Horse Creek Watershed Assessment
&
Conceptual Restoration Plan

The Prediction Level Assessment
Results of the Hayman Fire

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The *Horse Creek Watershed Assessment & Conceptual Restoration Plan* builds upon previous collaborative WARSSS assessments including the *Trail Creek Watershed Assessment and Conceptual Restoration Plan* (Rosgen, 2011) and the *Waldo Canyon Fire Watershed Assessment: The WARSSS Results* (2013). Much of the discussion in the assessment is referenced directly from these reports.

Table of Contents

List of Figures

List of Tables

List of Flowcharts

Abstract

The Hayman Fire of 2002 was the largest fire in Colorado's history, burning over 138,000 acres in the South Platte River watershed. Horse Creek is a tributary to the South Platte River, the source of nearly 80% of drinking water for the Denver/Aurora metro area. Several years of intense storm events over the fire area produced significant sediment delivery into the South Platte River and its tributary streams. Downstream reservoirs have lost capacity and Hayman Fire derived soils have been dredged out at a very high cost to water utility providers and customers. State Highway 67 occupies much of the Horse Creek floodplain and is one of the values at risk. Debris and sediment flows from Horse Creek and its tributaries continue to deposit on State Highway 67 causing emergency response.

This cumulative watershed effects analysis provides a basis for setting mitigation and restoration priorities linked to land uses, locations, processes, disproportionate sediment yields, and associated river impairments. The purpose of this restoration work will be to stabilize soil onsite in the Hayman Fire area by reducing erosion, thus improving water quality and fish habitat, and reducing impacts to critical infrastructure, including downstream reservoirs and the State Highway 67. Priorities were developed based on the total sediment supply from hillslopes, roads, and streambanks as determined by the *Watershed Assessment of River Stability and Sediment Supply (WARSSS)* methodology. Restoration priority is based upon access and sediment supply as well as values at risk. The specific restoration scenarios proposed will reduce the sediment supply most effectively for lowest cost at its source and restore the physical and biological function of the system.

Horse Creek Watershed Assessment & Conceptual Restoration Plan:

The *WARSSS-PLA* Results of the Hayman Fire

The *Horse Creek Watershed Assessment & Conceptual Restoration Plan* builds upon previous collaborative WARSSS assessments including the *Trail Creek Watershed Assessment and Conceptual Restoration Plan* (Rosgen, 2011) and the *Waldo Canyon Fire Watershed Assessment: The WARSSS Results* (2013). The *Watershed Assessment of River Stability and Sediment Supply (WARSSS)* is a three-phase methodology that assesses large watersheds with a practical, rapid screening component that integrates hillslope, hydrologic and channel processes (Rosgen, 2006/2009). It is designed to identify the location, nature, extent and consequences of various past, as well as proposed, land use impacts. Before changes in land use management and restoration are implemented, it is of utmost importance to first understand the cause of impairment.

The initial two phases of *WARSSS* involving the *Reconnaissance Level Assessment (RLA)* and the *Rapid Resource Inventory for Sediment and Stability Consequence (RRISSC)* levels were conducted on the 186 mi^2 Horse Creek Watershed on the Pike National Forest, Colorado in 2009 & 2010. The detailed results of these phases are documented in the report *Horse Creek Watershed RLA and RRISSC Assessments* (Rosgen and Rosgen, 2010). The third phase of WARSSS is the *Predictive Level Assessment (PLA).* This report documents the *PLA* results for Horse Creek as well as presents the conceptual restoration plan. This report and plan incorporates text from the upstream watershed assessment report for the Trail Creek Watershed as well as within the nearby Waldo Canyon fire area. The *Trail Creek Watershed Assessment and Conceptual Restoration Plan* (Rosgen, 2011) documents the research review of hydrology, hillslope processes, roads and OHV trails for the entire Hayman Fire, including Horse Creek, and the research and results are either referenced or incorporated here.

The Horse Creek *PLA* phase includes the following steps:

1. Identify the erosional and depositional processes that are disproportionately contributing sediment to Horse Creek
2. Quantify sediment loading by individual erosional process and location
3. Utilize reference reaches to analyze departure of the representative reaches from reference condition
4. Identify disproportionate sediment supply and river impairment by location, land use, and specific erosional or depositional process to develop a conceptual watershed and river restoration plan
5. Set priorities of specific sub-watersheds for restoration based on the magnitude and potential adverse consequences of sediment contributions and flood risks associated with the Hayman Fire
6. Identify stream succession scenarios to document the potential stable state of various stream types
7. Develop a conceptual plan for watershed restoration

This assessment report is designed to:

1. Reference and incorporate general principles related to watershed impacts from wildfires
2. Incorporate recently completed WARSSS Assessments and Designs in similar geological areas
3. Report the results of the *Horse Creek Prediction Level Assessment (PLA)*
4. Layout a conceptual watershed restoration plan that addresses stream impairment following the Hayman fire in the Horse Creek Watershed

The *WARSSS* textbook (Rosgen, 2006/2009) includes detailed descriptions of all the methodologies used in this report.

Included within this report are maps and tables that provide detailed information on the data that was collected in the field and the results of the *WARSSS* analysis

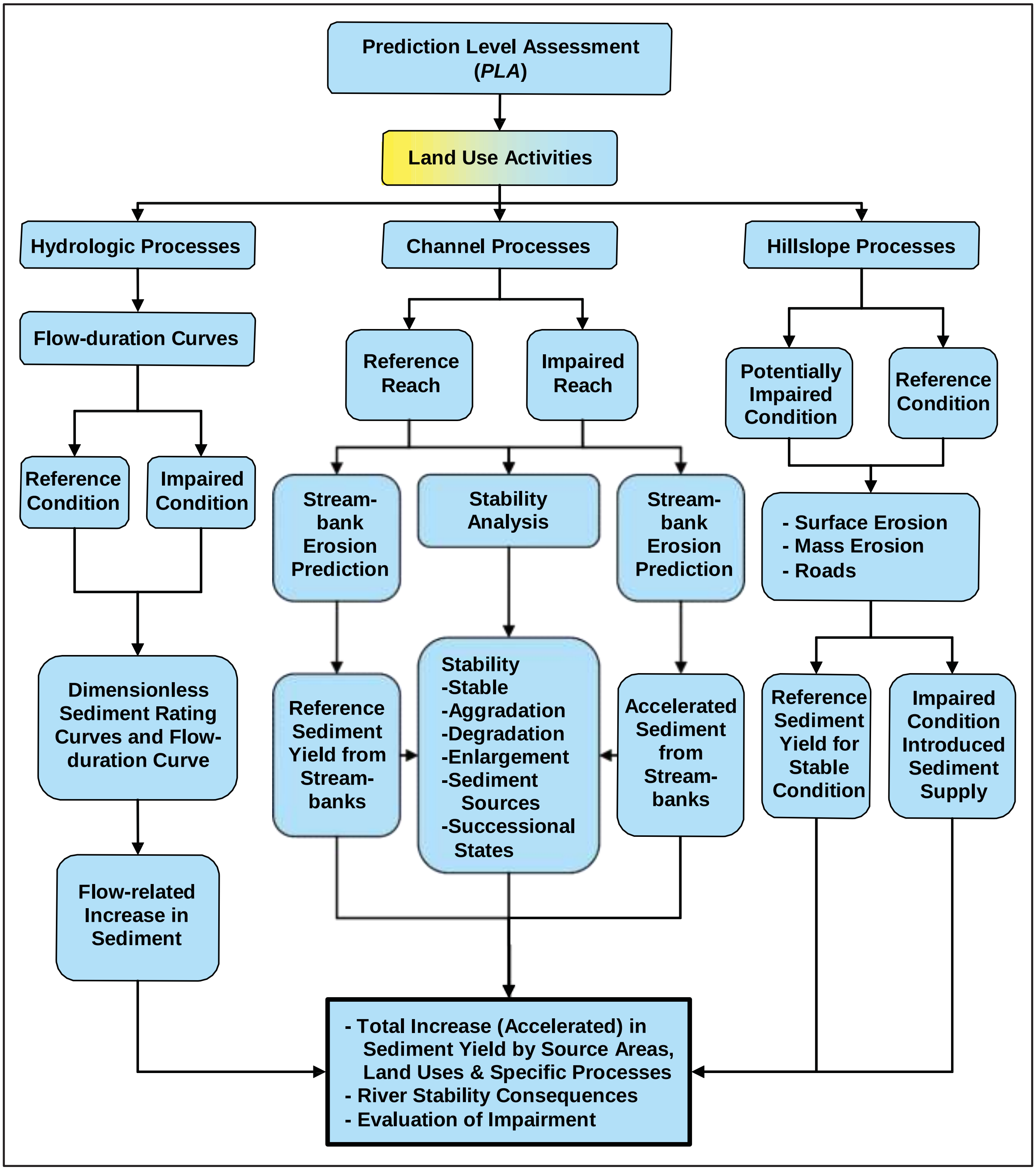
Maps

- (1) Locator Map
- (2) Sub-Watersheds
- (3) WRENSS Change in Water Yield
- (4) Stream Conditions
- (5) Streambank Erosion Rates
- (6) Delivered Sediment
- (7) Restoration Map

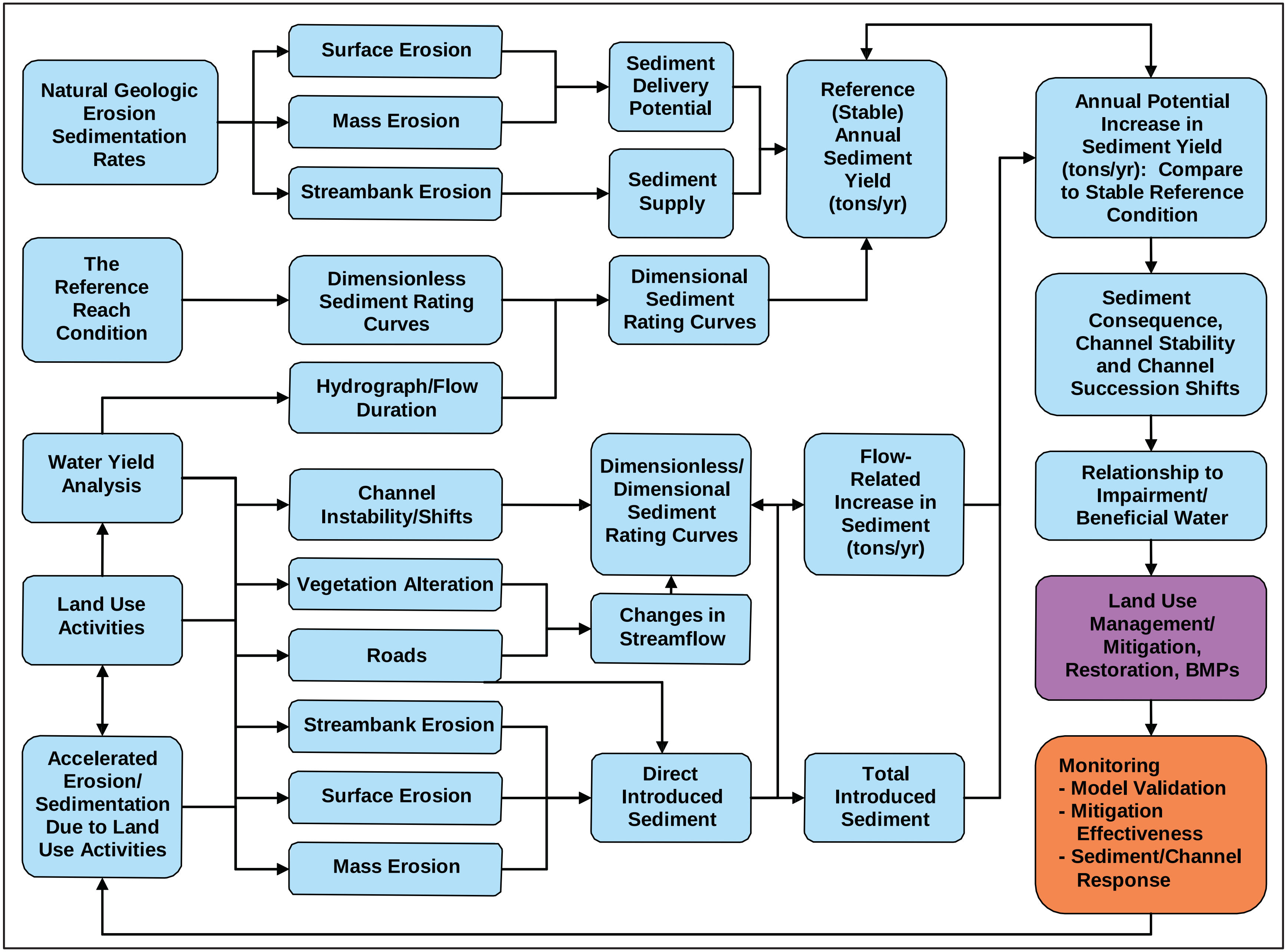
Tables

- (1) Priority Watersheds
- (2) Change in Water Yield
- (3) Pre & Post – Fire Water Yield
- (4)Flow Related Sediment
- (5) Hillslope-Delivered Sediment
- (6) Road Impact
- (7) Streambank Erosion Rates
- (8) Sediment Summary

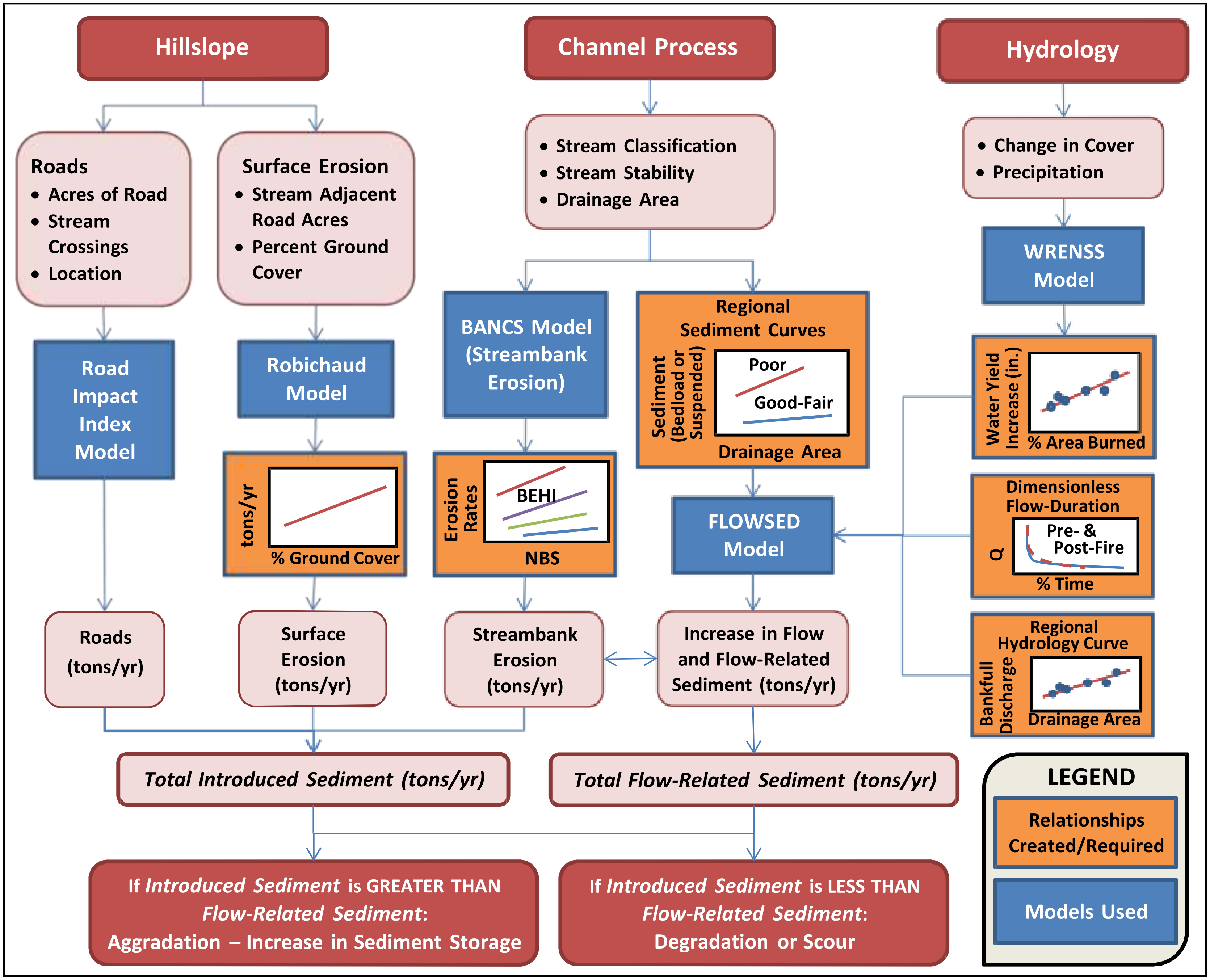
The procedure for the watershed assessment is summarized in Flowchart -1 and Flowchart -2 (Rosgen, 2006/2009). The organization of the data and models is shown in Flowchart -3 (Rosgen, 2006/2009). These flowcharts depict the assessment approach utilized to predict the total annual sediment yield and the associated erosional or depositional processes.



Flowchart 1. *PLA* comparative analysis of reference condition and impaired condition in parallel (Rosgen, 2006/2009).



Flowchart 2. The general organization of the procedural sequence for the *Prediction Level Assessment (PLA)* (Rosgen, 2006/2009).



Flowchart 3. Procedural flowchart of the quantification of sediment sources and channel response utilizing a variety of models. (Rosgen, 2006/2009)

Figure 1. Horse Creek project area Locator Map

Figure 2. Horse Creek project area sub-watersheds

Table 1. Summary and prioritization of sediment supply by source.

Priority	Watershed	Streambank Erosion (tons/yr)	Roads and Trails (tons/yr)	Hillslope Sediment (tons/yr)	Total Sediment (tons/yr)
1	HC_113 Camp Creek	15495.5	0.0	13.7	15509.2
2	HC_119	9626.4	1.6	7.7	9635.7
3	HC_121	9298.5	0.0	7.5	9305.9
4	HC_120	9134.5	0.0	9.7	9144.2
5	HC_83	3293.2	0.0	10.0	3303.2
6	HC_125	2623.2	0.0	1.7	2624.8
7	HC_118	2424.0	0.0	2.5	2426.5
8	HC_92	2139.7	0.0	5.6	2145.4
9	HC_93	1521.5	0.0	2.7	1524.2
10	HC_126	1487.3	0.0	4.2	1491.5
11	HC_91	1233.3	0.0	2.4	1235.6
12	HC_82	1095.9	0.0	4.8	1100.7
13	HC_97	1034.5	0.0	7.9	1042.3
14	HC_44	941.9	0.0	1.3	943.2
15	HC_45	849.9	0.0	0.6	850.4
16	HC_139	710.3	0.0	1.5	711.8
17	HC_128	637.7	0.0	0.9	638.6
18	HC_38	479.4	0.0	3.0	482.4
19	HC_40	402.7	0.0	1.3	404.0
20	HC_124	387.1	0.0	0.6	387.6
21	HC_131	345.5	0.0	0.5	346.1
22	HC_94	344.4	0.0	1.2	345.6
23	HC_51	327.4	0.0	0.2	327.6
24	HC_135	250.4	0.0	2.8	253.3
25	HC_88	214.9	0.0	2.9	217.9
26	HC_95	188.9	0.0	1.2	190.1
27	HC_85	172.2	0.0	0.5	172.7
28	HC_137	130.4	0.0	1.7	132.2
29	HC_138	84.5	0.0	4.1	88.7
30	HC_87	77.3	0.0	2.1	79.4
31	HC_136	51.7	0.0	2.3	54.0
32	HC_150	52.2	0.0	0.4	52.5
33	HC_130	22.7	0.0	0.6	23.3
34	HC_129	11.7	0.0	0.7	12.4
35	HC_98	5.9	0.0	1.9	7.8

Watershed condition and the changes in ***Hydrology***, ***Flow Related Sediment***, ***Hillslope Processes***, and ***Channel Processes*** were determined by the research and methods explained in the subsequent sections:

Hydrology:

Research Review

(Incorporated from Trail Creek Watershed Assessment and Conceptual Restoration Plan (Rosgen, 2011)

The following are excerpts from an interim report by Robichaud *et al*. (2002) that summarize the research pertaining to hydrology impacts after the Hayman wildfire (refer to Robichaud *et al*., 2003, for the final report).

> "Increases in annual water yield (runoff from a specified watershed) after wildfires and prescribed fires are highly variable (DeBano *et al*., 1998; Robichaud *et al*., 2000). The increase in runoff rates after wildfires can be attributed to several factors. In coniferous forests and certain other vegetation types, such as chaparral, the volatilization of organic compounds from the litter and soil can result in a water repellent layer at or near the soil surface (DeBano, 2000). The net effect of this water repellent layer is to decrease infiltration, which causes a shift in runoff processes from subsurface lateral flow to overland flow (Campbell *et al*., 1977; Inbar *et al*., 1998). The loss of the forest litter layer can further reduce infiltration rates through rainsplash erosion and soil sealing (Inbar *et al*., 1998; DeBano, 2000). Loss of the protective litter layer and soil water repellency has occurred in the Hayman Fire area. These two factors combined will likely cause a large increase in runoff, which should diminish within two to five years as vegetation regrows.
>
> Flood peak flows produce some of the most profound watershed and riparian impacts that forest managers have to consider. The effects of fire disturbance on storm peak flows are highly variable and complex. Intense short duration storms that are characterized by high rainfall intensity and low volume have been associated with high stream peak flows and significant erosion events after fires (DeBano *et al*., 1998; Neary *et al*., 1999; Moody and Martin, 2001).
>
> In the Intermountain West, high-intensity, short duration rainfall is relatively common (Farmer and Fletcher, 1972). Unusual rainfall intensities are often associated with increased peak flows from recently burned areas (Croft and Marston, 1950). Moody and Martin (2001) measured rainfall intensities after the Buffalo Creek Fire in the Front Range of Colorado that was greater than 0.4 in/hr (10 mm/hr). Even in short bursts of 15 to 30 minutes, rainfall of such intensity will likely exceed the average infiltration. Water repellent soils and cover loss will cause flood peaks to arrive faster, rise to higher levels, and entrain significantly greater amounts of bedload and suspended sediments. The thunderstorms that produce these rainfall intensities may be quite limited in areal extent but will produce profound localized flooding effects. Observations to date indicate that flood peak flows after fires in the Western United States can range up to three orders of magnitude greater than pre-wildfire conditions. Although most flood peak flows are much less than this catastrophic upper figure, flood peak increases of even twice pre-fire conditions can produce substantial damage.
>
> The concepts of stormflow timing are well understood within the context of wildland hydrology. However, definitive conclusions have been difficult to draw from some

> studies because of combined changes in volume, peak and timing at different locations in the watershed, and the severity and size of the disturbance in relation to the size of watershed (Brooks *et al*., 1997). As a result of the Hayman Fire, peak flows within the watersheds covered by the burned area are expected to be higher and occur quickly, but specific amounts are difficult to predict."

An excellent summary of the hydrology impacts is summarized by the efforts of the USDA Forest Service research team and Colorado State University (Robichaud *et al*., 2003). According to Moody and Martin (2001), flood peak increases of 140% of background conditions occurred following wildfires in Colorado as determined from the Buffalo fire. There was also a large flow-related measured sediment yield for the control (no surface ground cover treatment) between 2003 and 2005, generating *8.8 tons/acre* from a *1.7 inch/hr* storm, resulting in *650 csm* of runoff within the Hayman burn study plots (Robichaud & Wagenbrenner, 2006). In 2007, a *4.3 in/hr* storm for 10 minutes generated a high peak flow of *1,064 csm* (Robichaud & Wagenbrenner, 2008). The sediment yield from this storm, however, was lower due to increased ground cover, yielding less than *1.5 tons/acre*, much less than the *8.8–10 tons/acre* immediately following the fire associated with a much lower magnitude storm. This research data reflects the surface erosion and hillslope process recovery of ground cover density five years following the fire (Robichaud & Wagenbrenner, 2008).

Recent analysis by the USGS (Jarrett, 2009) documented extreme flood damage with stormflow events that are producing flood peaks greater than would be predicted by precipitation amounts. According to Jarrett (2009), there have been at least six rainstorms that have exceeded the 100-year event in the Hayman burn area in the Trail, West, Camp, Horse, Fourmile and Sixmile Creek basins since the 2002 fire.

Continued frequent and high magnitude storms will generate excess sediment yields based on flow-related channel response for the Horse Creek watershed as well as other tributaries involved in the Hayman fire. According to MacDonald (2009), the Hayman fire will continue to produce excessive sediment from the more extreme storm events due to limited recovery of vegetation, which results in evapotranspiration and interception losses. The vegetative regeneration on most of the Hayman fire is very poor due to the coarse-textured soils and low precipitation relative to potential evapotranspiration. Vegetative cover is not expected to increase much beyond the current levels in areas without coniferous trees for years or decades. Until overhead and ground cover returns to pre-fire levels, there will be a continuing susceptibility for a higher than normal streamflow "peak" response to high-intensity summer thunderstorms (MacDonald, 2009).

Hydrologic Processes and Methodology

Bankfull Discharge

Bankfull discharge is the frequent peak flow that fills the channel to the incipient level of flooding and may result in some inundation of the floodplain in flood-prone area. It often associated with a return interval of 1 to 2 years and is coincident with the effective discharge or channel forming flows. Bankfull (Q) was estimated using bankfull stage field indicators with the continuity equation (Q = A * u) by estimating mean velocity (u) and calculating the bankfull cross-sectional area (A). The calculated bankfull discharge was then compared to regional curves developed for this project representing bankfull discharge *vs*. drainage area. This regional curve is based on calibrated, field-determined bankfull values at USGS stream gages and other monitoring sites in the same hydro-physiographic province as the Hayman Fire. Velocity was estimated using a variety of methods, such as flow resistance to relative roughness and Manning's "*n*" by stream type in detailed cross-sections. The bankfull discharge for each sub-watershed (at the mouth) was determined from the regional curve of bankfull discharge *vs*. drainage area (**Figure 3**).

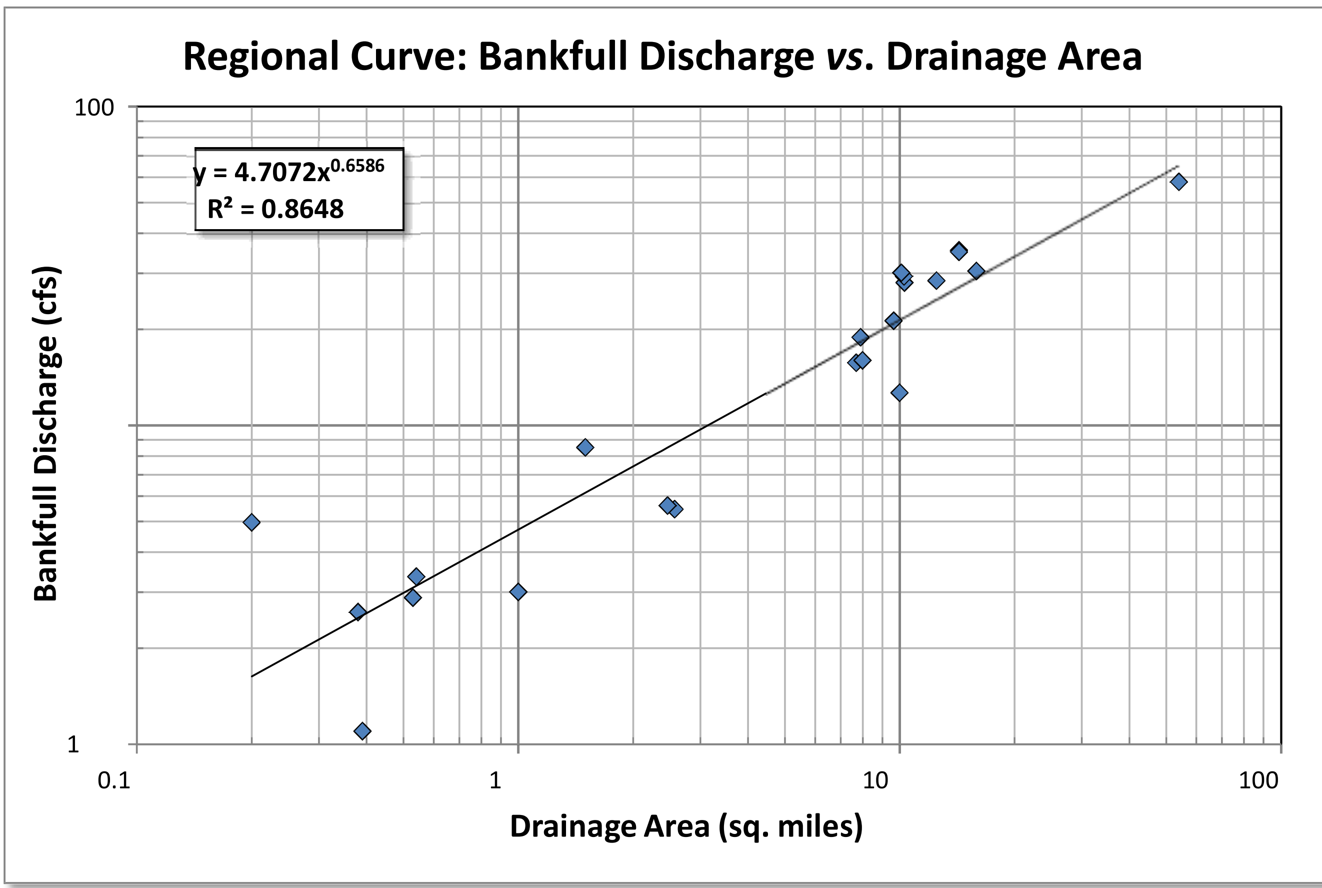


Figure 3. Bankfull discharge *vs*. drainage area relationship used for the Hayman Fire area. (Rosgen, 2013)

WRENSS Water Yield Model

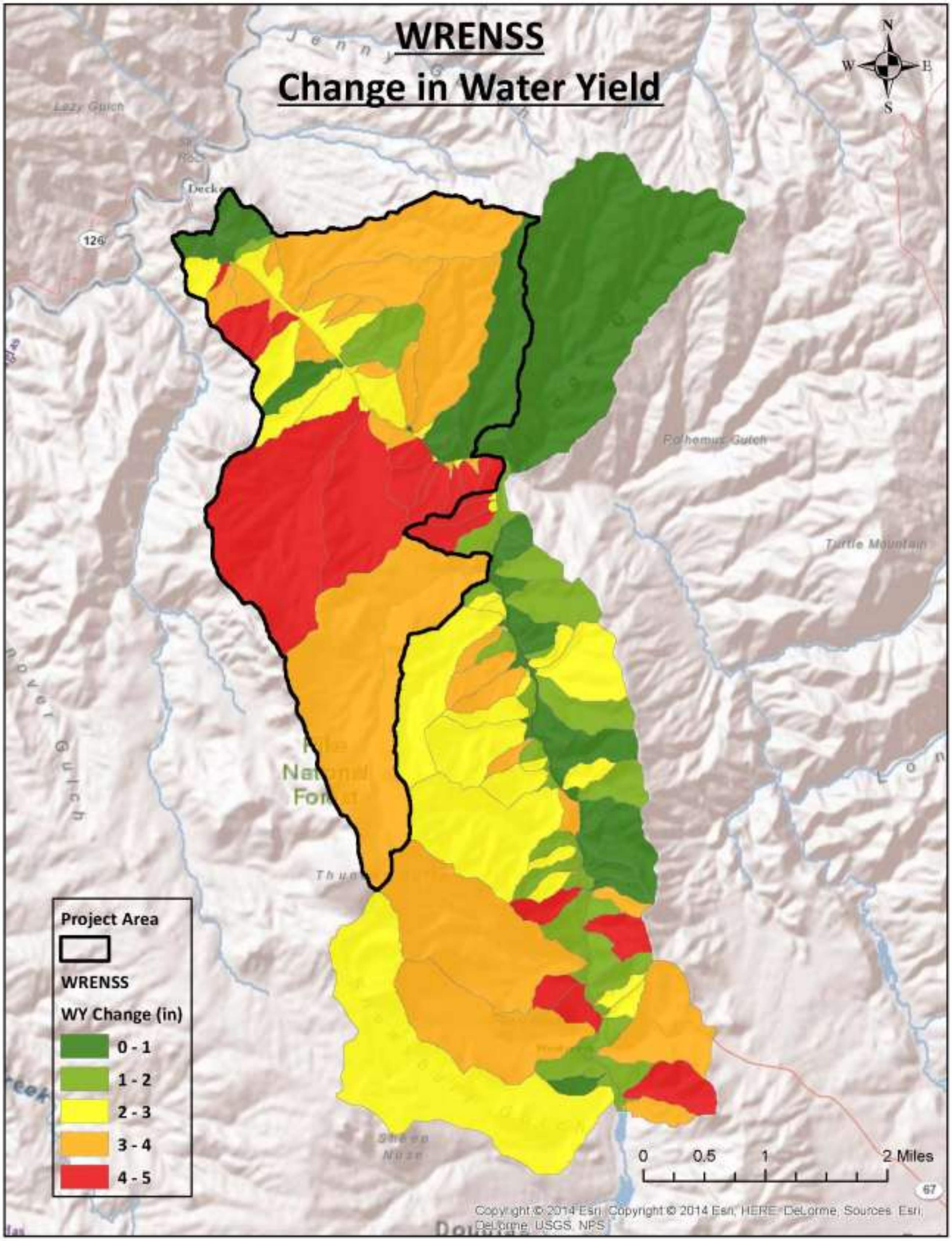
The reduction in vegetative cover, particularly forest-stand vegetation, following the Hayman Fire created a major reduction in evapotranspiration, leading to an increase in the magnitude and frequency of floods as a result of precipitation events. The assessment for Hayman Fire involves an application of the WRENSS water yield model (USEPA, 1980) completed by J. Nankervis, 2013, Blue Mountain Consultants. WRENSS simulates the increase in average water yield based on reduction in forest cover (forest-stand data was provided by B. Banks and M. McGann (USDA Forest Service)). The model is run for homogenous units of vegetation conditions (species and density), area, aspect, and the average monthly precipitation. The change in water yield is calculated based on the difference between pre- and post-fire vegetation condition. A linear regression was developed for each of the 35 sub-watersheds correlating change in water yield as a function of percent reduction in cover. Increase in water yield is depicted in **Figure 4**. These regressions allow a reasonable prediction of the changes in water yield for an infinite number of locations within each of the sub-watersheds. The incremental change in water yield for the sub-watersheds is reported in **Table 2**.

Table 2. Increased water yield for the sub-watersheds as a result of the Hayman Fire.

Watershed	Area (acres)	Change in Water Yield (in)
HC_38	54	3.3
HC_40	42	3.8
HC_44	38	3.4
HC_45	19	4.1
HC_51	6	3.1
HC_82	76	2.8
HC_83	131	2.4
HC_85	68	2.2
HC_87	31	1.6
HC_88	24	3.8
HC_91	94	2.8
HC_92	200	4.0
HC_93	97	4.3
HC_94	44	3.6
HC_95	51	2.7
HC_97	521	3.5
HC_98	41	0.0
HC_113	1324	3.1

Watershed	Area (acres)	Change in Water Yield (in)
HC_118	56	4.8
HC_119	415	3.9
HC_120	888	4.2
HC_121	422	4.8
HC_124	23	4.7
HC_125	51	4.7
HC_126	51	3.8
HC_128	32	4.8
HC_129	8	4.2
HC_130	12	4.4
HC_131	20	4.8
HC_135	16	1.1
HC_136	15	3.1
HC_137	23	3.7
HC_138	20	3.7
HC_139	18	4.8
HC_150	6	4.4

Figure 4. Map of increase in water yield for the sub-watersheds.



The pre-fire *vs.* post-fire water yields for the watersheds affected by the Hayman Fire are reported in **Table 3**. These increases in average annual water yield indicate that there is significant additional available water to erode streambanks and streambeds and increase sediment transport.

Table 3. Summary of pre- and post-fire water yield by sub-watershed

Watershed	Pre-Fire Water Yield (acre-ft)	Post-Fire Water Yield (acre-ft)	Increase Water Yield (acre-ft)
HC_38	100	120	20
HC_40	85	103	18
HC_44	80	95	15
HC_45	51	60	9
HC_51	23	26	2
HC_82	125	150	24
HC_83	180	215	35
HC_85	117	134	17
HC_87	69	74	5
HC_88	59	69	10
HC_91	145	174	30
HC_92	237	326	89
HC_93	147	194	47
HC_94	87	105	18
HC_95	96	112	16
HC_97	446	652	206
HC_98	83	83	0
HC_113	824	1293	469

Watershed	Pre-Fire Water Yield (acre-ft)	Post-Fire Water Yield (acre-ft)	Increase Water Yield (acre-ft)
HC_118	103	134	31
HC_119	384	565	181
HC_120	634	1051	417
HC_121	389	618	229
HC_124	57	69	12
HC_125	97	124	27
HC_126	96	118	22
HC_128	71	88	17
HC_129	28	32	4
HC_130	37	43	6
HC_131	52	62	11
HC_135	45	47	2
HC_136	44	49	5
HC_137	57	66	10
HC_138	52	60	8
HC_139	49	59	10
HC_150	24	27	3

Hillslope Processes (Surface Erosion):
Research Review

(Incorporated from Trail Creek Watershed Assessment and Conceptual Restoration Plan (Rosgen, 2011)

Sediment yields due to surface erosion from hillslopes can decrease by an order of magnitude following the first year, and by seven years, negligible surface erosion from hillslopes can result (Robichaud and Brown, 1999; Robichaud *et al*., 2002). In eastern Oregon, it took 7–14 years to return to the pre- fire condition (DeBano *et al*., 1998; Robichaud *et al*., 2002). For the Hayman burn area, MacDonald (2009) reports:

> "The amount of erosion is largely a function of the amount of ground cover. Prior to the fire there was less than 10% bare soil, as there was a nearly complete carpet of coniferous needles along with around 20–30% live vegetation. This ground cover, together with the high infiltration rates, created little to no overland flow or erosion on unburned slopes up to 50% even if the rainfall intensity was greater than two inches per hour. High severity post-fire areas had less than 10% surface cover (i.e., more than 90% bare soil and ash). Under these conditions a rainfall intensity of only one-third of an inch per hour generated substantial amounts of sediment. By summer 2004, erosion rates per unit rainfall intensity dropped to half of the values measured in 2002–2003, and by 2005–2006 most sites had more than 50% ground cover, and this was enough to greatly reduce hillslope erosion from most sites except from the most intense summer thunderstorms."

Robichaud and Wagenbrenner (2009) reported that increasing ground cover led to a major reduction in surface erosion source sediment yield between 2002 and 2008 in the Hayman burn area. For slopes in the 15–40% range and for ground cover greater than 50%, limited sediment yields from surface erosion is anticipated based on data six years following the fire. Sediment yields were greatly reduced from the initial erosion and sedimentation rates by 2008, even in the presence of high intensity rainstorms. Based on the conducted research, it may be inferred that the highest potential for sediment yields from surface erosion are more likely to occur adjacent to stream systems on very steep slopes with less than 20% ground coverage.

Hillslope Processes (Surface Erosion):
Methodology

The design of the surface erosion research conducted by the USDA Forest Service research station was to measure soil loss as exported to a weir that would represent delivered sediment for relatively short slope lengths and gradients between 20–40%. Variation in ground cover density and slope gradient was related to measured sediment yields. The research results by Robichaud and Wagenbrenner (2009) show relations between ground cover and sediment yield over time. As a result of their data, a negative exponential relationship of erosion rate (tons/acre) as a function of ground cover density (%) was developed for this analysis (**Figure 5**). The research by Robichaud and Wagenbrenner showed "no significant" differences in erosion rate between 20% and 40% slopes. The "nonwettable" or hydrophobic soil condition that reduces infiltration is reduced after the first three years (Robichaud & Wagenbrenner, 2009).

Ground cover densities were determined for small sections (polygons) within each sub-watershed to obtain the sediment yield from surface erosion in tons/acre/yr. The vegetation layer, provided B. Banks and M. McGanns (USFS), was used to obtain ground cover percentage in these polygons. Because much of the area in the watershed was outside the range of Robichaud and Wagenbrenner's data, a delivery ratio was applied to the erosion rate using the Sediment Delivery Index (USEPA, 1980). The Sediment Delivery Index estimates the portion of surface erosion that is delivered to the stream systems.

The following variables were used to calculate delivered sediment from surface erosion:

- Percent Ground Cover
  - Total tree crown cover (TTCC)
  - Percent shrub
  - Percent forb
  - Percent grass
  - Percent barren
  - Percent water
- Satellite Burn Severity
- Presence of Rills (visual approximation from ground and aerial photos)
- Slope
- Slope Shape (concave *vs*. convex)
- Slope Length
- Soil Texture
- Available Water (using 1.0 inch/hr runoff)

The following procedure was followed to calculate delivered sediment for each sub-watershed:

1. Delineate polygons within sub-watersheds by similar physical attributes
2. Calculate variables (see above list) for each polygon
3. Calculate average delivery distance to nearest channel for each polygon
4. Calculate erosion rate for each polygon using the relationship derived from Robichaud and Wagenbrenner (2009) (**Figure 5**)
5. Calculate sediment delivery ratio for each polygon using the Stiff Diagram (USEPA, 1980)
6. Calculate delivered sediment for each polygon
7. Sum the delivered sediment for each sub-watershed (tons/yr)

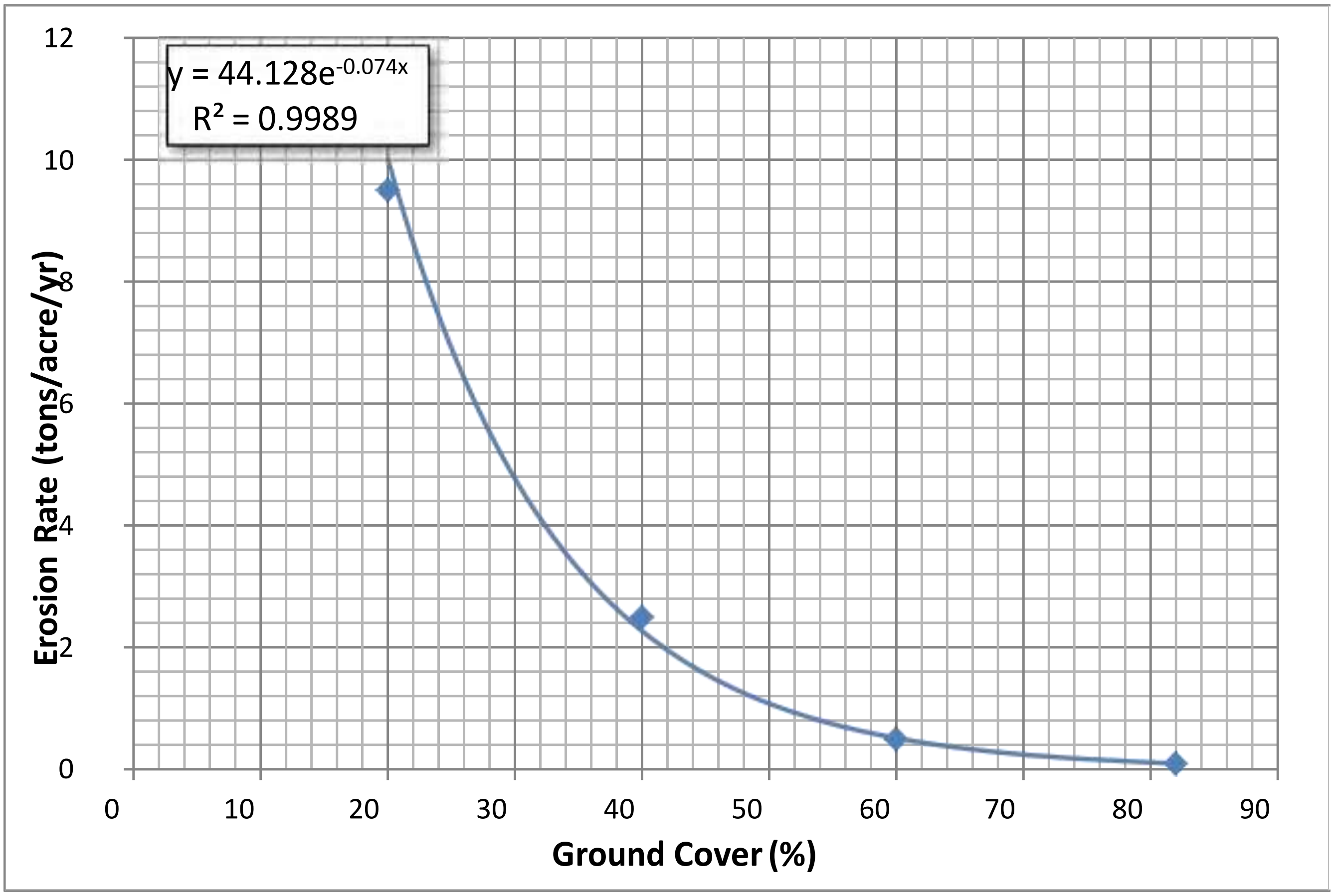


Figure 5. Surface erosion sediment yields by ground cover density for 20–40% slopes, as derived from Robichaud & Wagenbrenner (2009).

Hillslope erosion and associated sediment yield (tons/yr), average delivery ratios (percent of total surface erosion delivered as sediment), and sediment yield per unit of watershed (tons/acre/yr) are reported for the sub-watersheds in **Table 4**.

Table 4. Surface erosion results for the sub-watersheds.

Watershed	Hillslope Erosion (tons/yr)	Average Sediment Delivery	Delivered Sediment (tons/yr)	Delivered Sediment (tons/acre)	Watershed	Hillslope Erosion (tons/yr)	Average Sediment Delivery	Delivered Sediment (tons/yr)	Delivered Sediment (tons/acre)
HC_38	137	2.09%	3.0	0.06	HC_118	142	1.84%	2.5	0.04
HC_40	70	1.70%	1.3	0.03	HC_119	562	1.19%	7.7	0.02
HC_44	72	1.51%	1.3	0.03	HC_120	674	1.37%	9.7	0.01
HC_45	40	1.19%	0.6	0.03	HC_121	435	1.62%	7.5	0.02
HC_51	12	1.72%	0.2	0.03	HC_124	37	1.68%	0.6	0.02
HC_82	205	1.75%	4.8	0.06	HC_125	116	1.64%	1.7	0.03
HC_83	468	1.78%	10.0	0.08	HC_126	197	1.83%	4.2	0.08
HC_85	55	0.87%	0.5	0.01	HC_128	67	1.48%	0.9	0.03
HC_87	88	2.13%	2.1	0.07	HC_129	33	2.10%	0.7	0.09
HC_88	132	1.68%	2.9	0.12	HC_130	29	2.13%	0.6	0.05
HC_91	122	1.67%	2.4	0.03	HC_131	29	1.64%	0.5	0.03
HC_92	334	1.53%	5.6	0.03	HC_135	114	2.48%	2.8	0.18
HC_93	118	2.00%	2.7	0.03	HC_136	91	2.23%	2.3	0.15
HC_94	53	2.19%	1.2	0.03	HC_137	102	1.62%	1.7	0.08
HC_95	60	1.85%	1.2	0.02	HC_138	162	2.35%	4.1	0.21
HC_97	529	1.34%	7.9	0.02	HC_139	81	1.40%	1.5	0.08
HC_98	89	1.95%	1.9	0.05	HC_150	24	1.63%	0.4	0.06
HC_113	847	1.57%	13.7	0.01					

Hillslope Processes (Roads & Trails):
Research Review

(Incorporated from Trail Creek Watershed Assessment and Conceptual Restoration Plan (Rosgen, 2011)

Over the long-term, studies by Colorado State University indicate that roads and trails generate and deliver as much sediment to the stream channel network as high-severity wildfires (MacDonald, 2009). According to MacDonald (2009):

> "The estimated sediment production and delivery from roads and OHV trails was based on six years of road erosion monitoring, five years of post-fire erosion monitoring, nearly two years of monitoring sediment production from OHV trails, and extensive surveys of the connectivity of roads and OHV trails to streams.
>
> The exact balance between sediment from roads and OHV trails vs. high-severity wildfires depends on the assumed recurrence interval for high-severity wildfires. Charcoal dating, the extent of armoring on burned vs. unburned hillslopes, and the amount of accumulated sediment in channels all suggest that Hayman-type events are extremely rare. If this is true, then roads and OHV trails are quite possibly the dominant source of hillslope sediment because they produce large amounts of sediment from multiple storms every year."

Measured erosion rate values for roads resulted in *5.8 tons/acre* of road (Libohova, 2004). The measured erosion rates are similar to sediment yields from roads if such roads are located adjacent to stream courses or drainage structures that drain directly into streams. Delivered sediment from roads, based on USDA Forest Service research work on the Horse Creek Experimental area in Idaho and Fool Creek, Colorado, was converted to the Road Impact Index (RII) (Rosgen, 2006/2009) (RII = road density multiplied by the number of stream crossings). Sediment rates for the lower 1/3 slope position of roads with an RII of 0.1 resulted in delivered sediment to weir ponds of *5.7 tons/acre* of road (similar to the measurements by Libohova, 2004). However, up to *17.6 tons/acre* could potentially be delivered for RII values of 0.4 using the relationship for the lower 1/3 slope position of roads. For mid-to-upper slope positions, delivered sediment rates could potentially generate *0.15 tons/acre* for RII values of 0.1, and *1.1 tons/acre* for RII values of 0.4. Reasonable validation agreement of the measured road erosion rates from the Hayman fire research (Libohova, 2004) and the sediment yield prediction from roads using the RII (Rosgen, 2006/2009) suggests the Road Impact Index is an appropriate model utilized for this assessment.

Hillslope Processes (Roads & Trails):

Processes and Methodology

Stream encroachment, road crossings, cut bank erosion, fill erosion, and poor drainage structure design frequently result in disproportionate sediment yields. Another source of sediment is from the encroachment of the road system on stream channels that cut into the toe of alluvial fans; this over-steepens the channels causing headcuts and the routing of sediment from the fans directly into trunk streams. Also, routing ditch-line water and sediment from in-sloped roads leads to over-steepened A4 and G4 stream types, causing accelerated sediment delivery (see Waldo Canyon Fire WARSSS - Appendix B for stream type descriptions). <<DANA: WE SHOULD INCLUDE THE APPENDIX B HERE INSTEAD OF REFERRING TO APPENDIX IN WALDO REPORT.>>These activities have caused maintenance problems in addition to delivered sediment.

The delivered sediment from roads and trails in the Hayman Fire is determined by use of the Road Impact Index (RII) as discussed in the previous section. The RII is implemented by calculating the total acres of sub-watershed, the total acres of road, the number of stream crossings (including ephemeral channels), and the dominant slope position (lower slope position *vs*. mid-to-upper slope position). There is only one paved road (Highway 67) and one decommissioned road in the project area. The total amount of sediment attributed to roads and trails is 1.6 *tons/yr* (**Table 5**). Due to the objectives of this analysis, highway 67 is not included in the analysis.

Table 5. Summary of sediment derived from roads and trails.

Watershed	Roads and Trails			
	Total Acres of Road	Number of Stream Crossings	Sediment Delivered (tons/yr)	Percent of Total Introduced Sediment
HC_119	1.6	10	1.6	0.02%

Sediment yields from roads and trails can be effectively controlled by improving road drainage, implementing closer-spaced cross drains, out-sloping the road, relocating site-specific roads, routing the channel away from the road fills, stabilizing tributaries above and below the road, and other related best management practices to mitigate this sediment source. Because this area only contains one decommissioned road, with very low sediment yield, the conceptual design does not include a road and trail restoration design.

Several driveways with multiple culverts cross the mainstem of Horse Creek. Many of these driveways and culverts were installed during the post flooding, emergency response with the number one goal being access to private property. During large flood events, driveway failures have drastically altered stream channel morphology in the downstream reaches. Driveways with culverts have failed when the culvert capacity was exceeded and the driveway acted like a dam and catastrophically failed or when the culvert inlet was plugged and storm water flowed overtop of the driveway fill. Most of the driveway fill is made of the highly erosive Pikes Peak granitic native material. Driveway failures and poor design have created a sediment input that exceeds the bedload carrying capacities of the channel. Excess sediment and a lack of sediment transport leads to infilling of pools and unstable braided channels. During annual flood events, undersized culverts have resulted in an increased stream power causing downcutting and channel enlargement in the immediate downstream reaches. Water quality, fish and riparian habitat have all been affected due to increased turbidity and the creation of new cut-bank sediment sources. Driveway improvements should include proper culvert and bridge designs that drain the floodplain and also accommodate base flow without aggradation. New culverts should be designed and installed with a professional engineer's stamp of approval to ensure proper function and to protect the investment. Driveway improvements should be focused on proper culvert sizing, and reducing sediment delivery into Horse Creek. The hillslopes and tributary drainages are recovering on an upward trend, but the undersized, poorly designed driveway crossings are a permanent source of sediment and are a high risk for failure.

Figure 6. Image of sediment deposition from a driveway crossing Horse Creek to access Hwy 67.

Channel Processes:
Research Review

(Incorporated from Trail Creek Watershed Assessment and Conceptual Restoration Plan (Rosgen, 2011)

MacDonald (2009) reports the following related to channel processes for the Hayman burn area:

> "Most of the post-fire sediment is coming from rill, gully, and channel erosion rather than hillslopes. Almost all of the erosion occurs as a result of high-intensity summer thunderstorms, and the hillslopes play a critical role in terms of generating the surface runoff that then is concentrated into channels and induces flow-related erosion.
>
> Much of the sediment that is being generated from rills, gullies, and channels is then deposited in lower-gradient reaches. In ephemeral channels much of the sediment enters into storage, and is delivered to downstream reaches during larger storm events. In perennial channels there also is extensive sediment storage, but the accumulated sediment is primarily fine gravel and smaller. This means that the streams are able to transport this sediment into the downstream reaches at both high and low flows, and over time, much of the post-fire sediment will be excavated and delivered downstream."

Channel Processes:
Methodology

Wildfire-induced changes in the boundary conditions (riparian vegetation and flow resistance) and the flow and sediment regimes promote changes in river morphology (stream type and stability). Typical channel responses to the fire effects include increased streambank erosion, channel enlargement, aggradation, degradation, lateral migration, and channel avulsion. The extent, nature and direction of change is dictated by the valley type and stream type associated with a given stream reach and its condition prior to the fire. Recognizing disequilibrium or unstable reaches and understanding what the stable form should be is instrumental to this effort on the watersheds affected by the Hayman Fire.

Stream inventories conducted in the burn area document existing valley types, stream types, and conditions to locate and quantify disproportionate sediment sources (see **Appendix A**). To characterize the major reaches in the watershed, the following procedures were utilized and allow for extrapolation of observed, detailed channel process relations to other reaches of similar stream type and condition. Stream impairment and sediment supply estimates were developed in a two-phase process:

Phase I

- Development of typical, *Representative Reaches* that represent a range of ***River Stability and Sediment Supply*** conditions for the various stream types that occur within the Horse Creek Watershed – Completed as part of the Trail Creek and Waldo Canyon WARSSS
- Departure of the *Representative Reaches* from the stable, *Reference Reach* condition for various stream types and valley types with defined boundary conditions and controlling variables – Completed as part of the Trail Creek and Waldo Canyon WARSSS

Phase II

- Map stream types and conditions within the watersheds affected by the burn (**Appendix A**)
- Extrapolate variables from the representative reaches to the mapped streams
- Evaluate and predict sediment supply

The Reference Reaches

Reference reaches are established to document the stable dimensions, pattern, profile and materials of these reaches. Reference reaches for the Horse Creek watershed were established during the *Trail Creek PLA* phase and documented in the Trail Creek Watershed Assessment & Conceptual Restoration Plan – Appendix B. These data are used to extrapolate the dimensionless relations of the reference reach morphology, and provide the basis for the departure analysis when comparing reference reaches to unstable stream types. Thus, the same analysis that is completed for the reference reach is completed for comparable impaired reaches. If restoration designs are required, the reference-reach data is used to scale the morphological characteristics of the stable form to apply to the restoration reaches that have similar valley types, boundary conditions and controlling variables.

Five reference reaches were surveyed for departure analysis and restoration design purposes:

1. A1a+ Reference Reach
2. A4a+ Reference Reach
3. B4 Reference Reach
4. C4 Reference Reach
5. E4 Reference Reach

The Representative Reaches

The most detailed assessment of individual reach stability was conducted on the representative, or typical, stream types that occur within the Trail Creek Watershed. The sixth level Trail Creek HUC is located within the larger fifth level Horse Creek HUC. Representative Reaches were evaluated upstream in the Trail Creek Watershed and summarized in Trail Creek Watershed Assessment & Conceptual Restoration Plan – Appendix C. The results of this analysis were extrapolated to other similar reaches within the Horse Creek watershed. Data for each stream type and valley type include the morphological characterization (dimension, pattern, profile and channel materials) to determine the departure of each representative reach from the potential, stable stream type (reference reach).

Sixteen representative reaches were surveyed:

1. A4/1a+ Good-Fair Stability Reach
2. A4/1a+ Fair Stability Reach
3. A4/1a+ Fair Stability Reach 2
4. A4a+ Poor Stability South Reach
5. A4a+ Poor Stability Downstream Reach
6. B4 Good-Fair Stability Reach
7. B4 Fair Stability Reach
8. C4 Fair Reach
9. C4 Poor Reach
10. D4a+ Poor Reach
11. E4 Good Stability HWD
12. F4b Fair-Poor Stability Reach
13. F4b Poor Stability Mainstem Reach
14. F4b Poor Stability Trib. Reach
15. F4 Good-Fair Stability Reach
16. G4 Poor Stability Reach

Channel Processes (Continued)

Numerous models are used in the river stability evaluation and departure analysis of the representative reaches from their potential reference reach condition. Estimates of vertical and lateral stability, channel enlargement, and sediment supply are assessed, including channel competence and capacity evaluations. The BANCS model (*Bank Assessment for Non-point source Consequences of Sediment*, Rosgen, 2001, 2006/2009) is used to predict streambank erosion (tons/yr) and erosion rates (tons/yr/ft) for the reference reaches, representative reaches, and sub-watersheds. The BANCS model utilizes two tools to predict streambank erosion: 1) The Bank Erosion Hazard Index (BEHI), and 2) Near-Bank Stress (NBS). The BANCS model evaluates the bank characteristics and flow distribution along river reaches and maps BEHI and NBS risk ratings commensurate with streambank and channel changes. Annual erosion rates are estimated using the BEHI and NBS ratings, and then are multiplied by the bank height and corresponding bank length of a similar condition to estimate the tons of sediment per year.

Competence is determined using the revised Shields relation for initiation of motion (Rosgen, 2006/2009). The FLOWSED and POWERSED models (as programmed in RIVERMorph™) are used to analyze sediment yield and transport capacity to determine the bed stability (stable, aggradating or degradating) compared to the upstream sediment supply; the bed stability determination is based on the percentage of change between the upstream sediment supply and the sediment transport capacity of the existing condition. The POWERSED model uses only the suspended sand concentration, which is the hydraulically controlled sediment transport, rather than total suspended sediment as used in FLOWSED.

Site-specific data and analysis were extrapolated from the representative reaches to reaches of apparent similar type and condition. Once specific relations were established, this information was utilized for model application and interpretations for similar stream types and conditions elsewhere in the watershed. For example, for the typical "Poor" stability, F4 stream types (entrenched channels with high width/depth ratios and high banks on both sides), annual streambank erosion rates were predicted in tons/yr/ft using BEHI and NBS ratings with the corresponding bank height and stream lengths. These values are extrapolated to other similar ("Poor" stability) F4 reaches as unit erosion rates.

The final streambank sediment supply is summarized for each sub-watershed in tons/yr (**Table 6**) and mapped in tons/yr/ft to identify specific locations of particularly high rates (**Appendix A)**. Not all of the soil from streambank erosion is routed out of the basin, but the erosion reflects the supply entered into a stream channel, some of which contributes to sediment storage within the channel cross-section. The sediment supply from streambank erosion is summarized in **Table 6**.

Table 6. Summary of streambank erosion by sub- watershed.

Watershed	Streambank Erosion (tons/yr)
HC_38	479.4
HC_40	402.7
HC_44	941.9
HC_45	849.9
HC_51	327.4
HC_82	1095.9
HC_83	3293.2
HC_85	172.2
HC_87	77.3
HC_88	214.9
HC_91	1233.3
HC_92	2139.7
HC_93	1521.5
HC_94	344.4
HC_95	188.9
HC_97	1034.5
HC_98	5.9
HC_113	15495.5

Watershed	Streambank Erosion (tons/yr)
HC_118	2424.0
HC_119	9626.4
HC_120	9134.5
HC_121	9298.5
HC_124	387.1
HC_125	2623.2
HC_126	1487.3
HC_128	637.7
HC_129	11.7
HC_130	22.7
HC_131	345.5
HC_135	250.4
HC_136	51.7
HC_137	130.4
HC_138	84.5
HC_139	710.3
HC_150	52.2

Flow-Related Sediment Yield

The FLOWSED model (Rosgen, 2006/2009) uses the flow-duration curves and predicted sediment rating curves to compare increases in potential flow-related sediment yield based on increased streamflow from the Hayman Fire. The increased flows are routed through appropriate sediment rating curves (sediment *vs*. discharge) based on a sediment supply by stream channel type and stability condition.

Flow-related sediment yield represents an integration of all introduced sediment sources (hillslope, roads, and channel processes) with the flow-duration curve. One process that cannot be accounted for in the field is the net change in streambed elevation or base level shift. The flow-related sediment value output from FLOWSED accounts for this process. The difference in the flow-related sediment and the total field-estimated sediment by process (hillslope, roads, and streambank erosion) is the net stream bed elevation shift (aggradation/degradation).

Increases in post-fire streamflows following wildfires are significant and long lasting, not returning until vegetative cover is fully reestablished. The consequences of the increased magnitude, frequency, and duration of streamflows can generate a corresponding exponential increase in sediment. The rate of increase in sediment for a corresponding increase in streamflow (sediment rating curve) is dependent on the overall stability rating and the corresponding stream type. Stream types that are vertically contained (entrenchment ratios < 1.4), such as A, G and F stream types, and stream types that are actively incising (bank-height ratios > 1.2; bank-height ratio is the quantitative expression for degree of channel incision, equal to the study bank height divided by bankfull height; Rosgen, 2006/2009) are susceptible to continued degradation, lateral erosion, and channel enlargement processes.

The increased water yield is routed through dimensionless bedload and suspended sediment rating curves by stream stability for both pre- and post-fire hydrologic conditions. Dimensionless bedload and suspended sediment rating curves for "Good" or "Fair" stability streams are shown in **Figure 7** and **Figure 8**. This aspect of the flow-related sediment increase involves the use of the FLOWSED model (Rosgen, 2006/2009). Dimensionless bedload and suspended sediment rating curves are converted to actual, dimensional curves scaled for an individual river for a given condition by multiplying by the bankfull discharge and the bankfull sediment values. When the dimensional sediment rating curves are combined with the change in the flow-duration curves, flow-related sediment can be computed.

The bankfull discharge, as discussed previously, is determined from a regional curve of bankfull discharge *vs*. drainage area (see **Figure 3**). In the absence of measured bankfull sediment data, an approach similar to that used to estimate bankfull discharge is used to estimate bankfull bedload and suspended sediment data by drainage area based on geological characteristics. Thus, regional sediment curves were developed by stability type for the local batholith geology (Pikes Peak, grussic granite geology) as shown in **Figure 9** and **Figure 10**. The bankfull sediment values from the regional curves can then be used to convert the dimensionless sediment rating curves to dimensional curves that are unique and scaled for each sub-watershed.

To validate the sediment curves used for the Horse Creek Sub-watersheds, sediment-rating curves developed from bedload and suspended sediment data from 1984 were compared with 2010 measured bedload and suspended sediment in the Trail Creek Watershed (**Figure 11** and **Figure 12**). The increased sediment values for the same discharge reflect the post-fire sediment supply increase for bedload and suspended sediment.

The increase in water yield and flow-related sediment supply using the FLOWSED model comparing the pre- and post-fire conditions are reported in **Table 7.**

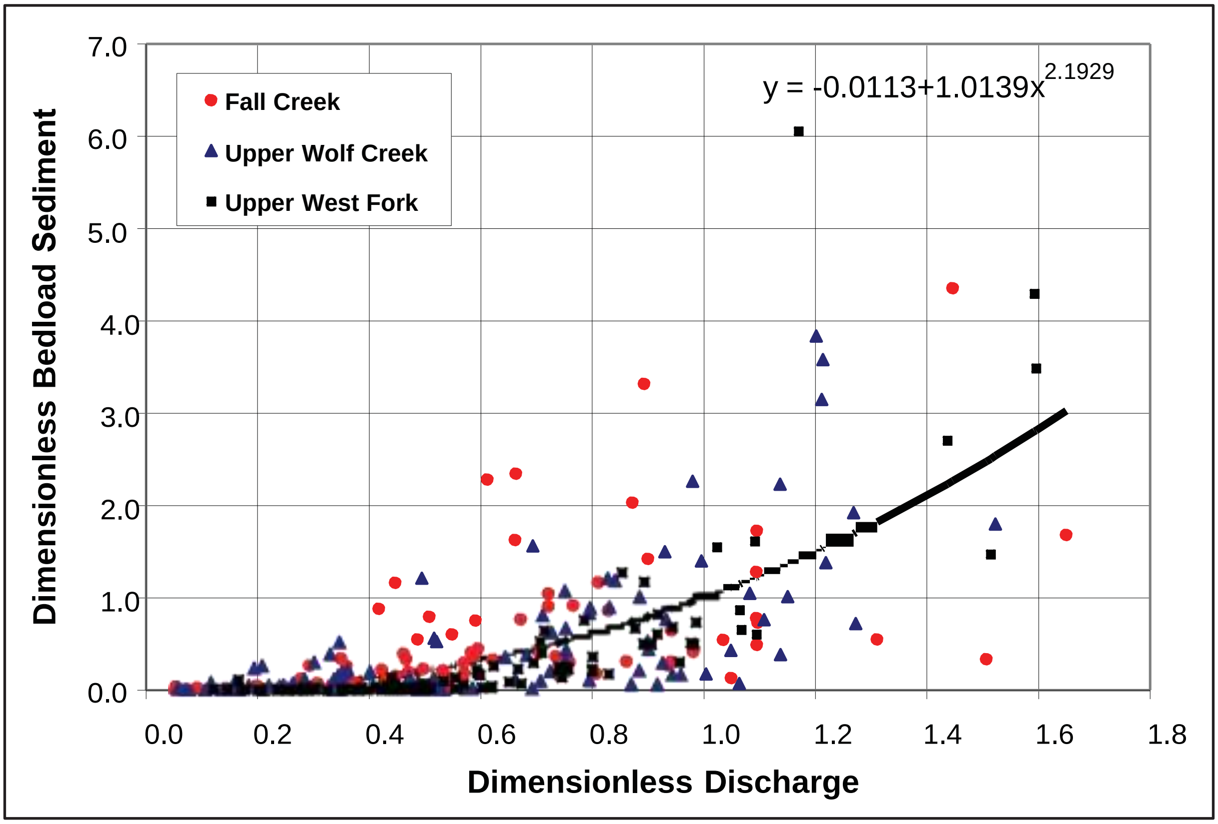


Figure 7. Dimensionless bedload sediment rating curves for "Good" and "Fair" stability streams derived from three streams in Pagosa Springs, Colorado. (Rosgen, 2013)

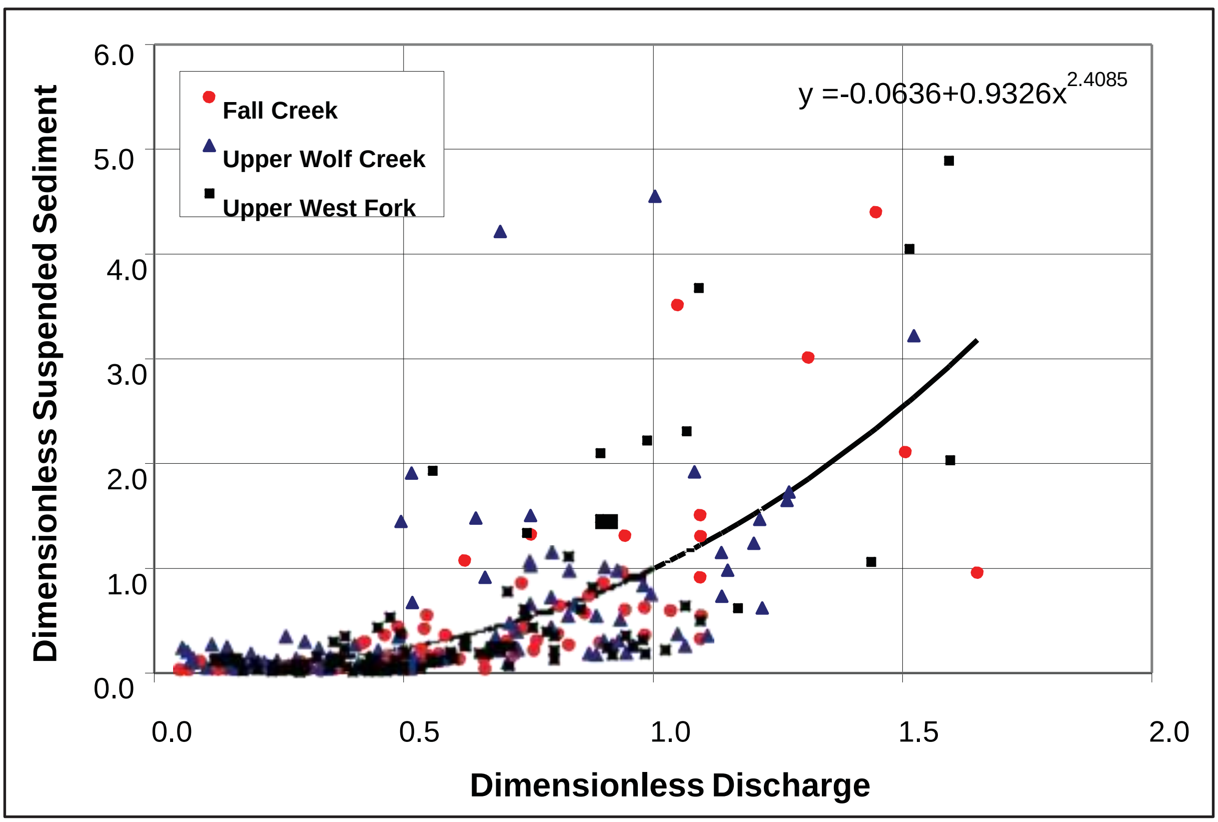


Figure 8. Dimensionless suspended sediment rating curves for "Good" and "Fair" stability streams derived from three streams in Pagosa Springs, Colorado. (Rosgen, 2013)

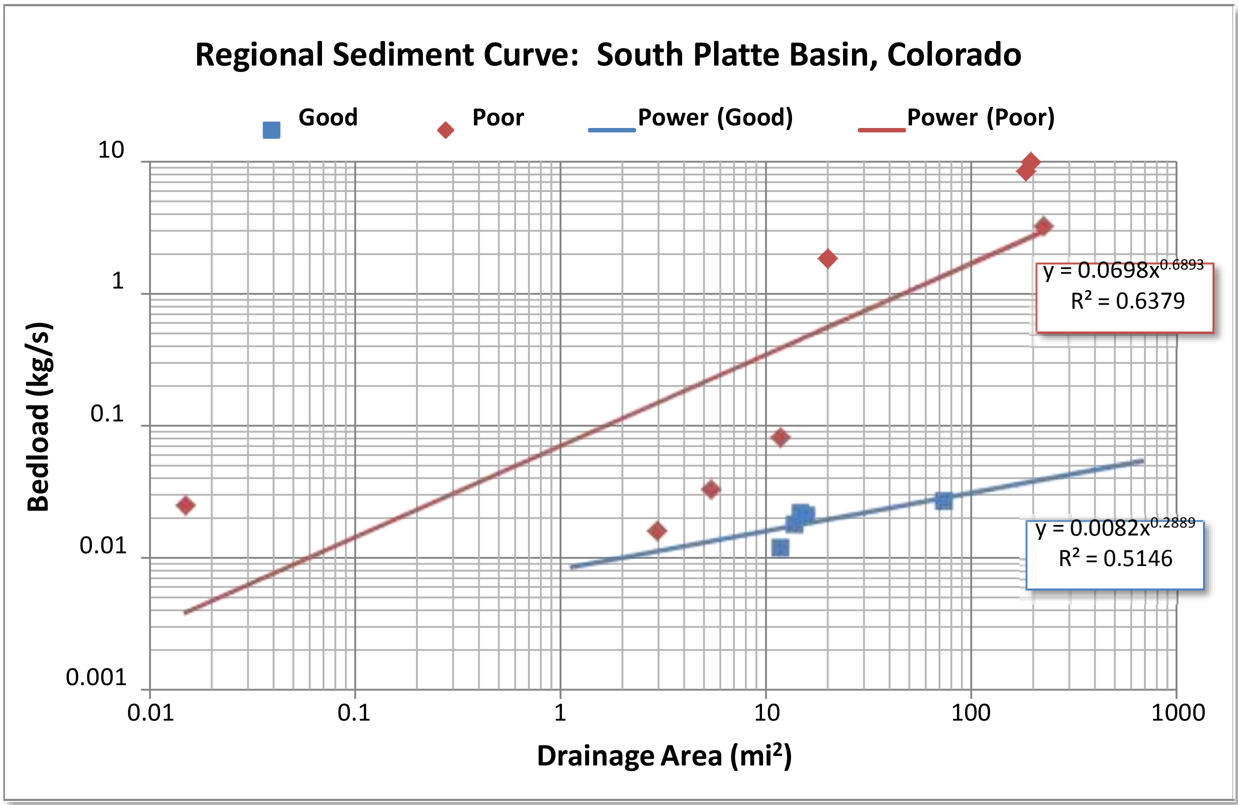


Figure 9. Regional bedload sediment curve: South Platte Basin, Colorado. (Rosgen, 2013)

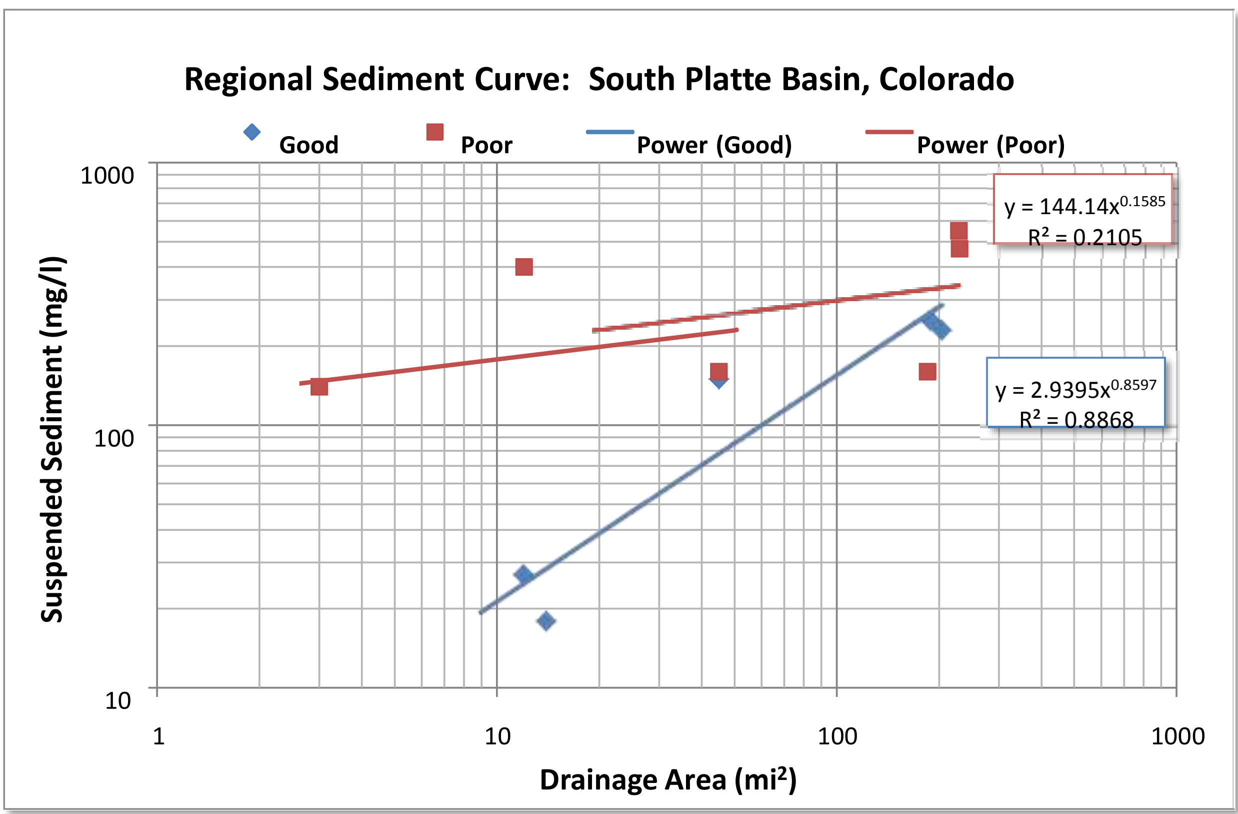


Figure 10. Regional suspended sediment curve: South Platte Basin, Colorado. (Rosgen, 2013)

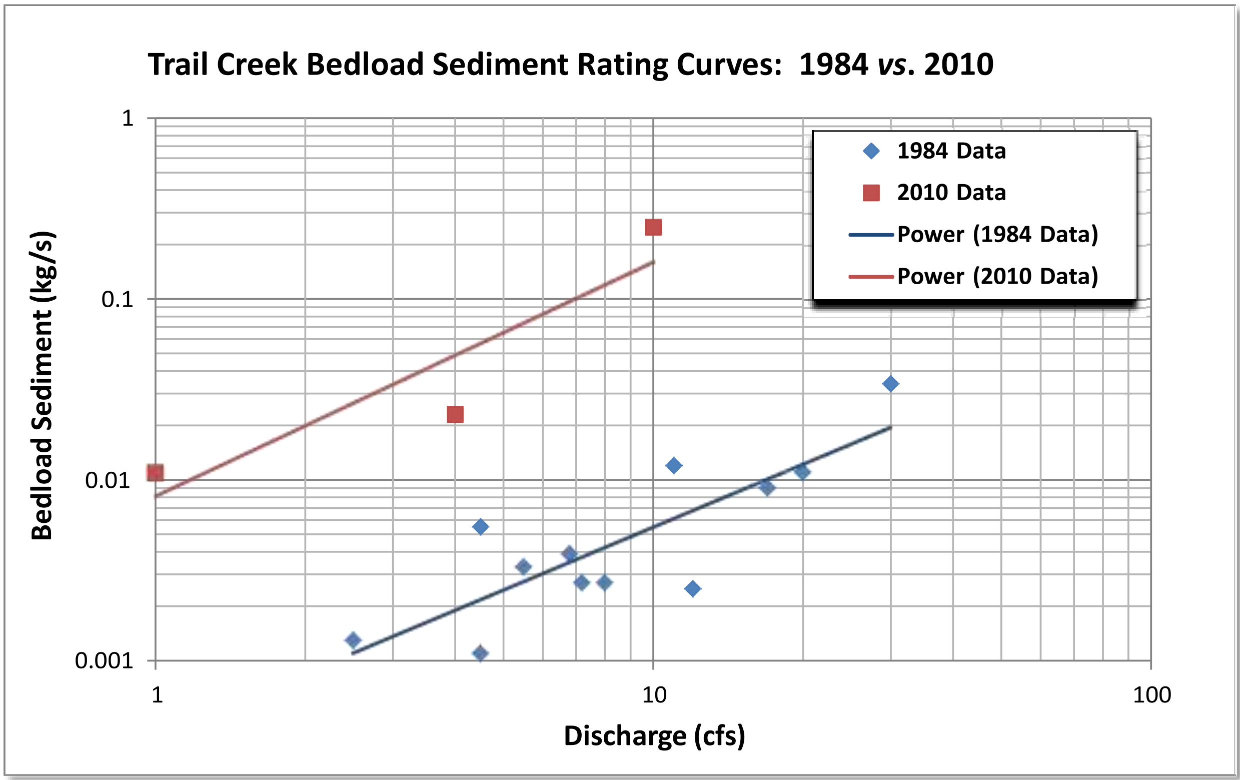


Figure 11. Bedload sediment rating curve from 1984 data compared to 2010 data reflecting the post-fire increase in sediment supply. (Rosgen, 2013)

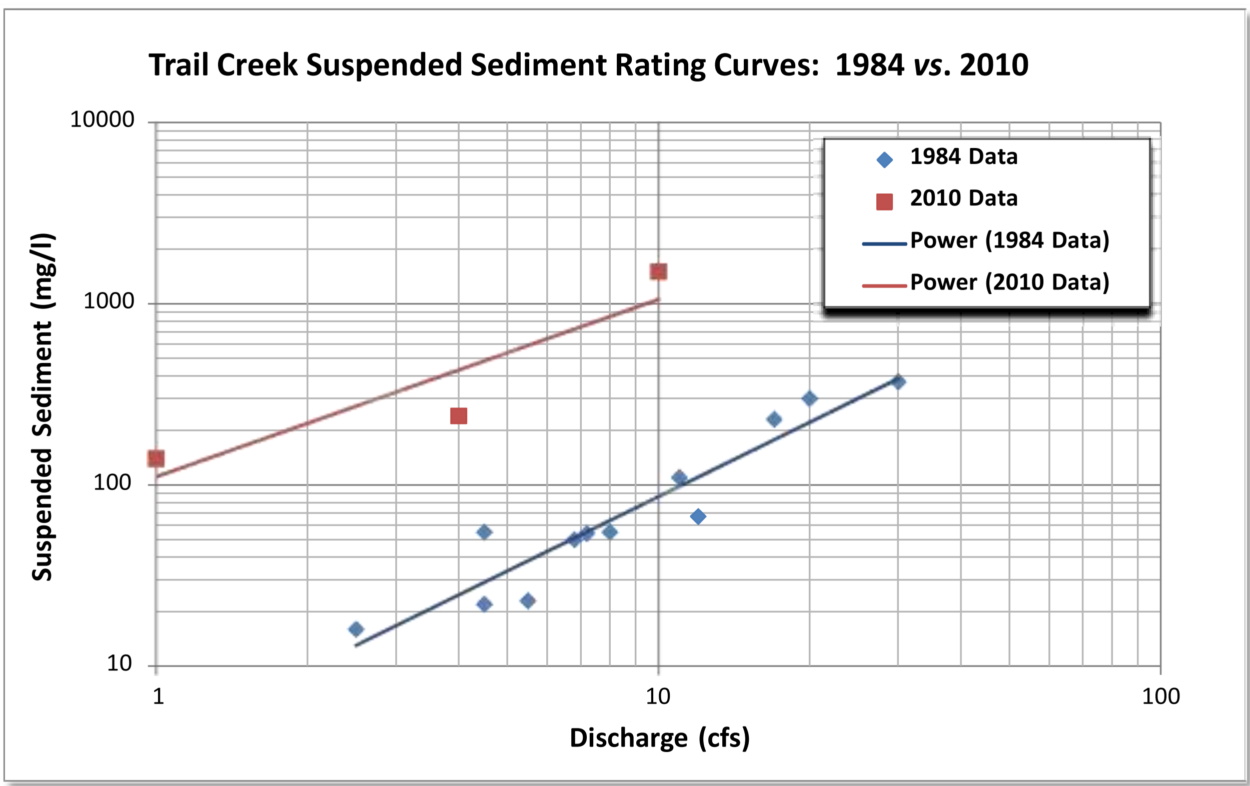


Figure 12. Suspended sediment rating curve from 1984 data compared to 2010 data reflecting the post-fire increase in sediment supply. (Rosgen, 2013)

Table 7. Summary of pre- and post-fire water and flow-related sediment yields by sub-watershed.

	Pre-Fire		Post-Fire		Increase	
Watershed	Water Yield (acre-ft)	Total Sediment (tons/yr)	Water Yield (acre-ft)	Total Sediment (tons/yr)	Water Yield (acre-ft)	Total Sediment (tons/yr)
HC_38	100.2	9.7	120.0	246.3	19.8	236.6
HC_40	84.9	9.0	102.9	216.4	18.0	207.4
HC_44	80.0	305.2	94.8	384.0	14.9	78.7
HC_45	51.0	7.2	59.9	131.5	8.9	124.4
HC_51	23.5	5.1	25.6	113.2	2.1	108.1
HC_82	125.5	10.7	149.6	581.6	24.1	570.9
HC_83	179.8	12.6	215.0	414.3	35.2	401.7
HC_85	117.2	10.4	134.0	513.6	16.8	503.3
HC_87	68.9	8.2	74.3	293.4	5.4	285.2
HC_88	58.9	7.7	69.2	287.2	10.3	279.6
HC_91	144.6	11.4	174.4	673.1	29.8	661.7
HC_92	237.2	14.3	326.4	1316.7	89.2	1302.4
HC_93	147.1	11.5	194.1	791.3	47.0	779.8
HC_94	87.3	9.1	105.1	425.5	17.9	416.4
HC_95	96.0	9.5	111.6	226.6	15.6	217.1
HC_97	446.2	19.5	652.3	1343.0	206.2	1323.5
HC_98	83.4	8.9	83.4	163.0	0.0	154.1
HC_113	824.5	28.2	1293.1	5387.7	468.6	5359.5
HC_118	103.1	9.8	133.9	557.7	30.8	547.9
HC_119	384.1	18.1	565.1	2324.7	181.0	2306.6
HC_120	633.5	23.8	1050.7	4741.8	417.2	4718.0
HC_121	388.5	18.2	617.5	2743.5	229.0	2725.3
HC_124	56.9	7.5	69.1	293.0	12.2	285.5
HC_125	97.1	9.5	124.1	514.7	27.0	505.2
HC_126	96.2	9.5	118.1	478.2	21.9	468.7
HC_128	71.0	8.3	88.3	370.8	17.2	362.5
HC_129	27.9	5.5	31.6	73.2	3.7	67.7
HC_130	37.3	6.3	43.3	187.4	6.0	181.2
HC_131	51.7	7.2	62.3	265.4	10.6	258.2
HC_135	45.0	6.8	47.1	192.4	2.0	185.6
HC_136	43.6	6.7	48.9	205.1	5.3	198.4
HC_137	56.6	7.5	66.1	275.1	9.5	267.6
HC_138	51.7	7.2	60.0	251.1	8.3	243.9
HC_139	49.0	7.1	58.8	251.6	9.8	244.6
HC_150	24.1	5.2	27.1	121.2	3.1	116.0

Sediment Summary

Total sediment contribution by process for the 35 sub-watersheds is presented in **Table 8** where net degradation (streambed scour) and net aggradation (increased channel sediment storage) is shown. Degradation occurs where energy exceeds supply; however, it is often observed that high streamflows following a previous aggrading event (excess supply/energy limited) create headcuts through previously deposited material. As a result of the increased peak flows and decreased flow resistance from destroyed riparian vegetation following the fire, an increase in the headward expansion of the drainage network is widespread. Headcuts result in an over-steepening of the energy slope and corresponding channel bed degradation. Consequently, slope rejuvenation occurs, leading to a corresponding accelerated increase in bed and bank erosion rates with increased sediment supply. Another cause of headcutting is the excess sediment deposition followed by the reworking of the sediment headward. Another process leading to headcuts is the lowering of the base level of a main trunk or receiving stream. In addition to incision processes, channel enlargement and accelerated streambank erosion are also associated with headcuts.

Excess sediment deposition results from a sediment supply greater than the transport capacity of the channel and generally relates to high width/depth ratio channels that encourage sediment deposition and aggradation processes. If high flows were to “flush out” the stored sediment, then the subsequent high flows that have occurred since the fire would have reduced the stored sediment. However, observations indicate that high flows have not reduced sediment in storage, to reestablish an equilibrium, but rather have contributed to increased sediment storage that is vulnerable to headcutting, bed, and bank erosion in subsequent high-flow regimes. Reducing potential sediment storage and its high-flow induced impacts is dependent upon establishing stream types that are associated with a “Good” stability condition and low sediment supply rather than a “Poor” stability condition. For example, G4 stream types with a “Poor” stability condition in many instances can be converted to B4 stream types that reflect a “Good” stability and associated low sediment supply. Converting F4 stream types to C4 stream types is a natural stream-succession direction associated with sediment supplies that are orders of magnitude less for the same discharge. Also, converting A4 stream types to braided, D4 stream types by directing the D4 stream types onto alluvial fans provides a natural sediment detention and storage condition. Stable stream types tolerate increased streamflows while significantly reducing sediment impacts downstream, and reduce, the greatest source of total sediment yield over time, which is associated with streambank erosion processes.

	Streambank Erosion		Roads and Trails		Hillslope		Total	Flow-	Aggrade or Degrade	
Watershed	Tons per Year	% Total Introduced Sediment	Tons per Year	% Total Introduced Sediment	Tons per Year	% Total Introduced Sediment	Introduced Sediment (tons/yr)	Related Sediment (tons/yr)	Aggrade or Degrade	Tons per Year
HC_38	479.4	99.38%	0.0	0.0%	3.01	0.62%	482.4	236.6	Aggrade	-236
HC_40	402.7	99.67%	0.0	0.0%	1.32	0.33%	404.0	207.4	Aggrade	-188
HC_44	941.9	99.86%	0.0	0.0%	1.31	0.14%	943.2	78.7	Aggrade	-559
HC_45	849.9	99.93%	0.0	0.0%	0.55	0.07%	850.4	124.4	Aggrade	-719
HC_51	327.4	99.94%	0.0	0.0%	0.20	0.06%	327.6	108.1	Aggrade	-214
HC_82	1095.9	99.56%	0.0	0.0%	4.81	0.44%	1100.7	570.9	Aggrade	-519
HC_83	3293.2	99.70%	0.0	0.0%	10.01	0.30%	3303.2	401.7	Aggrade	-2889
HC_85	172.2	99.73%	0.0	0.0%	0.46	0.27%	172.7	503.3	Degrade	341
HC_87	77.3	97.35%	0.0	0.0%	2.11	2.65%	79.4	285.2	Degrade	214
HC_88	214.9	98.66%	0.0	0.0%	2.93	1.34%	217.9	279.6	Degrade	69
HC_91	1233.3	99.81%	0.0	0.0%	2.39	0.19%	1235.6	661.7	Aggrade	-563
HC_92	2139.7	99.74%	0.0	0.0%	5.62	0.26%	2145.4	1302.4	Aggrade	-829
HC_93	1521.5	99.82%	0.0	0.0%	2.73	0.18%	1524.2	779.8	Aggrade	-733
HC_94	344.4	99.64%	0.0	0.0%	1.23	0.36%	345.6	416.4	Degrade	80
HC_95	188.9	99.37%	0.0	0.0%	1.20	0.63%	190.1	217.1	Degrade	36
HC_97	1034.5	99.24%	0.0	0.0%	7.88	0.76%	1042.3	1323.5	Degrade	301
HC_98	5.9	76.20%	0.0	0.0%	1.86	23.80%	7.8	154.1	Degrade	155
HC_113	15495.5	99.91%	0.0	0.0%	13.68	0.09%	15509.2	5359.5	Aggrade	-10121
HC_118	2424.0	99.90%	0.0	0.0%	2.49	0.10%	2426.5	547.9	Aggrade	-1869
HC_119	9626.4	99.90%	1.6	1.7%	7.71	0.08%	9635.7	2306.6	Aggrade	-7311
HC_120	9134.5	99.89%	0.0	0.0%	9.67	0.11%	9144.2	4718.0	Aggrade	-4402
HC_121	9298.5	99.92%	0.0	0.0%	7.47	0.08%	9305.9	2725.3	Aggrade	-6562
HC_124	387.1	99.86%	0.0	0.0%	0.55	0.14%	387.6	285.5	Aggrade	-95
HC_125	2623.2	99.94%	0.0	0.0%	1.65	0.06%	2624.8	505.2	Aggrade	-2110
HC_126	1487.3	99.72%	0.0	0.0%	4.22	0.28%	1491.5	468.7	Aggrade	-1013
HC_128	637.7	99.85%	0.0	0.0%	0.93	0.15%	638.6	362.5	Aggrade	-268
HC_129	11.7	94.10%	0.0	0.0%	0.73	5.90%	12.4	67.7	Aggrade	61
HC_130	22.7	97.36%	0.0	0.0%	0.62	2.64%	23.3	181.2	Degrade	164
HC_131	345.5	99.85%	0.0	0.0%	0.52	0.15%	346.1	258.2	Aggrade	-81
HC_135	250.4	98.88%	0.0	0.0%	2.84	1.12%	253.3	185.6	Aggrade	-61
HC_136	51.7	95.73%	0.0	0.0%	2.31	4.27%	54.0	198.4	Degrade	151
HC_137	130.4	98.68%	0.0	0.0%	1.75	1.32%	132.2	267.6	Degrade	143
HC_138	84.5	95.33%	0.0	0.0%	4.14	4.67%	88.7	243.9	Degrade	162
HC_139	710.3	99.80%	0.0	0.0%	1.45	0.20%	711.8	244.6	Aggrade	-460
HC_150	52.2	99.27%	0.0	0.0%	0.39	0.73%	52.5	116.0	Degrade	69
Totals	67096.4	98.44%	1.6	1.7%	112.7	1.56%	67210.8	26693.4		-39855.0

Table 8. Summary of sediment supply by sub- watershed.

The Conceptual Watershed & River Restoration Plan

The conceptual watershed and river restoration plan is based on the Natural Channel Design (NCD) methodology (Rosgen, 2007). The development of a conceptual plan is based on the *assumptions* that:

- The conceptual design plan will address the sediment sources, land uses, erosional processes and river impairment based on the output of the WARSSS cumulative effects analysis.
- Sediment supply can be reduced most effectively and at lowest cost at its source.
- The appropriate natural and stable stream morphology can be determined from selected *stream succession* scenarios.
- Streamflow peak magnitude and frequency related to the fire will have a long recovery period (50–75 years), but negative impacts can be mitigated.
- Reference reach, dimensionless relations can be extrapolated from reference reaches to inform restoration strategies in these unstable stream .
- There is uncertainty and risk in developing and implementing restoration scenarios, but the risk and potential benefits outweigh the "do nothing" alternative!

The following *goals* help define the proposed watershed and river system restoration plan:

1. Create cost-effective and low-risk restoration solutions.
2. Speed-up the recovery processes from the wildfire.
3. Reduce sediment supply from disproportionate sources (See Appendix A).
4. Utilize a natural channel design methodology that results in a natural appearance (aesthetics).
5. Be complimentary to the central tendency of natural systems.
6. Stabilize streambanks and streambeds to restore for human values, including:
    a. Providing ecological restoration (including birds, fish, mammals and amphibians).
    b. Providing for improved recreational opportunities.
    c. Improving water quality for drinking water supply.
7. Provide an opportunity for research and restoration monitoring.
8. Provide a demonstration reach for extrapolation of similar applications.
9. Provide areas that can help enlighten public dialog and understanding fire's role and its rehabilitation.

The Hayman Fire of 2002 was the largest fire in Colorado's history, burning over 138,000 acres in the South Platte River watershed. Horse Creek is a tributary to the South Platte River. Several years of intense storm events over the fire area produced significant sediment delivery into the South Platte River and its tributary streams, impacting the Denver metropolitan area's water supply and the world-class fishery found in the South Platte River.

Thirty five sub-watersheds and the mainstem of Horse Creek were analyzed through the prediction level, cumulative effects assessment. The conceptual restoration design by priority watershed is summarized in **Table 11, which identifies** the stable stream type and stabilization structures that will be applied to the priority watersheds. Priority watersheds are identified as those that have a large sediment supply, and where we can apply restoration techniques to achieve cost-effective success at reducing sediment delivery. This restoration plan provides specific design scenarios for the typical stream impairments found within these watersheds. These design techniques can be used for contracting and construction plans.

Three primary restoration techniques will be utilized to help achieve watershed and river restoration including:

1. Restoration by Stream Type Conversion
2. Restoration with Stabilization Structures
3. Handwork Restoration

Restoration by *Stream Type Conversion* and *Restoration with Stabilization Structures* will utilize heavy machinery for implementation. Heavy machinery may include excavators, dozers, haul trucks, skid steers, and front end loaders. Riparian areas and the mainstem of Horse Creek will be crossed at designated locations. Heavy equipment and natural materials (rocks and trees) will be harvested nearby if possible, and staged at approved locations. Off-road travel with ATVs may be utilized for access by contractors and specialists, but will not result in new trails or roads. Issues raised by biologists and archeological staff, as well as risks identified by the Forest Hydrologist and consultants will influence site selection. Best Management Practices (BMPs) and Forest Plan Standards, including noxious weed monitoring and post-construction weed treatment, will be incorporated into the contract. Where restoration work utilizes trees or rocks from nearby USFS managed lands disturbance will be minimized, with limited ground disturbance. All disturbed areas will be raked and seeded with approved native seed, and including recontouring as needed upon completion of the project.

Restoration by Stream Type Conversion

Stream type succession is used to interpret and predict the probable stable-morphological state. Sixteen stream succession scenarios and stream type shifts toward stable end points for each scenario are presented in **Figure 13** (Rosgen, 2006/2009). These scenarios represent various sequences from actual rivers and are used to assist in predicting a river's behavior based on documentation of desired response from similar stream types. To convert unstable, high-sediment-supply stream channels to a stable form, the most suitable stable-end-point stream types are selected. Restoration work includes reshaping the channel and floodplain and using stabilization structures. It is important to select the appropriate scenario and current stage of stream succession to assist in selecting the stable, end-point stream type for restoration.

Figure 14 illustrates cross section views of three *Restoration by Stream Type Conversions* that will be utilized for fan restoration. Stream type conversions include: G4 to B4 stream type conversion in a Valley Type III, and F4b to B4 and F4 to B4c stream type conversions in a confined alluvial fill valley - Valley Type VIII. These conversions result in substantially less sediment from streambank erosion and flow-related sediment. Log rollers may be used to create the stable B channel. Many of the alluvial fans are rejuvenating due to the encroachment of Horse Creek on the fan. In certain instances, the mainstem of Horse Creek will be moved away from the fan and the toe of the fan will be stabilized with root wads, toe wood or vanes. Upstream in the tributaries, oversteepened and eroding stream banks will be laid back to a slope that will encourage re-vegetation. A toe-catch or bank-full bench may be utilized to help stabilize these banks. The stream bank stabilization structures are summarized in the *Restoration with Stabilization Structures* section (**Table 9**).

To further reduce excess sediment delivery to Horse Creek, minor tributaries should be routed onto improved alluvial fans where the potential exists (**Figure 19**). Headcut channels that have been incised in the fan cause loss of fan function. Subsequent flows and sediment are rapidly routed downstream with resultant streambed and streambank erosion. The modification to scenarios #13 and #16 would be to raise the level of the fan and provide for the eventual creation of a braided, D channel back up to the original fan surface to restore function by dispersing flow energy and storing sediment. Directing the D4 stream types onto alluvial fans provides a natural sediment detention and storage condition. This design may incorporate one or several in-fan sediment detention basins. These basins, which are intended to fill in over time, will be built with trees and rocks that will be harvested onsite. They also provide fill material required to move the entrenched F4 stream type to the raised D4 stream on the surface of the fan (**Figures 20, 21**).

The proposed conversion of stream types reduces streambank erosion and the deposition or scour of the streambed, thereby greatly reducing the very high channel-source sediment supply. These stream type conversions will be implemented with specific ***Stabilization Structures*** for streambank and bed stability.

The stable stream type in the mainstem of Horse Creek is a C4 channel. In several scenarios, Horse Creek has shifted to a G4 stream type (e.g., Scenarios #1, #4, #8, #9 and #12 in **Figure 13**). The C4 to G4 stream type shift is due to either widening or an avulsion that then headcuts back into the previous, over-wide C4 stream type creating a G4 stream type. Restoration of Horse Creek to a stable C channel will utilize **Stabilization Structures** and

Reference Reaches for channel dimensions. See **Appendix B** for Wildland Hydrology Conceptual restoration design.

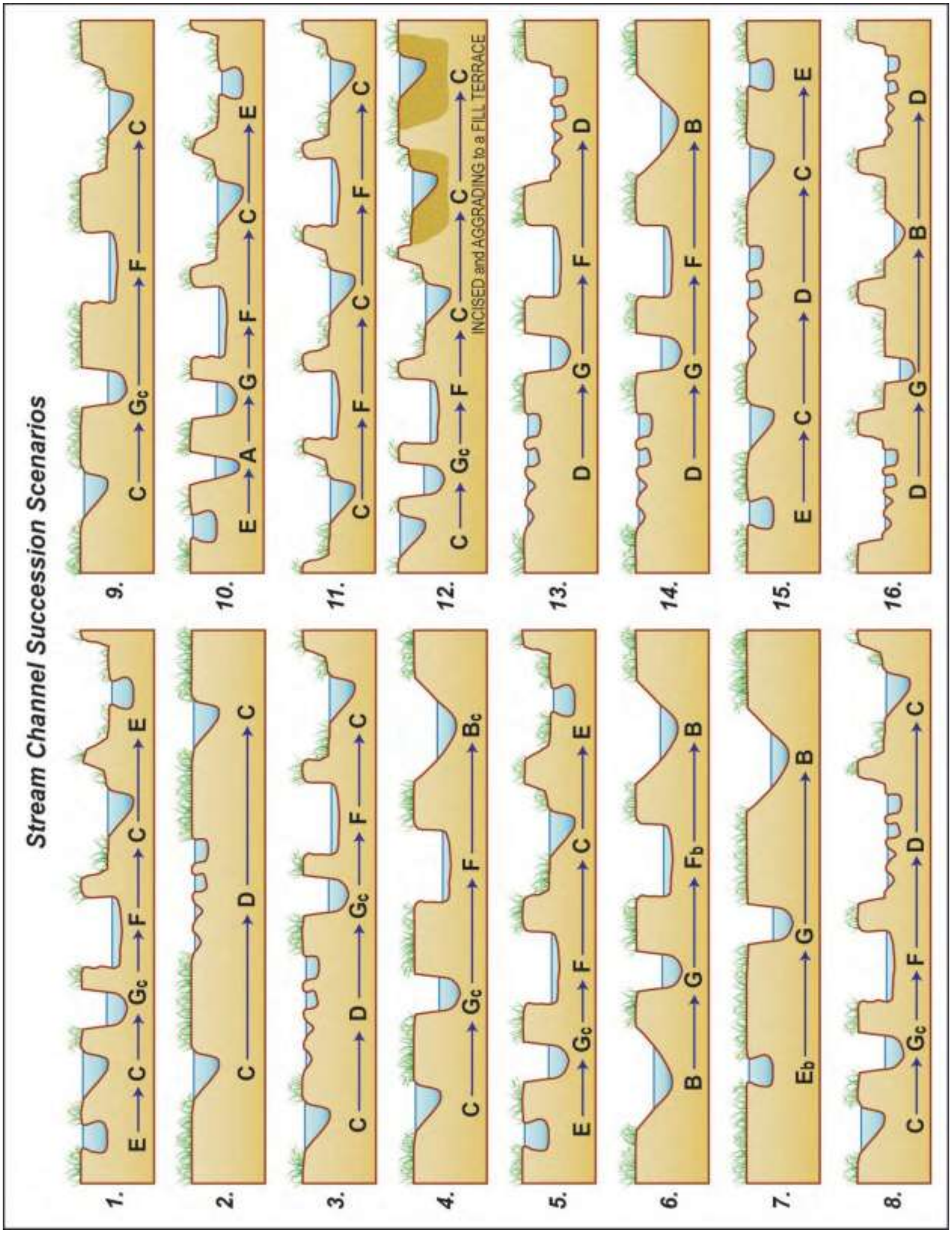
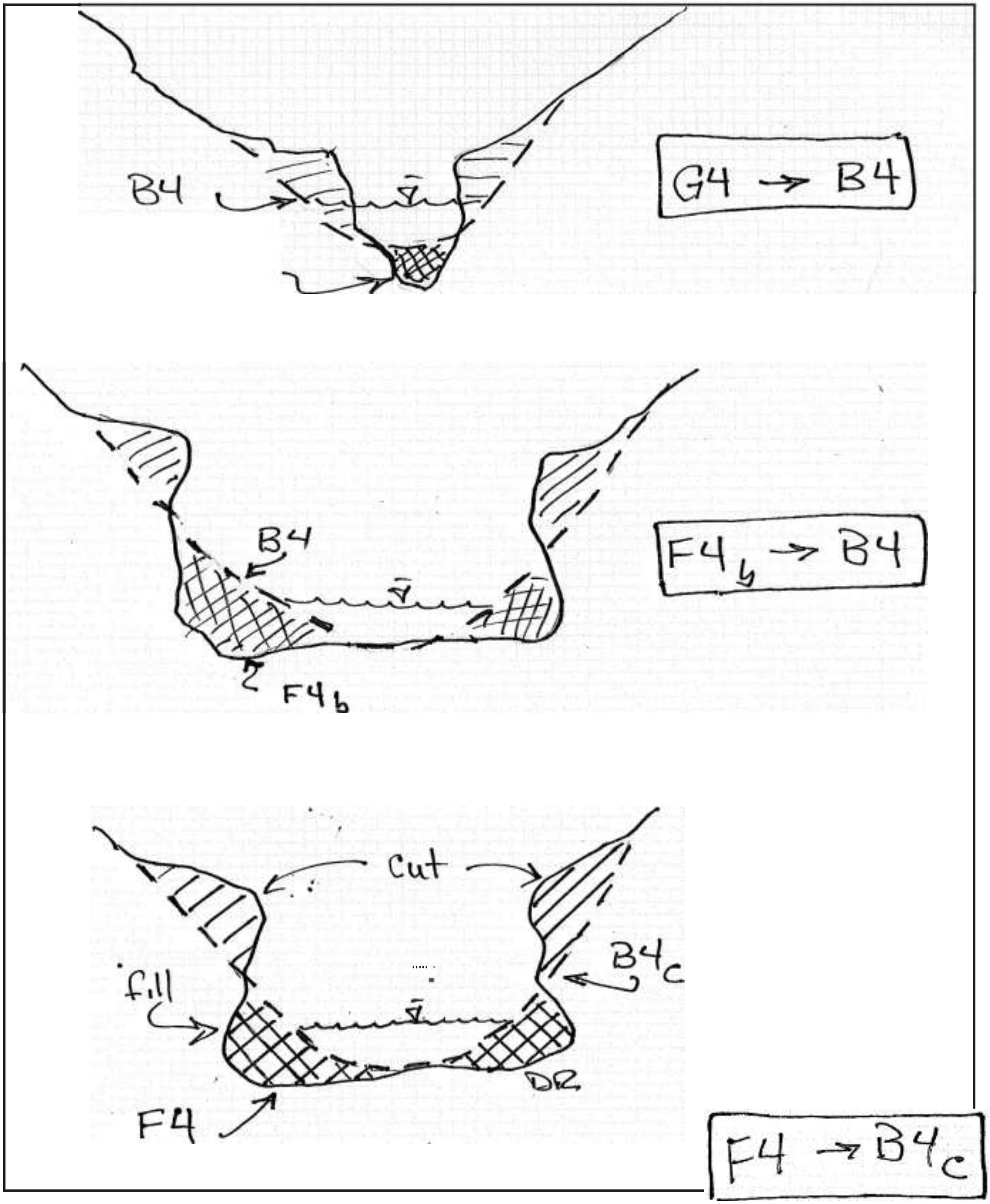


Figure 13. Stream Channel Succession Scenarios and corresponding stages of adjustment (Rosgen, 2013)

Figure 14. Cross Section views of the G4 → B4, F4b → B4 and F4 → B4c stream type conversions (Rosgen, 2013)



Restoration with Stabilization Structures

Structures are mandatory in all scenarios to allow time for riparian vegetation to recolonize and stabilize the existing soil material. Different structures accomplish different objectives (e.g., streambank stabilization, sediment deposition, flow attenuation, grade control, and energy distribution and dissipation). Individual structures are not universally applied but have specific application for specific scenarios (**Table 9**). J-hooks, cross-vanes, debris basin structures, and log sills must incorporate a geotextile fabric (600x Mirafi fabric) on the upstream side of the structure to prevent water from undermining the structure. Vegetation should be used in combination with all structures. Streambank stabilization and riparian function are greatly influenced by the establishment of a dense understory and overstory of riparian plants. Establishment of these riparian plants is proposed by transplanting adult plants of willow, alder, and cottonwood based on their availability. These plants are established on river banks, over the toe-wood structure on bankfull benches, and along the active-channel boundary. Frontend loaders and excavators are often used for the transplanting. Where these adult plants are not readily, available willow cuttings and native seed can be used. Willow cuttings are also utilized between soil lifts, sod mats, and various streambank structures. Donor sites for cuttings and transplants are often obtained within the watershed, but are collected away from existing streambank areas. Supplemental work with hand labor from volunteers can be effective in re-establishing the riparian vegetation. The following sections describe the stabilization structures in detail.

Table 9. List of structures recommended by scenario for watershed restoration in the areas affected by the fire

Structures	Scenarios				
	D4 to C4	F4, G4 to B4	G4 to C4	A4, F4, or G4 to D4	F4b to B4
J-Hook/Cross Vane *Figures 14, 15, 16*	X	X	X		X
Rock and Log Rollers (step-pool) *Figure 17*		X			X
Toe Wood *Figures 23, 24*	X	X	X		X
Sediment Detention Basins *Figure 18, 19, 20*				X	
Log Sills *Figures 21, 22*				X	

The stabilization structures are designed to reduce streambank erosion, provide grade control, dissipate excess energy, prevent headcutting, allow time to establish riparian vegetation, provide fish habitat enhancement, maintain floodplain connectivity, protect road fills from erosion, and generally reduce sediment supply. **Table 10** lists the structures primary objectives.

Table 10. List of structures recommended for watershed restoration for the areas affected by the fire and their primary objectives.

Structures	Streambank Stabilization	Sediment Deposition	Flow Attenuation	Grade Control	Energy Distribution and Dissipation
J-Hook / Cross Vane	✓			✓	✓
Rock and Log Rollers (step-pool)	✓			✓	✓
Toe Wood	✓				✓
Debris Basin*		✓	✓	✓	✓
Cross-Channel Sills				✓	✓

Root Wad, Log Vane, J-Hook Structure – Design

This structure is designed to decrease near-bank stress by redirecting high-velocity gradients away from the streambank and placing the erosive currents in the thalweg, or center of the stream (**Figure 14**). The structure also provides overhead cover for fish by creating an undercut bank. Macro-invertebrate habitat is also enhanced by the backfill use of small logs, tops and woody debris as a backing between the log and the bank. The structure also provides energy dissipation and creates longer, wider and deeper pools. The acceleration of the pool tail out (glide) creates potential spawning habitat. The appearance of the structure creates a visual representation of logs that naturally fall into the stream. Because the logs are embedded deep into the bank and bed, and are counter-buttressed with native rock, they are stable under flood flows.

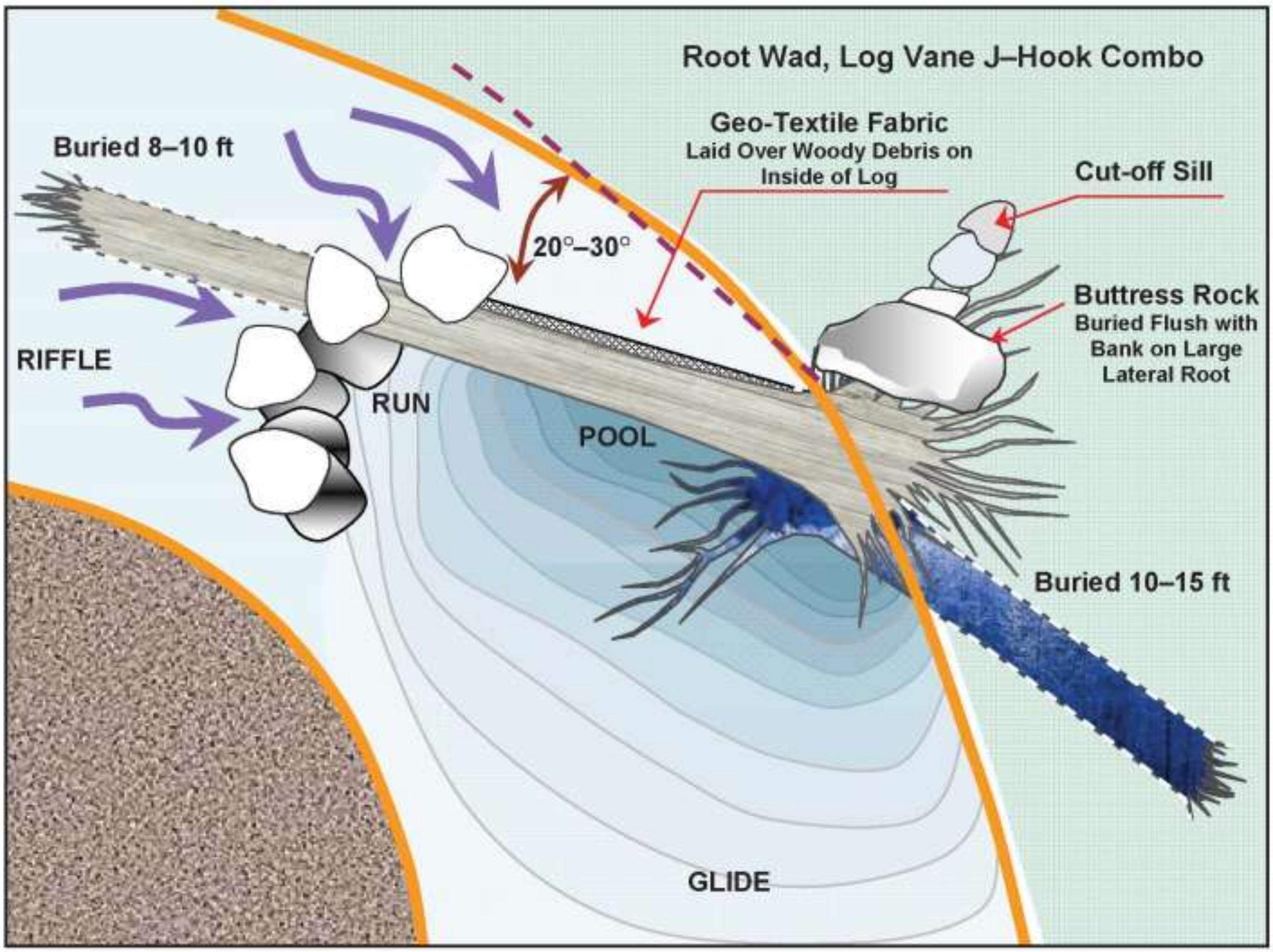


Figure 15. The root wad, log vane, J-hook structure for streambank stabilization and fish habitat (Rosgen, 2013)

Rock, J-Hook Vane Structure – Design

This structure is adapted for ephemeral and perennial streams for near-bank stress reduction, energy dissipation and fish habitat improvement (**Figure 15**). The hydraulic function is similar to the root wad, log vane, j-hook structure, but it is constructed with natural rock making it adaptable to ephemeral streams and larger perennial channels.

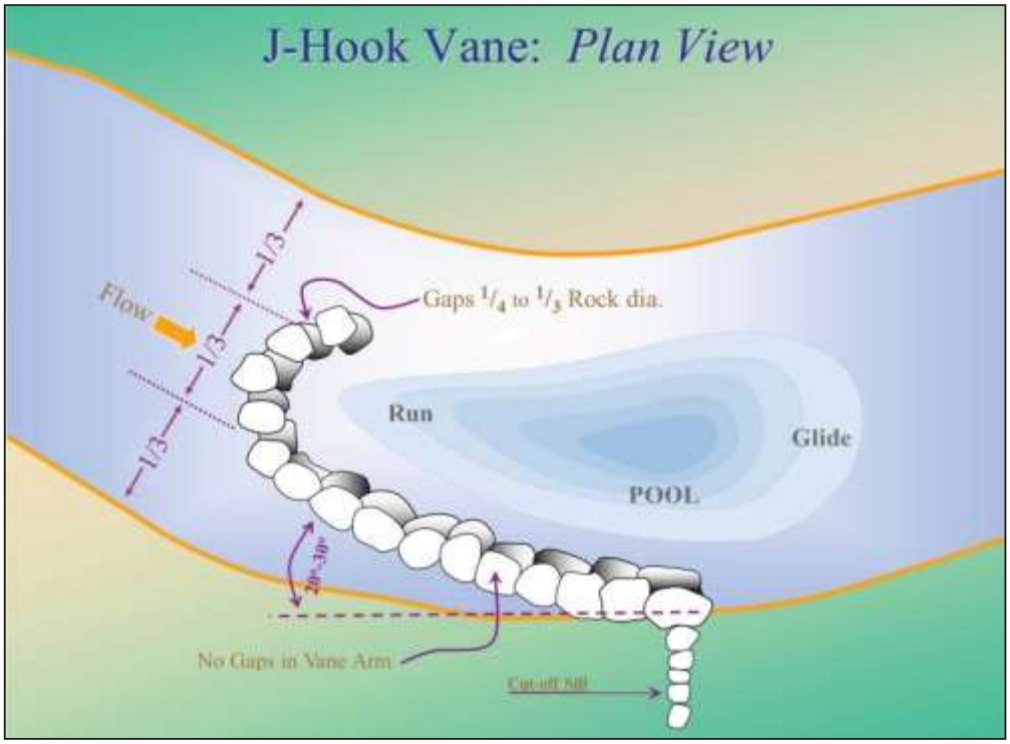


Figure 16. The rock vane, j-hook structure for streambank stabilization and fish habitat (Rosgen, 2013)

Rock Cross-Vanes - Design
This structure decreases near-bank stress and provides grade control (**Figure 16**). It is adaptable to both ephemeral and perennial channels. In perennial channels, improved fish habitat is associated with increased holding cover, enhanced pool quality and spawning habitat. This structure prevents downcutting of stream channels and provides floodplain connectivity.

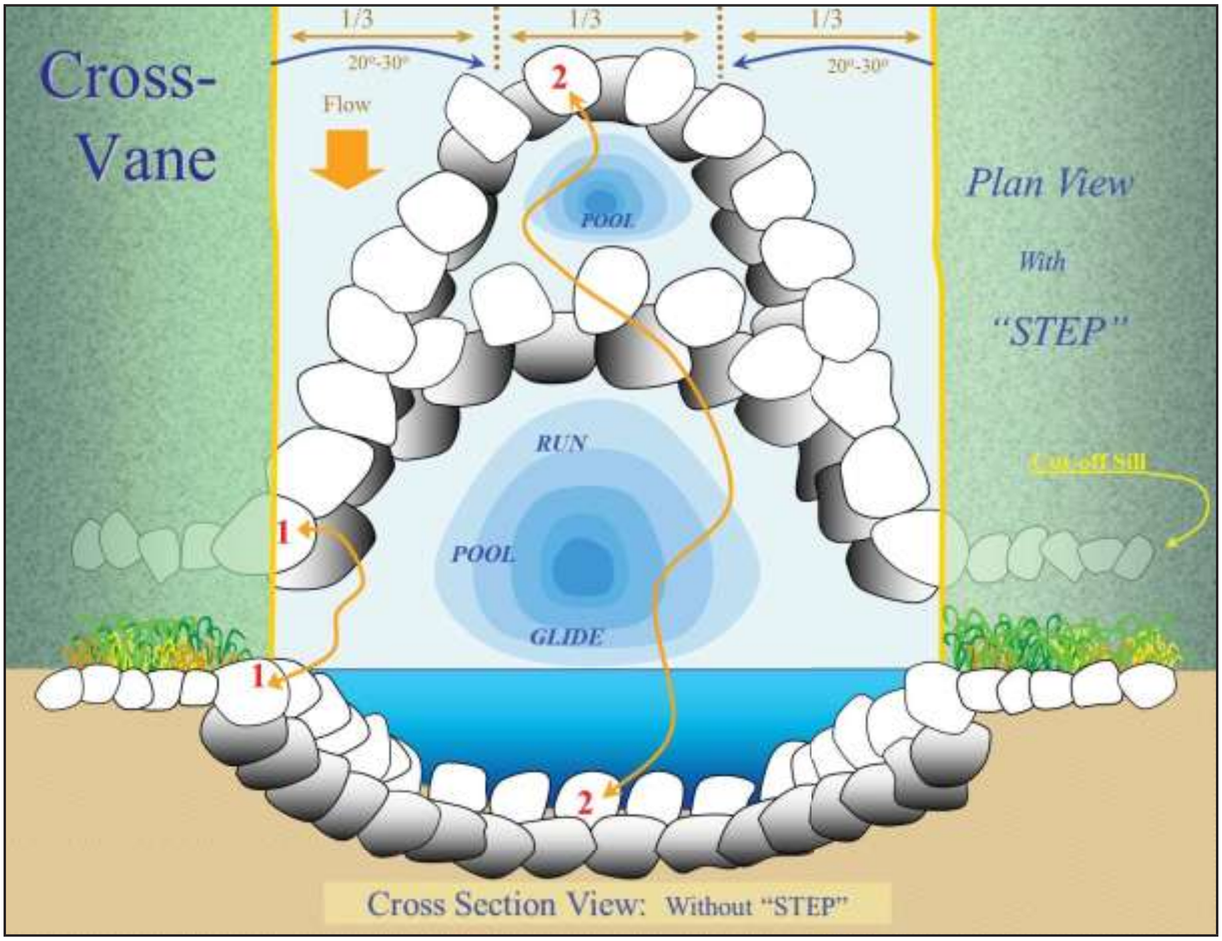


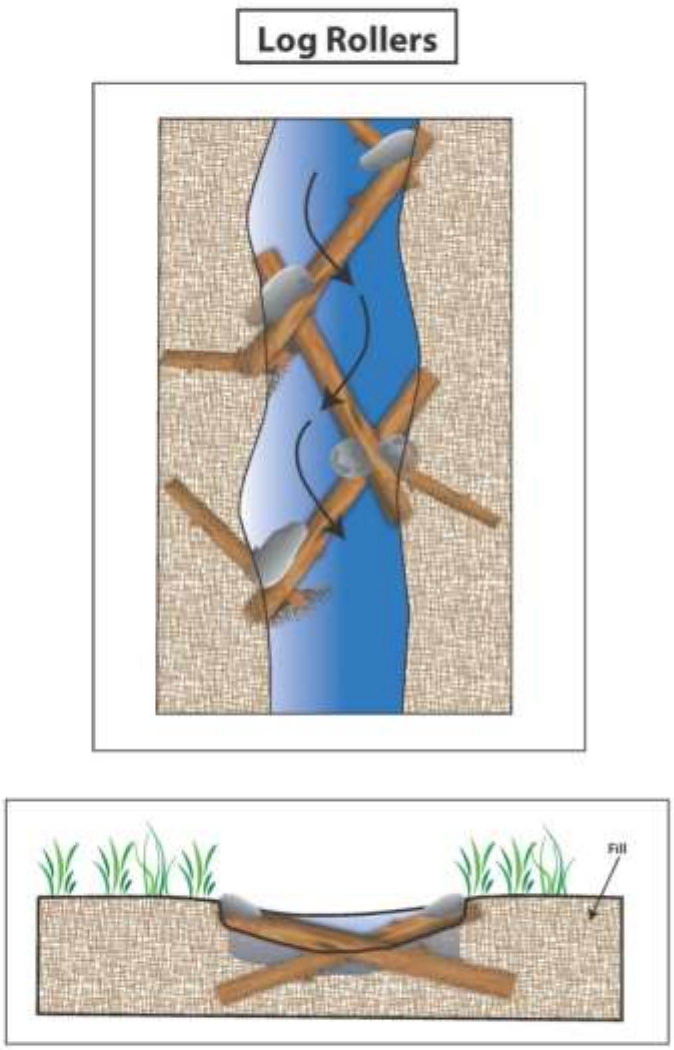
Figure 17. The rock step–pool, cross-vane structure for grade control, streambank stabilization and fish habitat. (Rosgen, 2013)

Rock & Log & Roller Structures - Design

These grade control and energy dissipation structures match natural features of stable A4 and B4 stream types. The structures also redirect erosive flow currents from streambanks to decrease near-bank shear stress and add flow resistance to dissipate excess energy. These structures have proven to reduce streambank erosion rates in similar designs. Thus restoration cannot only regain the physical and biological function of the stream channel and riparian system, but can also significantly reduce downstream and off-site adverse sediment impacts.

Install log rollers for grade control at appropriate interval for channel size and slope. Channels will route delivered sediment and will decrease channel source sediment due to reduced streambank and streambed erosion. Re-establish riparian vegetation.

Figure 18. Log Roller Design (Rosgen, 2013)



Log roller design.

Sediment Detention Basins - Design

Sediment detention basins will be excavated in Valley Types II, III, and VIII. These basins will store the excess sediment produced from 1st, 2nd and 3rd order ephemeral streams that are still producing excessive sediment related to post-fire instability. Sediment detention basins are more effective and economical if they are located in the transition zone where the valley changes from narrower and steeper to wider and flatter (**Figure 19**). The material from the excavation of the sediment detention basins will be used to fill the existing, entrenched channels up to the fan surface so that the braided, D4 stream types can effectively disperse flow energy (reduce stream power) and consequently spread the transported sediment on the fan surface through flow convergence and divergence processes related to braided channels. To prevent any headward advancement or gullying from these basins, log sills are installed within the D channel and old single-thread channels using native materials (**Figures 22** and **23**). **Figures 20** and **21** show a schematic for in-line sediment detention basins for use in colluvial and alluvial fill valleys (Valley Types II and VIII). Basins retain sediment and attenuate floods. By increasing the width/depth ratio of the existing entrenched channel, velocity is decreased, time of concentration is increased, and infiltration is increased all leading to flood attenuation. Sediment detention and flood attenuation are more pronounced as the surface area of the D channel increases.

At both the upstream and downstream extents of the basin, some form of structure must be put in place to stop headcuts from progressing upstream. Two structures are recommended for this purpose: at the upstream end a crib wall of rock or logs (depending on availability of native materials, size of structure, and gradient of the valley) is used, and at the downstream end a sill (or series of sills) is created of rock or trees. A “V” shaped log crib wall is most common (shown in **Figure 20**); it is created utilizing a series of interlocking logs stacked pointing upstream. This design will be used in situations where the flow from upstream is not omnidirectional and in wider valleys. In narrower valleys or omnidirectional flows, a straight wall of logs may be suitable.

Figure 19. Active and Inactive Alluvial Fan in a Valley Type III (Rosgen, 2013)

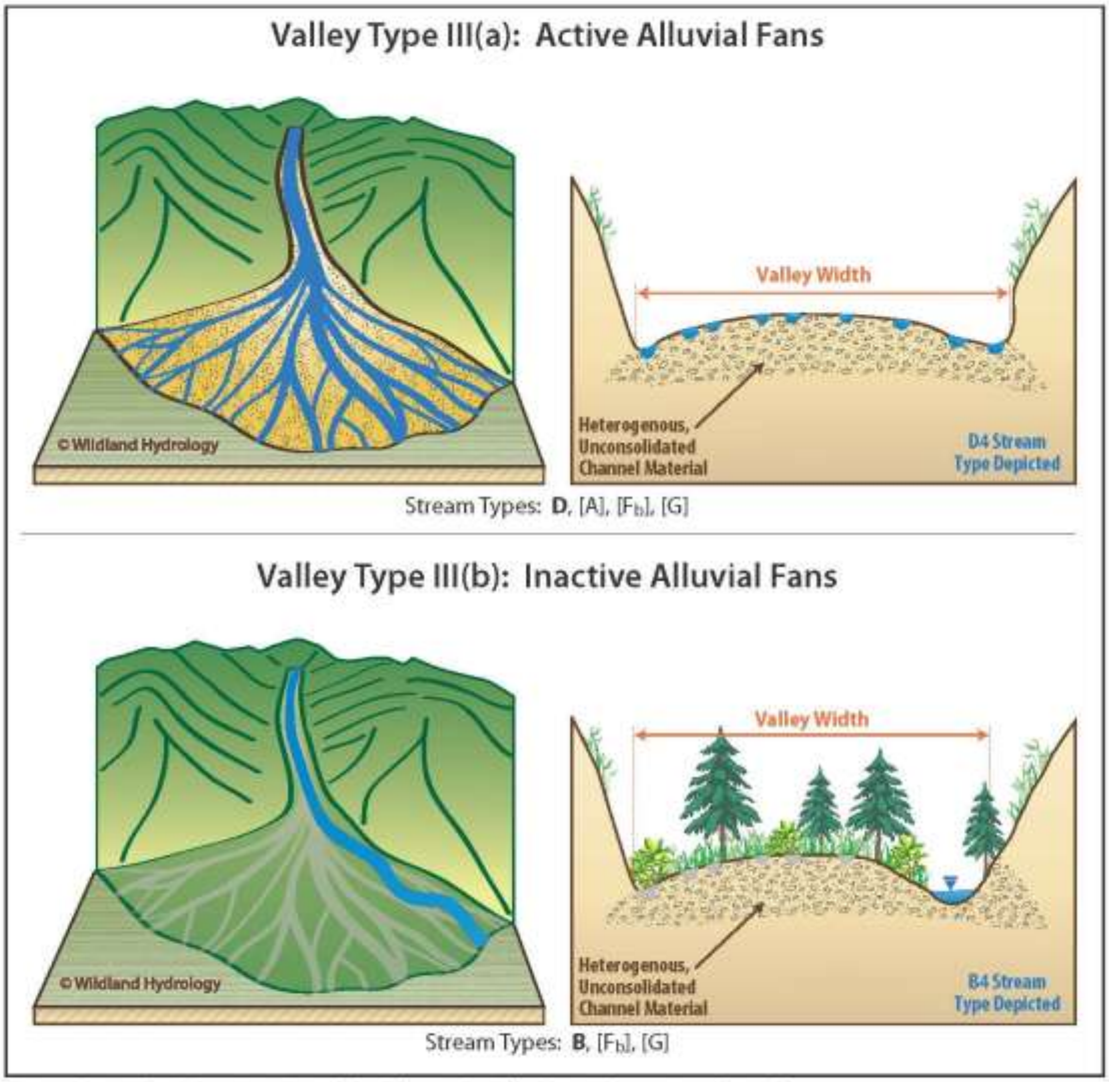
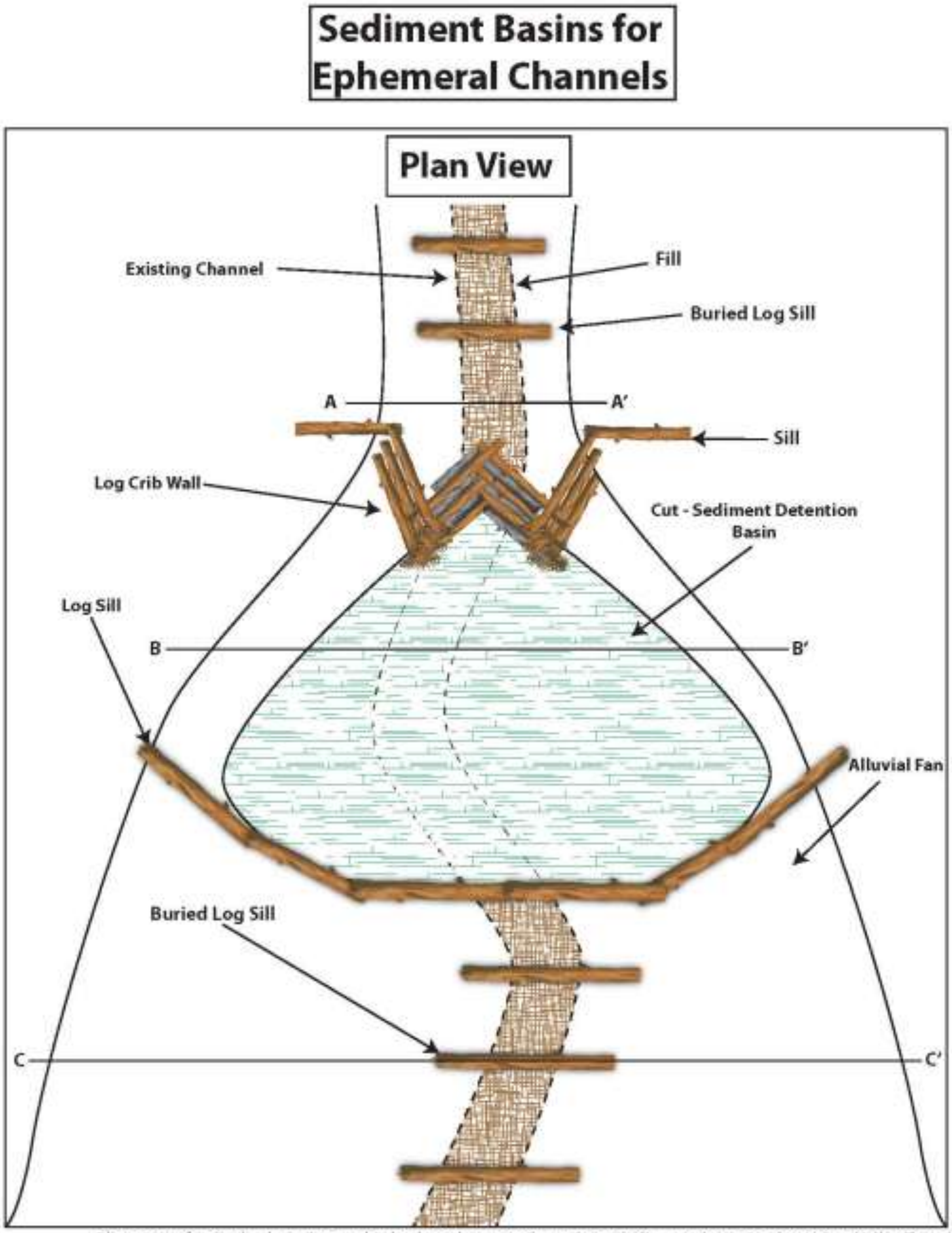


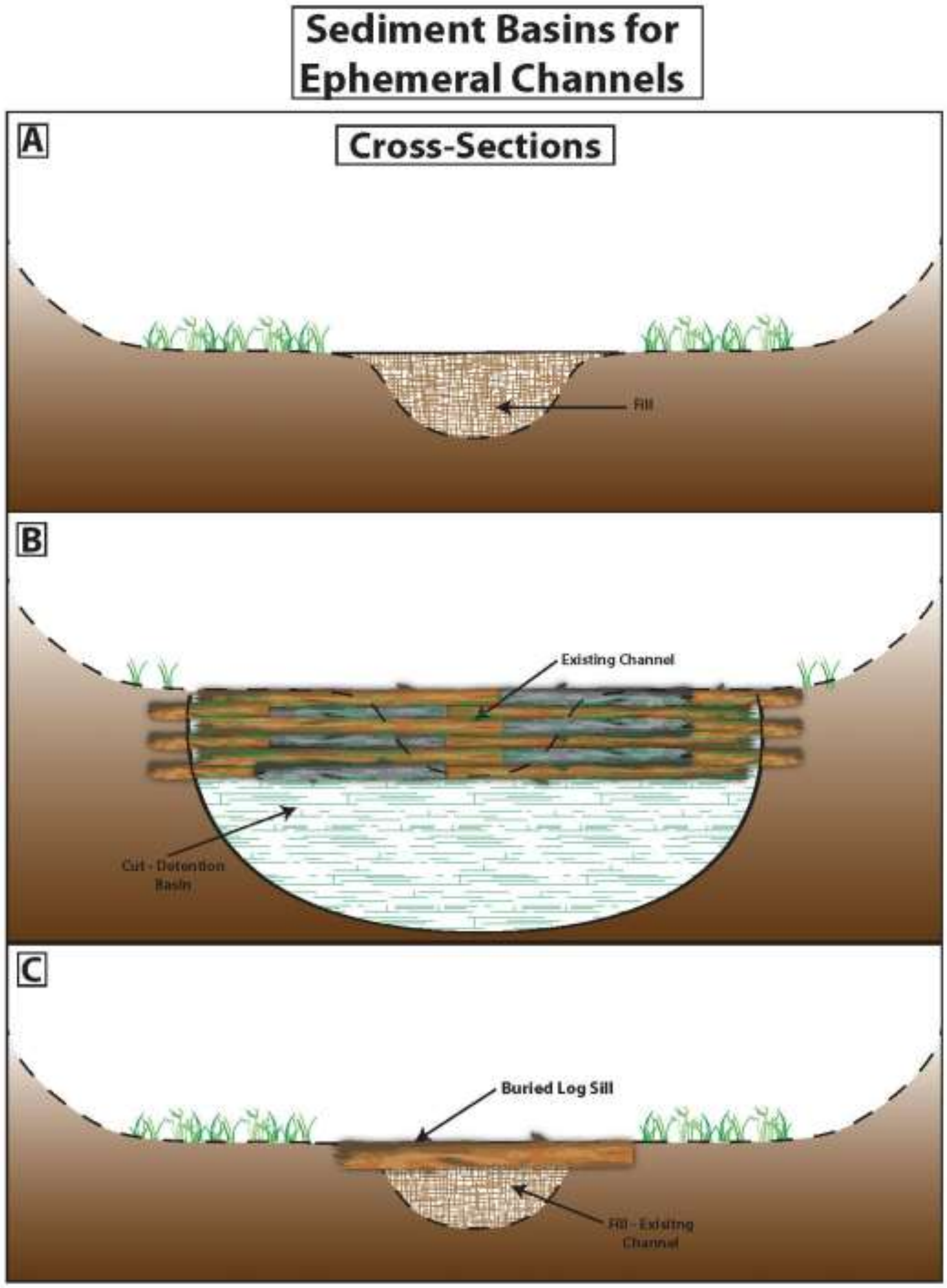
Figure B-8. Valley Type III(a), *Active* alluvial fan, and Valley Type III(b), *inactive* alluvial fan

Figure 20. Sediment Detention Basin for Ephemeral Channels Design – Plan View (Rosgen, 2013)



Plan view of a single-thread to multiple-thread conversion using a sediment detention basin in a Valley Type III.

Figure 21. Sediment Detention Basin Design – Cross Section View (Rosgen, 2013)



Cross-section views of a single-thread to multiple-thread conversion using a sediment detention basin in a Valley Type III

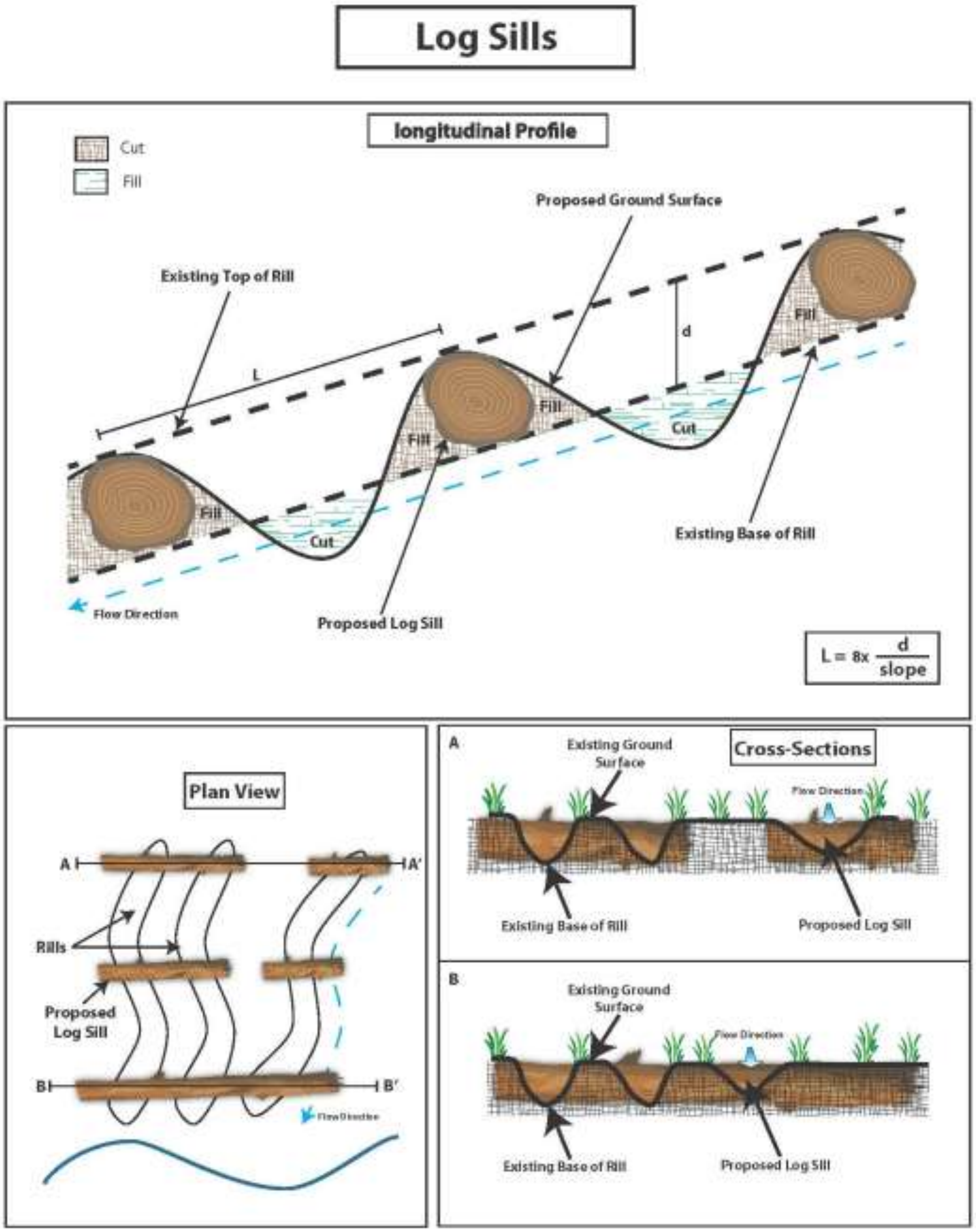
Sills - Design

Sills are used as a grade control structure in combination with other structures to prevent flows from cutting around and incising in functioning D stream types. They may be created using rock or logs; to sill top should be buried within 0.1 ft to 0.4 ft of the post-restoration ground surface and keyed into stable points. Their depth may vary depending on valley gradient and width.

When used in combination with basins and cross-channel structures (cross-vanes, J-hooks and log rollers), the end of the log should be tied into the end of the structure and extend past bankfull and tie into a stable location (hillslopes, rock outcrops, and existing or transplanted vegetation). Sills should be used in existing, D stream types in Valley Types II, III, and VIII to prevent headcuts advancing through depositional surfaces. In these situations, the sills should be buried across the entire channel width and tied into stable features (See **Figure 22**). Sills are incorporated into sediment detention basin and D channel restoration. Sills are installed upstream and downstream of sediment detention basins to prevent downcutting and to spread flows across the channel.

Figure 22. Log Sill Description

Figure 23. Log Sill Design (Rosgen, 2013)



Sill installation

The Toe Wood Structure - Design

The toe wood structure is designed to stabilize streambanks, maintain a low width/depth ratio of the design channel, and enhance fish habitat,. This stabilization structure will typically be used in perennial mainstem \ stream channels. These structures find best advantage where there is readily available toe wood material; when these trees with root wads are available the toe-wood structure provides low cost stabilization with, a more natural appearance than traditional stabilization materials, such as rock rip-rap, gabions, concrete, and interlocking block. This structure also increases the macro-invertebrate habitat and enhances fish habitat with overhead and instream cover.

This structure incorporates native woody material into a submerged undercut bank to replicate natural streambanks. The toe wood is placed at the toe of eroding streambanks on the lower 1/3 to 1/2 of the bank to ensure the wood is submerged year round to prevent wood deterioration. The structure is also used in conjunction with the design of a bankfull bench rather than placed against a vertical terrace or colluvial slope. The bankfull bench reduces convergence against the upper bank and places the vegetation on the bench in a higher water table site and therefore improves the vegetative survival rates. Vegetation transplants and/or cuttings are placed over the toe wood up to the bankfull stage.

Variations in the toe wood structure are available depending on the local vegetation available. One option is to use cuttings and transplanted sod mats that are staked and held down by interweaving shroud line (**Figure 24**). Another option uses woody transplants, such as willow, alder, cottonwood, or dogwood, instead of the cuttings and sod mats (**Figure 25**).

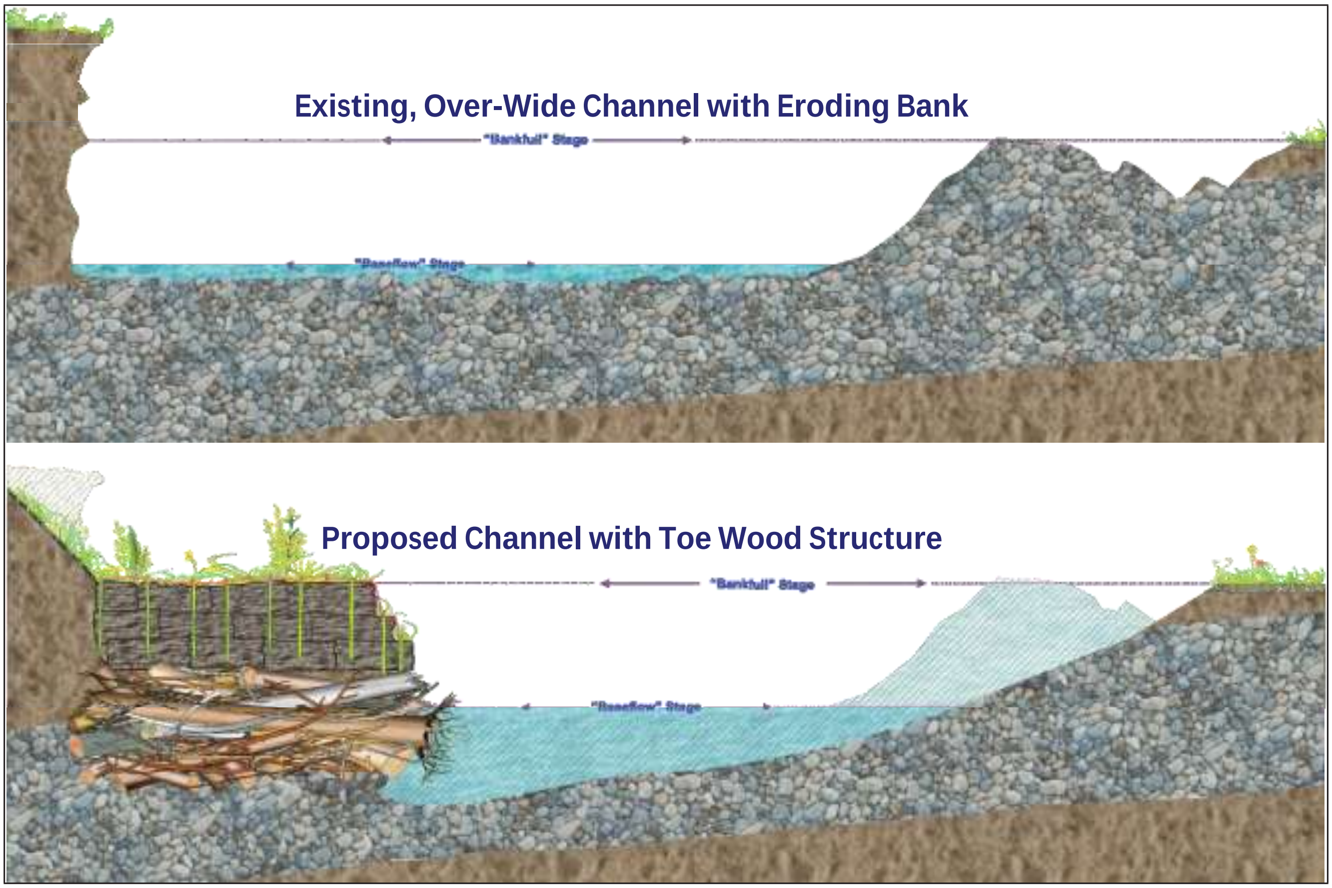


Figure 24. Cross-section view of a before *vs*. after scenario and stability condition using the toe wood structure with sod mats and woody transplants (Rosgen, 2013)

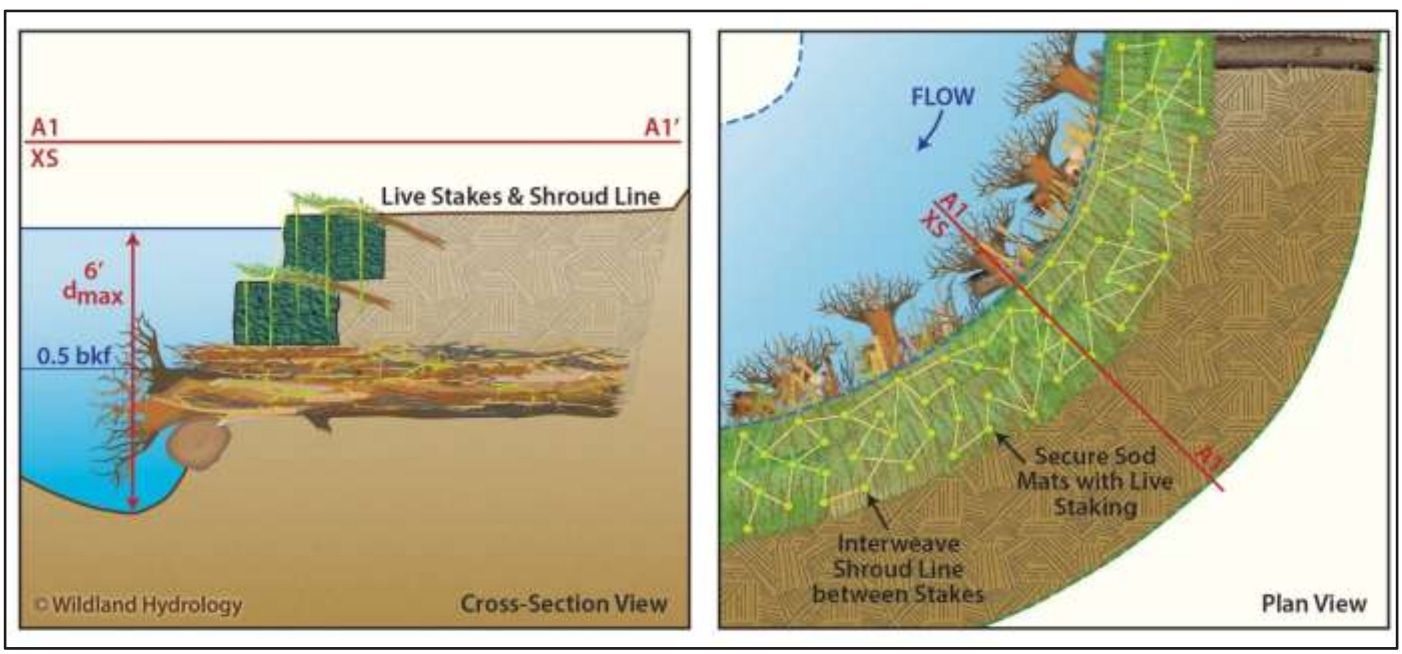


Figure 25. The toe wood structure with cuttings, sod mats, and live staking (Rosgen, 2013)

Toe Catch: Restoration Treatment for Direct Sediment Routing (Hand Work or Mechanical) - Design

Where sufficient space allows (Valley Types II, IIIa,b, and VIIIa,b,c), constructing a bench at the toe of the slope is recommended to prevent directly routing sediment into the stream channel. The bench is most appropriate adjacent to A, B, and C stream types. These features can be constructed with equipment or hand crews. Benches are constructed by laying logs perpendicular to the hill's slope and interconnecting each log in a continuous line. It is important that the end logs in the parallel series have adverse slopes and are tied into the hillslope to avoid concentrating water or creating lateral acceleration causing scour. Secure the log with stakes on the downhill side of the log, then excavate a sediment detention catch on the uphill side of the log; use that material to fill on the downhill side of log. (Heavy equipment can construct bankfull benches in the stream channel using toe wood or transplanted vegetation.) Using this technique, small discontinuous basins can be excavated behind the bankfull bench. Using transplants or seed and mulch will help stabilize the benches and act as a sediment filter and catch. Native bunchgrasses are well adapted to the more droughty conditions typical of the majority of these high risk sites. Toe catches and bankfull benches effectively decrease the slope at the toe of the contributing hillslope, and the small basins provide storage for sediment that otherwise would have been delivered to the channel.

Hillslope and Channel Handwork

Restoration Treatment for Rills and Gullies (Hand Work) - Design

Rills increase drainage density and provide a direct conduit for sediment delivery to streams. Treatment for rills consists of dispersing energy and making the rills discontinuous with sills and/or plugs. The highest treatment priorities are hillslope rills that are hydrologically-connected and rills on the lower 1/3 of the hillslope. In these areas there is a high likelihood of converting rills to gullies, which transport more sediment and are more difficult to treat. It has been twelve years since the Hayman Fire and many rills have already become gullies. Use log sills to disrupt the flow path for the entire length of the rill where rill/gully depth is greater than 0.5 ft (**Figure 23**).

Trench the logs so the top of the sill is level with the ground surface and space the log sills at eight times the depth of the rill divided by the slope. For example, at a rill/gully depth of 0.5 ft on a 20% slope, the sills would be spaced 20 ft apart; for the same rill depth on a 40% slope, the interval would be 10.0 ft. Log sills should span channels that are narrowly spaced, but where distance between the rills exceeds 5.0 ft the log sills can be discontinuous. This reduces unnecessary trenching and conserves wood. Disrupt the flow path between the sills by raking out the rills and using plugs and debris to add surface roughness. Apply seed and mulch to treated area to provide long-term effectiveness. Log rollers and head cut stabilization can also be effectively used by hand crews. Log rollers were described in the previous section for heavy machinery, but the concept and design are the same for hand crews. Head cut repair includes log falls, cross vanes or other methods to dissipate energy. The Coalition for the Upper South Platte and Rocky Mountain Field Institute have extensive experience working in channels and utilizing hand crews to reduce erosion. The latest treatment effectiveness reporting from these local nonprofits will be incorporated into site specific hillslope and channel handwork prescriptions.

Restoration Treatment for Exposed Soil (Hand Work or Mechanical) - Design

Ground cover density is directly related to erosion rates and sediment supply (see Waldo Canyon *WARSSS* report, Rosgen *et al*., 2013, Figure 17, p. 27). Any site with a ground cover density less than 40% will need treatment, with higher priority given to areas on the lower 1/3 of the hillslope. Estimates of delivered sediment from surface erosion by location within each sub-watershed have been used to identify high priority treatment areas (**Table 1, Table 11).** Treatments include re-seeding, tree plugs, adding debris, small logs, log erosion barriers and scattering treetops and branches; this will help reduce rain drop impact and particle detachment leading to excessive surface erosion. Seeding is only recommended on low ground cover sites with a high sediment delivery potential and in combination with the addition of ground cover or roughness treatments. Tree plugs of *Douglas Fir* and *Ponderosa Pine* seedlings can initiate the re-forestation of the hillslopes, particularly where burn intensity was high and eliminated the seed source over a broad area. Proper techniques for handling, planting and site preparation must be followed to enhance seedling survival. Early spring and late fall are the recommended seasons to implement this treatment to limit seedling desiccation. When scattering debris and installing log erosion barriers on the hillslope, it is important to disrupt the flow path all the way to the stream channel while not concentrating flow. Offsetting the ends of the various debris components will disperse overland flow energy, promote infiltration, and reduce surface erosion.

Conceptual Restoration Plan by Priority Watershed

The plan for restoration is based on disproportionate sediment supply contributions and the various sediment sources. These various erosional processes were identified and specific restoration scenarios are proposed to reduce the sediment supply and restore the physical and biological function. **Table 11** lists the priority watersheds by sediment supply with the appropriate stream type restoration scenario and stabilization structures. These watersheds have been ground-truthed and the previously described typical design techniques are identified for each watershed. These typical design scenarios have been extrapolated to the various stream types and conditions at a given location. **Table 10** also serves as a crosswalk between the alluvial Fan identification number from the Wildland Hydrology Conceptual Design (**Appendix B**) and the subwatershed number. **Figure 26** is the priority restoration locator map. Subwatershed 113 - Camp Creek is off of the restoration locator map but is identified in the **Figure 1** and **Figure 2** locator maps.

Figure 26. Priority Restoration Locator Map

Table 11. Restoration design by Priority Watershed

Priority	Watershed	Area (acres)	Total Sediment supply	Stream Restoration Scenario	Stream Stabilization Structures	Handwork	Ground Truth Comments (Validated 07/2014)	Wildland Hydrology Design
1	HC_113 Camp Creek	1324	15509	G→B; F→D Braided Channel	Culvert Stabilization, Sediment Detention Basins, Sills, Log Rollers, Debris Dam Removal	Yes	**Private Property,** Camp Creek, possible basin, culvert for driveway access, abundant debris dams, Da Poor	No
2	HC_119 (Fan 1)	415	9636	F→D Braided Channel	Sediment Detention Basins, Sills, Debris Dam Removal	Yes	Possible basin/culvert work, D poor, bedrock control and abundant veg upstream, NE side of 67	**Yes**
3	HC_121 (Fan 3)	422	9306	F→D Braided Channel	Culvert Stabilization, Sediment Detention Basins, Sills	Yes	**Private Property** recently altered by new owner (culvert and veg), Fb Poor	**Yes**
4	HC_120 (Fan 4)	888	9144	G→B; F→D Braided Channel	Culvert Stabilization, Step Pools, Sediment Detention Basins, Sills, Log Rollers	Yes	**Private Property** culvert for driveway access, currently functioning above house, possible basin above, Fb Fair	**Yes**
5	HC_83	131	3303	A Poor	Log Rollers, Slope Back Banks	Yes	**Private Property,** Face Drainage, possible drainage/hand work in 4 minor drainages, NE side of 67	No
6	HC_125 (Fan 10)	51	2625	F→D Braided Channel	Sediment Detention Basins, Sills, Toe Wood	Yes	Rejuvenating Fan, Possible basin, D Poor	**Yes**
7	HC_118 (Fan 8)	56	2426	F→D Braided Channel	Sediment Detention Basins, Sills, Toe Wood	Yes	Rejuvenating Fan, Possible basin, Da Poor, Colluvial/Hillslope Work	**Yes**
8	HC_92	200	2145	A		No	**Private Property,** Fair Condition-May need additional ground truthing for priorities	No
9	HC_93	97	1524	F→D Braided Channel	Sediment Detention Basins, Sills, Toe Wood	Yes	**Private Property,** Rejuvenating Fan, Possible basin, Da Poor, Abundant Veg on fan	No
10	HC_126 (Fan 2)	51	1491	G→B; F→D Braided Channel	Step Pools, Sediment Detention Basins, Sills, Log	Yes	**Private Property,** G Poor, Fb Poor, Colluvial/Hillslope Work	**Yes**

					Rollers			
11	HC_91	94	1236	F→D Braided Channel	Sediment Detention Basins, Sills, Toe Wood	Yes	**Private Property,** Rejuvenating Fan, Possible basin, Da Poor, Abundant Veg on fan	No
12	HC_82	76	1101			Yes	**Private Property,** Face Drainage, No Fan/Basin Work	**Yes**
13	HC_97	521	1042	F→D Braided Channel	Sediment Detention Basins, Sills	Yes	**Private Property**, currently functioning, possible drainage work on right stem, D Poor, NE side 67	No
14	HC_44 (Fan 5)	38	943			Yes	**Private Property,** Face Drainage, No Fan/Basin Work	**Yes**
15	HC_45 (Fan 7)	19	850			Yes	Face Drainage, No Fan/Basin Work	**Yes**
16	HC_139 (Fan 6)	18	712	A→B; F→D Braided Channel	Step Pools, Sediment Detention Basins, Sills, Log Rollers	Yes	**Private Property,** No Validation Points Taken	**Yes**
17	HC_128 (Fan 11)	32	639	F→D Braided Channel	Sediment Detention Basins, Sills, Toe Wood	Yes	Rejuvenating Fan, Toe Wood for Fan Stabilization, Possible Basin, Da Poor	**Yes**
18	HC_38	54	482		Slope Back Banks	Yes	**Private Property,** Rejuvenating Bank, Face Drainage	No
19	HC_40	42	404			Yes	**Private Property,** Face Drainage	No
20	HC_124 (Fan 12)	23	388			Yes	Beaver Pond, Mainstem Good Condition, currently functioning trib	**Yes**
21	HC_131 (Fan 9)	20	346		Sediment Detention Basins, Sills, Toe Wood	Yes	Rejuvenating Fan, Possible Basin, Da Poor	**Yes**
22	HC_94	44	346			No	**Private Property,** Good condition	No

23	HC_51	6	328			No	No Validation Points Taken	**Yes**
24	HC_135	16	253			No	No Validation Points Taken	No
25	HC_88	24	218	A Poor	Log Rollers, Slope Back Banks	Yes	**Private Property,** possible channel/hand work upstream, NE side of 67	No
26	HC_95	51	190			No	Good Condition	No
27	HC_85	68	173			No	Good Condition	No
28	HC_137	23	132			No	**Private Property**	No
29	HC_138	20	89			No	Good Condition	No
30	HC_87	31	79	A Poor	Log Rollers, Slope Back Banks	Yes	**Private Property,** possible channel/hand work upstream, NE side of 67	No
31	HC_136	15	54			No	**Private Property,** Good Condition	No
32	HC_150	6	53			No	Good Condition	No
33	HC_130	12	23			No	**Private Property,** Good Condition	No
34	HC_129	8	12			No	**Private Property,** Good Condition	No
35	HC_98	41	8			No	**Private Property,** Good Condition	No

Mitigation & Restoration Priority Summary

This cumulative watershed effects analysis provides a basis for setting mitigation and restoration priorities linked to land uses, locations, processes, disproportionate sediment yields, and associated river impairments. Priorities were developed based on the total sediment supply from hillslopes, roads, and streambanks as determined by the *WARSSS* methodology (**Table 1**). Restoration priority is based upon access and sediment supply as well as values at risk. Horse Creek is a tributary to the South Platte River and the source of nearly 80% of drinking water for the Denver/Aurora metro area. Downstream reservoirs have lost capacity and have had Hayman Fire derived soils dredged out at a very high cost to water utility providers and customers. State Highway 67 occupies much of the Horse Creek floodplain and is one of the values at risk. Debris flows from the tributaries continue to cover Highway 67 causing emergency response to reopen the highway. The South Platte River has been designated a Gold Medal Fisheries. The river is well known for its wild trophy population of brown trout and rainbow trout. As a result of the close proximity to Denver, the river sees thousands of fly fishing enthusiasts each year.

The purpose of this restoration work will be to stabilize soil onsite in the Hayman Fire area by reducing erosion, thus improving water quality and fish habitat, and reducing impacts to critical infrastructure, including downstream reservoirs and the State Highway (67). There are several priority tributaries to Horse Creek that are considered in this plan. At the upstream end of the planning area, Trout Creek comes downstream from the south (headwaters near the City of Woodland Park) on the east side of the Highway 67 cooridor, and West Creek comes down on the west side of the corridor. At their confluence, they become Horse Creek.. Camp Creek is a tributary to West Creek and is the top priority for restoration. Camp Creek, at 1,324 acres (much of which burned at high severity) has transported damaging quantities of trees, boulders and sediment into Horse Creek and onto Highway 67.

Priority tributaries are often adjacent to each other, meaning once the heavy machinery is staged, restoration work can be completed efficiently moving from one Tributary to the next. This ease of access is a factor for implementation and prioritization.

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