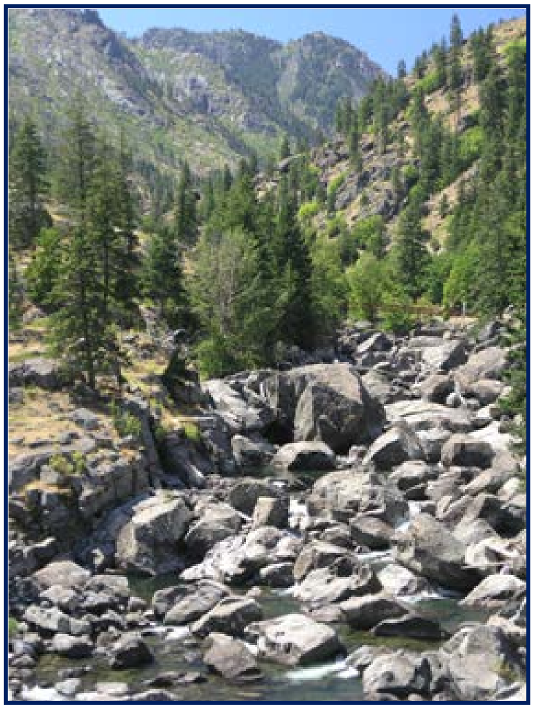
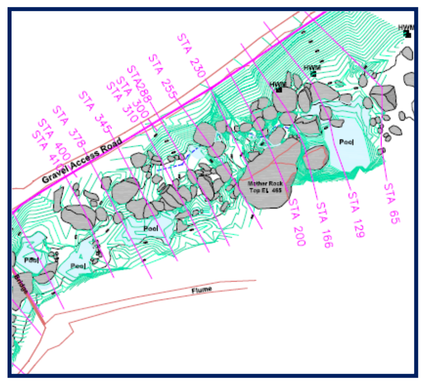
Icicle Creek Boulder Field Fish Passage Assessment

MAY 2013

Icicle Creek, Chelan County, WA





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Definitions:

Access Roads: years 1933- built Irrigation District access and 1924-built Forest Service road bench that parallel the left bank of Icicle Creek in the study reach.

Anchor Boulder: a specific boulder in the Middle Reach that is a principal focus of evaluating channel conditions for this study. It is related to a constricted area of the channel, area of potential anthropogenic influence, and a key bed elevation control by creating a historic boulder and cobble bedload impoundment.

Bank reference: Left Bank (LB) or Right Bank (RB) is referenced from a downstream-looking position.

Boulder Field: character of the stream bed within the whole study area. The study area is divided into the Lower, Middle and Upper reach.

Competence: the size of the largest particle that can be transported by a stream.

Conceptual Design: the project goal of developing a conceptual-level drawing, an estimate of design and construction costs, and some issue identification. Conceptual designs typically do not include detailed engineering and risk analysis.

Exceedance flows: a means to describe the percentage of time for which an observed stream-flow is greater than or equal to a defined stream-flow. For example, a hypothetical stream has a mean monthly flow in March of 45 cfs and a median monthly flow of 38cfs. The 50% exceedance flow in March is the median flow of 38 cfs. Thus the median March flow 5 out of every 10 years (50%) will be greater than or equal to 38 cfs.

Fluvial processes: external processes that involve running water, encompassing both overland flow and streamflow.

HEC-RAS (Hydrologic Engineering Centers-River Analysis System): a one dimensional flow model that projects the hydraulics of water flow through natural rivers and other channels to predict flood elevations in rivers.

Icicle/Peshastin Irrigation District Diversion Dam: the two districts operate more than 60 miles of canals between Leavenworth and Monitor with this diversion dam at RM 5.8 on Icicle Creek. The concrete structure, jointly owned by IPID and the city of Leavenworth, rises about 4 feet high, has 12 inch flashboards at minimum flow and runs 88 feet with the irrigation canal on the right abutment and the city intake on the left abutment.

Intrinsic Potential (IP): a modeled habitat valuation providing a means to identify at a large scale those portions of the landscape that can provide essential habitat for various fish species. IP modeling is based on the assumption that the relative value of aquatic habitat to specific fish species is strongly influenced by the persistent watershed geomorphology that is not easily modified by anthropogenic influences.

Knickpoint: a sharp irregularity (such as a waterfall, rapid, or cascade) in a stream-channel profile, commonly caused by abrupt changes in bedrock resistance. Knickpoints can induce streambed erosion that travels upstream.

Middle Reach: the most intensely surveyed study area and the primary focus of the study's fish passage analysis.

Thalweg: the deepest part of the channel, however through the Boulder Field it refers to where the main volume of surface flow occurs during lower flow periods which may or may not be the absolute deepest part of the channel at any given point.

Turbulence: a characteristic of water during high flow periods whereby air is infused into the water column. This element of flow characteristic was important during this assessment since hydrologic models have difficulty expressing its effects and fish migratory abilities are affected by density changes in their swimming medium.

Table of Contents

List of Tables

List of Figures

List of Photos

1 SUMMARY

Fish passage and geomorphic conditions of the Icicle Creek Boulder Field were assessed to document the extent of anthropogenic impact on fish passage as well as to identify fish passage alternatives for bull trout and steelhead. The study area includes a high gradient reach, the principal focus of this investigation, with natural and anthropogenic influences on channel constriction at RM 5.6.

There is general uncertainty regarding historic or contemporary passage of steelhead and bull trout through the Boulder Field. During a telemetry study conducted in 2000-2001(Cappellini 2001), radio-tagged adult steelhead and spring Chinook salmon moved to the base of the Anchor Boulder but were unable to pass upstream. No radio-tagged adult bull trout approached the area. However, observations of a few large bull trout upstream of the Boulder Field lead to the inference that the area appears to be passable for migratory fish under limited but unknown conditions.

Slope fill material from a road adjacent to the stream, encroaches into the natural channel width. However, the Boulder Field provides some indication that the area contains natural elements that contribute to impeding fish passage. Via geomorphic assessment and hydraulic analysis (HEC-RAS and a trial application of River FLO-2D), flows and physical channel conditions were assessed (including an evaluation of boulder configurations and features) to suggest the level of influence that the encroachment has on fish passage. Characterizing flow in reaches with very high turbulence levels and steep hydraulic gradient pushed HEC-RAS modeling to its practical limit. However, identification of the wetted edge at various flows did validate our modeled flow despite high turbulence levels at high flow. The confirmation of modeled flows, along with field observations, aided in identifying potential passage ways for fish and key elevations for fish passage design concepts.

Fish passage assessment for this study was based on methodology developed by Powers and Orsborn (1985), utilizing field measurements of potential migration barriers at a range of flows, professional judgment of identified passage routes and previous fish passage studies (Powers, 2011; Powers, et al., 2009). To determine passability, the length of adult fish recommended for evaluation was assigned to the maximum leaping profile (an assigned trajectory and height given sight conditions) calculated from the Powers and Orsborn method (1985).

In addition, a fish energetics model employing channel geometry and fish swimming and leaping capabilities was used to assess passage in the Boulder Field. Results showed that one large boulder (hereafter referred to as the "Anchor Boulder") and the material retained behind it, is the primary impediment during the majority of flows to bull trout and steelhead, the target fish species for this study. There is the potential for passage if fish detect a route formed by small surface flow that forms between 100 – 200 cfs along the left bank. Higher flows through this reach create sheet or highly turbulent flows over rock or falls with no jumping pools. A large pool below the Anchor Boulder where fish would most likely congregate/stage during upstream migration does not provide migratory pathways.

The cascade at the Anchor Boulder is the primary passage impediment. This location features a 25 ft vertical drop and 30% gradient. A secondary area of impediment is at the diversion dam at low flows. Addressing passage at these locations would resolve the majority of fish passage challenges through the Boulder Field and Irrigation District diversion dam. An area of difficult passage, not impassable, exists during higher flow periods approaching 1,500 cfs and above at the Irrigation District access bridge area. (Flows within the study reach at above 2500 cfs are likely a velocity/turbulence barrier). Steelhead and bull trout passage is likely through here but some channel modifications could improve the duration of the passage window. An alternative for passage is not provided for this reach although they would be similar to certain design concepts provided for the Anchor Boulder impediment. Yet, if passage is enhanced at the Anchor Boulder, fish could likely pass this area without modification.

Finally, based on the understanding of anthropogenic impacts, passage alternatives through the study reach are provided, that include conceptual designs and construction and engineering cost estimates for four Middle Reach alternatives at Anchor Boulder and two alternatives in the Upper Reach at the Diversion Dam. Varying approaches to fish passage were evaluated. Analysts agreed that further risk assessment or advanced design work could inform the feasibility of a preferred alternative. This assessment included, facilitated by project sponsor Trout Unlimited, solicitation of regional technical experts input as well as that of watershed stakeholders from which preferred alternatives were identified. Among the considerations for preferred alternatives were: biological, social, geographic, aesthetic, infrastructure constraints, target species and flows.

2 INTRODUCTION

Salmon recovery actions in the Upper Columbia are guided by regional scientific expertise. NOAA has identified assessing fish passage as priority research action (UCSRB 2007) while the Upper Columbia Regional Technical Team (RTT) has designated boulder field passage assessment and fish passage improvement as priorities (RTT 2013). The Draft Wenatchee Subbasin Plan (2004) identifies evaluating the feasibility and benefit/risks of enhancing fish passage through the Icicle Creek Boulder Field as a near-term restoration opportunity.

Review of modern fish use, passage and movement through Icicle Creek has been addressed by a few notable reviews (Nelson 2010 and 2012; Nelson et al. 2009 and 2011; Ringel 1997 and 1998, USFWS 2004). This project is a principal step in understanding anthropogenic impacts on fish passage at the study location, and implementing passage if determined that passage is desirable in meeting salmon recovery goals. Fish productivity and habitat capacity modeling[1] suggest that approximately 29 miles of mainstem habitat in Icicle Creek could be beneficial to overall salmon populations if anadromous and fluvial populations of steelhead and bull trout can access the entire area on a regular basis.

The project goal was to gain an accurate understanding of the physical structures and corresponding velocity and drops in elevation associated with the Boulder Field (RM 5.6) and geomorphic conditions. The analysis included an area 500 feet upstream of the Diversion Dam and 780 feet downstream of the high gradient area of the Boulder Field to the Snow Creek trail access bridge. The project also describes the likely extent of human influence on the Boulder Field. The project objectives were to:

1) review existing habitat, biologic, historic, passage information;
2) evaluate the anthropogenic influences on passage;
3) determine target species and flows for potential passage; and
4) develop concept designs and construction cost estimates for fish passage alternatives.

[1] Ecosystem Diagnosis and Treatment (EDT) and Interior Columbia Technical Review Team (ICTRT) intrinsic potential models predict very large increases in capacity for steelhead with access to the Upper Icicle Creek.

Background information provided by Trout Unlimited-Washington Water Project (TU-WWP) and technical experts was reviewed for relevant historical, ecological and geomorphological information. Historic documents related to road and irrigation diversion construction were analyzed at the Washington State archive facilities in Olympia and Ellensburg. More than five meetings were held to exchange and present information with the USFWS, NOAA, WDFW, Icicle and Peshastin Irrigation Districts, other technical experts and stakeholders of Upper Columbia River salmon recovery efforts. A geomorphological assessment of the study reach generally concurred with previous field observations (Rieman 2001) of there being some level of anthropogenic influence in the form of rock material and evidence of construction within the active channel.

Bull trout and steelhead adult migration passage was evaluated in a 2,700 ft. segment of Icicle Creek assessed as Lower, Middle (Boulder Field), and Upper (diversion dam) reaches. A physical feature in the study reach found to have the most influence on fish passage is a large boulder located in the Middle reach, hereafter referred to as the Anchor Boulder. While there are two identified passage impediments, there are four impassable conditions/locations:

1) at the Anchor Boulder;
2) upstream of the Anchor Boulder;
3) at the Anchor Boulder above 1,000 cfs; and
4) the diversion dam at low flows (120 cfs and potentially up to 500 cfs).

Creating an estimate of the flow in which the diversion dam is passable will require additional assessment including evaluation of the effects of dam on surface water hydraulics and development of a rating curve for the hydrology of that site. Certainly at 120 cfs there is little to no surface flow over the diversion dam, precluding bull trout migration for a considerable part of their migration period. Regarding the Boulder Field, in its current channel configuration, passage could potentially occur between 100 and 500 cfs, which occurs 90% of the time during the bull trout migration window of August to September. Steelhead are much less likely to encounter this low flow level during their migration.

3 STUDY AREA CHARACTERISTICS

Icicle Creek is a fifth order stream draining into the Wenatchee River (RM 25.6) near the town of Leavenworth, Chelan County, WA (**Figure 1)**. Icicle Creek provides spawning and rearing habitat for steelhead and bull trout. The Icicle Creek Boulder Field (RM 5.6) is a high gradient reach with an average of 8.2%, approaching 30% in some locations and in one location 52% (one short segment at the Anchor Boulder identified within a longitudinal profile). Two instances of stream adjacent parallel road construction, an Irrigation District access road (yrs. 1933-34 Civilian Conservation Corps) and a Forest Service road (yrs. 1964-1965), have led to questions as to the extent of influence of these floodplain encroachments on successful Icicle Creek adult upstream migration for steelhead and bull trout.

Icicle Creek experiences a large range of flows on a regular basis. Site visits during low and high water extremes assisted the study team in identifying challenges to the assessment and alternative development (**Photo 1**).

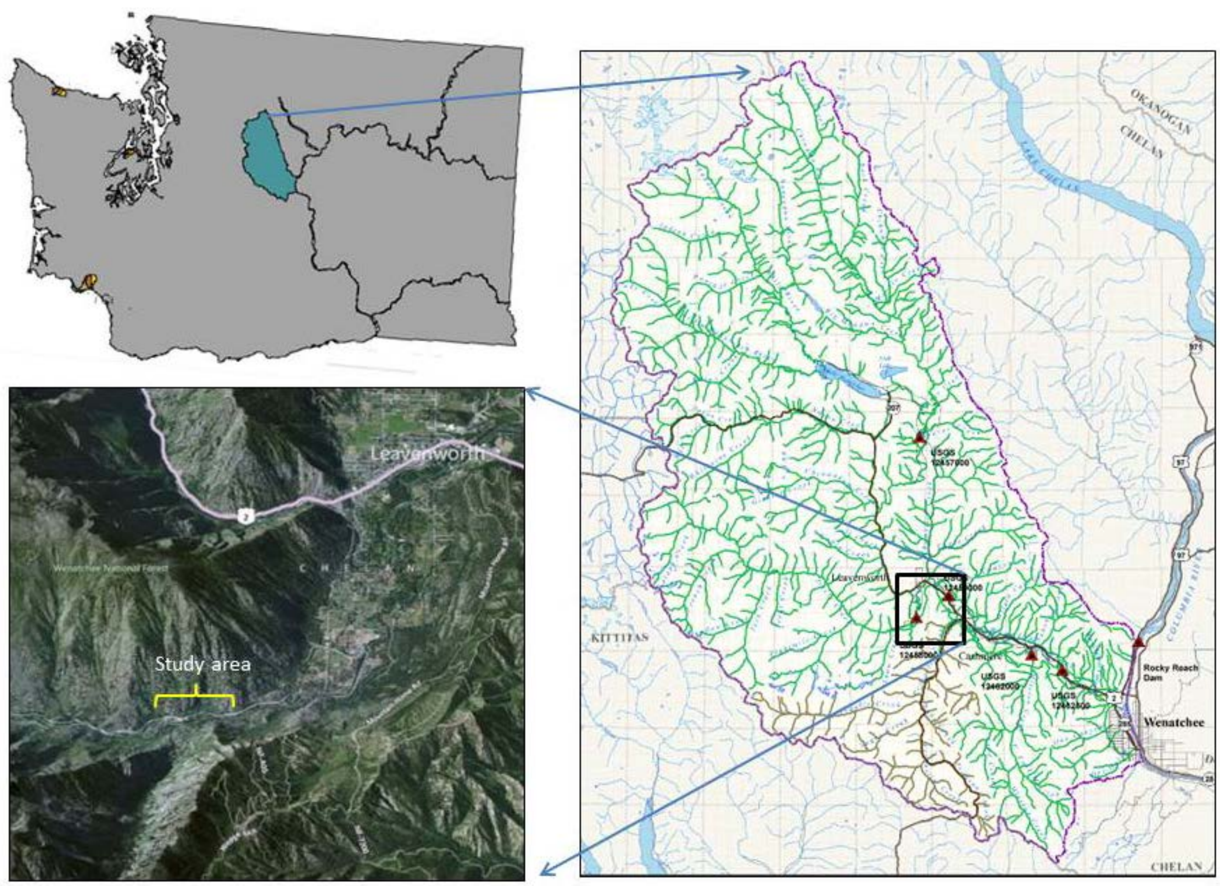

Figure 1 - Location map of study area (lower left) in Icicle Creek within the Wenatchee River Basin, Chelan County, WA.

Photo 1 - Side by side comparison of Anchor Boulder flow chute at 200 cfs (l) and 12,000 cfs (r). The 20,000 cfs 50-yr flood and site constraints of high velocity, large-sized sediment and debris transport limit the in-channel fish passage alternatives. (Arrows provide location reference).

Initial observations, in consultation with regional biologists and recovery experts, indicated that high-energy in-channel conditions would afford limited options and require further geologic investigation and risk evaluation. These observations validated the importance of channel bed stability in this reach and suggested that any alternatives developed would need to minimize the potential for undesirable (regular or high quantities) bedload movement. Imbricated and partially-buried boulders and cobbles throughout the reach gave some semblance of stream bed stability but fracturing and rapid erosion signs in mid-channel areas indicated that very large rocks could be mobilized through this reach. The stream energy evident in the right half of **Photo 1** is just a portion of what occurs during a 50-year + peak flow events that can range between 15,000 – 20,000 cfs.

The study area was divided into Lower, Middle, and Upper Reach based on gradient breaks and channel characteristics (**Figure 2**). The analysis focused primarily in the Middle Reach where topographical survey work and hydraulic analysis was conducted. The physical feature that is the main evaluation issue is the Anchor Boulder, in the center of the study reach (**Photo 1** (solid white arrow) and **Photo 2**), so named because of its prominent influence on the bed elevation.

Photo 2 - Anchor Boulder and surrounding area at crux of the Middle Reach analysis. Calibrated man-sized image inserted for approximate scale.

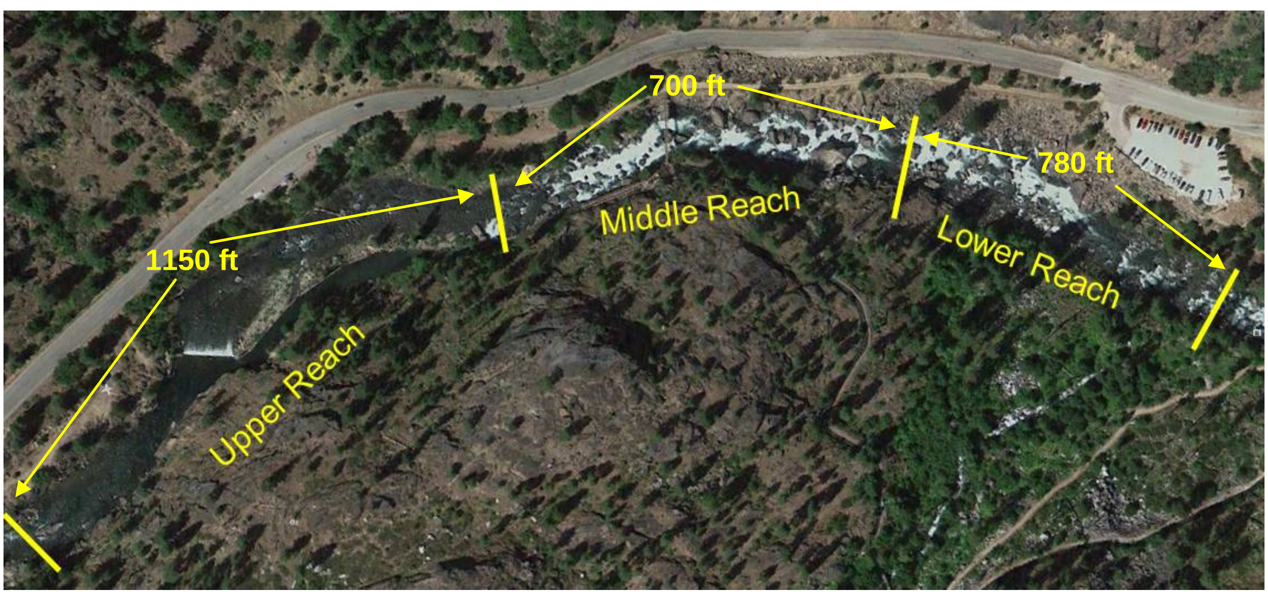

Figure 2 - Upper, Middle, and Lower reaches of the study area.

Physiography of the Icicle Creek Basin

The following are excerpts from a geologic assessment, a technical memorandum about Icicle Creek geology that is included in its entirety in **Appendix C (Geologic Assessment)**.

Most of the Icicle Creek valley has a narrow, U-shaped cross-section that reflects its history of alpine glaciation. The lower four miles of Icicle Creek flows through a broader alluvial and glacial plain. The upper Icicle Creek basin has extremely steep and rugged terrain. Icicle Creek flows through several cascades and Field as it negotiates the steep descent towards the Wenatchee River. Large tributary fans encroach upon the valley bottom and can pinch or otherwise influence the pattern of flow for Icicle Creek. Icicle Creek has many cascades and falls (**Appendix C Figure 1**), including the Boulder Field (RM 5.6 - the project reach) upstream of Snow Creek, boulder falls near Bridge Creek (RM 9), the chute and flume falls at Icicle Gorge (RM 16), waterfalls at Rock Island Campground (RM 18), and the complex falls at French Creek (RM 21.5) (Nelson et al. 2011). The high falls upstream of Leland Creek (RM 29) are considered impassable to migrating fish (Bryant and Parkhurst 1950).

Geomorphology of the Boulder Field Reach

Icicle Creek flows through a narrow, U-shaped valley in the study area that was carved by alpine glaciations. The rugged terrain is dominated by exposed bedrock on the steep valley walls (**Appendix C Figure 4**). The glacial ice flowed over and around a prominent rounded bedrock outcrop on the south side of Icicle Creek (**Appendix C Figure 5**). A lobe of ice appears to have cut behind the bedrock outcrop, carving a path through the present-day location of the Snow Creek alluvial debris fan. The irrigation diversion infrastructure and canal are carved into this bedrock outcrop. The right bank of Icicle Creek borders the bedrock outcrop along the entire length of the study reach (**Appendix C Figure 5**).

Rock outcrops, talus, and colluvium also confine the left bank of Icicle Creek, which has little to no floodplain within the study area. The Lower Reach of the Icicle Creek study area is adjacent to nearly vertical rock cliff that has been historically subject to rockfall and significant accumulations of talus. The left bank of Icicle Creek in the Middle Reach of the study area has been more directly impact by road construction. This reach is located below steep rock outcrops and accumulations of colluvium and talus. The left bank in the upper reach of the Icicle Creek study area is primarily confined by bedrock, although rockfall and mass wasting can still cause accumulations of rock and sediment in this area.

Icicle Creek is categorized as a cascade channel type with boulder substrate according to the Montgomery and Buffington (1997) classification system. The bedrock confinement and large substrate are indicative of a canyon-like setting, rather than a standard alluvial channel with bankfull channel and floodplain characteristics. Cascade channels are dominated by jet-and-wake flow over and around large individual rocks. The turbulent flow around these rock obstructions serve to dissipate much of the energy of the water. The largest bed-forming material in cascade channel types is effectively immobile, except during extremely large flows.

The approximate channel width for mean annual flood flows in the Middle Reach varies from about 100 to 140 feet. Most of the boulders in the Middle Reach are less than 20 feet in diameter, although the Anchor Boulder has a width of approximately 60 feet and extends about 75 feet across the channel (**Appendix C Figure 6**). The height of the Anchor Boulder is approximately 40 feet. The Anchor Boulder is such a large feature that it has constricted the channel and caused a large volume of boulders and other sediments to accumulate upstream.

A longitudinal slope profile of Icicle Creek was constructed from LIDAR elevation data to evaluate stream gradients (**Appendix C Figure 7**). The Boulder Field is about 1,000 feet in length with an average gradient of 8 percent. The reach above the Boulder Field extends for about 1,000 feet above the irrigation diversion at an average gradient of 1 percent. The constriction in valley width at the Anchor Boulder appears to have caused a significant accumulation of sediments that have influenced the channel gradient for about 2,000 feet upstream. The Snow Creek alluvial fan located at the bottom of the assessment area has moderated the gradient at its confluence with Icicle Creek, but does not appear to be having any significant influence on the upstream Boulder Field. Extrapolating the gradient of the channel above and below the influence of the Boulder Field suggests that without the Boulder Field, the average channel gradient could range from 4 to 6 percent. However, this conclusion assumes that the bedrock was scoured by glacial ice at a relatively uniform gradient without erosion resistant rock sills or dikes to act as knickpoints in the channel.

Sources of Rock in Boulder Field Reach

Field observations confirm that the rocks within the Icicle Creek channel are derived from both native and anthropogenic sources. The sources of rock within the Middle Reach were evaluated based on size, angularity, weathering, and coloration. The orientation of the rock and whether it is in a stacked or random formation can also provide clues to its origin. The use of local rock during road construction activities and the minimal differences between tonalite, granodiorite, and diorite rocks made it difficult to use rock type as a distinguishing factor between sources. Potential native rock sources include rockfall, glacial deposits, and alluvial deposits. Anthropogenic rock sources include blasted rock, road prism and sidecast material, and concrete aggregate. Other evidence of anthropogenic influence included drilling of holes into boulders and inserted smaller-diameter, round or square steel rods (**Appendix A of Geologic Assessment**). The purpose for placing the steel rods into the boulders is unknown.

In general, the native rock talus outside of the Icicle Creek channel is slightly weathered, angular diorite or rock of similar granitic composition. Minor discoloration on the surface, as well as along most discontinuity surfaces, indicates oxidation and weathering of rock material. Very little to no decomposition of the rock surfaces was observed. The hardness of the rock ranges from medium strong that can be fractured with a single hammer blow to extremely strong that can only be chipped or may require multiple hammer blows to fracture. Minor exfoliation of the rock surface layer was noted on many of the granitic rocks. Exfoliation involves thin sheeting joints that are generally flat, somewhat curved and parallel to the rock surface.

A discontinuity is a general term for all joints, fractures, bedding planes, contacts and faults (ISRM 1978). Joints or fractures are of geologic origin and represent a break in the continuity of the rock mass without visible displacement. For example, the bedrock on the right bank side of Icicle Creek has very wide spacing of orthogonal joints and very large blocks with less than one joint set per cubic meter of rock (**Appendix C Figure 8**). Coarse-grained granitic rocks have a high friction angle ranging from 34 to 40 degrees, which makes them generally stable at moderate angles (Wyllie and Norrish 1996). Most of the rockfall in the study area has occurred from natural weathering patterns and initiates preferentially along joints in the rock. During glacial advances, the flowing ice also plucked rock from naturally weak fracture zones.

Almost all of the boulders within the Boulder Field are native rock with signs of long-term weathering and water erosion. Many of the large boulders along the edge of the channel are sub-rounded to rounded in form, which suggests glacial transport. Within the channel most of the large boulders have evidence of significant fluvial weathering with smooth, scalloped forms and scour holes eroded into the rock. Most of the large boulders appear to be immobile and do not show evidence of being fluvially transported.

The Anchor Boulder appears to be an extremely large boulder that is not directly attached to bedrock on the right bank of Icicle Creek. Evidence of glacial grooves and striations, however, are indicative of in-situ placement with the glacier passing over the rock and scratching the rock surface (**Appendix C Figure 9**). The top of the Anchor Boulder also shows evidence of glacial polish. These facts suggest that the Anchor Boulder has not moved since at least before the last glaciation and was not deposited more recently by the ice. The Anchor Boulder does share similarities with the adjacent bedrock, including large gray inclusions within the rock mass (**Appendix C Figure 10**). While the downstream face of the Anchor Boulder does not show evidence of the same discontinuity extending from the left bank bedrock, the upstream face does include a joint at a similar elevation and orientation. The discontinuity on the Anchor Boulder also appears to extend into the large flat boulder adjacent to it in the channel (**Appendix C Figure 11**). It is possible that the flat boulder was also a part of the same rock mass but has since eroded into a separate rock. In all likelihood, the Anchor Boulder and possibly the adjacent flat boulder are derived from the local bedrock and have eroded into separate rocks.

The rocks on the left bank across from the Anchor Boulder appear to have both natural and anthropogenic sources of origin. Several of the boulders in this area are largely outside of the Icicle Creek channel, yet have a sub-rounded form (**Appendix C Figure 12**). These boulders appear to have been weathered from glacial, rather than fluvial transport, and have likely been in place since at least the last glacial recession approximately 12,000 years ago. The angular large boulders in the area are likely from historic rockfall. The coloration and weathering of these rocks suggests that they have been in place for at least hundreds, if not thousands of years. Smaller rocks and finer sediments were placed or dumped between the Anchor Boulders to construct a stable road prism for the original Icicle Creek Road (**Appendix C Figure 12**).

4 ANTHROPOGENIC IMPACTS ON BOULDER FIELD REACH

A number of sources were used to investigate and document potential anthropogenic impacts on the study area of Icicle Creek. The earliest historical records include 1905 General Land Office surveys of township and section boundaries. The 1905 map shows a trail on the south side of Icicle Creek, but no other signs of human disturbance (**Appendix C Figure 13**). The width of Icicle Creek at the section line near its confluence with Snow Creek is reported as 100 links or 66 feet. In 1914 topographic profiles were surveyed along Icicle Creek just prior to construction of the irrigation infrastructure (Marshall 1914). Again, no sign of human disturbance is noted in the study area.

Historic documents related to road and irrigation diversion construction were analyzed at the Washington State archive facilities in Olympia and Ellensburg. Although an abundance of records for irrigation canal planning, construction, and design were reviewed, there was no information that could contribute to site-specific historic conditions such as channel cross sections or drawings of the study site. Blue prints observed were of the irrigation canal system layout across the landscape and their location in relation to the Wenatchee River mainstem.

Rieman (2001) provides a detailed historical assessment of the anthropogenic or human-related activities in the area of the Boulder Field, including a reprinted newspaper article and photographs from 1934 during construction of the original Icicle Creek Road. The road currently used to access the irrigation diversion is a portion of the original Icicle Creek Road. The current Forest Road 7600 was constructed during 1964 to 1966 along the same route as the old Icicle Creek Road, except in the study area where the new road was built just upslope from the old road. Rieman (2001) documents how portions of Icicle Creek were filled with blasted rock boulders during the later construction. Greater volumes of rock and much larger rocks could be moved during construction of Forest Road 7600, than during the original road construction.

Historical aerial photographs from 1957 through 2011 were examined to document potential disturbance or change in the study area (**Appendix A of Geologic Assessment**). Table 1 - **Appendix C** provides a summary of the aerial photographs used in the assessment. With the confined nature of the study area, no channel migration or other changes in the channel location were identified over the photographic record. The area south of Icicle Creek is generally well forested, particularly around the Snow Creek fan during the 1950s through the 1990s. The only substantial alteration in vegetation occurred between 1992 and 2006 when a wildfire swept through the immediate area. No significant changes were observed in channel conditions during this time.

The left bank of Icicle Creek in the Boulder Field reach shows evidence of encroachment by road construction. A large boulder was blasted near the bridge crossing and two remaining pieces are present within the bankfull width of Icicle Creek (**Appendix C Figure 14**). A closer examination of the distances between drill holes in both large pieces confirms that they were originally part of one large rock. The diameter of the drill holes is consistent with 1930's construction practices (Rieman 2001). Drilled rocks are present along the road prism and in rock sidecast below the road. Rocks have been stacked along portions of the road prism, which is consistent with road construction practices during that time. Drilled and blasted rock was also observed on the right bank of Icicle Creek from the historical construction of the irrigation canal. Additional 2012 photographs of the study area are provided in **Appendix A** of the geologic assessment showing examples of drilled rocks and other anthropogenic impacts.

While it is difficult to make a definitive conclusion, the anthropogenic impacts within and adjacent to Icicle Creek do not appear to have caused a substantial change in the ability of fish to pass the Boulder Field since elevated areas of the channel margins are the main area of encroachment. Rieman's (2001) conclusions are valid that the study reach has probably been more impacted by the introduction of small rocks and boulders, rather than large ones. No evidence, however, was uncovered to indicate that anthropogenic rocks have themselves created a direct passage barrier. The introduction of small boulders and concrete into the channel may have an impact on the quality of habitat, but does not appear to contribute to fish passage impediment. The encroachment of the road on the left bank of Icicle Creek, primarily in the location from the Irrigation District access bridge to the Anchor Boulder, may have slightly altered the channel cross-sectional profile. The degree of encroachment cannot be determined unless more is known about the extent of the underlying bedrock. This would require excavation along that reach to reveal the parent material extent and elevation. When streamflows exceed 2,000 cfs, surface flows begin to spread and engage the irrigation access road prism material. At higher discharges water velocity begins to rapidly increase. Because of the high gradient, regardless of the channel width, water velocity becomes the more critical influence on fish passage through the Boulder Field. The Boulder Field does not contain uniformly erodible substrate. Historic post-glacial channel conditions may have been more uniform in gradient and what is present now is the revealing of large boulders that are too large or highly anchored to be fluvially-transported. Medium and smaller boulders could have routed downstream thus exposing these high gradient sections. It is conceivable that if the Boulder Field site can be verified to have had a more uniform rise via bedrock characteristics, the absence of the intermittent high gradient drops would have had less impact on fish passage through the Boulder Field. This could be evaluated by extensive exploratory excavation down to bedrock.

5 TARGET SPECIES

Review of modern fish use, passage and movement through Icicle Creek has been addressed by a few notable reviews (Nelson 2010 and 2012; Nelson et al. 2009; Ringel 1997, USFWS 2004). Migratory-sized bull trout were observed immediately upstream of the Anchor Boulder barrier. Conceivably, if specific factors aligned, such as ideal flow, favorable thalweg location, and presence of migratory bull trout or steelhead, fish passage through the difficult passage areas of the boulder field could be successful. Although efforts have been made to observe passability, there have been no documented fish passage incidents above the Anchor Boulder. Yet, even if observations could be made, there would still be uncertainty about what flow and conditions would allow a migration effort through this difficult reach.

Therefore, the construct for this analysis is that flow conditions in the early and latter portions of the ascending and descending hydrographs respectively, could provide narrow windows of fish passage given the alignment of other conditions affecting migration. Another factor that may inhibit regular passage is the shifting of fish passage routes when transported sediments block areas or open up others. These shifts which may occur year-to-year or over very long time periods (decades and centuries) are simply a testament to the dynamism in this reach. From a population scale perspective, such temporary impediments which occur across watersheds, areas in forms such as beaver dams, channel avulsions, or debris flow/landslide blockages, can contribute to the life history and genetic diversity of populations. This Boulder Field impediment (velocity and gradient) could in essence be a "temporary" impediment but on a much longer time scale than these shorter-term types.

In order to identify and assess fish passage impediments, this project took into account: physical stream channel characteristics, a range of stream flows, and fish swimming and leaping ability. The assessment considered the benefits of utilizing the full extent of the region's known steelhead and bull trout migration periods. Conceivably this would simulate a longer timing window for fish to migrate into Upper Icicle Creek somewhat in disregard for the unique timing and passage windows that historic Icicle Creek could have had in contributing to the region's fish population life history diversity. Natural flow conditions through the Boulder Field present a velocity barrier at high and low flows and could also be selective pressures for fitness and other fish characteristics. Preliminary review of habitat values of Upper Icicle Creek, suggest that it would primarily contribute toward spawning and early life history. This is foremost based on the presence of spawnable-sized gravel retained amongst large boulder habitat and the very cold temperatures that limit growth. Therefore, the focus for passage design considerations was on spawning adults. Based on the region's fish migration size and timing, in concurrence with local and regional experts, our fish passage through the study reach is based on the following specifications:

Table 1 - Target species selection and associated environmental attributes

Target Species	Target Life History	Range of Mean Daily flows[1] (cfs) during Migration Period	Design Flows[2] (cfs)	Adult Peak Migration Period	Target Fish size (in.)	Life history Significance
bull trout	Fluvial	175-900	20 - 1000	Aug - Sept	12 to 17	Spawning migration, foraging, distribution
steelhead	anadromous 1 and 2 salt[3]	225 – 1600	100 - 1200	Apr – May	25 to 31	Spawning migration, kelt movements

[1] Data used for the analysis was mean daily flows from April 1, 1997 to September 30, 2011

[2] Based on probable range of flows that adult migrants could successfully pass through the boulder field given gradient and discharge conditions where velocity would not impede fish passage.

[3] Number of years spent in sea, influences size of fish.

The above chart identifies the primary target flow ranges for bull trout and steelhead to move upstream. Initial field observations in October 2012 suggested that the flows most likely to pass fish in the channel's current condition would be approximately 200 cfs. A wide range of flows occur through the migration period (**Table 1 and Figure 3**). Timing of life history stages for Lower Icicle creek based on Wenatchee subbasin information and regional expert opinion are presented in **Table 2**. The main determinant for developing passage alternatives through the Boulder Field however would be flows, rather than explicit timing windows. For example, designs would assist steelhead in the spring that typically encounter higher flows and bull trout in the fall where low flows are encountered on the receding end of the hydrograph.

Figure 3 - Steelhead and bull trout migration timing windows (upright bands) overlaid on the estimated 10% and 90% exceedance flows.

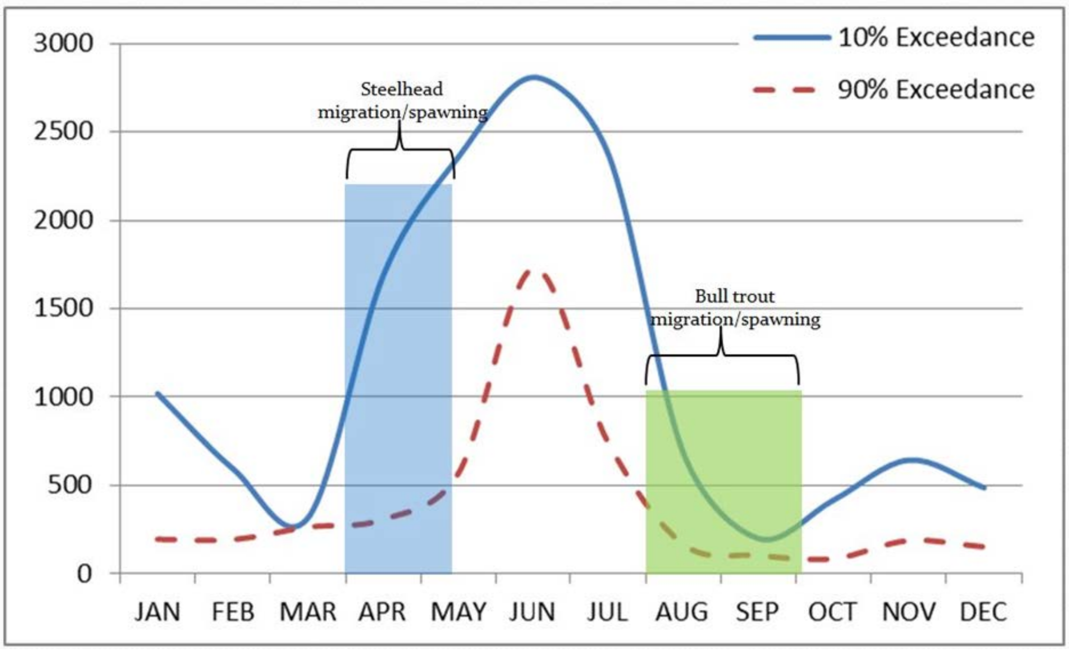

Table 2 - Icicle Creek periodicity chart for steelhead and bull trout

Species	Lifestage	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June	July	Aug	Sept
Steelhead	Spawning												
	Incubation												
	Rearing												
	In-migration												
Bull Trout	Spawning												
	Incubation												
	Rearing												

Key: Black indicates periods of heaviest use, grey is moderate, blank is little to none. M*odified from USDI-BOR 2005*

6 BASIN HYDROLOGY

Fish passage opportunities within the project reach are limited by stream flow. For the fish passage assessment and in considering design options, determining the range of flows in Icicle Creek was critical. Stream flow data is abundant on Icicle Creek and has been documented in several reports (Montgomery Water Group, 2004). Just upstream of the Icicle Peshastin Irrigation Diversion Dam is a USGS Gage (Icicle Creek above Snow Creek STA 12458000) at RM 5.8. This is not a real time gage but the historical data can be used to develop flow duration curves. Data used for the analysis was mean daily flows from April 1, 1997 to September 30, 2011. The time period for the flow duration analysis was based on the fish migration timing provided by regional fisheries experts. **Figure 4** is a summary of the flow data specific to the migration timing for bull trout and steelhead. The lines representing flows in **Figure 4** start at 10 percent exceedance (see Definitions) and end at 90 percent (left to right). These ranges were selected based on limits of the State and Federal agency criteria for fish passage design.

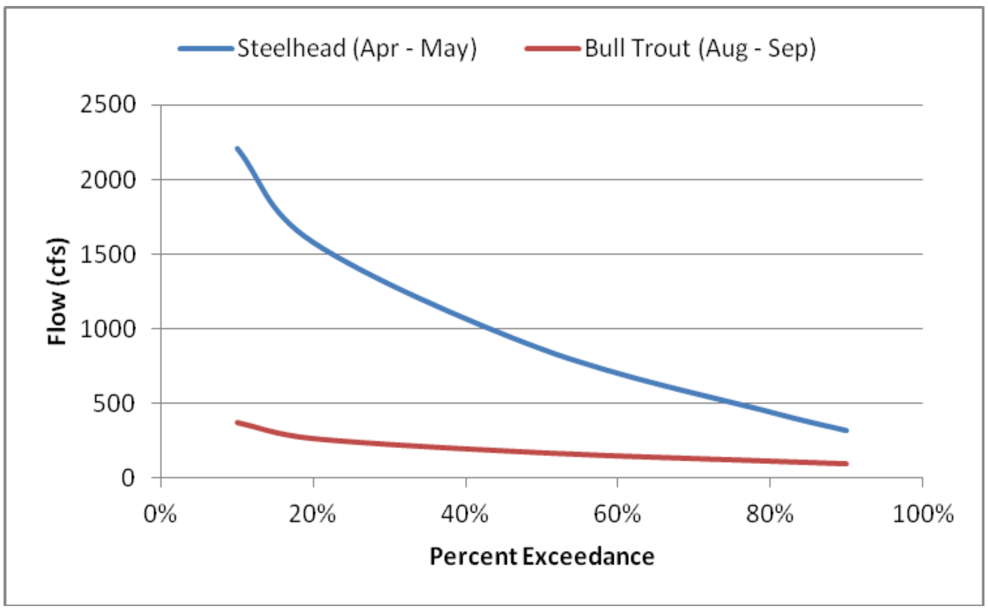

Figure 4 – Fish passage design flow range for steelhead and bull trout in Icicle Creek.

Figure 5 shows a comparison of the USGS gage to the real time station operated by the Department of Ecology at RM 2.2. The correlation between the two gages is very close (Pickett, 2011). The average difference for the months plotted in **Figure 5** are; April + 34 cfs, (i.e. the flow at the DOE Gage is greater than the USGS Gage), August -56 cfs (i.e. the flow at the DOE gage is less than the USGS gage), and September -18 cfs. Most of the flows reported during the observations periods were from the DOE gage. The difference between the two is not

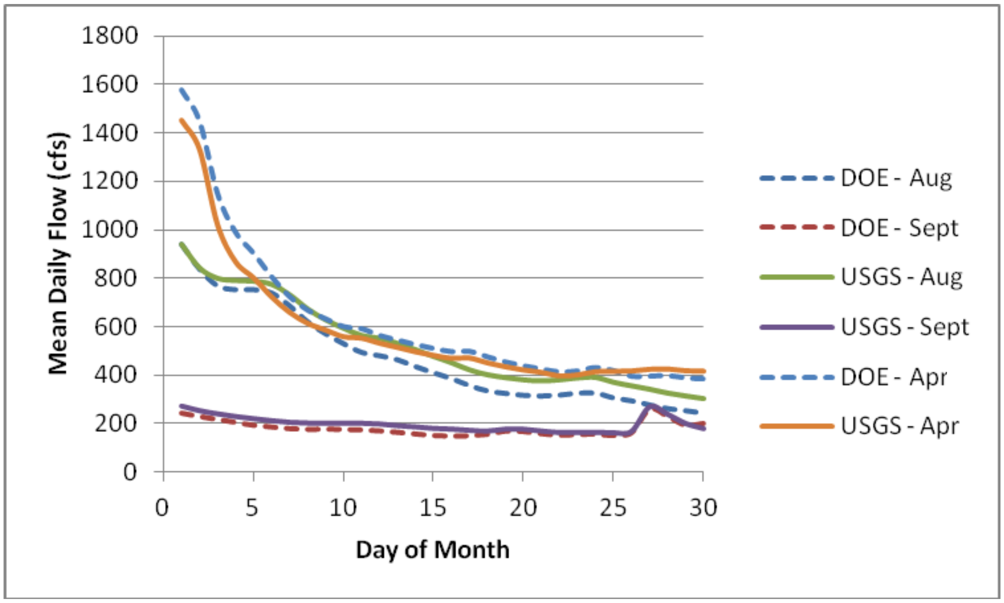

Figure 5 – Comparison of mean daily flows in 2011 for August, September and April for the USGS Gage and the DOE Gage.

significant enough to necessitate unique high or low-flow considerations per each design alternative. Essentially, the designs will provide passage function for a range of flows.
The project reach is very confined through the Anchor Boulder area and flood flows need to be considered in the design of any structures. Peak flood flows (**Figure 6**), are extremely high compared to typical flows for fish passage. The 10-year flood is estimate at 8000 cfs, and the 100 year flood is estimated at 18,000 cfs. The next step in the design process is to model these flows to estimate the range of water elevations and velocities in the channel. Historical photos of large floods with specific dates may be needed to calibrate such a model for these estimates.

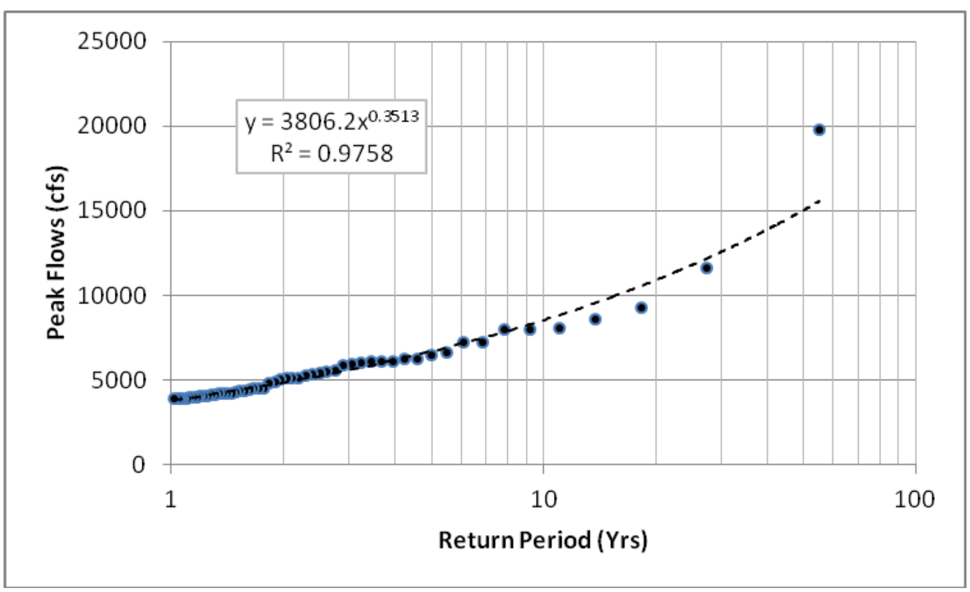

Figure 6 – Icicle Creek peak flood flows from USGS gage station 12458000.

7 FISH PASSAGE ASSESSMENT

Fish passage success at natural or naturalized (barriers of natural materials which may have anthropogenic influence) barriers (or impediments) is calculated by comparing fish leaping and/or swimming abilities to the geometry and hydraulics of the Boulder Field. Powers and Orsborn (1984) identified one approach for these calculations. More recent work (Powers 2008; Powers et al. 2009) further developed passage analysis concepts to include an energetics model for swimming and leaping, which accounts for total fish energy needed and expended at each impediment. These assessment tools are both spreadsheet models which require input of the site geometry and hydraulics. Details and background information for the passage calculations are explained in Powers et al. 2009. The energetics model assessed the energy expenditure of a fish attempting to swim through a channel and for this study the target fish size was a 31 inch steelhead to evaluate high flow scenarios and a 17 inch bull trout to evaluate low flow scenarios. The fish leaping model calculates the leaping height and distance, given a swimming speed and angle of trajectory for fish species.

For low gradient channels, where the mode of passage is swimming, the energetics model works well, but for high gradient channels with drops, where the mode of passage is leaping, the fish leaping model will be used. The threshold gradient of Boulder Field geometry where fish leap to pass instead of swimming is not clearly evident. For the purposes of this study, gradients in the 25 to 35 percent range will be used to define a fish attempt to pass as either leaping or swimming. Site-specific observations were also used.

Site Observations

Field observations to identify flow characteristics that would provide fish passage opportunities occurred at flows of 20, 200, 1000 and 2800 cfs. A site topographic survey was also performed at approximately 20 cfs in September 2012. The diversion canal at the Diversion Dam was conveying about 90 cfs, so the actual flow at the USGS gage was about 120 cfs (accounting for some surface flow loss through boulders). The main observation at 20 cfs was in the Middle Reach, a flow which was insufficient to bring the water to the surface (**Photo 3**). By observation some of the Middle Reach was determined passable, but a passage route could not be identified in the section through the Anchor Boulder. In the Upper Reach at the Diversion Dam, shallow sheet flow passed over the dam with a 4 to 5 foot drop (**Photo 4**).

Photo 3 – Icicle Creek Boulder Field Middle Reach. View is of left bank from top of Anchor Boulder depicting flows going under boulders.

Photo 4 – Concrete Diversion Dam with flashboards at 20 cfs.

In another observation, at 200 cfs in the Middle Reach, there appears to be passage opportunities, through the Anchor Boulder segment where there was enough surface flow and pool depth for a potential fish passage route (see **Figure 7** and **Photo 5)**. This is a viable route to develop an alternative for two reasons: 1) a velocity or drop could not be measured indicative of a barrier, and 2) while flows under boulders could be concentrated into a fish passage route. This situation was also observed along the right bank next to the Anchor Boulder where there is more direct leaping route within a 21 foot drop, but the crest is blocked by boulders wedged into the clear openings where fish would jump (**Figure 8, Photo 6**).

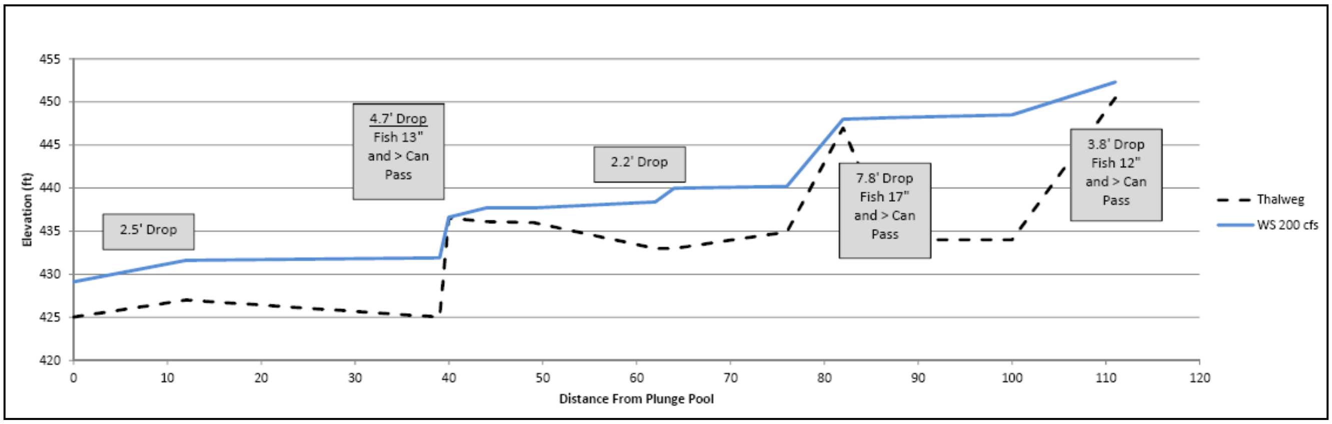

Figure 7 – Icicle Creek Boulder Field Middle Reach (Anchor Boulder) potential fish passage route at 200 cfs along left bank. The overall drop is 21 feet.

Photo 5 – Icicle Creek Boulder Field Middle Reach along LB. View is from top of Anchor Boulder at 200 cfs. Note sheet flow over rocks at several locations.

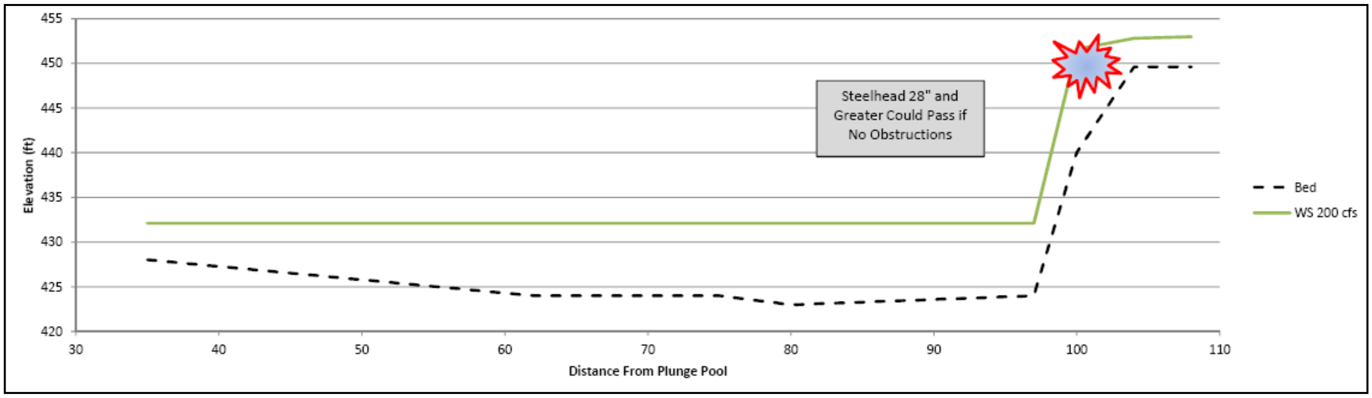

Figure 8 – Icicle Creek Boulder Field Middle Reach (Anchor Boulder Right Bank) at 200 cfs showing water surface and thalweg profile.

Photo 6 – Icicle Creek Boulder Field Middle Reach (Anchor Rock) showing 21 foot drop from right to left and the crest blocked by boulders (arrows) that have filled in the openings.

As expected the varying flows manifest different surface flow configurations. At 200 cfs, flow through the Middle Reach is in the form step/pool geometry, where fish have good resting areas and the drops are all within the 2 to 4 foot range (except for the Anchor Boulder area). At 1000 cfs, the flow starts to stream or short circuit the pools. The pools become very turbulent with fish passage more likely controlled by water velocity and refuge seeking behavior of fish along the channel margins. The potential passage routes identified at 200 cfs near the Anchor Boulder left bank area are too turbulent and washed out at 1000 cfs. Although there are limits to predictive accuracy of modeling in the high gradient Middle Reach, RAS-predicted water surface area and channel edge (**Figure 8**) support field observations that higher flows are needed to engage the areas that are encroached upon by road(s).

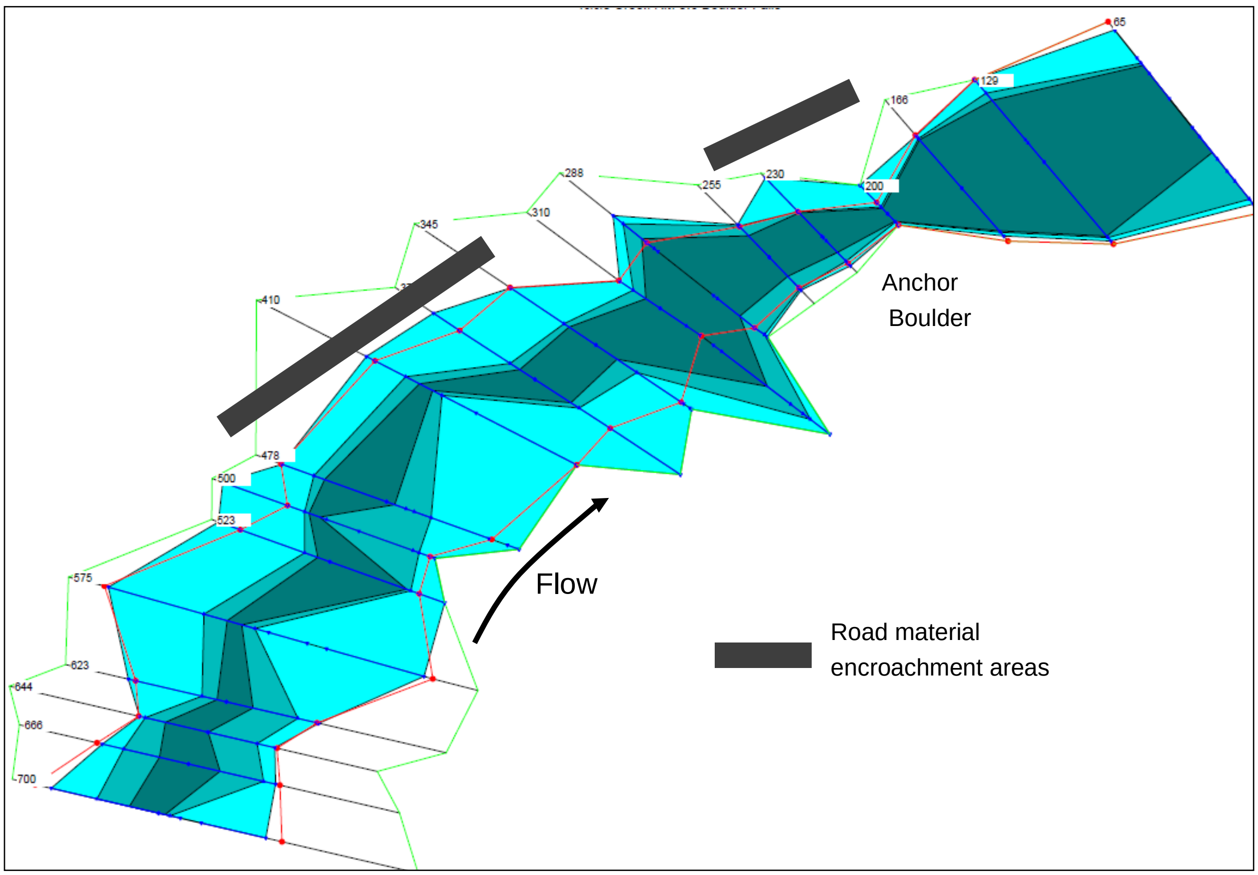

Figure 8 – HEC-RAS output of predicted water surface elevations in Middle Reach at 20 cfs (dark shade), 200 (medium shade) and 2800 (light shade).

To assess the Middle Reach for passage a HEC-RAS model (see Definitions) was developed to calculate the depths and velocities. HEC-RAS is a backwater computation model and cannot normally model gradients found on this site (**Figure 9**). Accounting for this caveat, water surface elevations were measured at a range of flows so the model could be calibrated and hydraulic gradients constructed (**Figure 10**). The Manning's *n* roughness factor was then adjusted until the modeled condition was close in value to the measured flow conditions (**Figure 9**). With the velocity and depth calculations from HEC-RAS, the fish energetics spreadsheet was used to calculate the energy expenditure balance of bull trout and steelhead attempting to swim through the Middle Reach. The velocities generated from the HEC RAS model are average velocities and therefore may not accurately represent what fish may encounter.

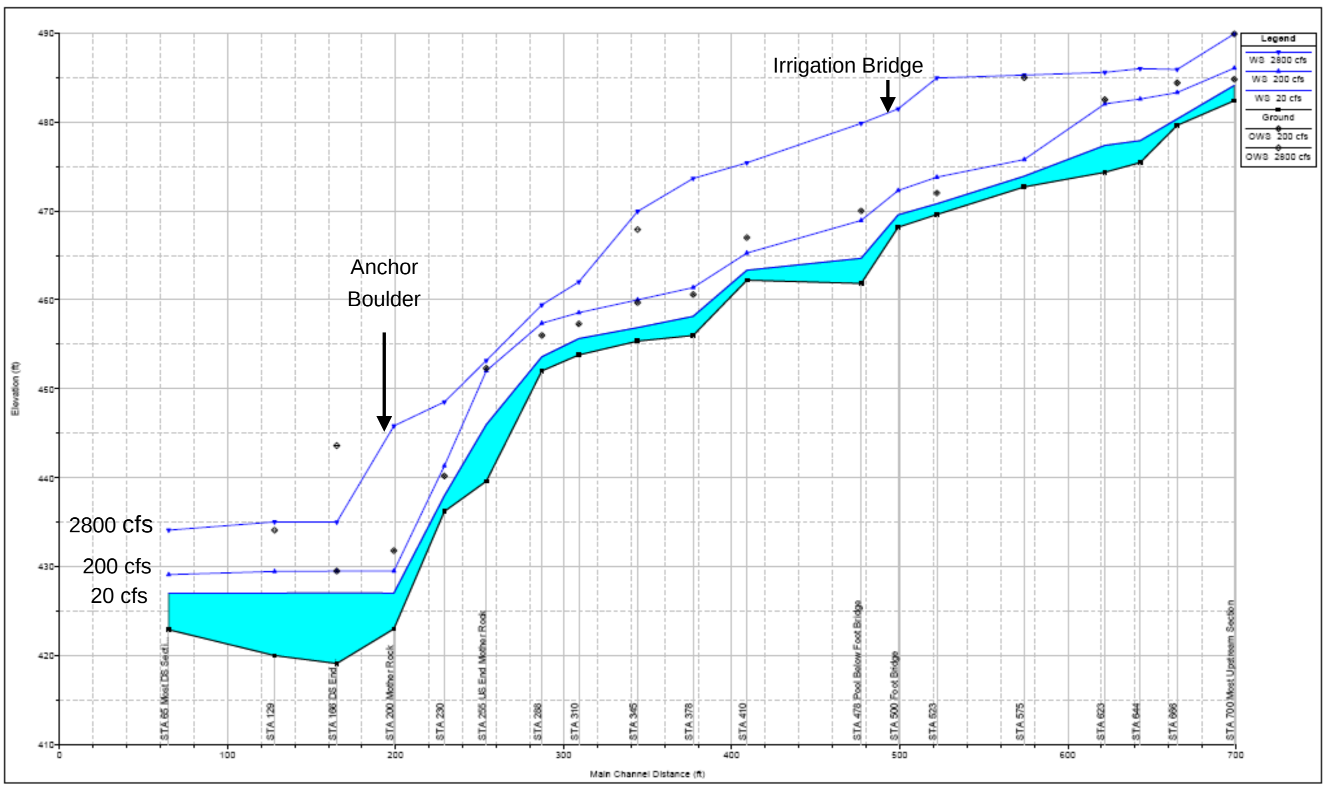

Figure 9 – HEC-RAS water surface profiles for the Middle Reach at 20, 200 and 2800 cfs. The dots along the lines are measured elevations.

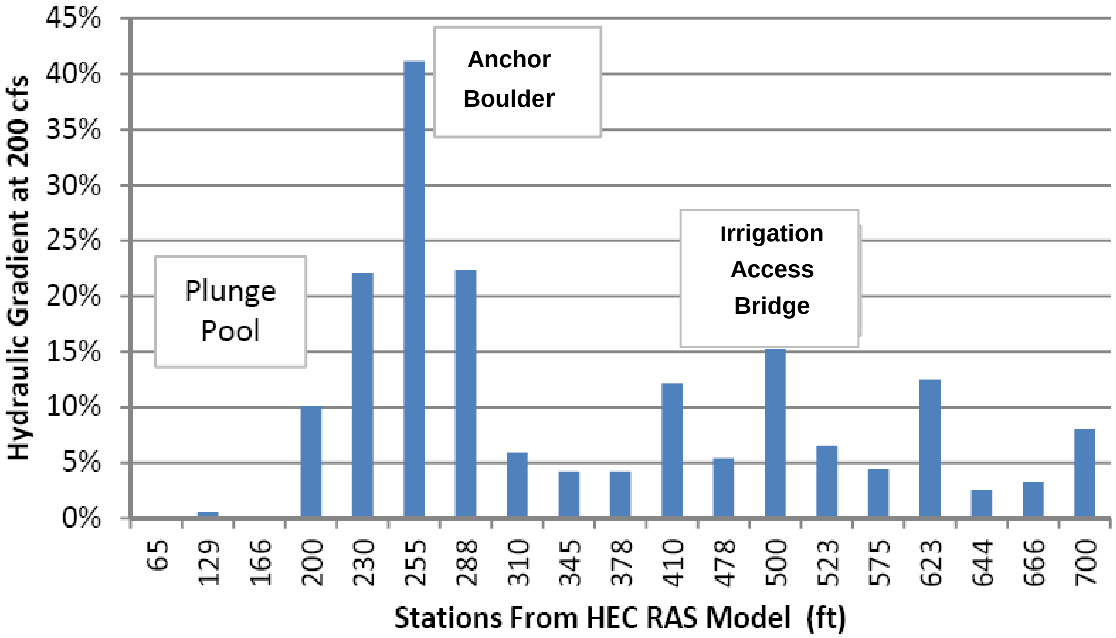

Figure 10 – Hydraulic gradient of the Middle Reach as calculated by the HEC-RAS model at 200 cfs

The complexity of the Boulder Field could provide for multiple fish passage routes with some areas exhibiting higher velocities and constricted flow with other areas with lower velocities but shallow or sheet flow over boulders. **Photo 7** shows the Middle Reach at 1000 cfs, a flow providing multiple pathways for a fish to negotiate are joining and increasing in turbulence to the point where pathways are potentially no longer detectable by fish.

Photo 7 – Middle Reach at Anchor Boulder (left) and upstream of Anchor Boulder (right) at 1000 cfs.

The results of the energetics model for 1000 cfs are shown in **Figure 11**. In this assessment scenario a 31-inch steelhead is the size of fish attempting to pass. This target size represents the best case scenario for predicting that an area is passable by using a large migratory steelhead that was assigned a strong condition. In reality, if the fish had an extensive migration or was holding for a long period of time in preparation for spawning and focusing its energies on gamete production, the fish would not necessarily be at full strength. The results for smaller sized steelhead and bull trout would show less passage success an even more rapid decline of energy through the reach and likely impassability at additional locations. **Figure 11** projects that the fish runs out of energy at the Anchor Boulder. Velocities in this area were modeled at

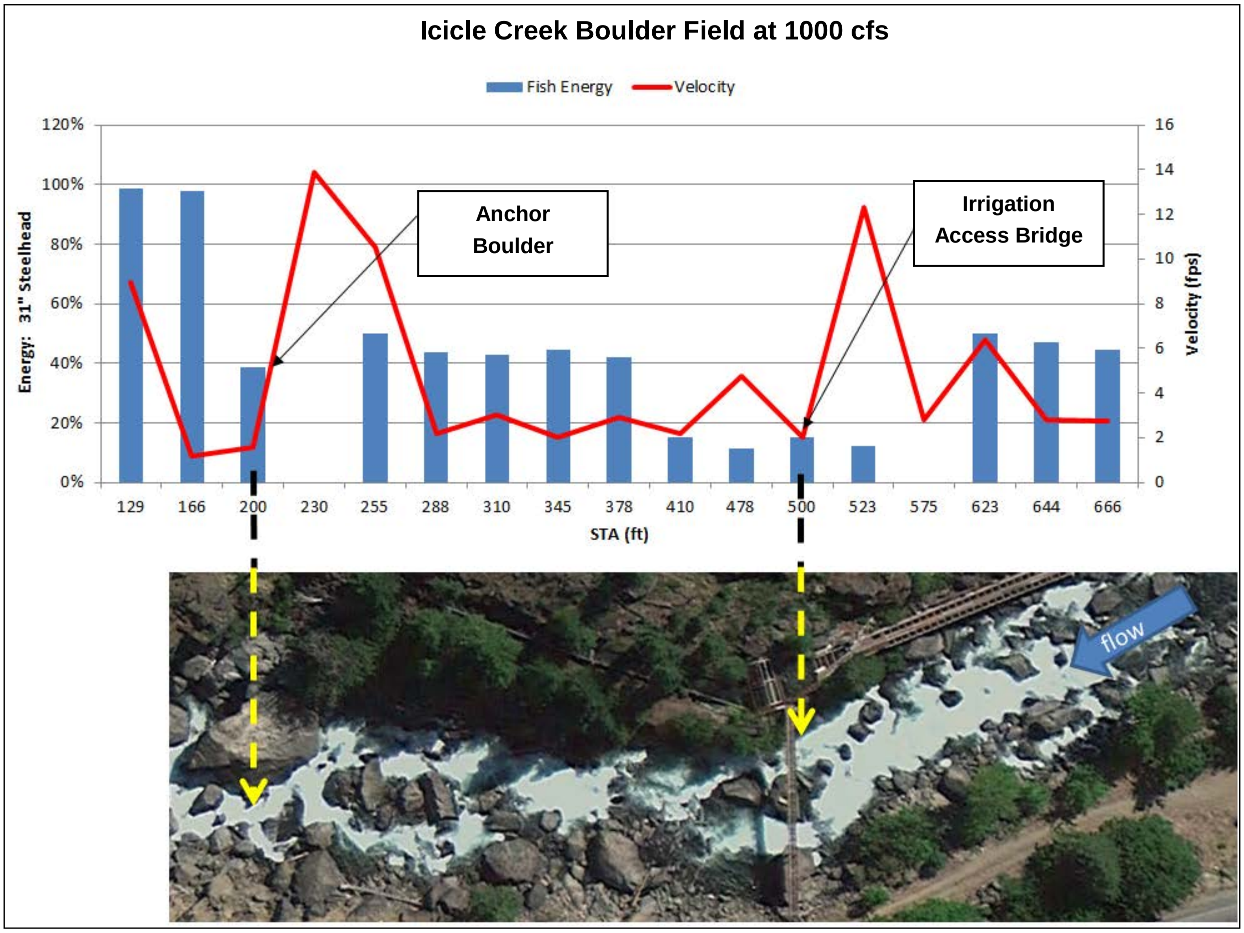

Figure 11 - Fish Passage Energetics Assessment in the Middle Reach at 1000 cfs. The red line is the average velocity and the blue bars represent the amount of energy in a 31 inch steelhead as it attempts to swim through the reach. At STA 200, an effectively impassable area at 1,000 cfs, fish energy reduces to 0%. At STA 255, 50% energy was input into the model to model passage through the rest of the Middle Reach. The reduced energy in the footbridge area suggests passage impediment from velocity.

over 12 feet per second. At STA 255 where fish energy reduced to zero percent (just upstream of the Anchor Boulder), an energy level of 50 percent was hand entered into the spreadsheet model to evaluate the potential for fish passage upstream of the Anchor Boulder. This simulates their condition if fish were to find a passage route around the Anchor Boulder. The results show the fish running out of energy upstream of the Irrigation access bridge. Observations at 1000 cfs along the left bank above the Anchor Boulder revealed 3 or 4 resting pockets where fish could recover energy and likely pass this section.

At flows exceeding 1000 cfs, site observations show velocities and turbulence increase dramatically and likely the entire Lower Reach and Middle Reach are barriers at flows above 1500 cfs. A flow of 2800 cfs was observed and it was estimated there would be no passage due to the surging turbulence and high velocities. The one exception to this estimation is the concrete Irrigation Diversion Dam in the Upper Reach. At flows above 1000 cfs, the channel water surface elevation downstream starts to backwater the dam, reducing the drop. A summary of the reaches and passability is provided in **Table 1**. **Table 1** is color coded to denote areas of passability. The 100 foot segment through the Middle Reach (500-600 ft distance) is the "bottle neck" for fish passage. Some potential passage may exist between flows of 200 to 500 cfs, but would be very limited and could vary year to year by changes in bed morphology.

Table 3 – Icicle Creek Boulder Field fish passage summary

			Icicle Creek Boulder Field Study Reaches						
			Lower Reach	Middle Reach			Upper Reach		
			0 - 500 ft	500 - 600 ft	600 - 800 ft	800-1000 ft	1000 -1650ft	1660 ft	1660 to 2160 ft
Icicle Creek Flow (cfs)	Percent of Time Flow is Exceeded Apr to May (steelhead)	Percent of Time Flow is Exceeded Aug to Sept (bull trout)	Snow Ck. Bridge to Anchor Boulder	Anchor Boulder Area	Downstream Footbridge	Upstream District Footbridge	Below Diversion Dam	Diversion Dam	Above Diversion Dam
20	99	99	P	IP	P	P	P	DPP	P
200	95	40	P	DPP	P	P	P	DPP	P
500	70	5	P	DPP/IP	P	P	P	P	P
1000	40	<1	P	IP	DPP	DPP	P	P	P
2000	15	<1	DPP	IP	IP	IP	P	P	P
>2000	10	<1	DPP	IP	IP	IP	P	P	P

P = Passable, DPP = Difficult or Partial Passage, IP = Impassable

8 FISH PASSAGE ALTERNATIVES

The following section briefly outlines alternatives not pursued and provides an overview of the uncertainties to consider when developing the alternatives and logic behind the recommended alternatives. Conceptual design drawings (**Appendix A**) indicate the location of the alternatives within the stream channel.

Alternatives Considered, Not Pursued

The assessment considered some alternative concepts that were not recommended or carried to design, primarily based on: viability, cost, natural aesthetics, extensive management and maintenance. The disregarded options are listed below with comments as to why they were not pursued in this analysis:

- **Fish ladder Boulder Field bypass using irrigation flume (right bank with fish entryway below Anchor Boulder)**
    - Difficult detection by fish to single fish ladder entryways have the potential for such structures to be under-utilized
    - Ladder construction would be highly visible in natural recreation area
    - Water use and management issues related to the flume currently operated for irrigation
    - Likely exorbitant design and construction costs; complex, unnatural, extensive environmental review process

- **Fish ladder Boulder Field bypass Left Bank constructed channel**
    - Cut into existing Irrigation District access road bench material puts slope stability at risk from 20-yr + flood levels
    - Fishway entries can be compromised due to bedload movement
    - Monitoring and maintenance requirement to determine if designed flow is routed through fishway consistently, shifts in fishway elevation could compromise long-term fish-use by altering the periods that the set elevation is hydrologicaly connected for fish use

- **Large boulder removal/major in-channel modification (***Note: this technique would require altering* *__below__* *the current channel bottom and the armored substrate. The alternative-Channel Profile Adjustment does not disturb below the stable streambed)*

    - Channel destabilization by removing boulders below the current channel bottom could introduce knickpoint with potential for down-cutting erosion which could reach the diversion dam
    - Downstream shoreline, bridges, properties may be at risk from if a large bedload volume is released in a short time period which could result in flooding, channel avulsion, loss of pool habitat and channel depth
    - Large and sudden releases of large boulders and cobble could develop into downstream passage issues or other unintended consequence to habitat values

- **Left bank Irrigation District access bridge area**

    - Although difficult passage at flows above 1,500 cfs, the reach is not entirely impassable *(note: at flows above 2500 cfs, the entire reach is a likely velocity/turbulence barrier)*
    - If passage is enhanced at the Anchor Boulder, fish could likely pass this area without modification, therefore no passage alternative provided

Considerations for Designs

The physical and hydrologic assessment and locations of alternatives suggest that concept design should make consideration for the alternative's functionality and resilience at the 20,000 cfs threshold. A risk analysis and further geotechnical analysis is appropriate for the next design phases, which could more thoroughly evaluate the preferred alternatives.

The following items are a preliminary list of considerations:

- No action at irrigation Diversion Dam. The structure's function and integrity may face potential of undermining flows, further narrowing the passage window.

- Design risk above 20,000 cfs. Cobble and boulder competence was not thoroughly evaluated at this stage of alternative development which could be accomplished with further geologic analysis, rock core sampling and risk assessment. Constructed riffles and any boulder modifications or re-positioning are additional considerations.
- Rock removal below the current stream bottom profile, could lead to unintended bed destabilization, affect target gradient and impact downstream habitat values.
- Alternatives that cut into existing Irrigation District access road bench material puts slope stability at risk from 20-yr + flood levels. This consideration is ameliorated by proper stable configuration and abandonment of the affected segment.
- Irrigation District access road segment abandonment would necessitate constructing access from the western edge of the District parcel. This access strategy has been determined viable by District officials.
- Fishway attraction areas and exit areas. Amidst a turbulent reach, underwater visibility can be poor and detection flows can be masked by general site turbulence. Concrete stem walls or boulder adjustments can resolve such issues. Fishway entrance and exit areas can be attractions for flotsam due to desirable eddy creation or slack water on margin habitats which may lead to blockages requiring maintenance.
- Uncertainty of underlying bedrock elevation. Channel profile adjustment strategies and fishway construction on channel margins may be affected by bedrock presence and require further geologic evaluation. In both circumstances, designs modification can be made for fishway re-alignment or strategies involving blasting or large scale hammering can be invoked, albeit affecting costs. Geologic evaluations will help determine the final choices for approach.

Lower Reach Alternatives

The lower reach of the study area, upstream of the Snow Creek trailhead bridge does not have fish passage impediments. Natural flow impediments exist at low flows where surface connectivity is lacking and at high flows above 3,000 cfs although the relatively lower gradient does have channel margin migration corridors most prominently on the left bank (**Photos 8, 9**).

Photo 8 - View upstream through Lower Reach from Snow Creek Trail bridge, about 1250 cfs. Channel margins and relatively lower gradient compared to Middle Reach in the distance allows fish passage through here.

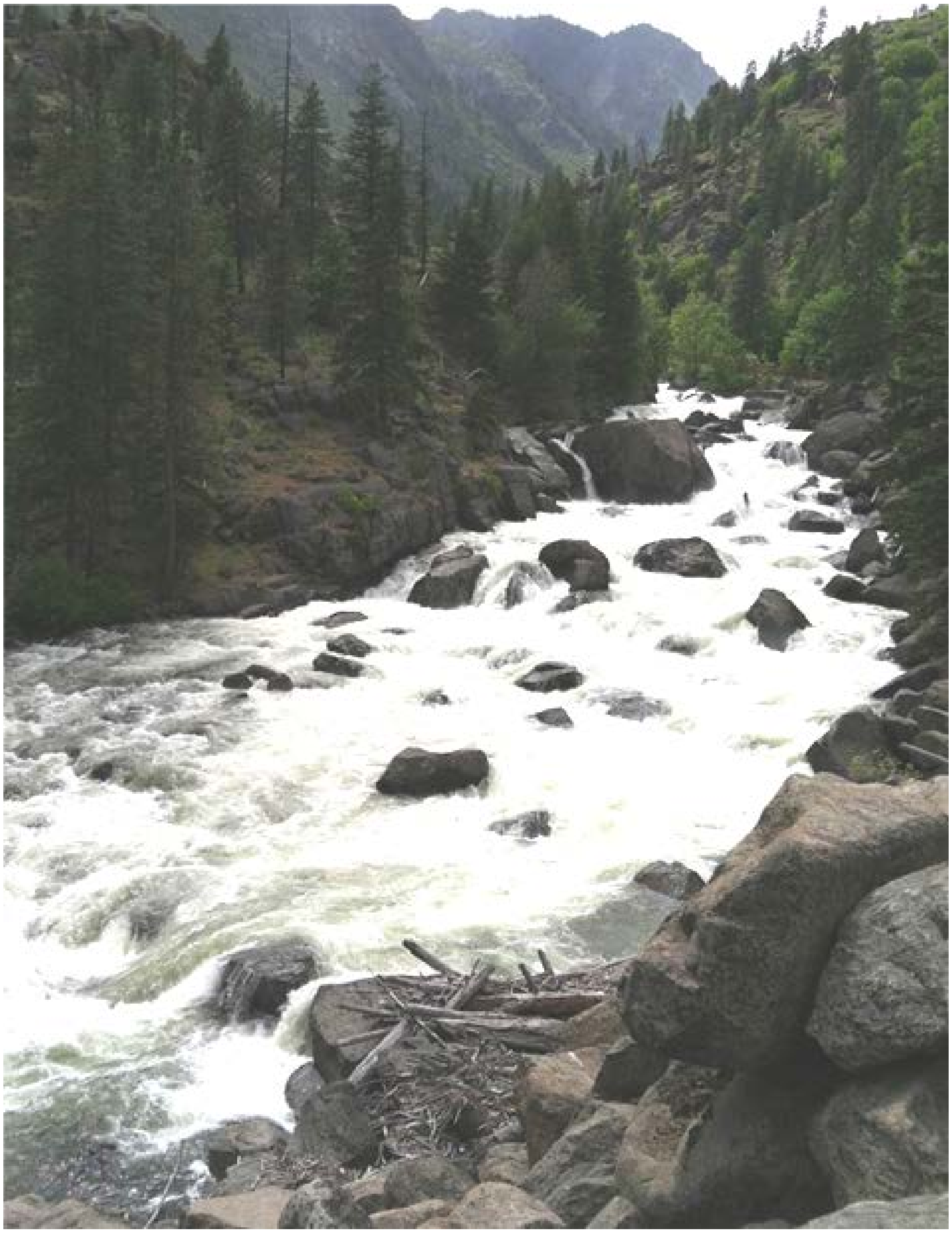

Photo 9 - Upper Portion of Lower Reach leading up to Anchor Boulder at about 2,500 cfs. Channel margins (foreground) and mid-channel areas provide ample fish passage routes leading up to the higher gradient middle reach.

Figure 12 provides a location map of the Middle Reach and Upper Reach Alternatives.

Figure 12 – Middle Reach and Upper Reach Alternatives location in relation to each other. 1) Channel profile adjustment, 2) Roughened channel, 3) Vertical slot fishway, 4) Low flow pool and weir fishway, 5) Pool and chute fishway, and 6) Constructed riffle.

Middle Reach Alternatives

The Middle Reach is the most ecologically complex reach and contains the largest exposed boulders and cobbles throughout the study area. Gaps between boulders that have filled in with smaller size substrate and woody debris complicate the understanding of current passability level because some of the material may be transient. This factor can affect surface flow characteristics in relation to fish passage at the low and high flow portions of the hydrograph. The consequence of material seasonally filling in between gaps in boulders or step pools is while there may be adequate flow for passage in the upper portions of this reach, the water may be forced to flow subsurface or directed over protruding rocks in sheet or turbulent flow (see **Photo 5**). The main strategies for the Middle Reach are to create conditions for surface flow connectivity or to bypass instream impediments through channel margin fishway construction.

The following alternatives were selected based on considerations which were most likely to achieve fish passage for migratory adult bull trout and steelhead while also reducing risk to: 1) unintended consequences of channel instability, 2) potentially impairing passage by channel shifts, or 3) altering flow conditions through fishways that would impact the natural spawner migration timing of bull trout and steelhead. Uncertainties have been identified during alternative development, and a risk analysis and further geotechnical assessment is appropriate for the next design phase. The Middle Reach alternatives following are titled with the flow range they are conceptually designed to operate for fish passage. The design drawings are included in Appendix A.

8.1.1 Middle Reach – Channel Profile Adjustment (100 – 1,500 cfs)

The Channel Profile Adjustment option is to remove a major constriction in the channel upstream of the Anchor Boulder, fill in the plunge pool and create a gradient (9 percent) similar to the natural gradient of Icicle Creek within this reach. With the resultant conditions of boulder re-alignment and channel width, fish passage would be good at low flows and would be adequate up to flows of 1500 cfs. This option would make modifications to the Anchor Boulder area by reducing the height of key boulders currently retaining sediments and shape the steep sections. There would be minor visual impact since the concept will just induce the movement of boulders and rocks in key areas. It is not the intent to construct a 9 percent roughened channel, but to remove enough constriction, and strategically fill, or allow flows to import substrate to fill, deeper areas so that the creek can re-grade naturally over time. It may take 5 to 10 years before the desired condition is met. This option requires a geotechnical investigation of rock beneath the channel bottom.

The re-grading will not be successful if bedrock is encountered at elevation close to current bed profile. Also, controlled blasting will likely be required to reduce the sizes of the larger boulders which cannot be moved by heavy equipment. This is a progressive alternative approaching the project in stages, such that each adjustment could be evaluated for level of passage success and if risk has been introduced due to the channel profile reconfiguration. In the plunge pool downstream of the Anchor Boulder, 1000 cubic yards of riprap would be needed to create a bankline for the initial channel configuration. For the excavation process, boulders of a predetermined size (3 feet and smaller), would be left in the channel. Larger rocks would be blasted horizontally at the target control elevation and fragmented and/or smaller rock would route downstream into the plunge pool. Unintended shifts of very large boulders could redirect high flows into the Irrigation District access road, however these potential impacts could be addressed by eliminating a section of the road (approximately 150 feet above and 150 feet below the Anchor Boulder) and widen the channel. An alternative entrance to the access road could be developed at the western edge of their parcel. A potential risk to this alternative is creation of a knickpoint that may result in head-cutting of the stream channel in an upstream direction. The risk is greatly reduced by designing not to alter boulders or parts of boulders below the desired gradient control elevation.

8.1.2 Middle Reach – Roughened Channel (100 – 1,000 cfs)

The design options for the Middle Reach around the Anchor Boulder have to address 25 feet of vertical elevation. This design option creates a passage way for fish by pulling back the left bank and constructing a channel along the toe of the slope. The design requires a large excavation along the left bank of the Boulder Field and construction of a 14 foot wide roughened channel. The Irrigation District access road would be utilized for construction access and the channel would need to be incorporated partly into the road prism making a section of the road at least 100 feet downstream of the irrigation footbridge unusable. The irrigation foot bridge could be accessed from the western portion of the IPID parcel with a new entrance developed for the access road. An example of a similar roughened channel is shown in **Photo 10**. Approximately 5000 cubic yards of rock material would be removed either by blasting or large excavator. The rock material would be pushed down into the low areas of the Anchor Boulder and plunge pool and allowed to sort through the Icicle Creek system over time. The slope of the new channel would be 11 percent over a length of approximately 240 feet. The channel would have some protection from frequent flood flows by creating a rock berm and protected entrance. Despite the protection, larger, infrequent would inundate the channel. These would be flows above when fish passage occurs. The channel would be comprised of a graded mix of boulders and cobble in the range of 6 inches to 4 feet, with isolated boulders up to 6 feet. A section of the access road would need to be removed, approximately 100 feet above and 150 feet below the Anchor Boulder, to make room for the channel. The slope excavation would be 1:1.

Photo 10 – Example of roughened channel fishway

There are several issues with the rock excavation which need to be resolved in terms of water lines, bedrock, etc. Geotechnical exploration and a detailed site survey would be required to insure feasibility. Several other minor channel modifications would be required. Concrete and rock sills would need to be constructed near the Boulder Field crest to ensure low flow into the channel. This design option would operate for fish passage between Icicle Creek flows of 100 to 1000 cfs. Below 100 cfs, there may not be enough surface flow for passage, and above 1000 cfs fish attraction into the roughened channel will be a major problem, as fish will be more attracted to the main flow coming through the Anchor Boulder area. The design flow for the roughened channel would be in the range 100 to 250 cfs (low flow range target). Average velocities would vary from 3 to 5 feet/second. Depth in the roughened channel would vary from 2 feet to 4 feet. When Icicle Creek flows at about 1000 cfs, the roughened channel flow would be 250 cfs, so there would be some false attraction problems for fish at the higher flows, primarily a problem for steelhead in May.

8.1.3 Vertical Slot Fishway (100 – 1,000 cfs)

This design option (**Photo 11**) would construct a 25 pool vertical slot fishway along the right bank between the Anchor Boulder and bank below the irrigation canal. There is bed rock in this area, so some of the fishway would be blasted into the rock and have rock walls, while other sections would have concrete walls. A detailed survey and geologic assessment is needed to further define the option. The entrance pool located adjacent to the large pool below the Anchor Boulder would be 8 feet wide by 10 feet long. The hydraulic drop through the slots would be one foot. The overall fishway length would be 250 feet. The upstream end (or fish exit) would have a protective wall with bulkhead gate which would be closed during the non-fish migration windows to reduce the potential for damage to the fishway and maintenance.

Photo 11 – Example of vertical slot fishway constructed within a rock trench excavated by blasting.

One of the most difficult features of this option is the lack of access to the left bank for construction and maintenance, with further evaluation with land owners or easement managers required, with an access agreement secured before starting the next survey and design phase.

8.1.4 Middle Reach – Low Flow Pool and Weir Fishway (100 – 500 cfs)

This design option would enhance the fish passage route which was observed at 200 cfs, by creating a series of pool and weirs (6 total) each with 3 to 4 feet of drop. The design flow for the fishway would range from 10 to 25 cfs. At 10 cfs in the fishway, the Icicle Creek flow would be about 100 cfs and at 25 cfs in the fishway, Icicle Creek flow would be about 400 to 500 cfs. Above 500 cfs in Icicle Creek, the fishway would become inundated with high water and would likely not function due to high velocity. The pool sizes would be approximately 10 to 12 feet wide, 12 to 14 feet long and 4 to 5 feet deep. The fishway operation range may be extended (additional hydrologic and design evaluation needed to determine that range) by increasing the pool size or configuring the pool into a pool and chute fishway design. The weirs/sills, walls would be formed by drilling into existing boulders for the rebar and forming them around the rocks. It is very likely that the floor of the fishway will be porous and to have 25 cfs flowing over the weirs requiring an additional 5 cfs flowing into the upper end. As with any of the options, flow control is needed in the flow pathways near the Anchor Boulder to ensure flow gets to the fishway. This will require some in-channel modifications resulting in some visual impact. Access for this option will be extremely difficult without removing a small section of the access road to build a road grade down to the site. The main considerations for this are appropriate locations of the weirs and walls that would be located in protected or relatively lower-energy areas so that large transported rocks would not damage them.

Upper Reach Alternatives

The Upper Reach includes the Irrigation Diversion Dam as the only fish passage impediment. The wide boulder-cobble channel provides multiple pathways during low flow periods and slower velocities on the channel margins relative to the mid-channel during high flow periods. The Diversion Dam creates some passage difficulty at moderately low flow (<150 cfs) when depths over the top of dam reduce to inches or flows are diverted into the substrate and through the diversion channel.   For both the pool and chute fishway and constructed riffle option there would need to be coordination with the other diversion needs at the site.

8.1.5 Upper Reach (Irrigation Diversion Dam) – Pool and Chute Fishway

This design option would remove a section of the existing dam and construct a concrete pool and chute fishway. The fishway would be 24 feet wide and have a high design flow of 120 cfs. Flows greater than 120 cfs would either pass over the existing dam with the use of stoplogs or divert through the irrigation diversion. An appropriate solution for a low head dam with a passage problem is a pool and chute fishway. Up to 100 cfs, all the flow would be in the fishway and there would not be false attraction. The fishway pool length would be 12 feet, with a vertical drop per weir of 0.8 feet and a slope of 6.7%.The fishway slope would be 6.7 percent. Design details of pool and chute fishway is provided in (Powers, 2007). At low flow the fishway would function as a pool and weir fishway and at high flow the water streams down the center of the fishway. An example of a 16 foot wide pool and chute fishway is shown in **Photo 12**.

Photo 12 – Pool and Chute Fishway at low flow (Silver Creek, Washington).

8.1.6 Upper Reach (Irrigation Diversion Dam) – Constructed Riffle

This design option would construct a series of riffles to backwater the existing concrete dam. An example of a series of constructed riffle is shown in **Photo 13**. The riffle would be 90 feet wide (channel width) and 35 feet long with a low flow thalweg in the center. The riffles would extend 210 feet downstream of the dam. The drop over each riffle would be one foot, but this one foot of drop would be in the form of water flowing over a 5 percent roughened channel with pools between the riffles.

Photo 13 – Cedar River Constructed Riffle backwatering a 6-ft high concrete diversion dam

9 COST ESTIMATES

Cost estimate spreadsheets were prepared for alternatives in the Middle and Upper Reach (See **Appendix B**). A summary is provided in the following table.

Table 4 – Icicle Creek Boulder Field design options and cost comparison

Design Alternatives	Flow Range Function (cfs)	Bull Trout Passage	Steelhead Passage	Estimated Cost
Middle Reach-Channel Profile Adjustment	***100-1500***	***90%***	***90%***	**$ 771,638**
Middle Reach-Pool And Weir Fishway	100-500	90%	90%	$ 259,551
Middle Reach-Roughened Channel	100-1000	90%	90%	$ 620,287
Middle Reach-Vertical Slot Fishway	100-1000	90%	30%	$ 995,587
Upper Reach-Pool and Chute Fishway	***<150***	***90%***	***90%***	**$ 257,750**
Upper Reach-Constructed Riffle	<150	90%	90%	$ 371,358

bold = Preferred Alternatives

10 CONCLUSIONS AND RECOMMENDATIONS

A fish passage assessment which includes good hydraulic modeling provides support for estimating fish passability. There is no more accurate substitution for determining fish passage than direct observation, however, uncertainties about historic abundance, life history diversity, and changes in historic channel conditions, allow for reasonable predictions of fish passage. With this assessment's passability predictions, questions remain regarding the variability in site conditions that can occur year-to year and decade to decade. The study site offers many considerations including: hydraulic complexities (large boulders, multiple cascades, transient fishway blockages, large cobble boulder transport, and flow management effects (flow diversion). Although the analysis for passage alternatives is conservative by using the migration windows for the area populations, the actual timing window for fluvial migrant bull trout to pass through the Boulder Field may be a shorter timespan than the window for steelhead. Migratory bull trout would need to negotiate high spring and summer flows in lower Icicle Creek to approach the Boulder Field during pre-spawning migrations. Then bull trout encounter the receding end of the hydrograph which drops rapidly into impassable low flows periods truncating the tail end of their migration timing window.

Regarding anthropogenic influences, there is evidence of introduced rock material into the channel over time. Material is evident within the channel and on channel margins. The magnitude of the amount added to the natural bed elevation cannot be ascertained in this project scope. However, given the locations of the observed encroachments on the channel margins, the gradient control produced by the Anchor Boulder as well as observed and modeled flood elevations, the encroachment impacts primarily exist at left bank channel margins at higher flow levels 1000 to 1500 cfs. Consequently, when flows approach these levels, many of the natural unaffected areas of the Boulder Field are already impassable primarily due to velocities and lack of prominent resting pools. These encroachments have impacted flow characteristics at higher flow rates, but not the likelihood of fish passage success during their typical migration period.

Alternatives were developed to address the two primary impediment areas identified in the study reach: the Anchor Boulder and the Irrigation Diversion Dam. At the Middle Reach, four alternatives were considered which addressed site specific conditions, flow range, construction viability, costs, uncertainties and other factors. At the Upper Reach, two alternatives were considered which were modified from USBR designs. Through the course of project development, boulder field assessment and alternatives analysis, project sponsor, Trout Unlimited, convened meetings and teleconference calls, to seek input from agencies, irrigation districts, environmental NGOs and other local stakeholders. Participants provided feedback, guidance, raised important questions and expressed preferences among the design alternatives. Considerations for alternative selections included: cost, flow range for passage of bull trout and steelhead, projected successful passage, visual and aesthetic considerations given impediment locations, construction viability, risk on existing infrastructure and maintenance. Of the alternatives presented, participants preferred the following:

- **Middle Reach**-Channel Profile Adjustment and
- **Upper Reach**-Pool and Chute Fishway.

The Channel Profile Adjustment was viewed as a progressive/staged approach which incorporated natural conditions, utilized the existing stream channel, flows and materials. The

Pool and Chute Fishway was viewed as effective, durable and compatible with an existing concrete structure.

Among any chosen alternatives and prior to construction of passage alternative, the range of ecological goals for Upper Icicle Creek should be clearly understood. For example, designs which provide passage for a wider flow range may reduce the selective pressure that partial or difficult passage could have on a population. Designing for prolonged periods of passage could also allow increased migration of foraging predators whereas the low flow barriers would otherwise minimize predation effects on resident salmonids and bull trout. While these are general considerations to keep in mind, proceeding with a more in depth geotechnical analysis and risk assessment will influence final design considerations for the preferred alternative(s), increase their viability, and also inform whether improved passage at these identified passage impediments is a desirable restoration action.

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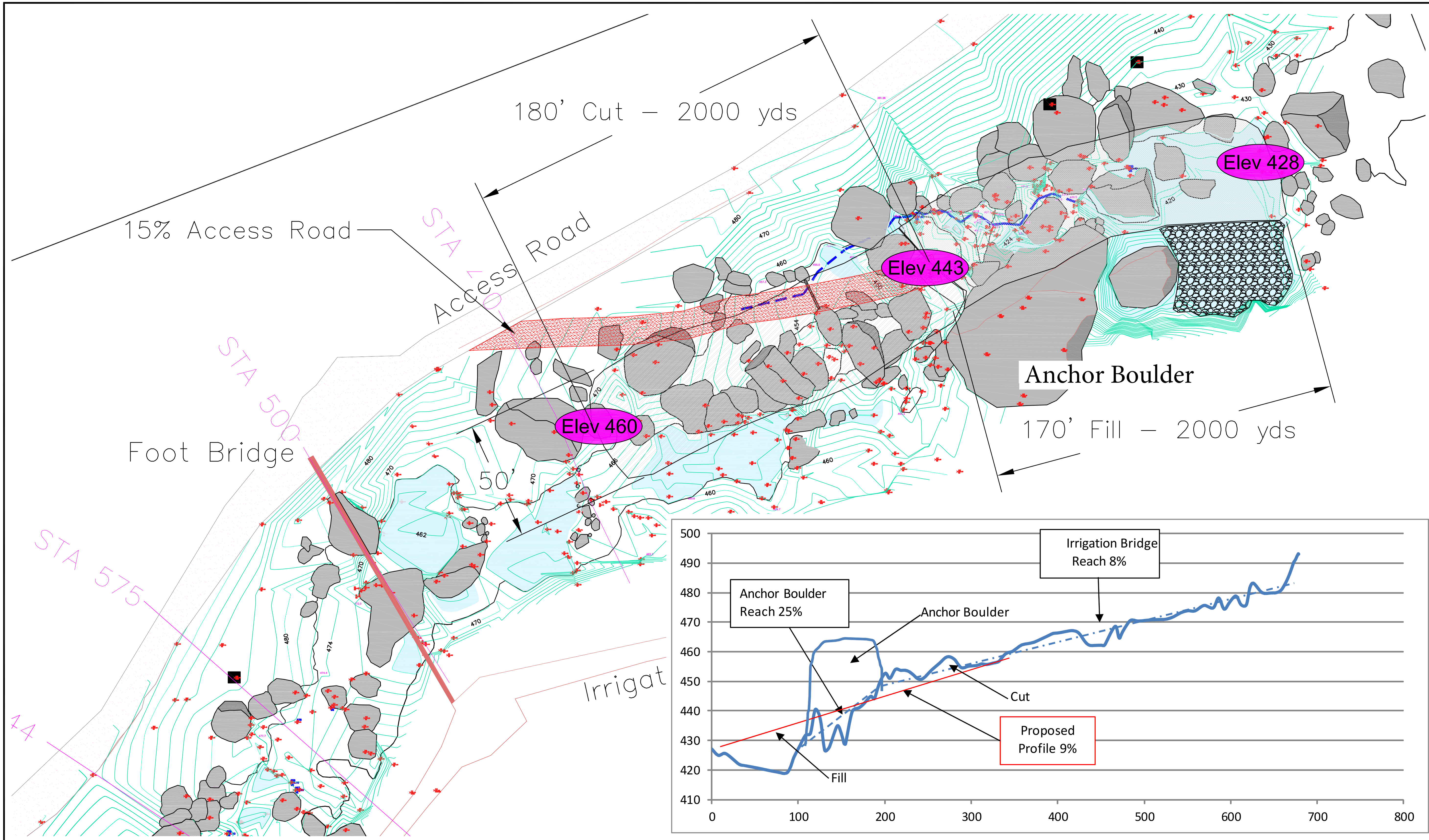
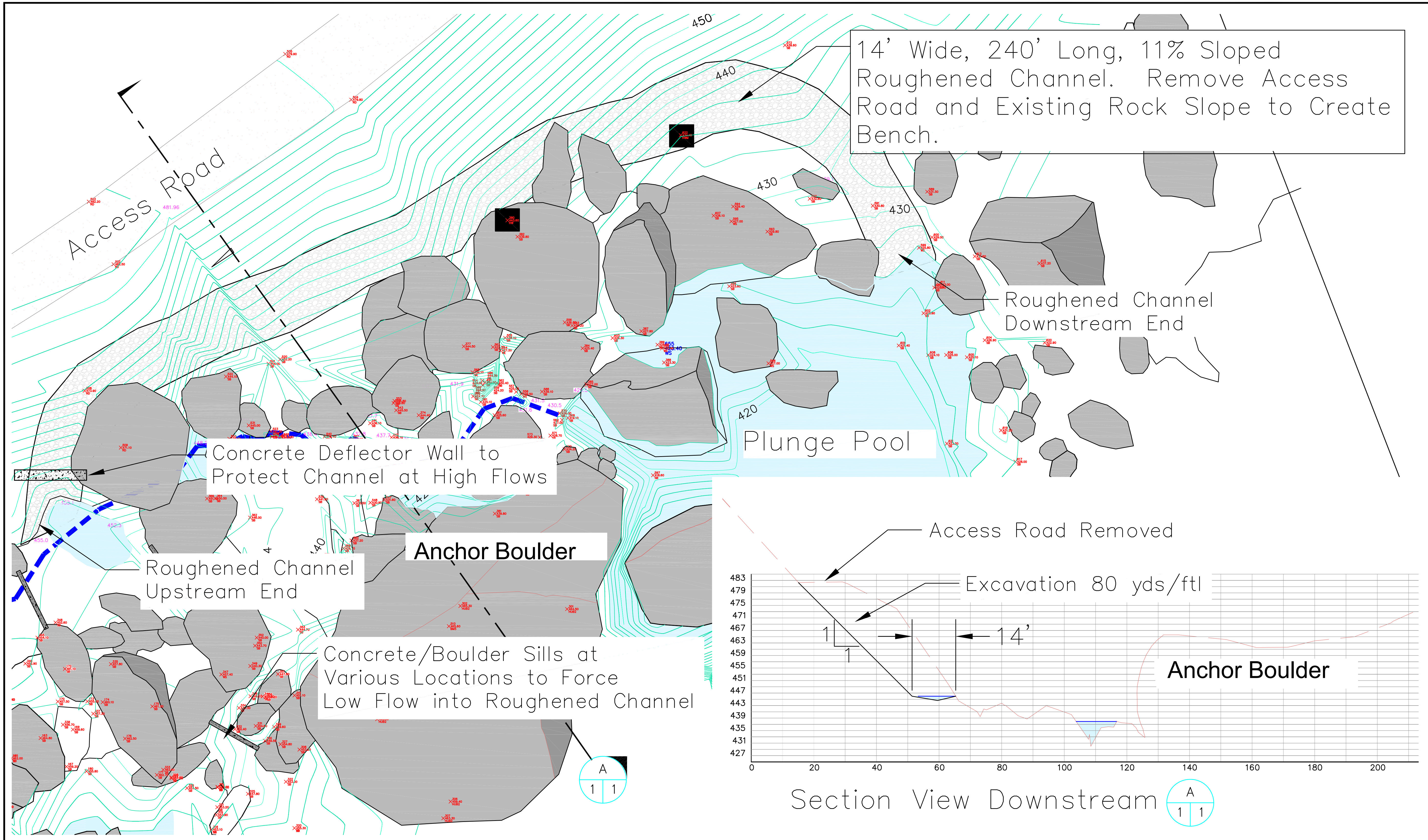
13 APPENDIX A: CONCEPTUAL DESIGN DRAWINGS



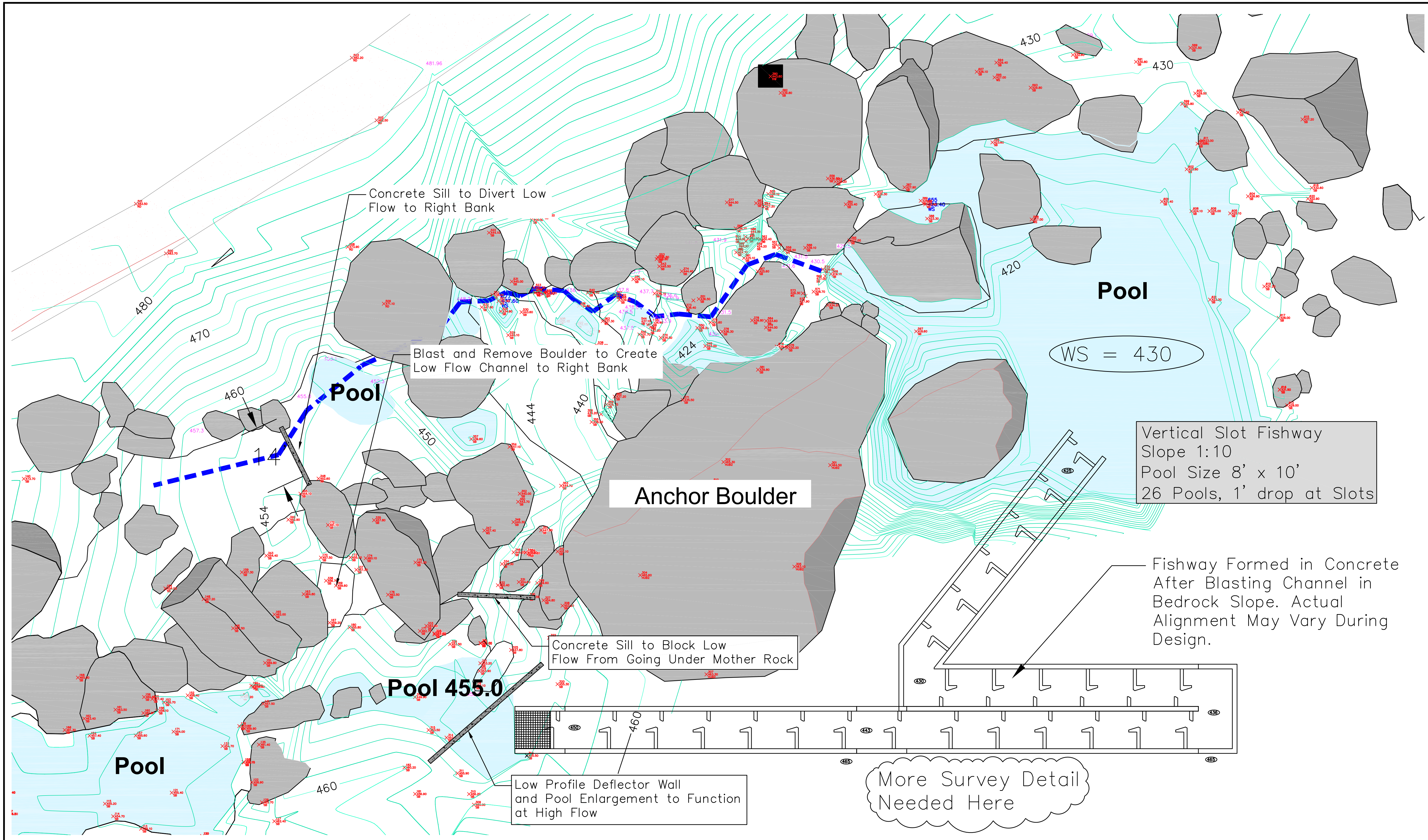
Middle Reach - Channel Profile Adjustment

Scale 1" = 40'



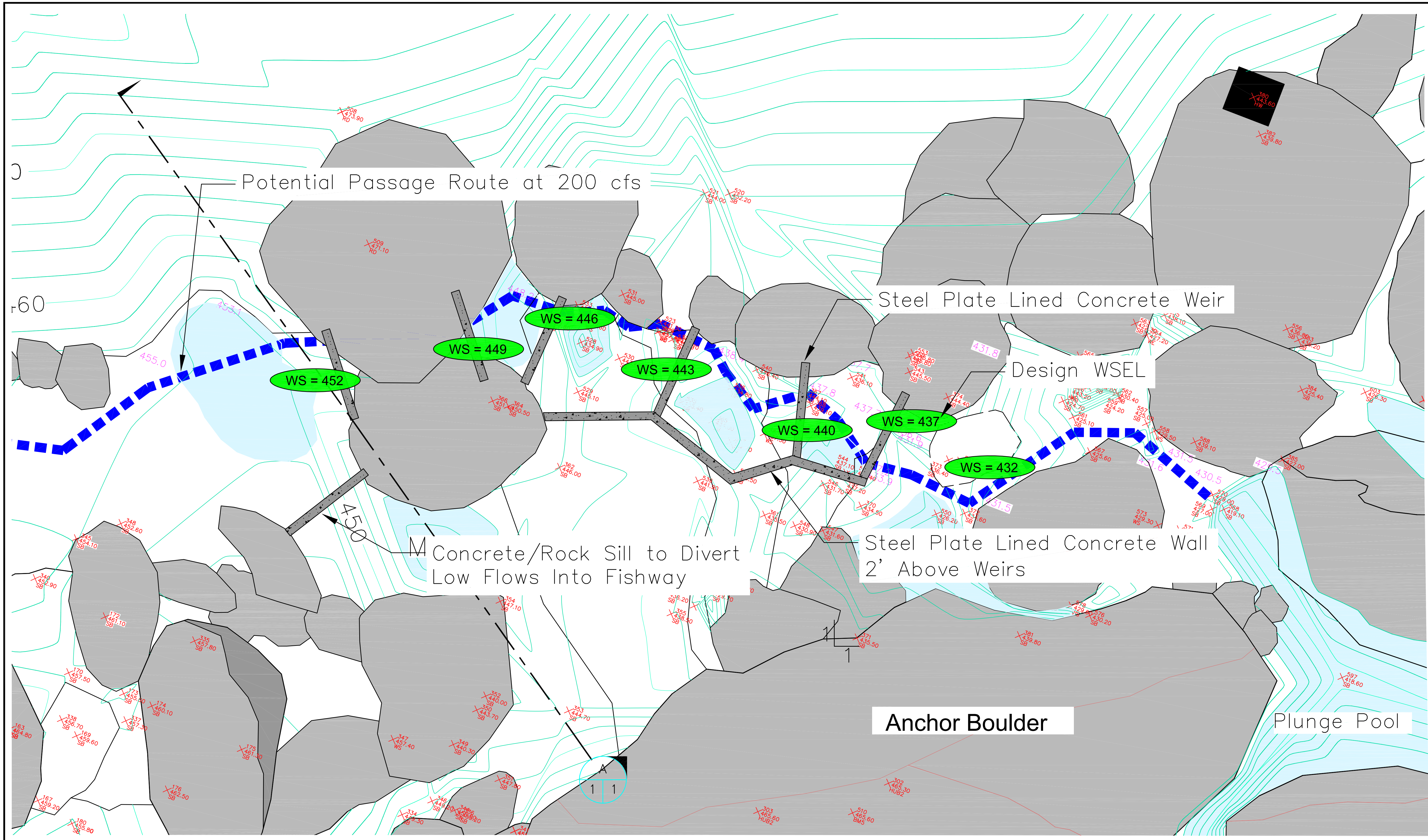
Middle Reach Roughened Channel

Scale 1" = 20'



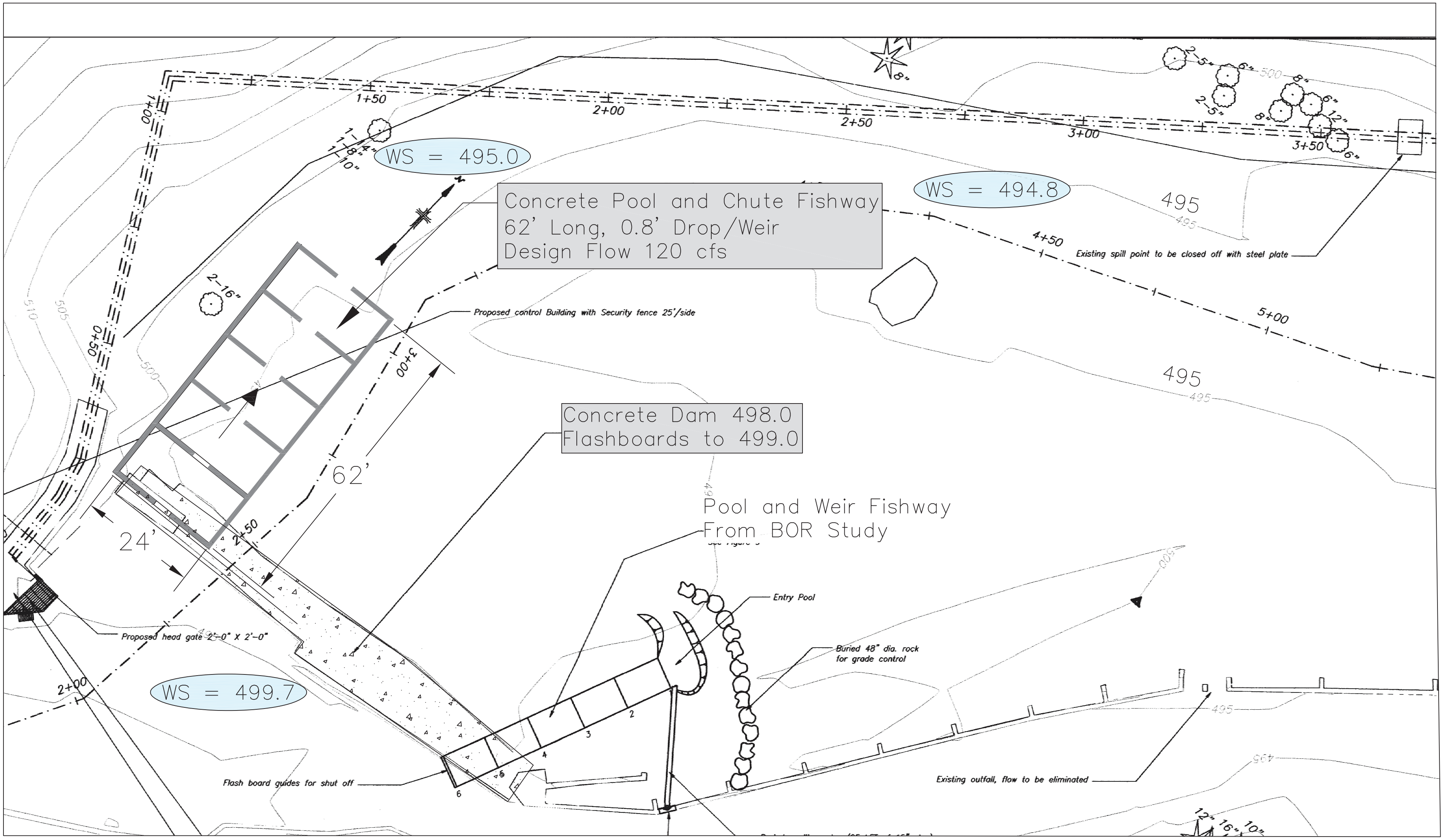
Middle Reach Vertical Slot Fishway

Scale 1" = 20'

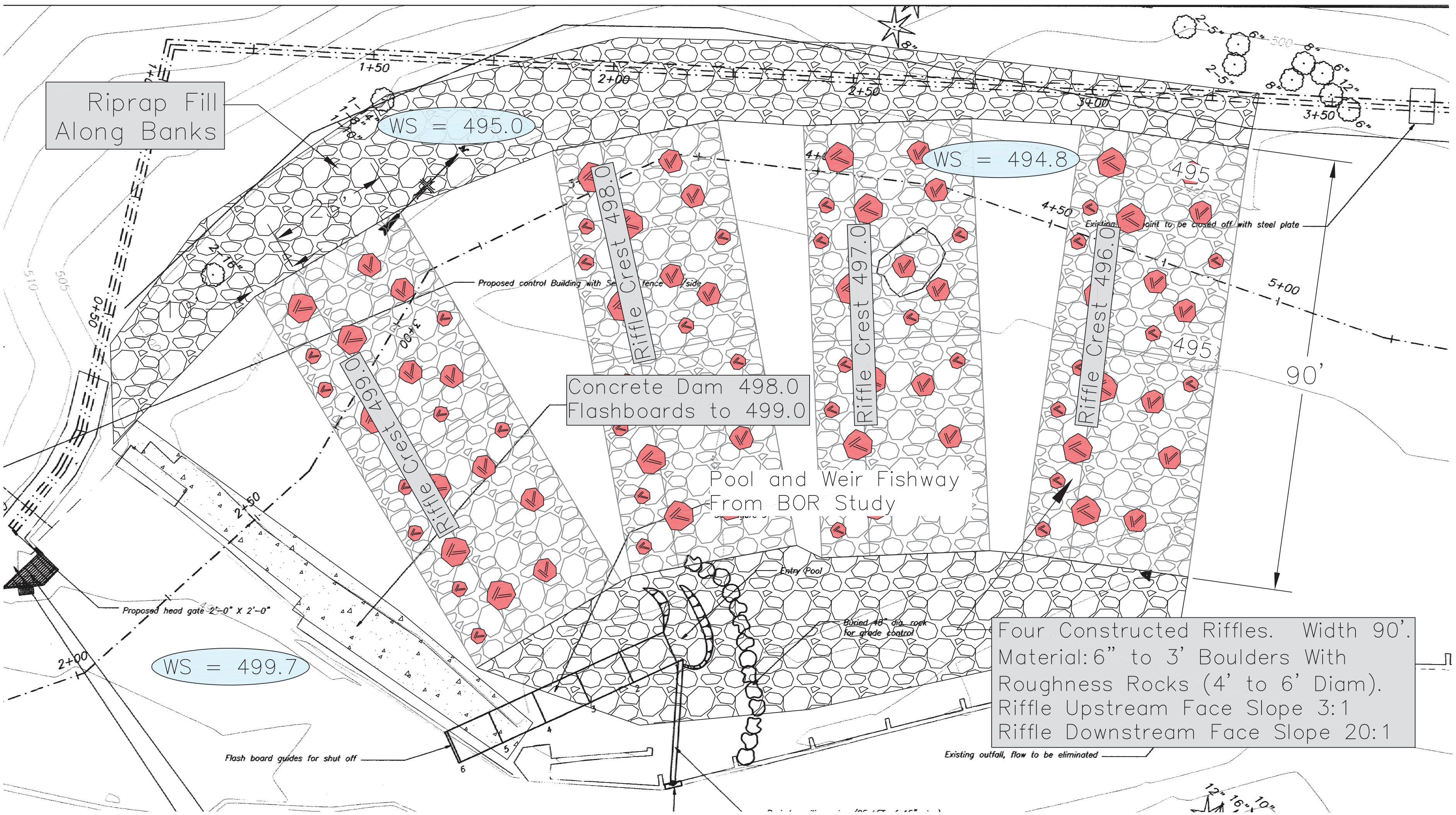


Middle Reach Low Flow Pool and Weir Fishway

Scale 1" = 10'



Icicle Creek Boulder Field - Upper Reach - Pool and Chute Fishway
Scale 1" = 20'



Icicle Creek Boulder Field - Upper Reach - Constructed Riffle
Scale 1" = 20'

14 APPENDIX B: COST ESTIMATE SPREADSHEETS

Icicle Creek Boulder Field - Conceptual Design Option

Reach/Design: Middle Reach - Channel Profile Adjustment
Date: 4/13/13
Estimate By: Waterfall Engineering

Proposed Correction: Remove channel boulder constriction and allow a regrade of 350' of channel 50' wide to a approx 9% slope.

Description	**Unit**	**Calc Quantity**	**Mult**	**Cost**	**Amount**	**Sub Total**	**Notes** Build
Mobilize	L.S.	1		$54,000.00	$54,000		
Access	L.S.	1		$6,000.00	$6,000		Road Down to Site
Stream Bypass	L.S.	1		$4,000.00	$4,000		
Clear and Grub Dewater	L.S.	1		$2,000.00	$2,000		
(Pumps, Etc) Fish	L.S.	1		$6,000.00	$6,000		
Removal Excavation,	L.S.	1		$1,200.00	$1,200		
Rock Rock Blasting	C.Y.	2000	1.2	$60.00	$144,000		
Large Boulder Blasting	C.Y.	400	1.2	$35.00	$16,800		Open Face Blast Towards Creek
Rock Riprap Fill	C.Y.	100	1.2	$55.00	$6,600		
Rock Fill Plunge Pool	C.Y.	1000	1.2	$125.00	$150,000		
Concrete Sills	C.Y.	2500	1.2	$45.00	$135,000		Rock to be Pushed Into Plunge Pool
	C.Y.	20	1.2	$1,000.00	$24,000		
CONSTRUCTION SUB TOTAL						$549,600	
Contingencies	30%					$164,880	
Sales Tax	8.0%					$57,158	
CONSTRUCTION TOTAL						$771,638	

Opinions of Probable Construction Cost

In providing opinions of probable construction cost, the Client understands that the Consultant (Waterfall Engineering, L.L.C.) has no control over the cost or availability of labor, equipment or materials, or over market condition or the Contractor's method of pricing, and the consultant's opinions of probable construction costs are made on the basis of the Consultant's professional judgment and experience. The Consultant makes no warranty, express of implied that the bids or the negotiated cost of the Work will not vary from the Consultant's opinion of probable construction cost.

Icicle Creek Boulder Field - Conceptual Design Options

Reach/Design: Middle Reach - Roughened Channel
Date: 4/13/13
Estimate By: Waterfall Engineering

Proposed Correction: Remove the access road and construct a 240' long, 11% sloped Roughened Channel Fishway. Operates Within flow range of 100 to 1000 cfs.

Description	Unit	Calc Quantity	Mult	Cost	Amount	Sub Total	Notes
Mobilize	L.S.	1		$14,000.00	$14,000		
Access	L.S.	1		$6,000.00	$6,000		Build Road Down to Site
Stream Bypass	L.S.	1		$4,000.00	$4,000		
Clear and Grub	L.S.	1		$2,000.00	$2,000		
Dewater (Pumps, Etc)	L.S.	1		$6,000.00	$6,000		
Fish Removal	L.S.	1		$1,200.00	$1,200		
Excavation, Rock	C.Y.	5000	1.2	$25.00	$150,000		
Rock Blasting	C.Y.	1000	1.2	$35.00	$42,000		Assumes Open Face Blast Towards Creek
Large Boulder Blasting	C.Y.	100	1.2	$55.00	$6,600		Assumes Rock to be Pushed Into Plunge Pool
Excavation Disposal	C.Y.	5000	1.2	$25.00	$150,000		
Roughened Channel Mix	C.Y.	400	1.2	$75.00	$36,000		Use Boulders on Site
Concrete Sills	C.Y.	20	1.2	$1,000.00	$24,000		
CONSTRUCTION SUB TOTAL						$441,800	
Contingencies	30%					$132,540	
Sales Tax	8.0%					$45,947	
CONSTRUCTION TOTAL						$620,287	

Opinions of Probable Construction Cost
In providing opinions of probable construction cost, the Client understands that the Consultant (Waterfall Engineering, L.L.C.) has no control over the cost availability of labor, equipment or materials, or over market condition or the Contractor's method of pricing, and the consultant's opinions of probable construction costs are made on the basis of the Consultant's professional judgment and experience. The Consultant makes no warranty, express of implied that the bids or the negotiated cost of the Work will not vary from the Consultant's opinion of probable construction costs.

Icicle Creek Boulder Field - Conceptual Design Option

Reach/Design:	Middle Reach - Vertical Slot Fishway
Date:	4/13/13
Estimate By:	Waterfall Engineering
Proposed Correction:	Excavate a 8' wide channel by rock blasting and form and pour a 25- pool vertical slot fishway with channel flow control.

Description	Unit	Calc Quantity	Mult	Cost	Amount	Sub Total	Notes
Mobilize	L.S.	1		$70,000.00	$70,000		
Access	L.S.	1		$40,000.00	$40,000		Needs Conceptual Discussion
Stream Bypass	L.S.	1		$4,000.00	$4,000		
Clear and Grub	L.S.	1		$2,000.00	$2,000		
Dewater (Pumps, Etc)	L.S.	1		$6,000.00	$6,000		
Fish Removal	L.S.	1		$1,200.00	$1,200		
Excavation, Rock	C.Y.	1500	1.2	$65.00	$117,000		
Rock Blasting	C.Y.	1500	1.2	$35.00	$63,000		Assumes Open Face Blast Towards Creek
Concrete	C.Y.	260	1.2	$1,200.00	$374,400		
Excavation Disposal	C.Y.	1500	1.2	$10.00	$18,000		Assumes Rock to be Pushed Into Plunge Pool
Bulkhead Walls	L.S.	1	1	$15,000.00	$15,000		
Concrete Sills	C.Y.	40	1.2	$1,200.00	$57,600		
CONSTRUCTION SUB TOTAL						$768,200	
Contingencies	20%					$153,640	
Sales Tax	8.0%					$73,747	
CONSTRUCTION TOTAL						$995,587	

Opinions of Probable Construction Cost

In providing opinions of probable construction cost, the Client understands that the Consultant (Waterfall Engineering, L.L.C.) has no control over the cost availability of labor, equipment or materials, or over market condition or the Contractor's method of pricing, and the consultant's opinions of probable construction costs are made on the basis of the Consultant's professional judgment and experience. The Consultant makes no warranty, express of implied that the bids or the negotiated cost of the Work will not vary from the Consultant's opinion of probable construction costs.

Icicle Creek Boulder Field - Conceptual Design Options

Reach/Design:	Middle Reach - Pool and Weir Fishway
Date:	4/13/13
Estimate By:	Waterfall Engineering
Proposed Correction:	By rock blasting and hand excavation pour and form concrete weirs into existing boulders to create a 6 step pool and weir fishway. Drops vary 3 to 4 feet.

Description	Unit	Calc Quantity	Mult	Cost	Amount	Sub Total	Notes
Mobilize	L.S.	1		$16,000.00	$16,000		
Access	L.S.	1		$35,000.00	$35,000		Requires Crane
Stream Bypass	L.S.	1		$4,000.00	$4,000		
Dewater (Pumps, Etc)	L.S.	1		$6,000.00	$6,000		
Fish Removal	L.S.	1		$1,200.00	$1,200		
Excavation, Rock	C.Y.	50	1	$800.00	$40,000		Jack Hammer, Crane Removal
Rock Blasting	C.Y.	20	1.2	$65.00	$1,560		Assumes Open Face Blast Towards Creek
Steel Plates	L.S.	1		$15,000.00	$15,000		Tops of Walls and Weirs
Concrete Walls and Weirs	C.Y.	26	1.2	$1,500.00	$46,800		
Excavation Disposal	C.Y.	50	1.2	$45.00	$2,700		Assumes Rock to be Pushed Into Plunge Pool
Concrete Sills	C.Y.	20	1.2	$1,000.00	$24,000		
CONSTRUCTION SUB TOTAL						$192,260	
Contingencies	25%					$48,065	
Sales Tax	8.0%					$19,226	
CONSTRUCTION TOTAL						$259,551	

Opinions of Probable Construction Cost

In providing opinions of probable construction cost, the Client understands that the Consultant (Waterfall Engineering, L.L.C.) has no control over the cost or availability of labor, equipment or materials, or over market condition or the Contractor's method of pricing, and the consultant's opinions of probable construction costs are made on the basis of the Consultant's professional judgment and experience. The Consultant makes no warranty, express of implied that the bids or the negotiated cost of the Work will not vary from the Consultant's opinion of probable construction cost.

Icicle Creek Boulder Field - Conceptual Design Options

Reach/Design:	Upper Reach - Pool and Chute Fishway
Date:	4/13/13
Estimate By:	Waterfall Engineering
Proposed Correction:	Construct a Pool and Chute Concrete Fishway by Removing a section of the dam.

Description	Unit	Calc Quantity	Mult	Cost	Amount	Sub Total	Notes
Mobilize	L.S.	1		$20,000.00	$20,000		
Access	L.S.	1		$8,000.00	$8,000		
Stream Bypass	L.S.	1		$4,000.00	$4,000		
Dewater (Pumps, Etc)	L.S.	1		$6,000.00	$6,000		
Fish Removal	L.S.	1		$1,200.00	$1,200		
Excavation, Rock	C.Y.	220	1.2	$25.00	$6,600		Dispose Along Stream Banks
Rock Blasting	C.Y.	20	1.2	$65.00	$1,560		Open Face Blast Towards Creek
Steel Plates	L.S.	1		$10,000.00	$10,000		Tops of Weirs
Concrete Walls and Weirs	C.Y.	100	1.1	$1,200.00	$132,000		
Excavation Disposal	C.Y.	220	1.2	$12.00	$3,168		
Partial Dam Removal	L.S.	1		$15,000.00	$15,000		
CONSTRUCTION SUB TOTAL						$207,528	
Contingencies	15%					$31,129	
Sales Tax	8.0%					$19,093	
CONSTRUCTION TOTAL						$257,750	

Opinions of Probable Construction Cost

In providing opinions of probable construction cost, the Client understands that the Consultant (Waterfall Engineering, L.L.C.) has no control over the cost or availability of labor, equipment or materials, or over market condition or the Contractor's method of pricing, and the consultant's opinions of probable construction costs are made on the basis of the Consultant's professional judgment and experience. The Consultant makes no warranty, express of implied that the bids or the negotiated cost of the Work will not vary from the Consultant's opinion of probable construction cost.

Icicle Creek Boulder Field - Conceptual Design Option

Reach/Design: Upper Reach - Constructed Riffle
Date: 4/13/13
Estimate By: Waterfall Engineering

Proposed Correction: Construct a Series of 4 Riffles, Spaced 50' Apart, 1' Drops, Downstream riffle face slope 5% to Backwater Existing Dam

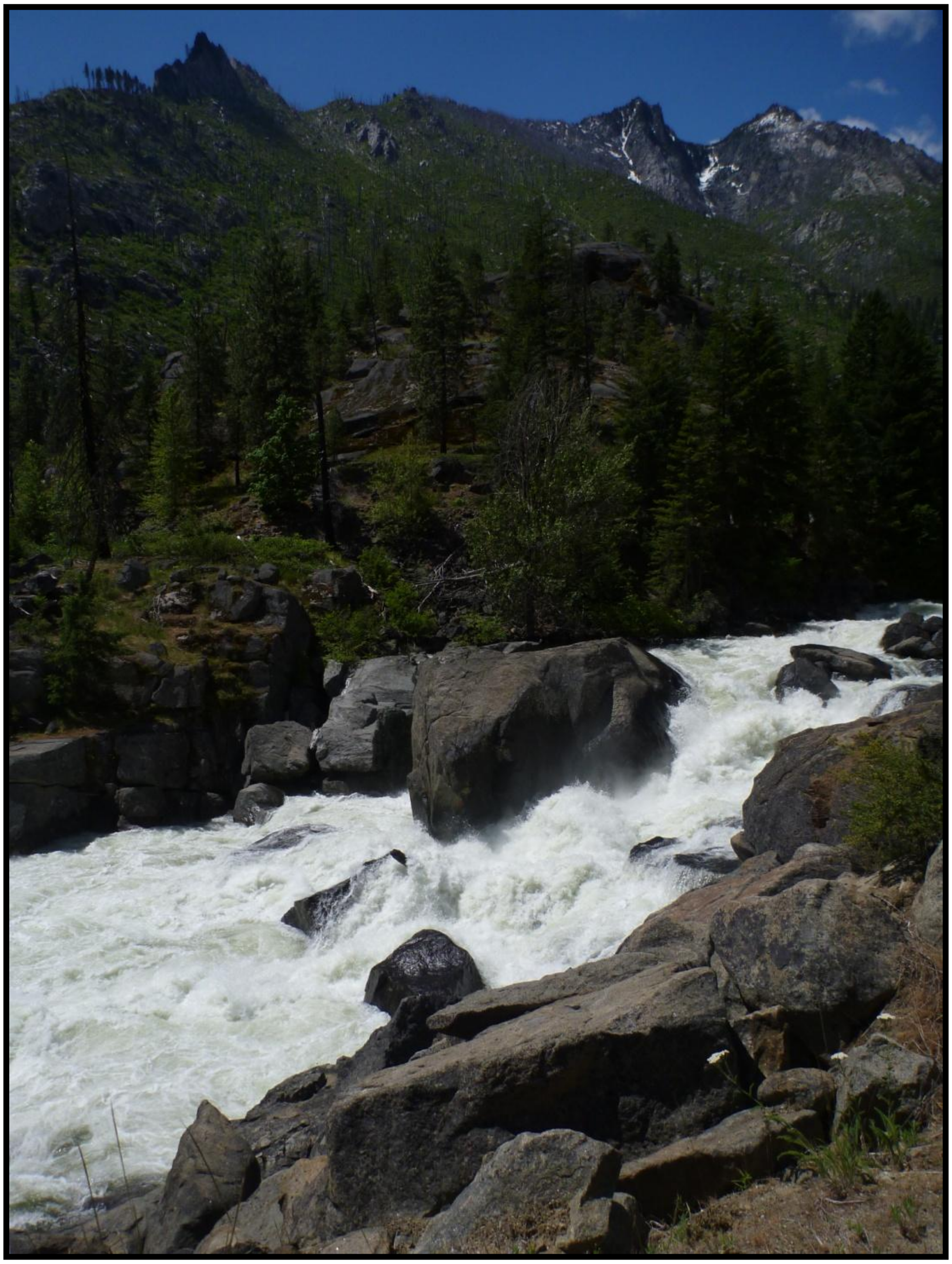
Description	Unit	Calc Quantity	Mult	Cost	Amount	Sub Total	Notes
Mobilize	L.S.	1		$29,000.00	$29,000		
Access	L.S.	1		$8,000.00	$8,000		
Stream Bypass	L.S.	1		$4,000.00	$4,000		
Dewater (Pumps, Etc) Fish	L.S.	1		$6,000.00	$6,000		
Removal	L.S.	1		$1,200.00	$1,200		
Excavation	C.Y.	400	1.2	$25.00	$12,000		
Disposal	C.Y.	400	1.2	$10.00	$4,800		Dispose Along Stream Banks
Constructed Riffle Mix	C.Y.	1900	1.2	$65.00	$148,200		
Constructed Riffle Boulders	C.Y.	200	1.2	$65.00	$15,600		
Riprap Bank Fil	C.Y.	900	1.2	$65.00	$70,200		
CONSTRUCTION SUB TOTAL						$299,000	
Contingencies	15%					$44,850	
Sales Tax	8.0%					$27,508	
CONSTRUCTION TOTAL						$371,358	

Opinions of Probable Construction Cost

In providing opinions of probable construction cost, the Client understands that the Consultant (Waterfall Engineering, L.L.C.) has no control over the cost or availability of labor, equipment or materials, or over market condition or the Contractor's method of pricing, and the consultant's opinions of probable construction costs are made on the basis of the Consultant's professional judgment and experience. The Consultant makes no warranty, express of implied that the bids or the negotiated cost of the Work will not vary from the Consultant's opinion of probable construction cost.

15 APPENDIX C: GEOLOGIC ASSESSMENT OF THE ICICLE CREEK BOULDER FIELD STUDY REACH

Geologic Assessment of the Icicle Creek Boulder Field Study Reach

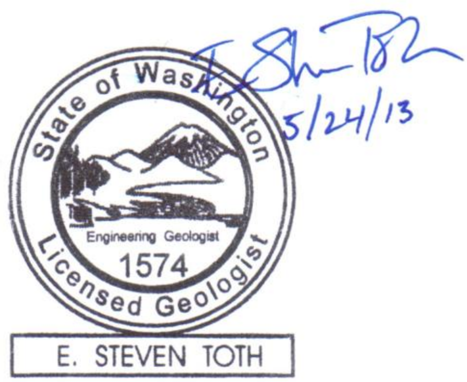


Technical Report
May 24, 2013

Geologic Assessment of the Icicle Creek Boulder Field Study Reach

Prepared For:

Trout Unlimited Washington Water Project
103 Palouse, Suite 14
Wenatchee, WA 98801
Contact: Mr. Jason Hatch



Prepared By:

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Physiography of the Icicle Creek Basin

Icicle Creek initiates from Josephine Lake at the eastern crest of the Cascade Range and flows east for approximately 32 miles before entering the Wenatchee River at the town of Leavenworth, Washington. The Icicle Creek basin is approximately 214 square miles (555 km^2) in size. The basin ranges in elevation from 9,416 feet above sea level on Mount Stuart to 1,100 feet above sea level in the City of Leavenworth.

Most of the Icicle Creek valley has a narrow, U-shaped cross-section that reflects its history of alpine glaciation. The lower four miles of Icicle Creek flows through a broader alluvial and glacial plain. The upper Icicle Creek basin has extremely steep and rugged terrain. Icicle Creek flows through several cascades and falls as it negotiates the steep descent towards the Wenatchee River. Large tributary fans encroach upon the valley bottom and can pinch or otherwise influence the pattern of flow for Icicle Creek. Icicle Creek has many cascades and falls (Figure 1), including the boulder falls upstream of Snow Creek (RM 5.6 - the project reach), boulder falls near Bridge Creek (RM 9), the chute and flume falls at Icicle Gorge (RM 16), waterfalls at Rock Island Campground (RM 18), and the complex falls at French Creek (RM 21.5) (Nelson et al. 2011). The high falls upstream of Leland Creek (RM 29) are considered impassable to migrating fish (Bryant and Parkhurst 1950).

Geology of the Icicle Creek Basin Area

Most of the Icicle Creek basin is located within the Mount Stuart granitic batholith. The Mount Stuart batholith is a granodiorite pluton that intruded the local metamorphic rocks approximately 60 million years ago (Tabor et al. 1987). The Ingalls Tectonic Complex and Nason Terrane are the two adjacent terranes of metamorphic rock. The Ingalls Tectonic complex consists of a mix of metamorphic, sedimentary, and igneous rocks deposited along an active subduction zone (Shannon and Wilson 2004). The Nason Terrane consists of Ingalls and Chiwaukum schists. No fault zones have been identified in the vicinity of the project area.

The Mount Stuart Batholith consists predominantly of medium-grained, granular hornblende-biotite tonalite or quartz diorite, with a considerable amount of granodiorite east of the project reach along Icicle Ridge. The Mount Stuart Batholith has isotopic ages that indicate the age of the eastern pluton at about 93 million years ago and the western pluton at about 85 million years ago (Tabor et al., 1987; and Dragovich et al. 2002). The bedrock in the project reach has been mapped by Tabor et al. (1987) and Dragovich et al. (2002) as pre-Tertiary diorite and gabbro and is near the contact with pre-Tertiary tonalite (Figure 2). The rocks are medium-grained hornblende diorite and gabbro, with the hornblende filling in and around plagioclase crystals. The contact with the tonalite is gradational and locally irregular (Tabor et al. 1987). The tonalite is differentiated by quartz crystals in addition to the plagioclase. The diorite, granodiorite, and tonalite of the project area are highly resistant to weathering. Long-term average weathering rates of granitic rock surfaces in the Icicle Creek area have been estimated at about 2 mm per 1,000 years (Porter and Swanson 2008).

Porter and Swanson (2008) did an extensive investigation of the advance and retreat of alpine glaciers in the Icicle Creek valley during the late Pleistocene (between 12,000 and 120,000 years ago). A sequence of five glacial moraines near the junction of the Wenatchee River and Icicle Creek provides evidence of multiple advances of a large east-flowing Cascade Range glacier system (Porter and Swanson 2008). A dozen steep northern tributary ice streams also flowed from an ice cap on the crest of Icicle Ridge. An equal number of southern tributary glaciers flow from cirques along the crest of the Stuart Range. During its greatest advance, the ice is estimated to have been over 1,200 feet (380 m) thick in the main valley. Sub-rounded granitic boulder up to 25 feet (8 meters) or more in diameter are present in lateral moraines along the Icicle Creek valley.

Rockfalls, snow avalanches, and debris flows are common mass wasting processes in the basin. Shallow landslides and debris flows are a significant source of sediment delivery and often originate along the interface between glacial till deposits and the underlying bedrock (USFS 1995). Numerous debris fans have been deposited on the valley floor increasing stream confinement and altering its alignment and gradient (USFS 1995). Stream erosion along the fan margins is a significant sediment delivery mechanism. Localized deep-seated landslides also have occurred along weak contacts or joints in the bedrock along the valley wall.

Fragmentation of bedrock exposed on cliffs often leads to rockfall and an accumulation of rock fragments of variable size at the base of the slope. These accumulations of rock fragments are known as talus. The rocks that accumulate often form a wedge-shaped deposit or talus slope (Turner 1996). The stability of talus slopes depends upon the interlocking of the larger rock fragments. Rock-supported talus is often inherently unstable because the weight of the deposit is transmitted as point loads among the fragments. In areas where finer sediments have accumulated, the rock talus transitions into a colluvial deposit. Colluvium is a poorly sorted mixture of angular rock fragments and weathered fine-grained sediments deposited as a result of the slow, long-term downslope creep of these materials. In the study area, the left bank side of the Icicle Creek valley consists of a steep rocky talus slope with colluvial deposits (Figure 3).

Forest Road 7600 closely parallels Icicle Creek for much of its route and has been prone to rock fall, snow avalanches, and debris flows. For example, a landslide in 1999 introduced a large volume of sediment into Icicle Creek just above the Snow Creek confluence. In 2008, a snow avalanche near Doctor Creek triggered two debris flows and redirected Icicle Creek flows down the roadway. Most recently in 2011, a large landslide and debris flow from Lion Creek blocked the road.

Geomorphology of the Boulder Field Reach

Icicle Creek flows through a narrow, U-shaped valley in the study area that was carved by alpine glaciations. The rugged terrain is dominated by exposed bedrock on the steep valley walls (Figure 4). The glacial ice flowed over and around a prominent rounded bedrock outcrop on the south side of Icicle Creek (Figure 5). A lobe of ice appears to have cut behind the bedrock outcrop, carving a path through the present-day location of the Snow Creek alluvial/debris fan. The irrigation diversion infrastructure and canal are carved into this bedrock outcrop. The right bank of Icicle Creek borders the bedrock outcrop along the entire length of the study reach (Figure 5).

Rock outcrops, talus, and colluvium also confine the left bank of Icicle Creek, which has little to no floodplain within the study area. The lower reach of the Icicle Creek study area is adjacent to nearly vertical rock cliff that has been historically subject to rockfall and significant accumulations of talus. The left bank of Icicle Creek in the middle reach of the study area has been more directly impact by road construction. This reach is located below steep rock outcrops and accumulations of colluvium and talus. The left bank in the upper reach of the Icicle Creek study area is primarily confined by bedrock, although rockfall and mass wasting can still cause accumulations of rock and sediment in this area.

Icicle Creek would be categorized as a cascade channel type with boulder substrate according to the Montgomery and Buffington (1997) classification system. The bedrock confinement and large substrate are indicative of a canyon-like setting, rather than a standard alluvial channel with bankfull channel and floodplain characteristics. Cascade channels are dominated by jet-and-wake flow over and around large individual rocks. The turbulent flow around these rock obstructions serve to dissipate much of the energy of the water. The largest bed-forming material in cascade channel types is effectively immobile, except during extremely large flows.

The approximate channel width for mean annual flood flows in the middle reach of the study area (i.e., the boulder field) varies from about 100 to 140 feet. Most of the boulders in the middle reach are less than 20 feet in diameter, although one particularly large boulder at the base of the reach, named the "Anchor Boulder," has a width of approximately 60 feet and extends about 75 feet across the channel (Figure 6). The height of the Anchor Boulder is approximately 40 feet. The Anchor Boulder is such a large feature that it has constricted the channel and caused a large volume of boulders and other sediments to accumulate upstream.

A longitudinal slope profile of Icicle Creek was constructed from the Lidar elevation data to evaluate stream gradients (Figure 7). The boulder field is about 1,000 feet in length with an average gradient of 8 percent. The reach above the boulder field extends for about 1,000 feet above the irrigation diversion at an average gradient of 1 percent. The constriction in valley width at the Anchor Boulder appears to have caused a significant accumulation of sediments that have influenced the channel gradient for about 2,000 feet upstream. The Snow Creek alluvial fan located at the bottom of the assessment area has moderated the gradient at its confluence with Icicle Creek, but does not appear to be having any significant influence on the upstream boulder field. Extrapolating the gradient of the channel above and below the influence of the boulder field suggests that without the boulder field, the average channel gradient could range from 4 to 6 percent. However, this conclusion assumes that the bedrock was scoured by glacial ice at a relatively uniform gradient without erosion resistant rock sills or dikes to act as knickpoints in the channel.

Sources of Rock in the Boulder Field Reach

Field observations confirm that the rocks within the Icicle Creek channel are derived from both native and anthropogenic sources. The sources of rock within the boulder falls reach were evaluated based on size, angularity, weathering, and coloration. The orientation of the rock and whether it is in a stacked or random formation can also provide clues to its origin. The use of local rock during road construction activities and the minimal differences between tonalite, granodiorite, and diorite rocks made it difficult to use rock type as a distinguishing factor between sources. Potential native rock sources include rockfall, glacial deposits, and alluvial deposits. Anthropogenic rock sources include blasted rock, road prism and sidecast material, and concrete aggregate. Other anthropogenic impacts to the study area included drilling of holes into boulders and inserting smaller-diameter, round or square steel rods (Appendix A). The purpose for placing the steel rods into the boulders is unknown at this time.

In general, the native rock talus outside of the Icicle Creek channel is slightly weathered, angular diorite or rock of similar granitic composition. Minor discoloration on the surface, as well as along most discontinuity surfaces, indicates oxidation and weathering of rock material. Very little to no decomposition of the rock surfaces was observed. The hardness of the rock ranges from medium strong that can be fractured with a single hammer blow to extremely strong that can only be chipped or may require multiple hammer blows to fracture. Minor exfoliation of the rock surface layer was noted on many of the granitic rocks. Exfoliation involves thin sheeting joints that are generally flat, somewhat curved and parallel to the rock surface.

A discontinuity is a general term for all joints, fractures, bedding planes, contacts and faults (ISRM 1978). Joints or fractures are of geologic origin and represent a break in the continuity of the rock mass without visible displacement. For example, the bedrock on the right bank side of Icicle Creek has very wide spacing of orthogonal joints and very large blocks with less than one joint set per cubic meter of rock (Figure 8). Coarse-grained granitic rocks have a high friction angle ranging from 34 to 40 degrees, which makes them generally stable at moderate angles (Wyllie and Norrish 1996). Most of the rockfall in the study area has occurred from natural weathering patterns and initiates preferentially along joints in the rock. During glacial advances, the flowing ice also plucked rock from naturally weak fracture zones.

Almost all of the boulders within the Icicle Creek study area are native rock with signs of long-term weathering and water erosion. Many of the large boulders along the edge of the channel are sub-rounded to rounded in form, which suggests glacial transport. Within the channel most of the large boulders have evidence of significant fluvial weathering with smooth, scalloped forms and scour holes eroded into the rock. Most of the large boulders appear to be immobile and do not show evidence of being fluvially transported.

The Anchor Boulder appears to be an extremely large boulder that is not directly attached to bedrock on the right bank of Icicle Creek. Evidence of glacial grooves and striations, however, are indicative of in-situ placement with the glacier passing over the rock and scratching the rock surface (Figure 9). The top of the Anchor Boulder also shows evidence of glacial polish. These facts suggest that the Anchor Boulder has not moved since at least before the last glaciation and was not deposited more recently by the ice. The Anchor Boulder does share similarities with the adjacent bedrock, including large gray inclusions within the rock mass (Figure 10). While the downstream face of the Anchor Boulder does not show evidence of the same discontinuity extending from the left bank bedrock, the upstream face does include a joint at a similar elevation and orientation. The discontinuity on the Anchor Boulder also appears to extend into the large flat boulder adjacent to it in the channel (Figure 11). It is possible that the flat boulder was also a part of the same rock mass but has since eroded into a separate rock. In all likelihood, the Anchor Boulder and possibly the adjacent flat boulder are likely derived from the local bedrock and have since become eroded into separate rocks.

The rocks on the left bank across from the Anchor Boulder appear to have both natural and anthropogenic sources of origin. Several of the boulders in this area are largely outside of the Icicle Creek channel, yet have a sub-rounded form (Figure 12). These boulders appear to have been weathered from glacial, rather than fluvial transport, and have likely been in place since at least the last glacial recession approximately 12,000 years ago. The angular large boulders in the area are likely from historical rockfall. The coloration and weathering of these rocks suggests that they have been in place for at least hundreds, if not thousands of years. Smaller rocks and finer sediments were placed or dumped between the large boulders to construct a stable road prism for the original Icicle Creek Road (Figure 12). The following section provides more details on the anthropogenic sources of rock observed in the study area and their potential impact on the Icicle Creek channel.

Anthropogenic Impacts on the Boulder Field Reach

A number of sources were used to investigate and document potential anthropogenic impacts on the study area of Icicle Creek. The earliest historical records include 1905 General Land Office surveys of township and section boundaries. The 1905 map shows a trail on the south side of Icicle Creek, but no other signs of human disturbance (Figure 13). The width of Icicle Creek at the section line near its confluence with Snow Creek is reported as 100 links or 66 feet. In 1914 topographic profiles were surveyed along Icicle Creek just prior to construction of the irrigation infrastructure (Marshall 1914). Again, no sign of human disturbance is noted in the study area.

Rieman (2001) provides a detailed historical assessment of the anthropogenic or human-related activities in the area of the boulder falls reach. He provides a reprinted newspaper article and photographs from 1934 during construction of the original Icicle Creek Road. The road currently used to access the irrigation diversion is a portion of the original Icicle Creek Road. The current Forest Road 7600 was constructed during 1964 to 1966 along the same route as the old Icicle Creek Road, except in the study area where the new road was built just upslope from the old road. Rieman (2001) documents how portions of Icicle Creek were filled with blasted rock boulders during the later construction. Greater volumes of rock and much larger rocks could be moved during construction of Forest Road 7600, than during the original road construction.

Historical aerial photographs from 1957 through 2011 were examined to document potential disturbance or change in the study area (Appendix A). Table 1 provides a summary of the aerial photographs used in the assessment. With the confined nature of the study area, no channel migration or other changes in the channel location were identified over the photographic record. The area south of Icicle Creek is generally well forested, particularly around the Snow Creek fan during the 1950s through the 1990s. The only substantial alteration in vegetation occurred between 1992 and 2006 when a wildfire swept through the immediate area. No significant changes were observed in channel conditions during this time.

The left bank of Icicle Creek in the boulder falls reach shows evidence of encroachment by road construction. A large boulder was blasted near the bridge crossing and two remaining pieces are present within the bankfull width of Icicle Creek (Figure 14). A closer examination of the distances between drill holes in both large pieces confirms that they were originally part of one large rock. The diameter of the drill holes is consistent with 1930's construction practices (Rieman 2001). Drilled rocks are present along the road prism and in rock sidecast below the road. Rocks have been stacked along portions of the road prism, which is consistent with road construction practices during that time. Drilled and blasted rock was also observed on the right bank of Icicle Creek from the historical construction of the irrigation canal. Additional photographs of the study area are provided in Appendix A showing examples of drilled rocks and other anthropogenic impacts.

While it is difficult to make a definitive conclusion, the anthropogenic impacts within and adjacent to Icicle Creek do not appear to have caused a substantial change in the ability of fish to pass the boulder field. We would agree with the conclusion of Rieman (2001) that the study reach has probably been more impacted by the introduction of small rocks and boulders, rather than large ones. No evidence, however, was uncovered to indicate that anthropogenic rocks have themselves created a direct passage barrier. The introduction of small boulders and concrete into the channel may have an impact on the quality of habitat, but does not appear to be responsible for fish passage issues. The encroachment of the road on the left bank of Icicle Creek may have slightly altered the channel cross-section, although again it is not clear that this minor encroachment has caused a passage barrier. The encroachment is only an issue at very high flows, and water velocity may be a more critical barrier along other points in the boulder field.

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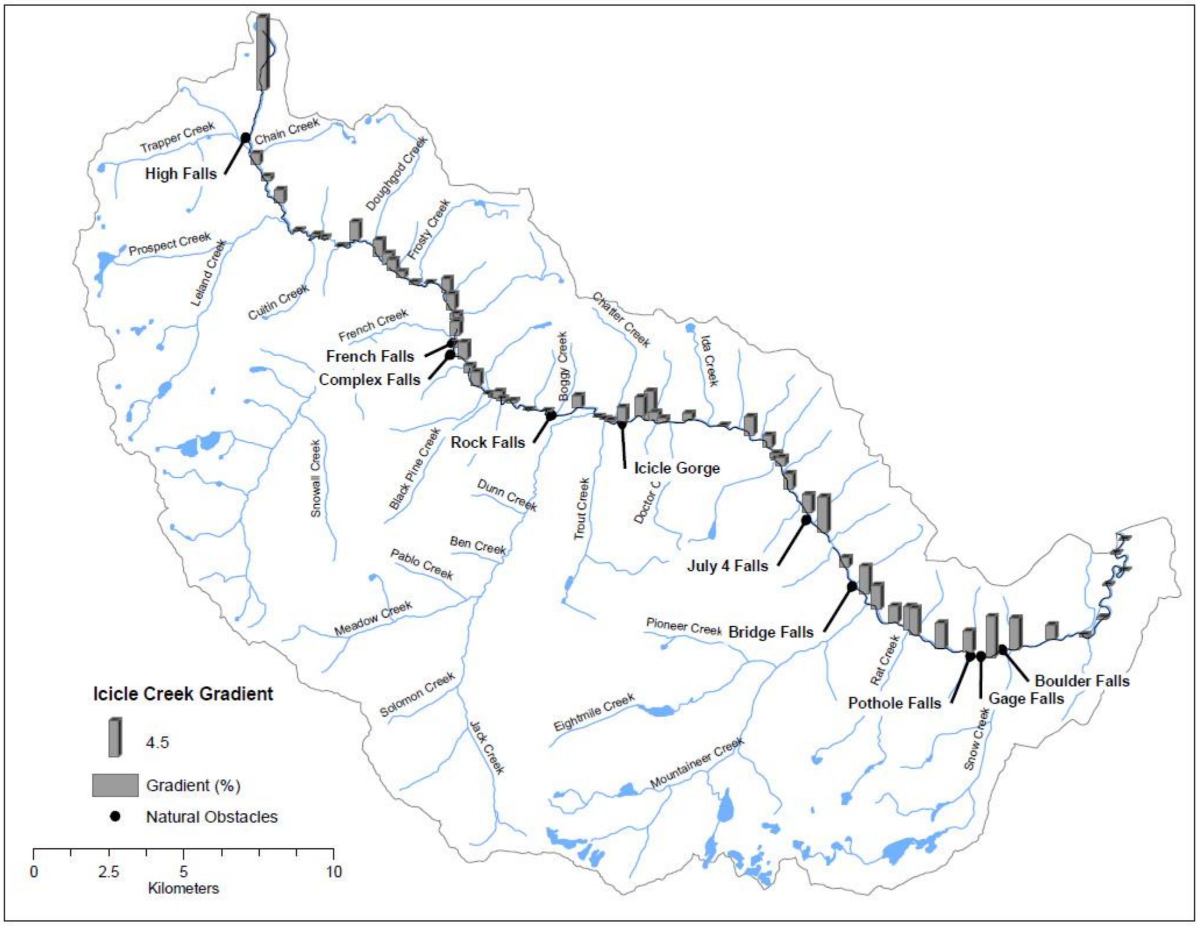
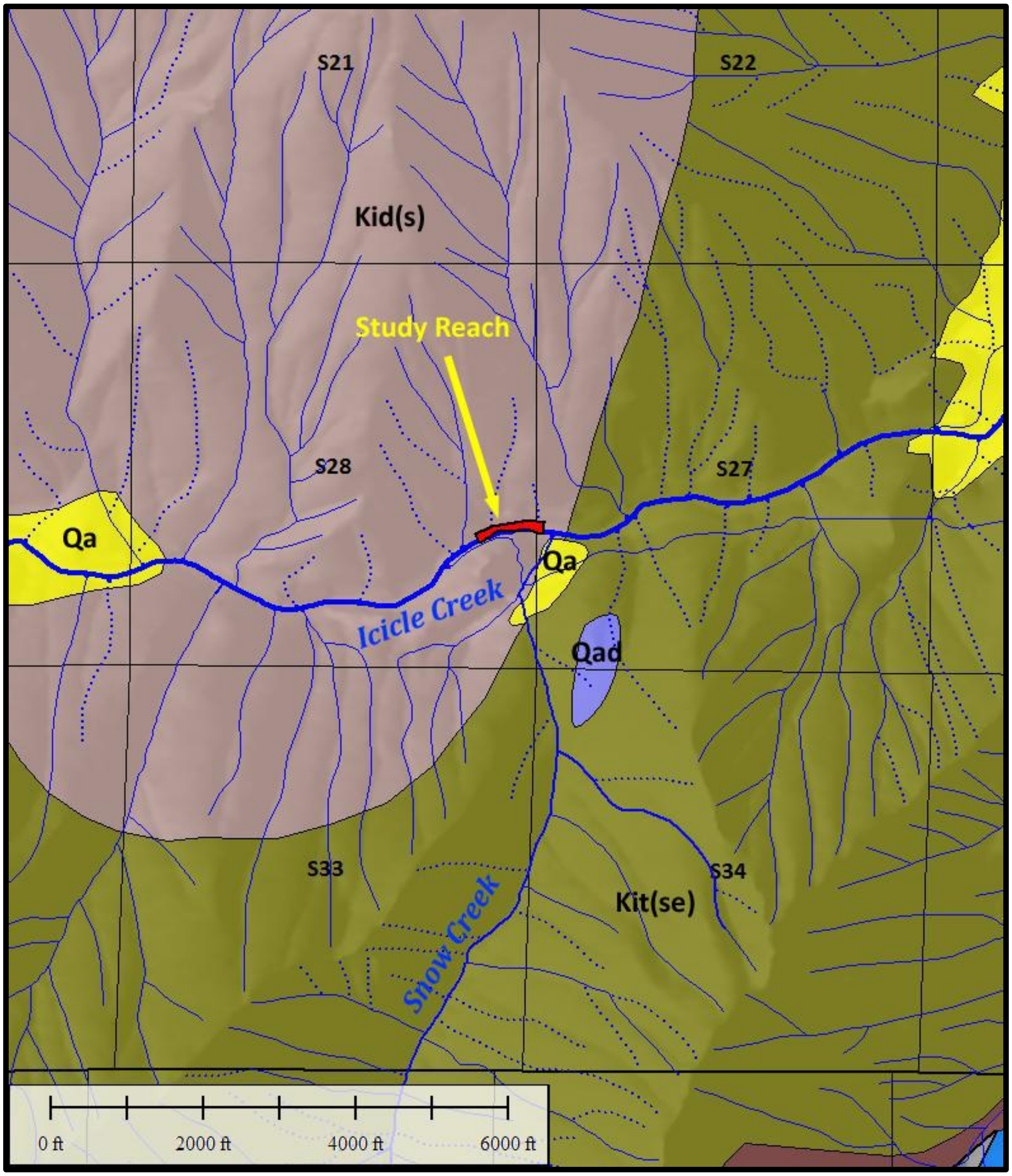


Figure 1. Icicle Creek basin showing gradients and select natural obstacles (from Nelson et al. 2011)



ALL BOUNDARIES ARE APPROXIMATE AND MAY NOT BE TO SCALE.

Key: *Kid(s)* – Diorite; Kit(se) – Tonalite; Qad – Alpine glacial drift*;* Qa –Alluvium

Figure 2. Geology map of the Icicle Creek Boulder Field project area (Dragovich 2002).

Figure 3. Colluvium in Forest Road 7600 cutslope above Icicle Creek and southwestern dipping joint planes of diorite bedrock in background.

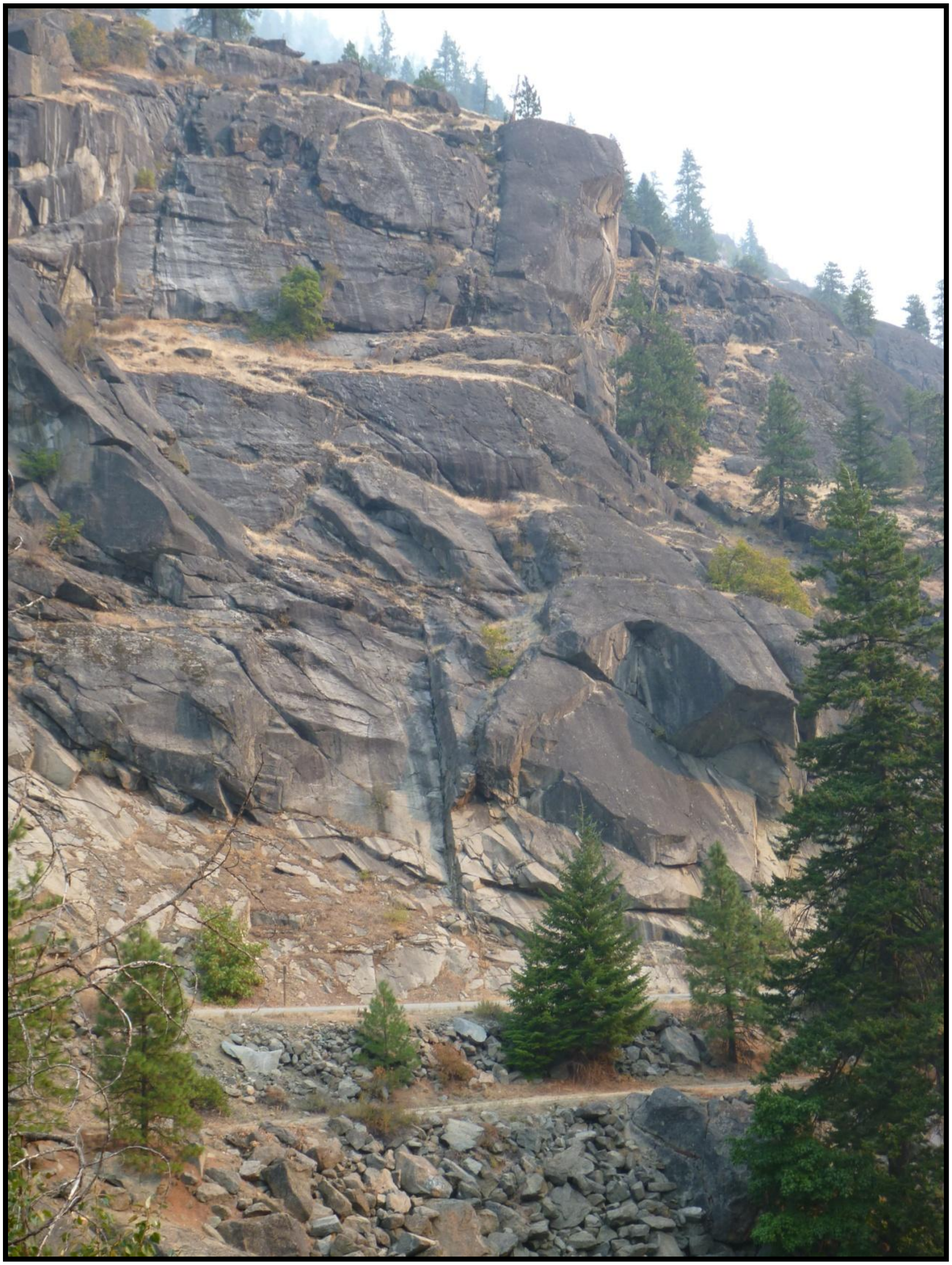
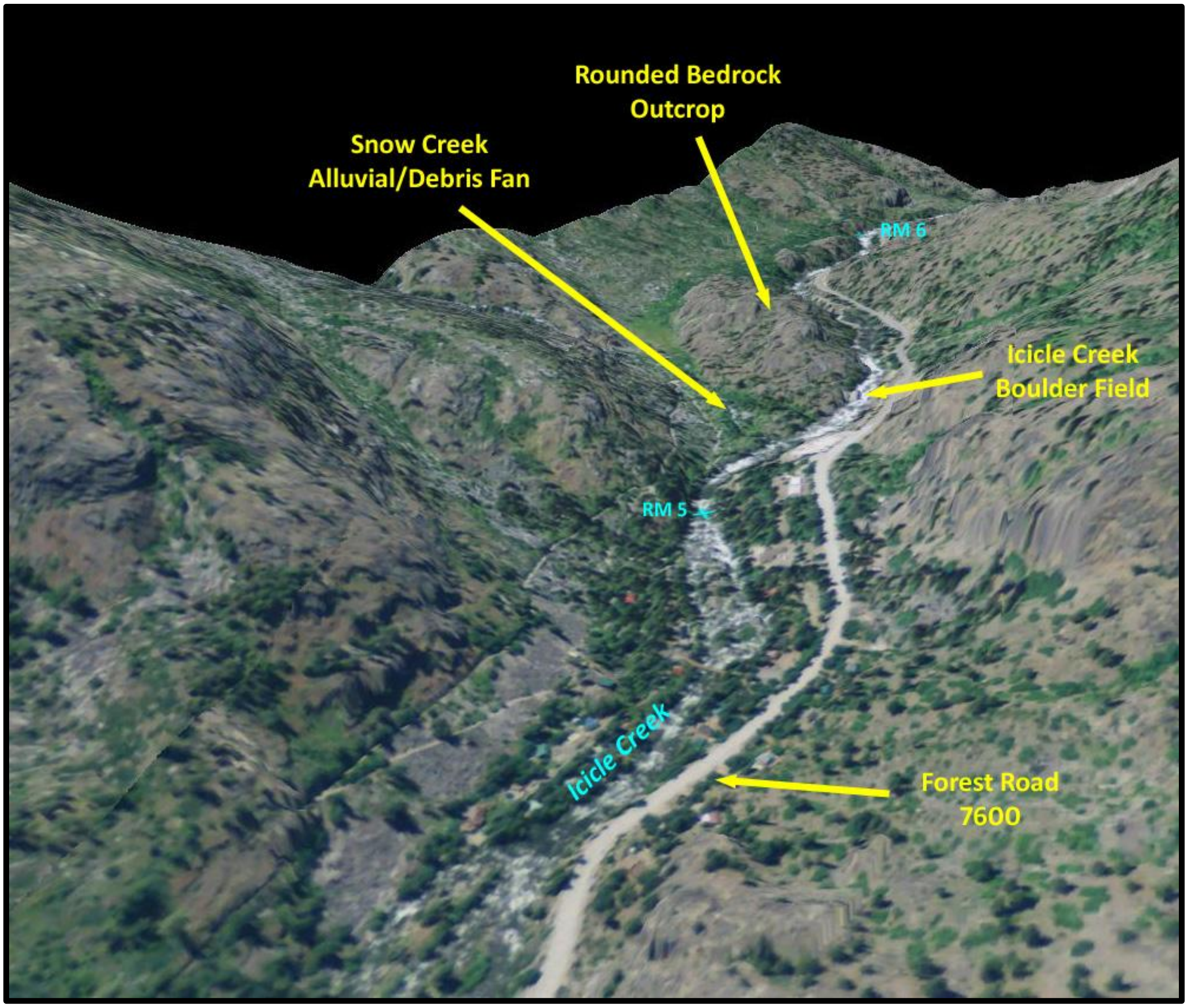


Figure 4. Glaciated north valley wall of diorite and gabbro above Icicle Creek.



Background imagery from 2009 NAIP aerial photography

Figure 5. Oblique view of Icicle Creek Boulder Field study reach showing channel confinement by bedrock.

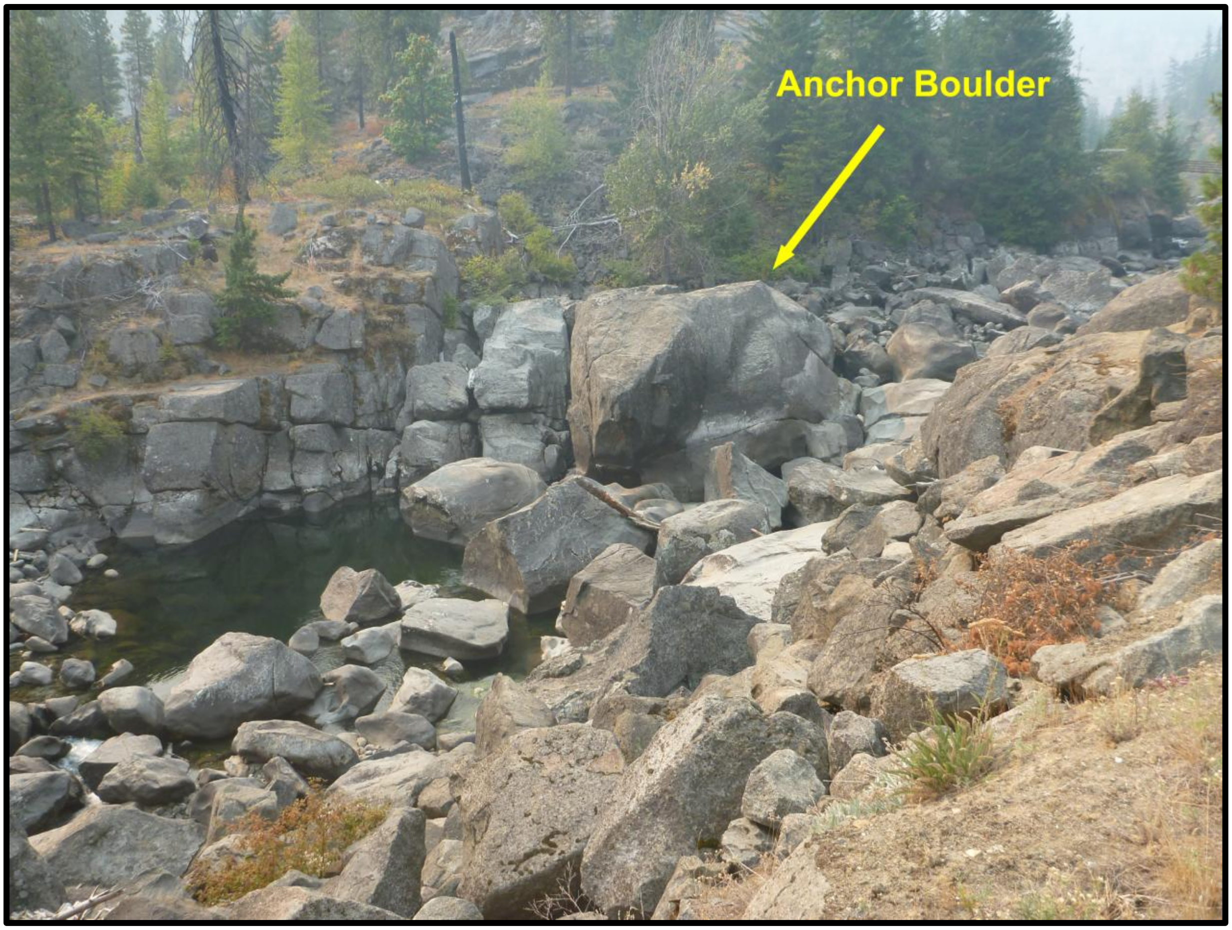


Figure 6. Anchor Boulder and the boulder field in the middle reach of the Icicle Creek study area.

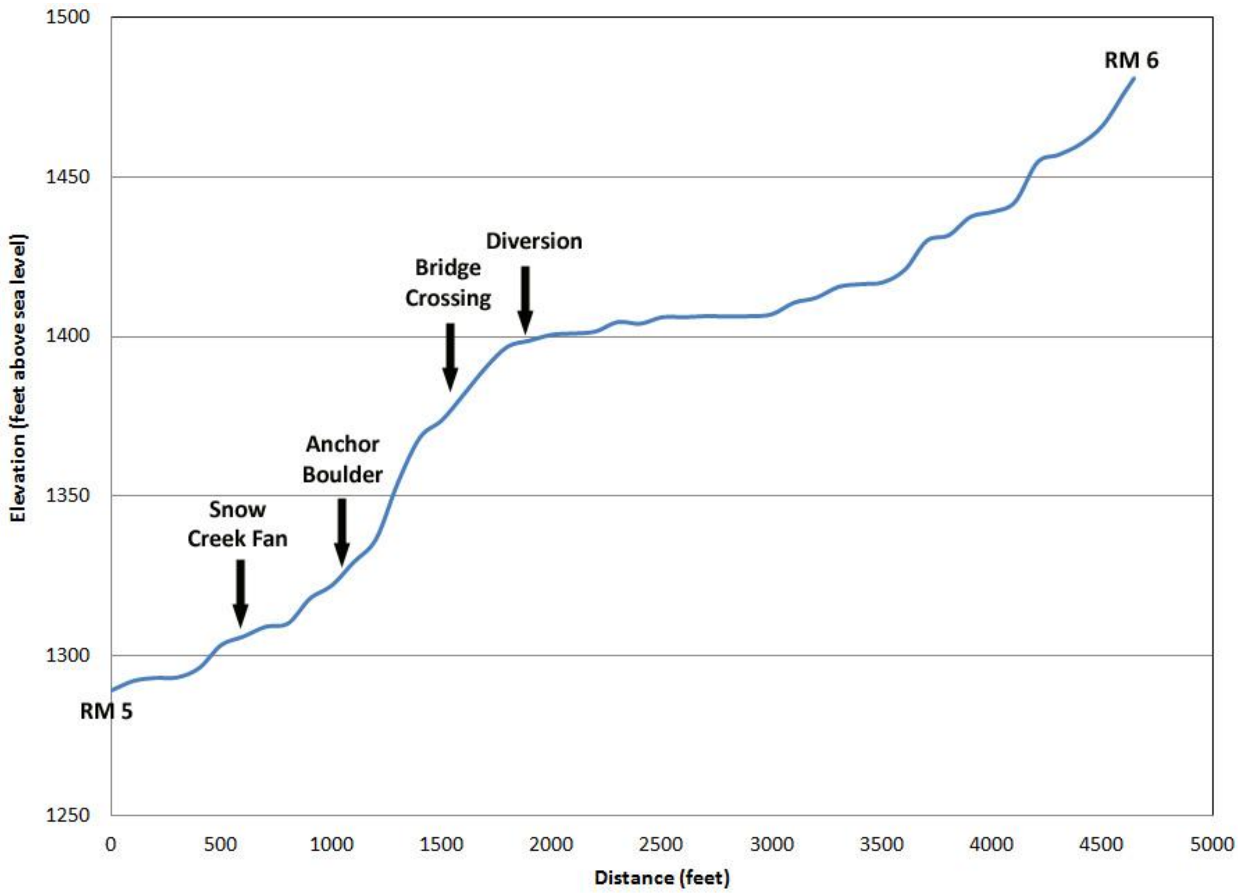


Figure 7. Longitudinal slope profile of Icicle Creek between River Mile (RM) 5 and RM 6.

Figure 8. Joint discontinuities in the bedrock on the right bank of Icicle Creek in the lower reach of the study area.

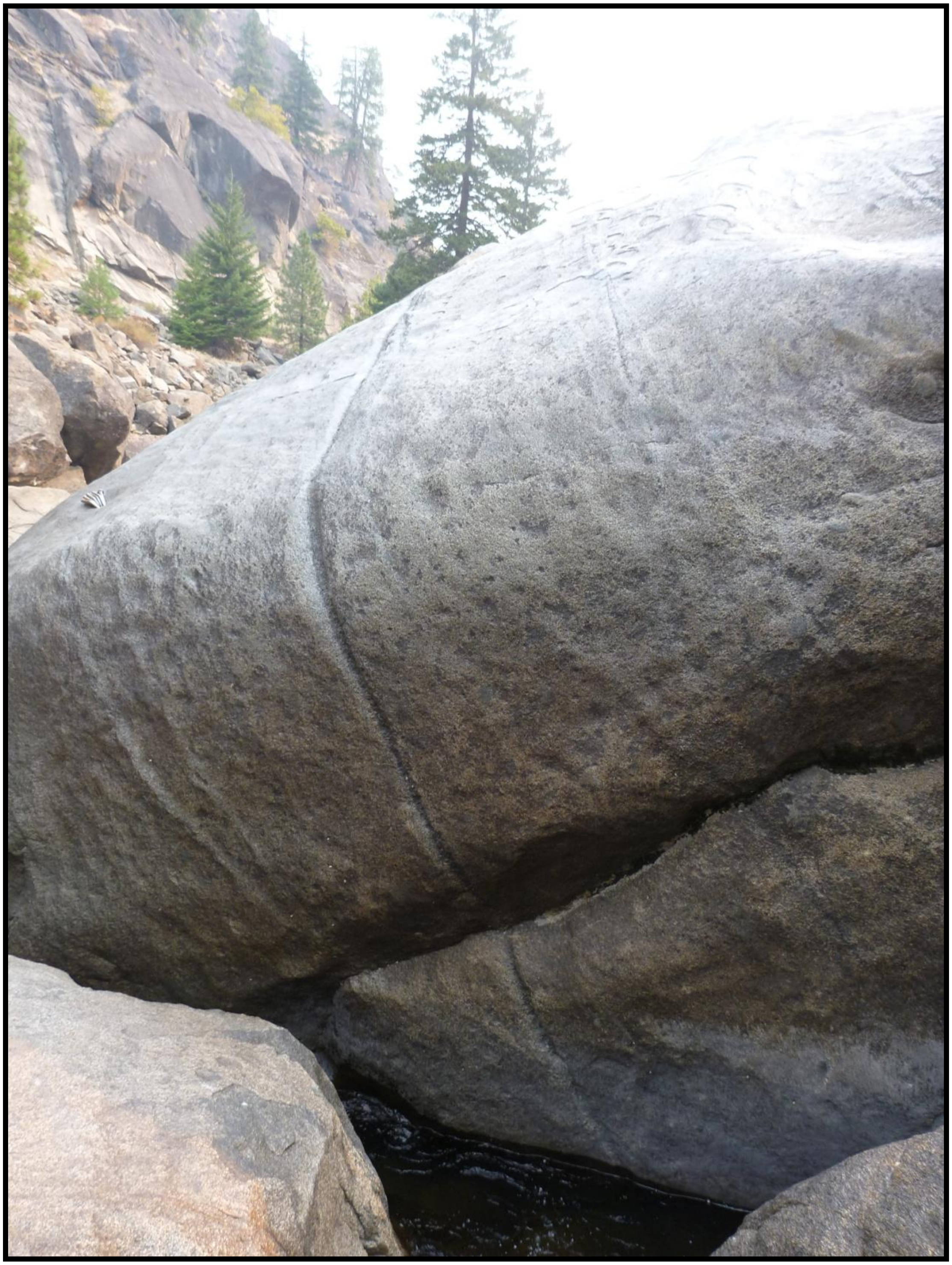


Figure 9. A vertical glacial groove and horizontal discontinuity on the upstream face of Anchor Boulder.

Figure 10. Gray inclusions in the bedrock on the right bank of Icicle Creek and in the Anchor Boulder.

Figure 11. The north face of the Anchor Boulder and the adjacent large flat boulder showing the potential extension of joint discontinuities (*black arrows*).

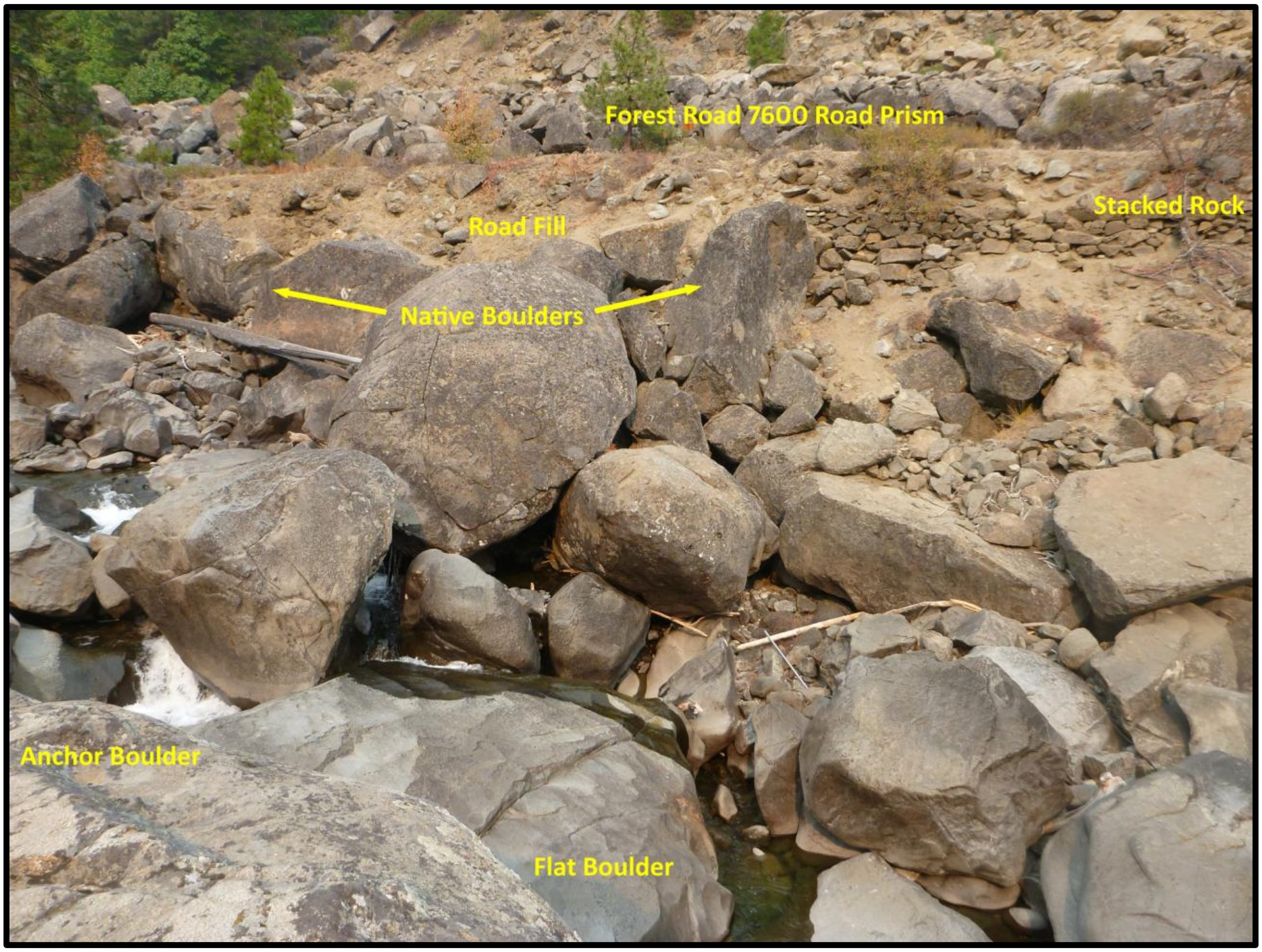


Figure 12. Large native boulders and anthropogenic rocks on the left bank of Icicle Creek across from the Anchor Boulder.

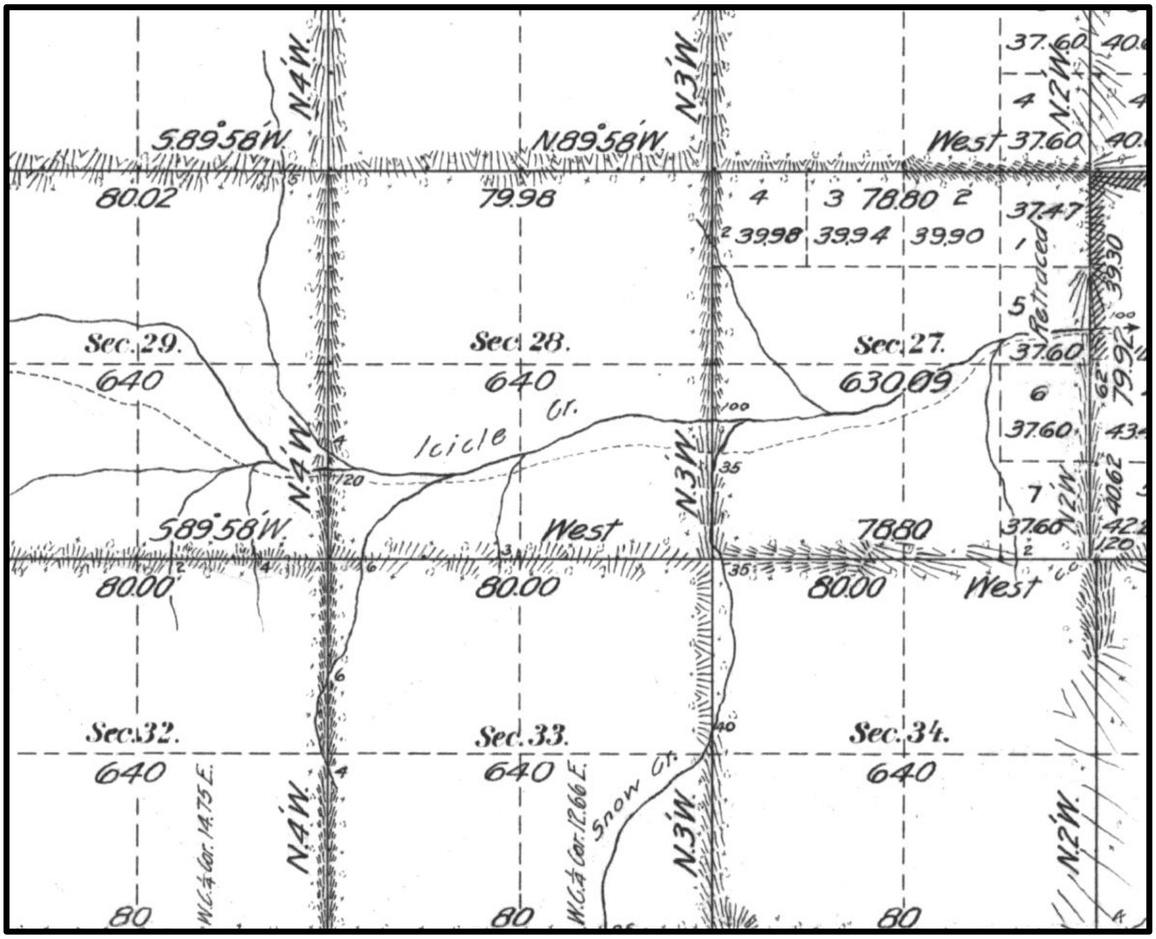


Figure 13. 1905 General Land Office survey map of the Icicle Creek study area.

Figure 14. Large boulder blasted into three parts during original Icicle Creek road construction.

Air Photo Year	Scale	Photo Number	Agency
1957	1: 62,000	ARA001600040082-83	Army Map Service
1963	1: 40,000	AR1VAUC0010045	U.S. Geological Survey
1963	1:20,000	AR1SVAUC0020013	U.S. Geological Survey
1973	1:125,000	AR5730013370756	NASA Ames Research Center
1985	1:24,000	AR1VFHWC0030032	U.S. Geological Survey
1992		Digital Orthophotos	U.S. Geological Survey
2006		Digital Orthophotos	USDA NAIP
2009		Digital Orthophotos	USDA NAIP
2011		Digital Orthophotos	USDA NAIP

Table 1. Historical aerial photographs examined for the Icicle Creek study area.

Appendix A - Icicle Creek Study Area 2012 Photographs and Historical Aerial Photographs

2012 Study Area Photographs

Figure A-1. Lower Reach of Icicle Creek study area below Anchor Boulder showing bedrock outcrop on the right bank and old Icicle Creek Road on left bank.

Figure A-2. Stacked rocks for old Icicle Creek Road prism on the left bank at the irrigation district bridge.

Figure A-3. Looking downstream in middle reach of Icicle Creek study area above Anchor Boulder showing left bank rocks and historical Icicle Creek Road.

Figure A-4. Glacially polished top surface of the Anchor Boulder and adjacent gray bedrock on the right bank of Icicle Creek.

Figure A-5. Fluvial erosion of notch in bedrock at the Anchor Boulder on the right bank of Icicle Creek.

Figure A-6. Looking downstream in the middle reach of the Icicle Creek study area at the boulder field associated with the Anchor Boulder (*large gray rock with vertical groove on the right side of photograph*).

Figure A-7. Fluvially sculpted, flat boulder within Icicle Creek on the north side of the Anchor Boulder.

2012 Photos of Anthropogenic Impacts on Icicle Creek Study Area

Figure A-8. Concrete block on boulder within Icicle Creek channel at the irrigation district bridge.

Figure A-9. Drill holes and grooves from blasted rock fragments in road prism along left bank of Icicle Creek.

Figure A-10. Drill hole grooves in blasted boulder from road prism along left bank of Icicle Creek.

Figure A-11. Concrete blocks in middle reach of Icicle Creek study area.

Figure A-12. Concrete block wedged between rocks on right bank of Icicle Creek.

Figure A-13. Drilled rock in the Icicle Creek channel near the right bank upstream of the Anchor Boulder.

Figure A-14.   Drilled rock on Left bank of Icicle Creek above the irrigation district bridge.

Figure A-15. Drill holes in rock sidecast along the old Icicle Creek Road in the lower reach of the Icicle Creek study area.

Figure A-16. Drill hole grooves in rock sidecast along the old Icicle Creek Road near the irrigation bridge.

Figure A-17. Bent steel rods jammed into a drill hole on the north end of the Anchor Boulder.

Historical Aerial Photographs of the Icicle Creek Study Area

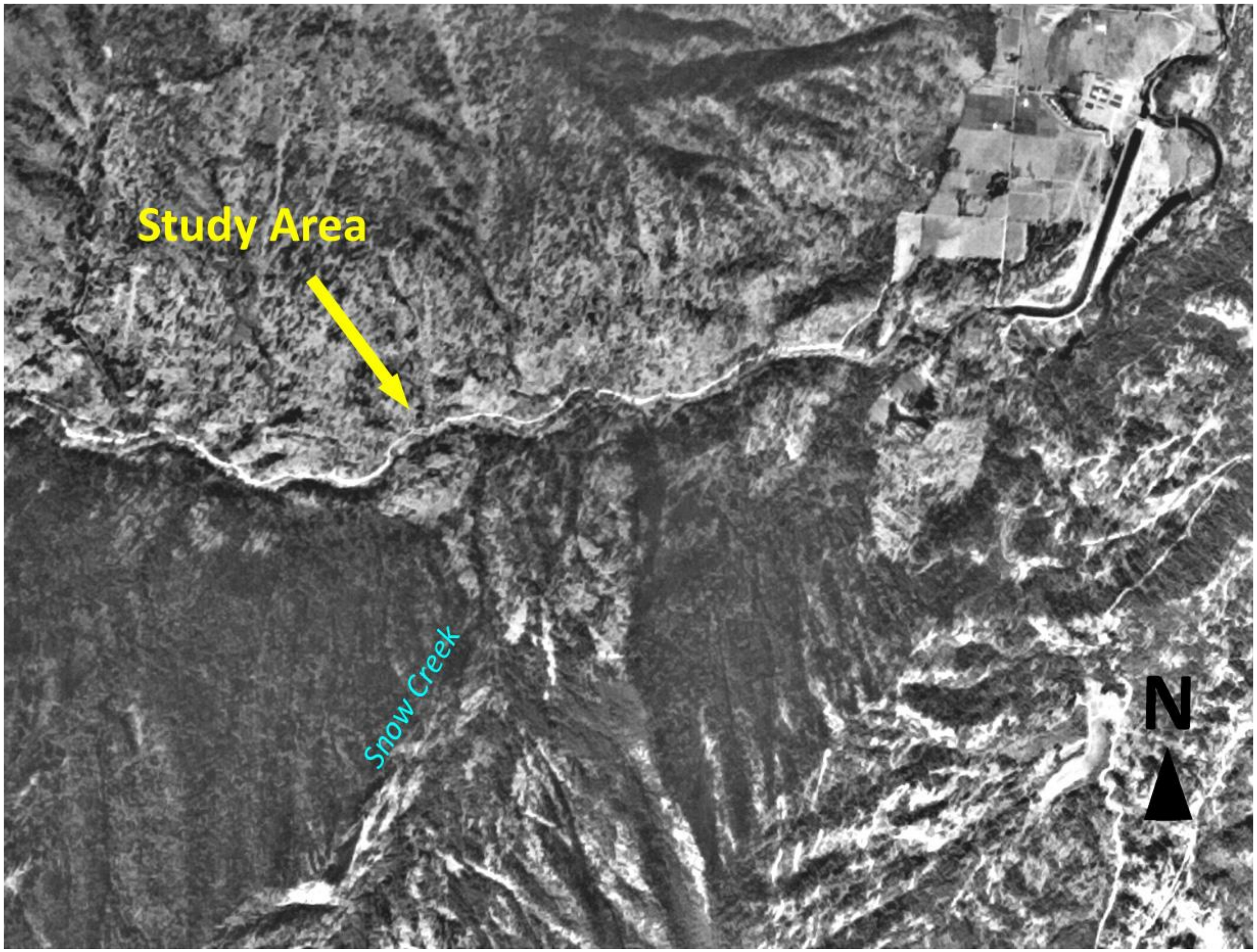


Figure A-18. 1957 aerial photograph of the Icicle Creek study area.

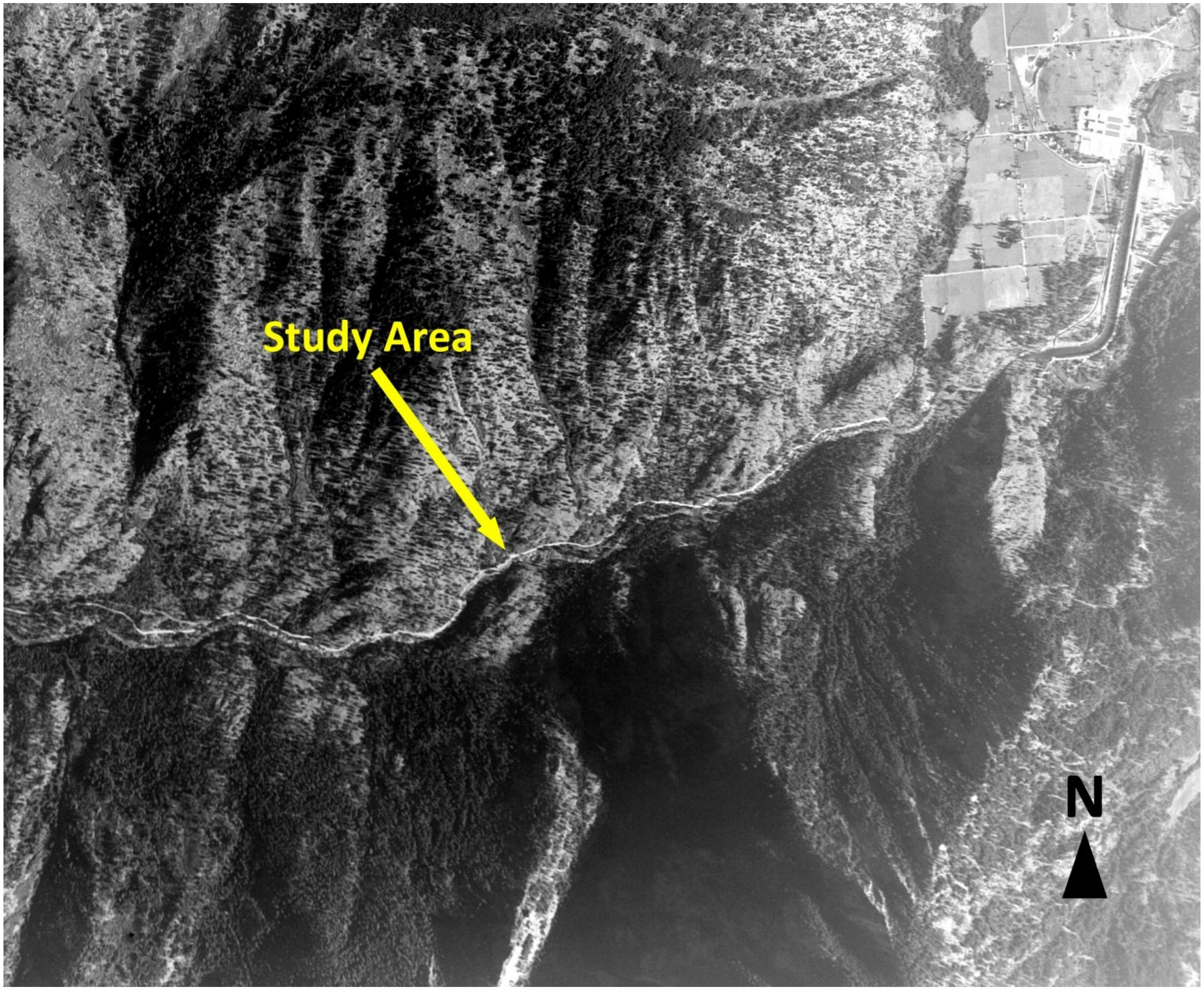


Figure A-19. 1963 aerial photograph of the Icicle Creek study area.

Figure A-20. 1985 aerial photograph of the Icicle Creek study area.

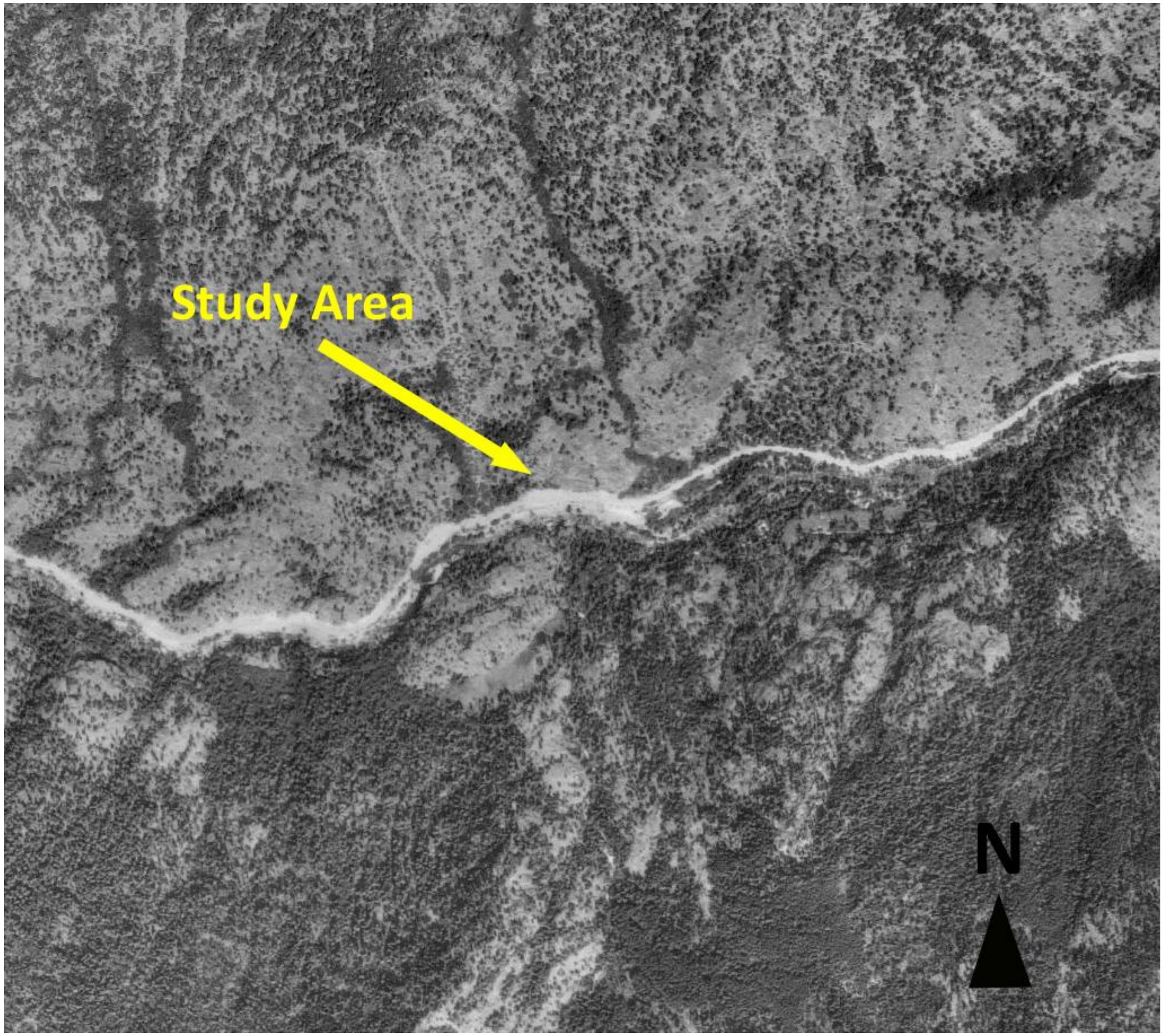


Figure A-21. 1992 aerial photograph of the Icicle Creek study area.

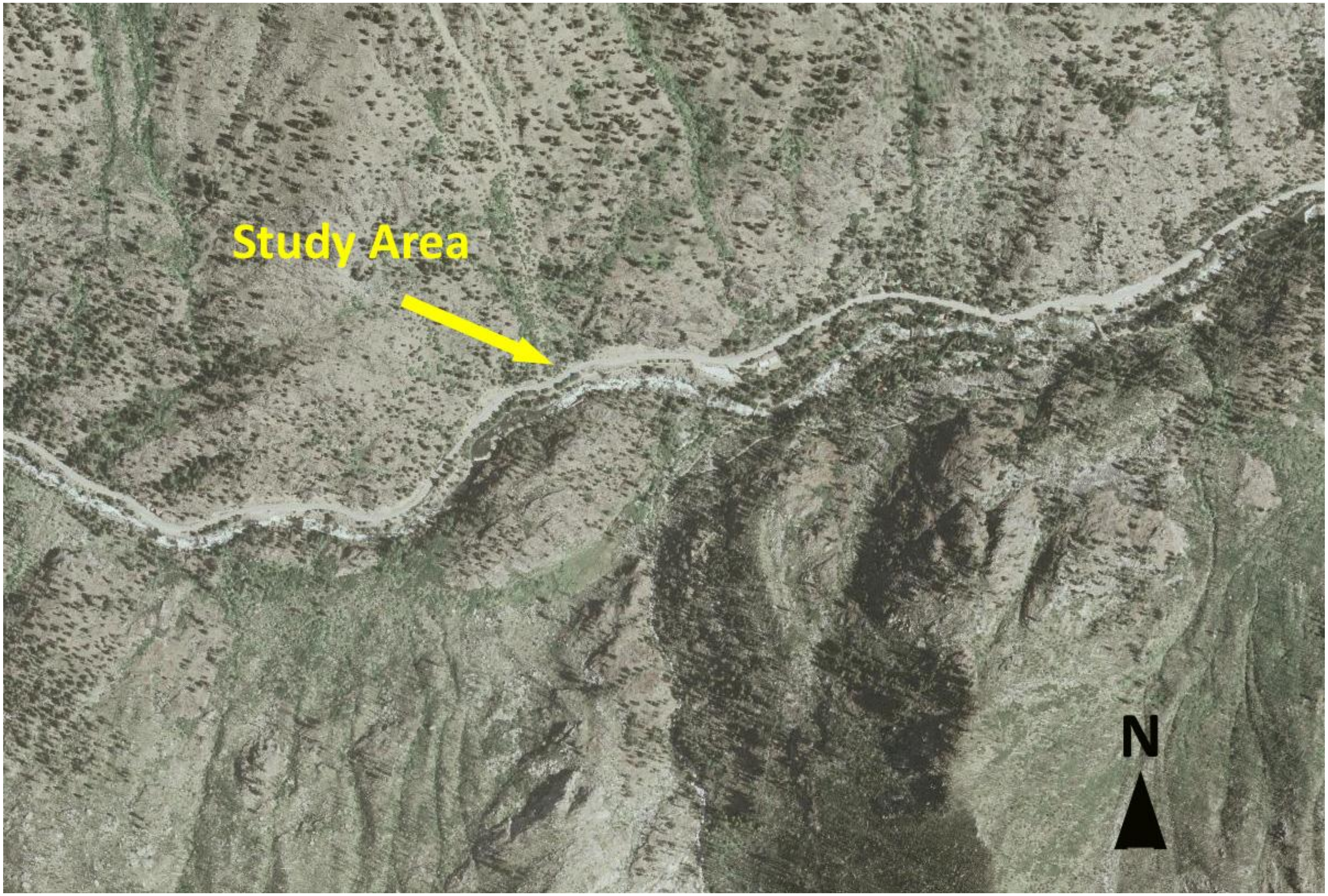


Figure A-22. 2006 aerial photograph of the Icicle Creek study area.

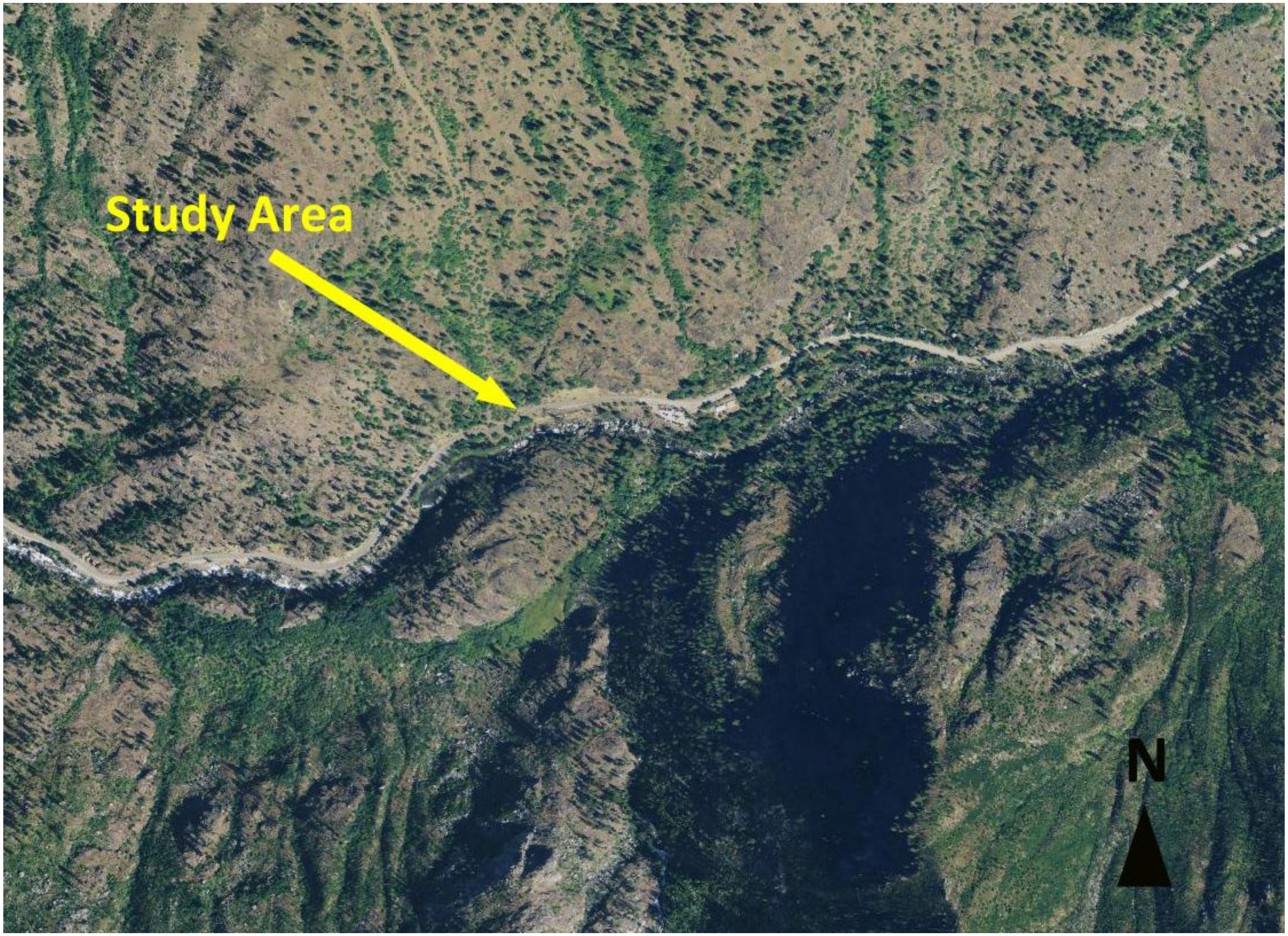


Figure A-23. 2011 aerial photograph of the Icicle Creek study area.

16 APPENDIX D: HEC-RAS MODEL REVIEW

HEC-RAS Model Review

By Stephen Blanton AECOM

1. Purpose

Hydraulic modeling of a section of Icicle Creek referred to as the Boulder Field (BF) has been conducted to support the assessment and identification of fish passage barriers for the species of concern, bull trout and steelhead, within the project reach. The modeling efforts are also intended to support potential mitigation design efforts. This Technical Memorandum (TM) provides a review of the appropriateness of the modeling approach, the results, and recommendations for alternative/additional modeling efforts.

2. Icicle Creek HEC-RAS Modeling

The HEC-RAS model was developed by Pat Power of Waterfall Engineering using detailed surveyed data. The survey data collection attempted to catch locations and elevations related to all boulders, pools, and topography that impact the hydraulic character of the project reach. **Figure 1** illustrates the resulting topographic map of the project reach and the locations of boulders and pools.

The HEC-RAS model uses steady state flows of 20, 200, 1500, and 2800 cfs. These flow rates are representative of seasonal flow rates associated with fish passage of Steelhead in the spring and Bull Trout in the late summer and early fall. The results shown in the attached figures and tables only contain the 200 and 2,800 cfs flow rates. The model uses a rating curve based on channel geometry to establish the downstream boundary condition and the upstream boundary is set to normal depth. The model is run assuming sub-critical flow so it is a back-water model, starting at the downstream end of the reach and then calculating water surface elevations and other hydraulic parameters in an upstream direction one cross-section (XS) at a time.

There are two geometry files used for the project reach; one has 7 XS labeled as 65-288, and the second has 19 XS that extend upstream from the initial seven cross section (65-288) ,up to cross section 700. The cross section number represents the length of the modeled stream reach. Through calibration efforts (**Figure 2**), the Manning "n" values were set to 0.06 for the channel and 0.10 for overbank.

As shown in the overall site plan (**Figure 1**), the modeled project reach is a series of drop pools. This is also evident in the velocity results provided in Figure 3 and Table 1, where the modeled velocities alternate from low velocities in the pool areas to high velocities in the drop areas. The low flow and high flow conditions in the model present a challenge in that during high flows the channel is near capacity with a single flow path. During low flows, the complex natural complexity of the Boulder Field allows for multiple flow paths. The HEC-RAS model assumes the multiple channels maintain a common water surface elevation across the entire stream section (Figure 4). However, actual field conditions will have variable water surface elevations depending on the flow path and volume of water conveyed along that path.

3. Recommendations

The steady flow HEC-RAS hydraulic developed for the project reach of Icicle Creek provides estimated flow velocity and depth results for the project. As a 1-D hydraulic model, HEC-RAS calculations assume all flow is conveyed perpendicular to the cross section and the water surface across the cross section is at a constant elevation.

For the modeled high flow conditions, the resulting flow depths and velocities appear reasonable, as Icicle Creek is a single flow channel during high flows. For low flow conditions where there are multiple flow paths with variable water surface elevations across the cross section, the HEC-RAS model may not provide accurate results.

The flow conditions within the Icicle Creek project reach are considered rapidly varying, with flow going from sub-critical to supercritical and back as the flow is conveyed through the steep channels. The current Icicle Creek HEC-RAS model with only cross sections representing the channel uses the Energy Equation which does not accurately predict water surface elevations in these flow conditions. Typically the Energy Equation is accurate for channels slopes up to 1:10. Many of the step pool formations in the Icicle Creek represent much steeper slopes. To correct for the model limitations related to rapidly changing flows and steep slopes, the HEC-RAS model can be edited to include weir structures to represent the step pools. This approach will allow the model to more accurately compute changes in water surface elevations based on momentum assumptions as opposed to energy balance assumption.

If the current HEC-RAS modeling approach is to be used for the development of design alternatives it is recommended that for low flow conditions, the model be revised to include multiple channel alignments representing the individual flow paths through the Boulder Field.

Another option for the HEC-RAS model would be to model the largest flow path through the Boulder Field with a representative percentage of the total stream flow. Both of these approaches would better address the complex nature of Icicle Creek during low flows but the model might still be a limited tool for design purposes.

Because of the highly variable natural flow in the Icicle Creek project reach, accurate hydraulic modeling of the flow velocities and depths may not be possible with a 1D model such as HEC-RAS. A 2-D model such as River 2D or River FLO2D may provide a more accurate simulation that can be used to better assess existing conditions as well as be used as a tool for the design of fish passage improvements. A 2D model allows for flow in multiple directions and will be better able to simulate the complexity of the multiple flow patterns through the Boulder Field but the accuracy of the model will be dependent on the developed stream bed surface and boulder placement.

ADDENDUM - From L. Dominguez

Trial Use of River Flo 2D

Upon initial site visits, it became apparent that the assumptions in the HEC-RAS steady flow simulation; that the flow is steady, the flow is gradually varied, the flow is one-dimensional, and the river channels have small slopes would be limitations in the analysis. Because of the complex flow dynamics in the reach, River Flo 2D (a Two-Dimensional Finite-Element River Dynamics Model) discharge scenarios were run using the same RAS data set for 200 and 1500 cfs. The outputs did not necessarily predict flow characteristics any more accurately than the RAS flood height predictions, its value would require many more survey points to document the individual rock features through the whole reach. The velocity vector outputs however, did validate the locations expected to have high, concentrated velocities (Figure 5). Because this was an exploratory assessment a report is not provided. Due to the high gradient and turbulent flows utilizing RAS for developing future plans is not recommended. A greater evaluation effort, potentially including more intensive field survey data, would be needed to determine the level of utility River Flo 2D to carry out final designs.

Figures and Tables

Figure 1. Icicle Creek Model Reach

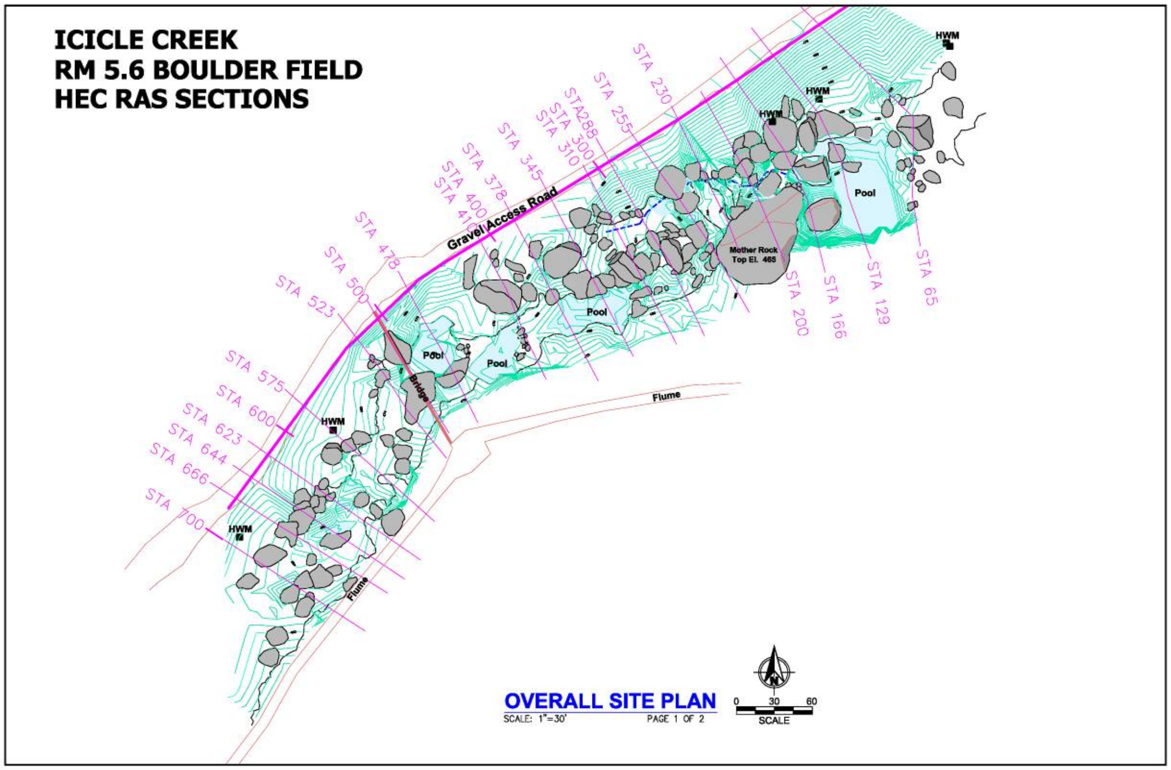


Figure 2. Calibrated Water Surface Elevations

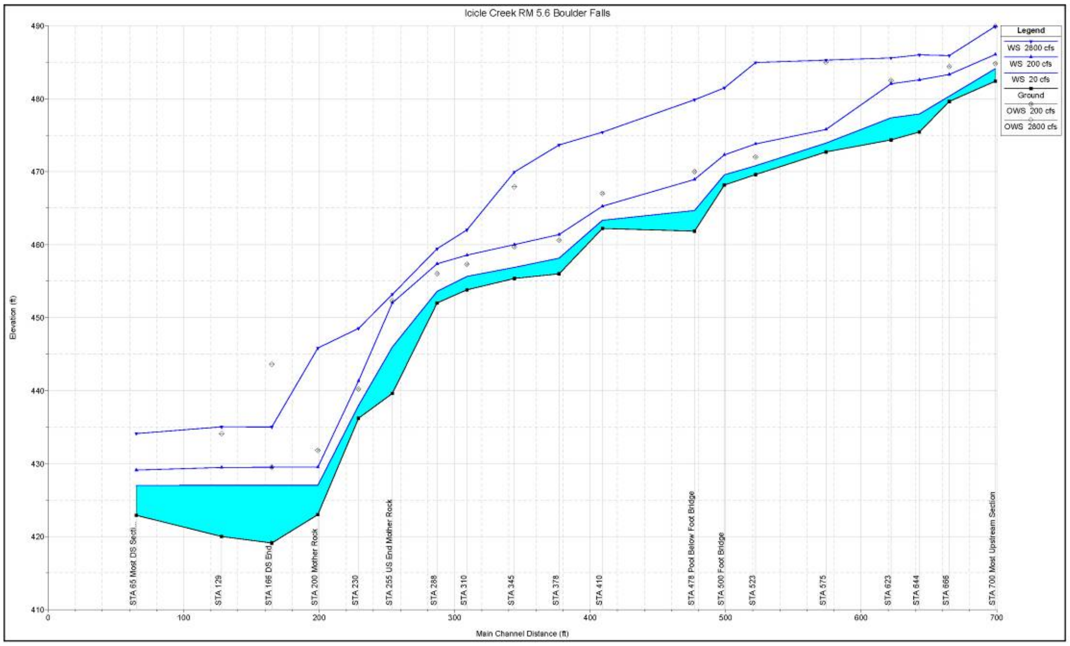


Figure 3. Icicle Creek HEC-RAS Velocities

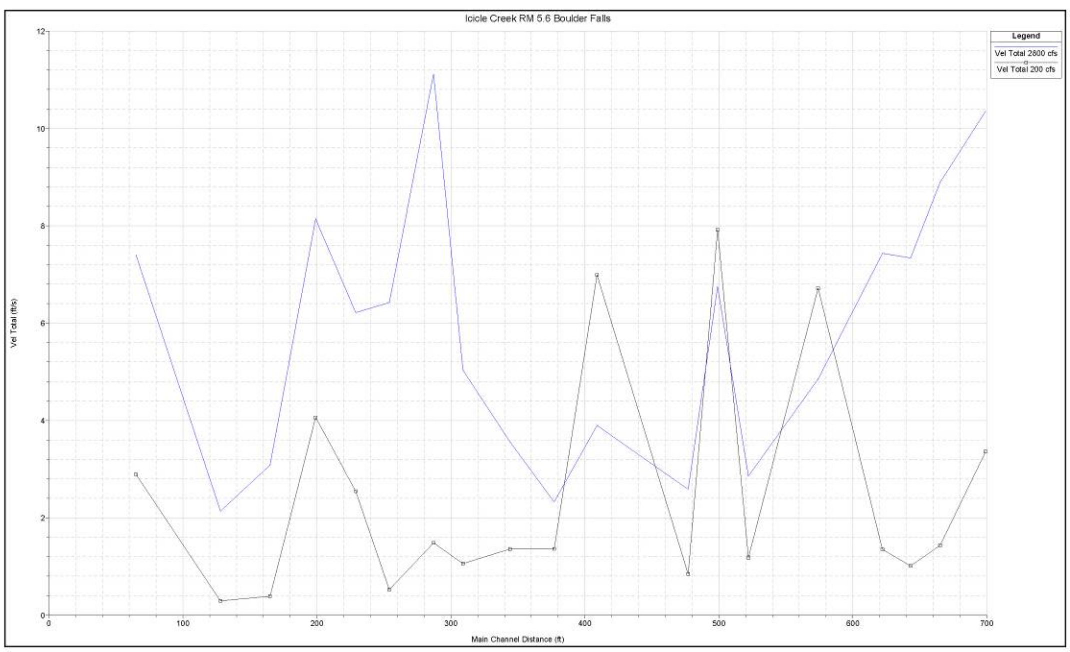


Figure 4. HEC-RAS Result Illustrating Multiple Flow Paths

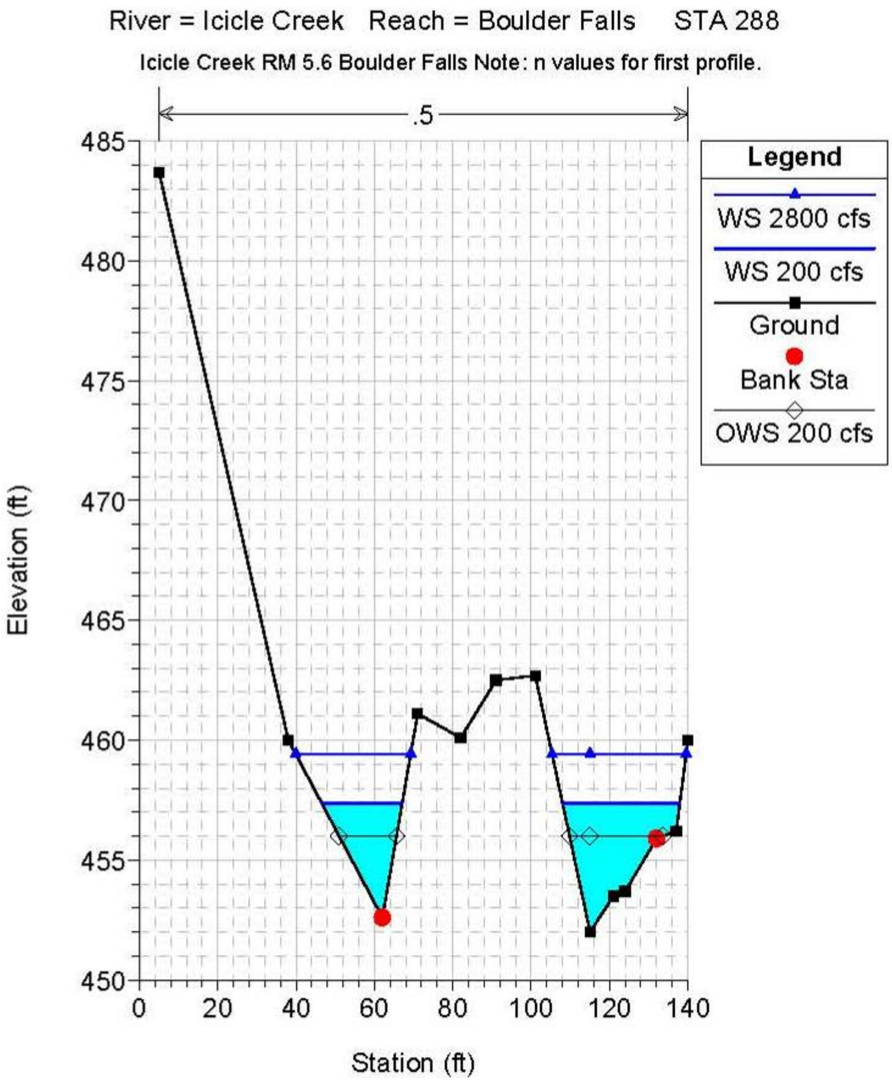


Figure 5 RiverFLO-2D application test to Middle Reach of Icicle Creek and expanded detail. Inflow discharge = 1500 cfs. Legend is velocity at feet per second. High velocity vectors validate field-estimated flow constrictions.

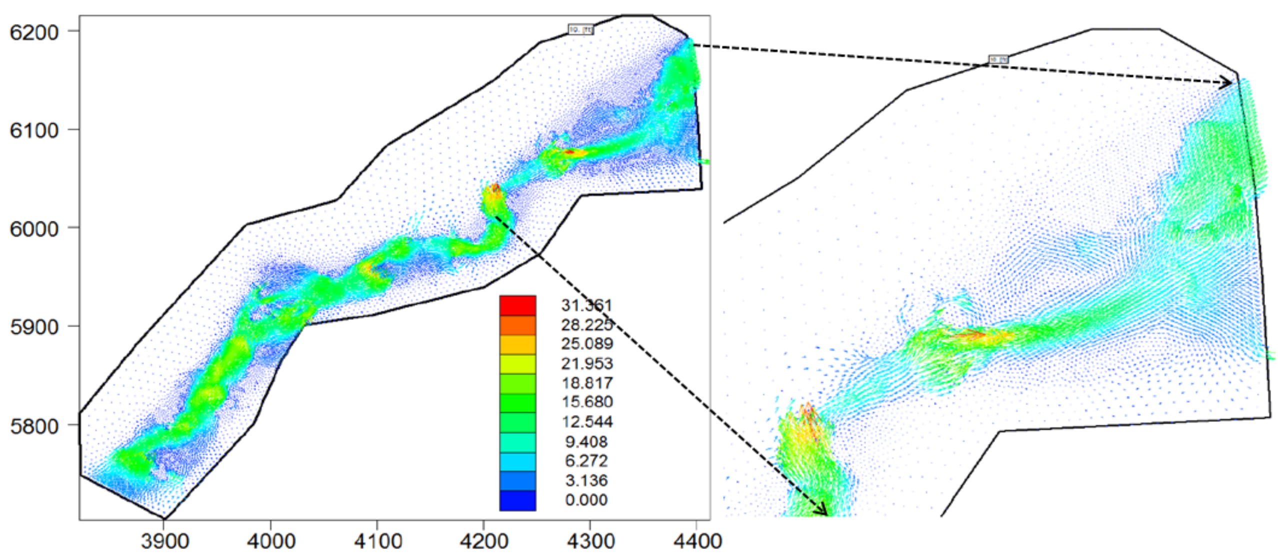


Table 1. HEC-RAS Model Results

HEC-RAS Plan: Plan 03 River: Icicle Creek Reach: Boulder Falls

Reach	River Sta	Profile	W.S. Elev	Vel Total	Max Chl Dpth	Top Width
			(ft)	(ft/s)	(ft)	(ft)
Boulder Falls	65	200 cfs	429.10	2.89	6.20	31.13
Boulder Falls	65	2800 cfs	434.10	7.40	11.20	85.03
Boulder Falls	129	200 cfs	429.45	0.29	9.45	103.33
Boulder Falls	129	2800 cfs	435.02	2.14	15.02	117.76
Boulder Falls	166	200 cfs	429.49	0.39	10.39	69.06
Boulder Falls	166	2800 cfs	435.00	3.09	15.90	73.73
Boulder Falls	200	200 cfs	429.50	4.06	6.50	11.42
Boulder Falls	200	2800 cfs	445.82	8.14	22.82	30.00
Boulder Falls	230	200 cfs	441.32	2.54	5.12	34.20
Boulder Falls	230	2800 cfs	448.51	6.22	12.31	66.37
Boulder Falls	255	200 cfs	452.02	0.53	12.42	47.36
Boulder Falls	255	2800 cfs	453.17	6.42	13.57	49.41
Boulder Falls	288	200 cfs	457.37	1.49	5.37	50.47
Boulder Falls	288	2800 cfs	459.43	11.11	7.43	63.64
Boulder Falls	310	200 cfs	458.55	1.06	4.88	80.02
Boulder Falls	310	2800 cfs	462.01	5.04	8.34	121.62
Boulder Falls	345	200 cfs	460.00	1.36	4.64	43.00
Boulder Falls	345	2800 cfs	469.94	3.57	14.59	103.21
Boulder Falls	378	200 cfs	461.38	1.36	5.39	39.96
Boulder Falls	378	2800 cfs	473.65	2.33	17.66	143.71
Boulder Falls	410	200 cfs	465.26	6.99	3.05	18.90
Boulder Falls	410	2800 cfs	475.40	3.90	13.20	109.59
Boulder Falls	478	200 cfs	468.93	0.85	7.09	50.46
Boulder Falls	478	2800 cfs	479.85	2.59	18.01	101.08
Boulder Falls	500	200 cfs	472.29	7.92	4.13	12.99
Boulder Falls	500	2800 cfs	481.47	6.75	13.31	97.96
Boulder Falls	523	200 cfs	473.79	1.18	4.20	49.02
Boulder Falls	523	2800 cfs	484.95	2.86	15.36	104.42
Boulder Falls	575	200 cfs	475.78	6.71	3.08	22.37
Boulder Falls	575	2800 cfs	485.27	4.85	12.58	130.24
Boulder Falls	623	200 cfs	482.04	1.35	7.69	40.94
Boulder Falls	623	2800 cfs	485.57	7.43	11.23	81.32
Boulder Falls	644	200 cfs	482.58	1.01	7.14	47.77
Boulder Falls	644	2800 cfs	486.00	7.34	10.56	57.78
Boulder Falls	666	200 cfs	483.31	1.43	3.69	59.69
Boulder Falls	666	2800 cfs	485.91	8.89	6.29	73.92
Boulder Falls	700	200 cfs	486.06	3.36	3.66	31.16
Boulder Falls	700	2800 cfs	489.91	10.36	7.52	82.69