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Effects of Beaver Dam Analogs on stream channel complexity and overbank flow recurrence on McGarvey Creek (Del Norte County, CA)

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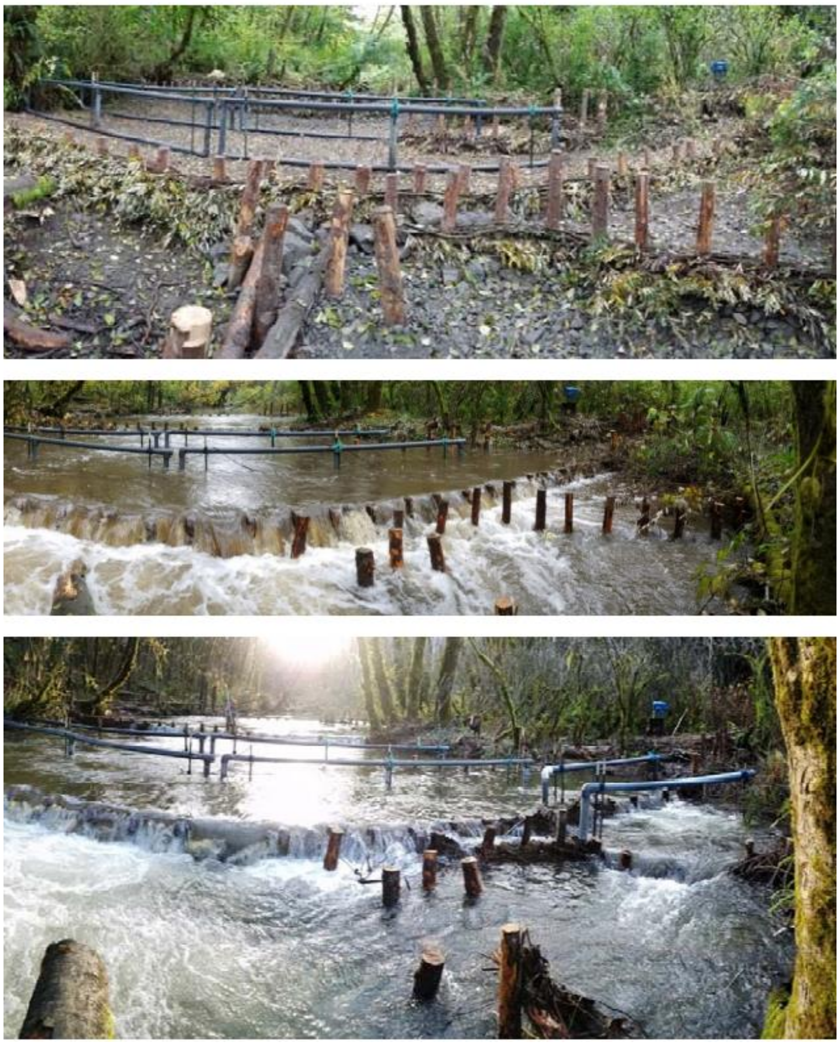

Photos of McGarvey Creek BDAs (photo credit: Sarah Beesley)

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Abstract

The North American Beaver (*Castor canadensis*) used to span nearly the entirety of North America but was nearly extirpated from many river systems due to human encroachment and exploitation. With the removal of these ecosystem engineers, streams and rivers lost a level of complexity that was previously provided by the presence of beaver dams. One river that has been affected is the Klamath River, which flows through 257 miles of southern Oregon and northern California and is essential to many communities, including the Yurok Tribe (USFWS, 2013). The Yurok Tribal Fisheries Program (YTFP) began installing Beaver Dam Analogs (BDAs) in McGarvey Creek in 2018 as a way of mitigating stream damage caused by historic land use and the decline in *Castor canadensis* populations. Objectives included increasing stream habitat complexity for native salmonids, including threatened Coho Salmon (*Oncorhynchus kisutch*). BDAs influence stream geomorphology, and monitoring the characteristics of these influences will further help us understand their potential role in restoration. Our study compared stream channel morphology of nine cross-sections at three BDAs at McGarvey Creek BDA Site 1 between two time periods: immediately following installation of the BDAs (2018), and three years post-BDA installation (2021). An overbank flow analysis was also conducted to observe changes in floodplain connectivity through the comparison of shear stress, wetted perimeter, and velocity values pre-BDA construction (2017), immediately following BDA installation (2018), and post-BDA installation (2021). The BDAs at our study site increased floodplain connectivity to adjacent hydrologic units and the addition of BDAs added a level of stream complexity previously lost. This study has provided further understanding of how BDAs influence stream geomorphology and fisheries habitat over time in McGarvey Creek.

Introduction

The historic range of the North American Beaver (*Castor canadensis*) spanned nearly the entirety of North America, with beavers acting as vital ecosystem engineers until their populations were nearly extirpated by the late 1800's from human activity (Mid-Klamath Watershed Council, 2021). Beaver dam construction added stream channel complexity, which can be defined as heterogeneity of stream channel morphology across a channel that also creates hydraulic diversity (U.S. Fish and Wildlife, 2017). Activities such as logging can decrease stream channel complexity through sedimentation and erosion resulting from timber harvest and road building (Gale & Randolph, 2000). However, beaver dam construction can alter stream flow in a way that allows for creation of deep pools, freshwater wetlands, and slowing of water to provide habitat variety needed by aquatic species (O'Keefe, 2021). The resulting pools reduce stream velocities and increase overbank flooding that can elevate water tables, recharge groundwater aquifers, and increase baseflow (U.S. Fish and Wildlife, 2017). Given the services beaver dams provide, their loss has led to reduced flows, channel incision, and decreased habitat complexity in rivers and streams across North America (Castro et al., 2018). Low flows are expected to be exacerbated by climate change trajectories (U.S. Fish and Wildlife, 2017), which poses a threat to aquatic species utilizing rivers and streams for summer habitat, particularly for cold-water species such as salmonids (EPA, 2021).

California and much of the West Coast is experiencing extreme drought conditions with increasing recurrence that can lead to a severe lack of summer stream flows (Castro et al., 2018). This inhibits the ability of rivers and streams to produce adequate pool habitat for freshwater aquatic species (O'Keefe, 2021). Streams impacted by activities that can result in excessive sedimentation or water diversion activities are even more vulnerable to low summer flows. The

Klamath River, which flows 257 miles from Oregon through California, is in an area susceptible to increased drought and watershed impacts resulting from historic and current land and water use. The Klamath River is a vital river system that sustains fisheries for the Yurok, Karuk, Hoopa, Shasta and Klamath Tribes as well as recreational and commercial fisherman (USFWS, 2013). Protecting and restoring aquatic habitats of the Klamath Basin is important to support ecosystem function and healthy wildlife populations. McGarvey Creek, a tributary of the lower Klamath River, provides important spawning grounds for many salmonids, including threatened anadromous Coho Salmon (*Oncorhynchus kisutch*) that are culturally significant to the Yurok Tribe (Carter et al., 2008).

To improve spawning and rearing conditions in tributaries of the lower Klamath River, the Yurok Tribal Fisheries Program (YTFP) in collaboration with Fiori GeoSciences (FGS) installed Beaver Dam Analogs (BDAs) at several sites within McGarvey Creek (Yurok Tribe, 2021). Beaver Dam Analogs are human-made structures that simulate the hydrologic functions of a beaver dam to enhance stream hydrology, connectivity to adjacent hydrologic units, and habitat for salmonid species (Figure 1) (Pollock et al., 2015; O'Keefe, 2021). Channel obstructions such as BDAs and associated aggradation of sediment and/or other stream materials upstream of these structures can increase overbank flooding, which increases water retention and floodplain connectivity (U.S. Fish and Wildlife, 2017). The pool, crest, and plunge are features of BDAs (Figure 1) that can be monitored over time to document geomorphic changes to the stream. BDAs have raised concern by some within the restoration field regarding their ability to create safe passage for fish, but studies have found that both juvenile Coho Salmon and steelhead trout are able to successfully pass BDAs (O'Keefe, 2021; Yurok Tribe, 2021). To increase salmonid habitat quality in McGarvey Creek, BDAs were installed at two sites to improve habitat complexity and ecological function, including formation and maintenance of deeper pools and increased floodplain connectivity to improve juvenile salmonid rearing habitat.

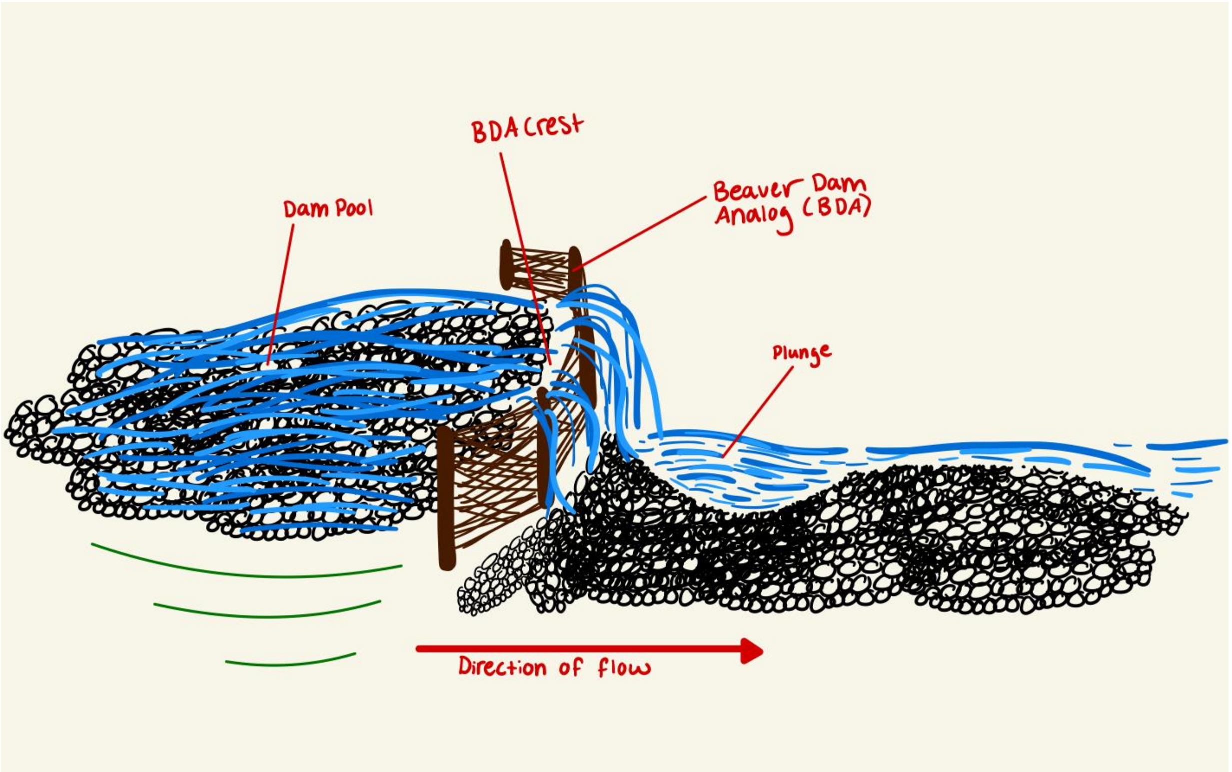

Figure 1: Beaver Dam Analog (BDA) diagram with BDA dam pool, crest, and plunge (Drawing by A. Khechfe).

Objectives and Hypothesis

Although the BDAs on McGarvey Creek show great potential for stream and river restoration efforts, few studies have examined how BDAs influence the surrounding channel morphology and overbank flow. The objective of this study is to assess the performance of BDAs on McGarvey Creek by re-surveying stream cross-sections at one of the two BDA sites (BDA Site 1). Re-surveying existing, monitored cross sections will allow for comparisons of stream channel topography and related hydrologic and hydraulic parameters (i.e. frequency and magnitude of overbank flows, wetted perimeter, velocity, and shear stress) at three stages: prior to restoration (Pre-Project, 2017), immediately after the BDAs were constructed (As-Built, 2018), and three-years post-BDA installation (Post-Project, October 2021). We used the most upstream BDA (BDA 1) crest cross-section to assess overbank flow characteristics and related hydraulic parameters from our three different time periods. Overbank flow can be described as: flows that occur when discharge exceeds the capacity of the main channel and pours onto and across adjacent floodplain surfaces and ancillary channels (USGS, 2021; Wohl, 2021; Westbrook et al., 2006; David et al, 2016). The overbank flow analysis was conducted for 1-, 1.5-, and 2-year flood recurrence intervals (Q1, Q1.5, & Q2). Stream channel topography comparisons focused on the 2018 As-Built and 2021 Post-Project Surveys and did not include the 2017 Pre-Project Survey.

Hypotheses: We expect elevations surveyed at the BDA Crest cross-sections to be higher in 2021 relative to the As-Built conditions (2018) due to aggradation and elevations within the downstream plunge pools of the BDAs to be lower relative to the As-Built conditions due to scour. When analyzing overbank flow at McGarvey BDA Site 1, we expect the As-Built conditions at BDA 1 Crest cross-section to show the highest level of floodplain connectivity to adjacent hydrologic units relative to the Pre-Project (2017) and Post-Project (2021) conditions.

Methods

Site Description

McGarvey Creek is a tributary to the lower Klamath River and its confluence is approximately six miles upriver from the mouth of Klamath River, just south of the town of Klamath in Northern California (Figure 2). The study site is located on McGarvey Creek approximately three-quarters of a mile upstream from the creek's confluence with the Klamath River. McGarvey Creek flows through Yurok tribal land near its confluence with the Klamath River. A majority of the watershed is owned by Green Diamond Resource Company and managed as industrial timberlands. McGarvey Creek is surrounded by a heavily vegetated, temperate, riparian ecosystem dominated by red alder (*Alnus rubra*) and vine maple (*Acer circinatum*) in the upper canopy and a mix of California blackberry (*Rubus ursinus*), stinging nettle (*Urtica dioica*), salmonberry (*Rubus spectabilis*), and various native fern species in the understory. McGarvey BDA Site 1 was constructed in fall 2018 as a dam complex (Appendix B) initially containing three BDAs (Figure 3). The most upstream dam, BDA 1, is the primary dam and was constructed to function as the major hydraulic control for overbank flooding, while BDAs 2 and 3 (secondary dams) were built to increase stream complexity and help maintain BDA Site 1 integrity (R. Fiori, pers. comm., 2021). About one year post-construction, two low profile BDAs were added downstream of BDA 3 to increase site integrity, but this study focuses only on BDAs 1-3.

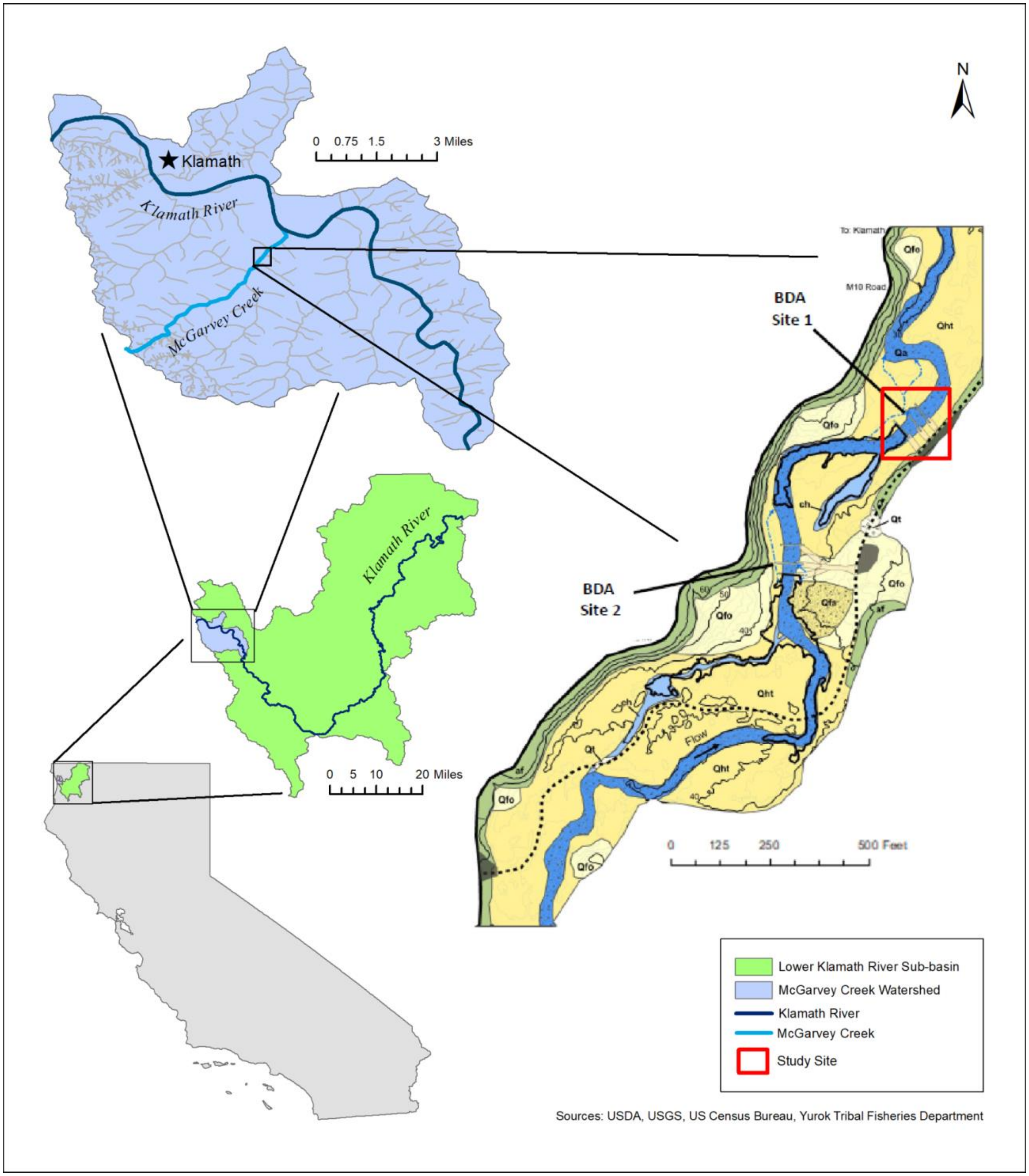

Figure 2: Location of the study site (McGarvey BDA Site 1) in McGarvey Creek, McGarvey Creek Watershed, Lower Klamath River Sub-basin, CA. Map credit: Rocco Fiori – Fiori GeoSciences.

Figure 3. Photograph of the McGarvey Creek study site (looking downstream) with the locations of the three BDAs. BDA 3 is not visible in the image, but its relative location downstream of BDA 2 is labeled. Photo taken by J. Anderson on 10/10/2021.

Project Background

The Yurok Tribal Fisheries Program (YTFP) formed in the late 1990s with a primary objective of restoring aquatic habitats, including McGarvey Creek, in the Lower Klamath Sub-basin for the support of healthy, natural, and sustainable populations of native anadromous fish, such as Coho Salmon (Gale & Randolph, 2000). Since the late 1990s, YTFP has monitored fish populations and implemented various habitat improvement projects within the McGarvey Creek watershed (Gale, 2008 & 2009; YTFP, 2009 & 2013; Antonetti et al., 2012 & 2014; Beesley & Fiori, 2014a, 2014b, 2016; YTFP, 2021). Restoration actions have included installation of constructed wood jams, creation of off-channel wetlands, riparian tree planting, and construction and maintenance of BDAs. As a tributary of the lower Klamath River, McGarvey Creek supports spawning populations of Chinook and Coho Salmon, steelhead, coastal cutthroat trout, and multiple lamprey species (natal fish) (Gale & Randolph, 2000). Additionally, the watershed provides vital rearing habitat for juvenile Coho from throughout the Klamath Basin (non-natal fish or not originating from McGarvey Creek) (YTFP, 2009; Yurok Tribe, 2021). Legacy watershed impacts and related lack of natural channel obstructions, including beaver dams, has greatly reduced habitat complexity within McGarvey Creek and thereby negatively impacting native fish (Yurok Tribe, 2021).

Cross Sectional Survey Data Collection

To help assess how BDAs in McGarvey Creek have influenced stream morphology since their installation in 2018, we re-surveyed topography at nine existing cross section transects in October 2021 (Figure 4). These cross sections were previously surveyed by YTFP to help document Pre-project, As-Built, and Post-Project conditions. Of these nine transects, crest and plunge features were re-surveyed for BDAs 1-3, and pool features were re-surveyed for BDAs 2 and 3. A transect for a riffle crest was also re-surveyed (Figure 4). A riffle crest is the naturally occurring crest in a riffle-pool system that acts as a hydraulic control in low flow periods (Rossi, 2012). We used standard stream channel surveying methods to measure the shape and topography of the stream channel at each of the nine transects (Harrelson et al., 1994). A Topcon AT-B4A automatic level and a CST/berger 06-925 MeasureMark fiberglass grade stadia rod were used to capture the elevations across each transect. A stadia rod was placed at major topographic changes along the transect to capture the stream channel morphology to compare with previously collected survey data. Locations along the transect were designated as “stations” and were measured in feet. Cross-sectional data were input into Excel to create figures depicting McGarvey Creek’s channel shape at the nine cross sections. The 2021 Post-Project cross sections were then plotted with the 2018 As-Built data to examine how the stream channel has changed over time.

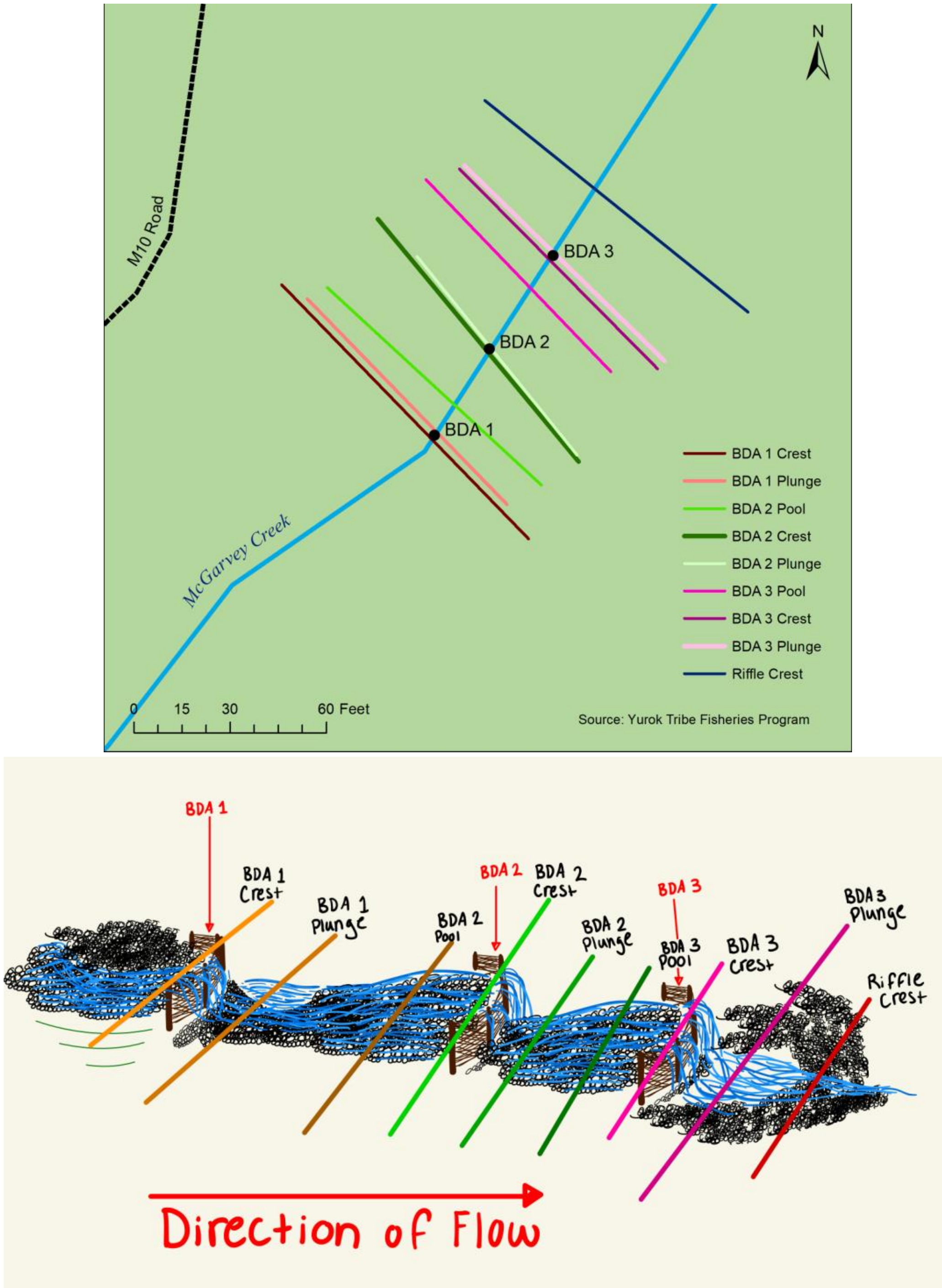

Figure 4: Aerial diagram (above) and longitudinal drawing (below) of the nine cross sections surveyed and locations of the BDAs at the McGarvey Creek study site (Drawing by A. Khechfe).

Overbank Flow Analysis

We used a combination of topographic data, hydrologic, and hydraulic analysis to evaluate changes in overbank flood frequency and related hydraulic parameters at BDA 1. For this analysis three different time periods were evaluated. These time periods, or stages of development, were recorded through repeat cross-section surveys at the crest of BDA 1 and defined as: 1) Pre-Project (2017), 2) As-Built (2018), and 3) Post-Project (2021). Hydrologic data for the McGarvey Creek Stream Gage (MCSG) was obtained from the Yurok Tribe Environmental Program (YTEP) and flood frequency statistics for the period of record were calculated by FGS following Bulletin 17B guidelines (Appendix A2) (Bulletin 17B Ref). At-a-station hydraulic parameters for the BDA 1 Crest cross-section were calculated using the NRCS Cross-Section Analyzer Tool (NRCS, 2019) for each stage of development. The most upstream BDA in a series of BDAs (i.e., BDA 1) provides a reach scale hydraulic control that is responsible for inducing backwater conditions, reducing velocity and shear stress, and forcing a portion of the stream flow out of the primary channel and onto the floodplain (Fiori et al., 2019). For this study we evaluated the impact of BDA 1 and subsequent channel changes at the site on overbank flows by comparing changes in the following hydraulic parameters, wetted perimeter, shear stress and velocity as a function of the Q1, Q1.5, and Q2 flows (Table 1).

Table 1: Stream flow frequency and hydraulic parameters (wetted perimeter, velocity, & shear stress) for McGarvey BDA Site 1 Dam 1 calculated using the NRCS Cross-Section Analyzer Tool (NRCS 2019). Discharge values for the displayed recurrence intervals were calculated by Fiori GeoSciences *from McGarvey Creek stream gauge data collected by the Yurok Tribe Environmental Program.*

Post-Project (2021)

Recurrence Interval (Yrs)	Wetted P	Velocity	Shear	Disharge
1	33.1	4.21	.504	250
1.2	145.2	6.64	.354	666
2	164.8	3.65	.385	824

As-Built (2018)

Recurrence Interval (Yrs)	Wetted P	Velocity	Shear	Disharge
1	79.4	2.98	.297	250
1.2	167.7	3.07	.364	666
2	180.8	3.12	.410	824

Pre-Treatment (2017)

Recurrence Interval (Yrs)	Wetted P	Velocity	Shear	Disharge
1	37.4	4.01	.469	250
1.2	78.5	4.68	.508	666
2	127.8	4.27	.423	824

Results

Cross-sectional results

The comparison of the October 2021 Post-Project and 2018 As-Built cross sections showed that most cross sections experienced incision or down-cutting (Figure 5). The BDA 1 Crest cross section depicts incision mostly on the left side of the channel around Station 30 (the location in feet from the beginning of the transect), while BDA 2 Crest downcut more evenly across the channel. BDA 3 Crest exhibited minor incision on the right side of the channel and a minor increase in channel form complexity (as defined previously). BDA 1 Plunge showed a flip in channel form compared to 2018, with incision on the left and aggradation on the right. BDA 2 Plunge and BDA 3 Plunge also showed incisions on the right side of the channel. BDA 2 Pool shows significant incision near the left bank and some aggradation on the right side, contributing to a wider channel overall. BDA 3 Pool mostly aggraded near the left bank from Station 30 to Station 60, while the 2021 Riffle Crest cross section was similar to that of the 2018 As-Built except that there was aggradation near the thalweg on the right side around Station 75.

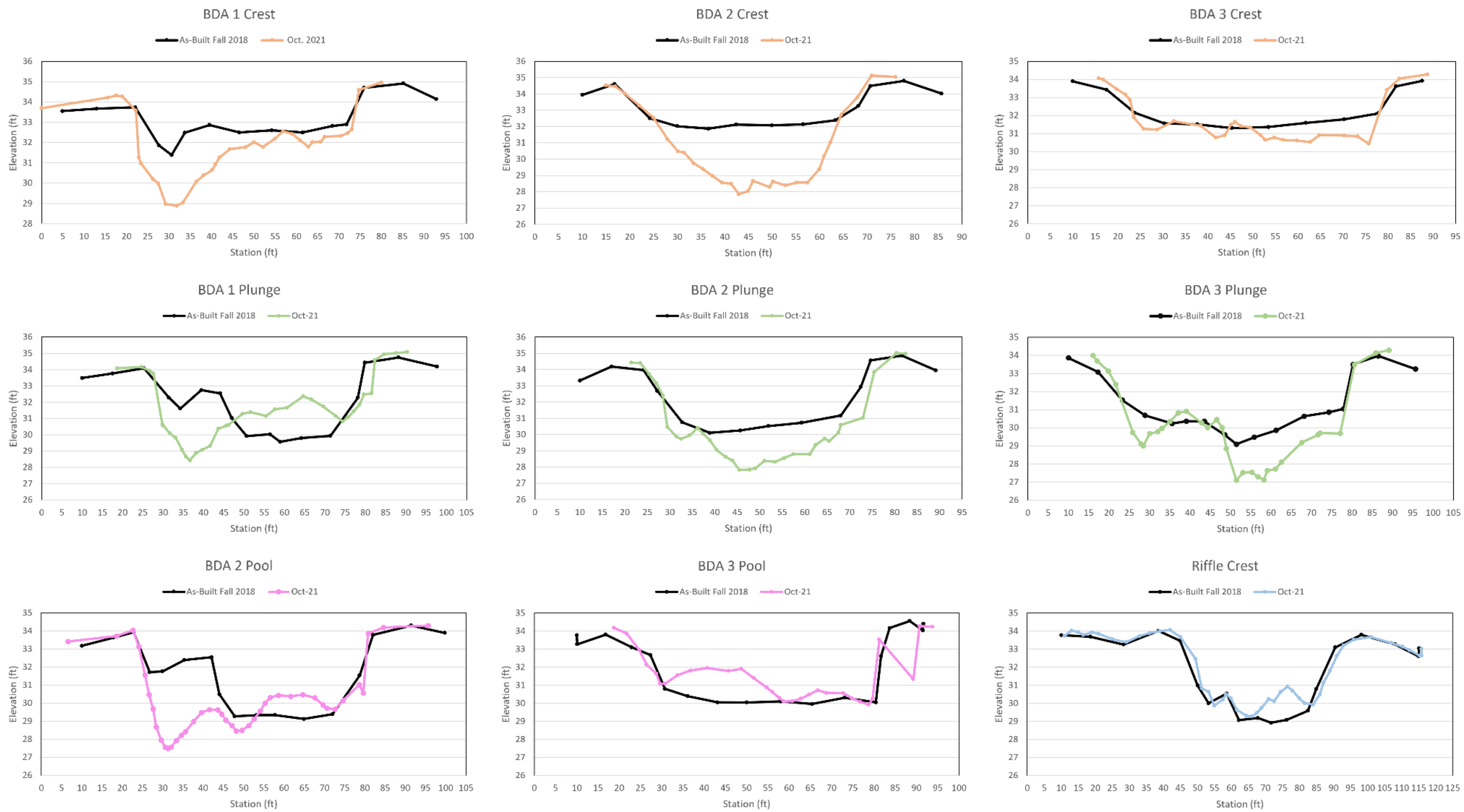

Figure 5: Cross sectional profiles of 2021 Post-Project data overlaid with the 2018 As-Built data for each of the nine cross sections surveyed. 2021 data is color coded by type of cross section for ease of understanding (crest is orange, plunge is green, pool is pink, riffle crest is blue). Elevation is given in reference to benchmark elevations, and position along the cross section is presented as Station numbers, going from the stream's left bank at Station 0 to the right bank on the right.

Overbank Flow Results

Results produced from use of the NRCS Tool are presented in Table 1 and Figure 6. Results indicated that the 2018 As-Built site on McGarvey Creek's crest had the highest wetted perimeter during 1-year flood recurrence flows (250 cf/s). Wetted perimeter is defined as the width of the streambed and stream banks in contact with water for an individual cross section; it was used to measure the availability of aquatic habitat over a range of discharges (USGS, 2016). Over a 1.5-year flood recurrence interval, the wetted perimeter was significantly higher in the 2018 As-Built dataset compared to the 2017 Pre-Project data. Over a 1-year flood recurrence interval flow, water velocity (ft/s) was calculated to be significantly higher in 2017 and 2021 relative to 2018 As-Built velocity (Appendix 1A). The 1.5- and 2-year flood recurrence interval flows showed the highest velocity with the 2018 As-Built crest having the lowest velocity among the three different surveys. The 2021 velocity data showed the 2017 pre-built conditions to have the highest values with the 2021 crest values as the second highest. Shear stress indicates how much force is being applied to the channel bed (Dingman, 2009) and was compared across the three datasets (2017 Pre-Project, 2018 As-Built, and 2021 Post-Project) as well. Shear stress calculations indicated that discharge at a 1-year flood recurrence interval was significantly higher in 2021 and 2017 than it was in the 2018 As-Built condition (Appendix 1A). For the 1.5-year flood recurrence discharge, the pre-built 2017 crest showed a significantly higher shear value relative to As-Built and Post-Project conditions.

Inputting discharge values (Appendix A2) corresponding with flood recurrence intervals at McGarvey Creek indicated that the addition of BDA 1 did increase floodplain connectivity. At a discharge of 824 cf/s, the addition of BDA 1 (based on the As-Built and Post-Project survey data) showed higher water surface elevation in adjacent floodplains than the 2017 Pre-Project conditions. 2018 As-Built and 2021 Post-Project conditions at BDA 1 showed greater floodplain connectivity at a discharge of 666 cf/s, relative to the Pre-Project condition (Figure 6). No difference in floodplain connectivity to adjacent hydrologic units was observed among the Pre- and Post-Project conditions at a discharge of 250 cf/s. Comparing calculated hydraulic parameters for all the input design discharges (Q1, Q1.5, and Q2.0) across the three datasets (2021, 2018, and 2017) indicated floodplain connectivity was greatest for the 2018 As-Built conditions and that floodplain connectivity was intermediate for the Post-Project conditions and lowest at the 2017 Pre-Project conditions.

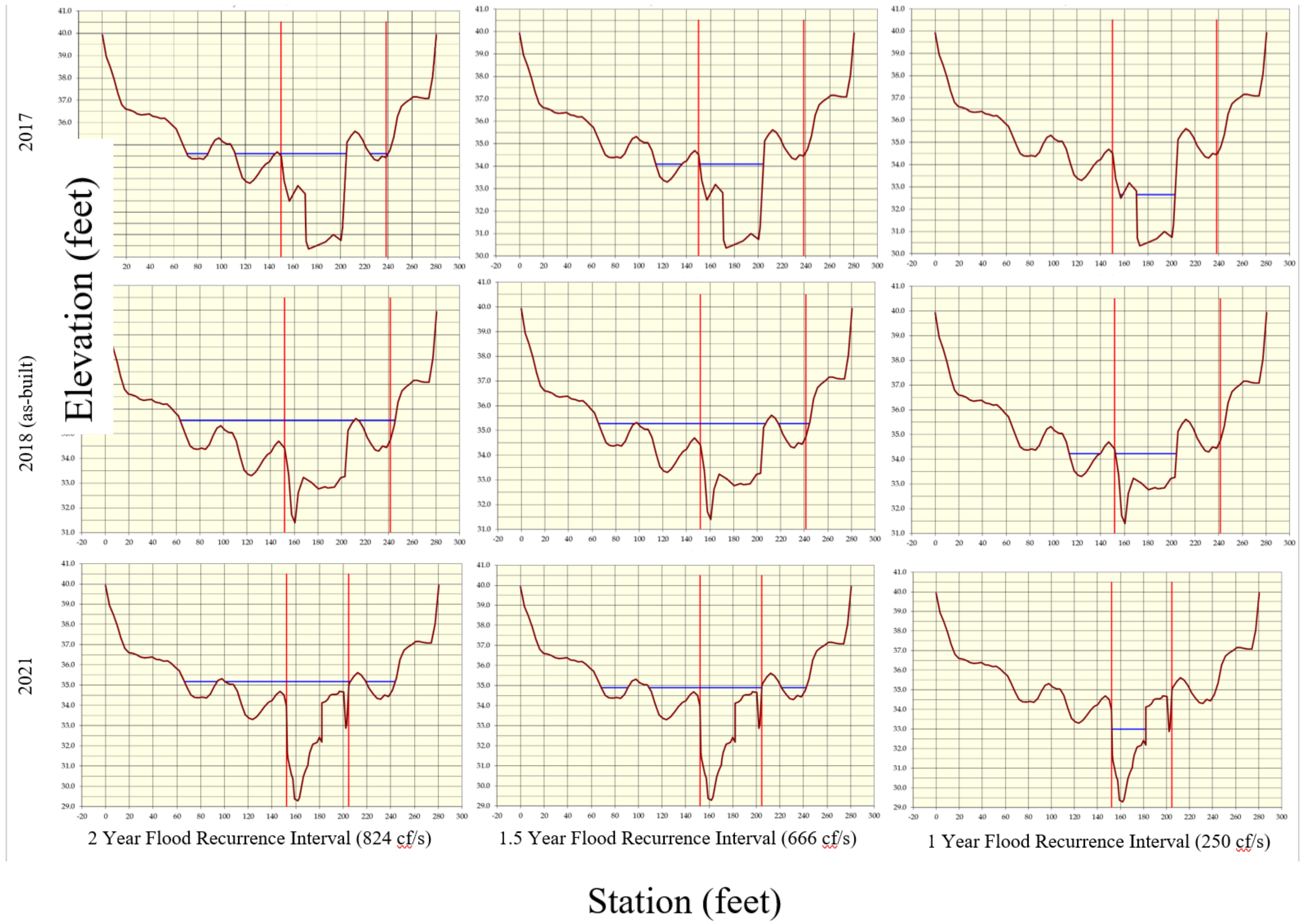

Figure 6: Cross sectional profiles of BDA crest controls (2017, 2018, and 2021) at discharge rates correlating with flood recurrence intervals (Appendix A2). Blue line represents the overbank flow of McGarvey Creek into adjacent hydrologic units.

Discussion

Cross Sections

Contrary to our hypotheses, we did not observe aggradation at the Crest cross-sections of the BDAs, but rather incision or channel degradation. BDA 1 Crest likely experienced an "end cut" around the dam, which occurs when high flows erode the stream bank around the end of the dam rather dispersing evenly across it (Figure 7) (US Fish and Wildlife, 2017). This creates incision in the path of the concentrated flow and prevents aggradation by carrying away sediment and material that would have built up at the crest. The incision observed in the BDA 1 Plunge and BDA 2 Pool cross sections shows this redirection of the stream channel to the left bank. BDA 2 experienced a blowout from high flows, which directed water flow under the dam, creating extensive scouring and degradation rather than a buildup of sediment that would be expected (S. Beesley, pers. comm., 2021). The more minor changes seen in the BDA 3 Crest were likely due to dissipating effects of the 2 previous dams on water forces before reaching BDA 3.

Figure 7: BDA Site 1 on McGarvey Creek showing the end cut around BDA 1 (above), and a plan view of an end cut (below) (Source: U.S. Fish and Wildlife, 2017).

We hypothesized that the Plunge cross sections would show incision and scouring downstream from the BDAs, and results indicated that they mostly did. BDA 1 Plunge also experienced aggradation on the right side of the channel, which was likely due to most of the flow being directed to the end cut, which allowed slower flows and deposition to occur opposite of the end cut. Our hypothesis that the Pool cross sections would have higher elevations than the Plunges was correct for BDA 3, but not for BDA 2. This was a possible result from the force of the end cut channel continuing to degrade BDA 2 Pool.

The changes observed in the cross-sections show that BDAs at the site did not necessarily change the stream channel in the ways that were expected, but did increase channel complexity and variable degradation and aggradation that could be adjusted through maintenance and/or alteration of the BDAs. BDAs require continual maintenance and adjustments to help ensure the structures achieve and maintain the highest level of benefits, particularly with respect to increasing floodplain connectivity (US Fish and Wildlife, 2017). End cutting, which we observed, is a common issue that is usually addressed by extending the length of the dam across the channel (Fish and Wildlife, 2017). The resulting stream cross sectional shapes (Figure 5) are informative of the streamflow behavior at the site, and these observations can provide insight on what measures could be applied to best achieve formation and maintenance of high quality salmonid habitat at McGarvey Creek BDA Site 1. Using the results from this project and O'Keefe's study of BDAs and fish passage (O'Keefe, 2021), future use of BDAs and implementation of the Lower Klamath River Sub-Basin Watershed Restoration Program can be better informed.

Overbank Flow Analysis

To conduct statistical analysis for our overbank flow assessment, our linear interpolator used data from (Appendix A2), and interpolated it over a small range of data collected over the years. This linear interpolator based on North Coast data overpredicted flow rates because it was based on hydrologic data from a wetter time period. Though the discharge data used for this analysis was slightly different, it does not change the results significantly. We compared shear stress (lbs/ft), velocity (ft/s), and wetted perimeter (ft) over Q1-, Q1.5-, and Q2s. These discharges were input into the NRCS Hydraulic Analyzer Tool and the calculated hydraulic parameter information was used to create Table 1 and Figure 5 (NRCS, 2021). When comparing the values in Table 1, we found that over a 1-year flood recurrence interval flow, velocity of the water (ft/s) was significantly higher in 2017 and 2021 than it was in the 2018 As-Built condition (Appendix 1A). This was most likely due to the sudden change in stream complexity (increased channel obstruction) from the construction of BDA Site 1 in 2018. In addition, we also observed that shear stress at Q1 was significantly higher in 2021 and 2017 relative to the 2018 As-Built condition. Shear stress measures the ability of streamflow to move streambed materials. It is understandable that calculated velocities were lowest among all the design discharges for the As-Built condition when BDA 1 was at its highest degree of function (i.e. providing the highest degree of channel obstruction). When looking at shear values for Q1.5, the 2017 Pre-Project crest showed a significantly higher shear value. This was most likely due to the fact that beaver dams significantly lower velocity, thus lowering shear stress (Majerova et al., 2020).

Our results agree with other studies that have found beaver dams significantly lower stream velocities (e.g., Majerova et al., 2020). Velocities across all flood recurrence intervals were highest at the 2017 Pre-Project condition. When looking at sites upstream of the BDAs, we found there was a plethora of gravel in all parts of the stream channel, showing the physical effects of shear stress on McGarvey Creek's bed substrate pre-BDA implementation. Reduced velocity and shear stress observed in 2018 As-Built data can be directly attributed to the BDA installation. It is well documented that beaver dams can significantly reduce stream velocity and thus reduce local shear stress values (Majerova et al., 2020). Improving our understanding of the hydrologic effects of BDAs on stream channel complexity, floodplain connectivity, shear stress, velocity, and wetted perimeters can better inform the restoration community and help guide future restoration actions.

Our overbank flow results (Figure 6) shed light on how BDAs at McGarvey Creek Site 1 influenced connectivity of the stream to adjacent floodplain habitats. At Q1-, Q1.5-, and Q2, we found that without BDAs present in 2017, there was little or low floodplain connectivity at the site. With the addition of BDA 1, floodplain connectivity greatly increased, as the stream's bankfull height was greatest in 2018 and there were intermediate increases in floodplain connectivity and bankfull height during the Post-Project phase (2021). Bankfull is known as the flow that fills a channel up to the top of its banks prior to flooding (NRCS, 2021). The increased floodplain connectivity observed in 2018 was most likely related to the installation of BDA 1 which caused more water to spread laterally and downstream of the dams relative to the unobstructed condition pre-project (Westbrook et al., 2006). Studies have found that beaver dams naturally increase overbank flow to adjacent units (Wohl, 2021), and our 2021 dataset showed that BDA site 1 added a level of stream complexity that was previously offered by the North American Beaver (*Castor canadensis*). Due to the population reduction of these ecosystem engineers along the Klamath River, the implementation of BDAs along streams with little stream complexity may prove to be a vital component of river restoration and floodplain geomorphology. BDAs as a restoration tool for streams and rivers require ongoing stewardship to understand the dynamic changes of these aquatic systems.

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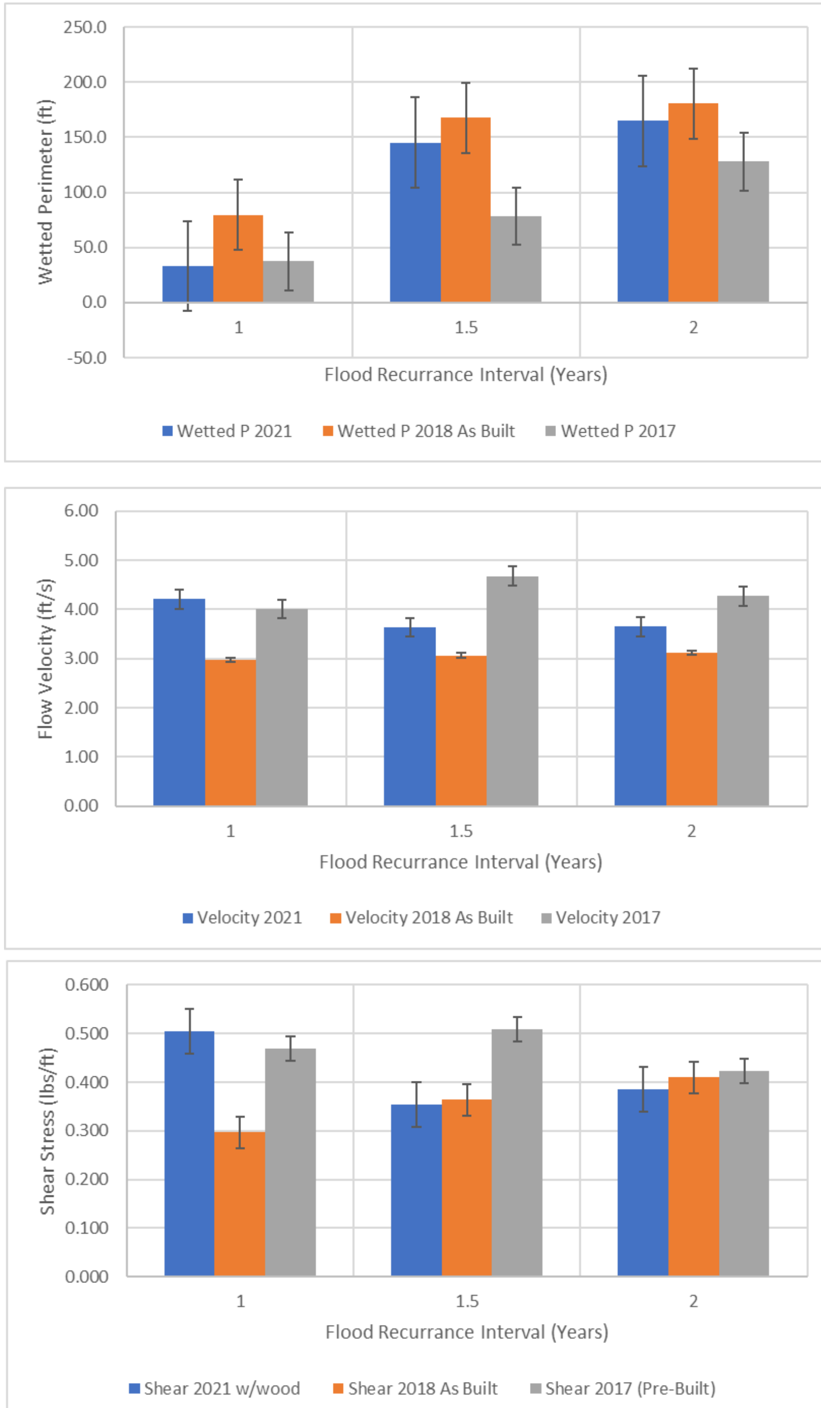
Appendix A

Wetted perimeter, flow velocity, and shear stress over 2 (824 cf/s), 1.5 (666 cf/s), and 1 (250 cf/s) year flood recurrence interval flow rates.

Appendix A consists of value comparisons for wetted perimeter, flow velocity, and shear stress of the BDA crest hydraulic control. Each figure was adapted from data in Table 1 and Appendix A2 using the NRCS Hydraulic Analyzer tool (NRCS, 2019).

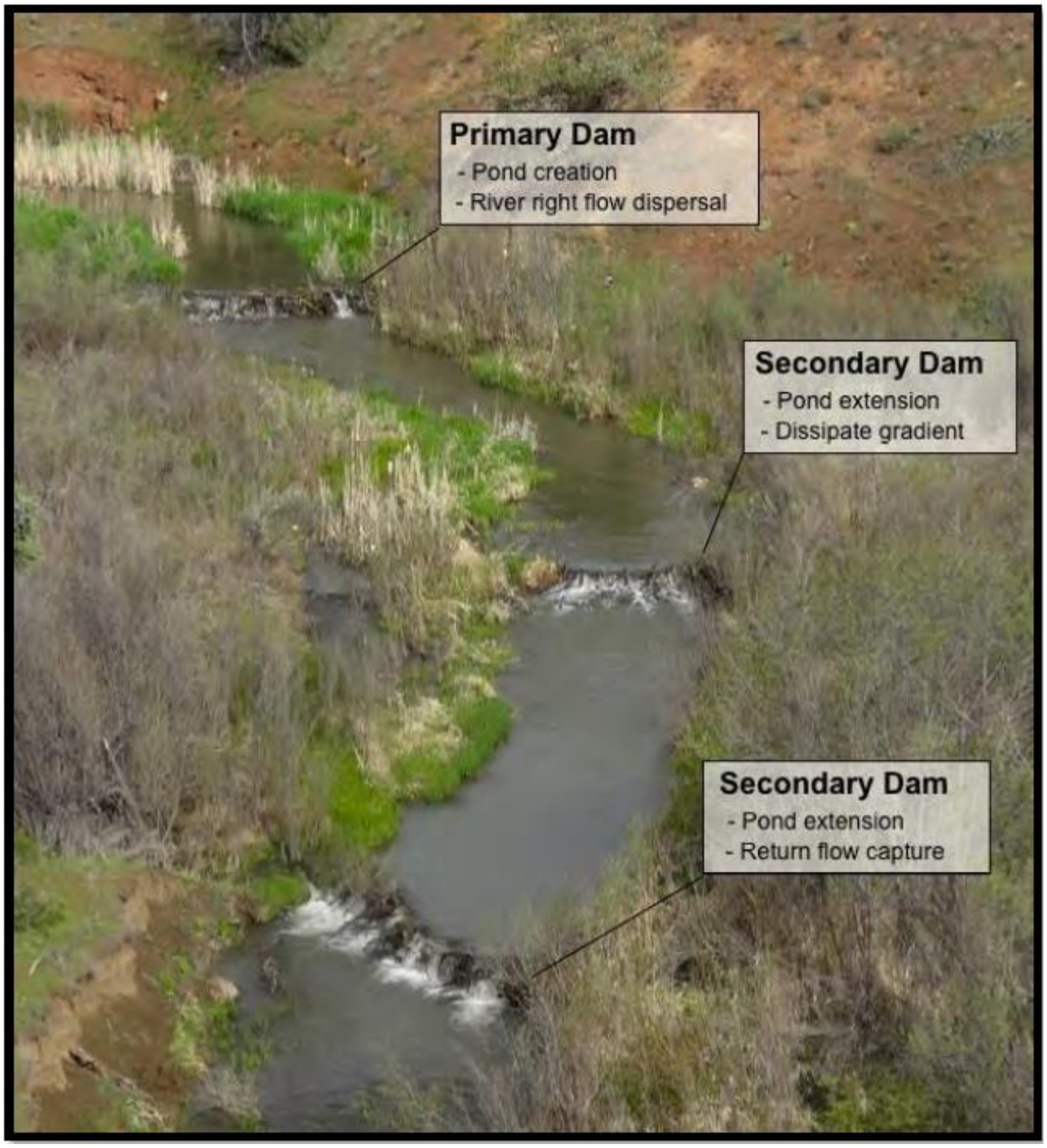


Appendix A1: Shear Stress (lbs/ft), Flow Velocity (ft/s), Wetted Perimeter (ft) over 1-, 1.5-, and 2-year flood recurrence interval discharge rates pre-BDA (2017), As-Built with BDA (2018), and three-years post-BDA installation (2021).

*Appendix A2: Peak-Flow Recurrence Statistics for McGarvey Creek BDA Site 1***.** *Discharge rates related to those seen at recurrence intervals 1.0, 1.5, and 2.0 years (YTEP Gage Data).*

Probability (%)	**Recurrence (years)**	**Discharge (cfs)**
5	20.000	1742
10	10.000	1487
20	5.000	1221
30	3.333	1055
40	2.500	930
50	2.000	824
60	1.667	730
67	1.500	666
70	1.429	639
80	1.250	546
90	1.111	436
95	1.053	361
98	1.020	290
99	1.010	250

Appendix B



Appendix B. A BDA dam complex at Bridge Creek, Oregon with the primary and secondary dam components identified. (Source: U.S. Fish and Wildlife, 2017).