability curves and can also accommodate user-created curves.

Habitat Preference Curves

HSI values range from 0 (unsuitable) to 1 (optimal), and are based on a combination of literature compilations and field observations providing a range of conditions in which individuals are observed. HSI values from 0.5 – 1.0 can be interpreted as good habitat, while values between 0 – 0.5 are considered poor habitat (McMahon 1983, Hale et al. 1985). This approach has been further modified to quantify the range of conditions supporting various life stages for Chinook and steelhead (eg. Raleigh et al. 1986, WDOE and WDFW 2016).

For this work, known preference curves for depth, velocity, substrate, and cover conditions from the Instream Flow Incremental Methodology (IFIM) Study published by Washington Department of Ecology and Washington Department of Fish and Wildlife (WDOE and WDFW 2016) were used. The use of habitat preference curves from the IFIM Study builds upon habitat suitability work performed in the historic channel from RM 2.8 to 3.8 in lower Icicle Creek by US Fish and Wildlife Service, which also used the IFIM curves for their analysis (Skalicky 2013). The depth and velocity curves are presented in Figure 3 - Figure 5 below. Preference scores for substrate and cover are discussed below.

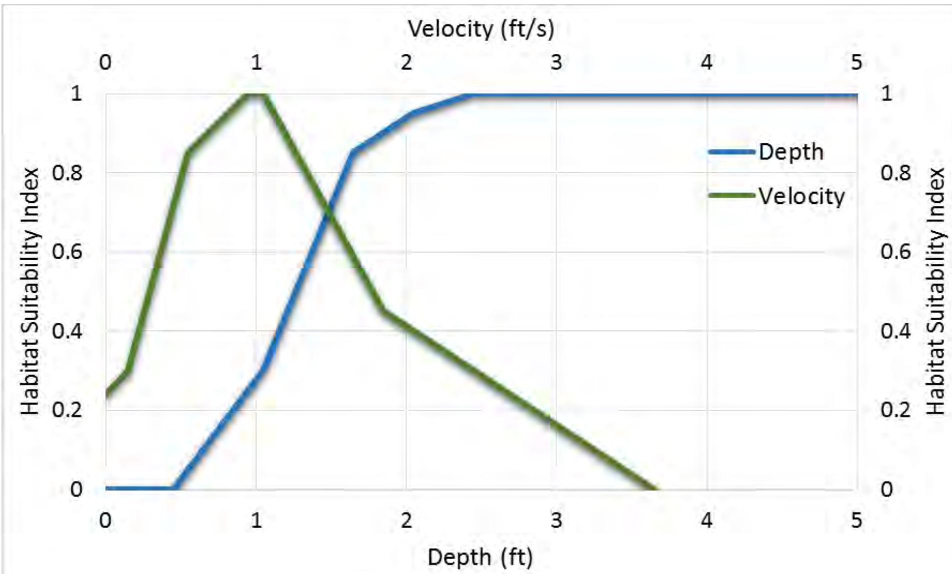

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Figure 3. HSI preference curve for juvenile Chinook rearing habitat (WDOE and WDFW 2016).

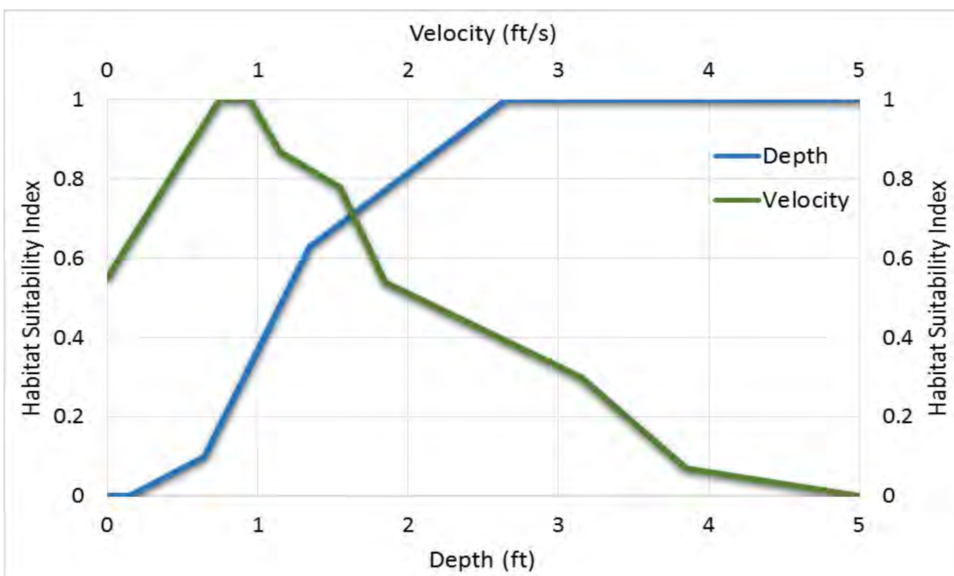

Figure 4. HSI preference curve for juvenile steelhead rearing habitat (WDOE and WDFW 2016).

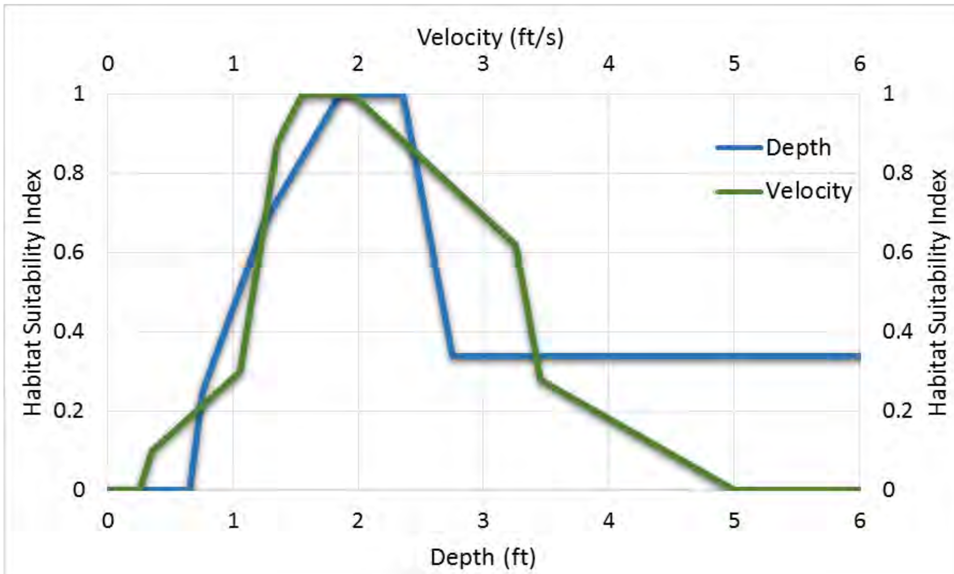

Figure 5. HSI preference curve for steelhead spawning habitat (WDOE and WDFW 2016).

Hydraulic Inputs

For water depth and velocity model inputs, we utilized a set of point data derived from a hydraulic model of Icicle Creek which was prepared as part of the Geomorphic and Hydraulic Assessment (NSD 2016). This model used Hydronia's RiverFlow-2D Plus GPU and Aquaveo SMS v12.1 computer software, which is a two-dimensional finite element computer model that provides depth averaged hydraulic parameters at nodes within a triangular mesh model domain. The model geometry incorporated bathymetric survey data collected by NSD in September 2016 to represent the low flow channel and topographic data from a 2015 LiDAR DEM to represent channel and floodplain areas outside of the bathymetric survey. Hydraulic resistance was characterized by polygons representing differing surface types such as channel, vegetated bar, forest, or pasture. The surface type polygons were classified with Manning's roughness coefficients. The model was calibrated through adjustment of the roughness coefficient to best match the water surface profile surveyed in the field September 7 and 8, 2016 (130 cfs).

Five representative flow scenarios were selected for evaluation of hydraulic parameters in Icicle Creek ranging between a summer base flow condition and the 100-year recurrence interval peak flow (Table 1). For reference, the representative flow scenarios utilized in the hydraulic analysis are plotted over the annual hydrograph for WY 2016 in Figure 6. Two flows were selected for the HSI modeling effort that correspond with key salmon and steelhead life history stages. These flows included:

- Summer base flow (130 cfs).
- Typical snowmelt/spring runoff (1,830 cfs).

Table 1. Streamflow statistics utilized in representative flow scenarios.

	STREAMFLOW (CFS)
Summer Base Flow	130
Typical Snowmelt/Spring Runoff	1,830
2-Year Peak Flow (Q2)	4,450
10-year Peak Flow (Q10)	8,300
100-Year Peak Flow (Q100)	15,200

Figure 6. Annual hydrograph for WY 2016 (Icicle Creek near E Leavenworth Road Bridge) with representative flows utilized in hydraulic analysis highlighted in green horizontal lines.

Summary statistics compiled for two flow scenarios are presented below in Table 2. Map outputs of flow depth and velocity each of the scenarios are presented in Appendix A.

Table 2. Summary statistics of 2-dimensional hydraulic model results for the baseflow, and spring runoff modeling scenarios

FLOW	DEPTH (FT)				VELOCITY (FT/S)			
	MIN	MAX	MEAN	SD	MIN	MAX	MEAN	SD
Baseflow	0.1	11.5	2.0	1.5	0.0	8.4	0.9	0.6
Spring Runoff	0.1	15.3	5.9	1.7	0.0	5.5	2.9	0.9

Juvenile steelhead and juvenile Chinook rearing curves were applied to the hydraulic results for the summer base flow (130 cfs). This flow corresponds with the average discharge for September, which is characterized of low flows and a lack of connectivity to off-channel habitats in Icicle Creek. Rearing habitat during spring high flow periods is also considered to be limited in the project reach and high flow was used to evaluate both steelhead and spring chinook rearing conditions. Spring high flows were used to evaluate spawning for steelhead based on the timing for steelhead spawning in Icicle Creek. Table 3 compares the flows used for modeling with the key salmon and steelhead life history stages.

Table 3. Summary of flow analysis and life history stage used in the HSI model.

FLOW	SPRING CHINOOK JUVENILE REARING	STEELHEAD SPAWNING	STEELHEAD JUVENILE REARING
Baseflow	X		X
Spring Runoff	X	X	X

Substrate and Cover

Substrate size classes and cover for the model were derived from the September 2016 field reconnaissance and then digitized for use in the modeling effort. The classification shown in Figure 7 was used to classify the substrate and cover conditions, and also lists the habitat preference values used in the HSI analysis for each category. It should be noted that cover elements would not be expected to be present in across the entire project area, but would, in a reference condition, likely be concentrated in areas of deposition (for large wood accumulations) or in areas of scour along stable banks, in the case of undercut banks. Root wads and log jams associated with key pieces would also likely occur in the reach, but at a low frequency. Reference estimates from Fox and Bolton (2007) for east side streams include 0.4 key pieces per 100 m and 17 pieces of wood (non-key pieces) per 100 m. With this in mind applications of cover index scores should likely be limited to areas where cover would be expected under an applicable reference condition.

Substrate Code	Description	Size (inch)	Spawning				Rearing		Holding
			salmon	steelhead	resident trout	bull trout	fry	juv.	adult
1	silt, clay, or organic		0.00	0.00	0.00	0.00	0.10	0.10	0.10
2	sand		0.00	0.00	0.00	0.00	0.10	0.10	0.10
3	sm gravel	0.1 - 0.5	0.30	0.50	0.80	1.00	0.10	0.10	0.10
4	med gravel	0.5 - 1.5	1.00	1.00	1.00	1.00	1.00	0.30	0.30
5	lrg gravel	1.5 - 3.0	1.00	1.00	0.80	1.00	1.00	0.30	0.30
6	sm cobble	3.0 - 6.0	1.00	1.00	0.50	0.70	1.00	0.50	0.30
7	lrg cobble	6.0 - 12.0	0.50	0.30	0.00	0.70	1.00	0.70	0.30
8	boulder	>12.0	0.00	0.00	0.00	0.00	1.00	1.00	1.00
9	bedrock	NA	0.00	0.00	0.00	0.00	0.10	0.30	0.30

Cover Code	Description (Note: Cover codes are not used for spawning)	Rearing		Holding
		fry	juv	adult
00.1	undercut bank	1.00	1.00	1.00
00.2	overhanging vegetation	1.00	1.00	1.00
00.3	root wad (including partly undercut)	1.00	1.00	1.00
00.4	log jam/submerged brush pile	1.00	1.00	1.00
00.5	log(s) parallel to bank/Rip-rap	0.30	0.80	0.80
00.6	aquatic vegetation	1.00	0.80	0.80
00.7	short (<1') terrestrial grass	0.40	0.10	0.10
00.8	tall (>3') dense grass	0.70	0.70	0.10
00.9	vegetation beyond the bank-full waters edge	0.20	0.20	0.20

Figure 7. Substrate and Cover classifications and habitat preference values from WDOE and WDFW 2016.

Substrate in the project area is composed of sediment that is a mixture of gravel- and cobble-sized particles with the occasional boulder sized piece of rip-rap residing in the active channel. Bed material was sampled at two riffle locations within the project area as part of the field survey in September 2016. Sampling was conducted using the Wolman Pebble Count method with a sample size of greater than 100 particles at each location (Wolman, 1954). The resulting grain size distributions of the sediment samples are presented in Figure 8.

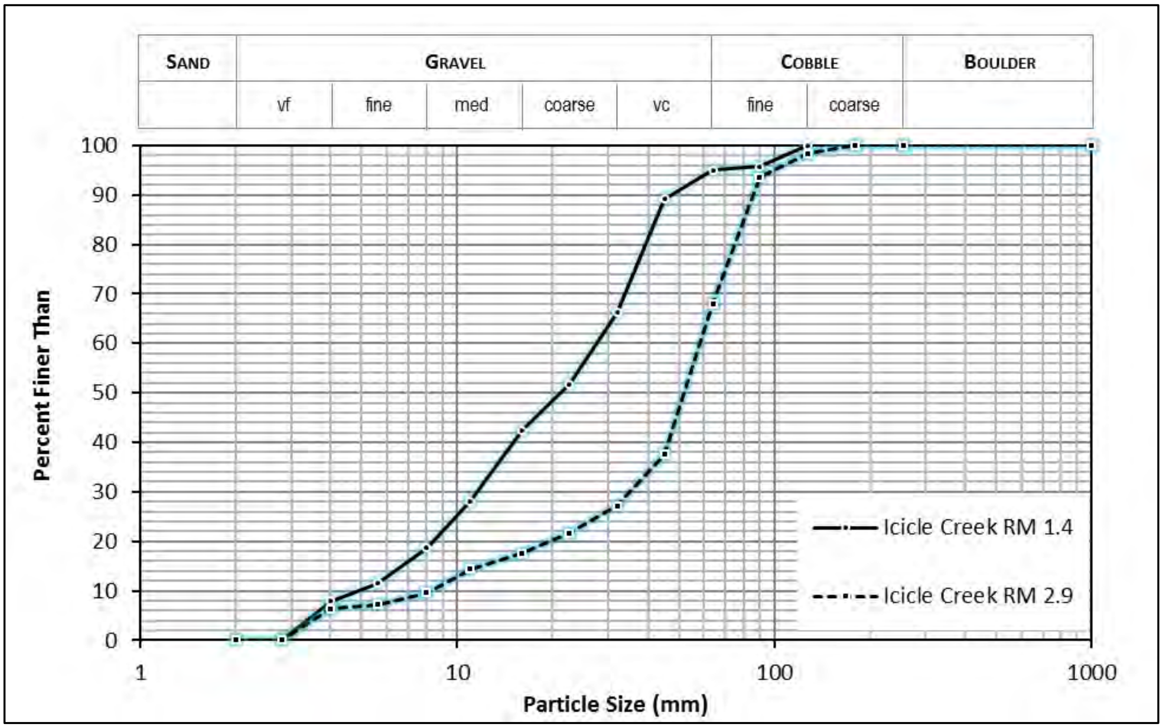

Figure 8. Grain size distribution plots of sediment samples collected from Icicle Creek on 9/7/16 and 9/8/16.

Median grain size (D_{50}) values range between 21 and 53 mm (coarse to very coarse gravel). The coarse fraction of the bed material, represented by the value for which 90 percent of the sampled particles are finer than (D_{90}), ranges between 53 and 86 mm (cobbles). There is a broad distribution of sediment size classes in both of the samples with sizes ranging from very fine gravels to fine cobbles (Figure 9). The D_{50}'s of the RM 1.4 and RM 2.9 samples are within the range of sizes preferred by spawning coho and Chinook salmon respectively (Kondolf and Wolman, 1993); however, salmonids often prefer well sorted gravels with narrow, uni-modal distributions which are not common within the project reach (Kondolf and Wolman, 1993).

Figure 9. Photo illustrating bed material and lack of cover near RM 2.77. Note the wide range of size classes and large sand fraction.

Cover within the project area is very limited and consists of narrow strips of overhanging vegetation and large wood. Within the lower Icicle Creek project reach large wood pieces were tallied to characterize the abundance and size of wood within the active channel. The wood tally noted length and diameter of 119 total pieces in the 3-mile-long project reach, however, most of the wood pieces surveyed range between 10-30 feet in length and are less than 20 inches in diameter. This number represents less than 2 percent of the wood load that would be expected in a reference condition. The wood that does exist in the channel is sparse and consists primarily of single pieces held stable by rip-rap or cabled to the bank (Figure 10). The general lack of wood is due to past impacts of land management practices that impaired natural wood recruitment and physically removed large wood from the stream channel.

Figure 10. View downstream of single piece of wood with a diameter of 15" and a length of 24' cabled to rip rap along right bank at RM 2.27.

RESULTS

Habitat Assessment

Habitat within the lower Icicle Creek project reach was assessed to quantify existing habitat availability and to identify opportunity areas with potential for restoration treatments. Establishing base habitat conditions also enables quantitative comparison with proposed condition analyses to be completed in future project phases. This assessment utilized a habitat survey in the late summer of 2016 as described in the Geomorphic and Hydraulic Assessment (NSD 2016).

The lower Icicle Creek reach is characterized by a single thread, meandering channel pattern with relatively uniform pool-riffle morphology. The unvegetated channel is approximately 140 feet wide (ranging between 120 and 160 feet) and 5 feet deep in typical riffle sections at bankfull stage. Figure 11 presents the habitat units as identified during the field survey. In total, we identified a total of 18 pools ranging in depth from 4 to 12.5 feet with average pool spacing of 750 ft. The primary mechanism driving pool formation is bend scour and most pools were located in areas with substantial bank armoring and along meander bends. No wood-forced pools were observed in the reach. The pools are separated by riffle-run sequences with exposed sediment deposits present in some locations during the baseflow conditions of the channel survey. Table 4 provides the percentage of pool, riffle, and glide habitat within the study reach.

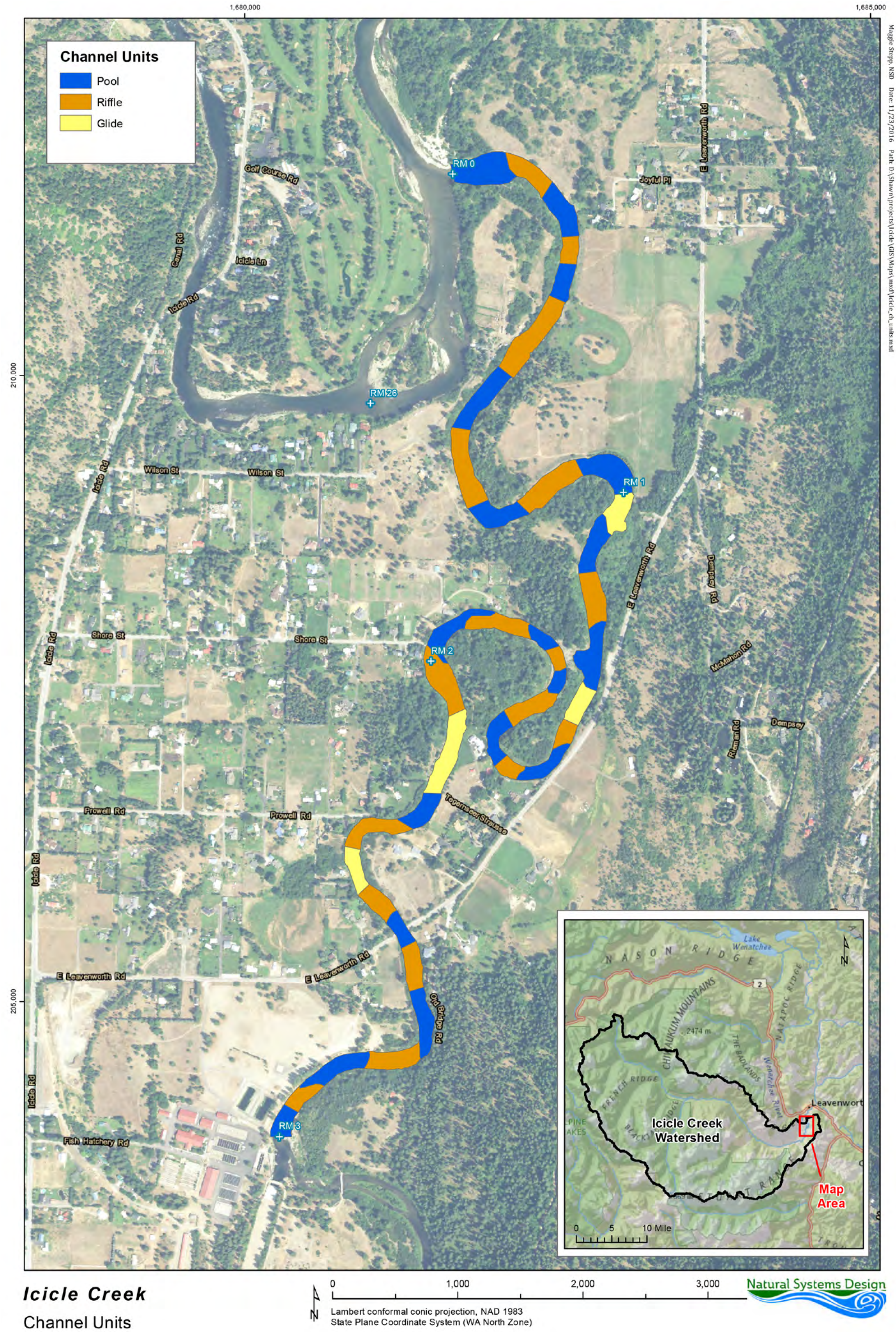

Figure 11. Pool, Riffle, and Glide channel unit mapping within Lower Icicle Creek (RM 0. 0 – 3.0).

Table 4. Percentage of pool, riffle, and glide habitat within the lower Icicle Creek study reach.

HABITAT UNIT	% TOTAL
Pool	46%
Riffle	44%
Glide	10%

Habitat Suitability Index Model Results

Results from the HSI modeling are attached as Appendix B and histograms of HSI values provided in Figure 12 – Figure 19, with key results from the assessment in Table 5. The only model run that averaged at or above 0.5 was for steelhead spawning habitat during spring runoff flows. All other runs averaged poor HSI results. A discussion of each of the model runs is provided below.

Table 5. HSI Summary Data for the lower Icicle Creek study reach.

SPECIES	LIFESTAGE	DISCHARGE	AVERAGE HSI
steelhead	spawner	Q1	0.50
steelhead	juvenile	baseflow	0.19
Steelhead	juvenile	Q1	0.22
Spring Chinook	juvenile	baseflow	0.17
Spring Chinook	juvenile	Q1	0.18

Juvenile Rearing Habitat

Steelhead

Rearing habitat for steelhead fry in the Icicle reach is poor during the 130 cfs summer base flow condition, with an average value of 0.19. During baseflow conditions, the low channel gradient and depth and velocity ranges typical throughout the lower Icicle trend toward favorable habitat conditions. Substrate is relatively uniform in the lower Icicle but does not provide the optimal size classes for juveniles. The extreme lack of cover has a severe negative effect on the HSI scoring for juvenile steelhead as evidenced in the histogram (Figure 12 and Figure 13) below, however, since cover elements would not be expected everywhere in the three mile reach the influence of cover should likely be tempered in this analysis. Pool locations tend to provide the highest quality juvenile rearing habitat but still score below the 0.5 threshold for higher quality habitat. The few instances of cover within pools resulted in the highest HSI scores.

HSI values for juvenile steelhead rearing at spring flows are similar to values during baseflow with an HSI average of 0.22. The primary factor for the reduced scores is the increased flow velocity during flood flows (Figure 14 and Figure 15). As with the HSI values at baseflow, opportunities to create areas of lower velocity with increased cover would improve the index values. In addition, the few areas of overbank flow into low-velocity off-channel habitats also provide increased index values.

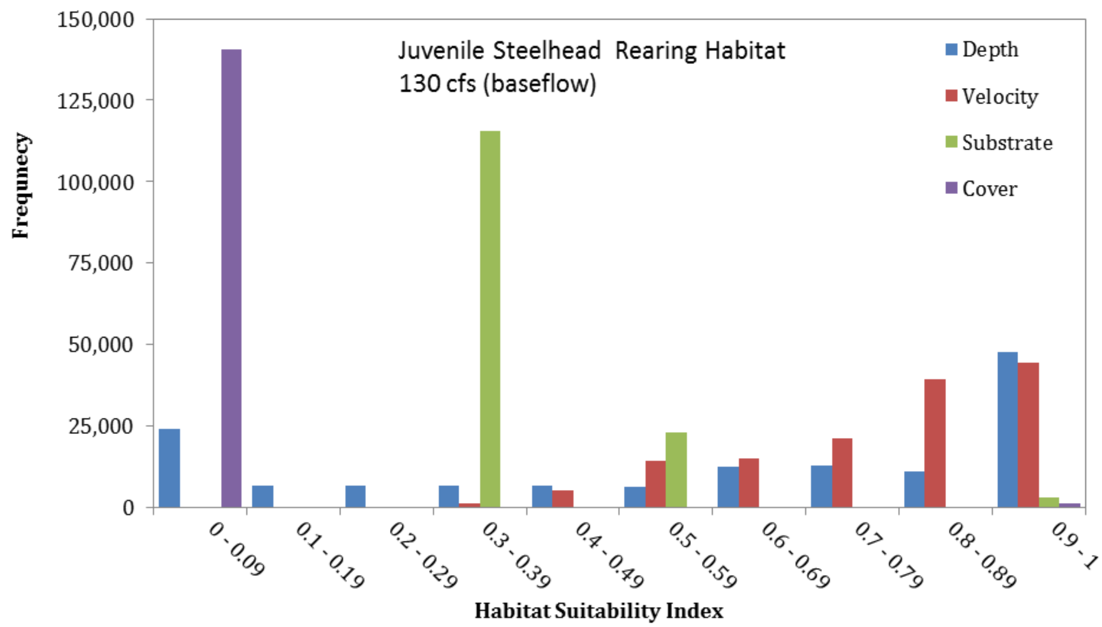

Figure 12. Frequency distribution of HSI values in Lower Icicle Creek at 130 cfs (baseflow) for individual input variables based on preference curves for Juvenile Steelhead.

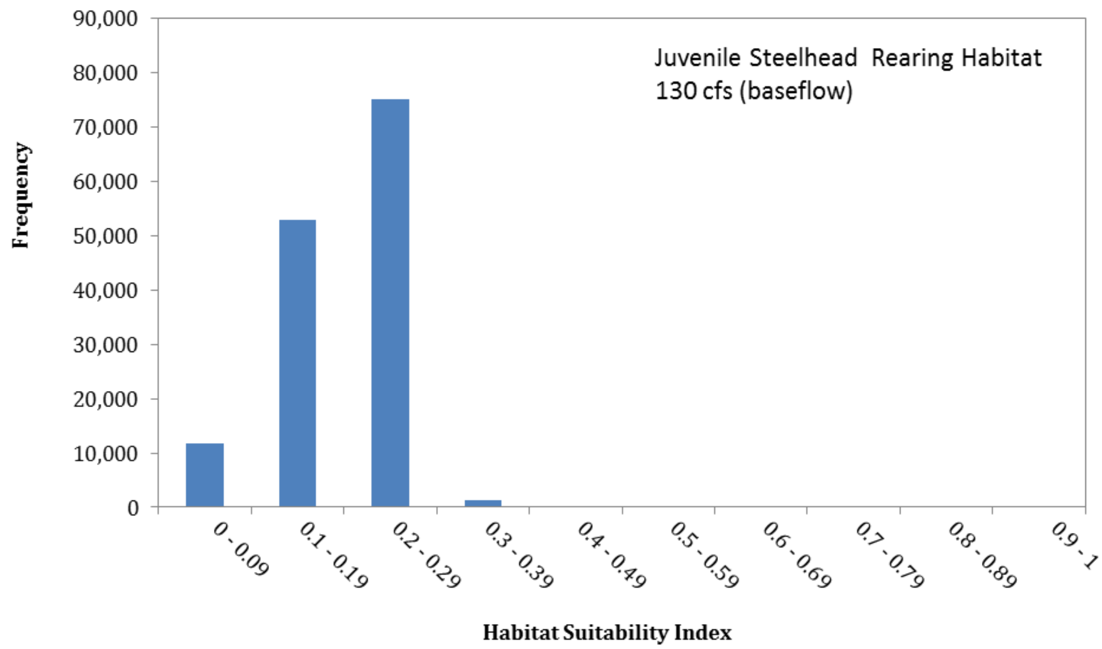

Figure 13. Frequency distribution of the composite HSI values in Lower Icicle Creek for juvenile steelhead rearing habitat at 130 cfs.

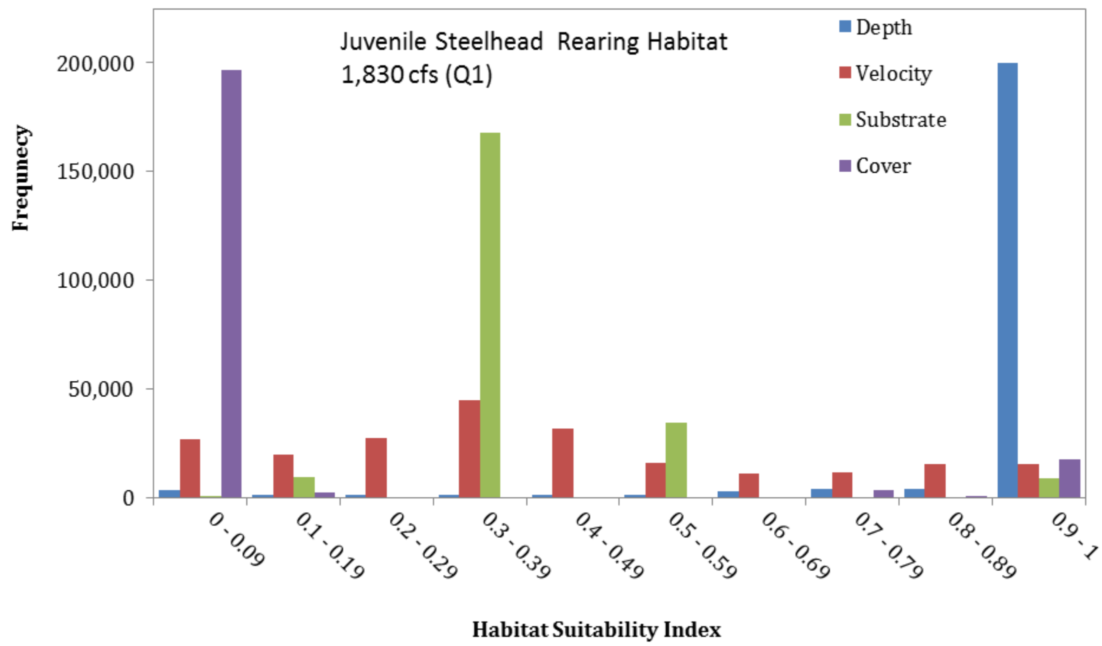

Figure 14. Frequency distribution of HSI values in Lower Icicle Creek at 1,830 cfs (baseflow) for individual input variables based on preference curves for Juvenile Steelhead.

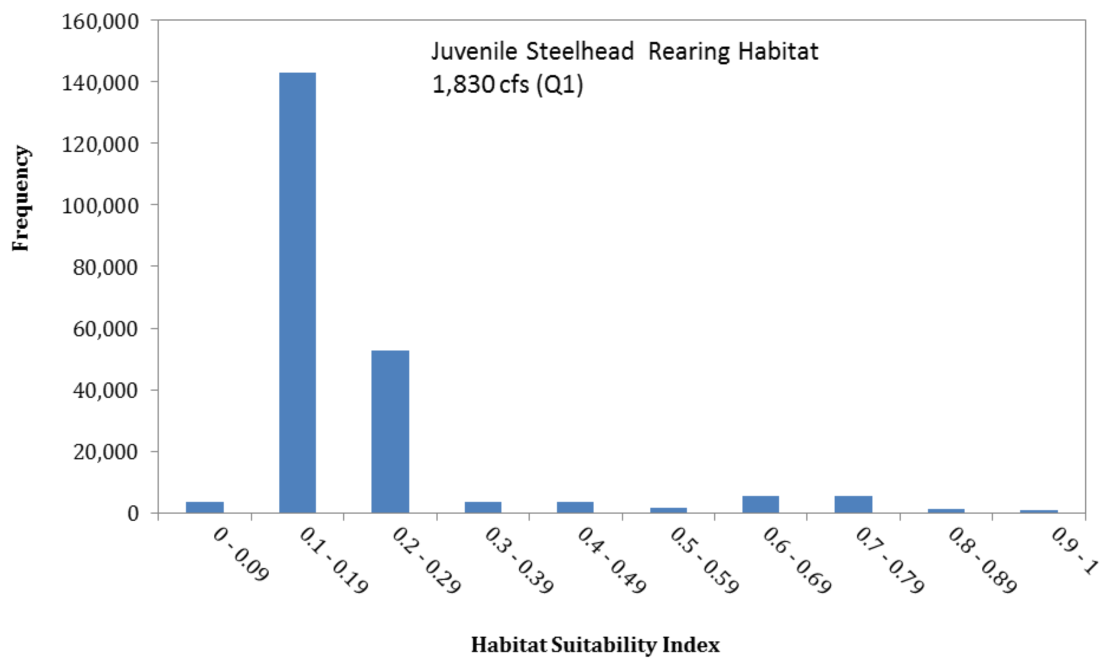

Figure 15. Frequency distribution of composite HSI values in Lower Icicle Creek for juvenile steelhead at 1,830 cfs.

Spring Chinook

HSI values for spring Chinook rearing for both summer baseflow and spring flow are poor and similar to those for steelhead. Average HSI value for baseflow is 0.17 and average HSI value for spring flow is 0.18. The extreme lack of cover has a severe negative effect on the HSI scoring as shown in the histograms below (Figure 16 – Figure 19). Pool locations tend to provide the highest quality juvenile rearing habitat but still score below the 0.5 threshold for higher quality habitat. The few instances of cover within pools resulted in the highest HSI scores.

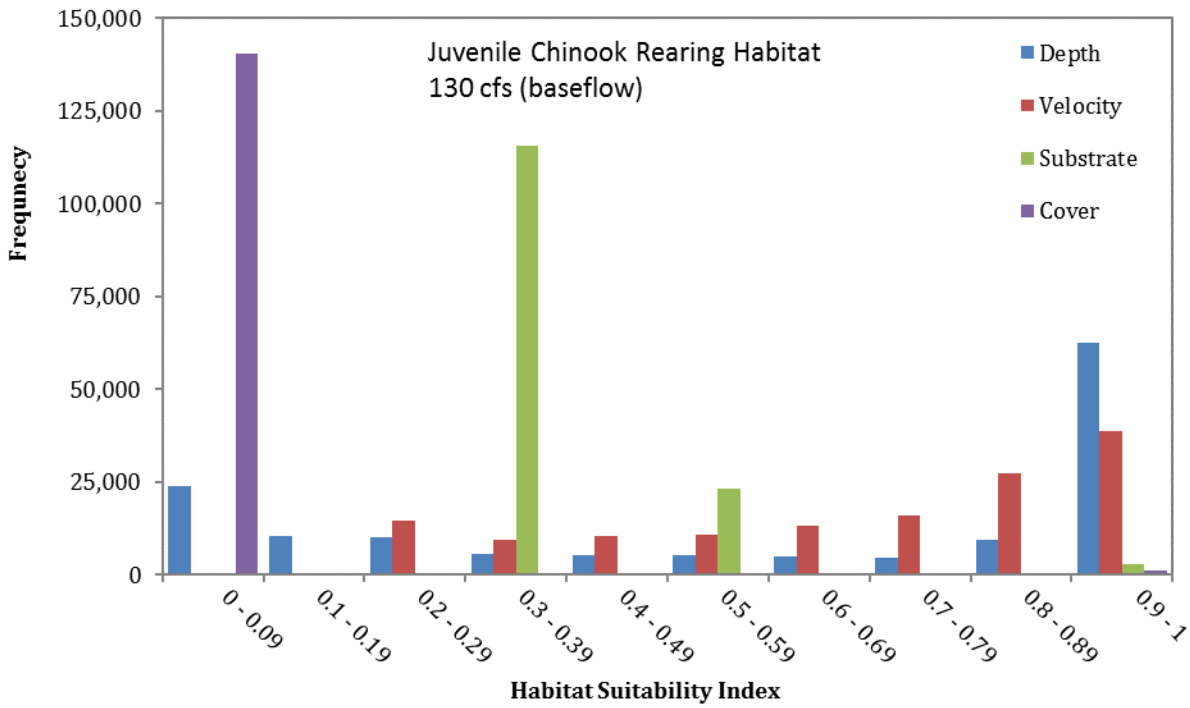

Figure 16. Frequency distribution of HSI values in Lower Icicle Creek at 130 cfs (baseflow) for individual input variables based on preference curves for juvenile spring Chinook.

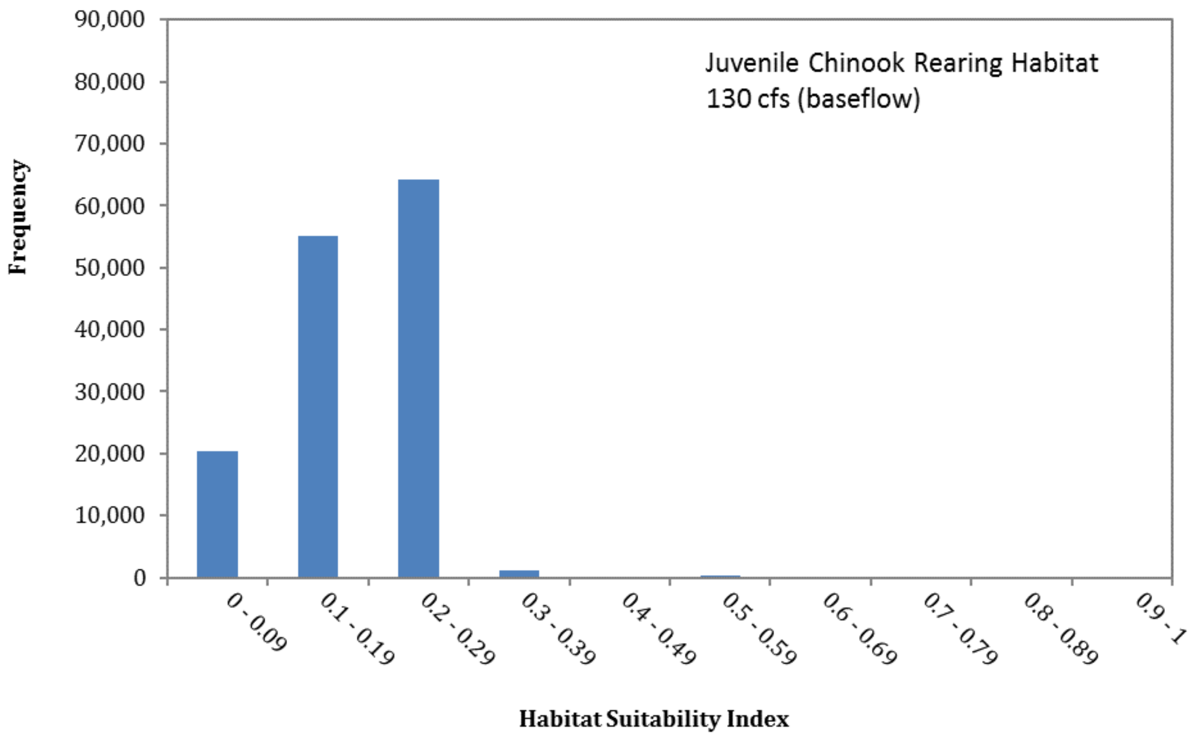

Figure 17. Frequency distribution of the composite HSI values in Lower Icicle Creek for juvenile spring Chinook rearing habitat at 130 cfs.

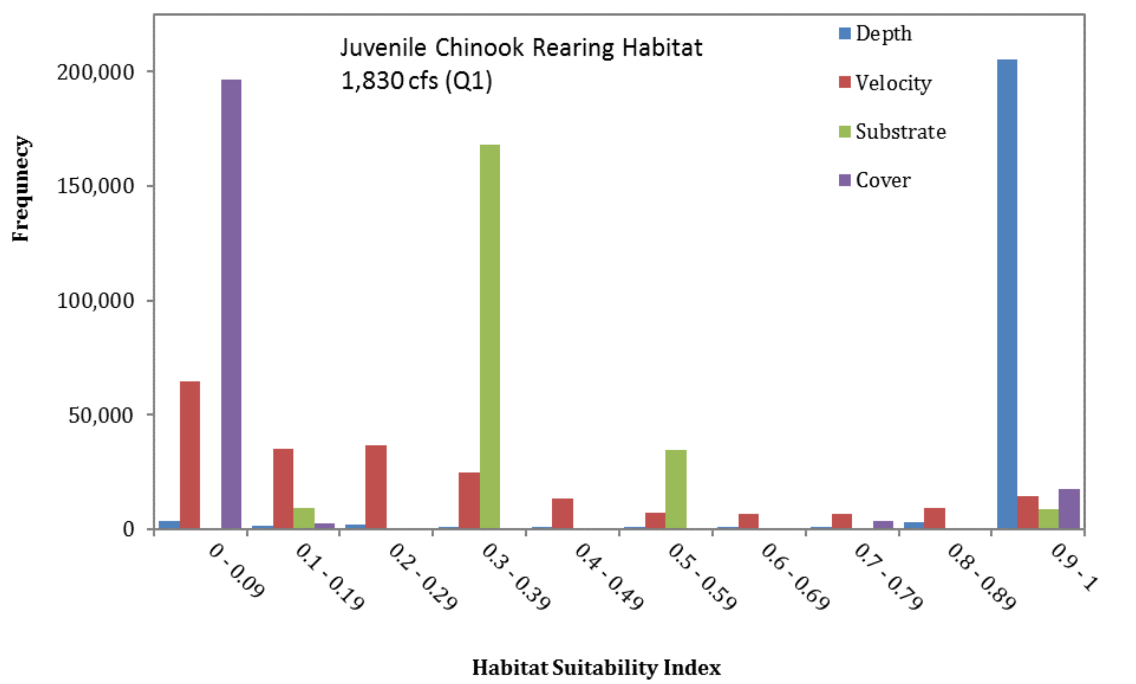

Figure 18. Frequency distribution of HSI values in Lower Icicle Creek at 1,830 cfs (baseflow) for individual input variables based on preference curves for juvenile spring Chinook.

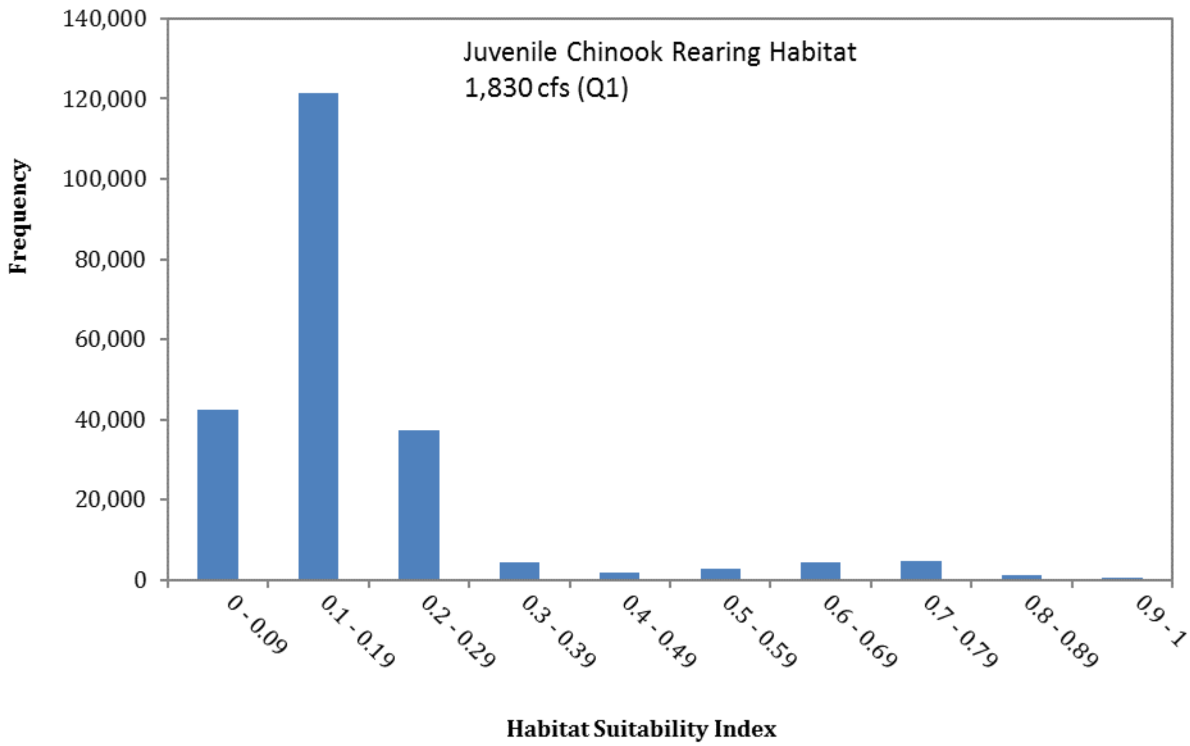

Figure 19. Frequency distribution of composite HSI values in Lower Icicle Creek for juvenile spring Chinook at 1,830 cfs.

Overall, the best juvenile rearing habitat in the lower Icicle Creek is associated with areas where lower velocities associated with cover components.

Steelhead Adult Spawning Habitat

Overall, spawning habitat for adult steelhead is good in the lower Icicle Creek project reach with an average HSI value of 0.50. As shown in the figure in Appendix B, higher quality spawning habitat typically coincides with pool tailout areas. The graphic also shows 2009 steelhead redd locations which also tend to occur in the higher HSI value areas.

Figure 20 shows the frequency of HSI values relative to the depth, velocity, and substrate values associated with spring flows. As observed in the field, substrate in riffle and glide sections of the river are well suited for steelhead spawning. Velocity is also well distributed across preferable and non-preferable values. The primary factor that reduces spawning suitability are depths exceeding 2 feet during the spring flows. This can likely be attributed to the channel incision which contains flows within the channel and increases flow depth. Optimal depths for adult steelhead spawning range from 1.8 to 2.3 feet. Typical depths in pool tailout areas during spring flows range from 3 – 5 feet.

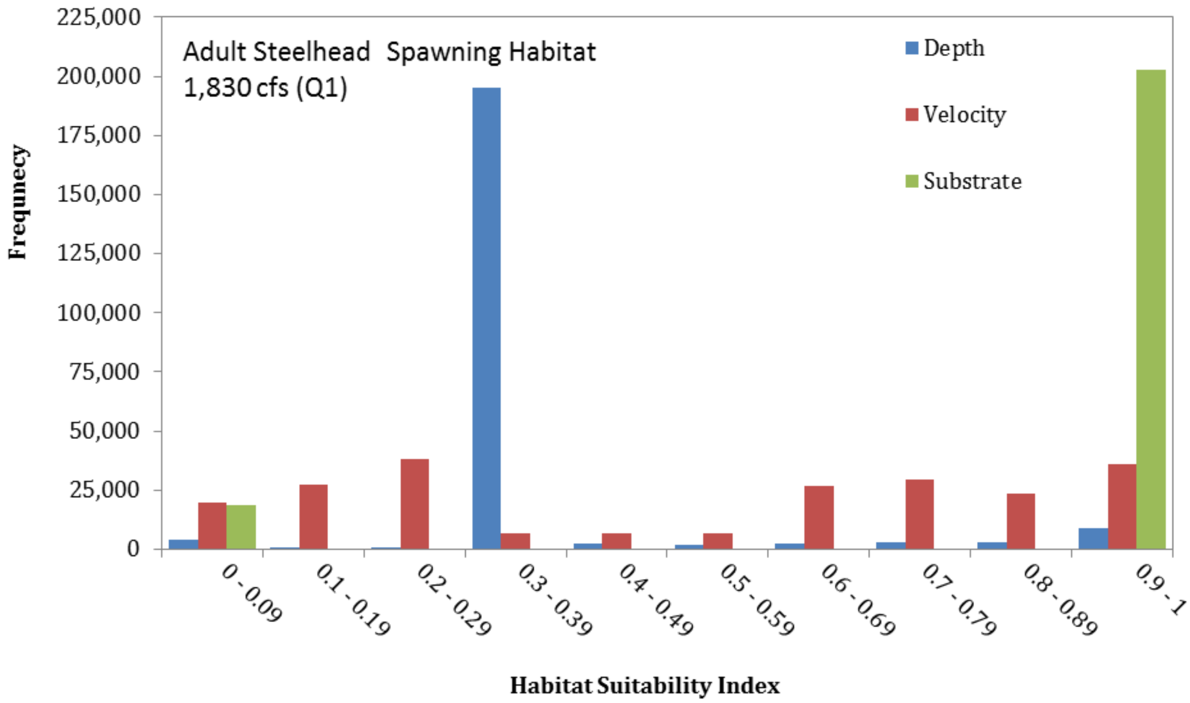

Figure 20. Frequency distribution of HSI values in Lower Icicle Creek for individual input variables based on preference curves for adult steelhead at 1,830 cfs.

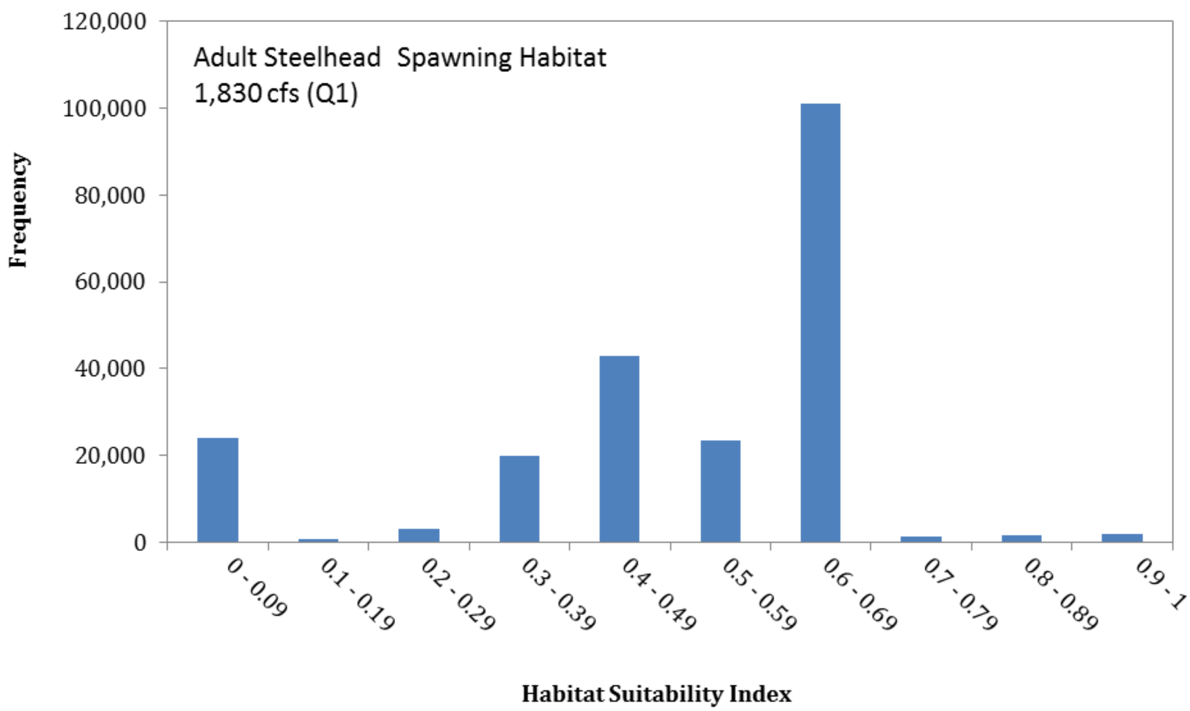

Figure 21. Frequency distribution of composite HSI values in Lower Icicle Creek for adult steelhead at 1,830 cfs.

CONCLUSIONS

The HSI analysis was able to provide an overview of the existing habitat suitability relative to steelhead spawning and rearing, and spring chinook rearing habitats within the lower 3 miles of Icicle Creek. When using the HSI output to provide a general overview of existing conditions it shows that the lower Icicle is significantly deficient in cover components which greatly reduces the quality of juvenile rearing habitats. Increasing cover in pools would significantly improve juvenile rearing in both low flow and spring flow conditions. The HSI modeling also shows a lack of off-channel habitat availability during spring flows. Increasing off-channel low velocity and deep (> 3 feet) habitats would benefit both steelhead and spring Chinook during spring floods.

HSI output for steelhead spawning showed a good correlation between higher scores and pool tailouts. The spawning habitat scores were pulled upward by the availability of good spawning gravels but were reduced due to deeper than preferred water during spring floods at the pool tailouts. Given the general lack of large wood in the channel due to historical impacts, questions remain about potential for salmonid egg pocket scour during floods. In the analysis of juvenile rearing habitat, cover values played a significant role in the relative value of the HSI output. To examine the relative influence of cover on the HSI model results, we conducted an analysis of the baseflow suitability for juvenile steelhead with and without cover as an input. With cover as an input, and with the very little cover observed in the lower Icicle, the HSI values trended between 0.1 – 0.3 in pools or areas of the river that could provide preferred rearing habitat based on flow depth and velocity preferences (Figure 22). However, these estimates may over represent the potential for cover across the reach, since the cover index score is applied for every cell in the reach. As stated earlier, we would not expect cover elements to exist everywhere in the reach, even in a reference site for this reach. Attaining the highest values for the HSI will be near impossible if the cover elements are included in the evaluation of every cell.

When the same depth, velocity, and substrate inputs were run without cover, the HSI values increased in pool areas to between 0.6 -0.8 (Figure 23). This exercise shows not only how important cover is to assessing existing habitat quality for juvenile salmonids, but also provides caution in accepting HSI model output that lacks critical input criteria; in this case the cover values.

Clearly, cover plays an important role in the quality of rearing habitat for juveniles and also holding habitat for adult fish. However, the application of a cover index in every cell in the reach is not a reasonable expectation for habitat function. An improvement in the analysis approach could include weighting the cover benefit scores for each cell by a cover probability rating, where by areas in the reach that are more likely to have cover elements (e.g. depositional areas, stable banks on the outside of bends, high points in the main channel that could be catch points for large wood) would be included in the cover analysis, and those areas of the reach with a low probability of catching and retaining cover elements would be excluded from the cover index scoring. This would allow for a more realistic assessment of the influence of cover in this reach, as compared to a reference condition.

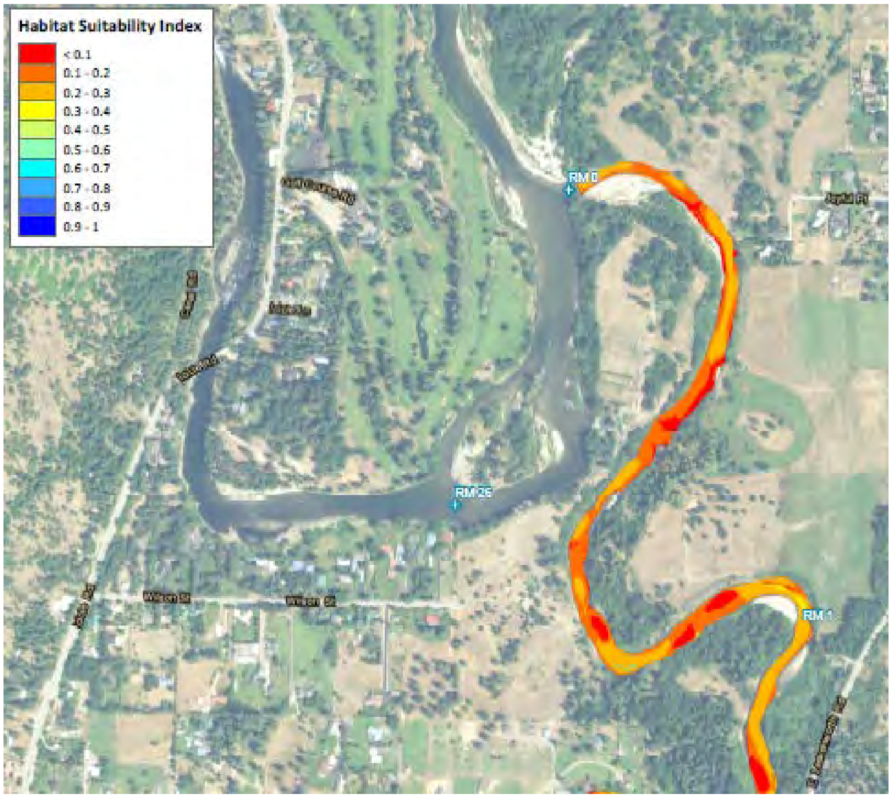

Figure 22. HSI values for juvenile steelhead during baseflow (130 cfs) conditions with depth, velocity, substrate, and cover inputs.

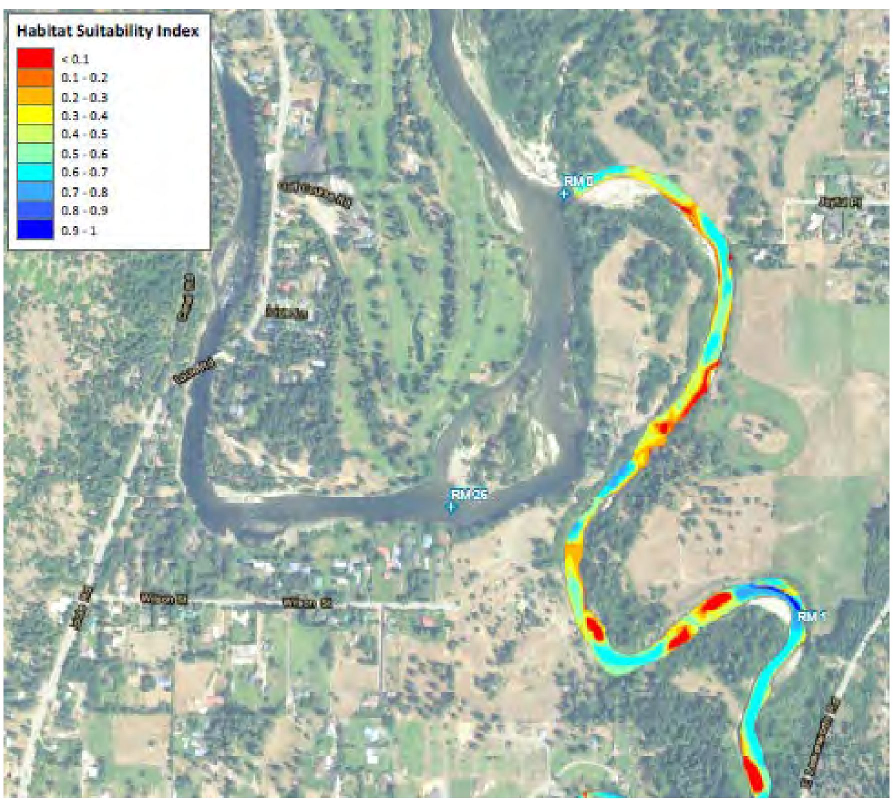

Figure 23. HSI values for juvenile steelhead during baseflow (130 cfs) conditions without cover inputs.

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Appendix A

Hydraulic Figures

Natural Systems Design

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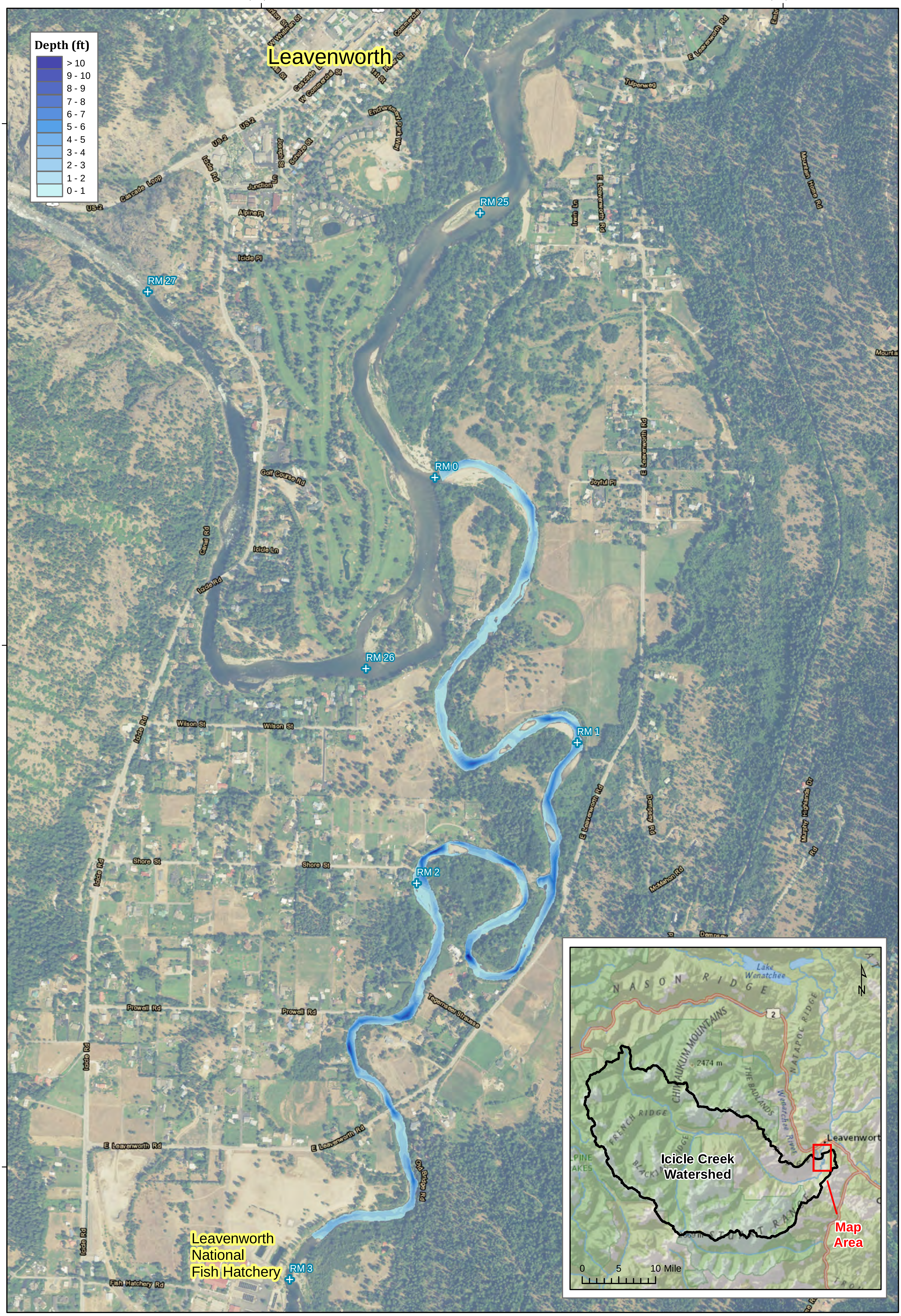

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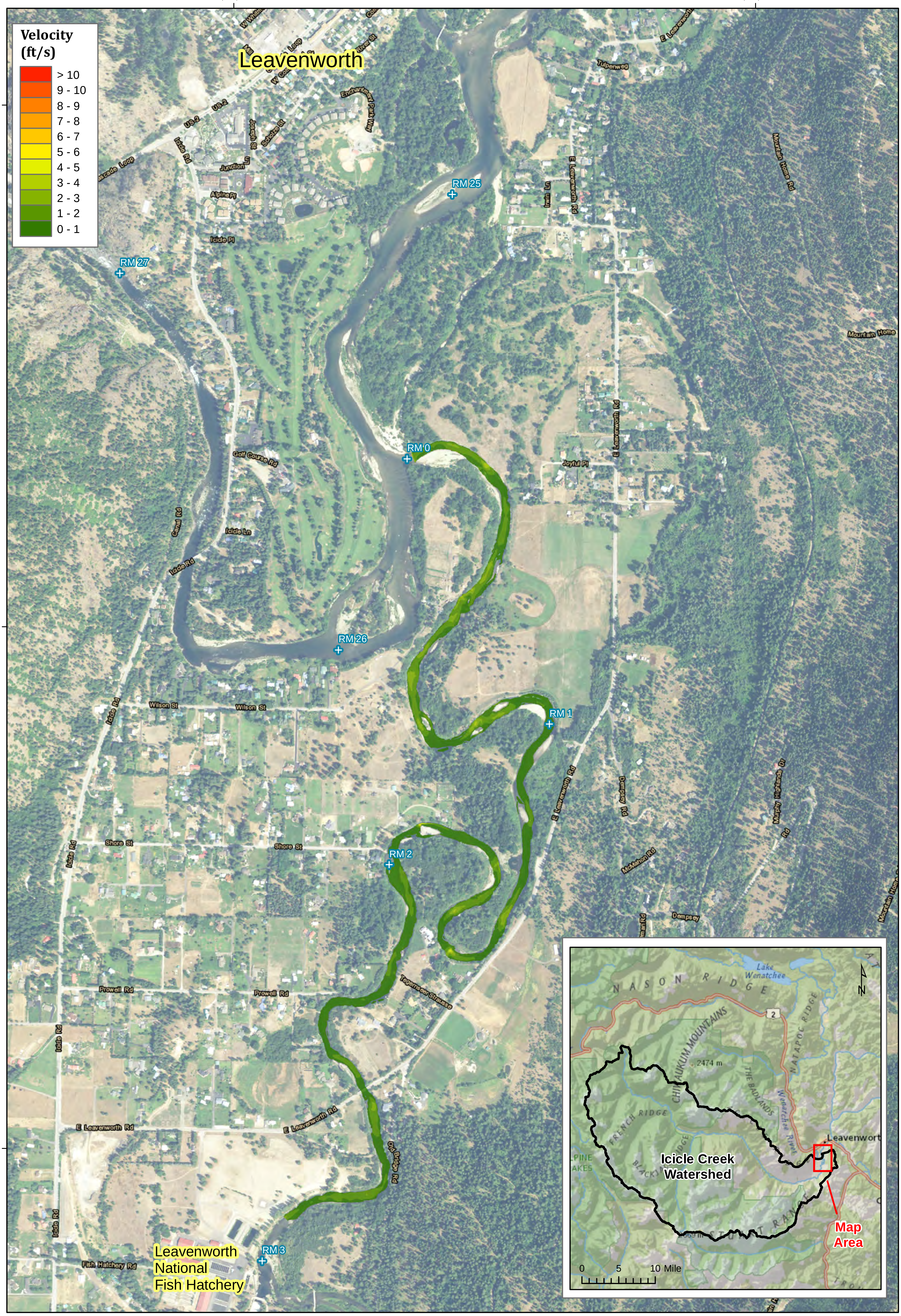
Icicle Creek

Hydraulic Model Output -
Baseflow (130 cfs) Flow Depth

0 1,000 2,000 3,000 4,000

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (WA North Zone)

Natural Systems Design



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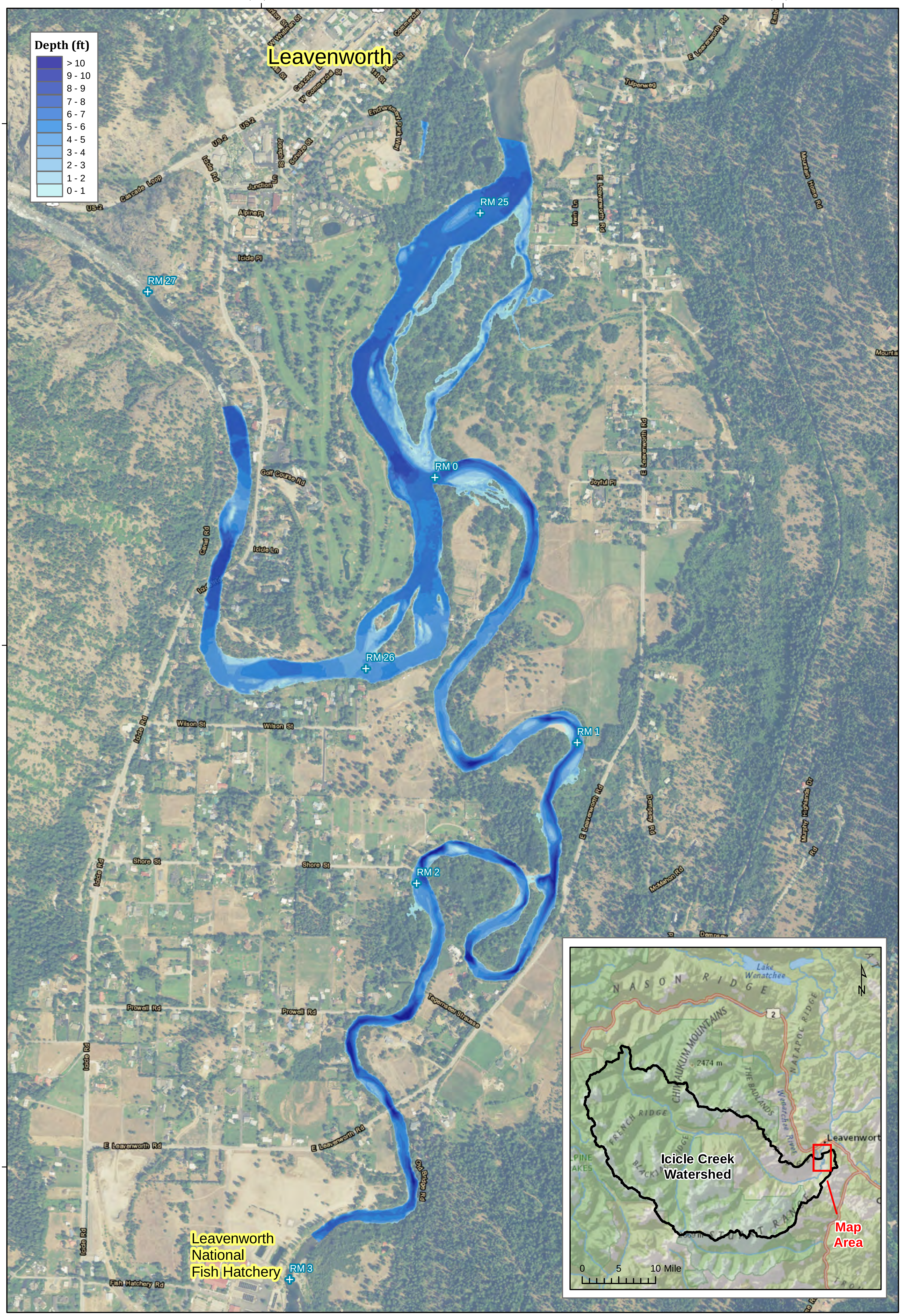
Icicle Creek

Hydraulic Model Output -
Baseflow (130 cfs) Flow Velocity

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (WA North Zone)

Natural Systems Design



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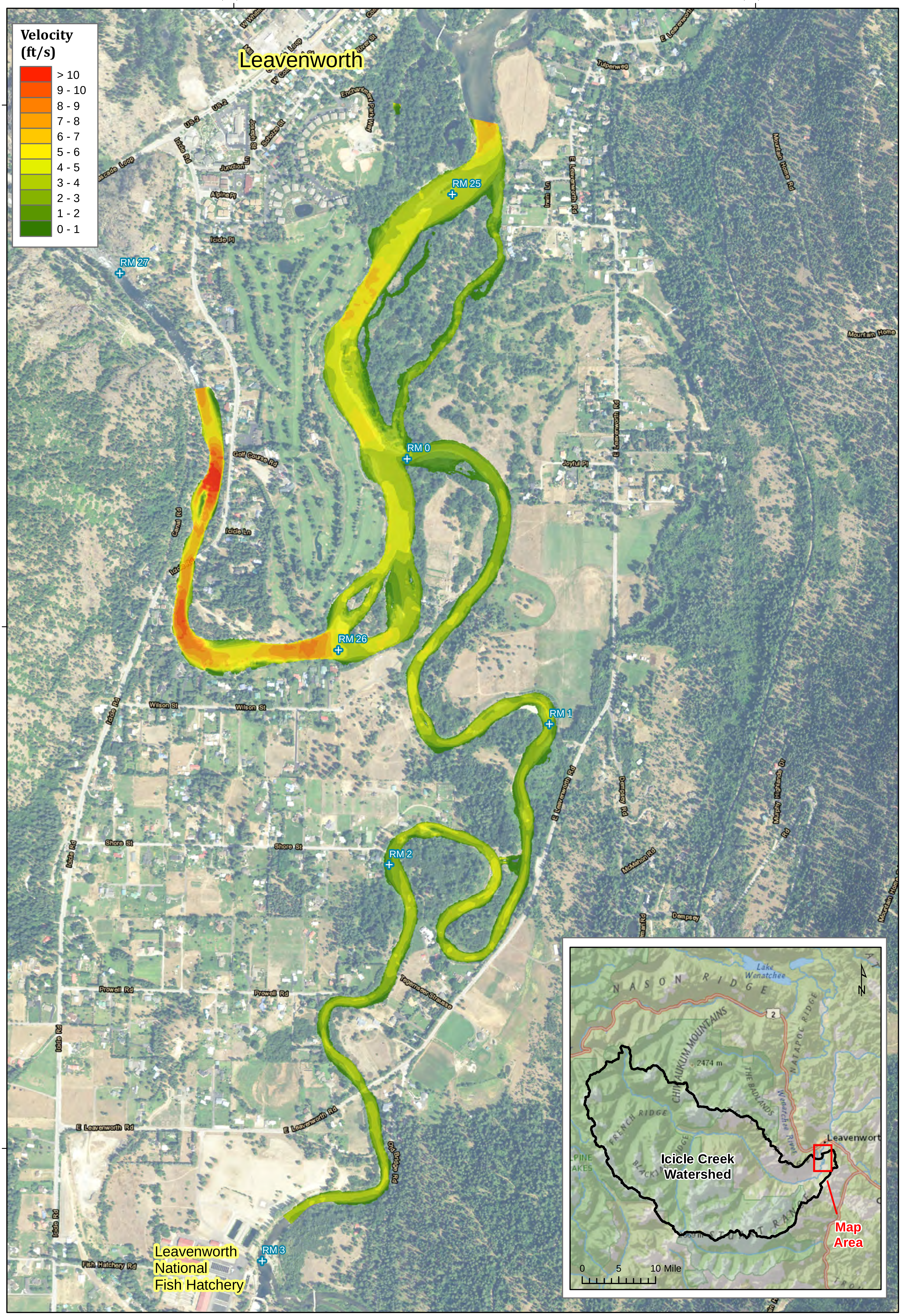
Icicle Creek

Hydraulic Model Output -
Spring Runoff (1830 cfs cfs) Flow Depth

0 1,000 2,000 3,000 4,000

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (WA North Zone)

Natural Systems Design



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Icicle Creek

Hydraulic Model Output -
Spring Runoff (1830 cfs) Flow Velocity

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (WA North Zone)

Natural Systems Design

Appendix B

HSI Model Output

Natural Systems Design

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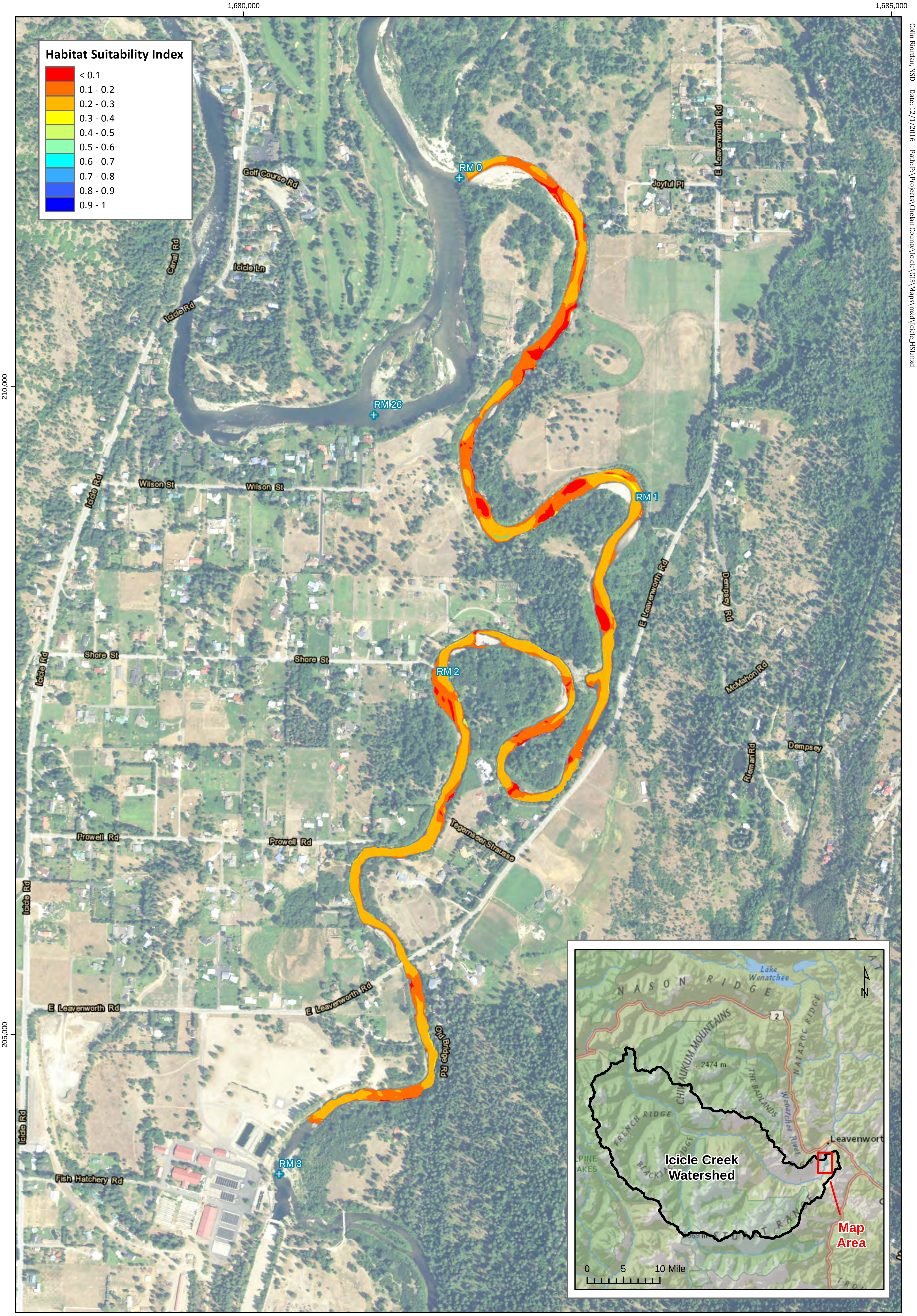

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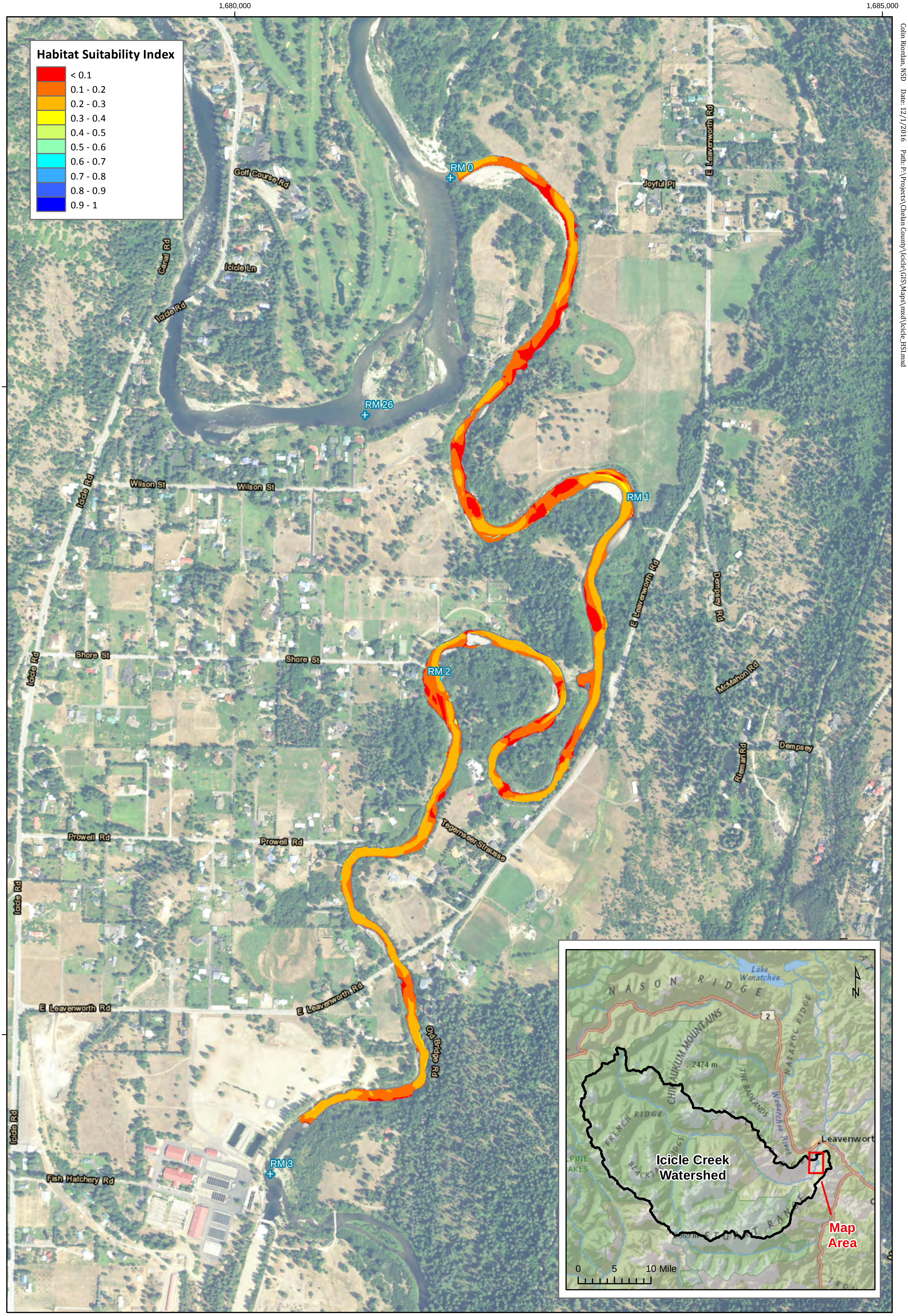
0 1,000 2,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (WA North Zone)

Icicle Creek

Steelhead juvenile rearing habitat
Summer base flow 130 cfs

Natural Systems Design



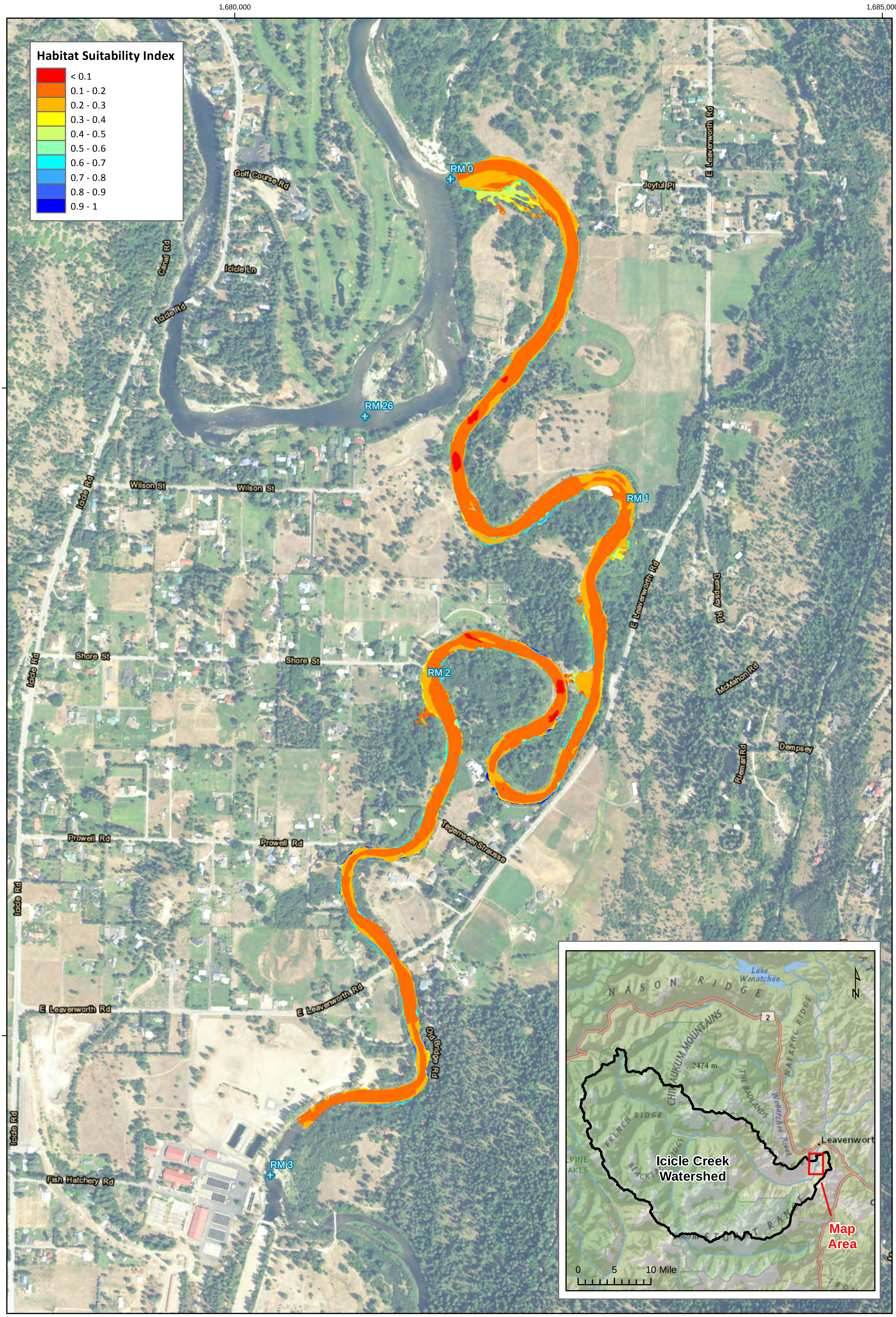
Icicle Creek

Chinook juvenile rearing habitat
Summer base flow 130 cfs

0 1,000 2,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (WA North Zone)

Natural Systems Design



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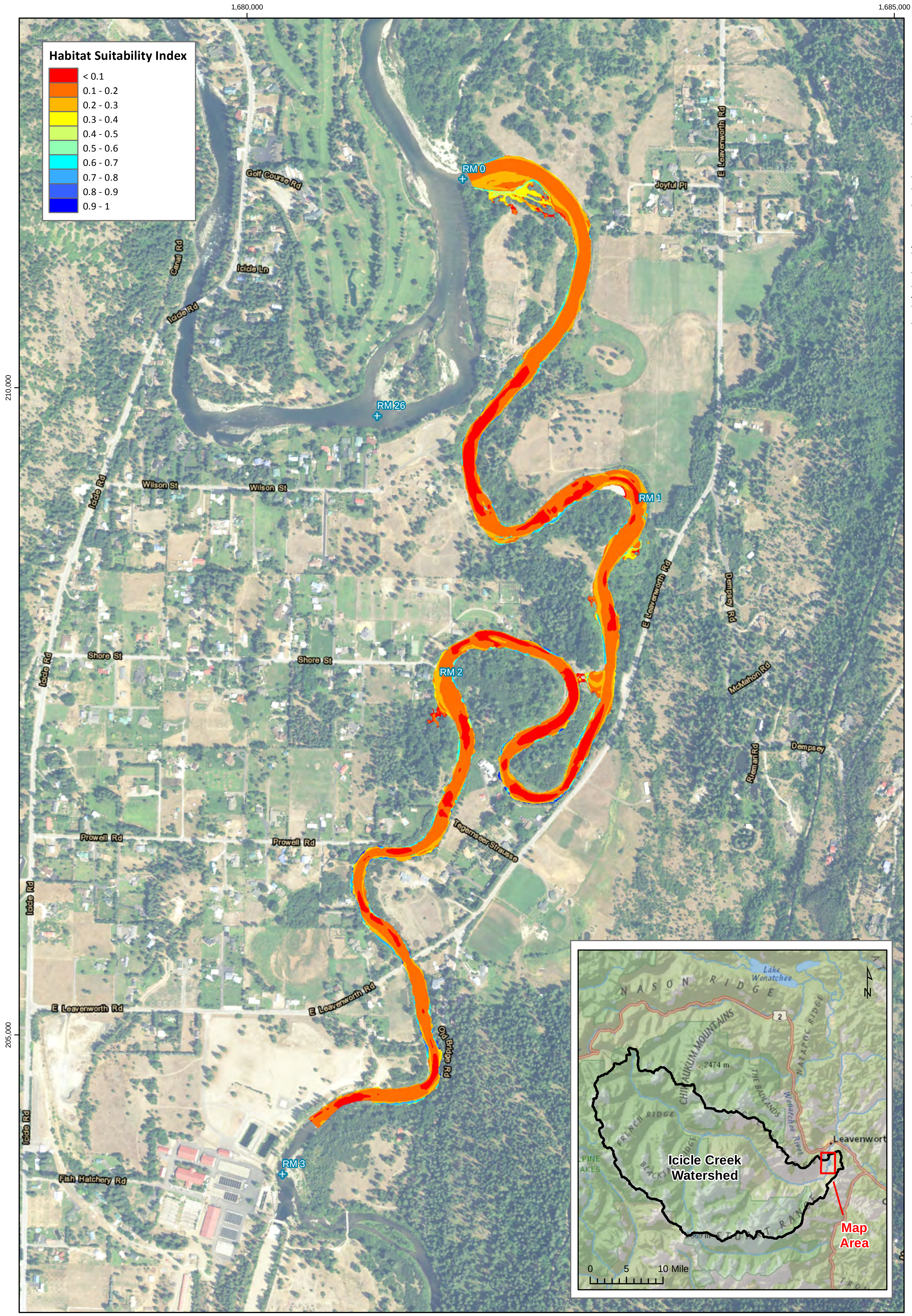
0 1,000 2,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (WA North Zone)

Natural Systems Design

Icicle Creek

Steelhead juvenile rearing habitat
Spring runoff flow (Q1) 1830 cfs



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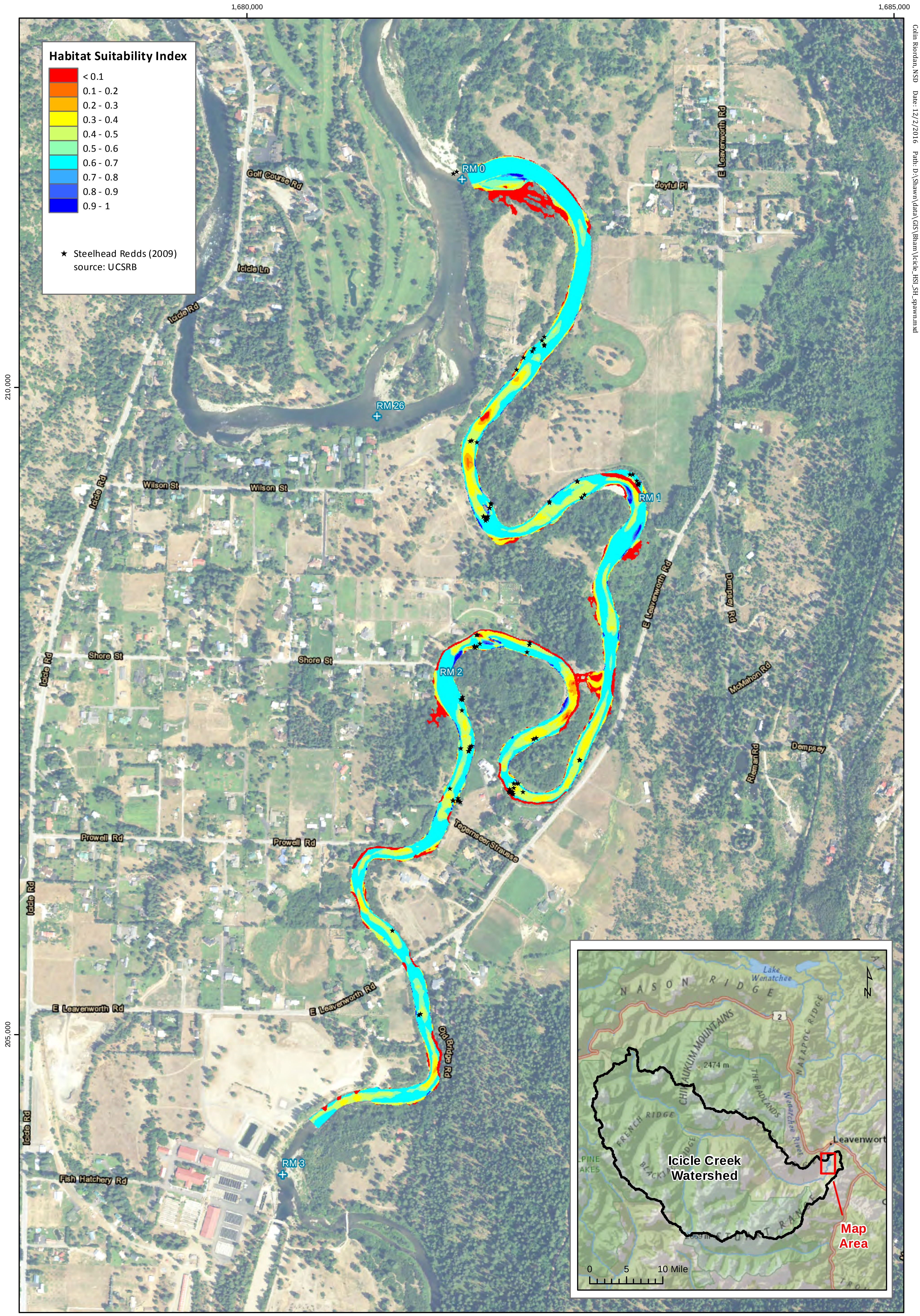
Icicle Creek

Chinook juvenile rearing habitat
Spring runoff flow (Q1) 1830 cfs

0 1,000 2,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (WA North Zone)

Natural Systems Design



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Icicle Creek

Steelhead spawning habitat
Spring runoff flow (Q1) 1,830 cfs

0 1,000 2,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (WA North Zone)

Natural Systems Design

Appendix C

Hydraulic Model Simulation Results

Natural Systems Design

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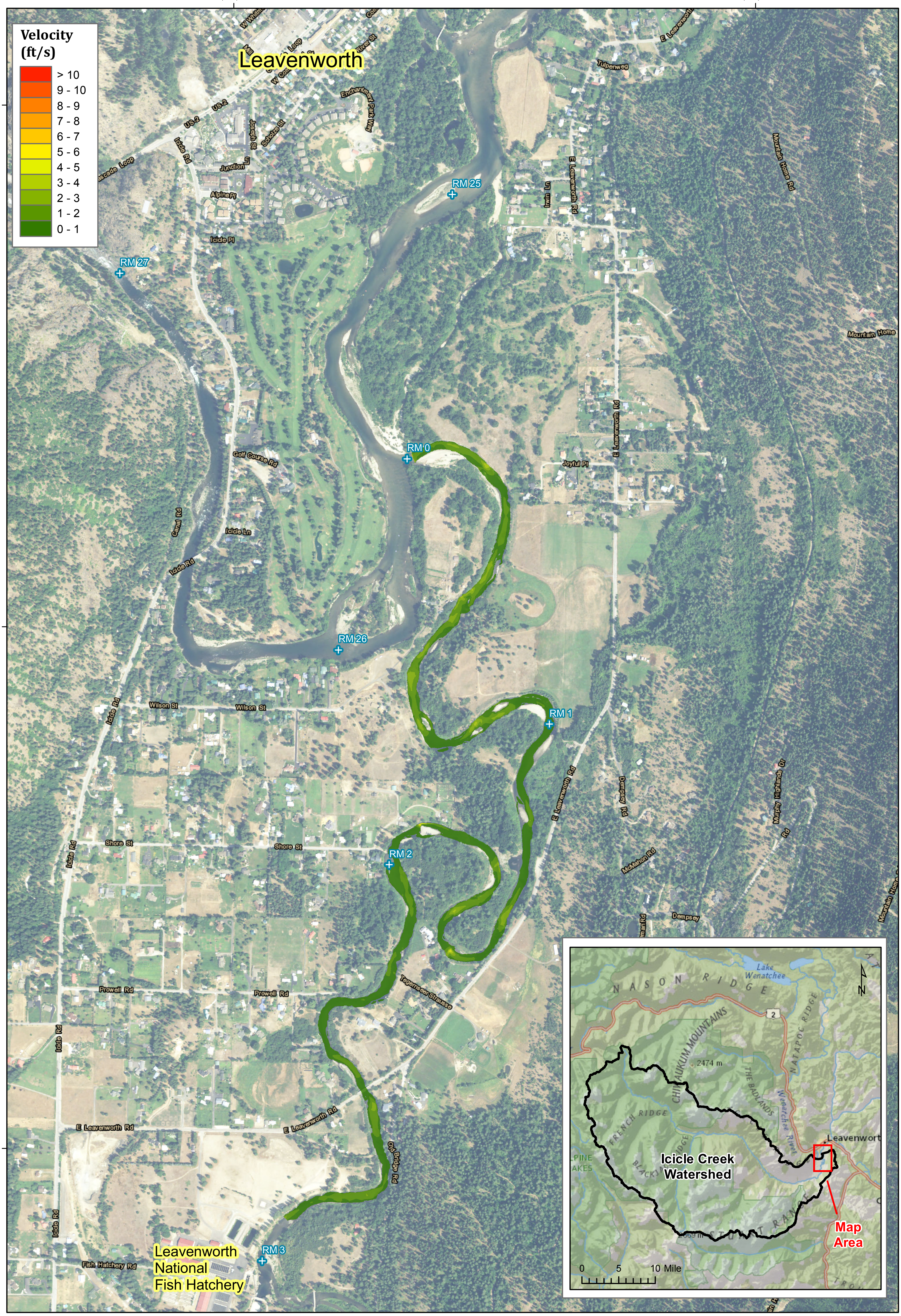
0 1,000 2,000 3,000 4,000

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (WA North Zone)

Natural Systems Design

Icicle Creek

Hydraulic Model Output - Baseflow (130 cfs) Flow Depth



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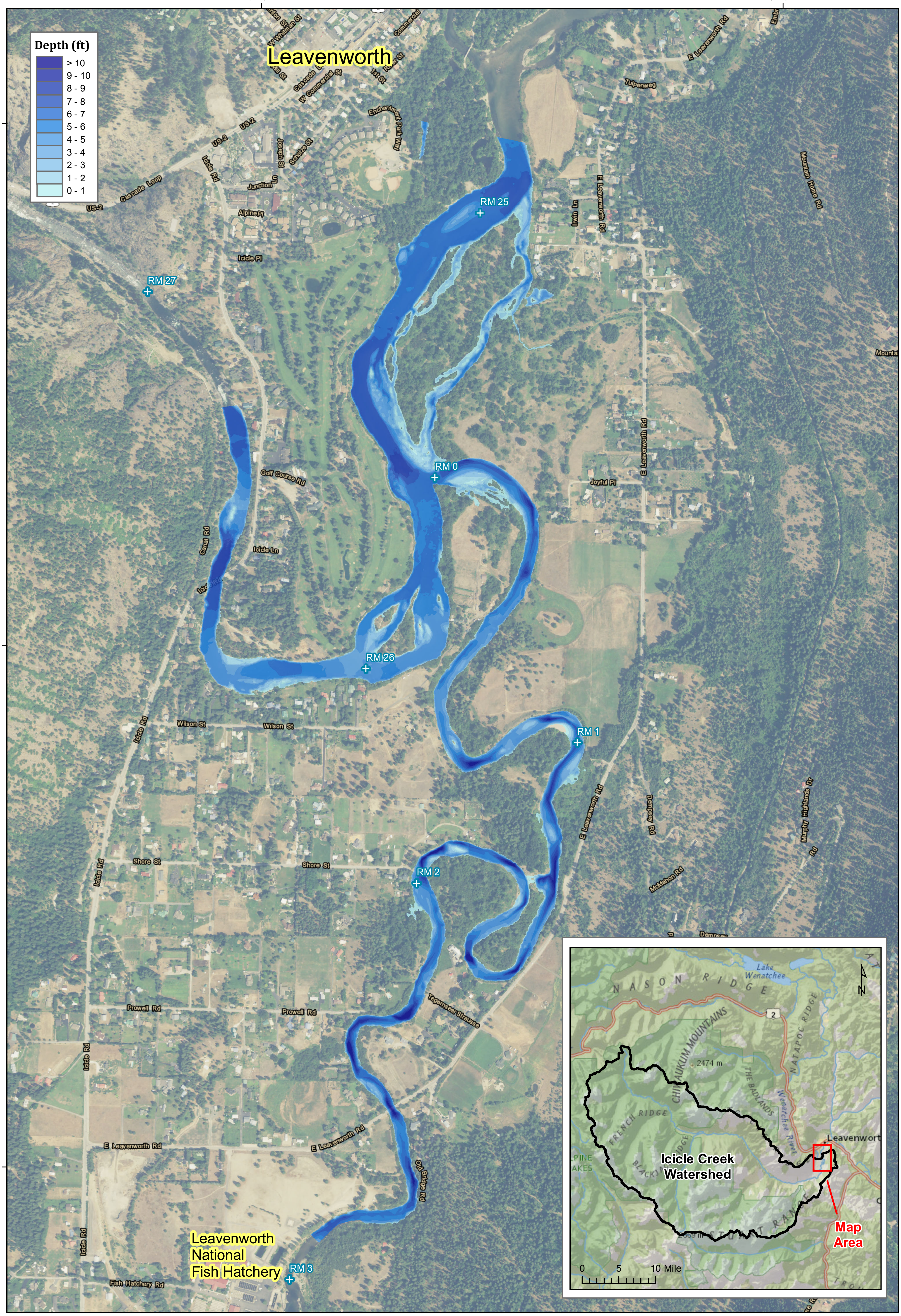
Icicle Creek

Hydraulic Model Output - Baseflow (130 cfs) Flow Velocity

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (WA North Zone)

Natural Systems Design



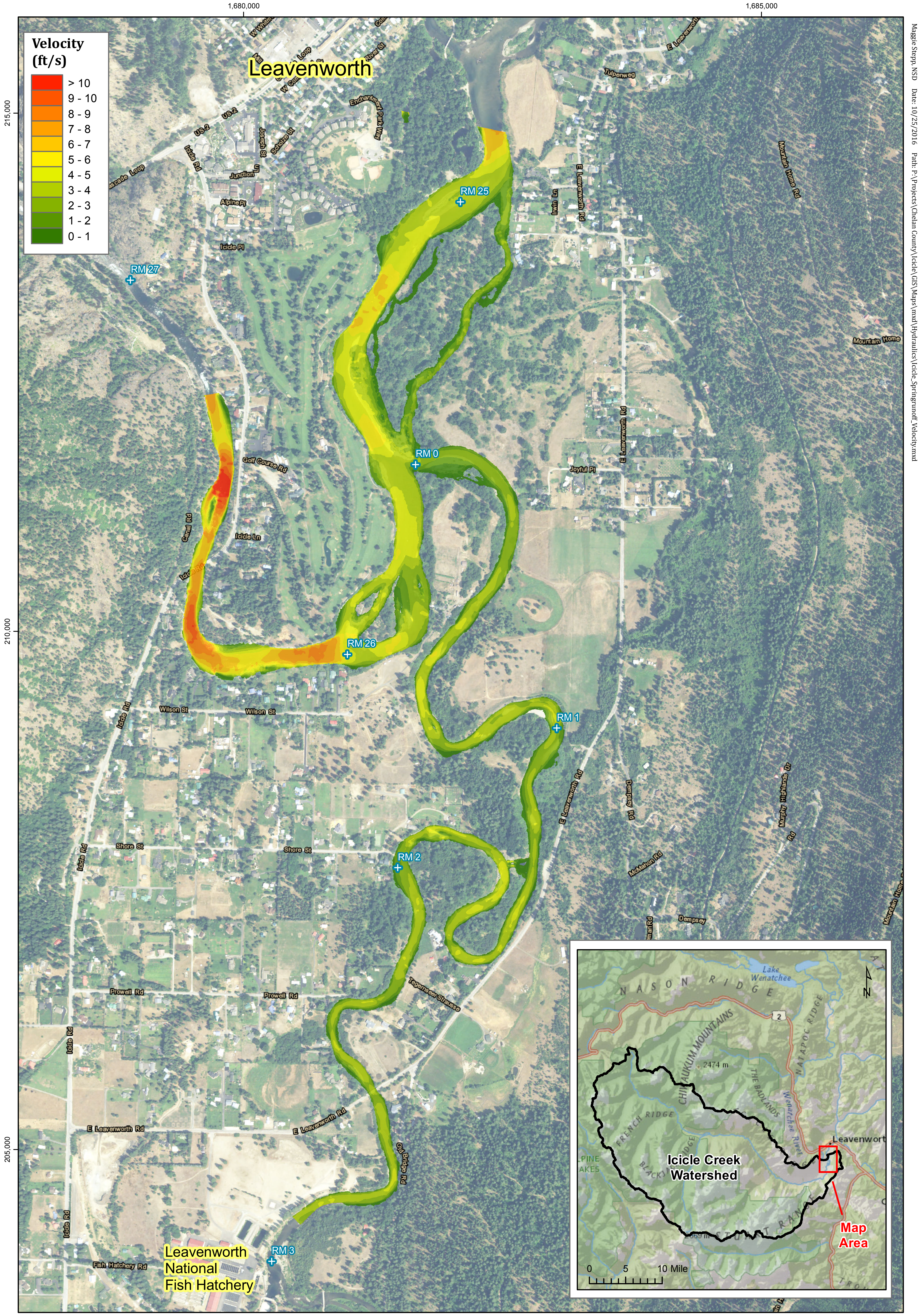
Icicle Creek

Hydraulic Model Output -
Spring Runoff (1830 cfs cfs) Flow Depth

0 1,000 2,000 3,000 4,000

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (WA North Zone)

Natural Systems Design



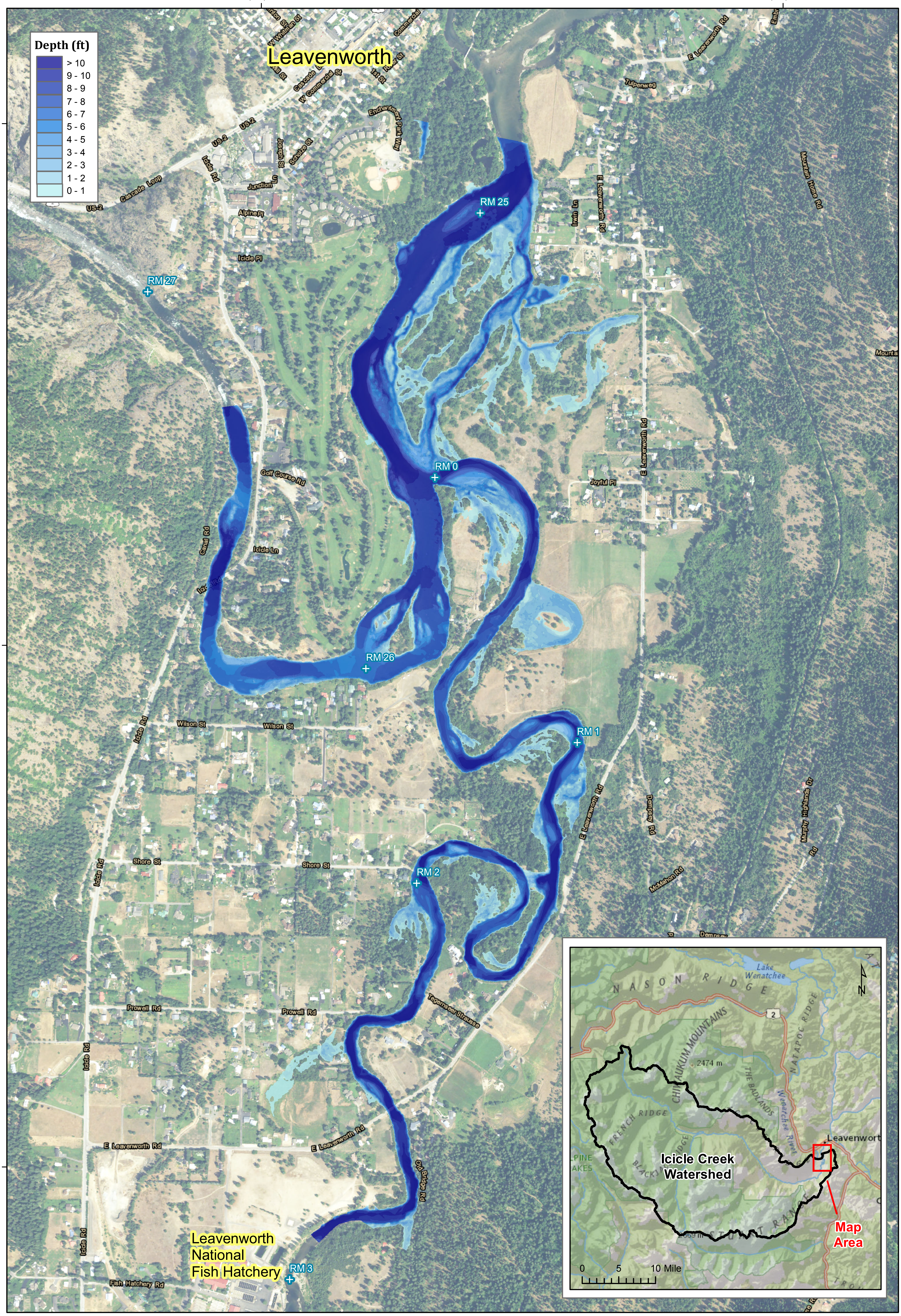
Icicle Creek

Hydraulic Model Output -
Spring Runoff (1830 cfs) Flow Velocity

0 1,000 2,000 3,000 4,000

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (WA North Zone)

Natural Systems Design



Icicle Creek

Hydraulic Model Output -
2 Year (4450 cfs) Flow Depth

0 1,000 2,000 3,000 4,000

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (WA North Zone)

Natural Systems Design

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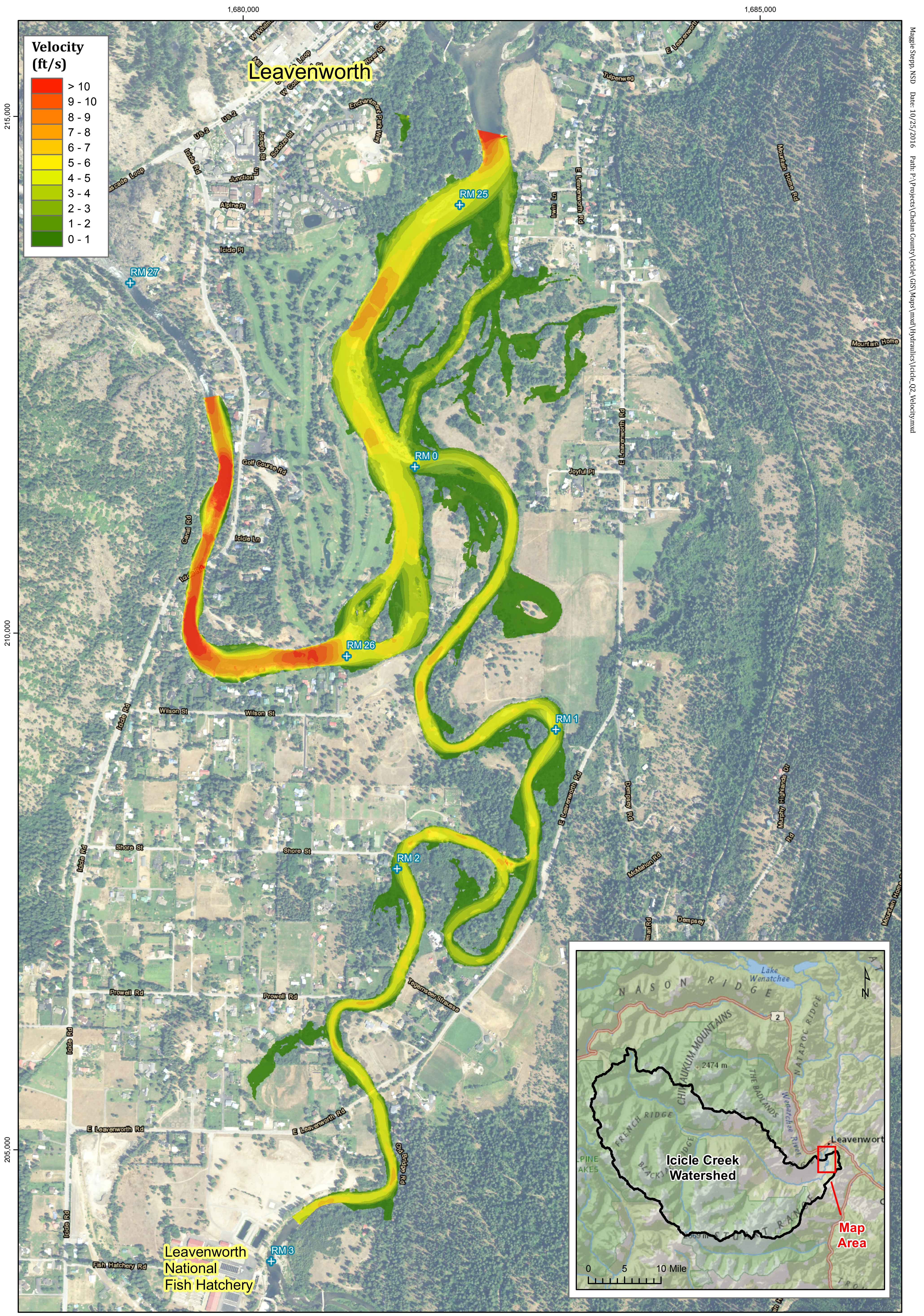


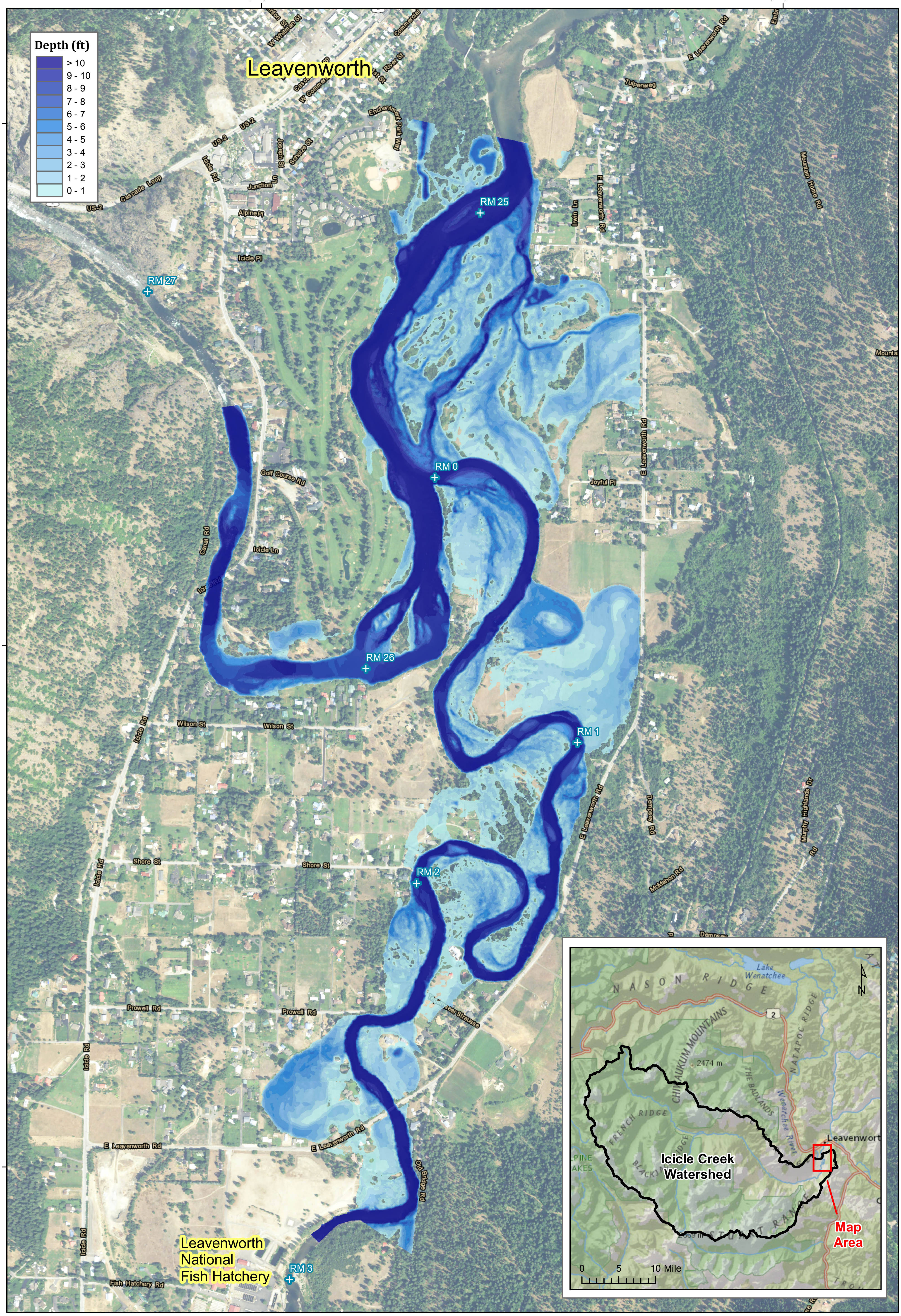
Icicle Creek

Hydraulic Model Output -
2 Year (4450 cfs) Flow Velocity

0 1,000 2,000 3,000 4,000

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (WA North Zone)

Natural Systems Design



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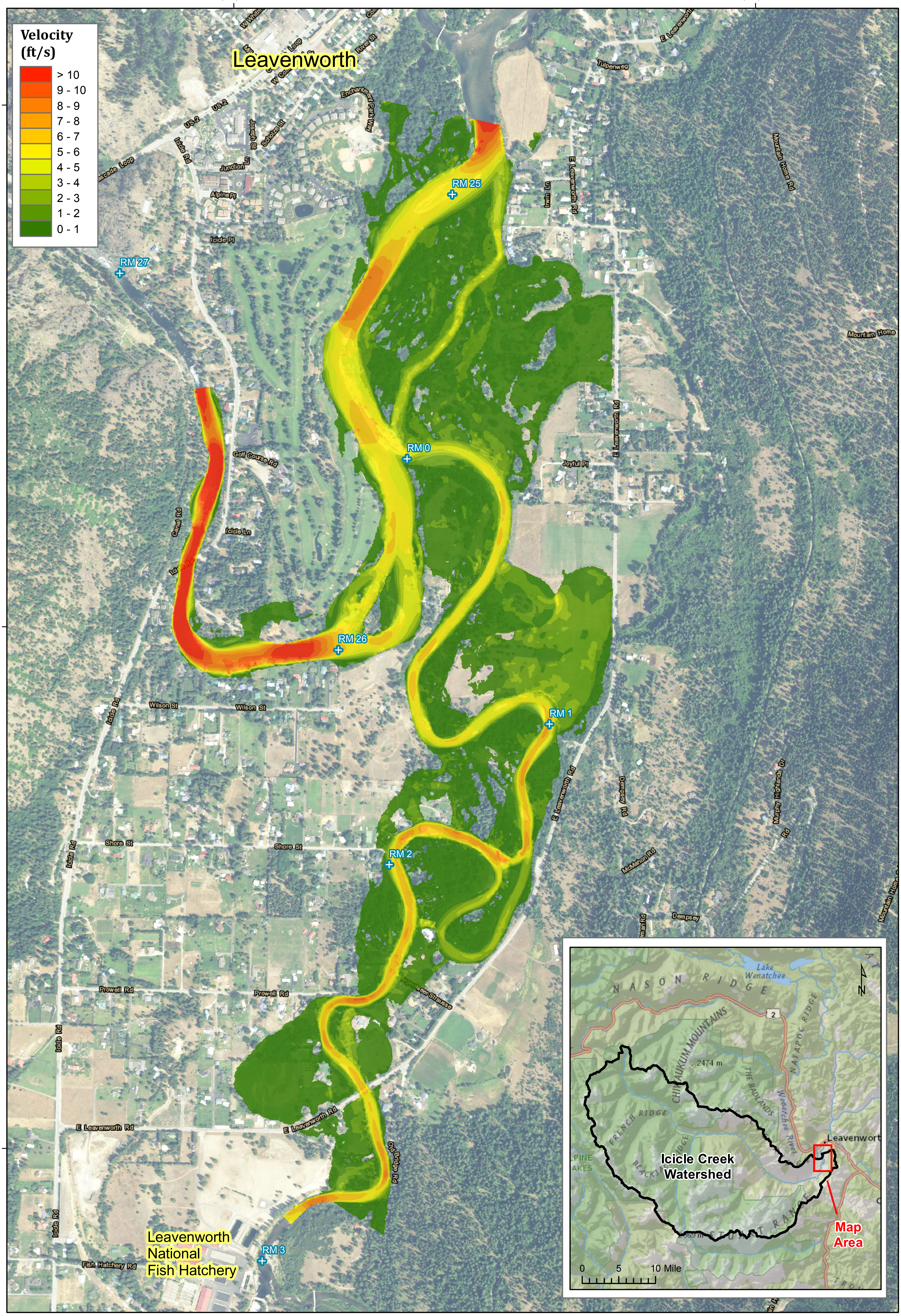
Icicle Creek

Hydraulic Model Output -
10 Year (8300 cfs) Flow Depth

0 | 1,000 | 2,000 | 3,000 | 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (WA North Zone)

Natural Systems Design



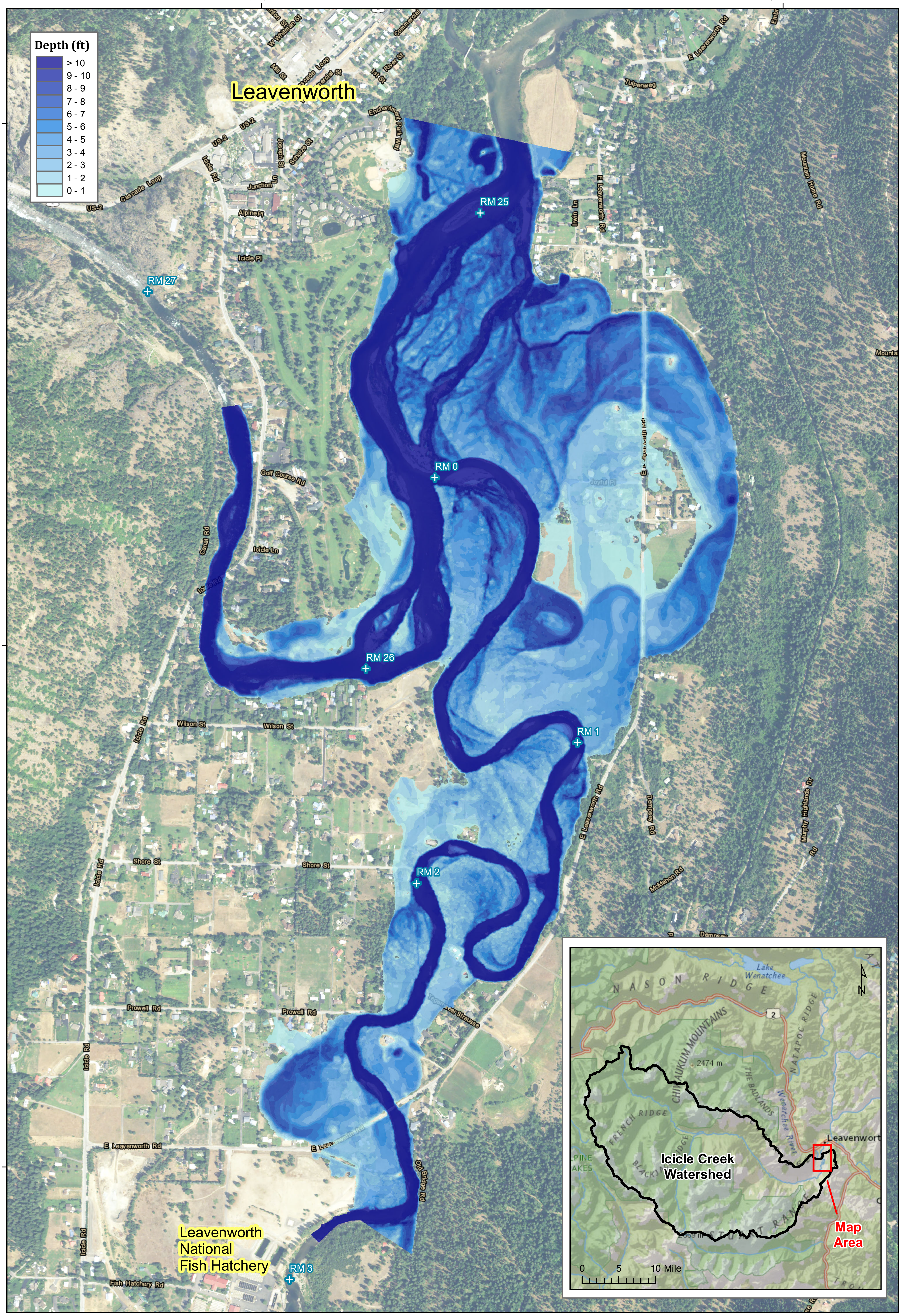
Icicle Creek

Hydraulic Model Output - 10 Year (8300 cfs) Flow Velocity

0 1,000 2,000 3,000 4,000

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (WA North Zone)

Natural Systems Design



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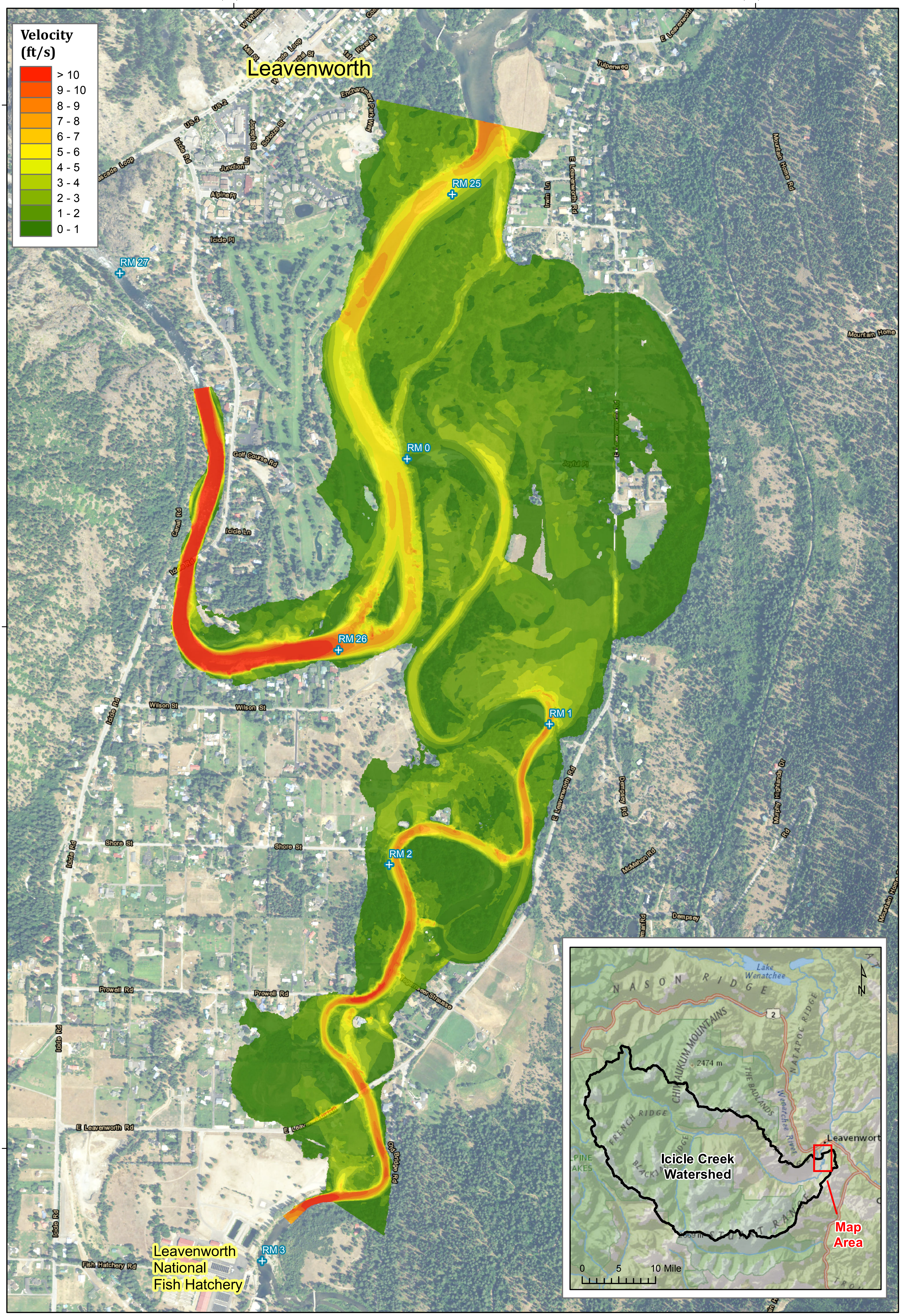
0 1,000 2,000 3,000 4,000

Natural Systems Design

Icicle Creek

Hydraulic Model Output -
100 Year (15200 cfs) Flow Depth

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (WA North Zone)



Icicle Creek

Hydraulic Model Output -
100 Year (15200 cfs) Flow Velocity

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (WA North Zone)

Natural Systems Design

Appendix D

Hydraulic Analysis Technical Supplement

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TECHNICAL SUPPLEMENT: HYDRAULIC ANALYSIS

Methods

A two-dimensional hydraulic model was conducted for baseflow, typical spring run-off, and 2 year, 10 year, and 100 year peak flow discharges described in the hydrologic analysis (Section 4) and below in the methods section (Section 5.2. All model runs were performed in steady state (discharge does not vary with time) with a non-deformable bed (no adjustments for scour, sediment transport or deposition). Hydraulic models were created to be representative of existing conditions using the Hydronia's RiverFlow-2D Plus GPU and Aquaveo SMS v12.1 computer software. RiverFlow-2D is a two-dimensional finite element computer model that provides depth averaged hydraulic parameters at nodes within a triangular model mesh domain. RiverFlow-2D determines depth averaged hydraulic parameters by solving the shallow water equations resulting from the integration of the Navier-Stokes equation. The Navier Stokes equation is derived from applying Newton's Second Law (Force = mass*acceleration) to fluid motion, and is generally expressed as:

$$\overbrace{\rho\Big(\underbrace{\frac{\partial \mathbf{v}}{\partial t}}_{\substack{\text{Unsteady}\\ \text{acceleration}}} + \underbrace{\mathbf{v}\cdot\nabla\mathbf{v}}_{\substack{\text{Convective}\\ \text{acceleration}}}\Big)}^{\text{Inertia (per volume)}} = \overbrace{\underbrace{-\nabla p}_{\substack{\text{Pressure}\\ \text{gradient}}} + \underbrace{\mu\nabla^2\mathbf{v}}_{\text{Viscosity}}}^{\text{Divergence of stress}} + \underbrace{\mathbf{f}}_{\substack{\text{Other}\\ \text{body}\\ \text{forces}}}.$$

Where ρ = fluid density

μ = dynamic viscosities

p = pressure

$\nabla =$ *del operator* (abbreviation for derivative (gradient) of 3D vector field)

f = term representing body forces acting on the fluid (per unit volume)

SMS is a GIS-based program that creates the triangular model mesh, model input files, and displays model results. The following sections provide more in-depth information on specific components of our hydraulic analysis, data development, and results. Actual model results and figures are provided in Appendix A.

Model Topography

All hydraulic models utilized a composite surface developed in AutoCAD Civil3D computer software. The surface is comprised of near infrared LiDAR data collected by Quantum Spatial, Inc. between 7/31/15-10/15/15 (Quantum Spatial, 2016), and real time kinetic (RTK) topographic survey data collected in wetted channel areas by NSD on 9/7/16-9/8/16. The surface data were then combined in Civil3D, using survey data where the LiDAR sensor did not capture channel bathymetry due to the limited water penetrating abilities of traditional (near infrared) LiDAR. Bathymetry was created by interpolating a thalweg, channel toes, and other grade breaks, from survey data points, using high resolution aerial imagery as a guide in areas of limited survey data points. The LiDAR water surface extents were used as a daylight line to mesh the bathymetry surface into the LiDAR surface and form the wetted channel banks. The horizontal and vertical datum of all data utilized and referenced in this report is Washington State Plane Coordinates North Zone NAD83 ft and NAVD 88 ft, respectively.

Computational Mesh

A mesh or wireframe is a key component to any 2D hydraulic model. The model derives one depth-averaged flow velocity (direction and magnitude) at each node of the 2D (x-y) mesh. To predict vertical variations in flow within the water column would require a 3D model. The mesh is composed of nodes and elements that are coded with elevation and roughness values needed to run the computational routine. RiverFlow-2D utilizes a flexible tri-angular mesh to solve for volume conservation and momentum in the x and y directions at each node (representing depth average).

There were two model meshes utilized for this project – 1 for baseflow conditions and 1 for high flow conditions. The baseflow condition assesses only the project reach while the high flow conditions incorporate an inflow from the Wenatchee River. This was done in order to accurately assess hydraulics near the junction of Icicle Creek and the Wenatchee River. The model mesh on Icicle Creek begins near RM 2.9 directly downstream from Leavenworth National Fish Hatchery's spillway and extends downstream 2.9 miles to the confluence of Icicle Creek and the Wenatchee River. The model mesh on the Wenatchee River begins near RM 26.5 in a valley constrained portion of the river adjacent to Icicle Rd. The mesh extends downstream past the confluence with Icicle Creek to RM 24.5 near Enchantment Park. For this project the base flow model mesh utilized 812,552 triangular elements and 407,289 nodes and high flow model mesh utilized 981,266 triangular elements and 491,656 nodes. The governing equations are applied at each node in an iterative routine until converging on a solution that achieves conservation of mass and energy to within an acceptable error.

To create the model mesh, a map consisting of arcs and regions delineating the channel, floodplain features, and material types was developed using Aquaveo's SMS software. Arcs were drawn along significant topographic features (top of bank, bars, side channels, roadways) and changes in roughness (forest type, riprap, grass pasture areas). Arcs function as breaklines during the mesh creation process to ensure the model mesh is an accurate representation of the channel/floodplain topography and to create regions within the map to which different roughness values can be assigned. The spacing of nodes along an arc also functions to affect the density or refinement of the model mesh. The level of refinement of a model mesh is an important consideration during 2D modeling, as a finer (more dense) mesh creates a more accurate representation of the channel and floodplain topography and reduces model instability issues, but increases model computation time. For this project, the spacing of nodes along each arc was adjusted to increase node density in areas of interest to between 5- and 10-ft (main channel, riprap, gravel bars etc.) and reduced in other regions to between 20- to 30-ft (outer edge of floodplain, forest regions, etc.). In this way, the model mesh was optimized to provide detailed information in areas of interest while also balanced with reduced computational times to increase the number of model iterations.

Calibration and Roughness

The model was calibrated by iteratively adjusting the roughness estimate of the channel to improve agreement between modeled and observed water surface elevations (WSE). Water surface elevations were measured along the channel thalweg for the baseflow model scenario by NSD on 9/7/16-9/8/16. These measurements correspond to the measured discharge used as an input to the baseflow scenario described in the hydrologic analysis section above and allow for detailed calibration of the hydraulic model.

Hydraulic analyses require an assessment of the resistance (drag force) the ground surface and other physical features exert against the movement of water. This drag force is commonly referred to as roughness. The most accepted method to assess roughness uses the Manning's n resistance factor (Chow, 1959). Common factors that affect roughness values include: channel sediment size, gradation, and shape; channel shape, channel meandering, bank and floodplain vegetation, obstructions to flow, flow depth, and flow rate. 2D hydraulic models explicitly calculate momentum losses caused by channel shape, meandering, and floodplain topography not normally accounted for in 1D hydraulic models. As such, Manning's n values in 2D models can generally be lower (up to 30%) than those normally used for 1D hydraulic models.

Manning's n values for this project were assigned to different roughness types using a hillshade image derived from the composite surface and 2014 aerial imagery from the USDA National Agriculture Imagery Program (NAIP) and in accordance with standard hydraulic reference manuals (Barnes, 1967; Chow, 1959; Hicks and Mason, 1998). Initial values of the channel were then iteratively adjusted until there was sufficient agreement between the modeled and measured WSE. The root mean square error of the calibrated measured vs. modeled WSE for the final channel roughness value was 0.25 ft and the average residual was -0.13 ft (Figure C-1). During the calibration process, a higher channel roughness value was chosen for the portion of the project reach above RM 2.45 in order to reach better agreement with the measured values.

Model roughness values are shown in Table C-1 below. These calibrated values were used for the additional higher flow scenarios.

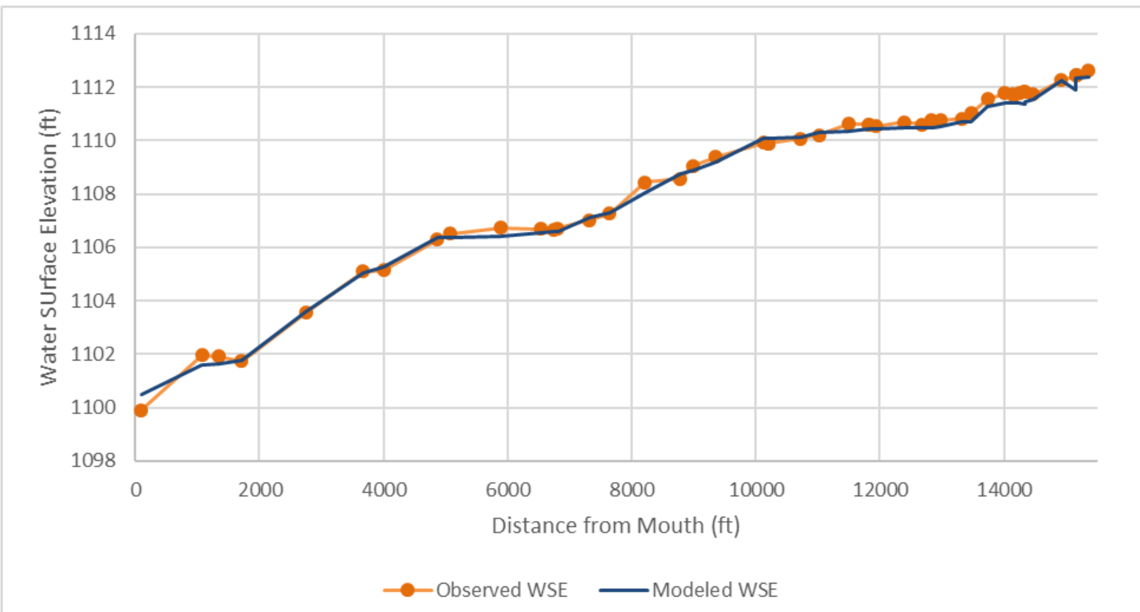

Figure C-1. Longitudinal profile of measured versus modeled water surface elevations for the baseflow (130 cfs) modeling scenario using calibrated roughness values.

Table C-1. Model roughness values assigned to land cover areas.

LAND COVER AREAS	MANNNG'S N VALUE
Channel, main	0.035
Channel, upper/side	0.045
Gravel bar	0.035
Gravel bar vegetated	0.07
Forest	0.12
Pasture/clearing	0.05

LAND COVER AREAS	MANNNG'S N VALUE
Road, Paved	0.01
Riprap	0.078

Boundary Conditions

All hydraulic models require the user to input a known boundary condition at the upstream and downstream extents to begin the computational routine. The boundary conditions utilized to develop the hydraulic model of the project reach are presented in Table C-2.

Table C-2. Boundary conditions utilized within the hydraulic model of the project reach. Data for the Wenatchee River was developed using FEMA's flood insurance study for Chelan County, and the Lower Wenatchee River Reach Assessment (FEMA, 2004; Tetra Tech, 2016).

FLOW SCENARIO	Q_{ICICLE} (CFS)	SOURCE	$Q_{WENATCHEE}$ (CFS)	SOURCE	$WSE_{DOWNSTREAM}$ (FT, NAVD 88)	SOURCE
Baseflow	130	NSD Measurement - 9/8/16	--	--	1099.9	NSD Survey - 9/8/16
Typical Spring Runoff	1830	WA Ecology Gage - 6/5/16, 12:00	6420	USGS Wenatchee River at Peshastin, WA - 6/5/16, 12:00 minus Q_{Icicle}	1101.6	Linear Regression from FEMA (2004)
Q2	4450	Peak Flow Estimate - USGS Icicle Creek Gage	11247	Q2 (15,697 cfs) for Wenatchee River between Icicle Creek and Chumstick Creek (Tetra Tech, 2016) minus Q_{Icicle}	1103.1	Linear Regression from FEMA (2004)
Q10	8300	Peak Flow Estimate - USGS Icicle Creek Gage	16000	Peak Flow Estimate - FEMA (2004) minus Q_{Icicle}	1106.0	FEMA (2004)
Q100	15200	Peak Flow Estimate - USGS Icicle Creek Gage	27100	Peak Flow Estimate - FEMA (2004) minus Q_{Icicle}	1112.0	FEMA (2004)

The upstream boundary conditions for all model runs include flow from Icicle Creek and from the Wenatchee River for the high flow model scenarios. Icicle Creek inflows include:

- ***Baseflow*** -130 cfs - NSD calculated discharge value
- ***Typical Spring Runoff*** – 1830 cfs - Discharge estimated by the WA Ecology gage on 6/5/16 @ 12:00 pm which corresponds to water surface elevation observations described in Section 4.
- ***Q2, Q10, and Q100*** -4450/8300/15200 cfs - Peak flow estimates for the 2, 10, and 100 year recurrence interval on the USGS Icicle Creek Gage described in Section 4.

Inflows for the Wenatchee River were based off of gage records at the USGS Wenatchee River at Peshastin, WA gage (Site # 12459000), from peak flow estimates presented in the Federal Emergency Management Agency's (FEMA) Flood Insurance Study of Chelan County, Washington (FEMA, 2004), and from the Yakima Nation's Lower Wenatchee River Reach Assessment (Tetra Tech, 2016). Inflow values were calculated by subtracting the Icicle Creek inflow values from USGS Wenatchee River at Peshastin gage discharge estimates. Wenatchee River inflows include:

- ***Baseflow*** – Not modeled
- ***Typical Spring Runoff*** – 6420 cfs - Discharge estimates for 6/5/16 at 12:00PM at the USGS Wenatchee River at Peshastin gage (6420 cfs) minus the discharge estimate at the WA Ecology gage on Icicle Creek (1830 cfs)
- ***Q2 –*** *11247 cfs* – Peak flow estimate for the Wenatchee River between Icicle Creek (RM 25.6) and Chumstick Creek (RM 23.5) minus the peak flow estimate for Icicle Creek presented in Section 4
- ***Q10 and Q100*** – 16000 / 27100 cfs – Peak flow estimates at the USGS Wenatchee River at Peshastin gage presented in FEMA, 2004 (24,300/42300 cfs) minus the peak flow estimates for Icicle Creek presented in Section 4.

The downstream boundary conditions consist of a defined water surface elevation (WSE) for the downstream portion of the computation mesh (Table C-2). The downstream boundary condition for the baseflow scenario consists of a WSE surveyed by NSD on 9/8/16 at the confluence of Icicle Creek with the Wenatchee River. The downstream boundary conditions for the remaining scenarios were based off WSEs presented in FEMA (2004) for FEMA cross-section FM. In FEMA (2004), WSE are presented for 10, 50, 100, and 500 year return intervals. Those WSE's are used directly for the Q10 and Q100 modeling scenarios. To estimate the WSE for the additional flow scenarios, a linear regression model was developed for FEMA cross-section FM using the published discharge and WSE data. The linear regression was then utilized to estimate the WSE for the modeled flow conditions. A figure illustrating the FEMA cross section data and the linear regression is shown below (Figure C-2). Downstream boundary conditions were not selected from Tetra Tech (2016) because WSEs were not presented in their report.

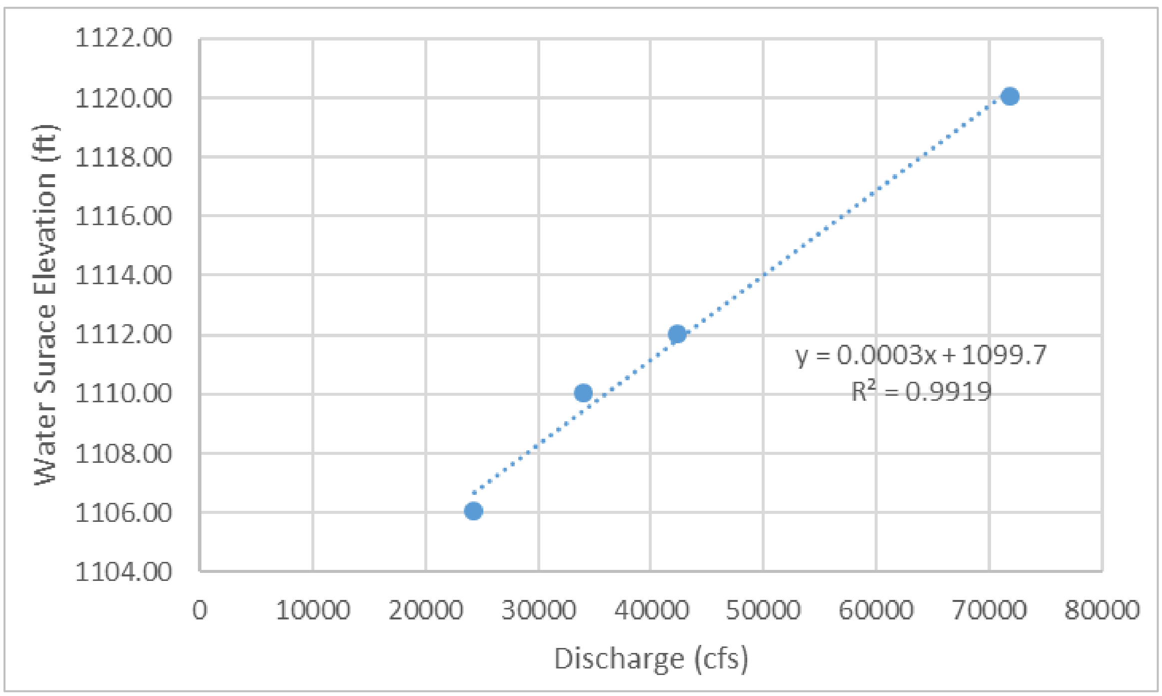

Figure C-2. Linear regression model used to estimate downstream water surface elevations for the model domain. Scatter data includes WSE and discharge estimates presented in FEMA (2004) for FEMA cross-section FM.

Results

The following sections describe the flow conditions within the project reach during the baseflow, spring runoff, Q2, Q10, and Q100 modeling scenarios. The results are then contextualized in terms of floodplain connectivity and hydraulic complexity. The modeling results will also be used to evaluate habitat suitability in a future report. Maps of the hydraulic outputs for each flow level are included at the end of this appendix.

Flow Summary

Table C-3. Summary statistics of 2-dimensional hydraulic model results for the baseflow, spring runoff, Q2, Q10, and Q100 modeling scenarios

FLOW	DEPTH (FT)				VELOCITY (FT/S)				SHEAR STRESS (LB/SQFT)		FLOODPLAIN AREA (ACRES)
	MIN	MAX	MEAN	SD	MIN	MAX	MEAN	SD	MEAN	SD	
Baseflow	0.1	11.5	2.0	1.5	0.0	8.4	0.9	0.6	0.0	0.1	0.0
Spring Runoff	0.1	15.3	5.9	1.7	0.0	5.5	2.9	0.9	0.2	0.1	16.2
Q2	2.1	18.5	9.1	1.8	0.0	6.9	4.1	1.2	0.4	0.2	60.9
Q10	4.3	20.9	11.7	2.0	0.0	9.6	4.9	1.8	0.5	0.3	203.6
Q100	6.9	23.4	14.2	2.2	0.0	15.2	4.5	3.0	0.5	0.6	327.0

Summer Baseflow

Icicle Creek is confined to the active channel during summer base flow conditions (Appendix A). The mean depth is 2.0 +/- 1.5 ft, however the pool-riffle morphology is well pronounced during this flow level with depths ranging from 0.1 ft -11.5 ft (Figure C-3). The channel primarily consists of riffle-run morphological units with the majority of depths estimated to be below 5 ft and the distribution of depths skewed towards shallower values. Velocities average 0.9 +/- 0.6 ft/s and range from 0.0-8.4 ft/s. The maximum value of 8.4 ft/s was calculated within a riffle segment downstream from the Shore St. access point and may be an overestimate of the actual velocity due to the difficulty of simulating complex hydraulics at low flows. The remainder of the velocities fall below 5 ft/s with the majority of the distribution below 1.5 ft/s. The velocity distribution is narrow and skewed toward slower values – demonstrating a lack of hydraulic complexity within the reach at baseflow. Shear stress values averaged 0.0 +/- 0.1 lb/sqft, which is to be expected due to the lack of sediment transport capacity at low flow conditions.

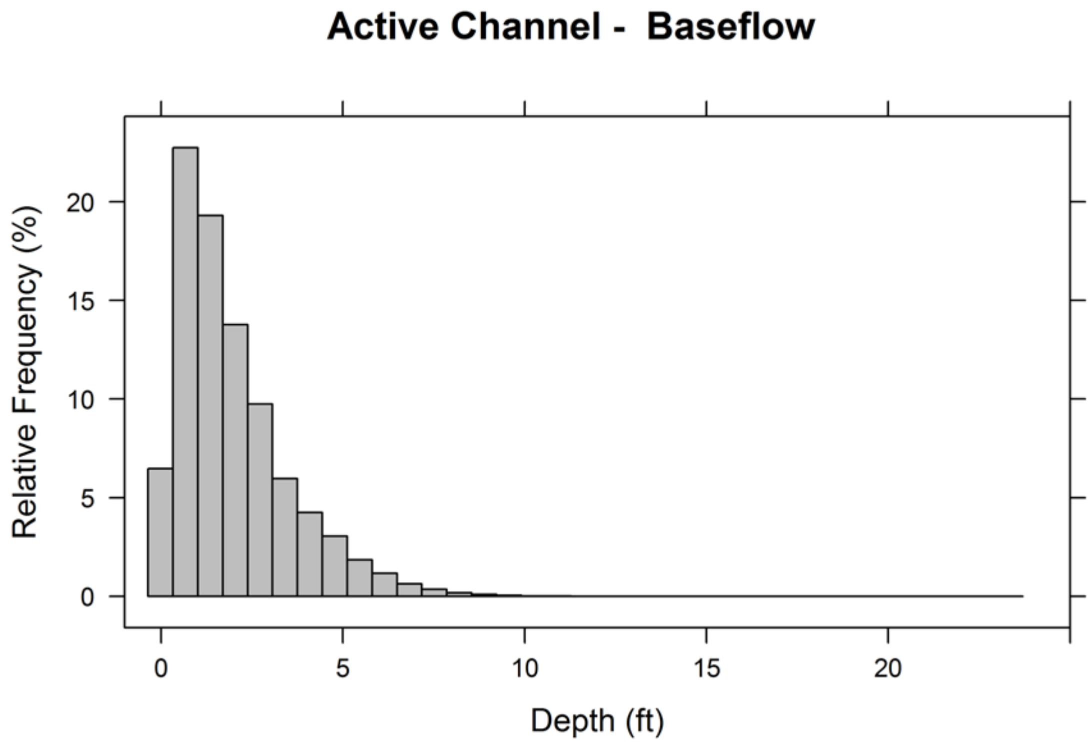

Figure C-3. Relative frequency distribution of estimated depths during the baseflow modeling scenario.

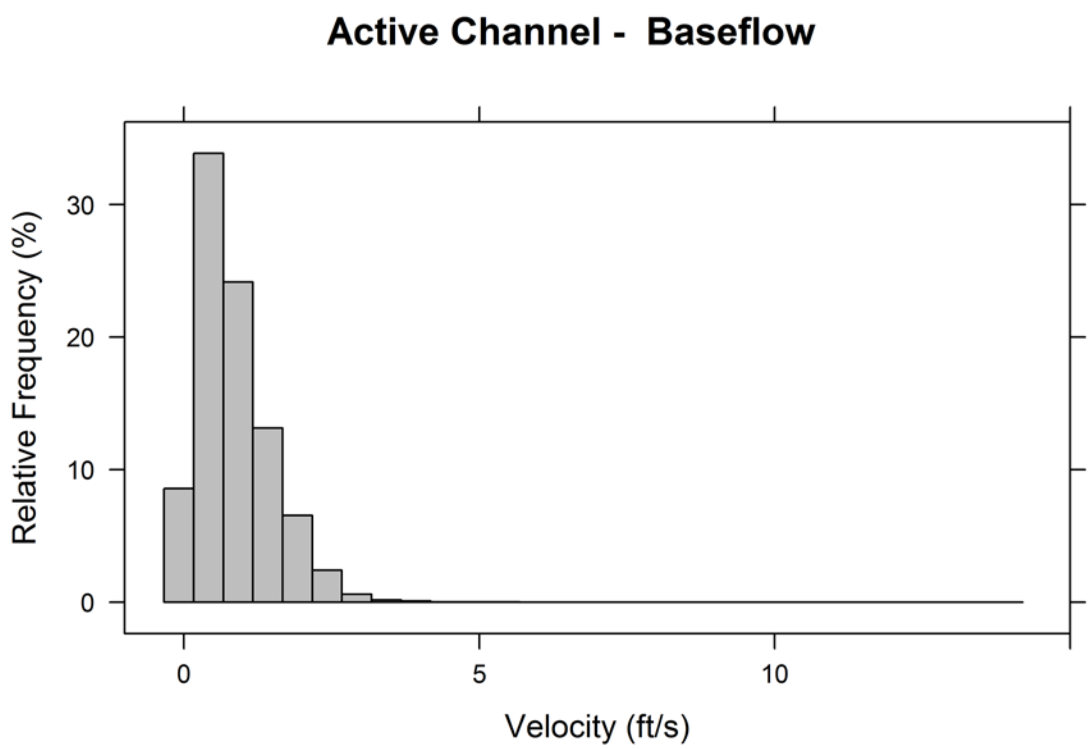

Figure C-4. Relative frequency distribution of estimated velocities during the baseflow modeling scenario.

Typical Spring Runoff

Icicle Creek within the project area is primarily confined to the active channel during the typical spring runoff modeling scenario (Figure C-5). The mean depth is 5.9 +/- 1.7 ft and ranges between 0.1-15.3 ft. The pool-riffle morphology is still evident at this flow level, with shallow depths exhibited over some of the higher elevation riffles (i.e. downstream of Shore Rd.). There is a wider distribution of depths than during the baseflow scenario, with the depth values being normally distributed throughout the reach (Figure C-6). The average velocity throughout the active channel is 2.9 +/- 0.9 ft/s and ranges between 0-5.5 ft/s. The velocity distribution is wider than during the baseflow scenario and is slightly right skewed. The velocity artifact present in the baseflow scenario (8.4 ft/s) is not present during this flow, which is likely due to the deeper estimated depths. There is a more heterogeneity in the hydraulics than the baseflow scenario as evidenced both by the spatial distribution and the wider frequency distribution. Mean shear stress is 0.2 +/- 0.1 lb/sqft which is capable of transporting very fine -fine gravel size classes.

There are 16.2 acres of inundated floodplain outside of the active channel during the spring runoff flow scenario. This area consists of locations directly adjacent to the active channel and correspond to point bars and low elevation inset floodplain benches (i.e. upstream of the meander bend at RM 1). There is however, a larger portion of floodplain engagement along the left bank near the confluence with the Wenatchee River. A hydraulic connection is also beginning to develop over the armored potential meander cutoff area at RM 1.7 during this flow level, although the majority of flow remains in the active channel downstream from this location.

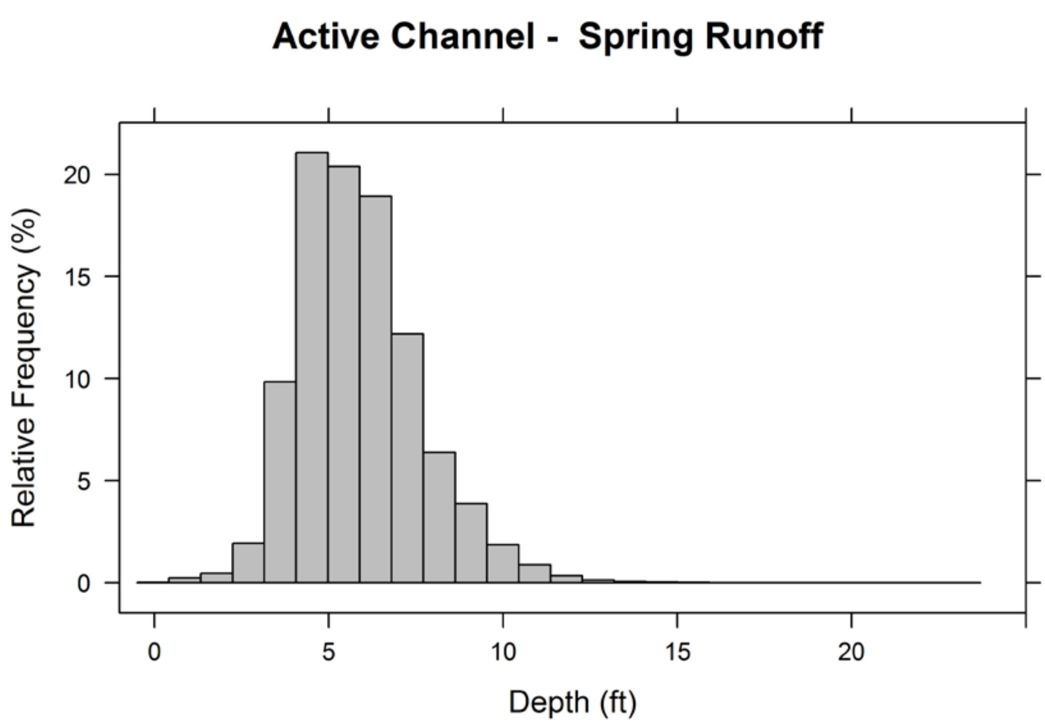

Figure C-5. Relative frequency distribution of estimated depth during the spring runoff modeling scenario.

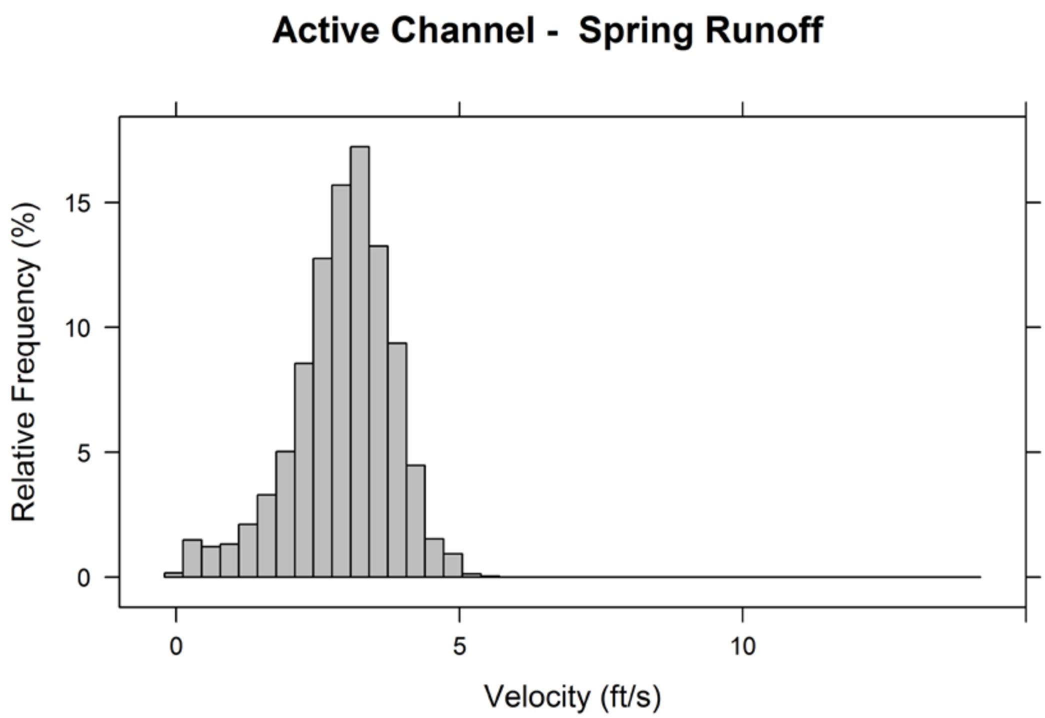

Figure C-6. Relative frequency distribution of estimated velocity during the spring runoff modeling scenario.

Q2

Icicle Creek begins to overtop its banks during the Q2 modeling scenario (Figure C-7). The mean depth is 9.1 +/- 1.8 ft and ranges between 2.1-18.5 ft. All of the in-channel bars are submerged with the lower depths confined to these areas. The depth distribution is shaped similarly to the spring runoff scenario and is shifted towards deeper values due to the higher discharge. The average velocity throughout the active channel is 4.1 +/- 1.2 ft/s and ranges from 0-6.9 ft/s. The distribution is similarly shaped to the spring runoff scenario with values skewed towards faster moving water. The Q2 velocities however, are faster than the spring runoff scenario. The spatial velocity distribution is relatively homogenous within the active channel, with regions of elevated velocities encompassing the majority of the flow area. The mean shear stress is 0.4 +/- 0.2 lb/sqft which is capable of transporting between medium and coarse sized gravels. A more detailed discussion of longitudinal variability in shear stress and sediment transport is found below.

There are 60.9 acres of inundated floodplain outside of the active channel during the Q2 flow scenario. It is during this flow level that larger portions of the floodplain begin to engage. These locations are primarily lower elevation alluvial features such as a relic meander bend near RM 0.5 which is almost fully engaged. Other inundated floodplain features include a backwater terrace near E. Leavenworth Rd. at RM 0.9 and the left bank floodplain near the Wenatchee River confluence. There is a strong hydraulic connection over the armored potential meander cutoff area at RM 1.7, with the majority of flow beginning to pass through this location instead of within the active channel.

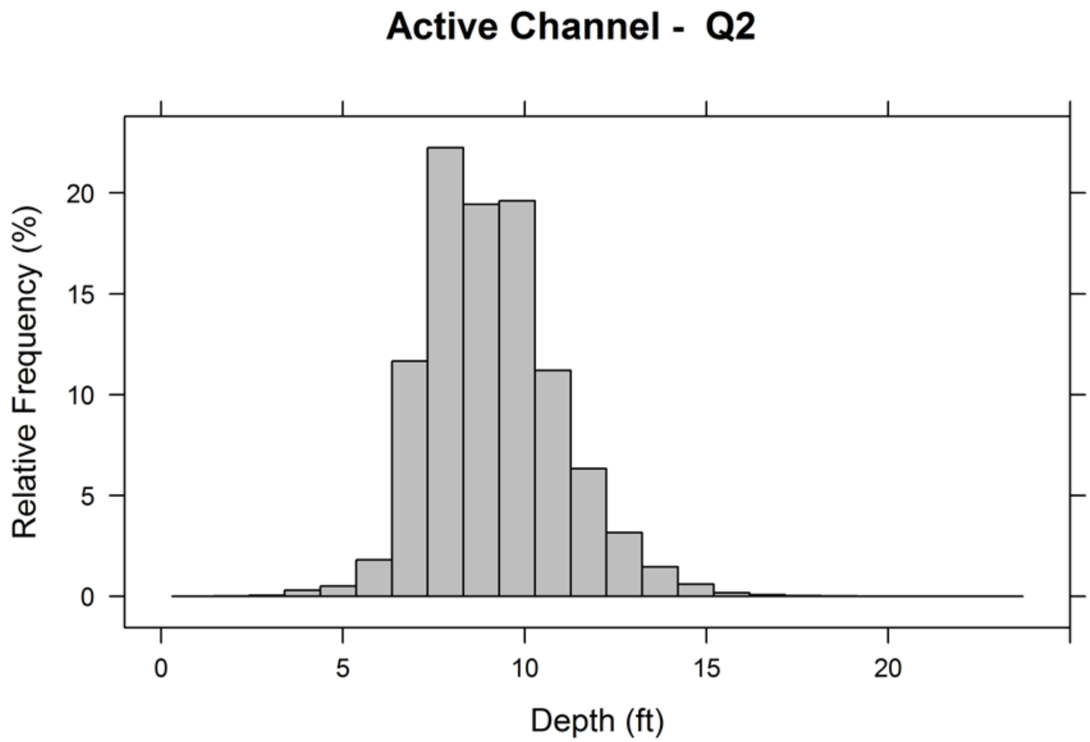

Figure C-7. Relative frequency distribution of estimate depth during the Q2 modeling scenario.

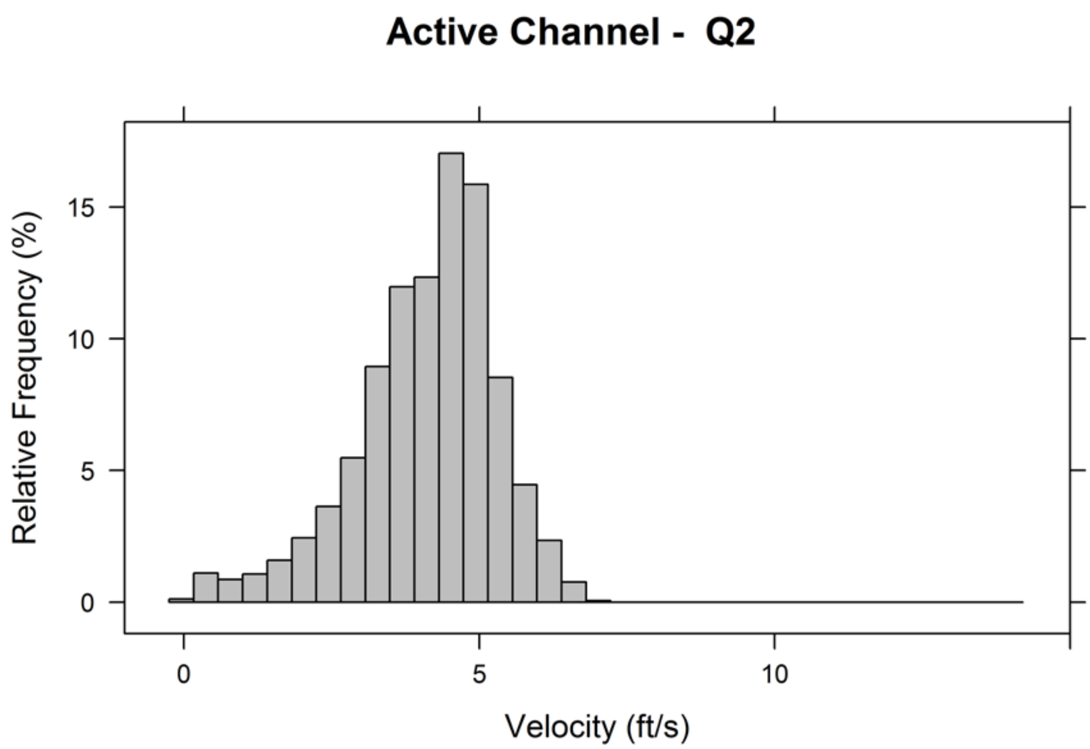

Figure C-8. Relative frequency distribution of estimated velocities during the Q2 modeling scenario.

Q10

Icicle Creek fully overtops the banks and is actively engaged with the floodplain during the Q10 modeling scenario. The mean depth within the active channel is 11.7 +/- 2.0 feet and ranges between 4.3-20.9 ft. The depth distribution is shaped similarly to the lower flood flows (i.e. Spring Runoff and Q2) and is normally distributed. The depths are shifted towards deeper values due to the larger discharge. The mean velocity within the active channel is 4.9 +/- 1.8 ft/s and ranges between 0.0-9.6 ft/s. The velocity distribution is broader and more heterogeneous than the Q2 flow with a higher proportion of slower velocities (Figure C-8). These regions are located in areas of the channel with a high degree of floodplain connectivity such as near RM 0.5. There is also a high proportion of slower velocities located within the tortuous meander bend downstream from RM 1.7. Throughout most of the upper 2 miles of channel however, there is homogenous high velocity flow throughout the entirety of the active channel. The mean shear stress is 0.5 +/- 0.3 lbs/sqft which is capable of transporting coarse sized gravels. The mean shear stress is only slightly higher than the Q2 flow which indicates that conditions were near bankfull in Q2.

There are 203.6 acres of inundated floodplain outside of the active channel during the Q10 modeling scenario. This corresponds to the primary floodplain areas along Icicle Creek and includes higher elevation relic alluvial features such as an abandoned meander bend near RM 1. The hydraulic connection across the armored potential meander cutoff at RM 1.7 is fully engaged, as well as a potential cutoff of the meander bend upstream. Flow is not predicted to overtop either the E. Leavenworth Rd. bridge or E Leavenworth Rd along the east side of the valley. The floodplain region between the Wenatchee River and Icicle Creek is also fully engaged at this flow level.

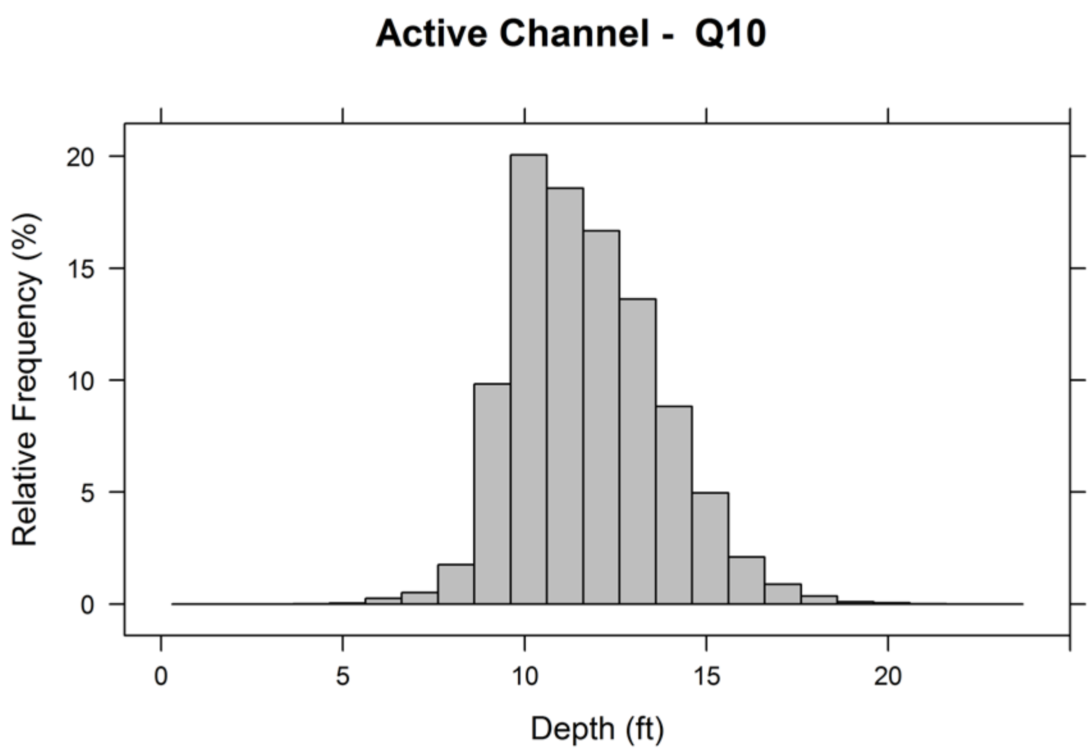

Figure C-9. Relative frequency distribution of estimated depths during the Q10 modeling scenario.

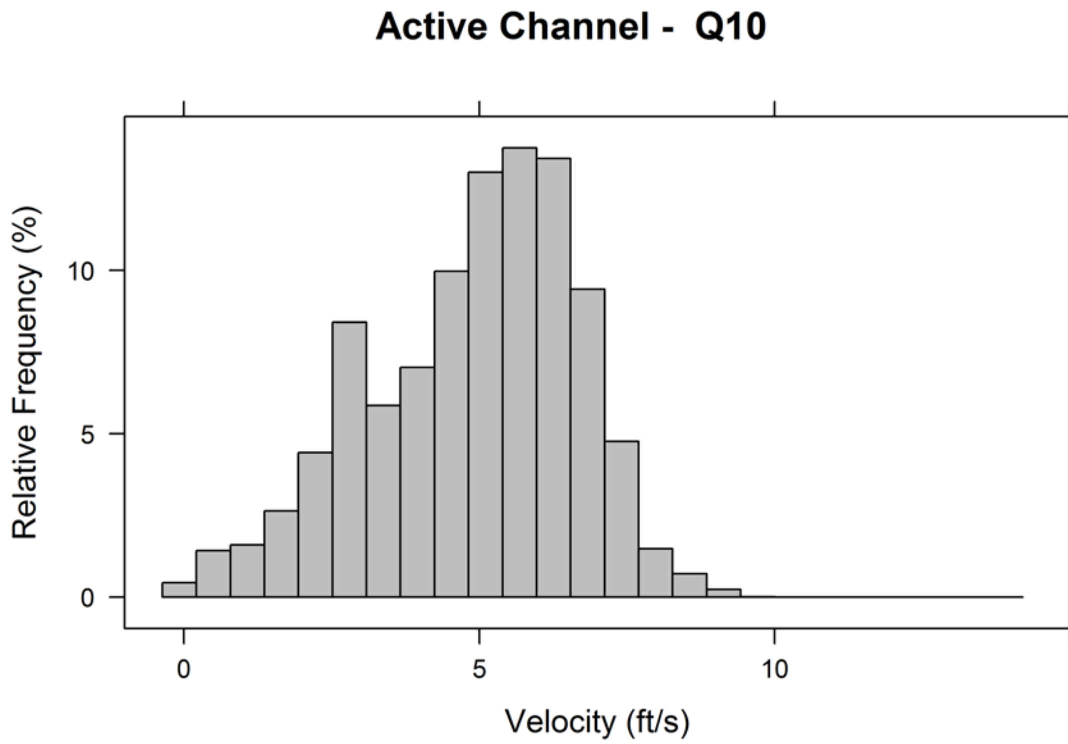

Figure C-10. Relative frequency distribution of estimated velocities during the Q10 modeling scenario.

Q100

Icicle Creek fully overtops its banks and is engaged within the entirety of the alluvial valley during the Q100 modeling scenario. The mean depth within the active channel is 14.2 +/- 2.2 ft and ranges from 6.9-23.4 ft. The depth distribution is normally distributed and shaped similarly to the lower flows. The mean velocity is 4.5 +/- 3.0 ft/s and ranges from 0-15.2 ft/s within the active channel. The mean velocity is lower than the Q10 modeling scenario and has a wider distribution with a greater proportion of slower velocity locations than during the Q10 flow. The lower average value and wider distribution are likely due to greater floodplain engagement throughout the entirety of the reach. Mean shear stress is 0.5 +/- 0.6 lb/sqft which is similar to the Q10 flow and is capable of transporting coarse sized gravels.

There are 327.0 acres of inundated floodplain outside of the active channel during the Q100 flow scenario. The entirety of the alluvial valley experiences floodplain engagement during this flow level as evidenced by flow encompassing a high elevation relic meander bend on the east side of E. Leavenworth Rd. near RM 0.5. Flow depths reach 6 ft in places along the floodplain and flow overtops E. Leavenworth Rd. near the bridge and along the east side of the valley. There is also a strong hydraulic connection between Icicle Creek and the Wenatchee River across both the left bank (of Icicle Creek) floodplain terrace and within the side channel network near the Icicle Creek Confluence.

The floodplain inundation results of the Q100 modeling scenario closely correspond to images recorded during the 11/30/1995 flood (Figure C-13). Video taken from a helicopter during the flood indicate a strong hydraulic connection between Icicle Creek and the Wenatchee River as well as full inundation of the large relic meander bend towards the east side of the valley. The images also demonstrate a high terrace and lack of connection between Icicle Creek and the Wenatchee along Wilson Street near RM 0.6 – results that closely agree with our Q100 model. These agreements provide greater confidence in the high flow modeling results.

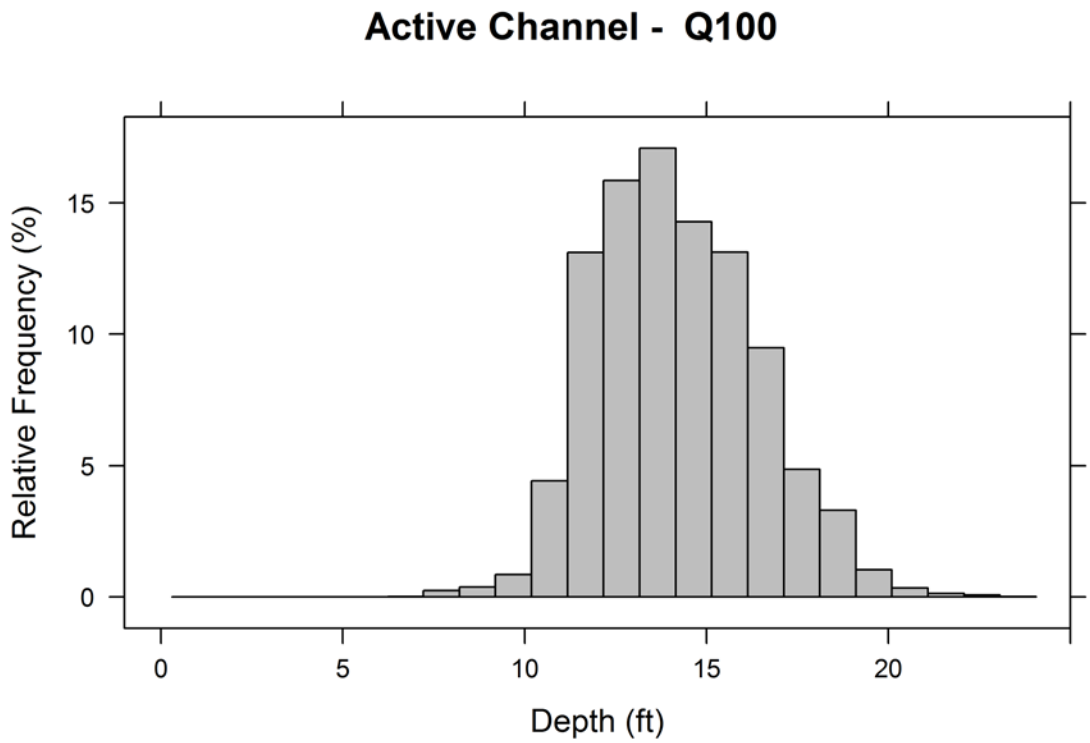

Figure C-11. Relative frequency distribution of estimated depths during the Q100 modeling scenario.

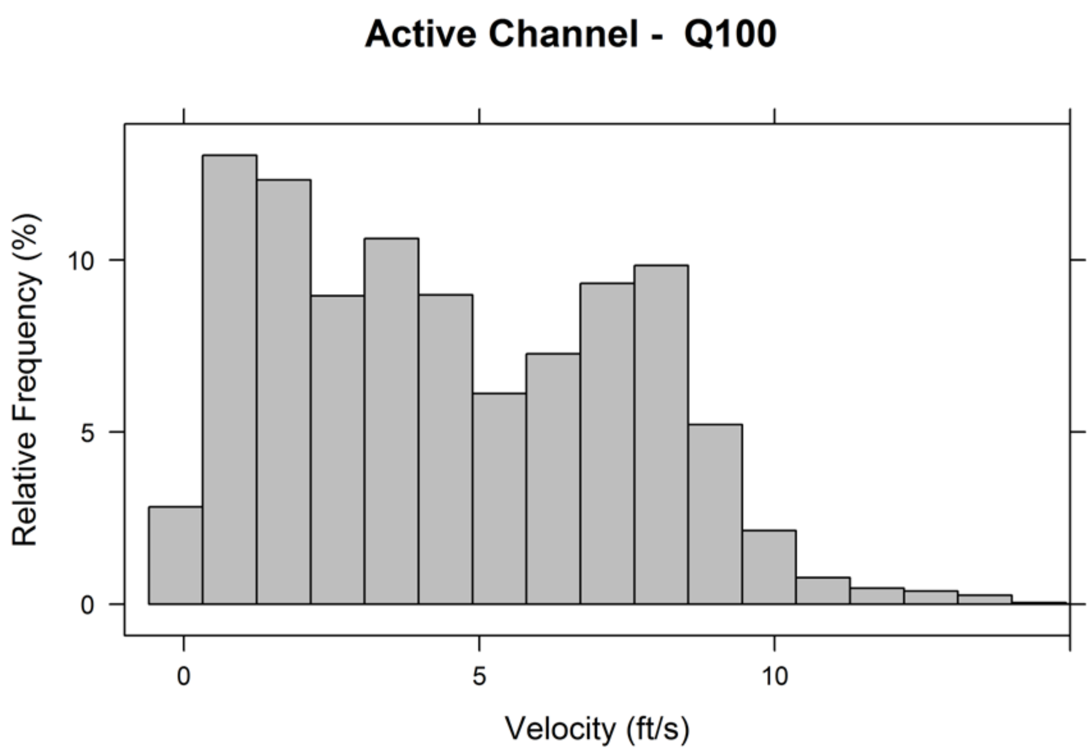

Figure C-12. Relative frequency distribution of estimated velocities during the Q100 modeling scenario.

Figure C-13. Confluence of Icicle Creek and the Wenatchee River on 11/30/1995. Daily mean discharge was measured as 8,540 cfs in the USGS gage along Icicle Creek and 38,900 cfs in the USGS gage along the Wenatchee River at Peshastin which corresponds closely to the Q100 modeling scenario.

Hydraulic Complexity

The degree of hydraulic complexity within the project reach can be assessed by comparing velocity distributions between flow levels. The velocity distributions presented in Figure C-4, Figure C-6, Figure C-8, Figure C-10, and Figure C-12 above summarize the spatial variability of flow within Icicle Creek. Narrow distributions indicate simplified hydraulics within channel while wider, more variable distributions show more heterogeneous flow.

Similarities amongst the velocity distributions of the Spring Runoff, Q2, and Q10 flow scenarios indicate a lack of hydraulic complexity within the project reach. The distributions are similarly shaped and right skewed, and as the flow increases between the scenarios, they shift towards faster velocities as expected. These similarities suggest that there is a lack of in-channel roughness, such as large wood or floodplain vegetation, to impose velocity gradients on the flow field as discharge increases. If present, these elements would become engaged at different points throughout the hydrograph and would act to both increase velocities in some areas and decrease velocities in others. Hydraulic These velocity gradients are not present in the project reach during the modeled flow scenarios, and thus there is a low degree of hydraulic complexity.

The lack of hydraulic complexity is not surprising given the lack of wood (Section 3.3), high degree of channel armoring, and development within the riparian area.

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