SECTION 319 NONPOINT SOURCE POLLUTION CONTROL PROGRAM

WATERSHED PROJECT FINAL REPORT

High Park Bum

Area

Reclamation by

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Fiscal Sponsor
Rocky Mountain Flycasters

2/1/2018

EXECUTIVE SUMMARY

Project Title: High Park Bum Area Reclamation

Project Start Date 9/01/2014 Project Completion Date: 2/28/2018

Funding TOTAL BUDGET: $334,000

TOTAL EPA GRANT: $200,000

TOTAL EXPENDITURES OF EPA FUNDS:

TOTAL SECTION 319 MATCH ACCRUED: $171,445.38

BUDGET REVISION: N/A

TOTAL EXPENDITURES: $194,934.56

SUMMARY ACCOMPLISHMENTS

In the summer of 2012, two wildfires caused significant post fire erosion problems in the Cache la Poudre watershed leading to water quality degradation, primarily from non point source sediment emanating from the burn area. The Coalition for the Poudre River Watershed (CPRW) received funding from Colorado Department Public Health & Environment's Non Point Source Program to address the non-point source water quality problems stemming from the High Park and Hewlett Gulch fires. CPRW worked collaboratively with local stakeholders and partners to define high priority sub-drainages that would benefit the most from post fire restoration actions. We identified three project sites: Skin Gulch, Seaman Reservoir, and Unnamed Tributary 3. We have completed work at Skin Gulch and have initiated work at the other two project sites. At our Skin Gulch site, we succeeded in restoring 1.1 miles miles of stream corridor in the Wild and Scenic Corridor, seeded & mulched 6.85 acres, weeded and removed trash on ~4 acres weeded/trash removed, plated ~2,200 native riparian plant cuttings & 1,210 native plant containers; installed 6 pools, 5 grade controls, 3 toe walls, 3 fascines, and 20 gulley structures. Post treatment monitoring indicates that the site has met its primary goals and the installed BMPs have created a more stable ecosystem.

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INTRODUCTION

High intensity wildfires not only burn trees & other forest vegetations, but cause widespread water quality damage from erosion, sediment deposition, and debris flows. In the summer of 2012, the Hewlett Gulch & High Park Fires combined burned 95,172 acres of the Cache La Poudre watershed (Poudre Watershed). The affected areas of the watershed responded with the predictable outcomes of increased runoff volume and speed, increased erosion and sediment yield and decreased water quality in receiving waters. Modelling work conducted by the Natural Resources Conservation Services predicted that in many catchments in the burn area, post fire conditions are predicted to cause a 50- or 100-year (pre-fire) flood to result from a 10-year rain event on burned landscapes. Throughout much of the burn area, these predictions held true with massive sediment and debris flows observed in the watershed.

Post fire restoration is designed to mitigate these problems at high priority sites. Hillslope mulching and re-vegetation projects provide surface roughness to slow down surface runoff and reduce erosion potential, while helping to re-establish native seed banks that may have been lost because of the fire. Increased runoff tends to de-stabilize stream banks, which in turn contributes more sediment to downstream receiving waters. Therefore, another primary post-fire restoration technique is do riparian, bank, and in-channel restoration work.

During the Burn Area Emergency Response (BAER) implementation on National Forest System lands within the High Park Fire burn area, considerable effort was put into erosion control and hazard tree removal along trails and roads. Places treated with aerial mulching included high priority areas of high and moderate soil burn severity on slopes between 20% and 60%. Mulching took place on 881 acres with approximately 5,286 tons of wood shreds applied over 30 days. Additional mulching on nearly 5,000 acres with straw was expected to take place in late spring or early summer of 2013.

General Watershed Information

The Poudre River connects the high elevations of the Rocky Mountains with the plains of eastern Colorado, emerging from two canyon mouths to eventually connect to the South Platte River about 5 miles east of Greeley. The Cache la Poudre watershed is one fourth-level 1 (eight-digit) watershed (HUC 10190007) that is 1,219,038 acres in size and contains 53 sixth-level watersheds. Flow in the Poudre River is snow melt dependent with peak flows occurring generally in June. During winter, most of the flow is trapped with resulting low flows for much of this season. The Poudre River is generally known as a 'working river' with flows being diverted for human as soon as the river leaves the canyon mouth. This radically changes the flow conditions and physical stream stability in the downstream portions of the river. The diversions create a river with flashier flows but lower peak flows, which in turn affect the ability of the river to move accumulated substrate in the system.

Catastrophic wildfires produce a well-known suite of water quality impacts in downstream receiving waters. High-severity fires can cause changes in watershed conditions that are capable of dramatically altering runoff and erosion processes in watersheds. Water and sediment yields may increase as more of the forest floor is affected by fire. The potential of a watershed to deliver sediments following wildfire depends on forest and soil conditions, the physical configuration of the watersheds, and the sequence and magnitude of rain falling on the burned area. These outcomes were widely observed in the Poudre River Watershed in the aftermath of the Hewlett and High Park fires, immediately following strong summer convective storms.

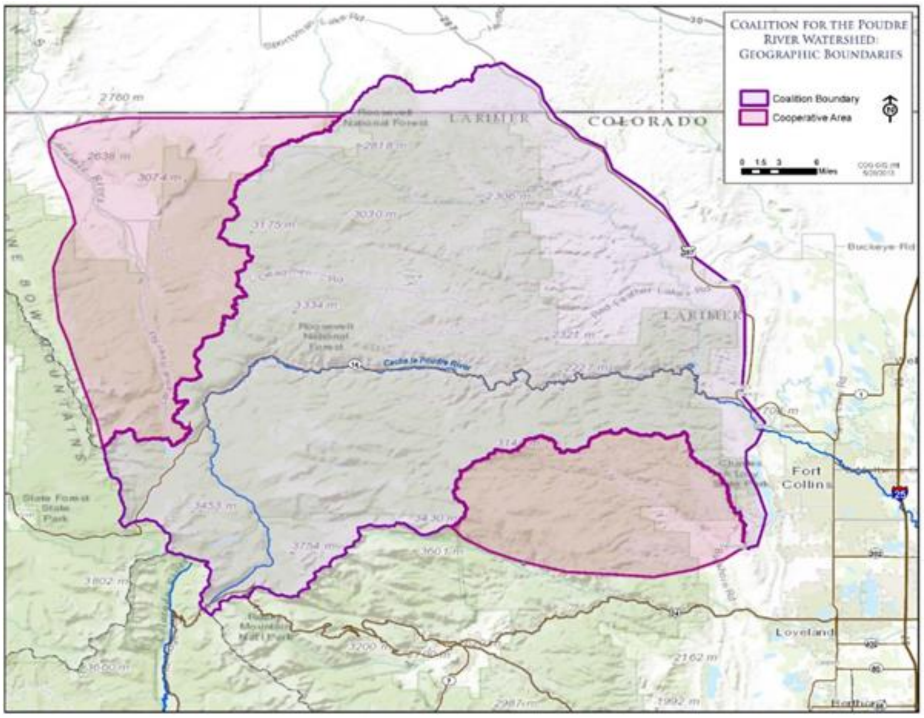


Figure 1: The upper Cache La Poudre Watershed.

Data from the Upper Cache La Poudre Collaborative Water Quality Monitoring Program indicate that standard measures of water quality changed dramatically – hardness, conductivity, pH, total dissolved solids, turbidity, total and dissolved nitrogen and phosphorus all increased post storm events after the High Park Fire. Field observation and photographic evidence indicated that Seaman Reservoir was impacted by sediment and debris runoff from storm events.

Immediately following the containment of the 2012 fires, thunderstorms occurred in the burn area. As predicted, mudslides and debris flows were observed in many burned drainages throughout the summer, delivering massive quantities of ash and sediment into the Poudre River as well as into Seaman Reservoir. Multiple spikes in turbidity measured by the City of Fort Collins during the first season following the fire demonstrated that even small, localized precipitation events caused dramatic changes in water quality and stream flow. In addition, numerous alluvial fans have formed along Hwy 14, which indicate actively eroding channels. It is expected that these channels continue to provide sediment and debris to the river until vegetation recovers sufficiently to stabilize the hillslopes higher in the drainage areas. These changes in water quality forced the local utilities to stop relying on the Poudre River as a primary source of drinking water in the summer of 2012 and portions of 2013.

Water Quality Priorities in the Poudre Basin

The 2012 Integrated Report[1] identified 1010.2 miles of stream and 1930.9 acres of lakes and reservoirs as water quality impaired in the Cache La Poudre basin. Pollutants causing water quality impairment in the watershed include cadmium, dissolved oxygen, lead, copper, selenium, temperature, *Escherichia coli* and mercury in fish tissue. A portion of the North Fork of the Cache La Poudre was listed as impaired due to sediment in the 1998 listing cycle. A TMDL[2] was approved for that impairment in 2002. Applicable standards for the sediment TMDL include: minimum trout biomass of 100 lb/acre; minimum of three year classes of trout in any five year period; total macroinvertebrate taxa of 44-52 below Halligan dam and 43-60 in Phantom Canyon; EPT abundance of 11-18 taxa below Halligan dam and 19-25 taxa in Phantom Canyon; and a TMDL goal of managing sediment flushing and release flows from Halligan Reservoir so as to attain the narrative sediment standard and fully support designated aquatic life uses[3].

[1] 2012 Integrated Report: http://iaspub.epa.gov/tmdl_waters10/attains_watershed.control
[2] http://ofmpub.epa.gov/tmdl_waters10/attains_impaired_waters.tmdl_report?p_tmdl_id=3989&p_report_type=T
[3] TMDL –No. Fork Cache La Poudre TOTAL MAXIMUM DAILY LOAD Assessment – Sediment. North Fork Cache La Poudre River, Segment 7 Larimer County, Colorado. March 15, 2002

Table 1: Sediment Related Water Quality Impairments in the Cache La Poudre Watershed. See text for a description of other water quality impairments in the watershed.

Waterbody ID	Beneficial Uses	WQ Impairment	TMDL Status
COSPCP07[4]: North Fork Cache la Poudre River Hall Res. to Cache la Poudre River	Aquatic Life Cold 2, Rec 1, water supply, agriculture	Sediment	Listed in 1998; TMDL approved

Immediately following the High Park Fire, a Burned Area Emergency Response analysis was completed ("High Park Fire Burned Area Emergency Response (BAER) Report July 17, 2012"). The BAER concluded that there was a very high risk for degradation of/damage to water quality, water diversion structures, flooding, debris flow, road wash-out, and recreation facilities. The BAER Report recommended hillslope stabilization techniques to be implemented to reduce the risk. This helped inform which treatment approaches we would implement.

In November 2010, the cities of Fort Collins and Greely funded a study titled "Cache la Poudre Wildfire /Watershed Assessment - Prioritization of watershed-based risks to water supplies". The report was designed to identify and prioritize sixth-level watersheds (12-digit HUCs) based upon their hazards of generating flooding, debris flows and increased sediment yields following wildfires that could have impacts on water supplies throughout the Upper Cache La Poudre Watershed. This work was completed prior to the High Park Fire, but the general approach informed how sub-watersheds were prioritized for treatment after the fires of 2012. After the fires, the same GIS approach was used to help determine where post-fire restoration work was completed in 2012 & 2013.

JW Associates applied the same GIS analysis model to the untreated portions of the watershed to define what areas remained in need of treatment after 2013. This analysis, entitled "High Park Fire Small Watershed Hazard Prioritization, February 2014" provided the foundation for identifying where restoration could occur in 2014 (Figure 2). All this information was combined into one document, "High Park & Hewlett Gulch Burned Areas Watershed Protection, Scope of Work"[5] as part of the process of acquiring USFS permission for aerial mulching on USFS land.

The project used existing spatial data, field reviews, and stakeholder input to target severe to moderately burned areas (yellow to red areas in Figure 2) that still needed treatment after the Emergency Watershed Program was complete. Our project focused on one main priority treatment area, Skin Gulch (circled in black in Figure 2). In addition, we used project funds to begin restoration implementation at a second post fire site, Unnamed Tributary 3 (UT3 – circled in hashed black) & help complete post fire restoration at the Milton-Seaman Reservoir.

Consistency with local water quality planning priorities

This project is consistent with approaches and priorities articulated in the Colorado NPS Management Plan. It addresses priorities through on-the-ground watershed restoration efforts, which reflects the NPS

[4] The 2012 Integrated Report does break the North Fork into two segments labelled as COSPC07-1000 &_103D. However, the TMDL Report for the Sediment TMDL (referenced above) does identify the sediment-listed segment as COSPCP07. The inconsistency in the nomenclature is not explained. However, the EPA website uses the COSPCP07 nomenclature when describing the sediment listed portion of the North Fork.

[5] http://www.jw-associates.org/Resources/High%20Park%20USFS%20EWP%20V2.pdf

Management Plan second tier of implementation. In addition, this project will incorporate several of the nine key elements described in the Management Plan by explicitly defining goals, objectives and strategies to help protect surface waters; developing strong partnerships and collaborations; and will contribute to the abatement of known water quality impairments resulting from nonpoint source pollution and help prevent significant threats to water quality. Finally, this project uses a watershed approach that relies on stakeholder involvement and watershed partnerships. Defining the initial post-fire restoration priorities was done as part of a collaborative stakeholder driven effort. Determining the location of restoration priorities was accomplished by analyzing watershed scale processes. The implementation of the restoration projects will continue to be accomplished through partnerships of watershed stakeholders (local government, natural resource agencies, and non-profits).

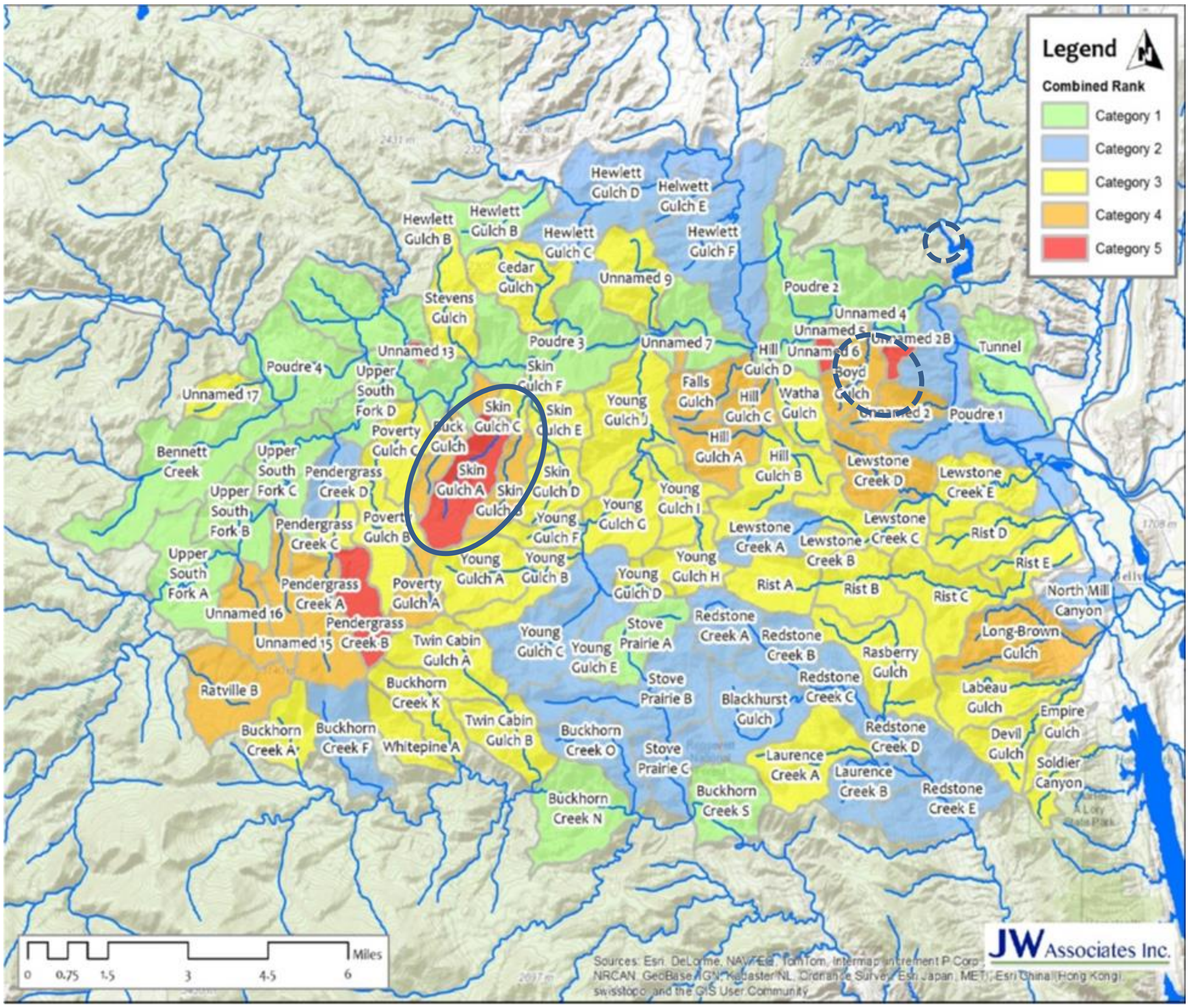


Figure 2. Sub-watershed treatment priority areas. Black circles indicate where CPRW focused post fire restoration projects with NPS funds.

General Project Description

Figure 3: Location of the Skin Gulch project site. Skin Gulch is a relatively small drainage that flows along Stove Prairie Rd and then under the Co-14 to enter the mainstem of the Poudre ~ 20 miles west from the canyon mouth

The primary purpose of this nonpoint source watershed project was to reduce the amount of nonpoint source pollutants, primarily sediment, emanating from high priority burn areas. Given the size of the burn area, the project could not address all sources of sediment. Instead, the project focused on high priority post fire areas that were not completely addressed during the immediate post fire Emergency Watershed Protection program and BAER program. CPRW worked with stakeholders and consultants to identify remaining post fire restoration needs. Within the project period, CPRW focused this project primarily on two areas of high concern. The first and largest project was the Skin Gulch Post Fire Restoration project. Skin Gulch is located ~20 miles west of the canyon mouth at the junction of CO-14 and Stove Prairie Rd (Figure 3). It was identified as a high priority during the Emergency Watershed Protection Program (EWP) but the EWP could not address the nonpoint source problems from Skin Gulch because the program ended prior to any jurisdiction being able to complete restoration.

Skin Gulch (HUC: 101900070303) is a 13,310-acre tributary to the Cache La Poudre River. It is primarily federal lands, with 89% of this area owned and managed by the USFS, Canyon Lakes Ranger district. After the 2012 High Park Fire, the USGS estimated a 486% increase in flow in this stream, and an estimated debris flow of over 100,000 m^3 in a 10-year 1-hr rainfall event of 1.69 in, making the restoration of this stream a high priority for CDOT, which manages a culvert where Skin flows under Highway 14, water utilities, and river recreationalists/fishing community. The September 2013 flood event resulted in significant debris flow, scouring of the upper portions of the watershed, and significant aggradation of the lower parts of the stream. Subsequent work by contractors to remove aggraded material and debris resulted in significant alteration to the entire floodplain where it is adjacent to CR 27 (Stove Prairie Road). The primary project site is approximately 2,200 feet in length, with an average width of 50 feet. The project site was divided into two design reaches: Reach A, the portion of Skin Gulch that flows parallel to Stove Prairie and Reach B: the upstream portion that flows from the hill slope perpendicular to Stove Prairie Rd.

As we completed our Skin Gulch project, we worked with stakeholders to re-evaluate what the status of other post fire unmet needs were. We identified the Unnamed Tributary 3 (UT 3, Figure 4) as a remaining high priority need due to its steep slopes and proximity to the main stem of the Poudre and the Munroe Gravity Tunnel. The UT3 watershed (HUC number 10190007141014) is a

210-acre sub-watershed characterized by steep, forested drainages and a variety of decomposed granite to clay-silt loams.

The 2012 High Park Fire burned over 50% of UT3 at a high soil and canopy severity, resulting in an estimated 531% increase in expected post-fire peak flows (BAER Report, July 17, 2012). Since the fire, and during the 2013 flood and subsequent high flow events, debris flows from this watershed caused the blockage of Munroe Tunnel, a primary water supply conveyance. Additionally, debris flow risks from this tributary continue to threaten the primary egress road for residents and the Colorado HWY 14. Despite previous post fire restoration work (revegetation, mulching, & directional felling) signs of substantial erosion in contributing gullies and in the main channel, indicated soil surface and shallow subsurface soil properties remain in a highly altered state in the contributing watershed.

Since the 2012 fire, road grading and realignments, culvert replacement, and other repair work has been performed by local residents. Additionally, recent property acquisitions and residential development has led to the construction of additional roads and road improvements necessary to maintain adequate access to properties in UT3. While current road conditions are an improvement over the immediate post-fire condition, results of a geomorphic assessment and hydraulic analysis indicated significant risk remains to the road, channel, and water quality in future flood events. Our re-evaluation of this drainage indicated that small storm events of 200 cfs would cause flooding due to poor structural design of infrastructure in the drainage.

The UT3 reach can be characterized geomorphologically as entrenched, with moderate width:depth and moderate sinuosity. It has a 4-10% grade, cobble bed, contains invasive vegetation, has poor culvert and check dam configuration; and has active degradation and widening. Our initial engineering analysis also showed that ~ 50TNs of sediment is trapped in the upper portions of this system, above the poorly configured culverts. Further design/engineering work estimated that there is a potential for approximately 325 TNs of sediments to be suspended and re-suspended as a result of the poor design and configuration of existing check dams and culverts within the drainage. A discharge of 200- 300cfs would result in major downstream sedimentation from this reach into the Poudre River as a result of anthropogenic structure failures. The focus of our post fire restoration at this site is therefore to improve the configuration of the culverts to reduce risk of failure, remove sediment retaining structures, and re-connect the channel to its floodplain, and increase riparian vegetation.

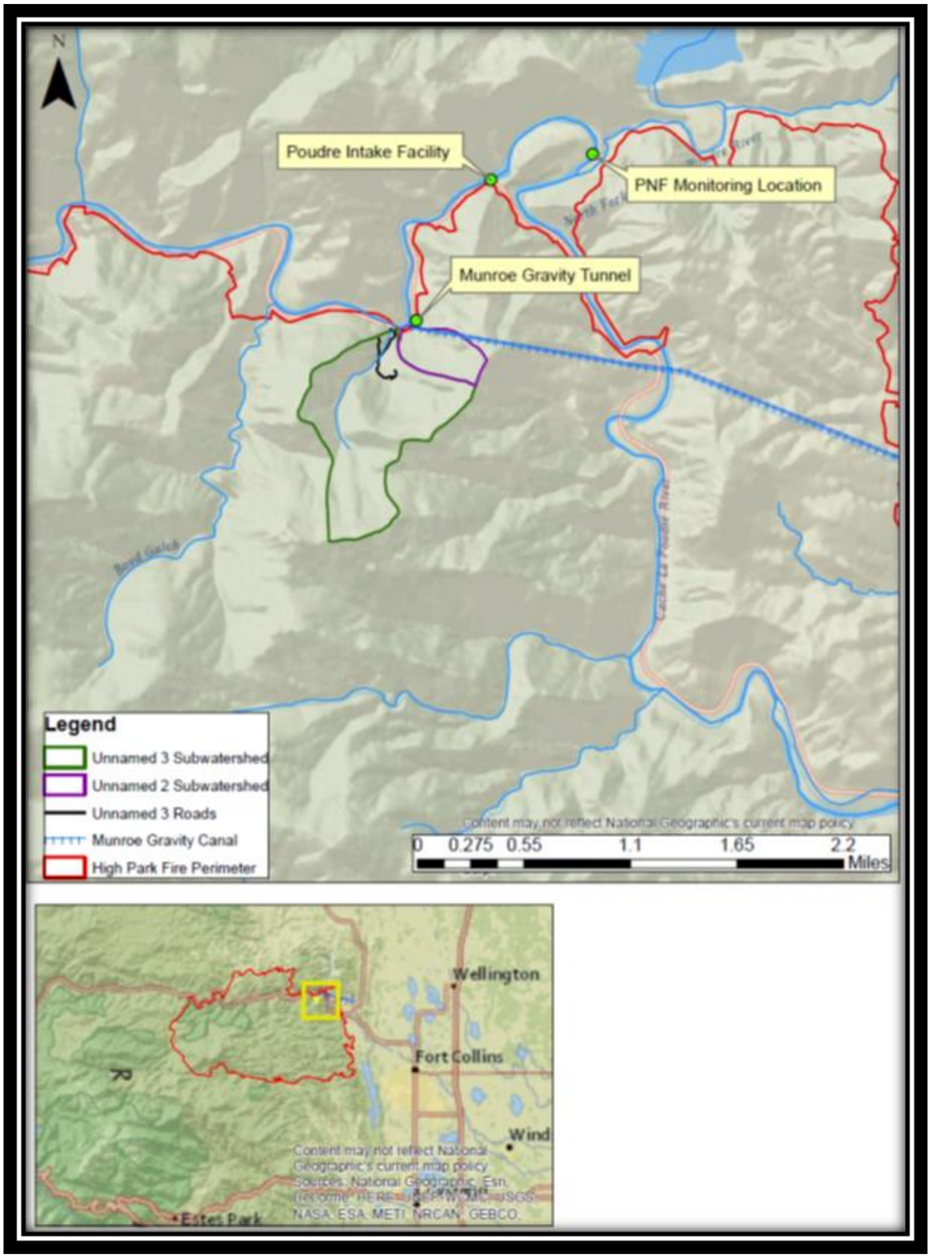


Figure 4: Location of the Unnamed 3 (UT 3) Post Fire Restoration Project. The project site has a small drainage but it is located close to critical water infrastructure including the Munroe Gravity Tunnel, Ft Collins Water Supply intake facility & Ft Collins water quality monitoring location.

Construction and BMP installation will not be fully complete at this site until the end of 2018. NPS project funds helped support acquisition of materials & supplies for restoration implementation in addition to supporting volunteer project to install gulley erosion control BMPs. Figure 5 shows the approximate location of the proposed BMPs for UT3.

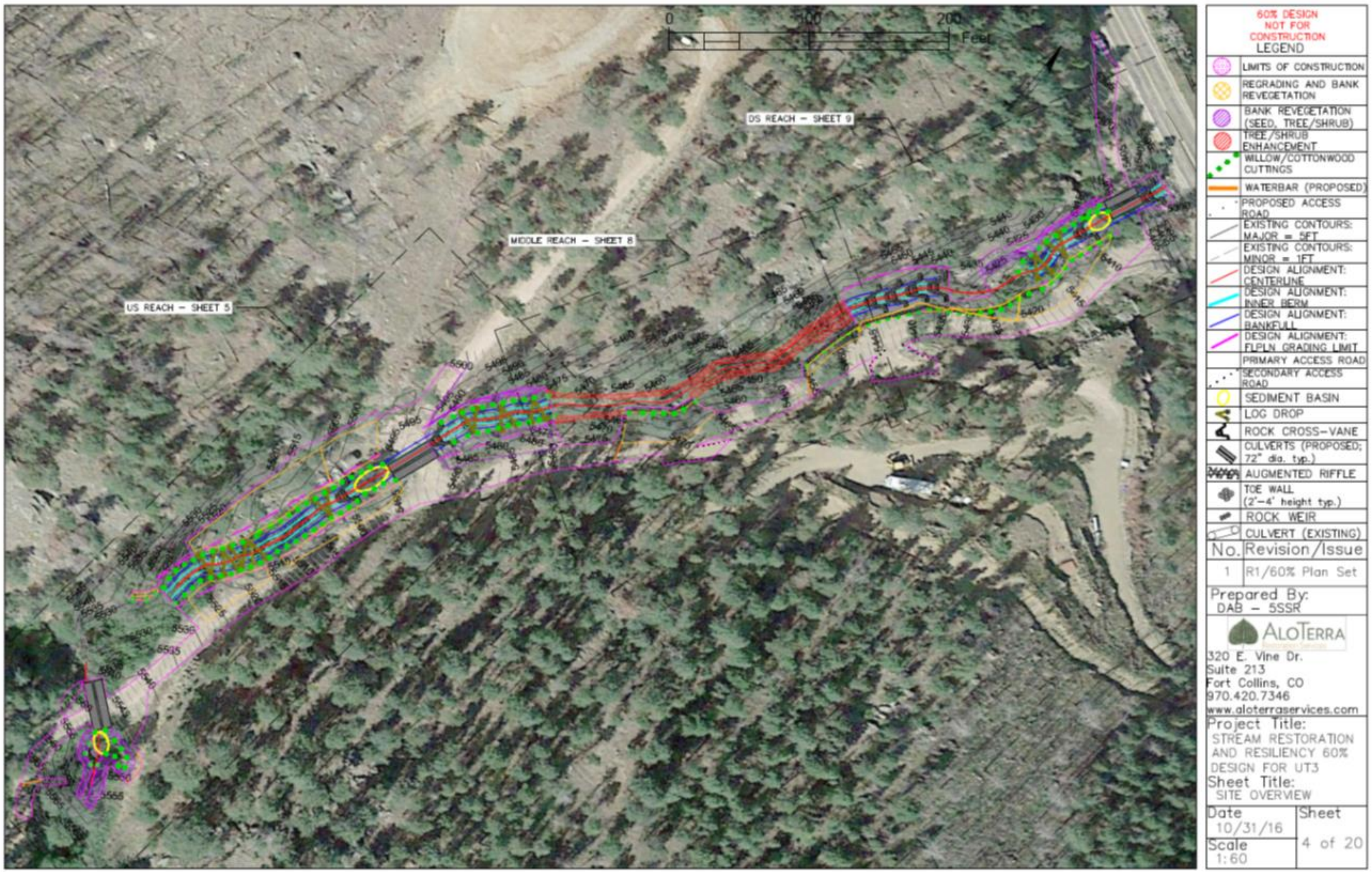
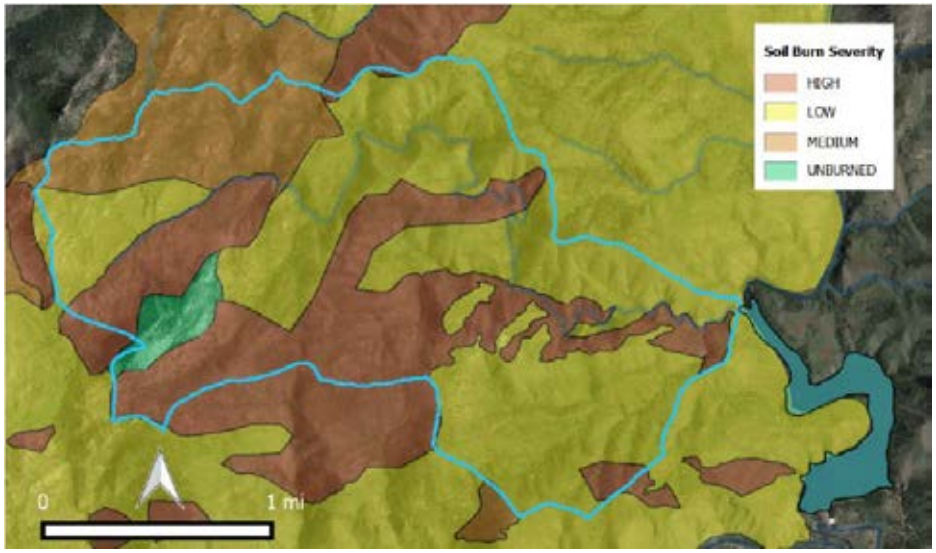


Figure 5: Approximate location of proposed BMPs for UT3 post fire restoration

Our third post fire restoration site supported by NPS funds is located at the Milton-Seaman Reservoir (Figure 6), which is in the North Fork of the Cache La Poudre river. The Hewlett Gulch Fire ignited northwest of Fort Collins, Colorado in May of 2012, burning 7,685 acres, mostly in ponderosa pine on north facing slopes. The Burned Area Emergency Report (BAER) documented 1,513 acres of high burn severity and 639 acres of moderate burn severity. Most of area of high burn severity was within the immediate drainage area of the Milton Seaman Reservoir, which is owned and operated by the City of Greeley, Colorado (Figure 6). The Hewlett Gulch BAER identified threats to public water supply as a likely probability with major magnitude of consequences. The BAER risk rating for threats to water supply was very high. The Hewlett fire has resulted in increased runoff, hillslope erosion, and sediment export to the reservoir, leading to an unconfined sediment delta perched in the northwest/inlet of the reservoir.

The City of Greeley (City) partnered with local, state, and federal agencies and private consultants to mitigate the impacts of the Hewlett Fire on the water quality and capacity of Seaman Reservoir. These mitigation efforts include mulching and seeding the burned areas of the watersheds draining to the reservoir (NRCS 2012). Despite these efforts, large quantities of sediment have eroded from the hillslopes, channel beds, and banks. This sediment has been delivered to the reservoir pool in the form of silt and clay material during runoff events and in the form of sand and gravel material that has deposited in a delta at the outlet of an unnamed tributary to the North Fork of the Poudre River at the northern end of Seaman Reservoir (Figure 6). Unless stabilized, the sediment in this delta poses a risk to the reservoir as it could further reduce reservoir capacity.

The primary goal of the project at this site is to stabilize the loose sediment in the delta & stabilize the newly formed channel and keep it in place. The design calls for extensive native plant revegetation, log checks installed in the delta to prevent channel migration and hardening the channel with rocks (Figure 6). NPS project funds were used to support acquisition of materials and supplies for post fire restoration. In addition, NPS funds were used to support youth corps time for implementing project work in the delta.



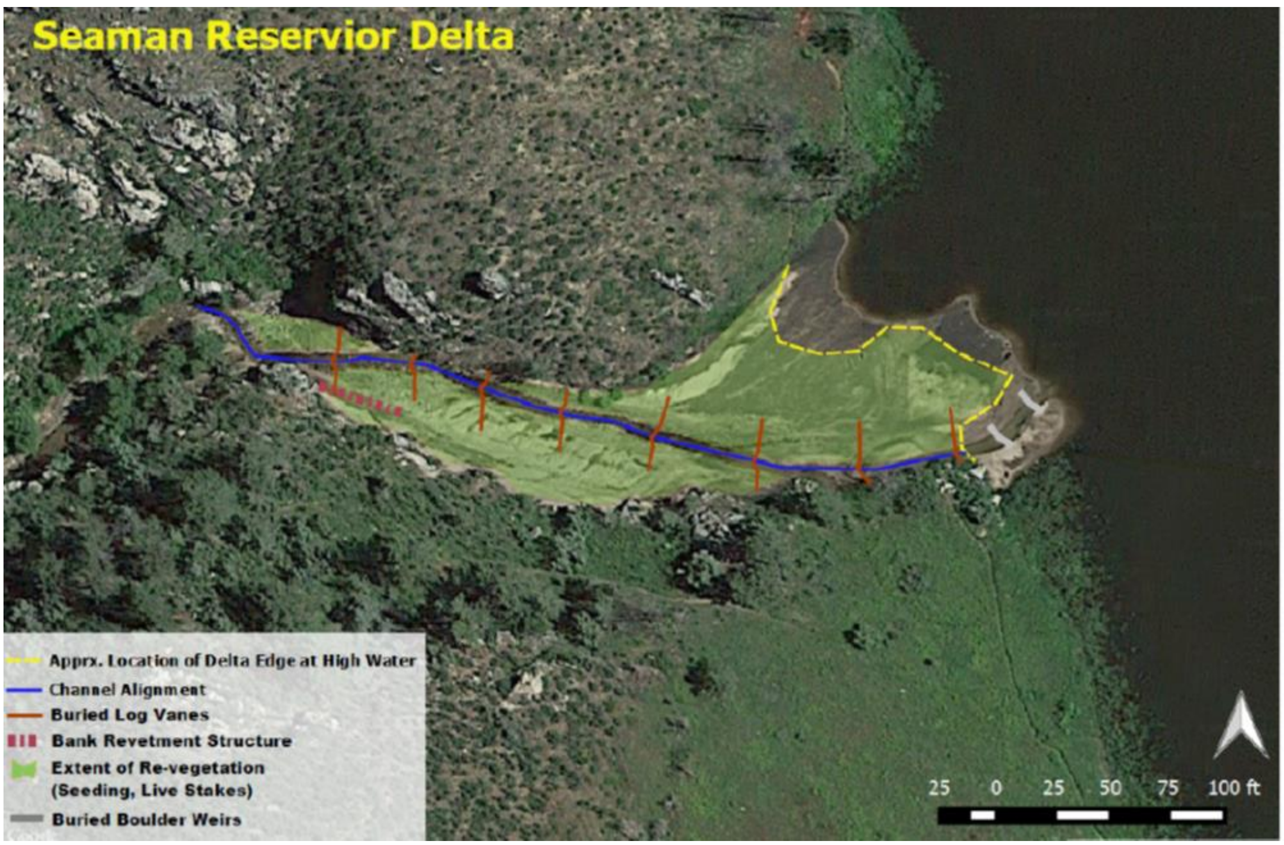


Figure 6: Top- Map of sub watersheds and their burn severity showing drainages flowing into Seaman Reservoir. Bottom: Map showing approximate location of main post fire restoration activities at Seaman Reservoir project site.

PROJECT GOALS, OBJECTIVES, AND ACTIVITIES

Goal: Reduce sediment loading to the Poudre River to improve high-quality cold-water fisheries and reduce other negative impacts of sedimentation upon the ecosystems and municipal water supplies.

Objectives:

1. Manage a successful collaboration that reduces erosion and subsequent sedimentation in the Poudre River Watershed
    a. Completion of semi-annual reports, final reports and reimbursement requests; submission of sub-contracts to NPS Program and distribution of funds to sub-contractors; maintenance of accounting and match records
2. Coordinate and implement best management practices that reduce erosion and runoff in high priority burn areas of the Poudre River Watershed
    a. Recruit, train, and communicate with volunteers to re-vegetate high priority burn areas to increase ground cover, reduce erosion, and help re-establish native plant communities
        i. Successful germination/survival of plants in 50% of monitoring plots
        ii. Consistent volunteer turnout for 70% of implemented projects
        iii. Results of volunteer projects posted on social media for 70% of volunteer events
    b. Assist the implementation of best management practices (including but not limited to bank stabilization, gulch/channel stabilization, log structures, tree felling) to reduce sediment delivery from high priority burned sub-drainages.
        i. Inspections that confirm BMPs were implemented appropriately in treated gulches/sub-drainages
        ii. Sediment observed being trapped by BMPs
    c. Apply mulch, seed, shrubs and trees, and other erosion control measures to reduce erosion, increase surface roughness, and slow down water movement in the burn area.
        i. Inspections and photo monitoring that confirm vegetation is

growing/surviving and erosion control structures are installed to specification

3. Monitor water quality in the Poudre River to assess if sedimentation levels are changing

Activities:

- conduct seeding in uplands on high priority areas.
- conduct tree felling in gulches pre-identified as priority areas.
- apply wood mulch in high to moderate burn severity areas within targeted watersheds.

Programmatic Goal: Manage and monitor for a successful, collaborative project that leverages resources effectively. This project facilitates achieving a strategic vision for a future built on a strong

PLANNED AND ACTUAL MILESTONES, PRODUCTS AND COMPLETION DATES

Table 2:Schedule and milestones for High Park Fire Burn Reclamation project.

	2014				2015				2016				2017				2018	
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2
design & permitting																		
Skin				■	■													
UT3											■	■					■	■
Seaman											■	■		■			■	■
install BMPs																		
Skin				■	■		■											
UT3															■			
Seaman															■			
volunteer restoration																		
Skin				■		■	■	■		■	■							
UT3														■	■			
Seaman														■	■			
monitoring																		
Skin				■			■				■				■			
UT3											■				■			
Seaman							■	■			■				■	■		

Milestones:

Skin: For our Skin Gulch project, our team met most of our highest priority milestones including completing the design on schedule, implementing volunteer restoration projects, conducting pre & post monitoring. One area where did not meet all of our milestones on time was with our heavy equipment work ('install BMPs'). Although initial work happened on schedule, we experienced a prolonged rain event in the spring of 2015 immediately after fresh channel work was completed. The prolonged high runoff on freshly moved earth caused damages & required us to return with heavy equipment to repair some channel structures. However, most of the plantings installed by volunteers survived and thrived post installation. We have repeatedly inspected the site both with USFS staff and as part of our annual post-project monitoring and are confident that all major objectives for this site were accomplished.

UT3: The UT3 post fire restoration project was initially delayed to accommodate one of the private landowners construction schedule. But it is now proceeding on schedule. Sixty percent design was completed on schedule in 2016 and final design is almost complete in keeping with our intended milestones. We installed log/rock erosion control structures in one a highest priority gulley. While there is still some minor work to complete in that gulley project, we completed the most important portions of the structure. Although we had initially hoped to have begun the major earth work by fall of 2017/winter 2018, construction being implemented by the private landowners pushed our construction timeline into the fall of 2018.

Seaman: Initial milestones were largely met with this project site. However, weather and equipment malfunction problems caused some delays with the Seaman Reservoir project. Large rain events and subsequent post rain erosion filled some of the post fire BMPs beyond their capacity forcing us to return to the site to address these problems. However, overall, the BMPs have held over two seasons and plantings are starting to grow in the delta.

EVALUATION OF GOAL ACHIEVEMENT AND RELATIONSHIP TO THE STATE NPS MANAGEMENT PLAN

Based on the successful implementation of post fire restoration at 3 high priority sites, with BMPs that have generally performed as expected through collaborative planning and implementation, we are confident that we have met our primary goals. This is bolstered by the outcomes of our monitoring (see Monitoring section below).

This project has made significant contributions to several of Colorado's 2012 NPS Management Plan. First, the project addressed the tier two priority of the NPS Management Plan by implementing on-the-ground watershed restoration efforts. Second, this project directly addressed several of the 9 key elements. The project defined explicit goals & objectives and implemented strategies/tactics to protect surface water from post fire sediment nonpoint source pollution. We leveraged strong working partnerships and collaboration with state, interstate, regional, and local entities (including water utilities), and Federal agencies such as the US Forest Service. We worked with these stakeholders to identify which sub-watershed were most threatened by potential non-point source pollution emanating from burn areas. Throughout the project, we relied on a watershed approach (Chapter 2.3.1.2 NPS Management Plan) to target where the most impactful work could be implemented and worked closely with stakeholders to ensure that we were targeting watersheds appropriately. Two out of three of our project sites required us to partner with federal agencies and at all three project sites we worked with local water utilities to plan, fund, and implement the projects.

In accordance with the Colorado NPS Management Plan, CPRW has worked to determine measurable results for our work and have evaluated the pre- and post-restoration conditions of the project site where work has been completed. Perhaps this project's most important contribution Colorado's NPS Management Plan is its clear nexus with Chapter 3.1.3 – NPS Category priority Silviculture/Forestry. The NPS plan acknowledges the important way that wildfires can lead to delivery of flow and sediment to rivers, impacting water quality. This project directly helped address this issue. Our project specifically worked to reduce sediment loads that impair surface waters or pose a significant threat to public drinking water supplies by implementing wildfire burn area rehabilitation.

SUPPLEMENTAL INFORMATION

Over the course of planning and implementing NPS restoration projects at the various project sites, we encountered several unexpected challenges that offer some lessons learned for future planning. Our primary project site, Skin Gulch, is located on national forest land. One portion of our project area is a popular but illegal recreational shooting area. The impacts of this on implementation were not well considered during the planning and budgeting phase of the project with regards to our volunteer restoration project days. To ensure the safety of our volunteers, we needed to hire off duty police officers to enforce no shooting rules at the site. USFS staff could not provide the service for free as their enforcement staff was so limited. Although this did not add a large cost to the project budget, it was not an anticipated cost. This situation did however offer an opportunity for us to help address some of the impacts of the rec shooting at the site. Volunteers were able to remove gun related trash & litter from over 1 acre of floodplain area. We will continue to work on this issue into the future at the site.

Another challenge we faced at this site was accommodating concerns that Larimer County Roads department. Geomorphology indicators at Skin Gulch pointed towards allowing the channel sinuosity to flow closer to the Stove Prairie Road than the county was comfortable with. We therefore adjusted our natural channel design at this section of the site and opted for a design that met the county's safety concerns but still added floodplain connectivity and more sinuosity. To accomplish this, we incorporated an emergency overflow channel closer to Stove Prairie Rd but kept the thalweg of the main channel farther from Stove Prairie Rd.

One other positive outcome of the work at Skin Gulch was the potential for creating new perennial fish habitat. The general assumption of land managers was that Skin Gulch was an ephemeral tributary prior to the High Park Fire. Post fire changes to hydrology have created a perennial system that seems to be persisting. With the consistent perennial flows trout have begun to congregate regularly on the downstream end of the culvert at the CO-14. CPRW had begun discussing with USFS about the possibility of retrofitting the culvert to make it fish passable and allowing the trout to access Skin Gulch.

Our post fire project at Seaman Reservoir presented an assortment of project implementation difficulties. The project was designed to address the unconsolidated sediment that was forming an unstable delta perched at the inflow of the storage reservoir. The unconsolidated nature of the sediment in the delta made design and implementation extremely difficult. The level of difficulty was further exacerbated by the fact that no heavy equipment could be brought to the site; all materials and equipment had to be hiked in or transported across the reservoir by boat. All rocks and logs used for structures had to be hand collected from the delta area and moved to project locations by hand. This was a labor intensive and time-consuming process.

Skin Gulch Project Photos

Figure 7. (Left) Skin Gulch showing damage resulting from rain event after the High Park Fire. Image shows the damage to Stove Prairie Rd and Co-14 and excessive sediment being delivered to the Poudre. Photo courtesy City of Ft Collins. (Right) Stove Prairie Road

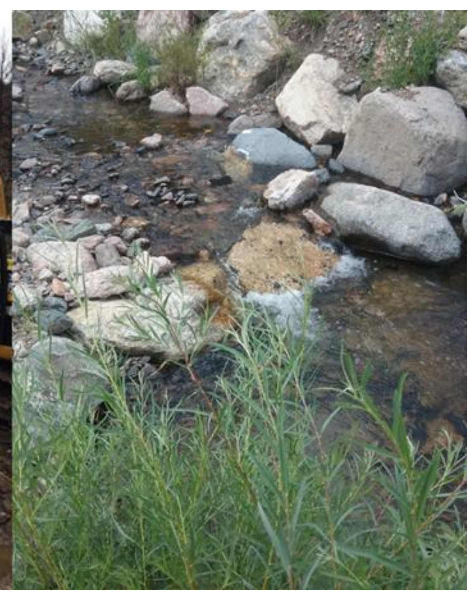


Figure 8. Heavy equipment working to create stable channel formation at Skin Gulch, 2015 (Left). An example of a rock/log grade control structure installed with heavy equipment at Skin Gulch (Right).

Figure 9. Red arrow indicating a willow fascine installed along the bank in Skin Gulch (left). Volunteers laying mulch over newly planted & seeded floodplain area in Skin Gulch (upper right). Volunteers seeding the floodplain at Skin Gulch (Lower left).

Figure 10: Post treatment monitoring images from Skin Gulch showing strong growth of willows and other plantings at Skin Gulch. On the left, the floodplain roughness logs are visible.

Seaman Reservoir Project Photos

Figure 11

Figure 12

Figure 13

Photos from the UT 3 Post Fire Restoration Project Site.

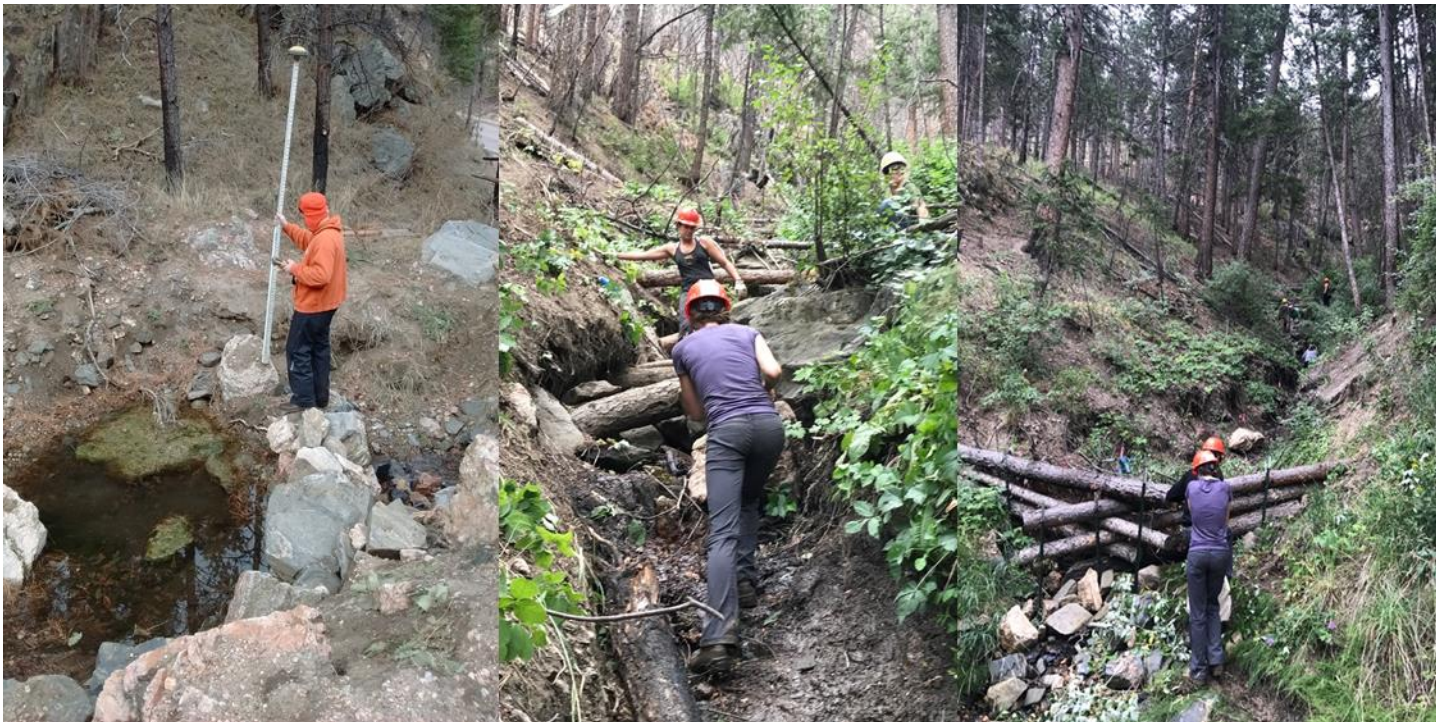


Figure 14

BEST MANAGEMENT PRACTICES DEVELOPED AND/OR REVISED

For all three projects sites, we generally relied on designing & implementing BMPs that have been used widely in other river restoration work, with a focus on natural channel design principles. Largely this involved helping to form stable channels, using native plants to stabilize the banks, rock/log structures to hold channel grade in place, and where necessary using logs and native plants to create floodplain roughness and increase biodiversity.

Skin Gulch

Figure 15 shows the final design and locations of BMPs used in the Skin Gulch project. This project site involved the largest channel reconstruction work of all three of our projects. This was because of how unstable and damaged the post fire channel had become after multiple rain events that damaged Stove Prairie Road and caused debris flows and excessive sediment. The project site was divided into two design reaches, Reach A, which flowed parallel to Stove Prairie Rd, and Reach B, the upstream portion of the site Heavy equipment was used to create a channel with a more natural sinuosity, create terraces/floodplain benches to connect the channels to its floodplain (Figure 8). Heavy equipment was also used to dig large trees with root wads into the floodplain to help create floodplain roughness features, which should help slow down high velocity flows and allow sediment to settle out in the floodplain. We also seeded the floodplain with native grass seeds and planted willows and other native vegetation throughout the floodplain. In addition, we re-used all sediment on site. All excavated sediment was used to cover pink riprap on the road embankment and then seeded that with native grass seeds, making this portion of the Wild & Scenic corridor remain more natural looking. For a complete description of the final design, see Appendix 1.

Overall, at this site our work resulted in:

- 5,746 feet (1.1 miles) miles of stream corridor designed and treated
- 6.85 acres seeded, mulched, protected with erosion matting, and improved with soil amendments:
- ~4 acres weeded/trash removed
- ~2,200 native riparian plant cuttings installed1,210 native plant containers planted
- Structures Installed (instream and bioengineering): Pools (6), Grade Control (5), Toe Wall (3), Fascines (3), gulley structures (20).
- Grading and Earthwork: included removal and redistribution of alluvium, channel relocation, floodplain conveyance improvements, and soil covered rip-rap.
- 3 gullies treated (approximately 150 feet)

The BMPs installed at Skin Gulch have all performed well. The system has been tested by multiple storms and the channel has remained in place, the road has not been damaged, willows and other native plants have grown well and there is now a thriving riparian vegetation community established. Although we did not do quantitative sampling of benthic macroinvertebrates at the site, anecdotal sampling of benthic invertebrates indicates a diverse benthic community is taking advantage of the newly established channel. The one area where our vegetation work did not thrive was in the upper reaches of the project site. This area already had very nutrient poor soils, which was compounded by post fire deposition of large cobble and rock. Even though we added soil amendments to this section, we did not have successful recruitment of native grasses or other riparian vegetation in the upper section of the project.

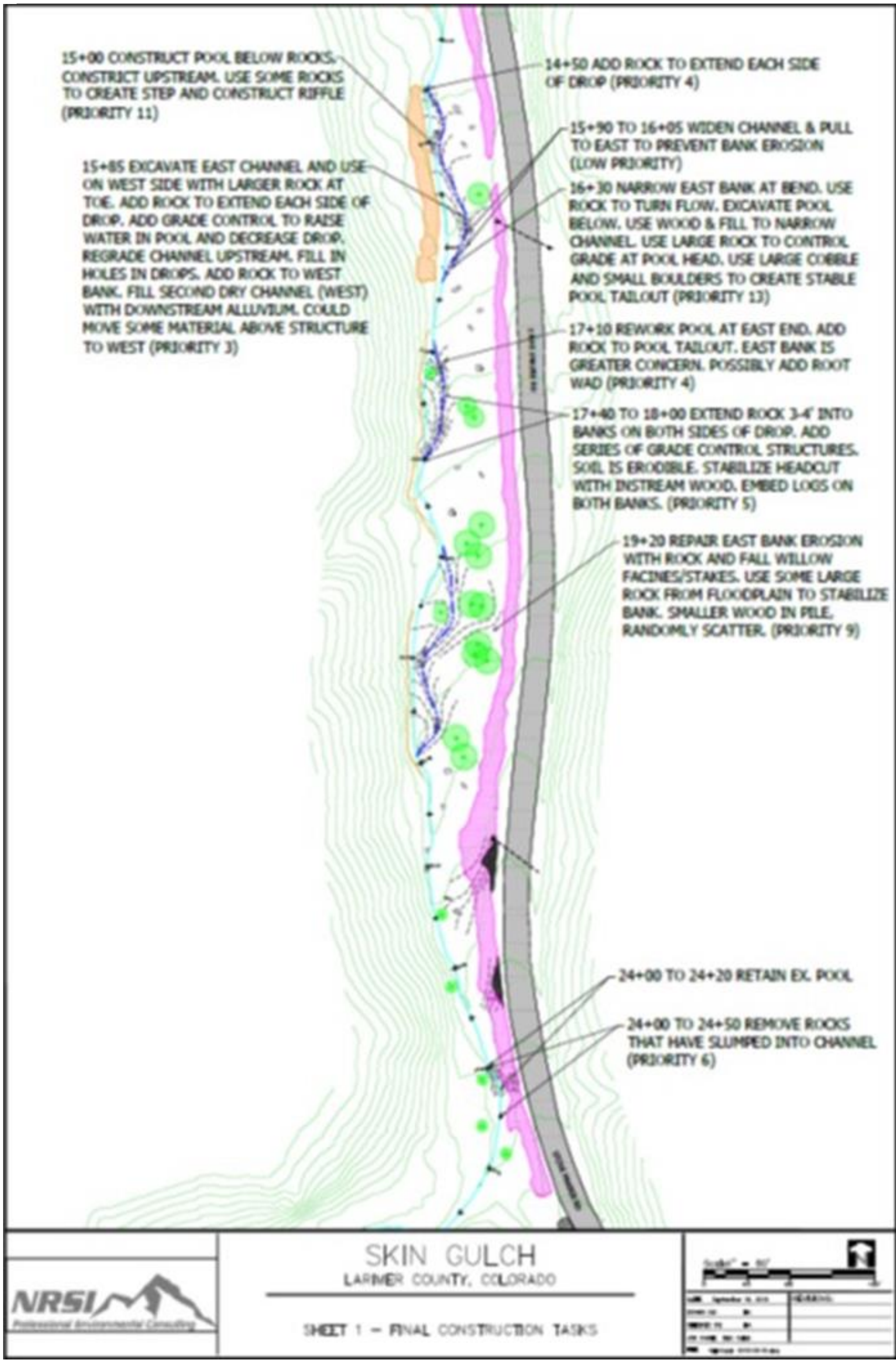

15+00 CONSTRUCT POOL BELOW ROCKS. CONSTRICT UPSTREAM. USE SOME ROCKS TO CREATE STEP AND CONSTRUCT RIFFLE (PRIORITY 11)
14+50 ADD ROCK TO EXTEND EACH SIDE OF DROP (PRIORITY 4)
15+90 TO 16+05 WIDEN CHANNEL & PULL TO EAST TO PREVENT BANK EROSION (LOW PRIORITY)
15+85 EXCAVATE EAST CHANNEL AND USE ON WEST SIDE WITH LARGER ROCK AT TOE. ADD ROCK TO EXTEND EACH SIDE OF DROP. ADD GRADE CONTROL TO RAISE WATER IN POOL AND DECREASE DROP. REGRADE CHANNEL UPSTREAM. FILL IN HOLES IN DROPS. ADD ROCK TO WEST BANK. FILL SECOND DRY CHANNEL (WEST) WITH DOWNSTREAM ALLUVIUM. COULD MOVE SOME MATERIAL ABOVE STRUCTURE TO WEST (PRIORITY 3)
16+30 NARROW EAST BANK AT BEND. USE ROCK TO TURN FLOW. EXCAVATE POOL BELOW. USE WOOD & FILL TO NARROW CHANNEL. USE LARGE ROCK TO CONTROL GRADE AT POOL HEAD. USE LARGE COBBLE AND SMALL BOULDERS TO CREATE STABLE POOL TAILOUT (PRIORITY 13)
17+10 REWORK POOL AT EAST END. ADD ROCK TO POOL TAILOUT. EAST BANK IS GREATER CONCERN. POSSIBLY ADD ROOT WAD (PRIORITY 4)
17+40 TO 18+00 EXTEND ROCK 3-4' INTO BANKS ON BOTH SIDES OF DROP. ADD SERIES OF GRADE CONTROL STRUCTURES. SOIL IS ERODIBLE. STABILIZE HEADCUT WITH INSTREAM WOOD. EMBED LOGS ON BOTH BANKS. (PRIORITY 5)
19+20 REPAIR EAST BANK EROSION WITH ROCK AND FALL WILLOW FACINES/STAKES. USE SOME LARGE ROCK FROM FLOODPLAIN TO STABILIZE BANK. SMALLER WOOD IN PILE. RANDOMLY SCATTER. (PRIORITY 9)
24+00 TO 24+20 RETAIN EX. POOL
24+00 TO 24+50 REMOVE ROCKS THAT HAVE SLUMPED INTO CHANNEL (PRIORITY 6)
SKIN GULCH
LARIMER COUNTY, COLORADO
SHEET 1 – FINAL CONSTRUCTION TASKS
NRSI
Professional Environmental Consulting

Figure 15

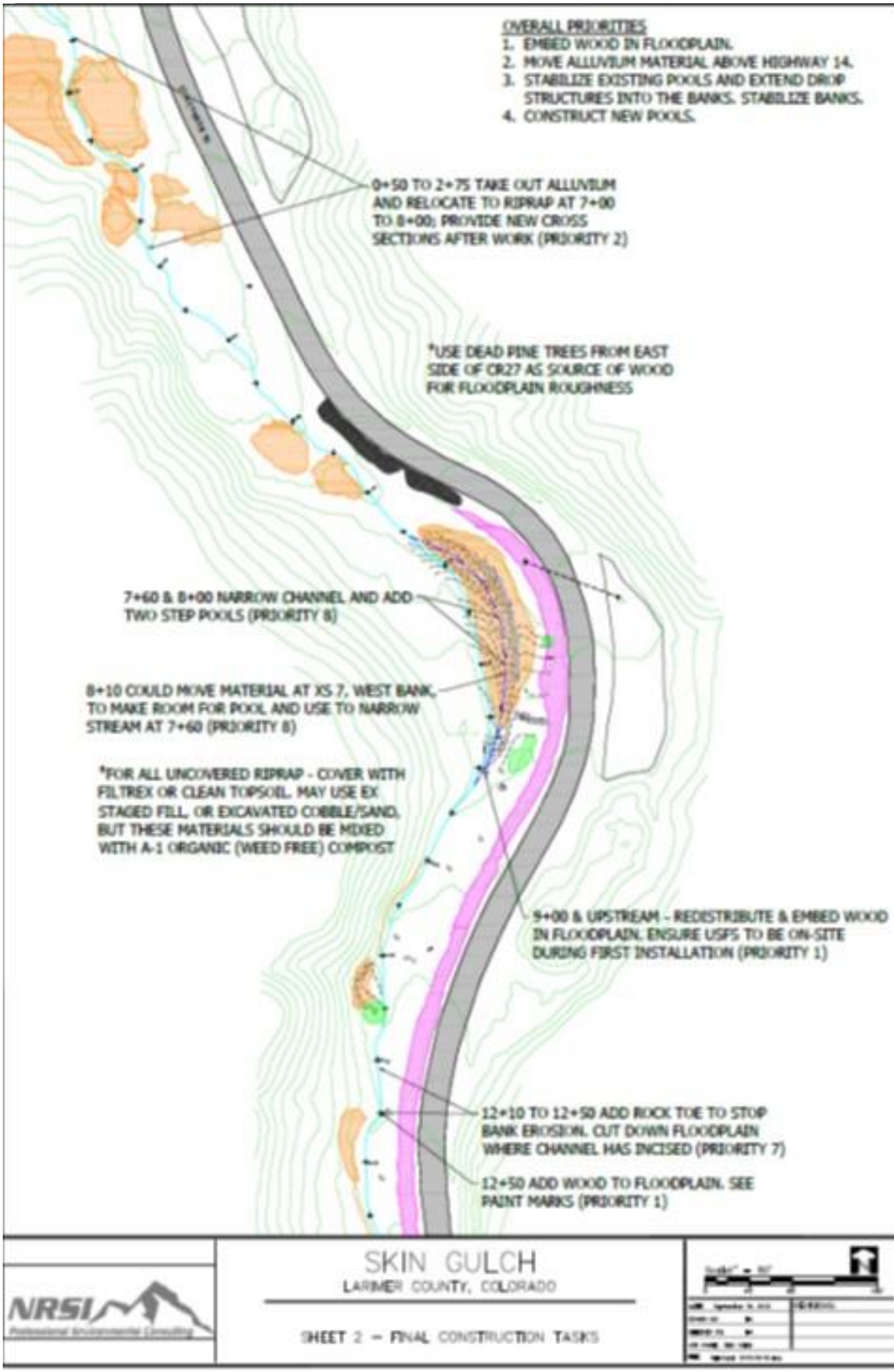

OVERALL PRIORITIES
1. EMBED WOOD IN FLOODPLAIN.
2. MOVE ALLUVIUM MATERIAL ABOVE HIGHWAY 14.
3. STABILIZE EXISTING POOLS AND EXTEND DROP STRUCTURES INTO THE BANKS. STABILIZE BANKS.
4. CONSTRUCT NEW POOLS.
0+50 TO 2+75 TAKE OUT ALLUVIUM AND RELOCATE TO RIPRAP AT 7+00 TO 8+00; PROVIDE NEW CROSS SECTIONS AFTER WORK (PRIORITY 2)
*USE DEAD PINE TREES FROM EAST SIDE OF CR27 AS SOURCE OF WOOD FOR FLOODPLAIN ROUGHNESS
7+60 & 8+00 NARROW CHANNEL AND ADD TWO STEP POOLS (PRIORITY 8)
8+10 COULD MOVE MATERIAL AT XS 7, WEST BANK, TO MAKE ROOM FOR POOL AND USE TO NARROW STREAM AT 7+60 (PRIORITY 8)
*FOR ALL UNCOVERED RIPRAP - COVER WITH FILTREX OR CLEAN TOPSOIL. MAY USE EX STAGED FILL, OR EXCAVATED COBBLE/SAND, BUT THESE MATERIALS SHOULD BE MIXED WITH A-1 ORGANIC (WEED FREE) COMPOST
9+00 & UPSTREAM - REDISTRIBUTE & EMBED WOOD IN FLOODPLAIN. ENSURE USFS TO BE ON-SITE DURING FIRST INSTALLATION (PRIORITY 1)
12+10 TO 12+50 ADD ROCK TOE TO STOP BANK EROSION. CUT DOWN FLOODPLAIN WHERE CHANNEL HAS INCISED (PRIORITY 7)
12+50 ADD WOOD TO FLOODPLAIN. SEE PAINT MARKS (PRIORITY 1)
NRSI
Professional Environmental Consulting
SKIN GULCH
LARIMER COUNTY, COLORADO
SHEET 2 - FINAL CONSTRUCTION TASKS

Figure 16.

Seaman

As previously described, the Seaman Reservoir project site presented many implementation challenges due to the remote location and the unconsolidated nature of the delta. While we did not develop new BMPs, we did need to think critically about refining existing techniques to meet the challenges of this site. For example, to stabilize the location of the channel, in normal conditions, we could rely on native riparian plantings and some rock/log structures to stabilize grade and bank. In this situation, we had to reinforce those BMPs by lining the channel the whole length with rocks, added willow fascines and added buried log veins that extended perpendicularly from the channel. We also added floodplain roughness logs but needed to design them with additional anchors to hold them in place. Finally, we also planted a higher density of native plants throughout the delta to increase the amount of root structures stabilizing the delta.

Another unique challenge at this site is related to it being a storage reservoir and thus water levels are raised and lowered on a regular basis. This is normal for reservoir operations but has the potential to cause head cutting in the BMPs we installed unless we identified a way to stabilize the face and toe of the delta. To further complicate the issue, because this is on USFS designated roadless land, we could not use any of the existing metal or plastic products on the market. To overcome these problems, we relied on using large quantities of coir erosion matting held in place by wooden stakes, covered with mud and then we planted wetland vegetation on the upper edge of the matting. We also installed several rock media lunas to help stabilize the tow of the delta face (Figure 13). All of this had to be timed opportunistically when the reservoir water levels dropped low enough for us to access the whole delta face.

To date, the BMPs have performed well. The riskiest BMP – the delta face erosion matting – has remained in place and the plantings have begun to grow. The channel has remained in its current location (primary goal of the BMP). However, the area is susceptible to strong localized storms and one such storm did deliver a much larger than anticipated quantity of sediment to the channel so maintenance work will need to occur to ensure the channel can still handle flows. We did scout the contributing drainage to identify whether there are any areas in the upper drainages that are actively eroding. None were identified therefore the assumption is that there is still considerable post fire sediment stored along the length of the contributing channels and will continue to deliver sediment for several more years.

Although the project is not completed yet (we return this season to continue work), our team did accomplish the installation of:

- 3-4 log/rock weirs
- 3-4 one rock dams
- 6 media lunas
- ~10 floodplain roughness logs
- Totaling ~260 ft of channel work
- 125 linear ft of bank armoring with local rocks on each bank
- Installation of ~400 sq yards erosion control matting
- Planting of ~2,200 native wetland and riparian plant cuttings/plants

Finally, in the initial phase of post fire planning, several local jurisdictions experimented with felling whole trees into gulleys as a BMP to control sediment delivery in higher elevation gulleys. This is different from installing rock/log structures, which are keyed into the channel walls and held in place with various anchoring methods. This technique involves simply having sawyers use chainsaws to fell whole trees directly into the channel, unanchored, effectively creating an unanchored log mesh within the channel. This technique was used throughout the burn area as part of the NRCS Emergency Watershed Protection program. We had initially contemplated using this technique as well, however, rapid assessments of the BMP led us to conclude that it would not be a cost-effective BMP for our work. While it can be done rapidly and in-expensively, it seemed to be fairly easy to do it incorrectly (logs did not have sufficient contact with ground surface to hold sediment back). Once done incorrectly, it was not possible to fix safely. We therefore opted to not pursue this BMP as part of our project work.

MONITORING RESULTS

Strategy:

We have attempted to create a monitoring strategy that will be suitable for multiple post-fire restoration needs & scenarios and provide information at different spatial scales. We monitored key data at the project specific scale, at an established research plot with two years of previous post-fire data, and at the receiving water (main stem Poudre) scale. It is our hope that this strategy will help inform not just the success of this project but will broadly help inform post fire restoration work across Colorado.

BMP EFFECTIVENESS EVALUATIONS

CPRW worked with our project consultants to develop a rapid assessment protocol that would allows us to understand whether we had met some of our key restoration implementation goals. This stream bank and bed assessment protocol was developed to allow a field crew of one to two people assess the stability of a stream reach rapidly, thoroughly, and in a spatially explicit manner so that stability concerns may be identified and located along a reach. This protocol was designed to allow inter-annual comparison and tracking changes over time. It is largely a visual assessment, conducted along a 100 – 200 ft sub-reach within which channel and bank information is aggregated. The protocol is a multi-metric protocol that combines five major indicators, each having multiple condition categories. Each indicator (Table 3) was chosen because of the critical role those factors play in forming a stable channel that will deliver sediment without causing negative impacts. See Appendix 2 for the complete protocol. Each indicator is scored 1 – 4, with 4 indicating the least stable form. Two years of post-treatment assessment indicate that the project area is clearly becoming more stable over time with site averages decreasing from 3.23 to 2.48 in reach A (Table 3). Reach B, the upper portion of the project area, did show improved scores but there was less of an improvement. This was largely driven by the lack of revegetation success in the portion of the project site. This was our first time deploying this assessment tool, but we will continue to monitor this site and others using this protocol in the coming years to inform the status of our restoration efforts.

Table 3: Results of pre-treatment and post-treatment monitoring. Data summarizes the results from a rapid assessment protocol developed for post fire river restoration. Indicators are scored 1 - 4, with 4 indicating most unstable conditions.

		A-1	A-2	A-3	A-4	A-5	A-6	Site Avg.	B-1	B-2	Site Avg.
Bank Stability	**Pre Treatment data**										
	Bank Composition	3.6	3.1	3.0	2.5	2.8	1.5	2.75	2.4	2.1	2.20
	Bank Angle - Degrees	1.3	1.9	1.5	1.6	1.9	2.1	1.72	2.9	1.8	2.35
	Bank Vegetation*	4.3	4.8	4.7	4.7	4.9	4.9	4.72	4.6	4.0	4.30
	Overbank Vegetaton*	2.8	4.0	4.7	4.8	4.8	4.8	4.32	3.4	4.3	3.85
	Active Bank Erosion	1.1	1.3	1.4	1.5	1.6	1.6	1.42	1.7	1.1	1.40
	Composite Bank Stability Score	***2.8***	***3.2***	***3.3***	***3.3***	***3.4***	***3.4***	***3.23***	***3.3***	***2.8***	***3.05***
Bank Stability	**2016 data**	**A-1**	**A-2**	**A-3**	**A-4**	**A-5**	**A-6**	**Site Avg.**	**B-1**	**B-2**	**Site Avg.**
	Bank Composition	1.5	2.4	2.6	2.4	2.2	2.2	2.19	1.8	1.8	1.78
	Bank Angle - Degrees	1.1	1.3	1.1	1.5	1.5	1.4	1.29	2.3	1.8	2.03
	Bank Vegetation*	4.6	4.8	4.7	4.7	5.2	5.4	4.87	4.7	4.9	4.78
	Riparian Vegetaton*	5.0	4.7	5.0	4.8	5.1	4.8	4.87	4.8	5.0	4.88
	Active Bank Erosion	1.0	1.0	1.1	1.1	1.2	1.1	1.06	1.0	1.0	1.00
	Composite Bank Stability Score	***2.6***	***2.8***	***2.9***	***2.9***	***3.0***	***3.0***	***2.86***	***2.9***	***2.9***	***2.89***
Bank Stability	**2017 data**	**A-1**	**A-2**	**A-3**	**A-4**	**A-5**	**A-6**	**Site Avg.**	**B-1**	**B-2**	**Site Avg.**
	Bank Composition	2.1	1.7	2.1	2.0	2.0	2.1	1.98	1.8	1.8	1.78
	Bank Angle - Degrees	1.0	1.0	1.1	1.2	1.3	1.0	1.09	2.3	1.8	2.03
	Bank Vegetation*	2.9	1.4	4.3	4.7	4.9	5.2	3.88	4.9	4.9	4.90
	Overbank Vegetaton*	3.4	4.2	4.6	4.8	5.1	4.7	4.47	4.9	5.0	4.93
	Active Bank Erosion	1.0	1.0	1.0	1.0	1.0	1.0	1.00	1.0	1.0	1.00
	Composite Bank Stability Score	***2.1***	***1.9***	***2.6***	***2.7***	***2.9***	***2.8***	***2.48***	***3.0***	***2.9***	***2.93***

SURFACE WATER IMPROVEMENTS

CHEMICAL & BIOLOGICAL.

The City of Fort Collins, the City of Greeley, & the Tri-Districts have been monitoring water quality in the Upper Cache La Poudre since 2008 to better understand the water quality of their source water supply. This dataset therefore provides a useful tool for understanding the watershed scale impacts of the 2012 wildfires. Of their monitoring sites, four are relevant to the burn area (Fig 17). The program measures 51 constituents, including metals, nutrients, *E. coli*, VOCs, turbidity, total dissolved solids, chlorophyll, geosmin, DO, and temperature. Monitoring occurs monthly in non-winter months. Monitoring from this program indicated significant impacts from the High Park Fire that persisted through time, in particular in the first three years post fire.

Three water quality parameters that showed post fire impacts at the watershed scale was total organic carbon (TOC), turbidity, and nutrients. TOC background concentrations did not change post fire. However, storm events caused a two times increase in peak TOC. Orthophosphate had a 6x increase from detection limit immediately post fire with a 177% increase in median orthophosphate concentrations. Median nitrate concentrations between the fire and 2016 increased 337%. Total dissolved solids concentrations increased 46.2% from pre-fire to post fire concentrations.

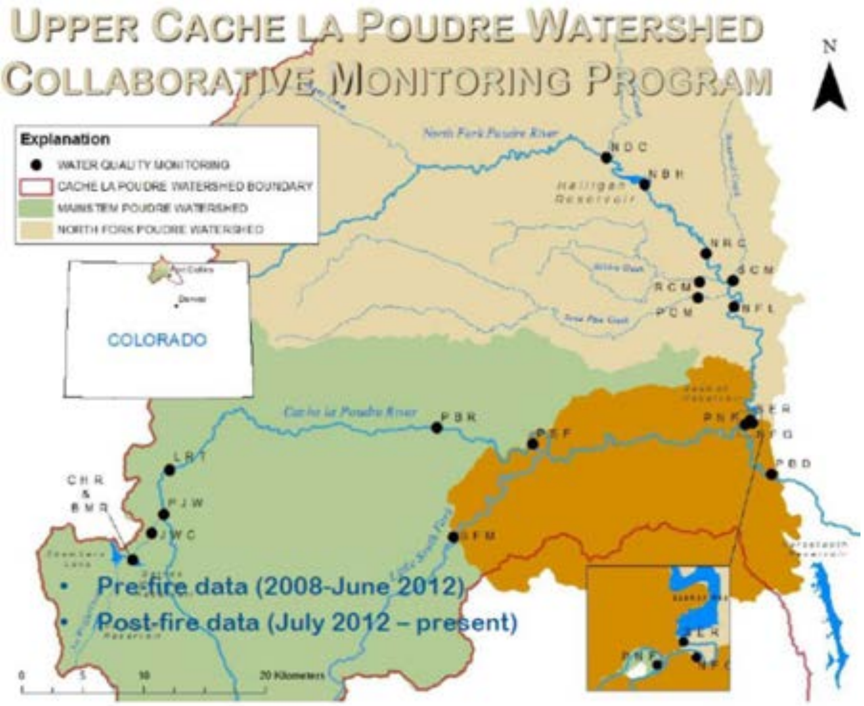


Figure 17: UCLP monitoring sites relative to the High Park Fire burn area (brown).

Turbidity also showed significant impacts from the wildfires. In 2013 and 2014, turbidity levels during the summer were greatly elevated compared to background levels (Figure 18).

Wildfire impacts to water quality were still evident in 2015. Background nutrient concentrations, specifically nitrate as nitrogen (NO3-N), ammonia as nitrogen (NH3-N), and ortho-phosphate (PO4), remained elevated in 2015 compared to pre-fire conditions. The 2015 rainy season had few storm events - there were only two storm events in 2015 that caused short term water quality impairment, one of which caused turbidity to spike from 2 NTU to 805 NTU over a 2 hour period.

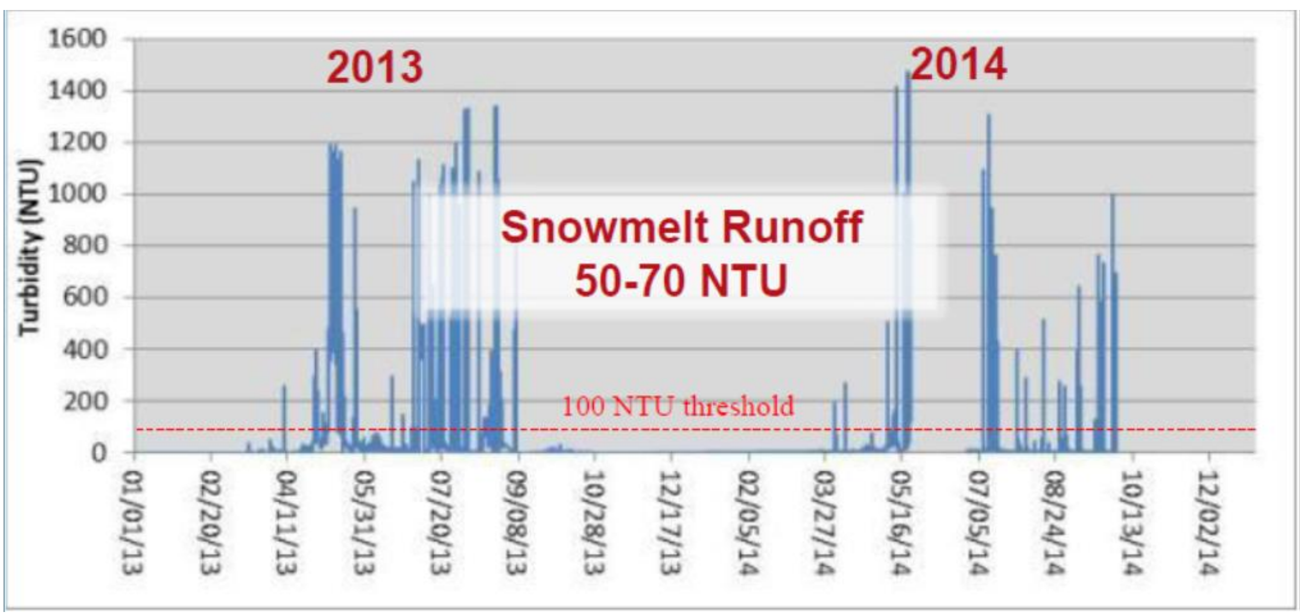


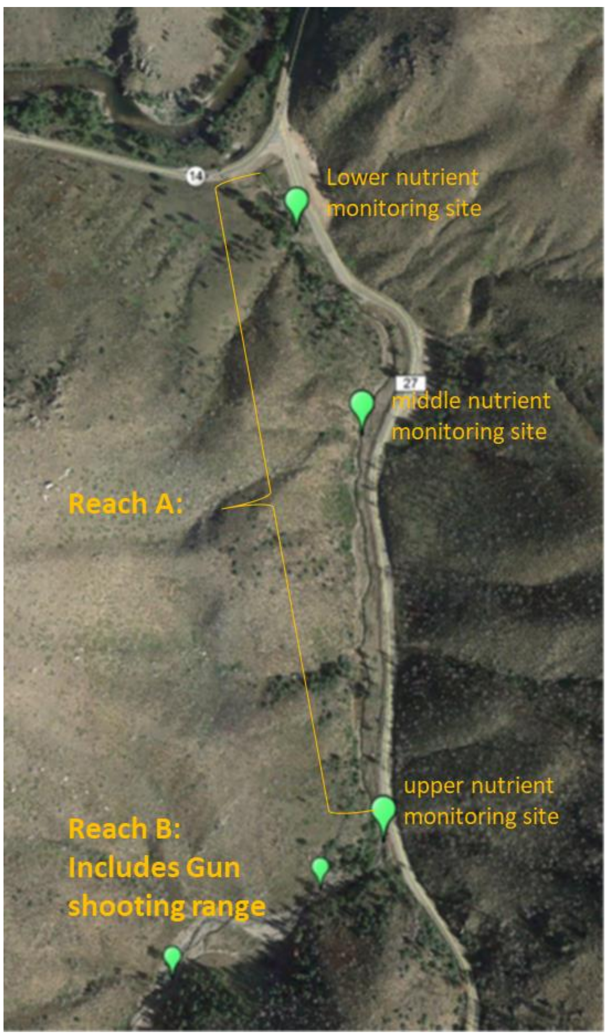
Figure 18: Turbidity concentrations in the Poudre in 2013 and 2014. Data courtesy of city of Fort Collins.

Fort Collins maintains strict quality control for the water monitoring program. A minimum of 10% of the total samples collected in the field are collected as field duplicate and/or field blank samples. Field duplicates (11 duplicates in total) were obtained at PNF during each monitoring event to determine precision of data, while field blanks (22 blanks in total) were collected at different monitoring locations on both the Mainstem and North Fork, to identify potential for sample contamination. In 2016, twelve percent (33 out of 183) of the environmental samples collected were QAQC samples. Precision is a measure of the deviation from the true value. For most constituents, duplicate determinations should agree within a relative percent difference of 10%. Duplicate samples that differ greater than 10% were flagged for further quality assurance and control measures. Blank samples should not contain analytes above the reporting limit. The results of the field quality assurance and control sampling indicate that precision and accuracy were acceptable. Ninety-five percent of field blank samples reported below the constituent's respective reporting limits in 2016. Equipment calibrations were conducted prior to field monitoring exhibitions using certified standards to assure the accuracy of sensors on the multi-parameter water quality sonde.

NUTRIENTS.

Wildfires can negatively affect nutrient cycling in receiving waters. Wildfires burn forest biomass and organic soil layers, which drastically increases short-term nutrient and carbon losses, and exposes catchments to post-fire erosion. Wildfires influence stream water quality and nutrient export by reducing plant demand, increasing soil nutrient availability in upland and riparian environments, and increasing erosional inputs of fine and coarse mineral materials. Hydrologic connectivity and transport from uplands to stream channels changes with post-fire reconfiguration of hillslope and stream channels. Fires also change within-stream processes that regulate nutrient uptake, release, and retention.

To evaluate if physical and vegetation treatments are enhancing the ecosystem processes responsible for nutrient retention, CPRW worked with Rocky Mountain Research Station to analyze stream nutrients at three locations along Skin Gulch as it flows through the restoration area (Fig 19). Monitoring was conducted during summer 2017, three years after channel realignment and two years after revegetation treatments.



Streamwater samples were collected and analyzed for nutrients, C and acid-base chemistry weekly during the receding limb of the stream hydrograph (June and July 2017) and less frequently during fall baseflow conditions. Nutrient samples were collected in opaque HDPE plastic bottles. Plastic bottles were washed with de-ionized water (electrical conductivity < 1.0 S cm-1) prior to use and then triple-rinsed with stream water at the time of sampling. Samples were refrigerated after collection then filtered through 0.45μm mesh membrane filters (Millipore Durapore PVDF, Billerica, MA). Dissolved organic carbon (DOC) samples were collected in pre-combusted (heated for 3 hours at 500oC) amber, glass bottles and then filtered through 0.7μm mesh glass fiber pre-filters (Millipore Corporation). Collected samples were shipped cold to the US Forest Service, Rocky Mountain Research Station Biogeochemistry Laboratory in Fort Collins, CO and stored a 4oC prior to analysis. Stream water anion and cation concentrations were determined by ion chromatography

Figure 19: Location of nutrient water quality monitoring sites at Skin Gulch

Most stream water constituents were no different between the upper to lower locations (Table 2).

Calcium and sulfate were the dominant cation and anion species in Skin Gulch water. Stream phosphate was below detectable levels. Nitrate represented the bulk of inorganic nitrogen (table 4). Stream nitrate-N did significantly decline along the length of the restoration reach (Fig 20) and this pattern was consistent seasonally. During June and baseflow season, nitrate concentrations declined by 30 and 50% downstream.

The monitoring also indicates that Skin has elevated nitrogen levels relative to other drainages in the burn area and compared to the Poudre main stem. Skin's nitrate and DTN concentrations greatly exceeded N concentrations representative of 'least-disturbed' reference streams of the Western Forest Region (e.g., 0.12 mg TN L^{-1} and 0.014 mg nitrate-N L^{-1}. This demonstrates the importance of restoring stability and function to this system. This study provides baseline information to permit longer-term evaluation of the effectiveness of stream realignment and riparian restoration for improving post-fire water quality and nutrient retention.

Table 4: Water quality chemistry results

Table 2 Skin Gulch Stream Riparian Restoration Project stream chemistry. Data are means of 11 samples dates, from June through October 2017, with standard deviatiation in parentheses. Upper, Middle, and Lower sample locations span the stream restoration reach along CR 27. Analyte concentrations in mg L^{-1}, expect where noted.

		Upper		Middle		Lower	
	pH*	8.2	(0.1)	8.2	(0.1)	8.2	(0.1)
Electrical Conductivity	EC**	208.1	(29.7)	201.2	(28.7)	201.2	(28.5)
Sodium	Na	8.4	(1.2)	8.2	(1.3)	8.2	(1.3)
Potassium	K	1.3	(0.2)	1.3	(0.2)	1.3	(0.2)
Magnesium	Mg	6.9	(1.1)	6.8	(1.1)	6.8	(1.1)
Calcium	Ca	24.8	(4.0)	24.3	(4.1)	24.3	(4.2)
Chloride	Cl	4.6	(1.3)	4.3	(0.8)	4.2	(0.8)
Orthophoshate	PO_4	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
Sulfate	SO_4	13.8	(1.7)	12.7	(3.1)	13.3	(1.8)
Nitrate-N	NO_3-N	0.28	(0.05)	0.24	(0.06)	0.20	(0.05)
Ammonium-N	NH_4-N	0.10	(0.04)	0.10	(0.05)	0.10	(0.05)
Dissolved Inorganic N	DIN	0.38	(0.05)	0.33	(0.06)	0.30	(0.05)
Dissolved Organic N	DON	0.04	(0.05)	0.06	(0.06)	0.06	(0.05)
Dissolved Total N	DTN	0.42	(0.07)	0.39	(0.07)	0.36	(0.06)
Dissolved Organic C	DOC	3.14	(0.93)	3.10	(0.91)	3.13	(0.87)

* pH is unitless; ** EC units: $\mu S\ cm^{-3}$

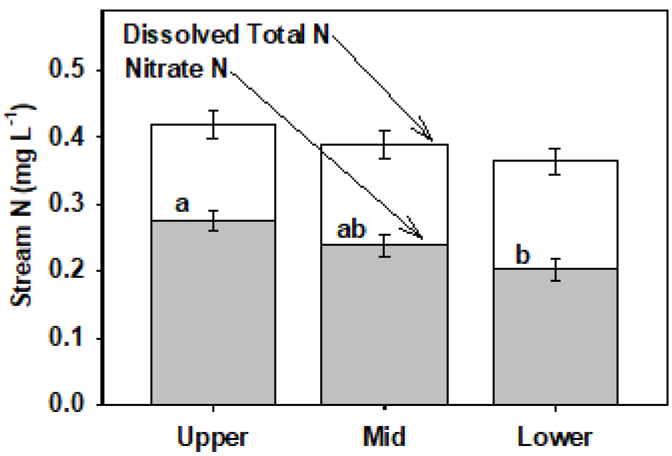


Figure 20: Dissolved total N and nitrate-N in Skin Gulch through the restoration area. Means from 11 sampling dates during 2017 with standard error bars.

OTHER MONITORING.

Seeding burned areas with native grass seeds &/or fast-growing grass species is a very common post-fire hillslope and floodplain erosion control strategy. As part of our monitoring strategy we sought to leverage an existing data set to help us understand the value of doing this kind of post fire rehab work. Because we took advantage of existing work, the site of the monitoring does not correspond to one of our project locations. However, the same techniques were used, therefore we assumed it is reflective of similar work done on our project sites.

The monitoring work was conducted in a different sub-watershed (Upper Laurence Creek), burned during the High Park Fire (Figure 21). The monitoring plots were initiated in November 2012. Twelve plots 15m x 45m were established in high burn severity areas. Plots had three treatment types: plots were seeded, and seeds raked in, then covered with weed free straw mulch; or seeds were spread but not raked in and then covered with mulch, or no treatments were applied (control). For complete description of methods, please see Appendix 3. Sampling transects were used to count the presence/absence of species data. Plots were monitored in 2013, 2014, & 2015.

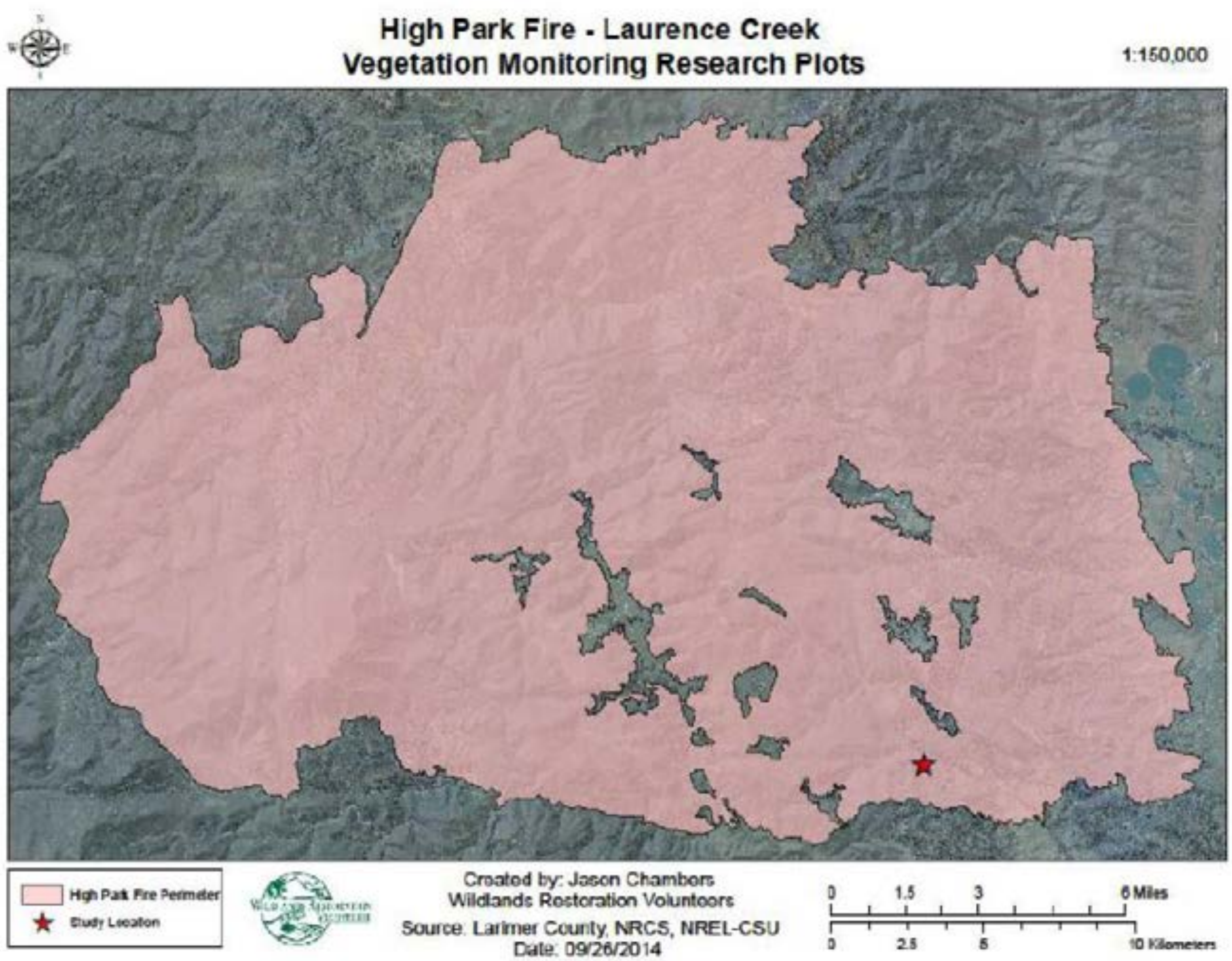


Figure 21: Location of post fire revegetation monitoring.

Generally, the results supported that seeding and mulching can successfully increase post fire ground cover over time (Fig 22). The results did not show a strong difference between the raked and non-raked plots in terms of total cover or species diversity. However, the levels of cover in the raked and unraked plots far exceeded the minimum 50% cover deemed adequate by many federal agencies for post-fire hillslope protection and erosion control. Further, the raked and unraked plots consistently exhibited far less weed cover than the control plots, higher cover of native perennial grasses (Figure 23). Conversely, the seeded plots had lower overall species richness (Table 5).

As part of this study, the research team applied the Water Erosion Prediction Project (WEPP*)* model to better understand how the treatments may impact hillslope erosion. The WEPP is a process-based, continuous simulation, erosion prediction model. The WEPP model integrates hydrology, plant science, hydraulics and erosion mechanics to predict erosion at the hillslope and watershed scale. Based on the model outputs (Figure 24), the seeding treatments greatly reduced the total expected erosion emanating from the hillslopes.

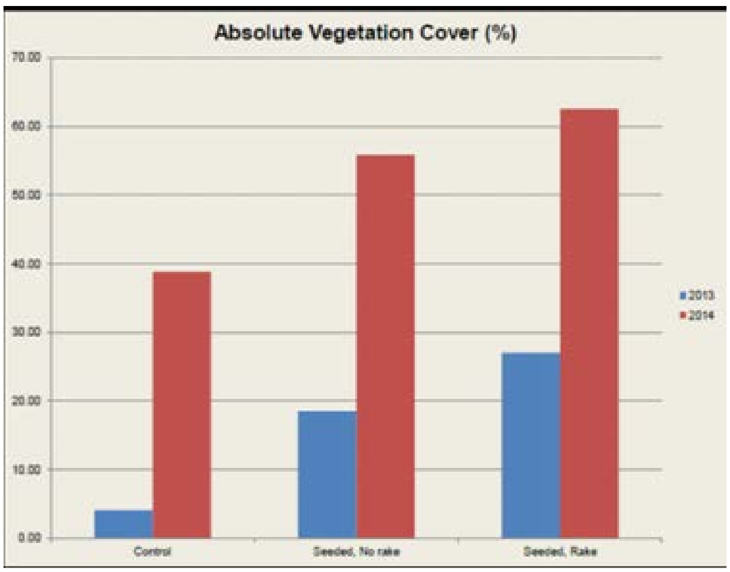


Figure 22: Differences in absolute vegetation cover across treatment types.

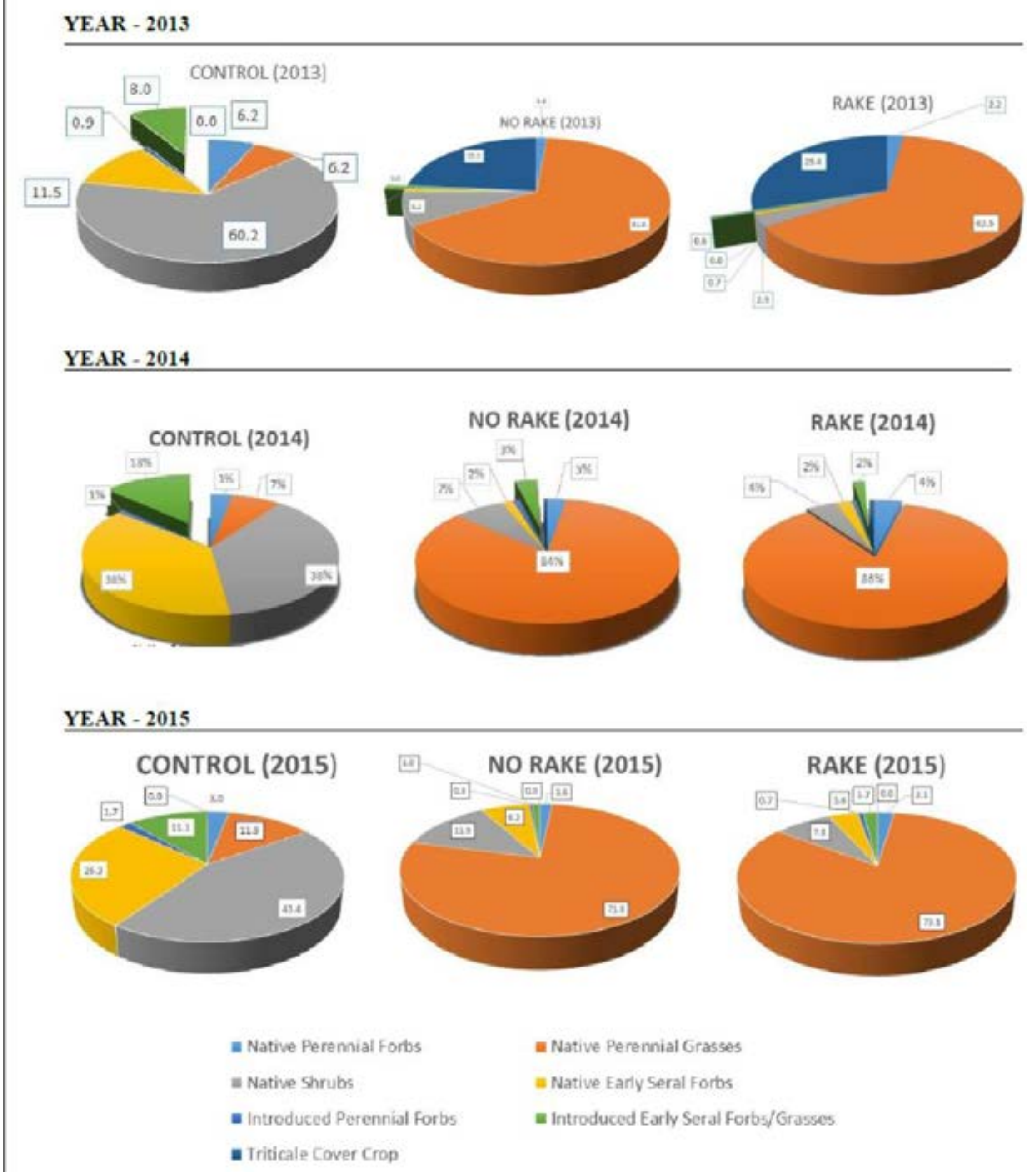


Figure 23: Relative vegetation cover (%) by vegetation categories, year and treatment type.

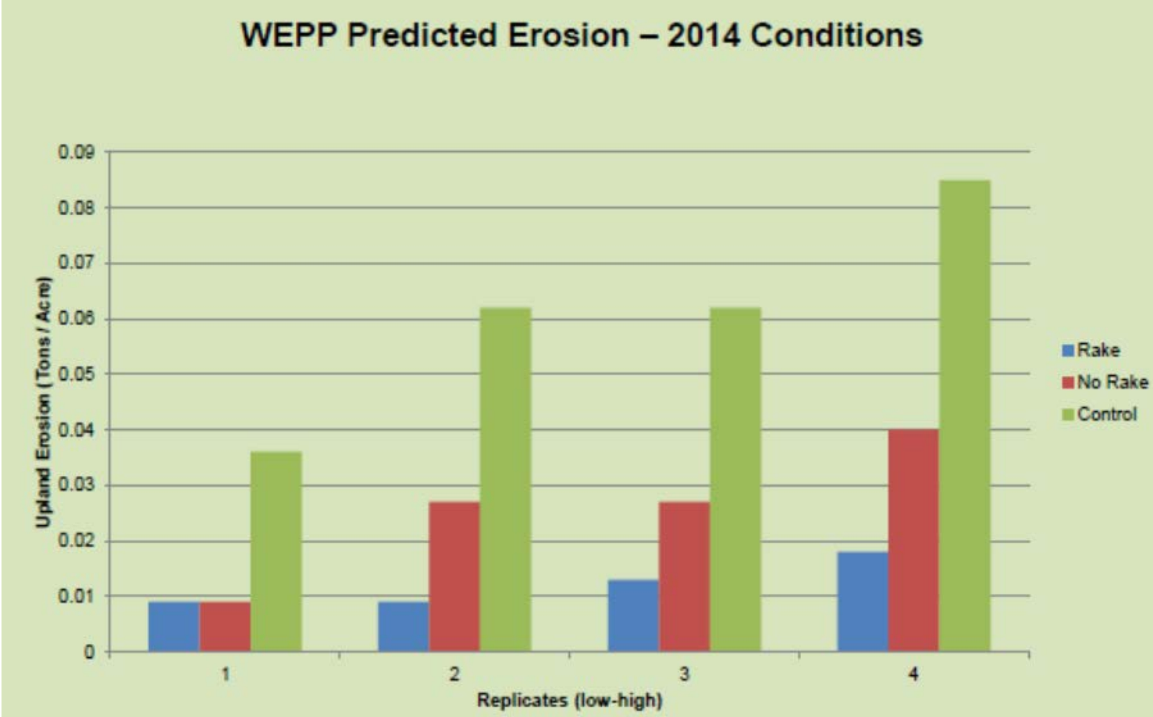


Figure 24: Results from erosion model predicting how seeding treatments might potentially impact hillslope erosion in treatment plots.

Table 5: Species richness, evenness, and diversity index by treatment type and year.

	2013			2014			2015		
VARIABLE	Rake	No Rake	Control	Rake	No Rake	Control	Rake	No Rake	Control
Number of Species	57	61	62	60	55	80	63	58	94
Eveness	0.96	0.86	0.87	0.87	0.86	0.89	0.89	0.88	0.9
Diversity (H')	3.9	3.6	3.5	3.57	3.48	3.91	3.68	3.59	4.08

Post Fire Science Workshop Results:

In addition to the monitoring efforts done specifically for this project, there were several other efforts to research and monitor post fire impacts to erosion, post fire rehab efforts, and water quality. CPRW hosted a one day post fire science workshop in 2016 to discuss and review this work. Research indicates that mulch is effective at reducing hillslope erosion. In Skin Gulch there is evidence that mulch reduced erosion 2 – 8% and 13 – 26% in other drainages.

Other research showed that even 3 years after the High Park Fire, post-fire runoff and sediment were still produced during high intensity precipitation event. For this event, the highest runoff and erosion were produced at the hillslope and headwater catchments. Event-runoff and eroded sediment were stored on hillslopes and within the channel network before reaching the watershed outlet.

All the presentation from this event are available at https://www.poudrewatershed.org/our-work/upper-watershed/collaboration-resources/. In addition, the Rocky Mountain Research Station published a summary in their Science You Can Use Bulletin https://www.fs.fed.us/rm/pubs_journals/2017/rmrs_2017_miller_s003.pdf.

COORDINATION EFFORTS & PUBLIC PARTICIPATION

Throughout the course of this project, we consulted extensively with various state, local, and federal entities. Two of our project sites are located on federal land and therefore necessitated us working closely with the United States Forest Service Arapaho Roosevelt – Canyon Lakes Ranger District. This required CPRW to establish contractual agreements, permitting, and meeting schedules with the USFS. USFS staff conducted annual site evaluations of both our Skin Gulch and Seaman Reservoir project to help determine whether we were meeting project goals, whether BMPs were installed properly and to discuss other opportunities at the site.

In addition, CPRW worked closely with our stakeholder group throughout the course of the project. Our stakeholder group has representatives from federal, state agencies, local water utilities, local nonprofits, and local researchers. This stakeholder group played an integral role in helping CPRW shape and prioritize remaining post fire restoration needs and also provided technical input and support throughout the project. All of these meetings are publicly advertised and open to the public. We also conducted several community meetings, including one in Poudre Park focused on the post fire restoration & science.

OTHER SOURCES OF FUNDS

As part of this contract, CPRW was obligated to provide $136,000 in match. Our primary source of match came from a grant from the Colorado Conservation Board for $100,000. Volunteer projects accumulated ~ $79,951 of in-kind value through donated labor or volunteer labor. CPRW also contributed $27,097 through other internal cash sources.

FUTURE ACTIVITY RECOMMENDATIONS.

Two of our project sites are still underway. We anticipate finishing construction at our UT3 this fall. We will continue implementation work at Seaman Reservoir this spring. However, we anticipate that Seaman will require regular maintenance work for the coming years. For our Skin Gulch project site, we have begun discussions with USFS about the feasibility of doing a fish passage retrofit to provide more fish habitat access. Significant planning and consultation work needs to occur before that is a possible additional project.

For all our project sites, we will continue to do post implementation monitoring to ensure that the BMPs we installed remain effective and to track changes in the system.

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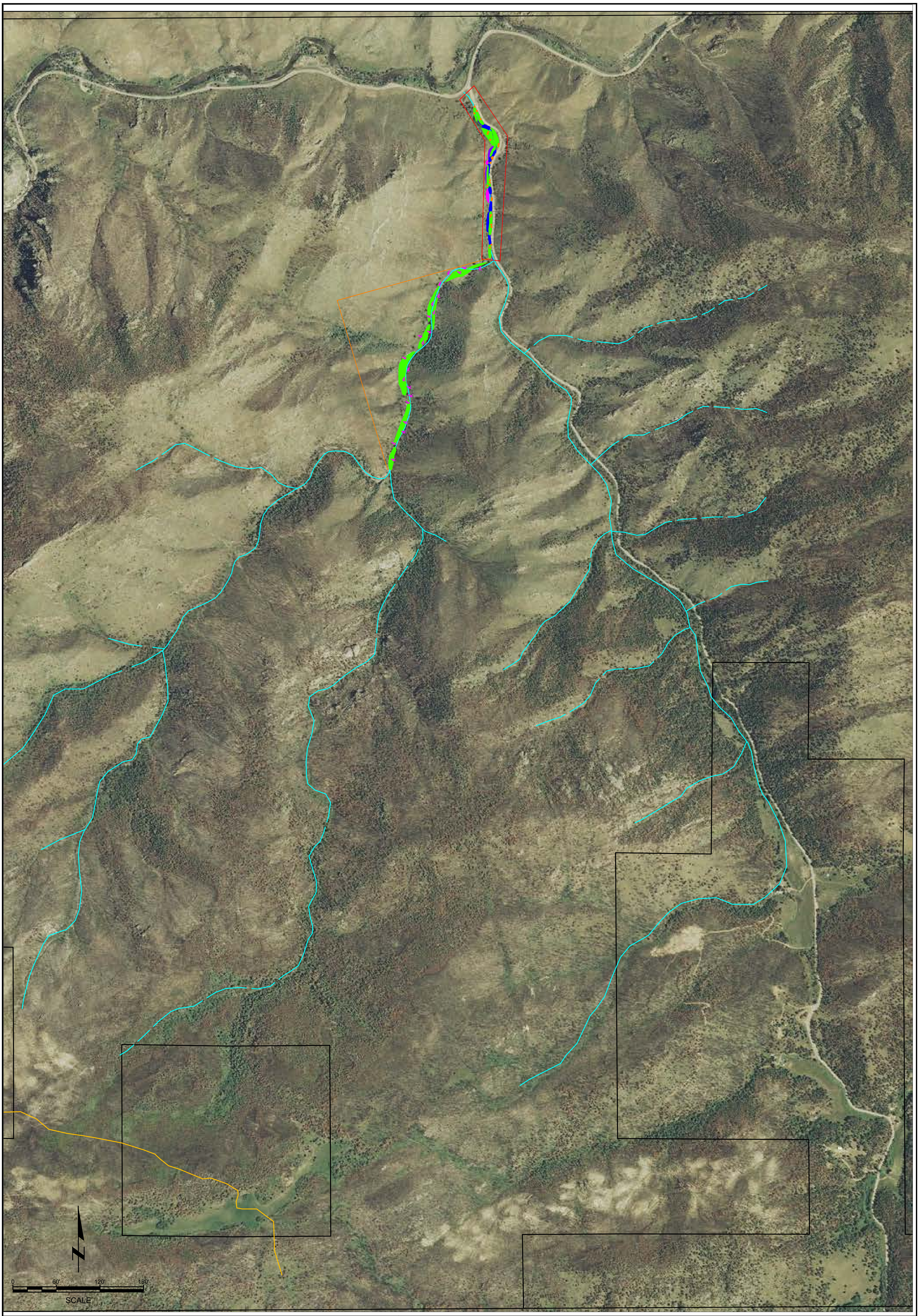
LIST OF TABLES

APPENDIX 1



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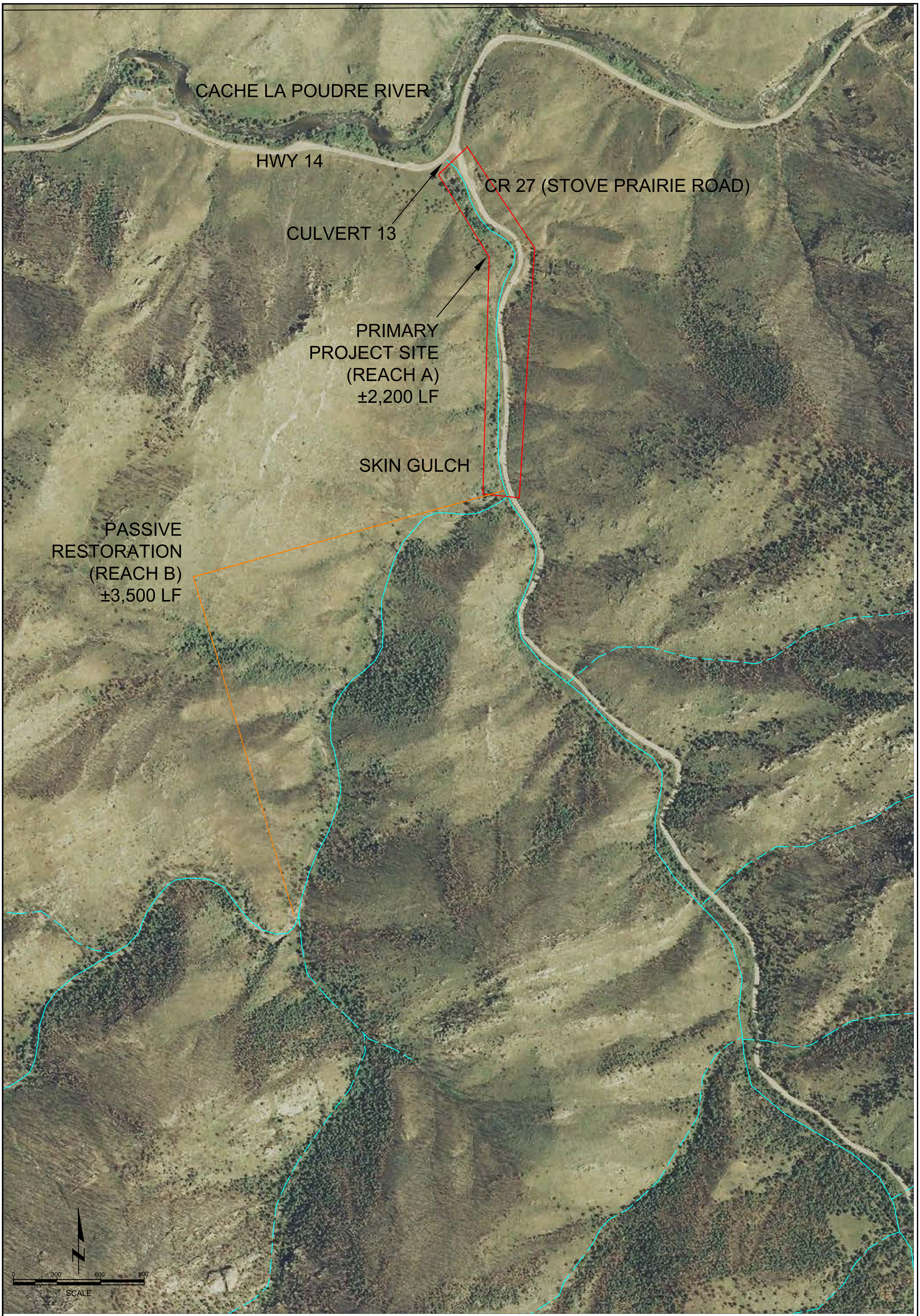
SKIN GULCH
CONCEPTUAL RESTORATION PLAN

PROJECT NO.	DATE:	ENGINEER:	DRAWN BY:
WA-0009038	08-27-14	BEV	BEV

FIGURE 1

PROJECT AREA OVERVIEW



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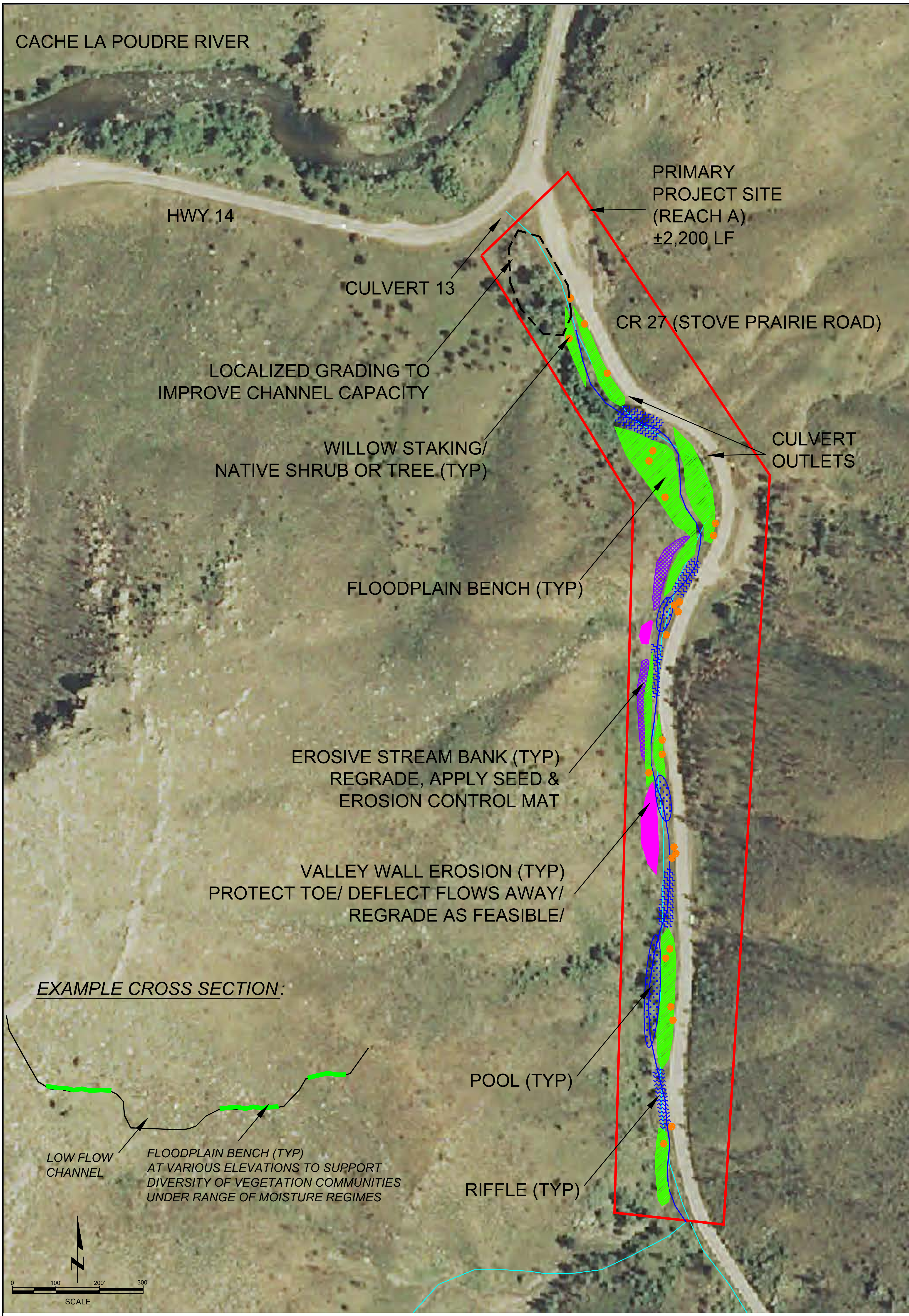

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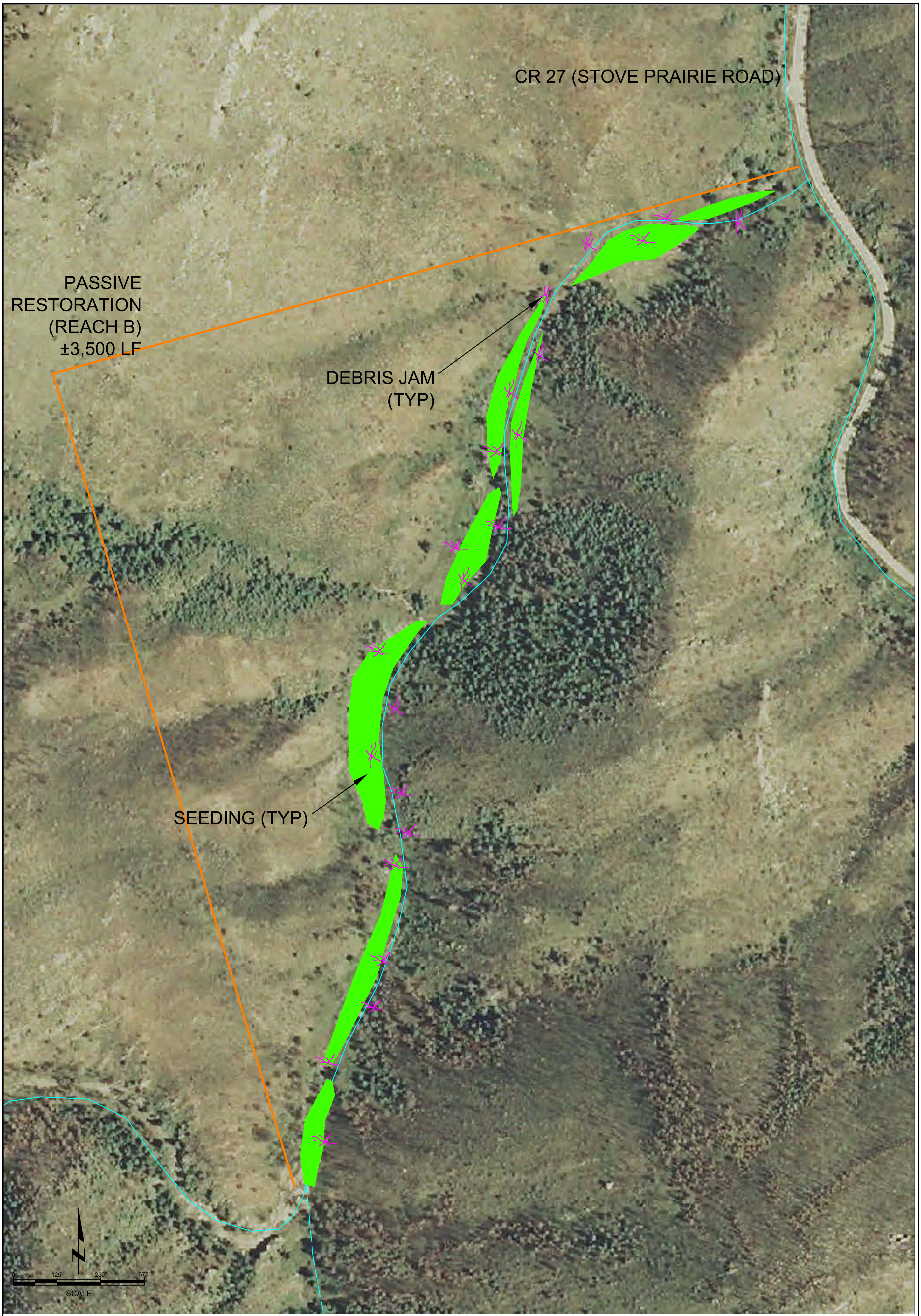
PROJECT NO.	DATE:	ENGINEER:	DRAWN BY:
WA-0009038	08-27-14	BEV	BEV

FIGURE 2

REACH A



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CONCEPTUAL RESTORATION PLAN

PROJECT NO.	DATE:	ENGINEER:	DRAWN BY:
WA-0009038	08-27-14	BEV	BEV

FIGURE 3

REACH B

APPENDIX 2

SKIN GULCH STREAM RESTORATION BASELINE MONITORING REPORT

DRAFT: MAY 9, 2016

Submitted To: Coalition for the Poudre River Watershed
Submitted by: AloTerra Restoration Services, LLC

AloTerra Restoration Services, LLC

BACKGROUND

Skin Gulch begins as a steep, foothills valley. It joins a tributary at Stove Prairie Road and parallels this road until it crosses under Colorado State Highway 14 at the Cache la Poudre River. The 2012 High Park Fire burned much of Skin Gulch's watershed. Severe summer rain storms in 2012 and 2013, and the rains from the September 2013 flood, caused massive runoff events which mobilized hillslope sediment, eroded hillslopes, and caused dramatic channel incision, migration, and deposition along lower reaches of the stream. Stove Prairie Road and the crossing under CO Hwy 14 were severely damaged as a result of these post-fire storm events.

As a result of the floods, the channel had formed a new path in the valley sharing Stove Prairie Road. Emergency repairs pushed the channel away from the road and next to the western hillslope. In addition, large amounts of boulder-sized riprap where installed in the repaired roadway embankment. Channel adjustment from the floods, unstable banks and hillslopes, sediment deposits from the floods, and impacts from emergency repairs left a relatively unstable channel. Channel, floodplain, and bank rehabilitation measures were subsequently planned for the main stem of Skin Gulch paralleling Stove Prairie Road as well as its western tributary.

This report documents the geomorphic stability of Skin Gulch prior to post-emergency channel and floodplain rehabilitation. AloTerra staff implemented the Stream Stability Assessment (SAA) as documented in Sholtes and Giordanengo (2014), **Appendix A**.

The rapid, visual-based SSA, developed by AloTerra relies on visual estimation of channel and bank stability parameters. It quantifies, relatively, bed and bank stability over sub-reaches (100 – 300ft) using rapidly-assessed metrics such as the percent of bank and riparian area coverage by vegetation type, bank and bed material composition, and percent length of actively eroding bank. These visual estimates can be obtained by observers from a wide variety of backgrounds with minimal training. Quantitative estimates of percent coverage and length of stability parameters are then integrated into an overall stability score for each sub-reach evaluated as well as for the entire project reach.

OBJECTIVES

We have implemented the SSA on segments of Skin Gulch prior to restoration (i.e., baseline) to document pre-restoration conditions of the channel, banks, and riparian zone. Post-restoration monitoring may then be compared to this baseline assessment to document any changes (improvements or deterioration) of channel and bank stability as well as riparian vegetation cover.

METHODS

Implementing the SSA protocol involves dividing a reach of interest into subreaches. For the present study our subreaches were 200 to 300 feet in length as measured along the channel thalweg with a measuring tape. We denoted the main stem of Skin Gulch along Stove Prairie Road as Reach A and the western tributary as Reach B. We divided Reach A into six subreaches and Reach B into two sub-reaches (Figures 1 and 2). Field work was conducted on June 6, 2015.

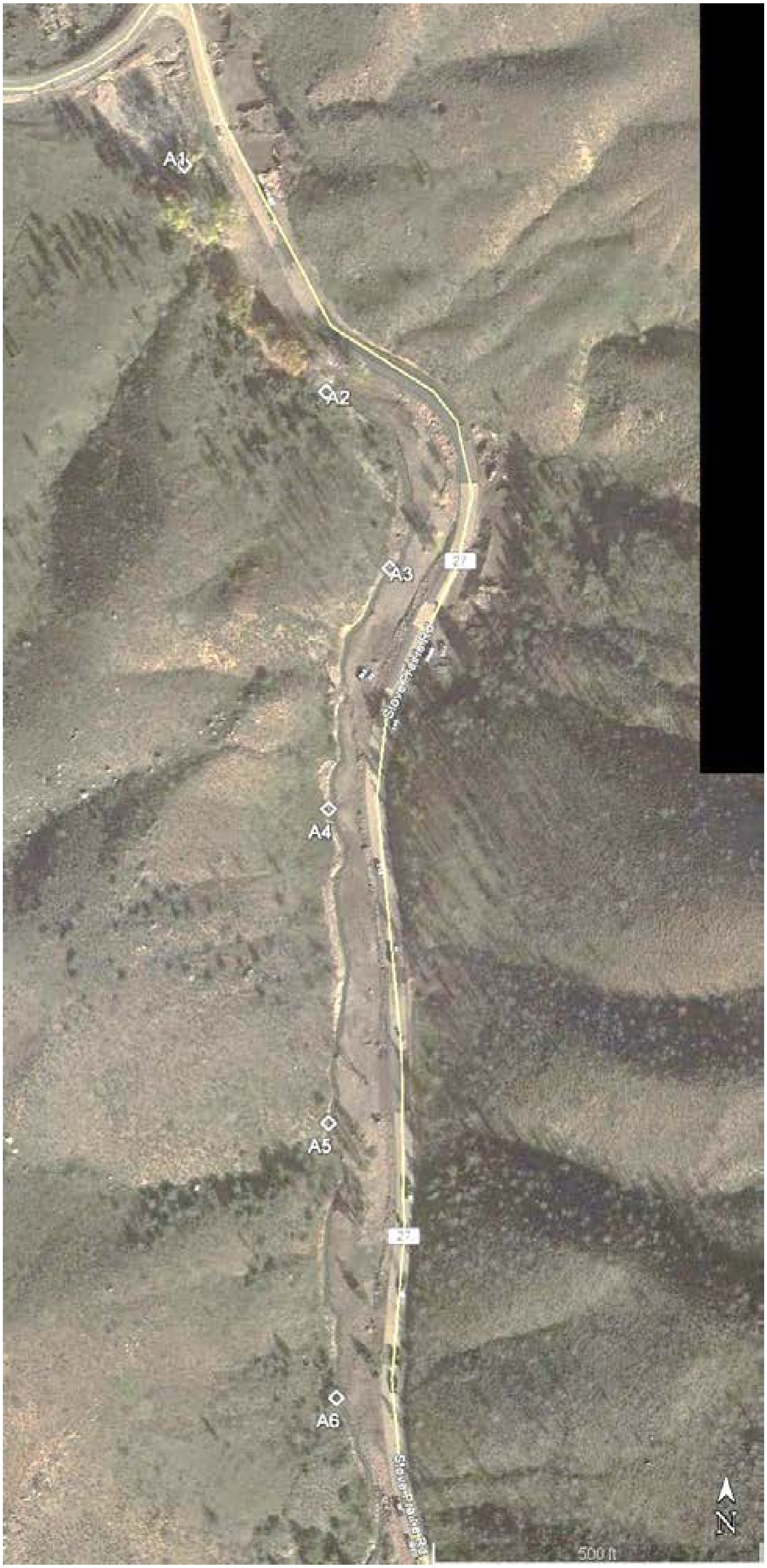

Figure 1. Map of Skin Gulch, Reach A. Subreach labels indicate the downstream origin of each subreach.

Figure 2. Map of Skin Gulch Reach B. Subreach labels indicate downstream origin of each subreach.

A handheld GPS unit was used to estimate the coordinates of the downstream origin of each subreach. We then conducted the SSA on each subreach. This involved visual observations of percent cover of vegetation along the banks and on the adjacent floodplain as well as composition of bed and bank material for each subreach. In addition, we assessed percent length of active erosion as well as severity of active vertical and lateral erosion or deposition.

These percent length values of various stability factors are then combined and averaged to create a relative stability score for each sub-reach and averaged across all sub-reaches for a reach-average score. Stability is assessed on a relative basis across subreaches within a stream and across monitoring years. One can use these stability scores to track channel stability over time and among reaches and rivers.

Details on the SSA protocol are provided in **Appendix A**. Observations were recorded at the sub-reach level and recorded in field forms provided in **Appendix B**. Photos were collected in the middle of each subreach in the upstream, downstream, left bank, and right bank directions. All field photos are provided in **Appendix B**.

RESULTS

Here we present overall results from our baseline geomorphic assessments Skin Gulch Reaches A and B. Summarized results from the SSA are presented in Table 1. Detailed results are presented in **Appendix B**. A stability score of 0-5 is assigned to each sub-reach for each stability metric, with 5 being very unstable and 1 being very stable. A weighted average of each score is then calculated as discussed in the Methods section for each overall study reach. These scores can be interpreted as indicating relative stability and are meant to be compared among different reaches to assess relative stability as well as within the same reach over time to track trends in stability.

Table 1. Summary table of stream stability assessment scores by reach and stability category.

		Reach ID									
		A-1	A-2	A-3	A-4	A-5	A-6	Site Avg.	B-1	B-2	Site Avg.
Bank Stability	Bank Composition	3.6	3.1	3.0	2.5	2.8	1.5	3.0	2.4	2.1	2.2
	Bank Angle - Degrees	1.3	1.9	1.5	1.6	1.9	2.1	1.6	2.9	1.8	2.4
	Bank Vegetation	4.3	4.8	4.7	4.7	4.9	4.9	4.6	4.6	4.0	4.3
	Riparian Vegetaton	2.8	4.0	4.7	4.8	4.8	4.4	4.1	3.4	4.3	3.8
	Active Bank Erosion	1.1	1.3	1.4	1.5	1.6	1.9	1.3	1.7	1.1	1.4
	Composite Bank Stability Score	2.8	3.2	3.3	3.3	3.4	3.1	3.1	3.3	2.8	3.0
Bed Stab.	Severity of incision	0	0	0	0	0	0	0	2	0	1.0
	Bed Material Composition	3.3	2.8	2.8	2.8	2.3	2.5	2.7	2.1	1.9	2.0
	Composite Stream Stability Score				**3.1**					**2.9**	

Skin Gulch Reach A

At the downstream end of Reach A, immediately upstream of the culvert through Hwy 14, Reach A is relatively steep with step-pool morphology and is dominated by mature narrow leaf cottonwood (*Populus angustifolia*) trees as well as large deposits of unconsolidated sediment.

This sediment ranges in size from sand to small boulders. Moving upstream, there is little to no vegetation cover in the riparian zone and along the banks with the exception of some exotic grasses and forbs (herbaceous dicots). This lack of vegetation is captured in the bank and riparian vegetation stability metrics in Table 1. Though limited active bank erosion was observed, most stream banks were composed on non-cohesive sand to cobble-sized material and were susceptible to erosion during high flows. Some evidence of hillslope erosion was observed where the channel has cut into and de-stabilized the western hillslope. The channel bed is relatively stable with the presence of boulder and cobble material with some gravel and sand visible. No active or historic incision was observed. The composite SSA score of 3.1 out of 5 indicates a moderately unstable stream, largely due to a lack of bank vegetation and unprotected non-cohesive sediment in the banks. Large deposits of non-cohesive sediment along the channel and in the floodplain represent a potential source of sediment during high flows. Lateral instability is of most concern here due to lack of bank stability. A representative sample of field photos from Reach A are provided in Figure 3. All field photos are provided in **Appendix C**.

Skin Gulch Reach B

Reach B begins at the confluence with the main stem of Skin Gulch at Stove Prairie Road. The majority of sub-reach B-1 is comprised of what is essentially an alluvial fan of sediment deposited from the recent floods. A larger quantity of this material, comprised of sand to large boulders, deposited at and upstream of the confluence. A low-flow channel is not defined and base flow seeps under and through this deposited material. Some channel incision through this material is evident. Some hillslope scour is evident here. The valley broadens along sub-reach B-2 where the channel meanders through newly deposited / scoured sand to boulder material. Bank angles are generally mild and bank material is non-cohesive sediment ranging from sand to small boulders. All woody vegetation has been scoured from this reach and all banks and riparian areas are largely devoid of vegetation save for some patches of mostly exotic grasses and herbaceous dicots (forbs). Isolated spots of hillslope erosion leaving unstable sediment at the toes of these hillslopes was observed along the left bank of sub-reach B-2. A composite SSA score of 2.9 out of 5 indicates a moderately unstable stream, again largely due to unvegetated, non-cohesive sediment in the banks. This means that lateral instability and lateral sources of sediment are of most concern. However, the alluvial fan deposit within sub-reach B-1 may be vertically instable and a source of coarse sediment for the main stem over time. A representative sample of field photos from Reach A and B are provided in Figure 4 and figure 5.

Figure 3. Field photos of Skin Gulch Reach A. Clockwise from top left: Looking downstream at subreach A-1 at deposited sediment piles. Looking downstream on subreach A-2 at relatively stable reach with low banks and low floodplain. Looking upstream on subreach A-4 at loose sand, gravel, and cobble material on both banks. Looking upstream on subreach A-6 at large riprap along right bank and eroded hillslope toe on left bank.

Figure 4. Field photos of Skin Gulch Reach B. Clockwise from top left: Looking upstream on subeach B-1 over sand to boulder material deposited in channel and floodplain. Here, low flow seeps underneath this large wedge of deposited material. Looking upstream on subeach B-2 at channel through newly-deposited sand to boulder material and eroded hillslope on left bank. Looking downstream on subeach B-2. Eroded hillslope with loosed sand to silt-sized material on left bank of subreach B-2.

Conclusion

Based on SSA results, both reach A and reach B are highly unstable. Based on the data, the primary reasons for this instability are lack of appropriate vegetation cover (and their associated root bulb dimensions) and a high degree of unconsolidated bank materials in each subreach. With regards to incision, SSA looks at existing incision patterns rather than the potential for future incision based on stream and valley gradient, bed material, bed control points, and other geomorphic features. As such, these results should not be interpreted to mean there is a low risk of channel instability. We anticipate, based on the scores, that the greatest source of stability over time will be the development of appropriate diversity and density of herbaceous and woody vegetation on the site.

References

Sholtes, J. S. and J. Giordanengo (2014). Stream Bank and Bed Stability Assessment Protocol. AloTerra Restoration Services, LLC, Fort Collins, Colorado. 9p.

Appendices

Appendix A: SSA protocol and sample field sheets.

Appendix B: SSA field forms and reach summary sheets

Appendix C: Field assessment photos.

APPENDIX A

Stream Bank and Bed Stability Assessment Protocol

Joel Sholtes, EIT, PhD Candidate
John Giordanengo, MS
AloTerra Restoration Services, LLC

Introduction

Streambank erosion is often part of equilibrium stream processes resulting from lateral migration stream meanders down valley over time. In this setting the coarse material eroded from the banks is generally deposition downstream in point bars resulting in a rough balance between erosion and deposition over time (Knighton 1998). However, disturbance to streams from land use change and the resulting changes in runoff hydrology, channel straightening, and flood impacts can lead to conditions in which banks become unstable and are a net source of sediment to a stream channel, exceeding its natural balance. In fact, sediment from bank erosion under these situations has been cited as one of the leading source of fine sediment to streams in the U.S. (EPA 2009).

This stream bank and bed stability assessment protocol has been developed to rapidly assess factors contributing to channel stability and identify which areas along a stream reach have the greatest amount of active erosion or are at the greatest risk of future erosion. It also considers the stability and effectiveness of channel restoration structures as a post-restoration monitoring class. Each sub-reach (100-200 feet) is evaluated for bed and bank material properties, bank slope and vegetation coverage, as well as evidence of active bed and bank erosion. An aggregated score is calculated for each sub-reach allowing one to identify which sub-reaches pose the greatest concern to channel stability along the reach as well as identify what factors contribute to this. Finally, this protocol can be used for repeated assessments to monitor change over time and compare pre- and post-restoration results in a manner that allows for targeted maintenance treatments necessary to address project goals.

We begin this protocol with background information on channel stability and instability processes. We follow with a description of the protocol, and end with a discussion on interpreting the results.

Background

Many models of channel evolution in response to a disturbance exist. One intuitive model introduced by Schumm et al. (1984) describes the series of stages a channel may go through in response to a disturbance such as channelization, urbanization, or flooding (Figure 1). Beginning with Stage III, post disturbance, channel incision occurs by degradation (incision) of the channel bed and migration of head cuts (break in slope in erodible material) upstream. This increases the heights of the banks, reduces their stability, and can lead to enhanced scour at the toes of the banks. Bank erosion and failure result and the channel widens (Stage IV). As the channel widens, the erosive force of the flow dissipates, deposition of sediment results (aggradation), and a new floodplain begins to form within the incised channel (Stage V). Over a period of time (10 to > 100 years depending on the flow regime, vegetation, and bed and bank material) a new stable channel forms (Stage VI). Bank erosion resulting from channel instability may be observed along Stages III to V.

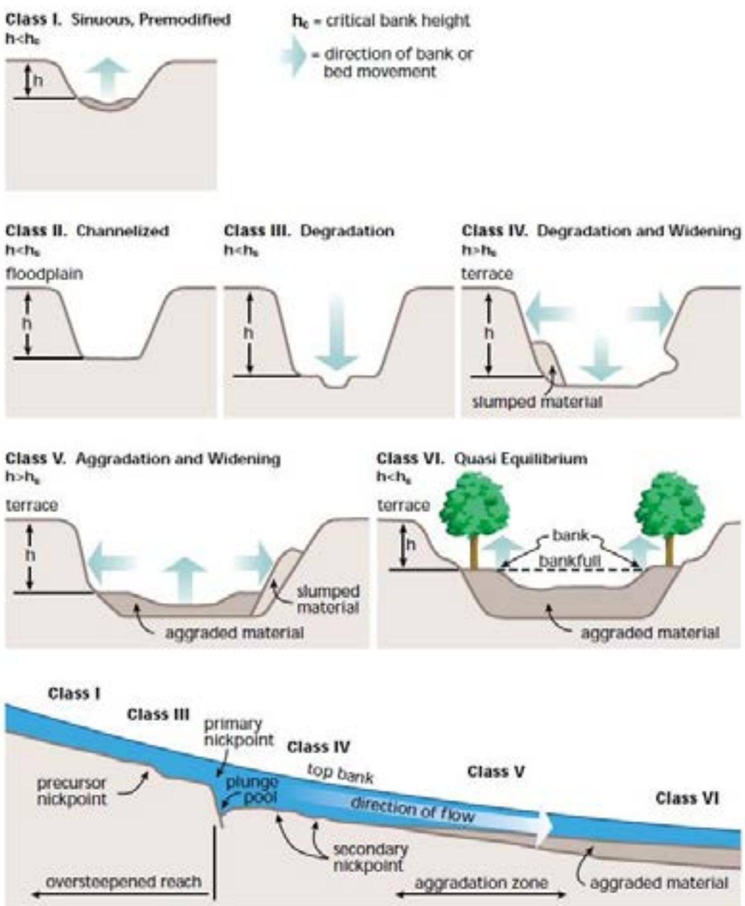

Figure 1. Channel evolution model following a disturbance (FISRWG 1998), modified from Schumm et al. (1984).

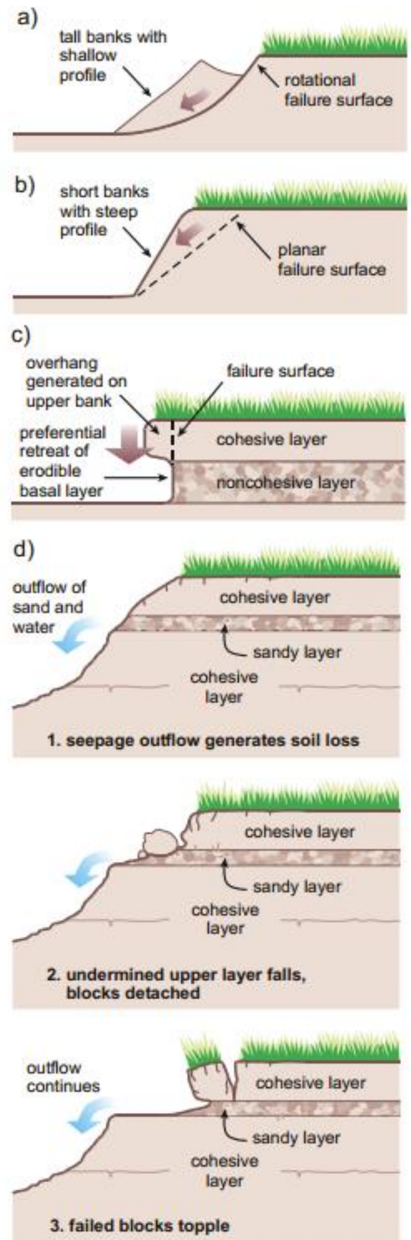

Figure 2. Bank failure mechanisms: a) rotational failure, b) planar failure, c) cantilever failure, d) piping or sapping failure from groundwater. (FISWRG 1998), modified from Hagerty (1991).

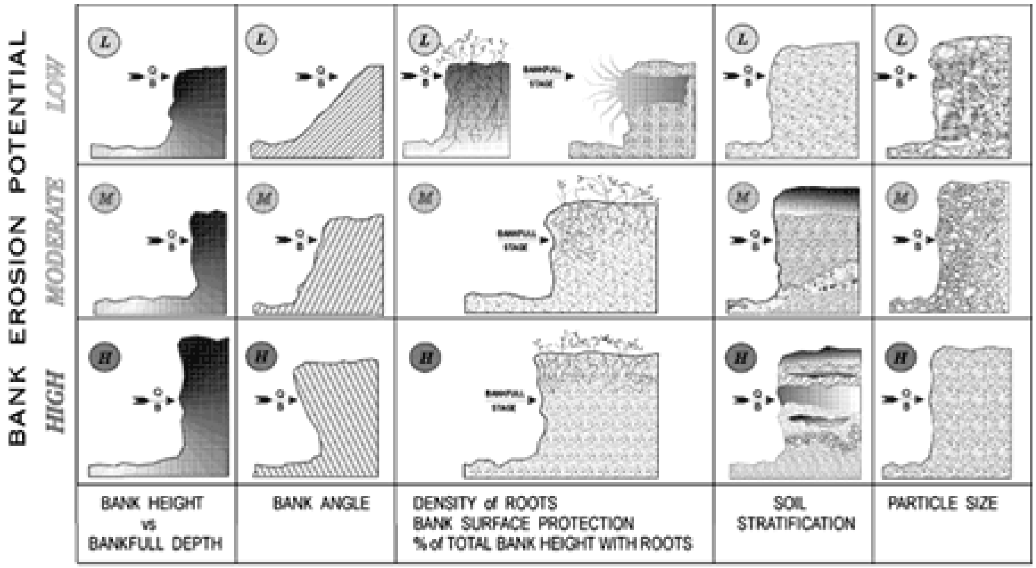

Figure 3. Bank erosion potential diagram as function of various factors. Arrows indicate bankfull height. (Rosgen 2006)

Loss of bank material to the channel occurs by two primary processes that work in tandem: slope instability and erosion. Slope stability is a geotechnical property of banks that involves the type of material comprising the banks, the angle of the banks, pressure from groundwater entering the banks, as well as the amount of roots in the bank. All materials have a natural "angle of repose" below which they are stable. Besides bedrock, cohesive bank materials such as silty and clayey soils have the largest stable angle of repose because of the inter-particle cohesion inherent in this material. However, they are susceptible to mass wasting or the loss of large chucks of bank material when they become geotechnically unstable (Haggerty 1991, Simon et al. 1999) (Figure 2a & b).

Scour at the toe of cohesive banks can lead to undercut banks and bank slumping or mass wasting (Figure 2c). Non-cohesive materials such as sand up through cobble material have lower angles of repose, with sand having the lowest. This means that for a sandy bank to be stable it must have a shallow angle. In deeply incised channels and gullies, the groundwater table may intersect the bank. Pressure in the pore space of bank material from this groundwater can reduce the stability of the bank and assist in bank failure (Figure 2d). Finally, roots from vegetation growing on the bank face and on the floodplain just beyond the bank face greatly assist in increasing the tensile strength of the bank. Dense shallow-rooted vegetation such as grasses can prevent erosion of the bank face, but do not contribute greatly to enhancing tensile strength, while deep-rooted woody vegetation (i.e., willows, cottonwoods, and other shrubs and trees) are most effective at increasing the tensile strength of the bank (Figure 3, middle column).

Bank erosion involves the properties of the bank sediment as well as the hydraulic (flow) conditions along the bank face. Bank material erodibility (susceptibility to erosion) tends to follow the angle of repose trends of different bank materials previously discussed with sand being the most erodible of non-cohesive sediments. The erodibility of cohesive sediments falls between sands and gravels and is a function of the relative percentages of sand, silt, and clay, as well as organic matter. Soils with larger percentages of sands and silts and lower percentages of organic matter tend to be more erodible (Schwab et al. 1981).

Banks may have horizontal layers of different types of material each with different erodibilities (soil stratification, Figure 2, 3).

Flow hydraulics near the bank also play an important role in erosion. Shear stress in flowing water—the friction-like stress working parallel to the bank and responsible for scour— is concentrated along the channel bed and toe of the bank. This can lead to toe scour, and cantilevered (undercut) banks, which are more susceptible to geotechnical failure, as described above (Figure 2c). Meandering channel form concentrates shear stress on the outside of meander bends resulting in a steeper "cutbank", which can be very steep in incised channels, eventually becoming unstable.

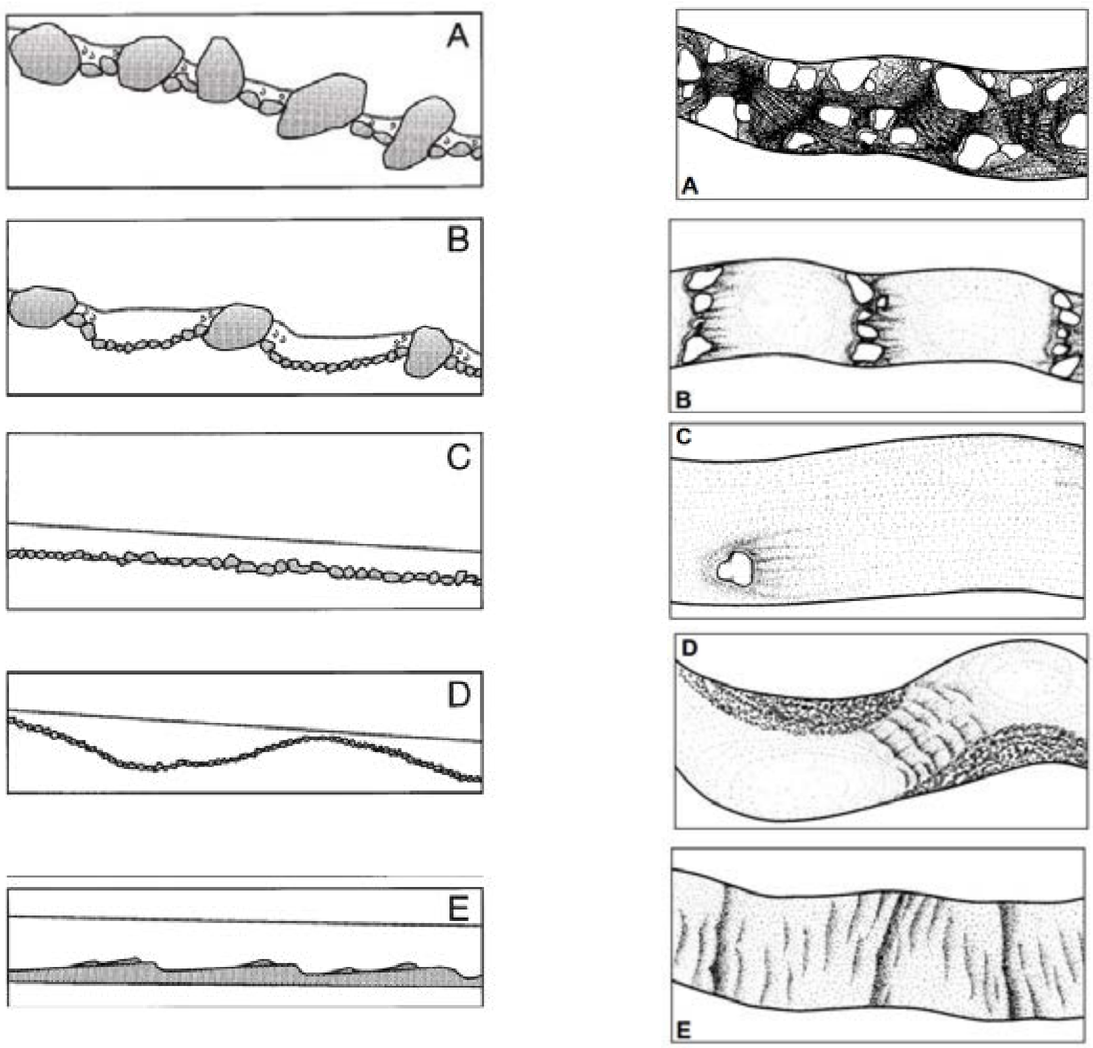

Figure 4. Channel morphologies and bedforms for mountain rivers. Longitudinal profile in left column, and planform view in right. (A) cascade; (B) step pool; (C) plane bed; (D) pool riffle; and (E) dune ripple. (Montgomery and Buffington, 1997). Reprinted under GSA Bulletin's Fair Use Policy.

Channel bed stability also plays an important role in overall stream stability and influences bank stability. Channel incision can lead to steeper banks and more concentrated flow, both of which contribute to bank instability and erosion. Bed material in most perennial natural channels is for the most part non-cohesive, that is, it is composed of sediment deposited by flow from upstream. Channel beds are often a mixture of many grain sizes ranging from purely sand and sand and gravel mixtures, up to boulder and cobble dominated beds (Figure 4). As a rule: the steeper the channel the coarser the bed material. This model excludes gullies and other channels that form in cohesive soils in dry climates.

While finer bed channels may be more susceptible to vertical incision, streams with fine beds tend to have mild slopes, and less vertical relief to erode. Steeper channels with coarser material are also susceptible to incision, especially where large boulders are lacking to provide grade control. Evidence of active incision often comes in the form of headcuts (or knickpoints), which are steps or discontinuities in the slope of the bed. Headcuts migrate upstream as their faces erode until they encounter a vertical grade control such a boulders or bedrock (Figure 1). They serve to reduce channel slope and erosive energy allowing a channel to adjust to the disturbance that initiated this vertical instability. A range of natural mountain stream types is shown in Figure 4, above.

A final consideration of channel stability concerns the stability and quality of installed grade control, habitat enhancement, and bank protection structures, otherwise known as restoration treatments. Hard engineering approaches such as rip-rapped banks and grade control vanes can be undermined or circumvented by erosion processes. Bank bioengineering treatments such as planted erosion control fabric, live stakes, and use of wood installed along the bank toe can fail if subjected to high flows before plant establishment or if installed improperly. These examples of restoration treatment failures are not exhaustive, and it is outside of the scope of this protocol to discuss different stream restoration treatments and their failure mechanisms. However, part of this protocol involves assessing the integrity of these structures as described below.

Assessment Protocol

This stream bank and bed assessment protocol was developed to allow a field crew of one to two people assess the stability of a stream reach rapidly, thoroughly, and in a spatially explicit manner so that stability concerns may be identified and located along a reach. The field team will ideally comprise at least one person with experience in fluvial geomorphology and another with experience in field botany. Factors leading to bank stability (or risk of instability) included in this protocol are: bank and channel material composition, bank angle, bank and riparian vegetation type and percent coverage, evidence of active or recent bank erosion, channel bed composition, bed morphology, and evidence and severity of recent vertical incision.

Figure 5. Example of mapped stability scores

This protocol was designed to allow inter-annual comparison and tracking changes over time, possibly after a restoration effort. It is largely a visual assessment, conducted along a 100 – 200 ft sub-reach within which channel and bank information is aggregated. The length of the sub-reach may vary according to the channel size, but its length should be on the order of 10 to 20 times the bankfull width of the channel (floodplain edge to floodplain edge). Each category of the stability assessment may be evaluated separately to identify specific factors leading to stability issues within a sub-reach or along the entire project reach. These factors are also aggregated to identify unstable sub-reaches within the larger reach. For example, lack of bank and riparian vegetation may be a leading cause of risk of instability along the project reach. Bank instability may only be an issue for select areas within a project reach, and not a pervasive problem. This assessment protocol will aid in identifying each of these.

The general assessment procedure involves laying a measuring tape along a stream bank for the specified length of the sub-reach and characterizing bed and bank properties along this sub-reach. A handheld GPS may be used to mark the starting point of each sub-reach as well as the location of any failed stream restoration structures. Stream stability information may be later incorporated into a GIS database allowing the stability metrics to be mapped (Figure 6). Photos should be taken in the middle of each sub-reach (upstream, downstream, leftbank, right bank), as well as of any noteworthy observations, such as a particularly severe example of erosion or a failure restoration structure. In addition to using the accompanying field sheet to document each sub-reach, notes should be taken of the photo numbers, any waypoints collected on the GPS, as well as one to two sentences of narrative describing the sub-reach.

The following is a description of each assessment category:

Bank Composition

Visually and tactilely (use your hands) assess the relative size of the bank material. Assign percent of sub-reach length to each material category. Note that cohesive banks are composed of soil, which has a certain percentage of silt and clay. Non-cohesive banks lack silt and clay, though can be a mixture of sands, gravel, cobbles, etc. Table 1 contains descriptions and lengths associated with each sediment class.

Table 1. Grain size descriptions

	Cohesive	***Non-Cohesive***			
Type	***Silt / Clay (soil)***	***Sand***	***Gravel***	***Cobble***	***Boulder***
Grain Size	< 0.062 mm	0.063 to 2 mm	2 to 64 mm	64 to 256 mm	256 + mm
Description	Fine texture, cohesive, smooth when rubbed between fingers	Fine sugar to kosher salt sized particles	Peppercorn to egg sized	Baseball to grapefruit sized	Melon sized and larger

Bank Angle

The bank angle categories are as follows: *Mild* (0°-30°), *Moderate* (30°-60°), *Steep* (60°-90°), and *Overhang* (> 90°). Evaluate percent of each sub-reach having each bank angle category.

Vegetation: Bank and Riparian Zone

Start each field day by following a line-intercept procedure (Herrick et al., 2005) over a representative 100-foot section of bank in order to calibrate the observers eyes. Assess percent of bank and stream edge (riparian zone) covered by *bare earth* (soil, rock, and/or organic litter), *nascent vegetation* (annual or biennial grasses or forbs, and juvenile perennial vegetation), *perennial grasses and forbs*, and *shrubs* and *trees*. This may represent the most challenging component of the stability assessment. Use of a vegetation density transect method may assist in estimating the relative percentages of cover within each vegetation category. Avoid looking upstream to assess vegetation coverage, as oblique visual assessments of vegetation cover often lead to gross cover overestimates. Rather, walk the bank while looking down and note the percent cover for that transect (measured distance of the cover for each vegetation category divided by the total transect length). For instance, if a combined 10 feet of a 100 foot transect is comprised a combination of annual forbs and grasses and/or 1-year-old (juvenile) perennial plant cover, the score for nascent vegetation would be 10 (10%). In estimating cover, include the gaps between the leaves as part of the canopy estimate. Imagine a polygon drawn around the very perimeter of the plant canopy in question, and tally the number of linear feet that canopy intercepts the tape measure.

Count understory vegetation separately from overstory vegetation. For example, if a shrub canopy covers the transect from 20-30 ft, and again from 50-60 ft, then the shrub cover is 20% [(10+10)/100]. If an understory of perennial grasses/sedges occurs under that shrub canopy, then record the percent cover of that perennial cover in addition to the shrub cover estimate and record it in the appropriate row on the form. In this regards, it may be possible in mature riparian stands to record a total vegetation cover greater than 100%.

Active Bank Erosion

The previous categories indicate bank susceptibility to erosion. This category assesses recent or ongoing bank erosion processes. Bare soil or bank material does not necessarily indicate active erosion. Look for clues such as vegetation, exposed roots, evidence of bank material deposited at the bank toe, and fresh erosion on bank faces. Here, instead of assigning a percent length to each category, pick the category that best matches the observed extent (percent length) of active bank erosion. Low (0 – 25%), Moderate (25 – 50%), High (50 – 75%), Severe (75 – 100%). Bank restoration treatments that are underperforming or failing may coincide with active bank erosion. Note the active erosion here and document the bank treatment under the "Restoration Treatment Assessment" described below.

Bed Stability

Equally as important as assessing bank stability is channel bed stability. For the sake of brevity, percent lengths are not included in this portion of the assessment. Rather, the field crew selects the dominant bed sediment type (following Table 1) and dominant morphology type (Figure 4) of the sub-reach. They note whether active or recent incision exists. Clues from positions of roots along the bank and presence of migrating headcuts help inform this. Finally, if recent or active incision exists, the field crew estimates the depth of erosion along the sub-reach. Active incision may occur at or as a result of a stream restoration structure failure. Please note the incision or instability here and document the structure under the "Restoration Treatment Assessment" described below.

Restoration Treatment Assessment

Here, the field team assesses the quality and integrity of any stream restoration treatments/structures in the channel (e.g., grade control vanes or habitat enhancements) and banks (e.g., erosion control fabric, live stakes, toe wood or root wads). Bank and in-channel treatments encountered are each numbered, identified by type, and then scored. This assessment follows the spirit of the bed stability assessment in that it does not consider percent lengths of each sub-reach. Rather, each structure or treatment encountered is scored as follows: *Good*: Stable and meeting design goals (e.g., bed or bank stability and reduction of erosion), *Moderate*: Could use some minor maintenance, *Poor*: evidence of erosion, plant death, or processes that may soon lead to restoration treatment failure, *Failed*: restoration treatment no longer serving its intended function and/or the structure/treatment is damaged to an extent that is problematic to the stability of the channel. The field crew should have an annotated "as-built" drawing of the reach that identifies what restoration treatments were installed where to aid in the inventory and assessment of these.

General Assessment Notes

Round estimates of percent length of each category to the nearest 10, 20, or 25%. Because this assessment protocol is visually based, precision beyond the nearest 10% is likely inaccurate and unnecessary. If working as a team, each team member should evaluate each category independently. Results can then be averaged. For a more comprehensive view of channel change over time, bank and channel bed monitoring should also incorporate repeated cross section and longitudinal profile surveys as well a repeated photographs from monumented locations. A good primer on stream surveying methods can be found in Harrelson et al. (1994).

Bank Erosion Hazard Score Calculations

To calculate bank stability scores, data collected on each sub-reach is entered into the "Calculations Spreadsheet" in which one column represents a sub-reach. Categories within each group (e.g., bank composition, bank vegetation) are assigned a value from 1 – 4 with 4 indicting the highest risk of instability. Based on the percent lengths attributed to each group category, a weighted average score is calculated for each bank for each category. These scores are then aggregated as a percent of total score, with higher scores indicating a higher risk of instability. Because this index-based approach is arbitrary (is bank angle equally as important as riparian vegetation coverage?), weights can be assigned to each category to give more or less weight to a particular category in the overall "Composite Bank Erosion Hazard Score". Currently, all categories have a weight of 1 with the exception of "Active Bank Erosion", which has a weight of 2.

Bed stability and stream restoration treatment assessments are scored separately from the composite bank erosion hazard score. Each sub-reach with active incision is flagged. Each restoration treatment is assessed and tallied for each category of quality / stability. These can then be inventoried at the project reach level.

Interpretation of Results

The results from this monitoring protocol may be used in a number of ways. They may be used to gather a baseline assessment of the stability of a reach of interest, and to document restoration needs. It can then be used to track the evolution of the channel's stability over time in response to restoration efforts. Repair and maintenance needs may also be identified by this protocol. These assessments cannot at this time be used to estimate the quantity of eroded sediment entering a stream or the rate of bank erosion. However, they can provide objective and transparent evaluations of bank and bed stability that can aid in documenting overall changes and / or improvements to stability as a result of a restoration effort.

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Bank - Channel Stability and Riparian Vegetation Field Assessment

Date		Stream		Crew	
Sub-Reach ID		**Sub-Reach Length**		**Lat.**	**Lon.**
Photos	**US:**	**DS:**	**LB:**	**RB:**	

		Right Bank	Left Bank
Bank Composition		*Percent of Length*	
Cohesive (Silt/Clay)			
Sand			
Gravel/Cobble			
Boulder/Bedrock			
Bank Angle	***Degrees***		
Mild	0-30		
Moderate	31-60		
Steep	61-90		
Overhang	91+		
Bank Vegetation			
Bare Earth			
Nascent Vegetation			
Perennial Vegetaton			
Shrubs			
Trees			
Riparian Vegetaton			
Bare Earth			
Nascent Vegetation			
Perennial Vegetaton			
Shrubs			
Trees			
Active Bank Erosion			
Low	0 - 25%		
Moderate	26 - 50%		
High	51 - 75%		
Severe	76 - 100%		

Stream Restoration Treatment Inventory

Bank Treatments

	Right Bank	Left Bank
Type		
Length		
Quality		
Photos		
Type		
Length		
Quality		
Photos		

Quality: Good: 4, Moderate: 3, Poor: 2, Failed: 1

In-Channel Treatments / Structures

Type

Number

Quality **Good Moderate Poor Failed**

Photos

Type

Number

Quality **Good Moderate Poor Failed**

Photos

Bed Stability

Bed Composition	**Cohesive**	**Sand**	**Gravel**	**Cobble**	**Bedrock/Boulder**
Bed Morphology	**Cascade**	**Step-pool**	**Riffle/Glide**	**Pool/Riffle**	**Dune/Ripple**
Recent/active incision?	**YES**	**NO**			
Severity of incision	**< 1 ft**	**1-2 ft**	**2-3 ft**	**> 3 ft**	

NOTES

Instructions: Enter percent length values into each white box for each sub-reach. The colored boxes will automatically calculated weighted averages within each category as well as the composite bank stability score. Category weights may also be adjusted as the user deems appropriate.

Bank Stability

Weights	Category	SCORE	REACH ID 1 Left Bank	REACH ID 1 Right Bank	REACH ID 2 Left Bank	REACH ID 2 Right Bank	REACH ID 3 Left Bank	REACH ID 3 Right Bank	REACH ID 4 Left Bank	REACH ID 4 Right Bank	Average Scores Left Bank	Average Scores Right Bank
			Percent of Length		*Percent of Length*		*Percent of Length*		*Percent of Length*			
1	**Bank Composition**											
	Cohesive (Silt/Clay)	4										
	Sand	3		25		25		25		25		
	Gravel/Cobble	2	60	75	60	75	60	75	60	75		
	Boulder/Bedrock	1	40		40		40		40			
			1.6	2.3	1.6	2.3	1.6	2.3	1.6	2.3	1.6	2.3
1	**Bank Angle - Degrees**											
	Mild - 0-30	1										
	Moderate - 30-60	2	50	50	50	50	50	50	50	50		
	Steep - 60-90	3	50	50	50	50	50	50	50	50		
	Overhang - > 90	4										
			2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
1	**Bank Vegetation**											
	Bare Earth	5	75	50	75	50	75	50	75	50		
	Nascent Vegetation	4	10	35	10	35	10	35	10	35		
	Perennial Vegetation	3	10	35	10	35	10	35	10	35		
	Shrubs	2	15	15	15	15	15	15	15	15		
	Trees	1										
			4.8	5.3	4.4	3.9	4.4	3.9	4.4	3.9	4.5	4.2
1	**Riparian Vegetaton**											
	Bare Earth	5	40	40	40	40	40	40	40	40		
	Nascent Vegetation	4	10	35	10	35	10	35	10	35		
	Perennial Vegetation	3	50	50	50	50	50	50	50	50		
	Shrubs	2	10	10	10	10	10	10	10	10		
	Trees	1										
			4.1	5.1	3.7	3.7	3.7	3.7	3.7	3.7	3.8	4.1
3	**Active Bank Erosion**											
	Low: 0 - 25%	1										
	Moderate: 25 - 50%	2		1		1		1		1		
	High: 50 - 75%	3										
	Severe: 75 - 100%	4	1		1		1		1			
			4	2	4	2	4	2	4	2	4.0	2.0
	Composite Bank Erosion Hazard Score		83%	70%	81%	61%	81%	61%	81%	61%	81%	63%

Bed Stability

		Reach 1	Reach 2	Reach 3	Reach 4	
Recent/active incision?	(Yes / No)	Yes	No	Yes	Yes	**No. Sub-Reachse w/ Incision:** 3
Severity of incision	> 1 ft	1				
	1 - 2 ft			1		
	2 - 3 ft				1	
	> 3 ft					
		1	0	2	3	**Average Incision Severity:** 1.5

Stream Restoration Treatment Inventory

Bank Treatments	Reach 1 Left Bank	Reach 1 Right Bank	Reach 2 Left Bank	Reach 2 Right Bank	Reach 3 Left Bank	Reach 3 Right Bank	Reach 4 Left Bank	Reach 4 Right Bank
Type	PECF	PECF			PECF	PECF	PECF	PECF
Length (ft)	100	100	0	0	100	100	100	100
Quality: (Good: 4, Mod: 3, Poor: 2, Fail: 1)	3	2			3	4	2	3
Type	Live stakes	Live stakes			Live Stakes	Live stakes	Toe Wood	Live stakes
Length	100	100	0	0	100	100	100	50
Quality: (Good: 4, Mod: 3, Poor: 2, Fail: 1)	4	3			4	2	2	3

Bank Treatment Summary

	Left Bank	Right Bank
Overall Length	600	550
Weighted Score	3.0	2.8

Channel Treatments / Structures	Reach 1	Reach 2	Reach 3	Reach 4
Type	Stone Cross Vanes		Log Vanes	
Number	3		2	
Quality: (Good: 4, Mod: 3, Poor: 2, Fail: 1)	3		3	
Type				
Number				
Quality: (Good: 4, Mod: 3, Poor: 2, Fail: 1)				

Channel Treatment Summary

Overall No. Structures	5
Weighted Score	3.0

Notes on Type Codes (Create your own as needed)

PECF: Planted Erosion Control Fabric

APPENDIX B

Bank - Channel Stability and Riparian Vegetation Field Assessment

Date	4/6/2015	**Stream**	Skin Gulch		**Crew**	Joel S & John G	
Sub-Reach ID	A1	**Sub-Reach Length**	200 ft		**Northing**	4503535	**Easting** 467097
Photos	**US: 7**	**DS: 8**	**LB:** 9	**RB:**	10		

		Left Bank		Right Bank	
Bank Composition		*% Length*	*% C/B*	*% Length*	*% C/B*
Cohesive (Silt/Clay)		25	10	25	10
Sand / Fine Gravel		75	30	75	30
Gravel/Cobble					
Boulder/Bedrock/Other					
Bank Angle	***Degrees***				
Mild	0-30	75		70	
Moderate	31-60	25		25	
Steep	61-90			5	
Overhang	91+				
Bank Vegetation					**Maturity**
Bare Earth		70		70	
Nascent Vegetation		4		4	2
Perennial Vegetaton		20		20	2
Shrubs		2		2	2
Trees		4		4	4

Maturity: (**1** = 1st yr; **2** = 1-5 yrs; **3** = mature; **4** = old growth)

		Left Bank		Right Bank	
Riparian Vegetation					**Maturity**
Bare Earth / Litter Cov.		38		38	
Nascent Vegetation		4		4	
Perennial Vegetaton		7		7	
Shrubs		1		1	
Trees		50		50	
Active Bank Erosion (% of Face)					
Low	0 - 25%	95		95	
Moderate	26 - 50%				
High	51 - 75%	5		5	
Severe	76 - 100%				

Stream Restoration Treatment Inventory

Bank Treatments

	Right Bank	Left Bank
Type		
Length		
Quality		
Photos		
Type		
Length		
Quality		
Photos		

Quality: *(* ***1*** *= Failed;* ***2*** *= Poor;* ***3*** *= Moderate;* ***4*** *= Good)*

In-Channel Treatments / Structures

Type

Number

Quality **Good Moderate Poor Failed**

Photos

Type

Number

Quality **Good Moderate Poor Failed**

Photos

Notes on Structures:

Bed Stability

Bed Composition (%)	**Cohesive**	**Sand**	50	**Gravel**	30	**Cbl/Bldr**	20	**Bedrock**	
Bed Morphology	**Cascade**	**Step-pool**	100	**Riff/Gld**		**Pool/Riff**		**Dune/Ripp**	
Recent/active incision?	**YES**	**NO**		Aggradation?		**YES**		**NO**	
Severity of incision	**< 1 ft**	**1-2 ft**		**2-3 ft**	**> 3 ft**				

REACH NOTES:

Bank - Channel Stability and Riparian Vegetation Field Assessment

Date	4/6/2015	**Stream**	Skin Gulch		**Crew**	Joel S & John G
Sub-Reach ID	A2	**Sub-Reach Length**	300 ft	**Northing** 4503429	**Easting**	467181
Photos	**US: 11**	**DS: 12**	**LB: 13**	**RB: 14**		

		Left Bank		Right Bank	
Bank Composition		*% Length*	*% C/B*	*% Length*	*% C/B*
Cohesive (Silt/Clay)		5		5	
Sand / Fine Gravel		95	30	95	30
Gravel/Cobble					
Boulder/Bedrock/Other					
Bank Angle	***Degrees***				
Mild	0-30			20	
Moderate	31-60	100		80	
Steep	61-90				
Overhang	91+				
Bank Vegetation					**Maturity**
Bare Earth		90		90	
Nascent Vegetation		5		5	
Perennial Vegetaton		3		3	
Shrubs					
Trees					

Maturity: (**1** = 1st yr; **2** = 1-5 yrs; **3** = mature; **4** = old growth)

		Left Bank	Right Bank	**Maturity**
Riparian Vegetation				
Bare Earth / Litter Cov.		85	15	
Nascent Vegetation		10	5	
Perennial Vegetaton		3	75	
Shrubs				2
Trees		2	5	
Active Bank Erosion (% of Face)				
Low	0 - 25%	75	75	
Moderate	26 - 50%	25	25	
High	51 - 75%			
Severe	76 - 100%			

Stream Restoration Treatment Inventory

Bank Treatments

	Right Bank	Left Bank
Type		
Length		
Quality		
Photos		
Type		
Length		
Quality		
Photos		

Quality: *(**1** = Failed; **2** = Poor; **3** = Moderate; **4** = Good)*

In-Channel Treatments / Structures

Type
Number
Quality **Good Moderate Poor Failed**
Photos

Type
Number
Quality **Good Moderate Poor Failed**
Photos

Notes on Structures:

Bed Stability

Bed Composition (%)	**Cohesive**	**Sand**	20	**Gravel**	40	**Cbl/Bldr**	40	**Bedrock**
Bed Morphology	**Cascade**	**Step-pool**		**Riff/Gld**	100	**Pool/Riff**		**Dune/Ripp**
Recent/active incision?	**YES**	**NO**		Aggradation?		**YES**		**NO**
Severity of incision	**< 1 ft**	**1-2 ft**		**2-3 ft**	**> 3 ft**			

REACH NOTES:

Bank - Channel Stability and Riparian Vegetation Field Assessment

Date 4/6/2015 **Stream** Skin Gulch **Crew** Joel S & John G

Sub-Reach ID A3 **Sub-Reach Length** 200 ft **Northing** 4503336 **Easting** 467203

Photos **US: 15** **DS: 16** **LB: 17** **RB: 18**

	Left Bank		Right Bank	
Bank Composition	*% Length*	*% C/B*	*% Length*	*% C/B*
Cohesive (Silt/Clay)			50	
Sand / Fine Gravel	50	25	50	25
Gravel/Cobble	40			
Boulder/Bedrock/Other	10			

Bank Angle	***Degrees***	Left Bank	Right Bank
Mild	0-30		100
Moderate	31-60	100	
Steep	61-90		
Overhang	91+		

Bank Vegetation	Left Bank	Right Bank	**Maturity**
Bare Earth	98	45	
Nascent Vegetation	2	50	2
Perennial Vegetaton	2	5	2
Shrubs			
Trees			

Maturity: (**1** = 1st yr; **2** = 1-5 yrs; **3** = mature; **4** = old growth)

Riparian Vegetation	Left Bank	Right Bank	**Maturity**
Bare Earth / Litter Cov.	86	94	
Nascent Vegetation	2	5	
Perennial Vegetaton	2	1	
Shrubs	2		4
Trees			

Active Bank Erosion (% of Face)		Left Bank	Right Bank
Low	0 - 25%	15	100
Moderate	26 - 50%	85	
High	51 - 75%		
Severe	76 - 100%		

Stream Restoration Treatment Inventory

Bank Treatments

	Right Bank	Left Bank
Type		
Length		
Quality		
Photos		

	Right Bank	Left Bank
Type		
Length		
Quality		
Photos		

Quality: *(**1** = Failed; **2** = Poor; **3** = Moderate; **4** = Good)*

In-Channel Treatments / Structures

Type
Number
Quality **Good Moderate Poor Failed**
Photos

Type
Number
Quality **Good Moderate Poor Failed**
Photos

Notes on Structures:

Bed Stability

Bed Composition (%)	**Cohesive**	**Sand**	20	**Gravel**	40	**Cbl/Bldr**	40	**Bedrock**	
Bed Morphology	**Cascade**	**Step-pool**	10	**Riff/Gld**	90	**Pool/Riff**		**Dune/Ripp**	
Recent/active incision?	**YES**	**NO**		Aggradation?		**YES**		**NO**	
Severity of incision	**< 1 ft**	**1-2 ft**		**2-3 ft**	**> 3 ft**				

REACH NOTES:

Bank - Channel Stability and Riparian Vegetation Field Assessment

Date	4/6/2015	**Stream**	Skin Gulch			**Crew**	Joel S & John G
Sub-Reach ID	A4	**Sub-Reach Length**	300 ft	**Northing**	4503199	**Easting**	467182
Photos	**US: 19**	**DS:**	**20**	**LB:**	**21**	**RB:**	**22**

	Left Bank *% Length*	Left Bank *% C/B*	Right Bank *% Length*	Right Bank *% C/B*
Bank Composition				
Cohesive (Silt/Clay)				
Sand / Fine Gravel	50	25	50	25
Gravel/Cobble	50		50	
Boulder/Bedrock/Other				

Bank Angle	***Degrees***	Left Bank	Right Bank
Mild	0-30		100
Moderate	31-60	75	
Steep	61-90	25	
Overhang	91+		

Bank Vegetation	Left Bank	Right Bank	**Maturity**
Bare Earth	98	50	
Nascent Vegetation	2	45	2
Perennial Vegetaton	2	5	2
Shrubs			
Trees			

Maturity: (**1** = 1st yr; **2** = 1-5 yrs; **3** = mature; **4** = old growth)

Riparian Vegetation	Left Bank	Right Bank	**Maturity**
Bare Earth / Litter Cov.	95	67	
Nascent Vegetation	5	30	
Perennial Vegetaton	1	3	
Shrubs			
Trees			

Active Bank Erosion (% of Face)		Left Bank	Right Bank
Low	0 - 25%	15	100
Moderate	26 - 50%	70	
High	51 - 75%	15	
Severe	76 - 100%		

Stream Restoration Treatment Inventory

Bank Treatments

	Right Bank	Left Bank
Type		
Length		
Quality		
Photos		
Type		
Length		
Quality		
Photos		

Quality: *(**1** = Failed; **2** = Poor; **3** = Moderate; **4** = Good)*

In-Channel Treatments / Structures

Type

Number

Quality **Good Moderate Poor Failed**

Photos

Type

Number

Quality **Good Moderate Poor Failed**

Photos

Notes on Structures:

Bed Stability

Bed Composition (%)	**Cohesive**	**Sand**	20	**Gravel**	40	**Cbl/Bldr**	40	**Bedrock**	
Bed Morphology	**Cascade**	**Step-pool**	15	**Riff/Gld**	85	**Pool/Riff**		**Dune/Ripp**	
Recent/active incision?	**YES**	**NO**		Aggradation?		**YES**		**NO**	
Severity of incision	**< 1 ft**	**1-2 ft**		**2-3 ft**	**> 3 ft**				

REACH NOTES:

Bedrock grade control at u/s end (5-10ft long)

Bank - Channel Stability and Riparian Vegetation Field Assessment

Date	4/6/2015	**Stream**	Skin Gulch	**Crew**	Joel S & John G		
Sub-Reach ID	A5	**Sub-Reach Length**	300 ft	**Northing**	4503075	**Easting**	467182
Photos	**US: 23**	**DS:**	**24**	**LB:**	**25**	**RB:**	**26**

	Left Bank		Right Bank	
Bank Composition	*% Length*	*% C/B*	*% Length*	*% C/B*
Cohesive (Silt/Clay)				
Sand / Fine Gravel	75	35	100	35
Gravel/Cobble	10			
Boulder/Bedrock/Other	15			

Bank Angle	***Degrees***	Left Bank	Right Bank
Mild	0-30		100
Moderate	31-60	25	
Steep	61-90	75	
Overhang	91+		

Bank Vegetation	Left Bank	Right Bank	**Maturity**
Bare Earth	97	90	
Nascent Vegetation	2	7	2
Perennial Vegetaton	1	3	2
Shrubs			
Trees			

Maturity: (**1** = 1st yr; **2** = 1-5 yrs; **3** = mature; **4** = old growth)

Riparian Vegetation	Left Bank	Right Bank	**Maturity**
Bare Earth / Litter Cov.	98	79	
Nascent Vegetation	1	15	
Perennial Vegetaton	1	3	
Shrubs		3	
Trees			

Active Bank Erosion (% of Face)		Left Bank	Right Bank
Low	0 - 25%	10	100
Moderate	26 - 50%	70	
High	51 - 75%	20	
Severe	76 - 100%		

Stream Restoration Treatment Inventory

Bank Treatments

	Right Bank	Left Bank
Type		
Length		
Quality		
Photos		

	Right Bank	Left Bank
Type		
Length		
Quality		
Photos		

Quality: (***1*** = *Failed;* ***2*** = *Poor;* ***3*** = *Moderate;* ***4*** = *Good*)

In-Channel Treatments / Structures

Type

Number

Quality **Good Moderate Poor Failed**

Photos

Type

Number

Quality **Good Moderate Poor Failed**

Photos

Notes on Structures:

Bed Stability

Bed Composition (%)	**Cohesive**	**Sand**	10	**Gravel**	20	**Cbl/Bldr**	60	**Bedrock**	10
Bed Morphology	**Cascade**	**Step-pool**	10	**Riff/Gld**	90	**Pool/Riff**		**Dune/Ripp**	
Recent/active incision?	**YES**	**NO**		Aggradation?		**YES**		**NO**	
Severity of incision	**< 1 ft**	**1-2 ft**		**2-3 ft**	**> 3 ft**				

REACH NOTES:

Good connection to floodplain in Reaches A2 to A5

Bank - Channel Stability and Riparian Vegetation Field Assessment

Date	4/6/2015	**Stream**	Skin Gulch		**Crew**	Joel S & John G	
Sub-Reach ID	A6	**Sub-Reach Length**	300 ft	**Northing**	4502957	**Easting**	467186
Photos	**US: 27**	**DS:**	**28**	**LB:**	**29**	**RB:**	**30**

	Left Bank % Length	Left Bank % C/B	Right Bank % Length	Right Bank % C/B
Bank Composition				
Cohesive (Silt/Clay)				
Sand / Fine Gravel				
Gravel/Cobble	70	25	30	25
Boulder/Bedrock/Other	30		70	

Bank Angle	***Degrees***	Left Bank	Right Bank
Mild	0-30	15	15
Moderate	31-60	45	85
Steep	61-90	40	
Overhang	91+		

Bank Vegetation	Left Bank	Right Bank	**Maturity**
Bare Earth	85	90	
Nascent Vegetation	5	5	2
Perennial Vegetaton	10	5	5
Shrubs			
Trees			

Maturity: (**1** = 1st yr; **2** = 1-5 yrs; **3** = mature; **4** = old growth)

Riparian Vegetation	Left Bank	Right Bank	**Maturity**
Bare Earth / Litter Cov.	55	90	
Nascent Vegetation	3	5	2
Perennial Vegetaton	35	5	2
Shrubs	2		
Trees	5		

Active Bank Erosion (% of Face)		Left Bank	Right Bank
Low	0 - 25%	50	100
Moderate	26 - 50%	20	
High	51 - 75%	30	
Severe	76 - 100%		

Stream Restoration Treatment Inventory

Bank Treatments

	Right Bank	Left Bank
Type		
Length		
Quality		
Photos		
Type		
Length		
Quality		
Photos		

Quality: *(**1** = Failed; **2** = Poor; **3** = Moderate; **4** = Good)*

In-Channel Treatments / Structures

Type

Number

Quality **Good Moderate Poor Failed**

Photos

Type

Number

Quality **Good Moderate Poor Failed**

Photos

Notes on Structures:

Bed Stability

Bed Composition (%)	**Cohesive**	**Sand**	25	**Gravel**	25	**Cbl/Bldr**	20	**Bedrock**	30
Bed Morphology	**Cascade**	**Step-pool**	80	**20**		**Pool/Riff**		**Dune/Ripp**	
Recent/active incision?	**YES**	**NO**		Aggradation?		**YES**		**NO**	
Severity of incision	**< 1 ft**	**1-2 ft**		**2-3 ft**	**> 3 ft**				

REACH NOTES:

RipRap Embankment along RB for most of the way
Reach ends at confluence with Reach B

Bank - Channel Stability and Riparian Vegetation Field Assessment

Date 4/6/2015 **Stream** Skin Gulch B **Crew** Joel S & John G

Sub-Reach ID B1 **Sub-Reach Length** 300 ft **Northing** 4502875 **Easting** 467196

Photos **US: 31** **DS: 32** **LB:** **33** **34**

	Left Bank		Right Bank	
Bank Composition	*% Length*	*% C/B*	*% Length*	*% C/B*
Cohesive (Silt/Clay)	20		40	50
Sand / Fine Gravel			10	30
Gravel/Cobble	80			
Boulder/Bedrock/Other			50	

Bank Angle	***Degrees***	Left Bank	Right Bank
Mild	0-30		
Moderate	31-60	30	75
Steep	61-90	70	25
Overhang	91+	20	

Bank Vegetation	Left Bank		Right Bank	**Maturity**
Bare Earth	75		95	**Maturity**
Nascent Vegetation	7		3	2
Perennial Vegetaton	3		2	4
Shrubs				
Trees	15			4

Maturity: (**1** = 1st yr; **2** = 1-5 yrs; **3** = mature; **4** = old growth)

Riparian Vegetation	Left Bank		Right Bank	**Maturity**
Bare Earth / Litter Cov.	50		5	**Maturity**
Nascent Vegetation	5		3	
Perennial Vegetaton	20		8	
Shrubs			5	
Trees	25		25	4

Active Bank Erosion (% of Face)		Left Bank	Right Bank
Low	0 - 25%	80	50
Moderate	26 - 50%		
High	51 - 75%	20	50
Severe	76 - 100%		

Stream Restoration Treatment Inventory

Bank Treatments

	Right Bank	Left Bank
Type		
Length		
Quality		
Photos		

	Right Bank	Left Bank
Type		
Length		
Quality		
Photos		

Quality: *(**1** = Failed; **2** = Poor; **3** = Moderate; **4** = Good)*

In-Channel Treatments / Structures

Type

Number

Quality **Good Moderate Poor Failed**

Photos

Type

Number

Quality **Good Moderate Poor Failed**

Photos

Notes on Structures:

Bed Stability

Bed Composition (%)	**Cohesive**		**Sand**	10	**Gravel**	15	**Cbl/Bldr**	50	**Bedrock**	25
Bed Morphology	**Cascade**		**Step-pool**	80	**Riff/Gld**	20	**Pool/Riff**		**Dune/Ripp**	
Recent/active incision?	**YES**	(Historic	**NO**		Aggradation?		**YES**		**NO**	
Severity of incision	**< 1 ft**		**1-2 ft**		**2-3 ft**	**> 3 ft**				

REACH NOTES:

Right and left banks serfer to outer floodplain because channel splits here and there is an interfluve. Interfluve banks not assessed.
Interfluve is mostly sand/gravel/cobble material, alluvial desposit.

Bank - Channel Stability and Riparian Vegetation Field Assessment

Date	4/6/2015	**Stream**	Skin Gulch B		**Crew**	Joel S & John G	
Sub-Reach ID	A2	**Sub-Reach Length**	300 ft		**Northing**	467050	**Easting** 4502824
Photos	**US: 35**	**DS:**	**36**	**LB:** **37**	**RB:**	**38**	

	Left Bank % Length	Left Bank % C/B	Right Bank % Length	Right Bank % C/B
Bank Composition				
Cohesive (Silt/Clay)				
Sand / Fine Gravel	5	30	5	30
Gravel/Cobble	95		95	
Boulder/Bedrock/Other				

Bank Angle	***Degrees***	Left Bank	Right Bank
Mild	0-30	20	15
Moderate	31-60	80	82
Steep	61-90		3
Overhang	91+		

Bank Vegetation	Left Bank	Right Bank	Maturity
Bare Earth	79	79	
Nascent Vegetation	20	20	2
Perennial Vegetaton	1	1	2
Shrubs			
Trees			

Maturity: (**1** = 1st yr; **2** = 1-5 yrs; **3** = mature; **4** = old growth)

Riparian Vegetation	Left Bank	Right Bank	Maturity
Bare Earth / Litter Cov.	85	85	
Nascent Vegetation	15	15	2
Perennial Vegetaton			
Shrubs			
Trees			

Active Bank Erosion (% of Face)		Left Bank	Right Bank
Low	0 - 25%	100	90
Moderate	26 - 50%		
High	51 - 75%		10
Severe	76 - 100%		

Stream Restoration Treatment Inventory

Bank Treatments

	Right Bank	Left Bank
Type		
Length		
Quality		
Photos		
Type		
Length		
Quality		
Photos		

Quality: (***1*** *= Failed;* ***2*** *= Poor;* ***3*** *= Moderate;* ***4*** *= Good)*

In-Channel Treatments / Structures

Type
Number
Quality **Good Moderate Poor Failed**
Photos

Type
Number
Quality **Good Moderate Poor Failed**
Photos

Notes on Structures:

Bed Stability

Bed Composition (%)	**Cohesive**	**Sand**	10	**Gravel**	10	**Cbl/Bldr**	40	**Bedrock**	40
Bed Morphology	**Cascade**	**Step-pool**	80	**Riff/Gld**	20	**Pool/Riff**		**Dune/Ripp**	
Recent/active incision?	**YES**	**NO**		Aggradation?		**YES**		**NO**	
Severity of incision	**< 1 ft**	**1-2 ft**		**2-3 ft**	**> 3 ft**				

REACH NOTES:

Instructions: Enter percent length values into each white box for each sub-reach. The colored boxes will automatically calculated weighted averages within each category as well as the composite bank stability score. Category weights may also be adjusted as the user deems appropriate.

Bank Stability

Weights		SCORE	REACH ID A1 Left Bank	REACH ID A1 Right Bank	REACH ID A2 Left Bank	REACH ID A2 Right Bank	REACH ID A3 Left Bank	REACH ID A3 Right Bank	REACH ID A4 Left Bank	REACH ID A4 Right Bank	REACH ID A5 Left Bank	REACH ID A5 Right Bank	REACH ID A6 Left Bank	REACH ID A6 Right Bank	Average Scores Left Bank	Average Scores Right Bank
			Percent of Length		*Percent of Length*		*Percent of Length*		*Percent of Length*		*Percent of Length*		*Percent of Length*			
1	**Bank Composition**															
	Cohesive (Silt/Clay)	4	25	25	5	5		50								
	Sand	3	75	75	95	95	50	50	50	50	75	100				
	Gravel/Cobble	2					40		50	50	10		70	30		
	Boulder/Bedrock	1		50			10				15		30	70		
			3.3	3.8	3.1	3.1	2.4	3.5	2.5	2.5	2.6	3.0	1.7	1.3	2.8	3.2
1	**Bank Angle - Degrees**															
	Mild - 0-30	1	75	70		20		100		100		100	15	15		
	Moderate - 30-60	2	25	25	100	80	100		75		25		45	85		
	Steep - 60-90	3		5					25		75		40			
	Overhang - > 90	4														
			1.3	1.4	2.0	1.8	2.0	1.0	2.3	1.0	2.8	1.0	2.3	1.9	1.9	1.3
2	**Bank Vegetation**															
	Bare Earth	5	70	70	90	90	98	45	98	50	97	90	85	90		
	Nascent Vegetation	4	4	4	5	5	2	50	2	45	2	7	5	5		
	Perennial Vegetation	3	20	20	3	3	2	5	2	5	1	3	10	5		
	Shrubs	2	2	2												
	Trees	1	4	4												
			4.3	4.3	4.8	4.8	5.0	4.4	5.0	4.5	5.0	4.9	4.8	4.9	4.8	4.5
1	**Riparian Vegetaton**															
	Bare Earth	5	38	38	85	15	86	94	95	67	98	79	55	90		
	Nascent Vegetation	4	4	4	10	5	2	5	5	30	1	15	3	5		
	Perennial Vegetation	3	7	7	3	75	2	1	1	3	1	3	35	5		
	Shrubs	2	1	1			2					3	2			
	Trees	1	50	50	2	5							5			
			2.8	2.8	4.8	3.3	4.5	4.9	5.0	4.6	5.0	4.7	4.0	4.9	4.3	3.9
3	**Active Bank Erosion**															
	Low: 0 - 25%	1	95	95	75	75	15	100	15	100	10	100	50	100		
	Moderate: 25 - 50%	2			25	25	85		70		70		20			
	High: 50 - 75%	3	5	5					15		20		30			
	Severe: 75 - 100%	4														
			1.1	1.1	1.25	1.25	1.85	1	2	1	2.1	1	1.8	1	1.6	1.1
	Composite Bank Erosion Hazard Score		55%	57%	66%	61%	70%	61%	74%	57%	76%	61%	65%	59%	66%	59%

Bed Stability

		A1	A2	A3	A4	A5	A6	
Recent/active incision?	(Yes / No)	NO	NO	NO	NO	NO	NO	**No. Sub-Reachse w/ Incision** 0
Severity of incision	> 1 ft							
	1 - 2 ft							
	2 - 3 ft							
	> 3 ft							
		0	0	0	0	0	0	**Average Incision Severity** 0.0
Bed Material Composition								
Cohesive	5							
Sand	4	50	20	20	20	10	25	
Gravel	3	30	40	40	40	20	25	
Cbl/Bldr	2	20	40	40	40	60	20	
Bedrock	1					10	30	
		3.3	2.8	2.8	2.8	2.3	2.5	**Average Bed Material Size** 2.7

Composite Stream Stability Score

3.1

Instructions: Enter percent length values into each white box for each sub-reach. The colored boxes will automatically calculated weighted averages within each category as well as the composite bank stability score. Category weights may also be adjusted as the user deems appropriate.

Bank Stability

Weights	Category	SCORE	REACH ID B1 Left Bank	REACH ID B1 Right Bank	REACH ID B2 Left Bank	REACH ID B2 Right Bank	Average Scores Left Bank	Average Scores Right Bank
			Percent of Length		*Percent of Length*			
1	**Bank Composition**							
	Cohesive (Silt/Clay)	4	20	40				
	Sand	3		10	5	5		
	Gravel/Cobble	2	80		95	95		
	Boulder/Bedrock	1		50				
			2.4	2.4	2.1	2.1	2.2	2.2
1	**Bank Angle - Degrees**							
	Mild - 0-30	1			20	15		
	Moderate - 30-60	2	30	75	80	82		
	Steep - 60-90	3	70	25		3		
	Overhang - > 90	4	20					
			3.5	2.3	1.8	1.9	2.7	2.1
2	**Bank Vegetation**							
	Bare Earth	5	75	95	79	79		
	Nascent Vegetation	4	7	3	20	20		
	Perennial Vegetation	3	3	2	1	1		
	Shrubs	2						
	Trees	1	15					
			4.3	4.9	4.0	4.0	4.1	4.5
1	**Riparian Vegetaton**							
	Bare Earth	5	50	50	85	85		
	Nascent Vegetation	4	5	3	15	15		
	Perennial Vegetation	3	20	8				
	Shrubs	2		5				
	Trees	1	25	25				
			3.6	3.2	4.3	4.3	3.9	3.7
3	**Active Bank Erosion**							
	Low: 0 - 25%	1	80	50	100	90		
	Moderate: 25 - 50%	2						
	High: 50 - 75%	3	20	50		10		
	Severe: 75 - 100%	4						
			1.4	2	1	1.2	1.2	1.6
	Composite Bank Erosion Hazard Score		63%	68%	54%	56%	0.6	0.6

Bed Stability

		REACH ID B1	REACH ID B2	
Recent/active incision?	(Yes / No)	YES	NO	**No. Sub-Reachse w/ Incision**: 1
Severity of incision	> 1 ft			
	1 - 2 ft	1		
	2 - 3 ft			
	> 3 ft			
		2	0	**Average Incision Severity**: 1.0
Bed Material Composition				
Cohesive	5			
Sand	4	10	10	
Gravel	3	15	10	
Cbl/Bldr	2	50	40	
Bedrock	1	25	40	
		2.1	1.9	**Average Bed Material Size**: 2.0

Composite Stream Stability Score

2.9

APPENDIX C

Skin Gulch, Subreach A1



Skin Gulch, Subeach A2

Skin Gulch, Subreach A3




Skin Gulch, Subreach A4

Skin Gulch, Subreach A5

Skin Gulch, Subreach A6

Skin Gulch, Subreach B1

Skin Gulch, Subreach B2

APPENDIX 3

AloTerra
Restoration Services

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970-420-7346

December 15, 2016

Jennifer Kovecses
Executive Director
Coalition for the Poudre River Watershed
320 E. Vine Drive, Suite 213
Fort Collins, CO 80524

RE: Final Report for High Park Fire Research Project

Hello Jen,

It has been a pleasure working with you and the CPRW stakeholders throughout the research period for this project. Acquiring three years of post-fire research data has provide some insights into plant community responses following post-fire watershed protection revegetation, the understanding of which can have management implications following future fires in the Cache la Poudre Watershed.

This report is organized with similar sections to a research paper, though does not contain an abstract. A while ago, Jeremy Sueltenfuss and I decided to convert the English units to Metric units in anticipation of submittals to peer reviewed publications. As such, some of the numbers contain odd fractions. I will be happy to provide the original English units at your request. I will be approaching Jeremy again this Winter to see if he is interested in co-authoring a paper with respect to this data. If you have any concerns questions about our pursuit of such a paper, please let me know.

We are grateful for the opportunity to work with you in this endeavor, and hope that you find this information useful.

Kind regards,

Owner/Principal Restoration Ecologist
AloTerra Restoration Services, LLC

Plant Community Response to Revegetation Treatments following the High Park Fire: Management Implications

INTRODUCTION

Fire is a natural element of disturbance in most North American ecosystems, with its severity, return interval, and patchiness varying widely by habitat type and other temporal and landscape level patterns. In the Southern Rockies Ecoregion (EPA Level III Ecoregion), forest fires often produce a variety of unburned, low, moderate, and high severity soil and canopy burn conditions, resulting in a landscape level matrix of post-fire habitats for a great variety of wildlife. High landscape-level habitat diversity, in turn, reduces the risk of future stand-replacing fires, and maintains multiple natural processes and functions essential to ecosystem health. The Front Range of Colorado, with a history of fire suppression that often leads to substantial increase in fuel loads and tree canopy density, and due to its arid conditions and natural fire-prone conditions, has experienced several catastrophic wildfires over the past two decades: Hayman Fire, 2002 (137,760 acres/55,750 hectares), Buffalo Creek Fire of 1996 (12,000 acres/4,856 hectares), Waldo Canyon Fire, 2012 (18,247 acres/7,384 hectares), the High Park and Hewlett Fires of 2012 (combined 90,000 acres, 36,421 hectares), and the West Fork Fire Complex (110,404 acres/44,679 hectares). The cost of property loss alone from the 2012 fires in Colorado exceeded $583,000,000 (Gabbert, B., 2012), with suppression costs of those fires exceeding $100,000,000 (Gabbert, B., 2012). These costs do not include the cost of emergency watershed protection, restoration, and infrastructure recovery, estimated at over $5,000,000 for the High Park Fire alone.

The frequency and intensity of wildfires has increased over the past decade in the Western United States (National Interagency Fire Center 2009) and the frequency of fires may increase further due to global climate change models that predict a drier climate (Kirtman, B. et al., 2013), lower snowpack in many regions of North America, including the Southern Rocky Mountains (IPCC, 2013; Sanford et. al., 2013). For these reasons, and given the impacts of fire on local and downstream communities, it is necessary to better understand the impacts of reclamation (i.e., NRCS's emergency watershed protection program) treatments on post-fire conditions. We use the term *reclamation* to describe treatments applied to accomplish one or more of the following outcomes: high plant productivity, high vegetation cover, reduced soil surface erosion, and rapid establishment of vegetation. While *ecological restoration* may share some of these goals, ecological restoration treatments are typically prescribed with goals such as diversity, resilience, and ecological/plant community function.

Front Range communities impacted by severe wildfires, such as Colorado Springs, Denver, Fort Collins, Greeley, and Loveland, have a legitimate concern for the effectiveness of post-fire emergency watershed protection measures, as a community's water supplies, irrigation infrastructure, roads, highways, and other downstream infrastructure are at risk from mudslides, siltation, debris flows, and chemical impacts, as well as the various impacts to recreational resources, forest agriculture, and aesthetics. Accelerated soil erosion and changes in soil surface hydrology have been reported under conditions of reduced vegetation cover and altered soil structure (Sampson 1918, McCalla et al. 1984, Khan et al. 1986, Linse 1992, Brooks et al. 1997, Pearce et al. 1998). Under post-fire conditions in steep forested areas, soil erosion rates approach some of the highest recorded under natural disturbance regimes in the United States. In the high park fire burn, soil erosion rates were estimated as high as 9 tonnes hectare^{-1} yr^{-1}.

Treatments that reduce run-off rates and sediment loss from hillsides are the focus of most post-fire reclamation efforts, with seeding alone or in combination with mulch providing the most common treatments. It has long been recognized that vegetation cover is an important controllable factor that affects surface runoff and erosion (Sampson 1918). Vegetation can influence sediment production and infiltration by reducing the velocity of overland flow, increasing surface roughness, creating soil pores through root activity, and by the soil binding properties of roots (Kilinc and Richardson 1973, Wilcox et al. 1988, Meeuwig 1969, Khan et al. 1986, Thurow et al. 1986, Linse 1992). In a laboratory experiment, Kahn et al. (1986) showed that soil loss decreased with an increase in mulch cover and near surface canopy cover. In an upland range study, Linse (1992) found that 70% total cover yielded effectively zero sediment production, while less than 30% cover resulted in dramatic increases in sediment production. Similar results were found by Shaxson (1981) who reported that vegetation cover less than 40% resulted in drastic increases in sediment production. McCalla et al. (1984) also reported that total vegetation cover and grass standing crop had a significant influence on sediment production.

On a cautionary note, Blackburn (1975) found that plant cover alone was poorly correlated with sediment production. Litter cover, surface roughness, soil organic matter, soil bulk density and root development are strongly correlated with vegetation cover and significantly influence soil surface hydrology (Blackburn 1975, Balliette et al. 1986, Benkobi et al. 1993, Mergen 1998). Meeuwig (1969) found that soil organic matter was the most important soil factor that influenced erosion. Soil organic matter binds soil particles into aggregates and expands the soil (Blackburn 1975), thereby enhancing infiltration. This results in reduced splash detachment and surface runoff. Soil bulk density, which decreases with an increase in soil organic matter, was also found to have a strong negative relationship with infiltration rate (Balliette et al. 1986). Several studies have shown that increases in litter cover are also positively correlated with infiltration and negatively correlated with sediment production (Meeuwig 1969, Tromble et al. 1974, Thurow et al. 1986, Benkobi et al. 1993). Summarizing these impacts, Brooks et al. (1997) claims the key to preventing water erosion is to maintain the surface soil in a condition that readily accepts water -- the more water that infiltrates into the soil, the better the chance for increased plant growth and a reduction in surface runoff.

As documented by DeBano et al. (1998) and Neary et al. (2005), high-intensity wildfire can destroy or greatly diminish all of the beneficial soil and ground cover qualities listed above, often resulting in greatly increased soil erosion rates. The influence of fire on soil erosion, and the influence of mulch on soil erosion following fire is well summarized by Robichaud et al. (2010). However, the impacts of revegetation efforts on post-fire plant community or soil erosion responses are poorly understood, and research results, where they do exist, are often confounded by variables such as poor time of seeding, drought conditions following seeding, poor documentation of seed mix, seeding technique, use of non-native plants, or all of the above.

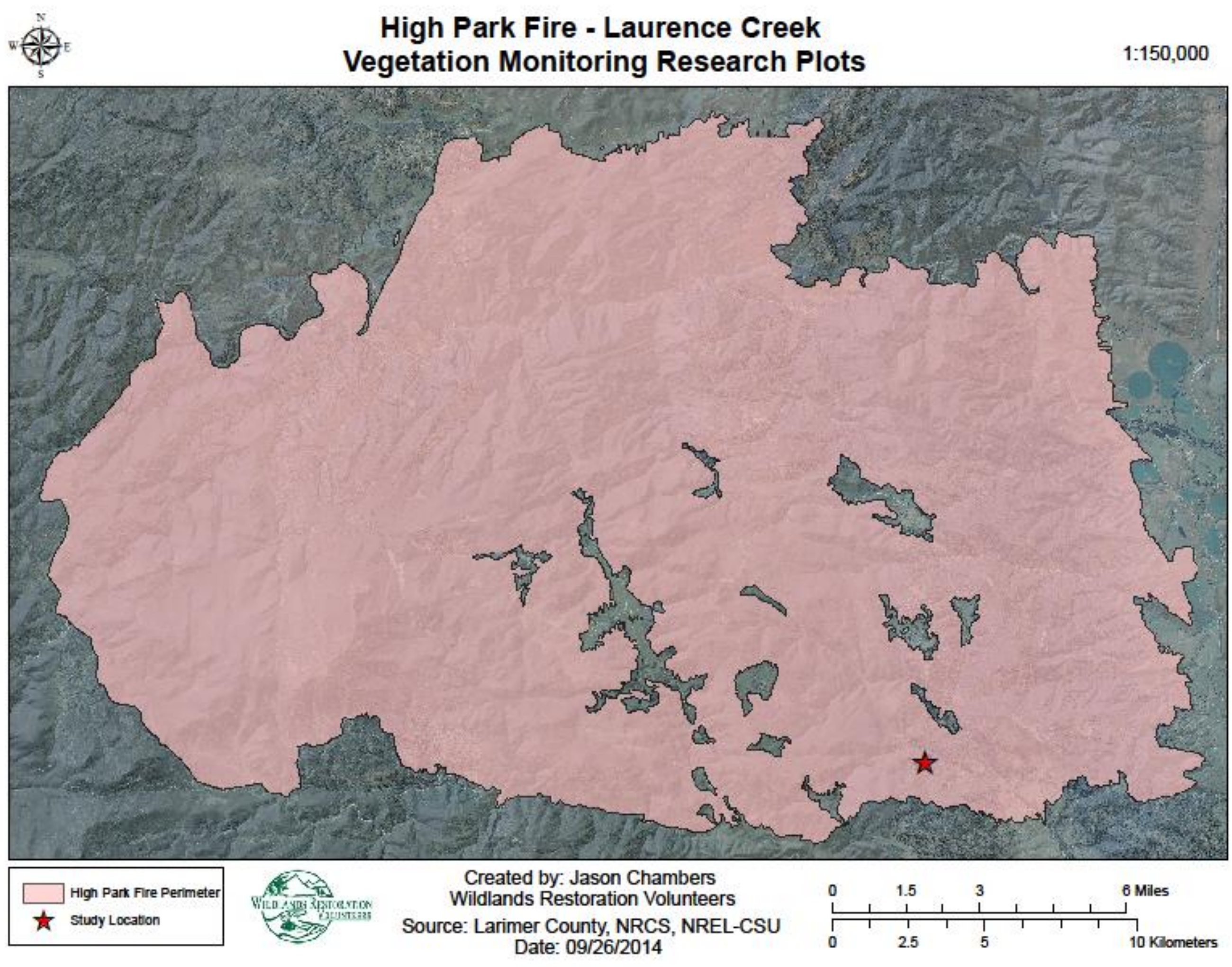
In a comprehensive summary of the literature, Peppin et al. (2010) reviewed 94 papers on post-fire seeding effectiveness in the Western U.S., concluding post-wildfire seeding does little to protect soil in the short-term, has equivocal effect on invasion of non-native species, and can have negative effects on native vegetation recovery, although long-term studies are needed to assess lasting impacts of seeded species. The Peppin et al. (2010) paper highlighted that a significant portion of the post-fire revegetation research was of low quality, evaluated the use of non-native species in post-fire restoration, or focused on short term (1-2 year) results. Our paper focuses on plant community responses to revegetation and mulching efforts following the High Park Fire of 2012, which impacted 87,487 acres in the Northern Front Range of Colorado. Estimates from the High Park Fire Burned Area Emergency Response Report (BAER report, July, 2012) predicted post-fire soil erosion rates as high as 9 tonnes ha^{-1} yr^{-1} in high severity burn areas, and a vegetative recovery period of 3-5 years before adequate plant-induced conditions provided effective hill slope stability. In Upper Laurence Creek, the site of our research, the BAER report (2012) estimated a 281% increase run-off rate, as compared to pre-burn conditions.

From our data, and in the context of the post-fire and erosion control literature presented above, we draw conclusions about the potential effects of post-fire seeding efforts on plant species richness, exotic plan invasion, native plant cover, and hill slope sediment loss.

METHODS

The research was conducted in a sub-watershed referred to as Upper Laurence Creek, which experienced a high-severity soil and canopy burn during in the 2012 High Park Fire (High Park Fire BAER Report, July 2012). Slopes within the research plots ranged from 25 to 47%, 348 to 48 degree aspect (magnetic north), and were dominated by a mixed forest type of mostly ponderosa pine (*Pinus ponderosa*), with a sub-dominance of Douglass fir (*Pseudotsuga menziessii*). Estimated tree density was greater than 100 trunks ha^{-1} before the fire, with 100% tree mortality following the fire. Elevation ranged from 2,011 meters a.s.l. and 2,072 meters a.s.l. Composite soil samples were taken to 10 cm deep across representative sites in each treatment, and were deemed to be similar enough as to not serve as a confounding variable among treatments. Soils were classified as sandy loams (60% sand, 20% silt, 20% clay), with pH ranging from 5 to 6, and EC of 0.1.

The research plots occurred wholly on private property, where restoration treatments were supported financially by the Natural Resources Conservation Service and the Community Foundation of Northern Colorado, and were planned and implemented by Widlands Restoration Volunteers in November, 2012. The NRCS seed mix (Table 1), was required for use on private lands where the land owner was to be reimbursed by the NRCS's Emergency Watershed Protection (EWP) program. Certified weed-free straw was applied, and the straw fields inspected by author, to ensure undesirable weed species were not present in the straw bales. Straw was applied over seeded areas at a rate of 2.5 tonnes ha^{-1}, while seed was hand broadcast seeded at 984 seeds m^{-1} (100 seeds s.f.$^{-1}$).



Bromus marginatus (Bromar, MT) *Elymus trachycaulus* (Pryor, MT) *Pascopyrum smithii* (Rosana, MT - unselected) *Poa secunda* (Mtn. home) Triticale (cover crop)

Table 1. EWP seed mix for low elevations ponderosa pine habitats.

A total of twelve research plots (15m x 45m) were established by the author in areas of high soil and canopy burn severity, and received either seed + straw mulch (**No Rake**; 4 plots), seed incorporated into the soil surface by means of raking + straw mulch (**Rake,** Figure 1; 4 plots), or no treatment (**Control**; 4 plots, control). In late July 2013, early August 2014, and late July 2015, vegetation and ground cover were monitored using a line-point intercept method (Herrick et. al. 2005), points taken with cross-hair PVC scopes or a laser scope (Figure 2). In each plot, ten (2013) 30.5m temporary transects were established at random origins and run vertically up the slope. Two sampling points were recorded every 0.9 meter (one on each side of the tape), for a total of 68 points per transect. Each transect also served as a 2m x 30.5m belt transect, in which presence-absence species data was recorded. The same protocol was followed in July-August of 2014, with the exception that seven temporary transects were established, the reduced number reflecting a realization that the ten transects per plot was far too high a sampling frequency with respect to the area of the plot.

Figure 1. Raking Seed

Figure 2. Monitoring Scope

Figure 3. Applying weed-free agricultural straw.

RESULTS

Ground Cover

Total % absolute vegetation cover is shown in **Figure 4**, with standard error bars. Total % absolute vegetation + litter cover is provided in **Figure 5**. In 2013, agricultural straw was by far the dominant form of litter in a plots. In 2014, natural above ground biomass quickly replaced straw as the dominant litter type, and by 2015 it was very difficult for observers to find any straw in the research plots.

Plant Community Data

The characteristics of any species of plant may be described in a variety of ways depending on the research questions being asked. For this study, as is typical with many vegetation monitoring studies aimed at quantifying plant community responses to restoration treatments, we have defined a variety of vegetation classes based on a combination of the following traits:

Origin: **N**ative or **I**ntroduced
Life History/Duration: **A**nnual, **B**iennial, or **P**erennial
Growth Form: **F**orb, **G**rass (including sedges and rushes), **S**hrub, or **T**ree.

The combination of these traits result in the following vegetation categories: Native Perennial Grass (NPG), Native Perennial Forb (NPF), Native Biennial Forb (NBF), Native Annual Forb (NAF), Native Annual Grass (NAG), Native Tree (NT), Native Shrub (NS), and the Introduced equivalent of these vegetation categories. **Figure 6** provides a summary of these vegetation categories over the course of three seasons, for each treatment.

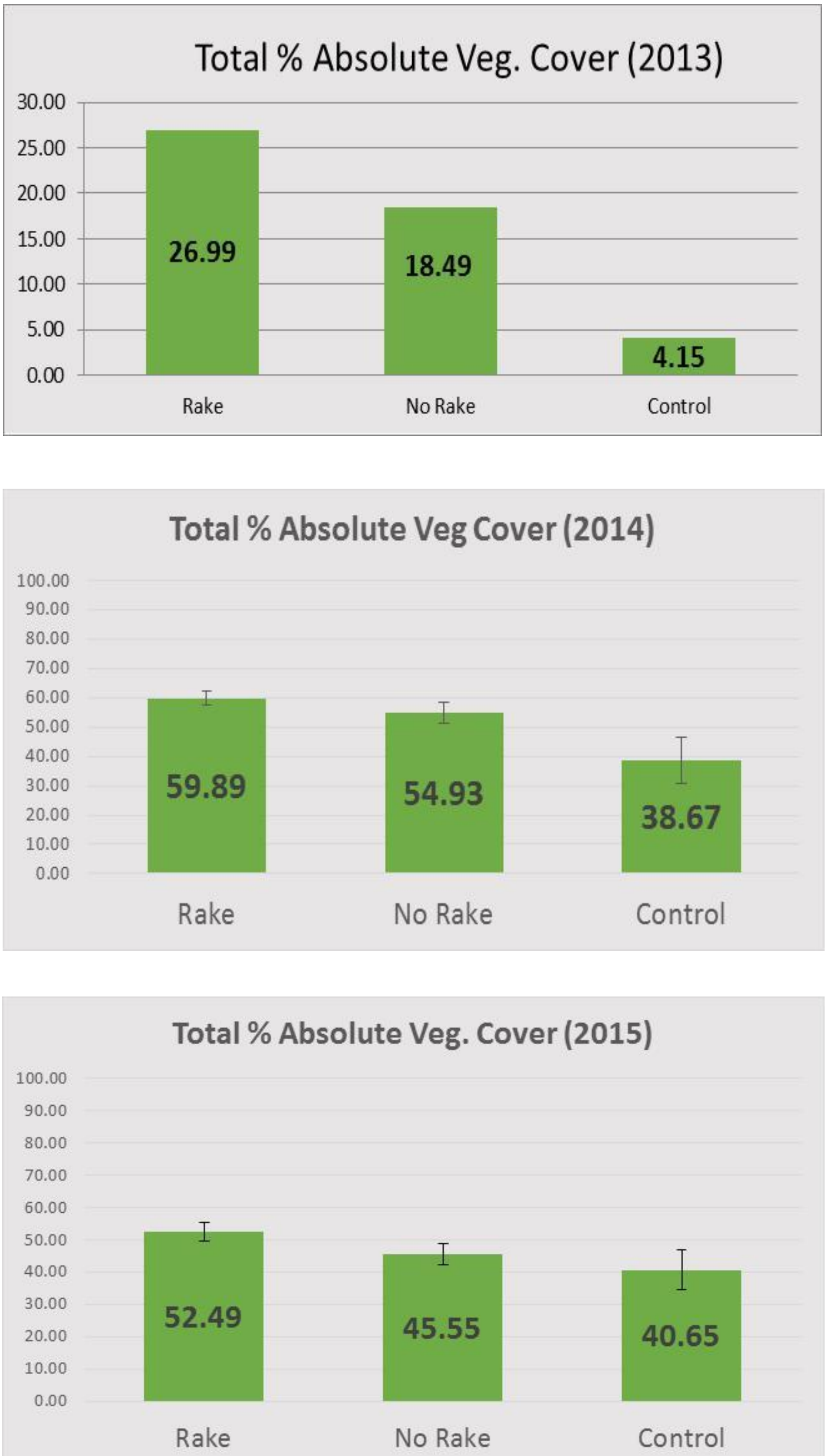


Figure 5. Total % Absolute Vegetation+Litter Cover*, All Years

* In 2013 majority of litter cover was agricultural straw.

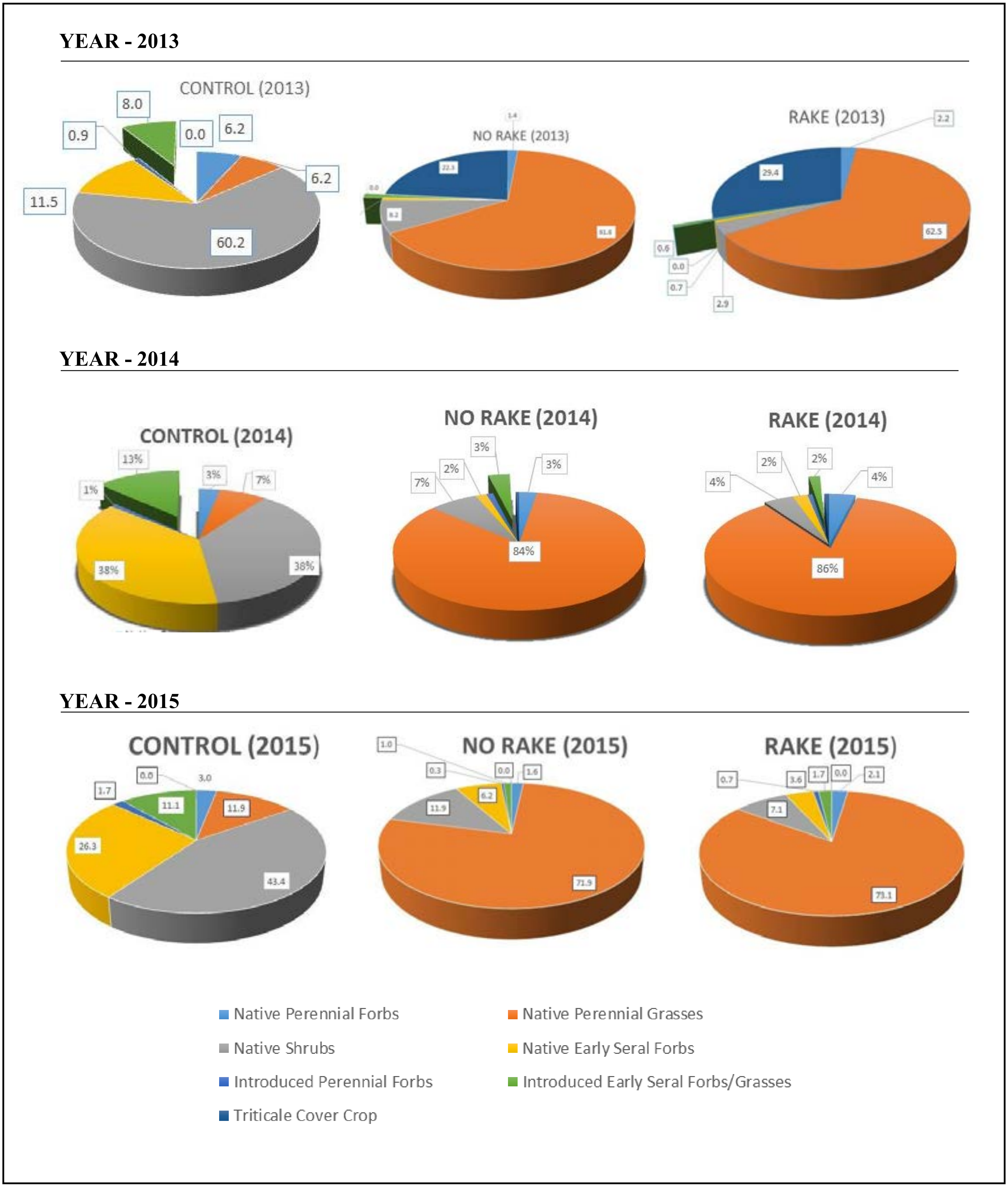


Figure 6. Relative Vegetation Cover (%) by vegetation categories, year, and treatment.

Richness and Diversity

Species richness and diversity (Shannon Diversity Index, Shannon 1948) were calculated based on presence/absence data in the belt transects, and are presented in **Table 1**.

VARIABLE	2013			2014			2015		
	Rake	No Rake	Control	Rake	No Rake	Control	Rake	No Rake	Control
Number of Species	57	61	62	60	55	80	63	58	94
Eveness	0.96	0.86	0.87	0.87	0.86	0.89	0.89	0.88	0.9
Diversity (H')	3.9	3.6	3.5	3.57	3.48	3.91	3.68	3.59	4.08

Table 1. Species Richness, Evenness, and Shannon Diversity Index.

Discussion

The raked and unraked plots exhibited similarly high vegetation and vegetation+litter cover over the three years of evaluation. The levels of cover in the raked and unraked plots far exceeded the minimum 50% cover deemed adequate by many federal agencies for post-fire hillslope protection and erosion control. Further, the raked and unraked plots consistently exhibited far less weed cover than the control plots, higher cover of native perennial grasses, yet lower overall species richness.

As compared to anecdotal evidence across other High Park Fire treated areas, the straw cover in our plots exhibited high permanence (i.e., it did not blow away). We attribute this to the coupled factors of timing of seeding (late fall), and high seeding success (in part due to late fall seeding).

	Introduced Veg. (Rel. % cover)		Native Perennial Grass (Rel. % Cover)		Total Vegetation (% Cover)		Veg+Litter (% Cover)		*Conyza canadensis** (% cover)	
Year	CONT	RAKE	CONT	RAKE	CONT	RAKE	CONT	RAKE	CONT	RAKE
2013	9	1	6	63	4	30	9	82	2	0
2014	14	2	7	86	39	60	47	87	15	2
2015	13	3	12	83	40	52	52	80	25	4

* *Conyza canadenzis* was included in native cover in all years

Table 2. Summary of vegetation cover, 2013-2015.

Management Implications

Vegetation Cover

Our results differ significantly from many precious studies that have concluded "seeding does not work." Some of the previous studies have claimed that seeding does not lead to increased vegetation cover, or that it results in an increase in introduced species. Clearly, based on the results of this project, seeding + weed-free straw resulted in increased vegetation cover, increased ground cover, and a significant decrease in the cover of introduced vegetation, as compared to the control plots.

Species Richness

However, the control plots had a higher species richness and diversity than the raked or unraked plots. While much of this species richness may have been the result of the presence of introduced species in the control plots, there was clearly much more native cover in the control plots than in the seeded plots.

Timing of Treatments

When the goal of treatments is emergency watershed protection, the results of this study indicate clearly that seeding+mulch treatments are more effective at achieving desired levels of ground cover than doing nothing. However, the timing of the application of treatments likely has a pronounced impact on results. There was much anecdotal evidence that, with a summer application of mulch in July, August, and September following the High Park Fire, much of this mulch blew away. Reapplications can cost as much as $4,000/acre. Further, summer seeding can be less effective than fall seeding as a high percentage of seedlings sown in summer are likely to desiccate, succumb to herbivory, wash downslope, and suffer some other fate before appropriate germination requirements are met (usually in early spring in the High Park Fire burn area). When successful, seeding results (i.e., increased vertical cover) will help to reduce wind velocities at the ground surface, increase surface roughness, and provide a continual source of herbaceous litter. All such outcomes provide substantial benefits to the reduction of erosion on post-burn slopes.

Introduced Species

When the practitioner pays attention to the weed content of sourced materials (i.e., straw and seed), the concern of increased cover of introduced species in post-burn treated areas can be greatly reduced. Further, the results of this study indicate that seeding of native species (especially with a seed mix dominated by quick growing perennial grasses) can result in the reduction of introduced species in post-burn sites, at least in the short term. If we had included *Conyza canadensis* in the introduced species cover (e.g., it has been included in native cover for this study), the difference in introduced vs native cover in the control vs raked/unraked plots would have been even more significant.

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Appendix A: Photos

2013 Evaluation Photos

Control *(July 2013)*

No Rake *(July 2013)*

2014 Evaluation Photos (Control)

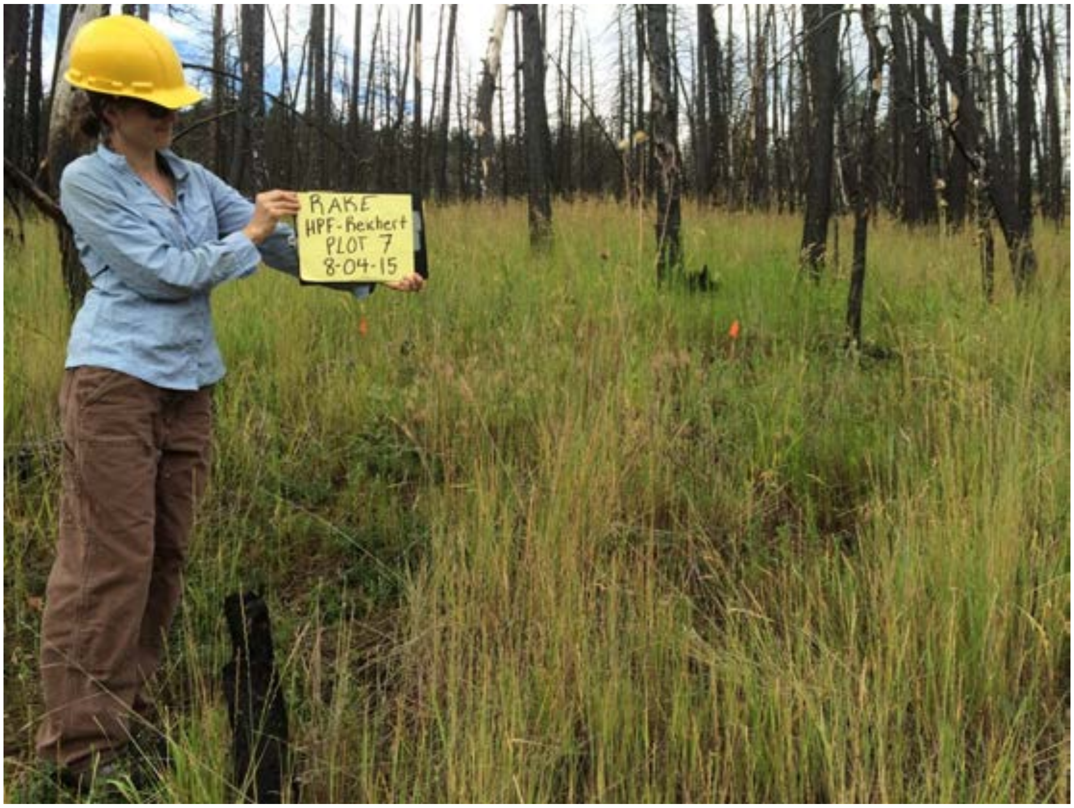
2014 Evaluation Photos (Rake)

This is actually Rake4

2014 Evaluation Photos (No Rake)

2015 Evaluation Photos (Control)

2015 Evaluation Photos (Rake)



2015 Evaluation Photos (No Rake)

APPENDIX 4

Monitoring the Initial Effects of Skin Gulch Restoration on Stream Nutrients

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Literature Citations upon request

Project Highlights

- Stream nutrient sampling and analysis took place throughout summer 2017, 2 years after the restoration activities were completed.
- Stream nitrate declined downstream and was significantly lower at the bottom of the restored stream segment compared to the upper portion. Nitrate concentrations were 30 to 50% lower in the downstream location for most of the sampling period.
- Total dissolved N showed a similar declining concentration, but differences were not statistically significant.
- There were no other decreases or increases in stream constituents along the restoration area.
- These findings indicate that the stream and riparian restoration is having a net positive effect on nutrient retention at this early stage.
- This monitoring effort provides a base line to evaluate post-fire changes in Skin Gulch and further evaluate the effectiveness of the restoration efforts on stream water quality.

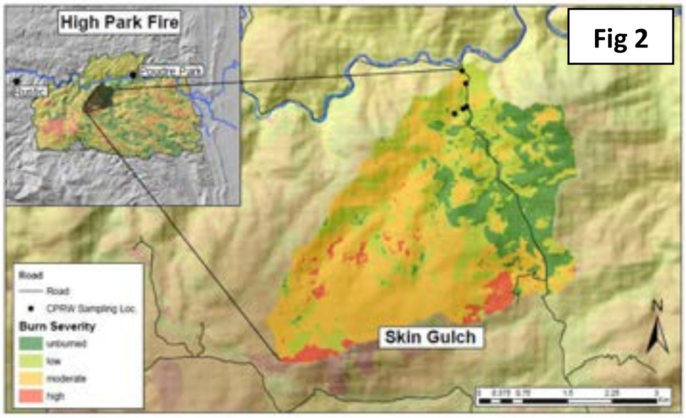
BACKGROUND

Wildfires shape the composition, structure and function of most western North American forest ecosystems (Agee, 1998; Turner, 2010). Fire frequency, size and severity have all increased in recent decades (Westerling, 2016), increasing concerns about the ability of forests to recover over space and time, and their capacities to sustain delivery of clean water and other ecosystem services. Combustion of forest biomass and organic soil layers drastically increases short-term nutrient and carbon losses (Bormann et al., 2008; Homann et al., 2011), and exposes catchments to post-fire erosion. Wildfires influence stream water quality and nutrient export by reducing plant demand, increasing soil nutrient availability in upland and riparian environments, and increasing erosional inputs of fine and coarse mineral materials (Certini, 2005; Turner et al., 2007; Wan et al., 2001). Hydrologic connectivity and transport from uplands to stream channels changes with post-fire reconfiguration of hillslope and stream channels (Hallema et al., 2017; Wagner et al., 2014). The legacies of fires also include large changes in within-stream processes that regulate nutrient uptake, release, and retention (Covino et al., 2010).

Excess nutrients are a primary cause of surface water impairment worldwide (US EPA 2000; Paulsen et al. 2008; Dodds et al. 2009). In the US, they are the single most common water quality concern for lakes and the third most important source for streams and rivers (Faustini et al. 2009). Excess nitrogen (N) and phosphorus (P) affect roughly one-third the total length of the nation's wadeable streams (USEPA 2006; Shapiro et al. 2008). To address this challenge and comply with the Clean Water Act of 1977 (P.L. 95-217), states are required to adopt, modify or develop water quality standards. The US Environmental Protection Agency proposed N and P concentration criteria for streams and rivers (USEPA 2000) that approximate nutrient levels for minimally-impacted streams in distinct ecoregions of the continental US (Omernik 1987). Numeric nutrient criteria aim to incorporate background concentrations and identify thresholds at which excessive algal growth and other biological responses are likely to occur (Dodds et al. 1998; Chambers et al. 2002).

Fig 1. Skin Gulch Stream Restoration Site. View to South along County Road 27 towards the High Park Fire.

In Colorado, the proximity of the 2002 Hayman and the 2013 High Park Fires to growing Front Range populations has brought the fundamental links between forest conditions, wildfire and water supply into sharp focus and highlighted the tenuous nature of water quality in watersheds vulnerable to severe wildfire. Water quality changes following the High Park Fire (Fig 2) compromised drinking water supply in the Cache la Poudre watershed, and water treatment and supply to > 250,000 homes and agricultural producers. For example, the City of Greeley was forced to stop using raw Poudre River water for 45 days in 2012 and 30 days in 2013 due to water quality concerns. To offset additional operational costs, the City of Fort Collins was forced to increase its water utilities rates by 4%. A recent study estimates that wildfire threatens 34 million acres of water supply source areas in forested watersheds of the western US (American Forest Foundation 2015).



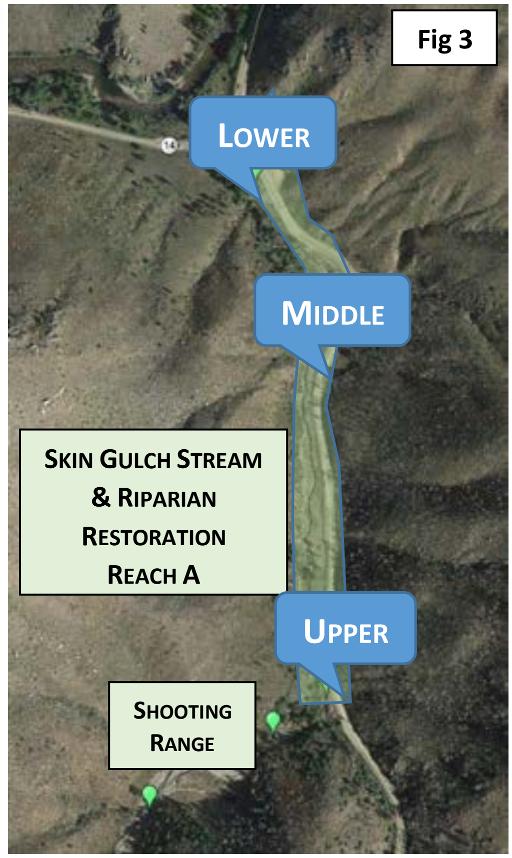


Table 1. Skin Gulch Stream Riparian Restoration Project stream monitoring locations. Upper, Middle, and Lower locations span the stream restoration reach along CR 27.

Sampling Site		Latitude	Longitude
Restoration Reach			
	Upper	40.67625	-105.3881
	Middle	40.67982	-105.3883
	Lower	40.68172	-105.3890
Shooting Range			
	Above	40.67515	-105.3889
	Below	40.67587	-105.3889

Skin Gulch Stream and Riparian Restoration

The general restoration objectives were to 1. Relocate active stream channel, 2. Provide short-term bank stabilization allowing for development of riparian vegetation, 3. Reconfigure stream channel planform (low flow), cross-sectional geometry, and reach gradient to support improved creek function, vegetation establishment, in-stream habitat, and sediment dynamics, and to restore channel capacity where currently limited and, 4. Connect stream with floodplain, to support wetland and riparian vegetation, to provide energy dissipation, and to allow for anticipated channel evolution.

Restoration involved active seeding, willow staking, and installation of native shrubs and trees in May 2015, with BioSol and humic acid/humate soil amendments to provide low quantity of slow release N, and to increase infiltration rates and nutrient/water holding capacity. The project also controls musk thistle, Canada thistle, and mullein, as desirable riparian vegetation becomes established. Woody debris or boulders were incorporated within the channel and along the floodplain to support in-stream habitat at a range of flows, provide velocity breaks, and promote seasonal inundation of revegetated areas.

Stream Nutrient Monitoring Project Objectives

To evaluate if physical and vegetation treatments are enhancing the ecosystem processes responsible for nutrient retention, we analyzed stream nutrients at three locations along Skin Gulch as it flows through the restoration area (Fig 3). Monitoring was conducted during summer 2017, three years after channel realignment and two years after revegetation treatments. As such, our inferences are limited due to the early post-restoration phase. However, this short-term study should help identify if there are negative consequences of the restoration treatments on stream nutrients and will establish a baseline to evaluate future changes.

STEAM WATER COLLECTION AND ANALYSIS

Streamwater samples were collected and analyzed for nutrients, C and acid-base chemistry weekly during the receding limb of the stream hydrograph (June and July 2017) and less frequently during fall baseflow conditions. Nutrient samples were collected in opaque HDPE plastic bottles. Plastic bottles were washed with de-ionized water (electrical conductivity < 1.0 $\mu S\ cm^{-1}$) prior to use and then triple-rinsed with stream water at the time of sampling. Samples were refrigerated after collection then filtered through 0.45μm mesh membrane filters (Millipore Durapore PVDF, Billerica, MA). Dissolved organic carbon (DOC) samples were collected in pre-combusted (heated for 3 hours at 500°C) amber, glass bottles and then filtered through 0.7μm mesh glass fiber pre-filters (Millipore Corporation). Collected samples were shipped cold to the US Forest Service, Rocky Mountain Research Station Biogeochemistry Laboratory in Fort Collins, CO and stored a 4°C prior to analysis.

Stream water anion and cation concentrations were determined by ion chromatography with electrical conductivity detection, using a AS12A Anion-Exchange column and AG12A guard column for NO_3-N (Dionex Corp, Sunnyvale, CA) and a IC-Pak Cation M/D column for NH_4-N (Waters, Co., Millford) (APHA, 1998a). Detection limits were 2 and 8 $\mu g\ L^{-1}$ for nitrate and ammonium, respectively. Dissolved total N (DTN) and organic C (DOC) were determined by high-temperature combustion catalytic oxidation using a Shimadzu TOC-V_{CPN} total organic carbon analyzer (Shimadzu Corporation Columbia, MD). Detection limits for DTN and DOC were 50 $\mu g\ L^{-1}$. Dissolved organic N (DON) was calculated as the difference of DTN and DIN (dissolved inorganic N = nitrate plus ammonium).

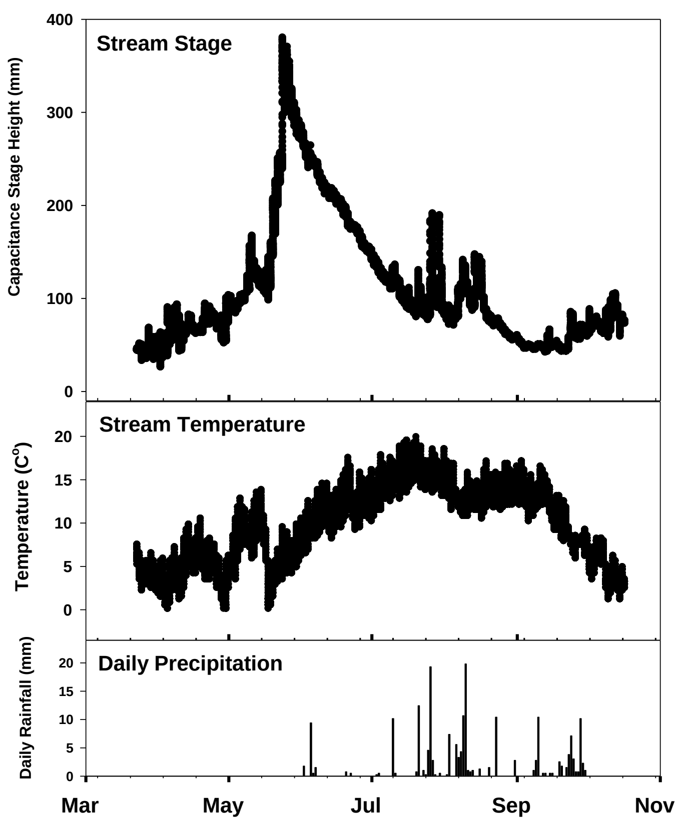


Fig 4. Seasonal patterns of stream height, temperature and daily precipitation for 2017 in the upper Cache la Poudre watershed. Stream data are from Sheep Creek and precipitation from Red Feather Lakes (Western Regional Climate Center; CO 6921).

RESULTS

Seasonal Patterns

Tributaries of the Cache la Poudre River show a distinct snowmelt hydrograph with peak flow in early June (Fig 4) reaching baseflow discharge conditions in September. During 2017, there were nine rainstorms that exceeded 7.5 mm (0.3") with the two largest days receiving almost 20 mm (0.76"). Individual rainstorms in late July and August increased streamflow and decreased temperature.

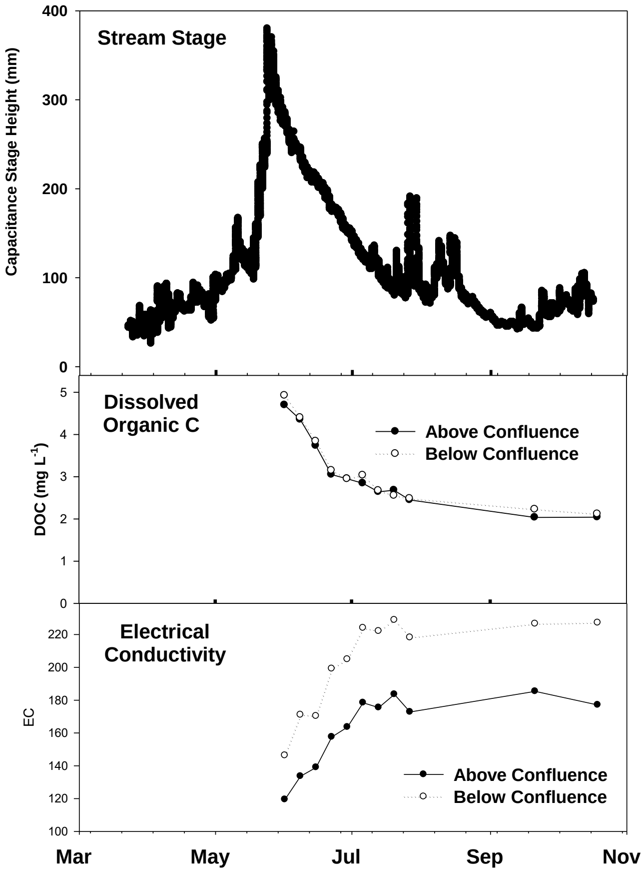


Fig 5. Seasonal patterns of stream height, for Sheep Creek with Dissolved organic C and electrical conductivity for Skin Gulch. The Above and Below Confluence correspond to the Restoration Reach A (Below) and the Shooting Range (Above).

Stream chemistry tracks discharge in headwater tributaries in regions with snowmelt-driven hydrology (Fig 5). Stream C peaks in spring as snowmelt delivers C released from terrestrial organic matter contained in mineral and organic soil layers. In Skin Gulch DOC declined by about half over the summer season. Conversely, electrical conductivity, the aggregation of charge bearing, soluble, non-biologically reactive elements is diluted by snowmelt streamflow and increases towards baseflow. The large differences in EC between the sites indicates that the two tributaries of Skin Gulch that meet at the upper portion of the restoration reach have distinct source water generated by different underlying geology or other factors associated with proximity the CR 27 or upper watershed land use.

Table 2 Skin Gulch Stream Riparian Restoration Project stream chemistry. Data are means of 11 samples dates, from June through October 2017, with standard deviatiation in parentheses. Upper, Middle, and Lower sample locations span the stream restoration reach along CR 27. Analyte concentrations in mg L^{-1}, expect where noted.

		Upper		Middle		Lower	
	pH*	8.2	(0.1)	8.2	(0.1)	8.2	(0.1)
Electrical Conductivity	EC**	208.1	(29.7)	201.2	(28.7)	201.2	(28.5)
Sodium	Na	8.4	(1.2)	8.2	(1.3)	8.2	(1.3)
Potassium	K	1.3	(0.2)	1.3	(0.2)	1.3	(0.2)
Magnesium	Mg	6.9	(1.1)	6.8	(1.1)	6.8	(1.1)
Calcium	Ca	24.8	(4.0)	24.3	(4.1)	24.3	(4.2)
Chloride	Cl	4.6	(1.3)	4.3	(0.8)	4.2	(0.8)
Orthophoshate	PO_4	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
Sulfate	SO_4	13.8	(1.7)	12.7	(3.1)	13.3	(1.8)
Nitrate-N	NO_3-N	0.28	(0.05)	0.24	(0.06)	0.20	(0.05)
Ammonium-N	NH_4-N	0.10	(0.04)	0.10	(0.05)	0.10	(0.05)
Dissolved Inorganic N	DIN	0.38	(0.05)	0.33	(0.06)	0.30	(0.05)
Dissolved Organic N	DON	0.04	(0.05)	0.06	(0.06)	0.06	(0.05)
Dissolved Total N	DTN	0.42	(0.07)	0.39	(0.07)	0.36	(0.06)
Dissolved Organic C	DOC	3.14	(0.93)	3.10	(0.91)	3.13	(0.87)

* pH is unitless; ** EC units: $\mu S\ cm^{-3}$

Restoration Effectiveness

Most stream water constituents were no different between the upper to lower locations (Table 2). Calcium and sulfate were the dominant cation and anion species in Skin Gulch water. Stream phosphate was below detectable levels. Nitrate represented the bulk of inorganic nitrogen. Organic stream N represented a small fraction (~10%) of the total dissolved N in Skin Gulch, where nitrate represented more than half of it.

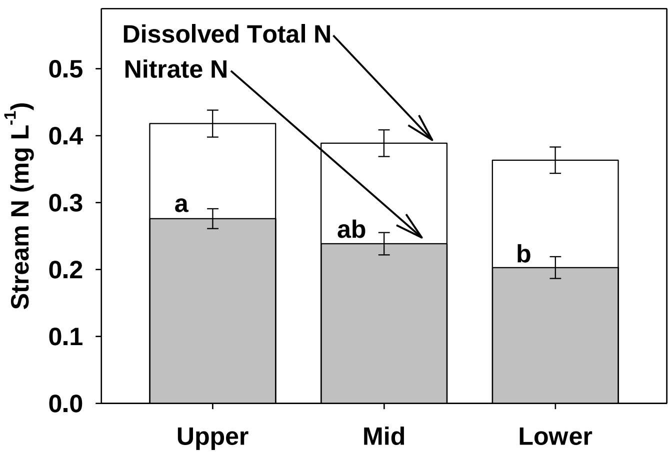


Fig 6. Dissolved total N and nitrate-N in Skin Gulch streamwater spanning the stream and riparian restoration area. Means from 11 sampling dates during 2017 with standard error bars. Different letters denote that mean nitrate values differ among sample locations.

The decline in stream nitrate-N along the length of the restoration reach was statistically significant (*$p < 0.05$; Fig 6*). There was a similar pattern for dissolved total N, though differences were not statistically significant. The proportion of DTN consisting of nitrate-N also decreased statistically downstream.

The relative downstream decline from the upper to the lower sample location was consistent seasonally. The greatest differences in nitrate N occurred in June and during the baseflow season. During those periods nitrate concentrations declined by 30 and 50% downstream.

Implications and Limitations

The small downstream declines in N concentrations are unlikely to represent dramatic changes in N release or retention, though the net response is positive. The consistent seasonal pattern suggests that the processes contributing to the decline may is independent of stream discharge or temperature.

With this short term data set it is not possible to conclude that the mechanical restoration operations or establishment of riparian vegetation are responsible for the decline in stream nutrients. Biological nutrient retention processes or dilution of the stream with low-N groundwater may explain some or all the decline.

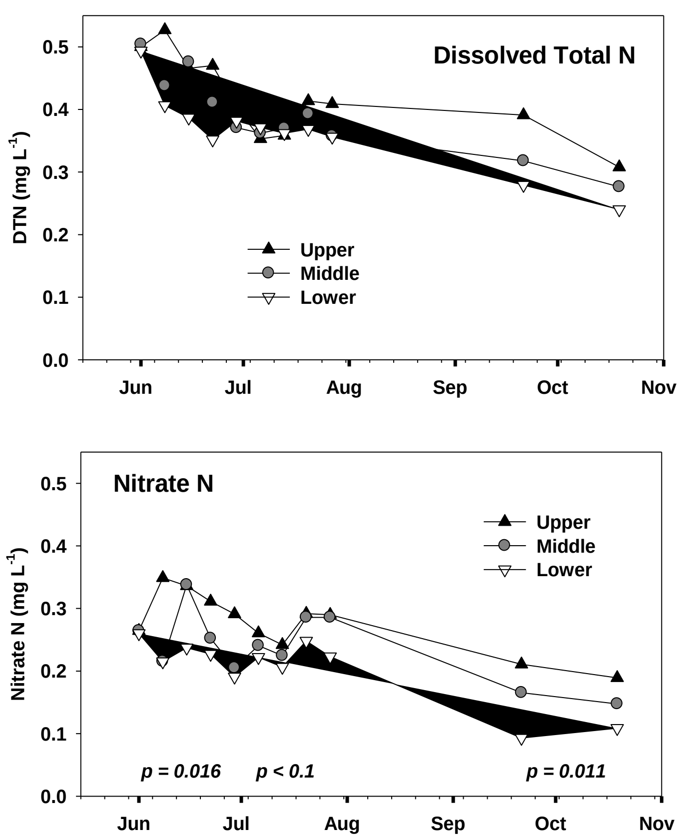


Fig 7. Season changes in stream dissolved total N and nitrate-N concentrations in Skin Gulch, 2017.

Nevertheless, we can conclude that the Skin Gulch stream restoration project has had not net negative effect on the stream nutrients analyzed. Importantly, the decline in N indicates that the biosol amendment used to assist revegetation did not enrich stream water with N.

Stream N concentrations in Skin Gulch were elevated high compared to the Poudre River or other catchments burned by the High Park Fire. For example, mean nitrate concentrations were about 10-times higher in Skin than Hill Gulch, a catchment of a similar size and extent high severity wildfire (high severity extent: Skin = 44%; Hill = 54%). Skin Gulch nitrate and DTN concentrations are similar to catchments affected by extensive, high severity wildfire during the Hayman Fire (Rhoades et al. 2011; Rhoades et al submitted).

Though the stream nitrate concentrations in Skin Gulch do not pose a threat to human health, aquatic resources in the Cache la Poudre may be at risk. Both nitrate and DTN concentrations greatly exceeded N concentrations representative of 'least-disturbed' reference streams of the Western Forest Region (e.g., 0.12 mg TN L^{-1} and 0.014 mg nitrate-N L^{-1}; (USEPA, 2000).

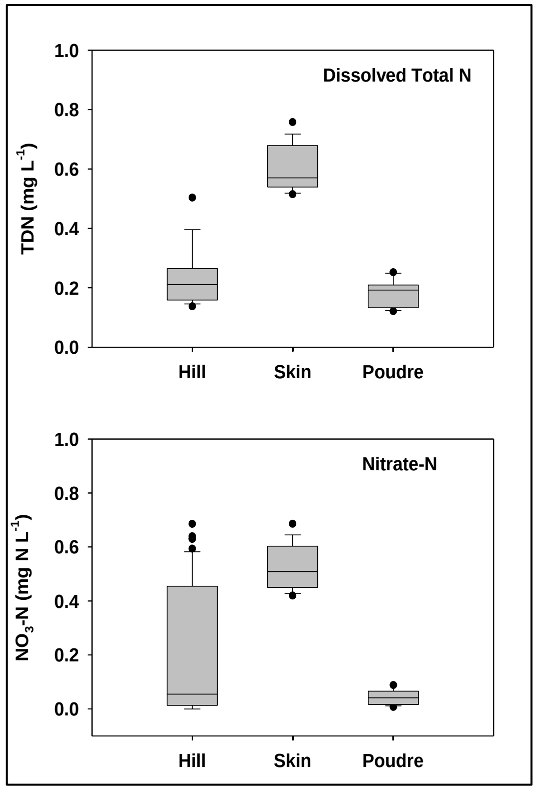


Fig 8. A 2014 comparison of stream N in two catchments affected by the High Park Fire with the Cache la Poudre sampled up-stream of the confluence with Skin Gulch. Boxes denote the 25th, 50th, 75th percentiles, bars denote the 5th and 95th percentiles, and dots denote outliers.

Restoration Effectiveness

This study provides baseline information to permit longer-term evaluation of the effectiveness of stream realignment and riparian restoration for improving post-fire water quality and nutrient retention.

Elevated post-fire N export from headwater catchments has obvious consequences for drinking water supply, municipal water treatment and aquatic habitat, yet they also underscore the prolonged response to severe wildfire. It is unknown if the continued nutrient losses in catchments burned by the High Park Fire are the consequence of lasting changes in soil nutrient availability and leaching (Certini, 2005; Jiménez-Esquilín et al., 2008; Turner et al., 2007), or merely because nutrient supply remains higher than plant demand. Within the Hayman Fire, we found that stream nitrate concentrations increased exponentially with the degree of riparian exposure (Rhoades et al. under review). The findings of this short-term monitoring activity provides initial support for the idea that planting within exposed riparian zones may facilitate the return to pre-fire stream nutrient levels.