STREAM HABITAT INVESTIGATIONS AND ASSISTANCE
PROJECT SUMMARY

Eric E. Richer
Aquatic Research Scientist/Hydrologist

Matthew C. Kondratieff
Aquatic Research Scientist

and

Madison Molter
Aquatic Technician

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STATE OF COLORADO

Jared Polis, Governor

COLORADO DEPARTMENT OF NATURAL RESOURCES

Dan Gibbs, Executive Director

COLORADO PARKS & WILDLIFE

Jeff Davis, Director

WILDLIFE COMMISSION

AQUATIC RESEARCH STAFF

George J. Schisler, Aquatic Research Leader
Brian W. Avila, Aquatic Research Scientist, Population Genetics
Peter J. Cadmus, Aquatic Research Scientist/Toxicologist, Water Pollution Studies
Kelly N. Carlson, Aquatic Research Program Assistant
Eric R. Fetherman, Aquatic Research Scientist, Salmonid Disease Studies
Ryan M. Fitzpatrick, Aquatic Research Scientist, Eastern Plains Native Fishes
Adam G. Hansen, Aquatic Research Scientist, Coldwater Lakes and Reservoirs
Zachary Hooley-Underwood, Aquatic Research Scientist, West Slope Three-Species Studies
Matthew C. Kondratieff, Aquatic Research Scientist, Stream Habitat Restoration
Dan A. Kowalski, Aquatic Research Scientist, Stream and River Ecology
Jesse M. Lepak, Aquatic Research Scientist, Warm and Coolwater Lakes and Reservoirs
Eric E. Richer, Aquatic Research Scientist/Hydrologist, Stream Habitat Restoration
Tawni B. Riepe, Aquatic Research Scientist, Aquatic Toxicology and Disease
Kevin B. Rogers, Aquatic Research Scientist, Colorado Cutthroat Studies
Andrew J. Treble, Aquatic Research Scientist, Aquatic Data Management and Analysis
Brad Neuschwanger, Hatchery Manager, Fish Research Hatchery
Tracy Davis, Hatchery Technician, Fish Research Hatchery
Troy Meyer, Hatchery Technician, Fish Research Hatchery
Karen Hertel, Librarian

Prepared by: ______________________________
Eric E. Richer, Aquatic Research Scientist/Hydrologist

Prepared by: ______________________________
Matthew C. Kondratieff, Aquatic Research Scientist

Approved by: ______________________________
George J. Schisler, Aquatic Wildlife Research Chief

Date: September 30, 2024

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STREAM HABITAT INVESTIGATIONS AND ASSISTANCE PROJECT SUMMARY

Period Covered: July 1, 2023 through June 30, 2024

PROJECT OBJECTIVE:

To advance the science of stream restoration for the benefit of sportfish management and native species conservation in Colorado; to collect data and conduct experiments for the evaluation of stream restoration and fish passage projects; to provide technical assistance in support of project assessment, design, and evaluation

RESEARCH PRIORITY:

Upper Arkansas River Habitat Restoration Project

OBJECTIVES

Project objectives were identified in the *Restoration Monitoring and Outreach Plan for the Upper Arkansas River Watershed* (Stratus 2010), including:

1) Increase fish population, fish health, and benthic macroinvertebrate metrics by at least 10% over baseline conditions by year 5
2) Increase riparian vegetation cover by at least 10% over baseline conditions in fenced and replanted areas by year 3
3) Increase habitat quality scores by at least 10% over baseline conditions by year 5
4) Demonstrate that 90% of habitat improvement structures were stable and functional by year 3

INTRODUCTION

The Upper Arkansas River Habitat Restoration Project was implemented to rehabilitate and enhance aquatic habitat for an 11-mile reach of the Arkansas River and Lake Fork near Leadville, Colorado. Funding for the project was obtained under the Natural Resource Damage Assessment provisions of the Comprehensive Environmental Response, Compensation, and Liability Act. Damages to natural resources were due to hazardous substances released from the California Gulch Superfund Site and physical disturbance from historic mining and land-use activities. The habitat project was designed to improve fish populations in the Upper Arkansas River (UAR) as partial compensation to the public. Colorado Parks and Wildlife (CPW) was responsible for habitat restoration on approximately five river miles with public fishing access within the Crystal Lakes State Trust Lands, Reddy State Wildlife Area, and Arkansas Headwaters Recreation Area. Restoration activities on the remaining six miles of river occurred on private lands and were implemented in partnership with the Lake County Conservation District, National Resource Conservation Service, and individual landowners. Instream construction occurred during summer and fall months from 2012 to 2015.

Project goals were focused on enhancing Brown Trout *Salmo trutta* populations in the UAR, including increased population density and biomass, improved body condition, and improved age and size class structure. Habitat treatments addressed these goals by stabilizing stream banks and promoting diverse stream morphology, reducing erosion and downstream sedimentation, enhancing overhead cover for trout, increasing spawning areas, and providing refuge for juvenile trout (Stratus 2010). Monitoring targets were identified to evaluate project goals and inform adaptive management. Primary monitoring targets were focused on instream habitat structures, riparian vegetation, fish populations, benthic macroinvertebrates, and habitat quality scores. Secondary monitoring targets included water quality and geomorphology. Results from monitoring riparian vegetation, fish populations, benthic macroinvertebrates, and habitat quality were presented in previous reports (Richer and Kondratieff 2023) and peer-review publications (Richer et al. 2019; Wolff et al. 2019; Wolf et al. 2021; Cubley et al. 2022; Richer et al. 2022; Wolff et al. 2022; Kotalik et al. 2023). The evaluation of instream habitat structures was published during this reporting period (Richer et al. 2024), and is briefly described below.

METHODS

Annual assessments conducted during 2014-2018 and 2020 were used to determine if at least 90% of all habitat improvement structures (n = 137) were stable and functional. Surveys utilized a rapid field assessment procedure developed by Miller and Kochel (2012) to evaluate integrity, erosion, and deposition at each structure. Rankings for integrity, erosion, and deposition were investigated with ordinal regression to determine if rankings varied by structure type and year, and structures that exhibited high failure rates were investigated further to determine if failures were due to deficiencies in engineering design or construction. The change in residual pool depths (RPD) was also investigated for 86 pools using ANOVA with repeated measures to determine if structures improved overwinter habitat, if RPD varied by structure type, and if any changes in RPD were sustained over time.

RESULTS AND DISCUSSION

Results from the rapid assessment indicated that more than 90% of all structures were stable and functional by year 3. However, structural integrity and function diminished over time and the likelihood of poorer rankings increased after a 36-year flood in 2019. Results from ordinal regression suggest that some structure types were more prone to failure than others, with higher failure rates observed for boulder toe, log vanes, log toe, and boulder vanes. Analysis of the change in RPDs suggests that pool depths increased in the first year following construction, decreased following the first runoff, and then remained relatively stable in subsequent years. Our results suggest that the lifespan of structures may depend on the adequacy of the engineering design and the magnitude of flows that occur following construction. The study also demonstrated that rapid assessment is a useful tool for evaluating structure performance and the need for project maintenance. We hope that this study will inform structure selection and design for future stream restoration projects located in similar geomorphic settings. More detailed results are available in Richer et al. (2024) and no additional surveys for instream structures are planned at this time.

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We would like to thank Greg Policky, Michael Atwood, and Alex Townsend for their work on fish population monitoring and project oversight. We thank Tracy Kittell for project design and management, and Kyle Hardie for oversight of maintenance activities. We also thank our many collaborators, including Dr. Will Clements, Dr. Dan Baker, and Dr. Brian Bledsoe, as well as the various students and research associates that have supported the project. We thank the many technicians and volunteers that have helped with fieldwork. Finally, we thank Kelly November Carlson and Rosemary Black for their invaluable efforts in support of contracting and accounting.

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RESEARCH PRIORITY:

Kemp-Breeze State Wildlife Area Habitat Project, Colorado River

OBJECTIVES

1) Increase sediment transport capacity and competence by manipulating channel dimensions
2) Decrease the prevalence of fine sediment and reduce embeddedness within riffle habitats
3) Increase the frequency of flushing flow events in riffle habitats under the future flow regime by manipulating channel dimensions
4) Activate floodplains with a frequency of 1-3 years under the future flow regime
5) Increase the density of native riparian vegetation along streambanks and floodplains to increase flood resilience and improve wildlife habitat
6) Increase the density of Mottled Sculpin and Salmonflies within the project reach
7) Increase trout population biomass (lbs/acre) and quality (# of fish > 14"/acre)
8) Increase Rainbow Trout reproduction (fry density) and recruitment (adult density)
9) Increase habitat suitability and diversity for Rainbow Trout, Brown Trout, and Mottled Sculpin by improving instream hydraulics
10) Increase the abundance, distribution, and diversity of benthic macroinvertebrates

INTRODUCTION

The Upper Colorado River Habitat Project (Habitat Project) was developed in coordination with the Municipal Subdistrict, Northern Colorado Water Conservancy District (Subdistrict) and Denver Water to address concerns raised by Colorado Parks and Wildlife (CPW) and other stakeholders regarding conditions of the aquatic ecosystem in the Colorado River downstream of Windy Gap Reservoir (Subdistrict 2011). Altered hydrologic and sediment regimes have adversely affected the ecological integrity of the Upper Colorado River (UCR). The accumulation of fine sediments has increased substrate embeddedness and degraded habitat for Mottled Sculpin *Cottus bairdii* and Salmonflies *Pteronarcys californica*, both of which are important prey resources for trout (Nehring et al. 2011; Kowalski and Heinold 2019). Sediment supplies have also been impacted by the construction of reservoirs, contributing to armoring of the streambed. Altered hydrology has reduced the frequency of flows with sufficient magnitude and duration to flush fine sediments from the riffle habitats that Sculpin and Salmonflies occupy. Trout populations between Windy Gap and Kremmling have also declined since the construction of Windy Gap Reservoir. In particular, Rainbow Trout *Oncorhynchus mykiss* populations in the Colorado River have decreased significantly due to the prevalence of whirling disease, which has been exacerbated by the favorable conditions for whirling disease within Windy Gap Reservoir and the river downstream.

Aquatic habitat restoration for a 16.7-mile reach of the UCR was identified as mitigation for the firming of water rights on the Colorado and Fraser rivers (Denver Water 2011; Subdistrict 2011). The goal of the Habitat Project is to design and implement a stream restoration program to improve the existing aquatic environment in the Colorado River from the Windy Gap Diversion to the lower terminus of the Kemp-Breeze State Wildlife Area (SWA) by returning the river to a more functional system considering current and future hydrology. Project objectives include improving sediment transport processes, floodplain connectivity, quality and diversity of trout habitat, habitat for Sculpin and Salmonflies, as well as restoring benthic macroinvertebrate populations and riparian corridors. Creating and maintaining interstitial habitat in riffles is critically important for the restoration of Sculpin, Salmonfly, and other benthic aquatic organisms in the Colorado River. Improving riffle habitats may also increase prey resources and spawning habitat, which should have beneficial effects on the trout fishery. Aquatic habitat restoration at the Kemp-Breeze SWA was selected for the first phase of the larger Habitat Project on the Colorado River. The restoration design for Kemp-Breeze was completed in spring 2021 and the first phase of construction began in August 2022. The second phase of construction at Kemp-Breeze was initiated in August 2023 and completed in December 2023, with final seeding and planting taking place in the summer and fall of 2024.

Understanding sediment transport is critically important for the assessment, design, and evaluation of the habitat restoration project. Target flow ranges for summer, winter, and flushing flows were identified for the Colorado River in the Grand County Stream Management Plan (Tetra Tech 2010). The Kemp-Breeze SWA is contained within the Grand County study reach that starts at the Williams Fork confluence and ends at the Kemp-Breeze Ditch. Flushing flows were identified as the flow threshold at which gravel mobilization was initiated, and were intended to periodically remove fine sediments (such as silts and sands) from the streambed surface and inter-gravel environment (Tetra Tech 2010) and ultimately create and maintain interstitial habitats in riffles. Flushing flows were estimated to occur at or above 800 cfs and recommended for a minimum of three days once every two years in late May to late June. Estimates for flushing flows were obtained from hydraulic and sediment transport models, but were not yet supported by empirical evidence. Target winter flows range from 150-250 cfs and target summer flows range from 250-500 cfs for Kemp-Breeze reach.

Salmonflies and Sculpin may serve as ecological indicators for improvements in sediment transport processes. The Salmonfly, or Giant Stonefly, is a large aquatic invertebrate that can reach high densities in some Colorado rivers. These invertebrates play an important ecological role as grazers in stream systems and can be extremely important for stream dwelling trout as a food source. Salmonflies have relatively specific environmental requirements and are considered intolerant of disturbance (Erickson 1983; Fore et al. 1996). Although they were once common in the UCR (USFWS 1951; Dames and Moore 1977; Erickson 1983), the abundance of Salmonflies has declined, especially downstream of Windy Gap Reservoir where flow alterations associated with trans-mountain water diversions are greatest (Nehring et al. 2011). Restoring sediment transport processes to improve habitat for Salmonflies is a critical design objective for the Habitat Project on the Colorado River.

Sculpin are an ecologically important part of freshwater ecosystems because they can occur in high densities in depauperate coldwater mountain streams (Adams and Schmetterling 2007). Mottled Sculpin prefer cool, high gradient mountain streams with cobble habitat and are rarely found in stream reaches where substrate is embedded with silt (Sigler and Miller 1973; Woodling 1985). As such, their habitat preferences for cobble substrate and high quality riffle-run habitat make Sculpin a good ecological indicator of stream health (Adams and Schmetterling 2007; Nehring et al. 2011). Sculpin were common in the main stem Colorado River prior to the construction of Windy Gap Reservoir, but are rare or absent after construction (Erickson 1983; Nehring et al. 2011; Kowalski and Heinold 2019). No Sculpin were detected within the Kemp-Breeze SWA during adult population or fry surveys in 2018-2021, and the last documented observation was reported in 1998. Restoring connectivity around Windy Gap Reservoir and addressing habitat limitations associated with flow and sediment regimes should improve conditions in the UCR for this important native fish.

The effectiveness of the restoration project will be evaluated with a combination of biological and physical monitoring. Salmonfly, benthic macroinvertebrate, and Sculpin monitoring will be conducted by CPW under the Colorado Coldwater Stream Ecology Investigations and Sport Fish Research Studies programs. Changes in adult trout populations will be evaluated by the CPW Aquatic Section. Changes in geomorphology and sediment transport will be monitored by the Stream Habitat Investigations research program. Construction of the project was divided into two phases, with the first phase being constructed in the fall/winter of 2022 and the second phase in the fall/winter of 2023. This report provides an update on activities that occurred during this reporting period, including construction of the Phase 2 project, as-built surveys, sediment surveys, and relocation of tracer rocks within the Phase 1 reach following runoff.

METHODS

Project Construction:
The conceptual design for the Kemp-Breeze project was developed by CPW (Richer et al. 2019). Stillwater Sciences and AlpineEco were then hired to develop preliminary (Stillwater Sciences 2020) and final (Stillwater Sciences 2021) designs for the restoration project, and L4 Environmental was hired to construct both phases of the project. Detailed information on design methods is available in the aforementioned reports. Project construction utilized a variety of heavy equipment, including excavators, haul trucks, loaders, and a bull-dozer. Project oversight was provided by CPW, Stillwater Sciences, and AlpineEco. Restoration activities included realignment of an irrigation ditch, construction of islands, side channels, overflow channels, new floodplain benches, log-jam structures, brush trenches, and pools. Vegetation treatments included willow, alder, cottonwood, and sod-mat transplants, as well as plantings, seeding, and mulching. Riffle dearmoring and gravel augmentation were also utilized as experimental treatments to improve sediment transport processes.

As-Built Surveys:
As-built surveys were conducted with a Trimble Survey-Grade Global Navigation Satellite System (GNSS) to document the post-construction topography of the new channels and floodplain. Bathymetric surveys were conducted with a SonTek Acoustic Doppler Current Profiler (ADCP) using the HydroSurveyor software application to provide additional survey data for the newly constructed channels. Survey data were post-processed, combined in ArcGIS, and used to create a triangular irregular network (TIN) to represent the post-construction surface. Three TINs were developed and used for analysis: (1) preexisting conditions from survey data collected during October 2018, (2) as-built conditions for the Phase 1 reach with survey data collected during April 2023, and (3) post-runoff conditions for the Phase 1 reach and as-built conditions for the Phase 2 reach with survey data collected during October 2023 and April 2024, respectively. Breaklines were digitized and used to edit the TINs in locations with distinct slope breaks, such as the top and bottom of stream banks. Longitudinal and cross-section profiles were then extracted from the TINs

and to evaluate changes in morphology. The location and extent of restoration treatments were also surveyed and digitized in GIS.

Log-jam structures were utilized to provide a variety of geomorphic functions, including localized scour to maintain pool habitat, creating depositional areas to help narrow the channel over time, and creating localized areas with increased shear to improve sediment transport capacity (Stillwater Sciences 2021). Structures were also expected to provide a variety of habitat benefits, such as overhead cover, slower velocity zones for different aquatic species and life stages, erosion/deposition on riparian benches for cottonwood regeneration, and a general increase in both aquatic and riparian habitat diversity and complexity. Log-jam structures were assessed during the as-built survey for the Phase 1 reach in April 2023, the post-runoff survey for Phase 1 in October 2023, and as-built survey for Phase 2 in April 2024 using a rapid-assessment procedure that was adapted from previously published methods (Bain and Stevenson 1999; Miller and Kochel 2013; Rosgen 2008; Weber et al. 2020). Structure types evaluated during the assessment included bar-apex jams, in-channel jams, bank jams, large-pool jams, downed cottonwood trees, and floodplain jams. The field procedure entails visiting each log-jam structure at least one time per year. Ideally, assessments would be conducted during baseflow and bankfull flows. Although assessments during moderate floods would be beneficial, access to all structures may not be feasible during overbank flooding. Aerial reconnaissance with a drone will be explored to support assessment during high flows. All structures were numbered and photographed from both the ground and air (i.e., drone) to support repeat surveys and document changes over time. Structural attributes evaluated during the log-jam assessments included condition, integrity, erosion, deposition, fish-passage risk, habitat, vegetation, and maintenance, among others. A more detailed description of the log-jam assessment procedure is available in Richer and Kondratieff (2023).

Sediment Surveys:
Grid-frame pebble counts (Bunte and Abt 2001) were conducted at previously surveyed locations following snowmelt runoff in September 2023. Site PC1A was the location of an experimental riffle dearmoring treatment, and site PC2A was located within the main channel in the Phase 1 reach. We also established a pebble count transect (site PC2B) within a newly constructed riffle where tracer rocks were deployed. A longitudinal pebble count was conducted with the grid-frame within one side channel to support monitoring of streambed evolution over time. Results were compared to pre-construction and as-built pebble counts to evaluate how gradations changed during the first post-construction runoff in the Phase 1 reach. Pebble counts in the Phase 2 reach could not be conducted during the spring of 2024 due to unseasonably high flows, but are scheduled for the fall of 2024.

Tracer Rocks:
Methods for the pre-construction tracer rock study were previously described in Kondratieff and Richer (2023), and included three years of tracer-rock relocation in 2019-2021. All tracer rocks deployed during the pre-construction monitoring period were removed prior to construction. Following completion of instream construction, tracer rocks were redeployed within three riffle locations (riffle 1, riffle 2A, and riffle 2B). Riffle 1 was located in the same location for both pre- and post-construction evaluations. As the channel morphology was greatly altered at riffle 2 during Phase 1 construction, rocks were deployed in two separate riffles (riffles 2A and 2B) for the post-construction evaluation. Two riffles were needed to represent riffle 2 in the post-construction study

because the channel was narrowed substantially and the area of the riffles was significantly smaller, which required that the tracer rocks be deployed in two riffles to meet the pre-construction sample size while avoiding issues with tag collision when PIT-tagged rocks are placed too close together. Tracer rocks were also deployed in transects over the top of all gravel augmentation locations and within two overflow channels as part of the post-construction evaluation. Tracer rocks in the Phase 1 reach were relocated during the fall of 2023 to evaluate movement during the first post-construction runoff cycle. Although we intended to deploy tracer rocks in the Phase 2 during the spring of 2024, higher-than-expected flows prevented the deployment of tracer rocks prior to runoff. We were able to deploy tracer rocks at gravel augmentation sites in the Phase 2 reach, but deployment of tracer rocks at riffle locations in the Phase 2 reach will have to wait until the fall of 2024.

The size distribution of tracer rocks changed between the pre- and post-construction studies. For the pre-construction study, the size distribution for tracer rocks was designed to match the gradation of the existing streambed, which lacked gravels, to determine the overall proportion of the streambed that moved. As the fill material utilized for construction of the Phase 1 channel had a larger size distribution that included more medium and coarse gravels that the pre-construction streambed, tracer rocks from those size classes were tagged with 12 mm PIT tags and incorporated into the post-construction study. The sample size for riffles 1 and 2 was held constant for both periods, which entailed reducing the number of large cobbles that were included in the post-construction study. However, 65 out of 100 tracer rocks from riffle 1 and 64 of 100 rocks from riffle 2 (riffles 2A and 2B combined) were utilized in both the pre- and post-construction studies to support a before-after analysis that utilizes the same sample of tracer rocks for both periods. All post-construction tracer rocks within the Phase 1 reach were deployed prior to snowmelt runoff in April 2023. The number of tracer rocks deployed in each location was summarized in Table 1. Tracer rocks were relocated in the fall of 2023 to assess distance moved by size class and study site, and for comparison to observations from the 3-year pre-construction study period.

Table 1. Number of PIT-tagged rocks for post-construction study sites within the Phase 1 project reach, including the size range for the intermediate axis of individual particles.

Size Class	**Riffle 1**	**Riffle 2A**	**Riffle 2B**	**Gravel Augmentation**	**Total**
Medium gravel	15	7	8	9	39
Coarse gravel	15	8	7	10	40
Very coarse gravel	24	12	11	10	57
Small cobble	33	16	17	9	75
Large cobble	10	5	5	2	22
Small boulder	3	2	2	0	7
Total	100	50	50	40	240
Size range (mm)	12-290	12-280	15-290	15-175	12-290

RESULTS AND DISCUSSION

Project Construction:

Phase 2 of the project was constructed during August-December 2023, focusing on the downstream half of project reach. Major activities included mass grading to narrow the channel and create a new floodplain bench, installation of log-jam structures, vegetation transplants, and gravel augmentation. Changes in channel and floodplain morphology are depicted in Figure 1. Although fill material had been stockpiled prior to construction, the amount of fill proved insufficient to meet design elevations for the large floodplain area on river right. As such, this new floodplain bench was left 1 ft lower than design elevations in many locations. Floodplain jams, vegetation transplants, brush trenches, and topographic complexity were utilized to provide stability and induce sediment deposition. Similar to Phase 1, the use of piles to anchor the log jams proved challenging, as the depth to bedrock was shallower than anticipated. All of the in-channel jams had to be relocated to the stream bank or floodplain, and alluvial sediment was used to provide

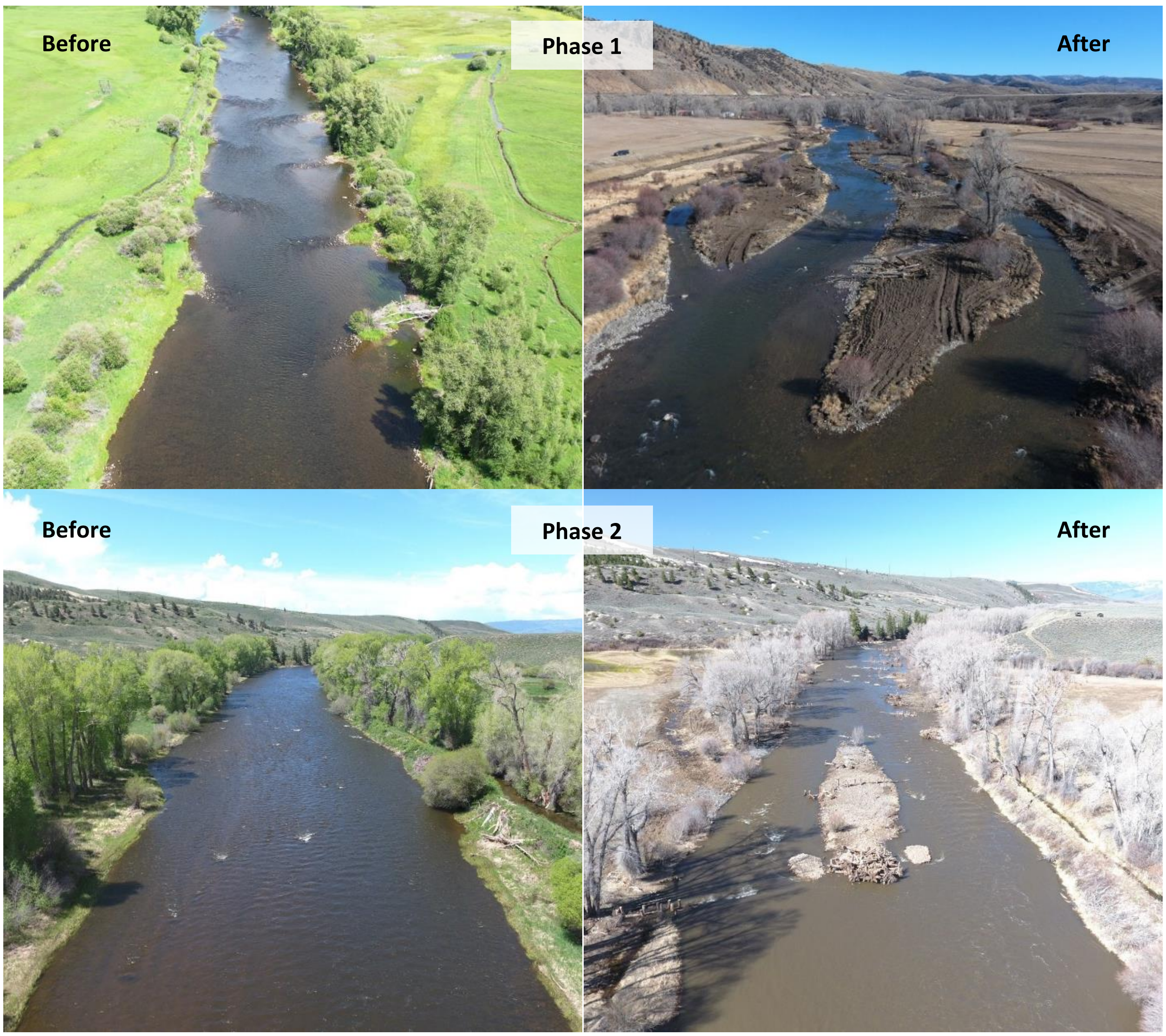

Figure 1. Before and after photographs for the Kemp-Breeze SWA Habitat Project on the Colorado River.

additional ballast for floodplain and bank jams. Willow staking and restoration of access roads were completed in the spring of 2024 prior to snowmelt runoff. Planting, seeding, and mulching were then conducted after runoff in summer and fall of 2024.

As-Built Surveys:
As-built surveys for the Phase 1 reach were conducted during April 2023, post-runoff surveys for Phase 1 were conducted during October 2023, and as-built surveys for the Phase 2 reach were conducted in April 2024. Survey data were used to estimate quantities for restoration treatments utilized during both phases of the project (Table 2). As-built drawings for the project were presented in Appendix A, including longitudinal and cross-section profiles.

Table 2. As-built quantities for restoration treatments at the Kemp-Breeze SWA Habitat Project on the Colorado River.

Category	Description	Quantity			Units
		Phase 1	Phase 2	Total	
Mobilization	Access roads	--	--	4.1	acre
	Staging area	--	--	2.3	acre
Mass grading	Ditch realignment	0.56	0	0.6	acre
	Floodplain development	0.60	1.84	2.4	acre
	Island construction	2.16	0.21	2.4	acre
	Overflow channel	1.29	0.94	2.2	acre
	Pool development	0.48	0.93	1.4	acre
	Riffle dearmoring	0.62	0.00	0.6	acre
	Side channel development	1.16	0.42	1.6	acre
	Borrow pit	1.21	0	1.2	acre
	Gravel augmentation	250	350	600	cy
Vegetation	Brush trench	385	767	1152	ft
	Sod mat	0.29	0.17	0.5	acre
	Alder transplant	16	25	41	each
	Cottonwood transplant	17	9	26	each
	Willow transplant	76	77	153	each
Log-jam structures	Bank jam	11	18	29	each
	Bar-apex jam	2	1	3	each
	Downed cottonwood tree	7	10	17	each
	Floodplain jam	5	10	15	each
	In-channel jam	1	0	1	each
	Large-pool jam	1	4	5	each

We used the log-jam assessment procedure (Richer and Kondratieff 2023) to evaluate 70 structures, including post-runoff conditions for 27 log-jams installed within the Phase 1 project reach and as-built conditions for 43 log-jam structures within the Phase 2 reach. Bank jams were the most common structure type (41%), followed by downed cottonwood trees (24%) and floodplain jams (21%). Large-pool jams and bar-apex jams were used less frequently (Table 2), and a lone in-channel jam was installed in a Phase 1 side-channel. In total, 279 piles, 233 horizontal logs without rootwads, 173 logs with rootwads, and 21 cottonwood trees were used in construction of the log jams. All but one of the structures was considered stable and intact during the as-built assessments. Flows were higher than average in 2023, peaking around 3,800 cfs (Figure 2) and inundating the newly constructed islands and floodplains (Figure 3). Some bank erosion was evident after the 6.5-year flood event, and 15% of the structures in the Phase 1 reach were damaged during runoff in 2023. However, all structures were still considered functional and only one structure was identified for maintenance. Additional piles were installed at the damaged bar-apex jam in the fall of 2023 to address the maintenance concerns.

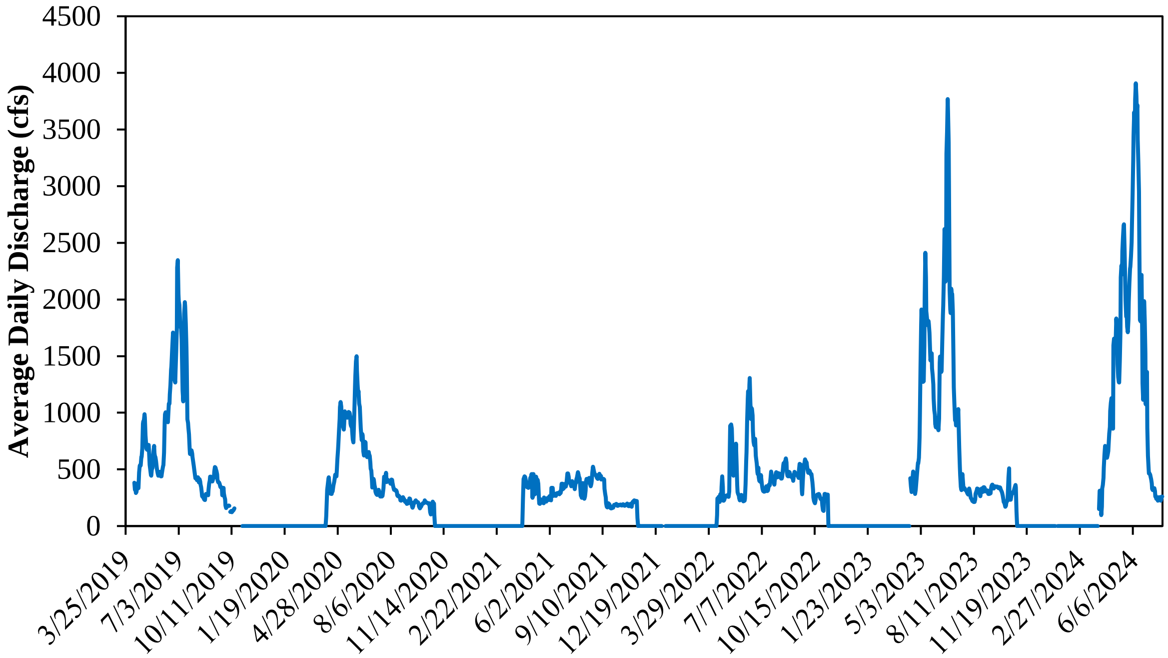

Figure 2. Average daily discharge (cfs) at the Kemp-Breeze SWA project site on the Colorado River, 2019-2024.

Minor erosion and deposition was common at log-jams following the high flows of 2023, occurring at 70% and 81% of the structures, respectively. Moderate to severe erosion was observed at eight structures (30%), while moderate deposition occurred at 19% of the log jams. No structures were considered a risk to fish passage. Habitat assessment indicated that 84% of the log jams provided overhead cover for fish, 94% created complex habitat, 70% provided depth cover, 73% provided juvenile refuge for trout, 80% provided foraging habitat, and 44% provided rearing habitat for trout fry. The percentage of structures that received poor vegetation rankings decreased from 81% in the spring to 44% in the fall. The number of structures that received vegetation rankings of fair to good increased from 15% to 52%, indicating that riparian vegetation cover was improving.

Figure 3. Time series of photos from the Kemp-Breeze SWA Habitat Project on the Colorado River showing flooding of newly constructed islands and side channels in 2023.

Sediment Surveys:
The fill material used to create the new channel, islands, and floodplain bench was sourced from an alluvial fan on a nearby hillslope. Material from the borrow pit at the alluvial fan was generally smaller than the specified gradations in the design plans (Richer and Kondratieff 2023), which were based on the existing stream bed. Therefore, observed gradations are expected to coarsen

over time as finer sediment is winnowed away during high flow events. Pebble counts for as-built and post-runoff conditions at riffles 1, 2A, and 2B were used to investigate changes in sediment gradation following the first runoff cycle after construction. Riffle 1 was treated with experimental dearmoring and riffles 2A and 2B received a top dressing with fill material from the borrow site to meet the design elevations and channel dimensions. Riffle dearmoring did not result in a substantial change in sediment gradations at riffle 1 (Table 3), although there is evidence that the D16 became somewhat finer following treatment, decreasing from 39 mm to 25 mm. Additionally, the D84 appeared to increase slightly from 144 mm to 165 mm, suggesting that riffle dearmoring increased heterogeneity in sediment size. Although the sediment classification for the D16 changed from very coarse gravel to coarse gravel following runoff, sediment classifications for the D50 and D84 remained unchanged and were classified as small and large cobble, respectively.

Table 3. Sediment gradations for pre-construction (before), as-built, and post-runoff conditions at three riffle locations (PC1A, PC2A, and PC2B) and one side channel (SC2) within the Phase 1 reach of the Kemp-Breeze SWA Habitat Project on the Colorado River.

Site	Date	Survey	D16 (mm)	D50 (mm)	D84 (mm)	n
PC1A	4/27/2022	Before	39	85	144	321
	9/28/2023	Post-Runoff	25	80	165	327
PC2A	4/29/2022	Before	15	76	165	372
	11/16/2022	As-Built	11	32	110	257
	9/28/2023	Post-Runoff	18	64	125	176
PC2B	11/17/2022	As-Built	14	34	100	235
	9/28/2023	Post-Runoff	22	70	200	184
SC2	9/21/2022	As-Built	4	19	64	331
	10/6/2022	Post-Runoff	9	30	100	332
	9/28/2023	Post-Runoff	8	35	115	224

More substantial changes in sediment size were observed at riffles 2A and 2B. Comparison to pre-construction pebble counts indicates that construction decreased the D16, D50, and D84 at both riffles 2A and 2B due the larger fraction of gravel-sized material in the fill material from the borrow pit (Table 3). As expected, sediment size coarsened following runoff at these riffle locations. The D16, D50, and D84 all increased following runoff at riffles 2A and 2B, with many values doubling in size between as-built and post-runoff pebble counts. The longitudinal profiles (Appendix A) show that channel elevations at riffle 2B degraded by approximately 1 ft, and that the newly-constructed streambed was mobilized during runoff in 2023. Riffle 2A also shows some evidence of incision, but less than was observed at riffle 2B. Coarsening of the streambed in side channel 2 was also observed following runoff (Table 3). However, streambed sediment in the side channel was generally finer-grained than main channel. Fill material from the borrow pit was used throughout the main channel during construction, but imported material was only placed at a few riffle locations within side channel 2. The as-built gradations were finer in the side channel compared to the main channel, so it is not surprising that sediment gradations remained finer in the side channels following runoff. Overall, the streambed coarsened during runoff in 2023 and will likely move towards an armored condition over time, suggesting that additional gravel augmentation will be needed to maintain a heterogeneous sediment gradation that includes spawning-sized gravels.

Tracer Rocks:

We deployed 240 PIT-tagged tracer rocks within the Phase 1 project reach prior to snowmelt runoff in the spring of 2023. Tracer rock ranged in size from 12 to 290 mm (Table 2), including size classes ranging from medium gravel to small boulder. The majority of rocks (n = 200) were placed in riffle locations, but additional tracer rocks were placed at gravel augmentation sites (n = 30) and within overflow channels (n = 10) to determine if sediment was mobilized in those locations. We relocated 170 (71%) tracer rocks during the fall of 2023. Preliminary results indicate the distance moved was much greater in 2023 when compared to the pre-construction surveys (Figure 4), with the average distance moved increasing from 0.5 ft to 88 ft (Table 4). The difference in distance moved is partially explained by the inclusion of smaller-sized particles in the after period (Table 4), but was primarily driven by the combination of high flows (Figure 2) and the placement of unconsolidated fill material at study riffles during construction. Gravel particles moved the farthest, followed by cobbles and boulders (Figure 5), and distance moved appeared to decrease with increasing sediment size (Figure 6). The greatest distances moved were observed in riffle 2 (2A and 2B combined), followed by gravel augmentation and overflow sites (Figure 7). Tracer rocks in riffle 1 moved shorter distances relative to other sites, but were transported farther in 2023 than any previous year prior to construction. Biological monitoring of benthic macroinvertebrates and sculpin will help determine if riffle dearmoring is an effective restoration treatment that should be utilized in future phases of the Habitat Project.

Table 4. Summary statistics for distance moved and tracer-rock size during the before (2019-2021) and after (2023) study periods. Note that SD = standard deviation.

Period	**n**	**Distance Moved (ft)**			
		Max	**Mean**	**Min**	**SD**
Before	899	11.3	0.49	0.01	1.1
After	170	1050	87.6	0.04	177
Period	**n**	**Particle Size (mm)**			
		Max	**Mean**	**Min**	**SD**
Before	899	290	101	41	45
After	170	290	93	15	62

The relocation rate for tracer rocks during the before period was very high (99%), but we were only able to relocate 70% of the tracer rocks in 2023 due the greater distances moved. We utilized a raft-based antenna to survey the entire river channel and then investigated each detection with backpack antennas. The revised relocation methods increased the number of tags we detected but also the amount of effort. Results from pebble counts, longitudinal profiles, and tracer rocks all indicate that bedload transport occurred within the Phase 1 reach during 2023, which redistributed tracer rocks through the study sites (Figures 8 and 9). Tracer rocks will be relocated the fall of 2024 and additional rocks will be deployed at riffle 3 in the Phase 2 reach to support further analysis. At least three years of post-construction tracer rock surveys are planned to investigate sediment transport in the restored reaches over a range of flows. Final analyses will be performed following completion of the post-restoration monitoring period.

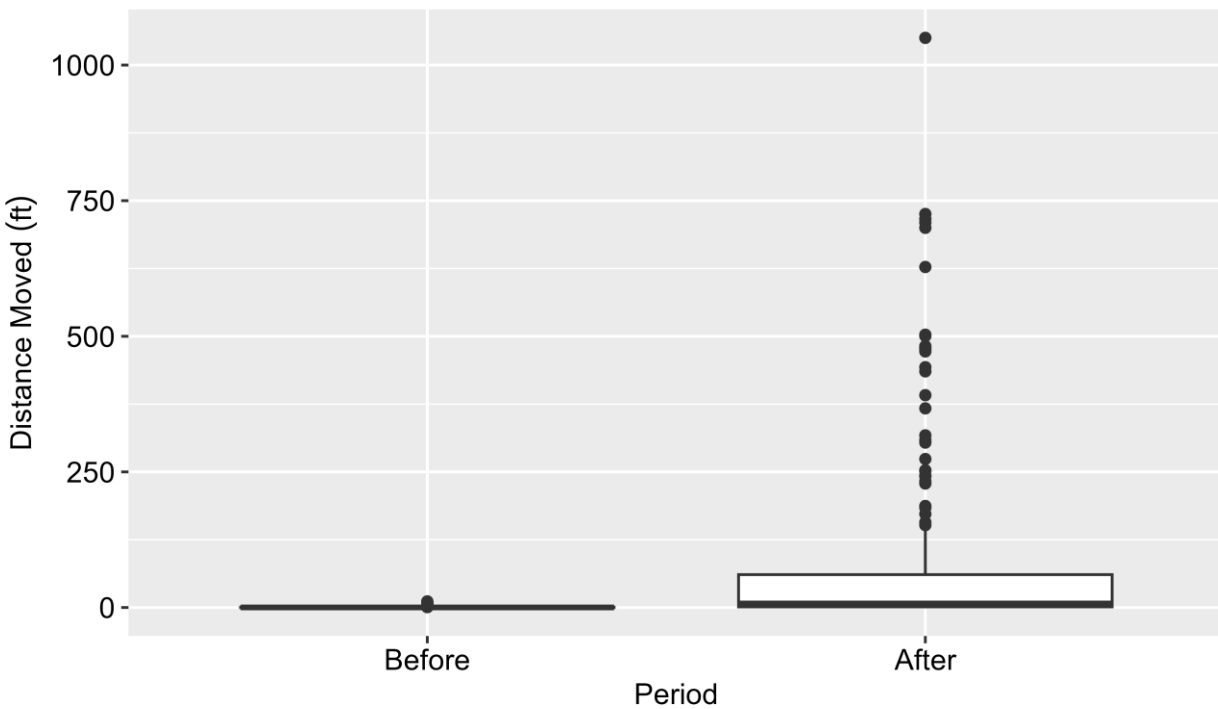

Figure 4. Boxplots for distance moved by tracer rocks during the before (2019-2021) and after periods (2023).

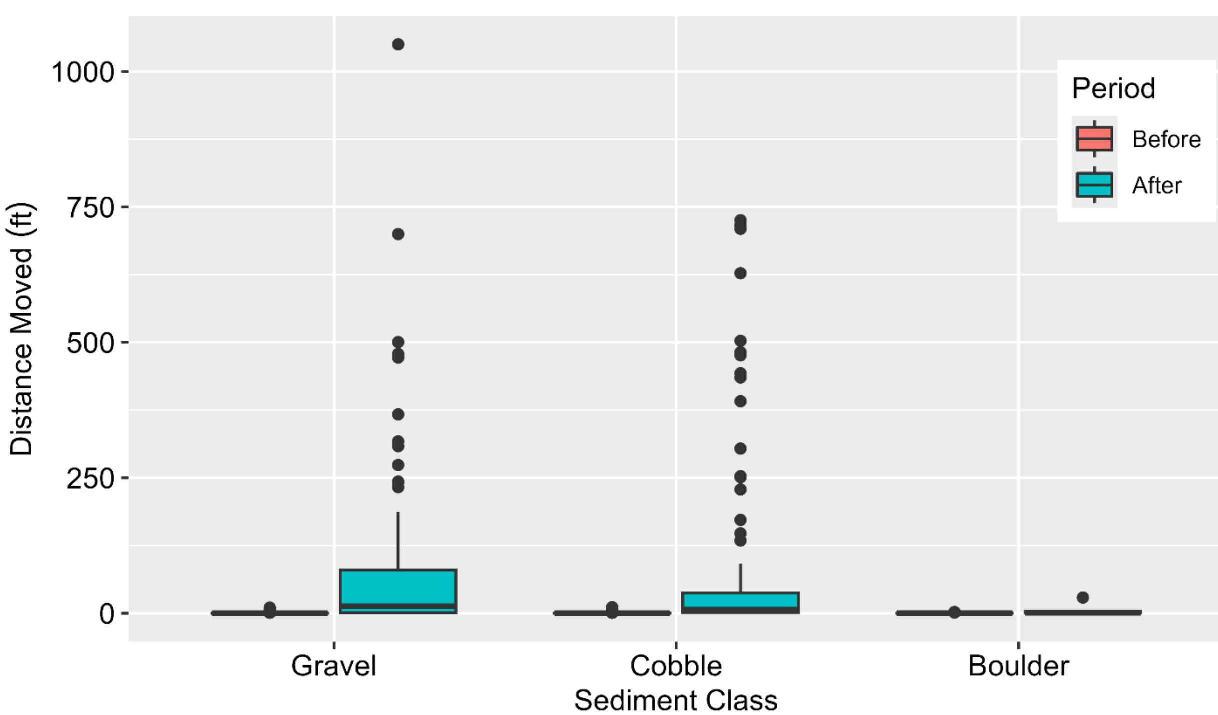

Figure 5. Boxplots by sediment size class for distance moved by tracer rocks during the before (2019-2021) and after periods (2023).

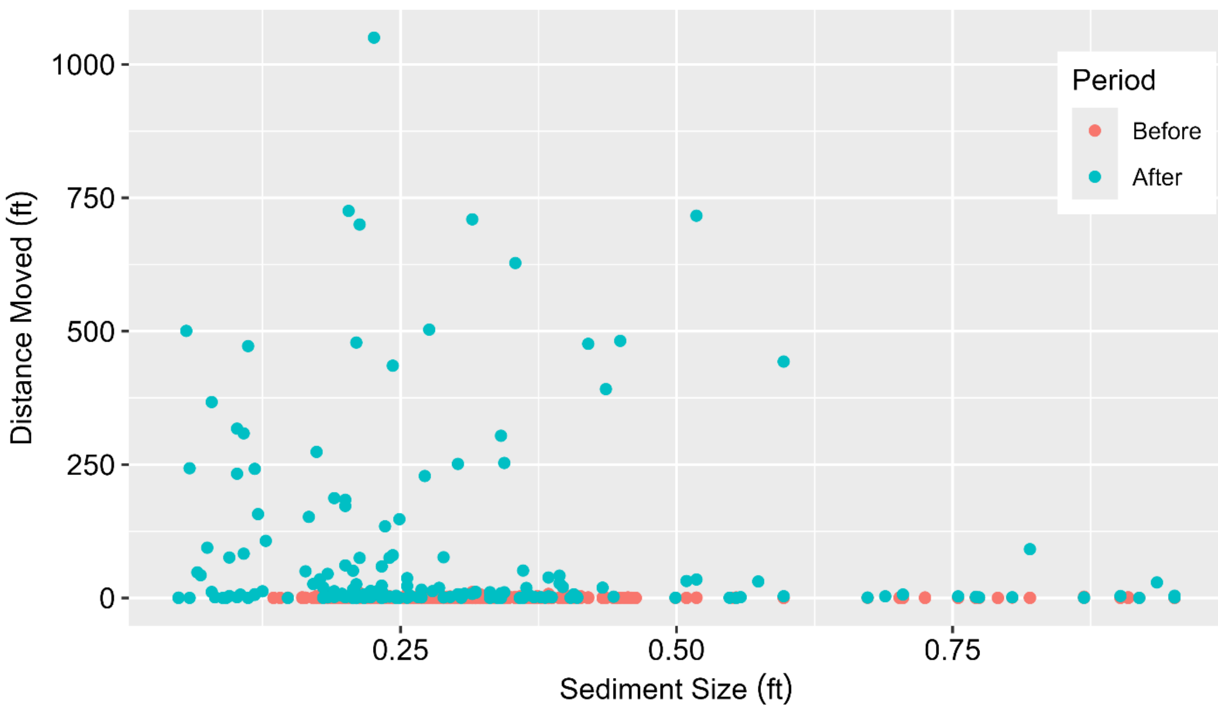

Figure 6. Comparison of sediment size and distance moved for tracer rocks that were relocated during the before (2019-2021) and after (2023) periods.

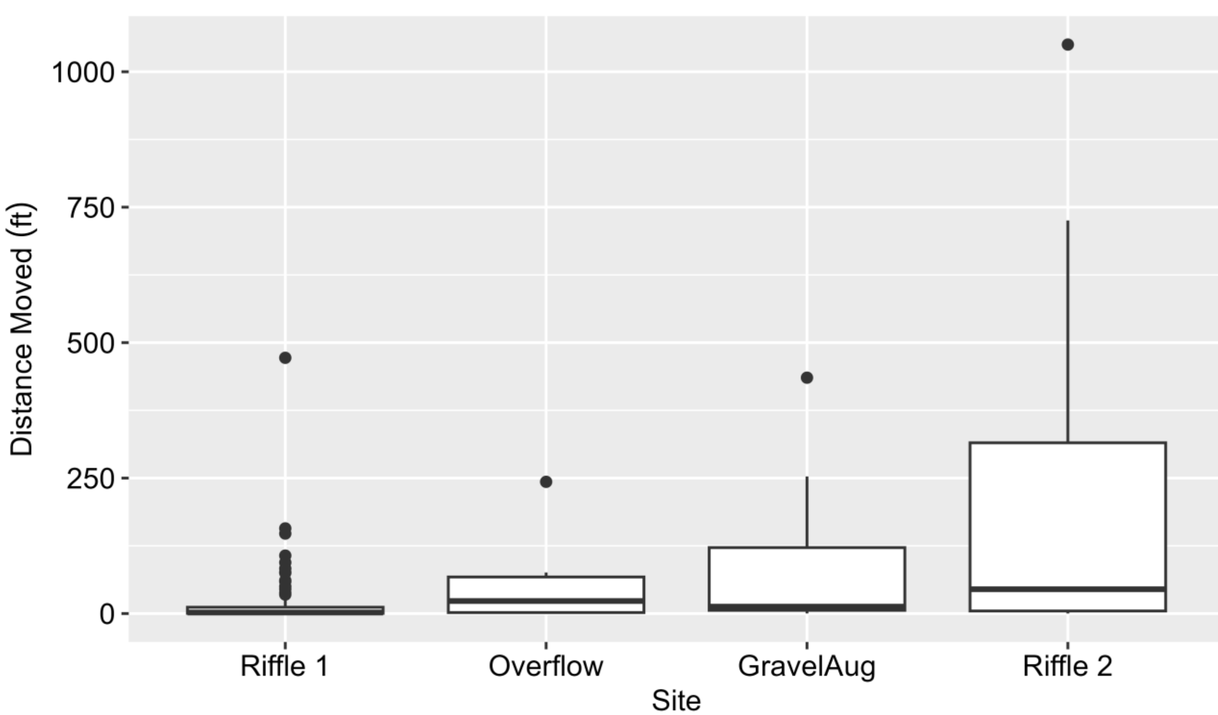

Figure 7. Distance moved by study site for tracer rocks that were relocated in 2023. Note that riffle 2 includes data from both riffles 2A and 2B.

Figure 8. Tracer rock locations following deployment in April 2023 and relocation in October 2023 at an experimental location that was treated with riffle dearmoring (riffle 1).

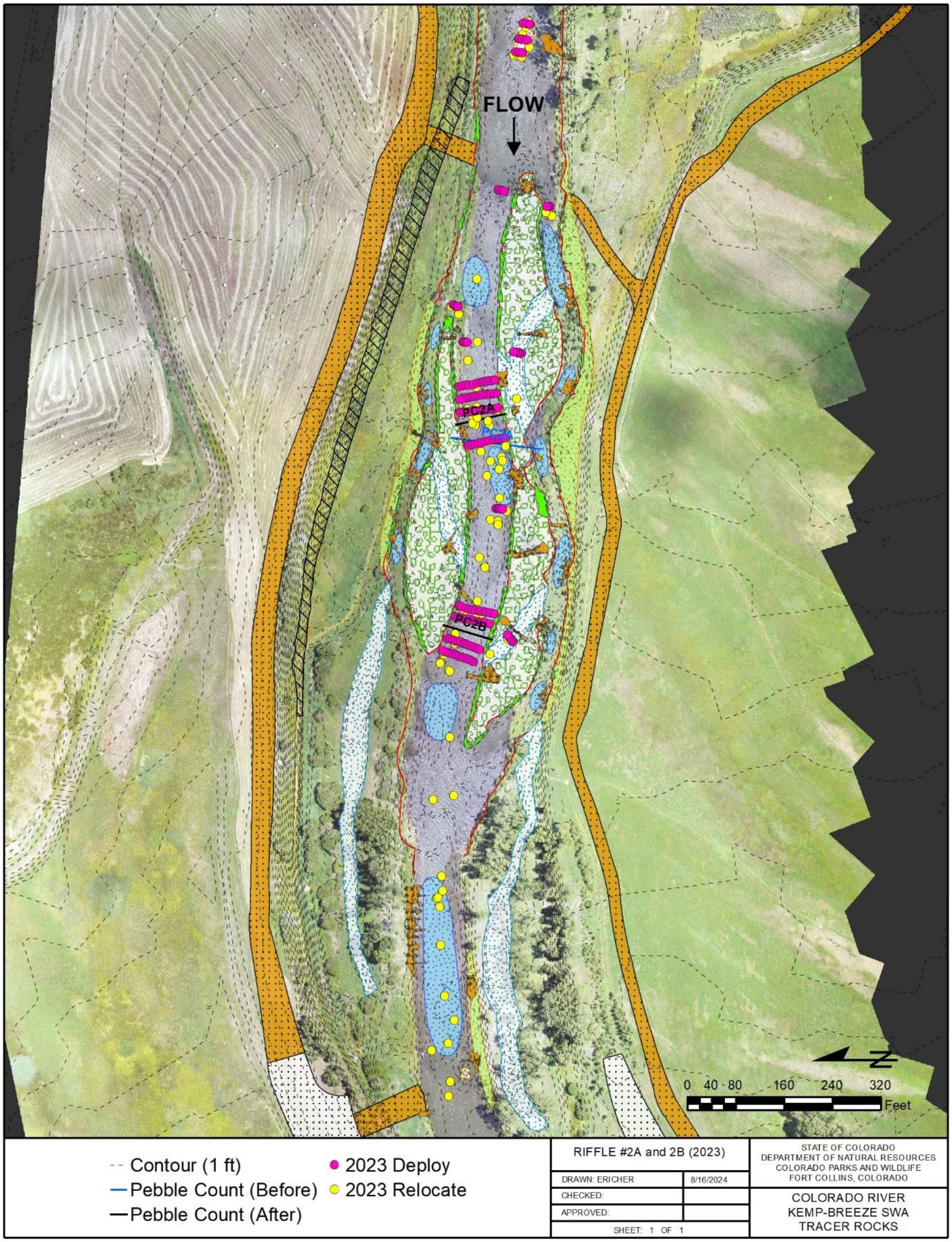

Figure 9. Tracer rock locations following deployment in April 2023 and relocation in October 2023 within the Phase 1 reach, including riffle, gravel augmentation, and overflow sites.

ACKNOWLEDGEMENTS

We would like to acknowledge Barry Nehring for his work documenting changes in benthic macroinvertebrates, Mottled Sculpin, and trout populations following construction of Windy Gap Reservoir that ultimately led to the development of the greater Habitat Project on the Colorado River. We also thank the various collaborators and technicians that have contributed to the data collection and analysis, including Jon Ewert, Eric Fetherman, and Dan Kowalski. Finally, we would like to thank George Schisler, Lori Martin, Karlyn Armstrong, Ken Kehmeier, and Sherman Hebein for their contributions to development and implementation of the fish and wildlife mitigation and enhancement plans for the Colorado River.

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<u>RESEARCH PRIORITY:</u>

White River Toe-Wood Study

OBJECTIVES

1) Design and construct a toe-wood bend to stabilize a lateral scour bend experiencing accelerated erosion and protect a wetland mitigation area on the Rio Blanco Lake State Wildlife Area (SWA), White River
2) Evaluate the response of pool depths and native Three Species (Bluehead Sucker, Flannelmouth Sucker, and Roundtail Chub) to the addition of large wood habitat treatments (i.e., toe wood) within pools

INTRODUCTION

The White River Toe-Wood study is a new concept, bridging stream habitat projects that historically focused on traditional non-native game species (i.e., Brown Trout *Salmo trutta* and Rainbow Trout *Oncorhynchus mykiss*), to native aquatic species of conservation concern. We will take knowledge and concepts learned from two decades of habitat restoration work on coldwater non-native salmonid streams and apply those techniques for the benefit of native Three Species (Roundtail Chub *Gila robusta*, Bluehead Sucker *Catostomas discobolus*, and Flannelmouth Sucker *Catostomas latipinnus*; Figures 10-12) as well as other native aquatic species found in the White River (i.e., Mountain Whitefish *Prosopium williamsoni*). We have documented from our previous stream habitat work that toe wood can increase fish abundance by 1.5 times and biomass by up to 10 times versus non-treated impaired reaches (Kondratieff and Richer 2022). This has not been attempted for Colorado native Three Species, but the results from salmonid habitat projects and the response of native species present (i.e., White Sucker *Catostomus commersonii*) indicate that this project should be successful at increasing the quality of habitat for these native fishes. We hope that by showing a successful response in native fish abundance and biomass in this small scale project on the White River, we can then begin to refine and apply these habitat projects in other parts of the Upper Colorado River Basin where stream habitat has been impaired. We are implementing a before-after, control-impact (BACI) design to monitor the response in the fish community and habitat pre and post construction and plan to publish our findings.


Figure 10. Roundtail Chub


Figure 11. Bluehead Sucker

Figure 12. Flannelmouth Sucker

The 550-foot section of the White River on the Rio Blanco Lake SWA is experiencing accelerated erosion due to historical agricultural practices and improperly installed in-channel grade control structures. The river is becoming over-wide, shallower, and experiencing a decrease in substrate size due to the erosional issue on the SWA. We plan to address the erosional issue to restore the proper geomorphology of the river, while also increasing native aquatic species habitat in the form of increased riparian vegetation and instream wood. Over the past century, throughout most of the United States, much of the instream wood that would normally migrate downstream and form log jams has been removed by humans. This instream wood is vital for increasing stream complexity, habitat complexity, and helping with bank stability. Along with the supporting evidence of fish preference for instream wood from our work in South Park, our local fisheries biologists also note that they commonly find a high abundance of our focal species in log jams they survey, so we anticipate that this project will help provide beneficial habitat. The project will also reduce the width to depth ratio of the stream and increase substrate size, thus reducing water temperature and increasing interstitial species for benthic invertebrate habitat and foraging opportunities for our focal species.

If we are not seeing a positive response in the native aquatic species community and river geomorphology we will attempt to determine the limiting factors (i.e., competition with non-native fishes, species-specific habitat suitability preferences, etc…). In some of the South Park treatments, we have had monsoonal flooding damage some of the habitat work the year after construction before vegetation is fully established to secure the bank. In these events we have gone back to conduct maintenance work by retreating toe wood banks with heavy equipment and additional vegetation to ensure the security of the habitat work.

There are very few non-native species present in the White River and the project site occurs at the transition zone between coldwater and warmwater habitats, so it is unlikely that salmonids will become so abundant that they exclude the native species. In the South Platte drainage, we have documented native suckers competing well with salmonids where they do overlap. We conduct extensive non-native fish control projects throughout western Colorado and will be ready to remove non-native fish in the event a new species is illegally introduced that may threaten the native fishes of the White River.

From our previous work in South Park, Colorado, we can anticipate a positive response in the fish community by increasing the abundance and biomass of the fish in the project reach versus untreated areas (Kondratieff and Richer 2022). We hope this will lead to an overall increase in the native fish community in the area surrounding the SWA. Instream wood is also known to be attractive habitat for macroinvertebrates which will provide forage for the focal species of the project. By stabilizing the bank, we have also documented streams responding by decreasing their width to depth ratio, leading to an increase in substrate size in treated areas. The larger substrate is preferable for spawning habitat and creates interstitial spaces for macroinvertebrates. By decreasing the width to depth ratio and encouraging riparian vegetative cover, we have also documented a drop in stream temperatures in treatment reaches. This drop in stream temperature will benefit fish populations, especially during hot summer months and in the face of climate change. Along with the aforementioned benefits, we also have documented an increase in residual pool depth, which will increase refugia during low-flow periods and additional cover from avian and terrestrial predators.

METHODS

Baseline Surveys:
Baseline fish population (Figure 13), hydraulic, and geomorphic (Figure 14) monitoring of the treatment site and control site began in October 2023. We will conduct another round of baseline sampling during the fall of 2024. Upon completion of construction we plan to conduct the same sampling 1 year, 3 years, 5 years, and 10 years after construction is complete to monitor the fish community and geomorphic response through time.

Figure 13. Collecting baseline fish population data in October 2023.

Figure 14. Collecting baseline geomorphic data in October 2023.

Concept Design Development:
Topographic surveys were conducted with a Trimble Survey-Grade Global Navigation Satellite System (GNSS) to document the existing conditions of the channel and floodplain (see Appendix B; Figure B1 for survey extent). Survey data were post-processed and then used to create a triangular irregular network (TIN) in ArcGIS Pro to represent the existing surface (Figure B2). Breaklines were digitized and used to edit the TIN in locations with distinct slope breaks. Longitudinal and cross-sectional profiles were extracted from the TIN to later be compared to the post-construction surface to document changes in morphology and develop concept designs (Figure B3 and B4). Using these profiles, bankfull width, cross sectional area, and average depth were calculated for each of the eight cross sections (Figures B5-B12). Under existing conditions, the average bankfull width is 143 ft and the average bankfull cross-sectional area is 445 ft^3.

The existing conditions survey and assessment will be used to develop a concept design including optimization of river alignment, bankfull channel dimensions, cut and fill calculations, optimal locations to install toe wood treatments, and appropriate locations for grading river bedform features such as runs, pools, glides, and riffles. A preliminary design based on existing conditions is shown in Figure B13.

RESULTS AND DISCUSSION

Baseline surveys for fisheries, hydraulic, and geomorphic data are still in the process of being collected. Geomorphic data from existing conditions will help inform concept designs and lead to a final construction design. Project construction is anticipated to occur in fall 2025 or 2026. No results for fisheries or final construction designs have been completed yet.

ACKNOWLEDGEMENTS

We would like to thank the many CPW aquatic biologists, researchers, and technicians that have contributed to data collection and analysis. Madison Molter, CPW Aquatic Research Technician, analyzed topographic survey data, created TINs for river existing conditions including longitudinal profiles and cross sections, and created preliminary design sheet. Area Aquatic Biologist Tory Eyre is responsible for project support, monitoring, outreach, and coordination with Rio Blanco Ranch. Native Aquatic Species Biologist Tyler Swarr is responsible for project support, monitoring, and outreach. Senior Aquatic Biologist Benjamin Felt and Native Aquatic Species Coordinator Jenn Logan are also responsible for project support. Heavy Equipment operator A.J. Stoffle and project manager Tyler Jacox is responsible for implementation and labor. Rio Blanco Ranch has offered to provide the trees and root wads needed for the project.

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RESEARCH PRIORITY:

South Platte River Temperature Study, Badger Basin SWA Habitat Project

OBJECTIVES

1) Determine the effect of stream restoration on water temperatures
2) Compare site-specific water temperatures to Colorado water quality standards

INTRODUCTION

Low flow refugia (i.e., overwinter) and adult trout habitat in the form of deep pools were identified as limiting factors for Brown Trout *Salmo trutta* and Rainbow Trout *Oncorhynchus mykiss* populations in degraded portions of the Middle Fork of the South Platte River near Hartsel, Colorado. To address this, a 2.1-mile habitat restoration project was initiated within the Badger Basin State Wildlife Area (SWA) from 2006-2011 with the purpose of converting shallow, over-widened pools into deeper, larger-volume pools to improve habitat. In addition to creating deeper pools, restoration actions included treatments intended to narrow stream banks (i.e., improve floodplain connection) and installation of native riparian deep-rooted plants (i.e., willows) to assist with bank stabilization, shading, and trout forage improvement (Figure 15). While the primary motivation for all of these restoration actions was to improve trout habitat, we hypothesized that these restoration actions would also indirectly lower reach-wide stream temperatures. Therefore, we conducted a temperature study to determine the effect of restoration on stream temperatures. Additional reach types included in the analyses were control reaches, which were representative of impaired habitat conditions found in the treatment reach before construction (Figure 16), and reference reaches (Figure 17), which represented the highest quality habitat in the vicinity of the project reach. Widespread degradation of fish habitat in South Park streams has resulted from past land use and management practices, including cattle and sheep overgrazing, mining, railway construction, hay production (conversion of woody to grass-dominated riparian zones), and beaver trapping. One or more of these factors are likely the cause of degradation characteristic of the control and treatment (pre-project) reach habitat conditions. Comparisons between treatment reaches with control (impaired) and reference (high-functioning) reaches can help with understanding the degree to which restoration work can help to reduce or stabilize water temperatures. This temperature study began with a preliminary evaluation of water temperatures across reach types showing that the treatment reach water temperatures decreased in contrast to an increase in water temperatures for control and reference reaches (Kondratieff and Richer 2015).

Observed temperature data collected from the three study reaches (treatment, control, and reference) were compared to established Colorado water quality standards for trout (i.e., cold water Tier 1 species) to determine which months and reaches were most susceptible to exceeding water quality thresholds for temperature, specifically daily maximums (DMs) and weekly average temperatures (WATs). The results of our temperature study will help inform management of trout populations within the Middle Fork of the South Platte River.

Figure 15. Photos showing riparian vegetation and bank conditions before (2007) and after (2021) construction at a haphazard toe wood-treated pool site. Note differences in deep-rooted willow abundance, large wood presence, and coarseness of sediments composing the streambed and point bar in before versus after photos.

Figure 16. Representative photos from the before treatment project reach (left photo) and control reach (right photo) showing impaired stream and riparian habitat conditions. The control reach had many characteristics similar to before treatment (pretreatment) conditions found in the project reach including over-wide stream banks, active livestock grazing, accelerated bank erosion along outside bends, and a shallow-rooted, grass-dominated riparian community.

Figure 17. A representative photo from the reference reach showing the high-quality stream and riparian habitat conditions.

Site Description:

The following trout habitat impairments were identified within control and treatment (pre-project) reaches in the Badger Basin SWA: over-widened channel, shallow water depths, shallow pools (lack of adult fish low-flow refugia and over-winter habitat), lack of deep-rooted riparian vegetation, lack of instream habitat complexity, and poor floodplain connection. These impairments were the primary drivers for restoration actions within the treatment reach. Lack of floodplain connection is characterized by vertical banks experiencing an accelerated rate of erosion and located at an elevation above bankfull. Revegetation and large-wood introduction (such as toe wood, log vanes, and horizontal log treatments) were used in the in the treatment reach to restore natural river processes, reduce riverbank erosion, narrow channel dimensions, and enhance trout habitat by increasing pool depths and habitat complexity (Kondratieff and Richer, 2022). For the purposes of this study, "site" refers to the location of a temperature logger and "reach" refers to the section of river with similar habitat characteristics spanning from an upstream to downstream logger site. Reach lengths were approximately 1.1 miles long (range = 1.05-1.17 miles; Figure 18). The Tomahawk (reference) reach is farthest upstream and is delineated by loggers TH1 and TH2 (Figure 19). The control reaches are located approximately 10 miles downstream and are delineated by loggers BBC0, BBC1, and BB1 (Figure 20). Finally, the treatment reach is the farthest downstream and delineated by loggers BB1 and BB2 (Figure 20). All sites were classified as having the same valley type (unconfined, wide, terraced alluvial valley; Type 8) and stream type (C4; pool/riffle meandering stream channel with gravel bed) according to the Rosgen stream classification system (Rosgen 1994). The elevation and basin area for each temperature monitoring site is shown in Table 5.

Table 5. Elevation and basin area for all temperature monitoring site on the Middle Fork South Platte River.

Site	Elevation (ft)	Basin Area (miles^2)
TH1	9064	164
TH2	9038	165
BBC0	8826	171
BBC1	8813	250
BB1	8797	251
BB2	8785	252

Within the treatment reach, stream restoration actions resulted in creating and maintaining (13 years post-construction) deeper, larger volume pools. Residual pool depths in the treatment reach increased by up to 161% for wood-treated pools (average RPD_{before} = 1.38 ft compared to average $RPD_{after/wood}$ = 3.6 ft) and increased up to 98% compared to control pools (average $RPD_{control}$ = 1.82 ft vs. average $RPD_{after/wood}$ = 3.6 ft). Residual pool depths from treated pools were on average 1.1 ft deeper than reference pools, 1.8 ft deeper than control pools, and 1.5 ft deeper than non-wood pools.

Stream restoration actions also decreased channel widths and improved floodplain connection by narrowing bankfull widths and lowering width-to-depth ratio (WDR) which is defined as Bankfull $Width_{RIFFLE}$ / Average $Depth_{RIFFLE}$. Average riffle bankfull widths were narrowest within the treatment reach (W_{bkf} = 40.8 ft) followed by the reference (+13.6%; W_{bkf} = 47.2 ft) and control (+19.4%; W_{bkf} = 50.6 ft) reaches. Average WDR values were lowest for the treatment reach (17.5) followed by the control (23.4) and reference (34.4). Smaller WDR values suggest an overall improved floodplain connection along with a narrower and deeper stream channel dimension.

Thousands of deep-rooted willows that were planted in the treatment reach have grown significantly and improved streamside shading by reducing the effect of solar radiation, thereby potentially decreasing stream temperatures (Figure 15).

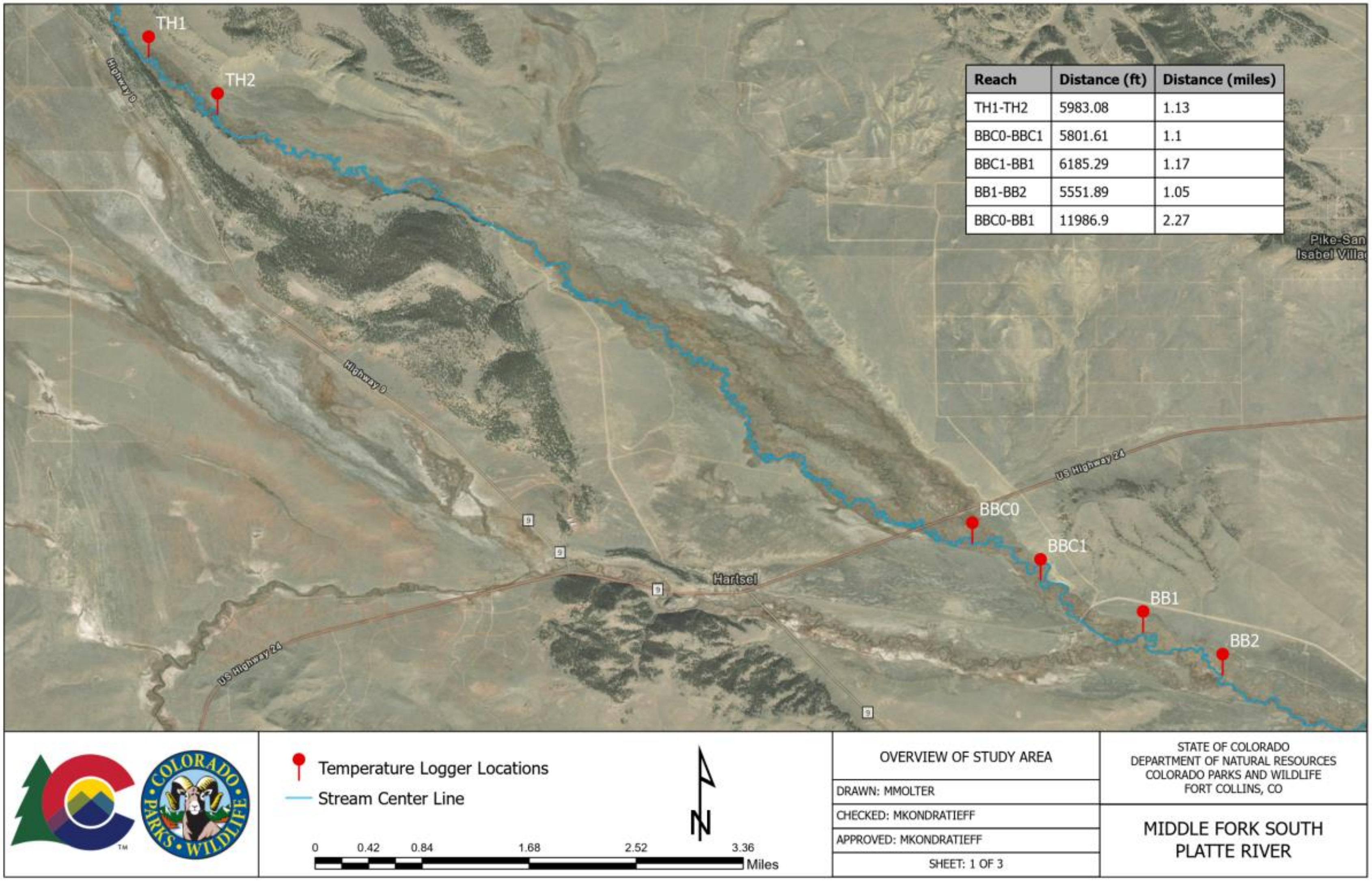

Figure 18. Locations of temperature sensors across reference, control, and treatment reaches for the temperature study on the Middle Fork South Platte River. Streamflow runs from top-left to bottom-right.

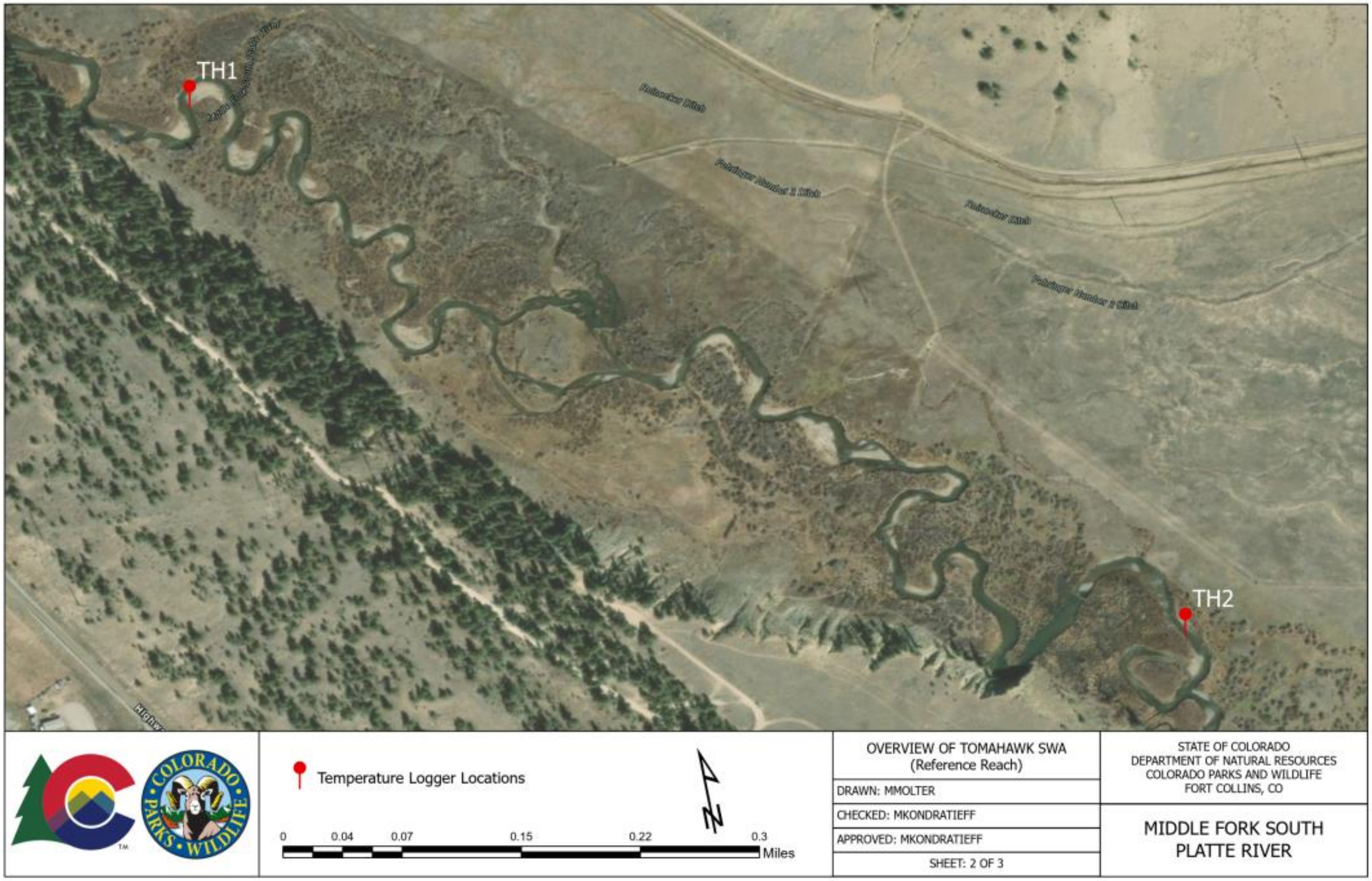

Figure 19. Locations of the two temperature sensors in the reference reach located on the Middle Fork of the South Platte River, Tomahawk SWA. Streamflow runs from top-left to bottom-right.

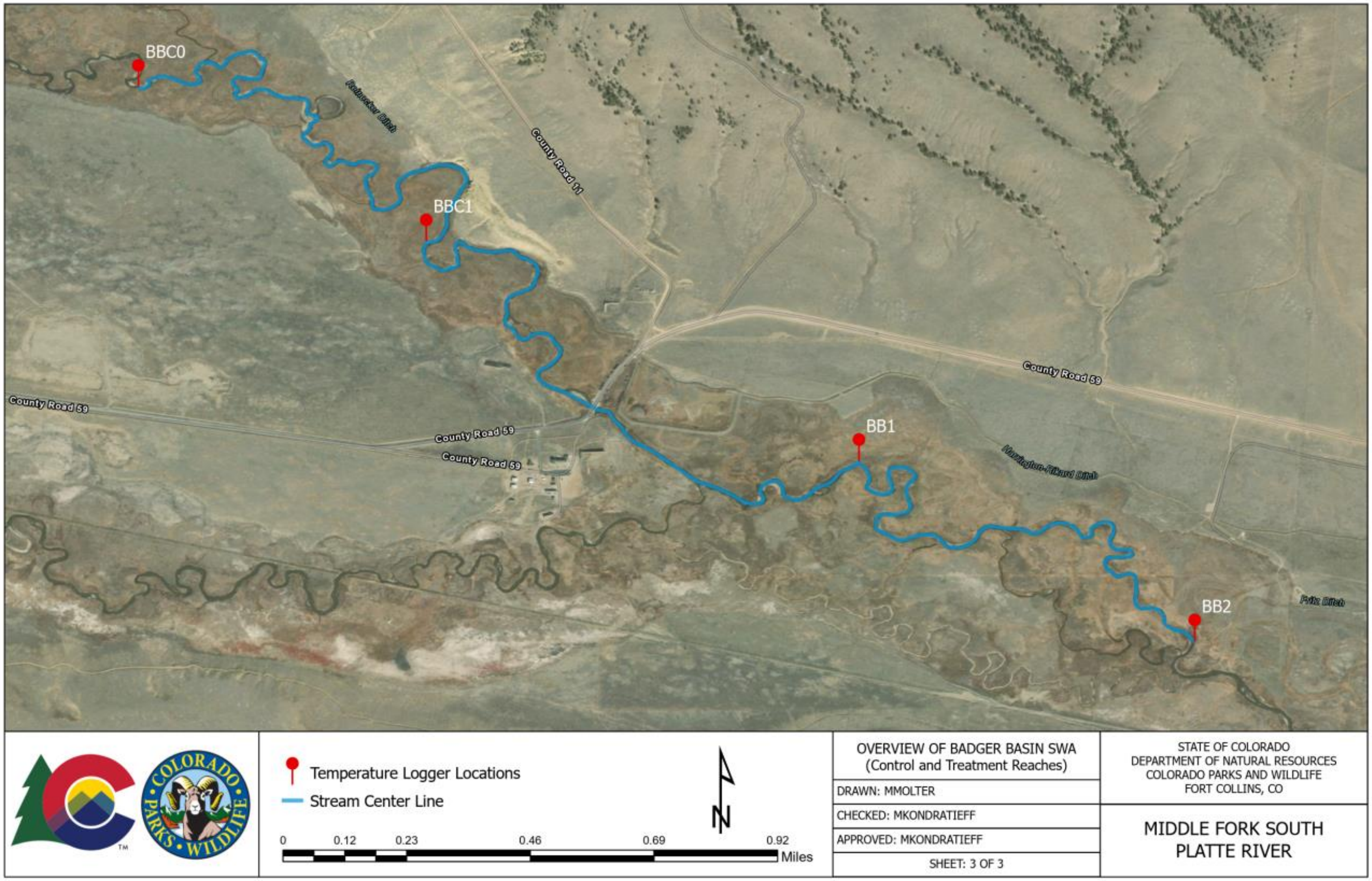

Figure 20. Locations of the four temperature sensors on the Middle Fork of the South Platte River on Badger Basin SWA, used as our control (upstream; BBCO or BBC1 to BB1) and treatment (downstream; BB1 to BB2) reaches. Streamflow runs from top-left to bottom-right

METHODS

Temperature Data Collection:
Water temperatures were monitored continuously by using six Onset Hobo™ Water Temperature Pro v2 Data Loggers deployed in each of the three study reaches. Figure 21 demonstrates how the loggers were installed, including a metal pipe to protect them from damage and shield them from direct sunlight. This housing was then clipped to rebar with a carabiner and anchored in the streambed with a rebar stake.

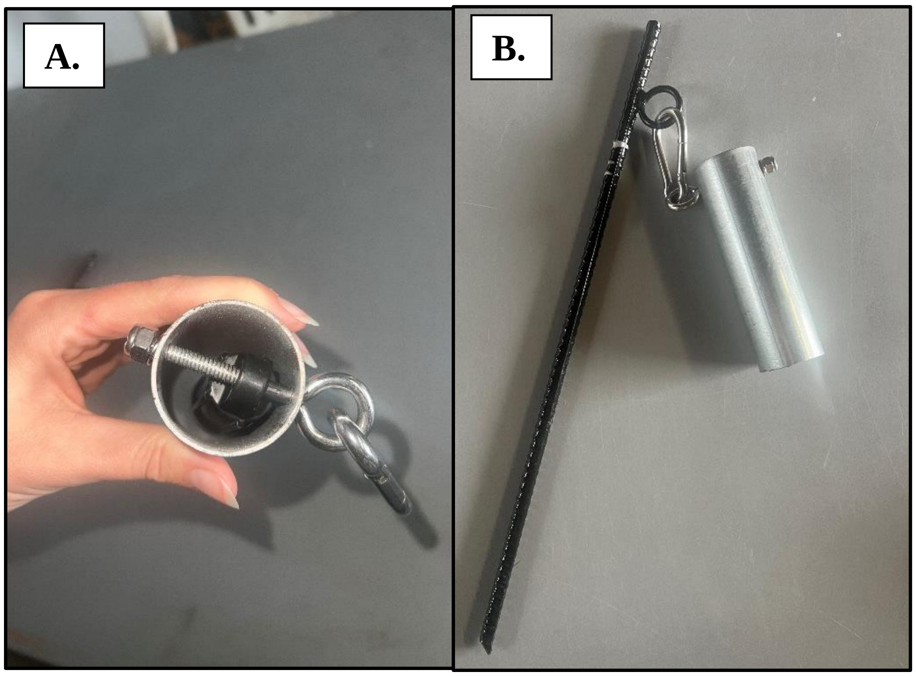

Figure 21. Photo showing (A) temperature logger inside metal housing and (B) temperature housing, carabiner, and rebar stake used to deploy temperature loggers in the field.

The loggers were programmed to record temperature every hour in all seasons. However, winter data (November through March) were removed from the final dataset as ice and frost heave led to issues with data quality. Data downloads and inspections occurred once or twice a year to ensure that loggers were still submerged and clear of debris and sediment accumulation. Temperature data were uploaded using an Onset Hobo™ U-DTW-1 Waterproof Shuttle and plotted using HoboWare™ software to visually inspect the data for any abnormality or corruption.

Data Analysis:
Temperature data were collected at each logger site on an hourly time step. Monthly average stream temperatures were calculated from raw data from the non-winter months of April to October across two years (April 2022-October 2023). As stated earlier, winter months were removed from this analysis due to rivers icing over. Monthly averages were then used to calculate reach-wide differences in temperature (i.e., deltas) by subtracting the average monthly temperature of the downstream site from the average monthly temperature of the upstream site. Reach lengths vary as a result of river morphology, logger placement, and logger removal. These individual reach lengths were used to standardize the change in temperature (°F) to a per mile basis for making

reach-wide comparisons. River center lines were digitized and measured in ArcGIS to determine exact distances between loggers. Due to a loss of data from both of the control sites at different times, the decision was made to treat BB1 as the downstream logger for the control reach and to use BBC1 as the upstream logger in 2022 and BBC0 as the upstream logger in 2023. Any differences in reach length were accounted for between years by standardizing data to a per mile basis. The only data gaps within our temperature study occurred in the control reach for October 2022 and April 2023.

To evaluate change in temperature between reaches and to test for significant effects, ANOVA and pairwise comparisons were run in RStudio using base R (Posit team 2024) and the "emmeans" package (Lenth et al., 2023). Reach, month, and year were all treated as categorical predictors for the initial model. The Shapiro-Wilk test and Bartlett's test were used to assess the normality and equal variance assumptions of ANOVA. As a result, the data were transformed using the Yeo-Johnson transformation to meet these assumptions (Yeo and Johnson 2000). Statistical significance was defined as $p < 0.05$ for all tests. As year did not affect the change in temperature ($p = 0.36$), it was removed from the final model used for analysis, which included reach and month as additive effects.

To understand how stream temperatures compare with Colorado water temperature standards, daily maximum (DM) temperature and weekly average temperature (WAT) were calculated to compare these values against the standards (WQCD 2024). The DM was determined by selecting the highest temperature between midnight and 11:00 pm for each day. The WAT was calculated by first computing the average daily temperature at each site and then calculating the WAT for each date using a rolling 7 day average with that date and the previous 6 days. The DM temperature is considered as an indicator of lethal or acute temperature effects on trout while the WAT temperature values were considered as an indicator of sub-lethal, chronic temperature effects.

RESULTS AND DISCUSSION

Temperature Response to Restoration:

Average monthly water temperature exhibited the expected trend of increasing as water flows downstream (Figure 22). The large increase in water temperature from the Tomahawk/reference sites (TH1 and TH2) to the control sites (BBC0, BBC1, and BB1) is mainly due to the distance between the two reaches (approximately 10 miles), which is much greater than the distance between control and treatment reaches (0 miles; Figure 18). The farther water travels downstream, the more it heats up, which makes sense especially considering the large impaired section of river that the water must flow through which lacks shading from vegetation and exhibits shallow pools depths with over-wide channel dimensions, all of which results in higher temperatures. Though we see the general trend of temperatures increasing downstream, this is not the case for the treatment reach between BB1 and BB2 sites. Instead, there is a cooling effect in the treatment reach which is explained later in the ANOVA and pairwise comparisons for standardized changes in water temperature (deltas).

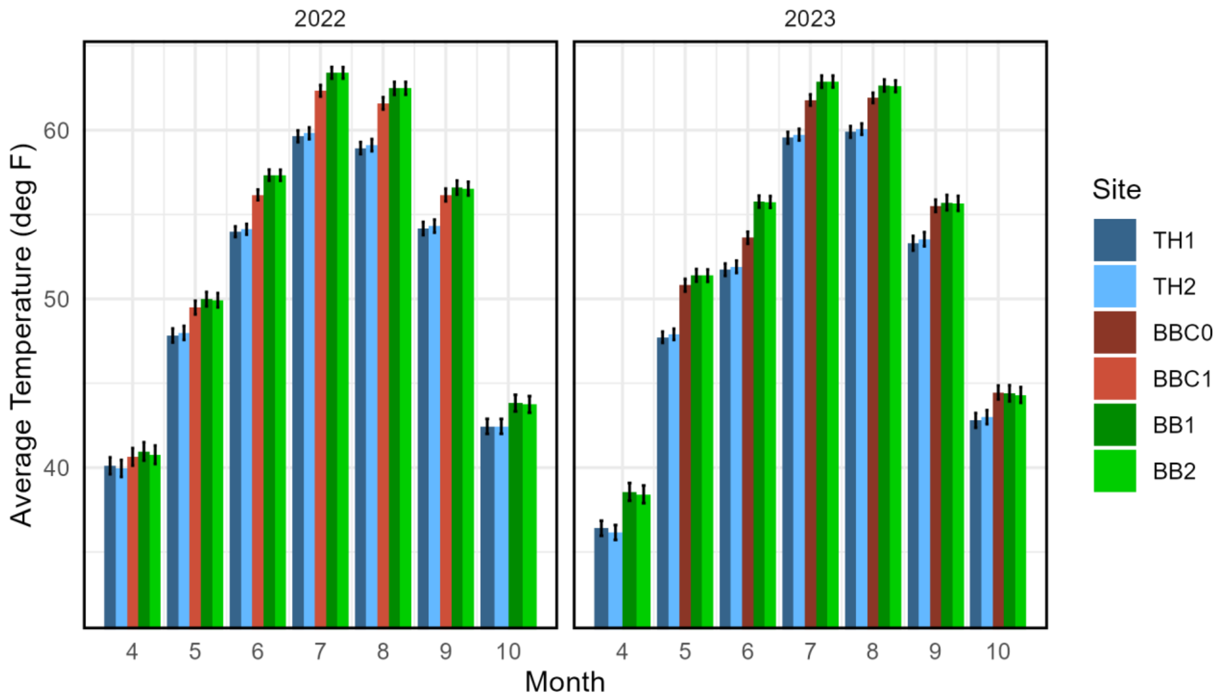

Figure 22. Average monthly water temperatures with 95% confidence intervals during 2022 and 2023 for all sites. Sites are listed from upstream to downstream: upstream Tomahawk (TH1), downstream Tomahawk (TH2), upstream Badger Basin Control (BBC0), downstream Badger Basin Control (BBC1), upstream Badger Basin treatment (BB1), and downstream Badger Basin (BB2).

The observed changes in temperature (deltas) were presented by reach (Figure 23) and month (Figure 24). By observing the change in temperature (delta) for reach alone averaged across time (month and year), we see a median increase of +0.4 °F/mile for the control reach (Figure 23). The control reach also exhibits a much higher degree of variability in the deltas with more widely dispersed interquartile ranges. In contrast, results from the reference and treatment reaches are much more stable with extremely low interquartile ranges. This is likely the result of temperature fluctuations being buffered by improved floodplain connectivity (ground water return) and shading from vegetation which is present in both of these reaches and not present in the control (Figures 15-17). However, the treatment reach consistently experiences a cooling effect through the reach (median = -0.03 °F/mile), whereas temperatures are slightly increasing (median = +0.15 °F/mile) through the reference reach. By examining the effect of month on the change in temperature (delta) it becomes clear that more extreme temperature fluctuations are seen in the control reach during the summer months where solar exposure and increased air temperature are more likely to have a larger effect on water temperature (Figure 24). The shoulder months of April and October are more stable as air temperatures start to drop and the river may begin thaw or freeze (resulting in a stable water temperature of ~32 °F). Within the control reach, water temperatures are more variable and usually increasing anywhere from 0.08 to 1.0 °F/mile (Figure 24). Only in October 2023 did we see a decrease in temperature of 0.02 °F/mile within the control reach. Interestingly, reference and treatment reaches still have much more stable temperatures during the summer, again likely a result of floodplain connectivity and vegetation to dampen the effects of temperature fluctuations.

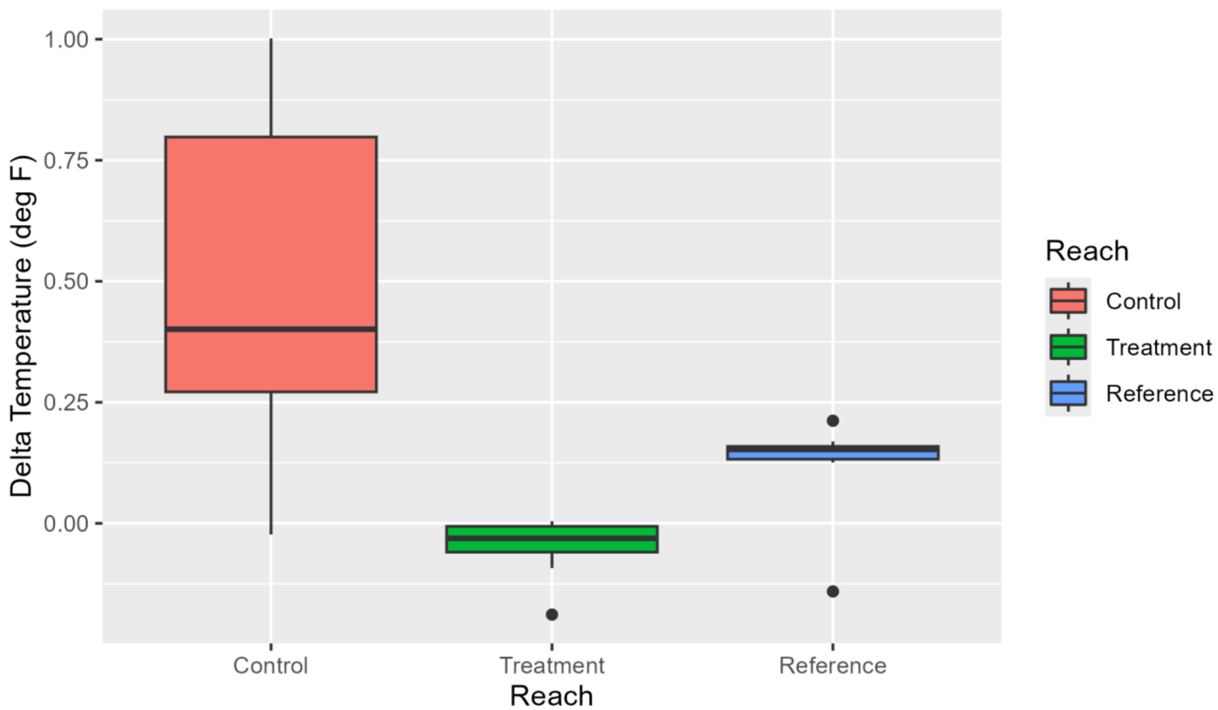

Figure 23. Change in water temperature by reach across months and years. Boxplots display median, 25%, and 75% interquartile ranges.

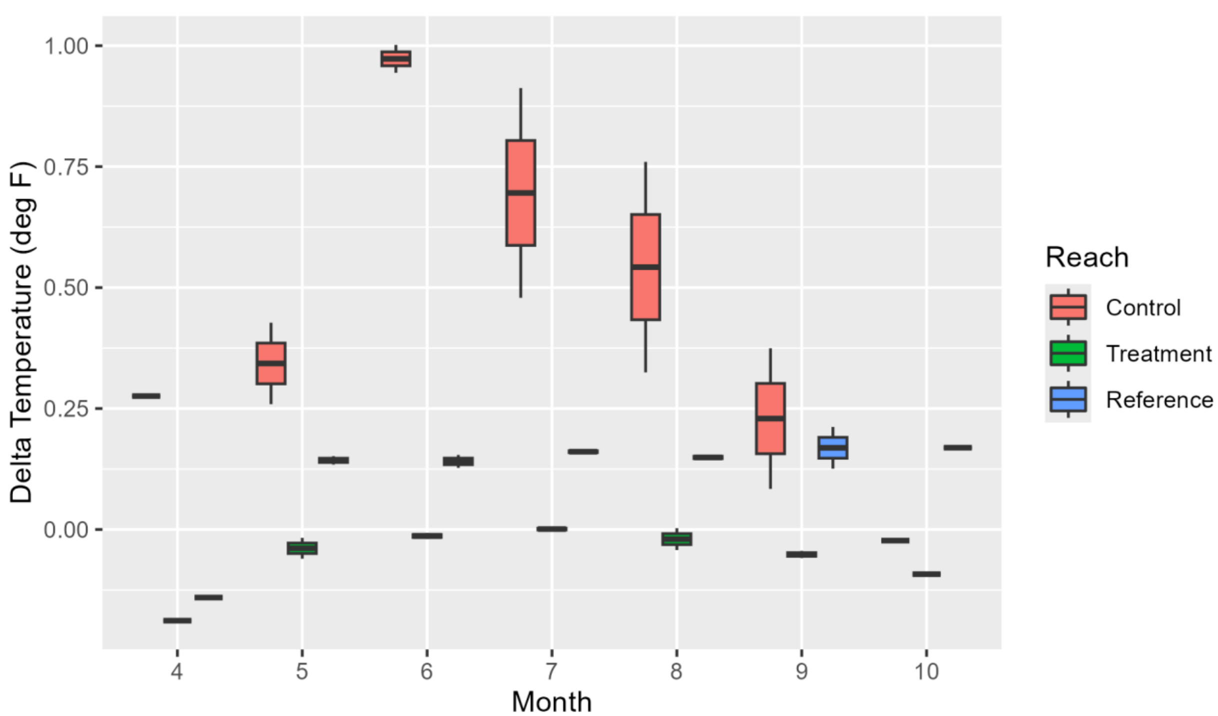

Figure 24. The change in water temperature by month and reach. Boxplots display median, 25%, and 75% interquartile ranges.

Results from ANOVA indicated that both reach ($p < 0.0001$) and month ($p = 0.0012$) affected the reach-wide change in temperature. Month being significant reflects the anticipated seasonal fluctuations in temperature from late spring to early fall. Year was not significant ($p = 0.36$) which is consistent with the expectation that river behavior tends to exhibit minimal interannual variation (Langan et al. 2001). Pairwise comparisons show that the change in temperature/mile differed between all three reaches (Table 6). Pairwise comparisons show that the change in temperature/mile between months averaged across reaches and years were significantly different only for the month of April when compared to May, June, July, and August but not for September and October (Table 7).

Table 6. Estimated marginal means (β) and pairwise comparisons from the two-way ANOVA for the change in water temperature at reference, treatment, and control reaches. Beta estimates, standard errors (SE), degrees of freedom (df), lower confidence limits (LCL), and upper confidence limits (UCL) were reported. T-ratios were provided for pairwise comparisons and statistical significance ($p < 0.05$) is indicated in bold.

Reach	**β**	**SE**	**df**	**LCL**	**UCL**
Control	0.345	0.0332	27	0.277	0.4135
Treatment	-0.108	0.0332	27	-0.176	-0.0396
Reference	0.125	0.0332	27	0.057	0.1931
Pairwise Comparisons	**β**	**SE**	**df**	**t ratio**	***p***
Control - Treatment	0.453	0.0461	27	9.823	**<.0001**
Control - Reference	0.22	0.0461	27	4.779	**0.0002**
Treatment - Reference	-0.233	0.0461	27	-5.044	**0.0001**

In summary, over the two year study period, the delta (change in temperatures from upstream to downstream) for the treatment reach was always negative or zero, meaning water temperatures decreased (-) or remained stable. The delta for the control (or impaired) reach always increased (+) from upstream to downstream with the exception of a single month (October 2023; delta decreased). The change in temperature from upstream to downstream for the control reach ranged from +0.08-1.0 °F with a median temperature change of +0.4 °F/mile. The delta for the reference reach always increased (+) from upstream to downstream with the exception of a single month (April 2022; delta decreased) and with a median temperature change of +0.15 °F/mile. While both the reference and control reaches experienced an increase from upstream to downstream, the change in temperature (delta) within the reference reach is 63% less than that observed within the control (impaired) across the same time period. Pairwise comparisons suggest that the change in water temperature (deltas) across all reaches are significantly different from one another.

Table 7. Estimated marginal means (β) and pairwise comparisons from the two-way ANOVA for the change in water temperature by month. Beta estimates, standard errors (SE), degrees of freedom (df), lower confidence limits (LCL), and upper confidence limits (UCL) were reported. T-ratios were provided for pairwise comparisons and statistical significance ($p < 0.05$) is indicated in bold.

Month	**β**	**SE**	**df**	**LCL**	**UCL**
4	-0.11281	0.0652	27	-0.247	0.021
5	0.15362	0.0461	27	0.059	0.248
6	0.25006	0.0461	27	0.155	0.345
7	0.23457	0.0461	27	0.14	0.329
8	0.19724	0.0461	27	0.103	0.292
9	0.12066	0.0461	27	0.026	0.215
10	0.00346	0.0652	27	-0.13	0.137
Pairwise Comparisons	**β**	**SE**	**df**	**t ratio**	***p***
Month4 - Month5	-0.2664	0.0799	27	-3.335	**0.0353**
Month4 - Month6	-0.3629	0.0799	27	-4.542	**0.0018**
Month4 - Month7	-0.3474	0.0799	27	-4.348	**0.0029**
Month4 - Month8	-0.31	0.0799	27	-3.881	**0.0096**
Month4 - Month9	-0.2335	0.0799	27	-2.922	0.0873
Month4 - Month10	-0.1163	0.0923	27	-1.26	0.8635
Month5 - Month6	-0.0964	0.0652	27	-1.478	0.7546
Month5 - Month7	-0.081	0.0652	27	-1.241	0.8717
Month5 - Month8	-0.0436	0.0652	27	-0.669	0.9933
Month5 - Month9	0.033	0.0652	27	0.505	0.9986
Month5 - Month10	0.1502	0.0799	27	1.88	0.5099
Month6 - Month7	0.0155	0.0652	27	0.237	1
Month6 - Month8	0.0528	0.0652	27	0.81	0.9819
Month6 - Month9	0.1294	0.0652	27	1.984	0.447
Month6 - Month10	0.2466	0.0799	27	3.087	0.0615
Month7 - Month8	0.0373	0.0652	27	0.572	0.9971
Month7 - Month9	0.1139	0.0652	27	1.746	0.5929
Month7 - Month10	0.2311	0.0799	27	2.893	0.0929
Month8 - Month9	0.0766	0.0652	27	1.174	0.8978
Month8 - Month10	0.1938	0.0799	27	2.425	0.2269
Month9 - Month10	0.1172	0.0799	27	1.467	0.761

Temperatures Standards:

Although we found a significant cooling effect in the treatment reach, is that cooling enough to counteract heating that comes from the miles of degraded stream habitat upstream? Comparing our observed temperatures to temperature standards provides insight on whether restoration is sufficient to provide adequate habitat for aquatic life or specifically, overcoming the acute (DM) or chronic (WAT) temperature thresholds for trout populations. By summarizing days of exceedance for the DM and maximum WAT standards it becomes clear that natural downstream warming is causing these sites to exceed standards many times throughout the year. Shoulder months (May and October) as well as peak summer months (July and August) are particularly problematic (Figures 25 and 26).

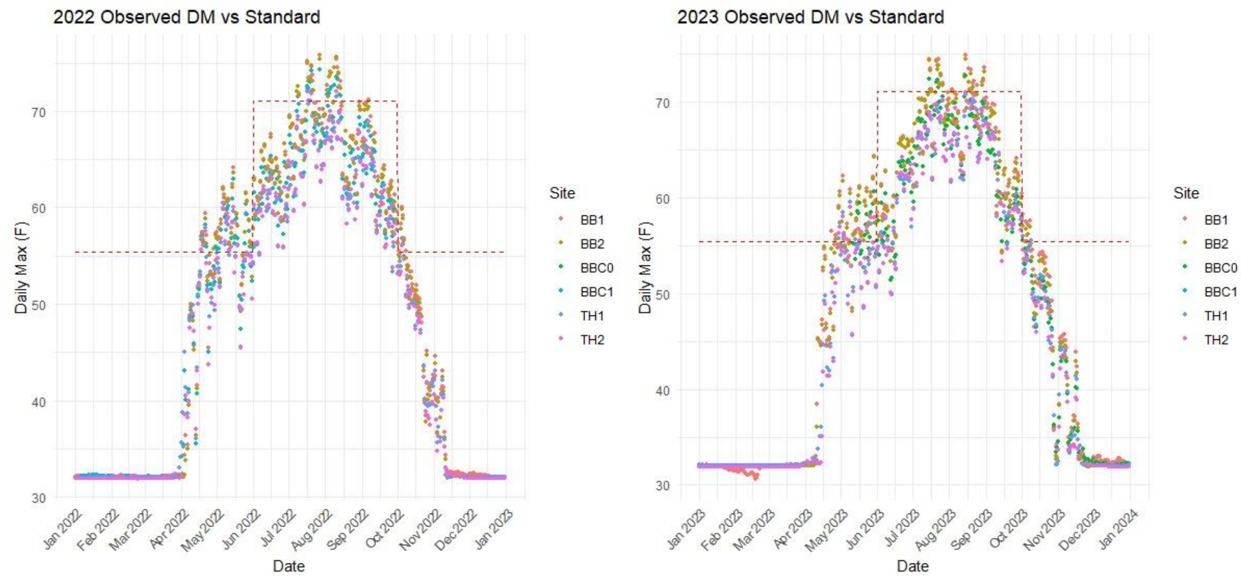

Figure 25. Observed daily maximum temperatures (DM) at each site in 2022 and 2023 compared to the Colorado Water Quality Temperature Standard for cold water Tier 1 (trout) depicted by the dashed red line.

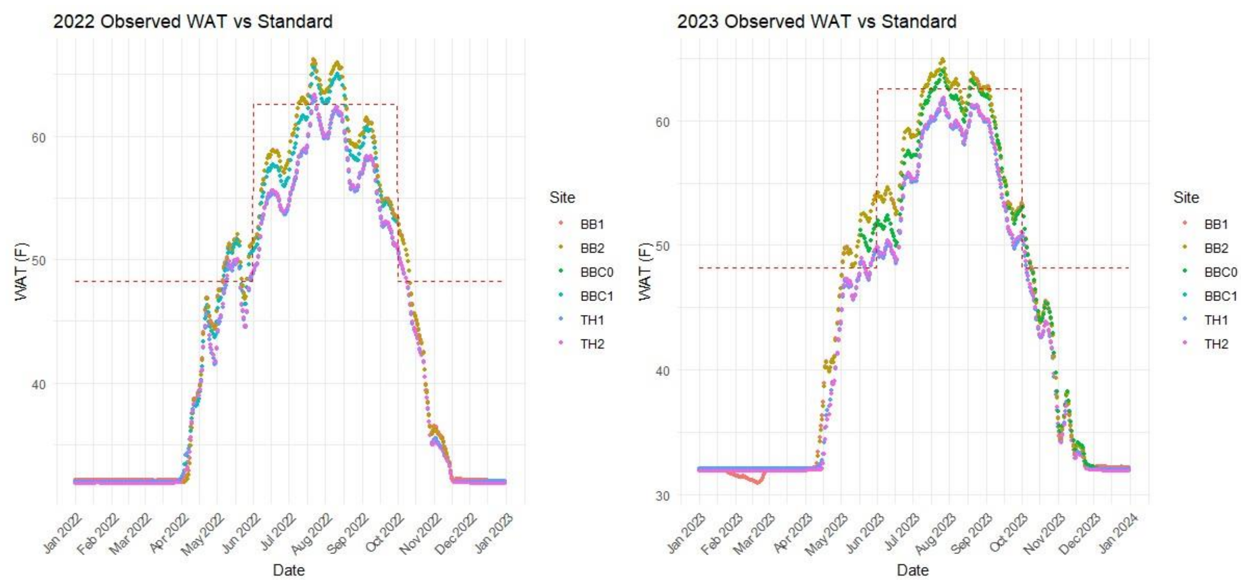

Figure 26. Observed weekly average temperature (WAT) at each site in 2022 and 2023 compared to the Colorado Water Quality Temperature Standard for cold water Tier 1 (trout) depicted by the dashed red line.

As we move downstream from the reference reach, our sites increase in days of exceedance for both WAT and DM. Though it is worth noting that for both 2022 and 2023 BB2 (treatment site, downstream) had fewer exceedances than BB1 (treatment site, upstream; highlighted cells in Table

8). This alludes to the positive impact restoration can have on downstream temperatures, especially if the cooling effect is enough to reduce the amount of days exceeding temperature standards. This evidence could indicate that if similar restoration actions took place upstream of the treatment reach, it could potentially decrease the number of days that temperatures are exceeded both in terms of DMs and WATs. However, the exact number of miles upstream of the treatment reach (upstream restoration project length) required to lower chronic and acute exceedances is unknown.

Table 8. Summary of total days exceeding temperatures standards (DM and WAT) by site and month in 2022 and 2023. Note the highlighted yellow cells show the only reduction in the total days of exceedance by site for the downstream treatment site (BB2).

Days of Exceedance in 2022									
Site	**Standard**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Total Days/ Year**
TH1	DM	4	13	0	2	1	0	2	22
	MWAT	0	14	0	4	0	0	8	26
TH2	DM	4	14	0	3	1	0	2	24
	MWAT	0	14	0	4	0	0	8	26
BBC	DM	6	23	0	7	9	0	0	45
	MWAT	0	19	0	13	17	0	0	49
BB1	DM	7	24	0	10	11	1	7	60
	MWAT	0	22	0	21	18	0	11	72
BB2	DM	7	24	0	10	11	0	5	57
	MWAT	0	21	0	21	18	0	11	71
All Sites	DM	28	98	0	32	33	1	16	--
	MWAT	0	90	0	63	53	0	38	--
Days of Exceedance in 2023									
Site	**Standard**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Total Days/ Year**
TH1	DM	2	7	0	0	0	0	3	12
	MWAT	0	9	0	0	0	0	5	14
TH2	DM	2	9	0	0	0	0	1	12
	MWAT	0	9	0	0	0	0	5	14
BBC0	DM	0	11	0	5	1	0	2	19
	MWAT	0	14	0	11	7	0	8	40
BB1	DM	4	27	0	9	13	0	6	59
	MWAT	0	29	0	21	21	3	9	83
BB2	DM	3	26	0	9	9	0	6	53
	MWAT	0	29	0	21	19	3	8	80
All Sites	DM	11	80	0	23	23	0	18	--
	MWAT	0	90	0	53	47	6	35	--

Study Limitations:
Through the execution of this temperature study, we encountered a number of challenges or limitations that should be considered in advance of any future attempts to monitor water temperature changes over time. First, we discovered that it is important to locate temperature loggers in locations that are not depositional in nature. If temperature sensors are located in streambed areas prone to deposition, such as the inside of bends or in near bank regions, the loggers are likely to become buried and fill in with silt or organic debris that not only make retrieval of loggers challenging, but also have unknown effects on temperature readings. The daily variability of water temperatures from loggers that were submerged by fine sediment or organic material appears to be less variable than from loggers that were clear of sediment (i.e., fine silt). Additionally, the accuracy of temperature loggers can be problematic when trying to monitor small scale differences in temperature within a reach. The accuracy of the HOBO temperature loggers used in our study was ±0.38 °F for loggers installed in streams with anticipated water temperatures ranging from 32-122 ºF. Installation of multiple temperature loggers (redundancy) at a site might provide more data to average across when estimating the true temperature at a site. Lastly, we had some instances of curious anglers or bystanders removing temperature loggers from the stream channel and leaving them near the shoreline of the river. Fortunately, we were able to find most of the missing temperature loggers with a metal detector but some of them were never able to be retrieved. It is important to locate loggers in locations that are as inconspicuous as possible.

ACKNOWLEDGEMENTS

We would like to thank the CPW Aquatic Biologists including Jeff Spohn and Tyler Swarr as well as CPW Aquatic Research technicians Kasey Kiel, Sam Graff, Sean Ingram, Mike Miller, and Madison Molter that have contributed to the data collection and analysis. Madison Molter, CPW Aquatic Research Technician, analyzed temperature data using RStudio for statistical analysis and generation of figures.

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RESEARCH PRIORITY:

Technical Assistance

OBJECTIVES

Provide at least 10 technical assistance reviews to CPW personnel, NGOs, and Federal agency personnel as requested.

INTRODUCTION

CPW and other state and federal personnel are frequently in need of technical assistance related to stream habitat restoration, conservation barriers, fish passage, whitewater park, and post-flood recovery projects. Technical assistance for projects will be provided as needed, including project identification, selection, design, evaluation, and permitting. Technical assistance includes design review for CPW biologists and district wildlife managers, site visits to proposed stream restoration locations, consultations with various agencies on stream restoration opportunities associated with highway and bridge improvement projects, project management, consultations and technical support related to stream mitigation work for 404 permits, technical assistance related to fish passage design, conservation barrier design and construction, and teaching at various technical training sessions for CPW and other state and federal personnel.

METHODS

Technical assistance includes the review of proposed stream habitat restoration, fish passage, and conservation barrier projects, including design, contractor selection, and permitting for CPW and other state and federal personnel as requested. Proposed designs for post-flood road reconstruction and stream restoration will be reviewed for the Colorado Department of Transportation as requested. We will also provide training to CPW and other state and federal personnel on stream restoration techniques and fish passage design criteria, including guidance for permitting.

RESULTS AND DISCUSSION

We provided technical assistance for the following projects:

1) Colorado River Connectivity Channel at Windy Gap
2) Windy Gap Fish Passage Study, Colorado River
3) Poudre Valley Canal Fish Passage and Screening Project, Cache la Poudre River
4) Mt. Shavano Diversion, Arkansas River
5) Scout Wave Whitewater Park, Arkansas River
6) Shoshone Diversion, Colorado River
7) Niwot Diversion Fish Passage Project, St. Vrain Creek
8) Metro Water Recovery Phase 5 Habitat Improvement, South Platte River
9) Pagosa Gateway Project, San Juan River
10) Continental-Hoosier System Project
11) Cherry Creek Stabilization Project

12) Yampa River and Walton Creek Confluence Restoration Project
13) Willow planting (cuttings and plantings) in a partnership with Pikes Peak Chapter of Trout Unlimited on the Charlie Meyer SWA, South Platte River
14) George Creek Cutthroat Trout Restoration
15) State Wildlife Action Plan 2025, Habitat Subcommittee
16) White River and Rio Blanco Reservoir Habitat Project, White River
17) Chuck Lewis Toe Wood Maintenance Project, Yampa River
18) Pueblo Tailwater Habitat Project and Bank Stabilization, Arkansas River
19) CDOT and CPW Partnership shared opportunities

ACKNOWLEDGEMENTS

We acknowledge and appreciate Dr. George Schisler for his support and leadership.

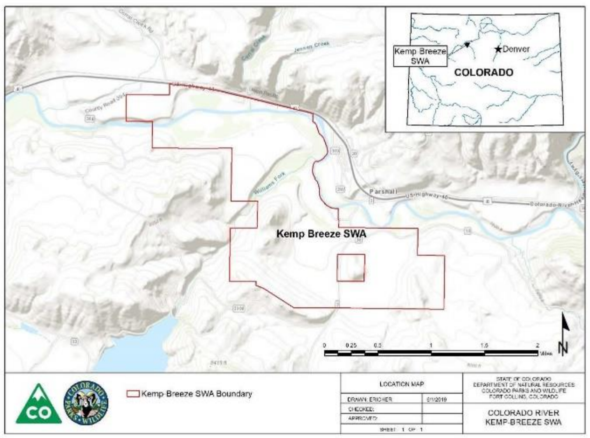
APPENDIX A

Kemp-Breeze SWA Habitat Project As-Built Drawings

COLORADO PARKS AND WILDLIFE

Kemp-Breeze SWA Habitat Project, Colorado River

As-Built Drawings



Prepared by:
Colorado Parks and Wildlife
Aquatic Research Section
317 W. Prospect Road
Fort Collins, CO 80526

August 9, 2024

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STATE OF COLORADO
DEPARTMENT OF NATURAL RESOURCES
COLORADO PARKS AND WILDLIFE
FORT COLLINS, COLORADO

Table 1. As-built quantities for restoration treatments by project phase at the Kemp-Breeze SWA Habitat Project on the Colorado River.

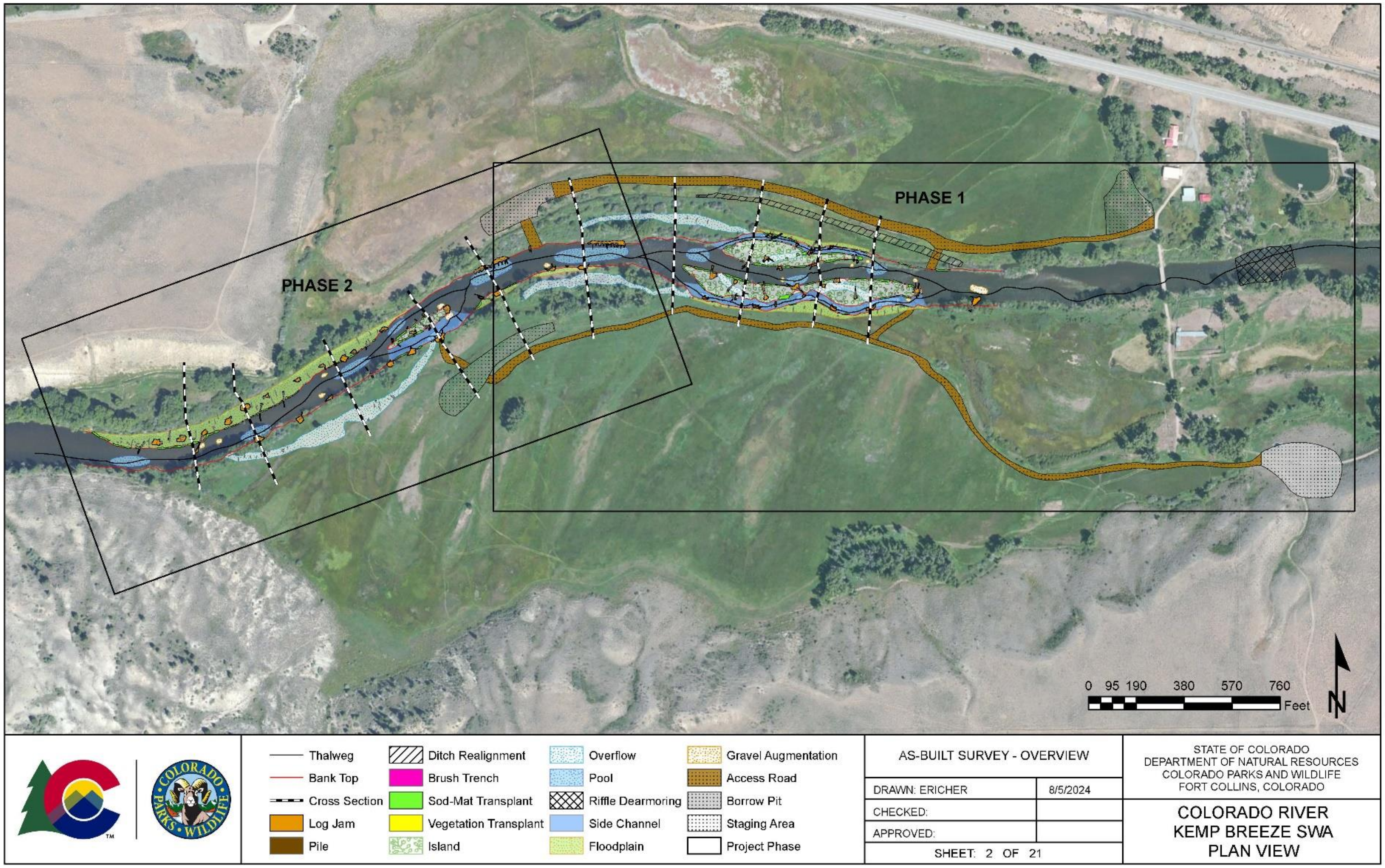
Category	Description	Quantity			
		Phase 1	Phase 2	Total	Units
Mobilization	Access roads	--	--	4.07	acre
	Staging area	--	--	2.34	acre
Mass grading	Ditch realignment	0.56	0	0.56	acre
	Floodplain development	0.60	1.84	2.44	acre
	Island construction	2.16	0.21	2.36	acre
	Overflow channel	1.29	0.94	2.23	acre
	Pool development	0.48	0.93	1.41	acre
	Riffle dearmoring	0.62	0.00	0.62	acre
	Side channel development	1.16	0.42	1.58	acre
	Borrow pit	1.21	0	1.21	acre
	Gravel augmentation	250	350	600	CY
Vegetation	Brush trench	385	767	1152	ft
	Sod mat	0.29	0.17	0.46	acre
	Alder transplant	16	25	41	each
	Cottonwood transplant	17	9	26	each
	Willow transplant	76	77	153	each
Log-jam structures	Bank jam	11	18	29	each
	Bar-apex jam	2	1	3	each
	Downed cottonwood tree	7	10	17	each
	Floodplain jam	5	10	15	each
	In-channel jam	1	0	1	each
	Large-pool jam	1	4	5	each

Survey Notes:

Survey data were collected in October 2018 to represent preexisting conditions at the project site (Before 2018).
As-built conditions for the Phase 1 reach were surveyed in April 2023 (As-Built 2023).
Post-runoff conditions for the Phase 1 reach were surveyed in October 2023 and as-built conditions for the Phase 2 reach were surveyed in April 2024. Survey data from the October 2023 and April 2024 surveys were combined to create a single surface for analysis (Post-Runoff 2023 for Phase 1 and As-Built 2024 for Phase 2)

All surveys involved collecting topographic survey data with survey-grade GPS (Coordinate Systems: Horizontal = NAD 1983 State Plane Colorado North; Vertical = NAVD88) and bathymetric data using a Acoustic Doppler Current Profiler (ADCP) with RTK (Coordinate Systems: Horizontal and Vertical = WGS 1984). ADCP data were reprojected into the same coordinate systems at the survey-grade GPS data, and then combined with the topographic survey data to create a Triangulated Irregular Network (TIN) for each survey. Profiles were then extracted from the TINs to illustrate changes in morphology.

AS-BUILT QUANTITIES		STATE OF COLORADO DEPARTMENT OF NATURAL RESOURCES COLORADO PARKS AND WILDLIFE FORT COLLINS, COLORADO
DRAWN: ERICHER	8/16/2024	COLORADO RIVER KEMP-BREEZE SWA AS-BUILT SURVEY
CHECKED:		
APPROVED:		
SHEET: 1 OF 21		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Feet
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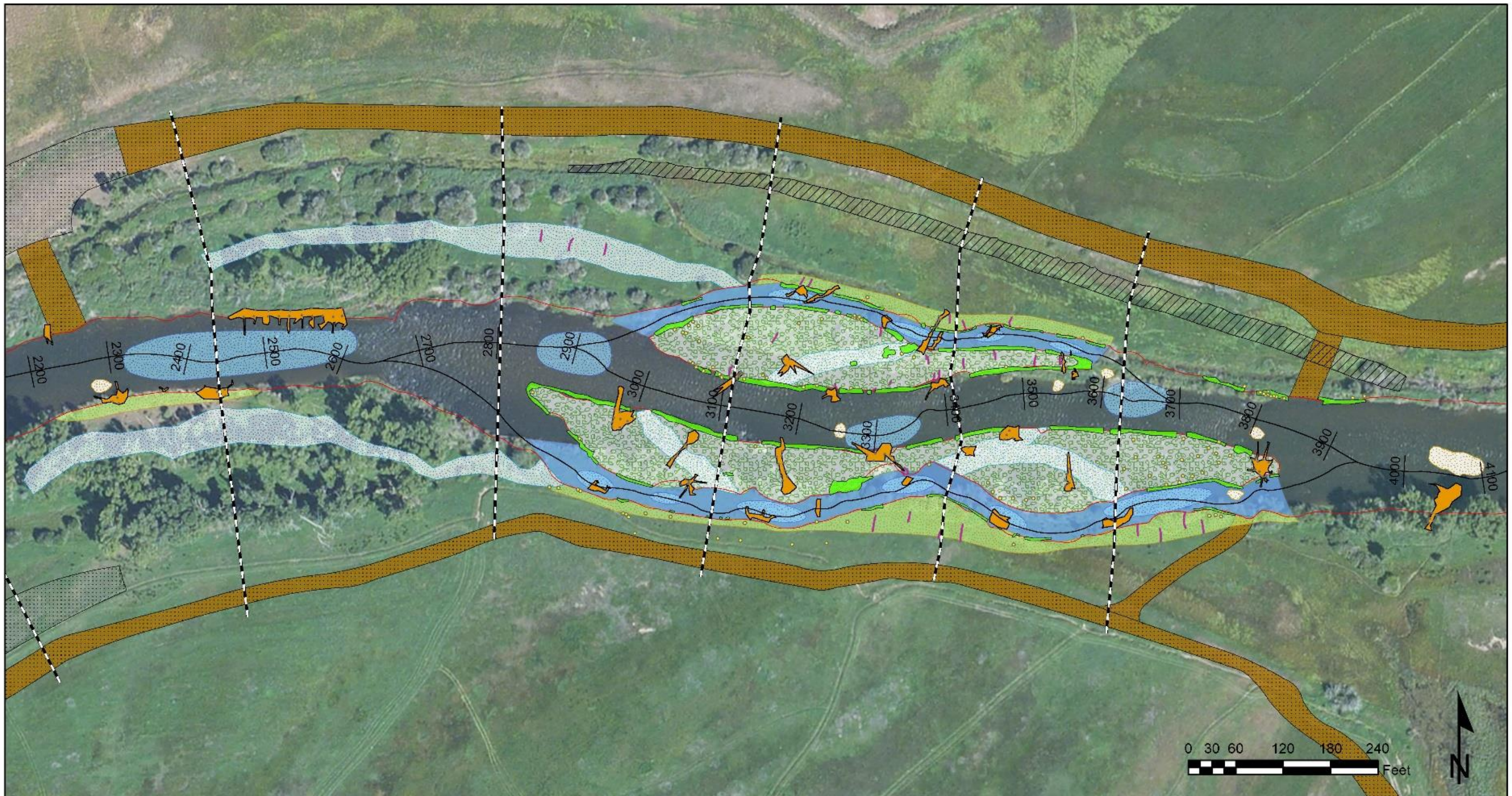
Thalweg
Bank Top
Cross Section
Log Jam
Pile
Ditch Realignment
Brush Trench
Sod-Mat Transplant
Vegetation Transplant
Island
Overflow
Pool
Riffle Dearmoring
Side Channel
Floodplain
Gravel Augmentation
Access Road
Borrow Pit
Staging Area
Project Phase
AS-BUILT SURVEY - OVERVIEW
DRAWN: ERICHER
8/5/2024
CHECKED:
APPROVED:
SHEET: 2 OF 21
STATE OF COLORADO
DEPARTMENT OF NATURAL RESOURCES
COLORADO PARKS AND WILDLIFE
FORT COLLINS, COLORADO
COLORADO RIVER
KEMP BREEZE SWA
PLAN VIEW

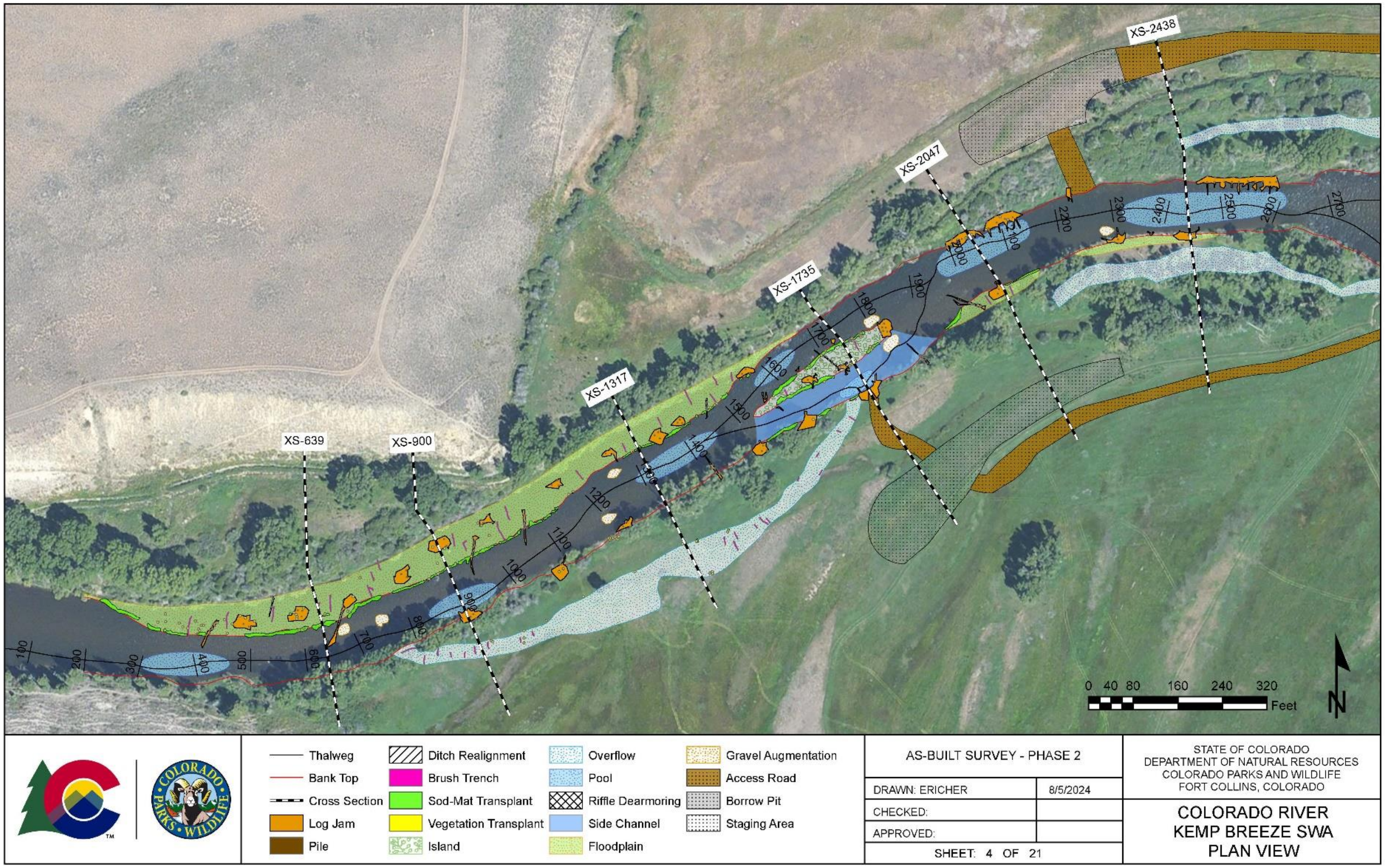


Thalweg	Ditch Realignment	Overflow	Gravel Augmentation
Bank Top	Brush Trench	Pool	Access Road
Cross Section	Sod-Mat Transplant	Riffle Dearmoring	Borrow Pit
Log Jam	Vegetation Transplant	Side Channel	Staging Area
Pile	Island	Floodplain	

AS-BUILT SURVEY - PHASE 1	
DRAWN: ERICHER	8/5/2024
CHECKED:	
APPROVED:	
SHEET: 3 OF 21	

STATE OF COLORADO
DEPARTMENT OF NATURAL RESOURCES
COLORADO PARKS AND WILDLIFE
FORT COLLINS, COLORADO

COLORADO RIVER
KEMP BREEZE SWA
PLAN VIEW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900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
2600
2700
0 40 80 160 240 320
Feet
N
Thalweg
Bank Top
Cross Section
Log Jam
Pile
Ditch Realignment
Brush Trench
Sod-Mat Transplant
Vegetation Transplant
Island
Overflow
Pool
Riffle Dearmoring
Side Channel
Floodplain
Gravel Augmentation
Access Road
Borrow Pit
Staging Area
AS-BUILT SURVEY - PHASE 2
DRAWN: ERICHER
8/5/2024
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APPROVED:
SHEET: 4 OF 21
STATE OF COLORADO
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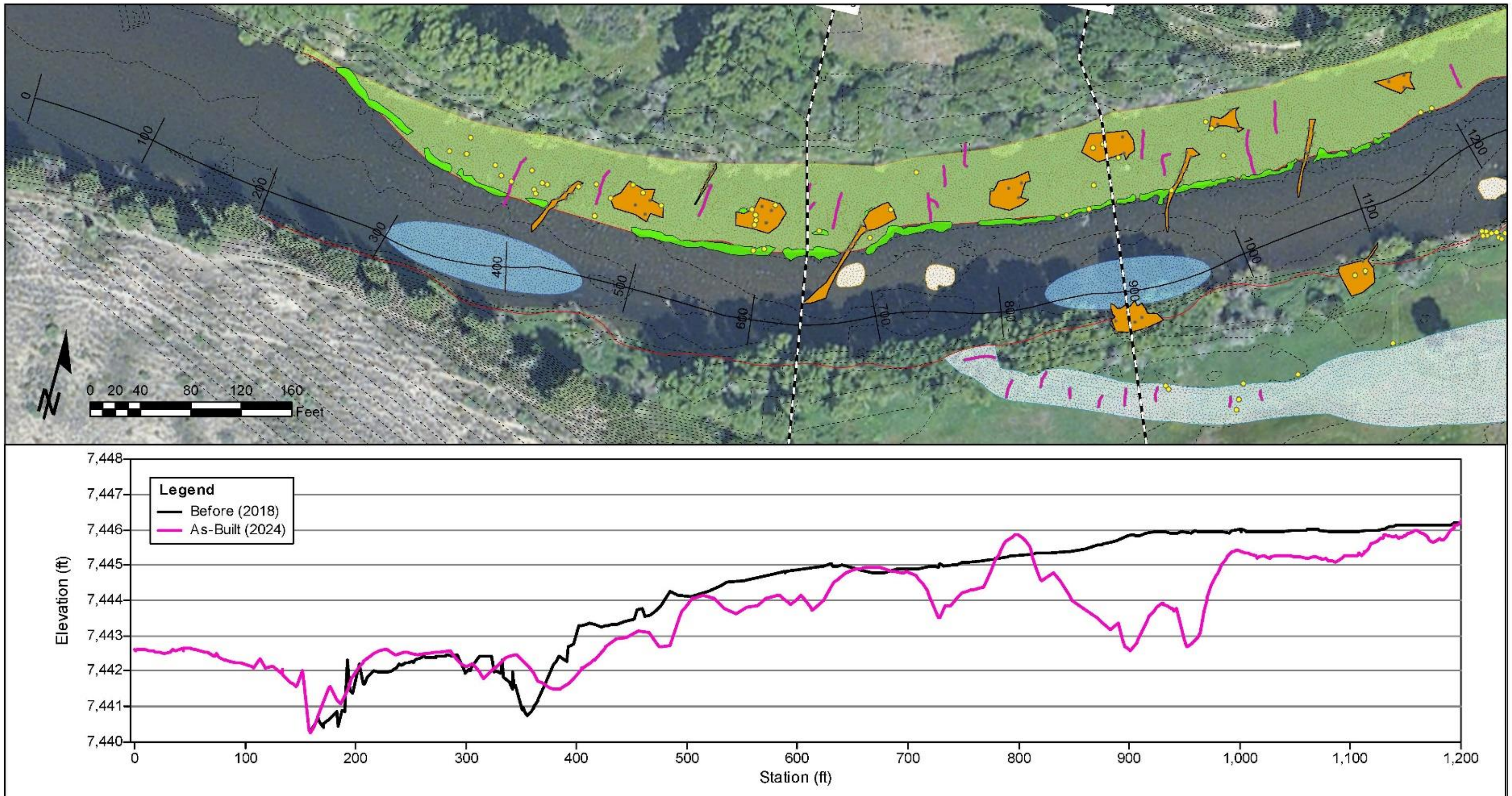
COLORADO PARKS AND WILDLIFE
FORT COLLINS, COLORADO
COLORADO RIVER
KEMP BREEZE SWA
PLAN VIEW



Thalweg
Bank Top
Cross Section
Log Jam
Pile
Ditch Realignment
Brush Trench
Sod-Mat Transplant
Vegetation Transplant
Island
Overflow
Pool
Riffle Dearmoring
Side Channel
Floodplain
Gravel Augmentation
Access Road
Borrow Pit
Staging Area
Contour (1 ft)

AS-BUILT LONGITUDINAL PROFILE

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STATE OF COLORADO
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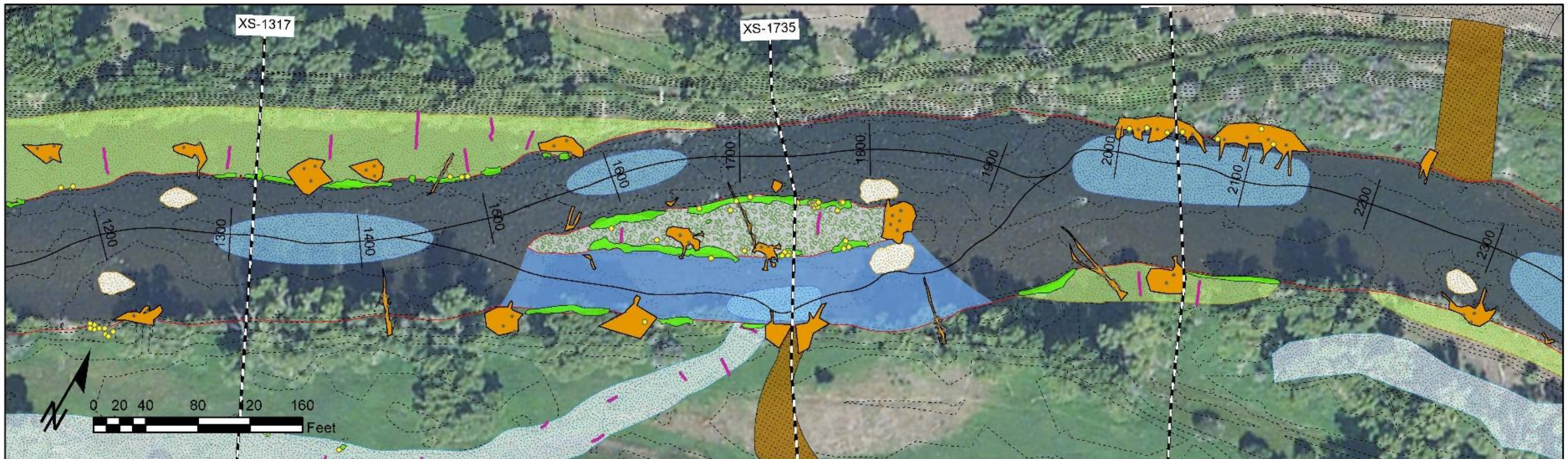
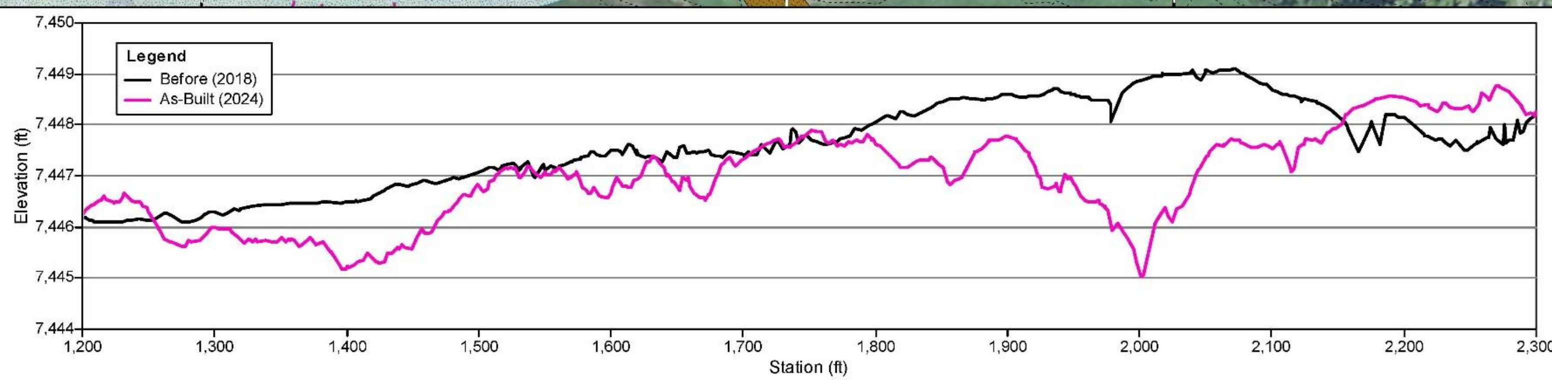
FORT COLLINS, COLORADO

COLORADO RIVER
KEMP BREEZE SWA
AS-BUILT SURVEY





Thalweg	Ditch Realignment	Overflow	Gravel Augmentation
Bank Top	Brush Trench	Pool	Access Road
Cross Section	Sod-Mat Transplant	Riffle Dearmoring	Borrow Pit
Log Jam	Vegetation Transplant	Side Channel	Staging Area
Pile	Island	Floodplain	Contour (1 ft)

AS-BUILT LONGITUDINAL PROFILE	
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SHEET: 6 OF 21	

STATE OF COLORADO
DEPARTMENT OF NATURAL RESOURCES
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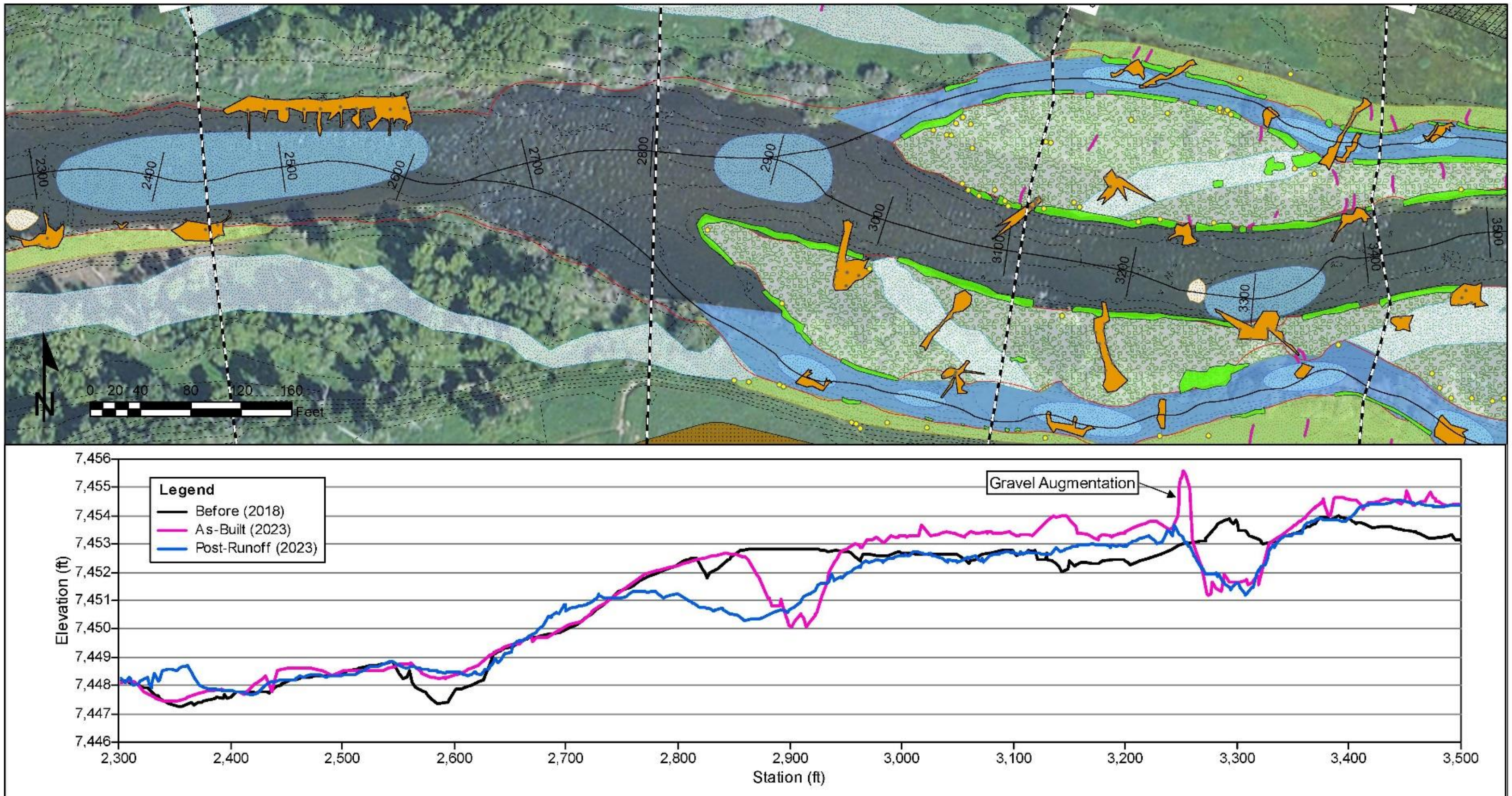
FORT COLLINS, COLORADO

COLORADO RIVER
KEMP BREEZE SWA
AS-BUILT SURVEY



Thalweg	Ditch Realignment	Overflow	Gravel Augmentation
Bank Top	Brush Trench	Pool	Access Road
Cross Section	Sod-Mat Transplant	Riffle Dearmoring	Borrow Pit
Log Jam	Vegetation Transplant	Side Channel	Staging Area
Pile	Island	Floodplain	Contour (1 ft)

AS-BUILT LONGITUDINAL PROFILE

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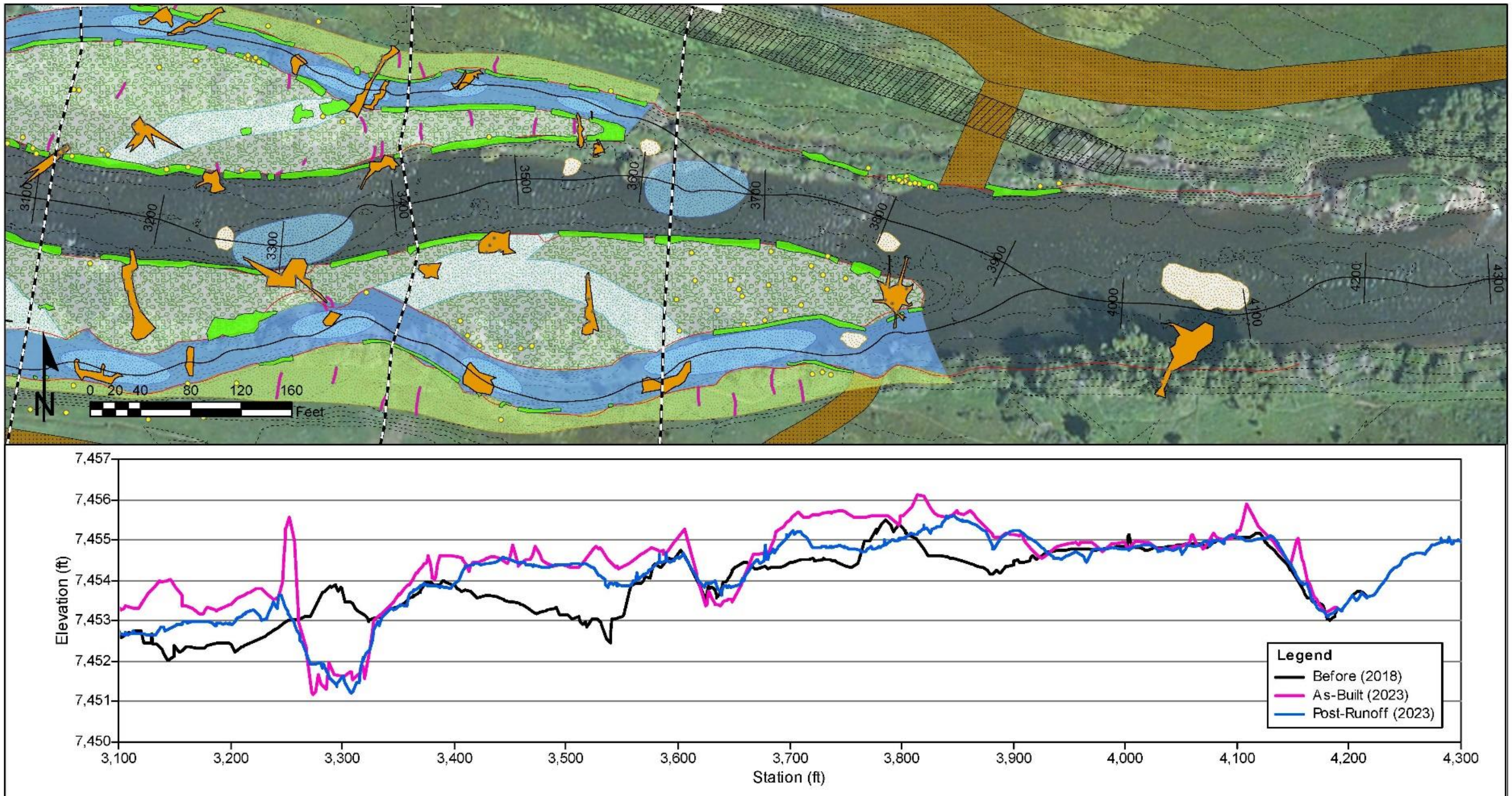
APPROVED:

SHEET 7 OF 21

STATE OF COLORADO
DEPARTMENT OF NATURAL RESOURCES
COLORADO PARKS AND WILDLIFE
FORT COLLINS, COLORADO

COLORADO RIVER
KEMP BREEZE SWA
AS-BUILT SURVEY



Thalweg
Bank Top
Cross Section
Log Jam
Pile
Ditch Realignment
Brush Trench
Sod-Mat Transplant
Vegetation Transplant
Island
Overflow
Pool
Riffle Dearmoring
Side Channel
Floodplain
Gravel Augmentation
Access Road
Borrow Pit
Staging Area
Contour (1 ft)

AS-BUILT LONGITUDINAL PROFILE	
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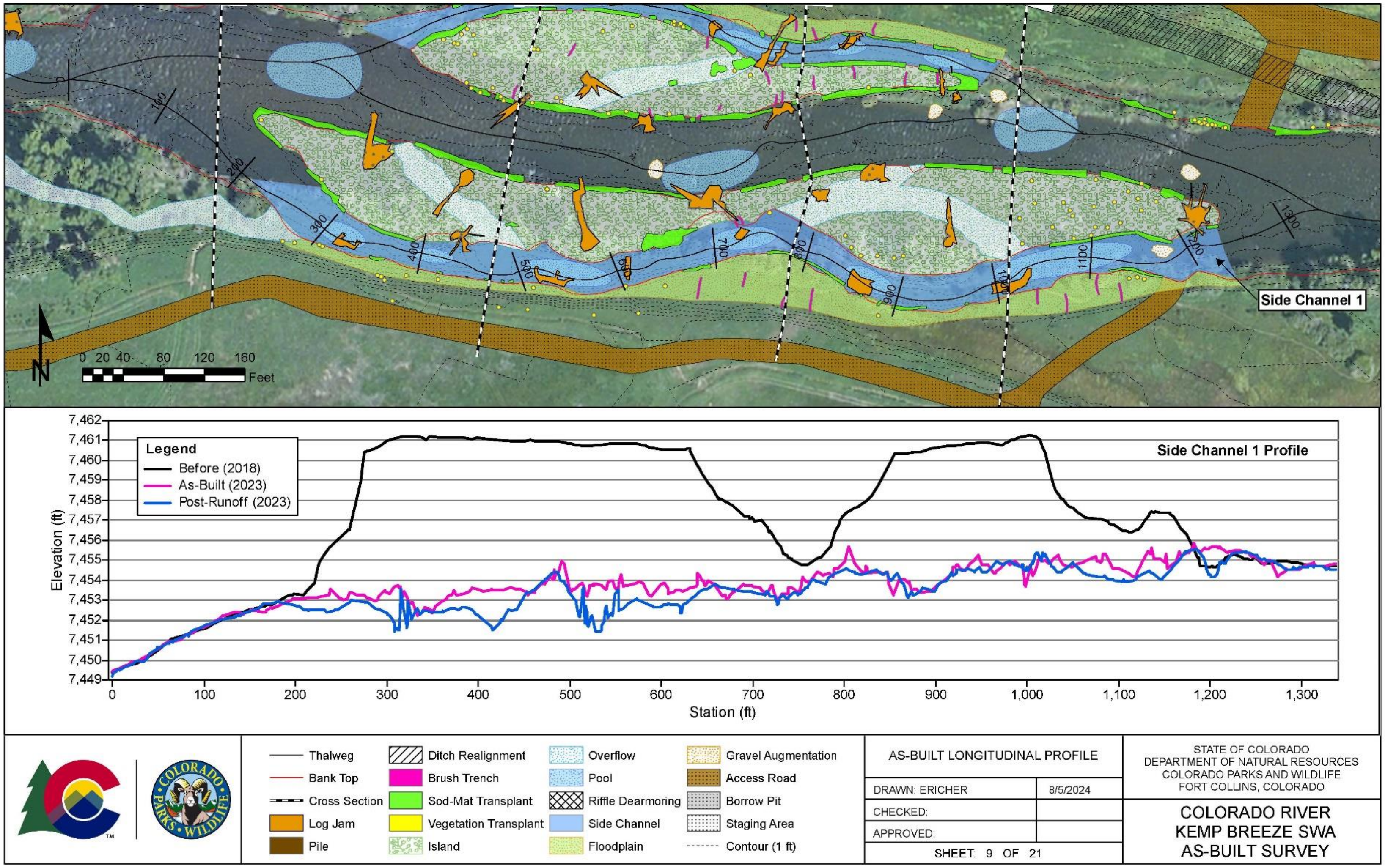
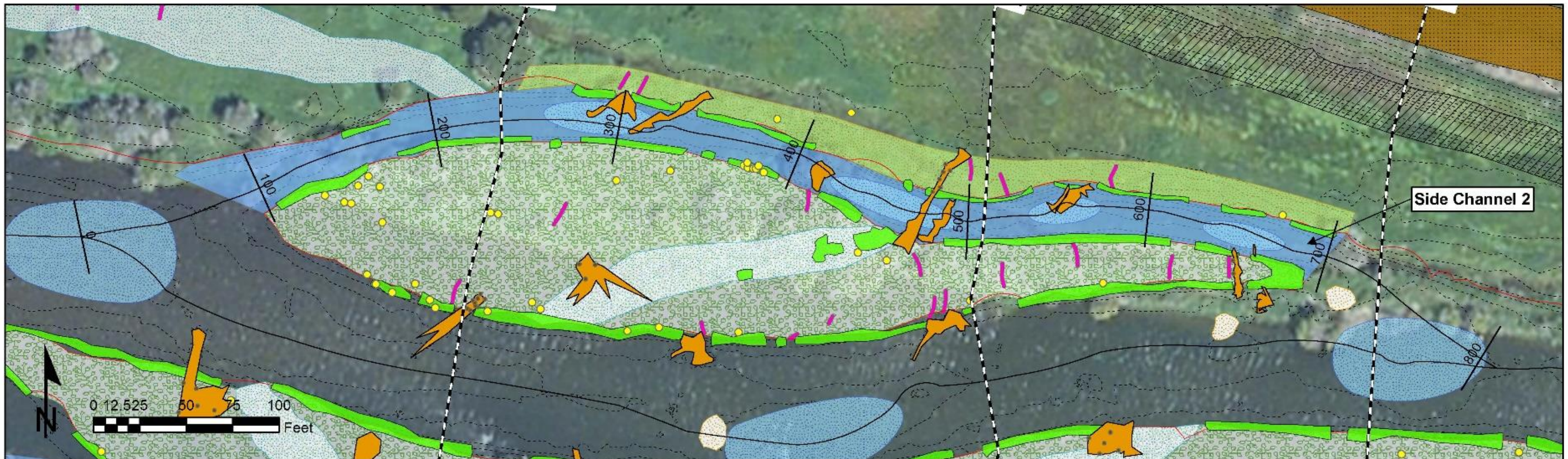
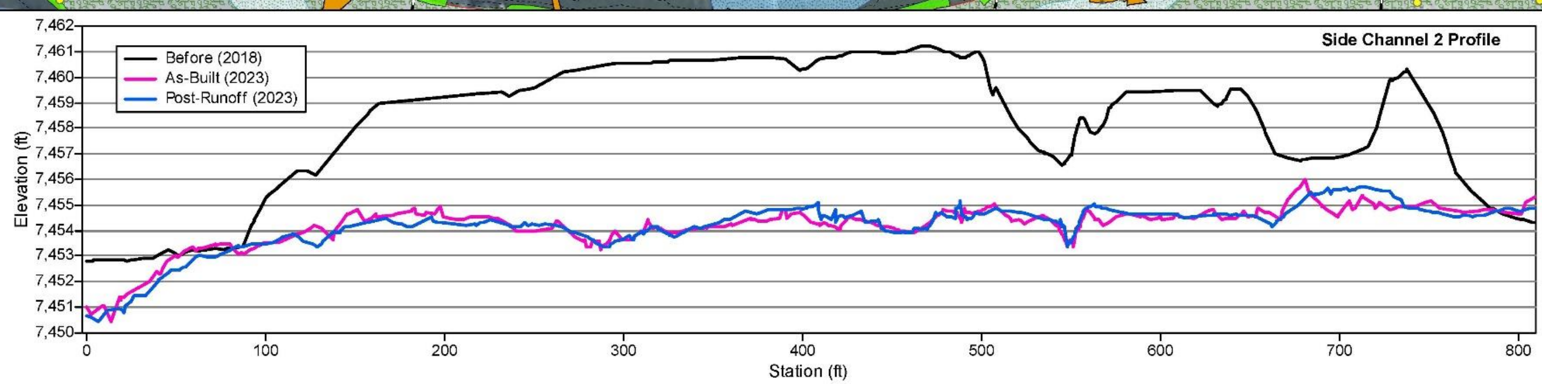
SHEET: 8 OF 21	

STATE OF COLORADO
DEPARTMENT OF NATURAL RESOURCES
COLORADO PARKS AND WILDLIFE
FORT COLLINS, COLORADO

COLORADO RIVER
KEMP BREEZE SWA
AS-BUILT SURVEY


Side Channel 1
0 20 40 80 120 160
Feet
N
Legend
Before (2018)
As-Built (2023)
Post-Runoff (2023)
Side Channel 1 Profile
Elevation (ft)
Station (ft)
Thalweg
Bank Top
Cross Section
Log Jam
Pile
Ditch Realignment
Brush Trench
Sod-Mat Transplant
Vegetation Transplant
Island
Overflow
Pool
Riffle Dearmoring
Side Channel
Floodplain
Gravel Augmentation
Access Road
Borrow Pit
Staging Area
Contour (1 ft)
AS-BUILT LONGITUDINAL PROFILE
DRAWN: ERICHER 8/5/2024
CHECKED:
APPROVED:
SHEET: 9 OF 21
STATE OF COLORADO
DEPARTMENT OF NATURAL RESOURCES
COLORADO PARKS AND WILDLIFE
FORT COLLINS, COLORADO
COLORADO RIVER
KEMP BREEZE SWA
AS-BUILT SURVEY



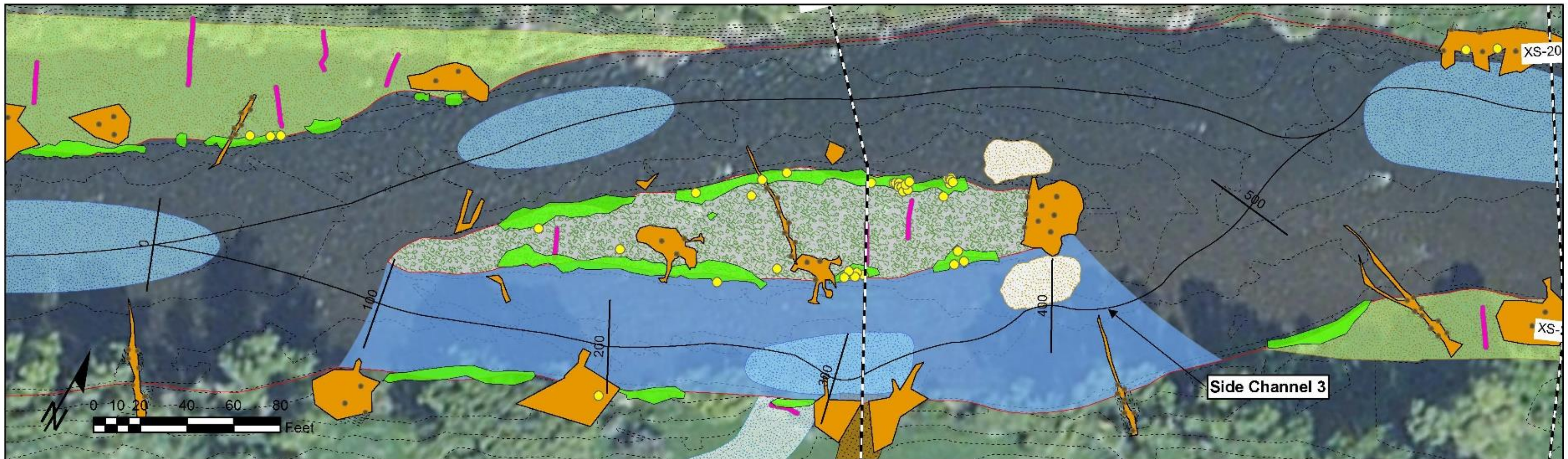


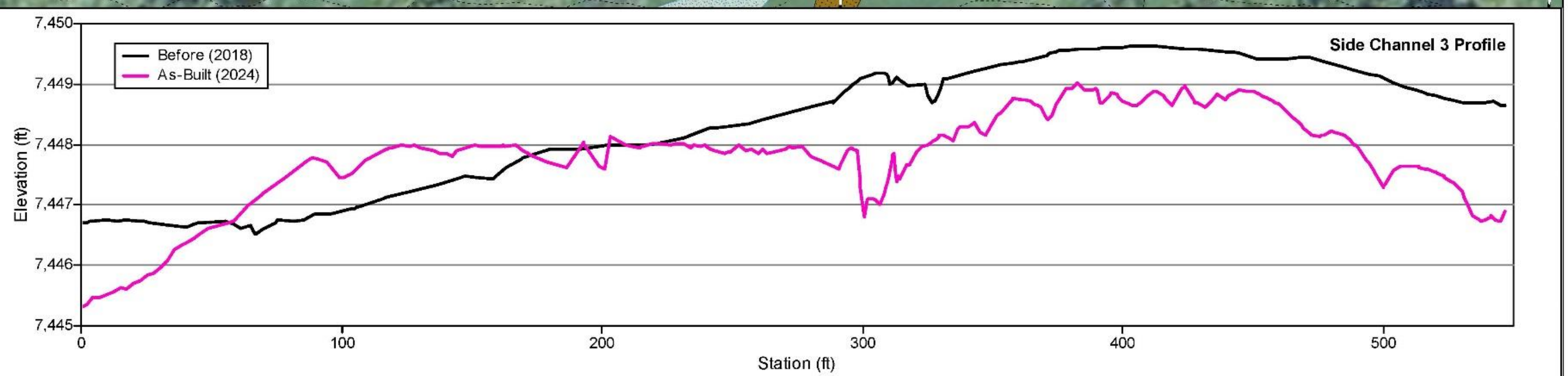
Thalweg	Ditch Realignment	Overflow	Gravel Augmentation
Bank Top	Brush Trench	Pool	Access Road
Cross Section	Sod-Mat Transplant	Riffle Dearmoring	Borrow Pit
Log Jam	Vegetation Transplant	Side Channel	Staging Area
Pile	Island	Floodplain	Contour (1 ft)

AS-BUILT LONGITUDINAL PROFILE	
DRAWN: ERICHER	8/5/2024
CHECKED:	
APPROVED:	
SHEET: 10 OF 21	

STATE OF COLORADO
DEPARTMENT OF NATURAL RESOURCES
COLORADO PARKS AND WILDLIFE
FORT COLLINS, COLORADO

COLORADO RIVER
KEMP BREEZE SWA
AS-BUILT SURVEY





Thalweg
Bank Top
Cross Section
Log Jam
Pile
Ditch Realignment
Brush Trench
Sod-Mat Transplant
Vegetation Transplant
Island
Overflow
Pool
Riffle Dearmoring
Side Channel
Floodplain
Gravel Augmentation
Access Road
Borrow Pit
Staging Area
Contour (1 ft)

AS-BUILT LONGITUDINAL PROFILE	
DRAWN: ERICHER	8/5/2024
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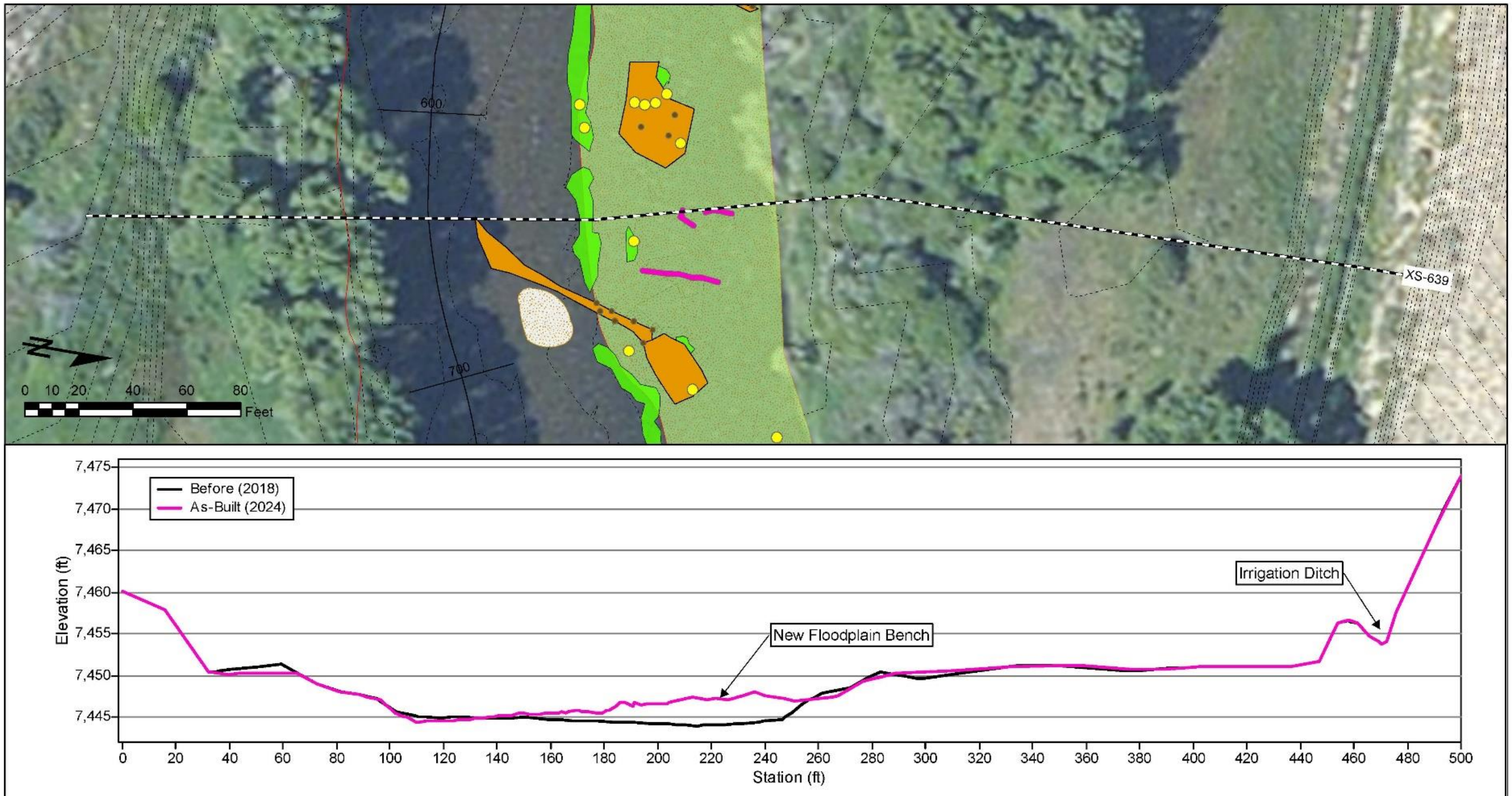
APPROVED:	
SHEET: 11 OF 21	

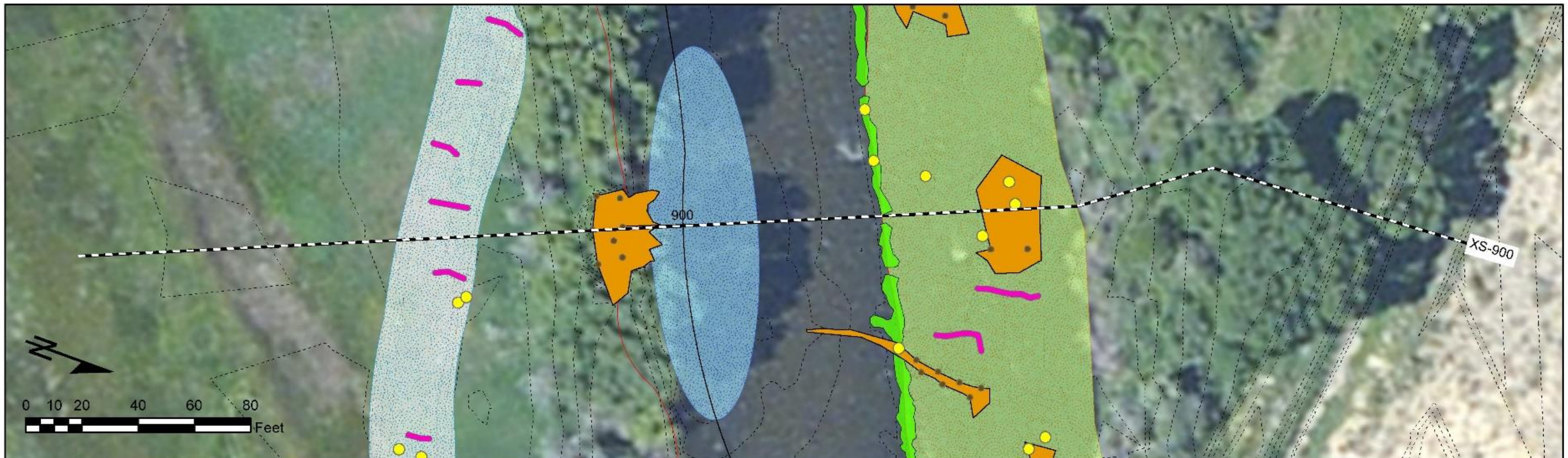
STATE OF COLORADO
DEPARTMENT OF NATURAL RESOURCES
COLORADO PARKS AND WILDLIFE
FORT COLLINS, COLORADO

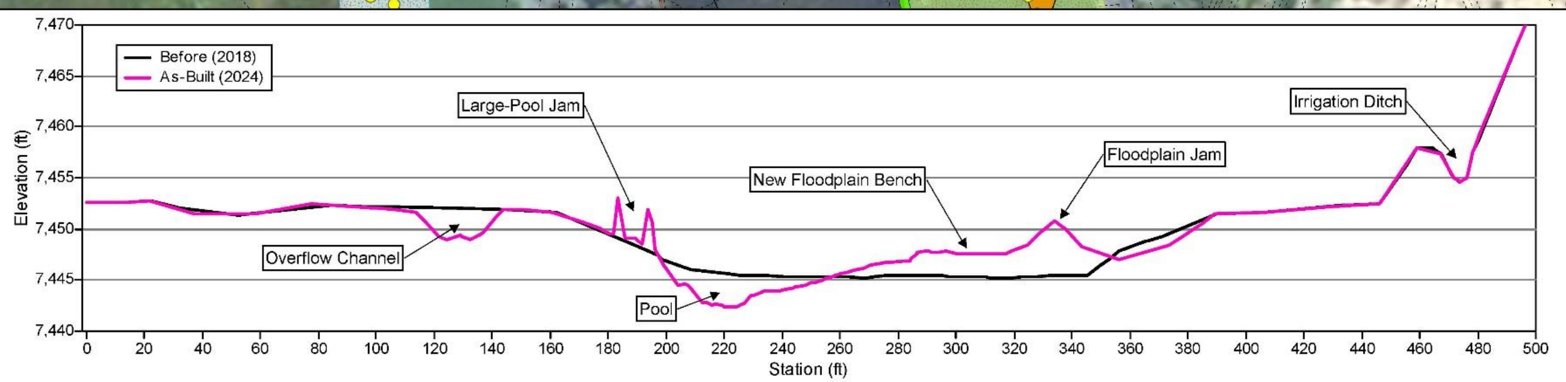
COLORADO RIVER
KEMP BREEZE SWA
AS-BUILT SURVEY



Thalweg	Ditch Realignment	Overflow	Gravel Augmentation
Bank Top	Brush Trench	Pool	Access Road
Cross Section	Sod-Mat Transplant	Riffle Dearmoring	Borrow Pit
Log Jam	Vegetation Transplant	Side Channel	Staging Area
Pile	Island	Floodplain	Contour (1 ft)

CROSS-SECTION PROFILE (XS-639)		STATE OF COLORADO DEPARTMENT OF NATURAL RESOURCES COLORADO PARKS AND WILDLIFE FORT COLLINS, COLORADO
DRAWN: ERICHER	8/8/2024	COLORADO RIVER KEMP BREEZE SWA AS-BUILT SURVEY
CHECKED:		
APPROVED:		
SHEET: 12 OF 21		





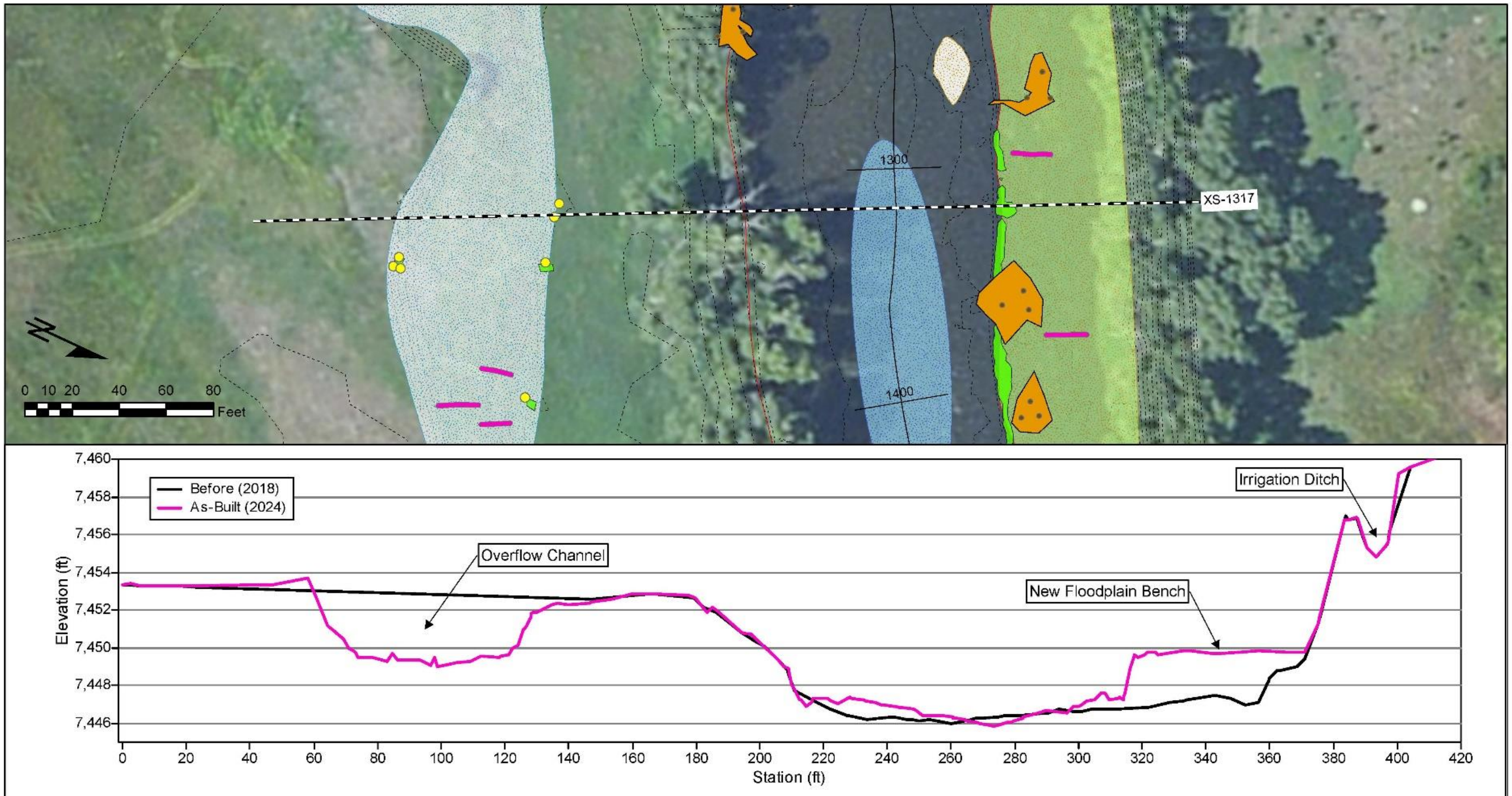
Thalweg
Bank Top
Cross Section
Log Jam
Pile
Ditch Realignment
Brush Trench
Sod-Mat Transplant
Vegetation Transplant
Island
Overflow
Pool
Riffle Dearmoring
Side Channel
Floodplain
Gravel Augmentation
Access Road
Borrow Pit
Staging Area
Contour (1 ft)

CROSS-SECTION PROFILE (XS-900)

DRAWN: ERICHER	8/8/2024
CHECKED:	
APPROVED:	
SHEET: 13 OF 21	

STATE OF COLORADO
DEPARTMENT OF NATURAL RESOURCES
COLORADO PARKS AND WILDLIFE
FORT COLLINS, COLORADO

COLORADO RIVER
KEMP BREEZE SWA
AS-BUILT SURVEY



Thalweg	Ditch Realignment	Overflow	Gravel Augmentation
Bank Top	Brush Trench	Pool	Access Road
Cross Section	Sod-Mat Transplant	Riffle Dearmoring	Borrow Pit
Log Jam	Vegetation Transplant	Side Channel	Staging Area
Pile	Island	Floodplain	Contour (1 ft)

CROSS-SECTION PROFILE (XS-1317)

DRAWN: ERICHER	8/9/2024
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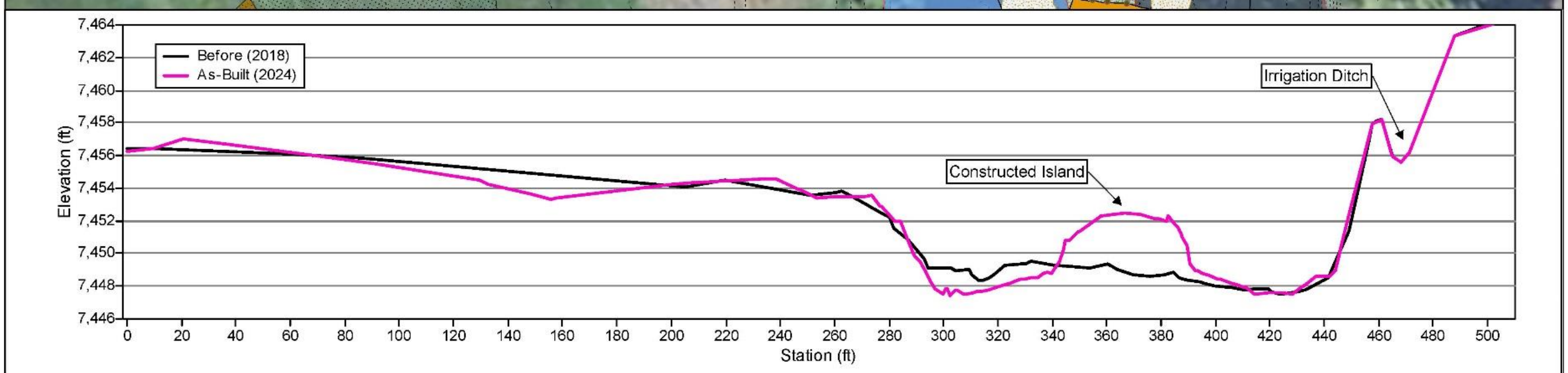
APPROVED:	
SHEET: 14 OF 21	

STATE OF COLORADO
DEPARTMENT OF NATURAL RESOURCES
COLORADO PARKS AND WILDLIFE
FORT COLLINS, COLORADO

COLORADO RIVER
KEMP BREEZE SWA
AS-BUILT SURVEY



Thalweg	Ditch Realignment	Overflow	Gravel Augmentation
Bank Top	Brush Trench	Pool	Access Road
Cross Section	Sod-Mat Transplant	Riffle Dearmoring	Borrow Pit
Log Jam	Vegetation Transplant	Side Channel	Staging Area
Pile	Island	Floodplain	Contour (1 ft)

CROSS-SECTION PROFILE (XS-1735)

DRAWN: ERICHER	8/9/2024
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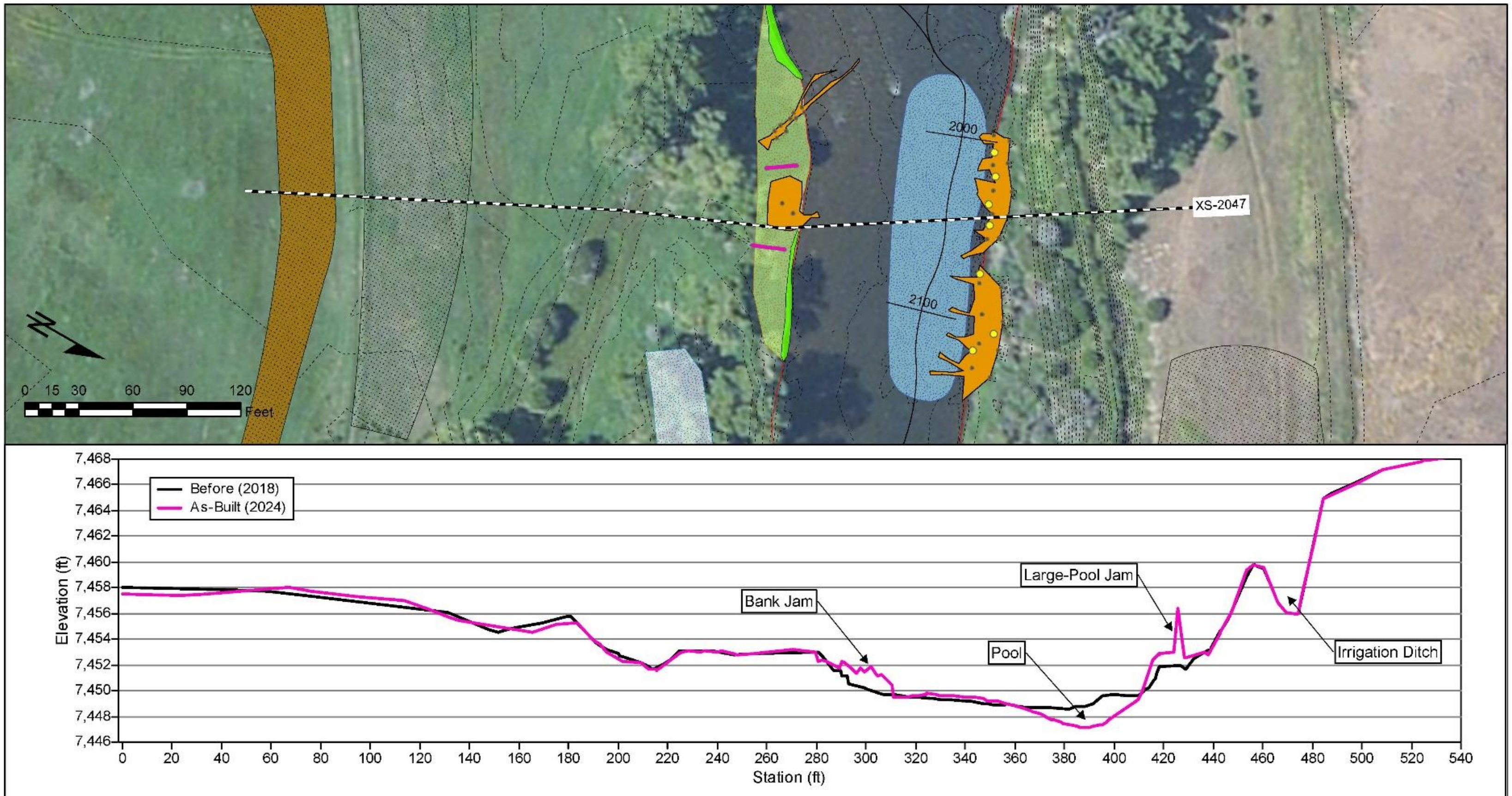
SHEET: 15 OF 21	

STATE OF COLORADO
DEPARTMENT OF NATURAL RESOURCES
COLORADO PARKS AND WILDLIFE
FORT COLLINS, COLORADO

COLORADO RIVER
KEMP BREEZE SWA
AS-BUILT SURVEY



Legend			
Thalweg	Ditch Realignment	Overflow	Gravel Augmentation
Bank Top	Brush Trench	Pool	Access Road
Cross Section	Sod-Mat Transplant	Riffle Dearmoring	Borrow Pit
Log Jam	Vegetation Transplant	Side Channel	Staging Area
Pile	Island	Floodplain	Contour (1 ft)

CROSS-SECTION PROFILE (XS-2047)

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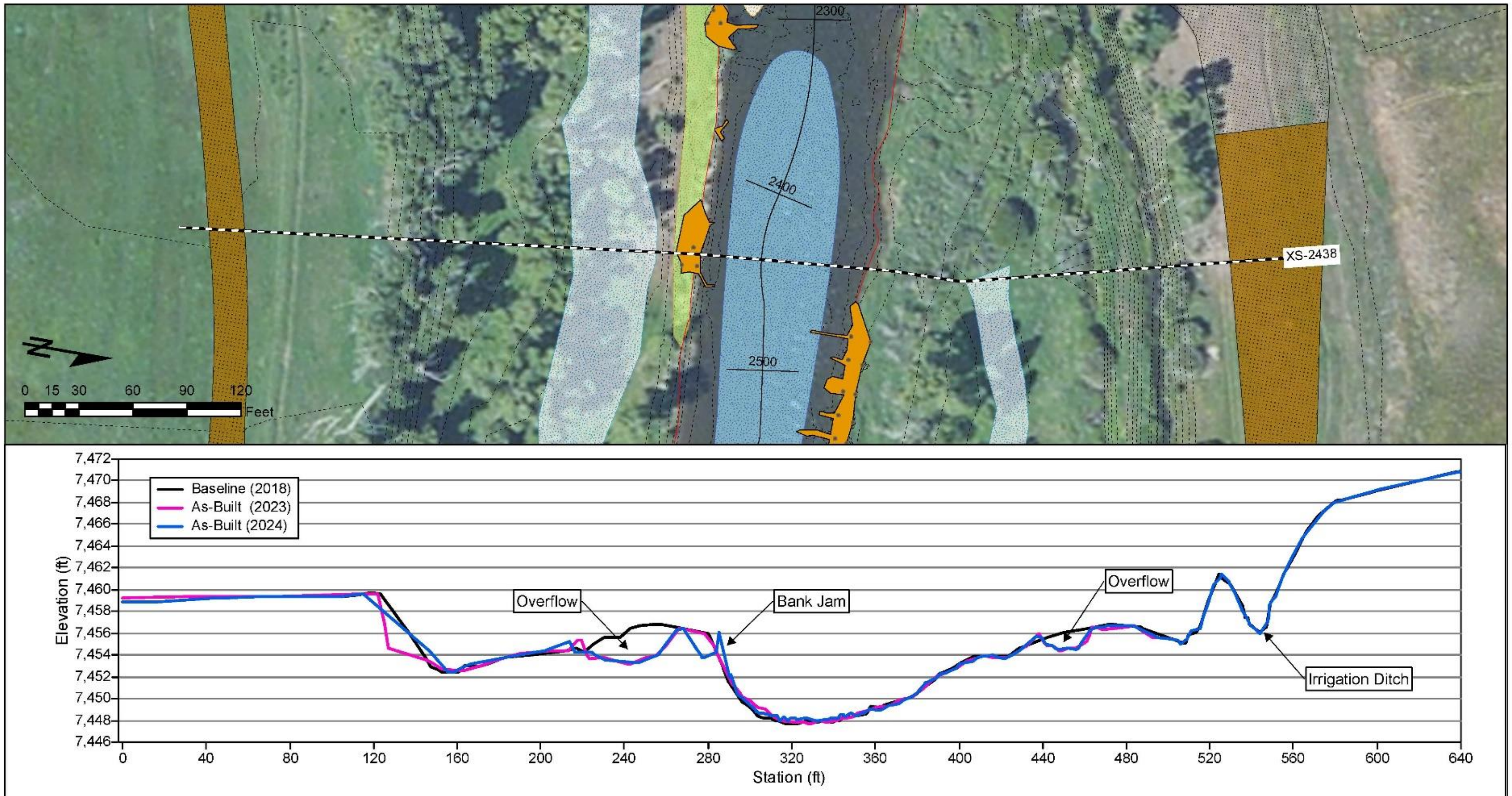
SHEET: 16 OF 21

STATE OF COLORADO
DEPARTMENT OF NATURAL RESOURCES
COLORADO PARKS AND WILDLIFE
FORT COLLINS, COLORADO

COLORADO RIVER
KEMP BREEZE SWA
AS-BUILT SURVEY



Thalweg	Ditch Realignment	Overflow	Gravel Augmentation
Bank Top	Brush Trench	Pool	Access Road
Cross Section	Sod-Mat Transplant	Riffle Dearmoring	Borrow Pit
Log Jam	Vegetation Transplant	Side Channel	Staging Area
Pile	Island	Floodplain	Contour (1 ft)

CROSS-SECTION PROFILE (XS-2438)

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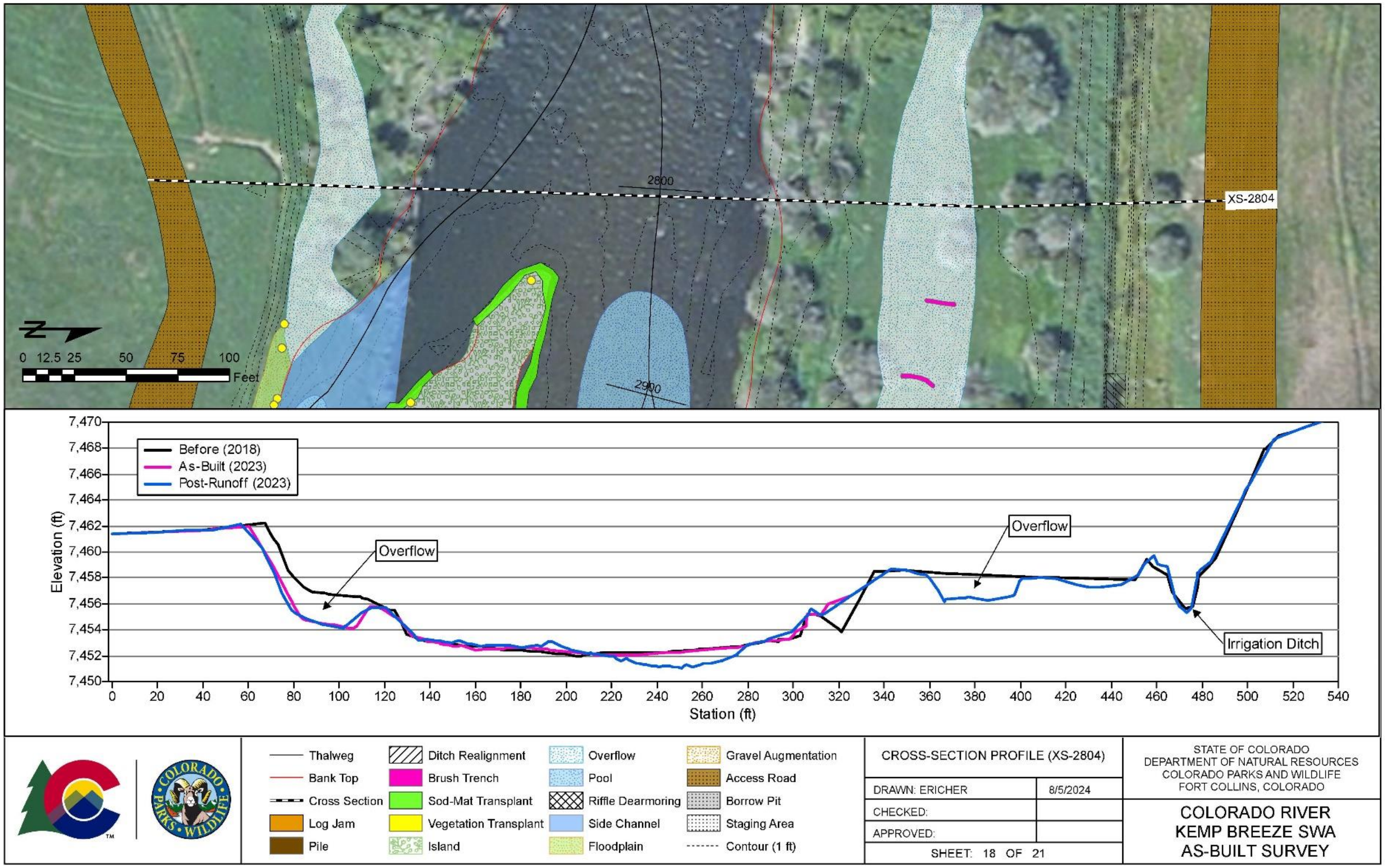
SHEET: 17 OF 21

STATE OF COLORADO
DEPARTMENT OF NATURAL RESOURCES
COLORADO PARKS AND WILDLIFE
FORT COLLINS, COLORADO

COLORADO RIVER
KEMP BREEZE SWA
AS-BUILT SURVEY


2800
2900
XS-2804
0 12.5 25 50 75 100
Feet
7,470
7,468
7,466
7,464
7,462
7,460
7,458
7,456
7,454
7,452
7,450
Elevation (ft)
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340 360 380 400 420 440 460 480 500 520 540
Station (ft)
Before (2018)
As-Built (2023)
Post-Runoff (2023)
Overflow
Overflow
Irrigation Ditch
Thalweg
Bank Top
Cross Section
Log Jam
Pile
Ditch Realignment
Brush Trench
Sod-Mat Transplant
Vegetation Transplant
Island
Overflow
Pool
Riffle Dearmoring
Side Channel
Floodplain
Gravel Augmentation
Access Road
Borrow Pit
Staging Area
Contour (1 ft)
CROSS-SECTION PROFILE (XS-2804)
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SHEET: 18 OF 21
STATE OF COLORADO
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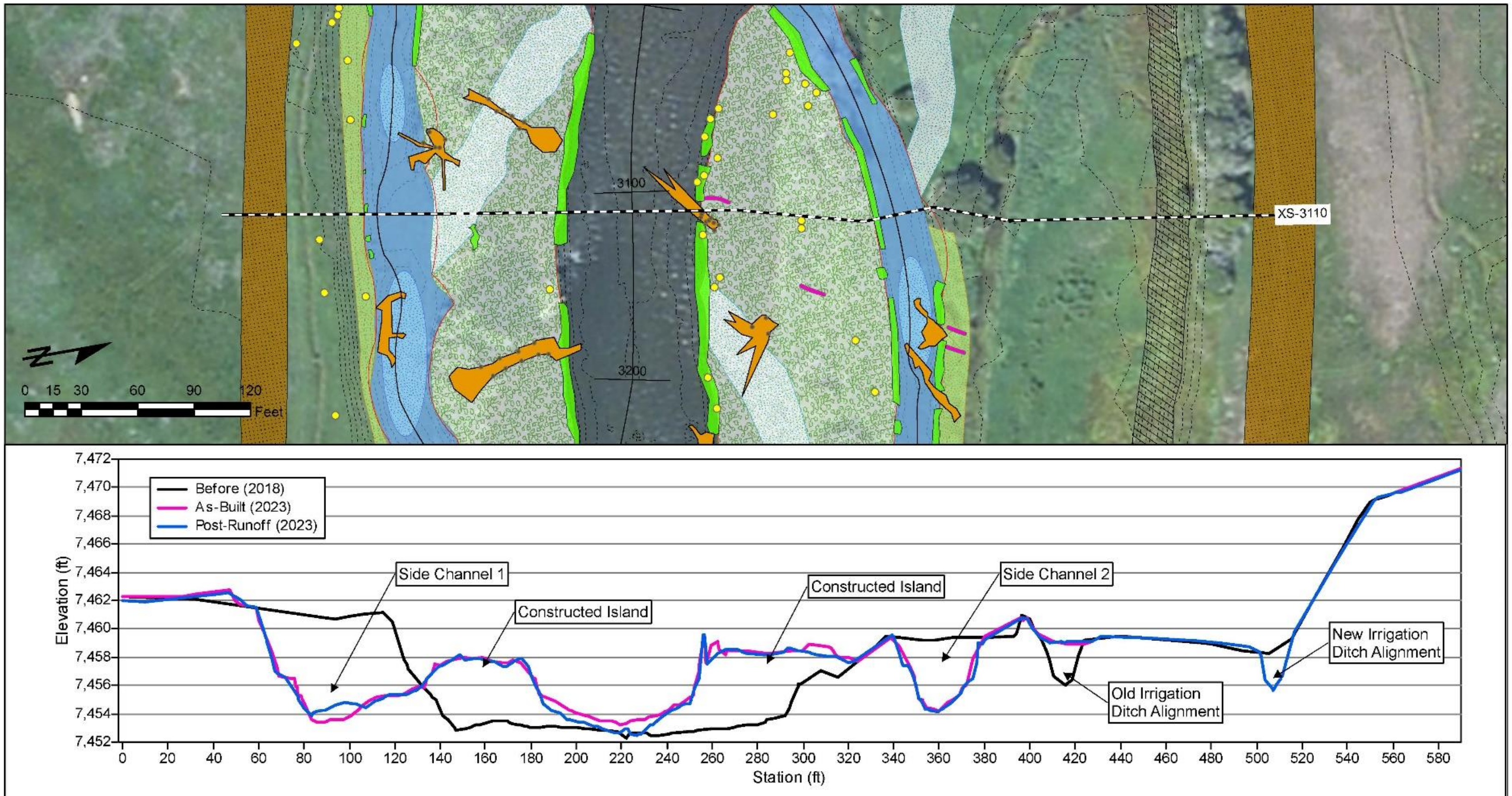
COLORADO PARKS AND WILDLIFE
FORT COLLINS, COLORADO
COLORADO RIVER
KEMP BREEZE SWA
AS-BUILT SURVEY



CROSS-SECTION PROFILE (XS-3110)

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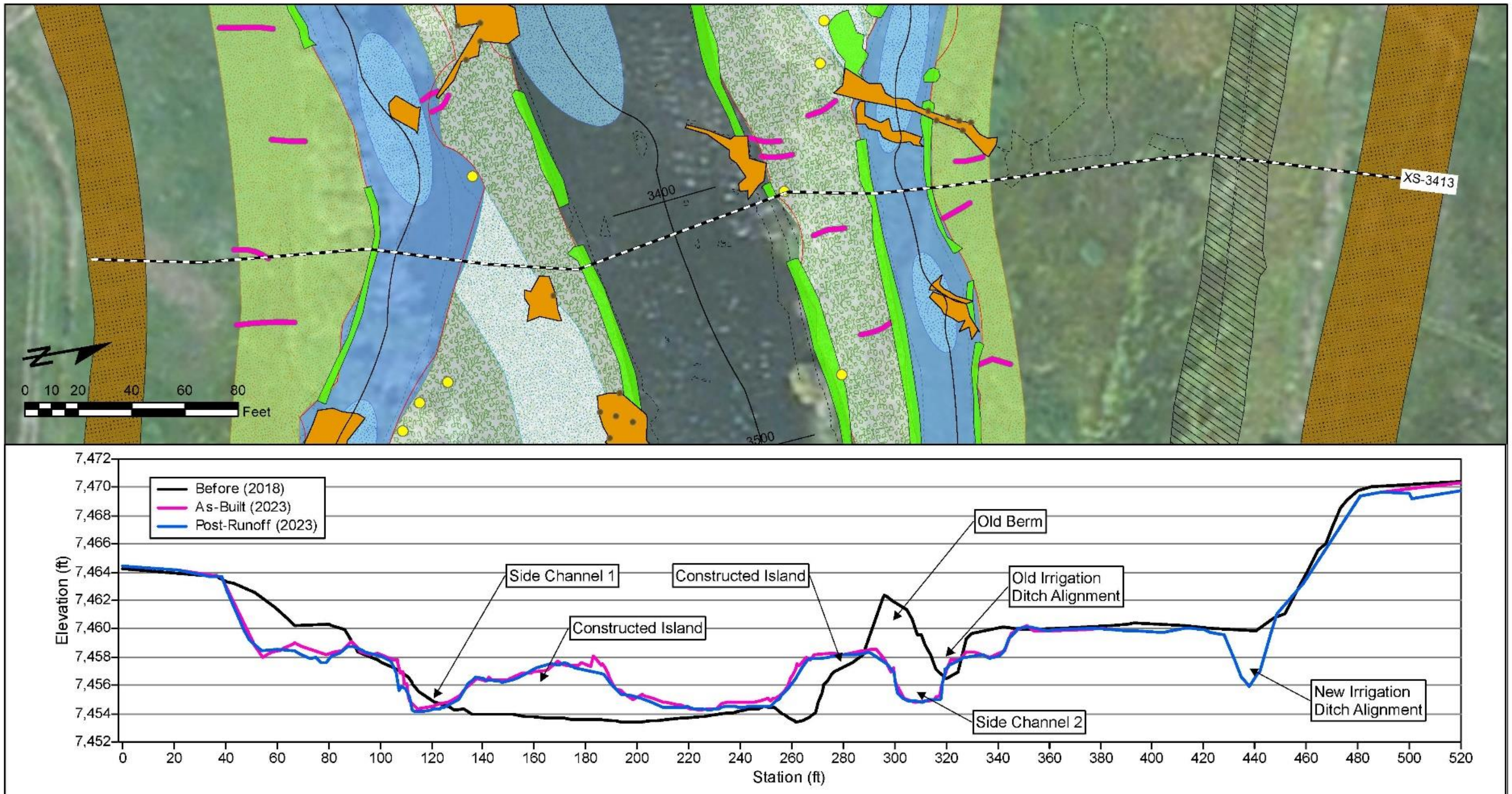
STATE OF COLORADO
DEPARTMENT OF NATURAL RESOURCES
COLORADO PARKS AND WILDLIFE
FORT COLLINS, COLORADO

COLORADO RIVER
KEMP BREEZE SWA
AS-BUILT SURVEY



Thalweg	Ditch Realignment	Overflow	Gravel Augmentation
Bank Top	Brush Trench	Pool	Access Road
Cross Section	Sod-Mat Transplant	Riffle Dearmoring	Borrow Pit
Log Jam	Vegetation Transplant	Side Channel	Staging Area
Pile	Island	Floodplain	Contour (1 ft)

CROSS-SECTION PROFILE (XS-3413)

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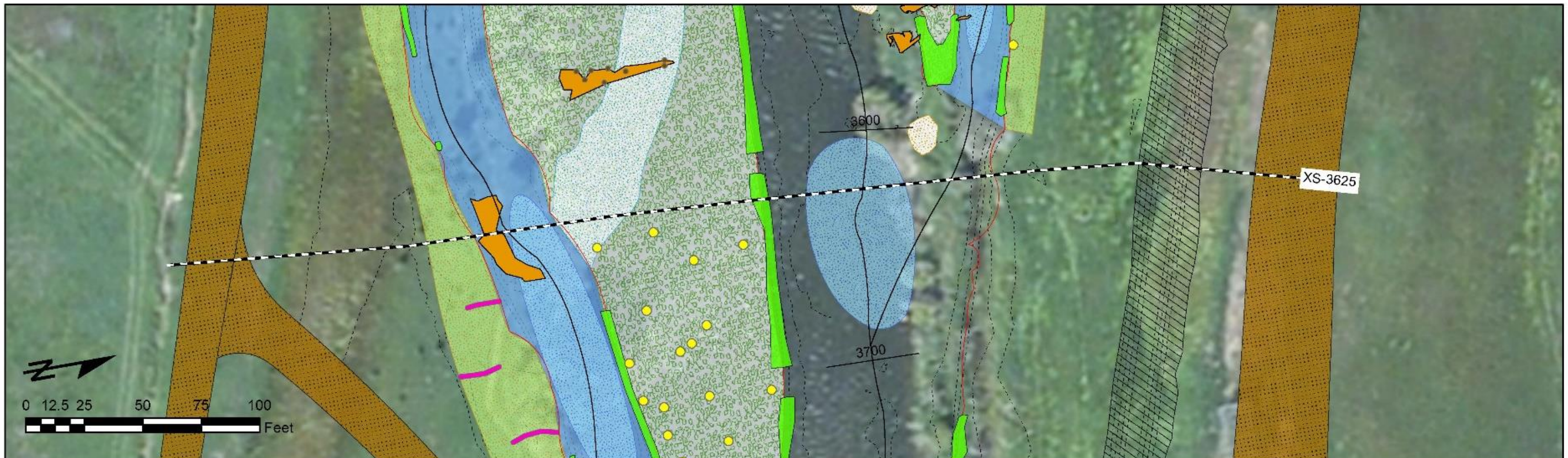
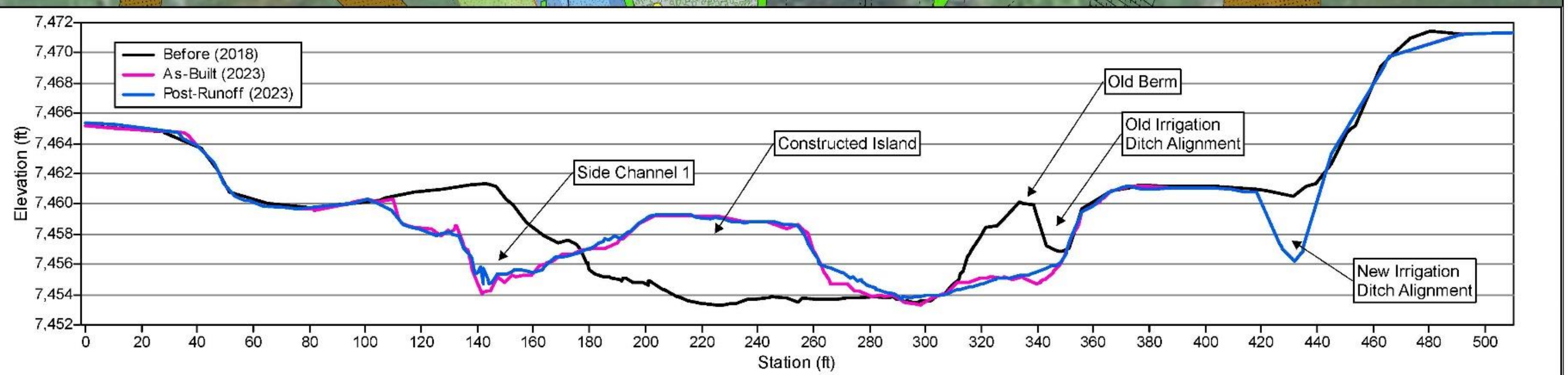
SHEET: 20 OF 21	

STATE OF COLORADO
DEPARTMENT OF NATURAL RESOURCES
COLORADO PARKS AND WILDLIFE
FORT COLLINS, COLORADO

COLORADO RIVER
KEMP BREEZE SWA
AS-BUILT SURVEY





Thalweg	Ditch Realignment	Overflow	Gravel Augmentation
Bank Top	Brush Trench	Pool	Access Road
Cross Section	Sod-Mat Transplant	Riffle Dearmoring	Borrow Pit
Log Jam	Vegetation Transplant	Side Channel	Staging Area
Pile	Island	Floodplain	Contour (1 ft)

CROSS-SECTION PROFILE (XS-3625)		STATE OF COLORADO DEPARTMENT OF NATURAL RESOURCES COLORADO PARKS AND WILDLIFE FORT COLLINS, COLORADO
DRAWN: ERICHER	8/5/2024	COLORADO RIVER KEMP BREEZE SWA AS-BUILT SURVEY
CHECKED:		
APPROVED:		
SHEET: 21 OF 21		

APPENDIX B

White River Survey Layout and Concept Design

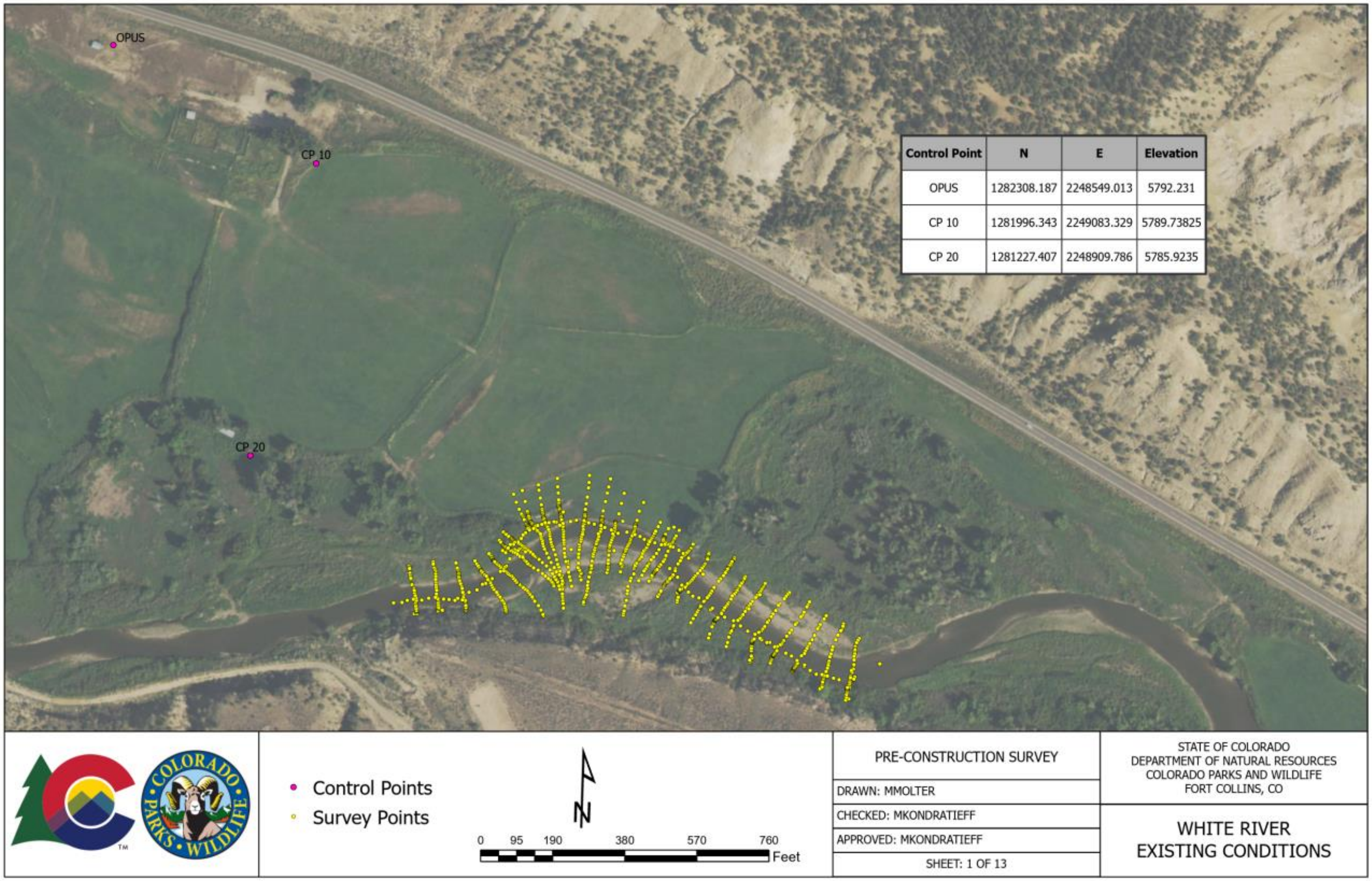


Figure B1. Locations of survey data points and control points at the project site on the White River.

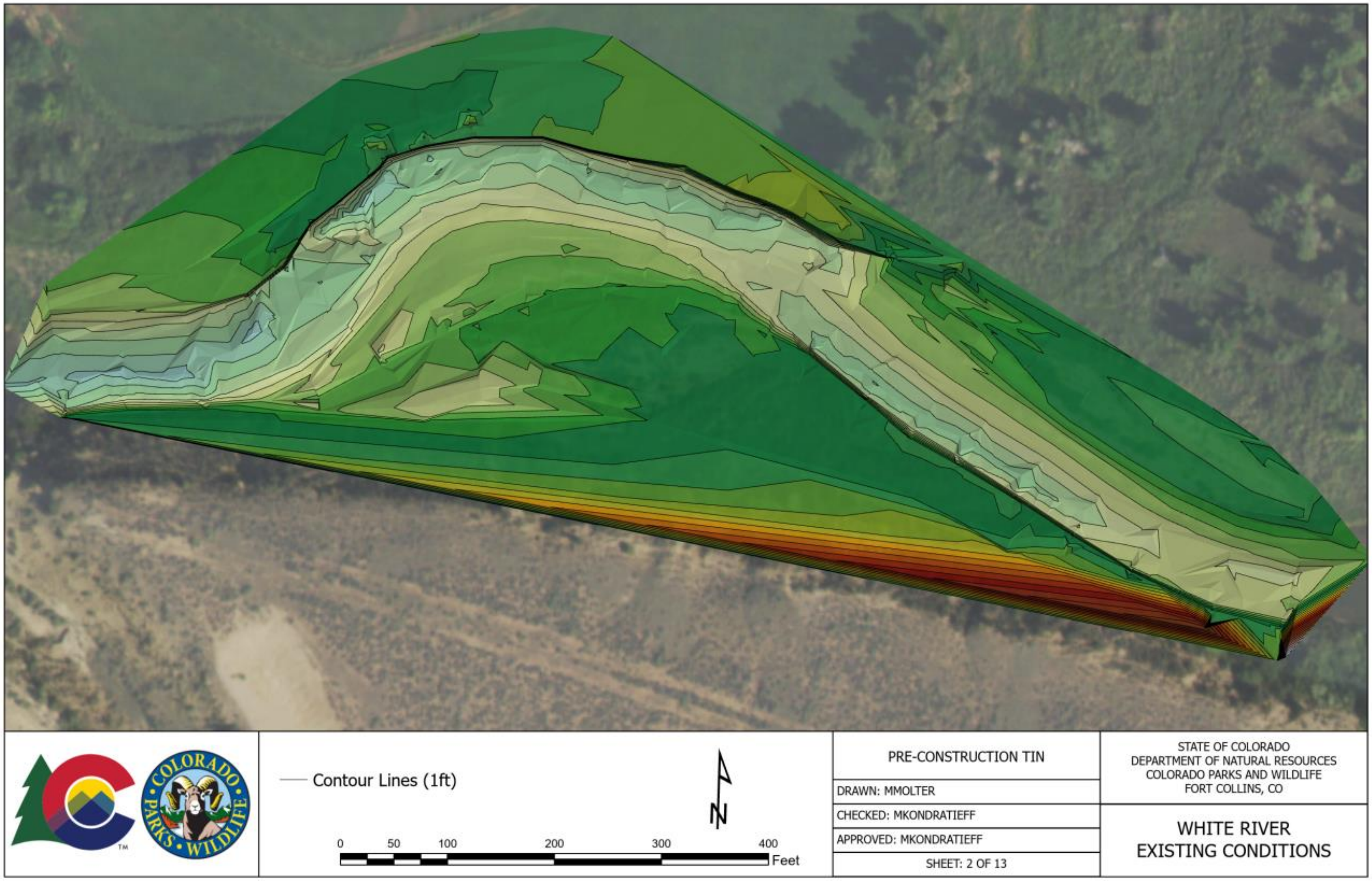


Figure B2. Triangulated irregular network (TIN) showing existing conditions of the channel through the project reach.

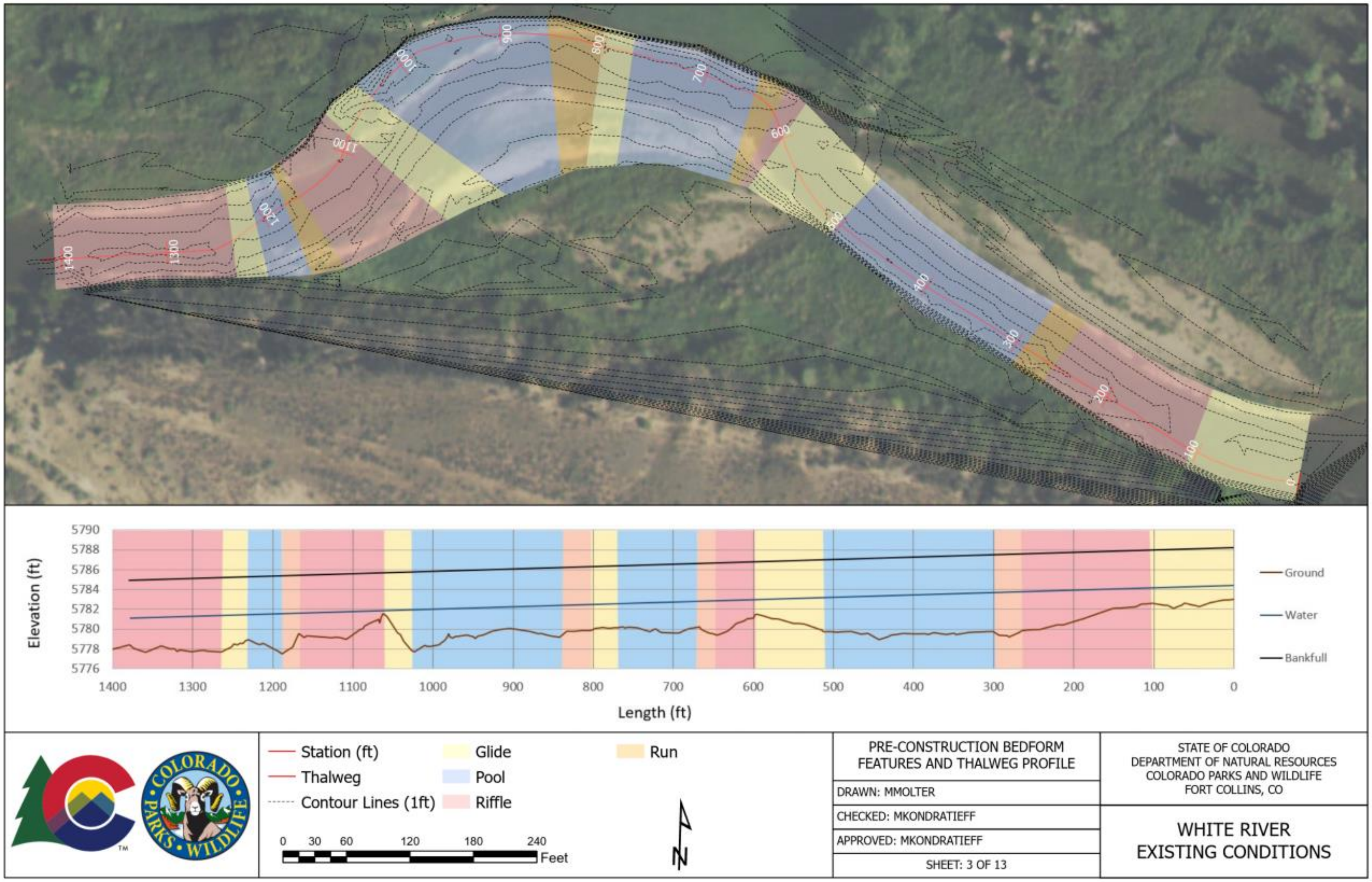


Figure B3. Channel bedforms and longitudinal profile graph with bankfull, water surface, and streambed (ground) elevations.

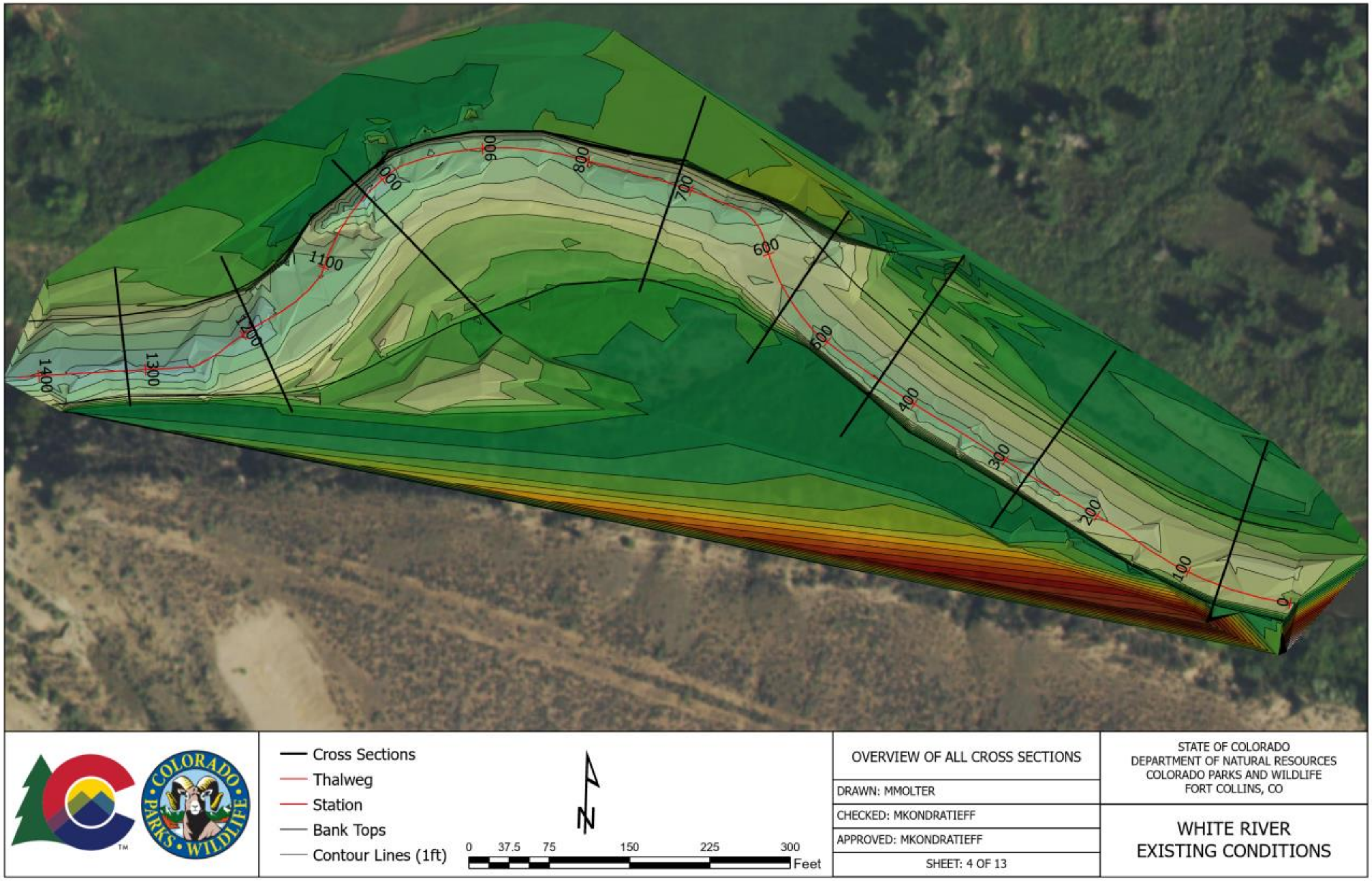


Figure B4. Cross section locations at the project site on the White River.

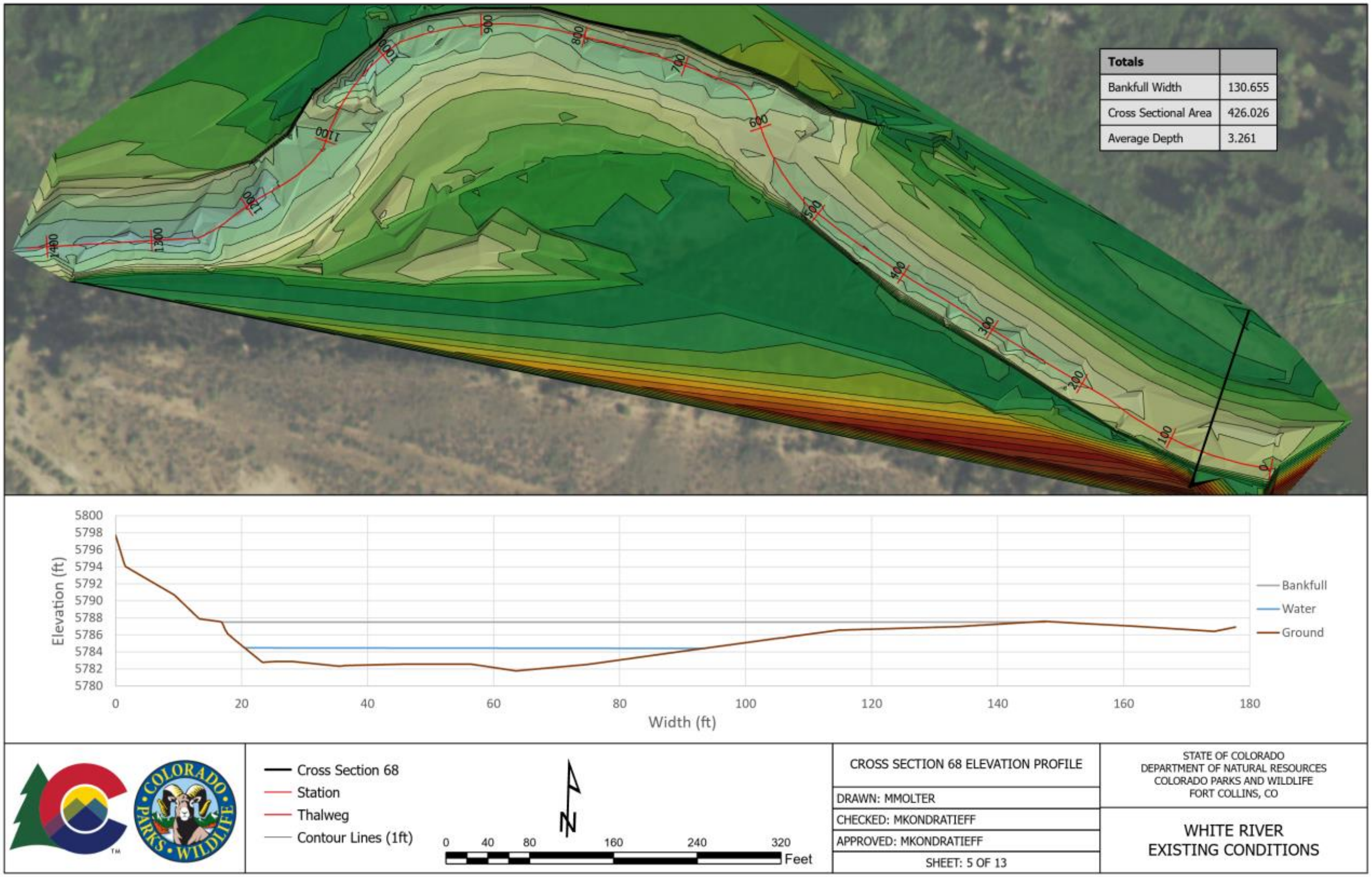


Figure B5. Location and profile graph for the cross section at station 68.

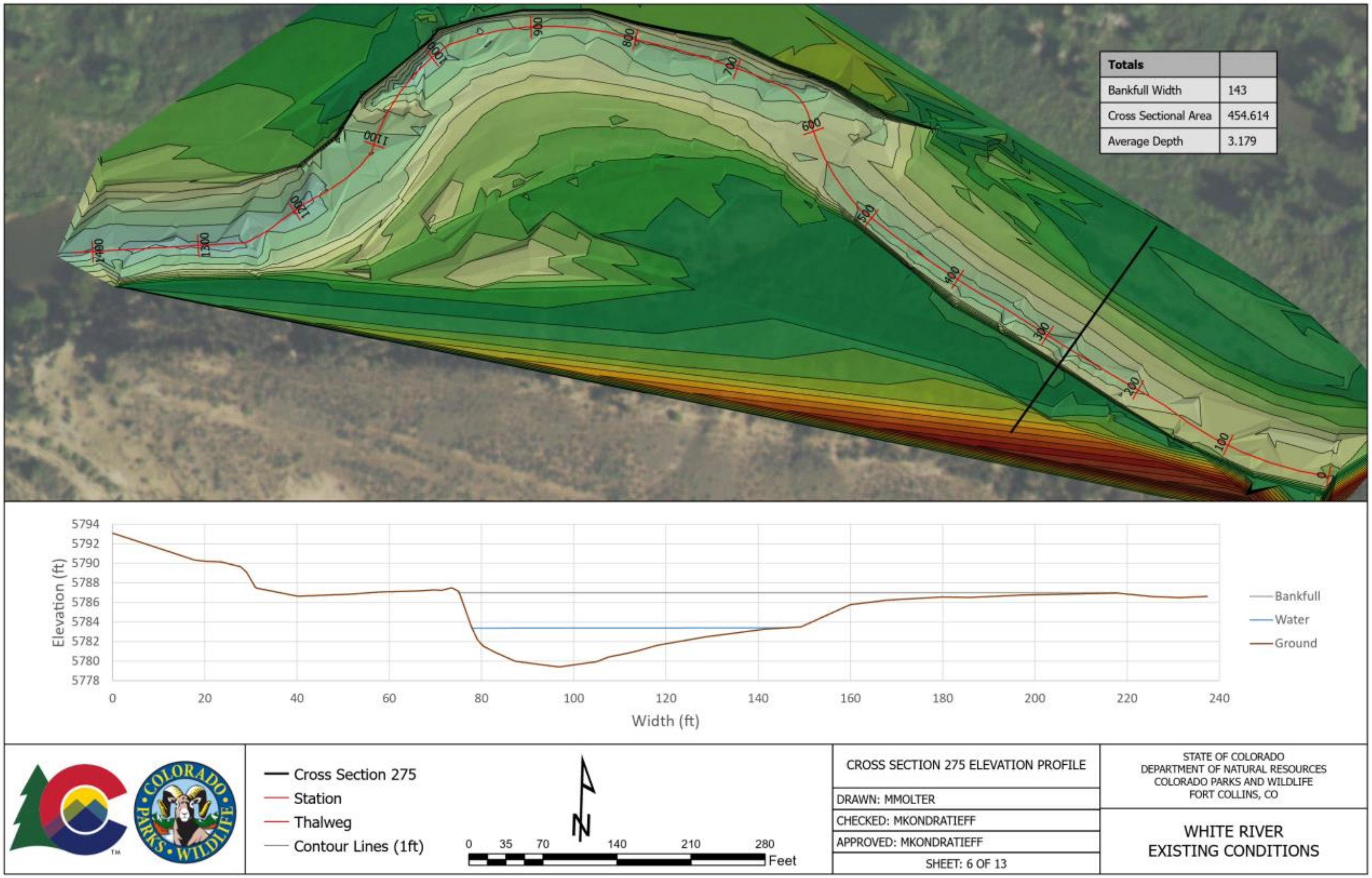


Figure B6. Location and profile graph for the cross section at station 275.

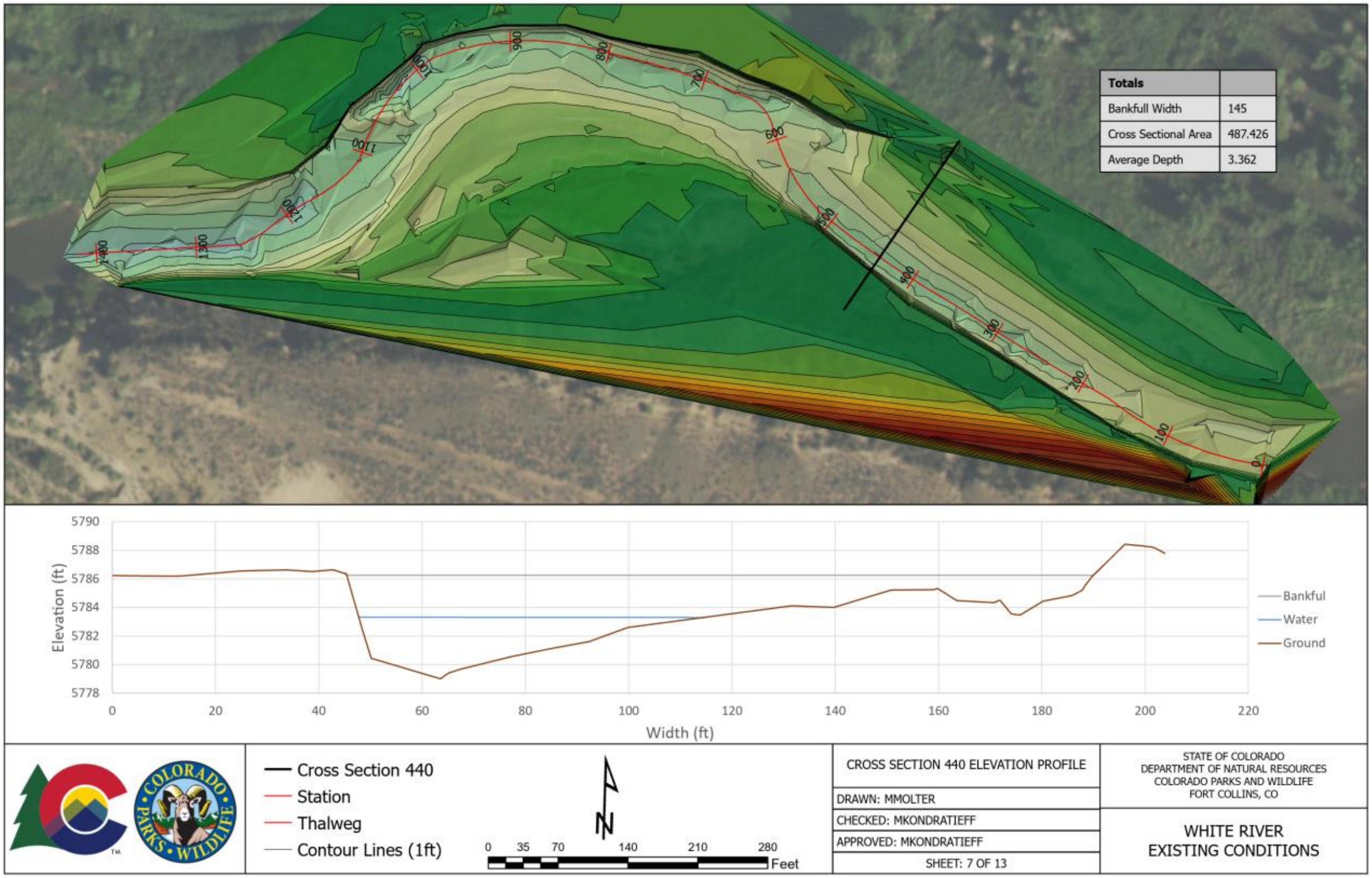


Figure B7. Location and profile graph for the cross section at station 440.

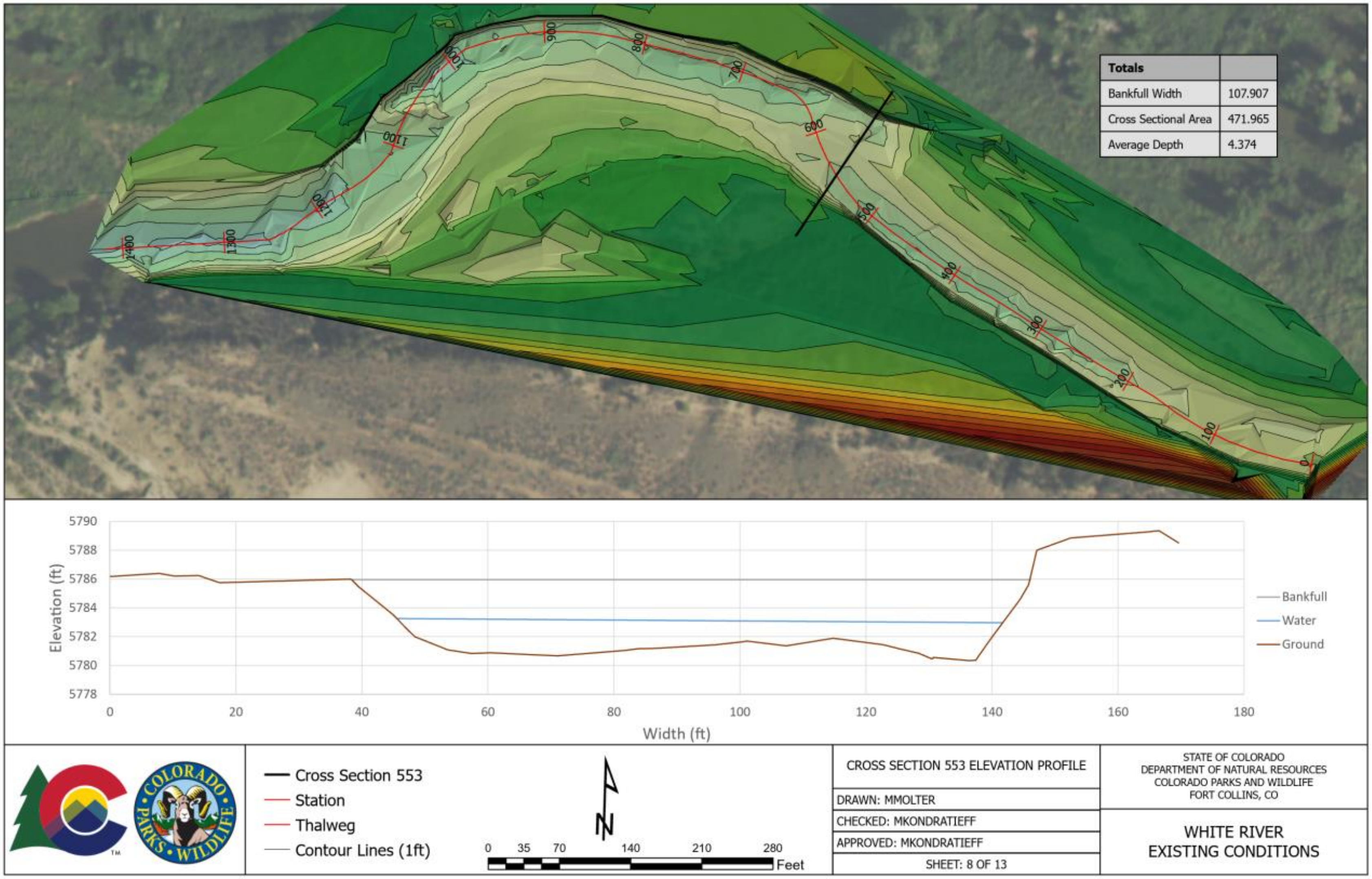


Figure B8. Location and profile graph for the cross section at station 553.

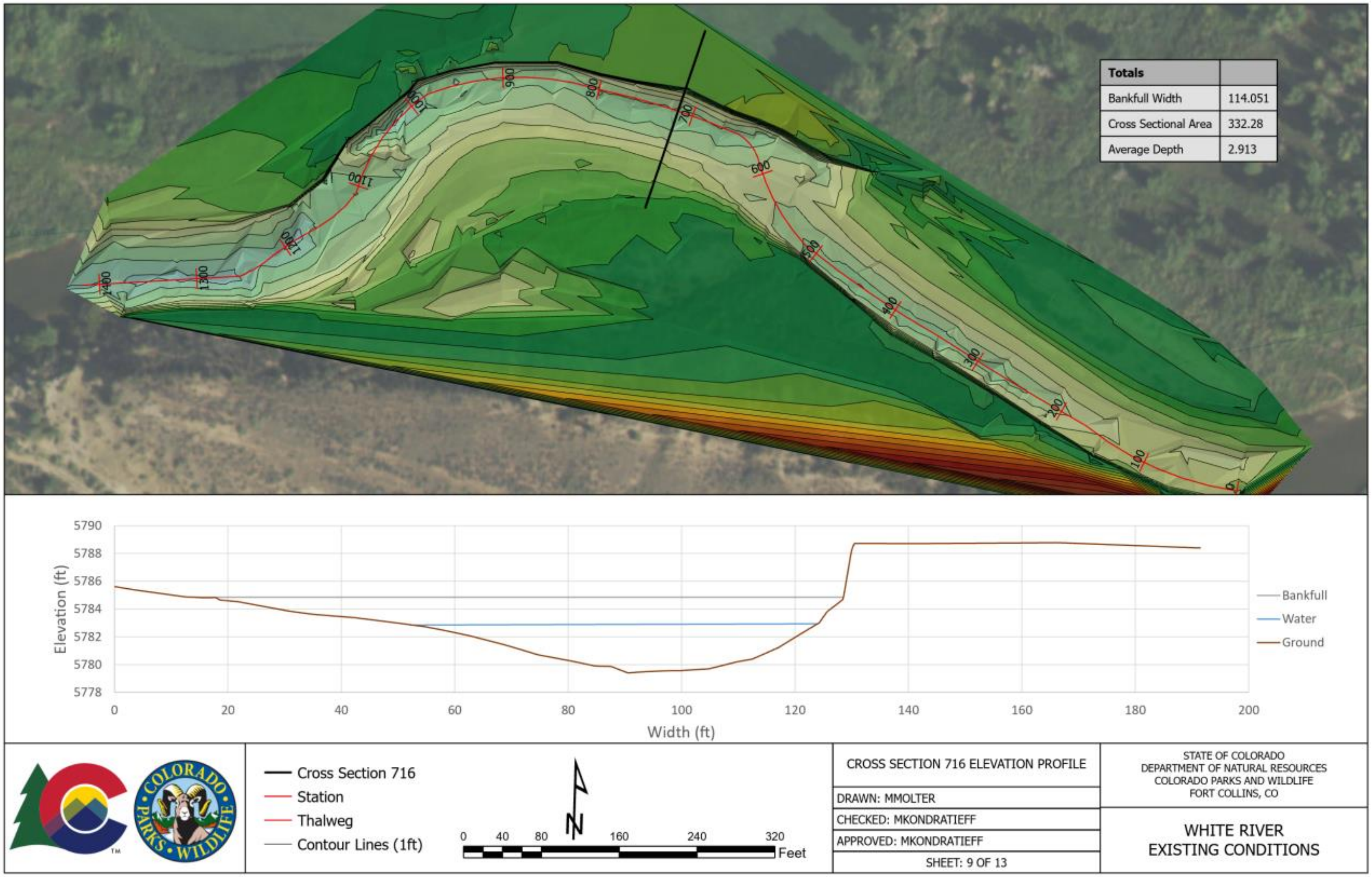


Figure B9. Location and profile graph for the cross section at station 716.

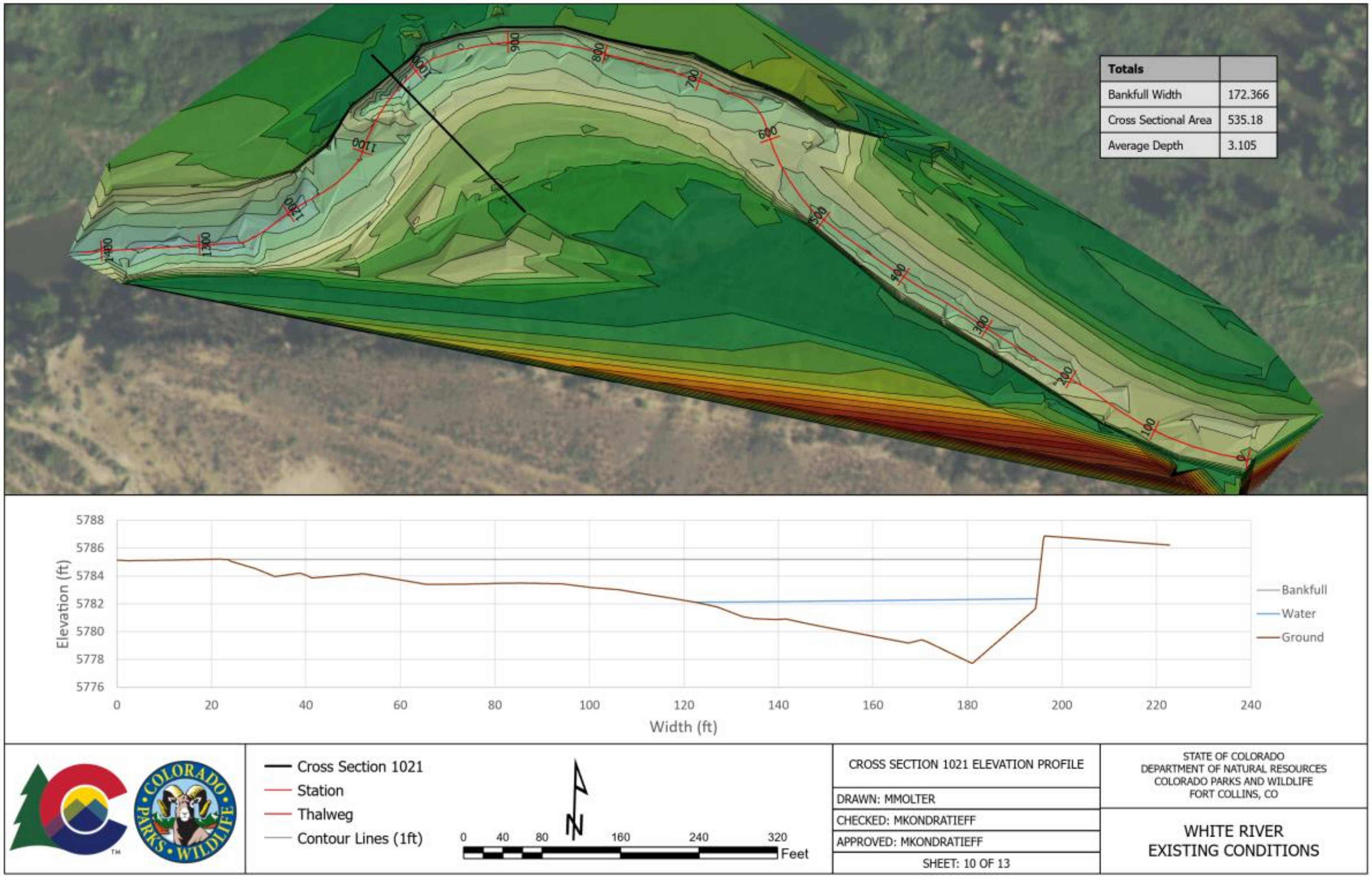


Figure B10. Location and profile graph for the cross section at station 1021.

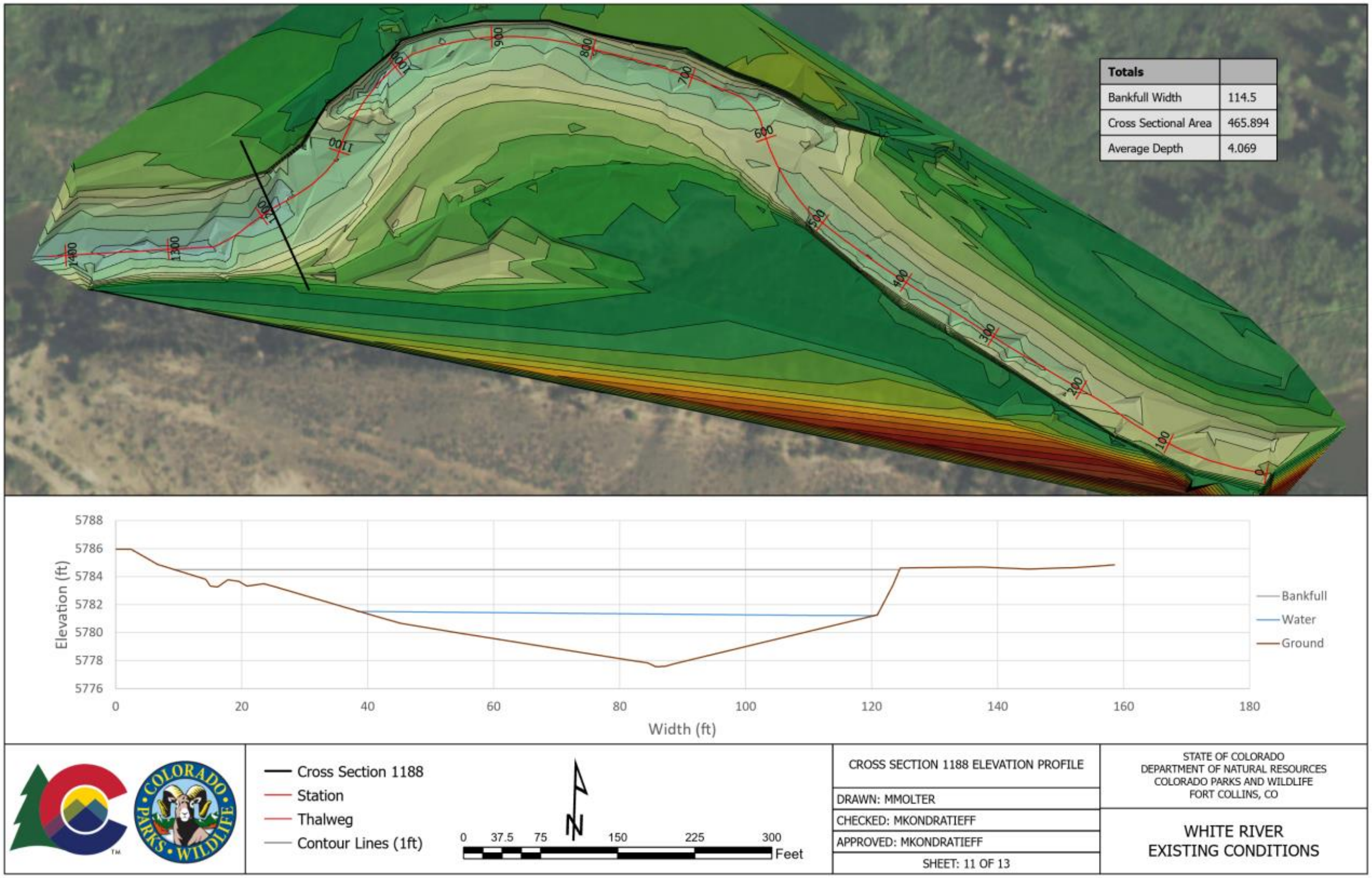


Figure B11. Location and profile graph for the cross section at station 1188.

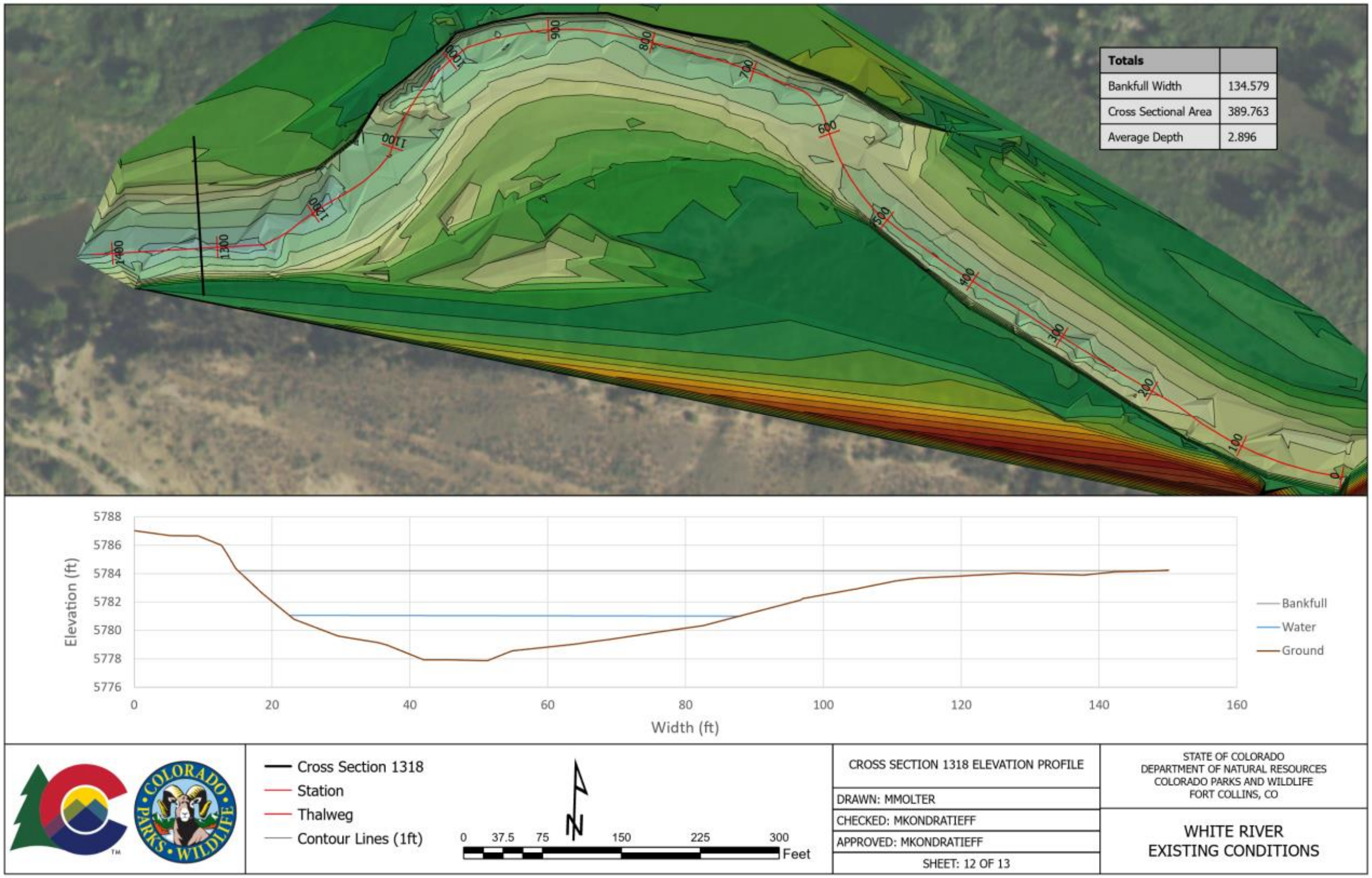


Figure B12. Location and profile graph for the cross section at station 1318.

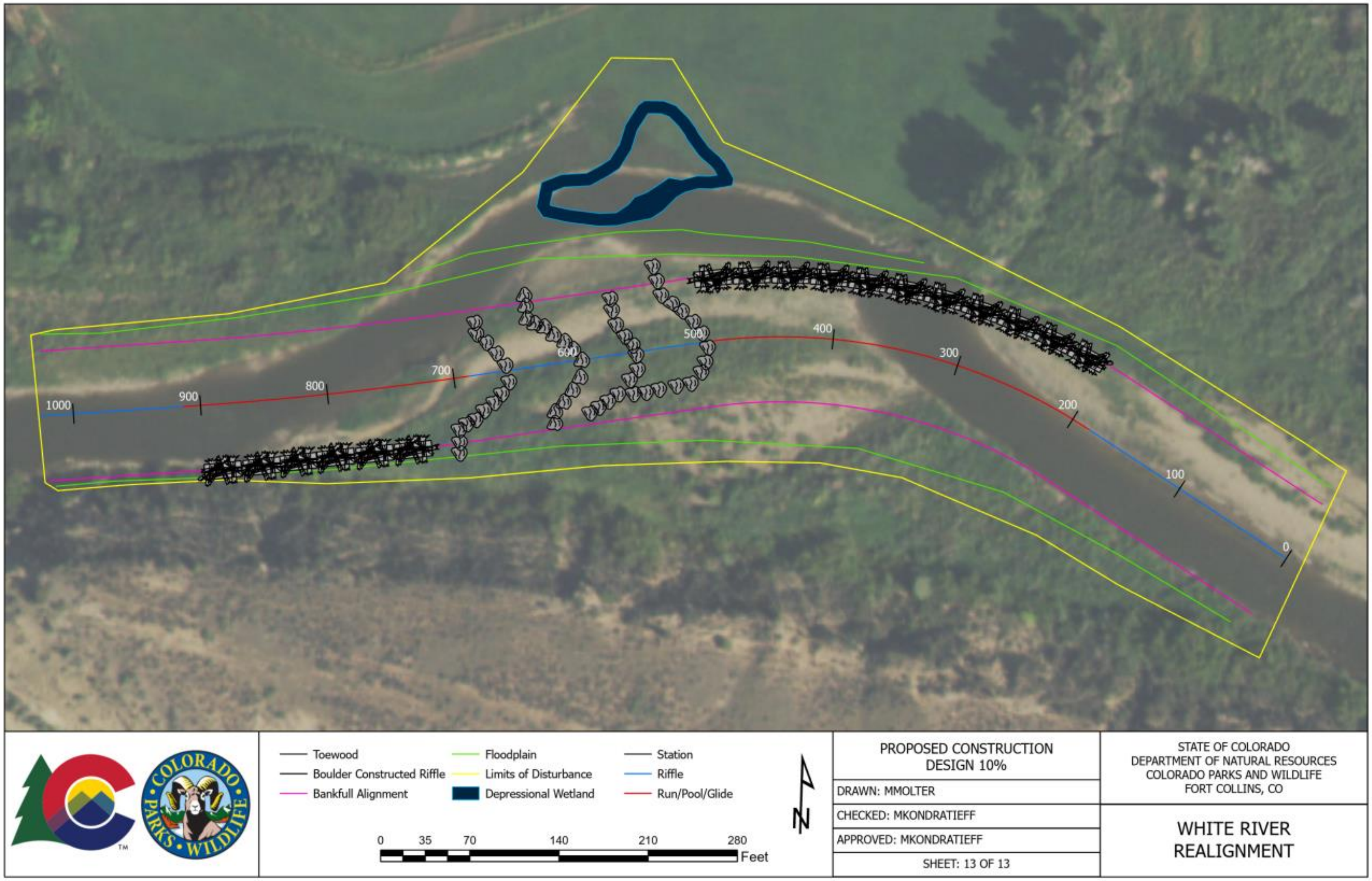


Figure B13. Conceptual design for channel realignment, including toewood bend and boulder constructed riffle.