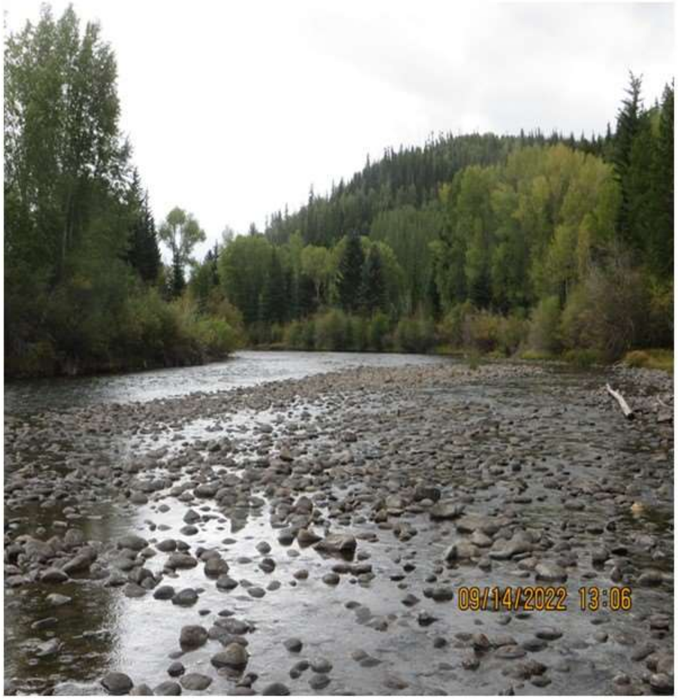
Blue River Integrated Water Management Plan

Assessment of Current Aquatic Habitat in the Blue River below Dillon Reservoir, Subreach 2.2



July 2023

TETRA TECH

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Assessment of Current Aquatic Habitat in the Blue River Below Dillon Reservoir, Subreach 2.2

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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 Dillon and Green Mountain Reservoirs. Phase 2 of the BRIWMP is the implementation of specific actions identified in Phase 1, including the development of reach-specific habitat assessments and restoration recommendations. This habitat assessment fits within Phase 2 of the BRIWMP and is the second such assessment conducted for the Blue River downstream of Dillon Reservoir. The first habitat assessment was initiated in 2021, completed in 2022, and extended from Dillon Reservoir for 2.4 miles, covering Subreach 2.1 as identified in the BRIWMP. The objective of the habitat assessment for Subreach 2.1 was to identify potential physical habitat features that may be limiting the function of the aquatic community, specifically the fishery between the Dillon and Green Mountain Reservoirs under low flow conditions.

This second habitat assessment is located within Subreach 2.2 as identified in the BRIWMP and seeks to extend a similar analysis as conducted in Subreach 2.1 at five additional sites of the Blue River from the Willow Grove Open Space at 13th Street in the Town of Silverthorne, to the Blue River Campground approximately 7.2 miles downstream from Site 3. Together Sites 2.1 and 2.2 comprise 10 miles of the Blue River downstream of the Dillon Reservoir dam outlet. For purposes of this report low flow is defined as being less than 100 cubic feet per second (cfs) which is the 'optimum' low flow that is considered protective of the fishery for long periods of time given adequate habitat (Nehring, 1988).

Between September 13 through 16, 2022, a habitat inventory was completed at the five habitat assessment sites. The inventory used a quantitative protocol developed by the U.S. Forest Service that requires the measurement of the surface area and depth of pools, riffles, and glides. In addition, the inventory requires a visual estimate of cover and stream substrate.

Survey data were also collected at these five sites including bathymetry, overbank surveys, and flow measurements. This data was used to calculate hydraulic parameters in the channel at the five habitat assessment sites for all three types of habitat including (1) wetted perimeter of the channel, (2) channel hydraulic depth, and (3) channel maximum depth. For hydraulic computations, six flows were selected between 50 and 1,000 cubic feet per second (cfs).

The results of this assessment and the assessment for Reach 2.1 showed all eight sites provide sufficient wetted perimeter even at 50 cfs, and average riffle depths are at or greater than the standards applied in minimum instream flow studies. These results indicate riffle habitat should be suitable to support benthic invertebrate production as a food source for higher trophic levels. Glide habitats across all eight sites also provide hydraulic conditions at low flows that are likely sufficient to provide foraging locations for fish. Pool habitat, however, is sparse, particularly at Sites 1 – 3 and Site 8, and where present, exhibit shallower average depths than the recommended 1.5 feet at low flows to provide adequate cover, resting, and refuge habitat. 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. Pools in Sites 4 through 8 were

associated with outside bends in the low flow channel or associated with mid-channel structures such as boulders. The limited number of pools in Sites 1 – 3 and Site 8, and the shallow depths present in all the pools may be contributing to the impairment of the trout fishery in Subreaches 2.1 and 2.2.

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, recommendations are offered to improve aquatic habitat. The recommendations are summarized below for all eight sites and described in further detail in Section 5.0 for Sites 4 through 8 of this report and in Section 5 for Sites 1 through 3 in the report prepared for Subreach 2.1 (Tt & MEC, 2022). The recommendations are as follows:

- Velocity measurements in Subreach 2.1, Site 2 at the boulder drops indicate fish passage may be impeded by these structures. The boulder drops also have created a very wide channel section with shallow depths and a lack of diversity in structure. Consider modifying the existing boulder weir drop structures and narrowing the river channel in Reach 2 to facilitate fish passage and deepen pool habitat. This could be achieved by removing the drops and adding cobble bars, small barbs, and/or constructed riffles. Coordinate with the Town of Silverthorne on plans for their kayak park and investigate the potential to incorporate the kayak park with other restoration recommendations.
- Identify other overly wide channel sections and construct bars to narrow and deepen flows. Consider the addition of wood, boulder clusters, and bank vegetation in areas lacking cover.
- Identify damaged channel banks at popular river access points where the loss of vegetation and erosion have occurred due to steep banks and frequent foot traffic. This is prevalent at Sites 1, 2, and 8. Revegetate the areas and stabilize the banks with constructed, delineated pedestrian access to the river such as gravel paths and/or steps up and down the banks.
- Modify portions of the channel to enhance the size and depth of existing pools and create new pools of sufficient depth. The flow regime and the potential for flooding impacts likely preclude the release of flows capable of scouring pools. Physical modification of the Blue River to create more pool habitat should prioritize narrower and deeper pools, located on the outer bends similar to Site 1 and Site 4.
- The absence of spawning gravels at Sites 1 through 8 indicates that suitable spawning substrate is not prevalent enough to sustain a natural reproducing population of trout in the Blue River downstream of Dillon Reservoir. While some material is being introduced through the tributaries, it is limited and does not provide sufficient amounts to support spawning until Subreach 2.3, 10 miles downstream of the Blue River Campground and just beyond the Boulder Creek confluence. The placement of spawning gravel should be considered and implemented carefully 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 deliver gravel sediment, such as the reach upstream of the Boulder Creek confluence.
- Continue to investigate the impact of water temperature, ramping of flow releases, and water quality on the biological community in the Blue River. Consider a limiting factor analysis to understand whether aquatic habitat or water quality is the greater limitation on the trout fishery.
- 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.

- Quantify river use and assess whether the number of people on the river is contributing to the decline in the trout fishery.
- Develop a monitoring program to track the impacts of restoration efforts.

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Acronyms/Abbreviations

Acronyms/Abbreviations	Definition
°C	Degrees Celsius
ACE	Annual Chance Exceedance
BRIWMP	Blue River Integrated Water Management Plan
BRWG	Blue River Watershed Group
CPW	Colorado Parks and Wildlife
FEMA	Federal Emergency Management Agency
HEC	Hydrologic Engineering Center
MEC	Miller Ecological Consultants, Inc.
TU	Trout Unlimited
USGS	U.S. Geological Survey
USFS	U.S. Forest Service

1.0 INTRODUCTION

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 and Green Mountain Reservoirs and to develop remedial measures.

Until 2016, Colorado Parks and Wildlife (CPW) designated the Blue River between the Dillon and Green Mountain Reservoirs 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). This policy decision was driven primarily by a fishery management report prepared in 2018 (Ewert, J. 2018) where CPW biologists indicated low productivity may be caused by a combination of suboptimal physical habitat under low releases from Dillon Reservoir (noted as being less than 100 cubic feet per second (cfs) (Nehring 1988) 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. Basin wide, the communities have placed a high priority on determining the cause(s) of the decline of the fishery and returning the Blue River to its once-productive condition.

Denver Water's water delivery operations from Dillon Reservoir affect the hydrology of the Blue River downstream of the Reservoir. In addition to affecting flows, the water delivery operations also impact water temperature. Regulated releases from Dillon Reservoir dam outlet 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. 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).

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 and Green Mountain Reservoirs. Phase 2 of the BRIWMP is the implementation of specific actions identified in Phase 1, including the development of reach-specific habitat assessments and restoration recommendations. In July 2022, a reach-specific habitat assessment titled *Blue River Integrated Water Management Plan. Assessment of Current Aquatic Habitat Hydrology and Hydraulics in the Blue River Downstream of the Dillon Reservoir Dam* was completed for approximately 2.5 miles of the Blue River from the Dillon Reservoir dam outlet to 13th Street located near the northern boundary of the Town of Silverthorne (Tt & MEC, 2022). This reach is identified as Subreach 2.1 in the Blue River Integrated Management Plan (BRIWMP). The habitat assessment for Subreach 2.1 evaluated conditions at three sites. Site 1 is immediately downstream of the Dillon Reservoir dam outlet, Site 2 is immediately downstream of Site 1 extending about 1,500 feet to the Silverthorne Outlets, and Site 3 is near 13th Street and the Willow Grove Open Space. This report addresses habitat conditions in Subreach 2.2, which begins at the downstream end of Subreach 2.1 and extends 7.5 miles downstream to the U.S. Forest Service (USFS) Blue River Campground. Five sites were evaluated, numbered sequentially (Sites 4 through 8) with those in Subreach 2.1 (Figure 1). Select data and pertinent information from the Subreach 2.1 habitat assessment is utilized and repeated where noted, to inform on data, assessments, and conclusions performed and conducted for Sites 4 through 8.

1.2 KEY OBJECTIVE

The assessment for both Subreach 2.1 and 2.2 focus on physical instream habitat for aquatic biota for a range of flows including low flow conditions in the Blue River downstream of the Dillon Reservoir dam outlet, and to identify potential physical habitat features that may be limiting the function of the aquatic community, specifically the fishery between Dillon and Green Mountain Reservoirs. The methodology 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). There may be other factors limiting the function of this fishery (such as water temperature and other water quality constituents), but detailed assessments of these other factors are outside the scope of this effort.

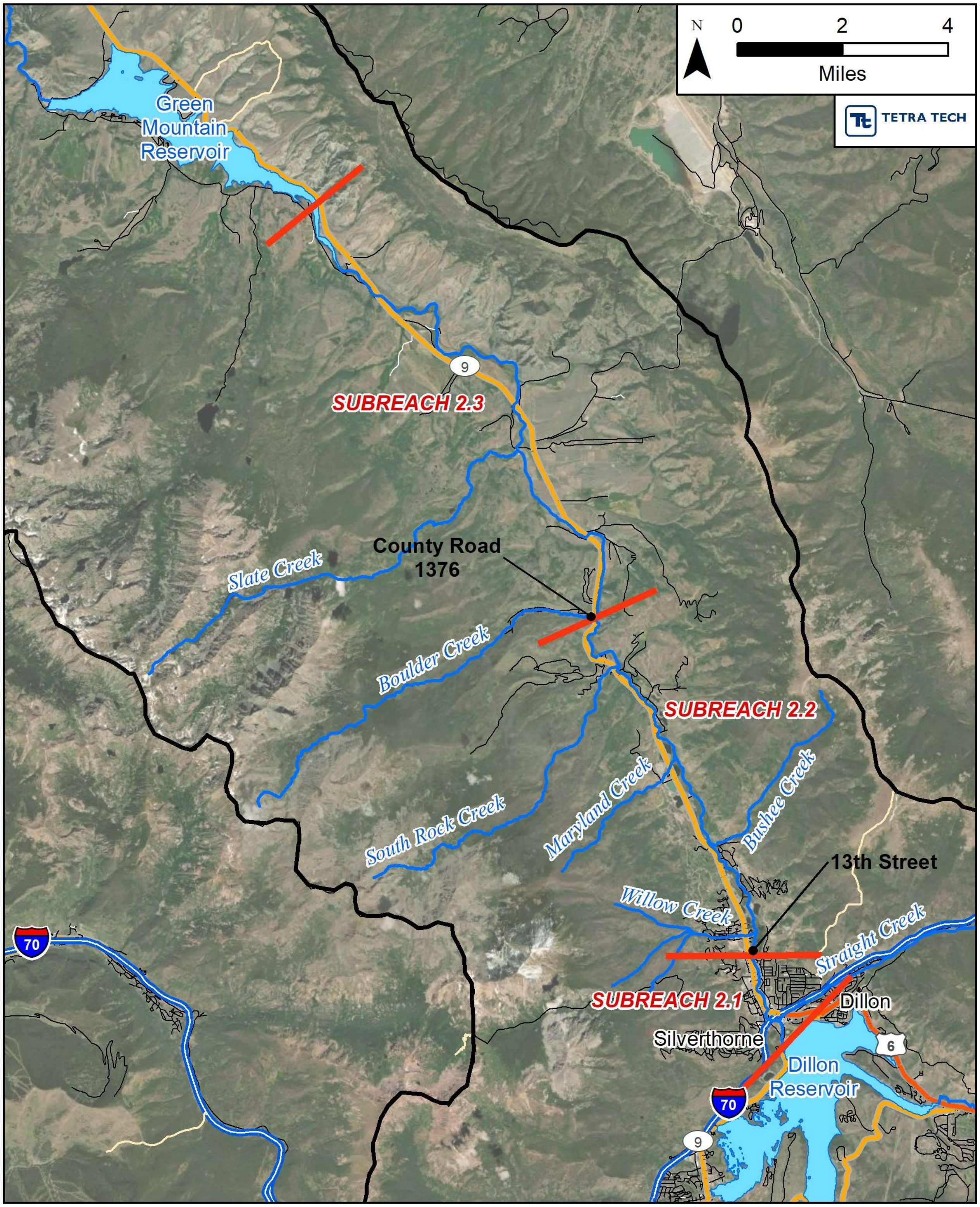


Figure 1. Subreaches of the Blue River between Dillon and Green Mountain Reservoirs

1.3 ASSESSMENT APPROACH

The approach for this habitat assessment includes 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 included channel wetted perimeter, average (hydraulic) depth of the channel, and channel maximum depth in three habitat types: riffles, glides, and pools. Riffles are straight and shallow sections of the channel with fast, turbulent water running over the channel bed. Riffle habitat is important for benthic invertebrate production and provides oxygenation to the river. Pools are deep pockets of water with slow velocities located on the outside bend of meandering streams. Pool habitat provides resting and refuge habitat for fish, especially at low flows. Glide habitat (synonymous with "Run" in some classification systems) is the transition between low velocity pool habitat and the fast velocity riffle habitat. Glide habitat is uniform in depth with very little water-surface disturbance from fast velocity and shallow depth.

This habitat assessment also includes quantification of cover, which is defined as a feature that serves to visually isolate a fish. Cover can include instream cover which are obstructions that provide shelter from excessive velocities; overhead cover such as overhanging vegetation, and pool depth cover. In addition to cover, embeddedness, the extent to which gravel cobble and boulders are surrounded by silt, sand, or mud was also assessed. Excess fine sediment on gravel beds can degrade habitat quality for stream biota.

1.4 DESKTOP ANALYSES

The first step in the habitat assessment was a desktop analysis of channel types along Reach 2 between Dillon and Green Mountain Reservoirs (Tt & MEC, 2022). Three general river channel types were identified: (1) single thread, (2) single thread with small, vegetated islands, and (3) multiple threads (Table 1). The single thread channel type comprises 84% of the channel type in all of Reach 2. The locations of small, vegetated islands and multiple threads are discontinuous over the full study reach, with side channels that are often inaccessible to the lower flow regime of interest in these studies.

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

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

A review of a pre-dam aerial map, captured in 1954 indicates the Blue River was a single thread channel for the first several miles below the current location of the Dillon Reservoir dam outlet, to about 11th Street in the Town of Silverthorne. Sinuosity is relatively low, and the channel banks are confined by vegetated banks.

Downstream of 11th Street, the Blue River planform in 1954 appeared to be single thread with small islands and/or multiple threads, except for two short reaches that are confined along the west overbank. Unlike today, however, the small islands and overbanks were not well vegetated. High season flows frequently accessed the overbanks and floodplain, depositing and moving cobbles and gravels in the overbanks, resulting in sparse vegetative cover. Many of these multiple channels and islands are still visible in 2019 aerial imagery. Since the construction of the dam, reduced peak flows have resulted in the emergence of a single thread channel with dense vegetation in the overbanks and side channels. Some of the single thread channels appear to be manmade, but most appear to be the result of reduced peak flows that are not of the magnitude required to reach the side channels and/or overbanks thereby allowing for the growth and establishment of vegetation which further confines the channel to a single thread.

1.5 FIELD RECONNAISSANCE

Between September 12 and September 17, 2022, Ksqrdfish Aquatics and Tetra Tech completed a field reconnaissance and habitat assessment of five sites in Subreach 2.2. These sites were selected for several reasons. First, these sites are located within a 'single thread' channel type which is the dominant channel type within Reach 2. Secondly, these sites are between four major tributaries and inform on flow and habitat change with changes in flow regimes from the tributaries. These five sites are numbered sequentially relative to the habitat assessment for Subreach 2.1, thus beginning with Site 4 and ending with Site 8.

Site 4 is located approximately 1 mile downstream of Site 3, midway between Bald Eagle Drive and Hamilton Creek Road. Site 5 is located upstream of Sage Creek Canyon Drive; Site 6 is located east of Maryland Creek Ranch on the Eagles Nest property upstream of Maryland Creek; Site 7 is located upstream of Antler Road adjacent to a public access area on lands managed by the USFS; and Site 8 is located at the USFS Blue River Campground. All five sites as well as Sites 1-3 in Subreach 2.1 are shown in Figure 2.

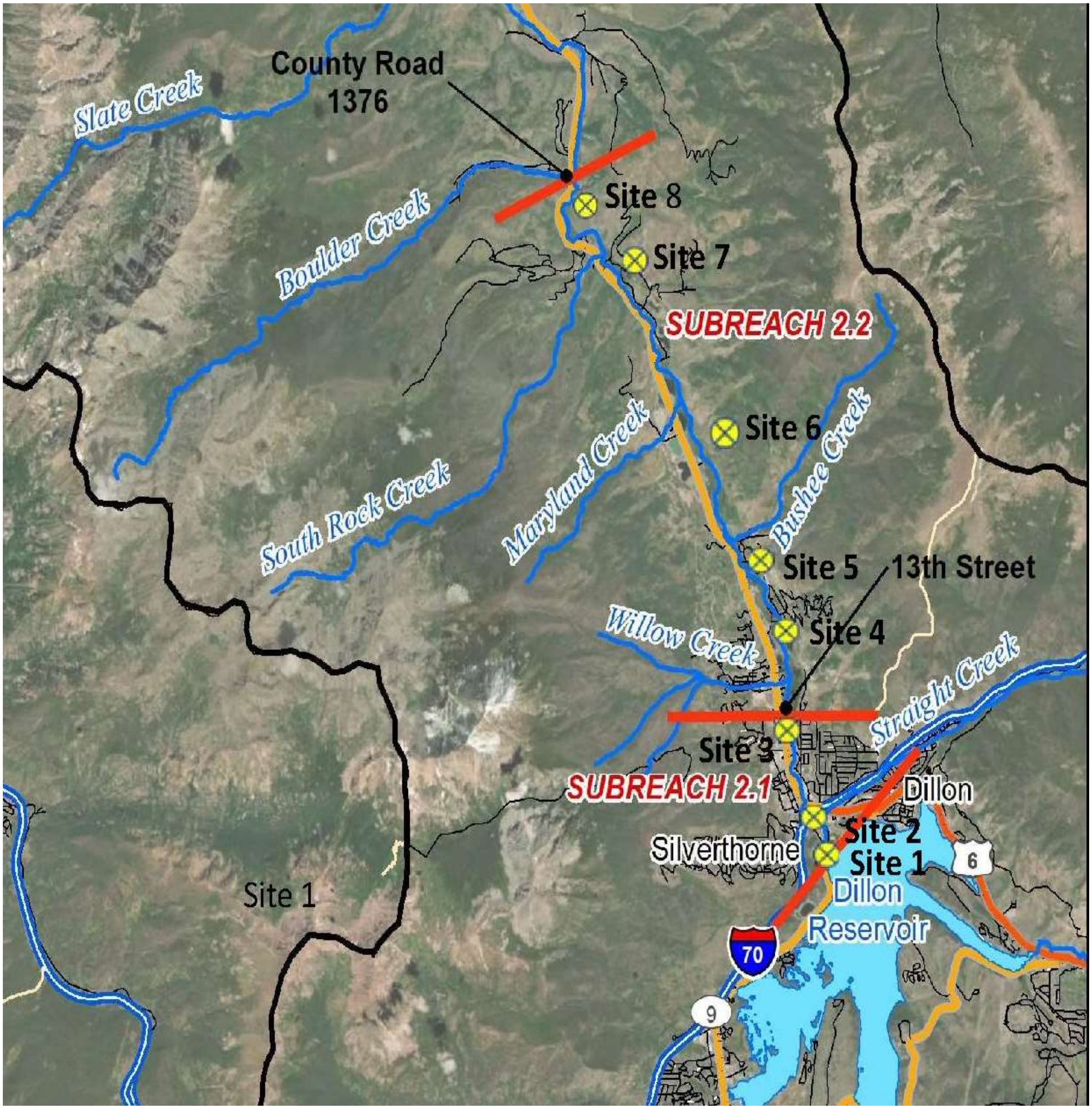


Figure 2. Habitat Assessment Study Sites

1.5.1 Site 4 – Town of Silverthorne downstream of Bald Eagle Road

The Blue River at Site 4 is relatively narrow compared to Sites 5 through 8. Habitat features are diverse with pools, glides, and riffles along a single thread channel with cobble bars and willows along the banks and floodplain. This site is located within a residential area. There is a residential development and a pedestrian bike path to the west of the river. A review of the 1954 aerial photo shows this area was primarily a single thread channel with multiple threads and large unvegetated gravel bar deposits in the overbanks. Today there are five existing ponds, three to the west and two to the east of the river. The five ponds were constructed sometime after 1954 and are gravel pits ponds. Based on visual observation, vegetation density is most abundant here compared to the other seven sites.

Figure 3. Site 4, looking downstream.

Figure 4. Site 4, looking upstream.

1.5.2 Site 5 – Sage Creek Canyon Drive

The Blue River at this location is relatively narrow with habitat features, including pools, glides, and riffles along a single thread channel and cobble bars and vegetation along the banks. Encroachments are present including residential development along the east bank, Highway 9 on the west bank, and the Sage Creek Canyon Drive bridge crossing downstream of the study site. Increased sediment is apparent due to runoff from State Highway 9. This site is approximately one-quarter mile downstream from the Blue River Wastewater Treatment Plant and increased nutrients are evident in the form of algae. There are three small ponds located immediately east of this reach, likely remnant gravel pits possibly with hydraulic conductivity to and from this reach of the Blue River. The residents in the subdivision stock the river in this area to maintain fishing quality.

Figure 5. Site 5, looking downstream.

Figure 6. Site 5, looking upstream.

1.5.3 Site 6 – Eagles Nest

The Blue River at this location is somewhat wider and shallower than the upstream sections but retains habitat features, including pools, glides, and riffles with cobble bars and vegetation along the banks. Portions of the left overbank are used for agricultural production and remnant oxbows can be seen in the fields in the 2019 Google Earth imagery. There are four gravel pit ponds located west of this reach of the Blue River, two west of State Highway 9, and two between the highway and the river. These ponds are not visible on 1985 aerial imagery so they would have been mined over the last 40 years and restored in compliance with state regulations requiring pond liners. Thus, these gravel pits may lack subsurface hydraulic connectivity with the river.

Figure 7. Site 6, looking downstream.

Figure 8. Site 6, looking upstream.

1.5.4 Site 7 – Colorado Parks and Wildlife (CPW)

This site is on lands managed by the CPW and the USFS including a popular pedestrian access off State Highway 9 near mile marker 109. The channel is wide when compared to the upstream sites and channel bar formation is less evident compared to the upstream reaches at low flows. The left overbank and the left channel banks show evidence of gravel and boulder deposits or mounds, lack of organic material, and little vegetation except for newly recruited lodgepole pine. Some of these deposits appear similar to the deposits created by gravel mining, however, further review indicates that this area may have been exposed at one time to a debris or avalanche event from the west drainage, resulting in these gravel deposits and possibly contributing to the overly wide channel.

Figure 9. Site 7 looking downstream.

Figure 10. Site 7 looking l upstream.

1.5.5 Site 8 – Blue River Campground

This site is located within USFS-managed lands including the Blue River Campground. The river at this site is moderately wide but does have one deep pool formation. Campground use and pedestrian traffic to and from the river have impacted the left channel banks and left overbanks. The upstream right channel bank is largely comprised of bedrock outcrop. The deep pool formation is located along this upstream bedrock outcrop. Further downstream the right bank transitions to a wetlands bar and the channel widens. Channel bar formation is less evident than the upstream reaches at low flows.

Figure 11. Site 8 looking upstream.

Figure 12. Site 8 looking downstream.

1.6 LOCATING HYDRAULIC MODELING CROSS SECTIONS

One cross section was selected at each site to survey and measure flows. The cross section and a channel profile were surveyed at each site to incorporate into Manning's equation to calculate uniform flow and estimate water surface depths and velocities. Manning's equation is an empirical equation that applies to uniform flow in open channels and is a function of the channel velocity, flow area, and channel slope. Calculations were performed using HEC-RAS software (HEC, 2019. Results from the Manning's Equation include the channel wetted perimeter, channel average (hydraulic) depth, and channel maximum depth for use in the habitat assessment. These results are combined with the assessment conducted in Subreach 2.1 to provide comparable values between each of the sites for these key parameters including depths and wetted perimeter in pools, glides, and riffles.

1.7 SITE SURVEYS AND FLOW MEASUREMENTS

Alden Labs was contracted to complete the bathymetric and overland survey at all five sites in Subreach 2.2 between September 26th and September 30th, 2022. In addition to survey data, flow data were also collected during this time. At each site, a representative cross section and profile were surveyed. The cross sections were located within glides to best approximate 'normal depth,' and profiles were collected to determine a representative reach slope. Where required, profiles were extended using Lidar data to supplement the surveyed profile for use in determining a representative slope. The average slope from below the Dillon Dam Reservoir outlet to the USFS Blue River Campground is estimated to be 0.7 percent varying from 0.4 to 1.9 percent along the 10-mile study area.

The bathymetric survey was carried out using a professional survey-grade Leica Total Station with a prism rod. At each site, the Total Station was located and leveled over a benchmark, either placed or existing, on stable ground with a clear view of the chosen cross section and profile lines. A second benchmark was established at each site, either on an existing object or on a place marker, to establish exact orientation. Approximate GPS coordinates and thorough descriptions of each benchmark were recorded, so that they could be precisely located in the future if desired. Once benchmarks were established at each site, cross section and profile points were recorded. Surveyed positions were annotated with geomorphic features such as the top of bank, toe of the bank, and channel bed, and hydraulic features such as the edges of the water. Cross section points were recorded approximately every foot, and profile points were recorded approximately every 5 feet. Surveyed positions were post-processed to station-elevation coordinate pairs by projecting points onto vectors defining segments of each cross section and profile. This post-processing enabled the surveyed channel morphology to be directly entered into the HEC-RAS software (HEC, 2019.).

In addition to the survey data collection, flow data was also collected at each site utilizing an OTT Hydromet MF Pro flowmeter, data collector, wading rod, and tag line/measuring tape. The chosen measurement cross sections had minimal turbulence and obstructions from boulders and pools to provide consistent and accurate flow measurements. At each chosen collection point, the tag line was set up across the channel and a spatial measurement interval was established so that between 20 and 30 measurements per cross section were collected at even spacing. Once all measurements were collected per cross section, the data collector computed the total flow at that site.

Aerial imagery of each surveyed site, coordinates, profiles, and cross sections are all provided in Appendix A.

2.0 HYDROLOGIC ANALYSES

A detailed hydrologic analysis was presented in Subreach 2.1 (Tt & MEC, 2022) for flows at the 'Blue River at Dillon' gage immediately downstream of the Dillon Reservoir dam outlet. The analysis included a review of low flows, flood flows, average daily flows, daily average flows with a 10%, 50%, and 90% exceedance probability, and flow duration curves. Ten flows were selected, ranging from 50 cfs to 1,000 cfs for assessing habitat in Subreach 2.1. For the assessment of Subreach 2.2, several intermediate flows were removed from the analysis as they showed relatively minor change in the noted parameters, leaving six flows for assessing habitat (Table 2).

Table 2. Flows selected for habitat assessment, Subreach 2.1 and 2.2

Selected Flow (cfs)	Rationale for Selection	Subreach 2.1	Subreach 2.2
50	Minimum appropriated ISF between Dillon Res. Dam and Willow Creek confluence	√	√
80	Lowest average daily average flow	√	
100	Optimum low flow and 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 wadable flow and minimum float boating flow	√	√
500	10 percent exceedance based on average of daily average flows WY88-WY21	√	√
600	Intermediate flow between and approximately the 1 to 2 yr flow	√	
1,000	Optimum flow for kayaking (Sanderson, 2012)	√	√

Bankfull discharge is defined as the dominant channel forming flow and is correlated to the maximum discharge the channel can convey without overtopping onto the floodplain, often correlated with the 1 to 2-year flow in natural undisturbed riverine systems. Based on the hydrologic analysis of the Blue River developed for Subreach 2.1 the 2-year flow (50% annual peak exceedance) is 1,280 cfs at the USGS Gage 0905700 located downstream of the Dillon Reservoir outlet.

An additional hydrologic analysis was completed to compare flows in the Blue River released from the Dillon Reservoir dam outlet to flows entering Green Mountain Reservoir. This analysis used USGS recorded flows released from the Dillon Reservoir dam outlet at gaging station 09050700 and the U.S. Bureau of Reclamation back-calculated inflows to Green Mountain Reservoir based on reservoir stage changes. The preliminary analysis focused on water year 2021 which shows that the inflow to Green Mountain Reservoir is at minimum about twice the release from the Dillon Reservoir dam outlet, measured at the downstream end of Green

Mountain Reservoir. Between September 26 and 30, 2022 flows were measured in Sites 4 through 8 and immediately upstream of Green Mountain Reservoir (downstream of the State Highway 9 bridge) near the turn-off to Heeney. Average flow releases out of the Dillon Reservoir dam outlet were reported to be 56 cfs at the USGS Gage 0905700 located downstream of the Dillon Reservoir with Sites 4 through 8 measured at approximately 59 to 88 cfs respectively. Flows upstream of Green Mountain Reservoir were measured at 120 cfs, confirming the initial conclusion that low flows at Green Mountain Reservoir are approximately double the releases from the Dillon Reservoir dam outlet.

This habitat assessment also required an estimate of flows at Sites 4 through 8 for a range of flows relative to the flows being released out of the Dillon Reservoir dam outlet. This was accomplished by averaging the discharges per square mile below Dillon Reservoir for both the surveyed flows and 2-year flows calculated using StreamStats (USGS 2022) to develop a blended rate of flow increase below Dillon Reservoir. The 'rate of increase' was multiplied by the drainage area below Dillon Reservoir for each site and then added to the flows being released out of the reservoir to estimate total flow at each site for the specified flow event.

This was done for each site assuming Dillon Reservoir dam outlet releases of 100 cfs to 1,000 cfs. Minimum instream flows are also provided (Table 3).

Table 3. Flows selected for habitat assessment, cfs

Dillon Releases (cfs)	Flows at sites (cfs)	Site 4	Site 5	Site 6	Site 7	Site 8
Instream flows versus surveyed flows						
	Surveyed flows (Sept 26-30, 2022)	59	73	74	76	88
	Minimum appropriated ISF downstream of Dillon Reservoir (at time of the survey, Sept 26-30, 2022)	75	75	75	75	90
Flows utilized to calculate hydraulic parameters for habitat assessments						
50	Minimum flows	59	73	74	76	88
100	Average daily average flow during winter months (Nov. – Mar., inclusive)	107	107	109	111	113
200	Anecdotally fills channel in widest reaches upstream of Willow Creek confluence	213	215	218	221	227
400	Anecdotal maximum wadable flow and minimum float boating flow	426	429	436	442	453
500	10 percent exceedance based on average of daily average flows WY88-WY21	533	537	545	553	566
1,000	Optimum flow for kayaking (Sanderson, 2012)	1066	1073	1089	1106	1133

3.0 HABITAT ASSESSMENT

3.1 HABITAT INVENTORY

The habitat inventory was conducted on September 13-15, 2022, at all five sites for the three habitat types; pools, riffles, and glides or runs. Daily average flow in the Blue River averaged from 59 cfs at Site 4 to 88 cfs at Site 8. The habitat inventory used a quantitative protocol developed for trout by the USFS (Winters and Gallager, 1997) to estimate physical habitat under low flow conditions. The methodology measures the area of each habitat type and the average depth of each habitat type and conducts visual estimates for cover and stream substrate. The quantitative approach provides a means to compare habitat across sites.

The length and width of each individual habitat were measured 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. Photos at each site were taken and are presented in Section 1.5 of this report. 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 the preparation of graphs for each site. The output for each of the sites was summarized into tables for comparison. To facilitate comparisons, these tables also include the results from Subreach 2.1, Sites 1-3 (Tt & MEC, 2022). Visual estimates of substrate type in each habitat type were also made and recorded, noting the approximate percentage of sand/silt (< 0.079 in.), gravel (0.079 – 2.5 in), cobble (2.5 - 10.1 in.), boulders (>10.1 inches) and bedrock. Embeddedness was assessed using visual observations and observations of rock mobility while wading in the channel during the habitat inventory.

Pie charts illustrate the distribution of habitat and cover types in each of the sites (Figures 13 through 17). 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 five sites (Figures 18 through 22).

Table 4. Percentages of substrate type by habitat assessment sites

Site	Habitat	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
4	Pool	0	8	37	55	0
	Riffle	0	10	55	35	0
	Glide	0	5	50	45	0
	Overall	0	8	48	45	0
5	Pool	0	5	15	80	0
	Riffle	0	0	10	85	5
	Glide	0	0	5	95	0
	Overall	0	2	10	86	2
6	Pool	0	10	60	30	0
	Riffle	5	5	90	0	0
	Glide	0	15	75	10	0
	0verall	0	10	70	20	0
7	Pool	13	12	75	0	0
	Riffle	0	12	88	0	0
	Glide	0	10	90	0	0
	Overall	5	11	84	0	0
8	Pool	0	5	30	60	5
	Riffle	0	7	93	0	0
	Glide	0	15	82	3	0
	0verall	0	9	68	21	2

Table 5. Results of Habitat Inventory

Parameter	Habitat Type	Site 1	Site 2	Site 3	Site 4 TOS	Site 5 Sage	Site 6 Eagle	Site 7 CPW	Site 8 Cmpg
Length (feet)	Total	726	1,726	1,011	616	464	679	616	842
	Pool	50	145	0	210	143	331	204	145
	Riffle	340	948	452	244	267	114	225	328
	Glide	335	633	559	161	154	234	188	368
Percent of Total Length	Pool	6.9	8.4	0	34.1	30.2	44.3	36.3	14.1
	Riffle	46.9	54.9	44.7	39.6	44.0	18.0	36.9	39.4
	Glide	46.2	36.7	55.3	26.2	25.8	37.7	27.7	46.5
Average Depth (feet)	Pool	2.0	1.7	0	2.2	1.8	2.2	1.6	2.7
	Riffle	1.1	0.7	0.7	0.9	0.9	0.8	0.7	0.9
	Glide	1.2	0.9	1.1	1.7	1.7	1.21	1.2	0.9
Average Width (feet)	Pool	42.0	69.5	0	38.2	51.9	45	63	65.7
	Riffle	38.7	65.6	58.7	39.6	64.7	56	68	79.6
	Glide	49.5	66.8	74.3	42.6	41.1	52	57	85.4
Residual Pool Average Depth (feet)	n/a	2.4	1.9	0	1.4	1.7	1.2	0.9	2.5

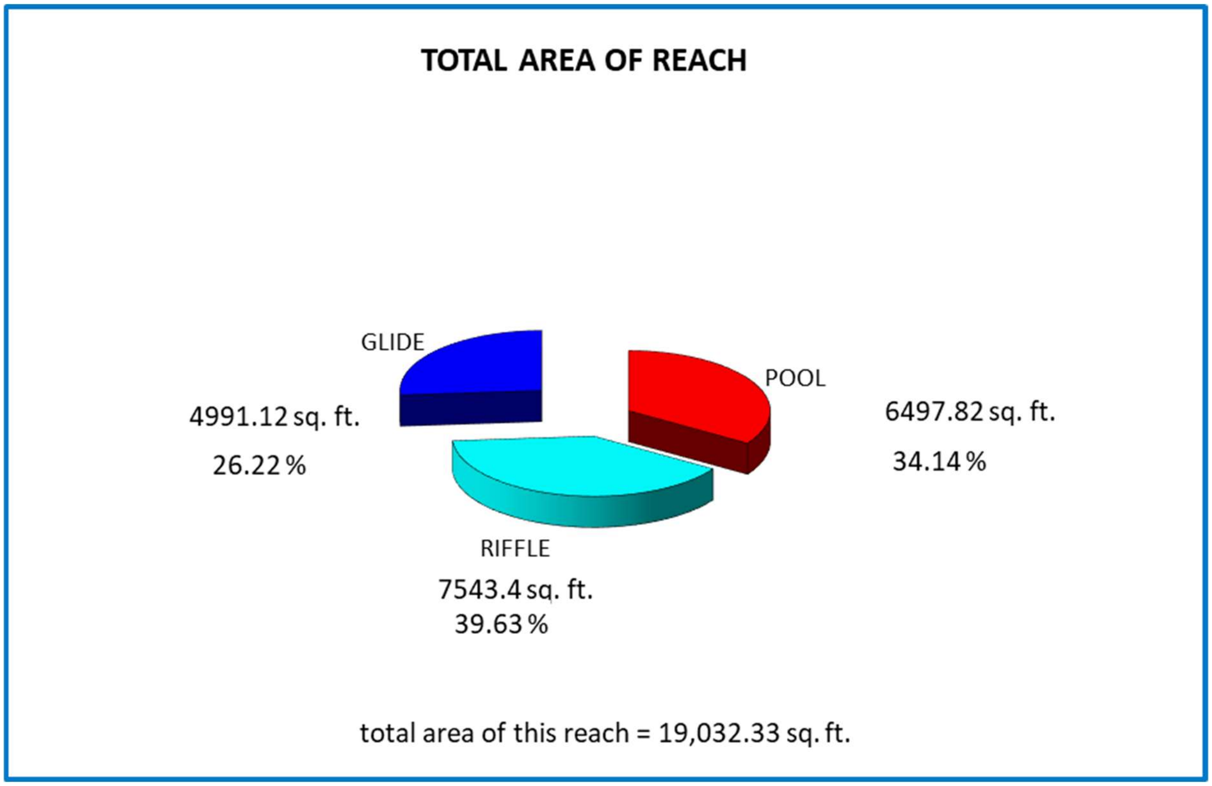


Figure 13. Habitat assessment Subreach 2.2, Site 4 Town of Silverthorne, habitat area by habitat type.

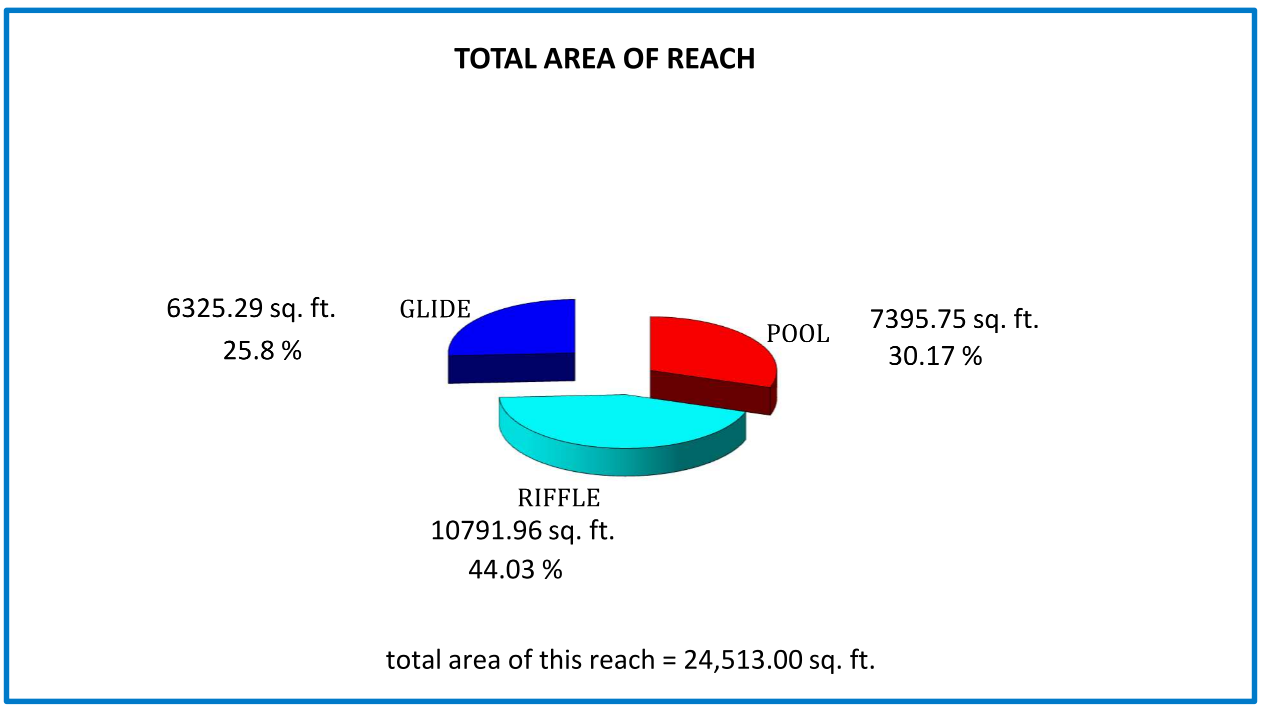


Figure 14. Habitat assessment Subreach 2.2, Site 5 Sage Creek, habitat area by habitat type.

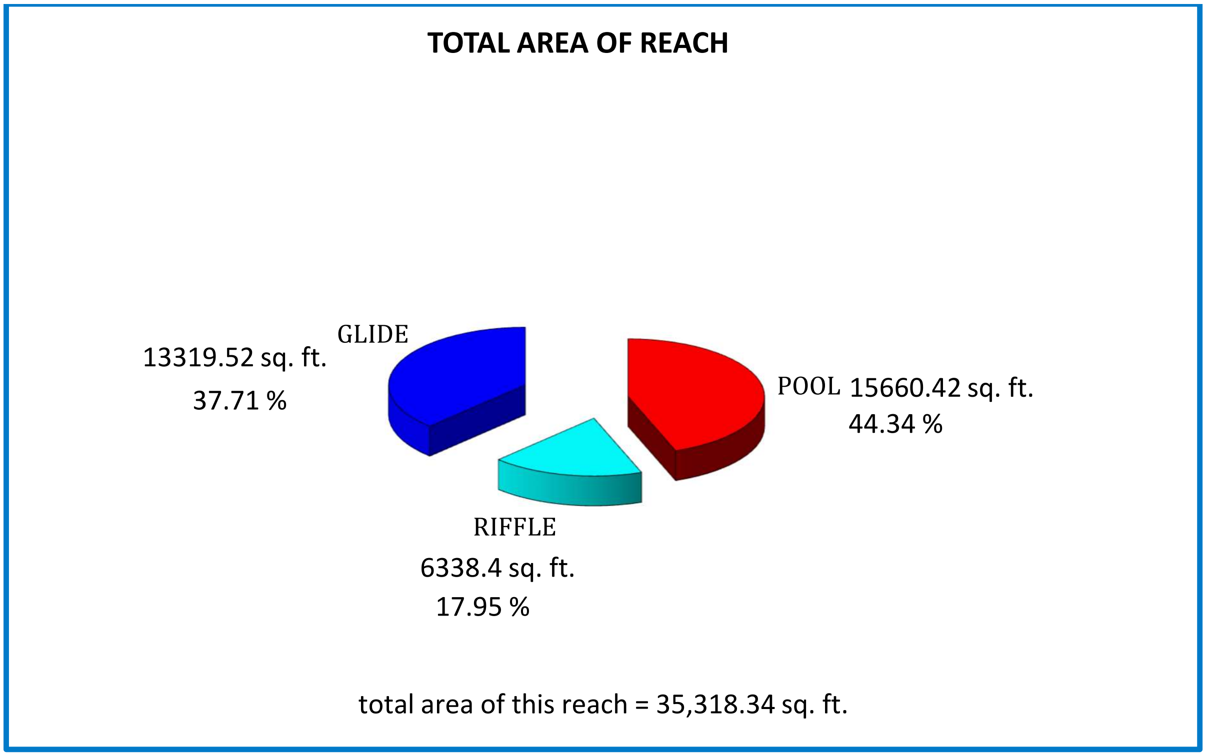


Figure 15. Habitat assessment Subreach 2.2, Site 6 Eagles Nest, habitat area by habitat type.

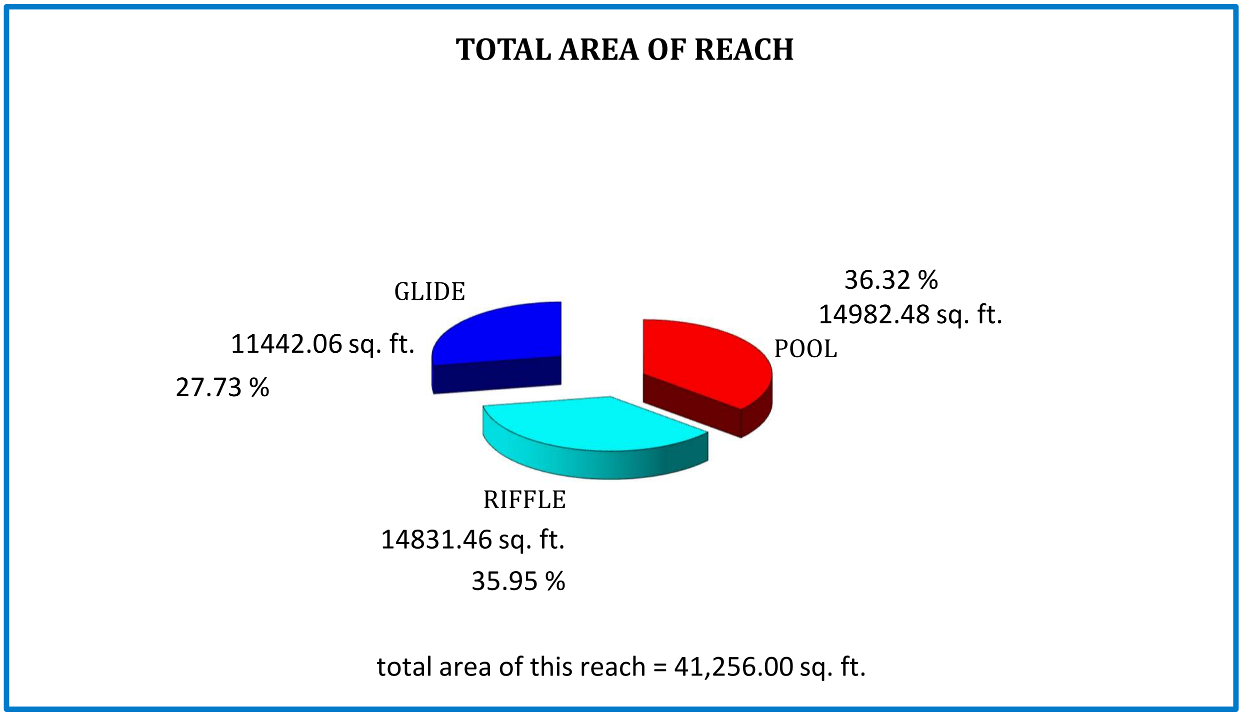


Figure 16. Habitat assessment Subreach 2.2, Site 7 CPW, habitat area by habitat type.

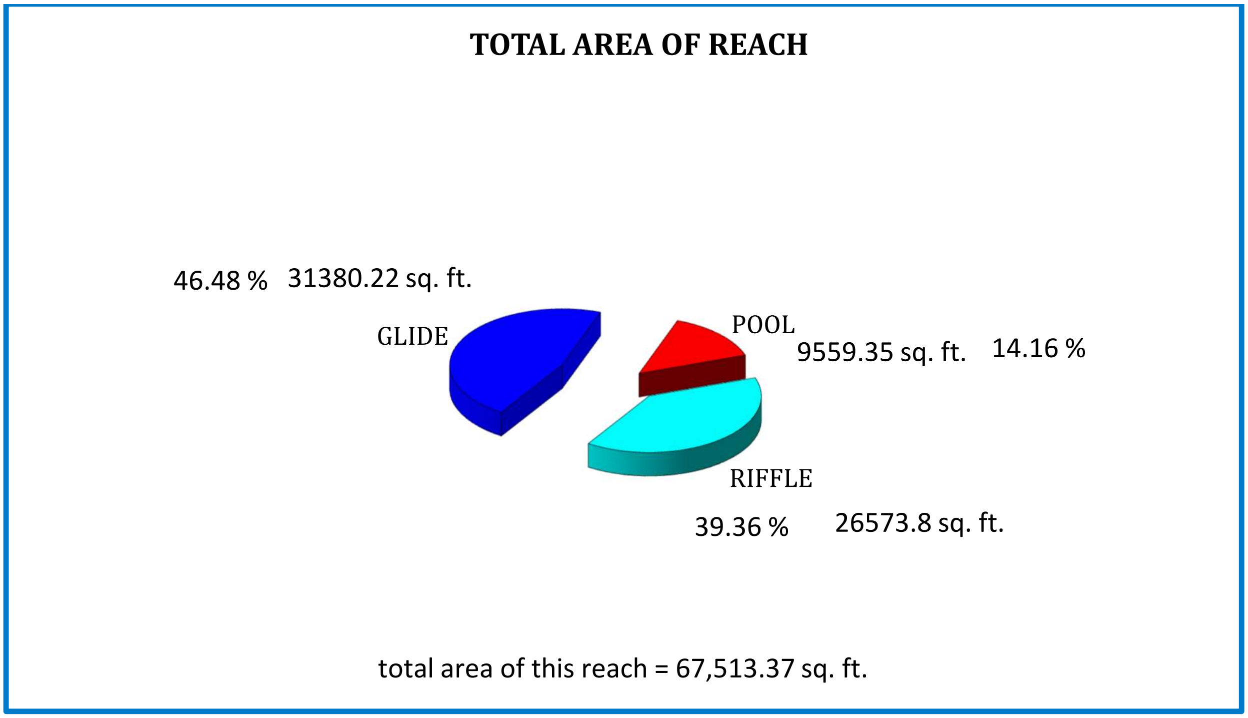


Figure 17. Habitat assessment Subreach 2.2, Site 8 USFS Campground, habitat area by habitat type.

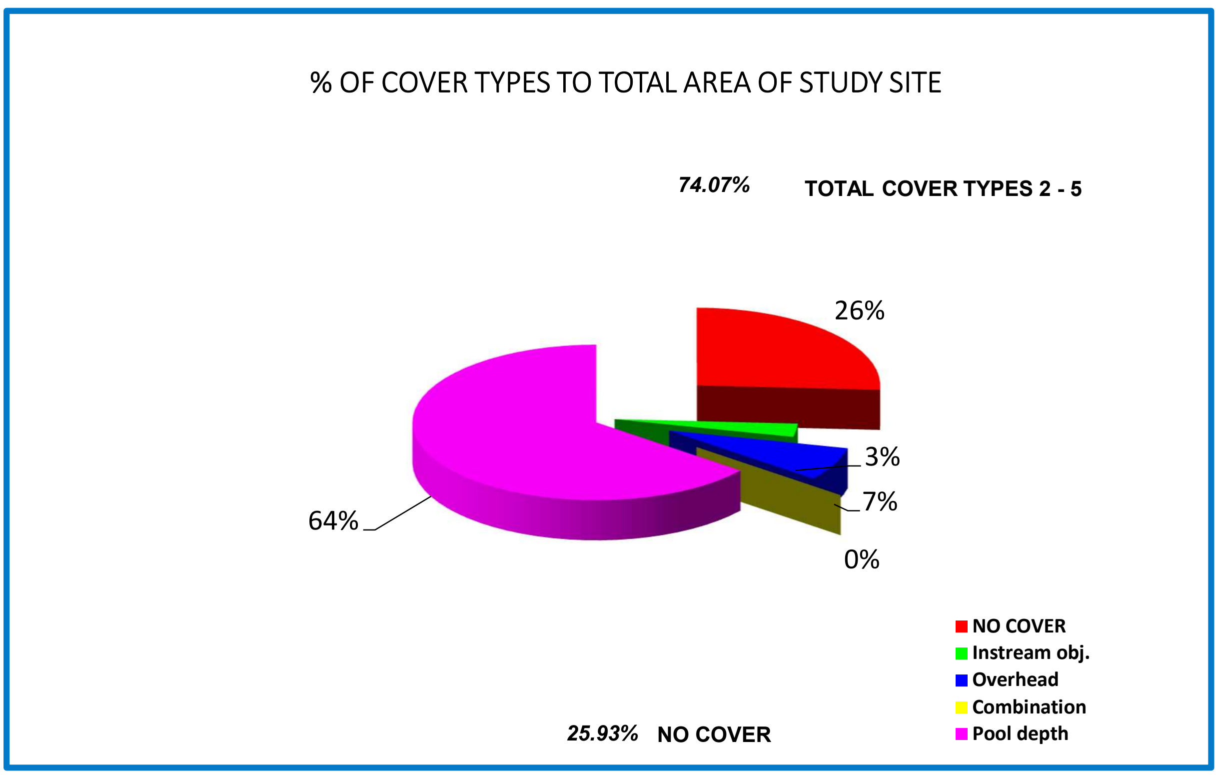


Figure 18. Habitat assessment Subreach 2.2, Site 4, Town of Silverthorne, percent cover by cover type.

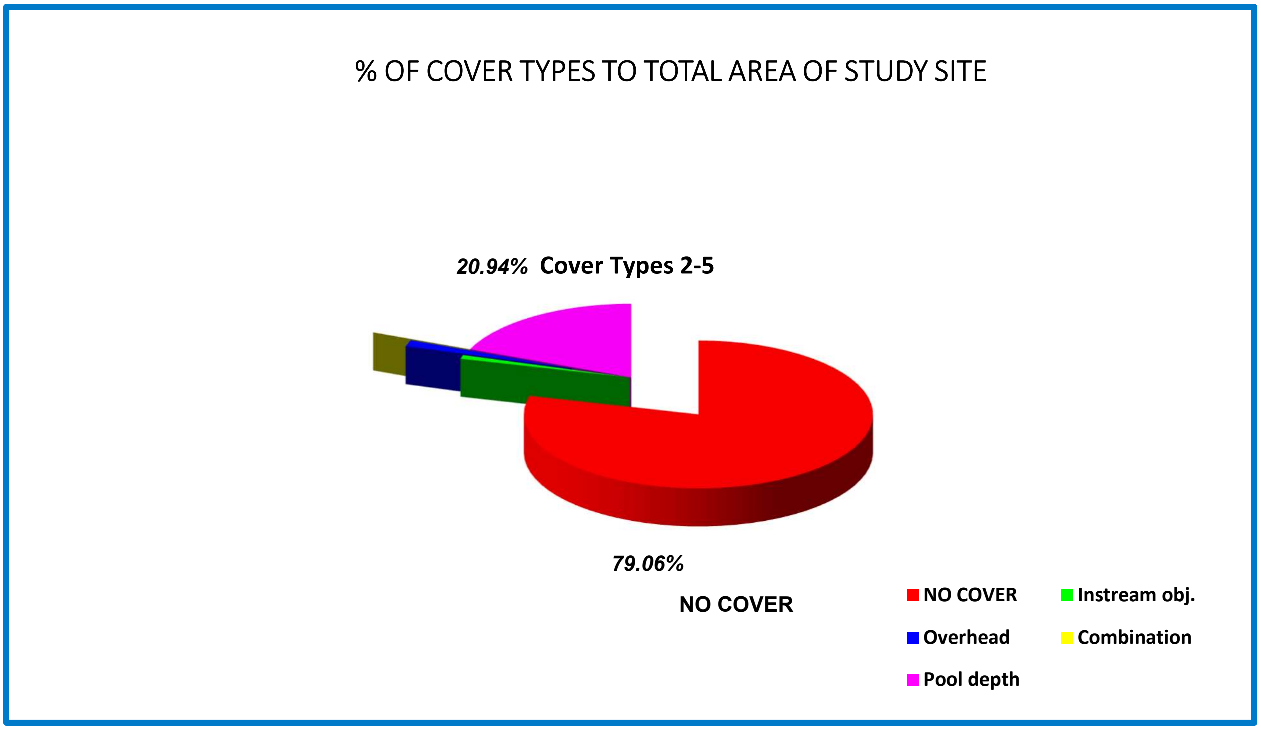


Figure 19. Habitat assessment Subreach 2.2 Site 5, Sage Creek Canyon Drive, percent cover by cover type.

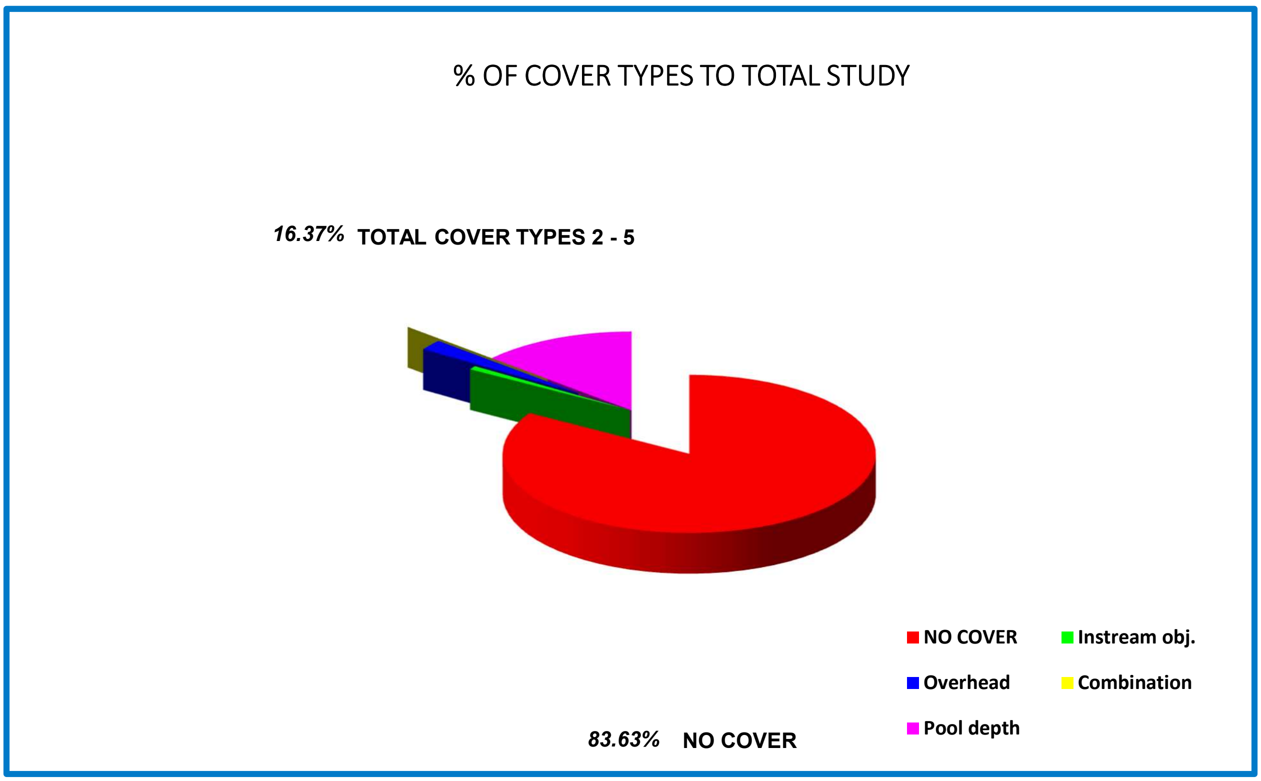


Figure 20. Habitat assessment Subreach 2.2 Site 6, Eagles Nest, percent cover by cover type.

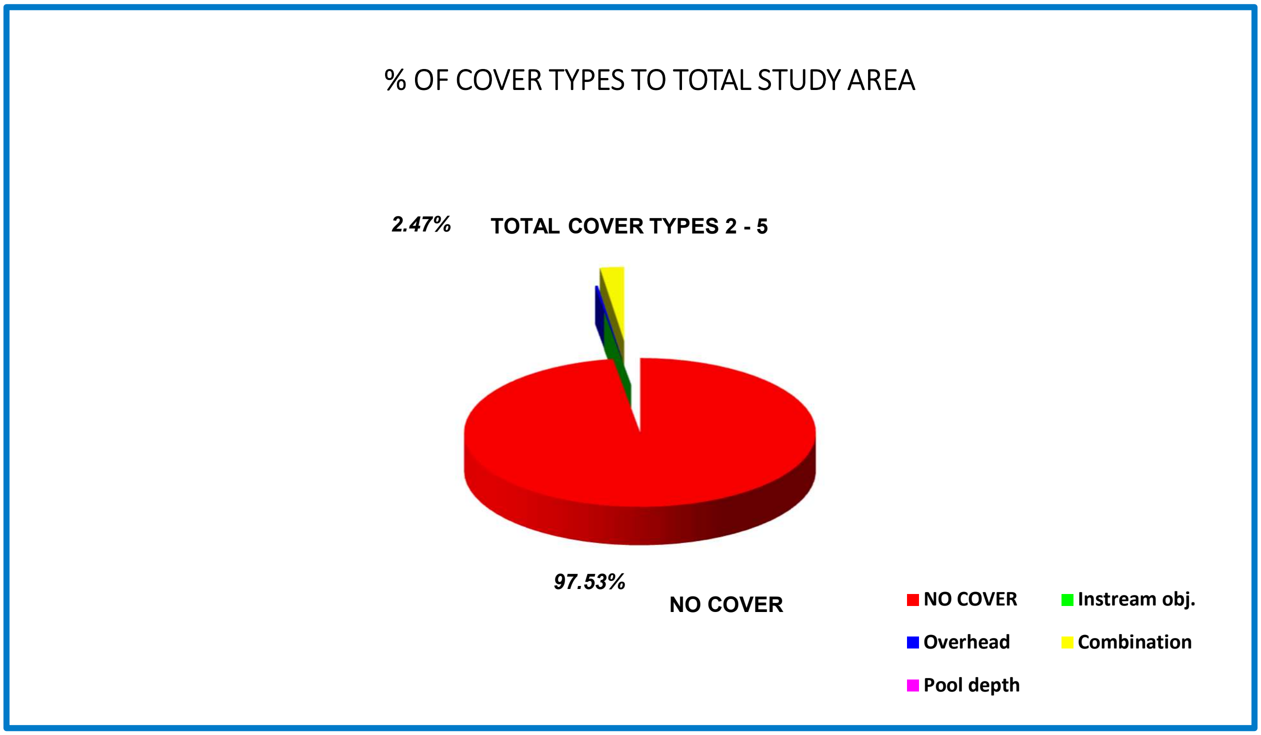


Figure 21. Habitat assessment Subreach 2.2 Site 7, CPW, percent cover by cover type.

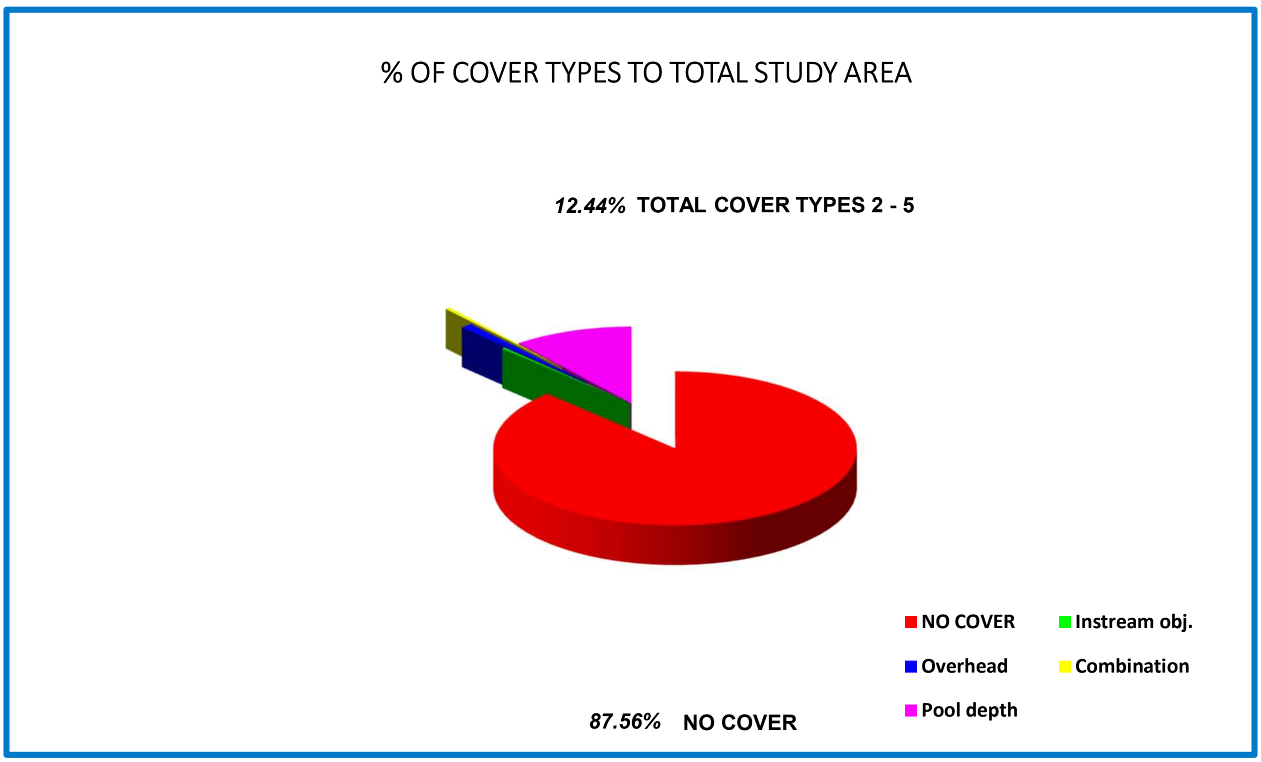


Figure 22. Habitat assessment Subreach 2.2 Site 8, USFS Campground, percent cover by cover type.

3.1.1 Site 4 – Town of Silverthorne downstream of Bald Eagle Road

Stream habitat at Site 4 is comprised primarily of pools (47.4%) and glides (39.9%). Pools were associated with the outside of the meanders seen in this area and averaged 2.0 feet deep (Table 5). Pool depth provides the dominant cover, with a limited overhead cover created by riparian willows. The channel substrate at Site 4 was predominantly small to medium size boulders and large cobbles (Table 4). Spawning gravels did not appear to be available in any quantities. Floodplain connectivity was limited to the point bars and a portion of the right overbank. Willows are encroaching onto the point bars. This site has the highest percentage of cover habitat compared to the other seven sites (Figure 18).

3.1.2 Site 5 – Sage Creek Canyon Drive

Riffle habitat features comprise 44% of the stream reach at Site 5 with pools making up approximately 30% of the stream reach. There is a significant loss of cover compared to Site 4 and the stream is wider than Site 4. Small to medium size boulders are the dominant substrate, with a larger portion of the substrate covered by algae due to nutrient influx from the local water treatment facility. Lesser amounts of sand deposits were observed in this reach, generated from winter sanding operations along State Highway 9 immediately to the west of the river.

3.1.3 Site 6 – Eagles Nest

Long shallow pools make up 44% of the habitat surveyed and glides make up 37%. The total cover is lower compared to Site 5 and is limited to pool depth. This is the first site where cobble comprises the majority of substrate (70%). Gravels are present (10%) and available for spawning. There is likely some connection to the floodplain on the left or west bank and there is evidence of active beaver use along the channel edges in one of the pools. The east or right bank showed some areas of exposed banks potentially from erosion during higher flows. There is a split side channel immediately upstream of the assessment area.

3.1.4 Site 7 – Colorado Parks and Wildlife (CPW)

While 36.3% of this site is comprised of pools, the overly wide channel, and shallow pools provide no cover, except for woody debris and willows associated with the pool edge. Glides (27.7%) and riffles (36.0%) comprise the remaining habitat features. Cobble is the dominant substrate with some gravel, sand, and silt in the areas of lower velocity associated with small pools along the right bank.

3.1.5 Site 8 – Blue River Campground

Glides (46.5%) and riffles (39.4%) comprise most of the habitat features at this site. Glide depths are shallow, and similar in depth to riffle sections, thus providing little to no cover (Table 5, Figure 22). One large pool associated with a bedrock outcrop on the right bank provides the only cover observed at this site with a residual pool depth deeper than in the upstream pools. The pool has several medium to large boulders that provide combination cover in the pool habitat. Overall, the cover component remained lower than in upstream narrower channels, however, some boulders in the glides would provide additional cover at higher flows. Spawning-sized gravels are available in small areas of the glide and riffle habitat.

3.1.6 Summary

Overall, the pool quality in Subreach 2.2 is poor. Pools lack quality due to shallow depth and lack of instream cover components such as boulders or wood. At higher flows, glides may create low quality pool habitat, however with limited instream structure that slow velocities, pools created by glides would provide very little quality fish habitat or cover. This is also the case for pools at low flows which provide little or no adequate cover for fish. The channel at Sites 5 through 8 is overly wide and lacks connection with the floodplain that would otherwise provide nutrients and velocity shelters for various life stages of fish populations.

The habitat inventory shows that Site 4 is the narrowest, most naturally appearing channel, with hydraulic conditions during low flows more conducive to supporting aquatic habitat for all aquatic species including trout. Compared to Sites 5 through 8, Site 4 has several pools averaging 1.7 feet. Site 8 is the widest of the sites and provides very little cover.

The stream substrate is comprised of cobbles and boulders with very few gravels and little to no sand or silts (Table 4). While some improvement is seen in the downstream sites, there remains a limited amount of gravel ranging in size from 0.5 to 1.0 inches needed for successful trout spawning. The channel bed at all study sites was free of silt, sand, and mud, and the substrate easily mobilized, indicating embeddedness is not present and therefore not a factor in the quality of aquatic habitat for stream biota.

3.2 HYDRAULIC HABITAT ASSESSMENT

A hydraulic model was developed to estimate relationships between channel hydraulics and low flow at the five habitat sites in Subreach 2.2. 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 all under low flow conditions. The model results are consistent with conditions observed and measured in the field and of a sufficient level of detail to inform on the channel hydraulics relative to flow. The hydraulic habitat assessment results are compared by habitat type for a range of flows from 50 to 1000 cfs. To avoid confusion the flows referenced in the tables, figures, and summaries are referenced using the volumetric flow releases at the Dillon Reservoir dam outlet. The actual hydraulics however were calculated using the flows outlined in Table 3. For example, a reference to 50 cfs would be 50 cfs at the Dillon Reservoir dam outlet, 59 cfs at Site 4, 73 cfs at Site 5, etc. Details of the model development and calibration are provided in Appendix B.

The cross sections were aggregated by major habitat type (i.e., pool, riffle, and glide), and the average for each parameter was calculated for each site (Tables 6-8). 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 23 riffle habitat rating curves are shown in Figure 26, and glide habitat rating curves are shown in Figure 29. To facilitate comparisons with Subreach 2.1 Tables 6-8 and Figures 23-31 include the results from Sites 1 through 3.

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

Parameter[1] ft	Flow at Dillon Res. Dam Outlet, cfs				
	50	100	200	400	1000
Site 1 Chnl. W.P.	34.0	42.4	53.9	60.0	60.0
Site 2 Chnl. W.P.	91.8	106.3	113.2	114.4	114.4
Site 3 Chnl. W.P.	60.3	64.6	67.9	67.9	67.9
Site 4 Chnl. W.P.	49.5	51.6	52.0	52.2	52.2
Site 5 Chnl. W.P.	56.6	59.0	62.8	65.0	67.7
Site 6 Chnl. W.P.	72.8	74.5	77.4	78.2	78.2
Site 7 Chnl. W.P.	66.1	68.5	70.4	72.0	73.0
Site 8 Chnl. W.P.	87.5	91.3	99.0	101.1	101.9
Site 1 Chnl. h_d	1.2	1.4	1.7	2.3	3.7
Site 2 Chnl. h_d	0.8	1.0	1.4	2.0	3.2
Site 3 Chnl. h_d	1.0	1.2	1.6	2.1	3.4
Site 4 Chnl. h_d	1.6	2.2	2.9	3.8	5.5
Site 5 Chnl. h_d	1.6	1.8	2.3	3.0	4.5
Site 6 Chnl. h_d	1.4	1.6	2.1	2.8	4.2
Site 7 Chnl. h_d	1.6	1.9	2.5	3.2	4.8
Site 8 Chnl. h_d	1.5	1.6	2.1	2.8	4.2
Site 1 Chnl. h_{max}	2.1	2.6	3.3	4.1	5.5
Site 2 Chnl. h_{max}	1.8	2.1	2.5	3.2	4.4
Site 3 Chnl. h_{max}	1.3	1.6	2.1	2.7	3.7
Site 4 Chnl. h_{max}	3.1	3.6	4.3	5.2	6.9
Site 5 Chnl. h_{max}	2.2	2.4	3.0	3.8	5.4
Site 6 Chnl. h_{max}	2.4	2.6	3.2	3.9	5.3
Site 7 Chnl. h_{max}	2.4	2.7	3.3	4.1	5.7
Site 8 Chnl. h_{max}	2.1	2.3	2.9	3.6	5.0

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] ft	Flow at Dillon Res. Dam Outlet , cfs				
	50	100	200	400	1000
Site 1 Chnl. W.P.	36.6	52.3	65.4	68.3	68.3
Site 2 Chnl. W.P.	53.6	62.7	70.5	75.2	77.3
Site 3 Chnl. W.P.	57.6	64.9	68.9	69.0	69.0
Site 4 Chnl. W.P.	32.5	47.1	51.2	52.0	52.2
Site 5 Chnl. W.P.	58.2	60.3	65.5	67.7	67.7
Site 6 Chnl. W.P.	71.6	73.2	76.8	78.2	78.2
Site 7 Chnl. W.P.	64.1	66.9	70.0	71.5	73.0
Site 8 Chnl. W.P.	71.5	76.2	91.1	98.8	101.9
Site 1 Chnl. h_d	1.0	1.1	1.4	2.2	3.6
Site 2 Chnl. h_d	0.7	0.9	1.3	1.9	3.1
Site 3 Chnl. h_d	0.6	0.9	1.3	2.0	3.3
Site 4 Chnl. h_d	1.1	1.2	1.7	2.6	4.2
Site 5 Chnl. h_d	1.6	1.8	2.3	3.1	4.8
Site 6 Chnl. h_d	1.2	1.4	1.9	2.6	4.1
Site 7 Chnl. h_d	1.4	1.6	2.2	3.0	4.6
Site 8 Chnl. h_d	1.0	1.1	1.5	2.0	3.3
Site 1 Chnl. h_{max}	1.6	2.0	2.7	3.4	4.9
Site 2 Chnl. h_{max}	1.2	1.6	2.1	2.8	4.0
Site 3 Chnl. h_{max}	1.0	1.4	1.8	2.5	3.8
Site 4 Chnl. h_{max}	1.9	2.4	3.1	3.9	5.5
Site 5 Chnl. h_{max}	2.2	2.5	3.2	4.0	5.8
Site 6 Chnl. h_{max}	2.1	2.4	3.0	3.7	5.2
Site 7 Chnl. h_{max}	2.1	2.3	3.0	3.9	5.5
Site 8 Chnl. h_{max}	1.4	1.6	2.2	2.9	4.2

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]	Flow at Dillon Res. Dam Outlet , cfs				
	50	100	200	400	1000
Site 1 Chnl. W.P.	41.4	50.0	62.9	70.6	70.7
Site 2 Chnl. W.P.	61.3	73.8	80.2	82.3	83.0
Site 3 Chnl. W.P.	64.1	68.3	70.2	71.5	71.9
Site 4 Chnl. W.P.	36.9	40.0	42.3	51.5	52.1
Site 5 Chnl. W.P.	42.5	49.4	54.6	60.1	67.7
Site 6 Chnl. W.P.	55.4	60.1	67.6	75.6	77.2
Site 7 Chnl. W.P.	51.3	54.4	61.1	66.7	71.4
Site 8 Chnl. W.P.	65.2	67.8	85.8	97.1	101.9
Site 1 Chnl. h_d	0.8	1.1	1.4	2.0	3.4
Site 2 Chnl. h_d	0.9	1.2	1.6	2.2	3.4
Site 3 Chnl. h_d	1.0	1.3	1.7	2.3	3.5
Site 4 Chnl. h_d	0.9	1.3	1.8	2.3	3.8
Site 5 Chnl. h_d	0.8	0.9	1.4	1.9	3.8
Site 6 Chnl. h_d	0.8	1.0	1.4	1.9	3.0
Site 7 Chnl. h_d	0.9	1.1	1.5	2.1	3.3
Site 8 Chnl. h_d	0.8	1.0	1.3	1.8	3.0
Site 1 Chnl. h_{max}	1.4	1.8	2.4	3.2	4.6
Site 2 Chnl. h_{max}	1.5	2.0	2.5	3.1	4.3
Site 3 Chnl. h_{max}	1.4	1.7	2.2	2.8	4.0
Site 4 Chnl. h_{max}	1.9	2.3	2.9	3.7	5.1
Site 5 Chnl. h_{max}	1.1	1.4	1.9	2.6	4.4
Site 6 Chnl. h_{max}	1.6	1.8	2.3	2.9	4.1
Site 7 Chnl. h_{max}	1.4	1.6	2.2	1.8	4.2
Site 8 Chnl. h_{max}	1.2	1.3	1.9	2.6	3.9

Note:

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

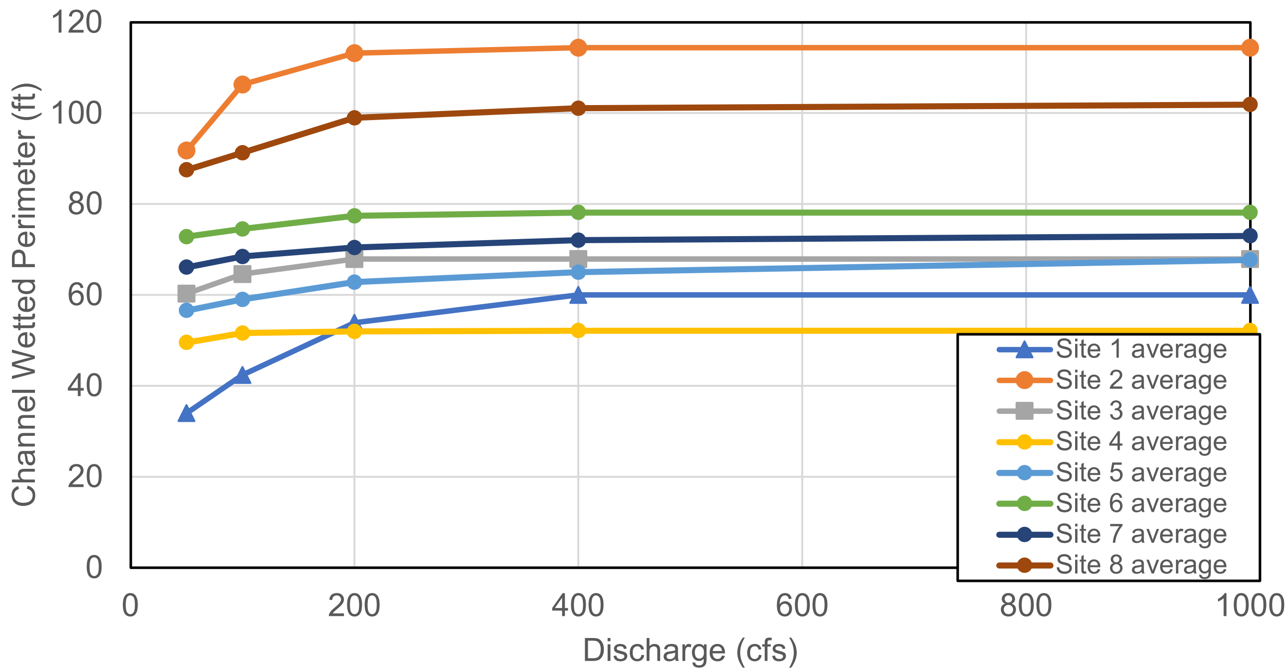


Figure 23. Pool habitat type rating curve for channel wetted perimeter

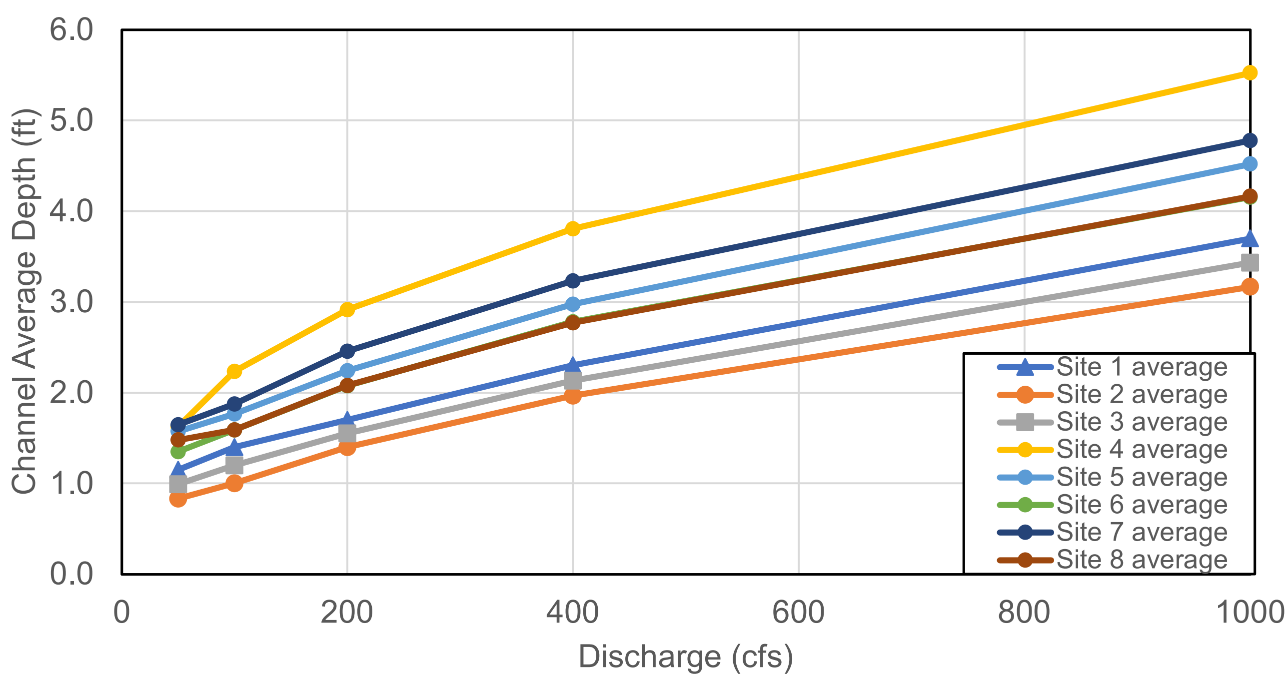


Figure 24. Pool habitat type rating curve for channel average (hydraulic) depth

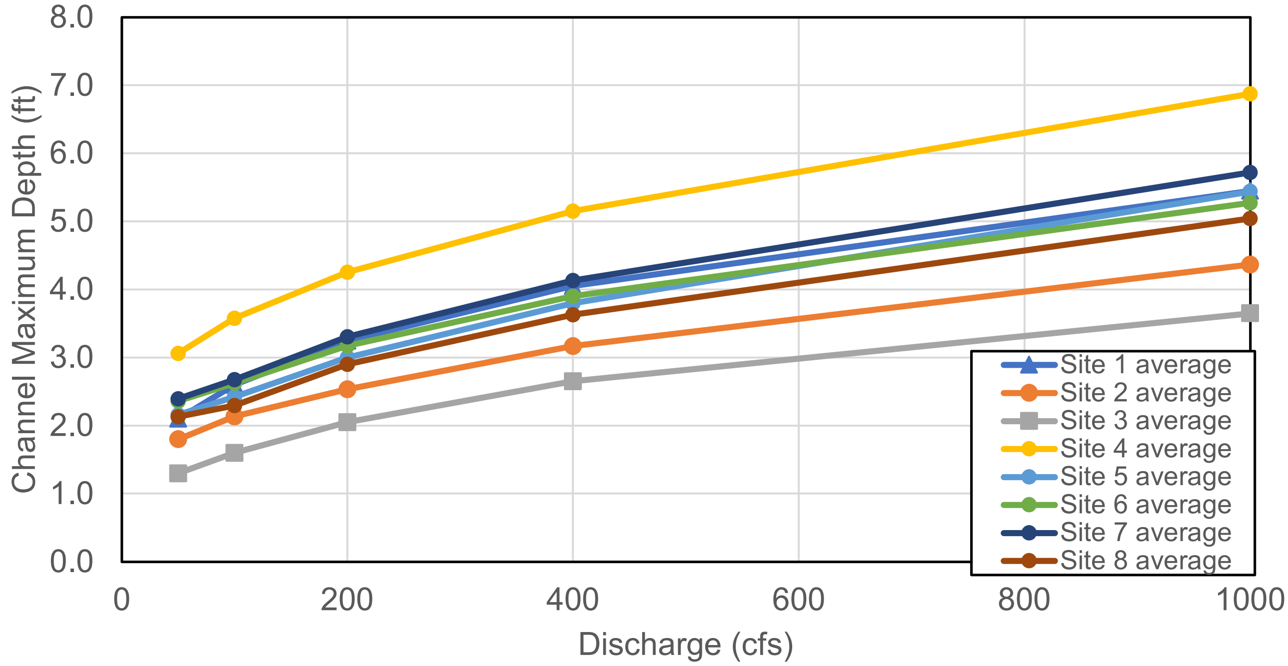


Figure 25. Pool habitat type rating curve for channel maximum depth

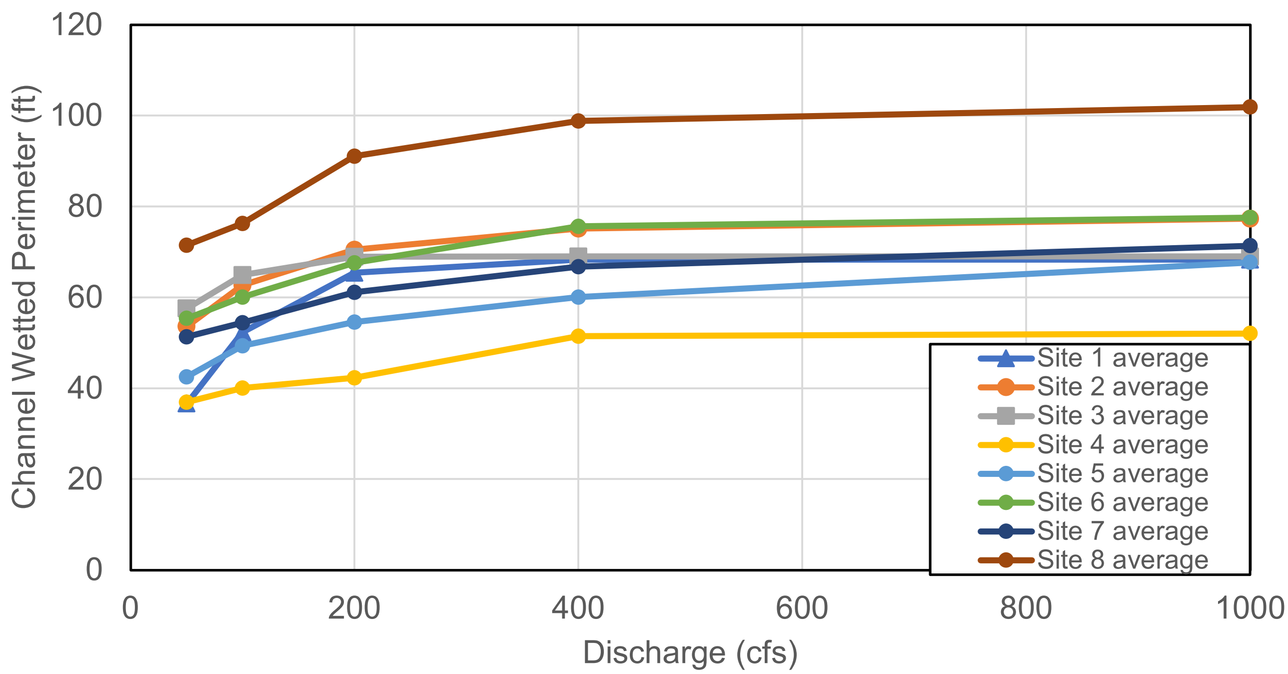


Figure 26. Riffle habitat type rating curve for channel wetted perimeter

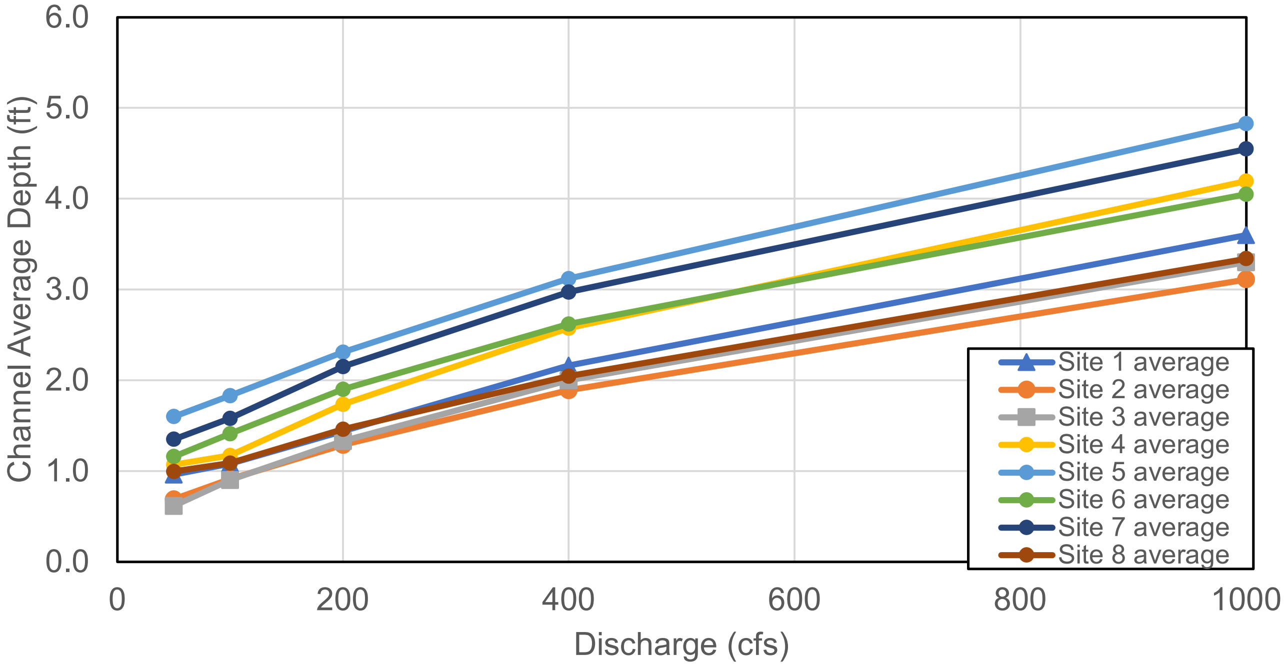


Figure 27. Riffle habitat type rating curve for channel average (hydraulic) depth

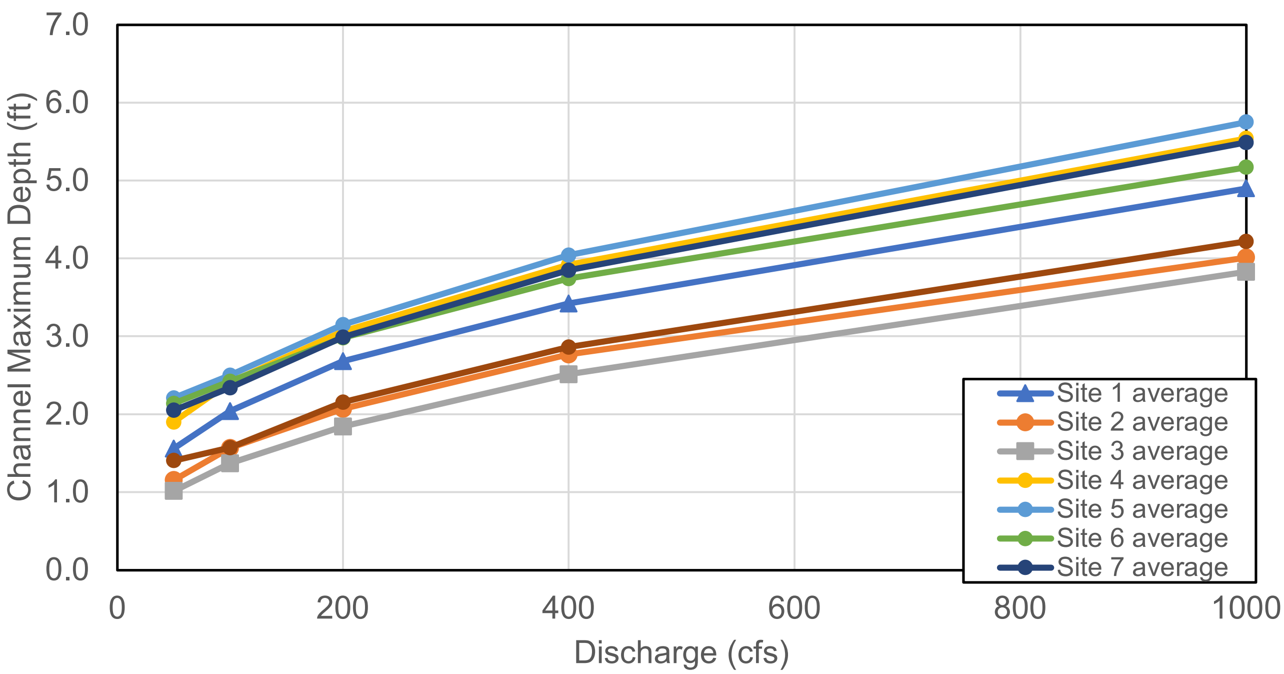


Figure 28. Riffle habitat type rating curve for channel maximum depth

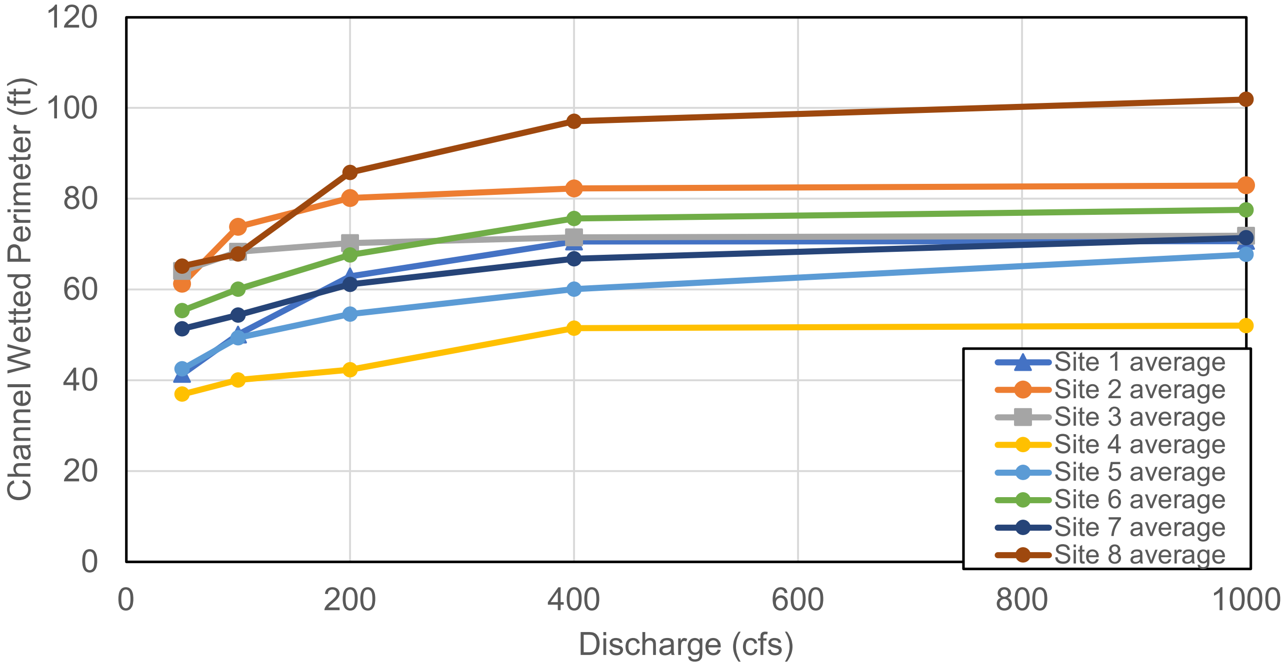


Figure 29. Glide habitat type rating curve for channel wetted perimeter

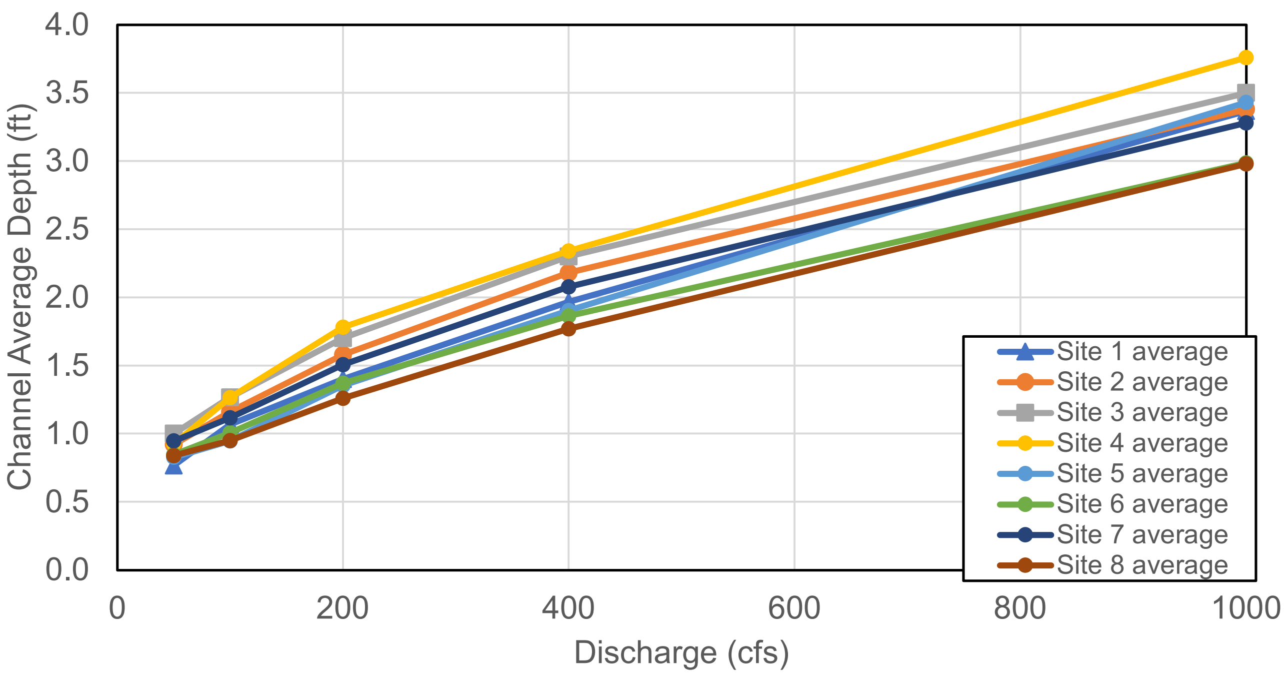


Figure 30. Glide habitat type rating curve for channel average (hydraulic) depth

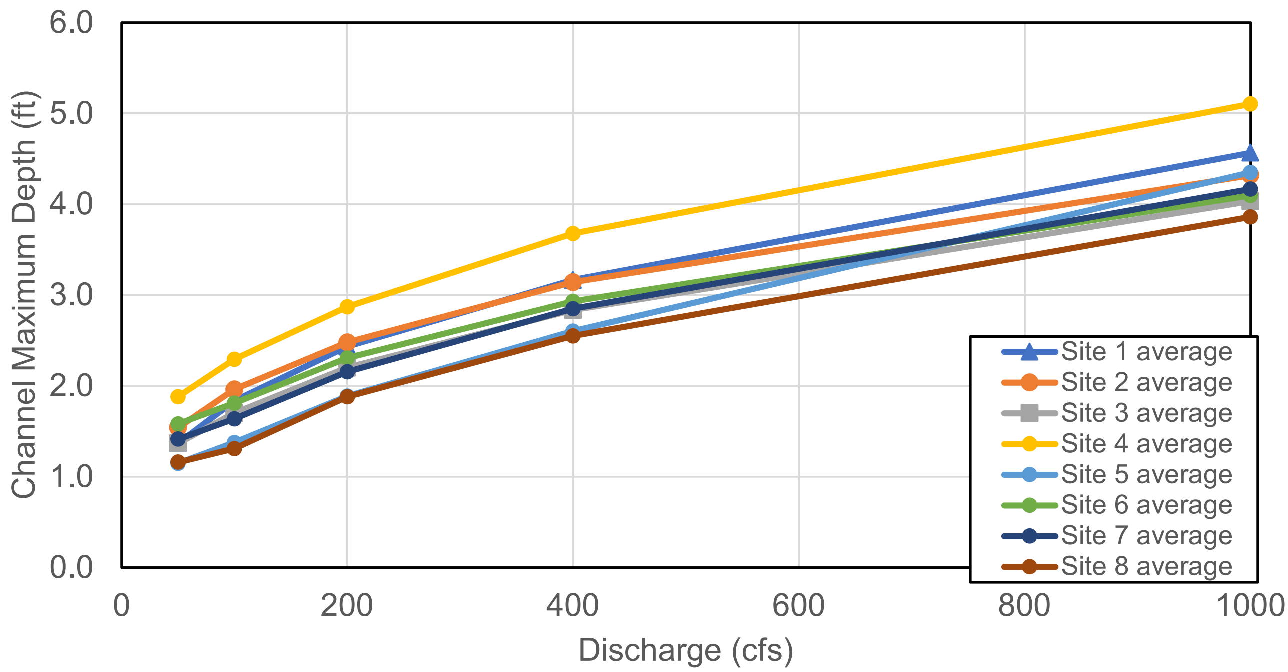


Figure 31. Glide habitat type rating curve for channel maximum depth

3.3 HABITAT COMPARISON

3.3.1 Pool habitat type comparison

Pool habitat provides resting and refuge habitat for fish, especially at low flows. Winters and Gallagher (1997) state that for most trout species pool depths of at least 1.5 feet are needed to adequately provide resting and refuge habitat. A pool-to-riffle ratio of 50:50 is considered optimal (Roberts et. Al., 2008) although for mountain rivers, pools are less frequent and therefore often a lower percentage.

As shown in Table 6 and Figure 24, the average pool depths through each site range from 0.8 feet to approximately 1.6 feet when flows at the Dillon Reservoir dam outlet are at 50 cfs. The Phase 1 report notes the average depths in pools at Sites 1 – 3 are less than 1.5 feet until flows reach or exceed 160 to 250 cfs which occurs on average about 20 to 43 percent of the year. Pool habitat for Sites 4-8 is slightly deeper with all five sites at or greater than 1.5 feet when flows at Dillon Reservoir dam outlet are 100 cfs, which occurs on average 68 percent of the year. Pool-to-riffle ratios for sites 5 - 7 range from 30.2 % to 44 %, slightly less than the 50:50 optimal values while Sites 1 – 3 and Site 8 are 0% to 8.4% well below optimum.

The wetted perimeter is narrowest for pools in Site 1 and widest for Site 2 (Figure 23) with all other sites (3 through 8) in between for flows between 50 and 200 cfs. Shorter wetted perimeters provide narrower and deeper channels, and for a given flow are associated with more efficient channel morphology for conveying water and sediment under the current hydrologic regime. As the flow increases, the wetted perimeter for pools at most Sites increases steadily until reaching the channel capacity at approximately 300 to 400 cfs.

Site 4 has the greatest maximum pool depth of the sites ranging from 3.1 feet at 50 cfs to 6.9 feet at 1000 cfs (Figure 25). The maximum depth at Site 3 was the lowest for all sites at 1.3 feet.

A time series analysis for average and maximum pool depths was completed for the Phase 1 report (Tt & MEC, 2022) using daily average flows between water years 1988 and 2021 to calculate both average and maximum pool depths (Figures 32 and 33). The Phase 1 report notes that this demonstrates most of the year, approximately 9 ½ to 10 months, the average depth of water in pools are between 0.8 to 1.6 feet. For an estimated 2 to 2 ½ months the pool depths increase during spring runoff with average pool depths of 3.5 feet to 5.0 feet. Likewise, Sites 4 through 8 experience extended periods, approximately 9 ½ to 10 months, where pools depths are shallow, typically less than 2 feet. Further the habitat analysis indicates po9ol habitat is sparse compared to the riffle and glide habitat. There results support recommendations concerning the potential for physical modification of the channel to enhance and create pool habitat.

3.3.2 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. The 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). The 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 Sites 1 and 4 and widest at Site 8 (Figure 26). 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 a capacity of around 300 cfs, but the shallower and wider channel through Site 2 does not. However, all sites including Sites 4 through 8 have more than 50 percent of the bank-to-bank wetted perimeter even at a flow of 50 cfs. Average riffle depth is at or greater than the 0.6-foot minimum recommended by Nehring (1979) for all eight sites and all assessed flows. Thus, riffle habitat may not be a strategic focus for physical modification of the channel to support the trout fishery; however, the existing riffles could provide morphologic templates for any constructed riffles under consideration to replace boulder weir drop structures.

3.3.3 Glide habitat type comparison

Adequate depth in glide habitat is required to provide feeding locations for fish. Depths no less than the minimum riffle depths, 0.6 to 1.0 feet, as recommended by Nehring (1979) should be available to provide appropriate functions as foraging locations. Depths greater than the minimum may provide enhanced function. The minimum depths in glides for 50 cfs exceed the recommended minimums at all eight sites.

These depths in conjunction with the range of average depths should provide adequate foraging habitat for fish. Like the interpretation of riffle habitat hydraulics, glide habitat hydraulics may not be a strategic focus for the physical modification of the channel to support the trout fishery.

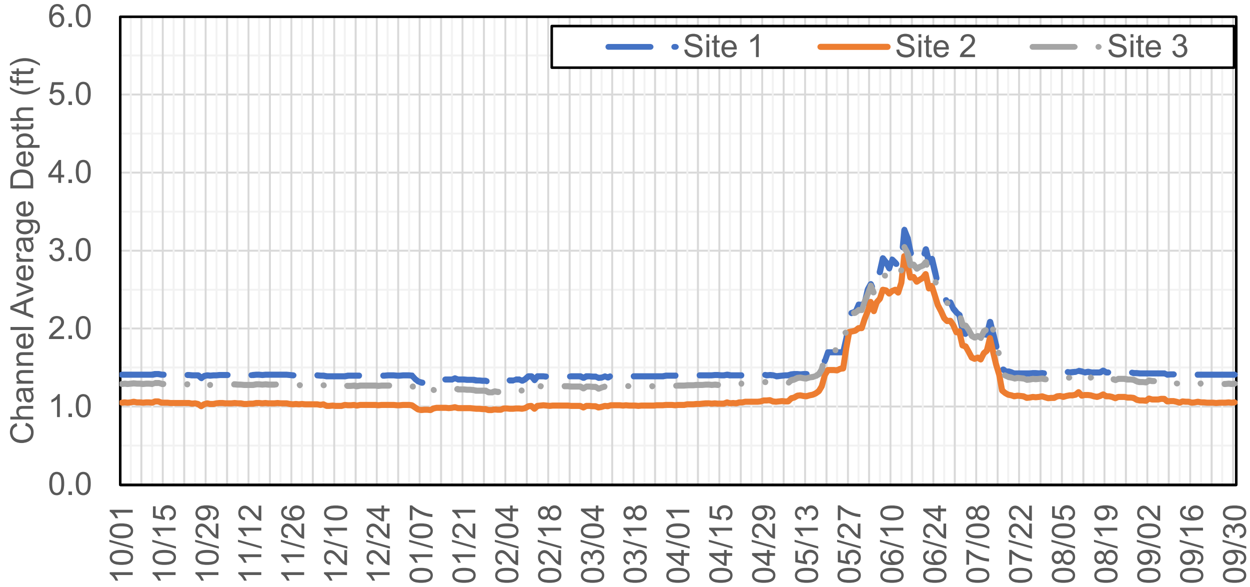


Figure 32. Time series of daily average pool depth for average hydrologic regime

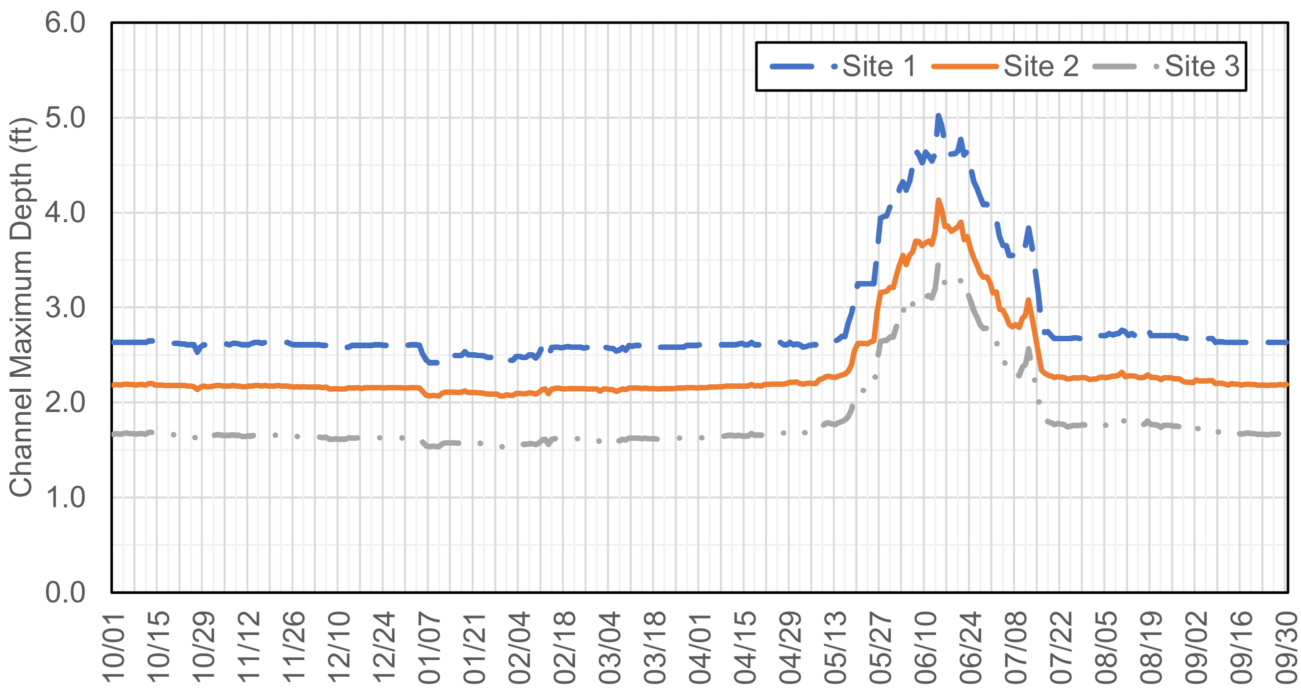


Figure 33. Time series of daily maximum pool depth for average hydrologic regime

4.0 SUMMARY

In 1988 the Colorado Division of Wildlife (CDW) (now Colorado Parks and Wildlife (CPW)), prepared a report titled Stream Fisheries Investigations (Nehring, 1988) which identified limiting life stages for both rainbow and brown trout and provided recommendations for optimum and critical flows. The report notes that flows should not be allowed to fall “if at all possible” below the ‘spawning’ level at any time during the spawning, incubation, and hatching periods for rainbow and brown trout. These life stages and critical time periods on the Blue River occur from October 15 through June 1, with minimum flows of 50 cfs and optimum flows of 100 cfs. The report also notes that these recommendations (minimum flows of 50 cfs and optimum flows of 100 cfs) should not be construed as being safe on a long-term basis, defined as being a year or more, but rather as short-term recommendations that will adequately protect the trout population through the various critical life stages. The report also notes that these flows alone do not necessarily protect the total aquatic stream ecosystem, citing the need for flushing flows to maintain riffles.

Hydraulic indicators targeted in this assessment included channel wetted perimeter, average (hydraulic) depth of the channel, and channel maximum depth in three habitat types: riffles, glides, and pools. This habitat assessment also included quantification of cover, which is defined as a feature that serves to visually isolate a fish. Cover can include instream cover which are obstructions that provide shelter from excessive velocities; overhead cover such as overhanging vegetation, and pool depth cover. In addition to cover, embeddedness, the extent to which gravel cobble and boulders are surrounded by silt, sand, or mud was also assessed. Excess fine sediment on gravel beds can degrade habitat quality for stream biota.

Based on the habitat assessments performed for the eight sites in Subreaches 2.1 and 2.2 habitat conditions can be summarized as follows:

- Average riffle depths (0.6 to 1 ft) and wetted permitter were at or slightly greater than the standards applied in minimum flow studies.
- Glide habitat provides hydraulic conditions at low flows that are likely sufficient to provide foraging locations for fish.
- Riffle and glide widths and depths are at the minimum targeted values for most of the year and higher during runoff.
- Pool habitat is sparse, particularly at Sites 1 – 3 and Site 8, and depths are at the minimum targeted depths for extended time periods except during spring runoff.
- Where present, pools are close to the minimum 1.5-foot depth at 50 to 100 cfs.
- Several reaches have pools that formed in the center of the channel as a result of the drop structures.
- There is a lack of spawning gravels.
- Embeddedness is not present at the Study Sites and therefore not a factor in the quality of aquatic habitat.

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 dam outlet, a lack of food, and/or limited biological productivity. Since 2016 ongoing monitoring, data collection, and assessments between Dillon and Green Mountain Reservoir also point to multiple factors impacting the fishery and aquatic habitat including low water temperature, altered flow regime, lack of spawning gravels, and fishing pressure.

5.0 RECOMMENDATIONS

The objective of this habitat assessment is to identify potential physical habitat features that may be limiting the function of the aquatic ecosystems, specifically the fishery community between the Dillon and Green Mountain Reservoir. This information will be utilized by the BRWG to develop a conceptual master plan from which to implement projects to improve the physical aquatic habitat.

Overall, the hydraulic habitat assessment of several sites, such as Sites 1 and 4, indicates the habitat quality should support a trout fishery, but the Gold Medal status is dependent on CPW stocking the Blue River with catchable rainbow trout. This could indicate that other factors are limiting the function of this fishery, such as water temperature and other water quality constituents. Addressing these issues will be needed in combination with habitat improvements to obtain the full functional uplift to slow or stop the decline in the fishery. Habitat improvements for both Subreach 2.1 and 2.2 are combined and presented below.

1. Velocity measurements in Subreach 2.1, Site 2 at the boulder drops indicate fish passage may be impeded by these unnatural structures. The boulder drops also have created a very wide channel section with shallow depths and a lack of diversity in structure. Consider modifying the existing boulder weir drop structures and narrowing the river channel in Reach 2 to facilitate fish passage and narrow and deepen pool habitat. This could be achieved by removing the drops, and adding cobble bars, or small barbs, and constructed riffles. Coordinate with the Town of Silverthorne on plans for their kayak park. Investigate the potential to incorporate the facility with other restoration recommendations.
2. Identify other overly wide channel sections and construct bars to narrow and deepen flows. Consider the addition of wood, boulder clusters, and native bank vegetation in areas lacking cover.
3. Identify damaged channel banks at popular river access points where the loss of vegetation and erosion have occurred on some of the steeper banks due to overly steep banks and frequent foot traffic. This is prevalent at Sites 1, 2, and 8. These areas should be revegetated and restabilized along the banks, with improved or delineated pedestrian access to the river.
4. Modify portions of the channel to enhance the size and depth of existing pools and to create new pools of sufficient depth. The flow regime and the potential for flooding impacts likely preclude the release of flows capable of scouring pools. Physical modification of the Blue River to create more pool habitat should prioritize narrower and deeper pools, located on the outer banks.
5. Absence of spawning gravels at Sites 1 through 8 indicates that suitable spawning substrate is not prevalent enough to sustain a natural reproducing population of trout in the Blue River downstream of Dillon Reservoir. While some material is being introduced through the tributaries, it is limited and does not provide sufficient amounts to support spawning until Subreach 2.3, 10 miles downstream of the Dillon Reservoir outlet near Boulder Creek. The placement of spawning gravel should be considered, including the placement of features such as woody debris to retain the gravels. 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 deliver gravel sediment, such as the reach upstream of the Willow Creek confluence.

6. Continue to investigate the impact of water temperature, flow releases, and water quality on the biological community in the Blue River.
7. 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 production to support the stocked and natural trout fishery.
8. Develop a monitoring program to track the impacts of restoration efforts.

6.0 REFERENCES

Annear, T. I. (2004). *Instream Flows for Riverine Resource Stewardship, Revised Edition* (Revised ed.). Cheyenne, WY: Instream Flow Council.

Bovee, K. D. (1998). *Stream habitat analysis using the instream flow incremental methodology.* Fort Collins: U.S. Geological Survey, Biological Resources Division.

Colorado State University. (2019). *R2Cross Field Guide, User's Manual & Technical Guide.* One Water Solutions Institute, Department of Civil and Environmental Engineering. Fort Collins: Colorado State University.

CPW. (2019). *Wild and Gold Medal Trout Management Policy.* Denver: Colorado Parks and Wildlife (CPW) Commission.

Ewert, J. (2018). *Blue River Fishery Management Report 2010-2017*. Colorado Parks and Wildlife (CPW) Commission.

HEC. (2019, March). HEC-RAS River Analysis System, Version 5.0.7. *HEC-RAS 5.0.7.* Davis, CA: U.S. Army Corps of Engineers, Hydrologic Engineering Center.

Miller, W. (1988). *Rainbow Trout Survival to Emergence as a Function of Temperature and Dissolved Oxygen.* Colorado State University, Fishery and Wildlife Biology. Fort Collins: Colorado State University, Department of Fishery and Wildlife Biology.

Nehring, R. (1979). *Evaluation of instream flow methods and determination of water quantity needs for stream in the State of Colorado.* Fort Collins: Colorado Division of Wildlife.

Nehring, R. (1988). *Stream Fisheries Investigations, Federal Aid Project F-51-R.* Fort Collins: Colorado Division of Wildlife.

Omasta, D. (2020). *Blue River Integrated Water Management Plan, Trout Unlimited Angler Survey Report.*

Reuter, J. (2002, Dec 11). *Fish Story.* Retrieved 04 28, 2022, from Summit Daily: www.summitdaily.com/news/fish-story/

Roberts, M.L., Bilby, R.E., Booth, D.B. (2008, March). *Hydraulic dispersion and reach-averaged velocity as indicators of enhanced organic matter transport in small Puget Lowland streams across an urban gradient.* Seattle: University of Washington.

Sanderson, J. B. (2012). *Colorado Basin Roundtable Watershed Flow Evaluation Tool Study.* The Nature Conservancy.

Stalnaker, C. B. (1995). *The Instream Flow Incremental Methodology - A Primer for IFIM.* Fort Collins: U.S. Department of the Interior, National Biological Service.

Tetra Tech. (2021). *Blue River Integrated Water Management Plan, Phase I Report.* Fort Collins: Tetra Tech.

Tetra Tech and Miller Ecological Consultants (Tt & MEC). (2022). *Blue River Integrated Water Management Plan. Assessment of Current Aquatic Habitat Hydrology and Hydraulics in the Blue River Downstream of the Dillon Reservoir Dam.* Prepared for the Blue River Watershed Group. July.

Timoshina, L. (1972). Embryonic development of the rainbow trout (Salmo gairdneri irideus) at different temperatures. *Journal of Ichthyology, 12*, 425-432.

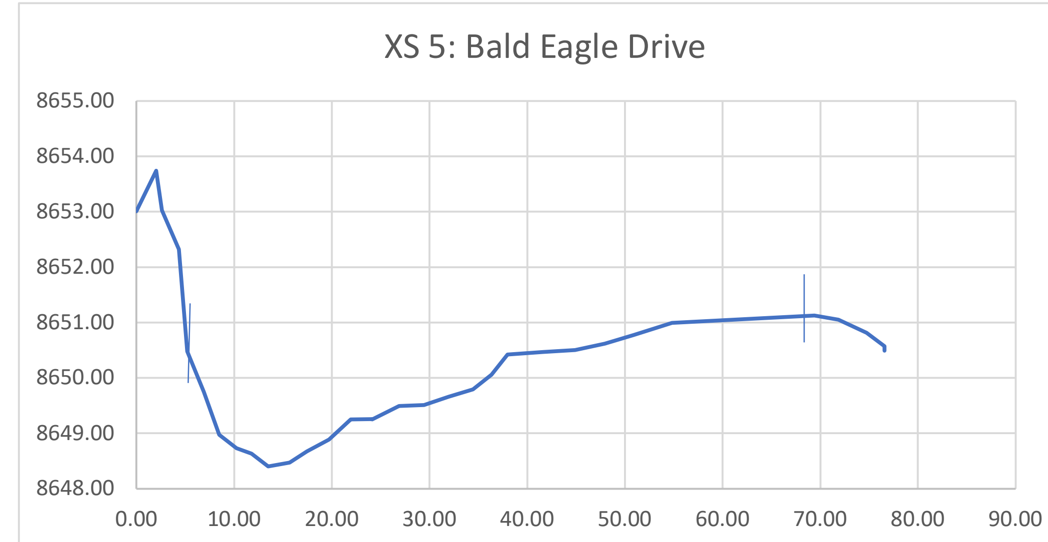
Winters, D. S. and J.P. Gallager. (1997). *Basin-wide Stream Habitat Inventory A protocol for the Pike and San Isabel National Forests & Cimarron and Comanche National Grasslands.* U.S. Forest Service. 31 p.

USGS. U.S. Geological Survey. Stream Stats (USGS) v4.11.1 at https://streamstats.usgs.gov/ss/. Accessed in March 2023.

APPENDIX A: SITE SURVEYS

Site 4: Town of Silverthorne downstream of Bald Eagle Drive

Surveyed XS and Profile Points (Green points) and Lidar Profile Line (Yellow Line)

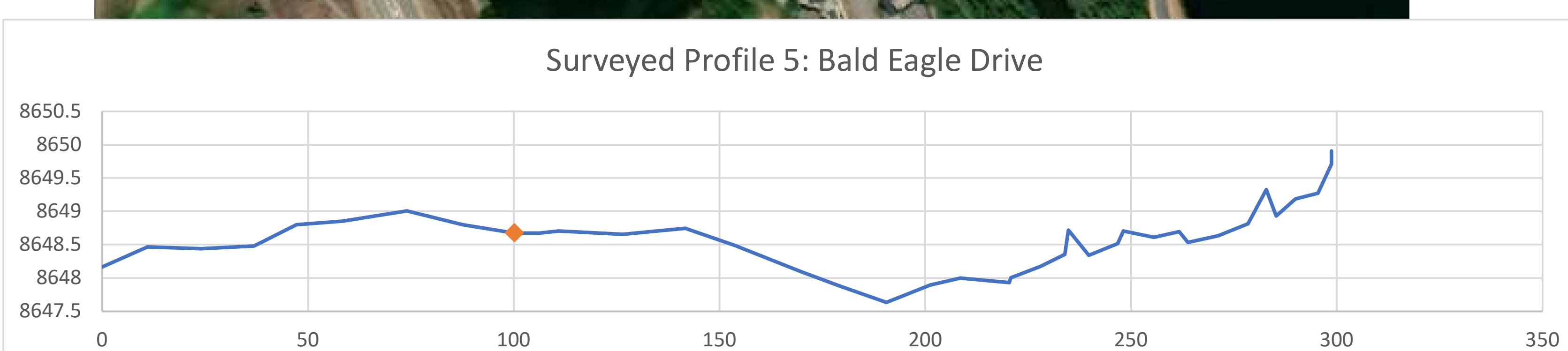


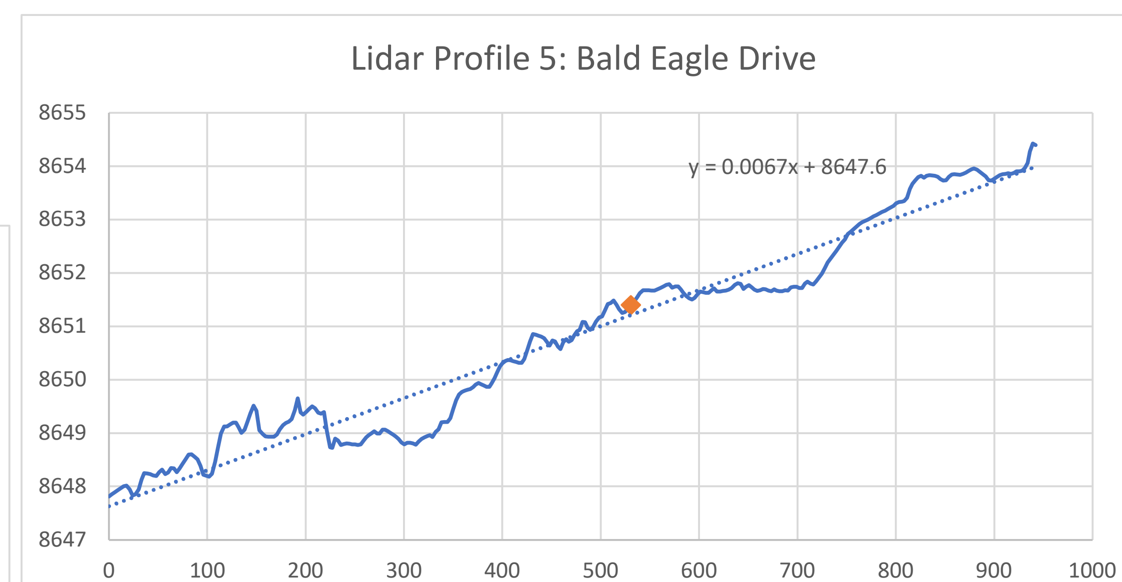
cross section looking downstream

bank to bank 65.0 ft

	X	Y	Z
LOB	2837005.248	1665421.059	8350.0
ROB	2837073.953	1665382.303	8347.5

Coord System: NAD 83 StatePlane Colorado Central FIPS 0502 (US Feet)

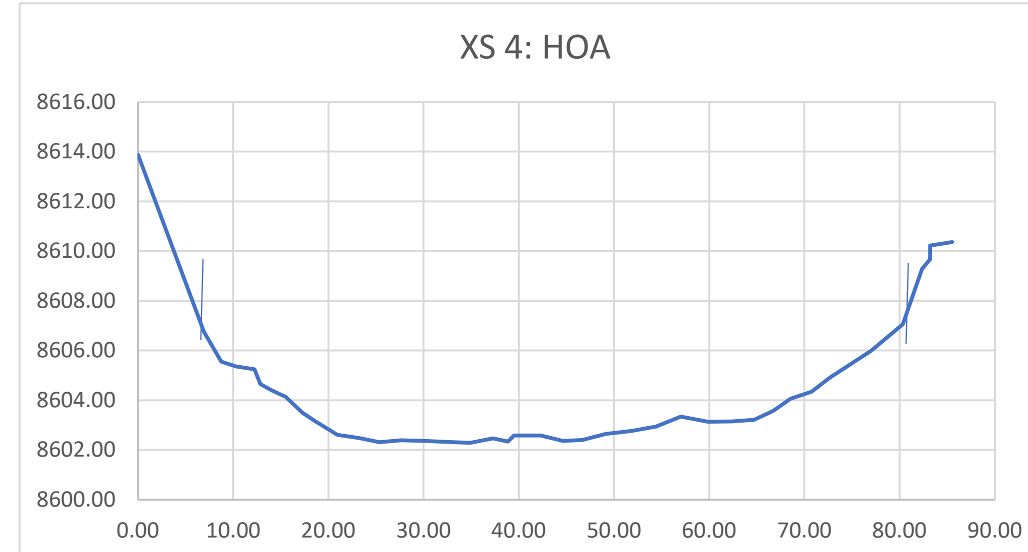




*Note: Surveyed data was based on elevation taken off a handheld GPS. Surveyed elevations for profiles and XS's were vertically adjusted based on lidar data and are approximate.

Site 5: Sage Creek Canyon (aka HOA)

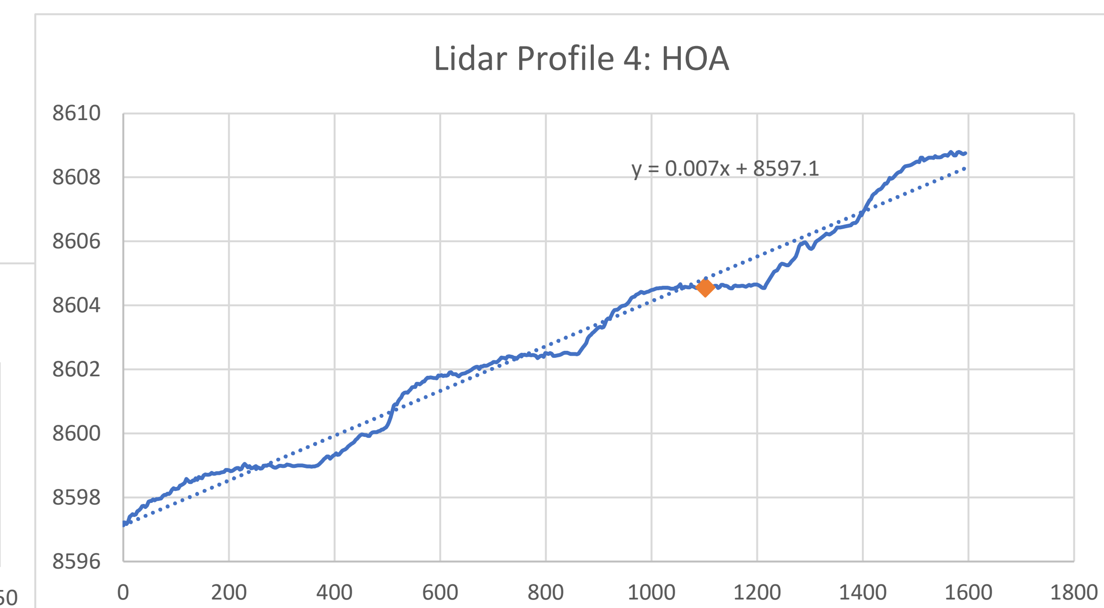
Surveyed XS and Profile Points (Green points) and Lidar Profile Line (Yellow Line)

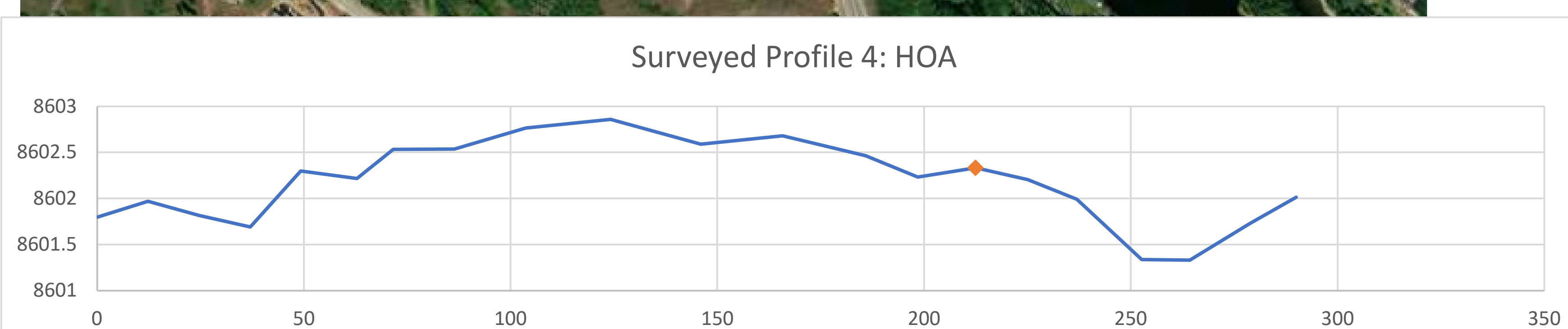


cross section looking downstream
bank to bank 75.4 ft

	X	Y	Z
LOB	2834085.618	1669795.284	8612.332
ROB	2834172.408	1669826.426	8608.661

Coord System: NAD 83 StatePlane Colorado Central FIPS 0502 (US Feet)

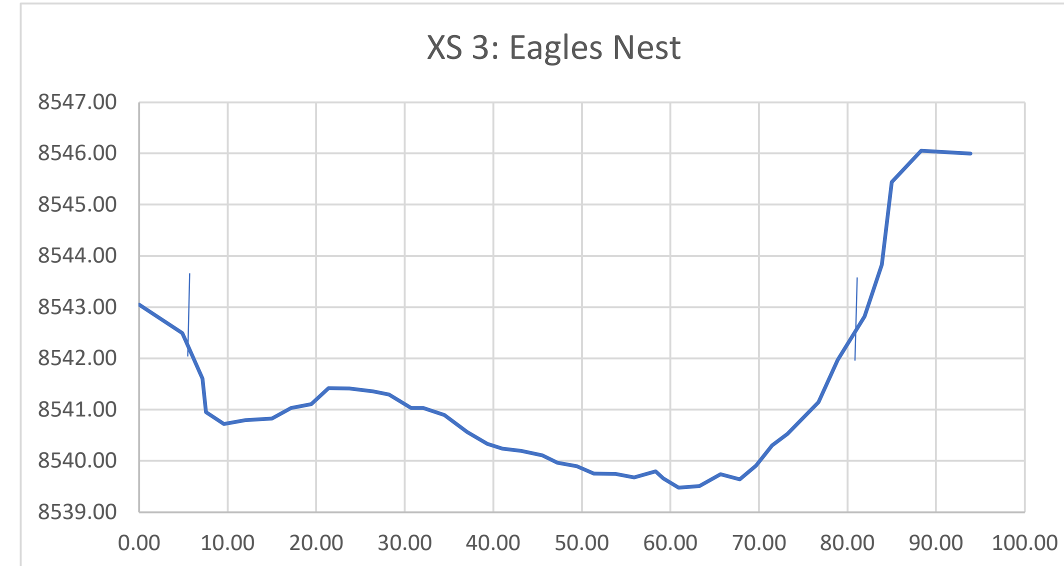




*Note: Surveyed data was based on elevation taken off a handheld GPS. Surveyed elevations for profiles and XS's were vertically adjusted based on lidar data and are approximate.

Site 6: Eagles Nest (aka Young Ranch)

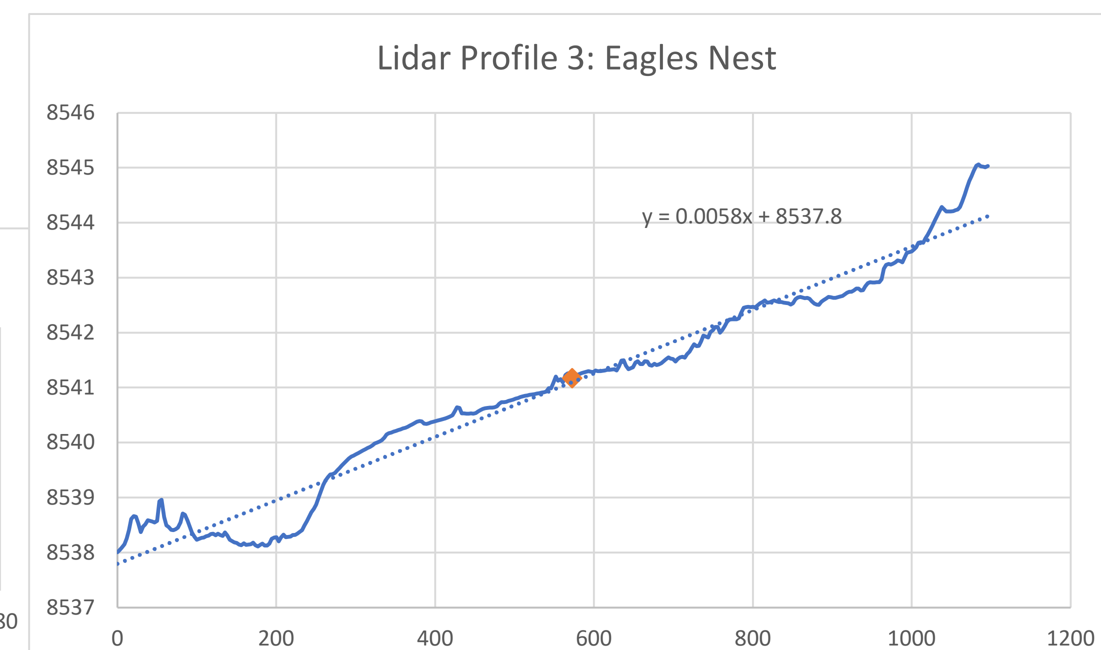
Surveyed XS and Profile Points (Green points) and Lidar Profile Line (Yellow Line)

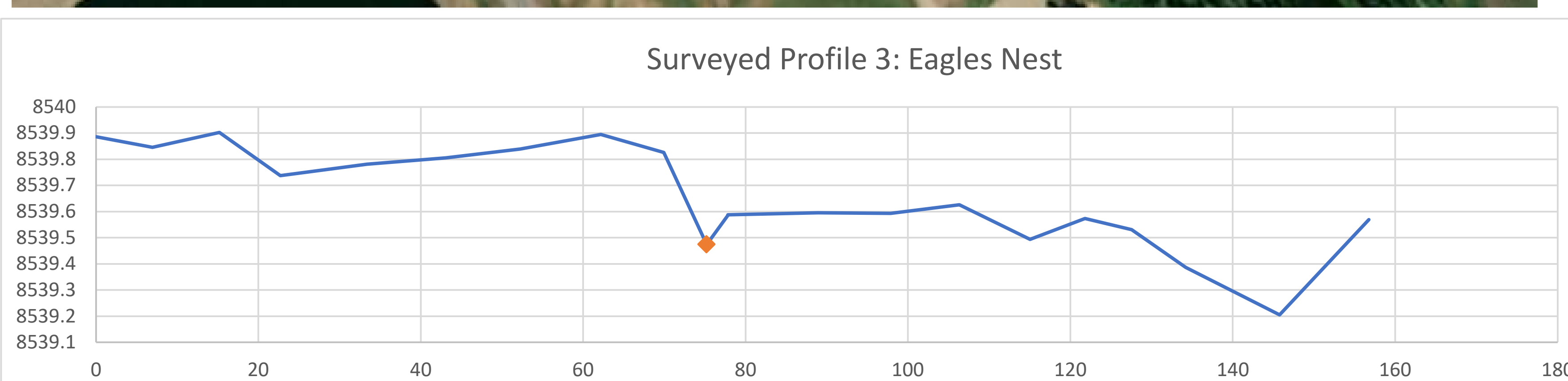


cross section looking downstream
bank to bank 79.0 ft

	X	Y	Z
LOB	2831099.326	1677227.359	8548.17
ROB	2831152.449	1677304.785	8551.118

Coord System: NAD 83 StatePlane Colorado Central FIPS 0502 (US Feet)

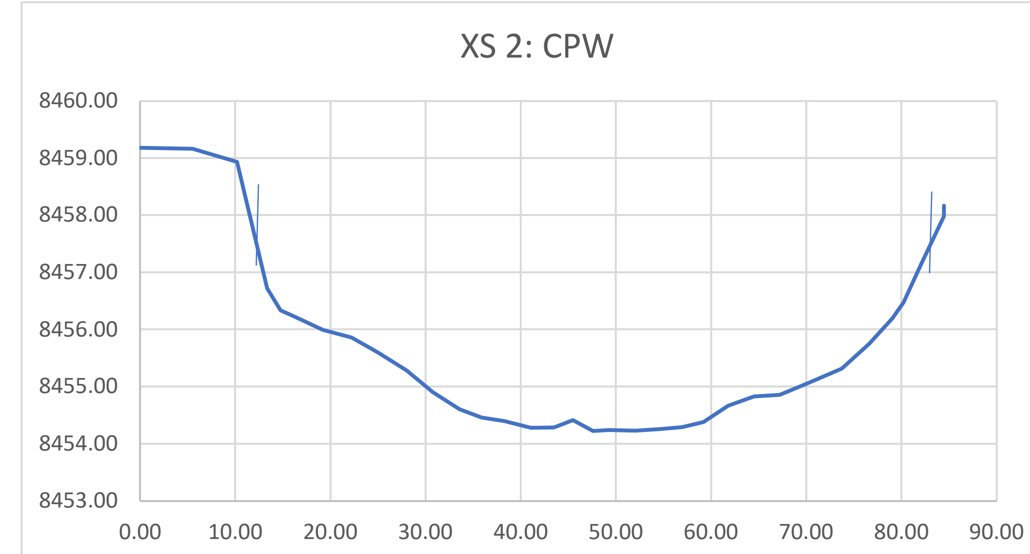




*Note: Surveyed data was based on elevation taken off a handheld GPS. Surveyed elevations for profiles and XS's were vertically adjusted based on lidar data and are approximate.

Site 7: CPW

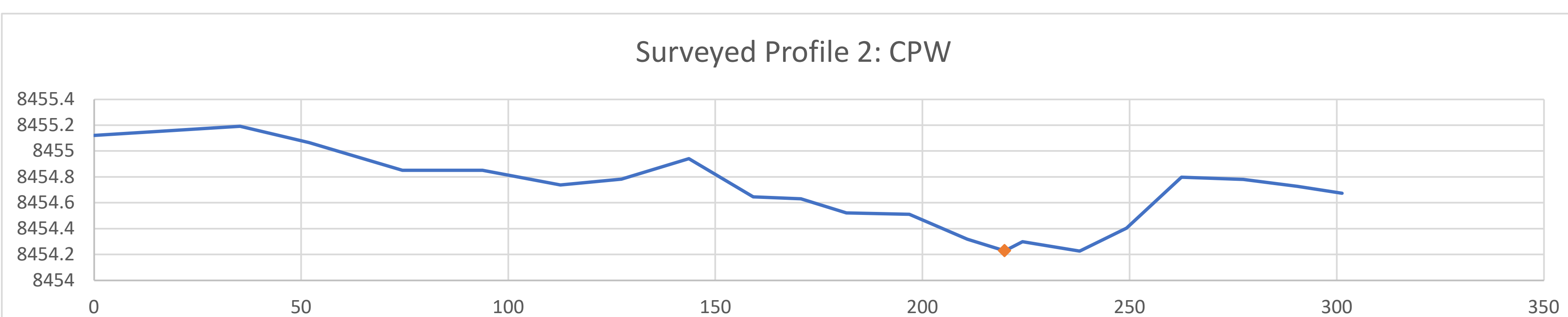
Surveyed XS and Profile Points (Green points) and Lidar Profile Line (Yellow Line)

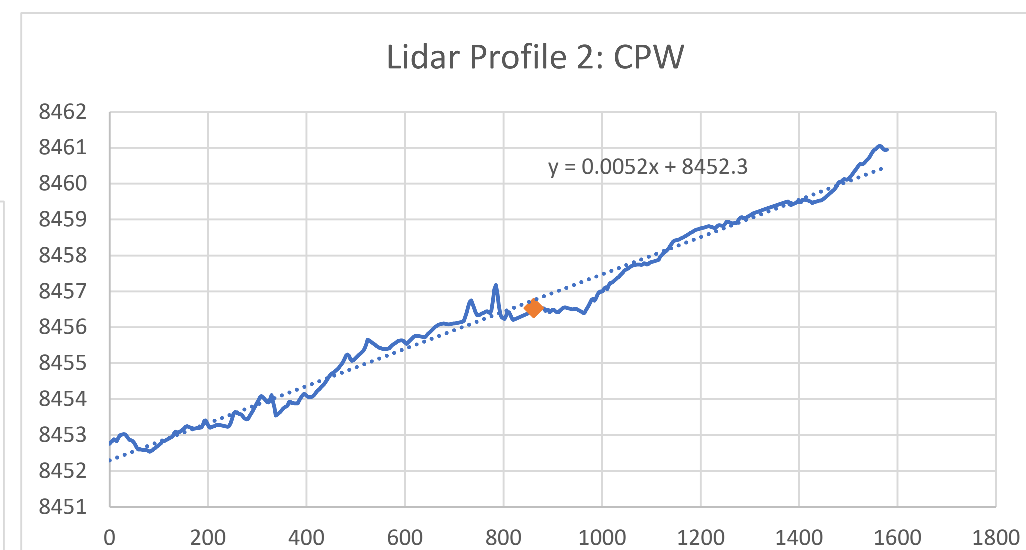


cross section looking downstream
bank to bank 74.3 ft

	X	Y	Z
LOB	2824827.195	1688070.969	8445.564
ROB	2824876.483	1688143.239	8444.546

Coord System: NAD 83 StatePlane Colorado Central FIPS 0502 (US Feet)

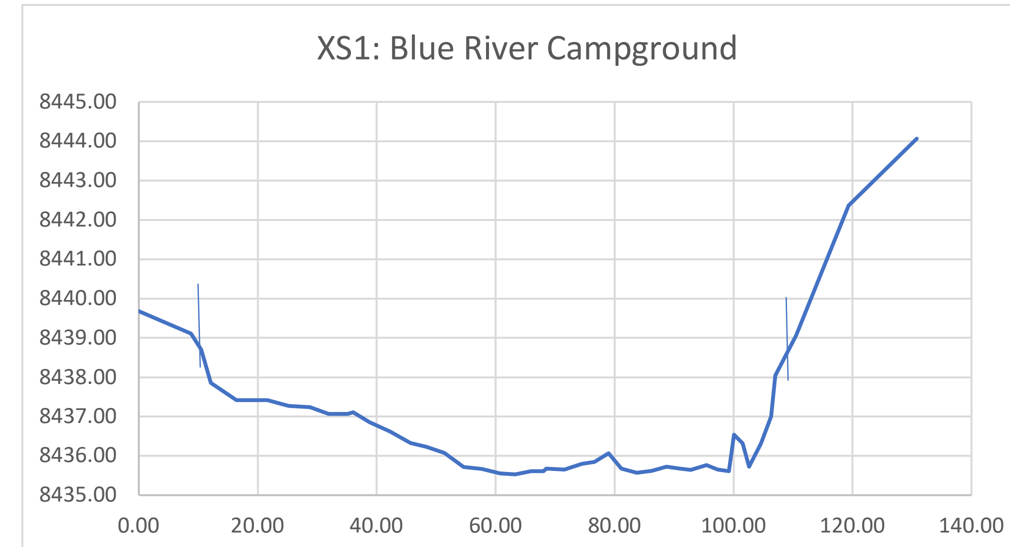




*Note: Surveyed data was based on elevation taken off a handheld GPS. Surveyed elevations for profiles and XS's were vertically adjusted based on lidar data and are approximate.

Site 8: Blue River Campground

Surveyed XS and Profile Points (Red points) and Lidar Profile Line (Yellow Line)

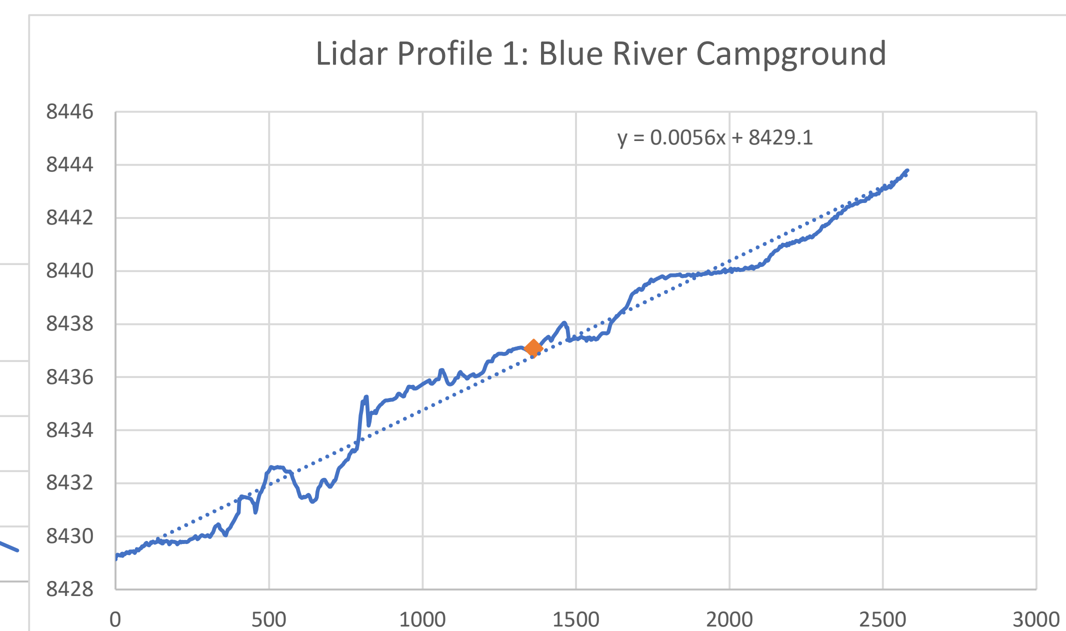


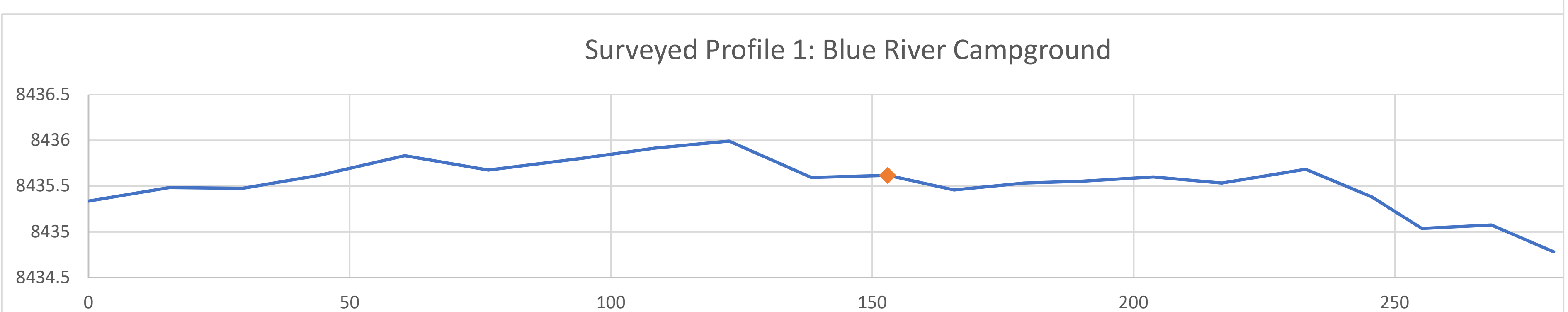
cross section looking downstream

bank to bank 108.9 ft

	X	Y	Z
LOB	2822798.634	1690441.953	8461.483
ROB	2822720.842	1690547.315	8465.865

Coord System: NAD 83 StatePlane Colorado Central FIPS 0502 (US Feet)





*Note: Surveyed data was based on elevation taken off a handheld GPS. Surveyed elevations for profiles and XS's were vertically adjusted based on lidar data and are approximate.

APPENDIX B: HYDRAULIC MODEL DEVELOPMENT

B-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 5.0.7 of the U.S. Army Corps of Engineers River Analysis System software (HEC-RAS) (HEC, 2019).

B-1.1 Bathymetric Survey

Alden Labs was contracted to complete a bathymetric and overland survey of the Blue River between September 26th and September 30th, 2022. In addition to survey data, flow data was also collected during this time. Five sites were identified to be surveyed and have flow data collected at. At each site, a representative cross section and profile were surveyed. The cross sections were typically located within glides, and profiles were done with the goal of determining a representative reach slope.

The bathymetric survey was carried out using a professional survey-grade Leica Total Station with a prism rod. At each site, the Total Station was located and leveled over a benchmark, either placed or existing, on stable ground with a clear view of the chosen cross section and profile lines. A second benchmark was established at each site, either on an existing object or on a place marker, to establish exact orientation. Approximate GPS coordinates and thorough descriptions of each benchmark were recorded, so that they could be precisely located in the future if desired. Once benchmarks were established at each site, cross section and profile points were recorded. 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. Cross section points were recorded approximately every foot, and profile points were recorded approximately every 5 feet. Surveyed positions were post-processed to station-elevation coordinate pairs by projecting points onto vectors defining segments of each cross section and profile. This post-processing enabled the surveyed channel morphology to be directly entered to the HEC-RAS software.

In addition to the survey data collection, flow data was also collected at each site utilizing an OTT Hydromet MF Pro flowmeter, data collector, wading rod and tag line/measuring tape. The chosen measurement cross sections had minimal turbulence and obstructions from boulders, pools and more to provide consistent and accurate flow measurements. At each chosen collection point, the tag line was setup across the channel and a spatial measurement interval was established so that between 20 and 30 measurements per cross section were collected at even spacing. Once all measurements were collected per cross section, the data collector would compute the total flow at that site.

B-1.2 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 five 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.

B-1.3 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 (Tt & MEC, 2022).

B-2. HYDROLOGIC INPUTS

A detailed hydrologic analysis was presented in the Subreach 2.1 (TT&MEC 2022) for flows at the 'Blue River at Dillon' gage immediately downstream of the Dillon Reservoir dam outlet. The analysis included review of flood flows, average daily flows, daily average flows with a 10%, 50% and 90% exceedance probability, and flow duration curves. Ten flows were selected, ranging from 50 cfs to 1,000 cfs for assessing habitat in Subreach 2.1. For assessment of Subreach 2.2 several intermediate flows were removed from the analysis as they showed relatively little change in the noted parameters, leaving six flows for assessing habitat.

This habitat assessment also required an estimate of flows at Sites 4 through 8 for a range of flows relative to the flows being released from the Dillon Reservoir dam outlet. This was accomplished by prorating the difference in flows below the reservoir to the flows measured at each site by the size of the drainage area below Dillon Reservoir. This was done for low flows using the measurements made in September and for the 2-year flows using FEMA FIS flows combined with Stream Stats. The averages of each flow ranged from 0.27 cfs/sq for the low flow (57 cfs) and 2.5 cfs/sq mi for the 2-year flow of 1530 cfs (TT&MEC 2022). This was done for each site assuming Dillon Reservoir dam outlet releases of 100 cfs to 1,000 cfs.

B-3. 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.