Waldo Fire Recovery

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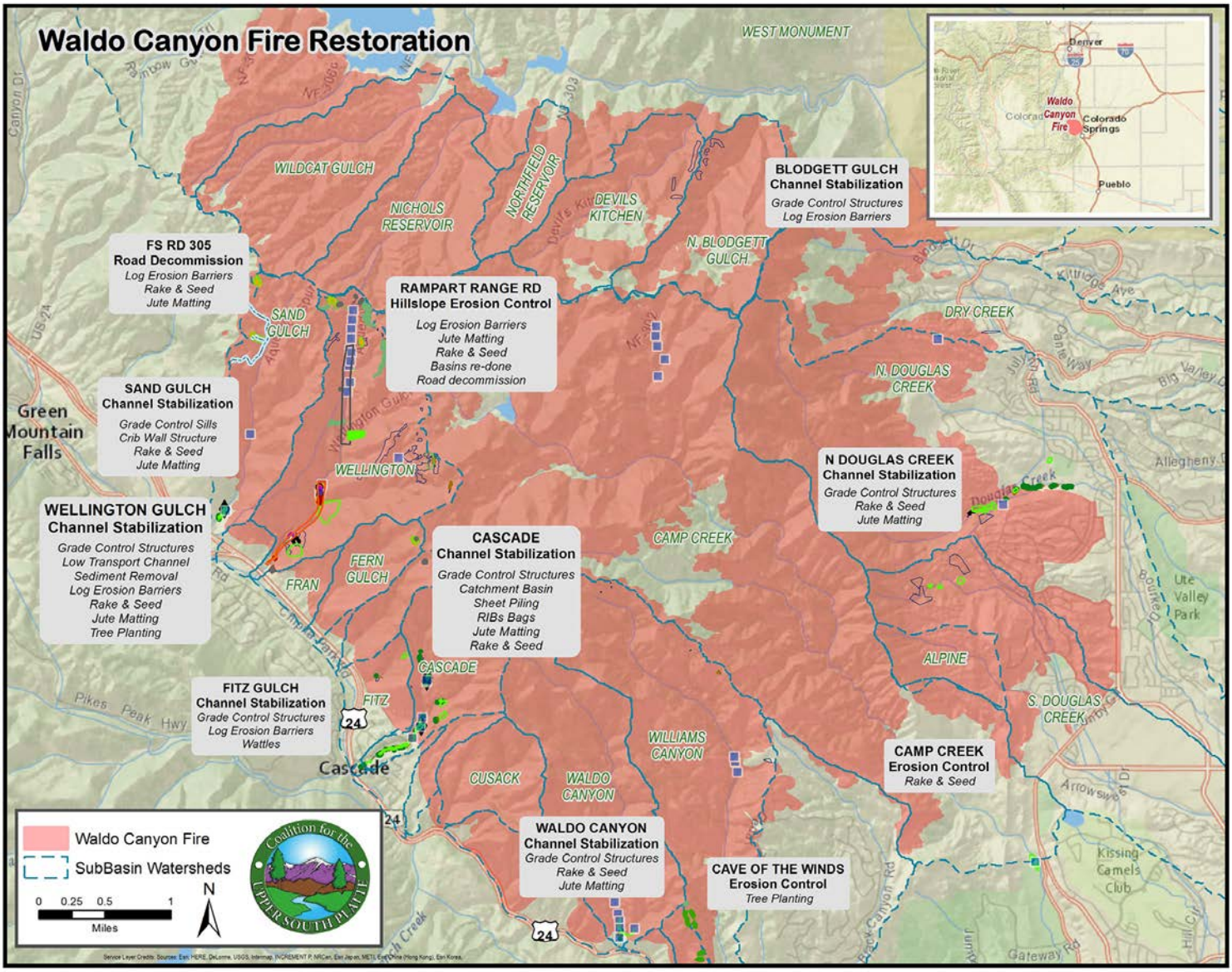
Overview

The Waldo Canyon Fire

Post-fire flooding in 2012 exposed Colorado Springs Utility's backup pipeline from Rampart Reservoir, making it unsafe to run water through until repairs could be completed.

Wispy smoke was first reported to Colorado Springs' 911 line on the evening of June 22, 2012. Based on the reports, the U.S. Forest Service (USFS) dispatched fire fighters to look for the source of the smoke around Blodgett Peak, on the northeast corner of the ultimate Waldo Canyon Fire scar, but they did not find active fire. The next morning they went looking again, and in early afternoon found the active fire burning in Waldo Canyon, south of the area where initial reports indicated smoke was coming from.

Waldo Canyon has long been home to a locally famous trail. The 6.9 mile loop trail would host thousands of residents and visitors each year. In 2012, an arsonist had been working during the spring and early summer, with over 40 arson starts in the weeks leading up to the Waldo Fire. When investigators found the site of ignition, it



Waldo Canyon Fire Scar--showing types of work done to mitigate post-fire flooding across the various subbasins.

was evident that it was started by an arsonist, in close proximity to the trail.

The fire was contained on July 10, 2012, and had burned 18,247 acres and 346 homes before it was contained. As the fire burned, over 32,000 residents were evacuated from parts of Colorado Springs, Manitou Springs, and unincorporated El Paso County.

Coincidently, 2012 was the 10th anniversary of the Hayman Fire. On June 21st and 22nd a committee of key stakeholders, including the Coalition for the Upper South Platte (CUSP), the USFS, and the National Forest Foundation, hosted a two-day post-fire science symposium and tour of the Trail Creek drain-

age in the Hayman Fire Scar, to discuss what had been learned about post-fire mitigation activities in the ten years since Hayman. Staff of Colorado Springs Utilities (CSU) were in attendance.

The Waldo burned around three of CSU's reservoirs, and through areas where several major water distribution pipe lines (as seen on page 2) transported West Slope supplies to their treatment plant, which is located just below the burn scar. As the fire was threatening this critical infrastructure, CSU reached out to CUSP and asked if we would be able to help them with post-fire response even though the fire was outside of CUSP's watershed boundary.

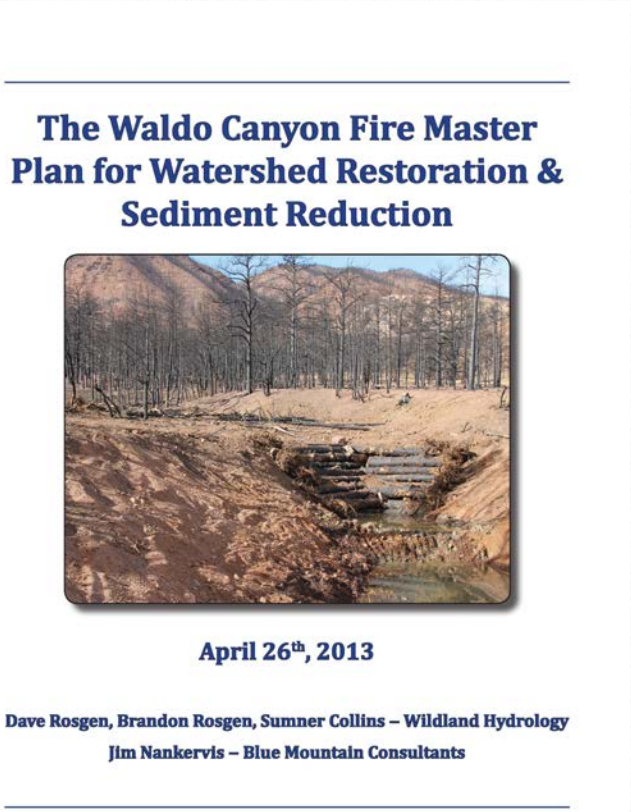
At the same time, and based on over a decade of working together on several fires within the Upper South Platte Watershed (including the Hayman) the USFS Forest Supervisor for the Pike National Forest, Jerri Marr, called CUSP and asked the same question.

CUSP's Board of Directors and management held a special meeting to discuss these inquiries on July 13th, and agreed that the fire's proximity to our watershed, impact on key partners, and potential impacts on our watershed if Highway 24 were to be significantly damaged by flooding, we agreed to help lead recovery effort.

Initial post-fire tour. USFS hydrologist, Dana Butler (with back to camera) points out conditions to Dave Rosgen (with Wildland Hydrology, in the cowboy hat) and Mark Shea (Colorado Springs Utilities, Watershed Program Manager)

CUSP had done its Trail Creek Restoration Project in Hayman with the assistance of Dave Rosgen, a nationally renowned hydrologist. Rosgen developed natural channel principals for restoration of waterways, and the *Watershed Analysis for River Stability and Sediment Supply* (aka WARSSS) process as a way of understanding sediment issues associated with poor stream channel **geomorphology**.

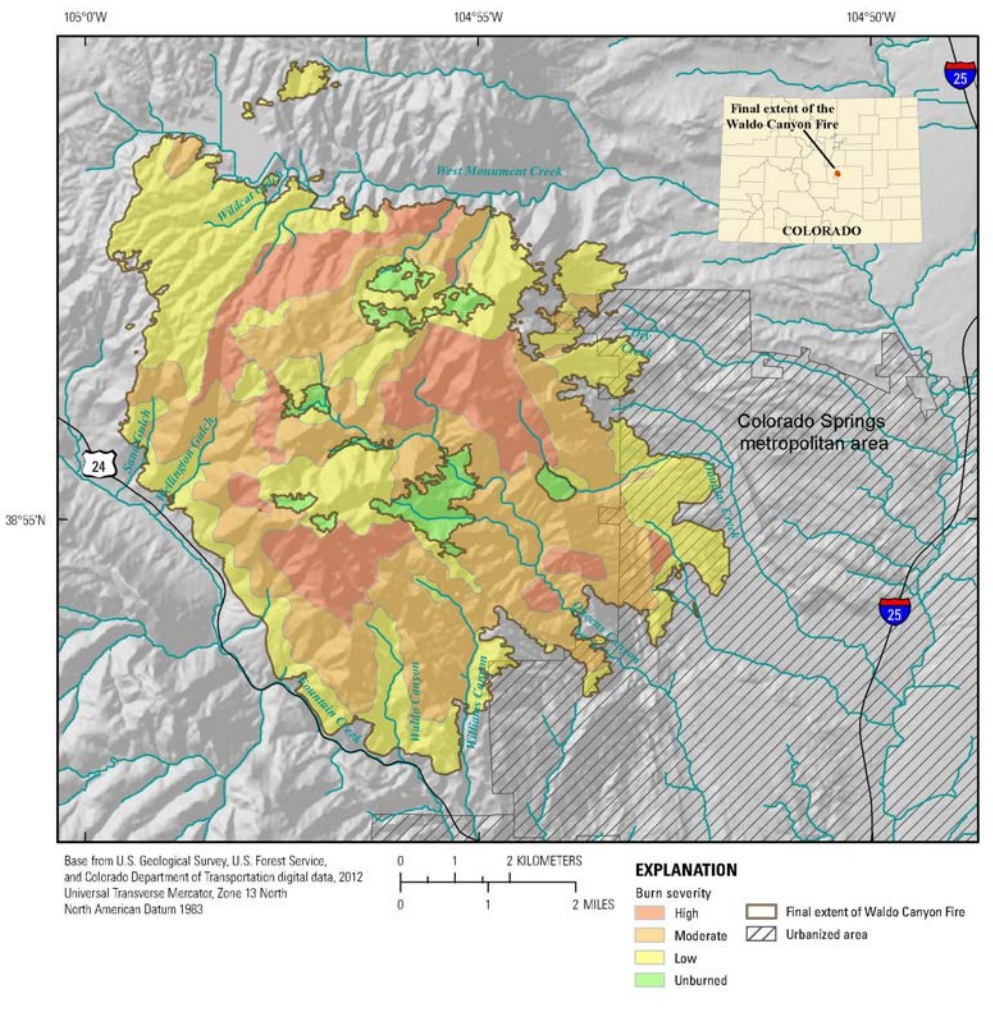
CUSP recruited Rosgen to assist in developing a plan of action for post-fire restoration in the Waldo fire. By April of 2013, a plan of recovery was ready for implementation.



The Waldo Canyon Fire Master Plan for Watershed Restoration & Sediment Reduction

April 26th, 2013

Dave Rosgen, Brandon Rosgen, Sumner Collins – Wildland Hydrology
Jim Nankervis – Blue Mountain Consultants



The Fire's Impacts

The Waldo Fire burned steep slopes at high intensity. It's proximity to Colorado Springs meant post-fire flooding impacts threatened over a billion dollars of property and infrastructure.View from Unnamed Drainage (M in table at right)

Flooding

Waldo burned across four major watersheds, Camp Creek, Douglas Creek, Fountain Creek, and West Monument Creek. The first flood occurred on July 23, closing Highway 24 for several hours due to a wall of sediment that covered the road.

In the days immediately following containment, the USFS Burned Area Emergency Response (BAER) Team began analyzing likely hydrologic changes across these watersheds and the smaller tributary watersheds, and they recruited the U.S. Geological Survey (USGS) to perform a debris flow analysis. Both BAER and USGS analysis provided insight into the potential risk from flooding. Estimated debris-flow volumes for rainfalls modeled ranged from a low of 1,500 cubic meters to a high of greater than 100,000 cubic meters. (Note: a cubic meter is about the size of a full-size washing machine.)

Land Ownership Acres Percent of Burned Area

USDA Forest Service (NFS lands) 14,422 79.0%
Private 3,678 20.2%
DOD (U.S. Air Force Academy) 147 0.8%

Subwatershed	Drainage Area (mi2)	Design storm (2 year 1 hr.)	
		Pre-Fire CFS	Post-Fire CFS
A - Sand Gulch	1.11	67.7	308.9
B - Wellington Gulch	1.73	101.3	739.9
C - Unnamed (Mud across Hwy1)	0.35	26.7	203.6
D - Unnamed (Mud across Hwy2)	0.24	20.2	119.8
E - Unnamed (Cascade)	0.77	49.4	394.8
F - Unnamed (Marygreen Pines)	0.18	4.9	33.7
G - Unnamed	0.52	38	306.2
H - Waldo Canyon	1.76	102.2	594.5
I - Cavern Gulch	0.15	12.1	21.3
J - Fountain Creek above Manitou Spgs*	68.3	988.7	1632.7
K - Williams Canyon	2.38	128.6	733.4
L - Camp Cr (Queens Canyon*	8.07	270.3	1586.3
M - Unnamed (Alpine)	0.37	13.5	167.8
N - S. Douglas Creek	1.97	89.6	593.2
O - N. Douglas Creek	0.19	4.4	11.9
P - Dry Creek	0.39	21	55.9
Q - W. Monument Creek above Filtration Plant*	15.4	403.4	996.1
R - Unnamed (N. Blodgett Gulch)	1.12	70.2	257.7
S - Unnamed (Devils Kitchen)	1.09	61.6	316.4
T - Unnamed (Northfield Res)	0.46	29.3	207.7
U - Unnamed (Nichols Res)	1.21	70.1	374.8
V - Wildcat Gulch	1.48	79	172.4
W - Unnamed (Rampart Res Shore 1)	0.41	23.8	55.3
X - Unnamed (Rampart Res Shore 2)	0.09	7.4	50.2
Y - Camp Creek above Eagle Camp 1	0.48	35.5	207
Z - Camp Creek above Eagle Camp 2	0.68	44.9	314.3

As seen in the table at left, stream discharges across the system were expected to increase significantly in all subwatershs. The team modeled three scenarios: the 2-year, 1-hour intensity storm, or the storm that has a 50% chance of occurring in any given year; the 5-year, 1-hour storm (or 20% chance in any year); and the 10-year, 1-hour storm (10% chance in any given year). Based on analysis, the greatest expected increases were for an unnamed tributary, dubbed Alpine by the team (seen in row M of the table). Alpine got its name from the fact that it was located directly above the Alpine Autism Center, a nonprofit school for autistic children in the Colorado Springs region. This location became a high focus for all partners in Waldo Recovery.

Ecology

Not unexpectedly, hillslope and upland vegetation has been slow to return in the Waldo area, resulting in reduced habitat quality for upland species. Increased sediment movement from storm events and decreased water quality has altered the aquatic habitat and impacted fish populations in the area. Some species have benefitted from the fire--Rocky Mountain Bighorn Sheep,

and wild turkeys both, like more open grassy terrain, and have responded well to life in the fire scar.

Adapted from:

- Waldo Canyon Fire Watershed Assessment: The WARSSS Results (http://cusp.ws/reports)
- The Waldo Canyon Fire Restoration Master Plan (http://cusp.ws/reports)
- Probability and Volume of Potential Postwildfire Debris Flows in the 2012 Waldo Canyon Burn Area near Colorado Springs, Colorado (https://pubs.er.usgs.gov/publication/ofr20121158)

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Lessons Learned

"We should not look back unless it is to derive useful lessons from past errors, and for the purpose of profiting by dearly bought experience."

– George Washington

A tree planted by volunteers thrives in Trail Creek, 2012

Project Goals

Emanating from the collaborative planning and WARSSS processes, the following restoration objectives were established in the:

1. Protect life and safety
2. Protect public infrastructure and private property
3. Reduce sediment supply from disproportionate sources identified by erosional process, land use and specific locations within the watershed
4. Quantify the sediment supply reduction by proposed restoration
5. Develop restoration scenarios that address impairment
6. Utilize a natural-channel-design methodology to stabilize streambanks and streambeds to maintain a natural appearance (aesthetics) while meeting other goals
7. Accelerate the recovery processes from the Waldo Fire

Purpose & Introduction to Lessons Learned

Mud flow line from a post-fire flood on a home in Cascade.

The purpose of this Lessons Learned chapter is to tell the *story* of the Waldo recovery from our view point.

When Jerri Marr, PSICC Forest Supervisor, called Carol Ekarius and asked if CUSP could help, one of the first things she asked for assistance with was bringing all the stakeholders together to build a collaborative approach to post-fire work. Jerri explained to Carol that the various local agencies and entities were calling the Forest Service and asking them to do things that really were outside their administrative and legal capabilities (such as working on private lands). She also explained to Carol that County and City did not have a good history of working together, but both Jerri and Carol recognized that the only way to address the post fire situation was for these entities to work closely together.

Based on this discussion, Jerri and Carol planned, and Carol facilitated a *Beyond BAER: The Waldo Futures Summit* meeting that would bring many of the key stakeholders together to discuss post-fire impacts and opportunities. The meeting was

Everybody is pulling together to try to deal with this situation.

Barack Obama, June 29, 2012, Fire Briefing, with Governor John Hickenlooper, Congressman Doug Lamborn, Senators Mark Udall and Michael Bennet, Mayor Steve Bach, USFS Chief Tom Tidwell and USFS Fire Team Incident Commander Rich Harvey

held September 13th, 2012 at the Glen Eyrie Castle, a historic property immediately below the fire scar, and that had already witnessed flooding from Queens Canyon.

The invitees included:

- Local Government: El Paso County, City of Colorado Springs, Colorado Springs Utilities (CSU), Manitou Springs, Green Mountain Falls, Teller County, El Paso County Office of Emergency Management (OEM), Colorado Springs Office of Emergency Management (OEM), Teller County Office of Emergency Management (OEM), Pikes Peak Regional Building, El Paso County Public Health, Fountain Creek Watershed, Flood Control and Greenway District, Pikes Peak Area Council of Governments (PPACG)

- Elected officials/staff: U.S. Senator Michael Bennet, U.S. Senator Mark Udall, U.S. Representative Lamborn, Colorado Governor John Hickenlooper, Colorado Senator Kent Lambert, Colorado Representative Bob Gardner

- FED: Natural Resources Conservation Service (NRCS), Federal Emergency Management Administration (FEMA), United States Air Force Academy (USAFA)

- State: Colorado Department of Local Affairs (DOLA), Colorado Department of Transportation (CDOT), State Office of Emergency Management (OEM), Colorado Water Conservation Board (CWCB), Colorado Geological Survey (CGS), Colorado Department of Public Health and Environment (CDPHE)

- NGOs & Funders Group: Colorado Springs Together, United Way, El Pomar Foundation, Pikes Peak Community Foundation, Mile High Youth Corp (MHYC), Rocky Mountain Field Institute (RMFI), National Forest Foundation, Joseph Henry Edmondson Foundation, Denver Foundation

- Other: Boulder County Four-Mile Fire Recovery Manager

Over 100 people attended the meeting. There were clear divisions in the room, but by the end of the session, the parties agreed to establish a Waldo Regional Recovery Group that would work together on post-fire efforts.

Considering the challenging relationship between the County and City prior to the Waldo Fire, the success of the Regional Recovery Group and the collaborative approach to post-fire work is a true silver lining for the fire. The City and County mended some very broken bridges, and continue to work together today in a much more positive way than they had in the past.

The Recovery Group (WRRG) sent a delegation to Washington DC in October, 2013. This group met with staff and elected officials on the hill, but all also with FEMA headquarters, USFS headquarters, and with then Under-Secretary of Agriculture, Harris Sherman. This initial trip actually went a long way in securing support for post-fire efforts, and toward *bonding* between the City, County, and a variety of other partners.

The WRRG changed its name in 2016 to the El Paso County Regional Resilience Group, and continues to work collaboratively on issues related to Waldo, and to broader resilience to other natural disasters ranging from future fires to floods.

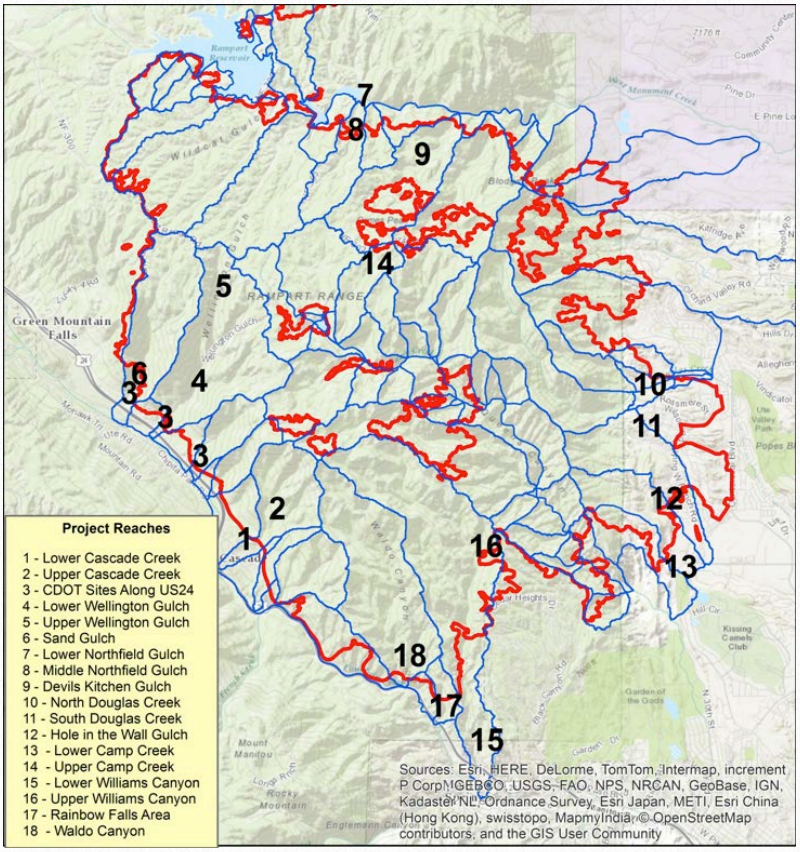
3

Monitoring: Lessons Learned

“Leadership and learning are indispensable to each other”

– John F. Kennedy

Stream Segments



Following post-wildfire flooding events and recovery efforts in late 2013 through 2016, the Coalition for the Upper South Platte undertook a large post-project effectiveness monitoring effort to assess the effectiveness and resilience of post-fire watershed treatments in the Waldo Canyon burn scar. The monitoring effort was funded through a grant to the Coalition for the Upper South Platte from the Colorado Dept. of Public, and was conducted by personnel from Fin-Up Habitat Consultants, Inc. of Manitou Springs, Colorado. Fin-Up has worked with CUSP frequently in the past, but did no work on Waldo, so they were the ideal candidate to help evaluate the work of not only CUSP, but also the USFS, Colorado Springs Utilities, and CDOT, as well as other entities and private land owners, and dozens of consultants and contractors. This is an honest, and serious look, but in spite of the problems outline here, the overall project did help save lives, reduce flood impacts to infrastructure and water quality. Tom Magnusson, the National Weather Service Director who has worked with us on fires over many years said, “There should have been worse

impacts from several of the rain events that hit this scar. Your work definitely saved lives, property, and infrastructure."

Post-project monitoring included an assessment of treatment effectiveness on 17 project reaches within twelve sub-basins in the burn area.

The overall success of recovery efforts was real, but we learned that techniques developed ten years after Hayman did not always work as planned. Some structure designs were changed over time to better withstand the dynamic nature of a new fire scar.

Monitoring tools included the use of photo points, available as-built drawings, previous geomorphic surveys, and on-site evaluations of structure and treatment effectiveness. For each project reach evaluated, an on-site reconnaissance was conducted. The overall effectiveness of the project reach was assessed, based on factors including goals/objectives of the project, stability of the channel, sediment transport function, and protection of critical infrastructure. The effectiveness assessment also included an analysis of each treatment within the project reach. Photo points and a GPS location were taken at each structure or treatment site, and each was evaluated for function and effectiveness, and classified under four distinct criteria described below.

FUNCTIONING (FUN): A structure or treatment was classified as Functioning if the structure was providing the function intended in the original project design. Functioning structures and treatments were characterized by little or no change or damage from previous flood events, and still providing the intended purpose, such as grade control, sediment detention or transport, or infrastructure protection.

FUNCTIONING AT RISK (FAR): A structure or treatment was classified as Functioning at Risk if the structure was providing the function intended in the original project design but had been damaged by previous events or was at risk of future damage due to failure of structures in the immediate vicinity

Functioning at Risk structures and treatments, while still providing the necessary function to be effective, were likely to fail in a future events without some maintenance.

PARTIAL FAILURE (P_FAIL): A structure or treatment was classified as Partially Failed if the structure had sustained damage in a previous event and was no longer providing full function as intended in the design criteria. Partially failed structures and treatments may still provide some limited function, and were likely to fail in a future event without significant maintenance or reconstruction.

FAILURE (FAIL): A structure or treatment was classified as Failed if the structure had sustained damage in a previous event and was no longer providing any function as intended in the design criteria. Failed structures and treatments provided no beneficial function, and frequently were found to be potentially further degrade the overall effectiveness of adjacent structures / treatments.**Project Reaches:**

For the purposes of this assessment, project reaches are described in detail by Sub-Basin. Treatment methods are described in each project reach. Treatment types in each reach are described and evaluated for effectiveness, and an overall evaluation of project effectiveness is presented. Several of the Sub Basins have one or more project reaches within the basin.

CUSP--Cascade Creek:

Work in Cascade Creek included a lower reach, extending down through the center of the town of Cascade to the confluence with Fountain Creek, and a second reach encompassing the headwater tributaries above the town of Cascade. The objective of the lower reach project was to protect lives, property, and critical infrastructure where the creek flows through a densely populated residential area. The lower Cascade Reach utilized many engineered hard treatments including grouted and non-grouted boulder rip-rap channels, rip rapped stream banks, bendway weirs, and sheet pilings. Work also included boulder drop structures (cross-vanes) and trap bag flood protection walls. A total of 45 structures were assessed in the lower reach. The table below lists the structures assessed and overall effectiveness of the treatments.

Structure Type	Functioning	Func at Risk	Partially Failed	Failed	Number
Boulder Bendway Wier		30%	40%	30%	10
Boulder Drop Structure	64%	9%	18%	9%	22
Hardened Water Crossing	100%				2
Rip Rap Banks	83%		17%		6
Rip Rapped Channel Bed	50%	50%			2
Sediment Basin	100%				1
Sheet Piling Lined Rip Rap Channel	100%				1
Trap Bag Wall	100%				1
Total Structures	56%	13%	20%	11%	45

The hard-engineered structures were somewhat effective, with the exception of the bendway weirs, where we observed that 70 % of these treatments were at least partially failed. Bendway weirs likely are not a good choice in this particular channel, given the small substrates found and the mobility of the decomposed granite materials comprising the channel bottom. In every case, we observed channel down cutting at the channel end of these weirs, resulting in the bed eroding to a lower level and increasing the slope of the banks in the immediate vicinity of the weir.

Bendway Weir causing channel down cutting in Lower Cascade Creek.

The boulder drop structures also had a disturbing higher rate of failure, with 36% functioning at risk or failed. Boulder drop structures in the reach typically failed through the center of the structure, where the geotextile fabric had torn and was allowing sediment to pass through the structure, or where the structure had been undermined by inadequate footings.

Overall, 56% of the treatments in the project reach were found to be fully functioning. 11% of the work had failed completely, and 33% was either partially failed or functioning at risk. We were concerned about channel down - cutting adjacent to the bendway weirs,and the failure of key boulder drop structures immediately above the benway weirs, which may indicate that a head cut is migrating through the middle portion of the project

reach. We did not, however, observe any failures that were catastrophic to the overall function of the reach. The work is performing as designed, and is protecting the nearby homes from further damage from flood events, but is likely functioning at risk, due to the instability in the middle of the project reach.

Boulder Drop Structures in Upper Cascade Creek

The upper reach of Cascade Creek extends upstream of the large sediment detention basin constructed immediately above the residential area in the lower reach, and consists mostly of softer natural channel restoration treatments including small detention basins, boulder drop structures, log corduroy channel hardening, land log sills. A few hard engi-

neered treatments are found at the large basin at the downstream boundary of the reach, and in the eastern most headwater tributary where these hardened treatments protect a road crossing the drainage. The primary objective of the upper reach treatments was to stabilize the headwater channels and reduce further down-cutting during large flood events, reducing the amount of sediment and debris reaching the lower reach.

Str Type	Functioning	Fun. at Risk	Partially Failed	Failed	Number
Basin Log Crib Wall		100%			1
Basin Log Sill	100%				2
Basin Boulder Sill				100%	1
Sediment Basin	100%				6
Boulder Drop Structure	80%	6%	11%	3%	35
Boulder Sill	80%		20%		5
Concrete Sill	100%				2
Log Sill	68%	28%	8%		25
Concrete Tiled Channel	100%				1
Culvert	100%				1
Grouted Rip Rap Sill	100%				1
Grouted Rip Rap Channel	100%				1
Hardened Water Crossing	100%				3
Log Corduroy Channel			100%		1
Rip Rapped Bank			100%		1
Rip Rapped Channel	50%	50%			2
Trap Bag Wall	100%				3
Total Structures	77%	12%	9%	2%	91

Both natural channel and engineered treatments have been effective in the upper Cascade Creek reach. Boulder drop structures and log sills were the most common treatments, which would be expected in this higher gradient transport reach. Failure rates of these structures were less than observed in other sub-basin. Sediment basins in the reach were still providing storage for flood debris and sediment, even though one crib wall was functioning at risk, and one basin sill had completely failed. We did observe that some of the hard treatments had not performed as well as expected, most notably a rip rapped bank that had partially failed due to collapse of the toe slope. Additionally, one of the two rip rapped channels observed in the lower segment of the reach appeared to functioning at risk, and may not withstand a future significant flood event. Overall, 77% of the treatments

in the project reach were found to be fully functioning. Only 2% of the work had failed completely and 9% was partially failed and not function at full potential. 12% of the treatments were functioning at risk. We did not observe any failures that were catastrophic to the overall function of the reach, and the work is performing as designed.

CDOT--US24 Corridor:

The Colorado Department of Transportation (CDOT) has completed several flood mitigation projects along US24 in the area from Crystola to the town of Cascade. Much of this work is focused on Spring Gulch, a small ephemeral draw 1/2 mile upstream of Cascade. Treatments are almost exclusively hardened engineered structures designed to prevent sediment and debris from impeding traffic along US24. Treatments include large sediment detention basins and trash racks, grouted boulder drop structures and channels, concrete sills and trap bag flood walls. Large, semi-permanent sediment detention basins, complete with steel flood debris racks and armored basin surfaces, have been constructed adjacent to the highway at Sand Gulch and Wellington Gulch. A massive grouted drop structure and concrete sill has been installed along the upslope side of the highway at Spring Gulch, and a grouted rip rap channel has been constructed on the downslope side of the highway immediately across the highway and downstream of the "Swiss Chalet". Trap bag flood walls have been installed to protect homes and business along the highway prone to flooding from Spring Gulch. A total of 14 structures were assessed in the CDOT project area. The table below lists the structures and treatments, effectiveness and overall function of the project area.

Str Type	Functioning	Fun. at Risk	Partially Failed	Failed	Number
Boulder Drop Structure		100%			1
Concrete Box Culvert			100%		1
Concrete Sill	100%				2
Grouted Boulder Drop Structure		100%			1
Grouted Rip Rap Channel	100%				2
Rip Rapped Bank		50%		50%	2
Sediment Basin	100%				1
Trap Bag Wall	75%	25%			4

The hard engineered structures are, for the most part, very effective, with the exception of a failed rip rap bank, which had failed due to undermining of the toe of the bank. A concrete box culvert had also partially failed, but was still functioning. Overall 86% of the work was still functioning as designed, although the sediment basins and the ditches along the highway downstream of Spring Gulch require regular maintenance after every storm. Increased run-off velocities are an issue, and tend to cause down cutting of channels immediately below the hardened channels. The ditch along the west bound lane of US24 immediately downstream of Spring Gulch is particularly susceptible to high flow erosion. Given the intensive maintenance requirements we rated the overall work as functioning at risk.

Massive Grouted Boulder Drop Structure & Basin at Spring Gulch.

CUSP/USFS--Wellington Gulch:

Work in Wellington Gulch included a middle reach, extending from a breached pond 1/3 mile upstream from US24 to a point where a large tributary basin enters the main channel from the west, and a second reach encompassing main stem of the gulch and the headwater tributaries immediately below Rampart Range Rd (FSR300). The objective of the middle reach project was to protect lives and property of several residential dwellings along

One of the key lessons throughout this evaluation, and that we took away fairly early, was that single-log sills do not work well in a brand new fire scar, though they were very effective 10 years after Hayman. Buried log sill walls, on the other hand, did perform well. Although they failed, during repeated cycles of flooding they would agrade again, and once vegetation reestablished they were functioning (circa 2016).

the creek channel. The middle Wellington Gulch reach project consisted of mostly natural channel stabilization techniques,. Including boulder drop structures (cross-vanes), log and boulder sills, sediment detention basins, and trap bag flood protection walls. A total of 55 structures were assessed in the middle reach. The table below lists the structures assessed and overall effectiveness of the treatments.

Str Type	Functioning	Functioning at Risk	Partially Failed	Failed	#
Basin Log Crib Wall	100%				2
Basin Log Sill				100%	1
Hardened Water Crossing	100%				2
Log Sill	11%	26%		63%	19
Rip Rapped Banks	74%	21%	5%		19
Sand Bag Walls	100%				3
Trap Bag Walls	100%				8
Toe Stabilization				100%	1
Total Structures	56%	16%	2%	25%	55

Overall, 56% of the treatments in the project reach were found to be fully functioning and 16% of the treatments were fully functioning but at risk. Only 25% of the work had failed completely, and these were mostly sills that had been undermined. 2% of the treatments were partially failed and not function at full potential. These consisted entirely of rip rapped banks that were being undermined in areas where the channel continues to down cut. While the project reach is still functioning as intended, and providing adequate protection to the dwellings nearby, we found that it is functioning at risk, due in part to the loss of critical structures in the reach, as well at from risksflood prone area of the lower portion of the basin. CDOT has in-

Failed sills in Middle Wellington

stalled a permanent sediment basin and box culvert at the bottom of the basin to protect US Highway 24. The lower first mile of the basin is located on private property, and the upper basin is entirely on USFS lands. Work in Sand Creek was limited to the private lands, due to lack of access and the very steep nature of the upper basin on USFS lands. The project reach extends from just above the CDOT basin and trash rack upstream to the USFS boundary. The lower half of the project reach is a depositional channel, while the steeper upper half functions as a transport reach. The primary objective of the project reach was to protect lives and property at the bottom of the basin by stabilizing the channel upstream and creating sediment and debris detention in the lower part of the reach. Sand Creek has experienced some of the most dramatic flood events in the burn area. During a single event in 2014, the channel in the lower half of the project reach aggraded nearly 15 feet in places, completely burying the much of work done in this segment. Subsequent flood events have cut through the deposited sediments, in several cases down to the original structures. In other segments, the treatments are still buried, and could not be assessed during the course of this study.

Str Type	Functioning	Functioning at Risk	Partially Failed	Failed	Number
Basin Log Crib Wall	75%		25%		4
Basin Log Sill	25%		25%	50%	4
Sediment Basin	20%		40%	40%	5
Drop Structures				100%	1
Earthen Berms				100%	2
Log Sills	22%	13%	4%	60%	68
Rip Rapped Banks			33%	67%	3
Toe Stabilization				100%	1
Total Structures	22%	10%	9%	58%	89

Upper Wellington provided another lesson. The USFS had a contractor available under an existing contract, but he had no experience with natural channel design concepts, and due the fact that this was the first project implemented, while planning was ongoing in other basins, he did not have adequate supervision for this type of work. Contractors new to natural channel design require high supervision.

Log sills were the most common treatment in the upper reach. Failure rates of these structures were consistent with of those found in other basins. There appeared to be too much reliance on log sills in the reach, which likely lead to the overall failure of the project. Many of the log sill treatments were lacking geotextile fabric, which likely increased the risk of undermining. Two sediment basins in the reach were still providing storage for flood debris and sediment, but the basin crib walls and basin sills had failed or partially failed in all of these features, likely limiting their future function. Two earthen berms were constructed in the reach, but both of these features had completely failed.

Upper Wellington Gulch had the highest failure rate of all of the project reaches assessed in 2015. Overall, 22% of the treatments in the project reach were found to be fully functioning and 10% of the treatments were fully functioning but at risk. 58% of the work had failed completely, and 9% of the treatments were partially failed and not function at full potential. Critical grade control features such as boulder drop structures had a 100% failure rate in the reach. It was clear that the downstream most grade control had failed in the reach, and the resulting head cut had migrated up through the project reach, undermining the structures upstream

CUSP--Sand Gulch:

Sand Gulch is a small tributary of Fountain Creek located on the west side of the Waldo Canyon burn. Almost the entire basin was severely burned during the fire, and the gulch has seen numerous significant flood events (with a storm event after work was completed that was ~ a 10-year return interval storm) since the burn. Several private homes are within the

flood prone area of the lower portion of the basin. CDOT has installed a permanent sediment basin and box culvert at the bottom of the basin to protect US Highway 24. The lower first mile of the basin is located on private property, and the upper basin is entirely on USFS lands. Work in Sand Creek was limited to the private lands, due to lack of access and the very steep nature of the upper basin on USFS lands. The project reach extends from just above the CDOT basin and trash rack upstream to the USFS boundary. The lower half of the project reach is a depositional channel, while the steeper upper half functions as a transport reach. The primary objective of the project reach was to protect lives and property at the bottom of the basin by stabilizing the channel upstream and creating sediment and debris detention in the lower part of the reach. Sand Creek has experienced some of the most dramatic flood events in the burn area. During a single event in 2014, the channel in the lower half of the project reach aggraded nearly 15 feet in places, completely burying the much of work done in this segment. Subsequent flood events have cut through the deposited sediments, in several cases down to the original structures. In other segments, the treatments are still buried, and could not be assessed during the course of this study.

Str Type	Functioning	Functioning at Risk	Partially Failed	Failed	Number
Basin Boulder Sill			100%		1
Basin Log Sill				100%	1
Basin Log Crib Wall		50%	50%		2
Sediment Basin		50%		50%	2
Gabion Basket Flood Wall	100%				1
Hardened Water Crossing		100%			1
Boulder Drop Structure		100%			3
Boulder Sill	64%	13%	13%	13%	8
Log Sill	6%	13%		81%	16
Log Vane				100%	3
Total Structures	21%	21%	8%	50%	38

Colorado Springs Utilities: Northfield Gulch:

Northfield Gulch is located along the northern edge of the burn, immediately east of Rampart Reservoir. The project reach begins at the confluence of Northfield Gulch and West Monument Creek, immediately downstream of the Northfield Reservoir Dam. The objective of the project reach was to stabilize the channel and reduce sediment and debris moving down into West Monument Creek. Critical water delivery infrastructure for Colorado Springs Utilities is located at the bottom of Northfield Gulch, and is at risk from flood debris and sediment coming from the gulch above. The original work in the drainage consisted entirely of natural channel stabilization techniques including sediment detention basins and numerous log sills. The original work did not include a boulder drop structure for grade control at the downstream end of the lower part of the basin. Severe flooding in 2013 completely destroyed the work in the lower part of the basin. In 2014, a second effort constructed a boulder step pool channel through approximately 1,500 ft of the lower basin. A total of 77 structures and treatments were assessed in the reach in 2015. The below lists the structures assessed and overall effectiveness of the treatments.

Str Type	Functioning	Functioning at Risk	Partially Failed	Failed	Number
Basin Log Crib Wall	11%	44%	22%	22%	9
Basin Log Sill			57%	43%	7
Basin Boulder Sill	100%				2
Sediment Basin	67%	33%			9
Boulder Step Pool Channel	100%				1
Log Sill	18%	4%	4%	75%	55
Straw Waddles				100%	2
Total Structures	25%	9%	6%	60%	77

The boulder step pool channel constructed in 2014 is very stable, and is performing as expected. This feature has sufficiently stabilized the lower basin channel and is protecting CSU's infrastructure at the bottom of the draw. Log sills are the most common treatments in the upper part of the reach. Failure rates of these structures are slightly higher than in other basins at 75%. Log sills mostly failed due to flows undermining the log and geotextile fabric. The nine sediment basins in the reach are still providing storage for flood debris and sediment, although none of the log basin sills are completely intact. Several of the ba-

sin log crib walls have failed, typically the result of lateral migration of the channel around the structure. Basin crib walls in this reach are of an older design; typically straight, without wing walls or spur logs embedded into the adjacent banks Straw waddles were installed along two segments in the middle of the basin, but neither of these features survived the floods in 2013.

Overall, only 25% of the treatments in the project reach were found to be fully functioning and 9% of the treatments were fully functioning but at risk. 60% of the work had failed completely, and 6% of the treatments were partially failed and not function at full potential. All of the treatment failures were in the upper and middle portions of the reach. The downstream boulder step pool channel constructed in 2014 is in good condition however, and is functioning to protect the basin from further unravelling. The sediment basins, although compromised, are still functioning to capture sediment and debris from the upper portion of the watershed. For these reasons, we concluded that the project is functioning as desired, but at risk to future failure as the capacity of the basins decreases over time.

Colorado Springs Utilities--Devils Kitchen Gulch:

Devils Kitchen Gulch is also located along the northern edge of the burn, approximately 1 mile east of Northfield Gulch. Devils Kitchen Gulch is another small intermittent tributary of West Monument Creek. The objective of the project reach was to stabilize the channel and reduce sediment and debris moving down into West Monument Creek. The work in the drainage consisted entirely of natural channel stabilization techniques including sediment detention basins, hardening the channel surface using log corduroy techniques, and many single log sills.

Str Type	Functioning	Functioning at Risk	Partially Failed	Failed	Number
Log Corduroy	0%		25%	75%	4
Basin Log Crib Walls				100%	2
Log Sills	7%		20%	73%	15
Sediment Basins	100%				2
Total Structures	13%		17%	70%	23

The two sediment basins in the project reach are still functioning to capture sediment and debris, despite the fact that the log crib walls and basin log sills on each feature have failed. The lower basin still has some storage capacity, but will likely fill up in the near future. A segment of the channel between the two basins was hardened by laying dozens of small diameter cut logs across the channel perpendicular to the flow (log corduroy). While this treatment may have helped add roughness to the surface, it failed in the first rain.

Log corduroy (left) and sediment basin (right)

Only 13% of the project reach was found to be in good condition and functioning as expected. 70% of the treatments in the reach have completely failed, and the remaining 17% will likely completely fail in the near future. We determined that the overall project reach was still meeting the objective of reducing sediment from reaching West Monument Creek, due to the residual capacity of the lower basin to continue to capture sediment and debris. The continued function of this basin is at risk.

City of Colorado Springs with CUSP--North Douglas Creek:


Step pool channel

North Douglas Creek is located on the northeast side of the Waldo Canyon burn, immediately west of the Mountain Shadows neighborhood in Colorado Springs. This watershed was severely burned during the fire, and poses a significant flood risk to the densely populated community immediately downstream. The project reach is entirely on property owned by the Flying W Ranch, and begins at eastern boundary fence of the ranch and continues approximately 1 mile upstream to the USFS boundary. The primary objective of the project reach is to protect life and property in the subdivision downstream of the ranch. The original work in the drainage consisted entirely of natural channel stabilization techniques including five sediment detention basins and many single log sills to stabilize the bed of the channel. The original project reach was subjected to severe flooding in the fall of 2013. Although the project was successful in preventing sediment and debris from reaching the residential area downstream, the reach sustained significant damage, including the complete filling of four of the five sediment detention basins. In 2014, a boulder step pool channel was constructed through approximately 2,500 ft of stream channel in the lower part of the project reach. Additionally, the City of Colorado Springs is in the process of installing a very large permanent sediment detention basin in the middle of the project reach. This structure was incomplete and not functional when we surveyed the project in 2015. A total of 76 structures and treatments were assessed in the reach in 2015.

Str Type	Functioning	Functioning at Risk	Partially Failed	Failed	Number
Basin Boulder Crib Wall	50%	50%			2
Basin Log Crib Wall	50%		50%		2
Basin Log Sill		33%		67%	3
Basin Boulder Sill				100%	1
Sediment Basin	20%			80%	5
Boulder Drop Structure	67%	27%	7%		15
Boulder Rock & Roll Str	100%				3
Boulder Grade Control Str	77%	13%	6%	4%	31
Boulder Sill	20%		20%	60%	5
Log Sill			12%	88%	8
Hardened Crossing	100%				1
Rip Rapped Bank	100%				1
Total Structures	58%	13%	8%	21%	76

As noted above, the sediment detention basins were completely inundated in the fall 2013 floods. The basin crib walls are still intact, but several are functioning at risk. The basin sills did not fare as well, with most of these features failing during the course of the flood event. Many of the log sills in the original project reach have been buried by sediment due to aggradation of the channel. Those log sills that are still exposed have, for the most part, completely failed. Downstream, the boulder step pool channel has fared better, although it has yet to sustain a flood of the magnitude seen in the original project reach. The boulder cross vanes, grade controls and step pool vanes (Rock & Roll features) are functioning as expected. We did have concern that a few of the boulder drop structures and grade controls have begun are beginning to show signs of failure. Several of these are at or near the bottom of treated segments. Failure of these structures may lead to formation of head cuts that may compromise functioning structures upstream.

Overall, 58% of the treatments in the project reach were found to be fully functioning and 13% of the treatments were fully functioning but at risk (71% functioning). 21% of the work had failed completely, and these were mostly the work completed prior to the 2013 floods. 8% of the treatments were partially failed and not function at full potential. Several of these are boulder sills and drop structures in the step pool channel in the lower part

of the reach. The project reach is still for the most part functioning as intended, providing flood attenuation and reducing risk to the residential areas downstream. We determined that the project reach is currently functioning at risk, due in part to the loss of critical structures in the lower part of the reach. With the completion of the large sediment detention basin in the middle of the reach, the risk will likely be reduced in the future.

City of Colorado Springs with CUSP--South Douglas Creek:

South Douglas Creek is located on the northeast side of the Waldo Canyon burn, immediately south of the North Douglas Creek drainage. This watershed was also severely burned during the fire, and poses a significant flood risk to the densely populated community of Mountain Shadows immediately downstream. The project reach in South Douglas creek is entirely on property owned by the Flying W Ranch, and begins at eastern boundary fence of the ranch and continues approximately 1 mile upstream to the USFS boundary. The project reach consists of several headwater tributaries which come together at the site of the former Flying W Ranch Chuck Wagon Facility, which was completely destroyed during the fire. The primary objective of the project reach is to protect life and property in the subdivisions downstream of the ranch. Work in the drainage consists mostly of natural channel stabilization techniques including four sediment detention basins and many single log sills to stabilize the bed of the channels. The project reach was subjected to severe flooding in the fall of 2013, sustaining significant damage to the sediment detention basins and many of the channel stabilization treatments. Maintenance of damaged structures and additional new structures was done following the floods in 2014.

Str Type	Functioning	Functioning at Risk	Partially Failed	Failed	Number
Basin Log Crib Wall		33%		67%	3
Basin Log Sill	67%	33%			1
Sediment Basin		25%		75%	4
Log Drop Structure	100%				2
Log Rock & Roll Str	100%				2
Log Corduroy Channel	100%				1
Log Sill	36%	35%	4%	25%	57
Slash Treatments				100%	2
Earthen Berm		100%			1
Total Structures	37%	35%	3%	25%	75

Three of the four sediment detention basins are no longer function, having been filled to capacity. Many of the log sills in the project reach were still functioning (71%), and other channel grade control treatments such as log drop structures and log rock & roll structures were found to be in good condition. One hand constructed log corduroy feature (parallel small logs placed longitudinally in the channel) was also found to be intact and functioning as expected. Two slash features in one of the channels were not effective at all.

Overall, 72% of the treatments in the project reach were found to be effective. The rate of complete structure failure was approximately 25%. The work in the reach appeared to be meeting the goals and objectives outlined for the project. Our one concern was that we observed 5 significant active head cuts within the project reach. These were typically in channel segments that did not receive treatments in the original project. These head cuts have the potential to migrate upstream in future flood events, and may jeopardize work that is currently functioning in the reach. For these reasons, we determined that the project is currently functioning as designed but at risk from future flood events.

City of Colorado Springs with CUSP--Hole in the Wall Gulch:

Hole in the Wall Guch is located on the east side of the Waldo Canyon burn, south of the South Douglas Creek drainage. This small tributary of Monument Creek was severely burned when the Waldo Canyon Fire burned into the Mountain Shadows neighborhood. The project reach in Hole in the Wall Gulch is located on property owned by the Flying W Ranch, beginning at the fence and gate immediately downstream of the “Hole in the Wall” feature (a gap in the Dakota sandstone hogback ridge that runs north/south through the area), and extends upstream for approximately 1/3 mile. A small private school, the Alpine Autism Center, is located immediately below the project reach within the flood prone area of the gulch. The primary objective of the project reach was to protect life and property in the immediate area around the school, and in the subdivision downstream. Work in the drainage consisted of natural channel stabilization techniques and hardened engineered structures, including a large sediment detention basin at the downstream boundary immediately above the school. Natural channel treatments included single log sills to stabilize the bed of the channels, and “whisker sills”, designed to capture small debris and reduce surface velocities in this ephemeral channel. These “whisker sills” are a relatively new sta-

bilization technique, and this is the only project reach in the Waldo Canyon burn where the treatment has been used. The project reach was subjected to severe flooding in the summer of 2015, sustaining damage to the sediment detention basin and many of the channel stabilization treatments. This storm event overwhelmed the large detention pond at the bottom of the reach, resulting in flooding and damage to the school below. Maintenance of damaged sediment detention pond was underway when our survey was conducted following the flood. A total of 25 structures and treatments were assessed in the reach in 2015.

Str Type	Functioning	Functioning at Risk	Partially Failed	Failed	Number
Boulder Drop	100%				1
Log Sills	30%	30%	0%	40%	10
Sediment Basins	100%				1
Trap Bag Walls	100%				1
Whisker Sills	10%		20%	70%	10
Total Structures	36%	12%	8%	44%	25

Damaged Whisker Sills: These were a new product recommended by a hydrologist, but they failed quickly.

The upper part of the reach sustained significant damage during the flood event. 40% of the log sills and 90% of the whisker sills sustained damage and were no longer full y functioning. Several of the whisker sills, which are constructed of PVC plastic pipe, had shattered, likely due to the large boulders and cobbles that were mobilized in the channel during the flood. The sediment basin, although damaged, was still functioning, and was being excavated by the City of Colorado Springs during the course of our survey. The trap bag walls surrounding the school were still fully intact, but flood was high enough to allow water to enter the building around these features.


Autism school

The overall project reach sustained total failure of 44% of the treatments, mostly in the upper half of the reach. Critical structures, such as the sediment basin, are still functional, and continue to protect the school and neighborhoods downstream from catastrophic flooding. The sediment basin will continue to need periodic maintenance to ensure full function, therefore we considered the entire project reach as functioning at risk at this time.

City of Colorado Springs & Navigators--Lower Camp Creek:

Work in Camp Creek included a lower reach, extending from the Dakota sandstone hogback ridge immediately west and upstream of the Glyn Eyrie complex owned by the Navigators (Palmer's Castle), downstream to Garden of the Gods Park, and a second reach on USFS Lands encompassing the headwater tributaries. The objective of the lower reach project was to protect lives, property, and critical infrastructure within the Navigators Glen Eyrie complex, and the Pleasant Valley neighborhood downstream of Garden of the Gods Park. The lower Camp Creek Reach exclusively utilized engineered hard treatments, including a 4,600ft long grouted boulder rip-rap channel, rip rapped stream banks, concrete

drop structure and sills, and a large permanent sediment detention basin . The lower Camp Creek project was likely one of the most costly flood mitigation efforts undertaken following the Waldo Canyon burn. A total of 7 structures were assessed in the lower reach. The table below lists the structures assessed and overall effectiveness of the treatments.

Str Type	Functioning	Functioning at Risk	Partially Failed	Failed	Number
GROUTED RIPRAP CHANNEL	100%				1
DEBRIS NET	100%				1
CONCRETE DROP STRUCTURE	100%				1
SEDIMENT BASIN	100%		100%		1
BOULDER SILLS				100%	3
Total Structures	43%		14%	43%	7


Riprap channel through Navigators

The hard engineered treatments through the Navigators compound appear to be very effective, although there was some evidence of sediment deposition and channel aggrading in some of the channel segments, which may indicate that the channel will lose capacity over time. The massive debris net at the upstream boundary has effectively captured larger debris coming into the reach from the watershed above. The feature, however, does have a limited lifespan, and we were unsure as to how future cleaning and maintenance will be accomplished. While the concrete drop structure/sill at the downstream boundary of the constructed trapezoidal rip rap channel is intact, the sediment basin below has partially failed, due to complete failure of the three boulder rip rap sills that were installed on the downstream side of the basin. The failure of these sills has resulted

in significant damage to the Camp Creek channel and stream side trail system downstream in Garden of the Gods Park.

USFS & CUSP--Lower Camp Creek:

The upper reach of Camp Creek is located on USFS lands within a severely burned headwater tributary immediately southwest of Ormes Peak. The work in the upper reach consists entirely of softer natural channel restoration treatments including small detention basins and single log sills. The primary objective of the upper reach treatments was to stabilize the channel in this severely burned reach, limiting sediment movement by reducing further down-cutting during large flood events. Treatments were designed to stabilize active head cuts in the reach and to capture flood debris.

Str Type	Functioning	Functioning at Risk	Partially Failed	Failed	Number
Basin Crib Walls	50%			50%	6
Basin Log Sills	75%	25%			4
Log Sill	74%	16%	5%	5%	19
Sediment Basins	100%				5
Total Structures	74%	12%	3%	12%	34

All of the sediment basins in the upper reach were functioning as designed, despite damage sustained in half of the basin crib walls in the reach. All of the basin sill logs were intact and functioning, which significantly contributed to the resilience of the sediment detention basins.

Seventy-five percent of the log sills in the project reach were in good condition, which represented some of the highest survival rates for log sills in the entire Waldo Canyon burn area.

Overall, 86% of the treatments in the project reach were found to be functioning as designed. Only 12% of the work had failed completely and 3% were partially failed and not functioning at full potential. We did not observe any failures that were catastrophic to the overall function of the reach, however, the three failed basin crib walls will likely limit the lifespan of the sediment detention basins immediately below. In total, the work is performing as designed and is considered successful, although it may be at risk from damage in future flood events.

Manitou Springs--Lower Williams Canyon:

Williams Canyon is a large watershed on the south side of the Waldo Canyon Burn. The headwaters of the canyon were severely burned during the fire, and the watershed was identified as one of the highest risk areas for subsequent flooding. The City of Manitou Springs is located at the bottom of the watershed, and the flood prone area where the creek runs through the city is densely populated. A large flood event in 2013 caused significant damage, including the complete loss of two homes.

Flood mitigation work in Williams Canyon included a lower reach, extending from the Cave of the Winds lower entrance at the Manitou Springs city limits to the confluence of Williams Canyon creek with Fountain Creek at Soda Springs Park. The sole objective of the lower reach project was to protect lives, property, and critical infrastructure along Canon Avenue and downstream of the confluence in the City of Manitou Springs. The lower Williams Canyon Reach consisted entirely of engineered hard treatments, including a 1,600ft long grouted boulder rip-rap channel, contained by 10 -15 ft concrete flood walls on either side of the channel, and a large permanent sediment detention basin. Additionally, several smaller steel debris nets were installed within the flood channel to capture larger materials to prevent clogging of the 1,000 ft long 5’x5’ box culvert running under Canon Avenue. At a cost of $6.1 million, the lower Williams Canyon project was the most costly, in terms of cost per foot of channel treated, of all flood mitigation efforts undertaken following the Waldo Canyon burn. A total of 7 structures were assessed in the lower reach.

Str Type	Functioning	Functioning at Risk	Partially Failed	Failed	Number
Concrete Box Culvert	100%				1
Concrete Flood Wall	100%				1
Debris Nets		100%			3
Grouted Rip Rap Channel	100%				1
Sediment Detention Basin		100%			1
Total Structures	43%	57%			7

Following the 2013 flood, the 1,000 ft long box culvert was excavated and is now functional. The new concrete and grouted boulder flood channel is in excellent condition, but has yet to sustain a significant flood event. The debris nets were almost completely full at the time of our survey, and will require regular maintenance in order to be effective. The sediment detention basin in the middle of the project reach is also functioning at risk, and will require regular cleaning in order to function as designed. Overall, the project reach is very effective in terms of the original goals and objectives of the project, but at a cost, both in treasure, and in natural aquatic and hydrologic function in the project reach.

USFS & CUSP--Upper Williams Canyon:

The upper reach of Williams Canyon is located on USFS lands where the two major headwater tributaries join to form the main channel through the basin. The project reach is approximately 2 miles upstream of the lower reach. The work in the upper reach consists entirely of softer natural channel restoration treatments including small detention basins, boulder grade control structures, and single log sills. The primary objective of the upper reach treatments was to stabilize the channel in this severely burned reach, limiting sediment and flood debris movement to the lower reach. Treatments were designed to stabilize active head cuts in the reach and to capture flood debris. A total of 37 structures were assessed in the upper reach. The table below lists the structures assessed and overall effectiveness of the treatments.

Str Type	Functioning	Functioning at Risk	Partially Failed	Failed	Number
Basin Log Crib Wall		100%			1
Basin Log Sill	100%				1
Sediment Detention Basin	100%				1
Boulder Drop Structure	86%	4%		10%	21
Boulder Vane	100%				1
Log Sill	100%				10
Toe Stabilization	100%				2
Total Structures	90%	5%		5%	37

The sediment basin in the upper reach was functioning as designed, however, the basin crib wall appeared to be at risk of failure in a future large event. The basin sill log was intact and functioning to maintain the integrity of the basin and prevent down cutting below the structure. Two of the boulder drop structures were no longer functioning, however, all of the other channel grade control and bank features were in good condition functioning as designed. The work on the upper reach represented some of the most stable and effective natural treatments in the entire Waldo Canyon burn area.

Overall, 95% of the treatments in the project reach were found to be functioning as designed. The two boulder drop structures that failed completely did not appear to threaten the integrity of other structures in the immediate vicinity. In total, the work is performing as designed and is considered successful.

El Paso County, CUSP, & CDOT--Upper Rainbow Falls Area Fountain Creek:

The Rainbow Falls area is located along Fountain Creek immediately west of the City of Manitou Springs. The area is under multiple ownership including El Paso County, the Colorado Division of Transportation, the City of Manitou Springs, and private land owners. The flood mitigation work undertaken on this perennial stream included a mix of hardened engineered treatments and natural river stabilization techniques. Work included construction of a large grouted boulder rip rap channel through Rainbow Falls Park, boulder rip-rap banks, sediment detention basins, boulder drop structures and trap bag flood walls. The principal objective of the work in this reach is protection of critical transportation infrastruc-

ture and reduction of sediment and flood debris transport into Manitou Springs. A total of 8 structures and treatments were assessed in the reach in 2015.

Str Type	Functioning	Functioning at Risk	Partially Failed	Failed	Number
Basin Boulder Sill		100%			1
Boulder Drop Structure	100%				1
Boulder Vane				100%	1
Grouted Boulder Channel	100%				1
Rip Rap Bank	50%			50%	2
Sediment Basin				100%	2
Trap Bag Wall		100%			1
Total Structures	37%	25%		38%	8

In the upstream portion of the project reach, above Rainbow Falls, project work included a large in-channel sediment/debris detention basin, boulder drop structures/vanes, and rip rap banks. The boulder drop structure at the top of the reach is intact and functional, but several other boulder features between this structure and the sediment detention pond are no longer present in the channel.

Manitou Springs & CDOT--Upper Rainbow Falls Area Fountain Creek:

Downstream in Rainbow Falls Park, the grouted boulder channel and rip rap banks are intact and functioning, however, there is still considerable instability in the river channel immediately downstream of the constructed channel extending ¼ mile downstream to the bridge at Serpentine Drive. The sediment basin immediately upstream of the grouted rip rap channel is completely full and no longer functional, for the same reasons as the sediment basin constructed above the falls. The trap bag flood wall along Serpentine Drive remains intact, although it is at risk, particularly from vandalism, and continues to confine the channel at this point, leading to further down cutting and transport of sediment into segments of the creek in Manitou Springs.

Overall, 62% of the treatments in the project reach were found to be functioning as designed. The project reach is continuing to provide some flood attenuation benefit to the transportation network and the City of Manitou Springs. In total, the work is performing as designed but is likely at risk to future flood events.

USFS, CUSP & CDOT--Waldo Canyon:

Waldo Canyon is a small intermittent tributary of Fountain Creek located on the south side of the Waldo Canyon burn, immediately upstream of the City of Manitou Springs. Waldo Canyon was the ignition point of the burn, and almost the entire basin was severely burned. The lower portion of the basin is located on private property, and the upper basin is entirely on USFS lands. The project reach extends from US24 upstream past the USFS boundary, and includes a small ephemeral tributary entering the main stem from the east. The primary objective of the project reach was to protect lives and property in Manitou Springs and to protect critical transportation infrastructure along US24. The lower half of the project reach, located on private lands, was treated exclusively with hardened engineered treatments. The upper reaches, located on USFS lands, received softer natural channel stabilization treatments. A total of 32 structures and treatments were assessed in the reach in 2015. The table below lists the structures assessed and overall effectiveness of the treatments.

Str Type	Functioning	Functioning at Risk	Partially Failed	Failed	Number
Basin Concrete Sill	100%				2
Basin Log Sill		100%			1
Basin Log Crib Wall	100%				1
Sediment Basin	34%	33%	33%		3
Grouted Rip Rap Channel	67%	33%			3
Boulder Step Pool Channel	100%				1
Concrete Box Culvert	100%				1
Debris Net	100%				1
Boulder Rip Rap Bank	50%	50%			2
Boulder Drop Structure	25%		50%	25%	4
Log Sill	8%	17%	33%	42%	12
Log Vane		100%			1

The hard engineered treatments included a 24 ft wide concrete box culvert under US24, a very large engineered permanent sediment detention basin just below the USFS boundary, and several segments of grouted rip rap channel both below and above the basin. For the most part these treatments were functioning effectively, but at least one of the grouted rip rap channels was functioning at risk due to scour undermining the downstream edge of the treatment. Several boulder drop structures between the lower grouted rip rap channel and the box culvert were also either failed or functioning at less than full potential.

Upstream on the USFS segments, log sills were the least effective treatment, with 42% of these structures having completely failed. The sediment detention basins on the USFS lands were still functioning, but had lost most of their capacity to store sediment and debris.

Overall, 60% of the treatments in the project reach were still functioning and effective, and 40% had failed or partially failed. The project reach was still meeting the objectives of protecting the highway and minimizing debris and sediment from moving downstream into Manitou Springs. The project will need continuous maintenance of the large en-gineered detention basin, however, and the lower grouted rip rap channel will likely require extensive repair at some future date. For these reasons we determined that the project reach was functioning at risk.

Grouted Rip Rap Channel functioning at risk as the toe begins to erode.

Structure Types

Seven hundred and thirty-two structures and treatments were assessed during the course of the 2015 post project monitoring study. These treatments were divided into basic types, including sediment detention structures, stream channel grade control structures, channel hardening treatments, and bank and flood protection treatments.

The following chapter describes each treatment type used within the Waldo Canyon burn, an assessment of the treatment effectiveness, and the failure rate observed with each treatment. The chart on the next page summarizes the overall effectiveness of all treatments reviewed across the fire scar.

Str Type	Functioning	Functioning at Risk	Partially Failed	Failed	Number
Sediment Basin Treatments					
Sediment Basin	58%	16%	6%	20%	45
Basin Log Crib Wall	33%	24%	15%	27%	33
Basin Boulder Crib Wall	50%	50%			2
Basin Log Sill	41%	18%	9%	32%	22
Basin Boulder Sill	25%	25%	25%	25%	4
Basin Grouted Rip Rap Sill	100%				1
Basin Concrete Sill	100%				1
Debris Net	40%	60%			5
Channel Grade Control					
Boulder Drop Structure	73%	13%	9%	5%	132
Boulder Bendway Weir		30%	40%	30%	10
Concrete Sills	100%				5
Boulder Sills	52%	3%	14%	31%	29
Boulder Vanes	50%			50%	3
Log Sills	31%	17%	5%	47%	314
Log Vanes		25%		75%	4
Log Drop Structures (& R&R)	100%				4
Whisker Sills	10%		20%	70%	10
Channel Hardening					
Grouted Rip Rap Channel	78%	22%			9
Concrete Paver Channel Lining	100%				1
Non-Grouted Rip Rap Channel	67%	33%			6
Boulder Step Pool Channel	100%				2
Log Corduroy Treatments	17%		33%	50%	6
Slash Treatment				100%	1
Hardened Crossings	100%				9
Bank Treatments					
Concrete Flood Wall	100%				1
Gabion Basket Flood Wall	100%				1
Trap Bag Flood Wall	89%	11%			19
Sand Bag Wall	100%				3
Staw Waddles				100%	2
Bank Toe Slope Hardening	50%			50%	4
Rip Rap Bank	61%	17%	11%	11%	36
Earthen Berm		33%		67%	3
Log Barrier				100%	1
Other Treatments					
Concrete Box Culvert	67%		33%		3
Other Culverts	100%				1
	62%	38%			
Total Structures	47%	15%	8%	30%	732

Sediment Basins

Engineered and Temporary Basins

Two different types of sediment basins were used in the Waldo Canyon burn. Engineered semi-permanent basins, complete with drains and hardened basin surfaces were utilized along US Highway 24 and above residential areas on the east and south side of the burn. These structures were designed according to urban drainage and flood control criteria, and were quite expensive. These structures have held up very well in subsequent flood events, but quickly fill with sediment and debris, requiring frequent maintenance, at additional cost.

Temporary, non-engineered, sediment detention basins were employed throughout the burn area. These structures are typically do not have a single point of drainage, and employ softer materials such as large wood in construction. This treatment type was originally developed to restore function of alluvial fans in ephemeral drainages. Enough material could be generated to fill down cut channels through the fan by excavating a basin near the top of the feature. The basin drain consisted of a log or rock sill that would spread the flow across the surface of the fan, avoiding convergence of flow at a single point, resulting in further cutting through the fan. These basins are designed to fill over time.

Basins have been an effective treatment in Waldo Canyon, with 74% of these structures still function at their full potential. The 20% failure rate is mostly due to inappropriate use treatment type or location in a less than suitable site. Examples of this include installation of sediment detention basins in perennial channels. Perennial streams in the highly erosive decomposed granite geology within the burn area move tremendous quantities of sediment, even at base flows, making sediment detention problematic in this stream type.

Basin Log and Boulder Crib Walls

Basin Crib Walls are a critical feature of the sediment basins used in the Waldo Canyon burn, and maintain the channel grade upstream of the basin. Basin crib walls may be constructed of large wood or boulders, and require geotextile fabric behind the structure to

prevent movement of fine sediment through the structure. The original crib walls used in Trail Creek and Waldo Canyon were typically a single drop structure straight across the channel. These structures are susceptible to erosion from lateral migration of the channel around the structure in high flow events. After observing multiple failures of these structures following flooding in 2013, the design was modified to an inverted V form, with boulder or log sills deeply embedded into the banks on either side of the feature.

Log basin crib wall failures were relatively high in the Waldo Burn with 47% of these structures being at least partially failed. All of the completely failed structures were of the original design. All of the boulder crib walls were functioning at full potential, however half of these appeared to be at risk, primarily due to failure of the fabric behind the structure, or risk of lateral migration.

Basin Sills

Basin sills are the other critical feature of a sediment detention basin, maintaining channel gradient and assuring flow divergence below the basin. Basin sills are constructed from varying materials including concrete, grouted rip rap, non-grouted boulders, and logs. Failure of the downstream basin sill may result in movement of stored sediment and debris into the channel below, and further down cutting of the channel. The one concrete basin sill and grouted rip rap sill observed in the burn were functioning as expected. 50% of the boulder basin sills had at least partially failed, 41% of the log basin sills had at least partially failed. Boulder basin sills typically failed due to failure of the fabric behind the structure, or lack of adequate footer boulders to prevent scour from undermining the structure. Log sills failed due to compromised fabric and construction flaws resulting in convergence of flow at a single point and subsequent down cutting and channelization.

Functioning basin sills in Northfield

Debris Nets

Five steel debris nets have been employed in Camp Creek, lower Williams Canyon and Waldo Canyon to capture larger cobble and boulders, as well as large wood and other organic matter. These structures range in size from the massive net above Glen Eyrie to much smaller detention structures in Waldo Canyon and Williams Canyon. These engineered structures have been very effective in capturing material before it can damage flood control infrastructure downstream, but are quite expensive to install and require frequent maintenance.

CDOT Debris Net in Waldo Canyon

Channel Grade Control Treatments

Boulder and Log Drop Structures

Drop structures in stream channels were a common and effective grade control treatment used extensively in the Waldo Canyon burn. These structures were typically constructed of medium and large boulders, and were lined with geotextile fabric to prevent migration of decomposed granite and fines through the structure. A few log structures were observed

in the burn as well, including a log “rock & roll“ alignment creating a step pool configuration. Many of the drop structures observed were constructed straight across the channel, with a slightly lower invert in the center of the structure to concentrate flow in the center of the channel. Straight structures were more susceptible to lateral migration and bank erosion than structures constructed using an inverted “V” configuration (Cross Vane).

Of the one hundred and thirty-two boulder drop structures assessed in 2015, 73% were still in good condition and fully functioning. 14% of the boulder drop structures had either partially failed, or failed completely. Boulder drop structures typically failed due to tearing of the fabric behind the structure, or lack of adequate footer boulders causing the center of the structure to collapse. We should note here that we commonly observed that drop structure failures occurred at the critical downstream structure, resulting in formation of a head cut that would migrate upstream through the project reach, compromising the other structures. This was likely due to the use of smaller materials as the stockpile of more suitable rock was consumed during the course of construction.

Typical boulder drop structure

Boulder Bendway Weirs

Bendway weirs are a common channel and bank stabilization technique employed throughout the US for flood control. Bendway weirs are typically installed perpendicular to the direction of flow, and extend across only a portion of the active channel. Bendway weirs were utilized in only one project reach in the Waldo Canyon burn, and were found to be ineffective in the highly erosive decomposed granite channels found in the burn area. We observed that the weirs actually accelerated erosion and down cutting of the channel bed surface, due to convergence of flow at the channel end of the structure, and 70% of these treatments had partially failed, or failed completely, and could threaten more functional treatments both upstream and downstream.

Failed, bendway weir

Boulder and Log Vanes

Boulder and log vanes are similar to Bendway weirs except that they extend upstream at an angle of 20-30 degrees from the river bank. The structure is designed to maintain a low

water surface slope along the stream bank through various flow stages, reducing velocity and shear along the bank. Boulder and log vanes can be very effective in reducing stream bank erosion, but their use is limited in highly erosive channel beds such as found in the Waldo Canyon burn. For this reason, very few of this treatment type were used in Waldo Canyon project reaches. Where this technique was employed, success was limited, with 75% of the log vanes and 50% of the boulder vanes completely failing.

Boulder Log Veins

Sills

Sills were by far the most common grade control treatment used in the Waldo Canyon burn project reaches. Sills extend across the channel surface and create a hard point in the channel to check head cuts migrating through the system. Sills come in various forms, and may be constructed with concrete, grouted rip rap, boulders and logs. With the exception of concrete and grouted boulder sills, this treatment is very inexpensive and relatively easy to install. As with most "easy"

treatments, however, rushed or sloppy construction, inappropriate location, and insufficient quantity has resulted in sills exhibiting one of the highest failure rates of treatment in the project reaches.

Concrete sills, as expected were found to be extremely effective, but at too high a cost to be employed universally. Boulder sills were found to be effective in more than 50% of the project reaches. The 31% total failure rate of boulder sills was typically the result of faulty construction, lack of fabric, and no footings. Log Sills were the most common of all treatments in the project reach, and over three hundred of these structures were assessed in the 2015 study. Log sills typically consisted a single log spanning the channel, with fabric attached to the upstream side of the log and buried under the channel surface. Inevitably, the fabric would tear or otherwise be compromised along some point on the sill, allowing flows to cut beneath the structure. Once the log was undercut, the fabric on either side of the failure point would fail, resulting in the log suspended above the new down cut channel. Within the project reaches, 47% of the log sills have completely failed. As a result, the log sill design has been modified over time, and later sills have incorporated two or even three rows of logs, staggered and stacked on top of each other, and completely wrapped on both sides by geotextile fabric (cigar roll). This newer design was observed to be far more resistant to failure. Additionally, some newer log sills have included boulder footings to project against undermining of the structure.

An experimental sill design, named a “whisker” sill, was employed in one project reach on the burn. This treatment consists of a PVC pipe embedded across the channel. This pipe has numerous smaller protrusions (whiskers) extending above the channel bed to create additional channel roughness and to capture smaller debris and sediment. Unfortunately, the basin where these were installed experienced a significant flood event immediately following construction resulting in significant damage to the treatments and a 70% catastrophic failure rate. It is likely that this event mobilized so much larger materials (cobble and boulder) that the PVC pipes were shattered when exposed during the flood.

Channel Surface Hardening Treatments

Channel surface hardening treatments, as opposed to site specific grade controls, are designed to completely stabilize the channel bed, effectively creating a static unchanging

channel dimension, pattern and profile. Channel hardening treatments are by their very nature very expensive, and are appropriate only in urban flood drainages to protect property and critical infrastructure. In addition to the engineered flood control treatments employed along the east and south side of the burn area, several softer treatments were utilized in other areas to varying effect.

Grouted Rip Rap Channels

Grouted rip rap channel treatments were found to be functioning as expected within the Waldo Canyon burn area. We did note, however, that a few of these structures were functioning at risk, due to the downstream edge of the hardened channel becoming undermined by high flow and scour of softer materials below the structure. We also note that the use of grouted rip rap almost invariably leads to problems with habitat connectivity and aquatic organism passage in reaches where self-sustaining populations of fish and macroinvertebrates are present, and thus have an additional less tangible long term cost beyond the initial investment in this treatment type.

Concrete/Tile Pavers

In addition to the use of grouted rip rap, we observed concrete tile pavers being utilized in many of the CDOT sediment detention basins and in one channel in the upper Cascade Creek project reach. Concrete pavers appeared to be effective for surface hardening, but suffer from the same disadvantages of grouted rip rap, being cost prohibitive to implement on a large scale, and having a negative impact on resident aquatic organisms.

Non Grouted Rip Rap Channels

Non grouted rip rap channels function similar to grouted channels, but at less cost and with less impact on aquatic ecosystems. Non grouted rip rap channel treatments were used on the south and east sides of the burn with good results similar to the more expensive grouted treatments. We did note during the course of the survey that both grouted and non-grouted channels tended to fill with sediment over time, reducing channel roughness and increasing velocity and shear along the channel and banks.

Non-grouted riprap channel

Boulder Step Pool Channels

Step pool channels are a softer natural treatment for channel hardening along a segment of stream. Step pool channels can be difficult and expensive to build, but are very effective in reducing flood energy and shear during a major flood event by mimicking a natural cascade and series of deposition pools. Step pool channels were typically constructed from boulders and geotextile fabric, and consist of a series of cross vanes and sills creating a step pool sequence. Step pool channels can also be constructed almost entirely of large wood, in a technique referred as “Rock & Rolling”. Although used extensively in Trail Creek (Hayman Burn) to good success, log rock & roll structures were employed in only limited amounts in the Waldo Canyon Burn. Step pool channel construction was very effective in the Waldo Canyon burn (100%), and the work completed in Northfield Gulch in 2014 is some of the best work we have observed on any burn in the region.

Log Corduroy Treatments

Log corduroy is a softer natural channel hardening treatment using smaller diameter logs placed either perpendicular or parallel to the direction of flow in the channel. This technique is useful for controlling head cutting in very small ephemeral tributaries, and has the advantage of being able to be constructed by hand crews without the need for heavy

equipment. Unfortunately, the log corduroy treatments we assessed in the Waldo Canyon project reaches were, for the most part, being used in segments of channel that were inappropriate for the technique.

Wood Slash

Dragging wood slash across the channel to create additional roughness is a throw-back to "directional felling" treatments used in burn mitigation in the 1980's and 1990s. Only one instance of this technique was observed in Waldo Canyon, and it had suffered a complete failure.

Hardened Transportation Water Crossings

Hardened water crossings were installed to maintain access to private properties and other facilities in the burn area. Hardened crossings were typically a boulder sill or drop structure installed immediately below the road to maintain channel elevation across the crossing. Nine of these crossings were assessed during the 2015 survey, and all were still functioning as designed.

Bank Treatments

Stream bank treatments ran the gamut, from complex engineered flood walls to simple techniques such as stream bank toe slope armoring and stabilization. The purpose of most bank treatments was to contain flood flows to the active channel where streams run through populated areas, and to limit stream bank erosion and lateral migration of the channels in the basin headwaters, limiting sediment and debris from inundating flood control structures downstream.

Concrete Flood Walls

Concrete flood walls are incredibly expensive, and were only utilized in the lower Williams Canyon project reach, where extreme measures were necessary to protect homes and critical flood control infrastructure. As expected, the concrete flood walls have performed as designed.

Gabion Basket Flood Walls

A single cobble filled gabion basket flood wall was installed at the bottom of Sand Gulch to protect a home immediately adjacent to the stream in a severely confined portion of the basin. The gabion basket wall has been very effective in protecting the home, but significantly confines the channel through this segment, causing the frequent loss of the road servicing several other homes upstream. Gabion baskets are also somewhat limited in durability, and may be prone to failure from rust.

Trap Bag Flood Walls

Trap bag flood walls are a relatively new treatment for flood protection, and consist of large cells of geotextile fabric filled with sand and small gravel. The cells are integrated to form a continuous trapezoidal wall of whatever length is desired to provide flood protection to roads, homes, and other infrastructure. While similar to sand bag walls, trap bag walls are require less manpower and are quicker to install, but at a somewhat higher cost. Trap bags were used extensively in the Waldo Canyon burn with a very high degree of success. No trap bag flood walls were observed to have failed in the project reaches, and all were still performing at full function.

Sand Bag Walls

Sand bag walls are cheap, and can be constructed by volunteers, making them a useful tool in the flood control tool kit. We assessed three sand bag walls during the course of this monitoring effort, and all were performing as expected.

Earthen Berms

Three earthen berms were constructed for flood protection in the project reaches. These features were less effective than desired, with two of the three structures having been completely breached and no longer functioning. We should note, however, that the two failed berms were both found in a project reach that had significant issues with construction quality assurance and quality control.

Stream Bank Toe Hardening

Stream bank toe stabilization is a technique used to protect from high shear along the bottom of a steep potentially unstable bank. Toe slope hardening can consist of armoring the stream bank edge with boulders, trees, or vegetation. Toe treatments were very limited in Waldo Canyon, with only four being assessed during the survey. Effectiveness was inconclusive, with 50% of the structures performing as expected and 50% having failed.

Rip Rap Stream Banks

Boulder Rip Rap stream bank treatments were used extensively in the eastern and southern project reaches of the Waldo Canyon Burn, and were typically utilized in conjunction with hardened channel treatments such as rip rap channels. Stream bank rip rap is susceptible to failure as water infiltrates behind the structure through the interstitial spaces between the boulders and begins to erode out the finer native bank materials behind the rip rap. This is particularly problematic in highly erosive soils such as decomposed granite found within the Waldo Canyon burn perimeter. Boulder stream bank rip rap treatments were moderately effective in the project reaches, with 22% of the structures having partially or completely failed. Rip Rap utilizing geotextile fabric and varying sizes of medium and large boulders was more effective than walls lacking fabric or consisting of uniform particle sizes.

Straw Waddles and Log Barriers

Straw waddles and log barriers treatments were rare in the project reaches, and were completely ineffective. Straw waddles were immediately overwhelmed by localized sediment movements, and the one log barrier treatment was poorly thought out and completely ineffective.

Project Lessons Learned

Project Reach effectiveness exceeded 72% for the burn rehab and flood mitigation undertaken following the Waldo Canyon Burn. Twenty eight percent of the project reaches were completely successful and fully functioning in 2015, and 44% were still fully functional but at risk to future degradation without some maintenance or repair. Only five of the seventeen project reaches were functioning at less than full potential, on only one of these was considered to be a complete loss.

Considering the near record flood events that occurred in late 2013 and 2014 on the Waldo Canyon burn, we consider the 72% success rate of projects to be acceptable.

During the course of this study, we observed several factors that likely lead to less than optimal outcomes in the project reaches and will proceed to describe them herein. These factors, for the most part, stemmed from the existing policies and procedures for implementing projects

across multiple jurisdictions, as well as from institutional limitations inherent in this type of work. Perhaps the most important component of successful projects was having appropriate well thought out design criteria, and fully implementing project designs across multiple jurisdictions and administrative boundaries.

Good design criteria starts with well thought out and peer review plans that utilize appropriate treatments for the given topology and are most likely to lead to desired project outcomes. In several instances, we observed treatments being utilized that were not appropriate to the channel type or project objective. A good case in point is the large numbers of single log sills that were installed along intermittent transport reaches subject to continuous flows as well as large flood events. Single large sills are more appropriate for use in spreading flows across broad ephemeral surfaces such as alluvial fans, and it is clear that single logs are not a good grade control technique in channels with more concentrated flow. Good design criterial is also important in determining the proper selection of treatments that weighs the cost and benefit of the treatment type. While it is clear from our assessment that hardened engineered treatments have a greater rate of success, it is clearly cost prohibitive and impractical to assume that we must use only these treatments for all effected streams. This also fails to address the less tangible costs of destroying habitat connectivity and aquatic/ hydrologic function in the implementation of these treatments.

Once a good design has been developed, it is critical that the project be adequately funded and fully implemented in order to succeed. We noted several project reaches where the project design was not fully implemented and the work stopped at an arbitrary boundary; whether due to inadequate funding, or, in several instances, where competing jurisdictions could not agree on the types of treatments to be used. Inevitably, these incomplete reaches began to unravel, requiring significant maintenance and repairs later on.

Hand in hand with good design criteria is the importance of being able to use adaptive management in both design and implementation of the projects. The one certainty in work of this nature is that you will eventually come upon something that is entirely unexpected or was never anticipated in the initial design. Adaptive design includes the ability to change designs “on the fly” with a streamlined process for approval and implementation. Key to suc-

cessful adaptive project design and implementation is the use of design/build contracting that accommodates changes that may be required between contract award and project completion. Adaptive management allows for easily changing project specifications to address continuing changes and modifications in treatment techniques.

Good project management, along with qualified and experienced contractors are integral to successful project completion, and less than adequate quality assurance/quality control (QAQC) can frequently be a key factor in projects not meeting the goals and objectives of the original design criteria. The one project reach in the Waldo Canyon burn area that was considered a complete failure is a good case in point regarding QAQC. In this instance, a barely qualified contractor was selected for the work, and the contract administration was conducted remotely from an Agency office more than fifty miles from the project. The project did not have a locally designated contract officer's representative, and the local agency inspector was not given any authority to require the contractor to correct problems as they arose. The contractor failed to construct the treatments as designed, but was not held accountable by the agency, and not surprisingly, the treatments failed in short order, threatening other work that had been conducted by other jurisdictions downstream.

Even the most qualified and experienced contractors may occasionally unintentionally cut corners or forget to fully complete work as designed, and it is the role and responsibility of the project manager and their staff to ensure that work is completed in full. Given that so many of the treatments described herein require hidden structure (footings, buried geotextile fabric, etc.) to be structurally sound, it is incumbent on the project manager to ensure that all of these details are completed. The role of the project manager cannot be underestimated as to its importance to a successful project. Indeed, permitting authorities such as the US Army Corps of Engineers now require the project manager to be on site at all times during construction of stream restoration projects authorized under permit authorities such as the Colorado Regional General Permit #12.

Another often overlooked role of the project manager is ensuring that suitable and adequate quantities of materials are available on site to construct the project as designed. We noted several areas where treatments were functioning at risk or had failed where it was clear that the last struc-

ture constructed had been compromised and lead to a head cut migrating upstream through other treatments. Typically, construction of this type of channel project begins at the upstream boundary of the project reach and proceeds downstream. Equipment operators are naturally biased toward selecting the best, easiest to work with materials first, particularly when it comes to boulders. The best materials can quickly consumed, leaving less suitable smaller materials for the key grade control structures at the bottom of the reach. Operators and project managers have a shared responsibility to ensure that suitable materials remain for building the keystone structures typically found at the bottom of the project reach. In nearly every case observed, these critical structures had clearly been assembled with whatever materials happened to remain on site.

1,000-hour fuels

Represents the modeled moisture content (typically in dead fuels in the inch diameter class) and the layer of the forest floor about four inches surface. The 1000-hr FM value is based on a running 7-day computed using length of day, daily temperature and relative humidity extremes (and minimum values) and the 24-hour precipitation duration values. Va range from 1 to 40 percent. The term was based on the fact that it typi about 1,000 hours, or over 40 days, for these larger fuels to reach mois librium with soil moisture levels.

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Geomorphology

The study of the physical features of the surface of the earth and their its geological structures.

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