Blue River Integrated Water Management Plan

Assessment of Current Aquatic Habitat, Hydrology, and Hydraulic Conditions in the Blue River Downstream of the Dillon Reservoir Dam

July 2022

TETRA TECH

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EXECUTIVE SUMMARY

Phase 1 of the Blue River Integrated Water Management Plan (BRIWMP), released in August 2021, confirmed the need to pinpoint effective strategies to address the declining fishery between the Dillon Reservoir Dam and Green Mountain Reservoir. Phase 2 of the BRIWMP is the implementation of specific actions identified in Phase 1, including development of reach-specific habitat assessments and restoration recommendations. This habitat assessment fits within Phase 2 of the BRIWMP. The objective of the habitat assessment is to identify potential physical habitat features that may be limiting the function of the aquatic community, specifically the fishery between the Dillon Reservoir Dam and Green Mountain Reservoir.

The approach for the habitat assessment focused on using channel cross section surveys, one-dimensional (1D) hydraulic modeling, and habitat quantification to characterize relationships between flow and hydraulic indicators of aquatic habitat quality. It is not the intent of this habitat assessment to propose new water delivery operations at Dillon Reservoir; the existing operations are assumed to be representative of the future flow regime. The intent is to quantify the existing hydraulic and habitat characteristics based on the existing hydrologic regime and, if appropriate, recommend channel modification or restoration to increase habitat conditions. The habitat assessment targeted the 20.6-mile-long Reach 2 of the Blue River from Dillon Reservoir to Green Mountain Reservoir.

Field reconnaissance was completed on July 12, 2021, at 10 locations from the Dillon Reservoir Dam to near the Boulder Creek confluence, covering approximately 12 river miles from Dillon Dam Reservoir to Boulder Creek. The purpose of the reconnaissance was to visually compare aquatic habitat conditions and select three sites for assessment of hydrology, hydraulics, and aquatic habitat. Site 1 is in the reach rehabilitated in 2003 near the Dillon Reservoir Dam outlet. Site 2 is in a reach extending about 1,500 feet upstream from the Silverthorne Outlets to the confluence with Straight Creek. Site 3 is located near Willow Grove Open Space, extending approximately 1,000 feet upstream from the Blue River Trail Bridge. These three sites were selected to quantify hydraulic conditions indicative of habitat quality for several reasons. First, they are all above the existing tributaries between Dillon and Green Mountain Reservoir representing the most hydrologically stressed sections of the river. Secondly these sites are located within a 'single thread' channel type which is the dominate channel type within Reach 2.

Hydrologic analyses were completed to identify the range of flows over which the aquatic habitat was assessed. Data sources included FEMA's Flood Insurance Study for Summit County, CO, the USGS's stream gaging records, and CWCB's instream flows. These data were used to compile representative hydrographs and flow duration analyses, and ultimately to select 10 flows between 50 and 1,000 cfs for hydraulic simulations. A one-dimensional numerical model (HEC-RAS) was developed and calibrated to simulate hydraulic conditions in the channel through the three habitat assessment sites. Channel hydraulics of key interest for the habitat assessment were (1) wetted perimeter of the channel, (2) channel hydraulic depth, and (3) channel maximum depth. Hydraulic rating curves presented the relationships of these variables to channel discharge.

On September 29, 2021, a habitat inventory was completed at the three habitat assessment sites to provide a means to compare habitat across sites. The inventory used a quantitative protocol the USFS developed to

measure the area of each habitat type and the average depth of the habitat type and to visually estimate cover and stream substrate. All three sites were dominated by riffle and run/glide habitat types, with pool habitat types making up under 10 percent of each site. Of the possible cover types, 'no cover' made up at least 98 percent of each site. Except Site 2 where about 10 to 20 percent of the three habitat types included gravel, the substrate was dominated by cobble and boulders. The habitat inventory showed the benefits of the early 2000s rehabilitation on diversity and quality of aquatic habitat types through Site 1, the potentially limiting quality of habitat types in Sites 2 and 3, and the potentially limiting cover and substrate through all three sites.

The hydraulic habitat assessment reinforced the potentially limiting aquatic habitat quality noted during the habitat inventory. This assessment focused on evaluating hydraulic conditions in each of the three habitat types. In riffles, the assessment showed all three sites provide sufficient wetted perimeter even at 50 cfs, and average riffle depths were at or greater than the standards applied in minimum flow studies. These results indicate riffle habitat should be suitable to support benthic invertebrate production as a food source for higher trophic levels. Run/glide habitats across all three sites provide hydraulic conditions at low flows that are likely sufficient to provide foraging locations for fish. Pool habitat, where present, exhibited shallower average depths than the recommended 1.5-feet to provide adequate cover, resting, and refuge habitat; however, the maximum pool depths were in excess (Sites 1 and 2) or close to (Site 3) this 1.5-foot depth recommendation. Pools in Site 1 were on the outside bend of a small low flow meander channel, pools in Site 2 were downstream of constructed boulder weir drop structures, and pools in Site 3 were extremely limited and located mid-channel. The limited number of pools and shallow depth present in the pools may be contributing to the impairment of the trout fishery through the assessed reach of the Blue River.

Based on the better understanding of the relationships between the Blue River hydrology, the morphology of the Blue River channel, and hydraulic indicators of aquatic habitat quality, recommendations are offered to improve aquatic habitat. The recommendations are summarized below and described in further detail in Section 7.0 of this report:

- Continue to investigate the impact of water quality from urban and roadway runoff on the biological community in the Blue River between the Dillon Reservoir Dam and Green Mountain Reservoir. Consider a limiting factor analysis to understand whether aquatic habitat or water quality is the greater limitation on the trout fishery. The hydraulic habitat assessment of Site 1 indicates the habitat quality should support a trout fishery, but the Gold Medal status is dependent on CPW's stocking this reach with catchable rainbow trout. This could indicate the water temperature or water quality are more limiting to the trout fishery at this site than the habitat. If this is the case, it could mean that addressing the water quality and other factors are needed before the habitat improvement can provide the needed functional uplift.
- Investigate the potential fish passage impediments the boulder weir drop structures create and modify these structures as required to allow fish passage and to promote longitudinal channel habitat connectivity. Constructed riffles of configuration like the rehabilitated riffles in Site 1 should be considered as potential templates to replace the drop structures with grade controls that do not impede upstream fish movement.

- Create and enhance pool habitat from around the I-70 crossing to Willow Creek Open Space. Physical modification of the Blue River should prioritize narrower and deeper pools similar to the rehabilitation of Site 1.
- Placement of spawning gravel should be considered. Gravel placement is most critical upstream of tributary confluences that delivery gravel sediment, such as the reach upstream of the Willow Creek confluence.
- Review previous stocking records from prior years in the reach from the Dillon Reservoir Dam downstream to the Hamilton Creek Road Bridge to investigate the change in management and the lack of successful recruitment of wild spawned rainbow trout.
- Conduct a simple bioenergetic study to determine the food requirements for each size of trout. Much of the needed input data for this desktop exercise is available.
- If not already completed or underway, a study should be considered to quantify river use, and assess whether the number of people on the river are creating enough disturbance to contributing to the decline in the trout fishery.
- Continue integrating studies to help determine causes of the fishery decline. This integration should include a comprehensive analysis of fish populations (all species, not just limited to trout), macroinvertebrate data, water quality data, and physical habitat. Integration across disciplines should be a precursor to development of an overall management plan.

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APPENDICES

Appendix A: Hydraulic Model Development

Appendix B: Habitat Inventory Technical Memorandum

ACRONYMS/ABBREVIATIONS

Acronyms/Abbreviations	Definition
°C	Degrees Celsius
1D	One Dimensional
ACE	Annual Chance Exceedance
ASPRS	American Society for Photogrammetry and Remote Sensing
BRIWMP	Blue River Integrated Water Management Plan
BRWG	Blue River Watershed Group
CPW	Colorado Parks and Wildlife
CWCB	Colorado Water Conservation Board
DEM	Digital Elevation Model
FEMA	Federal Emergency Management Agency
FIS	Flood Insurance Study
GIS	Geographic Information System
GNSS	Global Navigation Satellite Systems
GPS	Global Positioning System
HEC	Hydrologic Engineering Center
Hwy	Highway
I-70	Interstate 70
LiDAR	Light Detection and Ranging
MEC	Miller Ecological Consultants, Inc.
NAVD88	North American Vertical Datum of 1988
NFHL	National Flood Hazard Layer
NGS	National Geodetic Survey
NOAA	National Oceanic and Atmospheric Administration
OPUS	NOAA's Online Positioning User System
PMR	Physical Map Revision
RMSE	Root Mean Square Error
RTK	Real-time Kinematic
TU	Trout Unlimited
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey

1.0 INTRODUCTION

This section presents targeted background information, the key objective, and the approach of the work completed within the scope of the habitat assessment in the Blue River downstream of the Dillon Reservoir Dam, which includes assessments of hydrology, hydraulics, and current aquatic habitat.

1.1 BACKGROUND

The Blue River in Summit and Grand Counties Colorado is an ecological, economical, and recreational resource. The health and maintenance of the Blue River's water resource is vital to the local communities, the environment of the river and watershed, and to water users and transbasin diverters. In May 2018 Trout Unlimited (TU) and the Blue River Watershed Group (BRWG) began working together to produce an integrated water management plan for the Blue River basin. The first phase of the plan included a review of available existing data and reports to assess the physical health of the Blue River and the aquatic life it supports within its mainstem. A key objective of the first phase was to understand the reasons for the declining Blue River trout fishery, and this objective was pursued by tasks both to determine the causes for the declining fishery between the Dillon Reservoir Dam and Green Mountain Reservoir and to develop remedial measures.

Until 2016, Colorado Parks and Wildlife (CPW) designated the Blue River between the Dillon Reservoir Dam and Green Mountain Reservoir as a Gold Medal Fishery; this designation was removed downstream of the Hamilton Creek Road Bridge at the northern edge of the Town of Silverthorne because of failure to meet CPW's biological criteria (CPW, 2019). CPW biologists indicated the low productivity may be caused by a combination of suboptimal physical habitat under low releases from Dillon Reservoir (noted as being less than 100 cfs) and a lack of food and/or limited biological productivity. In 2020 TU conducted an angler survey and found 68 percent of participants were "neutral" or "dissatisfied" with the overall quality of the fishing and angling experiences on this reach of the Blue River (Omasta, 2020). The upstream portion of the reach retained its Gold Medal designation largely because of (1) the Town of Silverthorne's early-2000s in-channel river restoration efforts (Reuter, 2002), and (2) CPW's stocking this reach with catchable rainbow trout. Basinwide, the communities have placed high priority on determining the cause(s) of the decline of the fishery and returning the Blue River to its once-productive condition, thereby reestablishing the Gold Medal status to the entire reach.

Denver Water's water delivery operations affect the hydrology of the Blue River downstream from the Dillon Reservoir Dam. In addition to affecting flows, the water delivery operations also impact water temperature downstream from the dam. Regulated releases from Dillon Reservoir are typically drawn from the bottom of the reservoir, which results in a constant cold release temperature with little to no daily or seasonal variation. Release temperatures are generally less than 10°C. The low temperature affects the aquatic biota in several ways. Benthic macroinvertebrates that require natural seasonal temperature fluctuations to complete their life cycles are absent or in low numbers. Growth rates for fish are slowed because of lower metabolic rates. Trout spawning success can be decreased by the low water temperatures, especially for spring spawning species such as rainbow trout and cutthroat trout (Miller, 1988). These species normally experience rising water temperatures during egg incubation. Low water temperatures (less than 10°C) can delay embryo development and hatching in rainbow trout (Timoshina, 1972). Flow and surface-water temperature records collected by the USGS and Colorado TU also indicate that when flows are increased the rate of change in flow is often achieved by combining surface water spills through the morning glory spillway with bottom releases through the outlet pipe. This results in rapid fluctuations in flow, and rapid changes in water temperatures (Tetra Tech, 2021), both of which likely have a negative impact on the aquatic biota.

When Phase 1 of the Blue River Integrated Water Management Plan (BRIWMP) (Tetra Tech, 2021) was released in August 2021, the preliminary results confirmed the need to pinpoint effective strategies to address the declining fishery between the Dillon Reservoir Dam and Green Mountain Reservoir. Phase 2 of the BRIWMP is the implementation of specific actions identified in Phase 1, including development of reach-specific habitat assessments and restoration recommendations. Thus, this habitat assessment fits within Phase 2 of the BRIWMP.

1.2 KEY OBJECTIVE

This habitat assessment was completed to provide support to the BRWG for implementing the habitat assessment and restoration recommendations in the BRIWMP. The assessment focuses on physical instream habitat for aquatic biota in the Blue River downstream of the Dillon Reservoir Dam, and it generally follows the principles and guidance for instream flow and hydraulic-habitat evaluations as described in several foundational instream flow documents (Stalnaker et al., 1995; Bovee et al., 1998; Annear et al., 2004). The objective of this assessment is to identify potential physical habitat features that may be limiting the function of the aquatic community, specifically the fishery between the Dillon Reservoir Dam and Green Mountain Reservoir. There may be other factors limiting the function of this fishery (such as water temperature and other water quality constituents), but those factors are outside the scope of this assessment and are being addressed by others.

1.3 ASSESSMENT APPROACH

The approach for this habitat assessment of the Blue River mainstem downstream of the Dillon Reservoir Dam required professionals with expertise in evaluating stream ecology and aquatic habitat, bathymetric surveying, hydrologic analyses, and hydraulic modeling and analyses. Thus, the BRWG contracted with Miller Ecological Consultants, Inc. (MEC) and Tetra Tech to carry out the habitat assessment. MEC and Tetra Tech expected multiple assessments will be required to determine the cause(s) of decline of the fishery through this reach of the Blue River. The proposed approach for the assessments documented herein focused on using channel cross section surveys, one-dimensional (1D) hydraulic modeling, and habitat quantification to characterize relationships between flow and hydraulic indicators of aquatic habitat quality. These relationships are key to better understanding how channel hydraulics and habitat change as a function of flow. Hydraulic indicators targeted in this assessment include channel wetted perimeter, average (hydraulic) depth of the channel, and channel maximum depth.

Flows in the Blue River downstream of the Dillon Reservoir Dam are largely driven by water delivery operations between Dillon Reservoir and Green Mountain Reservoir. It is not the intent of this habitat assessment to propose new water delivery operations; rather, the intent is to quantify the existing hydraulic and habitat characteristics based on the existing hydrologic regime and, if appropriate, recommend channel modification or restoration to increase habitat conditions under the current flow regime.

2.0 RECONNAISSANCE

MEC and Tetra Tech initiated the habitat assessment with desktop analyses and field reconnaissance. The results of these efforts guided the selection of three habitat assessment sites.

2.1 ASSESSMENT AREA

The habitat assessment targeted the 20.6-mile-long Reach 2 of the Blue River from Dillon Reservoir to Green Mountain Reservoir (Figure 1).

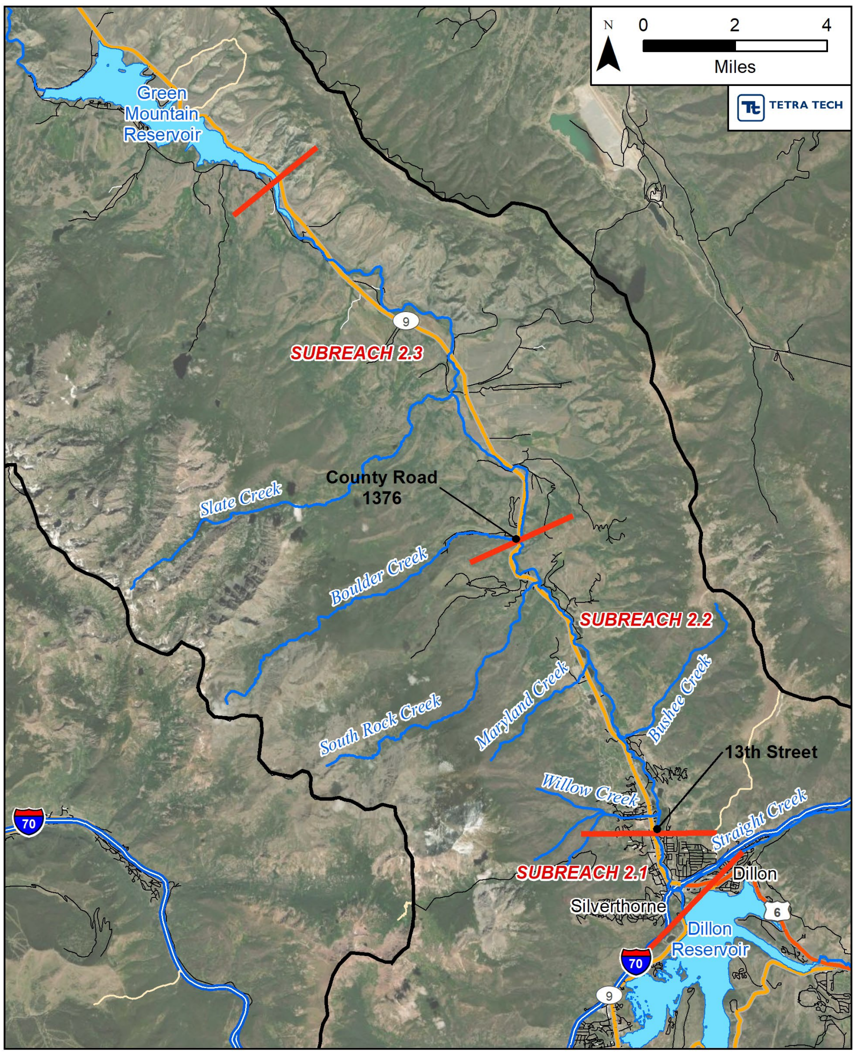

Figure 1. Subreaches of the Blue River Reach 2 between Dillon Reservoir and Green Mountain Reservoir

2.2 DESKTOP ANALYSES

Desktop analyses focused on the distribution of channel types along Reach 2, specifically Subreaches 2.1 and 2.2, and comparison of hydrology from Dillon Reservoir into Green Mountain Reservoir.

2.2.1 Distribution of Channel Types

The first step in the habitat assessment was a desktop analysis of channel types along Reach 2. Using Google Earth to view aerial imagery, MEC identified three general river channel types in this reach of the Blue River: (1) single thread, (2) single thread with small, vegetated islands, and (3) multiple threads (Table 1). The single thread channel type is dominant. The single thread with small, vegetated islands channel type generally occurs in the downstream half of Reach 2. The multiple threads channel type starts at the northern edge of the Town of Silverthorne and extends sporadically over the next 4 miles downstream.

Table 1. Blue River channel types between the Dillon Reservoir Dam and Green Mountain Reservoir

Channel Type	Length (miles)	Percent of Reach 2 Length
Single thread	17.4	84
Single thread w/ small, vegetated islands	1.3	6
Multiple threads	1.9	9

Given the prevalence of single thread channel types in Reach 2, MEC and Tetra Tech decided that the three sites for detailed habitat assessment should be targeted in this type of channel. Thus, MEC and Tetra Tech targeted field reconnaissance to the upper portion of Reach 2.

2.2.2 Hydrology between Dillon Reservoir Dam and Green Mountain Reservoir

A preliminary hydrologic analysis was completed to compare flows in the Blue River released from the Dillon Reservoir Dam to flows entering Green Mountain Reservoir. The USGS records flows released from the Dillon Reservoir Dam at gaging station 09050700; the Bureau of Reclamation back-calculates inflows to Green Mountain Reservoir based on reservoir stage changes. The preliminary analysis focused on water year 2021 (Figure 2). The analysis shows that the inflow to Green Mountain Reservoir is at minimum about twice the release from the Dillon Reservoir Dam. About one-quarter of the drainage area to the Blue River between the Dillon Reservoir Dam and Green Mountain Reservoir drains directly into Green Mountain Reservoir, and assuming inflow is proportional to drainage area, about three-quarters of the increase in inflow to the reservoir is conveyed down the Blue River.

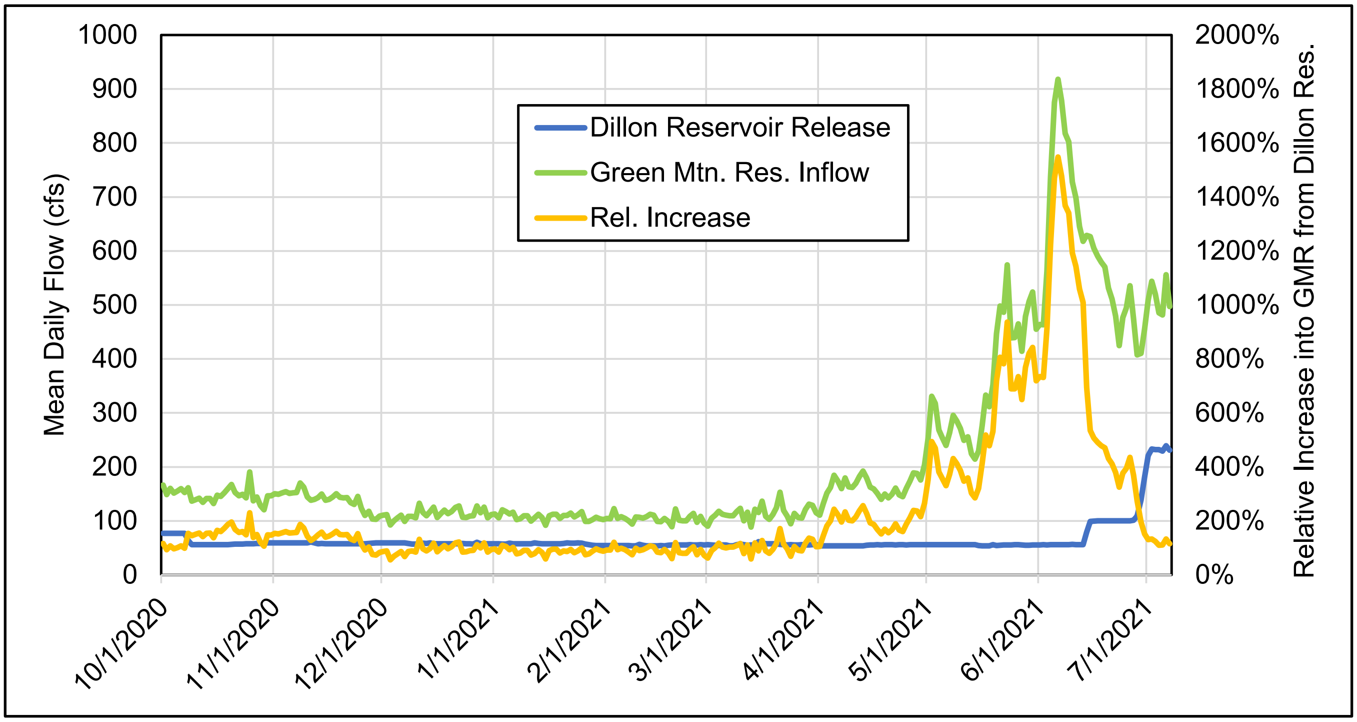

Figure 2. Blue River Reach 2 hydrologic analysis of water year 2021

As noted in the BRIWMP Phase 1 Report (Tetra Tech, 2021), and supported through review of aerial photography, tributaries to Reach 2 such as Willow Creek, Maryland Creek, Rock Creek, Boulder Creek and Slate Creek have a notable impact on the flow regime in the Blue River, particularly when compared to the flow releases from Dillon Reservoir (Figure 2). The tributaries may mitigate some of the impacts on the mainstem fishery, such as regulated flow releases from Dillon Reservoir, limited delivery of spawning-size sediment from the upper watershed, nearly constant cold-water releases from the bottom of Dillon Reservoir, water quality concerns from I-70 and U.S. Highway 9, and developed floodplains with reduced channel connectivity through Silverthorne. This preliminary hydrologic analysis supported MEC's and Tetra Tech's preference to target field reconnaissance and subsequent analyses to the more-impacted aquatic habitat in the upstream portion of the Blue River near the Dillon Reservoir Dam.

2.3 FIELD RECONNAISSANCE

On July 12, 2021, MEC and Tetra Tech completed field reconnaissance of the Blue River from the Dillon Reservoir Dam to near the Boulder Creek confluence downstream of the Blue River Campground, covering approximately 12 river miles. The purpose of the reconnaissance was to visually compare aquatic habitat conditions and select three sites for assessment of hydrology, hydraulics, and aquatic habitat. Daily average flow was about 165 cfs during the reconnaissance, with greater flows downstream of ungaged tributary confluences. The reconnaissance included stops at the following ten locations (Figure 3).

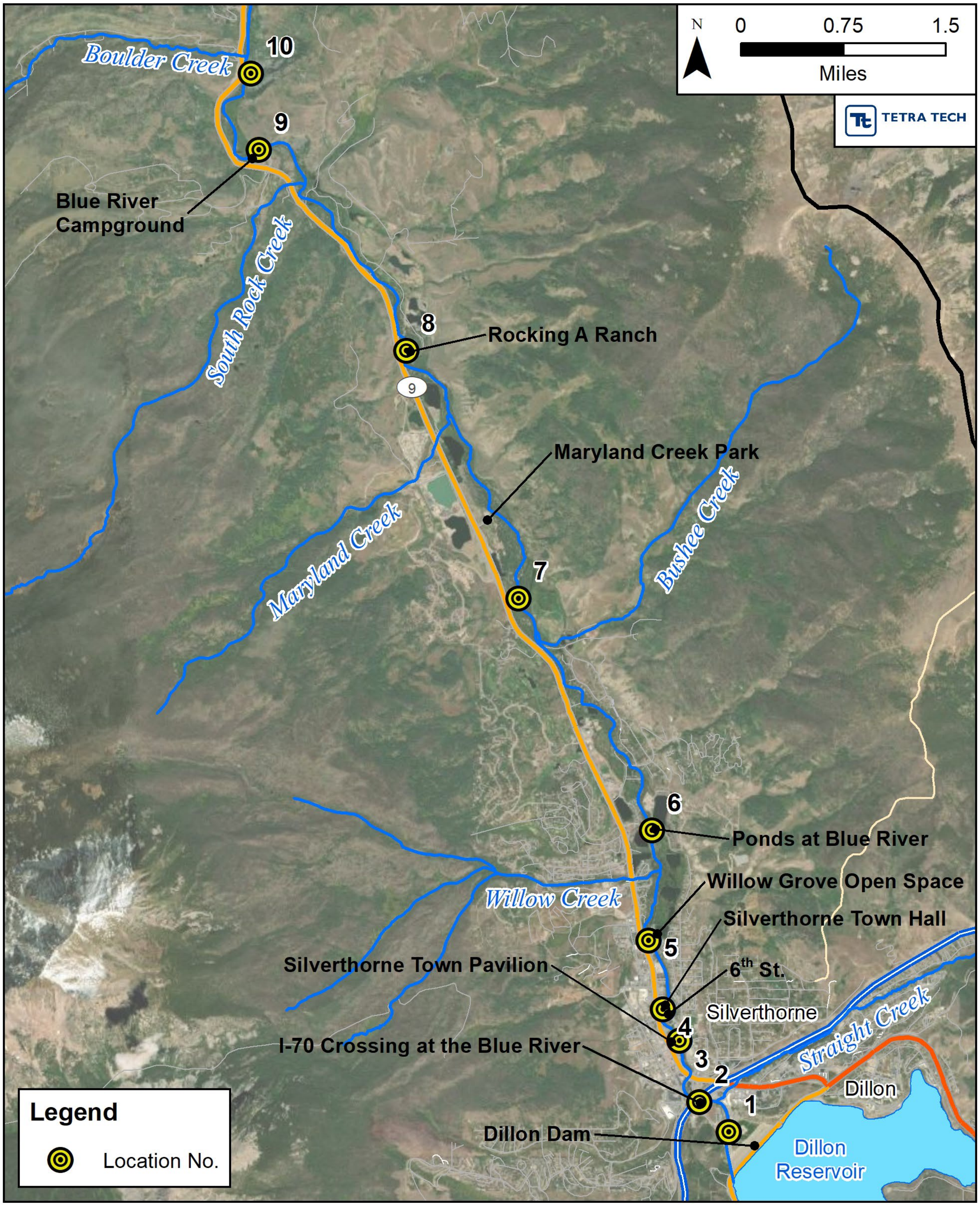

Figure 3. July 12, 2021 field reconnaissance locations

2.3.1 Location 1 – Near the Dillon Reservoir Dam Outlet

The Blue River at this location is approximately 50 to 55 feet-wide with diverse, naturally appearing habitat features, including pools, runs, and riffles along the meandering channel with vegetated banks (Figure 4). Substrate is primarily cobble and boulder with a near absence of gravel (Figure 5). This location is within a reach Ecological Resource Consultants (ERC) rehabilitated in 2003 through a [Colorado Division of Wildlife] Fishing is Fun grant (Troy Thompson, ERC, personal communication to Bill Miller, April 15, 2022).

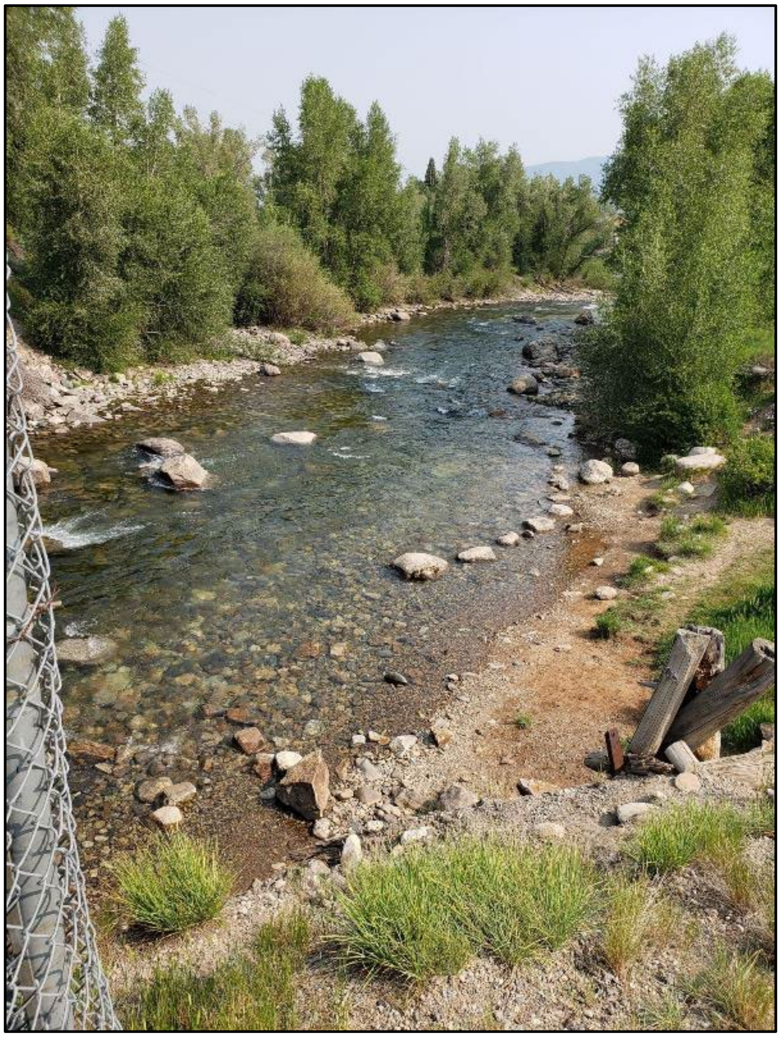

Figure 4. July 12, 2021, Blue River reconnaissance Location 1, facing downstream

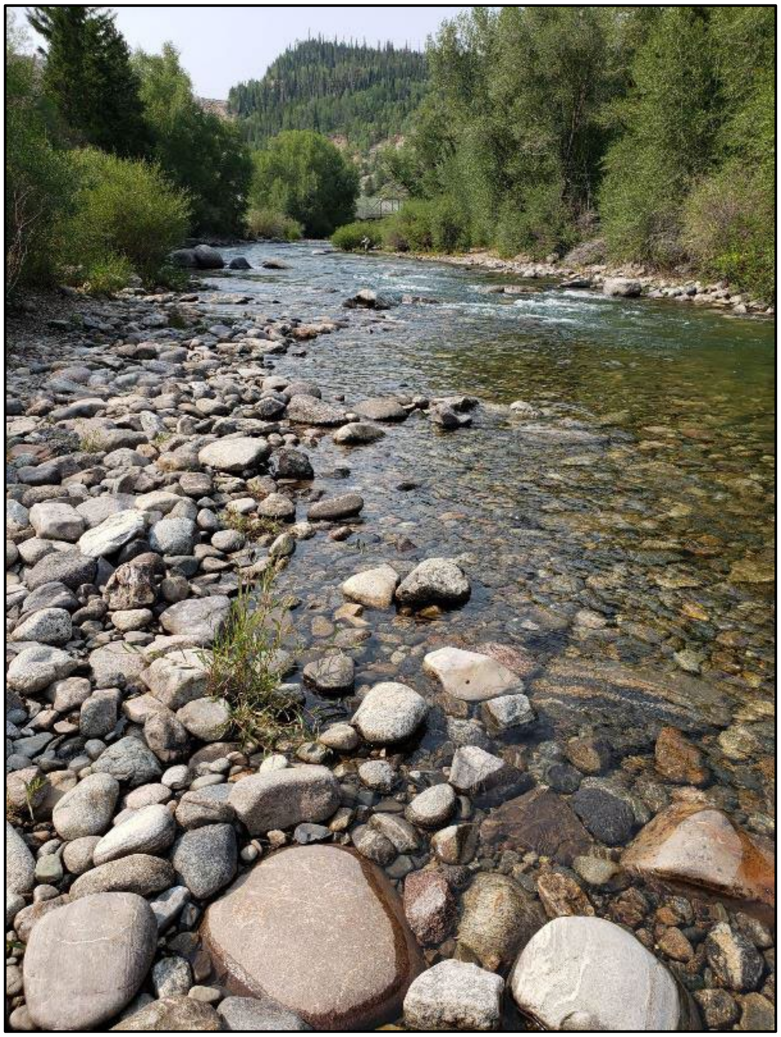

Figure 5. July 12, 2021, Blue River reconnaissance Location 1, facing upstream

2.3.2 Location 2 – Near I-70 Bridge Crossing

The river at this location is wider than Location 1, approximately 75 feet, likely reflecting the hydraulic response to the configuration of several boulder weir drop structures (Figure 6). Cobbles and boulders dominate the substrate. There is a small island upstream of the I-70 Bridge, but flows were too low to inundate the secondary channel along the right bank (facing downstream). No notches or ramps were observed in the drop structures to facilitate fish passage. Water velocity over the drops was very fast. The combination of the water-surface elevation drop and the fast velocity at these structures is likely a passage impediment to fish moving upstream. There are an estimated 12 drop structures along the river from upstream of I-70 bridge to upstream of the most-upstream pedestrian bridge at Silverthorne's 'Town Center' near Location 3.

Figure 6. July 12, 2021, Blue River reconnaissance Location 2, facing upstream

2.3.3 Location 3 – At Silverthorne Town Pavilion

The river in this location has several instream structures that were placed either as partial or complete channel drops (Figure 7). The river width at this location is approximately 80 feet. Substrate is predominately large cobble and boulders. There are numerous boulders downstream of the pedestrian bridge that may have been placed for fish habitat enhancement (Figure 8). A drop structure directly under the pedestrian bridge is placed perpendicular to the river flow and has a drop of approximately 1.5 feet (Figure 9). The structure is constructed of large boulders with very little to no gap between boulders.

Figure 7. July 12, 2021, Blue River reconnaissance Location 3, drop structures

Figure 8. July 12, 2021, Blue River reconnaissance Location 3, possible habitat boulders

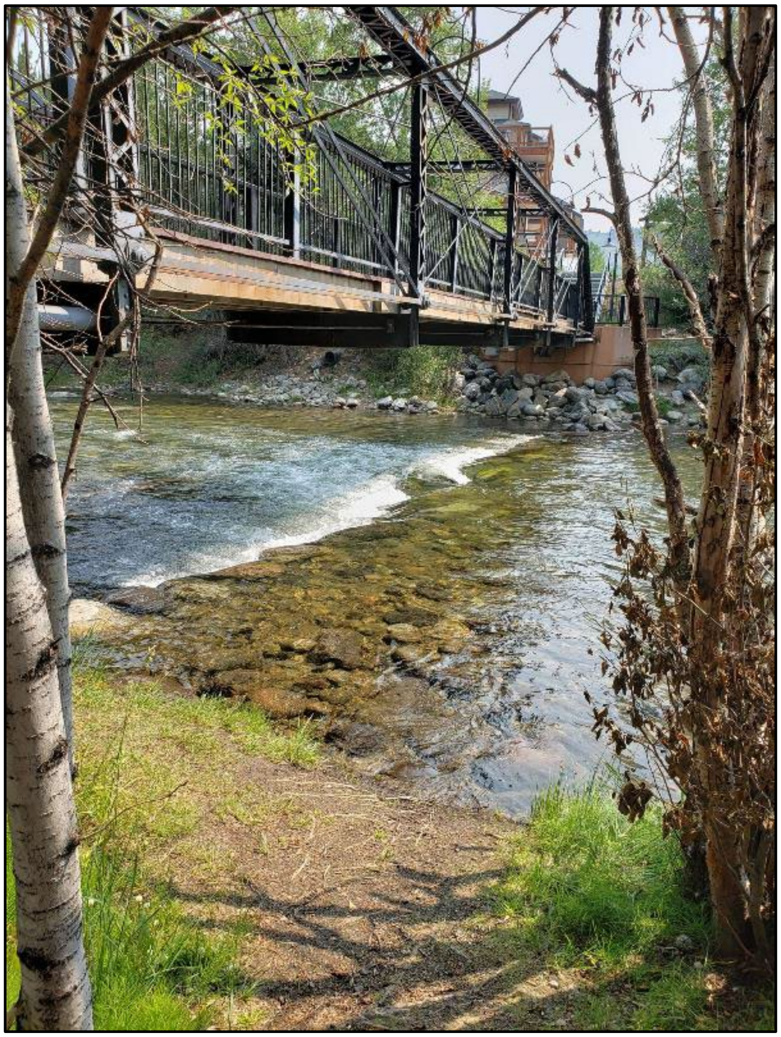

Figure 9. July 12, 2021, Blue River reconnaissance Location 3, drop structure under bridge

2.3.4 Location 4 – Silverthorne Town Hall

The river at this site is about 50 feet wide, narrower than at locations 3 through 5. The location was accessed from the Silverthorne Town Hall, just downstream from the 6th Street culvert crossing. The channel through this location appears to have been modified with a large gravel/cobble bar on river right and a hardened riffle constructed from boulders and cobble (Figure 10). This full channel width riffle does not create a drop like the upstream drop structures; it functions more like a natural riffle and thus does not appear to be a fish passage impediment.

Figure 10. July 12, 2021, Blue River reconnaissance Location 4, gravel bar and hardened riffle

2.3.5 Location 5 – Willow Grove Open Space

This location was accessed from the Willow Grove Open Space parking area at the north end of Willow Way, with reconnaissance facilitated by walking the Blue River Trail. The river at this location is a wider (about 70 feet), compared to Location 4 and is a single thread channel that splits around a large mid-channel island (Figure 11). The substrate is mostly cobbles with some small patches of gravel. There are some low bank areas that appear to allow connection to the small floodplain during higher flows. The island also has low banks, and it is likely inundated at higher flows.

Figure 11. July 12, 2021, Blue River reconnaissance Location 5, mid-channel island

2.3.6 Location 6 – The Ponds at Blue River

The river at this location, accessed where the Bald Eagle Road Bridge crosses the river, is less urban than the locations upstream. It appears that some channel manipulation has occurred at this location because of the straight channel, perhaps with straightening to accommodate the bridge (Figure 12). The substrate is mostly cobble with some large gravel; although, sand was present in a left bank bar. This is the first notable supply of sand observed downstream of Dillon Reservoir. The source of the sand is unknown; it could be delivered from Willow Creek, which joins the Blue River approximately one-quarter-mile upstream of this location, or it could be from winter sanding operations along Highway 9. Banks are relatively high and steep without much connection to the floodplain downstream of the bridge.

Figure 12. July 12, 2021, Blue River reconnaissance Location 6, sand bar at the Bald Eagle Rd. Bridge

2.3.7 Location 7 – Near Maryland Creek Park

This location was accessed from parking area on the east side of Highway 9 approximately one-quarter mile upstream from the Maryland Creek Park. The river at this location is approximately 65 feet wide. The habitat is primarily riffle and run with cobble-dominated substrate (Figure 13). Banks in this location appear relatively low and well vegetated with little urban encroachment. It is likely the floodplain is hydraulically connected during higher flows.

Figure 13. July 12, 2021, Blue River reconnaissance Location 7, facing upstream at runs and riffles

2.3.8 Location 8 – Rocking A Ranch Bridge

The river at this location is a single channel. The location was accessed from the parking area on the east side of Highway 9 at the turnoff for County Road 1870, which leads to a private bridge for the Rocking A Ranch. There is a cross-channel boulder weir structure installed downstream from the bridge that appears to act as stream barbs or wing dams (Figure 14), perhaps as a habitat feature. Stream substrate is cobble with some gravel. The additional supply of gravel is likely delivered from the Maryland Creek drainage, where the historical depositional fan at the Blue River confluence is upstream of this bridge.

Figure 14. July 12, 2021, Blue River reconnaissance Location 8, facing downstream at weir structure

2.3.9 Location 9 – Blue River Campground

The river at this location has more angular substrate in some locations, likely reflecting direct colluvial input from the adjacent hillslopes. One notable colluvial source is the bedrock outcrop upstream of the campground on the right bank (Figure 15). Downstream from the campground the river substrate is mostly cobble and gravel. The overbank area downstream from the campground has small gravel on the surface and shows evidence of overbank flows. The banks are lower in much of this area and have some lateral connectivity to the river at higher flows (Figure 16).

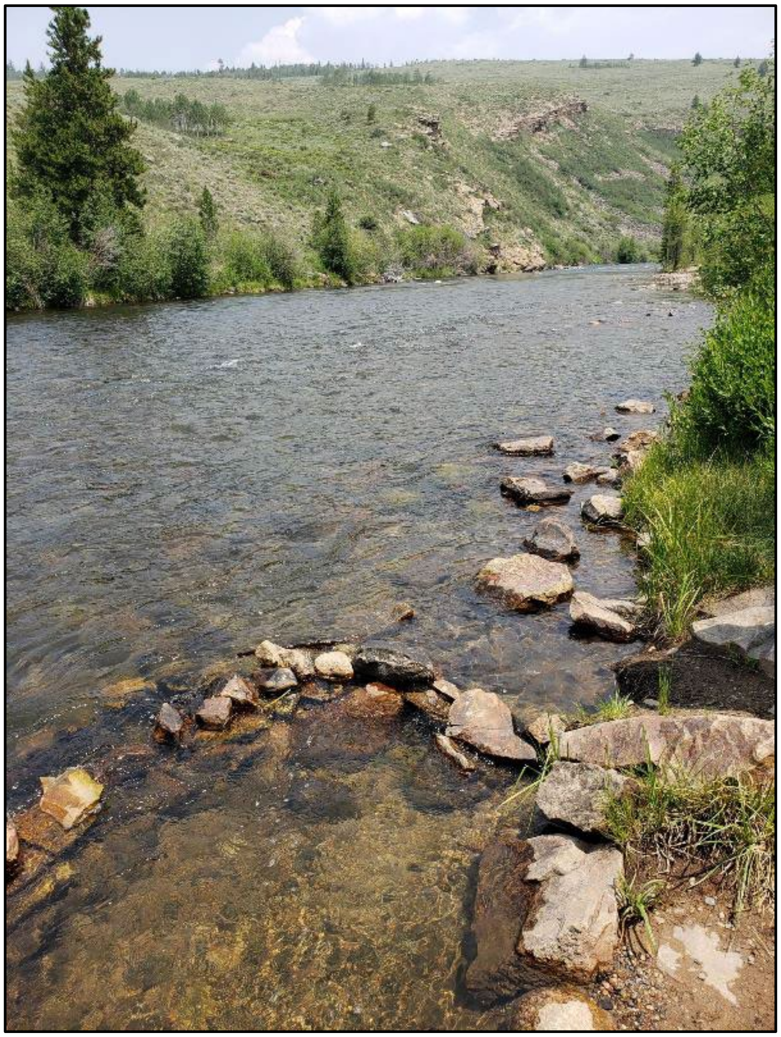

Figure 15. July 12, 2021, Blue River reconnaissance Location 9, facing upstream at adjacent hillslope

Figure 16. July 12, 2021, Blue River reconnaissance Location 9, facing downstream

2.3.10 Location 10 – Near Boulder Creek Confluence

This location was accessed from the parking area along the east side of Highway 9 about 500 feet upstream from the bridge over Boulder Creek. The river at this location has a lower gradient than most of the upper river, perhaps because of the grade control imposed immediately downstream at the confluence of Boulder Creek. Small Age 0 fish were observed at this site but were not identifiable; these fish indicate the presence of a naturally reproducing community. The substrate includes small cobble and various size gravel, and some large wood was noted in the channel (Figure 17).

Figure 17. July 12, 2021, Blue River reconnaissance Location 10, facing downstream

2.4 HABITAT SITES SELECTION

Completion of the desktop analyses and field reconnaissance provided the information needed for MEC and Tetra Tech to select three sites for assessment of hydrology, hydraulics, and aquatic habitat. A primary consideration was whether one of the three sites should be in a reach with islands. The desktop analyses showed that 84 percent of the channel in Reach 2 of the Blue River from the Dillon Reservoir Dam to Green Mountain Reservoir is single thread, so all three sites were targeted to single thread reaches. It was evident during the reconnaissance that most river users, either for fishing or recreating, were within the river through the Town of Silverthorne. Further, the mitigating influence of major tributaries on impacts to hydrology, sediment trapping, and channel structure was apparent during the reconnaissance downstream from Silverthorne. For these reasons MEC and Tetra Tech selected three sites in the area of highest use upstream of the confluences of major tributaries. The three sites are between the Dillon Reservoir Dam (Location 1) and Willow Grove Open Space (Location 5, Section 2.3.5), and specifically include Location 1 (Section 2.3.1), Location 2 (Section 2.3.2), and Location 5 (Section 2.3.5).

Figure 18. Selected habitat assessment sites

Site 1 is in the reach rehabilitated in 2003 near the Dillon Reservoir Dam outlet. This site was rehabilitated to better mimic natural habitat features and it is now relatively narrow for faster and deeper conditions during low releases from the Dillon Reservoir Dam. The channel contains habitat in pools, runs, and riffles, with occasional large boulders. An appealing aspect of this site was the potential to quantify targeted/reference conditions for overly wide sites downstream that may be candidates for rehabilitation of channel habitat.

Site 2 is in a reach extending about 1,500 feet upstream from the Silverthorne Outlets to the confluence with Straight Creek. This reach appears to be overly wide with numerous constructed boulder weir drop structures that appear to impede upstream fish passage. There are long sections of run habitat downstream from the I-70 Bridge, and there are some moderate gradient riffles upstream from the I-70 Bridge. Flow velocities are moderate to high depending on the habitat type (riffles vs. pools vs. runs) through this site.

Site 3 is located near Willow Grove Open Space, extending approximately 1,000 feet upstream from the Blue River Trail Bridge. This site is wider than Site 1 and slightly narrower than Site 2, with mostly riffle and run habitat. There are some mid-channel trench type pools, but they are small and widely spaced. Some of the riffle habitat extends more than several hundred feet.

In combination, these three sites were selected to quantify hydraulic conditions indicative of habitat quality over the range of ideal to poor aquatic habitat.

2.5 LOCATING HYDRAULIC MODELING CROSS SECTIONS

After selecting the three habitat assessment sites, MEC and Tetra Tech located cross sections for development of geometric inputs to a hydraulic model. The hydraulic model was used to simulate channel hydraulics in response to targeted flows and channel morphology. Thus, the cross sections were located in various habitat types (such as riffles, runs/glides, and pools) and at hydraulic controls. Tetra Tech noted coordinates for the end point of each cross section so a survey crew could return at a later day. Twelve cross sections were located for Site 1, 20 cross sections were located for Site 2, and 13 cross sections were located for Site 3 (Figure 19).

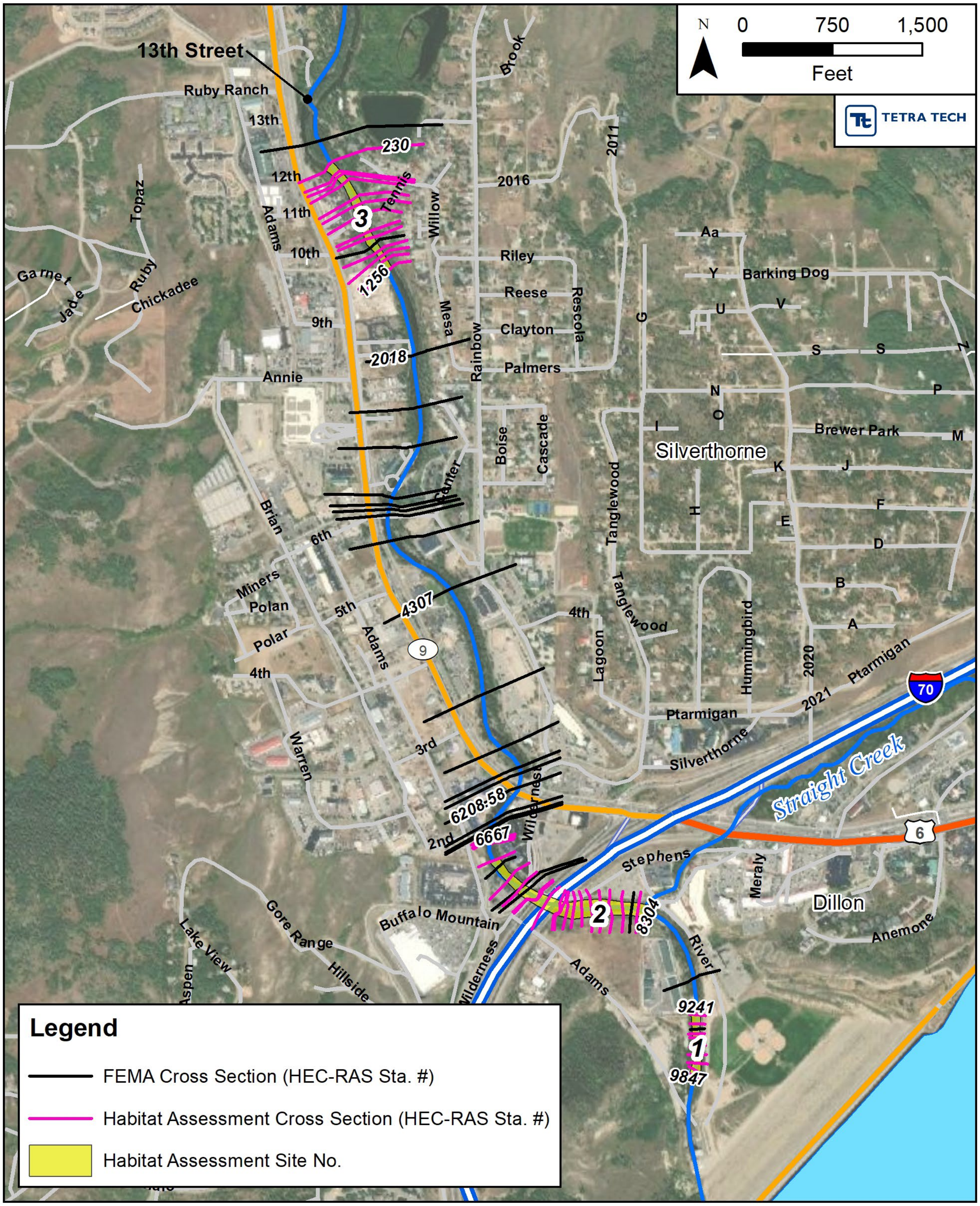

Figure 19. Hydraulic model cross sections

3.0 HYDROLOGIC ANALYSES

The hydrology of Reach 2 of the Blue River reflects Denver Water's regulated releases from Dillon Reservoir as well as the Colorado Water Conservation Board's (CWCB's) appropriated instream flows.

3.1.1 Regulated Releases from the Dillon Reservoir Dam

The outlet works at the Dillon Reservoir Dam consist of a 15-foot-diameter pipe with its inlet on the bottom of the reservoir about 1,800 feet upstream of the outlet, a small power plant, and a morning glory spillway. Construction of the dam was completed in 1963 and the power plant was completed in 1987. The bottom releases can be up to about 4,000 cfs; however, Denver Water aims to limit, when possible, the releases to 1,800 cfs to minimize flooding downstream (Tetra Tech, 2021). The Federal Emergency Management Agency's (FEMA's) Flood Insurance Study (FIS) for Summit County, Colorado, and incorporated areas (including the Town of Silverthorne) provides peak discharges for select annual chance exceedance (ACE) floods (Table 2) (FEMA, 2018).

Table 2. FIS Hydrology for Summit County, CO, and Incorporated Areas (FEMA, 2018)

Location along Blue River	Drainage Area (mi^2)	10% ACE Peak Flow (cfs)	2% ACE Peak Flow (cfs)	1% ACE Peak Flow (cfs)	0.2% ACE Peak Flow (cfs)
D/S Dillon Reservoir Dam	335.0	2,500	3,100	3,350	3,800
U/S Straight Creek	336.1	2,510	3,110	3,360	3,810
D/S Straight Creek	355.8	2,620	3,260	3,520	4,010
U/S Willow Creek	362.7	2,660	3,310	3,625	4,080
D/S Willow Creek	376.6	2,740	3,410	3,700	4,220
U/S Hamilton Creek	380.0	2,760	3,440	3,730	4,260
D/S Hamilton Creek	381.5	2,770	3,450	3,740	4,280
U/S Bushee Creek	383.8	2,780	3,470	3,760	4,300
D/S Bushee Creek	390.3	2,820	3,520	3,810	4,370
U/S Maryland Creek	394.7	2,840	3,550	3,775	4,420

Based on FEMA's peak discharges, the maximum controlled release of 4,000 cfs through the 15-foot-diameter pipe has an ACE less than 0.02 percent (corresponding to a long-term average annual recurrence interval exceeding 500 years), and Denver Water's targeted maximum release of 1,800 cfs has an ACE greater than 10% (corresponding to a long-term average annual recurrence interval of less than 10 years).

Average daily flows recorded at the USGS's gaging station downstream of the Dillon Reservoir Dam (Gage No. 09050700) were reviewed to evaluate the influence of power plant operations. The flow records were compiled starting after construction of the dam (1963) and after completion of the power plant (1987). Daily average flows indicated the power plant operations increase releases from January through April and decrease releases from mid-June through September (Figure 20). These differences constrained analyses of hydrology to water year 1988 and later based on the assumption that future releases will be best represented by historical releases reflecting recent operation of the power plant.

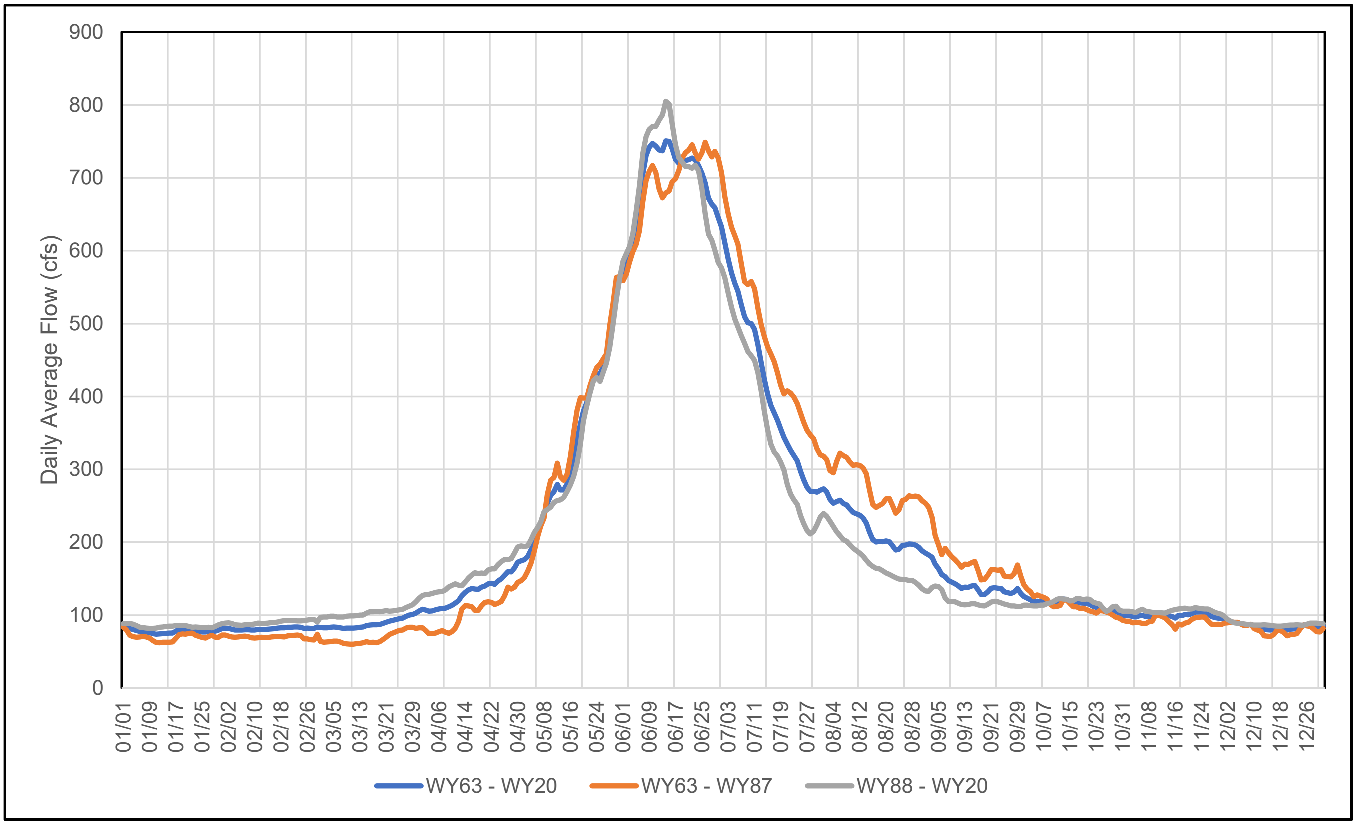

Figure 20. Daily average flows for selected periods following construction of the Dillon Reservoir Dam (1963) and the power plant (1987)

3.1.2 Instream Flows

In 1973 the Colorado General Assembly passed Senate Bill 97, vesting the CWCB with the authority, on behalf of the people of the state of Colorado, to appropriate or acquire such waters of natural streams and lakes. Colorado's Instream Flow (ISF) Act of 1973 authorized the CWCB to balance needs for water in streams and lakes to preserve the natural environment in sufficient quantity against the many diversions and uses of water for all other purposes (Bassi, 2019). Senate Bill 97 provided the means for Colorado to balance the environmental benefits that come from maintaining water in a stream with the State's long-established framework for diverting water rights within the confines of the prior appropriation system (Bassi, 2019). ISF water rights are in-channel appropriations of water for specified flow rates between two points on a stream.

According to the Instream Flow Water Rights Database (CWCB, 2021), Case No. 87CW0293 established a new appropriation in October 1987 for a minimum, year-round ISF of 50 cfs in the Blue River from the outlet of Dillon Reservoir to the confluence with Straight Creek (approximately 0.4 miles of the Blue River). Case No. 87CW0294 established a new appropriation in October 1987 for variable minimum ISFs in the Blue River from the confluence with Straight Creek to the confluence with Willow Creek (approximately 2 miles of the Blue

River). From October 1 through April 30, the ISF is 50 cfs, from May 1 through July 31 the ISF increases to 55 cfs, and from August 1 through September 30 the ISF is 52 cfs. Reviewing the USGS gaging station records starting in water year 1988 aligns with the CWCB's establishment of ISFs on the Blue River and corresponds with the Dillon Reservoir Dam power plant commencing operation.

3.1.3 Representative Hydrographs

The USGS reports daily average flows on the Blue River at the Dillon Reservoir Dam outlet (Gage No. 09050700) and on Straight Creek about 2 miles upstream of the Blue River confluence (Gage No. 09051050). Both gages have records back to the start of water year 1988, so flows on each day of the year were compiled between water years 1988 and 2021 (34 years). The Blue River gage was used to represent the hydrology of Site 1, and the summed gaging records were used to represent the hydrology of Sites 2 and 3. Exceedance hydrographs were developed, representing how often the flows have been exceeded in the recent past. For example, the 10 percent exceedance hydrograph presents the flows on each day of the year that were equaled or exceeded in 10 percent of the years evaluated. Thus, Figure 21 shows that in mid-June for 10 percent of the years between 1988 and 2021 (3.4 years) the combined flows for the Blue River and Straight Creek exceeded approximately 1,500 to 1,700 cfs. Likewise, the combined flows for both gages exceeded approximately 80 to 120 cfs in mid-June for 90 percent of the years between 1988 and 2021.

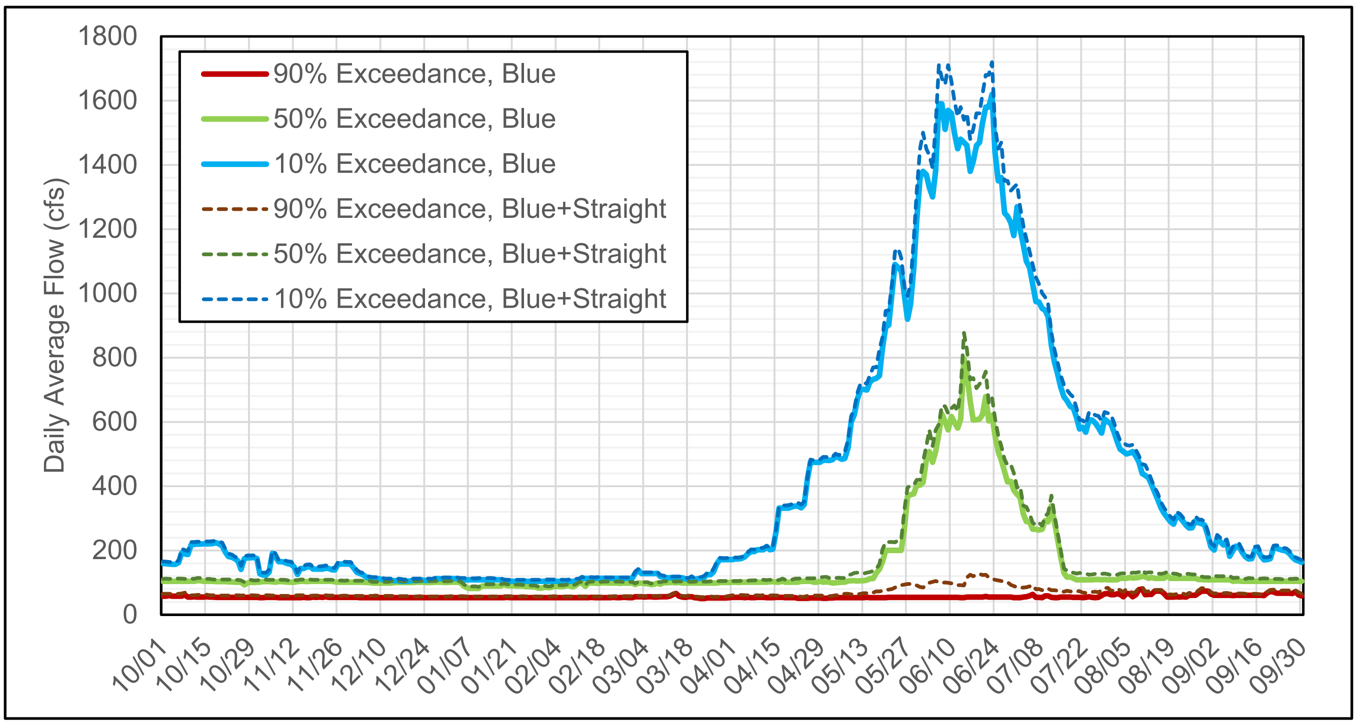

Figure 21. Representative exceedance hydrographs from water years 1988 to 2021

The gage data used for development of Figure 21 show that Denver Water's targeted maximum release of 1,800 cfs was met in 32 of 34 years between water years 1988 and 2021; the two times this targeted maximum was exceeded, the releases were 1,920 cfs (water year 1995) and 1,900 cfs (water year 2019). These analyses also show that CWCB's ISF minimums were met in 32 of the 34 years with the two minor deviations being water year 1989 with a minimum daily average flow of 38 cfs and water year 2005 with a minimum daily average flow of 46 cfs.

3.1.4 Flow Duration Analyses

The USGS's records provide a means for evaluating the amount of time certain flows are exceeded using flow duration curves. Daily average flows for water years 1988 through 2021 were compiled and ranked to plot the annual flow duration curve (Figure 22).

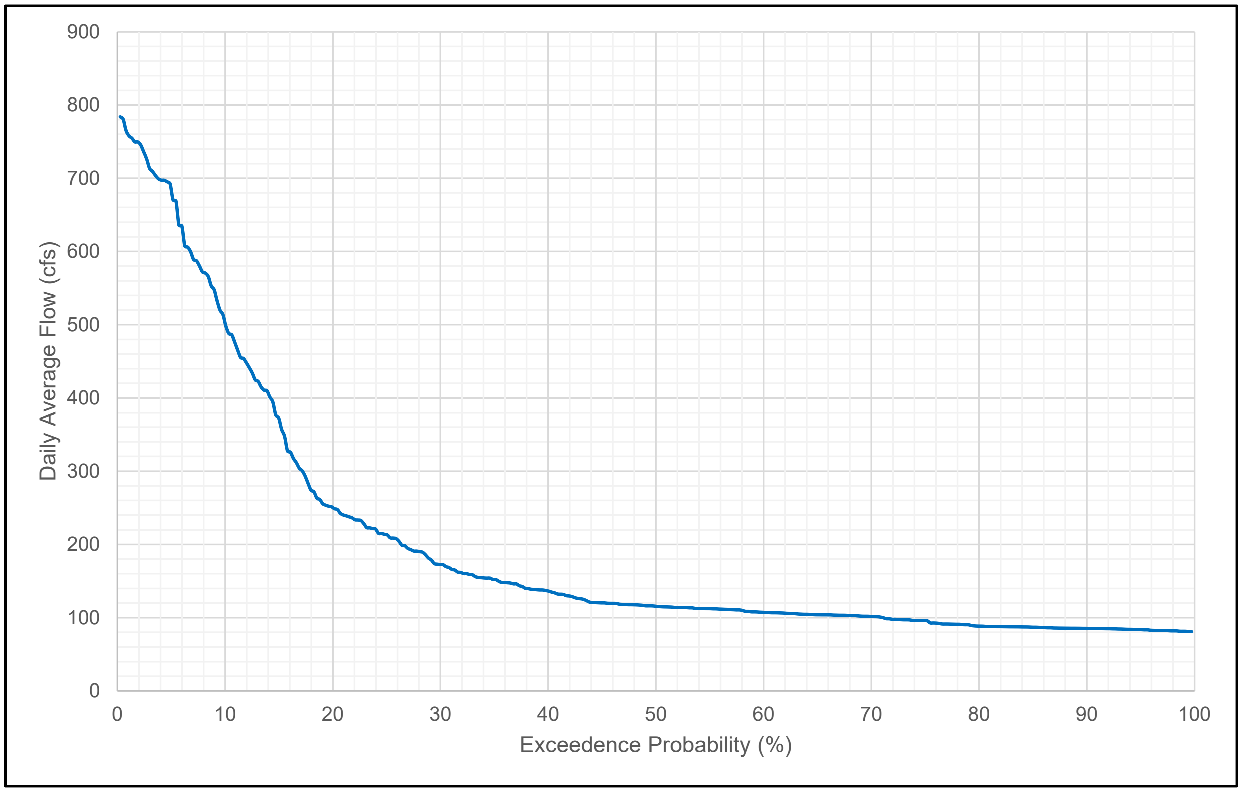

Figure 22. Blue River (USGS 09050700) annual flow duration for water years 1988 through 2021

The annual flow duration curve shows that approximately 10 percent of each year (about 5 weeks) daily average flows exceed about 500 cfs, that about 50 percent of each year daily average flows exceed 120 cfs, and that daily average flows are between about 80 and 120 cfs for 50 percent of each year. The months with the lowest daily average flows are December, January, and February, when flows are between 80 and 100 cfs (Figure 23). The lowest daily average flows occur in January.

March, October, and November experience similar ranges of daily average flows between about 95 and 125 cfs (Figure 24). Daily average flows in October are generally about 10 percent greater than daily average flows in March and November.

Daily average flows on the shoulders of the freshet are still typically modest, with maximums under about 250 cfs (Figure 25).

Daily average flows during the freshet are greatest, with June typically experiencing the peak flows that are notably greater than maximum daily average flows in May and July (Figure 26). While May and July can reach daily average flows of around 550 cfs, May's peak daily average flows top out just shy of 800 cfs.

To facilitate comparisons, Figure 27 presents the monthly flow duration curves on the same plot as the annual flow duration curve.

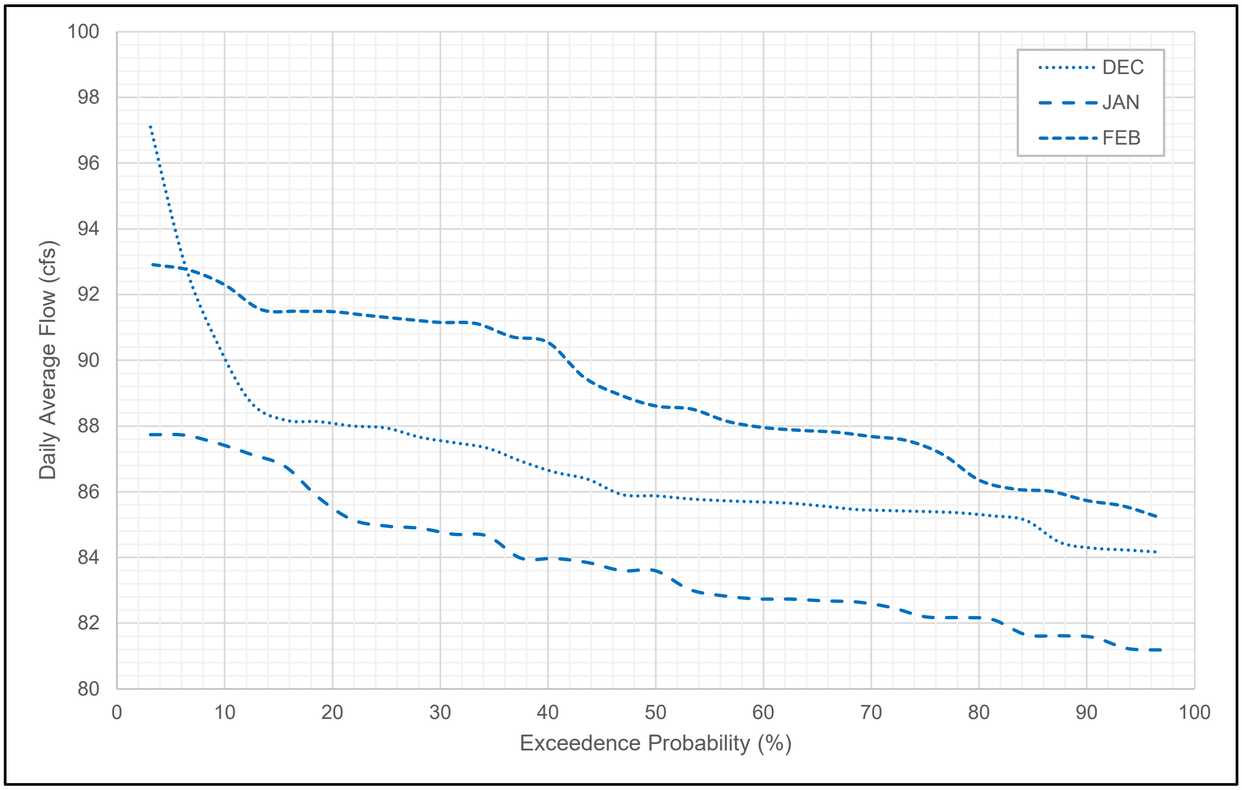

Figure 23. Blue River (USGS 09050700) monthly flow duration curves for water years 1988 through 2021

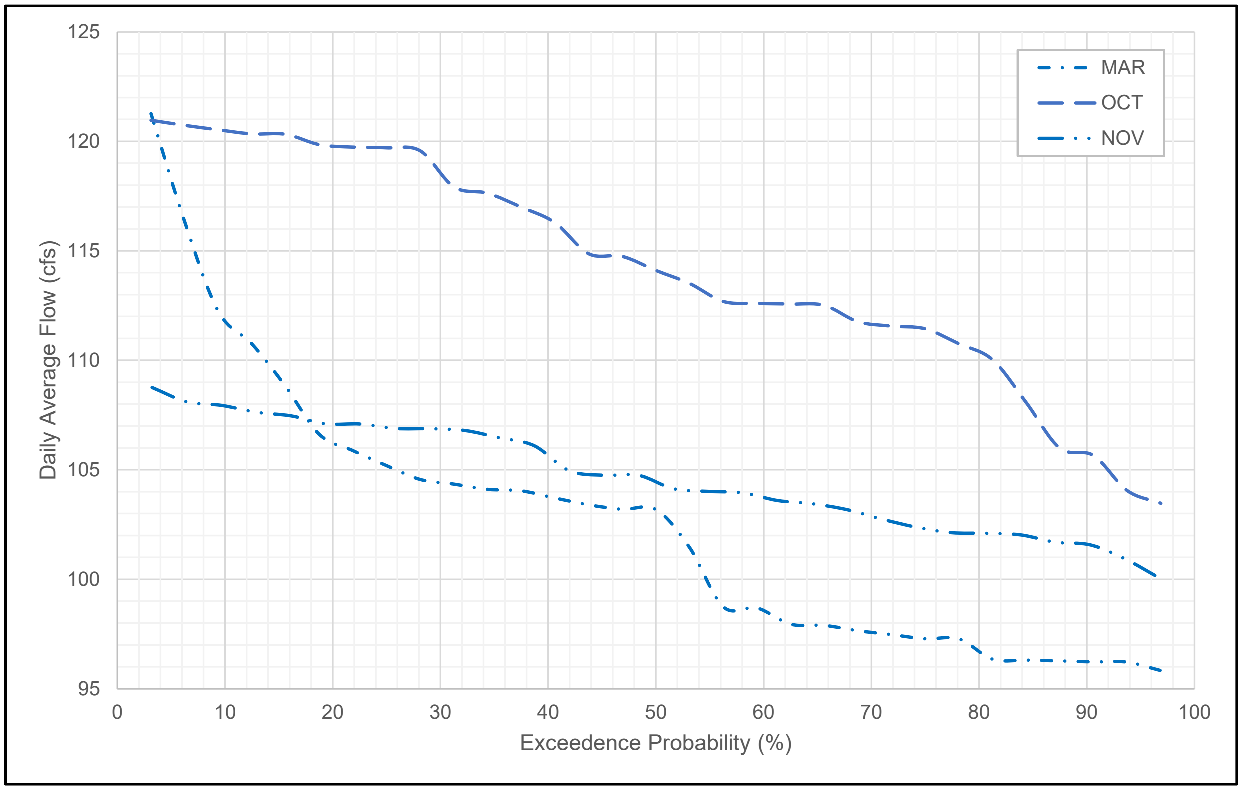

Figure 24. Blue River (USGS 09050700) monthly flow duration curves for water years 1988 through 2021

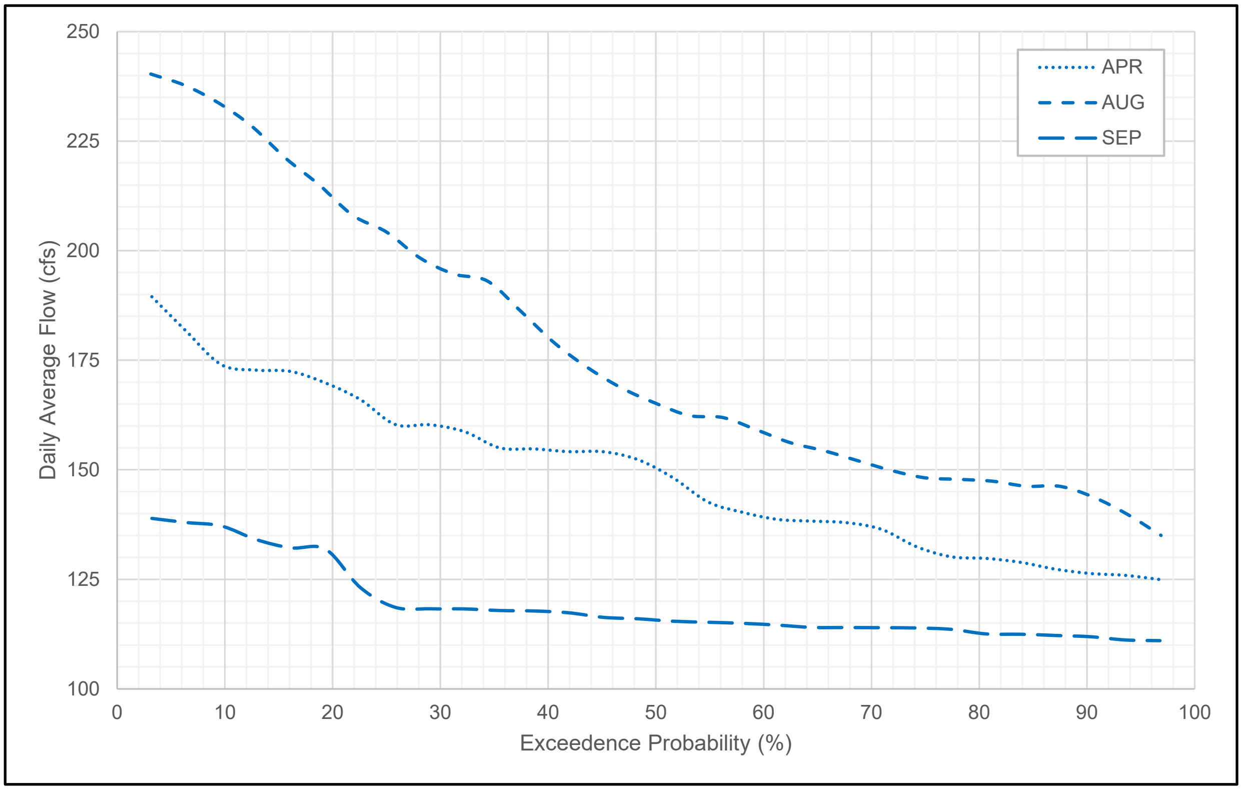

Figure 25. Blue River (USGS 09050700) monthly flow duration curves for water years 1988 through 2021

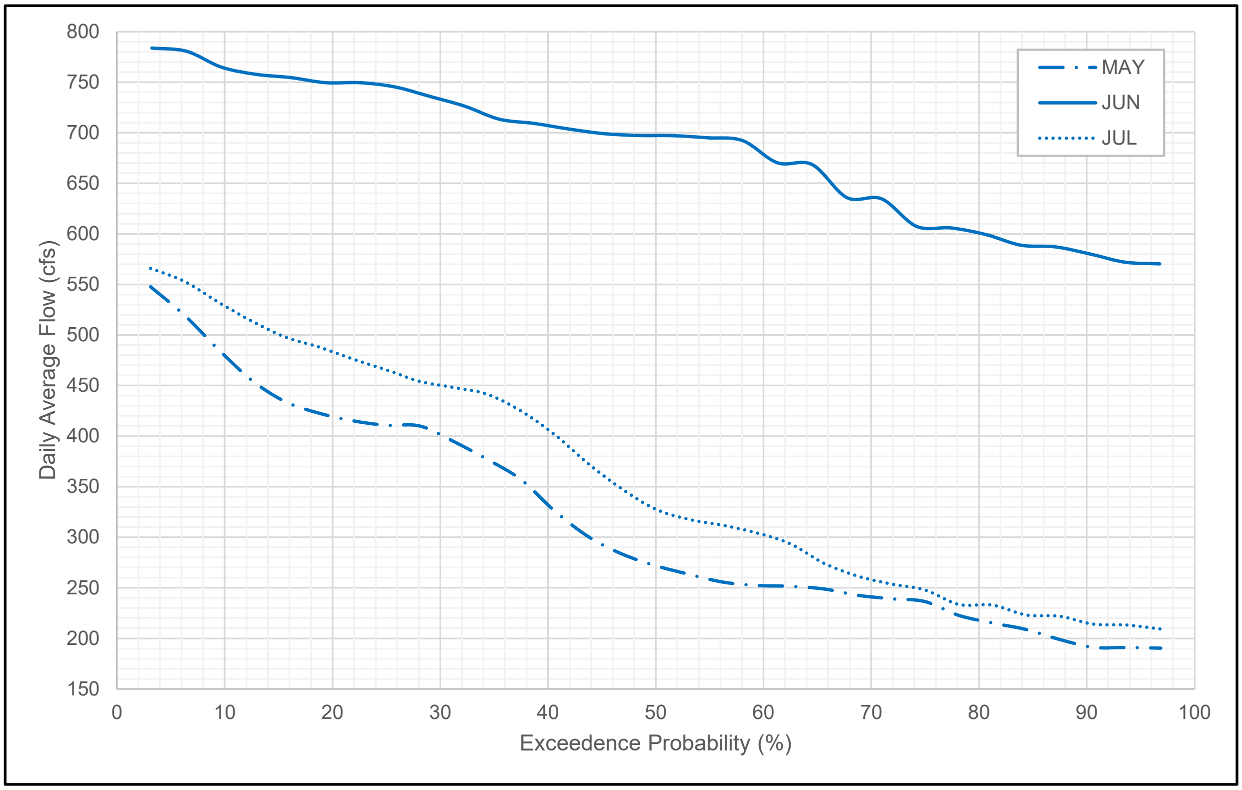

Figure 26. Blue River (USGS 09050700) monthly flow duration curves for water years 1988 through 2021

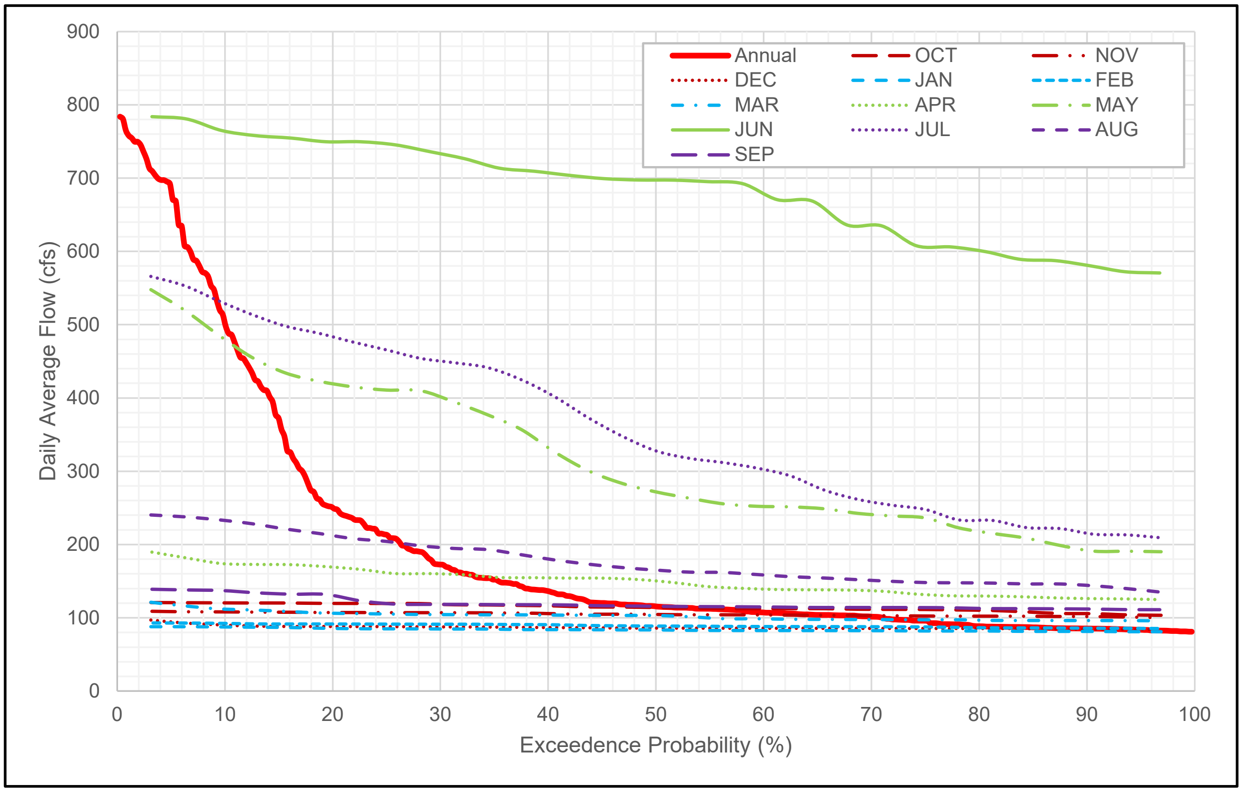

Figure 27. Comparison of annual and monthly flow duration curves

3.1.5 Flows Selected for Habitat Assessment

The hydrologic analyses informed selection of flows for use in the habitat assessment (Table 3). Ten flows were selected, ranging from 50 cfs to 1,000 cfs. The minimum appropriated ISF is 50 cfs, so it was selected as the lower limit of flows to be evaluated. The flow duration analyses show that the lowest average daily average flow from water year 1988 to 2021 is about 80 cfs. Over the winter months (November through March, inclusive), the average daily average flow from water year 1988 to 2021 is about 100 cfs. A flow of 200 cfs is anecdotally noted as approximately filling the channel width in the widest reaches of the Blue River between the Dillon Reservoir Dam and the Willow Creek confluence. A flow of 400 cfs is anecdotally reported as the maximum wadeable flow for fishing and the minimum flow for float boating. The optimum flow for kayaking being 1,000 cfs (Sanderson, 2012). Based on the average of daily average flows between water years 1988 and 2021, a flow of 500 cfs is exceeded about 10 percent of the year. Several additional intermediate flows were identified to better represent hydraulic rating curves between these selected flows.

Table 3. Flows selected for habitat assessment

Selected Flow (cfs)	Rationale for Selection
50	Minimum appropriated ISF between Dillon Res. Dam and Willow Creek confluence
80	Lowest average daily average flow
100	Average daily average flow during winter months (Nov. – Mar., inclusive)
150	Intermediate flow between 100 and 200 cfs
200	Anecdotally fills channel in widest reaches upstream of Willow Creek confluence
300	Intermediate flow between 200 and 400 cfs
400	Anecdotal maximum wadeable flow and minimum float boating flow
500	10 percent exceedance based on average of daily average flows WY88-WY21
600	Intermediate flow between 400 cfs and 1,000 cfs
1,000	Optimum flow for kayaking (Sanderson, 2012)

4.0 HYDRAULIC ANALYSES

Tetra Tech developed a 1D hydraulic model to simulate hydraulic conditions in the channel through the three habitat assessment sites. Tetra Tech developed the model using version 6.0.0 of the U.S. Army Corps of Engineers River Analysis System software (HEC-RAS) (HEC U. , 2021). Details of the model development and calibration are provided in Appendix A.

The hydraulic model was used to simulate relationships between channel hydraulics and flow. Channel hydraulics of specific interest for the habitat assessment are (1) wetted perimeter of the channel, (2) channel hydraulic depth, and (3) channel maximum depth. Tetra Tech extracted these hydraulic rating curves and provided the results to MEC to process by habitat type.

5.0 HABITAT ASSESSMENT

The habitat assessment included a habitat inventory as well as an assessment of hydraulics, both of which were completed through the three habitat assessment sites.

5.1 HABITAT INVENTORY

MEC led the habitat inventory on September 29, 2021, at the three assessment sites. Daily average flow in the Blue River between the Dillon Reservoir Dam and Straight Creek was 103 cfs; it was 108 cfs downstream of Straight Creek. The habitat inventory used a quantitative protocol the U. S. Forest Service developed (Winters, 1997). The methodology measures the area of each habitat type at each site and the average depth of the habitat type, and the methodology uses visual estimates for cover and stream substrate. The quantitative approach provides a means to compare habitat across sites.

5.1.1 Methods

MEC measured the length and width of each individual habitat using a laser range finder accurate to 0.5 feet with a maximum range of 900 feet. Stream depth was measured using a standard stadia rod marked in 0.01-foot increments. The data for each habitat was recorded on a field data form and later transferred to a Microsoft Excel spreadsheet for analysis. The spreadsheet facilitated calculations of the habitat quantities and preparation of graphs for each study site. The output for each of the three sites was summarized into tables for comparison. Full results of the habitat inventory are presented in Appendix B.

Run habitat (synonymous with “Glide” in some classification systems) is the transition between low velocity pool habitat and the fast velocity riffle habitat. Run habitat is generally uniform in depth with very little water-surface disturbance from fast velocity and shallow depth. Run habitat can have a range of substrate types depending on geomorphic association. Fish can use run habitat as feeding locations for emerging or drifting invertebrates. In this assessment, run and glide are used interchangeably.

5.1.2 Results

Figure 28, Figure 29, and Figure 30 Illustrate the conditions during the habitat inventory. Results of the habitat inventory are presented in Table 4 and Table 5. Pie charts illustrate the distribution of habitat and cover types in each of the three sites (Figure 31 through Figure 36).

Figure 28. Habitat assessment Site 1 facing upstream during habitat inventory

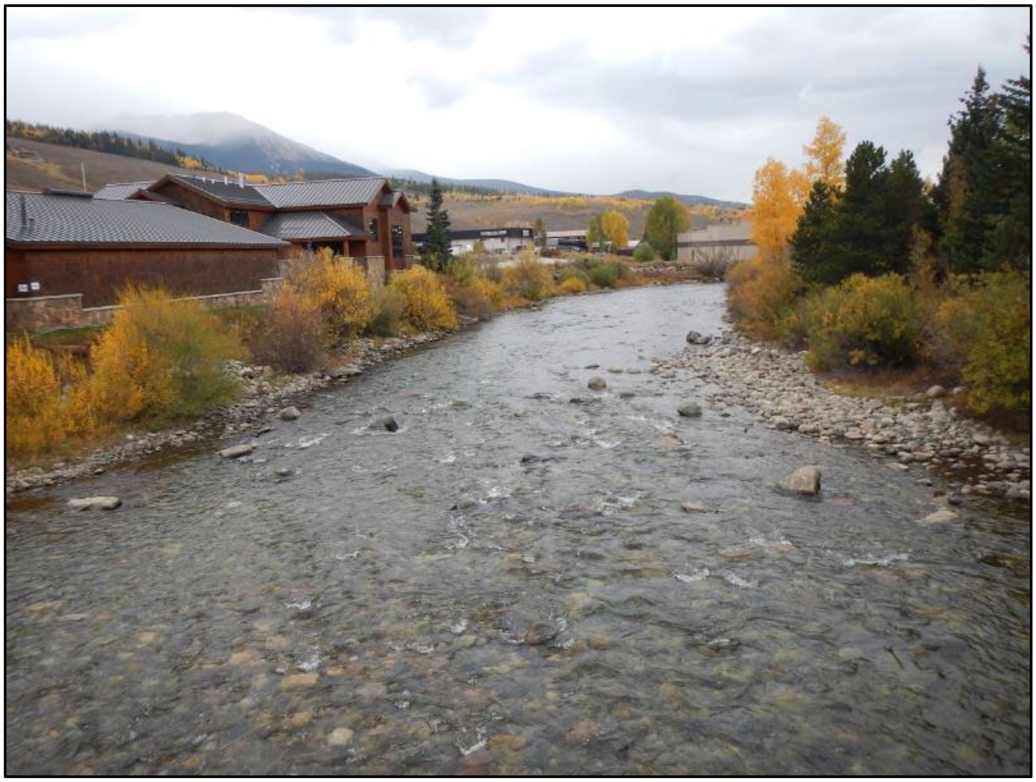

Figure 29. Habitat assessment Site 2 facing downstream during habitat inventory

Figure 30. Habitat assessment Site 3 facing upstream during habitat inventory

Table 4. Results of Habitat Inventory

Parameter	Habitat Type	Site 1	Site 2	Site 3
Length (feet)	Total	726	1,726	1,011
	Pool	50	145	0
	Riffle	340	948	452
	Glide	335	633	559
Percent of Total Length	Pool	6.9	8.4	0
	Riffle	46.9	54.9	44.7
	Glide	46.2	36.7	55.3
Average Depth (feet)	Pool	2.0	1.7	0
	Riffle	1.1	0.7	0.7
	Glide	1.2	0.9	1.1
Average Width (feet)	Pool	42.0	69.5	0
	Riffle	38.7	65.6	58.7
	Glide	49.5	66.8	74.3
Residual Pool Average Depth (feet)	n/a	2.4	1.9	0

Table 5. Percentages of substrate type by habitat assessment sites

Site	Habitat Type	Sand/Silt	Gravel	Cobble	Boulder	Bedrock
1	Pool	0	0	25	75	0
	Riffle	0	0	33	67	0
	Glide	0	0	38	63	0
	Overall Reach	0	0	32	68	0
2	Pool	0	0	63	38	0
	Riffle	0	11	50	39	0
	Glide	0	19	44	38	0
	Overall Reach	0	10	52	38	0
3	Pool	0	0	50	50	0
	Riffle	0	0	50	50	0
	Glide	0	0	58	42	0
	Overall Reach	0	0	53	47	0

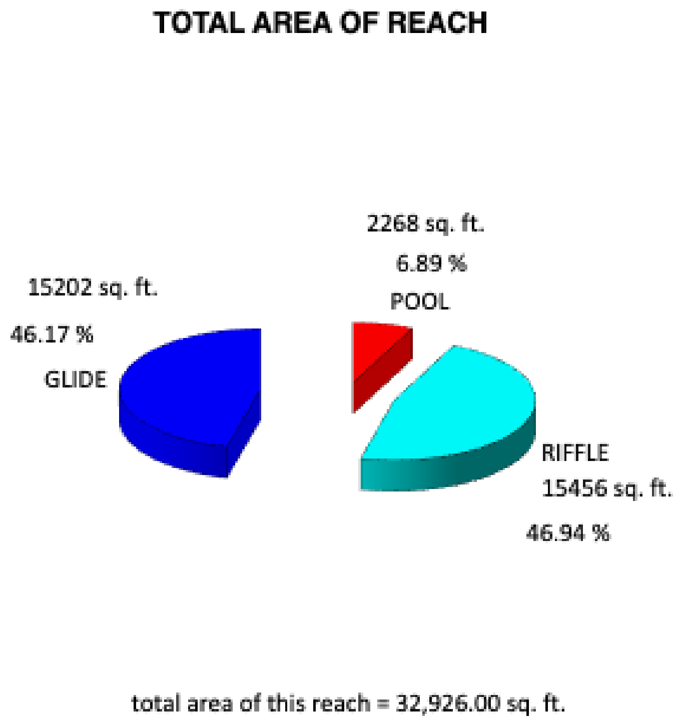

Figure 31. Habitat assessment Site 1 habitat areas by habitat type

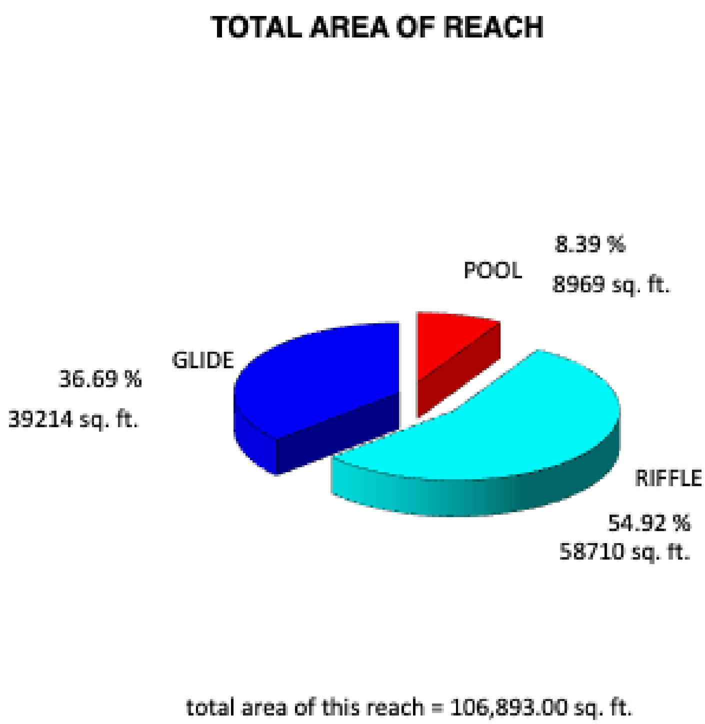

Figure 32. Habitat assessment Site 2 habitat areas by habitat type

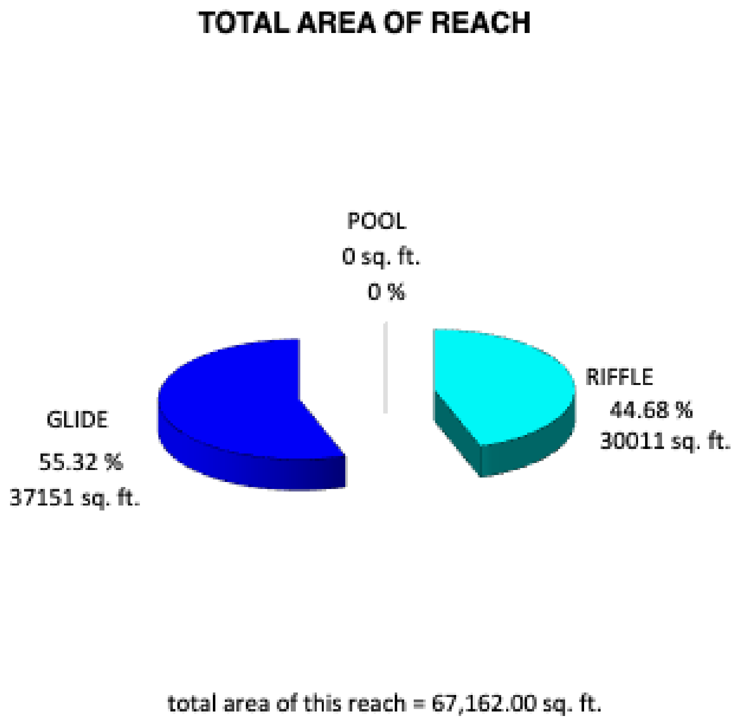

Figure 33. Habitat assessment Site 3, habitat areas by habitat type

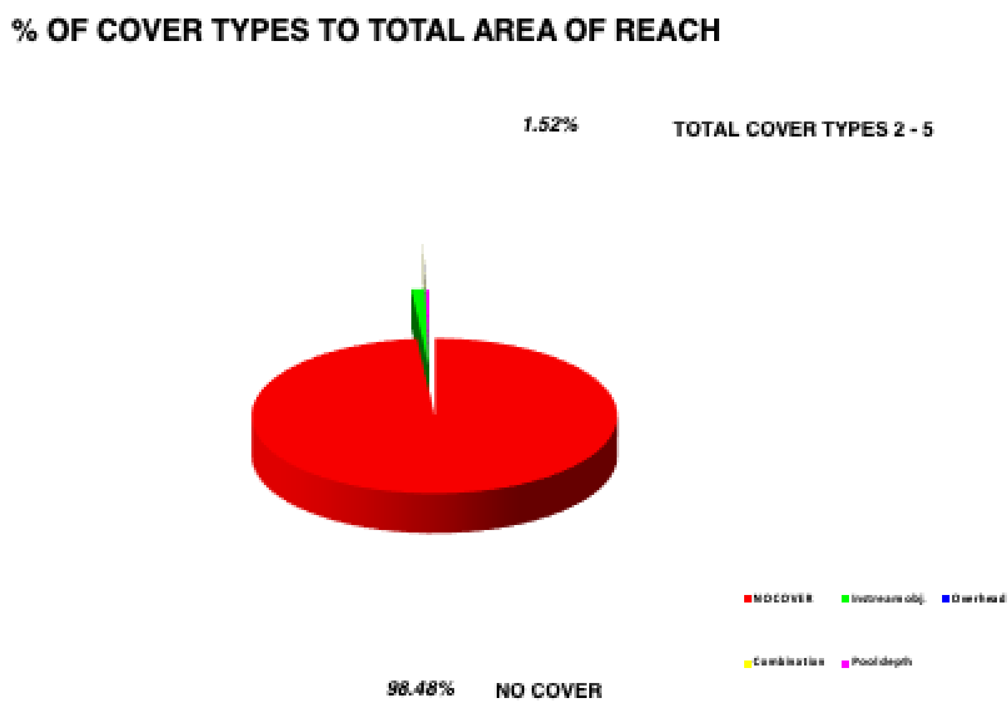

Figure 34. Habitat assessment Site 1, percent cover by cover type

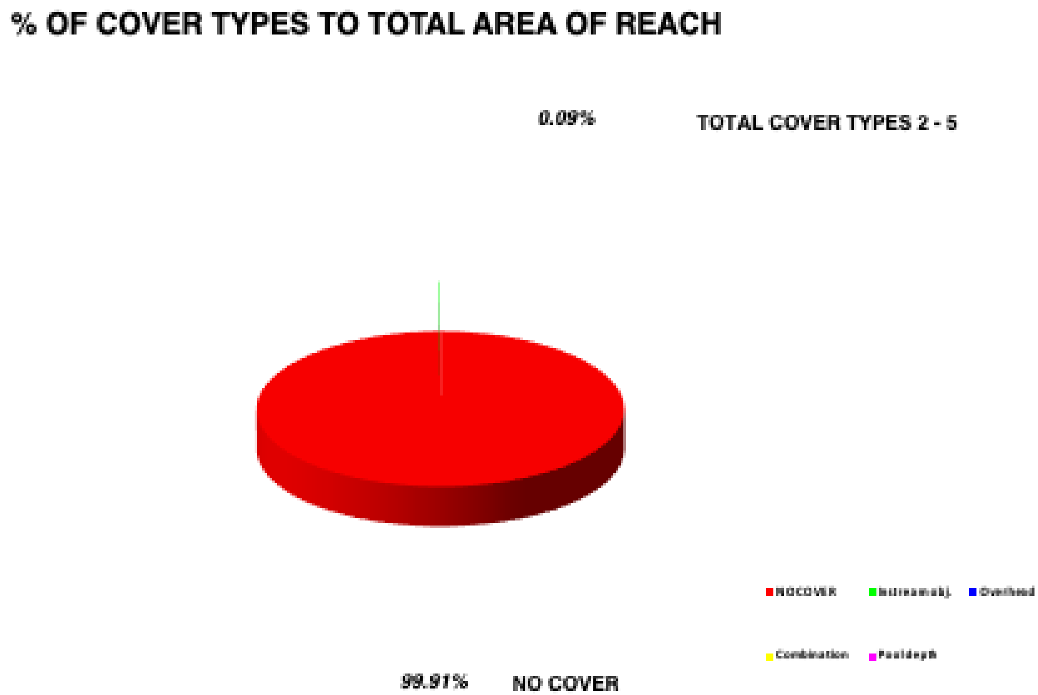

Figure 35. Habitat assessment Site 2, percent cover by cover type

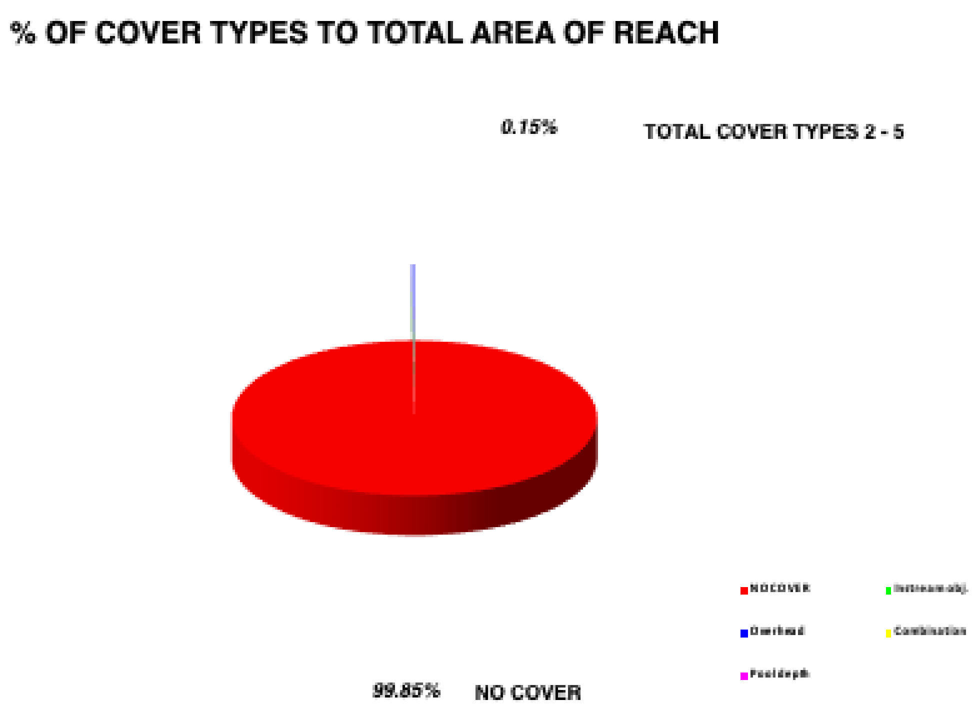

Figure 36. Habitat assessment Site 3, percent cover by cover type

5.1.2.1 Site 1

Site 1 has been rehabilitated to mimic a natural channel with a mixture of riffles, glides, and pools (Table 4). Stream substrate was dominated by cobbles and boulders (Table 5). Habitat area for glides and riffles was almost equal at approximately 46 percent of the total area, with pool habitat area making up the remaining 7 percent (Figure 31). Average channel width ranged from 38.7 feet for riffles to 49.5 feet for glides (Table 4). Residual pool depth (depth at near zero flow) was 2.4 feet (Table 4).

5.1.2.2 Site 2

The floodplain, where present along Site 2, was confined and the channel contained several instream drop structures (Figure 29). The drop structures include both partial- and full-channel width structures. The full-width drop structures do not include any fish passage channels and require upstream migrating fish to either jump over the drop or dart upstream at the low points between the large boulders. Stream velocity measured at several of these low points ranged from over 4 feet per second to over 6 feet per second. These velocities exceed the swimming speeds of small trout and the small nongame species in the river. Adult trout burst or darting speeds may allow some of the large fish to move upstream past the drop structures; however, the drops are likely impediments to upstream migration and passage.

Stream substrate was dominated by cobbles and boulders (Table 5). Habitat area for glides was approximately 37 percent, approximately 55 percent for riffles, and approximately 8 percent for pools (Table 4 and Figure 32). Average channel width ranged from 65.6 feet for riffles to 69.5 feet for pools (Table 4). Residual pool depth was 1.9 feet (Table 4).

5.1.2.3 Site 3

Site 3 had a less confined floodplain than Site 2 with some areas of floodplain connectivity (Figure 30). No constructed drop structures were in Site 3. The stream substrate was dominated by cobble and boulder (Table 5). Habitat area for glides was approximately 55 percent, riffle area was approximately 45 percent, and no pools were identified at the flow of 88 cfs during the inventory (Table 4 and Figure 33). Some of the glide habitat may become pool habitat at higher flows. Average channel width ranged from 58.7 feet for riffles to 74.3 feet for glides (Table 4).

5.1.2.4 Summary

The habitat inventory shows that the upstream reach at Site 1 is the narrowest, most naturally appearing channel, with hydraulic conditions during low flows most conducive to appropriate aquatic habitat for all aquatic species including trout. Site 1 has several deep pools for refuge habitat at low flows. Site 1 also does not have any impediments to fish movement. Site 2 is the widest of the three sites, especially for glide habitat. The stream width is controlled by the full channel width drop structures. These structures provide grade control, which reduces flow depth upstream of the structure and present impediments to upstream fish movement. The existing partial channel width, offset grade control structures function to control stream gradient and allow unimpeded fish movement. The impeded fish movement, especially by small trout and nongame species, may be a factor that controls fish populations in the Blue River in the reach through the Town of Silverthorne.

Stream substrate is dominated by cobbles and boulders with very little areas with gravels (Table 5). Clean, fine-sediment-free-gravel ranging in size from 0.5 to 1.0 inch is needed for successful trout spawning. The lack of this size gravel reduces the potential trout spawning habitat in the reach downstream from the Dillon Reservoir Dam until there is sufficient sediment input from either stream bank migration or tributaries.

5.2 HYDRAULC HABITAT ASSESSMENT

Building on the habitat inventory, the results of the hydraulic modeling were categorized by habitat type and used to calculate changes in several hydraulic habitat parameters as a function of discharge. These hydraulic parameters, calculated at all cross sections in the three habitat assessment sites, are channel wetted perimeter, channel average (hydraulic) depth, and maximum channel depth.

5.2.1 Results

The cross sections were aggregated by major habitat type (i.e., pool, riffle, and run/glide) and the average for each parameter was calculated for each site (Table 6 through Table 8). The average for each parameter as a function of discharge was graphed as a rating curve by habitat type to compare the hydraulic habitat characteristics between sites. Pool habitat rating curves are shown in Figure 37 through Figure 39, riffle habitat rating curves are shown in Figure 40 through Figure 42, and run habitat rating curves are shown in Figure 43 through Figure 45.

Table 6. Hydraulic habitat parameter averages (feet) for pool habitat type by flow (cfs)

Parameter[1]	50	80	100	150	200	300	400	500	600	1000
Site 1 Chnl. W.P.	34.0	39.5	42.4	49.4	53.9	59.9	60.0	60.0	60.0	60.0
Site 2 Chnl. W.P.	91.8	103.6	106.3	110.5	113.2	114.4	114.4	114.4	114.4	114.4
Site 3 Chnl. W.P.	60.3	63.2	64.6	67.2	67.9	67.9	67.9	67.9	67.9	67.9
Site 1 Chnl. h_d	1.2	1.3	1.4	1.6	1.7	2.0	2.3	2.6	2.9	3.7
Site 2 Chnl. h_d	0.8	0.9	1.0	1.2	1.4	1.7	2.0	2.2	2.4	3.2
Site 3 Chnl. h_d	1.0	1.1	1.2	1.4	1.6	1.8	2.1	2.4	2.6	3.4
Site 1 Chnl. h_{max}	2.1	2.4	2.6	3.0	3.3	3.7	4.1	4.3	4.6	5.5
Site 2 Chnl. h_{max}	1.8	2.0	2.1	2.4	2.5	2.9	3.2	3.4	3.6	4.4
Site 3 Chnl. h_{max}	1.3	1.5	1.6	1.9	2.1	2.4	2.7	2.9	3.1	3.7

Note:
[1] Chnl. W.P. = channel wetted perimeter; Chnl. h_d = channel average (hydraulic) depth; Chnl. h_{max} = channel maximum depth

Table 7. Hydraulic habitat parameter averages (feet) for riffle habitat type by flow (cfs)

Parameter[1]	50	80	100	150	200	300	400	500	600	1000
Site 1 Chnl. W.P.	36.6	47.1	52.3	60.9	65.4	68.3	68.3	68.3	68.3	68.3
Site 2 Chnl. W.P.	53.6	59.8	62.7	67.6	70.5	72.7	75.2	76.7	77.1	77.3
Site 3 Chnl. W.P.	57.6	63.5	64.9	67.6	68.9	69.0	69.0	69.0	69.0	69.0
Site 1 Chnl. h_d	1.0	1.0	1.1	1.3	1.4	1.8	2.2	2.5	2.7	3.6
Site 2 Chnl. h_d	0.7	0.9	0.9	1.1	1.3	1.6	1.9	2.1	2.3	3.1
Site 3 Chnl. h_d	0.6	0.8	0.9	1.1	1.3	1.7	2.0	2.2	2.5	3.3
Site 1 Chnl. h_{max}	1.6	1.9	2.0	2.4	2.7	3.1	3.4	3.7	4.0	4.9
Site 2 Chnl. h_{max}	1.2	1.4	1.6	1.9	2.1	2.5	2.8	3.0	3.2	4.0
Site 3 Chnl. h_{max}	1.0	1.2	1.4	1.6	1.8	2.2	2.5	2.8	3.0	3.8

Note:
[1] Chnl. W.P. = channel wetted perimeter; Chnl. h_d = channel average (hydraulic) depth; Chnl. h_{max} = channel maximum depth

Table 8. Hydraulic habitat parameter averages (feet) for glide habitat type by flow (cfs)

Parameter[1]	50	80	100	150	200	300	400	500	600	1000
Site 1 Chnl. W.P.	41.4	46.8	50.0	57.8	62.9	69.5	70.6	70.7	70.7	70.7
Site 2 Chnl. W.P.	61.3	71.1	73.8	78.3	80.2	82.0	82.3	82.5	82.7	83.0
Site 3 Chnl. W.P.	64.1	66.9	68.3	69.7	70.2	70.9	71.5	71.9	71.9	71.9
Site 1 Chnl. h_d	0.8	1.0	1.1	1.2	1.4	1.7	2.0	2.2	2.5	3.4
Site 2 Chnl. h_d	0.9	1.0	1.2	1.4	1.6	1.9	2.2	2.4	2.7	3.4
Site 3 Chnl. h_d	1.0	1.2	1.3	1.5	1.7	2.0	2.3	2.5	2.8	3.5
Site 1 Chnl. h_{max}	1.4	1.7	1.8	2.2	2.4	2.8	3.2	3.5	3.7	4.6
Site 2 Chnl. h_{max}	1.5	1.8	2.0	2.2	2.5	2.8	3.1	3.4	3.6	4.3
Site 3 Chnl. h_{max}	1.4	1.6	1.7	2.0	2.2	2.5	2.8	3.1	3.3	4.0

Note:
[1] Chnl. W.P. = channel wetted perimeter; Chnl. h_d = channel average (hydraulic) depth; Chnl. h_{max} = channel maximum depth

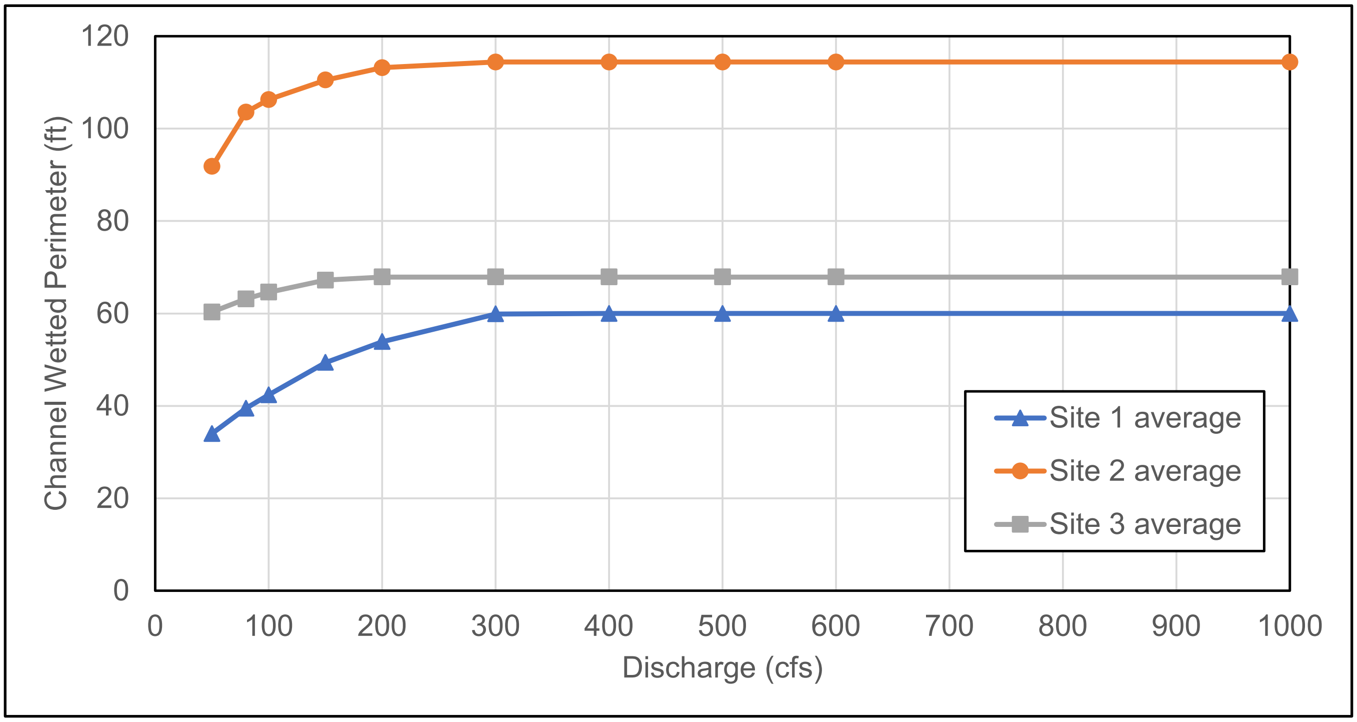

Figure 37. Pool habitat type rating curve for channel wetted perimeter

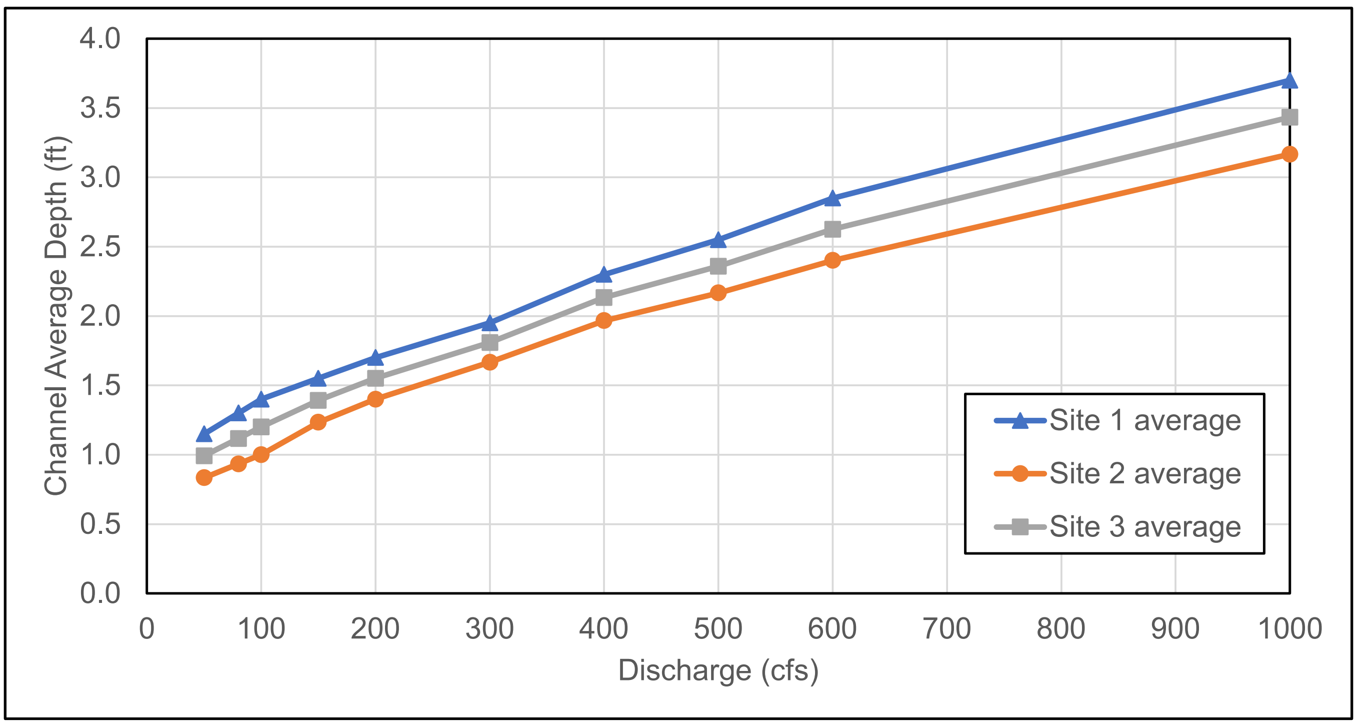

Figure 38. Pool habitat type rating curve for channel average (hydraulic) depth

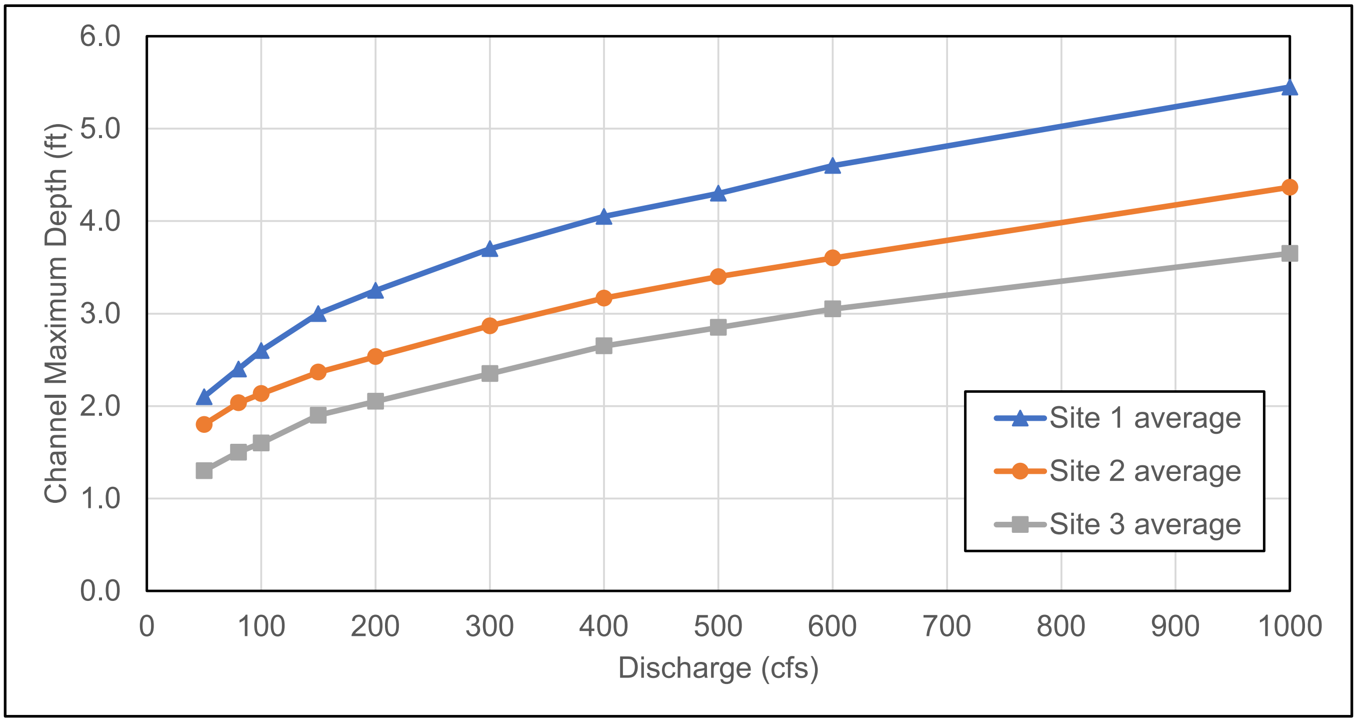

Figure 39. Pool habitat type rating curve for channel maximum depth

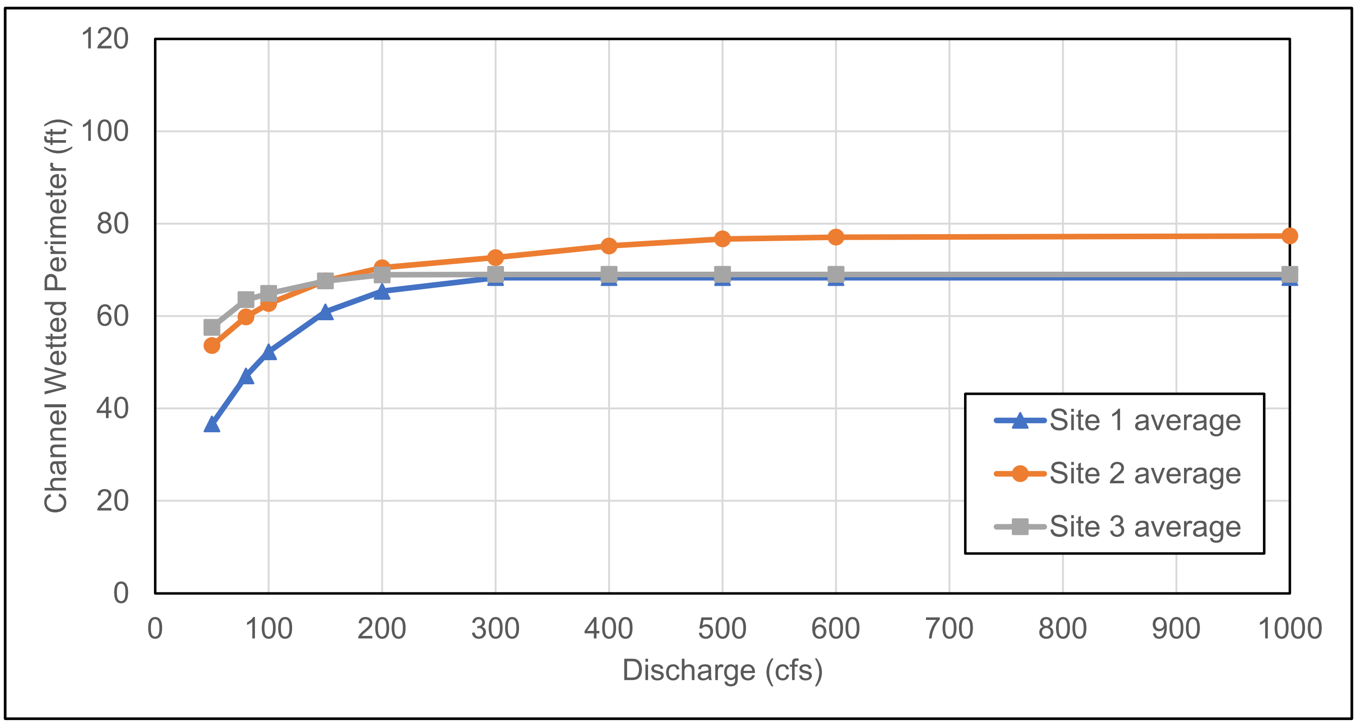

Figure 40. Riffle habitat type rating curve for channel wetted perimeter

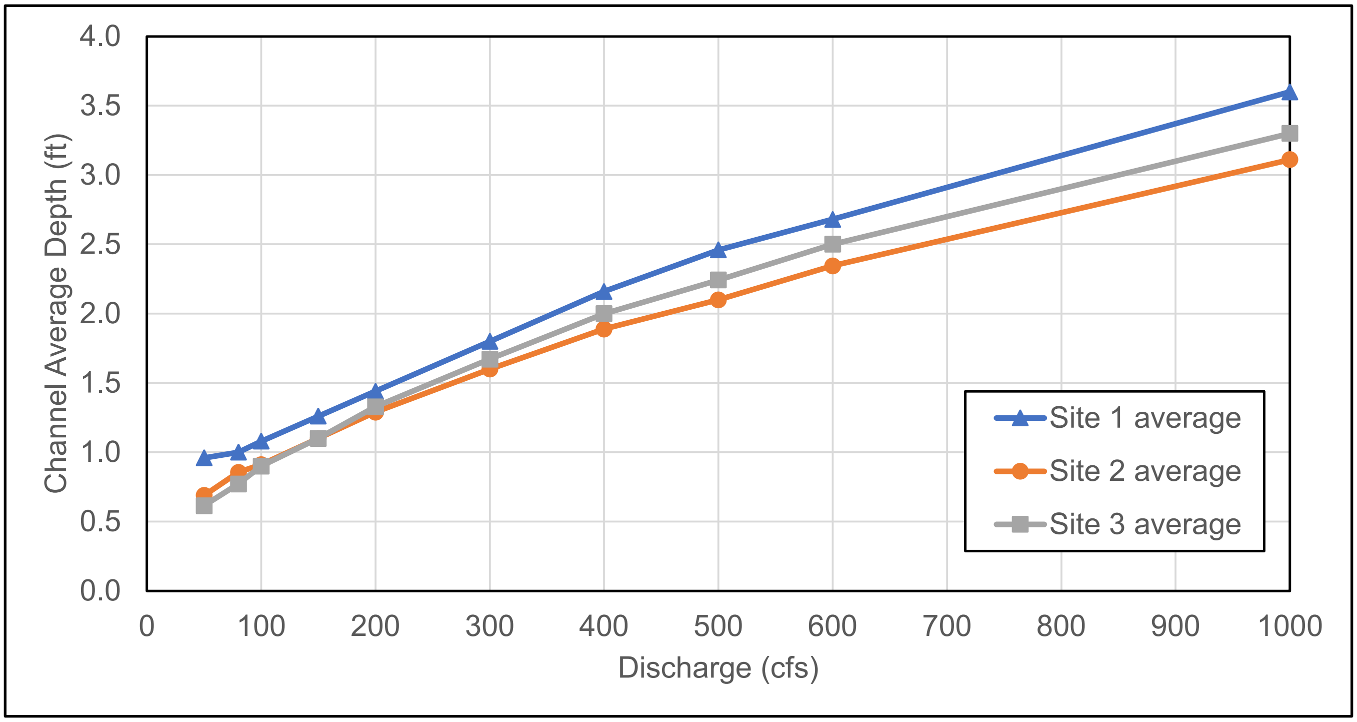

Figure 41. Riffle habitat type rating curve for channel average (hydraulic) depth

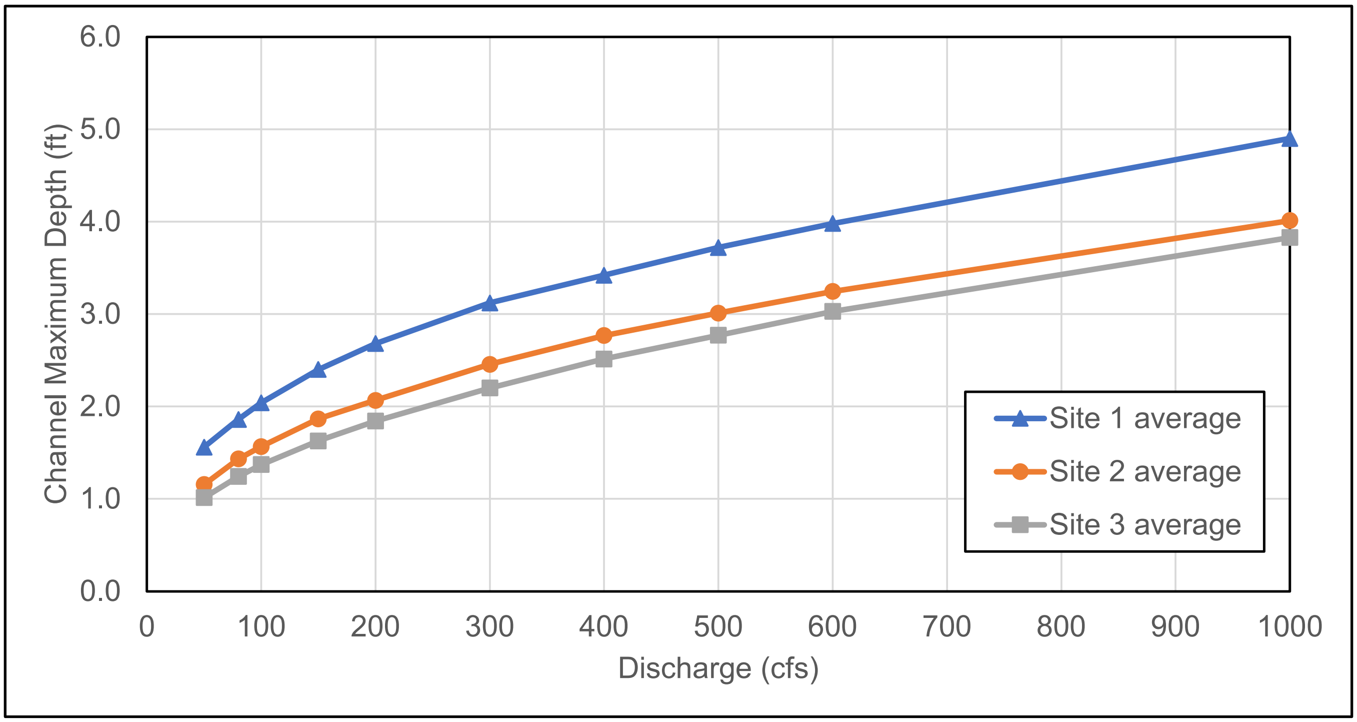

Figure 42. Riffle habitat type rating curve for channel maximum depth

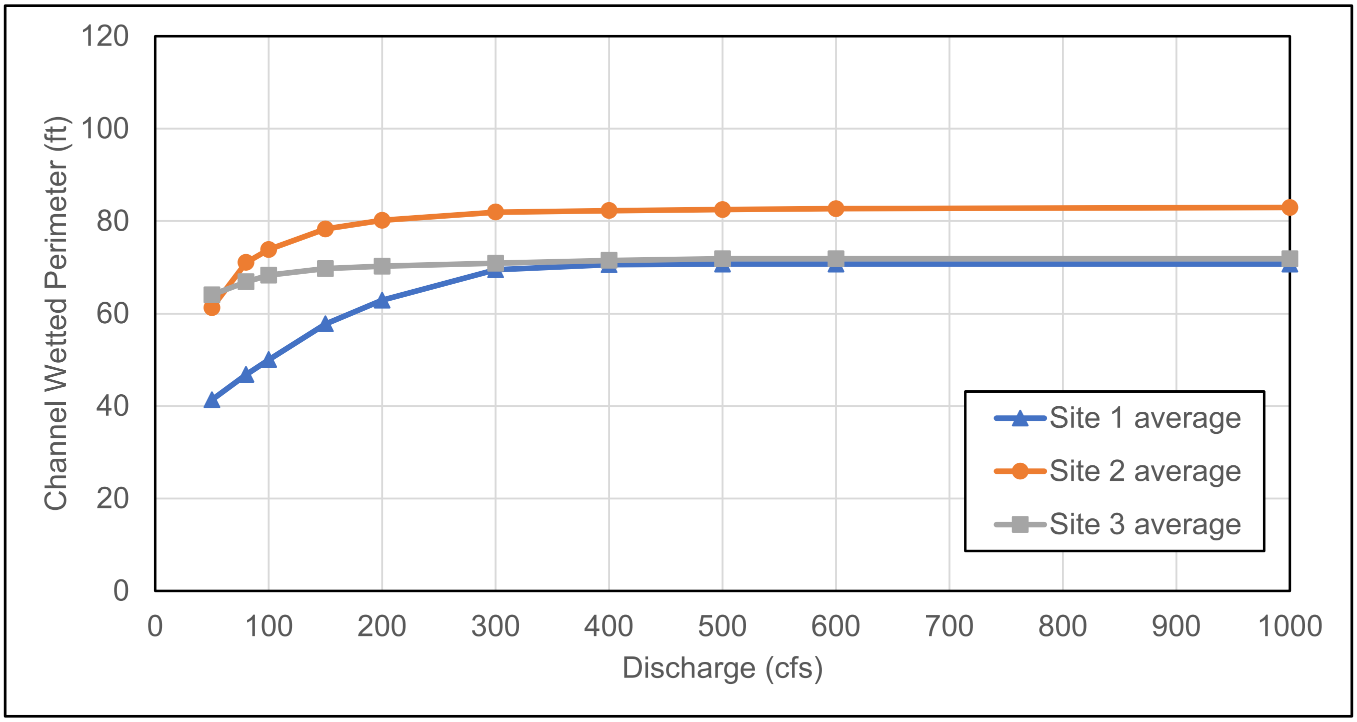

Figure 43. Run habitat type rating curve for channel wetted perimeter

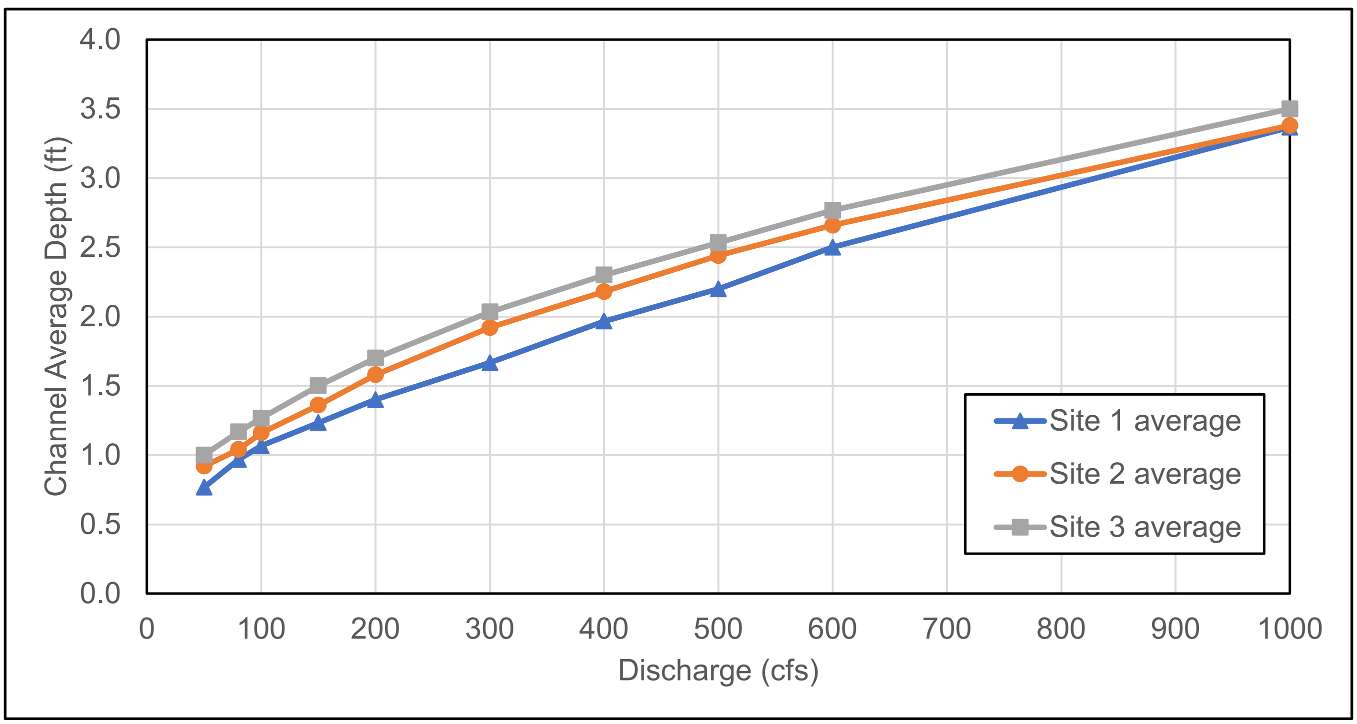

Figure 44. Run habitat type rating curve for channel average (hydraulic) depth

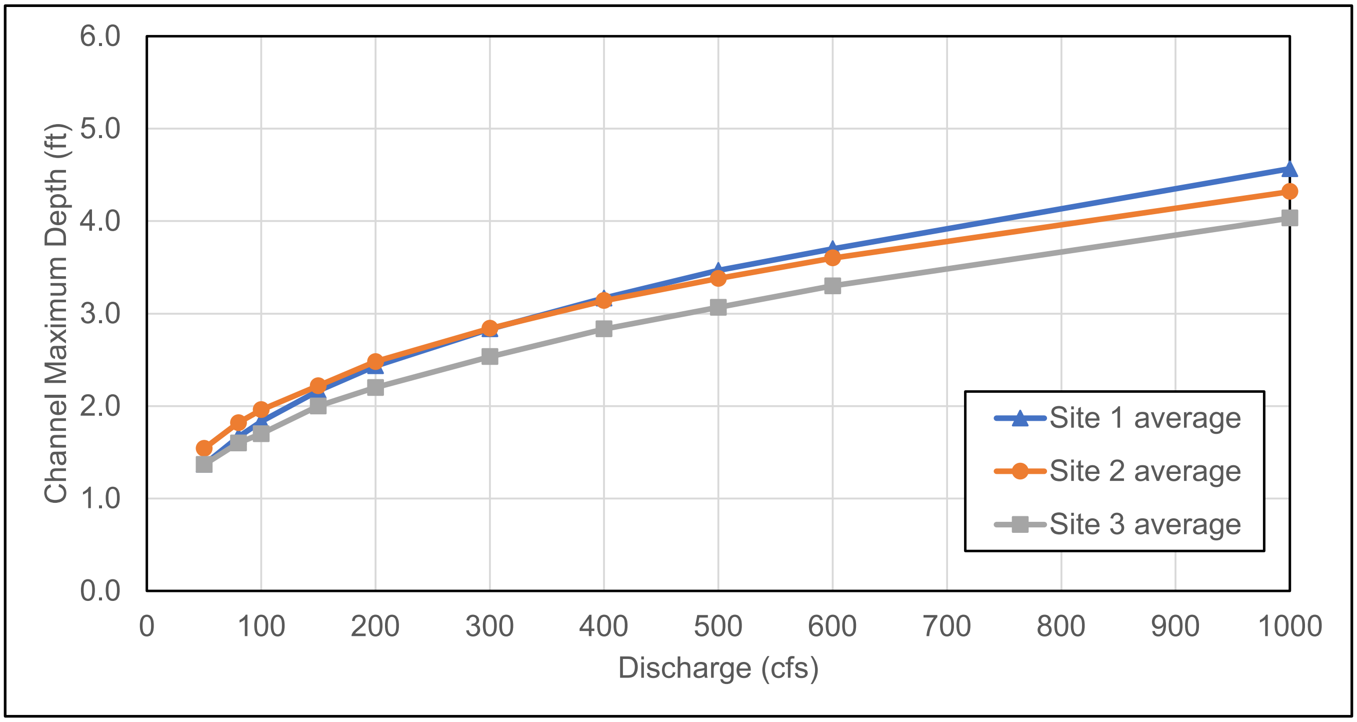

Figure 45. Run habitat type rating curve for channel maximum depth

5.2.2 Habitat Comparison by Site

The hydraulic habitat assessment results are compared by habitat type. Implications for differences are noted by study site.

5.2.2.1 Pool habitat type comparison

Pool habitat provides resting and refuge habitat for fish, especially at low flows. Winters and Gallagher (1997) state that pool depths of at least 1.5 feet are needed to adequately provide resting and refuge habitat. Pools in Site 1 were on the outside bend of a small low flow meander channel and deepest near the outer third of the channel. Pools in Site 2 were located downstream of the constructed drop structures and relatively short in downstream distance. Pools in Site 3 were extremely limited in occurrence and were located mid-channel. The Site 3 pool habitat observed during the initial site visit at approximately 160 cfs had changed to run habitat during the habitat inventory at approximately 90 cfs. As shown in Table 6 and Figure 38, the average of average pool depths through each site exceeds 1.5 feet at about 125 cfs in Site 1, at about 250 cfs in Site 2, and at about 175 cfs in Site 3. Referencing these flows to the annual flow duration curve shown in Figure 22, the pools in Site 1 provide 1.5 feet of average depth for 43 percent of the year. The exceedance drops to 30 percent of the year in Site 3, and 20 percent in Site 2. The shallower average pool depths in Sites 2 and 3 may be contributing to the impairment of the trout fishery through the assessed reach of the Blue River. The shallow pools may reflect the combination of regulated hydrology and altered stream channel at Site 2 and Site 3 that reduces flow depth and reduces energy to scour pools; however, physical modification of existing pools and creation of new pools could provide adequate pool habitat to support the trout fishery.

Wetted perimeter is narrowest for pools in Site 1 and widest for Site 2 (Figure 37). Shorter wetted perimeters for a given flow are associated with more efficient channel morphology for conveying water and sediment, meaning narrower and deeper channels. Wetted perimeter is relatively constant over the range of flows simulated for Site 2 and Site 3, because wider channels produce lower depth changes for incremental changes in flow relative to narrower channels. Pools in Site 1 were associated with alternate bars, likely reflecting the 2003 rehabilitation design. As the flow increases, the wetted perimeter at Site 1 pools increases steadily until it reaches the channel capacity at approximately 300 cfs.

Average (hydraulic) depth of pools over the range of simulated flows is greatest for Site 1 and lowest for Site 2 (Figure 38). Average depth for Site 1 ranged from 1.2 feet at 50 cfs to 3.7 feet at 1000 cfs (Table 6). Average depth for Site 2 was lowest and ranged from 0.8 feet to 3.2 feet. Average depth of pools in Site 3 ranged from 1.0 foot at 50 cfs to 3.4 feet at 1000 cfs.

Site 1 had the greatest maximum pool depths of the three sites. Maximum depth at Site 1 ranged from 2.1 feet at 50 cfs to 5.5 feet at 1000 cfs (Figure 39). Maximum depth at Site 2 ranged from 1.8 feet to 4.4 feet. Maximum depth for Site 3 ranged from 1.3 feet at 50 cfs to 3.7 feet at 1000 cfs.

A time series analysis for average and maximum pool depths was completed to evaluate pool function during an average hydrologic regime, which is represented by the 50-percent-exceedance daily average flow between water years 1988 and 2021 (Section 3.1.3). Most of the year during this average hydrologic regime the average depth for all sites is less than 1.5 feet, except during runoff (Figure 46). Site 1 average depth is closest to the 1.5-foot threshold Winters and Gallagher (1997) identify as adequate for habitat. Maximum depth for all three sites is greater than 1.5 feet except Site 3 in January (Figure 47). The time series results are consistent with the evaluation at specific discharges, and these results support the recommendations concerning potential for physical modification of the channel to enhance pool habitat.

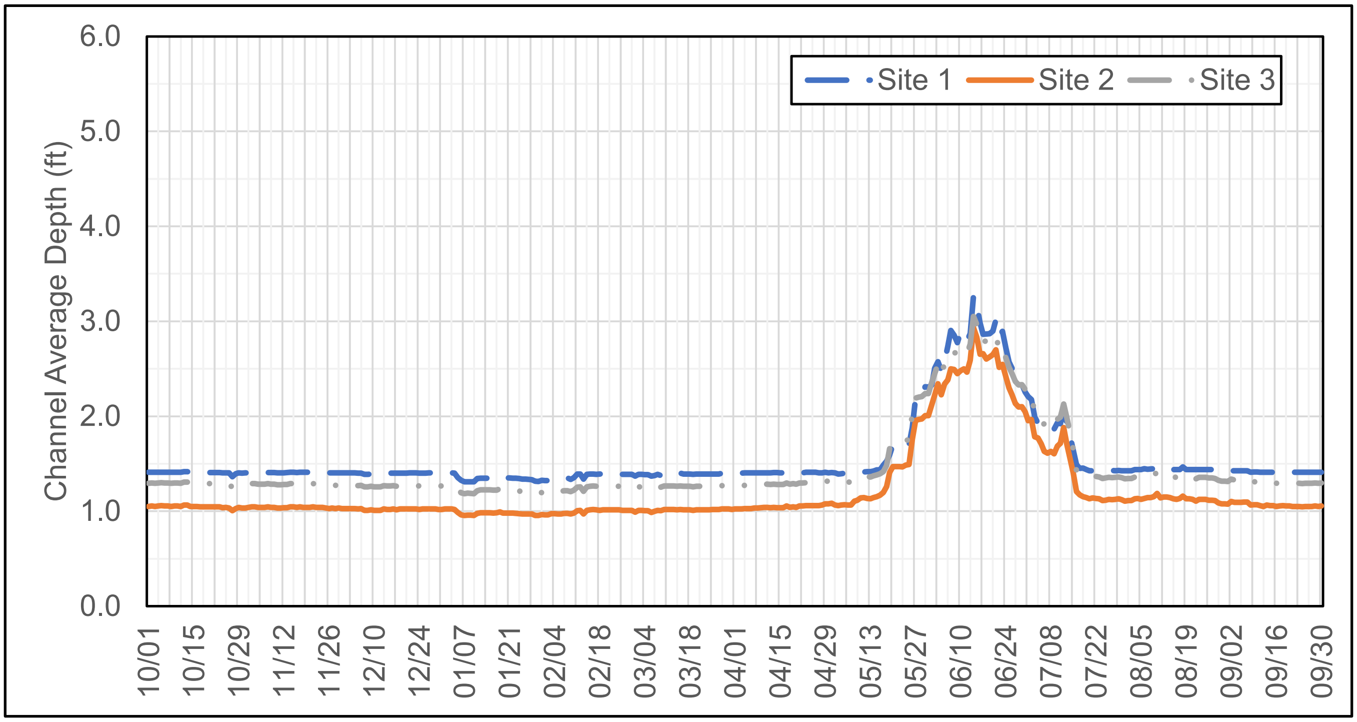

Figure 46. Time series of daily average pool depth for average hydrologic regime

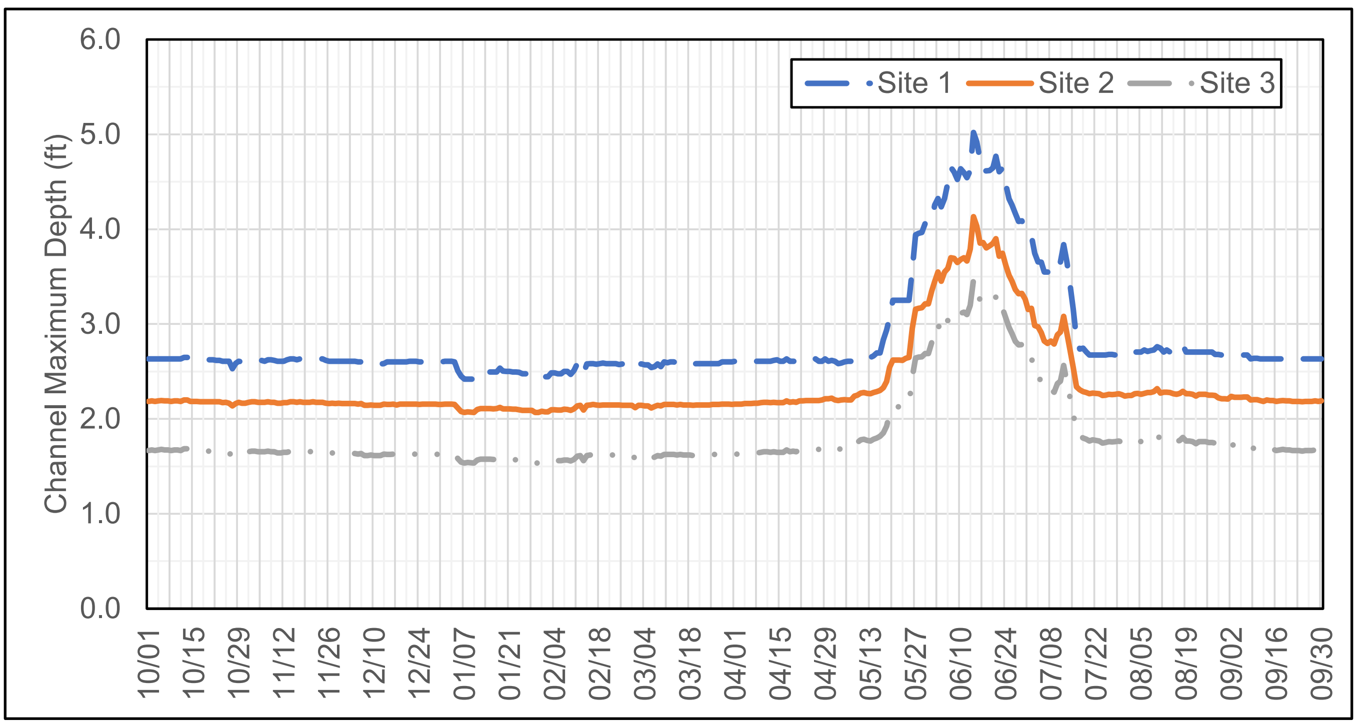

Figure 47. Time series of daily maximum pool depth for average hydrologic regime

5.2.2.2 Riffle habitat type comparison

Riffle habitat is important for benthic invertebrate production, which serves as a food source for higher trophic levels. Adequate width and depth in riffles are needed for benthic invertebrate production. The riffled water surface in this habitat type also provides oxygenation to the river and aids in supporting aquatic biota. Wider wetted width and wetted perimeter provide more habitat area for benthic production, which is beneficial to higher trophic levels. Minimum riffle wetted perimeter for a flow of interest in streams with the widths like the habitat assessment sites on the Blue River sites is 50 percent of the bank to bank (the bank elevation above sedges, willows, and other plants that may survive submerged under high flows (Colorado State University, 2019)) wetted perimeter (Nehring 1979). Minimum riffle depth for streams with the width range of the Blue River sites is 0.6 to 1.0 feet (Nehring, 1979). Adequate depth is needed for longitudinal habitat connectivity for fish species and for providing stable habitat for benthic species.

Riffle wetted perimeter was narrowest at Site 1 and widest at Site 2 (Figure 40). Wetted perimeter at Site 1 ranges from 36.6 feet at 50 cfs to 68.3 feet at 1000 cfs (Table 7). Wetted perimeter at Site 2 ranges from 53.6 feet at 50 cfs to 77.3 feet at 1000 cfs. Wetted perimeter at Site 3 ranges from 57.6 feet to 69.0 feet. Bank to bank wetted perimeter in the channel is reached at 300 cfs, for Sites 1 and 3 whereas bank to bank wetted perimeter continues to increase to 1000 cfs at Site 2. This is because the narrower and deeper channel through Sites 1 and 3 reaches capacity around 300 cfs, but the shallower and wider channel through Site 2 does not. However, all sites have more than 50 percent of the bank-to-bank wetted perimeter even at a flow of 50 cfs.

Riffle average depth is greatest at Site 1 and somewhat shallower for both Site 2 and Site 3 (Figure 41). Average riffle depth at Site 1 ranges from 1.0 foot at 50 cfs to 3.6 feet at 1000 cfs (Table 7). Average riffle depth at Site 2 ranges from 0.7 feet to 3.1 feet. Average riffle depth at Site 3 ranges from 0.6 feet to 3.3 feet. Average riffle depth is at or greater than the 0.6 foot minimum recommended by Nehring (1979). Thus, riffle habitat may not be a strategic focus for physical modification of the channel at the three study sites to support the trout fishery; perhaps the existing riffles can provide morphologic templates for any constructed riffles under consideration to replace boulder weir drop structures.

Maximum riffle depth is greatest at Site 1 and lowest at Site 3 (Figure 42). Maximum riffle depth at Site 1 ranges from 1.6 feet to 4.9 feet. Maximum riffle depth at Site 2 ranges from 1.2 feet to 4.0 feet. Maximum riffle depth at Site 3 ranges from 1.0 foot to 3.8 feet.

5.2.2.3 Run habitat type comparison

Adequate depth in run habitat is required to provide feeding locations for fish. Depths no less than the minimum riffle depths recommended by Nehring (1979) should be available to provide appropriate function as foraging locations. Depths greater than the minimum may provide enhanced function.

Run wetted perimeter as a function of discharge parallels the interpretation on pool and riffle wetted perimeter. Site 1 has the narrowest wetted perimeter at low flows and Site 3 has the widest wetted perimeter at low flows (Figure 43). Site 2 and Site 3 wetted perimeter is less variable over the range of flows than Site 1. Wetted perimeter at Site 1 ranges from 41.4 feet at 50 cfs to 70.7 feet at 1000 cfs. Maximum wetted perimeter at Site 1 is reached at 500 cfs (Table 8). Site 2 wetted perimeter ranges from 61.3 feet to 83 feet. Site 3 wetted perimeter ranges from 64.1 feet to 71.9 feet.

Average depth for run habitat is greatest for Site 3 and least for Site 1; however, all three sites have very similar average run depth (Figure 44). Site 1 average run depth ranges from 0.8 feet to 3.4 feet, from 50 cfs to 1000 cfs. Site 2 average run depth ranges from 0.9 feet at 50 cfs to 3.4 feet at 1000 cfs. Site 3 average run depth ranges from 1.0 foot to 3.5 feet. The average depths are likely sufficient to provide foraging locations for fish.

Maximum run depth is similar for all three sites at the lowest flow simulated. Maximum depths for Site 1 and Site 2 are similar at the higher end of the evaluated flows while Site 3 maximum run depth is consistently lower than either Site 1 or Site 2 at flows higher than 80 cfs (Figure 47). Site 1 maximum run depth ranges from 1.4 feet at 50 cfs to 4.6 feet at 1000 cfs. Site 2 maximum run depth ranges from 1.5 feet at 50 cfs to 4.3 feet at 1000 cfs. Site 3 maximum run depth ranges from 1.4 feet at 50 cfs to 4.0 feet at 1000 cfs. These maximum depths in conjunction with the range of average depths should provide adequate foraging habitat for fish. Like the interpretation of riffle habitat hydraulics, run habitat hydraulics may not be a strategic focus for physical modification of the channel to support the trout fishery.

6.0 SUMMARY

The Blue River downstream of the Dillon Reservoir Dam is heavily used by many types of recreationists and is a highly regarded fly fishing destination. The status of the fishery is important to these recreationists and the local community. CPW designates the Blue River fishery downstream of the dam to the Hamilton Creek Road Bridge (about a half-mile downstream of Location 6, including Sites 1, 2, and 3) as Gold Medal, defined as a river that supports at least 60 pounds per acre and at least 12 fish per acre of 14 inches and larger and has public access (CPW, 2019). CPW stocks this section of the Blue River. The Blue River in this section is restricted to fly/lure only fishing and catch and release limits. The Blue River downstream of the Gold Medal section from Hamilton Creek Road Bridge downstream to Green Mountain Reservoir is restricted to fly/lure only fishing and a two fish per day limit. When CPW biologists removed the Gold Medal designation downstream of Hamilton Creek Road Bridge in 2016 they indicated the low productivity may be caused by a combination of suboptimal physical habitat under low flow releases from Dillon Reservoir (noted as being less than 100 cfs), a lack of food, and/or limited biological productivity. There may be other factors limiting the function of this fishery (such as water temperature and other water quality constituents), and evaluation of these factors are being assessed by others concurrently with this habitat assessment.

The Blue River in the 2 miles downstream of the dam has three distinct stream channel types. The river from the dam downstream to approximately the Straight Creek confluence (upstream end of Site 2) has the most heterogeneous channel with a functioning complex of deep pools, which transition to run habitat into moderately steep riffles. The Blue River in this section is the narrowest in these 2 miles, likely reflecting the early-2000s rehabilitation project. The river from the Straight Creek confluence (upstream end of Site 2) downstream to approximately the 6th Street crossing (upstream of Location 4) is the widest of the 2-mile-long reach. This section also has numerous (18+) partial- and full-channel-width drop structures. These structures appear to have been installed sometime in the late-1980s into the early-1990s. These types of structures were typical of river habitat enhancement activities during this time; however, these drop structures are no longer seen as state of the art for river restoration given the departure from natural planform of rivers similar in size to the Blue River, and the numerous fish passage impediments created by the drop structures. The river downstream from the 6th Street crossing (upstream of Location 4) to near the pedestrian bridge in the Willow Grove Open Space (downstream end of Site 3) is dominated by long, low-gradient riffles and runs. The river is somewhat narrower than the upstream section but still wider than the section downstream of the dam. There is a lack of pool habitat in this reach and the habitat is not very diverse.

The Blue River downstream of the Town of Silverthorne's municipal limit is still dominated by a single thread channel with some shorter sections having vegetated islands and multiple channels. There are several short areas with some evidence of river restoration. Gradient in this reach is like the upper section with mostly riffle and run habitat that was observed in both recent aerial images and during the reconnaissance and habitat inventory. Stream bed substrate in this section of the Blue River is still mostly cobble, but it does have areas of smaller gravel substrate. The substrate size observed just downstream from the Blue River Campground, visually estimated to have a median size of approximately 1 inch, would be suitable for trout spawning, with the Age 0 fish observed during the field reconnaissance as supporting evidence.

The Blue River in the restored upper section downstream of the dam to I-70 has the most diverse aquatic habitat. The rehabilitated reach through Site 1 has the best overall habitat function in the form of deeper pools for rest and refuge and narrower, deeper riffles at all range of flows. The habitat in the section from I-70 downstream to 6th Street is highly fragmented by the numerous drop structures, which also cause the river to be overly wide and shallow upstream of each structure. The river downstream of 6th Street is over wide and shallow with little habitat diversity. Based on visual observations the river throughout the upper 2 miles lacks adequate gravel and hydraulic conditions at pool/riffle interfaces for trout spawning. In addition, there is a lack of adequate pool habitat for resting and refugia except at Site 1.

7.0 RECOMMENDATIONS

The overall goal of this habitat assessment is to develop scientifically valid strategies to improve aquatic habitat based on a better understanding of the relationships between the Blue River hydrology, the morphology of the Blue River channel, and hydraulic indicators of aquatic habitat quality. MEC and Tetra Tech expect multiple assessment will be required to determine the cause(s) of decline of the fishery through this reach of the Blue River; the following recommendations are a starting point. Based on the better understanding documented herein, recommendations include:

- Continue integrating studies to help determine causes of the fishery decline. This integration should include a comprehensive analysis of fish populations (all species, not just limited to trout), macroinvertebrate data, water quality data, and physical habitat. Integration across disciplines should be a precursor to development of an overall management plan. If not already completed or underway, a study should be considered to quantify river use, and assess whether the number of people on the river are creating enough disturbance to contributing to the decline in the trout fishery.

- Continue to investigate the impact of water quality from urban and roadway runoff on the biological community in the Blue River between the Dillon Reservoir Dam and Green Mountain Reservoir. Consider a limiting factor analysis to understand whether aquatic habitat or water quality is the greater limitation on the trout fishery. The hydraulic habitat assessment of Site 1 indicates the habitat quality should support a trout fishery, but the Gold Medal status is dependent on CPW's stocking this reach with catchable rainbow trout. This could indicate the water temperature or water quality are more limiting to the trout fishery at this site than the habitat. If this is the case, it could mean that addressing the water quality and other factors more limiting than habitat are needed before the habitat improvement can provide the needed functional uplift.
- Review previous stocking records from prior years in the reach from the Dillon Reservoir Dam downstream to the Hamilton Creek Road Bridge. The fish population in the Gold Medal section is comprised of almost equal proportions of rainbow trout and brown trout. Brown trout are wild spawned in either the river or tributaries. The rainbow trout population is supported by stocking. The trout population near the Blue River Campground is predominately brown trout with very few rainbow trout. CPW no longer stocks the downstream reach and the population seems to reflect that change in management and the lack of successful recruitment of wild spawned rainbow trout.
- Conduct a simple bioenergetic study to determine the food requirements for each size of trout. Much of the needed input data for this desktop exercise is available. The results on macroinvertebrate biomass and fish biomass by size class would be useful to determine the limitation of trophic resources and water quality on the trout species. These results will inform whether there is enough biomass to support the stocked and natural trout fishery.
- Investigate the potential fish passage impediments the boulder weir drop structures create. A study using tagged fish (either PIT tags or Floy tags) could provide the data needed to determine if the drop structures are limiting the upstream movement of smaller fish. The use of external Floy tags could be a way to engage the fishermen to assist in tracking fish movement. Each Floy tag can be individually numbered to document stocking or tagging location and recapture location.
    - If the existing boulder weir drop structures are impeding fish passage, modify these structures to allow fish passage and to promote longitudinal channel habitat connectivity. Constructed riffles of configuration like the rehabilitated riffles in Site 1 should be considered as potential templates to replace the drop structures with grade controls that do not impede upstream fish movement.
- Pool habitat from around the I-70 crossing to Willow Creek Open Space, where present, is infrequently of adequate depth to support the trout fishery; physical modification of the channel to create new pools of sufficient depth should be considered. The regulated flow regime and the potential for flooding impacts likely precludes release of flows capable of scouring pools.
- Physical modification of the Blue River to create more pool habitat should prioritize narrower and deeper pools similar to the rehabilitation of Site 1.
- Absence of spawning gravel in Sites 1 and 3, with limited gravel observed at locations conducive for spawning through Site 2, indicates that suitable spawning substrate is not prevalent enough to sustain a natural reproducing population of trout in the upper 2 miles of the Blue River downstream of the Dillon Reservoir Dam. Placement of spawning gravel should be considered. Such gravel, if placed within the channel, would require careful placement because the regulated flow regime and potential for flooding impacts may preclude hydraulic mobilization and distribution of launchable gravel piles. Gravel placement is most critical upstream of tributary confluences that delivery gravel sediment, such as the reach upstream of the Willow Creek confluence.

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APPENDIX A: HYDRAULIC MODEL DEVELOPMENT

A-1. HYDRAULIC MODEL DEVELOPMENT

Tetra Tech developed a one-dimensional numerical model to simulate hydraulic conditions in the channel through the three habitat assessment sites. Tetra Tech developed the model using version 6.0.0 of the U.S. Army Corps of Engineers River Analysis System software (HEC-RAS) (HEC U. , 2021).

A-1.1 GEOMETRIC INPUTS

The key inputs to develop the model geometry are the flowpaths and the cross sections. FEMA's National Flood Hazard Layer (NFHL) geospatial database of current effective flood hazard data contains the Blue River's centerline flowpath and mapped cross sections. FEMA's effective FIS model (HEC-2) provided additional geometric details, and includes unmapped cross sections not shown in the NFHL. Tetra Tech surveyed channel bathymetry in July 2021 within the three habitat assessment sites, and these cross sections were georeferenced to FEMA's centerline flowpath for the Blue River. Tetra Tech's surveys extended between the top of banks of the low flow channel, so geometric inputs were supplemented across the floodplains using CWCB's 2016 LiDAR mapping. Energy losses were characterized using Manning's n-values, which were initially based on field observations and then refined during model calibration.

A-1.1.1 FEMA FIS Model

The information in the following paragraph was extracted from the effective FEMA FIS for the Town of Silverthorne (FEMA, 2018). In 1978 FEMA originally completed hydrologic and hydraulic analyses of flooding risks within the Town of Silverthorne (including the Blue River between the Dillon Reservoir Dam and Green Mountain Reservoir); the restudy to incorporate detailed flood hazard information was completed in 1998. A Physical Map Revision (PMR) was published in 2018 to revise flood hazard areas along the Blue River. For the original study, the flow frequency relationship for the Blue River within Silverthorne was developed considering total inflow to Dillon Reservoir and routing through the reservoir; for the PMR results from statistical analysis of USGS peak flows (Gage No. 09050700) (Gingery Associates, Inc., 1978) were not significantly different from the original study, so the original flow frequencies were maintained. The hydraulic analysis was carried out using the USACE HEC-2 step backwater program (HEC, 1968). Cross sections were obtained from topographic maps and cross section surveys. The Town of Silverthorne topography from 1994 was combined with cross sections obtained by field survey for a complete representation of the floodplain. All bridges and culverts were field checked to obtain elevation data and structural geometry. Channel roughness factors were chosen by engineering judgment and field observations; the Blue River channel n-value was set to 0.040 and the overbanks to 0.100. All elevations are referenced to the NAVD88 in units of feet.

The reach lengths, cross section geometry, structure geometry, roughness factors, and other geometric parameters were copied from the HEC-2 model within and between the three habitat assessment sites. These data were a starting point for the development of the hydraulic model.

A-1.1.2 Tetra Tech July 2021 Bathymetric Survey

The geometric information available in the FIS HEC-2 model was insufficient for the habitat assessment, so on July 20th and 21st, 2021, Tetra Tech completed a bathymetric survey of the channel through the three habitat assessment sites. MEC and Tetra Tech identified the cross sections to be surveyed during the field reconnaissance completed July 12, 2021. The cross sections represent various habitat types (such as riffles, runs/glides, and pools) and hydraulic controls. Twelve cross sections were surveyed in Site 1, 20 cross sections were surveyed in Site 2, and 13 cross sections were surveyed in Site 3.

The bathymetric survey was carried out using professional survey-grade Leica GPS/GNSS rovers using GS14 antennae receiving real-time kinematic (RTK) corrections from a Leica base station with a GS12 antenna. The base station was setup near the Dillon Reservoir Dam to collect observations of position adjusted by static processing using NOAA's Online Positioning User Service (OPUS), which uses the same software that computes coordinates for the nation's geodetic control marks. The OPUS calculations of horizontal and vertical position were checked for accuracy by comparing calculated positions to the National Geodetic Survey (NGS) benchmark D 450 (PID DF5524). This benchmark is located on the pedestrian bridge over Straight Creek upstream of the Highway 6 crossing and provides both GPS and vertical control. Surveyed positions were annotated with geomorphic features such as top of bank, toe of bank, and channel bed, and hydraulic features such as the edges of water. Flow during the surveys was approximately 105 cfs upstream of the Straight Creek confluence and 111 cfs downstream of this confluence (based on records at the USGS gaging stations on the Blue River and Straight Creek). Three-dimensional positional accuracy (3D-CQ) targeted values no greater than 0.08 feet.

Surveyed positions were post-processed to station-elevation coordinate pairs (with elevations referenced to the NAVD88 in units of feet) by projecting points onto vectors defining segments of each cross section. For simple cross sections, the vector extended from one bank to the other; for complex cross sections, such as along the curved crest of boulder weir drop structures, multiple vectors were used. This post-processing enabled the surveyed channel morphology to be directly entered to the HEC-RAS software.

A-1.1.3 2016 LiDAR Mapping

The CWCB's Colorado Hazard Mapping & Risk Map Portal (https://coloradohazardmapping.com/lidarDownload) enables users to download Light Detection and Ranging (LiDAR) mapping available across Colorado. In Summit County, Merrick & Co. compiled a digital elevation model (DEM) of topography based on 2016 LiDAR surveys. Merrick & Co. processed the point cloud data and breaklines into 3,000-feet by 3,000-feet tiled DEMs of 3-feet-square raster elements with elevations referenced to the NAVD88 in units of feet. The LiDAR data was produced to meet American Society of Photogrammetry and Remote Sensing (ASPRS) positional accuracy standards for digital geospatial data for a 42.4 cm (1.4 feet) RMSEx/RMSEy horizontal accuracy class. The LiDAR data was tested to meet ASPRS positional accuracy standards for digital geospatial data for a 10.0 cm (0.33 feet) RMSEz vertical accuracy class.

The 2016 LiDAR mapping conformed closely with Tetra Tech's July 2021 survey along the channel margins, so HEC-RAS's RAS-Mapper tool was used to extend cross section topography landward of the bathymetric survey into the Blue River's floodplains.

A-1.1.4 Bank Stations

Tetra Tech set bank stations at each of the surveyed cross sections to delineate the bankfull channel. Based on observations during the field reconnaissance, the bankfull channel was typically apparent by a change in vegetation and a break in bank slope. Preliminary simulations of the HEC-RAS model showed the bankfull channel through the three sites coarsely corresponds with flows between 300 and 400 cfs. The simulated water-surface elevations for this flow range were used to check the reasonableness of the bank stations.

A-1.1.5 Manning's n-values

Energy losses were quantified using Manning's n-values, which were estimated for model development, then refined during model calibration. Tetra Tech estimated n-values using Cowan's method (Cowan, 1956), with the base n-value calculated using the Limerinos equation (Limerinos, 1970) using D_{84} sizes from visual estimates during the field reconnaissance. Tetra Tech estimated 8-inch D_{84} through Sites 1 and 2, and 6-inch D_{84} in Site 3. As flow depth increases, the relative smoothness (R_h/D_{84}) increases and the n-value decreases. Tetra Tech using the Limerinos equation with flow depths up to 3 feet, coupled with Cowan's method for other energy loss components to develop relationships of vertically varying n-values that were input to the HEC-RAS model.

A-1.1.6 Ineffective Flow Areas

Within the channel, which HEC-RAS defines using bank stations, features such as vegetated bars and islands exhibit greater potential for energy loss compared to the alluvial channel boundary. The HEC-RAS software can compute a composite channel n-value in such instances, and the method relies on wetted perimeter to weight varying n-values (Brunner, HEC-RAS River Analysis System, Hydraulic Reference Manual, Version 6.0, 2021). Wetted perimeter weighting can be problematic when flows barely submerge vegetated bars and islands because the wetted perimeter can be notable while associated conveyance is near zero. The compositing can produce n-values that are biased high. To avoid this potential error, Tetra Tech used ineffective flow areas to delineate vegetated bars and islands within the channel. Ineffective flow areas define areas of the cross section that contain water not actively conveyed, meaning the flow velocity in the downstream direction is close to or equal to zero and the ineffective flow area is excluded from the area of active flow (Brunner, HEC-RAS River Analysis System, User's Manual, Version 6.0, 2021).

A-1.1.7 Blocked Obstructions

Tetra Tech delineated blocked obstructions for structures in the floodplains, primarily homes and commercial buildings. Tetra Tech used recent aerial imagery and observations during the field reconnaissance to set the extents and heights of the blocked obstructions.

A-1.2 GEOMETRIC PROCESSING

Tetra Tech merged the FEMA FIS HEC-2 geometry with Tetra Tech's July 2021 bathymetric survey and CWCB's 2016 LiDAR mapping to develop the needed geometric inputs to HEC-RAS. The Blue River centerline flowpath from FEMA NFHL was overlaid on current aerial imagery in a GIS and confirmed to represent the current channel alignment. The mapped cross sections were referenced to the centerline stationing, and the surveyed cross sections were also stationed relative to this flowpath. The overbank flow paths were delineated using the LiDAR mapping to guide anticipated flowpaths, and these were not closely scrutinized because the focus of the modeling was to simulate channel hydraulics.

A-1.3 HYDROLOGIC INPUTS

A range of flows were simulated to produce rating curves for channel hydraulics as a function of flow. The ISF of 50 cfs and the 1,000 cfs optimum flow for kayaking were used to set the range of flows, and intermediate flows were selected to specified to produce a relatively smooth rating curve (Section 3.1.5).

A-1.4 MODEL SETUP

The model was setup to simulate hydraulics assuming a subcritical flow regime. While localized critical or even supercritical flows may occur, such as over the crest of boulder weir drop structures, flow through nearly all the habitat sites at the flows under consideration will be subcritical. The model was also set up to simulate hydraulics for steady, gradually varied flow.

A-2 MODEL CALIBRATION

The model was preliminary run to check errors, warnings, and notes. No errors occurred, and warning were reviewed and addressed as appropriate; notes were not closely reviewed. With the model tested and producing water-surface profiles that appeared reasonable, Tetra Tech focused on calibrating the model. The Manning's n-values were the primary target of the calibration. The edges-of-water surveyed during Tetra Tech's July 2021 bathymetric survey were entered into HEC-RAS and used to compare simulated and observed water-surface elevations. The surveyed hydrology was targeted as the basis of calibration because the model's intended purpose is to support characterizations of aquatic habitat during flow flows. Flows in the Blue River during the surveys were between about 103 and 105 cfs, with an average of 105 cfs (Gage No. 09050700). Flows in the Blue River downstream of the Straight Creek confluence during the surveys were between 109 and 112 cfs, with an average of 111 cfs (Gage No. 09050700 and Gage No. 09051050). Surveyed water-surface elevations considered differences between the right and left edges-of-water, as well as different vertical accuracy (quantified using Leica's reported CQ_1D) to set upper and lower bounds and calculate the average as the observed elevation. Through Site 1, simulated water-surface elevations were within +/- 0.60 feet of surveyed elevations. The cross sections with the largest differences were the cross sections with the largest difference between surveyed elevations at the right and left edges-of-water. Through Site 2, simulated water-surface elevations were within +/- 0.44 feet of surveyed elevations, with the greatest differences at the boulder weir drop structures. Through Site 3, differences were within +/- 0.37 feet. Through all three sites, the differences were comparable to the variability between surveyed right and left edge-of-water elevations, so Tetra Tech accepted the model as calibrated. Based on the calibration at the targeted flow, and lacking further calibration datasets, Tetra Tech assumed that the vertical variability in Manning's n-values was appropriate for the targeted range of flows.

APPENDIX B: HABITAT INVENTORY TECHNICAL MEMORANDUM

Technical Memorandum
Habitat Inventory – Blue River at Study Site 1, Site2, and Site 3.
October 29, 2021

Prepared for: Blue River Watershed Group
Silverthorne, Colorado

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Introduction

Habitat inventory was conducted on September 29, 2021 at three study sites on the Blue River. All three sites are in the first 3 miles downstream from Dillon Dam (Figure 1). The habitat inventory used a quantitative protocol developed by the US Forest Service (Winters and Gallagher 1997). The methodology measures the area of each habitat type at each site, the average depth of the habitat type and ocular estimates for cover and stream substrate. The quantitative approach provides a means to compare similarities and differences between study sites.

Methods

Length and width of each individual habitat was measured with a laser range finder accurate to 0.5 feet with a maximum range of 900 feet. Stream depth was measured using a standard stadia rod marked in 0.01 foot increments. The data for each habitat was recorded on a field data form and later transferred to an MS Excel spreadsheet for analysis. The computer spreadsheet program generated the habitat quantities and graphs for each study site. The output for each study site was summarized into tables for comparison. Full results of the habitat inventory are presented in Appendix A.

Results

Site 1

Site 1 is a relatively unmodified channel with a mixture of riffles, glides and pools. Stream substrate is dominated by cobbles and boulders (Figure 2 , Table 2). Habitat area for glides and riffles was almost equal at approximately 46% of the total area. Pool habitat area was approximately 7% (Figure 3). Average channel width ranged from 38.7 feet for riffles to 49.5 feet for glides. Residual pool depth was 2.4 feet (Table 1).

Site 2

Site 2 is a confined channel with several instream drop structures. The drop structures include both partial and full channel width structures. The full width drop structures do not include any fish passage channels and require upstream migrating fish to either jump over the drop or dart upstream at the low points between the large boulders. Stream velocity measured at several of these low points ranges from over 4 feet per second to over 6 feet per second. These velocities exceed the swimming speeds of small trout and the small nongame species in the river. Adult trout burst or darting speeds may allow some of the large fish to move upstream past the drop structures, however, the drops are likely impediments to upstream migration and passage.

Stream substrate is dominated by cobbles and boulders (Figure 4 , Table 2). Habitat area for glides was approximately 37% and riffle area was approximately 55%. Pool habitat area was approximately 8% (Figure 5). Average channel width ranged from 65.6 feet for riffles to 69.5 feet for pools. Residual pool depth was 1.9 feet (Table 1).

Site 3

Site 3 has a less confined channel than Site 2 with some areas of floodplain connectivity. No constructed drop structures are in Site 3. The stream substrate is dominated by cobble and boulder (Figure 6, Table 2). Habitat area for glides was approximately 55% and riffle area was approximately 45%. No pool habitat was measured in Site 3 at a flow of 88 cfs. Some of the glide habitat may become pool habitat at higher flows (Figure 7). Average channel width ranged from 58.7 feet for riffles to 74.3 feet for glides (Table 1).

Summary

The habitat inventory shows that the upstream reach at Site 1 is the narrowest and most natural appearing channel. Site 1 has several deep pools for refuge habitat at low flows. Site 1 also does not have any impediments to fish movement. Site 2 is the widest of the three sites, especially for glide habitat. The stream width is controlled by the full channel width drop structures. These structures capture any downstream transported stream substrate and reduce stream depth upstream of the drop structure. Partial channel width, offset grade control structures would function to control stream gradient and allow unimpeded fish movement. The impeded fish movement, especially by small trout and nongame species may be a factor that controls fish populations in the Blue River in the reach through Silverthorne.

Stream substrate is dominated by cobbles and boulders with very little areas with gravels. The lack of gravel substrate likely reduces the potential spawning habitat in the reach downstream from the dam. j

Table 1. Habitat area, average depths, and average widths for Blue River Sites 1, 2, and 3.

		Percent of Total Area			Average Depth (ft)			Average Width (ft)			Average Pool
Site	Total Length (ft)	Pool	Riffle	Glide	Pool	Riffle	Glide	Pool	Riffle	Glide	Residual Depth (ft)
1	726	6.9	46.9	46.2	2.0	1.1	1.2	42.0	38.7	49.5	2.4
2	1726	8.4	54.9	36.7	1.7	0.7	0.9	69.5	65.6	66.8	1.9
3	1011	0.0	44.7	55.3	0.0	0.7	1.1	0.0	58.7	74.3	0.0

Table 2. Blue River substrate type for Sites 1, 2, and 3.

		% of Substrate				
Site	Habitat Type	Sand/Silt	Gravel	Cobble	Boulder	Bedrock
1	Pool	0	0	25	75	0
	Riffle	0	0	33	67	0
	Glide	0	0	38	63	0
	Overall Reach	0	0	32	68	0
2	Pool	0	0	63	38	0
	Riffle	0	11	50	39	0
	Glide	0	19	44	38	0
	Overall Reach	0	10	52	38	0
3	Pool	0	0	50	50	0
	Riffle	0	0	50	50	0
	Glide	0	0	58	42	0
	Overall Reach	0	0	53	47	0

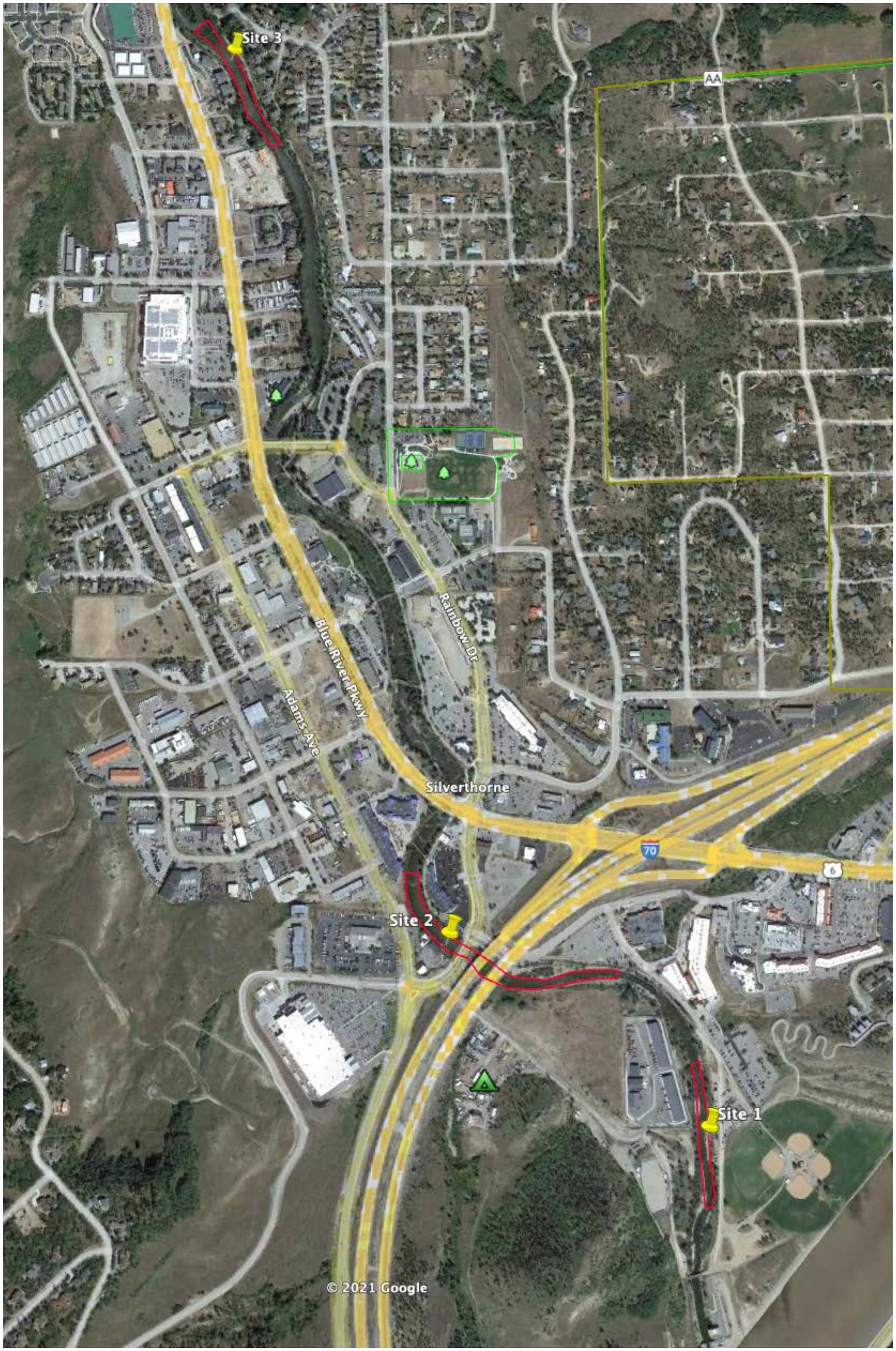

Figure 1. Blue River Study Sites downstream from Dillon Dam.

Figure 2. Site 1 looking upstream, September 29, 2021.

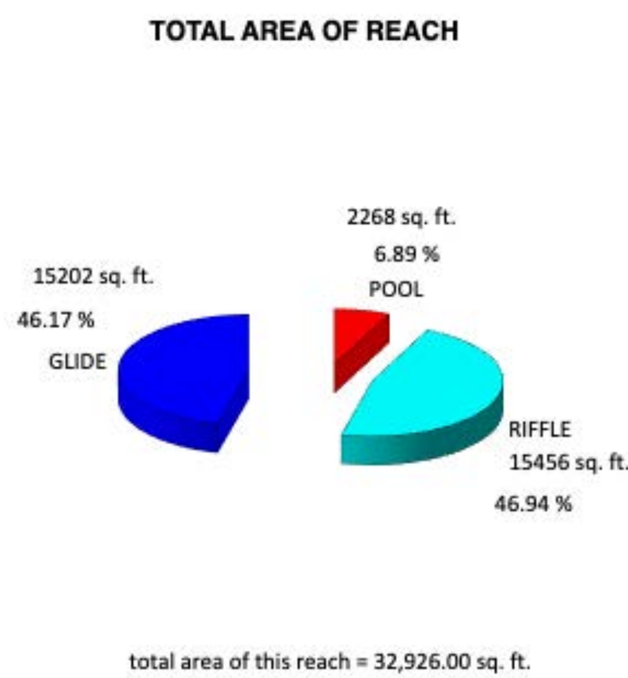

Figure 3. Habitat area by habitat type for Site 1.

Figure 4. Site 2 looking downstream from bridge.

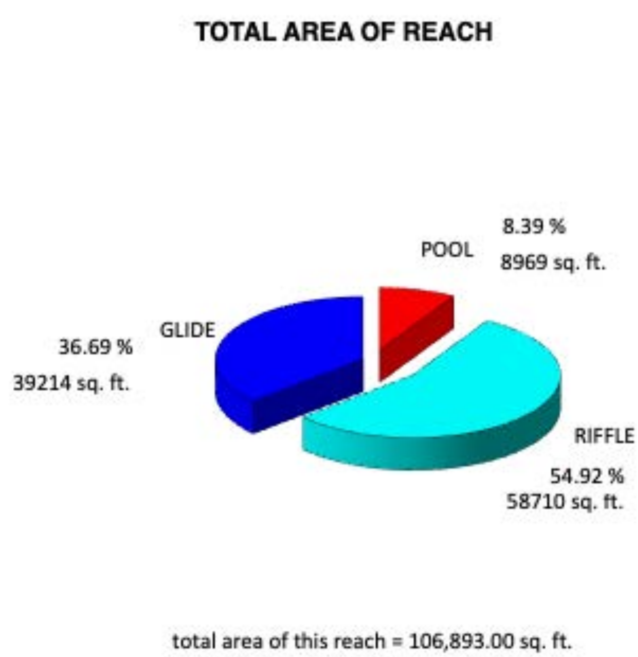

Figure 5. Habitat area by habitat type for Site 2.

Figure 6. Site 3 looking upstream.

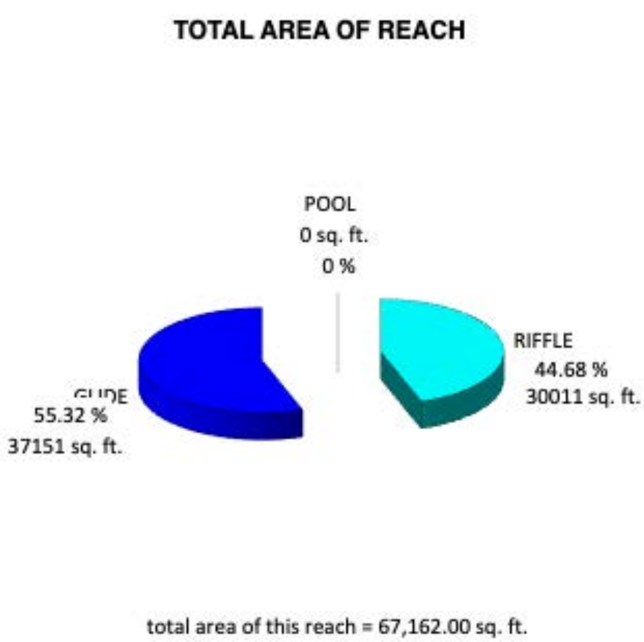

Figure 7. Habitat area by habitat type for Site 3.

Literature Cited

Winters, D. S. and J.P. Gallagher. 1997. Basin-wide stream habitat inventory. A protocol for the Pike and San Isabel National Forests, Cimarron and Comanche National Grasslands. U. S. Forest Service, 31 pp.

Appendix A – Habitat inventory data for Blue River Sites 1, 2, and 3, September 29, 2021

BASIN-WIDE STREAM HABITAT INVENTORY CHARACTER DEFINITIONS

1 Number, either Glide = G (1,2,3…) Pool = P (1,2,3…) Riffle = R (1,2,3…)

2 Type:

Glide	Pool	Riffle
Glide = 1	Pool =	Riffle =
	2. secondary channel	8. secondary channel
	3. backwater	9. bedrock
	4. trench	10. boulder
	5. plunge	11. cobble
	6. lateral scour	12. gravel
	7. dammed	13. sand/silt
		14. rapids
		15. cascades

3 Structural Association

- A - bar
- B - boulder
- C - culvert
- D - beaver dam
- E - bedrock
- F - falls
- L - LOD (4"dia.-3 ft long)
- M - meander
- O - other, (riffles low gradient)
- P - pocket water (riffles high gradient)
- R - rootwad
- S - structure
- W - debris dam/large wood

4 Length **5 Width** **6 Residual Pool Depth** (High-low=RPD)

7 Depth

8 Cover Types - record in sq ft of cover as visually determined:

1 - No cover - depth <0.5 ft, velocity >0.5/sec in riffle; pools <1.5 ft deep. No Security Cover

2 - Instream Objects - water level 1 ft deep behind objects 1 ft in width, reducing velocities to <0.5 cfs, LOD (tree trunks, root wads), boulders.

3 - Overhead - within 2 ft of water surface, vegetation like shrubs above glide or pool, undercut banks, protruding banks providing min. 1 ft of cover, H_2O min. 0.5 ft depth, velocity < 0.5 cfs, and offers no Velocity Shelter.

4 - Combination - water >0.5 ft, fallen trees, debris dams w/branches and/or root mass, overhanging banks w/roots, rubble or boulder piles within the stream channel; reduced velocities and overhead cover.

5 - Pool Depth - plunge pools over debris jam, lateral scour pools in undercut banks, any area of pool >1.5 ft deep after codes #2, 3, & 4 above have been measured; the remainder is considered pool cover.

9 Bank Stability

1 - Vegetated and Stable >50% vegetated, does not show stress
2 - Vegetated and Unstable >50% vegetated, does show stress
3 - Unvegetated and Stable <50% vegetated, does not show stress

4 - Unvegetated and Unstable <50% vegetated, does show stress

10 Bank Rock Content

2 - >65%, with large angular boulders, 12" diameter
4 - 40-65%, mostly small boulders to cobbles, 6-12" diameter
6 - 20-40%, with most in 3-6" diameter class
8 - <20%, rock fragments of gravel size, 1/8-3" diameter or less

11 Eroding Banks - measure amounts in linear feet of erosion on each bank and total

12 LOD - large organic debris, diameter > 4", length > 3.3', record total number of objects

13 Substrate

BLD - boulders, assess to 5% of the % of the streambed covered by size >12"
R - rubble (cobble)
G - gravel
S - sand/silt/mud
BRK - bedrock

Table A-1. Habitat characteristics for Blue River Site 1.

Blue River - Site 1

9/29/21

	POOL	RIFFLE	GLIDE	REACH TOTAL
TOTAL LENGTH OF HABITAT (ft.)	54.00	384.00	288.00	726.00
AVERAGE WIDTH OF HABITAT (	42.00	38.67	49.50	43.39
AVERAGE RESIDUAL DEPTH (ft	2.40	0.00	0.00	2.40
AVERAGE DEPTH (ft.)	2.00	1.10	1.15	2.00
TOTAL COVER TYPE 2 (sq. ft.)	0.00	250.00	150.00	400.00
AVE. TYPE 2 COVER PER UNIT	0.00	83.33	75.00	1.21
TOTAL COVER TYPE 3 (sq. ft.)	0.00	0.00	0.00	0.00
AVE. TYPE 3 COVER PER UNIT	0.00	0.00	0.00	0.00
TOTAL COVER TYPE 4 (sq. ft.)	0.00	0.00	0.00	0.00
AVE. TYPE 4 COVER PER UNIT	0.00	0.00	0.00	0.00
TOTAL COVER TYPE 5 (sq. ft.)	100.00	0.00	0.00	100.00
AVE. TYPE 5 COVER PER UNIT	100.00	0.00	0.00	0.30
% BANK STABILITY TYPE 1				
LEFT BANK	100.00	100.00	100.00	100.00
RIGHT BANK	100.00	100.00	100.00	100.00
% BANK STABILITY TYPE 2				
LEFT BANK	0.00	0.00	0.00	0.00
RIGHT BANK	0.00	0.00	0.00	0.00
% BANK STABILITY TYPE 3				
LEFT BANK	0.00	0.00	0.00	0.00
RIGHT BANK	0.00	0.00	0.00	0.00
% BANK STABILITY TYPE 4				
LEFT BANK	0.00	0.00	0.00	0.00
RIGHT BANK	0.00	0.00	0.00	0.00
TOTAL OF ERODING BANKS (ft.	0.00	0.00	0.00	0.00
TOTAL LRG. ORGANIC DEBRIS	0.00	0.00	0.00	0

	POOL	RIFFLE	GLIDE	REACH TOTAL
TOTAL AREA OF HABITAT (sq. f	2268.00	15456.00	15202.00	32926.00
% OF TOTAL NUM. OF HABITAT	16.67	50.00	33.33	100.00
HABITAT TYPE AS A % OF TOTAL AREA	6.89	46.94	46.17	100.00
% OF TOTAL COVERS 2 - 5 TO TOTAL HABITAT	4.41	1.62	0.99	1.52
% OF CVR 2 TO TOTAL AREA	0.00	1.62	0.99	1.21
% OF CVR 3 TO TOTAL AREA	0.00	0.00	0.00	0.00
% OF CVR 4 TO TOTAL AREA	0.00	0.00	0.00	0.00
% OF CVR 5 TO TOTAL AREA	4.41	0.00	0.00	0.30
% BANK ROCK CONTENT				
TYPE 2				
LEFT BANK	0.00	0.00	0.00	0.00
RIGHT BANK	0.00	0.00	0.00	0.00
TYPE 3				
LEFT BANK	0.00	0.00	0.00	0.00
RIGHT BANK	0.00	0.00	0.00	0.00
TYPE 4				
LEFT BANK	100.00	100.00	100.00	100.00
RIGHT BANK	100.00	100.00	100.00	100.00
TYPE 5				
LEFT BANK	0.00	0.00	0.00	0.00
RIGHT BANK	0.00	0.00	0.00	0.00
TYPE 6				
LEFT BANK	0.00	0.00	0.00	0.00
RIGHT BANK	0.00	0.00	0.00	0.00
TYPE 7				
LEFT BANK	0.00	0.00	0.00	0.00
RIGHT BANK	0.00	0.00	0.00	0.00
TYPE 8				
LEFT BANK	0.00	0.00	0.00	0.00
RIGHT BANK	0.00	0.00	0.00	0.00

AVERAGE OF SUBSTRATA TYPE FOR HABITAT ON THIS REACH

	POOL	RIFFLE	GLIDE	REACH TOTAL
PLANT DEBRIS	0.00	0.00	0.00	0.00
GRAVEL	0.00	0.00	0.00	0.00
BOULDER	75.00	66.67	62.50	68.06
SAND\SILT	0.00	0.00	0.00	0.00
RUBBLE	25.00	33.33	37.50	31.94
BEDROCK	0.00	0.00	0.00	0.00

Table A-1 concluded.

HABITAT TYPE ANALYSIS									
				TOTAL					TOTAL
NUMBER OF TYPE 2 HABITAT	0.00	0.00	0.00	0.00	NUMBER OF TYPE 9 HABITAT	0.00	0.00	0	0.00
% OF HABITAT	0.00	0.00	0.00	0.00	% OF HABITAT	0.00	0.00	0	0.00
NUMBER OF TYPE 3 HABITAT	0.00	0.00	0.00	0.00	NUMBER OF TYPE 10 HABITAT	0.00	3.00	0	3.00
% OF HABITAT	0.00	0.00	0.00	0.00	% OF HABITAT	0.00	100.00	0	50.00
NUMBER OF TYPE 4 HABITAT	1.00	0.00	0.00	1.00	NUMBER OF TYPE 11 HABITAT	0.00	0.00	0	0.00
% OF HABITAT	100.00	0.00	0.00	16.67	% OF HABITAT	0.00	0.00	0	0.00
NUMBER OF TYPE 5 HABITAT	0.00	0.00	0.00	0.00	NUMBER OF TYPE 12 HABITAT	0.00	0.00	0	0.00
% OF HABITAT	0.00	0.00	0.00	0.00	% OF HABITAT	0.00	0.00	0	0.00
NUMBER OF TYPE 6 HABITAT	0.00	0.00	0.00	0.00	NUMBER OF TYPE 13 HABITAT	0.00	0.00	0	0.00
% OF HABITAT	0.00	0.00	0.00	0.00	% OF HABITAT	0.00	0.00	0	0.00
NUMBER OF TYPE 7 HABITAT	0.00	0.00	0.00	0.00	NUMBER OF TYPE 14 HABITAT	0.00	0.00	0	0.00
% OF HABITAT	0.00	0.00	0.00	0.00	% OF HABITAT	0.00	0.00	0	0.00
NUMBER OF TYPE 8 HABITAT	0.00	0.00	0.00	0.00	NUMBER OF TYPE 15 HABITAT	0.00	0.00	0	0.00
% OF HABITAT	0.00	0.00	0.00	0.00	% OF HABITAT	0.00	0.00	0	0.00
TOTAL NUMBER OF HABITAT	1.00	3.00	2.00	6.00	NUMBER OF GLIDES	0.00	0.00	2	2.00
TOTAL % OF HABITAT	100.00	100.00	100.00	100.00		0.00	0.00	100.00	33.33

Table A-2. Habitat characteristics for Blue River Site 2.

Blue River - Site 2

9/29/21

	POOL	RIFFLE	GLIDE	REACH TOTAL
TOTAL LENGTH OF HABITAT (ft.)	136.00	967.00	623.00	1726.00
AVERAGE WIDTH OF HABITAT (	69.50	65.57	66.75	67.27
AVERAGE RESIDUAL DEPTH (ft	1.85	0.00	0.00	1.85
AVERAGE DEPTH (ft.)	1.65	0.69	0.88	1.65
TOTAL COVER TYPE 2 (sq. ft.)	0.00	0.00	100.00	100.00
AVE. TYPE 2 COVER PER UNIT	0.00	0.00	25.00	0.09
TOTAL COVER TYPE 3 (sq. ft.)	0.00	0.00	0.00	0.00
AVE. TYPE 3 COVER PER UNIT	0.00	0.00	0.00	0.00
TOTAL COVER TYPE 4 (sq. ft.)	0.00	0.00	0.00	0.00
AVE. TYPE 4 COVER PER UNIT	0.00	0.00	0.00	0.00
TOTAL COVER TYPE 5 (sq. ft.)	0.00	0.00	0.00	0.00
AVE. TYPE 5 COVER PER UNIT	0.00	0.00	0.00	0.00
% BANK STABILITY TYPE 1				
LEFT BANK	100.00	100.00	100.00	100.00
RIGHT BANK	100.00	100.00	100.00	100.00
% BANK STABILITY TYPE 2				
LEFT BANK	0.00	0.00	0.00	0.00
RIGHT BANK	0.00	0.00	0.00	0.00
% BANK STABILITY TYPE 3				
LEFT BANK	0.00	0.00	0.00	0.00
RIGHT BANK	0.00	0.00	0.00	0.00
% BANK STABILITY TYPE 4				
LEFT BANK	0.00	0.00	0.00	0.00
RIGHT BANK	0.00	0.00	0.00	0.00
TOTAL OF ERODING BANKS (ft.	0.00	0.00	0.00	0.00
TOTAL LRG. ORGANIC DEBRIS	0.00	0.00	0.00	0

	POOL	RIFFLE	GLIDE	REACH TOTAL
TOTAL AREA OF HABITAT (sq. f	8969.00	58710.00	39214.00	106893.00
% OF TOTAL NUM. OF HABITATS	15.38	53.85	30.77	100.00
HABITAT TYPE AS A % OF TOTAL AREA	8.39	54.92	36.69	100.00
% OF TOTAL COVERS 2 - 5 TO TOTAL HABITAT	0.00	0.00	0.26	0.09
% OF CVR 2 TO TOTAL AREA	0.00	0.00	0.26	0.09
% OF CVR 3 TO TOTAL AREA	0.00	0.00	0.00	0.00
% OF CVR 4 TO TOTAL AREA	0.00	0.00	0.00	0.00
% OF CVR 5 TO TOTAL AREA	0.00	0.00	0.00	0.00
% BANK ROCK CONTENT				
TYPE 2				
LEFT BANK	0.00	0.00	0.00	0.00
RIGHT BANK	0.00	0.00	0.00	0.00
TYPE 3				
LEFT BANK	0.00	0.00	0.00	0.00
RIGHT BANK	0.00	0.00	0.00	0.00
TYPE 4				
LEFT BANK	0.00	0.00	0.00	0.00
RIGHT BANK	0.00	0.00	0.00	0.00
TYPE 5				
LEFT BANK	0.00	0.00	0.00	0.00
RIGHT BANK	0.00	0.00	0.00	0.00
TYPE 6				
LEFT BANK	100.00	100.00	100.00	100.00
RIGHT BANK	100.00	100.00	100.00	100.00
TYPE 7				
LEFT BANK	0.00	0.00	0.00	0.00
RIGHT BANK	0.00	0.00	0.00	0.00
TYPE 8				
LEFT BANK	0.00	0.00	0.00	0.00
RIGHT BANK	0.00	0.00	0.00	0.00

AVERAGE OF SUBSTRATA TYPE FOR HABITAT ON THIS REACH

	POOL	RIFFLE	GLIDE	REACH TOTAL		POOL	RIFFLE	GLIDE	REACH TOTAL
PLANT DEBRIS	0.00	0.00	0.00	0.00	SAND\SILT	0.00	0.00	0.00	0.00
GRAVEL	0.00	10.71	18.75	9.82	RUBBLE	62.50	50.00	43.75	52.08
BOULDER	37.50	39.29	37.50	38.10	BEDROCK	0.00	0.00	0.00	0.00

Table A-2 concluded.

HABITAT TYPE ANALYSIS									
				TOTAL					TOTAL
NUMBER OF TYPE 2 HABITAT	0.00	0.00	0.00	0.00	NUMBER OF TYPE 9 HABITAT	0.00	0.00	0	0.00
% OF HABITAT	0.00	0.00	0.00	0.00	% OF HABITAT	0.00	0.00	0	0.00
NUMBER OF TYPE 3 HABITAT	0.00	0.00	0.00	0.00	NUMBER OF TYPE 10 HABITAT	0.00	3.00	0	3.00
% OF HABITAT	0.00	0.00	0.00	0.00	% OF HABITAT	0.00	50.19	0	23.08
NUMBER OF TYPE 4 HABITAT	0.00	0.00	0.00	0.00	NUMBER OF TYPE 11 HABITAT	0.00	3.00	0	3.00
% OF HABITAT	0.00	0.00	0.00	0.00	% OF HABITAT	0.00	47.56	0	23.08
NUMBER OF TYPE 5 HABITAT	0.00	0.00	0.00	0.00	NUMBER OF TYPE 12 HABITAT	0.00	0.00	0	0.00
% OF HABITAT	0.00	0.00	0.00	0.00	% OF HABITAT	0.00	0.00	0	0.00
NUMBER OF TYPE 6 HABITAT	0.00	0.00	0.00	0.00	NUMBER OF TYPE 13 HABITAT	0.00	0.00	0	0.00
% OF HABITAT	0.00	0.00	0.00	0.00	% OF HABITAT	0.00	0.00	0	0.00
NUMBER OF TYPE 7 HABITAT	2.00	0.00	0.00	2.00	NUMBER OF TYPE 14 HABITAT	0.00	1.00	0	1.00
% OF HABITAT	100.00	0.00	0.00	15.38	% OF HABITAT	0.00	2.25	0	7.69
NUMBER OF TYPE 8 HABITAT	0.00	0.00	0.00	0.00	NUMBER OF TYPE 15 HABITAT	0.00	0.00	0	0.00
% OF HABITAT	0.00	0.00	0.00	0.00	% OF HABITAT	0.00	0.00	0	0.00
TOTAL NUMBER OF HABITAT	2.00	7.00	4.00	13.00	NUMBER OF GLIDES	0.00	0.00	4	4.00
TOTAL % OF HABITAT	100.00	100.00	100.00	100.00		0.00	0.00	100.00	30.77

Table A-3. Habitat characteristics for Blue River Site 3.

Blue River - Site 3

9/29/21

	POOL	RIFFLE	GLIDE	REACH TOTAL		POOL	RIFFLE	GLIDE	REACH TOTAL
TOTAL LENGTH OF HABITAT (ft.)	0.00	509.00	502.00	1011.00	TOTAL AREA OF HABITAT (sq. f	0.00	30011.00	37151.00	67162.00
AVERAGE WIDTH OF HABITAT (	0.00	58.67	74.33	44.33	% OF TOTAL NUM. OF HABITATS	0.00	50.00	50.00	100.00
AVERAGE RESIDUAL DEPTH (ft	0.00	0.00	0.00	0.00	HABITAT TYPE	0.00	44.68	55.32	100.00
					AS A % OF TOTAL AREA				
AVERAGE DEPTH (ft.)	0.00	0.67	1.10	0.00					
					% OF TOTAL COVERS 2 - 5	0.00	0.00	0.27	0.15
TOTAL COVER TYPE 2 (sq. ft.)	0.00	0.00	0.00	0.00	TO TOTAL HABITAT				
AVE. TYPE 2 COVER PER UNIT	0.00	0.00	0.00	0.00					
					% OF CVR 2 TO TOTAL AREA	0.00	0.00	0.00	0.00
TOTAL COVER TYPE 3 (sq. ft.)	0.00	0.00	100.00	100.00	% OF CVR 3 TO TOTAL AREA	0.00	0.00	0.27	0.15
AVE. TYPE 3 COVER PER UNIT	0.00	0.00	33.33	0.15					
TOTAL COVER TYPE 4 (sq. ft.)	0.00	0.00	0.00	0.00	% OF CVR 4 TO TOTAL AREA	0.00	0.00	0.00	0.00
AVE. TYPE 4 COVER PER UNIT	0.00	0.00	0.00	0.00					
TOTAL COVER TYPE 5 (sq. ft.)	0.00	0.00	0.00	0.00	% OF CVR 5 TO TOTAL AREA	0.00	0.00	0.00	0.00
AVE. TYPE 5 COVER PER UNIT	0.00	0.00	0.00	0.00					
					% BANK ROCK CONTENT				
% BANK STABILITY TYPE 1					TYPE 2				
LEFT BANK	100.00	100.00	100.00	100.00	LEFT BANK	0.00	0.00	0.00	0.00
RIGHT BANK	100.00	100.00	100.00	100.00	RIGHT BANK	0.00	0.00	0.00	0.00
% BANK STABILITY TYPE 2					TYPE 3				
LEFT BANK	0.00	0.00	0.00	0.00	LEFT BANK	0.00	0.00	0.00	0.00
RIGHT BANK	0.00	0.00	0.00	0.00	RIGHT BANK	0.00	0.00	0.00	0.00
% BANK STABILITY TYPE 3					TYPE 4				
LEFT BANK	0.00	0.00	0.00	0.00	LEFT BANK	0.00	0.00	0.00	0.00
RIGHT BANK	0.00	0.00	0.00	0.00	RIGHT BANK	0.00	0.00	0.00	0.00
% BANK STABILITY TYPE 4					TYPE 5				
LEFT BANK	0.00	0.00	0.00	0.00	LEFT BANK	0.00	0.00	0.00	0.00
RIGHT BANK	0.00	0.00	0.00	0.00	RIGHT BANK	0.00	0.00	0.00	0.00
					TYPE 6				
					LEFT BANK	100.00	100.00	100.00	100.00
					RIGHT BANK	100.00	100.00	100.00	100.00
TOTAL OF ERODING BANKS (ft.	0.00	0.00	0.00	0.00					
					TYPE 7				
					LEFT BANK	0.00	0.00	0.00	0.00
					RIGHT BANK	0.00	0.00	0.00	0.00
TOTAL LRG. ORGANIC DEBRIS	0.00	0.00	0.00	0	TYPE 8				
					LEFT BANK	0.00	0.00	0.00	0.00
					RIGHT BANK	0.00	0.00	0.00	0.00
AVERAGE OF SUBSTRATA TYPE FOR HABITAT ON THIS REACH									
PLANT DEBRIS	0.00	0.00	0.00	0.00	SAND\SILT	0.00	0.00	0.00	0.00
GRAVEL	0.00	0.00	0.00	0.00	RUBBLE	50.00	50.00	58.33	52.78
BOULDER	50.00	50.00	41.67	47.22	BEDROCK	0.00	0.00	0.00	0.00

Table A-3 concluded.

HABITAT TYPE ANALYSIS

				TOTAL
NUMBER OF TYPE 2 HABITAT	0.00	0.00	0.00	0.00
% OF HABITAT	0.00	0.00	0.00	0.00
NUMBER OF TYPE 3 HABITAT	0.00	0.00	0.00	0.00
% OF HABITAT	0.00	0.00	0.00	0.00
NUMBER OF TYPE 4 HABITAT	0.00	0.00	0.00	0.00
% OF HABITAT	100.00	0.00	0.00	0.00
NUMBER OF TYPE 5 HABITAT	0.00	0.00	0.00	0.00
% OF HABITAT	0.00	0.00	0.00	0.00
NUMBER OF TYPE 6 HABITAT	0.00	0.00	0.00	0.00
% OF HABITAT	0.00	0.00	0.00	0.00
NUMBER OF TYPE 7 HABITAT	0.00	0.00	0.00	0.00
% OF HABITAT	0.00	0.00	0.00	0.00
NUMBER OF TYPE 8 HABITAT	0.00	0.00	0.00	0.00
% OF HABITAT	0.00	0.00	0.00	0.00
TOTAL NUMBER OF HABITAT	0.00	3.00	3.00	6.00
TOTAL % OF HABITAT	100.00	100.00	100.00	100.00

				TOTAL
NUMBER OF TYPE 9 HABITAT	0.00	0.00	0	0.00
% OF HABITAT	0.00	0.00	0	0.00
NUMBER OF TYPE 10 HABITAT	0.00	2.00	0	2.00
% OF HABITAT	0.00	72.46	0	33.33
NUMBER OF TYPE 11 HABITAT	0.00	1.00	0	1.00
% OF HABITAT	0.00	27.54	0	16.67
NUMBER OF TYPE 12 HABITAT	0.00	0.00	0	0.00
% OF HABITAT	0.00	0.00	0	0.00
NUMBER OF TYPE 13 HABITAT	0.00	0.00	0	0.00
% OF HABITAT	0.00	0.00	0	0.00
NUMBER OF TYPE 14 HABITAT	0.00	0.00	0	0.00
% OF HABITAT	0.00	0.00	0	0.00
NUMBER OF TYPE 15 HABITAT	0.00	0.00	0	0.00
% OF HABITAT	0.00	0.00	0	0.00
NUMBER OF GLIDES	0.00	0.00	3	3.00
	0.00	0.00	100.00	50.00