COLORADO PARKS & WILDLIFE

Upper Arkansas River Habitat Restoration Project:

2013–2015 Monitoring Report

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COVER PHOTOS

Top: Instream habitat restoration (Greg Policky)

Bottom, left to right: 1) Water quality sampling (Eric Richer); 2) Electrofishing survey (Mark Cole); 3) Weighing and measuring fish (Eric Richer); 4) Surveying habitat (Eric Richer)

Back cover: Instream habitat restoration (Tracy Kittell)

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Upper Arkansas River Habitat Restoration Project: 2013-2015 Monitoring Report

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Executive Summary

The objectives of habitat restoration were to rehabilitate and enhance aquatic habitat for an 11-mile reach of the Upper Arkansas River (UAR) on public and private lands. Funding for this project was obtained under the Natural Resource Damage Assessment (NRDA) provisions of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). 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 restoration project was designed to improve fish populations in the UAR as partial compensation to the public. Colorado Parks and Wildlife (CPW) is responsible for habitat restoration and monitoring on approximately five miles of public lands within the Crystal Lakes State Trust Lands (STL), Reddy State Wildlife Area (SWA), and Arkansas Headwaters Recreation Area (AHRA). Instream construction activities began in July 2013 and were completed in August 2014 for the CPW project reach.

Project goals were focused on enhancing the brown trout (*Salmo trutta*) population 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 streambanks, promoting diverse stream morphology, reducing erosion and downstream sedimentation, enhancing overhead cover for trout, increasing spawning areas, and providing refugia for juvenile trout. Project trustees identified monitoring targets 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, geomorphology, and metals accumulation in tree swallows. Progress towards project goals for primary monitoring targets are summarized in Table 1.

Table 1. Primary monitoring targets for the Upper Arkansas River habitat restoration project including a preliminary progress update for 2015.

Monitoring Target	Goal	Progress Update
Instream habitat structures	At least 90% of the habitat improvement structures are stable and functional by 2016	94% of habitat structures were stable and functional in 2014, but functional scores decreased to 87% in 2015. Maintenance activities were conducted during 2016 to improve stability and function.
Riparian vegetation	Increase riparian vegetation by at least 10% over baseline in fenced and replanted areas by 2018	Vegetation cover increased by 1% and 3% on average at treated and control sites, respectively. Additional vegetation work may be needed to meet this goal.
Fish populations	Increase fish population and fish health metrics by at least 10% over baseline conditions by 2018	Brown trout density declined by 6% at control sites, but increased by 4% at treatment sites on average. Biomass increased by 19% at treatment sites and 11% across all sites.
Benthic macroinvertebrates	Increase benthic macroinvertebrate metrics by at least 10% over baseline conditions by 2018	Metrics temporally declined at some sites, possibly due to impacts from metals pollution, high flows, or instream construction. Additional analyses are needed.
Habitat quality	Increase habitat quality scores by at least 10% over baseline conditions by 2018	Changes in habitat quality were 13.6% higher at treatment sites when compared to control sites.

Instream habitat structures, fish population metrics, and habitat quality scores have all achieved target goals. Over 90% of habitat structures were functional and stable when first assessed in 2014, but functional ratings decreased to 87% in 2015. Maintenance activities were subsequently conducted in 2016 for select structures in need of repair. Annual assessments will be used to monitor the performance of instream structures and assess the need for additional maintenance. Brown trout populations appear to have improved in the UAR despite ongoing issues with metals pollution. Although the density (#/acre) of fish has not increased significantly, metrics for fish biomass (lbs/acre) and quality (# ≥ 14"/acre) have increased by more than 10%, indicating that condition of the fish population has improved, presumably due to improved habitat conditions. Habitat suitability scores increased by an average of 10.0% at control sites as compared to a 23.6% increase at treatment sites. Net changes in habitat suitability were 13.6% greater at treatment sites compared to control sites, indicating that habitat restoration had achieved project goals for habitat quality. Future monitoring activities will determine if changes in brown trout populations and habitat quality are maintained.

Changes in riparian vegetation and benthic macroinvertebrate populations have not achieved project goals. Vegetation cover increased at both treated (1%) and control (3%) sites, but increases fell short of the 10% increase outlined in project goals. However, riparian seeding and willow planting occurred during the spring of 2015. Subsequent vegetation surveys were conducted in summer 2015, leaving little time for seeded and planted areas to respond to treatments. Additional surveys are scheduled for 2017 and 2019. Results from future surveys will be used to evaluate vegetation trends and inform the need for additional restoration activities. Benthic macroinvertebrate metrics exhibited substantial variability, possibly due to metals pollution, streambed mobilization, or impacts from instream construction activities. Benthic macroinvertebrate metrics showed temporary declines following construction, but decreases were observed at both control and treatment sites, suggesting that declines may be related to water quality or flow magnitudes rather than direct effects from instream construction. Additional analyses are needed to investigate the relationship between benthic macroinvertebrate metrics and potential explanatory variables.

Secondary monitoring targets included water quality, geomorphology, and tree swallows. Water quality monitoring during habitat restoration indicated that instream construction activities did not mobilize contaminated sediments at levels of concern. Although water quality has improved over time in response to remediation activities, chronic and/or acute standards for cadmium, lead, and zinc were exceeded at monitoring sites within the project reach. Exceeding chronic and acute water quality standards can impair aquatic and terrestrial resources, including fish, benthic macroinvertebrates, and riparian vegetation. Variability in benthic macroinvertebrate metrics could be related to ongoing issues with metals pollution. The duration and magnitude of exceeded water quality standards suggests that additional remediation activities could further improve fishery resources in the UAR.

Geomorphology monitoring included assessment of cross-sections, residual pool depths (RPD), and sediment gradation. The bankfull cross-sectional area decreased at many cross-sections, indicating that channel-narrowing activities were successful in addressing over-wide channel conditions and improving floodplain connectivity. Width/depth ratios decreased for low to medium flows at treated fish monitoring sites, while control sites exhibited little change in width/depth. Sediment gradation metrics decreased at most monitoring sites following instream construction, increasing the prevalence of spawning gravels in some locations. Sediment transport during high flows in 2014 likely contributed to the increase in spawning gravels, but reduced channel capacity from restoration activities could have improved sediment transport capacity and associated channel maintenance benefits.

Metals accumulation in tree swallows was not assessed during this reporting period. Monitoring activities for tree swallows are being directed by the U.S. Fish and Wildlife Service (USFWS) and are scheduled to take place during 2018-2019. Results from post-implementation monitoring will be compared to baseline data to evaluate if metals contamination in riparian bird communities has improved.

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Acknowledgements

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Chapter 1: Background

1.1 Introduction

The objectives of the Upper Arkansas River (UAR) habitat restoration project are to rehabilitate and enhance aquatic habitat for an 11-mile reach of the Arkansas River and Lake Fork on both public and private lands. Funding for this project was obtained under the Natural Resource Damage Assessment (NRDA) provisions of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) for harm to natural resources caused by metals pollution released from the California Gulch Superfund Site (Stratus, 2010a; 2010b). Physical disturbance during mining activities, historic land-use, and transbasin water diversions also contributed to aquatic habitat degradation in the UAR. The NRDA conducted for the UAR found evidence of injury to surface water, groundwater, riparian, and terrestrial resources (Industrial Economics, 2006). These damages included, but were not limited to, decreases in fish and benthic macroinvertebrate populations and degradation of riparian vegetation and river morphology (Stratus, 2010b). This project was designed to improve fish populations in the UAR as partial compensation to the public. Colorado Parks and Wildlife (CPW) is responsible for habitat restoration and monitoring on approximately five miles of public lands within the Crystal Lakes State Trust Lands (STL), Reddy State Wildlife Area (SWA), and Arkansas Headwaters Recreation Area (AHRA).

This document provides an overview of the monitoring program and presents results from two years of post-implementation monitoring. For monitoring purposes, the project extent was divided into two reaches: the (1) Crystal-Reddy reach, upstream of the US-24 Bridge (Figure 1.1); and the (2) Hayden Reach, from the US-24 Bridge downstream to the Kobe Bridge (Figure 1.2). The following goals for the restoration project were established by the NRDA Trustees Council (Stratus, 2010a):

1. Increase trout population density and biomass, including improvement in body condition and fish health.
2. Improve age and size-class structure by increasing spawning areas where possible and provide refugia for juvenile trout.

These goals were addressed by stabilizing streambanks, promoting diverse stream morphology, reducing erosion and downstream sedimentation, enhancing overhead cover for trout, increasing spawning areas, and providing refugia for juvenile trout (Stratus, 2010a). Instream construction activities began in July 2013 and were completed in August 2014. All instream work in the Reddy reach was completed in 2013. Instream construction in the Hayden reach was initiated in 2013 and completed in 2014. Riparian seeding and willow planting were conducted during spring 2015 in the Hayden Reach only. Treatments included boulder clusters, boulder- and log-vanes, point bar and pool development, wood-toe sod mat, grade control, willow transplants, willow planting, riparian seeding, side channel fill, island removal, and channel narrowing. Examples of restoration treatments are presented as before and after photographs in Figures 1.3-1.6. Final quantities for all major treatment types are presented in Table 1.1 and as-built drawings for the project are included in Appendix A.

1.2 Monitoring Targets

Monitoring targets were identified in Stratus (2010a) and approved by the NRDA trustees to provide measurable criteria for project evaluation. Monitoring activities were divided into three categories: baseline, implementation, and effectiveness. Data collected prior to instream construction were used to represent baseline conditions. Implementation monitoring focused on documenting restoration treatments, while effectiveness monitoring was used to evaluate project goals. Annual monitoring was scheduled for a five-year period following construction. Additional monitoring activities were scheduled for years seven and ten, but the scope of these activities will depend on available funding and results from the five-year post-construction monitoring period.

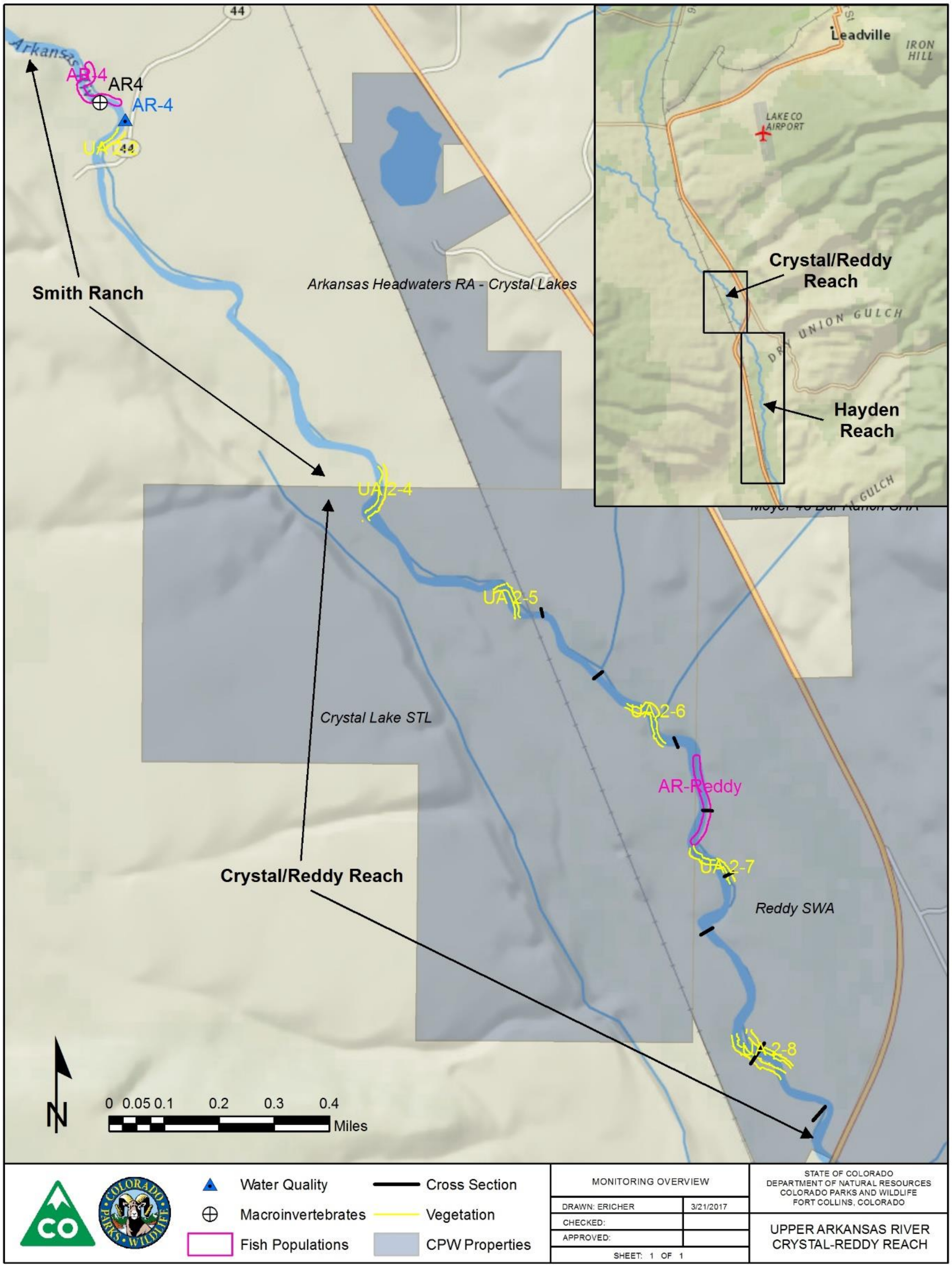


Figure 1.1. NRDA monitoring sites within the Crystal-Reddy Reach on the Upper Arkansas River.

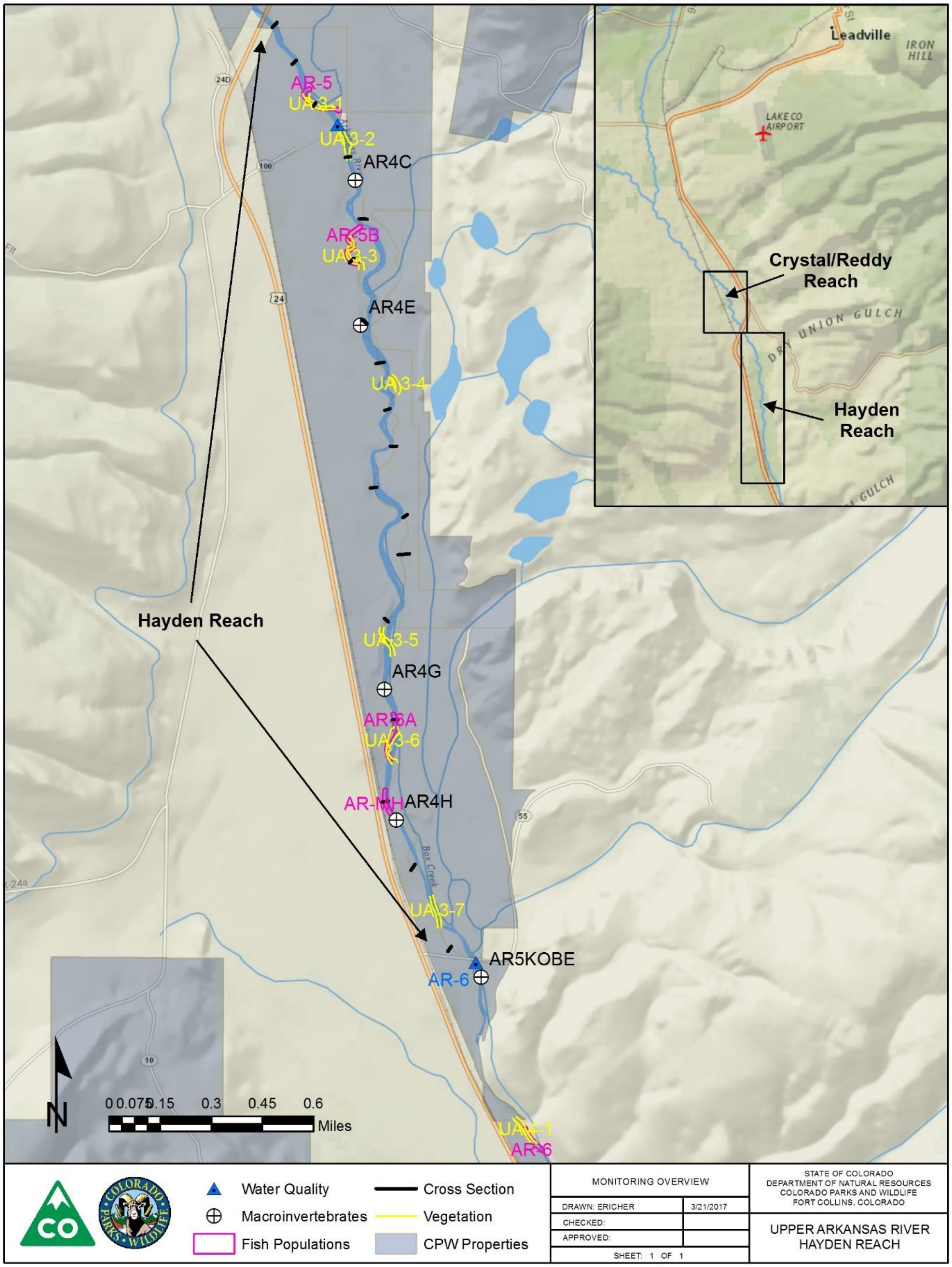


Figure 1.2. NRDA monitoring sites within the Hayden Reach on the Upper Arkansas River.

Figure 1.3. Before vs. after photos showing the treatment of excessive bank erosion with wood-toe, sod mats, and willow transplants on the Upper Arkansas River.

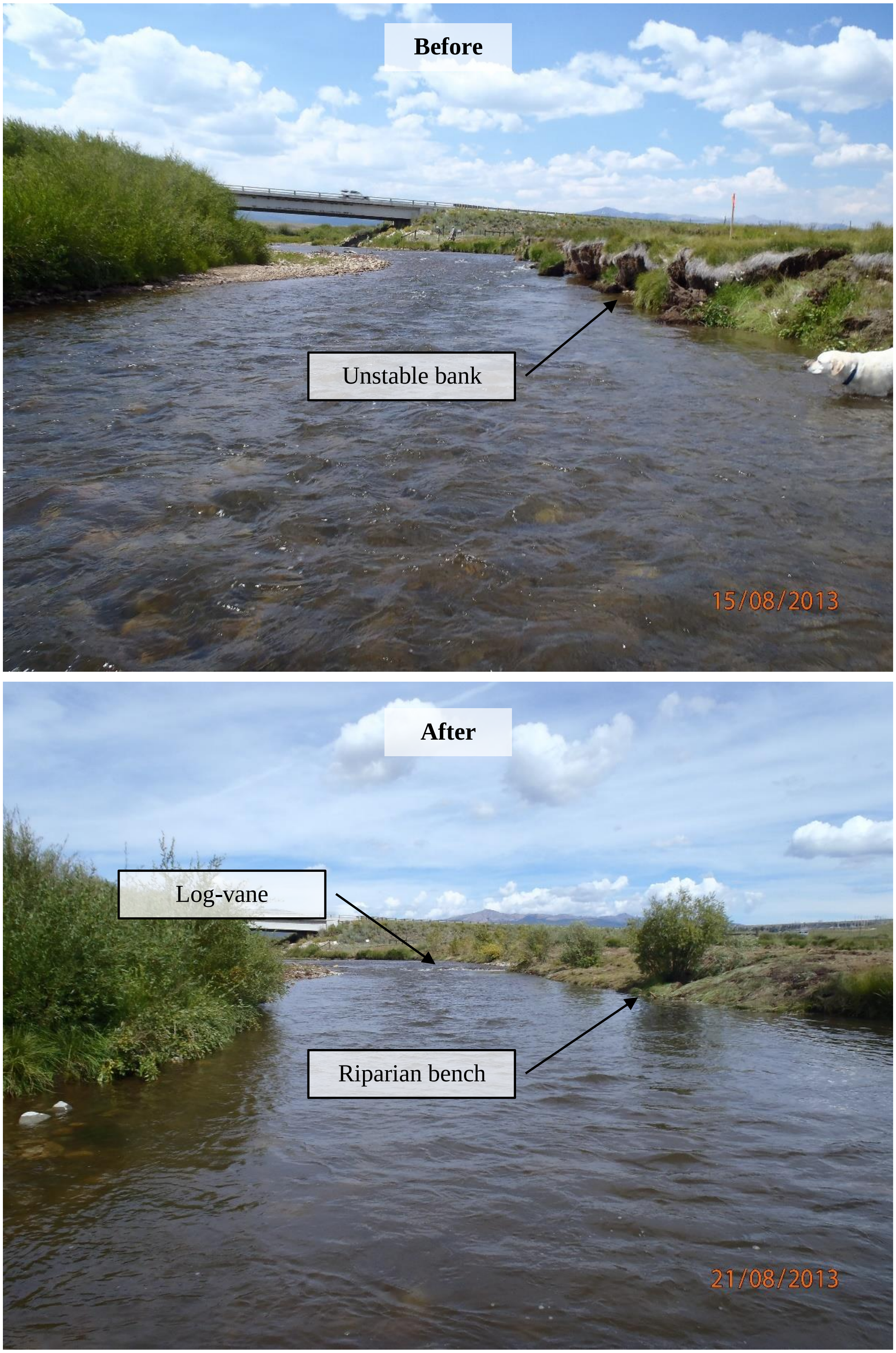
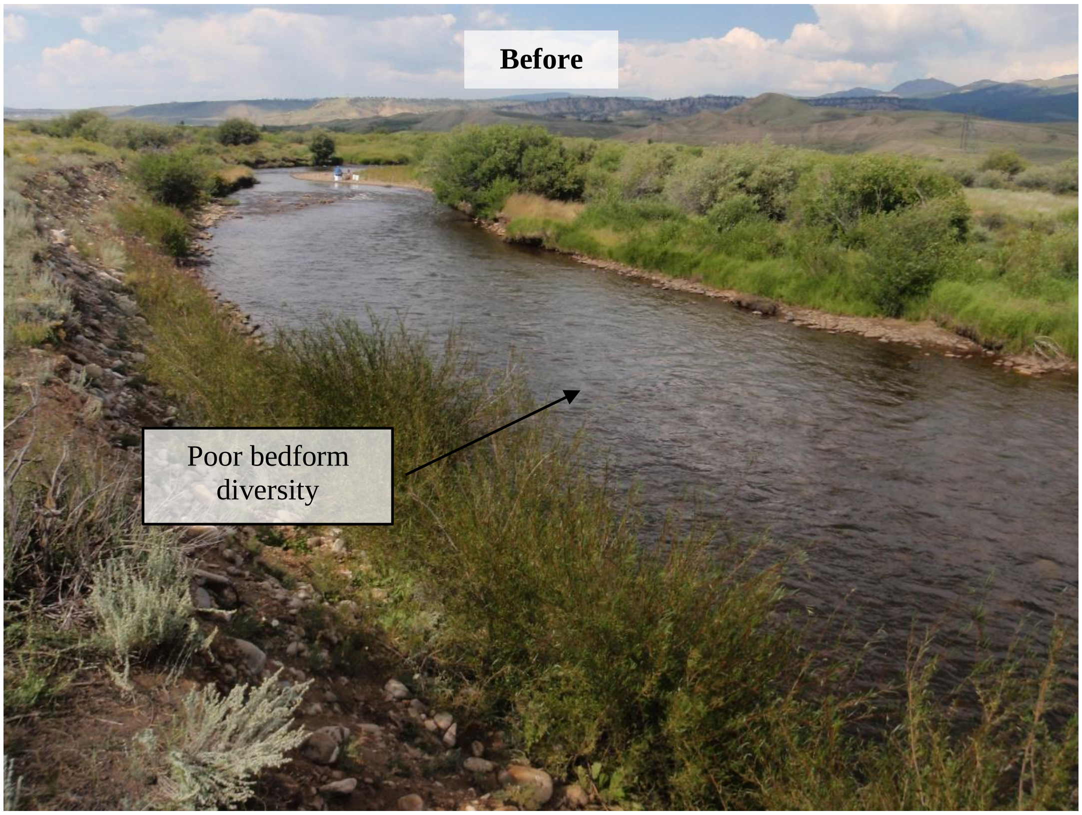


Figure 1.4. Before vs. after photos showing treatment of unstable bank with log-vanes and riparian bench consisting of sod mats and willow transplants on the Upper Arkansas River.



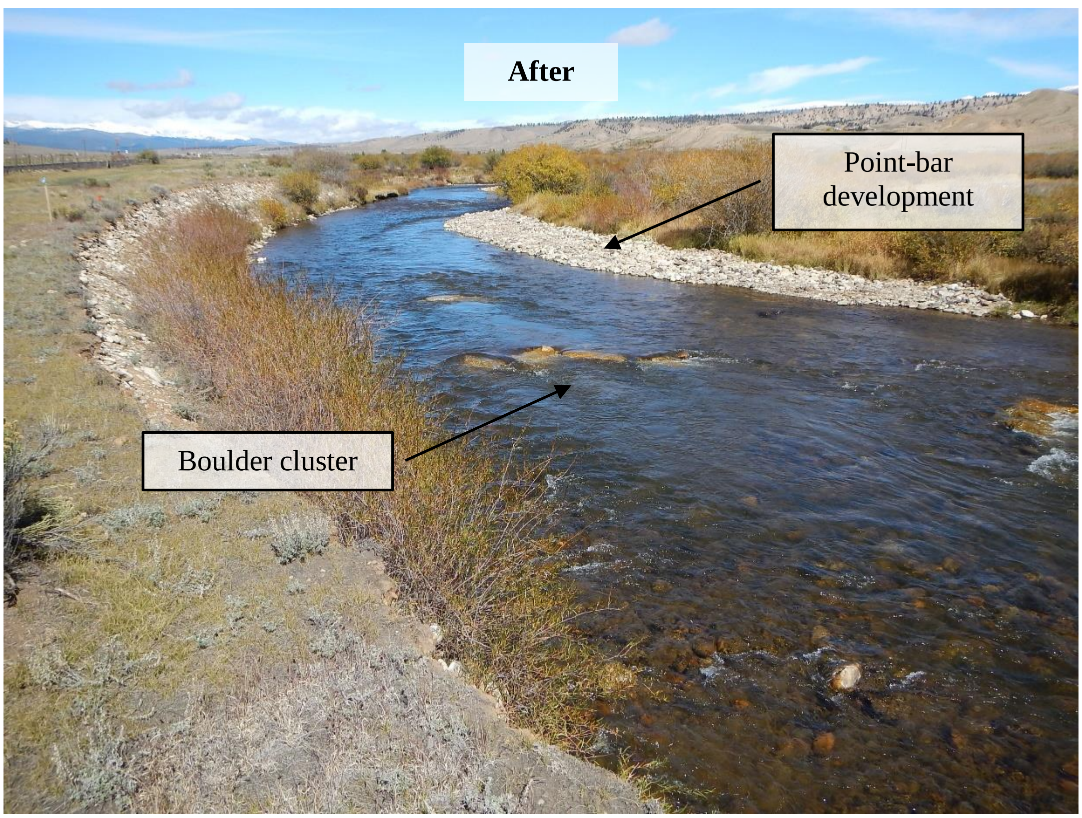


Figure 1.5. Before vs. after photos showing treatment of a reach characterized by poor bedform diversity with point-bar development, pool development, and boulder clusters on the Upper Arkansas River.

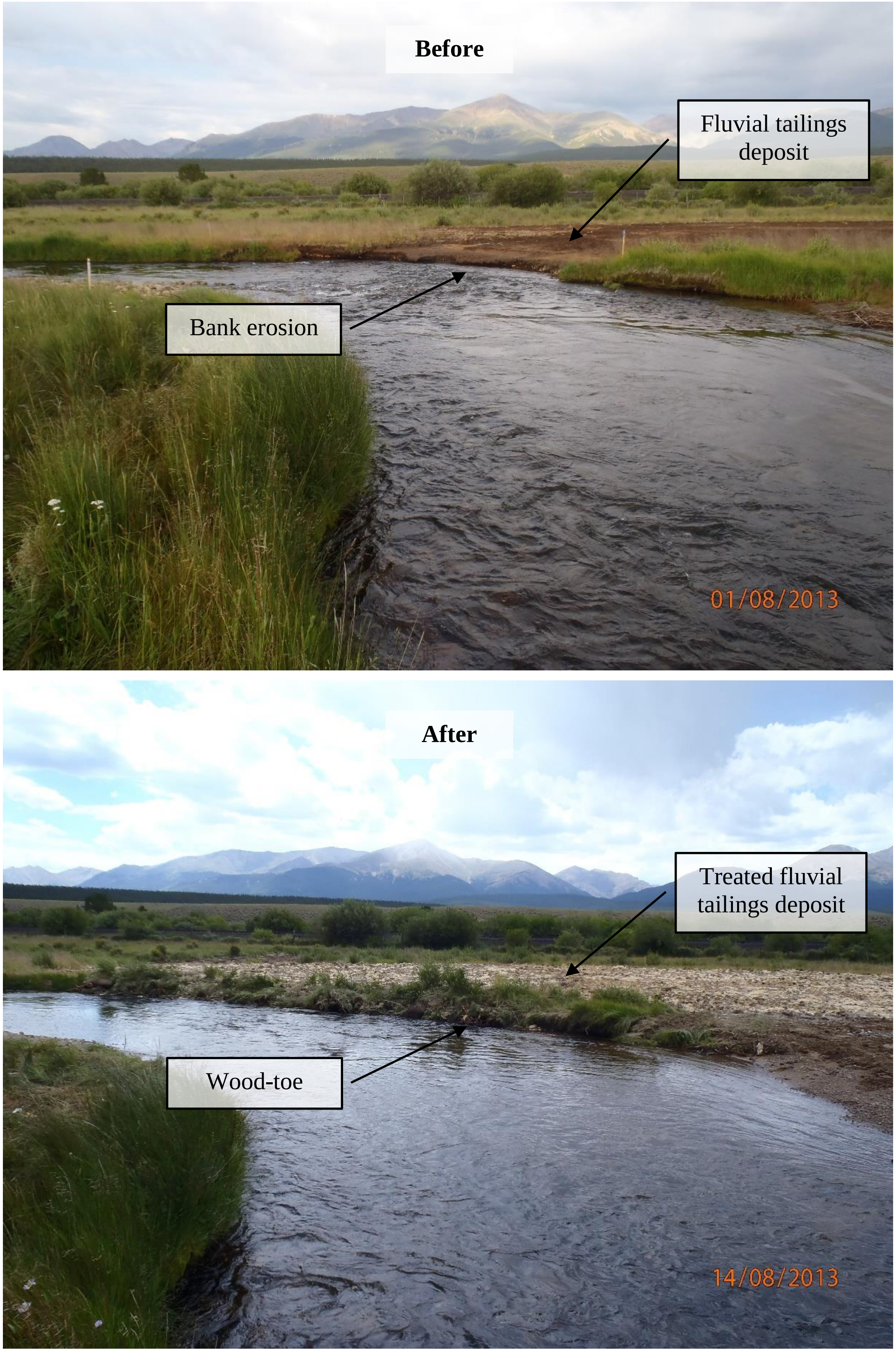


Figure 1.6. Before vs. after photos showing treatment of a fluvial tailing deposit and stabilization of an eroding bank with wood-toe on the Upper Arkansas River.

Table 1.1. Final treatment quantities for the Upper Arkansas River habitat restoration project.

Treatments	Unit	Quantity
Boulder-vane/j-hook	EA	15
Log-vane	EA	49
Boulder cluster	EA	64
Point bar & pool development	SF	5,780
Wood-toe sod mat	LF	1,320
Boulder grade control	LF	443
Mid-channel pool excavation	EA	10
Willow transplant	EA	315
Willow planting	SF	35,080
Riparian seeding	SF	41,490
Side channel fill/roughening	SF	4,475
Cobble-toe bank protection	LF	540
Mid-channel island removal	SF	3,050
Harvest and install sod mat	SF	13,112
Narrow channel with cobble	SF	1,920

Monitoring surveys were conducted to evaluate the condition of instream habitat structures and riparian fencing. Topographic surveys and habitat modeling were used to evaluate changes in geomorphology and habitat suitability. Biological monitoring assessed fish populations, benthic macroinvertebrate populations, riparian vegetation, and tree swallow populations using a Before-After-Control-Impact (BACI) study design (Stratus, 2010a). Due to the history of metals pollution in the UAR, water quality was monitored at historic sites within the project reach to support trend analysis and evaluate water quality standards. The project will utilize adaptive management to address any monitoring components that fail to meet their stated objectives. The monitoring program was designed to evaluate the following targets:

- By year three (after implementation), are at least 90% of the habitat improvement structures (e.g., boulders, constructed instream and bank structures, fencing, planted vegetation) stable and functional?

- By year three, has riparian vegetation cover become successfully established and increased by at least 10% over baseline in fenced and replanted areas?

- By year five, have brown trout population and benthic macroinvertebrate metrics in restored areas improved by a minimum of 10% over baseline conditions (with adjustments made for unusual weather or flow conditions)?

- By year five, have habitat quality scores for restored areas improved by a minimum of 10% over baseline conditions?

1.3 Monitoring Sites

The location of monitoring sites for fish populations, benthic macroinvertebrates, riparian vegetation, water quality, and geomorphology are depicted in Figures 1.1 and 1.2. Monitoring sites are also delineated on as-built drawings in Appendix A. As sites have been variously identified and named by an assortment of organizations, all site names are presented in Table 1.2 along with their status as control or treatment. The distribution of sites is presented from upstream to downstream with sites that occur in approximately the same location aligned horizontally (Table 1.2).

1.4 Monitoring Schedule

The monitoring schedule for the project is outlined in Table 1.3. The first year of effectiveness monitoring for instream structures, fish populations, benthic macroinvertebrates, geomorphology, habitat modeling, and water quality was 2014. Effectiveness monitoring for riparian vegetation was initiated in 2015. Post-construction creel surveys will begin in 2017, while post-construction tree swallow studies are scheduled to begin in 2018.

Table 1.2. Monitoring sites for the Upper Arkansas River habitat restoration project including control/treatment designation and year treated. Sites that occur in the same location are aligned horizontally.

Reach	Fish Populations	Macro-invertebrates	Riparian Vegetation	Water Quality	Control/ Treatment	Year Treated
Smith Ranch	AR-4	AR-4	UA 2-2	AR-4	Treatment	2012
Crystal Lake STL	--	--	UA 2-4	--	Control	--
	--	--	UA 2-5	--	Control	--
	--	--	UA 2-6	--	Treatment	2013
Reddy SWA	AR-R	--	--	--	Treatment	2013
	--	--	UA 2-7	--	Treatment	2013
	--	--	UA 2-8	--	Treatment	2013
Hayden Reach	AR-5	--	UA 3-1	AR-5	Treatment	2013
	--	--	UA 3-2	--	Treatment	2013
	--	AR-4.C	--	--	Treatment	2013
	AR-5B	--	--	--	Control	--
	--	--	UA 3-3	--	*Treatment	2013
	--	AR-4.E	--	--	Treatment	2013
	--	--	UA 3-4	--	Treatment	2013
	--	--	UA 3-5	--	Treatment	2014
	--	AR-4.G	--	--	Treatment	2014
	AR-6A	--	UA 3-6	--	Control	--
	AR-MH	AR-4.H	--	--	Treatment	2014
	--	--	UA 3-7	--	Treatment	2014
Kobe Reach	--	AR-5.Kobe	--	AR-6	Control	--
	AR-6	--	UA 4-1	--	Control	--

*UA 3-3 was initially delineated as a control site but was partially treated during construction.

Table 1.3. Monitoring schedule for the Upper Arkansas River habitat restoration project.

Target	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Construction		C	C									
Instream structures			I/E	E	E	E	E		E			E
Fencing integrity	E	E	E	E	E	E	E		E			E
Riparian vegetation	B			E		E		E				E
Photographic survey	B	B	I/E	E	E	E	E		E			E
Fish populations	B		E	E	E	E	E		E			E
Creel surveys	B					E			E			E
Benthic macroinvertebrates	B	B	E	E	E	E	E		E			E
Tree swallows							E	E				E
Geomorphology	B	B/I	E	E	E	E	E		E			E
Habitat modeling		B	I/E		E		E		E			E
Water quality		I	E	E	E	E	E		E			E

C = Construction; B = Baseline; I = Implementation; E = Effectiveness monitoring

1.5 References

Stratus Consulting, Inc. 2010a. Draft restoration monitoring and outreach plan for the upper Arkansas River watershed. Boulder, Colorado. 63 pp.

Stratus Consulting, Inc. 2010b. Restoration Plan and Environmental Assessment for the Upper Arkansas River Watershed. Boulder, Colorado. 103 pp.

Industrial Economics, Inc. 2006. Upper Arkansas River Basin Natural Resource Damage Assessment: Preliminary Estimate of Damages. Cambridge, Massachusetts. 79 pp.

Chapter 2: Water Quality

2.1 Introduction

Historical mining activities in the Upper Arkansas River (UAR) basin caused extensive heavy metal pollution and led to designation of the California Gulch Superfund Site. The California Gulch Superfund Site has an area of more than 15 square miles and contains at least 2,000 mine waste piles (Stratus, 2010). The site includes the Yak Drainage Tunnel, which discharges wastewater from numerous underground mines into California Gulch. The effluent from the Yak Tunnel has been treated since 1991 to reduce metal concentrations released into California Gulch. Numerous fluvial tailing deposits are located throughout riparian areas and have contributed to metals pollution in UAR. The Environmental Protection Agency (EPA) was responsible for treating fluvial tailings deposits to reduce metals loading and facilitate re-establishment of riparian vegetation. Other metals sources include the Sugarloaf Mining District, which drains to the Lake Fork of the Arkansas River. Given the history of metals pollution in the UAR, it was important to monitor water quality both during and following instream habitat restoration. The objectives of this chapter are to evaluate the impact of construction activities on water quality, present long-term water quality trends, and investigate exceedance of water quality standards.

2.2 Methods

Water Quality Sampling and Analysis

Baseline water quality data were collected at standard sampling sites from 1994-2005 (Brinkman et al., 2006). Additional water samples have been collected throughout the UAR basin by various entities and compiled into a water quality database that includes over 10,000 unique samples dating from 1967 to 2011. Given the history of water quality issues in the UAR basin, CPW monitored water quality during and following instream construction activities. In 2013, water samples were collected for implementation monitoring to evaluate the direct impacts of instream construction on metals concentrations. During construction, water samples were collected three times a day to evaluate metal concentrations (1) in the morning prior to construction activities, (2) mid-day during the peak of construction activities, and (3) in the evening after completion of construction activities. Post-construction water quality monitoring was conducted in 2014-2015. During these years, sampling occurred on a stratified schedule designed to capture the flushing effects associated with spring runoff. Samples were collected weekly during snowmelt runoff and less frequently during hydrograph recession and baseflow (Figure 2.1). Approximately 15 samples were collected from three monitoring sites (AR-4, AR-5, and AR-6) each year. These data were used to evaluate metal concentrations within the project reach and variability in fish and benthic macroinvertebrate populations.

For this report, data analysis was focused on three water quality monitoring sites: AR-4 (above the project reach), AR-5 (within the project reach), and AR-6 (below the project reach). The location of water quality sites addressed in this report, the California Gulch Superfund Site, and fluvial tailing deposits are shown in Figure 2.2. Two water quality sites were located adjacent to a benthic macroinvertebrate site (Table 1.2). Water samples were collected by Colorado Mountain College (CMC) and shipped to the River Watch laboratory in Fort Collins for analysis using spectrophotometry. Standard Environmental Protection Agency (EPA) water quality protocols were followed during sampling, processing, and shipping of water samples. Field splits and blanks were collected for QA/QC, comprising approximately 10% of all samples. All water samples were analyzed for total and dissolved metals and cations, including aluminum (Al), arsenic (As), calcium (Ca), cadmium (Cd), copper (Cu), iron (Fe), lead (Pb), magnesium (Mg), manganese (Mn), potassium (K), selenium (Se), sodium (Na), and zinc (Zn). Basic water chemistry (i.e., pH, alkalinity, conductivity, temperature, and dissolved oxygen) was

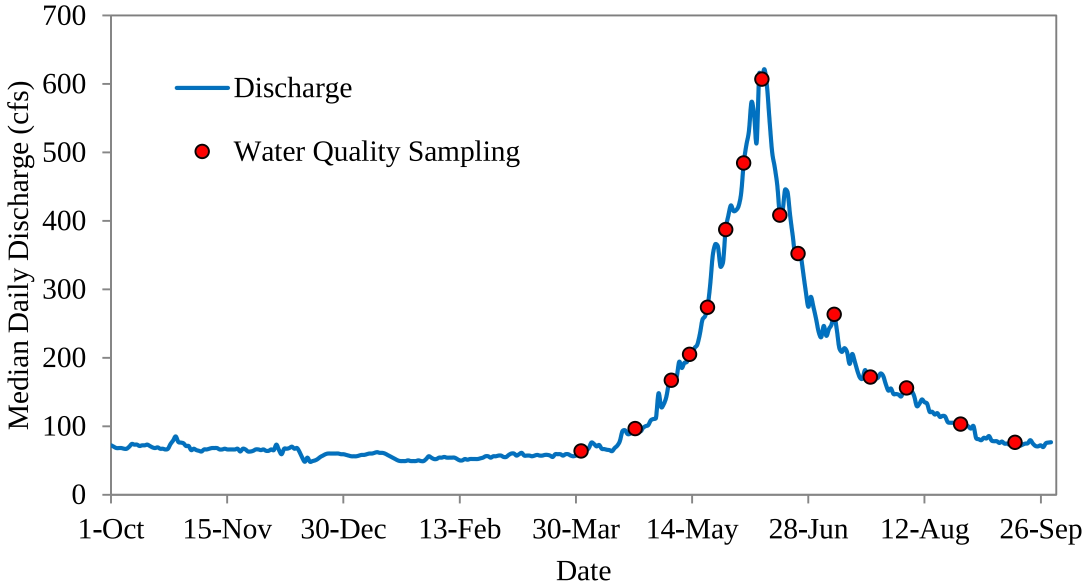


Figure 2.1. Water quality sampling schedule based on characteristic hydrology for the Upper Arkansas River below Empire Gulch.

measured and recorded in the field during all sampling events. Additional information on historical water quality methods can be found in Brinkman et al. (2006) and Clements et al. (2010). Water quality data from California Gulch (CG-6) and AR-1 were obtained from Tetra Tech (2016) and analyzed for 2014 to evaluate if the Superfund Site was still a significant source of metals to the UAR.

Numerous water quality studies have been conducted for the UAR (e.g., Davies et al., 1997; Davies et al., 2000; Davies et al., 2002; Brinkman et al., 2006) and previous research has shown that metal concentrations are typically highest during snowmelt runoff (Davies et al., 1997; EPA, 2004; Brinkman et al., 2006). Therefore, we evaluated metal concentrations on both an annual and seasonal (i.e., spring) basis. The spring season included the months of April, May, June, and July in accordance with Brinkman et al. (2006). Zinc and cadmium are the primary metals of concern for aquatic life based on the frequency and magnitude of exceeded water quality standards (Davies et al., 1997; Davies et al., 2000; Brinkman et al. 2006). Other metals, such as copper, iron, and aluminum, have also exceeded water quality criteria, but less frequently than zinc and cadmium (Brinkman et al., 2006).

For trend analysis, water quality data from 2013-2015 were compared to historical values in the UAR water quality dataset. As some observations were reported below the Method Detection Limit (MDL), the MDL was treated as the lower bounds for this analysis. The MDL is the minimum concentration of a substance that can be measured with 99% confidence that the concentration is greater than zero. Advances in technology have improved analytical capabilities and decreased MDLs, resulting in the appearance of decreasing concentrations through time for some metals. When observations represent only the MDL or changes in the MDL, clarification is provided in the figure caption. Water quality box plots provided a qualitative means to evaluate temporal and spatial trends for metal concentrations, but statistical analysis was not used to test for trend significance. For all box and whisker plots, the box represents the three quartiles and the whiskers represent minimum and maximum values, unless the subset of data includes outliers. Outliers are defined as any value outside 1.5 times the interquartile range. If outliers are present, whiskers will illustrate 1.5 times the interquartile range above the upper quartile and below the lower quartile. When present, outliers will appear as points above or below the whiskers.

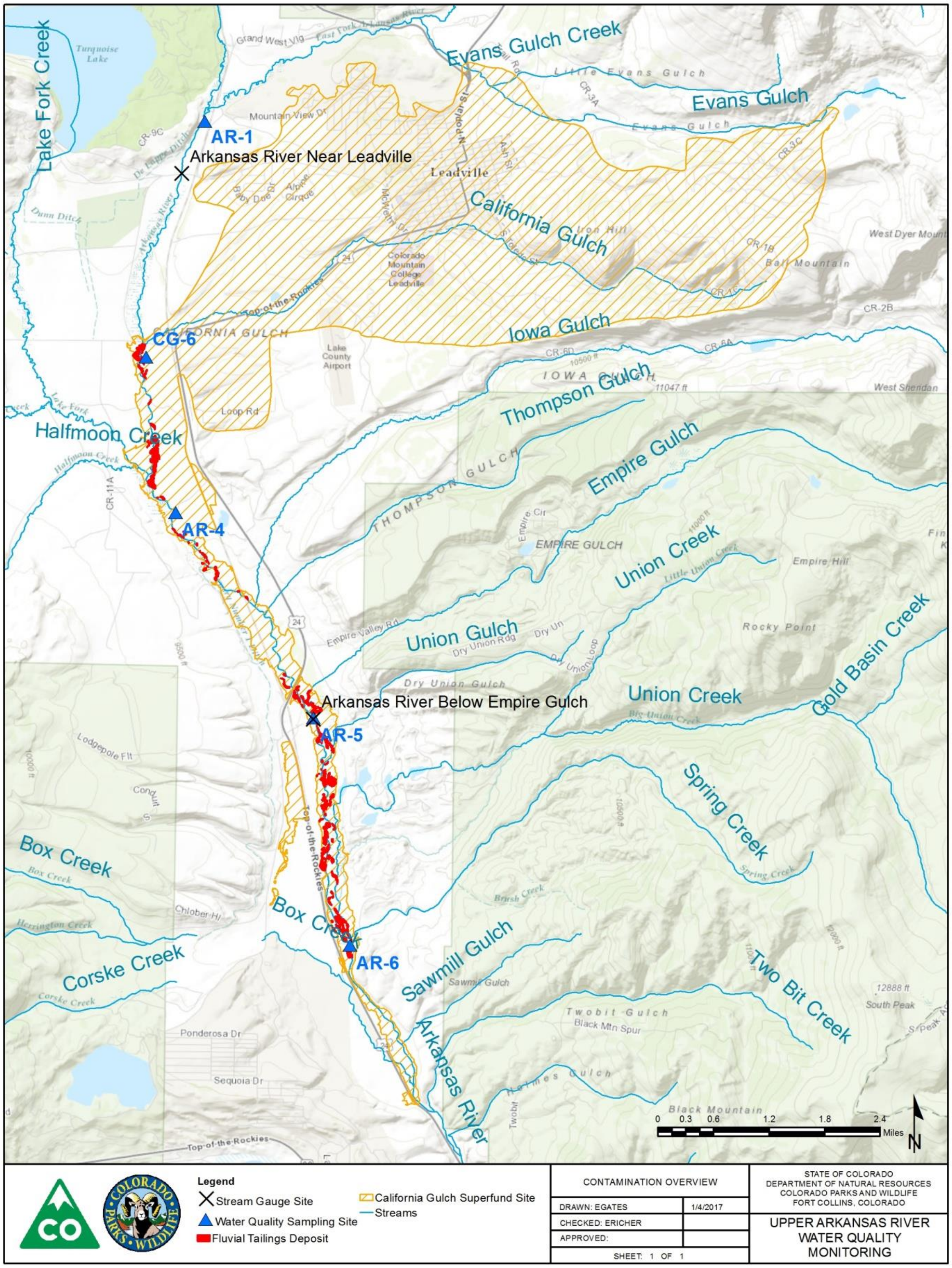


Figure 2.2. Contamination overview for the Upper Arkansas River including water quality monitoring sites addressed in this report, the California Gulch Superfund Site, and fluvial tailings deposits.

Hydrology

Average daily discharge data for the Arkansas River Below Empire Gulch Near Malta, CO (USGS 07083710) stream gauge were used to analyze hydrology for the project reach. This stream gauge is operated seasonally from May 1 to August 31, but did operate annually (October 1 to September 30) during water years (WY) 1991-1993. However, no discharge data were available from this stream gauge for WY 1994-2003. All available discharge data from 1990-2015 were used to calculate a median discharge value for each day of the WY. Historical median values were used to represent a "typical" hydrograph for the project reach. The historical medians were compared to observed discharge vales for WY 2013, 2014, and 2015. Flood frequency analysis (FFA) was also performed using the USGS PeakFQ application and all 16 years of available peak discharge data from 1990-2015. These analyses were used to evaluate the magnitude and timing of snowmelt runoff for each year.

Discharge data from the Arkansas River Near Leadville, CO (USGS 07081200) stream gauge were used to represent hydrology above the confluence with California Gulch. As this stream gauge operates annually, data can be used to evaluate the timing and magnitude of snowmelt runoff during the spring when the gauge below Empire Gulch is offline. In addition, this gauge has 42 years of historical peak discharge data to support FFA. However, the gauge is located above the confluences with the Lake Fork, Halfmoon Creek, Iowa Gulch, and Thompson Gulch. The additional flow from these tributaries is captured at the gauge below Empire Gulch, making data from that stream gauge more representative of flows within the project reach. The location of both stream gauges is depicted on Figure 2.2. FFA was also performed for the Leadville gauge to take advantage of the longer period of record for this site.

Water Quality Standards

Water quality samples collected during 2013-2015 were analyzed for dissolved and total metals and compared to acute and chronic water quality standards. As water hardness affects the toxicity of metals for aquatic biota (Stubblefield et al. 1997; Penttinen et al. 1998; Brinkman et al., 2006), water quality standards for some metals are based on hardness as mg/L $CaCO_3$. Aluminum, cadmium, copper, manganese, lead, and zinc all have hardness-based standards. Hardness was calculated using Equation 2.1 for all comparisons to water quality standards. The acute and chronic standards for aluminum, cadmium, copper, lead, manganese and zinc were calculated using Equations 2.2-2.13 below (CDPHE, 2013). Aluminum, arsenic, cadmium, copper, lead, manganese, selenium, and zinc concentrations were checked against water quality standards and only those that exceeded are discussed. The duration of exceedance was estimated by calculating the number of days between an observed exceedance and the next observation that did not exceed water quality standards. The duration of exceedance for each metal was then totaled by year.

Equation 2.1:

$$\text{Hardness}\,[\text{CaCO}_3](\text{mg}/\text{L}) = 2.5 * [\text{Ca}^{2+}] + 4.1 * [\text{Mg}^{2+}]$$

Equation 2.2:

$$\text{Al}_{\text{Acute Standard}}(\mu\text{g}/\text{L}) = e^{1.3695\times\ln(\text{Hardness}) + 1.8308}$$

Equation 2.3:

$$\text{Al}_{\text{Chronic Standard}}(\mu\text{g}/\text{L}) = e^{1.3695\times\ln(\text{Hardness}) - 0.1158}$$

Equation 2.4:

$$\text{Cd}_{\text{Acute Standard}}(\mu\text{g}/\text{L}) = (1.136672 - \ln(\text{Hardness}) \times 0.041838)e^{0.9151\times\ln(\text{Hardness}) - 3.1485}$$

Equation 2.5:

$$\mathrm{Cd}_{\text{Chronic Standard}}\left(\mu\mathrm{g}/\mathrm{L}\right) = (1.101672 - \ln(\text{Hardness}) \times 0.041838)e^{0.7998 \times \ln(\text{Hardness}) - 4.4451}$$

Equation 2.6:

$$\mathrm{Cu}_{\text{Acute Standard}}\left(\mu\mathrm{g}/\mathrm{L}\right) = e^{0.9422 \times \ln(\text{Hardness}) - 1.7408}$$

Equation 2.7:

$$\mathrm{Cu}_{\text{Chronic Standard}}\left(\mu\mathrm{g}/\mathrm{L}\right) = e^{0.8545 \times \ln(\text{Hardness}) - 1.7428}$$

Equation 2.8:

$$\mathrm{Pb}_{\text{Acute Standard}}\left(\mu\mathrm{g}/\mathrm{L}\right) = (1.46203 - \ln(\text{Hardness}) \times 0.145712)e^{1.273 \times \ln(\text{Hardness}) - 1.46}$$

Equation 2.9:

$$\mathrm{Pb}_{\text{Chronic Standard}}\left(\mu\mathrm{g}/\mathrm{L}\right) = (1.46203 - \ln(\text{Hardness}) \times 0.145712)e^{1.273 \times \ln(\text{Hardness}) - 4.705}$$

Equation 2.10:

$$\mathrm{Mn}_{\text{Acute Standard}}\left(\mu\mathrm{g}/\mathrm{L}\right) = e^{0.3331 \times \ln(\text{Hardness}) + 6.4676}$$

Equation 2.11:

$$\mathrm{Mn}_{\text{Chronic Standard}}\left(\mu\mathrm{g}/\mathrm{L}\right) = e^{0.3331 \times \ln(\text{Hardness}) + 5.8743}$$

Equation 2.12:

$$\mathrm{Zn}_{\text{Acute Standard}}\left(\mu\mathrm{g}/\mathrm{L}\right) = 0.978 \times e^{0.9094 \times \ln(\text{Hardness}) + 0.9095}$$

Equation 2.13:

$$\mathrm{Zn}_{\text{Chronic Standard}}\left(\mu\mathrm{g}/\mathrm{L}\right) = 0.986 \times e^{0.9094 \times \ln(\text{Hardness}) + 0.6235}$$

2.3 Results and Discussion

Water Quality Trends

All available water quality data were analyzed for long-term trends at sites AR-4, AR-5, and AR-6. Long-term trends for total and dissolved metals are presented for each site on an annual and seasonal (spring) basis. Because cadmium and zinc have been the two metals of primary concern in the UAR, seasonal observations for those metals are presented in Figures 2.3 and 2.4, respectively. Plots for all other metals, hardness, pH, and number of samples per year are included in Appendix B. Box plots show that cadmium and zinc concentrations have declined in magnitude and variability through time (Figures 2.3-2.4; Appendix B). Both metals show a distinct decrease in median concentration around 1998. Dissolved concentrations were typically lower than total concentrations, but data were not tested for statistical differences between total and dissolved concentrations. In general, metals concentrations decreased from upstream to downstream due to dilution from tributaries. However, declining metals concentrations were more evident between AR-4 and AR-6 than AR-4 and AR-5.

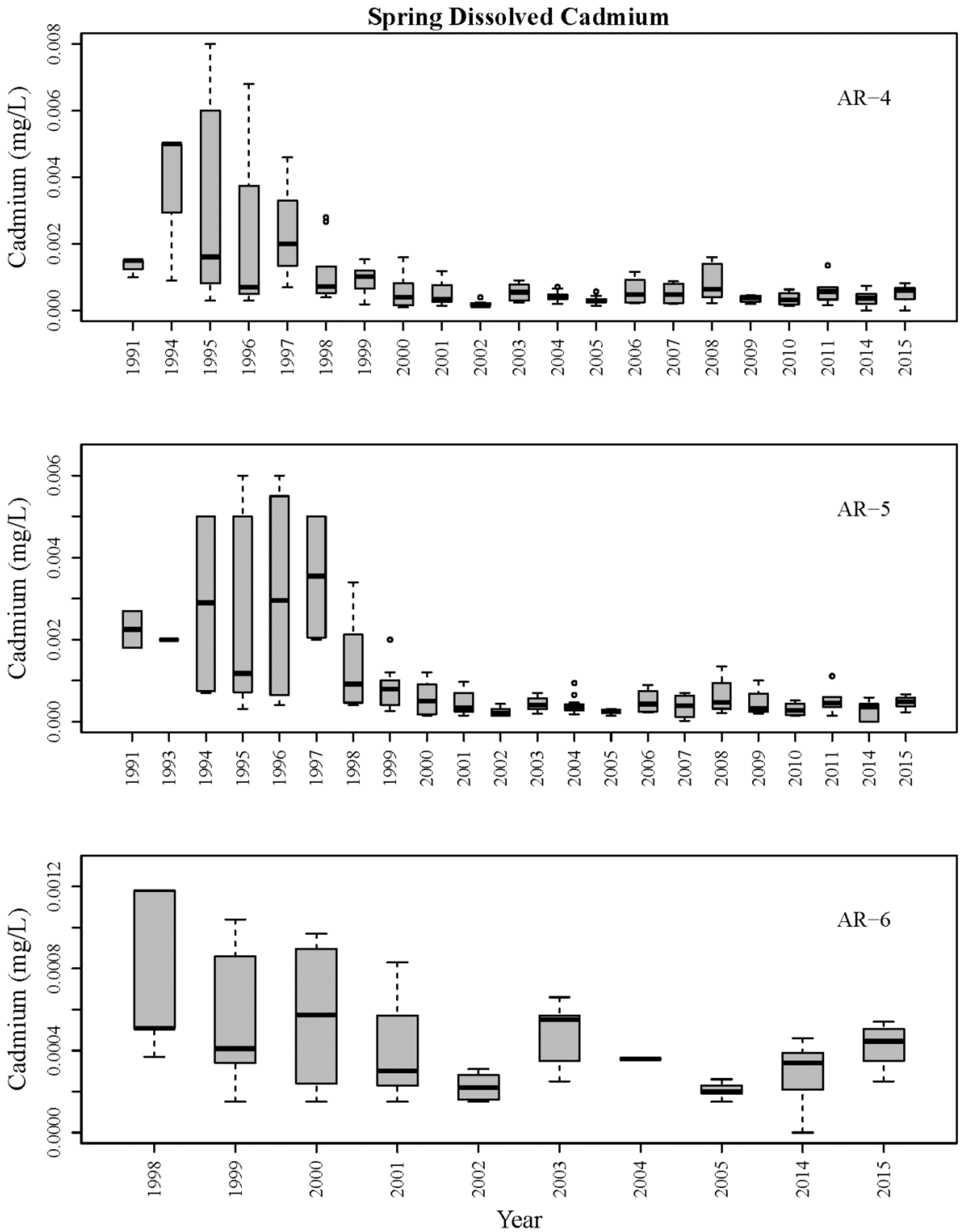


Figure 2.3. Dissolved cadmium concentrations summarized for the spring season (April-July) at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River. The y-axis was limited to exclude one observation at AR-5 of 0.03 mg/L in 1998, and one observation at AR-6 of 0.00254 mg/L in 1998.

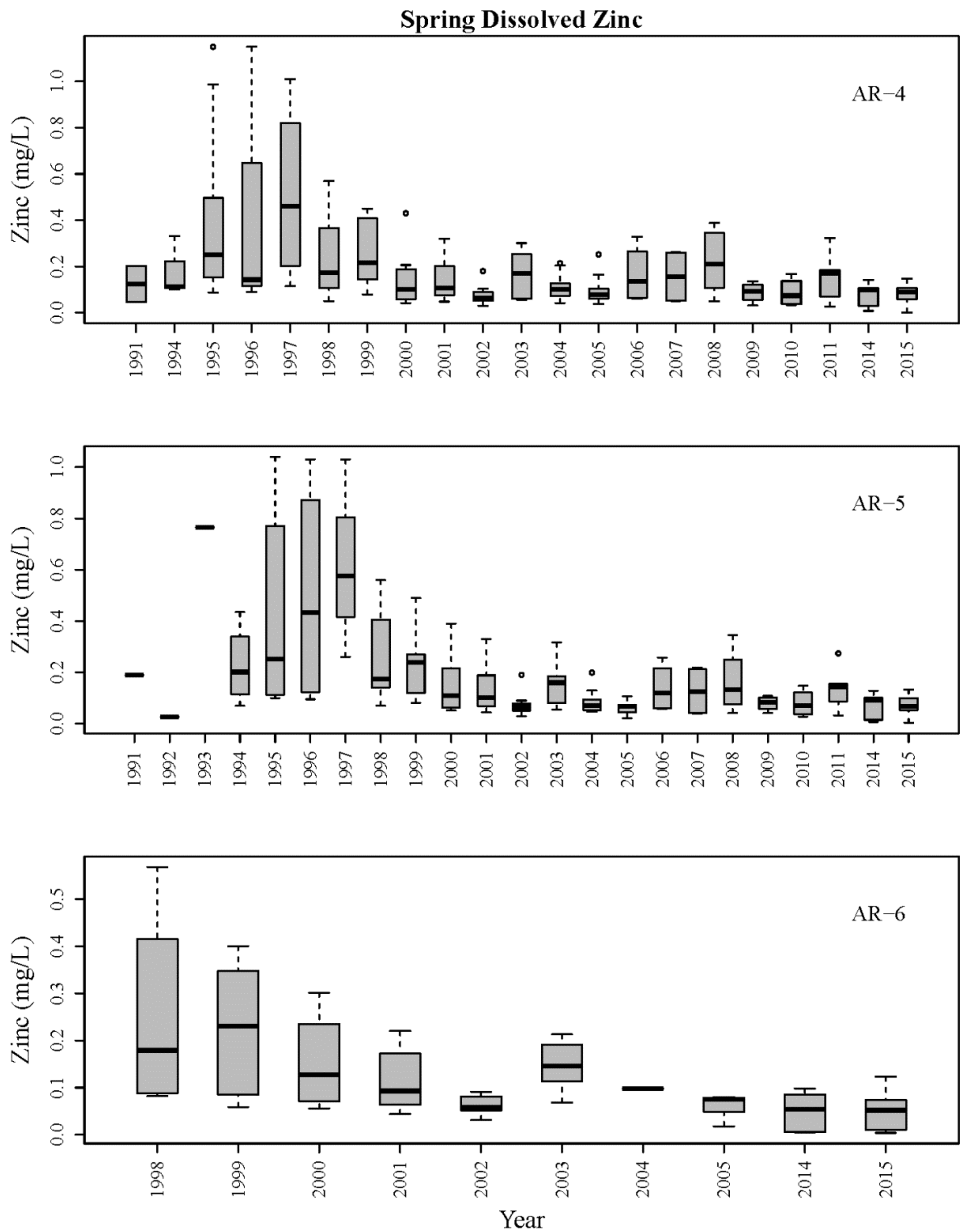


Figure 2.4. Dissolved zinc concentrations summarized for the spring season (April-July) at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River.

Hydrology

Average daily discharge values below Empire Gulch were compared to historical medians for WY 2013-2015 (Figure 2.5). Typical hydrology for the UAR was observed in WY 2013, with an observed maximum daily discharge value of 703 cfs on June 10, 2013 (Figure 2.5). This value was 13% greater than the typical maximum of 622 cfs. Higher flows were observed in WY 2014, with a maximum daily discharge value of 1,350 cfs occurring on May 31, 2014. The maximum daily discharge value in 2014 was 117% greater and occurred 10 days earlier than the typical maximum. In 2015, the maximum average daily discharge of 1,410 occurred on June 18 and was 127% greater than the typical maximum (Figure 2.5). Higher discharge values observed in 2014 and 2015 flooded riparian areas along the UAR. Flooding has the potential to mobilize metals from surficial sediments and increase leaching of metals from fluvial tailings deposits. Conversely, high water volumes associated with flooding could dilute the concentration of metals mobilized during floodplain inundation.

FFA was performed using 16 years of peak discharge data available for the stream gauge below Empire Gulch. Generally, a minimum of 30 years of peak discharge data is recommended for representative FFA. Given the lack of data below Empire Gulch, FFA was also performed for an upstream stream gauge near Leadville. Results from FAA are presented in Table 2.1. Flows in the project reach peaked at 801 cfs in 2013, with a return interval of 1.5-2.0 years. Discharge peaked at 1,430 cfs in 2014 within the project reach, representing a flood of 4.5-5.9 years. The highest discharge was observed in 2015 with flows peaking at 1,550 cfs, which corresponds to a return interval 8.3-10.9 years. Maximum flows derived from average daily discharge data (i.e., historical medians) will typically be lower than peak flows derived from instantaneous flow observations used for FFA that have not been averaged across an entire day, which is why values reported in Table 2.1 are higher than those presented in Figure 2.5.

Exceedance of Water Quality Standards

Surface water in the UAR has historically exceeded acute and chronic water quality criteria for cadmium, copper, lead, and zinc (Stratus, 2010). Water quality standards should not be exceeded more than once every three years on average (CDPHE, 2013). All of the water quality monitoring sites within the project reach (i.e., AR-4, AR-5, and AR-6) are located downstream of the confluence with California Gulch with a stream classification of Cold Water Aquatic Life Class 1. Dissolved metals concentrations were compared to numeric water quality standards at each site to evaluate exceedance of standards. Standards were exceeded if the observed concentration was greater than the MDL and calculated standard for the metal in question. Acute and/or chronic standards for dissolved cadmium, lead, or zinc were exceeded during 2013-2015 at all three monitoring sites. The duration of exceedance for chronic and acute standards at each site is summarized in Table 2.2.

Table 2.1. Results from flood frequency analysis (FFA) for the Arkansas River at two stream gauges, the Arkansas River Near Leadville, CO and the Arkansas River Below Empire Gulch, CO.

Year	Arkansas River Near Leadville		Arkansas River Below Empire Gulch	
	Peak Discharge (cfs)	Return Interval (years)	Peak Discharge (cfs)	Return Interval (years)
2013	648	2.0	801	1.5
2014	927	4.5	1,430	5.9
2015	1,140	10.9	1,550	8.3

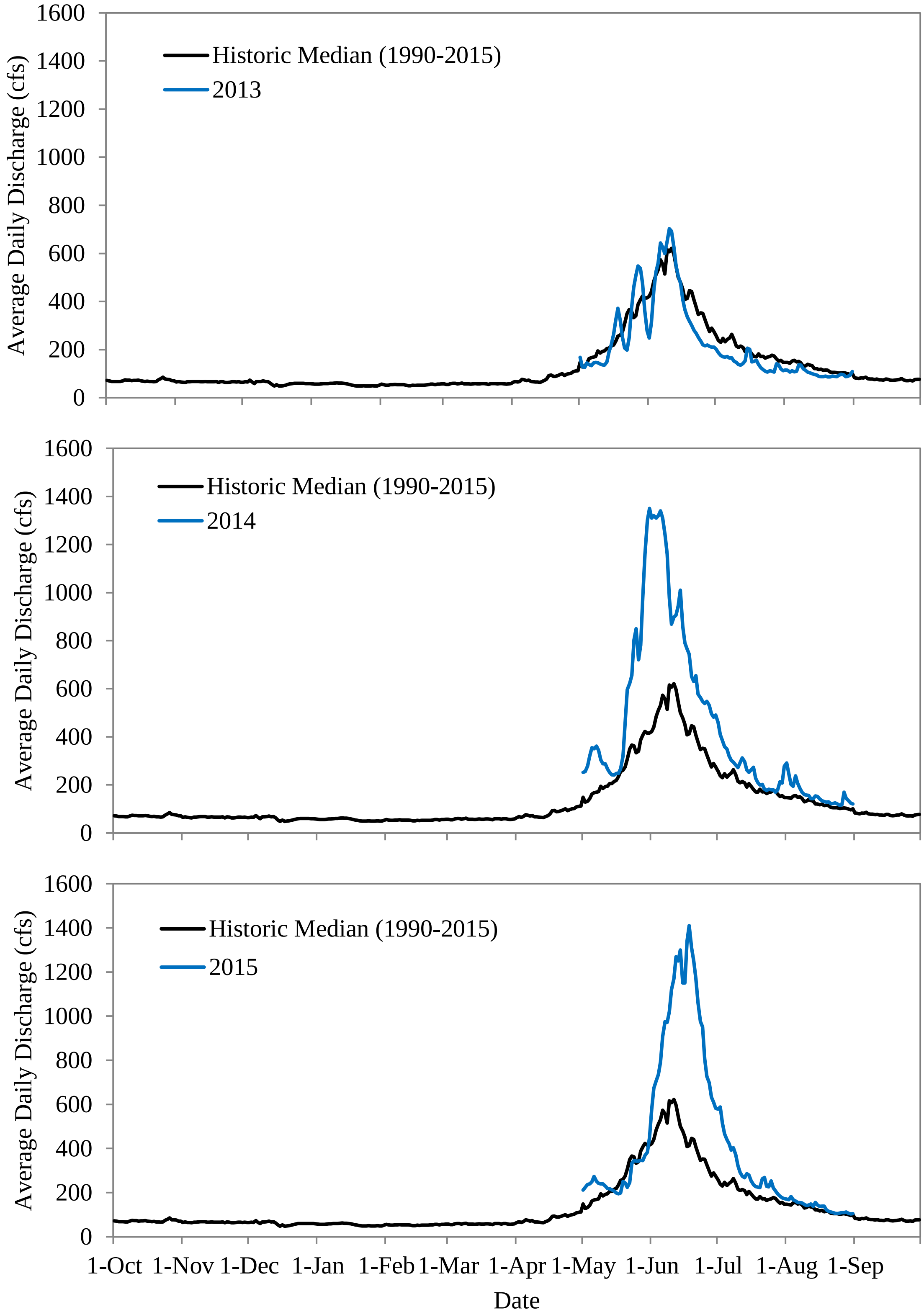


Figure 2.5. Comparison for historical and observed daily discharge (cfs) during WY 2013, 2014, and 2015 for the Arkansas River Below Empire Gulch Near Malta, CO.

Table 2.2. Days in exceedance of acute and chronic water quality standards for dissolved cadmium (Cd), lead (Pb), and zinc (Zn) at three monitoring sites on the Upper Arkansas River during 2013-2015.

Contaminant	Site	Standard	Days in Exceedance		
			2013*	2014	2015
Cd	AR-4	Acute	0	0	7
		Chronic	0.3	42	88
	AR-5	Acute	0	0	0
		Chronic	0	35	81
	AR-6	Acute	0	0	0
		Chronic	0	42	81
Pb	AR-4	Acute	0	0	0
		Chronic	0	28	0
	AR-5	Acute	0	0	0
		Chronic	0	42	0
	AR-6	Acute	0	0	0
		Chronic	1-27**	56	0
Zn	AR-4	Acute	0	35	31
		Chronic	0	42	60
	AR-5	Acute	0	35	20
		Chronic	0	35	27
	AR-6	Acute	0	28	5
		Chronic	0	28	20

*Water sampling in 2013 was conducted during August-October to monitor construction activities, while sampling in 2014-2015 was conducted during April/May-August to monitor snowmelt runoff.

**Duration of exceedance is uncertain due to extended time between samples, so a range is reported to represent the minimum and maximum possible duration.

In 2013, water sampling was conducted to evaluate the impact of instream construction on metal concentrations. Therefore, sampling did not take place during the spring when exceedances have historically occurred. Water quality sampling occurred during construction activities in 2013, beginning in August and continuing through October. The number of exceedances was lower in 2013 compared to 2014 and 2015 (Table 2.2), possibly due to the timing of sampling and magnitude of snowmelt runoff. Chronic cadmium standards were exceeded for less than a day at AR-4 (Table 2.2; Figure 2.6) and chronic lead standards were exceeded for a maximum of 27 days at AR-6 (Table 2.2; Figure 2.7) in 2013. Acute standards were not exceeded for any water samples collected in 2013. The chronic standard exceedance for cadmium at AR-4 in 2013 occurred mid-day and concentrations were back in compliance when evening samples were collected on the same day. As AR-4 is upstream of the CPW project extent, construction activities within the project reach were not responsible for this short cadmium exceedance in 2013. However, construction activities on private lands above AR-4 were ongoing during this time period, and could have contributed to episodic increases in metal concentrations.

The chronic lead exceedances observed in 2013 both occurred at AR-6 in the evening. These exceedances could have resulted from instream construction within the project reach. However, the high duration of the exceedance (27 days) is likely due to the extended period between the last observation in exceedance and next observation in compliance, and therefore represents the maximum possible duration. The actual duration of exceedance could have been much shorter, but no observations were available between these sampling events. As all other water samples were below the MDL for lead in 2013, it is likely that the duration of chronic lead exceedance was shorter than 27 days and is therefore reported as a range of 1-27 days in Table 2.2.

It is possible that instream construction disturbed and mobilized contaminated sediments from the streambanks or bed. High turbidity was noted throughout the 11-mile reach during instream construction activities. Increased turbidity indicates that fine sediments are being transported in suspension and metals will often bind to sediment and organic matter. Therefore, increasing the amount of suspended sediment could elevate metals concentrations. However, exceedances in 2013 could have resulted from metal inputs from contaminated areas within the California Gulch Superfund site, leaching from fluvial tailings deposits, instream construction activities taking place on private lands upstream, or other metal sources within the UAR basin. More detailed analyses of metals loading from throughout the UAR basin would be needed to identify the source of metals during observed exceedances in 2013 and distinguish if patterns of exceedance differ from previous years.

Sampling was temporally stratified in 2014 and 2015 (Figure 2.1) to target water quality during the spring when historical exceedances have been most prevalent. Cadmium concentrations exceeded chronic standards at all three monitoring sites in both 2014 and 2015. The duration of chronic cadmium exceedance ranged from 35-42 days in 2014 and 81-88 days in 2015 (Table 2.2; Figure 2.6). Acute cadmium standards were exceeded for seven days at AR-4 in 2015. Lead concentrations exceeded chronic water quality standard at all three monitoring sites in 2014, but no exceedances were observed in 2015. Chronic standards for lead were exceeded for 28 days at AR-4, 42 days at AR-5, and 56 days at AR-6 in 2014 (Table 2.2; Figure 2.7). Observed lead concentrations never exceeded acute standards at any of the monitoring sites during 2013-2015 (Table 2.2). Zinc concentrations exceeded acute and chronic thresholds in 2014 and 2015 at all three monitoring sites. The duration of chronic zinc exceedance ranged from 28-42 and 20-60 days in 2014 and 2015, respectively (Table 2.2; Figure 2.8). Acute zinc standards were exceeded for 28-35 days in 2014 and 5-31 days in 2015.

The duration of acute and chronic zinc exceedances decreased in the downstream direction in both 2014 and 2015. The decreasing duration of exceedance in the downstream direction suggests that zinc contamination may be coming from the California Gulch Superfund Site or other sources upstream of the CPW project reach. Conversely, the duration of chronic lead exceedance increased in the downstream direction. The increased duration of chronic lead exceedance at downstream sites could be due to dilution from tributaries. Tributary inputs could have decreased water hardness, thereby lowering standards and increasing the frequency of exceedance. However, hardness levels were similar at all three monitoring sites (Appendix B), suggesting that the increased duration of exceedance was not due to dilution from tributaries. There are numerous fluvial tailings deposits within the project reach (Figure 2.2). Metals leaching from these deposits could increase the frequency and duration of exceedances in a downstream direction. Constructions activities were ongoing in 2014 but did not take place in 2015. Chronic lead exceedances were observed during the months of May-July in 2014, but instream construction did not begin until the end of July that year, indicating that construction activities were not responsible for these exceedances. The timing of exceedances during spring runoff suggests that metals contamination is coming from known sources within the UAR basin, albeit at lesser concentrations than observed historically.

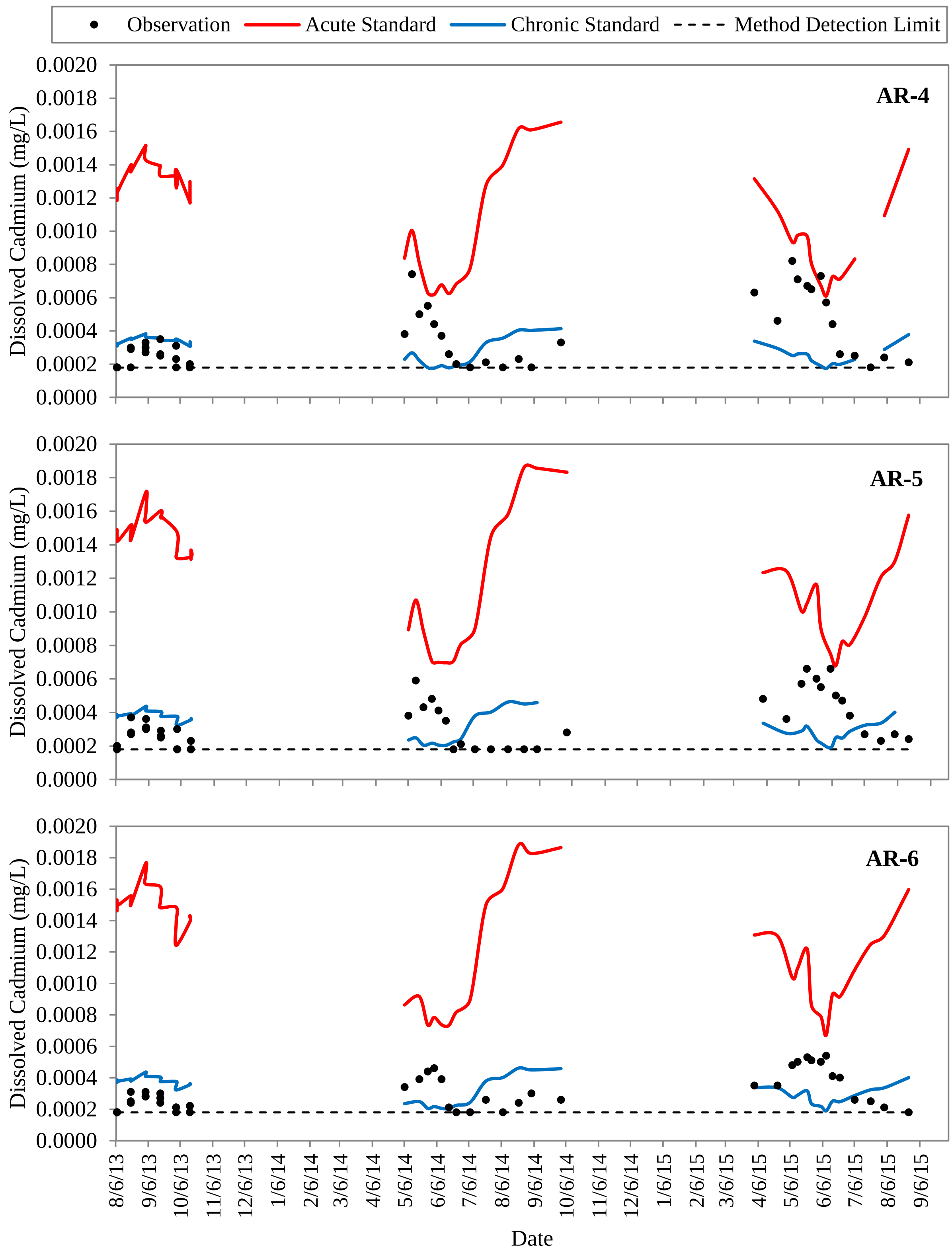


Figure 2.6. Dissolved cadmium concentrations compared to acute and chronic standards at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River.

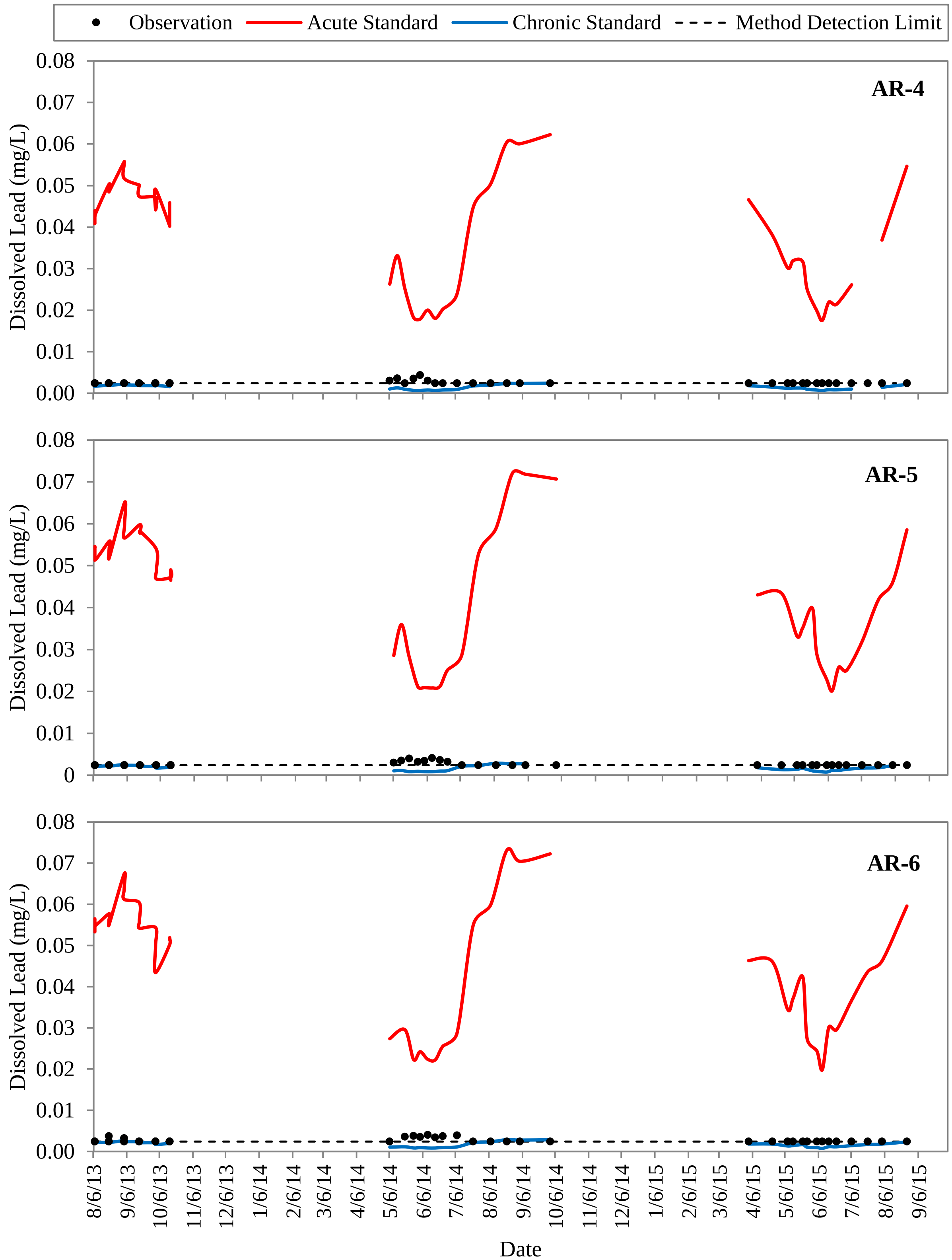


Figure 2.7. Dissolved lead concentrations compared to acute and chronic standards at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River.

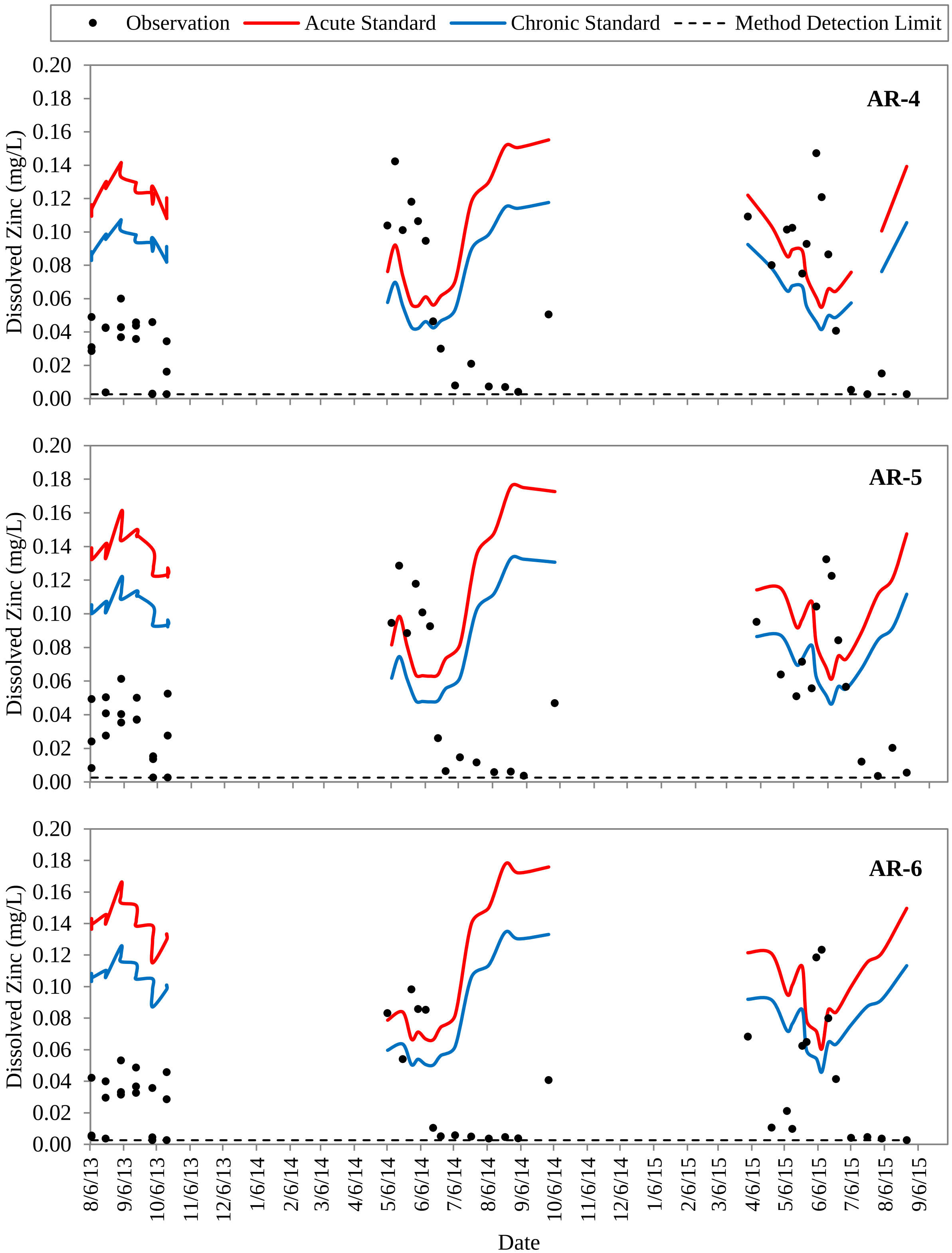


Figure 2.8. Dissolved zinc concentrations compared to acute and chronic standards at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River.

Metals Toxicity and Aquatic Life

Acute and chronic levels of toxicity can have negative impacts on aquatic life, including fish and benthic macroinvertebrates. Chronic exposure to cadmium and zinc can impair stress responses for brown trout, increasing sensitivity to predation, water temperature, and spawning stressors (Norris et al. 1999). Cadmium is very toxic to brown trout fry, with lethal concentrations (LC_{50}) of 0.00123 mg/L and chronic effects at 0.00102 mg/L when water hardness was low (30 mg/L; Brinkman et al., 2006). Zinc toxicity can have significant effects on brown trout during early life stages (ELS) when hardness is low, with LC_{50} observed at 0.367 mg/L for fry and chronic effects at 0.162 mg/L for ELS when hardness was 27-30 mg/L (Brinkman et al., 2006). Cadmium and zinc concentrations at CG-6 were an order of magnitude higher than LC_{50} values reported in Brinkman et al. (2006), indicating that the water coming from California Gulch is still toxic to aquatic life (Figure 2.9). Median hardness values in the UAR ranged from 38-43 mg/L in 2014 and 47-60 mg/L in 2015 during spring. These hardness values are near the lower bounds of toxicity tests (i.e., 30 mg/L) for brown trout (Brinkman et al., 2006), indicating that low hardness in the UAR increases metals toxicity for brown trout and other aquatic life. Heptageniid mayflies are particularly sensitive to cadmium and zinc contamination and can serve as indicator species (Brinkman and Johnston, 2008). Additionally, benthic macroinvertebrates can bioaccumulate heavy metals in hard tissues and are a major forage source for brown trout in the UAR, providing another pathway for metals toxicity in the local fish populations (Woodward et al., 1993).

Remediation Activities

Metal concentrations in the UAR have continued to exceed chronic and acute levels, despite an observed decline in concentrations when compared to historical values. Further improvements to water quality in the UAR could benefit aquatic, riparian, and terrestrial resources. Zinc and cadmium concentrations from California Gulch were an order of magnitude higher than the Arkansas River, indicating that the Superfund Site is still a significant source of metals (Figure 2.9). Additional remediation activities for water quality from California Gulch were identified in the Environmental Assessment (Stratus, 2010). Proposed remediation projects included a repository for contaminated soil, a seasonal bypass through a constructed wetland, and a pump station for treating specific springs below the Yak Tunnel. The increased duration of chronic lead exceedance in the downstream direction during 2014 could indicate that fluvial tailings deposits are leaching metals to the river. However, observed lead concentrations were typically close to the MDL and much lower than acute toxicity levels. Regardless, metals loading from fluvial tailing deposits should be evaluated to determine if these areas need further remediation. Projects or activities that could further improve water quality in the UAR should be considered if additional resources are available.

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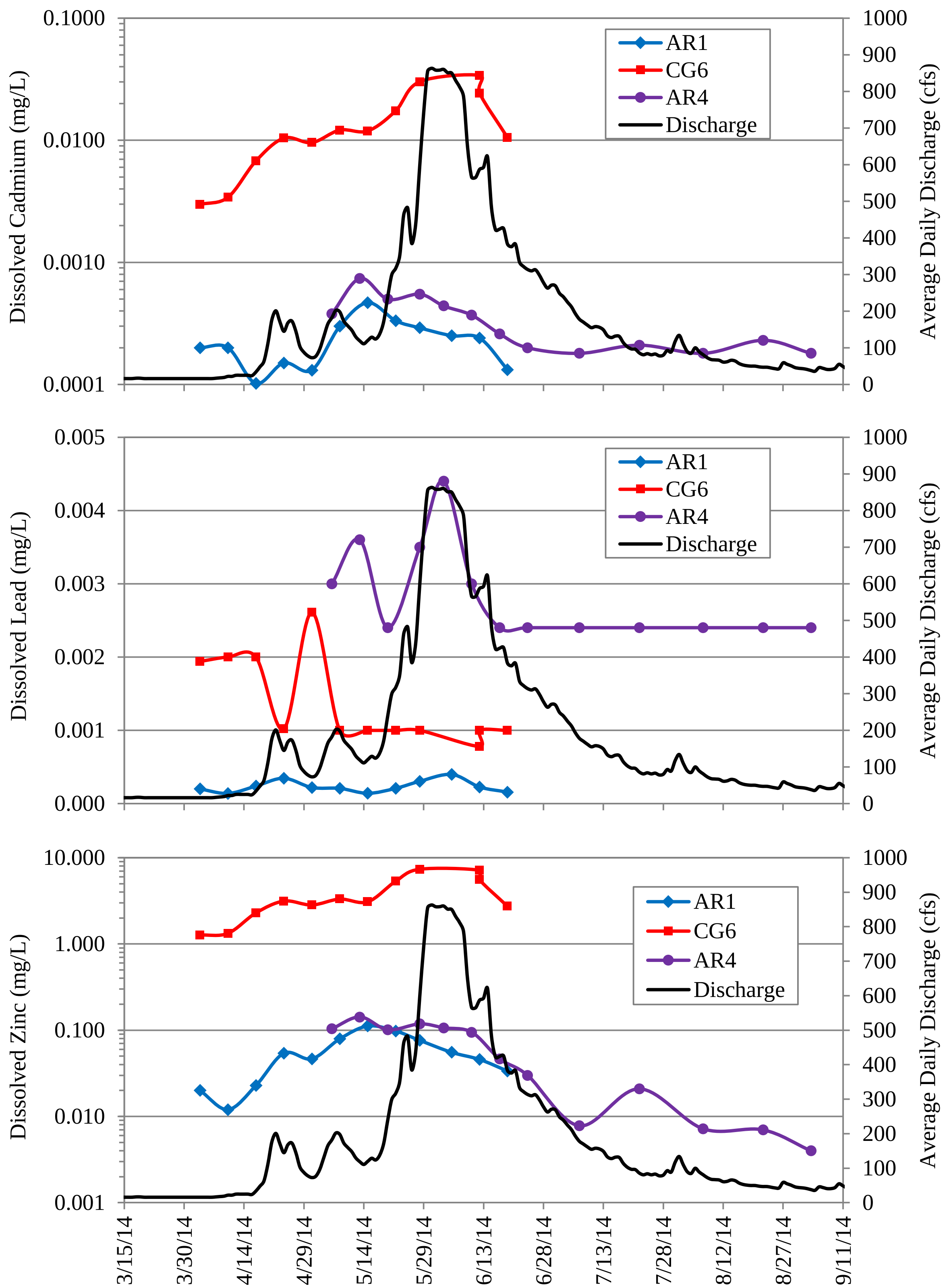

Figure 2.9. Dissolved cadmium, lead, and zinc concentrations from AR-1, CG-6, and AR-4 compared to average daily discharge for the Arkansas River Near Leadville stream gauge during spring 2014.

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Chapter 3: Fish Populations

3.1 Introduction

Trout populations in the Upper Arkansas River (UAR) were impaired by heavy metal pollution from historic mining activities and habitat degradation from land-use practices and transbasin diversions (Stratus, 2010). Habitat degradation had reduced availability of critical habitats (e.g., pools for overwinter survival, spawning substrate, and juvenile refugia), depressing trout populations and impairing the health of individual fish. Habitat restoration treatments were designed to stabilize streambanks, promote diverse stream morphology, reduce erosion and downstream sedimentation, enhance overhead cover for trout, and create diverse instream habitat including pools, riffles, and bars (Stratus, 2010). Brown trout (*Salmo trutta)* populations have improved substantially over the last two decades in response to improved water quality, leading to Gold Medal designation for over 100 miles of the UAR in 2014. Although the UAR fishery has improved substantially, instream habitat restoration was expected to improve fishery metrics for brown trout by 10% within five years of project completion. As habitat restoration and improvements in brown trout populations were expected to increase angler use in the project reach, creel surveys were used evaluate angler use, harvest, and satisfaction. The objectives of this chapter are to evaluate monitoring targets for fish populations, summarize trends in brown trout populations, and characterize angler use for the project reach.

3.2 Methods

Before-After-Control-Impact Study Design

Changes in fishery metrics were evaluated with a Before-After-Control-Impact (BACI) study design comparing three control (AR-5B, AR-6A, and AR-6) and treatment (AR-R, AR-5, and AR-MH) sites to determine the impact of habitat treatments on fish populations. Fishery metrics include brown trout density, biomass, quality, and condition. The locations of fish monitoring sites are shown in Figures 1.1-1.2, and included on as-built drawings in Appendix A. Treatment locations were overlaid on aerial images for each site and included in Appendix C. Baseline data were collected from various sites throughout the UAR basin during 1985-2012 (Policky, 2012). As fish monitoring sites in the UAR have different periods of record, data from 2008-2012 were selected to represent "before" conditions. For baseline surveys during 2008-2012, there were two years of data for sites AR-R and AR-MH, three years of data for site AR-5B, and four years of data for sites AR-5, AR-6A, and AR-6. Monitoring sites within the CPW project reach were not sampled in 2013 due to instream construction activities. Post-construction population surveys were conducted in 2014 and 2015 to represent "after" conditions for the BACI analysis.

Trout Population Estimation

Fish populations were sampled by electrofishing with a five-electrode array using two-pass depletion estimates. Fish lengths and weights were measured and recorded, and fish were released after sampling was completed. Data were processed in JakeOMatic v2.4 using the two-pass removal estimator (Bagenal, 1978; Rogers, 2006). Brown trout density (#/acre), biomass (lbs/acre), and quality (# ≥14"/acre) were estimated for all sites (Policky, 2012; Policky, 2014; Policky, 2015) and compared to Gold Medal standards. Gold Medal Trout Waters are defined as any river or stream segment at least two miles in length that produces a standing stock of at least 60 lbs/acre and at least 12 trout ≥14"/acre on a sustained basis

Fish Condition

Fish condition, the measure of "plumpness" or body weight compared to total length, was assessed using relative weight. Relative weight (*Wr*) compares the observed weight (*W*) of an individual to a length-specified standard weight (*Ws*) for the same length estimated from a length-weight regression, using Equation 3.1.

Equation 3.1:

$$Wr = \frac{W}{Ws}$$

Standard weights were estimated using the length-weight regression from Milewski and Brown (1994). To remove outliers and erroneous data points, the dataset was filtered to include only observations between the smallest (0.63) and largest (1.31) average relative weights reported in Milewski and Brown (1994). Median Wr were then calculated for each year and linear regression analysis was used to evaluate trends over time.

Creel Surveys

Creel surveys were used to estimate the amount of angling activity and harvest from the fishery. Post-restoration creel surveys will be used to evaluate the effects of habitat restoration on angler use and success. The information gathered during creel surveys can also be used to investigate the economic benefits associated with the restoration project. Baseline creel data were collected in 2008 and 2012 in two distinct reaches within the Hayden Flats area (Highway 24 to Two Bit Gulch). The Upper Hayden Flats reach (Highway 24 to Country Road 55) is within the project extent and represents a treated reach, whereas the Lower Hayden Flats reach (Country Road 55 to Two Bit Gulch) is outside of the project extent and represents a control reach.

Questions on the baseline creel survey included hours fished, fish caught, fish kept or released, preference of trout species caught, and overall satisfaction with the fishery. As it can take five years or more for a fishery to stabilize following instream habitat restoration (Hunt, 1976; Binns, 1994; Kondolf and Micheli, 1995), post-construction creel surveys will be conducted in 2017 (year-4), 2020 (year-7), and 2023 (year-10) to evaluate the long-term impacts of the project on angler use and satisfaction. Post-construction creel surveys will compare angler use in the project reach (Upper Hayden Flats) to angler use in a control reach (Lower Hayden Flats) where no habitat restoration occurred as another means to evaluate project effectiveness and economic impacts from aquatic habitat restoration.

3.3 Results and Discussion

Trout Population Estimation

Long-term improvements in water quality following remediation actions in California Gulch and surrounding areas have contributed to increased trout populations. Results for brown trout population estimates are presented for individual sites in Figures 3.1-3.6. Initial results from effectiveness monitoring indicate that brown trout biomass and quality are increasing at all control and treatment sites. All sites met Gold Medal criteria for biomass and quality in 2014 and 2015, with the exception of AR-MH in 2014. The decreased density, biomass, and quality at AR-MH in 2014 were likely due to temporary habitat disturbance during instream construction activities, which occurred the week prior to electrofishing surveys. The observed increase in all three metrics in 2015 is more representative of trout population trends for that site (Figure 3.5).

Overall trout abundance peaked in 2012 (Figures 3.1-3.6), most likely due to a combination of water quality improvements and low flows during the growing season stemming from a statewide drought (Policky, 2014). Stream flows have been artificially elevated in the UAR due to transbasin water diversions, which has negatively affected trout populations in some years (Policky, 2014). Following observed highs in 2012, trout populations decreased slightly in 2014. However, trout densities have increased compared to historic levels, indicating that improvements in water quality are having positive impacts on the ecosystem. Habitat restoration should result in further improvements to the fishery. As direct effects of habitat restoration on trout populations may not be evident until five to ten years following project completion, all results presented in this report should be considered preliminary. Additional surveys will be conducted in the future to evaluate long-term population trends for the UAR fishery as an indicator of restoration effectiveness.

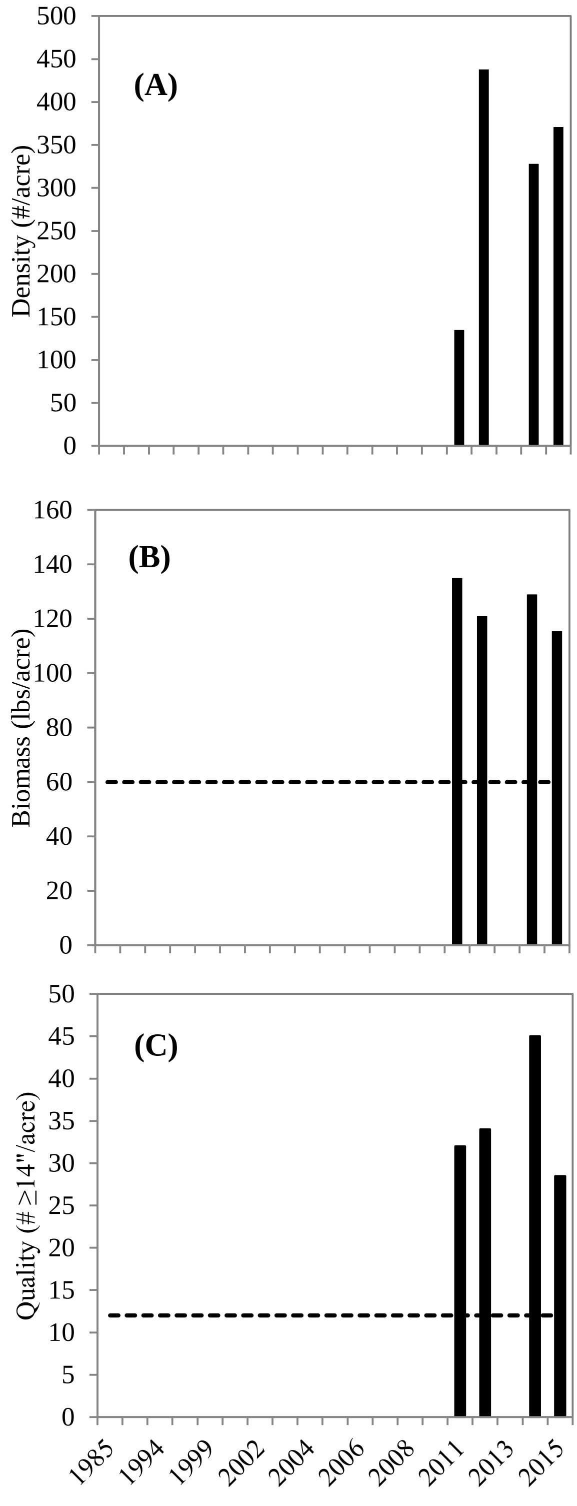

Figure 3.1. Brown trout (*Salmo trutta)* population density (A), biomass (B), and quality (C) at treatment site AR-R. Dashed lines represent Gold Medal standards.

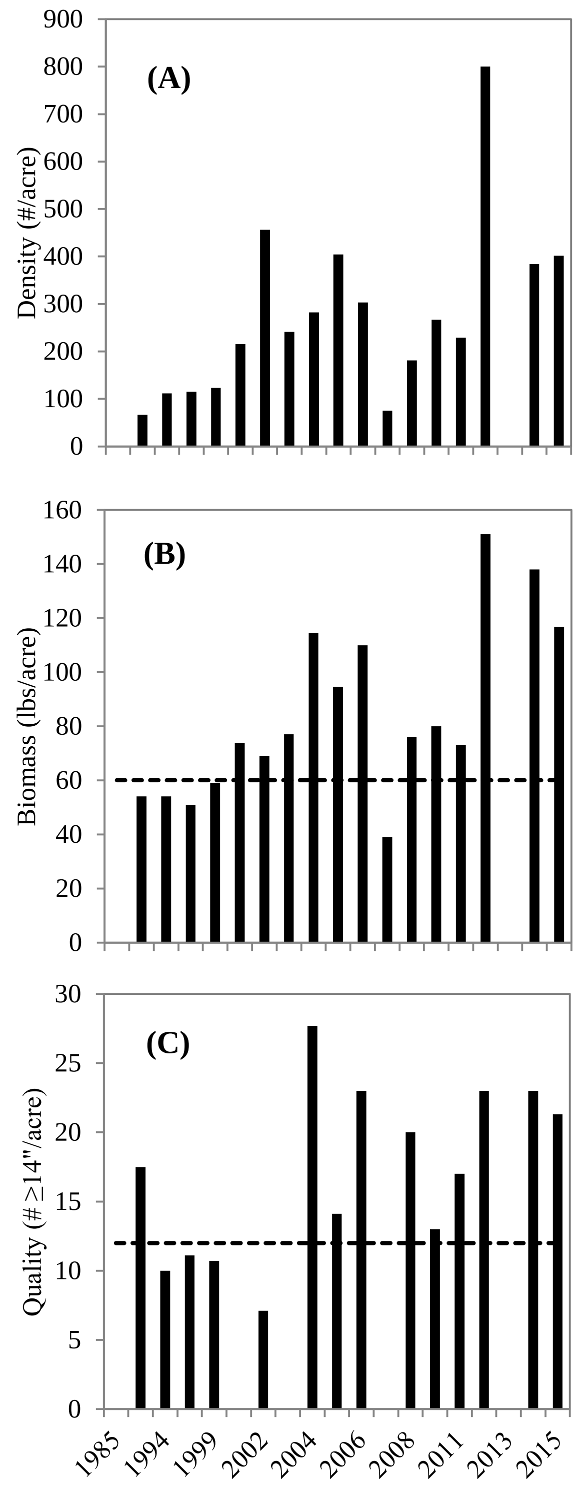

Figure 3.2. Brown trout (*Salmo trutta)* population density (A), biomass (B), and quality (C) at treatment site AR-5. Dashed lines represent Gold Medal standards.

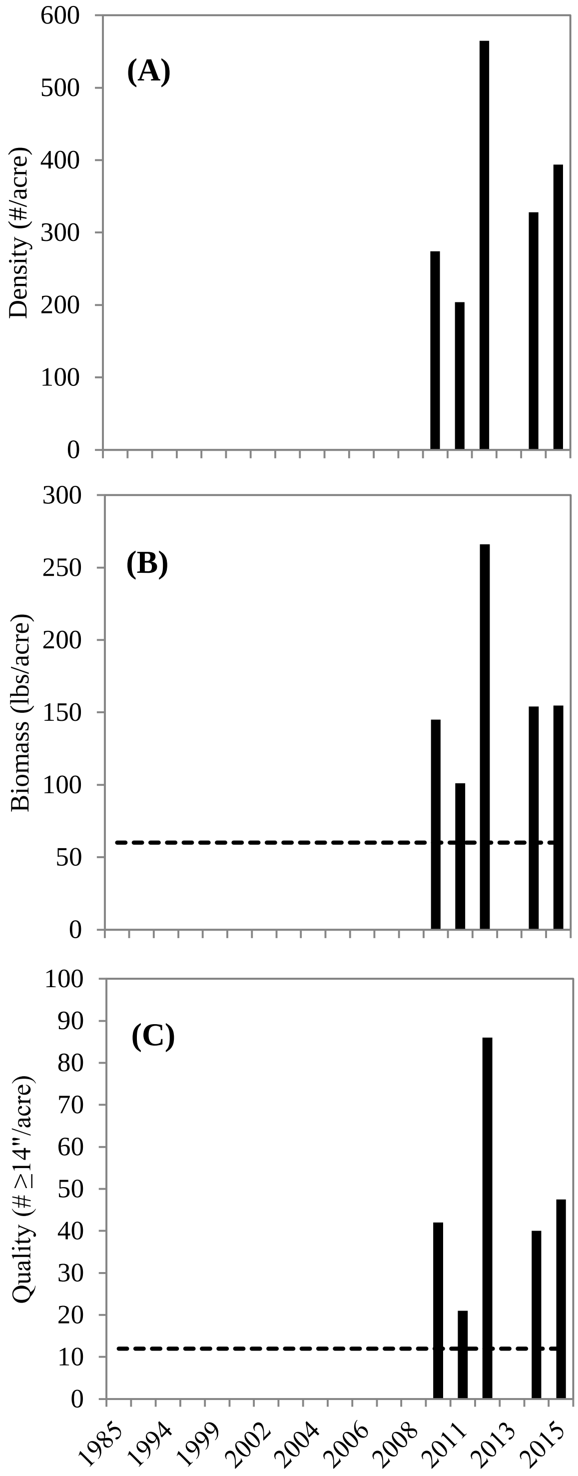

Figure 3.3. Brown trout (*Salmo trutta)* population density (A), biomass (B), and quality (C) at control site AR-5B. Dashed lines represent Gold Medal standards.

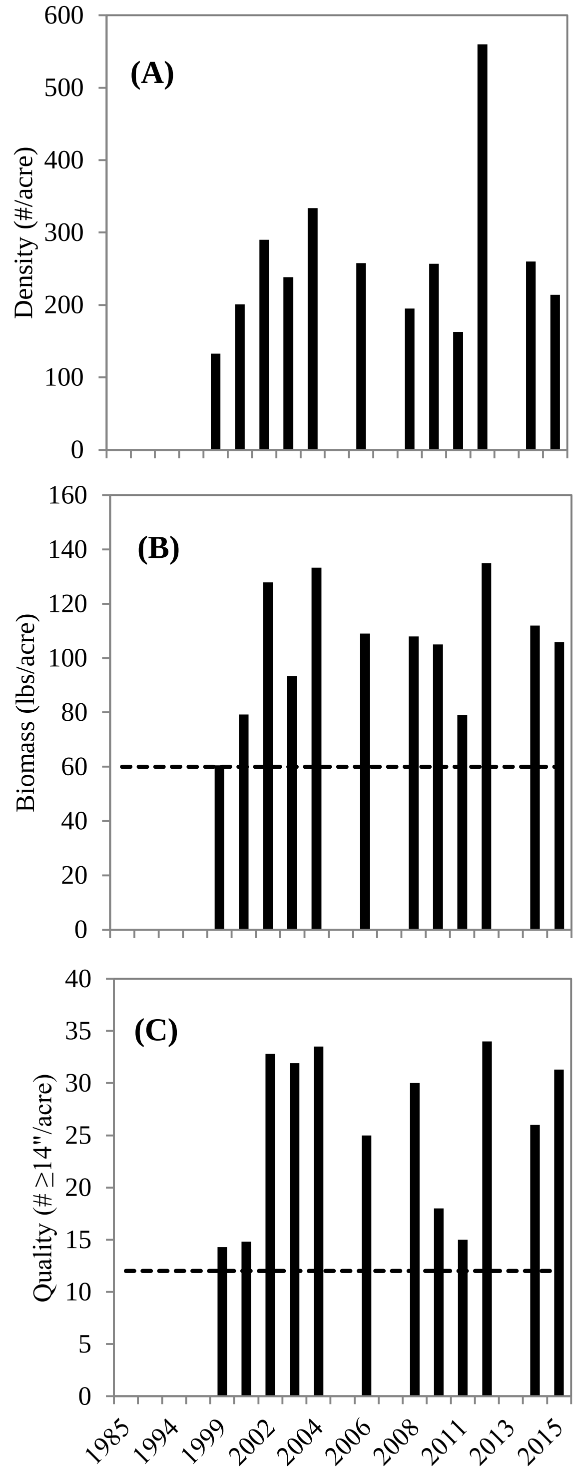

Figure 3.4. Brown trout (*Salmo trutta)* population density (A), biomass (B), and quality (C) at control site AR-6A. Dashed lines represent Gold Medal standards.

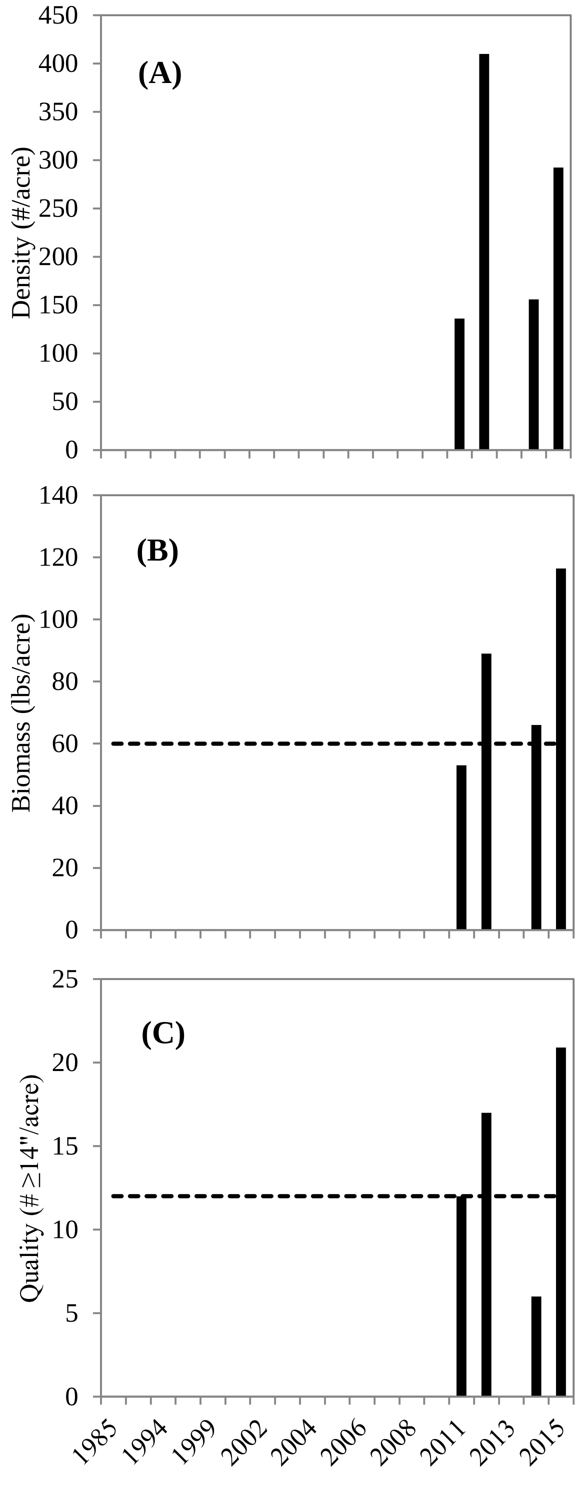

Figure 3.5. Brown trout (*Salmo trutta)* population density (A), biomass (B), and quality (C) at treatment site AR-MH. Dashed lines represent Gold Medal standards.

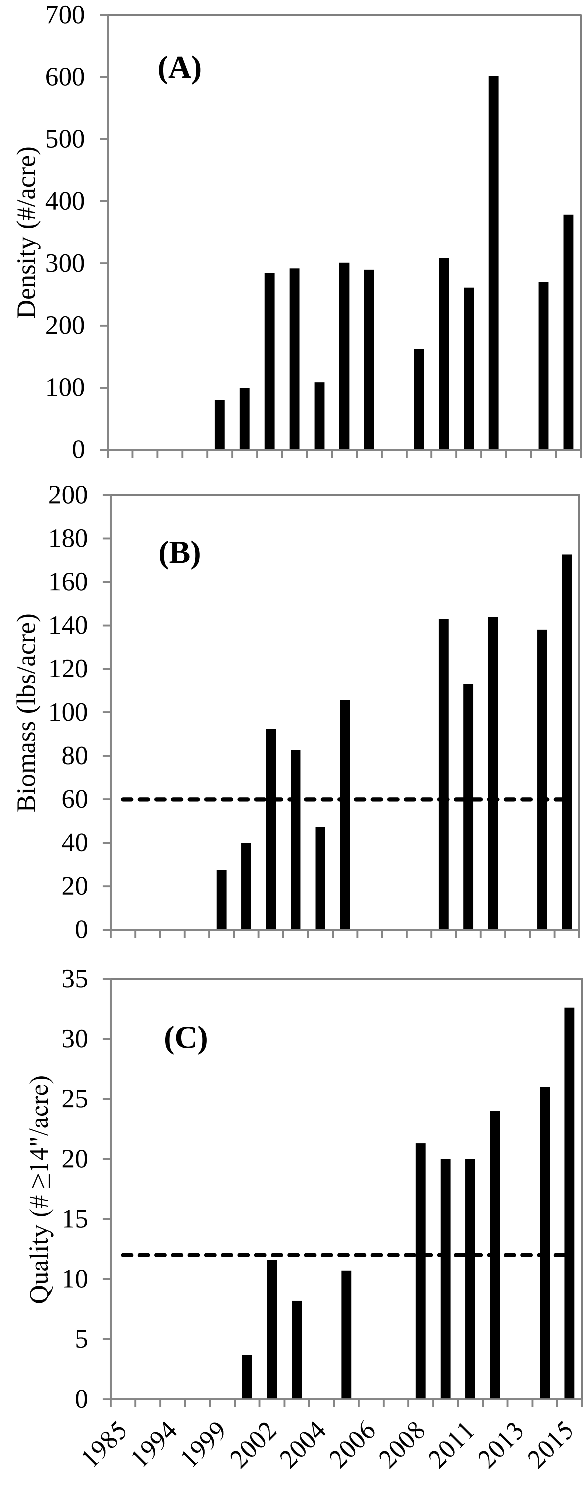

Figure 3.6. Brown trout (*Salmo trutta)* population density (A), biomass (B), and quality (C) at control site AR-6. Dashed lines represent Gold Medal standards.

The percent change in fisheries metrics between baseline and post-construction surveys was averaged across control and treatment sites (Table 3.1). The average change in fisheries metrics across all sites is also presented as an indicator of reach-scale impacts from habitat restoration, whereas averages for control and treatment sites are more indicative of site level impacts associated habitat treatments. Brown trout density declined slightly (6%) at control sites, but increased slightly (4%) at treatment sites, with an average decrease of 1% across all sites. These results indicate that the number of brown trout has not changed significantly between pre- and post-construction surveys. However, trout biomass increased by 19% at treatment sites, 3% at control sites, and 11% across all sites. The number of quality fish also increased for both control and treatment sites, with an average increase of 12% for all sites.

Table 3.1. Percent change in brown trout (*Salmo trutta*) density, biomass, and quality at control and treatment sites within the extent of the Upper Arkansas River habitat restoration project.

Fisheries Metric	Percent Change		
	Control	Treatment	All Sites
Density (#/acre)	-6%	4%	-1%
Biomass (lbs/acre)	3%	19%	11%
Quality (#≥14"/acre)	15%	8%	12%

Although trout numbers did not change overall, the positive changes in trout biomass and quality indicate that fish size, health, and life span are improving. Previous studies concluded that brown trout could not survive more than three years in the UAR near Salida due to degraded water quality (Policky, 2012). To evaluate survival and movement within the UAR, brown trout were tagged with Visible Implant Elastomer (VIE) during 2002-2005. One trout tagged in 2002 was recaptured at AR-6 during sampling in 2014, indicating that this fish was 12-years old and that life expectancy for brown trout in UAR has improved substantially. As trout populations are dynamic and influenced by various chemical, biological, and physical processes, additional monitoring will be needed to determine if the observed improvements in the UAR fishery are maintained.

Fish Condition

Although median relative weights show an increasing trend from the late 1990s to present, this trend was not statistically significant (p-value = 0.21) based on regression analysis (Figure 3.7). However, observations of increased biomass and number of quality-sized fish from population estimates suggest that fish condition has improved through time. Fish condition can be influenced by a variety of factors, including available prey resources, water quality, stream flow, and habitat. The highest median relative weight was observed in 2012, likely due to low flows observed that year (Policky, 2014). Low flows can increase water temperature, which can benefit brown trout in the UAR by increasing growth rates and extending the growing season. Water velocities are also lower in drought years, meaning trout expend less energy during feeding, which could also improve fish condition. Although brown trout condition appears to be improving (Figure 3.7), relative weights may still be limited by one or more factors.

Creel Surveys

The Upper Hayden Flats creel reach aligns with the Hayden reach depicted in Figure 1.2. Habitat restoration was conducted in the Upper Hayden Flats creel reach, but not in the Lower Hayden Flats creel reach. Baseline creel surveys were not conducted in the Crystal-Reddy reach, but this reach will be included in post-implementation creel surveys. The entire Hayden Flats creel reach has a regulation limiting harvest to one fish under 12 inches and method of take is limited to artificial flies or lures only. The Crystal-Reddy reach is managed with standard regulations, including a daily bag limit of four trout and no restrictions on method of take. Future creel surveys will be used to evaluate angler use, catch, and satisfaction relative to habitat restoration and different regulations on the UAR.

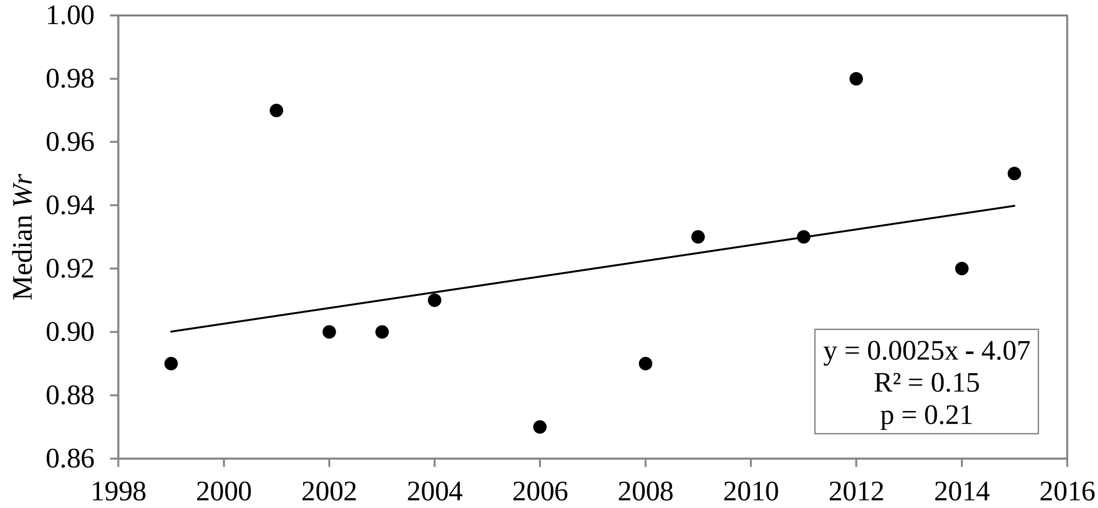

Figure 3.7. Median relative weight (*Wr*) by year for brown trout (*Salmo trutta*) sampled during fall at all fish monitoring sites within the extent of the Upper Arkansas River habitat restoration project.

Angler use in the UAR increased significantly in 2012 compared to the previous survey in 2008 (Table 3.2). The entire Hayden Flats reach accounted for a total of 11,879 angler hours in 2012, with the Upper Hayden Flats reach (CR 55 to HW 24) accounting for the highest proportion of use with 8,311 angler hours in 2012 (Table 3.2). The majority of anglers (80%) were from Colorado. Angler catch was high throughout the UAR in 2012 (21,750 total fish within the surveyed sections) and catch rate averaged 1.2 fish/hour, up from 0.91 fish/hour in 2008. Over 90% of fish caught were brown trout, and essentially all fish were released after capture (99.6%). Anglers preferred to fish with flies, with 86% of anglers electing to fly fish in 2008 and 2012. On average, 48% of respondents rated the quality of the fish they caught as good to excellent in 2012, which is down from 67% in 2008. The overall fishing experience was rated as good to excellent by 73% of anglers in 2012, which is down slightly from 77% in 2008. Anglers elected to fish the UAR for three primary reasons: (1) quality of the fishery (size and number of fish caught); (2) proximity to home; and (3) natural beauty (Policky, 2012).

Overall, angler satisfaction was high in the UAR during previous creel surveys in 2008 and 2012. Angler use, however, was at the highest recorded levels in 2012 and is expected to increase with the completion of the habitat-improvement project and Gold Medal designation in 2014. The Arkansas River is one of the top fishing destinations in the state of Colorado, and any efforts to enhance the fishery may lead to increased angling pressure on the river. Results from creel surveys scheduled for 2017, 2020, and 2023 will reflect any changes in angler use and satisfaction of the UAR in response to the restoration project. Improvements in chemical and physical habitat quality could push trout populations, fish condition, angler use, and angler satisfaction to new levels on the UAR.

Table 3.2. Historical creel census results for the Hayden Flats reach on the Upper Arkansas River. The Upper Hayden Flats reach occurs within the extent of habitat restoration project while the Lower Hayden Flats reach is located downstream of the project extent. NA = Not Available.

Location	Metric	2008	2012
Hayden Flats	Angler hours	4,769	11,879
	Anglers	1,967	5,156
Lower Hayden Flats	Angler hours	NA	3,568
	Anglers	NA	1,562
Upper Hayden Flats	Angler hours	NA	8,311
	Anglers	NA	3,594

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Chapter 4: Benthic Macroinvertebrates

4.1 Introduction

Dr. Will Clements with Colorado State University (CSU) is the principal investigator for the benthic macroinvertebrate component of the Upper Arkansas River (UAR) monitoring program. Dr. Clements has been investigating the response of macroinvertebrate communities to metal contamination in the UAR since 1989. Degradation of stream systems due to contamination can be reflected in the composition of benthic macroinvertebrate populations (Cairns and Pratt, 1993). Monitoring benthic macroinvertebrate populations in the UAR basin supports biological assessment of improved water quality and habitat restoration. Water quality, macroinvertebrate communities, and brown trout (*Salmo trutta*) populations in the UAR have improved following completion of water treatment facilities, treatment of fluvial tailing deposits, and stabilization of eroding banks (Clements et al., 2010). As benthic macroinvertebrates represent a primary food source for fish, improving benthic macroinvertebrate populations should improve foraging opportunities for brown trout in the UAR.

Monitoring targets include improving benthic macroinvertebrate metrics by a minimum of 10% over pre-restoration conditions by 2018. The objective of effectiveness monitoring for benthic macroinvertebrates is to determine if improved water quality, habitat quality, and riparian vegetation will result in improved aquatic macroinvertebrate and terrestrial prey resources for brown trout (Clements and Wolff, 2014). Specifically, hypotheses include: (1) abundance and diversity of benthic macroinvertebrate communities will continue to recover as a result of restoration activities; (2) terrestrial inputs from vegetation dominated by willows and grasses will be greatest due to the large amount of habitat heterogeneity; (3) the utilization of terrestrial prey resources by brown trout will increase as the quality of terrestrial vegetation improves; and (4) mesocosm experiments conducted with upstream and downstream communities will show similar responses to metals as a result of long-term changes in community composition (Clements and Wolff, 2015).

4.2 Methods

Benthic macroinvertebrate monitoring sites were established throughout the Hayden Reach (Figure 1.2), but no sites were established within the Crystal-Reddy reach (Figure 1.1). Aerial images for all benthic macroinvertebrate monitoring sites, including the location of habitat treatments, are presented in Appendix D. Although some sites align with the location of control and treatment sites, macroinvertebrate monitoring sites differ in nomenclature from other monitoring sites (Table 1.2). Macroinvertebrate monitoring sites were selected to coincide with planned restoration treatments, vegetation surveys, and fish sampling to support the Before-After-Control-Impact (BACI) study design (Clements and Wolff, 2014). However, all sites within the CPW project reach (AR4.C, AR4.E, AR4.G, and AR4.H) were impacted by instream construction activities. The downstream control site (AR5.Kobe) is directly below the project reach and was not disturbed during instream construction. In addition to stations within the CPW project reach, macroinvertebrate samples were also collected from four sites (i.e., AR1, AR2, AR3, and AR4) located upstream of the project reach. Although these sites can be used to compare responses of macroinvertebrate communities to restoration treatments within the context of long-term changes in water quality, only data from AR4 were included in this report to represent macroinvertebrate metrics upstream of the CPW project reach. AR4 was treated in 2012 as part of a separate restoration project on private land.

Replicate (n = 5) quantitative benthic macroinvertebrate Hess samples were collected from monitoring sites within the project extent (Clements and Wolff, 2014). To quantify seasonal variation, macroinvertebrate samples were collected in spring (late-April), summer

(August), and fall (early-October), but not all sites were sampled each season each year. Adult emergence, terrestrial inputs, and brown trout feeding habitats were also monitored. Baseline data were collected for all benthic monitoring sites from 2009-2013, while some sites have been sampled periodically since 1989. The level of identification for benthic invertebrates is consistent with baseline data from the UAR. This level of identification is usually genus or species for mayflies, stoneflies, caddisflies and most dipterans. The midge family Chironomidae was identified to the level of subfamily or tribe. Abundance of heptageniid mayflies, total macroinvertebrate abundance, and number of taxa were analyzed to evaluate changes in macroinvertebrate communities. Heptageniidae is a family of mayflies that is considered particularly sensitive to metals (Brinkman and Johnston, 2008; Clements, 1994).

4.3 Results and Discussion

The abundance of heptageniid mayflies appears to have declined at some monitoring sites during or following instream construction activities in 2013-2014 (Figures 4.1-4.6). This decline could be due to direct disturbance of benthic macroinvertebrate habitat during instream construction. This explanation is supported at treatment sites (AR4 and AR4.C) where heptageniid abundance appears to decline following construction (Figures 4.1-4.2). However, declines in heptageniid mayflies were observed at control site AR5.Kobe during or following instream construction as well (Figure 4.6). The apparent decline at both control and treatment sites may indicate that other factors, such as metals concentrations or high flows, negatively affected the abundance of heptageniid mayflies during construction. Metal concentrations for cadmium, lead, and zinc exceeded chronic and/or acute water quality standards within the project extent during 2013-2015 (see Chapter 2). The exceedance of water quality standards indicates that there are still issues with metals pollution in the UAR, and the long duration of chronic (up to 81 days) and acute (up to 35 days) exceedances indicates that benthic macroinvertebrate populations may still be limited by water quality.

The abundance of benthic macroinvertebrates appears to have increased at some treatment sites (AR4 and AR4.C; Figures 4.1-4.2) and decreased at other treatment sites (AR4.E and AR4.G; Figures 4.3-4.4). Macroinvertebrate abundance was relatively high at control site AR5.Kobe during construction years (2013-2014) but appears to have declined after construction was completed (Figure 4.6). Variability in benthic macroinvertebrate metrics relative to the timing of construction activities supports the possibility that observed declines in heptageniid mayfly and benthic macroinvertebrate abundance might be attributed to high flows or reach-wide water quality issues. Macroinvertebrate richness, or the total number of observed taxa, held steady or increased throughout the construction period, with the exceptions of treatment sites AR4 and AR4.C (Figures 4.1-4.6). While this could indicate that biodiversity can be maintained during disturbance and in the presence of moderate pollution, Clements (1994) cautions that there is a high likelihood of species replacement in moderately polluted systems, in which pollution tolerant species, such as some Chironomids, Trichopterans, and Dipterans, will increase in abundance when sensitive species decline. As such, trends in the richness of taxa observed in the UAR provide less meaningful indications for changes in benthic macroinvertebrate populations.

Benthic macroinvertebrate metrics can be highly variable in both space and time (Figures 4.1-4.6). Project goals include increasing these metrics by 10% by 2018. Additional monitoring will help determine if the declines observed in 2013-2014 were related to instream construction, ongoing issues with water quality, high flows, or a combination of these factors. Restoring riparian vegetation could increase nutrient and carbon inputs to the aquatic system, which could in turn increase the abundance of benthic macroinvertebrates. Increasing the abundance of forage could further improve brown trout populations. However, water quality issues could suppress any potential increase in benthic macroinvertebrates associated with improved instream habitat and riparian conditions. The timing of water quality exceedances and observed declines in benthic macroinvertebrate warrants

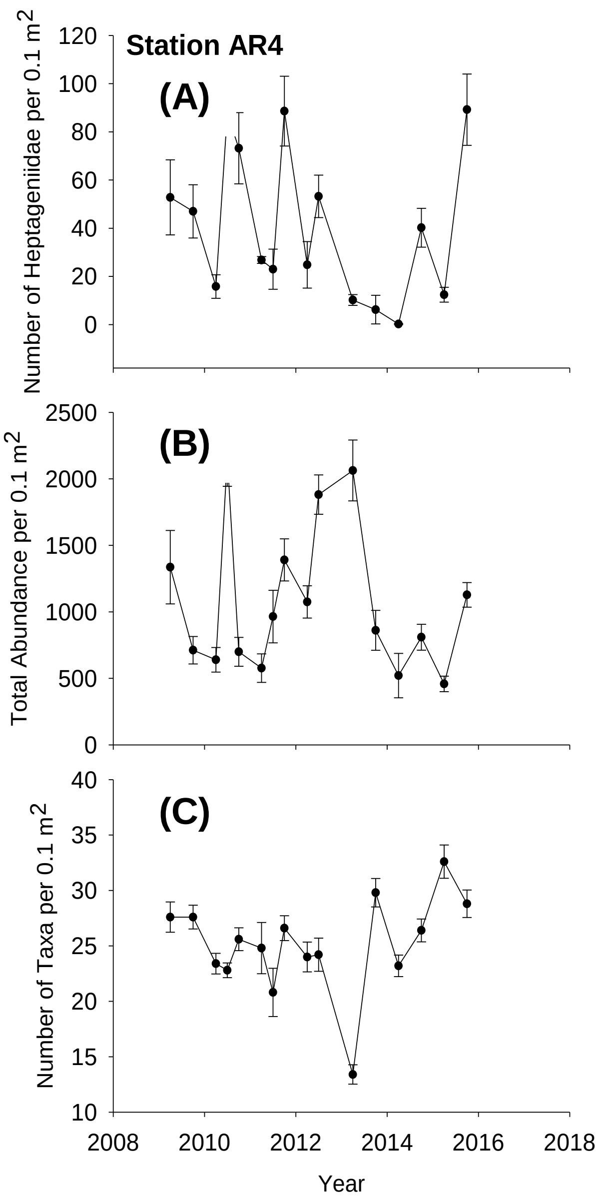

Figure 4.1. Long-term (2009-2015) changes in benthic macroinvertebrate metrics in the Upper Arkansas River, including changes in mean (+/- SE) abundance of heptageniid mayflies (A), total macroinvertebrate abundance (B) and number of taxa (C) at treatment site AR4. This site was treated in 2012.

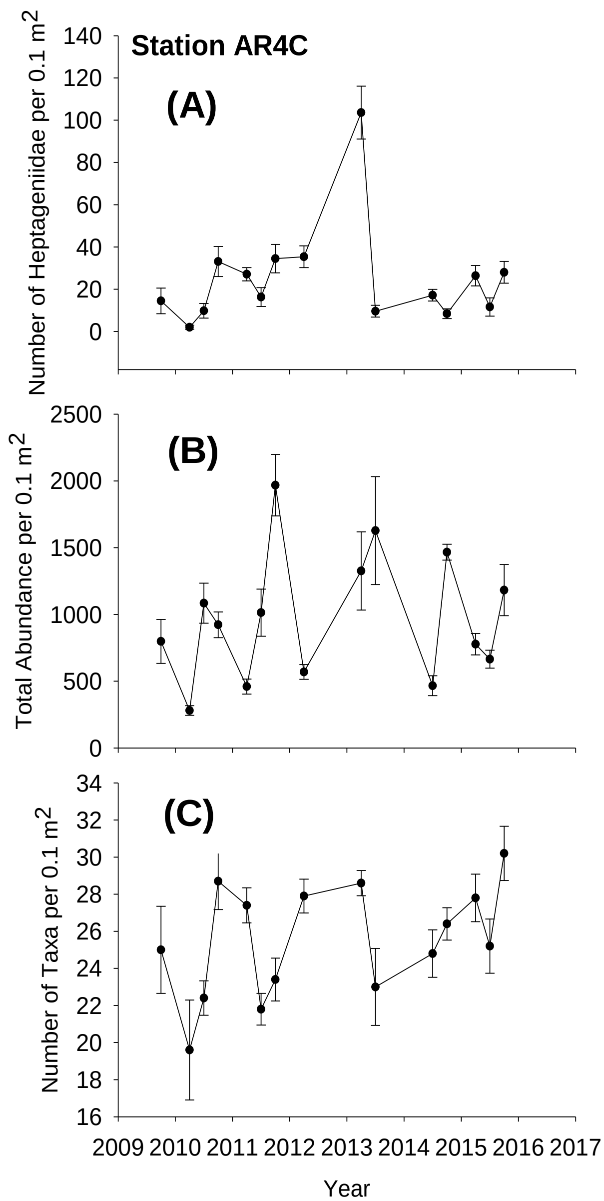

Figure 4.2. Long-term (2009-2015) changes in benthic macroinvertebrate metrics in the Upper Arkansas River, including changes in mean (+/- SE) abundance of heptageniid mayflies (A), total macroinvertebrate abundance (B) and number of taxa (C) at treatment site AR4.C. This site was treated in 2013.

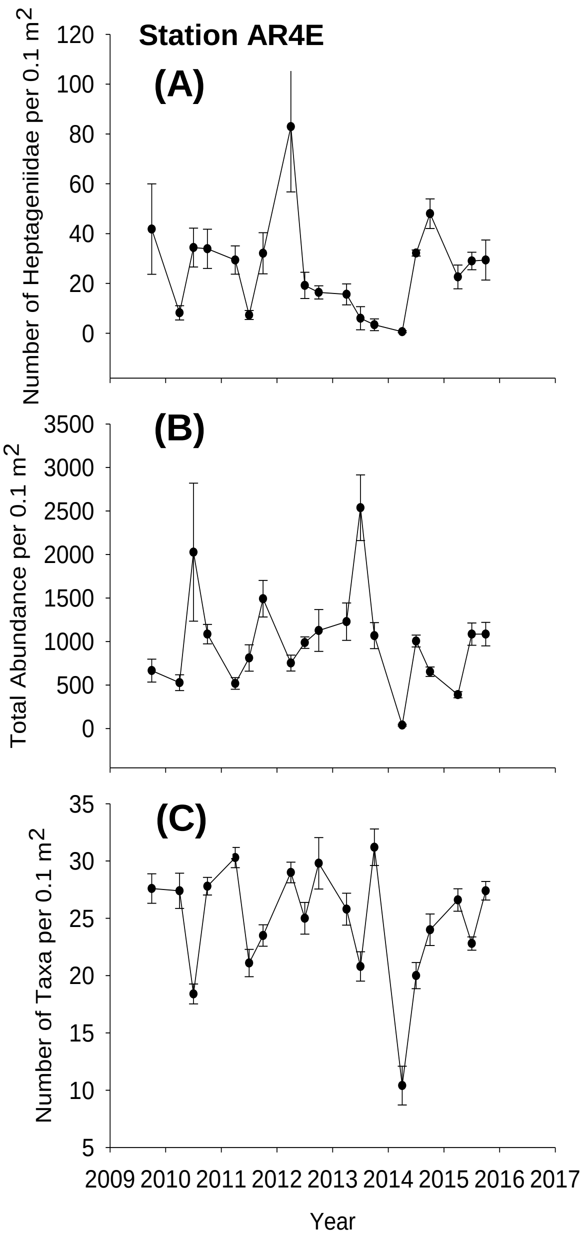

Figure 4.3. Long-term (2009-2015) changes in benthic macroinvertebrate metrics in the Upper Arkansas River, including changes in mean (+/-SE) abundance of heptageniid mayflies (A), total macroinvertebrate abundance (B) and number of taxa (C) at treatment site AR4.E. This site was treated in 2013.

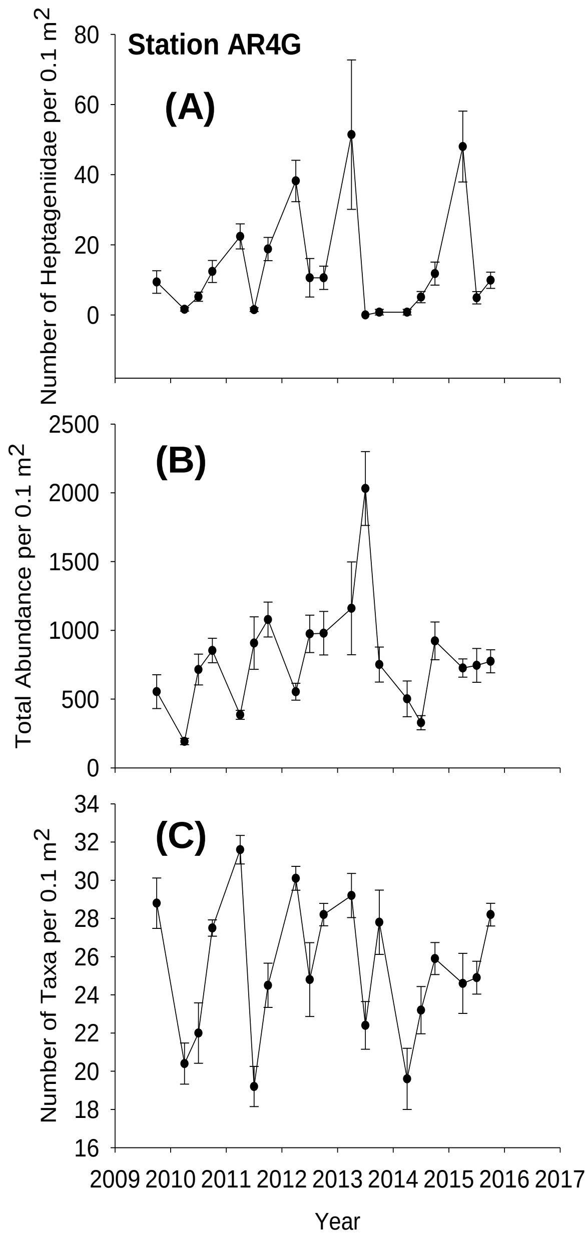

Figure 4.4. Long-term (2009-2015) changes in benthic macroinvertebrate metrics in the Upper Arkansas River, including changes in mean (+/-SE) abundance of heptageniid mayflies (A), total macroinvertebrate abundance (B) and number of taxa (C) at treatment site AR4.G. This site was treated in 2014.

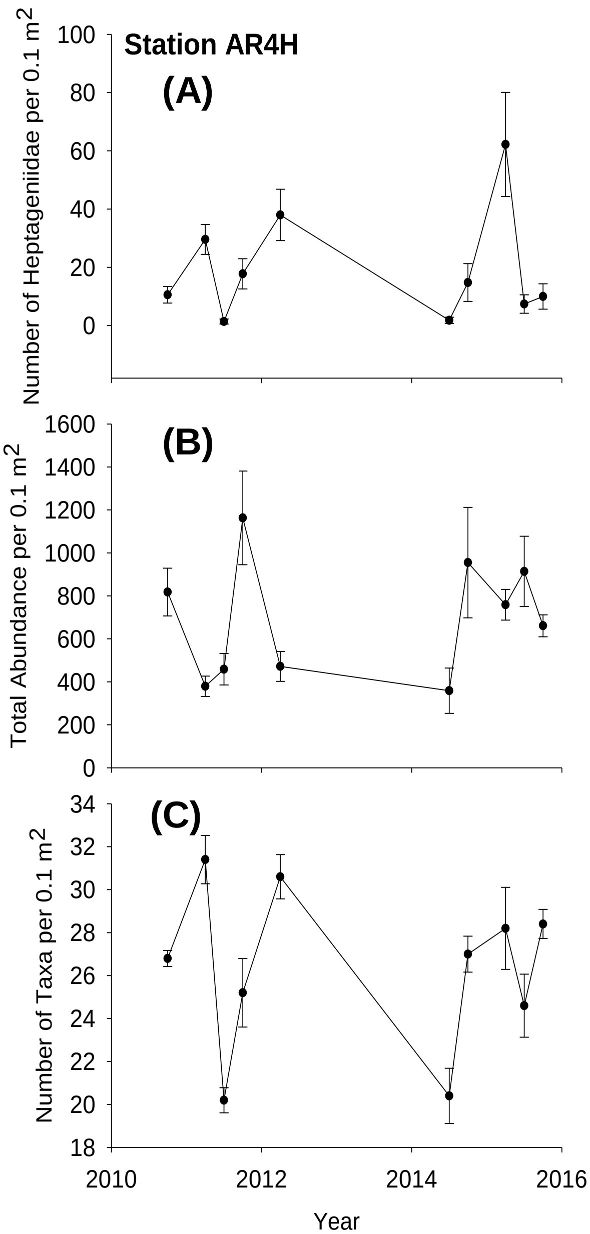

Figure 4.5. Long-term (2009-2015) changes in benthic macroinvertebrate metrics in the Upper Arkansas River, including changes in mean (+/-SE) abundance of heptageniid mayflies (A), total macroinvertebrate abundance (B) and number of taxa (C) at treatment site AR4.H. This site was treated in 2014.

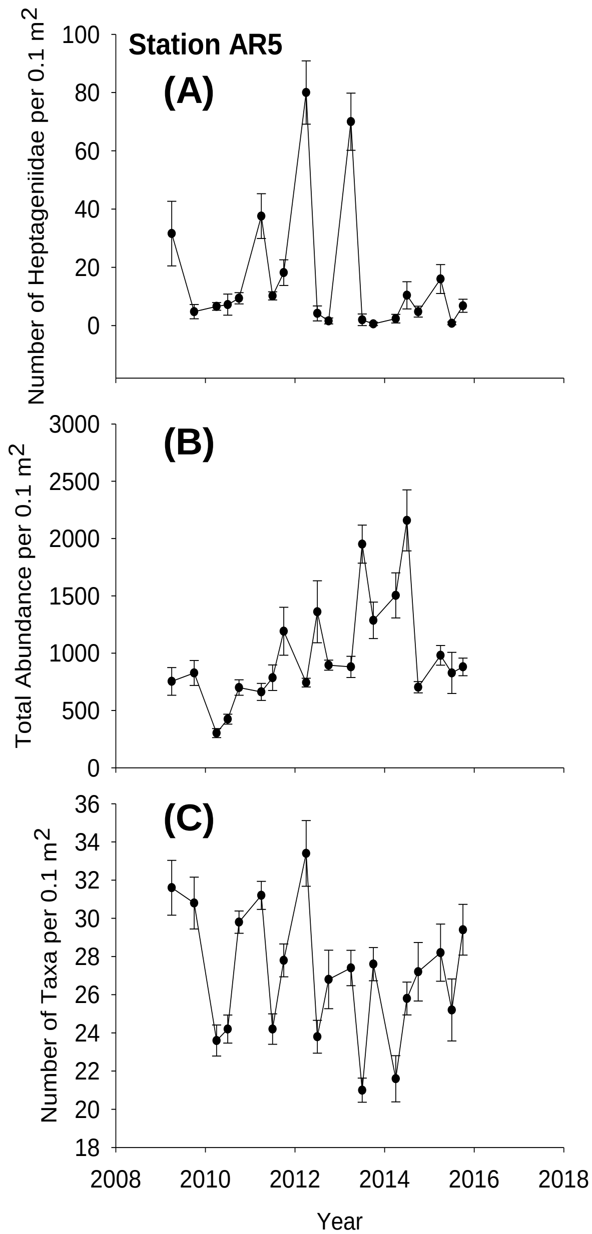

Figure 4.6. Long-term (2009-2015) changes in benthic macroinvertebrate metrics in the Upper Arkansas River, including changes in mean (+/-SE) abundance of heptageniid mayflies (A), total macroinvertebrate abundance (B) and number of taxa (C) at control site AR5.Kobe. This site was not treated.

further investigation. If water quality is limiting benthic macroinvertebrate populations, expectations regarding changes in brown trout populations may need to be tempered. Additional analysis could help evaluate the need for and priority of new remediation projects. However, it may be prudent to wait for results from all five years of post-construction monitoring before making specific recommendations regarding additional remediation activities.

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Chapter 5: Riparian Vegetation

5.1 Introduction

Dr. Dan Baker and Dr. Brian Bledsoe with Colorado State University are the principal investigators for riparian vegetation monitoring on the Upper Arkansas River (UAR). Riparian vegetation not only influences regional biodiversity (Naiman et al., 1993), but also contributes to riverbank stability, hydrologic function (Simon and Collison, 2001), and stream habitat quality (Wesche et al., 1987). In the UAR basin, historic land uses and transbasin diversions have disturbed riparian habitats (Stratus, 2010). Additionally, the deposition of fluvial tailings degraded riparian vegetation for extensive areas within the project extent (Figure 2.2). The historic use of contaminated water for irrigation of floodplain meadows also impaired riparian and floodplain habitats, impacting soils and vegetation at sufficient levels to injure wildlife and livestock (Industrial Economics, 2006). Prior to instream habitat restoration, the Environmental Protection Agency (EPA) prioritized fluvial tailings areas and treated select areas with a combination of lime, biosolids, seed, fertilizer, and straw. In some locations, the alignment of the river was configured to minimize the likelihood of channel avulsion into known fluvial tailings deposits.

During habitat restoration, willow (*Salix spp*.) transplants and stakes were used to enhance vegetation and stability along streambanks. Subsequent vegetation work included riparian seeding and bare-root willow planting in areas where channel narrowing, point-bar development, or lateral-bar development had occurred. Seeding and willow planting were completed during the spring of 2015 prior to snowmelt runoff. Riparian vegetation will be monitored with the goal of increasing vegetation cover by at least 10% over baseline by year-three in fenced or replanted areas. Planted vegetation should have a survival rate of 90% by year-three after implementation. Baseline data for riparian vegetation were collected in 2012 at 14 sites listed in Table 5.1 using procedures outlined in Kulchawik and Bledsoe (2013). These same procedures were used in vegetation surveys for effectiveness monitoring in 2015. Baseline vegetation surveys were conducted for the entire 11-mile reach, but effectiveness monitoring is focused on the Crystal-Reddy and Hayden reaches. Riparian vegetation monitoring includes greenline and plot surveys.

5.2 Methods

Greenline Survey

The location of the greenline and composition of vegetation plots were selected as the two parameters used to monitor riparian vegetation (Kulchawik and Bledsoe, 2013). The greenline survey was selected to monitor bank stability and vegetation persistence or encroachment. The greenline is defined as the first perennial vegetation that forms a lineal grouping of community types on or near the water's edge, most often occurring at or slightly below the bankfull stage (Winward 2000). The location of the greenline was surveyed with a total station in 2012 and survey-grade GPS in 2015 using methods outlined in Winward (2000) and Burton et al. (1999). Greenline observations were surveyed with sufficient density along both streambanks to provide adequate spatial representation at all vegetation-monitoring sites. Additional greenline surveys and analyses will occur in 2017 and 2019.

Bank stability was determined spatially by comparing the location of the greenline in 2012 to the location of the greenline in 2015. Where the location of the greenline differed from 2012 to 2015, the area between the two greenlines represented polygons of bank erosion or encroachment. Polygon attributes included bank movement type (erosion or encroachment), site type (control or treatment), and bank geometry (concave, straight, or convex). The difference between the total area of encroachment and the total area of erosion represents the net change at each site from 2012 to 2015. The magnitude of change, calculated as erosion plus encroachment, indicates the total extent of bank movement.

Table 5.1. Vegetation monitoring sites used for evaluation of the Upper Arkansas River habitat restoration project, including reach location, delineation as treatment or control sites, and type of treatment.

Reach	Site	Control/ Treatment	Type of Treatments
Smith Ranch	UA 2-2	Treatment	Channel realignment and rock-vanes
Crystal Lake STL	UA 2-4	Control	None
	UA 2-5	Control	None
	UA 2-6	Treatment	Log/rock-vanes, point-bar development, and pool development
Reddy SWA	UA 2-7	Treatment	Point-bar development and pool development
	UA 2-8	Treatment	Boulder clusters, erosion control, log-vanes, point-bar development, pool development, and wood-toe
Hayden	UA 3-1	Treatment	Cobble-toe, boulder clusters, point-bar development, and pool development
	UA 3-2	Treatment	Boulder clusters, point-bar development, pool development, and wood-toe
	UA 3-3	Treatment*	Log-vanes, point-bar development, pool development, and wood-toe
	UA 3-4	Treatment	Point-bar development, pool development, and rock-vanes
	UA 3-5	Treatment	Cobble-toe, log-rock vane, point bar development, and pool development
	UA 3-6	Control	None
	UA 3-7	Treatment	Boulder clusters, log-rock vanes, point bar development, and pool development
Kobe	UA 4-1	Control	None

*UA 3-3 was initially delineated as Control site in 2012 but is now considered a Treatment site.

Vegetation Monitoring Plots

Permanent vegetation monitoring plots were established in 2012 at each site listed in Table 5.1. Each plot had an area of three square-meters, with five plots located on each bank for a total of ten plots per site. The center of each plot was marked with rebar and orange plastic caps. Coordinates for the center of each plot were surveyed and recorded to facilitate relocation. The location of vegetation plots and greenline surveys are presented for each riparian vegetation site in Appendix E. Vegetation plots were relocated and surveyed in 2015 to evaluate changes in cover. In 2012 and 2015, vegetation cover was visually estimated in each plot using a one square-foot grid method adapted from Dethier et al. (1993). Distributions of vegetation type were drawn onto the one square-foot grid representing the plot area. Vegetation was identified using the following classifications: sagebrush (*Artemisia spp*.), sedge (*Carex spp*.), cinquefoil (*Dasiphora spp*.), horsetail (*Equisetum spp*.), iris (*Iris spp*.), rush (*Juncus spp*.), currant (*Ribes spp*.), willow (*Salix spp*.), forbs, graminoids (non-sedge or rush), and bare ground. Total percent cover and percent cover by vegetation type were calculated for each plot. To support visual estimation and qualitative comparison, each plot was photographed from a similar position and angle in 2012 and 2015. Vegetation plots will be re-surveyed in 2017 and 2019 to reevaluate progress towards project goals.

5.3 Results and Discussion

Greenline Survey

The 2012 and 2015 greenline surveys and polygons representing areas of erosion and encroachment can be found in Appendix E. Four treatment sites (UA 2-6, UA 2-8, UA 3-1, and UA

3-2) experienced a positive net change in bank area, indicating greater encroachment that erosion (Figure 5.1). Some of this encroachment can be directly attributed to the installation of sod mats, riparian seeding, or willow transplants (i.e., UA 2-6 and UA 3-2). The remaining treatment and control sites exhibit a negative net change, indicative of greater erosion than encroachment (Figure 5.1). Treatment sites UA 3-3, UA 3-4, and UA 3-5 experienced the highest relative erosion. While the net change for all the sites was negative, large areas of encroachment were still observed at UA 2-6, UA 2-7, UA 2-8, UA 3-1, UA 3-2, and UA 3-3. Treatment site UA 3-3 displayed the greatest erosion and encroachment in comparison to all other sites. This site is the most sinuous, indicating a large degree of expected dynamicity.

Treatment sites, on average, experienced less net bank change than control sites (Figure 5.2). However, treatment sites experienced greater erosion and encroachment when compared to control sites, indicating that treatment sites were generally more dynamic than control sites despite experiencing less net change. The higher degree of change observed at treatment sites was likely attributed to restoration activities. For example, riparian seeding, sod-mat transplants, and willow plantings would encourage encroachment while the development of a point bars could concurrently enhance erosion on the opposite bank by concentrating the flow of water and enhancing lateral scouring forces.

Higher rates of erosion generally occur on concave (outside) banks when compared to convex (inside) banks. Encroachment rates for straight, concave, and convex bank geometries were relatively similar (Figure 5.3). Concave bank sections, as expected, exhibited the largest amount of erosion. Erosion was, on average, more prevalent than encroachment at both treatment and control sites (Figure 5.3). When considering the dynamics of river sediments, equal rates of concave erosion and convex deposition should occur for a river in geomorphic equilibrium (Julien, 2002). However, vegetation

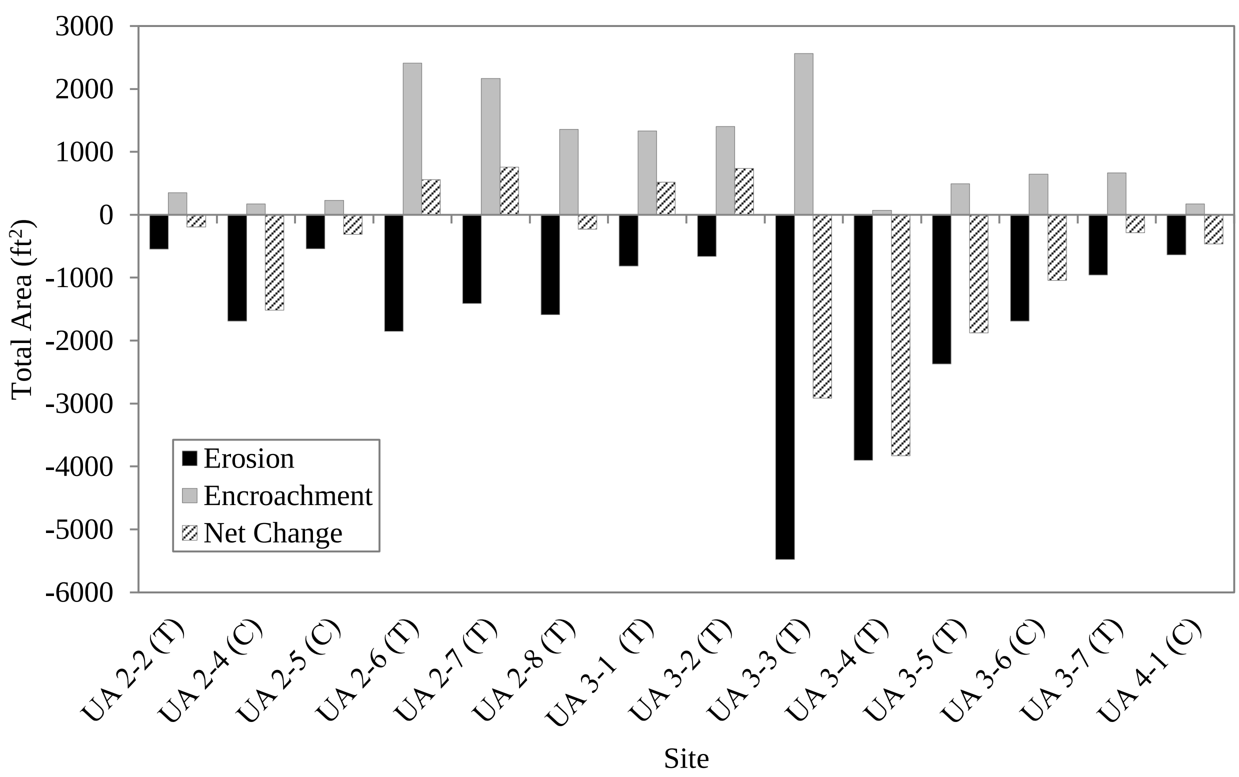

Figure 5.1. Total area of erosion and vegetation encroachment from greenline surveys in 2012 and 2015 at vegetation monitoring sites on the Upper Arkansas River. Treatment sites are denoted by (T) and control sites are denoted by (C).

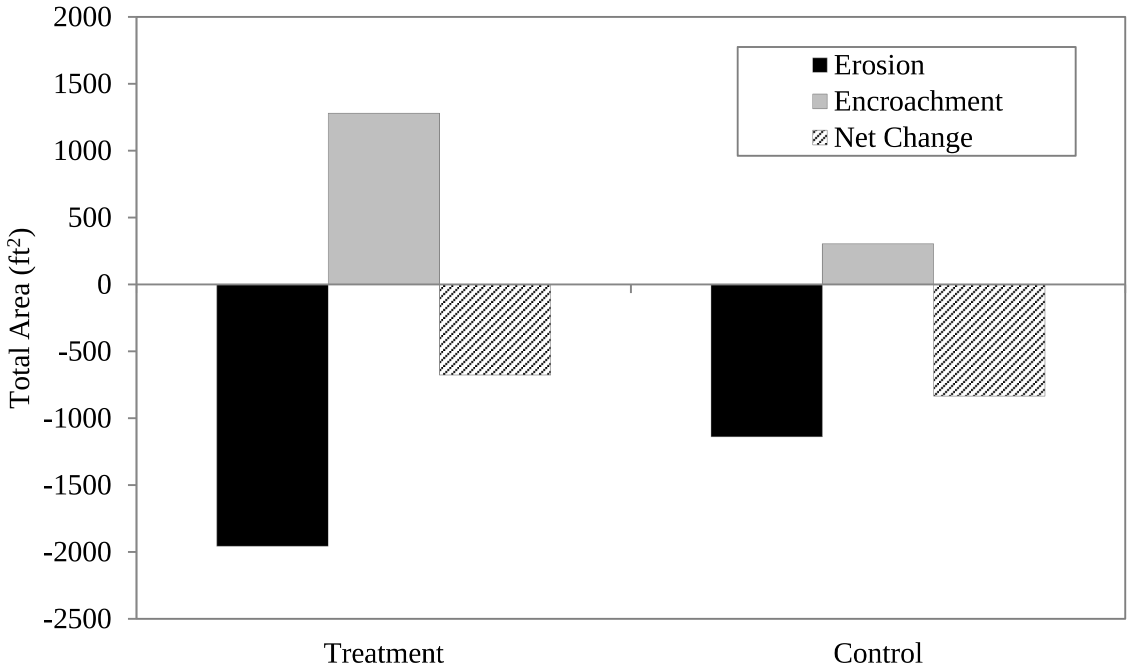

Figure 5.2. Average change in erosion and vegetation encroachment by total area for treatment and control sites on the Upper Arkansas River.

encroachment via colonization will not occur immediately after sediment deposition, accounting for the apparent lack of encroachment in relation to the degree of erosion. The observed magnitude of net change was relatively small and constant between sites UA 2-2 to UA 3-2 while an increase in erosion rates occurred at UA 3-3, UA 3-4, and UA 3-5 (Figure 5.1). Peak discharges in 2014 and 2015 corresponded to 5- and 10-year flood events, respectively. These flood events likely contributed to the high erosion rates and potentially inhibited vegetation encroachment during these years. If annual peak discharges in subsequent monitoring years are lower than in 2014 and 2015, rates of vegetation encroachment may increase.

Vegetation Cover

Average changes in total vegetation cover, willow, sedge, rush, and bare ground were calculated across control and treatment sites and presented in Figure 5.4. Vegetation cover increased on both treated (1%) and control (3%) sites, but increases fell short of the goal to increase riparian vegetation by 10% within three years of construction completion. Seeding and willow planting occurred in spring 2015, while vegetation plot surveys occurred in summer 2015, leaving little time for seeded and planted areas to respond to vegetation treatments. Additional surveys will take place in 2017 and 2019 to evaluate progress towards project goals for riparian vegetation. Observed increases in cover can mainly be attributed to increase in willows (4% on treated sites and 5% on control sites) and rush species (1% on control sites). Sedges decreased across all treated sites by 2%. Although these initial results fall short of the 10% increase in riparian vegetation, observed changes in cover indicate a positive trend toward project goals.

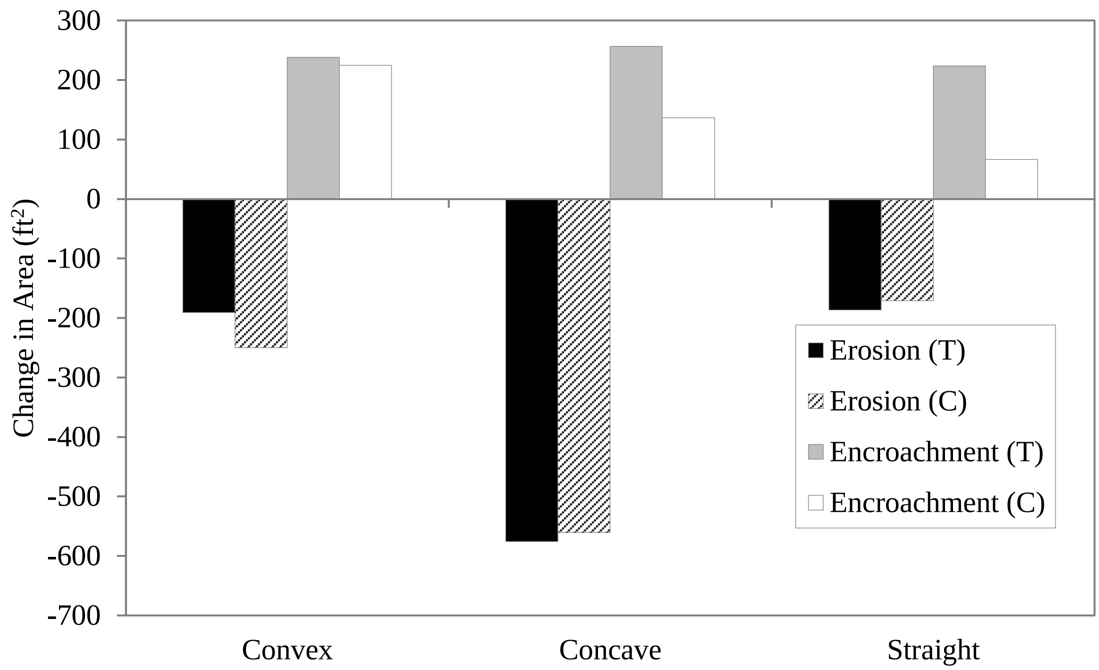

Figure 5.3. Average change in erosion and vegetation encroachment by area for convex, concave, and straight bank geometries at treatment (T) and control (C) sites on the Upper Arkansas River.

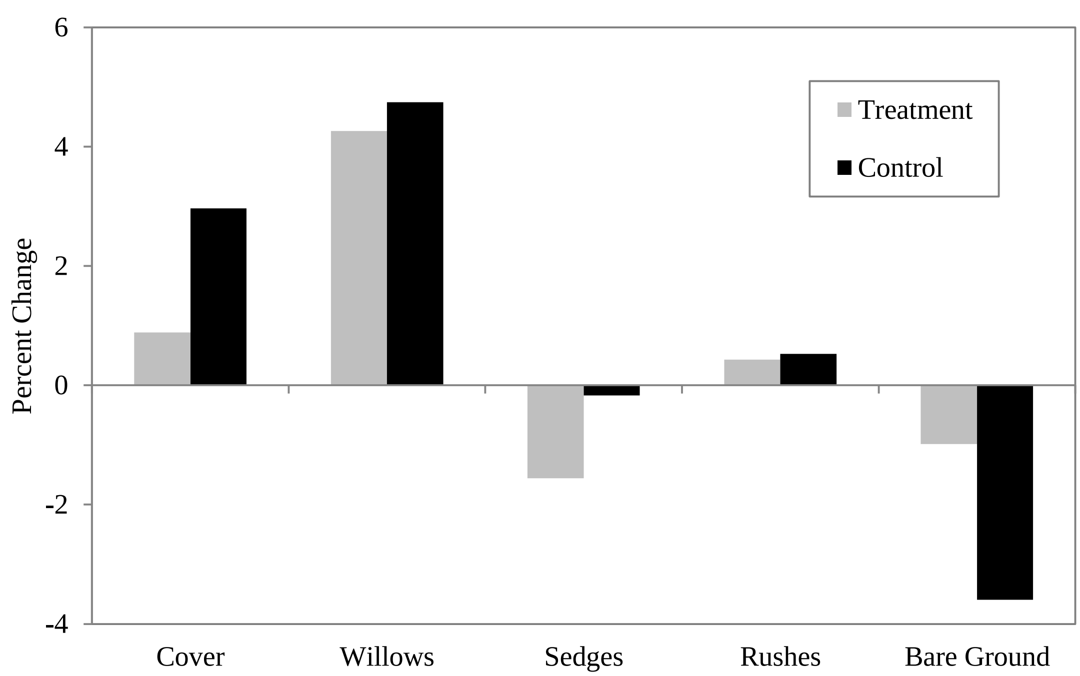

Figure 5.4. Percent change from 2012 to 2015 in select vegetation types for all control and treatment vegetation plots surveyed in both years on the Upper Arkansas River.

In general, total vegetative cover increased more at control sites when compared to treated sites and experienced no large component decreases, as was observed for sedges at treated sites (Figure 5.4). This apparent out-performance of the control sites compared to treated sites may stem from the proximity in time of some construction and planting activities to the 2015 summer sampling. While construction started in 2013 working from upstream to downstream, some construction activities were not completed until 2014 or were subsequently repaired following initial implementation. This undoubtedly caused disturbance and may have removed or hindered vegetation that had grown following the initial 2013 construction period, artificially depressing vegetation on some treated sites. Furthermore, some vegetation plantings were implemented in the spring of 2015, leaving little time for establishment and expansion prior to the summer 2015 sampling.

The observed increase in willow cover across treated and control sites represents a positive trend, as willows increase bank stability and enhance trout habitat through improved cover, shade, and nutrient cycling (Wesche et al., 1987). However, the concurrent reduction in sedge on treated sites partially negates this gain. Graminaceous wetland species have a bank stability safety factor of 70%, while willow species have a bank stability factor of 39% (Simon and Collison, 2001; Micheli and Kirchner, 2002). As wetland graminoids, such as sedges, provide more soil stability than their upland counterparts (Micheli and Kirchner, 2002), further monitoring of the sedge component within the riparian plant community is needed to evaluate the long-term effectiveness of riparian restoration.

Loss of Vegetation Plots

Due to construction activities, bank erosion, or data transformation issues, some vegetation plots were not relocated in 2015. Many of these plots were located on the outside of bends and were lost to bank erosion sometime between baseline surveys in 2012 and effectiveness surveys in 2015. The loss of plots decreased the amount of data collected, reducing statistical power and potentially skewing results towards more stable areas. Lost plots could be replaced prior to subsequent monitoring surveys using GPS coordinates, photographs, and aerial images, but data collected from relocated plots will not represent an "apples-to-apples" comparison to baseline surveys. The merits of replacing lost plots should be considered further prior to conducting effectiveness surveys in 2017. If lost plots are relocated, all of the relocated plots should be flagged and evaluated separately prior to inclusion in final analysis.

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Chapter 6: Fish Habitat Modeling

6.1 Introduction

As trout have different habitat requirements at various life stages, the diversity and quality of instream habitat can influence population density and biomass. In the Upper Arkansas River (UAR), trout habitat was negatively impacted by historic land-use and transbasin water diversions (Stratus, 2010). Metals pollution related to historic mining activities also impaired trout populations. Habitat restoration was initiated after the implementation of remediation activities to address water quality issues. Prior to restoration, habitat in the UAR was characterized by an over-wide channel that lacked low-velocity refuge areas during high flows and deep pools for over-winter habitat (Stratus, 2010). Large-scale habitat restoration was undertaken in the 11-mile reach of the UAR to benefit trout populations as compensation to the public for damages from historic mining activities. CPW was responsible for habitat restoration within a five-mile reach on public lands, including the Crystal-Reddy and Hayden reaches (Figures 1.1 and 1.2).

Habitat restoration treatments were designed to stabilize streambanks, promote diverse stream morphology, reduce erosion and downstream sedimentation, enhance overhead cover for trout, and create diverse instream habitat including pools, riffles, and bars (Stratus, 2010). Treatments utilized large wood and boulders to improve habitat complexity by increasing over-head cover, creating low velocity refuge areas, developing pools to improve over-winter habitat, and increasing spawning habitat availability. Construction activities were conducted in 2013 and 2014, beginning when flows dropped to sufficient levels in July and ending before October in 2013 and before September in 2014. Maintenance activities were conducted during spring 2016, as some structures had failed or been damaged during the 5-10 year flood events observed in 2014 and 2015. The objective of this chapter is to evaluate changes in habitat quality for pre- and post-construction conditions at all fish population monitoring sites within the CPW project reach.

6.2 Methods

Before-After-Control-Impact Study Design

The effectiveness of instream habitat restoration will be evaluated with reach scale monitoring using a Before-After-Control-Impact (BACI) study for habitat suitability conducted at all fish monitoring sites within the Crystal-Reddy and Hayden reaches (Figures 1.1 and 1.2). Aerial images for fish monitoring sites along with locations of habitat treatments are shown in Appendix C. Habitat suitability modeling was conducted with River2D to compare physical habitat quality at control and treatment sites before and after habitat restoration. River2D is a two-dimensional (2D) depth averaged model of river hydrodynamics and fish habitat (Steffler and Blackburn, 2002). The model was used to evaluate design options for instream restoration on the Reddy SWA (Hardie et al., 2013), and has been successfully applied to quantify changes in habitat following restoration (e.g., Boavida et al., 2012; Koljonen et al., 2013). Changes in habitat quality will be compared to changes in fishery metrics to evaluate the effectiveness of restoration treatments and inform future restoration projects. Baseline surveys for habitat suitability modeling were conducted in 2013. Effectiveness (post-construction) surveys for habitat modeling were conducted in 2014. Project goals include increasing habitat quality scores by 10% within five years of project completion. Additional surveys are scheduled for 2016 and 2018 and will be used for further evaluation of habitat restoration effectiveness.

Hydrologic Analysis

Average daily discharge data for the Arkansas River Below Empire Gulch Near Malta, CO (USGS 07083710) stream gauge were used to analyze hydrology for the project reach and select flows for habitat modeling. All available discharge data from 1990-2015 were used to calculate a median discharge value for each day of the water year (WY). Historical median values were used to represent a “typical” hydrograph for the project reach. Five flow values were selected to represent a range of flows for the project reach. As the UAR splits flow above the AR-R fish monitoring and habitat-modeling site, a stage-discharge relationship was developed to estimate flows for habitat analysis at AR-R (Reddy Reach). Habitat quality at all other fish monitoring sites was analyzed using the same suite of flows within the Hayden Reach. All flows used in habitat analysis are presented in Table 6.1.

Site Surveys

Fish monitoring sites were surveyed in 2013 to support 2D habitat modeling for pre-construction conditions. All sites were re-surveyed in 2014 following completion of instream construction to evaluate changes in habitat suitability at control and treatment sites. Topographic surveys were conducted using survey-grade GPS tied into pre-established control points. All survey data were collected in US survey feet using NAD 1983 US State Plane Central and NAVD 1988 coordinate systems, and then re-projected into UTM NAD 1983 13N to support analysis in River 2D. Five passes, or breaklines, were surveyed within the active channel. Streambed breaklines followed longitudinal slope breaks when present. If defined slope breaks were not evident, streambed breaklines were equally spaced between bank bottoms. Survey points were collected every 3-5 meters and at all major changes in slope along each breakline. Breaklines were also surveyed along the top and bottom of each bank and around any islands, as well as along the adjacent floodplain for each bank. Additional survey data were collected in areas with more geomorphic complexity, such as installed boulder clusters.

Habitat Modeling with River2D

One-dimensional (1D) hydraulic models for each study reach were created in HEC-RAS v4.1 (USACE, 2010) to estimate upstream and downstream boundary conditions for two-dimensional modeling with River2D (Steffler and Blackburn, 2002). Survey data were used to create a Triangulated Irregular Network (TIN) to represent channel morphology at each site for before and after conditions. HEC-GeoRAS (USACE, 2012) was used to extract stream geometry from TINs and import data into HEC-RAS for each site. HEC-RAS models were calibrated by varying Manning's n for the active channel until the difference between surveyed and modeled water surface elevations was minimized. After the 1D model was calibrated and run for each flow profile, steady-state flow analyses were performed in River2D using results from HEC-RAS models to inform upstream and downstream boundary conditions for each of the modeled discharges.

Survey data were imported into River2D and used to create a finite element mesh to represent before and after morphology for each site. Each mesh was initially developed using a uniform fill with 1.0 m spacing. Breaklines were then added at bank tops and bottoms to reduce discretization error along streambanks and around islands. Additional nodes were added in areas with more geomorphic complexity. River2D models were calibrated by iteratively changing the effective roughness height (k_s) to minimize the difference between surveyed and modeled water surface elevations (WSE) across the entire site, assuming that calibrating to WSE would result in accurate depth and velocity estimates.

Table 6.1. Discharge values used for habitat modeling at fish monitoring sites on the Upper Arkansas River.

Flow Profile	Discharge (cms)		Description
	Hayden Reach	Reddy Reach	
1	2.0	1.3	2nd Quartile from historic medians; Spawning; Low flow
2	4.0	2.5	3rd Quartile from historic medians
3	7.6	4.7	Intermediate flow from historic medians
4	16.4	10.0	Annual maximum from historic medians
5	20.7	12.5	Bankfull Estimate from flood-frequency analysis

Dominate substrate types were surveyed in 2015 and used to inform channel index files for each site. Survey data were used to create polygons for substrate areas using the following channel index classifications: plant detritus, clay, silt (<0.062 mm), sand (0.062-2 mm), gravel (2-64 mm), cobble (64-250 mm), boulder (>250 mm), and bedrock. Habitat suitability curves (HSC) for velocity, depth, and substrate were obtained for brown trout during adult, juvenile, fry, and spawning life stages (Figure 6.1). Juvenile and fry HSC were taken from Raleigh et al. (1986), while adult HSC were taken from Allyón et al. (2010), and spawning HSC were taken from Louhi et al. (2008). Total weighted usable area (WUA) was calculated in River2D for each life stage and flow at each site. WUA represents the spatial summation of area weighted by combined suitability (depth, velocity, and substrate) for brown trout life-stage at each site. Due to different model extents in 2013 and 2014, WUA was normalized by reach length to support direct comparison between before and after conditions. Results from habitat models were used to compare changes in normalized WUA across control and treatment sites.

6.3 Results and Discussion

Results from model calibration are presented in Table 6.2. Calibration resulted in good agreement between inflow and outflow discharges, with differences (deltas) typically less than 1% (Table 6.2). The difference between surveyed and modeled WSE averaged 0.005 m, with a range from -0.028 to 0.018 m (Table 6.2). All calibrated roughness values for after models either increased or remained the same. The same roughness (k_s) values were calibrated for before and after models at sites AR-6A and AR-5. Moderately higher roughness values were observed for after models at control site AR-6 and treatment sites AR-MH and AR-R. Higher roughness values at AR-MH and AR-R could be due to habitat treatments including log-vanes, boulder clusters, and channel narrowing. The higher roughness values for the after model at control site AR-6 could be due to discretization error or survey point density. As k_s tends to remain constant over a wider range of depths than Manning's *n* (Steffler and Blackburn, 2002), changes in discharge should have less influence on calibrated k_s values than changes in channel morphology or mesh quality.

Natural changes in channel morphology can occur during high flows, particularly in high bedload systems such as the UAR. Flood frequency analysis indicates that the project reach experienced a 5-year flood in the spring of 2014, prior to surveys conducted during September 2014. Flows of this magnitude can induce channel maintenance functions, including mobilization of bedload sediment, scour of vegetation from the channel, inundation of floodplains, lateral channel migration, and reshaped alluvial features (Schmidt and Potyondy, 2004). The significant increase in roughness (k_s) at control site AR-5B (Table 6.2) was likely due to reshaped alluvial features observed at the site following high flows in 2014, including substantial bank erosion and bedform alteration. Differences in channel morphology due to habitat restoration and natural processes

Table 6.2. Results from calibration of River2D models, including measured discharge values used for calibration (Q_{cal}), calibrated roughness height (k_s), percent difference in inflow and outflow discharge (Delta Q), and average difference between surveyed and calibrated water surface elevations (Delta WSE).

Site	Class	Q_{cal} (cms)		Roughness (k_s)		Delta Q (%)		Delta WSE (m)	
		Before	After	Before	After	Before	After	Before	After
AR-R	Treatment	2.15	2.39	0.50	0.65	0.09	1.84	-0.013	0.003
AR-5	Treatment	3.12	3.03	0.30	0.30	0.14	0.14	0.003	0.007
AR-5B	Control	2.78	1.94	0.30	0.65	0.27	-0.31	-0.028	0.012
AR-6A	Control	3.25	2.83	0.65	0.65	-0.03	-0.86	0.018	0.013
AR-MH	Treatment	2.53	2.85	0.50	0.70	-0.02	-0.10	0.012	0.013
AR-6	Control	3.46	3.10	0.50	0.60	0.05	-0.98	0.009	0.016

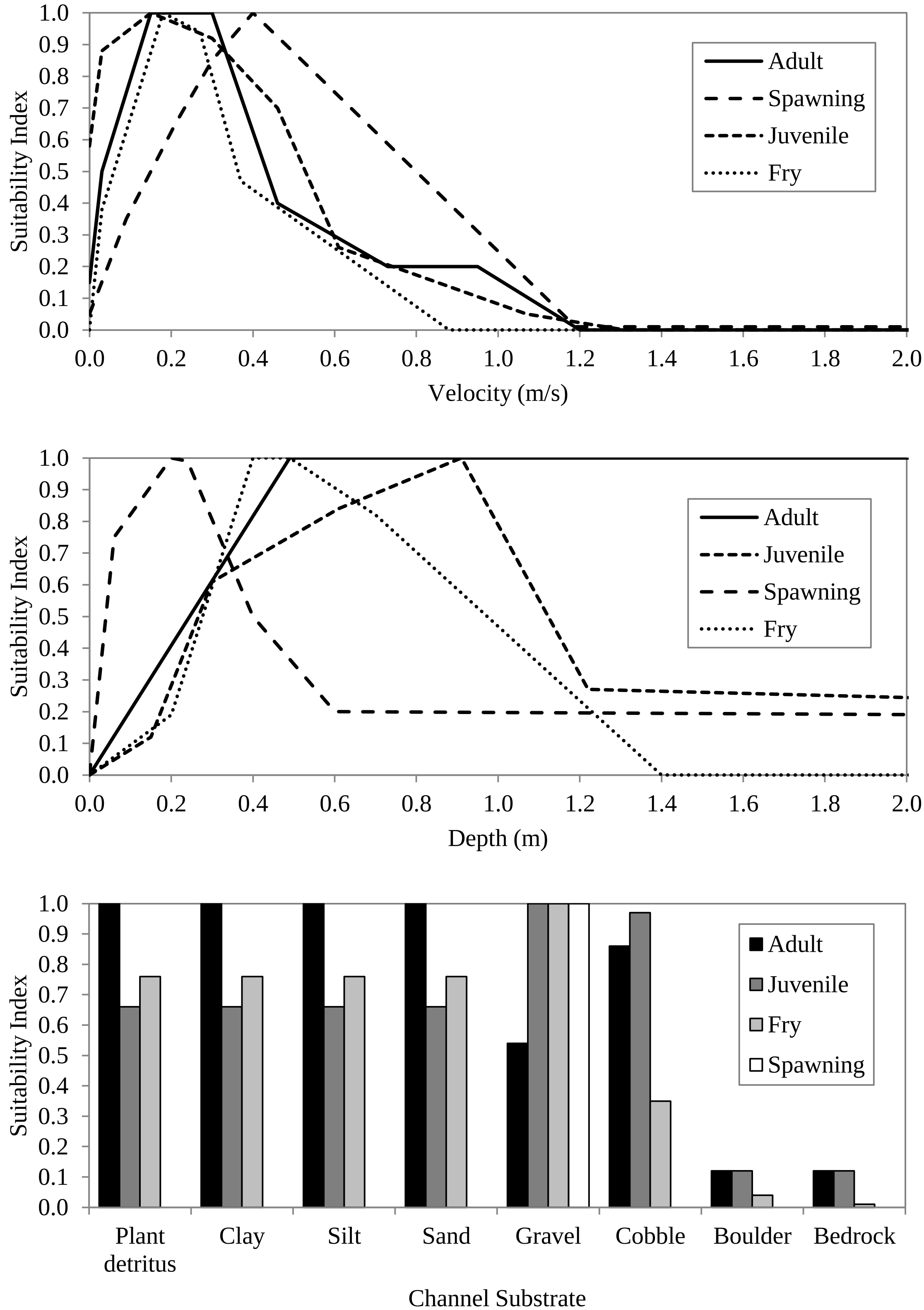

Figure 6.1. Habitat suitability curves for velocity, depth, and channel substrate used to analyze brown trout (*Salmo trutta*) habitat during adult, spawning, juvenile, and fry life stages.

will influence calibrated roughness (k_s) values, which can influence modeled depth and velocities used to calculate habitat scores. The BACI experiment design should account for any natural habitat changes that occurred across control and treatment sites.

Overall, the effects of the instream habitat treatments were positive in the treated reaches when comparing pre- and post-treatment habitat suitability (Figures 6.2-6.6). Before-after habitat comparisons for adult, juvenile, and spawning WUA at select flows are presented in Appendix F. The largest positive changes in habitat suitability for fry, juvenile, and adult life stages were seen at treatment site AR-R at the three lowest flows (1.3, 2.5, and 4.7 cms), and the two highest modeled flows (16.4 and 20.7cms) at AR-5 (Figures 6.2-6.6). The treatment site AR-MH showed an increase in spawning habitat and slight improvement in adult, juvenile, and fry habitat at low flows (Figures 6.2-6.5). Suitable spawning habitat was approximately doubled at AR-R (Figure 6.3) leading to average spawning habitat suitability being increased by approximately 40% in the treatment sections compared to a decrease in average spawning habitat (-10%) across the control reaches (Figure 6.6). The control sites showed some variability in habitat suitability from pre- to post-construction (Figures 6.2-6.5). Most notable were instances of overbank flow at the two higher discharges (e.g., AR-5B at 20.7 cms; Appendix F). Overbank flows created a large amount of suitable habitat for adult, juvenile, and fry life-stages outside of the main channel. As overbank bank flows could be related to increased bed roughness associated with habitat treatments, mesh configuration, or model calibration, they may exaggerate changes in habitat suitability for a given discharge and should be interpreted with less certainty.

Monitoring targets for habitat restoration included increasing habitat suitability by 10% for adult, juvenile, and spawning brown trout (Stratus, 2010). Changes in WUA were compared for control and treatment sites using different ranges of discharge. Due to the strong influence of overbank habitat on WUA at high flows and the increased uncertainty of modeling results at higher flows, changes in WUA were averaged across different flow ranges (Table 6.3). Changes in WUA for different life stages were also averaged across control and treatment sites (Figure 6.6). When overbank flows were excluded (i.e., 2.0-16.4 cms), habitat suitability scores increased by 10.0% at control sites and 23.6% at treatment sites on average (Table 6.3). As habitat scores increased at both treatment and control sites following instream construction, the difference between changes at treatment and control sites can be used to gauge the impact of habitat restoration at treatment sites relative to control sites. Changes in habitat were 13.6% higher at treatment sites compared to control sites (Table 6.3), indicating that habitat restoration had met project goals for increasing habitat quality by 10% (Stratus, 2010).

Table 6.3. Change in weighted usable area (WUA) from pre- and post-construction habitat models averaged across different discharge ranges at control and treatment sites for all brown trout life stages.

Discharge (cms)	Average Change in WUA (%)		
	Control	Treatment	Difference
2.0-4.0	3.1	14.4	11.4
2.0-7.6	6.1	16.8	10.7
2.0-16.4*	10.0	23.6	13.6
2.0-20.7	22.9	32.0	9.1

*Range of discharge used to evaluate project goals

Habitat Improvement and Trout Populations

Trout populations appear to be increasing in the treatment and control reaches following habitat restoration. This could indicate that the habitat treatments have improved the carrying capacity of the project reach to support more trout and/or improved trout condition. Although fish populations can take five to ten years to stabilize following habitat restoration, preliminary indicators suggest that restoration activities have improved habitat quality in the UAR and brown trout populations have responded favorably. Additional monitoring will determine if changes in habitat quality and fish populations are sustained or improved further.

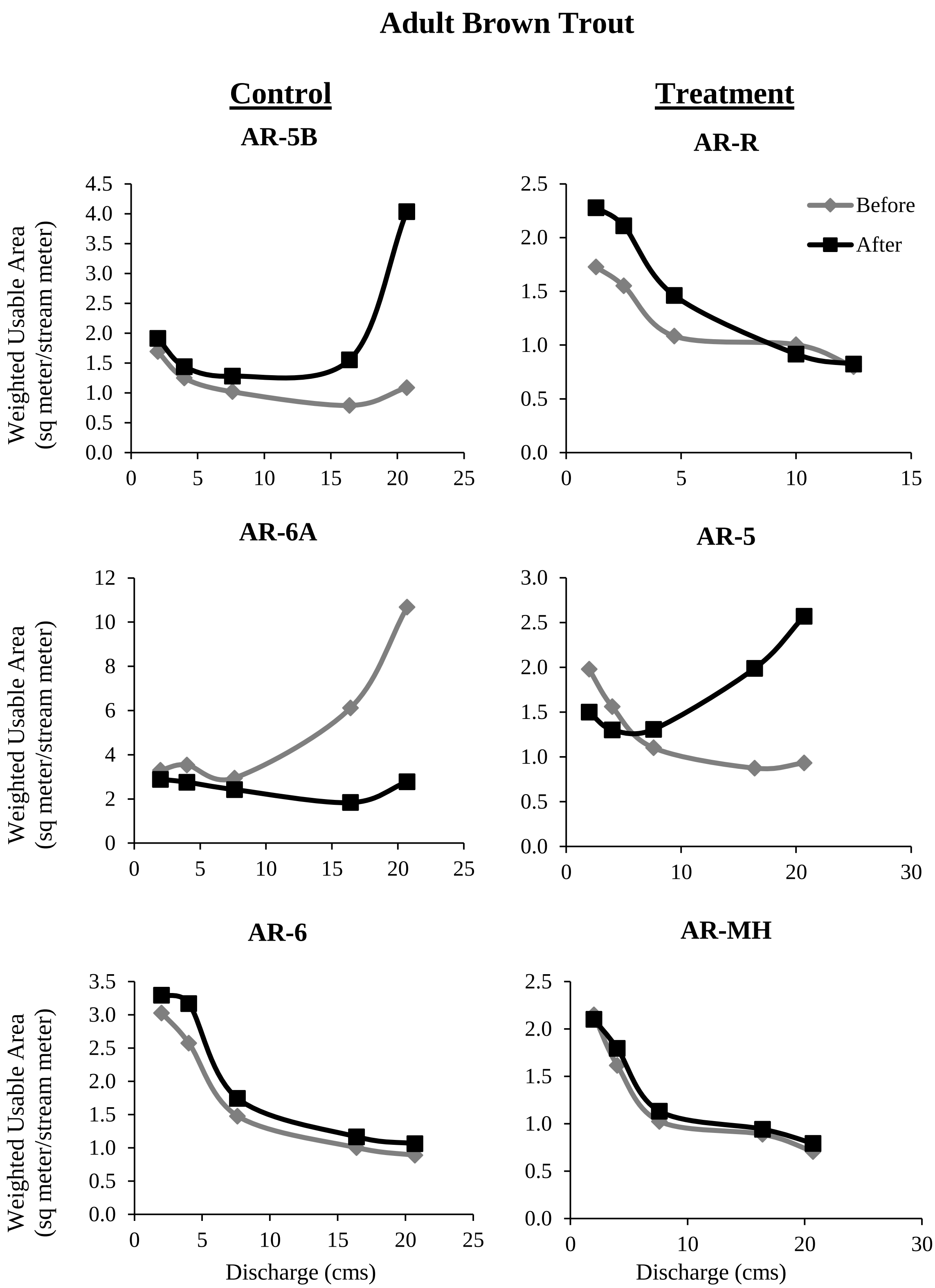

Figure 6.2. Weighted usable area (WUA) for adult brown trout at control and treatment sites on the Upper Arkansas River. Large WUA values (e.g., AR-6A Before) are influenced by overbank flow.

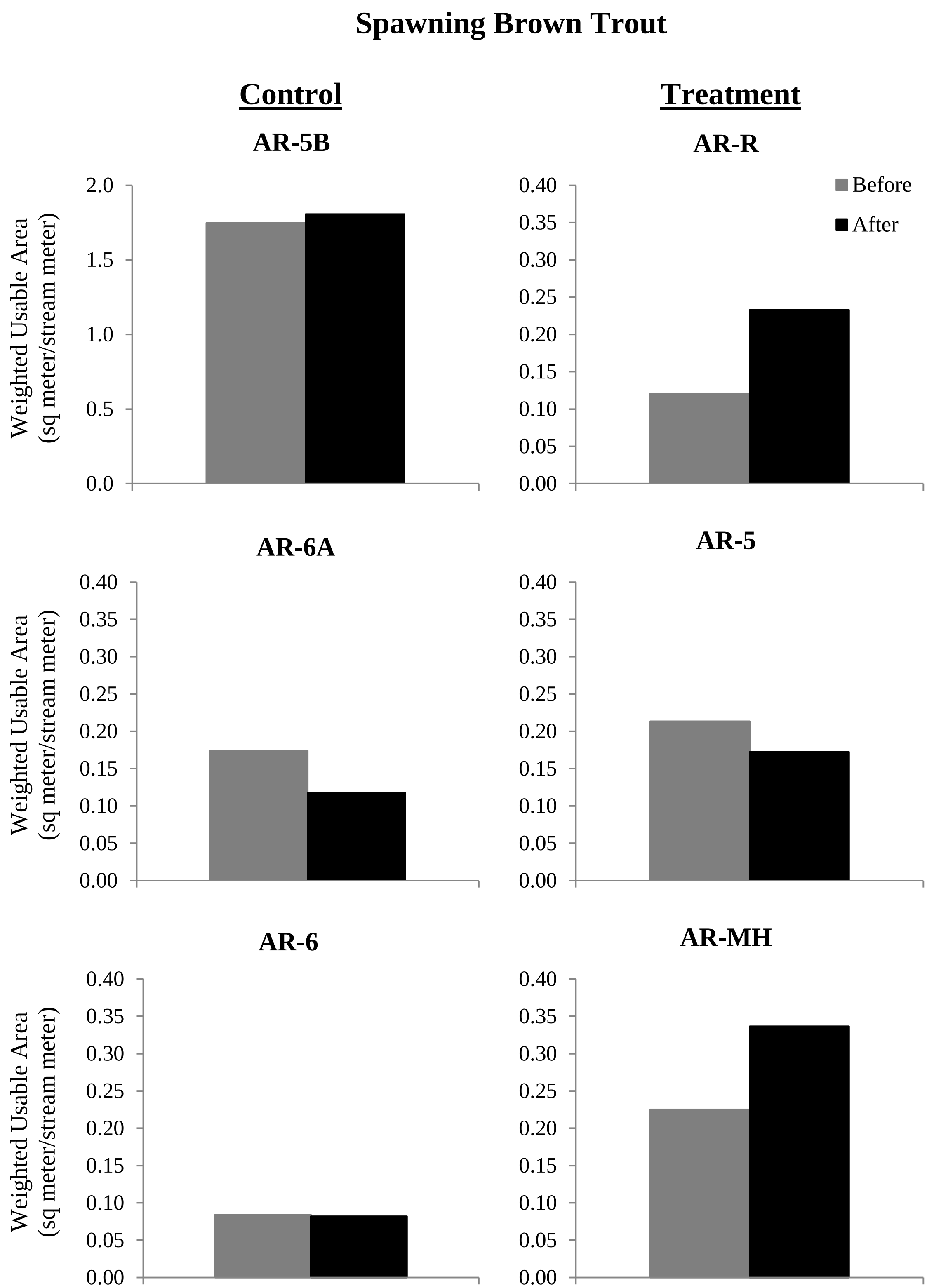

Figure 6.3. Weighted usable area (WUA) for spawning brown trout at control and treatment sites on the Upper Arkansas River. Note different y-axis at AR-5B.

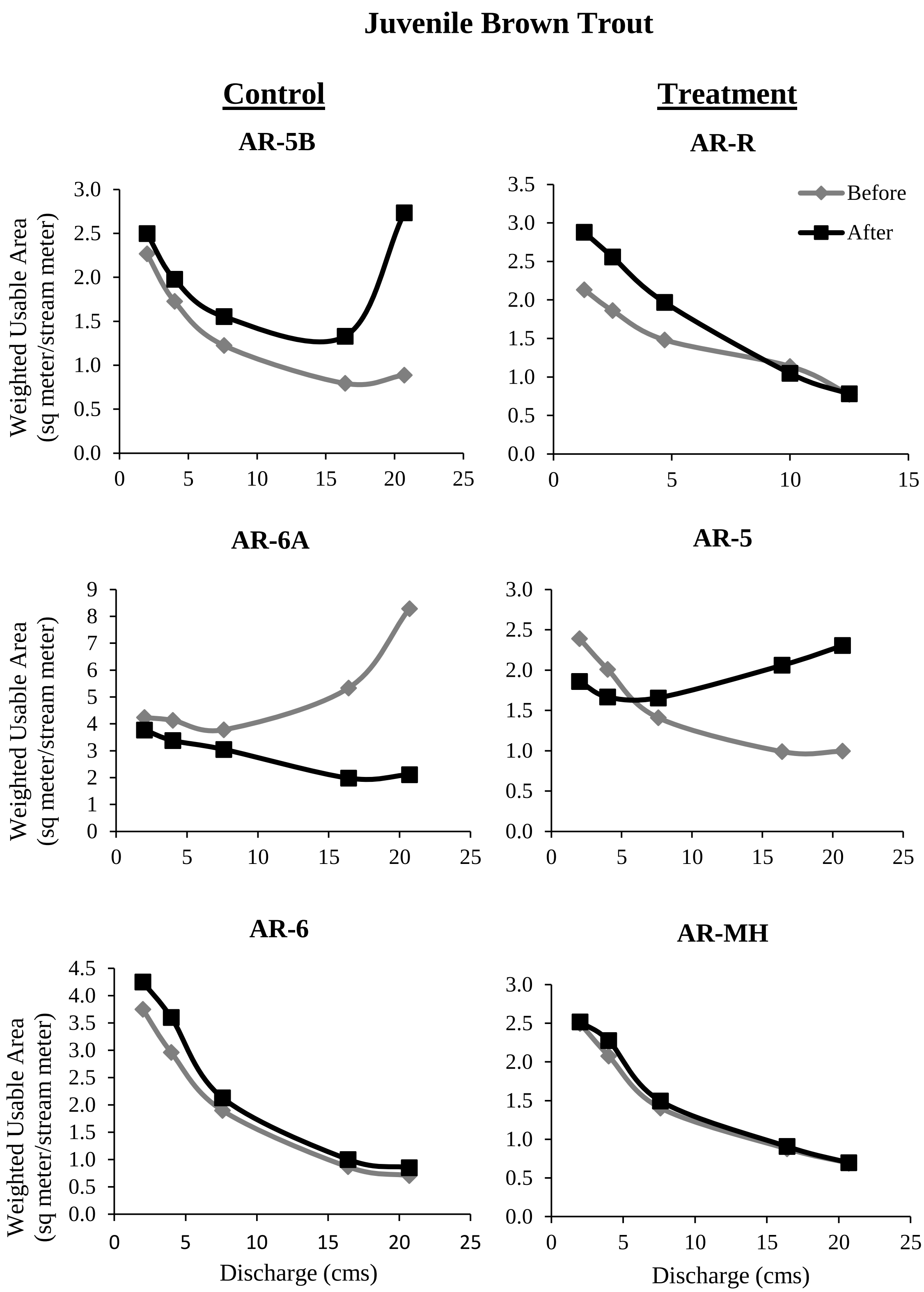

Figure 6.4. Weighted usable area (WUA) for juvenile brown trout at control and treatment sites on the Upper Arkansas River. Large WUA values (e.g., AR-6A at 20.7cms) are influenced by overbank flow.

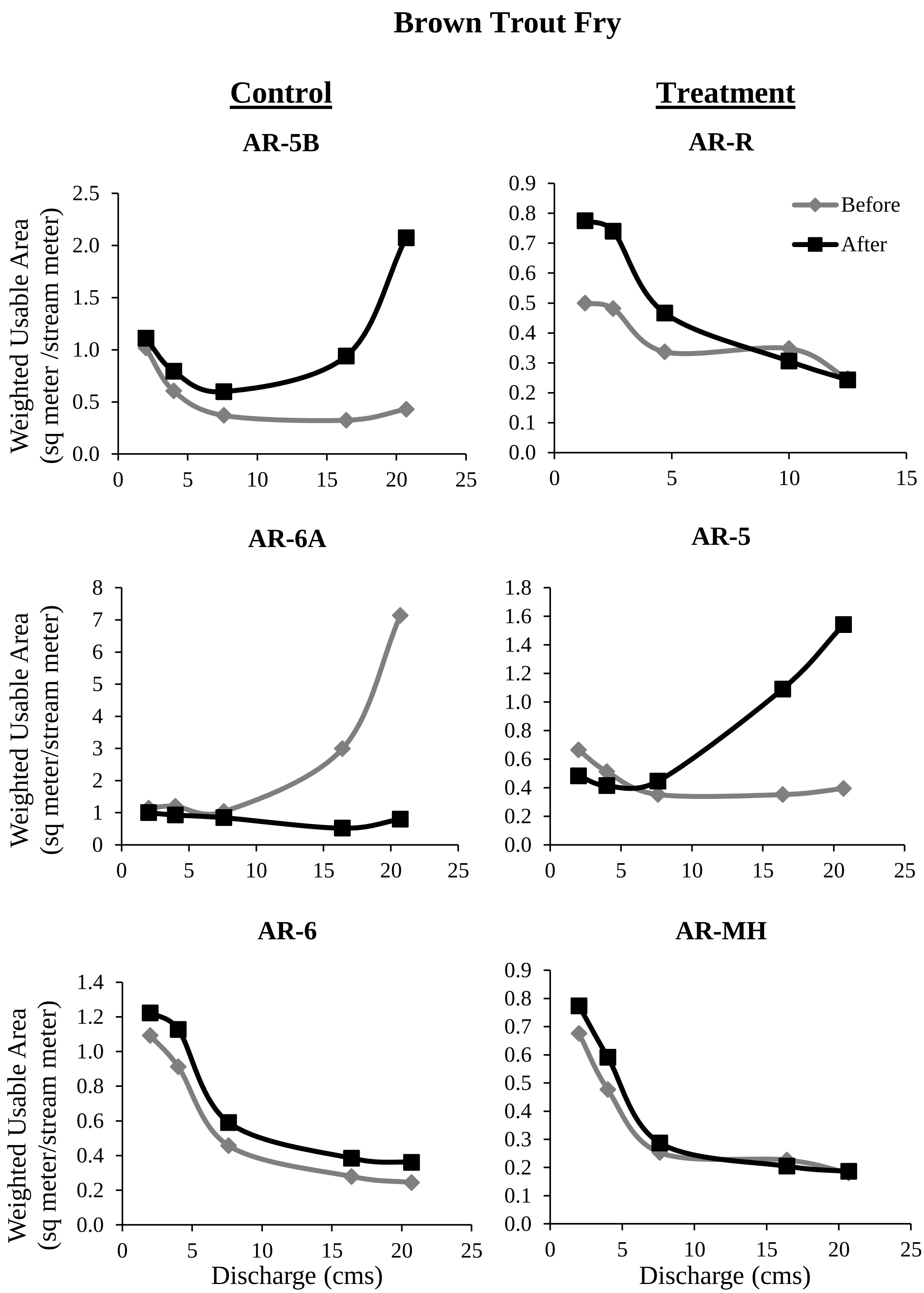

Figure 6.5. Weighted usable area (WUA) for brown trout fry at control and treatment sites on the Upper Arkansas River. Large WUA values (e.g., AR-6A at 20.7cms) are influenced by overbank flow.

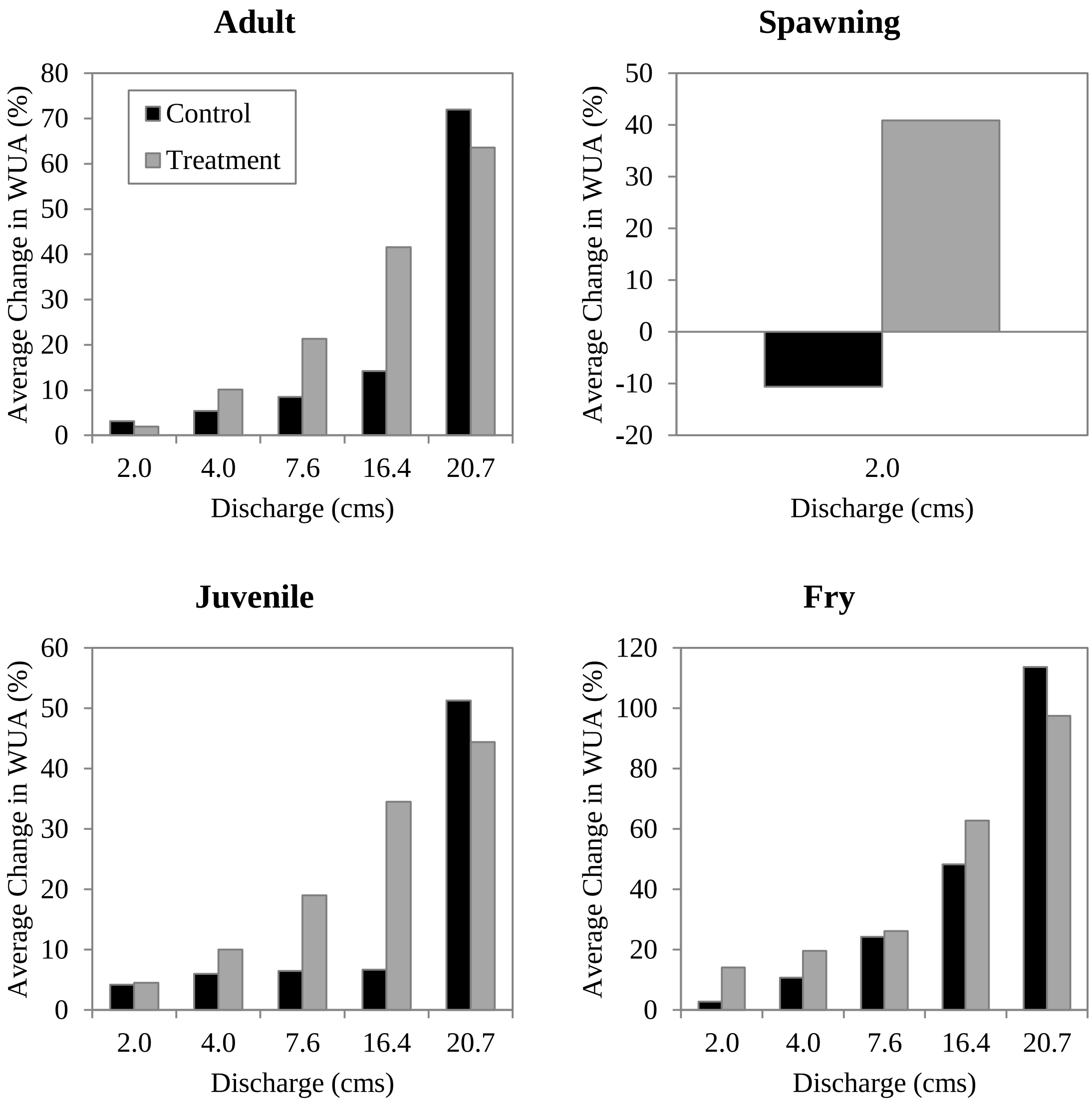

Figure 6.6. Average change in weighted usable area (WUA) for brown trout during adult, spawning, juvenile, and fry life-stages at control and treatment sites on the Upper Arkansas River.

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Chapter 7: Instream Habitat Structures

7.1 Introduction

Stream restoration and habitat enhancement projects utilize a variety of treatments designed to reduce erosion and improve aquatic habitat (Miller and Kochel, 2011). Instream structures and bank treatments are typically applied to control bank erosion until riparian vegetation becomes established. Some structures are designed to enhance aquatic habitat by providing velocity refuge, overhead cover, improved over-winter habitat, and more profitable feeding positions. However, the effectiveness of treatments is rarely evaluated for most stream restoration projects. Instream habitat structures used in the Upper Arkansas River (UAR) included boulder clusters, boulder-vanes (e.g., J-hooks and cross-vanes), and streambank structures (e.g., wood-toe, boulder/cobble toe, and log-vanes). Structure and treatment types are described in Table 7.1 along with their fishery benefits and expected functions. Photographic examples for typical boulder cluster, boulder cross-vane, rock-vane, log-vane, log/rock-vane, and wood-toe structures are shown in Figures 7.1 to 7.6, respectively. The location and extent of all structures were initially surveyed during as-built surveys. As-built drawings for the project show the location of all structures and are presented in Appendix A. In addition, all structures were documented with photographs. The goal of this assessment is to determine if at least 90% of all habitat improvement structures are stable and functional by year three after implementation (Stratus, 2010).

Table 7.1. Types of instream structures and habitat treatments used in the Upper Arkansas River habitat restoration project.

Structure or Treatment	Description	Fisheries Benefits
Boulder/cobble toe	Bank stabilization treatment consisting of boulder or cobble material placed along the bank toe, back filled with native alluvium, and covered with locally harvested sod mats or willow transplants.	• Stabilize eroding streambanks • Reduce point sources of sediment • Maintain channel dimensions • Protect sod mats from erosion • Support reestablishment of riparian vegetation
Boulder cluster (Figure 7.1)	Generally, 2-3 boulders placed near the channel thalweg, and set at an elevation below the bankfull stage.	• Provide mid-channel holding and refuge cover • Develop feeding lanes in flow separation zones • Increase habitat complexity
Cross-vane[1] (Figure 7.2)	Channel spanning boulder structure designed to establish grade control, reduce bank erosion, create a stable width/depth ratio, and maintain channel capacity, while maintaining sediment transport capacity and competence.	• Increase bank cover from differential raise in water surface in bank region • Create pool for holding and refuge cover during high and low flows • Develop feeding lanes in flow separation zones • Create spawning habitat in the glide portion of the pool • Increase habitat complexity
Fish condo	Bank stabilization and habitat enhancement treatment consisting of logs and root wads that are covered with fill material and locally harvested sod-mats, similar to wood-toe treatment but with an enhanced undercut bank.	• Stabilize eroding streambanks • Increase overhead cover by creating an undercut bank • Develop feeding lanes in flow separation zones • Increase habitat complexity • Provide organic material and nutrients for benthic macroinvertebrates

J-hook/rock-vane[1] (Figure 7.3)	Upstream-directed boulder structure on the outside of stream bends designed to reduce bank erosion by decreased near-bank slope, velocity, velocity gradient, stream power, and shear stress. The vane portion of the structure occupies 1/3 of the bankfull width, while the hook occupies the center 1/3.	• Increase bank cover from differential raise in water surface in bank region • Create pool for holding and refuge cover during high and low flows • Develop feeding lanes in flow separation zones • Create spawning habitat in the glide portion of the pool • Increase habitat complexity
Log-vane (Figure 7.4)	Bank stabilization and fish habitat treatment comprised of upstream-directed log structure used to deflect flows away from the bank and increase habitat complexity.	• Increase bank cover from differential raise in water surface in bank region • Create pool below the vane for holding and refuge cover • Develop feeding lanes in flow separation zones • Increase habitat complexity • Provide organic material and nutrients for benthic macroinvertebrates
Log/rock-vane (Figure 7.5)	Bank stabilization and fish habitat treatment comprised of upstream-directed log and rock structure used to deflect flows away from the bank, create a contraction scour pool, and increase habitat complexity. Typically one vane arm is constructed from a log while the other is constructed with boulders.	• Increase bank cover from differential raise in water surface in bank region • Create pool below the vane for holding and refuge cover • Develop feeding lanes in flow separation zones • Create spawning habitat in the glide portion of the pool • Increase habitat complexity • Provide organic material and nutrients for benthic macroinvertebrates
Point-bar development / Lateral-bar development	Treatment used to address stream channels with unnaturally high width/depth ratio or sinuosity that has been adversely modified. Bed material is imported or excavated from pool areas and used to develop bars, improving channel depth and velocity.	• Increase depth and holding habitat • Improve hydraulics, sediment transport, and geomorphology • Improve floodplain connectivity
Pool development	Treatment that involves excavation of pools and redistribution of excavated material back into the stream to address habitat degradation associated with sedimentation. Often used in conjunction with point bar development. Establishing channel dimensions that maintain sediment continuity is critical for sustaining excavated pools.	• Create pools for holding and refuge cover during high and low flows • Develop feeding lanes in flow separation zones • Develop spawning habitat on the glide portion of the pool • Improve over-winter habitat • Increase habitat complexity
Sod mat	Sod mats are transplanted from local riparian areas to provide top soil and vegetation at bank locations disturbed during construction, typically used in conjunction with wood-toe or at locations where instream structures are keyed into the bank.	• Provide "instant" riparian vegetation along newly constructed streambanks • Improve function and condition of riparian vegetation, which improves habitat for terrestrial insects • Improve overhead cover along banks
Willow, transplant	Individual or groups of willow plants transplanted from local riparian areas to improve vegetative cover and stability at	• Provide "instant" riparian vegetation along newly constructed streambanks

	bank locations disturbed during construction, typically used in conjunction with wood-toe or at locations where instream structures are keyed into the bank.	• Improve bank stability • Improve function and condition of riparian vegetation, which improves habitat for terrestrial insects • Decrease instream temperature • Improve overhead cover along banks
Willow, stakes	Willow cuttings that are harvested from local riparian areas to improve vegetative cover and stability at bank locations disturbed during construction or that have experienced riparian degradation.	• Improve bank stability • Improve function and condition of riparian vegetation, which improves habitat for terrestrial insects • Decrease instream temperature • Improve overhead cover along banks
Willow, bare root or containerized	Willow plants that are grown in nurseries and planted along riparian areas to improve vegetative cover and stability at bank locations disturbed during construction or that have experienced riparian degradation.	• Improve bank stability • Improve function and condition of riparian vegetation, which improves habitat for terrestrial insects • Decrease instream temperature • Improve overhead cover along banks
Wood-toe (Figure 7.6)	Bank stabilization treatment consisting of root wads layered along the bank toe and covered with fill material and locally harvested sod-mats.	• Stabilize eroding streambanks • Reduce point sources of sediment • Increase overhead cover by creating an undercut bank • Develop feeding lanes in flow separation zones • Increase habitat complexity • Provide organic material and nutrients for benthic macroinvertebrates

[1] Rosgen (2006)

7.2 Methods

The stability and function of all structures were evaluated using a rapid field assessment procedure developed by Miller and Kochel (2012). The following structure types were included in the rapid assessment: boulder/cobble toe, boulder cluster, cross-vane, fish condo, log-vane, log/rock-vane, rock-vane, and wood-toe. Vegetation treatments, including sod mats and all willow treatments, were excluded from the rapid assessment for instream structures. Pool, point-bar, and lateral-bar development were also excluded from the rapid assessment, but were evaluated during geomorphology monitoring. Rapid assessments were conducted during November 2014 and September 2015. The rapid assessment was used to evaluate all habitat structures for integrity and function, as well as unintended erosion or deposition. Structures that utilized root wads were given an additional performance rating for erosion. Rankings for all categories are detailed in Table 7.2. To evaluate stability and functional criteria outlined in Stratus (2010), scores ≤ 2 were considered stable and functional while scores ≥ 3 no longer functioned as intended. For erosion and deposition, scores ≥ 3 were flagged for additional monitoring and potential maintenance. For rootwad performance, scores ≥ 3 were considered indicative of impairment and further evaluated for maintenance needs.

Figure 7.1. Typical boulder cluster structure used during habitat restoration on the Upper Arkansas River.

Figure 7.2. Typical cross-vane structure used during habitat restoration on the Upper Arkansas River.

Figure 7.3. Typical rock-vane structure used during habitat restoration on the Upper Arkansas River.

Figure 7.4. Typical log-vane structure used during habitat restoration on the Upper Arkansas River.

Figure 7.5. Typical log/rock-vane structure used during habitat restoration on the Upper Arkansas River.

Figure 7.6. Typical wood-toe/sod mat structure used for habitat restoration on the Upper Arkansas River.

Table 7.2. Summary of rankings used in the rapid assessment procedure (Miller and Kochel, 2012).

(A) Rankings used to classify rock or log structures for **structural integrity**	
Ranking	**Description**
Intact (1)	No visible damage; fully operational in terms of integrity
Damaged (2)	Structure functions as intended; but at least 10% of the structure visibly damaged; usually involved movement of one or more boulders
Impaired (3)	Structural components in general location of original structure, but feature no longer functions as intended; 25-75% of structure remaining
Failed (4)	Significant part (>75%) have been removed from site; severely fragmented; incapable of achieving intended objective
Structures:	*Wood-toe, fish condo, j-hook rock vane, cross-vane, log-vane, log/rock-vane, boulder clusters, and boulder/cobble-toe*

(B) Ranking system used to categorize structures for **unintended erosion or deposition**		
Ranking	**Erosion**	**Deposition**
0	None visible	None visible
1	Minor localized erosion along margins of feature; structure maintains continuity with bank and bed; undermining of footings	Minor deposition over center of structure; pool remains well defined
2	Localized erosion visible, which is likely to continue. Eroded area likely to influence flow	Deposition along 25-50% of structure in channel; pool poorly developed and/or partially filled
3	Structure remains in contact with bank, but erosion has occurred along entire zone of contact with bank. Unintended erosion of channel bed must exceed 50 cm and be clearly related to the structure	Deposition occurs along 50-75% of structure's length in channel; pool very weakly defined or filled
4	Structure partially detached from bank; complete detachment eminent; feature no longer functions as intended	Sediments bury 75-90% of structure in channel; no pool present
5	Structure completely detached from bank; no longer performs function as intended	Sediments bury 90-100% of structure in channel; no pool present
Structures:	*J-hook rock vane, cross-vane, log-vane, and boulder/cobble toe*	

(C) Ranking system used to evaluate **performance of root wads**	
Ranking	**Description**
0	No visible erosion
1	Root wads intact, but minor localized erosion visible around <25% of root mass
2	Erosion visible around 25-90% of root mass; stem remains buried, or as presumed to be at time of construction
3	Erosion around entire root wad; stump locally exposed
4	Erosion around entire root wad; exposing stump; root wad no longer located along bank, but extends into channel and affects local flow field
5	Erosion has exposed most of buried stump; rootwad located in channel and affects flow field
Structures:	*Wood-toe and fish condo*

7.3 Results and Discussion

Over 90% of habitat structures were functional when first assessed in 2014 (Table 7.3). Following runoff in 2015, habitat structures were reassessed and functional ratings decreased from 94% to 87%, which is slightly below the monitoring target of 90%. Maintenance activities were subsequently conducted during the spring of 2016 to address issues with integrity and function at select structures. All structures were reassessed during the fall of 2016 to evaluate the effectiveness of maintenance activities. The following structure types were used to summarize assessment results: boulder cluster, boulder toe, cobble toe, cross-vane, fish condo, log-vane, log/rock-vane, rock-vanes, and wood-toe.

Table 7.3. Summary of rapid assessment results for integrity and function of all habitat structures used on the Upper Arkansas River habitat restoration project.

Rating	2014	2015
Functional	94%	87%
Intact	88%	78%
Damaged	6%	9%
Impaired	3%	5%
Failed	2%	8%

Wood-toe and fish condo treatments received high rankings for integrity and function in 2014 (Figure 7.7), but rankings declined slightly in 2015 (Figure 7.8). Boulder clusters also received high rankings for integrity and function (Figures 7.7-7.8), as well as unintended erosion and deposition (Figures 7.9-7.10). Log-vanes and rock-vanes exhibited relatively higher rates of impairment and failure (Figure 7.7-7.8). Boulder and cobble toe treatments also exhibited higher rates of failure in 2015 (Figures 7.7-7.8). Failure of these treatments was typically associated with streambank erosion (Figure 7.9).

Erosion issues were observed at log and rock-vanes, as well as a few wood-toe treatments. The lone fish condo treatment used on the project filled with sediment during the first major runoff event following construction (Figure 7.10). The fish condo was placed downstream of a log/rock-vane structure that creates eddies along the streambanks inducing sediment deposition. Relatively minor issues with sediment deposition were observed at a few rock and log-vanes (Figure 7.10). Erosion issues for root wad treatments (i.e., wood-toe and fish condo) were minor in 2014, but increased slightly in 2015 (Figure 7.11). One wood-toe site failed due to design constraints imposed on the river alignment to prevent erosion into fluvial tailing deposits.

In general, erosion issues at habitat structures were more prevalent than issues with sediment deposition. As the project experienced 5 and 10-year floods in 2014 and 2015, it is not surprising that some structures were affected by erosion or deposition. Overall, the majority of structures were intact and functional. Rapid assessments will be repeated during the monitoring period to evaluate the integrity and function of habitat structure and prescribe maintenance as needed.

7.5 References

Miller, J. R. and R. C. Kochel. 2012. Use and performance of instream structures for river restoration: a case study from North Carolina. Environmental Earth Science,

Rosgen, D. L. 2006. Cross-vane, w-weir, and j-hook vane structures: description, design and application for stream stabilization and river restoration. Wildland Hydrology, Fort Collins, Colorado.

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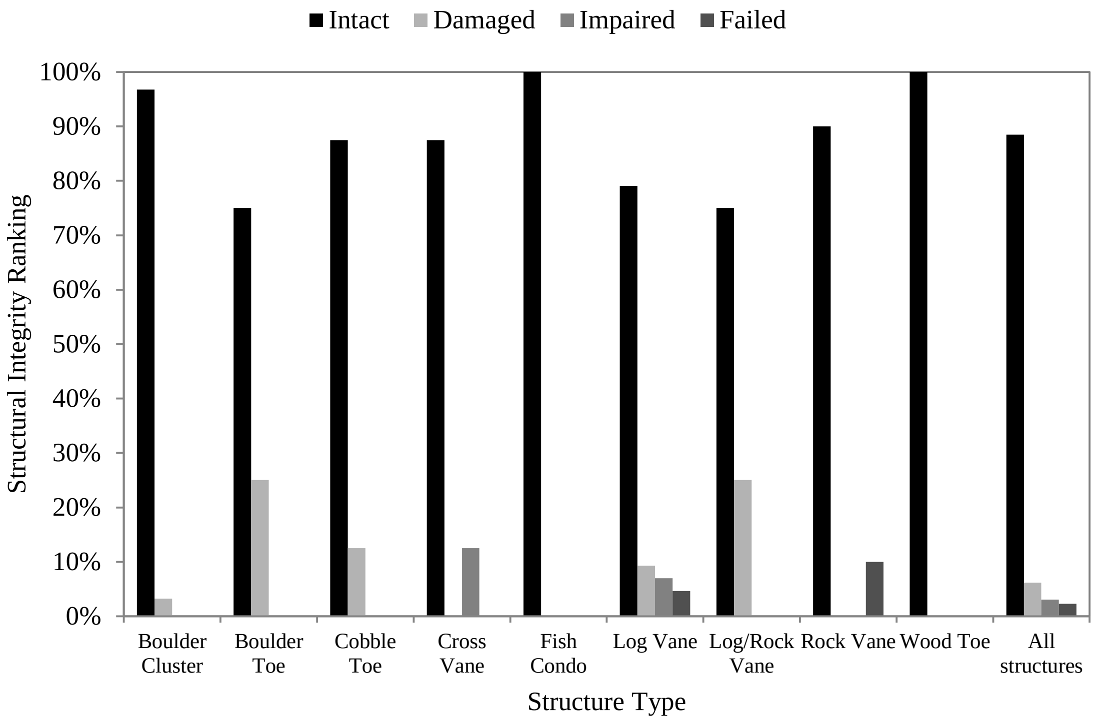

Figure 7.7. Rapid assessment results for integrity and function rankings by type of structure, 2014.

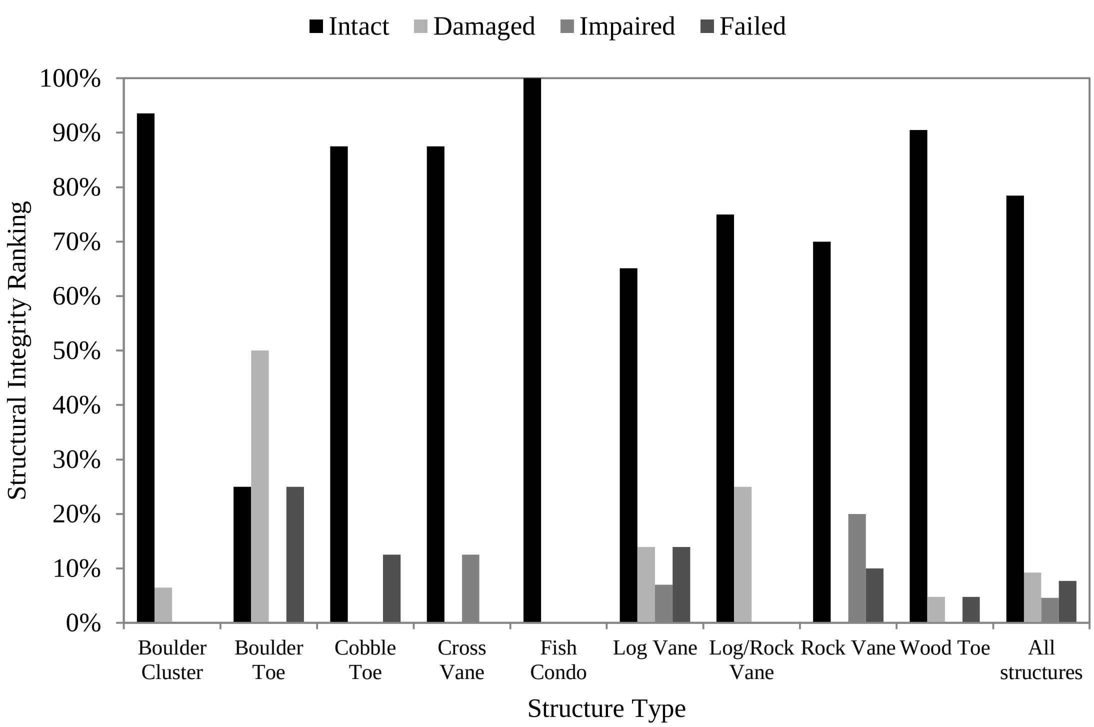

Figure 7.8. Rapid assessment results for integrity and function ranking by type of structure, 2015.

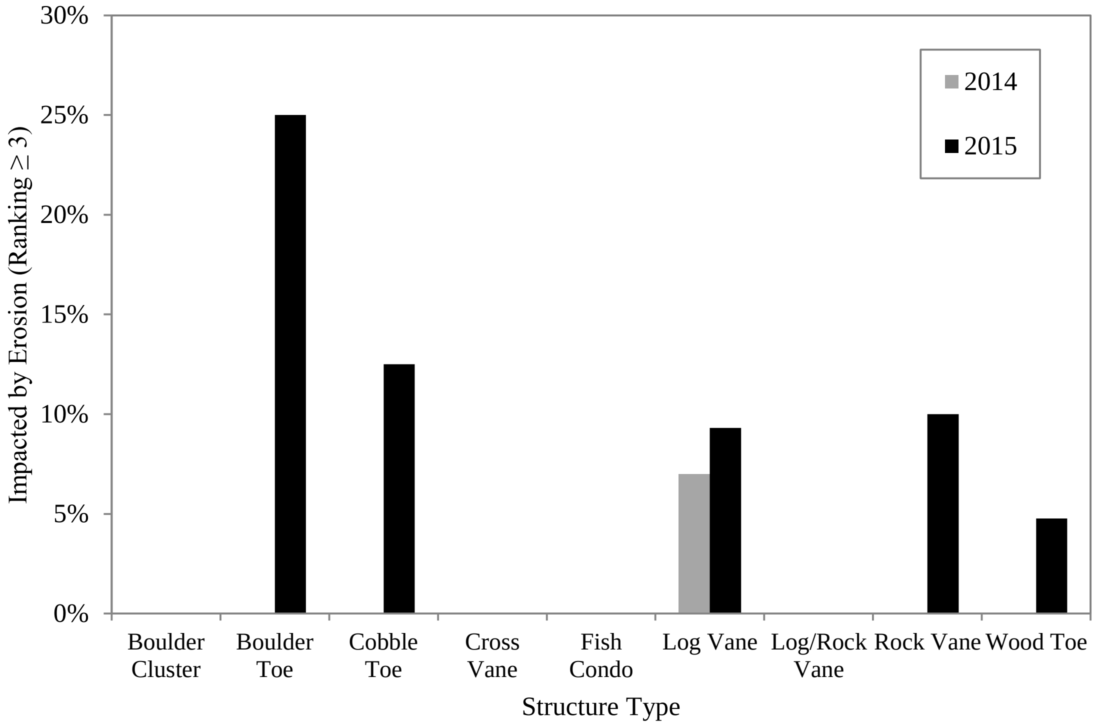

Figure 7.9. Rapid assessment results for unintended erosion showing percentage of structures that scored a ranking ≥ 3 for each structure type.

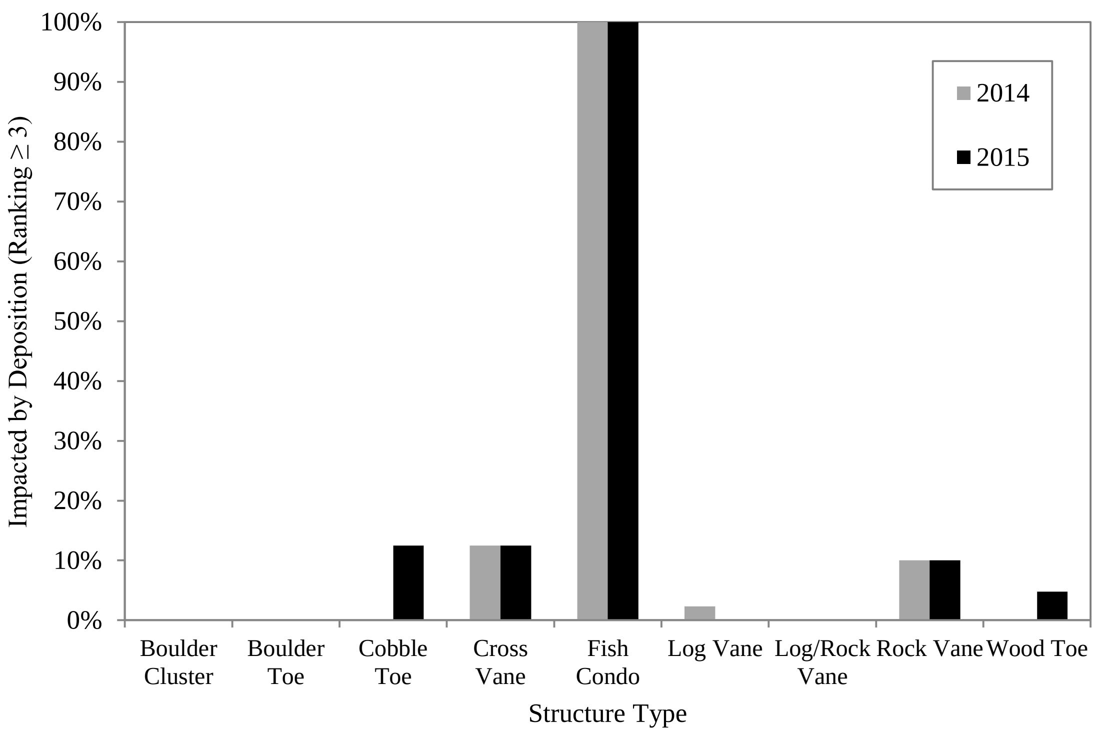

Figure 7.10. Rapid assessment results for unintended sediment deposition showing percentage of structures that scored a ranking ≥ 3 for each structure type.

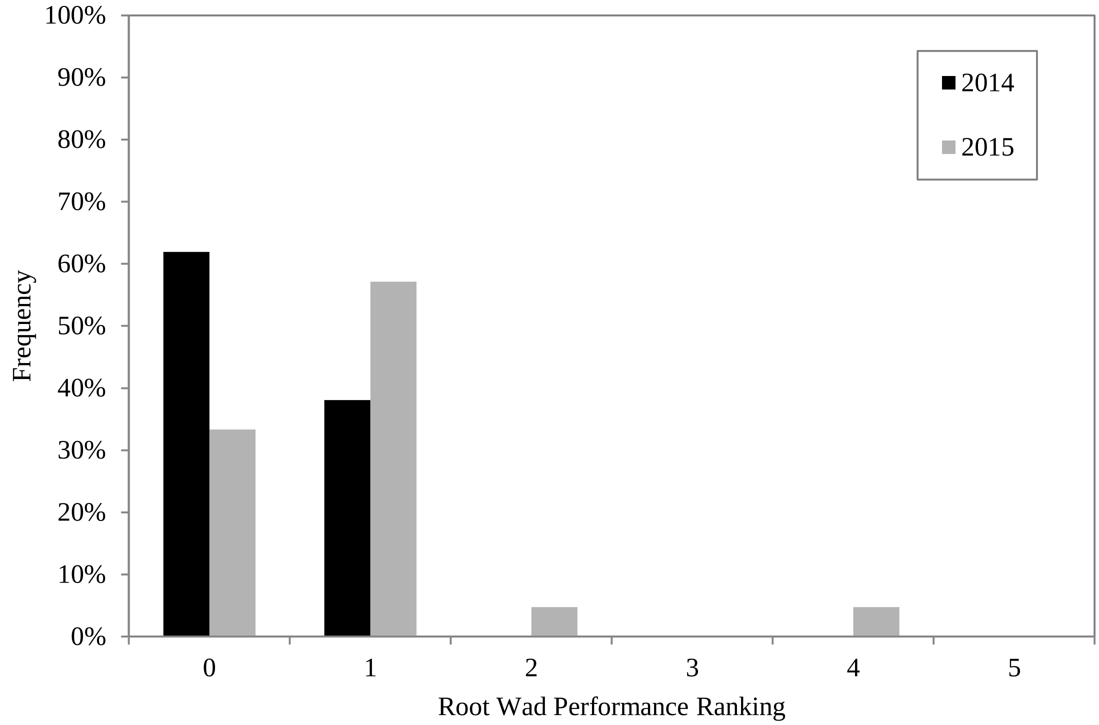

Figure 7.11. Rapid assessment results for performance of root wads, higher rankings are indicative of erosion issues.

Chapter 8: Geomorphology

8.1 Introduction

Aquatic habitat in Upper Arkansas River (UAR) basin was degraded from historic land-use practices and transbasin water diversions (Stratus, 2010). Historic placer mining operations mobilized and removed large amounts of sediment from the stream channel, which induced channel evolution processes that impaired aquatic habitat. The disturbance and erosion of streambanks associated with land-use activities resulted in sedimentation, loss of pools, channel widening, and impaired habitat diversity (Stratus, 2010). Habitat treatments were designed to increase geomorphic diversity and restore stream functions. Treatments included pool excavation in areas associated with habitat structures and areas where pools form naturally through contraction or lateral-scour processes. Locations that exhibited excess bank erosion were stabilized and with wood-toe, boulder/cobble toe, log-vane, or rock-vane treatments. Areas adjacent to bank treatments were re-vegetated with a combination of sod-mat transplants, willow transplants, willow stakes, bare-root willow plantings, and riparian seeding. Point-bar and lateral-bar development using local and imported material was conducted to narrow channels and improve water depth and velocity during periods of low flow. Point-bar development occurred on the inside of bends in locations adjacent to lateral scour pools, while lateral-bar development was typically applied in straight reaches with over-wide channel conditions. Narrowing the channel should improve sediment transport and bedform diversity, with the intention of moving the channel towards a dynamically stable form that minimizes the need for future intervention.

8.2 Methods

Geomorphology monitoring was conducted annually, including cross-section and longitudinal profile surveys. Sediment surveys were conducted in conjunction with topographic surveys at fish monitoring sites to support habitat modeling. Topographic surveys were conducted using survey grade GPS tied into pre-established control points to facilitate repeat surveys. Survey data were collected in NAD 1983 US State Plane Central and NAVD 1988 (US Survey Feet) coordinate systems and scaled to local coordinates for analysis. Survey data were used to create Triangulated Irregular Networks (TIN) with ArcGIS for the Crystal-Reddy and Hayden reaches. Breaklines for bank tops, bank bottoms, and river thalweg were applied to TINs to improve accuracy. Profiles along cross-sections and surveyed thalwegs were extracted from TINs to support analysis of channel dimensions and profiles.

Cross-Sections

Cross-sections were used to characterize channel morphology and monitor bank erosion. Monumented cross-sections were installed approximately every 1,000 ft prior to construction for a total of 26 monitoring locations. Eight cross-sections were established in the Crystal-Reddy reach (Figure 1.1; Appendix A), and the remaining 18 cross-sections were located in Hayden reach (Figure 1.2; Appendix A). Cross-sections were placed in variety of habitat types in both treated and control areas. Monitoring cross-section morphology will help evaluate channel stability and habitat quality, which will be used to inform maintenance needs. Cross-section profiles were used to estimate bankfull width, depth, and cross-sectional area. Bankfull elevations were derived from cross-section plots by identifying the incipient point of flooding at which water would spill out of the active channel and onto the floodplain, represented by the first, flat depositional surface adjacent to the active stream channel. Results from HEC-RAS models at fish monitoring sites were used to evaluate changes in width/depth (W/D) ratio at control and treatment sites across a range of flows. Analyzing model results across a range of discharge values will help evaluate changes in W/D ratios during low, medium, and high flow conditions.

Longitudinal Profiles

Longitudinal profiles characterize stream slopes and depths of various habitat types (e.g., riffles, pools, runs, and glides). Breaklines along the river thalweg, top of banks, bottom of banks, and edges of water were surveyed annually. More points were collected along the thalweg compared to bank breaklines, with observations made at all significant changes in the bed slope along the deepest portion of the channel. Points along bank breaklines were collected approximately every 20 meters and at all major inflection points along the bank. Baseline longitudinal profiles and cross-sections were surveyed during 2010-2013. As-built surveys for the Crystal-Reddy and Hayden reaches were conducted in 2013 and 2014, respectively. Additional surveys were conducted in 2014 and 2015 for the Crystal-Reddy reach and in 2015 for the Hayden reach to support effectiveness monitoring. Bed slope and sinuosity were derived from longitudinal profiles.

Residual Pool Depth

Residual pool depth (RPD) was used to monitor the depth and longevity of developed pools. RPDs were derived for each pool included in the as-built survey using different thalweg profiles for each year. Thalweg profiles were generated in ArcGIS then analyzed graphically with RStudio to determine minimum pool elevation (MPZ) and riffle crest elevation (RCZ). Residual pool depth was then calculated using Equation 8.1. Developed pools were characterized by pool type and associated structure if present. Pool and structure types are summarized in Table 8.1. Pools were occasionally associated with treatments that combined more than one type of structure (e.g., wood-toe/log-vane) or had no structure at all. Detailed descriptions for all structure types were presented in Chapter 7.

Equation 8.1

$$RPD = RCZ - MPZ$$

Pebble Counts

Pebble counts were used to characterize sediment gradation at fish monitoring sites in 2013 (pre-construction) and 2014 (post-construction) using the representative pebble count procedure detailed in Rosgen et al. (2008). Ten particle observations were made at ten transects located at either a riffle or pool for a total of 100 observations per site. The ratio of riffle to pool transects was representative of the

Table 8.1. Types of developed pools and associated structures used on the Upper Arkansas River habitat restoration project.

Pool Type	**Description**
Lateral scour	Pool located on the outside of a stream bend
Confluence	Pool located below the junction of two channels
Mid-channel	Pool located in center of the channel
Structure Type	**Description**
Boulder cluster	Groups of boulders placed near the channel thalweg
Boulder-vane	Upstream directed boulder structure used to deflect flows from the bank
Log-vane	Upstream directed log structure used to deflect flows from the bank
Log/boulder-vane	Upstream directed log/boulder structure used to deflect flows from the bank
Wood-toe	Root wads layered along the bank toe and covered with brush, fill material, and sod mats
Wood-toe/ boulder-vane	Wood-toe with boulder-vane placed upstream to deflect flows from the bank
Wood-toe/ log-vane	Wood-toe with log-vane placed upstream to deflect flows from the bank

morphological composition at each monitoring site (i.e., if 60% of the reach was classified as riffle then six of the ten transects were located in riffles). Pebble count data were assessed graphically to compare particle size class distributions. Particle sizes for the D_{16}, D_{50}, D_{84} and D_{90} were derived from pebble count plots.

8.3 Results and Discussion

Cross-Sections

The majority of cross-sections (85%) were impacted by habitat treatments during instream construction (Table 8.2). Point-bar development was the most frequent treatment at monitored cross-sections, followed by lateral-bar development, boulder clusters, pool development, and log-vanes. Only one cross-section occurred at a wood-toe treatment location. Graphical comparison of pre- and post-construction morphology for each cross-section are presented with as-built drawings in Appendix A. Untreated cross-sections exhibited a small increase (4.6%) in channel width (Table 8.2), which could be indicative of bank erosion or small survey discrepancies between years. Bankfull width decreased slightly (4.1%) when averaged across all treated cross-sections. Wood-toe and point-bar development resulted in the greatest changes in cross-sectional area, with decreases of 33.9% and 19.8%, respectively (Table 8.2). Cross-sectional area decreased by 10.6% on average for treated cross-sections, indicating the treatments improved over-wide channel conditions.

The relatively small decrease in bankfull width at treated cross-sections is somewhat misleading because channel-narrowing treatments, such as point and lateral-bar development, decreased cross-sectional area by 10% on average. However, these treatments did not typically change bankfull elevations or widths (e.g., Figure 8.1). As bankfull indicators were similar for pre- and post-construction conditions, the decrease in cross-sectional area associated with channel narrowing treatments actually increased W/D ratios. This geomorphic approach for evaluating monumented cross-sections fails to account for decreased discharge needed to fill the active channel following channel narrowing. As such, more accurate estimates of W/D ratios were obtained from HEC-RAS models used to inform habitat modeling at fish monitoring sites.

W/D ratios for all cross-sections used in pre- and post-construction HEC-RAS models were analyzed for each fish monitoring sites (Figures 8.2-8.7). The median W/D ratio for low flows (1.3, 2.5, and 4.7 cms in the Reddy reach; 2.0, 4.0, and 7.6 cms in the Hayden reach) decreased following construction activities at all treatment sites (Figures 8.2, 8.3, and 8.6). Treatments at

Table 8.2. Average change in estimated bankfull width, average bankfull depth, cross-sectional area, and width/depth ratio (W/D) for monitored cross-sections in the Upper Arkansas River project reach.

Treatment Group	n	Average Percent Difference			
		Width (%)	Depth (%)	Area (%)	W/D (%)
Boulder cluster and lateral bar	2	-10.2	4.5	-6.3	-13.9
Develop lateral bar	3	-1.5	-4.8	-5.8	4.6
Develop point bar	10	-7.9	-13.7	-19.8	11.2
Develop point bar and pool	2	14.9	-18.4	-7.6	44.5
Develop pool	2	2.3	9.1	11.6	-6.2
Log-vane	2	-1.0	11.1	10.3	-10.1
Wood-toe	1	-18.7	-18.7	-33.9	0.0
All control cross-sections	4	4.6	4.3	9.3	0.7
All treatment cross-sections	22	-4.1	-7.2	-10.6	7.0
All cross-sections	26	-2.7	-5.4	-7.5	6.1

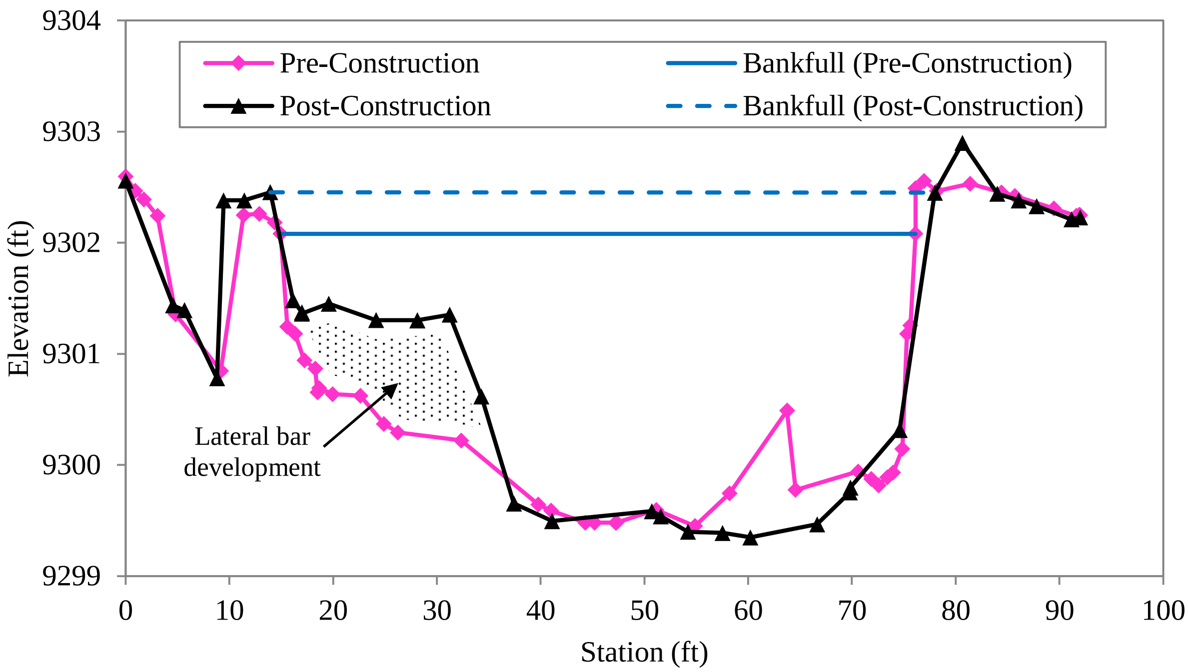

Figure 8.1. Comparison of pre- and post-construction morphology and bankfull elevations for treatment cross-section XS-10.

these sites included log-vanes, boulder clusters, point-bar development, and channel narrowing/lateral-bar development. The decrease in low-flow W/D ratio indicates that these treatments addressed over-wide channel conditions. W/D ratios either increased or remained similar for low-flows at control sites (Figures 8.4, 8.5, and 8.7), suggesting that the observed decrease in W/D at treatment sites was due to restoration activities. In general, W/D ratios for higher flows remained similar at control and treatment sites, with the exception of AR-5B (Figures 8.2-8.7). The significant decrease in W/D at control site AR-5B was likely due to changes in channel morphology at this site following high flows in 2014. Similar W/D ratios at modeled bankfull flows support results from bankfull analysis at monumented cross-sections. Maintaining bankfull width and decreasing cross-sectional area will result in higher W/D ratios for bankfull flows. For future projects, channel narrowing activities could be modified so fill material is concentrated along the channel margin and brought up to the bankfull elevation to create more favorable changes in bankfull W/D ratios.

Longitudinal Profiles

The longitudinal profiles for pre- and post-construction surveys were presented with as-built drawings in Appendix A. Comparison of before and after profiles highlight locations where pool development and channel realignment occurred. Boulder cluster and vanes may be apparent on longitudinal profiles as well. Channel bed slope and sinuosity were derived from longitudinal profile surveys, and exhibited little difference between years, indicating that habitat restoration did not affect these variables (Table 8.3).

Table 8.3. Slope and sinuosity derived from longitudinal profile surveys.

Variable	Reach	2013	2014	2015
Slope	Reddy	0.63%	0.63%	0.62%
	Hayden	0.65%	0.66%	0.64%
Sinuosity	Reddy	1.31	1.32	1.33
	Hayden	1.29	1.27	1.29

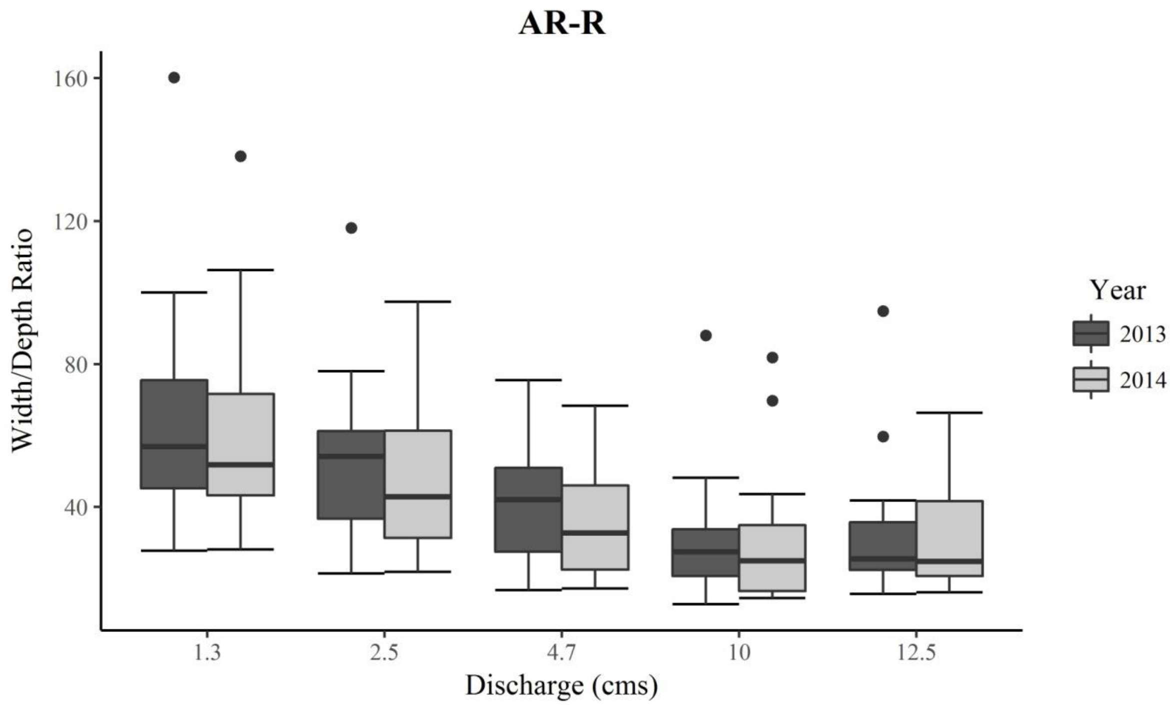

Figure 8.2. Comparison of before (2013) and after (2014) width/depth (W/D) ratios across a range of discharge values at treatment site AR-R on the Upper Arkansas River.

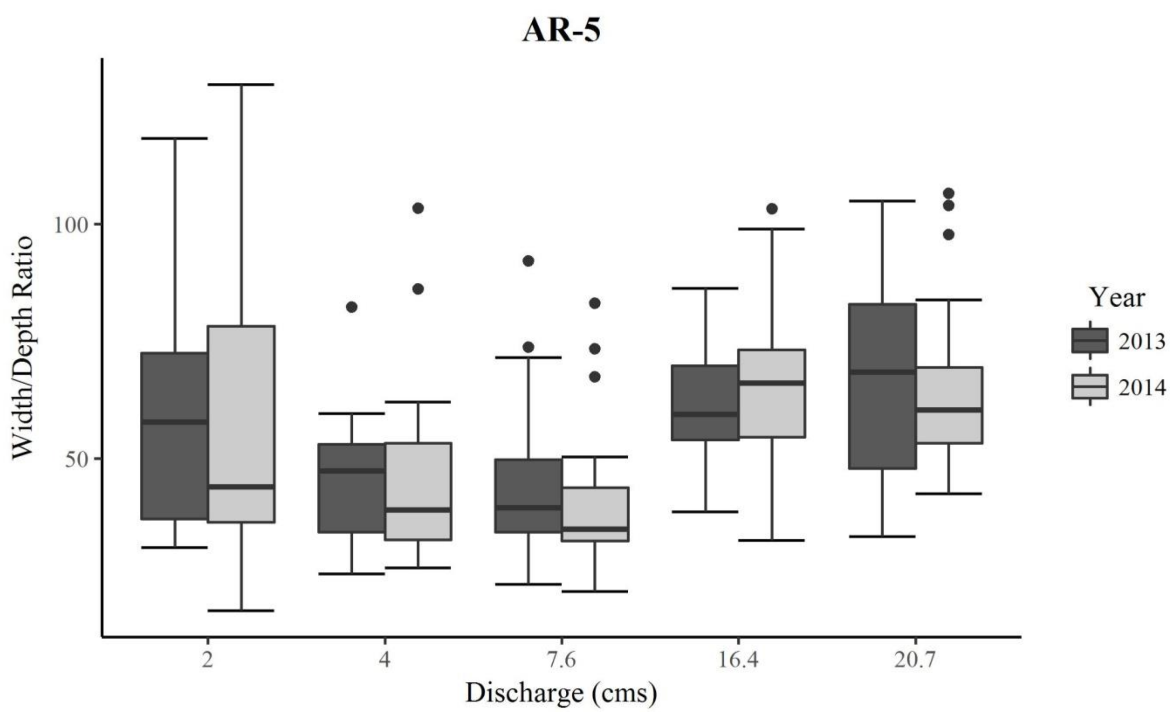

Figure 8.3. Comparison of before (2013) and after (2014) width/depth ratios (W/D) across a range of discharge values at treatment site AR-5 on the Upper Arkansas River.

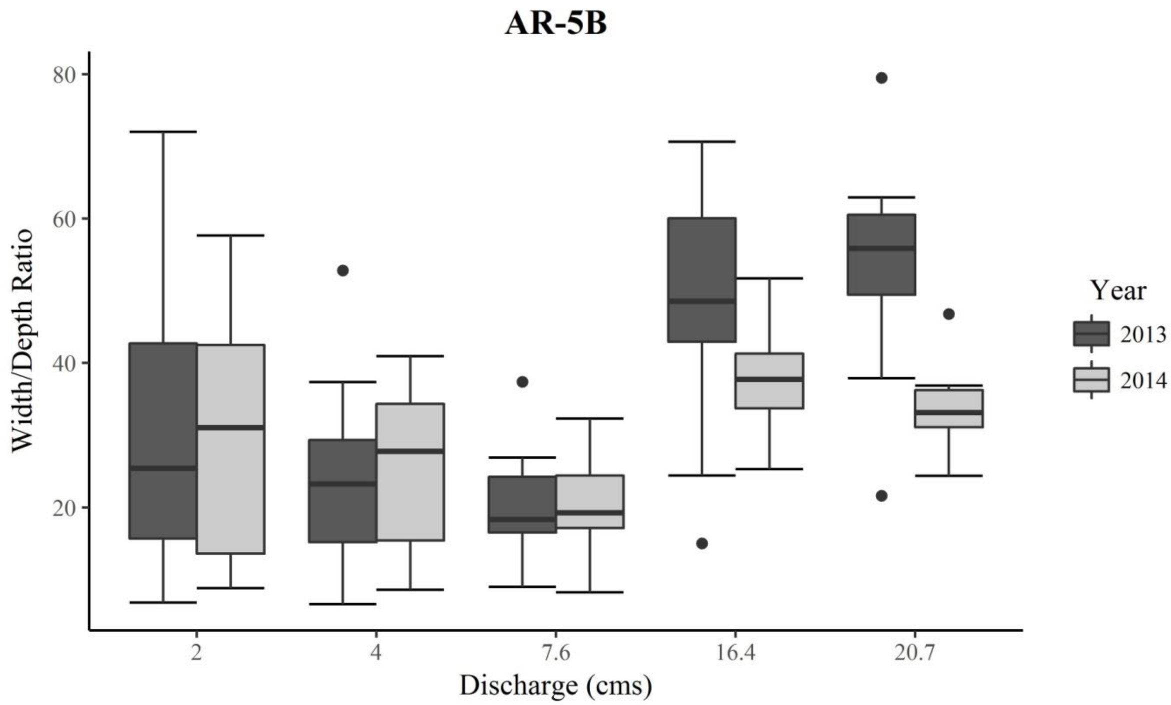

Figure 8.4. Comparison of before (2013) and after (2014) width/depth ratios (W/D) across a range of discharge values at control site AR-5B on the Upper Arkansas River.

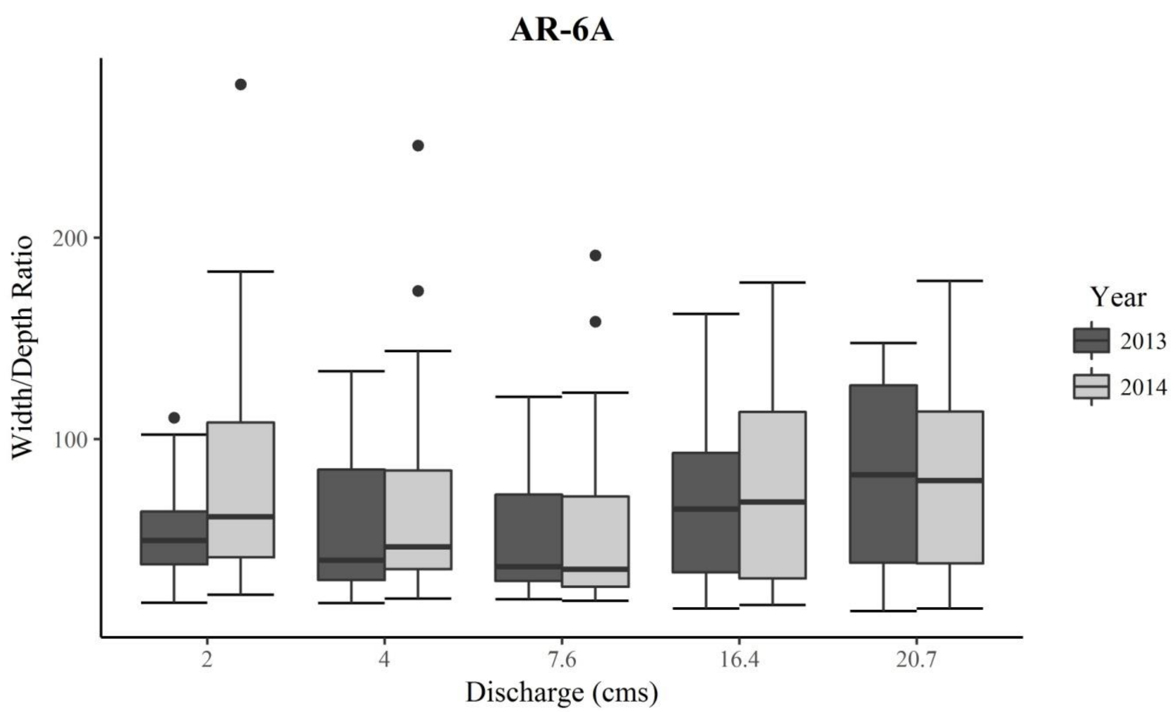

Figure 8.5. Comparison of before (2013) and after (2014) width/depth ratios (W/D) across a range of discharge values at control site AR-6A on the Upper Arkansas River.

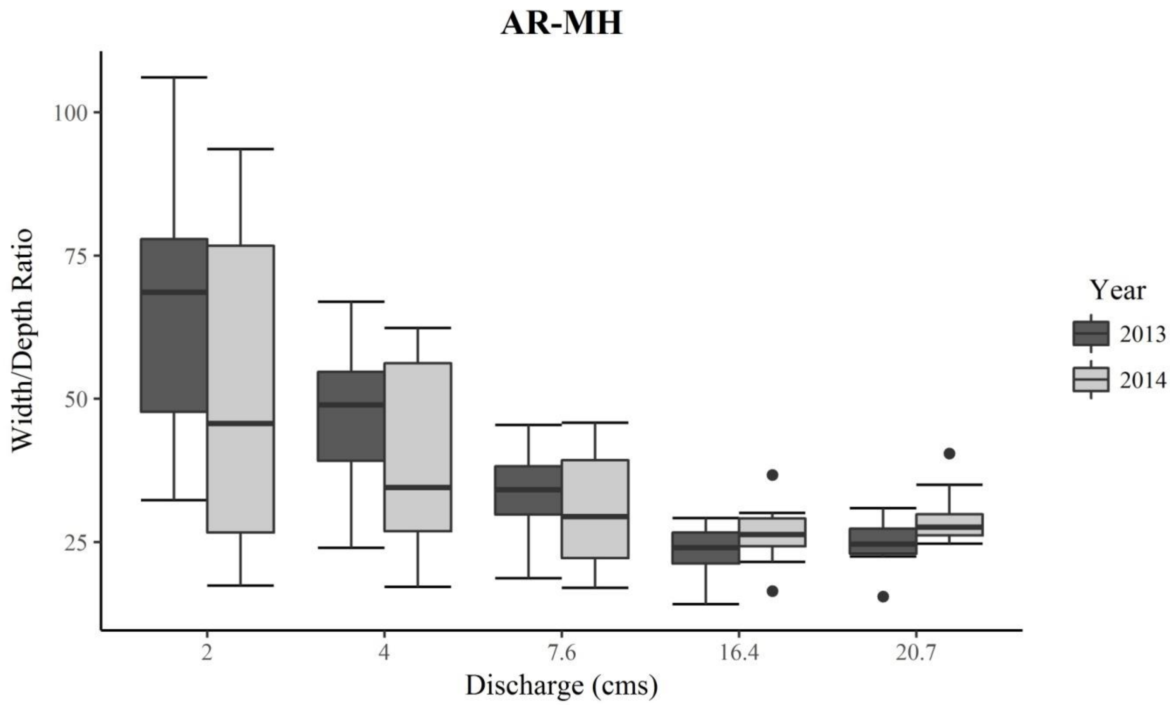

Figure 8.6. Comparison of before (2013) and after (2014) width/depth ratios (W/D) across a range of discharge values at treatment site AR-MH on the Upper Arkansas River.

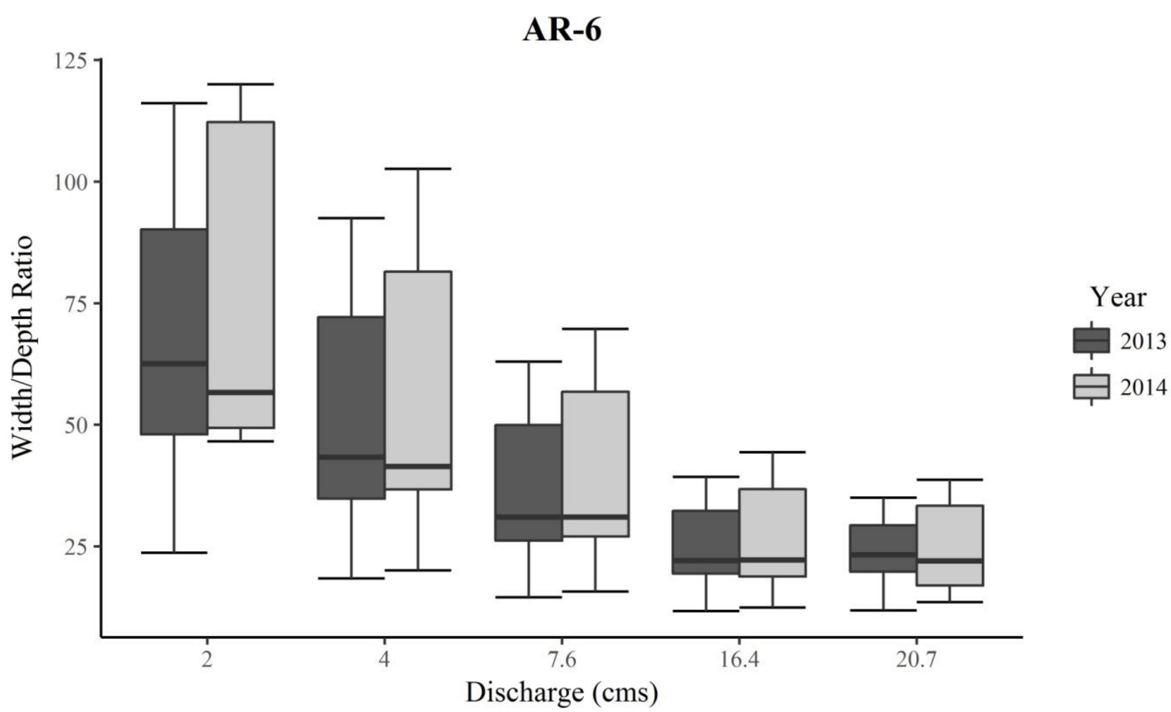

Figure 8.7. Comparison of before (2013) and after (2014) width/depth ratios (W/D) across a range of discharge values at treatment site AR-6 on the Upper Arkansas River.

Residual Pool Depths

RPDs were extracted from longitudinal profiles and used to evaluate the effectiveness of pool development treatments. Following cycles of runoff, pools are expected to accumulate sediment or scour, eventually stabilizing around a sustainable residual depth. Furthermore, developed pools were typically over-excavated; meaning pools were excavated to greater depths than occurred naturally, so some filling of excavated pools was expected. Changes in RPD were averaged by pool type (Table 8.4) and habitat structure type (Table 8.5).

Table 8.4. Average change in residual pool depth (RPD) by pool type.

Pool Type	n	Change in RPD (ft)		
		As-built	Year 1	Year 2
Lateral scour	84	0.89	-0.54	0.10
Mid-channel	14	0.70	-0.59	-0.37
Confluence	1	-0.44	-0.11	0.83
All	99	0.85	-0.54	0.08

Maintenance of developed pools was variable, depending on pool type, structure type, and whether a pool occurred in the location prior to development. Lateral scour pools were the most common type of developed pool (85%), followed by mid-channel (14%), and confluence (1%). As-built surveys were used to calculate the change in RPD due to habitat restoration activities. Habitat treatments increased RPD by 0.85 ft on average for all pool types (Table 8.4), indicating that constructed treatments increased bedform diversity and over-winter habitat. However, RPD decreased by 0.54 ft on average following the first runoff cycle (Year 1), but then increased slightly (0.08 ft) following the second runoff cycle (Year 2; Table 8.4). These results suggest that many pools filled to some degree following the first runoff cycle, but either scoured or filled slightly more following the second runoff cycle. Overall, 41% of developed pools completely filled following one runoff cycle. Lateral scour pools generally exhibited less filling than mid-channel pools, as RPD increased by 0.10 ft on average following the second post-construction runoff cycle.

All treatment types exhibited an increase in RPD following instream construction (Table 8.5), with log-vanes and wood-toe treatment showing the highest average increase. RPD declined on average for all treatment types following the first runoff cycle, with the exception of wood-toe/log-vane treatment combination. This treatment combination places a log-vane at the upstream extent of the wood-toe to direct flows away from the bank, and was the only treatment type that maintained RPD for two runoff cycles. For pools associated with the wood-toe/vane treatment combination, 42% maintained or increased RPD after one runoff event, while 33% decreased in RPD and 25% filled completely. These treatments are typically located on the outside of meander bends where lateral-scour processes can maintain pools. Locating treatments in these areas will increase the likelihood of maintaining RPD. However, wood-toe treatments installed without log-vanes exhibited an average decrease in RPD of 0.41 ft after one runoff event. This suggests that the log-vanes used in combination with wood-toe treatments are more effective at maintaining pool depths than wood-toe alone.

Table 8.5. Average change in residual pool depth (RPD) by habitat structure type.

Structure Type	n	Change in RPD (ft)		
		As-built	Year 1	Year 2
Boulder cluster	5	0.48	-0.51	-0.41
Boulder-vane	6	0.70	-0.23	NA
Log-vane	30	0.88	-0.85	0.09
Log/boulder-vane	1	1.99	-0.72	0.86
Wood-toe	8	1.33	-0.41	0.09
Wood-toe/boulder-vane	1	0.26	-0.70	NA
Wood-toe/log-vane	11	0.85	0.06	0.00
None	37	0.77	-0.55	0.04

Pools associated with log-vanes only had marginal success. RPD for log-vane pools increased by 0.88 ft on average following instream construction (Table 8.5). However, 70% of log-vane pools had completely filled following one runoff cycle. An additional 20% of log-vane pools experienced a decrease in RPD during this same period. Only 10% of log-vane pools maintained or increased in RPD following one runoff cycle. However, four pools (13%) associated with log-vanes re-scoured and increased RPD following a second runoff. The filling of pools may be due to high sediment loads that occurred during the 5-year flood observed in 2014 or in response to stream restoration activities throughout the 11-mile reach. Pools associated with a boulder-vane or wood-toe alone also exhibited relative success (Table 8.5). For pools associated with boulder-vanes, 50% maintained or increased RPD, while 50% had filled completely. For pools associated with wood-toe, 33% maintained or increased RPD one year post-construction, 22% decreased in residual depth, and 44% completely filled.

In general, developed pools resisted filling and retained RPD more consistently when applied in locations where a pool existed prior to construction. This was particularly true for pools developed with no associated structure. Of pools associated with no structure that maintained or increased RPD, 67% were located at a pre-existing pool. This is likely due to lateral or contraction scour processes that existed in these locations prior to construction. For example, pools located at meander bends are subjected to lateral scour forces as the water is concentrated on one side of the channel. These natural forces helped maintain or enhance developed pools, especially when no structure was present to aid in maintenance. In support of this explanation, 40% of mid-channel pools, where no natural erosive forces exist to aid in pool maintenance, had partially or completely filled within one year of construction. Approximately one-third of mid-channel pools were associated with boulder clusters, which would theoretically aid in pool maintenance. However, 75% of mid-channel pools associated with a boulder cluster had completely filled following one runoff cycle.

Pebble Counts

Results from pebble counts at fish monitoring sites are presented in Table 8.6 and Figures 8.8-8.13. Two monitoring sites, AR-5 and AR-MH, exhibited slightly less coarse conditions in 2014. Three sites, AR-6, AR-6A, and AR-R, exhibited little to no change and one site, AR-5B, was slightly coarser in particle size following construction. At treatment site AR-5, all sediment metrics were less coarse in 2014 than 2013 (Table 8.6). Specifically, D_{50} in 2013 was 100 mm compared to 50 mm in 2014, indicating a 50% reduction in particle size for 50% of the distribution. This reduction in particle size distribution can be attributed to an increase in gravel (2-64 mm), which increased the amount of available spawning habitat at this site. Treatment site AR-MH, also exhibited finer particle size distributions following instream construction (Table 8.6). The D_{50} in 2013 was 90 mm compared to 68 mm in 2014, indicating a 24% reduction in particle size for 50% of the distribution. The reduction in D_{90} from 220 mm to 155 mm indicates a 29% reduction in particle size for 90% of the distribution. These decreases in particle size distribution at AR-MH stem mainly from an increase in smaller cobbles (64-128 mm) coupled with a concurrent decrease in large cobbles (128-256 mm). As the dominant size class remained cobble, the reduction in particle size at AR-MH does not indicate any significant change in habitat quality.

Coarser particle sizes were observed at AR-5B in 2014 compared to 2013 (Table 8.6), which can be attributed to a decrease in sand and gravel particles and an increase in cobbles. This may represent a slight decrease in habitat suitability for spawning fish as particles suitable for redd development decreased (Bjornn and Reiser, 1991). However, this increase in particle size may improve habitat suitability for fry and juvenile trout, as well as benthic macroinvertebrates, by increasing interstitial spaces used for cover. Changes in sediment were likely influenced by streambed mobilization during the 5-year flood that occurred in 2014. However, changes in channel capacity from restoration treatments could have contributed to increased bedload and improved channel maintenance. Additional surveys will determine if changes in sediment gradation are maintained, merely an artifact of the dynamic nature of the UAR, or a byproduct of limitations associated with representative pebble count procedure.

Table 8.6. Comparison of pebble count results at all fish monitoring sites on the Upper Arkansas River for sediment gradation metrics (D_{16}, D_{50}, D_{84}, and D_{90}) from 2013 and 2014.

Site	Class	D_{16} (mm)		D_{50} (mm)		D_{84} (mm)		D_{90} (mm)	
		2013	2014	2013	2014	2013	2014	2013	2014
AR-R	Treatment	23	15	95	70	155	150	175	160
AR-5	Treatment	25	11	100	50	180	128	210	155
AR-5B	Control	4	29	37	49	65	100	85	115
AR-6A	Control	25	30	75	65	128	110	160	120
AR-MH	Treatment	15	32	90	68	185	126	220	155
AR-6	Control	27	32	100	100	270	290	200	210

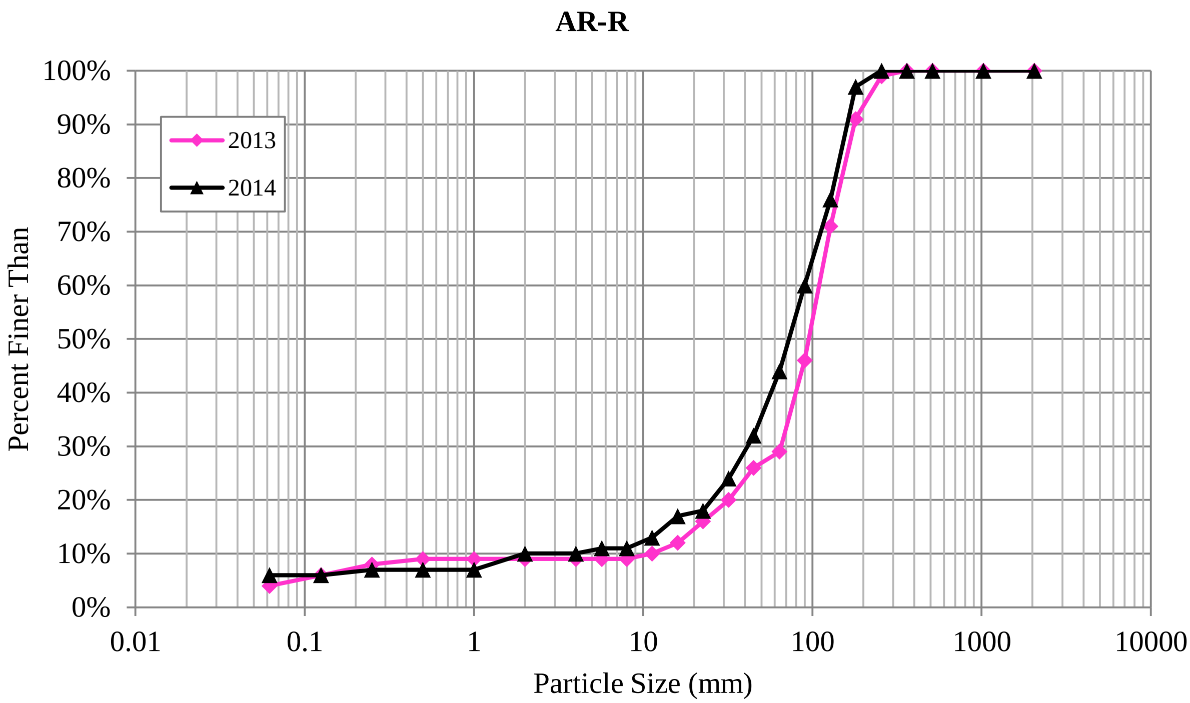

Figure 8.8. Comparison of before (2013) and after (2014) representative pebble counts for treatment site AR-R on the Upper Arkansas River.

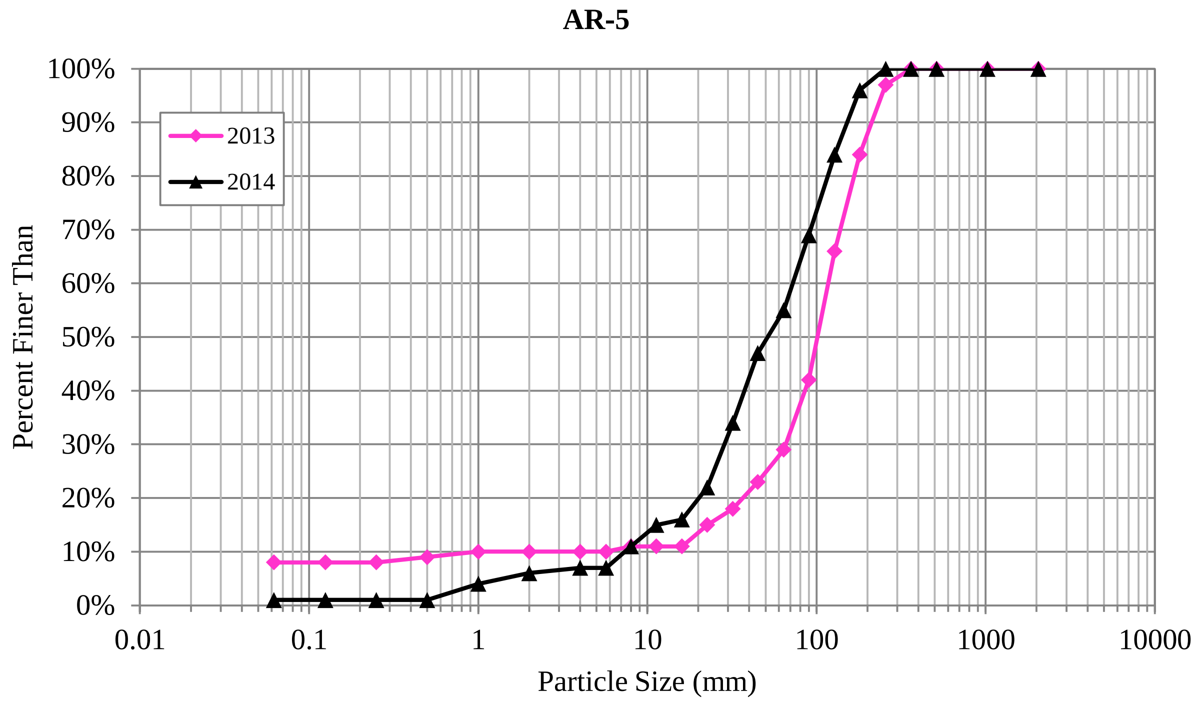

Figure 8.9. Comparison of before (2013) and after (2014) representative pebble counts for treatment site AR-5 on the Upper Arkansas River, Colorado.

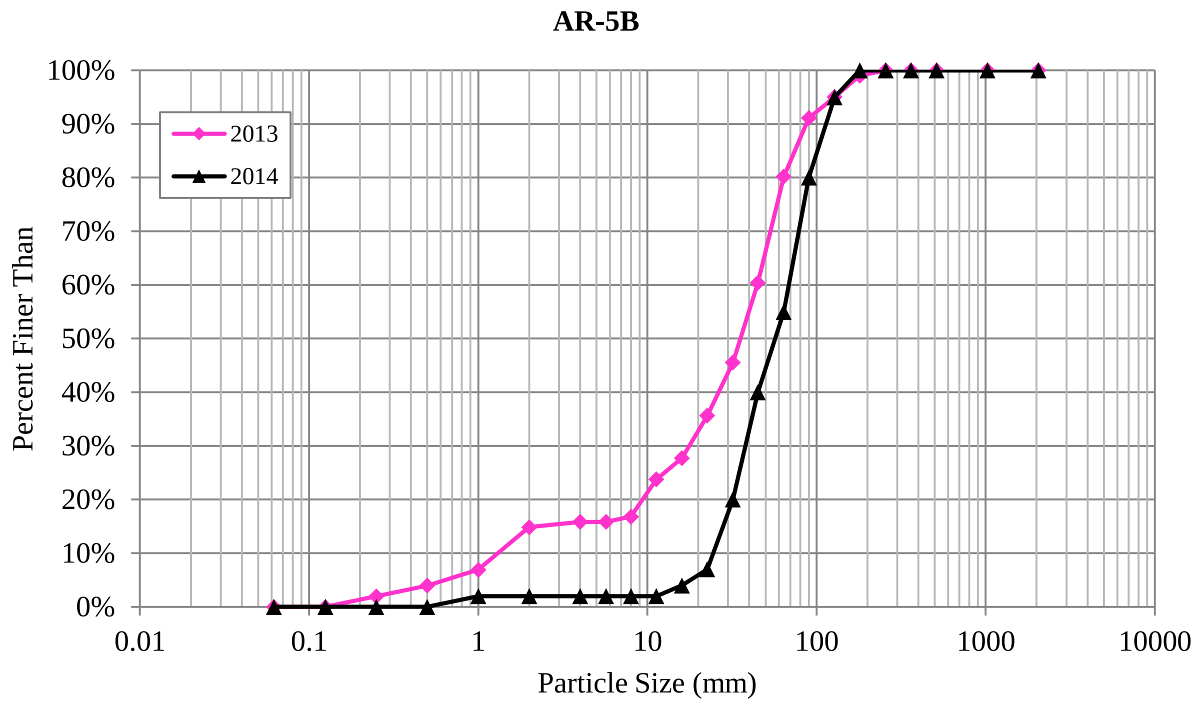

Figure 8.10. Comparison of before (2013) and after (2014) representative pebble counts for control site AR-5B on the Upper Arkansas River.

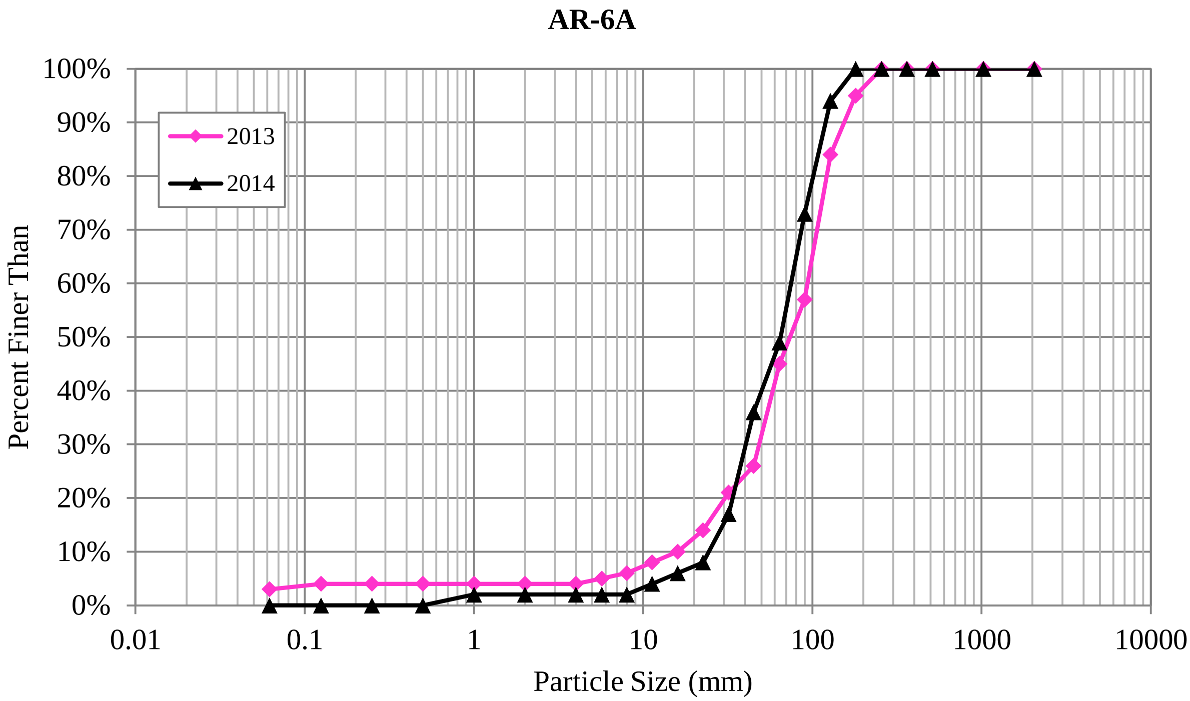

Figure 8.11. Comparison of before (2013) and after (2014) representative pebble counts for control site AR-6A on the Upper Arkansas River.

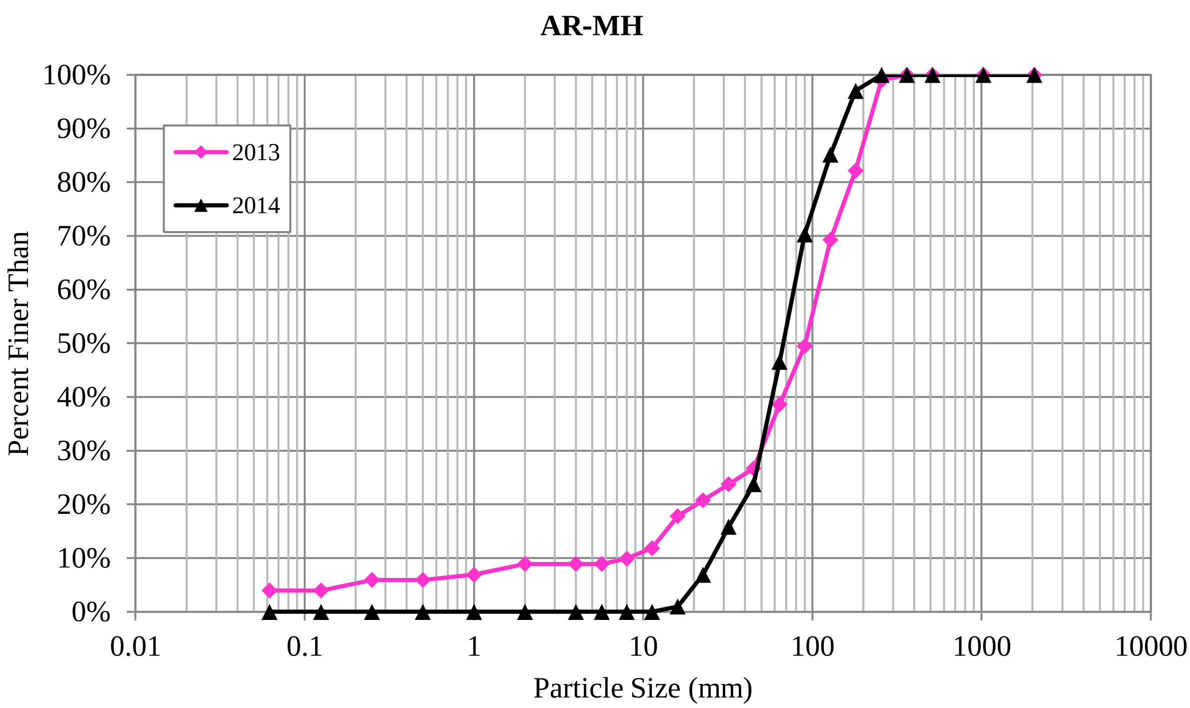

Figure 8.12. Comparison of before (2013) and after (2014) representative pebble counts for treatment site AR-MH on the Upper Arkansas River.

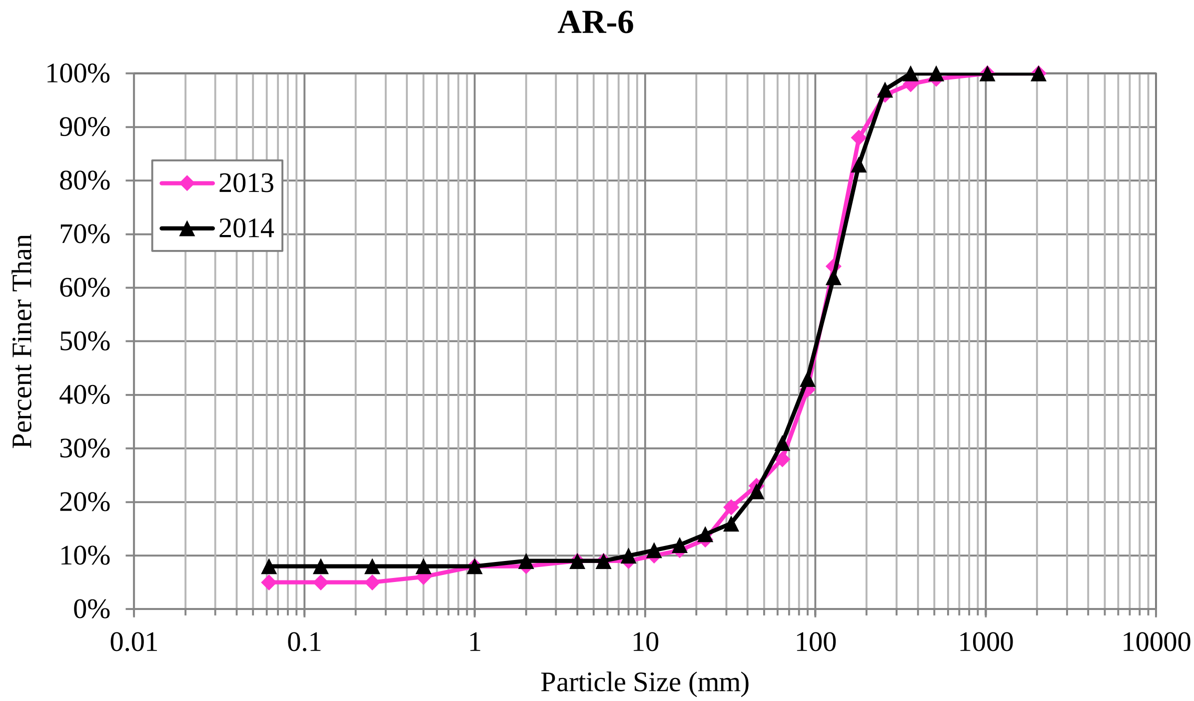

Figure 8.11. Comparison of before (2013) and after (2014) representative pebble counts for control site AR-6 on the Upper Arkansas River.

8.4 References

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Chapter 9: Tree Swallows

9.1 Introduction

Tree swallows (*Tachycineta bicolor*) can be used to evaluate the effects of environmental contaminants because: (1) they are widely distributed throughout the United States; (2) they can be attracted to study areas with nest boxes; and (3) they feed on terrestrial and emergent aquatic insects within a predictable proximity to their nest boxes (Custer and Custer, 2003; Brasso and Cristol, 2008; Custer, 2011). Metals contamination and habitat availability along the Upper Arkansas River (UAR) are expected to improve following remediation activities and restoration of riparian vegetation. To evaluate if these factors improve conditions for birds and other wildlife, tree swallow populations will be monitored for bioaccumulation of metals and reproductive success. Bioaccumulation of contaminants has the potential to reduce reproductive success by reducing egg volumes, causing chick deformities, reducing fledgling production, and decreasing territorial behaviors (Brasso and Cristol, 2008). Therefore, reducing metal concentrations in the UAR is expected to improve reproductive success in tree swallows. Reproductive success is also expected to improve due to increased diversity of prey base and improved habitat conditions along streambanks (Stratus, 2010). Furthermore, tree swallows are considered a “sentinel species” because the impacts of contamination on individual tree swallow populations can be indicative of the general effects on other avian species. The U.S. Fish and Wildlife Service (USFWS) is responsible for tree swallow monitoring along the UAR.

9.2 Methods

Contaminant concentrations in tree swallow eggs, carcass remainders, and livers were analyzed for sites throughout the UAR basin during 1997-1998 (Custer et al., 2003). These data will be used to represent baseline conditions for comparisons to post-restoration effectiveness surveys. Methods for effectiveness monitoring will follow those described in Custer et al. (2003). Study sites corresponding to treated and control sections will be selected along the UAR and approximately 15-35 nest boxes will be erected at each site. Nest boxes will be monitored to determine egg and nestling numbers. Clutch size and nestling success will be used to indicate reproductive success. Approximately two eggs and two nestlings will be collected from each box. The concentration of contaminants in eggs, nestling livers, and carcasses will be measured and compared to the 1997-1998 baseline data. Bioaccumulation and reproductive data will be used to evaluate whether remediation activities and habitat restoration have decreased tree swallow exposure to metals contamination. Post-restoration sampling is scheduled for 2018-2019.

9.3 Results and Discussion

Previous studies have successfully used nesting box and sampling techniques to document bioaccumulation and reproductive impacts of metal contamination in tree swallows. Brasso and Cristol (2008) documented a decrease in fledgling production at mercury-contaminated sites near the Shenandoah River, VA, particularly from nests belonging to young female tree swallows. Furthermore, this study indicated that an increase in blood mercury concentration was correlated to the observed decreases in reproductive success. In the UAR Basin from 1997-1998, Custer et al. (2003) documented high levels of lead, cadmium, boron, copper and selenium accumulation in the livers of tree swallow nestlings. Additionally, nests producing offspring with high lead accumulation in liver tissues were less successful than the nationwide average for swallow hatchling success.

As no post-implementation monitoring data for tree swallows have been collected at this time, there are no results to present in this report. Data collection, processing, and analysis for effectiveness evaluation are scheduled for 2018-2019. Result will provide an updated evaluation for the bioavailability of contaminants at impacted sites along the UAR. Preliminary results from effectiveness monitoring for tree swallow should be available by 2020.

9.4 References

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Stratus Consulting, Inc. 2010. Restoration Plan and Environmental Assessment for the Upper Arkansas River Watershed. Boulder, Colorado. 103 pp.

Chapter 10: Conclusions

Aquatic Habitat Restoration: Habitat restoration was conducted for approximately five miles of the Upper Arkansas River (UAR) with the goals of increasing brown trout population density and biomass, improving brown trout body condition, and improving brown trout age and size-class structure. Habitat treatments addressed these goals by stabilizing streambanks, promoting diverse stream morphology, reducing erosion and downstream sedimentation, enhancing overhead cover for trout, increasing spawning areas where possible, and providing refugia for juvenile trout. Instream construction activities began in July 2013 and were completed in August 2014 for the CPW project reach.

Water Quality: Although water quality has improved over time, chronic and/or acute standards for cadmium, lead, and zinc were exceeded at monitoring sites within the project reach. Exceeding chronic and acute water quality standards can impair aquatic and terrestrial resources, including fish, benthic macroinvertebrates, and riparian vegetation. The ongoing exceedance of water quality standards indicates that additional remediation activities could be needed to further improve fishery resources in the UAR. Water quality monitoring during habitat restoration did not indicate that instream construction activities had mobilized contaminated sediments at levels of concern.

Fish Populations: Brown trout populations appear to have improved in the UAR. Although the number of fish has not increased significantly, biomass (lbs/acre) and quality (# ≥14"/acre) have increased indicating that fish condition has improved, possibly in response to improved water quality and/or habitat conditions. Fish population metrics for biomass and quality have increased by more than 10%, which meets projects goals for fisheries. Although water quality standards were exceeded during this monitoring period, negative impacts on brown trout populations were not readily apparent as all sites within the CPW project reach met Gold Medal standards.

Macroinvertebrates: Benthic macroinvertebrate metrics exhibited substantial variability, possibly due to ongoing issues with metals pollution, high flows that mobilized sediment from the streambed, and impacts from instream construction activities. Declines in benthic macroinvertebrate metrics were observed at both control and treatment sites, which could indicate that decreases were related to water quality or flows rather than direct effects from instream construction. Additional analyses are needed to investigate the relationship between benthic macroinvertebrate metrics and potential explanatory variables.

Riparian Vegetation: Vegetation cover increased on both treated (1%) and control (3%) sites, but increases fell short of the project goal to increase riparian vegetation by 10% by 2018. Seeding and willow planting occurred in spring 2015, with vegetation plot surveys taking place during summer 2015, leaving little time for seeded and planted areas to respond to vegetation treatments. Additional surveys will take place in 2017 and 2019 to evaluate progress towards project goals and inform the need for additional vegetation work.

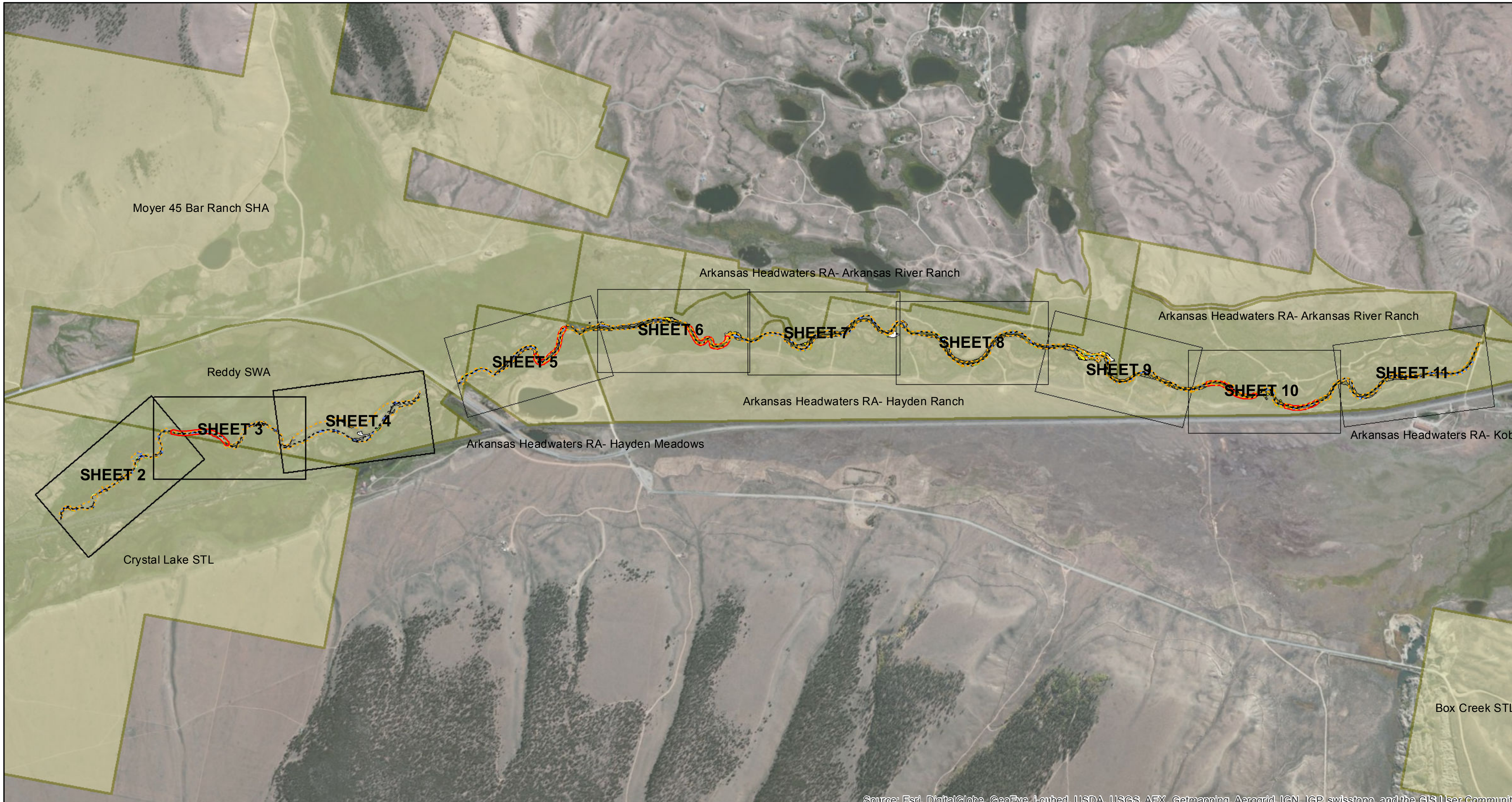
Fish Habitat Modeling: Goals for instream habitat restoration included increasing habitat quality scores for adult, juvenile, and spawning brown trout by 10%. On average, habitat suitability scores increased by 10.0% at control sites and 23.6% at treatment sites for all life-stages. As habitat scores increased at both treatment and control sites following construction, the difference between changes at treatment and control sites can be used to gauge the impact of habitat restoration at treatment sites relative to control. Changes in habitat were 13.6% higher at treatment sites compared to control sites, indicating that habitat restoration achieved project goals for habitat quality. Future monitoring activities will determine if changes in habitat are maintained.

Instream Habitat Structures: Over 90% of habitat structures were functional and stable when first assessed in 2014. Following a 10-year flood in 2015, habitat structures were reassessed and functional ratings decreased from 94% to 87%, which is slightly below the monitoring target of 90%. Maintenance activities were subsequently conducted during the spring of 2016 to address issues with integrity and function at select structures. All structures were reassessed during the fall of 2016 to evaluate the effectiveness of maintenance activities. Additional surveys are scheduled for 2017 and 2018 to monitor the need for additional maintenance and adaptive management.

Geomorphology: Geomorphology monitoring included assessments of cross-sectional area and width/depth (W/D) ratios at monumented cross-sections and fish monitoring sites, as well as changes in residual pool depth (RPD) and sediment gradation. The bankfull cross-sectional area decreased at treated cross-sections on average, indicating that channel-narrowing activities improved over-wide conditions and floodplain connectivity. W/D ratios decreased for low to medium flows at treated fish monitoring sites, while control sites exhibited little change in W/D. RPD increased following instream construction but subsequently decreased following annual runoff cycles. Some treatment types were more effective in maintaining RPD than others. Sediment gradation metrics decreased at most monitoring sites following instream construction, increasing the prevalence of spawning gravels. Changes in sediment were likely influenced by streambed mobilization during the 5-year flood that occurred in 2014. However, changes in channel capacity from restoration treatments could have contributed to increased bedload and improved channel maintenance functions.

Tree Swallows: Metals accumulation in tree swallows was not assessed during this reporting period. Monitoring activities for tree swallows are being directed by the USFWS and are scheduled to take place during 2017-2018. Results from post-implementation monitoring will be compared to baseline data to evaluate if metals contamination in riparian bird communities has improved.

Appendix A: As-Built Drawings



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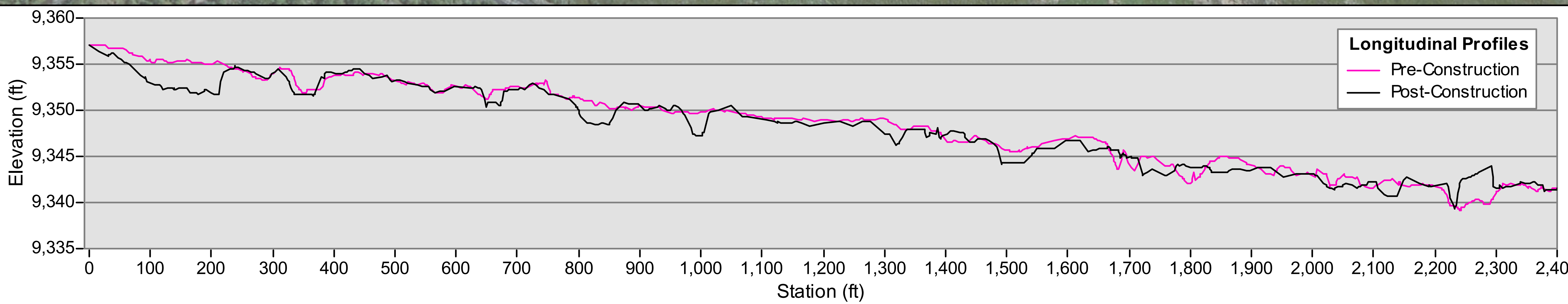

Cross Sections	Boulder Structure	Willow Transplants	Develop Lateral Bar
Thalweg	Cobble Toe	Sod Mat / Riparian Bench	Riparian Seeding
River Alignment	Log Vane	Develop Pool	Erosion Control
Fish Monitoring Sites	Wood Toe	Develop Point Bar	
Boulder Cluster	Willow Planting	Fill	

AS-BUILT DRAWINGS

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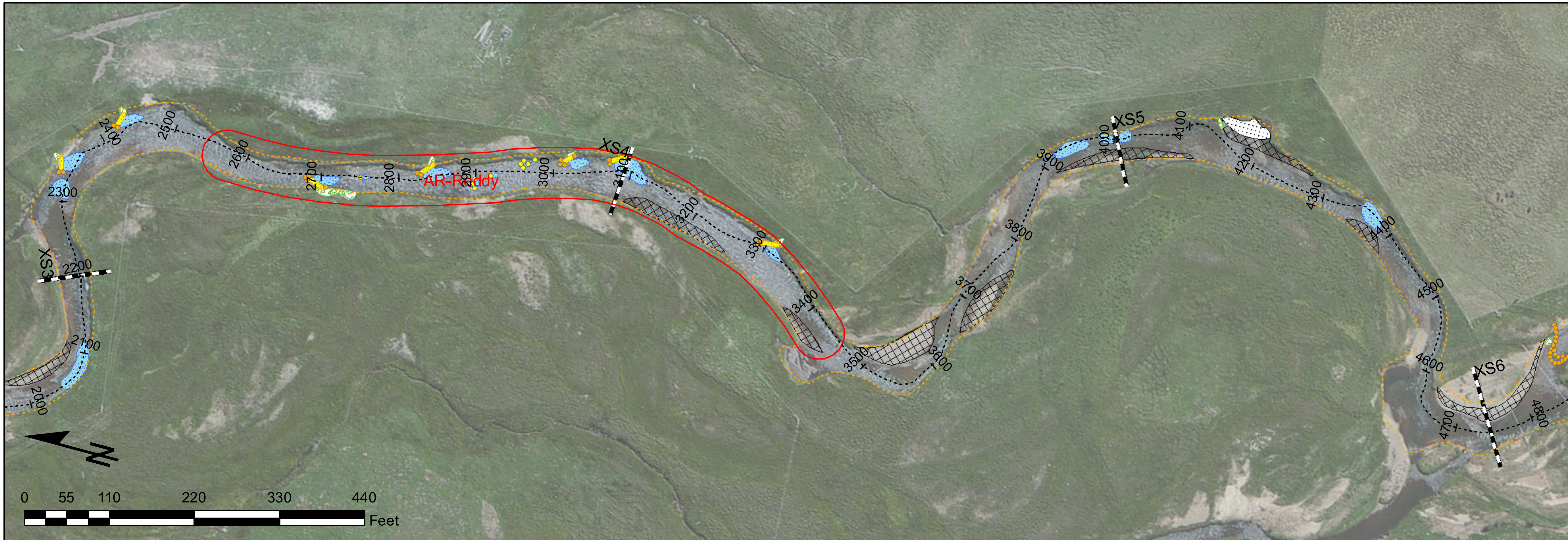
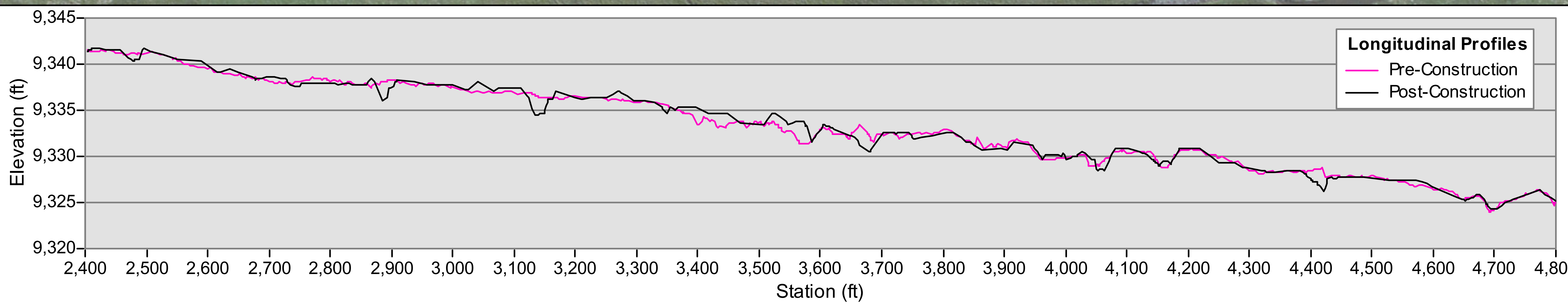
CRYSTAL/REDDY REACH





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AS-BUILT DRAWINGS	
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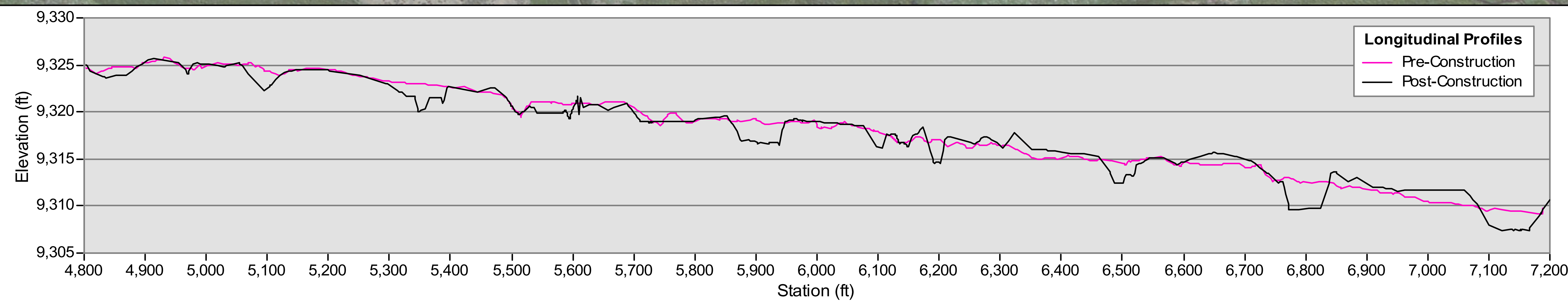

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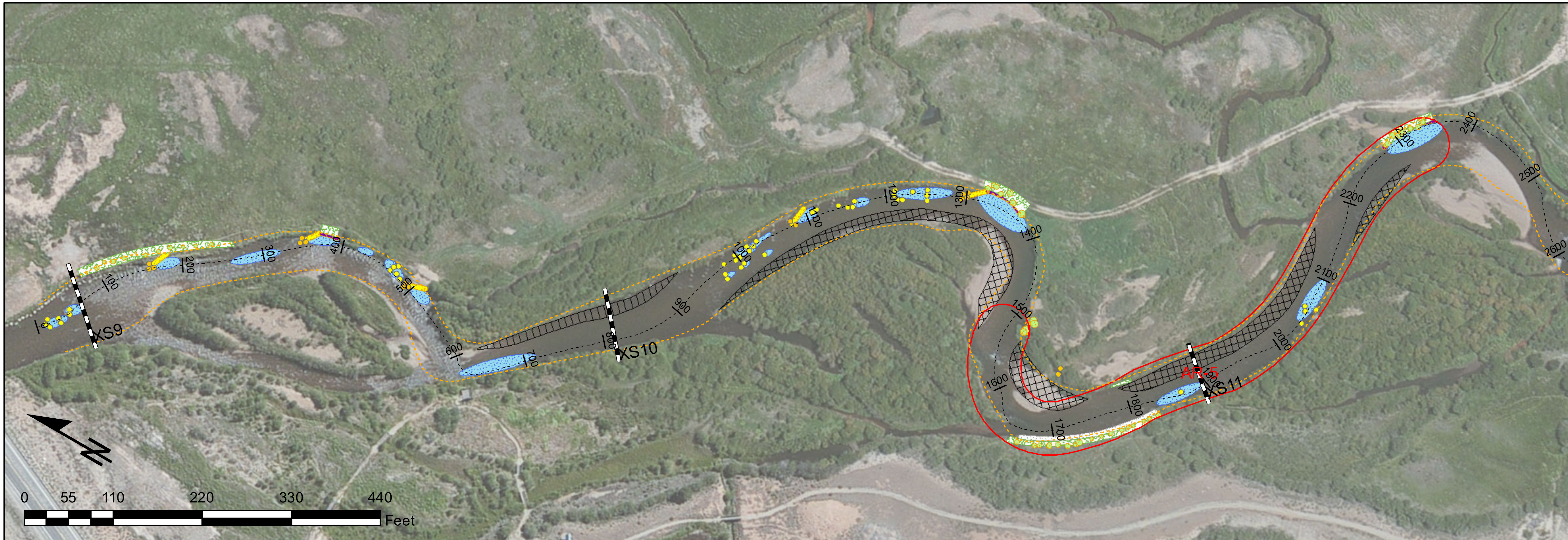

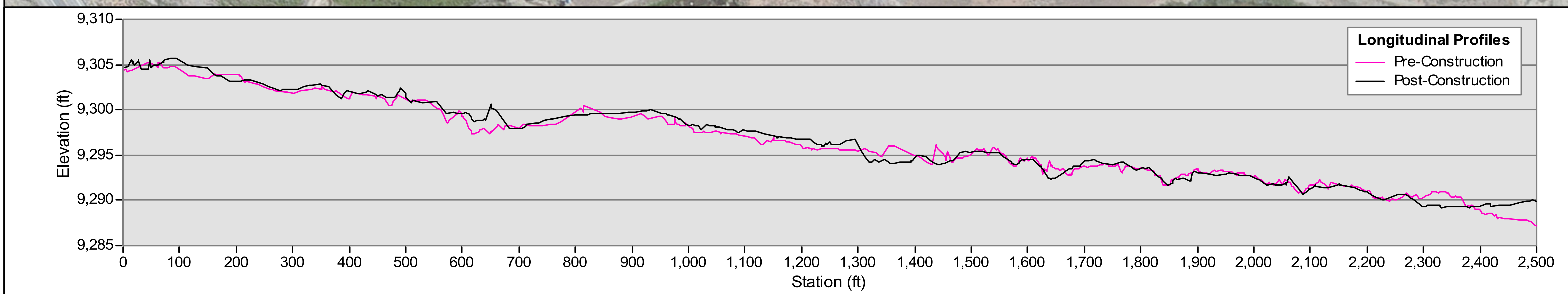

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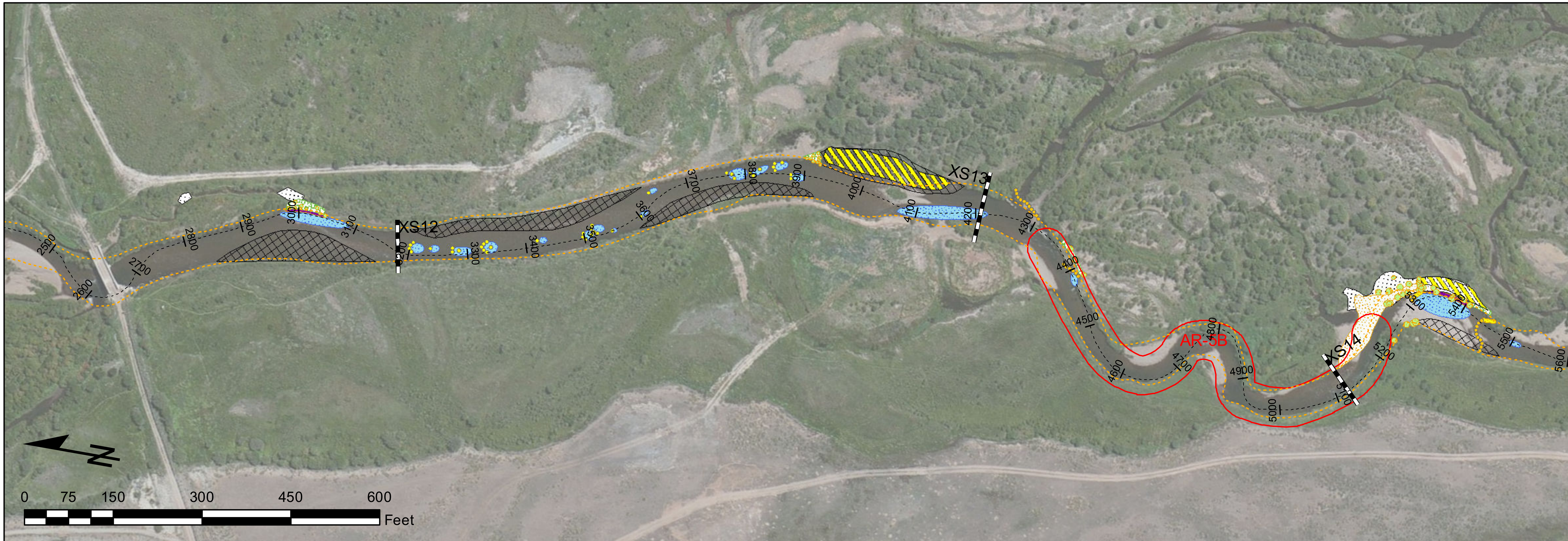

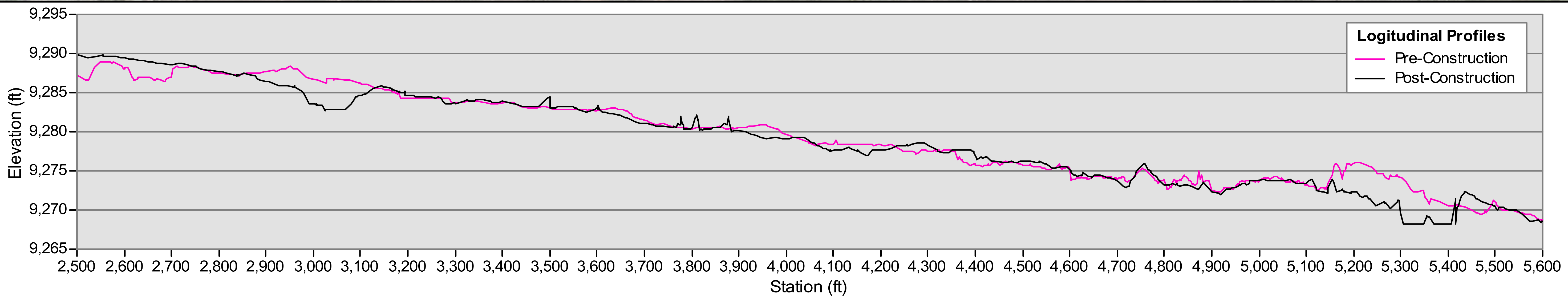

- Cross Sections
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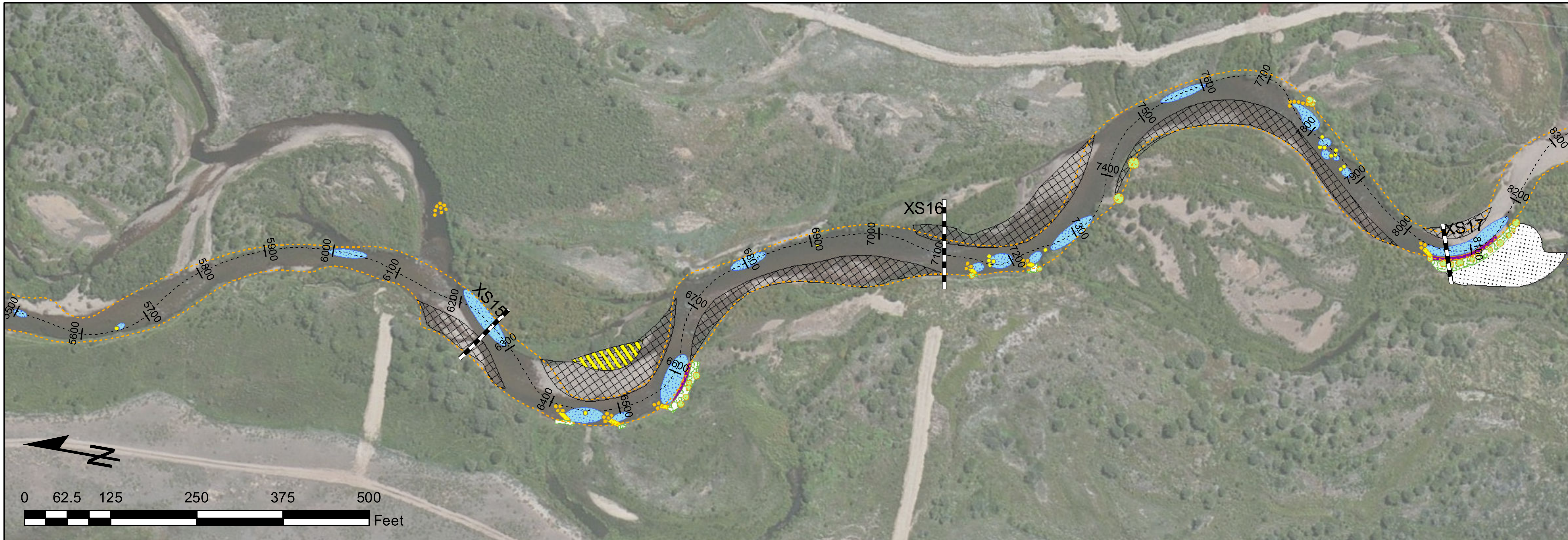

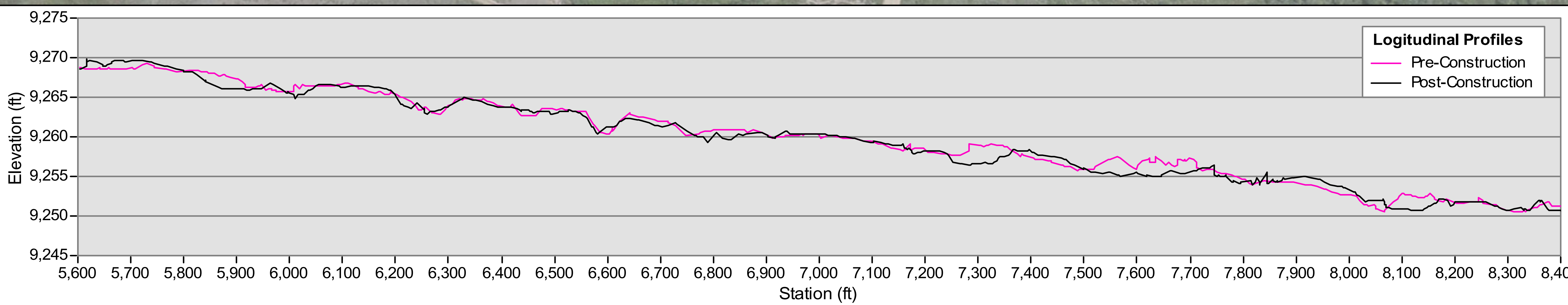

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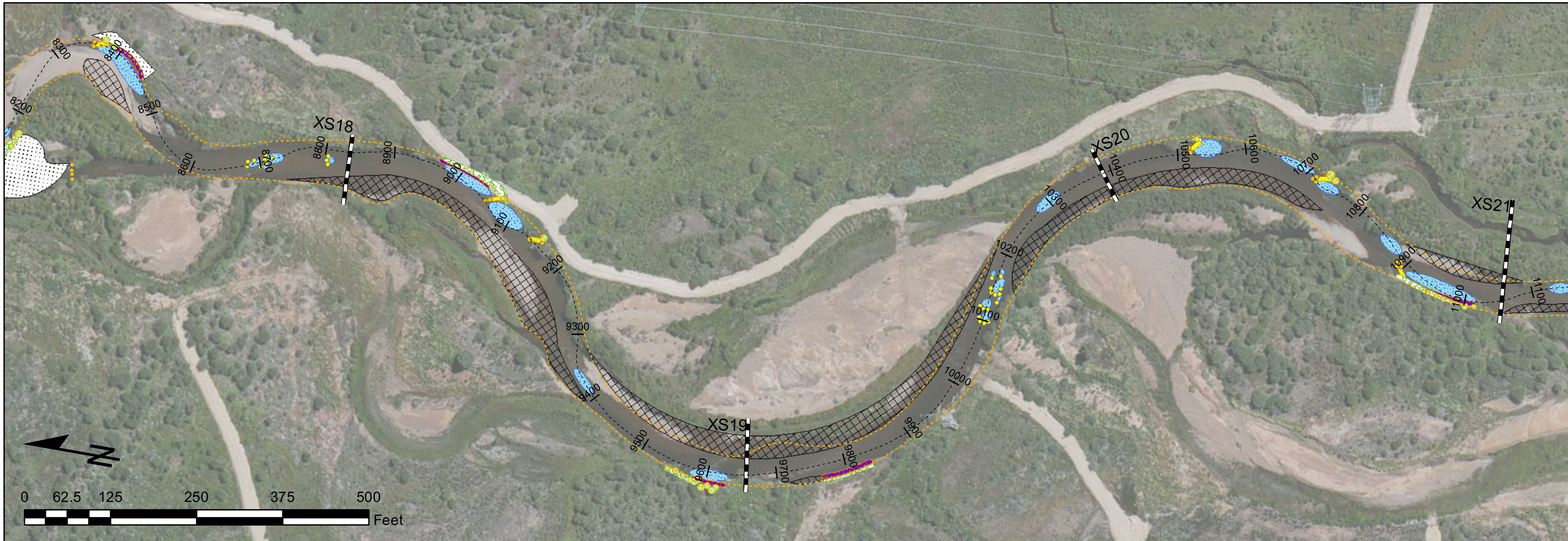
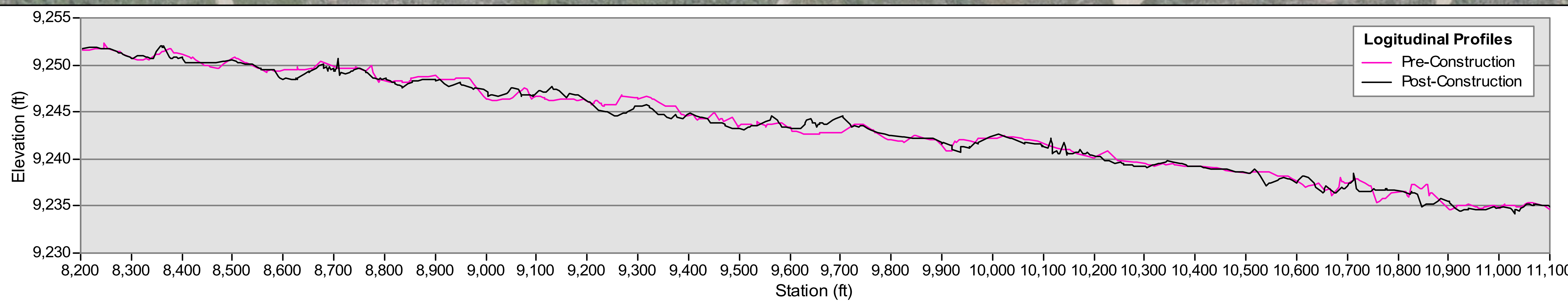
UPPER ARKANSAS RIVER AQUATIC HABITAT PROJECT HAYDEN REACH





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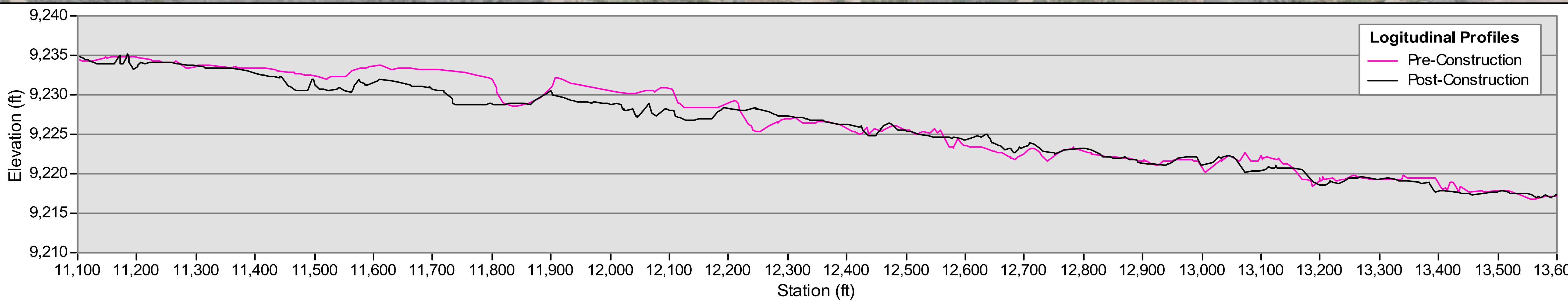

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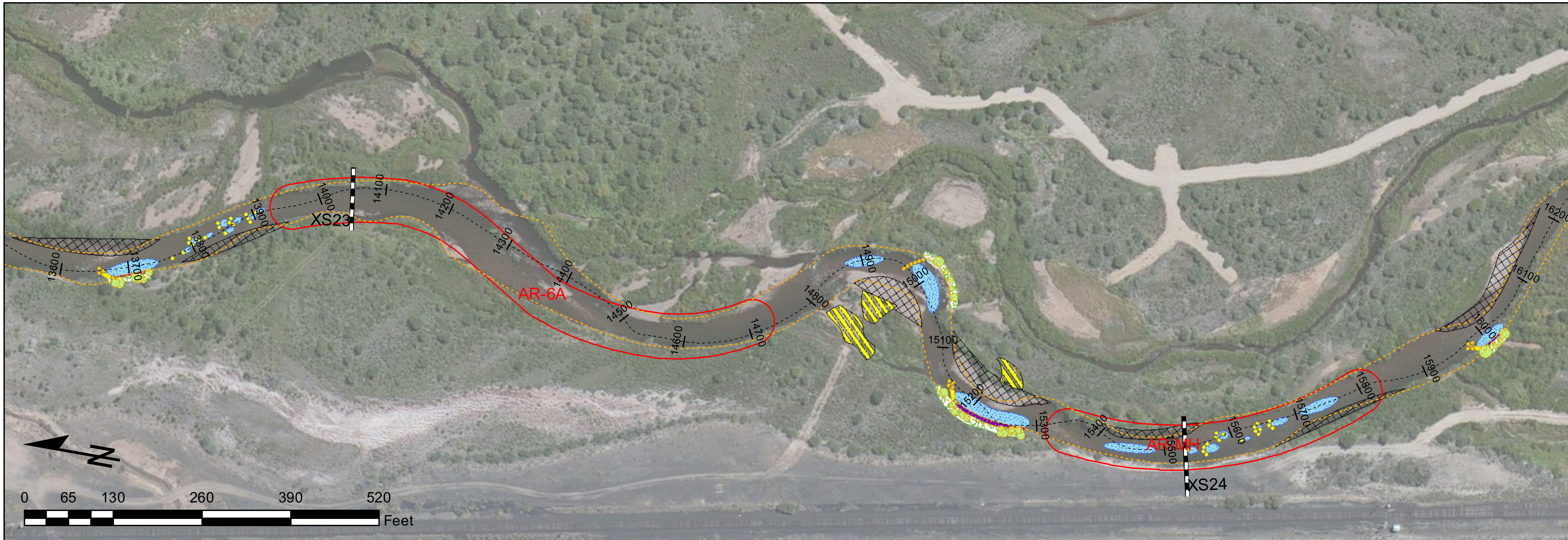
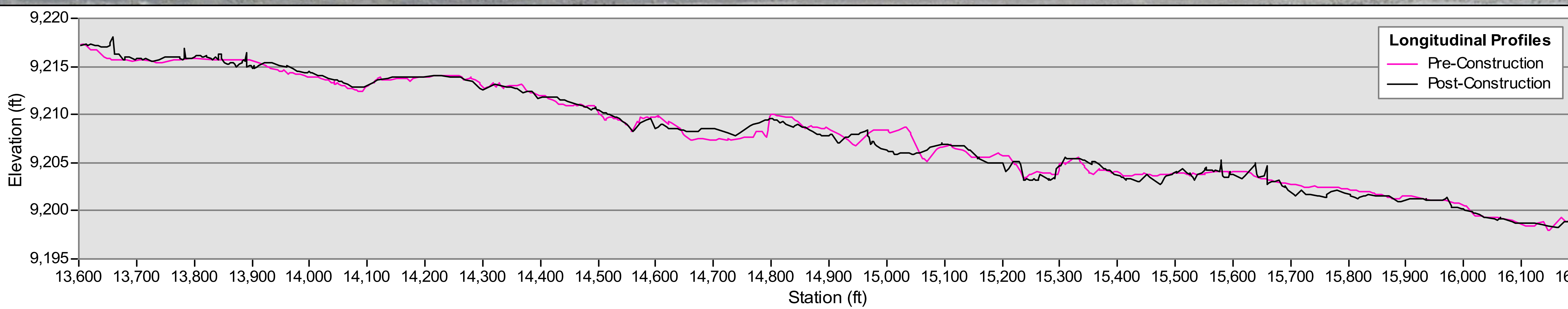
STATE OF COLORADO
DEPARTMENT OF NATURAL RESOURCES
COLORADO PARKS AND WILDLIFE
FORT COLLINS, COLORADO

UPPER ARKANSAS RIVER
AQUATIC HABITAT PROJECT
HAYDEN REACH





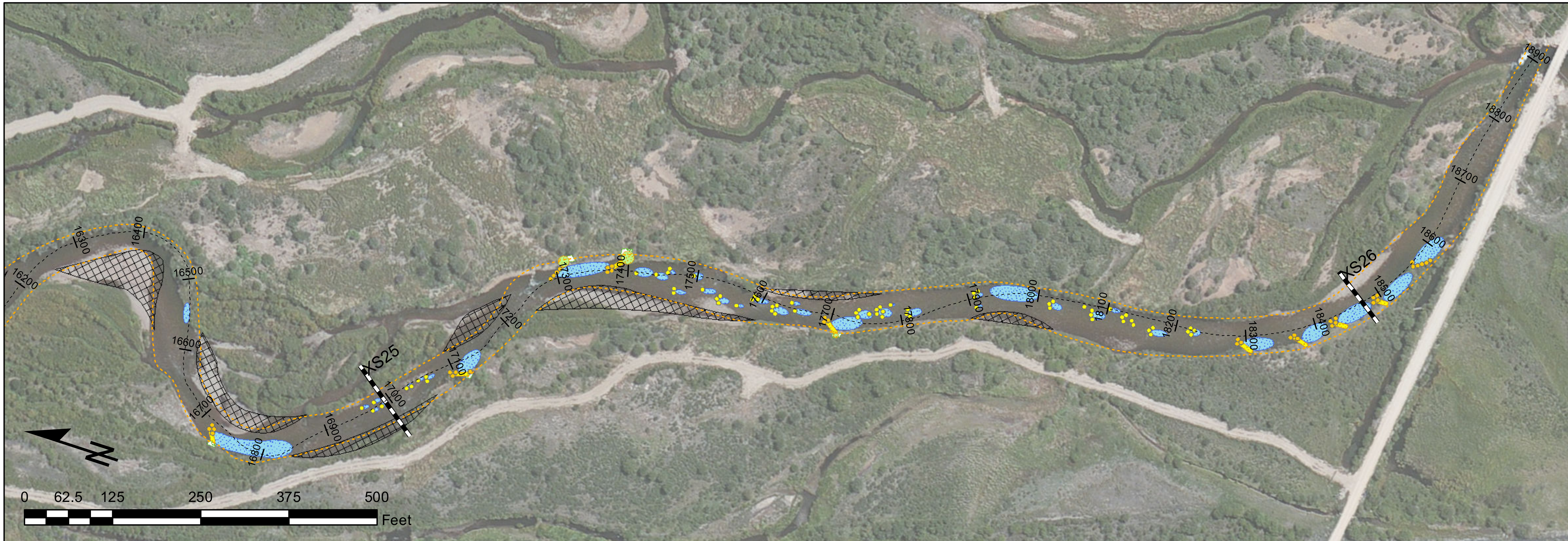
Cross Sections
Thalweg
River Alignment
Fish Monitoring Sites
Boulder Cluster
Boulder Structure
Cobble Toe
Log Vane
Wood Toe
Willow Planting
Willow Transplants
Sod Mat / Riparian Bench
Develop Pool
Develop Point Bar
Fill
Develop Lateral Bar
Riparian Seeding
Erosion Control

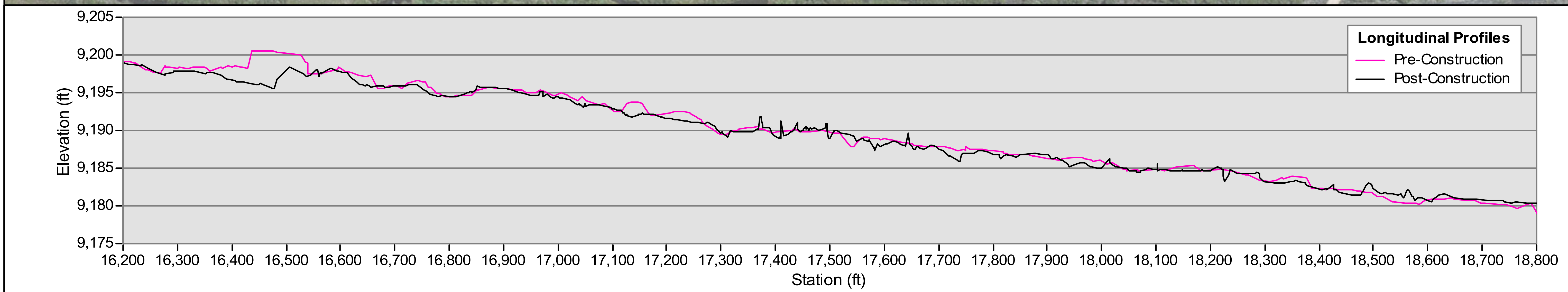
AS-BUILT DRAWINGS

DRAWN: TBARNES	2/26/2016
CHECKED: ERICHER	2/27/2016
APPROVED: TKITTELL	3/4/2016
SHEET: 10 OF 20	

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

UPPER ARKANSAS RIVER
AQUATIC HABITAT PROJECT
HAYDEN REACH





- Cross Sections
- Thalweg
- River Alignment
- Fish Monitoring Sites
- Boulder Cluster
- Boulder Structure
- Cobble Toe
- Log Vane
- Wood Toe
- Willow Planting
- Willow Transplants
- Sod Mat / Riparian Bench
- Develop Pool
- Develop Point Bar
- Fill
- Develop Lateral Bar
- Riparian Seeding
- Erosion Control

AS-BUILT DRAWINGS

DRAWN: TBARNES	2/26/2016
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APPROVED: TKITTELL	3/4/2016

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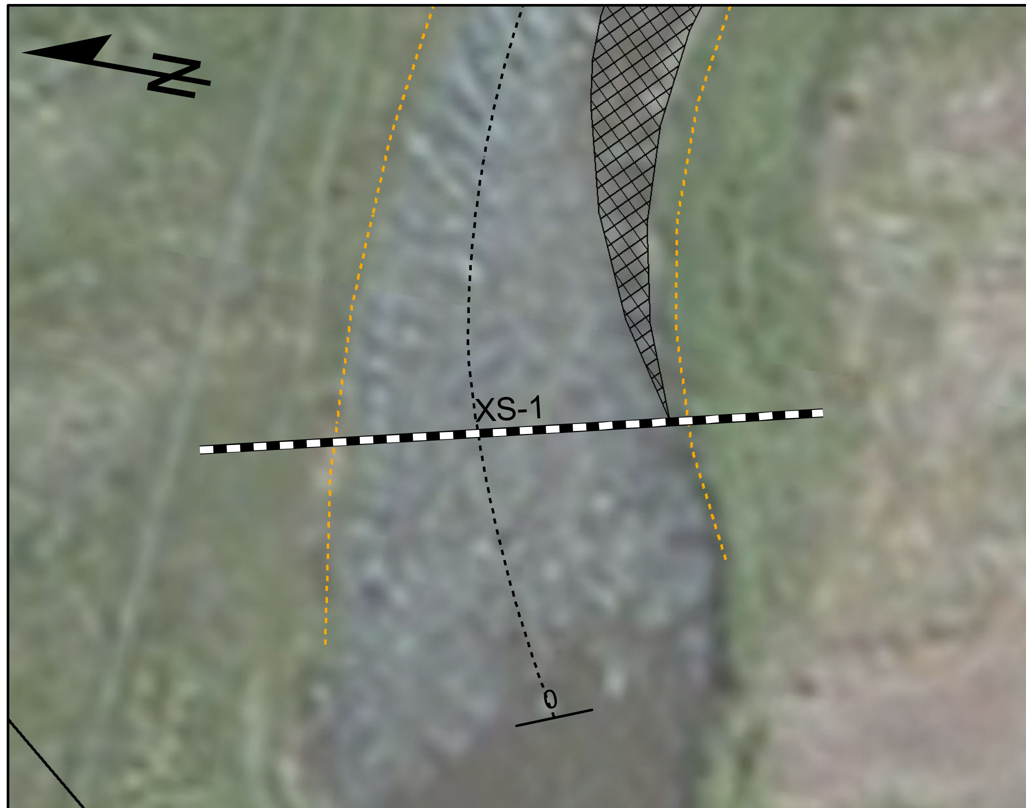
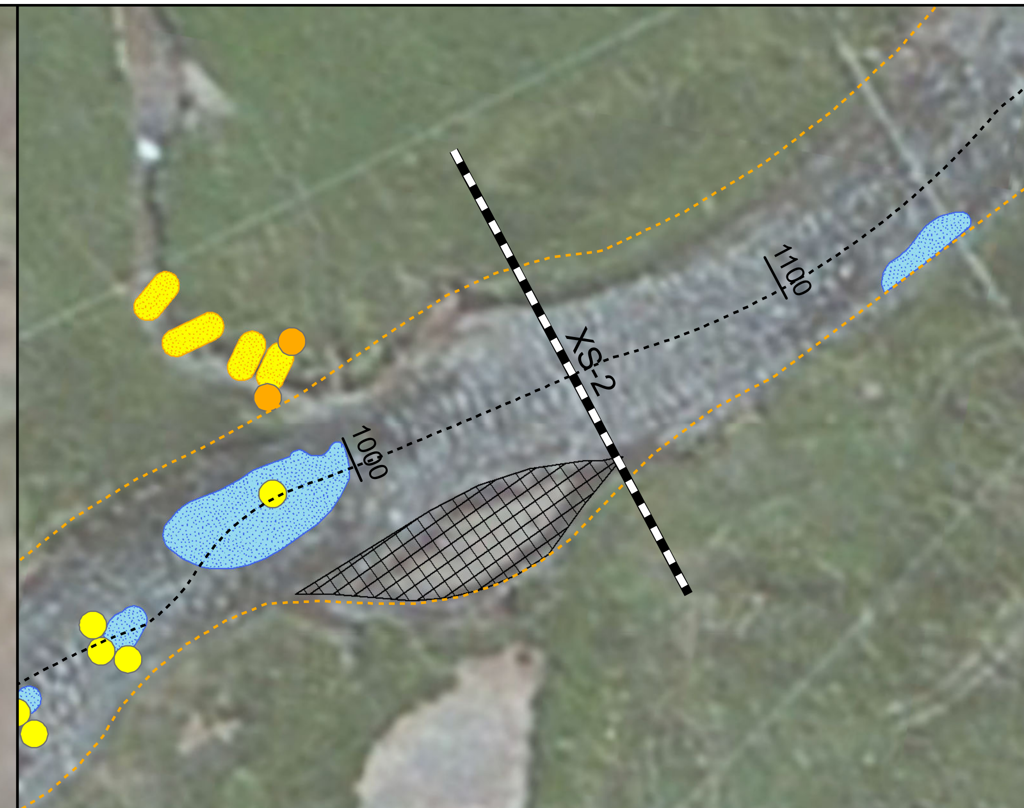
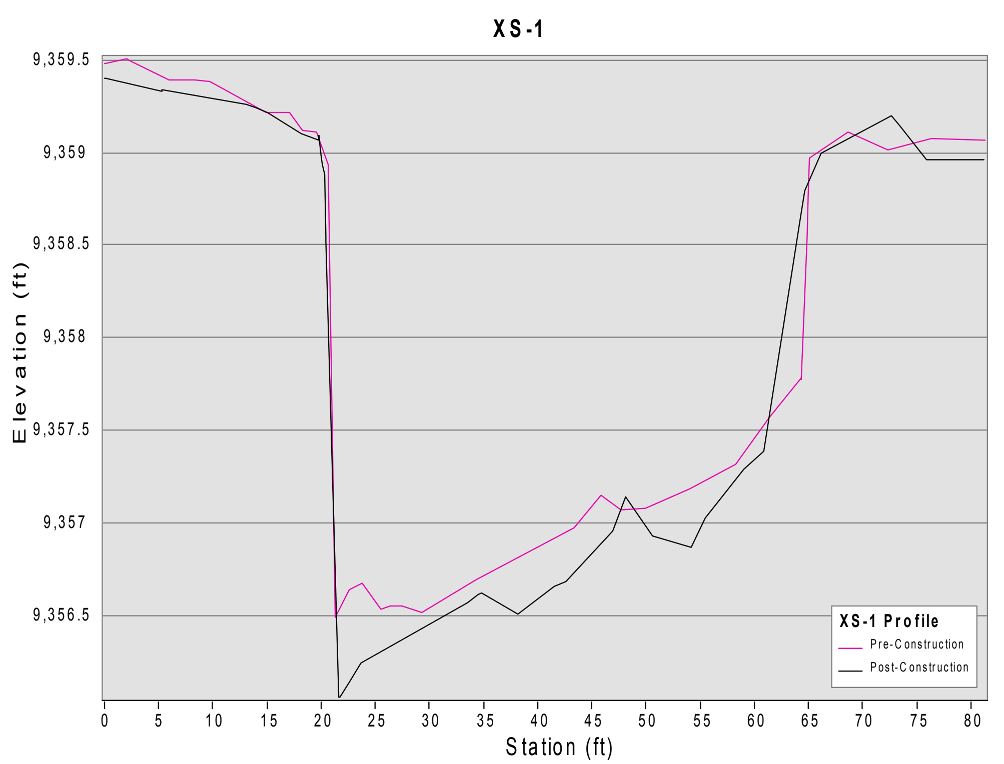
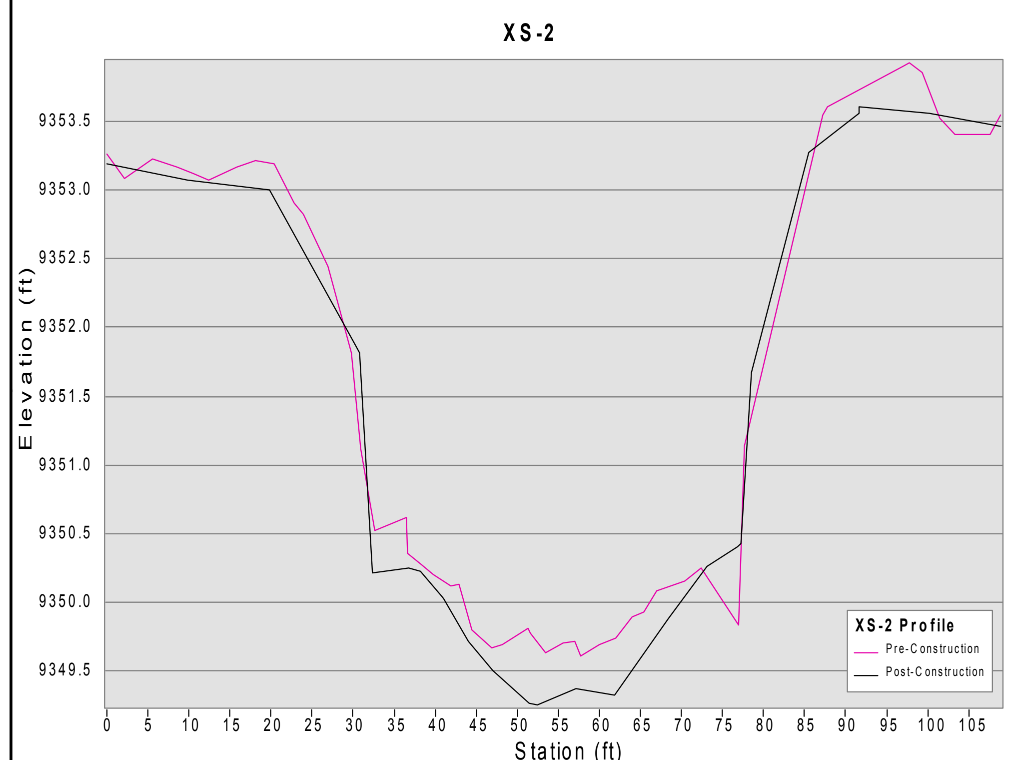
STATE OF COLORADO
DEPARTMENT OF NATURAL RESOURCES
COLORADO PARKS AND WILDLIFE
FORT COLLINS, COLORADO

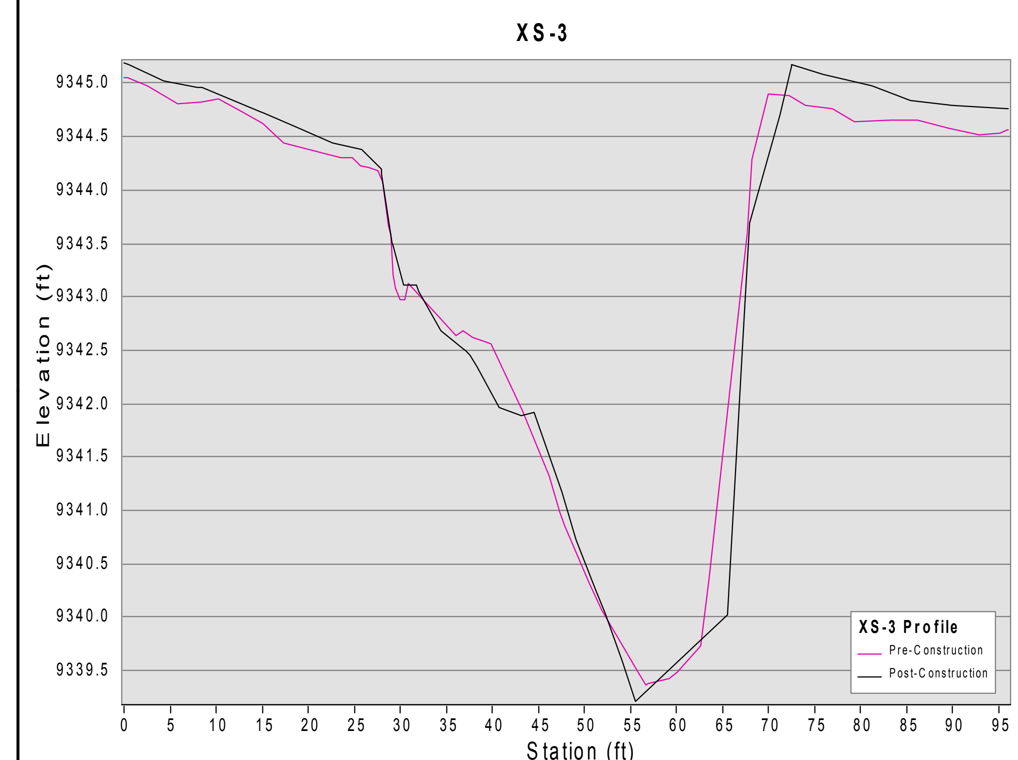
UPPER ARKANSAS RIVER
AQUATIC HABITAT PROJECT
HAYDEN REACH











Cross Sections
Thalweg
River Alignment
Fish Monitoring Sites
Boulder Cluster
Boulder Structure
Willow Planting
Willow Transplants
Sod Mat / Riparian Bench
Develop Pool
Develop Point Bar
Fill
Riparian Seeding
Develop Lateral Bar
Cobble Toe
Log Vane
Wood Toe
Erosion Control

CROSS SECTIONS 1-3

DRAWN: BSTAMPER	7/6/2016
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APPROVED: TKITTELL	7/15/2016
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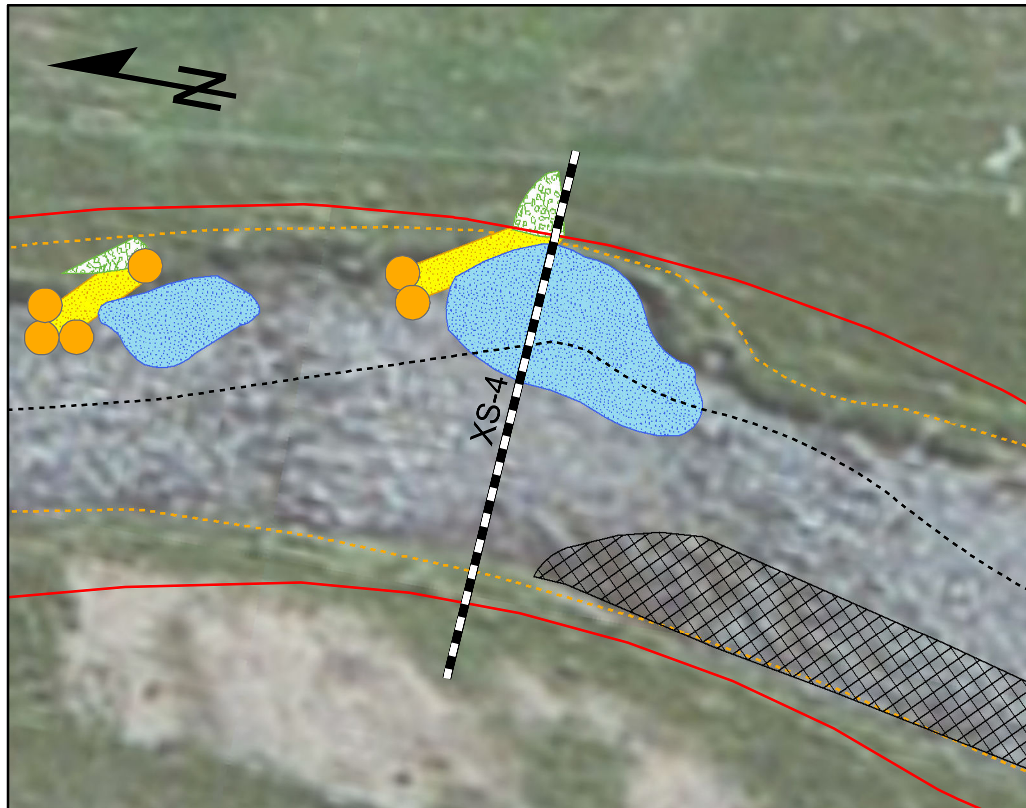
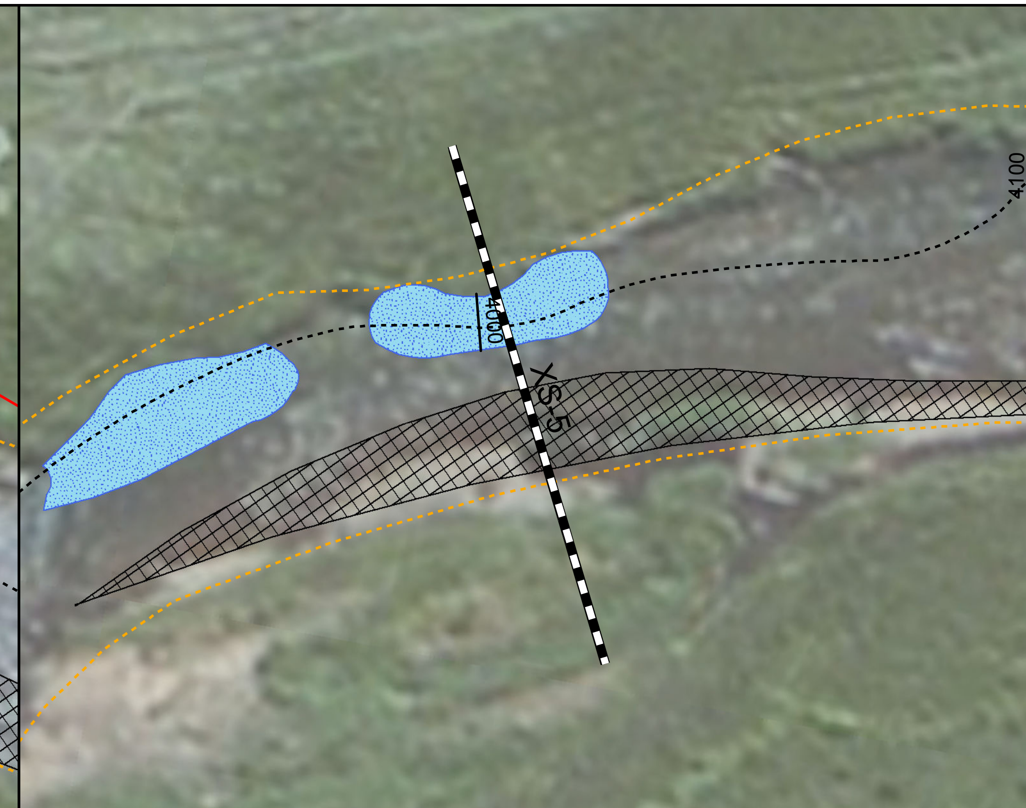
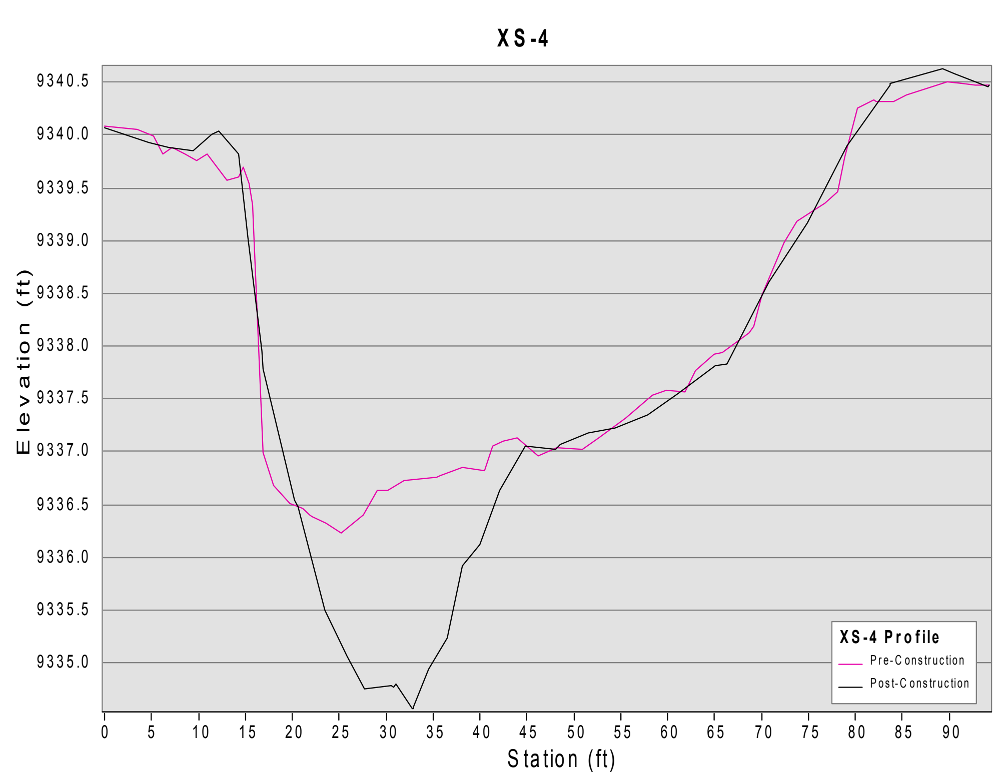
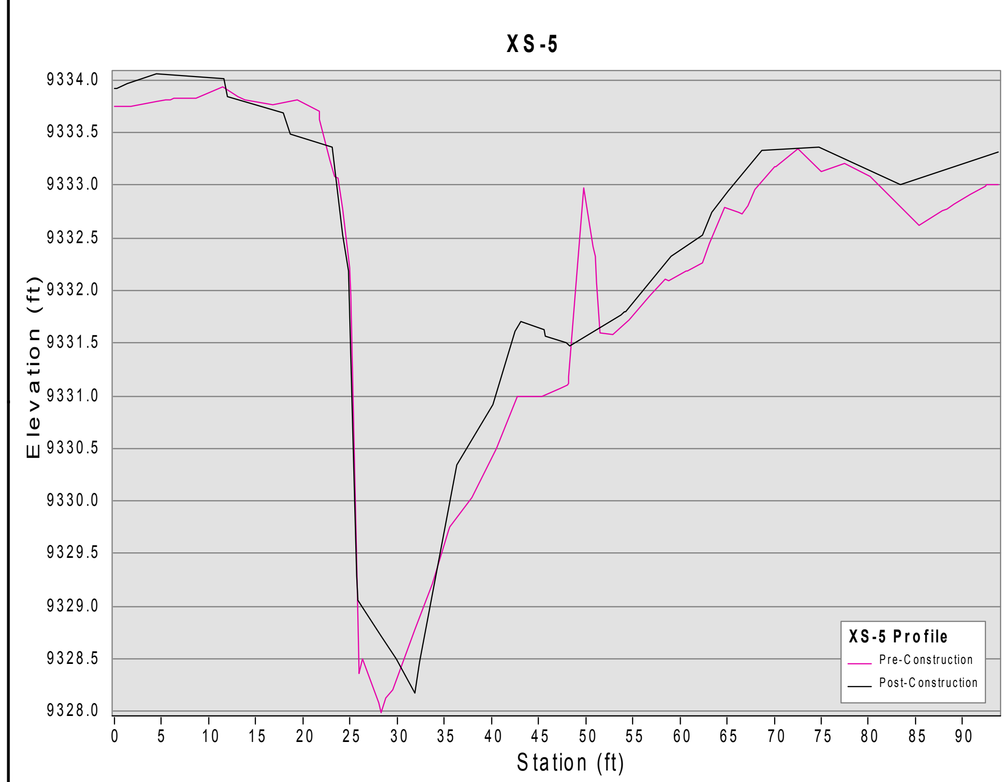
STATE OF COLORADO
DEPARTMENT OF NATURAL RESOURCES
COLORADO PARKS AND WILDLIFE
FORT COLLINS, COLORADO

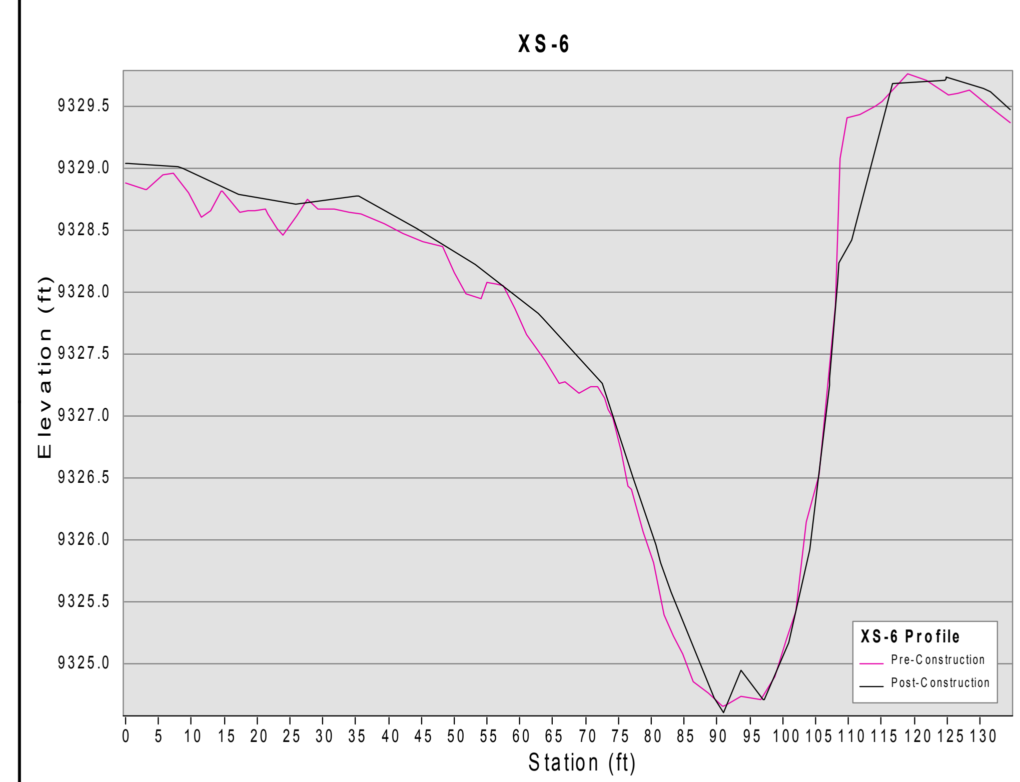
UPPER ARKANSAS RIVER AQUATIC HABITAT PROJECT CRYSTAL/REDDY REACH











Cross Sections
Thalweg
River Alignment
Fish Monitoring Sites
Boulder Cluster
Boulder Structure
Willow Planting
Willow Transplants
Sod Mat / Riparian Bench
Develop Pool
Develop Point Bar
Fill
Riparian Seeding
Develop Lateral Bar
Cobble Toe
Log Vane
Wood Toe
Erosion Control

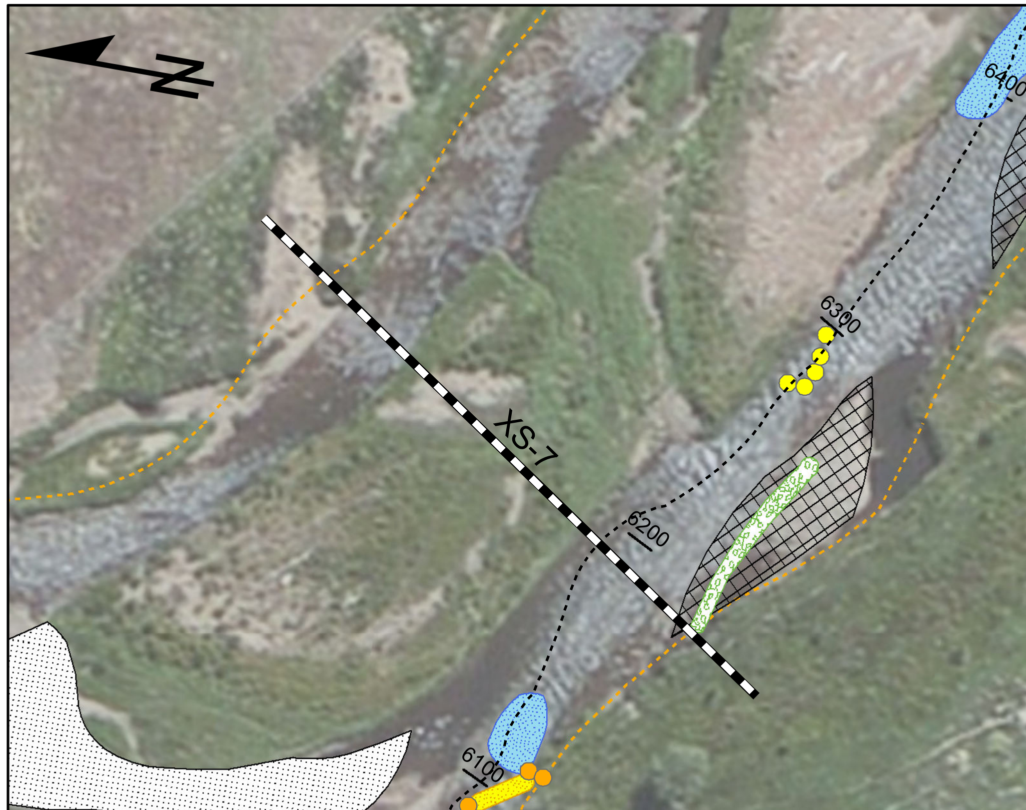
CROSS SECTIONS 4-6

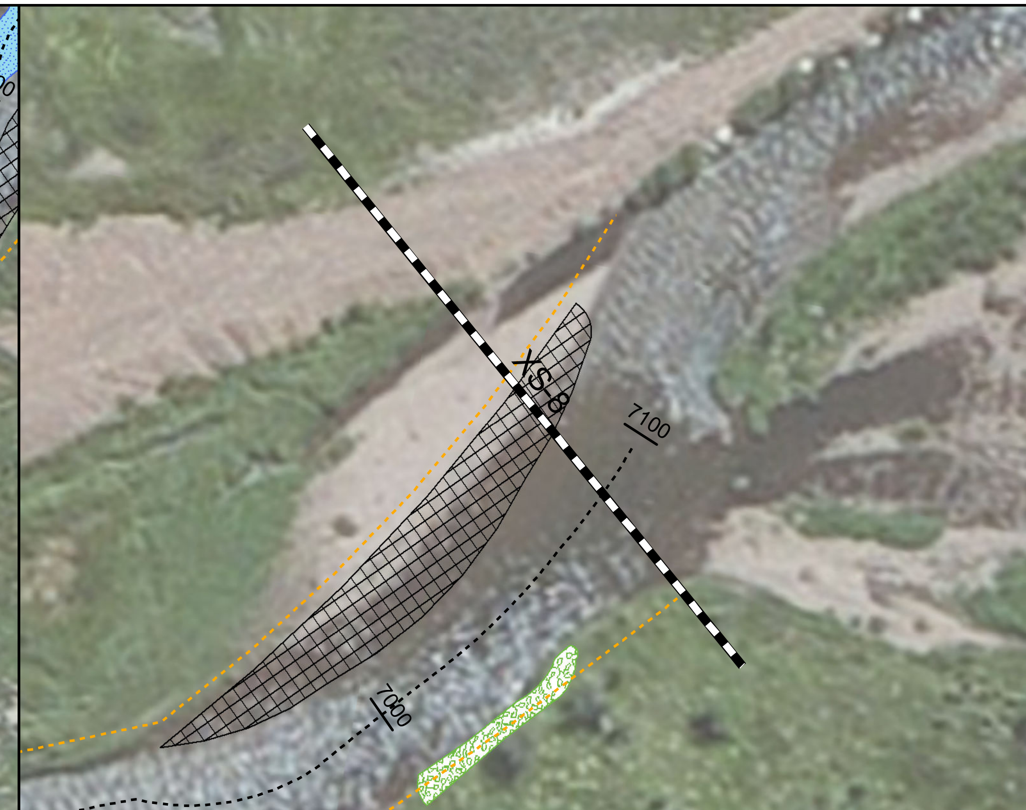
DRAWN: BSTAMPER	7/6/2016
CHECKED: ERICHER	7/13/2016
APPROVED: TKITTELL	7/15/2016

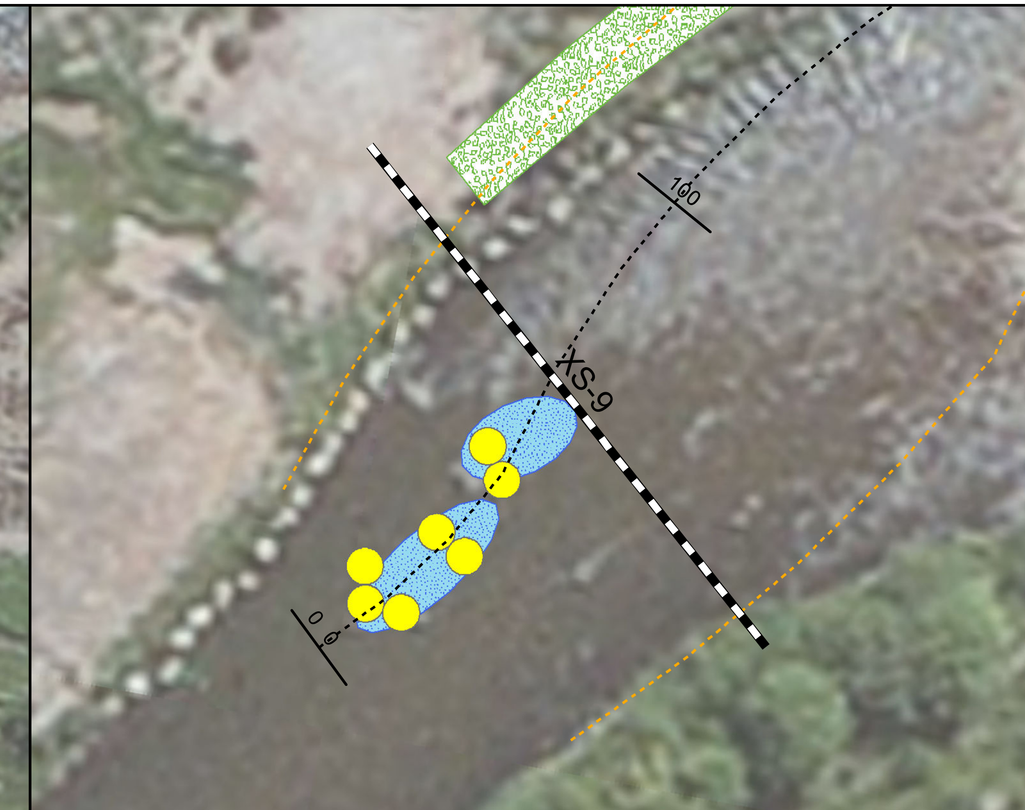
SHEET: 13 OF 20

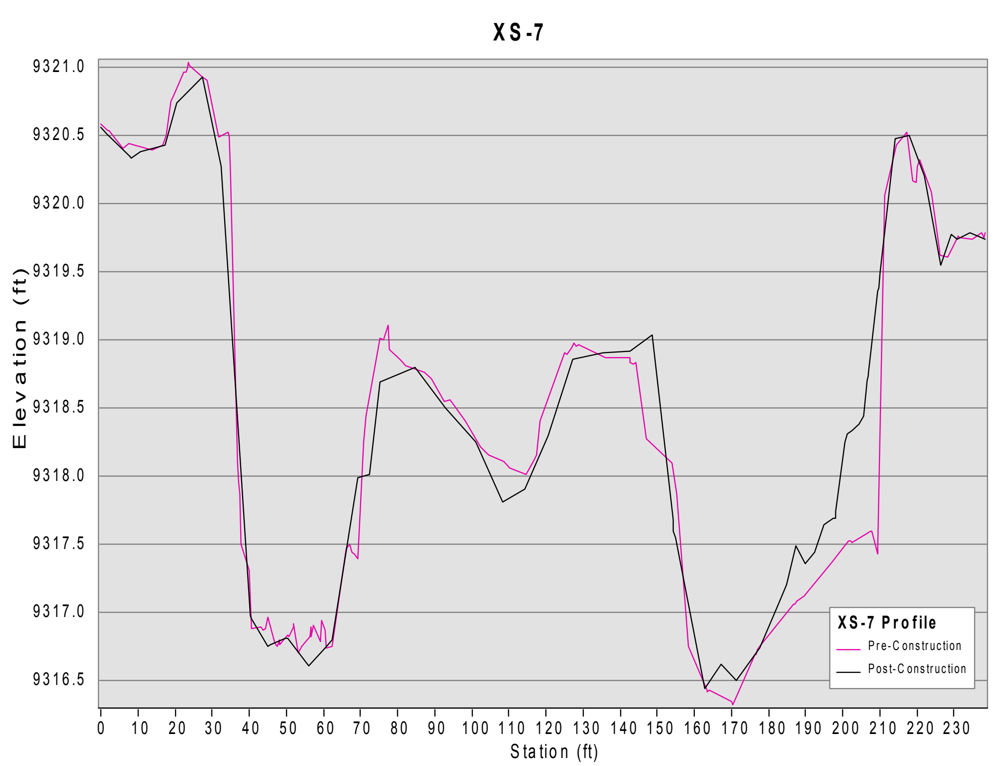
STATE OF COLORADO
DEPARTMENT OF NATURAL RESOURCES
COLORADO PARKS AND WILDLIFE
FORT COLLINS, COLORADO

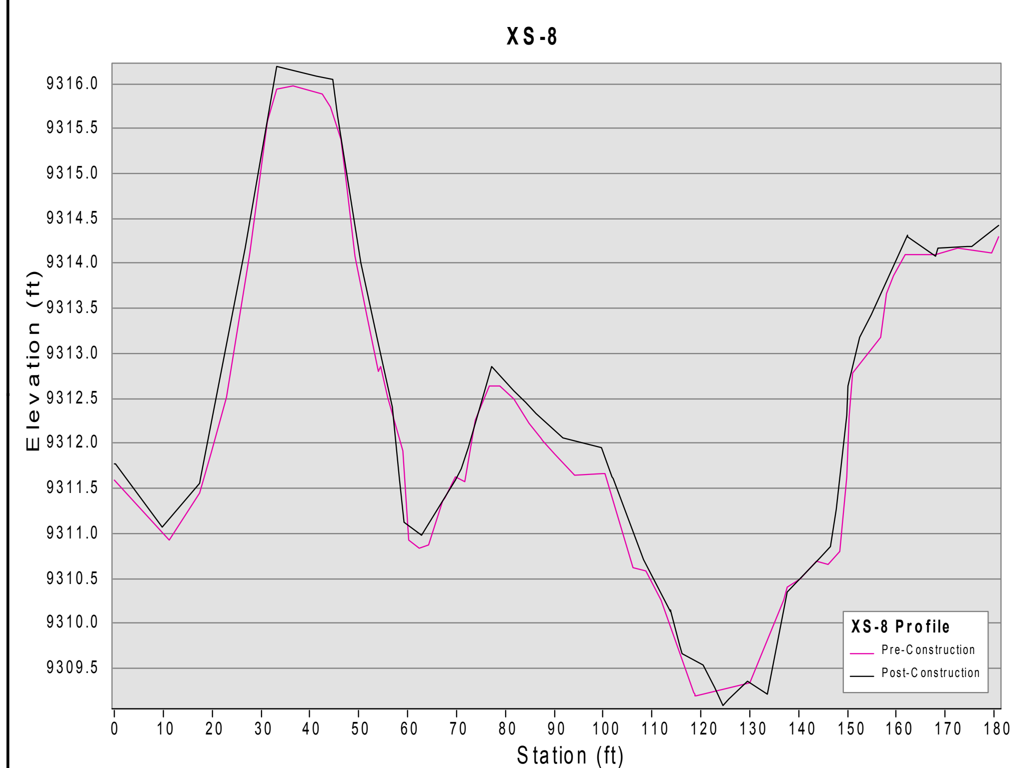
UPPER ARKANSAS RIVER
AQUATIC HABITAT PROJECT
CRYSTAL/REDDY REACH

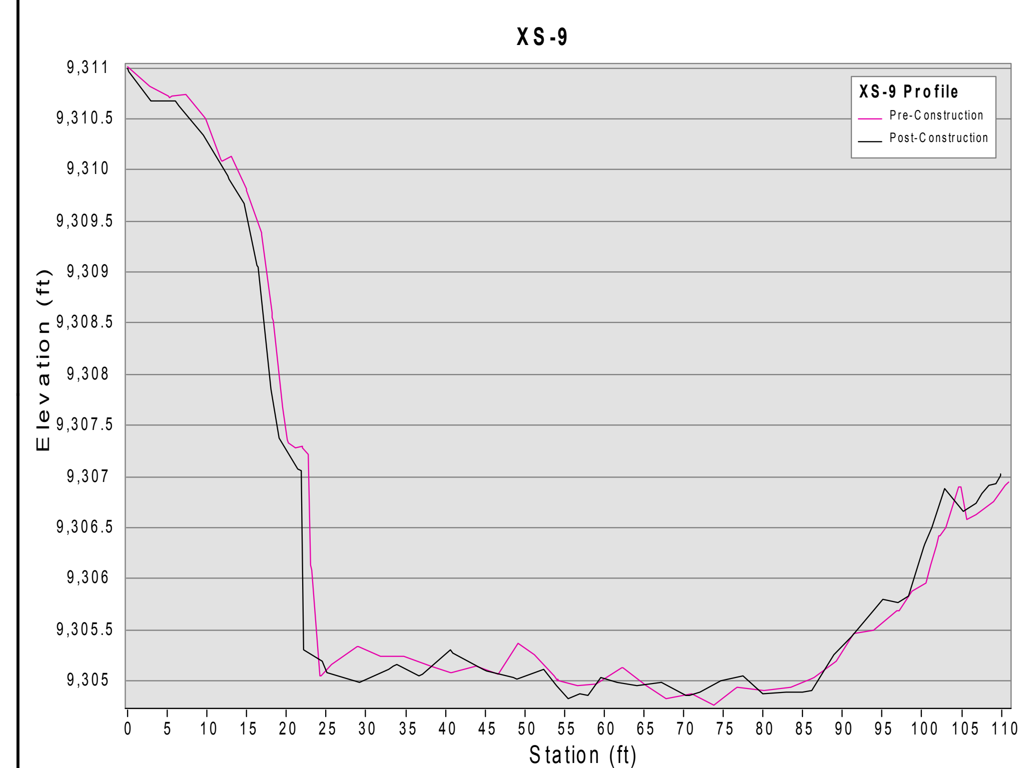










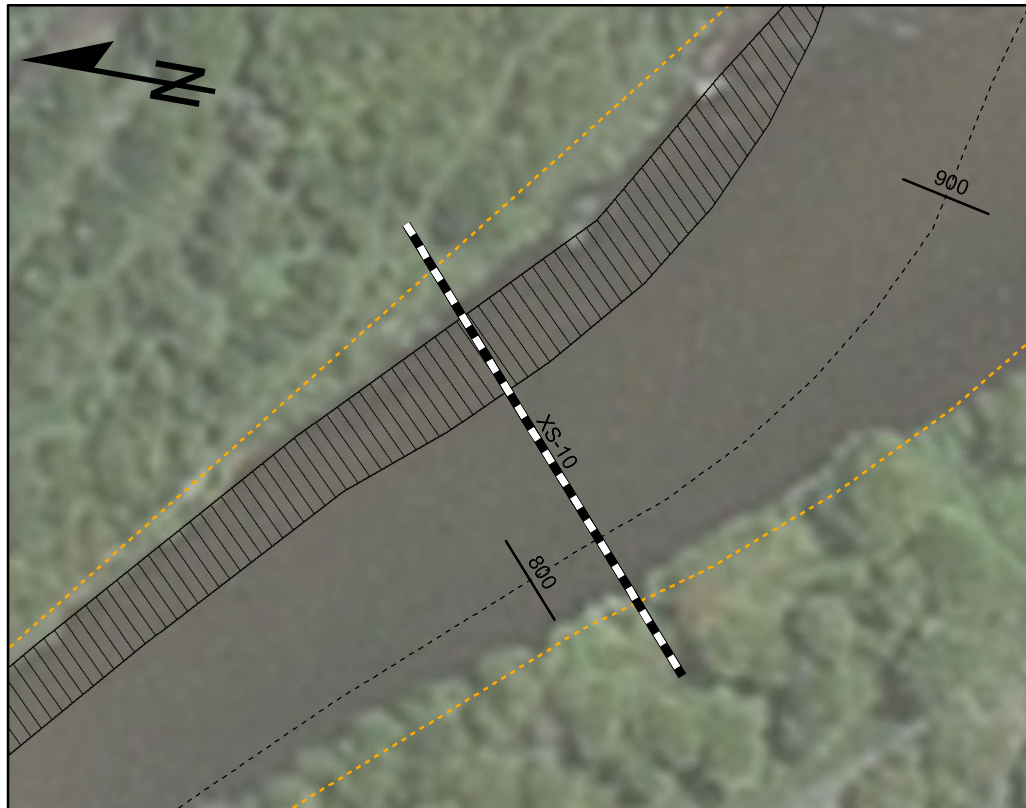


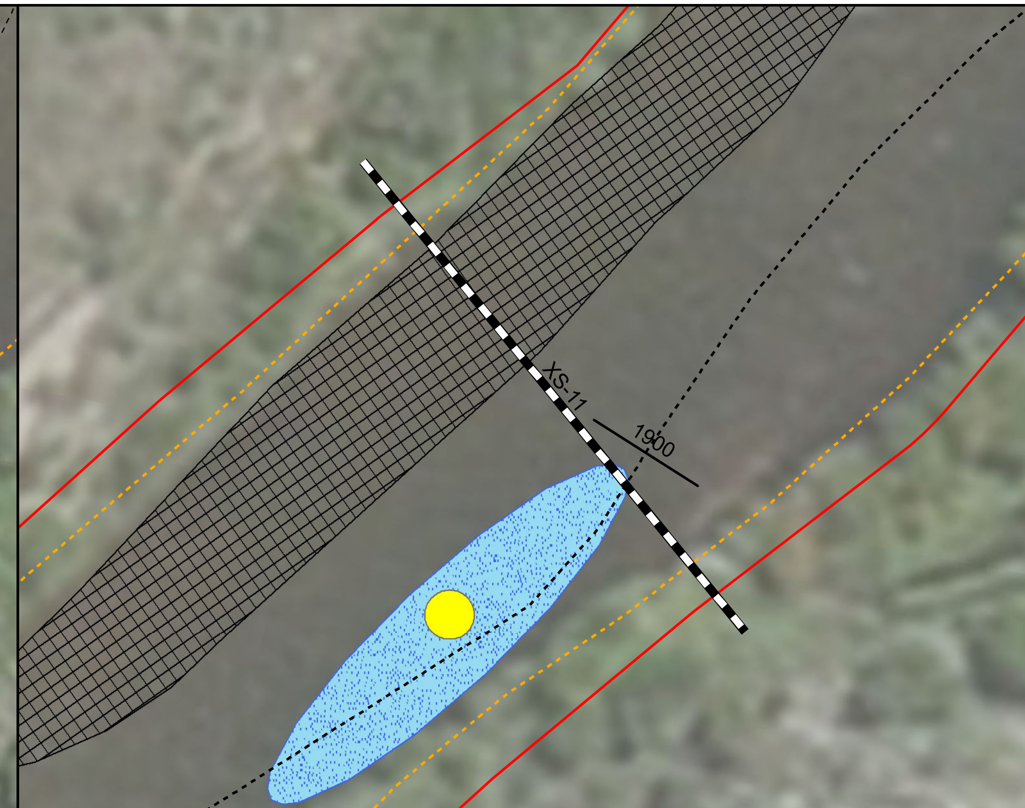
Cross Sections
Thalweg
River Alignment
Fish Monitoring Sites
Boulder Cluster
Boulder Structure
Willow Planting
Willow Transplants
Sod Mat / Riparian Bench
Develop Pool
Develop Point Bar
Fill
Riparian Seeding
Develop Lateral Bar
Cobble Toe
Log Vane
Wood Toe
Erosion Control

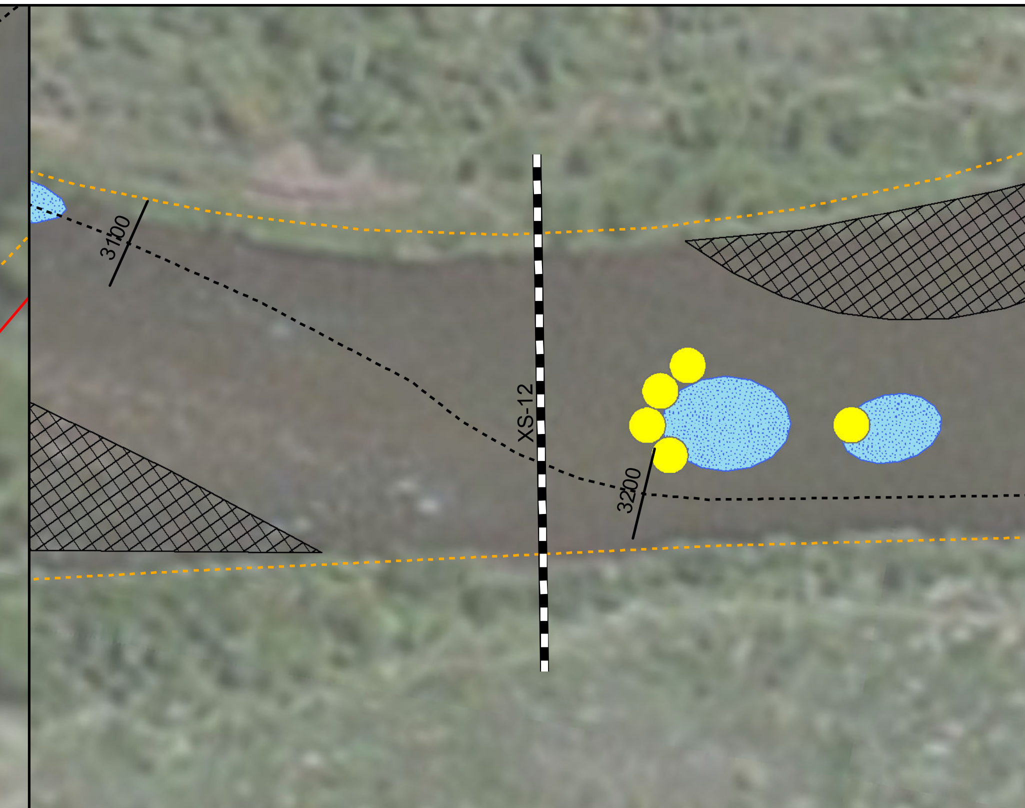
CROSS SECTIONS 7-9	
DRAWN: BSTAMPER	7/6/2016
CHECKED: ERICHER	7/13/2016
APPROVED: TKITTELL	7/15/2016
SHEET: 14 OF 20	

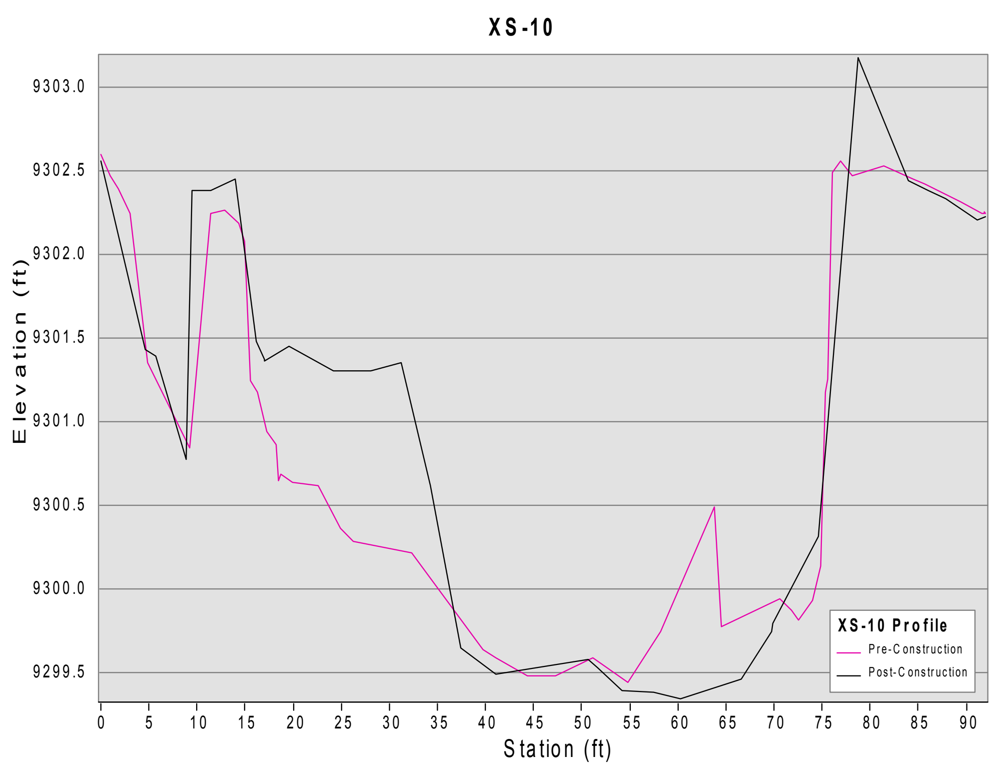
STATE OF COLORADO
DEPARTMENT OF NATURAL RESOURCES
COLORADO PARKS AND WILDLIFE
FORT COLLINS, COLORADO

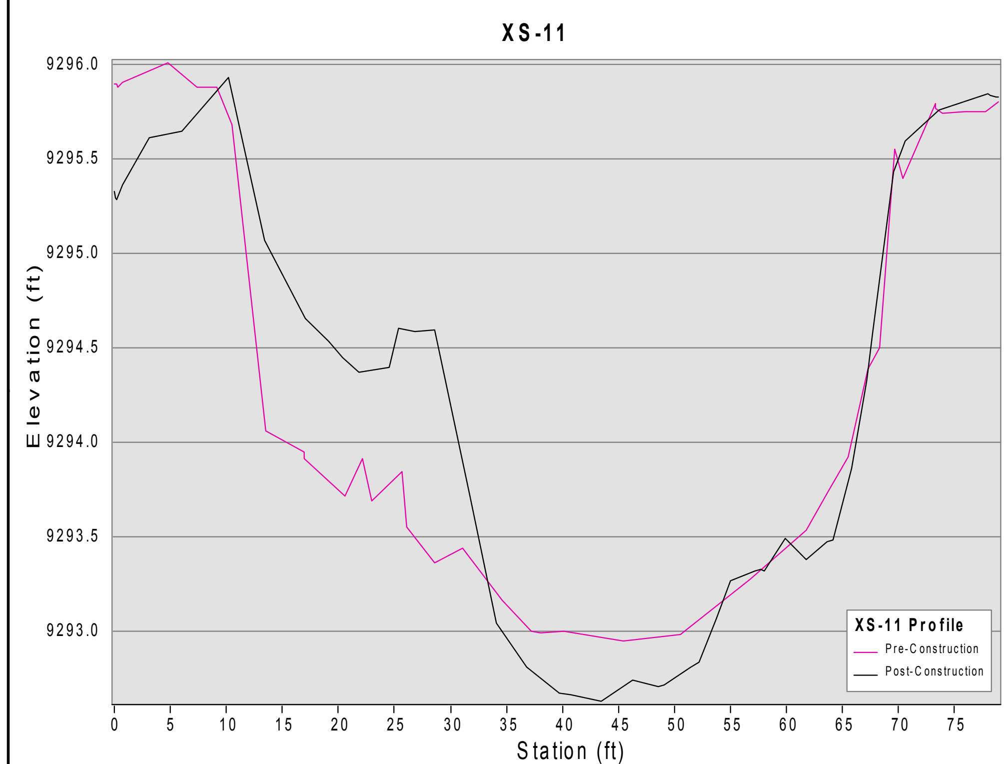
UPPER ARKANSAS RIVER
AQUATIC HABITAT PROJECT
REDDY/HAYDEN REACH

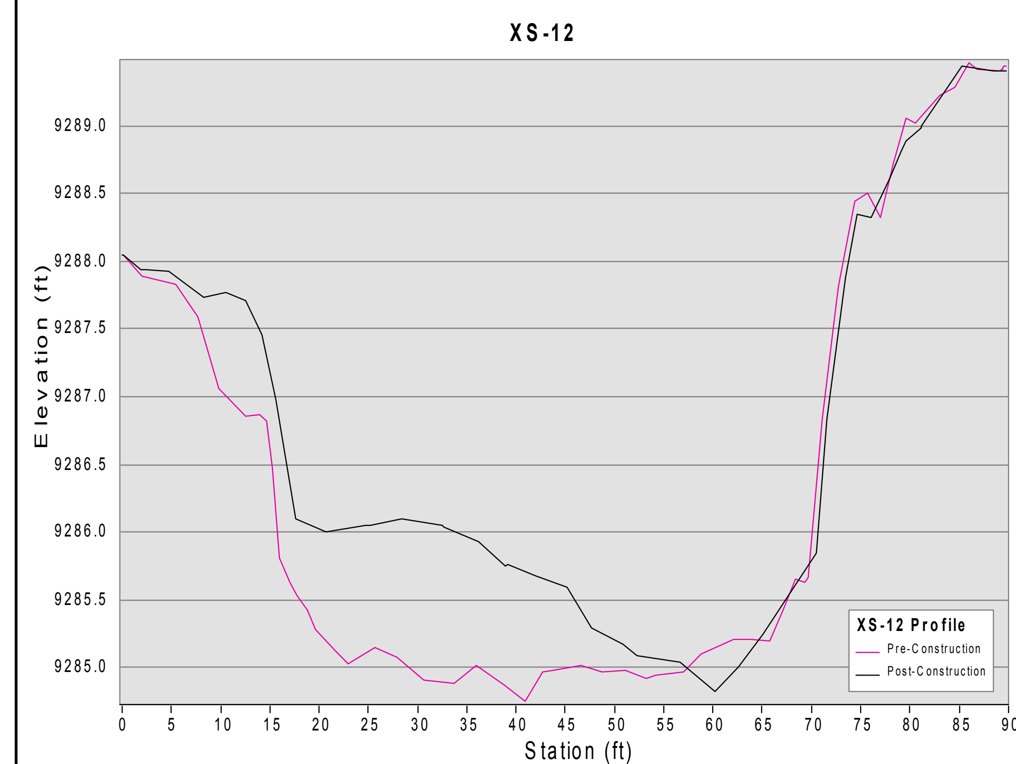












Cross Section	Boulder Structure	Develop Point Bar	Log Vane
Thalweg	Willow Planting	Fill	Wood Toe
River Alignment	Willow Transplants	Riparian Seeding	Erosion Control
Fish Monitoring Sites	Sod Mat / Riparian Bench	Develop Lateral Bar	
Boulder Cluster	Develop Pool	Cobble Toe	

CROSS SECTIONS 10-12

DRAWN: BSTAMPER	7/6/2016
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APPROVED: TKITTELL	7/15/2016

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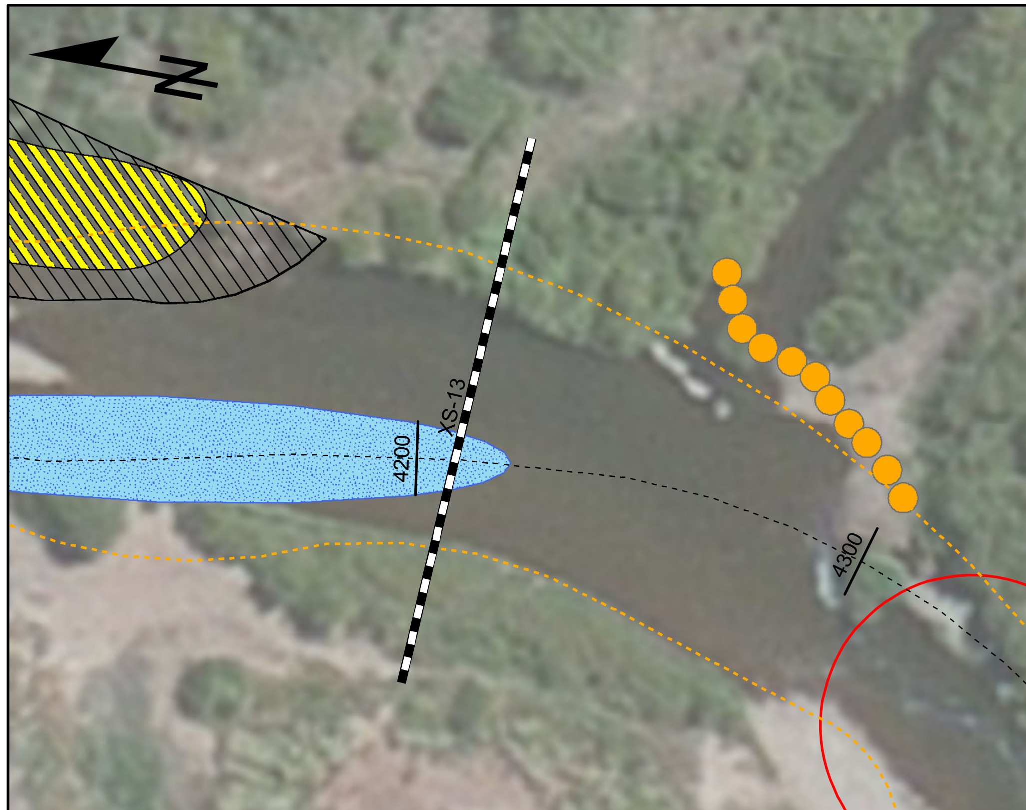
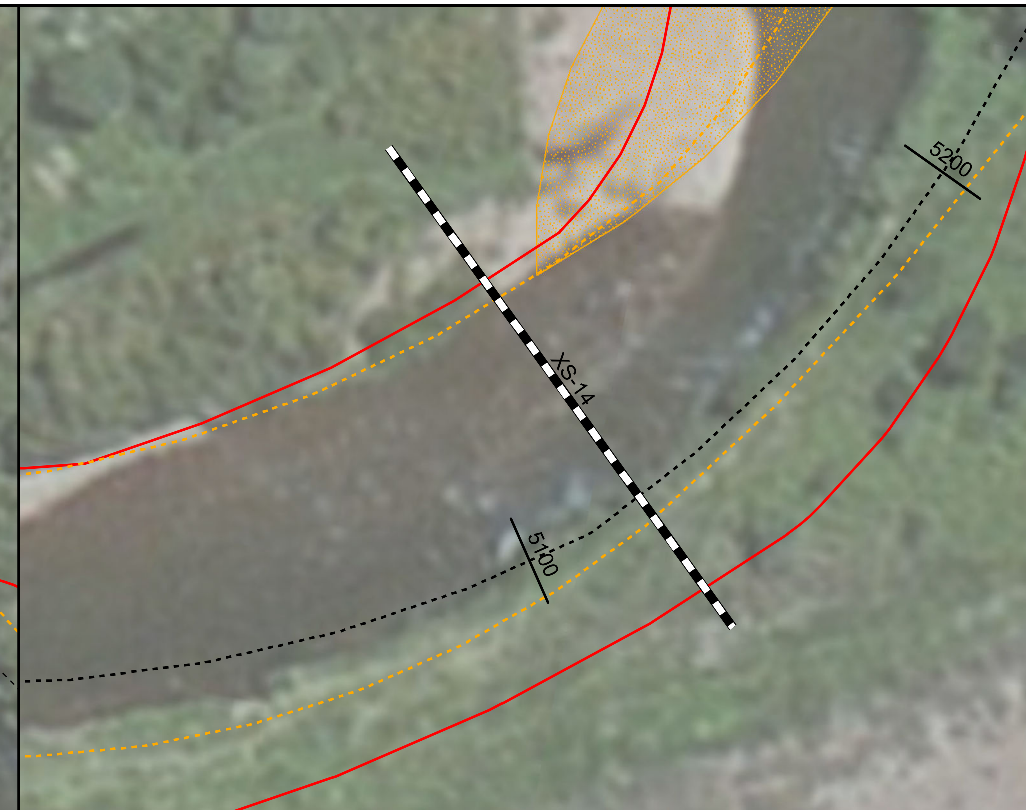
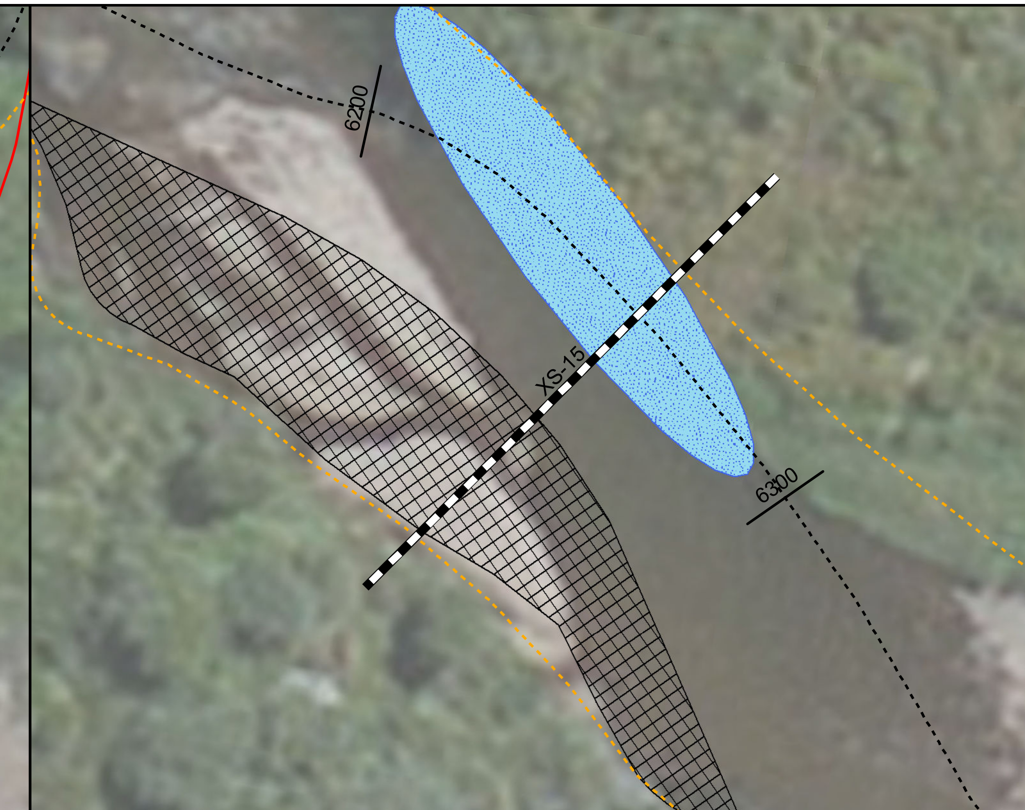
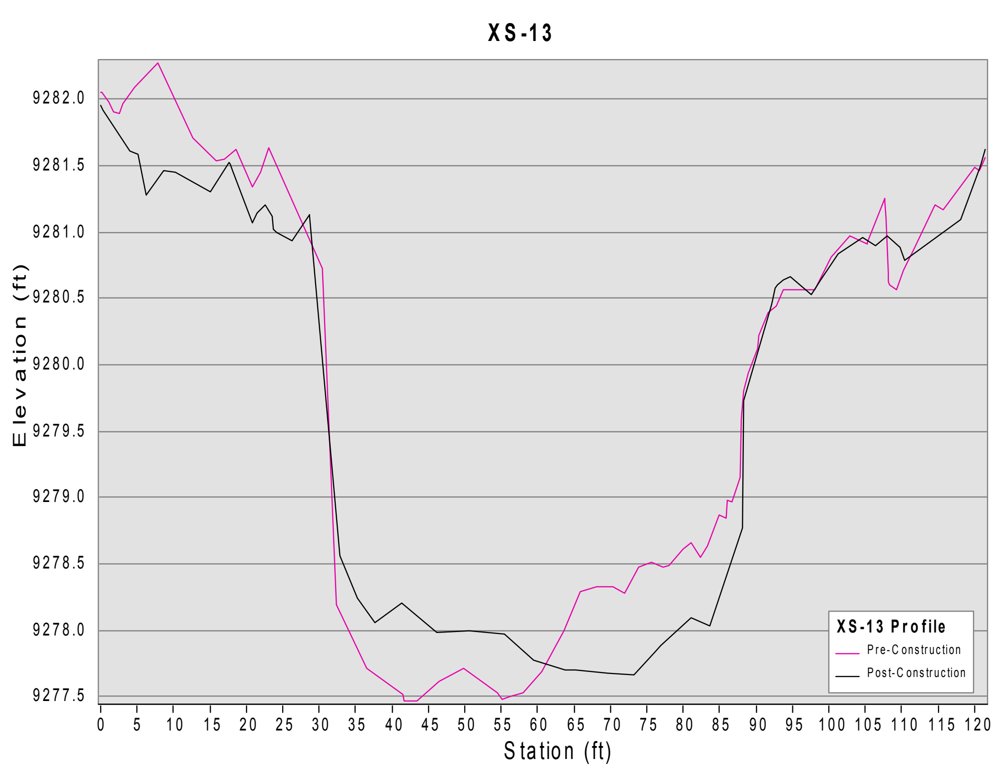
STATE OF COLORADO
DEPARTMENT OF NATURAL RESOURCES
COLORADO PARKS AND WILDLIFE
FORT COLLINS, COLORADO

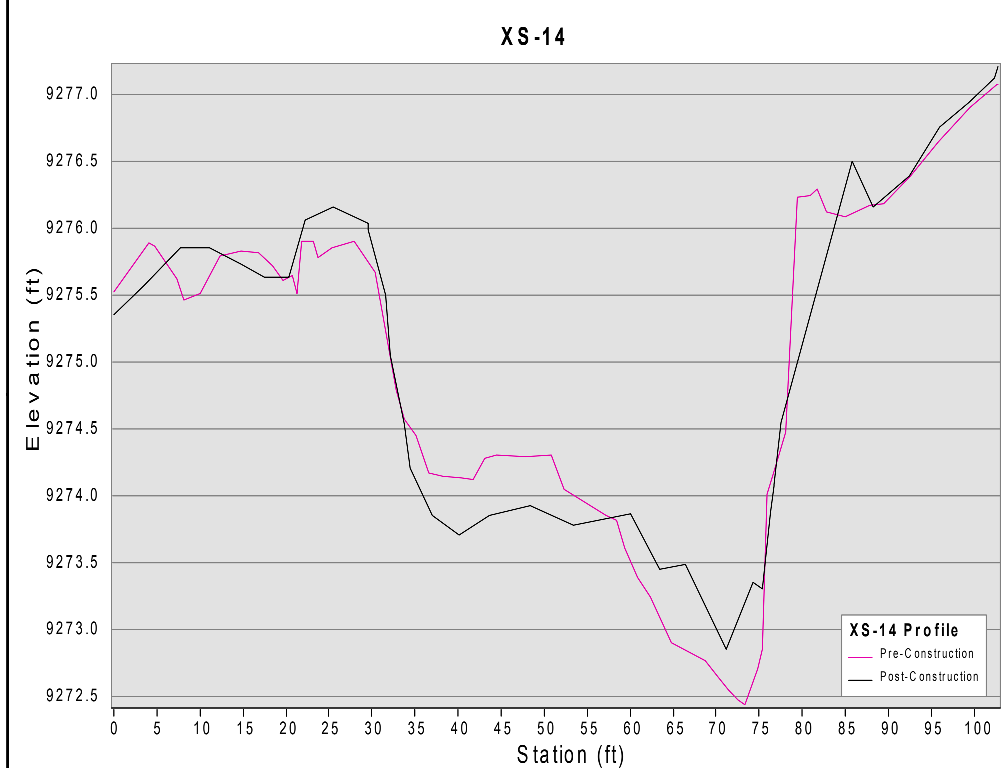
UPPER ARKANSAS RIVER AQUATIC HABITAT PROJECT HAYDEN REACH

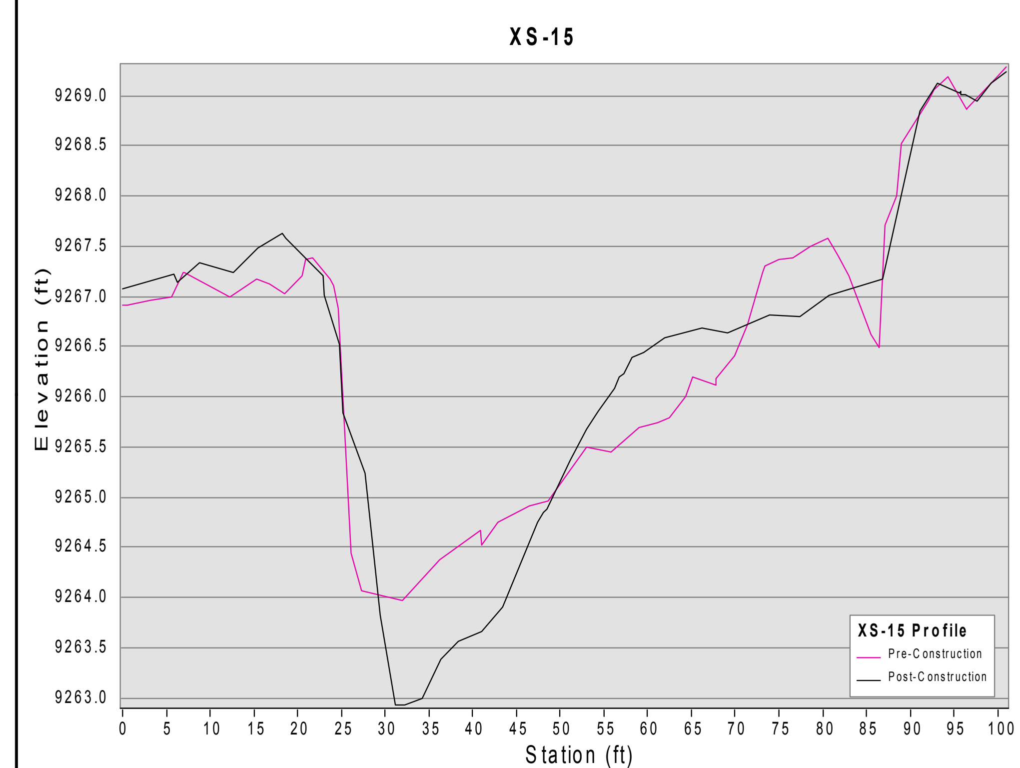












Cross Section
Thalweg
River Alignment
Fish Monitoring Sites
Boulder Cluster
Boulder Structure
Willow Planting
Willow Transplants
Sod Mat / Riparian Bench
Develop Pool
Develop Point Bar
Fill
Riparian Seeding
Develop Lateral Bar
Cobble Toe
Log Vane
Wood Toe
Erosion Control

CROSS SECTIONS 13-15

DRAWN: BSTAMPER	7/6/2016
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APPROVED: TKITTELL	7/15/2016

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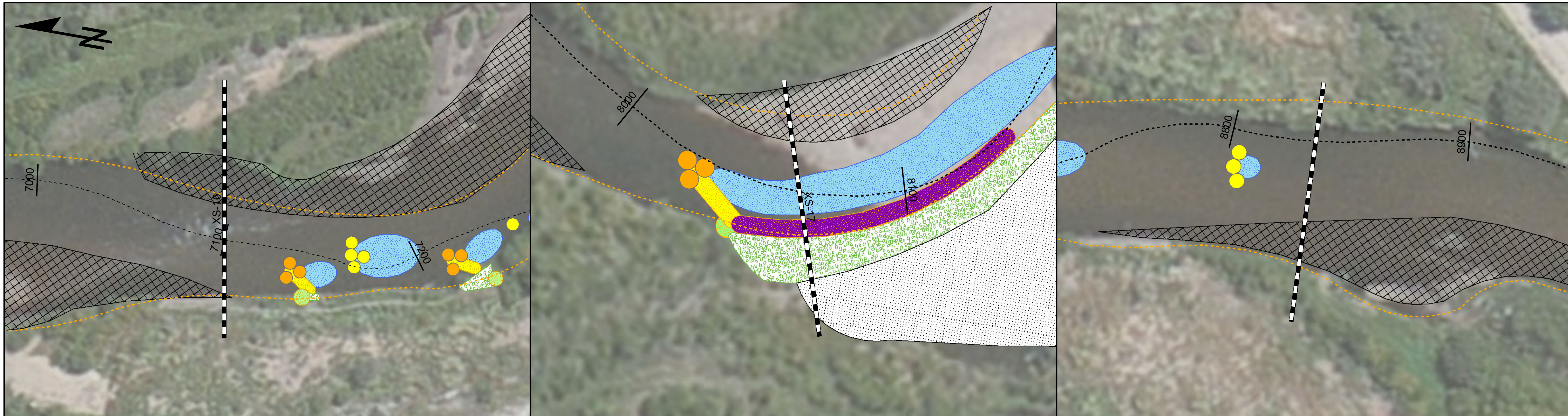
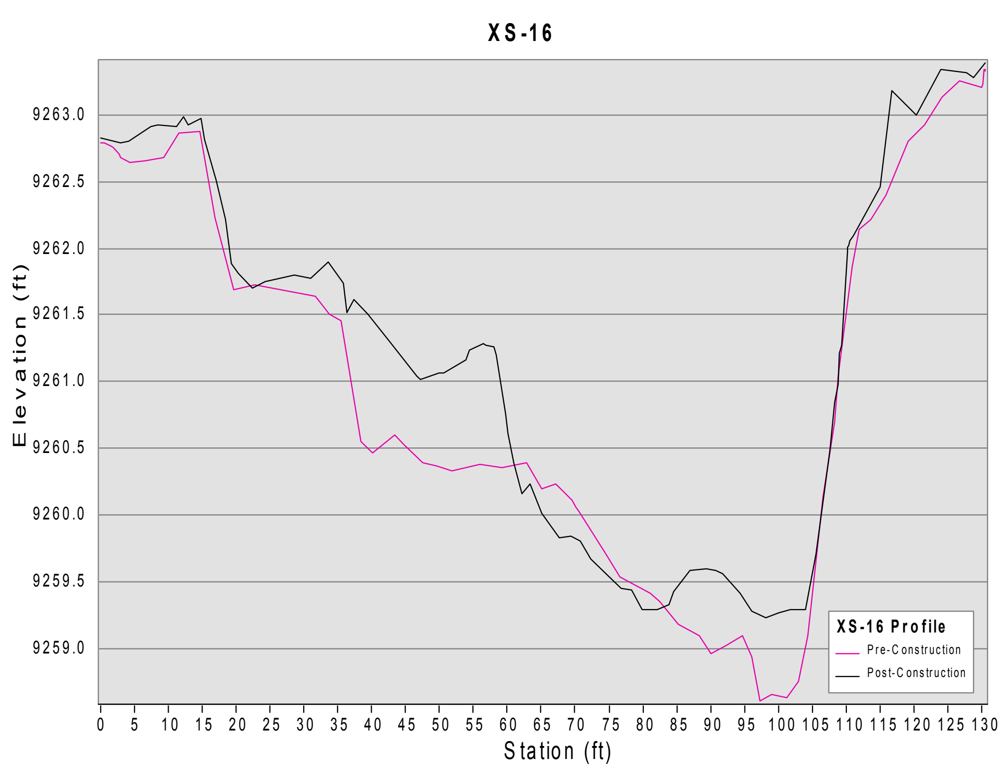
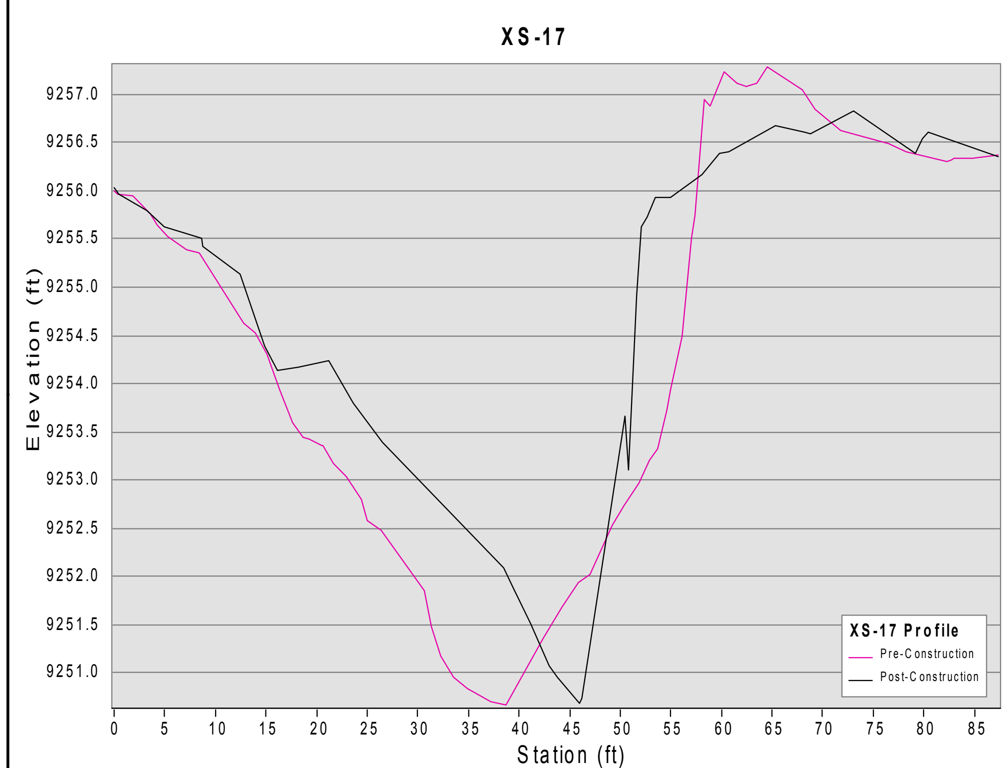
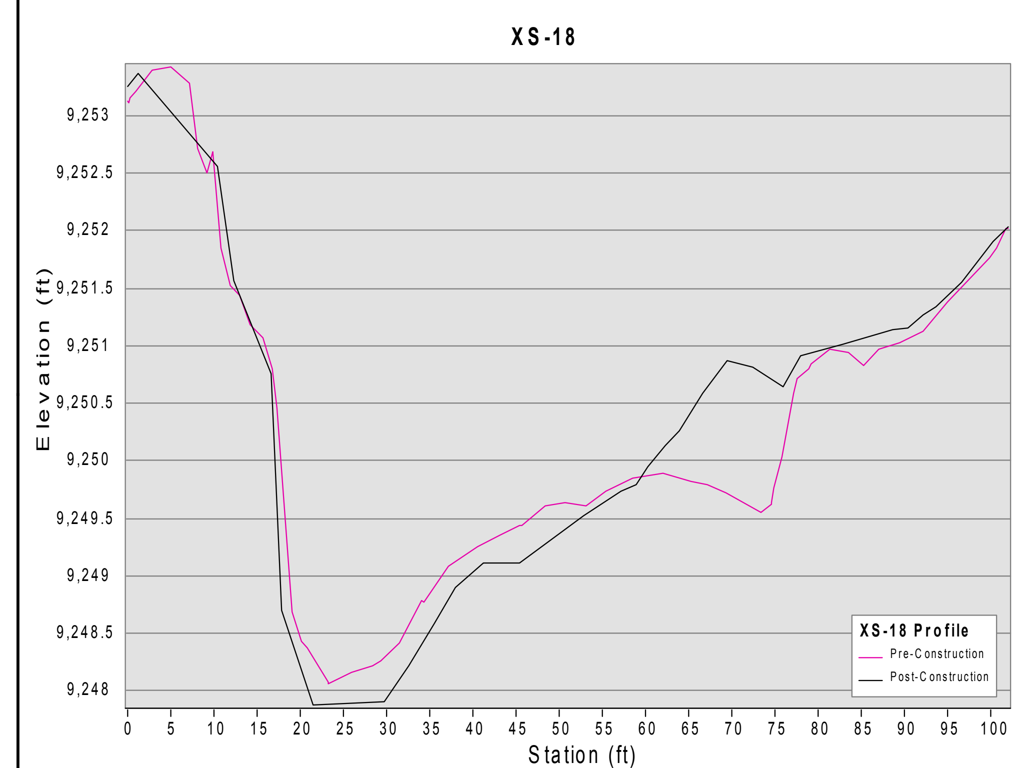
STATE OF COLORADO
DEPARTMENT OF NATURAL RESOURCES
COLORADO PARKS AND WILDLIFE
FORT COLLINS, COLORADO

UPPER ARKANSAS RIVER
AQUATIC HABITAT PROJECT
HAYDEN REACH









Cross Section
Thalweg
River Alignment
Fish Monitoring Sites
Boulder Cluster
Boulder Structure
Willow Planting
Willow Transplants
Sod Mat / Riparian Bench
Develop Pool
Develop Point Bar
Fill
Riparian Seeding
Develop Lateral Bar
Cobble Toe
Log Vane
Wood Toe
Erosion Control

CROSS SECTIONS 16-18	
DRAWN: BSTAMPER	7/6/2016
CHECKED: ERICHER	7/13/2016
APPROVED: TKITTELL	7/15/2016
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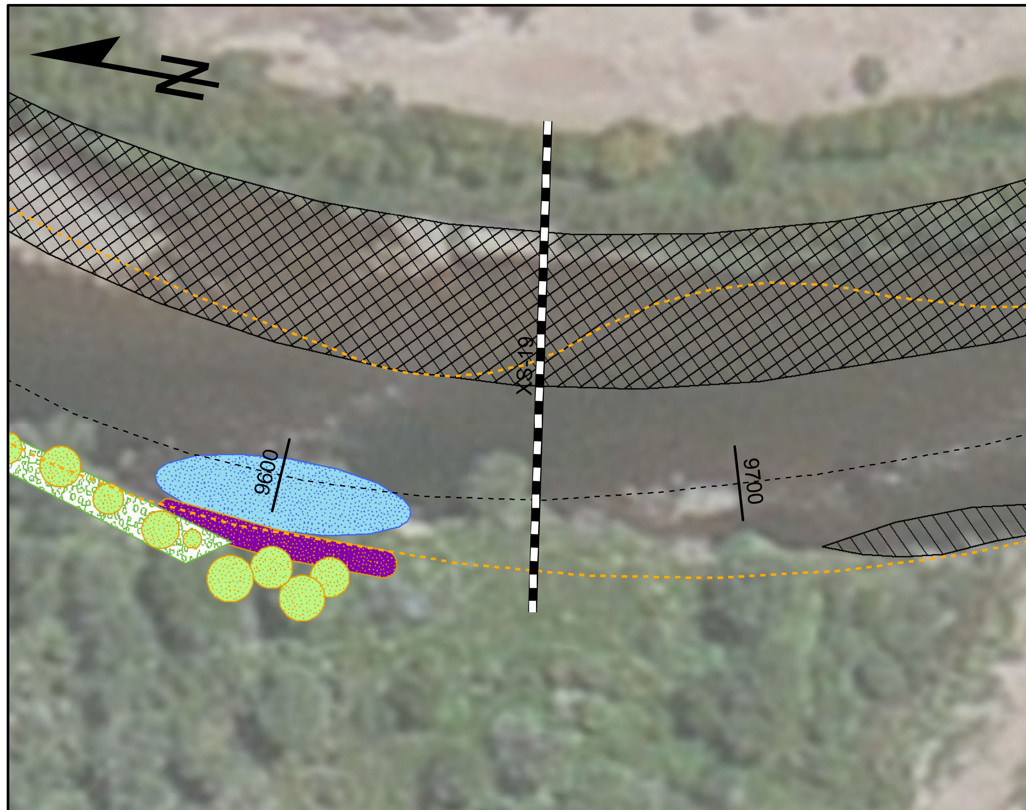
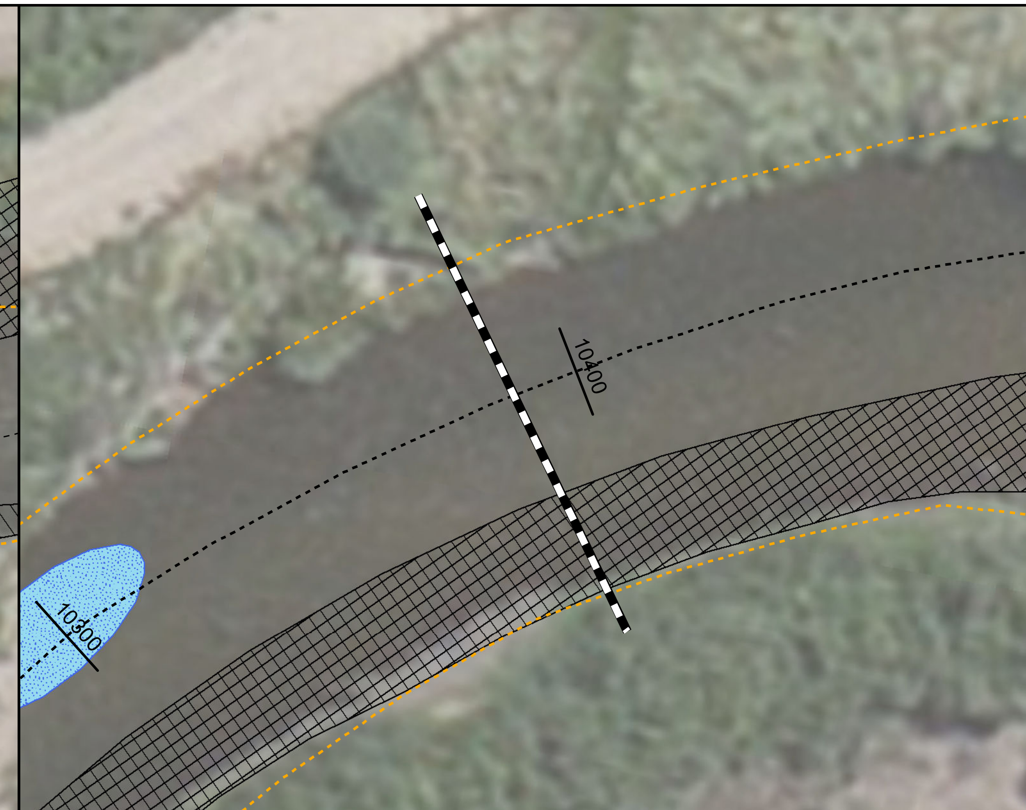
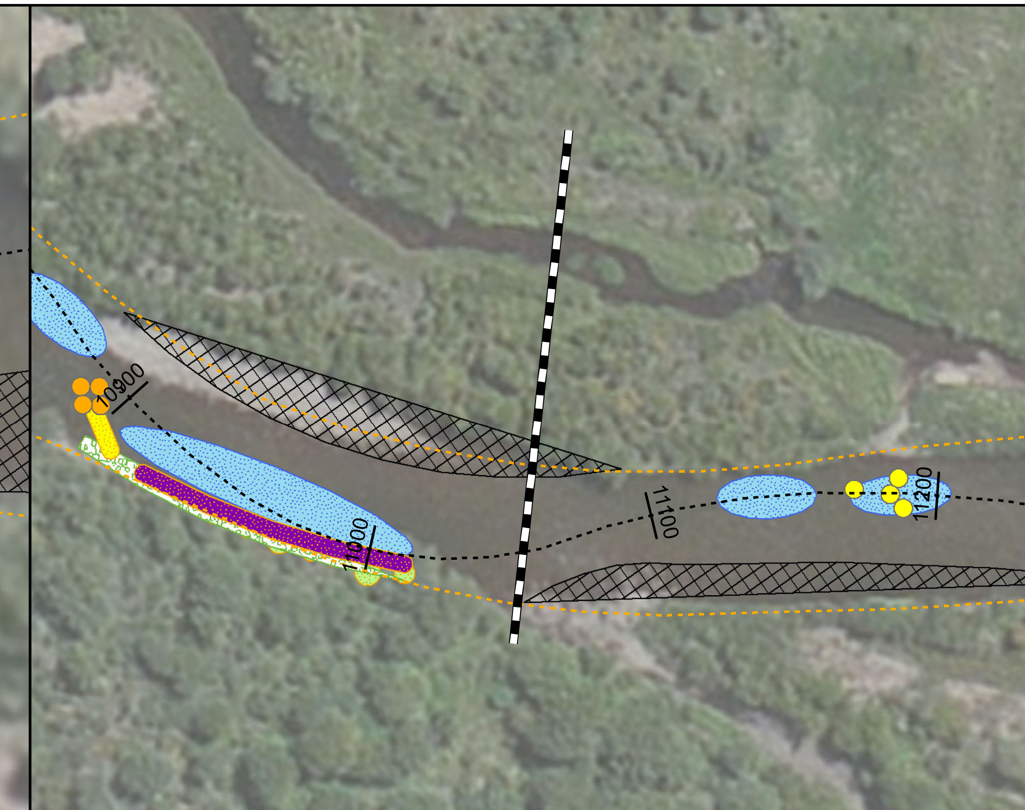
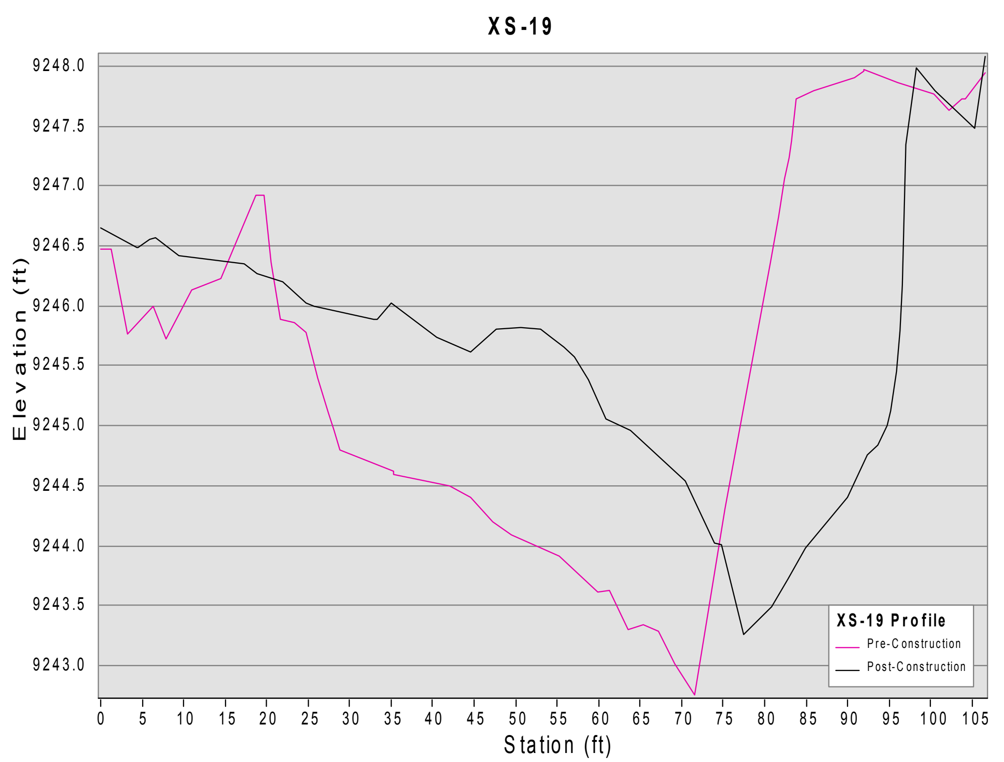
STATE OF COLORADO
DEPARTMENT OF NATURAL RESOURCES
COLORADO PARKS AND WILDLIFE
FORT COLLINS, COLORADO

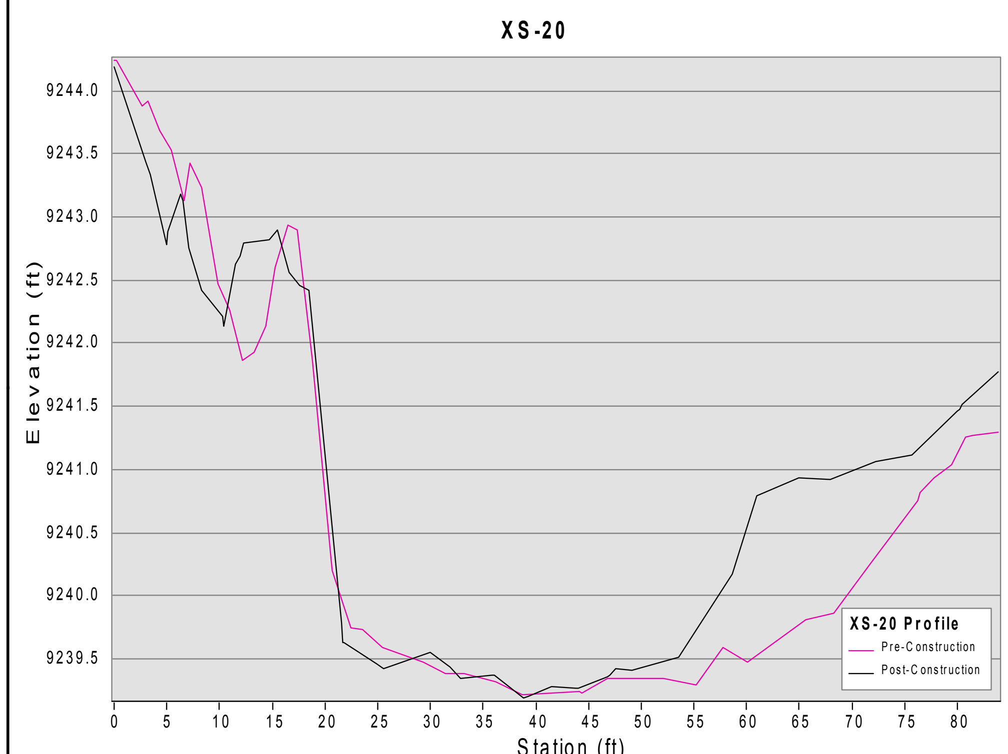
UPPER ARKANSAS RIVER
AQUATIC HABITAT PROJECT
HAYDEN REACH

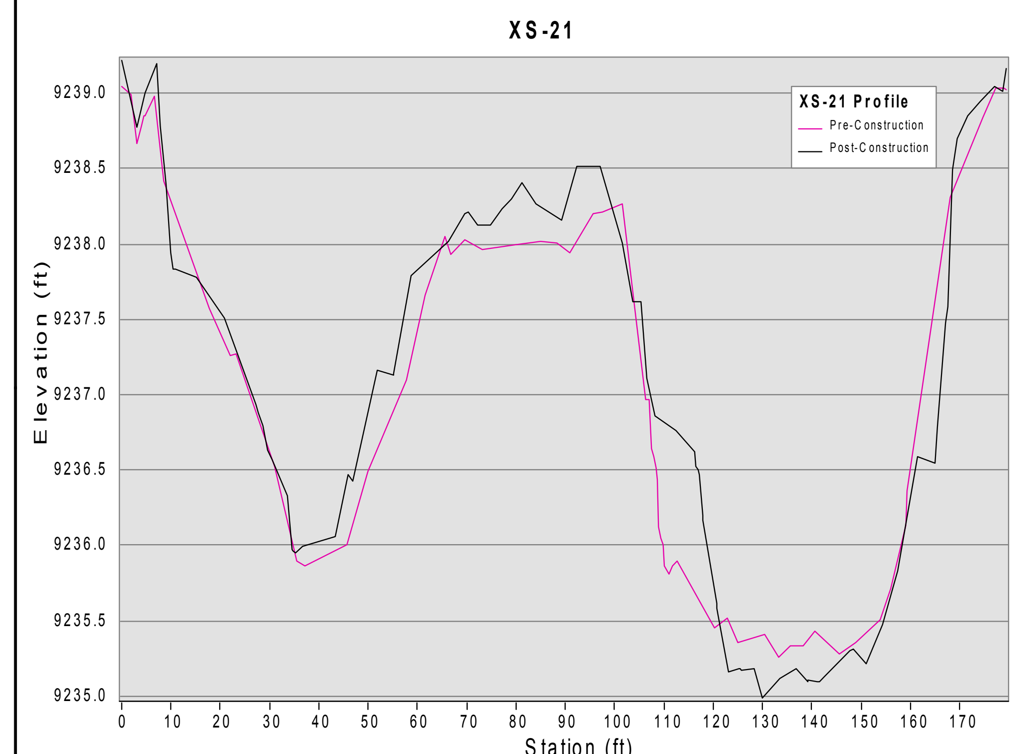












Cross Section
Thalweg
River Alignment
Fish Monitoring Sites
Boulder Cluster
Boulder Structure
Willow Planting
Willow Transplants
Sod Mat / Riparian Bench
Develop Pool
Develop Point Bar
Fill
Riparian Seeding
Develop Lateral Bar
Cobble Toe
Log Vane
Wood Toe
Erosion Control

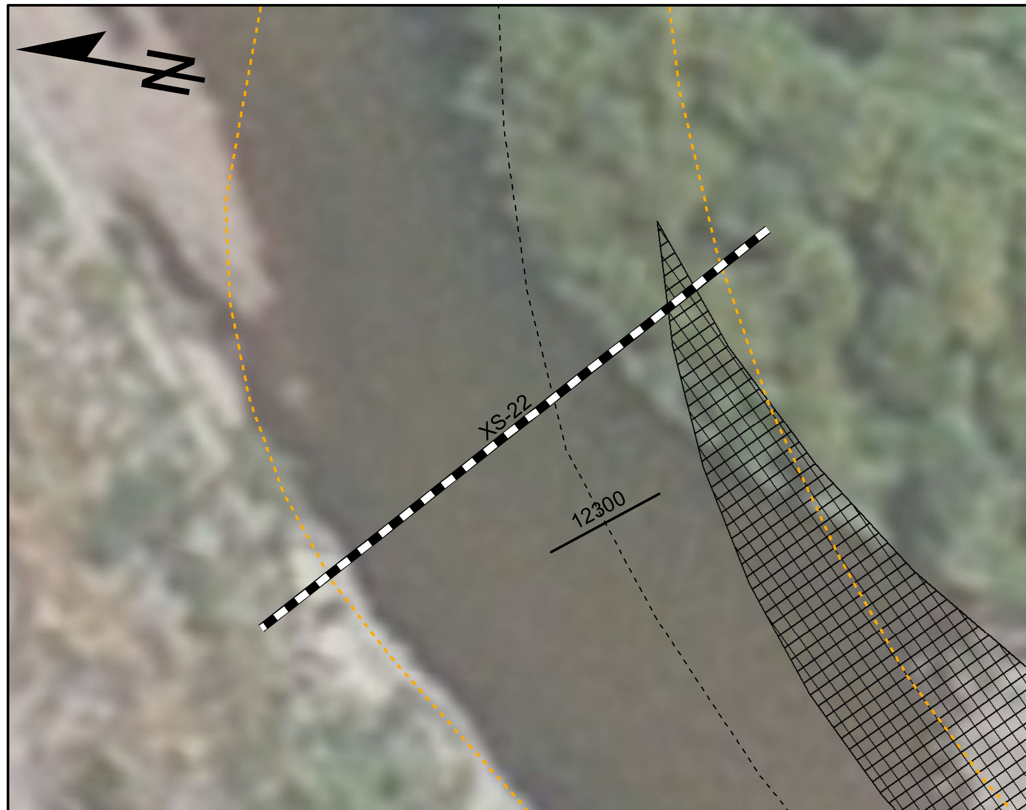
CROSS SECTIONS 19-21

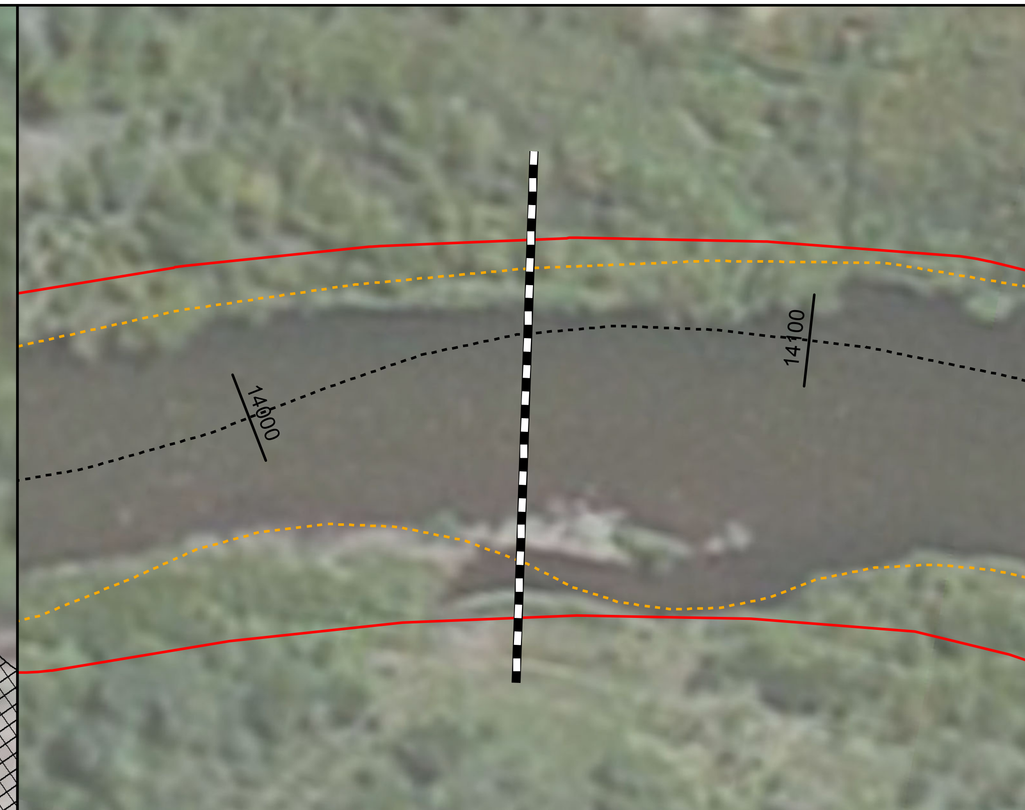
DRAWN: BSTAMPER	7/6/2016
CHECKED: ERICHER	7/13/2016
APPROVED: ERICHER	7/15/2016

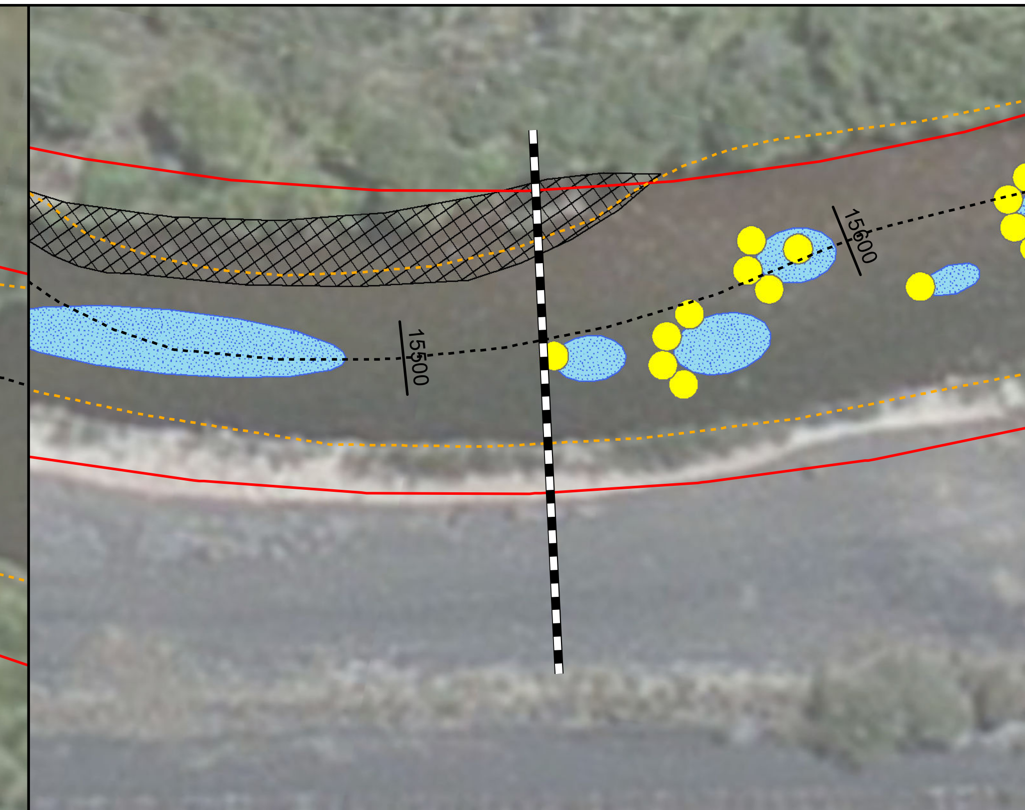
SHEET: 18 OF 20

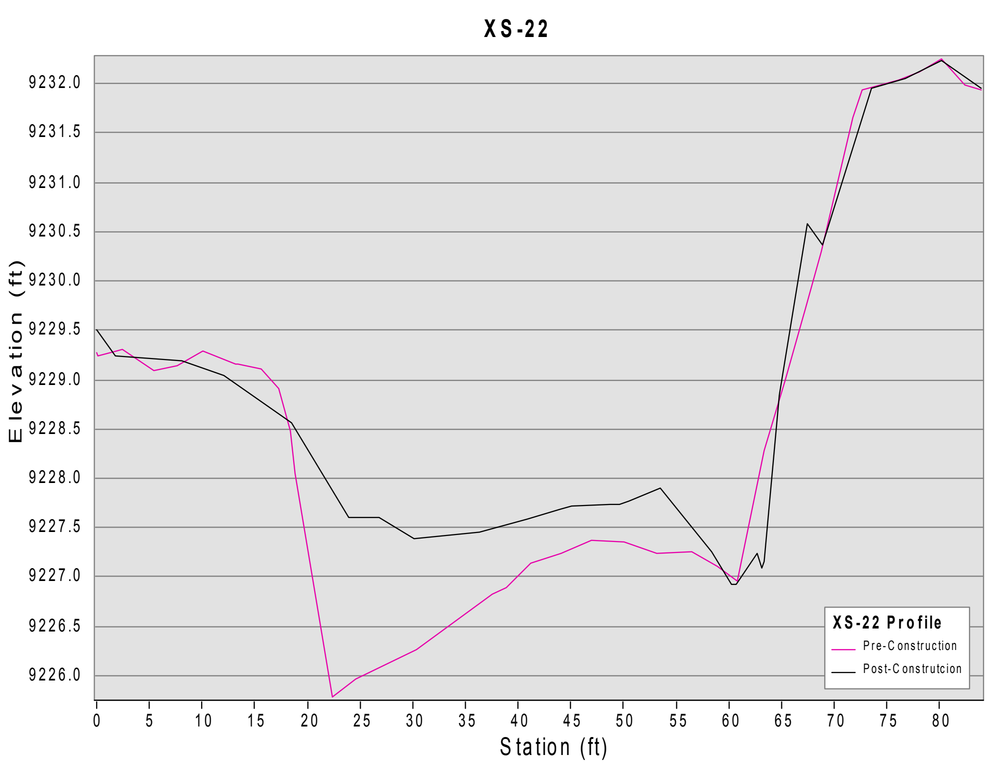
STATE OF COLORADO
DEPARTMENT OF NATURAL RESOURCES
COLORADO PARKS AND WILDLIFE
FORT COLLINS, COLORADO

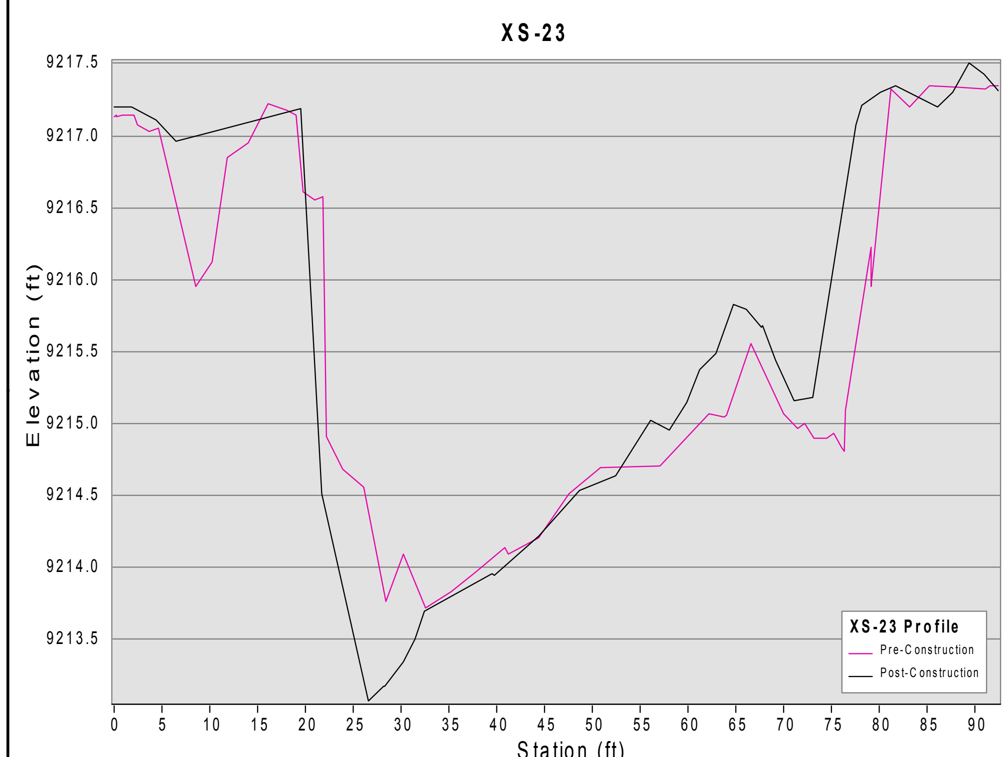
UPPER ARKANSAS RIVER
AQUATIC HABITAT PROJECT
HAYDEN REACH

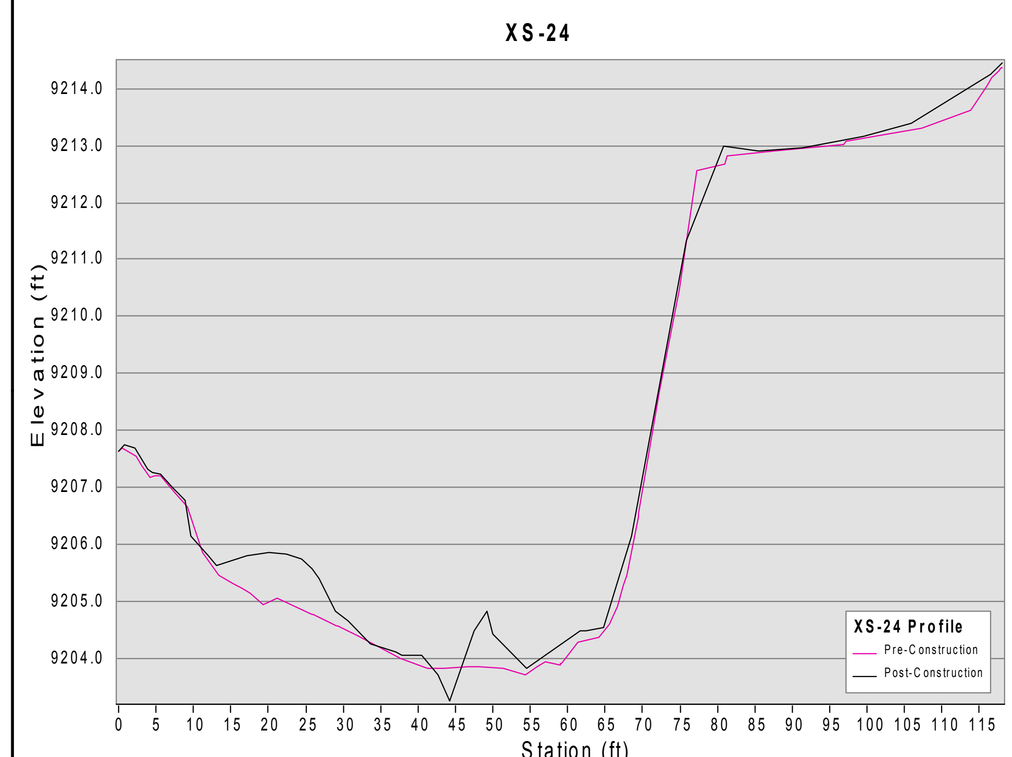












- Cross Section
- Thalweg
- River Alignment
- Fish Monitoring Sites
- Boulder Cluster
- Boulder Structure
- Willow Planting
- Willow Transplants
- Sod Mat / Riparian Bench
- Develop Pool
- Develop Point Bar
- Fill
- Riparian Seeding
- Develop Lateral Bar
- Cobble Toe
- Log Vane
- Wood Toe
- Erosion Control

CROSS SECTIONS 22-24

DRAWN: BSTAMPER	7/6/2016
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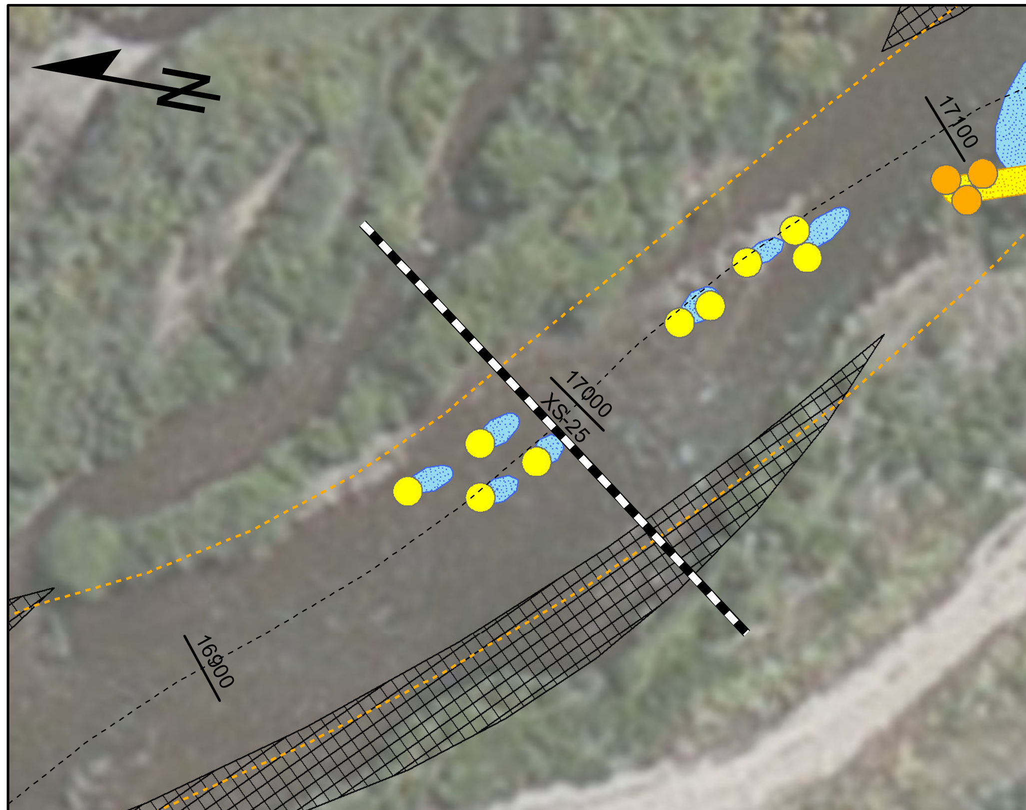
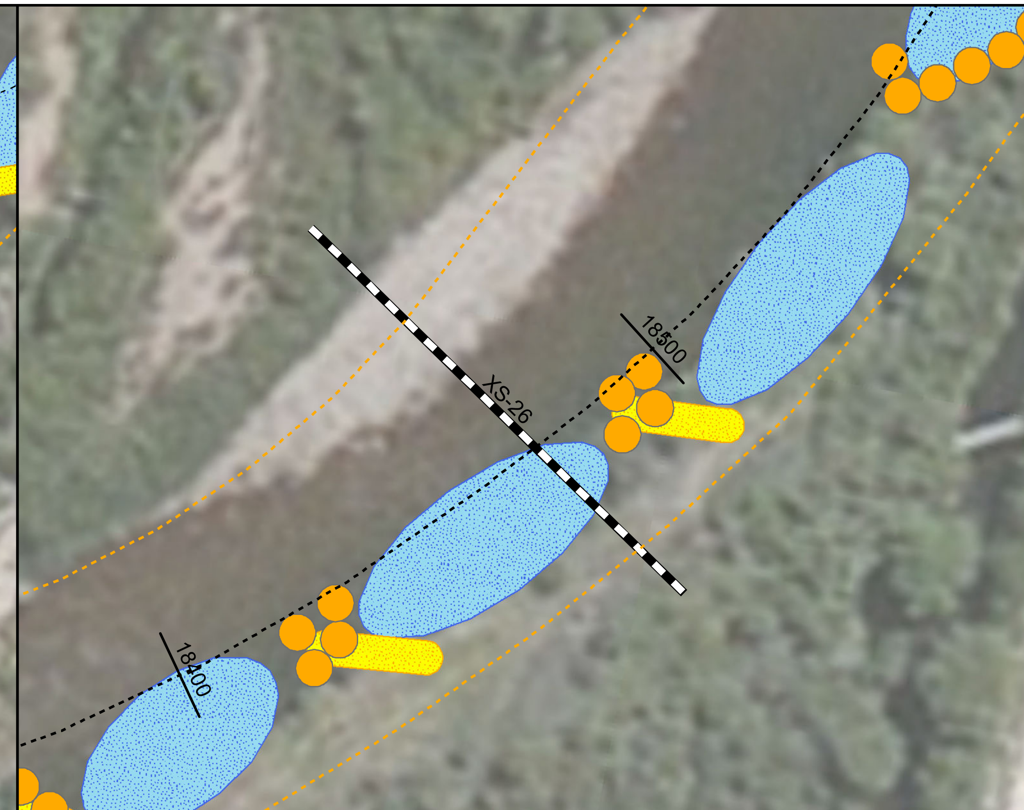
APPROVED: TKITTELL	7/15/2016

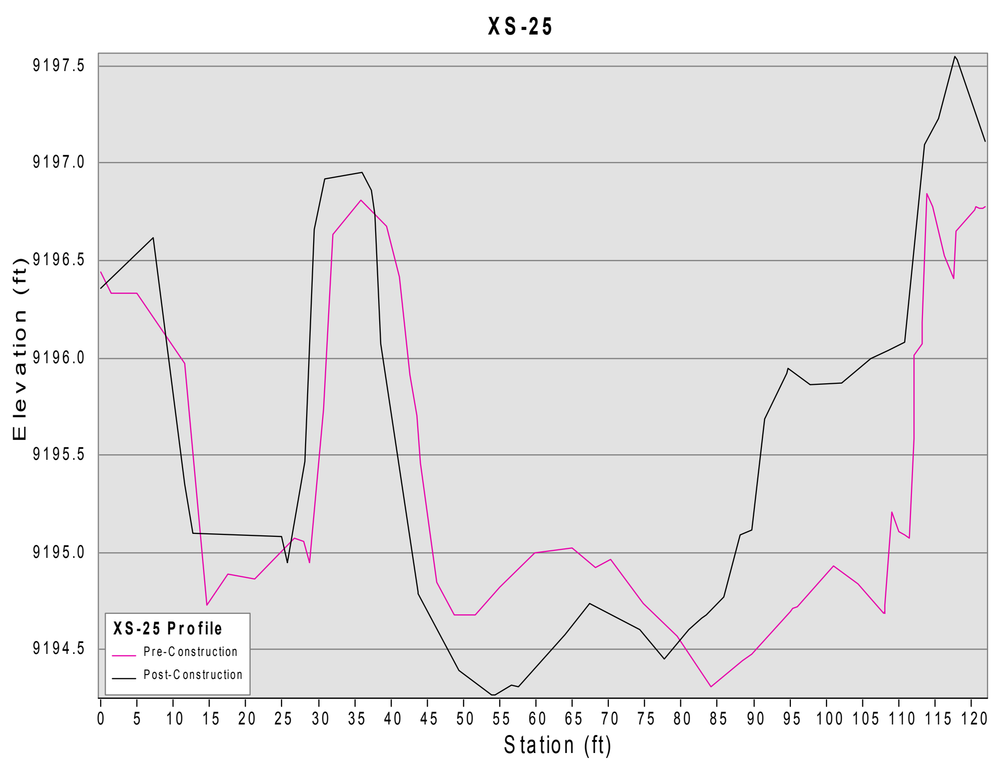
SHEET: 19 OF 20

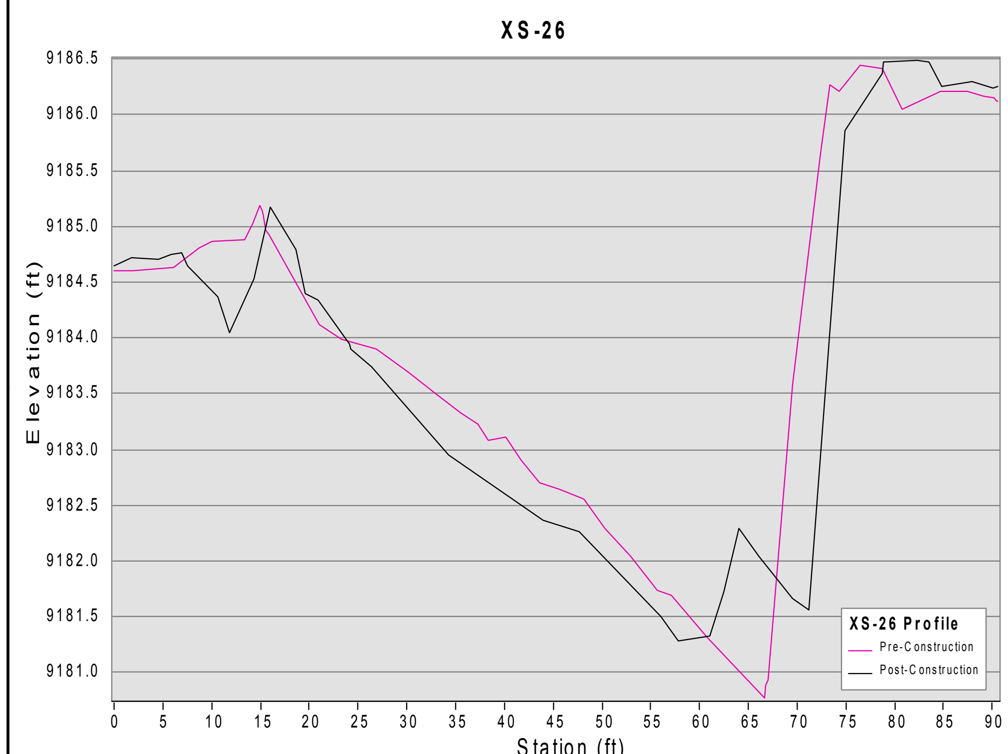
STATE OF COLORADO
DEPARTMENT OF NATURAL RESOURCES
COLORADO PARKS AND WILDLIFE
FORT COLLINS, COLORADO

UPPER ARKANSAS RIVER
AQUATIC HABITAT PROJECT
HAYDEN REACH









Cross Section	Boulder Structure	Develop Point Bar	Log Vane
Thalweg	Willow Planting	Fill	Wood Toe
River Alignment	Willow Transplants	Riparian Seeding	Erosion Control
Fish Monitoring Sites	Sod Mat / Riparian Bench	Develop Lateral Bar	
Boulder Cluster	Develop Pool	Cobble Toe	

CROSS SECTIONS 25-26

DRAWN: BSTAMPER	7/6/2016
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APPROVED: TKITTELL	7/15/2016

SHEET: 20 OF 20

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

UPPER ARKANSAS RIVER
AQUATIC HABITAT PROJECT
HAYDEN REACH

Appendix B: Water Quality Figures

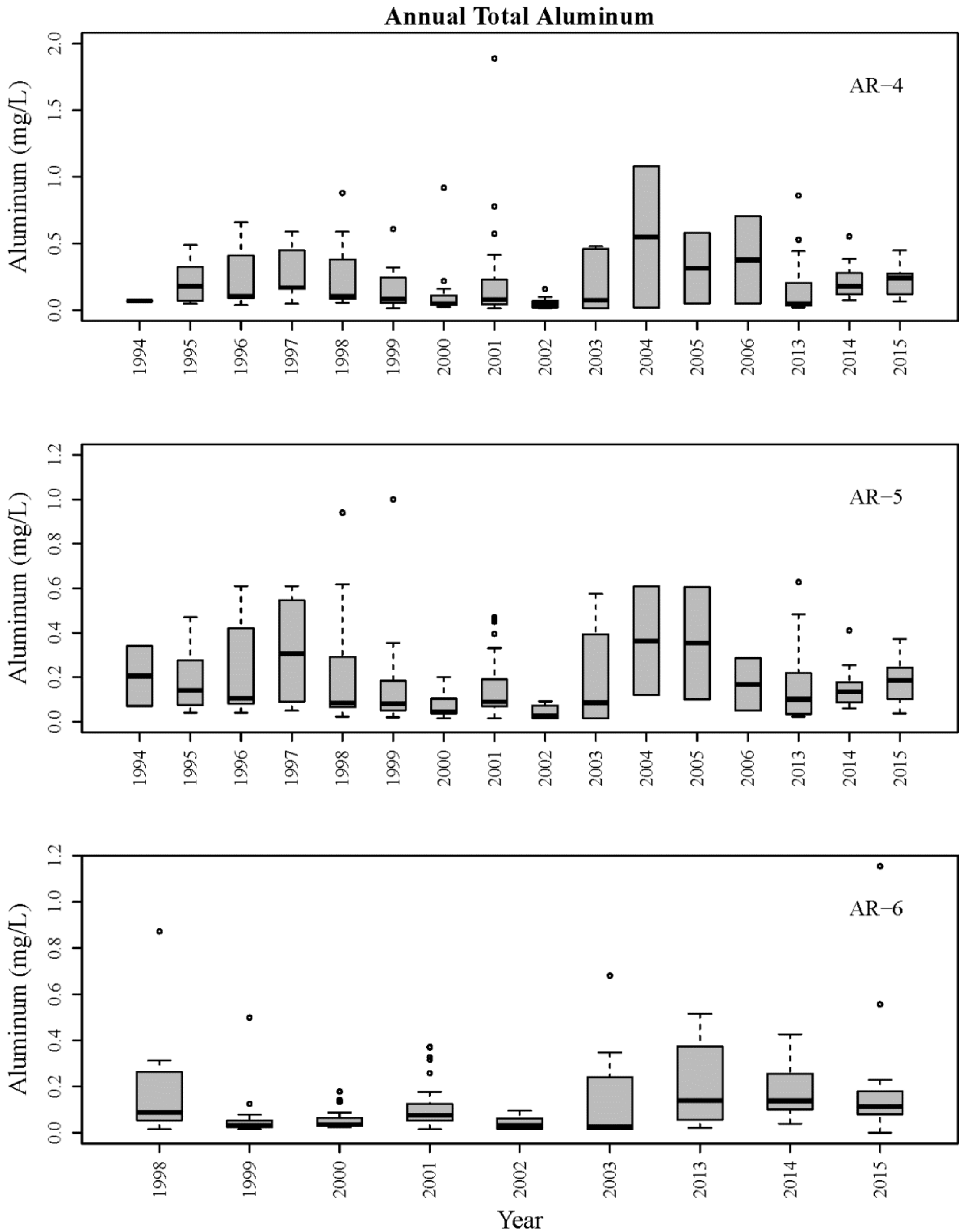


Figure B.1. Total aluminum concentrations summarized annually at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River. The y-axis was limited for clarity at AR-4, excluding one observation of 13.84 mg/L in 2003, and at AR-5 excluding two observations, 2.23 mg/L in 2000 and 2.631 mg/L in 2001.

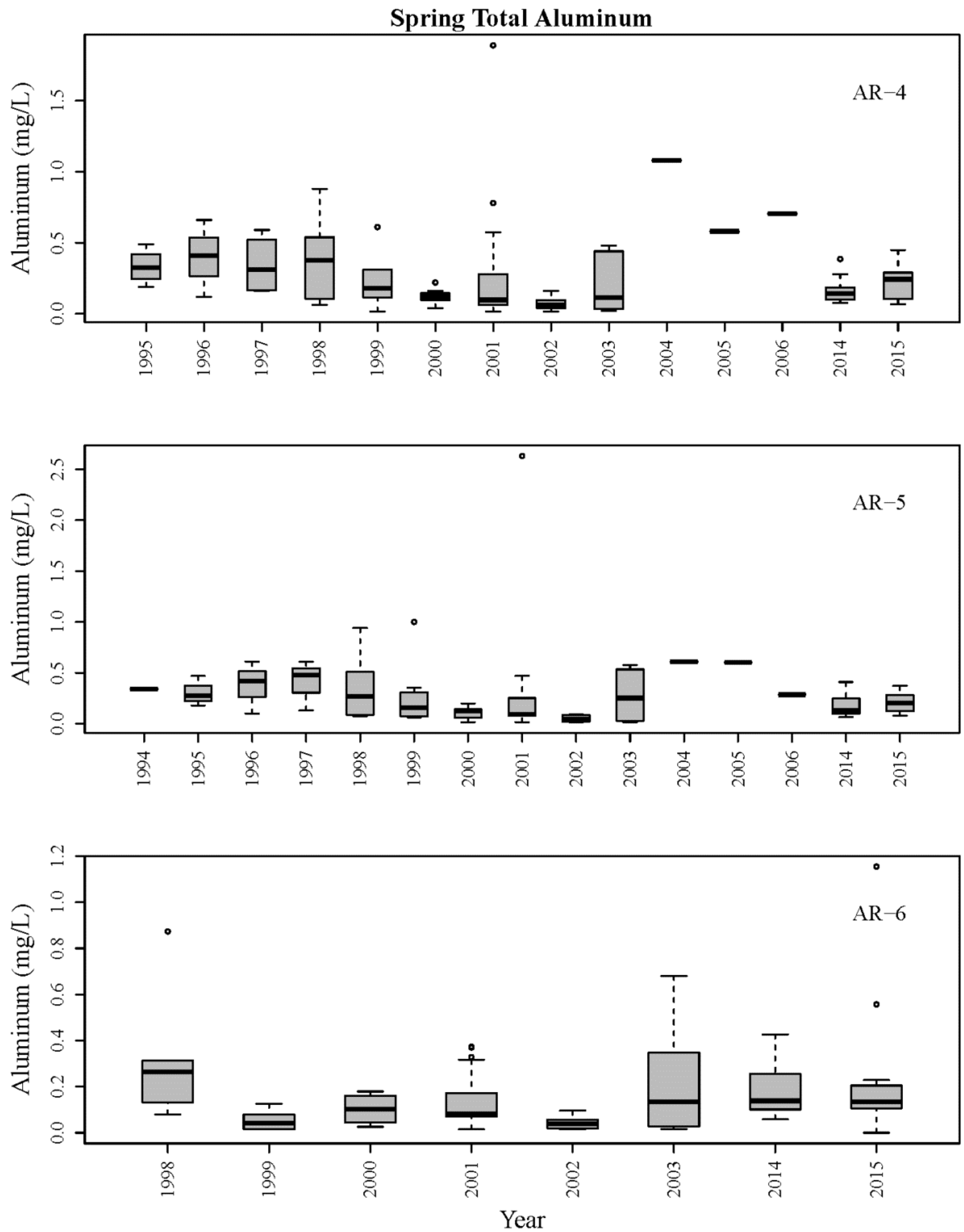


Figure B.2. Total aluminum concentrations summarized seasonally (April-July) at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River.

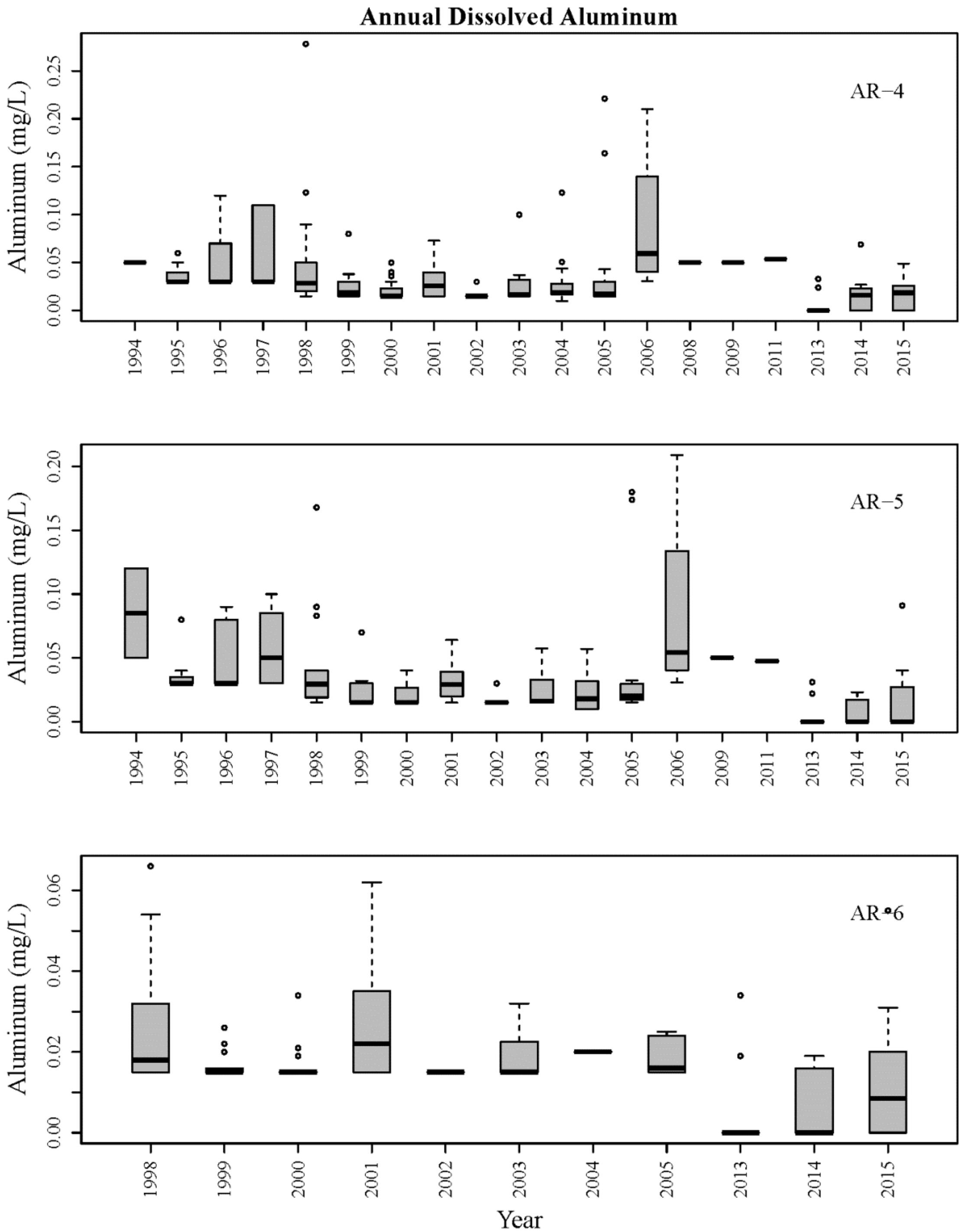


Figure B.3. Dissolved aluminum concentrations summarized annually at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River.

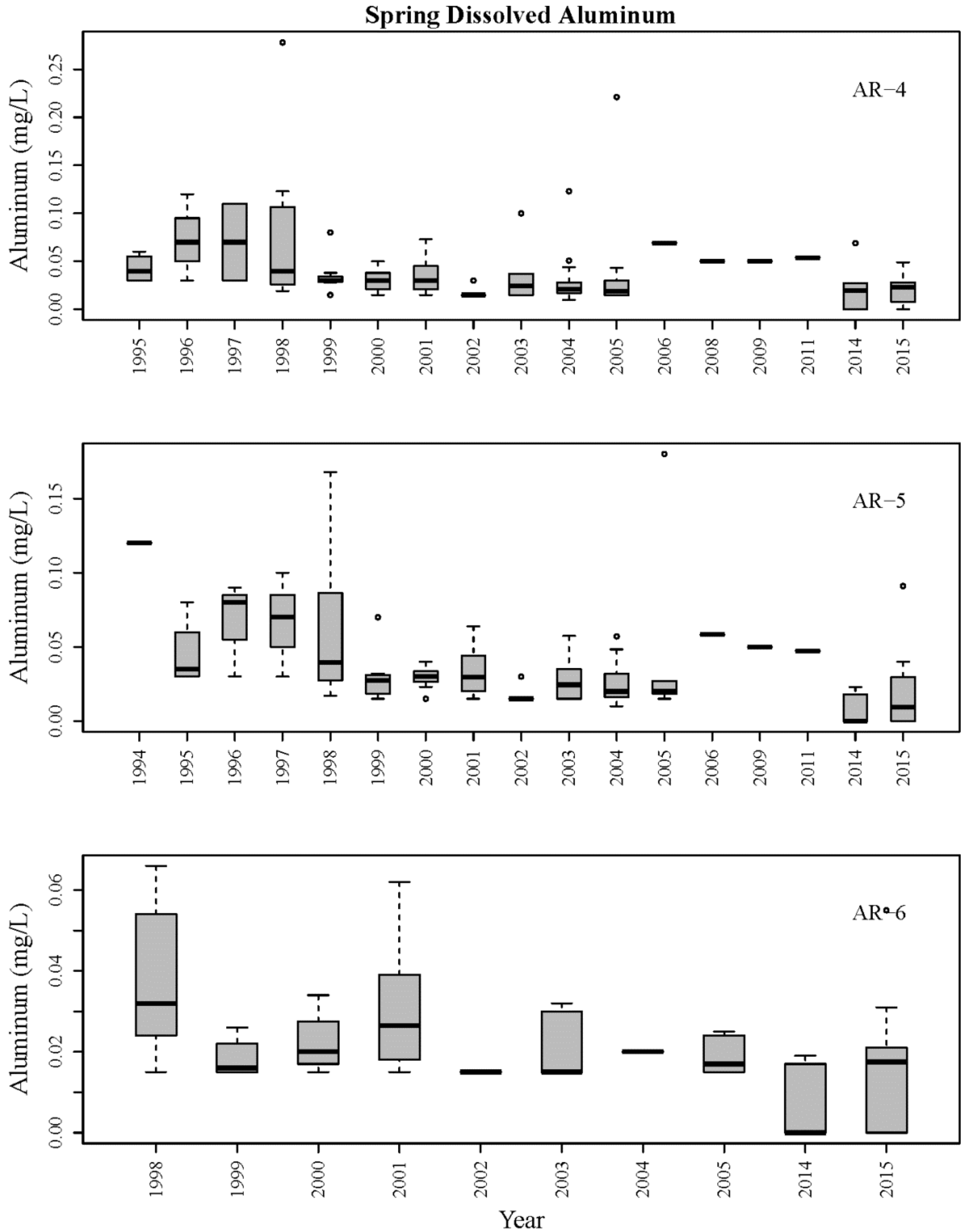


Figure B.4. Dissolved aluminum concentrations summarized seasonally (April-July) at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River.

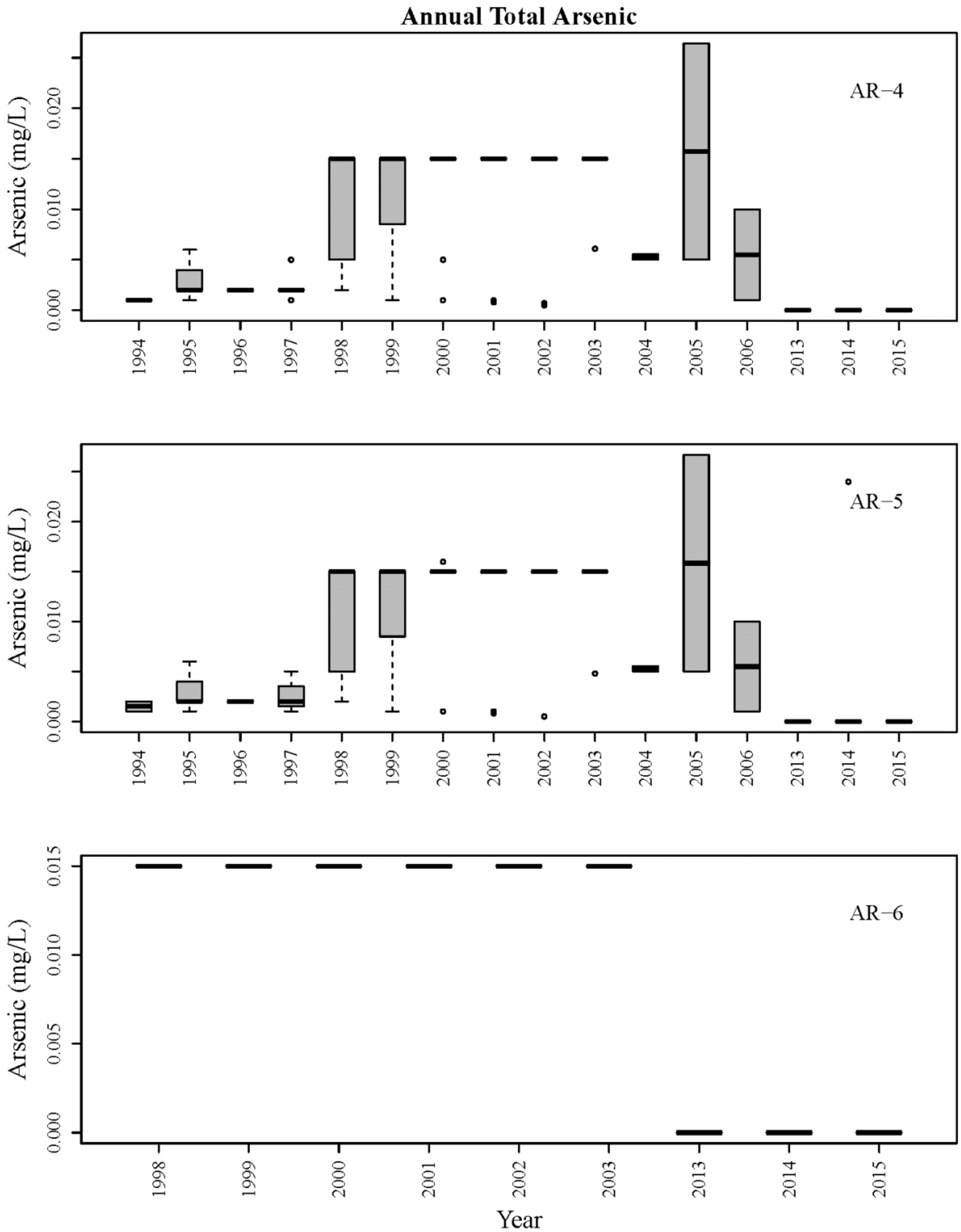


Figure B.5. Total arsenic concentrations summarized annually at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River. The method detection limit (MDL) is indicated by single, horizontal lines.

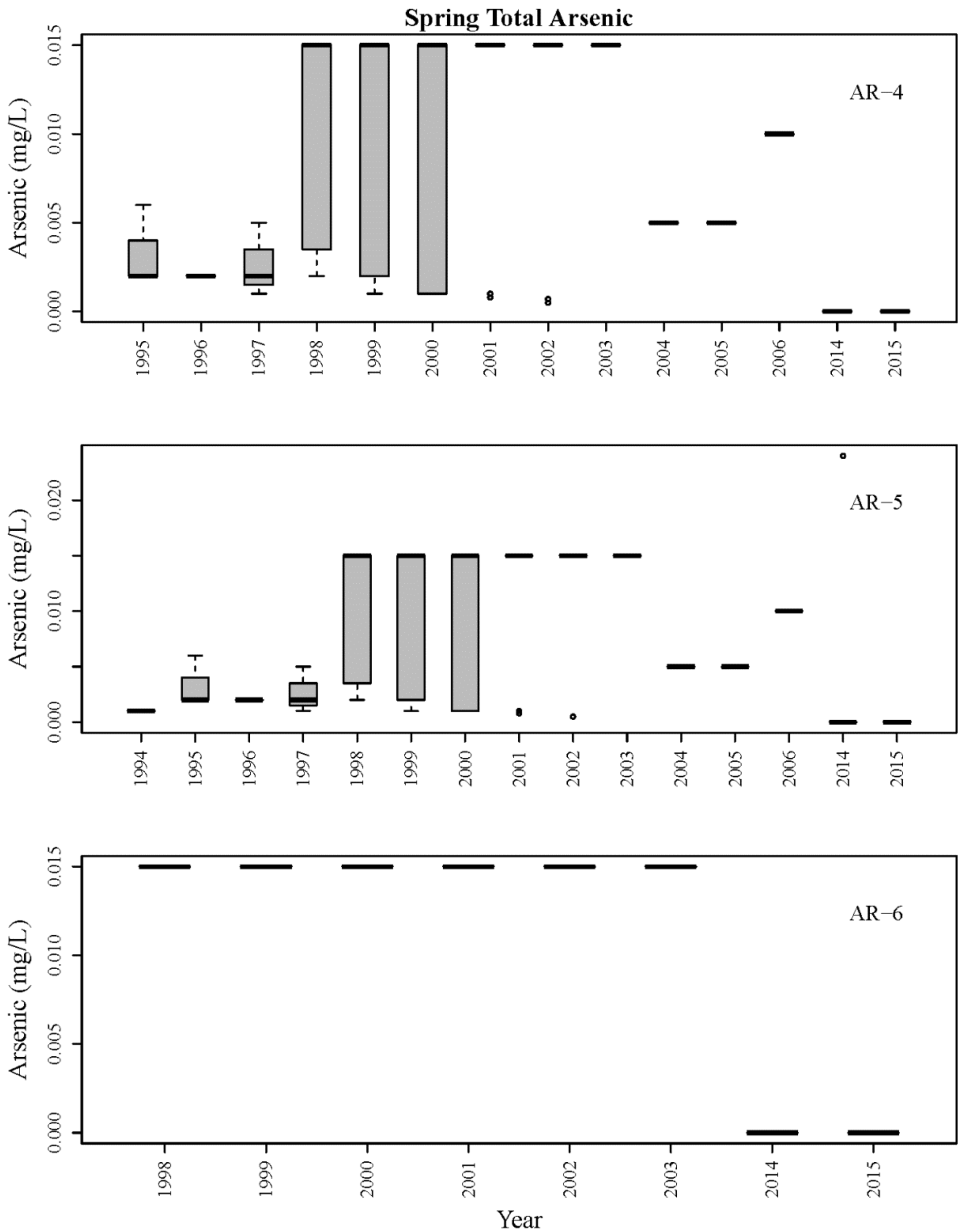


Figure B.6. Total arsenic concentrations summarized seasonally (April-July) at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River. The method detection limit (MDL) is indicated by single, horizontal lines.

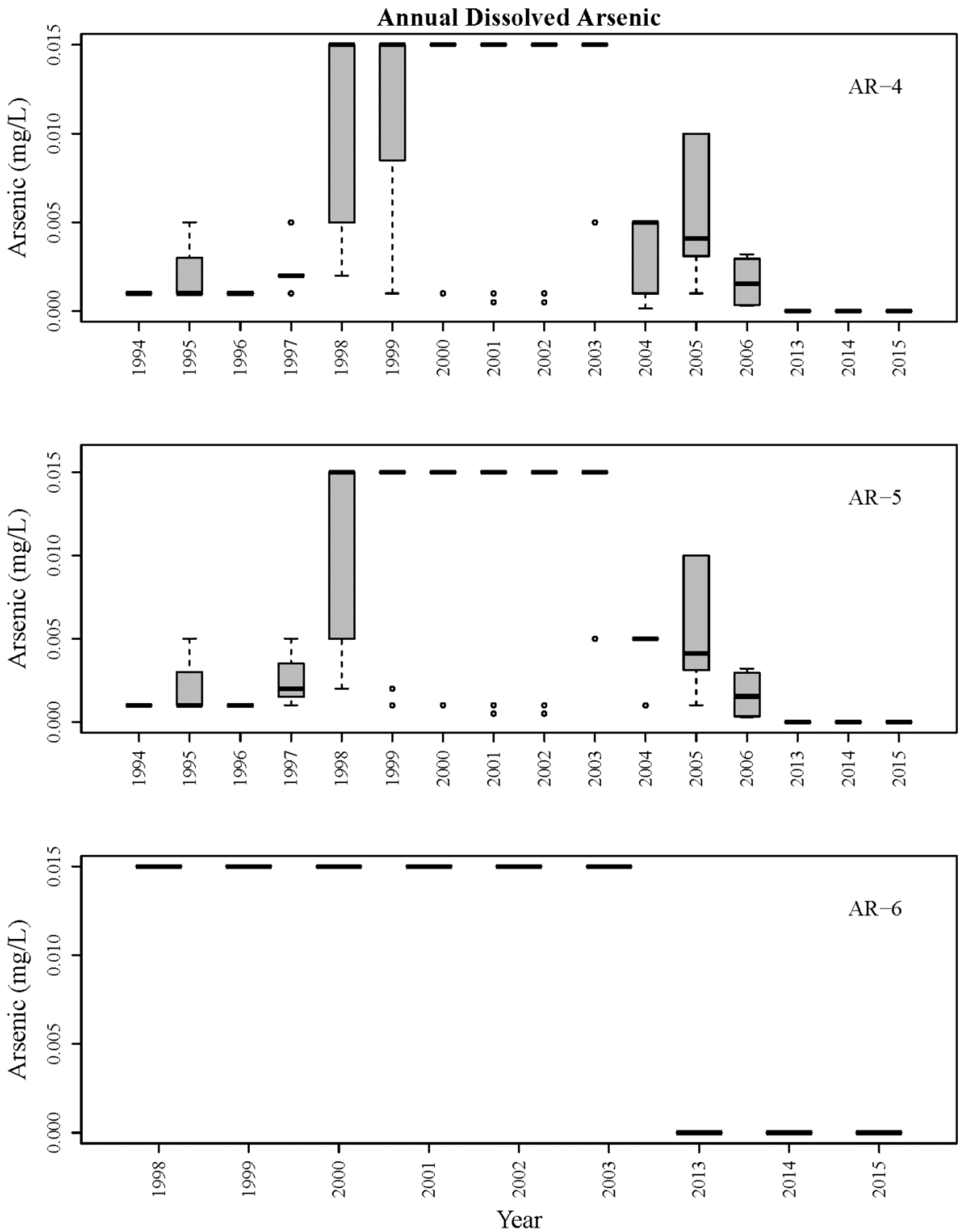


Figure B.7. Dissolved arsenic concentrations summarized annually at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River. The y-axis was limited to exclude one observation at AR-5 of 0.048 mg/L in 2004. The method detection limit (MDL) is indicated by single, horizontal lines.

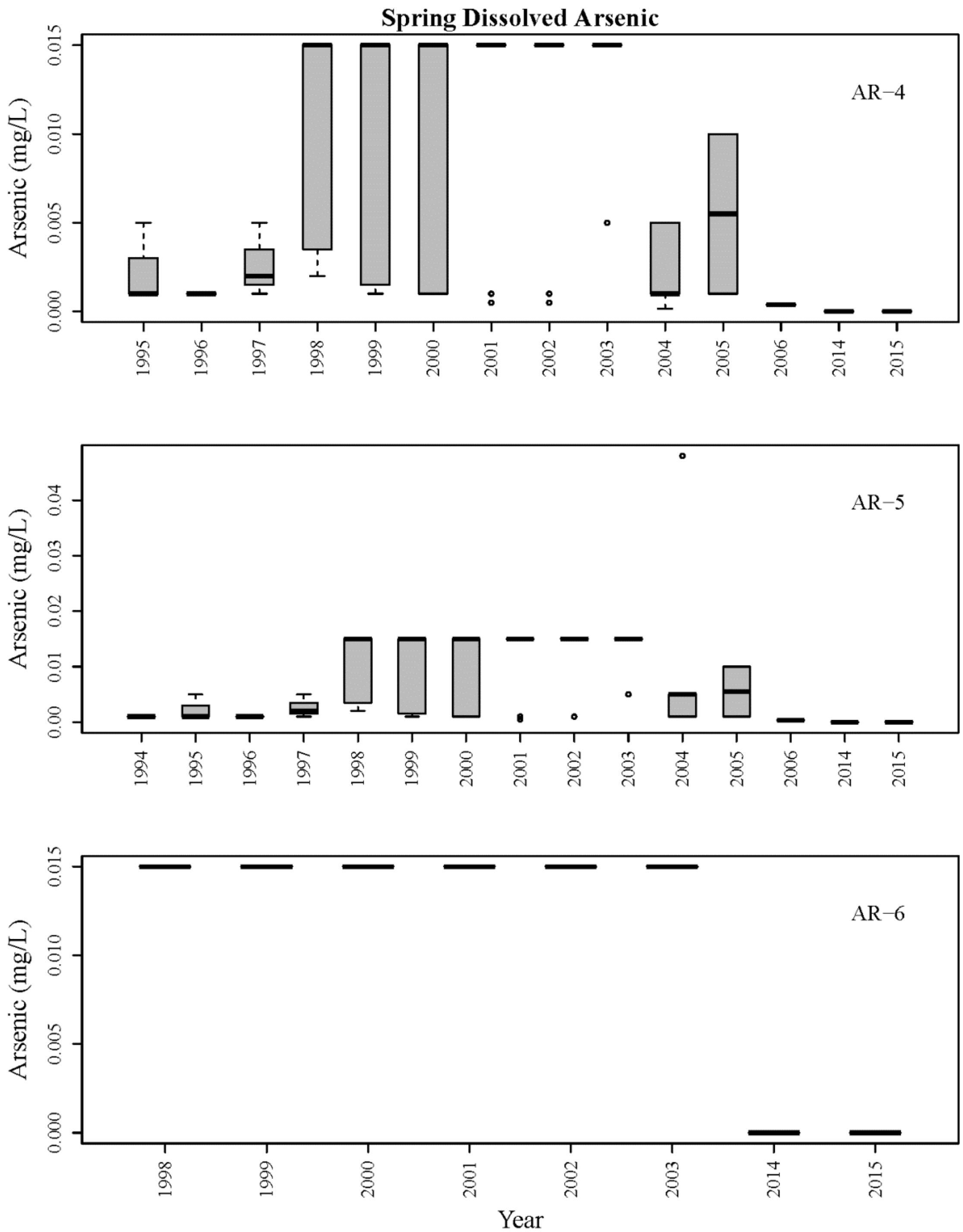


Figure B.8. Dissolved arsenic concentrations summarized seasonally (April-July) at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River. The method detection limit (MDL) is indicated by single, horizontal lines.

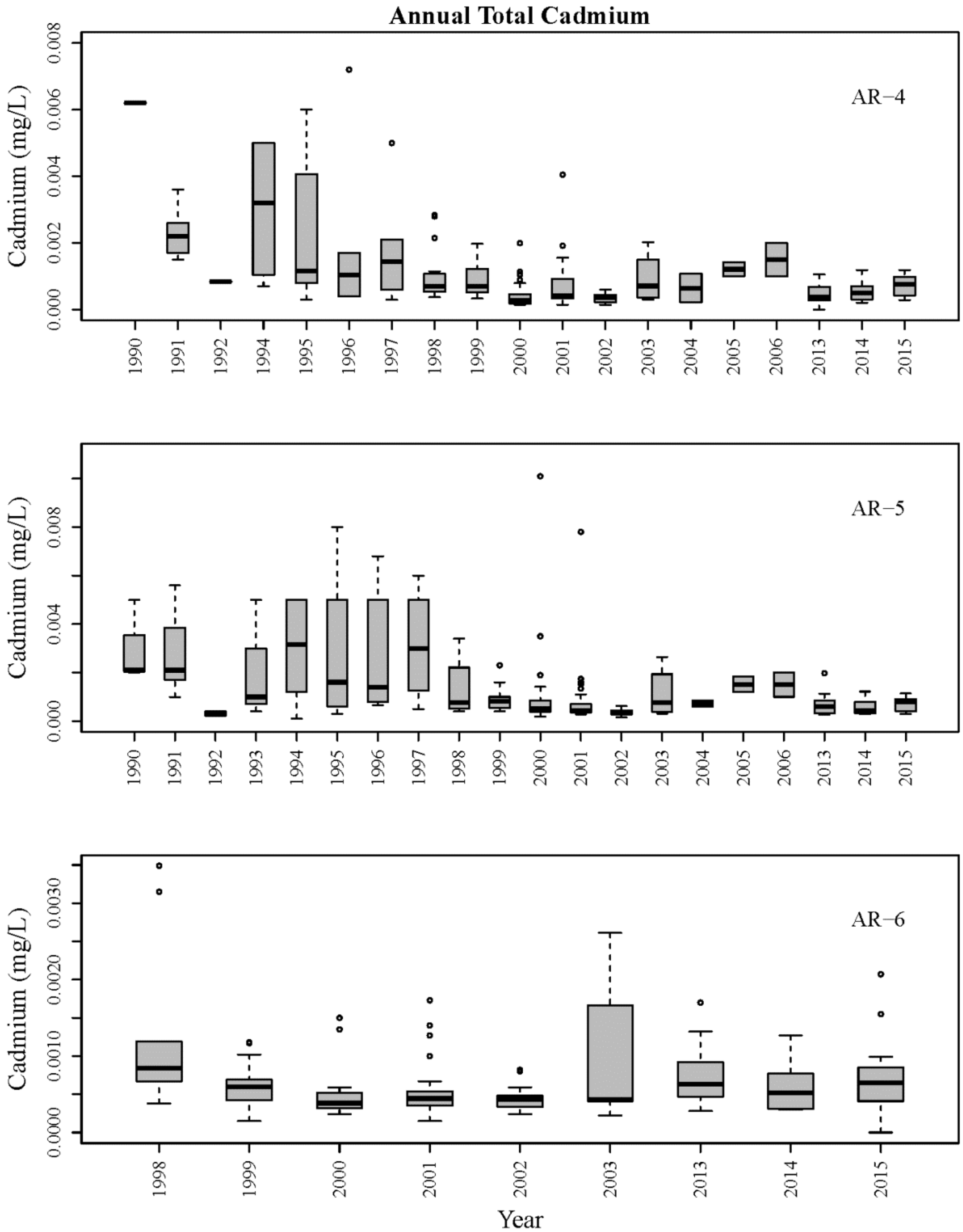


Figure B.9. Total cadmium concentrations summarized annually at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River. The y-axis was limited excluding one observation at AR-4 of 0.014 mg/L in 1995, and one observation at AR-5 of 0.038 mg/L in 1998.

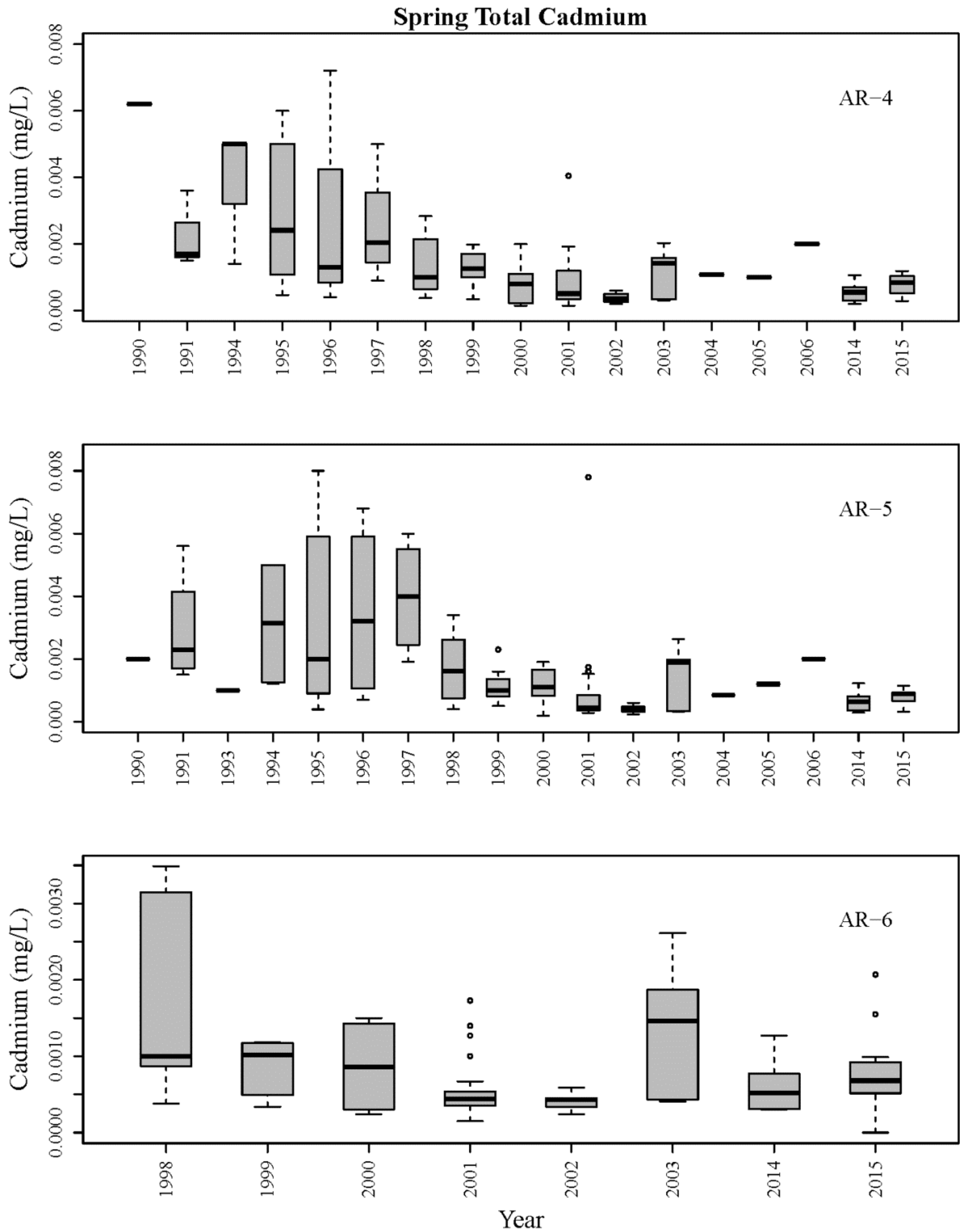


Figure B.10. Total cadmium concentrations summarized seasonally (April-July) at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River. The y-axis was limited to exclude one observation at AR-4 of 0.014 mg/L in 1995, and one observation at AR-5 of 0.038 mg/L in 1998.

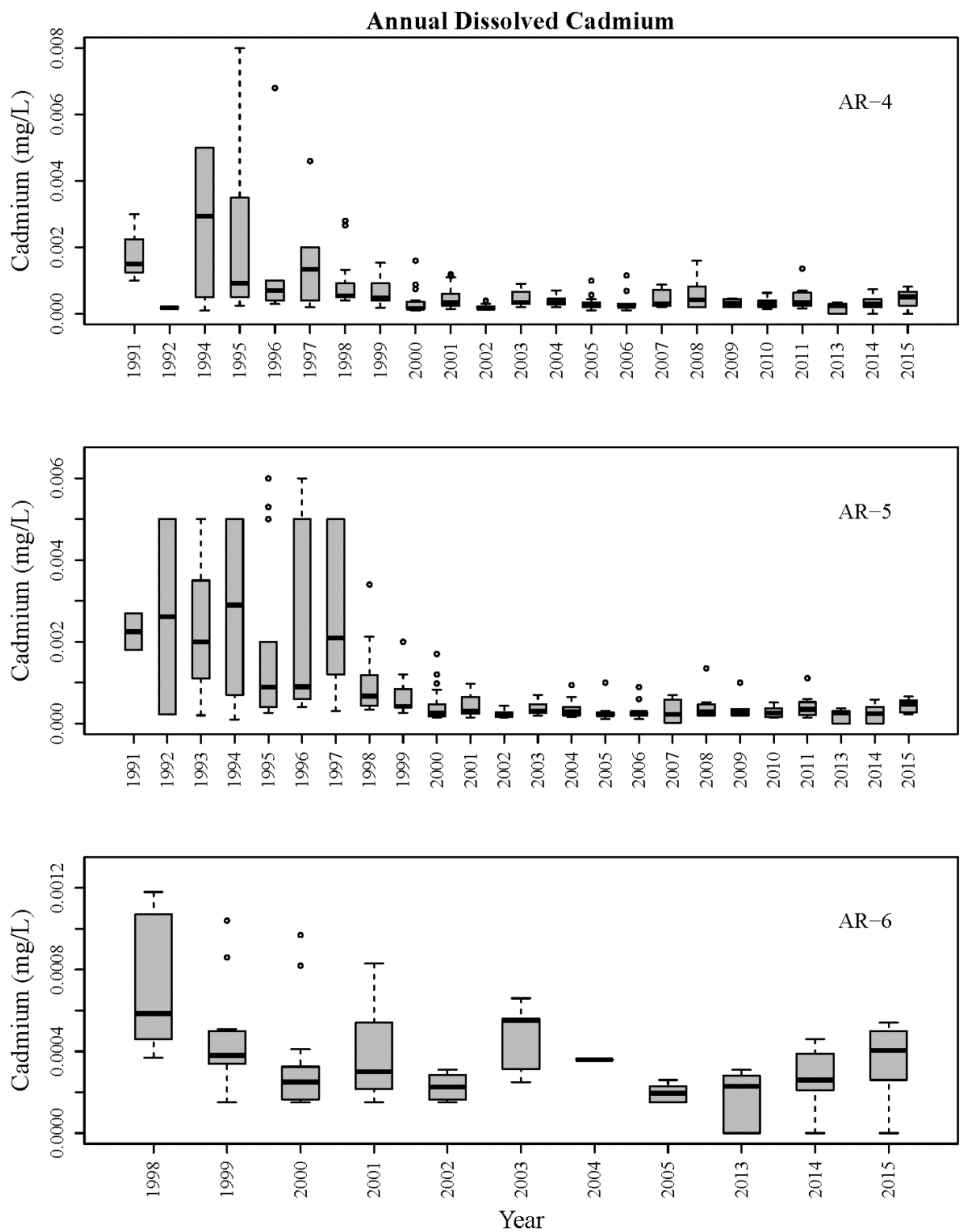


Figure B.11. Dissolved cadmium concentrations summarized annually at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River. The y-axis was limited to exclude one observation at AR-5 of 0.03 mg/L in 1998, and one observation at AR-6 of 0.00254 mg/L in 1998.

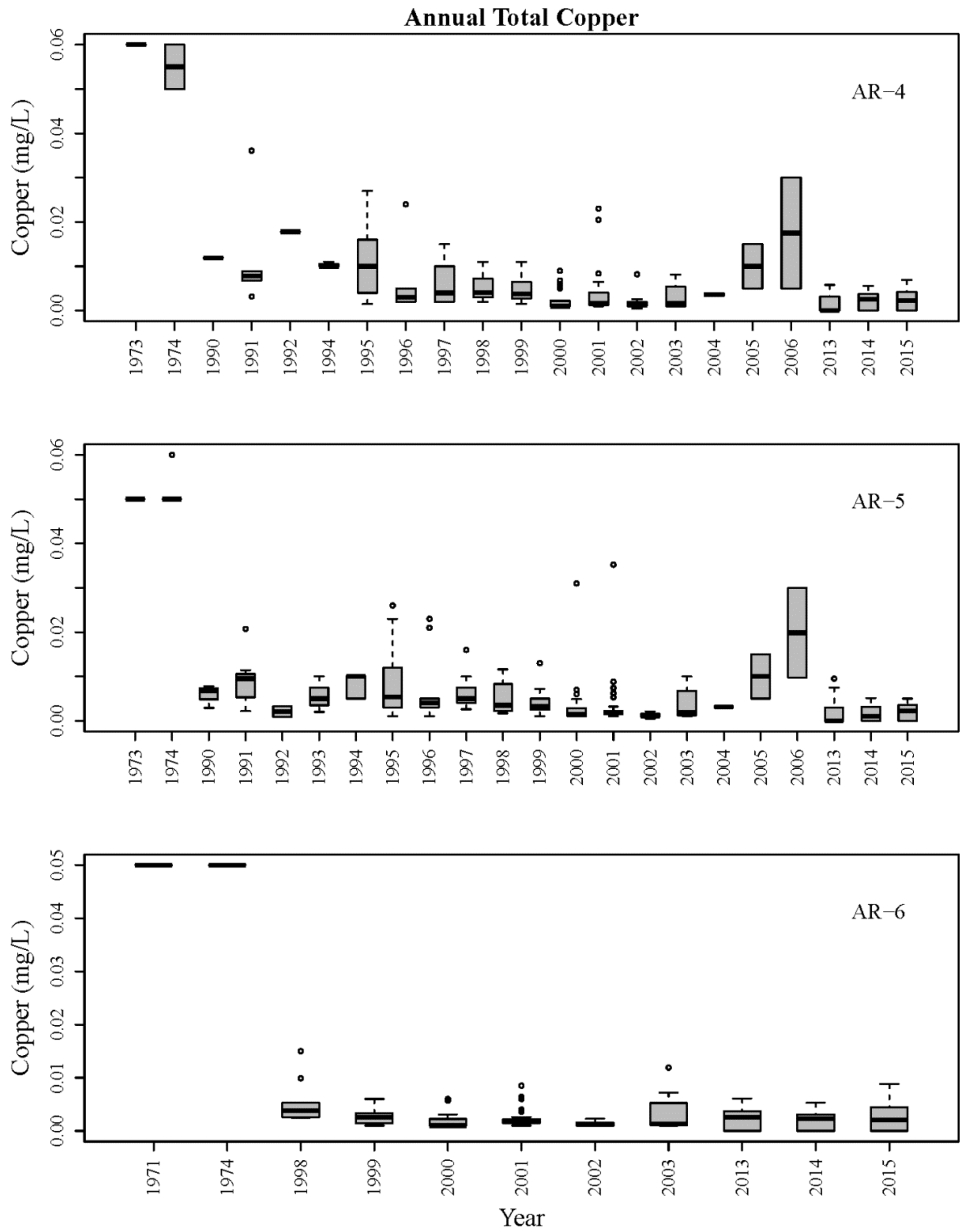


Figure B.12. Total copper concentrations summarized annually at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River.

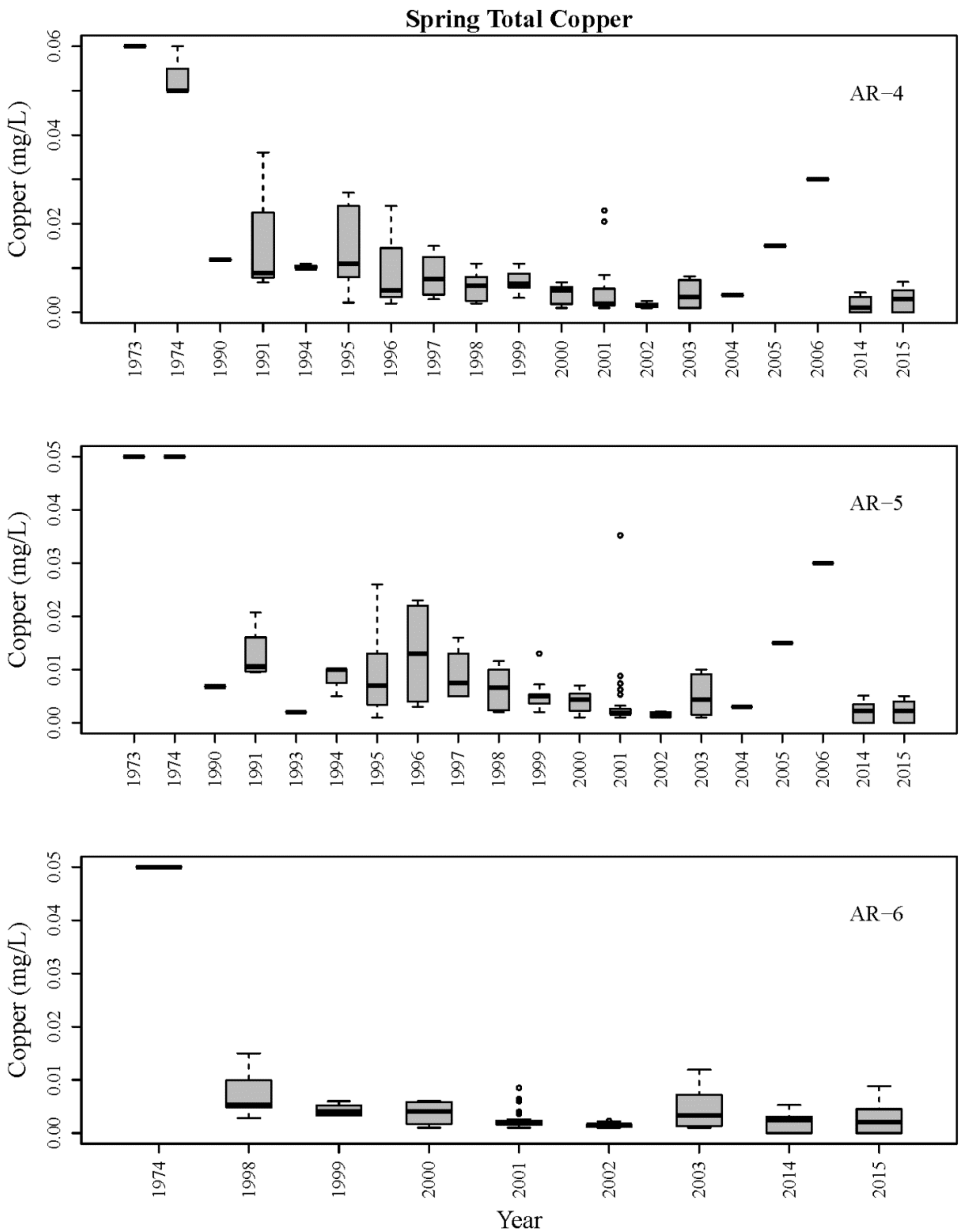


Figure B.13. Total copper concentrations summarized seasonally (April-July) at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River.

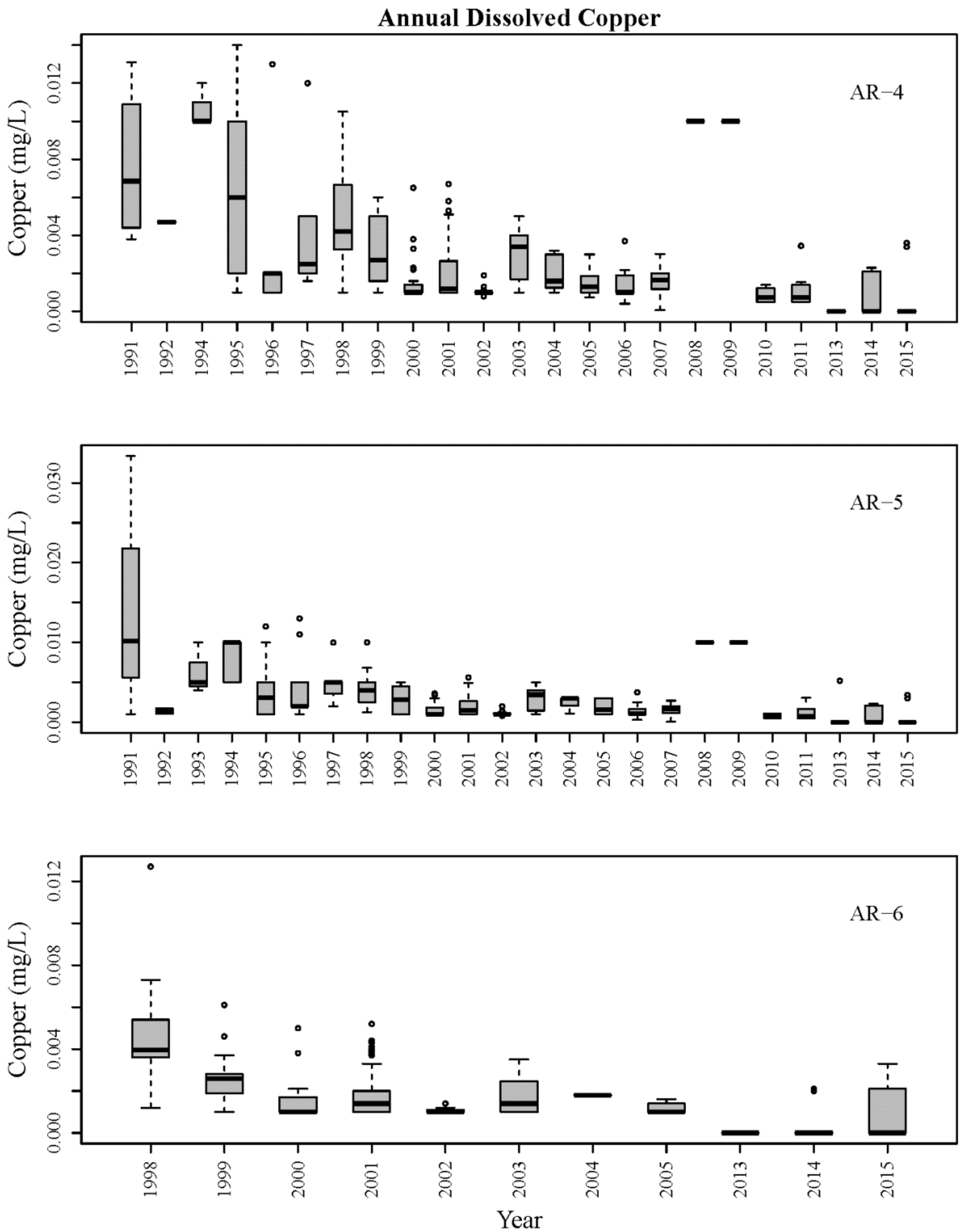


Figure B.14. Dissolved copper concentrations summarized annually at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River.

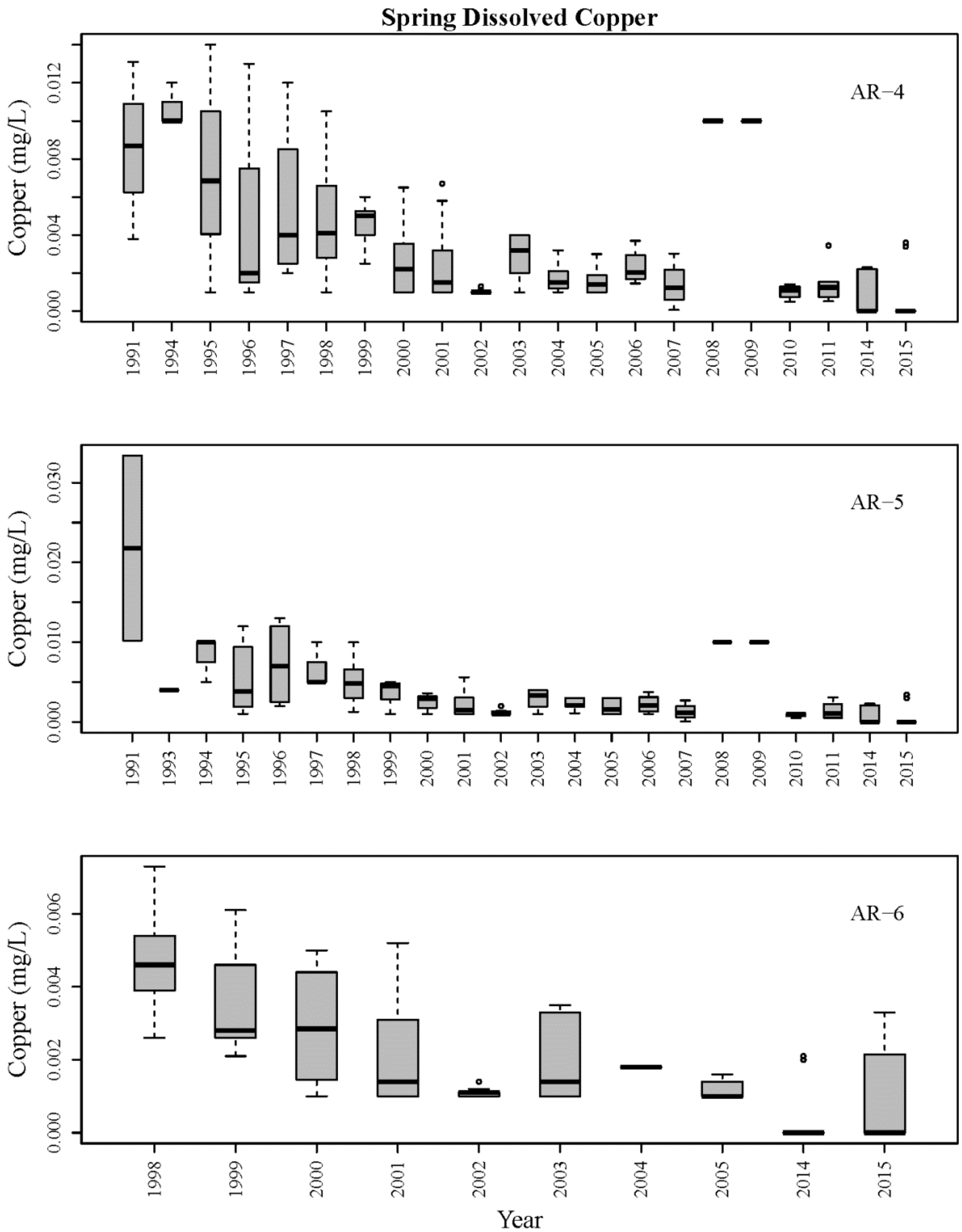


Figure B.15. Dissolved copper concentrations summarized seasonally (April-July) at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River.

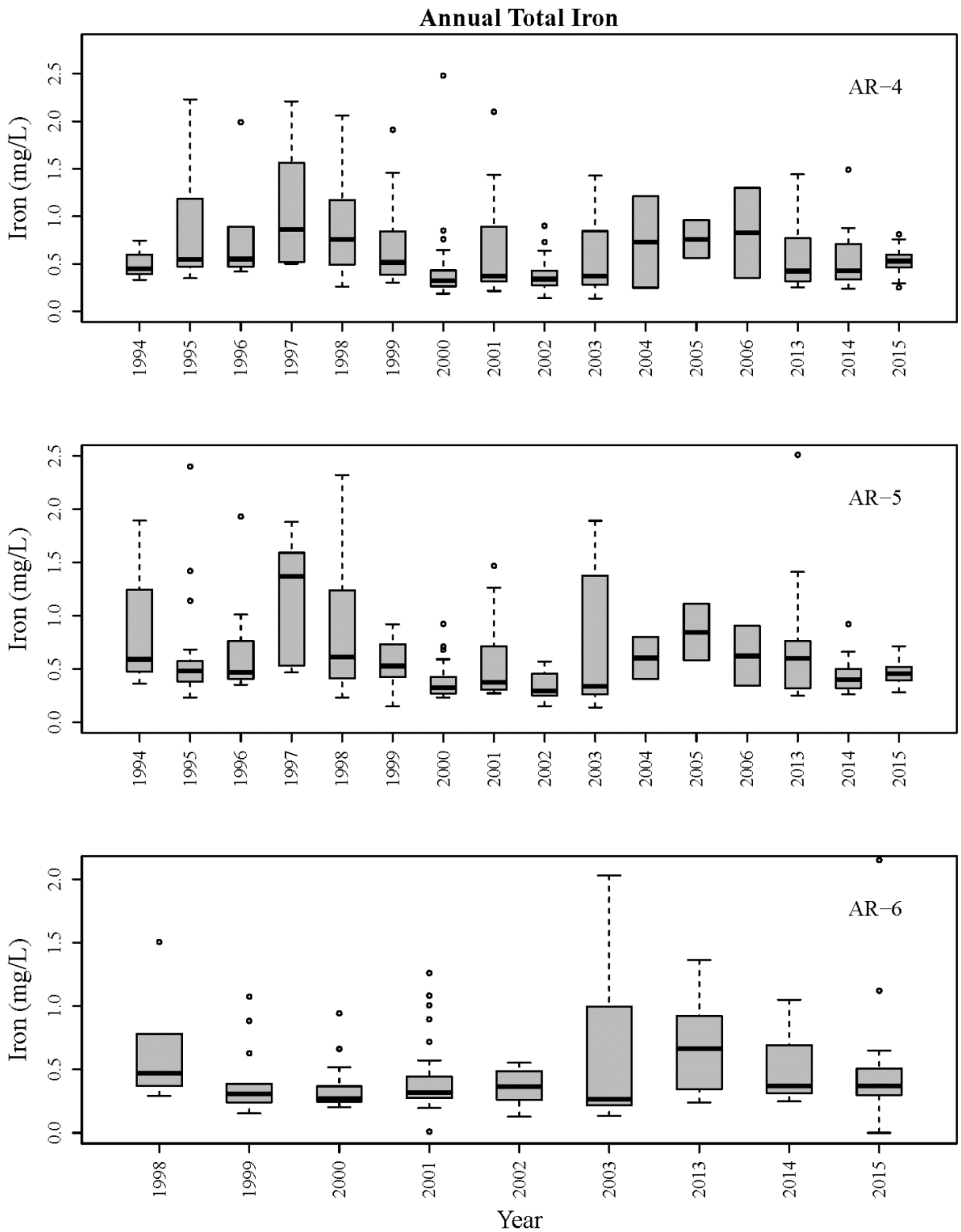


Figure B.16. Total iron concentrations summarized annually at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River. The y-axis was limited to exclude one observation at AR-4 of 5.849 mg/L in 2001, four observations at AR-5 of 5.01 and 2.85 mg/L in 1999, 8.14 mg/L in 2000, and 5.968 mg/L in 2001, and one observation at AR-6 of 3.207 mg/L in 1998.

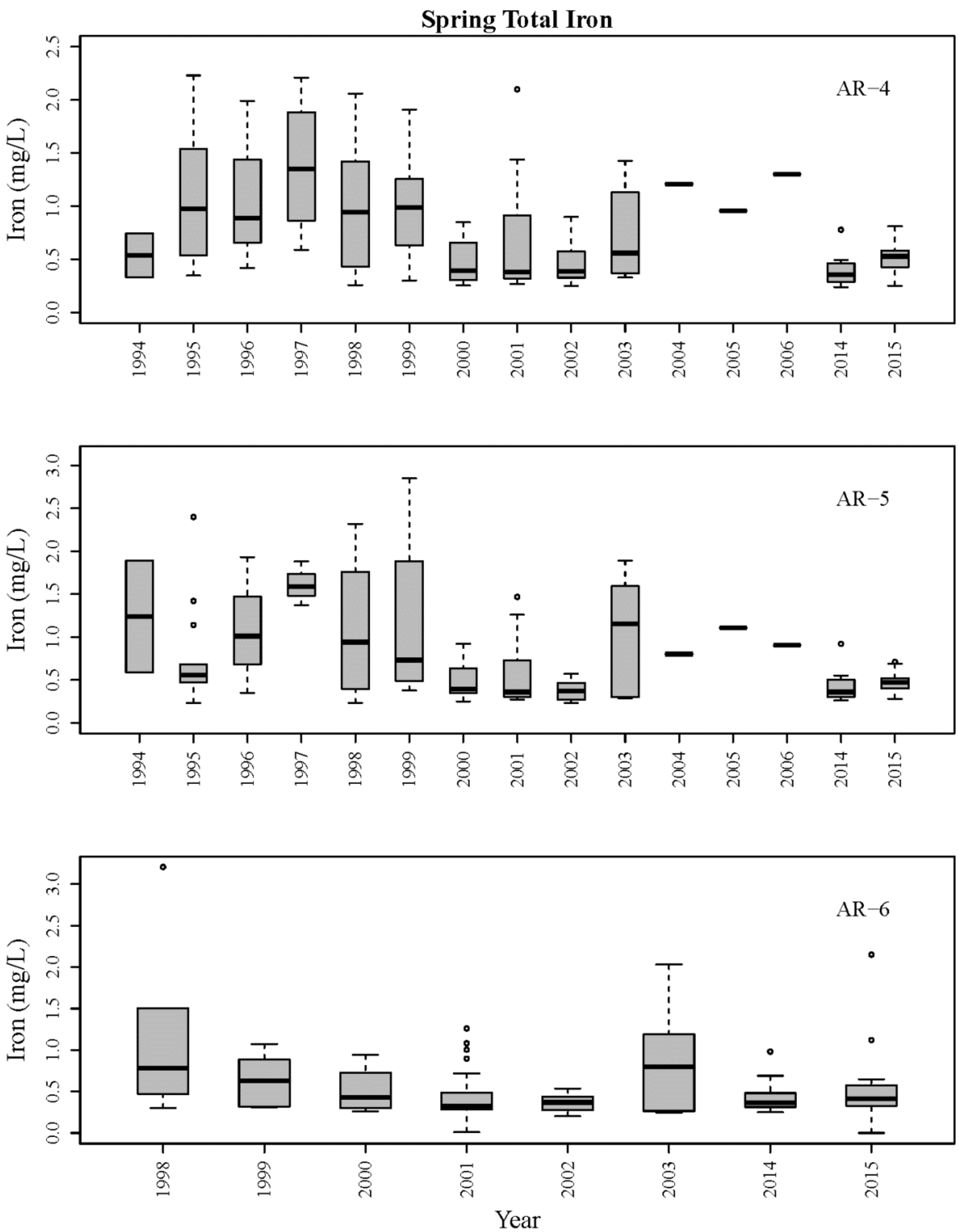


Figure B.17. Total iron concentrations summarized seasonally (April-July) at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River. The y-axis was limited to exclude one observation at AR-4 of 5.849 mg/L in 2001, and two observations at AR-5 of 5.01 mg/L in 1999 and 5.968 mg/L in 2001.

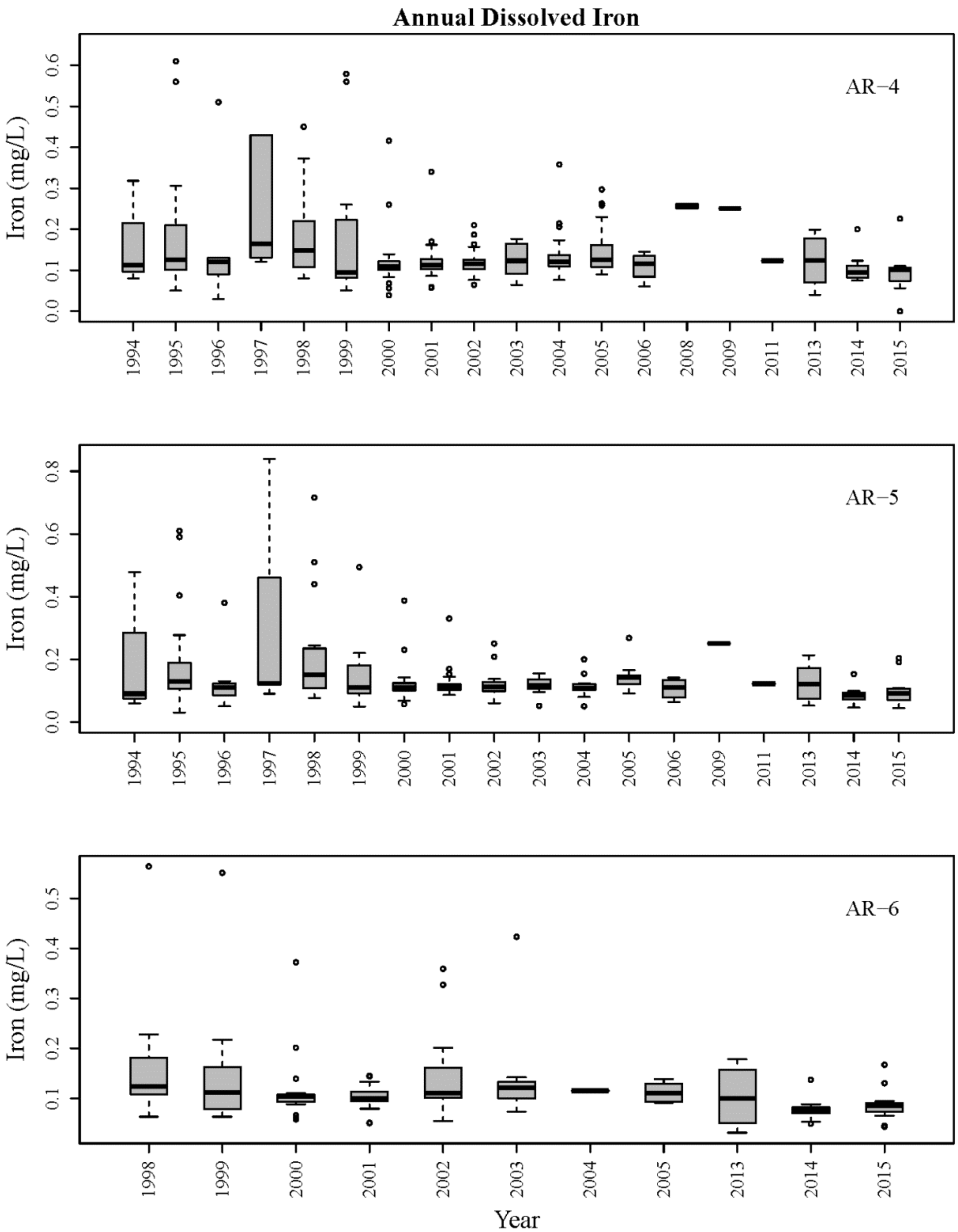


Figure B.18. Dissolved iron concentrations summarized annually at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River. The y-axis was limited to exclude one observation at AR-4 of 1.684 mg/L in 1998, and one observation at AR-5 of 1.24 mg/L in 1999.

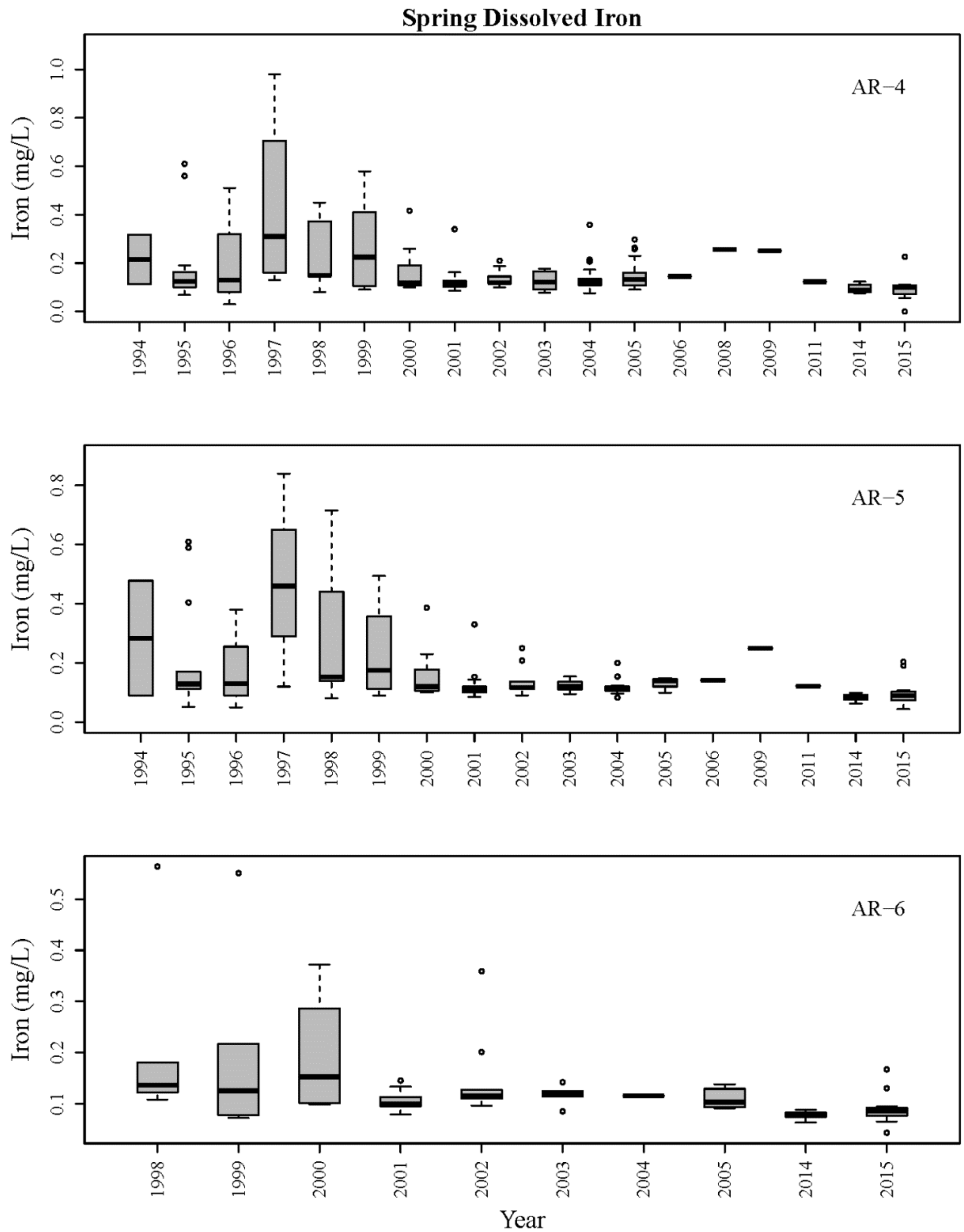


Figure B.19. Dissolved iron concentrations summarized seasonally (April-July) at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River. The y-axis was limited to exclude one observation at AR-4 of 1.684 mg/L in 1998, and one observation at AR-5 of 1.24 mg/L in 1999.

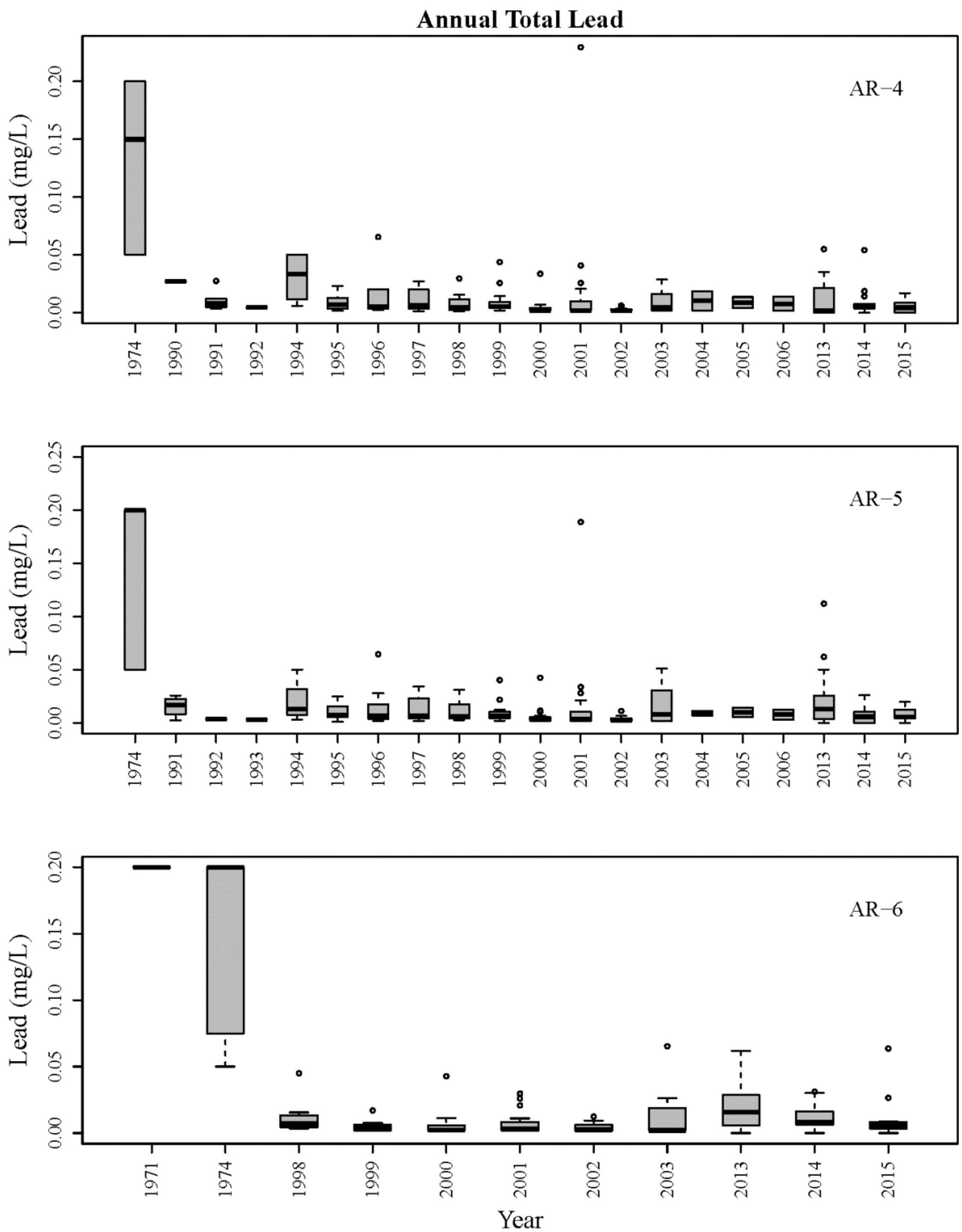


Figure B.20. Total lead concentrations summarized annually at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River. The y-axis was limited to exclude one observation at AR-4 of 0.454 mg/L in 2000, and one observation at AR-5 of 2.02 mg/L in 2000.

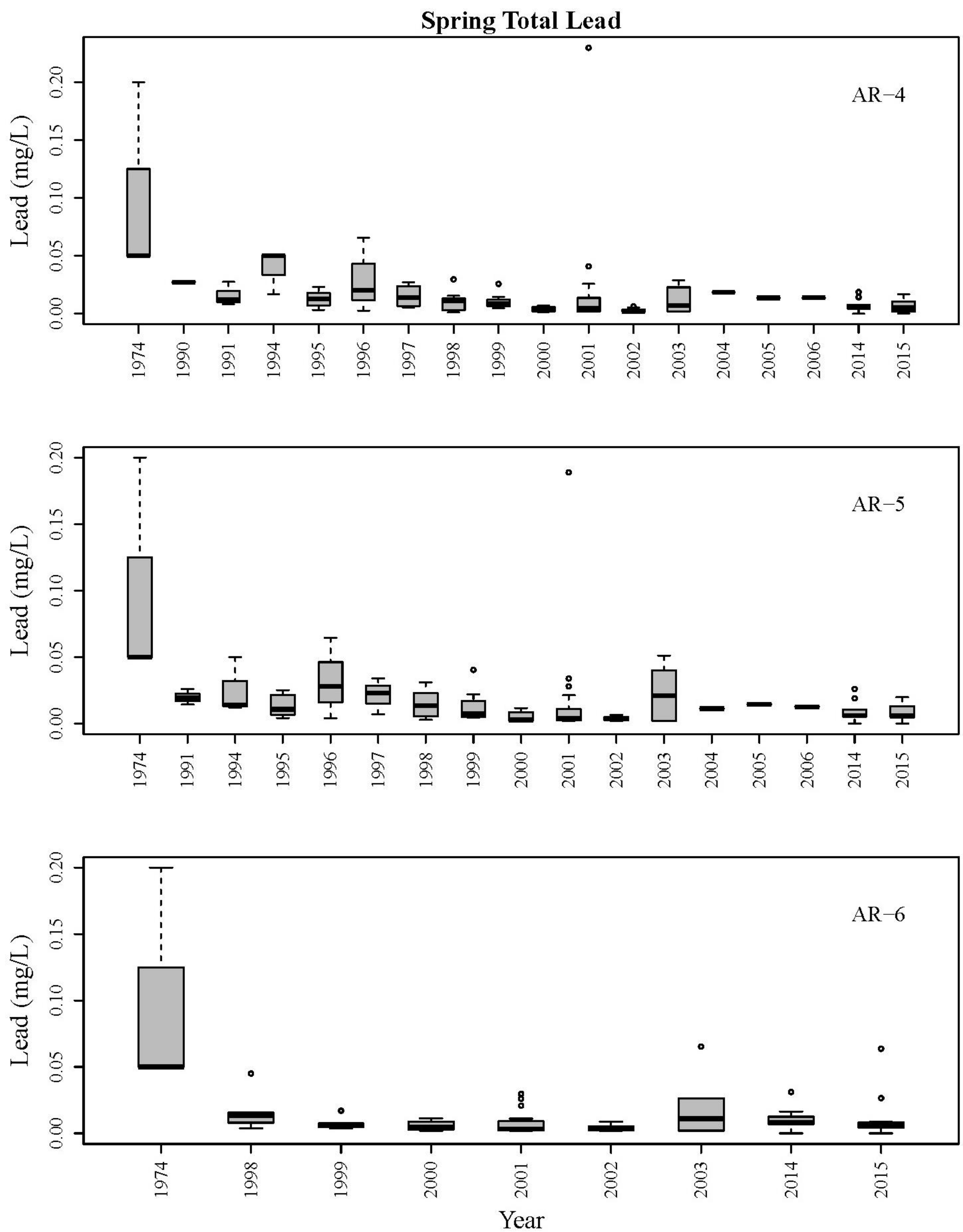


Figure B.21. Total lead concentrations summarized seasonally (April-July) at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River.

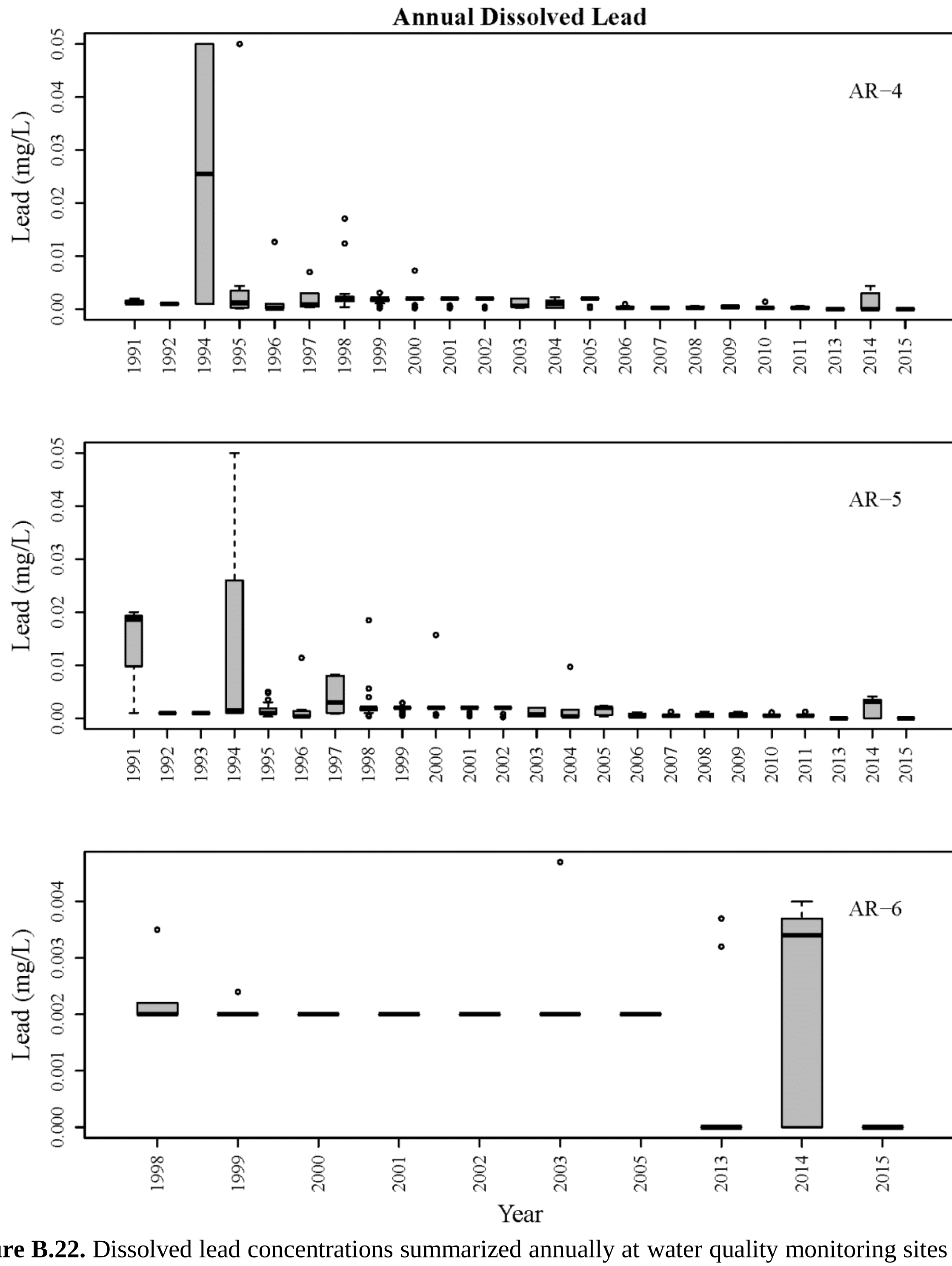


Figure B.22. Dissolved lead concentrations summarized annually at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River. The method detection limit (MDL) is indicated by single, horizontal lines.

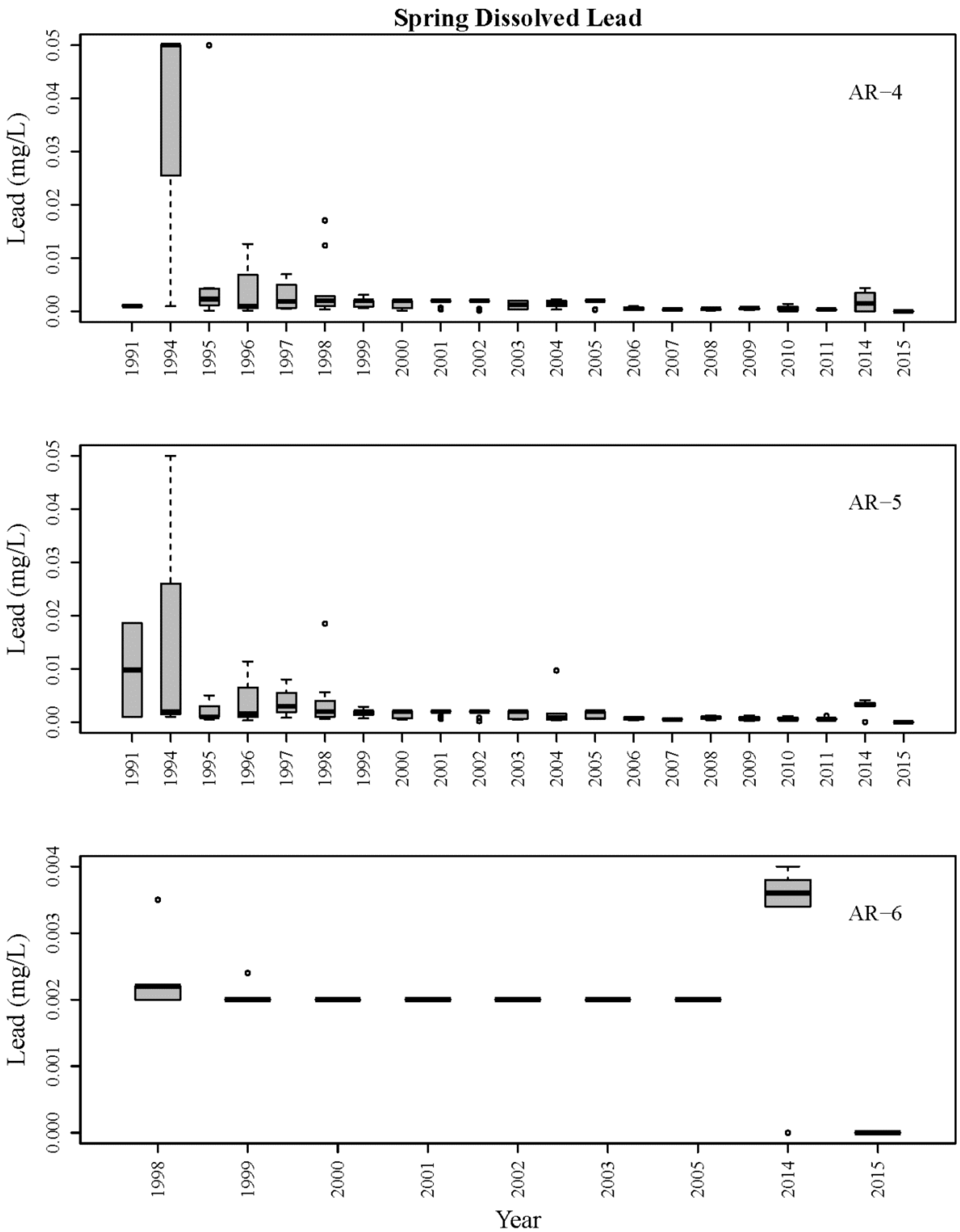


Figure B.23. Dissolved lead concentrations summarized seasonally (April-July) at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River. The method detection limit (MDL) is indicated by single, horizontal lines.

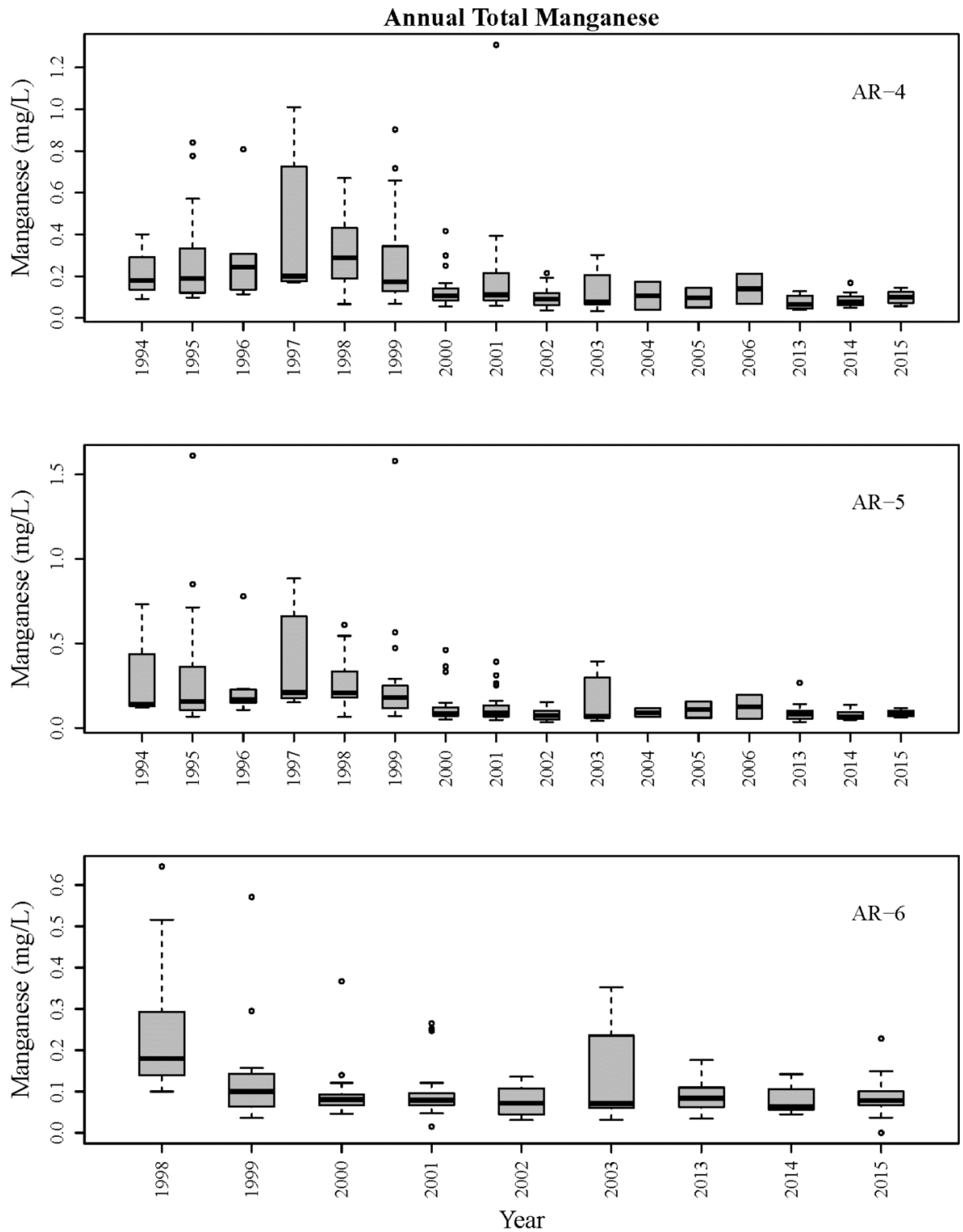


Figure B.24. Total manganese concentrations summarized annually at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River.

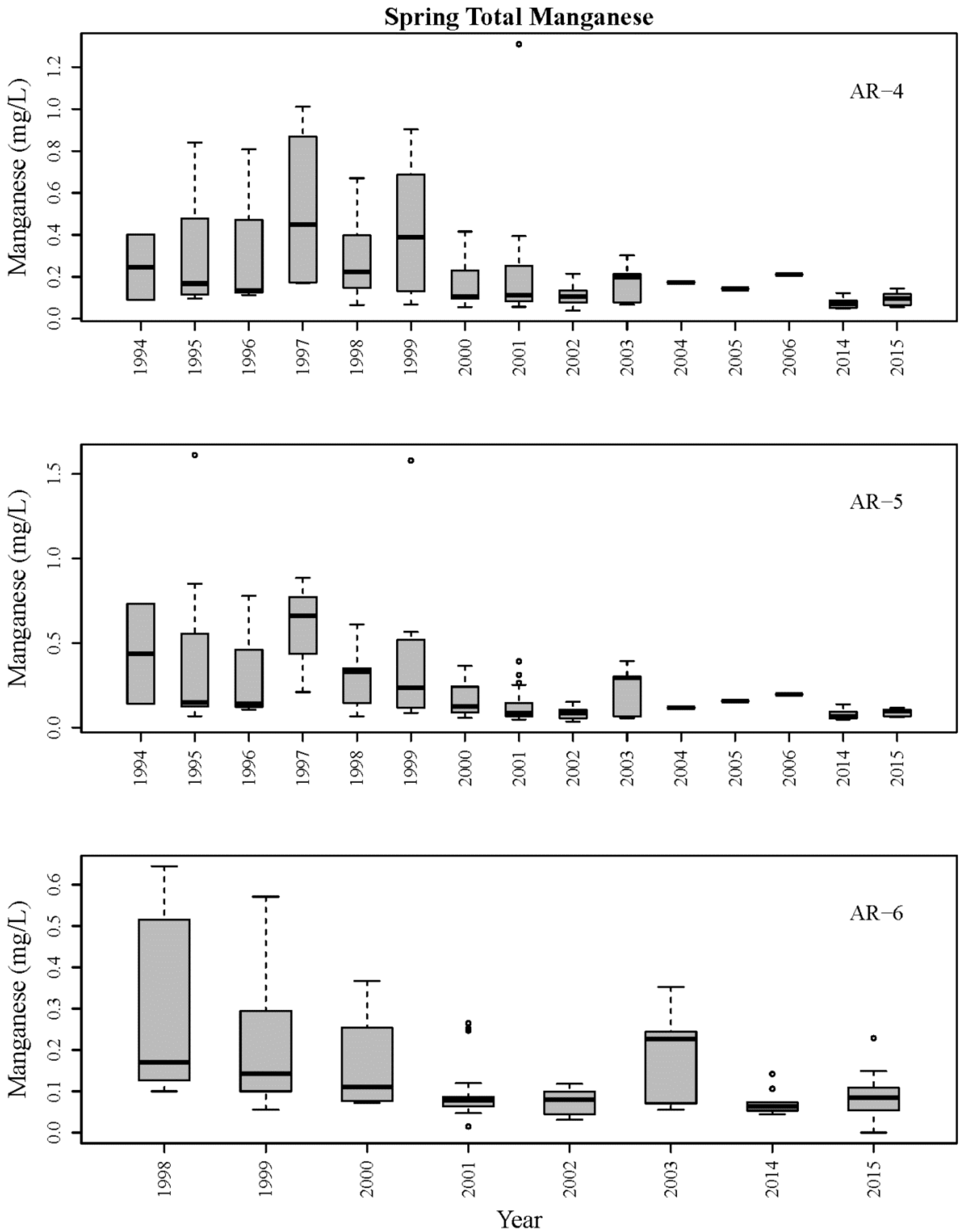


Figure B.25. Total manganese concentrations summarized seasonally (April-July) at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River.

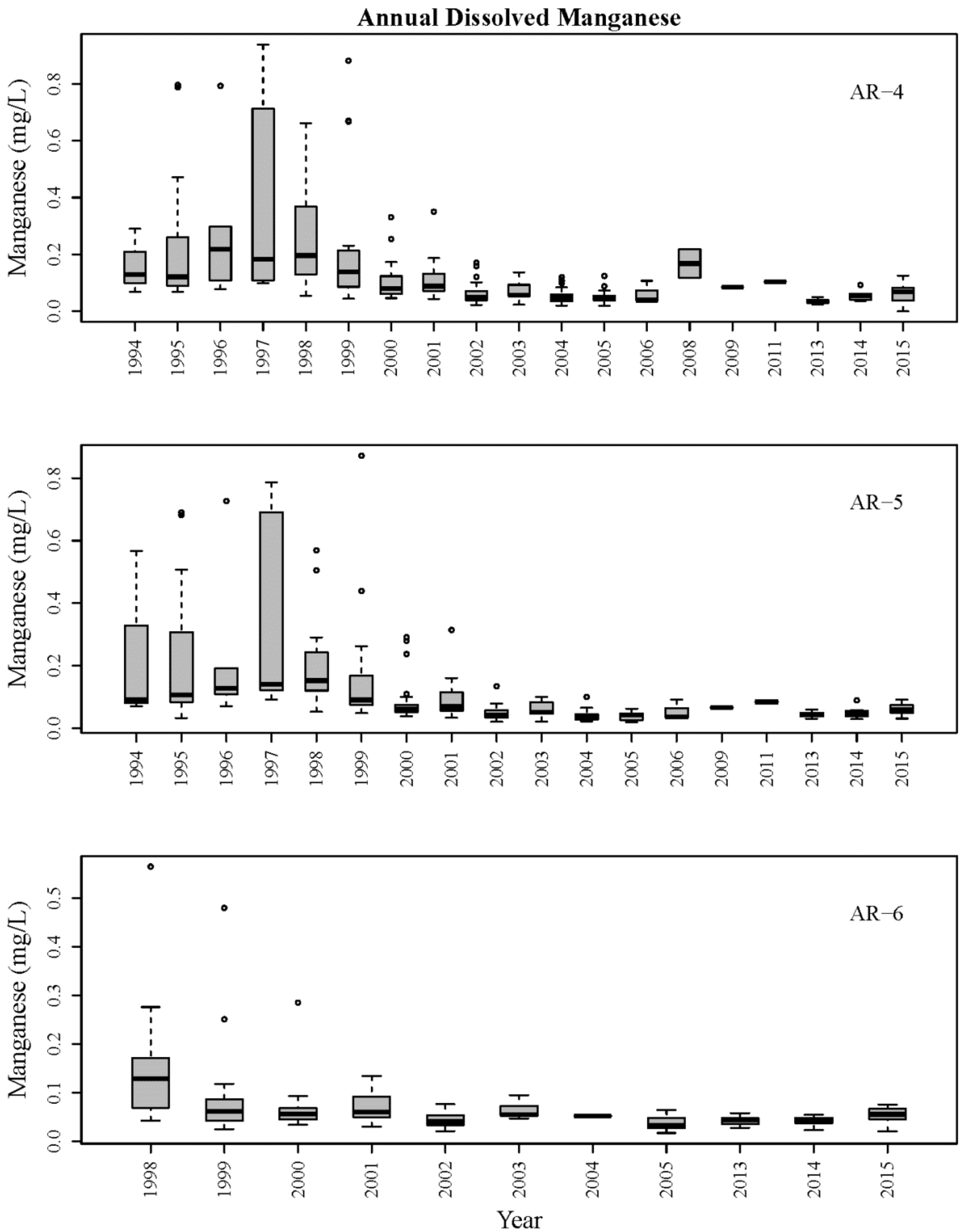


Figure B.26. Dissolved manganese concentrations summarized annually at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River.

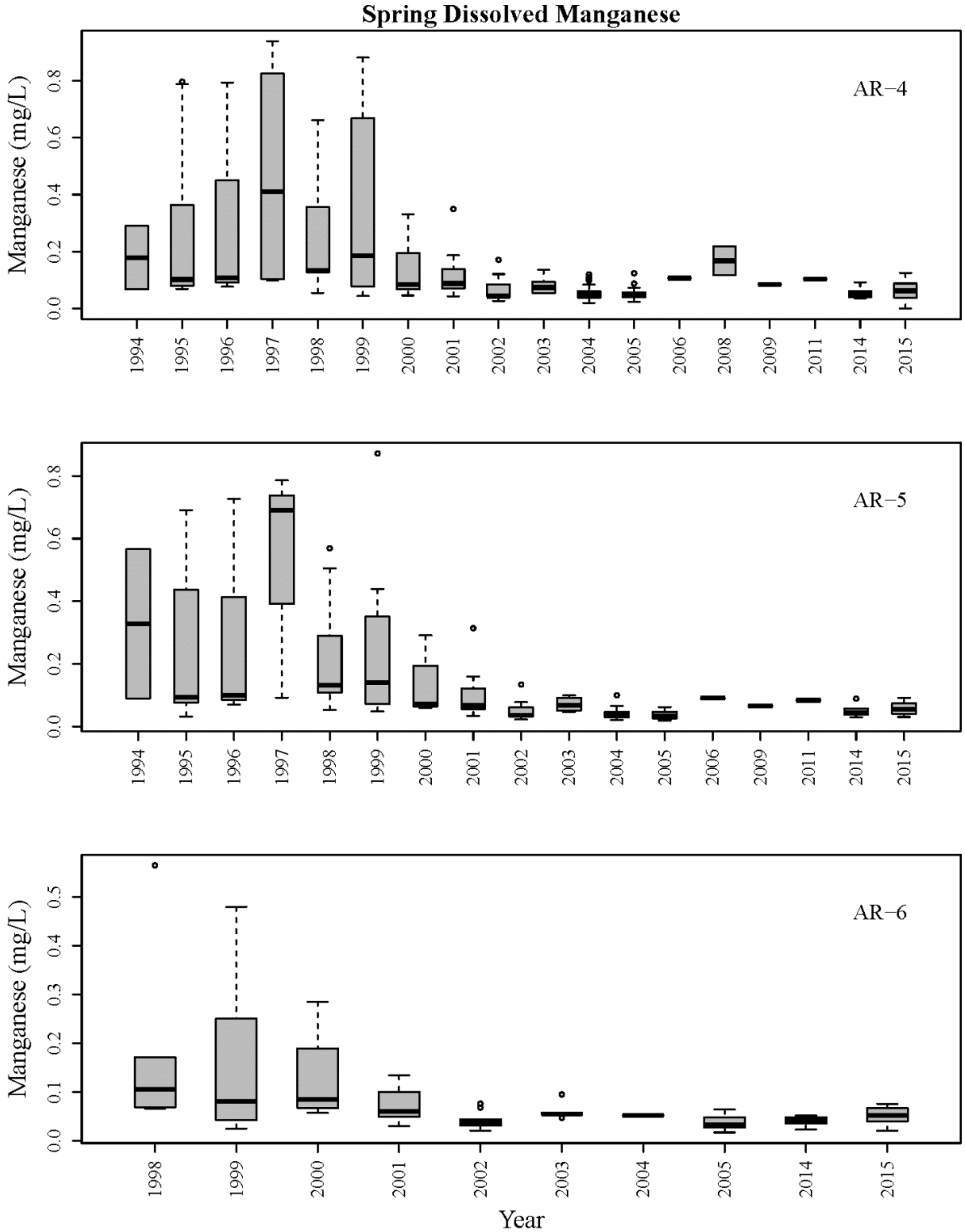


Figure B.27. Dissolved manganese concentrations summarized seasonally (April-July) at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River.

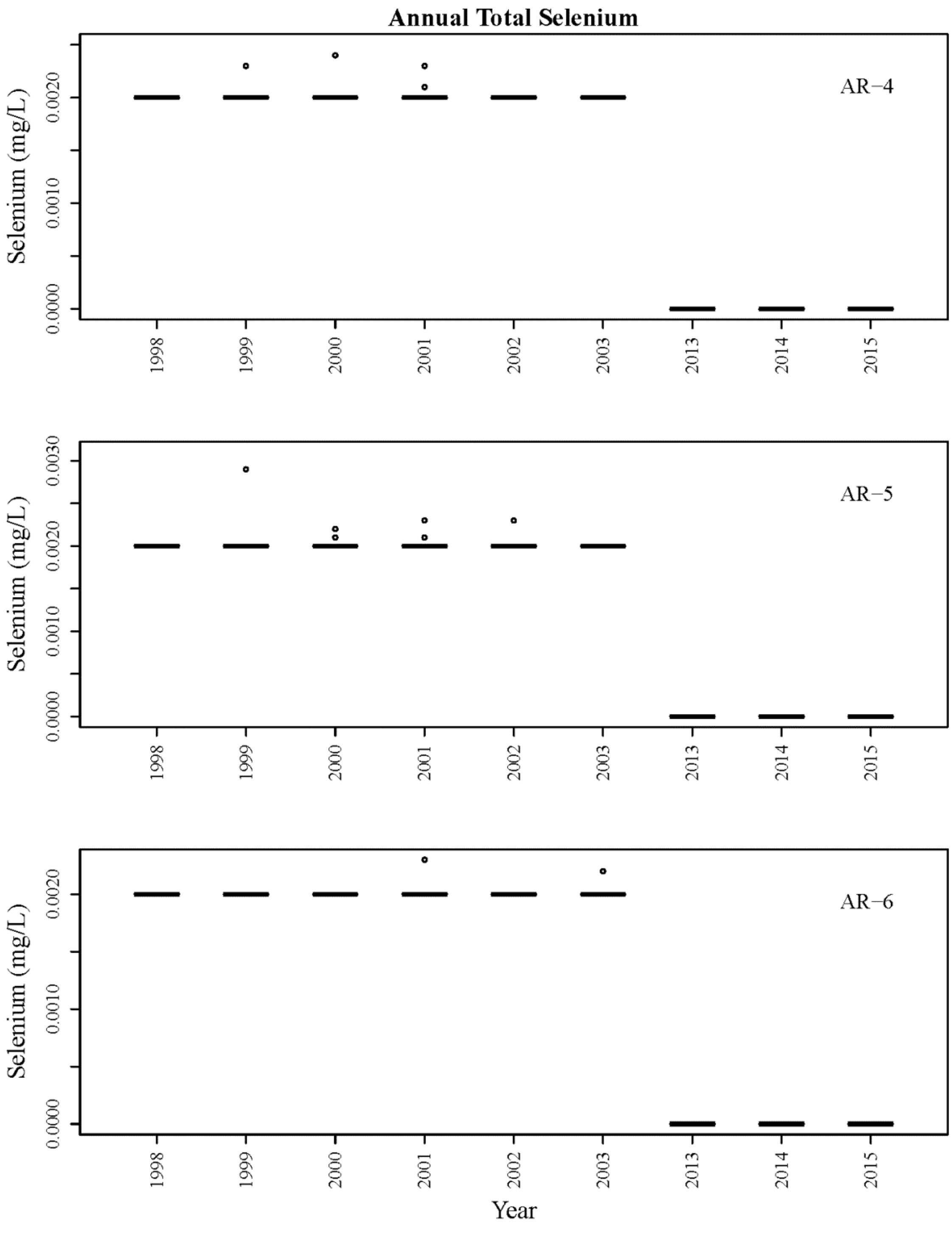


Figure B.28. Total selenium concentrations summarized annually at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River. The y-axis was limited to exclude one observation at AR-4 of 0.011 mg/L in 2003, and one observation at AR-5 of 0.007 mg/L in 2003. The method detection limit (MDL) is indicated by single, horizontal lines.

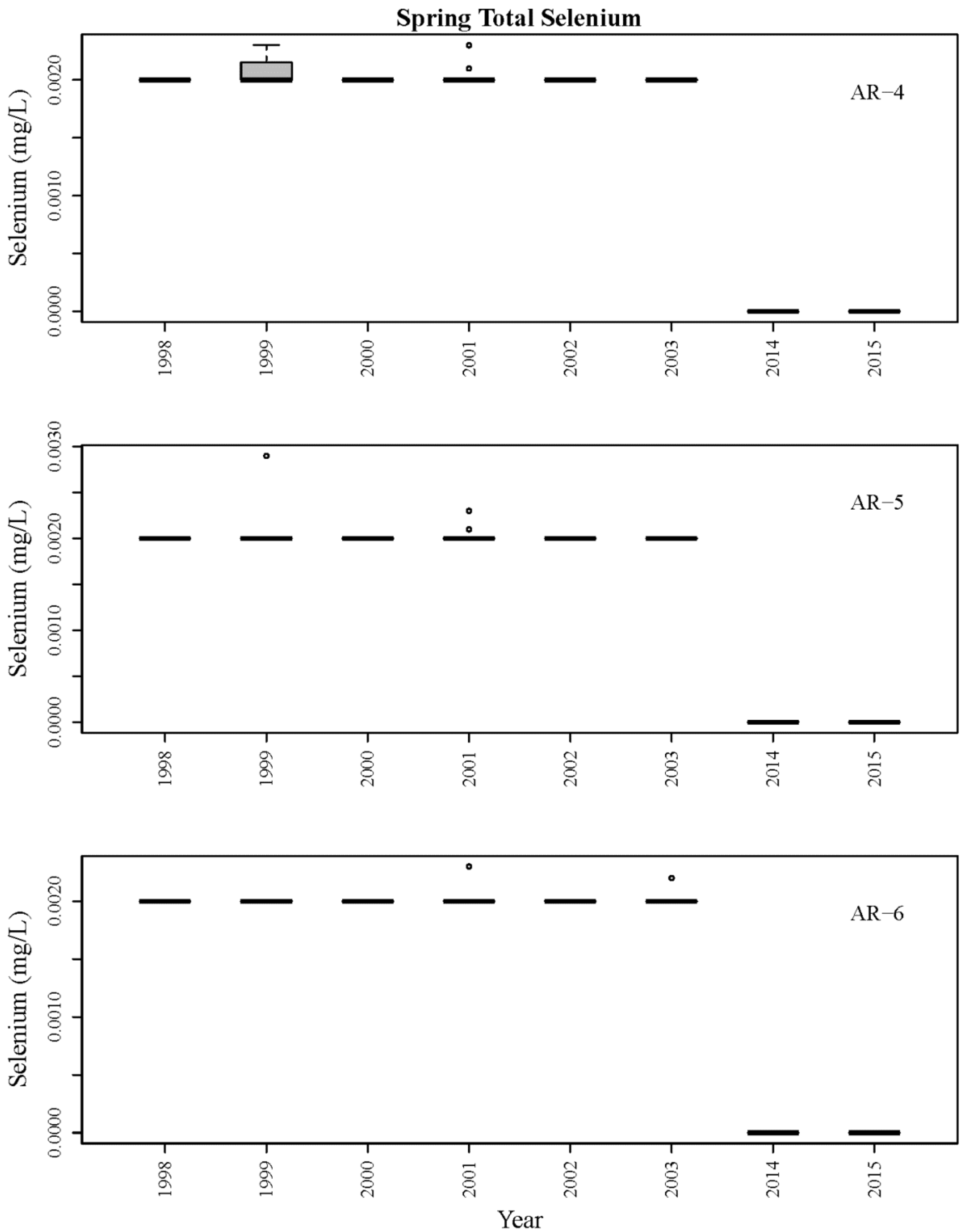


Figure B.29. Total selenium concentrations summarized seasonally (April-July) at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River. The method detection limit (MDL) is indicated by single, horizontal lines.

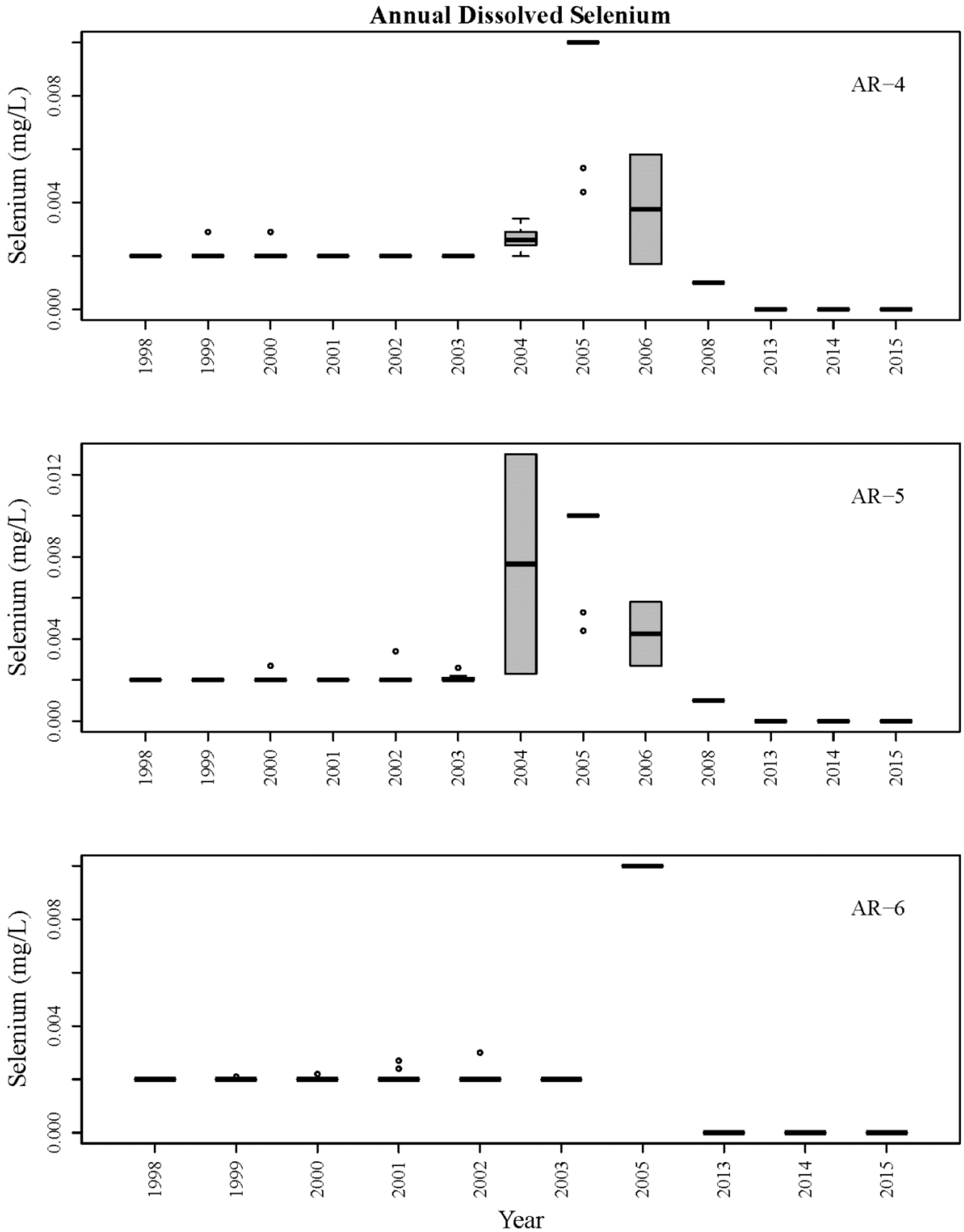


Figure B.30. Dissolved selenium concentrations summarized annually at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River. The y-axis was limited to exclude two observations at AR-4 of 0.035 mg/L in 2005, and observations at AR-5 of 0.035 mg/L in 2005. The method detection limit (MDL) is indicated by single, horizontal lines.

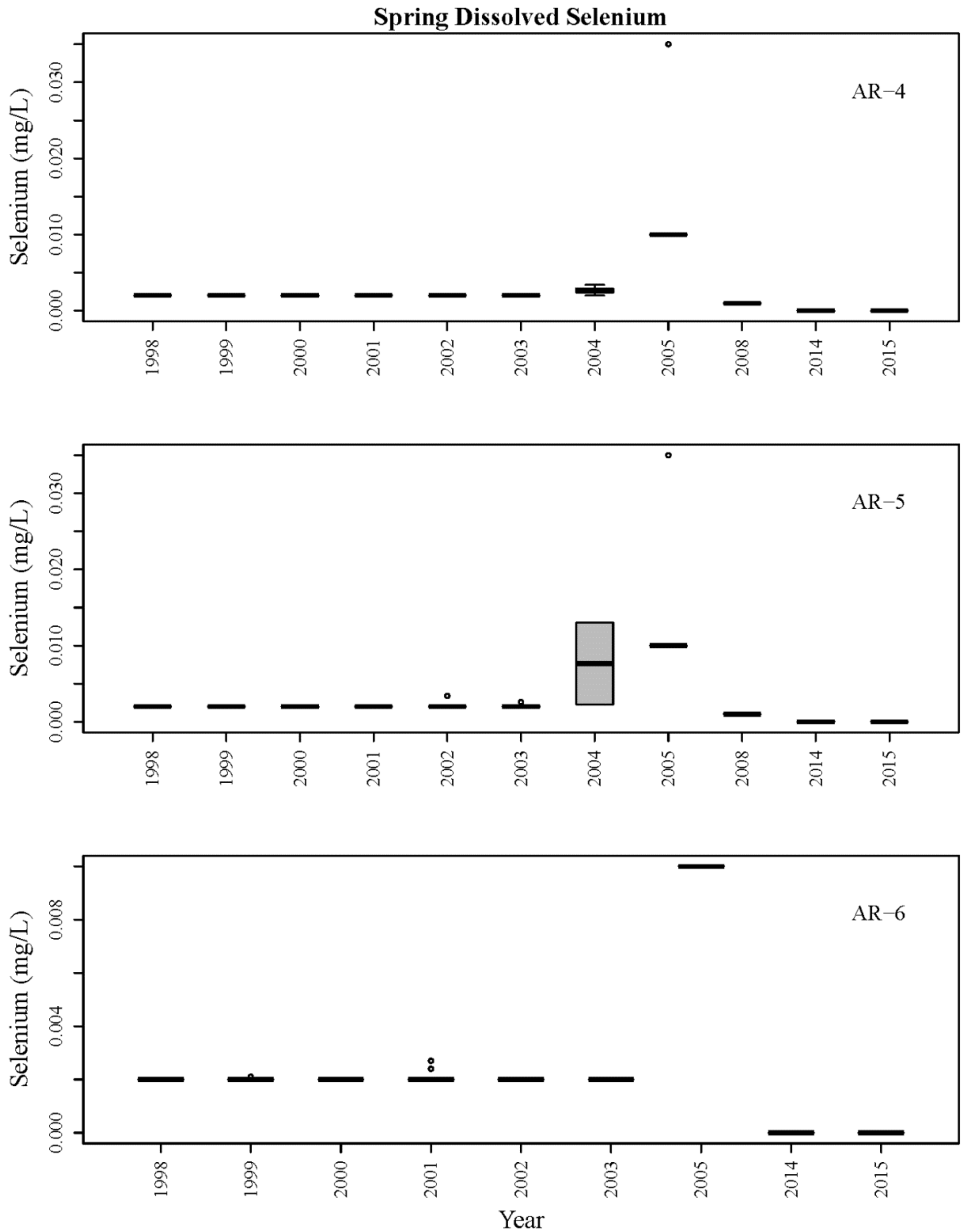


Figure B.31. Dissolved selenium concentrations summarized seasonally (April-July) at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River. The method detection limit (MDL) is indicated by single, horizontal lines.

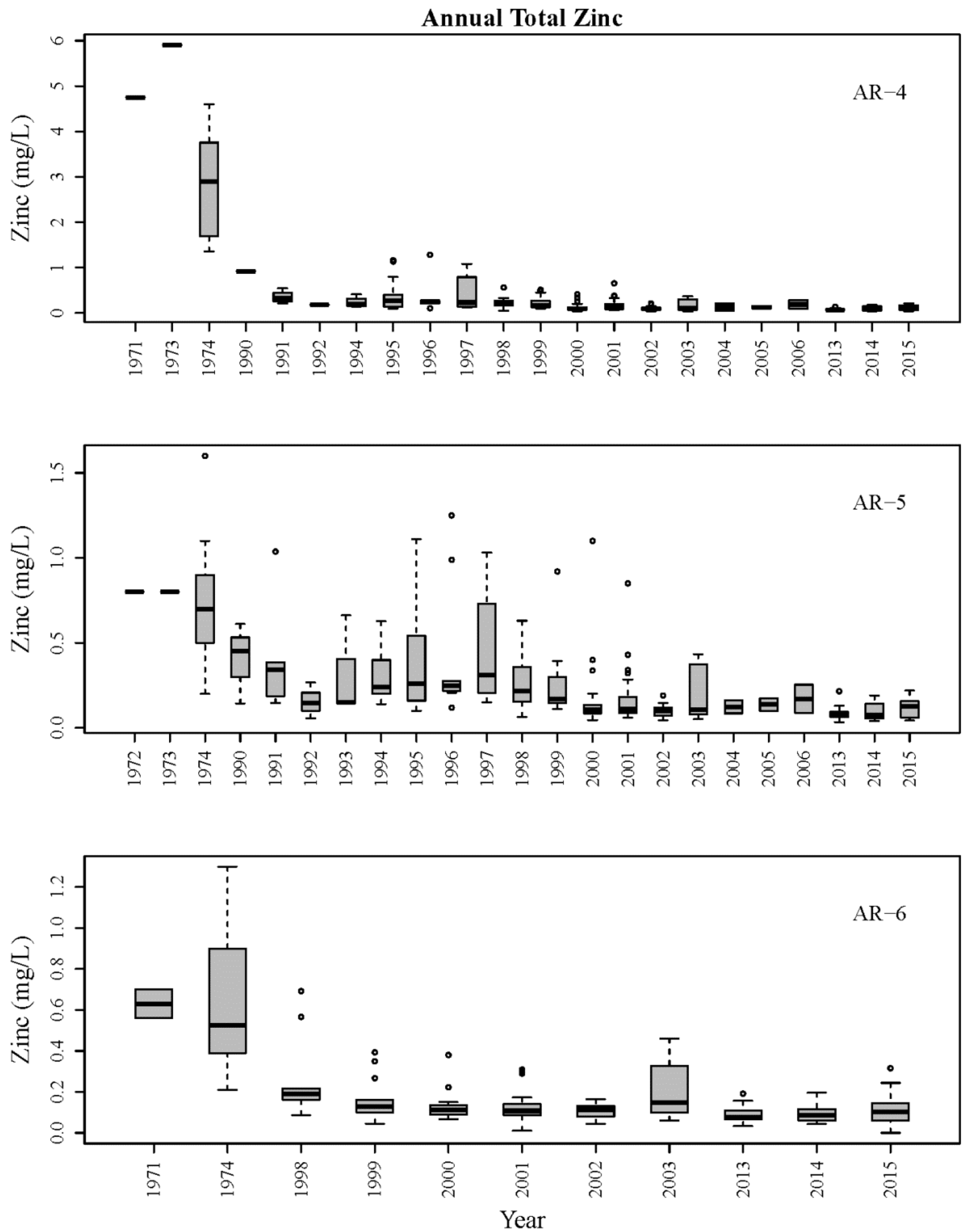


Figure B.32. Total zinc concentrations summarized annually at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River.

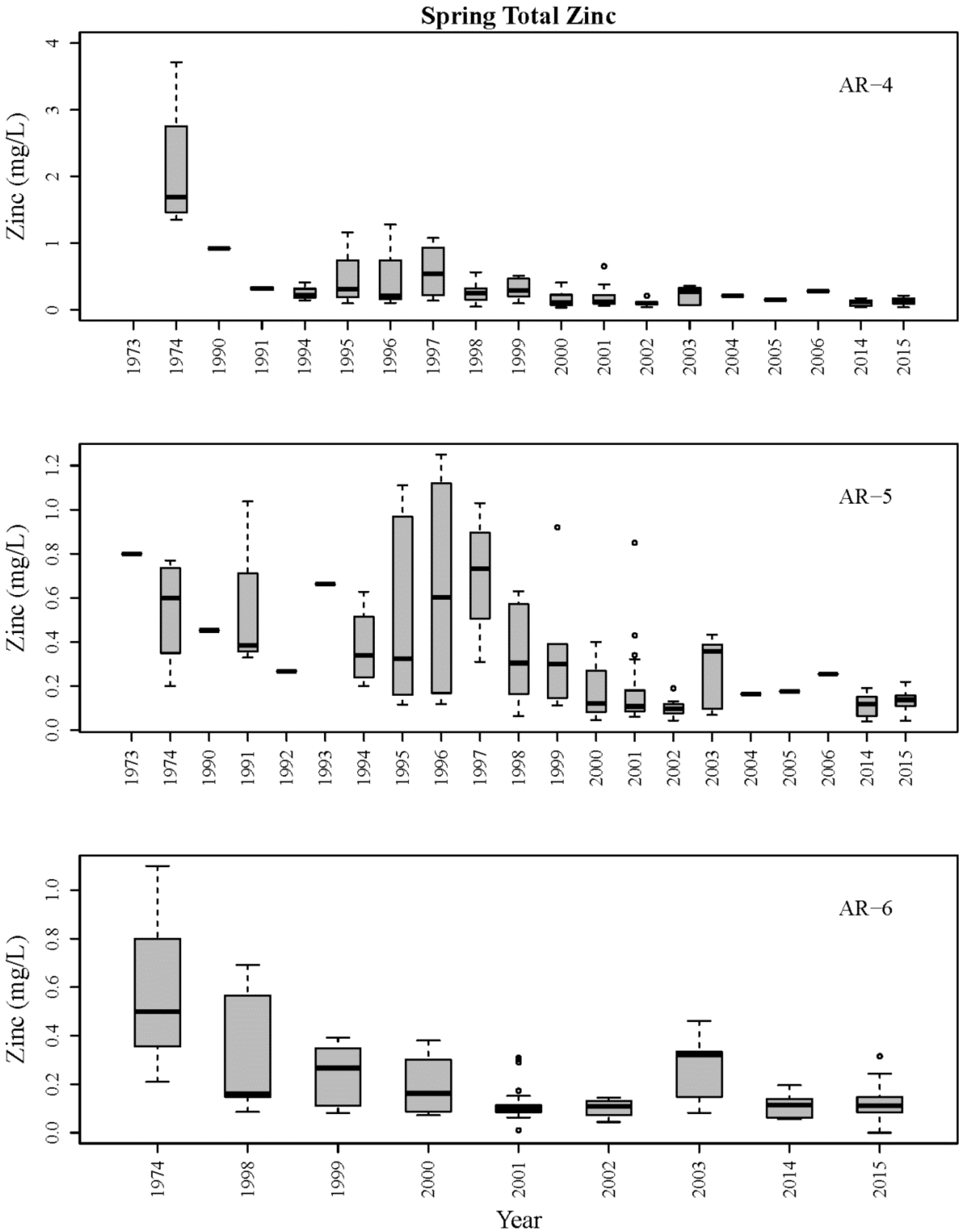


Figure B.33. Total zinc concentrations summarized seasonally (April-July) at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River. The y-axis was limited to exclude one observation at AR-4 of 5.9 mg/L in 1973.

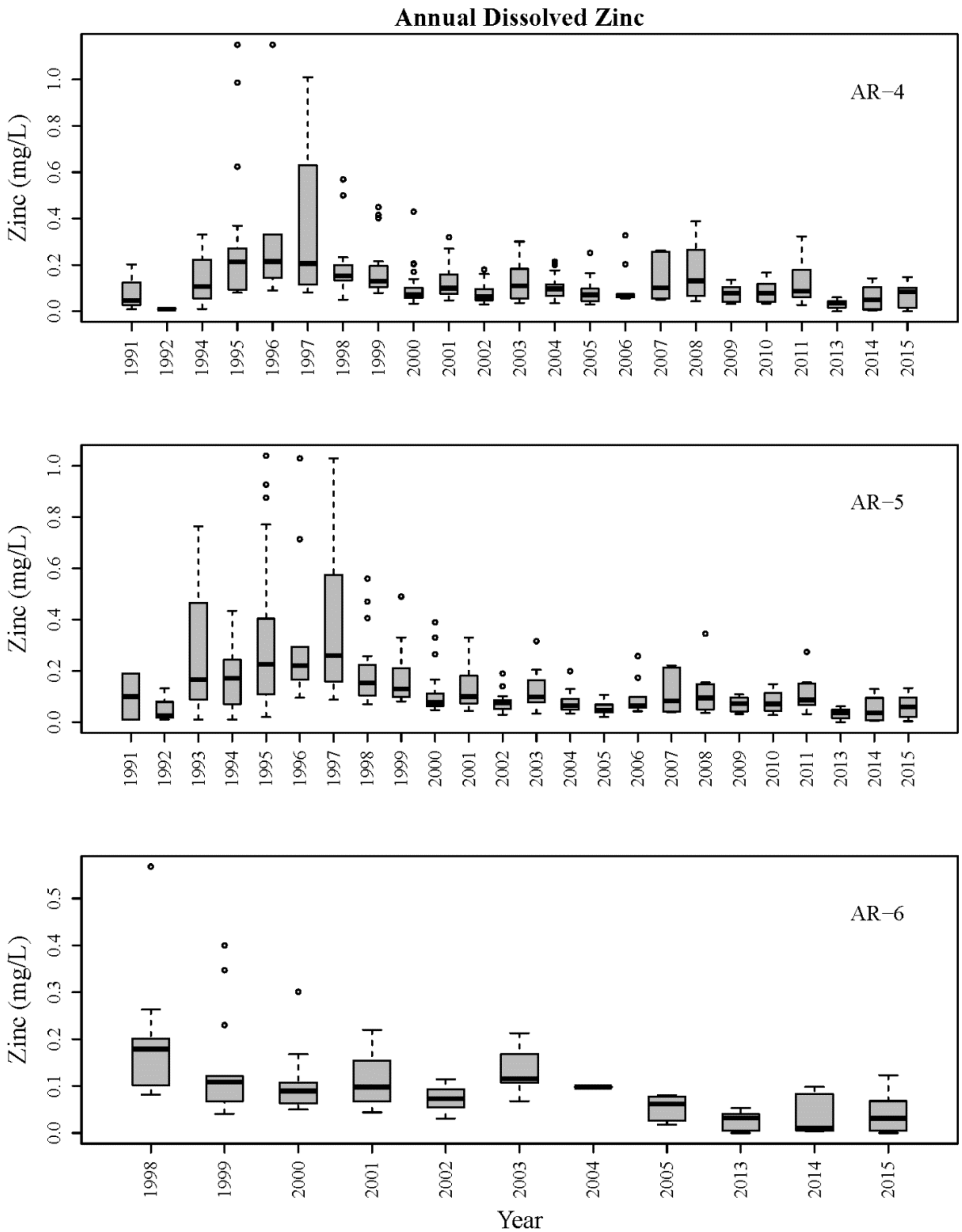


Figure B.34. Dissolved zinc concentrations summarized annually at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River.

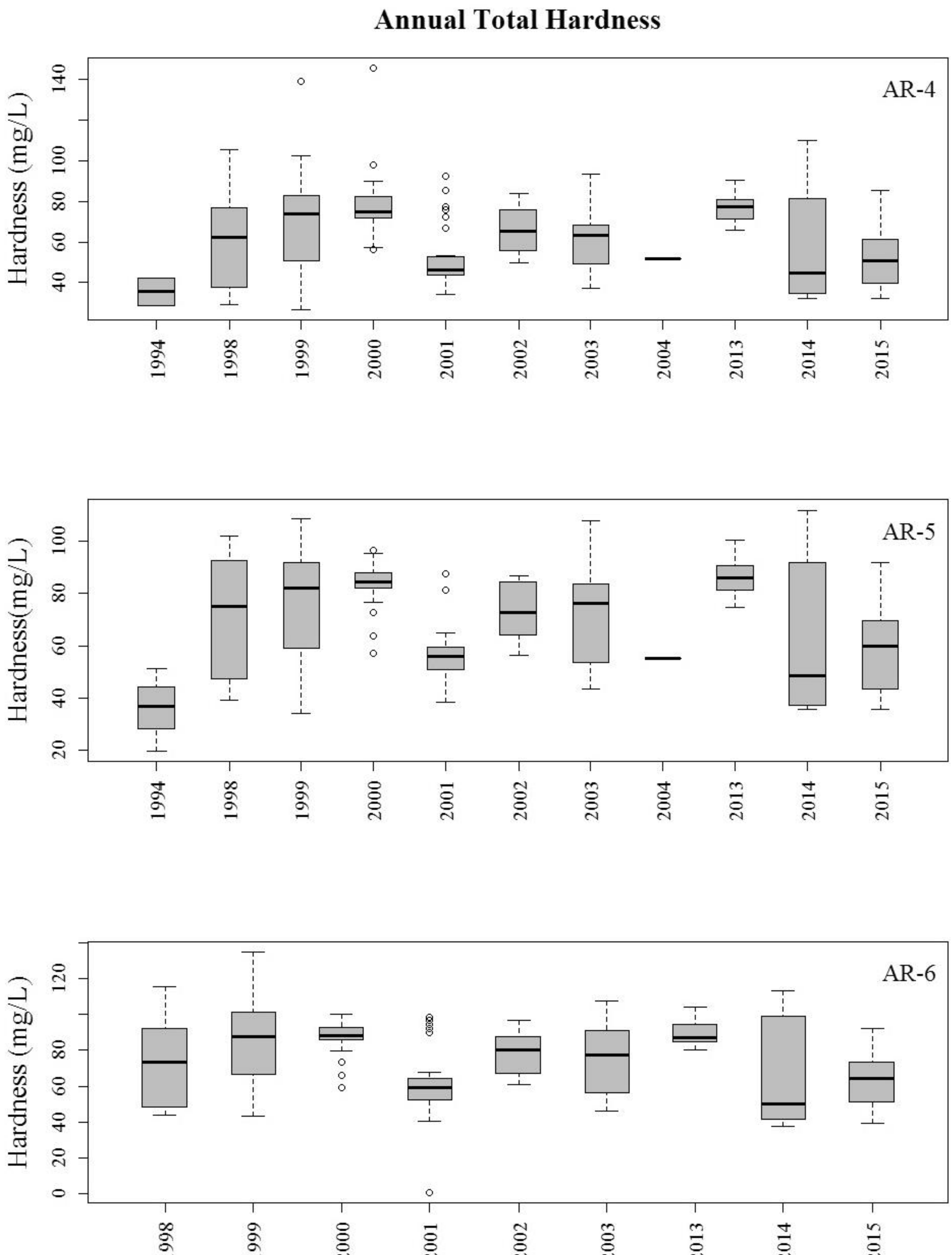


Figure B.35. Total water hardness (as mg/L $CaCO_3$) summarized annually at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River.

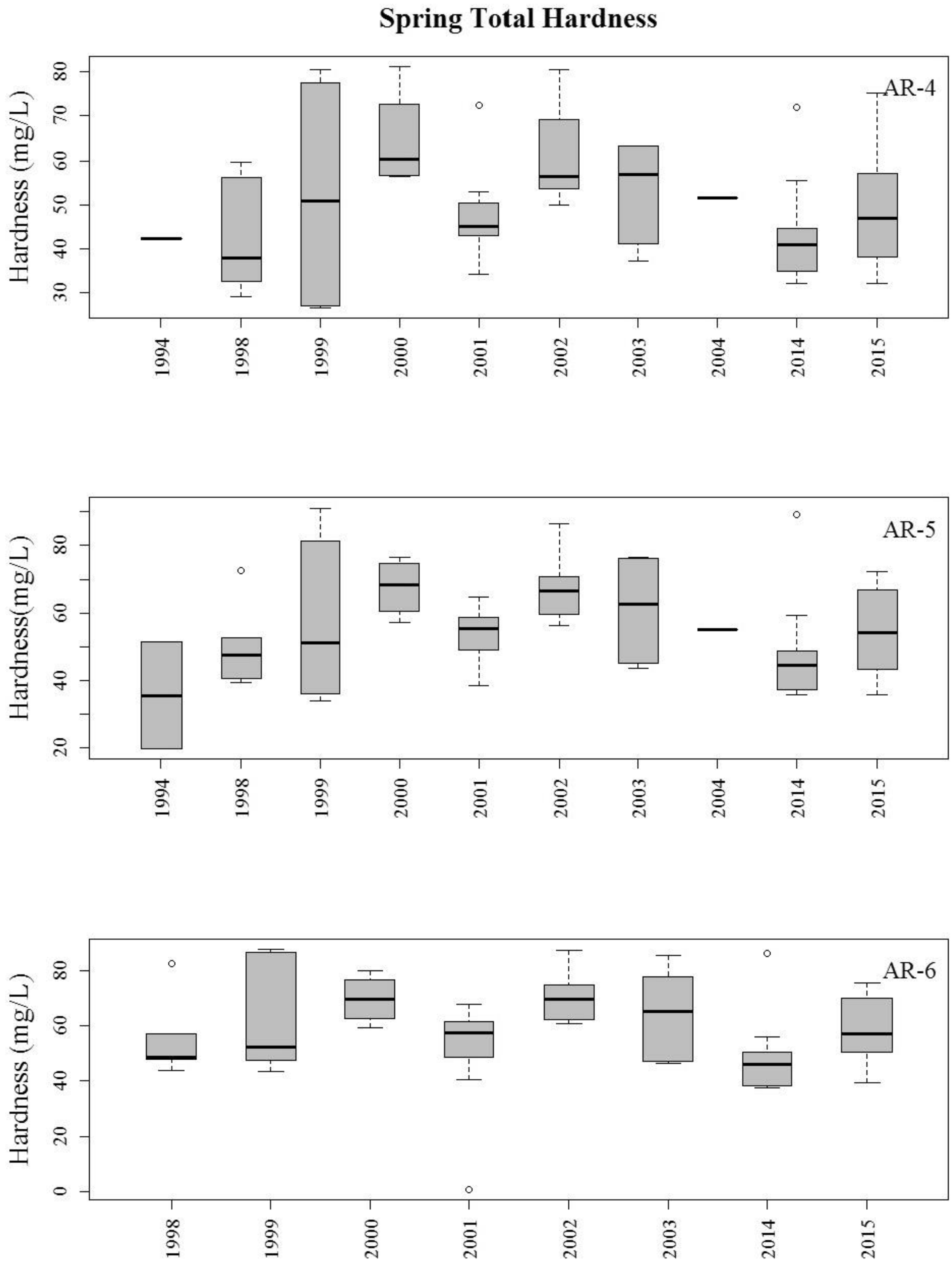


Figure B.36. Total water hardness (as mg/L $CaCO_3$) summarized seasonally (April-July) at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River.

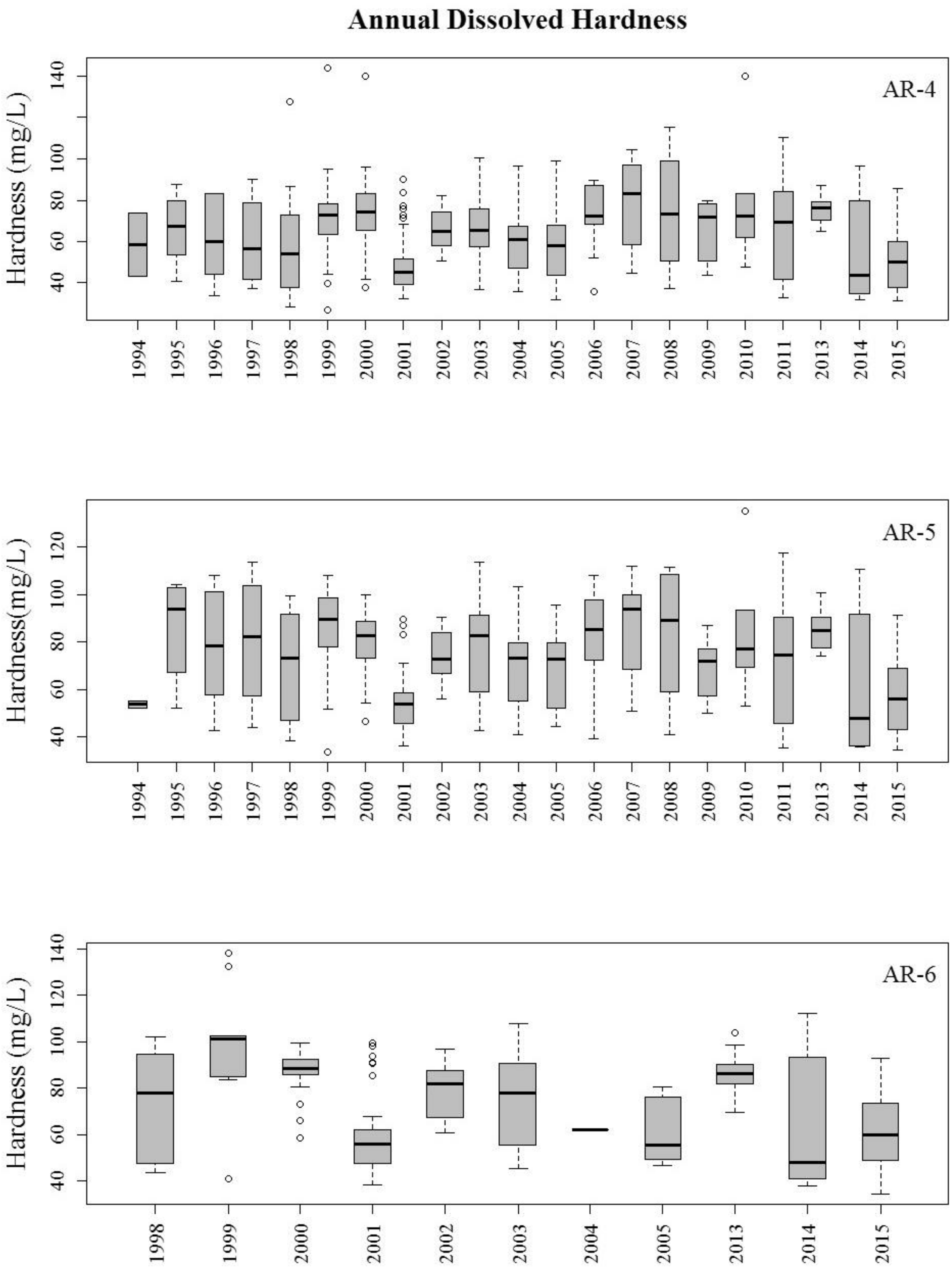


Figure B.37. Dissolved water hardness (as mg/L $CaCO_3$) summarized annually at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River.

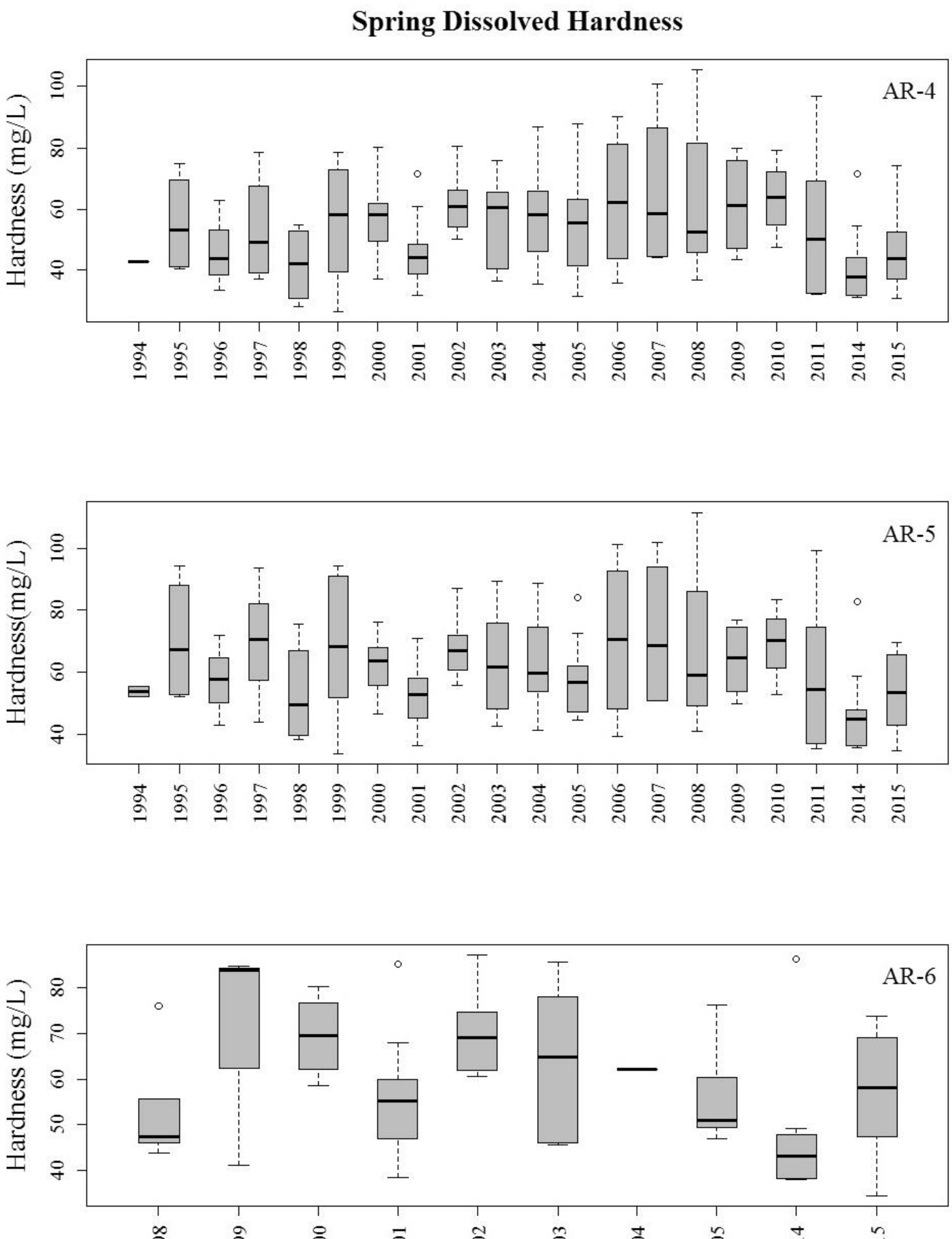


Figure B.38. Dissolved water hardness (as mg/L $CaCO_3$) summarized seasonally (April-July) at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River.

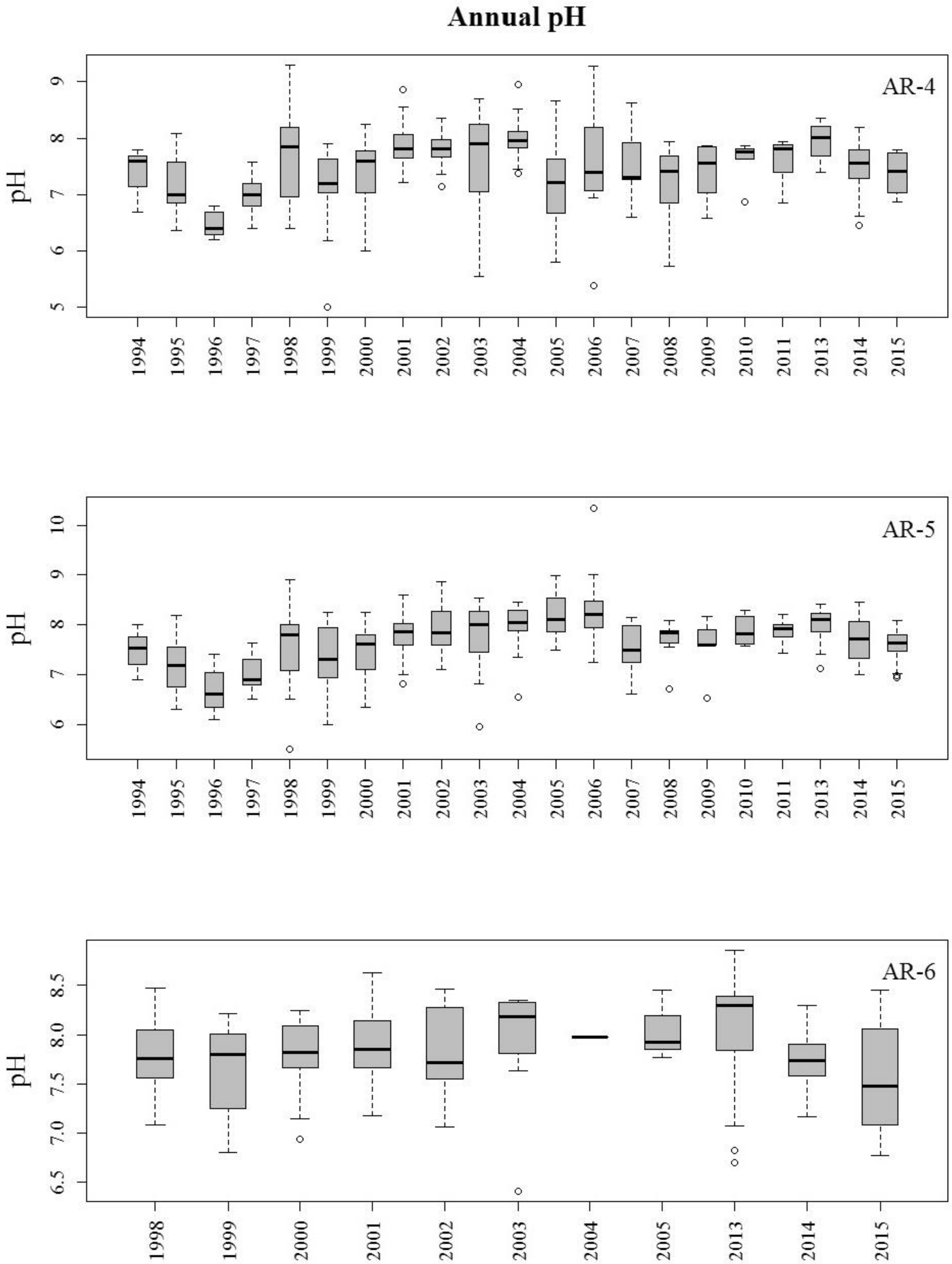


Figure B.39. Observed pH values summarized annually at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River.

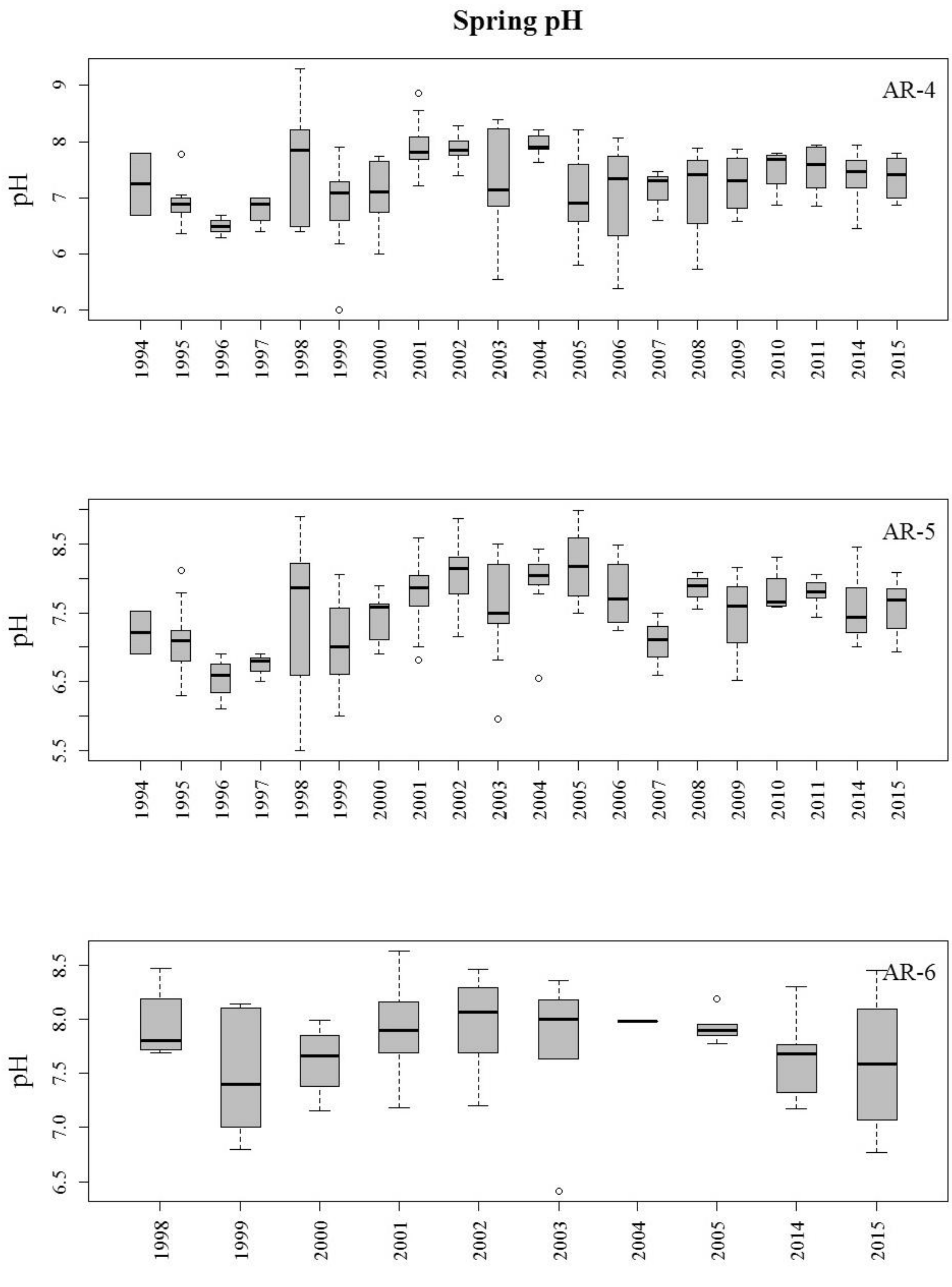


Figure B.40. Observed pH values summarized seasonally (April-July) at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River.

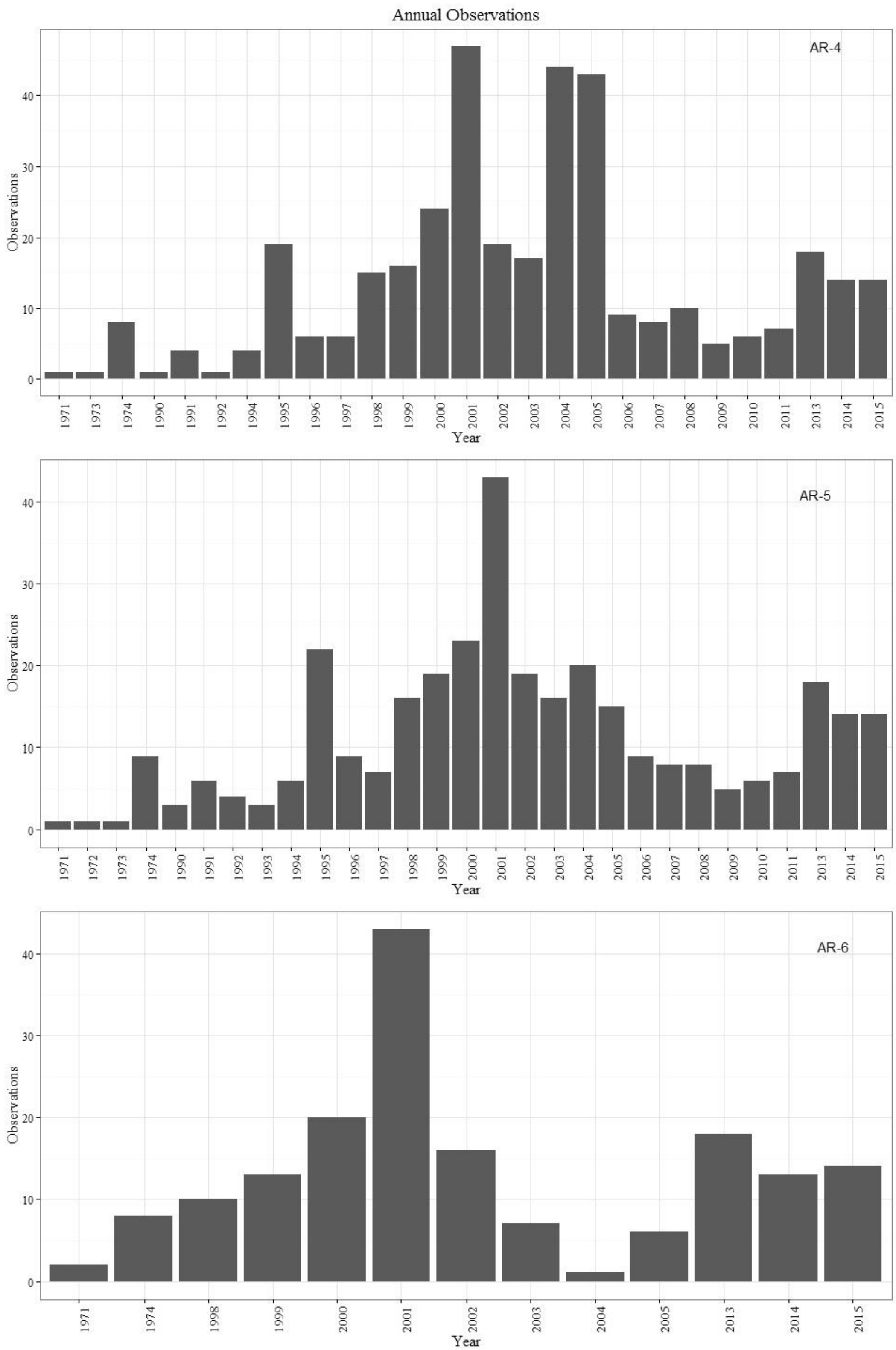


Figure B.41. Number of annual water quality samples for total and dissolved cadmium, lead, and zinc by at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River.

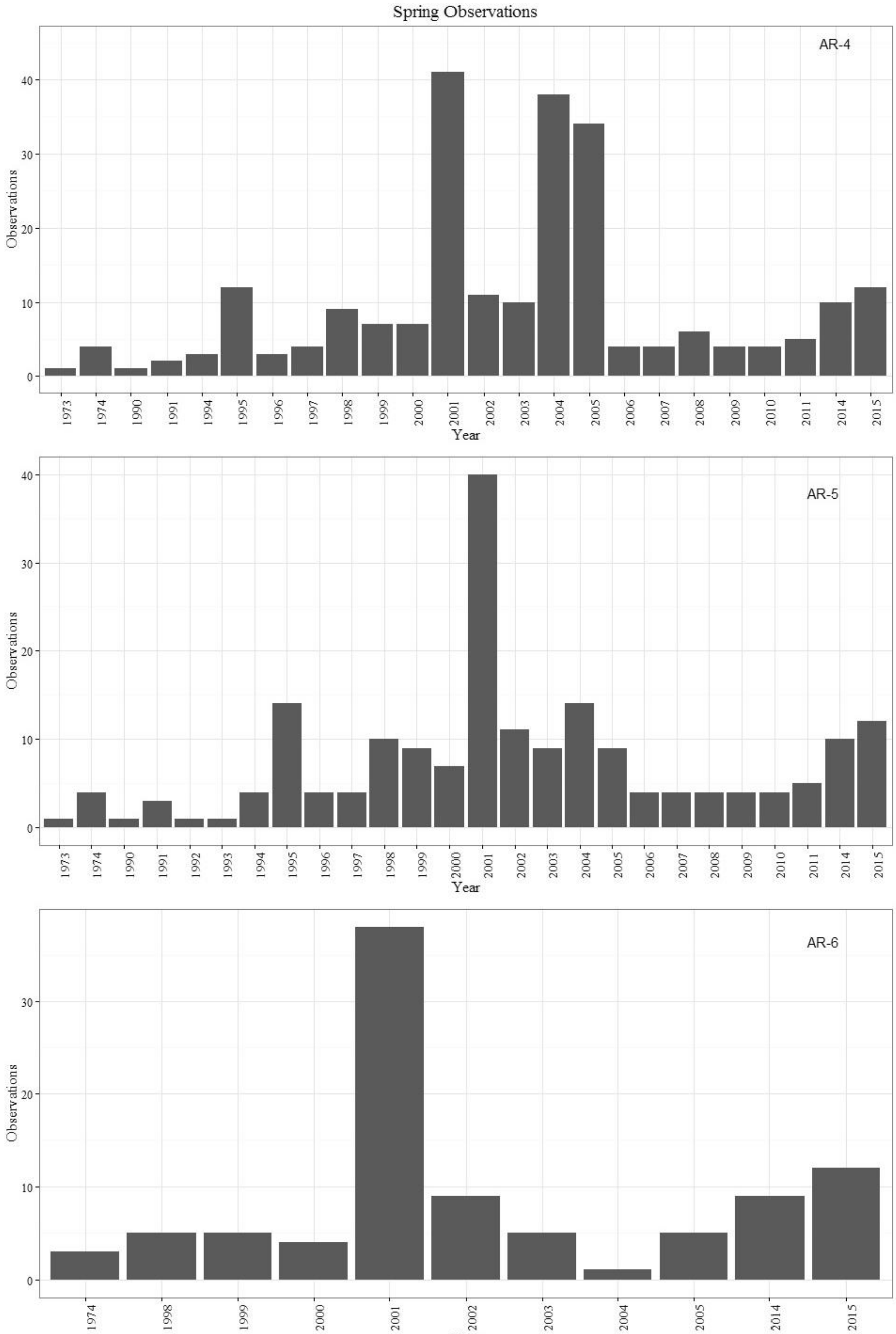


Figure B.42. Number of seasonal (April-July) water quality samples for total and dissolved cadmium, lead, and zinc by at water quality monitoring sites AR-4, AR-5, and AR-6 on the Upper Arkansas River.

Appendix C: Fish Population Monitoring Sites

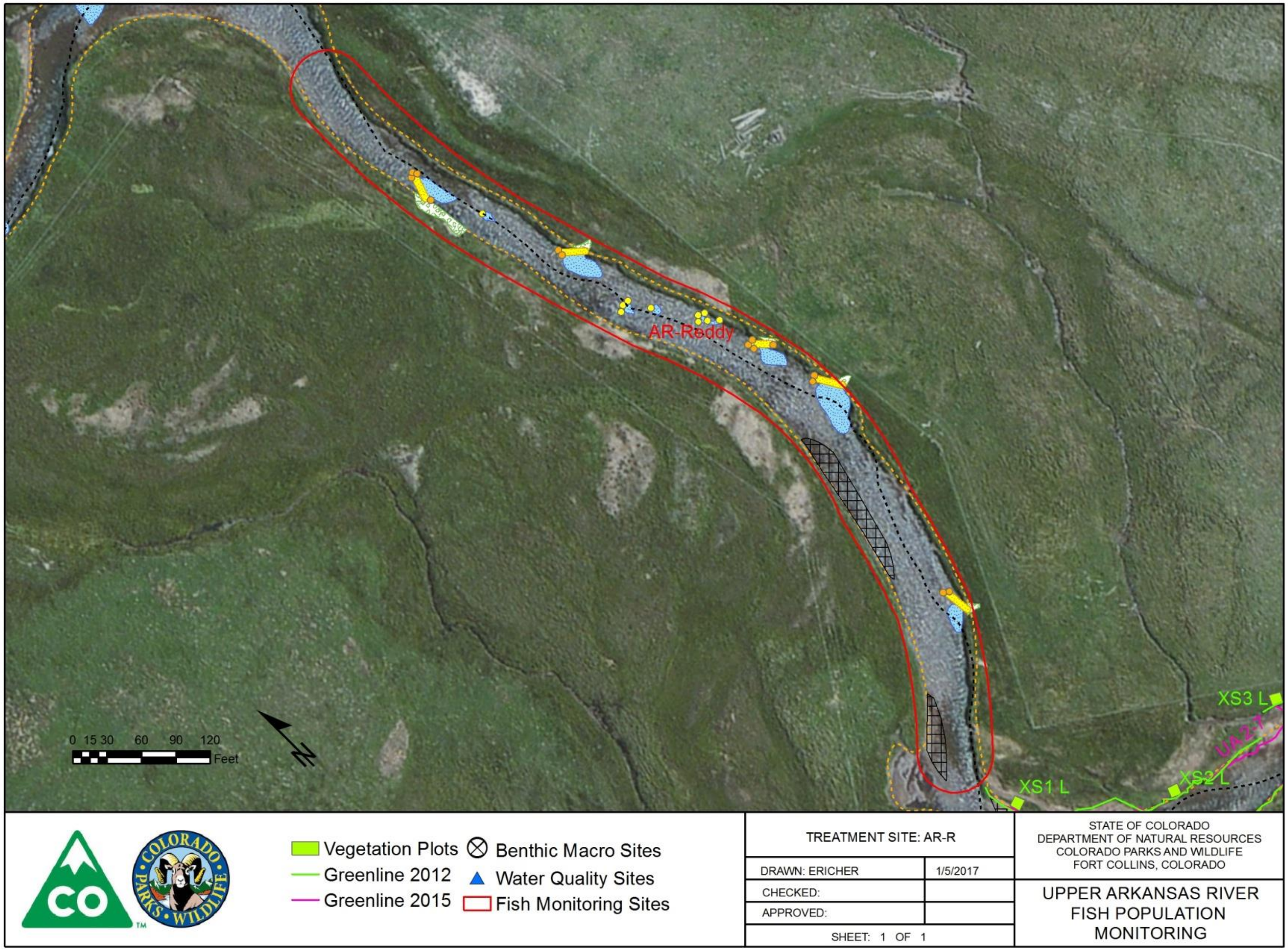


Figure C.1. Aerial image showing habitat treatments within fish monitoring site AR-R on the Upper Arkansas River.

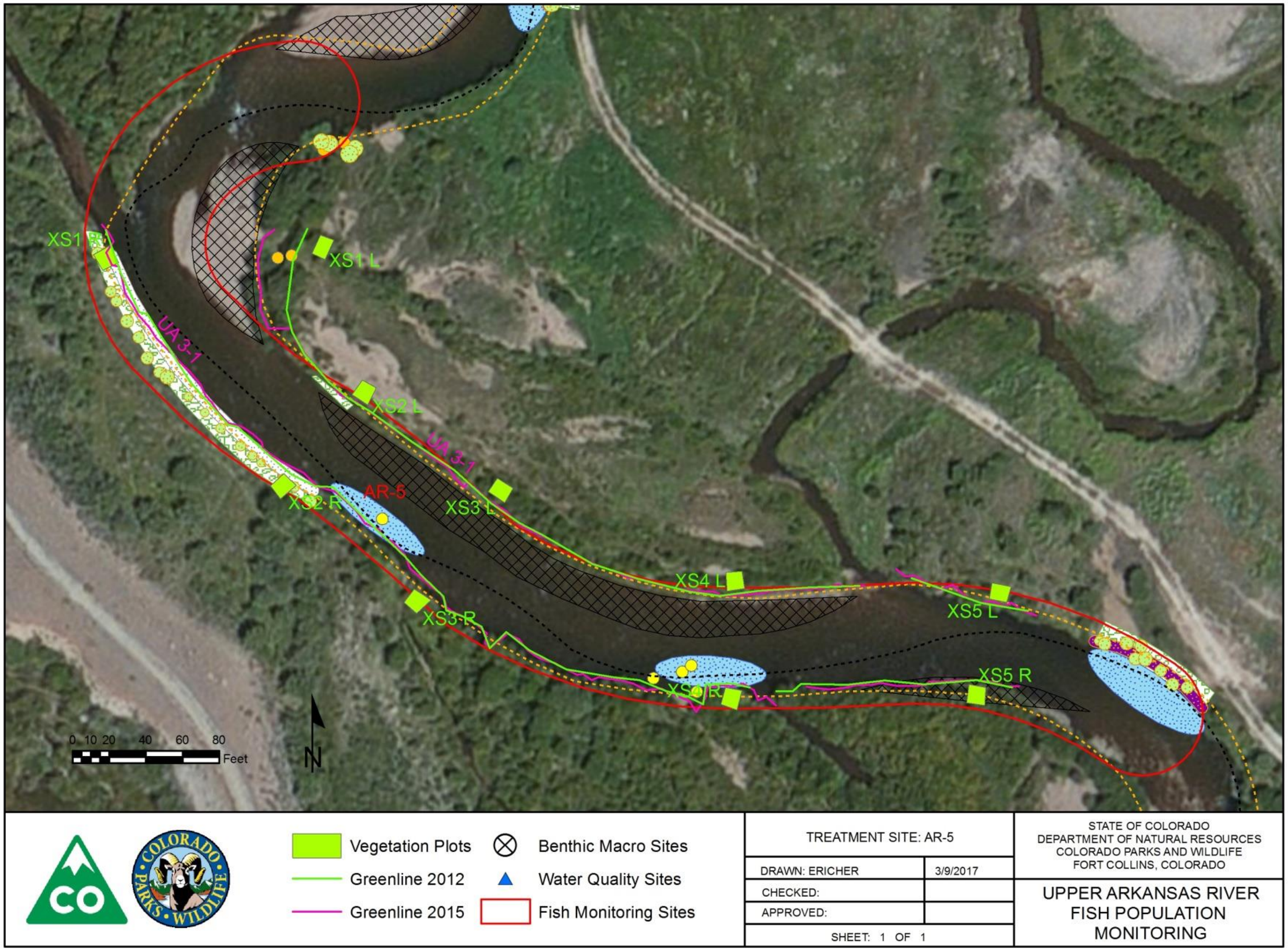


Figure C.2. Aerial image showing habitat treatments within fish monitoring site AR-5 on the Upper Arkansas River.

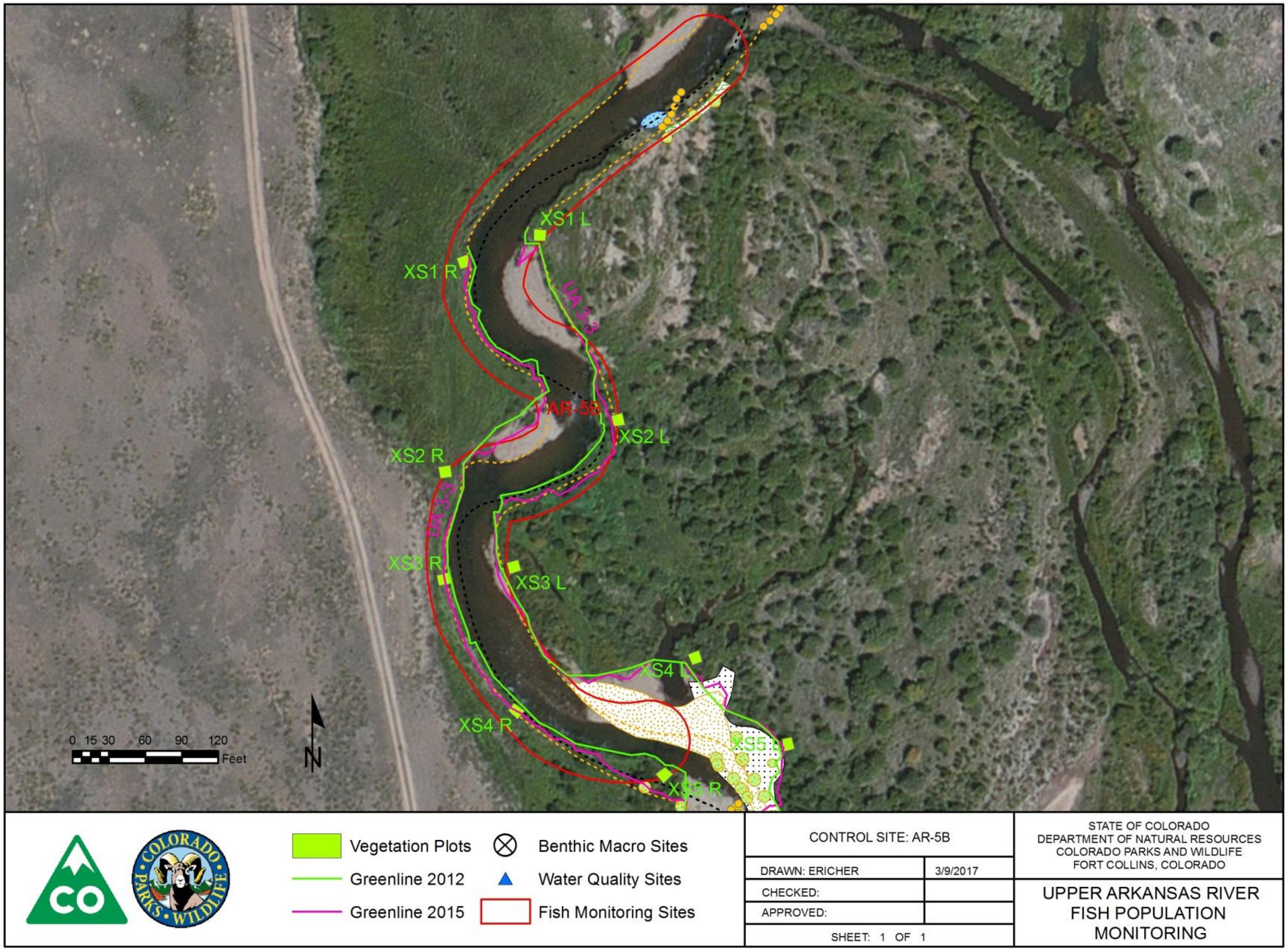


Figure C.3. Aerial image for fish monitoring control site AR-5B on the Upper Arkansas River.

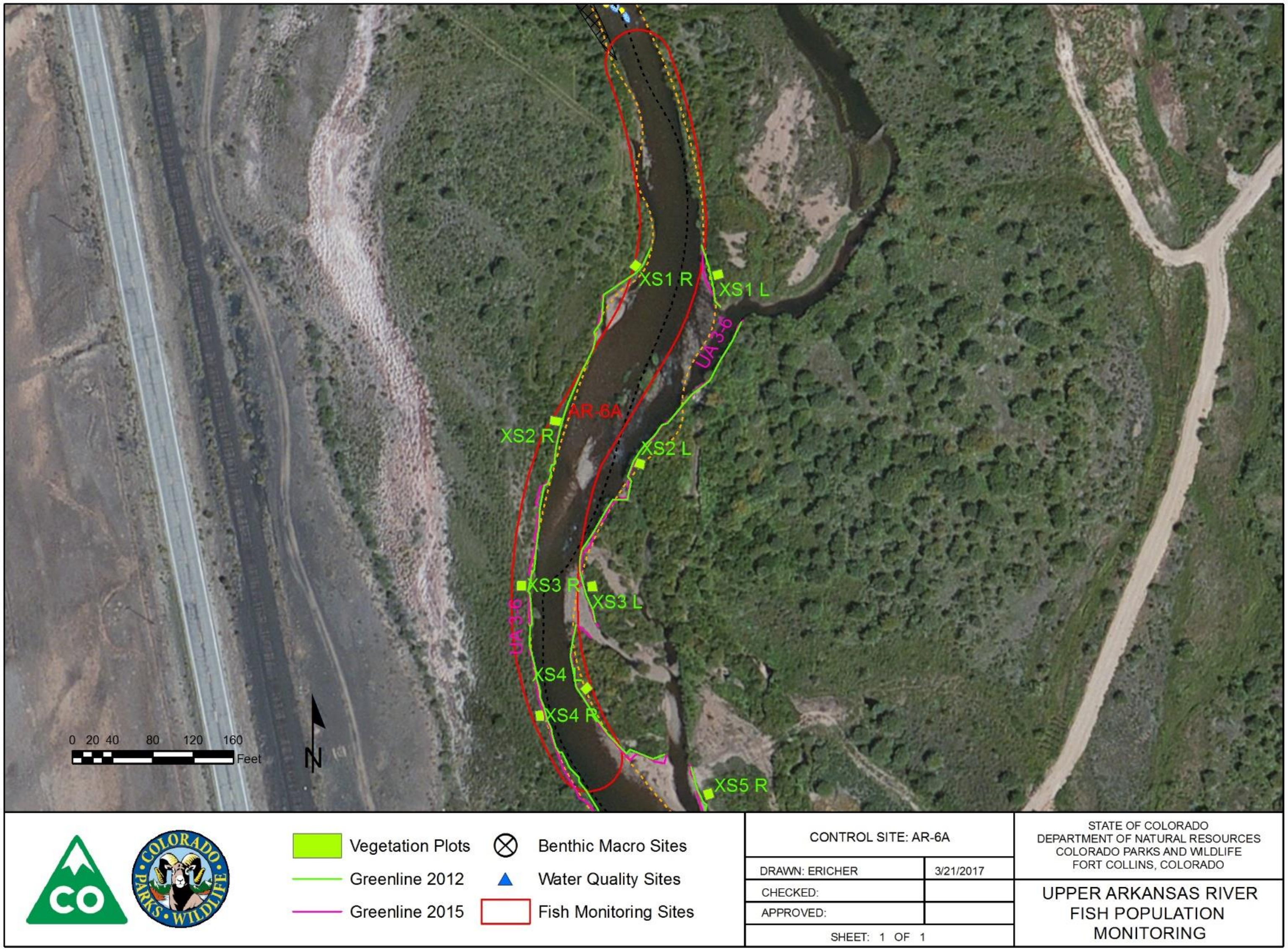


Figure C.4. Aerial image for fish monitoring control site AR-6A on the Upper Arkansas River.

Figure C.5. Aerial image showing habitat treatments within fish monitoring site AR-MH on the Upper Arkansas River.

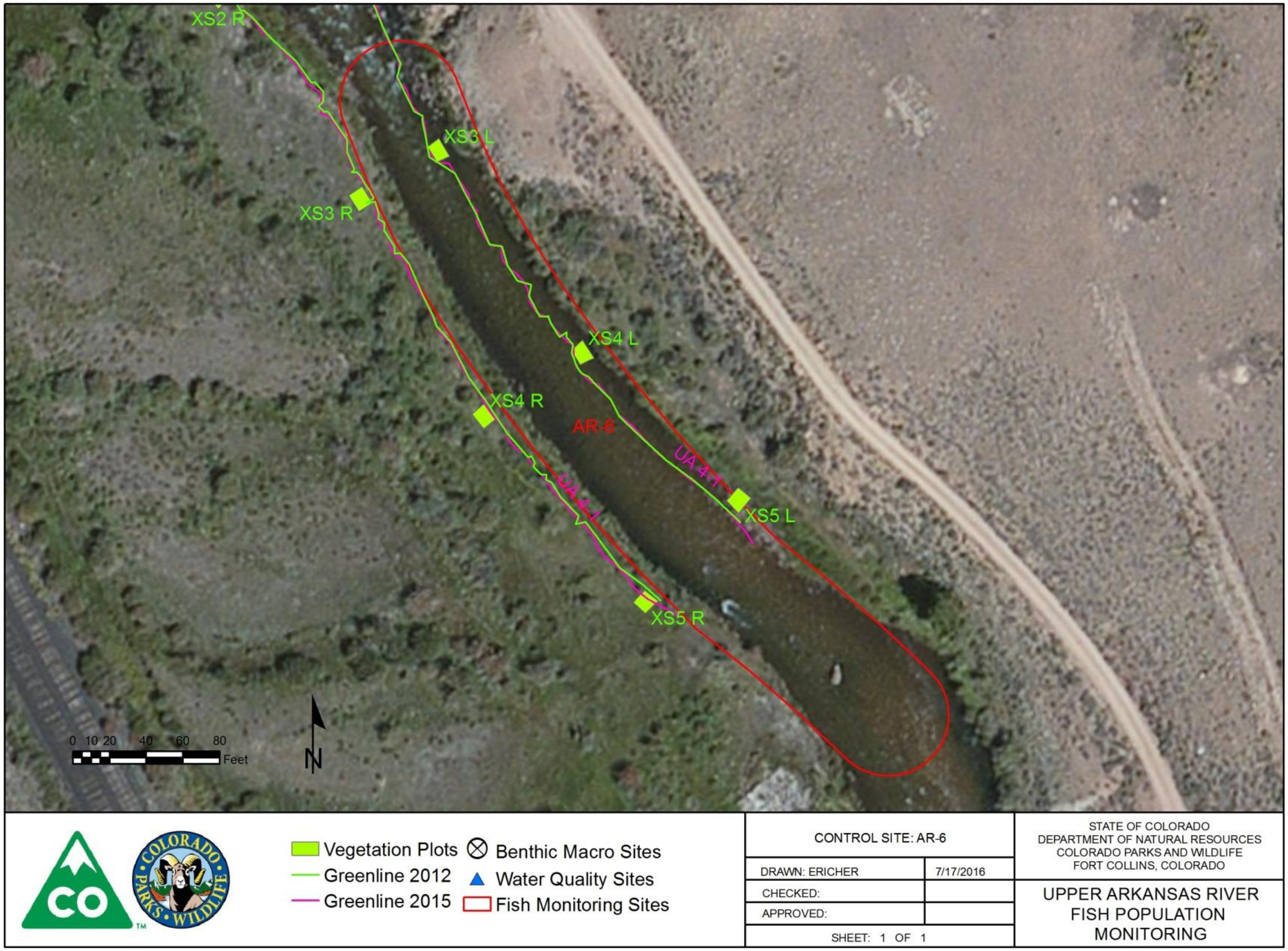


Figure C.6. Aerial image for fish monitoring control site AR-6 on the Upper Arkansas River.

Appendix D: Benthic Macroinvertebrate Monitoring Sites

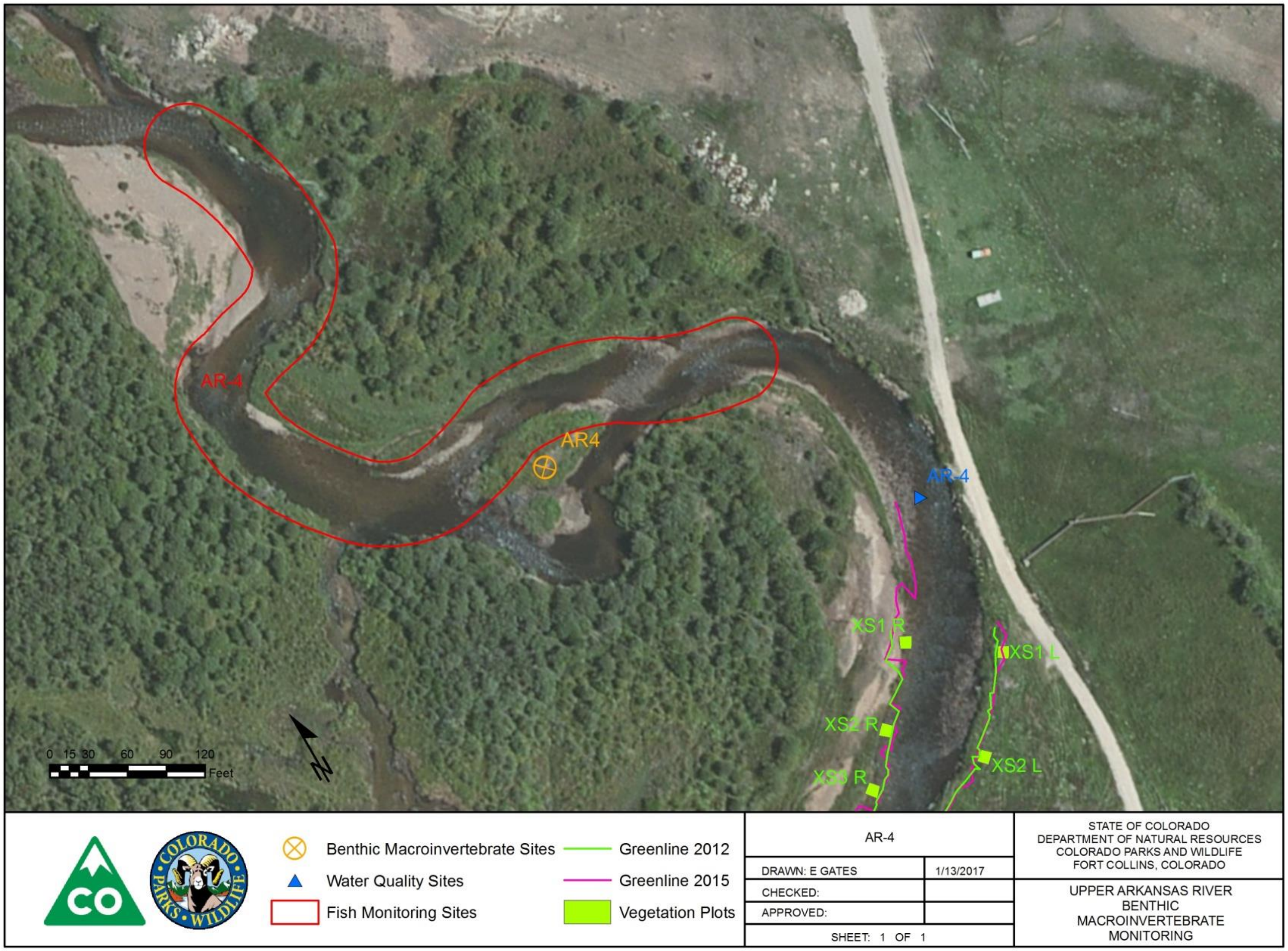


Figure D.1. Treatment site AR-4 used for benthic macroinvertebrate monitoring in the Upper Arkansas River, note that habitat treatments are not shown for this site.

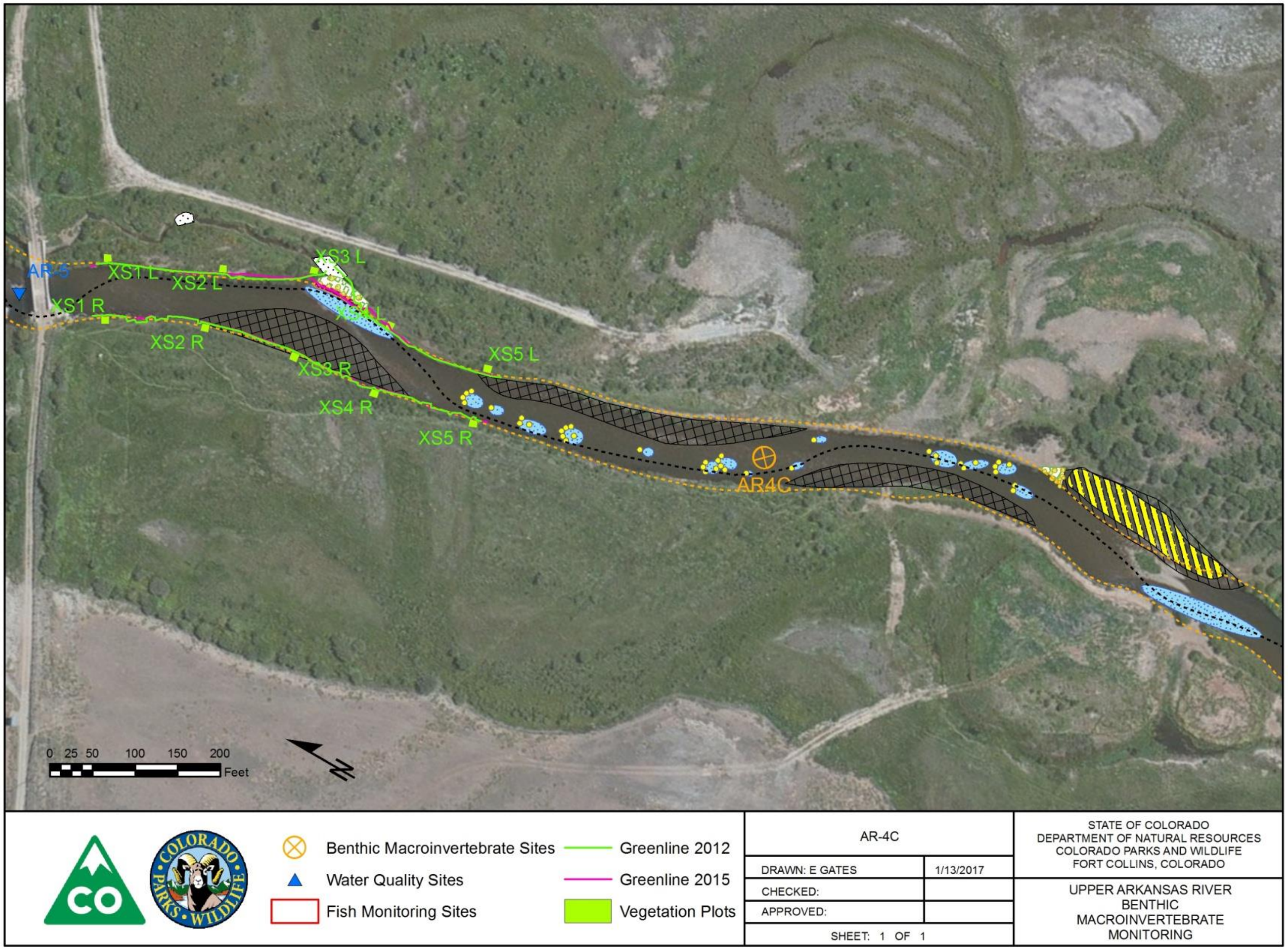


Figure D.2. Treatment site AR-4.C used for benthic macroinvertebrate monitoring in the Upper Arkansas River, including the location of habitat treatments.

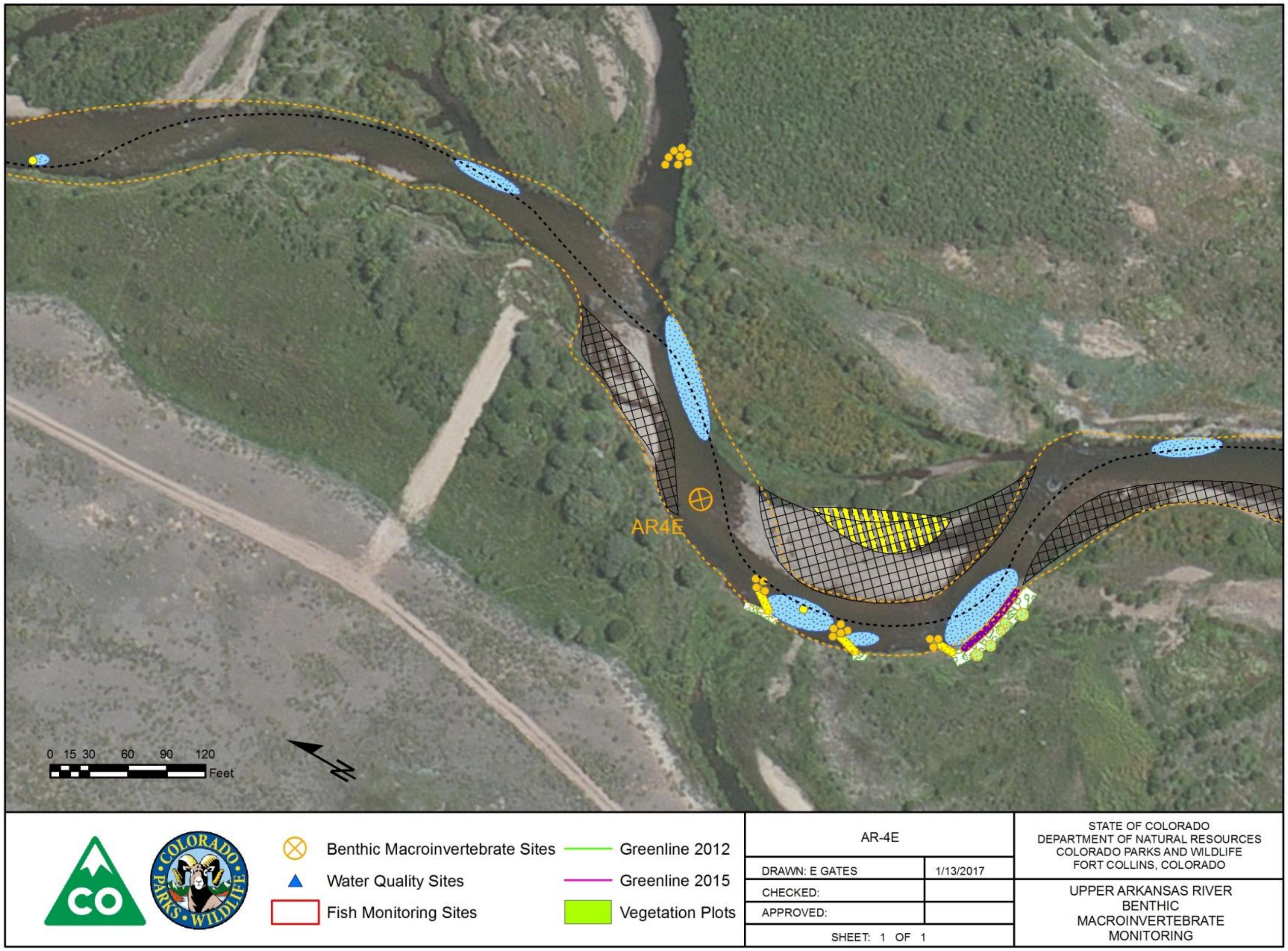


Figure D.3. Treatment site AR-4.E used for benthic macroinvertebrate monitoring in the Upper Arkansas River, including the location of habitat treatments.

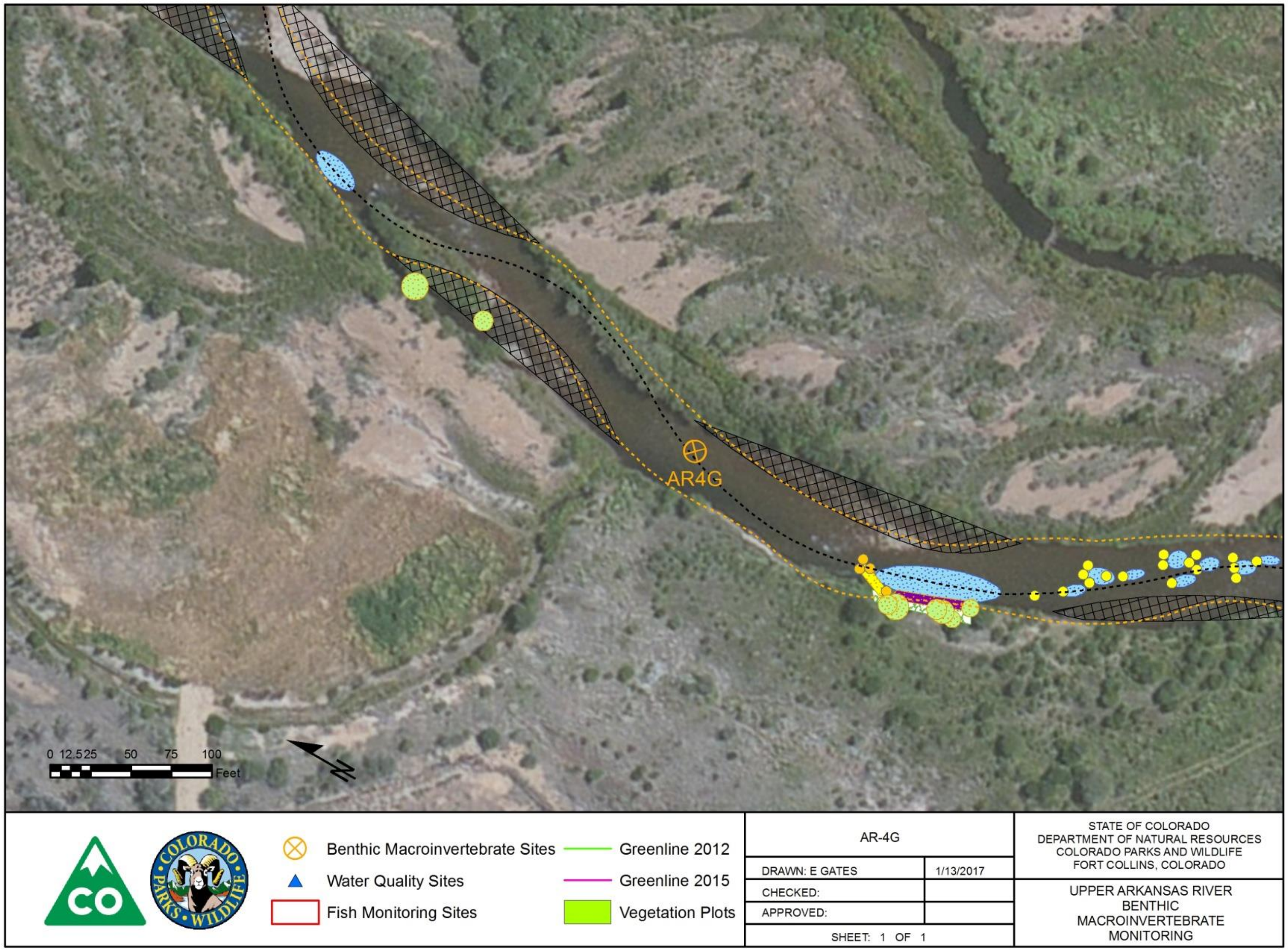


Figure D.4. Treatment site AR-4.G used for benthic macroinvertebrate monitoring in the Upper Arkansas River, including the location of habitat treatments.

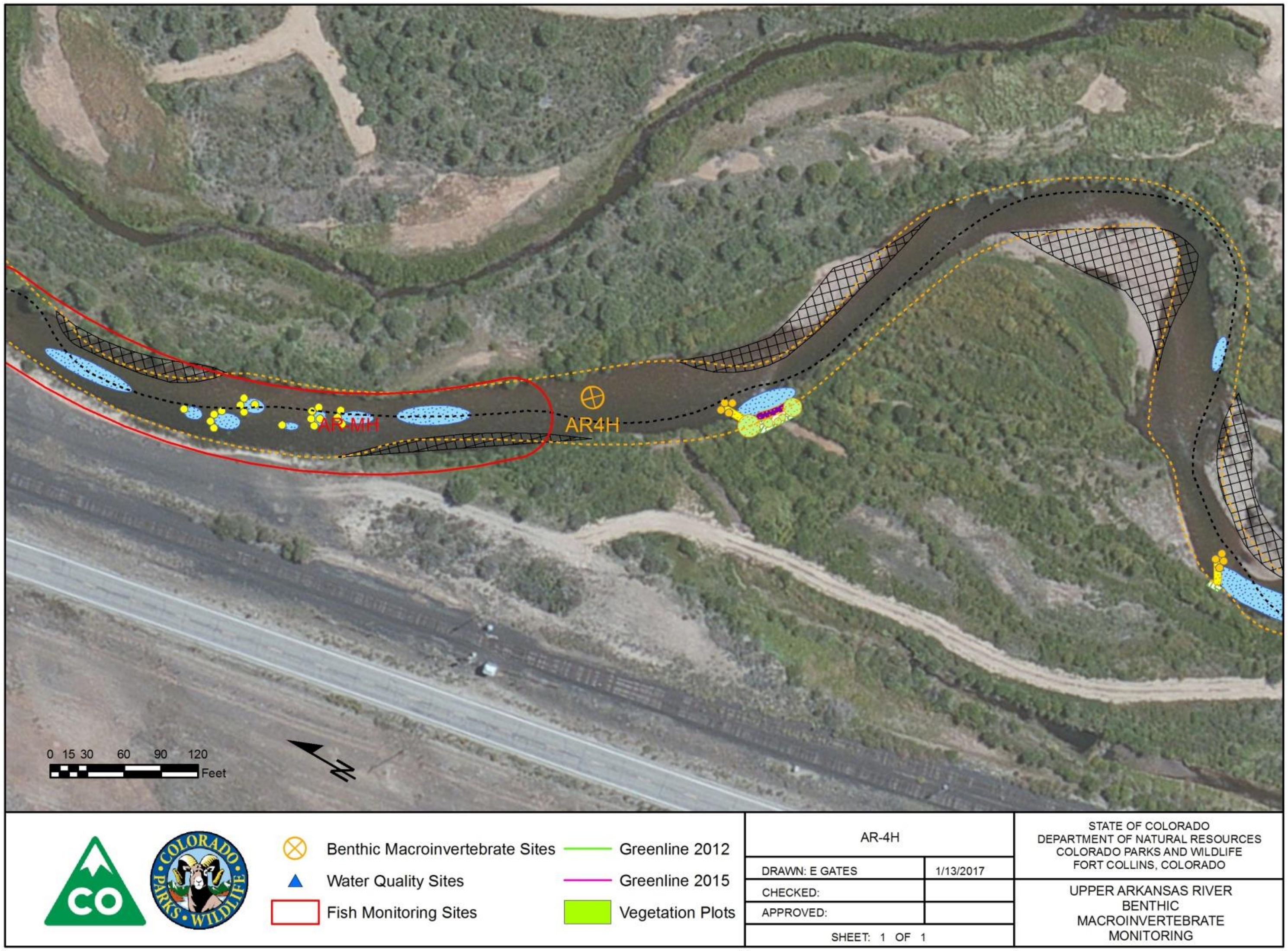


Figure D.5. Treatment site AR-4.H used for benthic macroinvertebrate monitoring in the Upper Arkansas River, including the location of habitat treatments.

Figure D.6. Control site AR-5.Kobe used for benthic macroinvertebrate monitoring in the Upper Arkansas River.

Appendix E: Riparian Vegetation Monitoring Sites

Figure E.1. Location map for vegetation plots and greenline surveys at vegetation control site 2-2 on the Upper Arkansas River, note that habitat treatments are not shown for this site.

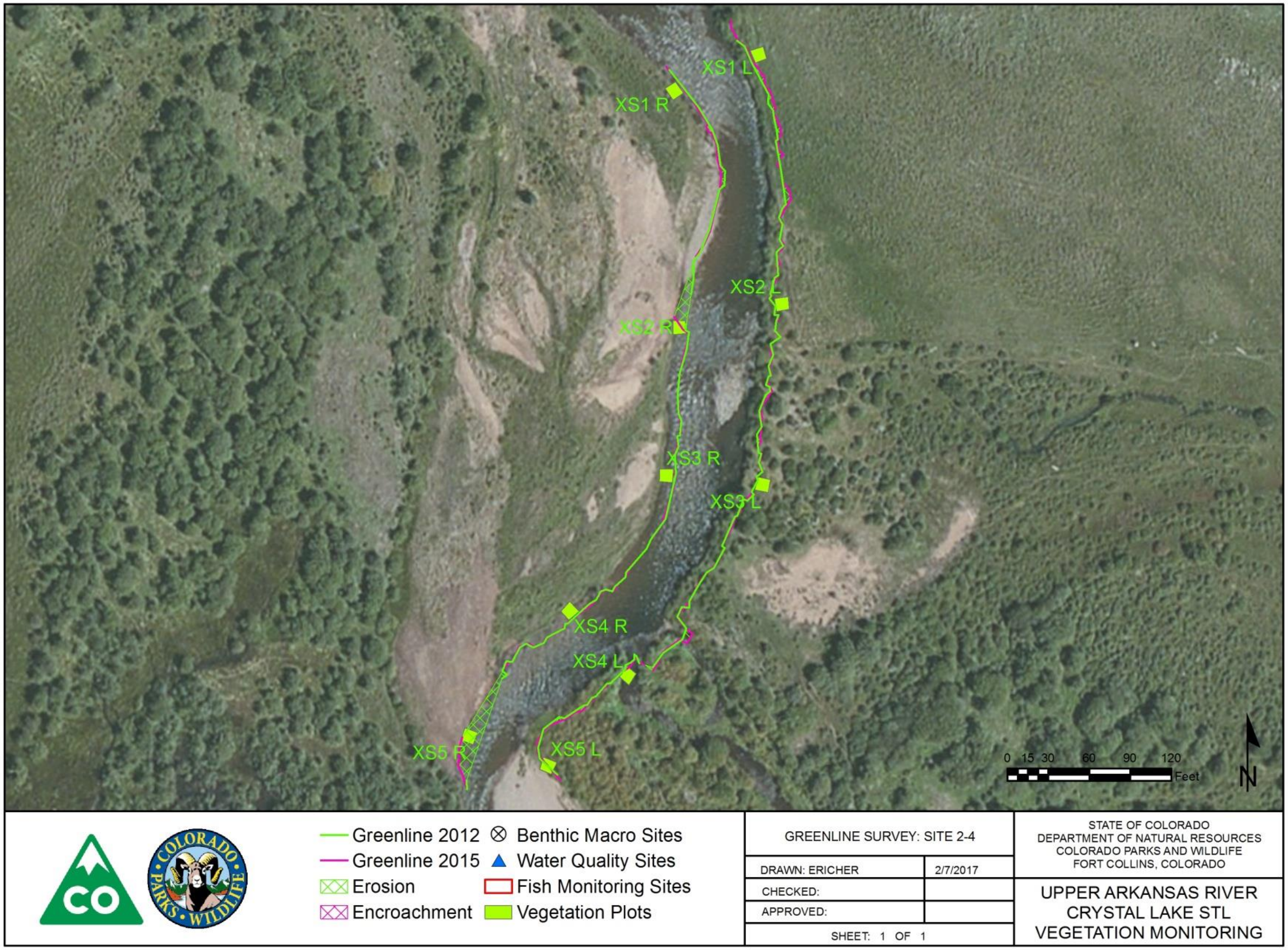


Figure E.2. Location map for vegetation plots and greenline surveys at vegetation control site 2-4 on the Upper Arkansas River.

Figure E.3. Location map for vegetation plots and greenline surveys at vegetation control site 2-5 on the Upper Arkansas River.

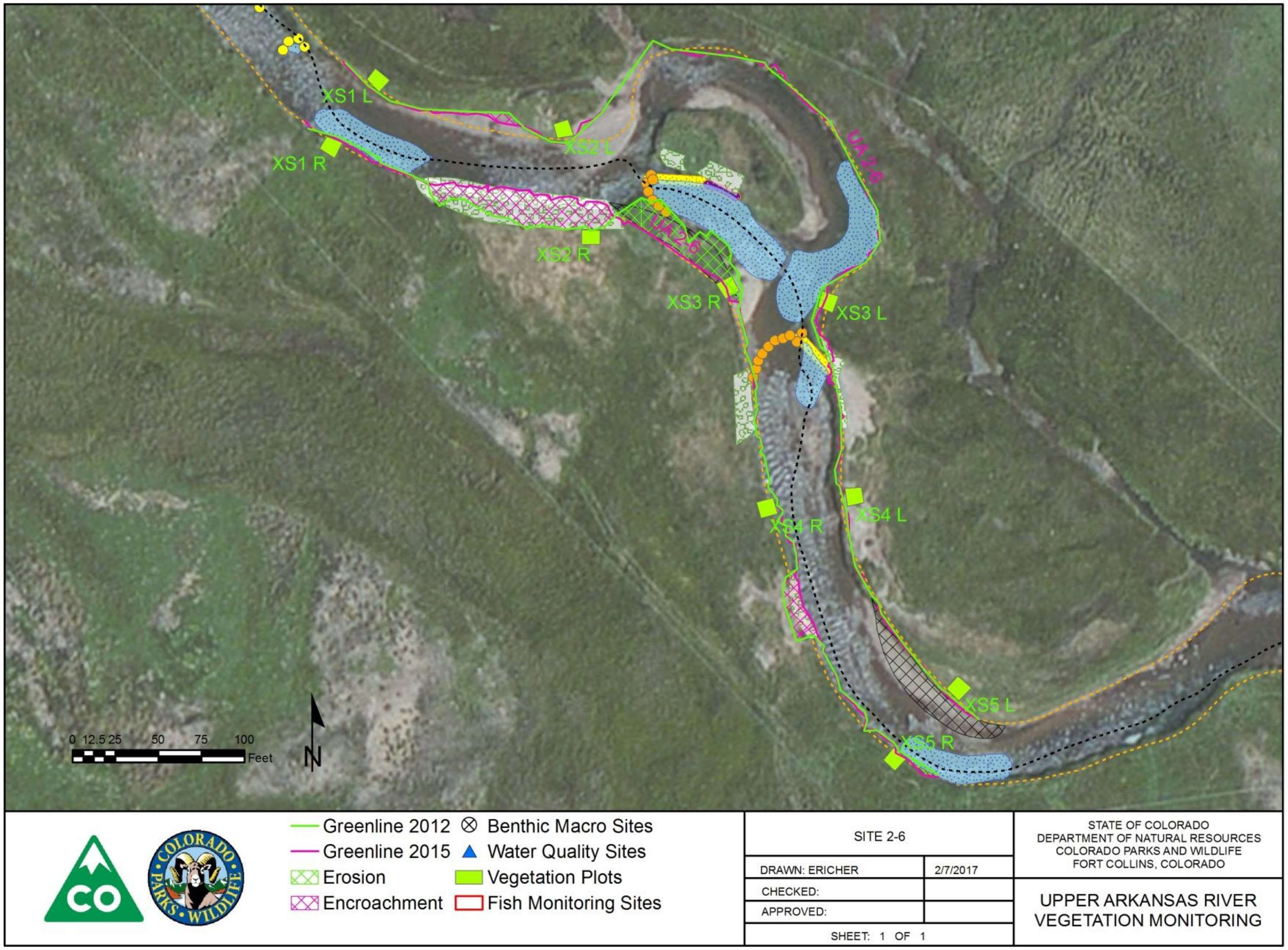


Figure E.4. Location map for vegetation plots and greenline surveys at vegetation treatment site 2-6 on the Upper Arkansas River.

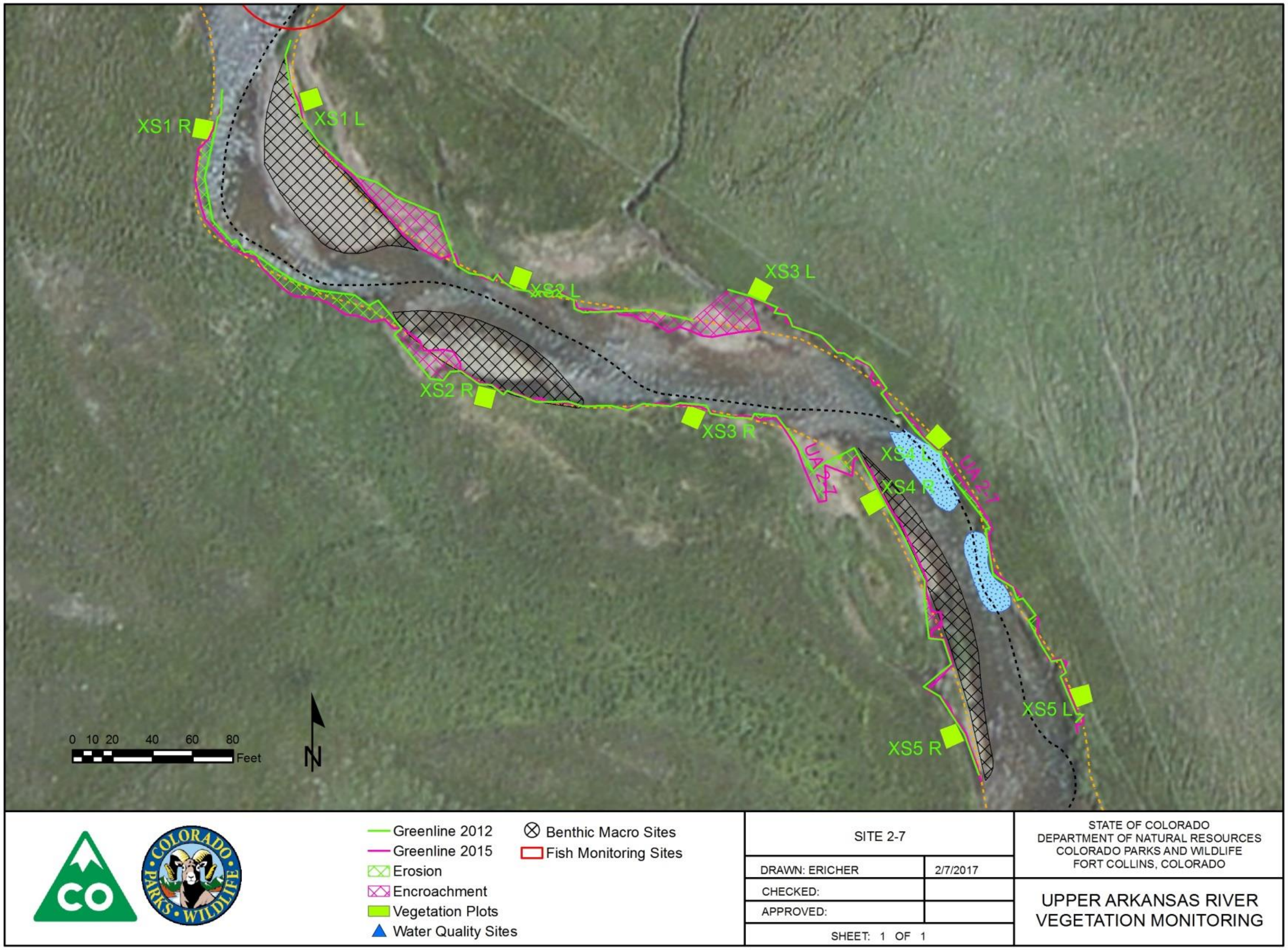


Figure E.5. Location map for vegetation plots and greenline surveys at vegetation treatment site 2-7 on the Upper Arkansas River.

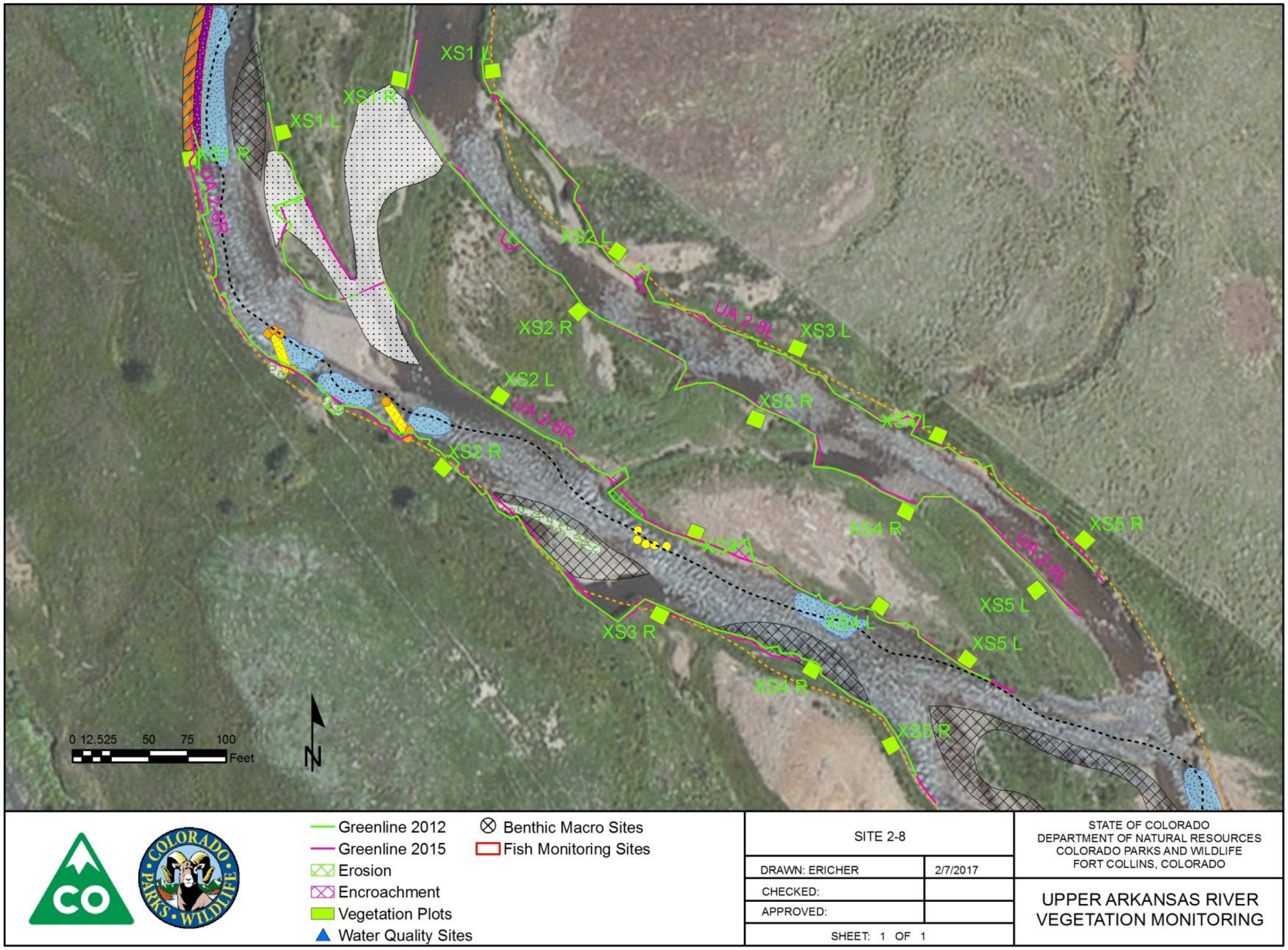


Figure E.6. Location map for vegetation plots and greenline surveys at vegetation treatment site 2-8 on the Upper Arkansas River.

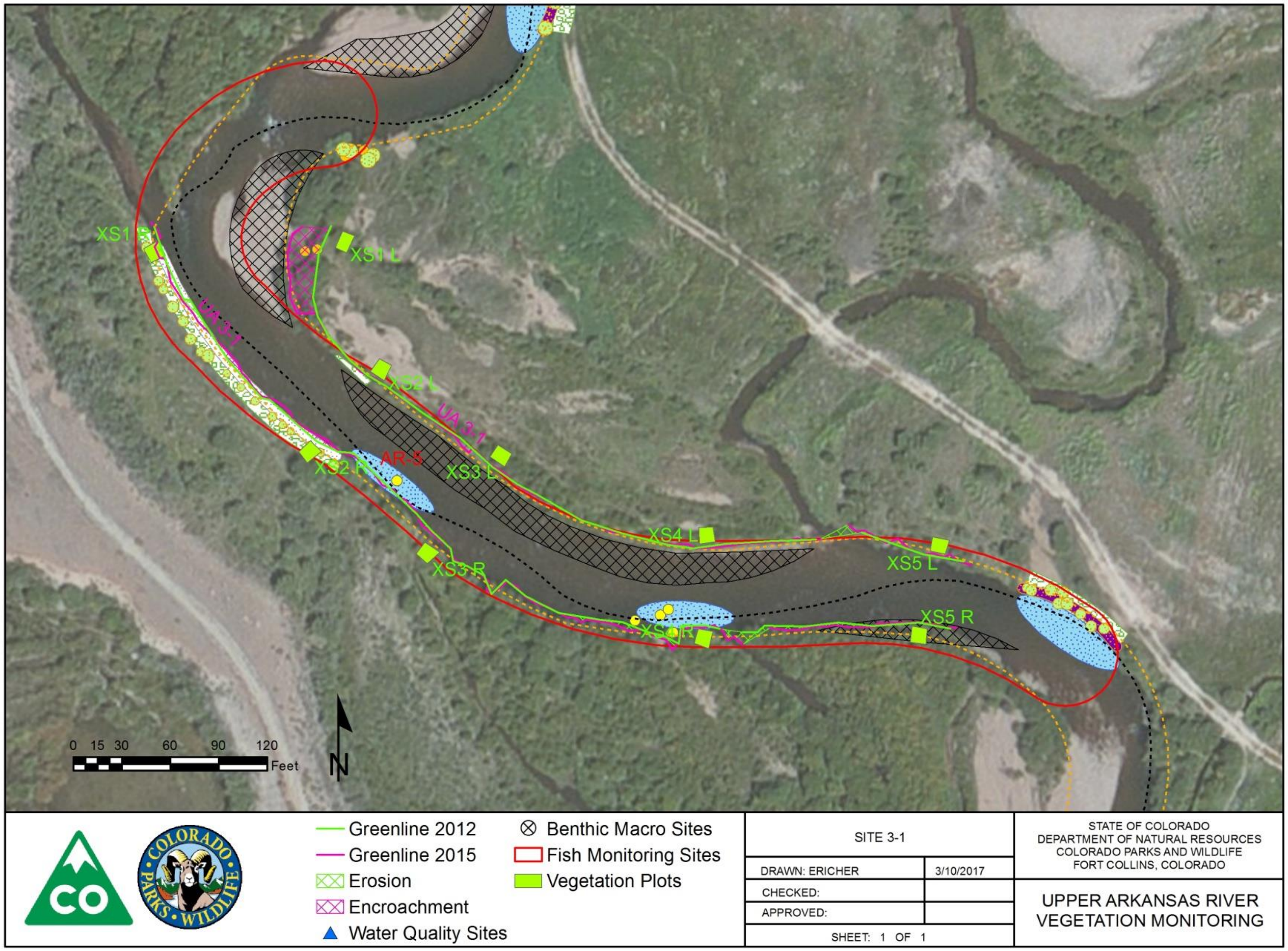


Figure E.7. Location map for vegetation plots and greenline surveys at vegetation treatment site 3-1 on the Upper Arkansas River.

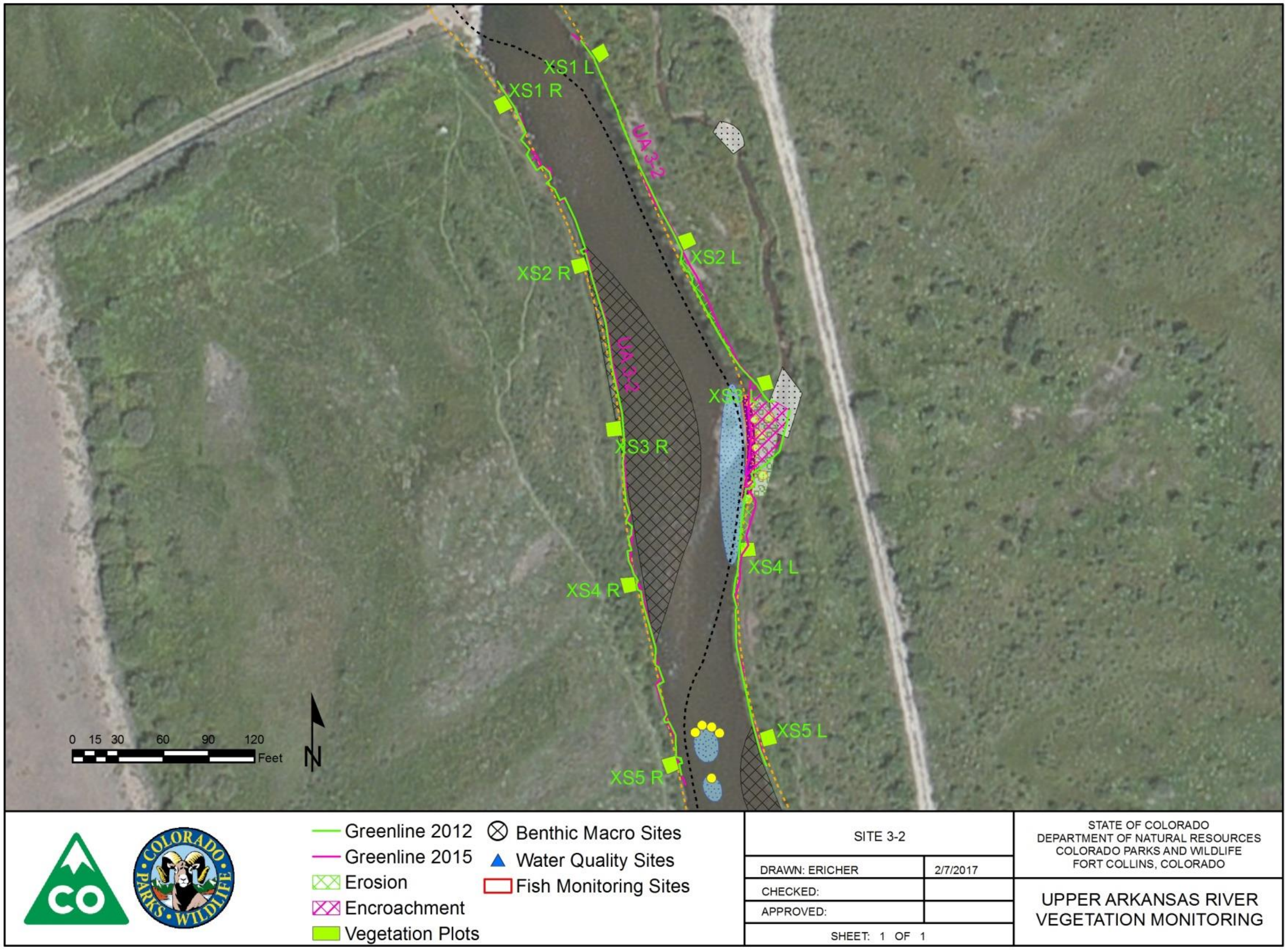


Figure E.8. Location map for vegetation plots and greenline surveys at vegetation treatment site 3-2 on the Upper Arkansas River.

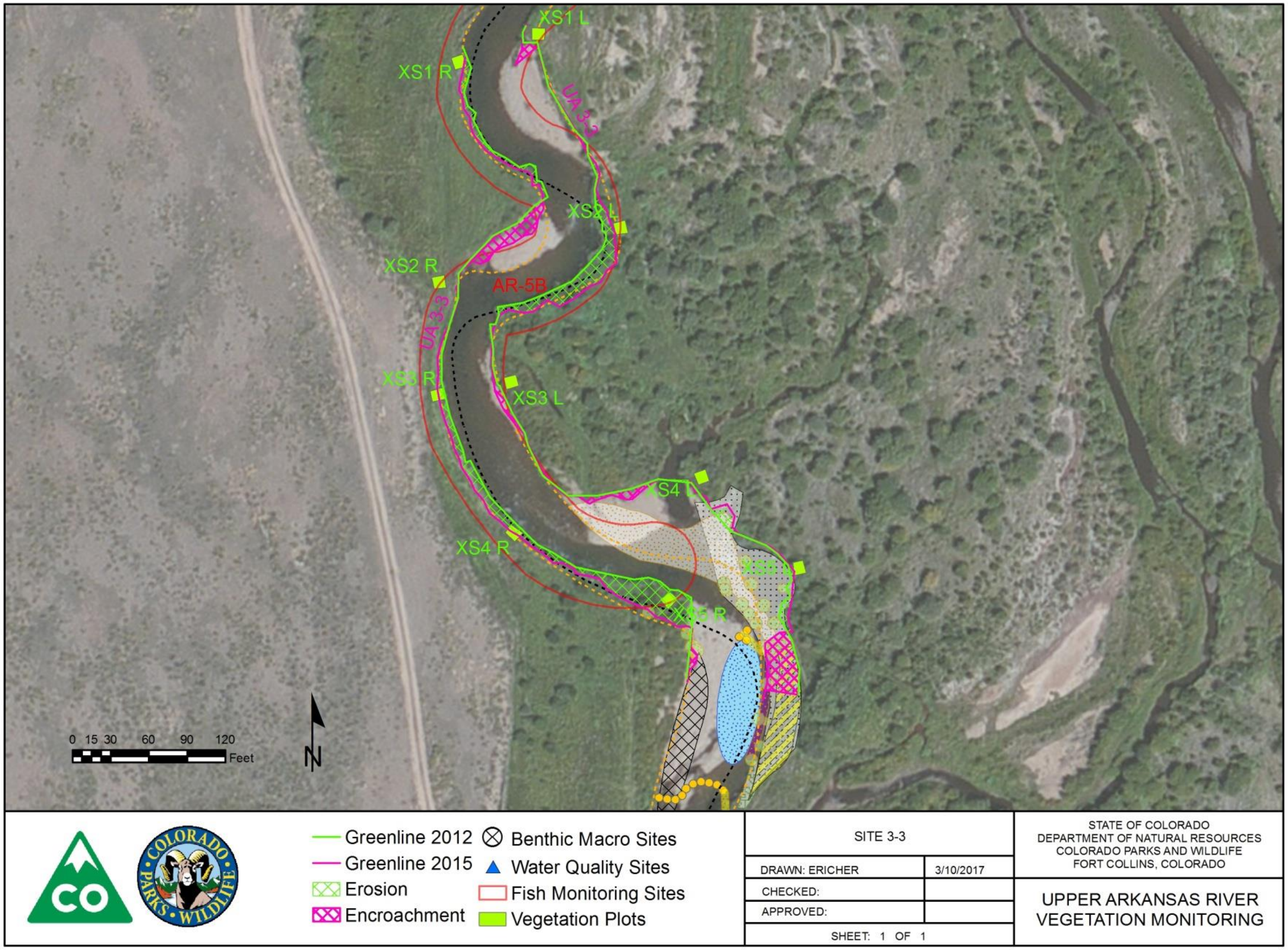


Figure E.9. Location map for vegetation plots and greenline surveys at vegetation treatment site 3-3 on the Upper Arkansas River, note that this site was initially delineated as a control site but is now considered a treatment site due to construction impacts on the lower portion of the site.

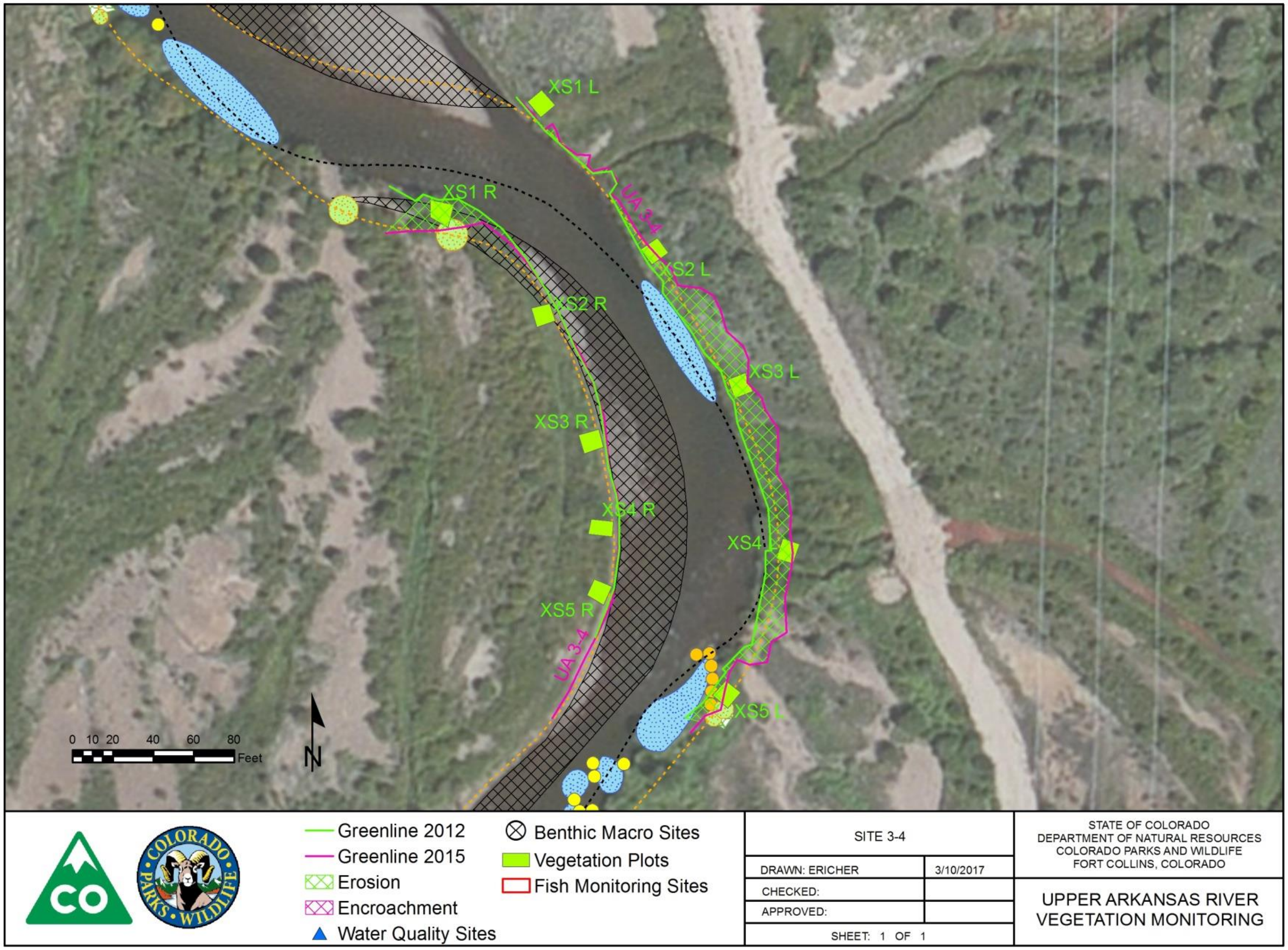


Figure E.10. Location map for vegetation plots and greenline surveys at vegetation treatment site 3-4 on the Upper Arkansas River.

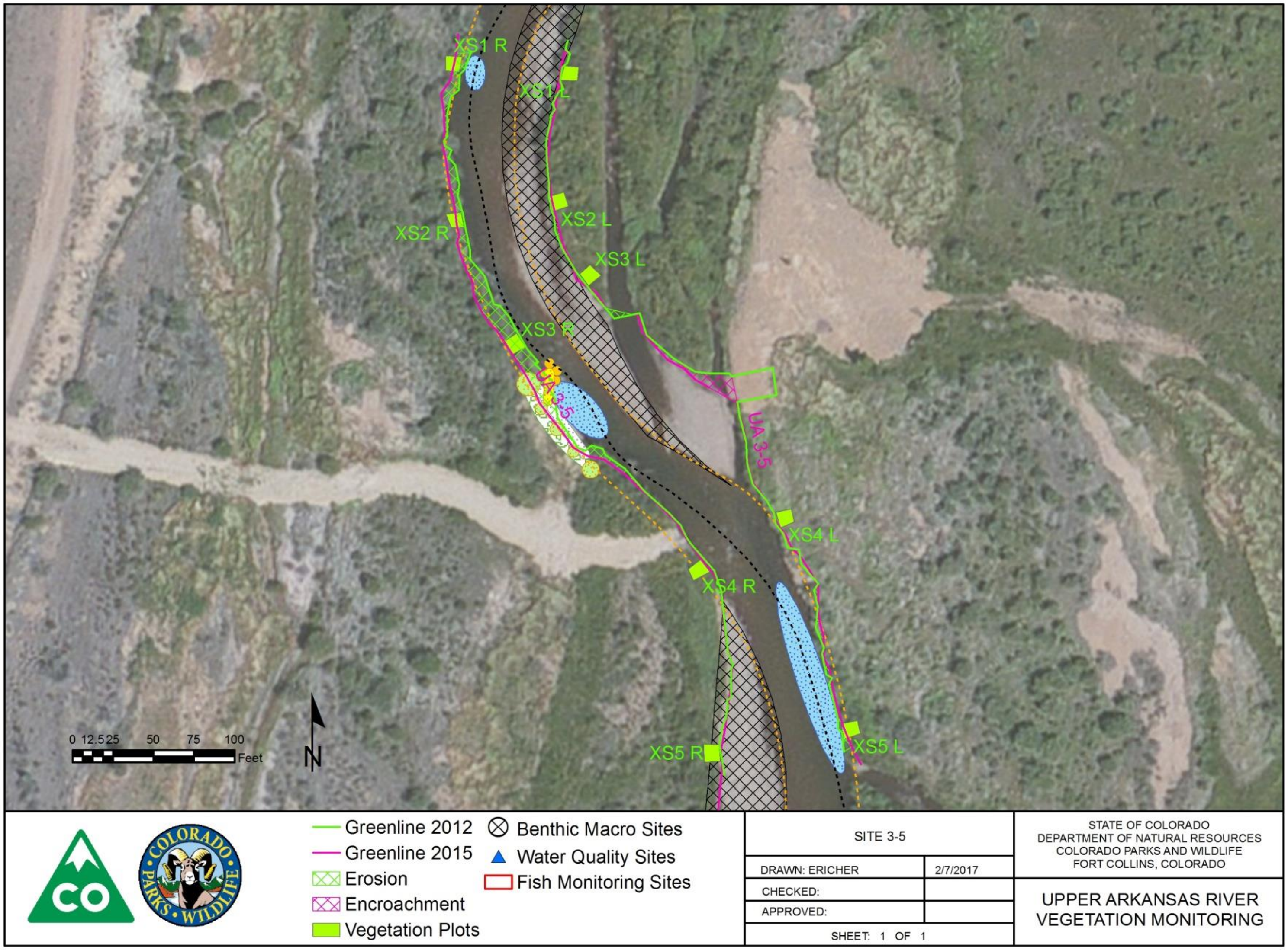


Figure E.11. Location map for vegetation plots and greenline surveys at vegetation treatment site 3-5 on the Upper Arkansas River.

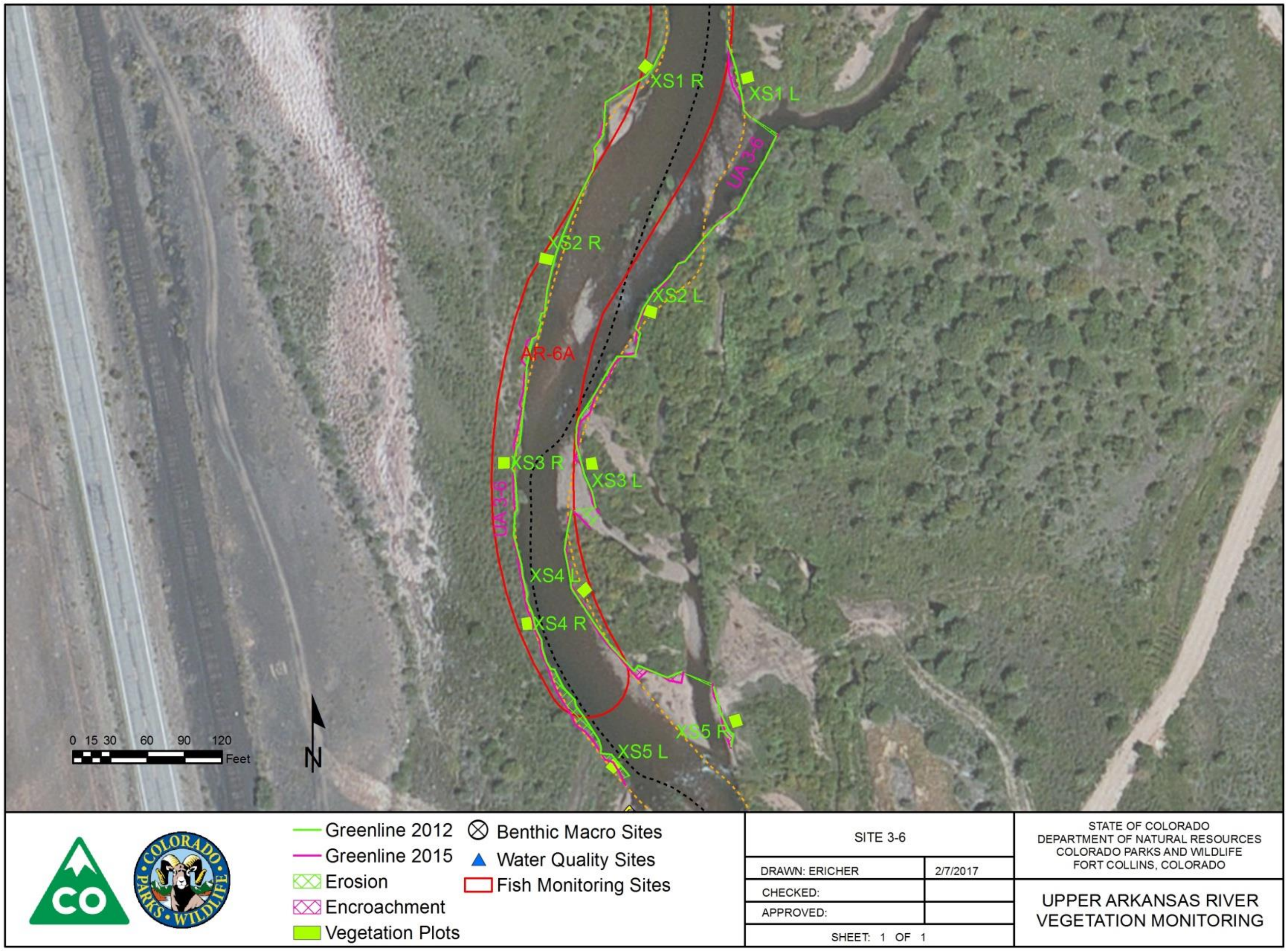


Figure E.12. Location map for vegetation plots and greenline surveys at vegetation control site 3-6 on the Upper Arkansas River.

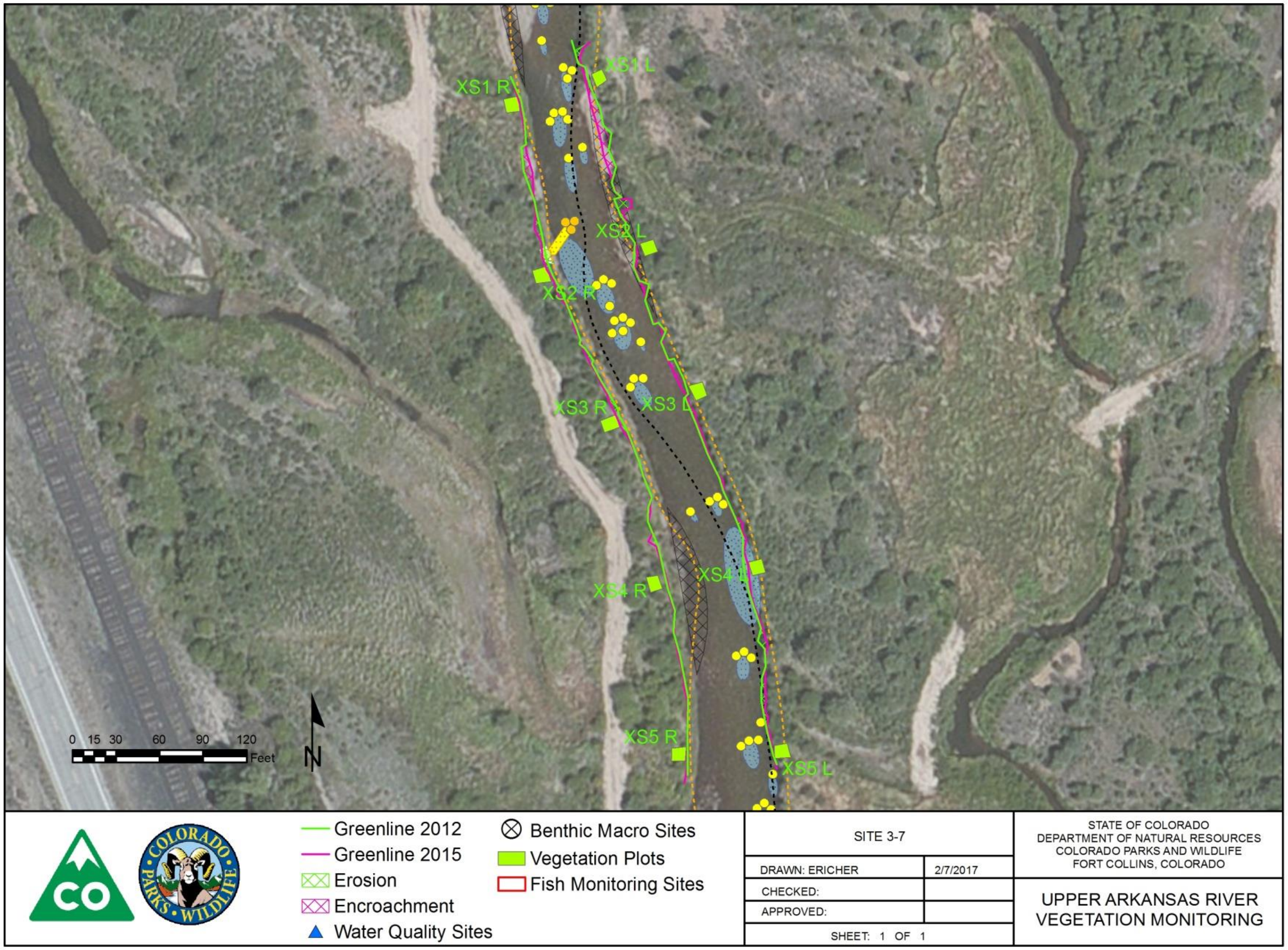


Figure E.13. Location map for vegetation plots and greenline surveys at vegetation treatment site 3-7 on the Upper Arkansas River.

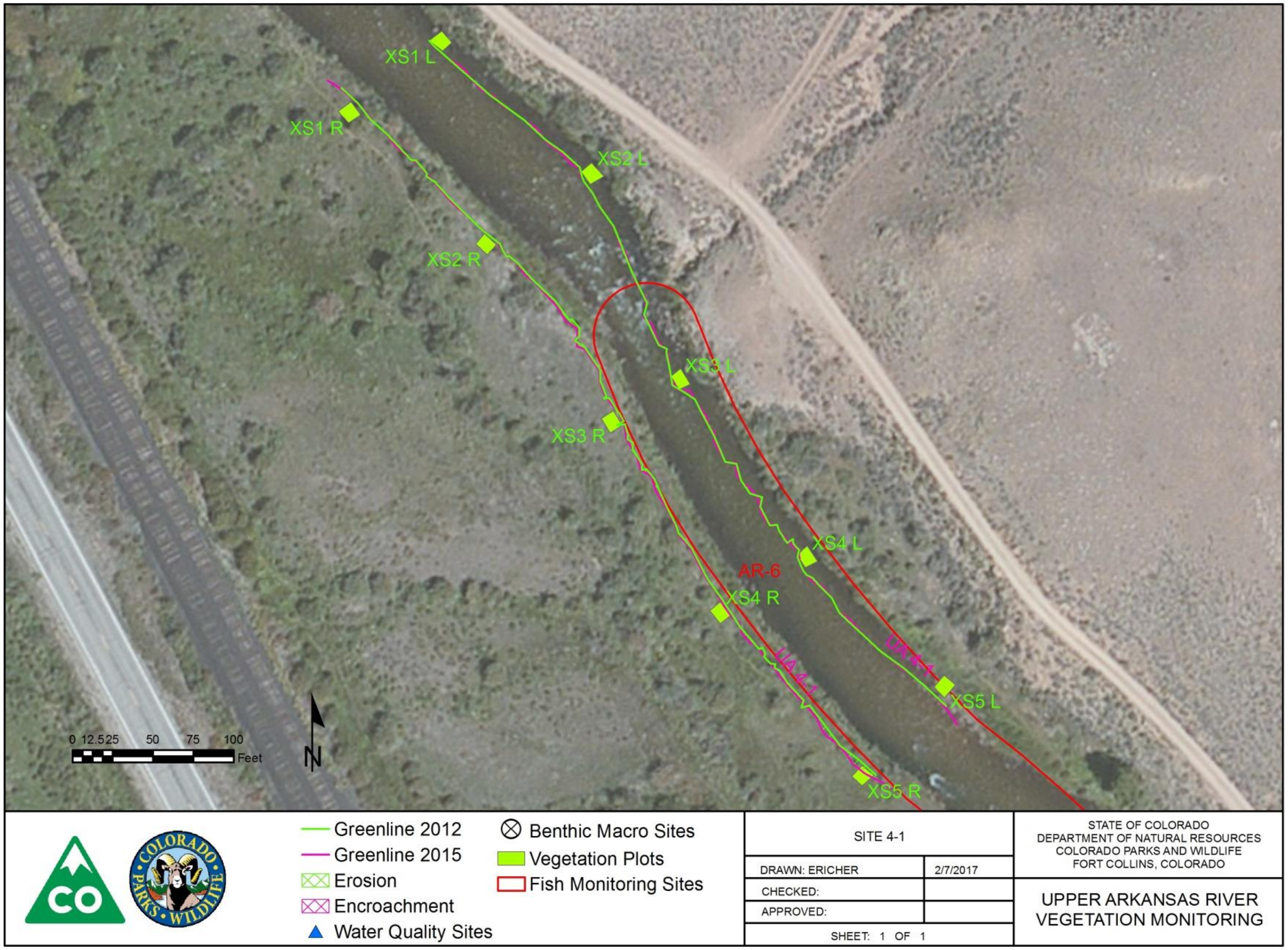


Figure E.14. Location map for vegetation plots and greenline surveys at vegetation control site 4-1 on the Upper Arkansas River.

Appendix F: Fish Habitat Modeling Results

AR-R, Adult Brown Trout, 1.3 cms

Before | **After**

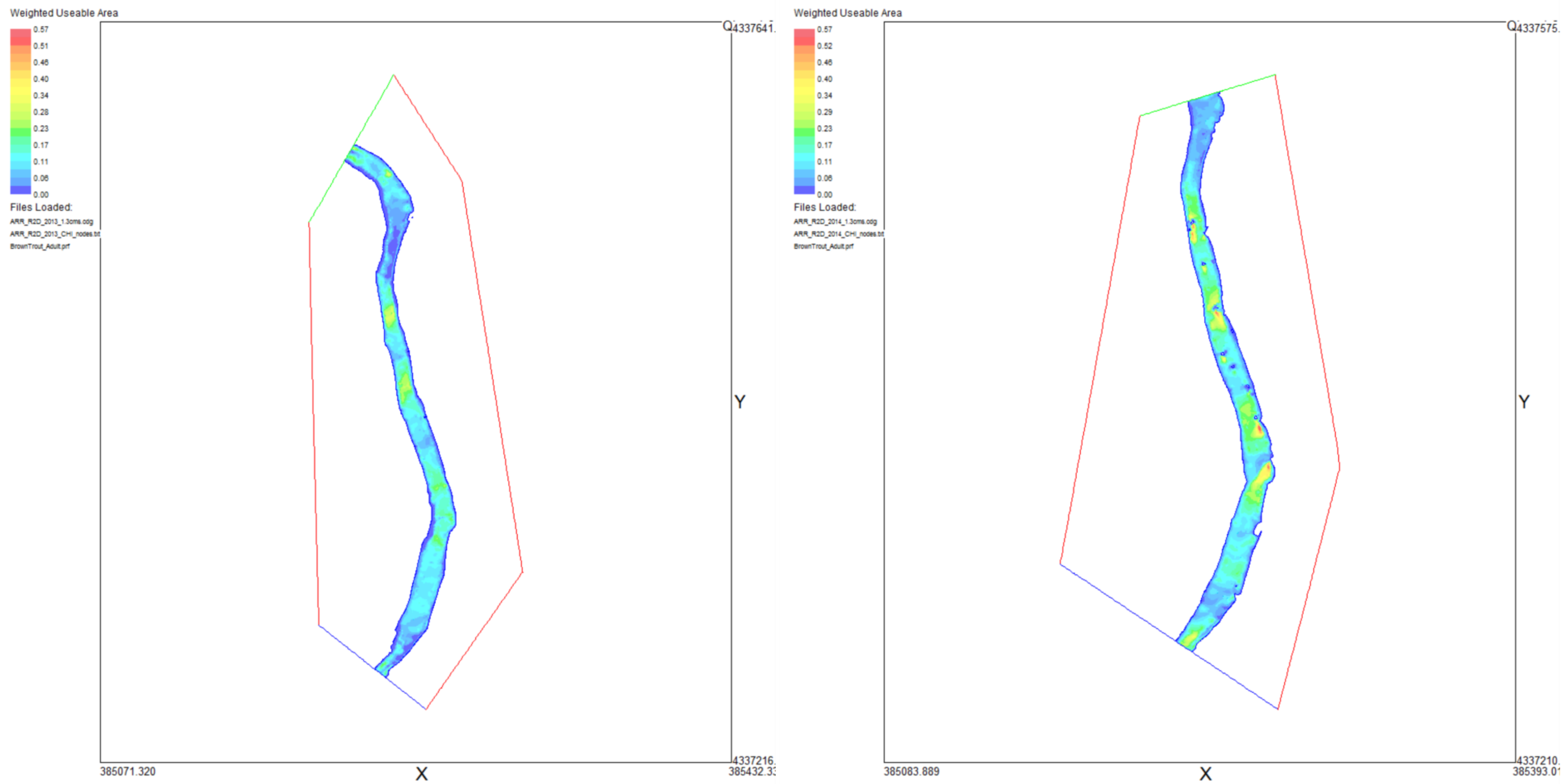


Figure F.1. Before and after comparison of weighted usable area (WUA) for adult brown trout at treatment site AR-R at 1.3 cms.

AR-R, Adult Brown Trout, 4.7 cms

Before **After**

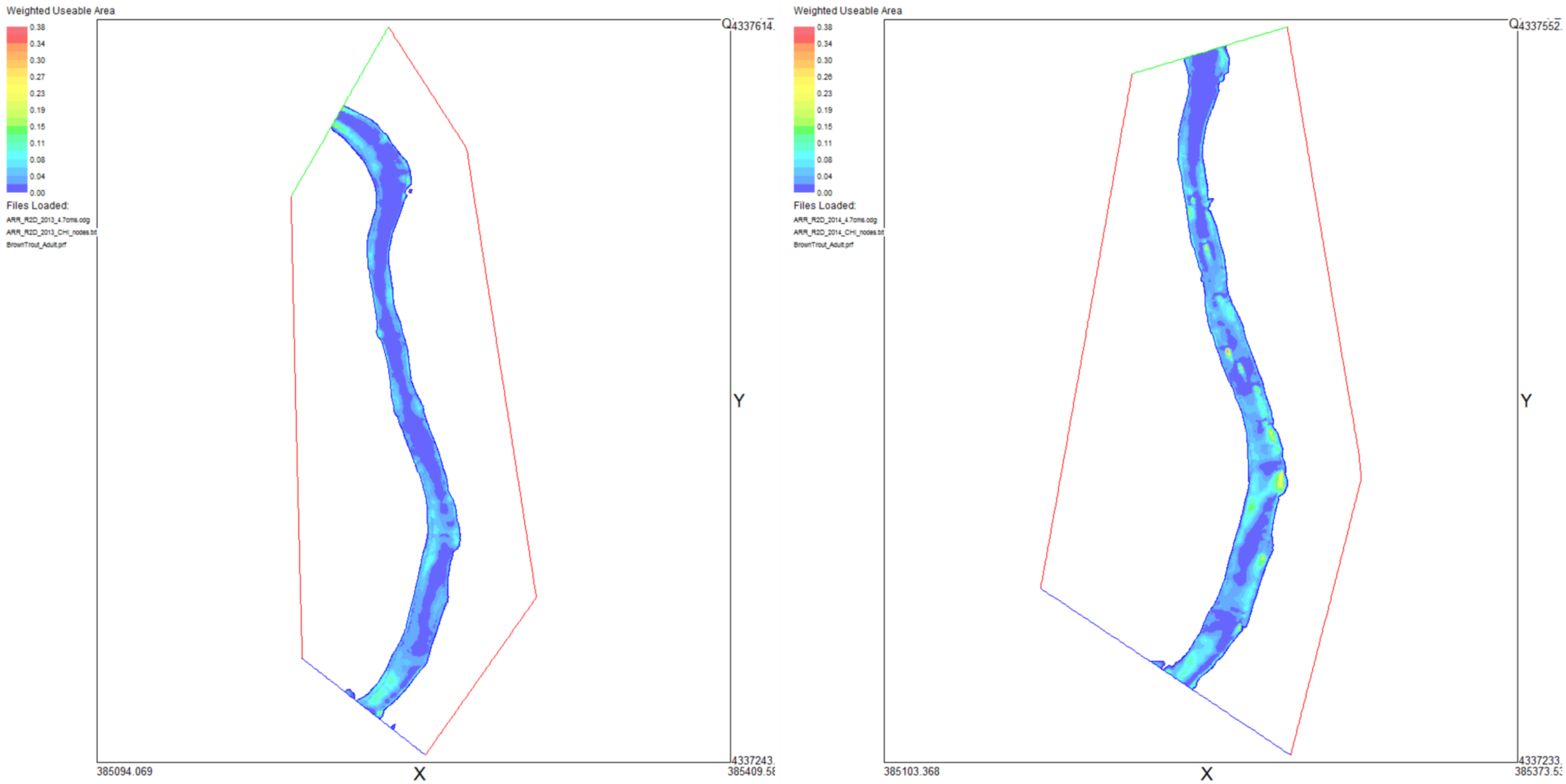
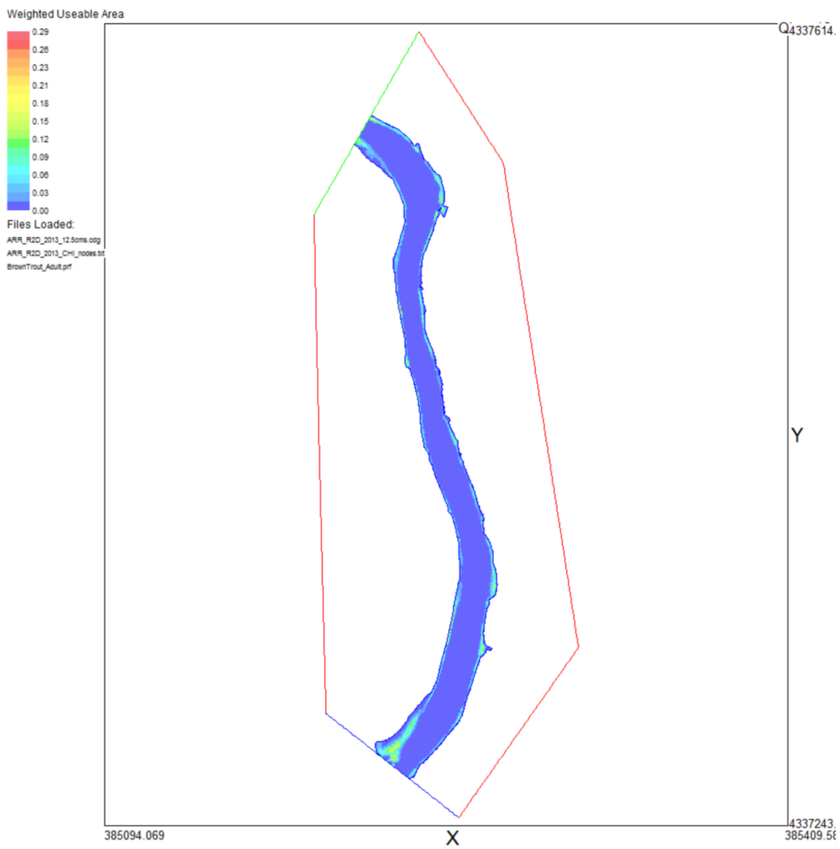


Figure F.2. Before and after comparison of weighted usable area (WUA) for adult brown trout at treatment site AR-R at 4.7 cms.

AR-R, Adult Brown Trout, 12.5 cms

Before



After

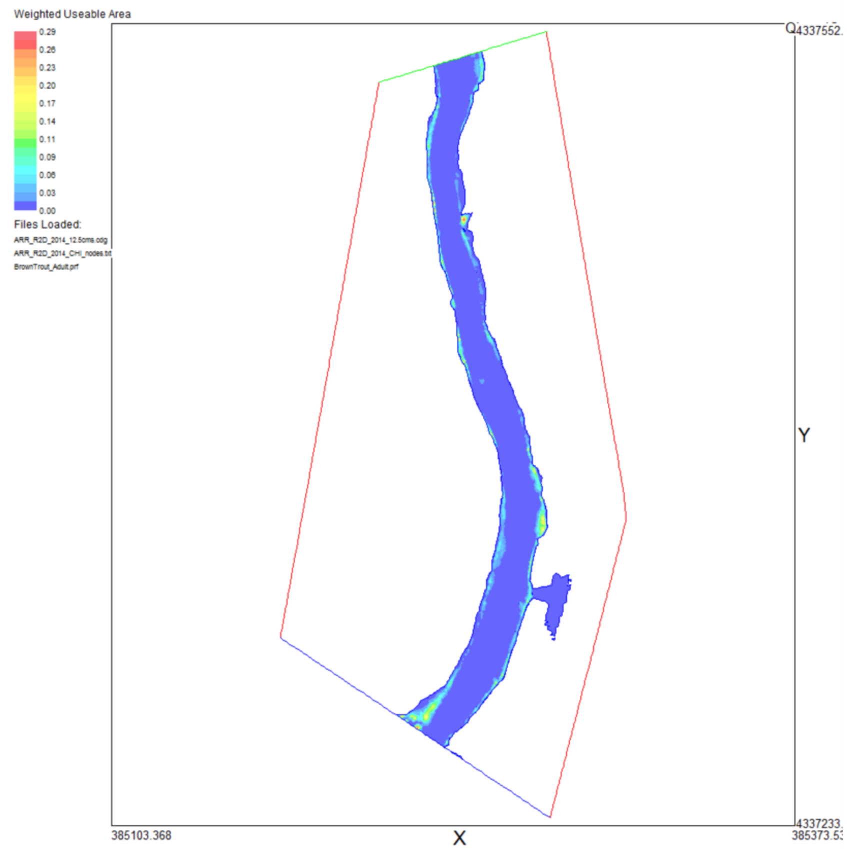


Figure F.3. Before and after comparison of weighted usable area (WUA) for adult brown trout at treatment site AR-R at 12.5 cms.

AR-R, Juvenile Brown Trout, 1.3 cms

Before | **After**

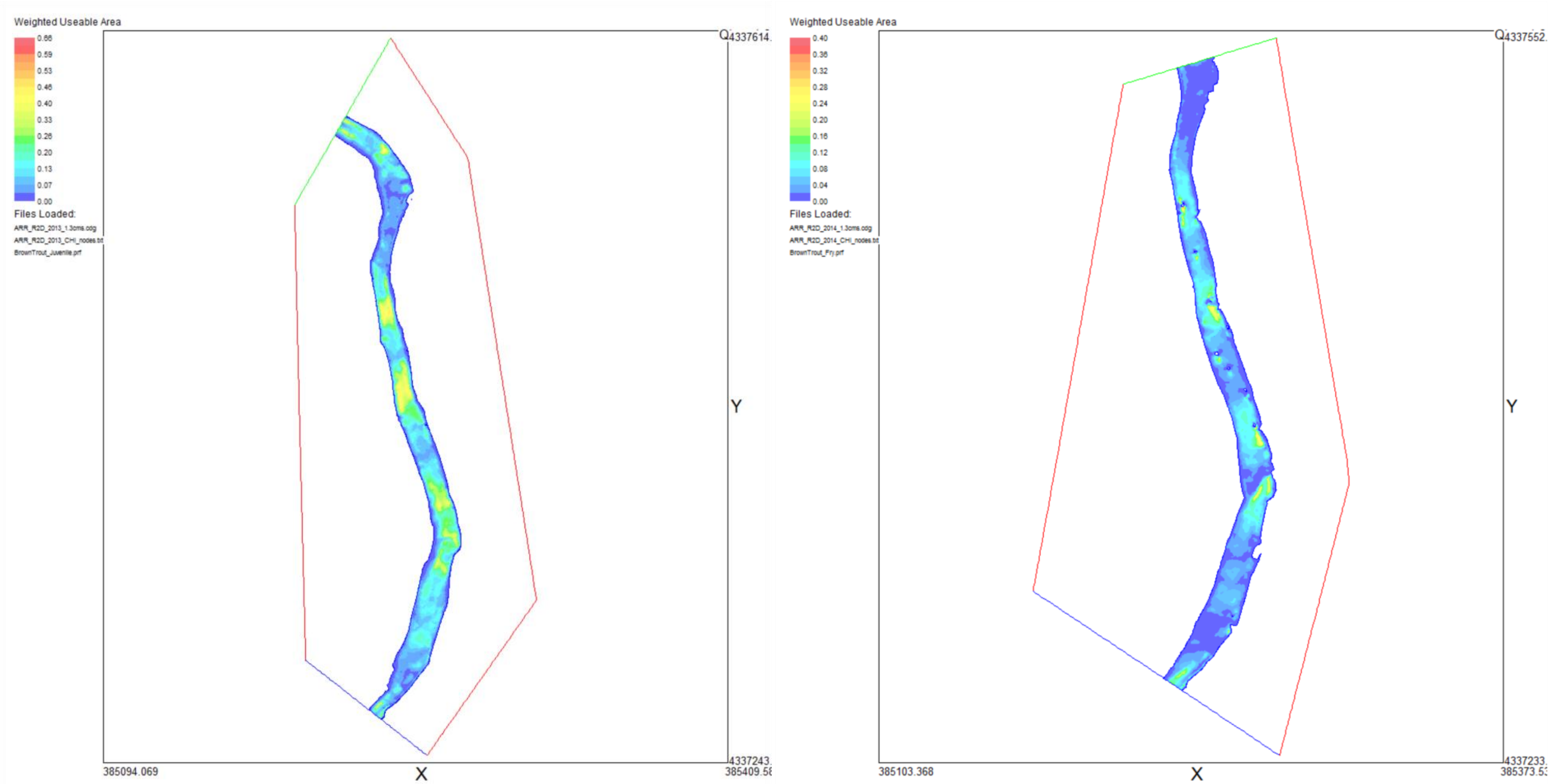


Figure F.4. Before and after comparison of weighted usable area (WUA) for juvenile brown trout at treatment site AR-R at 1.3 cms.

AR-R, Juvenile Brown Trout, 4.7 cms

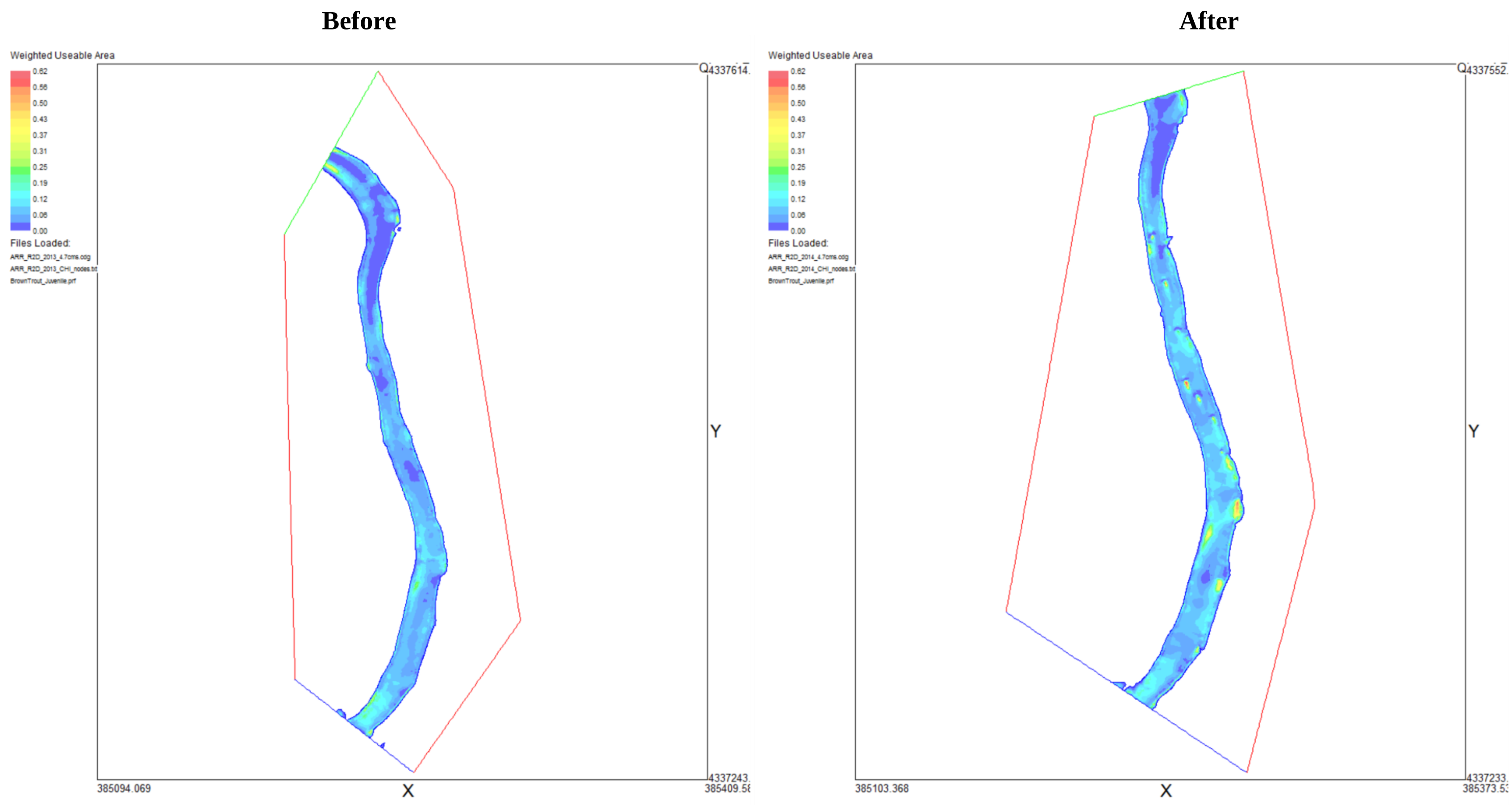


Figure F.5. Before and after comparison of weighted usable area (WUA) for juvenile brown trout at treatment site AR-R at 4.7 cms.

AR-R, Juvenile Brown Trout, 12.5 cm

Before **After**

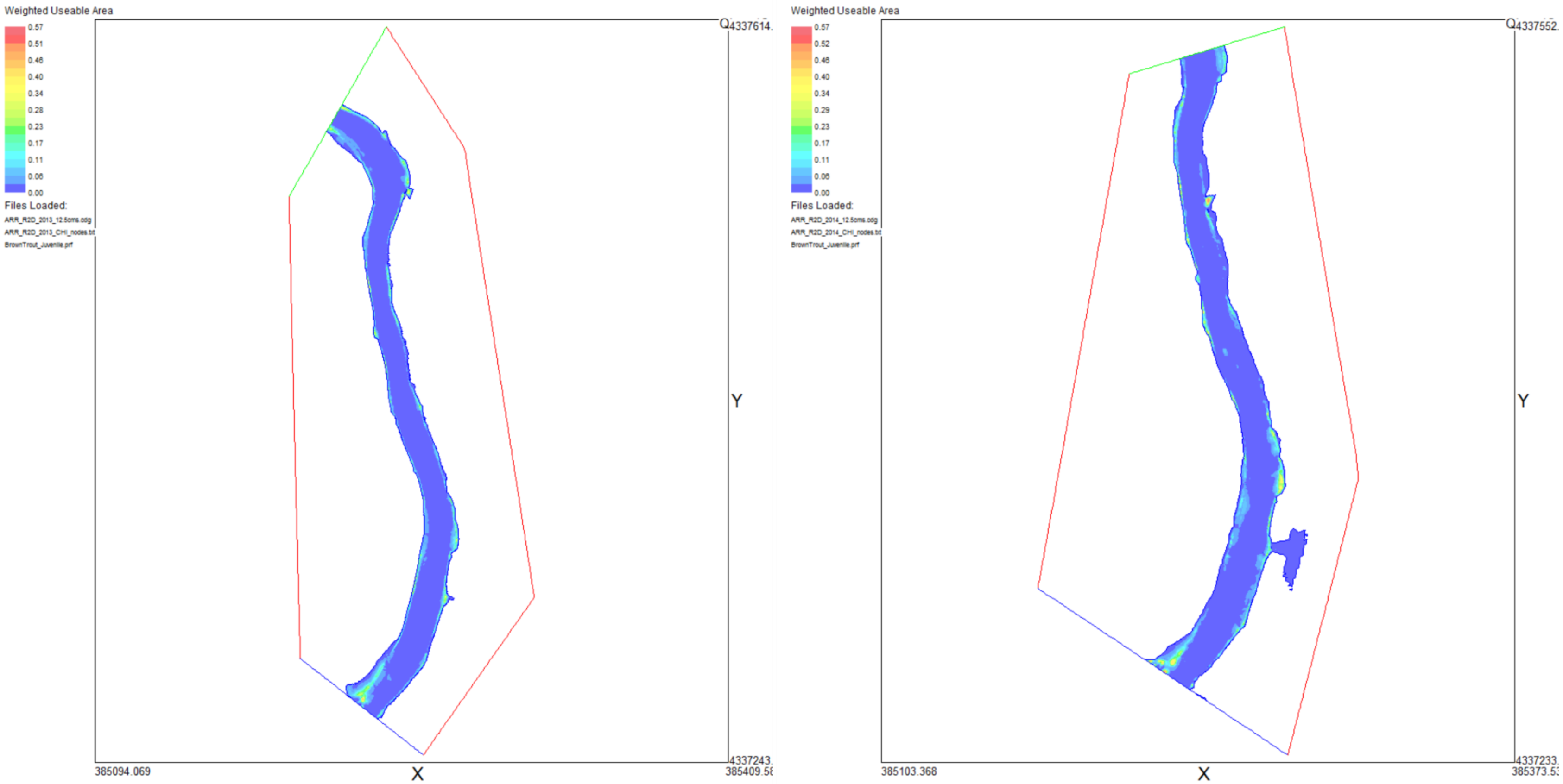


Figure F.6. Before and after comparison of weighted usable area (WUA) for juvenile brown trout at treatment site AR-R at 12.5 cms.

AR-R, Spawning Brown Trout, 1.3 cms

Before | **After**

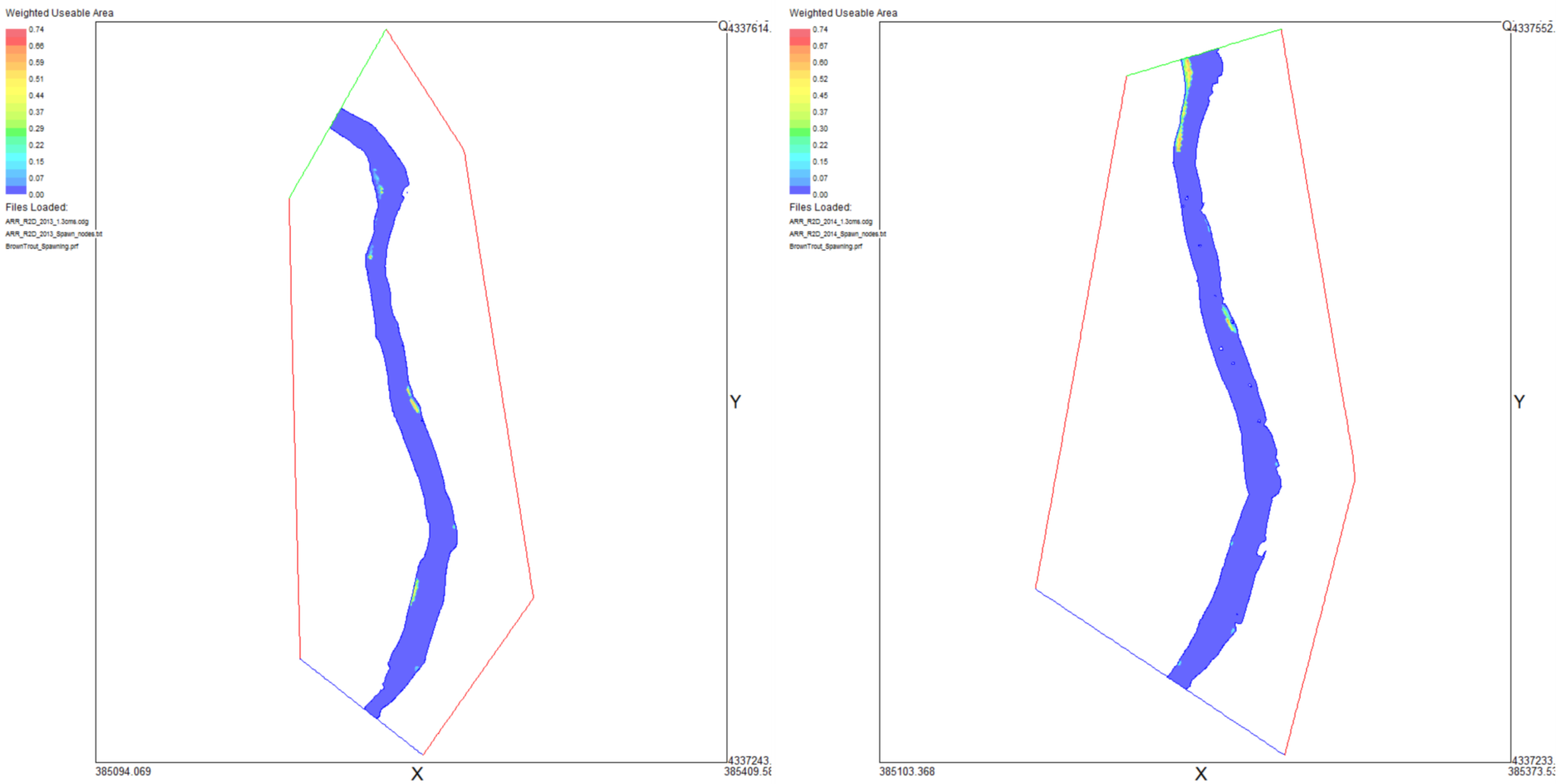


Figure F.7. Before and after comparison of weighted usable area (WUA) for spawning brown trout at treatment site AR-R at 1.3 cms.

AR-5, Adult Brown Trout, 2.0 cms

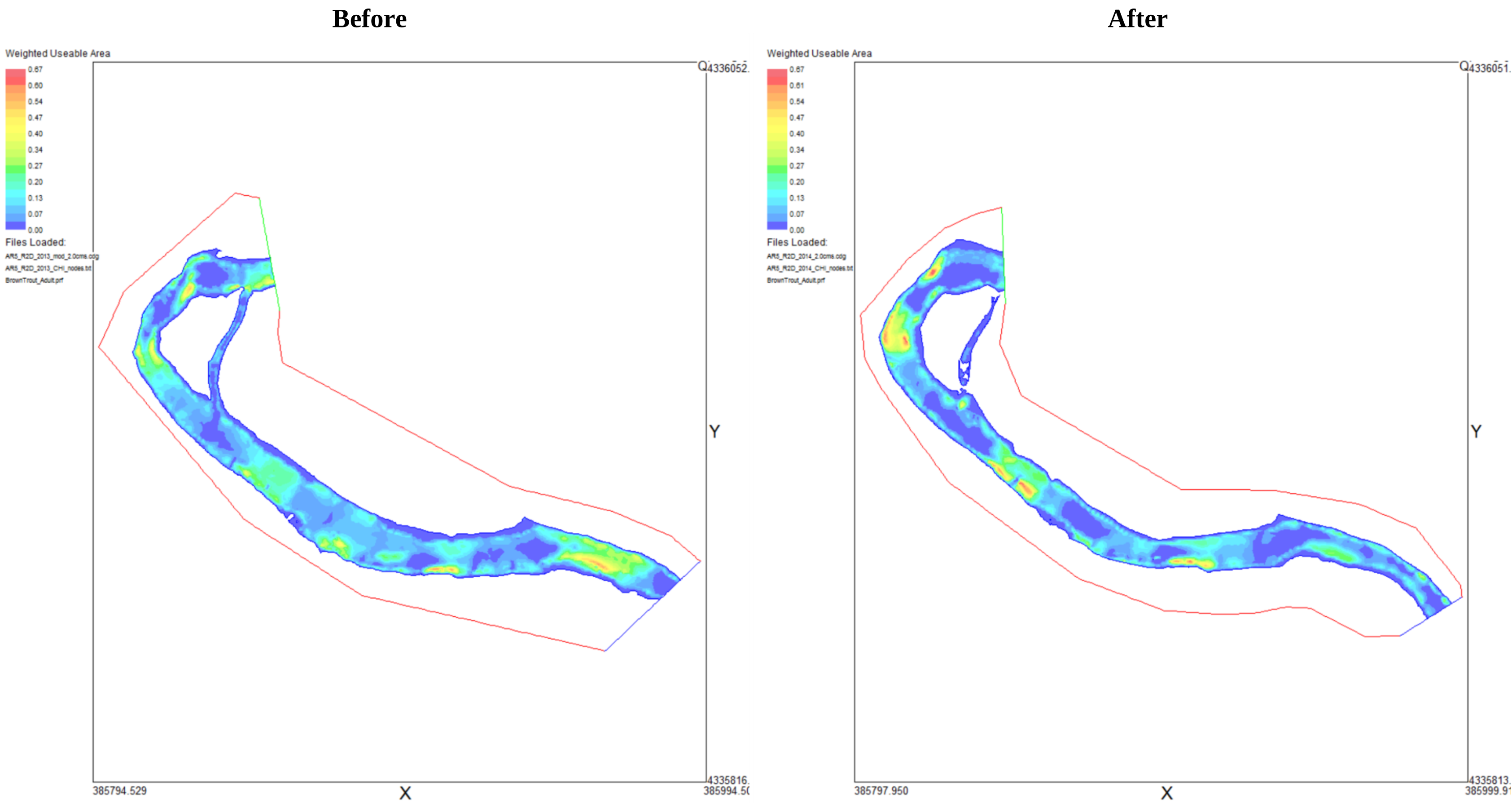


Figure F.8. Before and after comparison of weighted usable area (WUA) for adult brown trout at treatment site AR-5 at 2.0 cms.

AR-5, Adult Brown Trout, 7.6 cms

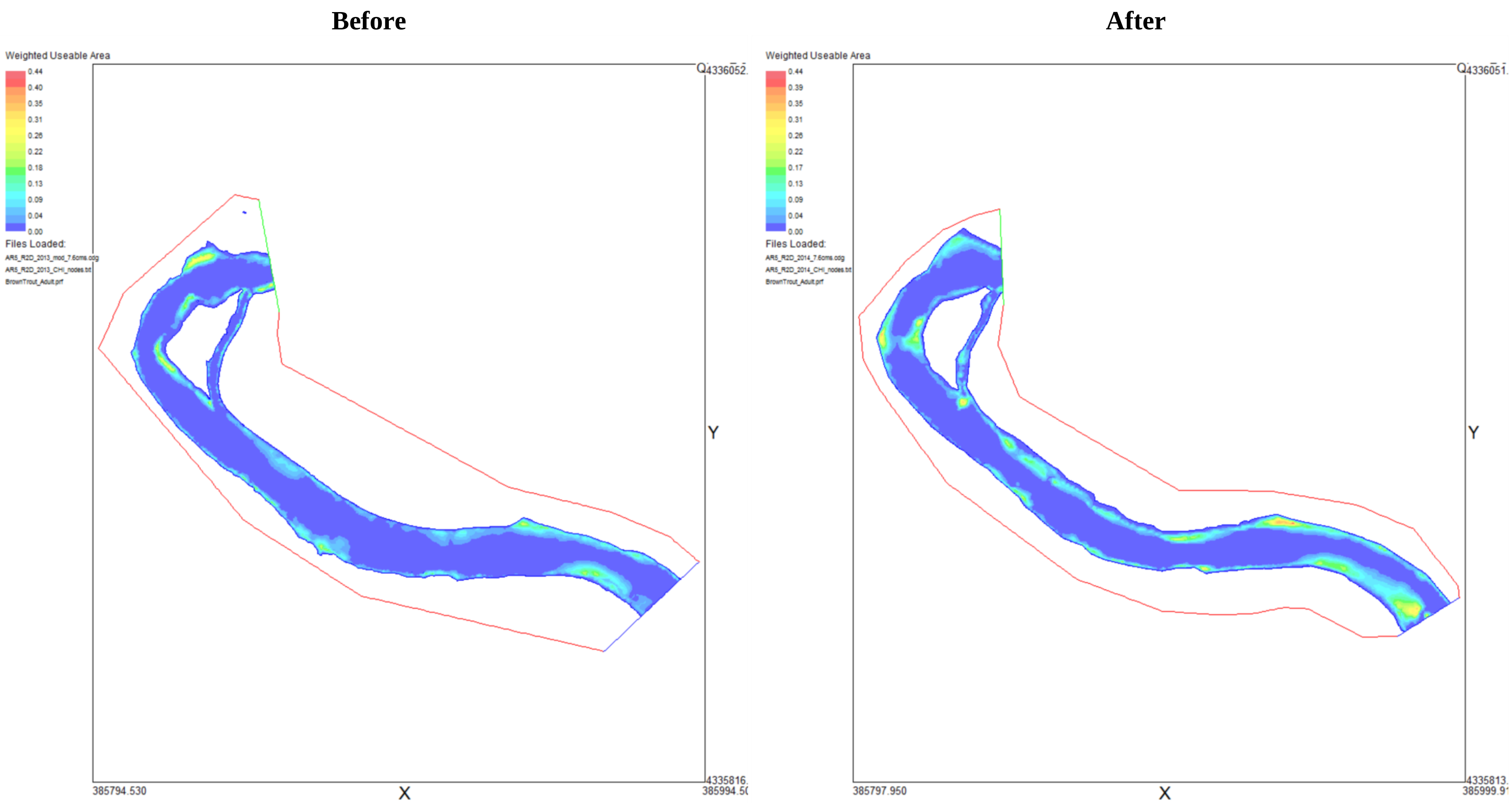


Figure F.9. Before and after comparison of weighted usable area (WUA) for adult brown trout at treatment site AR-5 at 7.6 cms.

AR-5, Adult Brown Trout, 20.7 cms

Before **After**

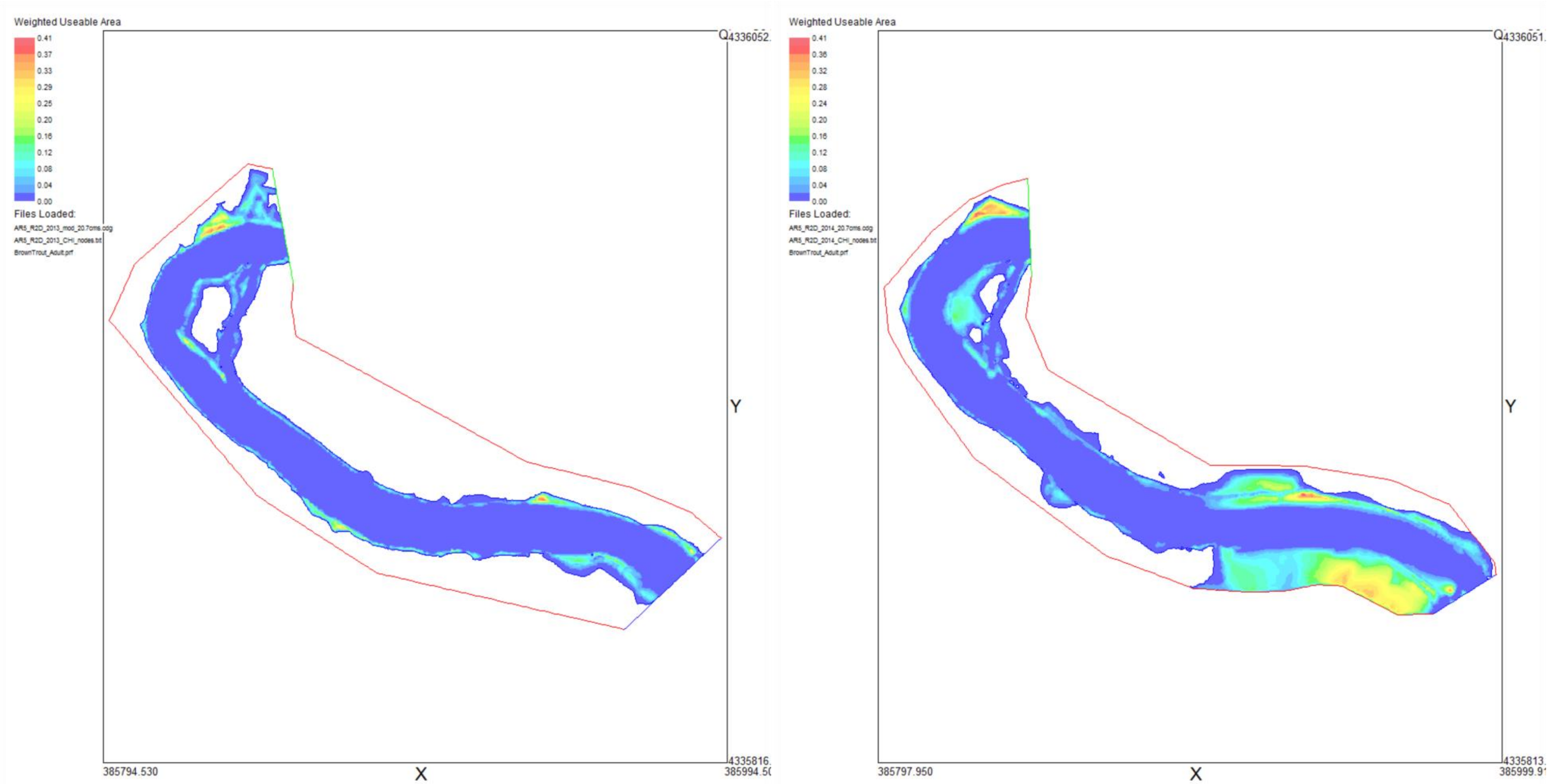


Figure F.10. Before and after comparison of weighted usable area (WUA) for adult brown trout at treatment site AR-5 at 20.7 cms.

AR-5, Juvenile Brown Trout, 2.0 cms

Before | **After**

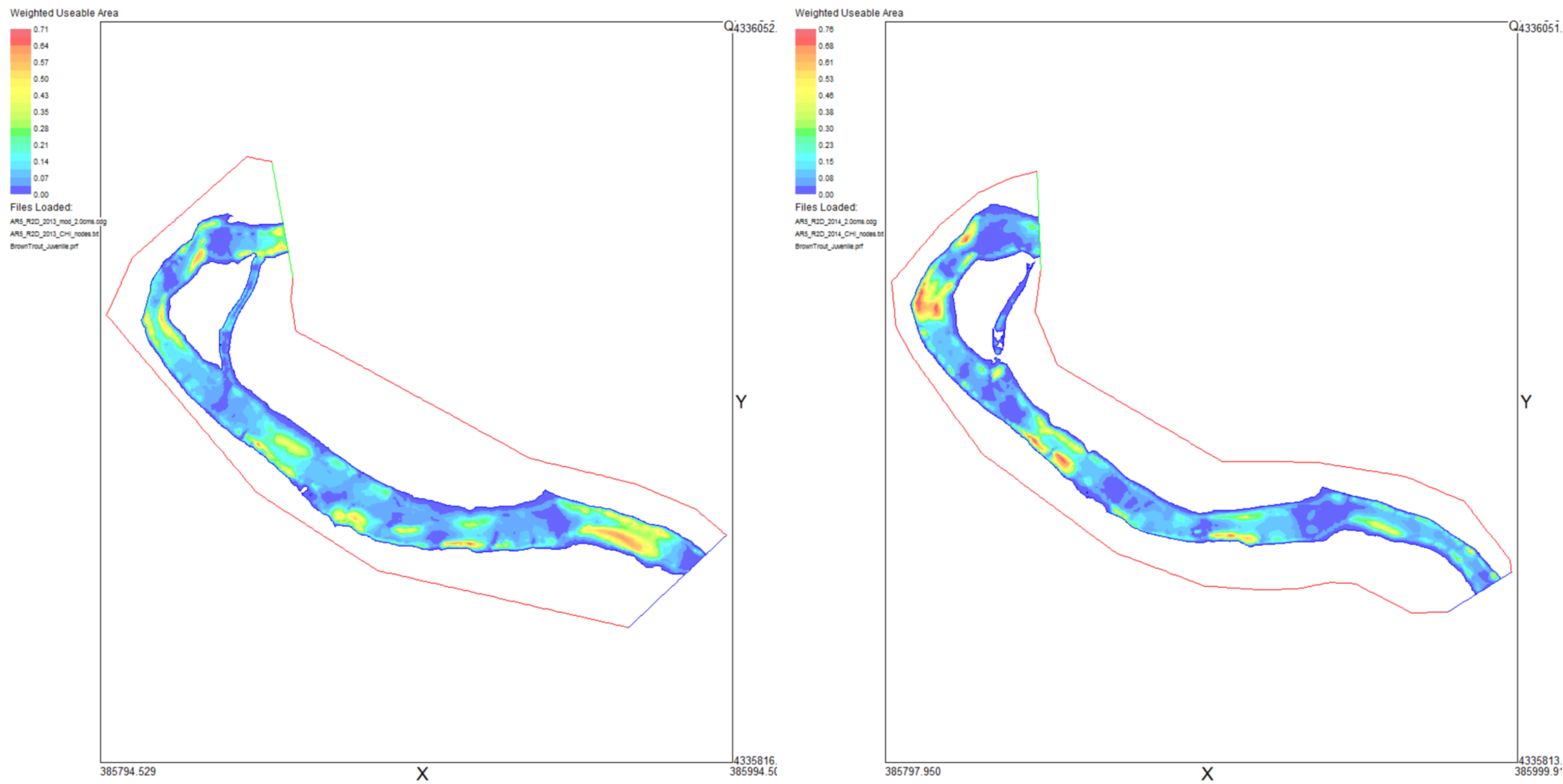


Figure F.11. Before and after comparison of weighted usable area (WUA) for juvenile brown trout at treatment site AR-5 at 2.0 cms.

AR-5, Juvenile Brown Trout, 7.6 cms

Before **After**

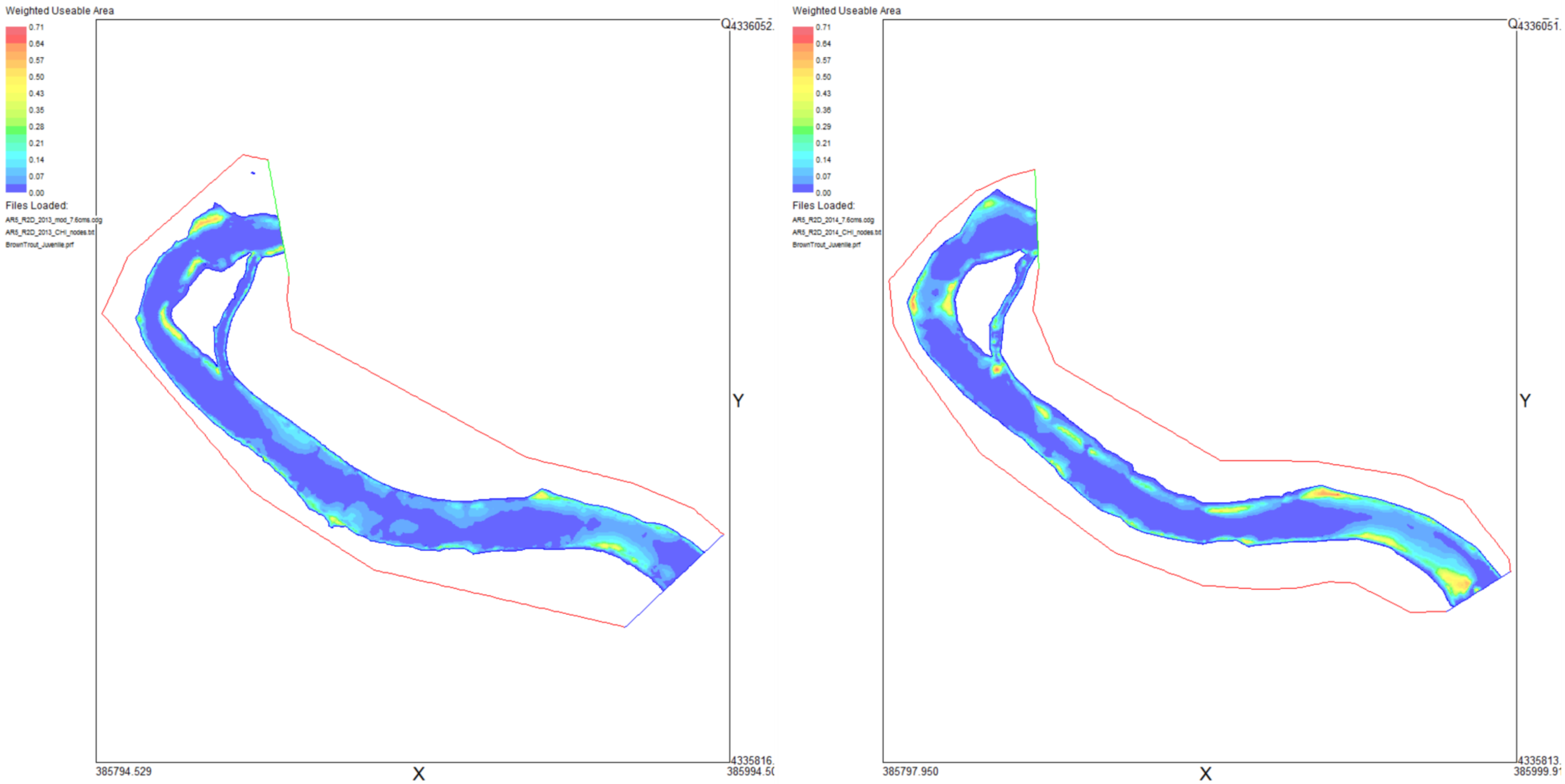


Figure F.12. Before and after comparison of weighted usable area (WUA) for juvenile brown trout at treatment site AR-5 at 7.6 cms.

AR-5, Juvenile Brown Trout, 20.7 cms

Before **After**

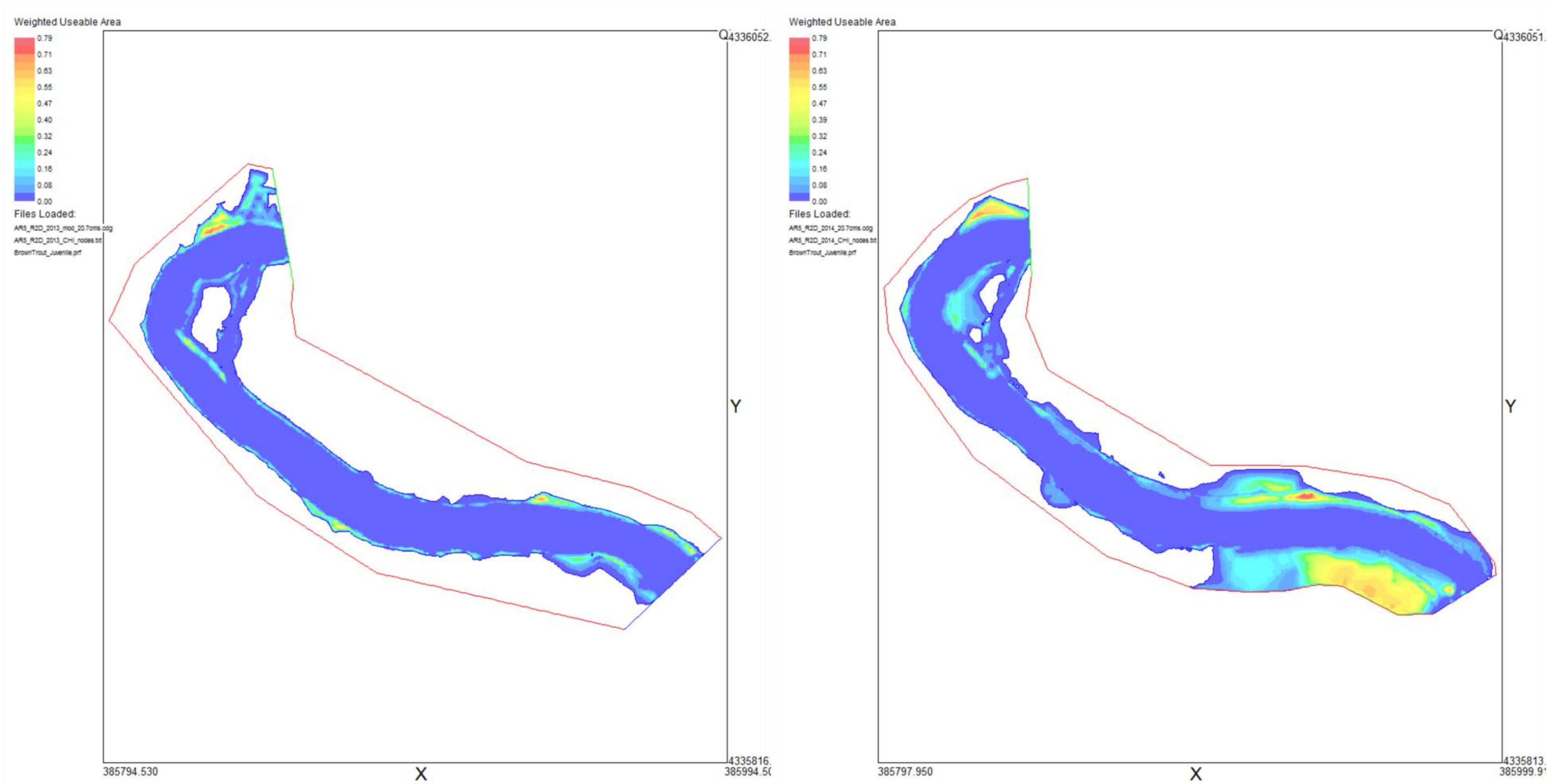


Figure F.13. Before and after comparison of weighted usable area (WUA) for juvenile brown trout at treatment site AR-5 at 20.7 cms.

AR-5, Spawning Brown Trout, 2.0 cms

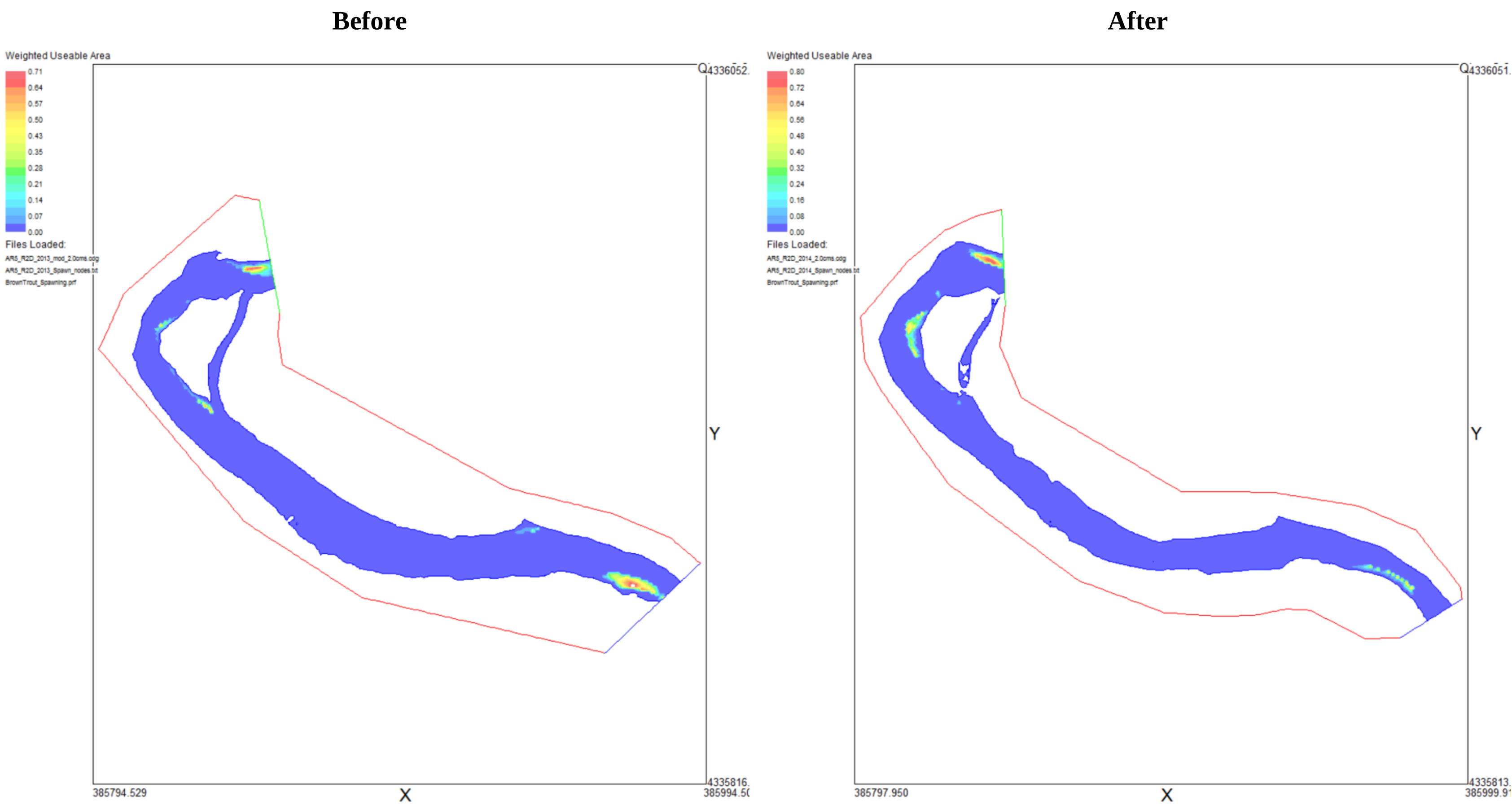


Figure F.14. Before and after comparison of weighted usable area (WUA) for spawning brown trout at treatment site AR-5 at 2.0 cms.

AR-5B, Adult Brown Trout, 2.0 cms

Before **After**

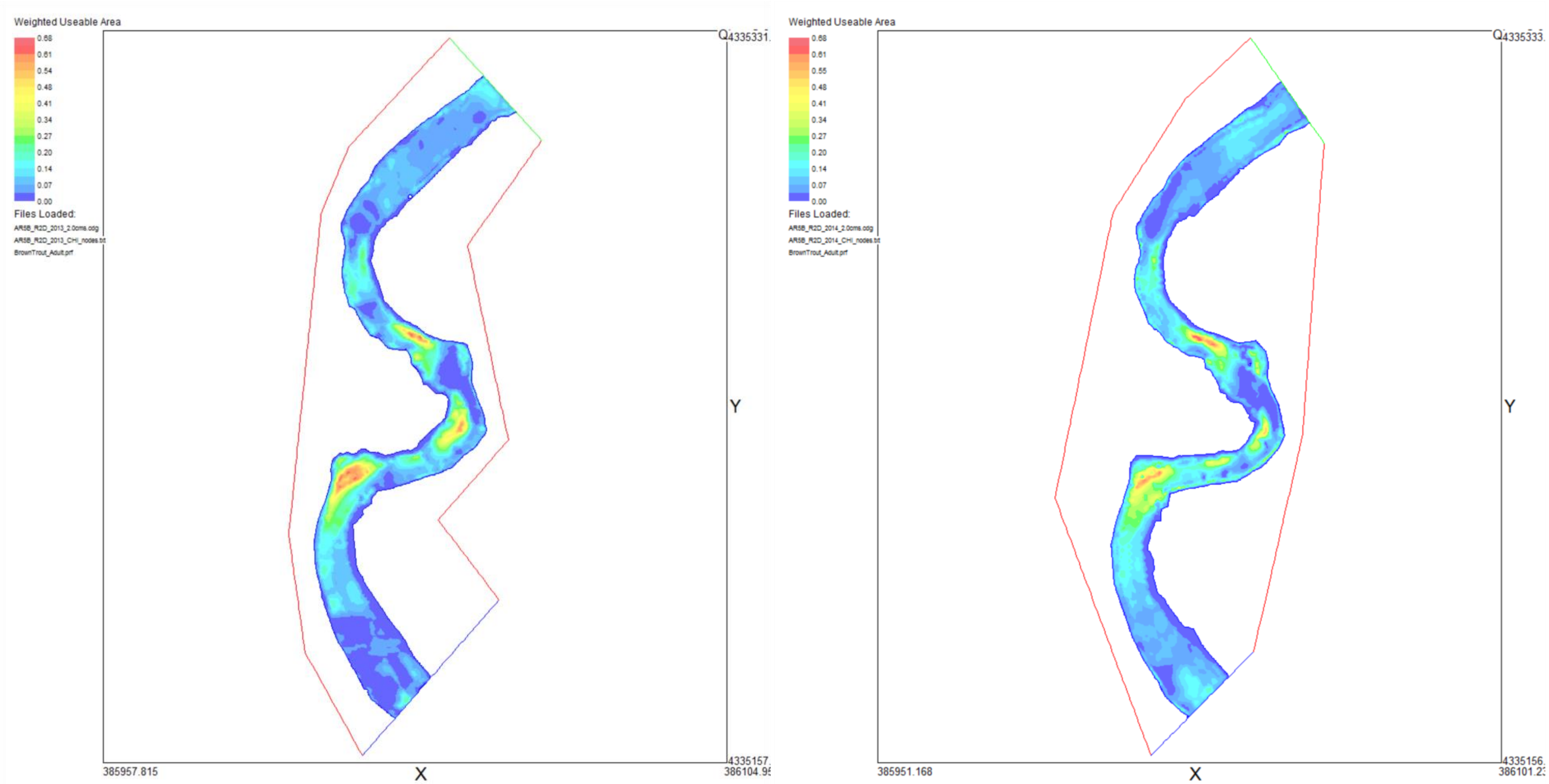


Figure F.15. Before and after comparison of weighted usable area (WUA) for adult brown trout at control site AR-5B at 2.0 cms.

AR-5B, Adult Brown Trout, 7.6 cms

Before | **After**

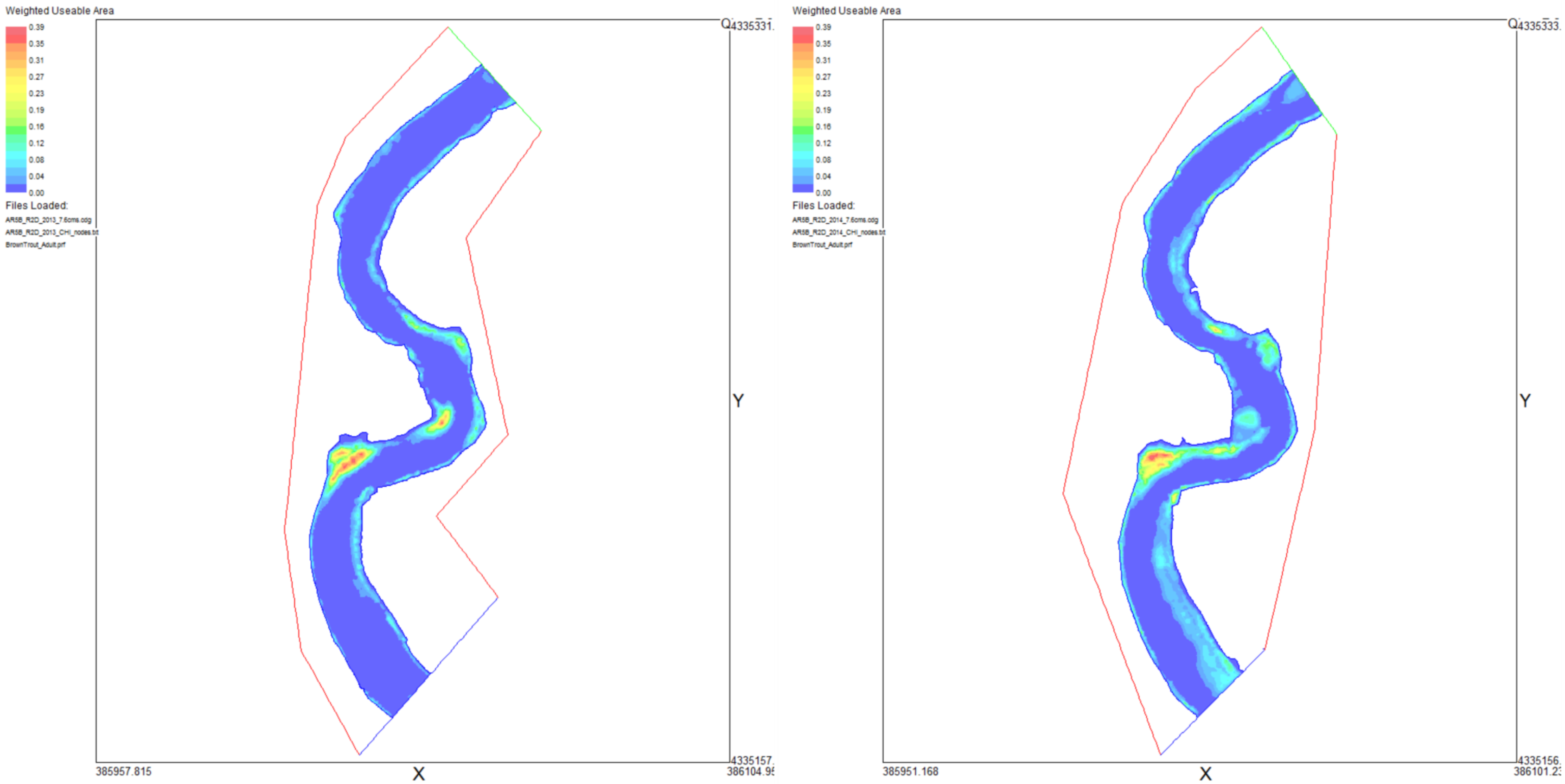


Figure F.16. Before and after comparison of weighted usable area (WUA) for adult brown trout at control site AR-5B at 7.6 cms.

AR-5B, Adult Brown Trout, 20.7 cms

Before **After**

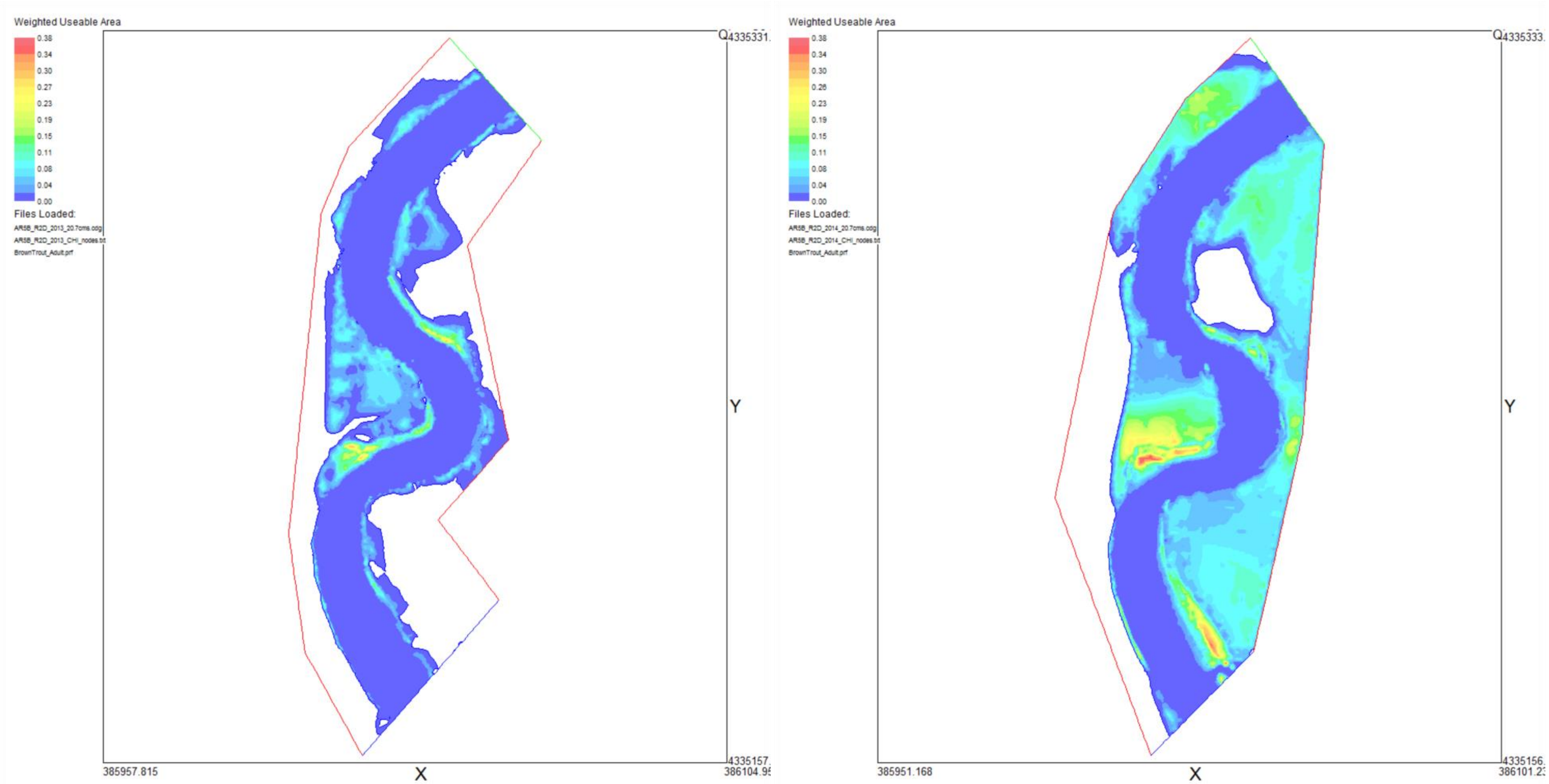
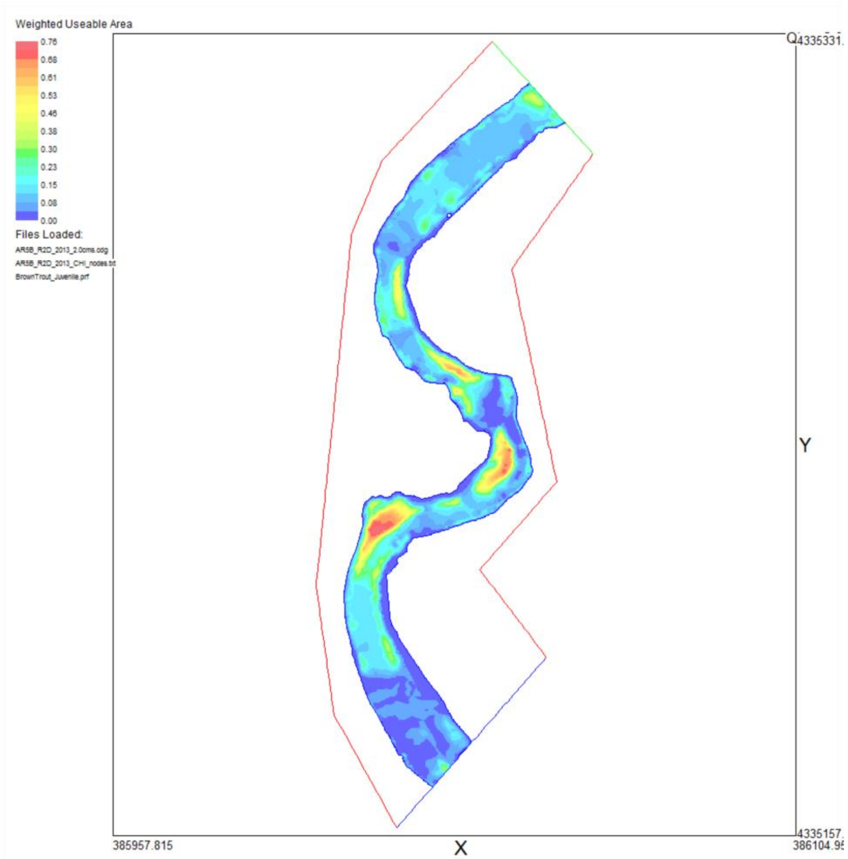


Figure F.17. Before and after comparison of weighted usable area (WUA) for adult brown trout at control site AR-5B at 20.7 cms.

AR-5B, Juvenile Brown Trout, 2.0 cms

Before



After

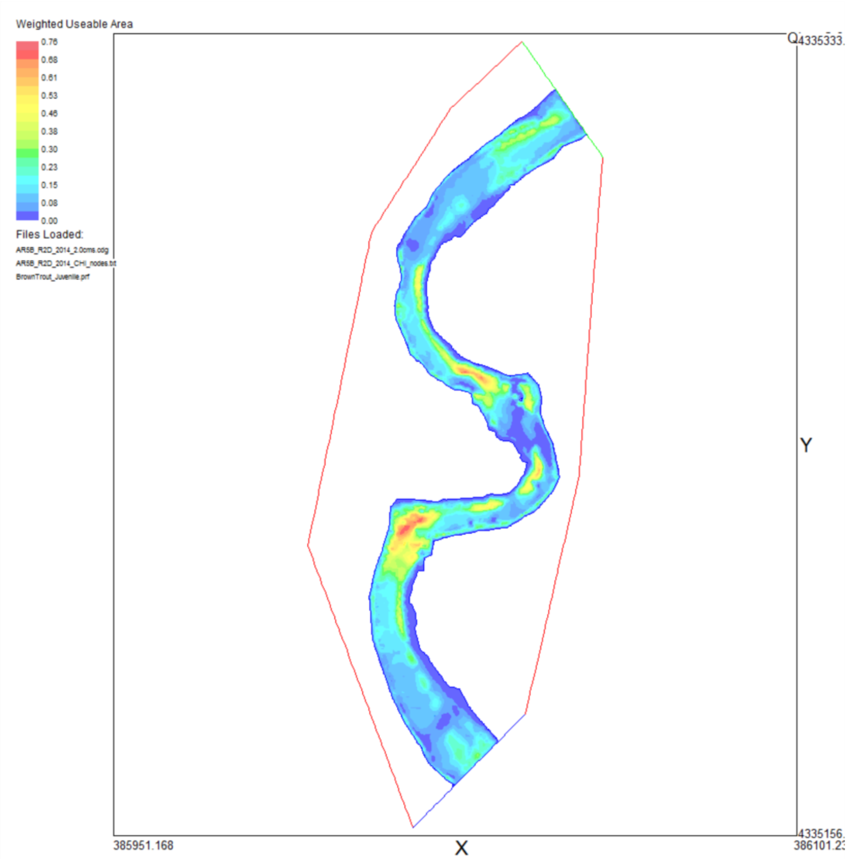


Figure F.18. Before and after comparison of weighted usable area (WUA) for juvenile brown trout at control site AR-5B at 2.0 cms.

AR-5B, Juvenile Brown Trout, 7.6 cms

Before **After**

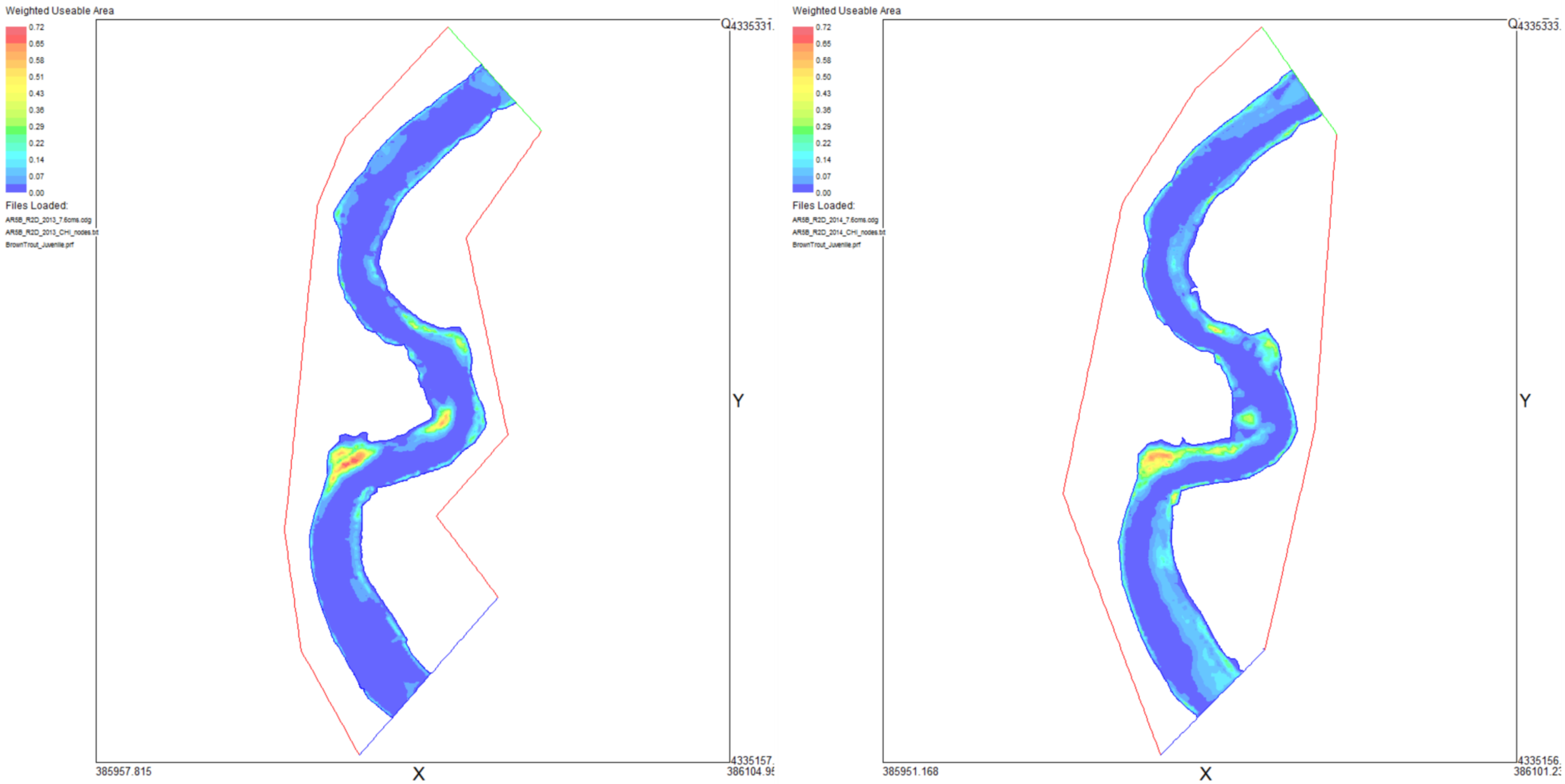
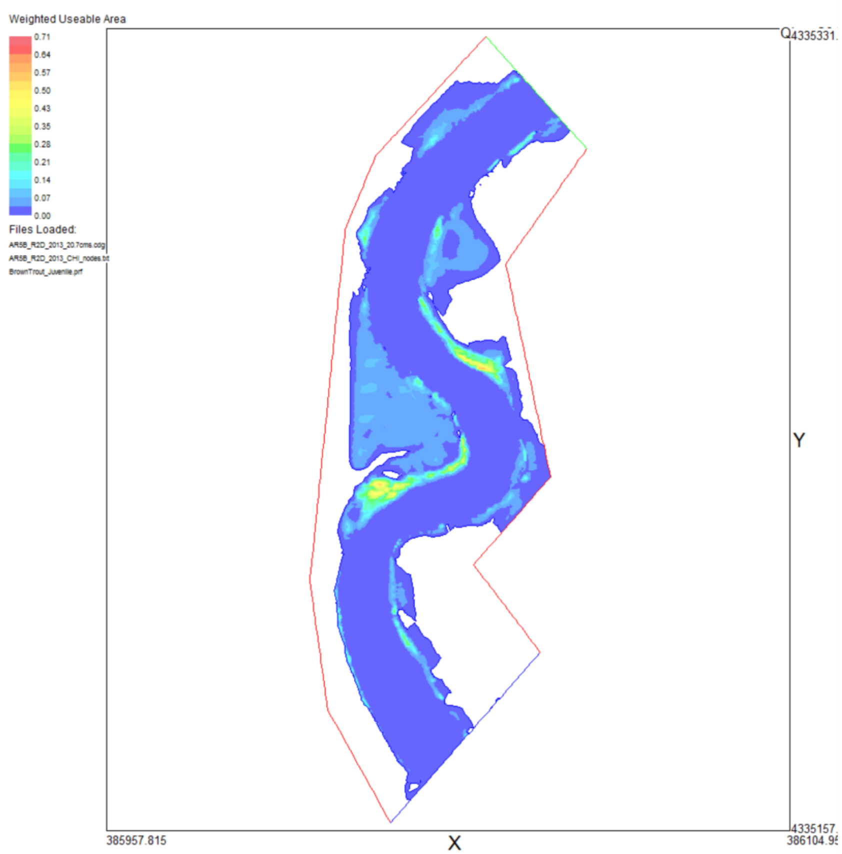


Figure F.19. Before and after comparison of weighted usable area (WUA) for juvenile brown trout at control site AR-5B at 7.6 cms.

AR-5B, Juvenile Brown Trout, 20.7 cms

Before



After

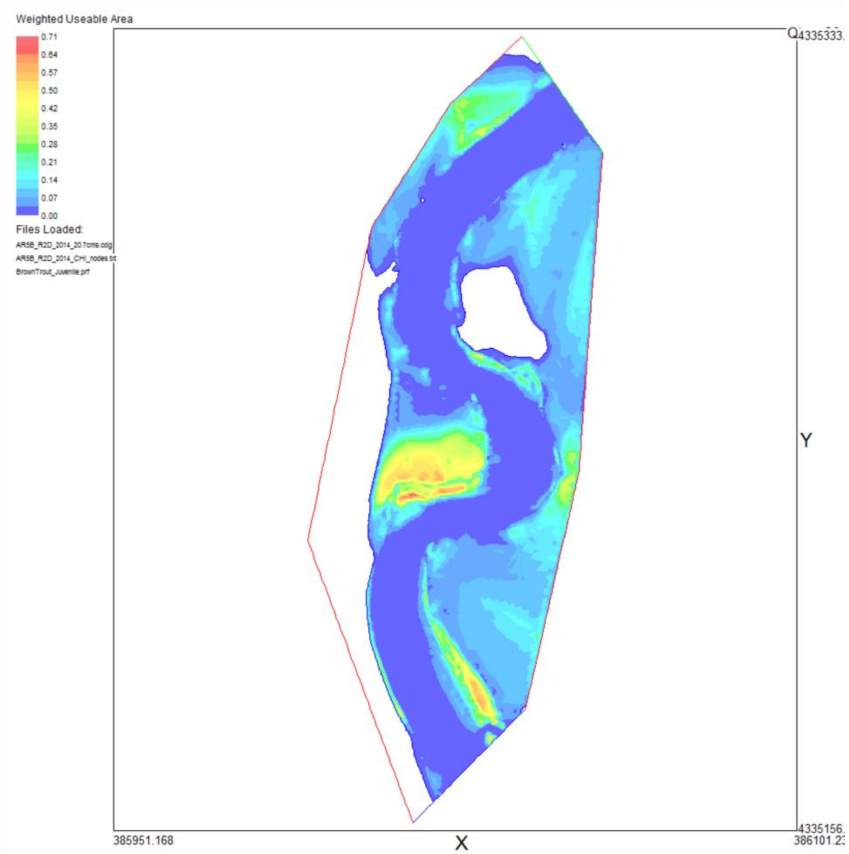


Figure F.20. Before and after comparison of weighted usable area (WUA) for juvenile brown trout at control site AR-5B at 20.7 cms.

AR-5B, Spawning Brown Trout, 2.0 cms

Before **After**

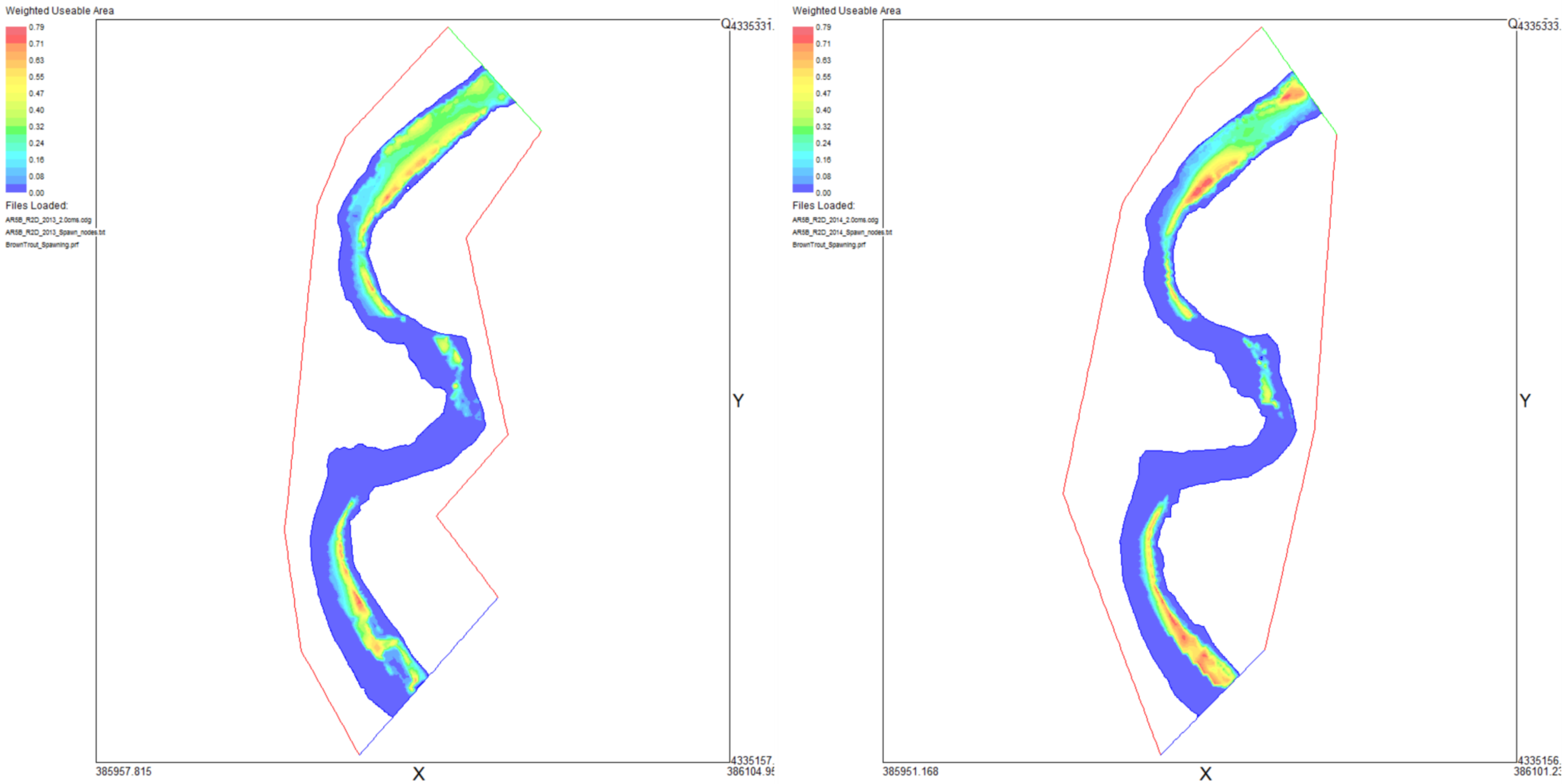


Figure F.21. Before and after comparison of weighted usable area (WUA) for spawning brown trout at control site AR-5B at 2.0 cms.

AR-6A, Adult Brown Trout, 2.0 cms

Before | **After**

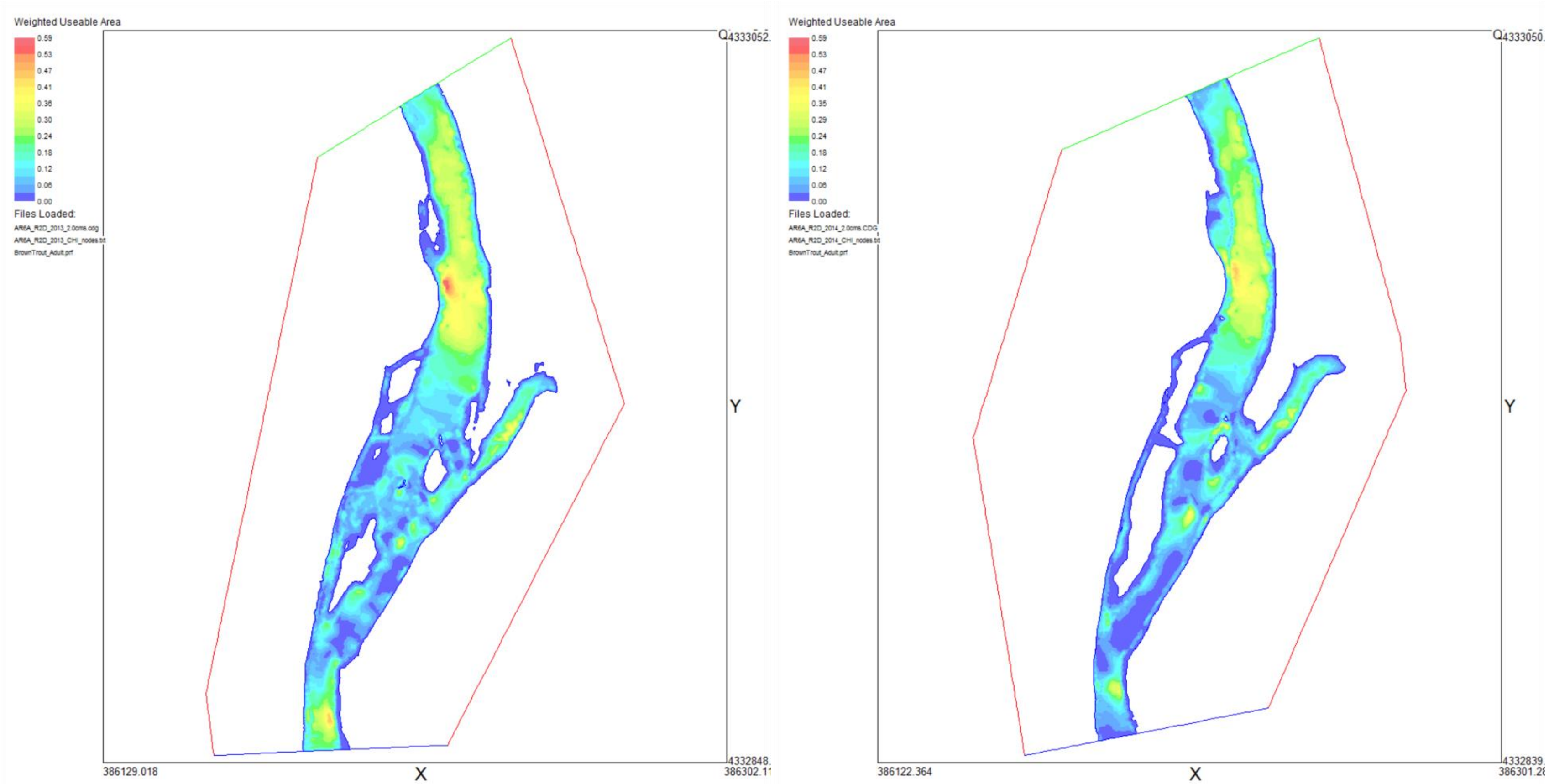


Figure F.22. Before and after comparison of weighted usable area (WUA) for adult brown trout at control site AR-6A at 2.0 cms.

AR-6A, Adult Brown Trout, 7.6 cms

Before **After**

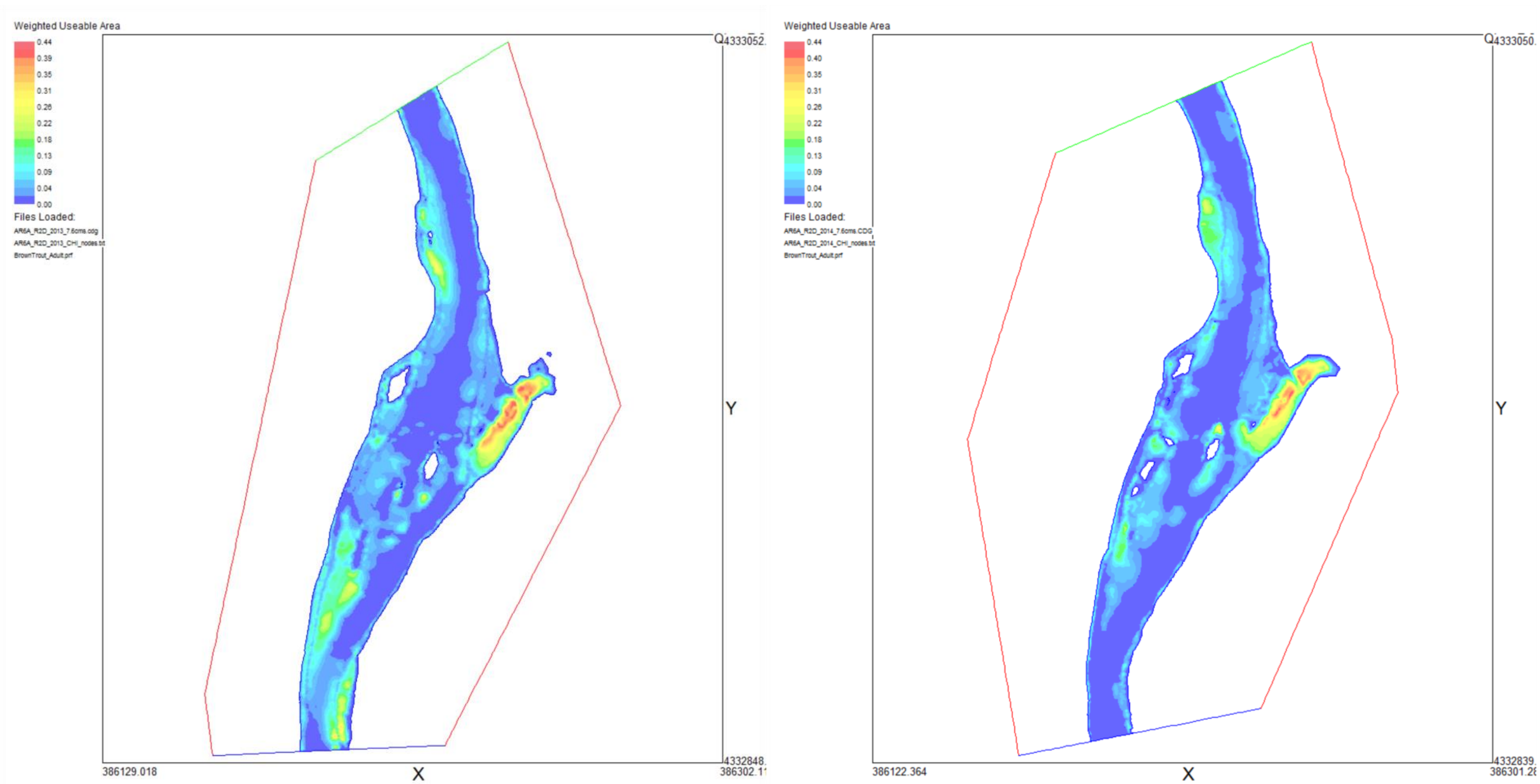


Figure F.23. Before and after comparison of weighted usable area (WUA) for adult brown trout at control site AR-6A at 7.6 cms.

AR-6A, Adult Brown Trout, 20.7 cms

Before | **After**

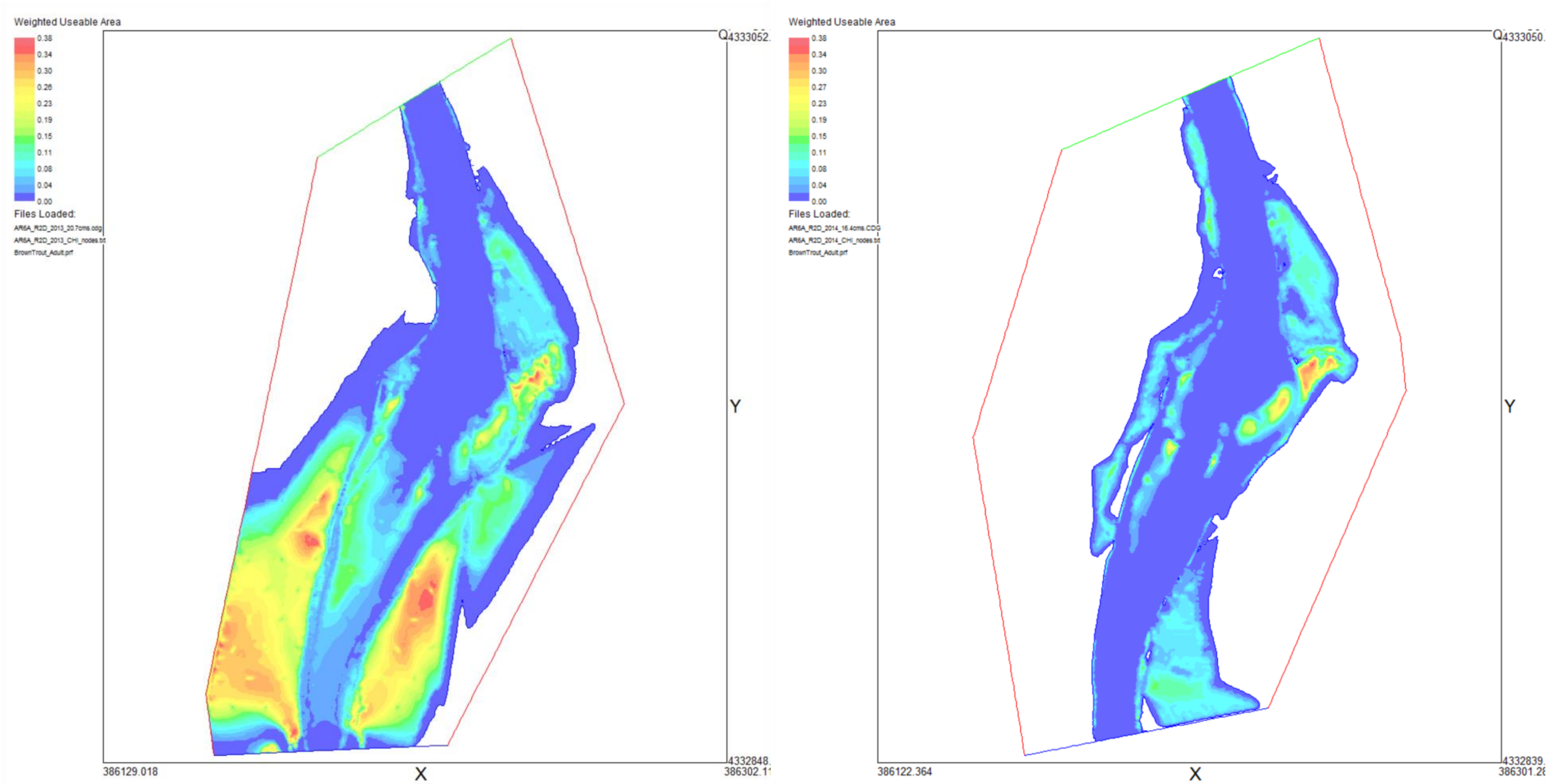


Figure F.24. Before and after comparison of weighted usable area (WUA) for adult brown trout at control site AR-6A at 20.7 cms.

AR-6A, Juvenile Brown Trout, 2.0 cms

Before **After**

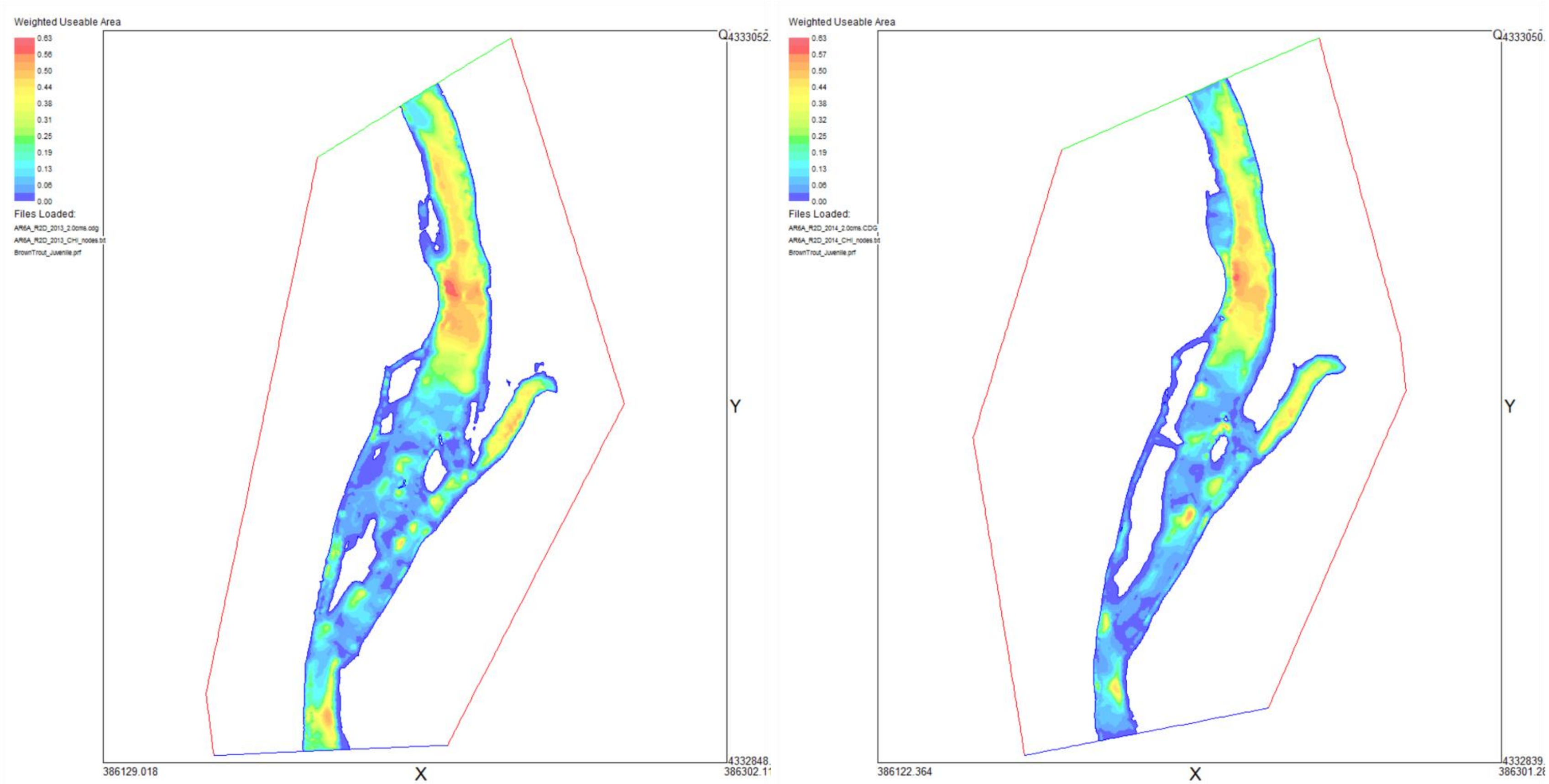
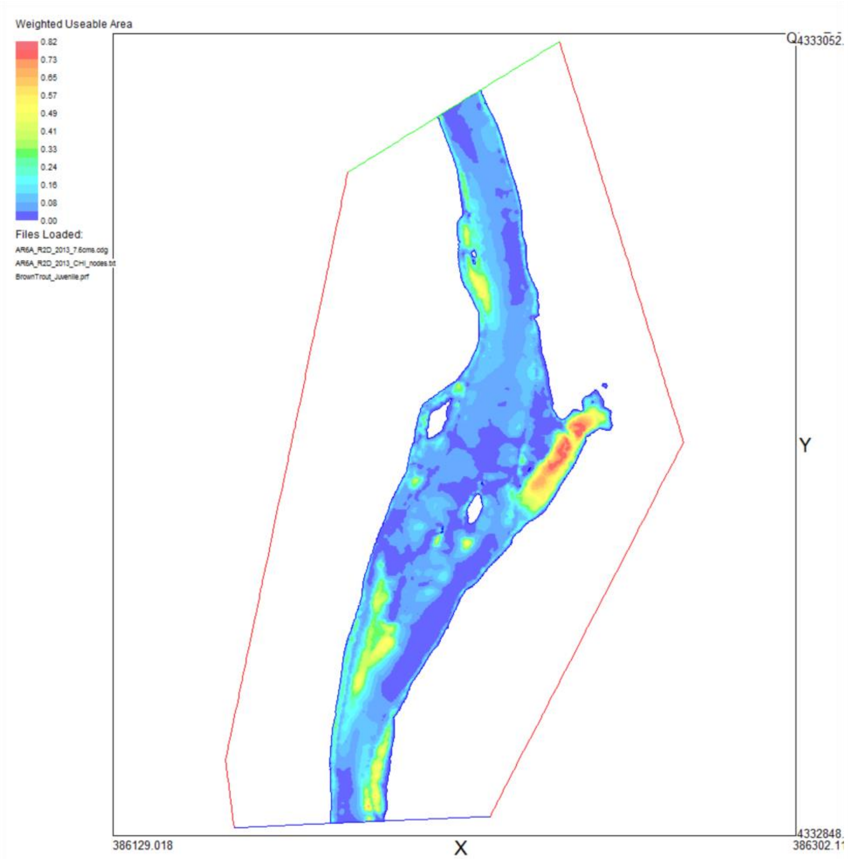


Figure F.25. Before and after comparison of weighted usable area (WUA) for juvenile brown trout at control site AR-6A at 2.0 cms.

AR-6A, Juvenile Brown Trout, 7.6 cms

Before



After

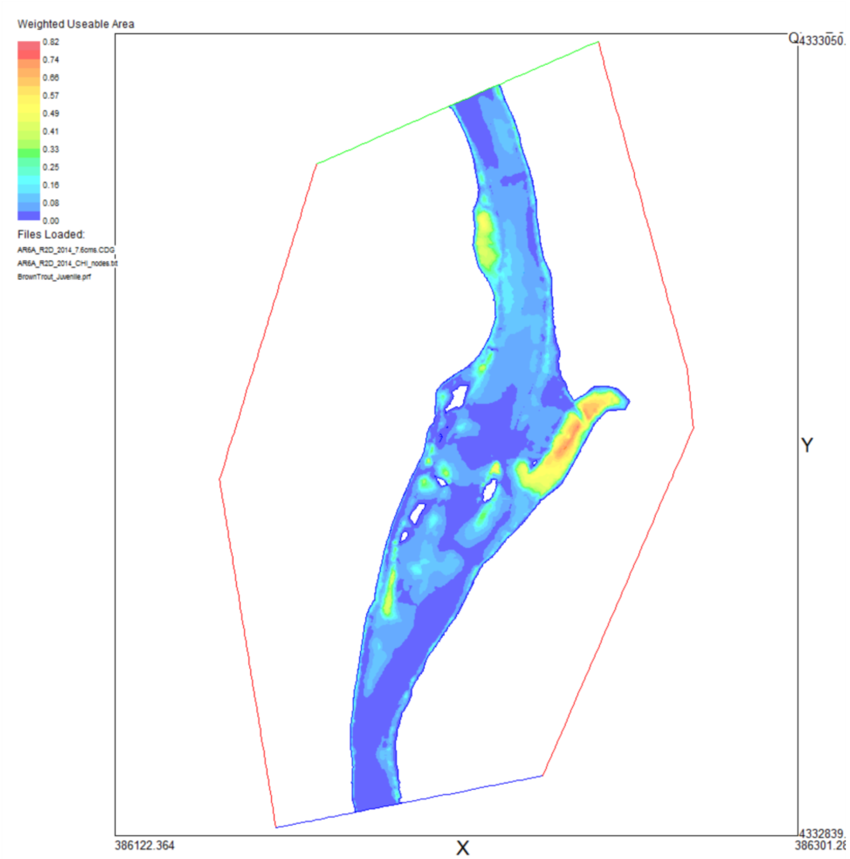


Figure F.26. Before and after comparison of weighted usable area (WUA) for juvenile brown trout at control site AR-6A at 7.6 cms.

AR-6A, Juvenile Brown Trout, 20.7 cms

Before **After**

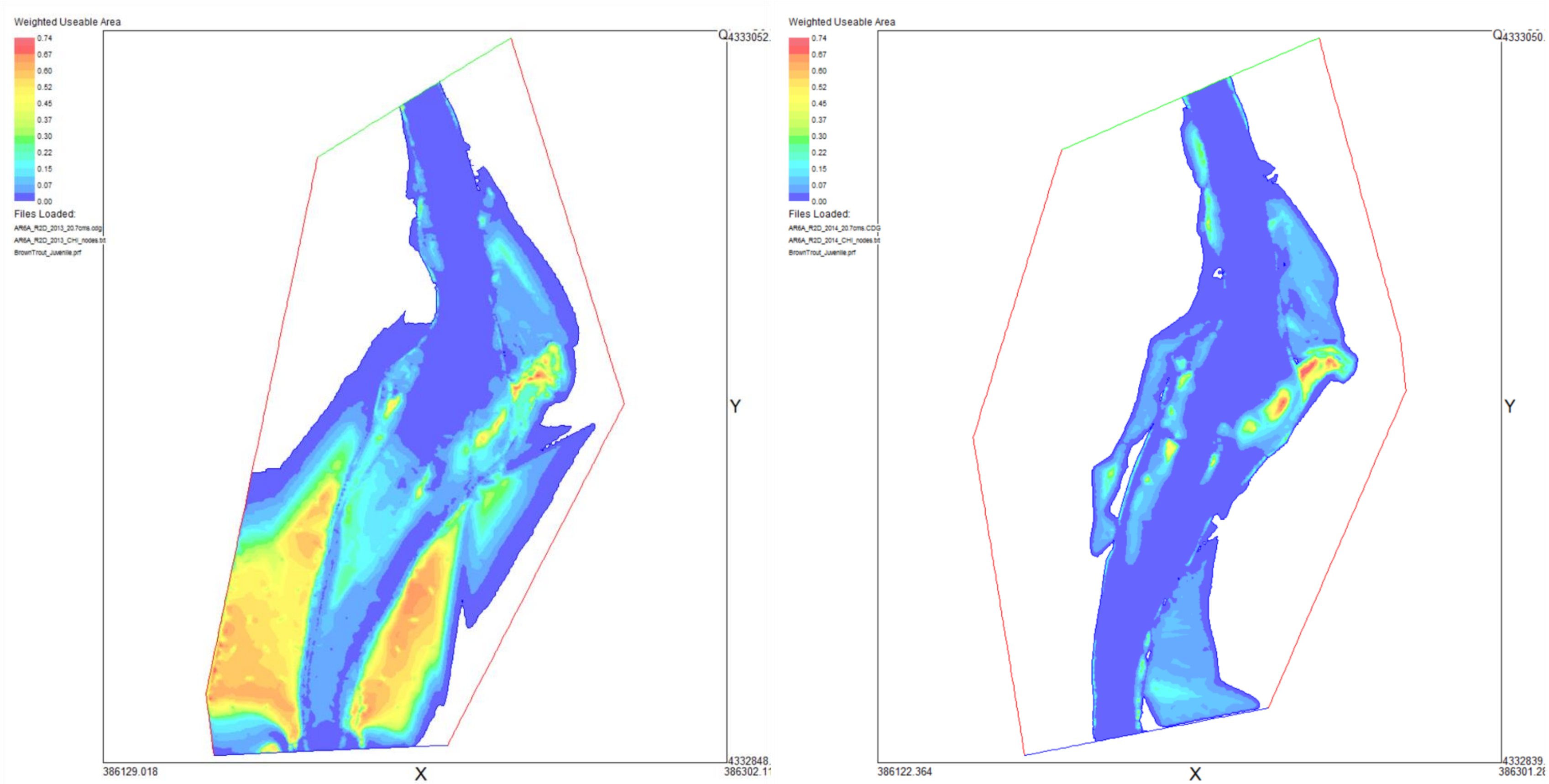


Figure F.27. Before and after comparison of weighted usable area (WUA) for juvenile brown trout at control site AR-6A at 20.7 cms.

AR-6A, Spawning Brown Trout, 2.0 cms

Before | **After**

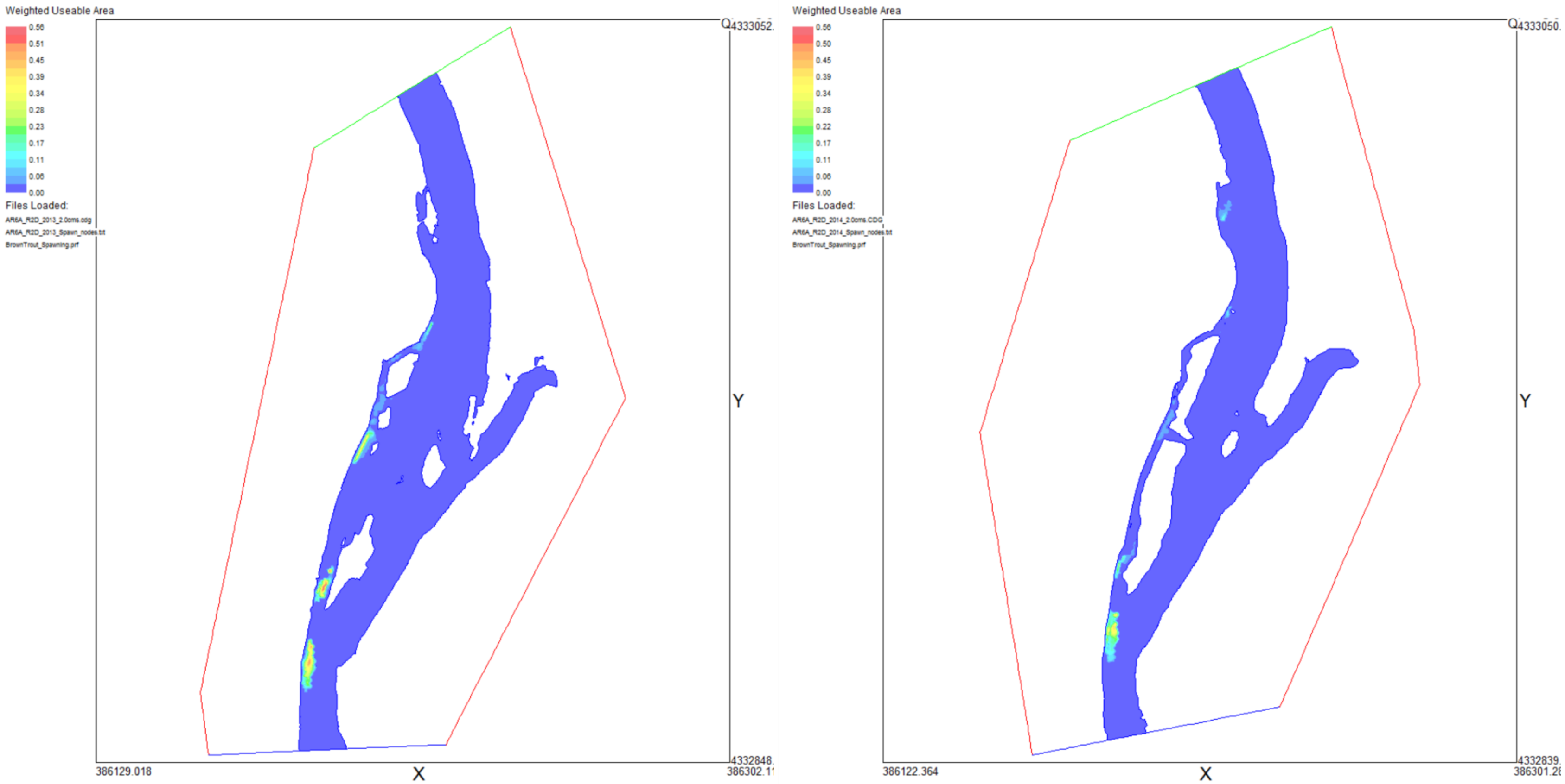


Figure F.28. Before and after comparison of weighted usable area (WUA) for spawning brown trout at control site AR-6A at 2.0 cms.

AR-MH, Adult Brown Trout, 2.0 cms

Before **After**

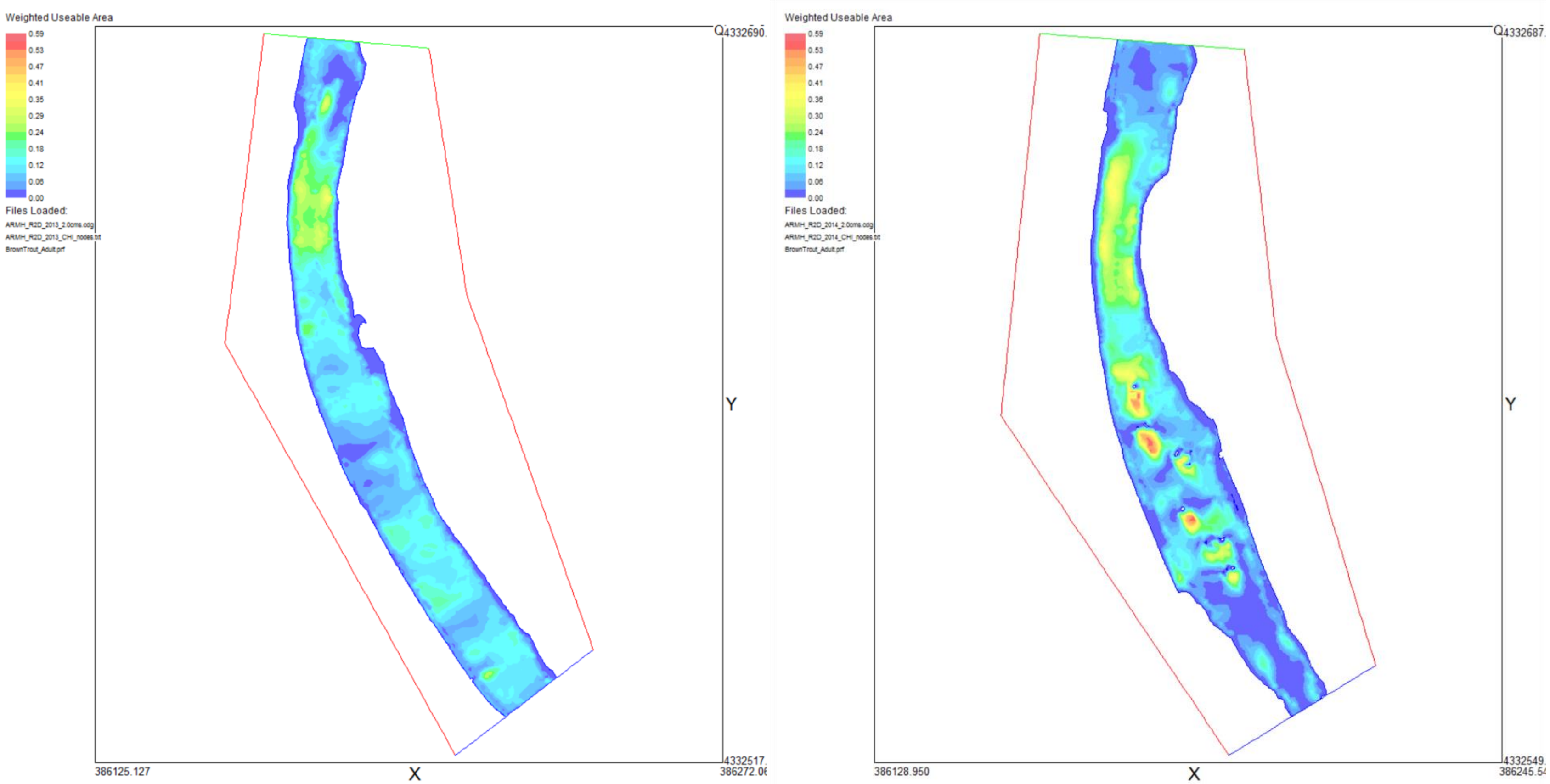


Figure F.29. Before and after comparison of weighted usable area (WUA) for adult brown trout at treatment site AR-MH at 2.0 cms.

AR-MH, Adult Brown Trout, 7.6 cms

Before **After**

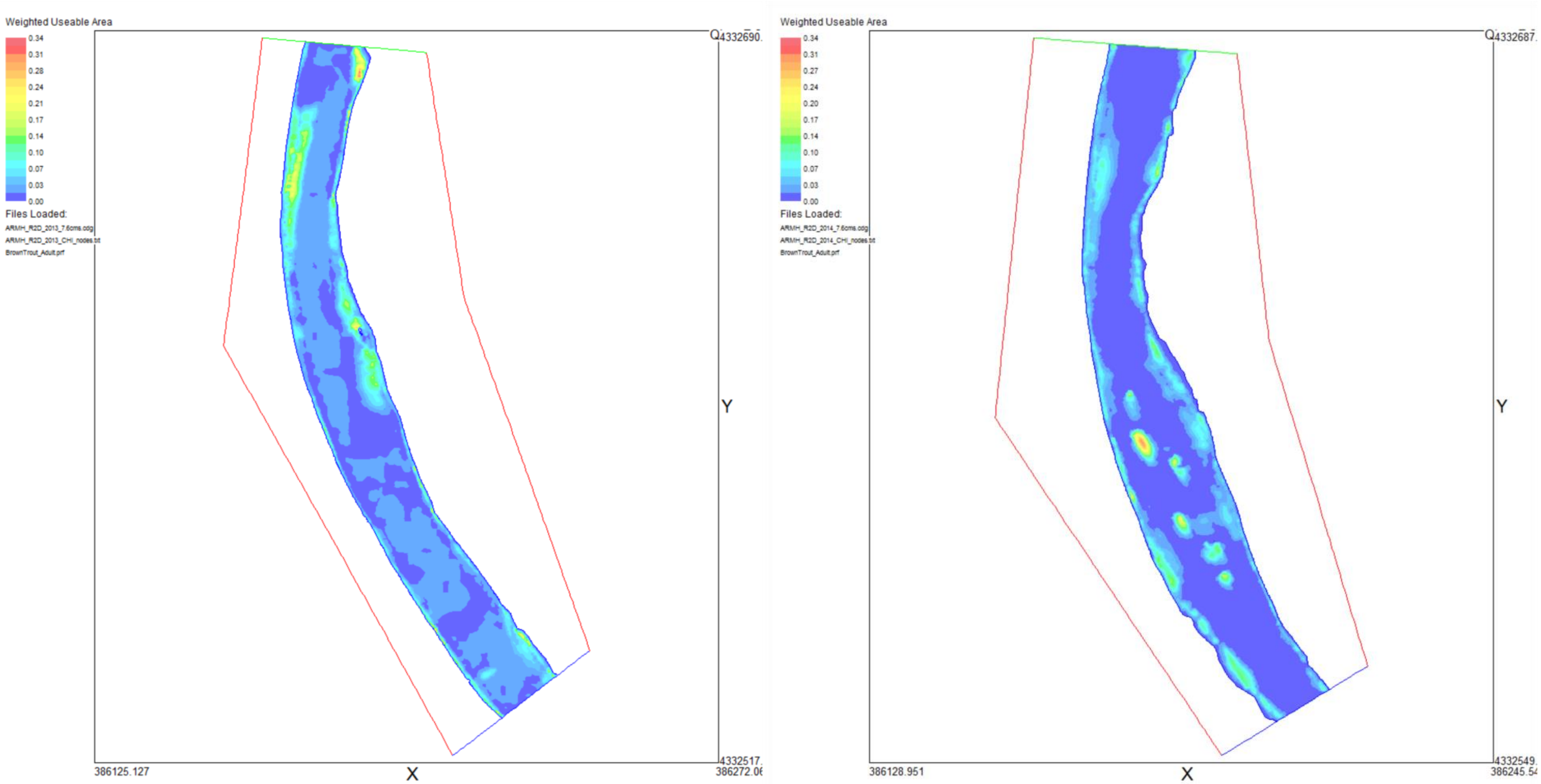


Figure F.30. Before and after comparison of weighted usable area (WUA) for adult brown trout at treatment site AR-MH at 7.6 cms.

AR-MH, Adult Brown Trout, 20.7 cms

Before **After**

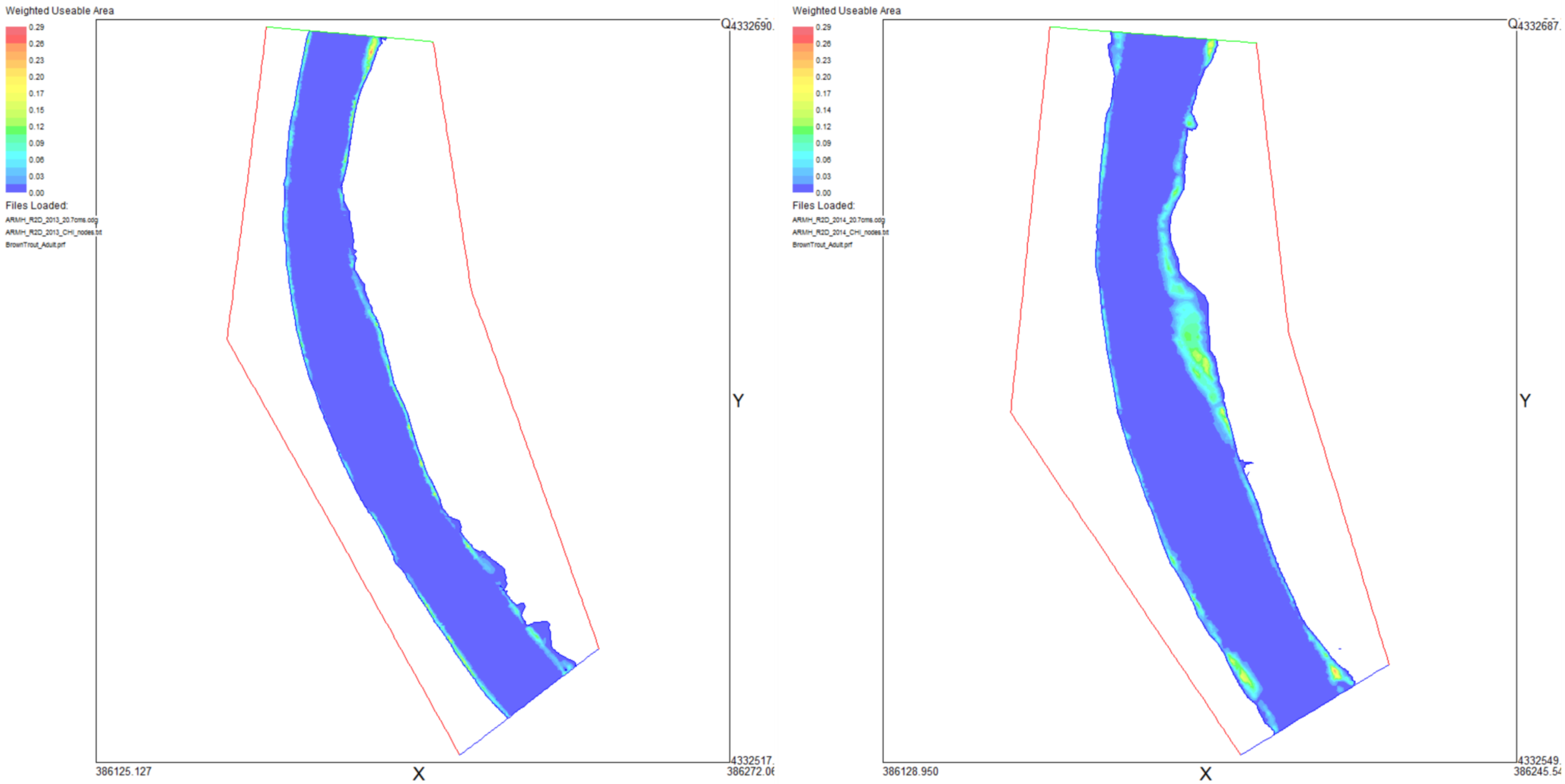
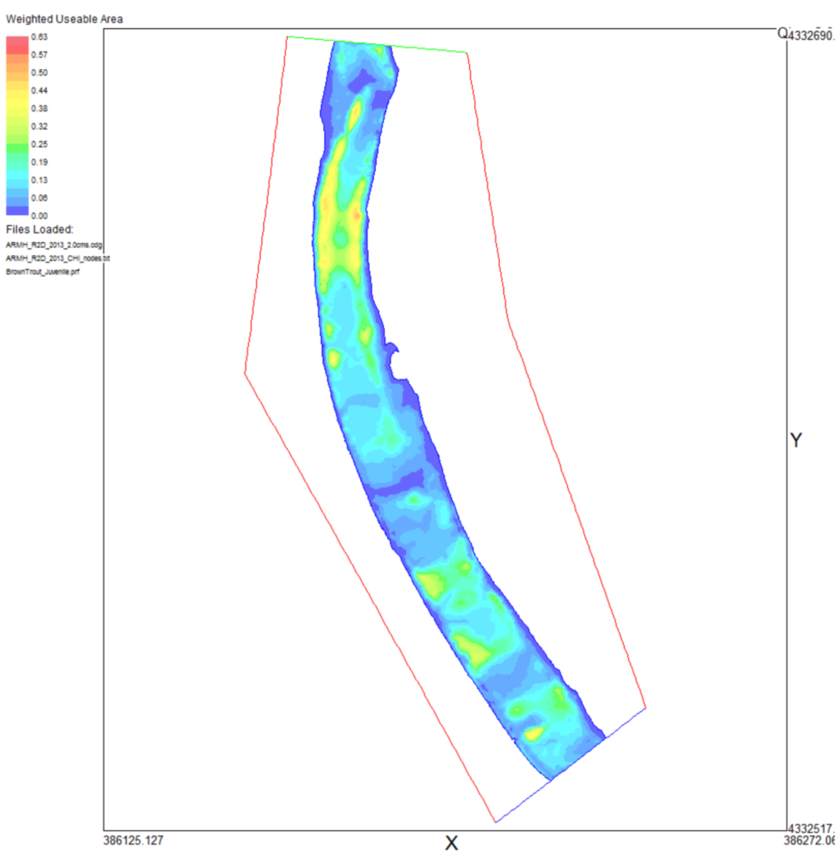


Figure F.31. Before and after comparison of weighted usable area (WUA) for adult brown trout at treatment site AR-MH at 20.7 cms.

AR-MH, Juvenile Brown Trout, 2.0 cms

Before



After

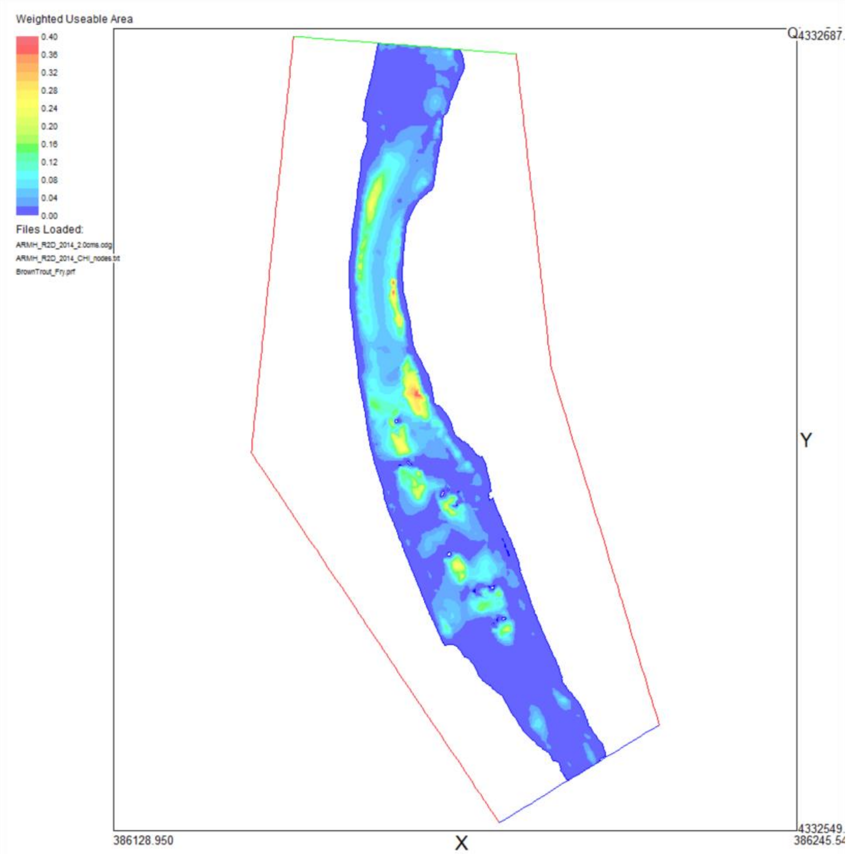


Figure F.32. Before and after comparison of weighted usable area (WUA) for juvenile brown trout at treatment site AR-MH at 2.0 cms.

AR-MH, Juvenile Brown Trout, 7.6 cms

Before **After**

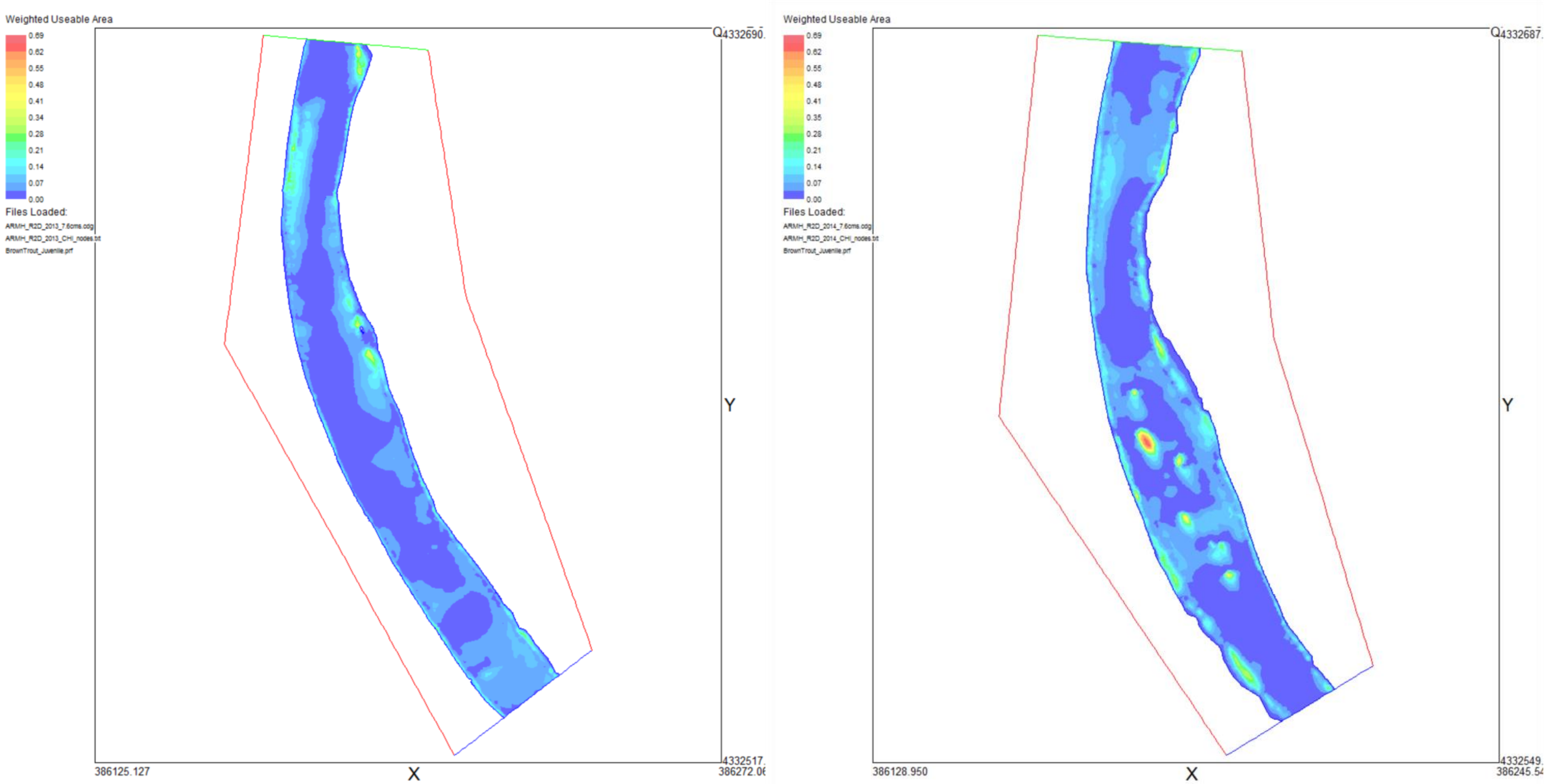


Figure F.33. Before and after comparison of weighted usable area (WUA) for juvenile brown trout at treatment site AR-MH at 7.6 cms.

AR-MH, Juvenile Brown Trout, 20.7 cms

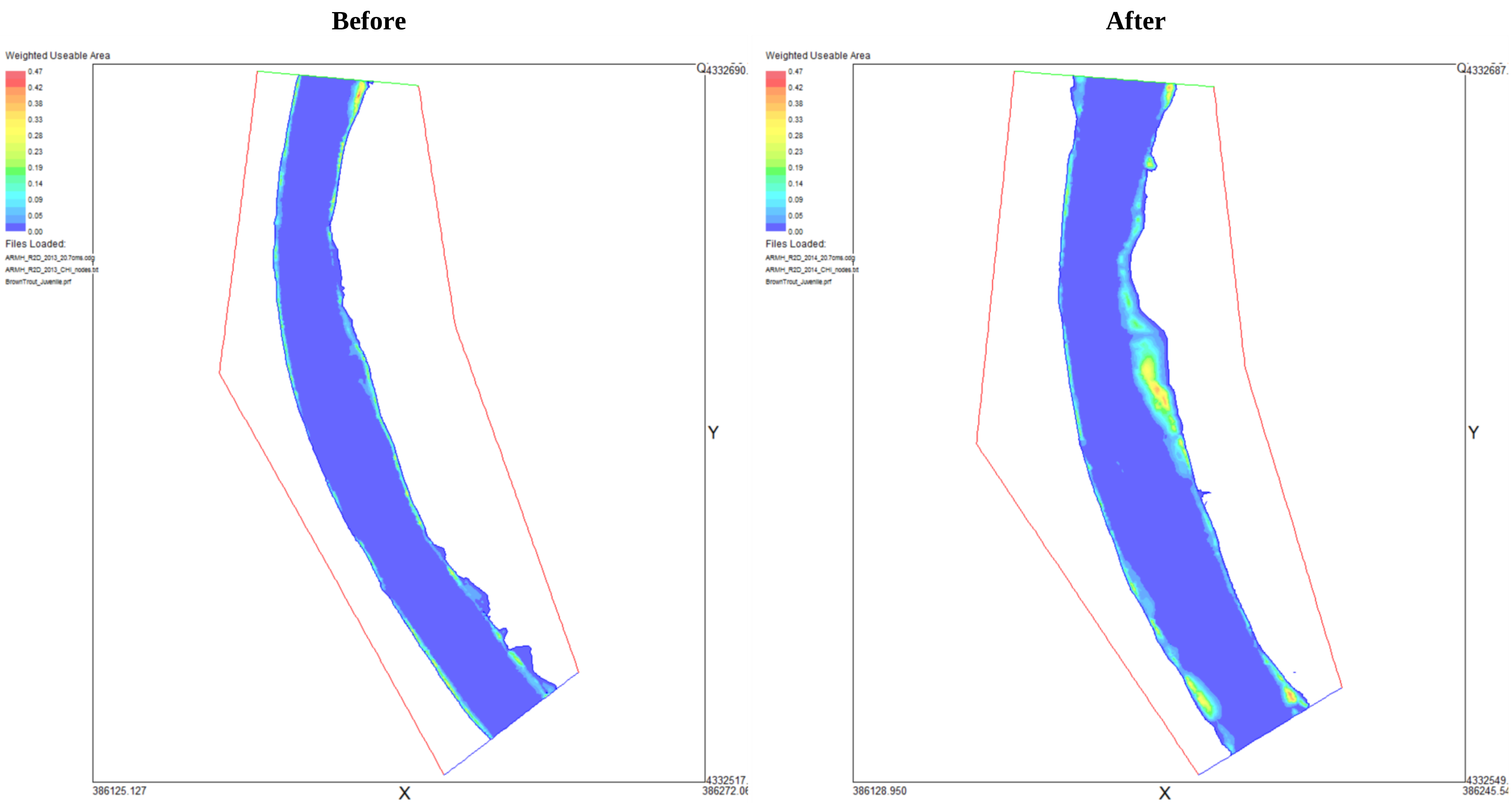


Figure F.34. Before and after comparison of weighted usable area (WUA) for juvenile brown trout at treatment site AR-MH at 20.7 cms.

AR-MH, Spawning Brown Trout, 2.0 cms

Before **After**

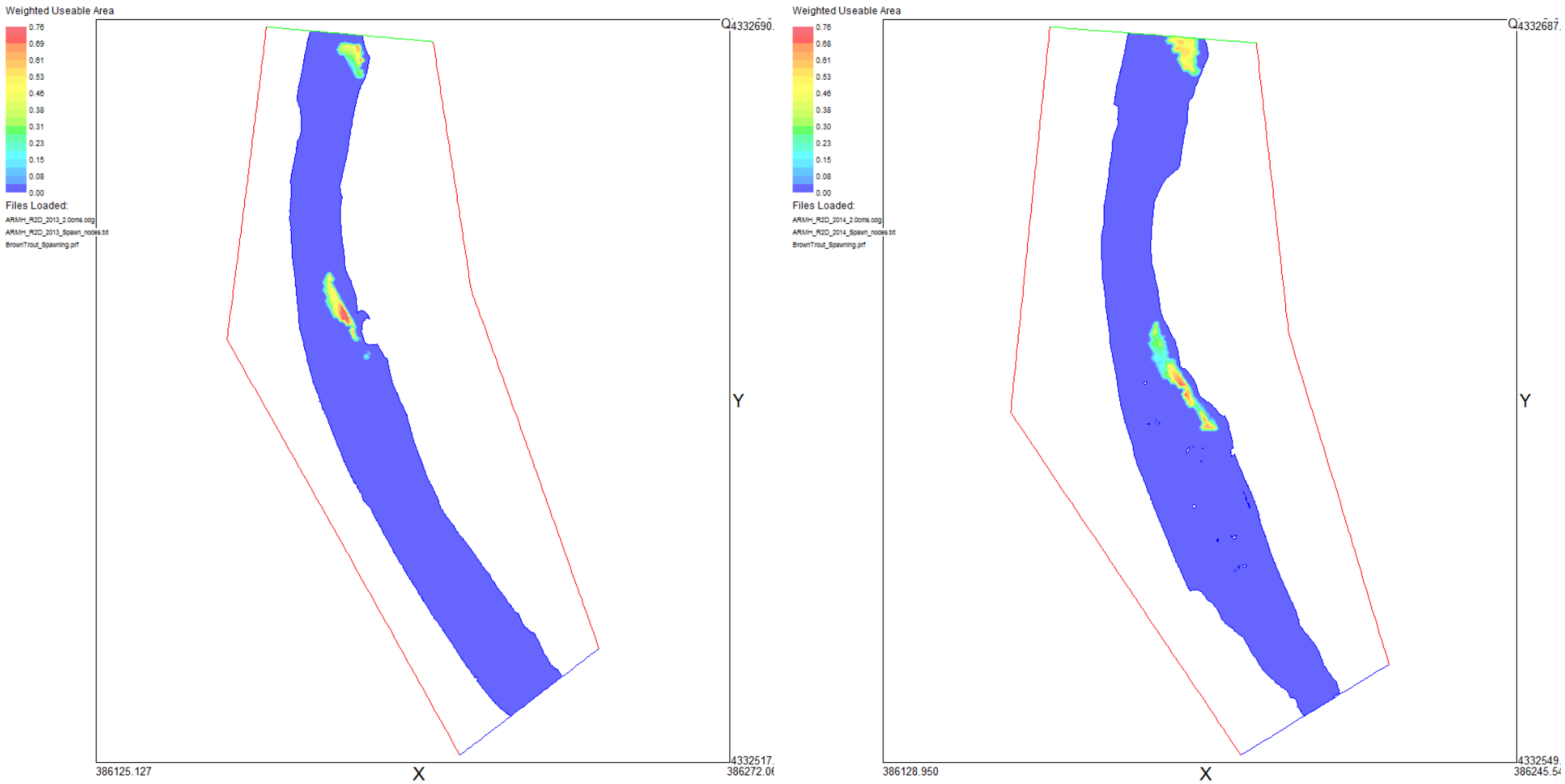


Figure F.35. Before and after comparison of weighted usable area (WUA) for spawning brown trout at treatment site AR-MH at 2.0 cms.

AR-6, Adult Brown Trout, 2.0 cms

Before **After**

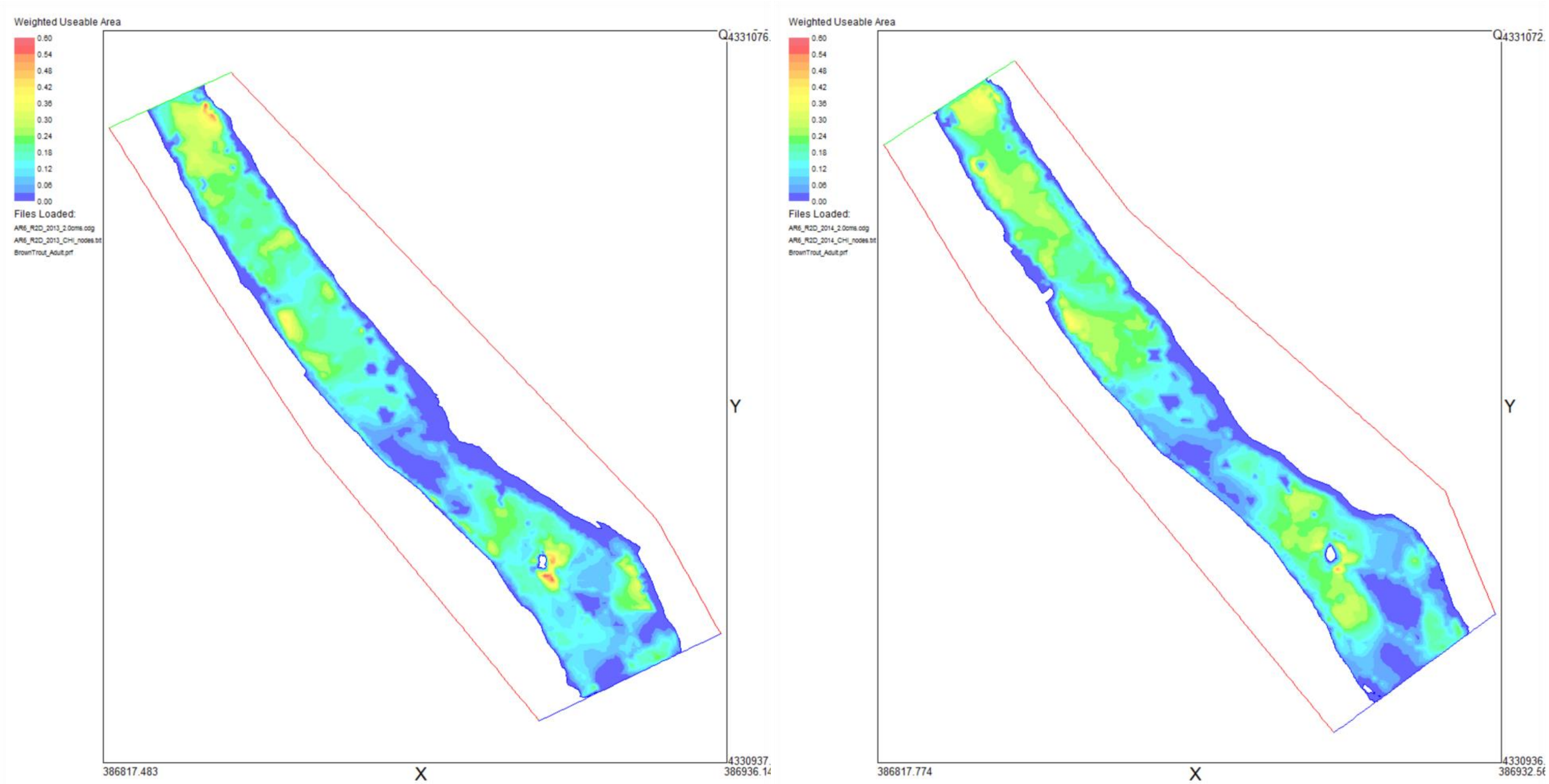


Figure F.36. Before and after comparison of weighted usable area (WUA) for adult brown trout at control site AR-6 at 2.0 cms.

AR-6, Adult Brown Trout, 7.6 cms

Before **After**

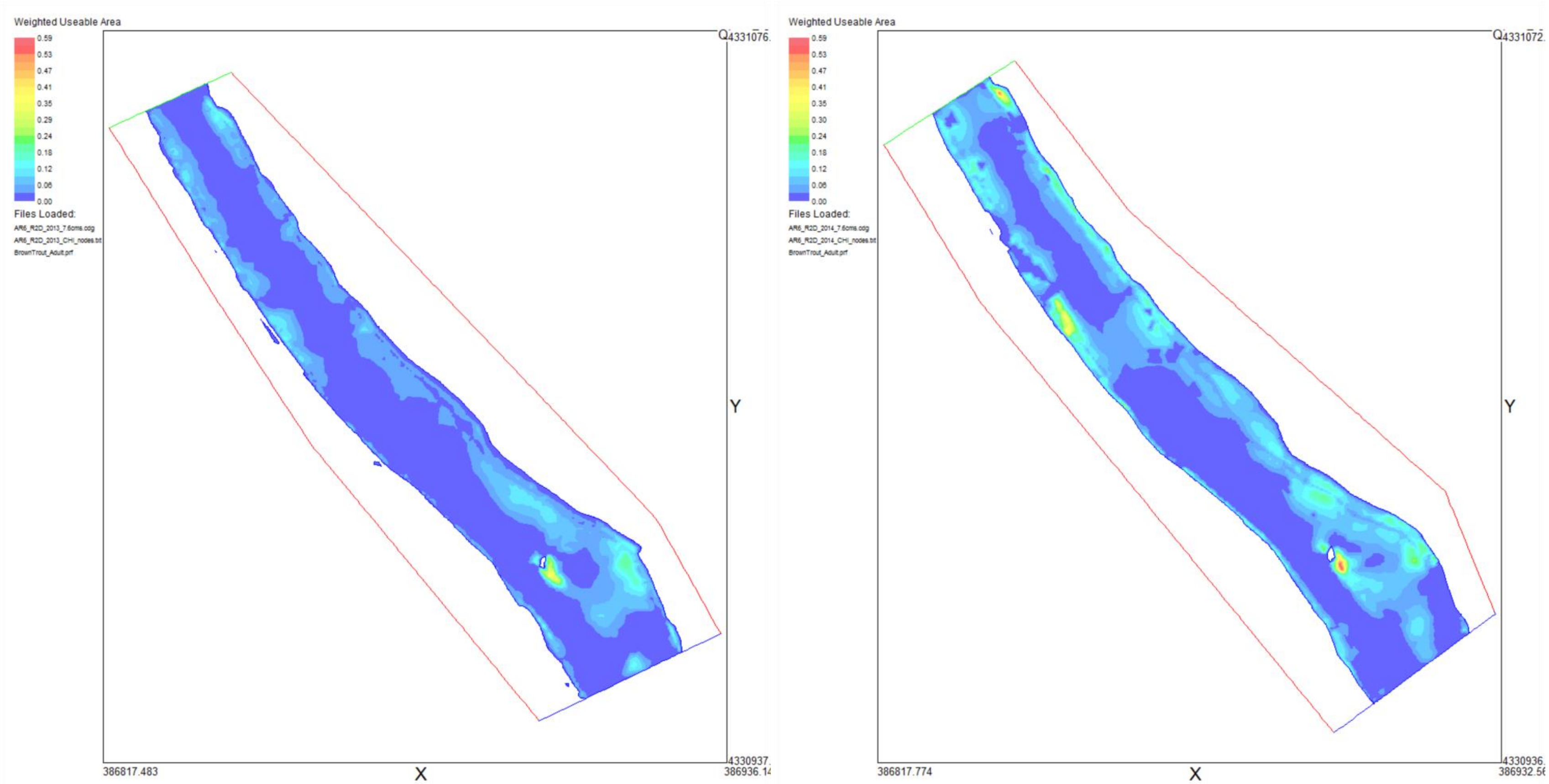


Figure F.37. Before and after comparison of weighted usable area (WUA) for adult brown trout at control site AR-6 at 7.6 cms.

AR-6, Adult Brown Trout, 20.7 cms

Before | **After**

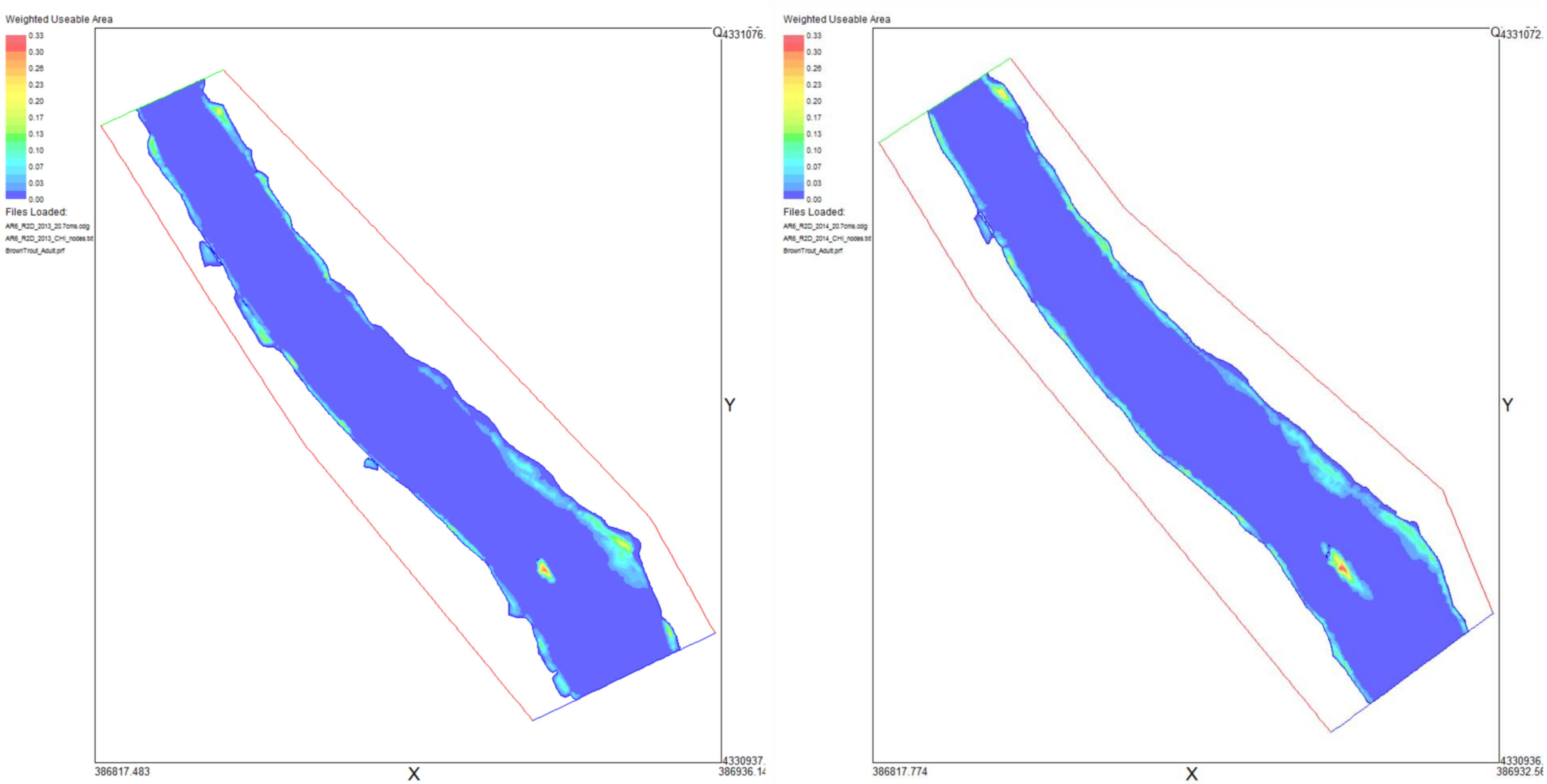


Figure F.38. Before and after comparison of weighted usable area (WUA) for adult brown trout at control site AR-6 at 20.7 cms.

AR-6, Juvenile Brown Trout, 2.0 cms

Before | **After**

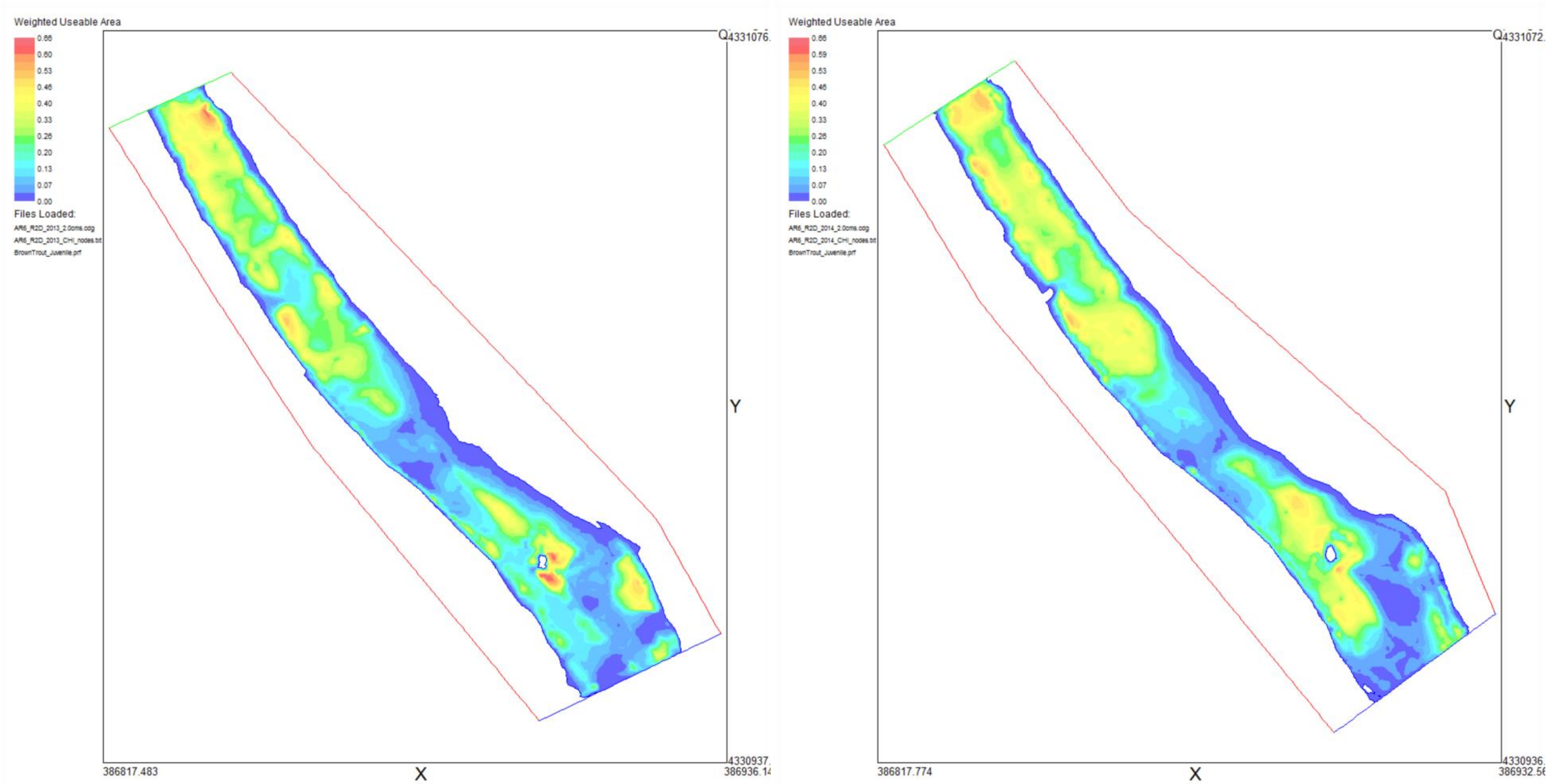


Figure F.39. Before and after comparison of weighted usable area (WUA) for juvenile brown trout at control site AR-6 at 2.0 cms.

AR-6, Juvenile Brown Trout, 7.6 cms

Before **After**

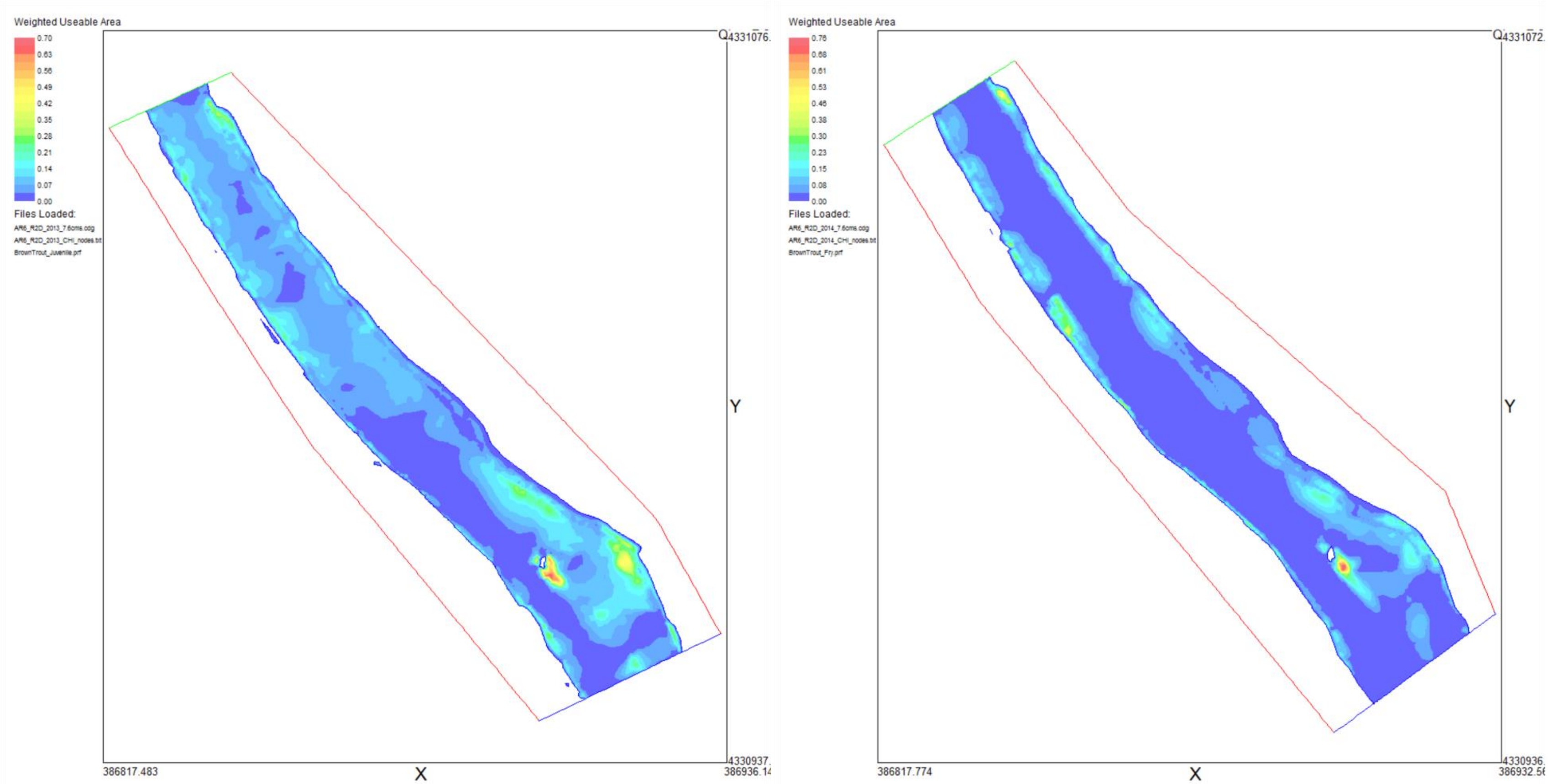


Figure F.40. Before and after comparison of weighted usable area (WUA) for juvenile brown trout at control site AR-6 at 7.6 cms.

AR-6, Juvenile Brown Trout, 20.7 cms

Before **After**

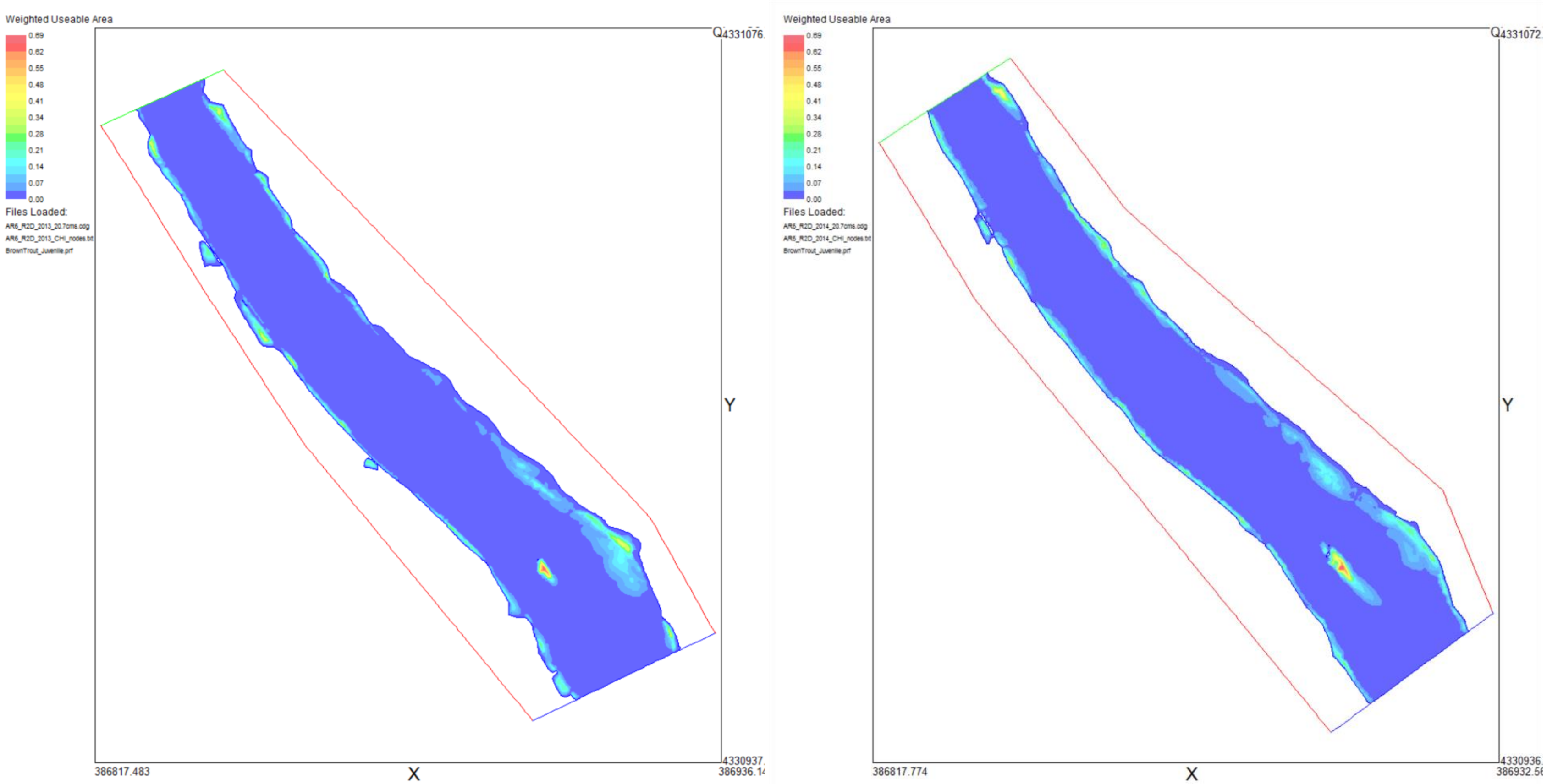


Figure F.41. Before and after comparison of weighted usable area (WUA) for juvenile brown trout at control site AR-6 at 20.7 cms.

AR-6, Spawning Brown Trout, 2.0 cms

Before | **After**

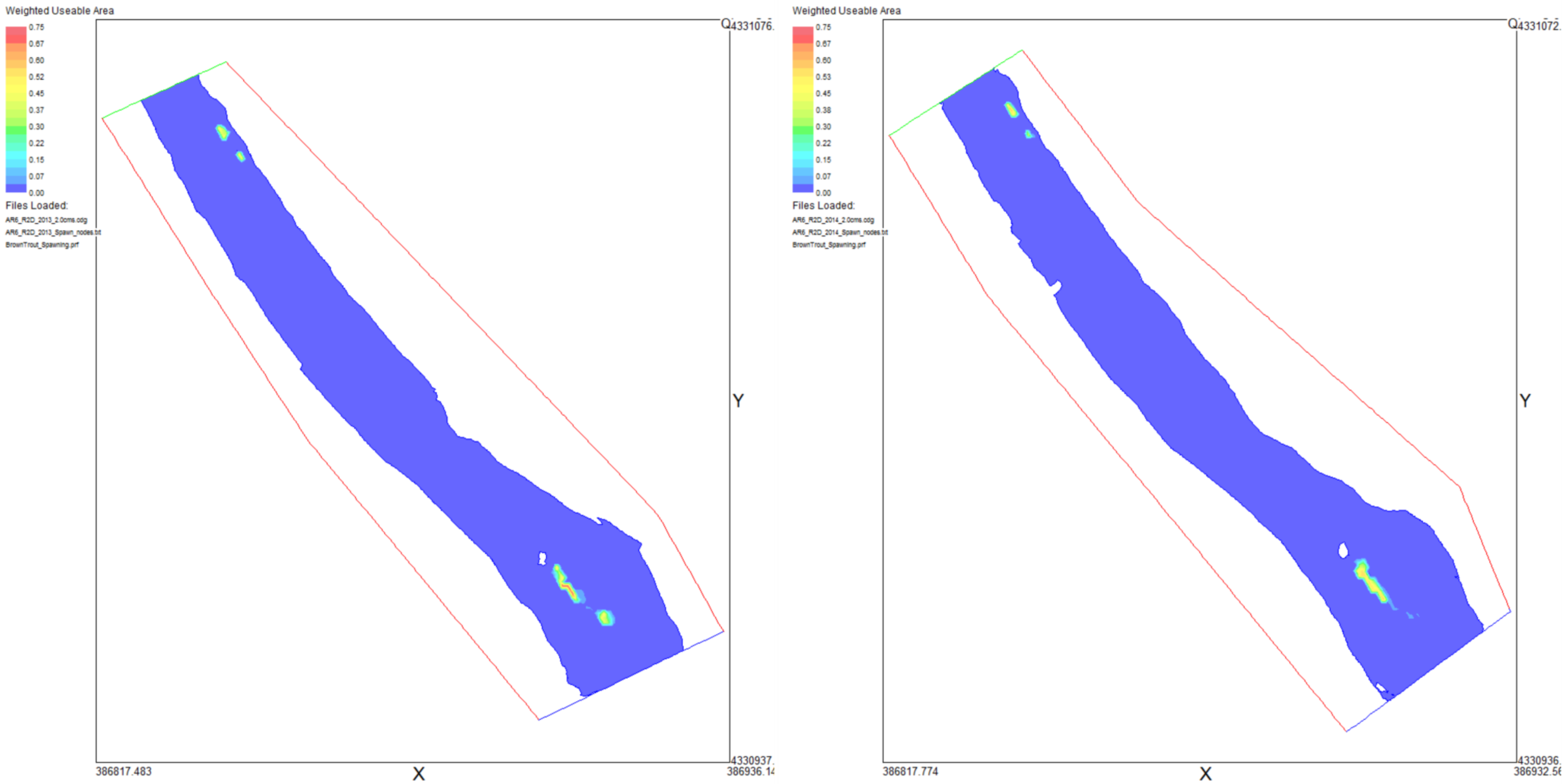


Figure F.42. Before and after comparison of weighted usable area (WUA) for spawning brown trout at control site AR-6 at 2.0 cms.

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