CITY OF BOULDER FUNDED RESEARCH PROGRAM

Final Report:

Restoring for resilience: Assessing the restoration success of flood recovery projects on Left Hand Creek, Boulder County, Colorado

LEFT HAND
watershed center

Submitted by:

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1. Introduction

The purpose of this report is to provide a final three-year assessment on post-flood recovery at two sites along Left Hand Creek that are managed by the City of Boulder Open Space and Mountain Parks (OSMP). This project was funded by OSMP's Funded Research Program from 2018 through 2020. The project goal entails implementing the Watershed Center's Adaptive Management Plan (AMP) and Monitoring and Assessment Framework (MAF) to monitor one flood-recovery restoration project site and one control site on OSMP properties for three years post-restoration (2018 through 2020). These findings are further integrated within our AMP monitoring efforts at 20 additional (non-OSMP) sites to provide a robust comparison of restored and unrestored reaches throughout Left Hand Creek. All findings are reported in our annual State of the Watershed report.

The September 2013 floods resulted in dramatic changes to the Left Hand Creek Watershed. Recovery efforts have included numerous restoration projects by different entities, including City of Boulder, Boulder County, and the Watershed Center. These restoration projects aimed to increase flood resilience, restore long-term stream health and stability, and improve aquatic and riparian habitat. Since 2018, the Watershed Center has implemented our AMP to monitor and assess watershed health and restoration projects' trajectories towards resilience. The purpose of this work was to provide OSMP with recommendations for management in the larger context of the watershed based on monitoring at the two OSMP sites and as envisioned through the Watershed Center's AMP. Between sampling years, we have made revisions to our AMP and MAF that improved our ability to comprehensively and quantitatively assess metrics on an annual basis and provide meaningful recommendations for management. These final results and recommendations are from three years of monitoring and address our revised AMP and questions. Our monitoring addressed the following questions:

(1) Are ecological measurements, as an indicator of watershed health at each site, indicating a positive trend toward recovery as defined in the Watershed Center's AMP? More specifically (within applicable monitoring years):

   a. Is floodplain connectivity improved or maintained? (2020)

   b. Is channel morphology and habitat condition improved or maintained? (2019, 2020)

   c. Is native riparian condition and the native plant community improved or maintained? (2018, 2019, 2020)

   d. Are water quality and fine sedimentation improved or maintained? (2018, 2019, 2020)

(2) How do these measurements compare between the restored and unrestored reach?

2. Methods

2.1 Framework and Monitoring Hypotheses

Our MAF is the foundation for our methods and data provided in this report. The Framework is used to assess the ecological condition (physical and biological) of restored sites to determine overall watershed health. Within each ecological category included in the Framework (Floodplain Connectivity, Channel Morphology and Habitat, Riparian Condition, Water Quality, Aquatic Community and Condition), we assess key monitoring hypotheses related to our restoration goals. Each hypothesis is assessed by different methods and metrics that are tied to performance standards. Based on our results, we determine if we are meeting each performance standard or if a monitoring or management action is needed.

We update our Framework annually based on what we learn as we evaluate data each year. While the Framework includes a comprehensive list of possible monitoring categories, some categories and hypotheses are not included each year based on our priorities and capacity. Below we provide the ecological categories, questions, and associated hypotheses that we monitored in this project to address each monitoring question and the trajectory towards ecological resilience. We do not have a hypothesis included for the restored and unrestored comparison, as unrestored monitoring was used for reference and providing management recommendations.

Category: Floodplain Connectivity

Question: Is floodplain connectivity improved or maintained?

- **Hypothesis:** Per designs, appropriate benches and channels are inundated at restored sites during peak seasonal flows each year.

Channel Morphology and Habitat

Question: Is channel morphology and habitat condition improved or maintained?

- **Hypothesis:** Percent of habitable pool* area relative to the wetted area will be greater than 20% at restored sites. **Habitable pools in the Canyons were defined as greater than 0.8 ft residual depth, or the residual depth at which canyons fish species (e.g. trout) can find appropriate refuge, per our MAF.*
- **Hypothesis:** Average percent sands (fine substrate) in riffles at restored sites will remain less than 27.5% or decrease from year to year.

Riparian Condition

Question: Is native riparian condition and the native plant community improved or maintained?

- **Hypothesis:** Average percent of native herbaceous and woody cover types at restored sites will increase or remain the same from year to year.
- **Hypothesis:** Average native richness (species number) at restored sites will increase or remain the same from year to year.

Water Quality

Question: Are water quality and fine sedimentation improved or maintained?

- **Hypothesis:** Multimetric Index (MMI) score per site will either attain the performance threshold based on location (Biotype 1 or 2) or will trend towards attainment from year to year.
- **Hypothesis:** Sediment Tolerance Indicator Value (TIV) score per site will either attain performance thresholds based on site location (Sediment Regions 1 through 3) or trend towards attainment from year to year.

2.2 Site Descriptions and Methods

Two reaches, one restored and one unrestored, located on OSMP property in Left Hand Canyon were selected for this monitoring from 2018 through 2020. The Upstream Buckingham site was restored in April 2017 (Construction complete in December 2016 and planting complete in April 2017) and is located upstream of Buckingham Park, the unrestored reach (Figure 1). These reaches were representative of stream characteristics throughout the canyons geomorphological zone of the watershed and both included upstream floodplain pockets and a downstream confined areas. Floodplain pockets are sections of creek with broader access to the floodplain, while confined areas have limited floodplains due to canyon walls, roads, or other development. Since 2018 monitoring, we assessed the ecological condition of these study reaches as indicators of watershed health and the watershed's trajectory towards resilience.

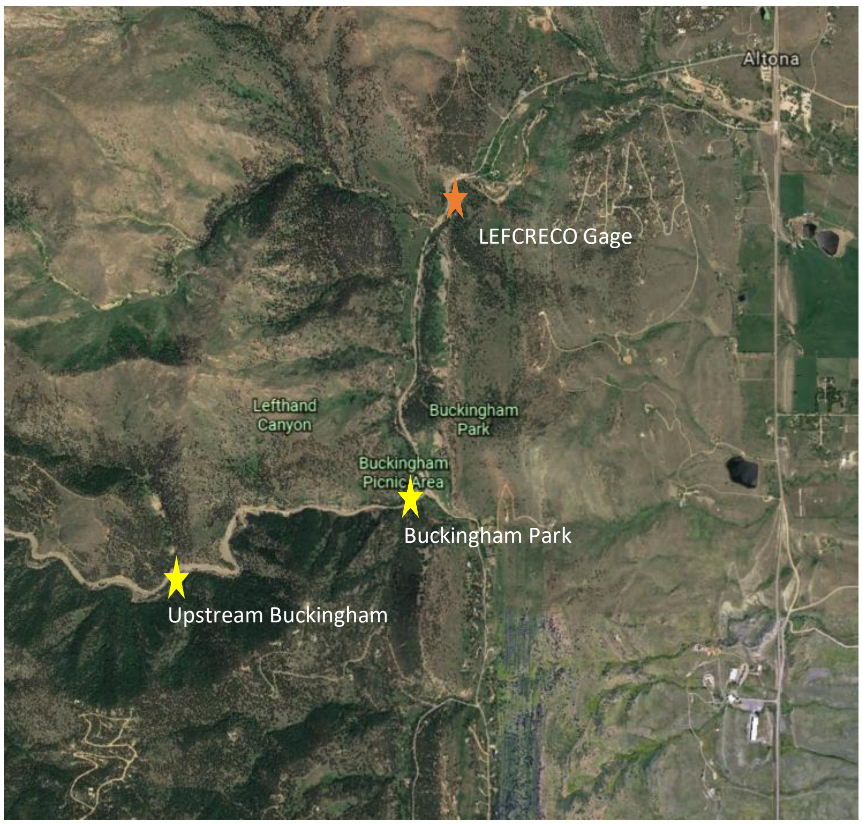


Figure 1. The sample reach locations for OSMP Buckingham Park and Upstream Buckingham properties and the LEFCRECO USGS stream gage on Left Hand Creek, Boulder County, Colorado.

Below we describe our methods for the four main assessment categories outlined in our revised MAF at each site. These assessments were completed annually from August through November and include: floodplain connectivity, morphology and physical habitat, riparian condition, and water quality. Specific details on methods can be found in our MAF.

Floodplain Connectivity

In 2020, we monitored floodplain connectivity at both OSMP sites. Floodplain connectivity was assessed based on visual (photo monitor) observations during peak seasonal flows, as informed by the LEFCRECO stream gage discharge readings in Left Hand Canyon (Figure 1). For the entirety of Left Hand watershed, we defined how restored sites are expected to accommodate a range of seasonal peak flows using restoration designs (prepared by Enginuity, Fly Water, and Otak) that used flow regime to determine appropriate floodplain elevations for inundation to occur at specific locations. Per designs, restored sites are expected to accommodate a range of seasonal peak flows (bankfull, high bench, and high flows) at expected floodplain locations (bankfull bench, side-channel, high bench, and overflow-channel) as described in Table 1 and visualized in Figure 2. While we expected peak seasonal bankfull flow at Upstream Buckingham to be between 150 to 290 cfs, please note that Table 1 and Figure 2 define the approximate flow range for bankfull flow for sites throughout the watershed as anything greater than low flow (15 cfs) and less than high bench flow (200-290 cfs, depending on location in the watershed). However, the variable and sometimes erratic flow regime of Left Hand Creek poses challenges for selecting appropriate elevations, reiterating the need for monitoring floodplain connectivity per designs.

Table 1. List of floodplain locations where inundation at restored sites is expected at various seasonal peak flow discharges for sites throughout Left Hand watershed. Approximate cfs (cubic feet per centimeter) describes an estimated discharge range associated with the potential seasonal peak flow, though actual discharge associated with specific floodplain locations varies by design and watershed zone. Approximate cfs ranges are informed by restoration projects throughout the Left Hand Watershed- not at one specific location. While we expect bankfull flow at Upstream Buckingham to be 150 to 290 cfs, this table defines the approximate cfs range for bankfull flow for sites throughout the watershed as anything greater than low flow (15 cfs) and less than high bench flow (200-290 cfs, depending on location in the watershed). Please note that this table shows an inclusive list of floodplain inundation locations that occur throughout the watershed but not at Upstream Buckingham (e.g. side and overflow channels).

Peak Seasonal Flow Description	Approximate cfs Range (for watershed)	Expected Floodplain Inundation Location
Bankfull Flow	15-290 cfs	Bankfull Bench
Bankfull Flow	15-290 cfs	Side-Channel
High Bench Flow	200-500 cfs	High Bench
High Flow	>2,000 cfs	Overflow-Channel

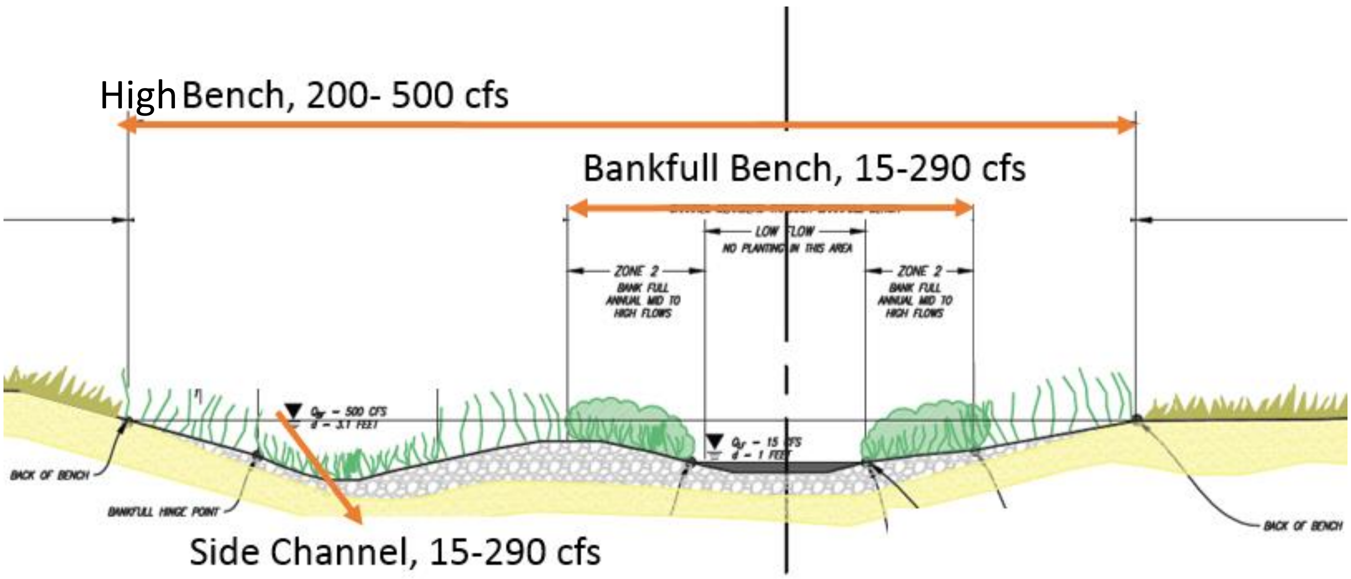


Figure 2. Supporting graphic for Table 1 showing three floodplain locations (bankfull bench, high bench, side channel) where inundation at restored sites is expected at various seasonal peak flow discharges. Please note that the flow ranges (cfs) are a range for all sites throughout the watershed. While we expect bankfull flow at Upstream Buckingham to be 150 to 290 cfs, this table defines the approximate cfs range for bankfull flow for sites throughout the watershed as anything greater than low flow (15 cfs) and less than high bench flow (200-290 cfs, depending on location in the watershed). Graphic courtesy of Enginuity, modified and by the Watershed Center.

Channel Morphology and Physical Habitat

Habitable Pools

In 2019 and 2020, we conducted physical habitat surveys of both OSMP sites in August each year to quantitatively assess pool habitat at each site. The surveyed reach at both sites were at least 20 X bankfull width in length. The surveyed metrics were representative of each sample reach and included: total wetted area, percent pool* area relative to wetted area, average residual pool depth, and pool count. Percent pool area was standardized by total surveyed wetted area to compare between sites. We analyzed percent pool area relative to wetted area and average residual depth for each site. **Habitable pools in the Canyons were defined as greater than 0.8 ft residual depth, or the residual depth at which canyons fish species (e.g. trout) can find appropriate refuge, per our MAF.*

Substrate

From 2018 through 2020, we conducted Wolman pebble counts at both OSMP sites during low flows (August or September) to quantitatively assess fine sedimentation (percent sands) in riffles at each site. For each pebble count, we recorded frequency of particles in each size class: sands, gravels, cobbles, boulders, and bedrock. Percent sands were calculated by dividing the frequency of sands by the total sample count per pebble count. We analyzed average percent sands at each site from year to year and to percent sand thresholds for Colorado Sediment Region 1 and 2.

Riparian Condition

From 2018 through 2020, we hired Biohabitats and/or CU Boulder botanists to conduct riparian vegetation surveys at both OSMP sites during the growing season (September 2018; August 2019, 2020). Our sampling timeframe was modified from 2018 methods, when we sampled later in the growing season (September 2018). At a minimum, we sampled four vegetation plots along two cross sectional transects per site. Each plot represented at least two vegetation zones: creek edge and upland on each bank. Creek edge plots were established adjacent to the bankfull edge of the creek and upland plots were established on the upper lip of the floodplain or where the floodplain ended due to infrastructure (e.g. roads, homes, pasture). Additional floodplain and upper riparian zones were identified and sampled at the discretion of the surveyors. Within each plot, absolute percent cover (bare ground, native woody, native herbaceous, and non-native stem cover) and native richness were recorded. We analyzed average absolute percent stem native herbaceous, woody, and non-native cover, and native richness from all plots from year to year. Based on results from our watershed-wide monitoring that highlight differences in native cover and richness between creek edge and upland plots, we also compared these metrics between creek edge and upland plots at Upstream Buckingham and Buckingham.

Water Quality

From 2018 through 2020, we assessed water quality by collecting BMI samples at both OSMP sites during low flow (September through November). For BMI samples, we used Colorado Department of Public Health and Environment Water Quality Control Division (CDPHE WQCD) kick sample methods in representative riffles and collected one sample from each site. Samples were processed by Timberline Aquatics. Each sample was sorted and identified to genus or species level. For analysis, Multimetric Index (MMI) scores were calculated based on sample composition and site location to assess water quality, and Tolerance Index Values (TIV) were calculated to assess sedimentation issues. Depending on site location, MMI were compared to CDPHE State Standards for Biotypes 1 or 2; TIV scores were compared to sedimentation thresholds for Colorado Sediment Regions 1 through 3.

In addition to these monitoring activities, we visually assessed channel morphology and riparian conditions at each site by photo monitoring during low flow (Attachment 1).

3. Results and Discussion

This section begins with highlighting the significance of hydrology and precipitation and then provides results, discussion, and recommendations for each ecological category.

Significance of Hydrology and Precipitation

Hydrology and precipitation is an underlying driver to all watershed processes and is key to understanding changes and variability in ecological parameters in the years post flood recovery. Characteristics of peak flows (timing, magnitude, and duration) impact the geomorphological and ecological condition of the creek such as promoting scour and floodplain inundation. The hydrograph of Left Hand Creek is characterized by a peak seasonal flow from May through July (driven by snowmelt) and low flows through the remainder of the year (driven by groundwater recharge and intermittent rainstorms). Flows in Left Hand Creek are also impacted artificially by ditch operations, as they provide water for agriculture and drinking water throughout the watershed. On average throughout history, seasonal peak flows are sustained at greater than 125 cfs from late May to early July (Figure 3). From 2018 through 2020, peak annual flows varied compared to the historic average timing, magnitude, and duration (Figure 3). This is likely due to changes in annual snowpack, rates of snow melt, and ditch company operations. For example, in 2019 we observed three distinct high flow peaks from June through July that were delayed in average timing, typical or greater than average magnitude, and short lived in average duration. That year's peak flow was impacted by a delayed snowmelt, a greater than average snowpack, and ditch company operations during runoff. Whereas in 2018 we observed an early and shorter duration peak flow, and in 2020 we observed an overall low peak flow with a very short peak at 212 cfs due to ditch operations (Figure 3). From year to year, variation in characteristics of peak flows will continue to impact the geomorphological and ecological condition of our study reaches.

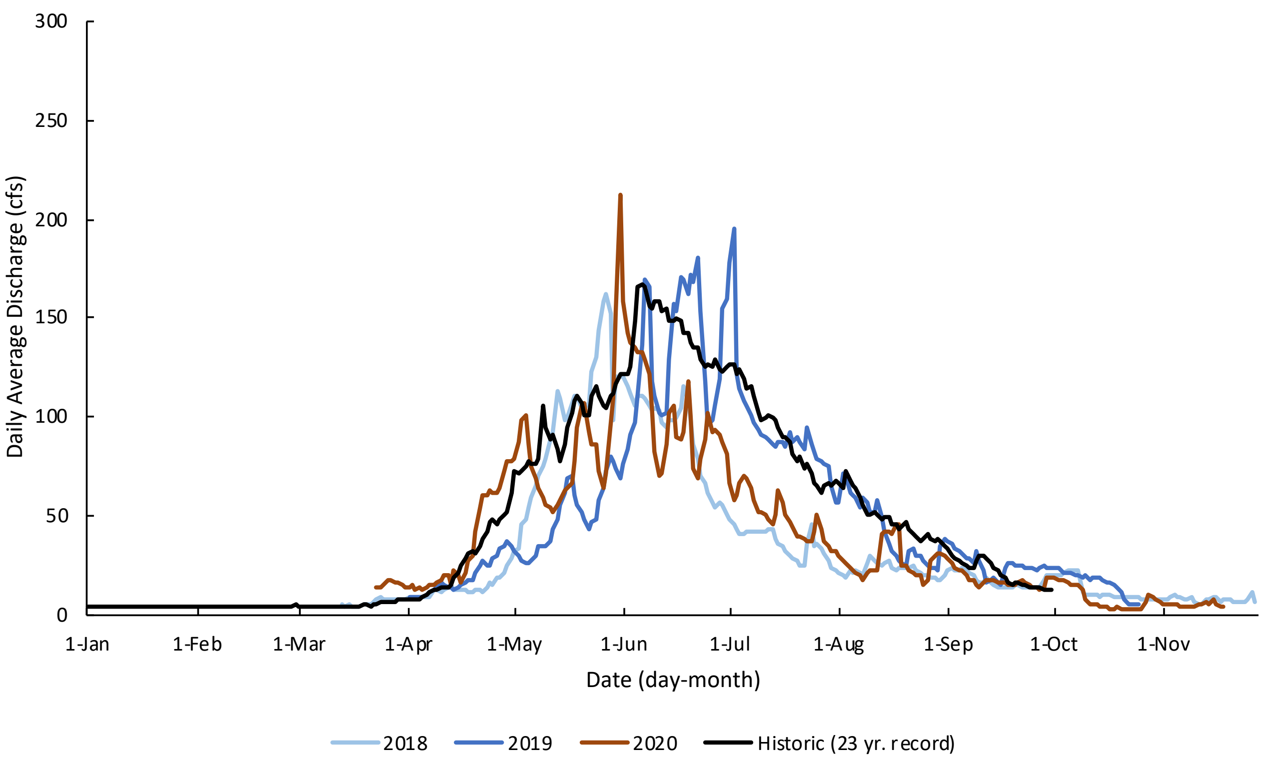


Figure 3. Historic (based on 23 years) and 2018 through 2020 annual average daily discharge (cfs) in Left Hand Creek canyon at the LEFCRECO gage. Data record provided by the Colorado Division of Water Resources.

Precipitation also impacts watershed processes and ecological condition, and annual variability in precipitation impacts our ecological parameters from year to year. Peak seasonal flows are driven by winter and early spring precipitation, especially snow accumulation in the mountainous region of the watershed. From spring through fall, precipitation (including ice, snowfall, and rainfall) also impacts instream flows and riparian condition. Precipitation during low flow provides critical water depths for the survival of aquatic organisms and water for the surrounding plant community during growing season. In Left Hand Creek, water diversion in the summer and fall exacerbate the effects of low precipitation by reducing instream and subsurface flow, potentially resulting in dry up periods. During the growing season in Boulder County, the 30 year climate average for total monthly precipitation is most variable but typically greatest from April through June (Figure 4). Higher precipitation during these months infiltrates the watershed and promotes vegetative growth. Precipitation is then sustained from July through September from 2 to 4 total inches per month on average. In recent years (2018 through 2020), there have been below average precipitation in the month of August. Notably, 2020 was particularly dry during the latter half of the growing season, as monthly precipitation was below the 30 year average range in July and August (Figure 4). Low precipitation during these months reduces instream flow and habitat, adversely affecting the growth and/or survival of riparian vegetation along the creek.

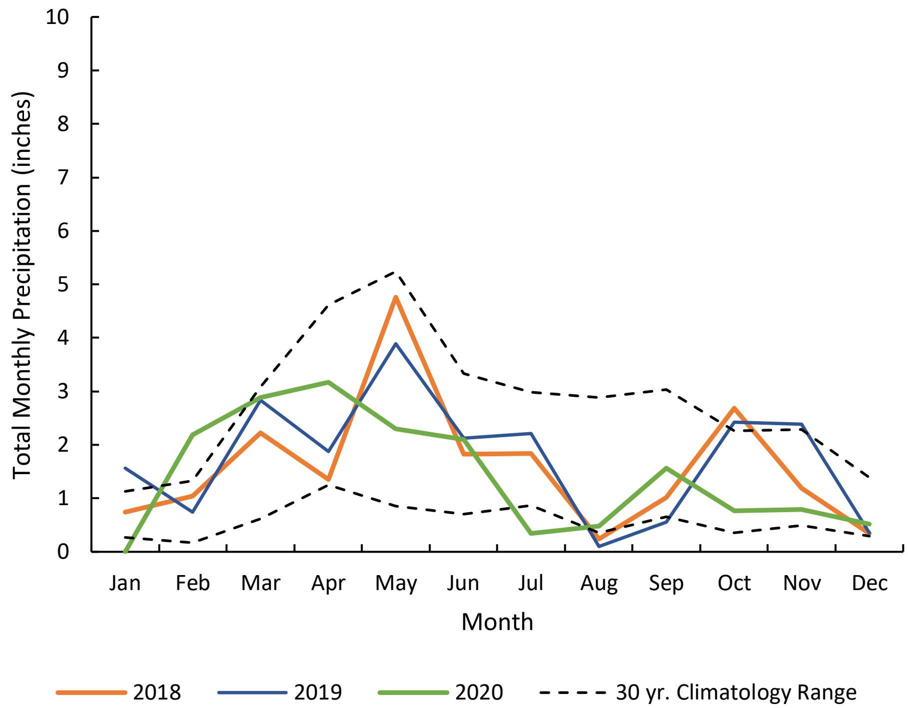


Figure 4. The 2018 through 2020 total monthly precipitation (inches) and the most recent 30 year precipitation climatology range (upper and lower limits shown on graph) for Boulder County (range is based on average total monthly precipitation +/- standard error from 1971 through 2000). For reference, total monthly precipitation in September 2013 (resulting in historic floods) was 18 inches. Precipitation includes all rain, snow, and hail. Snow/ice amounts are either directly measured or snow water equivalent of 1:10 is applied to measurements (1 inch precipitation to every 10 inches of snow/ice fall). Data provided by the National Oceanic and Atmospheric Administration's Physical Science Laboratory.

Floodplain Connectivity

Accessible floodplains offer room for rivers to move and accommodate high flow events. During high flow events, inundated floodplains are essential habitat for fish and wildlife because they provide protected and slow moving aquatic habitat. Floodplains also promote deposition of fine sediment and resilient plant communities. Connected floodplains reduce flood risk for properties downstream by attenuating (spreading out and slowing down) high flows and sediment. We evaluated floodplain connectivity using photo monitoring during seasonal peak flows and the following hypothesis:

1. Per designs, appropriate benches and channels are inundated at restored sites during peak seasonal flows each year.

In 2020, peak flow measured 212 cfs on Left Hand Creek occurred from May 31 through June 1, 2020 (Figure 3). Both Upstream Buckingham and Buckingham were monitored on June 2, 2020. While bankfull benches were activated at the floodplain pocket and confined sections of each site, we found that features within the bankfull bench (e.g. wetland vegetation, point bars) were activated differently depending on site. Floodplain pockets are sections of creek with broader access to the floodplain, while confined areas have limited floodplains due to canyon walls, roads, or other development. At Upstream Buckingham, we found that 2020 peak flow activated bankfull bench (see Figure 2 for reference) throughout the project area (both the upstream floodplain pocket and downstream confined area). More specifically, peak flows activated the upstream point bar (Figure 6, Photo A), submerged and flowed behind large wood structures (Photo A and B), submerged wetland vegetation (Photo C), and promoted seepage at the upstream OHV area drainage (Photo D). At Buckingham, we found that 2020 peak flows also activated the bankfull bench, but activated different features depending on location within the site area. In the upstream floodplain pocket, peak flows activated wetland vegetation, including the lower floodplain, and activated the side channel (Figure 7, Photo A). In the downstream confined area, peak flows did not activate wetland vegetation (Photo B). This is likely due to channel incision and less connectivity between the stream and floodplain at Buckingham compared to Upstream Buckingham.

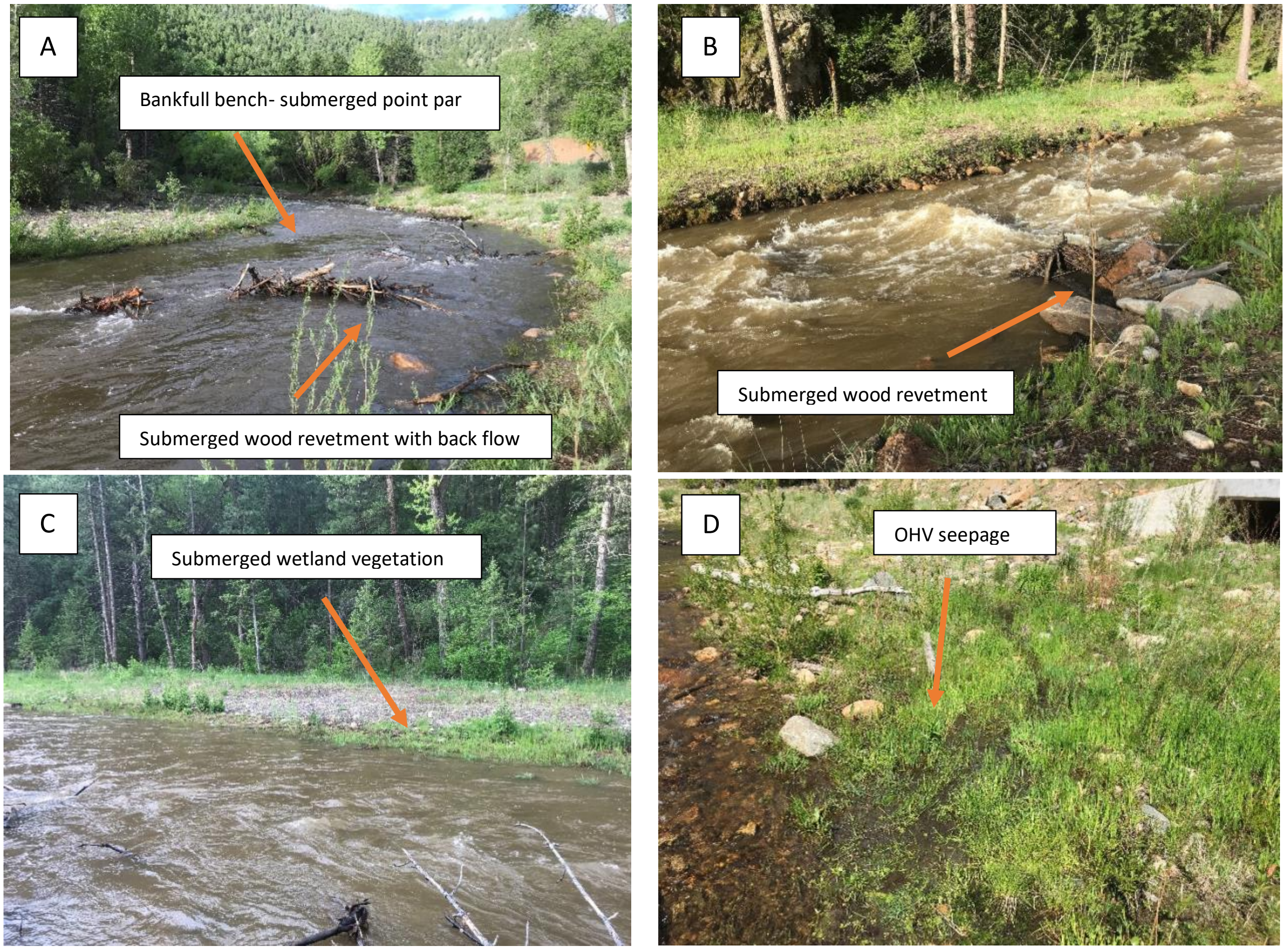


Figure 5. Peak seasonal flow observations from 6/2/2020 at restored Upstream Buckingham on Left Hand Creek. Photo description match letter and arrow: A. activated upstream bankfull bench, submerged point bar, and submerged wood revetment in upstream floodplain pocket; B. submerged wood revetment in downstream riffle in confined area; C. submerged wetland vegetation at downstream pool; D. seepage from upstream OHV drainage.

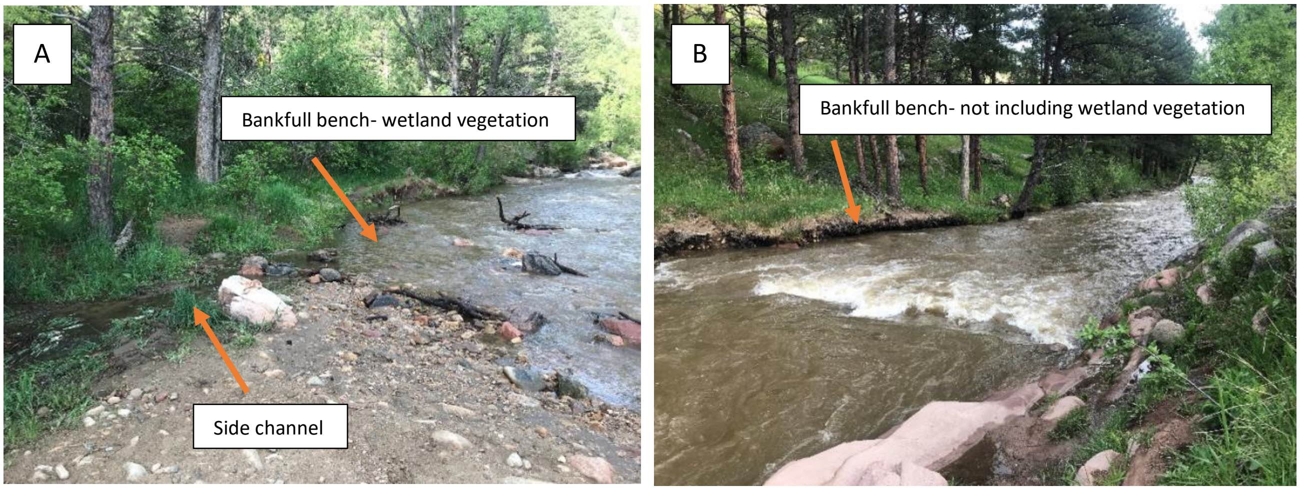


Figure 6. Peak seasonal flow observations from 6/2/2020 at unrestored Buckingham on Left Hand Creek. Photo description match letter and arrow: A. activated bankfull bench, including wetland vegetation, and side channel in floodplain pocket; B. activated downstream bankfull bench, not including wetland vegetation, in confined area downstream.

Key Takeaways:

- Addressing our hypothesis: yes, 2020 peak flow inundated the appropriate restored bankfull benches at Upstream Buckingham.
- Floodplain connectivity in floodplain pocket areas were similar at both sites. Peak flows activated bankfull benches, including wetland vegetation and point bar features, at both sites and activated the side channel at Buckingham.
- Floodplain connectivity in confined areas differs between sites due to channel incision at Buckingham. Peak flows at Upstream Buckingham activated bankfull benches and submerged riparian vegetation, while peak flows at Buckingham activated bankfull benches without submerging wetland vegetation.
- Peak flows submerged and flowed behind wood revetments at Upstream Buckingham. There were no signs of scour behind the revetments during subsequent low flow monitoring.

Management Recommendations:

- Continue monitoring wood revetments during peak flows for back flow and signs of scour that could erode the floodplain towards the road.

Channel Morphology and Habitat

Channel morphology and habitat features are essential for supporting aquatic life and are indicators of watershed processes including flow and sediment regime. We assessed channel morphology and habitat by testing the following sub-hypotheses.

1. Percent of habitable pool area relative to the wetted area will be greater than 20% at restored sites.
2. Average percent sands (fine substrate) in riffles at restored sites will remain less than 27.5% or decrease from year to year.

Pool Habitat

Habitat surveys were a new assessment added to our AMP in 2019. We conducted habitat surveys to assess habitable pools (greater than 0.8 ft residual depth, where fish species can find appropriate refuge) at both Upstream Buckingham and Buckingham during low flow (August) in 2019 and 2020. We found that the restored Upstream Buckingham site is maintaining a trajectory towards resilience, as it retained greater than 20% habitable pool area relative to the total wetted area in both 2019 and 2020 (Table 2). However, we found that the Buckingham site had greater % habitable pool area than Upstream Buckingham (Table 2). This is likely due to greater instream complexity at the unrestored Buckingham site. Throughout the unrestored reach, there are step pools, boulders, and large wood that create an abundance of pools and pocket pools (Figure 7). The Upstream Buckingham restoration project may have removed boulders and other instream features that created complexity in the reach.

Figure 7. Photo of habitat complexity at the Buckingham site on Left Hand Creek. August, 2020.

Additionally, we found that both sites decreased in percent pool area (Table 2). This is likely due to a methods modification. In 2020, methods were modified to more precisely measure pool area throughout each survey reach. In 2019, pool area was overestimated because all habitable pools were measured as entire channel units. This meant that all surveyed pools were assigned a channel length and channel wetted width, even if the pool did not span the entire channel or was a smaller pocket pool formed by singular boulders or on stream bends. In 2020, pool area measurements were improved by adding "pool width" and "pocket pool" measurements. These modifications improved the surveyor's accuracy in measuring pool area within each channel unit and throughout the survey reach when habitable pools did not span entire channel units.

Table 2. The 2019 and 2020 surveyed percent habitable pool area relative to total wetted area at Upstream Buckingham and Buckingham sites on Left Hand Creek.

Site	Sample Year	% Pool Area: Wetted Area
Buckingham	2019	49.8%
	2020	44.9%
US Buckingham	2019	33.7%
	2020	29.5 %

Key Takeaways:

- Addressing our hypothesis: yes, the restored Upstream Buckingham site attained greater than 20% habitable pool habitat for both 2019 and 2020.
- Habitable pool area is greater at the Buckingham site compared to the Upstream Buckingham site, likely due to more instream habitat complexity.

Management Recommendations:

- For future river restoration designs in canyon streams, consider using unrestored sites such as Buckingham as a reference for instream complexity and pool habitat. Please note that sections of the Buckingham site may not be a good reference for all restoration goals, such as floodplain connectivity. We found signs of channel incision and lack of floodplain connectivity during peak flows in the downstream confined areas of Buckingham.
- Conduct habitat surveys after high peak flows (greater than 5-year high flow event) or every three to five years to monitor changes in pool habitat.

Fine Substrate

Pebble counts were collected from 2018 through 2020. We conducted pebble counts in one to three representative riffles at both Upstream Buckingham and Buckingham during low flow (August or September) and sample size increased from year to year. We found that during all sampling years, percent sands at both sites remained below the 27.5 % threshold (Figure 8). Notably, percent sands at upstream Buckingham increased to 13.6% fines in 2020 compared to 7% to 8% in previous years. This may be due to fine sediment mobilization during recent restoration work upstream of the site in 2019, or it could be due to sampling variability. Furthermore, we found no evidence of sedimentation issues based on the benthic macroinvertebrate (BMI) Tolerance Index Value (TIV) score (see Water Quality results; Table 3).

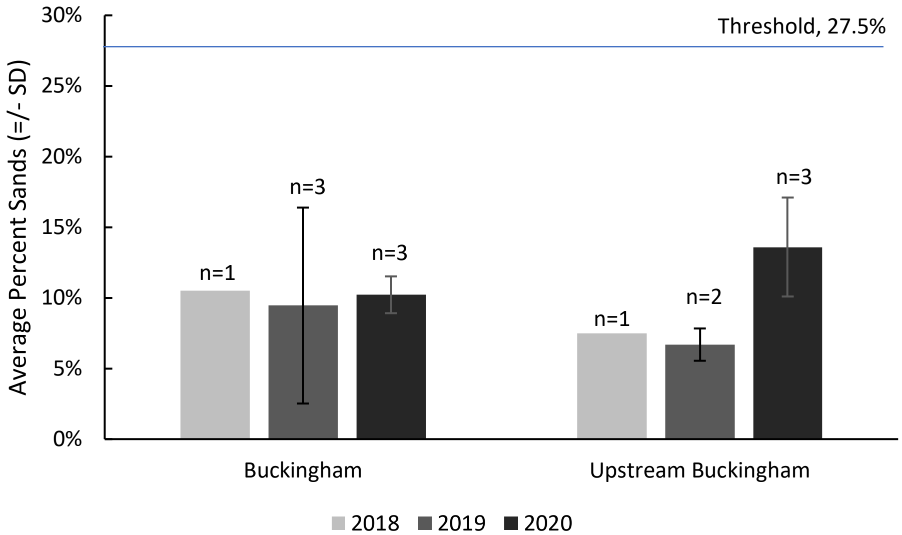


Figure 8. The 2018 through 2020 surveyed percent sands (=/- standard deviation) in riffles at Upstream Buckingham and Buckingham sites on Left Hand Creek. Sample size indicated by "n" above each average. Percent sands 27.5% threshold shown as a line and labeled.

Key Takeaways:

- Addressing our hypothesis: yes, percent sands at both sites remained less than the 27.5% threshold each year.
- Percent sands were elevated at Upstream Buckingham in 2020, but is not an indication of sedimentation issues.

Management Recommendations:

- Conduct pebble counts after high peak flows (greater than 5-year high flow event) or every three to five years to monitor sedimentation.

Riparian Condition

Riparian condition provides critical physical habitat for aquatic and terrestrial organisms, as well as bank stability. It also benefits overall ecological function by serving as a buffer for nutrient and mineral cycling. Riparian condition is an important indicator of watershed health because it depends on the interaction of flow regime and geomorphology, including floodplain connectivity. It is also dependent on annual precipitation and therefore variable from year to year. We assessed restored riparian condition by testing the following sub-hypotheses:

1. Average percent of native herbaceous and woody cover types at restored sites will increase or remain the same from year to year.
2. Average native richness (species number) at restored sites will increase or remain the same from year to year.

Riparian condition was monitored from 2018 through 2020. We conducted vegetation surveys within the growing season in August (2019 and 2020) and September (2018). A cumulative list of native and non-native species for each site is available in Attachment 2. Between 2018 and 2019, we adjusted our sampling timeframe to allow for more species identification and continued with this timeframe for consistency. Notably, large error bars in our figures below point to the need for more transects that would provide better site-scale comparison. At the watershed scale, we use our MAF for zone scale (plains, foothills, canyons) comparison, which increases sample count and reduces error. Over time, we found that average percent native herbaceous and woody stem cover and native richness remained the same at Upstream Buckingham (Figure 9; Figure 10). We also found that native richness at Upstream Buckingham was generally greater each year compared to Buckingham (Figure 10). These results indicate that Upstream Buckingham remains on the trajectory towards resilience.

Notably, we found that Buckingham had greater percent herbaceous cover in 2019 compared to 2018 and 2020 (Figure 9). This intermediate increase in cover is likely due to annual variability in sampling timeframe and precipitation. In 2018, we sampled in the end of September, when we suspected some herbaceous species had already died and were therefore classified as bare ground (described as thatch). In 2020, the uncharacteristically low precipitation in July and August may have accelerated herbaceous die-off and resulted in classification of dead herbaceous species as bare ground (Figure 4). The 2019 growing season precipitation was more typical of climate records and likely resulted in greater herbaceous survivorship during sampling in August. These results highlight the variability in year to year sampling and the need for more long term monitoring to identify trends.

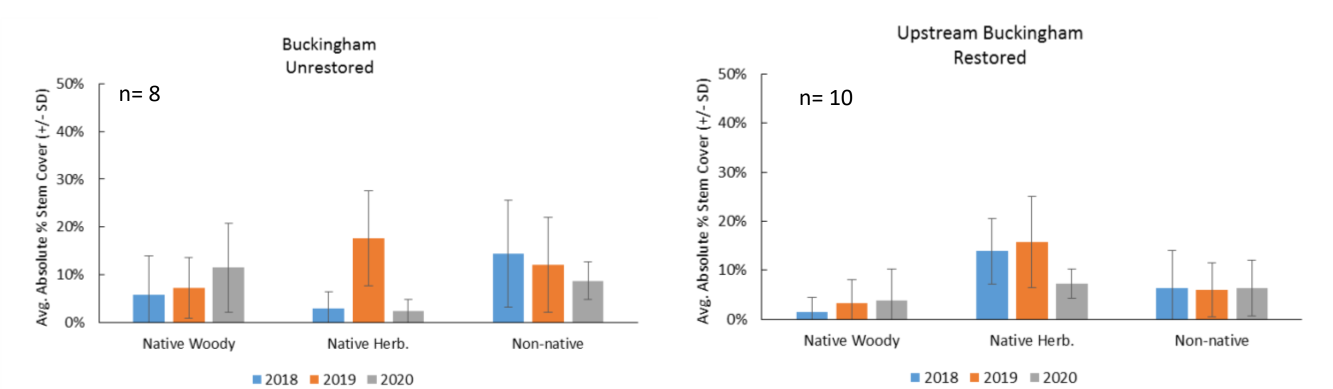


Figure 9. The 2018 through 2020 average absolute percent of cover types (+/- standard deviation) for all riparian plots at Buckingham and Upstream Buckingham on Left Hand Creek. Cover types are classified as Native Herbaceous, Native Woody, and Non-Native. Plot sample size for each site for all years is indicated by "n" value. See Attachment 2 for native and non-native species lists for each site.

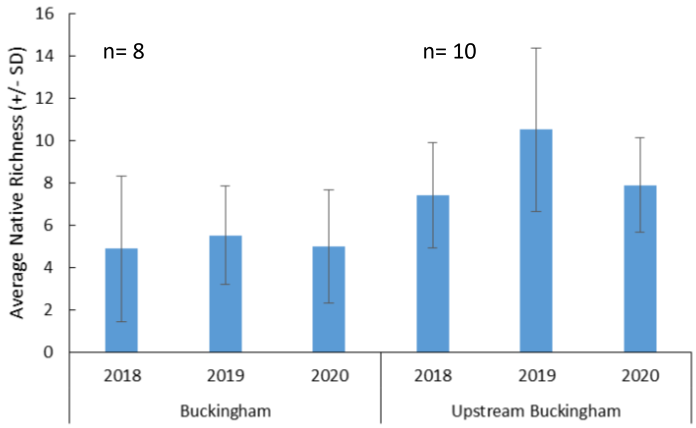


Figure 10. The 2018 through 2020 average native richness (+/- standard deviation) for all riparian plots at Buckingham and Upstream Buckingham on Left Hand Creek. Plot sample size for each site for all years is indicated by "n" value. See Attachment 2 for native species lists for each site.

Additionally, our watershed-wide monitoring results have shown that proximity to the creek may impact native cover and richness. In our 2020 State of the Watershed Report, we found that average native herbaceous cover and native richness at all restored sites at the watershed zone-scale were either similar or greater along the creek edge versus upland plots in 2018 and 2019 (Figure 11; Figure 12). At Upstream Buckingham and Buckingham, site-specific assessment of creek edge versus upland trends was limited by sample sizes. For completeness and to illustrate the variability, we present the results for creek and upland plots at each site in Figures 13 and 14.

Lastly, we found persistent crack willow encroachment at the Upstream Buckingham site (Figure 15). This is a common concern at restoration sites, as crack willow is highly invasive and disperses through cuttings in the water.

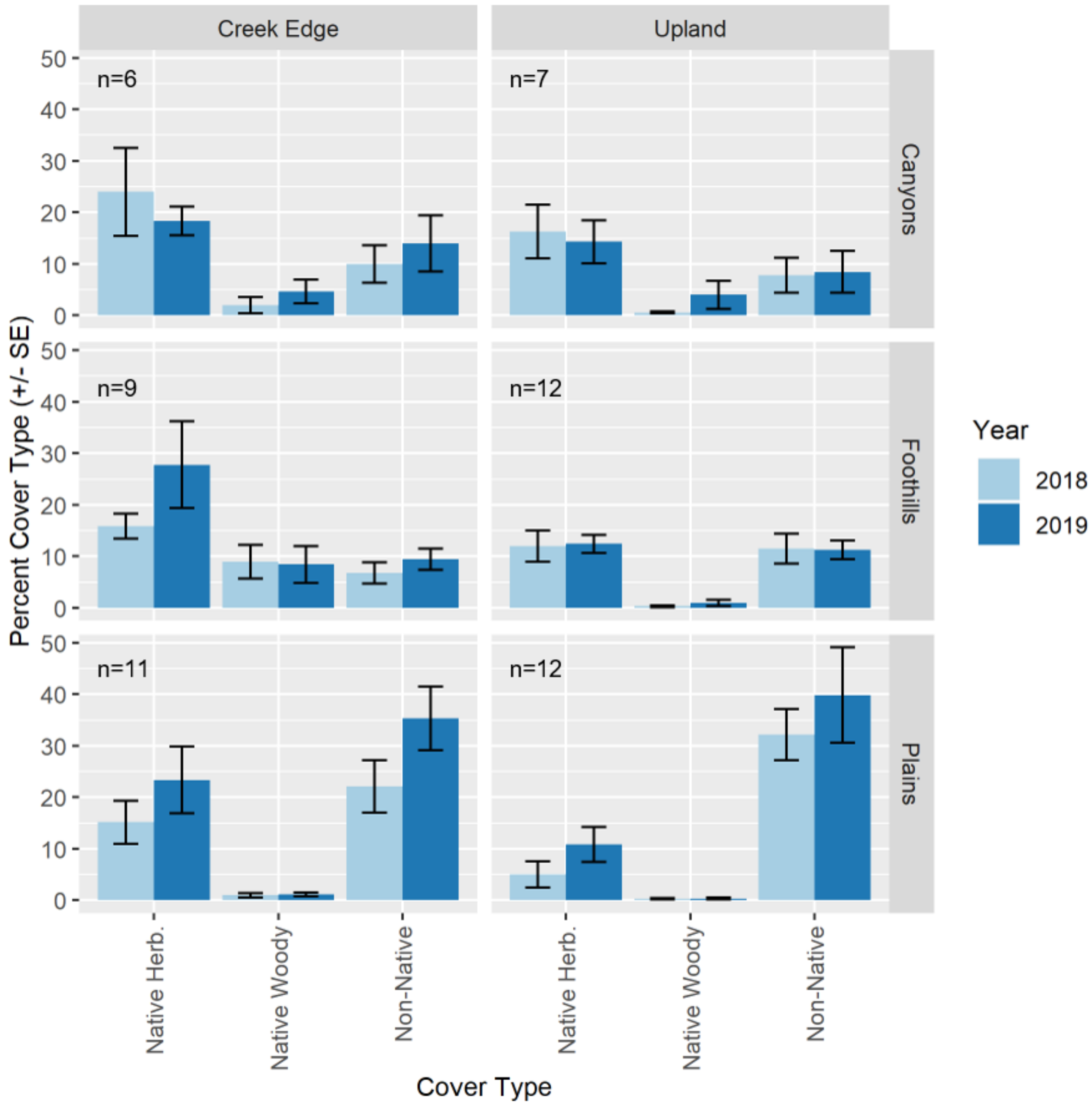


Figure 11. The 2020 State of the Watershed results for 2018 and 2019 average percent of cover types (+/- standard error) in Creek Edge and Upland riparian zones for all restored sites within each watershed zone of Left Hand Creek Watershed. Cover types are classified as Native Herbaceous, Native Woody, and Non-Native. Sample size indicated by ‘n’ value.

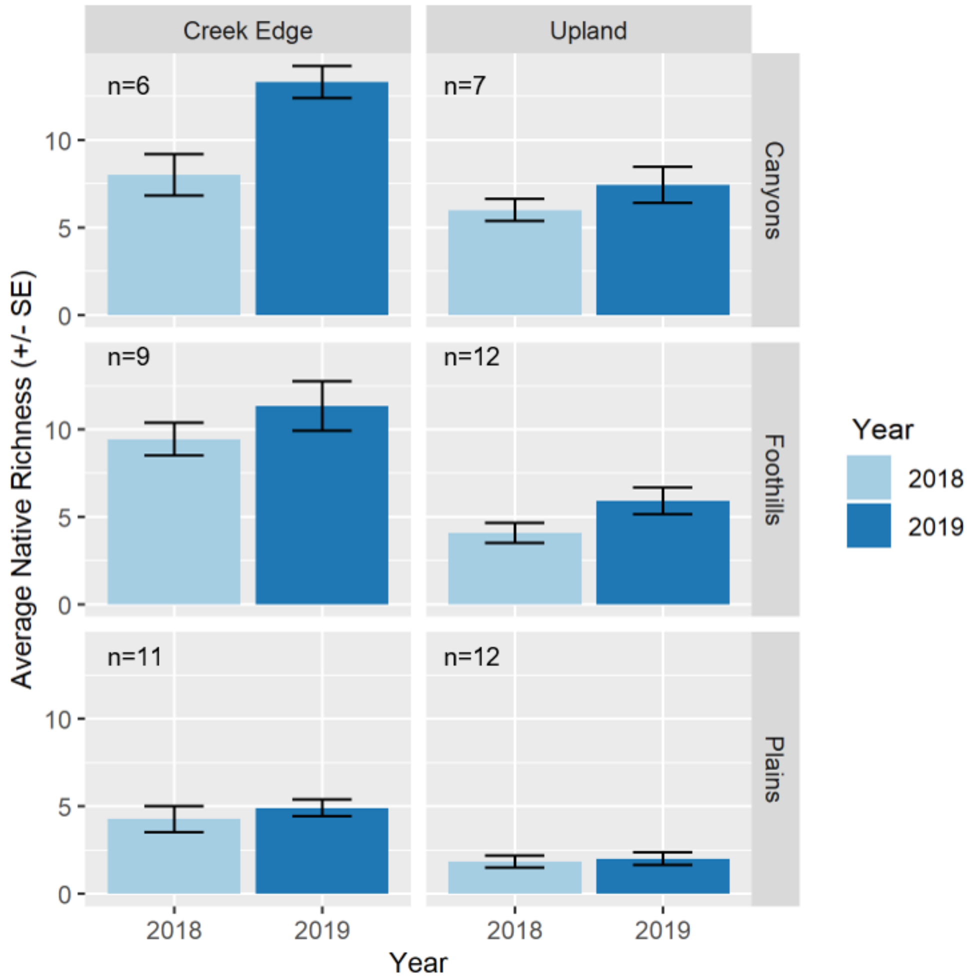


Figure 12. The 2020 State of the Watershed results for 2018 and 2019 average native richness (+/- standard error) in Creek Edge and Upland riparian zones for all restores sites within each watershed zone of Left Hand Creek Watershed. Sample size indicated by ‘n’ value.

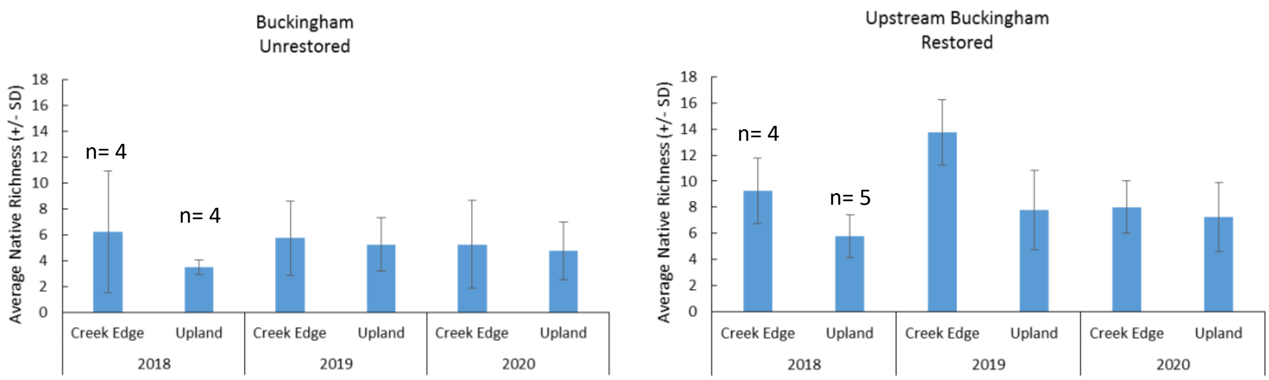


Figure 13. The 2018 through 2020 average native richness (+/- standard deviation) for Creek Edge versus Upland plots at Buckingham and Upstream Buckingham on Left Hand Creek. Sample size for each site and plot type for all years is indicated by “n”.

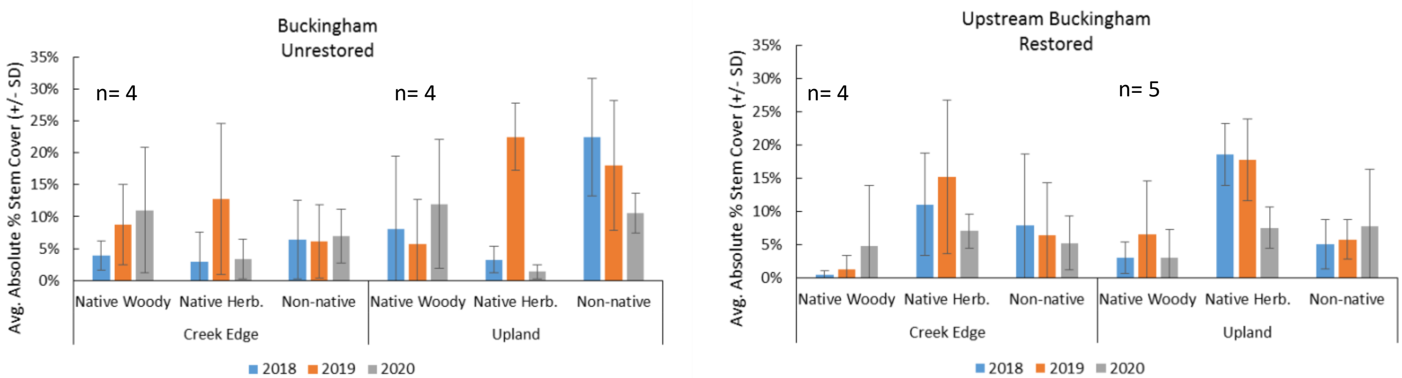
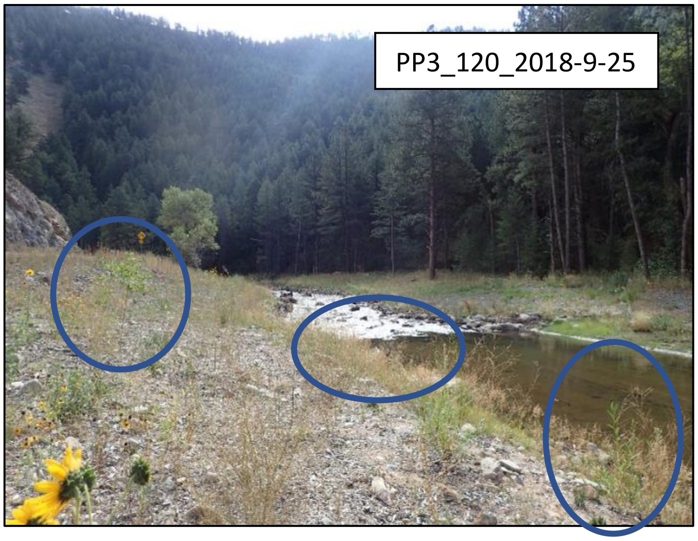
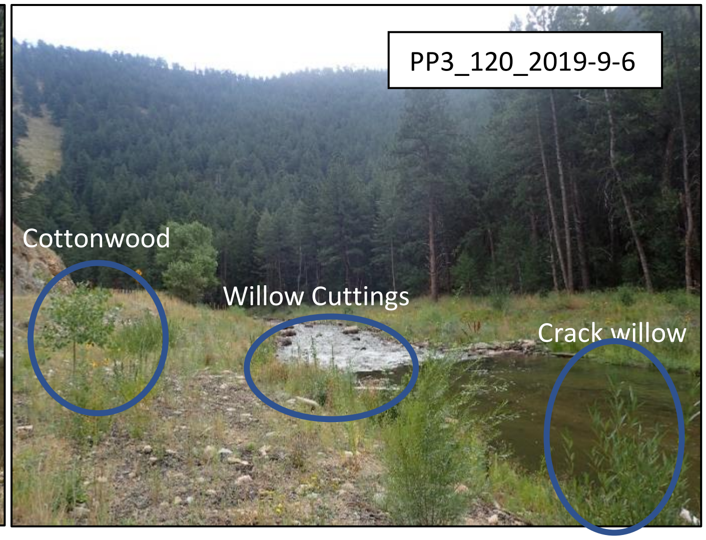


Figure 14. The 2018 through 2020 average absolute percent cover types (+/- standard deviation) for Creek Edge versus Upland plots at Buckingham and Upstream Buckingham on Left Hand Creek. Cover types are classified as Native Herbaceous, Native Woody, and Non-Native. Sample size for each site and plot type (upland or creek edge) for all years is indicated by “n”.





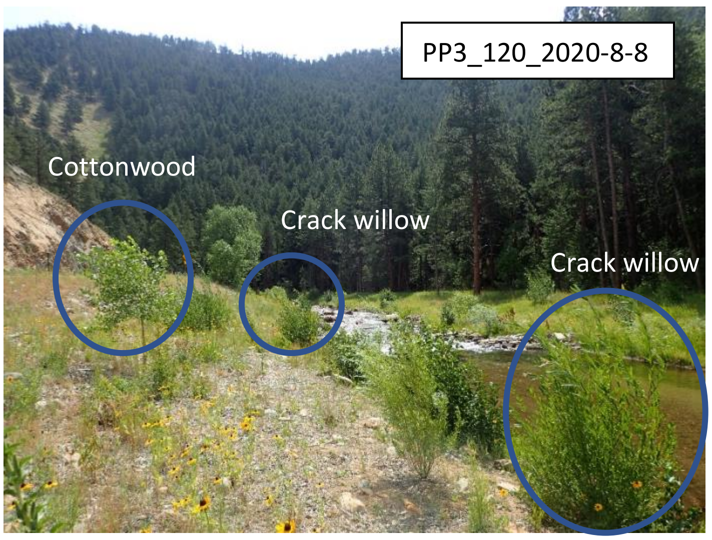


Figure 15. Upstream Buckingham photo point 3 (PP3) photos from 2018 through 2020 on Left Hand Creek. This photo shows year to year growth of container stock (cottonwood), cuttings (coyote willow) and establishment of non-native crack willow

Key Takeaways:

- Addressing our hypotheses: yes, Upstream Buckingham average percent native herbaceous and native woody stem cover remained the same from year to year, and native richness remained the same from year to year.
- Native richness at Upstream Buckingham was generally greater each year compared to Buckingham.
- Riparian condition is impacted year to year by variation in monthly precipitation throughout the growing season. This highlights the importance of continued long-term monitoring and adding more transects if understanding trends at the site scale is desired.

Management Recommendations:

- Continued weed control on the Upstream Buckingham site to reduce non-native establishment, notably the crack willow.

Water Quality

The benthic macroinvertebrate (BMI) community is an important indicator of water quality and can give indications of impairments or sedimentation issues. We assessed BMI throughout Left Hand Creek Watershed in from 2018 through 2020 by testing the following sub-hypotheses:

1. Multimetric Index (MMI) score per site will either attain the performance threshold based on location (Biotype 1 or 2) or will trend towards attainment from year to year.
2. Sediment Tolerance Indicator Value (TIV) score per site will either attain performance thresholds based on site location (Sediment Regions 1 through 3) or trend towards attainment from year to year.

Water quality was monitored from 2018 through 2020. BMI samples were collected during low flow (September through November) each year. MMI and TIV scores were evaluated in relation to applicable performance thresholds and trends over time. While we expect annual variability in our results due to low sample size and fluctuating conditions, MMI results suggested good water quality at Upstream Buckingham and Buckingham sites (Figure 16; Table 4). TIV results did not suggest sediment-related impairments at either site (Table 5).

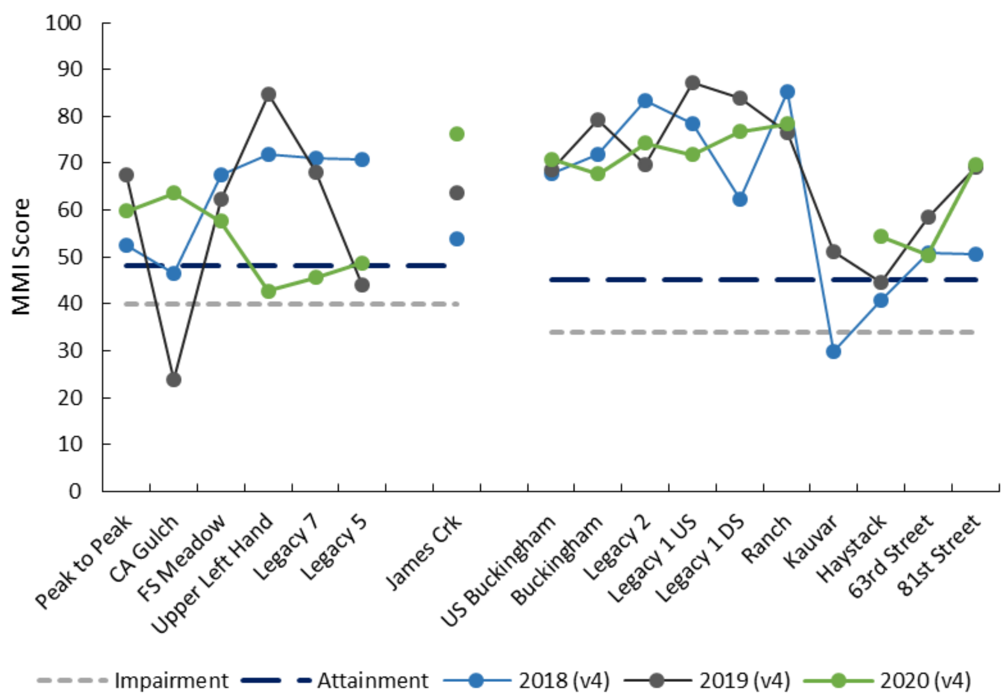


Figure 16. The 2018 through 2020 MMI Scores for Upstream Buckingham and Buckingham, as well as scores from 16 additional sites throughout Left Hand Watershed (16 on Left Hand Creek, 1 on James Creek). Attainment and Impairment thresholds, relative to watershed zone, indicated by dashed lines. MMI scoring version 4 was used for all sample analyses. Scores below the impairment threshold may indicate impaired water quality and scores between attainment and impairment need further assessment. Kauvar samples were not collected in 2020 due to dry conditions.

Table 4. The 2018 through 2020 MMI Scores for Upstream Buckingham and Buckingham sites illustrated in Figure 16.

	MMI Score per Year		
Site	2018	2019	2020
Upstream Buckingham	67.8	68.5	70.9
Buckingham	71.9	79.2	67.7

Table 5. The 2018 through 2020 Tolerance Index Value (TIV) Scores for Upstream Buckingham and Buckingham, as well as scores from nine other sites on Left Hand Creek. Sediment Regions 1 through 3 and applicable impairment score thresholds listed. Scores above sediment region thresholds indicate possible sedimentation issues. No impairments indicated.

		2018	2019	2020
Site	Sediment Region (impairment score)	TIV Score	TIV Score	TIV Score
Peak to Peak	R1 (6.1)	4.66	5.22	3.93
CA Gulch	R1 (6.1)	3.87	4.29	4.14
FS Meadow	R2 (7.0)	3.78	4.35	5.84
Upper Left Hand	R2 (7.0)	4.88	4.87	5.69
Legacy 7	R2 (7.0)	4.95	4.42	5.41
Legacy 5	R2 (7.0)	4.91	5.32	5.41
US Buckingham	R2 (7.0)	4.51	4.92	4.59
Buckingham	R3 ((6.3)	3.09	4.54	4.35
Legacy 2 US	R3 (6.3)	Not reported	4.97	4.09
Legacy 1 US	R3 (6.3)	Not reported	5.19	4.65
Legacy 1 DS	R3 (6.3)	Not reported	5.05	4.68
Ranch	NA			
Kauvar	NA			
Haystack	NA			
63rd Street	NA			
81st Street	NA			

Notably, water quality remains good at the Buckingham sites and other foothills sites (Legacy 2, Legacy 1, Ranch), while upstream areas (Upper Left Hand and Legacy 7) show possible impairments and downstream site scores (Kauvar, Haystack, 63rd Street, 81st Street) have improved or maintain attainment (Figure 16). While upstream water quality issues in 2018 and 2019 were likely related to acid mine drainage from the Captain Jack Mine, possible impairment issues at Upper Left Hand and Legacy 7 are under investigation.

Key Takeaways:

- Addressing our hypotheses: yes, MMI and TIV scores at Upstream Buckingham and Buckingham did not exceed impairment thresholds, indicating good water quality and no sedimentation issues, from year to year.
- Water quality remains good at the Buckingham sites and other foothills sites, while upstream areas show possible impairments.

Management Recommendations:

- Consider monitoring recreational use and potential impacts to water quality or aquatic communities (BMI or fish) at both sites as they show increased use.

4. Conclusions and Recommendations

This section provides a summary list of monitoring conclusions and management recommendations for each ecological category.

4.1 Conclusions

After three years of monitoring the Upstream Buckingham and Buckingham sites, we offer the following conclusions for each monitoring question:

(1) Are ecological measurements, as an indicator of watershed health, at each site indicating a positive trend toward recovery as defined in the Watershed Center's AMP? More specifically:

a. Is floodplain connectivity improved or maintained?

- Yes, 2020 peak flow inundated the appropriate restored bankfull benches at Upstream Buckingham.
- Peak flows submerged and flowed behind wood revetments at Upstream Buckingham. There were no signs of scour behind the revetments during subsequent low flow monitoring.

b. Is channel morphology and habitat condition improved or maintained?

- Yes, the restored Upstream Buckingham site attained greater than 20% habitable pool habitat for both 2019 and 2020.
- Yes, percent sands at both sites remained less than the 27.5% threshold each year.
- Percent sands were elevated at Upstream Buckingham in 2020, but is not an indication of sedimentation issues.

c. Is native riparian condition and the native plant community improved or maintained?

- Yes, Upstream Buckingham average percent native herbaceous and native woody stem cover remained the same from year to year, and native richness remained the same from year to year.
- Weed control should remain a management focus at the Upstream Buckingham site because preventing establishment of non-native species is typically more cost effective than trying to manage non-native species once they are established.
- Riparian condition is impacted year to year by variation in monthly precipitation throughout the growing season. This highlights the importance of continued long term monitoring to understand trends.

d. Are water quality and fine sedimentation improved or maintained?

- Yes, MMI and TIV scores at Upstream Buckingham and Buckingham did not exceed impairment thresholds, indicating good water quality and no sedimentation issues, from year to year.

- Water quality remains good in the watershed area including the Buckingham sites and other foothills sites, while upstream and downstream areas show possible impairment.

(2) How do these measurements compare between the restored and unrestored reach?

a. Floodplain Connectivity

- Floodplain connectivity in floodplain pocket areas are similar at both sites. Peak flows activated bankfull benches instream and on the floodplain at both sites and activated the side channel at Buckingham.
- Floodplain connectivity in confined areas differs between sites. Peak flows at Upstream Buckingham activated bankfull benches and submerged riparian vegetation, while peak flows at Buckingham primarily activated instream bankfull benches.

b. Channel Morphology and Habitat

- Habitable pool area is greater at the Buckingham site compared to the Upstream Buckingham site, likely due to more instream habitat complexity.
- No notable differences in percent sands between sites.

c. Riparian Condition

- Average native richness at Upstream Buckingham was generally greater each year compared to Buckingham.
- No notable differences in average percent native herbaceous or woody stem cover between sites.

d. Water Quality

- No notable difference in MMI or TIV scores between sites.

4.2 Recommendations

As expected, the results this year indicate need for multi-year monitoring and highlight the iterative nature of adaptive management. The overarching goal of our monitoring is to assess restored and unrestored reaches to identify trends towards resilience and possible management triggers, outlined in the MAF. The three-year post project monitoring timeframe for many flood recovery projects appears to be a minimum benchmark for this monitoring framework. After three years of monitoring, we have observed a variety of post- restoration responses, including pool adjustment and sedimentation or revegetation efforts and weed control. In addition, comparison between reference, pre, and post- restoration site monitoring is critical for making informed adaptive management decisions and to learn more about restoration efforts and responses over time. The following recommendations highlight some possible management concerns specific to the OSMP monitoring efforts for each ecological category:

a. Floodplain Connectivity

- Continue monitoring wood revetments during peak flows for back flow and signs of scour that could erode the floodplain towards the road.

b. Channel Morphology and Habitat

- For future river restoration designs in canyon streams, consider using unrestored sites such as Buckingham as a reference for instream complexity and pool habitat.

c. Riparian Condition

- Continued weed control on the Upstream Buckingham site to reduce non-native establishment.

d. Water Quality

- Consider monitoring recreational use and potential impacts to water quality or aquatic communities (BMI or fish) at both sites as they show increased use.

In summary, Upstream Buckingham remains on the trajectory towards resilience. It will be important to continue weed control activities at this site to prevent establishment of non-native species (as seen in the upland zone of Buckingham) and encroachment of crack willow and monitor restoration features such as wood revetments for signs of scour and erosion. Overall, both sites are highly functioning, providing floodplain access and instream habitat and good water quality for aquatic life and recreationalists. As recreationalists continue to access these sites, it will be important to monitor impacts to riparian vegetation, water quality, and aquatic communities.

Attachments

1. Photo monitoring
2. Plant Lists

Attachment 1

Photo Monitoring

Attachment 1. This attachment shows photo monitoring locations and three years (2018 through 2020) of photo monitoring at the Upstream Buckingham and Buckingham sites on Left Hand Creek.

Table 1. Coordinates for photo monitoring locations at Buckingham and Upstream Buckingham sites.

Site	Photo Point ID	Latitude	Longitude
Buckingham	PP_1	40.111991	-105.307074
	PP_2	40.112131	-105.307080
	PP_3	40.110301	-105.306804
	PP_4	40.110135	-105.307191
Upstream Buckingham	PP_1	40.106448	-105.322615
	PP_2	40.106490	-105.321961
	PP_3	40.106398	-105.320384

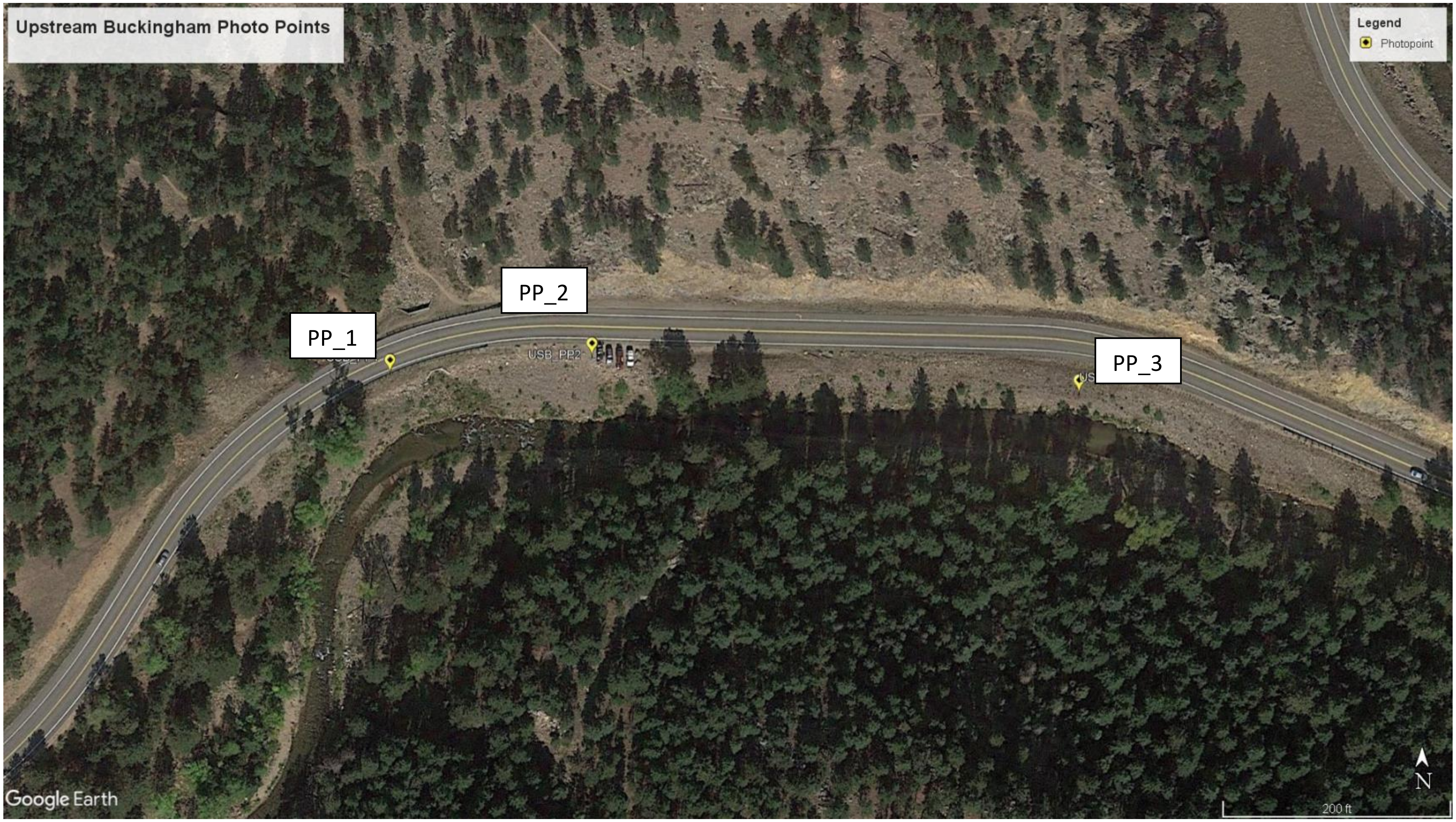


Figure 1. Photo points at Upstream Buckingham Park.

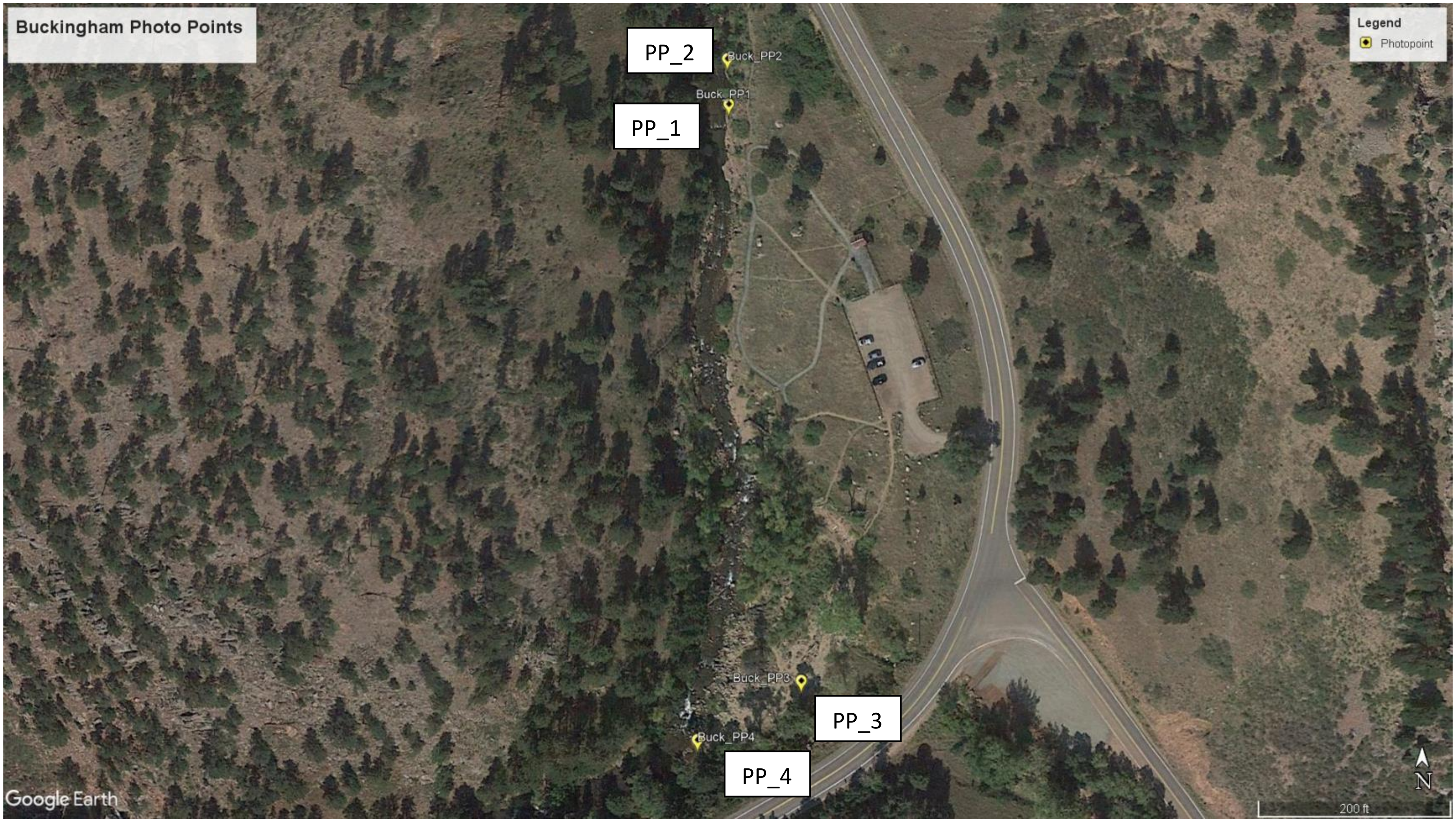


Figure 2. Photo points at Buckingham Park.

Figure 3. The 2018 through 2020 photos from photo point 1, azimuth 96 looking downstream from river left at Upstream Buckingham, Left Hand Creek.

Figure 4. The 2018 through 2020 photos from photo point 1, azimuth 138 looking across the creek from river left at Upstream Buckingham, Left Hand Creek.

Figure 5. The 2018 through 2020 photos from photo point 1, azimuth 176 looking upstream from river left at Upstream Buckingham, Left Hand Creek.

Figure 6. The 2018 through 2020 photos from photo point 2, azimuth 224 looking upstream from river left at Upstream Buckingham, Left Hand Creek.

Figure 7. The 2018 through 2020 photos from photo point 3, azimuth 120 looking downstream from river left at Upstream Buckingham, Left Hand Creek.

Figure 8. The 2018 through 2020 photos from photo point 3, azimuth 181 looking across from river left at Upstream Buckingham, Left Hand Creek.

Figure 9. The 2018 through 2020 photos from photo point 3, azimuth 255 looking upstream from river left at Upstream Buckingham, Left Hand Creek.

Figure 10. The 2018 through 2020 photos from photo point 1, azimuth 196 looking upstream from river right at Buckingham, Left Hand Creek.

Figure 11. The 2018 through 2020 photos from photo point 1, azimuth 335 looking downstream from river right at Buckingham, Left Hand Creek.

Figure 12. The 2018 through 2020 photos from photo point 2, azimuth 196 looking upstream from river right at Buckingham, Left Hand Creek.

Figure 13. The 2018 through 2020 photos from photo point 2, azimuth 333 looking downstream from river right at Buckingham, Left Hand Creek.

Figure 14. The 2019 and 2020 photos from photo point 4, azimuth 254 looking upstream from river right at Buckingham, Left Hand Creek. New photo point in 2019.

Figure 15. The 2019 and 2020 photos from photo point 4, azimuth 356 looking downstream from river right at Buckingham, Left Hand Creek. New photo point in 2019.

Attachment 2

Plant Lists

This attachment shows a list of all native and non-native species identified at the Upstream Buckingham and Buckingham sites during riparian surveys in 2020.

Figure 1. Native and non-native plant lists from 2020 riparian surveys at Upstream Buckingham and Buckingham Park. Species are listed by scientific and common name.

Upstream Buckingham			
Native		**Non-native**	
Scientific Name	**Common Name**	**Scientific Name**	**Common Name**
Achillea millefolium	Yarrow	*Agrostis gigantea*	Redtop bent
Alnus incana	Thinleaf alder	*Bromus inermis*	Smooth brome
Alopecurus sp.	--	*Cirsium arvense*	Canada thistle
Antennaria anaphaloides	Pearly pussy-toes	*Conyza canadensis*	Horseweed
Astragalus sp.	--	*Dactylis glomerata*	Orchardgrass
--	Basal Aster lvs	*Elymus repens*	Quackgrass, couchgrass
Bouteloua gracilis, Chondrosum gracile	Blue grama	*Lactuca serriola*	Prickly lettuce
Carex bebbii	Bebb's sedge	*Medicago lupulina*	Black medick
Carex sp.	--	*Medicago sativa*	Alfalfa
Clematis ligusticifolia	Western white virgin's-bower	*Melilotus albus*	White sweet clover
Deschampsia cespitosa	Tufted hair grass	*Phleum pratense*	Timothy
Elymus canadensis	Canada wildrye	*Plantago major*	Common plantain
Elymus elymoides	Squirreltail, bottlebrush	*Poa pratensis*	Kentucky bluegrass
Elymus glaucus	Common western / blue wildrye	*Rumex acetosella*	Sheep sorrel
Elymus trachycaulus	Slender wheatgrass	*Salix fragilis*	Crack willow
Epilobium brachycarpum	Panicled willow-herb	*Taraxacum officanale*	Common dandelion
Epilobium ciliatum	American / fringed willow-herb	*Tragopogon dubius*	Yellow salsify
Equisetum arvense	Field horsetail	*Trifolium pratense*	Red clover
Equisetum hyemale	Scouring-rush horsetail	*Trifolium repens*	White Dutch clover
Erigeron sp.	--		
Juncus arcticus	Arctic rush		
Juncus interior	Inland rush		
Mentha arvensis	Field mint		
Mint sp.	--		
Pascopyrum smithii	Western wheatgrass		
Pinus ponderosa	Ponderosa pine		
Poa palustris	Fowl bluegrass		
Populus deltoides	Plains cottonwood		
Pseudotsuga menziesii	Douglas-fir		
Ratibida columnifera	Prairie coneflower		
Ribes cereum	Wax currant		

Rosa blanda	Smooth rose (formerly *R. woodsii*)		
Rudbeckia hirta	Black-eyed Susan		
Salix exigua	Coyote, sandbar willow		
Salix irrorata	Bluestem willow		
Schizachyrium scoparium	Little Bluestem		
Scirpus pallidus	Cloaked bulrush		
Swida sericea	redosier dogwood		
Symphyotrichum laeve	Smooth blue aster		
--	Symphyotrichum lvs		
Toxicodendron rydbergii	Western poison ivy		
Veronica anagallis-aquatica	Water speedwell		
Prunus sp.	--		

Buckingham			
Native		**Non-native**	
Scientific Name	**Common Name**	**Scientific Name**	**Common Name**
Alnus incana	Thinleaf alder	*Bromus inermis*	Smooth brome
Ambrosia psilostachya	Western ragweed	*Cirsium arvense*	Canada thistle
Artemisia ludoviciana	Louisiana sagewort	*Dactylis glomerata*	Orchardgrass
Equisetum arvense	Field horsetail	*Melilotus albus*	White sweet clover
Equisetum hyemale	Scouring-rush horsetail	*Nepeta cataria*	Catnip
Geranium viscosissimum	Sticky purple geranium	*Poa pratensis*	Kentucky bluegrass
Mahonia repens	Oregon grape	*Taraxacum officanale*	Common dandelion
Pascopyrum smithii	Western wheatgrass	*Thinopyrum intermedium*	Intermediate wheatgrass
Pinus ponderosa	Ponderosa pine		
Poa palustris	Fowl bluegrass		
Populus angustifolia	Narrowleaf cottonwood		
Prunus americana	American plum		
Prunus virginiana	Chokecherry		
Ribes cereum	Wax currant		
Rosa acicularis	Prickly rose		
Symphyotrichum laeve	Smooth blue aster		
Symphoricarpos occidentalis	Snowberry		
Toxicodendron rydbergii	Western poison ivy		
Vicia americana	American vetch		
Virgulus (Symphyotrichum) falcata	white prairie aster		