Stream Habitat Investigations and Assistance

Federal Aid Project F-161-R25

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Federal Aid in Fish and Wildlife Restoration

Performance Report

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Aquatic Research Section

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The results of the research investigations contained in this report represent work of the authors and may or may not have been implemented as Colorado Parks & Wildlife policy by the Director or the Wildlife Commission.

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PERFORMANCE REPORT

State: Colorado

Project Number: F-161-R-25

Project Title: Stream Habitat Investigations and Assistance

Period Covered: July 1, 2018 through June 30, 2019

Principal Investigators: Matt C. Kondratieff and Eric E. Richer

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Project Objectives:

Job 1: Stream Restoration and Habitat Enhancement Studies

Need

Rivers and streams in Colorado have experienced substantial anthropogenic changes over the past 200 years. These changes were largely due to historic land use activities and water development, such as beaver trapping, placer and gravel mining, flow regulation, timber harvest and tie drives, and construction of roads and railroads (Wohl, 2011). Many streams have been channelized in an attempt to convey floods, protect infrastructure, and maximize crop production. Grazing of livestock in riparian areas has also led to accelerated bank erosion, loss of riparian vegetation, and impaired aquatic habitat. These impacts have degraded aquatic habitat and stream functions from the watershed to reach scales. Fortunately, stream restoration efforts show promise as a means to aid species recovery, improve water quality, and create new areas for wildlife habitat and recreational activities (Bernhardt et al., 2005). However, additional research on restoration methods and outcomes is needed to understand which techniques are most effective and sustainable.

Objectives

1. Survey and quantify salmonid populations at three project sites by June 30, 2019.
2. Survey salmonid habitat at three project sites by June 30, 2019.

Approach

Action #1:

- Level 1 Action Category: Data Collection and Analysis
- Level 2 Action Strategy: Research, survey or monitoring – fish and wildlife populations
- Level 3 Action Activities: Abundance determination; Age, size, and sex structure

Utilize Before-After Control-Impact (BACI) study designs to monitor and evaluate stream restoration and habitat enhancement projects. During summer and fall months, we will conduct electrofishing sampling to determine species composition, salmonid biomass, density, and individual fish lengths and weights in control and treatment sites. Fisheries data will be collected and/or analyzed from select pre- and post-treatment stream reaches with assistance from aquatic biologists and researchers. Project sites include the (1) Wason and LaGarita Ranches, Rio Grande River, (2) Twin Tunnels Project, Clear Creek, (3) Upper Arkansas River, (4) Middle Fork South Platte River, (5) Yampa River below Stagecoach Reservoir, and (6) Halfmoon Creek.

Action #1 Accomplishments:

Fish inventory surveys were conducted at five of the six sites listed above, including Clear Creek, Upper Arkansas River, Middle Fork South Platte River, Yampa River, and Halfmoon Creek with the goal of monitoring and evaluation of stream restoration and habitat enhancement projects. Electrofishing sampling was conducted during summer and fall months in cooperation with CPW biologists to determine species composition, salmonid biomass, densities, and individual fish lengths and weights in control and treatment sites. Analysis of fisheries data collected on the Rio Grande River is ongoing.

Rio Grande River

A large-scale habitat enhancement project was conducted on a 3.8-mile reach of the Rio Grande River flowing through the Wason Ranch near Creede, CO. Landowners believed that poor habitat conditions were responsible for declining trout quality and quantity over time. Project goals included: (1) improve fish quality (increase trout > 35cm TL), (2) improve fish quantity (increase trout density and biomass), (3) reduce bank erosion, (4) reduce width/depth ratio (i.e., increase river depths), (5) establish bedform features at correct spacing, (6) improve adult fish holding and overwinter habitat (i.e., develop deep pools) and (7) re-vegetate banks. After project completion in 2006, CPW has monitored trout and Giant Stonefly *Pteronarcys californica* response to habitat enhancements from 2008-2014. Giant Stonefly abundance was monitored because they provide an important food source for resident trout, are a riffle-dependent species, and are relatively easy to estimate abundance through exuviae counts. This study has unique value because it was conducted on a large river system, while most published habitat enhancement evaluations were conducted on smaller streams.

Research goals were: (1) to determine how the habitat project influenced trout population biomass (kg/ha), density (trout ≥15 cm TL/ha), and numbers of quality–sized trout (trout ≥35 cm TL/ha) and (2) to determine if river enhancement activities increased Giant Stonefly abundance on a reach-wide scale. Three reaches were identified for monitoring trout and four reaches for monitoring invertebrate response to varying intensities of habitat treatments. All reaches experienced the same historic land uses (over-grazing, water quality issues from mining, and logging impacts). The Upper Wason Reach (2.0-mile; heavy-treated) contains the most instream structures with frequent large, deeply-excavated pools. The Lower Wason Reach (1.8-mile; light-treated) consists mainly of randomly distributed boulders with fewer instream structures and deeply-excavated pools. The LaGarita Reach (2.4-mile; natural) and Airport Reach (0.8-mile) both contain no instream structures and serve as downstream and upstream controls, respectively. Topographic surveys for each study reach were conducted using GPS survey equipment and an ADCP to characterize habitat conditions for comparison. Fish sampling was conducted by electrofishing with two rafts equipped with throw electrodes. Data collected included fish population estimates based on mark/recapture techniques, fish size by relative abundance, age and growth (scales), and fish species composition data. Removal methods were used to estimate stonefly abundance in study reaches. Exuviae were collected and counted in 12 different 100-foot stations above (controls), within (treatment sections), and below (controls) the Wason Ranch study area. *Pteronarcys* abundance estimates collected as part of this Wason Ranch study were recently included in a larger regional study comparing spatial and temporal variation in Giant Stonefly emergence (biomass) and the importance of aquatic insect emergence to sustaining various components of healthy terrestrial and aquatic ecosystems (Walters et al., 2017). Field data survey and collection have been completed for fish, insects (*Pteronarcys*) and habitat (topographic surveys and pebble counts). Data analysis for trout, aquatic insects, and physical habitat is ongoing.

Clear Creek

Physical habitat characteristics of Clear Creek near Idaho Springs, Colorado, have been highly modified from historic conditions. The stream is generally confined along most of the stream corridor by a major Interstate highway (I-70) on one side and a historic railway grade on the other. As most of Clear Creek has been channelized and armored with riprap to accommodate infrastructure, there are very few locations with functional floodplains resembling historic conditions. The Twin Tunnels construction project was initiated by the Colorado Department of Transportation (CDOT). Once construction of the new tunnels was completed, a temporary frontage road was removed, providing a unique opportunity for riparian restoration within the I-70 corridor. The 0.4-mile riparian restoration and instream habitat project was completed in April 2015. Project goals were focused enhancing habitat for Brown Trout *Salmo trutta*, improving conditions and access for anglers, and restoring natural processes. Specific objectives included: removing armored riprap, improving floodplain connectivity by converting the existing single-stage channelized river to a nested, three-stage channel, establishing riparian vegetation, enhancing in-channel habitat features (e.g., spawning gravel substrate within enhanced glides and excavating deep lateral scour pools). Baseline monitoring of fish populations including fish population estimation, length-frequency distribution, and species composition were collected for a minimum of two years prior to construction activities. Fish population monitoring will continue for a total of five years (2015-2019) to evaluate project effectiveness.

Pre-construction baseline data were collected during the fall of 2012, 2013, and 2014 at two locations: upstream and downstream of the Doghouse Bridge at proposed high- and low-intensity habitat treatment sites. Pre-construction baseline data were collected at the high-intensity (two years) and low-intensity (three years) treatment sites. Fish sampling surveys established fish population composition, fish age-classes/sizes (length-frequency analysis), fish population size (number/mile), and fish biomass (lbs/acre) for populations within the project reach. Project effectiveness monitoring and analysis was based on data for Brown Trout only since they are wild and self-sustaining population (not stocked), a popular game species for anglers, and fairly robust to other confounding variables such as whirling disease since Brown Trout are more resistant to whirling disease than Rainbow Trout *Oncorhynchus mykiss*.

The high-intensity treatment site is an approximately 1,300-ft long stream segment upstream of the Dog House Bridge. Primary treatments within this site consisted of riprap removal and removal of excess bank material to create a new flood plain and shape a new active channel that would align with the current channel-forming discharge (bankfull Q). This involved conversion of the existing highly-confined, channelized and riprapped, single-stage Rosgen F-stream type (confinement ratio <1.4; channel slope < 2%) to a moderately-confined, three-stage Rosgen Bc-stream type (confinement ratio 1.4-2.2; channel slope= 0.9%). Confinement was defined as the width of the valley at two times the average depth at bankfull (bkf) elevation divided by the bkf channel width. The pre-construction single-stage channel was converted to a post-construction three-stage channel with functional floodplain. The average confinement pre-construction within the high-intensity treatment reach was 1.2 (Figure 1.1; highly-confined channel). The average confinement post-construction was increased to nearly 2.0 (Figure 1.2; moderately-confined channel) due to the removal of riprap and expansion of floodplain area by removal of fill material. Other treatments within the high-intensity site included: addition of 153 habitat boulders (65% of total for the project or 153 of 234 total), installation of eight boulder structures (J-hooks, boulder half vanes, and cross vanes; 89% of total for the project or eight of nine total), 2,458 linear feet (lf) of boulder toe (91% of total for the project or 2,458 lf of 2,708 lf total), 10 constructed pools (71% of total number of pools for the project or 10 out of 14 total), 5,420 square feet (sf) of point bar development (100% of total for the project), and 18,775 sf of new floodplain (or "riparian bench") development (100% of total for the project).

The low-intensity treatment site consisted of an approximately 650-ft long stream segment located downstream of the Dog House Bridge. Unlike the high-intensity site, the channel geometry was not altered in this reach (no removal of riprap or excess bank material, conversion of single-stage to three-stage channel, point bar development, or riparian bench development). The average confinement for this reach before (Figure 1.3) compared with after (Figure 1.4) the project did not change (1.2). The low-intensity treatment site remained highly confined, riprapped, and constrained between two roadways. Treatments in the low-intensity segment included addition of habitat boulders (35% of total for the project or 81 of 234 total), installation of one boulder structure (cross-vane; 11% of total for the project or one of nine total), 250 lf of boulder toe (9% of total for the project or 250 lf of 2,708 lf total), and four constructed pools of which three were located off the main channel in a side-channel (Figures 1.5 and 1.6; 29% of total number of pools for the project or four out of 14 total). No point bar development or riparian benches were constructed within the low-intensity treatment segment.

Four years of post-project monitoring of Brown Trout populations suggest that habitat treatments have resulted in an increase in Brown Trout density and biomass related to the fish habitat improvements in both high- (Figures 1.7 and 1.8) and low-intensity treatment sites (Figures 1.9 and 1.10). However, the magnitude of change within the high-intensity treatment site was higher for the total number of Brown Trout per mile (Table 1.1; 160% increase) compared with the low-intensity treatment site (Table 1.1; 77% increase). Brown Trout biomass, the total pounds of Brown Trout per area, increased even more within the high-intensity treatment site (Table 1.1; 408% increase) as compared with the low-intensity site (Table 1.1; 59% increase). This suggests that the Brown Trout population within the high-intensity site not only had more fish per linear distance (density increase) than the low-intensity site, but also the population within the high-intensity site experienced a shift toward larger, adult fish within the high-intensity treatment site (much larger increase in total Brown Trout biomass) as compared with the low-intensity treatment site. The final year of post-construction monitoring will be completed in 2019.

Figure 1.1. Pre-construction photo of the highly-confined "high-intensity" stream site as part of the Twin Tunnels project on Clear Creek.

Figure 1.2. Post-construction photo of the moderately-confined "high-intensity" stream site as part of the Twin Tunnels project on Clear Creek.

Figure 1.3. Pre-construction photo of the downstream "low-intensity" stream site as part of the Twin Tunnels project on Clear Creek.

Figure 1.4. Post-construction photo of the downstream "low-intensity" stream site as part of the Twin Tunnels project on Clear Creek.

Figure 1.5. Pre-construction photo of the downstream “low-intensity” stream site (side-channel treatment) as part of the Twin Tunnels project on Clear Creek.

Figure 1.6. Post-construction photo of the downstream “low-intensity” stream site (side-channel treatment) as part of the Twin Tunnels project on Clear Creek.

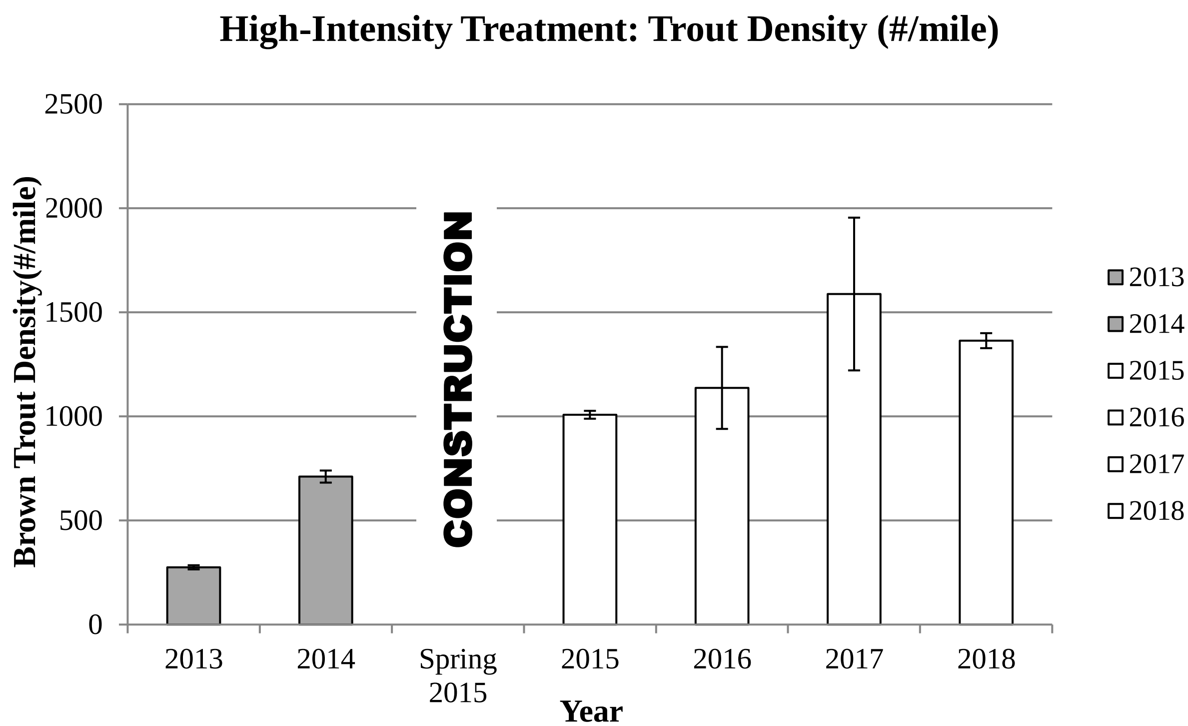

Figure 1.7. Brown Trout density (number/mile) within the "high-intensity" treatment site for pre- (shaded; 2013-2014) and post- (white; 2015-2018) construction years.

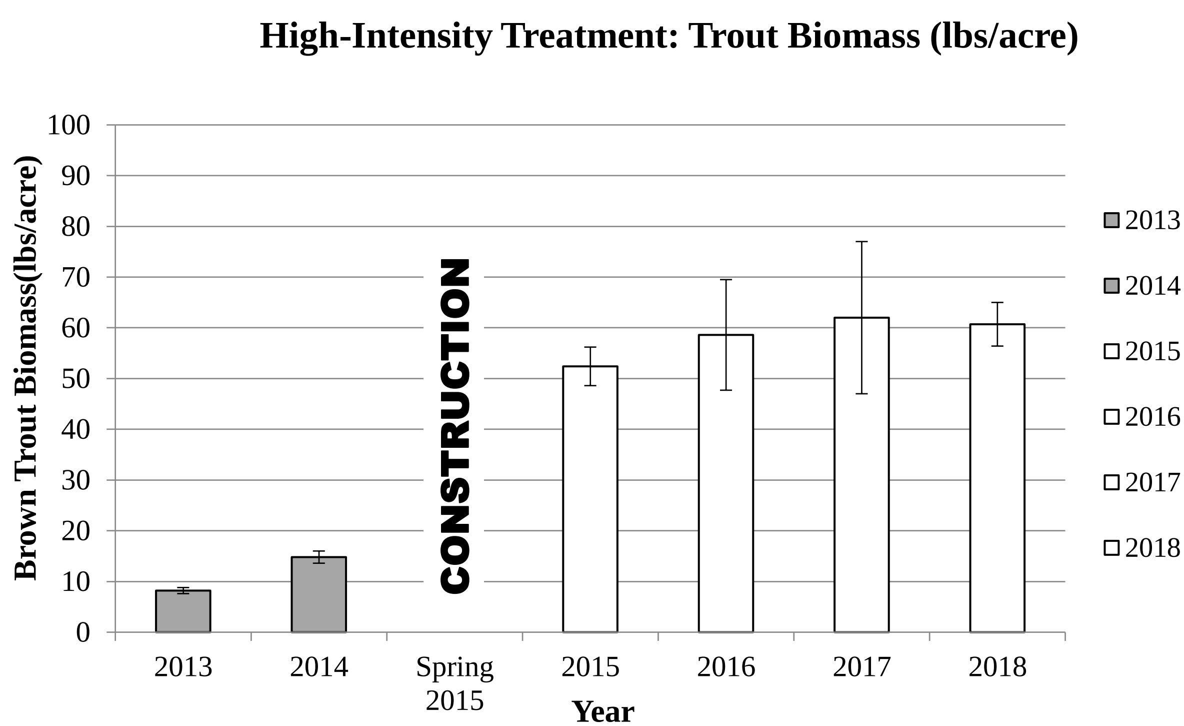

Figure 1.8. Brown Trout biomass (lbs/acre) within the "high-intensity" treatment site for pre- (shaded; 2013-2014) and post- (white; 2015-2018) construction years.

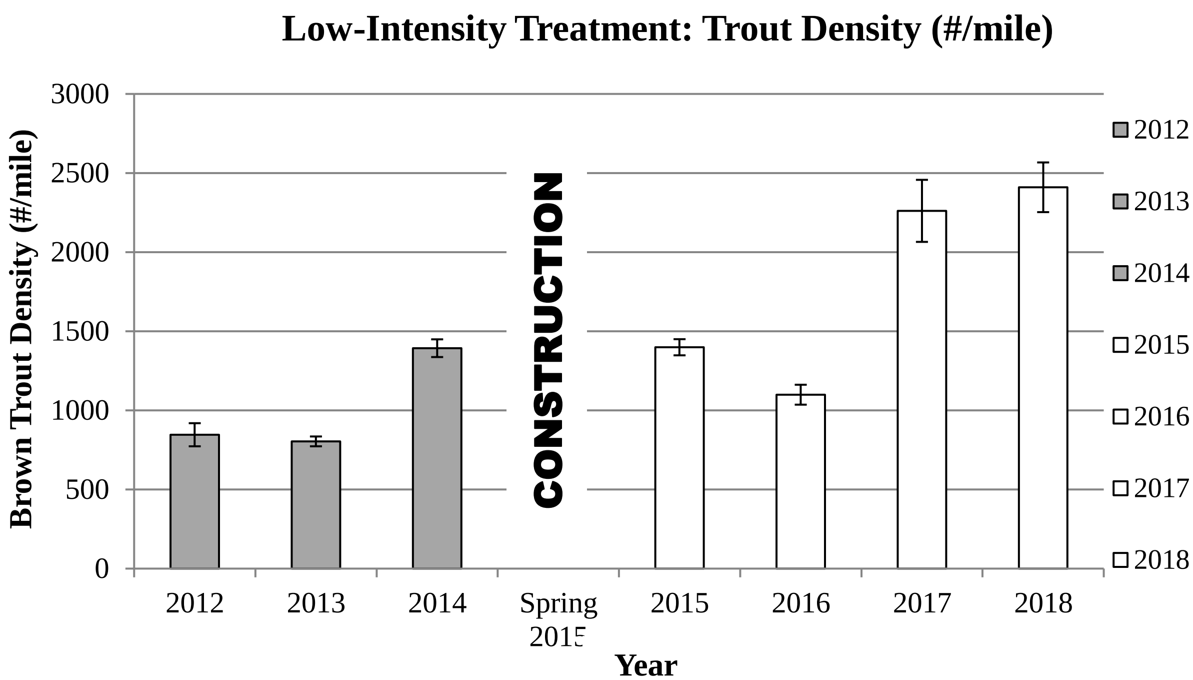

Figure 1.9. Brown Trout density (number/mile) within the "low-intensity" treatment site for pre- (shaded; 2013-2014) and post- (white; 2015-2018) construction years.

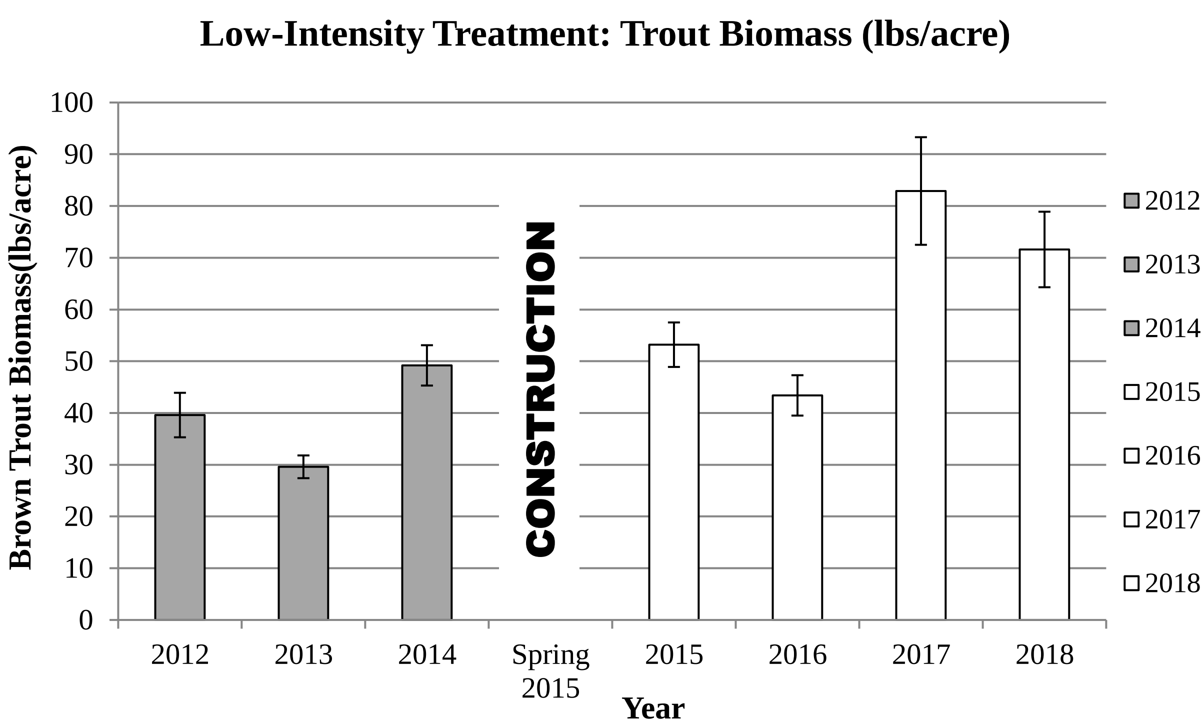

Figure 1.10. Brown Trout biomass (lbs/acre) within the "low-intensity" treatment site for pre- (shaded; 2013-2014) and post- (white; 2015-2018) construction years.

Table 1.1. Summary of Brown Trout density (n≥150 mm TL/mile) and biomass estimates (lbs/acre) and statistics for the heavy-treated (Upper Reach) and lightly-treated (Lower Reach) of Clear Creek, Twin Tunnels stream restoration project. 95% confidence intervals for density and biomass estimated are shown in parentheses. Pre-construction and post-construction surveys were conducted during fall 2012, 2013, and 2014 and fall 2015, 2016, 2017 and 2018, respectively.

Year	High-Intensity: Upper Reach		Low-Intensity: Lower Reach	
	Density (n/mile)	**Biomass (lbs/acre)**	**Density (n/mile)**	**Biomass (lbs/acre)**
	Pre-Habitat Improvement Treatment Period			
2012	N/A	N/A	846 (773-919)	39.6 (35.3-43.9)
2013	275 (265-285)	8.2 (7.6-8.8)	804 (773-835)	29.6 (27.3-31.8)
2014	711 (682-740)	13.6 (13.6-16.0)	1,393 (1337-1449)	49.2 (45.3-53.1)
Average	**493**	**11.5**	**1,014**	**39.5**
	Post - Habitat Improvement Treatment Period			
2015	1,008 (989-1027)	52.4 (48.7-56.2)	1,399 (1348-1450)	53.2 (48.9-57.5)
2016	1,137 (940-1,334)	58.6 (47.8-69.5)	1,099 (1,036-1,162)	43.4 (39.6-47.3)
2017	1,588 (1,221-1,955)	62.0 (47.0-77.0)	2,261 (2,065-2,457)	82.9 (72.5-93.3)
2018	1,364 (1,328-1,400)	60.7 (56.5-65.0)	2,410 (2,253-2,567)	71.6 (64.3-78.9)
Average	**1,274**	**58.4**	**1,792**	**62.8**
% Change (Magnitude)	**+158.0% (+2.6×)**	**+408.0% (+5.1×)**	**+77.0% (+1.8×)**	**+59. 1% (+1.6×)**

Preliminary results from fish population monitoring for the Clear Creek project were also presented by Kondratieff et al. (2019).

Yampa River

With some of the highest trout densities and biomass anywhere in Colorado, the Yampa River downstream of Stagecoach Reservoir is one of the most popular tailwater trout fishing destinations in the United States. Bank failure due to trampling from angler use, loss of stabilizing vegetation, and non-functional, in-channel boulder check dam features were the primary causes of habitat degradation and loss of trout productivity over time. Limiting factors to trout habitat included spawning habitat (exceedingly shallow depths or high concentrations of fine sediment), cover for adults (few undercut banks, deep pools, over-hanging bank vegetation, and large wood), and limited in-channel habitat complexity (in-channel structure to create resting areas and increase habitat complexity). Many of these limiting factors were addressed by a 0.25-mile habitat enhancement project that was completed in 2013. Target species for habitat enhancement include Rainbow Trout and Brown Trout.

Fish sampling was conducted for 14 years prior to habitat enhancement, providing a robust baseline dataset for post-project comparison. The fourth year of post-construction fish sampling was conducted in the fall of 2018 as part of a five-year monitoring study. Monitoring data will be used to evaluate fish population estimates, length-frequency distributions, and species composition in response to habitat enhancement activities. Since this is a unique tailwater reach, no suitable control site was located for comparison purposes. Therefore, habitat and fisheries response will be monitored as a before-after comparison only.

In 2016, a team of aquatic researchers (Eric Fetherman and Matt Kondratieff) and an aquatic biologist (Bill Atkinson) combined efforts to expand the small-scale monitoring of the Stagecoach Tailwater Habitat Project into a larger research project that includes evaluating survival of H×H Rainbow Trout in the Yampa River through a range of habitat conditions, manipulations of a resident Brown Trout population, and stocking strategies. Ultimately, results from this study will inform the management goal of re-establishing a wild Rainbow Trout fishery in the larger 7.7-mile channel reach between Lake Catamount and Stagecoach Reservoir (Appendix A). As such, this project has three primary objectives. The first is to determine if there is a length-specific effect on survival due to river habitat condition (restored versus impaired reaches). To accomplish this objective, the annual apparent survival rates of catchable and fingerling-size *M. cerebralis*-resistant Rainbow Trout will be estimated for fish stocked into both restored and impaired reaches of the Yampa River. The second objective of this study is to determine if large-scale Brown Trout removal will affect annual apparent survival rates of both catchable (competition) and fingerling (competition and predation) Rainbow Trout. To accomplish this objective, Brown Trout will be removed from the Yampa River on an annual basis during the study period. The third objective of this study is to determine if a reduced stocking density results in similar annual survival rates in fingerling Rainbow Trout, with potential implications for hatchery management. To meet this objective, the fingerling Rainbow Trout stocking density will be reduced in the third year of the study to less than half of what had been stocked in the two years previous.

Fish stocking began in 2017 and was completed in 2019. Fish surveys (electrofishing) began in 2017 and will continue until the fall of 2020. For additional details regarding our fish stocking, brown trout removal, and electrofishing surveys used to generate survival and population estimates as well as preliminary fish survey results, see Fetherman et al. (2018).

Arkansas River

The Upper Arkansas River Habitat Restoration Project near Leadville, Colorado, was implemented in 2013-2014 to address degraded fish habitat. Historic mining activities severely impaired water quality within the upper watershed and limited trout population abundance and growth rates in the Upper Arkansas River. Following the implementation of point and non-point source water quality remediation projects, fish populations have recovered to a degree. Fisheries biologists determined the next steps in recovering trout populations would come from addressing fish habitat limitations. Fish monitoring sites were established within project reaches to measure the effectiveness of habitat restoration. This project is unique in that some fish sampling sites have more than 16 years of baseline data collected prior to project implementation. These data provide baseline information for comparison with post-construction monitoring.

Post-construction fish surveys were initiated in 2014 following completion of instream construction activities and continued annually for five consecutive years. Fish population estimates, biomass, length-frequency distributions, and species composition were generated from fish surveys conducted on 14 sites in August 2018. Monitoring sites were grouped by four categories: Upstream Control, Private Impact, Public Impact, and Public Control. Upstream Control sites were located above the California Gulch Superfund Site and Leadville Mine Drainage Tunnel on the Arkansas River and East Fork Arkansas River. There is also an

Upstream Control site on the Lake Fork below Turquoise Dam. There were two impact sites on the Arkansas River and three impact sites on the Lake Fork located on private property. There were three impact and control sites located on property with public fishing access. These six sites with public fishing access were located on the lower five miles of the Arkansas River within the California Gulch Superfund Site.

An objective of habitat restoration was to increase fish population metrics by at least 10% over baseline conditions by 2018 or five years post-construction (Stratus Consulting, 2010). To evaluate effectiveness of the habitat restoration project, fish population estimates were evaluated using a BACI study design. The pre-construction period started in 2006 and ended on the last survey that occurred prior to habitat restoration at a particular site. CPW was responsible for restoring approximated five miles of the Arkansas River on properties with public fishing access, but has conducted fish population monitoring on both public and private project sites. Construction of the CPW project occurred during 2013-2014. Habitat restoration on private property began in 2012 and concluded in 2016.

To evaluate fishery objectives for habitat restoration, changes in adult Brown Trout population metrics by site category were presented in Table 1.2. Private Impact sites exhibited the lowest change in average density (1%), but also exhibited the second highest change in average biomass (26%). The change at Private Impact sites was driven primarily by the large increases in density and biomass at a single site located downstream of the confluence with California Gulch. Public Impact sites exhibited the greatest change in average density (18%) and biomass (35%). The change in density at Public Impact sites was only 5% greater than the observed change at Public Control sites, but the increase in biomass was 29% greater at Public Impact sites when compared to Public Control sites. Across all sites, average Brown Trout density increased by 5% and average biomass increased by 16%, indicating that fish population and health metrics have continued to improve following habitat restoration.

Table 1.2. Preliminary results for fish population monitoring associated with the Upper Arkansas River Habitat Restoration Project. The average percent change in Brown Trout *Salmo trutta* density and biomass between before and after periods presented for site categories. Changes greater than +10% were highlighted in green and changes less than 10% were highlighted in yellow.

Category	**Sites (n)**	**Change**	
		Density	**Biomass**
Upstream Control	3	9%	12%
Private Impact	4	1%	26%
Public Impact	3	18%	35%
Public Control	3	13%	6%
All Sites	13	5%	16%

The overall increase in Brown Trout density and biomass within the boundaries of the California Gulch Superfund Site was illustrated in Figures 1.11 and 1.12, respectively. The 10-year moving average was displayed on both figures to illustrate site-wide trends through time. Both density and biomass showed a marked increase around the year 2000, presumably in response to

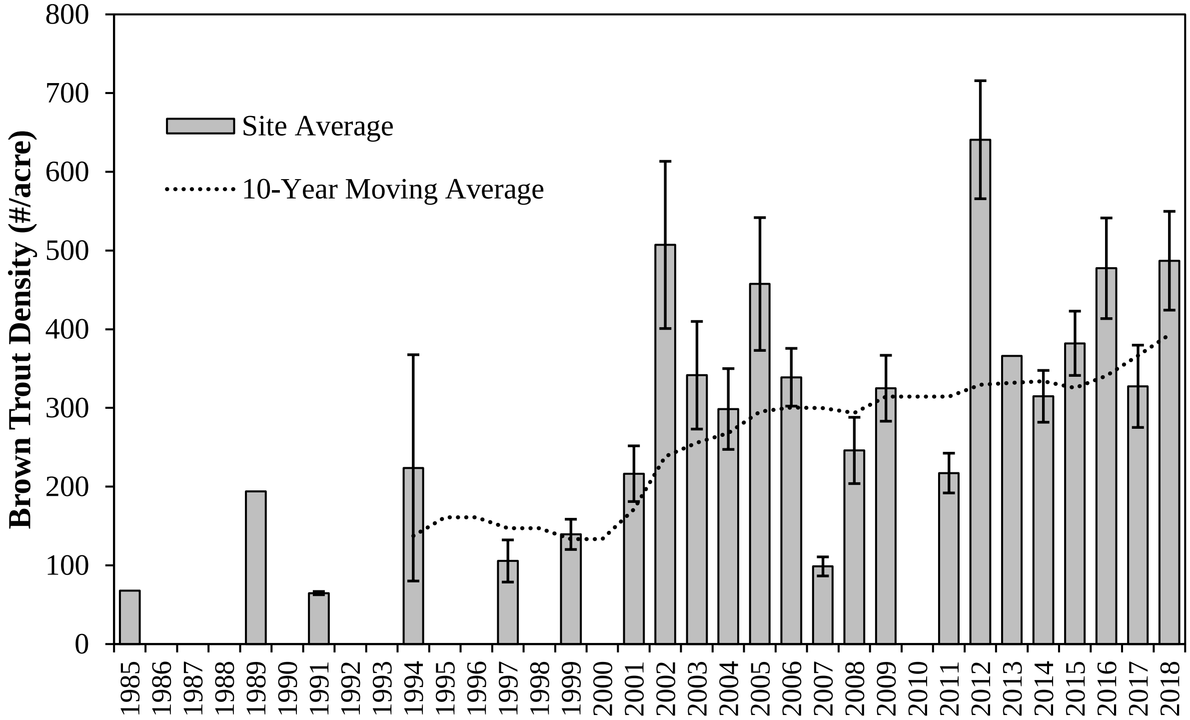

Figure 1.11. Average Brown Trout density (#/acre) by year for all monitoring sites located within the California Gulch Superfund Site. Error bars represent the standard error.

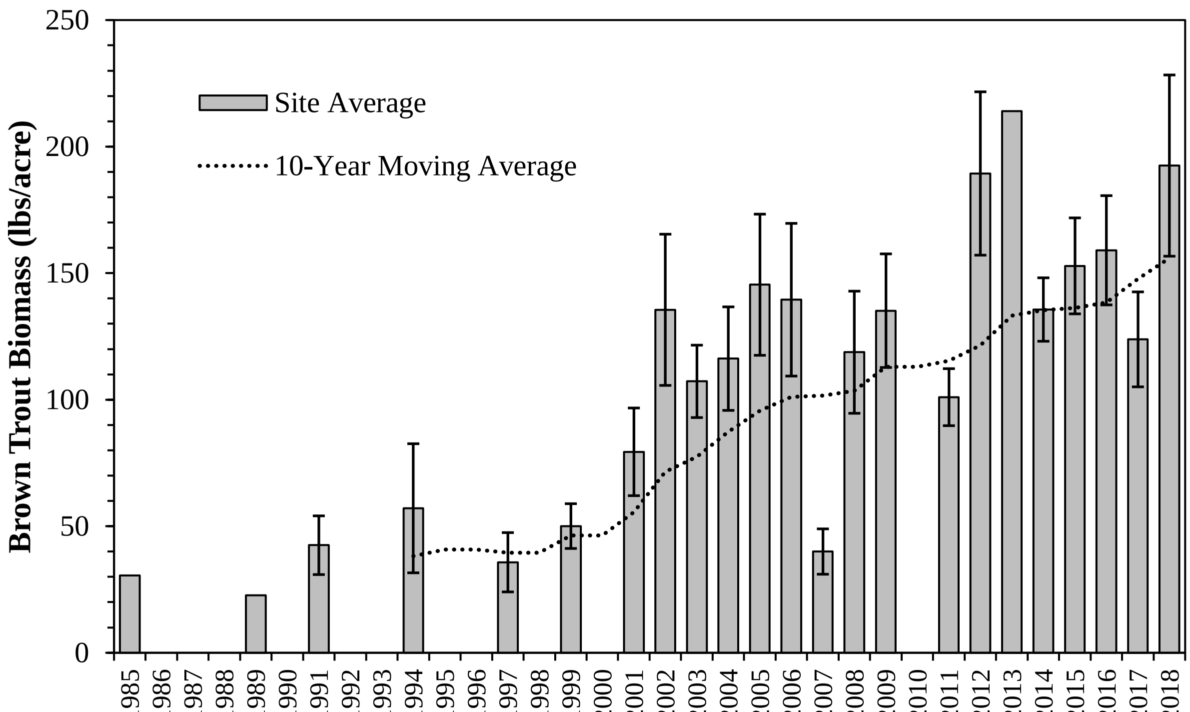

Figure 1.12. Average Brown Trout biomass (lbs/acre) by year for all monitoring sites located within the California Gulch Superfund Site. Error bars represent the standard error.

improved water quality associated with remediation activities. The increase in fish density appeared to plateau around 2006, and then increased in 2016 following completion of habitat restoration activities. Fish biomass exhibited a relatively constant and linear increase since 2000, indicating the fish health has continued to improve in response to both improved chemical and physical habitat conditions. These site-wide trends in Brown Trout density and biomass were both encouraging as they suggest that ecosystem health has continued to improve in the Upper Arkansas River.

Additional fish surveys are scheduled for 2020 (year-7) and 2023 (year-10) to support long-term evaluation of the project. Preliminary results from fish population monitoring were presented by Richer et al. (2019b) and synthesized in Richer (2019).

South Platte River

The Buckley Ranch Habitat Project was conducted because this site has good public access, active riparian grazing management enforcement, and adequate stream flows. The project area is managed by CPW and is part of the Upper Spinney SWA. Treatments were prescribed to restore natural river processes, reduce riverbank erosion and enhance trout habitat. Specifically, the following habitat limitations were identified: over widened channel, shallow water depths, lack of adult fish instream and overhead cover (vegetative cover and deep pools), actively eroding vertical banks, lack of over-winter trout habitat, and lack of instream habitat complexity. The following habitat treatments were applied in response to the limitations listed above: revegetation (seeding uplands and planting willow stubs), reducing river channel width with sod blocks, imported cobble and small boulders, pool excavation, boulder vortex structures, large boulders used to armor outside curves of pool areas, and willow bundles used for bank revetment installed along the outside curves of pool areas. The total length of stream restored was 0.4 miles and the treatment approach involved using predominantly large boulders and rock. Pre-project trout biomass data were collected for two years prior to construction in the project area (boulder-treated) and in a control (control-untreated) reach located downstream of the project area.

After restoration work was completed, trout population metrics have been monitored for 26 non-consecutive years following habitat improvement work in both treatment and control reaches. Biomass increased in the treatment area during the years following restoration work, with restored-reach biomass almost tripling compared to pre-treatment biomass nine years post-construction. A control reach located downstream of the project area showed a decrease in trout biomass with little evidence of trout population recovery over the monitoring period. In 2007, another section of the Middle Fork of the South Platte River was identified as a candidate for restoration and named the Badger Basin Habitat Project. This reach was located about 0.13 miles upstream of the Buckley Ranch Habitat Project reach. The project goals were similar to those identified in the Buckley Ranch Project, but the approach to restoration involved using treatments that utilized predominantly large wood (such as toe wood, log vanes, and horizontal log treatments). Since completion of the 1.5 mile long Badger Basin Habitat Project in 2010, river restoration and trout-habitat enhancement treatment methods (i.e., boulder-treated vs. toe wood-treated) are being evaluated with a long-term BACI study on the South Platte River and Middle Fork South Platte River in South Park, Colorado. Four long-term monitoring sites include an upstream reference (D. Tomahawk SWA), toe wood-treated (C. Badger Basin SWA), boulder-treated (B. Buckley Ranch on Upper Spinney SWA), and a downstream untreated control site (A. Buckley Ranch on Upper Spinney SWA) (Figure 1.14). The control-untreated site was selected since the habitat conditions within this site were representative of impaired habitat conditions found in proposed habitat restoration sites and within the surrounding watershed area. The reference site was selected based on historic fish population data since this site had the highest Brown Trout biomass in the watershed while still within the same geomorphic setting as the treatment sites (same valley and stream types based on the Rosgen classification method). Fisheries metrics have been collected at the boulder-treated and control-untreated sites since 1990 (28 year data set). Fish population data include population estimates (density), biomass, length-frequency distributions, and species composition collected during both spring and fall seasons. All fish sampling results presented here were collected during the fall season, typically from late-September to early October. Monitoring is being conducted as part of a long-term, nearly 30 year effort to measure the effectiveness of different approaches to fish habitat enhancement. Partial results related to Brown Trout biomass as a function of habitat conditions (treatment type, reference, and untreated-control) are as follows.

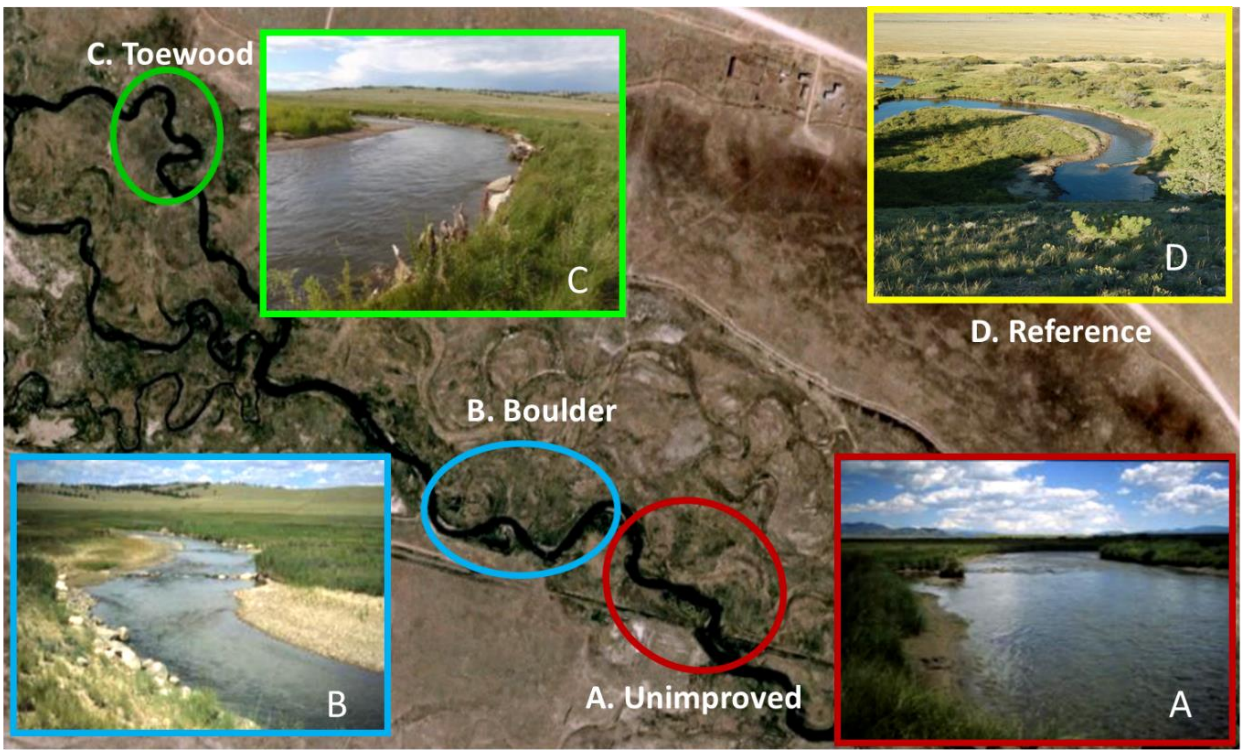

Figure 1.14. Four monitoring sites used to evaluate the effectiveness of different restoration approaches (toe wood-treated vs boulder-treated) in South Park, Colorado. Long-term monitoring includes fish population metrics from treated (B and C) and untreated (A and D) sites. Reference reach (D) is not depicted in the aerial photo and is located approximately 13 miles upstream of study sites A, B, and C.

The following results are pre- versus post-project Brown Trout biomass estimates from the boulder-treated habitat project compared to the control-untreated reach. The pre-project monitoring period includes two years (1990 and 1991) and serves as baseline data for the pre-treatment condition. The post-project monitoring period for the boulder-treated (Buckley Ranch

Habitat Project) and control-untreated reaches extends from 1992 to 2018 (26 years). After project completion, Brown Trout biomass increased 56% in the boulder-treated reach as compared to the baseline condition over the long term (26 years of post-project monitoring). For the same time period, Brown Trout biomass declined 53% in the control-untreated reach as compared to the initial baseline, pre-treatment condition.

After project completion, the boulder-treated reach averaged 32% higher Brown Trout biomass than the control-untreated reach for the length of the monitoring period. Brown Trout biomass estimates from the boulder-treated reach exceeded the control reach for every year of post-project monitoring. Within a given year, paired comparisons of post-project Brown Trout biomass averaged 1.8 times higher for boulder-treated over control-untreated (183%; range 10-472%) (Figure 1.15).

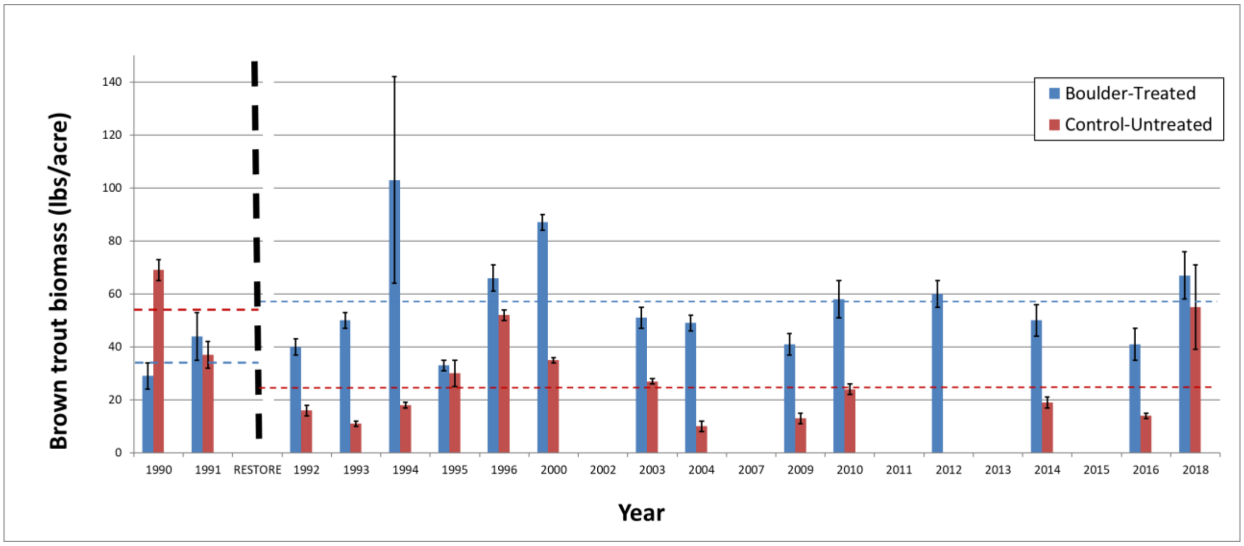

Figure 1.15. Brown Trout biomass (lbs/acre) plus 95% C.I.s collected from boulder-treated and downstream control-untreated sites. Pre-treatment baseline data were collected for two years in 1990 and 1991. Post-treatment data were collected from 1992 until the present.

The following results are post-project Brown Trout population biomass estimates from the toe wood-treated habitat project compared to the control-untreated reach. No pre-treatment data were collected prior to the construction of the toe wood-treated reach so no pre- versus post-project results are available. The post-project monitoring period for the toe wood-treated project reach (Badger Basin Habitat Project) extends eight years from 2010 to 2018.

After project completion, the toe wood-treated reach averaged 34% higher Brown Trout biomass than the control-untreated reach for the extent of the monitoring period. Brown Trout biomass estimates from the toe wood-treated reach exceeded the control reach every year of monitoring. Within a given year, paired comparisons of post-project Brown Trout biomass averaged 1.7 times higher for toe wood-treated over control-untreated (173%; range 40-245%) (Figure 1.16).

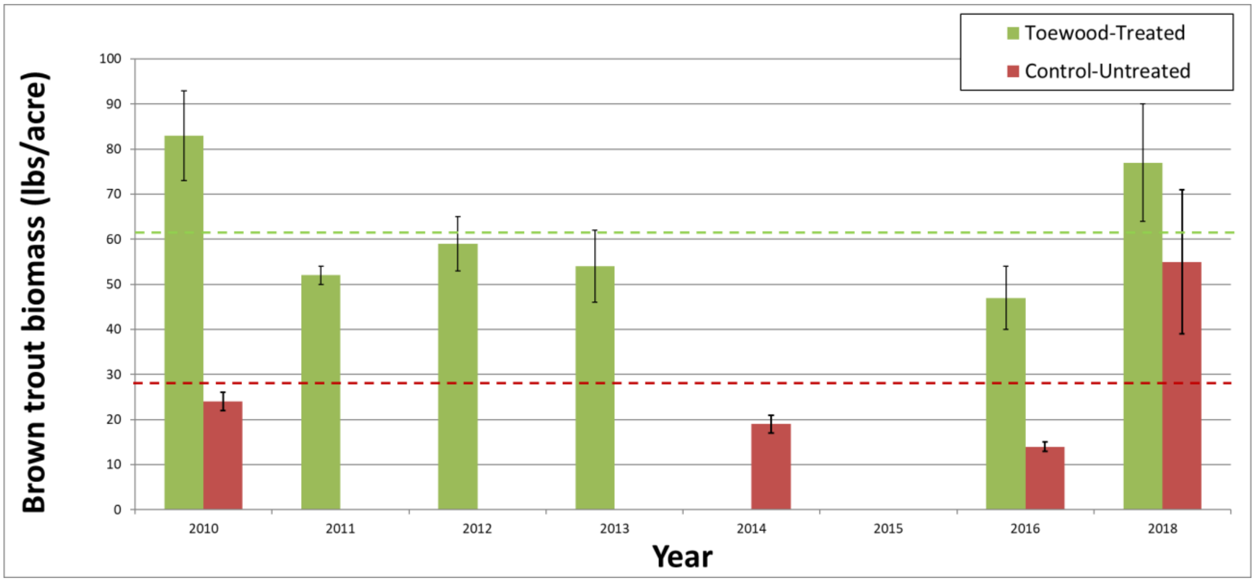

Figure 1.16. Brown Trout biomass (lbs/acre) collected from toe wood-treated and downstream control-untreated sites. Post-treatment data were collected from 2010 until the present.

The following results are post-project Brown Trout population biomass estimates from the toe wood-treated habitat project compared to the boulder-treated reach. No pre-treatment data were collected prior to the construction of the toe wood-treated reach so no pre- versus post-project results are available. The post-project monitoring period for the toe wood-treated project reach (Badger Basin Habitat Project) extends eight years from 2010 to 2018.

After project completion, the toe wood-treated reach averaged 7% higher Brown Trout biomass than the boulder-treated reach for the length of the monitoring period. Brown Trout biomass estimates from the toe wood-treated reach exceeded the boulder-treated three out of four monitoring occasions for which we have paired data. Within a given year, paired comparisons of post-project Brown Trout biomass averaged 18% higher for toe wood-treated over boulder treated (18%; range -2-43%) (Figure 1.17).

The following results are post-project Brown Trout population biomass estimates from the toe wood-treated habitat project compared to the reference reach. No pre-treatment data were collected prior to the construction of the toe wood-treated reach so no pre- versus post-project results are available. The post-project monitoring period for the toe wood-treated project reach (Badger Basin Habitat Project) extends eight years from 2010 to 2018.

After project completion, the reference reach averaged 107% higher Brown Trout biomass than the toe wood-treated reach for the extent of the monitoring period. Brown Trout biomass estimates from the reference reach exceeded the toe wood-treated site every year. Within a given year, paired comparisons of post-project Brown Trout biomass averaged 1.9 times higher for reference over toe wood-treated (194%; range 46-460%) (Figure 1.18).

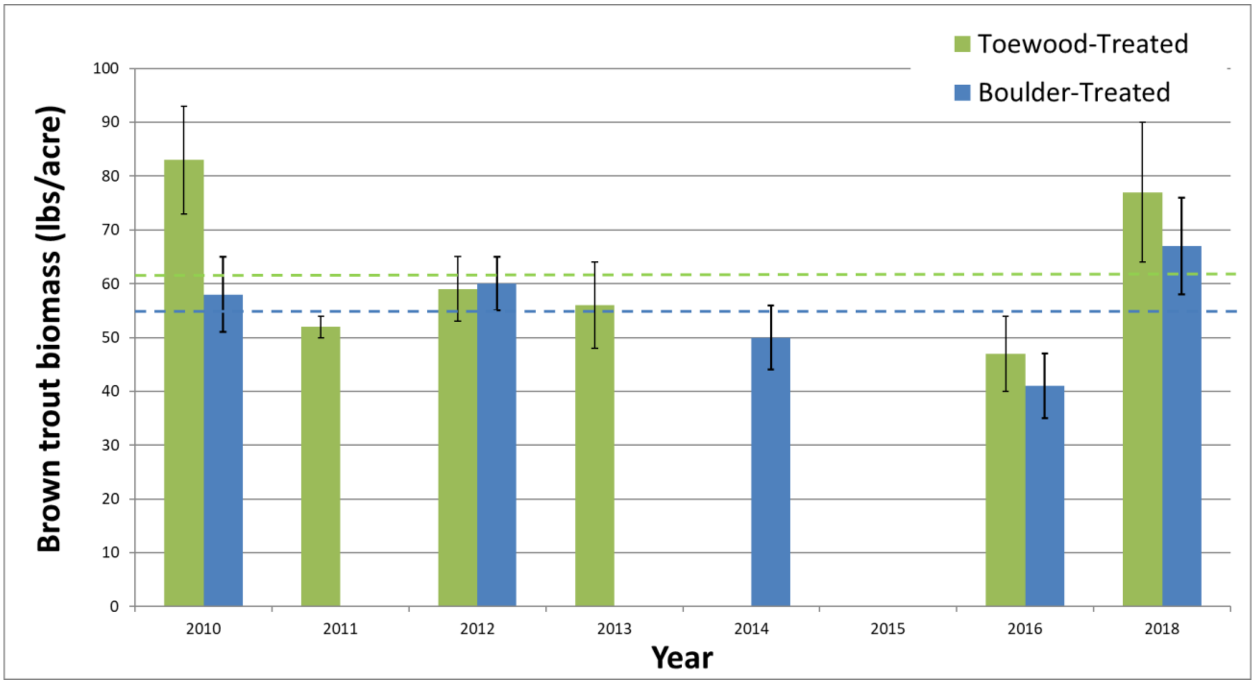

Figure 1.17. Brown Trout biomass (lbs/acre) collected from toe wood-treated and boulder-treated sites. Post-treatment data were collected from 2010 until the present.

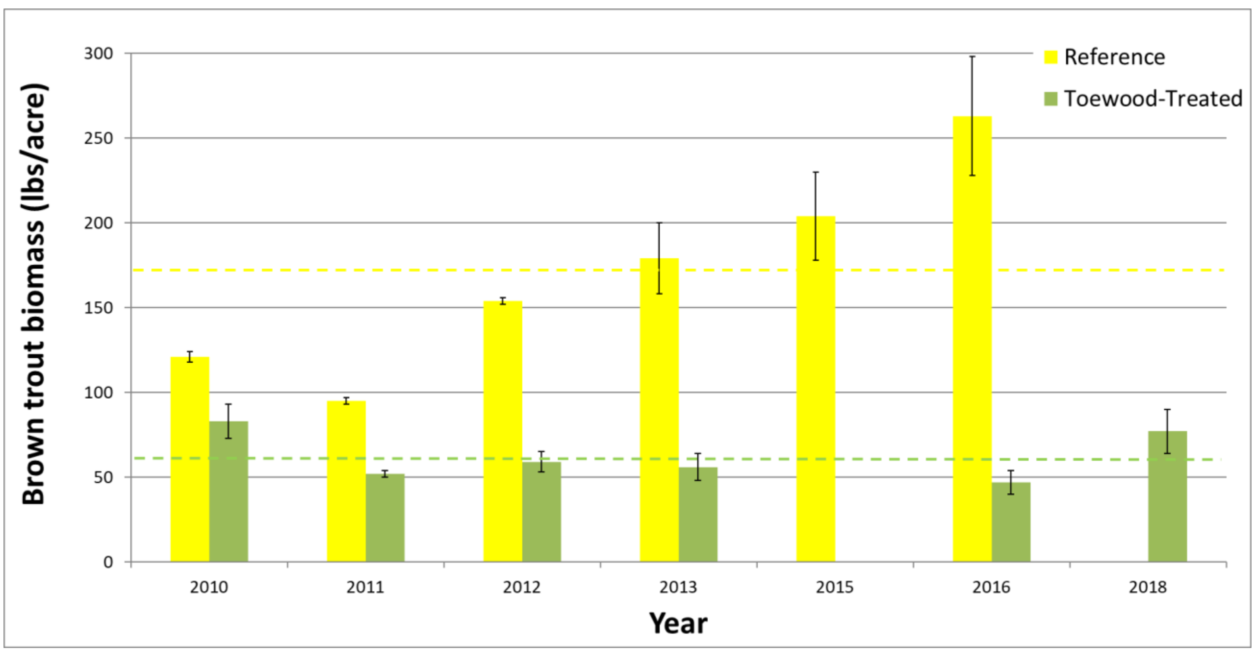

Figure 1.18. Brown Trout biomass (lbs/acre) collected from toe wood-treated and reference sites. Post-treatment data were collected from 2010 until the present.

A common concern among fish managers and anglers is that the toe wood treatment (combination of adding large wood and excavating deep, slower velocity pools) might provide habitat conditions more favorable to White Sucker *Catostomus commersonii* than trout. Deeper pools slow water velocities and the addition of large wood create instream cover and increased complexity that White Suckers might exploit and potentially out-compete with trout for desirable habitat. White Suckers have been implicated with competing with trout for limited forage resources in other locations throughout Colorado and in some cases, lakes and reservoirs have been treated with rotenone to reduce White Suckers and free trout from interspecific competition. We tested this assumption with respect to our toe wood treated habitat treatments by comparing species composition across monitoring sites in toe wood-treated, boulder-treated, and the downstream untreated control. Monitoring results suggest that white sucker biomass was lowest in the toe wood-treated site compared with either the boulder-treated or control-untreated (Figure 1.19). In addition, White Suckers composed the smallest proportion and trout the largest proportion of the total population in the toe wood-treated site as compared with the boulder-treated or control-untreated sites (Figure 1.20).

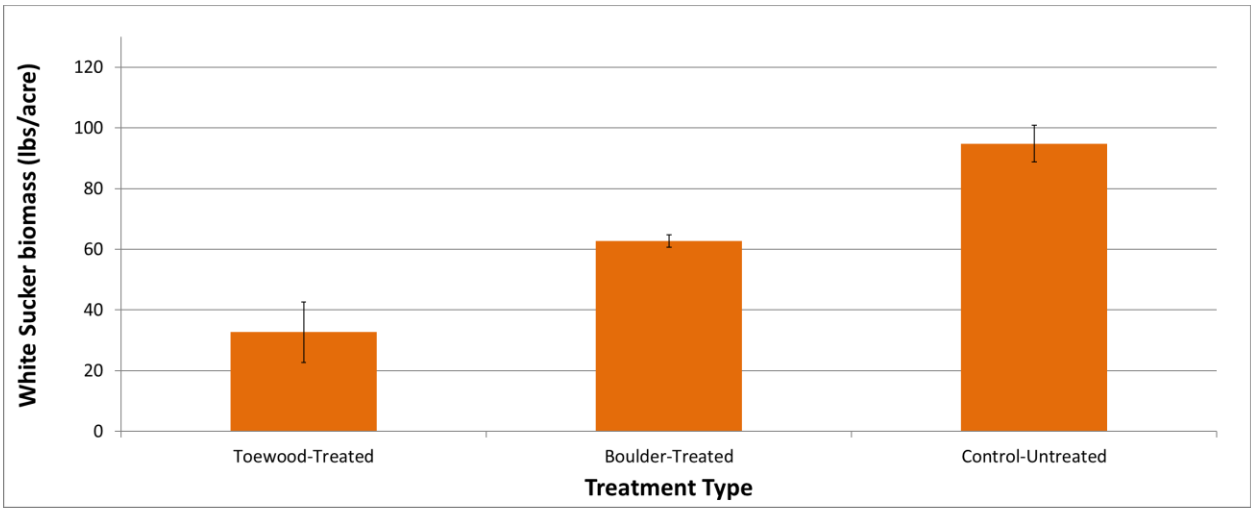

Figure 1.19. White sucker biomass as a function of treatment type (toe wood-treated, boulder-treated, and control-untreated).

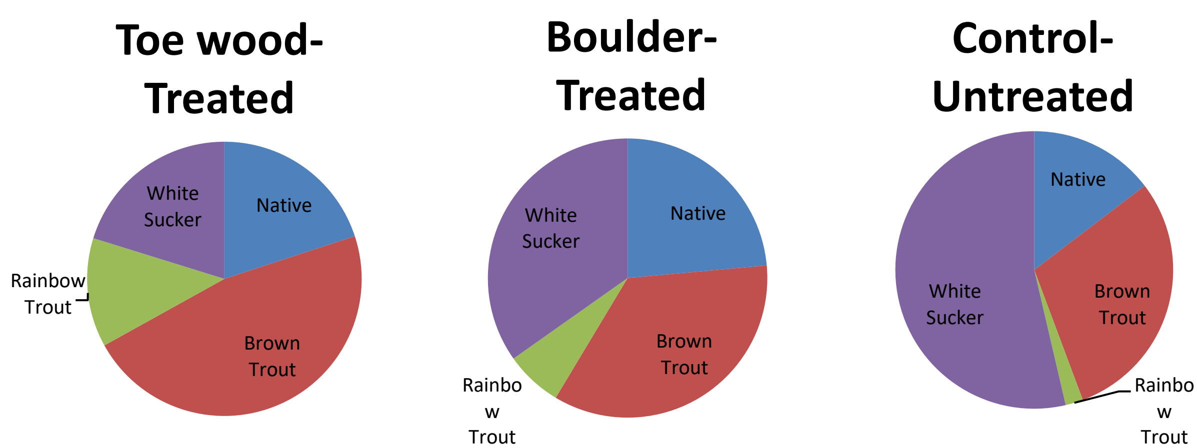

Figure 1.20. Species composition by treatment types. Note that the highest total proportion of trout and lowest proportion of white sucker occurred in the toe wood-treated site relative to boulder-treated or untreated-control.

Additional fish surveys are planned to support long-term evaluation of the project. Preliminary results from fish population monitoring were presented by Kondratieff (2018).

Halfmoon Creek

Two monitoring sites on Halfmoon Creek were surveyed to baseline trout population metrics during this reporting period. Monitoring data will be used to evaluate the changes in trout populations following implementation of potential habitat and fish passage projects on Halfmoon Creek. Both the habitat enhancement and fish passage projects on Halfmoon Creek are currently being evaluated for feasibility. Should the projects be deemed feasible by project stakeholders, they will move forward with evaluation of conceptual alternatives and designs.

Action #2:

- Level 1 Action Category: Data Collection and Analysis
- Level 2 Action Strategy: Research, survey or monitoring – habitat
- Level 3 Action Activities: Baseline inventory; Monitoring

Topographic and sediment surveys will be used to evaluate changes in longitudinal profile, cross-sections, sediment size, and habitat suitability. BACI studies will be conducted at appropriate site locations to evaluate changes in channel morphology following habitat treatments. For select sites, an Acoustic Doppler Current Profiler (ADCP) will be use to evaluate hydraulic conditions and habitat suitability. Project sites include (1) Wason and LaGarita Ranches, Rio Grande River, (2) Upper Arkansas River, (3) Charlie Meyers SWA, South Platte River, and (4) Yampa River below Stagecoach Reservoir.

Action #2 Accomplishments:

Collection and/or analysis of topographic and sediment data were successfully conducted at two of the sites listed above: Upper Arkansas River and Yampa River below Stagecoach Reservoir. Surveys for the Wason and LaGarita Ranches on the Rio Grande River and Charlie Meyers SWA were completed during previous reporting periods, but data analysis and reporting is still in process. Topographic, bathymetric, and sediment surveys were also conducted for the Kemp-Breeze SWA Habitat Restoration Project on the Colorado River, but this project was not included in Grant Narrative for this reporting period. Survey data were used to develop a site assessment and conceptual restoration design for the Kemp-Breeze SWA project (Richer et al., 2019c). Topographic and sediment data were also used to evaluate geomorphology and hydraulics for a study investigating the habitat preferences of the Giant Stonefly *Pteronarcys californica* in Colorado, but this project was not included in the Grant Narrative for this reporting period. Accomplishments for each project included in the Grant Narrative are described in more detail below.

Upper Arkansas River

Annual longitudinal and cross-section surveys were completed for the 5.0-mile Upper Arkansas River Habitat Restoration Project during the fall of 2018. Topographic and sediment surveys were also conducted at six fish monitoring sites to support 2D habitat modeling. The integrity and function and instream habitat structures were also evaluated using a rapid assessment procedure developed by Miller and Kochel (2012). Habitat modeling results were published in a peer-review journal article (Richer et al., 2019a). Preliminary monitoring results were also presented at the Rocky Mountain Stream Restoration Conference (Richer et al., 2019b) and synthesized into an annual site assessment report that was submitted to the Colorado Department of Public Health and Environment (CDPHE; Richer, 2019).

Yampa River below Stagecoach Reservoir

A large-scale research project began in 2017 with the goal of evaluating survival of Hofer×Harrison (H×H) Rainbow Trout in the Yampa River through a range of habitat conditions, manipulations of a resident Brown Trout population, and stocking strategies. As part of this study, five distinct reaches were identified to represent the range of habitat conditions present within the entire 7.7-mile stream segment between Stagecoach Reservoir and Lake Catamount (Appendix A). From upstream to downstream, the first reach Stagecoach State Park property, which extends from Stagecoach Dam downstream approximately 0.25 miles (Tailwater Section), was historically degraded but restored in 2013. The second reach is located on private land (Wellar Ranch) extending approximately 1.0 mile. The stream condition is severely degraded (over-widened channel devoid of riparian plant species with active lateral bank erosion) with ongoing land management problems. The third reach, comprised of approximately 0.75 miles, is situated on the Service Creek SWA. This reach has been historically impaired from past land use management activities. It is currently characterized as having vertical bank instability (accelerated bank erosion) and excessive sediment supply as well as rapidly evolving channel form. The fourth reach is located on BLM land extending approximately 1.0 mile. This stream segment has been impacted as a result of excessive sediment supply from upstream erosion, including a major tributary channel (Service Creek) as well as development of an adjacent roadway. The fifth and final reach is located on private land known as Green Creek Ranch and is approximately 0.5 miles upstream of Lake Catamount extending approximately 2.0 miles upstream. This segment is actively being restored through restoration activities.

The purpose of the recent habitat improvement projects (Stagecoach Tailwater Habitat Project and Green Creek Ranch Habitat Project) within the larger study reach is to restore the stream by creating a pattern, dimension and profile more appropriate to match the existing modified hydrology (based on upstream reservoir operations) and address historic, anthropogenic impairments. Specific project goals include a reduction in the rate of lateral bank erosion and overall sediment supply, fish habitat enhancement, as well as an increase in overall aquatic ecosystem function. Instream structures were constructed to enhance pool and riffle function, reduce the rate of lateral bank erosion and over-widening of the stream channel.

In order to characterize habitat conditions present within each of the five reaches, detailed topographic surveys were conducted using GPS topographic survey gear during the fall of 2018. Pebble counts were conducted to characterize bed materials and document proportion of fine sediments. Redd counts were completed to identify specific spawning locations and sediment characteristics. Riparian habitat assessment ratings were made to characterize differences in plant communities, cover elements such as large wood, and indirectly assess bank stability associated with vegetation types. Finally, aquatic insect collections were made as an indirect measure of habitat quality. All of these measurements were collected at sampling sites located within each of the five study reaches. Sampling sites based on how well the site represented overall habitat conditions found within the larger study reach (one through five).

Topographic surveys consisted of collecting stream geomorphic data such as longitudinal profiles, cross sections, and pebble counts. Longitudinal profiles will be used to generate estimates of channel length, stream and valley slope, sinuosity, identify bedform features, and measure residual pool depths across the five study reaches. Cross sections will be used to compare average bankfull widths, average bankfull depths, average width to depth ratios, bankfull cross sectional area, and average entrenchment ratios across all reaches. Pebble counts will be used to characterize bed materials, especially the percentage of fines in each of the five reaches. Additional habitat assessments were completed to monitor riparian vegetation condition, concentration of large wood, presence of various cover types, conduct stream classification (stream and valley types), monitor active bank erosion, compare baseflow to bankfull discharge ratios, and measure the degree of vertical and lateral connectivity (related to bed incision or aggradation respectively). Topographic survey data for the project is presented in Appendix A.

Historical land use and practices within the study segment (that contains the five study reaches) will be researched in order to understand underlying causes of stream impairment documented through various habitat assessments. Pre- and post-construction survey data from these restored reaches will be analyzed, as well as baseline survey data that was collected from the impaired reaches to form potential correlations between habitat attributes, or lack thereof, and retention of tagged fish. Habitat attributes (riffle to pool ratio, width/depth ratios, percent bank cover, and pool characteristics), as well as limiting factors will be assessed by reach to better formulate correlations. A stage-discharge relationship will be generated to characterize the hydrology within reaches for the extent of the study period. Thermographs may be deployed throughout the system in an effort to monitor potential temperature variations over the course of the study.

Data collection for this study including fisheries metrics and habitat associations are ongoing. Further details about this larger-scale study are found in Fetherman et al. (2018).

Expected Results and Benefits

Research findings will elucidate how stream restoration and habitat treatments improve fishery resources, as well as channel form and function. Study results will help refine techniques and maximize the benefit of habitat restoration on stream functions and Rainbow Trout *Oncorhynchus mykiss* and Brown Trout *Salmo trutta* fisheries. Results and analysis will be synthesized from multiple existing habitat improvement project sites to provide guidance for future sportfish habitat improvement projects as part of a multi-year analysis.

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Bet you're going fishing all of the time
Baby going fishing too
Bet your life, your sweet wife
She going to catch more fish than you
- Chris Smith

Job 2: Fish Passage Studies

Need

Upstream migration is a vital component of the salmonid life cycle. For example, trout are known to migrate upstream to find ideal spawning habitat and then move back downstream to over-winter in warmer, lower-velocity, and more productive waters. Connectivity between spawning, forage, and refugia habitats are essential components of a trout fishery (Schlosser and Angermeier, 1995). Vertical obstacles in streams and rivers, such as dams, waterfalls, culverts, and water-diversion structures, can affect fisheries by fragmenting migratory ranges. Therefore, it is important that fisheries managers identify and evaluate the impact of instream structures on fish populations.

Objectives

1. Provide guidance and technical assistance for two fish-passage feasibility studies by June 30, 2019.
2. Provide guidance and technical assistance for one fishway and entrainment evaluation study by June 30, 2019.

Approach

Action #1:

- Level 1 Action Category: Technical Assistance
- Level 2 Action Strategy: Technical Assistance
- Level 3 Action Activities: With individuals and groups involved in resource management decision making

Implementing fish passage at diversion structures in Colorado is a challenging process, due to design, funding, permitting, and legal constraints (Richer et al., 2015). Given these challenges, feasibility studies have been identified as a means to evaluate conceptual alternatives for fish passage while building support among project stakeholders. We will provide technical assistance for the following feasibility studies: (1) Niwot Ditch Fish Passage Project, St. Vrain Creek, (2) Watson Diversion Fish Passage Project, Cache la Poudre River, and (3) Halfmoon Creek Fish Passage Project. The objective of these projects is to provide fish passage for all species present in the project reaches, including Rainbow Trout *Oncorhynchus mykiss*, Brown Trout *Salmo trutta*, and various forage species.

Action #1 Accomplishments:

Guidance and technical assistance for all three fish passage projects referenced above was provided as detailed below. We also produced a fact sheet titled *Fish Passage at River Structures* that provides information on our fish passage projects, design guidelines for fish passage structures, fishway examples, and fish swimming performance criteria (Appendix B).

Niwot Ditch Fish Passage Project, St. Vrain Creek

The Fish Passage and Ditch Diversion Resiliency Project on St. Vrain Creek is focused on developing a 90% design for fish passage at the Niwot Ditch and conducting a conceptual alternatives analysis for fish passage at the South Flat Ditch. The U.S. Fish and Wildlife Service (USFWS) provided funding for the feasibility study in partnership with Trout Unlimited (TU), Boulder County, CPW, private landowners, and ditch companies. CPW has provided technical assistance to support project coordination, design, permitting, and funding for implementation. Implementing fish passage at both diversion structures will reconnect 2.6 miles of critical fish habitat in St. Vrain Creek. The conceptual alternatives analysis for the South Flat has been completed. Project stakeholders are waiting on successful implementation of the Niwot project before moving forward with additional work on the South Flat diversion structure. The 60% design for the Niwot Ditch was finalized and approved by all stakeholders during this reporting period. Hydraulic modeling indicated that the project would affect the 100-year floodplain, but stakeholders are currently in the process of obtaining a Conditional Letter of Map Revision (CLOMR) from Boulder County. Once the CLOMR process is completed and a Memorandum of Understanding (MOU) is signed by stakeholders, the 90% design will be finalized with the intention of constructing the project during the winter of 2019-2020. If those milestones cannot be achieved prior to the target construction window, the project will implemented during the winter of 2020-2021.

Watson Lake Fish Passage and Fish Screening Project, Cache la Poudre River

Watson Lake Fish Passage and Fish Screening project was constructed during the winter of 2018-2019. We provided technical support for the design, construction, and evaluation of an engineered rock-ramp fishway and cone fish screen. Target species for fish passage included Brown Trout, Rainbow Trout, Longnose Sucker *Catostomus catostomus*, White Sucker *Catostomus commersonii*, and Longnose Dace *Rhinichthys cataractae*. Fish passage criteria for the project included water velocities of 2-3 ft/s, a minimum depth of 0.3 ft, no vertical drops, year round passage for flows between 10-1,300 cfs, and attraction flows between 5-10% or higher. The engineered rock ramp was designed with a slope of 4% with resting pools (slope = 0%) spaced at regular intervals throughout the fishway (Figure 2.1). The fishway was designed with lower and upper tiers. The upper tier was designed to provide target velocities for fish passage under higher flow conditions. To evaluate fish passage, a pilot study was conducted during April 2019. This pilot study included hydraulic measurements for water depth and velocity, as well as a PIT-tag study to investigate fish passage success.

To evaluate hydraulics within the fishway, point measurements for water depth, bottom velocity, depth-average velocity, and surface velocity were collected along five transects under the same discharge conditions. Measurements were collected at six points along each transect, with three points located on the lower and upper tiers, respectively. Water depth ranged from 0.50-1.80 ft, with an average of 1.26 ft. Results for velocity measurements are presented in Figure 2.2, including average values with 95% confidence intervals for the lower tier, upper tier, and all points combined. Water velocities were typically lower on the upper tier when compared to the lower tier. Water velocities also increased from the bottom to the top of the water column. In general, bottom and depth-average water velocities agreed with the target fish passage criteria of 2-3 ft/s, and bottom velocities were less than 2 ft/s for all measurement locations. The average surface velocity was greater than 3 ft/s for the lower tier and all point combined, but averaged around 2.5 ft/s for the upper tier. These results suggest that the two-tier design did in fact provide lower velocities along the upper tier as was intended. Additional measurements are needed to evaluate hydraulic conditions across a wider range of flows.

Figure 2.1. Engineering rock-ramp fish passage structure at the Watson Lake diversion structure on the Cache la Poudre River, Colorado.

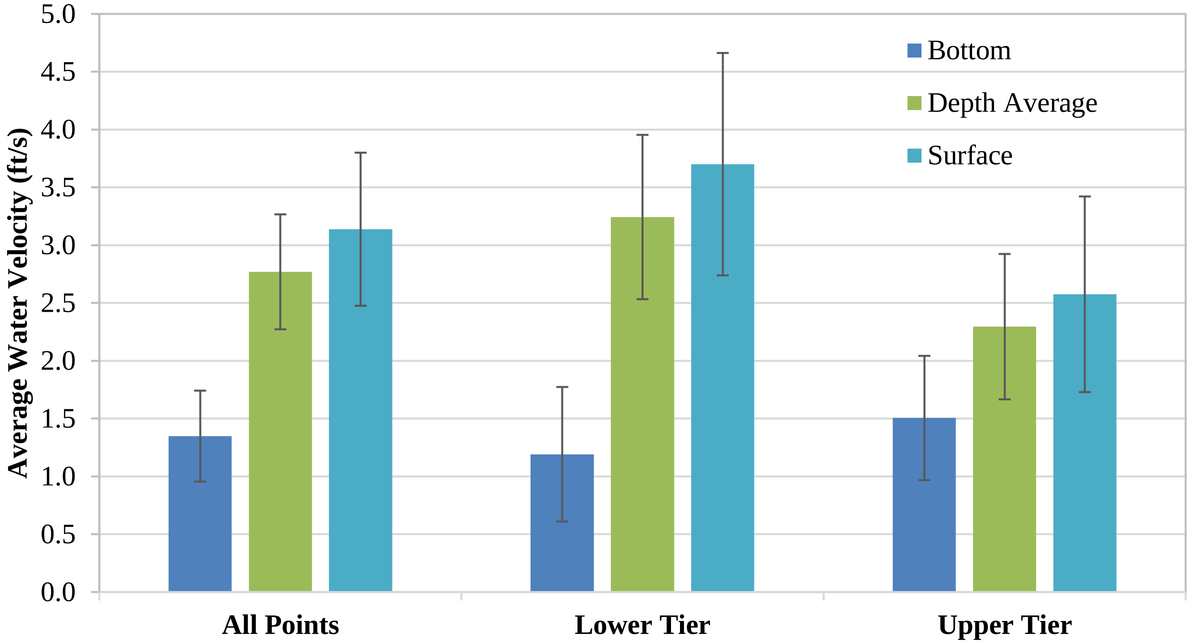

Figure 2.2. Average water velocity with 95% confidence intervals for all, lower tier, and upper tier within the Watson Lake diversion structure on the Cache la Poudre River, Colorado.

Fish passage success was directly evaluated with a PIT-tag study. Three PIT-tag antennas were installed within the fishway during April 2019 prior to collecting, PIT tagging, and releasing 70 fish into the downstream end of the fishway on April 26, 2019. Three species were tagged for the pilot study, including 39 Brown Trout, 27 Rainbow Trout, and 4 Longnose Suckers. As of June 25, 2019, 43% of all PIT-tagged fish had successfully ascending the fishway, including at least one individual from all three species. The majority (88%) of the fish detected on the lowest antenna successfully passed through the structure, which suggests that those fish who were motivated to move upstream were able to do so. The smallest fish to move upstream through the fishway was a 226 mm total length (TL) Brown Trout. The biggest fish to pass through the structure was a 405 mm TL Rainbow Trout. We will continue to monitor passage through the structure, and still need to determine if smaller age classes of suckers and Longnose Dace can successfully ascend the fishway.

Halfmoon Creek Fish Passage Project

The U.S. Bureau of Reclamation (BOR) operates a water diversion on Halfmoon Creek as part of the Fry-Ark transmountain diversion project. Halfmoon Creek is tributary to the Arkansas River, and previous investigations have determined that the structure typically functions as a migration barrier for resident trout and the fishery upstream of the diversion is likely limited by this barrier to movement. Currently, the feasibility of implementing a fish passage project at this diversion structure is being explored with the BOR, USFWS, and CDPHE. If approved by the BOR, the group of stakeholders hopes to conduct a formal feasibility study that investigates a variety of fish passage alternatives at the site. To date, efforts have been focused on collaboration among stakeholders with the hope of implementing the feasibility study in 2019-2020.

Action #2:

- Level 1 Action Category: Technical Assistance
- Level 2 Action Strategy: Technical Assistance
- Level 3 Action Activities: With individuals and groups involved in resource management decision making; With private landowners

Fish passage structures were constructed at select locations following severe flooding in the Colorado Front Range during September 2013. Various approaches for fish passage were applied at water diversion and whitewater park structures in flood-affected drainages, including pool-weir, engineered rock-ramps, bypass channels, geomorphic solutions, and others. The effectiveness of these fishways will be evaluated in cooperation with Colorado State University. Entrainment of fish into irrigation ditches will also be evaluated concurrently with the fish passage study. Target species for evaluation include Rainbow Trout *Oncorhynchus mykiss*, Brown Trout *Salmo trutta*, and various forage species.

Action #2 Accomplishments:

We provided guidance and technical assistance for the fish passage and entrainment evaluation in cooperation with Colorado State University. To date, PIT-tag antennas have been installed at two study sites, including an engineered rock ramp on the Cache la Poudre River and a bypass channel on St. Vrain Creek. PIT-tag antennas were also installed in the irrigation ditch at the

Cache la Poudre study site to investigate fish entrainment. Antenna installation is also planned for a constructed riffle structure on Boulder Creek and pool-weir fish ladder on St. Vrain Creek. Short-term enclosure studies are scheduled for the summers of 2019 and 2020 to evaluate movement probabilities for a variety of fish species. Fish movement and passage success will also be evaluated over extended monitoring periods (1-2 years) to investigate passage under natural conditions across a range of flows and other environmental conditions.

Expected Results and Benefits

Most rivers in the Colorado are fragmented by numerous diversion structures that prevent upstream migration of sportfish, adversely affect sediment transport, entrain downstream migrating fish in irrigation ditches, and sporadically dry up river segments during periods of drought or baseflow. The loss of Rainbow Trout *Oncorhynchus mykiss* and Brown Trout *Salmo trutta* from fragmentation, stranding, and entrainment is economically costly and represents a loss of public recreation opportunity, as fish are unavailable for capture and harvest. Fish passage research is focused on evaluating the effectiveness of fish passage structures and the impact of diversion structures on aquatic habitat, as well as the development of species-specific design criteria to improve connectivity in Colorado rivers.

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He that would fish, must venture his bait.
- Benjamin Franklin

Job 3: Whitewater Park Studies

Need

With more whitewater parks than any other state, Colorado has become the epicenter for whitewater park design and construction. Whitewater parks contribute to local communities by providing revenue from tourism, promoting public interest in rivers, and creating recreational opportunities. However, whitewater parks can create hydraulic conditions that impair upstream migration of fish (Fox et al., 2016; Stephens et al., 2015) and create unfavorable habitat conditions for fish (Kolden et al., 2015). As a variety of whitewater park designs are being used throughout Colorado, CPW will build upon previous research by studying different types of structures, including the effectiveness of fish passage designs and effects on trout habitat.

Objectives

1. Survey and analyze salmonid populations at two whitewater parks sites to evaluate impacts on fish passage and habitat by June 30, 2019.
2. Survey and analyze channel morphology and hydraulics at two whitewater parks sites to evaluate impacts on fish passage and habitat by June 30, 2019.
3. Results and analysis will be collated from multiple studies with the goal of producing management tools for development of fish-friendly whitewater parks (multi-year analysis).

Approach

Action #1:

- Level 1 Action Category: Data Collection and Analysis
- Level 2 Action Strategy: Research, survey or monitoring – fish and wildlife populations
- Level 3 Action Activities: Abundance determination; Age, size, and sex structure

Conduct Before-After studies on two new whitewater parks. Study sites are the Montrose Whitewater Park on the Uncompahgre River and the Gore Canyon Whitewater Park at Pumphouse on the Colorado River. Fish populations will be monitored with the assistance of biologists and researchers before and after construction of the whitewater parks to evaluate their impact on the trout fisheries. As data collection for this component of the study was completed in 2017, research efforts will now focus on data analysis and publication of results.

Action #1 Accomplishments:

The Montrose Whitewater Park was constructed during the winter of 2015-2016 and includes six channel-spanning structures. Each structure consists of a pre-cast concrete block placed in center of the channel with boulder wing walls extending laterally to each bank. Fishways were incorporated into one of the boulder wing walls at each structure. Fish sampling sites were established upstream, within, and downstream of the Montrose Whitewater Park. Upstream and downstream sites were not impacted during whitewater park construction and will serve as control sites for comparison to the whitewater park reach. One year of baseline fish monitoring data were collected at all three sites prior to construction. The third and final year of post-construction fish sampling was completed in November 2017. Fish monitoring data will be used to determine if the whitewater park structures alter fish populations or habitat.

The Gore Canyon Whitewater Park at Pumphouse consists of a single channel-spanning structure that splits flows into two chutes. One chute was intended to accommodate fish and drift-boat passage. The other chute was designed to provide whitewater recreation for kayaks and stand-up paddleboards (SUP). Construction of the project was completed during the spring of 2015. Fish sampling was conducted within the project reach during the fall of 2014 to establish one year of baseline, pre-construction data. The third and final year of post-construction fish sampling was completed in September 2017. Fisheries data will be used to determine if the whitewater park structure has altered fish populations upstream or downstream of the structure and provide evidence if the structure inhibits upstream fish passage.

Preliminary results for fish populations at the Montrose Whitewater Park and Gore Canyon Whitewater Park at Pumphouse were presented at the Sustaining Colorado Watersheds Conference (Richer et al., 2018) and CPW Aquatic Biologist Meeting (Richer et al., 2019d). No population level impacts were observed for Brown Trout or Mottled Sculpin at either study site three years following whitewater park construction. However, the density of sucker species was significantly higher below the structure on the Colorado River, which suggest that the structure could suppress passage for sucker species. For the Uncompahgre River study, Brown Trout density was lower at the whitewater park compared to upstream and downstream control sites. The biological results from this study are being summarized into a peer-reviewed publication.

Action #2:

- Level 1 Action Category: Data Collection and Analysis
- Level 2 Action Strategy: Research, survey or monitoring – habitat
- Level 3 Action Activities: Baseline inventory; Monitoring

Impacts to habitat quality and fish passage will be assessed by surveying water depth and velocity with an ADCP before and after project construction. In addition, topographic surveys will be conducted before and after construction to evaluate changes in channel morphology. Survey data will also be used to configure 2D models for assessing changes in habitat suitability across a range of flows. Results for ADCP measurements and 2D modeling will be combined to elucidate if whitewater park construction has affected fish passage at these study sites. As data collection for this component of the study was completed in 2017, research efforts will now focus on data analysis and publication of results.

Action #2 Accomplishments:

Survey data from the Montrose Whitewater Park on the Uncompahgre River were used to configure and calibrate HEC-RAS models for both pre-project and post-project conditions. Results from HEC-RAS models were used to evaluate changes in channel morphology and hydraulics, as well as inform boundary conditions for habitat modeling with River2D. Configuration and calibration of 2D models was completed during the previous reporting cycle. Results from hydraulic modeling are being used to evaluate the impact of whitewater park implementation on habitat suitability and fish passage. Data analysis for the Montrose Whitewater Park was completed during this reporting cycle.

Multiple surveys were conducted at the Gore Canyon Whitewater Park at Pumphouse on the Colorado River during previous reporting periods. Topographic and bathymetric surveys were conducted to document pre-project and post-project channel morphology. An ADCP was used to measure water depths and velocities throughout the project reach to provide calibration and validation data for hydraulic and habitat models. Survey data were used to configure and calibrate HEC-RAS and River2D models for both pre-construction and post-construction conditions. The before-after comparison will evaluate the impact of whitewater park implementation on habitat suitability and fish passage.

Fish passage at both study sites was evaluated by comparing modeled depths and velocities to fish passage criteria for juvenile, average-adult, and large-adult Brown Trout, Mottled Sculpin *Cottus bairdii*, and White Sucker *Catostomus commersonii*. Velocities and depths were extracted from 2D modeling results along potential passage pathway derived with the Least Cost Path tool in ArcGIS. The maximum velocity and minimum depth along each path was compared to passage criteria for both before and after conditions to evaluate changes in fish passage.

Data processing and analysis were completed for both study sites during this reporting period. Preliminary results for fish passage and habitat evaluations were presented at the Sustaining Colorado Watersheds Conference (Richer et al., 2018) and CPW Aquatic Biologist Meeting (Richer et al., 2019d). Habitat modeling indicates that Brown Trout and Mottled Sculpin habitat did not change following whitewater park implementation at the Gore Canyon site, but White Sucker habitat increased significantly (11-36%) depending on life stage. At the Montrose Whitewater Park, habitat models show increased habitat for Brown Trout and White Sucker following construction of the park. However, fish populations remained unchanged at the Montrose site, which suggests that habitat models may be overestimating the increase in habitat at the site. Mottled Sculpin habitat decreased at the Montrose site according to habitat models, but population monitoring indicates that the density of sculpin actually increased at multiple sites during the study period, including the whitewater park site and upstream/downstream controls.

Preliminary results indicate that Gore Canyon Whitewater Park is an obstacle for Brown Trout and Mottled Sculpin, and may function as a complete barrier for sucker species at some flows. Individual structures within the Montrose Whitewater Park may be a barrier for all species at some flows. Given these potential issues with fish passage, we strongly recommend that fishways be incorporated into the design of whitewater park structures. Fish habitat and passage results for both study sites will be synthesized into peer-review papers as soon as possible.
Action #3:

- Level 1 Action Category: Technical Assistance
- Level 2 Action Strategy: Technical Assistance
- Level 3 Action Activities: With individuals and groups involved in resource management and decision making

As research scientists, our responsibilities include disseminating research results to promote science-based resource management decisions to whitewater park designers, water management agencies, and aquatic resource management agencies.

Action #3 Accomplishments:

Previous whitewater park research was conducted at the Lyons Whitewater Park on the North Fork of St. Vrain Creek. These research projects produced three peer-reviewed publications (Kolden et al., 2015, Stephens et al., 2015; Fox et al., 2016) and five theses (Fox, 2013; Kolden, 2013; Stephens, 2014; Ryan, 2015; Hardee, 2017) to provide the foundation for scientifically defensible management tools and development of fish-friendly whitewater parks. These publications provide insight into potential impacts on fish passage, fish habitat, and methods for assessing fish passage using 2D and 3D hydraulic modeling methods.

The latest thesis was completed by Travis Hardee (Hardee, 2017), a graduate student from Colorado State University, and included two separate analyses. The first chapter of his thesis involved a comparison of less-expensive, simpler and data-intensive 2-dimensional (2D) hydraulic modeling techniques with 3-dimensional (3D) hydraulic modeling techniques. The second chapter of his thesis involved using the 2D hydraulic modeling techniques to evaluate the newly constructed whitewater park structures that were re-constructed after the 2013 flood on St Vrain Creek. The newly constructed structures incorporated a “fish notch” that was intended to provide upstream passage through the structure. The third chapter of his thesis provides guidance and methodology on how to apply the 2D hydraulic models to any other whitewater park structure for fish passage evaluation.

As part of the 2D vs. 3D hydraulic model evaluation, fish swimming paths were extracted from 2D models and evaluated for depth and velocity criteria for fish passage to yield a fraction of potential flow paths corresponding to any range of discharges for a given whitewater park structure. Results from the 2D analysis were used to predict fish passage at whitewater park structures for which we have collected real fish passage movement data from PIT-tagged fish. Results from his study suggested that 2D models were at least as good or better at predicting upstream fish passage as more expensive and data-intensive 3D models. The 2D models were useful for evaluating the complex hydraulic conditions fish encounter at whitewater park structures at scales relevant to upstream fish movement. A draft publication for this portion of the study is in preparation (Hardee et al., *in preparation*).

The second part of Travis’ study involved evaluating the transferability of the 2D methods to the newly reconstructed Lyons Whitewater Park structures that were destroyed during the 2013 flood. The reconstruction of the Lyons Whitewater Park in 2016 provided an opportunity to compare fish passage analyses for the old and new whitewater parks using similar methodology. Part of this analysis includes developing management tools for evaluating whitewater parks and informing fish-friendly whitewater park designs. Fish passage analyses for the new Lyons Whitewater Park and development of management tools is ongoing.

Expected Results and Benefits

Information from this study is being used to determine the impact of whitewater park structures on Rainbow Trout *Oncorhynchus mykiss*, Brown Trout *Salmo trutta*, and fish passage and movement rates. In addition, new techniques were developed for evaluating fish passage at whitewater parks that are less costly and time intensive with respect to data collection when compared with 3D modeling techniques. Results will be used to develop design guidelines for whitewater parks that optimize both recreational and ecological benefits.

References

Fox, B. 2013. Eco-hydraulic evaluation of whitewater parks as fish passage barriers. M.S. Thesis, Department of Civil and Environmental Engineering, Colorado State University.

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Stephens, T. A. 2014. Effects of whitewater parks on fish passage: a spatially explicit hydraulic analysis. M.S. Thesis, Department of Civil and Environmental Engineering, Colorado State University.

Stephens, T. A., B. P. Bledsoe, B. D. Fox, E. Kolden, and M. C. Kondratieff. 2015. Effects of whitewater parks on fish passage: a spatially explicit hydraulic analysis. Ecological Engineering 83:305-318.

In rivers, the water that you touch is the last of what has passed and the first of that which comes; so with present time.

- Leonardo da Vinci

Job 4: Technical Assistance

Need

CPW and other state and federal personnel are frequently in need of technical assistance related to stream habitat restoration, 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 (DWMs), 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 and construction, and teaching at various technical training sessions for CPW and other state and federal personnel.

Objectives

1. Provide at least 10 technical assistance reviews to CPW personnel, NGOs, and Federal agency personnel as requested by June 30, 2019.

Approach

Action #1:

- Level 1 Action Category: Technical Assistance
- Level 2 Action Strategy: Environmental Review
- Level 3 Action Activities: Review of proposed projects

Review proposed stream habitat restoration and fish passage projects, including design, contractor selection, and permitting for CPW and other state and federal personnel as requested. Review proposed designs for post-flood road reconstruction and stream restoration for the Colorado Department of Transportation (CDOT) as requested. Provide training to CPW and other state and federal personnel on stream restoration techniques and fish passage design criteria, including guidance for permitting.

Action #1 Accomplishments:

We provided technical assistance for the following stream restoration, fish passage, and whitewater park projects:

1) Canon City Whitewater Park, Arkansas River
2) Halligan Reservoir Expansion Project EIS, North Fork Cache la Poudre River
3) River Health Metrics for Colorado Water Plan
4) Substrate and Flow Work Group, Upper Colorado River Wild and Scenic Stakeholders
5) Moffat Mitigation Project, Williams Fork River
6) Renegade Ranch Aquatic Habitat Restoration Project, Colorado River
7) King Heatherly Diversion Fish Passage Project, Divide Creek
8) Fountain Creek Channel Stabilization at Riverside Project

9) Godfrey Ditch Fish Passage Project, South Platte River
10) Denver Confluence Project, South Platte River
11) Granby Fish Passage and Ditch Diversion Improvement Project, Fraser River
12) Cherry Creek Mitigation Bank
13) Rabbit Creek Mitigation Bank
14) Bear Creek Instream Habitat Restoration
15) Colorado Stream Quantification Tool
16) Fort Collins Whitewater Park, Cache la Poudre River
17) Floodplain Reconnection and River Restoration Work Group
18) Quantifying the Habitat Preferences of the Stonefly *Pteronarcys californica* in Colorado
19) Kemp-Breeze SWA Habitat Restoration Project, Colorado River
20) Colorado River Connectivity Channel at Windy Gap
21) Bohn Park Fish Habitat Project, South St Vrain Creek, Project Management
22) Crooked and Little Lime Creek Cutthroat Conservation Barrier Project
23) Swan River Cutthroat Conservation Barrier Project, Swan River
24) Big South Fork of Cache La Poudre River Cutthroat Barrier Project
25) Max Wave Whitewater Park, Clark Fork River, Missoula, Montana
26) Bobtail and Steelman Creeks Cutthroat Conservation Barrier Project
27) Stream Fisheries Improvements Using Natural Channel Design. CPW N.E. Region Biology Days, Denver, Colorado, Training Instructor
28) Whitewater Parks: Implications for Fish Habitat, Fish Passage, and Anglers, CPW N.W. Region Staff, Radium, Colorado, Training Instructor
29) Rosgen Level 1 Course: Applied Fluvial Geomorphology. Steamboat Springs, Colorado, Team Leader/Training Instructor
30) Rosgen Stream Classification, Field Training for EPA and USACOE staff, Training Instructor
31) Long-term monitoring of fish populations from NCD project sites. Environmental Law Institute Webinar Series, Stream Compensatory Webinar Series: Long-term performance of stream compensatory mitigation. Fort Collins, Colorado, Training Instructor https://www.eli.org/sites/default/files/docs/eliwebinar2019_kondratieff.pdf
32) Del Norte Whitewater Park, Rio Grande River
33) J Sheehan River Habitat Project, Little Snake River
34) Stafford Ranch Habitat Project, Middle Fork South Platte River
35) Roaring Fork Whitewater Park, Roaring Fork River
36) Eagle River Whitewater Park, Eagle River
37) Willow Planting Project, Arkansas River, Project Management
38) Willow Planting Project, South Platte River, Project Management

Expected Results and Benefits

As research scientists, part of our job is disseminating research results to promote science-based resource management decisions to resource users and other management agencies.

Personnel:

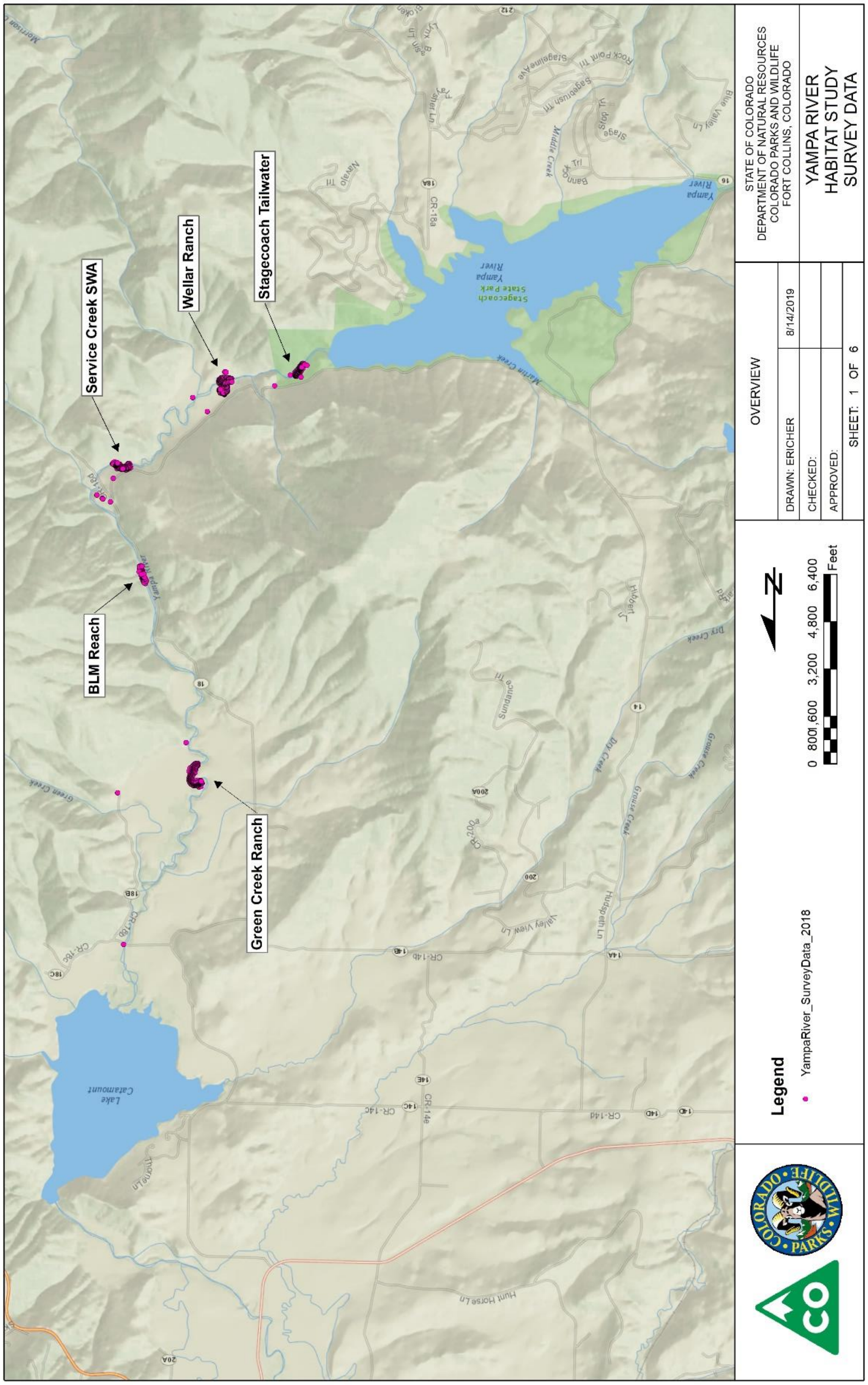
Matt C. Kondratieff	CPW, Aquatic Research Scientist	970-472-4316
Eric E. Richer	CPW, Aquatic Research Scientist	970-472-4373
Technician	CPW, Technician	
James Guthrie	CPW, Financial Initiatives Program Manager	303-291-7563
George Schisler	CPW, Aquatic Research Leader	970-472-4361

Eventually, all things merge into one, and a river runs through it. The river was cut by the world's great flood and runs over rocks from the basement of time. On some of the rocks are timeless raindrops. Under the rocks are the words, and some of the words are theirs. I am haunted by waters.

- Norman Maclean

Appendix A

Topographic Surveys for Stream Restoration and Habitat Enhancement Project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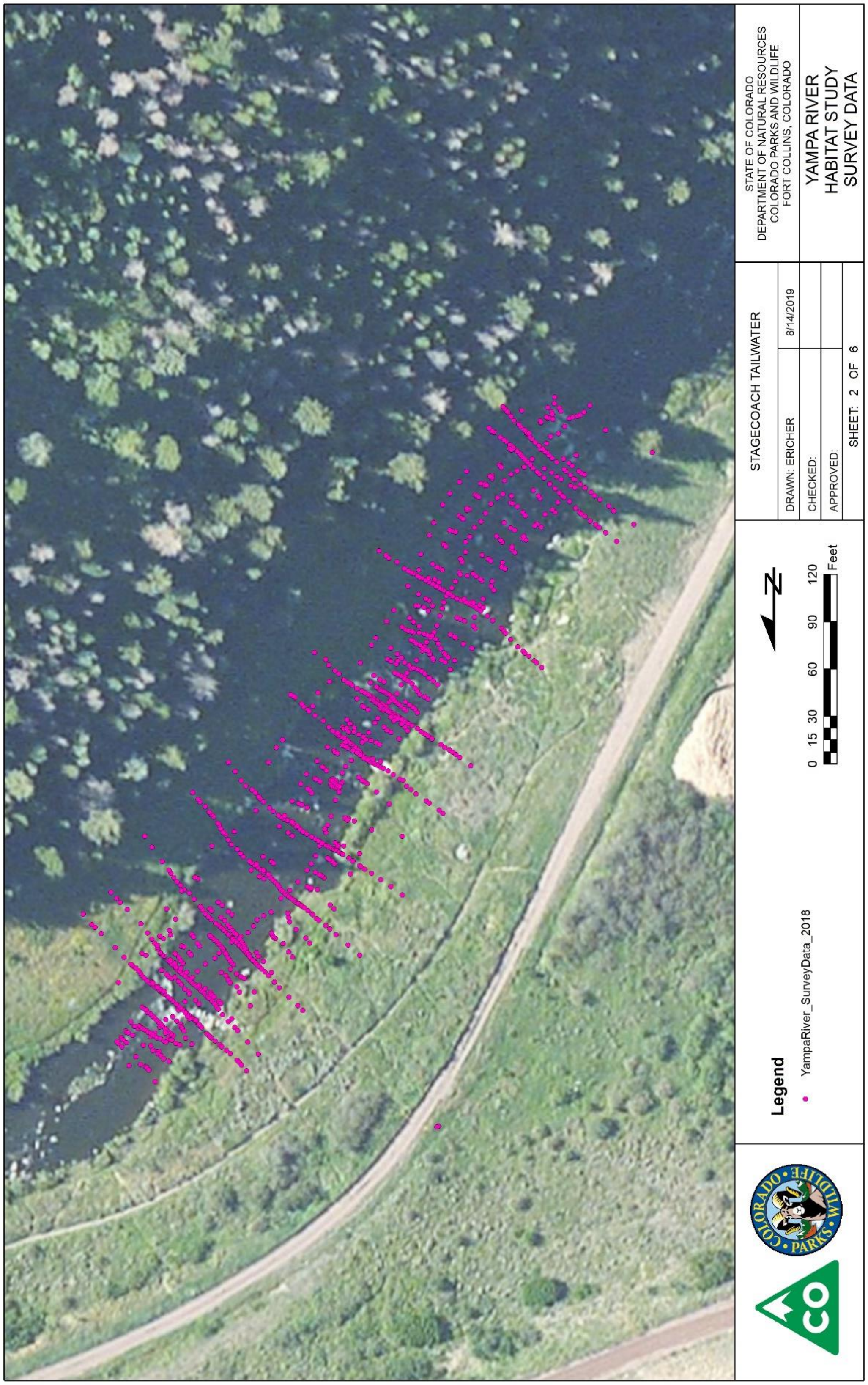
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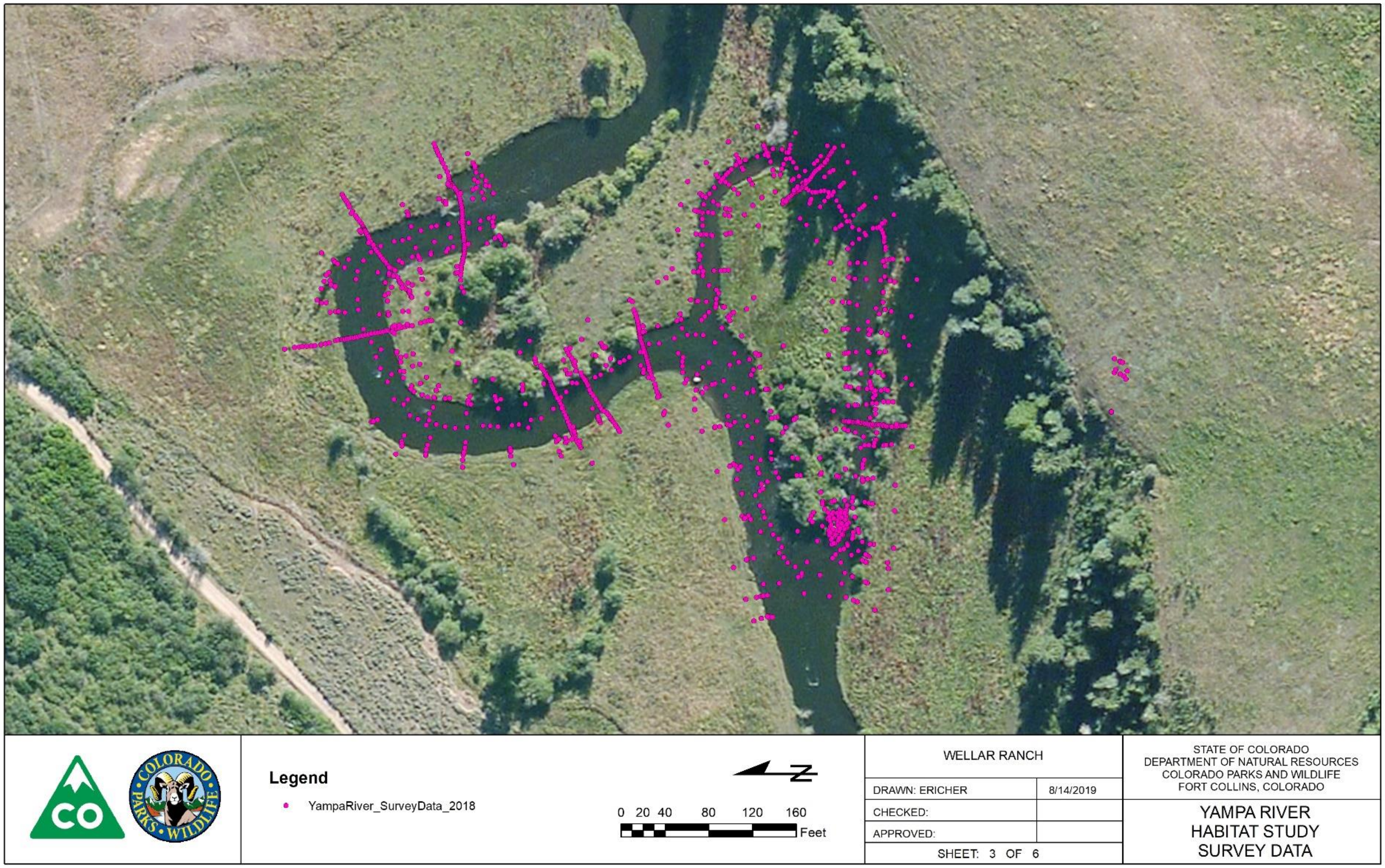
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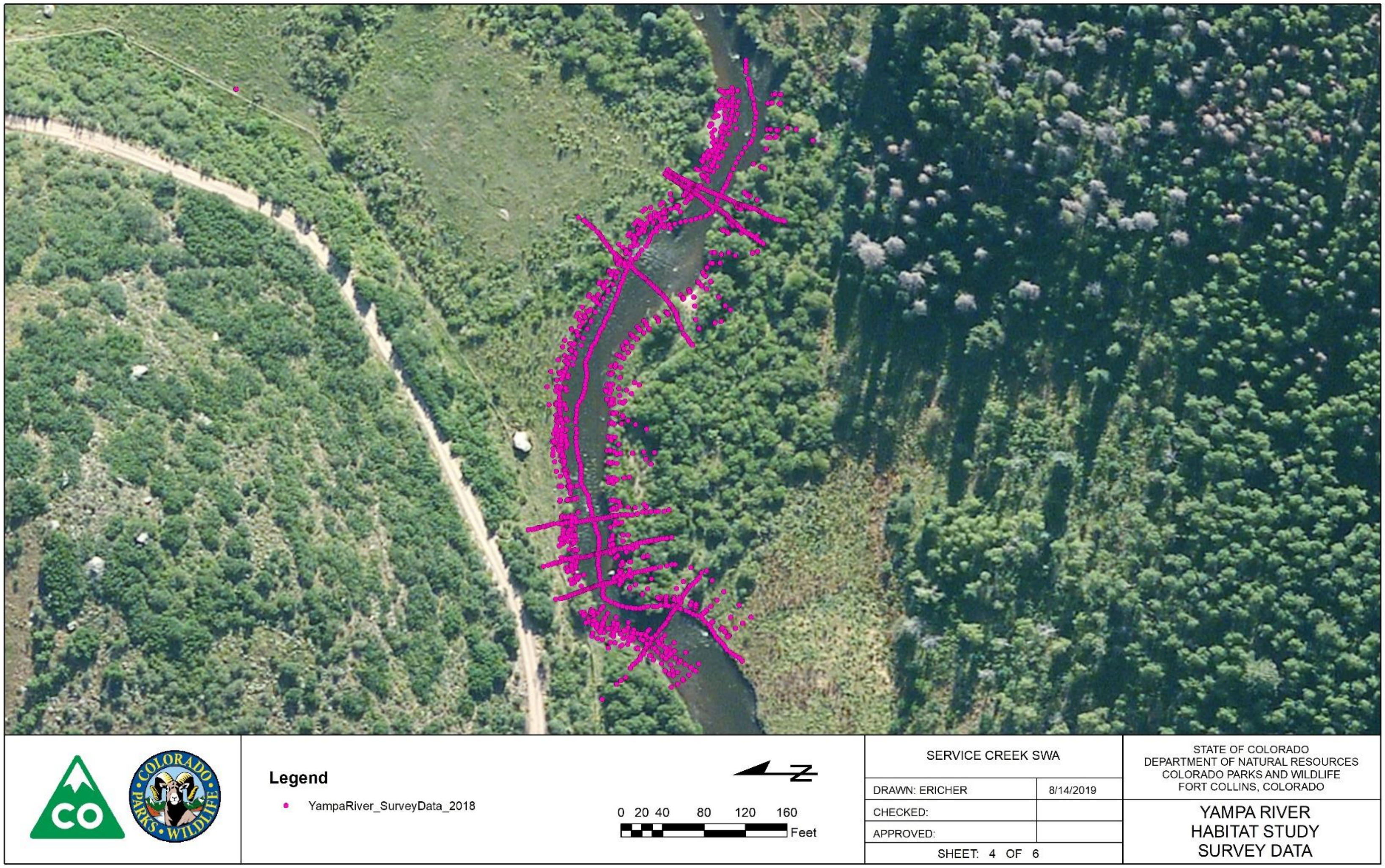
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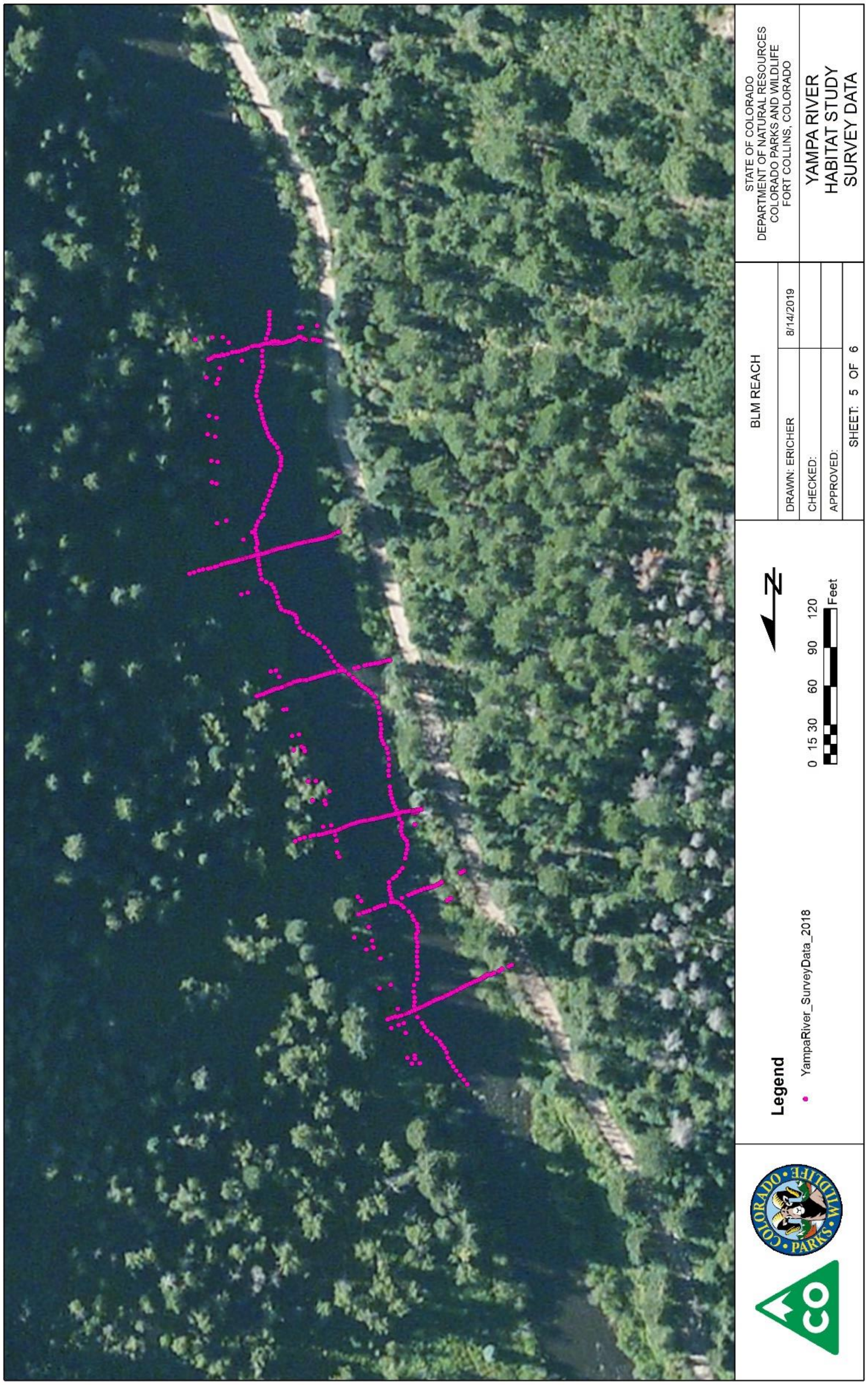
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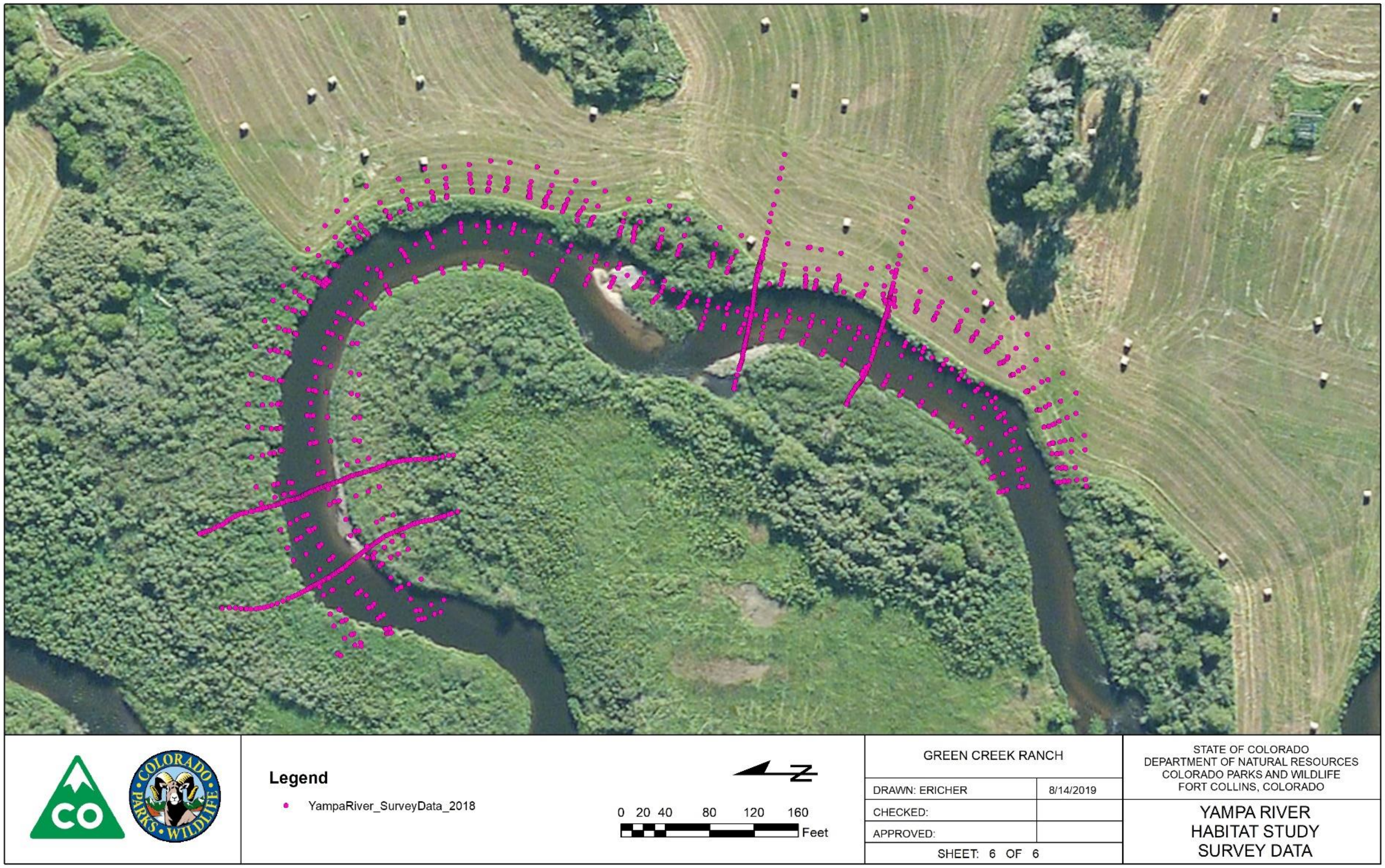
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Appendix B

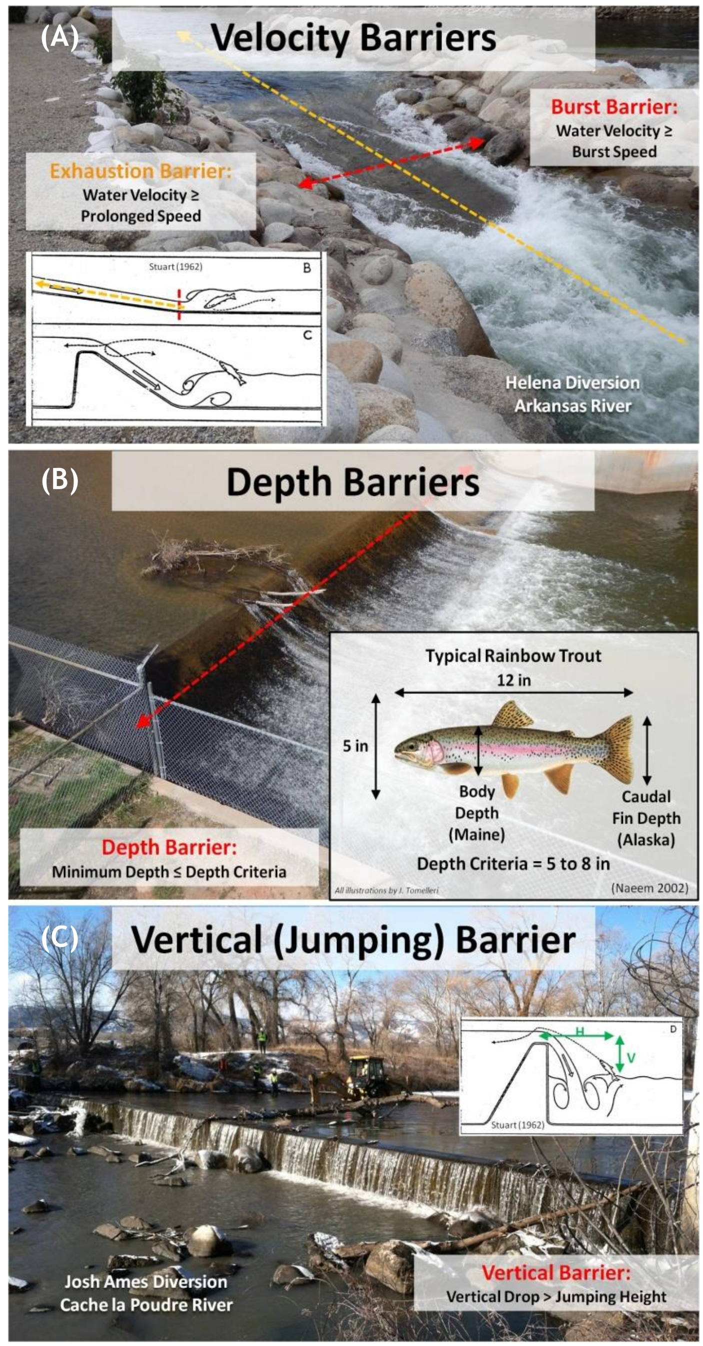
Fact Sheet: Fish Passage at River Structures

Fish Passage at River Structures

RESEARCH AND DESIGN GUIDELINES

Introduction

Instream structures, such as culverts, water diversions and dams, can negatively affect fish by fragmenting populations, reducing migratory ranges, and limiting access to habitat for spawning, feeding and refugia. Many rivers in Colorado contain man-made structures that create partial (obstacles) or complete barriers depending on the fish species and life stage. Habitat fragmentation associated with instream barriers is a serious threat to Colorado's Species of Greatest Conservation Need (SGCN) and sport fisheries. Therefore, it is important that fisheries managers identify and evaluate the influence of instream structures on fish populations.



Fish Passage Research Objectives

The primary goal of fish passage research is to restore connectivity in fragmented river systems by: (1) evaluating the effectiveness of existing fishways; (2) evaluating the barrier-potential of common river structures; and (3) establishing fish swim performance criteria for native and sport fishes.

Current Fish Passage Research Projects

Active fish passage research projects include: (1) evaluation of native fish passage at existing fishways located on Front Range transition zone streams; (2) evaluation of fish passage at instream whitewater park structures; (3) laboratory studies to develop fish swim and jump performance criteria for Colorado fishes where data is lacking; and (4) development of new techniques and technologies for investigating fish movement and passage in rivers.

Fishway Design

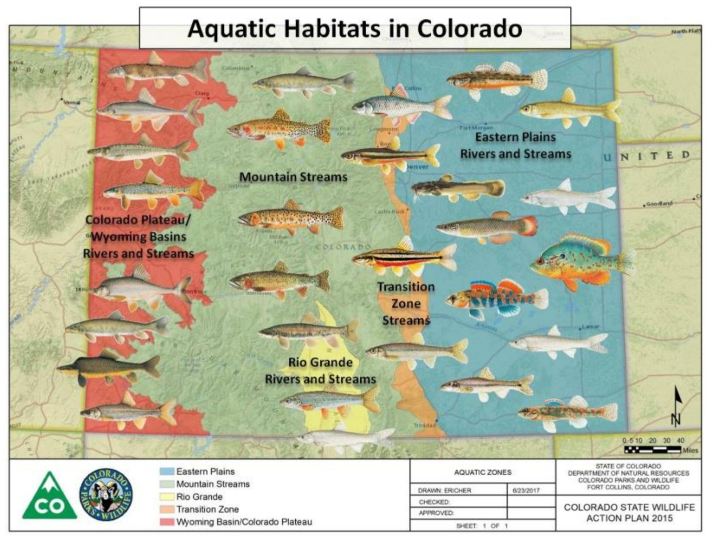
Fishways, or "fish ladders", are engineered structures designed to facilitate passage around an obstacle or barrier. Fishways attempt to incorporate species- and life stage-specific swimming and jumping abilities into designs. Common elements of successful fishways include: (1) low velocity pathways that do not exceed burst speeds or endurance capabilities for target species (Figure A); (2) water depths that do not limit swimming performance (Figure B); (3) vertical drops that do not exceed the jumping ability for target species - note that many species native to Colorado do not exhibit jumping behaviors (Figure C); (4) sufficient attraction flow, or the flow that emanates from a fishway entrance, to ensure that fish can locate the fishway; and (5) maintenance of the above design elements over the expected range of streamflows.

Fishway Examples

Some examples of successful fishways include engineered rock ramps (Figure D), constructed riffles (Figure E), and vertical slot fishways (Figure F). Each type of fishway has advantages and disadvantages related to which fish species and life stages are present and the conditions of the project site.

Aquatic Habitat Types

From the high-gradient, boulder-dominated, step-pool channels of snowmelt fed mountain streams to the low-gradient, well-vegetated, pool-riffle rivers of the eastern plains to the majestic, vertically-confined canyons on the arid Colorado Plateau, aquatic habitats in Colorado are as diverse as the geographic regions where they are found. Native Colorado fishes have unique morphological characteristics that are adapted to the natural conditions found in each aquatic habitat type. These adaptations affect the swimming abilities of fish, influencing how they move through and use diverse habitats. Fisheries managers must take the diversity of fish species into consideration when evaluating river structures and designing fishways.



All illustrations of fish © Joseph R. Tomelleri

Fish Swimming Performance by Family

Family Name	SGCN (#)	Prolonged Speed (ft/s)	Burst Speed (ft/s)	Jump Height (ft)	Habitat Types
Percidae (Perches)	3	0.4 - 1.2	NA - 2.4	0*	EP
Fundulidae (Topminnows)	1	1.3 - 1.6	2.6 - 3.4	0.1 - 0.2	EP
Cottidae (Sculpin)	0	1.4 - 1.7	3.3 - 3.9	0*	CP, MS
Ictaluridae (Catfish)	1	1.3 - 2.0	2.0 - NA	NA - 0.2	EP, TZ
Cyprinidae (Minnows)	13	1.3 - 2.4	2.4 - 4.4	0* - 0.5	CP, EP, MS, RG, TZ
Catostomidae (Suckers)	5	1.3 - 2.5	2.2 - 3.2	NA - 0.8	CP, EP, MS, RG, TZ
Centrarchidae (Sunfish)	1	1.1 - 2.9	2.6 - NA	0.4 - NA	EP
Salmonidae (Trout)	3	2.3 - 4.0	4.5 - 7.5	1.0 - 7.0	MS, RG, TZ

SGCN = Species of Greatest Conservation Need, # of species/subspecies; * = fish species does not exhibit jumping behavior; NA = data were not available; CP = Colorado Plateau, EP = Eastern Plains, MS = Mountain Streams, RG = Rio Grande; TZ = Transition Zone

The values reported above are summarized from multiple species within each family and are intended to support passage for juvenile life stages. Swim speeds and jumping abilities within species are size dependent. Species-specific performance criteria should be used whenever possible. The selection of target species for individual projects should be based on the management objectives for the site in question. Consultation with the local Area Aquatic Biologist at CPW is strongly encouraged during the early planning stages for any fish passage project in Colorado. The information in this fact sheet is based on the best available data and knowledge, but is subject to revision as more information becomes available.