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



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Submitted to:

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Colorado Water Conservation Board

Colorado Department of Transportation

The Navigators/Glen Eyrie

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Colorado Springs Utilities

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

Introduction

The Waldo Canyon Fire burned *18,247 acres* within the foothills and mountains of the Rampart Range immediately northwest of Colorado Springs, Colorado, in El Paso County. The general location and fire perimeter are displayed in **Figure 1**, which includes public and private lands. The fire started Saturday, June 23rd, 2012, and was fully contained Tuesday, July 10th, 2012, after destroying 346 homes. The four major watersheds affected by the Waldo Canyon Fire are Camp Creek, Douglas Creek, Fountain Creek, and West Monument Creek. Using GIS, these four watersheds were delineated into sub-watersheds and given unique number ID's as identified in **Figures 2–5**.

A post-fire *Watershed Assessment for River Stability and Sediment Supply (WARSSS)* study was initiated within the watersheds impacted by the Waldo Canyon Fire in the fall of 2012 and completed in April, 2013 (Rosgen, *et al*., 2013). The recent completion of the *WARSSS* study forms the foundation for the multi-watershed restoration master plan. The *WARSSS* study is a cumulative watershed effects analysis that quantifies changes in water yield, hillslope erosional processes, and stream channel impacts, including streambank erosion due to disturbance. In this case, the disturbance is related to the Waldo Canyon Fire overlaying existing watershed conditions from previous land uses to evaluate cumulative effects. The *WARSSS* study establishes consistent, quantitative, and reproducible criteria to develop design scenarios for post-fire restoration priorities. The design scenarios are directly related to individual erosional processes by specific sub-watershed location. Estimates of sediment reduction and related costs for various treatments for identified priority watersheds are summarized for planning purposes.

A post-fire *WARSSS* study was previously conducted in 2010 and 2011 in the Trail Creek Watershed of the South Platte River Basin that was affected by the Hayman Fire of 2002 (Rosgen, 2011a). The similar geology and hydrologic conditions of Trail Creek allowed the extrapolation of data collected and relations developed in the Trail Creek *WARSSS* study to be used for the Waldo Canyon Fire assessment and design.

Without the *WARSSS* study, the development of a watershed-based, post-fire restoration plan can be overwhelming when the following typical questions arise:

1. What can be done to reduce potential post-fire flood impacts?
2. Where does the work start?
3. How much of the watershed needs treatment or restoration?
4. How effective will the work be?
5. How expensive is the proposed work?
6. What will happen if we do nothing?
7. How will the work be accomplished?

These questions are addressed within the Waldo Canyon Fire master plan using the *WARSSS* study as the framework for the various restoration design scenarios presented.

The goal of the *WARSSS* study and this master restoration plan is to direct restoration efforts in a timely manner to those watersheds and processes identified that represent the highest significant risk for post-fire runoff and sediment yield and potential associated downstream damage. The *WARSSS* study quantified post-fire streamflow and sediment yields related to burn intensity, location, extent, and consequence of hillslope, hydrologic, and channel processes. In this manner, restoration efforts can be designed, directed, and prioritized to help reduce the severity of the potential adverse downstream impacts. This master plan provides typical design scenarios for a wide range of erosional processes impacted by the fire. Because site-specific details for individual reaches for the entire fire area are not practical, restoration scenarios have been developed to represent similar conditions from which specified restoration treatments can be extrapolated.

A similar approach was developed for the Trail Creek Watershed affected by the Hayman Fire where a range of design scenarios for specific processes were utilized and extrapolated to locations containing similar stream types, stability conditions, and erosional processes (Rosgen, 2011b). Implementation of the Trail Creek master restoration plan was initiated within 45 days of its completion. A similar goal is directed for this study that emphasizes the timely initiation of recommended restoration scenarios for a variety of high risk locations and processes. This study identifies the high risk watersheds where disproportionate sediment yields have been quantified for a range of processes, including surface erosion, mass-wasting/debris flows, roads, and flow-related sediment increases due to streambed and streambank erosion. The restoration plan targets such processes with specific design scenarios that can be applied where similar conditions occur in the presence of high risk and significant potential adverse consequences.

Included with this report are digital copies of the large format maps created for the master restoration plan for the watersheds affected by the Waldo Canyon Fire. The following are the maps included as digital copies:

- Change in Water Yield & Bank Erosion Rates
- Cumulative Sediment Sources
- Channel Treatments
- Stream Type & Condition

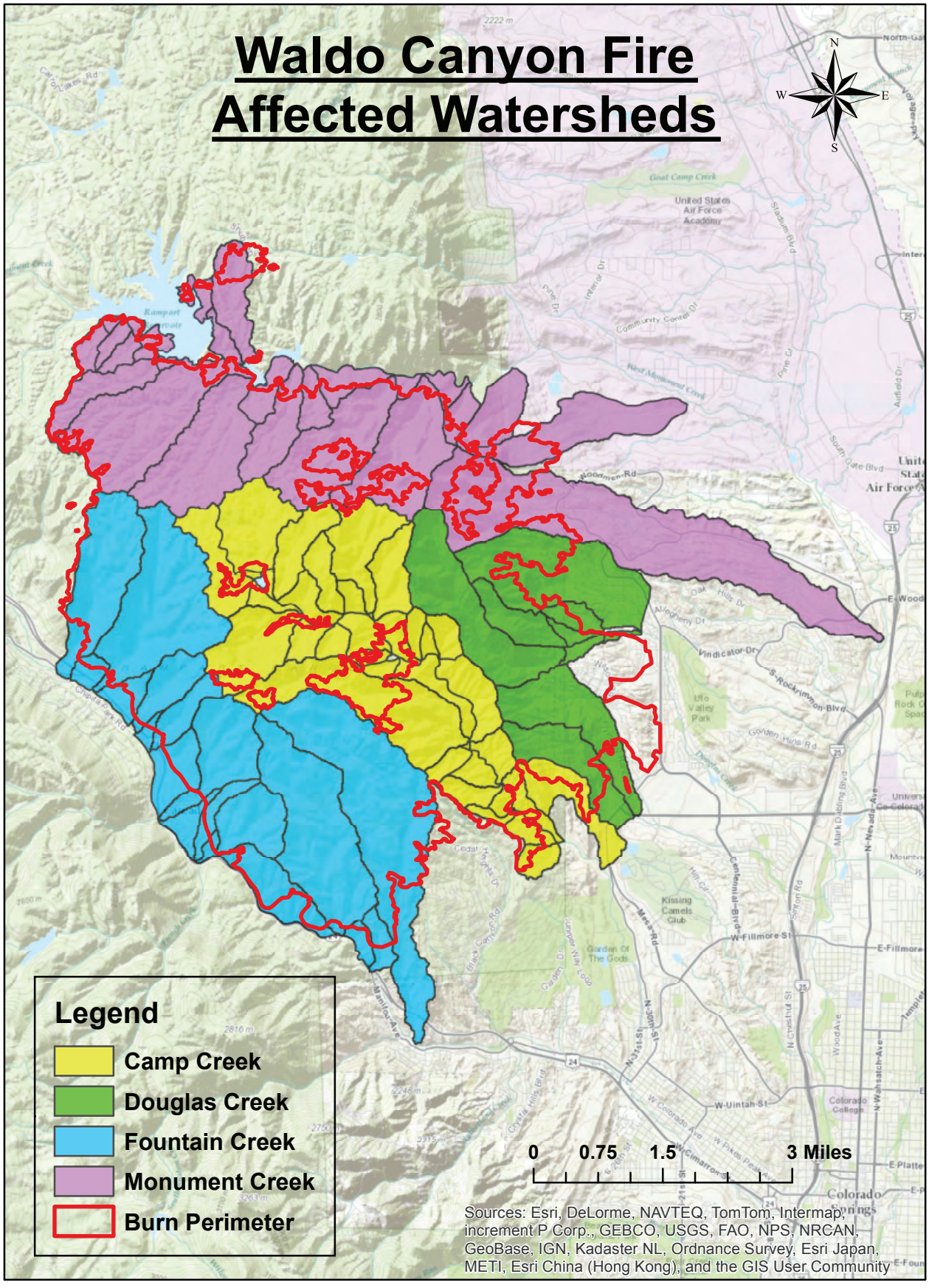


Figure 1. General location and Waldo Canyon Fire perimeter including major watershed delineation.

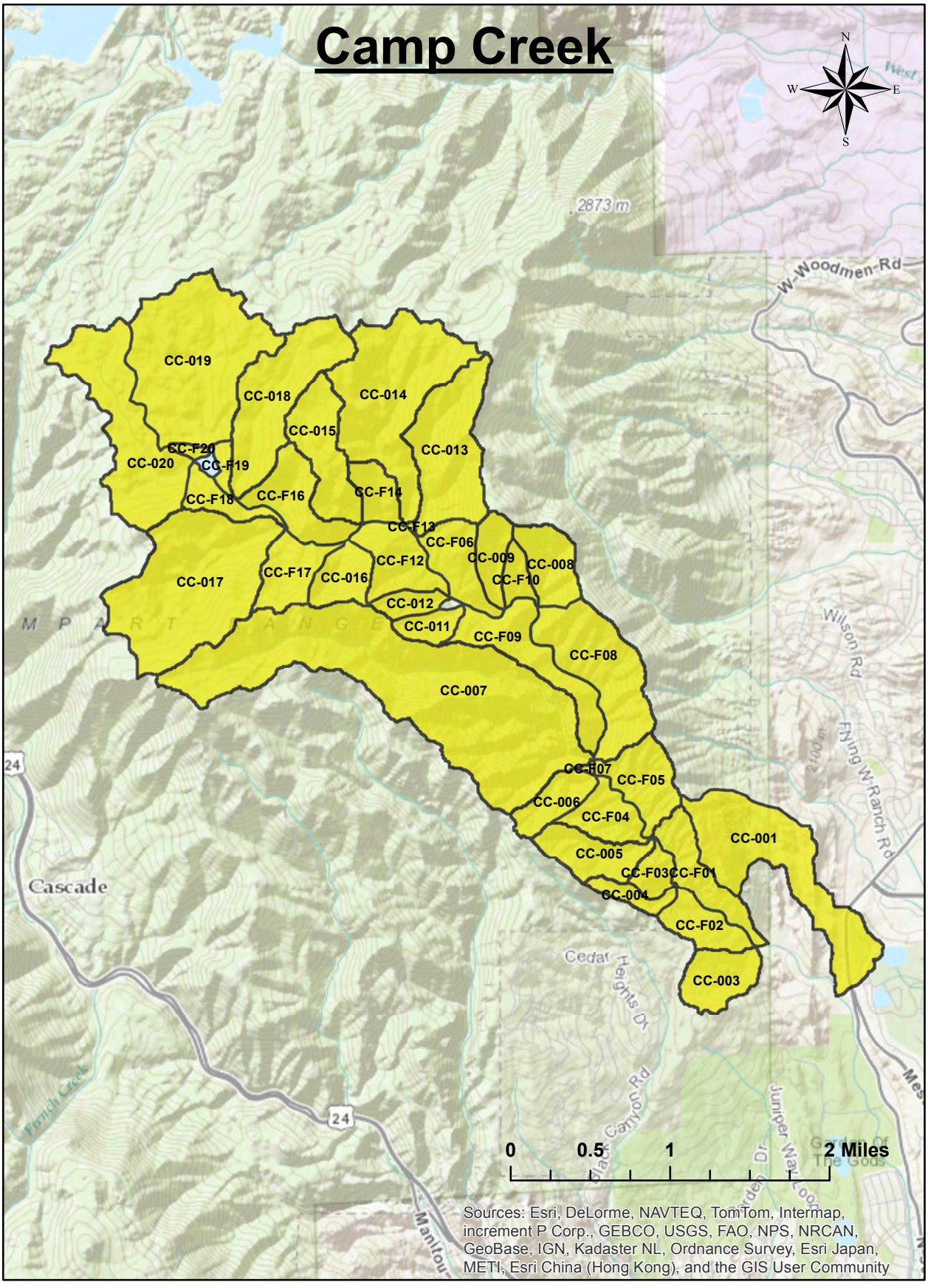


Figure 2. Camp creek sub-watershed delineation.

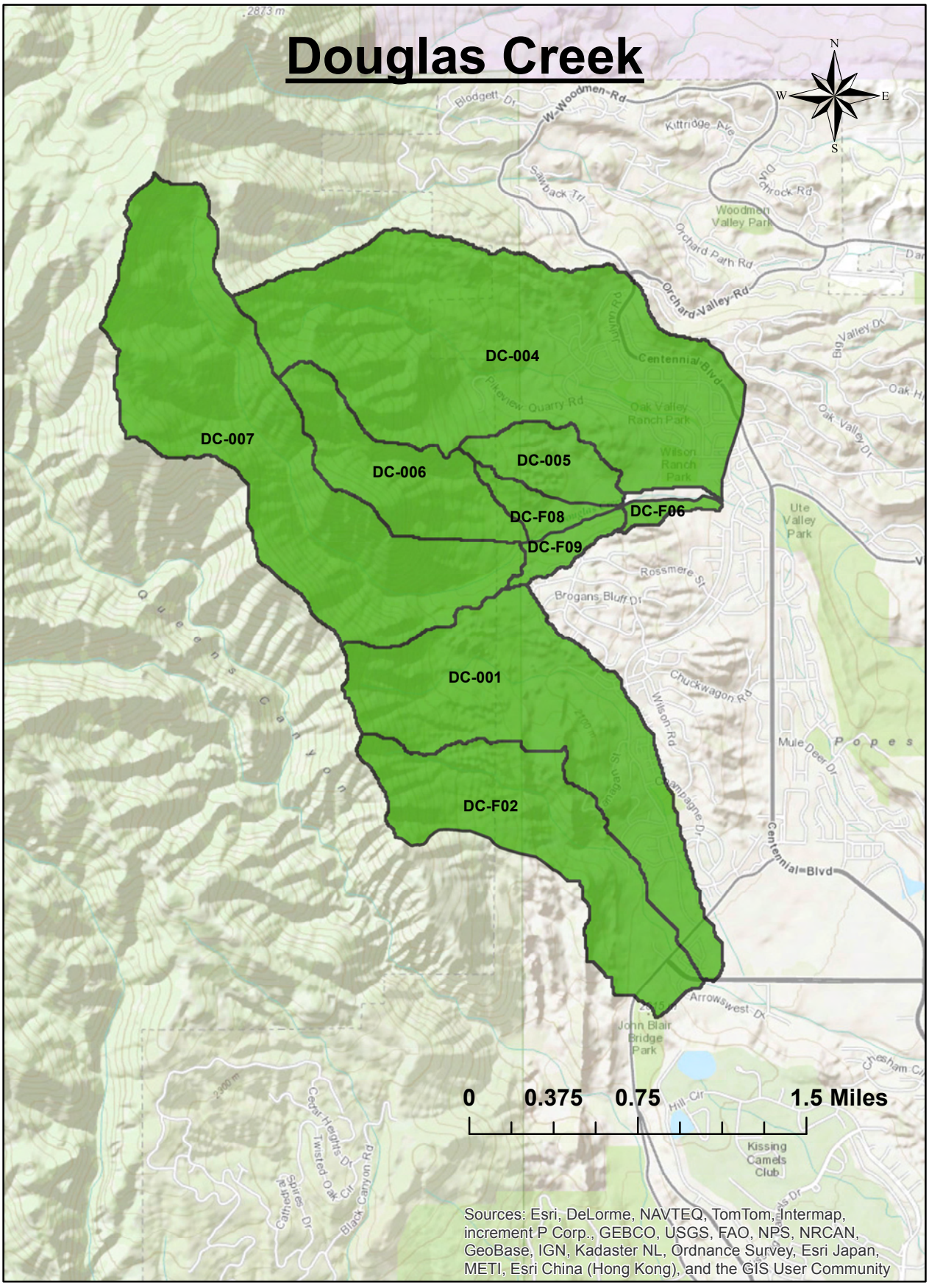


Figure 3. Douglas Creek sub-watershed delineation.

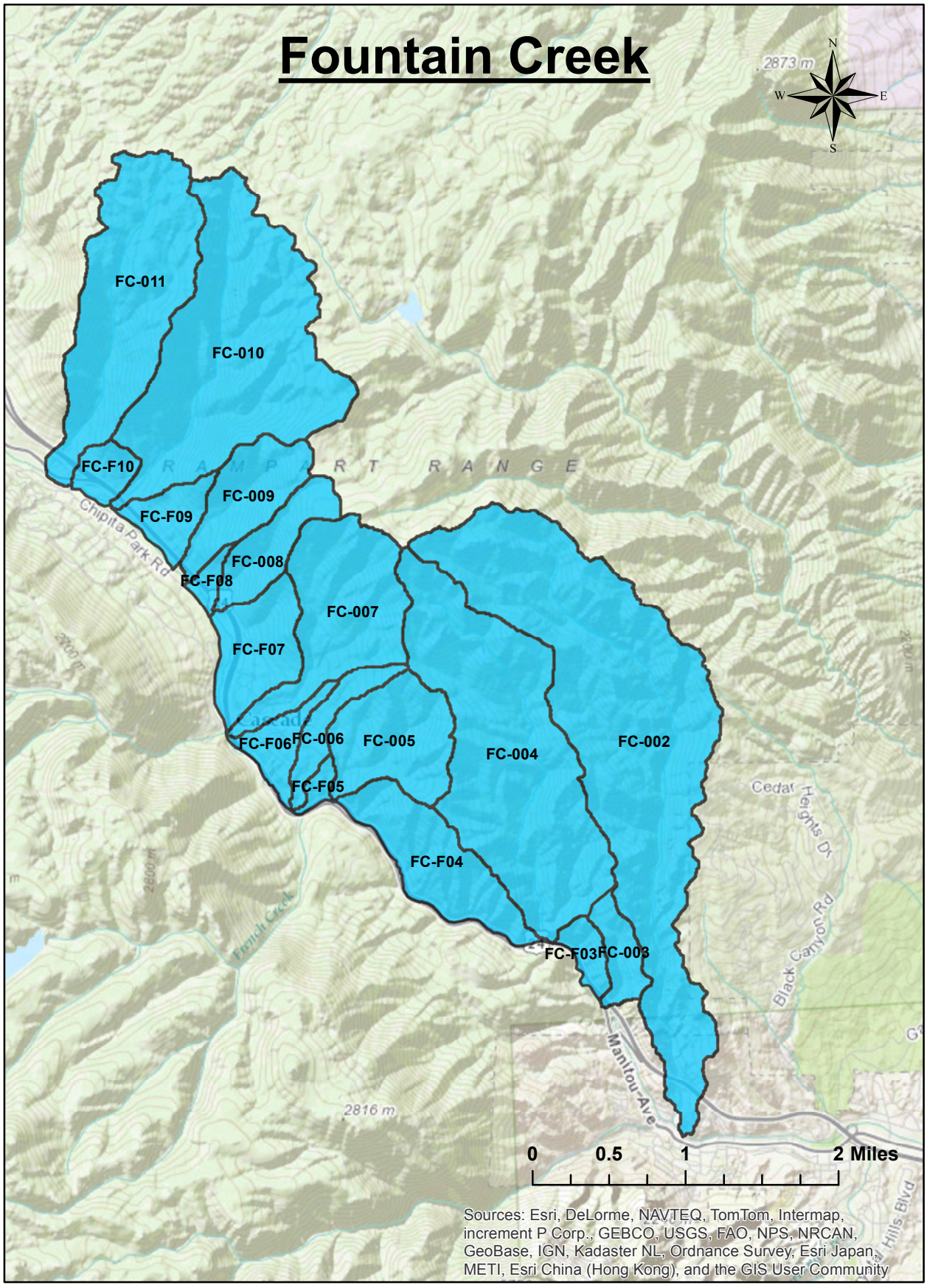


Figure 4. Fountain Creek sub-watershed delineation.

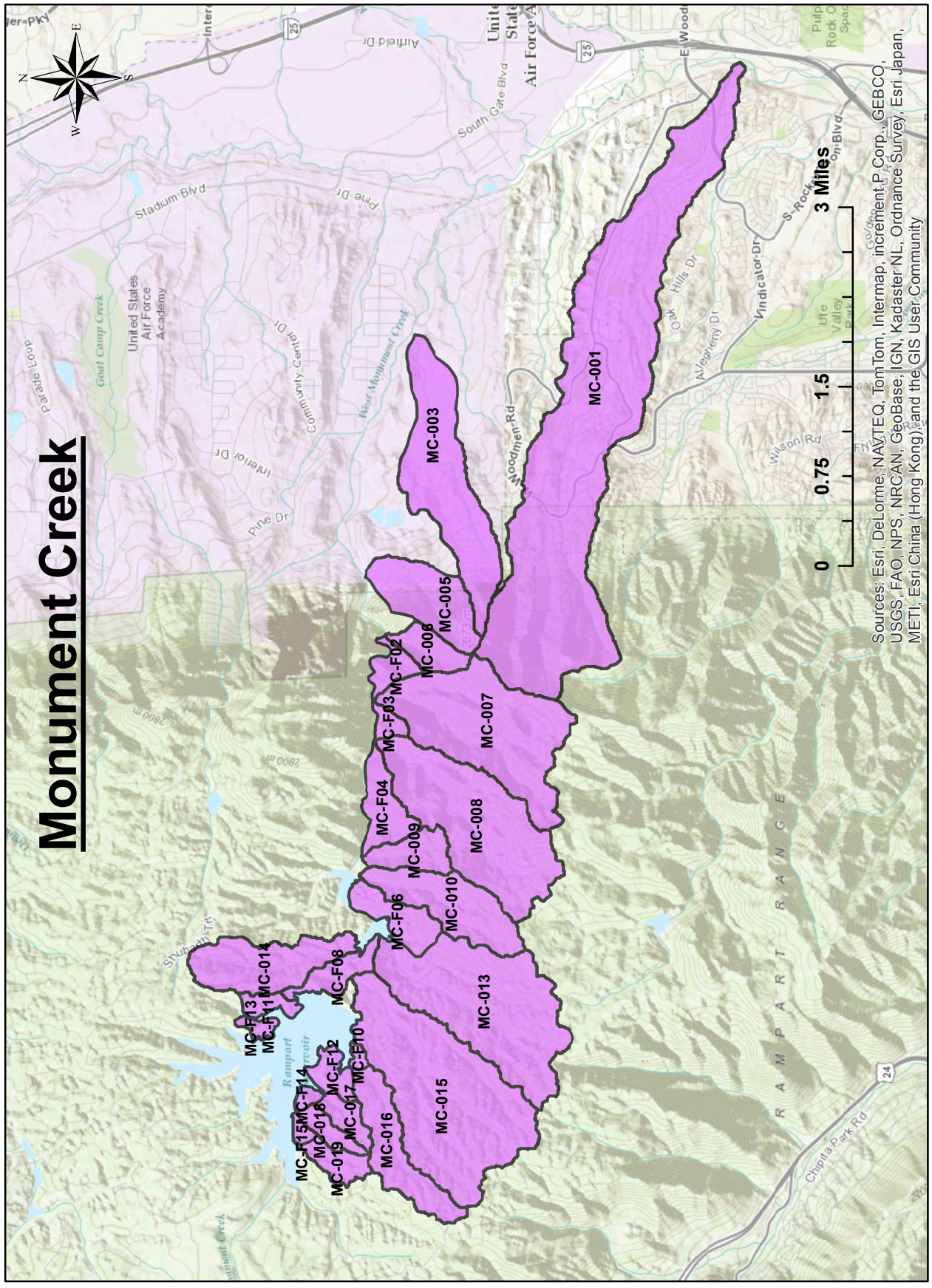


Figure 5. West Monument Creek sub-watershed delineation.

Summary of the Waldo Canyon Fire *WARSSS* Study

This master plan for restoration is developed to reduce the accelerated sediment yields following the Waldo Canyon Fire of 2012. This design relies on the results of a three-phase watershed assessment conducted in 2012 by Wildland Hydrology based on *WARSSS* methodology (*Watershed Assessment and River Stability and Sediment Supply*, Rosgen, 2006/2009). The initial two phases of *WARSSS*, the *Reconnaissance Level Assessment (RLA)* and the *Rapid Resource Inventory for Sediment Supply Consequences (RRISSC)*, were conducted on more than 52 mi^2 in the Camp, Douglas, Fountain, and West Monument Creek Watersheds on and bordering the Pike National Forest, Colorado. The initial *RLA* and the *RRISSC* assessments eliminated more than 14.5 mi^2 of drainage area from further evaluation and identified nearly 38 mi^2 as *High Risk* for disproportionate sediment supply and river impairment. The third phase of the assessment, the *Prediction Level Assessment (PLA)*, identified the erosional and depositional processes that are disproportionately contributing sediment and quantified the sediment loading by location and process. The detailed results of these phases are documented in the report *Waldo Canyon Fire Watershed Assessment: The WARSSS Results* (Rosgen *et al*., 2013).

In the areas affected by the Waldo Canyon Fire, 24,248 acres including 89 sub-watersheds were analyzed. Of the total watershed area, 71% burned (32% low intensity, 34% moderate intensity, and 5% high intensity) resulting in an average annual change in water yield of 2.1 inches. The total introduced sediment from the Waldo Canyon Fire is estimated to be *51,479 tons/yr*, of which 61% is from streambank erosion, 35% from surface erosion, and 4% from road contributions (**Table 1**). The FLOWSED model predicts *57,295 tons/yr* of flow-related sediment resulting in a net degradation of *5,816 tons/yr* for the entire burn area (channel bed scour), though a net aggradation (excess sediment deposition in the channel) is predicted in 30% of the sub-watersheds. Relative amounts of sediment contribution, by process, for each of the 89 sub-watersheds are depicted in **Figures 6–9**. All sediment yield estimates are based on a normal high flow runoff year (bankfull discharge), and stormflow-related surface erosion is based on a relatively frequent, two-year, one-hour storm. Sub-watershed priorities based on the magnitude of total introduced sediment are displayed in **Table 2**. These values are generally accompanied by high peak streamflows that generate a high percentage of channel source related sediment yields (see Table 1 in the *WARSSS* report, Rosgen *et al*., 2013, p. 14). The magnitude source and nature (aggradation/degradation) of the post-fire sediment yield (as shown in **Tables 1** and **2**) provide the fundamental direction for a range of restoration scenarios. The priorities for restoration are combined with the magnitude of impact with the potential adverse consequence of downstream flood and infrastructure damage.

Table 1. Summary of estimated pre- and post-fire sediment yields by process.

Watershed	Hydrologic Processes				Hillslope Processes	Roads and Trails	Channel Processes	Total Introduced Sediment (tons/yr)
	Water Yield (acre-ft/yr)		Flow-Related Sediment (tons/yr)		Surface Erosion (tons/yr)	(tons/yr)	Streambank Erosion (tons/yr)	
	Pre-Fire	Post-Fire	Pre-Fire	Post-Fire				
Camp Creek	2,115	3,702	71	16,897	4,193	751	6,750	11,694
Douglas Creek	1,511	2,156	47	7,834	4,057	236	6,108	10,401
Fountain Creek	2,500	4,822	90	25,075	7,303	619	11,318	19,241
West Monument Creek	2,747	4,035	104	7,489	2,532	429	7,183	10,143
Totals	**8,873**	**14,715**	**312**	**57,295**	**18,085**	**2,035**	**31,359**	**51,479**

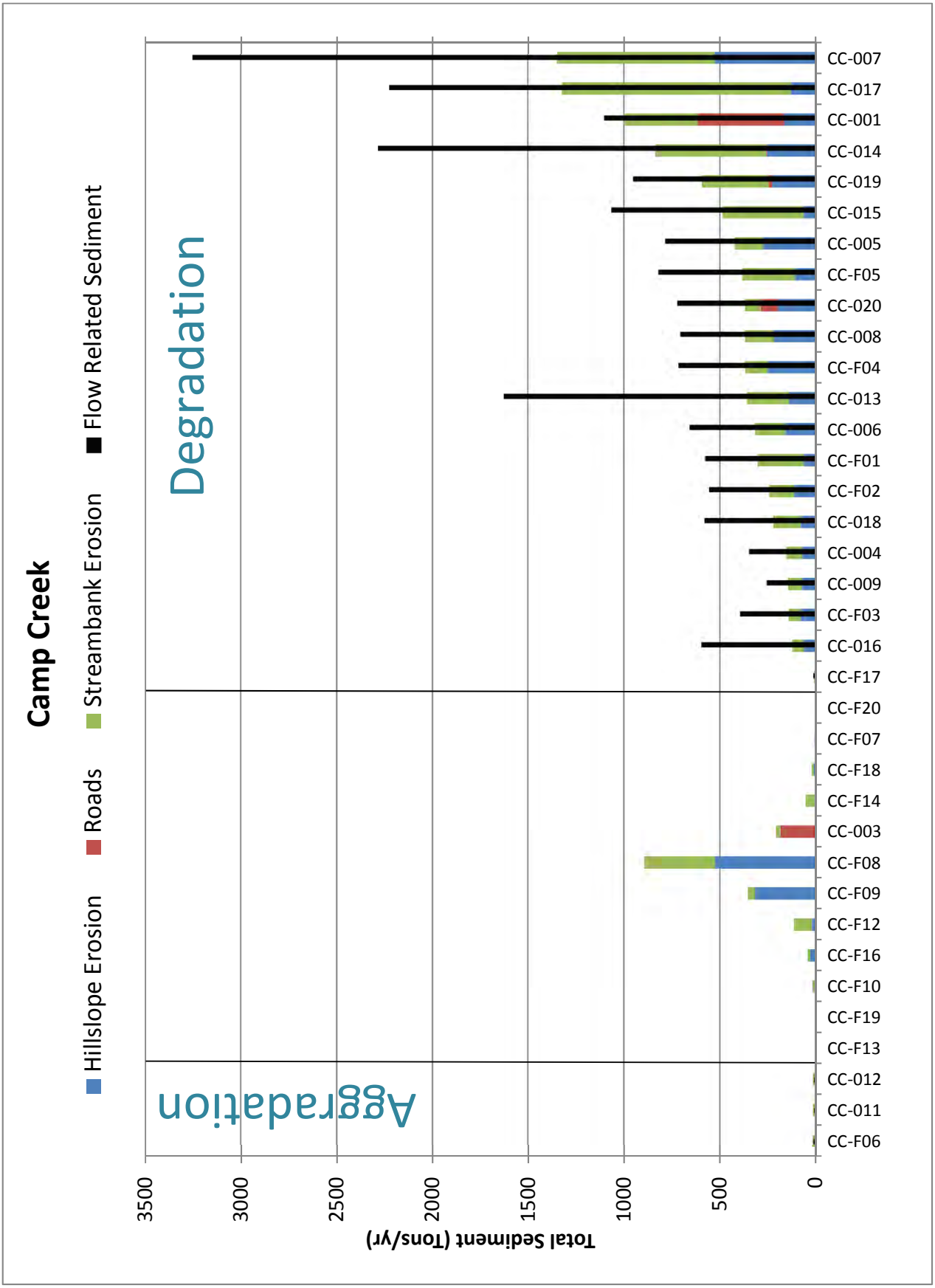


Figure 6. Camp Creek sub-watershed sediment contributions by process.

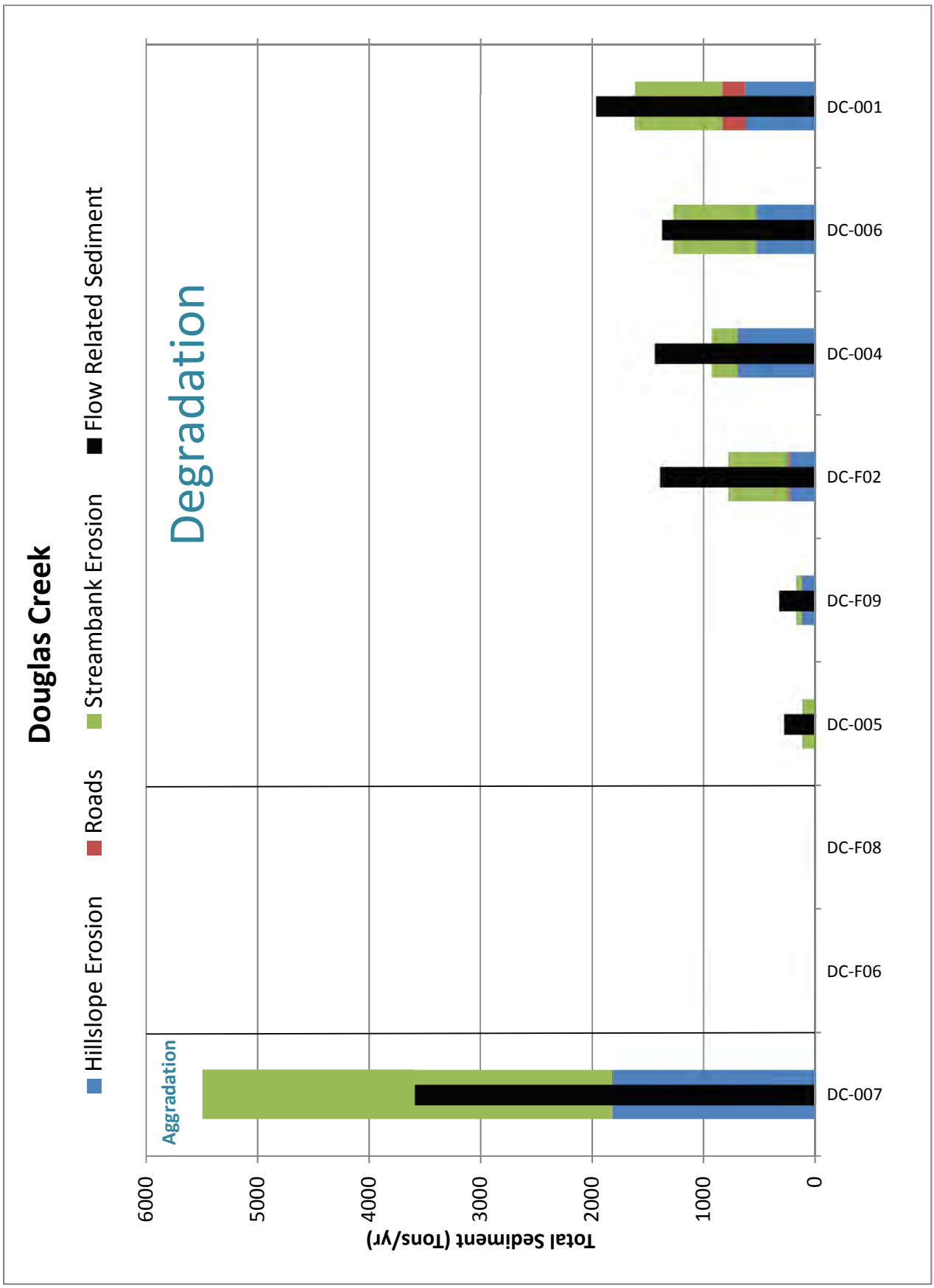


Figure 7. Douglas Creek sub-watershed sediment contributions by process.

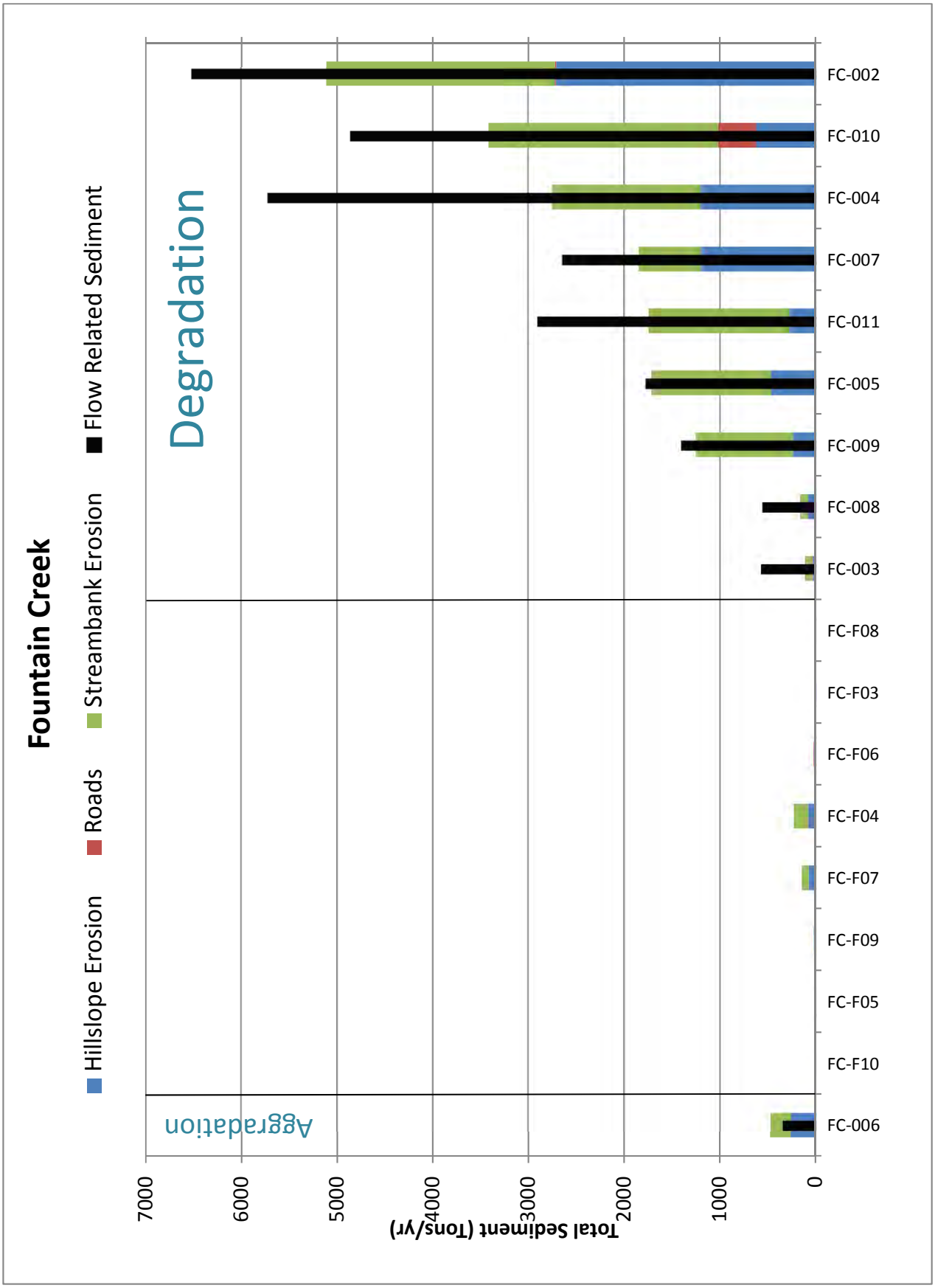


Figure 8. Fountain Creek sub-watershed sediment contributions by process.

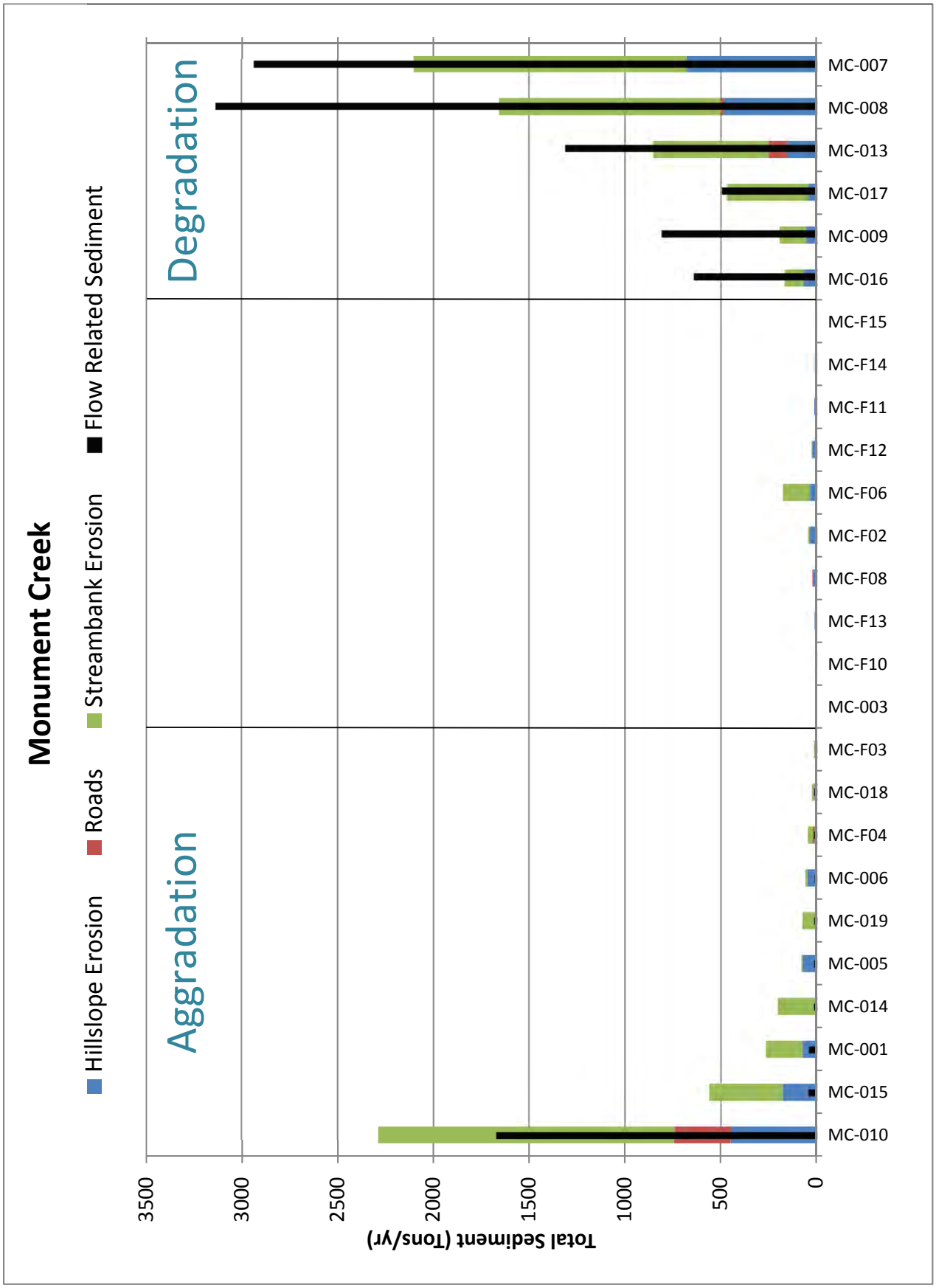


Figure 9. West Monument Creek sub-watershed sediment contributions by process.

Table 2. Sub-watershed priorities based on total introduced sediment.

Douglas Creek			Fountain Creek			West Monument Creek			Camp Creek		
Sub-Basin	Overall Rank	Sub-Basin Rank	Sub-Basin	Overall Rank	Sub-Basin Rank	Sub-Basin	Overall Rank	Sub-Basin Rank	Sub-Basin	Overall Rank	Sub-Basin Rank
DC-007	1	1	FC-002	2	1	MC-010	5	1	CC-007	12	1
DC-001	11	2	FC-010	3	2	MC-007	6	2	CC-017	13	2
DC-006	14	3	FC-004	4	3	MC-008	10	3	CC-001	16	3
DC-004	17	4	FC-007	7	4	MC-013	19	4	CC-F08	18	4
DC-F02	21	5	FC-011	8	5	MC-015	23	5	CC-014	20	5
DC-F09	44	6	FC-005	9	6	MC-017	26	6	CC-019	22	6
DC-005	51	7	FC-009	15	7	MC-001	36	7	CC-015	24	7
DC-F08	78	8	FC-006	25	8	MC-014	41	8	CC-005	27	8
DC-F06	79	9	FC-F04	38	9	MC-009	42	9	CC-F05	28	9
			FC-008	46	10	MC-F06	43	10	CC-020	29	10
			FC-F07	48	11	MC-016	45	11	CC-008	30	11
			FC-003	53	12	MC-005	55	12	CC-F04	31	12
			FC-F06	66	13	MC-019	56	13	CC-013	32	13
			FC-F09	67	14	MC-006	57	14	CC-F09	33	14
			FC-F03	77	15	MC-F04	59	15	CC-006	34	15
			FC-F05	81	16	MC-F02	60	16	CC-F01	35	16
			FC-F08	82	17	MC-F12	62	17	CC-F02	37	17
			FC-F10	84	18	MC-018	63	18	CC-018	39	18
						MC-F08	64	19	CC-003	40	19
						MC-F03	71	20	CC-004	47	20
						MC-F11	73	21	CC-009	49	21
						MC-F13	74	22	CC-F03	50	22
						MC-F14	75	23	CC-016	52	23
						MC-F10	83	24	CC-F12	54	24
						MC-F15	87	25	CC-F14	58	25
						MC-003	89	26	CC-F16	61	26
									CC-F18	65	27
									CC-F10	68	28
									CC-F06	69	29
									CC-011	70	30
									CC-012	72	31
									CC-F17	76	32
									CC-F07	80	33
									CC-F19	85	34
									CC-F20	86	35
									CC-F13	88	36

Restoration Design Approach & Objectives

The watershed and river restoration plan is based on the Natural Channel Design (NCD) methodology (Rosgen, 2007). The NCD approach is divided into ten major sequential phases as shown in **Flowchart 1**. *Phases I–V* have been completed and are documented in the Waldo Canyon Fire *WARSSS* report (Rosgen *et al*., 2013). *Phases VI–X* are discussed in the remainder of this report.

Using the data provided by the *WARSSS* analysis, design solutions were developed for areas with disproportionately high sediment yields throughout the watershed. The designs address the reduction of sediment yields for hillslope, road, and channel processes. This plan documents the restoration objectives, priorities, decision making process, and design scenarios for a wide range of sediment problems. The plan is designed to provide sufficient detail to secure the necessary permits from regulatory agencies to implement a watershed-based restoration and sediment reduction program for the areas affected by the Waldo Canyon Fire.

The development of a restoration plan is based on the following assumptions:

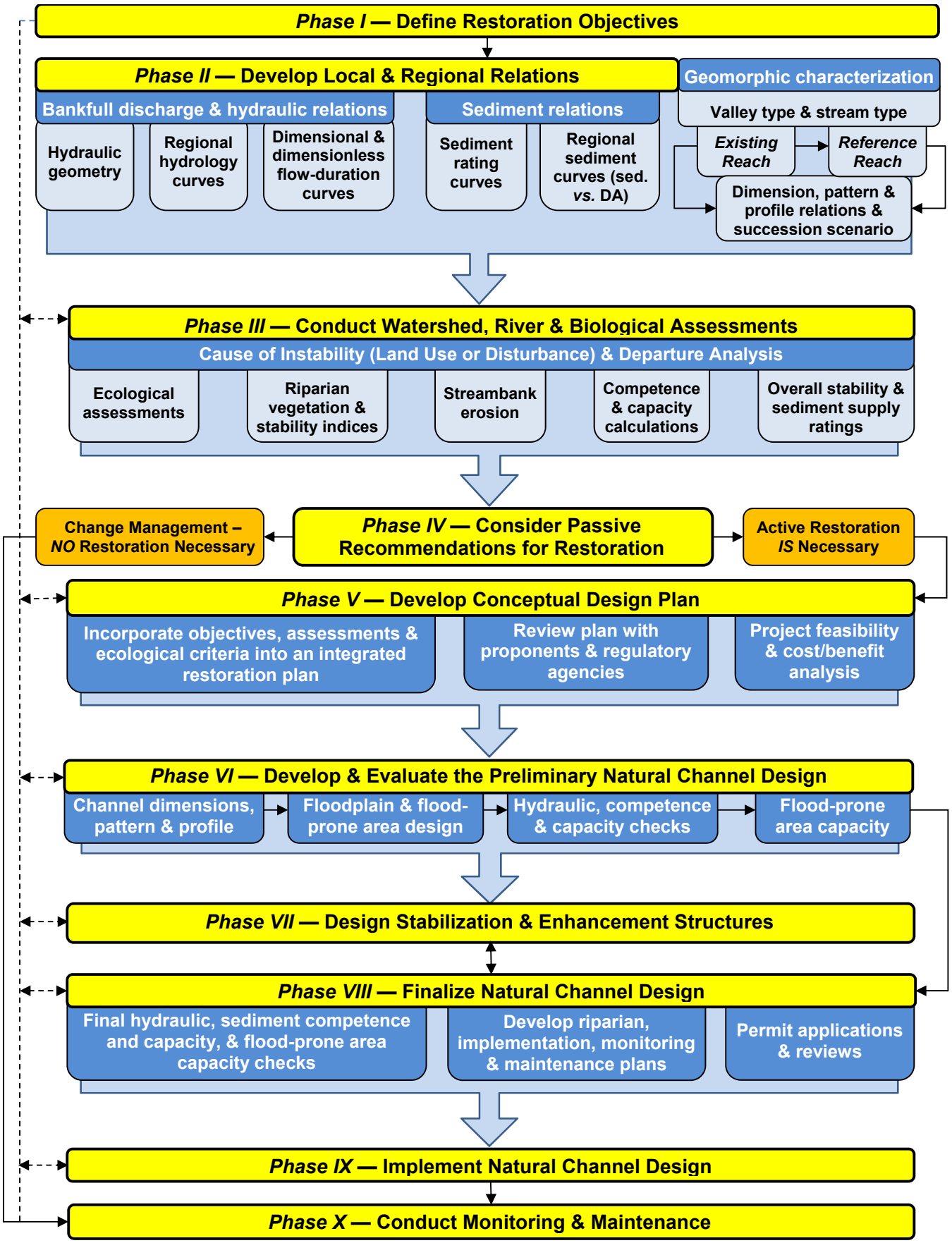
- The design plan will address the sediment sources, land uses, erosional processes, and river impairment based on the output of the cumulative effects analysis using *WARSSS*.
- The *WARSSS* procedure will assist in setting restoration priorities based on quantitative determinations of process-specific sediment contributions and channel impairment.
- Sediment supply can be reduced most effectively at its source.
- Streamflow peak magnitude and frequency related to the fire will have a long recovery period (50–75 years).
- Appropriate stable channel morphology can be determined from stream succession scenarios.
- Reference reach dimensionless relations can be extrapolated to unstable stream reaches for restoration purposes.
- There is uncertainty and risk in developing and implementing restoration scenarios, but the risk and potential benefits outweigh the "do nothing" alternative.

Detailed design criteria are identified to address specific sediment-producing processes by location. Scenarios are established to address existing conditions within the areas affected by the fire. A decision making process is presented to correctly apply the various restoration techniques to mitigate disproportionate sediment supply from hillslopes, roads, trails, and channel processes.

Restoration Goals and Objectives

The primary goal for post-fire restoration is to enhance hydrologic recovery to promote sustainable watershed function by working within the central tendency of natural systems. The following objectives help define the proposed watershed restoration and sediment reduction plan:

- Reduce sediment supply from disproportionate sources identified by erosional process, land use, and specific location within the watershed
- Reduce downstream risk to life, safety, and property
- Reduce flood stage
- Accommodate and attenuate frequent floods
- Provide channel connectivity where feasible
- Quantify sediment reduction by proposed restoration
- Provide an opportunity for riparian and watershed revegetation
- Improve fish habitat diversity and function in perennial streams
- Provide an opportunity for research and restoration monitoring



Flowchart 1. The ten phases in the Natural Channel Design (NCD) approach to river restoration (Rosgen, 2007).

Restoration Recommendations: Hillslope Processes

Quantities and locations of surface erosion in each of the 89 sub-watersheds within the Waldo Canyon Fire perimeter are described in the *WARSSS* assessment (Rosgen *et al.*, 2013). Approximately 35%, or *18,085 tons/yr*, of the total sediment is related to hillslope processes. Surface erosion reduction is most effective when concentrating on the lower third of the hillslope because this zone has the highest probability of sediment delivery. The highest priorities are set adjacent to perennial channels. The following recommendations are designed to reduce this sediment source and are separated by those that can be accomplished with hand crews and those that need heavy equipment (**Table 3**). **Figure 10** shows the estimated distribution of delivered sediment within the Waldo Canyon Fire area. This map can be used with field checks to identify areas within each sub-watershed that have been identified as priorities for treatment. **Figure 10** also shows the distribution of rills within the burn area. Objectives for hillslope sediment mitigation include:

- Increase time of concentration (increase infiltration)
- Reduce surface erosion processes:
  - raindrop impact
  - particle detachment
  - overland flow
- Reduce sediment delivery

Table 3. Design solutions for hillslope processes.

Hillslope Issue	Mitigation Techniques	Hand (H) or Mechanical (M)	Surface Roughness	Surface Protection	Flow Dispersion	Grade Control
Rills	Sills	H			✓	✓
	Plugs	H	✓		✓	✓
	Discontinuity	H			✓	
Exposed Soil	Mulch	H or M	✓	✓	✓	
	Seeding	H or M	✓	✓	✓	
	Tree Plugs	H	✓	✓	✓	
Direct Routing	Toe Catch	H or M			✓	✓
	Bankfull Bench	M			✓	✓

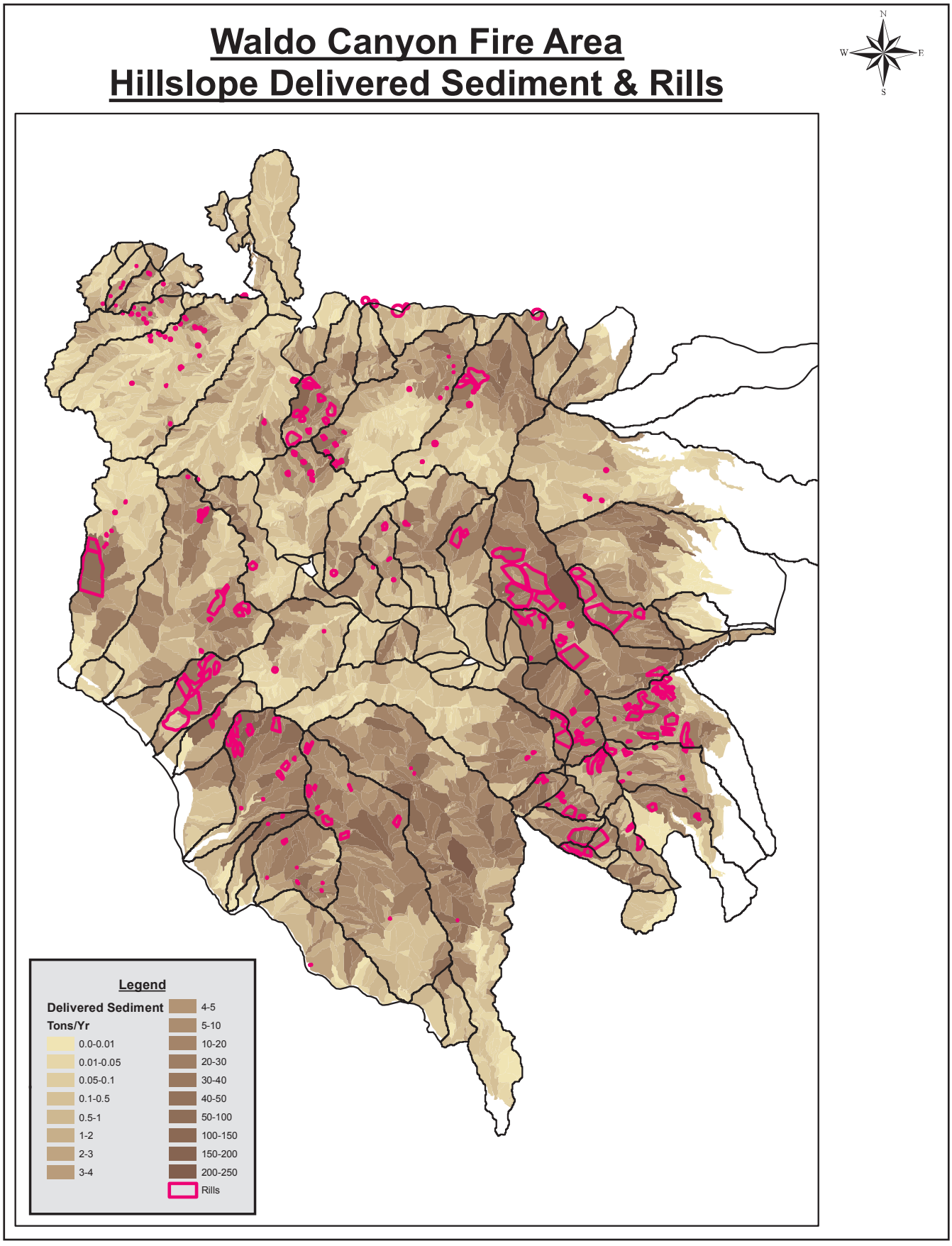


Figure 10. Distribution of delivered sediment from hillslopes within the Waldo Canyon Fire area.

Restoration Treatment for Rills (Hand Work)

Rills effectively increase drainage density and provide a direct conduit for sediment delivery to streams (**Figure 11**). 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. Rills in the upper 2/3 of the hillslope are the next priority as they have the potential to become hydrologically-connected.

Treatments: Use log sills to disrupt the flow path for the entire length of the rill where rill depth is greater than 0.5 ft (**Figure 12**). 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 (**Figure 13**). For example, at a rill 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.

Where rill depth is less than 0.5 ft (**Figure 14**), rake out the channels to make the flow path discontinuous and use plugs and debris to add surface roughness. Seed and mulch the area to enhance long-term effectiveness of the treatment.



Figure 11. Rills increase drainage density and provide a direct conduit for sediment delivery to streams.



Figure 12. Rills greater than 0.5 ft deep are candidates for sills.

Log Sills for Rills

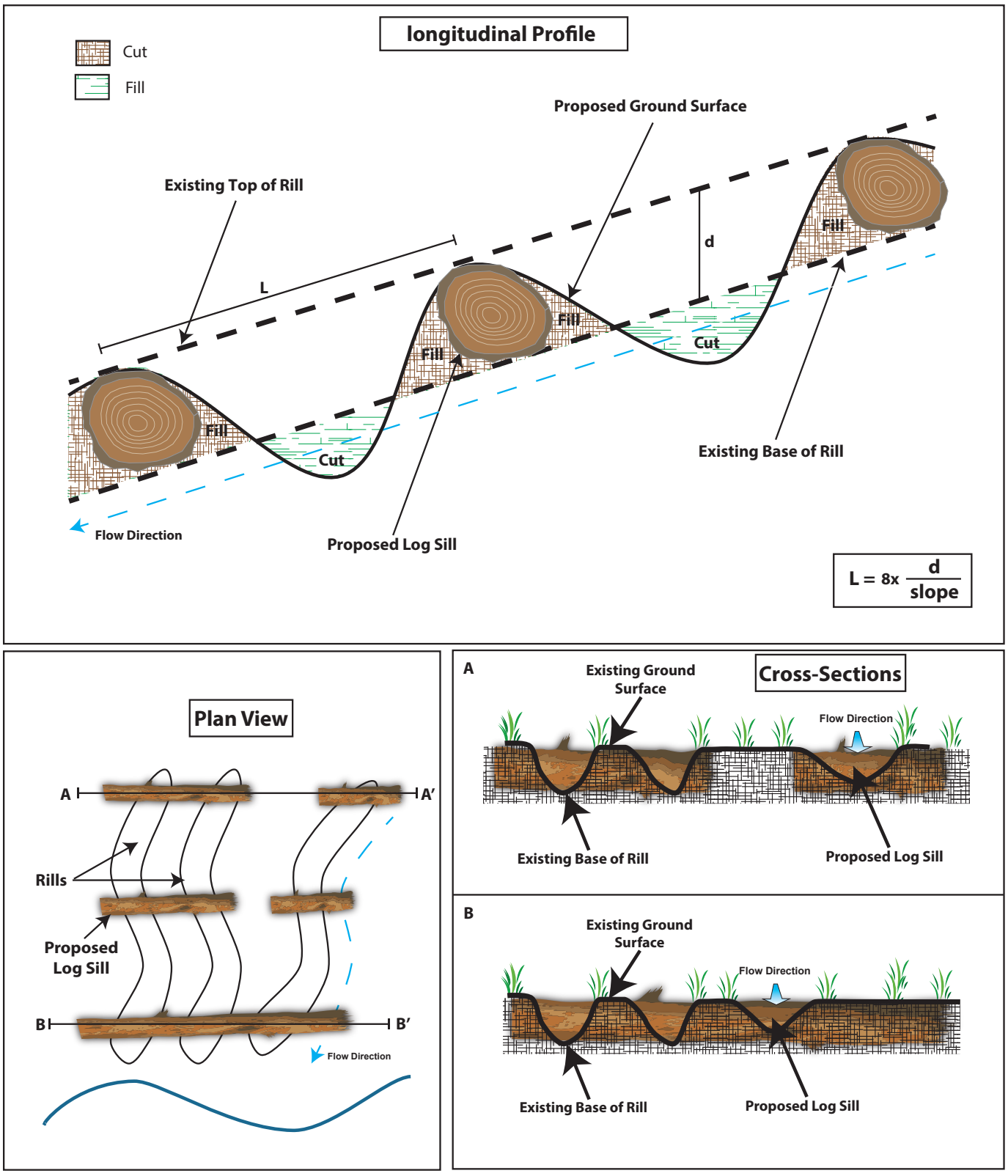


Figure 13. Sill installation technique for rills greater than 0.5 ft deep.



Figure 14. Rills less than 0.5 ft deep need to be made discontinuous.

Restoration Treatment for Exposed Soil (Hand Work or Mechanical)

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 (**Figure 15**), 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 can be used to identify high priority treatment areas (**Figure 10**).

Treatments include re-seeding combined with mulch (hay, straw, or wood), tree plugs, adding debris, small logs, and scattering treetops and branches; this will help reduce rain drop impact and particle detachment leading to excessive surface erosion (**Figure 16**). 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 (e.g., Douglas Creek). 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 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.



Figure 15. Surface protection less than 40%.



Figure 16. Application of wood mulch to a high severity burn slope.

Restoration Treatment for Direct Sediment Routing (Hand Work or Mechanical)

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 (**Figure 17**). 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 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. In both designs, using transplants or seed and mulch will help stabilize the benches and act as a sediment filter and catch. Native bunchgrasses, such as big mountain brome, 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.

Surface Erosion Summary

It is anticipated that at least 75% of the delivered sediment from treated hillslopes can be reduced by increasing ground cover to above 65%, treating rills, constructing benches, and establishing riparian vegetation on stream-adjacent slopes that are contributing to sediment delivery from surface erosion.

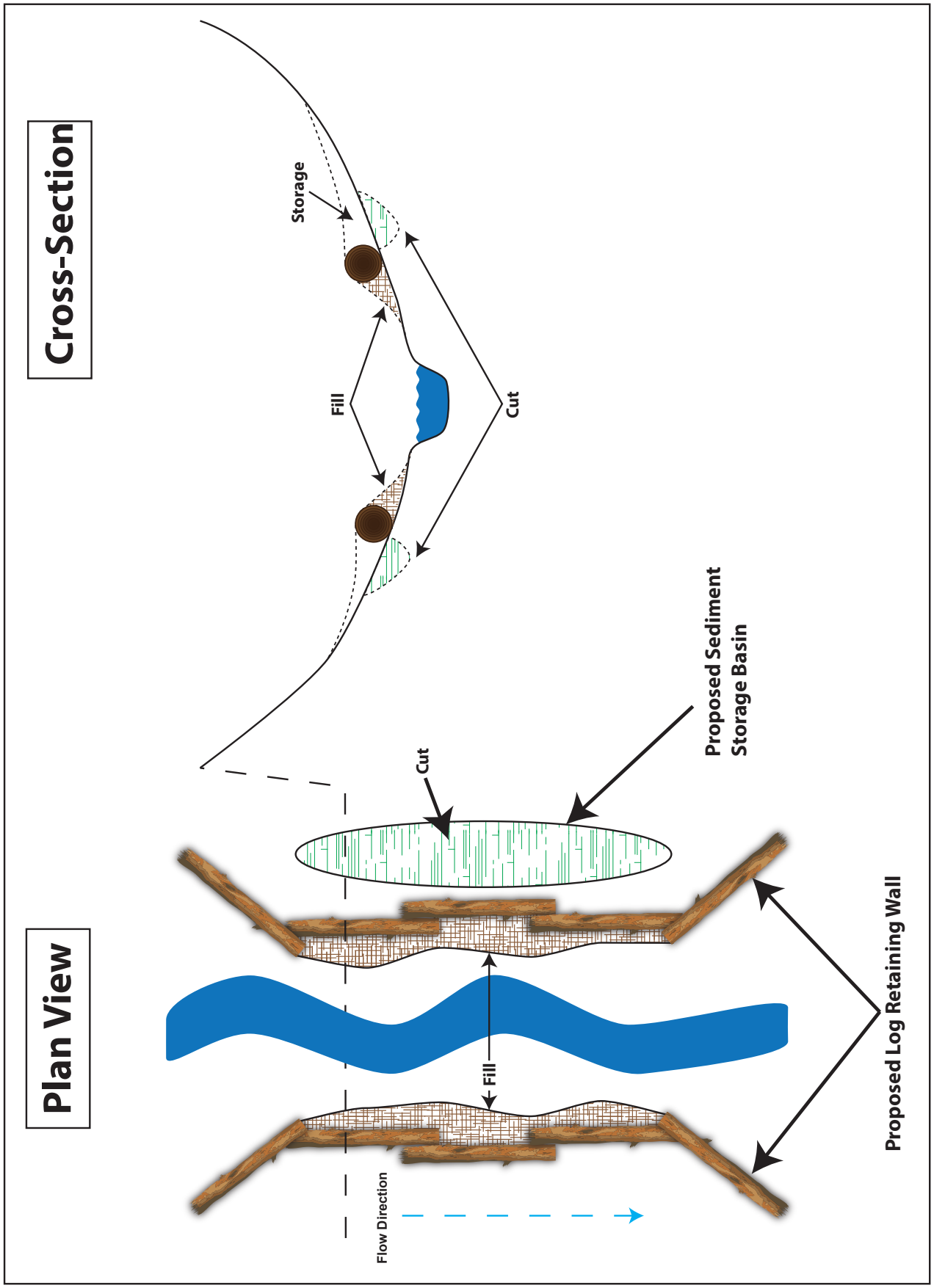


Figure 17. Plan and cross-section views of proposed "toe-catch" to reduce sediment supply to streams.

Restoration Treatments: Roads & Trails

Sub-surface flow interception, sediment routing, flow concentration in ditch lines, cut and fill bank erosion, stream crossings, and road encroachment on channels are all processes by which roads and trails route sediment rapidly and directly into stream channels (**Figure 18**). Within the Waldo Canyon Fire perimeter, road and trail sediment contribution affected sediment yields in only 29 of the 89 sub-watersheds. Although the total area of roads (435 acres) is small relative to the watershed area within the burn (24,248 acres), sediment yield from this source is estimated to be *2,035 tons/yr*, or about 4% of the total annual sediment yield (Rosgen *et al*., 2013). About 85% of the total annual sediment contribution from roads and trails comes from seven sub-watersheds (CC-001 (most), FC-010, MC-010, DC-001, CC-003, MC-013, and CC-020 (least)). Included in these estimates are contributions made from unauthorized trails and closed roads. The restoration objectives for roads include:

- Reduce sediment delivery from roads
- Reduce streamflow increases due to roads
- Reduce maintenance requirements by improved road drainage



Figure 18. A road directly routing sediment to streams.

Relocate Roads that are within Drainageways

Roads need to be relocated that are immediately adjacent to or contained within drainageways as shown in **Figure 19** (e.g., FC-009 and DC-001). Fords and stream crossings should be reduced. This will help reduce the direct input of sediment and the gully development that typically occurs on the roads as shown in **Figure 19**.



Figure 19. Road and stream channel occupying the same space in sub-watershed FC-009.

Road Surface & Ditch-Line Erosion

The ideal treatment is to surface the road, which is likely cost-prohibitive for this class of road (**Figure 20**). Recommended alternative techniques to improve the surface drainage are as follows:

1) Out-slope the road to reduce concentration of water and sediment on the inside ditch line; this avoids the concentration of water from sub-surface interception and disperses the flow instead of concentrating such flows on the road and in the ditch line
2) Place rolling "Kelly dips" on slope gradients greater than three percent
3) Construct sediment detention depressions at drainage outfalls or at drainage turnouts to encourage infiltration, sediment deposition, and energy dissipation



Figure 20. Ditch-line erosion in West Monument Creek.

Drainage Structures

Recommended practices are to increase frequency and quality of drainage structures to reduce concentration of water and sediment (**Figure 21**).



Figure 21. Undersized culvert overwhelmed with sediment.

Fill Erosion

To reduce sediment from eroding fill slopes (**Figure 22**), the following practices are recommended:

1) Relocate the channel away from the road fill slope to reduce the toe erosion from lateral channel migration
2) Place grass seed and native grass hay mulch or straw mulch over the seed on the fill slopes; native grass hay mulch is preferred as it is not as susceptible to wind transport as straw mulch and provides additional seed source
3) Move the localized road prism farther away from the channel without total relocation at various locations where feasible
4) Dissipate energy below culverts and stabilize channels cut through fills with step–pool grade control structures, side-slope reduction, and seeding and mulching
5) Place woody debris on fill slopes, including limbs, tops, branches, and small logs, perpendicular to the slope; seed and mulch the slopes
6) Construct small terraces perpendicular to the slope to reduce rill erosion; seed and mulch the terraces
7) Construct a bankfull bench between the toe of fill slope and the active channel where the channel impinges on fill
8) Install the toe wood structure with sod mats and willow transplants (or soil lifts with cuttings) on the bankfull bench to prevent streams from eroding the fill material



Figure 22. Fill slope erosion cause by concentrated water on road surface.

Headcut Channels Intercepted by Road

In Road adjacent channels, recommended practices are to stabilize advancing headcuts as shown in **Figure 23**. Step-pool and rock and log rollers are stabilization structures used for grade control to dissipate energy and reduce channel source sediment below culvert outfalls. These structures are described within the *Structures for Natural Channel Design* section.



Figure 23. Incised channel caused by "shotgun" culvert.

Increase Maintenance Frequency

Grading the road surface, outsloping the road to disperse runoff, and stabilizing the cut bank sediment source will help reduce the road-related sediment source shown in **Figure 24**.



Figure 24. Rills developing on road surface and high sediment supply from road cut bank (Rampart Range Road).

ORV Roads & Trails

To reduce sediment delivery where ORV roads and trails are in close proximity to stream channels or occupy steep slopes, the proposed recommendation is relocation along ridge routes that would not change the origin or destination points. Relocation should include obliteration of original road or trail to eliminate sediment delivery potential, restore hillslope function, and discourage continued use. Where relocation is not feasible, consider closing and stabilizing the road or install special cross-drains to eliminate the development of rills and gullies and disperse surface runoff.

Unauthorized Trails and Closed Roads

Vehicle use on unauthorized trails and closed roads can accelerate sediment and water delivery to stream channels (**Figure 25**). Road closures should be enforced with enough infrastructure (e.g., with fencing, boulders, or logs) to discourage continued use. Traces of both unauthorized trails and closed roads should be reclaimed. Reclamation of closed roads includes hydrologic closure that involves excavation of fill slopes and relocating to cut slopes, mulching, and reseeding (**Figure 26**). This is accomplished by a dozer or excavator. The results of this type of closure are to: a) reduce sub-surface flow interception; b) outslope road to reduce ditch-line and road surface runoff; c) reduce cut bank, road surface, and fill erosion; d) make it impossible for ORVs to traverse due to side slope "roll-over" risk, thus reducing unauthorized use; e) reduce compacted road surface; and f) provide an opportunity for revegetation of the road prism to put the land back into production. If roads are located in drainageways (**Figure 25**), closure should involve re-establishment of a natural stream channel. Because the road in **Figure 25** is located in a Valley Type II, a B4 stream type is the stable, natural morphology (see *Restoration Concepts for Channel Processes* section).



Figure 25. A "closed" road concentrating water that creates gullies, Devil's Kitchen, MC-008.

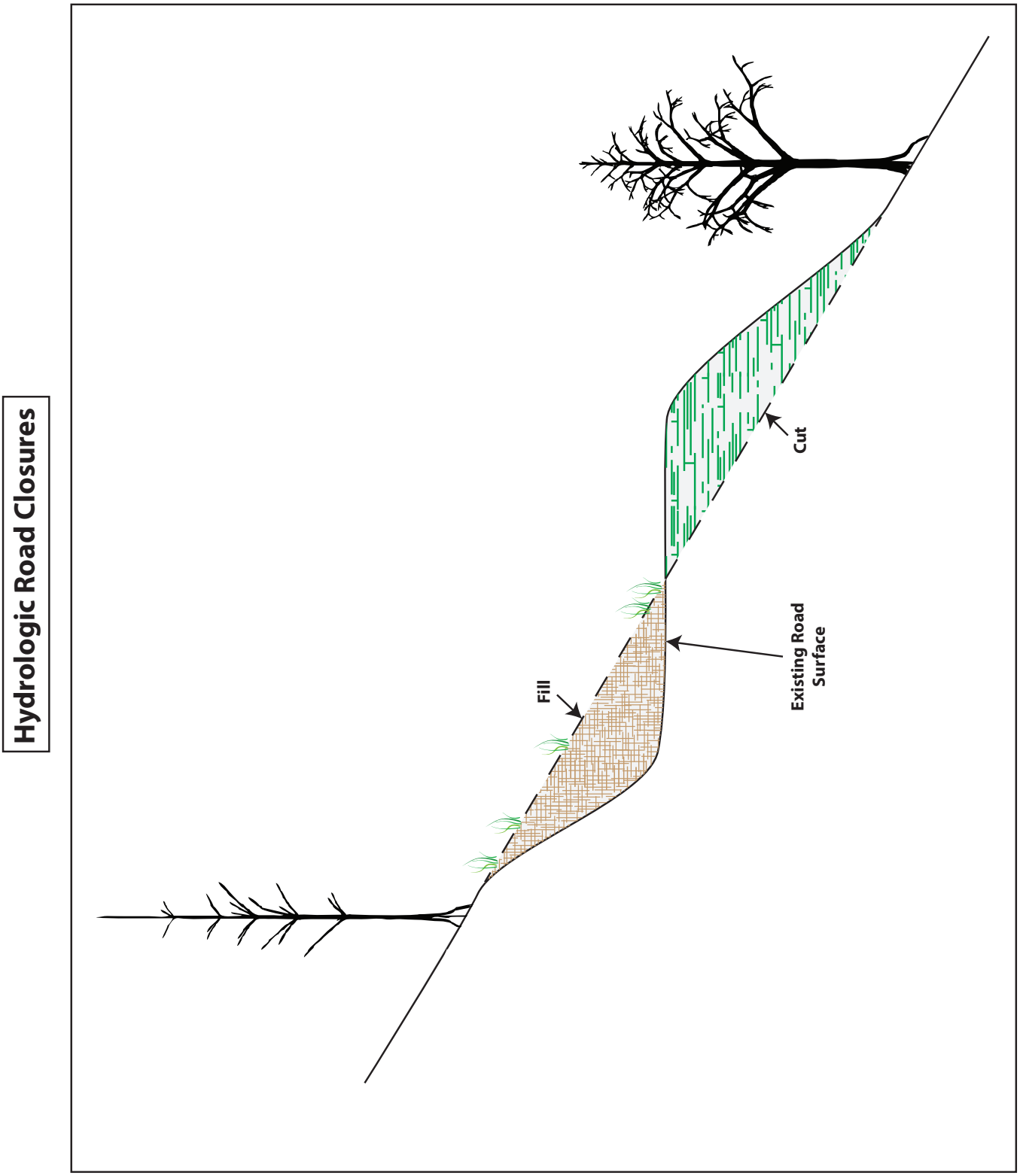


Figure 26. Re-grading schematic of hydrologic road closure treatment

Roads & Trails Summary

Reductions in road and trail sediment delivery to stream channels will depend on site-specific conditions and the practicality of carrying out the aforementioned recommendations. However, it is anticipated that if these mitigation measures are implemented appropriately and to all surfaces, regardless of ownership, the road and trail related sediment contributions from within the areas affected by the fire can be significantly reduced. It will take a cooperative and concerted effort between the various land owners/managers working toward a common goal to solve current and future river impairment issues as a result of roads and trails within the Waldo Canyon Fire.

Restoration Concepts for Channel Processes

Channel stability is defined as the river's ability in the present climate to transport the streamflow and sediment of its watershed over time such that the channel maintains its dimension, pattern, and profile without either aggrading or degrading (Rosgen 1996, 2006/2009). After large wildfires, changes in the sediment and water balance create channel instability that can deliver disproportionate amounts of channel source sediment downstream. The *WARSSS* assessment for the Waldo Canyon Fire (Rosgen *et al*., 2013) determined that two of the four major watersheds within the burn perimeter are aggrading (Douglas and West Monument Creeks) and that two are degrading (Camp and Fountain Creeks). In the following sections, methodologies and techniques to mitigate the processes creating the channel instabilities are discussed.

Stream Type Succession

Stream type succession was used to interpret and predict the potential stable morphological state of the impaired reaches (see Rosgen, 1994, 1996, or Rosgen *et al*., 2013, for stream type and stream succession descriptions). **Figure 27** illustrates the 16 observed scenario progressions that natural rivers experience in response to changes in the water/sediment balance due to disturbance.

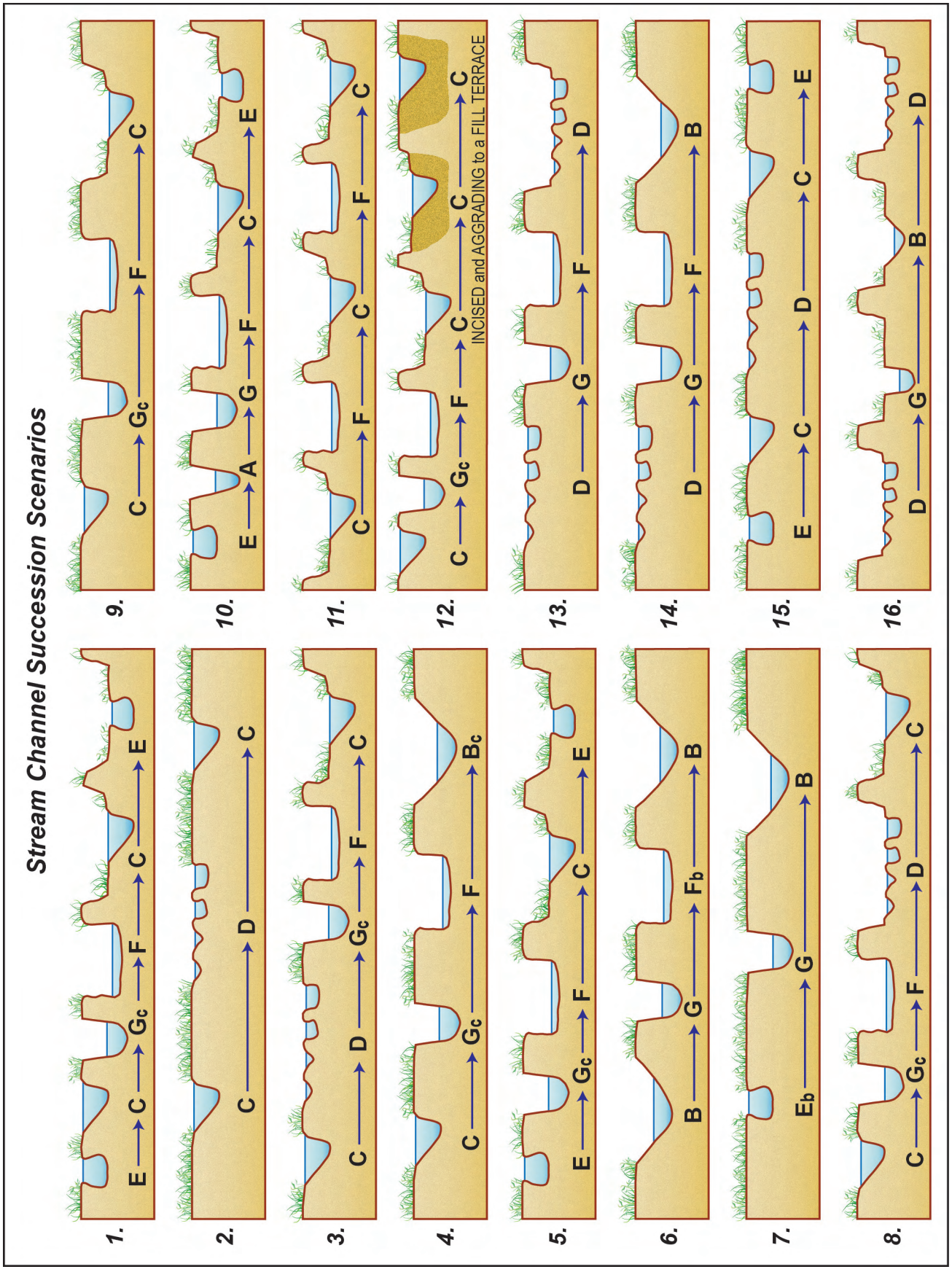


Figure 27. Sixteen observed scenarios for stream succession in natural rivers (Note: not all of these scenarios apply to the Waldo Canyon Fire Watersheds).

Where the upstream sediment supply overwhelms the carrying capacity of the channel, aggradation occurs (**Figure 28**). This is the first step in the natural evolution of the fluvial landscape in the presence of increased sediment supply due to a disturbance. In nature, small ephemeral streams (in Valley Types II and VIIIa,b,c) aggrade and become multiple-thread, D stream types, encouraging sediment deposition and storage. This process also increases infiltration by converting surface flow to subsurface flow, decreases average velocity, and attenuates peak flows by increasing duration on the rising limb of the hydrograph. Stabilizing existing braided channels encourages sediment deposition, prevents headcuts and channel incision, and becomes a priority design scenario for the appropriate valley type.

Alluvial fans function to store sediment from steeper gradient, high sediment supply channels by deposition on the fan surface. Incised tributaries (stream types A, G, and F) on alluvial fans (Valley Type IIIa,b) are presently conveying accelerated upstream sediment supply and are a large source of channel-derived sediment (**Figure 29**). These channels will continue to degrade without intervention. Also, A and G stream types have a higher competence (capable of moving larger particles) than non-incised channels, which leads to headcutting, channel incision, and further degradation. Converting A, F, and G stream types (**Figure 30**) to braided channels on such active alluvial fans as well as other appropriate alluvial fill valleys (**Figure 31**), are also a high priority. The natural evolution or stream succession of G and F stream types to D is shown in succession scenario #13 (**Figure 27**). This evolution typically occurs on alluvial fills (Valley Type VIIIa,b,c) and active alluvial fans (Valley Type IIIa). The central tendency of stream succession and the proper selection of the potential stable form and succession scenario for stream restoration is utilized for the Waldo Canyon Fire and is described in detail in the following sections. An overview of these scenarios is included below and detailed designs for large, active alluvial fans are provided in **Appendix II**.

On narrow alluvial fills, converting F and G stream types to B stream types (succession scenario #6, **Figure 27**) is necessary because there is insufficient room (valley length and width) for braided channels and sediment storage. The B stream types are laterally and vertically stable and will not contribute sediment to the mainstem streams, but will convey what is produced upstream. If upstream reaches deliver more sediment than the B stream type can transport, then those sediment sources need to be mitigated prior to B stream type conversion.

A high likelihood of debris flows/debris avalanche processes exists due to stormflow response and unstable channels in highly erodible grussic granite material. The prediction of such processes is extremely difficult. The USGS estimated thousands of tons of erosional debris from this process for 21 Waldo Canyon Fire sub-watersheds as shown in Table 7 of the Waldo Canyon Fire *WARSSS* report (Verdin *et al*., 2012; Rosgen *et al*., 2013). On-site mitigation for these processes is nearly impossible; thus channel reconnection and functional development of alluvial fans become critical geomorphic components.

Stream channel restoration and stabilization can effectively reduce sediment supply from post-fire, streamflow increases. The restoration work includes protecting streambeds and streambanks from the increased flows and re-establishing floodplain connectivity and the riparian corridor. Fisheries habitat will also be improved in perennial systems with river restoration and stabilization work. The remainder of this report focuses on the proposed restoration of the stream channels using the principles of natural channel design to reduce the accelerated sediment supply by converting unstable stream types to stable types, and reducing streambank erosion.



Figure 28. Aggradation due to disproportionate sediment supply.



Figure 29. Channel cut through alluvial fan (degradation).



Figure 30. F4b stream type post-fire before construction, Northfield Gulch, sub-watershed MC-010.



Figure 31. D4 stream type post-construction, Northfield Gulch, sub-watershed MC-010.

Streambank Erosion

Approximately 61% of the total sediment yield (*31,359 tons/yr*) within the Waldo Canyon Fire perimeter is from streambank erosion (Rosgen *et al*., 2013). The accelerated streambank erosion is primarily due to:

- Destroyed riparian vegetation
- Increased peak stormflow runoff rates
- Highly erodibile soils
- Excess inchannel sediment deposition forcing flow laterally into streambanks as shown in **Figure 32**

The BANCS model (Rosgen, 2001, 2006/2009) was utilized to predict streambank erosion rates, which involves two bank erosion estimation tools: 1) The Bank Erosion Hazard Index (BEHI), which includes the erodibility factors that involve study bank height, bankfull height, rooting depth and density, bank angle, surface protection, bank material, and stratification of bank material; and 2) Near-Bank Stress (NBS), or the distribution of energy against the streambank.

To effectively reduce streambank erosion rates, factors producing *High* and *Extreme* BEHI and NBS values must be offset. Not all of the sediment from streambank erosion is delivered to the mouth of the mainstem streams as substantial volumes are stored in the channel and made available for subsequent re-entrainment or subjected to channel incision and enlargement (**Figure 32**). Significantly reducing this sediment source is a high priority of the restoration design.



Figure 32. Significant streambank erosion, Sand Gulch.

Channel Incision & Headcuts

Many reaches of A and G stream types are associated with active headcuts (degradation) due to the increased peak and stormflow runoff after the fire (**Figure 33**). Restoration recommendations are provided in the *Typical Design Scenarios* section to reduce the post-fire accelerated headward advancement, channel enlargement, and increased streambank and streambed erosion from incised channels.



Figure 33. Channel incision caused by a progressing headcut, West Monument Creek.

Stream Restoration Objectives

The following objectives help define the proposed watershed and river system restoration and sediment reduction plan:

- Increase natural sediment storage
- Reduce streambank erosion
- Reduce channel incision
- Attenuate flood peaks by dispersing rather than concentrating flow energy
- Re-establish riparian function
- Re-establish channel connectivity

Restoration Concepts

Streambank Erosion: First it is essential to construct the stable dimension, pattern, and profile of the potential, stable stream type. This often involves reducing bank-height ratio, establishing riparian vegetation, and adding flow resistance to streambanks. Streambank stabilization structures are used in many instances to reduce streambank erosion rates and to buy time for riparian vegetation for long-term stability and function. The details of the structures used to reduce streambank erosion are documented in the *Structures in Natural Channel Design* section. Converting to stable stream types using stream succession principles is commonly implemented and is described in more detail under the various stream restoration design scenarios.

Incised/Entrenched Stream Channels: If the incised channels are actively degrading, grade control structures are designed for this process as documented in the *Structures in Natural Channel Design* section (**Figure 34**). Other treatments to reduce channel incision processes involve converting actively downcutting A and G stream types to braided, D stream types. This treatment involves raising the bed elevation and reconnecting to alluvial fan or alluvial fill slope surfaces. Such stream type conversions generally do not require grade control structures, but installing sills in newly deposited material will prevent scour and help maintain the depositional surface (see appropriate stream type conversion scenarios in the *Typical Design Scenarios* section).



Figure 34. Log rollers used for grade control and energy distribution in the post-fire restoration of Trail Creek, 2012.

Natural Channel Design (NCD) Methodology for Channel Processes

Proposed restoration designs must emulate natural stable channels so that such efforts work with the central tendency of stable channels. Dimensionless *reference reach* parameters are normalized by bankfull to scale to impaired or representative reaches of any size within similar valley types. The reference reach parameters are used to design the stable dimensions, pattern, and profile of the impaired reach. The established reference reach relations for use in the restoration design are documented in Appendix C of the Waldo Canyon Fire *WARSSS* report (Rosgen *et al*., 2013). Reference reach sites from the *WARSSS* assessment from Trail Creek (Rosgen, 2011a) were used to supplement this analysis. Once a given stream type is selected for the stable form within a given valley type, the dimensionless relations of the selected reference reach are converted to dimensional data for the proposed restoration reach using the appropriate normalization parameters.

The impaired reaches by valley and stream type are documented in the *representative reach* summary in Appendix C of the Waldo Canyon *WARSSS* report (Rosgen *et al*., 2013). This data is used to represent a given stability condition for a particular stream type and valley type location and provides the existing condition *vs*. the proposed condition for the design dimension, pattern, and profile. The representative reach stability analyses can be extrapolated to other locations with the same stream type and stability condition as mapped in Appendix D of the Waldo Canyon *WARSSS* analysis by sub-watershed (Rosgen *et al*., 2013). For example, streambank erosion rates of the *G4 Poor Representative Reach* can be extrapolated to other G4 *Poor* stability reaches without a detailed analysis to obtain an estimate of streambank erosion in tons/yr.

The methods and computational sequence for channel restoration using the Natural Channel Design (NCD) approach are included in detail in **Appendix I**; the computational sequence is outlined in **Flowchart 2**. A master table is used to organize the existing, reference, and proposed design reach data as shown in **Appendix I**. The data for the existing and reference reaches are compiled first and documented in the master table. Then, using the computational sequence outlined in **Flowchart 2** and described in detail in **Appendix I**, the dimension, pattern, and profile of the proposed design reach can be determined using the dimensionless relations of the reference reach and the appropriate normalization parameters. Streambank erosion, materials, sediment yield, and competence calculations are also documented in the master table. A design example using the NCD procedure is presented in the *Master Plan for Channel Processes* section for Northfield Gulch.

The design bankfull discharge and the corresponding cross-sectional area are obtained first when developing the proposed channel dimensions using validated regional curves (Rosgen, 2007). The regional curves for bankfull cross-sectional area *vs*. drainage area (**Figure 35**) and bankfull discharge *vs*. drainage area (**Figure 36**) developed for the Waldo Canyon Fire have excellent relationships (R^2 = 0.87 and 0.86, respectively), allowing reasonable estimates of cross-sectional area and bankfull discharge for the proposed channels. However, cross-sectional area cannot always be accurately determined from regional curves, particularly for 1) streams that are outside the range of the empirically-derived relation, or 2) for stream types that have extremely high values of width/depth ratio, such as braided D4 channels. In these instances, reasonable estimates of velocity are required to calculate a corresponding bankfull cross-sectional area based on flow continuity by dividing the bankfull discharge by velocity. For example, very small streams with *0.2 ft* to *0.3 ft* of bankfull mean depth on slopes between *4.0%* and *10.0%* generally have bankfull velocities of *1.0–1.5 ft/sec*. To calculate cross-sectional area for these very small streams, the bankfull discharge (derived from the regional curve) is divided by the mean bankfull velocity. Roughness coefficients by stream type, dominant bed material size, vegetation, logs, and step-pool morphology can be used to check the velocity estimates. For gravel-bed, braided D4 stream types, the very high width/depth ratios are associated with multi-thread small channels and associated

low mean bankfull velocity estimates. Most of these small channels have high boundary roughness due to their shallow depths of their multiple channels. Velocities for streamflows less than *10.0 cfs* on D4 stream types will average between *0.5* and *1.5 ft/sec*, and thus will require high cross-sectional areas for small discharges. Many of these D4 stream types are designed to have width/depth ratios greater than 200 that correspond with very wide and shallow channel dimensions. When regional curves are used to determine the cross-sectional area, a check on velocity is necessary to ensure reasonableness by using the continuity equation ($\bar{u} = Q/A$). Also, after the basic dimension, pattern, and profile relations are designed, a final check on velocity and the associated roughness relations is required using various methods outlined in the velocity form in **Appendix I**. Changes in the cross-sectional area or other morphological values may require adjustment following the velocity check, in addition to competence and capacity checks.

Once cross-sectional area is determined from a known bankfull discharge (from regional curve) and a reasonable bankfull velocity estimate, the bankfull dimensions are calculated. The bankfull width of the proposed reach is calculated as:

$$W_{bkf} = (A_{bkf} * W/d_{ref})^{1/2}$$

where: W_{bkf} = bankfull width

A_{bkf} = bankfull cross-sectional area

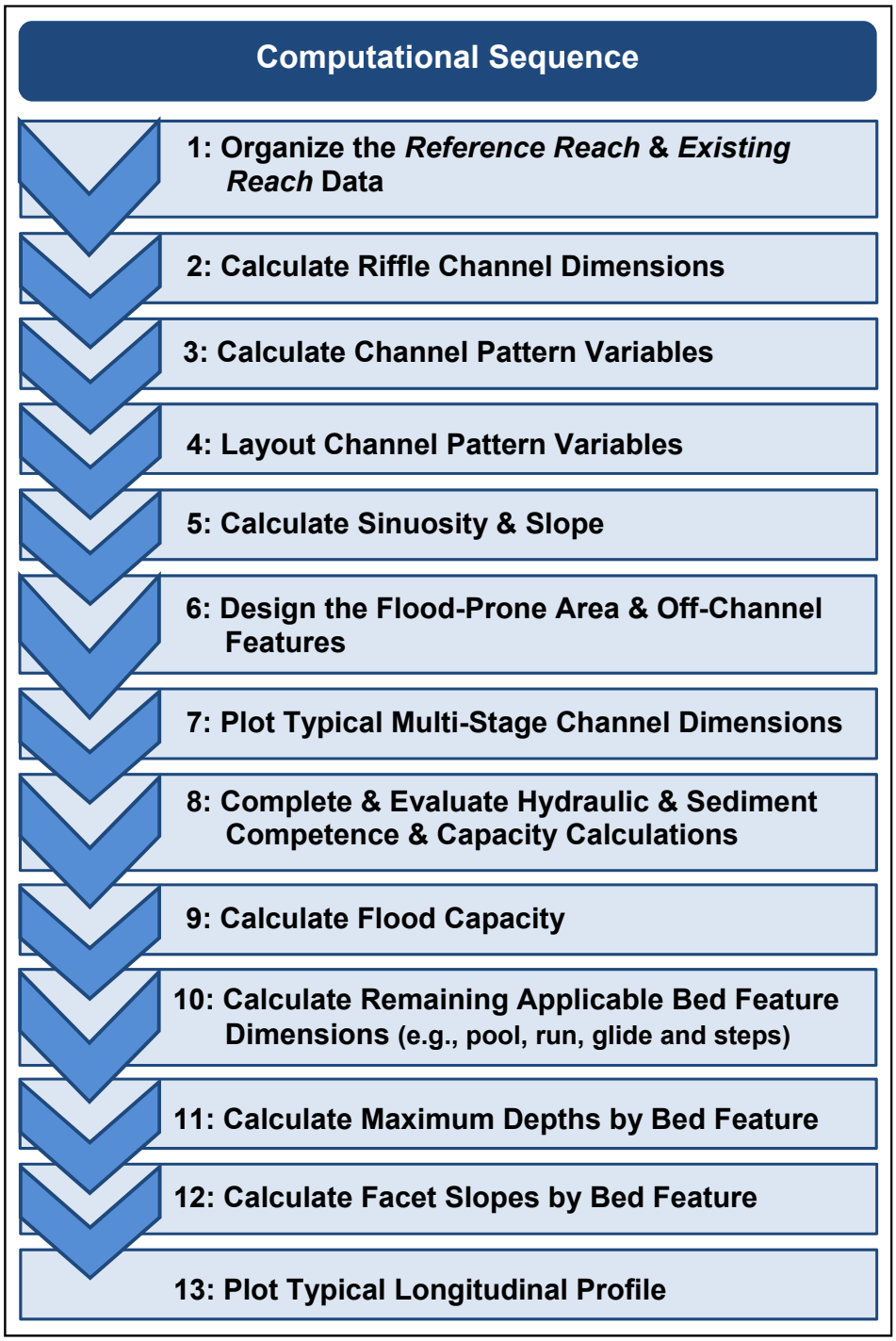
W/d_{ref} = bankfull width/depth ratio from the reference reach

Bankfull mean depth can then be computed by: $d_{bkf} = A_{bkf} / W_{bkf}$. Bankfull maximum depth and inner berm channel dimensions are then calculated using dimensionless data from the reference reach and scaled using the bankfull width of the proposed design reach. The *mean*, *minimum*, and *maximum* values for all dimensions must be computed from the ranges specified in the reference reach data. Dimensions are required for all bed features (e.g., riffles, runs, pools, glides, and steps) and also for the floodplain, low terrace, and/or flood-prone areas. The typical longitudinal profile for NCD involves a range of depths, slopes, and bed feature shapes designed specifically to quantitatively describe bed features.

A range of pattern data is also obtained from the dimensionless ratios from a reference reach. Sinuosity is generated from a channel layout incorporating the range of multiple pattern variables that represent natural planform variability, including linear wavelength, stream meander length, belt width, arc length, radius of curvature, riffle length, and pool length ratios. The resulting sinuosity is then determined by dividing the proposed design stream length by the valley length. The meander pattern and bed feature heterogeneity determined using NCD are important in energy dissipation and promoting hyporheic exchange function.

The initial channel slope of the proposed design reach is determined by dividing the valley slope by the design sinuosity. This analog method requires compatibility amongst valley and stream types of the reference reach dimensionless relations and the proposed bankfull width (used as a normalization parameter for pattern). This approach also accounts for any boundary constraints (e.g., terrain and vegetation) within the valley. The final design slope and dimensions are determined following verification of velocity, sediment transport capacity (load), and competence (maximum particle size moved).

This master plan for watershed restoration develops the criteria and corresponding computations and design parameters required for implementation for a range of representative conditions that exist within the Waldo Canyon Fire perimeter. Because the proposed master plan involves a watershed restoration with approximately 237 miles of stream channels, the natural channel design procedure is used to develop detailed examples and specific design criteria for typical scenarios as presented in the following section.



Flowchart 2. Computational sequence to determine and evaluate the dimension, pattern, and profile variables for the proposed design reach.

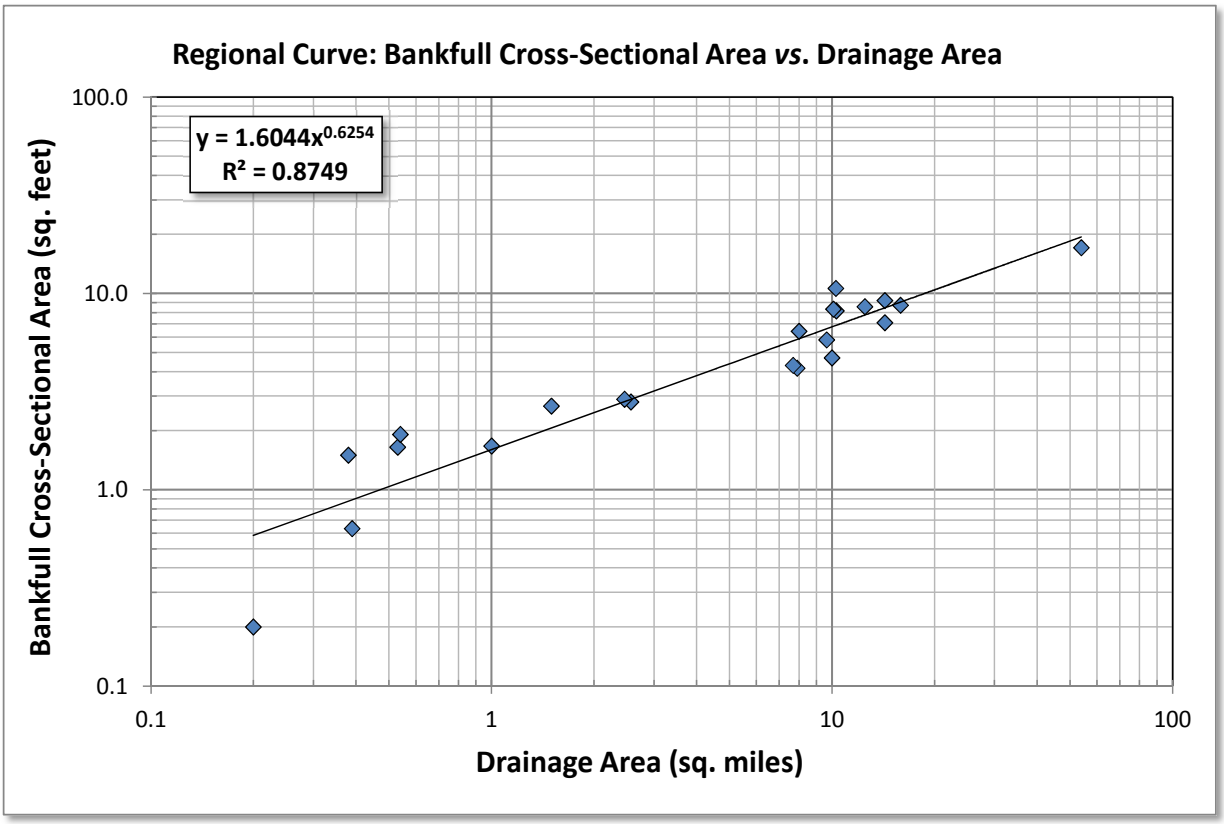


Figure 35. Regional curve of bankfull cross-sectional area *vs*. drainage area for the Waldo Canyon Fire watersheds.

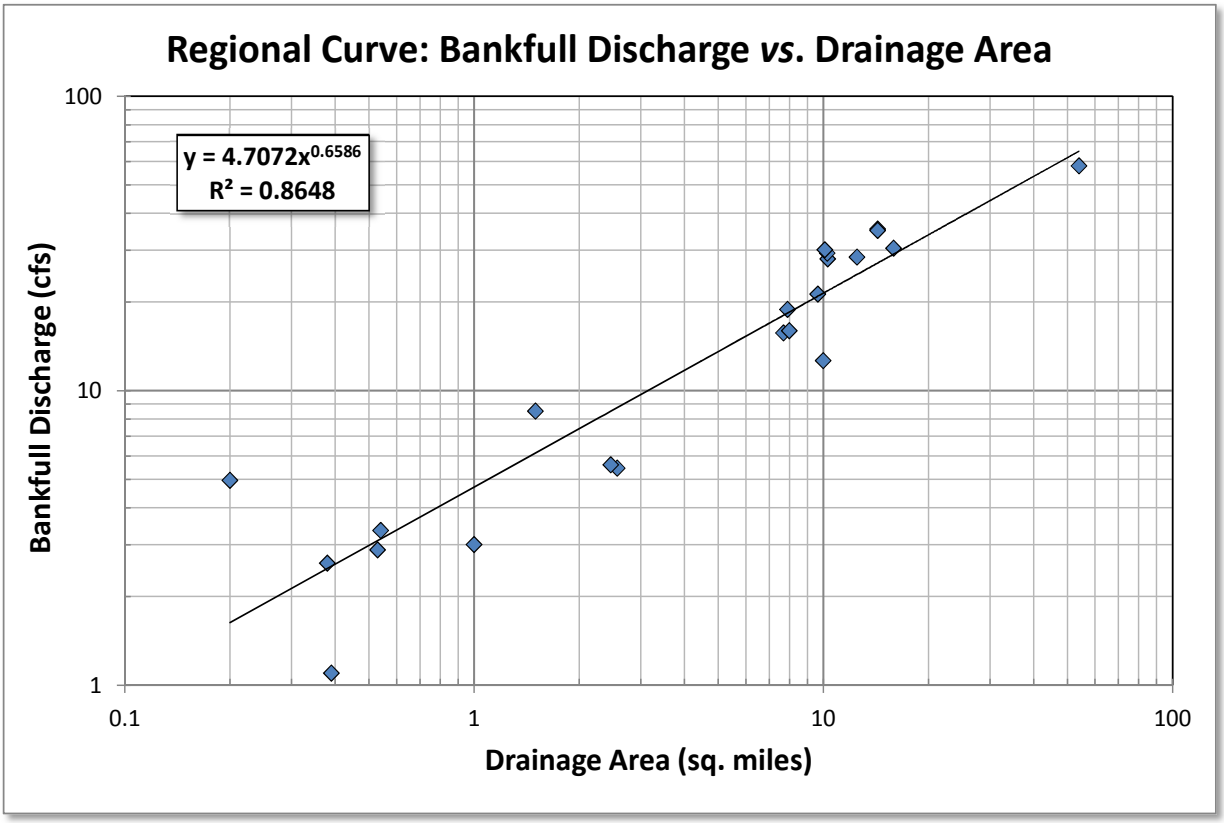


Figure 36. Regional curve of bankfull discharge *vs*. drainage area for the Waldo Canyon Fire watersheds.

Design Decision Process

Varying conditions and unique circumstances within the Waldo Canyon Fire perimeter will make the mitigation work challenging. Intimate knowledge of geomorphic features and processes is required when identifying the appropriate mitigation treatment. The rugged nature of the landscape affected by the Waldo Canyon Fire will limit the access for the use of heavy equipment; thus treatments have been divided into two categories: Mechanical and Hand Crew. A decision tree was developed to assist in selecting the appropriate treatment for a given stream type based on channel condition, location, sediment supply, valley type, and channel process. The dichotomous key below describes the decision tree flowchart (**Flowchart 3**). It is understood that sediment detention basins will ***NOT*** be constructed in perennial streams. Mitigation scenarios will be described in the next section of the document.

1) Condition: A-If *Good* DO NOTHING; B-If *Fair* or *Poor* go to **2**.

2) Location: A-Heavy equipment access go to **3**; B-No heavy equipment access go to **4**.

3) Upstream Sediment Supply: A-*High* go to **3-1**; B-*Low* go to **3-2**.

3-1) Existing or abandoned floodplain/fan surface present: A-*Yes* go to **3-1a**; B-*No* go to **3-1b**.

3-1a) Follow scenarios for A, D, F, and G stream types (Design Scenario #5).

3-1b) Can upstream sediment supply be reduced:

a) *Yes*: Identify and mitigate sediment sources upstream before treating reach then follow scenarios for A, F, and G stream types (Design Scenarios #2, #3, #6, #7, and #8)

b) *No*: DO NOTHING.

3-2) Condition: A-If *Fair* go to **3-2a**; B-If *Poor* go to **3-2b**.

3-2a) For stream types A, B, C, and E, DO NOTHING; If D stream type, follow Scenario #1

3-2b) If stream type is: A (Scenarios #7 or #8); C (Scenario #4); D (Scenario #1); F (Scenario #2); Fb (Scenario #6); G (Scenario #3); shape width/depth and entrenchment ratios for stable stream type.

4) Upstream Sediment Supply: A-*High* go to **4-1**; B-*Low* go to **4-2**.

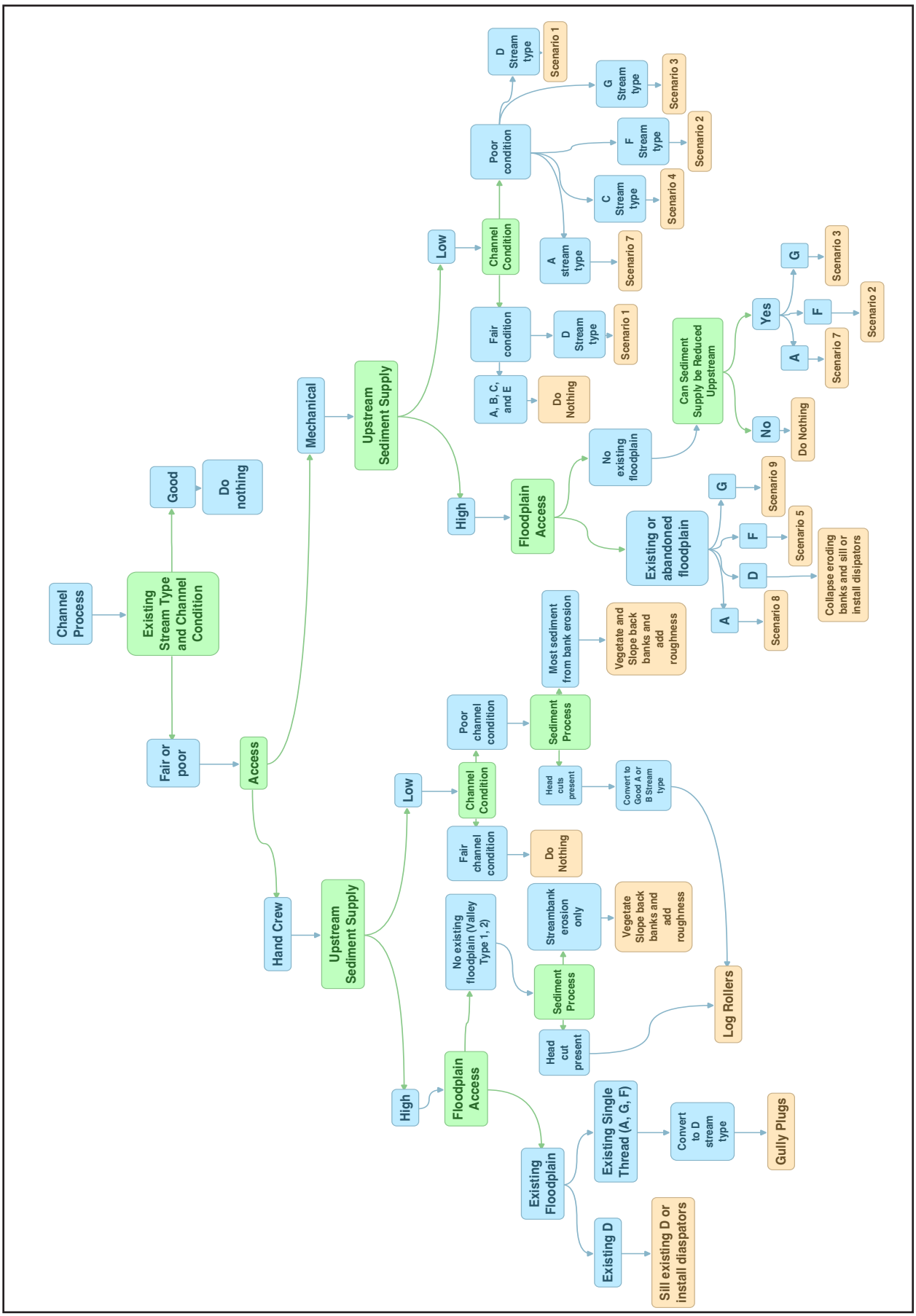
4-1) Existing or abandoned floodplain/fan surface present: A-*Yes* go to **4-1a**; B-*No* go to **4-1b**.

4-1a) For D stream types, install log sill or dissipator; for stream types A, F, and G, convert to D stream type using gulley plugs

4-1b) For headcuts, install log rollers; for streambank erosion, revegetate, slope banks back, seed, and add roughness; shape width/depth and entrenchment ratios for stable stream type

4-2) Condition: If *Fair*, DO NOTHING; if *Poor*, go to **4-3**

4-3) Process: For headcuts, convert to *Good* A or B stream types (log rollers); for streambank erosion, revegetate, slope banks back, seed, and add roughness; shape width/depth and entrenchment ratios for stable stream type



Flowchart 3. Template for identifying appropriate design scenario for a given stream type based on channel condition, location, sediment supply, valley type, and channel process.

Typical Design Scenarios & Restoration Details for Channel Processes

The *representative reaches* were established, measured, quantified, and evaluated in great detail to develop typical design scenarios that can be extrapolated to other locations in the Waldo Canyon Fire affected watersheds where this level of detail was not obtained (for time and budget reasons) but is assumed to be similar. *Reference reaches* were established to provide the stable design criteria to develop the proposed design for the representative reaches. *Reference reaches* from the Trail Creek *WARSSS* assessment (Rosgen, 2011a) were used to supplement the Reference Reach datasets surveyed in the Waldo Canyon Fire assessment. Eight design scenarios (**Table 4**) were developed to represent the range of stream types and stability conditions that require restoration within the Waldo Canyon Fire watersheds. The appropriate scenario can then be extrapolated to other reaches using the decision tree criteria in **Flowchart 3**.

The following sections include the detailed restoration designs for the stream type conversion scenarios (e.g., G4 to D4) and stability condition conversion scenarios (e.g., "A4 Poor to A4 Good") as shown in **Table 4**. Each typical design scenario includes detailed descriptions of the following:

- General Description & Morphological Data
- Bankfull Discharge, Cross-Sectional Area & Mean Velocity (**Appendix II**)
- Plan View Alignment (**Appendix II**)
- Cross-Section Dimensions (**Appendix II**)
- Longitudinal profile (**Appendix II**)
- Structures
- Riparian Vegetation (**Appendix II**)
- Cut & Fill Computations (**Appendix II**)
- Streambank Erosion (**Appendix II**)
- Flow-Related Sediment (**Appendix II**)
- Sediment Competence (**Appendix II**)

Table 4. The eight typical channel design scenarios developed for the Waldo Canyon Fire watersheds.

Typical Design Scenarios				
	Existing, Impaired Stream Type	**Existing Condition**	**Proposed, Stable Stream Type**	**Valley Type**
1.	D4	Poor	C4	VIIIb,c
2.	F4	Poor	B4c	II, IIIb, VIIIa,b
3.	G4	Poor	B4	II, IIIb, VIIIa,b
4.	C4	Poor	C4	VIIIa,b,c
5.	A4, F4, and G4	Poor	D4	II, IIIa, VIIIa,b,c
6.	F4b	Poor	B4	II, IIIb, VIIIa,b
7.	A4 or A4a+	Poor	A4 or A4a+	I, II
8.	A4 or Aa+	Poor	B4a	I, II, IIIb, VIIIa,b

Flow-Related Sediment

The flow-related sediment was assessed for each design scenario using the FLOWSED and POWERSED models, in addition to the BANCS model that assesses streambank erosion (Rosgen, 2001, 2006/2009). Similar to how streambank erosion is estimated, it is also necessary to proportionately scale the unit sediment yield from the FLOWSED runs by the stream length potentially treated. In relation to the *237 miles* (*1,251,360 ft*) of potential sediment contributions in the areas affected by Waldo Canyon Fire, the total annual sediment yield can be proportionately adjusted by local unit sediment transport rates by comparing the stability ("Good" *vs.* "Poor") and the POWERSED runs that indicate aggradation, degradation, or bed stability. The FLOWSED model was used to predict total annual sediment yields for pre- ("Good") and post- ("Poor") fire conditions in the four major watersheds; the sediment yields are reported in Tables 13 and 14 in the Waldo Canyon Fire *WARSSS* report (Rosgen *et al*., 2013). To obtain the unit erosion rates for each condition, the resultant sediment yield values were divided by the total sediment-contributing channel length of similar condition. The total annual sediment yield rate associated with a "Good" condition ranges from *0.0002-0.0003 tons/ft/yr* compared to a rate of *0.023-0.064 tons/ft/yr* associated with a "Poor" condition, two orders of magnitude greater than the "Good" condition (**Table 5**).

Table 5. Total annual sediment yield rate for the four watersheds in the Waldo Canyon Fire perimeter.

Watershed	Stream Length	Total Annual Sediment Yield Rate	
		Pre-Fire	Post-Fire
	(ft)	(tons/ft/yr)	(tons/ft/yr)
Camp Creek	342,641	0.00021	0.049
Douglas Creek	188,887	0.00025	0.041
Fountain Creek	389,566	0.00028	0.064
West Monument Creek	332,275	0.00031	0.023

Streambank erosion rates must also be considered as part of the channel source sediment. Not all of the streambank erosion is transferred downstream or "delivered" as much of the sediment is stored temporarily in the active channel. Bank erosion rates range from *0.004 tons/ft/yr* for stable stream types in "Good" condition to *0.658 tons/ft/yr* for unstable reaches, representing three orders of magnitude of accelerated erosion rates.

For the Waldo Canyon Fire, a recommended range of stream type conversions for stream channel restoration are recommended (**Table 4**). These stream type conversions are stratified by a range of valley types that can accommodate the potential stable form. Due to the very high sediment supply from these watersheds in this geology and from the fire effects, Valley Type II (colluvial valleys) have accumulated significant deposition of sand and small gravel on the valley floor, creating a flat-bottomed bed for ephemeral channels F4/5 and D4/5 stream types. These conditions in Valley Type II are hard to distinguish from Valley Type VIIIa,b, as they contain similar stream types. The stable, functioning stream type for these valleys in the presence of high sediment supply is the D4/5 stream type as depicted in succession scenario #13 (**Figure 27**) and identified in **Table 4**. In order to prescribe the recommended stable stream types to be restored and to scale the reaches for their respective drainage areas, the various design scenarios are presented in the next section. To facilitate the extrapolation of these various scenarios, existing stream types and valley types are mapped for each sub-watershed

for the Waldo Canyon Fire. The recommended conversion of stream types as shown in **Table 4** and described in detail in the next section form the basis for the potential reduction of sediment and flood stage attenuation as part of the restoration objectives. Such changes will help the stream channels accommodate post-fire increased peak flows without the presently observed high sediment supply and downstream delivery.

Design Scenario 1:

D4 to C4 Stream Type Conversion (VT VIIIb,c)

This typical design scenario is a stream type and stability conversion of a D4 *Poor* condition to a C4 *Good* stream type in alluvial fill valleys (Valley Type VIIIb,c) (**Figure 37**). Braided, D4 reaches are the result of the magnitude of the sediment supply from the watershed exceeding the sediment transport capacity, resulting in stream aggradation and high streambank erosion rates allowing channel enlargement. The D4 channel continues to aggrade resulting in a migration barrier because of decreased depths. To prevent accelerated sediment deposition and aggradation, a high width/depth ratio, braided D4 reach must be converted to a stable C4, low width/depth ratio, single-thread stream type (**Figure 38**). To restore this reach to a single-thread, stable channel, it is necessary to re-establish a local base level, redesign the stream crossing to prevent aggradation, and re-establish a riparian corridor along the streambanks of the proposed C4 stream type. The shear stress and increased velocity increase stream power that can efficiently transport the available sediment. The stream type conversion and road crossing design should allow for unobstructed fish passage for all ranges of discharge.

The specific objectives and direction of this restoration scenario to stabilize the reach are as follows:

- Decrease flood stage
- Re-establish a riparian corridor
- Reduce the aggradation rate of sediment
- Reduce the existing, accelerated streambank erosion
- Restore the biological and physical function of this reach
- Provide fish access
- Improve instream habitat with increased cover and low flow depth

The dimensionless relations of the *C4 Reference Reach* are used to generate the proposed C4 stable design criteria, including the dimension, pattern, and profile, by scaling the relations to the drainage area and bankfull discharge of the proposed reach. A detailed design example of a D4 to C4 conversion on Trail Ceek is included in **Appendix II**.

In most places within the upper watersheds affected by the Waldo Canyon Fire, the priority is to convert single-thread channels to multiple-thread channels to induce deposition and attenuate flood peaks. However, in perennial streams, single-thread streams are typically the stable form. After reducing upstream sediment supply, single-thread, C channels should be built where the flood stage must be lowered to protect homes or infrastructure. These streams may also have a fishery where habitat considerations can be met with the C stream types. This scenario is most likely to occur lower

in the watersheds of mainstem Fountain, Camp, and West Monument Creeks. A flood-stage reduction from the D4 to C4 stream type conversion is also anticipated primarily due to increasing velocities by lowering the channel width/depth ratio, reducing sediment supply from streambank erosion, and increasing sediment transport competence and capacity of the C4 stream type.

Structures

Several structures are designed in C stream types. Grade control structures such as cross-vanes are installed to ensure that the stream cannot degrade. Structures such as J-hooks and converging rock clusters are utilized to redistribute velocities and create roughness. Cross-vanes and J-hooks route sediment efficiently by increasing velocities in the center of the channel while decreasing velocities in the near-bank region, thereby decreasing streambank erosion. Toe wood is used to reduce streambank erosion in lateral scour pools. All of these structures add streambank and streambed stability and provide fish habitat while allowing time for riparian vegetation re-establishment. Structures should be accompanied with seeding and transplanting vegetation on banks and floodplains. Structure descriptions are provided in the *Structures in Natural Channel Design* section.

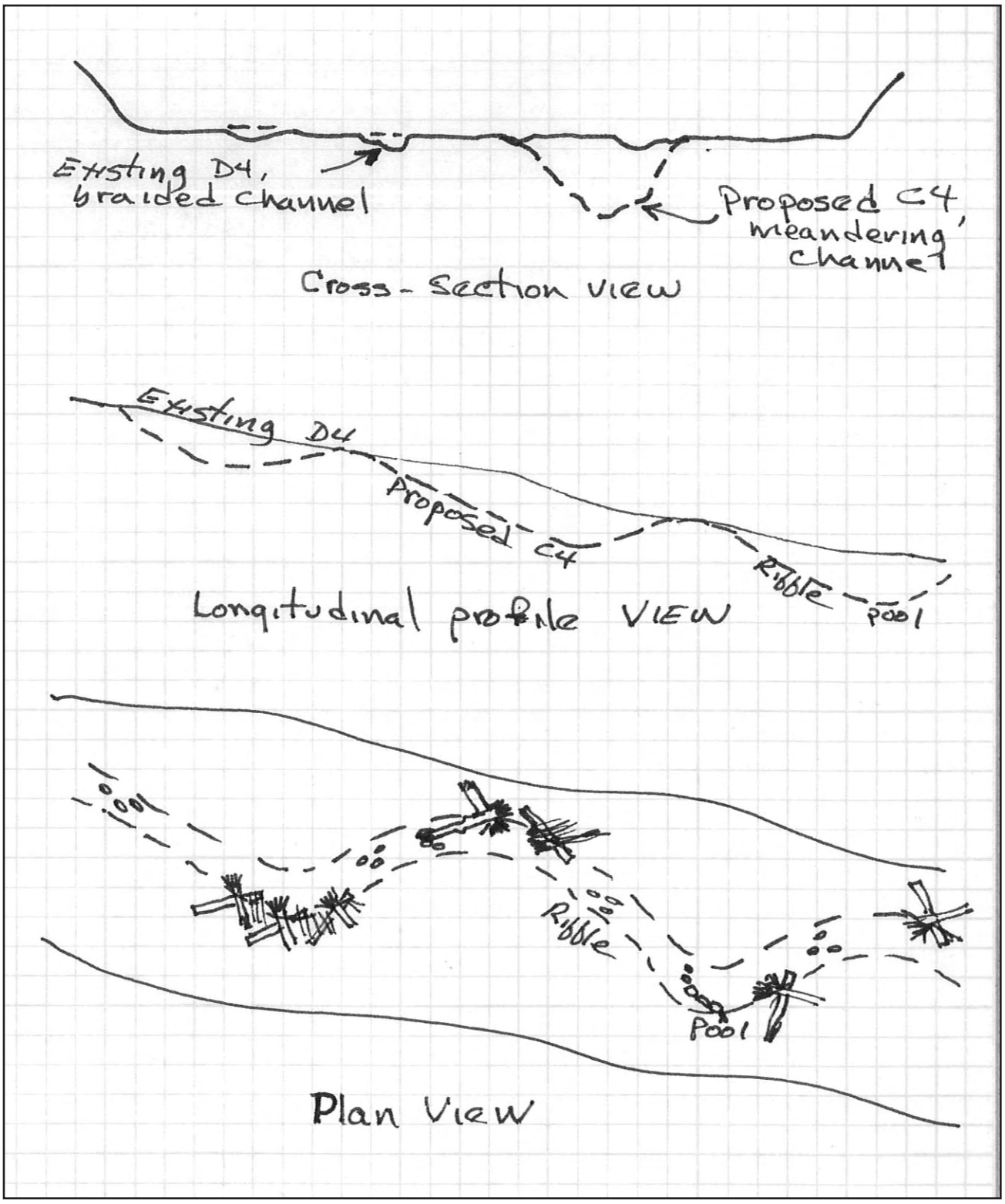


Figure 37. Cross-section, profile, and plan views of the existing *vs*. proposed D4 to C4 stream type conversion as described in Design Scenario #1.



Figure 38. Converted D4 to C4 stream type in the Trail Creek Watershed.

Design Scenario 2:

F4 to B4c Stream Type Conversion (VT II, IIIb, VIIIa,b)

This typical design scenario is a stream type and stability conversion from an F4 *Poor* condition to B4c *Good* stream type within colluvial valleys (Valley Type II, inactive alluvial fans (Valley Type IIIb), and alluvial valley fills (Valley Type VIII a,b) (**Figure 39**). This change in local base level will help to create a more sustainable energy grade. F4 stream types are associated with accelerated streambank erosion and excess deposition (**Figure 40**). The specific design objectives and direction for this design scenario to stabilize the reach are as follows:

- Reduce the accelerated sediment supply from streambank erosion
- Restore bed stability
- Restore the riparian function

The potential stable state conversion for stream succession is to convert the F4 to a B4c stream type. The direction of the stream succession is potentially related to stream succession scenarios #4, #6, and #14 (**Figure 27**). Due to the boundary conditions that influence valley width and slope, along with the channel confinement (lateral containment), the potential stable state of stream succession is a B4c stream type rather than the existing, entrenched F4 stream type.

Sediment and Hydrology

The conversion of an F4 to B4c stream type has many sedimentological and hydrologic advantages. The conversion will significantly reduce streambank erosion. The average bank erosion rate is *0.47 tons/ft/yr* for a typical F4 stream type and *0.0048* for a typical B4 stream type. This is a reduction of introduced sediment of *465 tons/yr* per *1,000 ft* of channel. B4 stream types have a lower width/depth ratio (12–14) than F4 stream types (15–50 in Trail Creek and Waldo Canyon areas) allowing B4 streams to route sediment more efficiently preventing channel aggradation. The POWERSED model indicates that by reducing the existing, high width/depth ratio, the B4 stream type is 81% more efficient at transporting bedload and suspended sand compared to the F4 stream type. The reduced streambank erosion, however, will require much less sediment to be transported. Hydrologically, increased floodplain connectivity allows for more conveyance for flood waters, reducing flood stage (**Figure 41**). **Appendix II** includes a detailed design example for this conversion from Trail Creek. Typical locations for this stream type conversion are at the lower end of South Douglas Creek, near the entrance to the Flying W Ranch, and the lower one-half mile of Northfield Gulch above the confluence with West Monument Creek.

Structures

The sediment competence calculations indicate excess energy for the proposed design of converting from an F4 to a B4c stream type; therefore, grade control at the head of each riffle/rapid is recommended. Converging rock clusters and the rock and log roller, step-pool structures are designed for grade control. The cross-vane is designed to direct the streamflow and sediment into the center of the channel and away from the banks. The cross-vane is also designed to maintain grade control and to reduce streambank and fill erosion. The other recommended structures for streambank stabilization, flow resistance, grade control, and fish habitat enhancement include J-hook vanes and the toe wood structure with sod mats and riparian transplants. Structure descriptions are provided in the *Structures in Natural Channel Design* section.

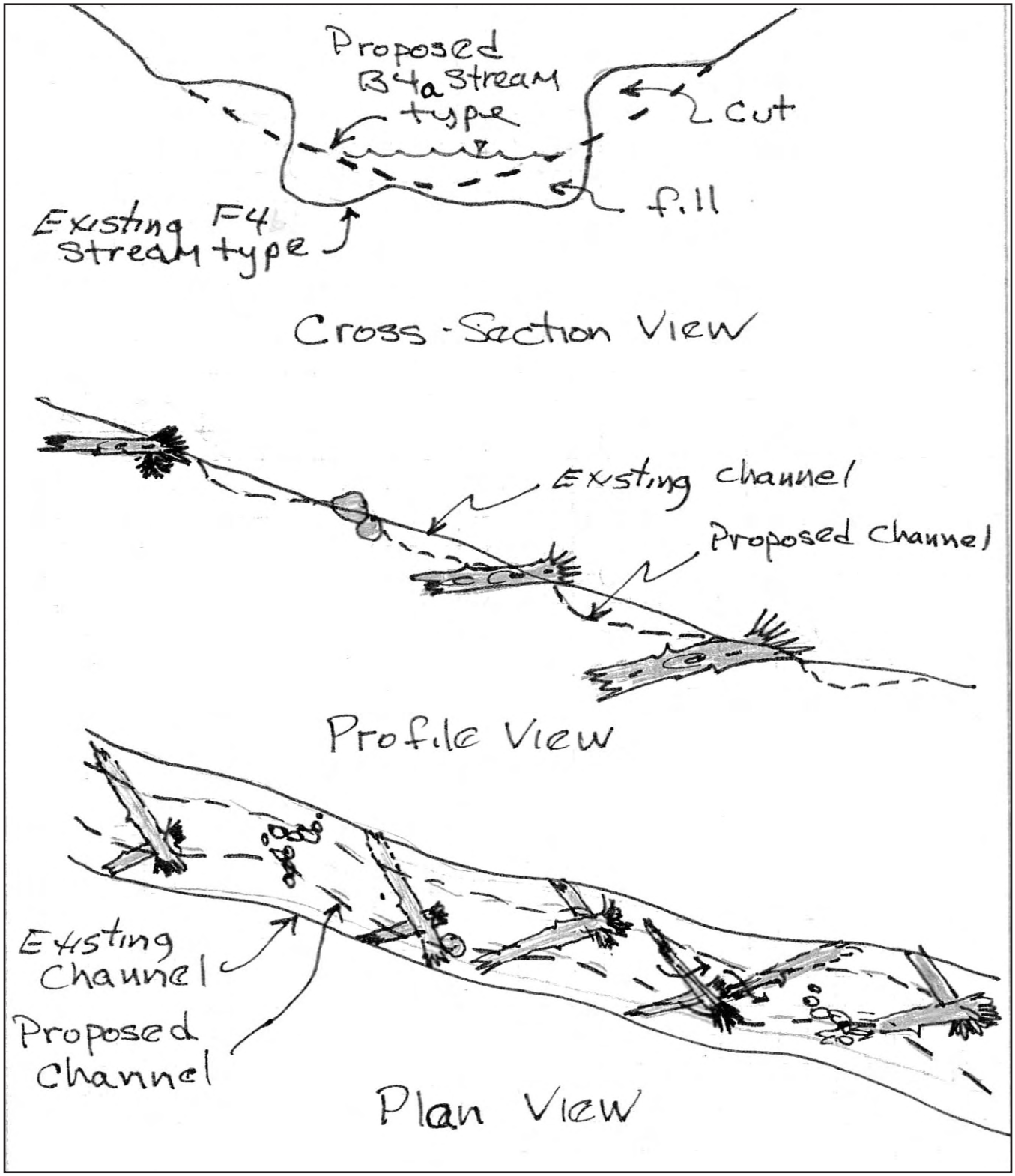


Figure 39. Cross-section, profile, and plan views of the proposed F4 to B4c stream type conversion as described in Design Scenario #2 using step-pool and rock and log roller structures.



Figure 40. A typical F4 stream type with accelerated streambank erosion in a colluvial Valley Type II.



Figure 41. Typical good stability, B4c stream type with a low width/depth ratio and negligible bank erosion, Trail Creek.

Design Scenario 3:

G4 to B4 Stream Type Conversion (VT II, IIIb, VIIIa,b)

This typical design scenario is a stream type and stability conversion from a G4 *Poor* condition to B4 *Stable* stream type within colluvial valleys (Valley Type II), inactive alluvial fans (Valley Type IIIb), and alluvial fill valleys (Valley Type VIIIa,b). The detailed characteristics and stability evaluation of the *G4 Poor Representative Reach* are documented in Appendix C of the Waldo Canyon Fire *WARSSS* analysis (Rosgen *et al*., 2013). The G stream type is incised, confined, and associated with a headcuts (**Figure 42**). The overall direction is to raise the channel by placing fill on the existing bed and incorporating structures to stabilize and restore to a new local base level and channel slope (**Figure 43**).

The specific objectives and direction for this design scenario to stabilize the reach are as follows:

- Reduce the sediment supply from the accelerated bed scour (degradation)
- Reduce the accelerated streambank erosion rates
- Restore the riparian function
- Enhance fish habitat in perennial streams

In relation to stream succession, these reaches were previously C or B stream types that were abandoned by channel incision resulting in the existing, G stream type. Because it is often difficult to raise the channel back to historic levels and to match the energy slope up- and down-valley, the potential stable state is a B stream type. The B4 stream types are naturally confined stream types that are stable and match the existing confinement of the G4 stream type. The conversion from a G4 to B4 stream type represents the central tendency of stream succession to a stable "end point" channel in both a confined and moderately entrenched stream system. The decrease in shear stress due to an increase of width/depth ratio is countered by an increase in entrenchment ratio (wider flood-prone area) to disperse flood-flow impacts. Log and rock step-pool structures are incorporated for grade control and to add flow resistance and habitat features. The increase in entrenchment ratio will exponentially reduce the high streambank and streambed erosion from flood flows associated with the G4 stream type. The B4 stream type rarely stores sediment for future re-entrainment and efficiently routes sediment through without adding channel source sediment to the sediment supply; thus the increased post-fire flood flows will have little adverse effects on the B4 stream type compared to the G4 stream type.

Sediment and Hydrology

Much like the F4 to B4 conversion, converting to a B4 from a G4 stream type reduces the amount of streambank erosion. The average bank erosion rate for a G4 is *0.66 tons/ft/yr* and *0.0048 tons/ft/yr* for a typical B4 stream type. Using this conversion, bank erosion is reduced *655.2 tons/yr* per *1,000 ft* of channel. G4 stream types tend to have a lower width/depth ratio when compared to B4 stream types. Increasing the width/depth ratio will reduce the stream power and protect against further incision. Hydrologically, more floodplain connectivity allows for more conveyance for flood waters, reducing flood stage. **Appendix II** includes a detailed design example for this conversion from Trail Creek.

Structures

The sediment competence calculations indicate excess energy for the proposed design of converting from a G4 to a B4 stream type; therefore, grade control at the head of each riffle is recommended. The converging rock clusters and the rock and log roller (step-pool) structures are designed for grade control.

The cross-vane is designed to direct the streamflow and sediment into the center of the channel and away from the banks. The cross-vane is also designed to maintain grade control and to reduce streambank and fill erosion. The other recommended structures for streambank stabilization, flow resistance, grade control, and fish habitat enhancement include J-hook vanes and the toe wood structure with sod mats and riparian transplants. Structures descriptions are provided in the *Structures in Natural Channel Design* section.



Figure 42. An entrenched and actively incising G4 stream type with accelerated streambank erosion on Douglas Creek.

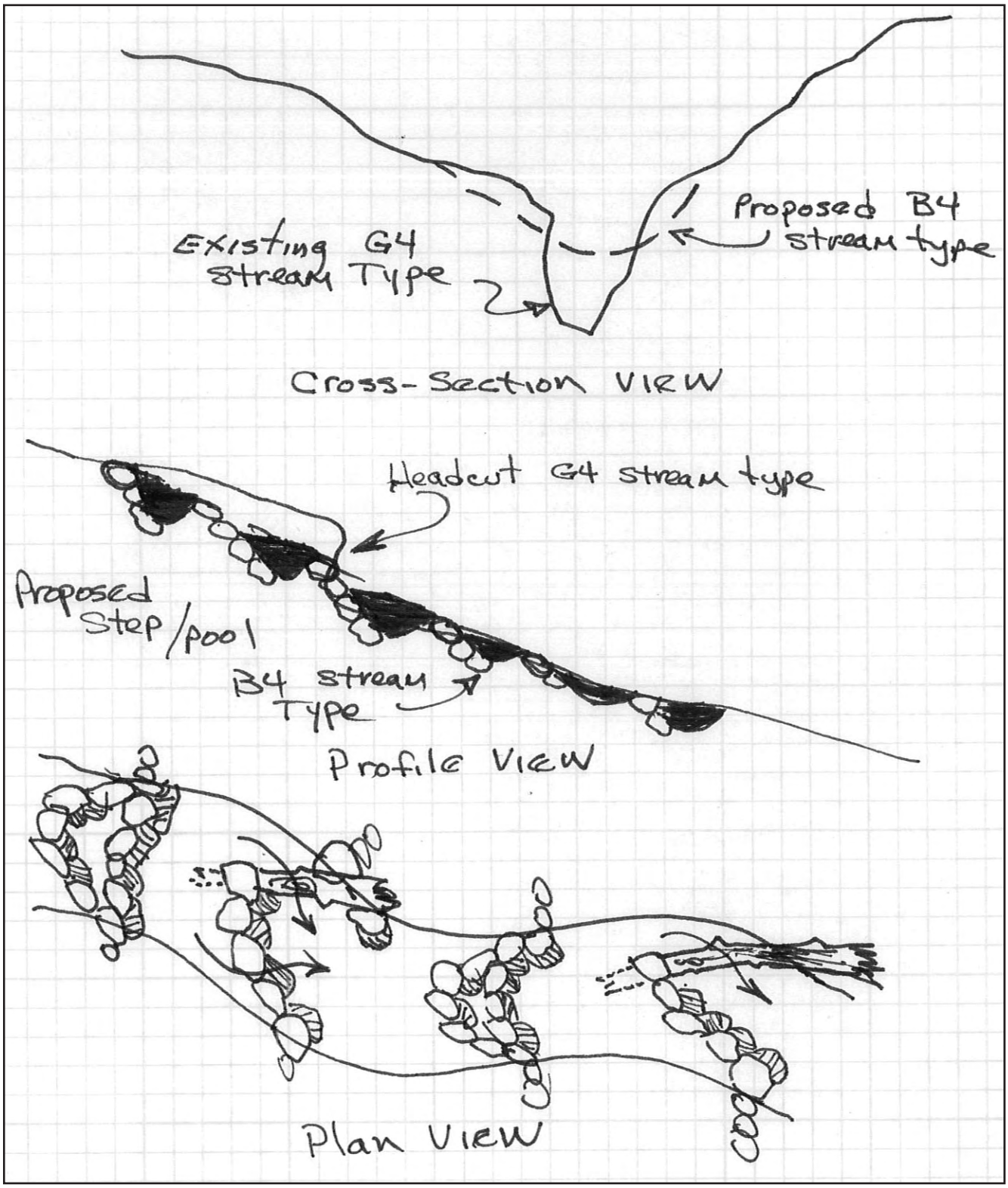


Figure 43. Cross-section, profile, and plan views of the proposed G4 to B4 stream type conversion as described in Design Scenario #3 using rock and log roller step-pool structures.

Design Scenario 4:

C4 Poor to C4 Stable Conversion (VT VIIIa,b,c)

This typical design scenario is a stability conversion of a C4 *Poor* condition to a C4 *Stable* stream type in alluvial valley fills (Valley Type VIIIa,b,c) (**Figure 44**). Many stream types exist that have not changed their morphological description (stream type) but have become highly unstable. Impaired C4 *Poor* stream types have instability associated with both streambank and streambed erosion. The stable end-point of stream succession is a C4 stream type and the stable features of a *C4 Reference Reach* must be integrated into the restoration consideration for this reach. The detailed characteristics and stability evaluation of this representative reach are documented in Appendix C7 of the Waldo Canyon Fire *WARSSS* report (Rosgen *et al*., 2013).

The specific objectives and direction for this design scenario to stabilize the reach are as follows:

- Reduce the sediment supply due to bed instability
- Reduce the accelerated streambank erosion rates
- Restore the floodplain connectivity
- Restore the riparian function
- Enhance fish habitat in perennial channels

Disturbed C stream types are usually associated with high bank erosion and high width/depth ratios. A typical C4 *Poor* stream type has a streambank erosion rate of *0.047 tons/ft/yr*, wheras a C4 reference reach has a streambank erosion rate of *0.0063 tons/ft/yr*. By stabilizing banks, the streambank erosion can be reduced by *40.7 tons/yr* per *1,000 ft* of channel. The C stream type with a high width/depth ratio in high sediment supply areas are prone to aggradation. By lowering the width/depth ratio, the channel transports bedload and suspended sediment more efficiently. The POWERSED model indicates that approximately 85% of the C4 *Poor* sediment supply would be transported rather than deposited if converted to a C4 *Stable* reach due to reducing the existing high width/depth ratio with the design. An example of the proposed dimension, pattern, and profile for a stable C4 design reach for Trail Creek is presented in **Appendix II** using the procedure in **Appendix I**.

Structures

Structures applicable for C stream types include cross-vanes, J-hooks, converging rock clusters, and toe wood. The proposed structures function as grade control, energy dissipation and distribution, bank stabilization and fish habitat. Revegetation, transplants, and seeding should be implemented concurrently as vegetation adds flow resistance, reducing bank erosion. Structure descriptions are provided in the *Structures in Natural Channel Design* section.

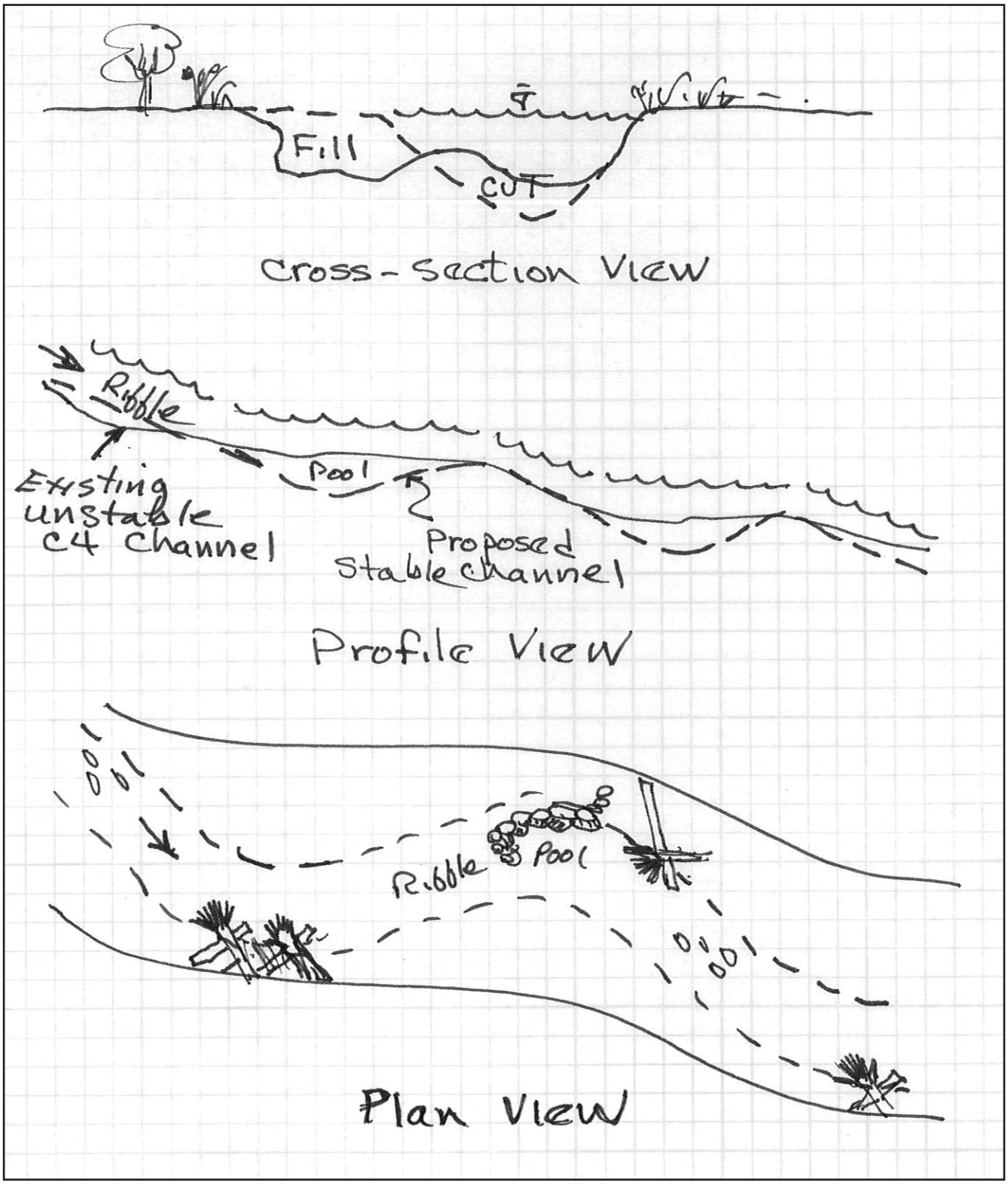


Figure 44. Cross-section, profile, and plan views of the proposed C4 *Poor* to C4 *Stable* stream type conversion as described in Design Scenario #4.

Design Scenario 5:

Tributary A4, F4b, or G4 to D4 Stream Type Conversion (VT II, IIIa, VIIIa,b,c)

This typical design scenario is an ephemeral stream type conversion from an A4, F4b, or G4 to a D4 stream type in ephemeral systems with valleys wide enough to support D channels (Valley Types II, IIIa, VIIIa,b,c) (**Figure 45**). Many restoration solutions are founded in basic geomorphic features. Active alluvial fans and braided channels are the natural solution to sediment detention of the upper slopes to prevent direct sediment introduction into main trunk streams. D4 stream types are often the natural stable form in such environments. When stream channels become incised in alluvial fans, they become high supply and high transport systems; thus the sediment yield is not only routed from farther upstream but is cut through portions of the fan deposit as well. Additionally, when the upstream sediment supply is excessive due to the elevated post-fire sediment yields, the construction of deep sediment detention basins can add sediment storage capacity to the fan. One or more of these constructed sediment detention basins will provide additional time to reduce delivered sediment yields until post-fire, flow-related sediment supply is reduced. The basins also reduce the required depositional storage requirement of the fan surface. This scenario can also be utilized in wide valleys under high sediment supply. In nature these valleys become sediment detention zones. Where possible, this scenario is the top priority for all ephemeral streams affected by the Waldo Canyon Fire. Another major advantage of this conversion is flood peak attenuation by lowering flow velocity, which promotes infiltration.

The specific objectives and direction for this design scenario are as follows:

- Store sediment before it is delivered to larger systems
- Reduce the accelerated streambank erosion rates
- Eliminate any advancing or future headcuts
- Develop sediment detention storage basins where needed
- Attenuate flood peaks

Using an example from Trail Creek, we can see the sedimentological benefits of this conversion from an F4b to a D4 stream type (see **Appendix II**). In this situation, the POWERSED model indicated that approximately 84% of the upstream delivered sediment would be deposited with the designed, braided D4 stream type. If the fan surface is reactivated, approximately *15,600 tons/yr* can be stored on the fan. The storage capacity of the sediment detention basins was approximately *6,474 tons*. Thus, the annual sediment yield of *5,261 tons/yr* could be stored on the fan surface and detention basins for approximately *3.3 years*. The detention basins could be re-excavated to regain storage capacity, but the new alluvial fan will continue to function and sediment will be deposited. The sediment detention basins and fan surface allow time to reduce the delivery of downstream sediment.

To determine if the valley width can accommodate the width of the braided, D4 stream type, the following procedure is recommended:

1. Obtain Drainage Area (DA) in mi^2
2. Calculate bankfull discharge (Q_{bkf}) in cfs from regional curve (**Figure 36**) where $Q_{bkf} = 4.7(DA)^{0.65}$
3. Estimate mean bankfull velocity ($\bar{u}_{bkf}$) for the braided, D4 stream type, which is typically between *0.5* and *1.0 ft/sec*
4. Calculate cross-sectional area (A_{bkf}) in ft^2 using: $A_{bkf} = Q_{bkf} / \bar{u}_{bkf}$
5. Obtain the width/depth ratio (W/d) of the D4 stream type (use *200*)
6. Calculate the bankfull width (W_{bkf}) in ft using: $W_{bkf} = (W/d * A_{bkf})^{0.5}$

Example:

1. $DA = 1.0\ mi^2$
2. $Q_{bkf} = 4.7\ cfs$
3. $\bar{u}_{bkf} = 0.5\ ft/sec$
4. $A_{bkf} = 4.7/0.5 = 9.4\ ft^2$
5. $W/d = 200$
6. $W_{bkf} = (200 * 9.4)^{0.5} = 43.3\ ft$

This design requires the use of buried log sills, placed intermittently through the braided reach especially over filled incised channels and at the top and bottom of each sediment detention basin as indicated in **Figure 46**. The log sills and log crib wall will prevent any potential headcutting associated with this design. Where applicable, sediment detention basins can be used for material needed to raise the base level of incised channels to reconnect with an existing floodplain or alluvial fan surface. Structure descriptions are provided in the *Structures in Natural Channel Design* section.

Where appropriate, Design Scenario #5 is the top priority for all ephemeral streams affected by the Waldo Canyon Fire. Inchannel sediment detention basins should not be implemented in perennial systems. Examples of this typical design scenario are included in **Appendix II**.

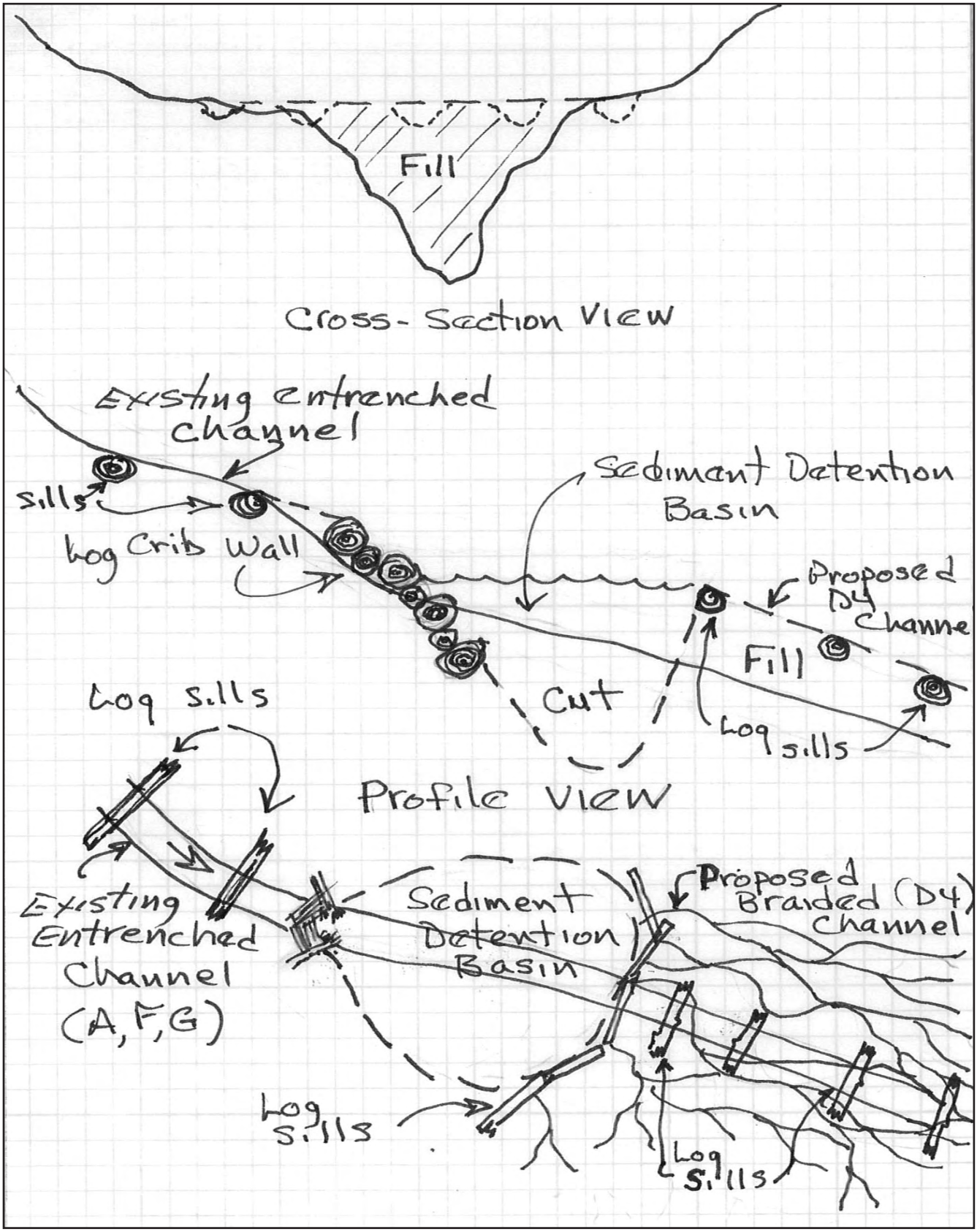


Figure 45. Cross-section, profile, and plan views of the existing *vs*. proposed conversion of the entrenched A4, F4, and G4 stream types to a D4, braided stream type with a sediment detention basin as described in Design Scenario #5.



Figure 46. Converting a G4 to a D4 stream type using sediment detention basins, Douglas Creek.

Design Scenario 6:

Tributary F4b to B4 Stream Type Conversion (VT II, IIIb, VIIIa,b)

This typical design scenario is a stream type and stability conversion from an F4b *Poor* to a B4 *Stable* stream within Valley Types II, IIIb, and VIIIa,b,c (**Figure 47**). The F4b channels are characterized as deeply incised, confined, and entrenched, many cutting through alluvial fans as depicted in **Figure 48**. With increased post-fire floods, F4b channels in this material have downcut with excessive, accelerated lateral erosion. If construction of alluvial fans and creating a braided channel on a fan surface (Design Scenario #5) are not feasible, Design Scenario #6 is often the next viable option. The specific objectives and direction of this design scenario to stabilize the reach are as follows:

- Reduce the sediment supply from the flow-related sediment yield increase
- Reduce the accelerated streambank erosion rates
- Incorporate grade control measures to stop the advancing headcuts
- Establish a stable toe of the alluvial fan
- Restore the riparian function

An example for this scenario from Trail Creek is reported in **Appendix II**. The characteristics of the watershed that contains the existing F4b tributary are included in **Appendix II**, which indicate the drainage area, streambank erosion rates, and the overall erosion summary for the sub-watershed. However, a detailed survey and corresponding stability assessment were not completed on the existing F4b reach in this sub-watershed as was done on the representative reaches. Consequently, the *F4b Poor Trib. Representative Reach* data was extrapolated to this existing site because of the similar stream type, condition, and valley type. The location of the *F4b Poor Trib. Representative Reach* is shown in **Figure II-1** in **Appendix II**, and the morphology and stability evaluation are documented in Appendix C14 of the Waldo Canyon Fire *WARSSS* report (Rosgen *et al*., 2013). An example of a design for this scenario is presented using Northfield Gulch (a tributary to West Monument Creek) in the *Master Plan for Channel Processes* section.

Sediment and Hydrology

The conversion of an F4b to B4 has many sedimentological and hydrologic advantages, including a significant reduction in streambank erosion. The average bank erosion rate is *0.47 tons/ft/yr* for a typical F4b stream type and *0.0048* for a typical B4 stream type. This is a reduction of introduced sediment of *465 tons/yr* per *1,000 ft* of channel. B4 stream types have a lower width/depth ratio (12–14) than F4 stream types (15–50 in Trail Creek and Waldo Canyon areas) allowing B4 streams to route sediment more efficiently. By lowering the existing high width/depth ratio of the F4b and creating a B4 stream type, the channel routes sediment more efficiently and is more resistant to impairment. The reduction in streambank erosion rates also creates less sediment to be routed. Hydrologically, more floodplain connectivity allows for more conveyance for flood waters reducing flood stage compared to the F4b stream type.

Structures

The sediment competence calculations indicate excess energy for the proposed design of converting from an F4 to a B4 stream type; therefore, grade control at the head of each riffle is recommended. The converging rock clusters and the rock and log roller (step-pool) structures are designed for grade control. The cross-vane is designed to direct the streamflow and sediment into the center of the channel and away from the banks. The cross-vane is also designed to maintain grade control and to reduce streambank and fill erosion. The other recommended structures for streambank stabilization, flow resistance, grade control, and fish habitat enhancement include J-hook vanes and the toe wood structure with sod mats and riparian transplants. Structures descriptions are provided in the *Structures in Natural Channel Design* section.

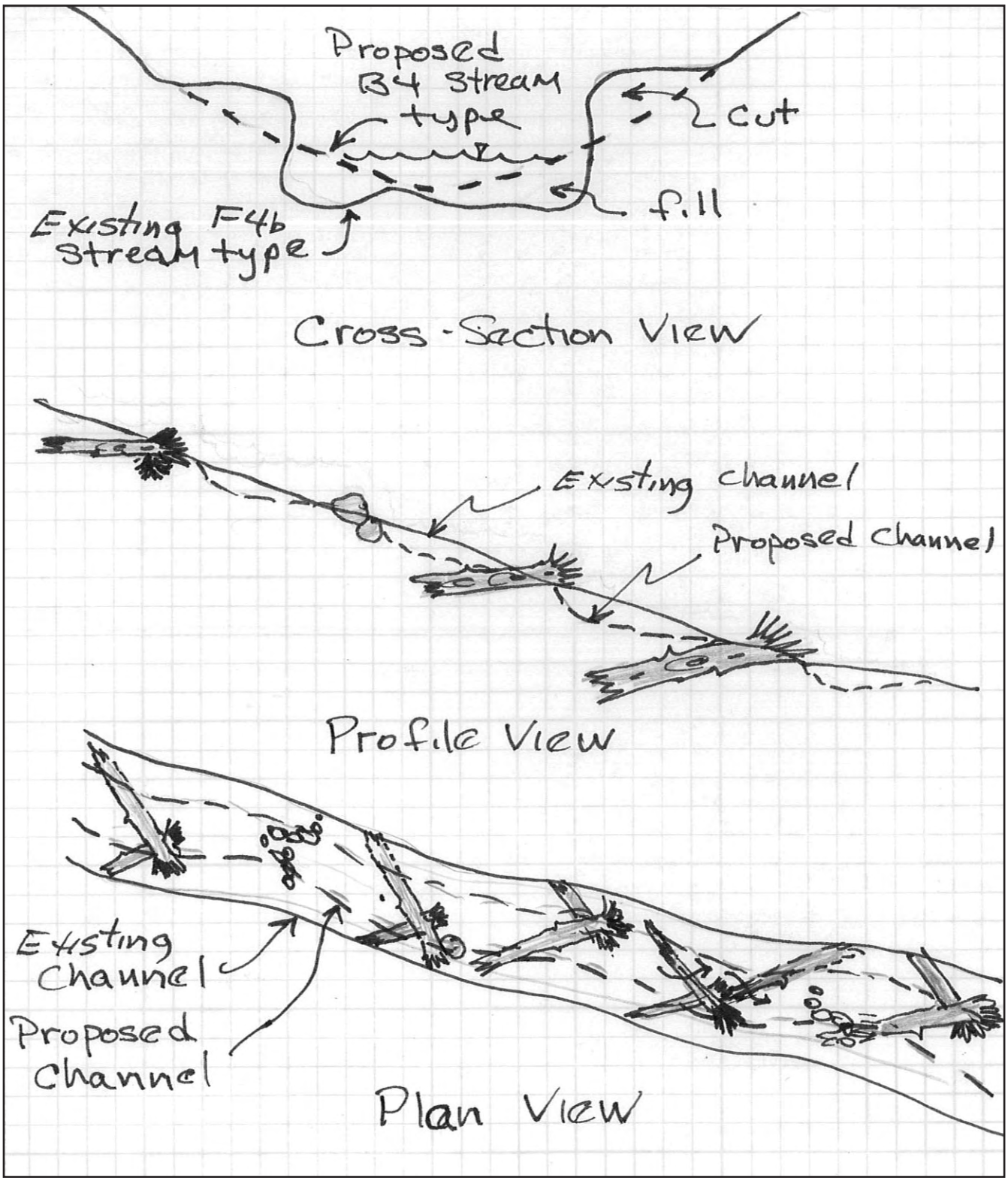


Figure 47. Cross-section, profile, and plan views of the proposed F4b to B4 stream type conversion as described in Design Scenario #6 using rock and log roller (step-pool) structures.



Figure 48. An F4 stream type in a Valley Type II, West Monument Creek.

Design Scenario 7:

Tributary A4a+ or A4 *Poor* to A4a+ or A4 *Stable* Conversion (VT I, II)

This typical design scenario is a stability conversion of an A4 or A4a+ *Poor* condition tributary to an A4 or A4a+ *Stable* condition in colluvial valleys (Valley Types I and II) (**Figure 49**). Many stream types exist that have not changed their morphological description (stream type) but have become highly unstable. The increased post-fire floods and the poor riparian condition in these reaches have created accelerated streambank and streambed erosion. Existing A4a+ *Poor* channels are deeply incised, confined, and entrenched, and are associated with headcuts advancing upstream. The specific objectives and direction of this design scenario to stabilize the reach are as follows:

- Reduce the sediment supply from the accelerated bed scour (degradation)
- Reduce the accelerated streambank erosion rates
- Initiate grade control measures to stop the advancing headcut
- Restore the riparian function

The dimensionless relations of the *A4a+ Reference Reach* are used to generate the stable, proposed reach design criteria (Rosgen *et al*., 2013).

A typical A4 *Poor* stream type has a streambank erosion rate of *0.036 tons/ft/yr* (**Figure 50**), compared to an A4 *Stable* reference stream that has a streambank erosion rate of *0.0017 tons/ft/yr* (**Figure 51**). By stabilizing the streambanks, the bank erosion can be reduced by *34 tons/yr* in *1,000 ft* of channel. A4 and A4a+ stream types typically have excess energy and without grade control (boulder or bedrock nick points) are prone to degradation (**Figure 52**). By stabilizing the bed of the channel with grade control structures, the channel cannot scour, reducing sediment input from the bed and bank. About 50% (110 miles) of the streams mapped within the Waldo Canyon Fire are A4 or A4a+. If all of these streams were converted to good condition, *19,760 tons/yr* of sediment that would otherwise be transported downstream would be stabilized in place. An example of the proposed dimension, pattern, and profile for a stable A4a+ design reach is presented in **Appendix II**.

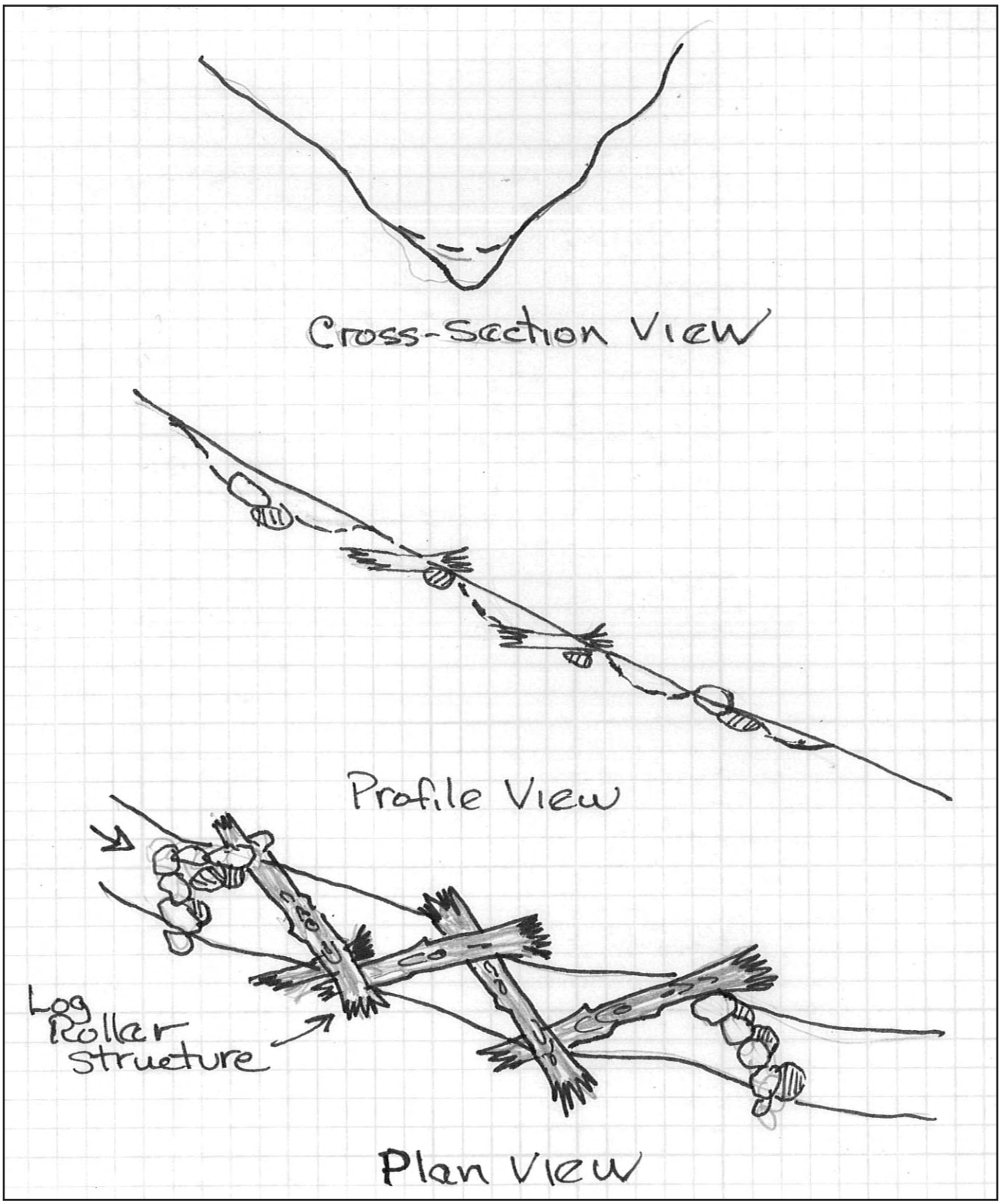


Figure 49. Cross-section, profile, and plan views of the proposed conversion of *unstable* A4 and A4a+ stream types to *stable* A4 and A4a+ stream types as described in Design Scenario #7 using rock and log roller (step-pool) structures.



Figure 50. A typical A4 *Poor* stream type.



Figure 51. A typical A4 reference stream type.



Figure 52. A typical A4 stream type with excess energy prone to channel incision and headcuts.

Design Scenario 8:

Tributary A4a+ or A4 to B4a Stream Type Conversion (VT I, II, IIIb, VIIIa,b)

This typical design scenario is a stream type and stability conversion from an A4a+ or A4 *Poor* condition tributary to a B4a *Stable* stream type within Valley Types I, II, IIIb, and VIIIa,b (**Figure 53**). The A4a+ and A4 channels are characterized as deeply incised, confined, and entrenched systems that have excess energy resulting in streambed scour and excessive streambank erosion. This scenario is recommended for incised channels were the valley constraints allow a larger flood-prone area. In steep alluvial fans that do not have sufficient length to support a D4 channel, B4a stream types should be built to convey sediment downstream. The B4a design reduces the channel source sediment of streambank and streambed erosion typical of the A4a+ stream types.

The specific objectives and direction of this design scenario to stabilize the reach are as follows:

- Reduce the high sediment supply from the accelerated bed scour (degradation)
- Reduce the accelerated streambank erosion rates
- Incorporate grade control measures to stop potentially advancing headcuts

A typical A4 *Poor* stream type has a streambank erosion rate of *0.036 tons/ft/yr* compared to a B4a reference reach that has a streambank erosion rate of *0.0076 tons/ft/yr*. By stabilizing streambanks, the bank erosion can be reduced by *28 tons/yr* in *1,000 ft* of channel. The A stream type typically has excess energy and without grade control (boulder or bedrock nick points) are prone to degradation. By stabilizing the bed with grade control structures and accessing a larger floodplain typical with B4a stream types, the energy is decreased, reducing sediment input from the bed and banks (**Figure 54**). An example of the proposed dimension, pattern, and profile for astable B4a design reach is presented in **Appendix II**.

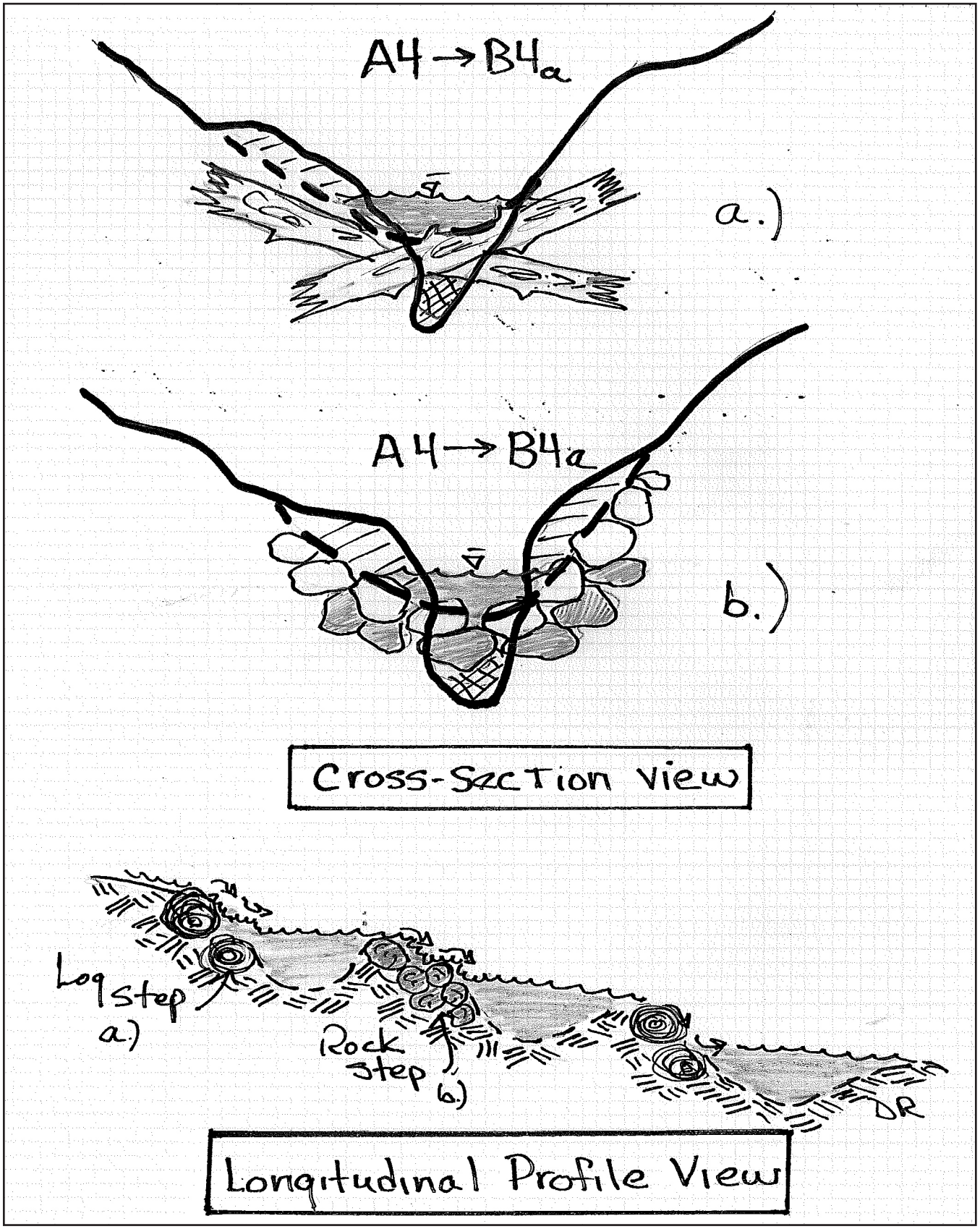


Figure 53. Cross-section, profile, and plan views of the proposed A4a to B4a stream type conversion as described in Design Scenario #8.



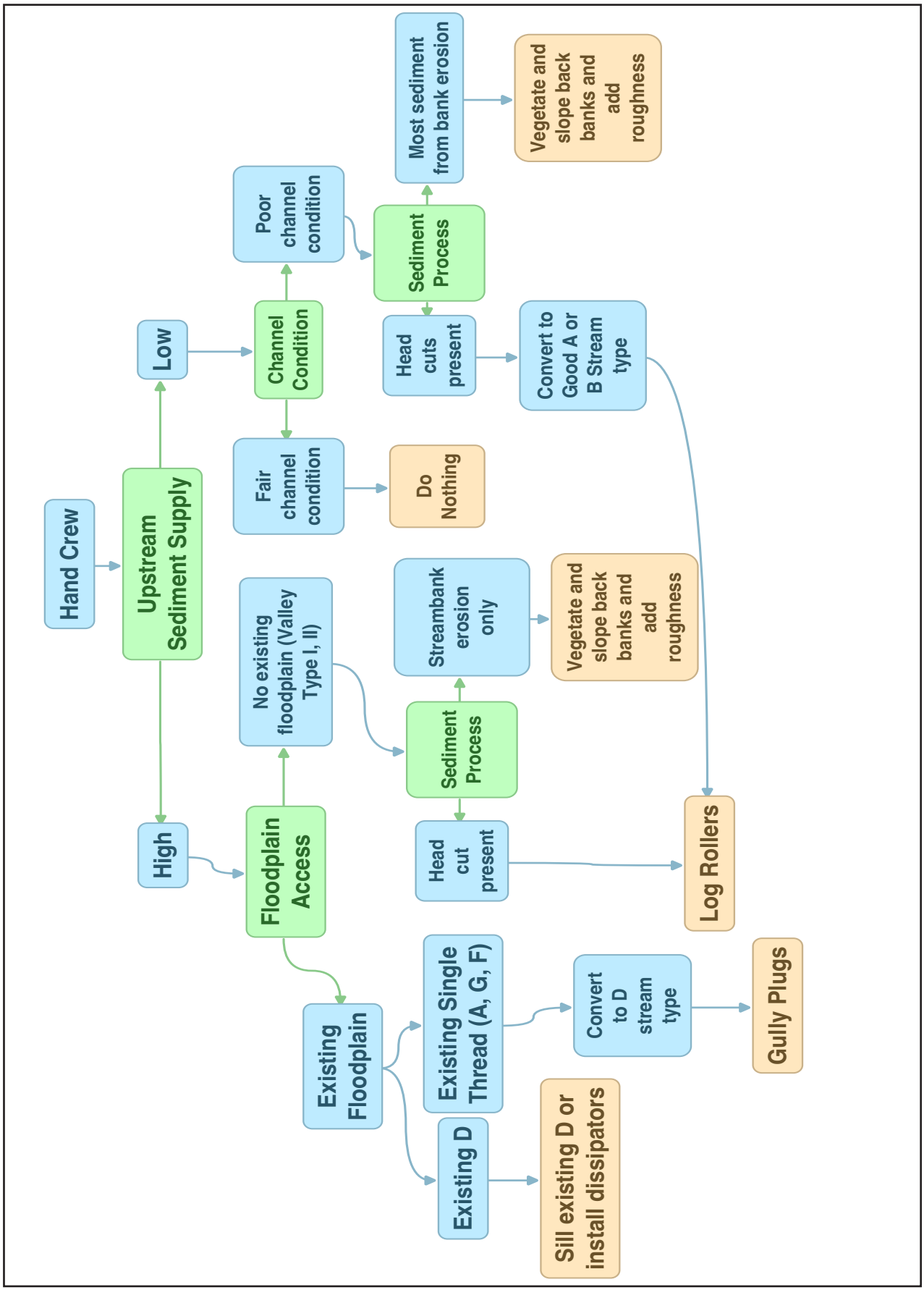
Figure 54. A stable B4a reference reach, West Monument Creek.

Recommendations for Hand Crew Treatments: Channel Processes

Where heavy equipment access is prohibitive, hand crews will be necessary to treat a variety of channel process problems (**Table 6**). The Decision Tree Flowchart (**Flowchart 4**) is used to select a treatment type based on sediment supply, stream type, valley type (presence of floodplain and/or fan surface), condition, and process. Within the Decision Tree, there are seven scenarios with five potential outcomes. These scenarios are determined from the channel transport capacity graph (see **Figure 84**) and the cumulative sediment sources map (see **Figure 85**). Criteria are based on whether the upstream sediment supply is high and if there is an existing floodplain and/or alluvial fan surface. If these criteria are met, then maintaining an existing D stream type or converting a single-thread channel to a braided channel is recommended (Design Scenario #5). This scenario would require a gully plug log crib wall. The floodplains and alluvial fan surfaces are natural features that store sediment, increase infiltration, and attenuate floods.

Table 6. Structures recommended for hand crews to treat a variety of channel process problems.

Structures	Streambank Stabilization	Sediment Deposition	Flow Attenuation	Grade Control
Cross-Channel Sills		✓	✓	✓
Gully Plug		✓	✓	✓
Log Rollers	✓			✓
Dissipators		✓	✓	✓



Flowchart 4. Channel process Decision Tree for hand crew treatments.

Treatment for High Upstream Sediment Supply, Existing Floodplain/Alluvial Fan Access, and Existing D Stream Type

Use log sills to prevent headcuts or install dissipators to act as grade control and encourage additional deposition over the entire surface area of the channel. Sills should be trenched in to grade (top of log flush with bed of the braided channel) and butt-joined to span the entire width of the channel. It is most important to stabilize the upper and lower ends of the braided channel and then intermittently space the sills in between as materials warrant. Use burned logs (snags, rather than live trees) onsite for sill material. Install dissipators (NVD™ patent pending) where onsite materials are lacking or the intention is to increase sediment storage volume (**Figure 55**). The dissipators come in 5.0 ft sections and can be transported and installed quickly in remote areas. Dissipators are most effective when installed in series spaced about 6–7 channel widths apart. The bases should be trenched in with the top of the base at grade and the sections butt-joined to span the entire width of the channel. Each 5.0 ft section of base needs a minimum of two 24.0 inch anchors. Expect at least 0.5 ft of aggradation over the entire surface area of the braided channel where dissipators are deployed.

Treatment for High Upstream Sediment Supply, Existing Floodplain, and Single-Thread A, F, or G Stream Types

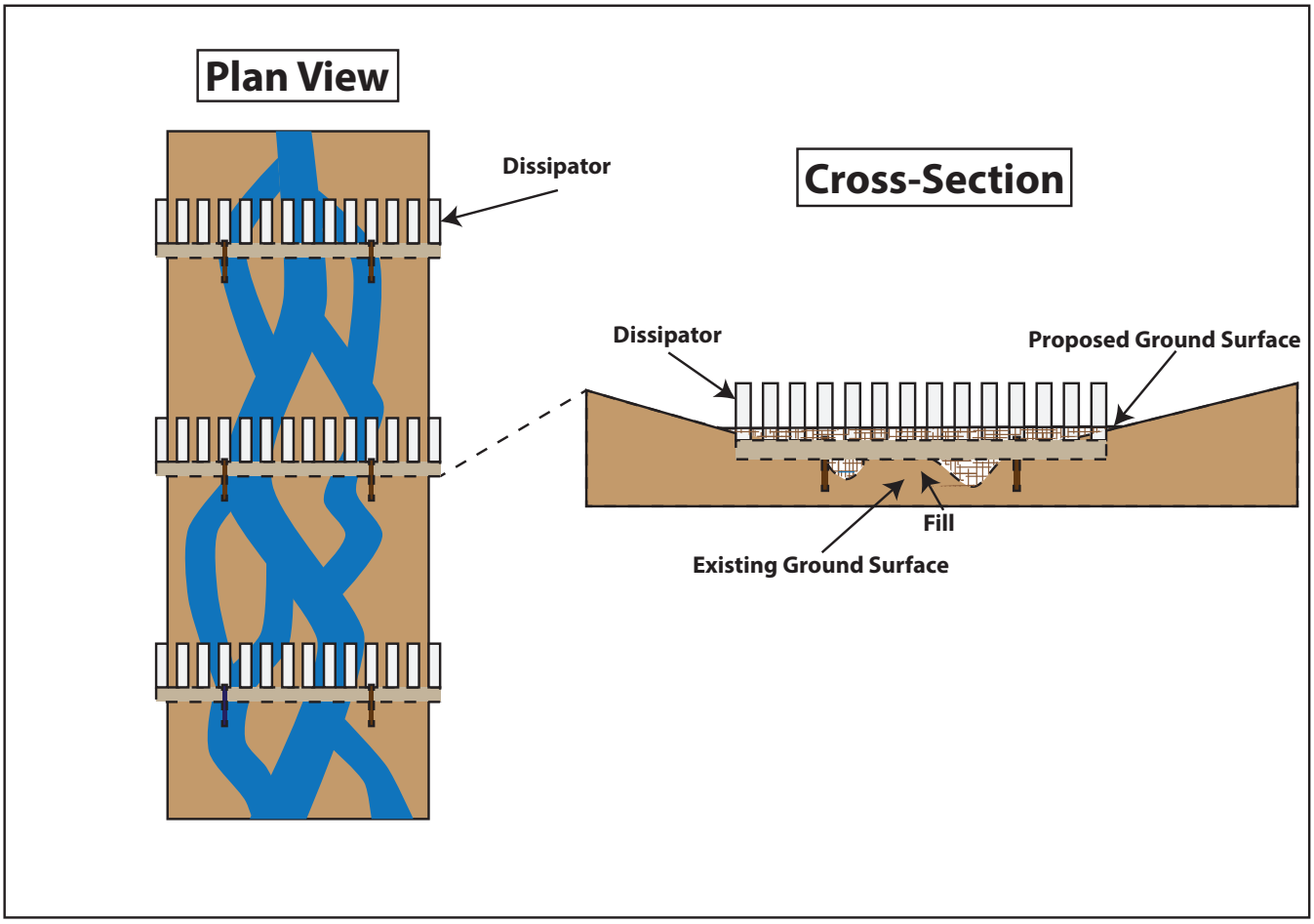
Convert to D stream type using log step crib wall plug (**Figure 56**) (see Design Scenario #5). First, determine if the valley width is sufficient to support a D channel using the procedure detailed in Design Scenario #5. If the existing valley width is greater than the calculated width, convert to a D steam type. If the valley width is too narrow, use treatments for no floodplain/alluvial fan access below.

The log step crib wall plug intercepts all sediment transport until the voids are full and sediment is flush with the floodplain or alluvial fan surface, creating a braided channel. The cut and fill should balance and all logs used for the crib walls and sills should be obtained onsite. Attach fabric (Mirafi 600x) to the upstream side of the crib wall and key it into the banks for stability and strength. It is critical to extend the sill logs to the left and right extent of the floodplain and/or alluvial fan to prevent headcutting.

Treatment for High Upstream Sediment Supply, No Floodplain/Alluvial Fan Access with Headcuts Present

Install log rollers (**Figure 57**) 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.

Dissipators



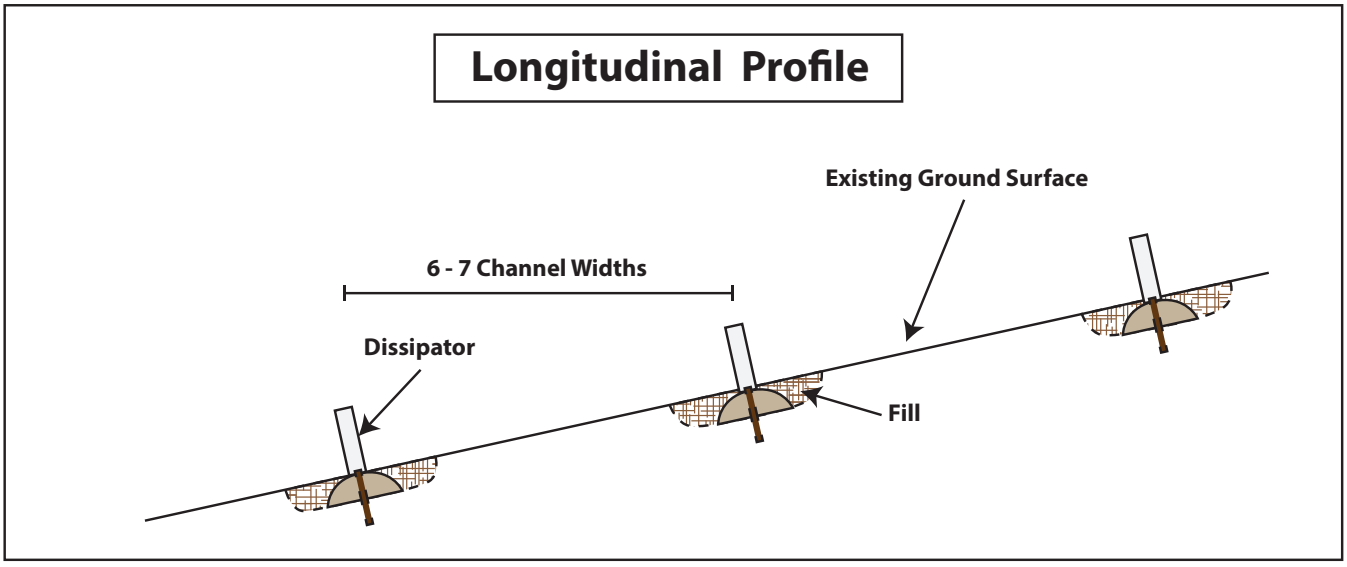


Figure 55. Stabilizing existing D stream type with NVD™ to encourage aggradation and long-term grade control.

Hand Crew Crib Wall Plugs

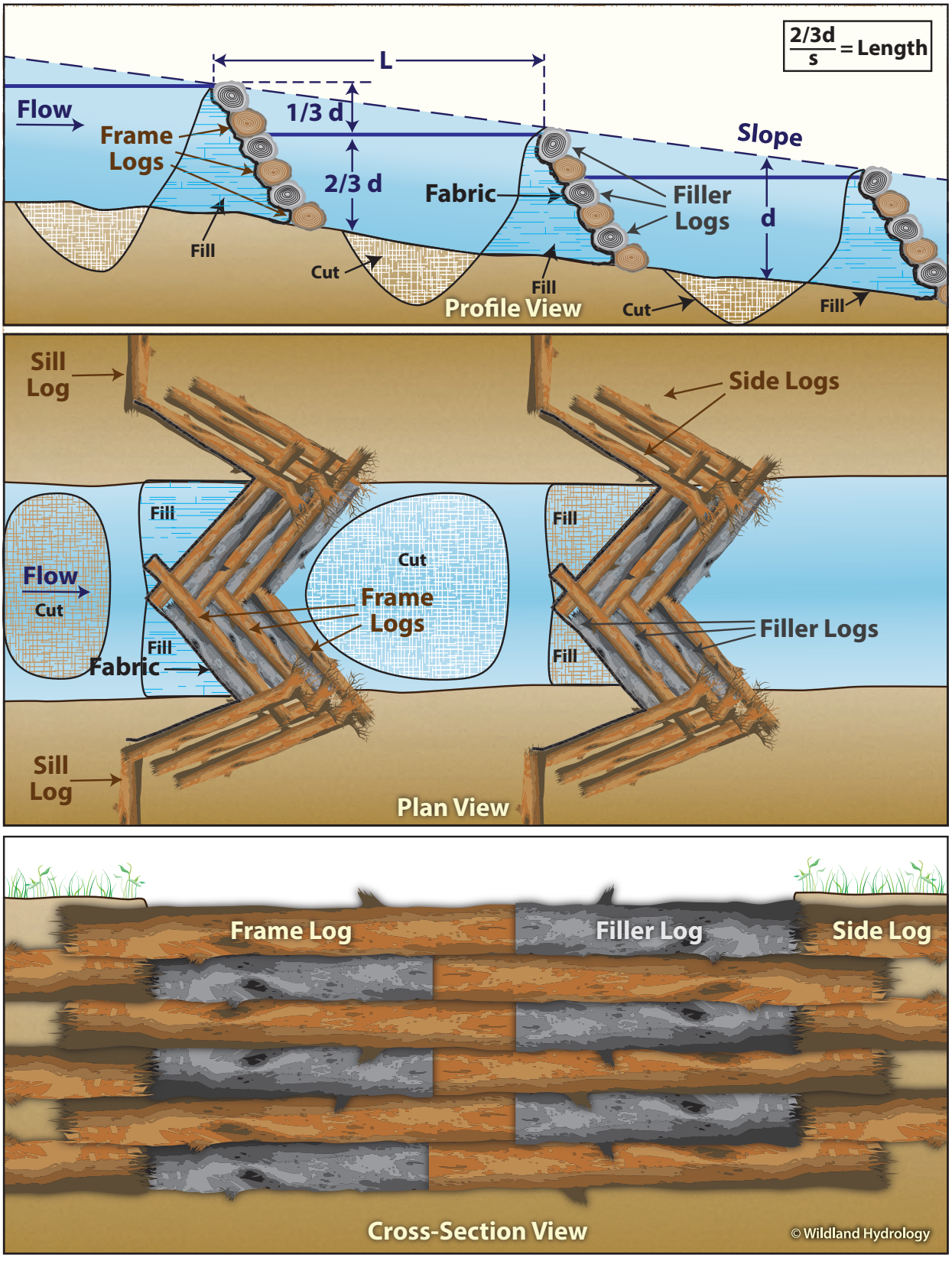
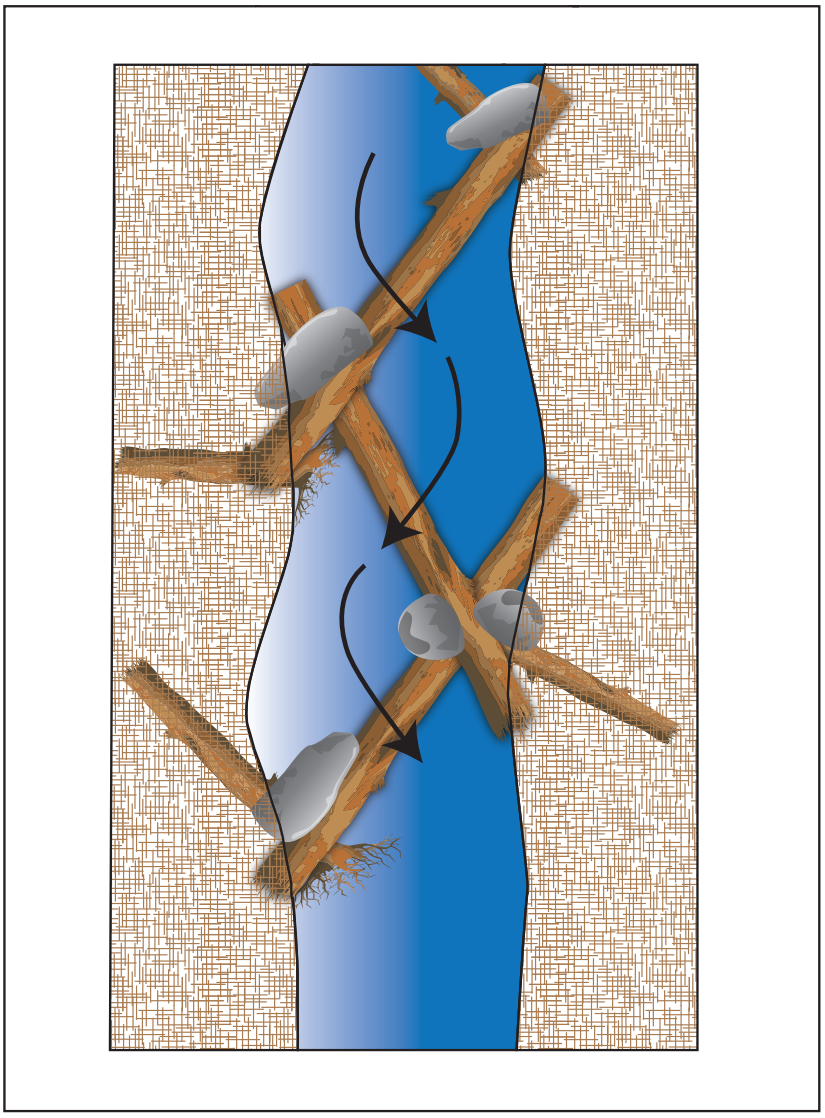


Figure 56. Converting a single-thread to braided system using log step crib wall plugs.

Log Rollers



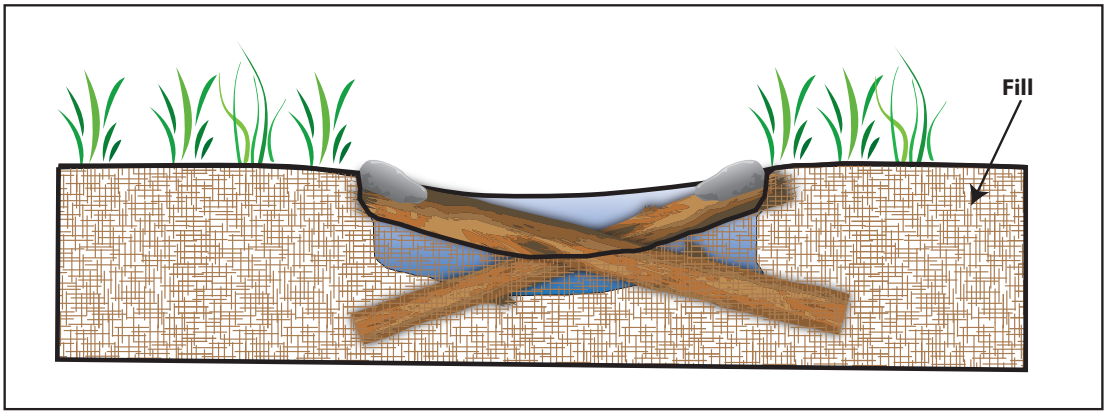


Figure 57. Log roller design.

Treatment for High Upstream Sediment Supply, No Floodplain Access, and Excessive Bank Erosion

Slope back banks, re-establish riparian vegetation, and add roughness to reduce bank contribution from reach. Channel shaping that changes width/depth ratio and entrenchment ratio is required when A4 stream types are converted to B4a (Design Scenario #8), or F4, F4b, and G4 stream types are converted to B4c or B4 stream types (Design Scenarios #2, #6, and #3).

Treatment for Low Upstream Sediment Supply and "Fair" Channel Condition

DO NOTHING.

Treatment for Low Upstream Sediment Supply, "Poor" Channel Condition, and Head-cuts Present

Convert to "Good" A or B stream type (see Design Scenarios #2, #3, #6, #7, and #8). Shape the width/depth ratio and entrenchment ratio appropriate for the stable stream type as summarized in the various scenarios for single-thread channels. Install log rollers (**Figure 57**) for grade control at appropriate intervals for channel size and slope. Channels will route delivered sediment but will not contribute to channel source sediment due to the reduced erosion from the channel bed and banks. Re-establish riparian vegetation.

Treatment for Low Upstream Sediment Supply, "Poor" Channel Condition, and Excessive Bank Erosion

Shape the channel width/depth ratio and entrenchment ratio appropriate to the stable stream type. Slope back banks, re-establish riparian vegetation, and add roughness to reduce bank contribution from reach. Review the design scenarios that convert poor condition stream types to good condition stream types.

Summary of Proposed Sediment Reduction Due to Restoration

The objectives of securing stable stream types, re-establishing floodplain and alluvial fan function, re-establishing riparian vegetation, decreasing the accelerated sediment supply, and helping to attenuate flood peaks can be met with this overall approach. Restoration treatments vary by the potential stable stream type; thus the various design scenarios reflect such differences. The typical Design Scenarios #1–4 involve reaches where the sediment supply and transport rates vary by stream type and condition; thus the annual unit sediment transport values are adjusted by the associated channel length of similar condition. The tributary reaches related to the Design Scenarios #6 and #7 utilize the total length of the tributary channels within the associated sub-watershed. Design Scenario #5 that converts A, F, and G stream types to the braided, D stream type with sediment detention basins (non-perennial systems) does not use the unit transport calculations for total export as these stream type conversions do not relate to restoring the reaches to a "Good" condition. Rather, the sediment detention basins and surface storage on the alluvial fan from the braided, D4 stream type are designed to store 100% of the sediment yield, and thus these scenarios are associated with a zero sediment transport to the mainstem.

Additionally, the POWERSED model was used to indicate the percentage of available sediment transported. The results indicate aggradation, degradation, or stable bed conditions. For a river to be stable it must have sufficient energy to transport the available sediment; thus a zero sediment yield goal is not compatible with a stable channel. Sediment supply is potentially reduced due to streambank and streambed stabilization measures as proposed, which can reduce the existing yields by three orders of magnitude (FLOWSED). The sediment supply that is made available must be transported (POWERSED). The exceptions to this are the proposed scenarios that are designed to store sediment (e.g., Design Scenarios #5: A, F, and G stream types converted to D stream types). In this scenario, the POWERSED model is used to show the amount of sediment that is deposited on the fan surface separate from the sediment detention basins based on the proposed stream type conversion to D4 stream types. If the POWERSED runs show degradation in other scenarios, then grade control for the design is required.

Structures in Natural Channel Design

The recommended 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. The structures listed in **Table 7** are recommended for use in the watershed restoration for a wide variety of situations and objectives. These structures are particularly adapted to A4, B4, C4, and D4 stream types. The G4 and F4 stream types must be converted to B, C, or D stream types before structures can be installed. The details of each of the structures in **Table 7** are described in this section.

Table 7. 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*				✓	✓
Converging Rock Clusters				✓	✓

* use only in ephemeral stream systems

Rock Vane, J-hook

Rock vane, J-hook structures are utilized for streambank stabilization, fish habitat, and energy dissipation (**Figure 58**). The streambank area protected is calculated as three times the length of the vane arm. The hydraulic function of this structure is similar to the root wad, log vane, J-hook structure, but instead it is constructed with rock making it adaptable to ephemeral streams and larger perennial channels. Because the availability of extensive rock is present in certain locations, the costs associated this structure are reasonable and its appearance in the channel would not be unnatural where rock is present.

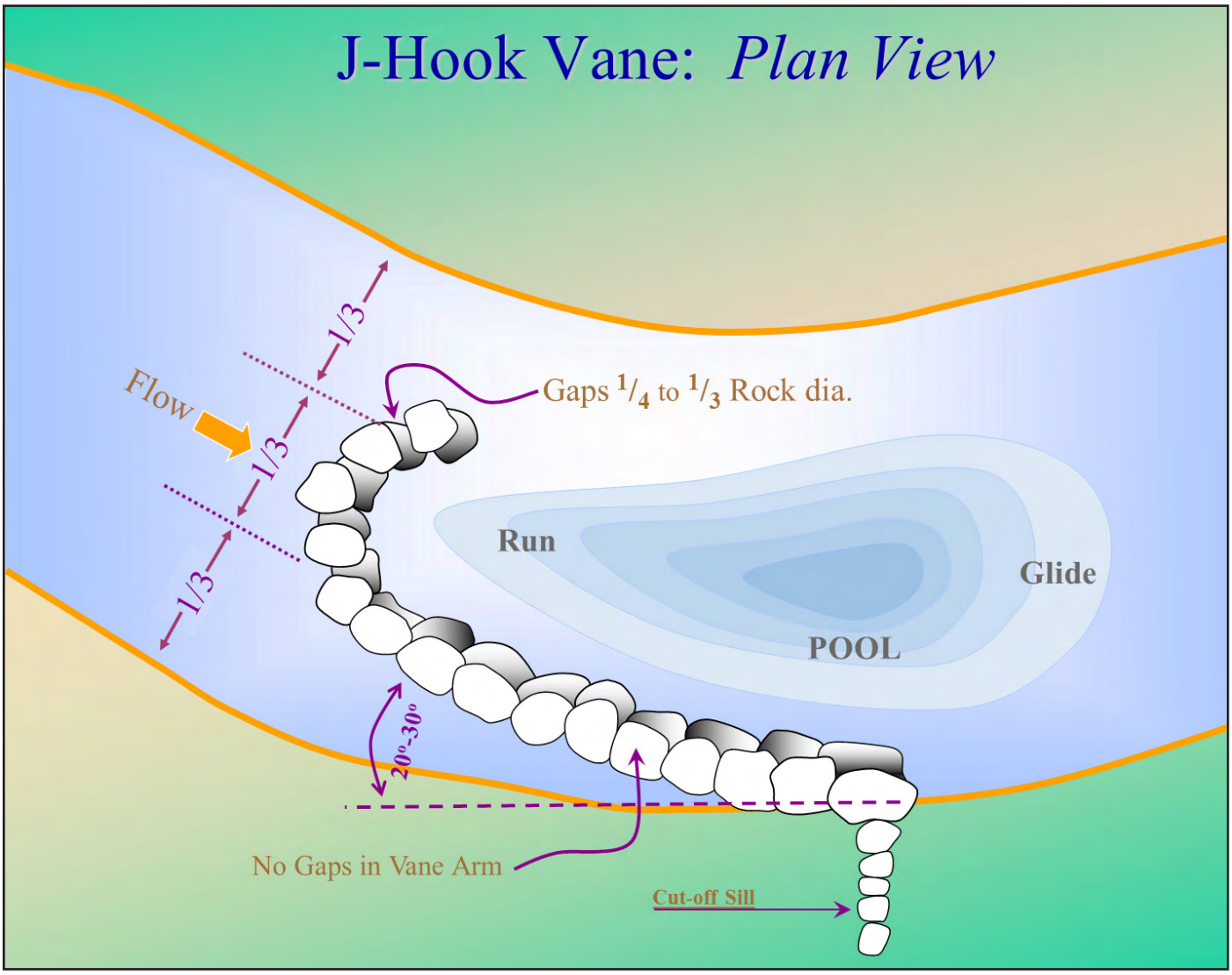


Figure 58. The rock vane, J-hook structure for streambank stabilization, fish habitat, and energy dissipation.

Root Wad, Log Vane, J-hook

The root wad, log vane, J-hook structure is designed to decrease near-bank shear stress to reduce streambank erosion by redirecting high velocity gradients away from the streambank and placing the erosive currents in the center of the stream (**Figure 59**). The structure also creates fish habitat and provides overhead cover for fish by creating a run-pool-glide complex and an undercut bank utilizing native logs. 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 tailout (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. This structure is intended for perennial flow channels to maintain saturation of logs.

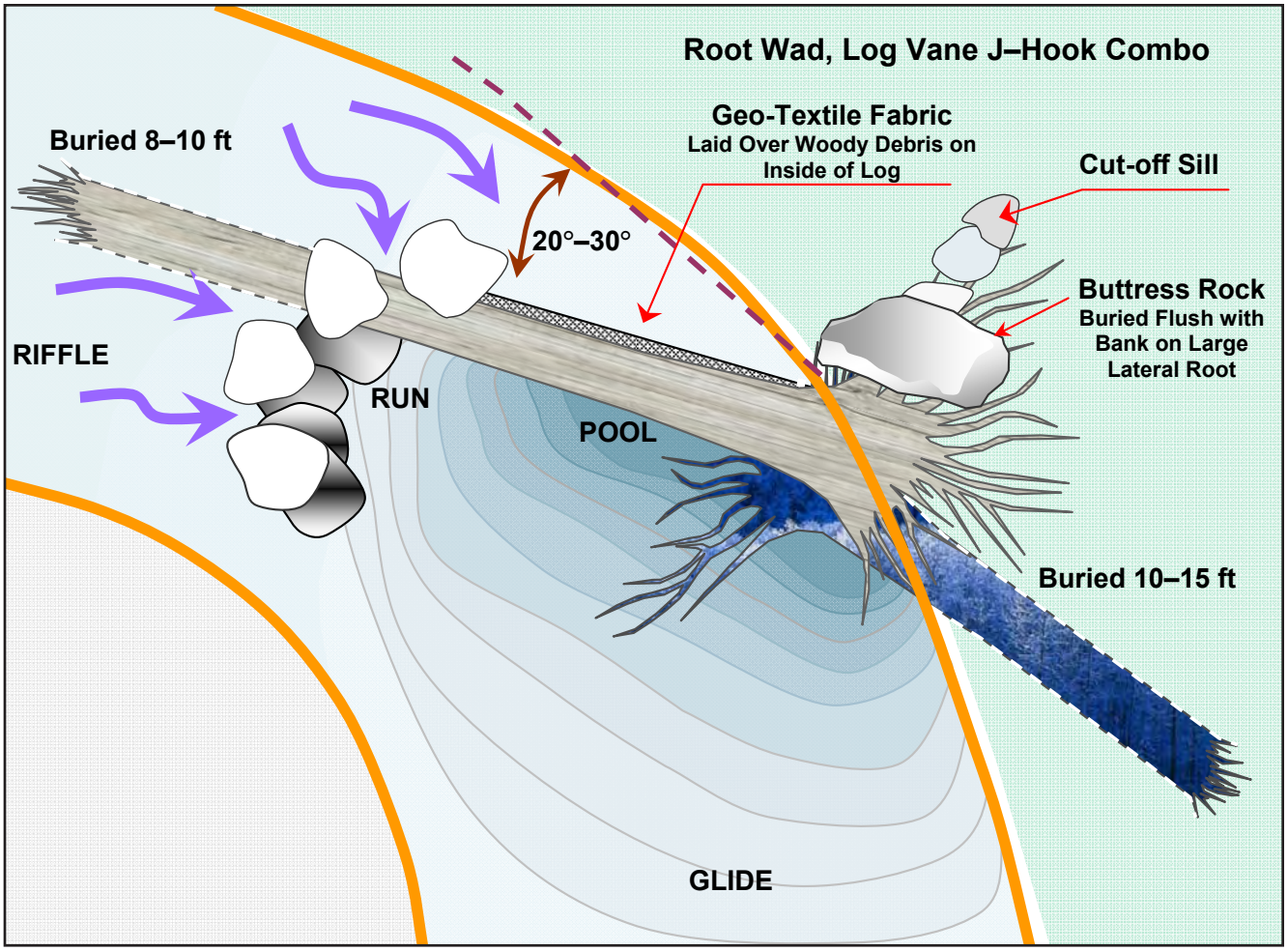


Figure 59. The root wad, log vane, J-hook structure for streambank stabilization, fish habitat, and energy dissipation.

Rock Cross-Vane

The rock cross-vane structure illustrated in **Figure 60** decreases near-bank stress and provides grade control. 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 also prevents downcutting of stream channels and provides floodplain connectivity. The rock cross-vane is also used at bridge crossings as in **Figure 61.** An implemented cross-vane on the Little Snake River, Colorado, is shown in **Figure 62**.

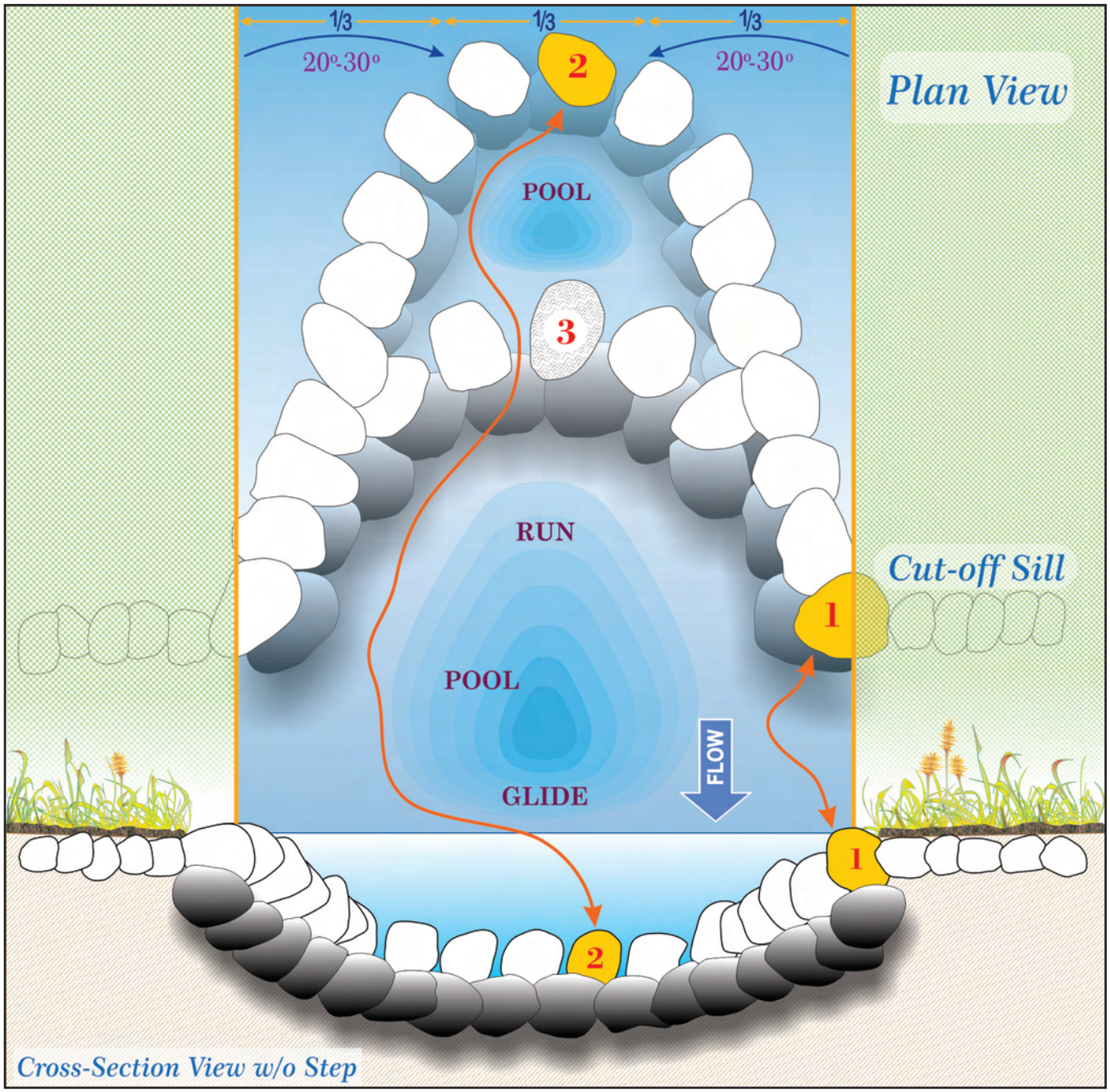


Figure 60. The rock cross-vane structure for grade control, streambank stabilization, and fish habitat.

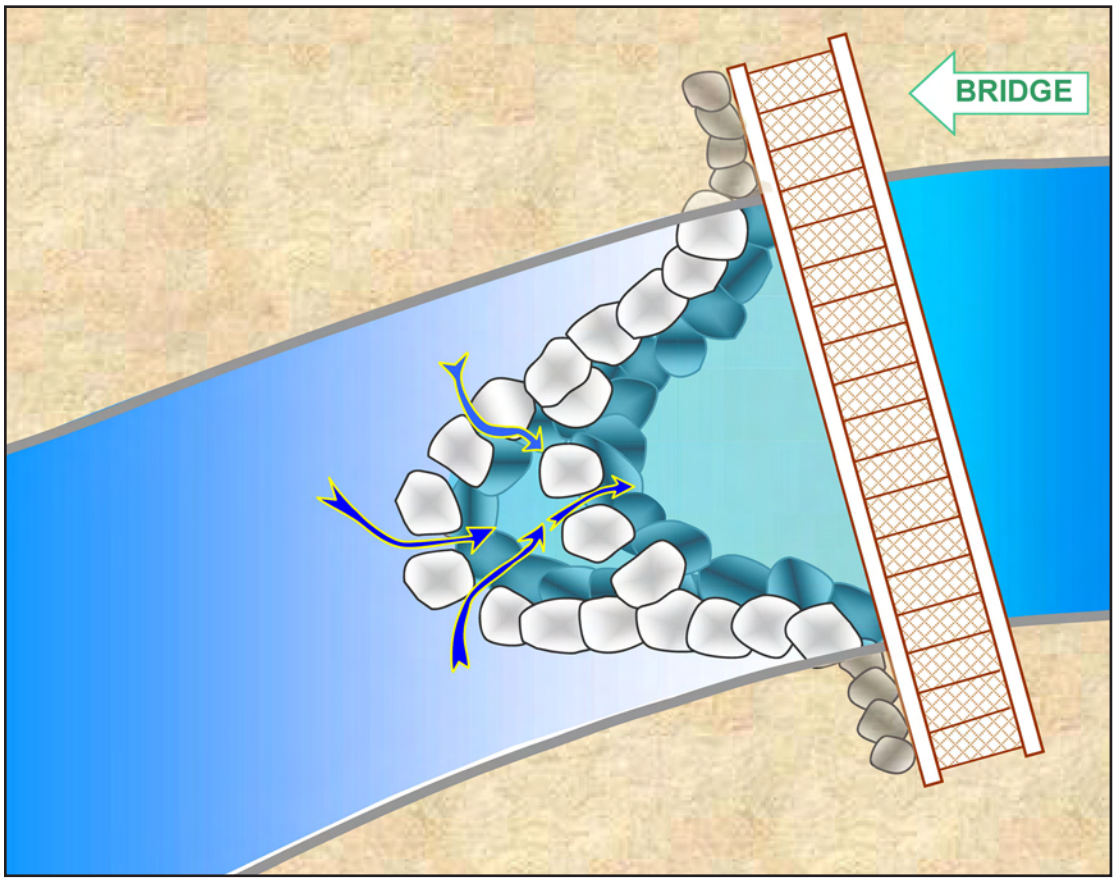


Figure 61. The application of the rock cross-vane for bridge and channel stability (Rosgen, 2001b).



Figure 62. A rock cross-vane at a bridge crossing on the mainstem Little Snake River, Colorado.

The Toe Wood Structure

The toe wood structure is designed to enhance fish habitat, stabilize streambanks, and maintain a low width/depth ratio of the design channel. The advantages of this structure are the availability of the toe wood material, the associated lower costs, and 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 63**). Another option uses woody transplants, such as willow, alder, cottonwood, or dogwood, instead of the cuttings and sod mats (**Figure 64**). Where sod mats and woody transplants are unavailable, cuttings are used with "burrito" soil lifts as in **Figure 65**. Examples of the implemented toe wood structure are shown in **Figure 66** and **Figure 67**.

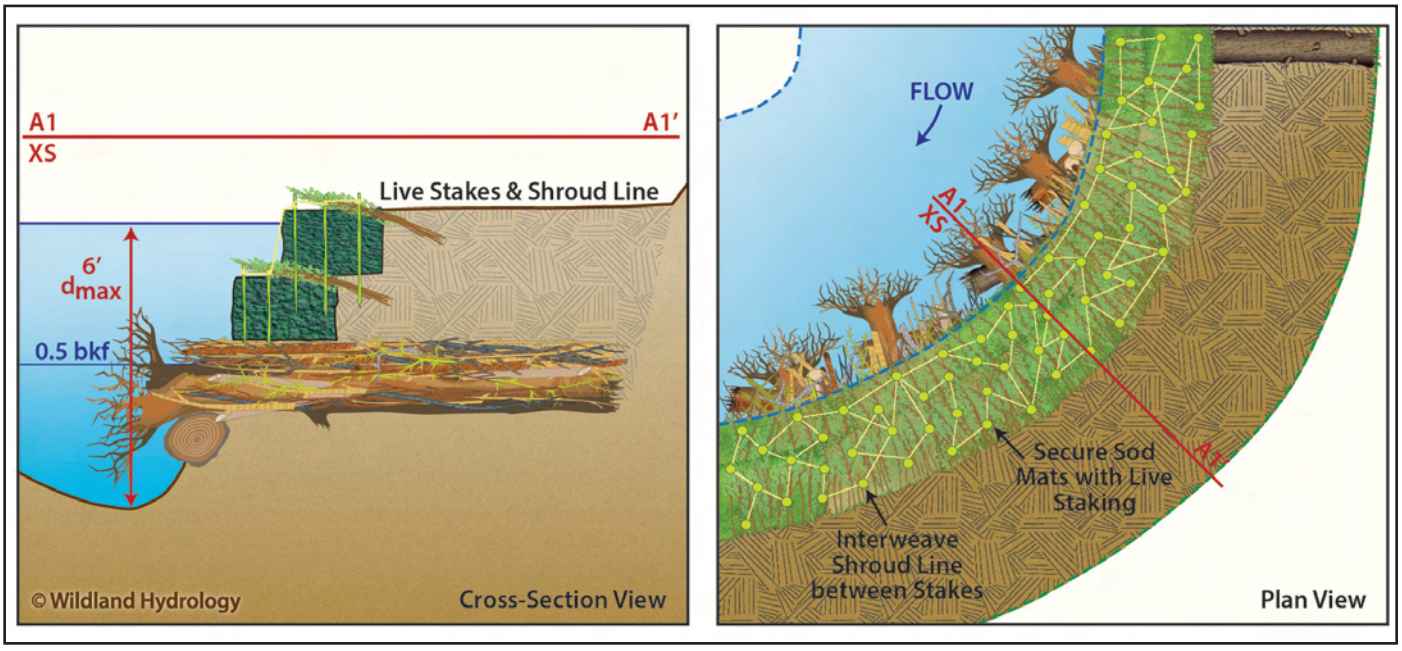


Figure 63. The toe wood structure with cuttings, sod mats, and live staking.

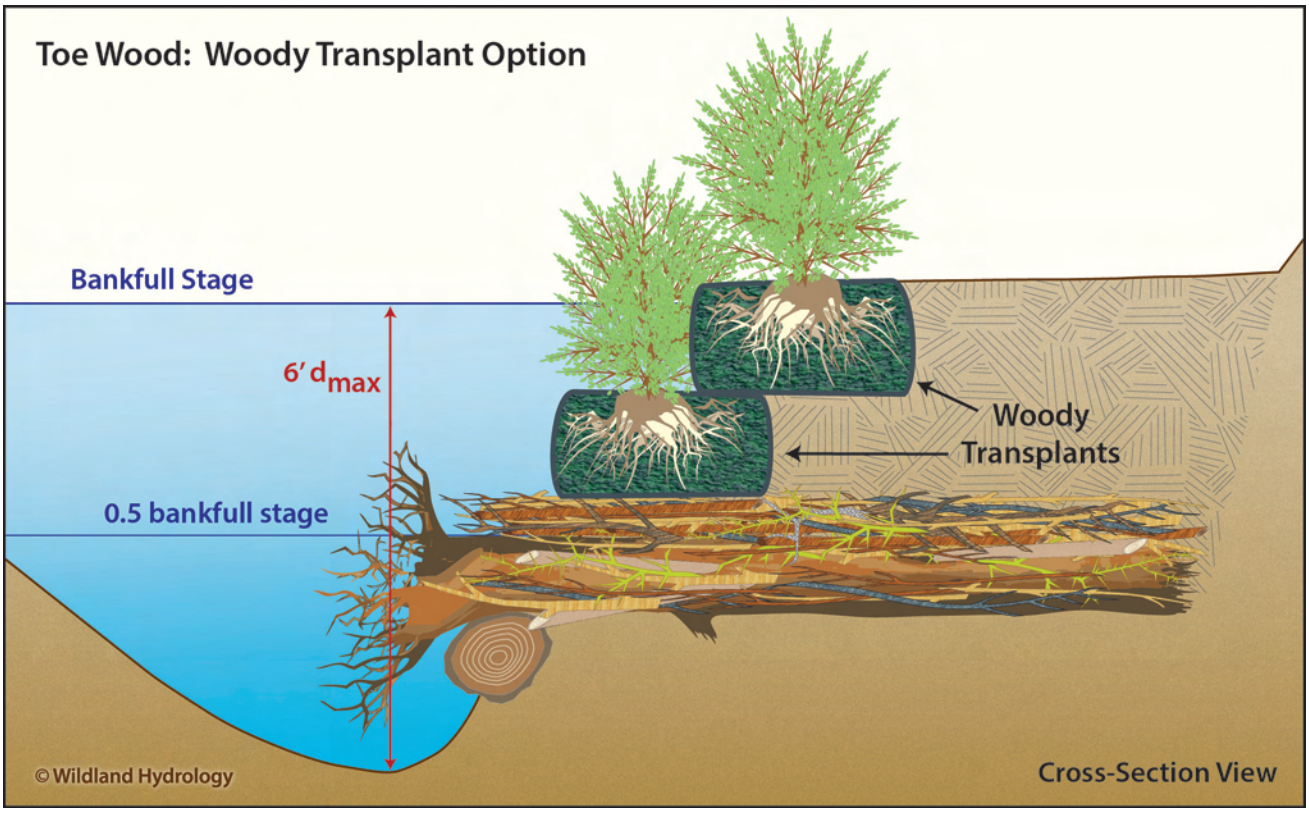


Figure 64. The toe wood structure with woody transplants.

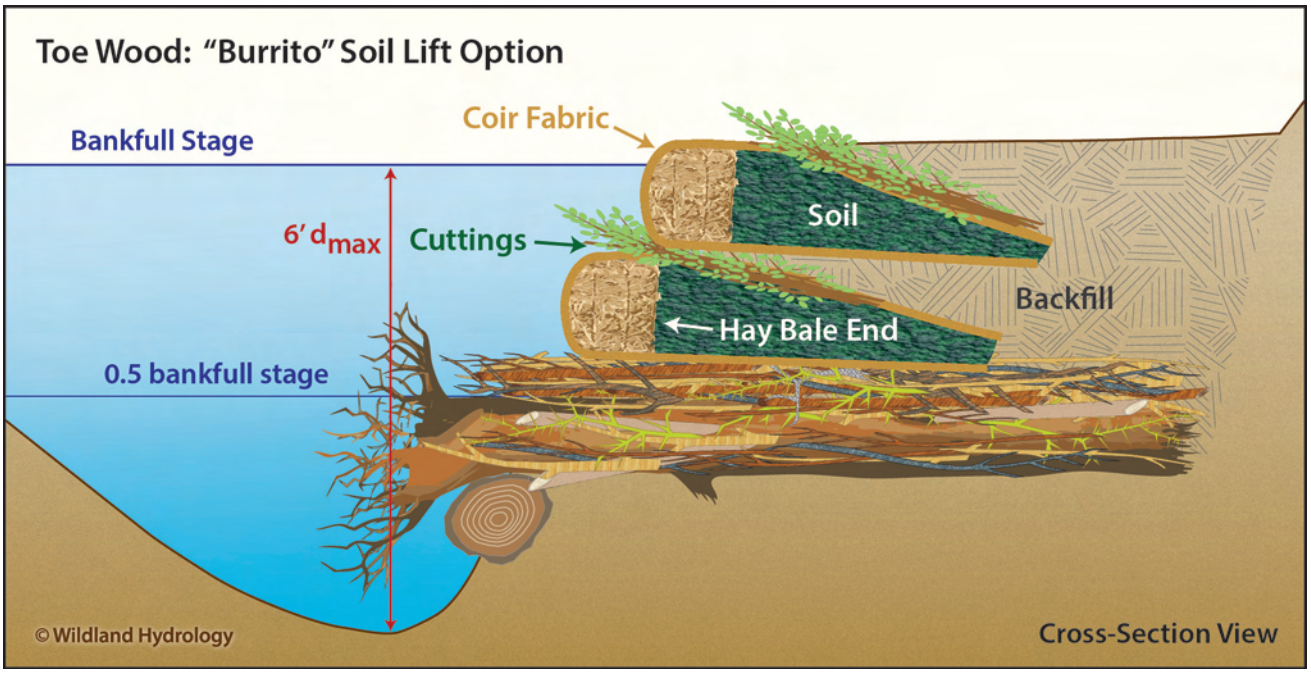


Figure 65. The toe wood structure with cuttings and "burrito" soil lifts.



Figure 66. Implemented toe wood structure, Heart Rock Ranch, Idaho.



Figure 67. Implemented toe wood structure, Heart Rock Ranch, Idaho.

Rock & Log Rollers Structures

The rock and log roller structures provide grade control and energy dissipation that are designed to 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. The logs also provide fish habitat by creating instream cover. The log structure is shown in **Figure 68** as implemented on a Colorado river, and a schematic of the structure is depicted in **Figure 57**.



Figure 68. The rock and log roller structure implemented on the Roaring Fork of the Little Snake River, Colorado.

Rock Step–Pool Structure

Rock step–pool structures are recommended for steep, A4 stream types and moderately steep B4 stream types to create step–pool morphology for energy dissipation, grade control, streambank stabilization, and fish habitat. A schematic of the structure is illustrated in **Figure 69**.

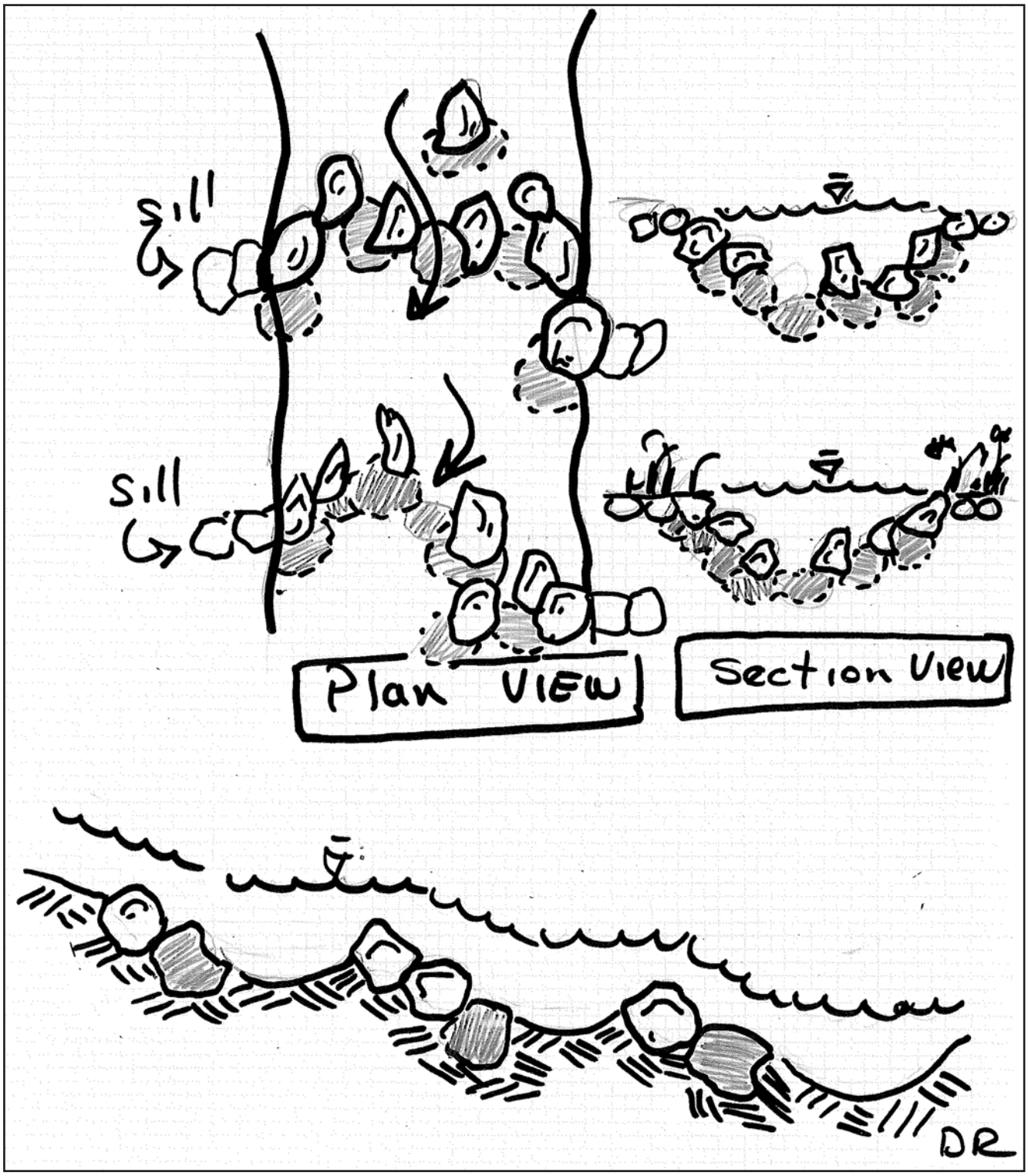


Figure 69. Rock step–pool structures for grade control, energy dissipation, streambank stabilization, and fish habitat.

Converging Rock Clusters

Converging rock clusters provide grade control at the head of riffles to keep the slopes of the glide and pool flat and the riffle/rapid steep. These structures also dissipate energy and provide instream cover. The rocks must be submerged below half of the bankfull stage. Converging rock clusters, as implemented on Ohio Creek in Colorado, are shown in **Figure 70**, and the structure design is illustrated in **Figure 71**.



Figure 70. Converging rock clusters at the head of a riffle as implemented on Ohio Creek, Colorado.

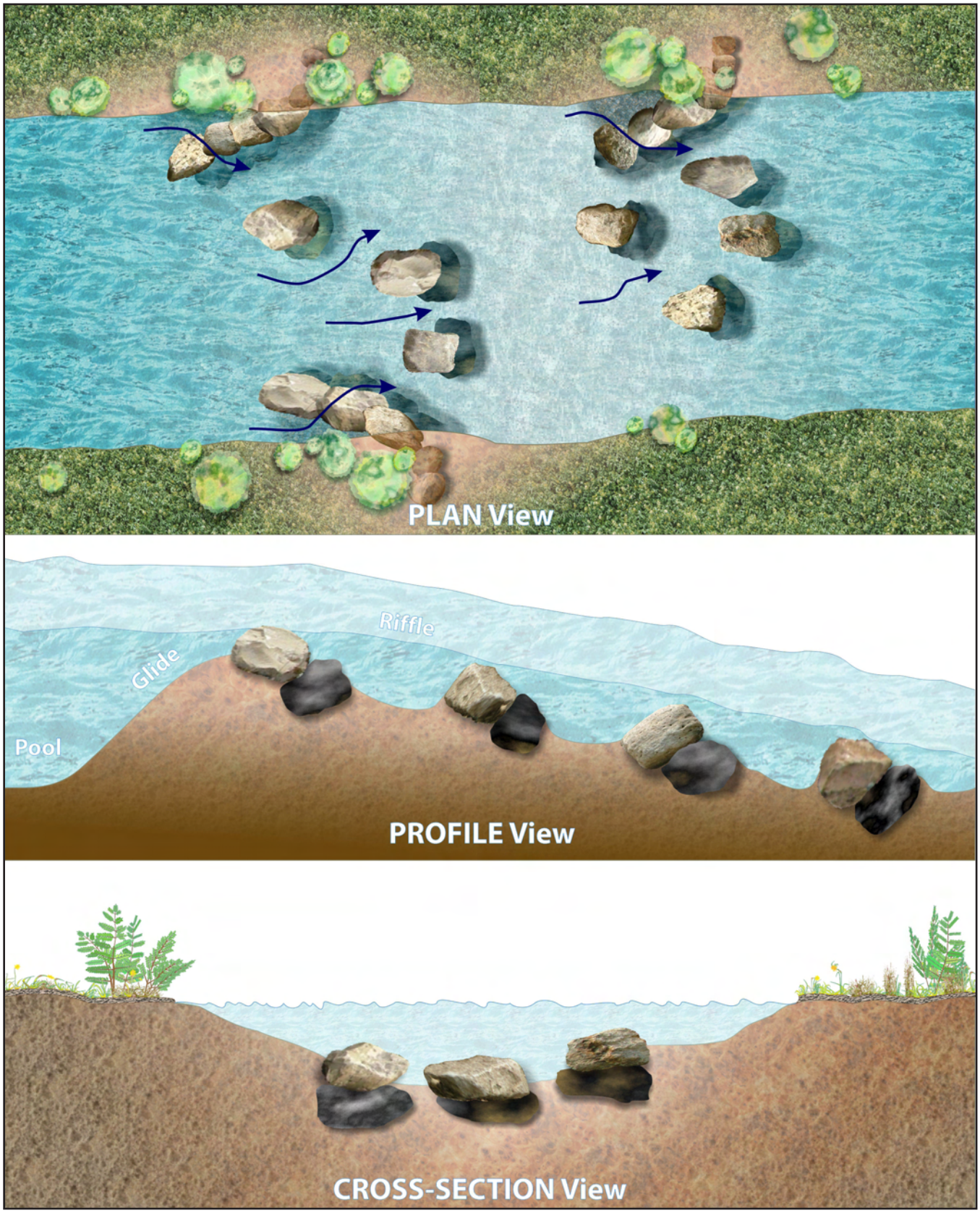


Figure 71. The plan, cross-section, and profile views of converging rock clusters.

Sediment Detention Basins

Sediment detention basins will be excavated *5.0* to *15.0 ft* deep 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 sediment related to post-fire instability. Sediment detention basins are more effective and economical if they are located in the transition where the valley transitions from narrow to wide. 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 72** and **73**). **Figures 72** and **73** show a sediment detention basin schematic for use in alluvial fans (VT III). **Figures 74** and **75** 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 the upstream extent of the basin, structures must be put in place to stop headcuts from progressing upstream. Two structures are recommended for this purpose. Log crib walls are shown in **Figures 72** through **75**, which are a series of interlocking logs stacked in a "V" shape pointing upstream. Log crib walls will be used in situations where the flow from upstream is not omnidirectional and in wider valleys. The second option is a series of log steps that drop water into the detention pond incrementally. Log steps are recommended in steep, narrow valleys where the direction of water entering the structure is omnidirectional.

Log Sills

Log 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. Log sills should be buried within 0.1 ft to 0.4 ft of the post-restoration ground surface and keyed into stable points. When used in combination with 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). Log sills should be used in existing, functioning, 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.

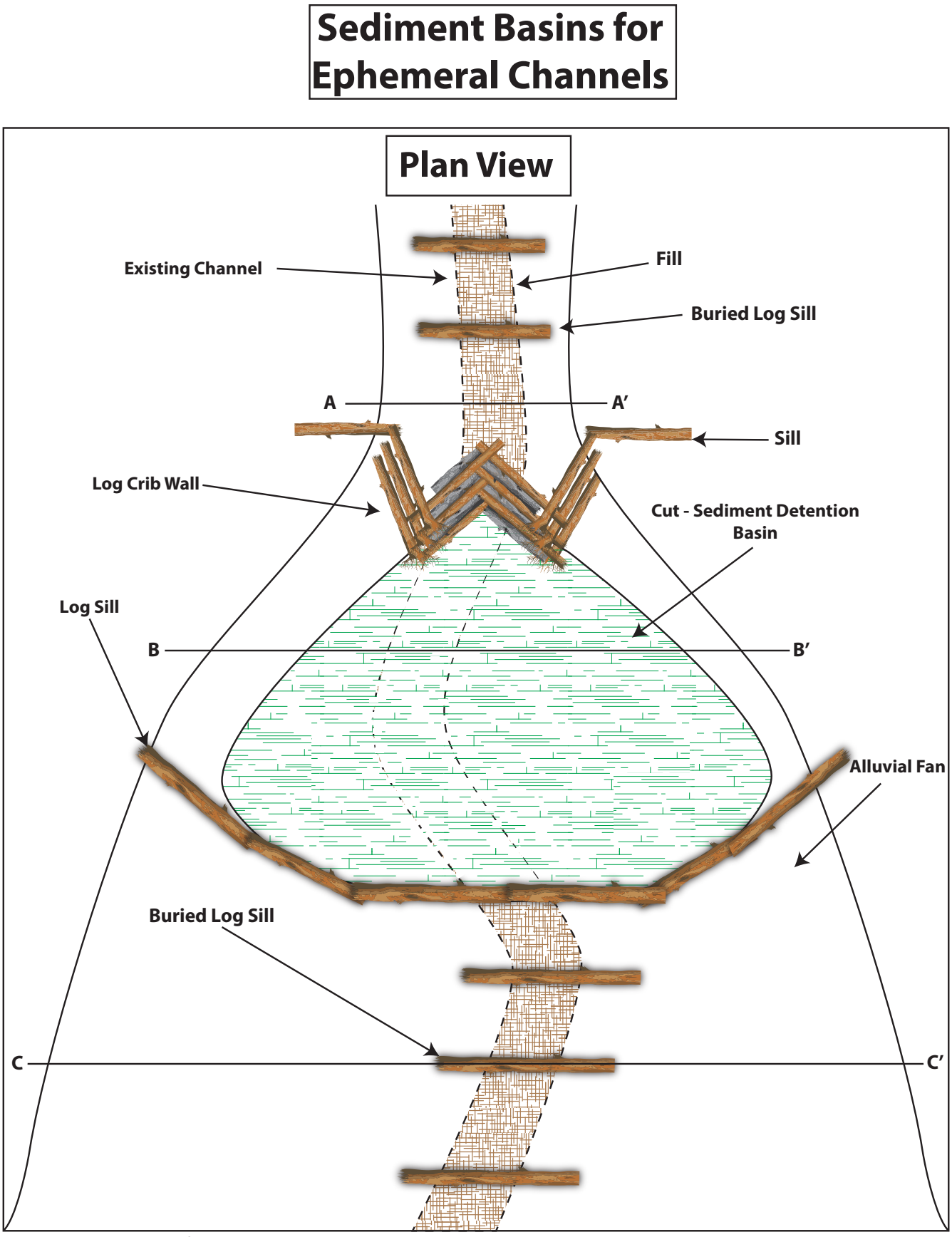


Figure 72. Plan view of a single-thread to multiple-thread conversion using a sediment detention basin in a Valley Type III.

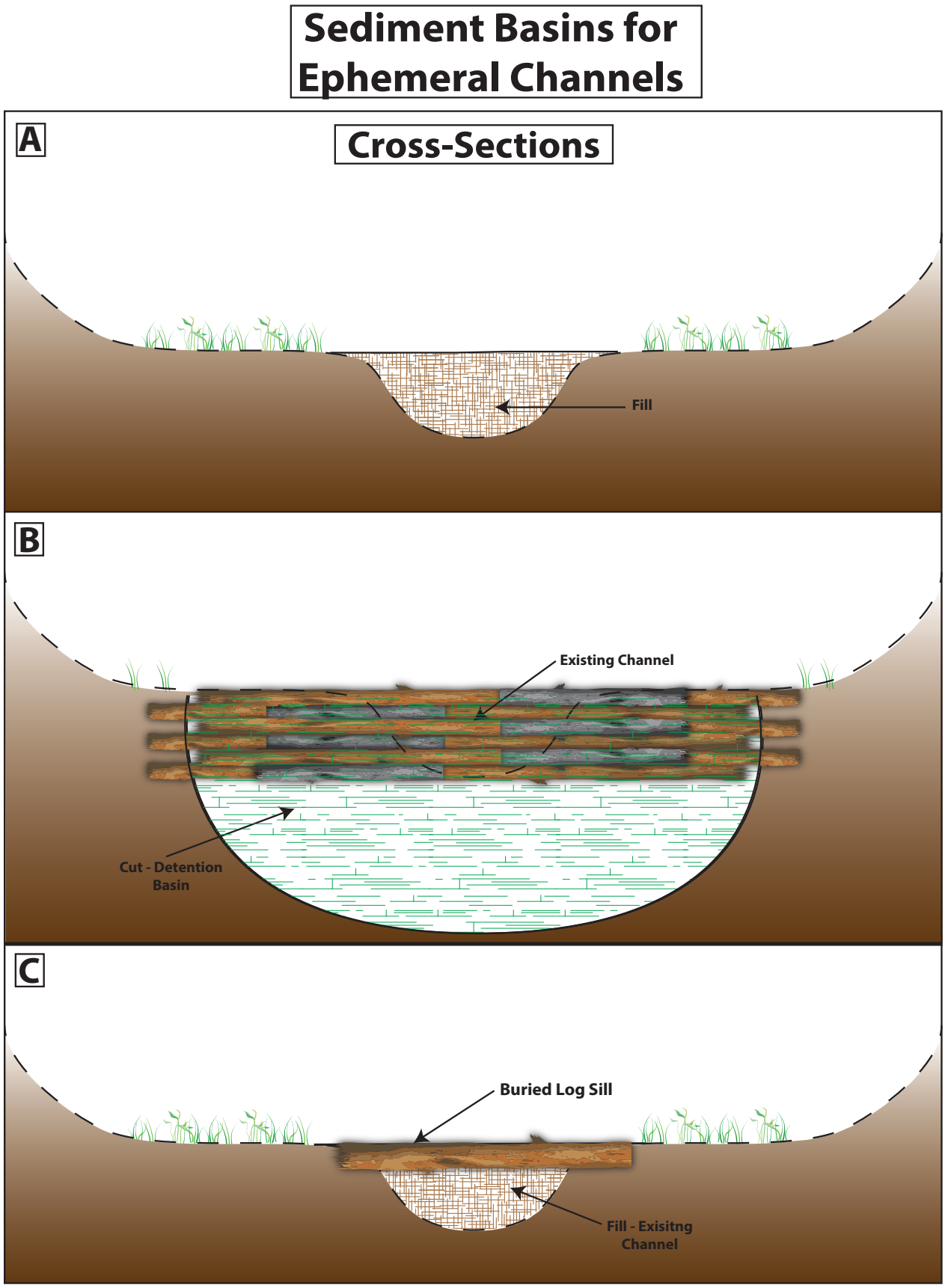


Figure 73. Cross-section views of a single-thread to multiple-thread conversion using a sediment detention basin in a Valley Type III.

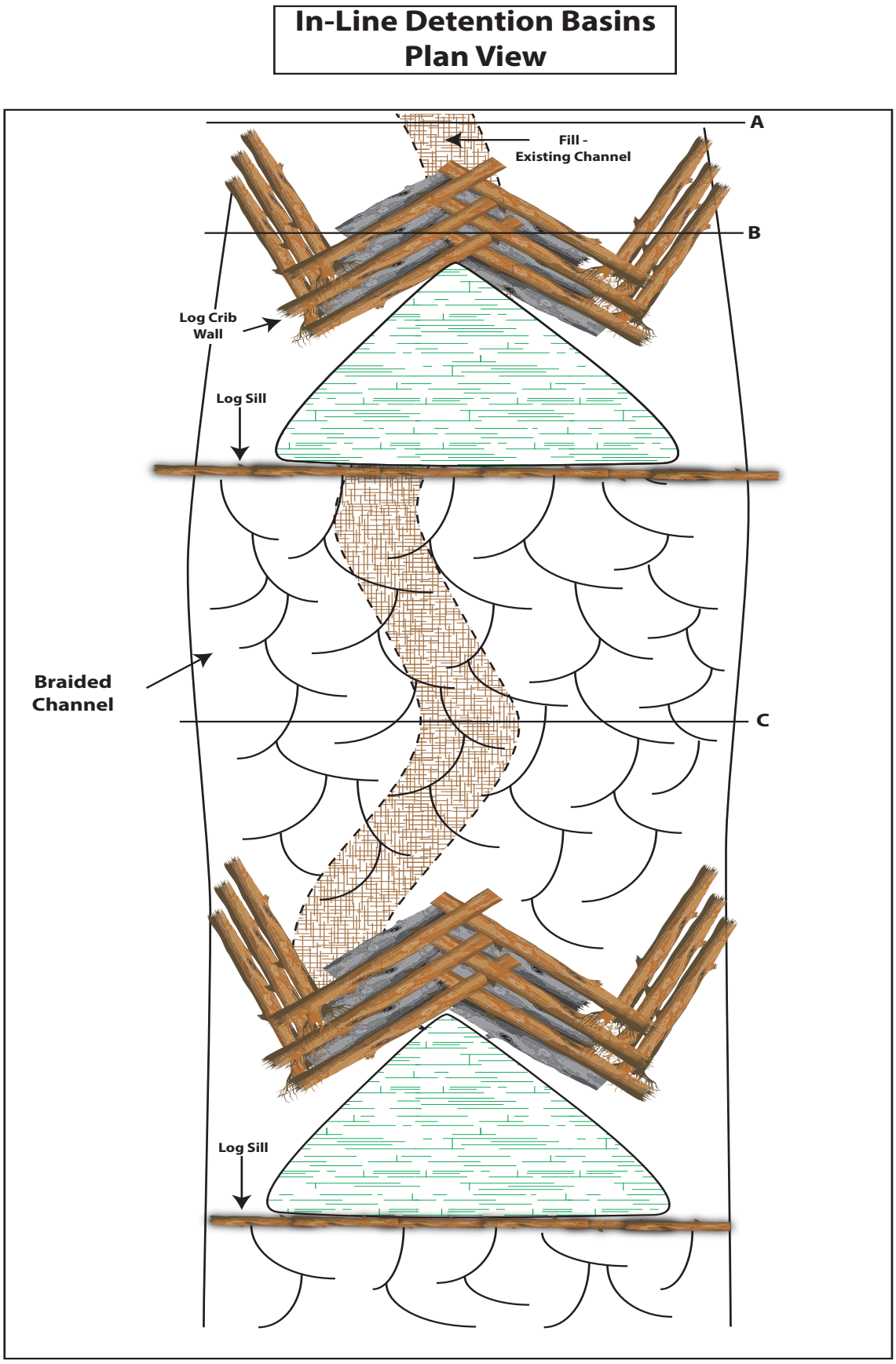


Figure 74. Plan view of a single-thread to multiple-thread conversion (Design Scenario #5) using sediment detention basins in Valley Types II and VIII.

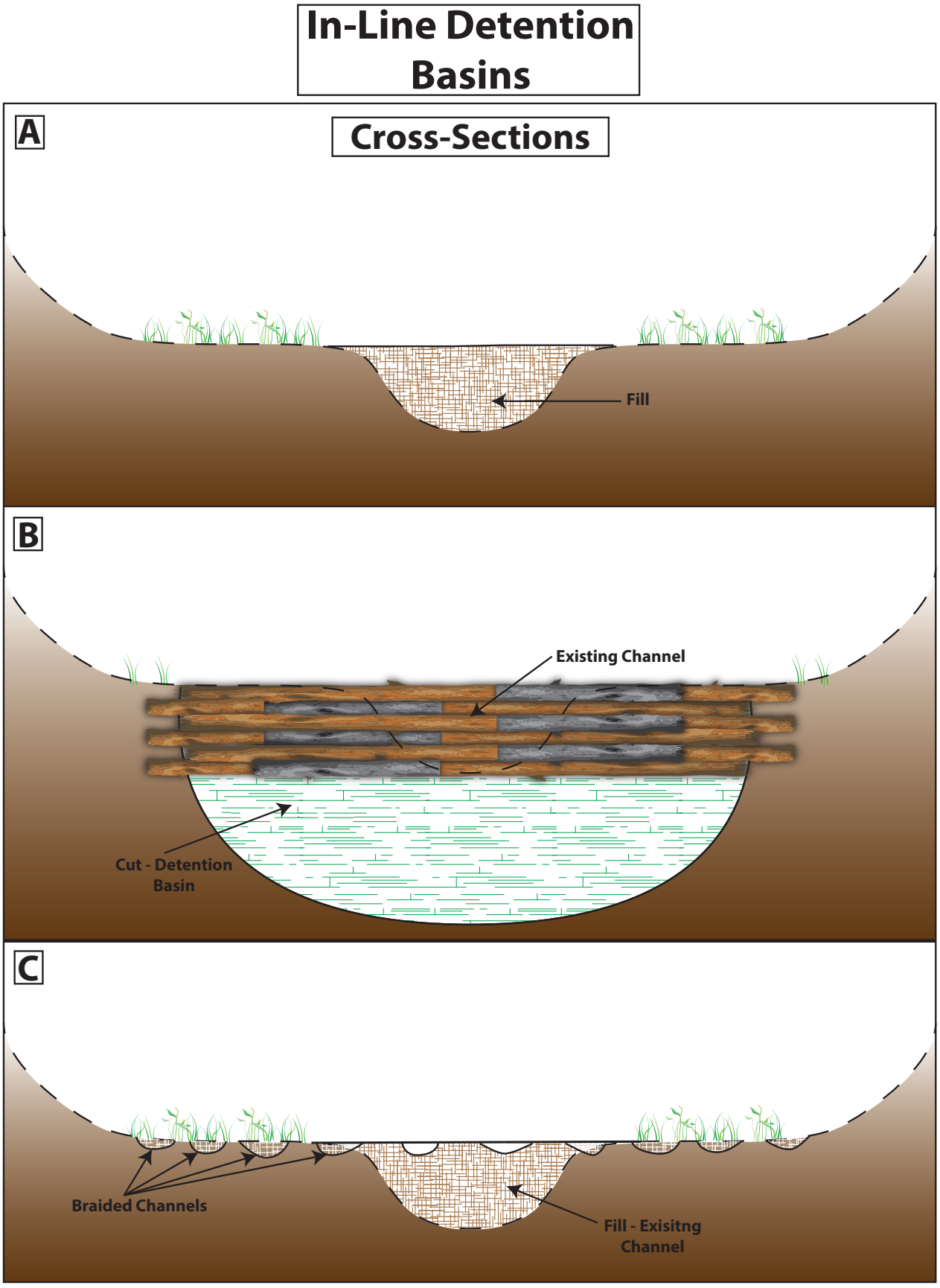


Figure 75. Cross-section views of a single-thread to multiple-thread conversion (Design Scenario #5) using sediment detention basins in Valley Types II and VIII.

Structures Summary

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 8**). J-hooks, cross-vanes, debris basin structures, and some 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. Front end loaders and excavators are often used for the transplanting. Where these adult plants are not readily, available willow cuttings and grass seed can be used in combination with mulch (wood or straw). 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.

Table 8. List of structures recommended by scenario for watershed restoration in the areas affected by the fire.

Structures	Scenarios						
	D4 to C4	F4 to B4	G4 to B4	C4 to C4	A4, F4, or G4 to D4	F4b to B4	A4 to A4
J-Hook / Cross Vane	✓	✓	✓	✓		✓	✓
Rock and Log Rollers (step-pool)		✓	✓			✓	✓
Toe Wood	✓	✓	✓	✓		✓	
Debris Basin *					✓		
Cross-Channel Sills *					✓		
Converging Rock Clusters	✓	✓	✓	✓		✓	

* use only in ephemeral stream systems

Developing the Restoration Master Plan

The primary objectives of the *WARSSS* analysis are to locate, quantify, and prioritize specific sources of disproportionate sediment and identify high risk watersheds and impaired stream channels so that practical and effective restoration treatments can be designed and implemented. There are four discreet levels in the decision making process, starting with utilizing the results of the *WARSSS* analysis and ending with implementation of the recommended treatments (**Flowchart 5**).

Level I – Conceptual Design: This phase is where the *WARSSS* analysis has identified potential treatments and design scenarios to address the sediment sources from hillslope, road, and channel processes. Design scenarios are established by valley type, stream type, and stream condition to meet specific objectives.

Level II – Field Validation: This phase is where existing condition, by location, as mapped in the *WARSSS* report (Rosgen *et al*., 2013), is verified and site specific data for the final detailed design is collected. For channel processes, this level is where the decision tree is implemented to ensure appropriate treatments are applied. Accessibility for mechanized equipment *vs.* hand implementation of proposed treatments is evaluated as part of the decision tree at this level.

Level III – Detailed Design: This phase provides the final design details, scaling, treatment, and revised cost estimates for implementation and sediment savings. The final design details are used to obtain necessary permits.

Level IV – Implementation Phase: This phase specifies contracting, equipment specification, sequencing of construction, access requirements, field supervision, training, quality control, and monitoring.

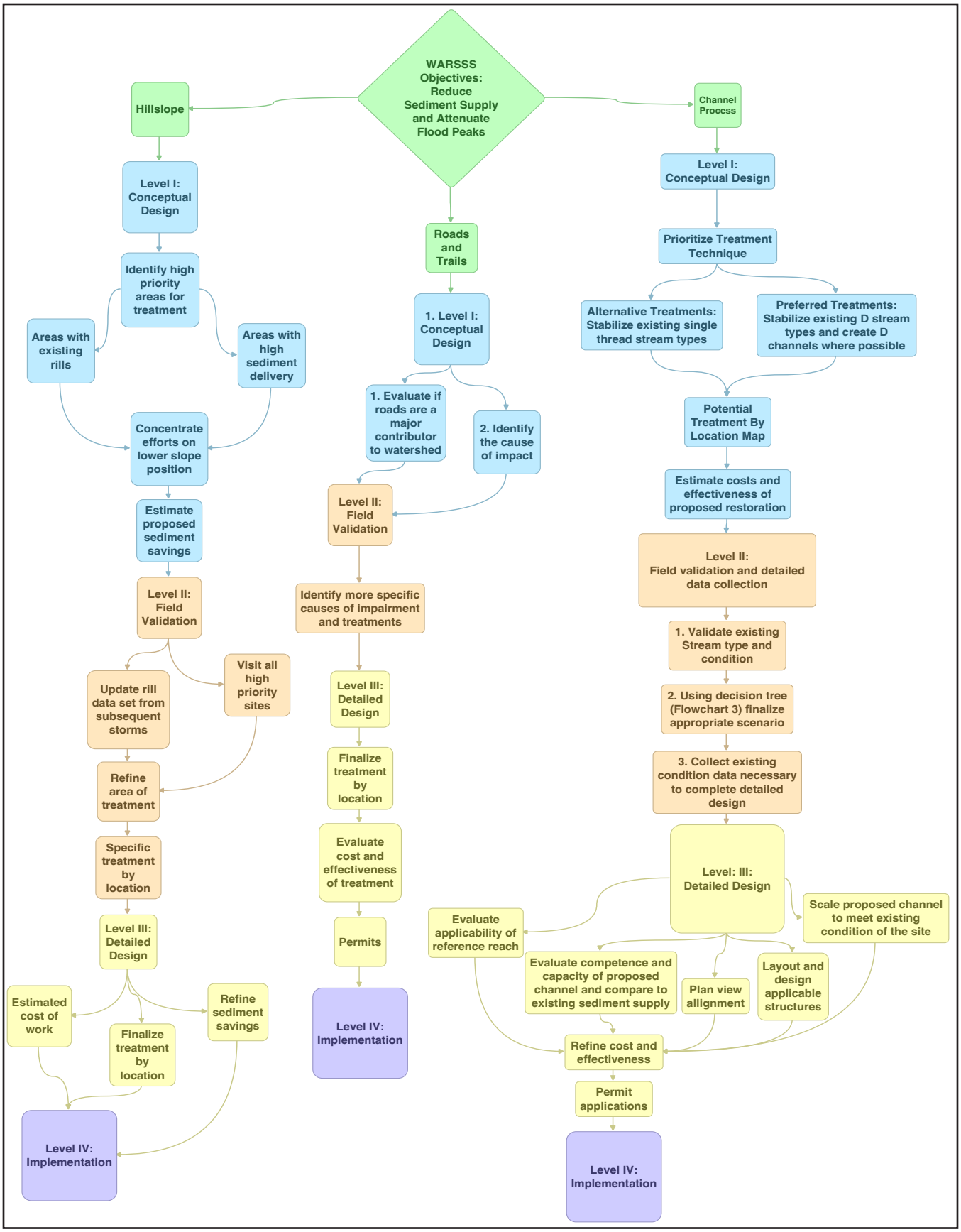
The following sections provide examples of the Level I Conceptual Design phase in Wellington Gulch (FC-010) and descriptions of Level II and III using Northfield Gulch (MC-010) for field verification and development of a detailed design.

WARSSS Results

The priority for the sub-watershed must be determined using the total introduced sediment contributions from hillslope, roads, and streambank erosion (**Figure 76** or **Table 2**). Relative contributions of hillslope, roads, and streambank erosion and the relationship to flow-related sediment (**Figure 77**) must be determined and prioritized by process.

WARSSS Summary: Wellington Gulch (FC-010) is priority #3 overall. The following are the relative sediment contributions:

- Hillslope = 18% (*625 tons/yr*)
- Roads = 11.6% (*395 tons/yr* – lowest priority)
- Streambank erosion 71% (*2,399 tons/yr* – highest priority)
- Flow-related sediment = *4,863 tons/yr* (net degradation = *1,444 tons/yr*)



Flowchart 5. Method for developing a restoration master plan.

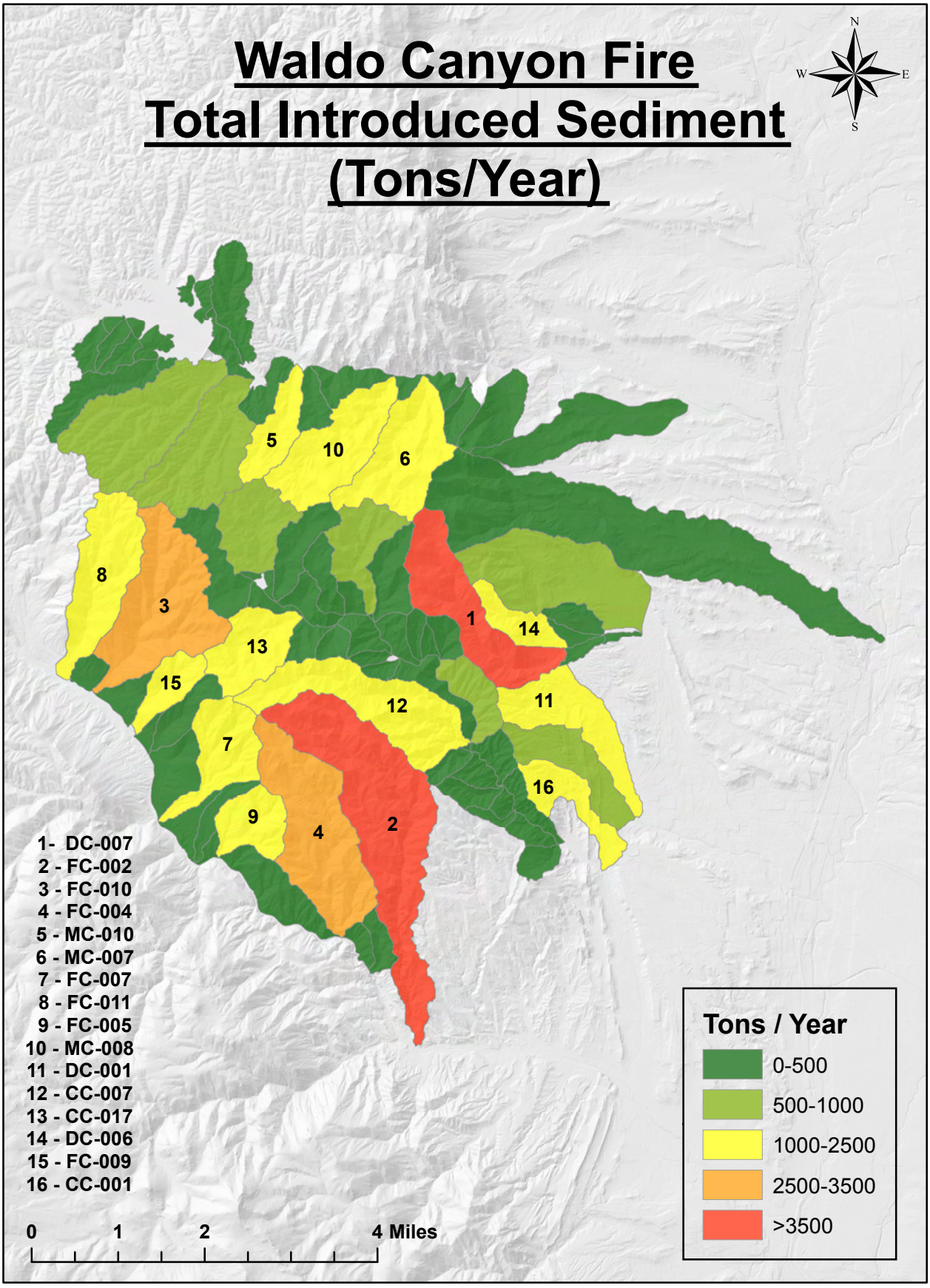


Figure 76. The top priorities for mitigation and restoration based on the disproportionate supply of introduced sediment.

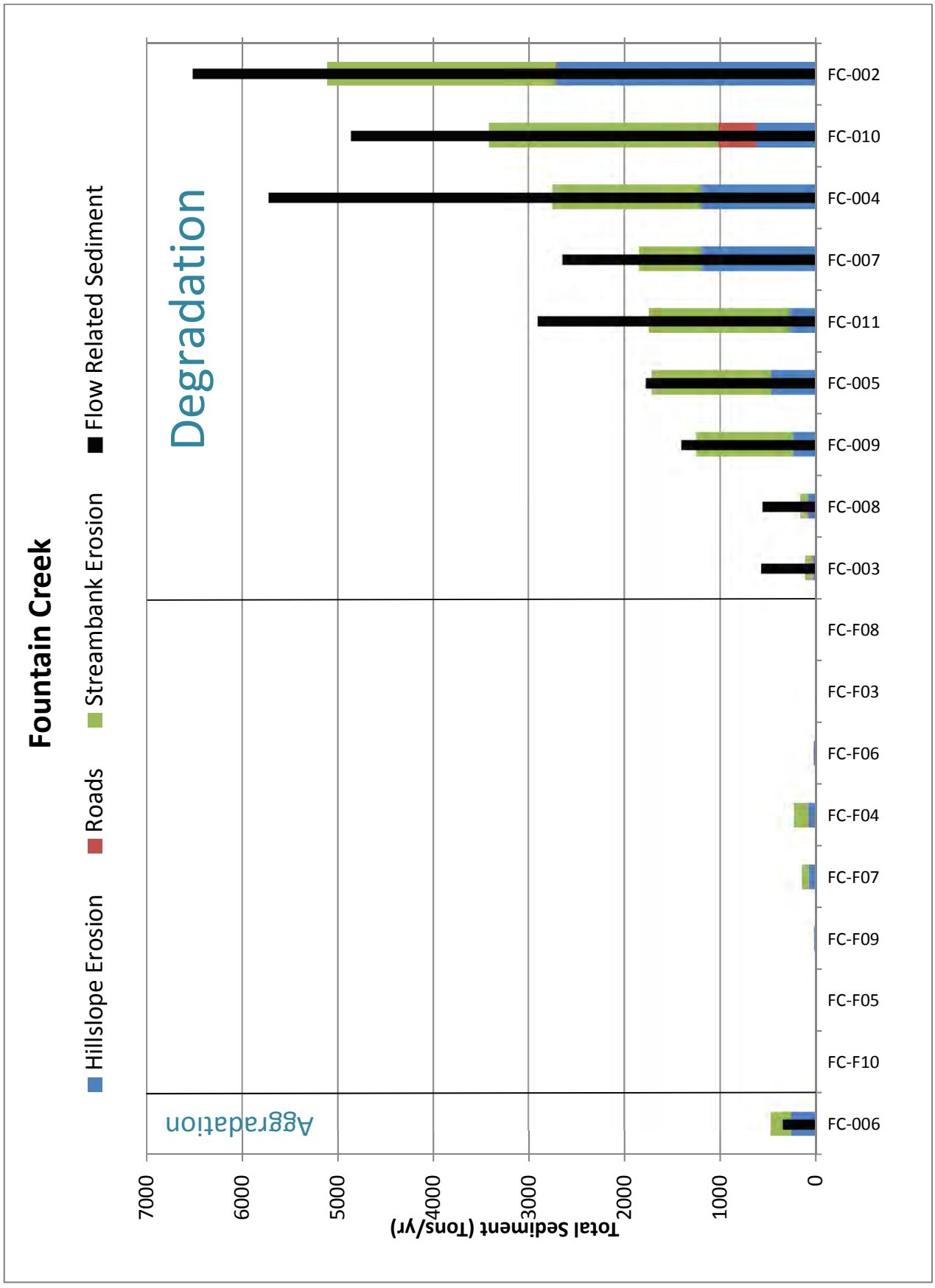


Figure 77. The relative contributions of sediment supply by process for the Fountain Creek sub-watersheds.

Master Plan for Hillslope Processes

Level I – Conceptual Design

This level predominantly uses the data provided by the Waldo Canyon *WARSSS* report to determine treatment priorities for hillslope processes by location (see **Table 9** for the top ten priority sub-watersheds and the corresponding hillslope sediment contributions). The primary tools used from the *WARSSS* data are the delivered sediment from hillslopes map with rill locations (**Figure 78**) and the GIS data file that summarizes the delivered sediment from hillslopes. **Figure 78** is reproduced for each of the top ten priority sub-watersheds in **Appendix III**. The highest priority areas within each sub-watershed of interest are identified by the following:

Priority 1 – Areas with hydrologically-connected rills

Priority 2 – Areas with rills in the lower 1/3 slope position

Priority 3 – Areas in the lower 1/3 slope position with a ground cover of 40% or less

Priority 4 – Areas with rills on any position of the slope

Priority 5 – Areas with a ground cover of 40% or less on any slope position

The process used to identify high priority areas for delivered sediment from hillslopes for a single watershed is as follows:

Step 1. Using the GIS data for hillslope delivery, calculate the tons per acre of delivered sediment for all polygons

Step 2. Calculate the median value of tons per acre; all areas higher than the median value are a high priority for treatment

Step 3. Identify any areas that have rills or ground covers less than 40% not represented by the above step, and add them to the priority areas

Step 4. Assume a reduction of 75% in delivered sediment from all potential treatment areas

The final product of the conceptual design phase (Level I) for hillslopes in sub-watersheds of interest is a map of priority areas by location and estimated sediment reduction from treated areas.

For Wellington Gulch: Annual delivered sediment from hillslopes in FC-010 = *625 tons/yr*. In Wellington Gulch, 92% (*575 tons/yr*) of the sediment from hillslopes is produced by 48% (527 acres) of the area (**Figure 79**). It is estimated that a 75% reduction in delivered sediment from treated hillslopes can be achieved using these methodologies, reducing hillslope sediment delivery from *575* to *144 tons/yr*, a reduction of 69% of the total delivered sediment (**Table 9**). Levels II and III must be completed for Wellington Gulch before implementation.

Level II – Field Validation

Step 1. Field validate the priority areas identified in Level I. Add to existing data any rills recently formed associated with subsequent storm events or any other changes in ground cover related to the sediment producing polygons not characterized in the *WARSSS* dataset.

Step 2. Visit all proposed high priority sites and refine treatment areas in addition to defining specific treatment by location.

Level III – Detailed Design

Step 1. Finalize treatment details and specific location

Step 2. Refine sediment savings due to treatment

Step 3. Estimate cost associated with work

Table 9. Hillslope sediment contribution and mitigation effectiveness for the top ten priority sub-watersheds in the Waldo Canyon Fire.

Sub-watershed	Total Acres	Priority Area (acres)	Priority Area (%)	Total Delivered Sediment (tons/yr)	Delivered Sediment from Priority Area (tons/yr)	Delivered Sediment from Priority Area (%)	Delivered Sediment Reduction (tons/yr)	Delivered Sediment Reduction (%)
DC-007	823	430	52%	1,815	1,484	81%	1,113	61%
FC-002	1,684	865	51%	2,710	2,519	92%	1,889	69%
FC-010	1,100	528	48%	625	575	92%	431	69%
FC-004	1,124	568	5%	1,202	1,041	86%	781	65%
MC-010	308	171	55%	446	410	92%	308	69%
MC-007	729	384	52%	678	670	98%	503	74%
FC-007	475	228	48%	1,199	1,016	84%	762	63%
FC-011	718	464	64%	280	278	99%	209	74%
FC-005	336	191	56%	470	422	89%	317	67%
MC-008	710	382	53%	486	481	99%	361	74%
Totals	8,006	4,211	53%	9,909	8,896	91%	6,675	69%

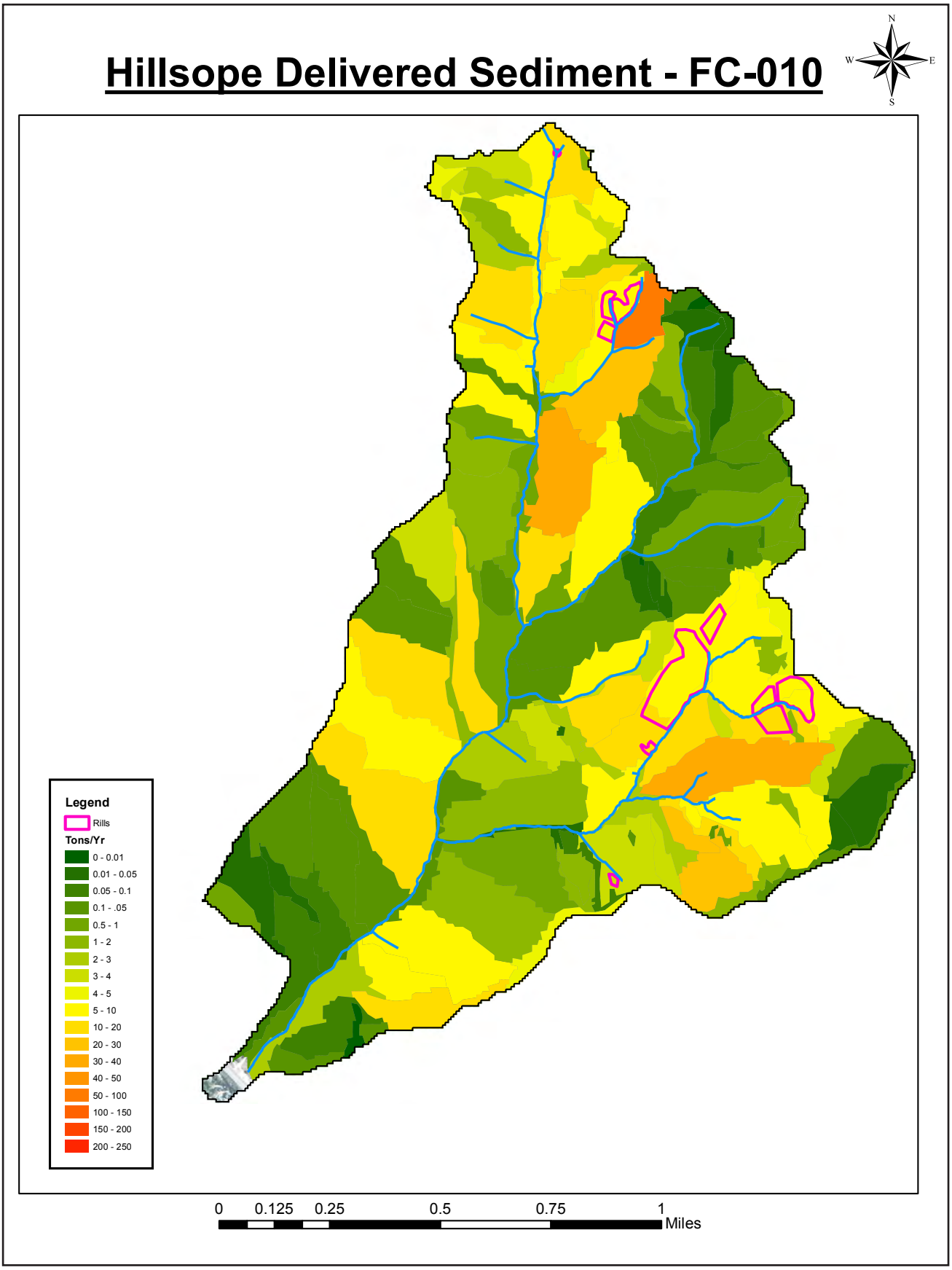


Figure 78. Distribution of delivered sediment from hillslope processes for Wellington Gulch (FC-010).

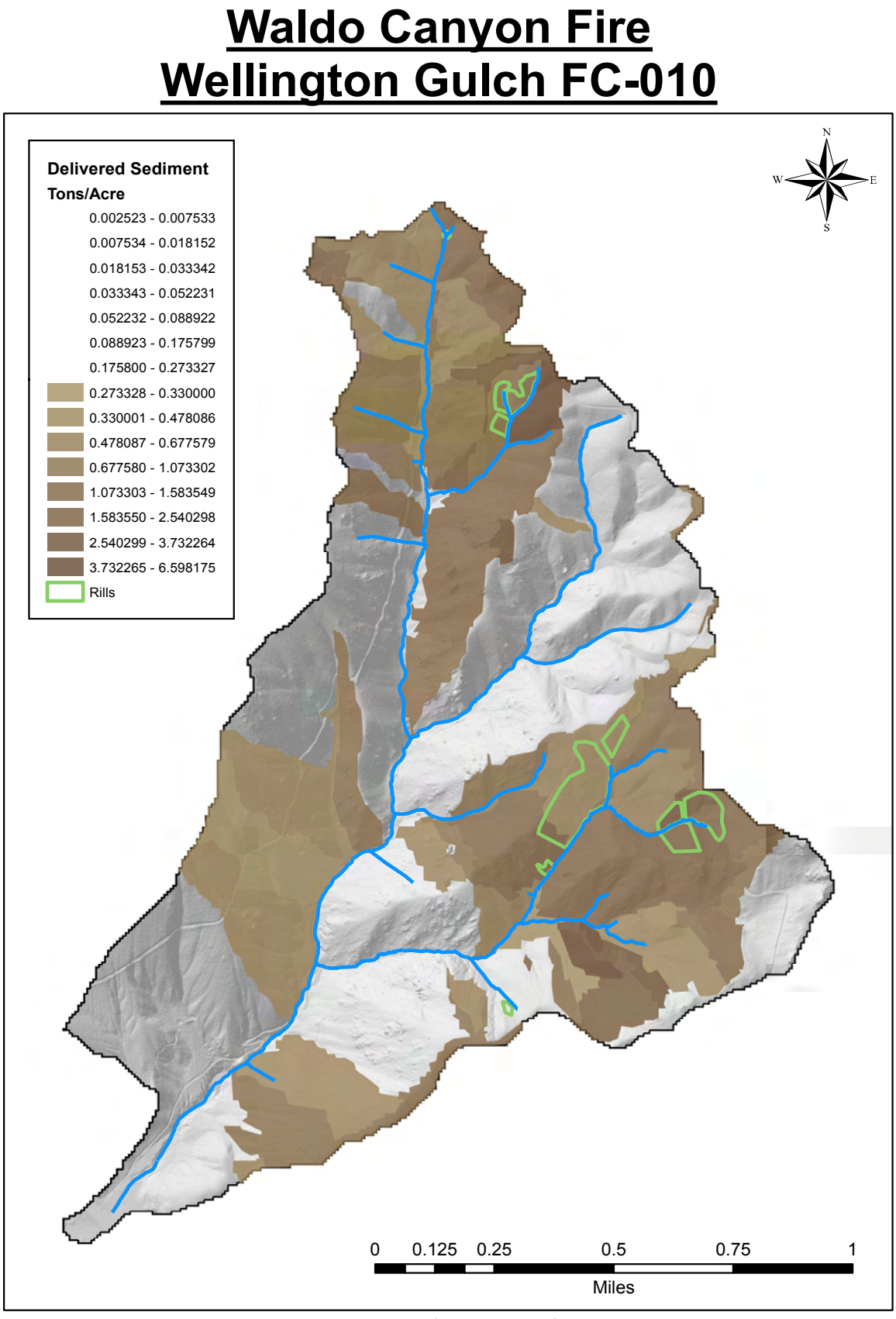


Figure 79. High priority hillslope areas proposed for treatment for Wellington Gulch (FC-010).

Master Plan for Roads and Trails

Level I – Conceptual Design

The *WARSSS* analysis provides a summary of the impact of roads and trails within each sub-watershed (Rosgen *et al*., 2013). This includes delivered sediment (tons/yr), acres and length of roads, number of stream crossings, and location. In Wellington Gulch, roads account for 12% (*395 tons/yr*) of the introduced sediment (**Figure 80**). The preliminary analysis identified 25.5 acres of road surface and 35,534 ft of road length with 15 stream crossings as potential sources of sediment. Reducing the amount of ditch-line water being delivered to drainageways, cross-drains or outsloping would potentially reduce the amount of sediment introduced per crossing. Stabilizing cut banks and road fills with vegetation would also help reduce road-related sediment supply.

Level II – Field Validation

In Level II, perform onsite evaluation and map specific treatment locations for possible relocation, cut and fill slope issues, road surface and drainage structures, and unauthorized trail usage.

Level III – Detailed Design

Design specific treatments based on recommendations to address sediment source and evaluate cost and effectiveness of each individual treatment. Obtain necessary permits to proceed with road and trail treatments.

Level IV – Implementation

Implement the recommended treatments.

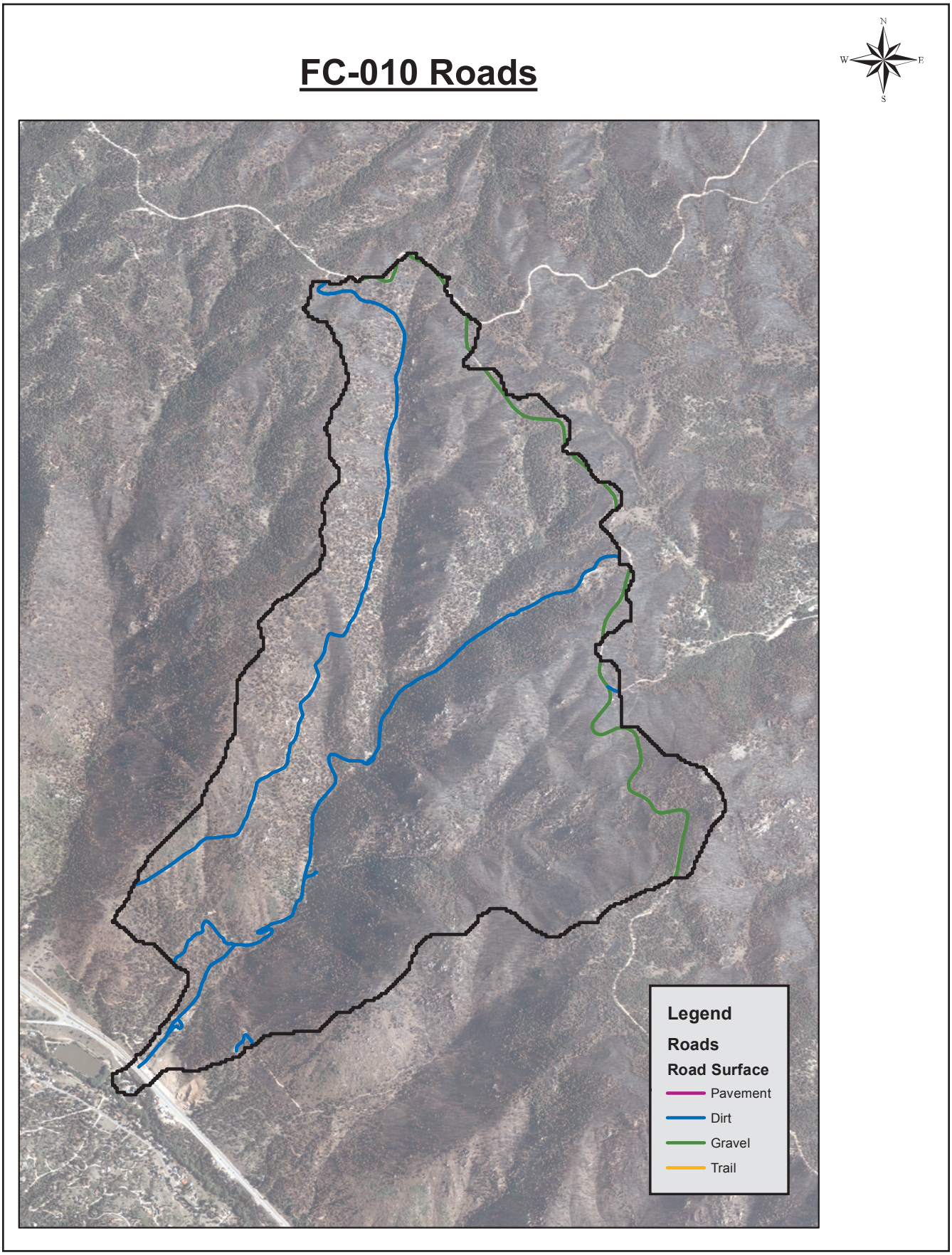


Figure 80. Location of roads in Wellington Gulch (FC-010).

Master Plan for Channel Processes

Level I – Conceptual Design

All decisions should be consistent with the decision making processes discussed in the master plan and the central tendency of natural rivers. The recommended priorities are based on meeting specific objectives of sediment reduction, flood attenuation, and re-establishing natural watershed function. The following progressive sequence is derived from the output of the decision tree (**Flowchart 3**) and establishes the overall priority of design scenarios and treatments:

Priority 1 – Stabilize existing D stream types to prevent channel incision

Priority 2 – Convert existing, single-thread channels to D stream types (Design Scenario #5)

Priority 3 – Convert existing A, F, and G stream types to B stream types (Design Scenarios #2, #3, #6, and #8)

Priority 4 – Convert existing, degraded, "Poor" A stream types to "Good" A stream types (Design Scenario #7)

Priority 5 – Where existing conditions and valley type require lowering the flood stage due to infrastructure or residences, convert "Poor" C or D stream types to "Good" C stream types (Design Scenarios #1 and #4). Incised or entrenched channels can also be potentially converted to C stream types as additional assessments may support at level II and III, which may match stream succession scenarios #3, #8, #9, and #11 (**Figure 27**).

The following steps are designed to take the existing condition data from *WARSSS* and produce a conceptual design:

Step 1. Identify all valley and stream types and conditions to be used in applying treatments.

Step 2. Identify areas for heavy equipment access using all available data (e.g., aerial photos, road maps, photos, and valley types included with the *WARSSS* assessment for the Waldo Canyon Fire, Rosgen *et al.*, 2013).

Step 3. Identify and locate existing D stream types on *Steam Type and Condition* maps to stabilize with log sills (map provided with *WARSSS* report). Differentiate potential areas for mechanical *vs*. hand work access.

Step 4. Identify and locate single-thread channels that are candidates for D stream type conversions (Design Scenario #5) based on valley width and differentiate potential mechanical *vs*. hand work locations using data from the *WARSSS* analysis. To determine if the valley width can accommodate the width of the braided, D4 stream type, use the following procedure:

1. Obtain Drainage Area (*DA*) in mi^2
2. Calculate bankfull discharge (Q_{bkf}) in cfs from regional curve (**Figure 36**) where $Q_{bkf} = 4.7(DA)^{0.65}$
3. Estimate mean bankfull velocity ($\bar{u}_{bkf}$) for the braided, D4 stream type, which is typically between *0.5* and *1.0 ft/sec*
4. Calculate cross-sectional area (A_{bkf}) in ft^2 using: $A_{bkf} = Q_{bkf} / \bar{u}_{bkf}$
5. Obtain the width/depth ratio (*W*/*d*) of the D4 stream type (use *200*)
6. Calculate the bankfull width (W_{bkf}) in ft using: $W_{bkf} = (W/d * A_{bkf})^{0.5}$

Step 5. Identify and locate streams with high bank erosion rates in narrow valleys that are not candidates for Design Scenario #5 (D stream type conversion), determine drainage area above stream reach, and differentiate between mechanical and hand work access using the digital maps provided with the *WARSSS* report. Use drainage area to calculate the proposed channel transport capacity (**Figure 81**) and compare to the upstream sediment supply (**Figure 82**). If sediment supply exceeds transport capacity by more than 10%, then identify and mitigate sediment sources upstream before treating reach. If channel capacity can route upstream sediment supply, identify the appropriate design scenario. Where lateral constraints allow, conversions to B stream types (Design Scenarios #2, #3, #6, and #8) are preferable due to increased floodplain access (as opposed to an A stream type (Design Scenario #7)). The final product of the conceptual design phase is a map of treatment potential by location, access (hand work or equipment), and design scenario (**Figure 83**).

Step 6. Estimate preliminary costs and effectiveness (tons of sediment stabilized or deposited) associated with the work by access and scenario (**Table 10 – 19**).

Level II – Field Validation:

Step 1. Field verify all channel conditions as recent post-fire landscapes can change rapidly, and utilize the decision tree (**Flowchart 3**) to validate:

- Existing stream type, valley type, and condition
- Access (mechanical or hand work)
- Sediment supply
- Floodplain access (valley width)
- Dominant channel process (aggradation, degradation, bank erosion)
- If Level I proposes D stream type:
  - Is valley wide enough to support D stream type?
  - Can D stream type be adequately tied into upstream and downstream conditions?
- If single-thread was proposed in Level I:
  - Confirm valley constraints will not support multiple-thread system (valley width)
  - Can single-thread system support the sediment supply?

Step 2. Define exact Design Scenario (#1–8) that applies by location

Step 3. Collect existing condition data required for detailed design

- Data requirements for any proposed D stream type conversion (Design Scenario #5):
  - Drainage area (bankfull discharge)
  - Slope
  - Vertical and lateral constraints
- Data requirements for single-thread conversions (Design Scenarios #1–4, #6–8):
  - Drainage area (cross-sectional area and bankfull discharge)
  - Longitudinal profile extending upstream and downstream of reach
  - Typical cross-sections for impaired and upstream condition
  - Sediment supply for upstream condition (*Good* or *Poor*)
  - Vertical and lateral constraints
  - Note departures from representative reaches (particle size)

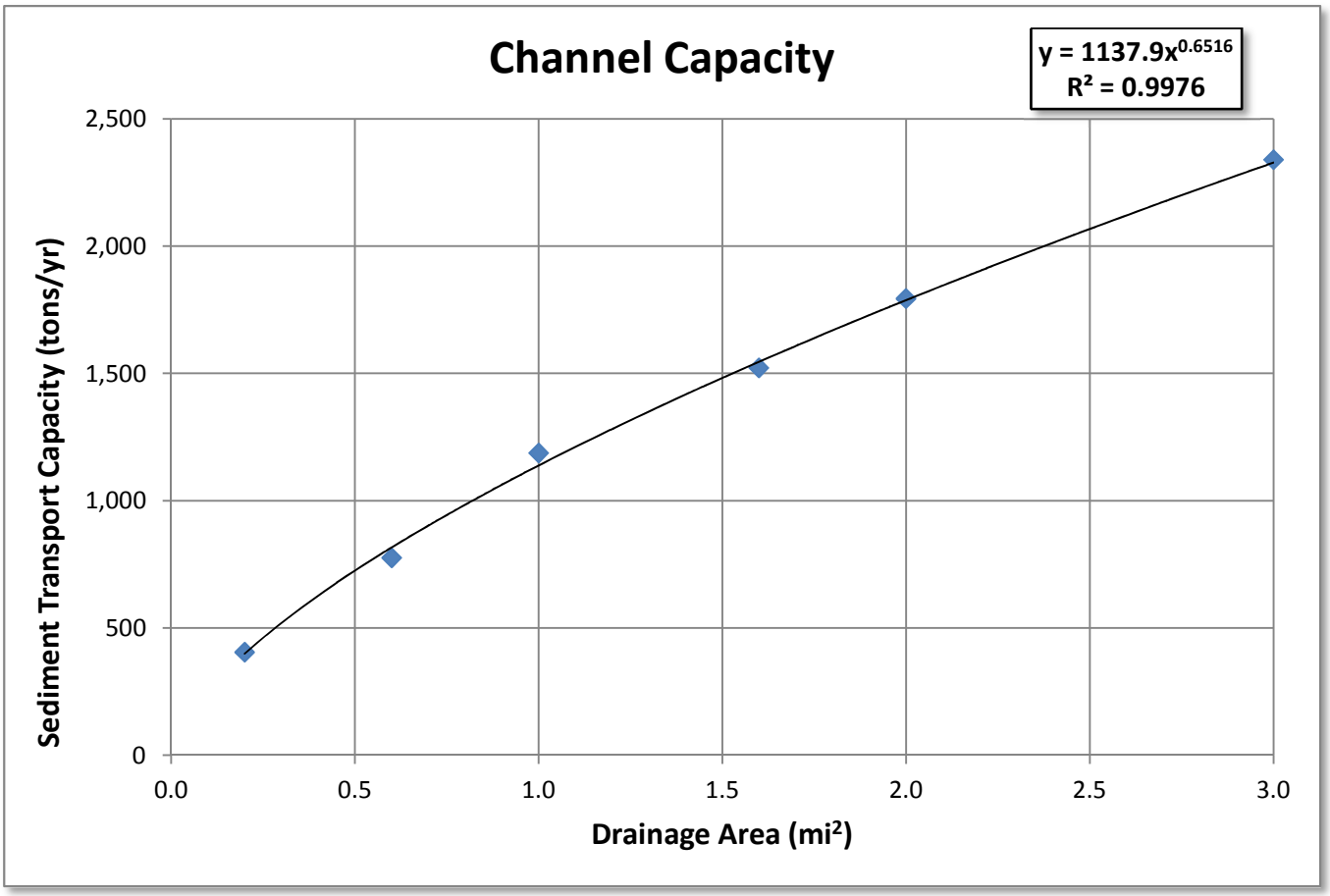


Figure 81. Relationship of channel transport capacity *vs*. drainage area for cumulative streamflows up to bankfull for an average year (based on "poor" sediment supply, a width/depth ratio of 12.0, and a typical slope of a B4 stream type simulated with the POWERSED model; drainage area is a surrogate for bankfull discharge and the post-fire flow duration curves developed for flow-related sediment).

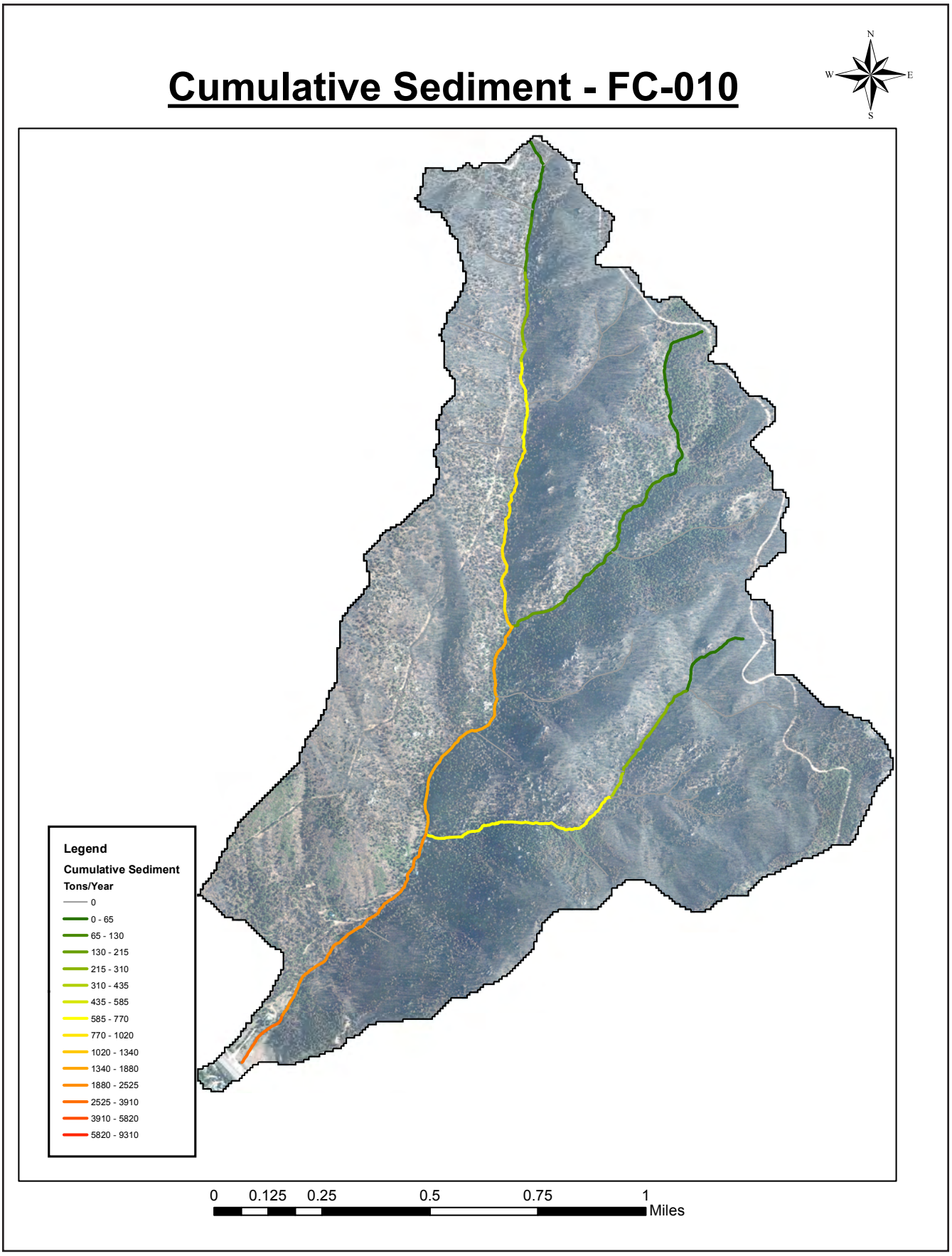


Figure 82. Cumulative introduced sediment sources for Wellington Gulch (FC-010).

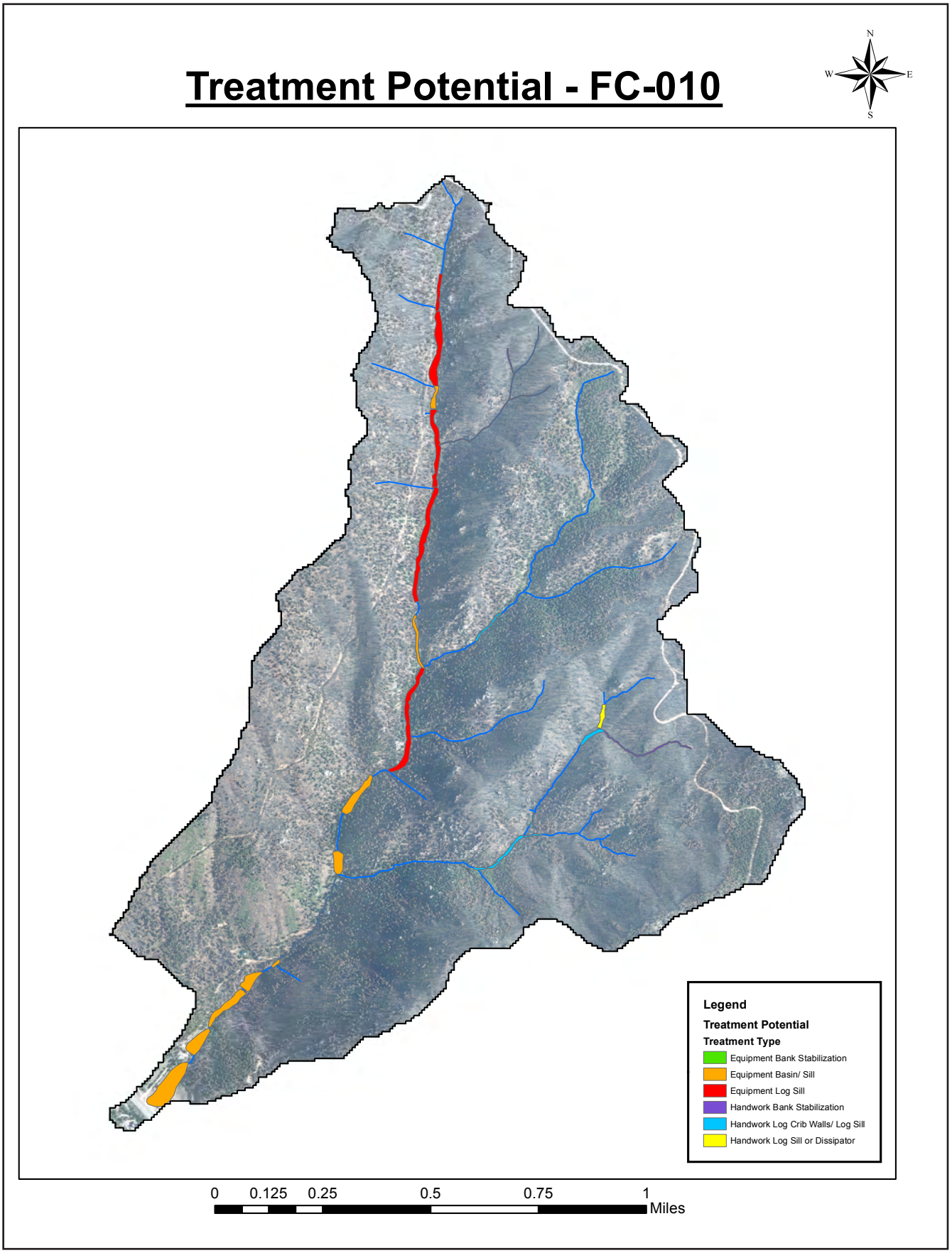


Figure 83. Treatment potential for Wellington Gulch (FC-010).

Table 10. Estimated cost per foot by scenario.

			Cost per ft (range)	Average Cost per ft
Mechanical Work	1	D4 to C4	$50 – 120	$85
	2	F4 to B4c	$40 – 80	$60
	3	G4 to B4	$80 – 80	$80
	4	*Unstable* C4 to *Stable* C4	$30 – 60	$45
	5	A4, F4, or G4 to D4	$20 – 60	$40
	6	F4b to B4	$40 – 80	$60
	7	*Unstable* A4a+ or A4 to *Stable* A4a+ or A4	$10 – 40	$25
	8	A4a+ or A4 to B4a	$40 – 80	$60
Hand Work		Gully Plugs	$30 – 50	$40
		Sills	$5 – 20	$12.50
		Dissipators	$30 – 50	$40
		Log Rollers	$15 – 30	$22.50
		Slope Bank, Add Roughness, & Revegetate	$5 – 15	$10

Table 11. Cost and sediment savings for stabilizing/enhancing D stream types with log sills (mechanical).

Sub-watersheds	Log Sills (Heavy Equipment)			
	Length of Treatment (ft)	Sediment Deposition & Stabilization (tons)	Cost / Ton	Cost / Foot of Treatment
DC-007				
FC-002				
FC-004				
FC-005				
FC-007	1,421	4,070	$6.02	$10.00 to $30.00
FC-010	5,365	6,433	$13.42	$10.00 to $30.00
FC-011	4,353	12,684	$4.54	$10.00 to $30.00
MC-007				
MC-008	6,353	9,305	$10.87	$10.00 to $30.00
MC-010	2,767	6,729	$6.33	$10.00 to $30.00
Grand Total	**20,259**	**39,221**	**$6.86**	**$10.00 to $30.00**

Table 12. Cost and sediment savings for stabilizing/enhancing D stream types with log sills (hand work).

Sub-watersheds	Log Sills (Hand Crew)			
	Length of Treatment (ft)	Sediment Deposition & Stabilization (tons)	Cost / Ton	Cost / Foot of Treatment
DC-007	1,159	799	$10.68	$5.00 to $20.00
FC-002	321	234	$20.71	
FC-004	585	423	$8.00	$5.00 to $20.00
FC-005				
FC-007				
FC-010	148	213	$3.85	$5.00 to $20.00
FC-011				
MC-007				
MC-008				
MC-010				
Grand Total	**2,213**	**3,342**	**$10.71**	**$5.00 to $20.00**

Table 13. Cost and sediment savings for stabilizing/enhancing D stream types with dissipators (hand work).

Sub-watersheds	Dissipators (Hand Crew)			
	Length of Treatment (ft)	Sediment Deposition & Stabilization (tons)	Cost / Ton	Cost / Foot of Treatment
DC-007	1,159	799	$18.00	$15.00 to $35.00
FC-002	321	234	$28.97	$15.00 to $35.00
FC-004	585	423	$22.64	$15.00 to $35.00
FC-005				
FC-007				
FC-010	148	213	$11.82	$15.00 to $35.00
FC-011				
MC-007				
MC-008				
MC-010				
Grand Total	**2,213**	**3,342**	**$18.49**	**$15.00 to $35.00**

Table 14. Cost and sediment savings converting A, F, and G to D stream types (mechanical).

Sub-watersheds	Sediment Detention Basin and D4 Channels (Equipment)			
	Length of Treatment (ft)	Sediment Deposition & Stabilization (tons)	Cost / Ton	Cost / Foot of Treatment
DC-007	2,950	18,535	$1.98	$12.50
FC-002	823	3,340	$5.69	$12.50
FC-004	489	2,429	$3.08	$12.50
FC-005	456	359	$15.86	$12.50
FC-007	2,606	11,762	$5.55	$12.50
FC-010	3,928	17,030	$3.90	$12.50
FC-011	2,955	6,580	$6.35	$12.50
MC-007	2,237	8,678	$2.89	$12.50
MC-008	4,893	20,643	$4.63	$12.50
MC-010	3,409	29,768	$1.37	$12.50
Grand Total	**24,746**	**119,130**	**$2.60**	**$12.50**

Table 15. Cost and sediment savings converting A, F, and G to D stream types (hand work).

Sub-watersheds	Log Step Crib Wall Plugs (Hand Crew)			
	Length of Treatment (ft)	Sediment Deposition & Stabilization (tons)	Cost / Ton	Cost / Foot of Treatment
DC-007	5,086	8,746	$24.78	$40.00
FC-002	8,354	18,454	$21.96	$40.00
FC-004	4,017	7,113	$31.52	$40.00
FC-005	3,034	8,836	$17.01	$40.00
FC-007				
FC-010	2,108	2,974	$31.71	$40.00
FC-011	671	696	$38.53	$40.00
MC-007	2,941	4,623	$29.92	$40.00
MC-008				
MC-010	1,951	7,383	$11.56	$40.00
Grand Total	**28,162**	**58,829**	**$19.00**	**$40.00**

Table 16. Cost and sediment savings converting A, F, and G to B4 stream types (mechanical).

Sub-watersheds	Converting to B4 Stream Type Using Heavy Equipment	
	Length of Stream Treated (ft)	Streambank Erosion Savings (tons/yr)
DC-007		
FC-002	964	68
FC-004		
FC-005		
FC-007	2,614	596
FC-010	965	346
FC-011	1,704	201
MC-007	248	11
MC-008	1,367	64
MC-010	1,437	241
Grand Total	**9,299**	**1,528**

Table 17. Cost and sediment savings converting A, F, and G to B4 stream types (hand work).

Sub-watersheds	Converting to B4 Stream Type using Hand Crews	
	Length of Stream Treated (ft)	Streambank Erosion Savings (tons/yr)
DC-007	4,047	558
FC-002	3,331	704
FC-004	3,541	319
FC-005	1,998	66
FC-007		
FC-010		
FC-011	88	5
MC-007	1,216	61
MC-008	1,011	38
MC-010	345	8
Grand Total	**15,577**	**1,759**

Table 18. Cost and sediment savings converting unstable A, F, and G to stable A4 stream types (mechanical).

Sub-watersheds	Converting to A4 Stream Type using Heavy Equipment	
	Length of Stream Treated (ft)	Streambank Erosion Savings (tons/yr)
DC-007		
FC-002	651	15
FC-004		
FC-005	114	6
FC-007		
FC-010	384	56
FC-011		
MC-007		
MC-008		
MC-010	145	2
Grand Total	**1,294**	**79**

Table 19. Cost and sediment savings converting unstable A, F, and G to stable A4 stream types (hand work).

Sub-watersheds	Converting to A4 Stream Type using Hand Crews	
	Length of Stream Treated (ft)	Streambank Erosion Savings (tons/yr)
DC-007	2,947	933
FC-002	2,671	109
FC-004	9,277	345
FC-005		
FC-007		
FC-010	4,180	356
FC-011	786	28
MC-007	437	6
MC-008		
MC-010		
Grand Total	**20,298**	**1,777**

Level III – Detailed Design: Extrapolation Procedures for Scaling Morphological Parameters

This procedure represents Level III of the restoration approach for the Waldo Canyon Fire. Level III is the procedure to develop the detailed design parameters based on earlier results from the conceptual design (Level I) and field validation and data collection (Level II).

Selection and evaluation of the appropriate reference reach database consistent with the boundary conditions and driving variables is an essential first step. The design concepts of applying *reference reach* relations to restore the high priority reaches and sub-watersheds can be applied using the *representative reaches* and by extrapolating the various restoration scenarios. The key to applying the various scenarios to other reach locations is to understand the causes of impairment and to implement similar restoration scenarios consistent with the *existing* and *proposed* stream types as presented. The user is advised to review **Table 4** that lists the stream type conversion recommendations by valley type. The following discussion provides the general procedure to extrapolate a recommended design scenario at a site-specific location within a watershed impacted by the Waldo Canyon Fire. Because it is not possible to provide all of the design details for every watershed that would be potentially restored, this procedure documents the step-wise methodology recommended to provide such design details when deemed necessary.

The natural channel design procedure included in **Appendix I** must be followed to develop the proposed design criteria. Because detailed assessments have already been conducted for the stream types and conditions that exist within the various watersheds impacted by the Waldo Canyon Fire, utilizing various design scenarios to correct disproportionate sediment supply can be appropriately directed. Developing the restoration design details for locations where specific application of a design scenario is deemed appropriate is summarized in this discussion. The Level II evaluation field-validated the selected design scenario with data collected to satisfy this design level.

Restoration Design Sequence for Channel Processes:

1. Obtain the summary of the validated, existing representative reach, including stream type, valley type, stability, and the natural potential stable stream type. Typical conditions by stream type and stability condition are mapped for the 237 miles of stream channels in the Waldo Canyon Fire watersheds.
2. Obtain the appropriate design scenario to meet specific restoration objectives (**Table 4**).
3. Obtain the drainage area in square miles.
4. From the regional curves, obtain the bankfull cross-sectional area (ft^2) and the bankfull discharge (**Figure 35** and **Figure 36**). If a braided, D channel is selected to be designed, obtain the bankfull discharge and calculate cross-sectional area from continuity ($A_{bkf} = Q / \bar{u}_{bkf}$)
5. Obtain the dimensionless ratios representing the dimension, pattern, and profile from the appropriate reference reach in the stream type conversion design scenario.
6. Convert the dimensionless ratios to the proposed, dimensional values following the procedure in **Appendix I** (***Note:*** caution must be exercised in the extrapolation of dimensionless relations from the reference reach if the stream being designed is very small or other boundary conditions and controlling variables necessitate modification of the design variables). This includes organizing and completing the existing, proposed, and reference reach data (see **Appendix I**)
7. Layout the proposed plan view restoration alignment on aerial photos and the typical dimensions and profile

8. Identify structure type and location. The structure recommendations are based on potential grade control, near-bank shear stress, streambank revetment, flow energy dissipation, flow resistance, and other processes. The structures are often designed to allow time for the riparian vegetation to become established and to function. There are a great number of various structures available to be implemented for specific objectives. Structures are shown in **Figures 55** through **75**.
9. Compare existing condition streambank erosion rates with proposed (from reference reach rates). Calculate the sediment reduction from streambanks for the proposed reach. The length of stream reach proposed for restoration should be used to compare total streambank erosion contribution using streambank erosion rates (tons/ft/yr).
10. Calculate the channel hydraulics, sediment competence, and sediment transport capacity as influenced by variations in depth and slope that change roughness, velocity, shear stress, and stream power. The software program, RIVERMorph, accelerates the computational process. For FLOWSED runs, the bankfull suspended and bedload data input is used for the "poor" curve for existing condition compared to the "good" condition input values for the proposed restored reach assessment. The bankfull sediment input values by stability and drainage area are shown in **Figure 84**. Flow-related sediment increases using the FLOWSED model will then properly reflect the existing, impaired condition associated with high sediment supply in contrast to the proposed low sediment supply restored reach. The sediment reduction related to the restored reach in the presence of high post-fire flows is related to the reduction of streambank erosion, entrainment of stored sediment, and channel bed scour. The FLOWSED model is applied to all of the sub-watersheds to reflect post-fire sediment conditions (see Appendix D in Waldo Canyon Fire *WARSSS* report (Rosgen *et al.*, 2013)).

    The POWERSED model predicts sediment transport capacity comparing pre- and post-restoration response. The POWERSED model not only predicts the sediment transport capacity for changes in sediment supply, but also the potential channel stability (aggradation/degradation, or stable bed). If a D4 stream type is designed on an alluvial fan, the POWERSED model can assist in the design dimensions and slope to ensure excess sediment deposition occurs as part of the objectives of the braided channel and alluvial fan function.
11. Define the riparian vegetation establishment. The riparian scorecard analysis used for the assessment reflects the existing and potential riparian community, including the species composition for overstory, midstory and understory plants. This information is used to select the riparian species and methods of establishment (seeding, cuttings, and/or transplants).
12. Describe implementation instructions including the nature and source of revetment materials, type of equipment recommended, unique constraints, water quality controls, and specific criteria identified in the various assessment phases.
13. Estimate costs of implementation and recommend contracting methods that allow for a cost-efficient, yet fair method.
14. Set-up monitoring requirements.
15. Complete and submit 404 permit application

Appropriate design scenarios (**Table 4**) can be extrapolated to various stream types and conditions at a given location with subsequent details as described in this summary that are suitable for implementation.

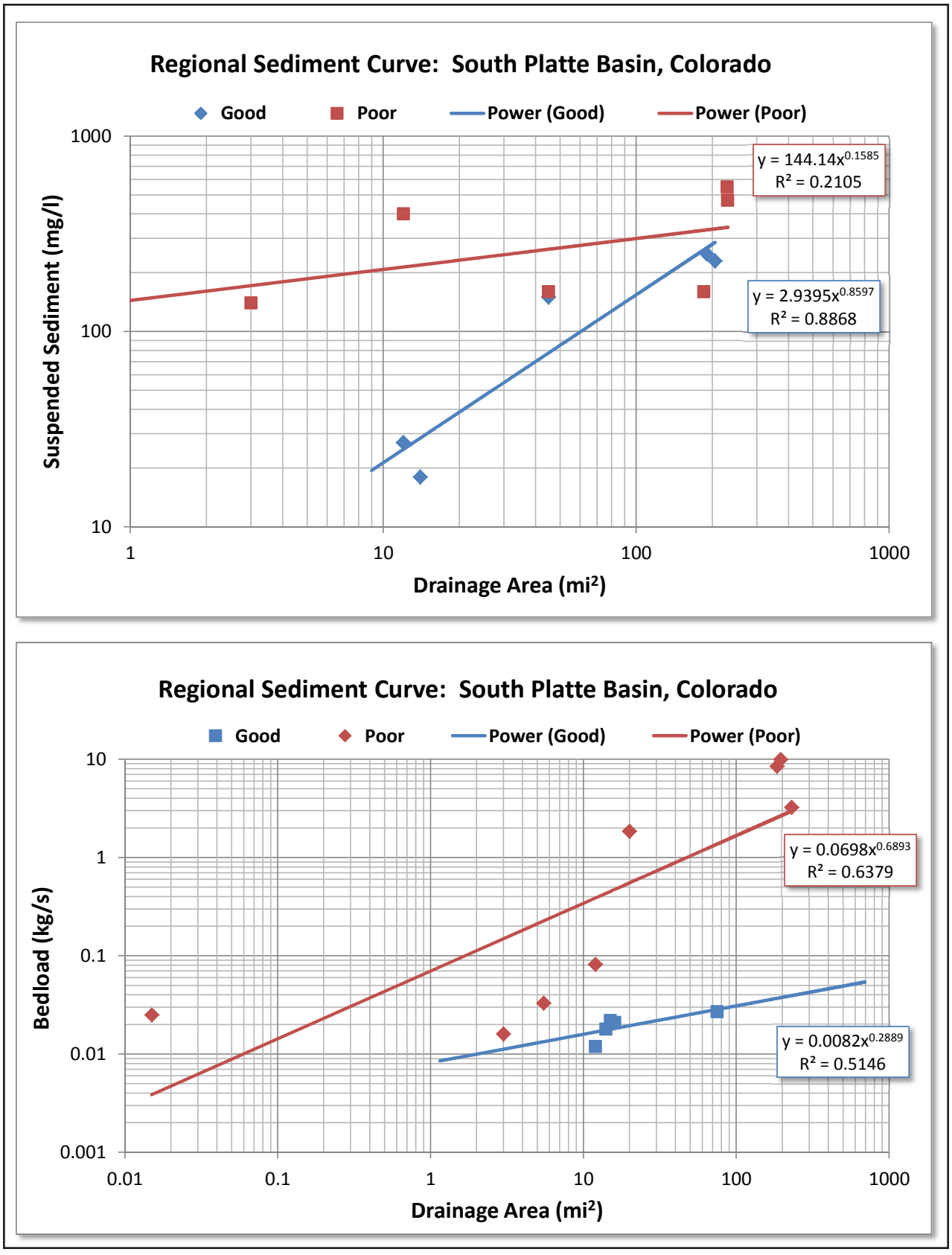


Figure 84. Regional sediment curves of suspended sediment and bedload *vs*. drainage area.

Example Detailed Channel Design: Northfield Gulch (MC-010)

The following is an example detailed channel design applied to the downstream reach of Northfield Gulch in the West Monument Watershed (MC-010) using the procedural steps 1–14:

Step 1. Existing (representative reach) stream type and condition: **F4b Poor**. Valley type: **VIIIb**. Stable reference reach: **B4 stream type**.

Step 2. Design Scenario #6: **F4b to B4 conversion**

Step 3. Drainage area: **0.5 mi^2**

Step 4. Bankfull discharge: **3.0 cfs**, Bankfull cross-sectional area: **1.0 ft^2**

Step 5. A B4 reference reach was surveyed and the dimensionless relations for extrapolation are summarized in **Table 20**.

Step 6. The existing and reference relations for channel dimension, pattern, profile, materials, velocity, sediment competence, and capacity are shown in **Table 20** for the Northfield Gulch proposed design. The proposed stream channel restoration variables are calculated from the conversion of the dimensionless to dimensional relations from the reference reach scaled to Northfield Gulch (**Table 20**).

Step 7. The proposed plan view alignment is shown as an overlay on an aerial photo at the lower *1,100 ft* of Northfield Gulch above the confluence with West Monument Creek (**Figure 85**). The meander length, belt width, and radius of curvature from the proposed values for Northfield Gulch from **Table 20** were scaled for this alignment. The sinuosity was calculated from the proposed alignment layout by measuring stream length divided by valley length.

Step 8. The recommended structures for the B4 stream type in Northfield Gulch are shown in **Figure 86**. These structures were selected to prevent downcutting, reduce near-bank shear stress, and provide flow resistance to prevent accelerated streambank erosion.

Step 9. The field predicted streambank erosion rates using the BANCS model (Rosgen, 2006/2009) were compared to the potential proposed rates for *1,100 ft* of length. The BANCS model predicted a unit bank erosion rate of *0.27 tons/ft/yr* for the F4b poor reach (**Table 21**). Applying that unit rate over the 1,100 foot reach equates to *297 tons/yr* of bank erosion. The restored *1,100 ft* reach of a B4 stream reach proposed would potentially yield *5.5 tons/yr* based on the reference reach erosion rate for a stable B4 stream type (**Table 20**). This represents a sediment reduction from streambank erosion of approximately *291.5 tons/yr*.

Step 10. The proposed mean depth, hydraulic radius, and stream slope for the existing bed materials in Northfield Gulch are used to calculate the proposed velocity (**Figure 87**, **Table 22**). The sediment transport competence calculations, using the proposed bankfull depth and slope required to calculate shear stress, are shown in **Table 23**. The values indicate the proposed B4 stream type at *3.0 cfs* could move up to 100 mm particles, the largest being 128 mm (D_{100}) of the bed. A stable bed is predicted; however, grade control structures are required because the new construction will have a loose assortment of particles on the bed without a sub-pavement coarsening (pre-runoff).

The FLOWSED model results are based on sediment supply inputs comparing the existing poor F4b stream type to the proposed B4 good stream type. The results of the analysis for Northfield Gulch (up to and including bankfull discharge) predict the F4b poor stability supply at *819.8 tons/yr* (for a bankfull discharge of 3.0 cfs) (**Table 24**), and *11.3 tons/yr* for the restored B4 good stream type (**Table 25**). Of this total sediment for the existing F4b poor reach, the streambank erosion rate for 1,100 ft is *297 tons.yr*; the natural erosion rate for the B4 good stream type is

5.5 tons/yr. The overall savings of sediment supply for this proposed restoration using the FLOWSED model is *808.5 tons/yr* (approximately 81, 10-yard end dump truck loads per year for the bankfull discharge, not including floods).

The significant sediment savings are due to the construction of several large sediment detention basins and a conversion of F and G stream types to D4 (Design Scenario #5) above the proposed F4b to B4 conversion. This allowed a conversion from a "poor," or high sediment supply, to "good," or low sediment supply, coming into the B4 design reach. The sediment savings of *291.5 tons/yr* for the 1,100 of B4 length is related to reduced streambank erosion contribution (Step 9).

The POWERSED model predicts the sediment transport capacity related to the existing, F4b poor condition compared to a stable B4 cross-section to indicate aggradation, degradation, or stable bed. The POWERSED model predicted an annual transport capacity of *617.7 tons/yr* for the F4b poor reach compared to *763.6 tons/yr* that a stable B4 cross-section can transport assuming the same sediment supply (**Table 26**), representing a reduction of *145.9 tons/yr*, or aggradation, for the F4b poor reach.

Step 11. The riparian plant community is a mixture of alder and willow, which will be transplanted from adjacent, off-channel areas on-site to streambanks. Most of the riparian vegetation transplants will be in association with outside streambank revetment, including toe wood

Step 12. Due to the direct access for large equipment, the implementation would utilize a large track hoe with hydraulic thumb, a front end loader for transplanting vegetation, and a large truck to haul and distribute material. Native rock and logs/root wads with trunks intact would need to be gathered from adjacent areas for channel revetment materials. A temporary diversion canal down the existing channel alignment would keep surface water away from the construction site.

Step 13. Estimated costs of implementation of the B4 stream type are $60.00/lineal ft of construction. Recommend contracting method is time (hourly rate) and materials. The construction costs are based on this method of contracting.

Step 14. The monitoring recommendations include: 1) two measured cross-sections for typical riffles; 2) two cross-sections for typical pools; 3) a longitudinal profile that traverses the measured cross-sections for at least 20–30 bankfull widths (120 ft); and 4) photo points depicting vegetative survival and structure success. The resurvey of the cross-sections and longitudinal profile should occur every other year following the first post-restoration runoff year after construction.

Table 20 (page 1). Morphological relations for Northfield Gulch, including existing, proposed, and reference reach data.

F4b Poor Representative Reach, Northfield Gulch, West Monument Watershed								
Reference Reach Stream & Location: B4, Trail Creek, Colorado								
Entry Number & Variable			Existing Reach		Proposed Design Reach		Reference Reach	
	1	Valley Type (I–XII)	VIIIa		VIIIa		VIII	
	2	Valley Width (W_{val})						
	3	Stream Type	F4b		B4		B4	
	4	Drainage Area, mi^2 (DA)	0.3		0.5		14.3	
	5	Bankfull Discharge, cfs (Q_{bkf})	2.92		3		32.78	
Riffle Dimensions	6	Riffle Width, ft (W_{bkf})	*Mean:*	5.2	*Mean:*	3.5	*Mean:*	9.5
			Min:	4.5	*Min:*	3.2	*Min:*	8.3
			Max:	5.8	*Max:*	4.0	*Max:*	10.8
	7	Riffle Mean Depth, ft (d_{bkf})	*Mean:*	0.27	*Mean:*	0.28	*Mean:*	0.75
			Min:	0.25	*Min:*	0.25	*Min:*	0.83
			Max:	0.31	*Max:*	0.32	*Max:*	0.67
	8	Riffle Width/Depth Ratio (W_{bkf}/d_{bkf})	*Mean:*	19.5	*Mean:*	12.6	*Mean:*	12.6
			Min:	14.6	*Min:*	10.0	*Min:*	10.0
			Max:	22.4	*Max:*	16.0	*Max:*	16.0
	9	Riffle Cross-Sectional Area, ft^2 (A_{bkf})	*Mean:*	1.4	*Mean:*	1.0	*Mean:*	7.1
			Min:	1.3			*Min:*	6.9
			Max:	1.5			*Max:*	7.3
	10	Riffle Maximum Depth (d_{max})	*Mean:*	0.52	*Mean:*	0.42	*Mean:*	1.13
			Min:	0.41	*Min:*	0.40	*Min:*	1.08
			Max:	0.64	*Max:*	0.45	*Max:*	1.18
	11	Riffle Maximum Depth to Riffle Mean Depth (d_{max}/d_{bkf})	*Mean:*	1.900	*Mean:*	1.508	*Mean:*	1.508
			Min:	1.577	*Min:*	1.421	*Min:*	1.421
			Max:	2.065	*Max:*	1.595	*Max:*	1.595
	12	Width of Flood-Prone Area at Elevation of 2 * d_{max}, ft (W_{fpa})	*Mean:*	6.2	*Mean:*	8.0	*Mean:*	16.4
			Min:	5.8	*Min:*	7.0	*Min:*	14.2
			Max:	6.6	*Max:*	8.5	*Max:*	18.5
	13	Entrenchment Ratio (W_{fpa}/W_{bkf})	*Mean:*	1.2	*Mean:*	2.3	*Mean:*	1.7
			Min:	1.1	*Min:*	2.0	*Min:*	1.5
			Max:	1.4	*Max:*	2.4	*Max:*	2.0
Riffle Inner Berm Dimensions	14	Riffle Inner Berm Width, ft (W_{ib})	*Mean:*	3.9	*Mean:*	2.2	*Mean:*	7.3
			Min:	2.6	*Min:*	1.7	*Min:*	5.6
			Max:	5.1	*Max:*	2.7	*Max:*	8.8
	15	Riffle Inner Berm Width to Riffle Width (W_{ib}/W_{bkf})	*Mean:*	0.743	*Mean:*	0.616	*Mean:*	0.616
			Min:	0.583	*Min:*	0.476	*Min:*	0.476
			Max:	0.903	*Max:*	0.750	*Max:*	0.750
	16	Riffle Inner Berm Mean Depth, ft (d_{ib})	*Mean:*	0.22	*Mean:*	0.12	*Mean:*	0.32
			Min:	0.17	*Min:*	0.08	*Min:*	0.20
			Max:	0.27	*Max:*	0.16	*Max:*	0.43
	17	Riffle Inner Berm Mean Depth to Riffle Mean Depth (d_{ib}/d_{bkf})	*Mean:*	0.781	*Mean:*	0.427	*Mean:*	0.427
			Min:	0.681	*Min:*	0.267	*Min:*	0.267
			Max:	0.883	*Max:*	0.573	*Max:*	0.573
	18	Riffle Inner Berm Width/Depth Ratio (W_{ib}/d_{ib})	*Mean:*	19.7	*Mean:*	23.6	*Mean:*	23.6
			Min:	9.6	*Min:*	20.5	*Min:*	20.5
			Max:	29.8	*Max:*	32.1	*Max:*	32.1
	19	Riffle Inner Berm Cross-Sectional Area (A_{ib})	*Mean:*	0.8	*Mean:*	0.3	*Mean:*	2.4
			Min:	0.7	*Min:*	0.2	*Min:*	1.3
			Max:	0.9	*Max:*	0.5	*Max:*	3.8
	20	Riffle Inner Berm Cross-Sectional Area to Riffle Cross-Sectional Area (A_{ib}/A_{bkf})	*Mean:*	0.566	*Mean:*	0.340	*Mean:*	0.340
			Min:	0.516	*Min:*	0.180	*Min:*	0.180
			Max:	0.615	*Max:*	0.533	*Max:*	0.533

Table 20 (page 2). Morphological relations for Northfield Gulch, including existing, proposed, and reference reach data.

	Entry Number & Variable		Existing Reach	Proposed Design Reach		Reference Reach	
Pool Dimensions	21	Pool Width, ft (W_{bkfp})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	**4.2** **2.5** **6.4**	*Mean:* *Min:* *Max:*	**14.0** **8.2** **21.1**
	22	Pool Width to Riffle Width (W_{bkfp}/W_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	**1.190** **0.695** **1.792**	*Mean:* *Min:* *Max:*	**1.190** **0.695** **1.792**
	23	Pool Mean Depth, ft (d_{bkfp})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	**0.30** **0.22** **0.39**	*Mean:* *Min:* *Max:*	**0.80** **0.59** **1.05**
	24	Pool Mean Depth to Riffle Mean Depth (d_{bkfp}/d_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	**1.067** **0.787** **1.400**	*Mean:* *Min:* *Max:*	**1.067** **0.787** **1.400**
	25	Pool Width/Depth Ratio (W_{bkfp}/d_{bkfp})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	**17.5** **7.8** **35.8**	*Mean:* *Min:* *Max:*	**17.5** **7.8** **35.8**
	26	Pool Cross-Sectional Area, ft^2 (A_{bkfp})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	**1.2** **1.2** **1.3**	*Mean:* *Min:* *Max:*	**8.9** **8.5** **9.6**
	27	Pool Area to Riffle Area (A_{bkfp}/A_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	**1.248** **1.189** **1.348**	*Mean:* *Min:* *Max:*	**1.248** **1.189** **1.348**
	28	Pool Maximum Depth (d_{maxp})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	**0.85** **0.70** **0.99**	*Mean:* *Min:* *Max:*	**1.56** **1.33** **1.85**
	29	Pool Maximum Depth to Riffle Mean Depth (d_{maxp}/d_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	**3.000** **2.500** **3.500**	*Mean:* *Min:* *Max:*	**3.000** **2.500** **3.500**
	30	Point Bar Slope (S_{pb})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	**0.290** **0.220** **0.360**	*Mean:* *Min:* *Max:*	**0.290** **0.220** **0.360**
Pool Inner Berm Dimensions	31	Pool Inner Berm Width, ft (W_{ibp})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	**1.2** **1.1** **1.3**	*Mean:* *Min:* *Max:*	**4.8** **4.5** **5.1**
	32	Pool Inner Berm Width to Pool Width (W_{ibp}/W_{bkfp})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	**0.288** **0.269** **0.304**	*Mean:* *Min:* *Max:*	**0.343** **0.320** **0.361**
	33	Pool Inner Berm Mean Depth, ft (d_{ibp})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	**0.12** **0.08** **0.15**	*Mean:* *Min:* *Max:*	**0.31** **0.22** **0.40**
	34	Pool Inner Berm Mean Depth to Pool Mean Depth (d_{ibp}/d_{bkfp})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	**0.388** **0.275** **0.500**	*Mean:* *Min:* *Max:*	**0.388** **0.275** **0.500**
	35	Pool Inner Berm Width/Depth Ratio (W_{ibp}/d_{ibp})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	**0.9** **0.8** **0.9**	*Mean:* *Min:* *Max:*	**0.9** **0.8** **0.9**
	36	Pool Inner Berm Cross-Sectional Area (A_{ibp})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	**0.2** **0.1** **0.3**	*Mean:* *Min:* *Max:*	**1.5** **1.0** **2.0**
	37	Pool Inner Berm Cross-Sectional Area to Pool Cross-Sectional Area (A_{ibp}/A_{bkfp})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	**0.172** **0.114** **0.226**	*Mean:* *Min:* *Max:*	**0.172** **0.114** **0.226**

Table 20 (page 3). Morphological relations for Northfield Gulch, including existing, proposed, and reference reach data.

	Entry Number & Variable	Existing Reach		Proposed Design Reach		Reference Reach	
Channel Pattern	72 Linear Wavelength, ft (λ)	*Mean:*	**63.0**	*Mean:*	**31.4**	*Mean:*	**104.0**
		Min:		*Min:*	**26.2**	*Min:*	**87.0**
		Max:		*Max:*	**38.9**	*Max:*	**129.0**
	73 Linear Wavelength to Riffle Width (λ/W_{bkf})	*Mean:*	**12.115**	*Mean:*	**8.832**	*Mean:*	**8.832**
		Min:		*Min:*	**7.389**	*Min:*	**7.389**
		Max:		*Max:*	**10.955**	*Max:*	**10.955**
	74 Stream Meander Length, ft (L_m)	*Mean:*	**68.0**	*Mean:*	**33.8**	*Mean:*	**112.0**
		Min:		*Min:*	**28.5**	*Min:*	**94.5**
		Max:		*Max:*	**40.7**	*Max:*	**135.0**
	75 Stream Meander Length Ratio (L_m/W_{bkf})	*Mean:*	**13.077**	*Mean:*	**9.512**	*Mean:*	**9.512**
		Min:		*Min:*	**8.025**	*Min:*	**8.025**
		Max:		*Max:*	**11.465**	*Max:*	**11.465**
	76 Belt Width, ft (W_{blt})	*Mean:*	**25.0**	*Mean:*	**8.2**	*Mean:*	**27.2**
		Min:		*Min:*	**4.4**	*Min:*	**14.6**
		Max:		*Max:*	**18.1**	*Max:*	**60.0**
	77 Meander Width Ratio (W_{blt}/W_{bkf})	*Mean:*	**10.450**	*Mean:*	**2.306**	*Mean:*	**2.306**
		Min:	**5.935**	*Min:*	**1.237**	*Min:*	**1.237**
		Max:	**18.510**	*Max:*	**5.096**	*Max:*	**5.096**
	78 Radius of Curvature, ft (R_c)	*Mean:*	**34.5**	*Mean:*	**18.9**	*Mean:*	**39.0**
		Min:	**32.0**	*Min:*	**11.9**	*Min:*	**10.5**
		Max:	**37.0**	*Max:*	**24.5**	*Max:*	**76.0**
	79 Radius of Curvature to Riffle Width (R_c/W_{bkf})	*Mean:*	**6.635**	*Mean:*	**5.400**	*Mean:*	**5.400**
		Min:	**6.154**	*Min:*	**3.400**	*Min:*	**3.400**
		Max:	**7.115**	*Max:*	**7.000**	*Max:*	**7.000**
	80 Arc Length, ft (L_a)	*Mean:*	**33.0**	*Mean:*	**11.9**	*Mean:*	**39.6**
		Min:	**33.0**	*Min:*	**3.0**	*Min:*	**10.0**
		Max:	**33.0**	*Max:*	**21.4**	*Max:*	**70.9**
	81 Arc Length to Riffle Width (L_a/W_{bkf})	*Mean:*	**6.346**	*Mean:*	**3.363**	*Mean:*	**3.363**
		Min:	**6.346**	*Min:*	**0.849**	*Min:*	**0.849**
		Max:	**6.346**	*Max:*	**6.021**	*Max:*	**6.021**
	82 Riffle Length (L_r), ft	*Mean:*	**20.4**	*Mean:*	**4.4**	*Mean:*	**14.7**
		Min:	**17.8**	*Min:*	**0.8**	*Min:*	**2.7**
		Max:	**24.4**	*Max:*	**8.5**	*Max:*	**28.2**
	83 Riffle Length to Riffle Width (L_r/W_{bkf})	*Mean:*	**3.923**	*Mean:*	**1.248**	*Mean:*	**1.248**
		Min:	**3.423**	*Min:*	**0.229**	*Min:*	**0.229**
		Max:	**4.692**	*Max:*	**2.395**	*Max:*	**2.395**
	84 Individual Pool Length, ft (L_p)	*Mean:*	**6.2**	*Mean:*	**18.1**	*Mean:*	**60.1**
		Min:	**5.0**	*Min:*	**6.9**	*Min:*	**23.0**
		Max:	**7.4**	*Max:*	**30.4**	*Max:*	**101.0**
	85 Pool Length to Riffle Width (L_p/W_{bkf})	*Mean:*	**1.194**	*Mean:*	**5.104**	*Mean:*	**5.104**
		Min:	**0.956**	*Min:*	**1.953**	*Min:*	**1.953**
		Max:	**1.431**	*Max:*	**8.577**	*Max:*	**8.577**
	86 Pool-to-Pool Spacing, ft (P_s)	*Mean:*	**66.1**	*Mean:*	**8.5**	*Mean:*	**28.1**
		Min:	**66.1**	*Min:*	**3.7**	*Min:*	**12.2**
		Max:	**66.1**	*Max:*	**14.3**	*Max:*	**47.3**
	87 Pool-to-Pool Spacing to Riffle Width (P_s/W_{bkf})	*Mean:*	**12.712**	*Mean:*	**2.387**	*Mean:*	**2.387**
		Min:	**12.712**	*Min:*	**1.039**	*Min:*	**1.039**
		Max:	**12.712**	*Max:*	**4.020**	*Max:*	**4.020**

Table 20 (page 4). Morphological relations for Northfield Gulch, including existing, proposed, and reference reach data.

	Entry Number & Variable	Existing Reach	Proposed Design Reach	Reference Reach
Sinuosity and Slope	**88** Stream Length (SL)	**167.0**	**1100.0**	**514.1**
	89 Valley Length (VL)	**159.0**	**950.0**	**581.0**
	90 Valley Slope (S_{val})	0.0378	**0.0378**	**0.0264**
	91 Sinuosity (k)	SL/VL: **1.05** VS/S: **1.05**	SL/VL: **1.16**	SL/VL: **1.13** VS/S: **1.09**
	92 Average Water Surface Slope (S)	**0.0360**	**0.0325**	**0.0242**
Degree of Incision	**99** Low Bank Height (LBH)	*Mean:* **3.23** *Min:* **2.09** *Max:* **4.37**	*Mean:* **0.42** *Min:* **0.40** *Max:* **0.45**	*Mean:* **1.13** *Min:* **1.08** *Max:* **1.18**
	100 Maximum Bankfull Depth (d_{max}) at Same Location as Low Bank Height (LBH) Measurement	*Mean:* **0.47** *Min:* **0.43** *Max:* **0.50**	*Mean:* **0.42** *Min:* **0.40** *Max:* **0.45**	*Mean:* **1.13** *Min:* **1.08** *Max:* **1.18**
	101 Bank-Height Ratio (LBH/d_{max})	*Mean:* **6.78** *Min:* **4.81** *Max:* **8.74**	*Mean:* **1.00** *Min:* **1.00** *Max:* **1.00**	*Mean:* **1.00** *Min:* **1.00** *Max:* **1.00**
Bed Feature Max Depth Measurements and Dimensionless Ratios from Profile	**102** Riffle Maximum Depth, ft (d_{max})	*Mean:* **0.54** *Min:* **0.49** *Max:* **0.57**	*Mean:* **0.40** *Min:* **0.35** *Max:* **0.44**	*Mean:* **1.06** *Min:* **0.93** *Max:* **1.18**
	103 Riffle Maximum Depth to Riffle Mean Depth (d_{max}/d_{bkf})	*Mean:* **2.000** *Min:* **1.815** *Max:* **2.111**	*Mean:* **1.413** *Min:* **1.240** *Max:* **1.573**	*Mean:* **1.413** *Min:* **1.240** *Max:* **1.573**
	104 Pool Maximum Depth, ft (d_{maxp})	*Mean:* **1.12** *Min:* **1.01** *Max:* **1.22**	*Mean:* **0.85** *Min:* **0.70** *Max:* **0.99**	*Mean:* **2.25** *Min:* **1.90** *Max:* **2.60**
	105 Pool Maximum Depth to Riffle Mean Depth (d_{maxp}/d_{bkf})	*Mean:* **4.148** *Min:* **3.741** *Max:* **4.519**	*Mean:* **3.000** *Min:* **2.500** *Max:* **3.500**	*Mean:* **3.000** *Min:* **2.500** *Max:* **3.500**
	106 Run Maximum Depth, ft (d_{maxr})	*Mean:* **0.82** *Min:* **0.68** *Max:* **0.96**	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	107 Run Maximum Depth to Riffle Mean Depth (d_{maxr}/d_{bkf})	*Mean:* **3.037** *Min:* **2.519** *Max:* **3.556**	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	108 Glide Maximum Depth, ft (d_{maxg})	*Mean:* **0.87** *Min:* **0.55** *Max:* **0.96**	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	109 Glide Maximum Depth to Riffle Mean Depth (d_{maxg}/d_{bkf})	*Mean:* **3.222** *Min:* **2.037** *Max:* **3.556**	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	110 Step Maximum Depth, ft (d_{maxs})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	111 Step Maximum Depth to Riffle Mean Depth (d_{maxs}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*

Table 20 (page 5). Morphological relations for Northfield Gulch, including existing, proposed, and reference reach data.

Entry Number & Variable			Existing Reach		Proposed Design Reach		Reference Reach	
Bed Feature Water Surface Facet Slopes and Dimensionless Ratios from Profile	112	Riffle Slope (water surface facet slope) (S_{rif})	*Mean:*	**0.5400**	*Mean:*	**0.0455**	*Mean:*	**0.0340**
			Min:	**0.4900**	*Min:*	**0.0215**	*Min:*	**0.0159**
			Max:	**0.5700**	*Max:*	**0.0780**	*Max:*	**0.0585**
	113	Riffle Slope to Average Water Surface Slope (S_{rif}/S)	*Mean:*	**15.0000**	*Mean:*	**1.4000**	*Mean:*	**1.4037**
			Min:	**13.6111**	*Min:*	**0.6000**	*Min:*	**0.6587**
			Max:	**15.8333**	*Max:*	**2.4000**	*Max:*	**2.4182**
	114	Pool Slope (water surface facet slope) (S_p)	*Mean:*	**1.1200**	*Mean:*	**0.0036**	*Mean:*	**0.0027**
			Min:	**1.0100**	*Min:*	**0.0013**	*Min:*	**0.0001**
			Max:	**1.2200**	*Max:*	**0.0130**	*Max:*	**0.0099**
	115	Pool Slope to Average Water Surface Slope (S_p/S)	*Mean:*	**31.1111**	*Mean:*	**0.1100**	*Mean:*	**0.1124**
			Min:	**28.0556**	*Min:*	**0.0041**	*Min:*	**0.0041**
			Max:	**33.8889**	*Max:*	**0.4100**	*Max:*	**0.4107**
	116	Run Slope (water surface facet slope) (S_{run})	*Mean:*	**0.8200**	*Mean:*	**N/A**	*Mean:*	**N/A**
			Min:	**0.6800**	*Min:*		*Min:*	
			Max:	**0.9600**	*Max:*		*Max:*	
	117	Run Slope to Average Water Surface Slope (S_{run}/S)	*Mean:*	**22.7778**	*Mean:*	**N/A**	*Mean:*	**N/A**
			Min:	**18.8889**	*Min:*		*Min:*	
			Max:	**26.6667**	*Max:*		*Max:*	
	118	Glide Slope (water surface facet slope) (S_g)	*Mean:*	**0.7800**	*Mean:*	**N/A**	*Mean:*	**N/A**
			Min:	**0.5500**	*Min:*		*Min:*	
			Max:	**0.9600**	*Max:*		*Max:*	
	119	Glide Slope to Average Water Surface Slope (S_g/S)	*Mean:*	**21.6667**	*Mean:*	**N/A**	*Mean:*	**N/A**
			Min:	**15.2778**	*Min:*		*Min:*	
			Max:	**26.6667**	*Max:*		*Max:*	
	120	Step Slope (water surface facet slope) (S_s)	*Mean:*	**N/A**	*Mean:*	**N/A**	*Mean:*	**1.0600**
			Min:		*Min:*		*Min:*	**0.9300**
			Max:		*Max:*		*Max:*	**1.1800**
	121	Step Slope to Average Water Surface Slope (S_s/S)	*Mean:*	**N/A**	*Mean:*	**N/A**	*Mean:*	**43.8017**
			Min:		*Min:*		*Min:*	**38.4298**
			Max:		*Max:*		*Max:*	**48.7603**

Table 20 (page 6). Morphological relations for Northfield Gulch, including existing, proposed, and reference reach data.

	Entry Number & Variable	Existing Reach	Proposed Design Reach	Reference Reach
Channel Materials	**122 Particle Size Distribution of Reach-wide Channel Materials**			
	D_{16} (mm)	**0.1**	**0.1**	**4.0**
	D_{35} (mm)	**2.7**	**2.7**	**11.0**
	D_{50} (mm)	**4.2**	**4.2**	**19.9**
	D_{84} (mm)	**12.3**	**12.3**	**62.6**
	D_{95} (mm)	**39.8**	**39.8**	**125.0**
	D_{100} (mm)	**128.0**	**128.0**	**256.0**
	123 Particle Size Distribution of Active Bed or Pavement Channel Materials			
	D_{16} (mm)	**0.7**	**0.7**	**5.1**
	D_{35} (mm)	**2.7**	**2.7**	**13.1**
	D_{50} (mm)	**4.8**	**4.8**	**22.6**
	D_{84} (mm)	**9.9**	**9.9**	**63.5**
	D_{95} (mm)	**20.5**	**20.5**	**125.5**
	D_{100} (mm)	**90.0**	**90.0**	**180.0**
	124 Particle Size Distribution of Bar Material or Sub-pavement			
	D_{16} (mm)	**N/A**	**N/A**	**2.0**
	D_{35} (mm)	**N/A**	**N/A**	**7.6**
	D_{50} (mm)	**N/A**	**N/A**	**14.5**
	D_{84} (mm)	**N/A**	**N/A**	**63.8**
	D_{95} (mm)	**N/A**	**N/A**	**88.7**
	D_{max} (mm)	**N/A**	**N/A**	**100.0**
Hydraulics & Flood Capacity	**125** Estimated Bankfull Mean Velocity, ft/sec ($\bar{u}_{bkf}$)	**1.91**	**3.0**	**4.7**
	126 Estimated Bankfull Discharge, cfs (Q_{bkf}); Compare with Regional Curve	**2.9**	**3.0**	**32.8**
	127 Floodplain Capacity: Discharge (Q_{fp})	**N/A**	**18.00**	**N/A**
	128 Floodplain Capacity: Cross-Sectional Area (A_{fp})	**N/A**	**7.2**	**N/A**
	129 Low Terrace Capacity: Discharge (Q_{lt})	**N/A**	**N/A**	**N/A**
	130 Low Terrace Capacity: Cross-Sectional Area (A_{lt})	**N/A**	**N/A**	**N/A**
	131 Flood-Prone Area Capacity: Discharge (Q_{fpa})	**N/A**	**640.0**	**N/A**
	132 Flood-Prone Area Capacity: Cross-Sectional Area (A_{fpa})	**N/A**	**320.0**	**N/A**

Table 20 (page 7). Morphological relations for Northfield Gulch, including existing, proposed, and reference reach data.

	Entry Number & Variable		Existing Reach	Proposed Design Reach	Reference Reach
Sediment Competence	133	Calculated bankfull shear stress value, lbs/ft^2 (τ)	0.568	0.570	1.117
	134	Predicted largest moveable particle size (mm) at bankfull shear stress, (τ)	Shields: 43.2	Shields: 35	Shields: 84.0
			Colo.: 100.0	Colo.: 101	Colo.: 180.0
	135	Largest particle size to be moved (D_{max}) (mm) (see #124: Particle Size Distribution of Bar Material)	125	125	100.0
	136	Predicted shear stress required to initiate movement of D_{max} (mm)	Shields: 1.573	Shields: N/A	Shields: 1.400
			Colo.: 0.766	Colo.: 0.600	Colo.: 0.580
	137	Predicted mean depth required to initiate movement of D_{max} (mm), $d = \tau/\gamma S$ (τ = predicted shear stress, γ = 62.4, S = existing or design slope)	Shields: 0.72	Shields: N/A	Shields: 0.93
			Colo.: 0.35	Colo.: 0.36	Colo.: 0.38
	138	Predicted slope required to initiate movement of D_{max} (mm) $S=\tau/\gamma d$ (τ = predicted shear stress, γ = 62.4, d = existing or design depth)	Shields: 0.0970	Shields: N/A	Shields: 0.0303
			Colo.: 0.0472	Colo.: 0.0340	Colo.: 0.0126
	139	Bankfull dimensionless shear stress (τ^*)	N/A	N/A	N/A
	140	Required bankfull mean depth d_{bkf} (ft) using dimensionless shear stress equation: $d_{bkf} = \tau^*(\gamma_s - 1)D_{max}/S$ (Note: D_{max} in ft)	N/A	N/A	N/A
	141	Required bankfull water surface slope S (ft) using dimensionless shear stress equation: $S = \tau^*(\gamma_s - 1)D_{max}/d_{bkf}$ (Note: D_{max} in ft)	N/A	N/A	N/A
Streambank Erosion	Streambank Erosion		Existing Reach	Proposed Design Reach	Reference Reach
	150	Stream Length Assessed (ft)	167 (1,100)	1,100	406.0
	151	Graph/Curve Used (e.g., Yellowstone or Colorado)	Colorado	Colorado	Colorado
	152	Streambank Erosion (tons/yr)	45.08 (297)	5.50	1.96
	153	Streambank Erosion Rate (tons/yr/ft)	0.2700	0.005	0.005



Figure 85. Conceptual plan-form design for F4b to B4 stream type conversion, Northfield Gulch.

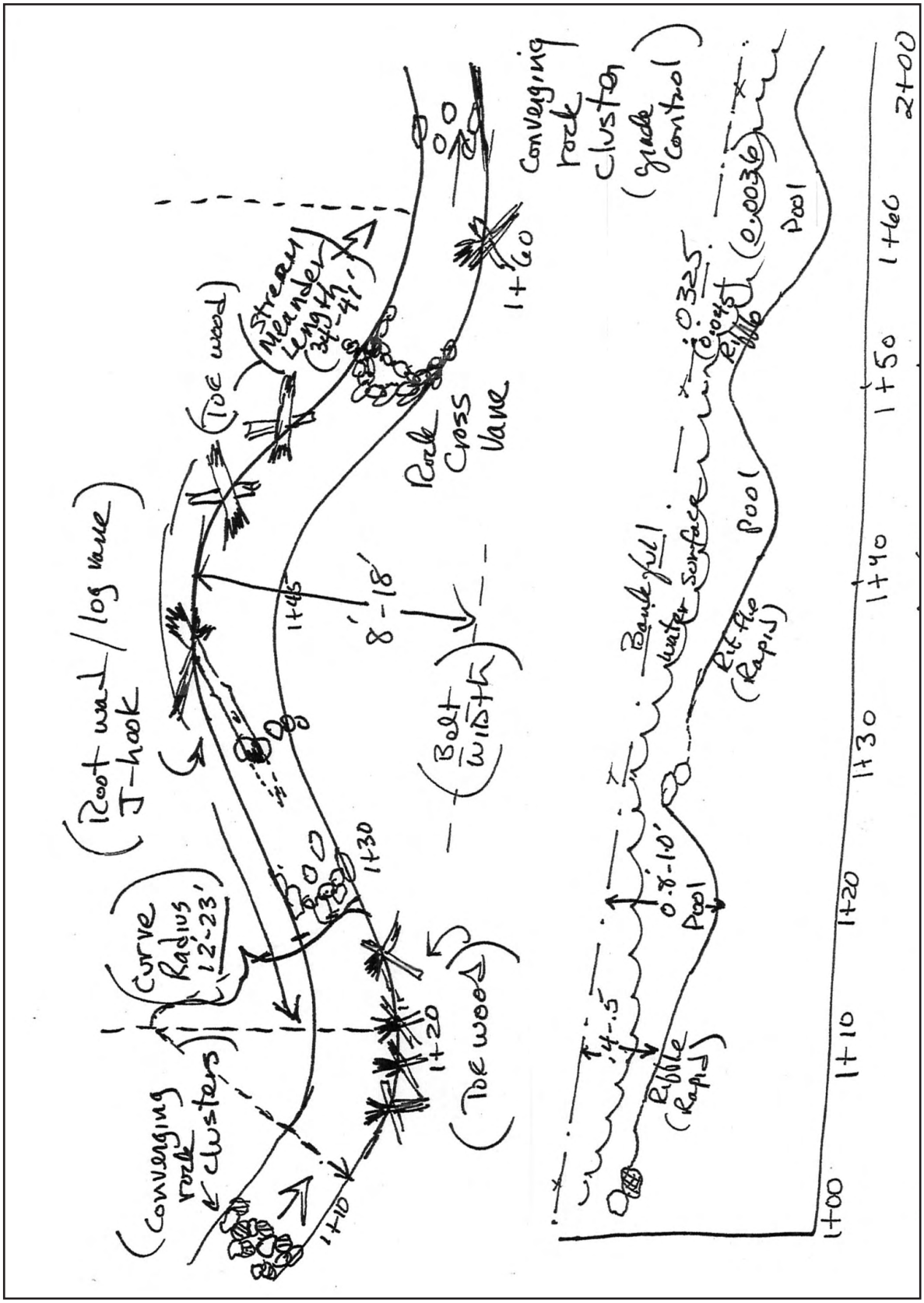


Figure 86. Proposed plan and profile views for B4 stream type on Northfield Gulch.

Table 21a. Predicted streambank erosion rate for the F4b Poor reach, Northfield Gulch.

Stream:	**Northfield Gulch Fb4 Poor**		Location: **Fb4 Poor**				
Graph Used:	**Colorado**	Total Stream Length (ft): **167**				Date: **11/2/2012**	
Observers:	**Rosgen et. al.**		Valley Type: **VIIIa**			Stream Type: **F4b**	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Station (ft)	**BEHI rating (Worksheet 3-11) (adjective)**	**NBS rating (Worksheet 3-12) (adjective)**	**Bank erosion rate (Figure 3-9 or 3-10) (ft/yr)**	**Length of bank (ft)**	**Study bank height (ft)**	**Erosion subtotal [(4)×(5)×(6)] (ft^3/yr)**	**Erosion Rate (tons/yr/ft) {[(7)/27] × 1.3 / (5)}**
1. **L0 -12**	**Extreme**	**Very Low**	**0.165**	**12.0**	**4.3**	**8.51**	**0.03420**
2. **L12-28**	**Extreme**	**Very High**	**7.027**	**16.0**	**4.2**	**472.21**	**1.42100**
3. **L28-36**	**Extreme**	**Very Low**	**0.165**	**8.0**	**2.9**	**3.83**	**0.02300**
4. **L36-49**	**High**	**Very Low**	**0.165**	**13.0**	**3.9**	**8.36**	**0.03100**
5. **L49-75**	**Very High**	**High**	**0.664**	**26.0**	**4.2**	**72.52**	**0.13430**
6. **L78-88**	**Very High**	**Low**	**0.250**	**10.0**	**3.8**	**9.50**	**0.04570**
7. **L88-100**	**Very High**	**Low**	**0.529**	**12.0**	**3.8**	**24.12**	**0.09680**
8. **L100-116**	**Very High**	**Very Low**	**0.190**	**16.0**	**3.0**	**9.12**	**0.02744**
9. **L116-123**	**Very High**	**Very Low**	**0.165**	**7.0**	**2.1**	**2.42**	**0.01670**
10. **L123-131**	**Very High**	**Very High**	**2.066**	**8.0**	**2.0**	**32.40**	**0.19500**
11. **L131-135**	**High**	**Low**	**0.529**	**4.0**	**2.0**	**4.15**	**0.05000**
12. **L135-141**	**High**	**Low**	**0.529**	**6.0**	**2.5**	**7.94**	**0.06370**
13. **L141-152**	**High**	**Low**	**0.529**	**9.0**	**2.2**	**10.47**	**0.05600**
14. **L152-167**	**Moderate**	**Low**	**0.168**	**15.0**	**1.8**	**4.54**	**0.01460**
15. **R0-17**	**Very High**	**Very High**	**0.832**	**17.0**	**5.1**	**72.17**	**0.20440**
16 **R17-28**	**Very High**	**Very Low**	**0.190**	**11.0**	**4.0**	**8.36**	**0.03659**
17 **R28-42**	**High**	**High**	**0.664**	**14.0**	**4.9**	**45.56**	**0.15670**
18 **R42-49**	**High**	**Very Low**	**0.160**	**7.0**	**5.4**	**6.03**	**0.04150**
19 **R49-75**	**Moderate**	**Very Low**	**0.090**	**26.0**	**4.5**	**10.53**	**0.01950**
20 **R75-83**	**Very High**	**Moderate**	**0.380**	**8.0**	**5.7**	**17.33**	**0.10430**
21 **R83-100**	**Very High**	**Low**	**0.529**	**17.0**	**5.1**	**45.86**	**0.13000**

Table 21b. Predicted streambank erosion rate for the F4b Poor reach, Northfield Gulch.

Stream: **Northfield Gulch Fb4 Poor**				Location: **Fb4 Poor**			
Graph Used: **Colorado**		Total Stream Length (ft): **167**				Date: **11/2/2012**	
Observers: **Rosgen et. al.**			Valley Type: **VIIIa**			Stream Type: **F4b**	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Station (ft)	**BEHI rating (Worksheet 3-11) (adjective)**	**NBS rating (Worksheet 3-12) (adjective)**	**Bank erosion rate (Figure 3-9 or 3-10) (ft/yr)**	**Length of bank (ft)**	**Study bank height (ft)**	**Erosion subtotal [(4)×(5)×(6)] (ft^3/yr)**	**Erosion Rate (tons/yr/ft) {[(7)/27] × 1.3 / (5)}**
22 **R100-119**	**Extreme**	**Very Low**	**0.200**	**19.0**	**3.3**	**12.54**	**0.03178**
23 **R119-124**	**Very High**	**Very Low**	**0.368**	**5.0**	**2.3**	**4.23**	**0.04070**
24 **R124-137**	**Low**	**Moderate**	**0.100**	**13.0**	**2.5**	**3.19**	**0.01180**
25 **R137-145**	**Very High**	**Very High**	**1.573**	**8.0**	**2.1**	**26.43**	**0.15910**
26 **R145-154**	**Very High**	**Low**	**0.529**	**9.0**	**2.1**	**10.00**	**0.05350**
27 **R154-167**	**Moderate**	**Low**	**0.168**	**13.0**	**1.9**	**4.04**	**0.01500**
28							
29							
30							
31							
32							
33							
34							
Sum erosion subtotals in Column (7) for each BEHI/NBS combination					**Total Erosion (ft^3/yr)**	**936.36**	
Convert erosion in ft^3/yr to yds^3/yr {divide Total Erosion (ft^3/yr) by 27}					**Total Erosion (yds^3/yr)**	**34.68**	
Convert erosion in yds^3/yr to tons/yr {multiply Total Erosion (yds^3/yr) by 1.3}					**Total Erosion (tons/yr)**	**45.08**	
Calculate erosion per unit length of channel {divide Total Erosion (tons/yr) by total length of stream (ft) surveyed}					**Unit Erosion Rate (tons/yr/ft)**	**0.2700**	

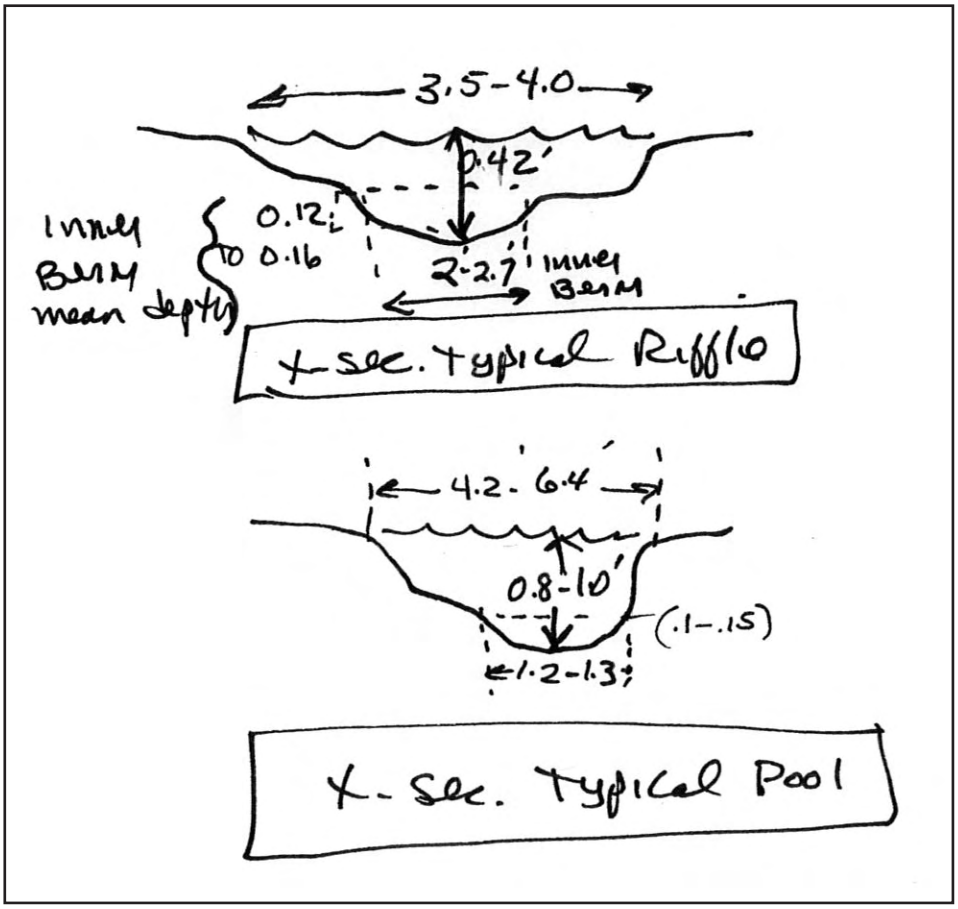


Figure 87. Typical riffle and pool dimensions for Northfield Gulch, proposed B4 stream type.

Table 22. Proposed velocity estimates for the B4 stream type, Northfield Gulch.

Bankfull VELOCITY & DISCHARGE Estimates

Stream:	**Northfield Gulch**		Location:	**West Monument**	
Date:		Stream Type: **B4**	Valley Type:	**VIIIa**	
Observers:			HUC:	_ _ _ _ _ _ _ _ _ _ _ _	

Input Variables for PROPOSED Design

Bankfull Riffle Cross-Sectional AREA	**1.0**	**A_{bkf}** (ft^2)
Bankfull Riffle WIDTH	**3.5**	**W_{bkf}** (ft)
D_{84} at Riffle	**9.9**	**Dia.** (mm)
Bankfull SLOPE	**0.0325**	**S_{bkf}** (ft / ft)
Gravitational Acceleration	**32.2**	**g** (ft / sec^2)
Drainage Area	**0.5**	**DA** (mi^2)

Output Variables for PROPOSED Design

Bankfull Riffle Mean DEPTH	**0.28**	**d_{bkf}** (ft)
Wetted PERIMETER ~ $(2 * d_{bkf}) + W_{bkf}$	**4.11**	**W_p** (ft)
D_{84} (mm) / 304.8	**0.03**	**D_{84}** (ft)
Hydraulic RADIUS A_{bkf} / W_p	**0.24**	**R** (ft)
Relative Roughness R(ft) / D_{84} (ft)	**7.48**	**R / D_{84}**
Shear Velocity $u^* = (gRS)^{½}$	**0.504**	**u*** (ft/sec)

ESTIMATION METHODS	Bankfull VELOCITY		Bankfull DISCHARGE	
1. Friction Factor / Relative Roughness $\bar{u} = [\ 2.83 + 5.66 * Log\ \{ R / D_{84} \}\ ]\ u^*$	**3.92**	ft / sec	**3.92**	cfs
2. Roughness Coefficient: a) Manning's *n* from Friction Factor / Relative Roughness (Figs. 4-44, 4-45) $\bar{u} = 1.49 * R^{2/3} * S^{1/2} / n$ $n =$ **0.055**	**1.90**	ft / sec	**1.90**	cfs
2. Roughness Coefficient: b) Manning's *n* from Stream Type (Fig. 4-46) $\bar{u} = 1.49 * R^{2/3} * S^{1/2} / n$ $n =$ **0.058**	**1.80**	ft / sec	**1.80**	cfs
2. Roughness Coefficient: c) Manning's *n* from Jarrett (USGS): $\bar{u} = 1.49 * R^{2/3} * S^{1/2} / n$ $n = 0.39 * S^{0.38} * R^{-0.16}$ **Note:** This equation is applicable to **steep, step/pool, high boundary roughness, cobble- and boulder-dominated stream systems**; i.e., for Stream Types A1, A2, A3, B1, B2, B3, C2 & E3 $n =$ **0.133**	**0.79**	ft / sec	**3.00**	cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)		ft / sec		cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)		ft / sec		cfs
4. Continuity Equations: a) USGS Gage Data $\bar{u} = Q / A$ **Return Period for Bankfull Q** $Q =$ _____ **year**		ft / sec		cfs
4. Continuity Equations: b) Regional Curves $\bar{u} = Q / A$	**3.00**	ft / sec	**3.0**	cfs

Protrusion Height Options for the D_{84} Term in the Relative Roughness Relation (R/D_{84}) – Estimation Method 1

Option 1.	For **sand-bed** channels: Measure 100 **"protrusion heights"** of sand dunes from the downstream side of feature to the top of feature. Substitute the D_{84} sand dune protrusion height in ft for the D_{84} term in method 1.
Option 2.	For **boulder-dominated** channels: Measure 100 **"protrusion heights"** of boulders on the sides from the bed elevation to the top of the rock on that side. Substitute the D_{84} boulder protrusion height in ft for the D_{84} term in method 1.
Option 3.	For **bedrock-dominated** channels: Measure 100 **"protrusion heights"** of rock separations, steps, joints or uplifted surfaces above channel bed elevation. Substitute the D_{84} bedrock protrusion height in ft for the D_{84} term in method 1.
Option 4.	For **log-influenced** channels: Measure "**protrustion heights**" proportionate to channel width of log diameters or the height of the log on upstream side if embedded. Substitute the D_{84} protrusion height in ft for the D_{84} term in method 1.

Table 23. Proposed competence estimates for the B4 stream type, Northfield Gulch.

Stream:	**Northfield Gulch**		Stream Type: **F4b poor to B4**		
Location:	**West Monument Creek**		Valley Type: **VIIIa**		
Observers:			Date:		
Enter Required Information for PROPOSED Design Condition					
4.8	D_{50}	Median particle size of riffle bed material (mm)			
N/A	$\hat{D}_{50}$	Median particle size of bar or sub-pavement sample (mm)			
0.39	D_{max}	Largest particle from bar sample (ft)	**120**	**(mm)**	304.8 mm/ft
0.03250	S	Proposed design bankfull water surface slope (ft/ft)			
0.28	d	Proposed design bankfull mean depth (ft)			
1.65	γ_s-γ/γ	Immersed specific gravity of sediment			
Select the Appropriate Equation and Calculate Critical Dimensionless Shear Stress					
N/A	$D_{50}/\hat{D}_{50}$	Range: 3 – 7	Use EQUATION 1: $\tau^* = 0.0834\ (\ D_{50}/\hat{D}_{50})^{-0.872}$		
N/A	D_{max}/D_{50}	Range: 1.3 – 3.0	Use EQUATION 2: $\tau^* = 0.0384\ (D_{max}/D_{50})^{-0.887}$		
N/A	τ^*	Bankfull Dimensionless Shear Stress	EQUATION USED:		**#VALUE!**
Calculate Bankfull Mean Depth Required for Entrainment of Largest Particle in Bar Sample					
N/A	**d**	Required bankfull mean depth (ft) $d = \frac{\tau^*(\gamma_s - 1)D_{max}}{S}$	(use D_{max} in ft)		
Calculate Bankfull Water Surface Slope Required for Entrainment of Largest Particle in Bar Sample					
N/A	**S**	Required bankfull water surface slope (ft/ft) $S = \frac{\tau^*(\gamma_s - 1)D_{max}}{d}$	(use D_{max} in ft)		
Check: ☐ Stable ☐ Aggrading ☐ Degrading					
Sediment Competence Using Dimensional Shear Stress					
0.571		Bankfull shear stress $\tau = \gamma dS$ (lbs/ft^2) (substitute hydraulic radius, R, with mean depth, d) γ = 62.4, d = proposed design depth, S = proposed design slope			
Shields **43.51**	CO **100.7**	Predicted largest moveable particle size (mm) at bankfull shear stress τ **(Figure 5-49)**			
Shields **1.513**	CO **0.725**	Predicted shear stress required to initiate movement of measured D_{max} (mm) **(Figure 5-49)**			
Shields **0.75**	CO **0.36**	Predicted mean depth required to initiate movement of measured D_{max} (mm) $d = \frac{\tau}{\gamma S}$ τ = predicted shear stress, γ = 62.4, S = proposed design slope			
Shields **0.0860**	CO **0.0412**	Predicted slope required to initiate movement of measured D_{max} (mm) $S = \frac{\tau}{\gamma d}$ τ = predicted shear stress, γ = 62.4, d = proposed design depth			
Check: ☑ Stable ☐ Aggrading ☐ Degrading					

Table 24. Total annual sediment yield for the post-fire, impaired F4b poor stream type using the FLOWSED model.

Stream: **Waldo Reference and Representative Reaches**					Location: **F4b Poor (Northfield)**					Date: **11/02/2012**			
Observers: **Rosgen et al.**					Gage Station #: **N/A**					Stream Type: **F4b**		Valley Type: **VIIIa**	
Equation type	**Intercept**	**Coefficient**	**Exponent**	**Form (e.g., linear, non-linear, etc.)**	**Equation name**	**Bankfull discharge (cfs)**		**Bankfull bedload (kg/s)**		**Bankfull suspended (mg/l)**			
1. Bedload (dimensionless)	**0.07176**	**1.02176**	**2.37716**	**Non-Linear**	**Pagosa Springs Reference Curve**	**2.92**		**0.1992**		**129.143**			
2. Suspended sediment (dimensionless)	**0.0989**	**0.9213**	**3.659**	**Non-Linear**	**Pagosa Springs Reference Curve**								
3. User-defined relations (bedload)						Notes: **Poor Sediment Curves, Poor Regional Sediment Curves (using washload and suspended sand), Post-Fire Regional Curves (3.81 WY Change)**							
4. User-defined relations (suspended sediment)													
From dimensioned flow-duration curve							**From sediment rating curves**				**Calculate**	**Calculate sediment yield**		
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**	**(11)**	**(12)**	**(13)**	**(14)**	**(15)**
Flow exceedence	Daily mean discharge	Mid-ordinate	Time increment (percent)	Time increment (days)	Mid-ordinate streamflow	Dimension-less streamflow	Dimension-less suspended sediment discharge	Suspended sediment discharge	Dimension-less bedload discharge	Bedload	Time adjusted streamflow	Suspended sediment **[(5)×(9)]**	Bedload sediment **[(5)×(11)]**	Suspended + bedload **[(13)+(14)]**
(%)	(cfs)	(%)	(%)	(days)	(cfs)	(Q/Q_{bkf})	(S/S_{bkf})	(tons/day)	(b_s/b_{bkf})	(tons/day)	(cfs)	(tons)	(tons)	(tons)
100.000	**0.0**													
90.000	**0.1**	**95.00**	**10.00**	**36.50**	**0.1**	**0.02**	**5.9**	**0.0**	**0.0253**	**1.38**	**0.50**	**0.00**	**50.37**	**50.37**
80.000	**0.1**	**85.00**	**10.00**	**36.50**	**0.1**	**0.03**	**5.9**	**0.0**	**0.0253**	**1.38**	**1.00**	**0.00**	**50.37**	**50.37**
70.000	**0.1**	**75.00**	**10.00**	**36.50**	**0.1**	**0.04**	**5.9**	**0.0**	**0.0253**	**1.38**	**1.10**	**0.00**	**50.37**	**50.37**
60.000	**0.2**	**65.00**	**10.00**	**36.50**	**0.1**	**0.05**	**5.9**	**0.0**	**0.0253**	**1.38**	**1.40**	**0.00**	**50.37**	**50.37**
50.000	**0.2**	**55.00**	**10.00**	**36.50**	**0.2**	**0.06**	**5.9**	**0.0**	**0.0253**	**1.38**	**1.70**	**0.36**	**50.37**	**50.73**
40.000	**0.3**	**45.00**	**10.00**	**36.50**	**0.2**	**0.08**	**5.9**	**0.0**	**0.0253**	**1.43**	**2.30**	**0.36**	**52.20**	**52.56**
30.000	**0.4**	**35.00**	**10.00**	**36.50**	**0.3**	**0.11**	**6.0**	**0.0**	**0.0261**	**1.47**	**3.30**	**0.36**	**53.66**	**54.02**
20.000	**0.9**	**25.00**	**10.00**	**36.50**	**0.7**	**0.22**	**6.2**	**0.0**	**0.0340**	**1.90**	**6.50**	**0.73**	**69.35**	**70.08**
10.000	**1.8**	**15.00**	**10.00**	**36.50**	**1.4**	**0.46**	**9.4**	**0.1**	**0.0791**	**4.45**	**13.50**	**2.56**	**162.43**	**164.99**
5.000	**2.7**	**7.50**	**5.00**	**18.25**	**2.3**	**0.78**	**28.2**	**0.4**	**0.2114**	**12.01**	**11.35**	**6.75**	**219.18**	**225.93**
											Annual totals:	**11.1** (tons/yr)	**808.7** (tons/yr)	**819.8** (tons/yr)

Table 25. Total annual sediment yield for the post-fire, proposed B4 (good stability) stream type using the FLOWSED model.

Stream: **Waldo Reference and Representative Reaches** Location: **F4b Poor (Northfield) converted to B4 Stream Type** Date: **11/02/2012**

Observers: **Rosgen et al.** Gage Station #: **N/A** Stream Type: **B4** Valley Type: **VIIIa**

Equation type	Intercept	Coefficient	Exponent	Form (e.g., linear, non-linear, etc.)	Equation name	Bankfull discharge (cfs)	Bankfull bedload (kg/s)	Bankfull suspended (mg/l)
1. Bedload (dimensionless)	-0.0113	1.0139	2.1929	Non-Linear	Pagosa Springs Reference Curve	2.92	0.0067	1.62
2. Suspended sediment (dimensionless)	0.0636	0.9326	2.4085	Non-Linear	Pagosa Springs Reference Curve			
3. User-defined relations (bedload)						Notes: Good Sediment Curves, Good Regional Sediment Curves (using washload and suspended sand), Post-Fire Regional Curves (3.81 WY Change)		
4. User-defined relations (suspended sediment)								

From dimensioned flow-duration curve							From sediment rating curves				Calculate	Calculate sediment yield		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Flow exceedence	Daily mean discharge	Mid-ordinate	Time increment (percent)	Time increment (days)	Mid-ordinate streamflow	Dimension-less streamflow	Dimension-less suspended sediment discharge	Suspended sediment discharge	Dimension-less bedload discharge	Bedload	Time adjusted streamflow	Suspended sediment [(5)×(9)]	Bedload sediment [(5)×(11)]	Suspended + bedload [(13)+(14)]
(%)	(cfs)	(%)	(%)	(days)	(cfs)	(Q/Q_{bkf})	(S/S_{bkf})	(tons/day)	(b_s/b_{bkf})	(tons/day)	(cfs)	(tons)	(tons)	(tons)
100.000	0.0													
90.000	0.1	95.00	10.00	36.50	0.1	0.02	5.9	0.0	0.0253	0.00	0.50	0.00	0.00	0.00
80.000	0.1	85.00	10.00	36.50	0.1	0.03	5.9	0.0	0.0253	0.00	1.00	0.00	0.00	0.00
70.000	0.1	75.00	10.00	36.50	0.1	0.04	5.9	0.0	0.0253	0.00	1.10	0.00	0.00	0.00
60.000	0.2	65.00	10.00	36.50	0.1	0.05	5.9	0.0	0.0253	0.00	1.40	0.00	0.00	0.00
50.000	0.2	55.00	10.00	36.50	0.2	0.06	5.9	0.0	0.0253	0.00	1.70	0.00	0.00	0.00
40.000	0.3	45.00	10.00	36.50	0.2	0.08	5.9	0.0	0.0253	0.00	2.30	0.00	0.00	0.00
30.000	0.4	35.00	10.00	36.50	0.3	0.11	6.0	0.0	0.0261	0.00	3.30	0.00	0.00	0.00
20.000	0.9	25.00	10.00	36.50	0.7	0.22	6.2	0.0	0.0340	0.00	6.50	0.00	0.00	0.00
10.000	1.8	15.00	10.00	36.50	1.4	0.46	9.4	0.0	0.0791	0.13	13.50	0.00	4.75	4.75
5.000	2.7	7.50	5.00	18.25	2.3	0.78	28.2	0.0	0.2114	0.35	11.35	0.18	6.39	6.57
											Annual totals:	0.2 (tons/yr)	11.1 (tons/yr)	11.3 (tons/yr)

Table 26. Bedload and suspended sand bed-material load transport prediction for the impaired F4b stream type using the POWERSED model, indicating aggradation for the existing, impaired F4b stream type compared to the stable, proposed B4 stream type assuming the same sediment supply.

Flow-duration curve		Calculate	Hydraulic geometry				Measure	Calculate									
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Percentage of time	Daily mean discharge	Mid-ordinate stream-flow	Area	Width	Depth	Velocity	Slope	Shear stress	Stream power	Unit power	Time increment	Time increment	Daily mean bedload transport	Daily mean suspended sand transport	Time adjusted bedload transport [(13)×(14)]	Time adjusted suspended sand transport [(13)×(15)]	Time adjusted total transport [(16)+(17)]
(%)	(cfs)	(cfs)	(ft^2)	(ft)	(ft)	(ft/s)	(ft/ft)	(lb/ft^2)	(lb/s)	(lb/ft/s)	(%)	(days)	(tons/day)	(tons/day)	(tons)	(tons)	(tons)
100.000	0.02								0.00						0.00	0.00	0.00
90.000	0.08	0.05	0.07	1.45	0.05	0.61	0.0360	0.11	0.11	0.08	10.000	36.50	1.38	0.00	50.00	0.00	50.00
80.000	0.11	0.10	0.11	1.71	0.06	0.73	0.0360	0.14	0.22	0.13	10.000	36.50	1.38	0.00	50.00	0.00	50.00
70.000	0.12	0.11	0.11	1.76	0.06	0.75	0.0360	0.14	0.25	0.14	10.000	36.50	1.38	0.00	50.00	0.00	50.00
60.000	0.15	0.14	0.14	1.92	0.07	0.82	0.0360	0.16	0.31	0.16	10.000	36.50	1.38	0.00	50.00	0.00	50.00
50.000	0.20	0.17	0.16	2.07	0.08	0.89	0.0360	0.17	0.38	0.18	10.000	36.50	1.38	0.00	50.00	0.00	50.00
40.000	0.26	0.23	0.21	2.38	0.09	1.03	0.0360	0.19	0.52	0.22	10.000	36.50	1.43	0.00	52.00	0.00	52.00
30.000	0.41	0.33	0.27	2.63	0.10	1.15	0.0360	0.22	0.74	0.28	10.000	36.50	1.47	0.01	54.00	0.00	54.00
20.000	0.88	0.65	0.45	3.16	0.14	1.39	0.0360	0.31	1.46	0.46	10.000	36.50	1.77	0.01	65.00	0.00	65.00
10.000	1.83	1.35	0.82	4.64	0.18	1.63	0.0360	0.38	3.03	0.65	10.000	36.50	2.51	0.03	92.00	1.00	93.00
5.000	2.70	2.27	1.18	5.46	0.22	1.87	0.0360	0.47	5.10	0.93	5.000	18.25	4.10	0.06	75.00	1.00	76.00
4.000	2.94	2.82	1.36	5.58	0.24	2.03	0.0360	0.52	6.33	1.13	1.000	3.65	6.96	0.13	25.00	0.00	26.00

Notes:

Total annual sediment yield (bedload and suspended sand bed-material load) (tons/yr):	614.3	3.5	617.7
Upstream total annual sediment comparative reach (tons/yr):	759.9	3.7	763.6
Difference in sediment transport capacity (tons/yr) (+ or -):	-145.6	-0.2	-145.9
Stability evaluation: Aggradation, Degradation or Stable:	F4b Aggradation		

Summary of Sediment Reductions with the Master Plan

Hillslope Processes (Surface Erosion)

For the top ten priority sub-watersheds, 91% of the surface erosion is delivered by just 53% of the area (**Table 27**). Implementing the recommended practices for surface erosion prevention on the high priority areas would potentially reduce the sediment introduction by approximately *6,675 tons/yr* (69%) for the 10 sub-watersheds. The beneficial recommendations include eliminating rills, increasing ground cover to over 65% (particularly on the lower 1/3 of the hillslope), and constructing bankfull benches or toe "catches" to reduce direct sediment delivery.

Table 27. Proposed sediment reduction in the top 10 priority sub-watersheds for hillslope processes.

Hillslope Processes							
Total Acres	Priority Area (acres)	Priority Area (%)	Total Delivered Sediment (tons/yr)	Delivered Sediment from Priority Area (tons/yr)	Delivered Sediment from Priority Area (%)	Delivered Sediment Reduction (tons/yr)	Delivered Sediment Reduction (%)
8,006	4,211	53%	9,909	8,896	91%	6,675	69%

Roads and Trails

Re-routing of roads and eliminating fords, in addition to the recommended fill stabilization, channel alignment away from road fills, stabilization of ditch-line induced tributary "headcuts", and better drainage, will significantly reduce road and trail derived sediment yields. This recommended work involves closing, sloping, draining, and seeding the abandoned roads and trails in addition to good drainage and erosion control features. Additionally, Best Management Practices (BMPs) are necessary for any road or trail relocations.

Channel Processes

By implementing the proposed stream restoration design scenarios on 31% (23.5 miles) of the stream miles in the top 10 priority sub-watersheds, potential sediment reduction from streambank erosion alone is *14,705 tons/yr*, or 84% of the total annual bank erosion (**Table 28**); this reduction is about 46% of the total annual streambank erosion from all the watersheds affected by the fire. Average cost per ton of sediment stored or stabilized is $14.00. With the current sediment availability (flow-related) of *35,758 tons/yr*, the lifespan of the channel storage (alluvial fan, alluvial fill, and sediment basins) created is expected to be 13 years.

Table 28. Proposed sediment reduction and associated costs for the top 10 priority sub-watersheds for channel processes.

Channel Processes: Sediment Reduction & Costs for Top 10 Priority Watersheds							
Total Length of Channel (ft)	Total Length of Channel Treated (ft)	Channel Treated (%)	Total Sediment Reduction from Bank Erosion (tons/yr)	Reduction of Bank Erosion (%)	Total Sediment Stabilized and Deposited (tons)	Estimated Storage Lifespan (years)	Cost / Ton of Channel Work
400,027	124,060	31%	14,705	84%	225,667	13 years	$14.00

Discussion & Summary

The Waldo Canyon Fire master plan for watershed restoration and sediment reduction is the result of a detailed watershed assessment that has directed the proposed restoration of impaired streams. The assessment also identified the source of impairment, including hillslope, roads, hydrology, and channel processes. The master plan has identified priorities of restoration based on disproportionate sediment supply contributions and the various sources, including streambed and streambank erosion from post-fire related streamflow increases, and direct introduction by surface erosion and roads and trails. These various erosional processes were identified and specific restoration scenarios are proposed to reduce the sediment supply and restore the physical and biological function.

The multiple objectives for this master restoration design for the Waldo Canyon Fire watersheds are potentially met with the implementation of the various scenarios and locations proposed. Monitoring will validate if the stated objectives are met. Overall, the various restoration scenarios within the Waldo Canyon Fire Watersheds were developed to:

1) Extrapolate general hydrology, sedimentological, and morphological relations and create the dimension, pattern, and profile of stable stream types scaled for individual reaches
2) Secure a 404 permit to implement the designs
3) Plan construction in 2013 to implement these typical designs and to provide a demonstration of the methods and associated effectiveness of meeting the stated goals of restoration

The eight typical design scenarios utilize the procedures detailed in **Appendix I** to determine the final restoration designs. These typical design scenarios can be extrapolated to the various stream types and conditions at a given location by following this procedure. The subsequent designs are intended to accelerate the recovery of the watersheds from the adverse impacts of the Waldo Canyon Fire. The proposed design scenarios and subsequent implementation will potentially direct the future of watershed restoration following large wildfires. The implementation of this plan will provide a framework to demonstrate the nature of the restoration that could be applied elsewhere. Additional research and monitoring opportunities can be utilized to provide an understanding of the benefits of restoration in relation to accelerating watershed recovery.

This restoration will help reduce some of the flood risk for normal precipitation occurrences but will not significantly alter the impacts from potential catastrophic events as the hydrologic recovery will extend for many decades. Homes located on existing 100 year floodplains and alluvial fans will continue to be at risk. Future development on flood-prone areas should be discouraged as the potential flood risk will still be present.

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Appendix I

The Natural Channel Design Procedure

The Natural Channel Design Procedure

The Waldo Canyon Fire master plan for watershed restoration and sediment reduction is based on the Natural Channel Design (NCD) methodology as depicted in **Flowchart 1** in the main report. The NCD approach is divided into ten major sequential phases:

Phase I	**Define Restoration Objectives**
Phase II	**Develop Local & Regional Relations**
Phase III	**Conduct Watershed, River & Biological Assessments**
Phase IV	**Consider Passive Recommendations for Restoration**
Phase V	**Develop Conceptual Design Plan**
Phase VI	**Develop & Evaluate the Preliminary Natural Channel Design**
Phase VII	**Design Stabilization & Enhancement Structures**
Phase VIII	**Finalize Natural Channel Design**
Phase IX	**Implement Natural Channel Design**
Phase X	**Conduct Monitoring & Maintenance**

Phases I–V have been completed and are documented in the Waldo Canyon Fire *WARSSS* report (Rosgen *et al*., 2013). Phase VI that develops and evaluates the preliminary natural channel design using the dimensionless relations from reference reaches is presented in this appendix. The remaining phases are addressed in the main report.

Phase VI — Develop & Evaluate the Preliminary Natural Channel Design

Phase VI includes the computational sequence to obtain and evaluate the morphological characteristics for the preliminary natural channel design. *Phase VI* combines the results of *Phase II* and *Phase III*. A good design can only follow a good assessment to provide solutions to restoration that will offset the cause of the problem and allow for the river to be self-maintaining. The objectives that led to the conceptual design in *Phase V* must also be consistent and be designed with more detail at this phase. The computational sequence incorporates the watershed and river assessment that predicts the consequence of streamflow, sediment supply and channel change. This design phase utilizes the reference reach ratios that represent similar potential controlling variables and boundary conditions, including valley type, riparian vegetation and sediment and flow regimes. The early sequence calculates the required variables to initially test whether the hydraulic and sediment relations associated with the proposed design reach and the reference reach are compatible prior to advancing through the entire computational sequence.

Along with *mean* values of morphological characteristics, the *minimum* and *maximum* values are also calculated. Natural channel design uses the range of values to account for the natural variability in river systems. This allows the designer the flexibility to utilize terrain and existing vegetation to optimize the stream design. This flexibility is necessary for a range of situations. Take, for example, a laterally constrained reach (low valley width) with a proposed entrenchment ratio that ranges from 3.0–5.0, then using the *minimum* width/depth ratio value and the *minimum* entrenchment ratio would generate the greatest corresponding channel depth. Consequently, shear stress, velocity and stream power would be higher and flood levels would be increased in a reach that was laterally constrained. However, for locations where the valley slope is relatively steep associated with a coarse, high bedload sediment supply regime, a large radius of curvature to bankfull width ratio would be observed along with and an arc length ratio of 3.0–4.0 widths forming a compound pool. These relations must be reflected in the design. In this instance, the width/depth ratio corresponding to the above controlling variables would require the *maximum* value in the range rather than the *minimum* value. Thoroughly reviewing the field data and the corresponding reference reach data ranges will help determine which combination of values (*mean*, *minimum* or *maximum*) to select.

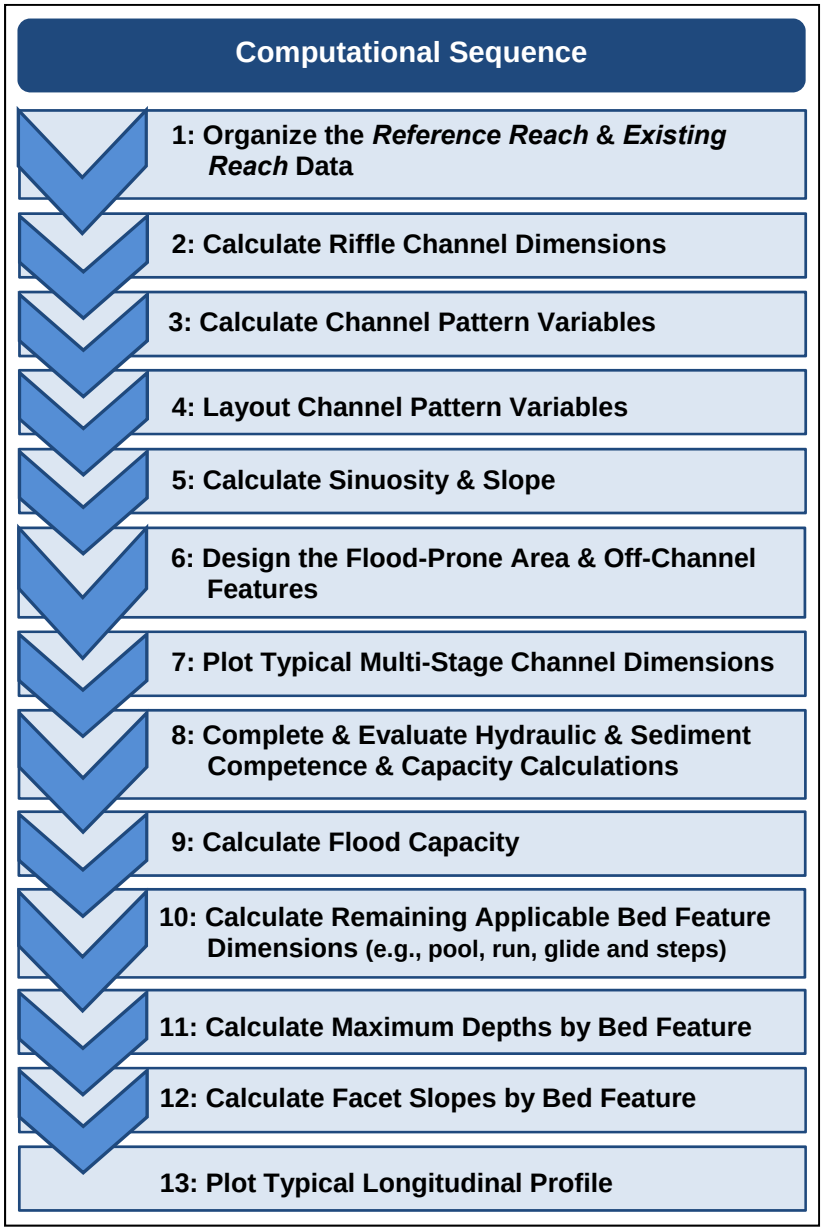
The *mean*, *minimum* and *maximum* values for the proposed design reach are also used for monitoring and maintenance criteria. Stream adjustment that stays within the range of morphological values is appropriate; however, when the morphological variables depart from the range of values, maintenance is recommended.

The user has the option to select the morphological values that best represent the boundary conditions of the proposed channel and requirements to meet specific objectives, and sometimes the values for the proposed design reach will depart from the reference reach ratios. For example, if the limiting factor for trout was over-wintering habitat, then the designer may be inclined to select a ratio of bankfull pool maximum depth to bankfull mean depth that is greater than the range derived from the reference reach dataset. Monitoring is essential when the designer feels compelled to depart from existing reference reach ratios. Departure from the dimensionless relations for natural channel design requires experience and judgment, but it is necessary to exercise appropriate options; selecting ratios blindly is never good practice.

Computational Sequence

The computational sequence outlined in **Flowchart I-1** determines and evaluates the dimension, pattern and profile variables for the preliminary natural channel design, which includes the floodplain and flood-prone area. **Table I-1** lists the required variables that must be determined for the proposed design reach using the reference reach ratios (indicated by the ratio followed by the subscript "ref"). The reference reach ratios are multiplied by the appropriate normalization parameter of the proposed design reach. For example, all pattern data is normalized by the bankfull riffle width; to determine the belt width of the proposed design reach, the dimensionless ratio of belt width to bankfull riffle width of the reference reach ($[W_{blt}/W_{bkf}]_{ref}$) is multiplied by the determined bankfull riffle width of the proposed design reach.

All morphological characteristics are recorded in **Table I-2** for the existing, proposed design and reference reaches. References to specific entry items in **Table I-2** are included throughout the sequence to locate where to record the proposed design reach variables. A detailed discussion of each procedural sequence follows **Table I-2**.



Flowchart I-1. Computational sequence to determine and evaluate the dimension, pattern, and profile of the preliminary natural channel design.

Table I-1. The dimension, pattern, and profile variables that must be predicted for natural channel design using reference reach dimensionless ratios.

Morphological Variables Predicted for Natural Channel Design Using Reference Reach Dimensionless Ratios	
Channel Dimensions	
Riffle Dimensions	*Riffle Inner Berm Dimensions*
1 Riffle Width (W_{bkf})	**5** Riffle Inner Berm Width (W_{ib})
2 Riffle Mean Depth (d_{bkf})	**6** Riffle Inner Berm Mean Depth (d_{ib})
3 Riffle Width/Depth Ratio (W_{bkf}/d_{bkf})	**7** Riffle Inner Berm Cross-Sectional Area (A_{ib})
4 Riffle Maximum Depth (d_{max})	**8** Riffle Inner Berm Width/Depth Ratio (W_{ib}/d_{ib})
Pool Dimensions	
9 Pool Width (W_{bkfp})	*Pool Inner Berm Dimensions*
10 Pool Mean Depth (d_{bkfp})	**15** Pool Inner Berm Width (W_{ibp})
11 Pool Cross-Sectional Area (A_{bkfp})	**16** Pool Inner Berm Mean Depth (d_{ibp})
12 Pool Width/Depth Ratio (W_{bkfp}/d_{bkfp})	**17** Pool Inner Berm Cross-Sectional Area (A_{ibp})
13 Pool Maximum Depth (d_{maxp})	**18** Pool Inner Berm Width/Depth Ratio (W_{ibp}/d_{ibp})
14 Point Bar Slope (S_{pb})	
Glide Dimensions	*Glide Inner Berm Dimensions*
19 Glide Width (W_{bkfg})	**24** Glide Inner Berm Width (W_{ibg})
20 Glide Mean Depth (d_{bkfg})	**25** Glidel Inner Berm Mean Depth (d_{ibg})
21 Glide Cross-Sectional Area (A_{bkfg})	**26** Glide Inner Berm Cross-Sectional Area (A_{ibg})
22 Glide Width/Depth Ratio (W_{bkfg}/d_{bkfg})	**27** Glide Inner Berm Width/Depth Ratio (W_{ibg}/d_{ibg})
23 Glide Maximum Depth (d_{maxg})	
Run Dimensions	***Step Dimensions***
28 Run Width (W_{bkfr})	**33** Step Width (W_{bkfs})
29 Run Mean Depth (d_{bkfr})	**34** Step Mean Depth (d_{bkfs})
30 Run Cross-Sectional Area (A_{bkfr})	**35** Step Cross-Sectional Area (A_{bkfs})
31 Run Width/Depth Ratio (W_{bkfr}/d_{bkfr})	**36** Step Width/Depth Ratio (W_{bkfs}/d_{bkfs})
32 Run Maximum Depth (d_{maxr})	**37** Step Maximum Depth (d_{maxs})
Channel Pattern	
38 Linear Wavelength (λ)	**42** Arc Length (L_a)
39 Stream Meander Length (L_m)	**43** Riffle Length (L_r)
40 Belt Width (W_{blt})	**44** Individual Pool Length (L_p)
41 Radius of Curvature (R_c)	**45** Pool-to-Pool Spacing (P_s)
Channel Profile	
Bankfull Maximum Depths from Profile	***Water Surface Facet Slopes***
46 Riffle Maximum Depth (d_{max})	**51** Riffle Slope (S_{rif})
47 Pool Maximum Depth (d_{maxp})	**52** Pool Slope (S_p)
48 Run Maximum Depth (d_{maxr})	**53** Run Slope (S_{run})
49 Glide Maximum Depth (d_{maxg})	**54** Glide Slope (S_g)
50 Step Maximum Depth (d_{maxs})	**55** Step Slope (S_s)

Table I-2. Morphological characteristics of the existing, proposed design & reference reaches. Page 1/10

Existing Reach Stream & Location:				
Reference Reach Stream & Location:				
Entry Number & Variable		**Existing Reach**	**Proposed Design Reach**	**Reference Reach**
	1 Valley Type (I–XII)			
	2 Valley Width (W_{val})			
	3 Stream Type			
	4 Drainage Area, mi^2 (DA)			
	5 Bankfull Discharge, cfs (Q_{bkf})			
Riffle Dimensions	**6** Riffle Width, ft (W_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	7 Riffle Mean Depth, ft (d_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	8 Riffle Width/Depth Ratio (W_{bkf}/d_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	9 Riffle Cross-Sectional Area, ft^2 (A_{bkf})	*Mean:* *Min:* *Max:*	*Mean:*	*Mean:* *Min:* *Max:*
	10 Riffle Maximum Depth (d_{max})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	11 Riffle Maximum Depth to Riffle Mean Depth (d_{max}/d_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	12 Width of Flood-Prone Area at Elevation of 2 * d_{max}, ft (W_{fpa})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	13 Entrenchment Ratio (W_{fpa}/W_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
Riffle Inner Berm Dimensions	**14** Riffle Inner Berm Width, ft (W_{ib})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	15 Riffle Inner Berm Width to Riffle Width (W_{ib}/W_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	16 Riffle Inner Berm Mean Depth, ft (d_{ib})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	17 Riffle Inner Berm Mean Depth to Riffle Mean Depth (d_{ib}/d_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	18 Riffle Inner Berm Width/Depth Ratio (W_{ib}/d_{ib})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	19 Riffle Inner Berm Cross-Sectional Area (A_{ib})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	20 Riffle Inner Berm Cross-Sectional Area to Riffle Cross-Sectional Area (A_{ib}/A_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*

Table I-2. Morphological characteristics of the existing, proposed design & reference reaches. Page 2/10

	Entry Number & Variable	Existing Reach	Proposed Design Reach	Reference Reach
Pool Dimensions	**21** Pool Width, ft (W_{bkfp})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	22 Pool Width to Riffle Width (W_{bkfp}/W_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	23 Pool Mean Depth, ft (d_{bkfp})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	24 Pool Mean Depth to Riffle Mean Depth (d_{bkfp}/d_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	25 Pool Width/Depth Ratio (W_{bkfp}/d_{bkfp})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	26 Pool Cross-Sectional Area, ft^2 (A_{bkfp})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	27 Pool Area to Riffle Area (A_{bkfp}/A_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	28 Pool Maximum Depth (d_{maxp})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	29 Pool Maximum Depth to Riffle Mean Depth (d_{maxp}/d_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	30 Point Bar Slope (S_{pb})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
Pool Inner Berm Dimensions	**31** Pool Inner Berm Width, ft (W_{ibp})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	32 Pool Inner Berm Width to Pool Width (W_{ibp}/W_{bkfp})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	33 Pool Inner Berm Mean Depth, ft (d_{ibp})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	34 Pool Inner Berm Mean Depth to Pool Mean Depth (d_{ibp}/d_{bkfp})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	35 Pool Inner Berm Width/Depth Ratio (W_{ibp}/d_{ibp})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	36 Pool Inner Berm Cross-Sectional Area (A_{ibp})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	37 Pool Inner Berm Cross-Sectional Area to Pool Cross-Sectional Area (A_{ibp}/A_{bkfp})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*

Table I-2. Morphological characteristics of the existing, proposed design & reference reaches. Page 3/10

	Entry Number & Variable	Existing Reach	Proposed Design Reach	Reference Reach
Run Dimensions	**38** Run Width, ft (W_{bkfr})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	39 Run Width to Riffle Width (W_{bkfr}/W_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	40 Run Mean Depth, ft (d_{bkfr})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	41 Run Mean Depth to Riffle Mean Depth (d_{bkfr}/d_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	42 Run Width/Depth Ratio (W_{bkfr}/d_{bkfr})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	43 Run Cross-Sectional Area, ft^2 (A_{bkfr})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	44 Run Area to Riffle Area (A_{bkfr}/A_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	45 Run Maximum Depth (d_{maxr})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	46 Run Maximum Depth to Riffle Mean Depth (d_{maxr}/d_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
Glide Dimensions	**47** Glide Width, ft (W_{bkfg})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	48 Glide Width to Riffle Width (W_{bkfg}/W_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	49 Glide Mean Depth, ft (d_{bkfg})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	50 Glide Mean Depth to Riffle Mean Depth (d_{bkfg}/d_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	51 Glide Width/Depth Ratio (W_{bkfg}/d_{bkfg})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	52 Glide Cross-Sectional Area, ft^2 (A_{bkfg})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	53 Glide Area to Riffle Area (A_{bkfg}/A_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	54 Glide Maximum Depth (d_{maxg})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	55 Glide Maximum Depth to Riffle Mean Depth (d_{maxg}/d_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*

Table I-2. Morphological characteristics of the existing, proposed design & reference reaches. Page 4/10

Entry Number & Variable			Existing Reach	Proposed Design Reach	Reference Reach
Glide Inner Berm Dimensions	56	Glide Inner Berm Width, ft (W_{ibg})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	57	Glide Inner Berm Width to Glide Width (W_{ibg}/W_{bkfg})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	58	Glide Inner Berm Mean Depth, ft (d_{ibg})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	59	Glide Inner Berm Mean Depth to Glide Mean Depth (d_{ibg}/d_{bkfg})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	60	Glide Inner Berm Width/Depth Ratio (W_{ibg}/d_{ibg})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	61	Glide Inner Berm Cross-Sectional Area (A_{ibg})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	62	Glide Inner Berm Area to Glide Area (A_{ibg}/A_{bkfg})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
Step Dimensions	63	Step Width, ft (W_{bkfs})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	64	Step Width to Riffle Width (W_{bkfs}/W_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	65	Step Mean Depth, ft (d_{bkfs})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	66	Step Mean Depth to Riffle Mean Depth (d_{bkfs}/d_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	67	Step Width/Depth Ratio (W_{bkfs}/d_{bkfs})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	68	Step Cross-Sectional Area, ft^2 (A_{bkfs})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	69	Step Area to Riffle Area (A_{bkfs}/A_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	70	Step Maximum Depth (d_{maxs})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	71	Step Maximum Depth to Riffle Mean Depth (d_{maxs}/d_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*

Table I-2. Morphological characteristics of the existing, proposed design & reference reaches. Page 5/10

	Entry Number & Variable		Existing Reach	Proposed Design Reach	Reference Reach
Channel Pattern	**72**	Linear Wavelength, ft (λ)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	73	Linear Wavelength to Riffle Width (λ/W_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	74	Stream Meander Length, ft (L_m)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	75	Stream Meander Length Ratio (L_m/W_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	76	Belt Width, ft (W_{blt})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	77	Meander Width Ratio (W_{blt}/W_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	78	Radius of Curvature, ft (R_c)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	79	Radius of Curvature to Riffle Width (R_c/W_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	80	Arc Length, ft (L_a)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	81	Arc Length to Riffle Width (L_a/W_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	82	Riffle Length (L_r), ft	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	83	Riffle Length to Riffle Width (L_r/W_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	84	Individual Pool Length, ft (L_p)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	85	Pool Length to Riffle Width (L_p/W_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	86	Pool-to-Pool Spacing, ft (P_s)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	87	Pool-to-Pool Spacing to Riffle Width (P_s/W_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*

Table I-2. Morphological characteristics of the existing, proposed design & reference reaches. Page 6/10

Entry Number & Variable		Existing Reach	Proposed Design Reach	Reference Reach
Sinuosity and Slope	**88** Stream Length (SL)			
	89 Valley Length (VL)			
	90 Valley Slope (S_{val})			
	91 Sinuosity (k)	SL/VL: VS/S:	SL/VL:	SL/VL: VS/S:
	92 Average Water Surface Slope (S)		$S = S_{val}/k$	
Floodplain	**93** Floodplain Width, ft (W_f)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	94 Floodplain Surface Depth Limit, ft (d_f)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
Low Terrace	**95** Low Terrace Width, ft (W_{lt})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	96 Low Terrace Surface Depth Limit, ft (d_{lt})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
Flood-Prone Area	**97** Flood-Prone Area Width, ft (W_{fpa})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	98 Flood-Prone Area Surface Depth Limit, ft (d_{fpa})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
Degree of Incision	**99** Low Bank Height (LBH)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	100 Maximum Bankfull Depth (d_{max}) at Same Location as Low Bank Height (LBH) Measurement	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	101 Bank-Height Ratio (LBH/d_{max})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*

Table I-2. Morphological characteristics of the existing, proposed design & reference reaches. Page 7/10

	Entry Number & Variable	Existing Reach	Proposed Design Reach	Reference Reach
Bed Feature Max Depth Measurements and Dimensionless Ratios from Profile	**102** Riffle Maximum Depth, ft (d_{max})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	103 Riffle Maximum Depth to Riffle Mean Depth (d_{max}/d_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	104 Pool Maximum Depth, ft (d_{maxp})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	105 Pool Maximum Depth to Riffle Mean Depth (d_{maxp}/d_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	106 Run Maximum Depth, ft (d_{maxr})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	107 Run Maximum Depth to Riffle Mean Depth (d_{maxr}/d_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	108 Glide Maximum Depth, ft (d_{maxg})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	109 Glide Maximum Depth to Riffle Mean Depth (d_{maxg}/d_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	110 Step Maximum Depth, ft (d_{maxs})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	111 Step Maximum Depth to Riffle Mean Depth (d_{maxs}/d_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
Bed Feature Water Surface Facet Slopes and Dimensionless Ratios from Profile	**112** Riffle Slope (water surface facet slope) (S_{rif})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	113 Riffle Slope to Average Water Surface Slope (S_{rif}/S)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	114 Pool Slope (water surface facet slope) (S_p)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	115 Pool Slope to Average Water Surface Slope (S_p/S)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	116 Run Slope (water surface facet slope) (S_{run})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	117 Run Slope to Average Water Surface Slope (S_{run}/S)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	118 Glide Slope (water surface facet slope) (S_g)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	119 Glide Slope to Average Water Surface Slope (S_g/S)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	120 Step Slope (water surface facet slope) (S_s)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	121 Step Slope to Average Water Surface Slope (S_s/S)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*

Table I-2. Morphological characteristics of the existing, proposed design & reference reaches. Page 8/10

	Entry Number & Variable	Existing Reach	Proposed Design Reach	Reference Reach
Channel Materials	**122 Particle Size Distribution of Reach-wide Channel Materials**			
	D_{16} (mm)			
	D_{35} (mm)			
	D_{50} (mm)			
	D_{84} (mm)			
	D_{95} (mm)			
	D_{100} (mm)			
	123 Particle Size Distribution of Active Bed or Pavement Channel Materials			
	D_{16} (mm)			
	D_{35} (mm)			
	D_{50} (mm)			
	D_{84} (mm)			
	D_{95} (mm)			
	D_{100} (mm)			
	124 Particle Size Distribution of Bar Material or Sub-pavement			
	D_{16} (mm)			
	D_{35} (mm)			
	D_{50} (mm)			
	D_{84} (mm)			
	D_{95} (mm)			
	D_{max} (mm)			
Hydraulics & Flood Capacity	**125** Estimated Bankfull Mean Velocity, ft/sec ($\bar{u}_{bkf}$)			
	126 Estimated Bankfull Discharge, cfs (Q_{bkf}); Compare with Regional Curve			
	127 Floodplain Capacity: Discharge (Q_{fp})			
	128 Floodplain Capacity: Cross-Sectional Area (A_{fp})			
	129 Low Terrace Capacity: Discharge (Q_{lt})			
	130 Low Terrace Capacity: Cross-Sectional Area (A_{lt})			
	131 Flood-Prone Area Capacity: Discharge (Q_{fpa})			
	132 Flood-Prone Area Capacity: Cross-Sectional Area (A_{fpa})			

Table I-2. Morphological characteristics of the existing, proposed design & reference reaches. Page 9/10

	Entry Number & Variable		Existing Reach	Proposed Design Reach	Reference Reach
Sediment Competence	133	Calculated bankfull shear stress value, lbs/ft^2 (τ)			
	134	Predicted largest moveable particle size (mm) at bankfull shear stress, (τ)	Shields:	Shields:	Shields:
			Colo.:	Colo.:	Colo.:
	135	Largest particle size to be moved (D_{max}) (mm) (see #124: Particle Size Distribution of Bar Material)			
	136	Predicted shear stress required to initiate movement of D_{max} (mm)	Shields:	Shields:	Shields:
			Colo.:	Colo.:	Colo.:
	137	Predicted mean depth required to initiate movement of D_{max} (mm), d = $\tau/\gamma S$ (τ = predicted shear stress, γ = 62.4, S = existing or design slope)	Shields:	Shields:	Shields:
			Colo.:	Colo.:	Colo.:
	138	Predicted slope required to initiate movement of D_{max} (mm) S=τ/γd (τ = predicted shear stress, γ = 62.4, d = existing or design depth)	Shields:	Shields:	Shields:
			Colo.:	Colo.:	Colo.:
	139	Bankfull dimensionless shear stress (τ^*)			
	140	Required bankfull mean depth d_{bkf} (ft) using dimensionless shear stress equation: $d_{bkf} = \tau^*(\gamma_s - 1)D_{max}/S$ (Note: D_{max} in ft)			
	141	Required bankfull water surface slope S (ft) using dimensionless shear stress equation: $S = \tau^*(\gamma_s - 1)D_{max}/d_{bkf}$ (Note: D_{max} in ft)			
Sediment Yield	**Sediment Yield (FLOWSED)**		**Existing Reach**	**Proposed Design Reach**	**Difference in Sediment Yield**
	142	Bedload Sediment Yield (tons/yr)			
	143	Suspended Sediment Yield (tons/yr)			
	144	Suspended Sand Sediment Yield (tons/yr)			
	145	Total Annual Sediment Yield (tons/yr)			
Sediment Transport	**Sediment Yield (POWERSED)**		**Existing Reach**	**Proposed Design Reach**	**Difference in Sed. Transport**
	146	Bedload Sediment Transport (tons/yr)			
	147	Suspended Sediment Transport (tons/yr)			
	148	Suspended Sand Sediment Transport (tons/yr)			
	149	Total Annual Sediment Transport (tons/yr)			

Table I-2. Morphological characteristics of the existing, proposed design & reference reaches. Page 10/10

	Streambank Erosion	Existing Reach	Proposed Design Reach	Reference Reach
Streambank Erosion	**150** Stream Length Assessed (ft)			
	151 Graph/Curve Used (e.g., Yellowstone or Colorado)			
	152 Streambank Erosion (tons/yr)			
	153 Streambank Erosion Rate (tons/yr/ft)			

Computational Sequence 1: Organize the Reference Reach & Existing Reach Data

1a — Organize the Reference Reach Data

Obtain the reference reach data collected in *Phase II* and *Phase III*, which includes the morphological characterization and stability analyses. Be certain that the reference reach has similar boundary conditions and controlling variables as the proposed design reach. Complete the *Reference Reach* column in **Table I-2** to organize all morphological characteristics and analyses. The reference reach data represents the dimensionless ratios used to generate the design values for the proposed reach; thus it is critical that the dimension, pattern and profile data is representative of the reference reach condition.

1b — Organize the Existing Reach Data

Complete the *Existing Reach* column in **Table I-2** to organize all morphological characteristics and analyses.

Computational Sequence 2: Calculate Riffle Channel Dimensions

Items ***2a–2k*** include the procedure to calculate the required riffle channel dimensions of the proposed design reach, including the inner berm feature. **Note:** Include rapids and chutes in riffle category for rapids-dominated and step–pool systems.

2a — Obtain Bankfull Discharge & Corresponding Cross-Sectional Area (A_{bkf})

Obtain the bankfull discharge (Q_{bkf}) and corresponding cross-sectional area (A_{bkf}) for the proposed design reach using the drainage area and regional curves from *Phase II* (record bankfull discharge, cross-sectional area and drainage area in **Table I-2**, Entries 5, 9 and 4). **Note:** The cross-sectional area is recorded as the "*mean*" value in Entry 9 and this value is used in the remaining computations that involve riffle area.

Be sure to validate the regional curves and ensure that the curves are appropriate for the hydro-physiographic province of the existing or proposed design reach. Regional curves of cross-sectional area *vs*. drainage area generally have an excellent correlation coefficient and low variance making it acceptable to determine the cross-sectional area of the proposed design reach. However, predicting bankfull width and bankfull depth from regional curves is discouraged due to the consistent higher error term in the relation and the fact that the regional curves are not stratified by stream type, thereby reflecting the variation in width/depth ratio.

In scenarios where regional curves are not available or cannot be used (e.g., when project location is below a reservoir), cross-sectional area can also be calculated from continuity ($A_{bkf} = Q_{bkf} / \bar{u}_{bkf}$) by knowing bankfull discharge and either knowing or estimating the bankfull mean velocity ($\bar{u}_{bkf}$). Be sure to check the reasonableness of the mean velocity; generally the bankfull velocity ranges from 3.0–5.0 ft/sec with an average of 4.0 ft/sec. The bankfull mean velocity of the proposed design reach will be checked with resistance and roughness relations in the computational sequence after riffle channel dimensions and average water surface slope are calculated.

2b — Calculate Bankfull Riffle Width (W_{bkf})

Calculate the bankfull riffle width (W_{bkf}) for the proposed design reach for the *mean*, *minimum* and *maximum* values (record in **Table I-2**, Entry 6):

$$Mean\ W_{bkf} = [mean\ (W_{bkf} / d_{bkf})_{ref} * mean\ A_{bkf}\ ]^{1/2} \quad \textbf{Equation 1}$$

$$Minimum\ W_{bkf} = [minimum\ (W_{bkf} / d_{bkf})_{ref} * mean\ A_{bkf}\ ]^{1/2} \quad \textbf{Equation 2}$$

$$Maximum\ W_{bkf} = [maximum\ (W_{bkf} / d_{bkf})_{ref} * mean\ A_{bkf}\ ]^{1/2} \quad \textbf{Equation 3}$$

The *mean* value of the riffle cross-sectional area of the proposed design reach is used as a normalization parameter to convert the dimensionless ratios of the reference reach to the design values for the bankfull riffle width of the proposed design reach.

2c — Calculate Bankfull Riffle Mean Depth (d_{bkf})

Calculate the bankfull riffle mean depth (d_{bkf}) for the proposed design reach for the *mean*, *minimum* and *maximum* values (record in **Table I-2**, Entry 7):

$$Mean\ d_{bkf} = mean\ A_{bkf} / mean\ W_{bkf} \quad \textbf{Equation 4}$$

or

$$Mean\ d_{bkf} = mean\ W_{bkf} / mean\ (W_{bkf} / d_{bkf})_{ref} \quad \textbf{Equation 5}$$

$$Minimum\ d_{bkf} = mean\ A_{bkf} / maximum\ W_{bkf} \quad \textbf{Equation 6}$$

or

$$Minimum\ d_{bkf} = maximum\ W_{bkf} / maximum\ (W_{bkf} / d_{bkf})_{ref} \quad \textbf{Equation 7}$$

$$Maximum\ d_{bkf} = mean\ A_{bkf} / minimum\ W_{bkf} \quad \textbf{Equation 8}$$

or

$$Maximum\ d_{bkf} = minimum\ W_{bkf} / minimum\ (W_{bkf} / d_{bkf})_{ref} \quad \textbf{Equation 9}$$

2d — Determine Bankfull Riffle Width/Depth Ratio (W_{bkf}/d_{bkf})

Determine the bankfull riffle width/depth ratio (W_{bkf}/d_{bkf}) for the proposed design reach for the *mean*, *minimum* and *maximum* values; these values are equal to the respective *mean*, *minimum* and *maximum* width/depth ratio values of the reference reach (record in **Table I-2**, Entry 8).

Mean W_{bkf}/d_{bkf} = *mean* $(W_{bkf} / d_{bkf})_{ref}$ **Equation 10**

Minimum W_{bkf}/d_{bkf} = *minimum* $(W_{bkf} / d_{bkf})_{ref}$ **Equation 11**

Maximum W_{bkf}/d_{bkf} = *maximum* $(W_{bkf} / d_{bkf})_{ref}$ **Equation 12**

2e — Calculate Bankfull Riffle Maximum Depth (d_{max})

Obtain the bankfull riffle maximum depth (d_{max}) for the proposed design reach for the *mean*, *minimum* and *maximum* values (record in **Table I-2**, Entry 10):

Mean d_{max} = [*mean* $(d_{max} / d_{bkf})_{ref}$] * *mean* d_{bkf} **Equation 13**

Minimum d_{max} = [*minimum* $(d_{max} / d_{bkf})_{ref}$] * *mean* d_{bkf} **Equation 14**

Maximum d_{max} = [*maximum* $(d_{max} / d_{bkf})_{ref}$] * *mean* d_{bkf} **Equation 15**

Riffle Inner Berm Channel Dimensions (Applicable to B and C Stream Types)

The inner berm characterizes the low flow channel and assists in defining the shape of the channel beyond the bankfull width, mean depth and maximum depth. The inner berm is related to mean annual discharge and often corresponds to a flow of 10–40% of the bankfull channel depending on the ratio of the low flow discharge to bankfull discharge within rain-on-snow, snowmelt and stormflow regimes. The inner berm also improves the sediment transport capacity due to its influence on the hydraulic geometry, shear stress and stream power of the channel. Inner berms are most prominent in B and C stream types and are most commonly found in riffles, pools and glides.

2f — Calculate Riffle Inner Berm Width (W_{ib})

Calculate the riffle inner berm width (W_{ib}) for the proposed design reach for the *mean*, *minimum* and *maximum* values (record in **Table I-2**, Entry 14):

Mean W_{ib} = *mean* $(W_{ib} / W_{bkf})_{ref}$ * *mean* W_{bkf} **Equation 16**

Minimum W_{ib} = *minimum* $(W_{ib} / W_{bkf})_{ref}$ * *mean* W_{bkf} **Equation 17**

Maximum W_{ib} = *maximum* $(W_{ib} / W_{bkf})_{ref}$ * *mean* W_{bkf} **Equation 18**

2g — Calculate Riffle Inner Berm Mean Depth (d_{ib})

Calculate the riffle inner berm mean depth (d_{ib}) for the *mean*, *minimum* and *maximum* values (record in **Table I-2**, Entry 16):

Mean d_{ib} = *mean* $(d_{ib} / d_{bkf})_{ref}$ * *mean* d_{bkf} **Equation 19**

Minimum d_{ib} = *minimum* $(d_{ib} / d_{bkf})_{ref}$ * *mean* d_{bkf} **Equation 20**

Maximum d_{ib} = *maximum* $(d_{ib} / d_{bkf})_{ref}$ * *mean* d_{bkf} **Equation 21**

2h — Calculate Riffle Inner Berm Area (A_{ib})

Calculate the riffle inner berm cross-sectional area (A_{ib}) for the *mean*, *minimum* and *maximum* values (record in **Table I-2**, Entry 19):

Mean A_{ib} = *mean* $(A_{ib} / A_{bkf})_{ref}$ * *mean* A_{bkf} **Equation 22**

Minimum A_{ib} = *minimum* $(A_{ib} / A_{bkf})_{ref}$ * *mean* A_{bkf} **Equation 23**

Maximum A_{ib} = *maximum* $(A_{ib} / A_{bkf})_{ref}$ * *mean* A_{bkf} **Equation 24**

2i — Determine Riffle Inner Berm Width/Depth Ratio (W_{ib}/d_{ib})

Determine the riffle inner berm width/depth ratio (W_{ib}/d_{ib}) for the *mean*, *minimum* and *maximum* values; these values equal the respective *mean*, *minimum* and *maximum* values of the riffle inner berm width/depth ratio of the reference reach (record in **Table I-2**, Entry 18):

Mean W_{ib}/d_{ib}= *mean* $(W_{ib} / d_{ib})_{ref}$ **Equation 25**

Minimum W_{ib}/d_{ib}= *minimum* $(W_{ib} / d_{ib})_{ref}$ **Equation 26**

Maximum W_{ib}/d_{ib}= *maximum* $(W_{ib} / d_{ib})_{ref}$ **Equation 27**

Vertical Containment

Entrenchment ratio is used to describe the degree of vertical containment of river channels and is defined as the ratio of the width of the flood-prone area to the bankfull riffle width. The width of the flood-prone area is determined at an elevation at two times the maximum bankfull depth and is controlled by the valley width and local valley configuration. The area at this elevation often includes a low terrace or portions of a colluvial slope where infrequent flooding occurs on the higher surfaces. This elevation does not have a particular flood frequency relation but describes the area that is available to the river for flooding within the valley. The width of the flood-prone area is also used in the flood capacity computations of the proposed design.

The width of the flood-prone area and entrenchment ratio must be determined at specific valley locations of the proposed design reach. The designed riffle dimensions must be fit within the existing valley to compute the width of the flood-prone area and entrenchment ratio.

2j — Determine Width of Flood-Prone Area (W_{fpa})

Calculate the width of the flood-prone area (W_{fpa}) at an elevation of twice the bankfull riffle maximum depth of the proposed design at a riffle section for the *mean*, *minimum* and *maximum* values (record in **Table I-2**, Entry 12).

2k — Calculate Entrenchment Ratio (ER)

Calculate the Entrenchment Ratio (ER) of the proposed design reach at a riffle section for the *mean*, *minimum* and *maximum* values (record in **Table I-2**, Entry 13). Note that the width of the flood-prone area (W_{fpa}) and bankfull riffle width (W_{bkf}) must be at the same riffle location within the valley to calculate the entrenchment ratios. The *mean*, *minimum* and *maximum* values can then be determined by ordering the various entrenchment ratio values calculated for the entire proposed design reach.

$ER = W_{fpa} / W_{bkf}$ **Equation 28**

Computational Sequence 3: Calculate Channel Pattern Variables

All channel pattern variables are normalized by the *mean* bankfull riffle width of the proposed design reach. These variables are determined early in the computational sequence so that they can be designed within the valley, and hence sinuosity and slope can be determined.

3a — Calculate Linear Wavelength (λ)

Calculate the linear wavelength (λ) for the proposed design reach for the *mean*, *minimum* and *maximum* values (record in **Table I-2**, Entry 72):

Mean λ = *mean* $(\lambda / W_{bkf})_{ref}$ * *mean* W_{bkf} **Equation 29**

Minimum λ = *minimum* $(\lambda / W_{bkf})_{ref}$ * *mean* W_{bkf} **Equation 30**

Maximum λ = *maximum* $(\lambda / W_{bkf})_{ref}$ * *mean* W_{bkf} **Equation 31**

3b — Calculate Stream Meander Length (L_m)

Calculate the stream meander length (L_m) for the proposed design reach for the *mean*, *minimum* and *maximum* values (record in **Table I-2**, Entry 74). Note that the dimensionless ratio of stream meander length to bankfull riffle width (L_m/W_{bkf}) is termed *Meander Length Ratio (MLR)*.

Mean L_m = *mean* MLR_{ref} * *mean* W_{bkf} **Equation 32**

Minimum L_m = *minimum* MLR_{ref} * *mean* W_{bkf} **Equation 33**

Maximum L_m = *maximum* MLR_{ref} * *mean* W_{bkf} **Equation 34**

3c — Calculate Belt Width (W_{blt})

Calculate the belt width (W_{blt}) for the proposed design reach for the *mean*, *minimum* and *maximum* values (record in **Table I-2**, Entry 76). Note that the dimensionless ratio of belt width to bankfull riffle width (W_{blt}/W_{bkf}) is termed Meander Width Ratio (MWR).

Mean W_{blt}= *mean* MWR_{ref} * *mean* W_{bkf} **Equation 35**

Minimum W_{blt}= *minimum* MWR_{ref} * *mean* W_{bkf} **Equation 36**

Maximum W_{blt}= *maximum* MWR_{ref} * *mean* W_{bkf} **Equation 37**

3d — Calculate Radius of Curvature (R_c)

Calculate the radius of curvature (R_c) for the proposed design reach for the *mean*, *minimum* and *maximum* values (record in **Table I-2**, Entry 78):

Mean R_c = *mean* $(R_c / W_{bkf})_{ref}$ * *mean* W_{bkf} **Equation 38**

Minimum R_c = *minimum* $(R_c / W_{bkf})_{ref}$ * *mean* W_{bkf} **Equation 39**

Maximum R_c = *maximum* $(R_c / W_{bkf})_{ref}$ * *mean* W_{bkf} **Equation 40**

3e — Calculate Arc Length (L_a)

Calculate the arc length (L_a) for the proposed design reach for the *mean*, *minimum* and *maximum* values (record in **Table I-2**, Entry 80):

Mean L_a = *mean* $(L_a / W_{bkf})_{ref}$ * *mean* W_{bkf} **Equation 41**

Minimum L_a = *minimum* $(L_a / W_{bkf})_{ref}$ * *mean* W_{bkf} **Equation 42**

Maximum L_a = *maximum* $(L_a / W_{bkf})_{ref}$ * *mean* W_{bkf} **Equation 43**

3f — Calculate Riffle Length (L_r)

Calculate the riffle length (L_r) for the proposed design reach for the *mean*, *minimum* and *maximum* values (record in **Table I-2**, Entry 82):

Mean L_r = *mean* $(L_r / W_{bkf})_{ref}$ * *mean* W_{bkf} **Equation 44**

Minimum L_r = *minimum* $(L_r / W_{bkf})_{ref}$ * *mean* W_{bkf} **Equation 45**

Maximum L_r = *maximum* $(L_r / W_{bkf})_{ref}$ * *mean* W_{bkf} **Equation 46**

3g — Calculate Individual Pool Length (L_p)

Calculate the pool length (L_p) for the proposed design reach for the *mean*, *minimum* and *maximum* values (record in **Table I-2**, Entry 84):

Mean L_p = *mean* $(L_p / W_{bkf})_{ref}$ * *mean* W_{bkf} **Equation 47**

Minimum L_p = *minimum* $(L_p / W_{bkf})_{ref}$ * *mean* W_{bkf} **Equation 48**

Maximum L_p = *maximum* $(L_p / W_{bkf})_{ref}$ * *mean* W_{bkf} **Equation 49**

where:

$(L_p / W_{bkf})_{ref}$ = *maximum* reference reach pool length to bankfull riffle width

W_{bkf} = *mean* bankfull riffle width of the proposed design reach

3h — Calculate Pool-to-Pool Spacing (P_s)

Calculate the pool-to-pool spacing (P_s) for the proposed design reach for the *mean*, *minimum* and *maximum* values (record in **Table I-2**, Entry 86):

Mean P_s = *mean* $(P_s / W_{bkf})_{ref}$ * *mean* W_{bkf} **Equation 50**

Minimum P_s = *minimum* $(P_s / W_{bkf})_{ref}$ * *mean* W_{bkf} **Equation 51**

Maximum P_s = *maximum* $(P_s / W_{bkf})_{ref}$ * *mean* W_{bkf} **Equation 52**

Computational Sequence 4: Layout Channel Pattern Variables

4 — Layout Channel Pattern Variables

Layout the design channel's meander geometry that includes the range of values for the linear wavelength (λ), stream meander length (L_m), belt width (W_{blt}), radius of curvature (R_c), arc length (L_a), riffle length (L_r), individual pool length (L_p) and pool-to-pool spacing (P_s) on a detailed topographic map or an aerial photo that depicts vegetation, channel features and terrain character. Adjust the pattern to utilize terrain features and existing vegetation where possible within the range of the pattern variables.

Computational Sequence 5: Calculate Sinuosity & Slope

5a — Measure Stream Length (SL) & Valley Length (VL)

Measure Stream Length (SL) of the proposed design reach and Valley Length (VL) (**Note:** Measure Valley Length (VL) following the fall line of the valley rather than straight line segments between meanders) (record in **Table I-2**, Entries 88 and 89).

5b — Calculate Sinuosity (k)

Calculate sinuosity (k) of the proposed design reach (record in **Table I-2**, Entry 91):

$$k = SL / VL \qquad \textbf{Equation 53}$$

5c — Calculate Valley Slope (S_{val})

Calculate valley slope (S_{val}) (record in **Table I-2**, Entry 90). Measure the water surface elevation difference (DE) between the same bed features along the fall line of the valley using Valley Length (VL), where:

$$S_{val} = DE / VL \qquad \textbf{Equation 54}$$

5d — Calculate Average Water Surface Slope (S)

Calculate the average water surface slope (S) for the proposed design reach (record in **Table I-2**, Entry 92):

$$S = S_{val} / k \qquad \textbf{Equation 55}$$

Computational Sequence 6: Design the Flood-prone Area & Off-Channel Features

The first approximation of flood-prone area is determined at an elevation at two times the bankfull riffle maximum depth of the proposed channel. The flood-prone area consists of the active floodplain and low terrace features where present (e.g., C stream type in a terraced alluvial valley, VT VIII(c)). Two-stage channels comprise of the bankfull channel and active floodplain (Stage 2), which makes up the flood-prone area; e.g., E stream type in a lacustrine valley, VT X). Three-stage channels include just the flood-prone area (Stage 3), while four-stage channels comprise of the active floodplain (Stage 3) and the low terrace feature (Stage 4), which together make up the flood-prone area. If a low terrace feature is within the approximated flood-prone area, then the active floodplain and low terrace dimensions can be calculated as part of a four-stage channel design. The low terrace feature break generally starts at 1.6–1.7 times the bankfull maximum depth. **Figure I-1** illustrates the three- and four-stage channels and their associated flood-prone area dimensions of width and surface depth limit.

Generally, the flood-prone area in three-stage channels should accommodate the largest flood possible within imposed constraints; the minimum would be the 100-year flood. For four-stage channels, the active floodplain should accommodate the 20-year flood or frequent floods, and

the low terrace should accommodate the 100-year or larger flood. Calculations of flood capacity for all flood-prone area features are necessary in *Computational Sequence 9*, which may indicate that the active floodplain, low terrace and/or flood-prone area dimensions need to be adjusted.

Floodplains, low terraces and/or flood-prone areas must be designed for the following scenarios:

a) For braided, D stream types converted to meandering, C stream types in terraced alluvial valleys, VT VIII(c)
b) For Priority 1 (G_c → C stream type) and Priority 2 (F → C or E stream type) restorations that reconnect the channel with floodplain and fluvial features
c) For Priority 3 restorations that convert G → B stream types or F → B_c stream types
d) For converting G or F_b → B stream types in colluvial valleys, VT II, and for designed A stream types in steep, V-notched or colluvial valleys, VT I and II

A grading and floodplain design for a C4 stream type in a terraced alluvial valley, VT VIII(c), is shown in **Figures I-2** through **I-5**.

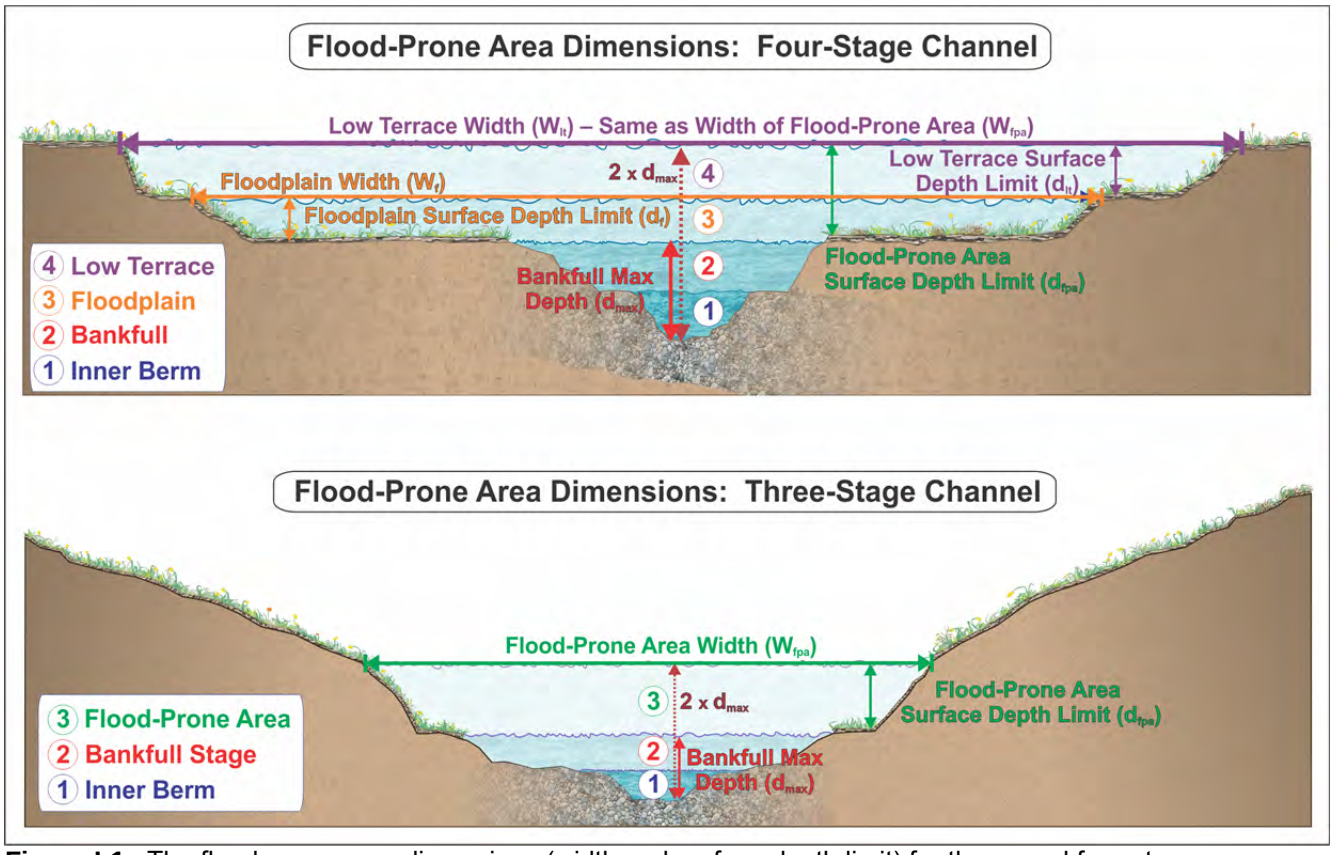


Figure I-1. The flood-prone area dimensions (width and surface depth limit) for three- and four-stage channels.

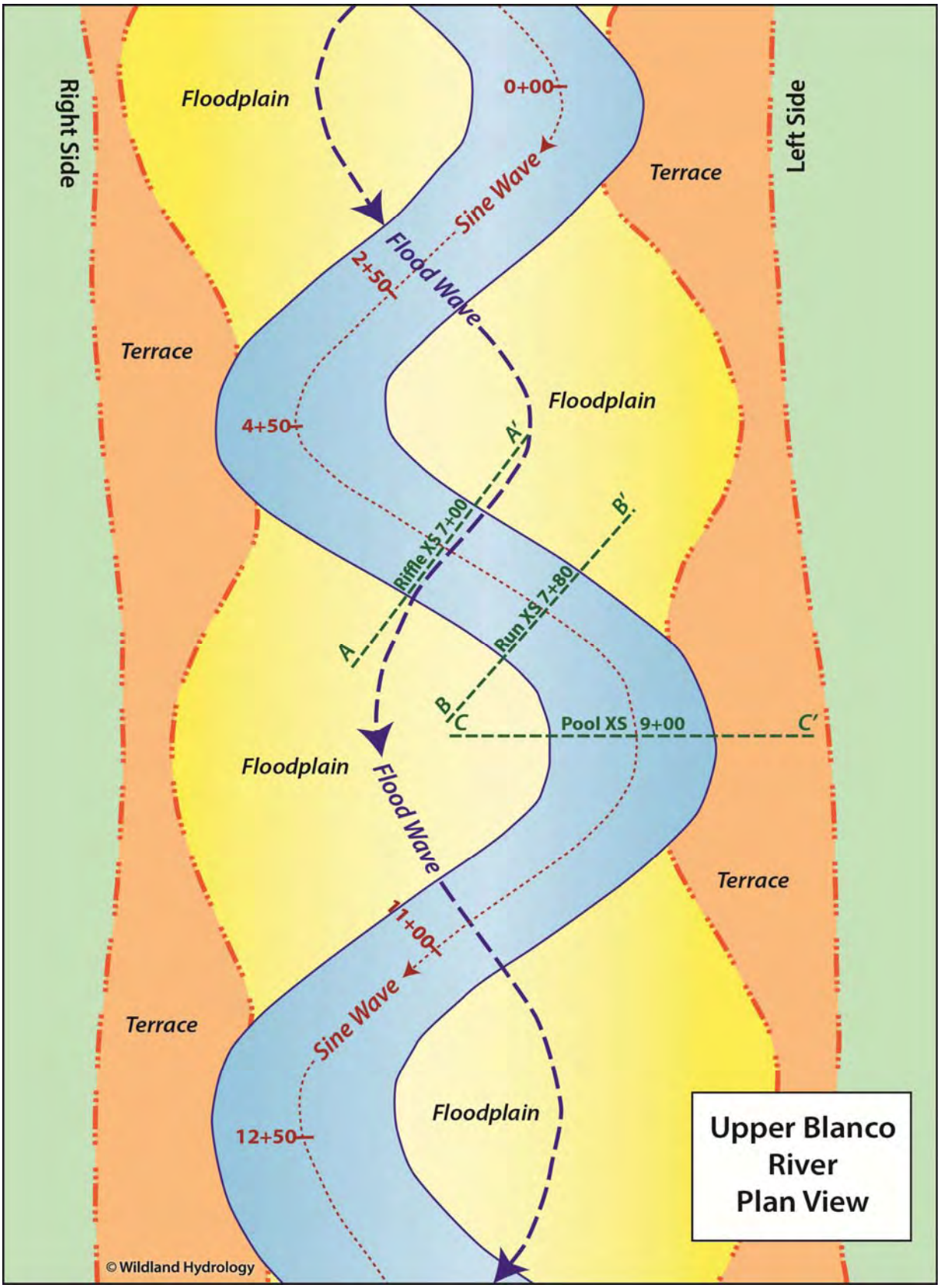


Figure I-2. Plan view of the grading design for a newly constructed floodplain and a C4 stream type in a terraced alluvial valley, VT VIII(c), upper Blanco River, Colorado.

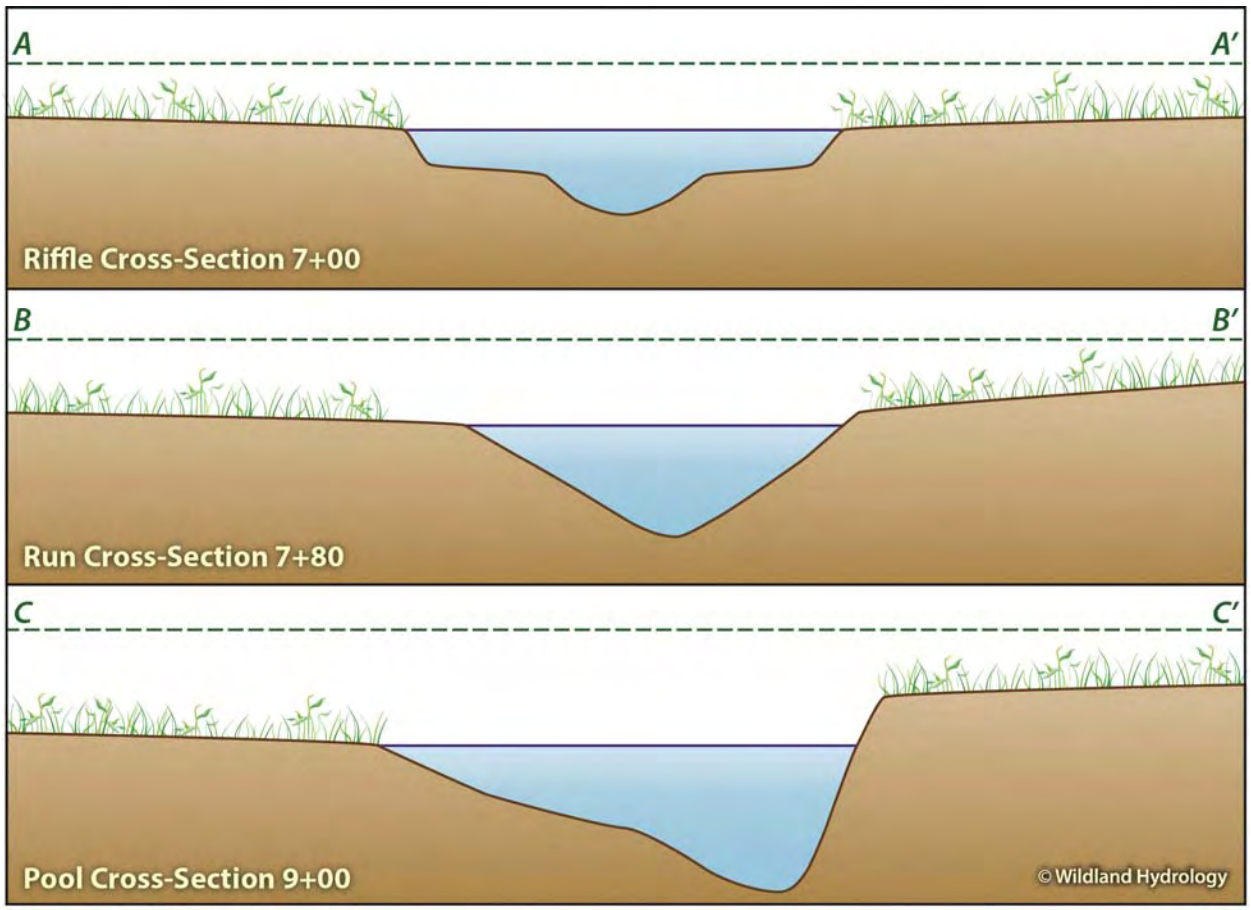


Figure I-3. Cross-section views of the proposed floodplain design on the upper Blanco River, Colorado.

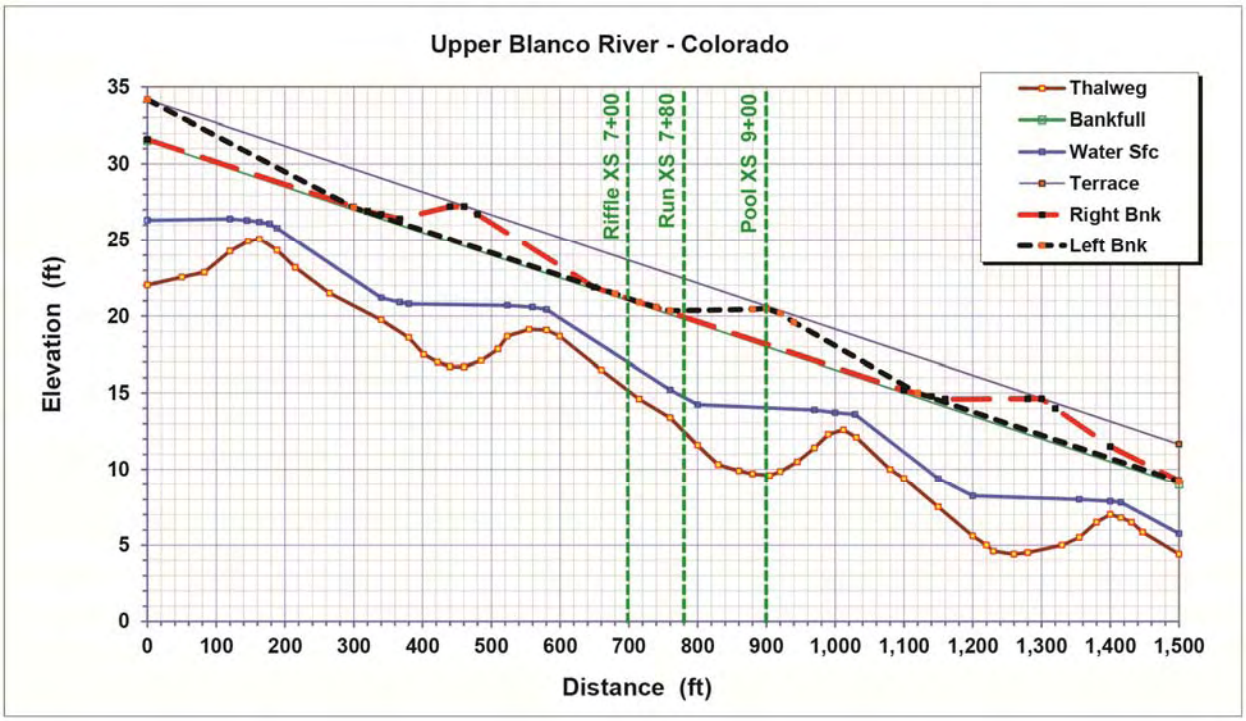


Figure I-4. Longitudinal profile view of floodplain design for the upper Blanco River, Colorado.



Figure I-5. Constructed floodplain on the upper Blanco River, Colorado.

Floodplain Dimensions

Floodplain dimensions are calculated for four-stage channels, most commonly C stream types in terraced alluvial valleys, VT VIII(c), and also two-stage channels, such as for E stream types in lacustrine valleys, VT X.

6a — Calculate Floodplain Width (W_f)

Calculate the floodplain width (W_f) for the proposed design reach for the *mean*, *minimum* and *maximum* values (record in **Table I-2**, Entry 93).

6b — Calculate Floodplain Surface Depth Limit (d_f)

Calculate the floodplain surface depth limit (d_f) for the proposed design reach for the *mean*, *minimum* and *maximum* values (record in **Table I-2**, Entry 94). Note that this value is not a mean depth value, but rather a depth measured from the elevation of the bankfull channel to the top elevation of the floodplain, as indicated in **Figure I-1**.

Low Terrace Dimensions

Low terrace dimensions are calculated for four-stage channels, most commonly C stream types in terraced alluvial valleys, VT VIII(c).

6c — Calculate Low Terrace Width (W_{lt})

Calculate the low terrace width (W_{lt}) for the proposed design reach for the *mean*, *minimum* and *maximum* values (record in **Table I-2**, Entry 95).

6d — Calculate Low Terrace Surface Depth Limit (d_{lt})

Calculate the low terrace mean depth (d_{lt}) for the proposed design reach for the *mean*, *minimum* and *maximum* values (record in **Table I-2**, Entry 96). This depth is measured from the top elevation of the active floodplain to the top elevation of the low terrace, as indicated in **Figure I-1**.

Flood-Prone Area Dimensions

The preliminary flood-prone area is approximated at a riffle cross-section at an elevation of two times the bankfull riffle maximum depth of the proposed design reach. The flood-prone area width and surface depth limit can then be calculated at this elevation based on the valley dimensions of the existing or proposed condition. The flood-prone area width is often the same as the low terrace width for four-stage channel designs, unless the dimensions are adjusted for flood capacity requirements.

6e — Calculate Flood-Prone Area Width (W_{fpa})

Calculate the flood-prone area width (W_{fpa}) for the proposed design reach for the *mean*, *minimum* and *maximum* values (record in **Table I-2**, Entry 97).

6f — Calculate Flood-Prone Area Surface Depth Limit (d_{fpa})

Calculate the flood-prone area surface depth limit (d_{fpa}) for the proposed design reach for the *mean*, *minimum* and *maximum* values (record in **Table I-2**, Entry 98). This depth is measured from the elevation of the bankfull channel to the elevation of the flood-prone area, as indicated in **Figure I-1**. Because the flood-prone area width is determined at an elevation of two times the bankfull riffle maximum depth, this depth is equal to the bankfull riffle maximum depth.

Off-Channel Features

6g — Layout Off-Channel Features

Layout all off-channel features, including oxbows, food plots, interconnect channels, diversions and emergent wetlands, as specified within the conceptual design phase.

Computational Sequence 7: Plot Typical Multi-Stage Channel Dimensions

7 — Plot Typical Multi-Stage Channel Cross-Sections

Plot typical multi-stage cross-sections representing the riffle and flood-prone area dimensions, including the active floodplain and low terrace if applicable.

Computational Sequence 8: Complete & Evaluate Hydraulic & Sediment Competency & Capacity Calculations

Hydraulic and sediment competence and capacity calculations are completed to ensure reasonableness of the design thus far, prior to calculating the remaining bed feature dimensions and longitudinal profile facet slopes and maximum depths.

8a — Calculate Bankfull Mean Velocity ($\bar{u}_{bkf}$)

Calculate the bankfull mean velocity ($\bar{u}_{bkf}$) and corresponding bankfull discharge for the proposed design reach estimated in **Worksheet I-1** (record in **Table I-2**, Entries 125 and 126). Check that the estimated bankfull discharge is similar to the bankfull mean velocity calculated using the continuity equation from regional curves:

$$\bar{u}_{bkf} = Q_{bkf} / A_{bkf} \text{ (continuity)} \qquad \textbf{Equation 56}$$

Worksheet I-1. Computations of velocity and bankfull discharge using various methods for the proposed design reach.

Bankfull VELOCITY & DISCHARGE Estimates

Stream:		Location:	
Date:	Stream Type:	Valley Type:	
Observers:		HUC:	_ _ _ _ _ _ _ _ _ _ _ _

Input Variables for PROPOSED Design			Output Variables for PROPOSED Design		
Bankfull Riffle Cross-Sectional AREA		**A_{bkf}** (ft^2)	Bankfull Riffle Mean DEPTH		**d_{bkf}** (ft)
Bankfull Riffle WIDTH		**W_{bkf}** (ft)	Wetted PERIMETER ~ (2 * d_{bkf}) + W_{bkf}		**W_p** (ft)
D_{84} at Riffle		**Dia.** (mm)	D_{84} (mm) / 304.8		**D_{84}** (ft)
Bankfull SLOPE		**S_{bkf}** (ft / ft)	Hydraulic RADIUS A_{bkf} / W_p		**R** (ft)
Gravitational Acceleration	**32.2**	**g** (ft / sec^2)	Relative Roughness R(ft) / D_{84} (ft)		**R / D_{84}**
Drainage Area		**DA** (mi^2)	Shear Velocity $u^* = (gRS)^{½}$		**u*** (ft/sec)

ESTIMATION METHODS	Bankfull VELOCITY		Bankfull DISCHARGE	
1. Friction Factor / Relative Roughness $\bar{u} = [\ 2.83 + 5.66 * Log\ \{\ R / D_{84}\ \}\ ]\ u^*$		ft / sec		cfs
2. Roughness Coefficient: a) Manning's *n* from Friction Factor / Relativ Roughness (Figs. 4-44, 4-45) $\bar{u} = 1.49 * R^{2/3} * S^{1/2} / n$ **n =**		ft / sec		cfs
2. Roughness Coefficient: b) Manning's *n* from Stream Type (Fig. 4-46) $\bar{u} = 1.49 * R^{2/3} * S^{1/2} / n$ **n =**		ft / sec		cfs
2. Roughness Coefficient: c) Manning's *n* from Jarrett (USGS): $\bar{u} = 1.49 * R^{2/3} * S^{1/2} / n$ $n = 0.39 * S^{0.38} * R^{-0.16}$ **Note:** This equation is applicable to **steep, step/pool, high boundary roughness, cobble- and boulder-dominated stream systems**; i.e., for Stream Types A1, A2, A3, B1, B2, B3, C2 & E3 **n =**		ft / sec		cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)		ft / sec		cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)		ft / sec		cfs
4. Continuity Equations: a) USGS Gage Data $\bar{u} = Q / A$ **Return Period for Bankfull Q** **Q =** ____ **year**		ft / sec		cfs
4. Continuity Equations: b) Regional Curves $\bar{u} = Q / A$		ft / sec		cfs

Protrusion Height Options for the D_{84} Term in the Relative Roughness Relation (R/D_{84}) – Estimation Method 1

Option 1.	For **sand-bed** channels: Measure 100 **"protrusion heights"** of sand dunes from the downstream side of feature to the top of feature. Substitute the D_{84} sand dune protrusion height in ft for the D_{84} term in method 1.
Option 2.	For **boulder-dominated** channels: Measure 100 **"protrusion heights"** of boulders on the sides from the bed elevation to the top of the rock on that side. Substitute the D_{84} boulder protrusion height in ft for the D_{84} term in method 1.
Option 3.	For **bedrock-dominated** channels: Measure 100 **"protrusion heights"** of rock separations, steps, joints or uplifted surfaces above channel bed elevation. Substitute the D_{84} bedrock protrusion height in ft for the D_{84} term in method 1.
Option 4.	For **log-influenced** channels: Measure **"protrustion heights"** proportionate to channel width of log diameters or the height of the log on upstream side if embedded. Substitute the D_{84} protrusion height in ft for the D_{84} term in method 1.

8b — Calculate Stream Competence / Entrainment

Calculate the stream competence/entrainment for the proposed design reach using the procedure detailed in *Phase III* and **Worksheet I-2** (record in **Table I-2**, Entries 133–141). The competence calculation using **Worksheet I-2** uses the average water surface slope (S) and bankfull riffle mean depth (d_{bkf}) of the proposed design reach to assess whether the design channel can transport the largest particle made available from the immediate upstream supply. The existing riffle bed material D_{50}, the bar (or sub-pavement) sample $D\hat{}_{50}$ and the largest particle from the bar (or sub-pavement) sample D_{max} of the existing reach are used. Calculate both dimensional and dimensionless shear stress.

Worksheet I-2. Sediment competence calculations to assess bed stability for the proposed design reach.

Stream:			Stream Type:		
Location:			Valley Type:		
Observers:			Date:		
Enter Required Information for PROPOSED Design Condition					
	D_{50}	Median particle size of riffle bed material (mm)			
	$\hat{D}_{50}$	Median particle size of bar or sub-pavement sample (mm)			
	D_{max}	Largest particle from bar sample (ft)		**(mm)**	304.8 mm/ft
	S	Proposed design bankfull water surface slope (ft/ft)			
	d	Proposed design bankfull mean depth (ft)			
1.65	γ_s-γ/γ	Immersed specific gravity of sediment			
Select the Appropriate Equation and Calculate Critical Dimensionless Shear Stress					
	$D_{50}/\hat{D}_{50}$	Range: 3 – 7	Use EQUATION 1: $\tau^* = 0.0834\,(D_{50}/\hat{D}_{50})^{-0.872}$		
	D_{max}/D_{50}	Range: 1.3 – 3.0	Use EQUATION 2: $\tau^* = 0.0384\,(D_{max}/D_{50})^{-0.887}$		
	τ^*	Bankfull Dimensionless Shear Stress	EQUATION USED:		
Calculate Bankfull Mean Depth Required for Entrainment of Largest Particle in Bar Sample					
	d	Required bankfull mean depth (ft) $d = \frac{\tau^*(\gamma_s - 1)D_{max}}{S}$ (use D_{max} in ft)			
Calculate Bankfull Water Surface Slope Required for Entrainment of Largest Particle in Bar Sample					
	S	Required bankfull water surface slope (ft/ft) $S = \frac{\tau^*(\gamma_s - 1)D_{max}}{d}$ (use D_{max} in ft)			
Check: ☐ Stable ☐ Aggrading ☐ Degrading					
Sediment Competence Using Dimensional Shear Stress					
		Bankfull shear stress $\tau = \gamma dS$ (lbs/ft^2) (substitute hydraulic radius, R, with mean depth, d) γ = 62.4, d = proposed design depth, S = proposed design slope			
Shields	CO	Predicted largest moveable particle size (mm) at bankfull shear stress τ **(Figure 5-49)**			
Shields	CO	Predicted shear stress required to initiate movement of measured D_{max} (mm) **(Figure 5-49)**			
Shields	CO	Predicted mean depth required to initiate movement of measured D_{max} (mm) $d = \frac{\tau}{\gamma S}$ τ = predicted shear stress, γ = 62.4, S = proposed design slope			
Shields	CO	Predicted slope required to initiate movement of measured D_{max} (mm) $S = \frac{\tau}{\gamma d}$ τ = predicted shear stress, γ = 62.4, d = proposed design depth			
Check: ☐ Stable ☐ Aggrading ☐ Degrading					

8c — Compute Sediment Transport Capacity

Compute sediment transport capacity using the FLOWSED and POWERSED models detailed in *Phase III* for the proposed design reach (record in **Table I-2**, Entries 142–149).

8d — Evaluate the Sediment Competence & Transport Capacity Results

Evaluate the sediment competence and transport capacity results for the proposed design reach. To maintain stability, a stream must be competent to transport the largest size of sediment and have the capacity to transport the load on an annual basis. If both the competence and capacity calculations indicate a stable channel, then continue with the computational sequence. If either the competence evaluation or the capacity calculation indicates an aggrading or degrading channel, the depth and/or slope need to be adjusted by recalculating the ***Computational Sequence 2–7*** until both competence and capacity indicate stability.

The preliminary calculated values for the proposed design channel often are modified for the final design to satisfy sediment continuity and stability. If the dimension, pattern and profile of the proposed design do not satisfy the sediment competence or capacity by indicating insufficient energy or aggradation, then the shear stress, velocity, unit power and/or slope must be increased. The first recommendation to increase sediment transport is to *decrease* width/depth ratio. This will increase the mean depth and consequently will increase shear stress, velocity and unit stream power. If this is not sufficient and the width/depth ratio is decreased too far below expected values for a particular stream type, then the next recommendation is to revise the plan-view layout and change pattern to decrease sinuosity to increase slope. The designer should stay within the natural range of pattern variables but select the values that will generate a lower sinuosity.

If the sediment competence or capacity indicates excess energy or potential degradation, then shear stress, velocity, unit power and/or slope must be decreased. The first recommendation is to increase width/depth ratio. Then, if needed, pattern would be adjusted to increase sinuosity to decrease slope.

Computational Sequence 9: Calculate Flood Capacity

9 — Calculate Flood Capacity

Calculating flood capacity involves estimating velocity associated with the cross-sectional area and slope of the stream channel and flood-prone area. Use the valley slope for hydraulic calculations for the flood-prone area. Estimate roughness from Manning's equation based on vegetative cover and other roughness elements. HEC–2, HEC–RAS or other models can be used to obtain the corresponding discharge of the flood-prone area. Calculate the 20-, 50- and 100-year flood levels based on the proposed design. Use the bankfull mean velocity from ***Computational Sequence 8***.

In three-stage channels, the flood-prone area capacity encompasses stages 1–3 in **Figure I-1**. In four-stage channels, the floodplain capacity includes stages 1–3 while the low terrace capacity includes stages 1–4 (**Figure I-1**). Record the cross-sectional area and discharge respective to each feature in Entries 127–132.

Computational Sequence 10: Calculate and Plot Remaining Applicable Bed Feature Dimensions

Pool Dimensions (Lateral Scour, Step–Pool, Contraction Scour or Convergence Pools)

10a — Calculate Bankfull Pool Width (W_{bkfp})

Calculate the bankfull pool width (W_{bkfp}) for the proposed design reach for the *mean*, *minimum* and *maximum* values (record in **Table I-2**, Entry 21):

Mean W_{bkfp} = *mean* $(W_{bkfp} / W_{bkf})_{ref}$ * *mean* W_{bkf} **Equation 57**

Minimum W_{bkfp} = *minimum* $(W_{bkfp} / W_{bkf})_{ref}$ * *mean* W_{bkf} **Equation 58**

Maximum W_{bkfp} = *maximum* $(W_{bkfp} / W_{bkf})_{ref}$ * *mean* W_{bkf} **Equation 59**

10b — Calculate Bankfull Pool Mean Depth (d_{bkfp})

Calculate the bankfull pool mean depth (d_{bkfp}) for the proposed design reach for the *mean*, *minimum* and *maximum* values (record in **Table I-2**, Entry 23):

Mean d_{bkfp} = *mean* $(d_{bkfp} / d_{bkf})_{ref}$ * *mean* d_{bkf} **Equation 60**

Minimum d_{bkfp} = *minimum* $(d_{bkfp} / d_{bkf})_{ref}$ * *mean* d_{bkf} **Equation 61**

Maximum d_{bkfp} = *maximum* $(d_{bkfp} / d_{bkf})_{ref}$ * *mean* d_{bkf} **Equation 62**

10c — Calculate Bankfull Pool Cross-Sectional Area (A_{bkfp})

Calculate the bankfull pool cross-sectional area (A_{bkfp}) for the proposed design reach for the *mean*, *minimum* and *maximum* values (record in **Table I-2**, Entry 26).

Mean A_{bkfp} = *mean* $(A_{bkfp} / A_{bkf})_{ref}$ * *mean* A_{bkf} **Equation 63**

Minimum A_{bkfp} = *minimum* $(A_{bkfp} / A_{bkf})_{ref}$ * *mean* A_{bkf} **Equation 64**

Maximum A_{bkfp} = *maximum* $(A_{bkfp} / A_{bkf})_{ref}$ * *mean* A_{bkf} **Equation 65**

10d — Determine Bankfull Pool Width/Depth Ratio (W_{bkfp}/d_{bkfp})

Determine the bankfull pool width/depth ratio (W_{bkfp}/d_{bkfp}) for the proposed design reach for the *mean*, *minimum* and *maximum* values; these values are equal to the respective *mean*, *minimum* and *maximum* values of the pool width/depth ratio of the reference reach (record in **Table I-2**, Entry 25):

Mean W_{bkfp}/d_{bkfp} = *mean* $(W_{bkfp} / d_{bkfp})_{ref}$ **Equation 66**

Minimum W_{bkfp}/d_{bkfp} = *minimum* $(W_{bkfp} / d_{bkfp})_{ref}$ **Equation 67**

Maximum W_{bkfp}/d_{bkfp} = *maximum* $(W_{bkfp} / d_{bkfp})_{ref}$ **Equation 68**

10e — Calculate Bankfull Pool Maximum Depth (d_{maxp})

Calculate the bankfull pool maximum depth (d_{maxr}) for the proposed design reach for the *mean*, *minimum* and *maximum* values (record in **Table I-2**, Entry 28):

Mean d_{maxp} = *mean* $(d_{maxp} / d_{bkf})_{ref}$ * *mean* d_{bkf} **Equation 69**

Minimum d_{maxp} = *minimum* $(d_{maxp} / d_{bkf})_{ref}$ * *mean* d_{bkf} **Equation 70**

Maximum d_{maxp} = *maximum* $(d_{maxp} / d_{bkf})_{ref}$ * *mean* d_{bkf} **Equation 71**

Pool Inner Berm Channel Dimensions (Applicable to B & C Stream Types)

10f — Calculate Pool Inner Berm Width (W_{ibp})

Calculate the pool inner berm width (W_{ibp}) for the proposed design reach for the *mean*, *minimum* and *maximum* values (record in **Table I-2**, Entry 31):

Mean W_{ibp} = *mean* $(W_{ibp} / W_{bkfp})_{ref}$ * *mean* W_{bkfp} **Equation 72**

Minimum W_{ibp} = *minimum* $(W_{ibp} / W_{bkfp})_{ref}$ * *mean* W_{bkfp} **Equation 73**

Maximum W_{ibp} = *maximum* $(W_{ibp} / W_{bkfp})_{ref}$ * *mean* W_{bkfp} **Equation 74**

10g — Calculate Pool Inner Berm Mean Depth (d_{ibp})

Calculate the pool inner berm mean depth (d_{ibp}) for the proposed design reach for the *mean*, *minimum* and *maximum* values (record in **Table 2**, Entry 33):

Mean d_{ibp} = *mean* $(d_{ibp} / d_{bkfp})_{ref}$ * *mean* d_{bkfp} **Equation 75**

Minimum d_{ibp} = *minimum* $(d_{ibp} / d_{bkfp})_{ref}$ * *mean* d_{bkfp} **Equation 76**

Maximum d_{ibp} = *maximum* $(d_{ibp} / d_{bkfp})_{ref}$ * *mean* d_{bkfp} **Equation 77**

10h — Calculate Pool Inner Berm Cross-Sectional Area (A_{ibp})

Calculate the pool inner berm cross-sectional area (A_{ibp}) for the proposed design reach for the *mean*, *minimum* and *maximum* values (record in **Table I-2**, Entry 36):

Mean A_{ibp} = *mean* $(A_{ibp} / A_{bkfp})_{ref}$ * *mean* A_{bkfp} **Equation 78**

Minimum A_{ibp} = *minimum* $(A_{ibp} / A_{bkfp})_{ref}$ * *mean* A_{bkfp} **Equation 79**

Maximum A_{ibp} = *maximum* $(A_{ibp} / A_{bkfp})_{ref}$ * *mean* A_{bkfp} **Equation 80**

10i — Determine Pool Inner Berm Width/Depth Ratio (W_{ibp}/d_{ibp})

Determine the pool inner berm width/depth ratio (W_{ibp}/d_{ibp}) for the proposed design reach for the *mean*, *minimum* and *maximum* values; these values are equal to the respective *mean*, *minimum* and *maximum* values of the pool inner berm width/depth ratio of the reference reach (record in **Table I-2**, Entry 35):

Mean W_{ibp}/d_{ibp} = *mean* $(W_{ibp} / d_{ibp})_{ref}$ **Equation 81**

Minimum W_{ibp}/d_{ibp} = *minimum* $(W_{ibp} / d_{ibp})_{ref}$ **Equation 82**

Maximum W_{ibp}/d_{ibp} = *maximum* $(W_{ibp} / d_{ibp})_{ref}$ **Equation 83**

10j — Determine Point Bar Slope (S_{pb})

Determine the point bar slope (S_{pb}) for the proposed design reach for the *mean*, *minimum* and *maximum* values; these values are equal to the respective mean, minimum and maximum values of the reference reach point bar slope (record in **Table I-2**, Entry 30).

Mean S_{pb} = *mean* $(S_{pb})_{ref}$ **Equation 84**

Minimum S_{pb} = *minimum* $(S_{pb})_{ref}$ **Equation 85**

Maximum S_{pb} = *maximum* $(S_{pb})_{ref}$ **Equation 86**

Remaining Bed Feature Dimensions

10k — Calculate Remaining Bed Feature Dimensions

The remaining, applicable bed features for the proposed design reach must be calculated similar to the sequence for calculating the pool dimensions. Run and glide dimensions must be determined for C stream types; step dimensions must be determined for step–pool stream types (e.g., A and B stream types). **Table I-3** includes the additional dimensions that must be determined for runs, glides and steps. These dimensions are recorded in Entries 38–71.

Table I-3. Required dimensions for runs, glides and steps.

Additional Dimensions for Run, Glide & Step Bed Features
Run Dimensions (Riffle–Pool Systems)
Bankfull Run Width (W_{bkfr})
Bankfull Run Mean Depth (d_{bkfr})
Bankfull Run Cross-Sectional Area (A_{bkfr})
Bankfull Run Width/Depth Ratio (W_{bkfr}/d_{bkfr})
Bankfull Run Maximum Depth (d_{maxr})
Glide Dimensions (Riffle–Pool Systems)
Bankfull Glide Width (W_{bkfg})
Bankfull Glide Mean Depth (d_{bkfg})
Bankfull Glide Cross-Sectional Area (A_{bkfg})
Bankfull Glide Width/Depth Ratio (W_{bkfr}/d_{bkfg})
Bankfull Glide Maximum Depth (d_{maxg})
Glide Inner Berm Channel Dimensions
Glide Inner Berm Width (W_{ibg})
Glide Inner Berm Mean Depth (d_{ibg})
Glide Inner Berm Cross-Sectional Area (A_{ibg})
Glide Inner Berm Width/Depth Ratio (W_{ibg}/d_{ibg})
Step Dimensions (Step–Pool Systems)
Bankfull Step Width (W_{bkfs})
Bankfull Step Mean Depth (d_{bkfs})
Bankfull Step Cross-Sectional Area (A_{bkfs})
Bankfull Step Width/Depth Ratio (W_{bkfr}/d_{bkfs})
Bankfull Step Maximum Depth (d_{maxs})

Plot Typical Bed Feature Cross-Sections

10l — Plot Typical Cross-Sections

Plot typical cross-sections for all applicable remaining bed features (i.e., runs, pools, glides and steps).

Computational Sequence 11: Calculate Longitudinal Profile Maximum Depths

11a — Calculate Bankfull Riffle Maximum Depth (d_{max})

Calculate the bankfull riffle maximum depth (d_{max}) for the proposed design reach for the *mean*, *minimum* and *maximum* values (record in **Table I-2**, Entry 102):

Mean d_{max} = *mean* $(d_{max} / d_{bkf})_{ref}$ * *mean* d_{bkf} **Equation 87**

Minimum d_{max} = *minimum* $(d_{max} / d_{bkf})_{ref}$ * *mean* d_{bkf} **Equation 88**

Maximum d_{max} = *maximum* $(d_{max} / d_{bkf})_{ref}$ * *mean* d_{bkf} **Equation 89**

11b — Calculate Bankfull Pool Maximum Depth (d_{maxp})

Calculate the bankfull pool maximum depth (d_{maxp}) for the proposed design reach for the *mean*, *minimum* and *maximum* values (record in **Table I-2**, Entry 104):

Mean d_{maxp} = *mean* $(d_{maxp} / d_{bkf})_{ref}$ * *mean* d_{bkf} **Equation 90**

Minimum d_{maxp} = *minimum* $(d_{maxp} / d_{bkf})_{ref}$ * *mean* d_{bkf} **Equation 91**

Maximum d_{maxp} = *maximum* $(d_{maxp} / d_{bkf})_{ref}$ * *mean* d_{bkf} **Equation 92**

11c — Calculate Remaining Bed Feature Maximum Depths

Calculate the remaining bed feature maximum depths applicable to the proposed design reach following the equations used to calculate the pool maximum depths. Record the *mean*, *minimum* and *maximum* values by bed feature in **Table I-2**, Entry 106 for *run* maximum depths (d_{maxr}), Entry 108 for *glide* maximum depths (d_{maxg}) and Entry 110 for *step* maximum depths (d_{maxs}).

Computational Sequence 12: Calculate Longitudinal Profile Facet Slopes

12a — Calculate Riffle Facet Slope (S_{rif})

Calculate the riffle slope (S_{rif}) (water surface facet slope) for the proposed design reach for the *mean*, *minimum* and *maximum* values using average water surface slope (S) as the normalization parameter (record in **Table I-2**, Entry 112):

Mean S_{rif} = *mean* $(S_{rif} / S)_{ref}$ * S **Equation 93**

Minimum S_{rif} = *minimum* $(S_{rif} / S)_{ref}$ * S **Equation 94**

Maximum S_{rif} = *maximum* $(S_{rif} / S)_{ref}$ * S **Equation 95**

12b — Calculate Pool Facet Slope (S_p)

Calculate the pool slope (S_p) (water surface facet slope) for the proposed design reach for the *mean*, *minimum* and *maximum* values (record in **Table I-2**, Entry 114):

Mean S_p = *mean* $(S_p / S)_{ref}$ * S **Equation 96**

Minimum S_p = *minimum* $(S_p / S)_{ref}$ * S **Equation 97**

Maximum S_p = *maximum* $(S_p / S)_{ref}$ * S **Equation 98**

12c — Calculate Remaining Bed Feature Facet Slopes

Calculate the remaining bed feature facet slopes applicable to the proposed design reach following the equations used to calculate the pool facet slopes. Record the *mean*, *minimum* and *maximum* values by bed feature in **Table I-2**, Entry 116 for *run* facet slopes (S_{run}), Entry 118 for *glide* facet slopes (S_g) and Entry 120 for *step* facet slopes (S_s).

Computational Sequence 13: Plot Typical Longitudinal Profile

13 — Plot Typical Longitudinal Profile

Plot a typical longitudinal profile. Use the maximum depth values of the ***typical cross-sections*** for given bed features to design the longitudinal profile. The maximum depth value of a bed feature is critical as it determines its facet slope.

The range of the maximum depth values from the longitudinal profile can be selected to vary the design due to the vertical constraints of the reach, such as buried utility lines. Also, the range of the maximum depths and facet slopes from the longitudinal profile is used in post-construction monitoring to ensure that the profile variables stay within the range of natural variability.

Appendix II

Typical Design Scenario Examples

Typical Design Scenario Examples & Restoration Details for Channel Processes

The *representative reaches* were established, measured, quantified, and evaluated in great detail to develop **typical design scenarios that can be extrapolated to other locations in the watersheds affected by the Waldo Canyon Fire where this level of detail was not obtained but is assumed to be similar**. The *reference reaches* were established to provide the stable design criteria to develop the proposed design for the representative reaches. The eight design scenarios shown in **Table II-1** were developed to represent the range of stream types and stability conditions that require restoration within the Waldo Canyon Fire watersheds. The appropriate scenario can then be extrapolated to other reaches of the same stream type, valley type, and stability condition as the representative reach.

The following sections include examples of the detailed restoration designs for the stream type conversion scenarios (e.g., D4 to C4) and stability condition conversion scenarios (e.g., "C4 *Poor* to C4 *Stable* ") as shown in **Table II-1**. These examples are modified from the master restoration plan for the Trail Creek Watershed that was burned by the Hayman Fire in 2002 (Rosgen, 2011b). The locations of the representative and reference reaches in these examples are shown in **Figure II-1**. Each typical design scenario example includes detailed descriptions of the following:

- General Description & Morphological Data
- Bankfull Discharge, Cross-Sectional Area, & Mean Velocity
- Plan View Alignment, Cross-Section Dimensions, & Longitudinal Profile
- Structures & Riparian Vegetation
- Cut & Fill Computations
- Streambank Erosion, Flow-Related Sediment, & Sediment Competence

Table II-1. The eight typical design scenarios developed to extrapolate to other locations in the Waldo Canyon Fire Watersheds for restoration.

Typical Design Scenarios				
	Existing, Impaired Stream Type	**Existing Condition**	**Proposed, Stable Stream Type**	**Valley Type**
1.	D4	Poor	C4	VIIIb,c
2.	F4	Poor	B4c	II, IIIb, VIIIa,b
3.	G4	Poor	B4	II, IIIb, VIIIa,b
4.	C4	Poor	C4	VIIIa,b,c
5.	A4, F4, and G4	Poor	D4	II, IIIa, VIIIa,b,c
6.	F4b	Poor	B4	II, IIIb, VIIIa,b
7.	A4 or A4a+	Poor	A4 or A4a+	I, II
8.	A4 or Aa+	Poor	B4a	I, II, IIIb, VIIIa,b

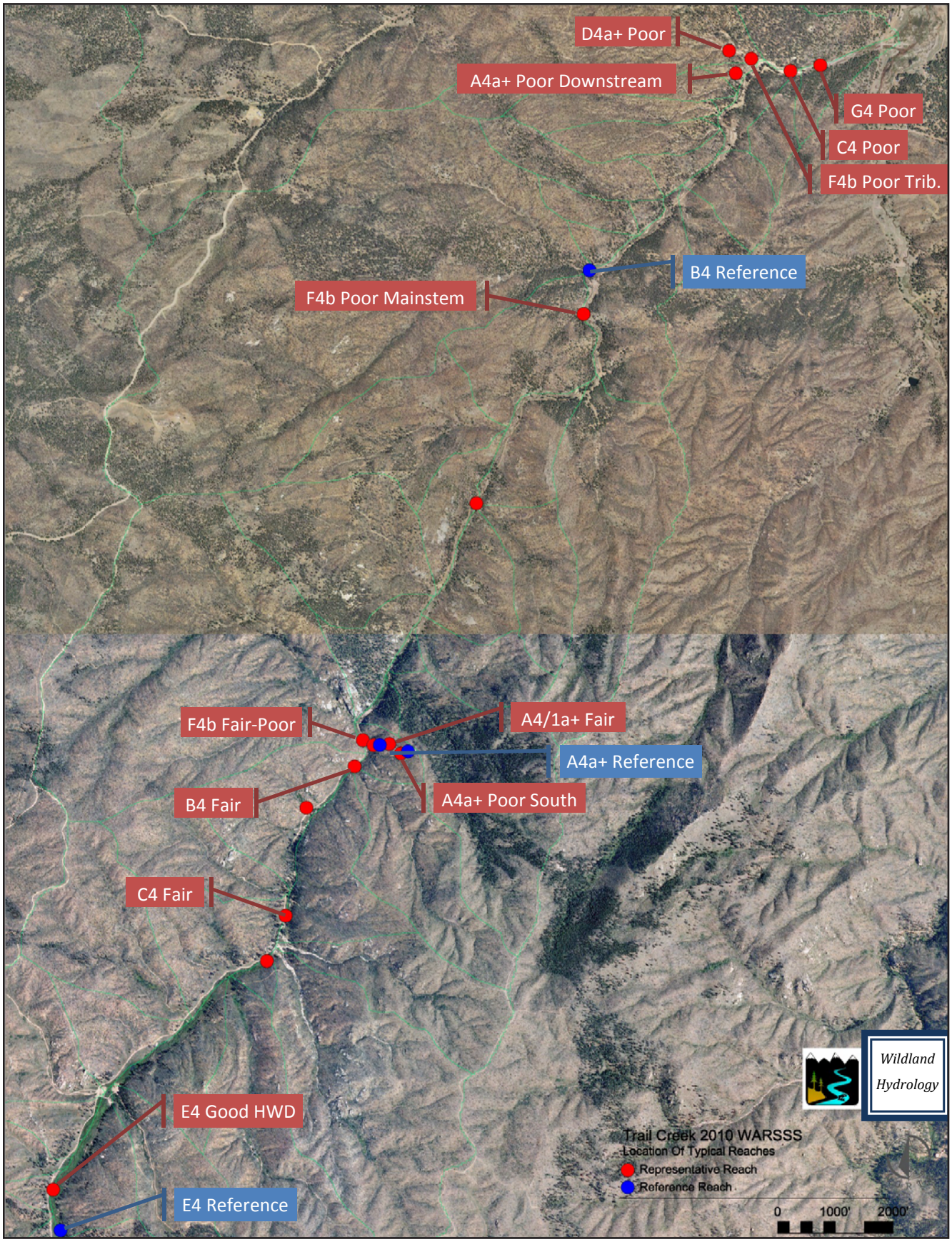


Figure II-1. Location of the reference and representative reaches within the Trail Creek Watershed.

Typical Design Scenario 1 Example

D4 to C4 Stream Type Conversion

(Valley Type VIII)

D4 to C4 Stream Type Conversion (VT VIII): Typical Design Scenario 1 Example

General Description & Morphological Data

This typical design scenario example is a stream type and stability conversion of a D4 *Poor* condition to a C4 *Stable* stream type. The existing, braided D4 reach is located at the Mouth of Trail Creek with the confluence of West Creek (**Figure II-2**). The causes of the braided, D4 reach involve the following multiple conditions:

1) The magnitude of the sediment supply from the watershed exceeded the sediment transport capacity that resulted in stream aggradation.
2) The box culvert associated with the West Creek road in the stream channel near the mouth has a width/depth ratio that is 100% larger than necessary for sediment transport capacity; consequently, the reach aggraded *6.0 ft* to the top of the box culvert.
3) The riparian vegetation occupies a narrow part of the valley thereby allowing a wide channel without flow resistance afforded by the willows.
4) High streambank erosion rates occur allowing channel enlargement.

The D4 channel continues to aggrade resulting in a migration barrier because of decreased depths in addition to the existing box culvert with *12.0"* pipes sitting over the box. To prevent accelerated sediment deposition and aggradation, the proposed design for this reach converts the existing, high width/depth ratio, braided D4 reach to a C4 stable , low width/depth ratio, single-thread stream type. To restore this reach to a single-thread, stable channel, it is necessary to re-establish the local base level (*4.5 ft* lower), redesign the stream crossing to prevent aggradation, and re-establish a riparian corridor along the streambanks of the proposed C4 stream type. The shear stress and increased velocity combine to increase stream power that can efficiently transport the available sediment. The stream type conversion and road crossing design should allow for unobstructed fish passage for all ranges of discharge.

The specific objectives and direction of this restoration scenario to stabilize the reach are as follows:

- Provide fish access to Trail Creek
- Improve instream habitat with increased cover and low flow depth
- Reduce the existing, accelerated streambank erosion
- Reduce the aggradation rate of sediment
- Decrease flood risk
- Restore the biological and physical function of this reach
- Re-establish a riparian corridor
- Redesign the existing crossing of the West Creek road

The dimensionless relations of the *C4 Reference Reach* are used to generate the proposed C4 stable design criteria, including the dimension, pattern, and profile, by scaling the relations to the drainage area and bankfull discharge of the proposed reach. The detailed characteristics and stability evaluation of the *C4 Reference Reach* are documented in *Appendix C20* of the Waldo Canyon Fire *WARSSS* analysis (Rosgen *et al*., 2013).

The resultant proposed dimension, pattern, and profile for the stable C4 stream type are documented in **Table II-2** using the procedure in **Appendix I**. Additionally, this table also includes a summary of the morphological descriptions and corresponding analyses of the existing, impaired D4 reach and the *C4 Reference Reach*. The following sections include the proposed design details of the stable C4 stream type.



Figure II-2. Aggradation and the corresponding D4 stream type at the mouth of Trail Creek causing flooding of adjacent landowner (note the wall on river left for flood protection).

Table II-2. The morphological characteristics of the existing, proposed design and reference reaches for the D4 to C4 stream type conversion in a Valley Type VIII.

Existing Reach Stream & Location:			**D4 Below Culvert on Lower Trail Creek above Mouth**					
Reference Reach Stream & Location:			**C4 Reference on Trout Creek**					
Entry Number & Variable			**Existing Reach**		**Proposed Design Reach**		**Reference Reach**	
	1	Valley Type	**VIII**		**VIII**		**VIII**	
	2	Valley Width						
	3	Stream Type	**D4**		**C4**		**C4**	
	4	Drainage Area, mi^2	**15.9**		**15.9**		**71**	
	5	Bankfull Discharge, cfs (Q_{bkf})	**40**		**40**		**51.6**	
Riffle Dimensions	**6**	Riffle Width, ft (W_{bkf})	*Mean:* *Min:* *Max:*	**79.9**	*Mean:* *Min:* *Max:*	**13.5** **12.0** **15.0**	*Mean:* *Min:* *Max:*	**18.5** **16.3** **19.9**
	7	Riffle Mean Depth, ft (d_{bkf})	*Mean:* *Min:* *Max:*	**0.24**	*Mean:* *Min:* *Max:*	**0.99** **0.89** **1.09**	*Mean:* *Min:* *Max:*	**1.04** **0.89** **1.19**
	8	Riffle Width/Depth Ratio (W_{bkf}/d_{bkf})	*Mean:* *Min:* *Max:*	**333.1**	*Mean:* *Min:* *Max:*	**13.7** **11.0** **16.9**	*Mean:* *Min:* *Max:*	**18.1** **13.7** **21.8**
	9	Riffle Cross-Sectional Area, ft^2 (A_{bkf})	*Mean:* *Min:* *Max:*	**19.2**	*Mean:*	**13.3**	*Mean:* *Min:* *Max:*	**19.2** **17.3** **20.9**
	10	Riffle Maximum Depth (d_{max})	*Mean:* *Min:* *Max:*	**2.24**	*Mean:* *Min:* *Max:*	**1.70** **1.55** **1.85**	*Mean:* *Min:* *Max:*	**1.64** **1.40** **1.81**
	11	Riffle Maximum Depth to Riffle Mean Depth (d_{max}/d_{bkf})	*Mean:* *Min:* *Max:*	**9.333**	*Mean:* *Min:* *Max:*	**1.717** **1.566** **1.869**	*Mean:* *Min:* *Max:*	**1.575** **1.429** **1.724**
	12	Width of Flood-Prone Area at Elevation of 2 * d_{max}, ft (W_{fpa})	*Mean:* *Min:* *Max:*	**280.6**	*Mean:* *Min:* *Max:*	**40.5** **29.7** **81.0**	*Mean:* *Min:* *Max:*	**58.8** **41.9** **69.4**
	13	Entrenchment Ratio (W_{fpa}/W_{bkf})	*Mean:* *Min:* *Max:*	**3.5**	*Mean:* *Min:* *Max:*	**3.0** **2.2** **6.0**	*Mean:* *Min:* *Max:*	**3.2** **2.2** **4.0**
Riffle Inner Berm Dimensions	**14**	Riffle Inner Berm Width, ft (W_{ib})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**6.5** **5.0** **8.0**	*Mean:* *Min:* *Max:*	**11.4** **10.4** **12.9**
	15	Riffle Inner Berm Width to Riffle Width (W_{ib}/W_{bkf})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**0.481** **0.370** **0.593**	*Mean:* *Min:* *Max:*	**0.619** **0.522** **0.668**
	16	Riffle Inner Berm Mean Depth, ft (d_{ib})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**0.74** **0.50** **0.90**	*Mean:* *Min:* *Max:*	**0.57** **0.38** **0.73**
	17	Riffle Inner Berm Mean Depth to Riffle Mean Depth (d_{ib}/d_{bkf})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**0.747** **0.505** **0.909**	*Mean:* *Min:* *Max:*	**0.537** **0.319** **0.820**
	18	Riffle Inner Berm Width/Depth Ratio (W_{ib}/d_{ib})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**8.8** **5.6** **12.0**	*Mean:* *Min:* *Max:*	**21.3** **17.6** **28.7**
	19	Riffle Inner Berm Cross-Sectional Area (A_{ib})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**4.8** **3.2** **6.8**	*Mean:* *Min:* *Max:*	**6.5** **4.1** **9.4**
	20	Riffle Inner Berm Cross-Sectional Area to Riffle Cross-Sectional Area (A_{ib}/A_{bkf})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**0.361** **0.241** **0.511**	*Mean:* *Min:* *Max:*	**0.349** **0.214** **0.542**

Table II-2 (page 2). The morphological characteristics of the existing, proposed design and reference reaches for the D4 to C4 stream type conversion in a Valley Type VIII.

	Entry Number & Variable		Existing Reach		Proposed Design Reach		Reference Reach	
Pool Dimensions	**21**	Pool Width, ft (W_{bkfp})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**13.4** **13.0** **14.0**	*Mean:* *Min:* *Max:*	**26.5**
	22	Pool Width to Riffle Width (W_{bkfp}/W_{bkf})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**0.993** **0.963** **1.037**	*Mean:* *Min:* *Max:*	**1.432**
	23	Pool Mean Depth, ft (d_{bkfp})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**1.39** **1.20** **1.40**	*Mean:* *Min:* *Max:*	**1.02**
	24	Pool Mean Depth to Riffle Mean Depth (d_{bkfp}/d_{bkf})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**1.404** **1.212** **1.414**	*Mean:* *Min:* *Max:*	**0.981**
	25	Pool Width/Depth Ratio (W_{bkfp}/d_{bkfp})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**9.6** **9.3** **11.7**	*Mean:* *Min:* *Max:*	**26.0**
	26	Pool Cross-Sectional Area, ft^2 (A_{bkfp})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**18.6** **16.0** **22.0**	*Mean:* *Min:* *Max:*	**27.1**
	27	Pool Area to Riffle Area (A_{bkfp}/A_{bkf})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**1.398** **1.203** **1.654**	*Mean:* *Min:* *Max:*	**1.409**
	28	Pool Maximum Depth (d_{maxp})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**3.10** **2.80** **3.50**	*Mean:* *Min:* *Max:*	**2.91**
	29	Pool Maximum Depth to Riffle Mean Depth (d_{maxp}/d_{bkf})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**3.131** **2.828** **3.535**	*Mean:* *Min:* *Max:*	**2.798**
	30	Point Bar Slope (S_{pb})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**0.350** **0.260** **0.400**	*Mean:* *Min:* *Max:*	**0.260**
Pool Inner Berm Dimensions	**31**	Pool Inner Berm Width, ft (W_{ibp})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**8.2**	*Mean:* *Min:* *Max:*	**9.4**
	32	Pool Inner Berm Width to Pool Width (W_{ibp}/W_{bkfp})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**0.612**	*Mean:* *Min:* *Max:*	**0.354**
	33	Pool Inner Berm Mean Depth, ft (d_{ibp})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**1.39**	*Mean:* *Min:* *Max:*	**0.92**
	34	Pool Inner Berm Mean Depth to Pool Mean Depth (d_{ibp}/d_{bkfp})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**1.000**	*Mean:* *Min:* *Max:*	**0.902**
	35	Pool Inner Berm Width/Depth Ratio (W_{ibp}/d_{ibp})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**5.9**	*Mean:* *Min:* *Max:*	**10.2**
	36	Pool Inner Berm Cross-Sectional Area (A_{ibp})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**9.1**	*Mean:* *Min:* *Max:*	**8.6**
	37	Pool Inner Berm Cross-Sectional Area to Pool Cross-Sectional Area (A_{ibp}/A_{bkfp})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**0.490**	*Mean:* *Min:* *Max:*	**0.319**

Table II-2 (page 3). The morphological characteristics of the existing, proposed design and reference reaches for the D4 to C4 stream type conversion in a Valley Type VIII.

	Entry Number & Variable		Existing Reach	Proposed Design Reach	Reference Reach
Run Dimensions	**38**	Run Width, ft (W_{bkfr})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **12.5** *Min:* *Max:*	*Mean:* **24.2** *Min:* *Max:*
	39	Run Width to Riffle Width (W_{bkfr}/W_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.926** *Min:* *Max:*	*Mean:* **1.308** *Min:* *Max:*
	40	Run Mean Depth, ft (d_{bkfr})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.38** *Min:* **1.30** *Max:* **1.40**	*Mean:* **0.62** *Min:* *Max:*
	41	Run Mean Depth to Riffle Mean Depth (d_{bkfr}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.394** *Min:* **1.313** *Max:* **1.414**	*Mean:* **0.596** *Min:* *Max:*
	42	Run Width/Depth Ratio (W_{bkfr}/d_{bkfr})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **9.1** *Min:* *Max:*	*Mean:* **39.1** *Min:* *Max:*
	43	Run Cross-Sectional Area, ft^2 (A_{bkfr})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **17.2** *Min:* *Max:*	*Mean:* **15.1** *Min:* *Max:*
	44	Run Area to Riffle Area (A_{bkfr}/A_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.293** *Min:* *Max:*	*Mean:* **0.785** *Min:* *Max:*
	45	Run Maximum Depth (d_{maxr})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **2.00** *Min:* *Max:*	*Mean:* **1.50** *Min:* *Max:*
	46	Run Maximum Depth to Riffle Mean Depth (d_{maxr}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **2.020** *Min:* *Max:*	*Mean:* **1.442** *Min:* *Max:*
Glide Dimensions	**47**	Glide Width, ft (W_{bkfg})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **14.6** *Min:* **14.0** *Max:* **15.0**	*Mean:* **22.0** *Min:* *Max:*
	48	Glide Width to Riffle Width (W_{bkfg}/W_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.081** *Min:* **1.037** *Max:* **1.111**	*Mean:* **1.189** *Min:* *Max:*
	49	Glide Mean Depth, ft (d_{bkfg})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.80** *Min:* *Max:*	*Mean:* **0.98** *Min:* *Max:*
	50	Glide Mean Depth to Riffle Mean Depth (d_{bkfg}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.808** *Min:* *Max:*	*Mean:* **0.942** *Min:* *Max:*
	51	Glide Width/Depth Ratio (W_{bkfg}/d_{bkfg})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **18.25** *Min:* *Max:*	*Mean:* **22.5** *Min:* *Max:*
	52	Glide Cross-Sectional Area, ft^2 (A_{bkfg})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **11.6** *Min:* *Max:*	*Mean:* **21.5** *Min:* *Max:*
	53	Glide Area to Riffle Area (A_{bkfg}/A_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.872** *Min:* *Max:*	*Mean:* **1.122** *Min:* *Max:*
	54	Glide Maximum Depth (d_{maxg})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.10** *Min:* *Max:*	*Mean:* **1.62** *Min:* *Max:*
	55	Glide Maximum Depth to Riffle Mean Depth (d_{maxg}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.111** *Min:* *Max:*	*Mean:* **1.558** *Min:* *Max:*

Table II-2 (page 4). The morphological characteristics of the existing, proposed design and reference reaches for the D4 to C4 stream type conversion in a Valley Type VIII.

Entry Number & Variable			Existing Reach		Proposed Design Reach		Reference Reach	
Glide Inner Berm Dimensions	**56**	Glide Inner Berm Width, ft (W_{ibg})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**8.2**	*Mean:* *Min:* *Max:*	**12.9**
	57	Glide Inner Berm Width to Glide Width (W_{ibg}/W_{bkfg})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**0.562**	*Mean:* *Min:* *Max:*	**0.583**
	58	Glide Inner Berm Mean Depth, ft (d_{ibg})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**0.56**	*Mean:* *Min:* *Max:*	**0.48**
	59	Glide Inner Berm Mean Depth to Glide Mean Depth (d_{ibg}/d_{bkfg})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**0.700**	*Mean:* *Min:* *Max:*	**0.490**
	60	Glide Inner Berm Width/Depth Ratio (W_{ibg}/d_{ibg})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**14.6**	*Mean:* *Min:* *Max:*	**26.8**
	61	Glide Inner Berm Cross-Sectional Area (A_{ibg})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**4.6**	*Mean:* *Min:* *Max:*	**6.2**
	62	Glide Inner Berm Area to Glide Area (A_{ibg}/A_{bkfg})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**0.393**	*Mean:* *Min:* *Max:*	**0.287**

Table II-2 (page 5). The morphological characteristics of the existing, proposed design and reference reaches for the D4 to C4 stream type conversion in a Valley Type VIII.

	Entry Number & Variable		Existing Reach		Proposed Design Reach		Reference Reach	
Channel Pattern	**72**	Linear Wavelength, ft (λ)	*Mean:*	**N/A**	*Mean:*	**96.0**	*Mean:*	**84.5**
			Min:		*Min:*	**75.0**	*Min:*	**62.0**
			Max:		*Max:*	**117.0**	*Max:*	**114.5**
	73	Linear Wavelength to Riffle Width (λ/W_{bkf})	*Mean:*	**N/A**	*Mean:*	**7.111**	*Mean:*	**4.558**
			Min:		*Min:*	**5.556**	*Min:*	**3.345**
			Max:		*Max:*	**8.667**	*Max:*	**6.178**
	74	Stream Meander Length, ft (L_m)	*Mean:*	**N/A**	*Mean:*	**138.0**	*Mean:*	**104.6**
			Min:		*Min:*	**108.0**	*Min:*	**72.6**
			Max:		*Max:*	**168.0**	*Max:*	**161.0**
	75	Stream Meander Length Ratio (L_m/W_{bkf})	*Mean:*	**N/A**	*Mean:*	**10.222**	*Mean:*	**5.645**
			Min:		*Min:*	**8.000**	*Min:*	**3.917**
			Max:		*Max:*	**12.444**	*Max:*	**8.687**
	76	Belt Width, ft (W_{blt})	*Mean:*	**N/A**	*Mean:*	**60.0**	*Mean:*	**66.1**
			Min:		*Min:*	**40.5**	*Min:*	**42.8**
			Max:		*Max:*	**82.0**	*Max:*	**82.8**
	77	Meander Width Ratio (W_{blt}/W_{bkf})	*Mean:*	**N/A**	*Mean:*	**4.444**	*Mean:*	**3.567**
			Min:		*Min:*	**3.000**	*Min:*	**2.309**
			Max:		*Max:*	**6.074**	*Max:*	**4.468**
	78	Radius of Curvature, ft (R_c)	*Mean:*	**N/A**	*Mean:*	**42.0**	*Mean:*	**31.1**
			Min:		*Min:*	**36.0**	*Min:*	**23.9**
			Max:		*Max:*	**56.0**	*Max:*	**41.7**
	79	Radius of Curvature to Riffle Width (R_c/W_{bkf})	*Mean:*	**N/A**	*Mean:*	**3.111**	*Mean:*	**1.677**
			Min:		*Min:*	**2.667**	*Min:*	**1.290**
			Max:		*Max:*	**4.148**	*Max:*	**2.250**
	80	Arc Length, ft (L_a)	*Mean:*	**N/A**	*Mean:*	**27.5**	*Mean:*	**37.7**
			Min:		*Min:*	**14.7**	*Min:*	**20.1**
			Max:		*Max:*	**33.5**	*Max:*	**46.0**
	81	Arc Length to Riffle Width (L_a/W_{bkf})	*Mean:*	**N/A**	*Mean:*	**2.033**	*Mean:*	**2.033**
			Min:		*Min:*	**1.085**	*Min:*	**1.085**
			Max:		*Max:*	**2.482**	*Max:*	**2.482**
	82	Riffle Length (L_r), ft	*Mean:*	**N/A**	*Mean:*	**30.4**	*Mean:*	**23.1**
			Min:		*Min:*	**13.5**	*Min:*	**8.5**
			Max:		*Max:*	**54.0**	*Max:*	**82.4**
	83	Riffle Length to Riffle Width (L_r/W_{bkf})	*Mean:*	**N/A**	*Mean:*	**2.252**	*Mean:*	**1.245**
			Min:		*Min:*	**1.000**	*Min:*	**0.459**
			Max:		*Max:*	**4.000**	*Max:*	**4.446**
	84	Individual Pool Length, ft (L_p)	*Mean:*	**N/A**	*Mean:*	**20.3**	*Mean:*	**17.6**
			Min:		*Min:*	**13.5**	*Min:*	**8.5**
			Max:		*Max:*	**27.0**	*Max:*	**27.5**
	85	Pool Length to Riffle Width (L_p/W_{bkf})	*Mean:*	**N/A**	*Mean:*	**1.504**	*Mean:*	**0.949**
			Min:		*Min:*	**1.000**	*Min:*	**0.459**
			Max:		*Max:*	**2.000**	*Max:*	**1.485**
	86	Pool to Pool Spacing, ft (P_s)	*Mean:*	**N/A**	*Mean:*	**75.0**	*Mean:*	**55.5**
			Min:		*Min:*	**60.0**	*Min:*	**22.0**
			Max:		*Max:*	**90.0**	*Max:*	**107.5**
	87	Pool to Pool Spacing to Riffle Width (P_s/W_{bkf})	*Mean:*	**N/A**	*Mean:*	**5.556**	*Mean:*	**2.996**
			Min:		*Min:*	**4.444**	*Min:*	**1.187**
			Max:		*Max:*	**6.667**	*Max:*	**5.800**

Table II-2 (page 6). The morphological characteristics of the existing, proposed design and reference reaches for the D4 to C4 stream type conversion in a Valley Type VIII.

	Entry Number & Variable	Existing Reach	Proposed Design Reach	Reference Reach
Sinuosity and Slope	**88** Stream Length (SL)	**400.0**	**450.0**	**567.7**
	89 Valley Length (VL)	**400.0**	**323.7**	**783.4**
	90 Valley Slope (S_{val})	**0.010**	**0.010**	**0.0061**
	91 Sinuosity (k)	SL/VL: **1.00** VS/S: **1.00**	SL/VL: **1.39**	SL/VL: **1.38** VS/S: **1.38**
	92 Average Water Surface Slope (S)	**0.010**	$S = S_{val}/k$ **0.0072**	**0.0044**
Flood-Prone Area Dim.	**93** Flood-Prone Area Width, ft (W_{fpa})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* **40.7** *Min:* *Max:*
	94 Flood-Prone Area Mean Depth, ft (d_{fpa})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* **1.89** *Min:* *Max:*
	95 Flood-Prone Area Cross-Sectional Area, ft^2 (A_{fpa})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* **76.8** *Min:* *Max:*
Floodplain Dimensions	**96** Floodplain Width, ft (W_f)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	97 Floodplain Mean Depth, ft (d_f)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	98 Floodplain Cross-Sectional Area, ft^2 (A_f)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
Low Terrace Dim.	**99** Low Terrace Width, ft (W_{lt})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	100 Low Terrace Mean Depth, ft (d_{lt})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	101 Low Terrace Cross-Sectional Area, ft^2 (A_{lt})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*

Table II-2 (page 7). The morphological characteristics of the existing, proposed design and reference reaches for the D4 to C4 stream type conversion in a Valley Type VIII.

	Entry Number & Variable		Existing Reach		Proposed Design Reach		Reference Reach	
Bed Feature Water Surface Facet Slopes and Dimensionless Ratios from Profile	**105**	Riffle Slope (water surface facet slope) (S_{rif})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**0.0156** **0.0099** **0.0189**	*Mean:* *Min:* *Max:*	**0.0045** **0.0029** **0.0054**
	106	Riffle Slope to Average Water Surface Slope (S_{rif}/S)	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**1.0205** **0.6477** **1.2341**	*Mean:* *Min:* *Max:*	**1.0205** **0.6477** **1.2341**
	107	Pool Slope (water surface facet slope) (S_p)	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**0.0080** **0.0028** **0.0132**	*Mean:* *Min:* *Max:*	**0.0023** **0.0008** **0.0038**
	108	Pool Slope to Average Water Surface Slope (S_p/S)	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**0.5250** **0.1841** **0.8636**	*Mean:* *Min:* *Max:*	**0.5250** **0.1841** **0.8636**
	109	Run Slope (water surface facet slope) (S_{run})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**0.0392** **0.0230** **0.0485**	*Mean:* *Min:* *Max:*	**0.0113** **0.0066** **0.0140**
	110	Run Slope to Average Water Surface Slope (S_{run}/S)	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**2.5614** **1.5000** **3.1705**	*Mean:* *Min:* *Max:*	**2.5614** **1.5000** **3.1705**
	111	Glide Slope (water surface facet slope) (S_g)	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**0.0119** **0.0090** **0.0136**	*Mean:* *Min:* *Max:*	**0.0034** **0.0026** **0.0039**
	112	Glide Slope to Average Water Surface Slope (S_g/S)	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**0.7750** **0.5909** **0.8864**	*Mean:* *Min:* *Max:*	**0.7750** **0.5909** **0.8864**
	113	Step Slope (water surface facet slope) (S_s)	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**N/A**
	114	Step Slope to Average Water Surface Slope (S_s/S)	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**N/A**

Table II-2 (page 8). The morphological characteristics of the existing, proposed design and reference reaches for the D4 to C4 stream type conversion in a Valley Type VIII.

	Entry Number & Variable	Existing Reach	Proposed Design Reach	Reference Reach
Bed Feature Max Depth Measurements and Dimensionless Ratios from Profile	**115** Riffle Maximum Depth, ft (d_{max})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.70** *Min:* **1.41** *Max:* **1.80**	*Mean:* **1.60** *Min:* **1.40** *Max:* **1.75**
	116 Riffle Maximum Depth to Riffle Mean Depth (d_{max}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.717** *Min:* **1.424** *Max:* **1.818**	*Mean:* **1.534** *Min:* **1.342** *Max:* **1.677**
	117 Pool Maximum Depth, ft (d_{maxp})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **3.10** *Min:* **2.80** *Max:* **3.50**	*Mean:* **2.46** *Min:* **2.12** *Max:* **2.95**
	118 Pool Maximum Depth to Riffle Mean Depth (d_{maxp}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **3.131** *Min:* **2.828** *Max:* **3.535**	*Mean:* **2.358** *Min:* **2.038** *Max:* **2.837**
	119 Run Maximum Depth, ft (d_{maxr})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **2.00** *Min:* **1.50** *Max:* **2.20**	*Mean:* **1.74** *Min:* **1.57** *Max:* **1.95**
	120 Run Maximum Depth to Riffle Mean Depth (d_{maxr}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **2.020** *Min:* **1.515** *Max:* **2.222**	*Mean:* **1.668** *Min:* **1.505** *Max:* **1.869**
	121 Glide Maximum Depth, ft (d_{maxg})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.10** *Min:* **1.00** *Max:* **1.30**	*Mean:* **1.55** *Min:* **1.33** *Max:* **1.78**
	122 Glide Maximum Depth to Riffle Mean Depth (d_{maxg}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.111** *Min:* **1.010** *Max:* **1.313**	*Mean:* **1.486** *Min:* **1.275** *Max:* **1.706**
	123 Step Maximum Depth, ft (d_{maxs})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	124 Step Maximum Depth to Riffle Mean Depth (d_{maxs}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
Channel Materials	**125 Particle Size Distribution of Channel Material (Active Bed) or Pavement**			
	D_{16} (mm)	**2.0**	**2.0**	**4.3**
	D_{35} (mm)	**4.0**	**4.0**	**7.1**
	D_{50} (mm)	**8.0**	**8.0**	**9.7**
	D_{84} (mm)	**26.0**	**26.0**	**26.4**
	D_{95} (mm)	**44.0**	**44.0**	**42.5**
	D_{100} (mm)	**90.0**	**90.0**	**180.0**
	126 Particle Size Distribution of Bar Material or Sub-pavement			
	D_{16} (mm)	**0.0**	**0.0**	**0.0**
	D_{35} (mm)	**3.0**	**3.0**	**4.5**
	D_{50} (mm)	**6.0**	**6.0**	**7.7**
	D_{84} (mm)	**31.0**	**31.0**	**41.7**
	D_{95} (mm)	**65.0**	**65.0**	**69.6**
	D_{max}: Largest size particle at the toe (lower third) of bar (mm) or sub-pavement	**80.0**	**80.0**	**74.0**

Table II-2 (page 9). The morphological characteristics of the existing, proposed design and reference reaches for the D4 to C4 stream type conversion in a Valley Type VIII.

Entry Number & Variable			Existing Reach	Proposed Design Reach	Reference Reach
Hydraulics	127	Estimated Bankfull Mean Velocity, ft/sec (u_{bkf})	**2.0**	**3.0**	**3.0**
	128	Estimated Bankfull Discharge, cfs (Q_{bkf}); Compare with Regional Curve	**40.0**	**40.0**	**51.6**
Sediment Competence	129	Calculated bankfull shear stress value, lbs/ft^2 (τ)	**0.150**	**0.445**	**0.327**
	130	Predicted largest moveable particle size (mm) at bankfull shear stress, τ, using the original **Shields** relation	**10.8**	**34**	**24.0**
	131	Predicted largest moveable particle size (mm) at bankfull shear stress, τ, using the **Colorado** relation	**37.6**	**84**	**70.0**
	132	Largest particle size to be moved (D_{max}) (mm) (see #126: Particle Size Distribution of Bar Material)	**80**	**80**	**74.0**
	133	Predicted shear stress required to initiate movement of D_{max} (mm) using the original **Shields** relation	**1.025**	**1.025**	**1.000**
	134	Predicted shear stress required to initiate movement of D_{max} (mm) using the **Colorado** relation	**0.418**	**0.418**	**0.350**
	135	Predicted mean depth required to initiate movement of D_{max} (mm), d = $\tau/\gamma S$ (τ = predicted shear stress, γ = 62.4, S = existing or design slope) (**Shields**)	**1.64**	**2.28**	**3.64**
	136	Predicted mean depth required to initiate movement of D_{max} (mm), d = $\tau/\gamma S$ (τ = predicted shear stress, γ = 62.4, S = existing or design slope) (**Colorado**)	**1.64**	**0.93**	**3.64**
	137	Predicted slope required to initiate movement of D_{max} (mm) S=$\tau/\gamma d$ (τ = predicted shear stress, γ = 62.4, d = existing or design depth) (**Shields**)	**0.0684**	**0.0166**	**0.0135**
	138	Predicted slope required to initiate movement of D_{max} (mm) S=$\tau/\gamma d$ (τ = predicted shear stress, γ = 62.4, d = existing or design depth) (**Colorado**)	**0.0279**	**0.0068**	**0.0047**
	139	Bankfull dimensionless shear stress (τ^*) (see competence form)	**N/A**	**N/A**	**N/A**
	140	Required bankfull mean depth d_{bkf} (ft) using dimensionless shear stress equation: $d_{bkf} = \tau^*(\gamma_s - 1)D_{max}/S$ (Note: D_{max} in ft)	**N/A**	**N/A**	**N/A**
	141	Required bankfull water surface slope S (ft) using dimensionless shear stress equation: $S = \tau^*(\gamma_s - 1)D_{max}/d_{bkf}$ (Note: D_{max} in ft)	**N/A**	**N/A**	**N/A**

Table II-2 (page 10). The morphological characteristics of the existing, proposed design and reference reaches for the D4 to C4 stream type conversion in a Valley Type VIII.

	Entry Number & Variable	Existing Reach	Proposed Design Reach	Reference Reach
Sediment Yield	**Sediment Yield (FLOWSED)***	**Existing Reach***	**Proposed Design Reach***	**Difference in Sediment Yield***
	141 Bedload Sediment Yield (tons/yr)	**5,416.0**	**144.0**	**5,272.0**
	142 Suspended Sediment Yield (tons/yr)	**18,774.4**	**700.5**	**18,073.9**
	143 Suspended Sand Sediment Yield (tons/yr)	**9,387.2**	**350.3**	**9,037.0**
	144 Total Annual Sediment Yield (tons/yr)	**24,190.4**	**844.6**	**23,345.8**
	***Reduction in sediment supply due to using "Good" sediment supply bankfull values by drainage area and "Good" dimensionless sediment rating curves vs "Poor" as a result of converting from the D4 (Poor) to C4 (Good) stream type.**			
Bank Erosion	**Streambank Erosion**	**Existing Reach**** **Extrapolated from D4a Rep. Reach	**Proposed Design Reach**	**Reference Reach**
	145 Stream Length Assessed (ft)	**400**	**450**	**463**
	146 Graph/Curve Used (e.g., Yellowstone or Colorado)	**Colorado**	**Colorado**	**Colorado**
	147 Streambank Erosion (tons/yr)	**287.3**	**2.85**	**2.94**
	148 Streambank Erosion (tons/yr/ft)	**0.7183****	**0.0063**	**0.0063**

Bankfull Discharge, Cross-Sectional Area & Mean Velocity

With a drainage area of *15.9 mi^2* for the proposed C4 stream type, the bankfull discharge is *40 cfs* and the proposed bankfull riffle cross-sectional area is *13.3 ft^2* as shown in **Table II-2**. Using continuity, the corresponding mean velocity for the proposed design reach is *3.0 ft/sec* as shown in **Worksheet II-1**. This worksheet is also used to check for reasonable velocities using the proposed design dimensions and slope using a variety of methods; these methods, particularly manning's "*n*" from stream type and friction factor to relative roughness relations, agree with the velocity estimate from continuity.

Plan View Alignment

The proposed C4 stream type alignment is shown on the aerial photograph in **Figure II-3**, which corresponds with the proposed pattern values developed from the dimensionless ratios of the *C4 Reference Reach* in **Table II-2**. The existing cross-section locations of the D4 stream type are also shown in **Figure II-3**.

Cross-Section Dimensions

Table II-2 includes the proposed dimensions for riffles, pools, glides, and runs for the proposed C4 design reach that were developed and scaled from the reference reach dimensionless relations. The typical cross-sections for these bed features are depicted in **Figure II-4**, **Figure II-5**, **Figure II-6** and **Figure II-7**, respectively. A typical schematic of the proposed excavation and shaping of a multi-stage channel and valley cross-section is shown in **Figure II-8**. The overlay of the existing D4 cross-section 2+29 *vs*. proposed C4 *riffle* cross-section indicating the cut recommendations is shown in **Figure II-9**. Similarly, the existing D4 cross-section 1+28 *vs*. the proposed C4 *pool* cross-section is shown in **Figure II-10**. The locations of cross-section 1+28 and cross-section 2+29 are indicated in **Figure II-3**.

Longitudinal Profile

The typical longitudinal profile for the proposed C4 design reach is shown in **Figure II-11** compared to the existing D4 profile. The proposed elevations of the streambed and bankfull stage, the energy slope, and the typical locations of the various bed features that correspond to the plan view are shown (**Figure II-11**). Additionally, the locations of the cross-section overlays in **Figure II-9** and **Figure II-10** are depicted on the typical longitudinal profile that corresponds with the proposed design bed features.

Structures

The proposed river stability and fish enhancement structures are shown on the plan view layout in **Figure II-12**. The rock cross-vane structure is tied into the concrete box culvert, in conjunction with the revised design as presented. The cross-vane is designed to direct the streamflow and sediment into the box culvert for the proper bankfull width to minimize problems of flow convergence and recirculation eddies. The cross-vane is also designed to maintain grade control and to reduce streambank and fill erosion. The outflow of the box culvert and the head of all riffles have converging rock clusters to dissipate energy and to prevent contraction scour and bed degradation. Additionally, the proposed design reach also includes the toe wood structure with sod mats and riparian transplants for streambank stabilization and instream fish habitat.

Worksheet II-1. The mean velocity estimates for the proposed C4 stable reach to be converted from the existing, D4 stream type.

Bankfull VELOCITY & DISCHARGE Estimates

Stream:	**Proposed C4 Stream Type**	Location:	**Lower Trail Creek - Existing D4**
Date:	**8/11/2010**	Stream Type:	**C4**
Observers:	**Rosgen *et al*.**	Valley Type:	**VIII**
		HUC:	__ __ __ __ __ __ __ __ __ __ __ __

Input Variables for PROPOSED Design			Output Variables for PROPOSED Design		
Bankfull Riffle Cross-Sectional AREA	**13.3**	**A_{bkf}** (ft^2)	Bankfull Riffle Mean DEPTH	**0.99**	**d_{bkf}** (ft)
Bankfull Riffle WIDTH	**13.5**	**W_{bkf}** (ft)	Wetted PERMIMETER ~ (2 * d_{bkf}) + W_{bkf}	**15.47**	**W_p** (ft)
D_{84} at Riffle	**26.0**	**Dia.** (mm)	D_{84} (mm) / 304.8	**0.09**	**D_{84}** (ft)
Bankfull SLOPE	**0.0072**	**S_{bkf}** (ft / ft)	Hydraulic RADIUS A_{bkf} / W_p	**0.86**	**R** (ft)
Gravitational Acceleration	**32.2**	**g** (ft / sec^2)	Relative Roughness R(ft) / D_{84} (ft)	**10.08**	**R / D_{84}**
Drainage Area	**15.9**	**DA** (mi^2)	Shear Velocity $u^* = (gRS)^{½}$	**0.446**	**u*** (ft/sec)

ESTIMATION METHODS	Bankfull VELOCITY		Bankfull DISCHARGE	
1. Friction Factor / Relative Roughness $u = [\ 2.83 + 5.66 * Log\ \{\ R / D_{84}\ \}\ ]\ u^*$	**3.80**	ft / sec	**50.53**	cfs
2. Roughness Coefficient: a) Manning's *n* from Friction Factor / Relative Roughness (Figs. 5-7, 5-8) $u = 1.49*R^{2/3}*S^{1/2}/n$ **n =** **0.0345**	**3.31**	ft / sec	**44.07**	cfs
2. Roughness Coefficient: b) Manning's *n* from Stream Type (Fig. 5-9) $u = 1.49*R^{2/3}*S^{1/2}/n$ **n =** **0.04**	**2.86**	ft / sec	**38.01**	cfs
2. Roughness Coefficient: c) Manning's *n* from Jarrett (USGS): $u = 1.49*R^{2/3}*S^{1/2}/n$ $n = 0.39*S^{0.38}*R^{-0.16}$ **Note:** This equation is applicable to **steep, step/pool, high boundary roughness, cobble- and boulder-dominated stream systems**; i.e., for Stream Types A1, A2, A3, B1, B2, B3, C2 & E3 **n =** **N/A**	**N/A**	ft / sec	**N/A**	cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)		ft / sec		cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)		ft / sec		cfs
4. Continuity Equations: a) USGS Gage Data $u = Q / A$ **Return Period for Bankfull Q** **Q =** ____ **year**		ft / sec		cfs
4. Continuity Equations: b) Regional Curves $u = Q / A$	**3.01**	ft / sec	**40.0**	cfs

Protrusion Height Options for the D_{84} Term in the Relative Roughness Relation (R/D_{84}) – Estimation Method 1

Option 1.	For **sand-bed** channels: Measure 100 **"protrusion heights"** of sand dunes from the downstream side of feature to the top of feature. Substitute the D_{84} sand dune protrusion height in ft for the D_{84} term in method 1.
Option 2.	For **boulder-dominated** channels: Measure 100 **"protrusion heights"** of boulders on the sides from the bed elevation to the top of the rock on that side. Substitute the D_{84} boulder protrusion height in ft for the D_{84} term in method 1.
Option 3.	For **bedrock-dominated** channels: Measure 100 **"protrusion heights"** of rock separations, steps, joints or uplifted surfaces above channel bed elevation. Substitute the D_{84} bedrock protrusion height in ft for the D_{84} term in method 1.
Option 4.	For **log-influenced** channels: Measure **"protrustion heights"** proportionate to channel width of log diameters or the height of the log on upstream side if embedded. Substitute the D_{84} protrusion height in ft for the D_{84} term in method 1.

Insert 11 x 17 Figure II-3 Here

Figure II-3. Plan view of the alignment for the proposed C4 stream type, including the existing cross-section locations of the D4 stream type.

Insert 11 x 17 Figure II-3 Here

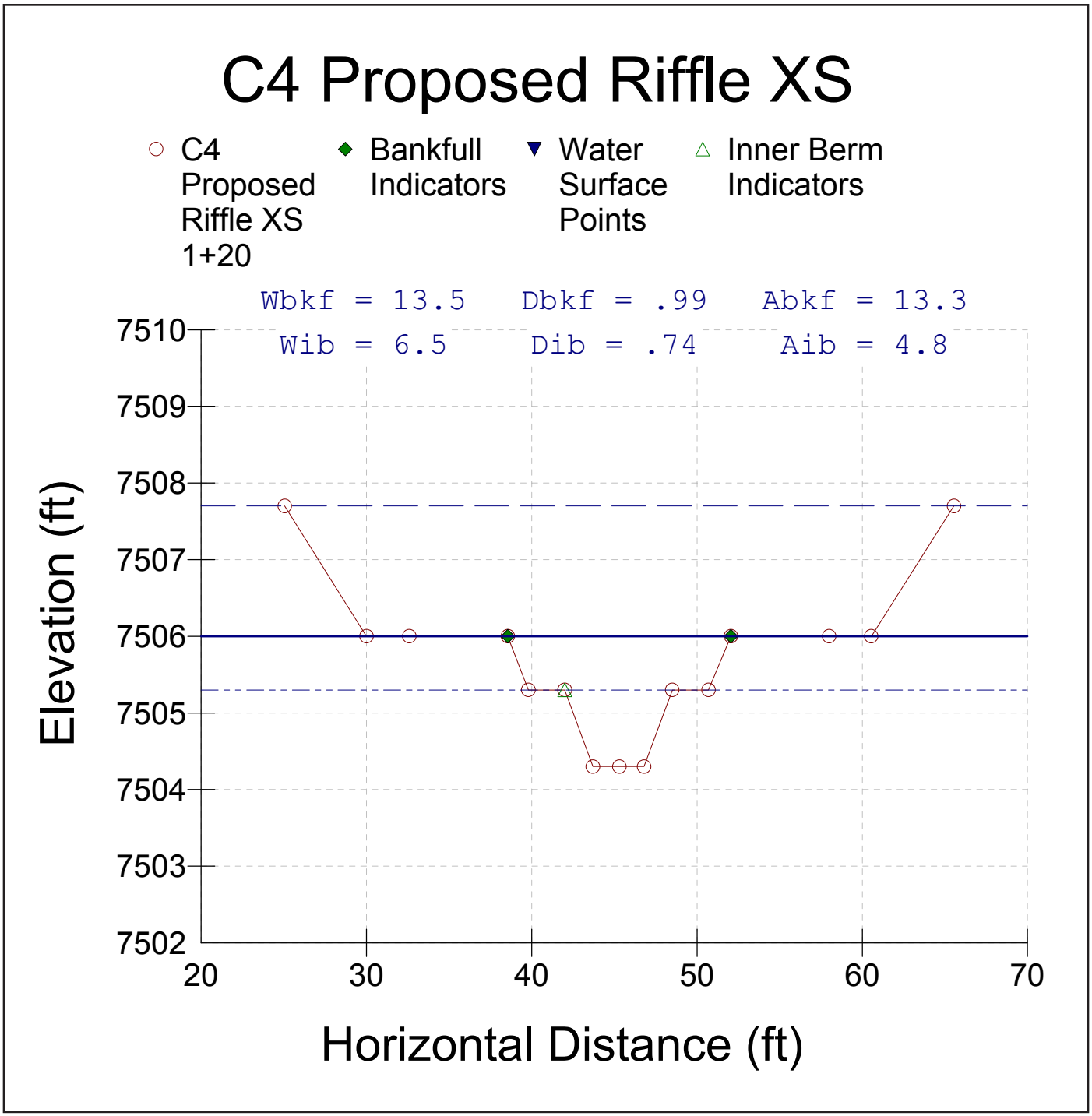


Figure II-4. The typical *riffle* cross-section for the proposed C4 reach below the West Creek road.

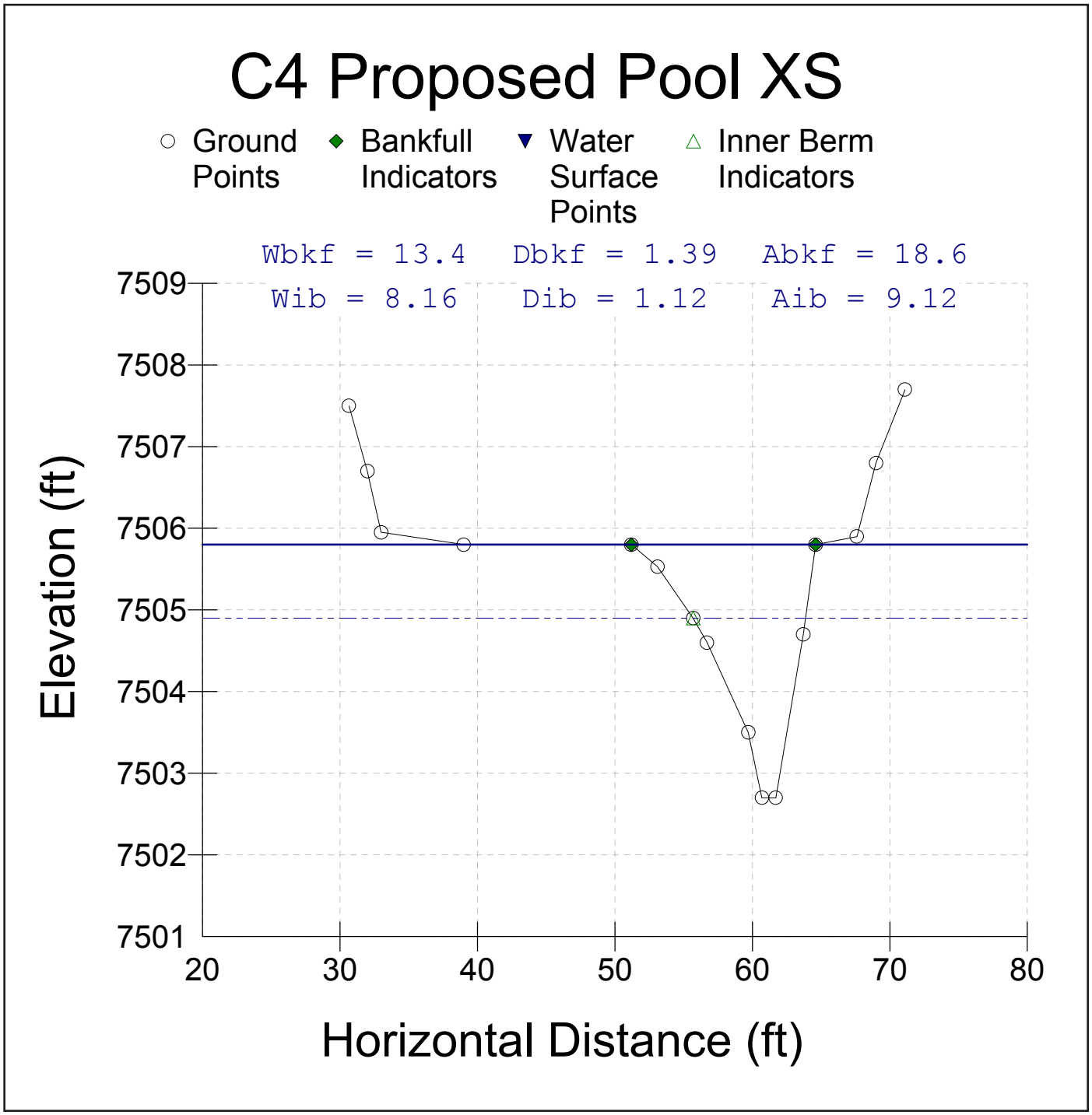


Figure II-5. The typical *pool* cross-section for the proposed C4 reach below the West Creek road.

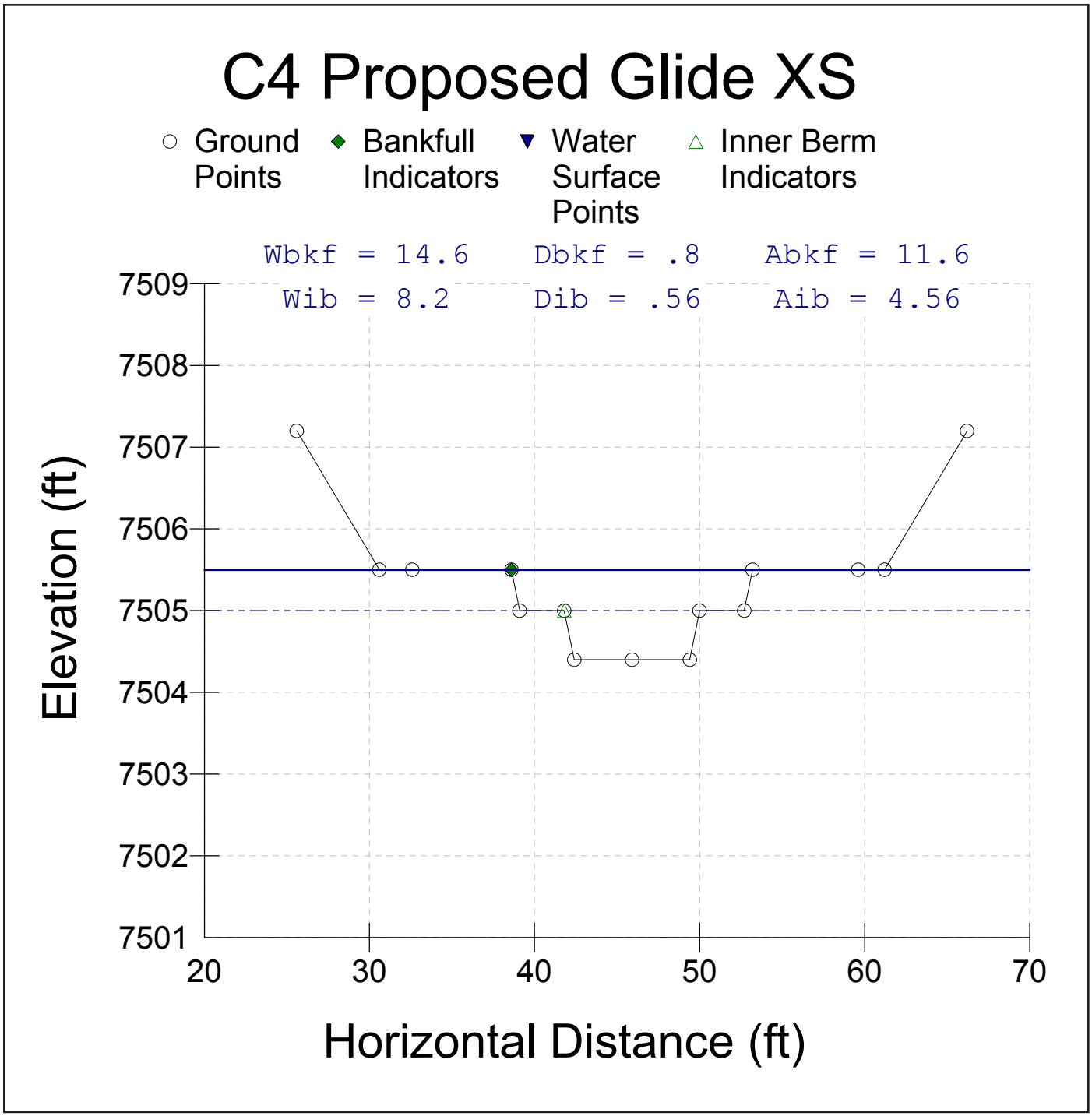


Figure II-6. The typical *glide* cross-section for the proposed C4 reach below the West Creek road.

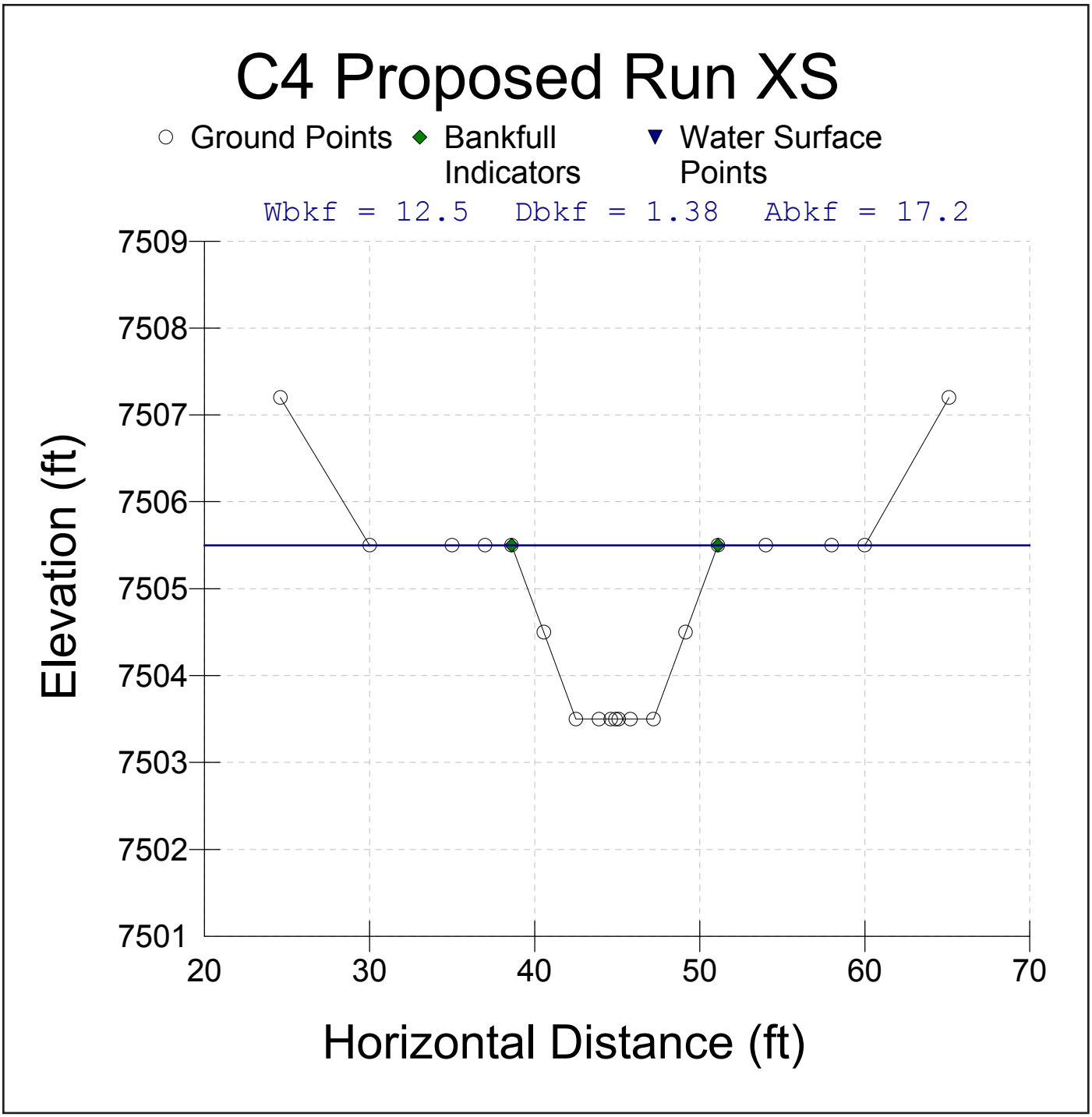


Figure II-7. The typical *run* cross-section for the proposed C4 reach below the West Creek road.

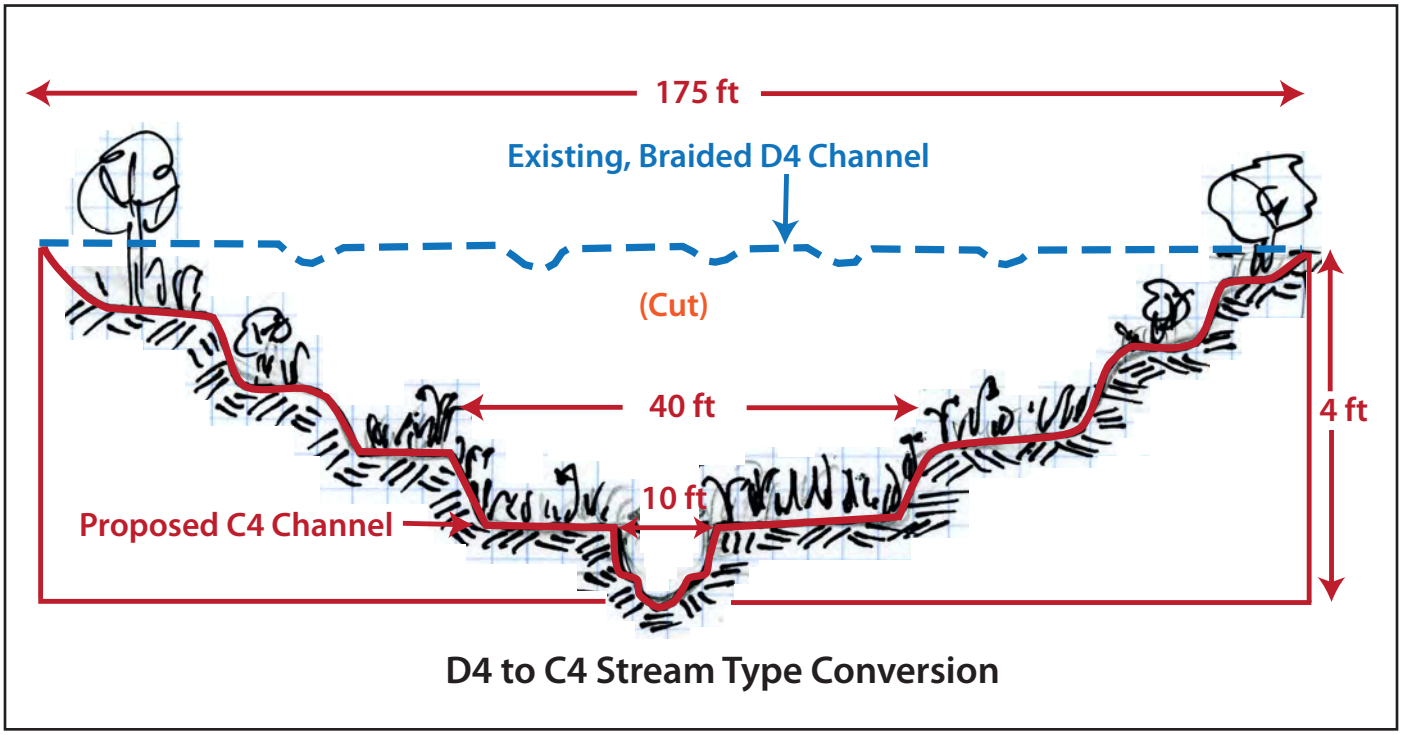


Figure II-8. Schematic of the proposed excavation and shaping of a multi-stage channel and valley cross-section for the D4 to C4 stream type conversion below the West Creek road crossing.

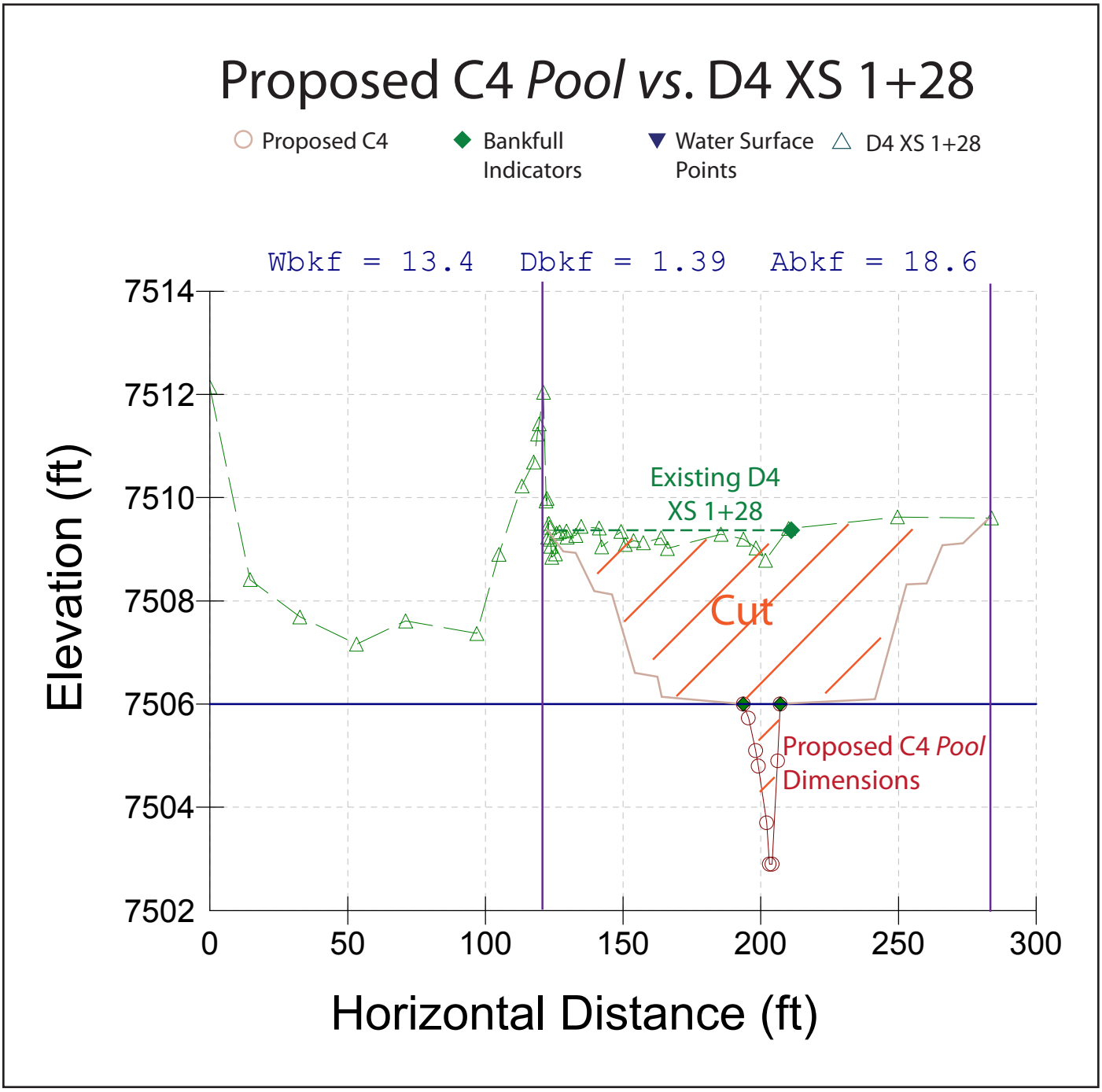


Figure II-9. The proposed C4 *pool* cross-section compared to the existing D4 cross-section 1+28 below the West Creek road.

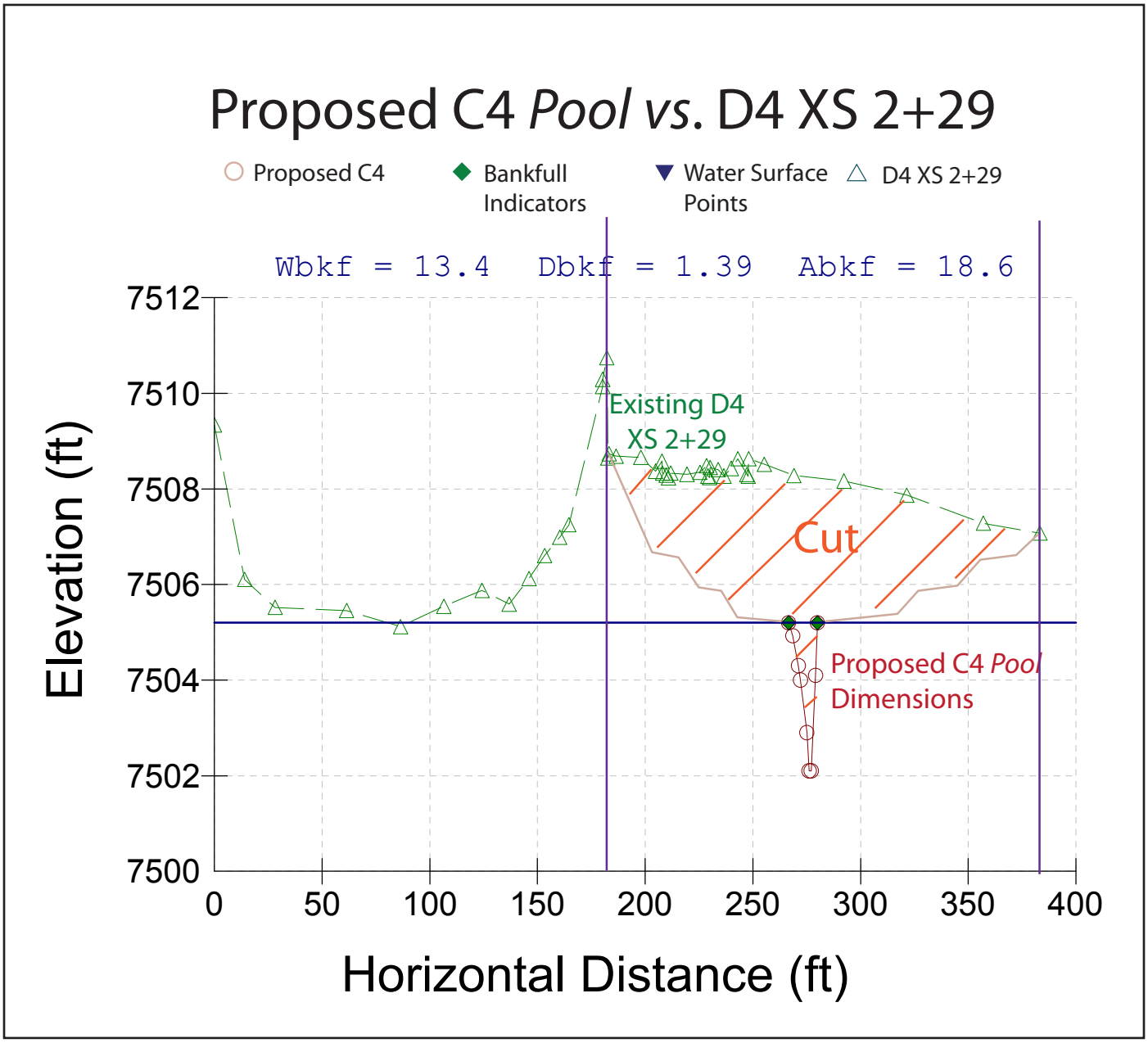


Figure II-10. The proposed C4 *pool* cross-section compared to the existing D4 cross-section 2+29 below the West Creek road.

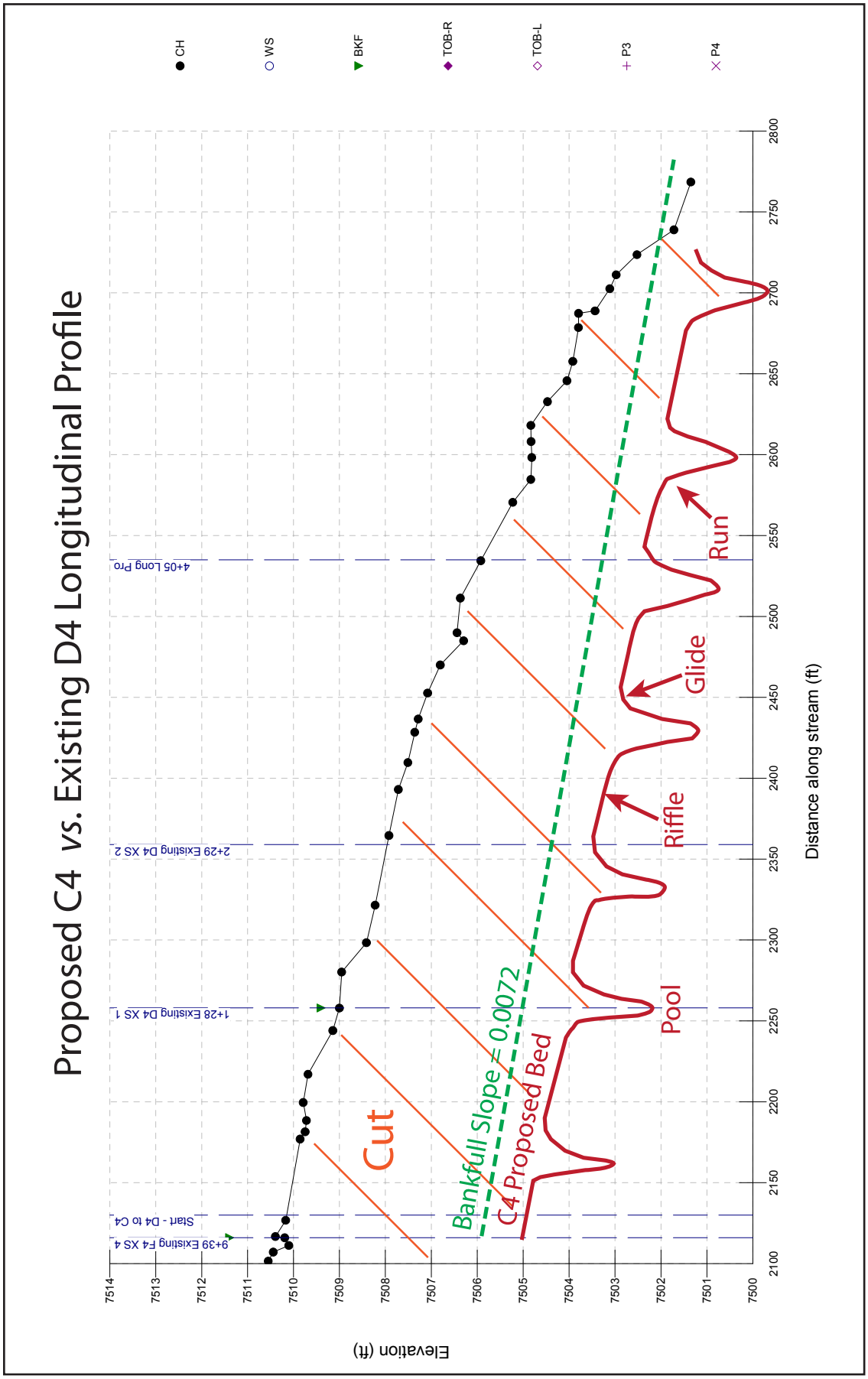


Figure II-11. The existing *vs.* proposed design longitudinal profile for the D4 to C4 stream type conversion in Valley Type VIII below the West Creek road, lower Trail Creek.

Insert 11 x 17 Figure II-12 Here

Figure II-12. Plan view of the alignment for the proposed C4 stream type, including stream stabilization and fish enhancement structures.

Insert 11 x 17 Figure II-12 Here

Riparian Vegetation

The exposed cut area within the flood-prone area and multi-stage valley (**Figure II-8**) will require a native grass understory and a mid-story stand of willows and alders. Sod mats comprised of Carex and Juncus are recommended to be transplanted from adjacent riparian areas to the areas next to the proposed channel over the toe wood structures. The revegetation is critical for the long-term physical stability and biological function.

Cut & Fill Computations

The cut and fill computations are obtained from the existing *vs*. proposed cross-sections for that particular bed feature with lengths obtained from the plan and profile data of the proposed design. The proposed design results in approximately *6,481 yds*^{3} of excess excavation. Approximately *3,091 yds*^{3} of this material will be end-hauled and placed for road fill on the Trail Creek road relocation proposals. The remaining fill will be used to help rebuild the toe of large alluvial fans previously eroded. The fans are located within the first mile of river on the northwest side of the valley.

Streambank Erosion

The streambank erosion that is expected for the proposed C4 design reach, which includes the toe wood structure, is *2.85 tons/yr* for *450 ft* of designed channel *vs*. *287.3 tons/yr* for *400 ft* of the existing condition (**Table II-2**), representing a reduction of *284.5 tons/yr* for this reach. These values are based on the extrapolation of annual erosion rates per foot of reach of the *C4 Reference Reach* (*0.0063 tons/yr/ft*) and the *D4a Poor Representative Reach* (*0.7183 tons/yr/ft*).

Flow-Related Sediment

The FLOWSED model indicates that by converting from a "Poor" condition to a "Good" condition throughout the watershed, the flow-related sediment yields would be reduced from *24,190.4 tons/yr* (**Worksheet II-2a**) to *844.6 tons/yr* (**Worksheet II-2b**) as a result of the restoration. The corresponding sediment supply reductions based on converting from "Poor" to "Good" conditions are *5,272 tons/yr* for bedload and *18,073.9 tons/yr* for suspended sediment, representing a total sediment reduction of *23,345.8 tons/yr*. These sediment reductions are still assuming a high post-fire runoff response and continued increased stormflow peak runoff. These reductions are also associated with treating the majority of the stream length of the watershed above this reach.

The reductions in sediment supply associated with restoring *400 ft* of the existing D4 *Poor* stream type to *450 ft* of the proposed C4 *Stable* design reach are *284.5 tons/yr* of streambank erosion, *39.8 tons/yr* of bedload, *136.3 tons/yr* of suspended sediment and *176.1 tons/yr* of total sediment yield reduction. The total sediment yield value includes streambank erosion contributions and streambed sources. Streambank erosion rates are sometimes higher than the total sediment yield because not all of the soil eroded from the bank is delivered; considerable amounts go into storage on the streambed and are available for re-entrainment during the next high flow. The sediment reductions associated with the local channel source sediment for this design scenario are based on sediment yield rates determined from taking the sediment yield values generated from FLOWSED and dividing by the total stream length of potential sediment contributions. For this scenario, it was determined that approximately *10 miles* (*52,800 ft*) of the mainstem Trail Creek is potentially contributing sediment. The tributaries also contribute sediment but at a lower rate; thus their stream lengths were not included in the unit sediment transport rate. The resultant sediment yield rates were then multiplied by the existing and proposed design reach lengths for this scenario to obtain the local sediment reductions.

The POWERSED model to evaluate sediment transport capacity indicates that by lowering the existing, high width/depth ratio, the C4 stream type is *85%* more efficient at transporting both bedload and suspended sand compared to the D4 stream type. This result is evident as observed by the existing excess sediment deposition and aggradation of the valley floor related to the D4 stream type. The existing, deposited sediment is available for re-entrainment during higher flows and the aggradation raises the flood stage and accelerates the streambank erosion as the depositional bars create an increase in near-bank shear stress. Conversely, if the existing D4 stream type is not restored, the POWERSED results indicate that approximately *85%* of the annual tons of sediment yield would be deposited at the mouth of Trail Creek. The long-term objective is to reduce the sediment supply before it enters this lowest reach in addition to routing the lower sediment supply to encourage fish passage and channel stability.

Sediment Competence

The sediment competence calculations using **Worksheet II-3** show a stable bed with this design by converting from a D4 to C4 stream type. Because, following construction, there is no pavement/ sub-pavement material due to dispersive stress, it will be necessary to provide grade control at the head of each riffle as recommended for this design. The converging rock clusters are the structures recommended for grade control.

Worksheet II-2a. The existing sediment supply at the D4 reach using the FLOWSED model and generated by using the dimensionless sediment rating curves and bankfull sediment values related to the "Poor" condition.

Stream: **D4 Lower Trail Creek** Location: **Above Mouth below Road Crossing** Date: **3/15/11**

Observers: **Rosgen *et al*.** Gage Station #: **Goose Creek Gage** Stream Type: **D4** Valley Type: **VIII**

Equation Type	Equation Source	Equation	Bankfull Discharge (cfs)	Bankfull Bedload Sediment (kg/s)	Bankfull Suspended Sediment (mg/l)
1. Bedload Sediment	"Poor" Pagosa	$y = 0.07176+1.02176x^{2.3772}$	40	0.4699	223.46
2. Suspended Sediment	"Poor" Pagosa	$y = 0.0989+0.9213x^{3.659}$			

From Dimensional Flow-Duration Curve							From Sediment Rating Curves				Calculate	Calculate Sediment Yield		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Percentage of Time	Daily Mean Discharge	Mid-Ordinate	Time Increment (percent)	Time Increment (days)	Mid-Ordinate Streamflow	Dimension-less Streamflow	Dimension-less Suspended Sediment Discharge	Suspended Sediment Discharge	Dimension- less Bedload Discharge	Bedload Sediment Discharge	Time Adjusted Streamflow [(5)×(6)]	Suspended Sediment [(5)×(9)]	Bedload Sediment [(5)×(11)]	Suspended + Bedload Sediment [(13)+(14)]
(%)	(cfs)	(%)	(%)	(days)	(cfs)	(Q/Q_{bkf})	(S/S_{bkf})	(tons/day)	(b_s/b_{bkf})	(tons/day)	(cfs)	(tons)	(tons)	(tons)
0%	178.8													
0.10%	153.5	0.05%	0.09%	0.34	166.2	4.154	168.918	16935.10	30.244	1353.84	57.0	5810.43	464.50	6274.94
0.25%	132.9	0.08%	0.15%	0.55	143.2	3.579	97.999	8465.64	21.249	951.18	78.4	4634.94	520.77	5155.71
0.50%	114.8	0.13%	0.25%	0.91	123.8	3.095	57.637	4305.77	15.065	674.38	113.0	3929.01	615.37	4544.38
0.75%	98.0	0.13%	0.25%	0.91	106.4	2.660	33.137	2127.25	10.528	471.26	97.1	1941.11	430.03	2371.14
1%	84.8	0.13%	0.25%	0.91	91.4	2.285	19.049	1050.51	7.358	329.39	83.4	958.59	300.57	1259.16
1.5%	60.7	0.25%	0.50%	1.83	72.8	1.819	8.322	365.32	4.308	192.84	132.8	666.70	351.93	1018.64
2%	51.1	0.25%	0.50%	1.83	55.9	1.398	3.236	109.15	2.337	104.60	102.0	199.20	190.89	390.10
3%	43.7	0.50%	1.00%	3.65	47.4	1.185	1.812	51.83	1.601	71.66	173.0	189.17	261.57	450.74
4%	38.9	0.50%	1.00%	3.65	41.3	1.032	1.133	28.22	1.173	52.52	150.7	103.02	191.69	294.71
5%	34.4	0.50%	1.00%	3.65	36.7	0.916	0.768	16.99	0.902	40.38	133.8	62.02	147.38	209.40
10%	24.4	2.50%	5.00%	18.25	29.4	0.736	0.399	7.08	0.565	25.28	537.2	129.28	461.28	590.56
20%	13.3	5.00%	10.00%	36.50	18.9	0.472	0.158	1.80	0.243	10.89	689.2	65.71	397.57	463.27
30%	8.9	5.00%	10.00%	36.50	11.1	0.278	0.107	0.72	0.120	5.39	405.4	26.27	196.65	222.92
40%	6.3	5.00%	10.00%	36.50	7.6	0.190	0.101	0.46	0.091	4.09	277.0	16.88	149.36	166.25
50%	4.8	5.00%	10.00%	36.50	5.6	0.139	0.100	0.33	0.081	3.63	202.7	12.18	132.53	144.71
60%	3.7	5.00%	10.00%	36.50	4.3	0.106	0.099	0.25	0.077	3.43	155.4	9.30	125.38	134.67
70%	3.0	5.00%	10.00%	36.50	3.3	0.083	0.099	0.20	0.075	3.34	121.6	7.27	121.79	129.05
80%	2.6	5.00%	10.00%	36.50	2.8	0.069	0.099	0.17	0.074	3.29	101.4	6.05	120.19	126.24
90%	1.9	5.00%	10.00%	36.50	2.2	0.056	0.099	0.13	0.073	3.26	81.1	4.84	118.98	123.82
100%	0.4	5.00%	10.00%	36.50	1.1	0.028	0.099	0.07	0.072	3.22	40.5	2.42	117.58	120.00
									Annual Totals:		3,732.8 (cfs) 7,404.1 (acre-ft)	18,774.4 (tons/yr)	5,416.0 (tons/yr)	24,190.4 (tons/yr)

Worksheet II-2b. The proposed sediment supply at the proposed C4 reach using the FLOWSED model and generated by using the dimensionless sediment rating curves and bankfull sediment values related to the restored "Good" condition (assuming that the watershed area above this reach is also restored to "Good" conditions).

Stream: **C4 Proposed converted from D4, Lower Trail Creek** Location: **Above Mouth below Road Crossing** Date: **3/15/11**

Observers **Rosgen *et al*.** Gage Station #: **Goose Creek Gage** Stream Type: **C4** Valley Type: **VIII**

Equation Type	Equation Source	Equation	Bankfull Discharge (cfs)	Bankfull Bedload Sediment (kg/s)	Bankfull Suspended Sediment (mg/l)
1. Bedload Sediment	"Good/Fair" Pagosa	$y = -0.0113+1.0139x^{2.1929}$	40	0.0182	31.70
2. Suspended Sediment	"Good/Fair" Pagosa	$y = 0.0636+0.9326x^{2.4085}$			

From Dimensional Flow-Duration Curve							From Sediment Rating Curves				Calculate	Calculate Sediment Yield		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Percentage of Time	Daily Mean Discharge	Mid-Ordinate	Time Increment (percent)	Time Increment (days)	Mid-Ordinate Streamflow	Dimension-less Streamflow	Dimension-less Suspended Sediment Discharge	Suspended Sediment Discharge	Dimension-less Bedload Discharge	Bedload Sediment Discharge	Time Adjusted Streamflow [(5)×(6)]	Suspended Sediment [(5)×(9)]	Bedload Sediment [(5)×(11)]	Suspended + Bedload Sediment [(13)+(14)]
(%)	(cfs)	(%)	(%)	(days)	(cfs)	(Q/Q_{bkf})	(S/S_{bkf})	(tons/day)	(b_s/b_{bkf})	(tons/day)	(cfs)	(tons)	(tons)	(tons)
0%	178.8													
0.10%	153.5	0.05%	0.09%	0.34	166.2	4.154	28.858	410.47	23.017	39.99	57.0	140.83	13.72	154.55
0.25%	132.9	0.08%	0.15%	0.55	143.2	3.579	20.180	247.32	16.601	28.84	78.4	135.41	15.79	151.20
0.50%	114.8	0.13%	0.25%	0.91	123.8	3.095	14.241	150.94	12.070	20.97	113.0	137.73	19.13	156.87
0.75%	98.0	0.13%	0.25%	0.91	106.4	2.660	9.904	90.20	8.652	15.03	97.1	82.31	13.72	96.02
1%	84.8	0.13%	0.25%	0.91	91.4	2.285	6.889	53.90	6.198	10.77	83.4	49.18	9.82	59.01
1.5%	60.7	0.25%	0.50%	1.83	72.8	1.819	4.003	24.93	3.753	6.52	132.8	45.50	11.90	57.40
2%	51.1	0.25%	0.50%	1.83	55.9	1.398	2.153	10.30	2.102	3.65	102.0	18.80	6.66	25.46
3%	43.7	0.50%	1.00%	3.65	47.4	1.185	1.467	5.95	1.459	2.54	173.0	21.72	9.25	30.97
4%	38.9	0.50%	1.00%	3.65	41.3	1.032	1.070	3.78	1.075	1.87	150.7	13.80	6.82	20.62
5%	34.4	0.50%	1.00%	3.65	36.7	0.916	0.819	2.57	0.826	1.43	133.8	9.38	5.24	14.62
10%	24.4	2.50%	5.00%	18.25	29.4	0.736	0.509	1.28	0.506	0.88	537.2	23.41	16.05	39.46
20%	13.3	5.00%	10.00%	36.50	18.9	0.472	0.217	0.35	0.184	0.32	689.2	12.78	11.68	24.46
30%	8.9	5.00%	10.00%	36.50	11.1	0.278	0.106	0.10	0.050	0.09	405.4	3.69	3.16	6.84
40%	6.3	5.00%	10.00%	36.50	7.6	0.190	0.081	0.05	0.015	0.03	277.0	1.91	0.96	2.88
50%	4.8	5.00%	10.00%	36.50	5.6	0.139	0.072	0.03	0.002	0.00	202.7	1.24	0.13	1.37
60%	3.7	5.00%	10.00%	36.50	4.3	0.106	0.068	0.02	0.000	0.00	155.4	0.90	0.00	0.90
70%	3.0	5.00%	10.00%	36.50	3.3	0.083	0.066	0.02	0.000	0.00	121.6	0.69	0.00	0.69
80%	2.6	5.00%	10.00%	36.50	2.8	0.069	0.065	0.02	0.000	0.00	101.4	0.56	0.00	0.56
90%	1.9	5.00%	10.00%	36.50	2.2	0.056	0.064	0.01	0.000	0.00	81.1	0.45	0.00	0.45
100%	0.4	5.00%	10.00%	36.50	1.1	0.028	0.064	0.01	0.000	0.00	40.5	0.22	0.00	0.22
									Annual Totals:		3,732.8 (cfs) 7,404.1 (acre-ft)	700.5 (tons/yr)	144.0 (tons/yr)	844.6 (tons/yr)

Worksheet II-3. The sediment competence calculations for the proposed C4 stream type below the West Creek road to be converted from the existing D4 stream type.

Stream:	**Proposed C4 converted from D4**		Stream Type: **C4**		
Location:	**Lower Trail Creek below W. Ck Road**		Valley Type: **VIII**		
Observers:	**Rosgen *et al*.**		Date: **3/15/11**		
Enter Required Information for PROPOSED Design Condition					
8.0	D_{50}	Median particle size of riffle bed material (mm)			
6.0	$D_{50}^{\wedge}$	Median particle size of bar or sub-pavement sample (mm)			
0.26	D_{max}	Largest particle from bar sample (ft)	**80**	**(mm)**	304.8 mm/ft
0.00720	S	Proposed design bankfull water surface slope (ft/ft)			
0.99	d	Proposed design bankfull mean depth (ft)			
1.65	γ_s-γ/γ	Immersed specific gravity of sediment			
Select the Appropriate Equation and Calculate Critical Dimensionless Shear Stress					
N/A	$D_{50}/D_{50}^{\wedge}$	Range: 3 – 7	Use EQUATION 1: $\tau^* = 0.0834\ (\ D_{50}/D_{50}^{\wedge})^{-0.872}$		
N/A	D_{max}/D_{50}	Range: 1.3 – 3.0	Use EQUATION 2: $\tau^* = 0.0384\ (D_{max}/D_{50})^{-0.887}$		
N/A	τ^*	Bankfull Dimensionless Shear Stress	EQUATION USED:		
Calculate Bankfull Mean Depth Required for Entrainment of Largest Particle in Bar Sample					
N/A	**d**	Required bankfull mean depth (ft) $d = \frac{\tau^*(\gamma_s - 1)D_{max}}{S}$ (use D_{max} in ft)			
Calculate Bankfull Water Surface Slope Required for Entrainment of Largest Particle in Bar Sample					
N/A	**S**	Required bankfull water surface slope (ft/ft) $S = \frac{\tau^*(\gamma_s - 1)D_{max}}{d}$ (use D_{max} in ft)			
Check: ☐ Stable ☐ Aggrading ☐ Degrading					
Sediment Competence Using Dimensional Shear Stress					
0.445		Bankfull shear stress $\tau = \gamma dS$ (lbs/ft^2) (substitute hydraulic radius, R, with mean depth, d) γ = 62.4, d = proposed design depth, S = proposed design slope			
Shields **33.52**	CO **83.78**	Predicted largest moveable particle size (mm) at bankfull shear stress τ **(Figure 5-49)**			
Shields **1.025**	CO **0.418**	Predicted shear stress required to initiate movement of measured D_{max} (mm) **(Figure 5-49)**			
Shields **2.28**	CO **0.93**	Predicted mean depth required to initiate movement of measured D_{max} (mm) $d = \frac{\tau}{\gamma S}$ τ = predicted shear stress, γ = 62.4, S = proposed design slope			
Shields **0.0166**	CO **0.0068**	Predicted slope required to initiate movement of measured D_{max} (mm) $S = \frac{\tau}{\gamma d}$ τ = predicted shear stress, γ = 62.4, d = proposed design depth			
Check: ☑ Stable ☐ Aggrading ☐ Degrading					

Stream Crossing Design

The existing, aggraded concrete culvert (*6.0 ft x 20.0 ft*) with *12.0"* culverts on the West Creek road and crossing Trail Creek is shown on the plan view photo overlay in **Figure II-12** and in the photographs in **Figure II-13** (looking downstream) and **Figure II-14** (looking upstream). The proposed redesign of the West Creek road crossing is shown in **Figure II-15**. The initial invert of the *10.0 ft* wide box is designed to pass the bankfull discharge along with feet of freeboard for anticipated flood stages. The second cell is designed to act as a floodplain as *1.2 ft* of fill will be left in this cell. Five, 36-inch culverts will be placed at the same invert elevation as floodplain drains. The proposed design lowers the existing high width/depth ratio, which, if left as is, will continue to aggrade. This design also provides for flood capacity without sacrificing sediment transport capacity of the mainstem Trail Creek. The key to this design is the lowering of the base level to previous levels and the conversion of a D4 to a C4 stream type. The upstream reduction of sediment supply from streambank stabilization and other mitigative efforts will help sustain this design and provide for fish passage.

Sediment Analysis for the Proposed Stream Crossing Design

The POWERSED model was used to determine the bed stability of the proposed stream crossing design that has *10.0 ft* of width compared to the existing design that has *20.0 ft* of width. The results indicate that the design will accommodate an increase over the present drainage system by transporting *77%* more sediment through the culvert using half of the width of the box. The remaining cross-sectional area (above the *1.2 ft* of stage) is used to accommodate floods. However, if the existing width of *20.0 ft* remains, the box culvert will fill with sediment after the first bankfull runoff event.

The proposed design that has *10.0 ft* of width is more efficient because the stream power (shear stress multiplied by velocity) is proportionately higher for increases in flow stage resulting in a higher sediment transport capacity. This design does require, however, that the floodplain be drained through the road fill; thus the remainder of the box (above the *1.2 ft* level) is at the floodplain invert (the bankfull stage or incipient point of flooding). The five, *36.0"* culverts as recommended will accommodate the higher peak flows associated with the Hayman fire. Although some believe that increasing the channel size is necessary to handle floods, one must increase the floodplain capacity and not the channel; if the channel is over-sized, there is a decrease in sediment transport capacity, which eventually aggrades the channel and additionally decreases the flow conveyance capacity.

Even though it is imperative to reduce the sediment supply from upstream sources, a stable channel must move the sediment (size and volume) presented without aggradation or degradation. The proposed design of the crossing and the greatly reduced width/depth ratio of the proposed C4 stream type indicate a stable bed by maintaining sediment transport capacity. This design should also eliminate cleaning of the box culvert to maintain its capacity and should allow for unobstructed fish passage.



Figure II-13. The aggrading box culvert (*6.0 ft x 20.0 ft*) and the *12.0"* culverts on the West Creek road (looking downstream).



Figure II-14. The existing stream crossing on West Creek road showing the undersized, *12.0"* culverts and the associated, high width/depth ratio, D4 stream type (looking upstream).

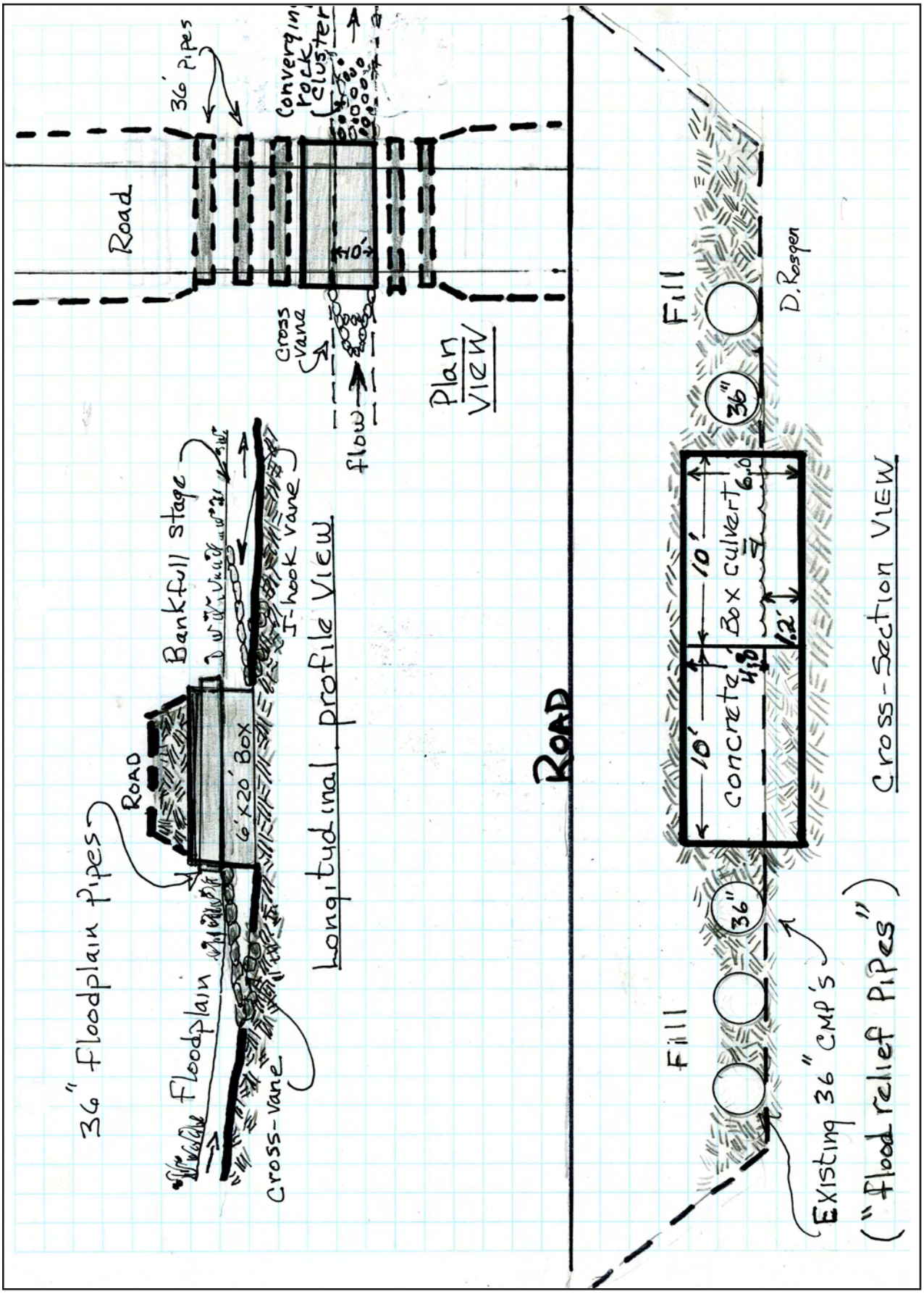


Figure II-15. The proposed stream crossing for the West Creek road over Trail Creek based on lowering the base level of the proposed C4 design reach

Summary of D4 to C4 Conversion (VT VIII)

The implementation of this high priority design scenario will meet the multiple objectives to reduce sediment supply from streambank erosion, decrease flood stage, allow for fish migration, improve the stream crossing, reduce high maintenance on the stream crossing, handle floods more efficiently, establish a functioning riparian community, and improve the channel stability. Overall it is often desirable and the least risky to reduce the sediment of the entire watershed prior to working at the mouth by progressing from the upper end of the river system to the mouth. However, to obtain fish passage, reduce the crossing instability, and to reduce flood stage, this design scenario is proposed to be implemented first due to the high risk of this reach. There is a certain assumed risk that this reach could require maintenance based on the status of reduced sediment supply.

Typical Design Scenario 2 Example

F4 to B4 Stream Type Conversion

(Valley Type VIII)

F4 to B4 Stream Type Conversion (VT VIII): Typical Design Scenario 2 Example

General Description & Morphological Data

This typical design scenario is a stream type and stability conversion from an F4 *Poor* condition to B4 *Stable* stream type within a terraced, alluvial valley (Valley Type VIII). This reach starts above the concrete box crossing at the West Creek road and extends upstream approximately *1,000 ft* to the over-steepened, G4 stream type reach. The longitudinal profile of lower Trail Creek through these multiple reaches indicates that much of the streambed of the entrenched and confined F4 reach must be lowered on the farthest downstream portion of the reach (*300 ft*), and that the streambed must be raised on the upstream remaining *700 ft*. This change in local base level will help to create a more sustainable energy grade. The existing condition of this F4 stream type is associated with accelerated streambank erosion and excess deposition (**Figure II-16**). At very low flows, the high width/depth ratio F4 reach provides insufficient depth to hold fish.

The specific design objectives and direction for this design scenario to stabilize the reach are as follows:

- Reduce the accelerated sediment supply from streambank erosion
- Restore bed stability
- Improve fish habitat by adding instream structures that create pocket water habitat
- Restore the riparian function

The potential stable state conversion for stream succession is to convert the F4 to a B4 stream type. The direction of the stream succession is related to the current impairment as the stream has changed from a meandering C4 (more sinuous, < 0.02 slope) to a G4 (> 0.02 slope), and to the current stream type of the entrenched and confined F4 stream type. Due the boundary conditions that influence valley width and slope, along with the channel confinement (lateral containment), the potential stable state of stream succession is a B4 stream type rather than the historic C4 stream type.

The dimensionless relations of the *B4 Reference Reach* are used to generate the proposed B4 stable design criteria by scaling the relations to the proposed bankfull discharge and area. The location of the *B4 Reference Reach* is shown in **Figure II-1** and the detailed characteristics and stability evaluation are documented in *Appendix C18* of the Waldo Canyon Fire *WARSSS* analysis (Rosgen *et al*., 2013).

The resultant proposed dimension, pattern, and profile for the stable B4 stream type are documented in **Table II-3** using the procedure in **Appendix I**. Additionally, this table also includes a summary of the morphological descriptions and corresponding analyses of the existing F4 reach and the *B4 Reference Reach*. The following sections include the proposed design details of the proposed B4 design reach.



Figure II-16. The entrenched, high width/depth ratio F4 stream type on lower Trail Creek showing accelerated streambank erosion and excess sediment deposition.

Table II-3. The morphological characteristics of the existing, proposed design and reference reaches for the F4 to B4 stream type conversion in a Valley Type VIII.

Existing Reach Stream & Location:			F4 Reach, Lower Trail Creek above Mouth					
Reference Reach Stream & Location:			B4 Reference Reach, Lower Mainstem Trail Creek					
	Entry Number & Variable		Existing Reach		Proposed Design Reach		Reference Reach	
	1	Valley Type	VIII		VIII		VIII	
	2	Valley Width	60		60		70	
	3	Stream Type	F4		B4		B4	
	4	Drainage Area, mi^2	15.9		15.9		14.3	
	5	Bankfull Discharge, cfs (Q_{bkf})	40		40		32.78	
Riffle Dimensions	6	Riffle Width, ft (W_{bkf})	*Mean:* *Min:* *Max:*	19.4 12.9 25.2	*Mean:* *Min:* *Max:*	10.4 9.4 11.4	*Mean:* *Min:* *Max:*	11.8 9.3 14.2
	7	Riffle Mean Depth, ft (d_{bkf})	*Mean:* *Min:* *Max:*	0.69 0.62 0.83	*Mean:* *Min:* *Max:*	0.85 0.70 0.90	*Mean:* *Min:* *Max:*	0.75 0.74 0.76
	8	Riffle Width/Depth Ratio (W_{bkf}/d_{bkf})	*Mean:* *Min:* *Max:*	29.5 15.5 40.6	*Mean:* *Min:* *Max:*	12.24 12.0 12.5	*Mean:* *Min:* *Max:*	12.60 12.58 12.62
	9	Riffle Cross-Sectional Area, ft^2 (A_{bkf})	*Mean:* *Min:* *Max:*	12.9 10.6 15.6	*Mean:*	8.8	*Mean:* *Min:* *Max:*	7.1 6.9 7.3
	10	Riffle Maximum Depth (d_{max})	*Mean:* *Min:* *Max:*	1.22 1.10 1.36	*Mean:* *Min:* *Max:*	1.20 1.00 1.40	*Mean:* *Min:* *Max:*	1.13 1.08 1.18
	11	Riffle Maximum Depth to Riffle Mean Depth (d_{max}/d_{bkf})	*Mean:* *Min:* *Max:*	1.780 1.640 1.940	*Mean:* *Min:* *Max:*	1.412 1.176 1.647	*Mean:* *Min:* *Max:*	1.508 1.421 1.595
	12	Width of Flood-Prone Area at Elevation of 2 * d_{max}, ft (W_{fpa})	*Mean:* *Min:* *Max:*	30.7 27.4 32.4	*Mean:* *Min:* *Max:*	22.4 14.6 22.9	*Mean:* *Min:* *Max:*	16.4 14.2 18.5
	13	Entrenchment Ratio (W_{fpa}/W_{bkf})	*Mean:* *Min:* *Max:*	1.5 1.3 1.6	*Mean:* *Min:* *Max:*	2.15 1.4 2.2	*Mean:* *Min:* *Max:*	1.7 1.5 2.0
Riffle Inner Berm Dimensions	14	Riffle Inner Berm Width, ft (W_{ib})	*Mean:* *Min:* *Max:*	N/A	*Mean:* *Min:* *Max:*	6.2 5.2 7.2	*Mean:* *Min:* *Max:*	7.3 5.6 8.8
	15	Riffle Inner Berm Width to Riffle Width (W_{ib}/W_{bkf})	*Mean:* *Min:* *Max:*	N/A	*Mean:* *Min:* *Max:*	0.596 0.500 0.692	*Mean:* *Min:* *Max:*	0.616 0.476 0.750
	16	Riffle Inner Berm Mean Depth, ft (d_{ib})	*Mean:* *Min:* *Max:*	N/A	*Mean:* *Min:* *Max:*	0.52 0.42 0.72	*Mean:* *Min:* *Max:*	0.32 0.20 0.43
	17	Riffle Inner Berm Mean Depth to Riffle Mean Depth (d_{ib}/d_{bkf})	*Mean:* *Min:* *Max:*	N/A	*Mean:* *Min:* *Max:*	0.612 0.494 0.847	*Mean:* *Min:* *Max:*	0.427 0.267 0.573
	18	Riffle Inner Berm Width/Depth Ratio (W_{ib}/d_{ib})	*Mean:* *Min:* *Max:*	N/A	*Mean:* *Min:* *Max:*	11.9 7.2 17.1	*Mean:* *Min:* *Max:*	23.6 20.5 32.1
	19	Riffle Inner Berm Cross-Sectional Area (A_{ib})	*Mean:* *Min:* *Max:*	N/A	*Mean:* *Min:* *Max:*	3.9 2.9 4.9	*Mean:* *Min:* *Max:*	2.4 1.3 3.8
	20	Riffle Inner Berm Cross-Sectional Area to Riffle Cross-Sectional Area (A_{ib}/A_{bkf})	*Mean:* *Min:* *Max:*	N/A	*Mean:* *Min:* *Max:*	0.438 0.330 0.557	*Mean:* *Min:* *Max:*	0.340 0.180 0.533

Table II-3 (page 2). The morphological characteristics of the existing, proposed design and reference reaches for the F4 to B4 stream type conversion in a Valley Type VIII.

	Entry Number & Variable		Existing Reach		Proposed Design Reach		Reference Reach	
Pool Dimensions	**21**	Pool Width, ft (W_{bkfp})	*Mean:*	**N/A**	*Mean:*	**12.3**	*Mean:*	**14.0**
			Min:		*Min:*	**7.2**	*Min:*	**8.2**
			Max:		*Max:*	**18.4**	*Max:*	**21.1**
	22	Pool Width to Riffle Width (W_{bkfp}/W_{bkf})	*Mean:*	**N/A**	*Mean:*	**1.183**	*Mean:*	**1.190**
			Min:		*Min:*	**0.692**	*Min:*	**0.695**
			Max:		*Max:*	**1.769**	*Max:*	**1.792**
	23	Pool Mean Depth, ft (d_{bkfp})	*Mean:*	**N/A**	*Mean:*	**1.01**	*Mean:*	**0.80**
			Min:		*Min:*	**0.85**	*Min:*	**0.59**
			Max:		*Max:*	**1.20**	*Max:*	**1.05**
	24	Pool Mean Depth to Riffle Mean Depth (d_{bkfp}/d_{bkf})	*Mean:*	**N/A**	*Mean:*	**1.188**	*Mean:*	**1.067**
			Min:		*Min:*	**1.000**	*Min:*	**0.787**
			Max:		*Max:*	**1.412**	*Max:*	**1.400**
	25	Pool Width/Depth Ratio (W_{bkfp}/d_{bkfp})	*Mean:*	**N/A**	*Mean:*	**12.2**	*Mean:*	**17.5**
			Min:		*Min:*	**6.0**	*Min:*	**7.8**
			Max:		*Max:*	**21.6**	*Max:*	**35.8**
	26	Pool Cross-Sectional Area, ft^2 (A_{bkfp})	*Mean:*	**N/A**	*Mean:*	**12.5**	*Mean:*	**8.9**
			Min:		*Min:*	**8.5**	*Min:*	**8.5**
			Max:		*Max:*	**18.0**	*Max:*	**9.6**
	27	Pool Area to Riffle Area (A_{bkfp}/A_{bkf})	*Mean:*	**N/A**	*Mean:*	**1.415**	*Mean:*	**1.248**
			Min:		*Min:*	**0.966**	*Min:*	**1.189**
			Max:		*Max:*	**2.045**	*Max:*	**1.348**
	28	Pool Maximum Depth (d_{maxp})	*Mean:*	**N/A**	*Mean:*	**1.90**	*Mean:*	**1.56**
			Min:		*Min:*	**1.50**	*Min:*	**1.33**
			Max:		*Max:*	**2.10**	*Max:*	**1.85**
	29	Pool Maximum Depth to Riffle Mean Depth (d_{maxp}/d_{bkf})	*Mean:*	**N/A**	*Mean:*	**2.235**	*Mean:*	**2.080**
			Min:		*Min:*	**1.765**	*Min:*	**1.773**
			Max:		*Max:*	**2.471**	*Max:*	**2.467**
	30	Point Bar Slope (S_{pb})	*Mean:*	**N/A**	*Mean:*	**0.380**	*Mean:*	**0.290**
			Min:		*Min:*	**0.280**	*Min:*	**0.220**
			Max:		*Max:*	**0.400**	*Max:*	**0.360**
Pool Inner Berm Dimensions	**31**	Pool Inner Berm Width, ft (W_{ibp})	*Mean:*	**N/A**	*Mean:*	**8.2**	*Mean:*	**4.8**
			Min:		*Min:*	**4.0**	*Min:*	**4.5**
			Max:		*Max:*	**10.0**	*Max:*	**5.1**
	32	Pool Inner Berm Width to Pool Width (W_{ibp}/W_{bkfp})	*Mean:*	**N/A**	*Mean:*	**0.665**	*Mean:*	**0.343**
			Min:		*Min:*	**0.325**	*Min:*	**0.320**
			Max:		*Max:*	**0.813**	*Max:*	**0.361**
	33	Pool Inner Berm Mean Depth, ft (d_{ibp})	*Mean:*	**N/A**	*Mean:*	**0.90**	*Mean:*	**0.31**
			Min:		*Min:*	**0.50**	*Min:*	**0.22**
			Max:		*Max:*	**0.95**	*Max:*	**0.40**
	34	Pool Inner Berm Mean Depth to Pool Mean Depth (d_{ibp}/d_{bkfp})	*Mean:*	**N/A**	*Mean:*	**0.891**	*Mean:*	**0.388**
			Min:		*Min:*	**0.495**	*Min:*	**0.275**
			Max:		*Max:*	**0.941**	*Max:*	**0.500**
	35	Pool Inner Berm Width/Depth Ratio (W_{ibp}/d_{ibp})	*Mean:*	**N/A**	*Mean:*	**9.1**	*Mean:*	**0.9**
			Min:		*Min:*	**4.2**	*Min:*	**0.8**
			Max:		*Max:*	**20.0**	*Max:*	**0.9**
	36	Pool Inner Berm Cross-Sectional Area (A_{ibp})	*Mean:*	**N/A**	*Mean:*	**7.36**	*Mean:*	**1.5**
			Min:		*Min:*	**3.8**	*Min:*	**1.0**
			Max:		*Max:*	**5.0**	*Max:*	**2.0**
	37	Pool Inner Berm Cross-Sectional Area to Pool Cross-Sectional Area (A_{ibp}/A_{bkfp})	*Mean:*	**N/A**	*Mean:*	**0.591**	*Mean:*	**0.172**
			Min:		*Min:*	**0.305**	*Min:*	**0.114**
			Max:		*Max:*	**0.402**	*Max:*	**0.226**

Table II-3 (page 3). The morphological characteristics of the existing, proposed design and reference reaches for the F4 to B4 stream type conversion in a Valley Type VIII.

	Entry Number & Variable	Existing Reach		Proposed Design Reach		Reference Reach	
Channel Pattern	**72** Linear Wavelength, ft (λ)	*Mean:*	**N/A**	*Mean:*	**107.0**	*Mean:*	**104.0**
		Min:		*Min:*	**82.0**	*Min:*	**87.0**
		Max:		*Max:*	**124.0**	*Max:*	**129.0**
	73 Linear Wavelength to Riffle Width (λ/W_{bkf})	*Mean:*	**N/A**	*Mean:*	**10.288**	*Mean:*	**8.832**
		Min:		*Min:*	**7.885**	*Min:*	**7.389**
		Max:		*Max:*	**11.923**	*Max:*	**10.955**
	74 Stream Meander Length, ft (L_m)	*Mean:*	**N/A**	*Mean:*	**115.0**	*Mean:*	**112.0**
		Min:		*Min:*	**93.0**	*Min:*	**94.5**
		Max:		*Max:*	**144.0**	*Max:*	**135.0**
	75 Stream Meander Length Ratio (L_m/W_{bkf})	*Mean:*	**N/A**	*Mean:*	**11.058**	*Mean:*	**9.512**
		Min:		*Min:*	**8.942**	*Min:*	**8.025**
		Max:		*Max:*	**13.846**	*Max:*	**11.465**
	76 Belt Width, ft (W_{blt})	*Mean:*	**N/A**	*Mean:*	**22.9**	*Mean:*	**27.2**
		Min:		*Min:*	**14.6**	*Min:*	**14.6**
		Max:		*Max:*	**31.2**	*Max:*	**60.0**
	77 Meander Width Ratio (W_{blt}/W_{bkf})	*Mean:*	**N/A**	*Mean:*	**2.200**	*Mean:*	**2.306**
		Min:		*Min:*	**1.400**	*Min:*	**1.237**
		Max:		*Max:*	**3.000**	*Max:*	**5.096**
	78 Radius of Curvature, ft (R_c)	*Mean:*	**N/A**	*Mean:*	**49.9**	*Mean:*	**50.7**
		Min:		*Min:*	**21.8**	*Min:*	**21.8**
		Max:		*Max:*	**78.0**	*Max:*	**76.0**
	79 Radius of Curvature to Riffle Width (R_c/W_{bkf})	*Mean:*	**N/A**	*Mean:*	**4.800**	*Mean:*	**4.300**
		Min:		*Min:*	**2.096**	*Min:*	**2.100**
		Max:		*Max:*	**7.500**	*Max:*	**6.454**
	80 Arc Length, ft (L_a)	*Mean:*	**N/A**	*Mean:*	**35.0**	*Mean:*	**39.6**
		Min:		*Min:*	**8.8**	*Min:*	**10.0**
		Max:		*Max:*	**62.6**	*Max:*	**70.9**
	81 Arc Length to Riffle Width (L_a/W_{bkf})	*Mean:*	**N/A**	*Mean:*	**3.363**	*Mean:*	**3.363**
		Min:		*Min:*	**0.849**	*Min:*	**0.849**
		Max:		*Max:*	**6.021**	*Max:*	**6.021**
	82 Riffle Length (L_r), ft ***Refers to a Step Length - Not Riffle**	*Mean:*	**N/A**	*Mean:*	**15.0**	*Mean:*	**14.7**
		Min:		*Min:*	**3.0***	*Min:*	**2.7***
		Max:		*Max:*	**29.0**	*Max:*	**28.2**
	83 Riffle Length to Riffle Width (L_r/W_{bkf}) ***Refers to a Step Length - Not Riffle**	*Mean:*	**N/A**	*Mean:*	**1.442**	*Mean:*	**1.248**
		Min:		*Min:*	**0.288***	*Min:*	**0.229***
		Max:		*Max:*	**2.788**	*Max:*	**2.395**
	84 Individual Pool Length, ft (L_p)	*Mean:*	**N/A**	*Mean:*	**62.0**	*Mean:*	**60.1**
		Min:		*Min:*	**24.0**	*Min:*	**23.0**
		Max:		*Max:*	**103.0**	*Max:*	**101.0**
	85 Pool Length to Riffle Width (L_p/W_{bkf})	*Mean:*	**N/A**	*Mean:*	**5.962**	*Mean:*	**5.104**
		Min:		*Min:*	**2.308**	*Min:*	**1.953**
		Max:		*Max:*	**9.904**	*Max:*	**8.577**
	86 Pool to Pool Spacing, ft (P_s)	*Mean:*	**N/A**	*Mean:*	**29.0**	*Mean:*	**28.1**
		Min:		*Min:*	**12.4**	*Min:*	**12.2**
		Max:		*Max:*	**48.0**	*Max:*	**47.3**
	87 Pool to Pool Spacing to Riffle Width (P_s/W_{bkf})	*Mean:*	**N/A**	*Mean:*	**2.788**	*Mean:*	**2.387**
		Min:		*Min:*	**1.192**	*Min:*	**1.039**
		Max:		*Max:*	**4.615**	*Max:*	**4.020**

Table II-3 (page 4). The morphological characteristics of the existing, proposed design and reference reaches for the F4 to B4 stream type conversion in a Valley Type VIII.

	Entry Number & Variable	Existing Reach	Proposed Design Reach	Reference Reach
Sinuosity and Slope	**88** Stream Length (SL)	**930**	**1,000**	**514.1**
	89 Valley Length (VL)	**885**	**885**	**581.0**
	90 Valley Slope (S_{val})	**0.0107**	**0.0253**	**0.0273**
	91 Sinuosity (k)	SL/VL: **1.05** VS/S: **1.05**	SL/VL: **1.13**	SL/VL: **1.13** VS/S: **1.13**
	92 Average Water Surface Slope (S)	**0.0102* Aggrading Reach**	$S = S_{val}/k$ **0.0224**	**0.0242**
Flood-Prone Area Dim.	**93** Flood-Prone Area Width, ft (W_{fpa})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **22.2** *Min:* *Max:*	*Mean:* **18.5** *Min:* *Max:*
	94 Flood-Prone Area Mean Depth, ft (d_{fpa})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.32** *Min:* *Max:*	*Mean:* **1.41** *Min:* *Max:*
	95 Flood-Prone Area Cross-Sectional Area, ft^2 (A_{fpa})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **29.2** *Min:* *Max:*	*Mean:* **26.0** *Min:* *Max:*
	Entry Number & Variable	**Existing Reach**	**Proposed Design Reach**	**Reference Reach**
Bed Feature Water Surface Facet Slopes and Dimensionless Ratios from Profile	**105** Riffle Slope (water surface facet slope) (S_{rif})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.0314** *Min:* **0.0148** *Max:* **0.0542**	*Mean:* **0.0340** *Min:* **0.0159** *Max:* **0.0585**
	106 Riffle Slope to Average Water Surface Slope (S_{rif}/S)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.4037** *Min:* **0.6587** *Max:* **2.4182**	*Mean:* **1.4037** *Min:* **0.6587** *Max:* **2.4182**
	107 Pool Slope (water surface facet slope) (S_p)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.0025** *Min:* **0.0001** *Max:* **0.0092**	*Mean:* **0.0027** *Min:* **0.0001** *Max:* **0.0099**
	108 Pool Slope to Average Water Surface Slope (S_p/S)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.1124** *Min:* **0.0041** *Max:* **0.4107**	*Mean:* **0.1124** *Min:* **0.0041** *Max:* **0.4107**
	109 Run Slope (water surface facet slope) (S_{run})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	110 Run Slope to Average Water Surface Slope (S_{run}/S)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	111 Glide Slope (water surface facet slope) (S_g)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	112 Glide Slope to Average Water Surface Slope (S_g/S)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	113 Step Slope (water surface facet slope) (S_s)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.9812** *Min:* **0.8608** *Max:* **1.0922**	*Mean:* **1.0600** *Min:* **0.9300** *Max:* **1.1800**
	114 Step Slope to Average Water Surface Slope (S_s/S)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **43.8017** *Min:* **38.4298** *Max:* **48.7603**	*Mean:* **43.8017** *Min:* **38.4298** *Max:* **48.7603**

Table II-3 (page 5). The morphological characteristics of the existing, proposed design and reference reaches for the F4 to B4 stream type conversion in a Valley Type VIII.

	Entry Number & Variable	Existing Reach	Proposed Design Reach	Reference Reach
Bed Feature Max Depth Measurements and Dimensionless Ratios from Profile	**115** Riffle Maximum Depth, ft (d_{max})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.20** *Min:* **1.00** *Max:* **1.40**	*Mean:* **1.06** *Min:* **0.93** *Max:* **1.18**
	116 Riffle Maximum Depth to Riffle Mean Depth (d_{max}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.412** *Min:* **1.176** *Max:* **1.647**	*Mean:* **1.413** *Min:* **1.240** *Max:* **1.573**
	117 Pool Maximum Depth, ft (d_{maxp})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.90** *Min:* **1.50** *Max:* **2.10**	*Mean:* **1.52** *Min:* **1.33** *Max:* **1.85**
	118 Pool Maximum Depth to Riffle Mean Depth (d_{maxp}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **2.235** *Min:* **1.765** *Max:* **2.471**	*Mean:* **2.027** *Min:* **1.773** *Max:* **2.467**
	119 Run Maximum Depth, ft (d_{maxr})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	120 Run Maximum Depth to Riffle Mean Depth (d_{maxr}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	121 Glide Maximum Depth, ft (d_{maxg})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	122 Glide Maximum Depth to Riffle Mean Depth (d_{maxg}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	123 Step Maximum Depth, ft (d_{maxs})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	124 Step Maximum Depth to Riffle Mean Depth (d_{maxs}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
Channel Materials	**125 Particle Size Distribution of Channel Material (Active Bed) or Pavement**			
	D_{16} (mm)	**2.0**	**2.0**	**5.1**
	D_{35} (mm)	**4.0**	**4.0**	**13.1**
	D_{50} (mm)	**8.0**	**8.0**	**22.6**
	D_{84} (mm)	**26.0**	**26.0**	**63.5**
	D_{95} (mm)	**44.0**	**44.0**	**125.5**
	D_{100} (mm)	**90.0**	**90.0**	**180.0**
	126 Particle Size Distribution of Bar Material or Sub-pavement			
	D_{16} (mm)	**0.0**	**0.0**	**2.0**
	D_{35} (mm)	**3.0**	**3.0**	**7.6**
	D_{50} (mm)	**6.0**	**6.0**	**14.5**
	D_{84} (mm)	**31.0**	**31.0**	**63.8**
	D_{95} (mm)	**65.0**	**65.0**	**88.7**
	D_{max}: Largest size particle at the toe (lower third) of bar (mm) or sub-pavement	**80.0**	**80.0**	**100.0**

Table II-3 (page 6). The morphological characteristics of the existing, proposed design and reference reaches for the F4 to B4 stream type conversion in a Valley Type VIII.

Entry Number & Variable			Existing Reach	Proposed Design Reach	Reference Reach
Hydraulics	127	Estimated Bankfull Mean Velocity, ft/sec (u_{bkf})	**3.10**	**4.55**	**4.7**
	128	Estimated Bankfull Discharge, cfs (Q_{bkf}); Compare with Regional Curve	**40.0**	**40.0**	**32.8**
Sediment Competence	129	Calculated bankfull shear stress value, lbs/ft^2 (τ)	**0.461**	**1.188**	**1.117**
	130	Predicted largest moveable particle size (mm) at bankfull shear stress, τ, using the original **Shields** relation	**34.8**	**93**	**84.0**
	131	Predicted largest moveable particle size (mm) at bankfull shear stress, τ, using the **Colorado** relation	**86.0**	**173**	**180.0**
	132	Largest particle size to be moved (D_{max}) (mm) (see #126: Particle Size Distribution of Bar Material)	**80**	**80**	**100.0**
	133	Predicted shear stress required to initiate movement of D_{max} (mm) using the original **Shields** relation	**1.025**	**1.025**	**1.400**
	134	Predicted shear stress required to initiate movement of D_{max} (mm) using the **Colorado** relation	**0.418**	**0.418**	**0.580**
	135	Predicted mean depth required to initiate movement of D_{max} (mm), d = $\tau/\gamma S$ (τ = predicted shear stress, γ = 62.4, S = existing or design slope) (**Shields**)	**1.54**	**0.73**	**0.93**
	136	Predicted mean depth required to initiate movement of D_{max} (mm), d = $\tau/\gamma S$ (τ = predicted shear stress, γ = 62.4, S = existing or design slope) (**Colorado**)	**1.54**	**0.30**	**0.93**
	137	Predicted slope required to initiate movement of D_{max} (mm) $S=\tau/\gamma d$ (τ = predicted shear stress, γ = 62.4, d = existing or design depth) (**Shields**)	**0.0238**	**0.0193**	**0.0303**
	138	Predicted slope required to initiate movement of D_{max} (mm) $S=\tau/\gamma d$ (τ = predicted shear stress, γ = 62.4, d = existing or design depth) (**Colorado**)	**0.0097**	**0.0079**	**0.0126**
	139	Bankfull dimensionless shear stress (τ^*) (see competence form)	**N/A**	**N/A**	**N/A**
	140	Required bankfull mean depth d_{bkf} (ft) using dimensionless shear stress equation: $d_{bkf} = \tau^*(\gamma_s - 1)D_{max}/S$ (Note: D_{max} in ft)	**N/A**	**N/A**	**N/A**
	141	Required bankfull water surface slope S (ft) using dimensionless shear stress equation: $S = \tau^*(\gamma_s - 1)D_{max}/d_{bkf}$ (Note: D_{max} in ft)	**N/A**	**N/A**	**N/A**

Table II-3 (page 7). The morphological characteristics of the existing, proposed design and reference reaches for the F4 to B4 stream type conversion in a Valley Type VIII.

Entry Number & Variable		Existing Reach	Proposed Design Reach	Reference Reach
Sediment Yield	**Sediment Yield (FLOWSED)***	**Existing Reach***	**Proposed Design Reach***	**Difference in Sediment Yield***
	141 Bedload Sediment Yield (tons/yr)	**5,416.0**	**144.0**	**5,272.0**
	142 Suspended Sediment Yield (tons/yr)	**18,774.4**	**700.5**	**18,073.9**
	143 Suspended Sand Sediment Yield (tons/yr)	**9,387.2**	**350.3**	**9,037.0**
	144 Total Annual Sediment Yield (tons/yr)	**24,190.4**	**844.6**	**23,345.8**
***Reduction in sediment supply due to using "Good" sediment supply bankfull values by drainage area and "Good" dimensionless sediment rating curves vs "Poor" as a result of converting from the F4 (Poor) to B4 (Good) stream type.**				
Bank Erosion	**Streambank Erosion**	**Existing Reach**** ****Extrapolated from F4b Poor Mainstem Rep.**	**Proposed Design Reach**	**Reference Reach**
	145 Stream Length Assessed (ft)	**930**	**1,000**	**406.0**
	146 Graph/Curve Used (e.g., Yellowstone or Colorado)	**Colorado**	**Colorado**	**Colorado**
	147 Streambank Erosion (tons/yr)	**439.1**	**4.84**	**1.96**
	148 Streambank Erosion (tons/yr/ft)	**0.4721****	**0.0048**	**0.0048**

Bankfull Discharge, Cross-Sectional Area & Mean Velocity

With a drainage area of *15.9 mi^2* for the proposed B4 stream type, the bankfull discharge is *40.0 cfs* and the proposed bankfull riffle cross-sectional area is *8.8 ft^2* as shown in **Table II-3**. Using continuity, the corresponding mean velocity for the proposed design reach is *4.55 ft/sec* as shown in **Worksheet II-4**. This worksheet is also used to check for reasonable velocities using the proposed design dimensions and slope using a variety of methods; these methods, particularly the friction factor to relative roughness relation, agree with the velocity estimate using continuity.

Worksheet II-4. The mean velocity estimates for the proposed B4 stable reach to be converted from the existing, F4 stream type.

Bankfull VELOCITY & DISCHARGE Estimates

Stream:	**Proposed B4 from Existing F4**	Location:	**Lower Trail Creek above Mouth**
Date:	**3/15/2011**	Stream Type:	**B4**
Observers:	**Rosgen *et al*.**	Valley Type:	**VIII**
		HUC:	_ _ _ _ _ _ _ _ _ _ _ _

Input Variables for PROPOSED Design			Output Variables for PROPOSED Design		
Bankfull Riffle Cross-Sectional AREA	**8.80**	**A_{bkf}** (ft^2)	Bankfull Riffle Mean DEPTH	**0.85**	**d_{bkf}** (ft)
Bankfull Riffle WIDTH	**10.4**	**W_{bkf}** (ft)	Wetted PERMIMETER ~ (2 * d_{bkf}) + W_{bkf}	**12.09**	**W_p** (ft)
Protrusion Height of Dunes	**61.0**	**Dia.** (mm)	***Prot. Height*** (mm) / 304.8	**0.20**	**D_{84}** (ft)
Bankfull SLOPE	**0.0224**	**S_{bkf}** (ft / ft)	Hydraulic RADIUS A_{bkf} / W_p	**0.73**	**R** (ft)
Gravitational Acceleration	**32.2**	**g** (ft / sec^2)	Relative Roughness R(ft) / D_{84} (ft)	**3.64**	**R / D_{84}**
Drainage Area	**15.9**	**DA** (mi^2)	Shear Velocity $u^* = (gRS)^{½}$	**0.725**	**u*** (ft/sec)

ESTIMATION METHODS	Bankfull VELOCITY		Bankfull DISCHARGE	
1. Friction Factor / Relative Roughness $u = [\ 2.83 + 5.66 * Log\ \{ R / D_{84} \}\ ]\ u^*$	**4.35**	ft / sec	**38.27**	cfs
2. Roughness Coefficient: a) Manning's *n* from Friction Factor / Relative Roughness (Figs. 5-7, 5-8) $u = 1.49*R^{2/3}*S^{1/2} / n$ $n =$ **0.048**	**3.76**	ft / sec	**33.08**	cfs
2. Roughness Coefficient: b) Manning's *n* from Stream Type (Fig. 5-9) $u = 1.49*R^{2/3}*S^{1/2} / n$ $n =$ **0.058**	**3.11**	ft / sec	**27.37**	cfs
2. Roughness Coefficient: c) Manning's *n* from Jarrett (USGS): $u = 1.49*R^{2/3}*S^{1/2} / n$ $n = 0.39*S^{0.38}*R^{-0.16}$ **Note:** This equation is applicable to **steep, step/pool, high boundary roughness, cobble- and boulder-dominated stream systems**; i.e., for Stream Types A1, A2, A3, B1, B2, B3, C2 & E3 $n =$ **N/A**	**N/A**	ft / sec	**N/A**	cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)		ft / sec		cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)		ft / sec		cfs
4. Continuity Equations: a) USGS Gage Data $u = Q / A$ **Return Period for Bankfull Dis.** $Q =$ _____ **year**		ft / sec		cfs
4. Continuity Equations: b) Regional Curves $u = Q / A$	**4.55**	ft / sec	**40.0**	cfs

Protrusion Height Options for the D_{84} Term in the Relative Roughness Relation (R/D_{84}) – Estimation Method 1

Option 1.	For **sand-bed** channels: Measure 100 **"protrusion heights"** of sand dunes from the downstream side of feature to the top of feature. Substitute the D_{84} sand dune protrusion height in ft for the D_{84} term in method 1.
Option 2.	For **boulder-dominated** channels: Measure 100 **"protrusion heights"** of boulders on the sides from the bed elevation to the top of the rock on that side. Substitute the D_{84} boulder protrusion height in ft for the D_{84} term in method 1.
Option 3.	For **bedrock-dominated** channels: Measure 100 **"protrusion heights"** of rock separations, steps, joints or uplifted surfaces above channel bed elevation. Substitute the D_{84} bedrock protrusion height in ft for the D_{84} term in method 1.
Option 4.	For **log-influenced** channels: Measure "**protrustion heights**" proportionate to channel width of log diameters or the height of the log on upstream side if embedded. Substitute the D_{84} protrusion height in ft for the D_{84} term in method 1.

Plan View Alignment

The overlay of the alignment of the proposed conversion of the F4 to B4 stream type is shown on the aerial photograph in **Figure II-17** and is based on the channel pattern data converted from the dimensionless ratios of the *B4 Reference Reach* that were scaled for this drainage area and bankfull discharge (**Table II-3**). The existing cross-section locations of the F4 stream type are also shown in **Figure II-17**.

Cross-Section Dimensions

Table II-3 includes the proposed dimensions for riffles and pools for the proposed B4 design reach that were scaled from the reference reach dimensionless relations. The locations of the existing F4 cross-sections 1+30, 4+44, 7+93 and 9+39 are indicated in **Figure II-17**. To establish the stable base level and slope, the existing channel must be excavated into the deposition for the lower *600 ft* of this reach, while the situation is reversed for the remaining *400 ft* upstream where the stream channel requires fill below the proposed bed elevation. **Figure II-18** depicts the overlay of the existing F4 cross-section 1+30 *vs*. proposed B4 *pool* cross-section, indicating the pool design dimensions, new bankfull elevation and substantial fill requirements. The overlay of the existing F4 cross-section 4+44 *vs*. proposed B4 *pool* cross-section is shown in **Figure II-19**. **Figure II-20** shows the overlay of the existing F4 cross-section 7+93 *vs*. proposed B4 *riffle* cross-section, indicating the riffle design dimensions, new bankfull elevations and cut requirements. Similarly, **Figure II-21** shows the overlay of the existing F4 cross-section 9+39 *vs*. proposed B4 *riffle* cross-section.

Longitudinal Profile

The typical longitudinal profile for the proposed B4 design reach is shown in **Figure II-22** compared to the existing F4 profile. The profile also shows the need to balance the energy slope and local base level by excavation on the lower half and the required fill on the upper half of the *1,000 ft* reach (**Figure II-22**). Additionally, the locations of the cross-section overlays in **Figures II-18** through **II-21** are depicted on the typical longitudinal profile that corresponds with the proposed design bed features.

Insert 11 x 17 Figure II-17 Here

Figure II-17. Plan view of the proposed conversion of the F4 to B4 stream type from the West Creek road upstream *1,000 ft* to proposed station 25+40, including the existing F4 cross-section locations.

Insert 11 x 17 Figure II-17 Here

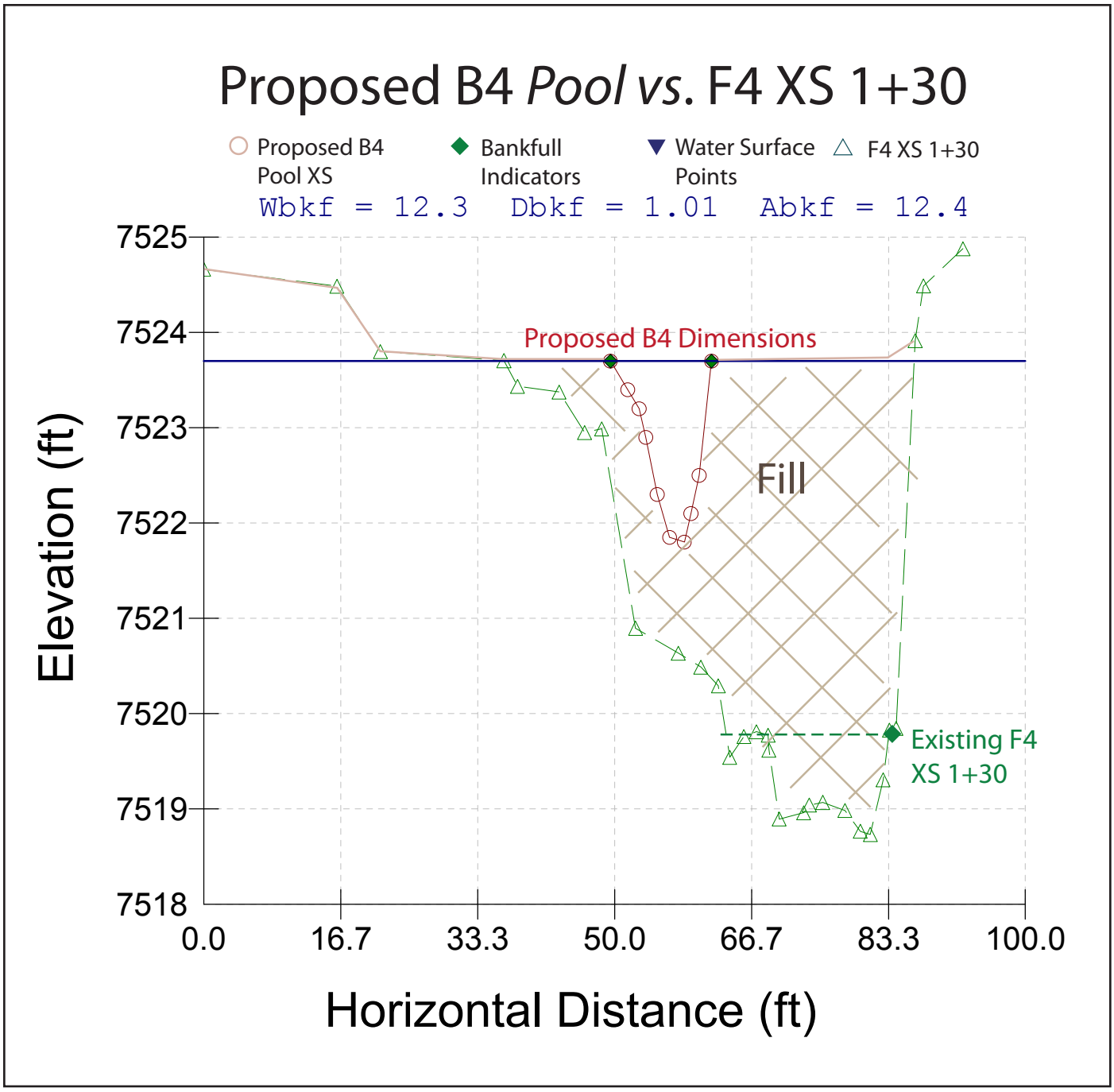


Figure II-18. The proposed B4 *pool* cross-section compared to the existing F4 cross-section 1+30, indicating the substantial fill requirements and new bankfull elevation.

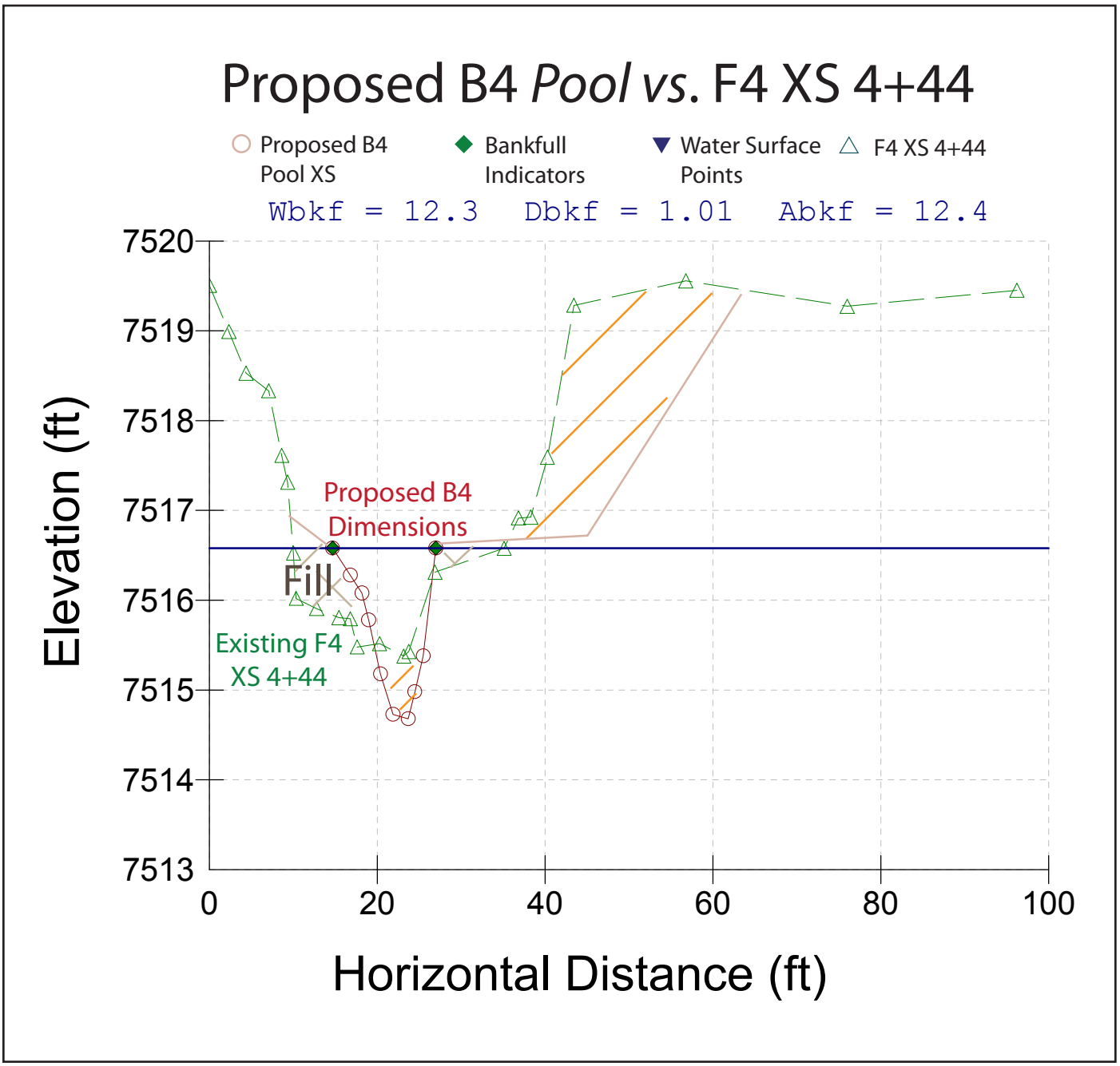


Figure II-19. The proposed B4 *pool* cross-section compared to the existing F4 cross-section 4+44, indicating the cut and fill requirements.

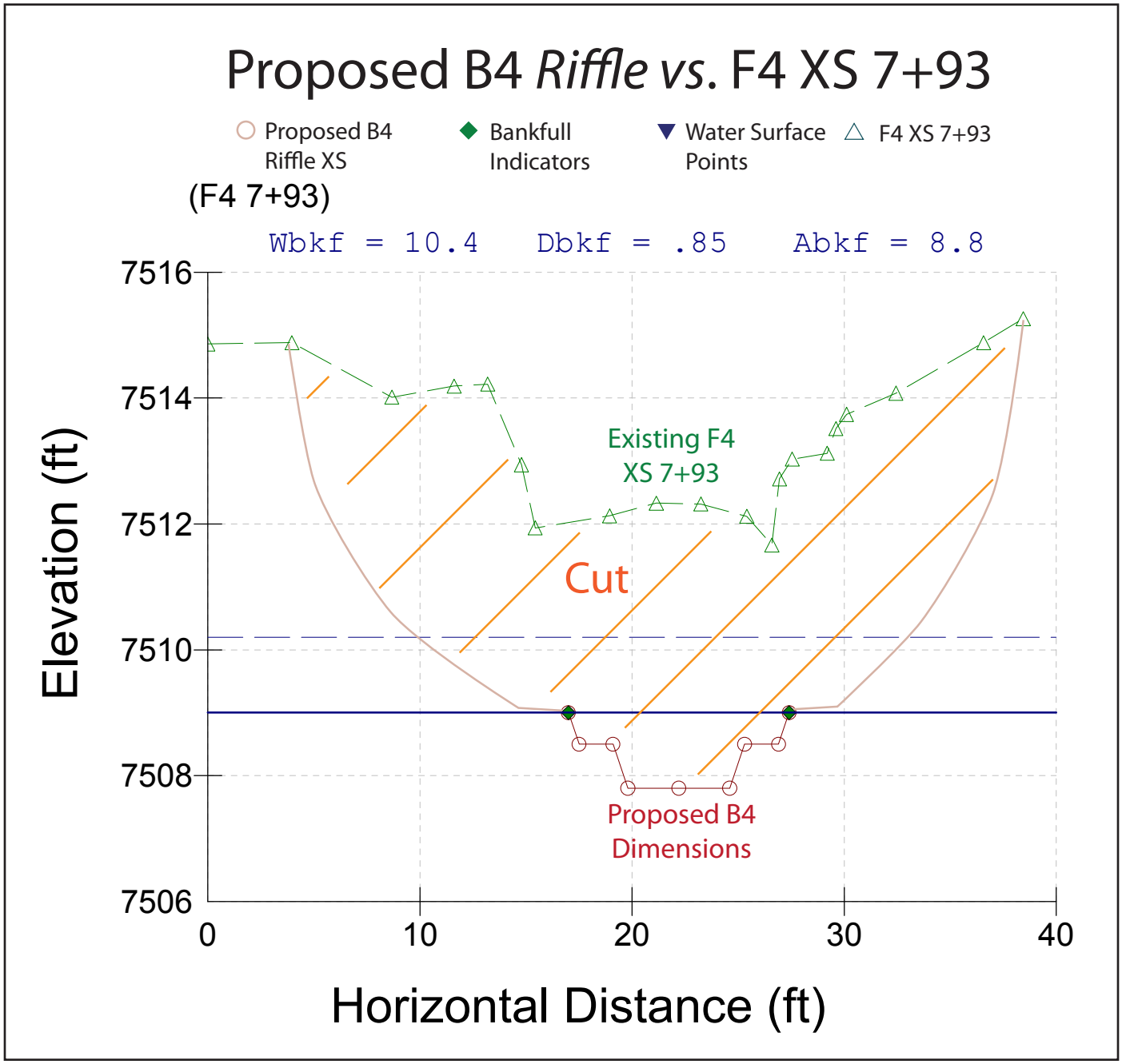


Figure II-20. The proposed B4 *riffle* cross-section compared to the existing F4 cross-section 7+93, indicating the substantial excavation required.

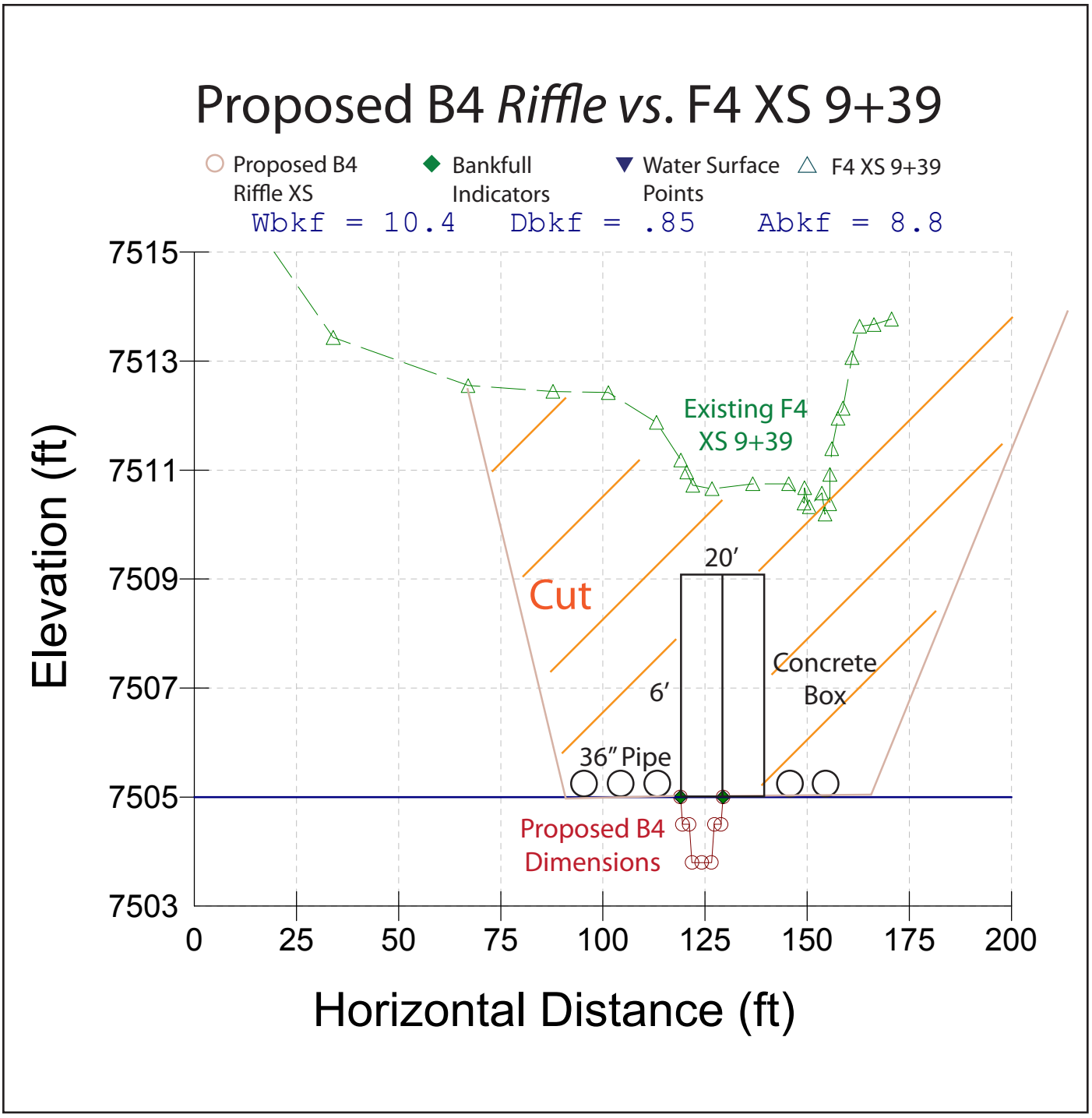


Figure II-21. The proposed B4 *riffle* cross-section compared to the existing F4 cross-section 9+39, indicating the substantial excavation required.

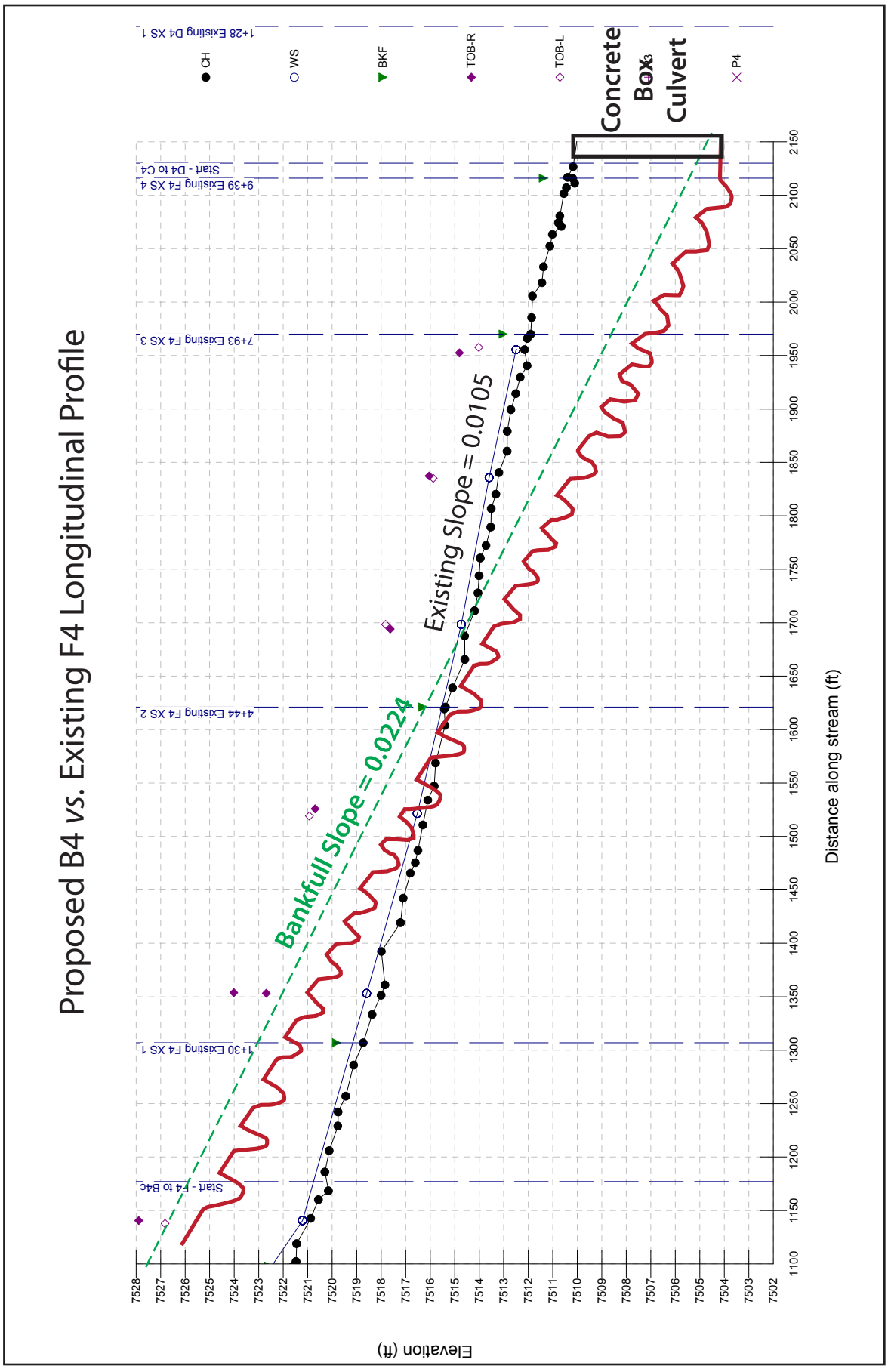


Figure II-22. The longitudinal profile comparing the elevations and slopes of the existing F4 *vs.* proposed B4 stream type.

Structures

The proposed streambank stabilization and fish habitat enhancement structures are shown in the plan view layout in **Figure II-23**. The rock cross-vane structure is tied into the concrete box culvert located at the end of the reach. The cross-vane is designed to direct the streamflow and sediment into the box culvert for the proper bankfull width to minimize problems of flow convergence and recirculation eddies (see the preceding *D4 to C4 Stream Type Conversion* for the detailed box culvert design). The cross-vane is also designed to maintain grade control and to reduce streambank and fill erosion. The other recommended structures for streambank stabilization, flow resistance, grade control and fish habitat enhancement include converging rock clusters; the root wad, log vane, J-hook; the rock vane, J-hook; the rock and log roller structure; and the toe wood structure with sod mats and riparian transplants. The materials for these structures will be obtained from on-site sources. Many of the burned logs will be salvaged to use for the root wad, log vane, J-hook, and toe wood structures. Riparian transplants will be salvaged from local excavation disturbance.

Riparian Vegetation

It is a key requirement to re-establish a woody riparian community of willow and alder along this corridor. This is accomplished by planting willow cuttings and transplants. The toe wood structure provides a site for transplanted willow and alder, or willow cuttings. Native grasses of Carex and Juncus where available will be transplanted to the stream-adjacent toe wood structures or seeded along the lower elevation, wet sites. Native bunch grasses, such as big mountain brome, are recommended for seeding the flood-prone areas that do not have soil saturation and are droughty. The revegetation is critical for the long-term physical stability and biological function.

Cut & Fill Computations

The cut and fill computations are obtained from the existing *vs.* proposed cross-sections for that particular bed feature with lengths obtained from the plan and profile data of the proposed design. The proposed design requires approximately *1,600 yds*^{3} of excavation and *1,422 yds*^{3} of fill material. Most of the required excavation is on the lower half of this proposed *1,000 ft* reach while fill material is needed on the upper half of the reach. The majority of the material will be balanced by transporting the excavated material to the upstream reach requiring the fill. Approximately *178 yds*^{3} of excess excavation can be transported for road fill requirements or to help build out alluvial fans within one-quarter mile of this reach.

Insert 11 x 17 Figure II-23 Here

Figure II-23. The proposed plan view layout of the F4 to B4 conversion depicting the stabilization and fish enhancement structures.

Insert 11 x 17 Figure II-23 Here

Streambank Erosion

The streambank erosion that is expected for the proposed B4 design reach is *4.8 tons/yr* for *1,000 ft* of designed channel *vs*. *439.1 tons/yr* for *930 ft* of the existing condition (**Table II-3**), representing a significant, potential reduction of *434.3 tons/yr* for this reach. These values are based on the extrapolation of annual erosion rates of the *B4 Reference Reach* (*0.0048 tons/yr/ft*) and the *F4b Poor Mainstem Representative Reach* (*0.4721 tons/yr/ft*). This reduction assumes that the various structures designed and located on the plan view map in **Figure II-23** are implemented, such as the toe wood and the J-hook structures. The reduction in BEHI can be greatly reduced with the toe wood structure, and NBS can be reduced with the rock and log vane, J-hook structures. These structures have proven to reduce streambank erosion rates by three orders of magnitude. These same structures also provide for flow resistance and fish habitat enhancement by incorporating instream cover.

Flow-Related Sediment

The FLOWSED model indicates that by converting from a "Poor" condition to a "Good" condition throughout the watershed, the flow-related sediment yields would be reduced from *24,190.4 tons/yr* (**Worksheet II-5a**) to *844.6 tons/yr* (**Worksheet II-5b**) as a result of the restoration. The corresponding sediment supply reductions based on converting from "Poor" to "Good" conditions are *5,272 tons/yr* for bedload and *18,073.9 tons/yr* for suspended sediment, representing a total sediment reduction of *23,345.8 tons/yr*. These sediment reductions are still assuming a high post-fire runoff response and continued increased stormflow peak runoff. These reductions are also associated with treating the majority of the stream length of the watershed above this reach.

The reductions in sediment supply associated with restoring *930 ft* of the existing F4 *Poor* stream type to *1,000* ft of the proposed B4 *Stable* design reach are *434.3 tons/yr* of streambank erosion, *92.7 tons/yr* of bedload, *317.4 tons/yr* of suspended sediment and *410.1 tons/yr* of total sediment yield reduction. The total sediment yield value includes streambank erosion contributions and streambed sources. Streambank erosion rates are sometimes higher than the total sediment yield because not all of the soil eroded from the bank is delivered; considerable amounts go into storage on the streambed and are available for re-entrainment during the next high flow. The sediment reductions associated with the local channel source sediment for this design scenario are based on sediment yield rates determined from taking the sediment yield values generated from FLOWSED and dividing by the total stream length of potential sediment contributions. For this scenario, it was determined that approximately *10 miles* (*52,800 ft*) of the mainstem Trail Creek is potentially contributing sediment. The tributaries also contribute sediment but at a lower rate; thus their stream lengths were not included in the unit sediment transport rate. The resultant sediment yield rates were then multiplied by the existing and proposed design reach lengths for this scenario to obtain the local sediment reductions.

The POWERSED model to evaluate sediment transport capacity indicates that by lowering the existing, high width/depth ratio, the B4 stream type is *81%* more efficient at transporting both bedload and suspended sand compared to the F4 stream type.

Overall, this reach contains approximately *7,704 yds*^{3} of aggraded sediment. The proposed *1000 ft* of restoration will reduce the sediment supply from streambank erosion in this reach by approximately *434.3 tons/yr*, and the total sediment yield (bedload and suspended sediment) by *410.1 tons/yr*, which will help reduce the downstream sediment supply and stabilize the F4 reach by converting to a B4 stream type.

Sediment Competence

The sediment competence calculations indicate excess energy for the proposed design of converting from an F4 to a B4 stream type (**Worksheet II-6**); therefore, grade control at the head of each riffle is warranted and recommended. The converging rock clusters and the rock and log roller structures are designed for grade control.

Worksheet II-5a. The existing sediment supply at the F4 reach using the FLOWSED model and generated by using the dimensionless sediment rating curves and bankfull sediment values related to the "Poor" condition.

Stream: **Lower Trail Creek F4 Stream Type** Location: **Above Mouth above Road Crossing** Date: **3/15/11**

Observers: **Rosgen *et al*.** Gage Station #: **Goose Creek Gage** Stream Type: **F4** Valley Type: **VIII**

Equation Type	Equation Source	Equation	Bankfull Discharge (cfs)	Bankfull Bedload Sediment (kg/s)	Bankfull Suspended Sediment (mg/l)
1. Bedload Sediment	"Poor" Pagosa	$y = 0.07176+1.02176x^{2.3772}$	40	0.4699	223.46
2. Suspended Sediment	"Poor" Pagosa	$y = 0.0989+0.9213x^{3.659}$			

From Dimensional Flow-Duration Curve							From Sediment Rating Curves				Calculate	Calculate Sediment Yield		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Percentage of Time	Daily Mean Discharge	Mid-Ordinate	Time Increment (percent)	Time Increment (days)	Mid-Ordinate Streamflow	Dimension-less Streamflow	Dimension-less Suspended Sediment Discharge	Suspended Sediment Discharge	Dimension- less Bedload Discharge	Bedload Sediment Discharge	Time Adjusted Streamflow [(5)×(6)]	Suspended Sediment [(5)×(9)]	Bedload Sediment [(5)×(11)]	Suspended + Bedload Sediment [(13)+(14)]
(%)	(cfs)	(%)	(%)	(days)	(cfs)	(Q/Q_{bkf})	(S/S_{bkf})	(tons/day)	(b_s/b_{bkf})	(tons/day)	(cfs)	(tons)	(tons)	(tons)
0%	178.8													
0.10%	153.5	0.05%	0.09%	0.34	166.2	4.154	168.918	16935.10	30.244	1353.84	57.0	5810.43	464.50	6274.94
0.25%	132.9	0.08%	0.15%	0.55	143.2	3.579	97.999	8465.64	21.249	951.18	78.4	4634.94	520.77	5155.71
0.50%	114.8	0.13%	0.25%	0.91	123.8	3.095	57.637	4305.77	15.065	674.38	113.0	3929.01	615.37	4544.38
0.75%	98.0	0.13%	0.25%	0.91	106.4	2.660	33.137	2127.25	10.528	471.26	97.1	1941.11	430.03	2371.14
1%	84.8	0.13%	0.25%	0.91	91.4	2.285	19.049	1050.51	7.358	329.39	83.4	958.59	300.57	1259.16
1.5%	60.7	0.25%	0.50%	1.83	72.8	1.819	8.322	365.32	4.308	192.84	132.8	666.70	351.93	1018.64
2%	51.1	0.25%	0.50%	1.83	55.9	1.398	3.236	109.15	2.337	104.60	102.0	199.20	190.89	390.10
3%	43.7	0.50%	1.00%	3.65	47.4	1.185	1.812	51.83	1.601	71.66	173.0	189.17	261.57	450.74
4%	38.9	0.50%	1.00%	3.65	41.3	1.032	1.133	28.22	1.173	52.52	150.7	103.02	191.69	294.71
5%	34.4	0.50%	1.00%	3.65	36.7	0.916	0.768	16.99	0.902	40.38	133.8	62.02	147.38	209.40
10%	24.4	2.50%	5.00%	18.25	29.4	0.736	0.399	7.08	0.565	25.28	537.2	129.28	461.28	590.56
20%	13.3	5.00%	10.00%	36.50	18.9	0.472	0.158	1.80	0.243	10.89	689.2	65.71	397.57	463.27
30%	8.9	5.00%	10.00%	36.50	11.1	0.278	0.107	0.72	0.120	5.39	405.4	26.27	196.65	222.92
40%	6.3	5.00%	10.00%	36.50	7.6	0.190	0.101	0.46	0.091	4.09	277.0	16.88	149.36	166.25
50%	4.8	5.00%	10.00%	36.50	5.6	0.139	0.100	0.33	0.081	3.63	202.7	12.18	132.53	144.71
60%	3.7	5.00%	10.00%	36.50	4.3	0.106	0.099	0.25	0.077	3.43	155.4	9.30	125.38	134.67
70%	3.0	5.00%	10.00%	36.50	3.3	0.083	0.099	0.20	0.075	3.34	121.6	7.27	121.79	129.05
80%	2.6	5.00%	10.00%	36.50	2.8	0.069	0.099	0.17	0.074	3.29	101.4	6.05	120.19	126.24
90%	1.9	5.00%	10.00%	36.50	2.2	0.056	0.099	0.13	0.073	3.26	81.1	4.84	118.98	123.82
100%	0.4	5.00%	10.00%	36.50	1.1	0.028	0.099	0.07	0.072	3.22	40.5	2.42	117.58	120.00
									Annual Totals:		3,732.8 (cfs) 7,404.1 (acre-ft)	18,774.4 (tons/yr)	5,416.0 (tons/yr)	24,190.4 (tons/yr)

Worksheet II-5b. The proposed sediment supply at the proposed B4 reach using the FLOWSED model and generated by using the dimensionless sediment rating curves and bankfull sediment values related to the restored "Good" condition (assuming that the watershed area above this reach is also restored to "Good" conditions).

Stream: **B4 Proposed Conversion from F4, Lower Trail Creek** Location: **Above Mouth above Road Crossing** Date: **3/15/11**

Observers **Rosgen *et al*.** Gage Station #: **Goose Creek Gage** Stream Type: **B4** Valley Type: **VIII**

Equation Type	Equation Source	Equation	Bankfull Discharge (cfs)	Bankfull Bedload Sediment (kg/s)	Bankfull Suspended Sediment (mg/l)
1. Bedload Sediment	"Good/Fair" Pagosa	$y = -0.0113+1.0139x^{2.1929}$	40	0.0182	31.70
2. Suspended Sediment	"Good/Fair" Pagosa	$y = 0.0636+0.9326x^{2.4085}$			

From Dimensional Flow-Duration Curve							From Sediment Rating Curves				Calculate	Calculate Sediment Yield		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Percentage of Time	Daily Mean Discharge	Mid-Ordinate	Time Increment (percent)	Time Increment (days)	Mid-Ordinate Streamflow	Dimension-less Streamflow	Dimension-less Suspended Sediment Discharge	Suspended Sediment Discharge	Dimension-less Bedload Discharge	Bedload Sediment Discharge	Time Adjusted Streamflow [(5)×(6)]	Suspended Sediment [(5)×(9)]	Bedload Sediment [(5)×(11)]	Suspended + Bedload Sediment [(13)+(14)]
(%)	(cfs)	(%)	(%)	(days)	(cfs)	(Q/Q_{bkf})	(S/S_{bkf})	(tons/day)	(b_s/b_{bkf})	(tons/day)	(cfs)	(tons)	(tons)	(tons)
0%	178.8													
0.10%	153.5	0.05%	0.09%	0.34	166.2	4.154	28.858	410.47	23.017	39.99	57.0	140.83	13.72	154.55
0.25%	132.9	0.08%	0.15%	0.55	143.2	3.579	20.180	247.32	16.601	28.84	78.4	135.41	15.79	151.20
0.50%	114.8	0.13%	0.25%	0.91	123.8	3.095	14.241	150.94	12.070	20.97	113.0	137.73	19.13	156.87
0.75%	98.0	0.13%	0.25%	0.91	106.4	2.660	9.904	90.20	8.652	15.03	97.1	82.31	13.72	96.02
1%	84.8	0.13%	0.25%	0.91	91.4	2.285	6.889	53.90	6.198	10.77	83.4	49.18	9.82	59.01
1.5%	60.7	0.25%	0.50%	1.83	72.8	1.819	4.003	24.93	3.753	6.52	132.8	45.50	11.90	57.40
2%	51.1	0.25%	0.50%	1.83	55.9	1.398	2.153	10.30	2.102	3.65	102.0	18.80	6.66	25.46
3%	43.7	0.50%	1.00%	3.65	47.4	1.185	1.467	5.95	1.459	2.54	173.0	21.72	9.25	30.97
4%	38.9	0.50%	1.00%	3.65	41.3	1.032	1.070	3.78	1.075	1.87	150.7	13.80	6.82	20.62
5%	34.4	0.50%	1.00%	3.65	36.7	0.916	0.819	2.57	0.826	1.43	133.8	9.38	5.24	14.62
10%	24.4	2.50%	5.00%	18.25	29.4	0.736	0.509	1.28	0.506	0.88	537.2	23.41	16.05	39.46
20%	13.3	5.00%	10.00%	36.50	18.9	0.472	0.217	0.35	0.184	0.32	689.2	12.78	11.68	24.46
30%	8.9	5.00%	10.00%	36.50	11.1	0.278	0.106	0.10	0.050	0.09	405.4	3.69	3.16	6.84
40%	6.3	5.00%	10.00%	36.50	7.6	0.190	0.081	0.05	0.015	0.03	277.0	1.91	0.96	2.88
50%	4.8	5.00%	10.00%	36.50	5.6	0.139	0.072	0.03	0.002	0.00	202.7	1.24	0.13	1.37
60%	3.7	5.00%	10.00%	36.50	4.3	0.106	0.068	0.02	0.000	0.00	155.4	0.90	0.00	0.90
70%	3.0	5.00%	10.00%	36.50	3.3	0.083	0.066	0.02	0.000	0.00	121.6	0.69	0.00	0.69
80%	2.6	5.00%	10.00%	36.50	2.8	0.069	0.065	0.02	0.000	0.00	101.4	0.56	0.00	0.56
90%	1.9	5.00%	10.00%	36.50	2.2	0.056	0.064	0.01	0.000	0.00	81.1	0.45	0.00	0.45
100%	0.4	5.00%	10.00%	36.50	1.1	0.028	0.064	0.01	0.000	0.00	40.5	0.22	0.00	0.22
										Annual Totals:	3,732.8 (cfs) / 7,404.1 (acre-ft)	700.5 (tons/yr)	144.0 (tons/yr)	844.6 (tons/yr)

Worksheet II-6. The sediment competence calculations for the proposed B4 stream type to be converted from the F4 stream type above the West Creek road, lower Trail Creek.

Stream:	**Existing F4 Poor to Proposed B4**		Stream Type: **B4**		
Location:	**Lower Trail Creek above Mouth**		Valley Type: **VIII**		
Observers:	**Rosgen *et al*.**		Date: **3/15/2011**		
Enter Required Information for PROPOSED Design Condition					
8.0	D_{50}	Median particle size of riffle bed material (mm)			
6.0	$D_{50}^{\wedge}$	Median particle size of bar or sub-pavement sample (mm)			
0.26	D_{max}	Largest particle from bar sample (ft)	**80**	**(mm)**	304.8 mm/ft
0.0224	***S***	Proposed design bankfull water surface slope (ft/ft)			
0.85	***d***	Proposed design bankfull mean depth (ft)			
1.65	γ_s-γ/γ	Immersed specific gravity of sediment			
Select the Appropriate Equation and Calculate Critical Dimensionless Shear Stress					
1.33	$D_{50}/D_{50}^{\wedge}$	Range: 3 – 7	Use EQUATION 1: $\tau^* = 0.0834 \left(D_{50}/D_{50}^{\wedge} \right)^{-0.872}$		
10.00	D_{max}/D_{50}	Range: 1.3 – 3.0	Use EQUATION 2: $\tau^* = 0.0384 \left(D_{max}/D_{50} \right)^{-0.887}$		
N/A	τ^*	Bankfull Dimensionless Shear Stress	EQUATION USED:		**N/A**
Calculate Bankfull Mean Depth Required for Entrainment of Largest Particle in Bar Sample					
N/A	**d**	Required bankfull mean depth (ft) $d = \frac{\tau^* (\gamma_s - 1) D_{max}}{S}$		(use D_{max} in ft)	
Calculate Bankfull Water Surface Slope Required for Entrainment of Largest Particle in Bar Sample					
N/A	**S**	Required bankfull water surface slope (ft/ft) $S = \frac{\tau^* (\gamma_s - 1) D_{max}}{d}$		(use D_{max} in ft)	
Check: ☐ Stable ☐ Aggrading ☐ Degrading					
Sediment Competence Using Dimensional Shear Stress					
1.188		Bankfull shear stress $\tau = \gamma dS$ (lbs/ft^2) (substitute hydraulic radius, R, with mean depth, d) γ = 62.4, d = proposed design depth, S = proposed design slope			
Shields **93.3**	CO **172.6**	Predicted largest moveable particle size (mm) at bankfull shear stress τ **(Figure 5-49)**			
Shields **1.025**	CO **0.418**	Predicted shear stress required to initiate movement of measured D_{max} (mm) **(Figure 5-49)**			
Shields **0.73**	CO **0.30**	Predicted mean depth required to initiate movement of measured D_{max} (mm) τ = predicted shear stress, γ = 62.4, S = proposed design slope $d = \frac{\tau}{\gamma S}$			
Shields **0.0193**	CO **0.0079**	Predicted slope required to initiate movement of measured D_{max} (mm) τ = predicted shear stress, γ = 62.4, d = proposed design depth $S = \frac{\tau}{\gamma d}$			
Check: ☐ Stable ☐ Aggrading ☑ **Degrading***					

***Due to potential degradation, must incorporate grade control and high flow resistance bed structures**

Summary of the F4 to B4 Stream Type Conversion

The conversion from F4 to B4 stream types represents the central tendency of stream succession to a stable "end point" channel in a confined (laterally contained) stream system. The increase in shear stress due to a decrease in width/depth ratio in the proposed design is countered by increased log and rock structures to add flow resistance and habitat features. The increase in entrenchment ratio to re-establish floodplain connectivity will exponentially reduce streambank erosion from flood flows. The B4 stream type rarely stores sediment for future re-entrainment and efficiently routes sediment through without adding channel source sediment to the sediment supply. The increased post-fire flood flows will have small adverse effects on the B4 stream type compared to the F4 associated with high streambank erosion rates and sediment deposition.

Typical Design Scenario 3 Example

G4 to B4 Stream Type Conversion

(Valley Type VIII)

G4 to B4 Stream Type Conversion (VT VIII): Typical Design Scenario 3 Example

General Description & Morphological Data

This typical design scenario example is a stream type and stability conversion from a G4 *Poor* condition to B4 *Stable* stream type within a terraced, alluvial valley (Valley Type VIII). The existing, impaired stream is the *G4 Poor Representative Reach* that is located approximately *1,500–2,000 ft* upstream of the mouth of Trail Creek and depicted on the general map in **Figure II-1**. The detailed characteristics and stability evaluation of this representative reach are documented in *Appendix C15* of the Waldo Canyon Fire *WARSSS* analysis (Rosgen *et al*., 2013). The existing reach length to be converted from a G4 to B4 stream type is approximately *275 ft*. The reach is incised, confined and associated with a headcut that is converting the upstream C4 stream type into an advancing G4 stream type. The active streambank erosion and channel incision typical in the reach are depicted in **Figure II-24**. The overall direction is to raise the channel up by placing fill on the existing bed and incorporating structures to stabilize and restore to a new local base level and channel slope.

The specific objectives and direction for this design scenario to stabilize the reach are as follows:

- Reduce the sediment supply from the accelerated bed scour (degradation)
- Reduce the accelerated streambank erosion rates
- Enhance fish habitat
- Restore the riparian function

In relation to stream succession, this reach was previously a C4 stream type that was abandoned by channel incision resulting in the existing, G4 stream type. Because it will be difficult to raise the channel back to historic levels and to match the energy slope up- and down-valley, the potential stable state is a B4 stream type. The B4 stream types are naturally confined stream types that are stable and match the existing confinement of the G4 stream type.

The dimensionless relations of the *B4 Reference Reach* are used to generate the proposed B4 stable design criteria by scaling the relations to the proposed bankfull discharge and area. The location of the *B4 Reference Reach* is shown in **Figure II-1** and the detailed characteristics and stability evaluation are documented in *Appendix C18* of the Waldo Canyon Fire *WARSSS* analysis (Rosgen *et al*., 2013).

The resultant proposed dimension, pattern, and profile for the stable B4 stream type are documented in **Table II-4** using the procedure in **Appendix I**. Additionally, this table also includes a summary of the morphological descriptions and corresponding analyses of the existing *G4 Poor Representative Reach* and the *B4 Reference Reach*. The following sections include the proposed design details of the proposed B4 reach.



Figure II-24. The G4 *Poor* reach to be converted to a stable B4 stream type on the mainstem Trail Creek showing the active streambank erosion and channel incision.

Table II-4. The morphological characteristics of the existing, proposed design and reference reaches for the G4 to B4 stream type conversion in a confined Valley Type VIII.

Existing Reach Stream & Location:			G4 Poor Reach, Lower Trail Creek above Mouth					
Reference Reach Stream & Location:			B4 Reference Reach, Mainstem Trail Creek					
	Entry Number & Variable		Existing Reach		Proposed Design Reach		Reference Reach	
	1	Valley Type	VIII		VIII		VIII	
	2	Valley Width	60		60		70	
	3	Stream Type	G4		B4		B4	
	4	Drainage Area, mi^2	15.9		15.9		14.3	
	5	Bankfull Discharge, cfs (Q_{bkf})	30.3		40		32.78	
Riffle Dimensions	6	Riffle Width, ft (W_{bkf})	*Mean:* *Min:* *Max:*	**6.4** **5.8** **9.8**	*Mean:* *Min:* *Max:*	**10.4** **9.4** **11.4**	*Mean:* *Min:* *Max:*	**11.8** **9.3** **14.2**
	7	Riffle Mean Depth, ft (d_{bkf})	*Mean:* *Min:* *Max:*	**1.08** **0.89** **1.29**	*Mean:* *Min:* *Max:*	**0.85** **0.70** **0.90**	*Mean:* *Min:* *Max:*	**0.75** **0.74** **0.76**
	8	Riffle Width/Depth Ratio (W_{bkf}/d_{bkf})	*Mean:* *Min:* *Max:*	**7.2** **4.5** **11.0**	*Mean:* *Min:* *Max:*	**12.24** **12.0** **12.5**	*Mean:* *Min:* *Max:*	**12.60** **12.58** **12.62**
	9	Riffle Cross-Sectional Area, ft^2 (A_{bkf})	*Mean:* *Min:* *Max:*	**7.6** **6.7** **8.7**	*Mean:*	**8.8**	*Mean:* *Min:* *Max:*	**7.1** **6.9** **7.3**
	10	Riffle Maximum Depth (d_{max})	*Mean:* *Min:* *Max:*	**1.29** **1.15** **1.56**	*Mean:* *Min:* *Max:*	**1.20** **1.00** **1.40**	*Mean:* *Min:* *Max:*	**1.13** **1.08** **1.18**
	11	Riffle Maximum Depth to Riffle Mean Depth (d_{max}/d_{bkf})	*Mean:* *Min:* *Max:*	**1.203** **1.085** **1.315**	*Mean:* *Min:* *Max:*	**1.412** **1.176** **1.647**	*Mean:* *Min:* *Max:*	**1.508** **1.421** **1.595**
	12	Width of Flood-Prone Area at Elevation of 2 * d_{max}, ft (W_{fpa})	*Mean:* *Min:* *Max:*	**10.0** **8.4** **12.4**	*Mean:* *Min:* *Max:*	**22.4** **14.6** **22.9**	*Mean:* *Min:* *Max:*	**16.4** **14.2** **18.5**
	13	Entrenchment Ratio (W_{fpa}/W_{bkf})	*Mean:* *Min:* *Max:*	**1.4** **1.2** **1.3**	*Mean:* *Min:* *Max:*	**2.15** **1.4** **2.2**	*Mean:* *Min:* *Max:*	**1.7** **1.5** **2.0**
Riffle Inner Berm Dimensions	14	Riffle Inner Berm Width, ft (W_{ib})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**6.2** **5.2** **7.2**	*Mean:* *Min:* *Max:*	**7.3** **5.6** **8.8**
	15	Riffle Inner Berm Width to Riffle Width (W_{ib}/W_{bkf})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**0.596** **0.500** **0.692**	*Mean:* *Min:* *Max:*	**0.616** **0.476** **0.750**
	16	Riffle Inner Berm Mean Depth, ft (d_{ib})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**0.52** **0.42** **0.72**	*Mean:* *Min:* *Max:*	**0.32** **0.20** **0.43**
	17	Riffle Inner Berm Mean Depth to Riffle Mean Depth (d_{ib}/d_{bkf})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**0.612** **0.494** **0.847**	*Mean:* *Min:* *Max:*	**0.427** **0.267** **0.573**
	18	Riffle Inner Berm Width/Depth Ratio (W_{ib}/d_{ib})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**11.9** **7.2** **17.1**	*Mean:* *Min:* *Max:*	**23.6** **20.5** **32.1**
	19	Riffle Inner Berm Cross-Sectional Area (A_{ib})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**3.9** **2.9** **4.9**	*Mean:* *Min:* *Max:*	**2.4** **1.3** **3.8**
	20	Riffle Inner Berm Cross-Sectional Area to Riffle Cross-Sectional Area (A_{ib}/A_{bkf})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**0.438** **0.330** **0.557**	*Mean:* *Min:* *Max:*	**0.340** **0.180** **0.533**

Table II-4 (page 2). The morphological characteristics of the existing, proposed design and reference reaches for the G4 to B4 stream type conversion in a confined Valley Type VIII.

	Entry Number & Variable		Existing Reach		Proposed Design Reach		Reference Reach	
Pool Dimensions	**21**	Pool Width, ft (W_{bkfp})	*Mean:*	**9.6**	*Mean:*	**12.3**	*Mean:*	**14.0**
			Min:	**8.6**	*Min:*	**7.2**	*Min:*	**8.2**
			Max:	**10.6**	*Max:*	**18.4**	*Max:*	**21.1**
	22	Pool Width to Riffle Width (W_{bkfp}/W_{bkf})	*Mean:*	**1.500**	*Mean:*	**1.183**	*Mean:*	**1.190**
			Min:	**1.340**	*Min:*	**0.692**	*Min:*	**0.695**
			Max:	**1.660**	*Max:*	**1.769**	*Max:*	**1.792**
	23	Pool Mean Depth, ft (d_{bkfp})	*Mean:*	**0.81**	*Mean:*	**1.01**	*Mean:*	**0.80**
			Min:	**0.67**	*Min:*	**0.85**	*Min:*	**0.59**
			Max:	**0.95**	*Max:*	**1.20**	*Max:*	**1.05**
	24	Pool Mean Depth to Riffle Mean Depth (d_{bkfp}/d_{bkf})	*Mean:*	**0.750**	*Mean:*	**1.188**	*Mean:*	**1.067**
			Min:	**0.620**	*Min:*	**1.000**	*Min:*	**0.787**
			Max:	**0.880**	*Max:*	**1.412**	*Max:*	**1.400**
	25	Pool Width/Depth Ratio (W_{bkfp}/d_{bkfp})	*Mean:*	**11.8**	*Mean:*	**12.2**	*Mean:*	**17.5**
			Min:	**9.0**	*Min:*	**6.0**	*Min:*	**7.8**
			Max:	**15.8**	*Max:*	**21.6**	*Max:*	**35.8**
	26	Pool Cross-Sectional Area, ft^2 (A_{bkfp})	*Mean:*	**7.9**	*Mean:*	**12.5**	*Mean:*	**8.9**
			Min:	**5.7**	*Min:*	**8.5**	*Min:*	**8.5**
			Max:	**10.0**	*Max:*	**18.0**	*Max:*	**9.6**
	27	Pool Area to Riffle Area (A_{bkfp}/A_{bkf})	*Mean:*	**1.031**	*Mean:*	**1.415**	*Mean:*	**1.248**
			Min:	**0.749**	*Min:*	**0.966**	*Min:*	**1.189**
			Max:	**1.313**	*Max:*	**2.045**	*Max:*	**1.348**
	28	Pool Maximum Depth (d_{maxp})	*Mean:*	**1.51**	*Mean:*	**1.90**	*Mean:*	**1.56**
			Min:	**1.40**	*Min:*	**1.50**	*Min:*	**1.33**
			Max:	**1.61**	*Max:*	**2.10**	*Max:*	**1.85**
	29	Pool Maximum Depth to Riffle Mean Depth (d_{maxp}/d_{bkf})	*Mean:*	**1.398**	*Mean:*	**2.235**	*Mean:*	**2.080**
			Min:	**1.296**	*Min:*	**1.765**	*Min:*	**1.773**
			Max:	**1.491**	*Max:*	**2.471**	*Max:*	**2.467**
	30	Point Bar Slope (S_{pb})	*Mean:*	**N/A**	*Mean:*	**0.380**	*Mean:*	**0.290**
			Min:		*Min:*	**0.280**	*Min:*	**0.220**
			Max:		*Max:*	**0.400**	*Max:*	**0.360**
Pool Inner Berm Dimensions	**31**	Pool Inner Berm Width, ft (W_{ibp})	*Mean:*	**N/A**	*Mean:*	**8.2**	*Mean:*	**4.8**
			Min:		*Min:*	**4.0**	*Min:*	**4.5**
			Max:		*Max:*	**10.0**	*Max:*	**5.1**
	32	Pool Inner Berm Width to Pool Width (W_{ibp}/W_{bkfp})	*Mean:*	**N/A**	*Mean:*	**0.665**	*Mean:*	**0.343**
			Min:		*Min:*	**0.325**	*Min:*	**0.320**
			Max:		*Max:*	**0.813**	*Max:*	**0.361**
	33	Pool Inner Berm Mean Depth, ft (d_{ibp})	*Mean:*	**N/A**	*Mean:*	**0.90**	*Mean:*	**0.31**
			Min:		*Min:*	**0.50**	*Min:*	**0.22**
			Max:		*Max:*	**0.95**	*Max:*	**0.40**
	34	Pool Inner Berm Mean Depth to Pool Mean Depth (d_{ibp}/d_{bkfp})	*Mean:*	**N/A**	*Mean:*	**0.891**	*Mean:*	**0.388**
			Min:		*Min:*	**0.495**	*Min:*	**0.275**
			Max:		*Max:*	**0.941**	*Max:*	**0.500**
	35	Pool Inner Berm Width/Depth Ratio (W_{ibp}/d_{ibp})	*Mean:*	**N/A**	*Mean:*	**9.1**	*Mean:*	**0.9**
			Min:		*Min:*	**4.2**	*Min:*	**0.8**
			Max:		*Max:*	**20.0**	*Max:*	**0.9**
	36	Pool Inner Berm Cross-Sectional Area (A_{ibp})	*Mean:*	**N/A**	*Mean:*	**7.36**	*Mean:*	**1.5**
			Min:		*Min:*	**3.8**	*Min:*	**1.0**
			Max:		*Max:*	**5.0**	*Max:*	**2.0**
	37	Pool Inner Berm Cross-Sectional Area to Pool Cross-Sectional Area (A_{ibp}/A_{bkfp})	*Mean:*	**N/A**	*Mean:*	**0.591**	*Mean:*	**0.172**
			Min:		*Min:*	**0.305**	*Min:*	**0.114**
			Max:		*Max:*	**0.402**	*Max:*	**0.226**

Table II-4 (page 3). The morphological characteristics of the existing, proposed design and reference reaches for the G4 to B4 stream type conversion in a confined Valley Type VIII.

	Entry Number & Variable		Existing Reach	Proposed Design Reach	Reference Reach
Run Dimensions	**38**	Run Width, ft (W_{bkfr})	*Mean:* **9.7** *Min:* **8.7** *Max:* **10.8**	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	39	Run Width to Riffle Width (W_{bkfr}/W_{bkf})	*Mean:* **1.527** *Min:* **1.359** *Max:* **1.694**	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	40	Run Mean Depth, ft (d_{bkfr})	*Mean:* **1.69** *Min:* **1.65** *Max:* **1.73**	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	41	Run Mean Depth to Riffle Mean Depth (d_{bkfr}/d_{bkf})	*Mean:* **1.565** *Min:* **1.528** *Max:* **1.602**	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	42	Run Width/Depth Ratio (W_{bkfr}/d_{bkfr})	*Mean:* **5.7** *Min:* **5.3** *Max:* **6.2**	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	43	Run Cross-Sectional Area, ft^2 (A_{bkfr})	*Mean:* **10.0** *Min:* **9.6** *Max:* **10.4**	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	44	Run Area to Riffle Area (A_{bkfr}/A_{bkf})	*Mean:* **1.313** *Min:* **1.259** *Max:* **1.366**	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	45	Run Maximum Depth (d_{maxr})	*Mean:* **1.7** *Min:* **1.7** *Max:* **1.7**	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	46	Run Maximum Depth to Riffle Mean Depth (d_{maxr}/d_{bkf})	*Mean:* **1.565** *Min:* **1.528** *Max:* **1.602**	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
Glide Dimensions	**47**	Glide Width, ft (W_{bkfg})	*Mean:* **10.5** *Min:* **10.3** *Max:* **10.6**	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	48	Glide Width to Riffle Width (W_{bkfg}/W_{bkf})	*Mean:* **1.639** *Min:* **1.621** *Max:* **1.658**	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	49	Glide Mean Depth, ft (d_{bkfg})	*Mean:* **1.40** *Min:* **1.18** *Max:* **1.61**	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	50	Glide Mean Depth to Riffle Mean Depth (d_{bkfg}/d_{bkf})	*Mean:* **1.296** *Min:* **1.093** *Max:* **1.491**	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	51	Glide Width/Depth Ratio (W_{bkfg}/d_{bkfg})	*Mean:* **7.5** *Min:* **8.7** *Max:* **6.6**	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	52	Glide Cross-Sectional Area, ft^2 (A_{bkfg})	*Mean:* **9.6** *Min:* **9.3** *Max:* **10.0**	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	53	Glide Area to Riffle Area (A_{bkfg}/A_{bkf})	*Mean:* **1.262** *Min:* **1.217** *Max:* **1.302**	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	54	Glide Maximum Depth (d_{maxg})	*Mean:* **1.40** *Min:* **1.18** *Max:* **1.61**	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	55	Glide Maximum Depth to Riffle Mean Depth (d_{maxg}/d_{bkf})	*Mean:* **1.296** *Min:* **1.093** *Max:* **1.491**	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*

Table II-4 (page 4). The morphological characteristics of the existing, proposed design and reference reaches for the G4 to B4 stream type conversion in a confined Valley Type VIII.

	Entry Number & Variable	Existing Reach	Proposed Design Reach	Reference Reach
Channel Pattern	**72** Linear Wavelength, ft (λ)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **107.0** *Min:* **82.0** *Max:* **124.0**	*Mean:* **104.0** *Min:* **87.0** *Max:* **129.0**
	73 Linear Wavelength to Riffle Width (λ/W_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **10.288** *Min:* **7.885** *Max:* **11.923**	*Mean:* **8.832** *Min:* **7.389** *Max:* **10.955**
	74 Stream Meander Length, ft (L_m)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **115.0** *Min:* **93.0** *Max:* **144.0**	*Mean:* **112.0** *Min:* **94.5** *Max:* **135.0**
	75 Stream Meander Length Ratio (L_m/W_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **11.058** *Min:* **8.942** *Max:* **13.846**	*Mean:* **9.512** *Min:* **8.025** *Max:* **11.465**
	76 Belt Width, ft (W_{blt})	*Mean:* **14.6** *Min:* *Max:*	*Mean:* **22.9** *Min:* **14.6** *Max:* **31.2**	*Mean:* **27.2** *Min:* **14.6** *Max:* **60.0**
	77 Meander Width Ratio (W_{blt}/W_{bkf})	*Mean:* **2.288** *Min:* *Max:*	*Mean:* **2.200** *Min:* **1.400** *Max:* **3.000**	*Mean:* **2.306** *Min:* **1.237** *Max:* **5.096**
	78 Radius of Curvature, ft (R_c)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **49.9** *Min:* **21.8** *Max:* **78.0**	*Mean:* **50.7** *Min:* **21.8** *Max:* **76.0**
	79 Radius of Curvature to Riffle Width (R_c/W_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **4.800** *Min:* **2.096** *Max:* **7.500**	*Mean:* **4.300** *Min:* **2.100** *Max:* **6.454**
	80 Arc Length, ft (L_a)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **35.0** *Min:* **8.8** *Max:* **62.6**	*Mean:* **39.6** *Min:* **10.0** *Max:* **70.9**
	81 Arc Length to Riffle Width (L_a/W_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **3.363** *Min:* **0.849** *Max:* **6.021**	*Mean:* **3.363** *Min:* **0.849** *Max:* **6.021**
	82 Riffle Length (L_r), ft ***Refers to a Step Length - Not Riffle**	*Mean:* **4.6** *Min:* **1.3** *Max:* **9.1**	*Mean:* **15.0** *Min:* **3.0 *** *Max:* **29.0**	*Mean:* **14.7** *Min:* **2.7 *** *Max:* **28.2**
	83 Riffle Length to Riffle Width (L_r/W_{bkf}) ***Refers to a Step Length - Not Riffle**	*Mean:* **0.721** *Min:* **0.204** *Max:* **1.426**	*Mean:* **1.442** *Min:* **0.288 *** *Max:* **2.788**	*Mean:* **1.248** *Min:* **0.229 *** *Max:* **2.395**
	84 Individual Pool Length, ft (L_p)	*Mean:* **7.8** *Min:* **4.1** *Max:* **11.4**	*Mean:* **62.0** *Min:* **24.0** *Max:* **103.0**	*Mean:* **60.1** *Min:* **23.0** *Max:* **101.0**
	85 Pool Length to Riffle Width (L_p/W_{bkf})	*Mean:* **1.223** *Min:* **0.643** *Max:* **1.787**	*Mean:* **5.962** *Min:* **2.308** *Max:* **9.904**	*Mean:* **5.104** *Min:* **1.953** *Max:* **8.577**
	86 Pool to Pool Spacing, ft (P_s)	*Mean:* **163.0** *Min:* **7.6** *Max:* **24.2**	*Mean:* **29.0** *Min:* **12.4** *Max:* **48.0**	*Mean:* **28.1** *Min:* **12.2** *Max:* **47.3**
	87 Pool to Pool Spacing to Riffle Width (P_s/W_{bkf})	*Mean:* **25.549** *Min:* **1.191** *Max:* **3.793**	*Mean:* **2.788** *Min:* **1.192** *Max:* **4.615**	*Mean:* **2.387** *Min:* **1.039** *Max:* **4.020**

Table II-4 (page 5). The morphological characteristics of the existing, proposed design and reference reaches for the G4 to B4 stream type conversion in a confined Valley Type VIII.

	Entry Number & Variable	Existing Reach	Proposed Design Reach	Reference Reach
Sinuosity and Slope	**88** Stream Length (SL)	**275**	**300**	**514.1**
	89 Valley Length (VL)	**265**	**265**	**581.0**
	90 Valley Slope (S_{val})	**0.0272**	**0.0272**	**0.0273**
	91 Sinuosity (k)	SL/VL: **1.04** VS/S: **1.05**	SL/VL: **1.13**	SL/VL: **1.13** VS/S: **1.13**
	92 Average Water Surface Slope (S)	**0.0258**	$S = S_{val}/k$ **0.0241**	**0.0242**
Flood-Prone Area Dim.	**93** Flood-Prone Area Width, ft (W_{fpa})	*Mean:* **8.4** *Min:* **(no active** *Max:* **floodplain)**	*Mean:* **22.2** *Min:* *Max:*	*Mean:* **18.5** *Min:* *Max:*
	94 Flood-Prone Area Mean Depth, ft (d_{fpa})	*Mean:* **1.79** *Min:* **(no active** *Max:* **floodplain)**	*Mean:* **1.32** *Min:* *Max:*	*Mean:* **1.41** *Min:* *Max:*
	95 Flood-Prone Area Cross-Sectional Area, ft^2 (A_{fpa})	*Mean:* **15.0** *Min:* **(no active** *Max:* **floodplain)**	*Mean:* **29.2** *Min:* *Max:*	*Mean:* **26.0** *Min:* *Max:*
Degree of Incision	**102** Low Bank Height (LBH)	*Mean:* **2.25** *Min:* **2.00** *Max:* **2.50**	*Mean:* **1.55** *Min:* **1.20** *Max:* **1.90**	*Mean:* **1.13** *Min:* **1.08** *Max:* **1.18**
	103 Maximum Bankfull Depth (d_{max}) at Same Location as Low Bank Height (LBH) Measurement	*Mean:* **1.10** *Min:* **1.10** *Max:* **1.10**	*Mean:* **1.55** *Min:* **1.20** *Max:* **1.90**	*Mean:* **1.13** *Min:* **1.08** *Max:* **1.18**
	104 Bank-Height Ratio (LBH/d_{max})	*Mean:* **2.05** *Min:* **1.80** *Max:* **2.30**	*Mean:* **1.00** *Min:* **1.00** *Max:* **1.00**	*Mean:* **1.00** *Min:* **1.00** *Max:* **1.00**
Bed Feature Water Surface Facet Slopes and Dimensionless Ratios from Profile	**105** Riffle Slope (water surface facet slope) (S_{rif})	*Mean:* **0.0240** *Min:* **0.0150** *Max:* **0.0370**	*Mean:* **0.0338** *Min:* **0.0159** *Max:* **0.0583**	*Mean:* **0.0340** *Min:* **0.0159** *Max:* **0.0585**
	106 Riffle Slope to Average Water Surface Slope (S_{rif}/S)	*Mean:* **0.9302** *Min:* **0.5814** *Max:* **1.4341**	*Mean:* **1.4037** *Min:* **0.6587** *Max:* **2.4182**	*Mean:* **1.4037** *Min:* **0.6587** *Max:* **2.4182**
	107 Pool Slope (water surface facet slope) (S_p)	*Mean:* **0.0130** *Min:* **0.0060** *Max:* **0.0200**	*Mean:* **0.0027** *Min:* **0.0001** *Max:* **0.0099**	*Mean:* **0.0027** *Min:* **0.0001** *Max:* **0.0099**
	108 Pool Slope to Average Water Surface Slope (S_p/S)	*Mean:* **0.5039** *Min:* **0.2326** *Max:* **0.7752**	*Mean:* **0.1124** *Min:* **0.0041** *Max:* **0.4107**	*Mean:* **0.1124** *Min:* **0.0041** *Max:* **0.4107**
	109 Run Slope (water surface facet slope) (S_{run})	*Mean:* **0.0690** *Min:* **0.0180** *Max:* **0.1110**	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	110 Run Slope to Average Water Surface Slope (S_{run}/S)	*Mean:* **2.6744** *Min:* **0.6977** *Max:* **4.3023**	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	111 Glide Slope (water surface facet slope) (S_g)	*Mean:* **0.0240** *Min:* **0.0060** *Max:* **0.0620**	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	112 Glide Slope to Average Water Surface Slope (S_g/S)	*Mean:* **0.9302** *Min:* **0.2326** *Max:* **2.4031**	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	113 Step Slope (water surface facet slope) (S_s)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.0556** *Min:* **0.9262** *Max:* **1.1751**	*Mean:* **1.0600** *Min:* **0.9300** *Max:* **1.1800**
	114 Step Slope to Average Water Surface Slope (S_s/S)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **43.8017** *Min:* **38.4298** *Max:* **48.7603**	*Mean:* **43.8017** *Min:* **38.4298** *Max:* **48.7603**

Table II-4 (page 6). The morphological characteristics of the existing, proposed design and reference reaches for the G4 to B4 stream type conversion in a confined Valley Type VIII.

	Entry Number & Variable	Existing Reach	Proposed Design Reach	Reference Reach
Bed Feature Max Depth Measurements and Dimensionless Ratios from Profile	**115** Riffle Maximum Depth, ft (d_{max})	*Mean:* **1.29** *Min:* **1.15** *Max:* **1.56**	*Mean:* **1.20** *Min:* **1.00** *Max:* **1.40**	*Mean:* **1.06** *Min:* **0.93** *Max:* **1.18**
	116 Riffle Maximum Depth to Riffle Mean Depth (d_{max}/d_{bkf})	*Mean:* **1.194** *Min:* **1.065** *Max:* **1.444**	*Mean:* **1.412** *Min:* **1.176** *Max:* **1.647**	*Mean:* **1.413** *Min:* **1.240** *Max:* **1.573**
	117 Pool Maximum Depth, ft (d_{maxp})	*Mean:* **1.51** *Min:* **1.40** *Max:* **1.61**	*Mean:* **1.90** *Min:* **1.50** *Max:* **2.10**	*Mean:* **1.52** *Min:* **1.33** *Max:* **1.85**
	118 Pool Maximum Depth to Riffle Mean Depth (d_{maxp}/d_{bkf})	*Mean:* **1.398** *Min:* **1.296** *Max:* **1.491**	*Mean:* **2.235** *Min:* **1.765** *Max:* **2.471**	*Mean:* **2.027** *Min:* **1.773** *Max:* **2.467**
	119 Run Maximum Depth, ft (d_{maxr})	*Mean:* **1.73** *Min:* **1.65** *Max:* **1.96**	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	120 Run Maximum Depth to Riffle Mean Depth (d_{maxr}/d_{bkf})	*Mean:* **1.602** *Min:* **1.528** *Max:* **1.815**	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	121 Glide Maximum Depth, ft (d_{maxg})	*Mean:* **1.40** *Min:* **1.18** *Max:* **1.61**	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	122 Glide Maximum Depth to Riffle Mean Depth (d_{maxg}/d_{bkf})	*Mean:* **1.296** *Min:* **1.093** *Max:* **1.491**	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	123 Step Maximum Depth, ft (d_{maxs})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	124 Step Maximum Depth to Riffle Mean Depth (d_{maxs}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
Channel Materials	**125 Particle Size Distribution of Channel Material (Active Bed) or Pavement**			
	D_{16} (mm)	**2.0**	**2.0**	**5.1**
	D_{35} (mm)	**4.0**	**4.0**	**13.1**
	D_{50} (mm)	**8.0**	**8.0**	**22.6**
	D_{84} (mm)	**26.0**	**26.0**	**63.5**
	D_{95} (mm)	**44.0**	**44.0**	**125.5**
	D_{100} (mm)	**90.0**	**90.0**	**180.0**
	126 Particle Size Distribution of Bar Material or Sub-pavement			
	D_{16} (mm)	**0.0**	**0.0**	**2.0**
	D_{35} (mm)	**3.0**	**3.0**	**7.6**
	D_{50} (mm)	**6.0**	**6.0**	**14.5**
	D_{84} (mm)	**31.0**	**31.0**	**63.8**
	D_{95} (mm)	**65.0**	**65.0**	**88.7**
	D_{max}: Largest size particle at the toe (lower third) of bar (mm) or sub-pavement	**80.0**	**80.0**	**100.0**

Table II-4 (page 7). The morphological characteristics of the existing, proposed design and reference reaches for the G4 to B4 stream type conversion in a confined Valley Type VIII.

	Entry Number & Variable		Existing Reach	Proposed Design Reach	Reference Reach
Hydraulics	127	Estimated Bankfull Mean Velocity, ft/sec (u_{bkf})	**3.51**	**4.55**	**4.7**
	128	Estimated Bankfull Discharge, cfs (Q_{bkf}); Compare with Regional Curve	**30.3**	**40.0**	**32.8**
Sediment Competence	129	Calculated bankfull shear stress value, lbs/ft^2 (τ)	**1.433**	**1.278**	**1.117**
	130	Predicted largest moveable particle size (mm) at bankfull shear stress, τ, using the original **Shields** relation	**99.0**	**101**	**84.0**
	131	Predicted largest moveable particle size (mm) at bankfull shear stress, τ, using the **Colorado** relation	**190.0**	**182**	**180.0**
	132	Largest particle size to be moved (D_{max}) (mm) (see #126: Particle Size Distribution of Bar Material)	**80**	**80**	**100.0**
	133	Predicted shear stress required to initiate movement of D_{max} (mm) using the original **Shields** relation	**1.010**	**1.025**	**1.400**
	134	Predicted shear stress required to initiate movement of D_{max} (mm) using the **Colorado** relation	**0.400**	**0.418**	**0.580**
	135	Predicted mean depth required to initiate movement of D_{max} (mm), $d = \tau/\gamma S$ (τ = predicted shear stress, γ = 62.4, S = existing or design slope) (**Shields**)	**0.63**	**0.68**	**0.93**
	136	Predicted mean depth required to initiate movement of D_{max} (mm), $d = \tau/\gamma S$ (τ = predicted shear stress, γ = 62.4, S = existing or design slope) (**Colorado**)	**0.63**	**0.28**	**0.93**
	137	Predicted slope required to initiate movement of D_{max} (mm) $S=\tau/\gamma d$ (τ = predicted shear stress, γ = 62.4, d = existing or design depth) (**Shields**)	**0.0182**	**0.0193**	**0.0303**
	138	Predicted slope required to initiate movement of D_{max} (mm) $S=\tau/\gamma d$ (τ = predicted shear stress, γ = 62.4, d = existing or design depth) (**Colorado**)	**0.0072**	**0.0079**	**0.0126**
	139	Bankfull dimensionless shear stress (τ^*) (see competence form)	**N/A**	**N/A**	**N/A**
	140	Required bankfull mean depth d_{bkf} (ft) using dimensionless shear stress equation: $d_{bkf} = \tau^*(\gamma_s - 1)D_{max}/S$ (Note: D_{max} in ft)	**N/A**	**N/A**	**N/A**
	141	Required bankfull water surface slope S (ft) using dimensionless shear stress equation: $S = \tau^*(\gamma_s - 1)D_{max}/d_{bkf}$ (Note: D_{max} in ft)	**N/A**	**N/A**	**N/A**

Table II-4 (page 8). The morphological characteristics of the existing, proposed design and reference reaches for the G4 to B4 stream type conversion in a confined Valley Type VIII.

	Entry Number & Variable	Existing Reach	Proposed Design Reach	Reference Reach
Sediment Yield	**Sediment Yield (FLOWSED)***	**Existing Reach***	**Proposed Design Reach***	**Difference in Sediment Yield***
	141 Bedload Sediment Yield (tons/yr)	**5,416.0**	**144.0**	**5,272.0**
	142 Suspended Sediment Yield (tons/yr)	**18,774.4**	**700.5**	**18,073.9**
	143 Suspended Sand Sediment Yield (tons/yr)	**9,387.2**	**350.3**	**9,037.0**
	144 Total Annual Sediment Yield (tons/yr)	**24,190.4**	**844.6**	**23,345.8**
***Reduction in sediment supply due to using "Good" sediment supply bankfull values by drainage area and "Good" dimensionless sediment rating curves vs "Poor" as a result of converting from the G4 (Poor) to B4 (Good) stream type.**				
Bank Erosion	**Streambank Erosion**	**Existing Reach**	**Proposed Design Reach**	**Reference Reach**
	145 Stream Length Assessed (ft)	**275**	**300**	**406.0**
	146 Graph/Curve Used (e.g., Yellowstone or Colorado)	**Colorado**	**Colorado**	**Colorado**
	147 Streambank Erosion (tons/yr)	**181.1**	**1.45**	**1.96**
	148 Streambank Erosion (tons/yr/ft)	**0.6584**	**0.0048**	**0.0048**

Bankfull Discharge, Cross-Sectional Area & Mean Velocity

With a drainage area of *15.9 mi*^{2} for the proposed B4 stream type, the bankfull discharge is *40.0 cfs* and the proposed bankfull riffle cross-sectional area is *8.8 ft*^{2} as shown in **Table II-4**. Using continuity, the corresponding mean velocity for the proposed design reach is *4.55 ft/sec* as shown in **Worksheet II-7**. This worksheet is also used to check for reasonable velocities using the proposed design dimensions and slope using a variety of methods; these methods, particularly the friction factor to relative roughness relation, agree with the velocity estimate using continuity.

Plan View Alignment

The overlay of the alignment of the proposed conversion of the G4 to B4 stream type is shown on the aerial photograph in **Figure II-25** and is based on the channel pattern data converted from the dimensionless ratios of the *B4 Reference Reach* that were scaled for this drainage area and bankfull discharge (**Table II-4**). The existing cross-section locations of the G4 stream type are also shown **Figure II-25**.

Cross-Section Dimensions

The proposed channel dimensions for riffles and pools for the proposed B4 design that were developed from the reference reach dimensionless relations are included in **Table II-4**. The locations of existing cross-sections are displayed in **Figure II-25**. To establish the stable base level and slope, the proposed channel must be placed over new fill in the existing channel. **Figure II-26** depicts the overlay of the existing G4 cross-section 0+47.5 *vs*. proposed B4 *riffle* cross-section, indicating the proposed dimensions, new bankfull elevation, and associated cut and fill requirements. A proposed pool cross-section is compared to the existing G4 cross-section 0+62 (**Figure II-27**). Additional proposed cross-sections for riffles and pools are shown in the existing *vs*. proposed cross-section overlays in **Figure II-28** (*pool*), **Figure II-29** (*riffle*), **Figure II-30** (*pool*), **Figure II-31** (*pool*), **Figure II-32** (*riffle*) and **Figure II-33** (*pool*). These overlays are used to compute the cut and fill required for the design based on the respective lengths for each feature.

Longitudinal Profile

The typical longitudinal profile for the proposed B4 design reach is shown in **Figure II-34** compared to the existing G4 profile. The profile shows the proposed elevations of the bed and bankfull stage, energy slope and bed features that match the plan view in **Figure II-25**. The profile shows the need to balance the energy slope and local base level with more fill required in the lower portion of the reach than the upper portion. The bankfull stage and the depths from bankfull describe the bed features of riffles and pools that are proportionately scaled and positioned on the longitudinal profile in **Figure II-34**. Additionally, the locations of the cross-section overlays in **Figures II-26** through **II-33** are depicted on the typical longitudinal profile that corresponds with the proposed design bed features.

Worksheet II-7. The mean velocity estimates for the proposed B4 stable reach to be converted from the existing, G4 stream type.

Bankfull VELOCITY & DISCHARGE Estimates

Stream:	**Proposed B4 from Existing G4**	Location:	**Lower Trail Creek above Mouth**
Date:	**3/15/2011**	Stream Type:	**B4**
Valley Type:	**VIII**		
Observers:	**Rosgen *et al*.**	HUC:	__ __ __ __ __ __ __ __ __ __ __ __

Input Variables for PROPOSED Design			Output Variables for PROPOSED Design		
Bankfull Riffle Cross-Sectional AREA	**8.80**	**A_{bkf}** (ft^2)	Bankfull Riffle Mean DEPTH	**0.85**	**d_{bkf}** (ft)
Bankfull Riffle WIDTH	**10.4**	**W_{bkf}** (ft)	Wetted PERMIMETER ~ $(2 * d_{bkf}) + W_{bkf}$	**12.09**	**W_p** (ft)
Protrusion Height of Dunes	**61.0**	**Dia.** (mm)	***Prot. Height*** (mm) / 304.8	**0.20**	**D_{84}** (ft)
Bankfull SLOPE	**0.0241**	**S_{bkf}** (ft / ft)	Hydraulic RADIUS A_{bkf} / W_p	**0.73**	**R** (ft)
Gravitational Acceleration	**32.2**	**g** (ft / sec^2)	Relative Roughness R(ft) / D_{84} (ft)	**3.64**	**R / D_{84}**
Drainage Area	**15.9**	**DA** (mi^2)	Shear Velocity $u^* = (gRS)^{½}$	**0.751**	**u*** (ft/sec)

ESTIMATION METHODS	Bankfull VELOCITY		Bankfull DISCHARGE	
1. Friction Factor / Relative Roughness $u = [2.83 + 5.66 * Log \{ R / D_{84} \}] u^*$	**4.51**	ft / sec	**39.70**	cfs
2. Roughness Coefficient: a) Manning's *n* from Friction Factor / Relative Roughness (Figs. 5-7, 5-8) $u = 1.49*R^{2/3}*S^{1/2}/n$ **n =** **0.048**	**3.90**	ft / sec	**34.31**	cfs
2. Roughness Coefficient: b) Manning's *n* from Stream Type (Fig. 5-9) $u = 1.49*R^{2/3}*S^{1/2}/n$ **n =** **0.058**	**3.23**	ft / sec	**28.39**	cfs
2. Roughness Coefficient: c) Manning's *n* from Jarrett (USGS): $n = 0.39*S^{0.38}*R^{-0.16}$ **Note:** This equation is applicable to **steep, step/pool, high boundary roughness, cobble- and boulder-dominated stream systems**; i.e., for Stream Types A1, A2, A3, B1, B2, B3, C2 & E3 **n =** **N/A**	**N/A**	ft / sec	**N/A**	cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)		ft / sec		cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)		ft / sec		cfs
4. Continuity Equations: a) USGS Gage Data $u = Q / A$ **Return Period for Bankfull Dis.** **Q =** ____ **year**		ft / sec		cfs
4. Continuity Equations: b) Regional Curves $u = Q / A$	**4.55**	ft / sec	**40.0**	cfs

Protrusion Height Options for the D_{84} Term in the Relative Roughness Relation (R/D_{84}) – Estimation Method 1

Option 1.	For **sand-bed** channels: Measure 100 **"protrusion heights"** of sand dunes from the downstream side of feature to the top of feature. Substitute the D_{84} sand dune protrusion height in ft for the D_{84} term in method 1.
Option 2.	For **boulder-dominated** channels: Measure 100 **"protrusion heights"** of boulders on the sides from the bed elevation to the top of the rock on that side. Substitute the D_{84} boulder protrusion height in ft for the D_{84} term in method 1.
Option 3.	For **bedrock-dominated** channels: Measure 100 **"protrusion heights"** of rock separations, steps, joints or uplifted surfaces above channel bed elevation. Substitute the D_{84} bedrock protrusion height in ft for the D_{84} term in method 1.
Option 4.	For **log-influenced** channels: Measure **"protrustion heights"** proportionate to channel width of log diameters or the height of the log on upstream side if embedded. Substitute the D_{84} protrusion height in ft for the D_{84} term in method 1.

Insert 11 x 17 Figure II-25 Here

Figure II-25. Plan view of the proposed conversion of the G4 to B4 stream type, including the existing G4 cross-section locations.

Insert 11 x 17 Figure II-25 Here

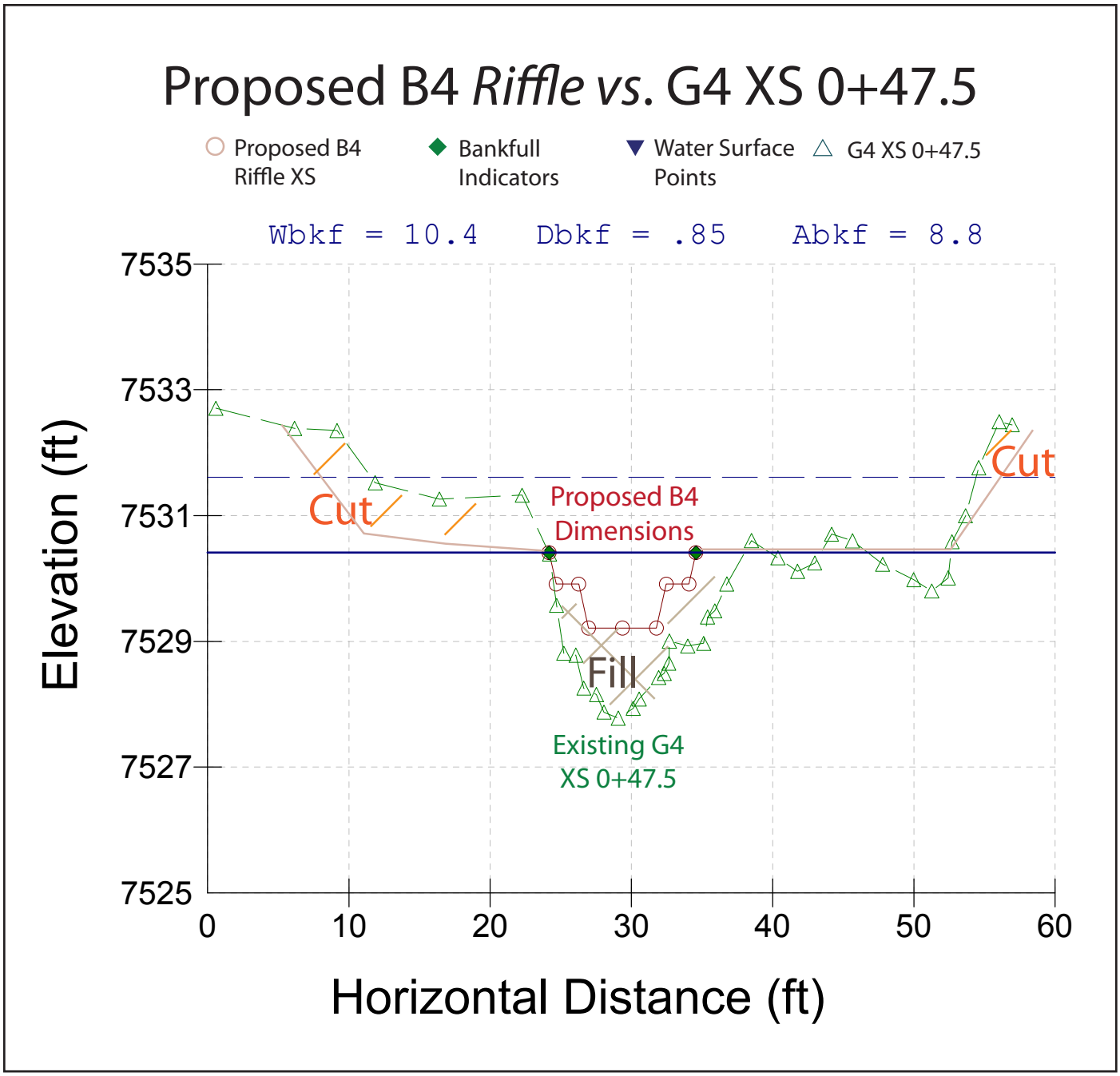


Figure II-26. The proposed B4 *riffle* cross-section compared to the existing G4 cross-section 0+47.5, indicating the cut and fill requirements and new bankfull elevation.

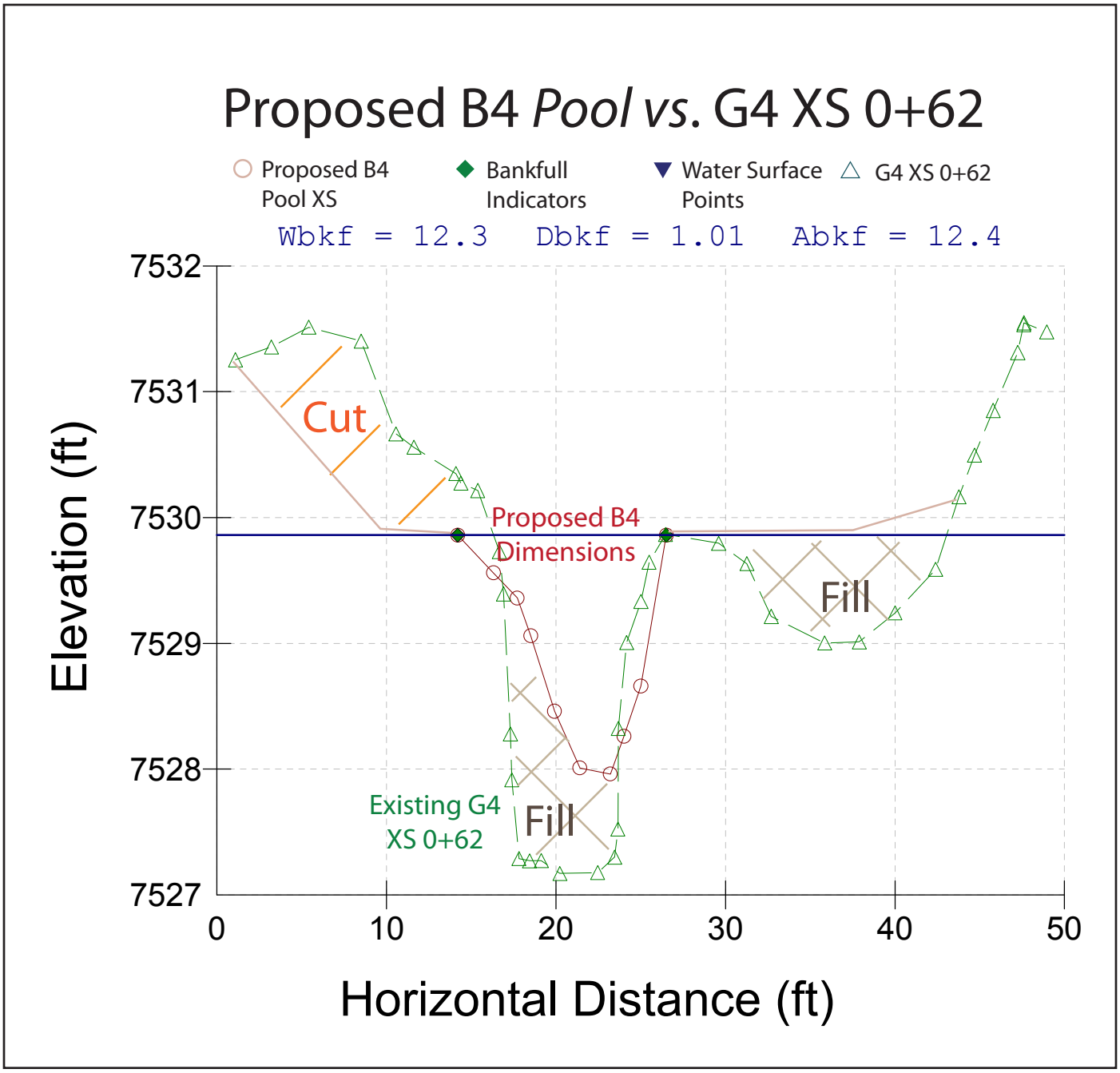


Figure II-27. The proposed B4 *pool* cross-section compared to the existing G4 cross-section 0+62, indicating the cut and fill requirements and new bankfull elevation.

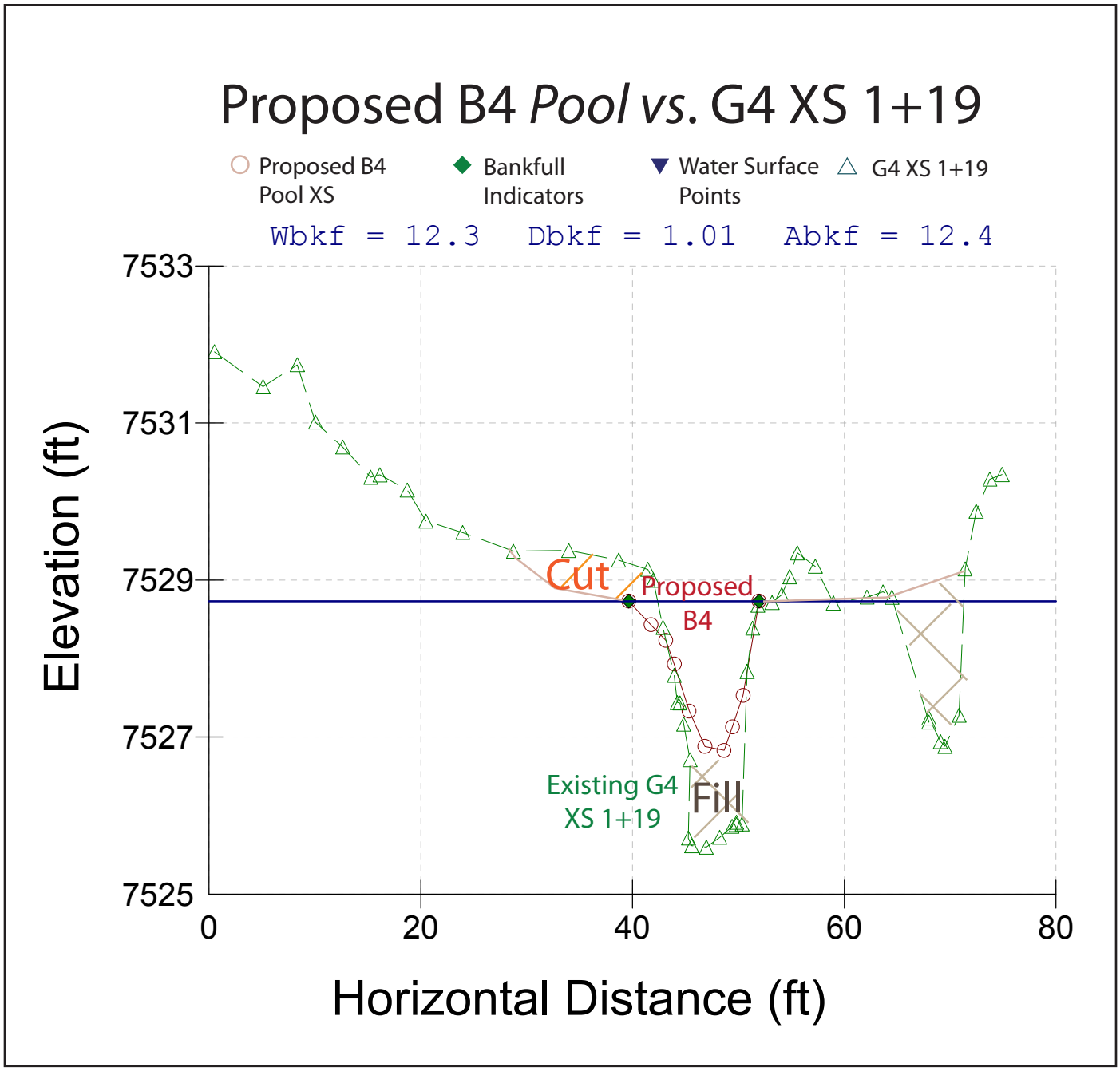


Figure II-28. The proposed B4 *pool* cross-section compared to the existing G4 cross-section 1+19, indicating the cut and fill requirements and new bankfull elevation.

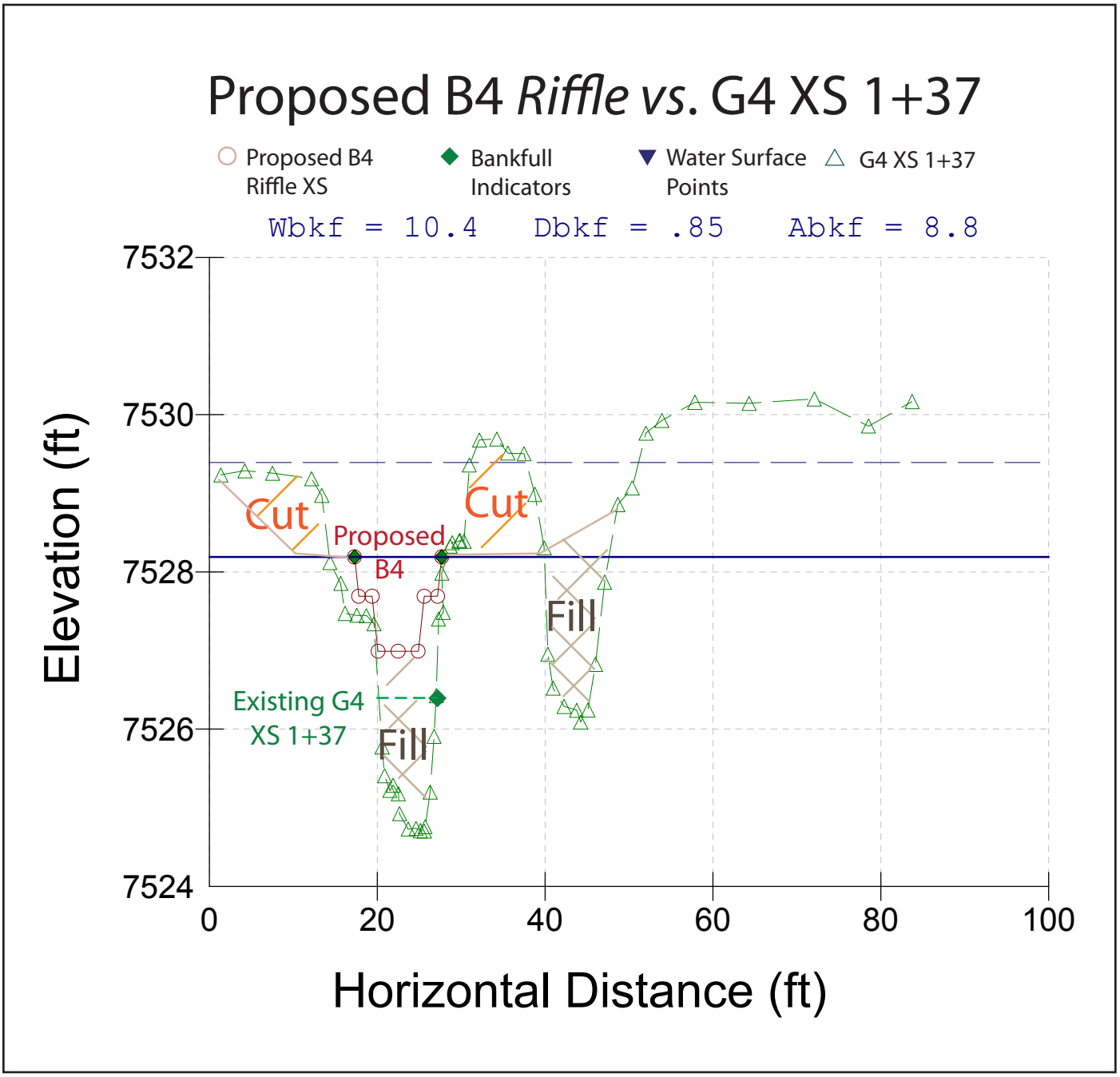


Figure II-29. The proposed B4 *riffle* cross-section compared to the existing G4 cross-section 1+37, indicating the cut and fill requirements and new bankfull elevation.

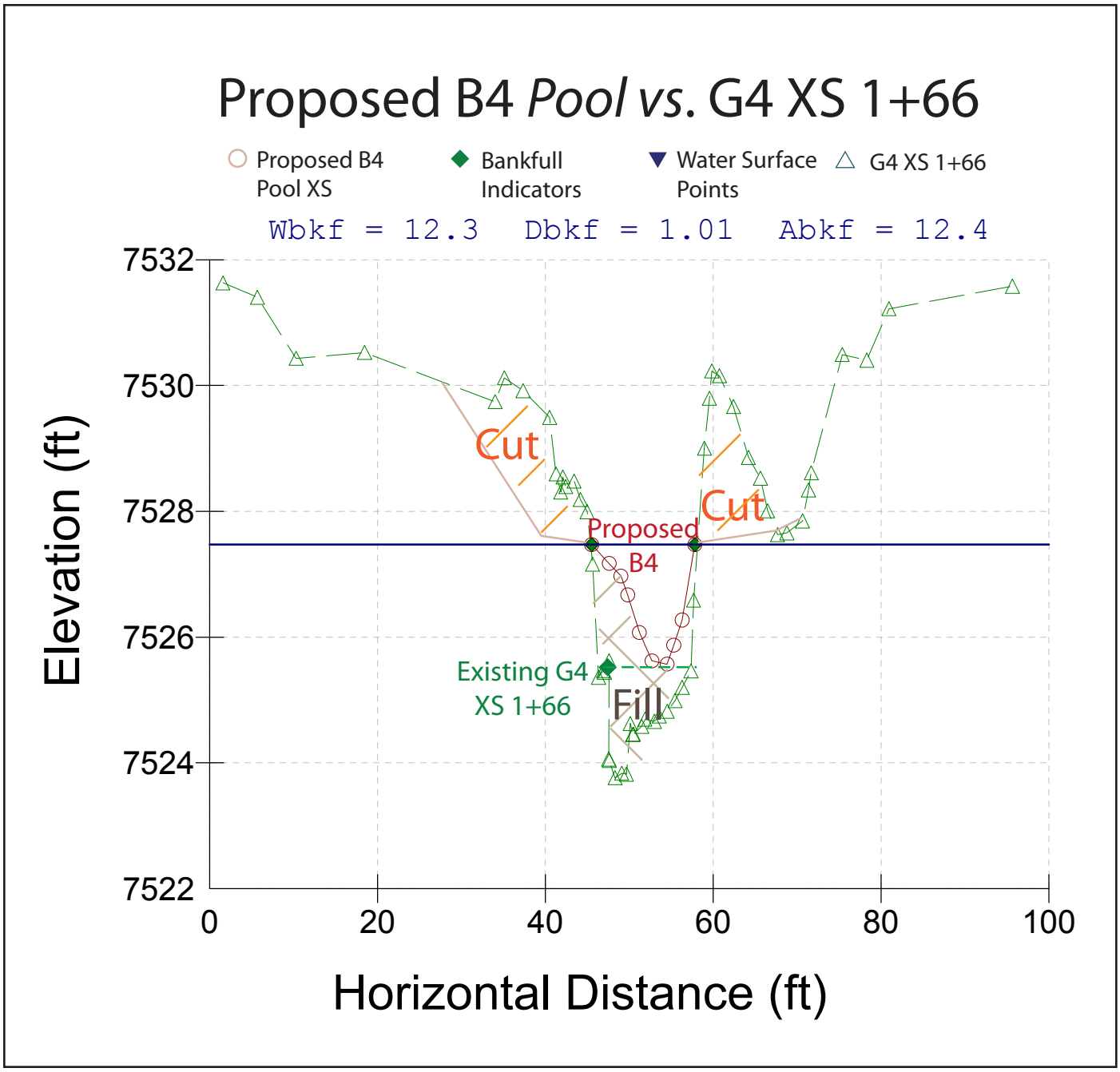


Figure II-30. The proposed B4 *pool* cross-section compared to the existing G4 cross-section 1+66, indicating the cut and fill requirements and new bankfull elevation.

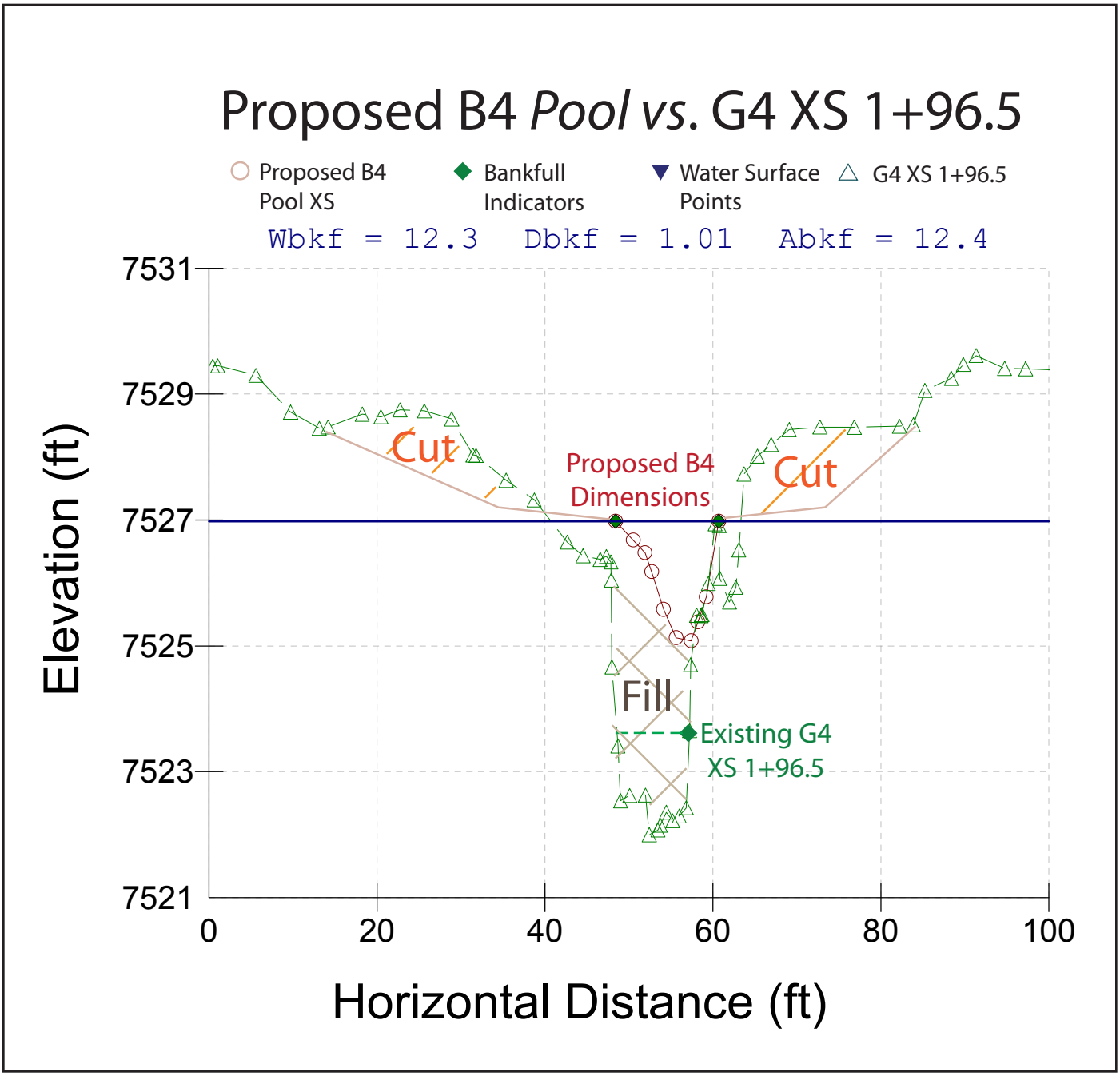


Figure II-31. The proposed B4 *pool* cross-section compared to the existing G4 cross-section 1+96.5, indicating the cut and fill requirements and new bankfull elevation.

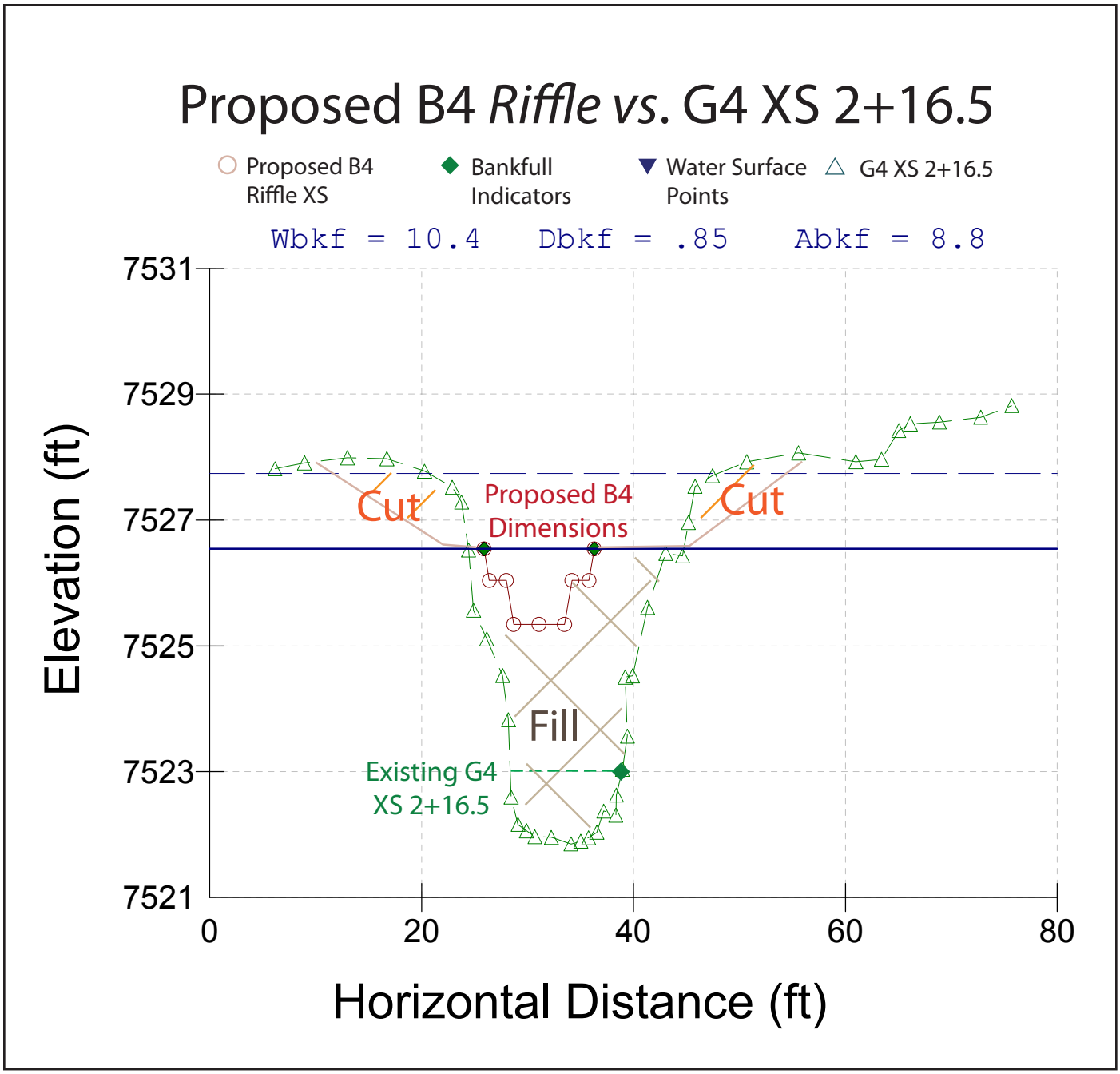


Figure II-32. The proposed B4 *riffle* cross-section compared to the existing G4 cross-section 2+16.5, indicating the cut and fill requirements and new bankfull elevation.

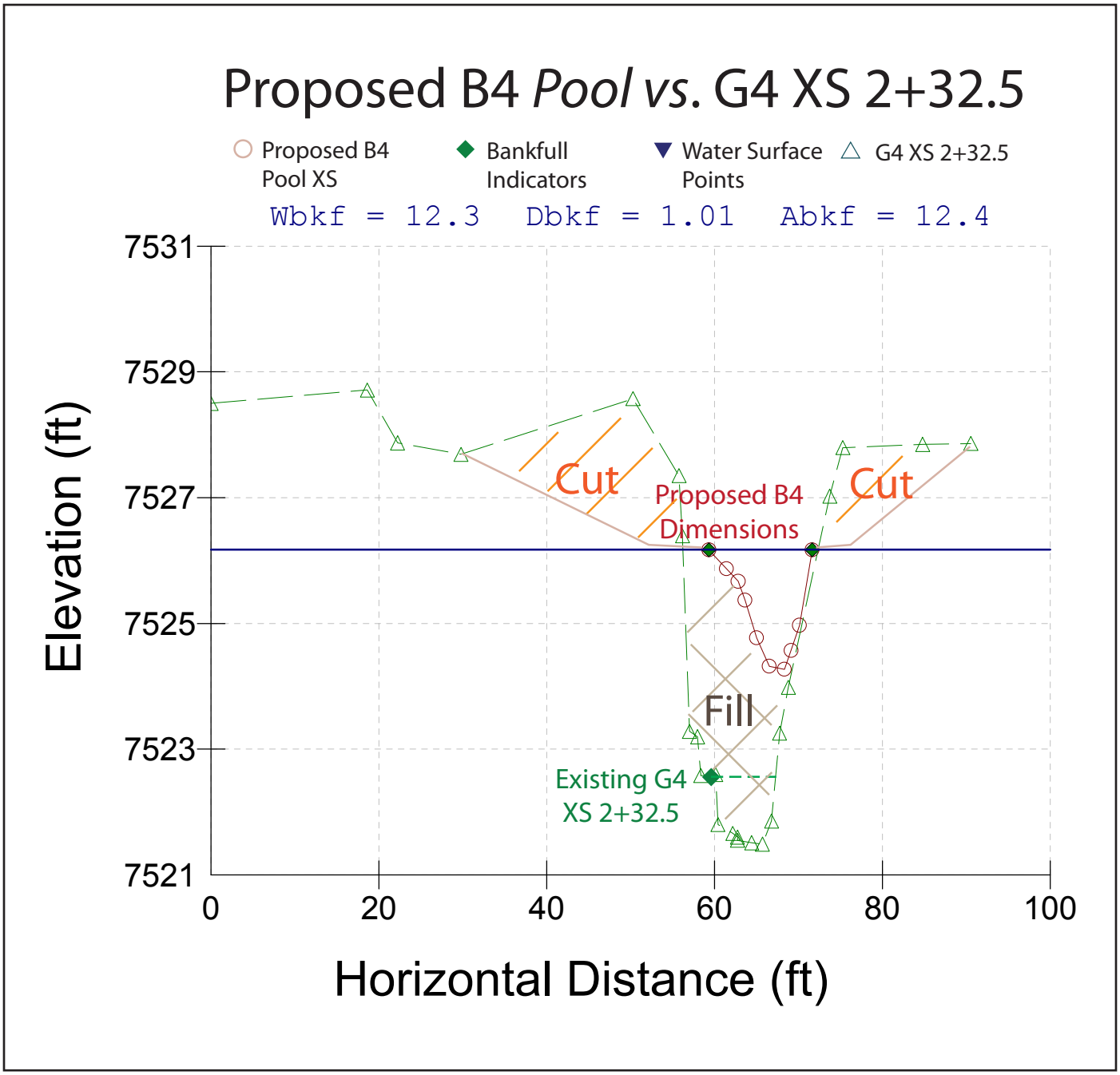


Figure II-33. The proposed B4 *pool* cross-section compared to the existing G4 cross-section 2+32.5, indicating the cut and fill requirements and new bankfull elevation.

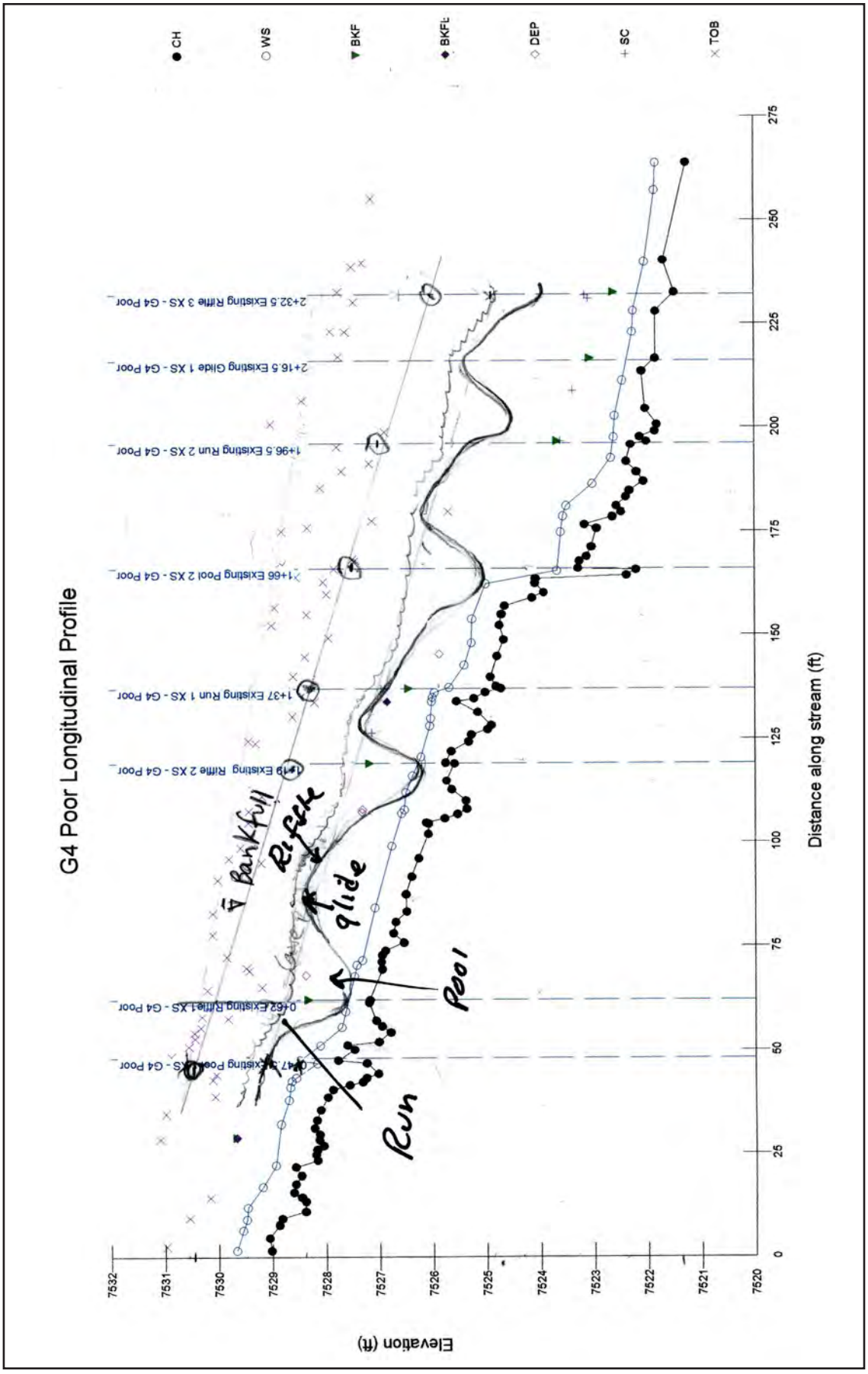


Figure II-34. The longitudinal profile comparing the elevations, slopes, and fill requirements of the existing G4 *vs.* proposed B4 stream type.

Structures

The proposed structures for streambank stabilization, flow resistance, grade control, and fish habitat enhancement are shown in the plan view layout in **Figure II-35**. The structures include converging rock clusters; the root wad, log vane, J-hook; the rock vane, J-hook; the rock and log roller structure; and the toe wood structure with sod mats and riparian transplants. The materials for these structures will be obtained from on-site sources. Many of the burned logs will be salvaged to use for the root wad, log vane, J-hook, and toe wood structures. Riparian transplants will be salvaged from local excavation disturbance.

Riparian Vegetation

It is a key requirement to re-establish a woody riparian community of willow and alder along this corridor. This is accomplished by planting willow cuttings and transplants. The toe wood structure provides a site for transplanted willow and alder, or willow cuttings. Native grasses of Carex and Juncus where available will be transplanted to the stream-adjacent toe wood structures or seeded along the lower elevation, wet sites. Native bunch grasses, such as big mountain brome, are recommended for seeding the flood-prone areas that do not have soil saturation and are droughty. The revegetation is critical for the long-term physical stability and biological function.

Cut & Fill Computations

The cut and fill computations are obtained from the existing *vs*. proposed cross-sections for that particular bed feature with lengths obtained from the plan and profile data of the proposed design. The proposed design requires approximately *2,661 yds*^{3} of excavation and *2,344 yds*^{3} of fill material with a balance of *317 yds*^{3}. More fill is required on the lower portion of this reach. The fill related to the structures designed for this reach involving rock, logs and woody material is approximately *300 yds*^{3}. Thus the revetment and enhancement material would balance the excavation and fill requirements for this reach; subsequently, end-hauling to dispose of material is not necessary.

Insert 11 x 17 Figure II-35 Here

Figure II-35. The proposed plan view layout of the G4 to B4 conversion depicting the stabilization and fish enhancement structures.

Insert 11 x 17 Figure II-35 Here

Streambank Erosion

The streambank erosion that is expected for the proposed B4 design reach is *1.4 tons/yr* for *300 ft* of designed channel *vs*. *181.1 tons/yr* for *275 ft* of the existing condition (**Table II-4**), representing a significant, potential reduction of *179.6 tons/yr* for this reach. These values are based on the annual erosion rate of the *G4 Poor Representative Reach* (*0.6584 tons/yr/ft*) and the extrapolation of the annual erosion rate of the *B4 Reference Reach* (*0.0048 tons/yr/ft*) to the proposed B4 design. This reduction assumes that the various structures designed and located on the plan view map in **Figure II-35** are implemented, such as the toe wood and the J-hook structures. The reduction in BEHI can be greatly reduced with the toe wood structure, and NBS can be reduced with the rock and log vane, J-hook structures. These structures have proven to reduce streambank erosion rates by three orders of magnitude, and also provide for flow resistance and fish habitat enhancement. These significant reductions in streambank erosion are extremely important as *84%* of the total sediment source of the watershed is from streambank erosion. Thus restoration can not 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.

Flow-Related Sediment

The FLOWSED model indicates that by converting from a "Poor" condition to a "Good" condition throughout the watershed, the flow-related sediment yields would be reduced from *24,190.4 tons/yr* (**Worksheet II-8a**) to *844.6 tons/yr* (**Worksheet II-8b**) as a result of the restoration. The corresponding sediment supply reductions based on converting from "Poor" to "Good" conditions are *5,272 tons/yr* for bedload and *18,073.9 tons/yr* for suspended sediment, representing a total sediment reduction of *23,345.8 tons/yr*. These sediment reductions are still assuming a high post-fire runoff response and continued increased stormflow peak runoff. These reductions are also associated with treating the majority of the stream length of the watershed above this reach.

The reductions in sediment supply associated with restoring *275 ft* of the existing G4 *Poor* stream type to *300 ft* of the proposed C4 *Stable* design reach are *179.6 tons/yr* of streambank erosion, *27.4 tons/yr* of bedload, *93.8 tons/yr* of suspended sediment and *121.2 tons/yr* of total sediment yield reduction. The total sediment yield value includes streambank erosion contributions and streambed sources. Streambank erosion rates are sometimes higher than the total sediment yield because not all of the soil eroded from the bank is delivered; considerable amounts go into storage on the streambed and are available for re-entrainment during the next high flow. The sediment reductions associated with the local channel source sediment for this design scenario are based on sediment yield rates determined from taking the sediment yield values generated from FLOWSED and dividing by the total stream length of potential sediment contributions. For this scenario, it was determined that approximately *10 miles* (*52,800 ft*) of the mainstem Trail Creek is potentially contributing sediment. The tributaries also contribute sediment but at a lower rate; thus their stream lengths were not included in the unit sediment transport rate. The resultant sediment yield rates were then multiplied by the existing and proposed design reach lengths for this scenario to obtain the local sediment reductions.

The POWERSED model to evaluate sediment transport capacity indicates that by increasing the existing, very low width/depth ratio, approximately *68%* of the G4 sediment supply would be deposited.

Overall there is approximately *3,700 yds*^{3} of recently aggraded sediment in this reach (within the last ten years). The proposed restoration will reduce the sediment supply from streambank erosion in this reach by approximately *179.6 tons/yr*, and the total sediment yield (bedload and suspended sediment) by *121.2 tons/yr*, which will help reduce the exported volumes and help stabilize the currently impaired G4 stream type by converting to a B4 stream type.

Sediment Competence

The sediment competence calculations indicate excess energy for the proposed design of converting from a G4 to a B4 stream type (**Worksheet II-9**); therefore, grade control at the head of riffles is warranted and recommended. The converging rock clusters and the rock and log roller structures are designed for grade control.

Worksheet II-8a. The existing sediment supply at the G4 reach using the FLOWSED model and generated by using the dimensionless sediment rating curves and bankfull sediment values related to the "Poor" condition.

Stream: **G4 Poor Representative Reach** Location: **Lower Trail Creek above Mouth** Date: **3/15/11**

Observers: **Rosgen *et al*.** Gage Station #: **Goose Creek Gage** Stream Type: **G4** Valley Type: **VIII**

Equation Type	Equation Source	Equation	Bankfull Discharge (cfs)	Bankfull Bedload Sediment (kg/s)	Bankfull Suspended Sediment (mg/l)
1. Bedload Sediment	"Poor" Pagosa	$y = 0.07176+1.02176x^{2.3772}$	40	0.4699	223.46
2. Suspended Sediment	"Poor" Pagosa	$y = 0.0989+0.9213x^{3.659}$			

From Dimensional Flow-Duration Curve							From Sediment Rating Curves				Calculate	Calculate Sediment Yield		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Percentage of Time	Daily Mean Discharge	Mid-Ordinate	Time Increment (percent)	Time Increment (days)	Mid-Ordinate Streamflow	Dimension-less Streamflow	Dimension-less Suspended Sediment Discharge	Suspended Sediment Discharge	Dimension- less Bedload Discharge	Bedload Sediment Discharge	Time Adjusted Streamflow [(5)×(6)]	Suspended Sediment [(5)×(9)]	Bedload Sediment [(5)×(11)]	Suspended + Bedload Sediment [(13)+(14)]
(%)	(cfs)	(%)	(%)	(days)	(cfs)	(Q/Q_{bkf})	(S/S_{bkf})	(tons/day)	(b_s/b_{bkf})	(tons/day)	(cfs)	(tons)	(tons)	(tons)
0%	178.8													
0.10%	153.5	0.05%	0.09%	0.34	166.2	4.154	168.918	16935.10	30.244	1353.84	57.0	5810.43	464.50	6274.94
0.25%	132.9	0.08%	0.15%	0.55	143.2	3.579	97.999	8465.64	21.249	951.18	78.4	4634.94	520.77	5155.71
0.50%	114.8	0.13%	0.25%	0.91	123.8	3.095	57.637	4305.77	15.065	674.38	113.0	3929.01	615.37	4544.38
0.75%	98.0	0.13%	0.25%	0.91	106.4	2.660	33.137	2127.25	10.528	471.26	97.1	1941.11	430.03	2371.14
1%	84.8	0.13%	0.25%	0.91	91.4	2.285	19.049	1050.51	7.358	329.39	83.4	958.59	300.57	1259.16
1.5%	60.7	0.25%	0.50%	1.83	72.8	1.819	8.322	365.32	4.308	192.84	132.8	666.70	351.93	1018.64
2%	51.1	0.25%	0.50%	1.83	55.9	1.398	3.236	109.15	2.337	104.60	102.0	199.20	190.89	390.10
3%	43.7	0.50%	1.00%	3.65	47.4	1.185	1.812	51.83	1.601	71.66	173.0	189.17	261.57	450.74
4%	38.9	0.50%	1.00%	3.65	41.3	1.032	1.133	28.22	1.173	52.52	150.7	103.02	191.69	294.71
5%	34.4	0.50%	1.00%	3.65	36.7	0.916	0.768	16.99	0.902	40.38	133.8	62.02	147.38	209.40
10%	24.4	2.50%	5.00%	18.25	29.4	0.736	0.399	7.08	0.565	25.28	537.2	129.28	461.28	590.56
20%	13.3	5.00%	10.00%	36.50	18.9	0.472	0.158	1.80	0.243	10.89	689.2	65.71	397.57	463.27
30%	8.9	5.00%	10.00%	36.50	11.1	0.278	0.107	0.72	0.120	5.39	405.4	26.27	196.65	222.92
40%	6.3	5.00%	10.00%	36.50	7.6	0.190	0.101	0.46	0.091	4.09	277.0	16.88	149.36	166.25
50%	4.8	5.00%	10.00%	36.50	5.6	0.139	0.100	0.33	0.081	3.63	202.7	12.18	132.53	144.71
60%	3.7	5.00%	10.00%	36.50	4.3	0.106	0.099	0.25	0.077	3.43	155.4	9.30	125.38	134.67
70%	3.0	5.00%	10.00%	36.50	3.3	0.083	0.099	0.20	0.075	3.34	121.6	7.27	121.79	129.05
80%	2.6	5.00%	10.00%	36.50	2.8	0.069	0.099	0.17	0.074	3.29	101.4	6.05	120.19	126.24
90%	1.9	5.00%	10.00%	36.50	2.2	0.056	0.099	0.13	0.073	3.26	81.1	4.84	118.98	123.82
100%	0.4	5.00%	10.00%	36.50	1.1	0.028	0.099	0.07	0.072	3.22	40.5	2.42	117.58	120.00
									Annual Totals:		3,732.8 (cfs) 7,404.1 (acre-ft)	18,774.4 (tons/yr)	5,416.0 (tons/yr)	24,190.4 (tons/yr)

Worksheet II-8b. The proposed sediment supply at the proposed C4 reach using the FLOWSED model and generated by using the dimensionless sediment rating curves and bankfull sediment values related to the restored "Good" condition (assuming that the watershed area above this reach is also restored to "Good" conditions).

Stream: **B4 Proposed Restoration Reach** Location: **Lower Trail Creek above Mouth** Date: **3/15/11**

Observers **Rosgen *et al*.** Gage Station #: **Goose Creek Gage** Stream Type: **B4** Valley Type: **VIII**

Equation Type	Equation Source	Equation	Bankfull Discharge (cfs)	Bankfull Bedload Sediment (kg/s)	Bankfull Suspended Sediment (mg/l)
1. Bedload Sediment	"Good/Fair" Pagosa	$y = -0.0113+1.0139x^{2.1929}$	40	0.0182	31.70
2. Suspended Sediment	"Good/Fair" Pagosa	$y = 0.0636+0.9326x^{2.4085}$			

From Dimensional Flow-Duration Curve							From Sediment Rating Curves				Calculate	Calculate Sediment Yield		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Percentage of Time	Daily Mean Discharge	Mid-Ordinate	Time Increment (percent)	Time Increment (days)	Mid-Ordinate Streamflow	Dimension-less Streamflow	Dimension-less Suspended Sediment Discharge	Suspended Sediment Discharge	Dimension-less Bedload Discharge	Bedload Sediment Discharge	Time Adjusted Streamflow [(5)×(6)]	Suspended Sediment [(5)×(9)]	Bedload Sediment [(5)×(11)]	Suspended + Bedload Sediment [(13)+(14)]
(%)	(cfs)	(%)	(%)	(days)	(cfs)	(Q/Q_{bkf})	(S/S_{bkf})	(tons/day)	(b_s/b_{bkf})	(tons/day)	(cfs)	(tons)	(tons)	(tons)
0%	178.8													
0.10%	153.5	0.05%	0.09%	0.34	166.2	4.154	28.858	410.47	23.017	39.99	57.0	140.83	13.72	154.55
0.25%	132.9	0.08%	0.15%	0.55	143.2	3.579	20.180	247.32	16.601	28.84	78.4	135.41	15.79	151.20
0.50%	114.8	0.13%	0.25%	0.91	123.8	3.095	14.241	150.94	12.070	20.97	113.0	137.73	19.13	156.87
0.75%	98.0	0.13%	0.25%	0.91	106.4	2.660	9.904	90.20	8.652	15.03	97.1	82.31	13.72	96.02
1%	84.8	0.13%	0.25%	0.91	91.4	2.285	6.889	53.90	6.198	10.77	83.4	49.18	9.82	59.01
1.5%	60.7	0.25%	0.50%	1.83	72.8	1.819	4.003	24.93	3.753	6.52	132.8	45.50	11.90	57.40
2%	51.1	0.25%	0.50%	1.83	55.9	1.398	2.153	10.30	2.102	3.65	102.0	18.80	6.66	25.46
3%	43.7	0.50%	1.00%	3.65	47.4	1.185	1.467	5.95	1.459	2.54	173.0	21.72	9.25	30.97
4%	38.9	0.50%	1.00%	3.65	41.3	1.032	1.070	3.78	1.075	1.87	150.7	13.80	6.82	20.62
5%	34.4	0.50%	1.00%	3.65	36.7	0.916	0.819	2.57	0.826	1.43	133.8	9.38	5.24	14.62
10%	24.4	2.50%	5.00%	18.25	29.4	0.736	0.509	1.28	0.506	0.88	537.2	23.41	16.05	39.46
20%	13.3	5.00%	10.00%	36.50	18.9	0.472	0.217	0.35	0.184	0.32	689.2	12.78	11.68	24.46
30%	8.9	5.00%	10.00%	36.50	11.1	0.278	0.106	0.10	0.050	0.09	405.4	3.69	3.16	6.84
40%	6.3	5.00%	10.00%	36.50	7.6	0.190	0.081	0.05	0.015	0.03	277.0	1.91	0.96	2.88
50%	4.8	5.00%	10.00%	36.50	5.6	0.139	0.072	0.03	0.002	0.00	202.7	1.24	0.13	1.37
60%	3.7	5.00%	10.00%	36.50	4.3	0.106	0.068	0.02	0.000	0.00	155.4	0.90	0.00	0.90
70%	3.0	5.00%	10.00%	36.50	3.3	0.083	0.066	0.02	0.000	0.00	121.6	0.69	0.00	0.69
80%	2.6	5.00%	10.00%	36.50	2.8	0.069	0.065	0.02	0.000	0.00	101.4	0.56	0.00	0.56
90%	1.9	5.00%	10.00%	36.50	2.2	0.056	0.064	0.01	0.000	0.00	81.1	0.45	0.00	0.45
100%	0.4	5.00%	10.00%	36.50	1.1	0.028	0.064	0.01	0.000	0.00	40.5	0.22	0.00	0.22
										Annual Totals:	3,732.8 (cfs) 7,404.1 (acre-ft)	700.5 (tons/yr)	144.0 (tons/yr)	844.6 (tons/yr)

Worksheet II-9. The sediment competence calculations for the proposed B4 stream type to be converted from the existing G stream type, lower Trail Creek.

Stream:	**Existing G4 Poor to Proposed B4**		Stream Type: **B4**		
Location:	**Lower Trail Creek above Mouth**		Valley Type: **VIII**		
Observers:	**Rosgen *et al*.**		Date: **3/15/2011**		
Enter Required Information for PROPOSED Design Condition					
8.0	D_{50}	Median particle size of riffle bed material (mm)			
6.0	$D^{\wedge}_{50}$	Median particle size of bar or sub-pavement sample (mm)			
0.26	D_{max}	Largest particle from bar sample (ft)	**80**	**(mm)**	304.8 mm/ft
0.0241	S	Proposed design bankfull water surface slope (ft/ft)			
0.85	d	Proposed design bankfull mean depth (ft)			
1.65	γ_s-γ/γ	Immersed specific gravity of sediment			
Select the Appropriate Equation and Calculate Critical Dimensionless Shear Stress					
1.33	$D_{50}/D^{\wedge}_{50}$	Range: 3 – 7	Use EQUATION 1: $\tau^* = 0.0834\ (\ D_{50}/D^{\wedge}_{50})^{-0.872}$		
10.00	D_{max}/D_{50}	Range: 1.3 – 3.0	Use EQUATION 2: $\tau^* = 0.0384\ (D_{max}/D_{50})^{-0.887}$		
N/A	τ^*	Bankfull Dimensionless Shear Stress	EQUATION USED:		**N/A**
Calculate Bankfull Mean Depth Required for Entrainment of Largest Particle in Bar Sample					
N/A	**d**	Required bankfull mean depth (ft)	$d = \frac{\tau^*(\gamma_s - 1)D_{max}}{S}$		(use D_{max} in ft)
Calculate Bankfull Water Surface Slope Required for Entrainment of Largest Particle in Bar Sample					
N/A	**S**	Required bankfull water surface slope (ft/ft)	$S = \frac{\tau^*(\gamma_s - 1)D_{max}}{d}$		(use D_{max} in ft)
Check: ☐ Stable ☐ Aggrading ☐ Degrading					
Sediment Competence Using Dimensional Shear Stress					
1.278		Bankfull shear stress $\tau = \gamma dS$ (lbs/ft^2) (substitute hydraulic radius, R, with mean depth, d) γ = 62.4, d = proposed design depth, S = proposed design slope			
Shields **100.7**	CO **182.1**	Predicted largest moveable particle size (mm) at bankfull shear stress τ **(Figure 5-49)**			
Shields **1.025**	CO **0.418**	Predicted shear stress required to initiate movement of measured D_{max} (mm) **(Figure 5-49)**			
Shields **0.68**	CO **0.28**	Predicted mean depth required to initiate movement of measured D_{max} (mm) τ = predicted shear stress, γ = 62.4, S = proposed design slope	$d = \frac{\tau}{\gamma S}$		
Shields **0.0193**	CO **0.0079**	Predicted slope required to initiate movement of measured D_{max} (mm) τ = predicted shear stress, γ = 62.4, d = proposed design depth	$S = \frac{\tau}{\gamma d}$		
Check: ☐ Stable ☐ Aggrading ☑ **Degrading***					

***Due to potential degradation, must incorporate grade control and high flow resistance bed structures**

Summary of the G4 to B4 Stream Type Conversion

The conversion from a G4 to B4 stream type represents the central tendency of stream succession to a stable "end point" channel in both a confined and entrenched stream system. The decrease in shear stress due to an increase of width/depth ratio is countered by an increase in entrenchment ratio (wider flood-prone area) to disperse flood-flow impacts. Log and rock structures are incorporated for grade control and to add flow resistance and habitat features. The increase in entrenchment ratio will exponentially reduce the very high streambank and streambed erosion from flood flows associated with the G4 stream type. The B4 stream type rarely stores sediment for future re-entrainment and efficiently routes sediment through without adding channel source sediment to the sediment supply; thus the increased post-fire flood flows will have small adverse effects on the B4 stream type compared to the G4 stream type.

Typical Design Scenario 4 Example

C4 *Poor* to C4 *Stable* Stability Conversion

(Valley Type VIII)

C4 Poor to C4 Stable Conversion (VT VIII): Typical Design Scenario 4 Example

General Description & Morphological Data

This typical design scenario is a stability conversion of a C4 *Poor* condition to a C4 *Stable* stream type. This existing, impaired condition is the *C4 Poor Representative Reach* that is located approximately *2,400 ft* upstream of the mouth of Trail Creek and is depicted on the general map in **Figure II-1**. The detailed characteristics and stability evaluation of this representative reach are documented in *Appendix C7* of the Waldo Canyon Fire *WARSSS* analysis (Rosgen *et al*., 2013). The existing reach is partially incised and confined, and is located above the existing G4 reach associated with an advancing headcut that is converting the C4 to an advancing G4 stream type. The typical characteristics and minimum vegetative influence associated with active streambank erosion for the existing C4 *Poor* reach are depicted in **Figure II-36**. For this design scenario, the reach length to be converted from a C4 *Poor* to C4 *Good* stability is approximately *300 ft*.

The specific objectives and direction for this design scenario to stabilize the reach are as follows:

- Reduce the sediment supply due to bed instability
- Reduce the accelerated streambank erosion rates
- Enhance fish habitat
- Restore the floodplain connectivity
- Restore the riparian function

The dimensionless relations of the *C4 Reference Reach* are used to generate the proposed C4 *Stable* design criteria, including the dimension, pattern, and profile, by scaling the relations to the drainage area and bankfull discharge of the proposed reach. The detailed characteristics and stability evaluation of the *C4 Reference Reach* are documented in *Appendix C20* of the Waldo Canyon Fire *WARSSS* analysis (Rosgen *et al*., 2013).

The resultant proposed dimension, pattern, and profile for the stable C4 design reach are documented in **Table II-5** using the procedure in **Appendix I**. Additionally, this table also includes a summary of the morphological descriptions and corresponding analyses of the existing *C4 Poor Representative Reach* and the *C4 Reference Reach*. The following sections include the proposed design details of the C4 *Stable* stream type.

Bankfull Discharge, Cross-Sectional Area & Mean Velocity

With a drainage area of *15.9 mi*^{2} for the proposed C4 stream type, the bankfull discharge is *40 cfs* and the proposed bankfull riffle cross-sectional area is *13.3 ft*^{2} as shown in **Table II-5**. Using continuity, the corresponding mean velocity for the proposed design reach is *3.0 ft/sec* as shown in **Worksheet II-10**. This worksheet is also used to check for reasonable velocities using the proposed design dimensions and slope using a variety of methods; these methods agree with the velocity estimate using continuity.



Figure II-36. The C4 *Poor* reach to be converted to a stable C4 stream type on the mainstem Trail Creek showing the minimal vegetative influence and associated active bank erosion.

Table II-5. The morphological characteristics of the existing, proposed design and reference reaches for the C4 *Poor* to C4 *Stable* conversion in a Valley Type VIII.

Existing Reach Stream & Location:			C4 Poor on Lower Trail Creek above Mouth					
Reference Reach Stream & Location:			C4 Reference on Trout Creek					
Entry Number & Variable			Existing Reach		Proposed Design Reach		Reference Reach	
	1	Valley Type	VIII		VIII		VIII	
	2	Valley Width	60		60			
	3	Stream Type	C4 Poor		C4		C4	
	4	Drainage Area, mi^2	15.9		15.9		71	
	5	Bankfull Discharge, cfs (Q_{bkf})	47.64		40		51.6	
Riffle Dimensions	6	Riffle Width, ft (W_{bkf})	*Mean:* *Min:* *Max:*	29.0	*Mean:* *Min:* *Max:*	13.5 12.0 15.0	*Mean:* *Min:* *Max:*	18.5 16.3 19.9
	7	Riffle Mean Depth, ft (d_{bkf})	*Mean:* *Min:* *Max:*	0.48	*Mean:* *Min:* *Max:*	0.99 0.89 1.09	*Mean:* *Min:* *Max:*	1.04 0.89 1.19
	8	Riffle Width/Depth Ratio (W_{bkf}/d_{bkf})	*Mean:* *Min:* *Max:*	60.5	*Mean:* *Min:* *Max:*	13.7 11.0 16.9	*Mean:* *Min:* *Max:*	18.1 13.7 21.8
	9	Riffle Cross-Sectional Area, ft^2 (A_{bkf})	*Mean:* *Min:* *Max:*	14.0	*Mean:*	13.3	*Mean:* *Min:* *Max:*	19.2 17.3 20.9
	10	Riffle Maximum Depth (d_{max})	*Mean:* *Min:* *Max:*	1.12	*Mean:* *Min:* *Max:*	1.70 1.55 1.85	*Mean:* *Min:* *Max:*	1.64 1.40 1.81
	11	Riffle Maximum Depth to Riffle Mean Depth (d_{max}/d_{bkf})	*Mean:* *Min:* *Max:*	2.333	*Mean:* *Min:* *Max:*	1.717 1.566 1.869	*Mean:* *Min:* *Max:*	1.575 1.429 1.724
	12	Width of Flood-Prone Area at Elevation of 2 * d_{max}, ft (W_{fpa})	*Mean:* *Min:* *Max:*	59.0	*Mean:* *Min:* *Max:*	40.5 29.7 81.0	*Mean:* *Min:* *Max:*	58.8 41.9 69.4
	13	Entrenchment Ratio (W_{fpa}/W_{bkf})	*Mean:* *Min:* *Max:*	2.0	*Mean:* *Min:* *Max:*	3.0 2.2 6.0	*Mean:* *Min:* *Max:*	3.2 2.2 4.0
Riffle Inner Berm Dimensions	14	Riffle Inner Berm Width, ft (W_{ib})	*Mean:* *Min:* *Max:*	14.4	*Mean:* *Min:* *Max:*	6.5 5.0 8.0	*Mean:* *Min:* *Max:*	11.4 10.4 12.9
	15	Riffle Inner Berm Width to Riffle Width (W_{ib}/W_{bkf})	*Mean:* *Min:* *Max:*	0.496	*Mean:* *Min:* *Max:*	0.481 0.370 0.593	*Mean:* *Min:* *Max:*	0.619 0.522 0.668
	16	Riffle Inner Berm Mean Depth, ft (d_{ib})	*Mean:* *Min:* *Max:*	0.35	*Mean:* *Min:* *Max:*	0.74 0.50 0.90	*Mean:* *Min:* *Max:*	0.57 0.38 0.73
	17	Riffle Inner Berm Mean Depth to Riffle Mean Depth (d_{ib}/d_{bkf})	*Mean:* *Min:* *Max:*	0.729	*Mean:* *Min:* *Max:*	0.747 0.505 0.909	*Mean:* *Min:* *Max:*	0.537 0.319 0.820
	18	Riffle Inner Berm Width/Depth Ratio (W_{ib}/d_{ib})	*Mean:* *Min:* *Max:*	41.1	*Mean:* *Min:* *Max:*	8.8 5.6 12.0	*Mean:* *Min:* *Max:*	21.3 17.6 28.7
	19	Riffle Inner Berm Cross-Sectional Area (A_{ib})	*Mean:* *Min:* *Max:*	5.0	*Mean:* *Min:* *Max:*	4.8 3.2 6.8	*Mean:* *Min:* *Max:*	6.5 4.1 9.4
	20	Riffle Inner Berm Cross-Sectional Area to Riffle Cross-Sectional Area (A_{ib}/A_{bkf})	*Mean:* *Min:* *Max:*	0.358	*Mean:* *Min:* *Max:*	0.361 0.241 0.511	*Mean:* *Min:* *Max:*	0.349 0.214 0.542

Table II-5 (Page 2). The morphological characteristics of the existing, proposed design and reference reaches for the C4 *Poor* to C4 *Stable* conversion in a Valley Type VIII.

	Entry Number & Variable		Existing Reach	Proposed Design Reach	Reference Reach
Pool Dimensions	**21**	Pool Width, ft (W_{bkfp})	*Mean:* **16.3** *Min:* *Max:*	*Mean:* **13.4** *Min:* **13.0** *Max:* **14.0**	*Mean:* **26.5** *Min:* *Max:*
	22	Pool Width to Riffle Width (W_{bkfp}/W_{bkf})	*Mean:* **0.563** *Min:* *Max:*	*Mean:* **0.993** *Min:* **0.963** *Max:* **1.037**	*Mean:* **1.432** *Min:* *Max:*
	23	Pool Mean Depth, ft (d_{bkfp})	*Mean:* **0.81** *Min:* *Max:*	*Mean:* **1.39** *Min:* **1.20** *Max:* **1.40**	*Mean:* **1.02** *Min:* *Max:*
	24	Pool Mean Depth to Riffle Mean Depth (d_{bkfp}/d_{bkf})	*Mean:* **1.688** *Min:* *Max:*	*Mean:* **1.404** *Min:* **1.212** *Max:* **1.414**	*Mean:* **0.981** *Min:* *Max:*
	25	Pool Width/Depth Ratio (W_{bkfp}/d_{bkfp})	*Mean:* **20.2** *Min:* *Max:*	*Mean:* **9.6** *Min:* **9.3** *Max:* **11.7**	*Mean:* **26.0** *Min:* *Max:*
	26	Pool Cross-Sectional Area, ft^2 (A_{bkfp})	*Mean:* **13.3** *Min:* *Max:*	*Mean:* **18.6** *Min:* **16.0** *Max:* **22.0**	*Mean:* **27.1** *Min:* *Max:*
	27	Pool Area to Riffle Area (A_{bkfp}/A_{bkf})	*Mean:* **0.951** *Min:* *Max:*	*Mean:* **1.398** *Min:* **1.203** *Max:* **1.654**	*Mean:* **1.409** *Min:* *Max:*
	28	Pool Maximum Depth (d_{maxp})	*Mean:* **1.54** *Min:* *Max:*	*Mean:* **3.10** *Min:* **2.80** *Max:* **3.50**	*Mean:* **2.91** *Min:* *Max:*
	29	Pool Maximum Depth to Riffle Mean Depth (d_{maxp}/d_{bkf})	*Mean:* **3.208** *Min:* *Max:*	*Mean:* **3.131** *Min:* **2.828** *Max:* **3.535**	*Mean:* **2.798** *Min:* *Max:*
	30	Point Bar Slope (S_{pb})	*Mean:* **0.220** *Min:* *Max:*	*Mean:* **0.350** *Min:* **0.260** *Max:* **0.400**	*Mean:* **0.260** *Min:* *Max:*
Pool Inner Berm Dimensions	**31**	Pool Inner Berm Width, ft (W_{ibp})	*Mean:* **12.7** *Min:* *Max:*	*Mean:* **8.2** *Min:* *Max:*	*Mean:* **9.4** *Min:* *Max:*
	32	Pool Inner Berm Width to Pool Width (W_{ibp}/W_{bkfp})	*Mean:* **0.778** *Min:* *Max:*	*Mean:* **0.612** *Min:* *Max:*	*Mean:* **0.354** *Min:* *Max:*
	33	Pool Inner Berm Mean Depth, ft (d_{ibp})	*Mean:* **0.50** *Min:* *Max:*	*Mean:* **1.39** *Min:* *Max:*	*Mean:* **0.92** *Min:* *Max:*
	34	Pool Inner Berm Mean Depth to Pool Mean Depth (d_{ibp}/d_{bkfp})	*Mean:* **0.617** *Min:* *Max:*	*Mean:* **1.000** *Min:* *Max:*	*Mean:* **0.902** *Min:* *Max:*
	35	Pool Inner Berm Width/Depth Ratio (W_{ibp}/d_{ibp})	*Mean:* **25.4** *Min:* *Max:*	*Mean:* **5.9** *Min:* *Max:*	*Mean:* **10.2** *Min:* *Max:*
	36	Pool Inner Berm Cross-Sectional Area (A_{ibp})	*Mean:* **6.4** *Min:* *Max:*	*Mean:* **9.1** *Min:* *Max:*	*Mean:* **8.6** *Min:* *Max:*
	37	Pool Inner Berm Cross-Sectional Area to Pool Cross-Sectional Area (A_{ibp}/A_{bkfp})	*Mean:* **0.483** *Min:* *Max:*	*Mean:* **0.490** *Min:* *Max:*	*Mean:* **0.319** *Min:* *Max:*

Table II-5 (Page 3). The morphological characteristics of the existing, proposed design and reference reaches for the C4 *Poor* to C4 *Stable* conversion in a Valley Type VIII.

	Entry Number & Variable		Existing Reach	Proposed Design Reach	Reference Reach
Run Dimensions	**38**	Run Width, ft (W_{bkfr})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **12.5** *Min:* *Max:*	*Mean:* **24.2** *Min:* *Max:*
	39	Run Width to Riffle Width (W_{bkfr}/W_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.926** *Min:* *Max:*	*Mean:* **1.308** *Min:* *Max:*
	40	Run Mean Depth, ft (d_{bkfr})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.38** *Min:* **1.30** *Max:* **1.40**	*Mean:* **0.62** *Min:* *Max:*
	41	Run Mean Depth to Riffle Mean Depth (d_{bkfr}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.394** *Min:* **1.313** *Max:* **1.414**	*Mean:* **0.596** *Min:* *Max:*
	42	Run Width/Depth Ratio (W_{bkfr}/d_{bkfr})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **9.1** *Min:* *Max:*	*Mean:* **39.1** *Min:* *Max:*
	43	Run Cross-Sectional Area, ft^2 (A_{bkfr})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **17.2** *Min:* *Max:*	*Mean:* **15.1** *Min:* *Max:*
	44	Run Area to Riffle Area (A_{bkfr}/A_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.293** *Min:* *Max:*	*Mean:* **0.785** *Min:* *Max:*
	45	Run Maximum Depth (d_{maxr})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **2.00** *Min:* *Max:*	*Mean:* **1.50** *Min:* *Max:*
	46	Run Maximum Depth to Riffle Mean Depth (d_{maxr}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **2.020** *Min:* *Max:*	*Mean:* **1.442** *Min:* *Max:*
Glide Dimensions	**47**	Glide Width, ft (W_{bkfg})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **14.6** *Min:* **14.0** *Max:* **15.0**	*Mean:* **22.0** *Min:* *Max:*
	48	Glide Width to Riffle Width (W_{bkfg}/W_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.081** *Min:* **1.037** *Max:* **1.111**	*Mean:* **1.189** *Min:* *Max:*
	49	Glide Mean Depth, ft (d_{bkfg})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.80** *Min:* *Max:*	*Mean:* **0.98** *Min:* *Max:*
	50	Glide Mean Depth to Riffle Mean Depth (d_{bkfg}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.808** *Min:* *Max:*	*Mean:* **0.942** *Min:* *Max:*
	51	Glide Width/Depth Ratio (W_{bkfg}/d_{bkfg})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **18.25** *Min:* *Max:*	*Mean:* **22.5** *Min:* *Max:*
	52	Glide Cross-Sectional Area, ft^2 (A_{bkfg})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **11.6** *Min:* *Max:*	*Mean:* **21.5** *Min:* *Max:*
	53	Glide Area to Riffle Area (A_{bkfg}/A_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.872** *Min:* *Max:*	*Mean:* **1.122** *Min:* *Max:*
	54	Glide Maximum Depth (d_{maxg})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.10** *Min:* *Max:*	*Mean:* **1.62** *Min:* *Max:*
	55	Glide Maximum Depth to Riffle Mean Depth (d_{maxg}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.111** *Min:* *Max:*	*Mean:* **1.558** *Min:* *Max:*

Table II-5 (Page 4). The morphological characteristics of the existing, proposed design and reference reaches for the C4 *Poor* to C4 *Stable* conversion in a Valley Type VIII.

Entry Number & Variable		Existing Reach	Proposed Design Reach	Reference Reach
Glide Inner Berm Dimensions	**56** Glide Inner Berm Width, ft (W_{ibg})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **8.2** *Min:* *Max:*	*Mean:* **12.9** *Min:* *Max:*
	57 Glide Inner Berm Width to Glide Width (W_{ibg}/W_{bkfg})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.562** *Min:* *Max:*	*Mean:* **0.583** *Min:* *Max:*
	58 Glide Inner Berm Mean Depth, ft (d_{ibg})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.56** *Min:* *Max:*	*Mean:* **0.48** *Min:* *Max:*
	59 Glide Inner Berm Mean Depth to Glide Mean Depth (d_{ibg}/d_{bkfg})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.700** *Min:* *Max:*	*Mean:* **0.490** *Min:* *Max:*
	60 Glide Inner Berm Width/Depth Ratio (W_{ibg}/d_{ibg})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **14.6** *Min:* *Max:*	*Mean:* **26.8** *Min:* *Max:*
	61 Glide Inner Berm Cross-Sectional Area (A_{ibg})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **4.6** *Min:* *Max:*	*Mean:* **6.2** *Min:* *Max:*
	62 Glide Inner Berm Area to Glide Area (A_{ibg}/A_{bkfg})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.393** *Min:* *Max:*	*Mean:* **0.287** *Min:* *Max:*

Table II-5 (Page 5). The morphological characteristics of the existing, proposed design and reference reaches for the C4 *Poor* to C4 *Stable* conversion in a Valley Type VIII.

	Entry Number & Variable		Existing Reach		Proposed Design Reach		Reference Reach	
Channel Pattern	**72**	Linear Wavelength, ft (λ)	*Mean:*	**89.1**	*Mean:*	**96.0**	*Mean:*	**84.5**
			Min:		*Min:*	**75.0**	*Min:*	**62.0**
			Max:		*Max:*	**117.0**	*Max:*	**114.5**
	73	Linear Wavelength to Riffle Width (λ/W_{bkf})	*Mean:*	**3.070**	*Mean:*	**7.111**	*Mean:*	**4.558**
			Min:		*Min:*	**5.556**	*Min:*	**3.345**
			Max:		*Max:*	**8.667**	*Max:*	**6.178**
	74	Stream Meander Length, ft (L_m)	*Mean:*	**123.0**	*Mean:*	**138.0**	*Mean:*	**104.6**
			Min:		*Min:*	**108.0**	*Min:*	**72.6**
			Max:		*Max:*	**168.0**	*Max:*	**161.0**
	75	Stream Meander Length Ratio (L_m/W_{bkf})	*Mean:*	**4.238**	*Mean:*	**10.222**	*Mean:*	**5.645**
			Min:		*Min:*	**8.000**	*Min:*	**3.917**
			Max:		*Max:*	**12.444**	*Max:*	**8.687**
	76	Belt Width, ft (W_{blt})	*Mean:*	**40.1**	*Mean:*	**60.0**	*Mean:*	**66.1**
			Min:	**24.1**	*Min:*	**40.5**	*Min:*	**42.8**
			Max:	**48.2**	*Max:*	**82.0**	*Max:*	**82.8**
	77	Meander Width Ratio (W_{blt}/W_{bkf})	*Mean:*	**1.382**	*Mean:*	**4.444**	*Mean:*	**3.567**
			Min:	**0.830**	*Min:*	**3.000**	*Min:*	**2.309**
			Max:	**1.661**	*Max:*	**6.074**	*Max:*	**4.468**
	78	Radius of Curvature, ft (R_c)	*Mean:*	**34.2**	*Mean:*	**42.0**	*Mean:*	**31.1**
			Min:	**19.5**	*Min:*	**36.0**	*Min:*	**23.9**
			Max:	**55.3**	*Max:*	**56.0**	*Max:*	**41.7**
	79	Radius of Curvature to Riffle Width (R_c/W_{bkf})	*Mean:*	**1.178**	*Mean:*	**3.111**	*Mean:*	**1.677**
			Min:	**0.672**	*Min:*	**2.667**	*Min:*	**1.290**
			Max:	**1.906**	*Max:*	**4.148**	*Max:*	**2.250**
	80	Arc Length, ft (L_a)	*Mean:*	**N/A**	*Mean:*	**27.4**	*Mean:*	**37.7**
			Min:		*Min:*	**14.6**	*Min:*	**20.1**
			Max:		*Max:*	**33.5**	*Max:*	**46.0**
	81	Arc Length to Riffle Width (L_a/W_{bkf})	*Mean:*	**N/A**	*Mean:*	**2.033**	*Mean:*	**2.033**
			Min:		*Min:*	**1.085**	*Min:*	**1.085**
			Max:		*Max:*	**2.482**	*Max:*	**2.482**
	82	Riffle Length (L_r), ft	*Mean:*	**18.8**	*Mean:*	**30.4**	*Mean:*	**23.1**
			Min:	**16.1**	*Min:*	**13.5**	*Min:*	**8.5**
			Max:	**23.2**	*Max:*	**54.0**	*Max:*	**82.4**
	83	Riffle Length to Riffle Width (L_r/W_{bkf})	*Mean:*	**0.648**	*Mean:*	**2.252**	*Mean:*	**1.245**
			Min:	**0.555**	*Min:*	**1.000**	*Min:*	**0.459**
			Max:	**0.799**	*Max:*	**4.000**	*Max:*	**4.446**
	84	Individual Pool Length, ft (L_p)	*Mean:*	**6.7**	*Mean:*	**20.3**	*Mean:*	**17.6**
			Min:	**2.0**	*Min:*	**13.5**	*Min:*	**8.5**
			Max:	**12.0**	*Max:*	**27.0**	*Max:*	**27.5**
	85	Pool Length to Riffle Width (L_p/W_{bkf})	*Mean:*	**0.232**	*Mean:*	**1.504**	*Mean:*	**0.949**
			Min:	**0.067**	*Min:*	**1.000**	*Min:*	**0.459**
			Max:	**0.414**	*Max:*	**2.000**	*Max:*	**1.485**
	86	Pool to Pool Spacing, ft (P_s)	*Mean:*	**33.4**	*Mean:*	**75.0**	*Mean:*	**55.5**
			Min:	**8.8**	*Min:*	**60.0**	*Min:*	**22.0**
			Max:	**131.0**	*Max:*	**90.0**	*Max:*	**107.5**
	87	Pool to Pool Spacing to Riffle Width (P_s/W_{bkf})	*Mean:*	**1.151**	*Mean:*	**5.556**	*Mean:*	**2.996**
			Min:	**0.303**	*Min:*	**4.444**	*Min:*	**1.187**
			Max:	**4.514**	*Max:*	**6.667**	*Max:*	**5.800**

Table II-5 (Page 6). The morphological characteristics of the existing, proposed design and reference reaches for the C4 *Poor* to C4 *Stable* conversion in a Valley Type VIII.

	Entry Number & Variable	Existing Reach	Proposed Design Reach	Reference Reach
Sinuosity and Slope	**88** Stream Length (SL)	**300.0**	**300.0**	**567.7**
	89 Valley Length (VL)	**217.4**	**217.4**	**411.3**
	90 Valley Slope (S_{val})	**0.0200**	**0.0200**	**0.0061**
	91 Sinuosity (k)	SL/VL: **1.38** VS/S: **1.38**	SL/VL: **1.38**	SL/VL: **1.38** VS/S: **1.38**
	92 Average Water Surface Slope (S)	**0.0145**	$S = S_{val}/k$ **0.0145**	**0.0044**
Flood-Prone Area Dim.	**93** Flood-Prone Area Width, ft (W_{fpa})	*Mean:* **59.2** *Min:* *Max:*	*Mean:* **40.5** *Min:* *Max:*	*Mean:* **40.7** *Min:* *Max:*
	94 Flood-Prone Area Mean Depth, ft (d_{fpa})	*Mean:* **1.00** *Min:* *Max:*	*Mean:* **1.82** *Min:* *Max:*	*Mean:* **1.89** *Min:* *Max:*
	95 Flood-Prone Area Cross-Sectional Area, ft^2 (A_{fpa})	*Mean:* **59.0** *Min:* *Max:*	*Mean:* **73.7** *Min:* *Max:*	*Mean:* **76.8** *Min:* *Max:*
Floodplain Dimensions	**96** Floodplain Width, ft (W_f)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	97 Floodplain Mean Depth, ft (d_f)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	98 Floodplain Cross-Sectional Area, ft^2 (A_f)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
Low Terrace Dim.	**99** Low Terrace Width, ft (W_{lt})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	100 Low Terrace Mean Depth, ft (d_{lt})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	101 Low Terrace Cross-Sectional Area, ft^2 (A_{lt})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
Degree of Incision	**102** Low Bank Height (LBH)	*Mean:* **1.33** *Min:* **1.12** *Max:* **1.54**	*Mean:* **2.10** *Min:* **1.10** *Max:* **3.10**	*Mean:* **1.60** *Min:* **1.40** *Max:* **1.80**
	103 Maximum Bankfull Depth (d_{max}) at Same Location as Low Bank Height (LBH) Measurement	*Mean:* **1.33** *Min:* **1.12** *Max:* **1.54**	*Mean:* **2.10** *Min:* **1.10** *Max:* **3.10**	*Mean:* **1.60** *Min:* **1.40** *Max:* **1.80**
	104 Bank-Height Ratio (LBH/d_{max})	*Mean:* **1.00** *Min:* **1.00** *Max:* **1.00**	*Mean:* **1.00** *Min:* **1.00** *Max:* **1.00**	*Mean:* **1.00** *Min:* **1.00** *Max:* **1.00**

Table II-5 (Page 7). The morphological characteristics of the existing, proposed design and reference reaches for the C4 *Poor* to C4 *Stable* conversion in a Valley Type VIII.

	Entry Number & Variable		Existing Reach		Proposed Design Reach		Reference Reach	
Bed Feature Water Surface Facet Slopes and Dimensionless Ratios from Profile	**105**	Riffle Slope (water surface facet slope) (S_{rif})	*Mean:* *Min:* *Max:*	**0.0160**	*Mean:* *Min:* *Max:*	**0.0148** **0.0094** **0.0179**	*Mean:* *Min:* *Max:*	**0.0045** **0.0029** **0.0054**
	106	Riffle Slope to Average Water Surface Slope (S_{rif}/S)	*Mean:* *Min:* *Max:*	**1.1034**	*Mean:* *Min:* *Max:*	**1.0205** **0.6477** **1.2341**	*Mean:* *Min:* *Max:*	**1.0205** **0.6477** **1.2341**
	107	Pool Slope (water surface facet slope) (S_p)	*Mean:* *Min:* *Max:*	**0.0110**	*Mean:* *Min:* *Max:*	**0.0076** **0.0027** **0.0125**	*Mean:* *Min:* *Max:*	**0.0023** **0.0008** **0.0038**
	108	Pool Slope to Average Water Surface Slope (S_p/S)	*Mean:* *Min:* *Max:*	**0.7586**	*Mean:* *Min:* *Max:*	**0.5250** **0.1841** **0.8636**	*Mean:* *Min:* *Max:*	**0.5250** **0.1841** **0.8636**
	109	Run Slope (water surface facet slope) (S_{run})	*Mean:* *Min:* *Max:*	**0.0240**	*Mean:* *Min:* *Max:*	**0.0371** **0.0218** **0.0460**	*Mean:* *Min:* *Max:*	**0.0113** **0.0066** **0.0140**
	110	Run Slope to Average Water Surface Slope (S_{run}/S)	*Mean:* *Min:* *Max:*	**1.6552**	*Mean:* *Min:* *Max:*	**2.5614** **1.5000** **3.1705**	*Mean:* *Min:* *Max:*	**2.5614** **1.5000** **3.1705**
	111	Glide Slope (water surface facet slope) (S_g)	*Mean:* *Min:* *Max:*	**0.0170**	*Mean:* *Min:* *Max:*	**0.0112** **0.0086** **0.0129**	*Mean:* *Min:* *Max:*	**0.0034** **0.0026** **0.0039**
	112	Glide Slope to Average Water Surface Slope (S_g/S)	*Mean:* *Min:* *Max:*	**1.1724**	*Mean:* *Min:* *Max:*	**0.7750** **0.5909** **0.8864**	*Mean:* *Min:* *Max:*	**0.7750** **0.5909** **0.8864**
	113	Step Slope (water surface facet slope) (S_s)	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**N/A**
	114	Step Slope to Average Water Surface Slope (S_s/S)	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**N/A**

Table II-5 (Page 8). The morphological characteristics of the existing, proposed design and reference reaches for the C4 *Poor* to C4 *Stable* conversion in a Valley Type VIII.

	Entry Number & Variable	Existing Reach	Proposed Design Reach	Reference Reach
Bed Feature Max Depth Measurements and Dimensionless Ratios from Profile	**115** Riffle Maximum Depth, ft (d_{max})	*Mean:* **1.56** *Min:* **1.34** *Max:* **1.71**	*Mean:* **1.70** *Min:* **1.41** *Max:* **1.80**	*Mean:* **1.60** *Min:* **1.40** *Max:* **1.75**
	116 Riffle Maximum Depth to Riffle Mean Depth (d_{max}/d_{bkf})	*Mean:* **3.250** *Min:* **2.792** *Max:* **3.563**	*Mean:* **1.717** *Min:* **1.424** *Max:* **1.818**	*Mean:* **1.534** *Min:* **1.342** *Max:* **1.677**
	117 Pool Maximum Depth, ft (d_{maxp})	*Mean:* **1.77** *Min:* **1.60** *Max:* **1.99**	*Mean:* **3.10** *Min:* **2.80** *Max:* **3.50**	*Mean:* **2.46** *Min:* **2.12** *Max:* **2.95**
	118 Pool Maximum Depth to Riffle Mean Depth (d_{maxp}/d_{bkf})	*Mean:* **3.688** *Min:* **3.333** *Max:* **4.146**	*Mean:* **3.131** *Min:* **2.828** *Max:* **3.535**	*Mean:* **2.358** *Min:* **2.038** *Max:* **2.837**
	119 Run Maximum Depth, ft (d_{maxr})	*Mean:* **1.50** *Min:* **1.35** *Max:* **1.65**	*Mean:* **2.00** *Min:* **1.50** *Max:* **2.20**	*Mean:* **1.74** *Min:* **1.57** *Max:* **1.95**
	120 Run Maximum Depth to Riffle Mean Depth (d_{maxr}/d_{bkf})	*Mean:* **3.125** *Min:* **2.813** *Max:* **3.438**	*Mean:* **2.020** *Min:* **1.515** *Max:* **2.222**	*Mean:* **1.668** *Min:* **1.505** *Max:* **1.869**
	121 Glide Maximum Depth, ft (d_{maxg})	*Mean:* **1.66** *Min:* **1.59** *Max:* **1.82**	*Mean:* **1.10** *Min:* **1.00** *Max:* **1.30**	*Mean:* **1.25** *Min:* **1.00** *Max:* **1.40**
	122 Glide Maximum Depth to Riffle Mean Depth (d_{maxg}/d_{bkf})	*Mean:* **3.458** *Min:* **3.313** *Max:* **3.792**	*Mean:* **1.111** *Min:* **1.010** *Max:* **1.313**	*Mean:* **1.200** *Min:* **0.960** *Max:* **1.340**
	123 Step Maximum Depth, ft (d_{maxs})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	124 Step Maximum Depth to Riffle Mean Depth (d_{maxs}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
Channel Materials	**125 Particle Size Distribution of Channel Material (Active Bed) or Pavement**			
	D_{16} (mm)	**1.9**	**1.9**	**4.3**
	D_{35} (mm)	**5.0**	**5.0**	**7.1**
	D_{50} (mm)	**7.2**	**7.2**	**9.7**
	D_{84} (mm)	**18.3**	**18.3**	**26.4**
	D_{95} (mm)	**50.1**	**50.1**	**42.5**
	D_{100} (mm)	**90.0**	**90.0**	**180.0**
	126 Particle Size Distribution of Bar Material or Sub-pavement			
	D_{16} (mm)	**0.0**	**0.0**	**0.0**
	D_{35} (mm)	**0.0**	**0.0**	**4.5**
	D_{50} (mm)	**4.2**	**4.2**	**7.7**
	D_{84} (mm)	**53.2**	**53.2**	**41.7**
	D_{95} (mm)	**89.8**	**89.8**	**69.6**
	D_{max}: Largest size particle at the toe (lower third) of bar (mm) or sub-pavement	**110.0**	**110.0**	**74.0**

Table II-5 (Page 9). The morphological characteristics of the existing, proposed design and reference reaches for the C4 *Poor* to C4 *Stable* conversion in a Valley Type VIII.

	Entry Number & Variable		Existing Reach	Proposed Design Reach	Reference Reach
Hydraulics	127	Estimated Bankfull Mean Velocity, ft/sec (u_{bkf})	**3.41**	**3.0**	**3.0**
	128	Estimated Bankfull Discharge, cfs (Q_{bkf}); Compare with Regional Curve	**47.6**	**40.0**	**51.6**
Sediment Competence	129	Calculated bankfull shear stress value, lbs/ft^2 (τ)	**0.419**	**0.896**	**0.327**
	130	Predicted largest moveable particle size (mm) at bankfull shear stress, τ, using the original **Shields** relation	**30.0**	**70**	**24.0**
	131	Predicted largest moveable particle size (mm) at bankfull shear stress, τ, using the **Colorado** relation	**80.0**	**140**	**70.0**
	132	Largest particle size to be moved (D_{max}) (mm) (see #126: Particle Size Distribution of Bar Material)	**110**	**110**	**74.0**
	133	Predicted shear stress required to initiate movement of D_{max} (mm) using the original **Shields** relation	**1.600**	**1.391**	**1.000**
	134	Predicted shear stress required to initiate movement of D_{max} (mm) using the **Colorado** relation	**0.660**	**0.644**	**0.350**
	135	Predicted mean depth required to initiate movement of D_{max} (mm), d = $\tau/\gamma S$ (τ = predicted shear stress, γ = 62.4, S = existing or design slope) (**Shields**)	**1.83**	**1.54**	**3.64**
	136	Predicted mean depth required to initiate movement of D_{max} (mm), d = $\tau/\gamma S$ (τ = predicted shear stress, γ = 62.4, S = existing or design slope) (**Colorado**)	**1.83**	**0.71**	**3.64**
	137	Predicted slope required to initiate movement of D_{max} (mm) $S=\tau/\gamma d$ (τ = predicted shear stress, γ = 62.4, d = existing or design depth) (**Shields**)	**0.0534**	**0.0225**	**0.0135**
	138	Predicted slope required to initiate movement of D_{max} (mm) $S=\tau/\gamma d$ (τ = predicted shear stress, γ = 62.4, d = existing or design depth) (**Colorado**)	**0.0220**	**0.0104**	**0.0047**
	139	Bankfull dimensionless shear stress (τ^*) (see competence form)	**N/A**	**N/A**	**N/A**
	140	Required bankfull mean depth d_{bkf} (ft) using dimensionless shear stress equation: $d_{bkf} = \tau^*(\gamma_s - 1)D_{max}/S$ (Note: D_{max} in ft)	**N/A**	**N/A**	**N/A**
	141	Required bankfull water surface slope S (ft) using dimensionless shear stress equation: $S = \tau^*(\gamma_s - 1)D_{max}/d_{bkf}$ (Note: D_{max} in ft)	**N/A**	**N/A**	**N/A**

Table II-5 (Page 10). The morphological characteristics of the existing, proposed design and reference reaches for the C4 *Poor* to C4 *Stable* conversion in a Valley Type VIII.

	Entry Number & Variable	Existing Reach	Proposed Design Reach	Reference Reach
Sediment Yield	**Sediment Yield (FLOWSED)***	**Existing Reach***	**Proposed Design Reach***	**Difference in Sediment Yield***
	141 Bedload Sediment Yield (tons/yr)	**5,416.0**	**144.0**	**5,272.0**
	142 Suspended Sediment Yield (tons/yr)	**18,774.4**	**700.5**	**18,073.9**
	143 Suspended Sand Sediment Yield (tons/yr)	**9,387.2**	**350.3**	**9,037.0**
	144 Total Annual Sediment Yield (tons/yr)	**24,190.4**	**844.6**	**23,345.8**
***Reduction in sediment supply due to using "Good" sediment supply bankfull values by drainage area and "Good" dimensionless sediment rating curves vs "Poor" as a result of converting from the C4 (Poor) to C4 (Good) stream type.**				
Bank Erosion	**Streambank Erosion**	**Existing Reach**	**Proposed Design Reach**	**Reference Reach**
	145 Stream Length Assessed (ft)	**300**	**300**	**463**
	146 Graph/Curve Used (e.g., Yellowstone or Colorado)	**Colorado**	**Colorado**	**Colorado**
	147 Streambank Erosion (tons/yr)	**14.15**	**1.90**	**2.94**
	148 Streambank Erosion (tons/yr/ft)	**0.0472**	**0.0063**	**0.0063**

Worksheet II-10. The mean velocity estimates for the proposed C4 *Stable* reach to be converted from the existing, C4 *Poor* condition stream type, Valley Type VIII.

Bankfull VELOCITY & DISCHARGE Estimates

Stream:	**Proposed B4 from Existing G4**			Location:	**Lower Trail Creek above Mouth**
Date:	**3/15/2011**	Stream Type:	**B4**	Valley Type:	**VIII**
Observers:	**Rosgen *et al*.**			HUC:	_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

Input Variables for PROPOSED Design			Output Variables for PROPOSED Design		
Bankfull Riffle Cross-Sectional AREA	**8.80**	**A_{bkf}** (ft^2)	Bankfull Riffle Mean DEPTH	**0.85**	**d_{bkf}** (ft)
Bankfull Riffle WIDTH	**10.4**	**W_{bkf}** (ft)	Wetted PERMIMETER ~ (2 * d_{bkf}) + W_{bkf}	**12.09**	**W_p** (ft)
Protrusion Height of Dunes	**61.0**	**Dia.** (mm)	***Prot. Height*** (mm) / 304.8	**0.20**	**D_{84}** (ft)
Bankfull SLOPE	**0.0241**	**S_{bkf}** (ft / ft)	Hydraulic RADIUS A_{bkf} / W_p	**0.73**	**R** (ft)
Gravitational Acceleration	**32.2**	**g** (ft / sec^2)	Relative Roughness R(ft) / D_{84} (ft)	**3.64**	**R / D_{84}**
Drainage Area	**15.9**	**DA** (mi^2)	Shear Velocity $u^* = (gRS)^{½}$	**0.751**	**u*** (ft/sec)

ESTIMATION METHODS	Bankfull VELOCITY		Bankfull DISCHARGE	
1. Friction Factor / Relative Roughness $u = [\ 2.83 + 5.66 * Log\ \{ R / D_{84} \}\ ]\ u^*$	**4.51**	ft / sec	**39.70**	cfs
2. Roughness Coefficient: a) Manning's *n* from Friction Factor / Relative Roughness (Figs. 5-7, 5-8) $u = 1.49*R^{2/3}*S^{1/2} / n$ ***n* =** **0.048**	**3.90**	ft / sec	**34.31**	cfs
2. Roughness Coefficient: b) Manning's *n* from Stream Type (Fig. 5-9) $u = 1.49*R^{2/3}*S^{1/2} / n$ ***n* =** **0.058**	**3.23**	ft / sec	**28.39**	cfs
2. Roughness Coefficient: c) Manning's *n* from Jarrett (USGS): $u = 1.49*R^{2/3}*S^{1/2} / n$ $n = 0.39*S^{0.38}*R^{-0.16}$ **Note:** This equation is applicable to **steep, step/pool, high boundary roughness, cobble- and boulder-dominated stream systems**; i.e., for Stream Types A1, A2, A3, B1, B2, B3, C2 & E3 ***n* =** **N/A**	**N/A**	ft / sec	**N/A**	cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)		ft / sec		cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)		ft / sec		cfs
4. Continuity Equations: a) USGS Gage Data $u = Q / A$ **Return Period for Bankfull Dis. Q =** _____ **year**		ft / sec		cfs
4. Continuity Equations: b) Regional Curves $u = Q / A$	**4.55**	ft / sec	**40.0**	cfs

Protrusion Height Options for the D_{84} Term in the Relative Roughness Relation (R/D_{84}) – Estimation Method 1

Option 1.	For **sand-bed** channels: Measure 100 **"protrusion heights"** of sand dunes from the downstream side of feature to the top of feature. Substitute the D_{84} sand dune protrusion height in ft for the D_{84} term in method 1.
Option 2.	For **boulder-dominated** channels: Measure 100 **"protrusion heights"** of boulders on the sides from the bed elevation to the top of the rock on that side. Substitute the D_{84} boulder protrusion height in ft for the D_{84} term in method 1.
Option 3.	For **bedrock-dominated** channels: Measure 100 **"protrusion heights"** of rock separations, steps, joints or uplifted surfaces above channel bed elevation. Substitute the D_{84} bedrock protrusion height in ft for the D_{84} term in method 1.
Option 4.	For **log-influenced** channels: Measure "**protrustion heights**" proportionate to channel width of log diameters or the height of the log on upstream side if embedded. Substitute the D_{84} protrusion height in ft for the D_{84} term in method 1.

Plan View Alignment

The proposed C4 *Stable* alignment over the existing reach is shown on the aerial photograph in **Figure II-37**, which corresponds with the proposed pattern values developed from the dimensionless ratios of the *C4 Reference Reach* in **Table II-5**. The existing cross-section locations of the C4 *Poor* condition stream type are also shown in **Figure II-37**.

Cross-Section Dimensions

Table II-5 includes the proposed dimensions for riffles, pools, glides and runs for the proposed C4 design reach that were developed and scaled from the reference reach dimensionless relations. The overlay of the existing C4 *Poor* cross-section 0+27 *vs*. proposed C4 *riffle* cross-section, indicating the proposed reach dimensions and cut and fill requirements, is shown in **Figure II-38**. This overlay also shows the reduction of the bank-height ratio to reconnect the proposed channel with the active floodplain. Similarly, the existing C4 *Poor* cross-section 1+27.3 *vs*. the proposed C4 *pool* cross-section is shown in **Figure II-39**. The locations of cross-section 0+27 and cross-section 1+27.3 are indicated in **Figure II-37**. Typical design cross-sections and dimensions are also shown for a *glide* in **Figure II-40**, and for a *run* in **Figure II-41**.

Longitudinal Profile

The typical longitudinal profile for the proposed C4 *Stable* design reach is shown in **Figure II-42** compared to the existing C4 *Poor* profile. The proposed elevations of the streambed and bankfull stage, the energy slope, and the typical locations of the various bed features that correspond to the plan view are also shown (**Figure II-42**). Additionally, the locations of the cross-section overlays in **Figure II-38** and **Figure II-39** are depicted on the typical longitudinal profile that corresponds with the proposed design bed features.

Insert 11 x 17 Figure II-37 Here

Figure II-37. Plan view of the alignment for the proposed C4 stream type, including the existing cross-section locations of the C4 *Poor* condition stream type.

Insert 11 x 17 Figure II-37 Here

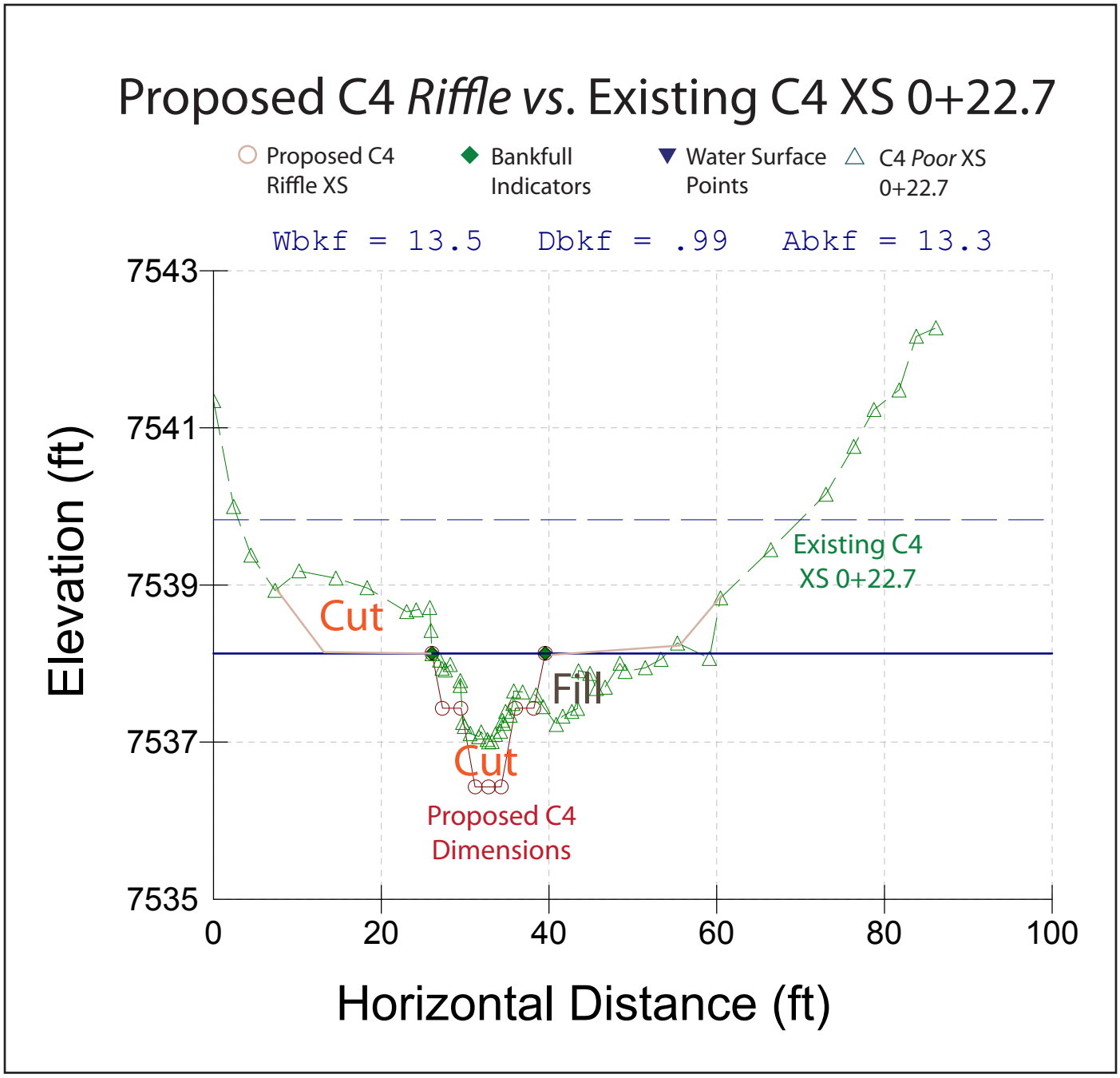


Figure II-38. The proposed C4 *Stable riffle* cross-section compared to the existing C4 *Poor* cross-section 0+27 showing the cut and fill recommendations and reconnecting the channel with the floodplain.

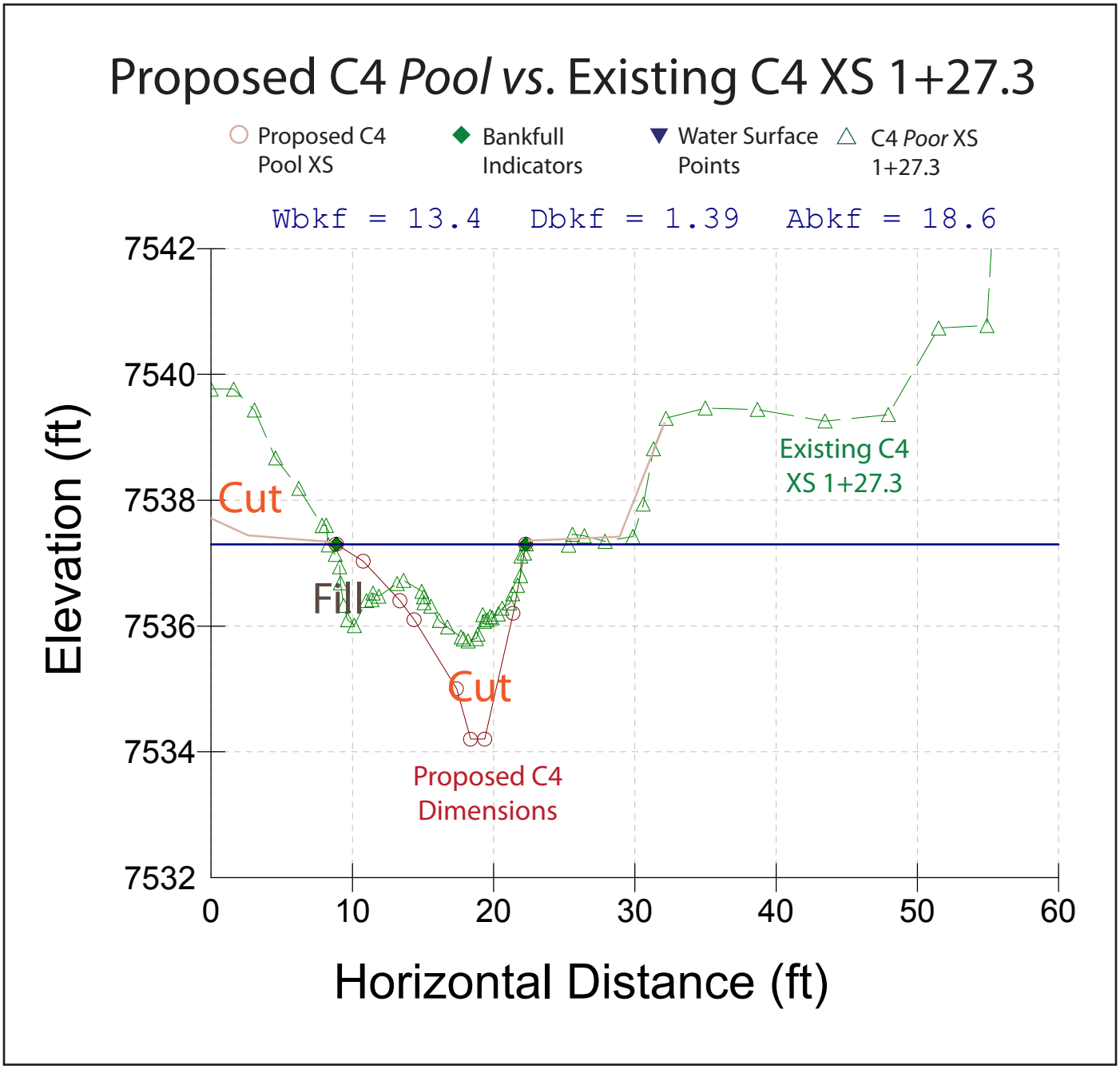


Figure II-39. The proposed C4 *Stable pool* cross-section compared to the existing C4 *Poor* cross-section 1+27.3 showing the cut and fill recommendations and reconnecting the channel with the floodplain.

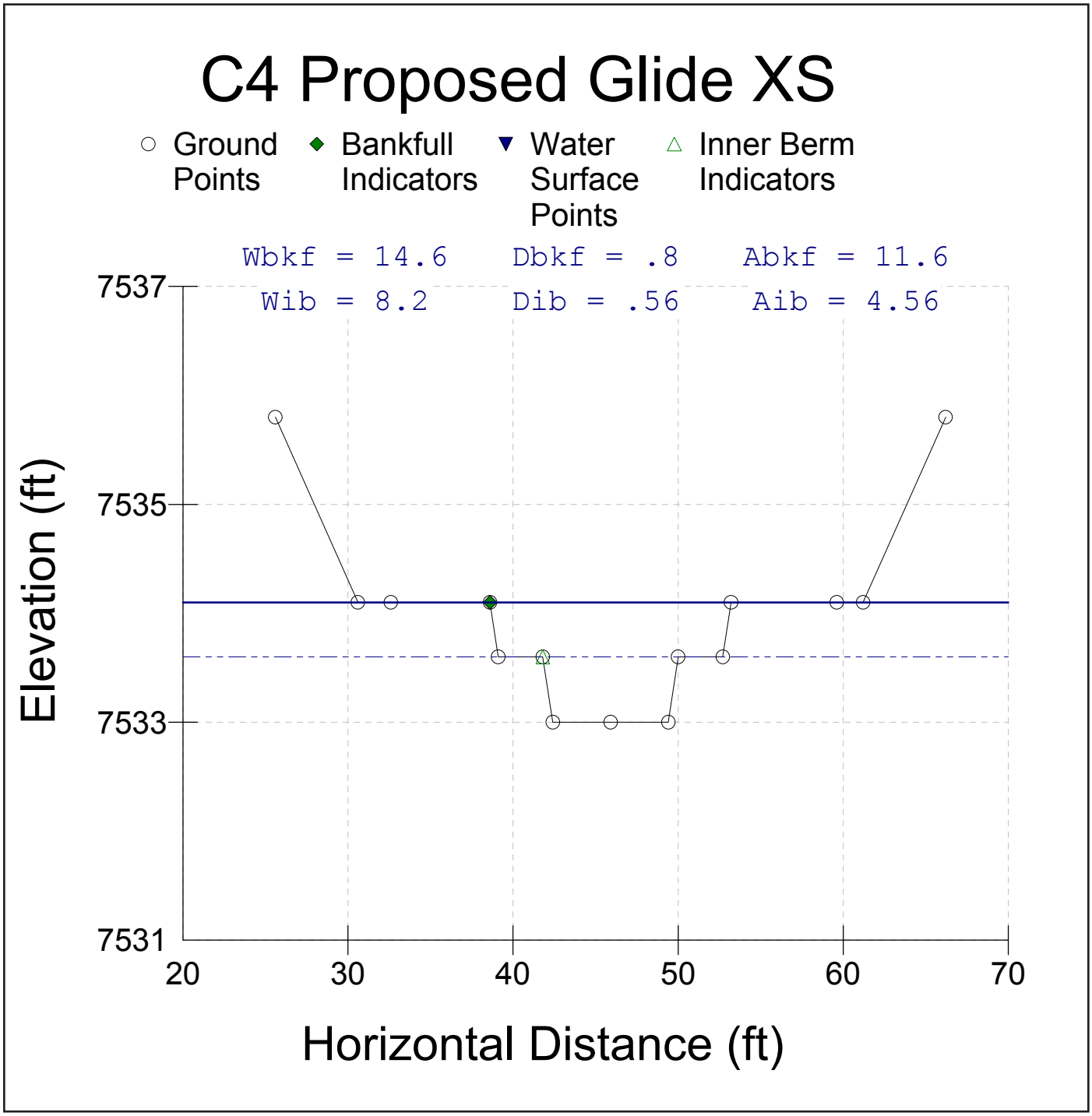


Figure II-40. The typical *glide* cross-section for the proposed C4 *Stable* design converted from the existing C4 *Poor* condition stream type.

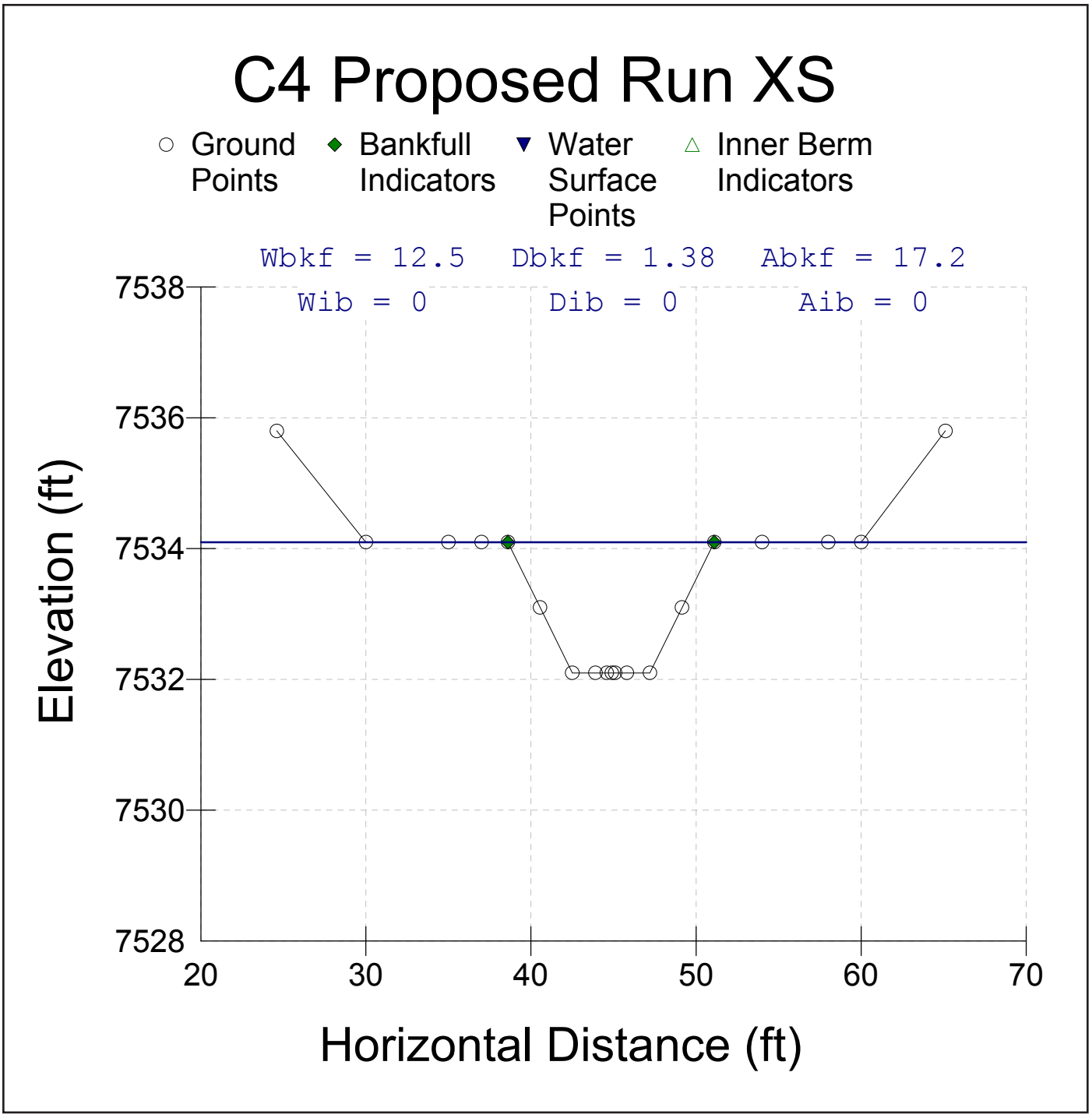


Figure II-41. The typical *run* cross-section for the proposed C4 *Stable* design converted from the existing C4 *Poor* condition stream type.

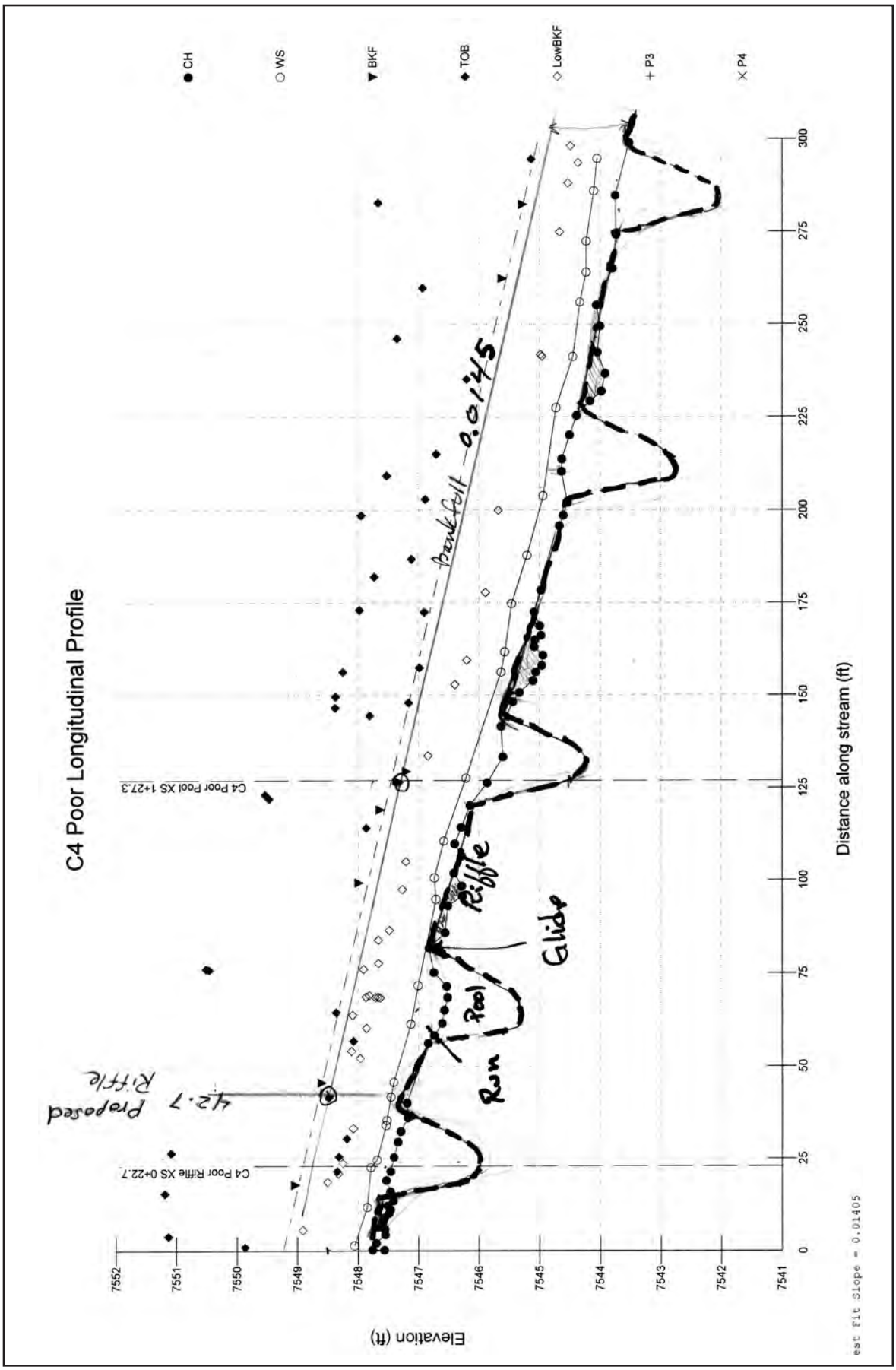


Figure II-42. The existing *vs.* proposed design longitudinal profile for the *C4 Poor* to *C4 Stable* conversion in Valley Type VIII.

Structures

The recommended structures for the C4 design reach include converging rock clusters; the root wad, log vane, J-hook; the rock vane, J-hook; and the toe wood structure with sod mats and riparian transplants. These structures are recommended for streambank stabilization, flow resistance, grade control, and fish habitat enhancement. The materials for these structures will be obtained from on-site sources. Many of the burned logs will be salvaged to use for the root wad, log vane, J-hook, and toe wood structures. Riparian transplants will be salvaged from local excavation disturbance.

Riparian Vegetation

It is a key requirement to re-establish a woody riparian community of willow and alder along this corridor. This is accomplished by planting willow cuttings and transplants. The toe wood structure provides a site for transplanted willow and alder, or willow cuttings. Native grasses of Carex and Juncus where available will be transplanted to the stream-adjacent toe wood structures or seeded along the lower elevation, wet sites. Native bunch grasses, such as big mountain brome, are recommended for seeding the flood-prone areas that do not have soil saturation and are droughty. The revegetation is critical for the long-term physical stability and biological function.

Cut & Fill Computations

The cut and fill computations are obtained from the existing *vs*. proposed cross-sections for that particular bed feature with lengths obtained from the plan and profile data of the proposed design. The proposed design results in approximately *278 yds*^{3} of excavation and *300 yds*^{3} of fill required with a balance of *22 yds*^{3}. The fill related to the structures planned for this *300 ft* reach involving rock, logs and woody material is approximately *30 yds*^{3}. Thus the revetment and enhancement material will balance the excavation and fill requirements for this reach; subsequently, end-hauling to dispose of material is not necessary.

Streambank Erosion

The streambank erosion that is expected for the proposed C4 design reach is *1.9 tons/yr* for *300 ft* of designed channel *vs*. the existing *14.2 tons/yr* for *300 ft* of the existing condition (**Table II-5**), representing a potential reduction of *12.3 tons/yr* for this reach. These values are based on the erosion rate of *0.0472 tons/yr/ft* for the *C4 Poor Representative Reach* and the extrapolation of the erosion rate of *0.0063 tons/yr/ft* for the *C4 Reference Reach* to the proposed reach. For one mile of restoration of this scenario, a reduction of *216 tons/yr*, or an *87%* decrease, of streambank erosion would be expected. These significant reductions in streambank erosion are extremely important as *84%* of the total sediment source of the Trail Creek Watershed is from streambank erosion. Thus the proposed restoration can not 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.

The sediment reduction assumes that the various structures designed and located on the plan view map in **Figure II-42** are implemented, such as the toe wood and the J-hook structures. The BEHI ratings can be greatly reduced with toe wood and NBS is also reduced with both the rock and log J-hook vanes. These structures have proven to reduce streambank erosion rates by three orders of magnitude, and also provide for flow resistance and fish habitat enhancement.

Insert 11 x 17 Figure II-43 Here

Figure II-43. Plan view of the alignment for the proposed C4 stream type, including stream stabilization and fish enhancement structures.

Insert 11 x 17 Figure II-43 Here

Flow-Related Sediment

The FLOWSED model indicates that by converting from a "Poor" condition to a "Good" condition throughout the watershed, the flow-related sediment yields would be reduced from *24,190.4 tons/yr* (**Worksheet II-11a**) to *844.6 tons/yr* (**Worksheet II-11b**) as a result of the restoration. The corresponding sediment supply reductions based on converting from "Poor" to "Good" conditions are *5,272 tons/yr* for bedload and *18,073.9 tons/yr* for suspended sediment, representing a total sediment reduction of *23,345.8 tons/yr*. These sediment reductions are still assuming a high post-fire runoff response and continued increased stormflow peak runoff. These reductions are also associated with treating the majority of the stream length of the watershed above this reach.

The reductions in sediment supply associated with restoring *300 ft* of the existing C4 *Poor* stream type to *300 ft* of the proposed C4 *Stable* design reach are *12.3 tons/yr* of streambank erosion, *30.0 tons/yr* of bedload, *102.7 tons/yr* of suspended sediment and *132.6 tons/yr* of total sediment yield reduction. The total sediment yield value includes streambank erosion contributions and streambed sources. The sediment reductions associated with the local channel source sediment for this design scenario are based on sediment yield rates determined from taking the sediment yield values generated from FLOWSED and dividing by the total stream length of potential sediment contributions. For this scenario, it was determined that approximately *10 miles* (*52,800 ft*) of the mainstem Trail Creek is potentially contributing sediment. The tributaries also contribute sediment but at a lower rate; thus their stream lengths were not included in the unit sediment transport rate. The resultant sediment yield rates were then multiplied by the existing and proposed design reach lengths for this scenario to obtain the local sediment reductions.

The POWERSED model to evaluate sediment transport capacity indicates that approximately *85%* of the C4 *Poor* sediment supply would be transported rather than deposited if converted to a C4 *Stable* reach due to reducing the existing high width/depth ratio with the design. The existing longitudinal profile as shown in **Figure II-42** indicates several sites of deposition and the overall stability evaluation of aggradation for the *C4 Poor Representative Reach* coincide with the POWERSED results. The lower width/depth ratio of the design will prevent further aggradation, yet will allow the transport of a lower sediment supply.

Sediment Competence

The sediment competence calculations based on the proposed design indicate a stable bed (**Worksheet II-12**). Converging rock clusters for grade control are designed at the head of riffles to further ensure bed stability.

Summary of the C4 Poor to C4 Stable Conversion

Many stream types exist that have not changed their morphological description (stream type) but have become highly unstable. The existing, impaired C4 *Poor* stream type has instability associated with both streambank and streambed erosion. The stable end-point of stream succession is a C4 stream type; however, the stable features of the *C4 Reference Reach* must be integrated into the restoration proposal for this reach. The proposed structures for habitat will also be effective at reducing streambank and streambed erosion. The toe wood structure with sod mats and transplants also add flow resistance and create undercut banks for instream cover for fish. By stabilizing the streambanks and road fills with toe wood, the encroachment and corresponding high sediment supply from road fills can be greatly reduced and will concurrently accelerate the recovery of the riparian community.

Worksheet II-11a. The existing sediment supply at the C4 *Poor* reach using the FLOWSED model and generated by using the dimensionless sediment rating curves and bankfull sediment values related to the "Poor" condition.

Stream: **C4 Poor Representative Reach** Location: **Lower Trail Creek above Mouth** Date: **3/15/11**

Observers: **Rosgen *et al*.** Gage Station #: **Goose Creek Gage** Stream Type: **C4** Valley Type: **VIII**

Equation Type	Equation Source	Equation	Bankfull Discharge (cfs)	Bankfull Bedload Sediment (kg/s)	Bankfull Suspended Sediment (mg/l)
1. Bedload Sediment	"Poor" Pagosa	$y = 0.07176+1.02176x^{2.3772}$	40	0.4699	223.46
2. Suspended Sediment	"Poor" Pagosa	$y = 0.0989+0.9213x^{3.659}$			

From Dimensional Flow-Duration Curve							From Sediment Rating Curves				Calculate	Calculate Sediment Yield		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Percentage of Time	Daily Mean Discharge	Mid-Ordinate	Time Increment (percent)	Time Increment (days)	Mid-Ordinate Streamflow	Dimension-less Streamflow	Dimension-less Suspended Sediment Discharge	Suspended Sediment Discharge	Dimension- less Bedload Discharge	Bedload Sediment Discharge	Time Adjusted Streamflow [(5)×(6)]	Suspended Sediment [(5)×(9)]	Bedload Sediment [(5)×(11)]	Suspended + Bedload Sediment [(13)+(14)]
(%)	(cfs)	(%)	(%)	(days)	(cfs)	(Q/Q_{bkf})	(S/S_{bkf})	(tons/day)	(b_s/b_{bkf})	(tons/day)	(cfs)	(tons)	(tons)	(tons)
0%	178.8													
0.10%	153.5	0.05%	0.09%	0.34	166.2	4.154	168.918	16935.10	30.244	1353.84	57.0	5810.43	464.50	6274.94
0.25%	132.9	0.08%	0.15%	0.55	143.2	3.579	97.999	8465.64	21.249	951.18	78.4	4634.94	520.77	5155.71
0.50%	114.8	0.13%	0.25%	0.91	123.8	3.095	57.637	4305.77	15.065	674.38	113.0	3929.01	615.37	4544.38
0.75%	98.0	0.13%	0.25%	0.91	106.4	2.660	33.137	2127.25	10.528	471.26	97.1	1941.11	430.03	2371.14
1%	84.8	0.13%	0.25%	0.91	91.4	2.285	19.049	1050.51	7.358	329.39	83.4	958.59	300.57	1259.16
1.5%	60.7	0.25%	0.50%	1.83	72.8	1.819	8.322	365.32	4.308	192.84	132.8	666.70	351.93	1018.64
2%	51.1	0.25%	0.50%	1.83	55.9	1.398	3.236	109.15	2.337	104.60	102.0	199.20	190.89	390.10
3%	43.7	0.50%	1.00%	3.65	47.4	1.185	1.812	51.83	1.601	71.66	173.0	189.17	261.57	450.74
4%	38.9	0.50%	1.00%	3.65	41.3	1.032	1.133	28.22	1.173	52.52	150.7	103.02	191.69	294.71
5%	34.4	0.50%	1.00%	3.65	36.7	0.916	0.768	16.99	0.902	40.38	133.8	62.02	147.38	209.40
10%	24.4	2.50%	5.00%	18.25	29.4	0.736	0.399	7.08	0.565	25.28	537.2	129.28	461.28	590.56
20%	13.3	5.00%	10.00%	36.50	18.9	0.472	0.158	1.80	0.243	10.89	689.2	65.71	397.57	463.27
30%	8.9	5.00%	10.00%	36.50	11.1	0.278	0.107	0.72	0.120	5.39	405.4	26.27	196.65	222.92
40%	6.3	5.00%	10.00%	36.50	7.6	0.190	0.101	0.46	0.091	4.09	277.0	16.88	149.36	166.25
50%	4.8	5.00%	10.00%	36.50	5.6	0.139	0.100	0.33	0.081	3.63	202.7	12.18	132.53	144.71
60%	3.7	5.00%	10.00%	36.50	4.3	0.106	0.099	0.25	0.077	3.43	155.4	9.30	125.38	134.67
70%	3.0	5.00%	10.00%	36.50	3.3	0.083	0.099	0.20	0.075	3.34	121.6	7.27	121.79	129.05
80%	2.6	5.00%	10.00%	36.50	2.8	0.069	0.099	0.17	0.074	3.29	101.4	6.05	120.19	126.24
90%	1.9	5.00%	10.00%	36.50	2.2	0.056	0.099	0.13	0.073	3.26	81.1	4.84	118.98	123.82
100%	0.4	5.00%	10.00%	36.50	1.1	0.028	0.099	0.07	0.072	3.22	40.5	2.42	117.58	120.00
									Annual Totals:		3,732.8 (cfs) 7,404.1 (acre-ft)	18,774.4 (tons/yr)	5,416.0 (tons/yr)	24,190.4 (tons/yr)

Worksheet II-11b. The proposed sediment supply at the proposed C4 *Stable* reach using the FLOWSED model and generated by using the dimensionless sediment rating curves and bankfull sediment values related to the restored "Good" condition (assuming that the watershed area above this reach is also restored to "Good" conditions).

Stream: **C4 Proposed Restoration Reach from C4 *Poor*** Location: **Existing C4 Poor Rep. Reach, Lower Trail Creek** Date: **3/15/11**

Observers: **Rosgen *et al*.** Gage Station #: **Goose Creek Gage** Stream Type: **C4** Valley Type: **VIII**

Equation Type	Equation Source	Equation	Bankfull Discharge (cfs)	Bankfull Bedload Sediment (kg/s)	Bankfull Suspended Sediment (mg/l)
1. Bedload Sediment	"Good/Fair" Pagosa	$y = -0.0113+1.0139x^{2.1929}$	40	0.01823	31.70
2. Suspended Sediment	"Good/Fair" Pagosa	$y = 0.0636+0.9326x^{2.4085}$			

From Dimensional Flow-Duration Curve							From Sediment Rating Curves				Calculate	Calculate Sediment Yield		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Percentage of Time	Daily Mean Discharge	Mid-Ordinate	Time Increment (percent)	Time Increment (days)	Mid-Ordinate Streamflow	Dimension-less Streamflow	Dimension-less Suspended Sediment Discharge	Suspended Sediment Discharge	Dimension-less Bedload Discharge	Bedload Sediment Discharge	Time Adjusted Streamflow [(5)×(6)]	Suspended Sediment [(5)×(9)]	Bedload Sediment [(5)×(11)]	Suspended + Bedload Sediment [(13)+(14)]
(%)	(cfs)	(%)	(%)	(days)	(cfs)	(Q/Q_{bkf})	(S/S_{bkf})	(tons/day)	(b_s/b_{bkf})	(tons/day)	(cfs)	(tons)	(tons)	(tons)
0%	178.8													
0.10%	153.5	0.05%	0.09%	0.34	166.2	4.154	28.858	410.47	23.017	39.99	57.0	140.83	13.72	154.55
0.25%	132.9	0.08%	0.15%	0.55	143.2	3.579	20.180	247.32	16.601	28.84	78.4	135.41	15.79	151.20
0.50%	114.8	0.13%	0.25%	0.91	123.8	3.095	14.241	150.94	12.070	20.97	113.0	137.73	19.13	156.87
0.75%	98.0	0.13%	0.25%	0.91	106.4	2.660	9.904	90.20	8.652	15.03	97.1	82.31	13.72	96.02
1%	84.8	0.13%	0.25%	0.91	91.4	2.285	6.889	53.90	6.198	10.77	83.4	49.18	9.82	59.01
1.5%	60.7	0.25%	0.50%	1.83	72.8	1.819	4.003	24.93	3.753	6.52	132.8	45.50	11.90	57.40
2%	51.1	0.25%	0.50%	1.83	55.9	1.398	2.153	10.30	2.102	3.65	102.0	18.80	6.66	25.46
3%	43.7	0.50%	1.00%	3.65	47.4	1.185	1.467	5.95	1.459	2.54	173.0	21.72	9.25	30.97
4%	38.9	0.50%	1.00%	3.65	41.3	1.032	1.070	3.78	1.075	1.87	150.7	13.80	6.82	20.62
5%	34.4	0.50%	1.00%	3.65	36.7	0.916	0.819	2.57	0.826	1.43	133.8	9.38	5.24	14.62
10%	24.4	2.50%	5.00%	18.25	29.4	0.736	0.509	1.28	0.506	0.88	537.2	23.41	16.05	39.46
20%	13.3	5.00%	10.00%	36.50	18.9	0.472	0.217	0.35	0.184	0.32	689.2	12.78	11.68	24.46
30%	8.9	5.00%	10.00%	36.50	11.1	0.278	0.106	0.10	0.050	0.09	405.4	3.69	3.16	6.84
40%	6.3	5.00%	10.00%	36.50	7.6	0.190	0.081	0.05	0.015	0.03	277.0	1.91	0.96	2.88
50%	4.8	5.00%	10.00%	36.50	5.6	0.139	0.072	0.03	0.002	0.00	202.7	1.24	0.13	1.37
60%	3.7	5.00%	10.00%	36.50	4.3	0.106	0.068	0.02	0.000	0.00	155.4	0.90	0.00	0.90
70%	3.0	5.00%	10.00%	36.50	3.3	0.083	0.066	0.02	0.000	0.00	121.6	0.69	0.00	0.69
80%	2.6	5.00%	10.00%	36.50	2.8	0.069	0.065	0.02	0.000	0.00	101.4	0.56	0.00	0.56
90%	1.9	5.00%	10.00%	36.50	2.2	0.056	0.064	0.01	0.000	0.00	81.1	0.45	0.00	0.45
100%	0.4	5.00%	10.00%	36.50	1.1	0.028	0.064	0.01	0.000	0.00	40.5	0.22	0.00	0.22
										Annual Totals:	3,732.8 (cfs) / 7,404.1 (acre-ft)	700.5 (tons/yr)	144.0 (tons/yr)	844.6 (tons/yr)

Worksheet II-12. The sediment competence calculations indicating bed stability for the proposed C4 *Stable* design to be converted from the C4 *Poor* reach, lower Trail Creek.

Stream:	**C4 *Stable* converted from C4 *Poor***		Stream Type: **C4**		
Location:	**Lower Trail Creek above Mouth**		Valley Type: **VIII**		
Observers:	**Rosgen *et al*.**		Date: **3/15/11**		
Enter Required Information for PROPOSED Design Condition					
7.2	D_{50}	Median particle size of riffle bed material (mm)			
4.2	$\hat{D}_{50}$	Median particle size of bar or sub-pavement sample (mm)			
0.26	D_{max}	Largest particle from bar sample (ft)	**110**	**(mm)**	304.8 mm/ft
0.0145	***S***	Proposed design bankfull water surface slope (ft/ft)			
0.99	***d***	Proposed design bankfull mean depth (ft)			
1.65	γ_s-γ/γ	Immersed specific gravity of sediment			
Select the Appropriate Equation and Calculate Critical Dimensionless Shear Stress					
1.33	$D_{50}/\hat{D}_{50}$	Range: 3 – 7	Use EQUATION 1: $\tau^* = 0.0834\,(D_{50}/\hat{D}_{50})^{-0.872}$		
10.00	D_{max}/D_{50}	Range: 1.3 – 3.0	Use EQUATION 2: $\tau^* = 0.0384\,(D_{max}/D_{50})^{-0.887}$		
N/A	τ^*	Bankfull Dimensionless Shear Stress	EQUATION USED:		**N/A**
Calculate Bankfull Mean Depth Required for Entrainment of Largest Particle in Bar Sample					
N/A	**d**	Required bankfull mean depth (ft) $d = \frac{\tau^*(\gamma_s - 1)D_{max}}{S}$	(use D_{max} in ft)		
Calculate Bankfull Water Surface Slope Required for Entrainment of Largest Particle in Bar Sample					
N/A	**S**	Required bankfull water surface slope (ft/ft) $S = \frac{\tau^*(\gamma_s - 1)D_{max}}{d}$	(use D_{max} in ft)		
Check: ☐ Stable ☐ Aggrading ☐ Degrading					
Sediment Competence Using Dimensional Shear Stress					
0.896		Bankfull shear stress $\tau = \gamma dS$ (lbs/ft^2) (substitute hydraulic radius, R, with mean depth, d) γ = 62.4, d = proposed design depth, S = proposed design slope			
Shields **69.52**	CO **140.2**	Predicted largest moveable particle size (mm) at bankfull shear stress τ **(Figure 5-49)**			
Shields **1.391**	CO **0.644**	Predicted shear stress required to initiate movement of measured D_{max} (mm) **(Figure 5-49)**			
Shields **1.54**	CO **0.71**	Predicted mean depth required to initiate movement of measured D_{max} (mm) $d = \frac{\tau}{\gamma S}$ τ = predicted shear stress, γ = 62.4, S = proposed design slope			
Shields **0.0225**	CO **0.0104**	Predicted slope required to initiate movement of measured D_{max} (mm) $S = \frac{\tau}{\gamma d}$ τ = predicted shear stress, γ = 62.4, d = proposed design depth			
Check: ☑ Stable ☐ Aggrading ☐ Degrading					

Typical Design Scenario 5a Example

Tributary F4b to D4 Stream Type Conversion

(Valley Type III – Large)

Tributary F4b to D4 Stream Type Conversion (VT III): Typical Design Scenario 5a Example

General Description & Morphological Data

This typical design scenario example is a stream type conversion from an F4b tributary reach to a D4 stream type on a long and wide alluvial fan (Valley Type III). This impaired F4b tributary reach is located one-third mile upstream from the mouth of Trail Creek, draining the Sheep Nose area of Sub-Watershed 6. This sub-watershed has the highest priority for restoration of the 59 sub-watersheds in the Trail Creek Watershed due to the large, combined sediment yields from roads, surface erosion, streambank erosion, and post-fire excess peak flows. The majority of the channels within this sub-watershed are incised, confined, and associated with headcuts.

The existing, impaired tributary in this design scenario is the *F4b Poor Trib. Representative Reach* depicted in **Figure II-44** and located on the general map in **Figure II-1**. The detailed characteristics and stability evaluation of this representative reach are documented in *Appendix C14* of the Waldo Canyon Fire *WARSSS* analysis (Rosgen *et al*., 2013). The tributary is associated with accelerated streambank erosion rates and accelerated channel source sediment that is delivered to the mainstem Trail Creek. Furthermore, an advancing headcut is evident on the existing F4b longitudinal profile.

The overall direction of the design is to reduce the delivered sediment to Trail Creek by developing a braided, D4 stream type. Until the sediment in this high priority sub-watershed can be reduced by restoring the entire sub-watershed, it is recommended to store the sediment on the fan and in the sediment detention basins. Thus a B4 *Stable* stream type conversion is not recommended for the existing conditions because a B4 stream type would route this high sediment supply generated above the existing reach directly to the mainstem Trail Creek. The braided, D4 channel is characterized by bar deposition that is associated with convergence/divergence bed features to deposit the high sediment supply on the alluvial fan surface and by storing sediment in detention basins. The D4 stream type is the preferred stream type for alluvial fans and functions well unless the fan has been cut off at the lower end due to road encroachment or lateral migration by the main trunk stem. The alluvial fan for this existing reach is adequately-sized to accommodate the D4 stream type and usable depositional area. Because the majority of alluvial fans are ephemeral, they do not need to provide fish habitat enhancement or fish migration; hence, the design is intended to store as much sediment produced from upstream as possible on the valley flat.

The specific objectives and direction for this design scenario are as follows:

- Store sediment before it is delivered to the trunk stream
- Reduce the accelerated streambank erosion rates
- Eliminate any advancing headcuts
- Develop sediment detention storage basins in three locations

If the proposed design of converting the F4b tributary to a braided, D4 stream type is not implemented, the existing reach will continue to headcut and provide high sediment yields to Trail Creek. A D4 "reference reach" was not established for this project and therefore the proposed characteristics of the D4 stream type for this scenario are adapted from D4 characteristics studied

in detail by the restoration practitioner. The resultant morphology and design parameters for the proposed D4 reach are documented in **Table II-6**. Additionally, this table also includes the morphological descriptions of the existing *F4b Poor Tributary Representative Reach*. The following sections include the proposed design details of the braided, D4 stream type.



Figure II-44. The existing, F4b *Poor* tributary showing the unstable banks and the high width/depth ratio channel that encourages increased sediment deposition in the streambed.

Table II-6. The morphological characteristics of the existing, F4b tributary and the proposed D4 design reach for this stream type conversion in a Valley Type III.

Existing Reach Stream & Location:			**F4b Poor Trib., Lower Trail Creek**			
Reference Reach Stream & Location:			**N/A**			
	Entry Number	**Variable**	**Existing Reach**		**Proposed Design Reach**	
	1	Valley Type	**III**		**III**	
	2	Valley Width	**40-50**		**40-50**	
	3	Stream Type	**F4b**		**D4**	
	4	Drainage Area, mi^2	**1.5**		**2.5**	
	5	Bankfull Discharge, cfs (Q_{bkf})	**8.43**		**13**	
Riffle Dimensions	**6**	Riffle Width, ft (W_{bkf})	*Mean:* *Min:* *Max:*	**12.8** **11.4** **14.9**	*Mean:* *Min:* *Max:*	**29.0** **(3.6 Wbkf for** **8 channels)**
	7	Riffle Mean Depth, ft (d_{bkf})	*Mean:* *Min:* *Max:*	**0.19** **0.16** **0.24**	*Mean:* *Min:* *Max:*	**0.29** **for each** **channel**
	8	Riffle Width/Depth Ratio (W_{bkf}/d_{bkf})	*Mean:* *Min:* *Max:*	**68.4** **47.3** **77.4**	*Mean:* *Min:* *Max:*	**100.0**
	9	Riffle Cross-Sectional Area, ft^2 (A_{bkf})	*Mean:* *Min:* *Max:*	**2.4** **2.0** **2.9**	*Mean:*	**8.4**
	10	Riffle Maximum Depth (d_{max})	*Mean:* *Min:* *Max:*	**0.34** **0.27** **0.41**	*Mean:* *Min:* *Max:*	**0.29**
	11	Riffle Maximum Depth to Riffle Mean Depth (d_{max}/d_{bkf})	*Mean:* *Min:* *Max:*	**1.752** **1.588** **2.063**	*Mean:* *Min:* *Max:*	**1.000**
	12	Width of Flood-Prone Area at Elevation of 2 * d_{max}, ft (W_{fpa})	*Mean:* *Min:* *Max:*	**13.9** **12.8** **15.4**	*Mean:* *Min:* *Max:*	**N/A**
	13	Entrenchment Ratio (W_{fpa}/W_{bkf})	*Mean:* *Min:* *Max:*	**1.1** **1.0** **1.2**	*Mean:* *Min:* *Max:*	**N/A**

Table II-6 (page 2). The morphological characteristics of the existing, F4b tributary and the proposed D4 design reach for this stream type conversion in a Valley Type III.

	Entry Number & Variable	Existing Reach	Proposed Design Reach
Sinuosity and Slope	**88** Stream Length (SL)	**337.0**	**337.0**
	89 Valley Length (VL)	**324.0**	**337.0**
	90 Valley Slope (S_{val})	**0.0430**	**0.0430**
	91 Sinuosity (k)	SL/VL: **1.04** VS/S: **1.05**	SL/VL: **1.00**
	92 Average Water Surface Slope (S)	**0.0410**	$S = S_{val}/k$ **0.0430**
Channel Materials	**125 Particle Size Distribution of Channel Material (Active Bed) or Pavement**		
	D_{16} (mm)	**0.6**	**0.6**
	D_{35} (mm)	**1.0**	**1.0**
	D_{50} (mm)	**2.3**	**2.3**
	D_{84} (mm)	**7.1**	**7.1**
	D_{95} (mm)	**10.3**	**10.3**
	D_{100} (mm)	**16.0**	**16.0**
	126 Particle Size Distribution of Bar Material or Sub-pavement		
	D_{16} (mm)	**0.6**	**0.6**
	D_{35} (mm)	**1.0**	**1.0**
	D_{50} (mm)	**2.3**	**2.3**
	D_{84} (mm)	**7.1**	**7.1**
	D_{95} (mm)	**10.3**	**10.3**
	D_{max}: Largest size particle at the toe (lower third) of bar (mm) or sub-pavement	**16.0**	**16.0**

Table II-6 (page 3). The morphological characteristics of the existing, F4b tributary and the proposed D4 design reach for this stream type conversion in a Valley Type III.

Entry Number & Variable			Existing Reach	Proposed Design Reach
Hydraulics	127	Estimated Bankfull Mean Velocity, ft/sec (u_{bkf})	**3.16**	**1.5**
	128	Estimated Bankfull Discharge, cfs (Q_{bkf}); Compare with Regional Curve	**8.4**	**13.0**
Sediment Competence	129	Calculated bankfull shear stress value, lbs/ft^2 (τ)	**0.599**	**0.778**
	130	Predicted largest moveable particle size (mm) at bankfull shear stress, τ, using the original **Shields** relation	**43.0**	**60**
	131	Predicted largest moveable particle size (mm) at bankfull shear stress, τ, using the **Colorado** relation	**105.0**	**126**
	132	Largest particle size to be moved (D_{max}) (mm) (see #126: Particle Size Distribution of Bar Material)	**16**	**16**
	133	Predicted shear stress required to initiate movement of D_{max} (mm) using the original **Shields** relation	**0.210**	**0.219**
	134	Predicted shear stress required to initiate movement of D_{max} (mm) using the **Colorado** relation	**0.043**	**0.047**
	135	Predicted mean depth required to initiate movement of D_{max} (mm), $d = \tau/\gamma S$ (τ = predicted shear stress, γ = 62.4, S = existing or design slope) (**Shields**)	**0.08**	**0.08**
	136	Predicted mean depth required to initiate movement of D_{max} (mm), $d = \tau/\gamma S$ (τ = predicted shear stress, γ = 62.4, S = existing or design slope) (**Colorado**)	**0.08**	**0.02**
	137	Predicted slope required to initiate movement of D_{max} (mm) $S=\tau/\gamma d$ (τ = predicted shear stress, γ = 62.4, d = existing or design depth) (**Shields**)	**0.0140**	**0.0121**
	138	Predicted slope required to initiate movement of D_{max} (mm) $S=\tau/\gamma d$ (τ = predicted shear stress, γ = 62.4, d = existing or design depth) (**Colorado**)	**0.0029**	**0.0026**
	139	Bankfull dimensionless shear stress (τ^*) (see competence form)	**N/A**	**N/A**
	140	Required bankfull mean depth d_{bkf} (ft) using dimensionless shear stress equation: $d_{bkf} = \tau^*(\gamma_s - 1)D_{max}/S$ (Note: D_{max} in ft)	**N/A**	**N/A**
	141	Required bankfull water surface slope S (ft) using dimensionless shear stress equation: $S = \tau^*(\gamma_s - 1)D_{max}/d_{bkf}$ (Note: D_{max} in ft)	**N/A**	**N/A**

Table II-6 (page 4). The morphological characteristics of the existing, F4b tributary and the proposed D4 design reach for this stream type conversion in a Valley Type III.

Entry Number & Variable		Existing Reach	Proposed Design Reach
Sediment Yield	**Sediment Yield (FLOWSED)**	**Existing Reach**	**Proposed Design Reach**
	141 Bedload Sediment Yield (tons/yr)	**1,064.0**	**1,064.0**
	142 Suspended Sediment Yield (tons/yr)	**4,197.0**	**4,197.0**
	143 Suspended Sand Sediment Yield (tons/yr)	**2,098.5**	**2,098.5**
	144 Total Annual Sediment Yield (tons/yr)	**5,261.0**	**5,261.0**
Bank Erosion	**Streambank Erosion**	**Existing Reach**	**Proposed Design Reach**
	145 Stream Length Assessed (ft)	**337.0**	**337.0**
	146 Graph/Curve Used (e.g., Yellowstone or Colorado)	**Colorado**	**Colorado**
	147 Streambank Erosion (tons/yr)	**132.4**	**12.8**
	148 Streambank Erosion (tons/yr/ft)	**0.3929**	**0.0380**

Bankfull Discharge, Cross-Sectional Area & Mean Velocity

With a drainage area of *2.5 mi^2* for the proposed D4 stream type, the bankfull discharge is *13.0 cfs* and the proposed bankfull riffle cross-sectional area is *8.7 ft^2* as shown in **Table II-6**. The cross-sectional area is divided among eight channels, each designed as having *3.6 ft* of width and *0.29 ft* of depth. Using continuity, the corresponding mean velocity for the multiple-channel, D4 stream type is *1.5 ft/sec* as shown in **Worksheet II-13**. Velocities of *1.5 ft/sec* are common for braided channels on similar slopes with similar bed material for depths less than *0.5 ft*.

Plan View Alignment & the B2, Step/Pool Stream Type

The overlay of the alignment and design of the proposed conversion of the F4b to D4 stream type is shown in **Figure II-45** and is based on the channel pattern data that is consistent for multiple-thread, braided channels whose features are scaled for this drainage area and bankfull discharge (**Table II-6**). The existing cross-section locations of the F4b tributary are also shown **Figure II-45**. Sediment detention (storage) basins designed with log sills to prevent headcuts are also part of the design to store sediment (**Figure II-45**). Potential maintenance of the basins may be required with a good stockpile repository area at the toe of the remaining fan where Trail Creek has previously removed thousands of yards of material. The proposed design routes Trail Creek away from the toe of the fan to prevent further lateral erosion.

Furthermore, the lower end of the fan at the outflow of the last sediment detention basin is designed to be a B2, step–pool channel. This stream type is designed to prevent headcutting at the toe of the fan and to transition the concentrated flow from the sediment detention basin into a single-thread step–pool channel. The B2 stream type is also designed to dissipate energy and route water from the last sediment detention basin to Trail Creek. The dimension, pattern, and profile for the B2 channel are summarized in **Table II-7**. A design sketch in **Figure II-46** indicates the cross-section, plan, and profile views of the proposed B2 step–pool design.

Worksheet II-13. The mean velocity estimates for the proposed D4 reach converted from the existing, F4b stream

Bankfull VELOCITY & DISCHARGE Estimates

Stream:	**D4 Proposed Reach**			Location:	**F4b Trib., Lower Trail Creek**
Date:	**3/15/2011**	Stream Type:	**D4**	Valley Type:	**III**
Observers:	**Rosgen *et al*.**			HUC:	_ _ _ _ _ _ _ _ _ _ _ _

Input Variables for PROPOSED Design			Output Variables for PROPOSED Design		
Bankfull Riffle Cross-Sectional AREA	**8.4**	**A_{bkf}** (ft^2)	Bankfull Riffle Mean DEPTH	**0.29**	**d_{bkf}** (ft)
Bankfull Riffle WIDTH	**29.0**	**W_{bkf}** (ft)	Wetted PERMIMETER ~ (2 * d_{bkf}) + W_{bkf}	**29.58**	**W_p** (ft)
D_{84} at Riffle	**7.1**	**Dia.** (mm)	D_{84} (mm) / 304.8	**0.02**	**D_{84}** (ft)
Bankfull SLOPE	**0.0430**	**S_{bkf}** (ft / ft)	Hydraulic RADIUS A_{bkf} / W_p	**0.28**	**R** (ft)
Gravitational Acceleration	**32.2**	**g** (ft / sec^2)	Relative Roughness R(ft) / D_{84} (ft)	**12.17**	**R / D_{84}**
Drainage Area	**2.5**	**DA** (mi^2)	Shear Velocity $u^* = (gRS)^{½}$	**0.626**	**u*** (ft/sec)

ESTIMATION METHODS	Bankfull VELOCITY		Bankfull DISCHARGE	
1. Friction Factor / Relative Roughness $u = [\ 2.83 + 5.66 * Log\ \{ R / D_{84} \}\ ]\ u^*$	**N/A**	ft / sec	**N/A**	cfs
2. Roughness Coefficient: a) Manning's *n* from Friction Factor / Relative Roughness (Figs. 5-7, 5-8) $u = 1.49*R^{2/3}*S^{1/2} / n$ $n =$		ft / sec		cfs
2. Roughness Coefficient: b) Manning's *n* from Stream Type (Fig. 5-9) $u = 1.49*R^{2/3}*S^{1/2} / n$ $n =$		ft / sec		cfs
2. Roughness Coefficient: c) Manning's *n* from Jarrett (USGS): $u = 1.49*R^{2/3}*S^{1/2} / n$ $n = 0.39*S^{0.38}*R^{-0.16}$ **Note:** This equation is applicable to **steep, step/pool, high boundary roughness, cobble- and boulder-dominated stream systems**; i.e., for $n =$ **0.144**	**0.92**	ft / sec	**7.70**	cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)		ft / sec		cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)		ft / sec		cfs
4. Continuity Equations: a) USGS Gage Data $u = Q / A$ **Return Period for Bankfull Q** $Q =$ **year**		ft / sec		cfs
4. Continuity Equations: b) Regional Curves $u = Q / A$	**1.5**	ft / sec	**13**	cfs

Protrusion Height Options for the D_{84} Term in the Relative Roughness Relation (R/D_{84}) – Estimation Method 1

Option 1.	For **sand-bed** channels: Measure 100 **"protrusion heights"** of sand dunes from the downstream side of feature to the top of feature. Substitute the D_{84} sand dune protrusion height in ft for the D_{84} term in method 1.
Option 2.	For **boulder-dominated** channels: Measure 100 **"protrusion heights"** of boulders on the sides from the bed elevation to the top of the rock on that side. Substitute the D_{84} boulder protrusion height in ft for the D_{84} term in method 1.
Option 3.	For **bedrock-dominated** channels: Measure 100 **"protrusion heights"** of rock separations, steps, joints or uplifted surfaces above channel bed elevation. Substitute the D_{84} bedrock protrusion height in ft for the D_{84} term in method 1.
Option 4.	For **log-influenced** channels: Measure "**protrustion heights**" proportionate to channel width of log diameters or the height of the log on upstream side if embedded. Substitute the D_{84} protrusion height in ft for the D_{84} term in method 1.

Insert 11 x 17 Figure II-45 Here

Figure II-45. Plan view of the proposed conversion of the F4b to D4 stream type, including the existing F4b cross-section locations, the designed sediment detention basins and the proposed B2 step–pool channel.

Insert 11 x 17 Figure II-45 Here

Table II-7. The proposed dimensions, pattern and profile for the B2 stream type.

Proposed B2 Stream Type: Morphological Characteristics	
Bankfull Discharge	13 cfs
Bankfull Cross-Sectional Area	5.2 ft^2
Bankfull Width	12.0 ft
Bankfull Mean Depth	0.7 ft
Width/Depth Ratio	8.0
Bankfull Maximum Depth	1.0 ft
Average Water Surface Slope	0.033 ft/ft
Bankfull Velocity	2.5 ft/sec
Pool Length	12–16 ft
Rapid Length	18–25 ft
Step Length	2–4 ft
Pool-to-Pool Spacing	20–30 ft
Sinuosity	1.2
Belt Width	20 ft
Radius of Curvature	50–80 ft

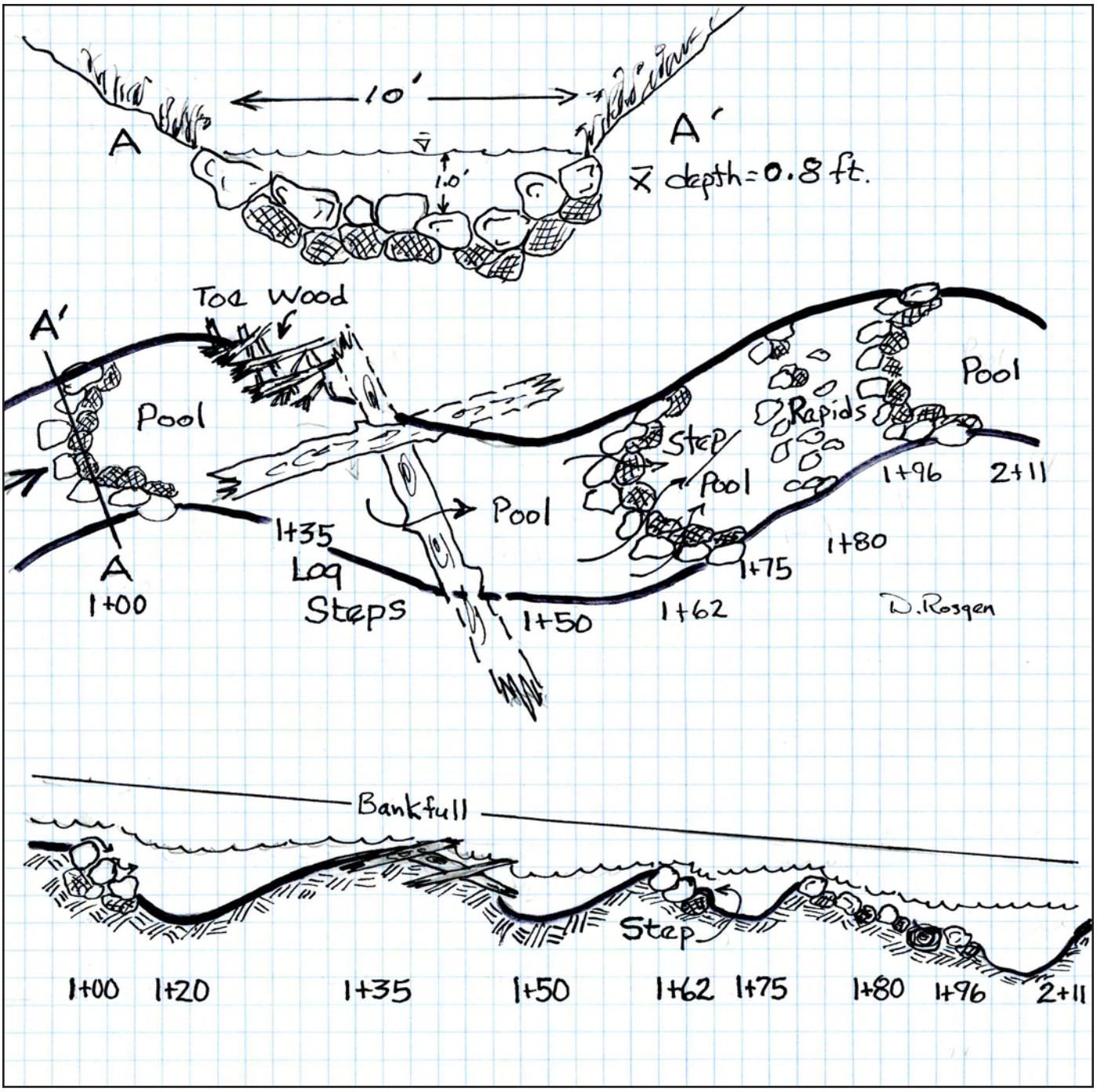


Figure II-46. Typical cross-section, plan and profile views of the proposed B2 stream type and associated structures.

Cross-Section Dimensions

The proposed channel dimensions for the multiple-thread, braided D4 stream type are included in **Table II-6**. The total designed bankfull width is *29.0 ft* with a corresponding mean depth of *0.29 ft* as determined from the bankfull cross-sectional area of *8.4 ft*^{2} and width/depth ratio of *100*. The total bankfull width of *29.0 ft* is distributed over eight channels, each with *3.6 ft* of width and *0.29 ft* of depth.

The locations of existing cross-sections are displayed in **Figure II-45**. **Figure II-47** depicts the multiple channels and dimensions of the proposed D4 stream type. This figure also shows the overlay of the existing F4b cross-section 0+40.2 and the extensive fill required to raise the bed level to obtain connectivity to the alluvial fan. The fill material is obtained from the excavation of the sediment detention basins as shown in **Figure II-45**. The raised bed elevation is also to encourage deposition from the braided D4 stream type through the convergence/divergence bed features of building bars on alluvial fan surfaces. The overlay of the existing F4b cross-section 2+10.7 *vs*. proposed D4 cross-section, also indicating the new bankfull elevation and extensive fill requirements, is shown in **Figure II-48**. Additional cross-section overlays are also included for the locations associated with the existing F4b cross-section 2+47 (**Figure II-49**) and cross-section 2+80 (**Figure II-50**). These overlays are used to compute the fill required for the design based on the total proposed reach length.

Longitudinal Profile

The longitudinal profile in **Figure II-51** compares the existing *vs*. proposed bed elevations, the extensive fill required and the energy slope, and also shows a sediment detention basin to store the excess sediment. The plan view layout in **Figure II-45** shows three basins for an extended length of restoration beyond the representative reach displayed in **Figure II-51** to help reduce delivered sediment to Trail Creek from the excess sediment disproportionately produced by the impaired Sub-Watershed 6. Additionally, the locations of the cross-section overlays in **Figures II-47** through **II-50** are depicted on the typical longitudinal profile in **Figure II-51**. The schematic longitudinal profile in **Figure II-52** shows the three sediment detention basins along with the proposed D4 and B2 (step–pool) channels.

Structures

This design requires that buried, log sills are placed at the top and bottom of each sediment detention basin as indicated in **Figure II-45** and **Figure II-52**. The log sills will prevent any potential headcutting associated with this design and the B2 stream type that connects the toe of the fan with Trail Creek.

Riparian Vegetation

It is a key requirement to re-establish a woody riparian community of willow and alder along this proposed D4 stream type. The vegetation will add flow resistance, will induce long-term deposition and will prevent excess lateral adjustment due to braiding. In addition to establishing a woody vegetation community, native bunch grasses, such as big mountain brome, are recommended for seeding the alluvial fan.

Cut & Fill Computations

The cut and fill computations are obtained from the existing *vs*. proposed cross-sections and the sediment detention basins with corresponding lengths obtained from the proposed plan and profile. The proposed design results in approximately *1,685 yds*^{3} of fill and *1,600 yds*^{3} of excavated sediment basin material for the proposed restoration.

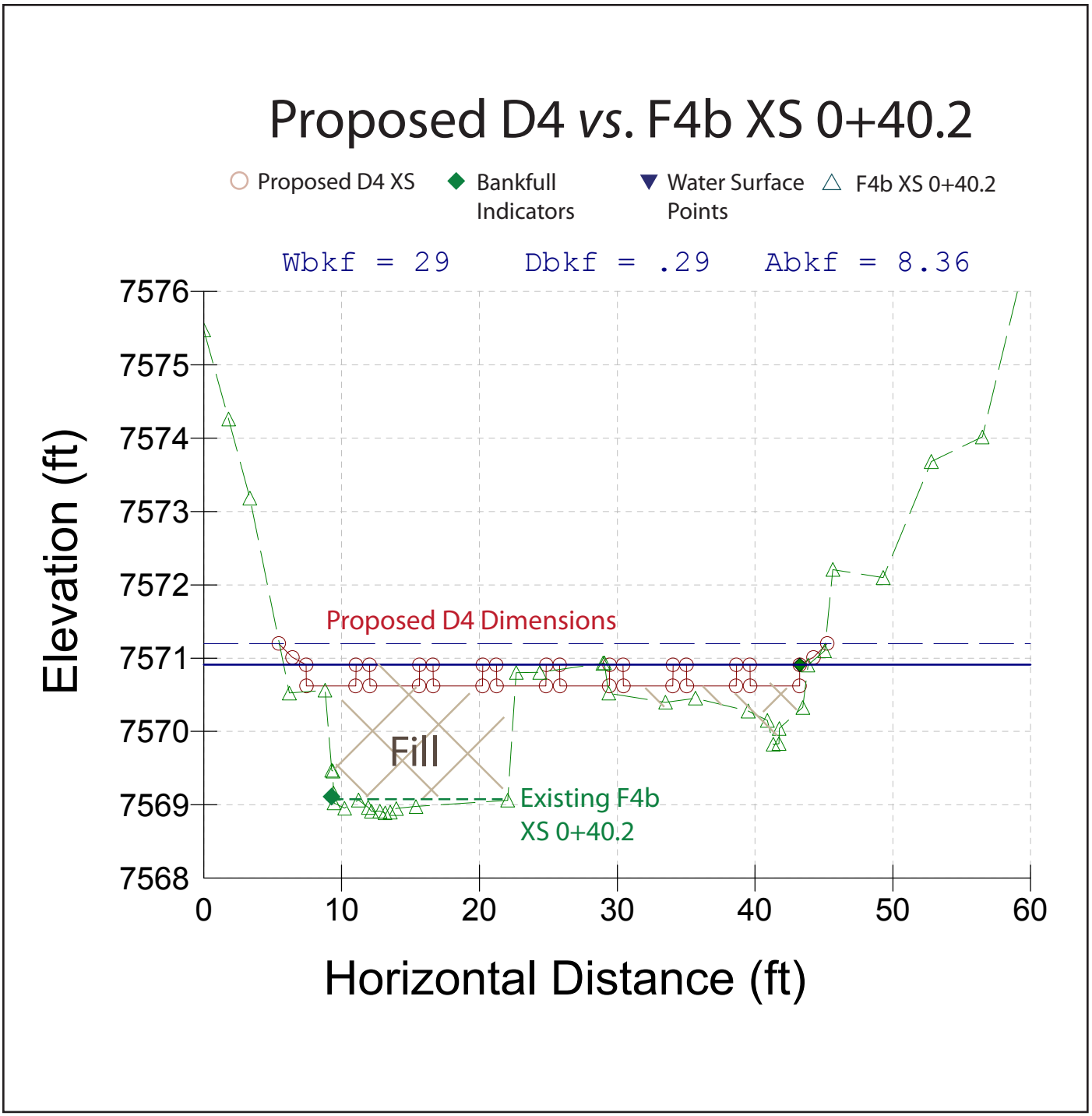


Figure II-47. The typical, proposed D4 cross-section dimensions compared to the existing F4b cross-section 0+40.2, indicating the extensive fill requirements and new bankfull elevation.

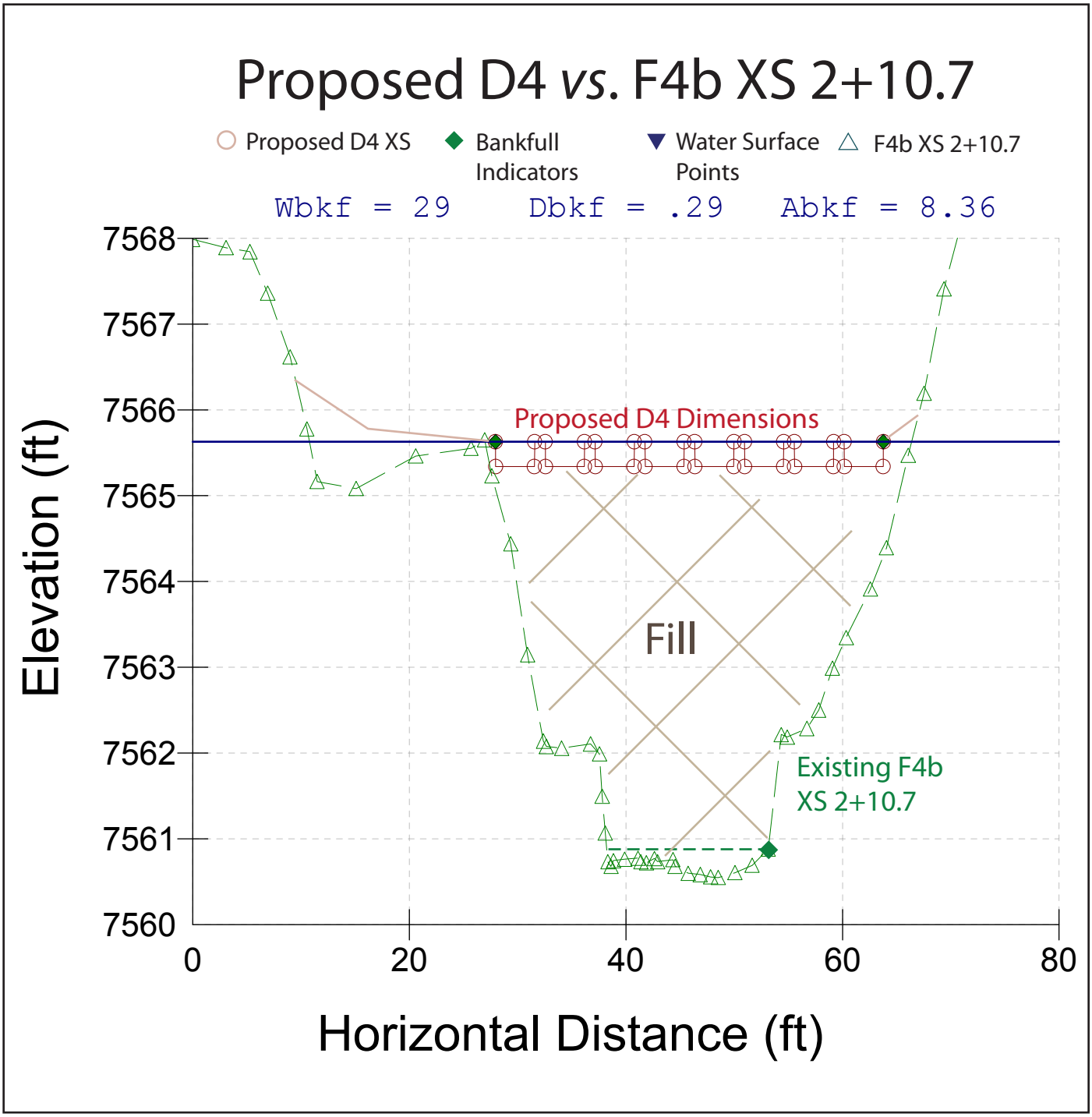


Figure II-48. The typical, proposed D4 cross-section dimensions compared to the existing F4b cross-section 2+10.7, indicating the extensive fill requirements and new bankfull elevation.

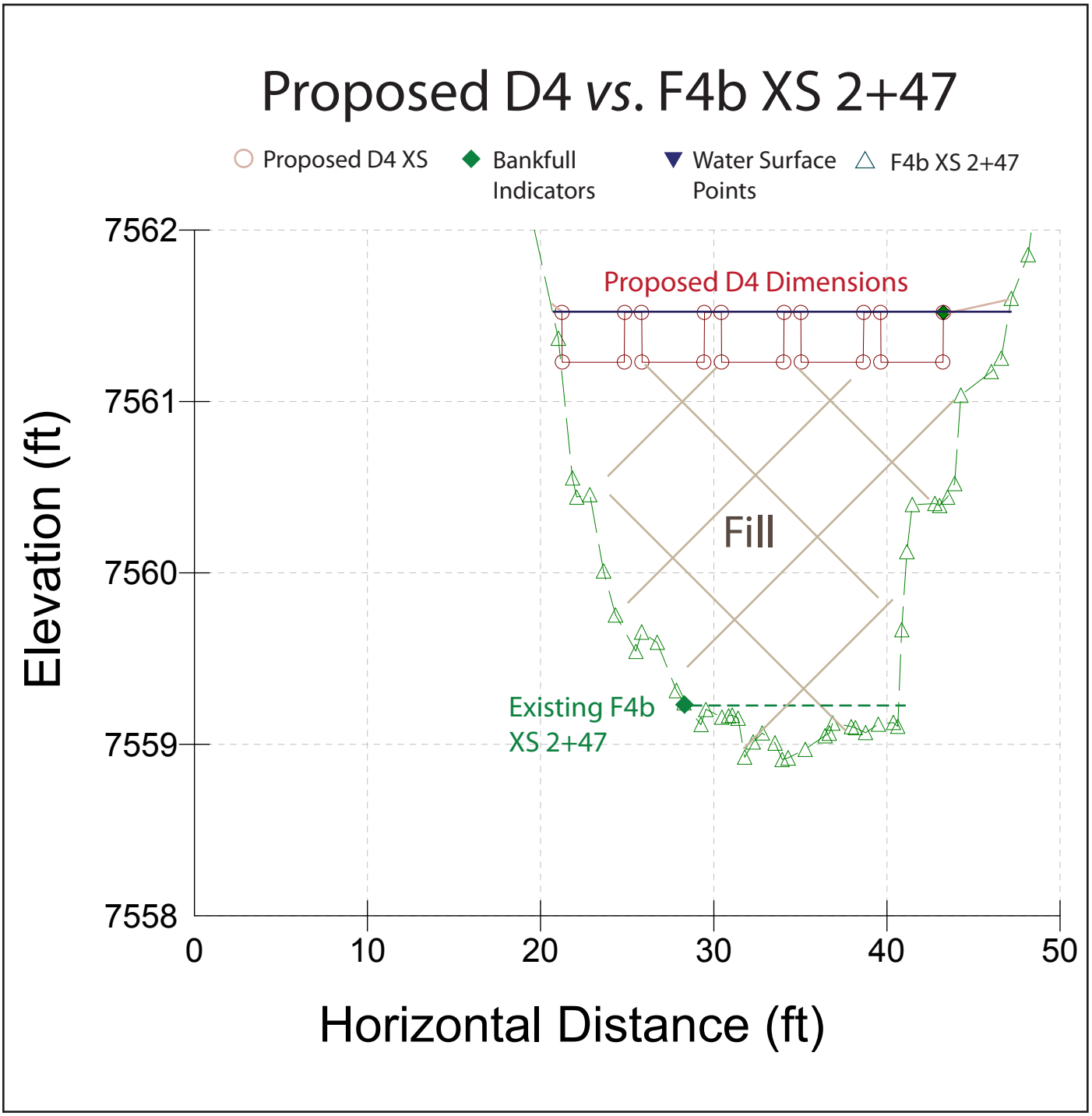


Figure II-49. The typical, proposed D4 cross-section dimensions compared to the existing F4b cross-section 2+47, indicating the extensive fill requirements and new bankfull elevation.

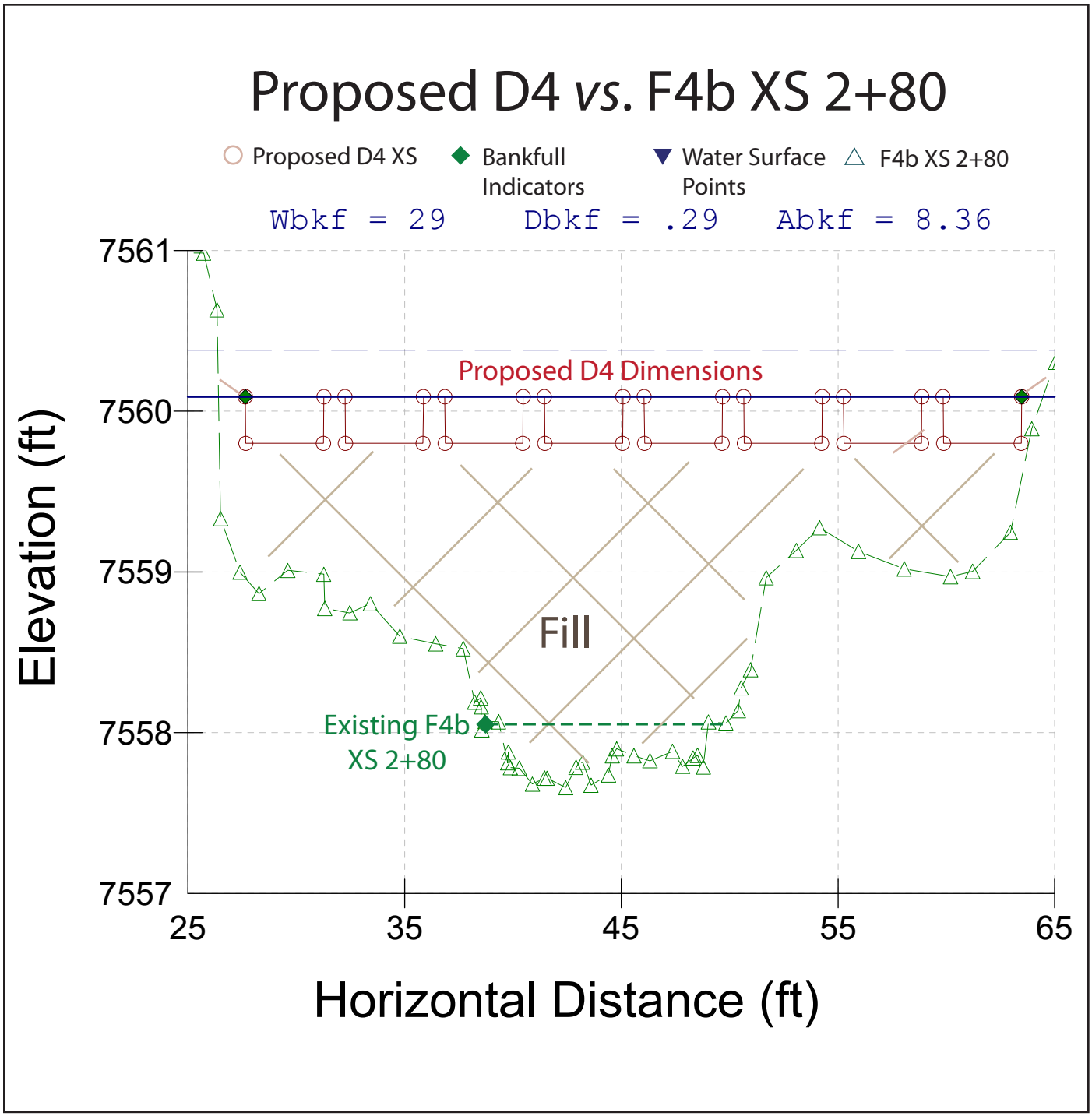


Figure II-50. The typical, proposed D4 cross-section dimensions compared to the existing F4b cross-section 2+80, indicating the extensive fill requirements and new bankfull elevation.

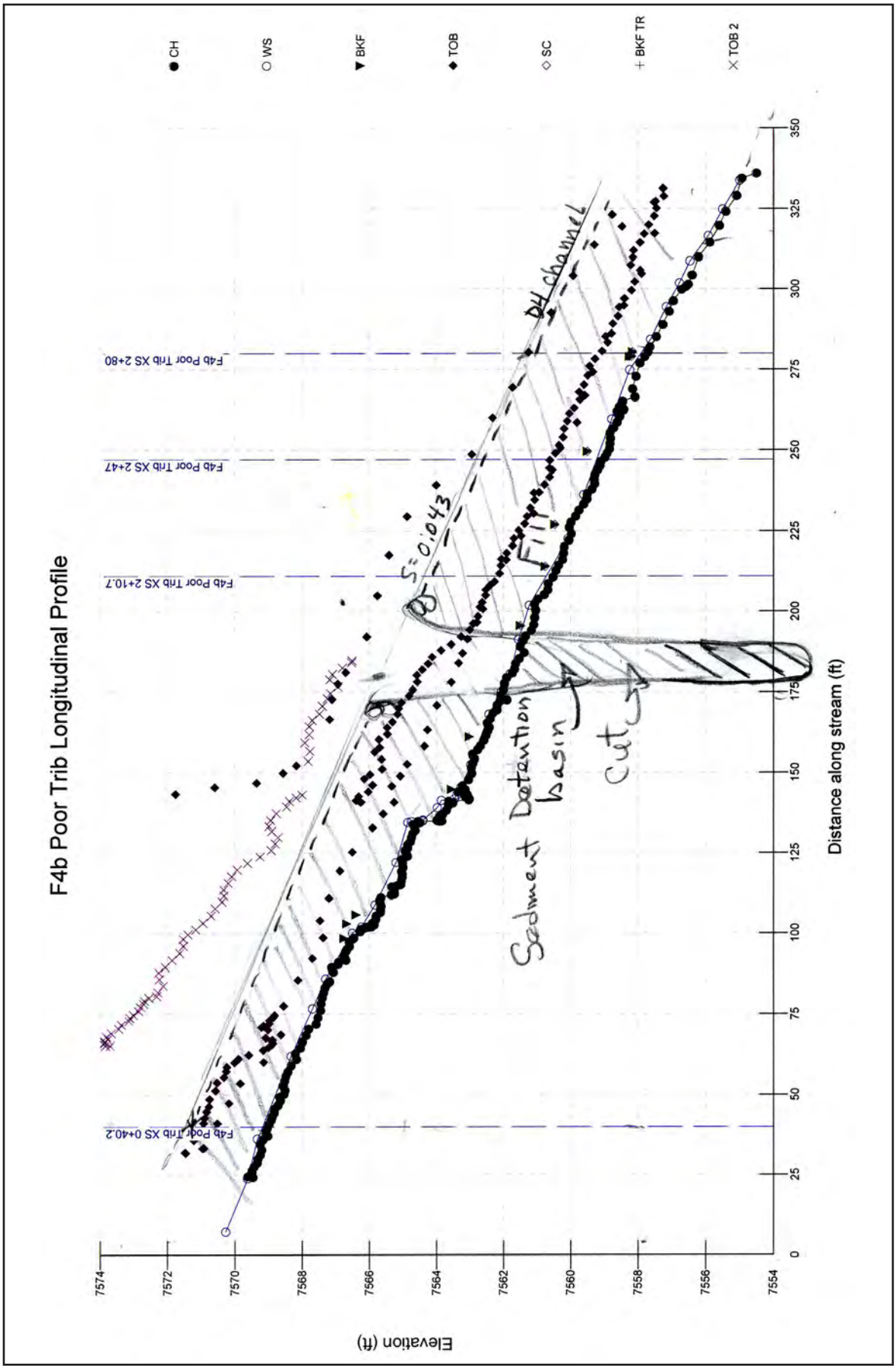


Figure II-51. The longitudinal profile showing a sediment detention basin and also comparing the elevations, slopes, and fill requirements of the existing F4b *vs.* proposed D4 stream type.

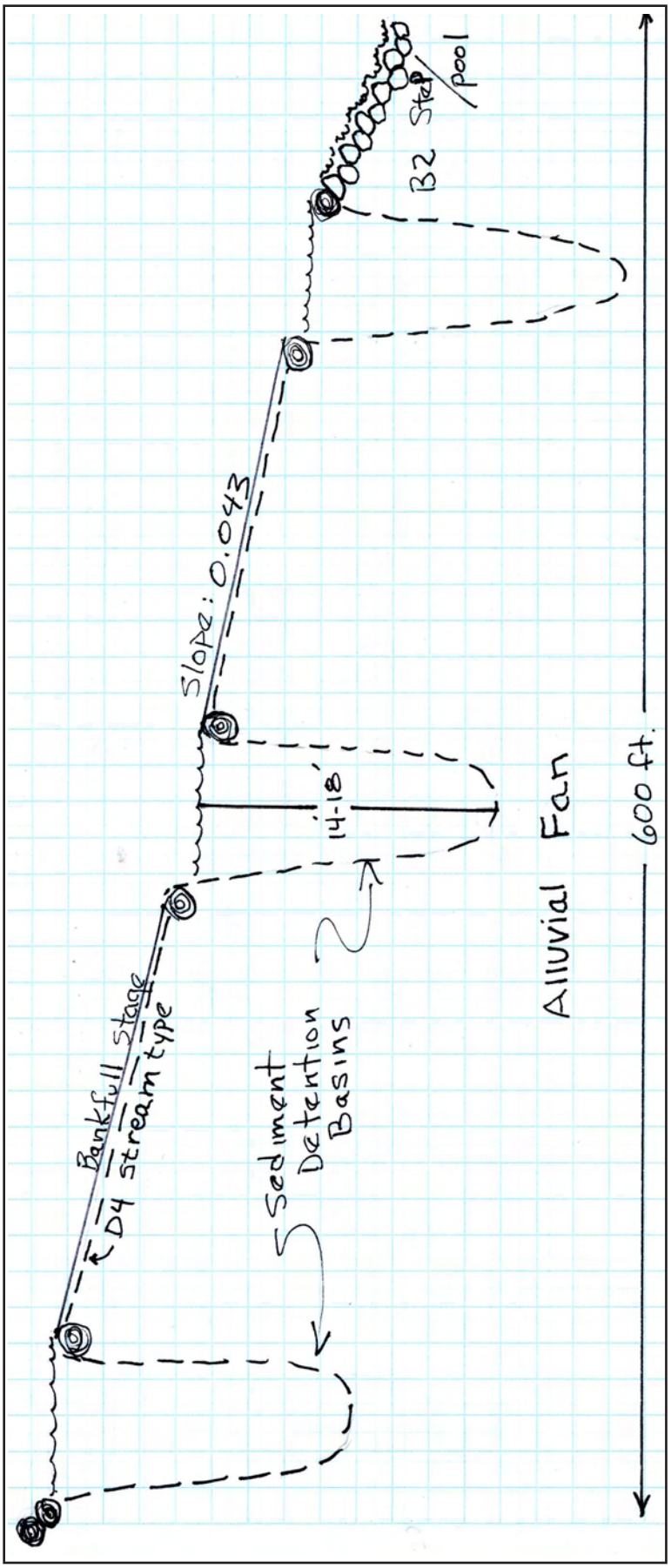


Figure II-52. A schematic of the proposed longitudinal profile of the F4b to D4 stream type conversion showing the three sediment detention basins and the designed B2, step–pool channel.

Streambank Erosion

The streambank erosion that is expected for the proposed D4 design reach is *12.8 tons/yr* for *337 ft* of designed channel *vs. 132.4 tons/yr* for the existing condition (**Table II-6**), representing a reduction of *119.6 tons/yr* for this reach. These values are based on the erosion rate of *0.3929 tons/ft/yr* for the *F4b Poor Trib. Representative Reach* and *0.038 tons/yr/ft* for the proposed D4 reach. The erosion rate for the proposed D4 reach was extrapolated from other D4 stream types but was decreased an order of magnitude by splitting the flow into multiple channels that would reduce the amount of flow convergence in each channel.

Flow-Related Sediment

The FLOWSED model does not indicate a change in the flow-related sediment yields as a result of the proposed F4b to D4 conversion because the proposed D4 channel is not being restored to a "Good" condition. The flow-related sediment yields are *1,064 tons/yr* for bedload, *4,197 tons/yr* for suspended sediment for a total annual sediment yield of *5,261 tons/yr* for both the F4b tributary and the proposed D4 channel (**Worksheet II-14**). These values represent the sediment yield produced from all upstream sources from approximately *17,770 ft* of stream channel and are generated using the dimensionless sediment rating curves and bankfull sediment values related to "Poor" stability for a given drainage area.

However, rather than route the sediment directly into Trail Creek, the D4 stream type was designed specifically to deposit the high flow-related sediment onto the alluvial fan surface and into sediment detention basins. The POWERSED model indicates that approximately *84%* of the upstream delivered sediment will be deposited with the designed, braided D4 stream type. If the fan surface is reactivated, approximately *15,600 tons/yr* can be stored on the fan. The storage capacity of the sediment detention basins is approximately *6,474 tons*. Thus, the annual sediment yield of *5,261 tons/yr* can be stored on the fan surface and detention basins for approximately *3.3 years*. At this time, the detention basins could be re-excavated to regain storage capacity, but the best solution is to reduce the sediment supply at its source. By relocating Trail Creek away from the toe of the fan, additional sediment storage could be accommodated by the Trail Creek floodplain. Nonetheless, this large sediment-producing tributary can be mitigated most successfully for the long-term, sustainable benefits if the hillslope and channel process restoration is implemented above this reach.

Overall, sub-watershed 6, being the highest priority for restoration in the Trail Creek Watershed due to the excessive sediment supply from flow-related sediment, surface erosion and roads, is responsible for adverse downstream impairment and active sediment delivery to the mainstem Trail Creek. The recommended restoration practices for this sub-watershed are critical to implement soon if the proposed restoration of this F4b to D4 stream type conversion is to have long term benefits.

Sediment Competence

The typical sediment competence calculations are not appropriate as the relations are for single-thread channels and therefore do not accurately reflect the shear stress for bankfull discharge distributed into multiple channels. The design of D4 stream types is to induce sediment deposition due to the typical bed forms of convergence/divergence (bars that form and reform with each storm). Due to the steepness of the slope of the fan, log sills are used on both the upper and lower ends of the sediment detention basins (**Figure II-45**). The B4 stream type that is designed to connect the last debris basin with the mainstem Trail Creek incorporates grade control and high flow resistance based on the designed structures (**Figure II-45**, **Figure II-46** and **Figure II-52**).

Worksheet II-14. The existing, F4b and the proposed D4 sediment supply using the FLOWSED model and generated by using the dimensionless sediment rating curves and bankfull sediment values related to the "Poor" condition.

Stream: **F4b Poor Tributary Representative Reach & Proposed D4** Location: **Lower Trail Creek Trib. above Mouth** Date: **3/15/11**

Observers: **Rosgen *et al*.** Gage Station #: **Goose Creek Gage** Stream Type: **F4b & D4** Valley Type: **III**

Equation Type	Equation Source	Equation	Bankfull Discharge (cfs)	Bankfull Bedload Sediment (kg/s)	Bankfull Suspended Sediment (mg/l)
1. Bedload Sediment	"Poor" Pagosa	$y = 0.07176+1.02176x^{2.3772}$	13	0.0923	153.71
2. Suspended Sediment	"Poor" Pagosa	$y = 0.0989+0.9213x^{3.659}$			

From Dimensional Flow-Duration Curve							From Sediment Rating Curves				Calculate	Calculate Sediment Yield		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Percentage of Time	Daily Mean Discharge	Mid-Ordinate	Time Increment (percent)	Time Increment (days)	Mid-Ordinate Streamflow	Dimension-less Streamflow	Dimension-less Suspended Sediment Discharge	Suspended Sediment Discharge	Dimension- less Bedload Discharge	Bedload Sediment Discharge	Time Adjusted Streamflow [(5)×(6)]	Suspended Sediment [(5)×(9)]	Bedload Sediment [(5)×(11)]	Suspended + Bedload Sediment [(13)+(14)]
(%)	(cfs)	(%)	(%)	(days)	(cfs)	(Q/Q_{bkf})	(S/S_{bkf})	(tons/day)	(b_s/b_{bkf})	(tons/day)	(cfs)	(tons)	(tons)	(tons)
0%	58.1													
0.10%	49.9	0.05%	0.09%	0.34	54.0	4.154	168.918	3785.82	30.244	265.97	18.5	1298.92	91.25	1390.17
0.25%	43.2	0.08%	0.15%	0.55	46.5	3.579	97.999	1892.48	21.249	186.86	25.5	1036.13	102.31	1138.44
0.50%	37.3	0.13%	0.25%	0.91	40.2	3.095	57.637	962.55	15.065	132.48	36.7	878.33	120.89	999.22
0.75%	31.9	0.13%	0.25%	0.91	34.6	2.660	33.137	475.54	10.528	92.58	31.6	433.93	84.48	518.41
1%	27.6	0.13%	0.25%	0.91	29.7	2.285	19.049	234.84	7.358	64.71	27.1	214.29	59.05	273.34
1.5%	19.7	0.25%	0.50%	1.83	23.6	1.819	8.322	81.67	4.308	37.88	43.2	149.04	69.14	218.18
2%	16.6	0.25%	0.50%	1.83	18.2	1.398	3.236	24.40	2.337	20.55	33.2	44.53	37.50	82.03
3%	14.2	0.50%	1.00%	3.65	15.4	1.185	1.812	11.59	1.601	14.08	56.2	42.29	51.39	93.68
4%	12.6	0.50%	1.00%	3.65	13.4	1.032	1.133	6.31	1.173	10.32	49.0	23.03	37.66	60.69
5%	11.2	0.50%	1.00%	3.65	11.9	0.916	0.768	3.80	0.902	7.93	43.5	13.86	28.95	42.82
10%	7.9	2.50%	5.00%	18.25	9.6	0.736	0.399	1.58	0.565	4.97	174.6	28.90	90.62	119.52
20%	4.3	5.00%	10.00%	36.50	6.1	0.472	0.158	0.40	0.243	2.14	224.0	14.69	78.10	92.79
30%	2.9	5.00%	10.00%	36.50	3.6	0.278	0.107	0.16	0.120	1.06	131.8	5.87	38.63	44.50
40%	2.0	5.00%	10.00%	36.50	2.5	0.190	0.101	0.10	0.091	0.80	90.0	3.77	29.34	33.12
50%	1.6	5.00%	10.00%	36.50	1.8	0.139	0.100	0.07	0.081	0.71	65.9	2.72	26.04	28.76
60%	1.2	5.00%	10.00%	36.50	1.4	0.106	0.099	0.06	0.077	0.67	50.5	2.08	24.63	26.71
70%	1.0	5.00%	10.00%	36.50	1.1	0.083	0.099	0.04	0.075	0.66	39.5	1.62	23.93	25.55
80%	0.8	5.00%	10.00%	36.50	0.9	0.069	0.099	0.04	0.074	0.65	32.9	1.35	23.61	24.96
90%	0.6	5.00%	10.00%	36.50	0.7	0.056	0.099	0.03	0.073	0.64	26.4	1.08	23.37	24.46
100%	0.1	5.00%	10.00%	36.50	0.4	0.028	0.099	0.01	0.072	0.63	13.2	0.54	23.10	23.64
									Annual Totals:		1,213.2 (cfs) 2,406.3 (acre-ft)	4,197.0 (tons/yr)	1,064.0 (tons/yr)	5,261.0 (tons/yr)

Summary of the Tributary F4b to D4 Stream Type Conversion

Many restoration solutions are founded in basic geomorphological features. Active alluvial fans and braided channels are the natural solution to sediment detention of the upper slopes to prevent direct sediment introduction into the main trunk stream. D4 stream types are often the natural stable form in such environments. When stream channels become incised in alluvial fans, they become high supply and high transport systems; thus the sediment yield is not only routed from farther upstream but is cut through portions of the fan deposit as well. Additionally, when the upstream sediment supply due to the elevated post-fire sediment yields is excessive, the construction of deep sediment detention basins can add storage capacity to the fan. One or more of these constructed sediment detention basins will provide additional time to reduce delivered sediment yields until post-fire, flow-related sediment yields are eventually reduced. The basins also reduce the required depositional storage requirement of the fan. The transition B2 stream type at the toe is designed to transfer the concentrated water from the last basin into a stable , single-thread, step–pool channel to join Trail Creek. This restoration is implemented under the assumption that the mainstem Trail Creek will be relocated away from the toe of this large fan to allow for full function and to keep sediment from entering Trail Creek.

Many fans can be restored back to their intended function following this typical design scenario. The numerous tributary channels associated with F4b stream types and alluvial fans that are long and wide enough are candidates for this design to reduce the associated high sediment yields that are transported directly to the mainstem Trail Creek. The tributary channels and associated conditions are mapped by sub-watershed in *Appendix D* of the Trail Creek *WARSSS* analysis (Rosgen, 2011a).

Typical Design Scenario 5b Example

Tributary A4a+ to D4 Stream Type Conversion

(Valley Type III – Large)

Tributary A4a+ to D4 Stream Type Conversion (VT III): Typical Design Scenario 5b Example

General Description & Morphological Data

This typical design scenario example is a stream type conversion of an A4a+ *Poor* condition tributary to a braided, D4 stream type within a wide and long alluvial fan (Valley Type III). The existing, impaired tributary is the *A4a+ Poor Stability Downstream Representative Reach*, as identified in the general map in **Figure II-1**. The tributary is located at the mouth of a face drainage south of Sub-Watershed 6 of the Trail Creek Watershed as shown in **Figure II-53**. The detailed characteristics and stability evaluation of this representative reach are documented in *Appendix C4* of the Waldo Canyon Fire *WARSSS* analysis (Rosgen *et al*., 2013). This channel is deeply incised, confined and entrenched, and is associated with advancing headcuts, which are typical in the majority of A4a+ reaches in the presence of post-fire, peak flows. The *A4a+ Poor Downstream Representative Reach* is only *60.0 ft* in length; however, a *300 ft* reach is used for this typical design scenario to include the alluvial fan at the outflow onto the valley floor and the confluence with Trail Creek. Hence, this design scenario demonstrates the recommended restoration for this ephemeral stream system that can be appropriately applied to numerous other similar systems with large alluvial fans.

Figure II-54 depicts the incised and actively eroding A4a+ stream type cut through an alluvial fan. The high peak flows of the post-fire floods and the over-steepening of the toe of the fan from Trail Creek have accelerated this erosion. The toe of the alluvial fan has also been eroded away by Trail Creek; thus part of the long-term solution is to relocate Trail Creek away from the fan. Because the existing A4a+ tributary drains onto a large alluvial fan, and the location of Trail Creek will be relocated away from the toe of the fan, the proposed solution at this site is to create a braided, D4 stream type on the fan surface to naturally deposit sediment and to store sediment in a detention basin.

The specific objectives and direction of this design are as follows:

- Reduce the sediment supply from the accelerated bed scour (degradation)
- Reduce the accelerated streambank erosion rates
- Store sediment before it is transmitted to Trail Creek
- Build out and establish a stable toe of the alluvial fan in conjunction with the relocation of Trail Creek.

The proposed restoration of converting the A4a+ *Poor* reach to a braided D4 stream type involves *300 ft* of length starting at the confluence with the valley floor and floodplain of Trail Creek and extending upstream. If this reach is not restored, it will continue to headcut and provide high sediment yields to Trail Creek. The increased post-fire floods will continue to downcut and laterally erode this reach unless the impairment is reversed. A D4 "reference reach" was not established for this project and therefore the proposed characteristics of the D4 stream type for this scenario are adapted from D4 characteristics studied in detail by the restoration practitioner.

The resultant morphology and design parameters for the proposed D4 reach are documented in **Table II-8**. Additionally, this table also includes the morphological descriptions and corresponding analyses of the existing *A4a+ Poor Stability Downstream Representative Reach*. The following sections include the proposed design details of the braided, D4 stream type.

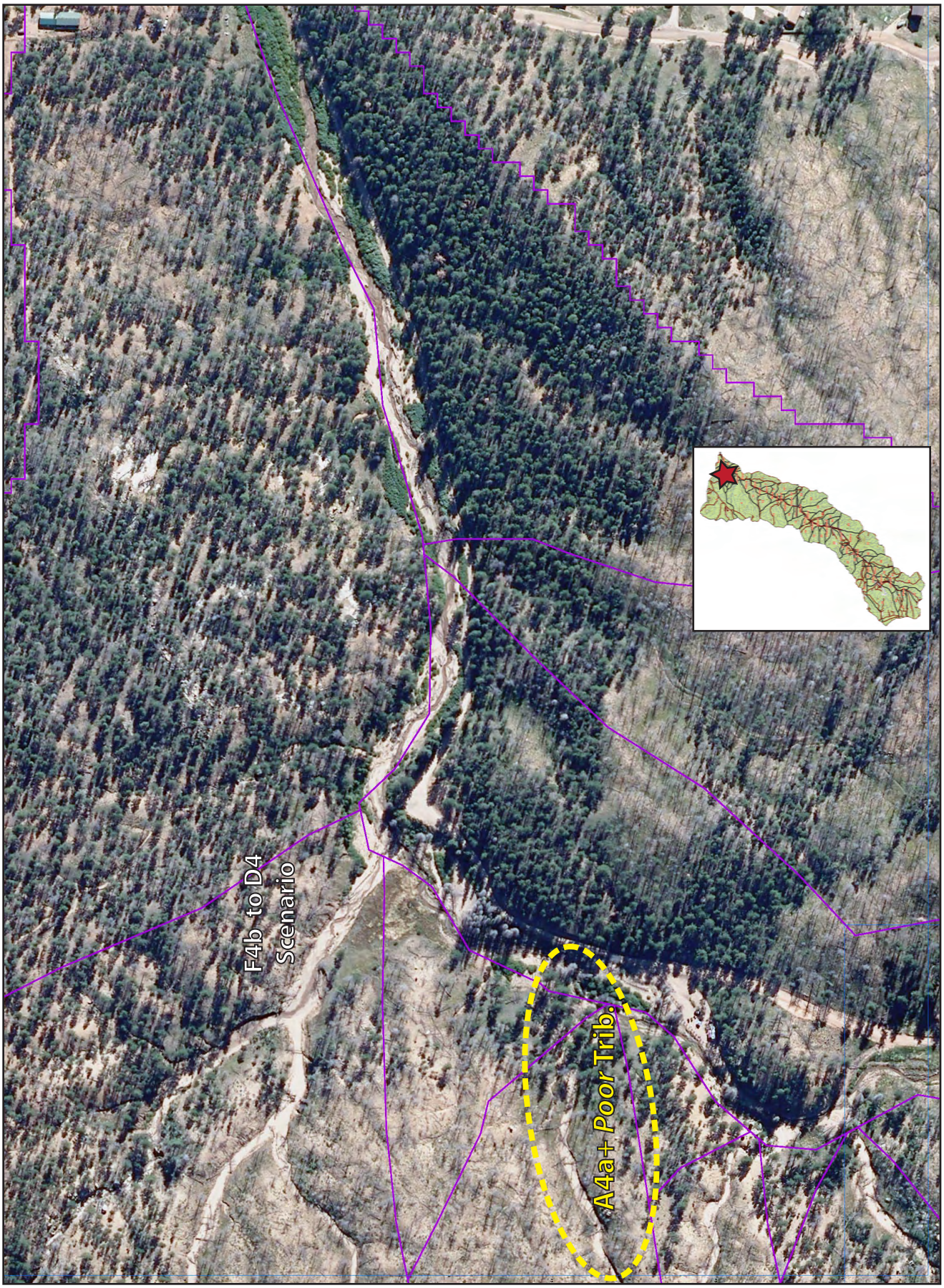


Figure II-53. The location of the existing, impaired *A4a+ Poor Stability Downstream Representative Reach* within Sub-Watershed 6 in the Trail Creek Watershed.



Figure II-54. The existing, incised A*4a+ Poor Stability Downstream Representative Reach* showing the active erosion and transport of sediment near the mouth of the reach on an alluvial fan.

Table II-8. The morphological characteristics of the existing and proposed design reaches for the A4a+ tributary to D4 stream type conversion in a wide and long alluvial fan – Valley Type III.

Existing Reach Stream & Location:			**Trail Creek Trib., A4a+ Poor Downstream**			
Reference Reach Stream & Location:			**Typical D4 characteristics used**			
	Entry Number & Variable		**Existing Reach**		**Proposed Design Reach**	
	1	Valley Type	**III**		**III**	
	2	Valley Width				
	3	Stream Type	**A4a+**		**D4**	
	4	Drainage Area, mi^2	**0.0027**		**0.0027**	
	5	Bankfull Discharge, cfs (Q_{bkf})	**0.412**		**0.412**	
Riffle Dimensions	**6**	Riffle Width, ft (W_{bkf})	*Mean:* *Min:* *Max:*	**2.2** **1.7** **2.7**	*Mean:* *Min:* *Max:*	**8.0**
	7	Riffle Mean Depth, ft (d_{bkf})	*Mean:* *Min:* *Max:*	**0.19** **0.17** **0.24**	*Mean:* *Min:* *Max:*	**0.10**
	8	Riffle Width/Depth Ratio (W_{bkf}/d_{bkf})	*Mean:* *Min:* *Max:*	**11.7** **9.2** **15.7**	*Mean:* *Min:* *Max:*	**80.0**
	9	Riffle Cross-Sectional Area, ft^2 (A_{bkf})	*Mean:* *Min:* *Max:*	**0.4** **0.3** **0.5**	*Mean:*	**0.8**
	10	Riffle Maximum Depth (d_{max})	*Mean:* *Min:* *Max:*	**0.29** **0.24** **0.40**	*Mean:* *Min:* *Max:*	**0.15**
	11	Riffle Maximum Depth to Riffle Mean Depth (d_{max}/d_{bkf})	*Mean:* *Min:* *Max:*	**1.497** **1.411** **1.667**	*Mean:* *Min:* *Max:*	**1.500**
	12	Width of Flood-Prone Area at Elevation of 2 * d_{max}, ft (W_{fpa})	*Mean:* *Min:* *Max:*	**2.9** **2.0** **4.0**	*Mean:* *Min:* *Max:*	**N/A**
	13	Entrenchment Ratio (W_{fpa}/W_{bkf})	*Mean:* *Min:* *Max:*	**1.3** **1.2** **1.5**	*Mean:* *Min:* *Max:*	**N/A**

Table II-8 (page 2). The morphological characteristics of the existing and proposed design reaches for the A4a+ tributary to D4 stream type conversion in a wide and long alluvial fan – Valley Type III.

	Entry Number & Variable	Existing Reach	Proposed Design Reach
Sinuosity and Slope	**88** Stream Length (SL)	**72.1**	**300.0**
	89 Valley Length (VL)	**66.0**	**300.0**
	90 Valley Slope (S_{val})	**0.1347**	**0.1347**
	91 Sinuosity (k)	SL/VL: **1.09** VS/S: **1.09**	**1.00**
	92 Average Water Surface Slope (S)	**0.1236**	$S = S_{val}/k$ **0.1347**
Degree of Incision	**102** Low Bank Height (LBH)	*Mean:* **2.05** *Min:* *Max:*	*Mean:* **0.15** *Min:* *Max:*
	103 Maximum Bankfull Depth (d_{max}) at Same Location as Low Bank Height (LBH) Measurement	*Mean:* **0.40** *Min:* *Max:*	*Mean:* **0.15** *Min:* *Max:*
	104 Bank-Height Ratio (LBH/d_{max})	*Mean:* **5.10** *Min:* *Max:*	*Mean:* **1.00** *Min:* *Max:*
Channel Materials	**125 Particle Size Distribution of Channel Material (Active Bed) or Pavement**		
	D_{16} (mm)	**1.3**	**1.3**
	D_{35} (mm)	**3.3**	**3.3**
	D_{50} (mm)	**6.0**	**6.0**
	D_{84} (mm)	**10.8**	**10.8**
	D_{95} (mm)	**42.1**	**42.1**
	D_{100} (mm)	**362.0**	**362.0**
	126 Particle Size Distribution of Bar Material or Sub-pavement		
	D_{16} (mm)	**N/A**	**N/A**
	D_{35} (mm)	**N/A**	**N/A**
	D_{50} (mm)	**N/A**	**N/A**
	D_{84} (mm)	**N/A**	**N/A**
	D_{95} (mm)	**N/A**	**N/A**
	D_{max}: Largest size particle at the toe (lower third) of bar (mm) or sub-pavement	**N/A**	**N/A**

Table II-8 (page 3). The morphological characteristics of the existing and proposed design reaches for the A4a+ tributary to D4 stream type conversion in a wide and long alluvial fan – Valley Type III.

	Entry Number & Variable	Existing Reach	Proposed Design Reach
Hydraulics	**127** Estimated Bankfull Mean Velocity, ft/sec (u_{bkf})	**0.78**	**0.52**
	128 Estimated Bankfull Discharge, cfs (Q_{bkf}); Compare with Regional Curve	**0.412**	**0.412**
Sediment Yield	**Sediment Yield (FLOWSED)**	**Existing Reach**	**Proposed Design Reach**
	141 Bedload Sediment Yield (tons/yr)	**36.9**	**36.9**
	142 Suspended Sediment Yield (tons/yr)	**169.8**	**169.8**
	143 Suspended Sand Sediment Yield (tons/yr)	**84.9**	**84.9**
	144 Total Annual Sediment Yield (tons/yr)	**206.7**	**206.7**
Bank Erosion	**Streambank Erosion**	**Existing Reach**	**Proposed Design Reach**
	145 Stream Length Assessed (ft)	**300**	**300**
	146 Graph/Curve Used (e.g., Yellowstone or Colorado)	**Colorado**	**Colorado**
	147 Streambank Erosion (tons/yr)	**23.55**	**11.40**
	148 Streambank Erosion (tons/yr/ft)	**0.0785**	**0.038**

Bankfull Discharge, Cross-Sectional Area & Mean Velocity

With a drainage area of *0.0027 mi²* for the proposed D4 stream type, the bankfull discharge is *0.412 cfs* and the proposed bankfull riffle cross-sectional area is *0.8 ft²* as shown in **Table II-8**. Using continuity, the corresponding mean velocity for the proposed design reach is *0.52 ft/sec* as shown in **Worksheet II-15**.

Plan View Alignment

The design sketch in **Figure II-55** shows the plan and cross-section views of the proposed restoration design, including the designed sediment detention basin and the stabilization of the toe of the alluvial fan.

Cross-Section Dimensions

Table II-8 includes the proposed dimensions for the proposed D4 design reach. The overlay of the existing A4a+ cross-section 0+9.84 *vs*. proposed D4 cross-section, indicating the extensive fill requirements, is shown in **Figure II-56**. The proposed sediment detention basin is shown in **Figure II-57** where it is planned to be excavated at the existing A4a+ cross-section 0+30.8. The comparison of an additional proposed D4 cross-section *vs*. the existing, entrenched A4a+ cross-section 0+53.9 is shown in **Figure II-58**.

Longitudinal Profile

A schematic of the slope profile for the proposed A4a+ to D4 stream type conversion within an alluvial valley is shown in **Figure II-59**. The sketch illustrates the cut and fill requirements, the proposed sediment detention basin, and the fill required for the toe of the fan. The elevation of the bed is raised to near the fan surface to allow for sufficient, shallow depth for the multiple-thread, braided, D4 stream type. This connection allows the fan to serve its purpose of storing sediment produced from upstream. The D4 stream type will also deposit sediment on the fan surface by the development of divergence and convergence bed features of sediment bars. The sediment detention basin will provide additional storage and will provide the fill to raise the existing A4a+ stream type up to the fan surface.

The longitudinal profile in **Figure II-60** for the surveyed section of the A4a+ tributary shows the existing *vs*. proposed elevations of the bed and bankfull stage, the energy slope and sediment detention basin that correspond with the plan view in **Figure II-55**.

Structures

Log sills are required for the sediment detention basin on both the upper and lower banks to prevent headcutting. The material for the sills will be obtained from on-site sources. No other structures are recommended.

Worksheet II-15. The mean velocity estimates for the proposed D4 stream type to be converted from the existing, A4a+ tributary within an alluvial fan.

Bankfull VELOCITY & DISCHARGE Estimates

Stream:	**Proposed D4 from A4a+ Poor**			Location:	**A4a+ Poor Downstream Rep. Reach**
Date:	**3/15/2011**	Stream Type:	**D4**	Valley Type:	**III**
Observers:	**Rosgen *et al*.**			HUC:	_ _ _ _ _ _ _ _ _ _ _ _

Input Variables for PROPOSED Design			Output Variables for PROPOSED Design		
Bankfull Riffle Cross-Sectional AREA	**0.8**	**A_{bkf}** (ft^2)	Bankfull Riffle Mean DEPTH	**0.10**	**d_{bkf}** (ft)
Bankfull Riffle WIDTH	**8.0**	**W_{bkf}** (ft)	Wetted PERMIMETER ~ $(2 * d_{bkf}) + W_{bkf}$	**8.20**	**W_p** (ft)
D_{84} at Riffle	**10.8**	**Dia.** (mm)	D_{84} (mm) / 304.8	**0.04**	**D_{84}** (ft)
Bankfull SLOPE	**0.1347**	**S_{bkf}** (ft / ft)	Hydraulic RADIUS A_{bkf} / W_p	**0.10**	**R** (ft)
Gravitational Acceleration	**32.2**	**g** (ft / sec^2)	Relative Roughness R(ft) / D_{84} (ft)	**2.76**	**R / D_{84}**
Drainage Area	**0.0027**	**DA** (mi^2)	Shear Velocity $u^* = (gRS)^{½}$	**0.651**	**u*** (ft/sec)

ESTIMATION METHODS	Bankfull VELOCITY		Bankfull DISCHARGE	
1. Friction Factor / Relative Roughness $u = [2.83 + 5.66 * Log \{ R / D_{84} \}] u^*$	**N/A**	ft / sec	**N/A**	cfs
2. Roughness Coefficient: a) Manning's *n* from Friction Factor / Relative Roughness (Figs. 5-7, 5-8) $u = 1.49*R^{2/3}*S^{1/2} / n$ $n =$		ft / sec		cfs
2. Roughness Coefficient: b) Manning's *n* from Stream Type (Fig. 5-9) $u = 1.49*R^{2/3}*S^{1/2} / n$ $n =$		ft / sec		cfs
2. Roughness Coefficient: c) Manning's *n* from Jarrett (USGS): $u = 1.49*R^{2/3}*S^{1/2} / n$ $n = 0.39*S^{0.38}*R^{-0.16}$ **Note:** This equation is applicable to **steep, step/pool, high boundary roughness, cobble- and boulder-dominated stream systems**; i.e., for Stream Types A1, A2, A3, B1, B2, B3, C2 & E3 $n =$ **0.264**	**0.44**	ft / sec	**0.35**	cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)		ft / sec		cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)		ft / sec		cfs
4. Continuity Equations: a) USGS Gage Data $u = Q / A$ **Return Period for Bankfull Q** $Q =$ ____ **year**		ft / sec		cfs
4. Continuity Equations: b) Regional Curves $u = Q / A$	**0.52**	ft / sec	**0.412**	cfs

Protrusion Height Options for the D_{84} Term in the Relative Roughness Relation (R/D_{84}) – Estimation Method 1

Option 1.	For **sand-bed** channels: Measure 100 **"protrusion heights"** of sand dunes from the downstream side of feature to the top of feature. Substitute the D_{84} sand dune protrusion height in ft for the D_{84} term in method 1.
Option 2.	For **boulder-dominated** channels: Measure 100 **"protrusion heights"** of boulders on the sides from the bed elevation to the top of the rock on that side. Substitute the D_{84} boulder protrusion height in ft for the D_{84} term in method 1.
Option 3.	For **bedrock-dominated** channels: Measure 100 **"protrusion heights"** of rock separations, steps, joints or uplifted surfaces above channel bed elevation. Substitute the D_{84} bedrock protrusion height in ft for the D_{84} term in method 1.
Option 4.	For **log-influenced** channels: Measure "**protrustion heights**" proportionate to channel width of log diameters or the height of the log on upstream side if embedded. Substitute the D_{84} protrusion height in ft for the D_{84} term in method 1.

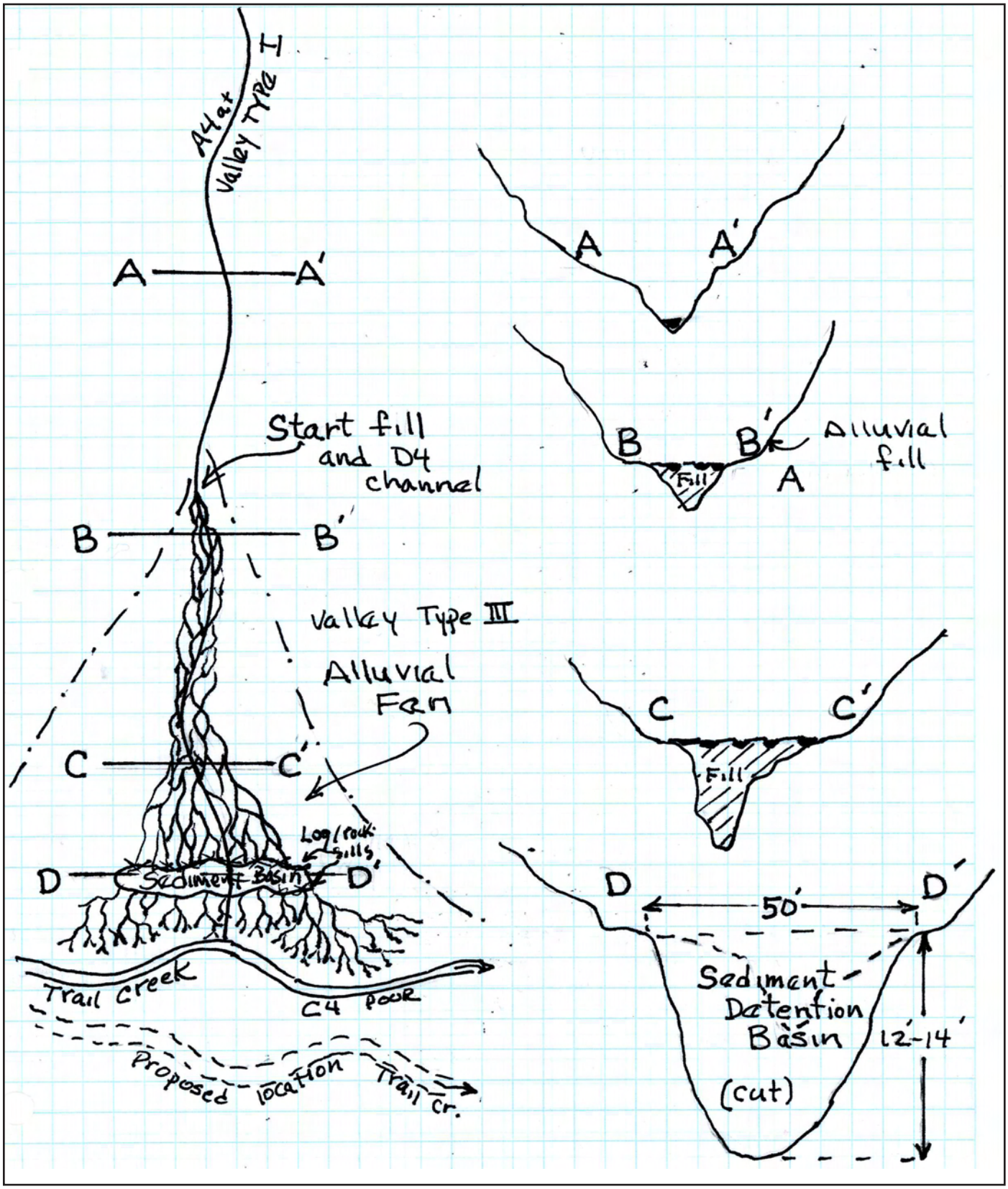


Figure II-55. The plan and cross-section views of the proposed A4a+ to D4 stream type conversion with a sediment detention basin, Valley Type III.

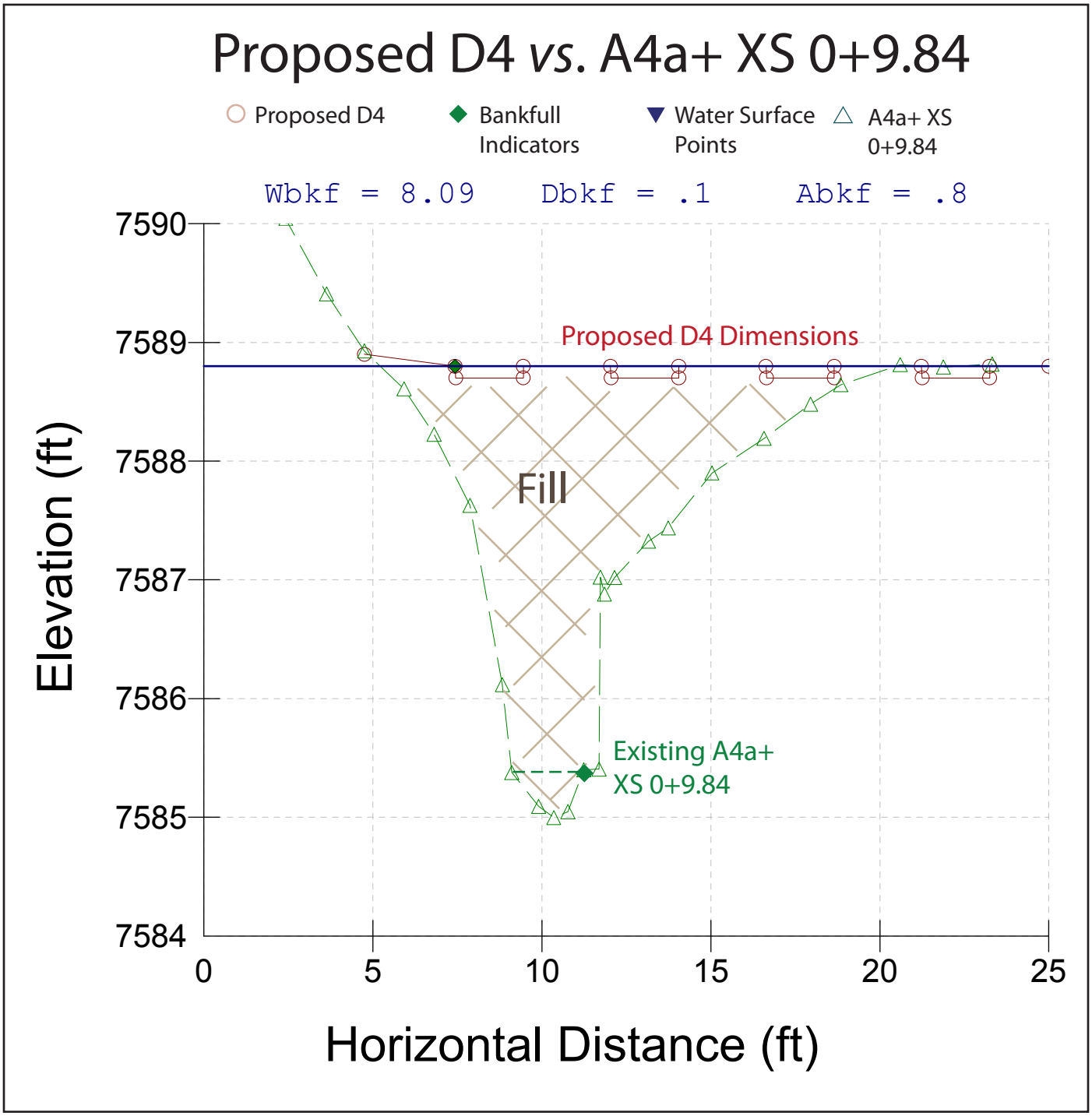


Figure II-56. The proposed D4 cross-section *vs*. the existing A4a+ cross-section 0+9.84 indicating the extensive fill requirements.

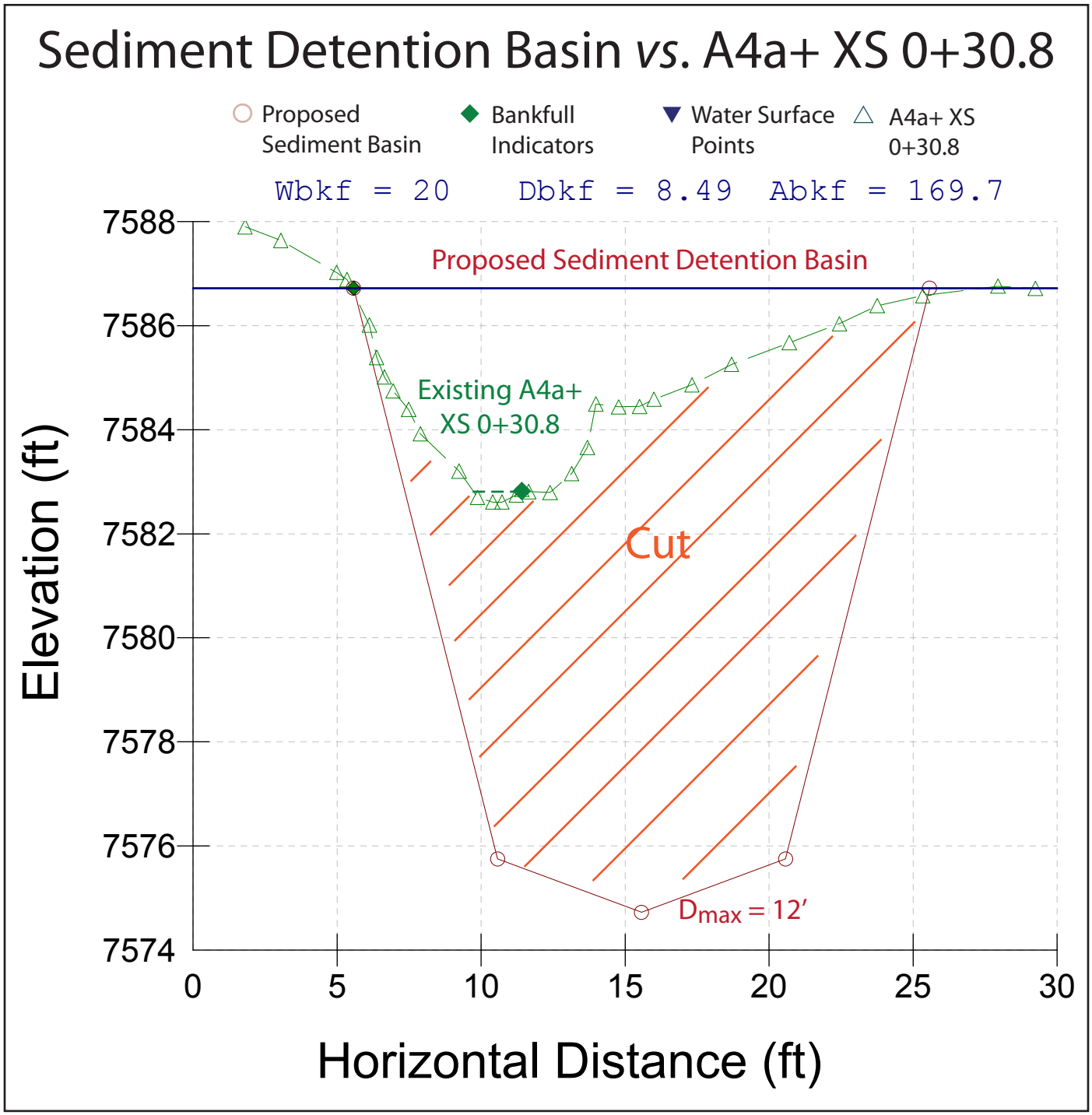


Figure II-57. The proposed sediment detention basin located at the existing A4a+ cross-section 0+30.8.

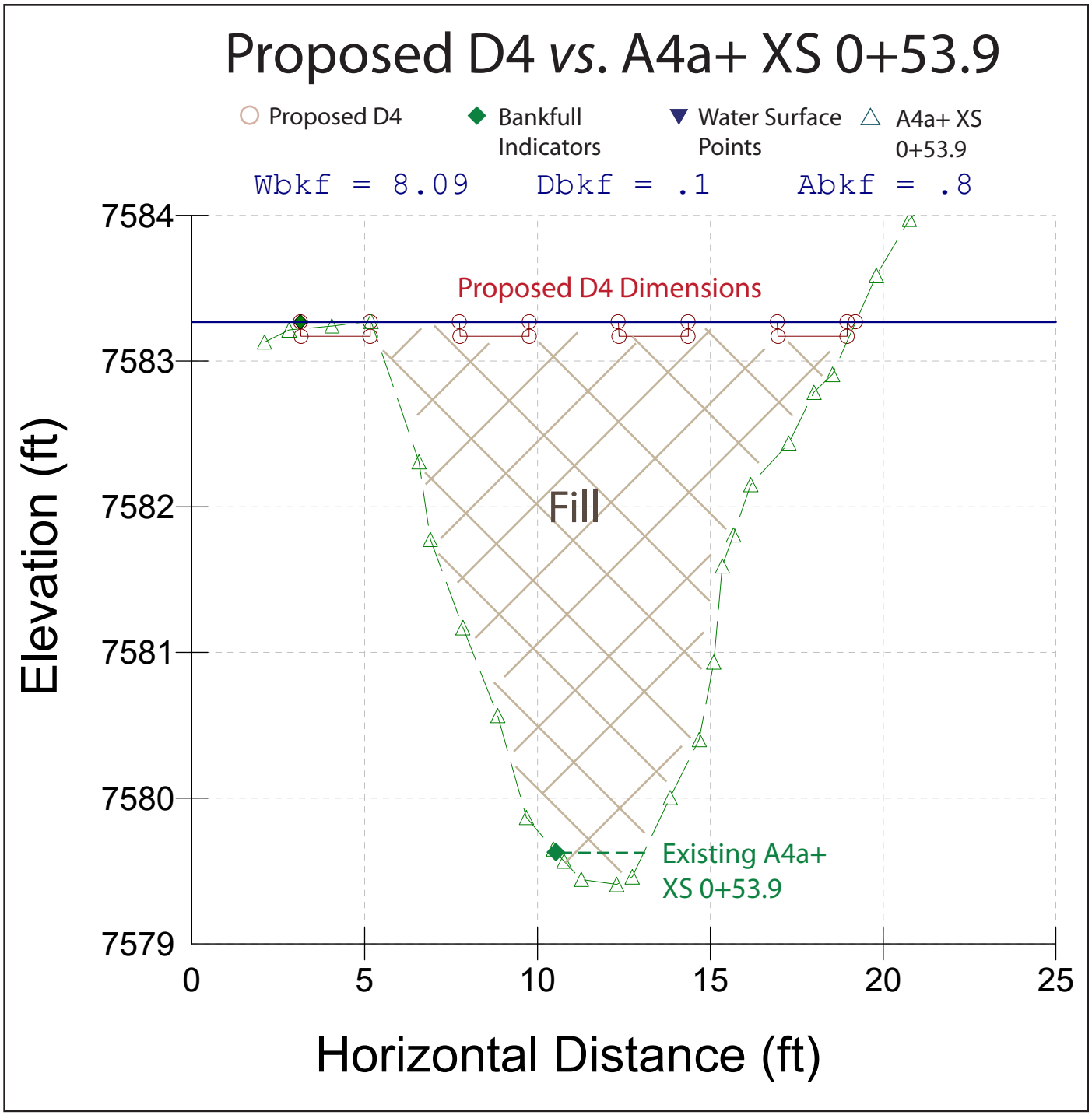


Figure II-58. The proposed D4 cross-section *vs*. the existing A4a+ cross-section 0+53.9 indicating the extensive fill requirements.

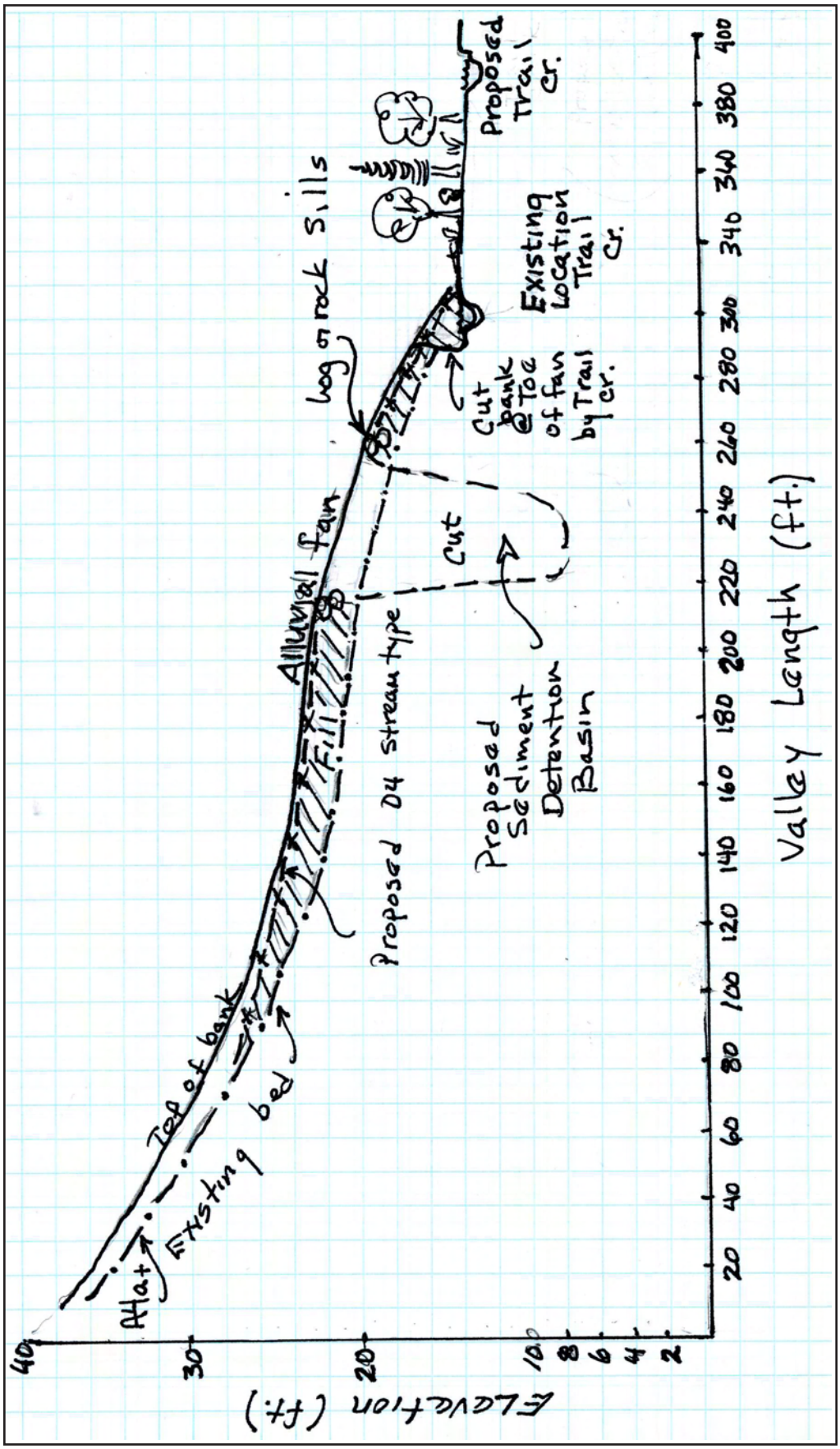


Figure II-59. The slope profile of the proposed A4a+ to D4 stream type conversion, Valley Type III, with a sediment detention basin and fill of the fan toe.

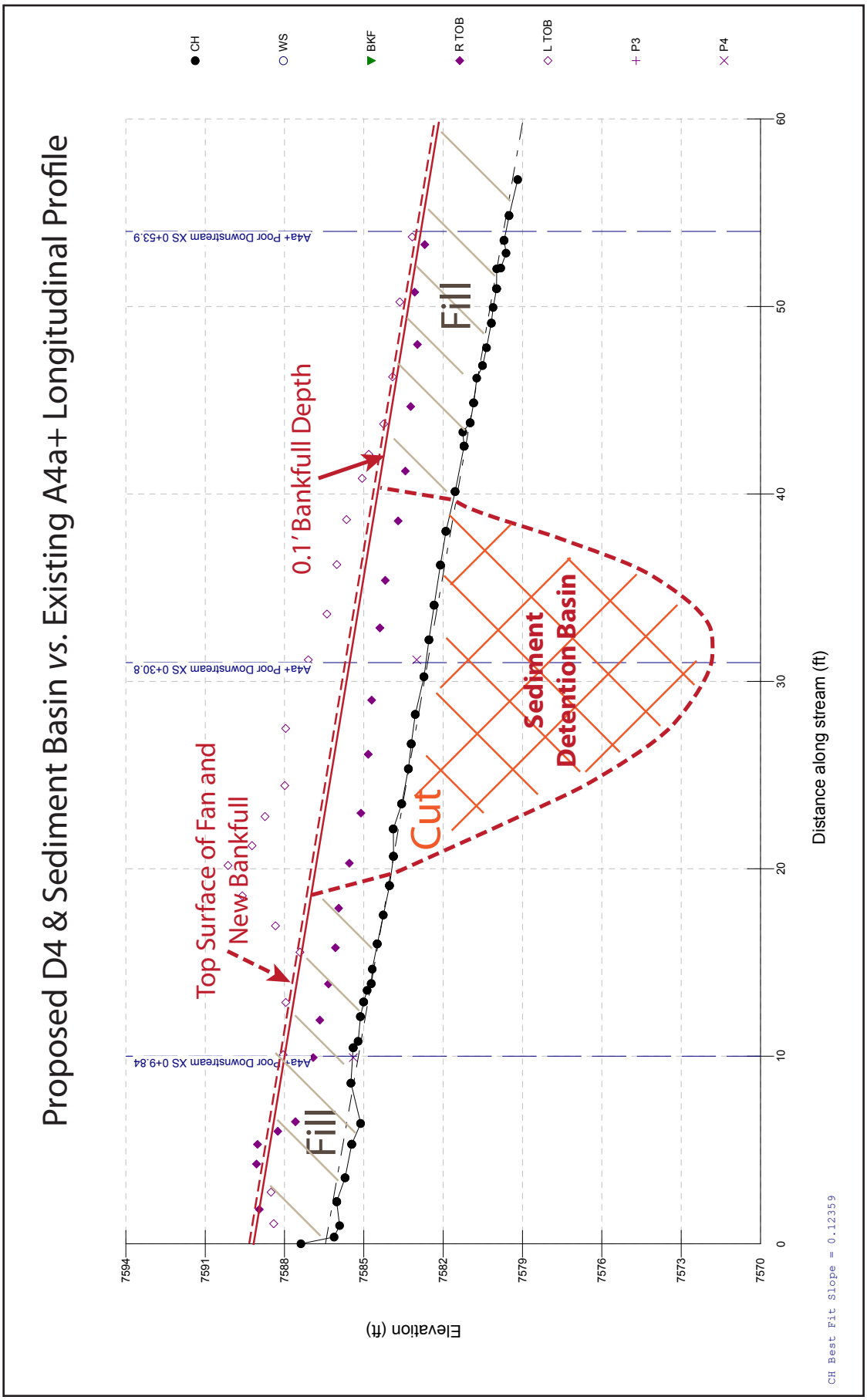


Figure II-60. A localized longitudinal profile of the proposed D4 over the existing A4a+ stream type, showing the sediment detention basin.

Riparian Vegetation

It is a key requirement to re-establish a woody riparian community of willow and alder along this proposed D4 stream type. The vegetation will add flow resistance, will induce long-term deposition and will prevent excess lateral adjustment due to braiding. In addition to establishing a woody vegetation community, native bunch grasses, such as big mountain brome, are recommended for seeding the alluvial fan.

Cut & Fill Computations

The cut and fill material is balanced by excavating what is needed from the sediment detention basin to raise the bed of the A4a+ channel up to the fan surface and to build out the toe of the fan. It is estimated that *155 yds*^{3} will be needed for both.

Streambank Erosion

The streambank erosion that is expected for *300 ft* of the proposed D4 design reach is *11.4 tons/yr* compared to *23.6 tons/yr* for the existing condition (**Table II-8**), representing a reduction of *12.2 tons/yr* for this proposed design scenario (a *50%* reduction). These values are based on the erosion rate of *0.0785 tons/yr/ft* for the *A4a+ Poor Downstream Representative Reach* and the erosion rate of *0.0380 tons/yr/ft* for the proposed D4 design reach. The erosion rate for the proposed D4 reach was extrapolated from other D4 stream types but was decreased an order of magnitude by splitting the flow into multiple channels that would reduce the amount of flow convergence in each channel. However, because the majority of the streambank erosion from upstream sources will be deposited in sediment detention basin, potentially *99%* of the delivered sediment to the mainstem Trail Creek from streambank erosion will be reduced.

Flow-Related Sediment

The FLOWSED model does not indicate a change in the flow-related sediment yields as a result of the proposed A4a+ to D4 stream type conversion because the proposed D4 channel is not being restored to a "Good" condition. However, rather than route the sediment directly into Trail Creek, the D4 stream type is specifically designed to deposit the high flow-related sediment onto the alluvial fan surface and detention basin. The flow-related sediment yields are *36.9 tons/yr* for bedload, *169.8 tons/yr* for suspended sediment for a total annual sediment yield of *206.7 tons/yr* for both the A4+ tributary and the proposed D4 channel (**Worksheet II-16**). These values are generated using the dimensionless sediment rating curves and bankfull sediment values related to "Poor" stability for a given drainage area.

The POWERSED model indicates a reduction in transport capacity by inducing deposition (by design) due to the high width/depth ratio of the D4 stream type. The alluvial fan with the braided, D4 stream type has the capacity to hold approximately *1,481 yds*^{3}, and the sediment detention basin can hold approximately *3,407 yds*^{3}, for a total capacity of approximately *3,407 yds*^{3}. Based on the total annual sediment yield of *206.7 tons/yr* (*159 yds*^{3}), the combined storage would last for approximately *21.4 years*. This design scenario and associated sediment reduction would not only reduce the delivered sediment to the mainstem Trail Creek, but it also buys time for the vegetation to recover with a corresponding reduced sediment supply due to the fire.

Sediment Competence

The typical sediment competence calculations are not appropriate as the relations are for single-thread channels and therefore do not accurately reflect the shear stress for bankfull discharge distributed into multiple channels. The design of D4 stream types is to induce sediment deposition due to the typical bed forms of convergence/divergence (bars that form and reform with each storm). The sediment competence based on the proposed design would show insufficient energy relating to deposition due to placing the bankfull discharge into four separate channels that greatly disperses flow energy compared to single-thread channels on the same slope. Due to the steepness of the slope of the fan, log sills are used on both the upper and lower ends of the sediment detention basin to prevent headcutting.

Worksheet II-16. The existing A4a+ tributary and the proposed D4 sediment supply using the FLOWSED model and generated by using the dimensionless sediment rating curves and bankfull sediment values related to a "Poor" condition.

Stream: **A4a+ Poor Downstream Rep. Reach & Proposed D4** Location: **Tributary to Mainstem Trail Creek** Date: **3/15/11**

Observers: **Rosgen *et al*.** Gage Station #: **Goose Creek Gage** Stream Type: **A4a+ & D4** Valley Type: **III**

Equation Type	Equation Source	Equation	Bankfull Discharge (cfs)	Bankfull Bedload Sediment (kg/s)	Bankfull Suspended Sediment (mg/l)
1. Bedload Sediment	"Poor" Pagosa	$y = 0.07176+1.02176x^{2.3772}$	0.412	0.0019	56.45
2. Suspended Sediment	"Poor" Pagosa	$y = 0.0989+0.9213x^{3.659}$			

From Dimensional Flow-Duration Curve							From Sediment Rating Curves				Calculate	Calculate Sediment Yield		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Percentage of Time	Daily Mean Discharge	Mid-Ordinate	Time Increment (percent)	Time Increment (days)	Mid-Ordinate Streamflow	Dimension-less Streamflow	Dimension-less Suspended Sediment Discharge	Suspended Sediment Discharge	Dimension- less Bedload Discharge	Bedload Sediment Discharge	Time Adjusted Streamflow [(5)×(6)]	Suspended Sediment [(5)×(9)]	Bedload Sediment [(5)×(11)]	Suspended + Bedload Sediment [(13)+(14)]
(%)	(cfs)	(%)	(%)	(days)	(cfs)	(Q/Q_{bkf})	(S/S_{bkf})	(tons/day)	(b_s/b_{bkf})	(tons/day)	(cfs)	(tons)	(tons)	(tons)
0%	2.4													
0.10%	2.1	0.05%	0.09%	0.34	2.2	5.436	451.771	154.21	57.256	10.27	0.8	52.91	3.52	56.44
0.25%	1.8	0.08%	0.15%	0.55	1.9	4.684	262.028	77.07	40.208	7.21	1.1	42.20	3.95	46.15
0.50%	1.5	0.13%	0.25%	0.91	1.7	4.051	154.039	39.18	28.488	5.11	1.5	35.75	4.66	40.42
0.75%	1.3	0.13%	0.25%	0.91	1.4	3.481	88.492	19.34	19.889	3.57	1.3	17.65	3.26	20.91
1%	1.1	0.13%	0.25%	0.91	1.2	2.990	50.799	9.54	13.882	2.49	1.1	8.70	2.27	10.98
1.5%	0.8	0.25%	0.50%	1.83	1.0	2.380	22.100	3.30	8.100	1.45	1.8	6.03	2.65	8.68
2%	0.7	0.25%	0.50%	1.83	0.8	1.829	8.492	0.98	4.364	0.78	1.4	1.78	1.43	3.21
3%	0.6	0.50%	1.00%	3.65	0.6	1.550	4.684	0.46	2.970	0.53	2.3	1.66	1.95	3.61
4%	0.5	0.50%	1.00%	3.65	0.6	1.351	2.866	0.24	2.159	0.39	2.0	0.89	1.41	2.30
5%	0.5	0.50%	1.00%	3.65	0.5	1.199	1.890	0.14	1.645	0.30	1.8	0.52	1.08	1.60
10%	0.3	2.50%	5.00%	18.25	0.4	0.963	0.901	0.05	1.006	0.18	7.2	0.99	3.29	4.29
20%	0.2	5.00%	10.00%	36.50	0.3	0.618	0.257	0.01	0.397	0.07	9.3	0.36	2.60	2.96
30%	0.1	5.00%	10.00%	36.50	0.1	0.363	0.122	0.00	0.164	0.03	5.5	0.10	1.07	1.17
40%	0.1	5.00%	10.00%	36.50	0.1	0.248	0.105	0.00	0.109	0.02	3.7	0.06	0.71	0.77
50%	0.1	5.00%	10.00%	36.50	0.1	0.182	0.101	0.00	0.089	0.02	2.7	0.04	0.59	0.63
60%	0.0	5.00%	10.00%	36.50	0.1	0.139	0.100	0.00	0.081	0.01	2.1	0.03	0.53	0.56
70%	0.0	5.00%	10.00%	36.50	0.0	0.109	0.099	0.00	0.077	0.01	1.6	0.02	0.50	0.53
80%	0.0	5.00%	10.00%	36.50	0.0	0.091	0.099	0.00	0.075	0.01	1.4	0.02	0.49	0.51
90%	0.0	5.00%	10.00%	36.50	0.0	0.073	0.099	0.00	0.074	0.01	1.1	0.02	0.48	0.50
100%	0.0	5.00%	10.00%	36.50	0.0	0.036	0.099	0.00	0.072	0.01	0.5	0.01	0.47	0.48
									Annual Totals:		50.3 (cfs) / 99.8 (acre-ft)	169.8 (tons/yr)	36.9 (tons/yr)	206.7 (tons/yr)

Summary of the Tributary A4a+ to D4 Stream Type Conversion

For many tributaries that occur within long and wide alluvial fans, this proposed design to increase the sediment storage on the fan and deposit sediment in the detention basin is a feasible solution to reduce the delivered sediment. For the areas with short fans, the conversion recommendations are associated with B4 stream types. Although other reaches may not have the detailed representative data, the relations established in this typical design scenario can be extrapolated to similar stream types and conditions.

Typical Design Scenario 6 Example

Tributary F4b to B4 Stream Type Conversion

(Valley Type III – Small)

Tributary F4b to B4 Stream Type Conversion (VT III): Typical Design Scenario 6 Example

General Description & Morphological Data

This typical design scenario example is a stream type and stability conversion from an F4b *Poor* condition tributary to a B4 *Stable* stream type within a "short" alluvial fan, Valley Type III. The existing, impaired F4b tributary is located at the mouth of Sub-Watershed 63 (**Figure II-61**). This channel is deeply incised, confined and entrenched, and cuts through an alluvial fan as depicted in **Figure II-62**. The increased, post-fire floods continue to downcut and laterally erode this reach, and a headcut is advancing in this lower channel. The face of the fan has also been eroded by Trail Creek, and the "short" fan exists due to the channel encroachment created by the Trail Creek road. Consequently, building out the alluvial fan and creating a braided channel on the fan surface to naturally deposit sediment is not feasible at this site. However, the secondary option is to convert the F4b *Poor* condition to a B4 *Stable* stream type for approximately *500 ft* of reach length.

The specific objectives and direction of this design scenario to stabilize the reach are as follows:

- Reduce the sediment supply from the flow-related sediment yield increase
- Reduce the accelerated streambank erosion rates
- Incorporate grade control measures to stop the advancing headcut
- Establish a stable toe of the alluvial fan and the road fill that are both being eroded by Trail Creek
- Restore the riparian function

The characteristics of Sub-Watershed 63 in the Trail Creek Watershed that contains the existing F4b tributary are included in **Table II-9**, which indicate the drainage area, streambank erosion rates, and the overall erosion summary for the sub-watershed. However, a detailed survey and corresponding stability assessment were not completed on the existing F4b reach in this sub-watershed as was done on the representative reaches. Consequently, the *F4b Poor Trib. Representative Reach* data was extrapolated to this existing site because of the similar stream type, condition and valley type. Reviewing the stability analysis of the representative reach is helpful to understand the unstable characteristics of the existing reach in Sub-Watershed 63 for design purposes. The location of the *F4b Poor Trib. Representative Reach* is shown in **Figure II-1** and the morphology and stability evaluation are documented in *Appendix C14* of the Waldo Canyon Fire *WARSSS* analysis (Rosgen *et al*., 2013).

The dimensionless relations of the *B4 Reference Reach* are used to generate the proposed B4 *Stable* design criteria by scaling the relations to the proposed bankfull discharge and area. The location of the *B4 Reference Reach* is shown in **Figure II-1** and the detailed characteristics and stability evaluation are documented in *Appendix C18* of the Waldo Canyon Fire *WARSSS* analysis (Rosgen *et al*., 2013).

The resultant proposed dimension, pattern, and profile for the stable B4 stream type are documented in **Table II-10** using the procedure in **Appendix I**. Additionally, this table also includes a summary of the morphological descriptions and corresponding analyses of the existing F4b reach, the *F4b Poor Trib. Representative Reach*, and the *B4 Reference Reach*. The following sections include the proposed details of the stable B4 design reach.

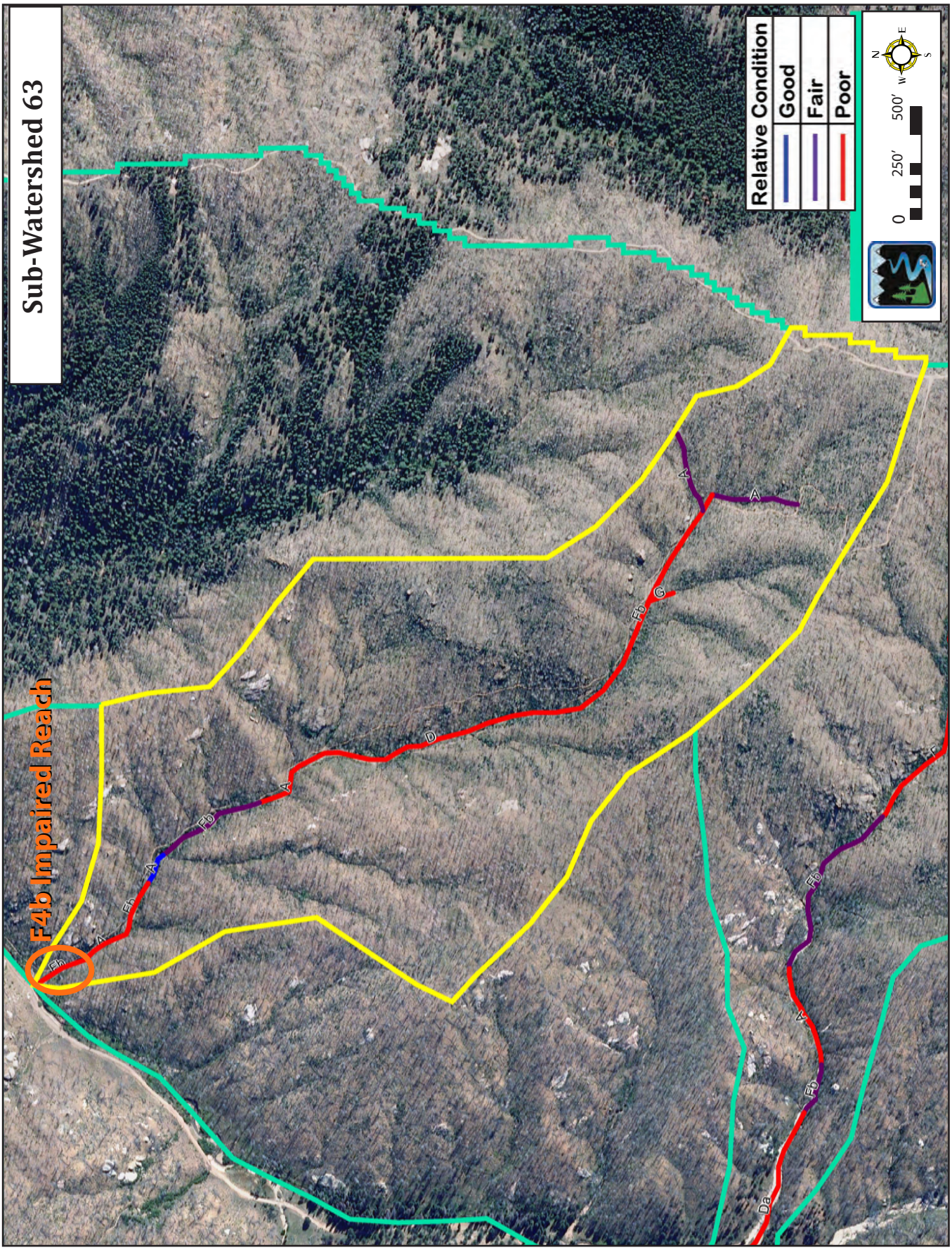


Figure II-61. The location of the existing F4b *Poor* impaired tributary at the mouth of Sub-Watershed 63 and the confluence with Trail Creek



Figure II-62. The existing F4b *Poor* tributary at the confluence with Trail Creek at the lower end of Sub-Watershed 63. Note the incised channel in the fan and the erosion of the fan by Trail Creek.

Table II-9. The summary of Sub-Watershed 63 in the Trail Creek Watershed including watershed characteristics, streambank erosion rates, and the overall sediment yield summary.

Watershed Summary Stream: **Trail Creek Watershed** Sub-Watershed: **63**

Watershed Characteristics

Drainage Area (mi^2)	0.34
Drainage Density	11.8

Burn Severity (%)	High	Moderate	Low	Unburned
	7.2%	90.5%	2.3%	0.0%

Percent of Aspect	N	NE	E	SE	S	SW	W	NW
	29%	7%	0%	0%	0%	0%	20%	43%

Stream Types (%)	Aa+	A	B	C	D	Da+	E	F	Fb	G
	0%	29%	0%	0%	23%	0%	0%	0%	45%	2%

Streambank Erosion

Percent of Stream Conditions	Good	Fair	Poor
	3%	25%	72%

Total Erosion (tons/yr): 1,931

Percent of Erosion Categories	Erosion Rate (tons/yr/ft)	0	0-0.001	0.001-0.005	0.005-0.01	0.01-0.05	0.05-0.1	0.1-0.5	0.5-1.0	>1.0
		0%	0%	0%	29%	34%	2%	35%	0%	0%

Hillslope

Length of Road (ft)	3,750	Sediment from Surface Erosion (tons/yr)	52
Total Sediment from Roads (tons/yr)	5.2	Total Introduced Sediment (tons/yr)	57.2

Hydrology

Zone A		Pre-Fire	Post-Fire	Post-Restoration
Q_{bkf} cfs	3.41	DA (mi^2)	0.173	
Water Yield (ac-ft)		372	423	423
Flow-Related Sediment (tons/yr)		12	231	71

N/A

	Pre-Fire	Post-Fire	Post-Restoration
Q_{bkf} cfs		DA (mi^2)	
Water Yield (ac-ft)			
Flow-Related Sediment (tons/yr)			

N/A

	Pre-Fire	Post-Fire	Post-Restoration
Q_{bkf} cfs		DA (mi^2)	
Water Yield (ac-ft)			
Flow-Related Sediment (tons/yr)			

N/A

	Pre-Fire	Post-Fire	Post-Restoration
Q_{bkf} cfs		DA (mi^2)	
Water Yield (ac-ft)			
Flow-Related Sediment (tons/yr)			

N/A

	Pre-Fire	Post-Fire	Post-Restoration
Q_{bkf} cfs		DA (mi^2)	
Water Yield (ac-ft)			
Flow-Related Sediment (tons/yr)			

Totals from all Zones

	Pre-Fire	Post-Fire	Total Increase	Post-Restoration	Reduction Post-Rest.
Water Yield (ac-ft)	372	423	51	423	
Flow-Related Sediment (tons)	12	231	219	71	-160

Erosion Summary

Total Existing Water Yield (ac-ft)	423
Total Existing Sediment Yield (tons/yr)	231

	Banks	Roads	Surface Erosion	Streambed
Sediment (tons/yr)	1,931	5	52	-1,757
Percent of Total Yield	97%	0%	3%	88%

Deposition or Scour: Deposition

Hydrologic Zones of Watershed

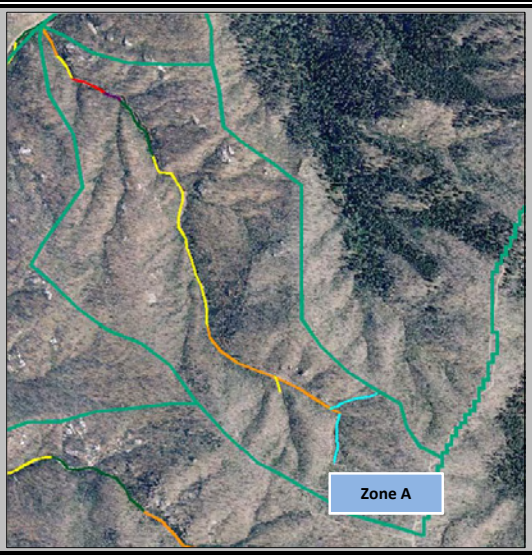


Table II-10. The morphological characteristics of the existing, proposed design, reference and representative reaches for the F4b tributary to B4 stream type conversion in a Valley Type III – short alluvial fan.

Existing Reach Stream & Location:			**F4b Poor Tributary to Mainstem Trail Creek in Sub-Watershed 63**			
Reference Reach Stream & Location:			**B4 Reference Reach, Trail Creek**			
	Entry Number	**Variable**	**Existing Reach**	**F4b Poor Trib. Rep. Reach**	**Proposed Design Reach**	**Reference Reach**
	1	Valley Type	**III - Short Fan**	**III**	**III - Short Fan**	**VIII**
	2	Valley Width		**40-50**		**70**
	3	Stream Type	**F4b**	**F4b**	**B4**	**B4**
	4	Drainage Area, mi^2	**0.34**	**1.5**	**0.34**	**14.3**
	5	Bankfull Discharge, cfs (Q_{bkf})	**4.8**	**8.43**	**4.8**	**32.78**
Riffle Dimensions	**6**	Riffle Width, ft (W_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **12.8** *Min:* **11.4** *Max:* **14.9**	*Mean:* **5.50** *Min:* **5.00** *Max:* **6.00**	*Mean:* **11.8** *Min:* **9.3** *Max:* **14.2**
	7	Riffle Mean Depth, ft (d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.19** *Min:* **0.16** *Max:* **0.24**	*Mean:* **0.440** *Min:* **0.400** *Max:* **0.480**	*Mean:* **0.75** *Min:* **0.74** *Max:* **0.76**
	8	Riffle Width/Depth Ratio (W_{bkf}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **68.4** *Min:* **47.3** *Max:* **77.4**	*Mean:* **12.5** *Min:* **10.4** *Max:* **15.0**	*Mean:* **12.60** *Min:* **12.58** *Max:* **12.62**
	9	Riffle Cross-Sectional Area, ft^2 (A_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **2.4** *Min:* **2.0** *Max:* **2.9**	*Mean:* **2.4**	*Mean:* **7.1** *Min:* **6.9** *Max:* **7.3**
	10	Riffle Maximum Depth (d_{max})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.34** *Min:* **0.27** *Max:* **0.41**	*Mean:* **0.66** *Min:* **0.63** *Max:* **0.70**	*Mean:* **1.13** *Min:* **1.08** *Max:* **1.18**
	11	Riffle Maximum Depth to Riffle Mean Depth (d_{max}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.752** *Min:* **1.588** *Max:* **2.063**	*Mean:* **1.508** *Min:* **1.421** *Max:* **1.595**	*Mean:* **1.508** *Min:* **1.421** *Max:* **1.595**
	12	Width of Flood-Prone Area at Elevation of 2 * d_{max}, ft (W_{fpa})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **13.9** *Min:* **12.8** *Max:* **15.4**	*Mean:* **9.4** *Min:* **8.3** *Max:* **11.0**	*Mean:* **16.4** *Min:* **14.2** *Max:* **18.5**
	13	Entrenchment Ratio (W_{fpa}/W_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.1** *Min:* **1.0** *Max:* **1.2**	*Mean:* **1.7** *Min:* **1.5** *Max:* **2.0**	*Mean:* **1.7** *Min:* **1.5** *Max:* **2.0**

Table II-10 (Page 2). The morphological characteristics of the existing, proposed design, reference and representative reaches for the F4b tributary to B4 stream type conversion in a Valley Type III – short alluvial fan.

	Entry Number & Variable		Existing Reach	F4b Poor Trib. Rep. Reach	Proposed Design Reach	Reference Reach
Pool Dimensions	**21**	Pool Width, ft (W_{bkfp})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **6.0** *Min:* **3.8** *Max:* **9.9**	*Mean:* **14.0** *Min:* **8.2** *Max:* **21.1**
	22	Pool Width to Riffle Width (W_{bkfp}/W_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.091** *Min:* **0.695** *Max:* **1.792**	*Mean:* **1.190** *Min:* **0.695** *Max:* **1.792**
	23	Pool Mean Depth, ft (d_{bkfp})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.52** *Min:* **0.44** *Max:* **0.62**	*Mean:* **0.80** *Min:* **0.59** *Max:* **1.05**
	24	Pool Mean Depth to Riffle Mean Depth (d_{bkfp}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.180** *Min:* **1.000** *Max:* **1.400**	*Mean:* **1.067** *Min:* **0.787** *Max:* **1.400**
	25	Pool Width/Depth Ratio (W_{bkfp}/d_{bkfp})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **11.5** *Min:* **6.2** *Max:* **22.4**	*Mean:* **17.5** *Min:* **7.8** *Max:* **35.8**
	26	Pool Cross-Sectional Area, ft^2 (A_{bkfp})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **3.1** *Min:* **2.9** *Max:* **3.2**	*Mean:* **8.9** *Min:* **8.5** *Max:* **9.6**
	27	Pool Area to Riffle Area (A_{bkfp}/A_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.300** *Min:* **1.189** *Max:* **1.348**	*Mean:* **1.248** *Min:* **1.189** *Max:* **1.348**
	28	Pool Maximum Depth (d_{maxp})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.00** *Min:* **0.90** *Max:* **1.10**	*Mean:* **1.56** *Min:* **1.33** *Max:* **1.85**
	29	Pool Maximum Depth to Riffle Mean Depth (d_{maxp}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **2.273** *Min:* **2.045** *Max:* **2.500**	*Mean:* **2.080** *Min:* **1.773** *Max:* **2.467**
	30	Point Bar Slope (S_{pb})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.380** *Min:* **0.280** *Max:* **0.400**	*Mean:* **0.290** *Min:* **0.220** *Max:* **0.360**

Table II-10 (Page 3). The morphological characteristics of the existing, proposed design, reference and representative reaches for the F4b tributary to B4 stream type conversion in a Valley Type III – short alluvial fan.

	Entry Number & Variable	Existing Reach	F4b Poor Trib. Rep. Reach	Proposed Design Reach	Reference Reach
Channel Pattern	**72** Linear Wavelength, ft (λ)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **48.6** *Min:* **40.6** *Max:* **60.3**	*Mean:* **104.0** *Min:* **87.0** *Max:* **129.0**
	73 Linear Wavelength to Riffle Width (λ/W_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **8.832** *Min:* **7.389** *Max:* **10.955**	*Mean:* **8.832** *Min:* **7.389** *Max:* **10.955**
	74 Stream Meander Length, ft (L_m)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **52.3** *Min:* **44.1** *Max:* **63.1**	*Mean:* **112.0** *Min:* **94.5** *Max:* **135.0**
	75 Stream Meander Length Ratio (L_m/W_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **9.512** *Min:* **8.025** *Max:* **11.465**	*Mean:* **9.512** *Min:* **8.025** *Max:* **11.465**
	76 Belt Width, ft (W_{blt})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **18.3** *Min:* **14.0** *Max:* **27.4**	*Mean:* **12.7** *Min:* **6.8** *Max:* **28.0**	*Mean:* **27.2** *Min:* **14.6** *Max:* **60.0**
	77 Meander Width Ratio (W_{blt}/W_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.427** *Min:* **1.092** *Max:* **2.136**	*Mean:* **2.306** *Min:* **1.237** *Max:* **5.096**	*Mean:* **2.306** *Min:* **1.237** *Max:* **5.096**
	78 Radius of Curvature, ft (R_c)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **23.7** *Min:* **11.6** *Max:* **35.5**	*Mean:* **50.7** *Min:* **21.8** *Max:* **76.0**
	79 Radius of Curvature to Riffle Width (R_c/W_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **4.300** *Min:* **2.100** *Max:* **6.454**	*Mean:* **4.300** *Min:* **2.100** *Max:* **6.454**
	80 Arc Length, ft (L_a)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **18.5** *Min:* **4.7** *Max:* **33.1**	*Mean:* **39.6** *Min:* **10.0** *Max:* **70.9**
	81 Arc Length to Riffle Width (L_a/W_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **3.363** *Min:* **0.849** *Max:* **6.021**	*Mean:* **3.363** *Min:* **0.849** *Max:* **6.021**
	82 Riffle Length (L_r), ft ***Refers to a Step Length - Not Riffle**	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **8.2** *Min:* **1.6*** *Max:* **15.0**	*Mean:* **14.7** *Min:* **2.7** *Max:* **28.2**
	83 Riffle Length to Riffle Width (L_r/W_{bkf}) ***Refers to a Step Length - Not Riffle**	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.500** *Min:* **0.300*** *Max:* **2.800**	*Mean:* **1.248** *Min:* **0.229** *Max:* **2.395**
	84 Individual Pool Length, ft (L_p)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **28.1** *Min:* **10.7** *Max:* **47.2**	*Mean:* **60.1** *Min:* **23.0** *Max:* **101.0**
	85 Pool Length to Riffle Width (L_p/W_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **5.104** *Min:* **1.953** *Max:* **8.577**	*Mean:* **5.104** *Min:* **1.953** *Max:* **8.577**
	86 Pool to Pool Spacing, ft (P_s)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **15.0** *Min:* **7.0** *Max:* **26.0**	*Mean:* **28.1** *Min:* **12.2** *Max:* **47.3**
	87 Pool to Pool Spacing to Riffle Width (P_s/W_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **2.788** *Min:* **1.190** *Max:* **4.615**	*Mean:* **2.387** *Min:* **1.039** *Max:* **4.020**

Table II-10 (Page 4). The morphological characteristics of the existing, proposed design, reference and representative reaches for the F4b tributary to B4 stream type conversion in a Valley Type III – short alluvial fan.

	Entry Number & Variable		Existing Reach	F4b Poor Trib. Rep. Reach	Proposed Design Reach	Reference Reach
Sinuosity and Slope	**88**	Stream Length (SL)	**N/A**	**304.3**	**500**	**514.1**
	89	Valley Length (VL)	**455.0**	**293.4**	**455**	**455.0**
	90	Valley Slope (S_{val})	**0.035**	**0.0430**	**0.035**	**0.0264**
	91	Sinuosity (k)	SL/VL: **N/A** VS/S: **N/A**	SL/VL: **1.04** VS/S: **1.05**	SL/VL: **1.10**	SL/VL: **1.13** VS/S: **1.09**
	92	Average Water Surface Slope (S)	**N/A**	**0.0410**	$S = S_{val}/k$ **0.0320**	**0.0242**
Bed Feature Water Surface Facet Slopes and Dimensionless Ratios from Profile	**105**	Riffle Slope (water surface facet slope) (S_{rif})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.0690** *Min:* **0.0280** *Max:* **0.0880**	*Mean:* **0.0449** *Min:* **0.0211** *Max:* **0.0774**	*Mean:* **0.0340** *Min:* **0.0159** *Max:* **0.0585**
	106	Riffle Slope to Average Water Surface Slope (S_{rif}/S)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.6829** *Min:* **0.6829** *Max:* **2.1463**	*Mean:* **1.4037** *Min:* **0.6587** *Max:* **2.4182**	*Mean:* **1.4037** *Min:* **0.6587** *Max:* **2.4182**
	107	Pool Slope (water surface facet slope) (S_p)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.0036** *Min:* **0.0001** *Max:* **0.0131**	*Mean:* **0.0027** *Min:* **0.0001** *Max:* **0.0099**
	108	Pool Slope to Average Water Surface Slope (S_p/S)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.1124** *Min:* **0.0041** *Max:* **0.4107**	*Mean:* **0.1124** *Min:* **0.0041** *Max:* **0.4107**
	109	Run Slope (water surface facet slope) (S_{run})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	110	Run Slope to Average Water Surface Slope (S_{run}/S)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	111	Glide Slope (water surface facet slope) (S_g)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	112	Glide Slope to Average Water Surface Slope (S_g/S)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	113	Step Slope (water surface facet slope) (S_s)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.4017** *Min:* **1.2298** *Max:* **1.5603**	*Mean:* **1.0600** *Min:* **0.9300** *Max:* **1.1800**
	114	Step Slope to Average Water Surface Slope (S_s/S)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **43.8017** *Min:* **38.4298** *Max:* **48.7603**	*Mean:* **43.8017** *Min:* **38.4298** *Max:* **48.7603**

Table II-10 (Page 5). The morphological characteristics of the existing, proposed design, reference and representative reaches for the F4b tributary to B4 stream type conversion in a Valley Type III – short alluvial fan.

	Entry Number & Variable		Existing Reach	F4b Poor Trib. Rep. Reach	Proposed Design Reach	Reference Reach
Bed Feature Max Depth Measurements and Dimensionless Ratios from Profile	**115**	Riffle Maximum Depth, ft (d_{max})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.34** *Min:* **0.27** *Max:* **0.41**	*Mean:* **0.62** *Min:* **0.55** *Max:* **0.69**	*Mean:* **1.06** *Min:* **0.93** *Max:* **1.18**
	116	Riffle Maximum Depth to Riffle Mean Depth (d_{max}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.740** *Min:* **1.403** *Max:* **2.130**	*Mean:* **1.413** *Min:* **1.240** *Max:* **1.573**	*Mean:* **1.413** *Min:* **1.240** *Max:* **1.573**
	117	Pool Maximum Depth, ft (d_{maxp})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.89** *Min:* **0.78** *Max:* **1.09**	*Mean:* **1.52** *Min:* **1.33** *Max:* **1.85**
	118	Pool Maximum Depth to Riffle Mean Depth (d_{maxp}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **2.027** *Min:* **1.773** *Max:* **2.467**	*Mean:* **2.027** *Min:* **1.773** *Max:* **2.467**
	119	Run Maximum Depth, ft (d_{maxr})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	120	Run Maximum Depth to Riffle Mean Depth (d_{maxr}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	121	Glide Maximum Depth, ft (d_{maxg})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	122	Glide Maximum Depth to Riffle Mean Depth (d_{maxg}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	123	Step Maximum Depth, ft (d_{maxs})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	124	Step Maximum Depth to Riffle Mean Depth (d_{maxs}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
Hydraulics	**127**	Estimated Bankfull Mean Velocity, ft/sec (u_{bkf})	**N/A**	**3.16**	**2.0**	**4.7**
	128	Estimated Bankfull Discharge, cfs (Q_{bkf}); Compare with Regional Curve	**4.8**	**8.4**	**4.8**	**32.8**

Table II-10 (Page 6). The morphological characteristics of the existing, proposed design, reference and representative reaches for the F4b tributary to B4 stream type conversion in a Valley Type III – short alluvial fan.

Sediment Yield	**Sediment Yield (FLOWSED)**	**Existing Reach**		**Proposed Design Reach**	**Difference in Sediment Yield**
	141 Bedload Sediment Yield (tons/yr)	**650.8**		**86.5**	**564.3**
	142 Suspended Sediment Yield (tons/yr)	**4,256.3**		**7.6**	**4,248.7**
	143 Suspended Sand Sediment Yield (tons/yr)	**2,128.2**		**3.8**	**2,124.4**
	144 Total Annual Sediment Yield (tons/yr)	**4,907.1**		**94.1**	**4,813.0**
Bank Erosion	**Streambank Erosion**	**Existing Reach**	**Representative Reach**	**Proposed Design Reach**	**Reference Reach**
	145 Stream Length Assessed (ft)	**500.0**	**337.0**	**500**	**406.0**
	146 Graph/Curve Used (e.g., Yellowstone or Colorado)	**Colorado**	**Colorado**	**Colorado**	**Colorado**
	147 Streambank Erosion (tons/yr)	**196.45**	**132.39**	**2.42**	**1.96**
	148 Streambank Erosion (tons/yr/ft)	**0.3929**	**0.3929**	**0.0048**	**0.0048**

Bankfull Discharge, Cross-Sectional Area and Mean Velocity

With a drainage area of *0.34 mi^2* for the proposed B4 stream type, the bankfull discharge is *4.8 cfs* and the proposed bankfull riffle cross-sectional area is *2.4 ft^2* as shown in **Table II-10**. Using continuity, the corresponding mean velocity for the proposed design reach is *2.0 ft/sec* as shown in **Worksheet II-17**.

Plan View Alignment, Cross-Section Dimensions & Longitudinal Profile

The plan view alignment for the proposed B4 reach is shown in **Figure II-100**, which follows the pattern data for the stable B4 stream type developed from dimensionless relations of the *B4 Reference Reach* (**Table II-10**).

The proposed B4 channel dimensions are also recorded in **Table II-10** as derived from scaled values of the *B4 Reference Reach* data. The typical cross-sections that correspond to the plan view and longitudinal profile are also shown in **Figure II-63**. The typical proposed riffle and pool cross-sections of the proposed B4 stream type compared to the F4b stream type are illustrated in **Figure II-64**.

The typical longitudinal profile for the proposed B4 stream type illustrates the depths, slopes, lengths and spacing of bed features in addition to the placement locations and types of structures for this design scenario (**Figure II-63**).

Structures

The proposed structures for streambank stabilization, flow resistance, and grade control are shown in the plan, cross-section, and longitudinal views in **Figure II-63**. The structures include converging rock clusters; the root wad, log vane, J-hook; the rock and log roller structure; the toe wood structure with sod mats and riparian transplants; and the rock step–pool structure. The materials for these structures will be obtained from on-site sources. Many of the burned logs will be salvaged to use for the rock and log roller structure, the root wad, log vane, J-hook, and toe wood structures. Local rock sources will be used for the converging rock clusters and the rock step–pool structure. Riparian transplants of willow and alder will be salvaged from local donor areas.

Riparian Vegetation

It is a key requirement to re-establish a woody riparian community of willow and alder along this B4 stream type. This is accomplished by transplanting from available nearby donor areas. Native bunch grasses, such as big mountain brome, are recommended for seeding the side slopes. The revegetation is critical for the long-term physical stability of the reach.

Cut & Fill Computations

The cut and fill material is generally balanced by sloping the upper banks and shaping the B4 channel in this stream type conversion as illustrated in **Figure II-64**. The fill associated with the structures for this size would vary from *35–55 yds^3* for the *500 ft* of channel. The anticipated excavation and fill are generally balanced with this design without requiring disposal or end-hauling.

Worksheet II-17. The mean velocity estimates for the proposed B4 *Stable* reach to be converted from the existing, F4b *Poor* condition tributary at the mouth of Sub-Watershed 63 and the confluence of Trail Creek.

Bankfull VELOCITY & DISCHARGE Estimates

Stream:	**Proposed B4 from F4b Trib**	Location:	**Sub-Watershed 63**
Date: **3/15/2011**	Stream Type: **B4**	Valley Type:	**III - Short Alluvial Fan**
Observers:	**Rosgen *et al*.**	HUC:	_ _ _ _ _ _ _ _ _ _ _ _ _ _

Input Variables for PROPOSED Design			Output Variables for PROPOSED Design		
Bankfull Riffle Cross-Sectional AREA	**2.4**	**A_{bkf}** (ft^2)	Bankfull Riffle Mean DEPTH	**0.44**	**d_{bkf}** (ft)
Bankfull Riffle WIDTH	**5.5**	**W_{bkf}** (ft)	Wetted PERMIMETER ~ (2 * d_{bkf}) + W_{bkf}	**6.37**	**W_p** (ft)
D_{84} at Riffle	**N/A**	**Dia.** (mm)	D_{84} (mm) / 304.8	**N/A**	**D_{84}** (ft)
Bankfull SLOPE	**0.0320**	**S_{bkf}** (ft / ft)	Hydraulic RADIUS A_{bkf} / W_p	**0.38**	**R** (ft)
Gravitational Acceleration	**32.2**	**g** (ft / sec^2)	Relative Roughness R(ft) / D_{84} (ft)	**N/A**	**R / D_{84}**
Drainage Area	**0.34**	**DA** (mi^2)	Shear Velocity $u^* = (gRS)^{½}$	**0.623**	**u*** (ft/sec)

ESTIMATION METHODS	Bankfull VELOCITY		Bankfull DISCHARGE	
1. Friction Factor / Relative Roughness $u = [\ 2.83 + 5.66 * Log\ \{\ R / D_{84}\ \}\ ]\ u^*$		ft / sec		cfs
2. Roughness Coefficient: a) Manning's *n* from Friction Factor / Relative Roughness (Figs. 5-7, 5-8) $u = 1.49 * R^{2/3} * S^{1/2} / n$ $n =$		ft / sec		cfs
2. Roughness Coefficient: b) Manning's *n* from Stream Type (Fig. 5-9) $u = 1.49 * R^{2/3} * S^{1/2} / n$ $n =$ **0.062**	**2.24**	ft / sec	**5.38**	cfs
2. Roughness Coefficient: c) Manning's *n* from Jarrett (USGS): $u = 1.49 * R^{2/3} * S^{1/2} / n$ $n = 0.39 * S^{0.38} * R^{-0.16}$ **Note:** This equation is applicable to **steep, step/pool, high boundary roughness, cobble- and boulder-dominated stream systems**; i.e., for Stream Types A1, A2, A3, B1, B2, B3, C2 & E3 $n =$ **0.123**	**1.13**	ft / sec	**2.71**	cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)		ft / sec		cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)		ft / sec		cfs
4. Continuity Equations: a) USGS Gage Data $u = Q / A$ **Return Period for Bankfull Q** $Q =$ **year**		ft / sec		cfs
4. Continuity Equations: b) Regional Curves $u = Q / A$	**2.00**	ft / sec	**4.8**	cfs

Protrusion Height Options for the D_{84} Term in the Relative Roughness Relation (R/D_{84}) – Estimation Method 1

Option 1.	For **sand-bed** channels: Measure 100 **"protrusion heights"** of sand dunes from the downstream side of feature to the top of feature. Substitute the D_{84} sand dune protrusion height in ft for the D_{84} term in method 1.
Option 2.	For **boulder-dominated** channels: Measure 100 **"protrusion heights"** of boulders on the sides from the bed elevation to the top of the rock on that side. Substitute the D_{84} boulder protrusion height in ft for the D_{84} term in method 1.
Option 3.	For **bedrock-dominated** channels: Measure 100 **"protrusion heights"** of rock separations, steps, joints or uplifted surfaces above channel bed elevation. Substitute the D_{84} bedrock protrusion height in ft for the D_{84} term in method 1.
Option 4.	For **log-influenced** channels: Measure "**protrustion heights**" proportionate to channel width of log diameters or the height of the log on upstream side if embedded. Substitute the D_{84} protrusion height in ft for the D_{84} term in method 1.

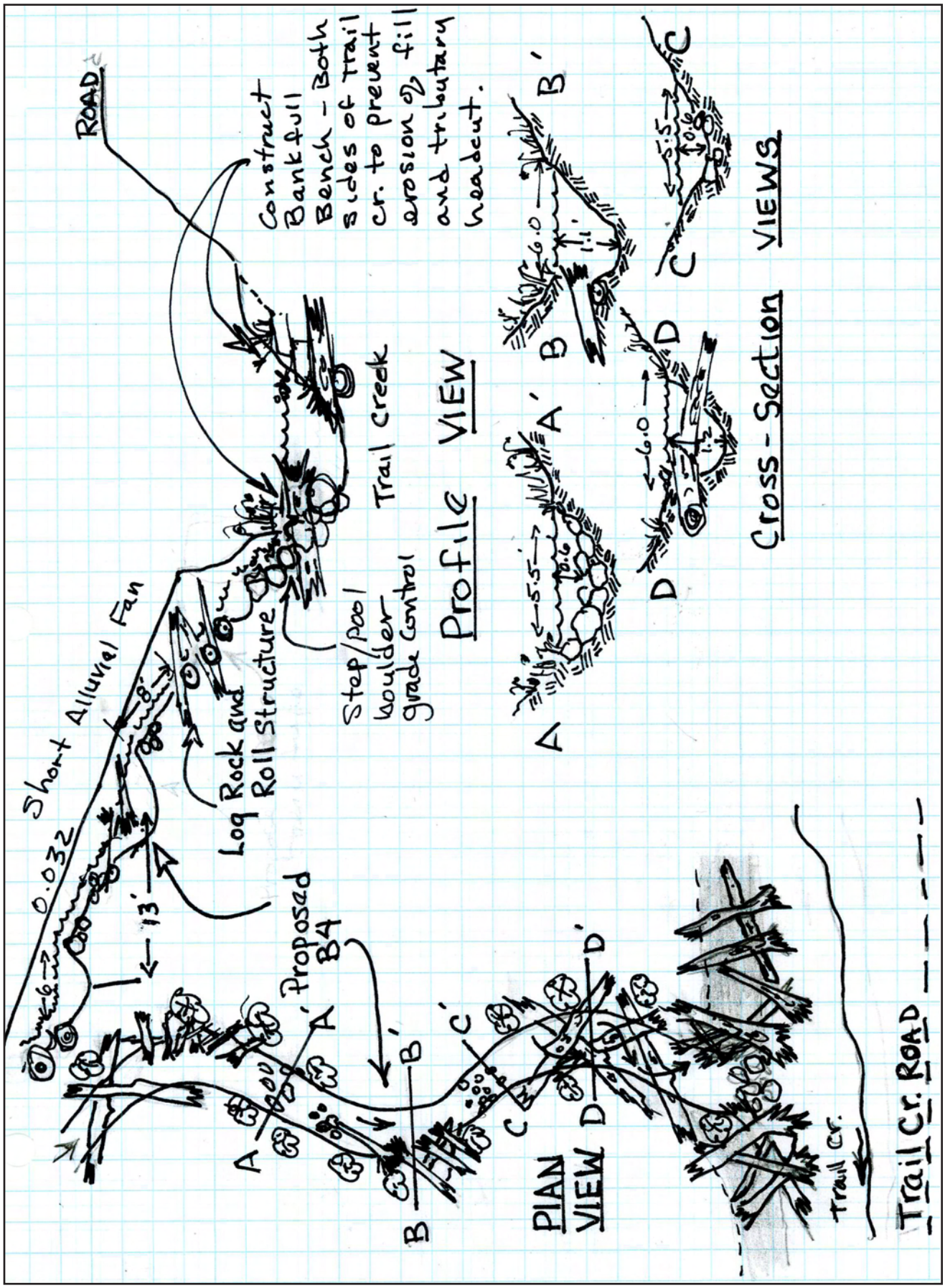


Figure II-63. The designed alignment, cross-sections and longitudinal profile for the proposed B4 reach to be converted from the existing F4b *Poor* tributary at the mouth of Sub-Watershed 63 and the confluence of Trail Creek.

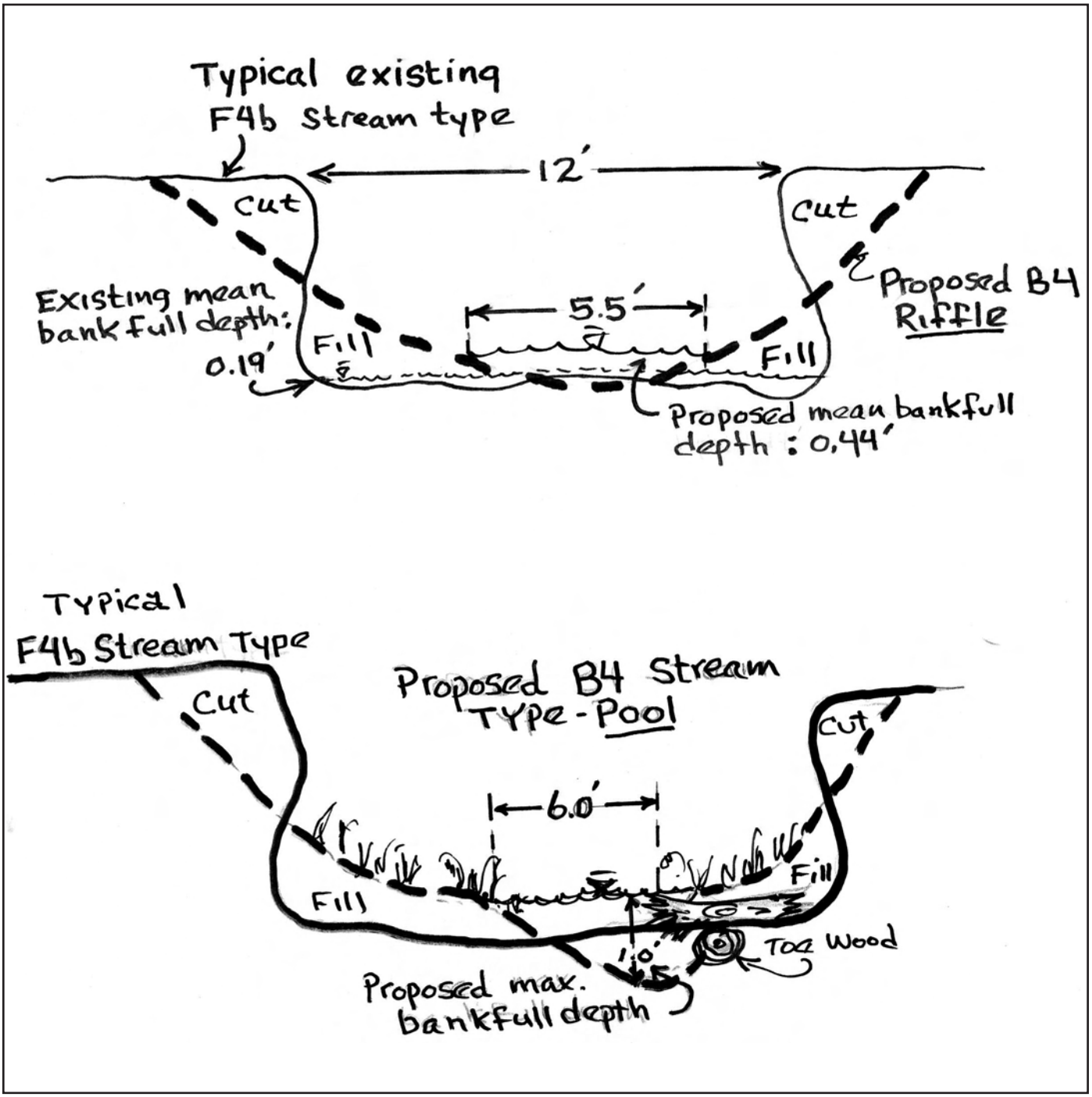


Figure II-64. The typical riffle and pool cross-sections for the proposed B4 reach to be converted from the existing F4b tributary at the mouth of Sub-Watershed 63.

Streambank Erosion

The streambank erosion that is expected for the proposed B4 design reach is *2.4 tons/yr* for *500 ft* of designed channel *vs*. the existing *196.5 tons/yr* for the F4b *Poor* tributary (**Table II-10**), representing a significant, potential reduction of *194.1 tons/yr* for this reach. These values are based on the extrapolation of annual erosion rates of the *B4 Reference Reach* (*0.0048 tons/yr/ft*) and the *F4b Poor Trib. Representative Reach* (*0.3929 tons/yr/ft*). This reduction assumes that the various structures designed and located in **Figure II-63** are implemented, such as the toe wood, J-hook and rock and log roller structures. These structures have proven to reduce streambank erosion rates in similar designs. These significant reductions in streambank erosion are extremely important as *84%* of the total sediment source of the watershed is from streambank erosion. Thus restoration can not 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.

Flow-Related Sediment

The FLOWSED model indicates that by converting from a "Poor" condition to a "Good" condition throughout the sub-watershed, the flow-related sediment yields would be reduced from *4,907.1 tons/yr* (**Worksheet II-18a**) to *94.1 tons/yr* (**Worksheet II-18b**) as a result of the restoration. The corresponding sediment supply reductions based on converting from "Poor" to "Good" conditions are *564.3 tons/yr* for bedload and *4,248.7 tons/yr* for suspended sediment, representing a total sediment reduction of *4,813 tons/yr*. These sediment reductions are still assuming a high post-fire runoff response and continued increased stormflow peak runoff. These reductions are also associated with treating the majority of the stream length of the sub-watershed above this reach.

The reductions in sediment supply associated with restoring *500 ft* of the existing F4b *Poor* tributary to the proposed B4 *Stable* design reach are *194.1 tons/yr* of streambank erosion, *68.8 tons/yr* of bedload, *518.1 tons/yr* of suspended sediment and *587 tons/yr* of total sediment yield reduction. The total sediment yield value includes streambank erosion contributions and streambed sources. The sediment reductions associated with the local channel source sediment for this design scenario are based on sediment yield rates determined from taking the sediment yield values generated from FLOWSED and dividing by the total stream length of potential sediment contributions. For this scenario, it was determined that approximately *4,100 ft* of tributary reach is potentially contributing sediment. The resultant sediment yield rates were then multiplied by the existing and proposed design reach lengths for this scenario to obtain the local sediment reductions.

The POWERSED model could not be used for this scenario because no existing cross-sections of the F4b *Poor* tributary were surveyed. However, characteristic of the F4b stream type is a high width/depth ratio. By lowering the width/depth ratio with the proposed B4 design, the POWERSED model would indicate that a large percentage of the sediment supply would be transported rather than deposited. In the similar F4 to B4 stream type conversion scenario in a Valley Type VIII (previously presented), the POWERSED model indicated that *83%* more sediment would be transported for the B4 design reach compared to the F4 stream type.

Sediment Competence

Based on the small particle sizes and the steeper slopes in the tributary channels in the Trail Creek Watershed, the sediment competence would show excess energy for this proposed design. Thus grade control structure are recommended and designed to add flow resistance and prevent downcutting to counteract the increased shear stress.

Worksheet II-18a. The existing sediment supply at the F4b *Poor* tributary reach using the FLOWSED model and generated by using the dimensionless sediment rating curves and bankfull sediment values related to the "Poor" condition.

Stream: **F4b Poor Tributary, Sub-Watershed 63** Location: **Trail Creek Tributary** Date: **3/15/11**

Observers: **Rosgen *et al*.** Gage Station #: **Goose Creek Gage** Stream Type: **F4b** Valley Type: **III**

Equation Type	Equation Source	Equation	Bankfull Discharge (cfs)	Bankfull Bedload Sediment (kg/s)	Bankfull Suspended Sediment (mg/l)
1. Bedload Sediment	"Poor" Pagosa	$y = 0.07176+1.02176x^{2.3772}$	4.8	0.0332	121.49
2. Suspended Sediment	"Poor" Pagosa	$y = 0.0989+0.9213x^{3.659}$			

From Dimensional Flow-Duration Curve							From Sediment Rating Curves				Calculate	Calculate Sediment Yield		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Percentage of Time	Daily Mean Discharge	Mid-Ordinate	Time Increment (percent)	Time Increment (days)	Mid-Ordinate Streamflow	Dimension-less Streamflow	Dimension-less Suspended Sediment Discharge	Suspended Sediment Discharge	Dimension- less Bedload Discharge	Bedload Sediment Discharge	Time Adjusted Streamflow [(5)×(6)]	Suspended Sediment [(5)×(9)]	Bedload Sediment [(5)×(11)]	Suspended + Bedload Sediment [(13)+(14)]
(%)	(cfs)	(%)	(%)	(days)	(cfs)	(Q/Q_{bkf})	(S/S_{bkf})	(tons/day)	(b_s/b_{bkf})	(tons/day)	(cfs)	(tons)	(tons)	(tons)
0%	28.1													
0.10%	24.1	0.05%	0.09%	0.34	26.1	5.436	451.771	3866.66	57.256	181.00	9.0	1326.65	62.10	1388.75
0.25%	20.9	0.08%	0.15%	0.55	22.5	4.684	262.028	1932.38	40.208	127.11	12.3	1057.98	69.59	1127.57
0.50%	18.0	0.13%	0.25%	0.91	19.4	4.051	154.039	982.41	28.488	90.06	17.7	896.45	82.18	978.62
0.75%	15.4	0.13%	0.25%	0.91	16.7	3.481	88.492	484.97	19.889	62.87	15.2	442.53	57.37	499.90
1%	13.3	0.13%	0.25%	0.91	14.4	2.990	50.799	239.16	13.882	43.88	13.1	218.24	40.04	258.28
1.5%	9.5	0.25%	0.50%	1.83	11.4	2.380	22.100	82.82	8.100	25.61	20.9	151.15	46.73	197.88
2%	8.0	0.25%	0.50%	1.83	8.8	1.829	8.492	24.45	4.364	13.80	16.0	44.63	25.18	69.81
3%	6.9	0.50%	1.00%	3.65	7.4	1.550	4.684	11.43	2.970	9.39	27.2	41.73	34.27	76.00
4%	6.1	0.50%	1.00%	3.65	6.5	1.351	2.866	6.09	2.159	6.83	23.7	22.24	24.92	47.16
5%	5.4	0.50%	1.00%	3.65	5.8	1.199	1.890	3.57	1.645	5.20	21.0	13.02	18.98	32.01
10%	3.8	2.50%	5.00%	18.25	4.6	0.963	0.901	1.37	1.006	3.18	84.4	24.94	58.03	82.98
20%	2.1	5.00%	10.00%	36.50	3.0	0.618	0.257	0.25	0.397	1.25	108.2	9.13	45.80	54.92
30%	1.4	5.00%	10.00%	36.50	1.7	0.363	0.122	0.07	0.164	0.52	63.7	2.54	18.91	21.45
40%	1.0	5.00%	10.00%	36.50	1.2	0.248	0.105	0.04	0.109	0.34	43.5	1.49	12.58	14.07
50%	0.8	5.00%	10.00%	36.50	0.9	0.182	0.101	0.03	0.089	0.28	31.8	1.05	10.33	11.38
60%	0.6	5.00%	10.00%	36.50	0.7	0.139	0.100	0.02	0.081	0.26	24.4	0.80	9.37	10.16
70%	0.5	5.00%	10.00%	36.50	0.5	0.109	0.099	0.02	0.077	0.24	19.1	0.62	8.89	9.51
80%	0.4	5.00%	10.00%	36.50	0.4	0.091	0.099	0.01	0.075	0.24	15.9	0.52	8.67	9.19
90%	0.3	5.00%	10.00%	36.50	0.3	0.073	0.099	0.01	0.074	0.23	12.7	0.41	8.51	8.93
100%	0.1	5.00%	10.00%	36.50	0.2	0.036	0.099	0.01	0.072	0.23	6.4	0.21	8.32	8.53
									Annual Totals:		586.2 (cfs) / 1,162.7 (acre-ft)	4,256.3 (tons/yr)	650.8 (tons/yr)	4,907.1 (tons/yr)

Worksheet II-18b. The proposed sediment supply at the proposed B4 reach using the FLOWSED model and generated by using the dimensionless sediment rating curves and bankfull sediment values related to the restored "Good" condition (assuming that the watershed area above this reach is also restored to "Good" conditions).

Stream: **Proposed B4 Design Reach in Sub-Watershed 63** Location: **Tributary to Mainstem Trail Creek** Date: **3/15/11**

Observers **Rosgen *et al*.** Gage Station #: **Goose Creek Gage** Stream Type: **B4** Valley Type: **III**

Equation Type	Equation Source	Equation	Bankfull Discharge (cfs)	Bankfull Bedload Sediment (kg/s)	Bankfull Suspended Sediment (mg/l)
1. Bedload Sediment	"Good/Fair" Pagosa	$y = -0.0113+1.0139x^{2.1929}$	4.8	0.0060	1.163
2. Suspended Sediment	"Good/Fair" Pagosa	$y = 0.0636+0.9326x^{2.4085}$			

From Dimensional Flow-Duration Curve							From Sediment Rating Curves				Calculate	Calculate Sediment Yield		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Percentage of Time	Daily Mean Discharge	Mid-Ordinate	Time Increment (percent)	Time Increment (days)	Mid-Ordinate Streamflow	Dimension-less Streamflow	Dimension-less Suspended Sediment Discharge	Suspended Sediment Discharge	Dimension-less Bedload Discharge	Bedload Sediment Discharge	Time Adjusted Streamflow [(5)×(6)]	Suspended Sediment [(5)×(9)]	Bedload Sediment [(5)×(11)]	Suspended + Bedload Sediment [(13)+(14)]
(%)	(cfs)	(%)	(%)	(days)	(cfs)	(Q/Q_{bkf})	(S/S_{bkf})	(tons/day)	(b_s/b_{bkf})	(tons/day)	(cfs)	(tons)	(tons)	(tons)
0%	28.1													
0.10%	24.1	0.05%	0.09%	0.34	26.1	5.436	55.099	4.51	41.523	23.75	9.0	1.55	8.15	9.70
0.25%	20.9	0.08%	0.15%	0.55	22.5	4.684	38.512	2.72	29.952	17.13	12.3	1.49	9.38	10.87
0.50%	18.0	0.13%	0.25%	0.91	19.4	4.051	27.161	1.66	21.778	12.46	17.7	1.51	11.37	12.88
0.75%	15.4	0.13%	0.25%	0.91	16.7	3.481	18.871	0.99	15.615	8.93	15.2	0.90	8.15	9.05
1%	13.3	0.13%	0.25%	0.91	14.4	2.990	13.108	0.59	11.188	6.40	13.1	0.54	5.84	6.38
1.5%	9.5	0.25%	0.50%	1.83	11.4	2.380	7.593	0.27	6.779	3.88	20.9	0.50	7.08	7.57
2%	8.0	0.25%	0.50%	1.83	8.8	1.829	4.056	0.11	3.800	2.17	16.0	0.20	3.97	4.17
3%	6.9	0.50%	1.00%	3.65	7.4	1.550	2.745	0.06	2.641	1.51	27.2	0.23	5.51	5.75
4%	6.1	0.50%	1.00%	3.65	6.5	1.351	1.987	0.04	1.949	1.11	23.7	0.15	4.07	4.22
5%	5.4	0.50%	1.00%	3.65	5.8	1.199	1.508	0.03	1.499	0.86	21.0	0.10	3.13	3.23
10%	3.8	2.50%	5.00%	18.25	4.6	0.963	0.915	0.01	0.922	0.53	84.4	0.24	9.63	9.87
20%	2.1	5.00%	10.00%	36.50	3.0	0.618	0.356	0.00	0.341	0.20	108.2	0.12	7.13	7.25
30%	1.4	5.00%	10.00%	36.50	1.7	0.363	0.145	0.00	0.099	0.06	63.7	0.03	2.06	2.09
40%	1.0	5.00%	10.00%	36.50	1.2	0.248	0.096	0.00	0.036	0.02	43.5	0.01	0.76	0.77
50%	0.8	5.00%	10.00%	36.50	0.9	0.182	0.079	0.00	0.013	0.01	31.8	0.01	0.27	0.27
60%	0.6	5.00%	10.00%	36.50	0.7	0.139	0.072	0.00	0.002	0.00	24.4	0.01	0.04	0.05
70%	0.5	5.00%	10.00%	36.50	0.5	0.109	0.068	0.00	0.000	0.00	19.1	0.00	0.00	0.00
80%	0.4	5.00%	10.00%	36.50	0.4	0.091	0.066	0.00	0.000	0.00	15.9	0.00	0.00	0.00
90%	0.3	5.00%	10.00%	36.50	0.3	0.073	0.065	0.00	0.000	0.00	12.7	0.00	0.00	0.00
100%	0.1	5.00%	10.00%	36.50	0.2	0.036	0.064	0.00	0.000	0.00	6.4	0.00	0.00	0.00
									Annual Totals:		586.2 (cfs) / 1,162.7 (acre-ft)	7.6 (tons/yr)	86.5 (tons/yr)	94.1 (tons/yr)

Summary of the Tributary F4b to B4 Conversion

Numerous F4b reaches suffer similar impacts and consequences, yet do not have the detailed assessment as performed for the representative reaches. This scenario is an example of extrapolating the *F4b Poor Trib. Representative Reach* stability analysis to the existing F4b *Poor* reach condition and extrapolating the dimensionless relations of the *B4 Reference Reach* to develop the design criteria. The F4b tributary reaches are prime candidates for this conversion scenario that exist in cut-off or "short" alluvial fans, Valley Type III, where designing a D4 braided channel is not an option. If proportionate savings in the sediment supply can result, then restoring similar reaches will help reduce sediment.

Typical Design Scenario 7 Example

Tributary A4a+ *Poor* to A4a+ *Stable* Conversion

(Valley Type I)

Tributary A4a+ Poor to A4a+ Stable Conversion (VT I): Typical Design Scenario 7 Example

General Description & Morphological Data

This typical design scenario is a stability conversion of an A4a+ *Poor* condition tributary to an A4a+ *Stable* condition. The existing, impaired stream used for the typical design is the *A4a+ Poor Stability South Representative Reach* that is depicted in **Figure II-65** and located on the general map in **Figure II-1**. The detailed characteristics and stability evaluation of this representative reach are documented in *Appendix C3* of the Waldo Canyon Fire *WARSSS* analysis (Rosgen *et al*., 2013). The increased post-fire floods and the poor riparian condition in this reach have created accelerated streambank and streambed erosion. The existing channel is deeply incised, confined, and entrenched, and is associated with a headcut at the lower end that is advancing toward the stable *A4a+ Reference Reach* that is immediately upstream. This headcut is shown in **Figure II-66**. The reach length to be converted from the existing, impaired A4a+ *Poor* reach to an A4a+ *Stable* stream type is approximately *175 ft*, which begins at the start of the *A4a+ Poor Stability South Representative Reach* and extends approximately an additional *100 ft* downstream of the reach.

The specific objectives and direction of this design scenario to stabilize the reach are as follows:

- Reduce the sediment supply from the accelerated bed scour (degradation)
- Reduce the accelerated streambank erosion rates
- Initiate grade control measures to stop the advancing headcut
- Restore the riparian function

The dimensionless relations of the *A4a+ Reference Reach* are used to generate the stable, proposed reach design criteria. This reach is located immediately above the existing reach and thus scaling of the dimensionless relations is not required (**Figure II-1**). The detailed characteristics and stability evaluation of the *A4a+ Reference Reach* are documented in *Appendix C16* of the Waldo Canyon Fire *WARSSS* analysis (Rosgen *et al*., 2013).

The resultant proposed dimension, pattern, and profile for the stable A4a+ design reach are documented in **Table II-11** using the procedure in **Appendix I**. Additionally, this table also includes a summary of the morphological descriptions and corresponding analyses of the existing *A4a+ Poor Stability South Representative Reach* and the *A4a+ Reference Reach*. Due to the high gradient and nature of the A4a+ stream type, step–pool data was utilized from the longitudinal profile of the reference reach to assist in establishing the proper depth, slope, and spacing of the steps and pools that occur frequently for the stable stream type (**Table II-11**). The following sections include the proposed design details of the stable A4a+, step–pool stream type.

Bankfull Discharge, Cross-Sectional Area & Mean Velocity

With a drainage area of *0.002 mi*^{2} for the proposed A4a+ stream type, the bankfull discharge is *0.36 cfs* and the proposed bankfull riffle cross-sectional area is *0.736 ft*^{2} as shown in **Table II-11**. Using continuity, the corresponding mean velocity for the proposed design reach is *0.5 ft/sec* as shown in **Worksheet II-19**.



Figure II-65. The deeply incised, confined and entrenched *A4a+ Poor Stability South Representative Reach*.



Figure II-66. The advancing headcut in the *A4a+ Poor Stability South Representative Reach*.

Table II-11. The morphological characteristics of the existing, proposed design and reference reaches for the A4a+ *Poor* Tributary to A4a+ *Stable* stream type conversion in a Valley Type I.

Existing Reach Stream & Location:			**A4a+ Poor South Tributary to Mainstem Trail Creek**					
Reference Reach Stream & Location:			**A4a+ Reference Reach, Tributary to Mainstem Trail Creek**					
Entry Number & Variable			**Existing Reach**		**Proposed Design Reach**		**Reference Reach**	
	1	Valley Type	**I**		**I**		**I**	
	2	Valley Width						
	3	Stream Type	**A4a+**		**A4a+**		**A4a+**	
	4	Drainage Area, mi^2	**0.002**		**0.002**		**0.002**	
	5	Bankfull Discharge, cfs (Q_{bkf})	**0.32**		**0.36**		**0.36**	
Riffle (Rapid/Chute) Dimensions	**6**	Riffle Width, ft (W_{bkf})	*Mean:* *Min:* *Max:*	**1.7** **1.4** **2.0**	*Mean:* *Min:* *Max:*	**2.3** **2.0** **2.6**	*Mean:* *Min:* *Max:*	**3.0** **2.3** **3.6**
	7	Riffle Mean Depth, ft (d_{bkf})	*Mean:* *Min:* *Max:*	**0.20** **0.18** **0.22**	*Mean:* *Min:* *Max:*	**0.32** **0.28** **0.37**	*Mean:* *Min:* *Max:*	**0.22** **0.18** **0.26**
	8	Riffle Width/Depth Ratio (W_{bkf}/d_{bkf})	*Mean:* *Min:* *Max:*	**8.4** **7.8** **9.0**	*Mean:* *Min:* *Max:*	**7.2** **5.4** **9.2**	*Mean:* *Min:* *Max:*	**11.2** **11.0** **11.4**
	9	Riffle Cross-Sectional Area, ft^2 (A_{bkf})	*Mean:* *Min:* *Max:*	**0.3** **0.3** **0.4**	*Mean:*	**0.736**	*Mean:* *Min:* *Max:*	**0.6** **0.5** **0.8**
	10	Riffle Maximum Depth (d_{max})	*Mean:* *Min:* *Max:*	**0.40** **0.37** **0.43**	*Mean:* *Min:* *Max:*	**0.50** **0.41** **0.60**	*Mean:* *Min:* *Max:*	**0.33** **0.27** **0.39**
	11	Riffle Maximum Depth to Riffle Mean Depth (d_{max}/d_{bkf})	*Mean:* *Min:* *Max:*	**2.005** **1.955** **2.056**	*Mean:* *Min:* *Max:*	**1.558** **1.286** **1.889**	*Mean:* *Min:* *Max:*	**1.558** **1.286** **1.889**
	12	Width of Flood-Prone Area at Elevation of 2 * d_{max}, ft (W_{fpa})	*Mean:* *Min:* *Max:*	**2.40** **1.88** **2.91**	*Mean:* *Min:* *Max:*	**5.0** **3.7** **5.9**	*Mean:* *Min:* *Max:*	**5.02** **3.65** **5.85**
	13	Entrenchment Ratio (W_{fpa}/W_{bkf})	*Mean:* *Min:* *Max:*	**1.41** **1.35** **1.47**	*Mean:* *Min:* *Max:*	**1.55** **1.53** **1.58**	*Mean:* *Min:* *Max:*	**1.55** **1.53** **1.58**

Table II-11 (Page 2). The morphological characteristics of the existing, proposed design and reference reaches for the A4a+ *Poor* Tributary to A4a+ *Stable* stream type conversion in a Valley Type I.

	Entry Number & Variable	Existing Reach		Proposed Design Reach		Reference Reach	
Pool Dimensions	**21** Pool Width, ft (W_{bkfp})	*Mean:*	**N/A**	*Mean:*	**2.9**	*Mean:*	**2.9**
		Min:		*Min:*	**2.8**	*Min:*	**2.8**
		Max:		*Max:*	**3.0**	*Max:*	**3.0**
	22 Pool Width to Riffle Width (W_{bkfp}/W_{bkf})	*Mean:*	**N/A**	*Mean:*	**1.261**	*Mean:*	**1.261**
		Min:		*Min:*	**1.217**	*Min:*	**1.217**
		Max:		*Max:*	**1.304**	*Max:*	**1.304**
	23 Pool Mean Depth, ft (d_{bkfp})	*Mean:*	**N/A**	*Mean:*	**0.80**	*Mean:*	**0.80**
		Min:		*Min:*	**0.60**	*Min:*	**0.60**
		Max:		*Max:*	**1.00**	*Max:*	**1.00**
	24 Pool Mean Depth to Riffle Mean Depth (d_{bkfp}/d_{bkf})	*Mean:*	**N/A**	*Mean:*	**1.200**	*Mean:*	**1.200**
		Min:		*Min:*	**1.100**	*Min:*	**1.100**
		Max:		*Max:*	**1.300**	*Max:*	**1.300**
	25 Pool Width/Depth Ratio (W_{bkfp}/d_{bkfp})	*Mean:*	**N/A**	*Mean:*	**3.6**	*Mean:*	**3.6**
		Min:		*Min:*	**2.8**	*Min:*	**2.8**
		Max:		*Max:*	**5.0**	*Max:*	**5.0**
	26 Pool Cross-Sectional Area, ft^2 (A_{bkfp})	*Mean:*	**N/A**	*Mean:*	**2.3**	*Mean:*	**2.3**
		Min:		*Min:*	**1.6**	*Min:*	**1.6**
		Max:		*Max:*	**3.0**	*Max:*	**3.0**
	27 Pool Area to Riffle Area (A_{bkfp}/A_{bkf})	*Mean:*	**N/A**	*Mean:*	**3.125**	*Mean:*	**3.125**
		Min:		*Min:*	**2.174**	*Min:*	**2.174**
		Max:		*Max:*	**4.076**	*Max:*	**4.076**
	28 Pool Maximum Depth (d_{maxp})	*Mean:*	**N/A**	*Mean:*	**1.20**	*Mean:*	**1.20**
		Min:		*Min:*	**1.10**	*Min:*	**1.10**
		Max:		*Max:*	**1.30**	*Max:*	**1.30**
	29 Pool Maximum Depth to Riffle Mean Depth (d_{maxp}/d_{bkf})	*Mean:*	**N/A**	*Mean:*	**3.750**	*Mean:*	**3.750**
		Min:		*Min:*	**3.438**	*Min:*	**3.438**
		Max:		*Max:*	**4.063**	*Max:*	**4.063**
	30 Point Bar Slope (S_{pb})	*Mean:*	**N/A**	*Mean:*	**N/A**	*Mean:*	**N/A**
		Min:		*Min:*		*Min:*	
		Max:		*Max:*		*Max:*	

Table II-11 (Page 3). The morphological characteristics of the existing, proposed design and reference reaches for the A4a+ *Poor* Tributary to A4a+ *Stable* stream type conversion in a Valley Type I.

Entry Number & Variable		Existing Reach	Proposed Design Reach	Reference Reach
Channel Pattern	**72** Linear Wavelength, ft (λ)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	73 Linear Wavelength to Riffle Width (λ/W_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	74 Stream Meander Length, ft (L_m)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	75 Stream Meander Length Ratio (L_m/W_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	76 Belt Width, ft (W_{blt})	*Mean:* **2.6** *Min:* *Max:*	*Mean:* **4.5** *Min:* *Max:*	*Mean:* **4.5** *Min:* *Max:*
	77 Meander Width Ratio (W_{blt}/W_{bkf})	*Mean:* **1.509** *Min:* *Max:*	*Mean:* **1.500** *Min:* *Max:*	*Mean:* **1.515** *Min:* *Max:*
	78 Radius of Curvature, ft (R_c)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	79 Radius of Curvature to Riffle Width (R_c/W_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	80 Rapid (Riffle) Length, ft (L_a)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **5.1** *Min:* **3.5** *Max:* **6.9**	*Mean:* **5.1** *Min:* **3.5** *Max:* **6.9**
	81 Rapid (Riffle) Length to Riffle Width (L_a/W_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **2.200** *Min:* **1.500** *Max:* **3.000**	*Mean:* **2.200** *Min:* **1.500** *Max:* **3.000**
	82 Step Length (L_r), ft	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.75** *Min:* **0.50** *Max:* **1.00**	*Mean:* **0.8** *Min:* **0.5** *Max:* **1.0**
	83 Step Length to Riffle Width (L_r/W_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.326** *Min:* **0.217** *Max:* **0.435**	*Mean:* **0.326** *Min:* **0.217** *Max:* **0.435**
	84 Individual Pool Length, ft (L_p)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **2.2** *Min:* **1.0** *Max:* **3.0**	*Mean:* **2.2** *Min:* **1.0** *Max:* **3.0**
	85 Pool Length to Riffle Width (L_p/W_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.960** *Min:* **0.450** *Max:* **1.300**	*Mean:* **0.960** *Min:* **0.450** *Max:* **1.300**
	86 Pool to Pool Spacing, ft (P_s)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **3.9** *Min:* **1.8** *Max:* **6.0**	*Mean:* **3.9** *Min:* **1.8** *Max:* **6.0**
	87 Pool to Pool Spacing to Riffle Width (P_s/W_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.700** *Min:* **0.800** *Max:* **2.600**	*Mean:* **1.700** *Min:* **0.800** *Max:* **2.600**

Table II-11 (Page 4). The morphological characteristics of the existing, proposed design and reference reaches for the A4a+ *Poor* Tributary to A4a+ *Stable* stream type conversion in a Valley Type I.

	Entry Number & Variable		Existing Reach	Proposed Design Reach	Reference Reach
Sinuosity and Slope	**88**	Stream Length (SL)	**175**	**175**	**70**
	89	Valley Length (VL)	**173**	**173**	**63**
	90	Valley Slope (S_{val})	**0.1293**	**0.1293**	**0.2200**
	91	Sinuosity (k)	SL/VL: **1.01** VS/S: **1.01**	SL/VL: **1.01**	SL/VL: **1.11** VS/S: **1.11**
	92	Average Water Surface Slope (S)	**0.128**	$S = S_{val}/k$ **0.128**	**0.198**
Bed Feature Water Surface Facet Slopes and Dimensionless Ratios from Profile	**105**	Riffle (Rapid) Slope (water surface facet slope) (S_{rif})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.1280** *Min:* *Max:*	*Mean:* **0.1980** *Min:* *Max:*
	106	Riffle (Rapid) Slope to Average Water Surface Slope (S_{rif}/S)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.0000** *Min:* *Max:*	*Mean:* **1.0000** *Min:* *Max:*
	107	Pool Slope (water surface facet slope) (S_p)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.0450** *Min:* **0.0300** *Max:* **0.0600**	*Mean:* **0.1041** *Min:* **0.0465** *Max:* **0.0931**
	108	Pool Slope to Average Water Surface Slope (S_p/S)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.3515** *Min:* **0.2343** *Max:* **0.4687**	*Mean:* **0.5260** *Min:* **0.2351** *Max:* **0.4701**
	109	Run Slope (water surface facet slope) (S_{run})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	110	Run Slope to Average Water Surface Slope (S_{run}/S)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	111	Glide Slope (water surface facet slope) (S_g)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	112	Glide Slope to Average Water Surface Slope (S_g/S)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	113	Step Slope (water surface facet slope) (S_s)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.0384** *Min:* **0.0320** *Max:* **0.0448**	*Mean:* **0.0594** *Min:* **0.0495** *Max:* **0.0693**
	114	Step Slope to Average Water Surface Slope (S_s/S)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.3000** *Min:* **0.2500** *Max:* **0.3500**	*Mean:* **0.3000** *Min:* **0.2500** *Max:* **0.3500**

Table II-11 (Page 5). The morphological characteristics of the existing, proposed design and reference reaches for the A4a+ *Poor* Tributary to A4a+ *Stable* stream type conversion in a Valley Type I.

	Entry Number & Variable	Existing Reach	Proposed Design Reach	Reference Reach
Bed Feature Max Depth Measurements and Dimensionless Ratios from Profile	**115** Riffle (Rapid) Maximum Depth, ft (d_{max})	*Mean:* **0.48** *Min:* **0.37** *Max:* **0.61**	*Mean:* **0.49** *Min:* **0.35** *Max:* **0.63**	*Mean:* **0.38** *Min:* **0.27** *Max:* **0.49**
	116 Riffle (Rapid) Maximum Depth to Riffle Mean Depth (d_{max}/d_{bkf})	*Mean:* **2.400** *Min:* **1.850** *Max:* **3.050**	*Mean:* **1.520** *Min:* **1.080** *Max:* **1.960**	*Mean:* **1.520** *Min:* **1.080** *Max:* **1.960**
	117 Pool Maximum Depth, ft (d_{maxp})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.20** *Min:* **1.10** *Max:* **1.30**	*Mean:* **1.20** *Min:* **1.10** *Max:* **1.30**
	118 Pool Maximum Depth to Riffle Mean Depth (d_{maxp}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **3.750** *Min:* **3.438** *Max:* **4.063**	*Mean:* **3.750** *Min:* **3.438** *Max:* **4.063**
	119 Run Maximum Depth, ft (d_{maxr})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	120 Run Maximum Depth to Riffle Mean Depth (d_{maxr}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	121 Glide Maximum Depth, ft (d_{maxg})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	122 Glide Maximum Depth to Riffle Mean Depth (d_{maxg}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	123 Step Maximum Depth, ft (d_{maxs})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	124 Step Maximum Depth to Riffle Mean Depth (d_{maxs}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
Channel Materials	**125 Particle Size Distribution of Channel Material (Active Bed) or Pavement**			
	D_{16} (mm)	**1.0**	**1.0**	**1.3**
	D_{35} (mm)	**2.4**	**2.4**	**3.0**
	D_{50} (mm)	**4.8**	**4.8**	**6.4**
	D_{84} (mm)	**10.4**	**10.4**	**13.0**
	D_{95} (mm)	**14.4**	**14.4**	**23.9**
	D_{100} (mm)	**90.0**	**90.0**	**256.0**
	126 Particle Size Distribution of Bar Material or Sub-pavement			
	D_{16} (mm)	**N/A**	**N/A**	**N/A**
	D_{35} (mm)	**N/A**	**N/A**	**N/A**
	D_{50} (mm)	**N/A**	**N/A**	**N/A**
	D_{84} (mm)	**N/A**	**N/A**	**N/A**
	D_{95} (mm)	**N/A**	**N/A**	**N/A**
	D_{max}: Largest size particle at the toe (lower third) of bar (mm) or sub-pavement	**N/A**	**N/A**	**N/A**

Table II-11 (Page 6). The morphological characteristics of the existing, proposed design and reference reaches for the A4a+ *Poor* Tributary to A4a+ *Stable* stream type conversion in a Valley Type I.

	Entry Number & Variable	Existing Reach	Proposed Design Reach	Reference Reach
Hydraulics	127 Estimated Bankfull Mean Velocity, ft/sec (u_{bkf})	0.73	0.5	0.75
	128 Estimated Bankfull Discharge, cfs (Q_{bkf}); Compare with Regional Curve	0.32	0.36	0.36
Sediment Yield	**Sediment Yield (FLOWSED)**	**Existing Reach**	**Proposed Design Reach**	**Difference in Sediment Yield**
	141 Bedload Sediment Yield (tons/yr)	33.9	19.6	14.2
	142 Suspended Sediment Yield (tons/yr)	141.4	0.0	141.4
	143 Suspended Sand Sediment Yield (tons/yr)	70.7	0.0	70.7
	144 Total Annual Sediment Yield (tons/yr)	175.3	19.6	155.7
Bank Erosion	**Streambank Erosion**	**Existing Reach**	**Proposed Design Reach**	**Reference Reach**
	145 Stream Length Assessed (ft)	175	175	70.0
	146 Graph/Curve Used (e.g., Yellowstone or Colorado)	Colorado	Colorado	Colorado
	147 Streambank Erosion (tons/yr)	6.21	0.30	0.12
	148 Streambank Erosion (tons/yr/ft)	0.0355	0.0017	0.0017

Worksheet II-19. The mean velocity estimates for the proposed A4a+ *Stable* reach to be converted from the existing, A4+ *Poor* stream type.

Bankfull VELOCITY & DISCHARGE Estimates

Stream:	**A4a+ *Stable* from A4a+ *Poor***			Location:	**A4a+ Poor Stability South Reach**
Date:	**3/15/2011**	Stream Type:	**A4a+**	Valley Type:	**I**
Observers:	**Rosgen *et al*.**			HUC:	_ _

Input Variables for PROPOSED Design			Output Variables for PROPOSED Design		
Bankfull Riffle Cross-Sectional AREA	**0.736**	**A_{bkf}** (ft^2)	Bankfull Riffle Mean DEPTH	**0.32**	**d_{bkf}** (ft)
Bankfull Riffle WIDTH	**2.3**	**W_{bkf}** (ft)	Wetted PERMIMETER ~ (2 * d_{bkf}) + W_{bkf}	**2.94**	**W_p** (ft)
D_{84} at Riffle	**10.4**	**Dia.** (mm)	D_{84} (mm) / 304.8	**0.03**	**D_{84}** (ft)
Bankfull SLOPE	**0.1280**	**S_{bkf}** (ft / ft)	Hydraulic RADIUS A_{bkf} / W_p	**0.25**	**R** (ft)
Gravitational Acceleration	**32.2**	**g** (ft / sec^2)	Relative Roughness R(ft) / D_{84} (ft)	**7.32**	**R / D_{84}**
Drainage Area	**0.002**	**DA** (mi^2)	Shear Velocity $u^* = (gRS)^{½}$	**1.016**	**u*** (ft/sec)

ESTIMATION METHODS	Bankfull VELOCITY		Bankfull DISCHARGE	
1. Friction Factor / Relative Roughness $u = [\ 2.83 + 5.66 * Log\ \{\ R / D_{84}\ \}\ ]\ u^*$		ft / sec		cfs
2. Roughness Coefficient: a) Manning's *n* from Friction Factor / Relative Roughness (Figs. 5-7, 5-8) $u = 1.49*R^{2/3}*S^{1/2}/n$ $n =$		ft / sec		cfs
2. Roughness Coefficient: b) Manning's *n* from Stream Type (Fig. 5-9) $u = 1.49*R^{2/3}*S^{1/2}/n$ $n =$		ft / sec		cfs
2. Roughness Coefficient: c) Manning's *n* from Jarrett (USGS): $u = 1.49*R^{2/3}*S^{1/2}/n$ $n = 0.39*S^{0.38}*R^{-0.16}$ **Note:** This equation is applicable to **steep, step/pool, high boundary roughness, cobble- and boulder-dominated stream systems**; i.e., for Stream Types A1, A2, A3, B1, B2, B3, C2 & E3 $n =$ **0.223**	**0.95**	ft / sec	**0.70**	cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)		ft / sec		cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)		ft / sec		cfs
4. Continuity Equations: a) USGS Gage Data $u = Q / A$ **Return Period for Bankfull Q** $Q =$ **year**		ft / sec		cfs
4. Continuity Equations: b) Regional Curves $u = Q / A$	**0.5**	ft / sec	**0.36**	cfs

Protrusion Height Options for the D_{84} Term in the Relative Roughness Relation (R/D_{84}) – Estimation Method 1

Option 1.	For **sand-bed** channels: Measure 100 **"protrusion heights"** of sand dunes from the downstream side of feature to the top of feature. Substitute the D_{84} sand dune protrusion height in ft for the D_{84} term in method 1.
Option 2.	For **boulder-dominated** channels: Measure 100 **"protrusion heights"** of boulders on the sides from the bed elevation to the top of the rock on that side. Substitute the D_{84} boulder protrusion height in ft for the D_{84} term in method 1.
Option 3.	For **bedrock-dominated** channels: Measure 100 **"protrusion heights"** of rock separations, steps, joints or uplifted surfaces above channel bed elevation. Substitute the D_{84} bedrock protrusion height in ft for the D_{84} term in method 1.
Option 4.	For **log-influenced** channels: Measure "**protrustion heights**" proportionate to channel width of log diameters or the height of the log on upstream side if embedded. Substitute the D_{84} protrusion height in ft for the D_{84} term in method 1.

Plan View Alignment

The proposed plan view of the alignment for the A4a+ *Poor* stream type to stable A4a+ step–pool conversion is shown in **Figure II-67**, which follows the reference reach data for the stable A4a+ stream type (**Table II-11**). Individual typical cross-sections and structures are also shown on this plan view.

Cross-Section Dimensions

The channel dimensions for the proposed A4a+ *Stable* step–pool design are derived from the *A4a+ Reference Reach* in **Table II-11**. **Figure II-67** illustrates the typical cross-sections in relation to the plan view. The typical rapid/chute (riffle) cross-section dimensions are shown in **Figure II-68**. The overlay of the existing A4a+ *Poor* cross-section 0+99.1 *vs*. proposed A4a+ *Stable* pool cross-section, indicating the proposed pool dimensions, new bankfull elevation, and associated cut and fill requirements, is shown in **Figure II-69**. Similarly, the overlay of the existing cross-section 1+52.7 *vs*. proposed pool cross-section is shown in **Figure II-70**. These overlays are used to compute the cut and fill required for the design based on the reach length.

Longitudinal Profile

A typical longitudinal profile for *10 ft* of channel length of the proposed A4a+ *Stable* design is shown in **Figure II-71**. The depths, slopes, lengths, and spacing of bed features, in addition to the placement locations and types of structures, are illustrated. The typical longitudinal profile corresponds to the plan and cross-section views in **Figure II-67**.

Figure II-72 depicts the existing *vs*. proposed longitudinal profile that shows the proposed elevations of the bed and bankfull stage and the energy slope. The location and scaling of the step–pool bed features are also depicted in **Figure II-72** as derived from **Table II-11**. The upper section of the profile is slightly steeper to transition between the *A4a+ Reference Reach* with a slope of *0.198* and the existing A4a+ *Poor* reach with a slope of *0.128*. The last *25 ft* of the profile indicates a fill requirement to gradually lower the bank height of a local headcut section. The fill can be obtained by shaping the upper banks as indicated in the cross-section overlays (**Figure II-69** and **Figure II-70**).

Structures

This typical design scenario recommends converging rock clusters, rock and log roller structures, and rock step–pool structures for streambank stabilization, energy dissipation, and grade control. The location of these recommended structures are illustrated in **Figure II-67**, **Figure II-71**, and **Figure II-72**. The materials for these structures can be obtained from on-site sources. Many of the burned logs will be salvaged to use for the rock and log roller structure, and local rock will be used for the converging rock clusters and boulder step–pool structures. Vegetation transplants of alder and aspen will be salvaged from the local excavation required to reshape the banks.

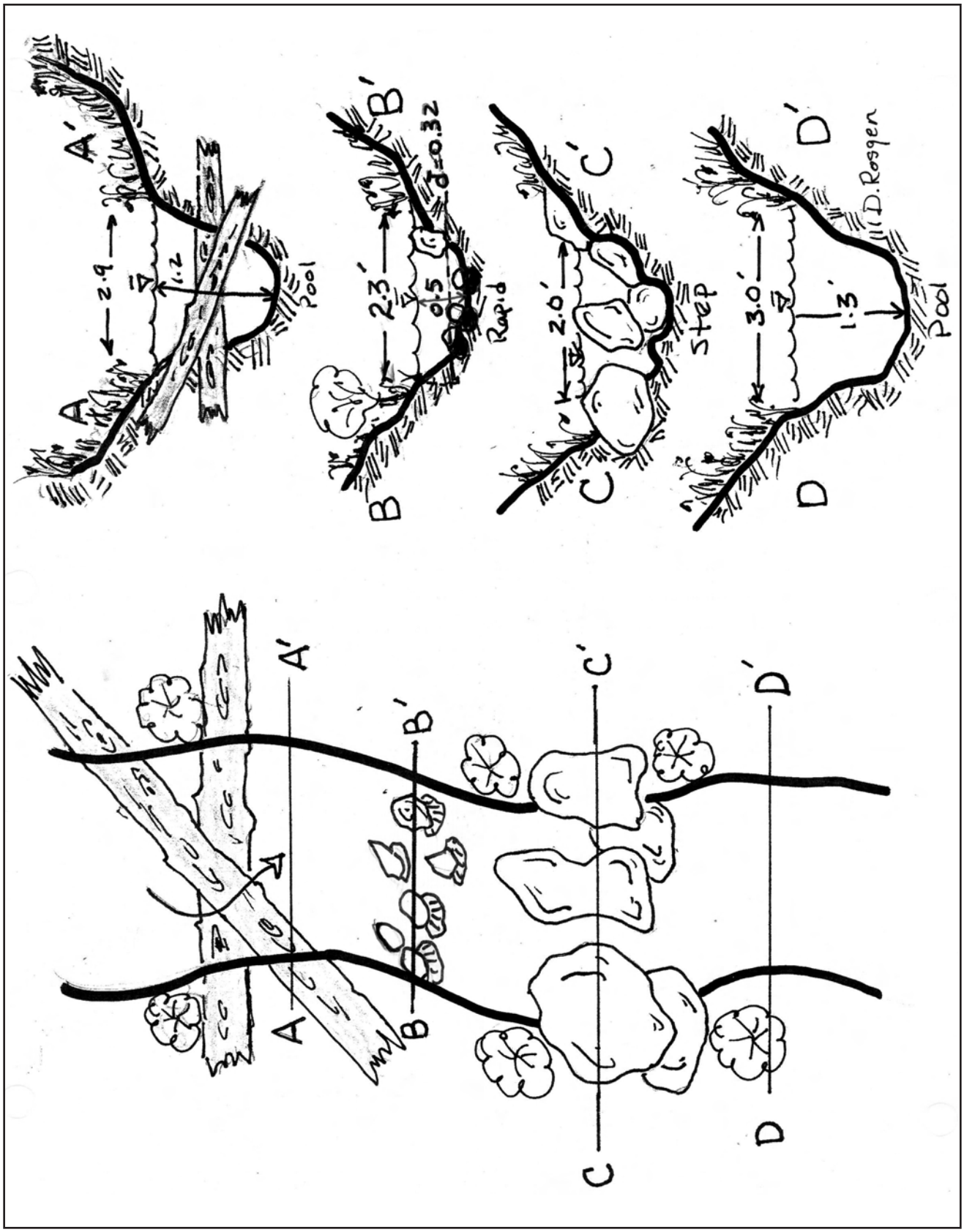


Figure II-67. Typical plan view alignment with corresponding cross-section dimensions and structure locations.

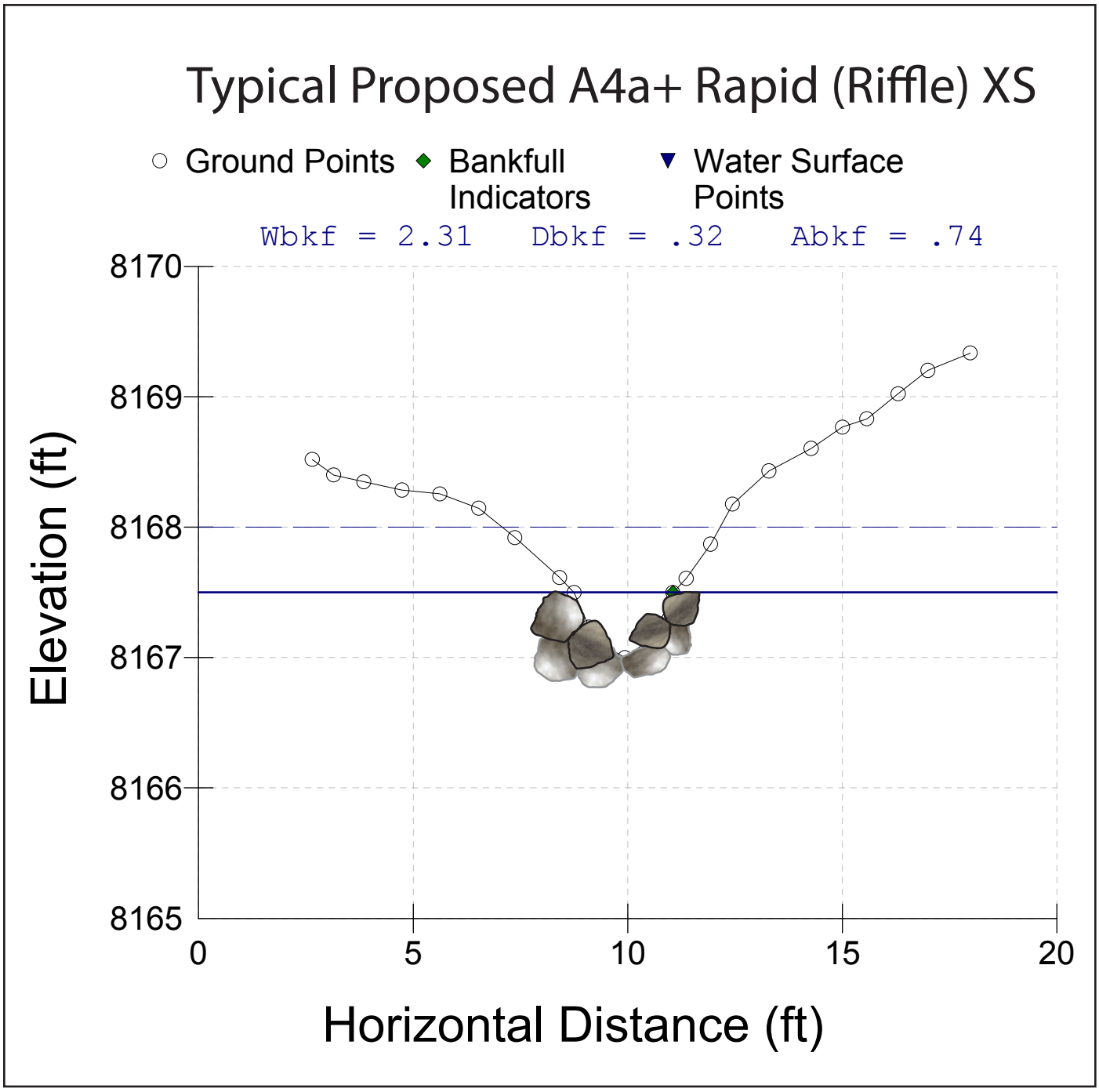


Figure II-68. The typical rapid/chute (riffle) cross-section for the proposed A4a+ *Stable* step–pool design.

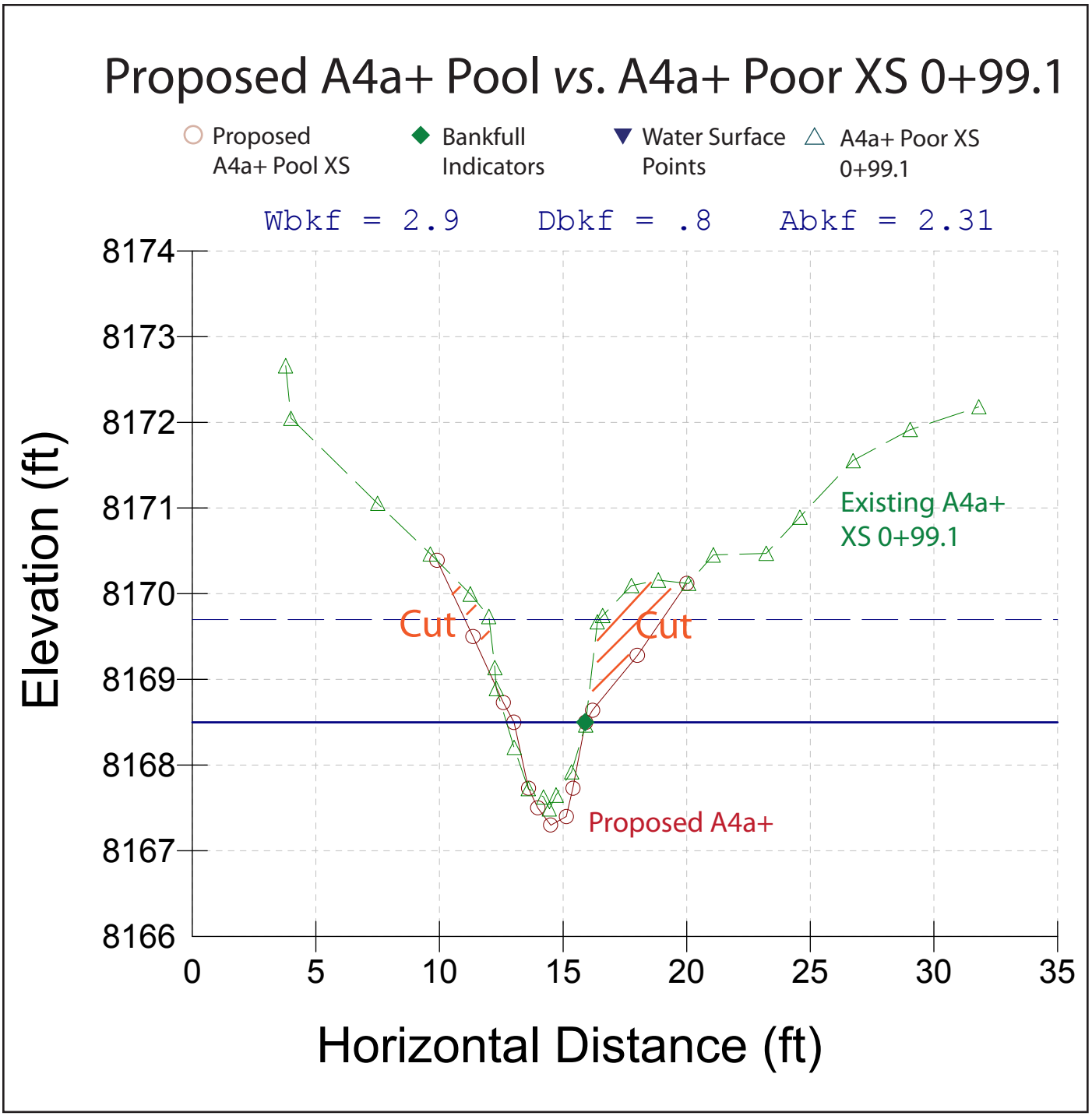


Figure II-69. The overlay of the existing cross-section 0+99.1 *vs.* proposed pool cross-section indicating the cut and fill recommendations for the A4a+ *Poor* to A4a+ *Stable* step–pool conversion.

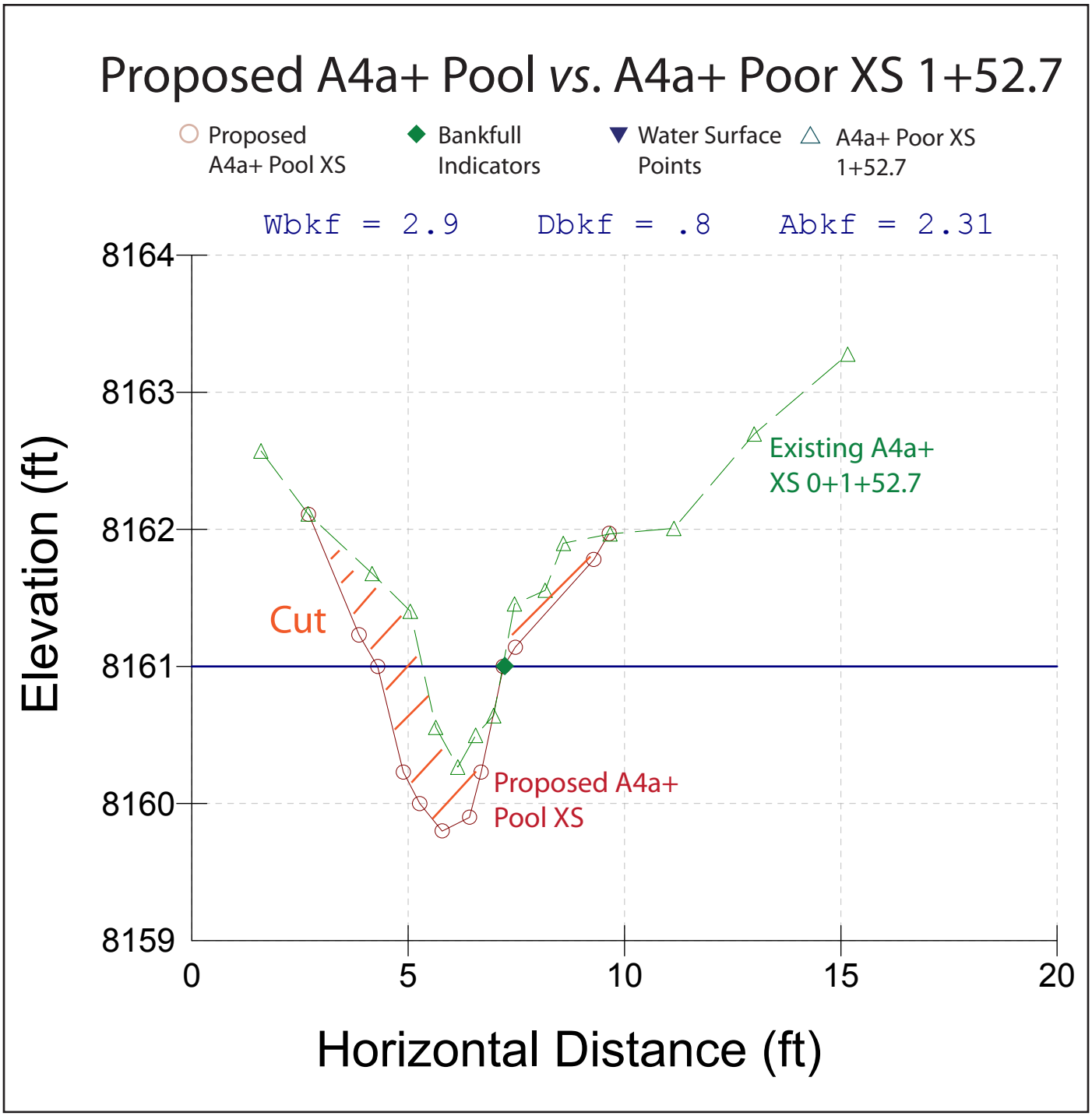


Figure II-70. The overlay of the existing cross-section 1+52.7 *vs.* proposed pool cross-section indicating the cut and fill recommendations for the A4a+ *Poor* to A4a+ *Stable* step–pool conversion.

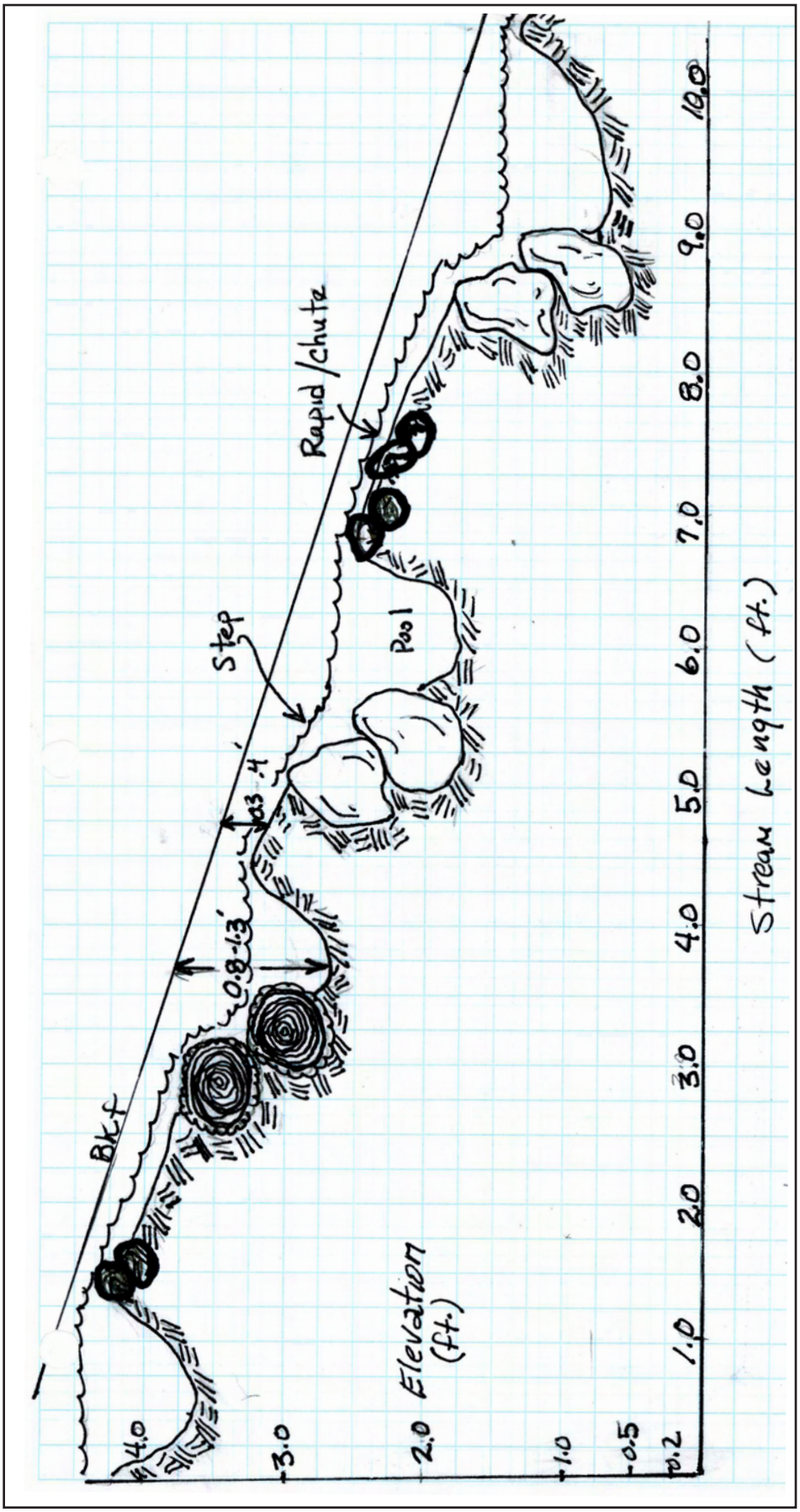


Figure II-71. The typical longitudinal profile for *10 ft* of the proposed A4a+ *Stable* step–pool design, including the structure placement and the depths, slopes, lengths and spacing of bed features.

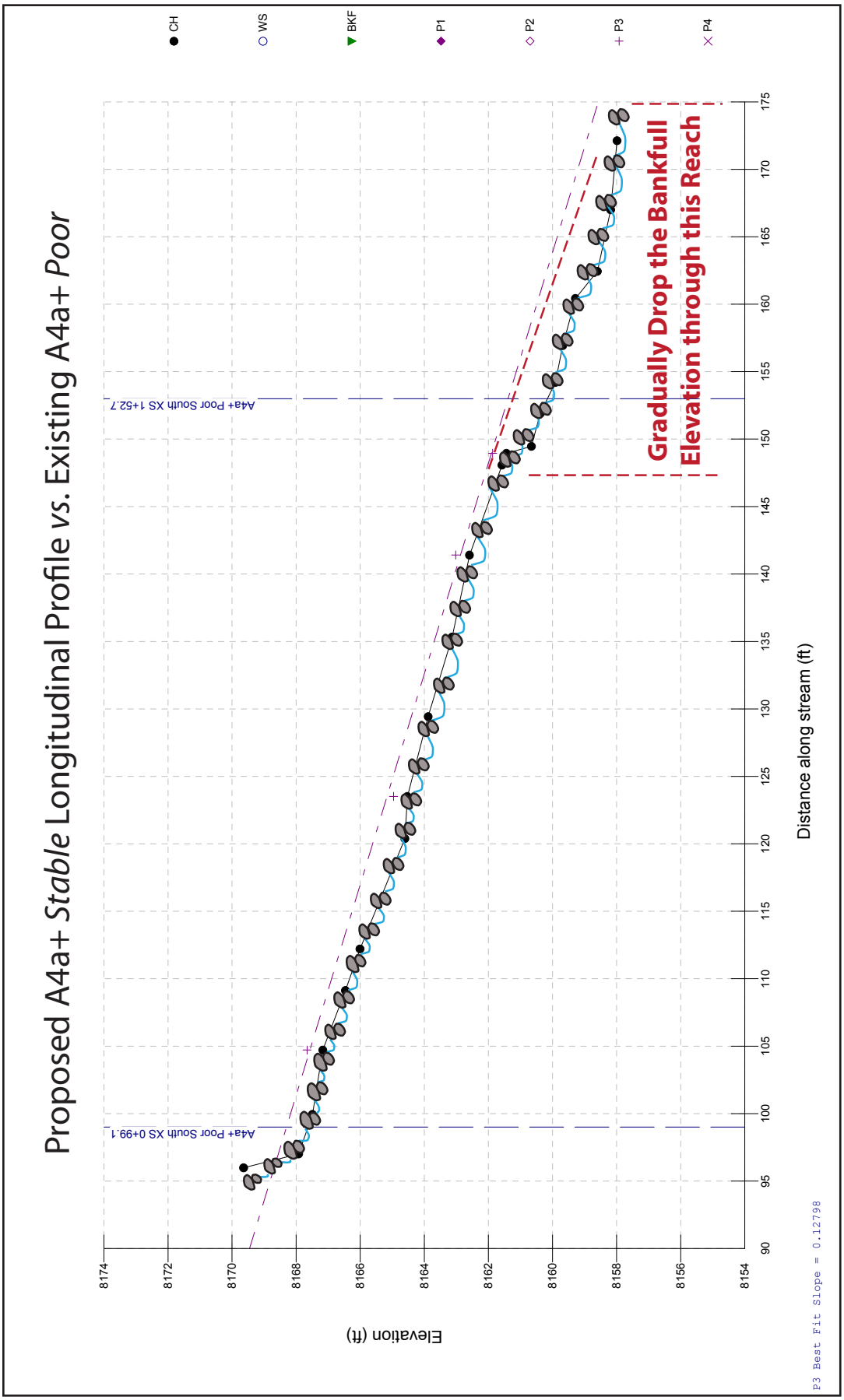


Figure II-72. The proposed longitudinal profile compared to the existing *A4a+ Poor South Representative Reach* profile.

Riparian Vegetation

It is a key requirement to re-establish a woody riparian community of aspen and alder along this steep and narrow riparian corridor. This is accomplished by transplanting from available nearby plants. Native bunch grasses, such as big mountain brome, are recommended for seeding the side slopes.

Cut & Fill Computations

The cut and fill balance is obtained from the existing *vs*. proposed cross-sections with lengths obtained from the proposed design profile. For this design, the cut and fill balance will not require any end-haul in or out of the site as there is approximately *32 yds*^{3} of cut and fill within the *175 ft* of restoration. The fill related to the structures planned for this reach involving rock and logs is included in the cut and fill balance.

Streambank Erosion

By converting the A4a+ *Poor* reach to the A4a+ *Stable* form, the estimated streambank erosion is reduced from *6.2 tons/yr* to *0.3 tons/yr*, representing a *95%* reduction for *175 ft* of distance (**Table II-11**). These values are based on the annual erosion rate of *0.0355 tons/yr/ft* for the *A4a+ Poor Stability South Representative Reach* and the extrapolation of the erosion rates of *0.0017 tons/yr/ft* for the *A4+ Reference Reach* to the proposed design reach. This sediment reduction assumes that the various structures designed and located on the plan view map in **Figure II-67** are implemented. These structures have been proven to reduce streambank erosion rates in similar design scenarios.

Flow-Related Sediment

The FLOWSED model indicates that by converting from a "Poor" condition to a "Good" condition throughout the sub-watershed, the flow-related sediment yields would be reduced from *175.3 tons/yr* (**Worksheet II-20a**) to *19.6 tons/yr* (**Worksheet II-20b**) as a result of the restoration. The corresponding sediment supply reductions based on converting from "Poor" to "Good" conditions are *14.2 tons/yr* for bedload and *141.4 tons/yr* for suspended sediment, representing a total sediment reduction of *155.7 tons/yr*. These sediment reductions are still assuming a high post-fire runoff response and continued increased stormflow peak runoff. These reductions also assume that the majority of the existing reaches in the sub-watershed are associated with a "Poor" condition, and that the restored values are associated with treating the majority of the stream length of the watershed above this reach.

The reductions in sediment supply associated with restoring *175 ft* of the existing A4a+ *Poor* stream type to the proposed A4a+ *Stable* design reach are *5.9 tons/yr* of streambank erosion, *5.0 tons/yr* of bedload, *49.5 tons/yr* of suspended sediment and *54.5 tons/yr* of total sediment yield reduction. The total sediment yield value includes streambank erosion contributions and streambed sources. The sediment reductions associated with the local channel source sediment for this design scenario are based on sediment yield rates determined from taking the sediment yield values generated from FLOWSED and dividing by the total stream length of potential sediment contributions. For this scenario, it was determined that approximately *500 ft* of tributary channel is potentially contributing sediment. The resultant sediment yield rates were then multiplied by the existing and proposed design reach lengths for this scenario to obtain the local sediment reductions.

The POWERSED model was not run for this scenario because the existing reach has the same stream type and similar slope as the reference reach that is located immediately above the existing reach. A large portion of the *54.4 tons/yr* of flow-related sediment is coming from the streambanks and from the short headcut area. The sediment reductions will be generated by implementing the design structures to greatly reduce bed and bank erosion. The proposed A4a+ *Stable* design reach will prevent further channel degradation and will protect the upstream *A4a+ Reference Reach* from the advancing headcut.

Sediment Competence

A4a+ stream types are high energy systems because of the steep slopes associated with this stream type; thus sediment competence calculations would indicate excess energy. Therefore grade control is warranted and recommended using converging rock clusters and the rock and log roller structures as designed in **Figure II-67** and **Figure II-71**.

Worksheet II-20a. The existing sediment supply at the A4a+ *Poor* reach using the FLOWSED model and generated by using the dimensionless sediment rating curves and bankfull sediment values related to the "Poor" condition.

Stream: **A4a+ Poor South Representative Reach** Location: **Trail Creek Tributary** Date: **3/15/11**

Observers: **Rosgen *et al*.** Gage Station #: **Goose Creek Gage** Stream Type: **A4a+** Valley Type: **I**

Equation Type	Equation Source	Equation	Bankfull Discharge (cfs)	Bankfull Bedload Sediment (kg/s)	Bankfull Suspended Sediment (mg/l)
1. Bedload Sediment	"Poor" Pagosa	$y = 0.07176+1.02176x^{2.3772}$	0.36	0.0017	53.83
2. Suspended Sediment	"Poor" Pagosa	$y = 0.0989+0.9213x^{3.659}$			

From Dimensional Flow-Duration Curve							From Sediment Rating Curves				Calculate	Calculate Sediment Yield		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Percentage of Time	Daily Mean Discharge	Mid-Ordinate	Time Increment (percent)	Time Increment (days)	Mid-Ordinate Streamflow	Dimension-less Streamflow	Dimension-less Suspended Sediment Discharge	Suspended Sediment Discharge	Dimension- less Bedload Discharge	Bedload Sediment Discharge	Time Adjusted Streamflow [(5)×(6)]	Suspended Sediment [(5)×(9)]	Bedload Sediment [(5)×(11)]	Suspended + Bedload Sediment [(13)+(14)]
(%)	(cfs)	(%)	(%)	(days)	(cfs)	(Q/Q_{bkf})	(S/S_{bkf})	(tons/day)	(b_s/b_{bkf})	(tons/day)	(cfs)	(tons)	(tons)	(tons)
0%	2.1													
0.10%	1.8	0.05%	0.09%	0.34	2.0	5.436	451.771	128.49	57.256	9.42	0.7	44.09	3.23	47.32
0.25%	1.6	0.08%	0.15%	0.55	1.7	4.684	262.028	64.21	40.208	6.62	0.9	35.16	3.62	38.78
0.50%	1.4	0.13%	0.25%	0.91	1.5	4.051	154.039	32.65	28.488	4.69	1.3	29.79	4.28	34.07
0.75%	1.2	0.13%	0.25%	0.91	1.3	3.481	88.492	16.12	19.889	3.27	1.1	14.71	2.99	17.69
1%	1.0	0.13%	0.25%	0.91	1.1	2.990	50.799	7.95	13.882	2.28	1.0	7.25	2.08	9.34
1.5%	0.7	0.25%	0.50%	1.83	0.9	2.380	22.100	2.75	8.100	1.33	1.6	5.02	2.43	7.45
2%	0.6	0.25%	0.50%	1.83	0.7	1.829	8.492	0.81	4.364	0.72	1.2	1.48	1.31	2.79
3%	0.5	0.50%	1.00%	3.65	0.6	1.550	4.684	0.38	2.970	0.49	2.0	1.39	1.78	3.17
4%	0.5	0.50%	1.00%	3.65	0.5	1.351	2.866	0.20	2.159	0.36	1.8	0.74	1.30	2.04
5%	0.4	0.50%	1.00%	3.65	0.4	1.199	1.890	0.12	1.645	0.27	1.6	0.43	0.99	1.42
10%	0.3	2.50%	5.00%	18.25	0.3	0.963	0.901	0.05	1.006	0.17	6.3	0.83	3.02	3.85
20%	0.2	5.00%	10.00%	36.50	0.2	0.618	0.257	0.01	0.397	0.07	8.1	0.30	2.38	2.69
30%	0.1	5.00%	10.00%	36.50	0.1	0.363	0.122	0.00	0.164	0.03	4.8	0.08	0.98	1.07
40%	0.1	5.00%	10.00%	36.50	0.1	0.248	0.105	0.00	0.109	0.02	3.3	0.05	0.65	0.70
50%	0.1	5.00%	10.00%	36.50	0.1	0.182	0.101	0.00	0.089	0.01	2.4	0.03	0.54	0.57
60%	0.0	5.00%	10.00%	36.50	0.1	0.139	0.100	0.00	0.081	0.01	1.8	0.03	0.49	0.51
70%	0.0	5.00%	10.00%	36.50	0.0	0.109	0.099	0.00	0.077	0.01	1.4	0.02	0.46	0.48
80%	0.0	5.00%	10.00%	36.50	0.0	0.091	0.099	0.00	0.075	0.01	1.2	0.02	0.45	0.47
90%	0.0	5.00%	10.00%	36.50	0.0	0.073	0.099	0.00	0.074	0.01	1.0	0.01	0.44	0.46
100%	0.0	5.00%	10.00%	36.50	0.0	0.036	0.099	0.00	0.072	0.01	0.5	0.01	0.43	0.44
									Annual Totals:		44.0 (cfs) / 87.2 (acre-ft)	141.4 (tons/yr)	33.9 (tons/yr)	175.3 (tons/yr)

Worksheet II-20b. The proposed sediment supply at the proposed A4a+ *Stable* reach using the FLOWSED model and generated by using the dimensionless sediment rating curves and bankfull sediment values related to the restored "Good" condition (assuming that the watershed area above this reach is also restored to "Good" conditions).

Stream: **Proposed A4a+ Step/Pool Design** Location: **Tributary to Mainstem Trail Creek** Date: **3/15/11**

Observers **Rosgen *et al*.** Gage Station #: **Goose Creek Gage** Stream Type: **A4a+** Valley Type: **I**

Equation Type	Equation Source	Equation	Bankfull Discharge (cfs)	Bankfull Bedload Sediment (kg/s)	Bankfull Suspended Sediment (mg/l)
1. Bedload Sediment	"Good/Fair" Pagosa	$y = -0.0113+1.0139x^{2.1929}$	0.36	0.0014	0.014
2. Suspended Sediment	"Good/Fair" Pagosa	$y = 0.0636+0.9326x^{2.4085}$			

From Dimensional Flow-Duration Curve							From Sediment Rating Curves				Calculate	Calculate Sediment Yield		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Percentage of Time	Daily Mean Discharge	Mid-Ordinate	Time Increment (percent)	Time Increment (days)	Mid-Ordinate Streamflow	Dimension-less Streamflow	Dimension-less Suspended Sediment Discharge	Suspended Sediment Discharge	Dimension-less Bedload Discharge	Bedload Sediment Discharge	Time Adjusted Streamflow [(5)×(6)]	Suspended Sediment [(5)×(9)]	Bedload Sediment [(5)×(11)]	Suspended + Bedload Sediment [(13)+(14)]
(%)	(cfs)	(%)	(%)	(days)	(cfs)	(Q/Q_{bkf})	(S/S_{bkf})	(tons/day)	(b_s/b_{bkf})	(tons/day)	(cfs)	(tons)	(tons)	(tons)
0%	2.1													
0.10%	1.8	0.05%	0.09%	0.34	2.0	5.436	55.099	0.00	41.523	5.39	0.7	0.00	1.85	1.85
0.25%	1.6	0.08%	0.15%	0.55	1.7	4.684	38.512	0.00	29.952	3.89	0.9	0.00	2.13	2.13
0.50%	1.4	0.13%	0.25%	0.91	1.5	4.051	27.161	0.00	21.778	2.83	1.3	0.00	2.58	2.58
0.75%	1.2	0.13%	0.25%	0.91	1.3	3.481	18.871	0.00	15.615	2.03	1.1	0.00	1.85	1.85
1%	1.0	0.13%	0.25%	0.91	1.1	2.990	13.108	0.00	11.188	1.45	1.0	0.00	1.32	1.32
1.5%	0.7	0.25%	0.50%	1.83	0.9	2.380	7.593	0.00	6.779	0.88	1.6	0.00	1.60	1.61
2%	0.6	0.25%	0.50%	1.83	0.7	1.829	4.056	0.00	3.800	0.49	1.2	0.00	0.90	0.90
3%	0.5	0.50%	1.00%	3.65	0.6	1.550	2.745	0.00	2.641	0.34	2.0	0.00	1.25	1.25
4%	0.5	0.50%	1.00%	3.65	0.5	1.351	1.987	0.00	1.949	0.25	1.8	0.00	0.92	0.92
5%	0.4	0.50%	1.00%	3.65	0.4	1.199	1.508	0.00	1.499	0.19	1.6	0.00	0.71	0.71
10%	0.3	2.50%	5.00%	18.25	0.3	0.963	0.915	0.00	0.922	0.12	6.3	0.00	2.18	2.18
20%	0.2	5.00%	10.00%	36.50	0.2	0.618	0.356	0.00	0.341	0.04	8.1	0.00	1.62	1.62
30%	0.1	5.00%	10.00%	36.50	0.1	0.363	0.145	0.00	0.099	0.01	4.8	0.00	0.47	0.47
40%	0.1	5.00%	10.00%	36.50	0.1	0.248	0.096	0.00	0.036	0.00	3.3	0.00	0.17	0.17
50%	0.1	5.00%	10.00%	36.50	0.1	0.182	0.079	0.00	0.013	0.00	2.4	0.00	0.06	0.06
60%	0.0	5.00%	10.00%	36.50	0.1	0.139	0.072	0.00	0.002	0.00	1.8	0.00	0.01	0.01
70%	0.0	5.00%	10.00%	36.50	0.0	0.109	0.068	0.00	0.000	0.00	1.4	0.00	0.00	0.00
80%	0.0	5.00%	10.00%	36.50	0.0	0.091	0.066	0.00	0.000	0.00	1.2	0.00	0.00	0.00
90%	0.0	5.00%	10.00%	36.50	0.0	0.073	0.065	0.00	0.000	0.00	1.0	0.00	0.00	0.00
100%	0.0	5.00%	10.00%	36.50	0.0	0.036	0.064	0.00	0.000	0.00	0.5	0.00	0.00	0.00
									Annual Totals:		44.0 (cfs) / 87.2 (acre-ft)	0.0 (tons/yr)	19.6 (tons/yr)	19.6 (tons/yr)

Summary of the Tributary A4a+ Poor to A4a+ Stable Conversion

This proposed design scenario can be effective at reducing disproportionately high sediment sources from the numerous small headcut streams that are similar to this scenario. The increased flows due to the fire will continue but the flow-related sediment increases in this actively downcutting channel will be potentially reduced by *54.5 tons/yr* (seven, 10-yard end-dump truck loads per year) for treating just *175 ft* of this small, but highly unstable stream type.

Typical Design Scenario 8 Example

Tributary A4a+ to B4a Stream Type Conversion

(Valley Type III – Small)

Tributary A4a+ to B4a Stream Type Conversion (VT III): Typical Design Scenario 8 Example

General Description & Morphological Data

This typical design scenario example is a stream type and stability conversion from an A4a+ *Poor* condition tributary to a B4a *Stable* stream type within a "short" alluvial fan, Valley Type III. This scenario is recommended for incised channels that do not have sufficient capacity of their downstream fans to store sediment through the use of braided, D4 stream types. The B4a design reduces the channel source sediment of streambank and streambed erosion typical of the A4a+ stream types.

The existing, impaired A4a+ tributary is located at the mouth of a face drainage to Trail Creek within the north-east part of Sub-Watershed 4 in the Trail Creek Watershed (**Figure II-73**). The reach begins at the mouth and confluence with Trail Creek and extends upstream approximately *300 ft* in reach length (**Figure II-74**). The A4a+ tributary is deeply incised, confined and entrenched, creating accelerated streambed and streambank erosion. The toe slope of the fan has been eroded away by Trail Creek resulting in a "short" fan and precluding the option to construct a D4 stream type. If this reach is not restored, the increased post-fire floods will continue to downcut and laterally erode this reach.

The specific objectives and direction of this design scenario to stabilize the reach are as follows:

- Reduce the high sediment supply from the accelerated bed scour (degradation),
- Reduce the accelerated streambank erosion rates
- Incorporate grade control measures to stop potentially advancing headcuts

The existing A4a+ tributary was assessed as a *Poor* condition reach due to the obvious streambank erosion, the existing morphology, and high sediment supply observed. The drainage area and bankfull discharge for this existing reach are documented in **Table II-12**. However, a detailed survey and corresponding stability assessment were not completed on the existing A4a+ tributary as was done on the representative reaches. Consequently, the *A4a+ Poor Stability Downstream Representative Reach* data was extrapolated to the existing site because of the similar characteristics, including the same stream type, condition and valley type. Reviewing the stability analysis of the representative reach is helpful to understand the unstable characteristics of the existing A4a+ tributary for design purposes. The location of the *A4a+ Poor Stability Downstream Representative Reach* is shown in **Figure II-1** and the morphology and stability evaluation are documented in *Appendix C4* of the Waldo Canyon Fire *WARSSS* analysis (Rosgen *et al*., 2013).

Because of the similarities between B4a and B4 stream types, the dimensionless relations of the *B4 Reference Reach* are used to generate the proposed B4a stable design criteria by scaling the relations to the proposed bankfull discharge and area. The location of the *B4 Reference Reach* is shown in **Figure II-1** and the detailed characteristics and stability evaluation are documented in *Appendix C18* of the Waldo Canyon Fire *WARSSS* analysis (Rosgen *et al*., 2013). However, the B4a stream type has a steeper slope than the B4 stream type; hence, some of the stable design criteria requires adjustment from the reference reach values to agree with the morphology of channels with steeper slopes, including pool-to-pool spacing, sinuosity and width/depth ratio. Pools occur much closer together on steeper slopes and consequently the pool-to-pool spacing lengths are lower for the B4a

stream type based on the relation in **Figure II-75**. The sinuosity is also much lower with steeper slopes as shown the relationship in **Figure II-76**. Width/depth ratio is also adjusted to the lower range for the B4a stream type. The steeper gradient also requires grade control and increased bed roughness (flow resistance) by log and rock structures to accommodate the increase in bankfull shear stress. These changes are necessary for the steeper B4a stream types to ensure a sustainable morphology based on their central tendency.

The resultant proposed dimensions, pattern, and profile for the stable B4a design reach are documented in **Table II-12**. Additionally, this table also includes a summary of the morphological descriptions of the existing A4a+ *Poor* reach, the *A4a+ Poor Stability Downstream Representative Reach*, and the *B4 Reference Reach*. The following sections include the proposed design details of the stable B4 stream type.

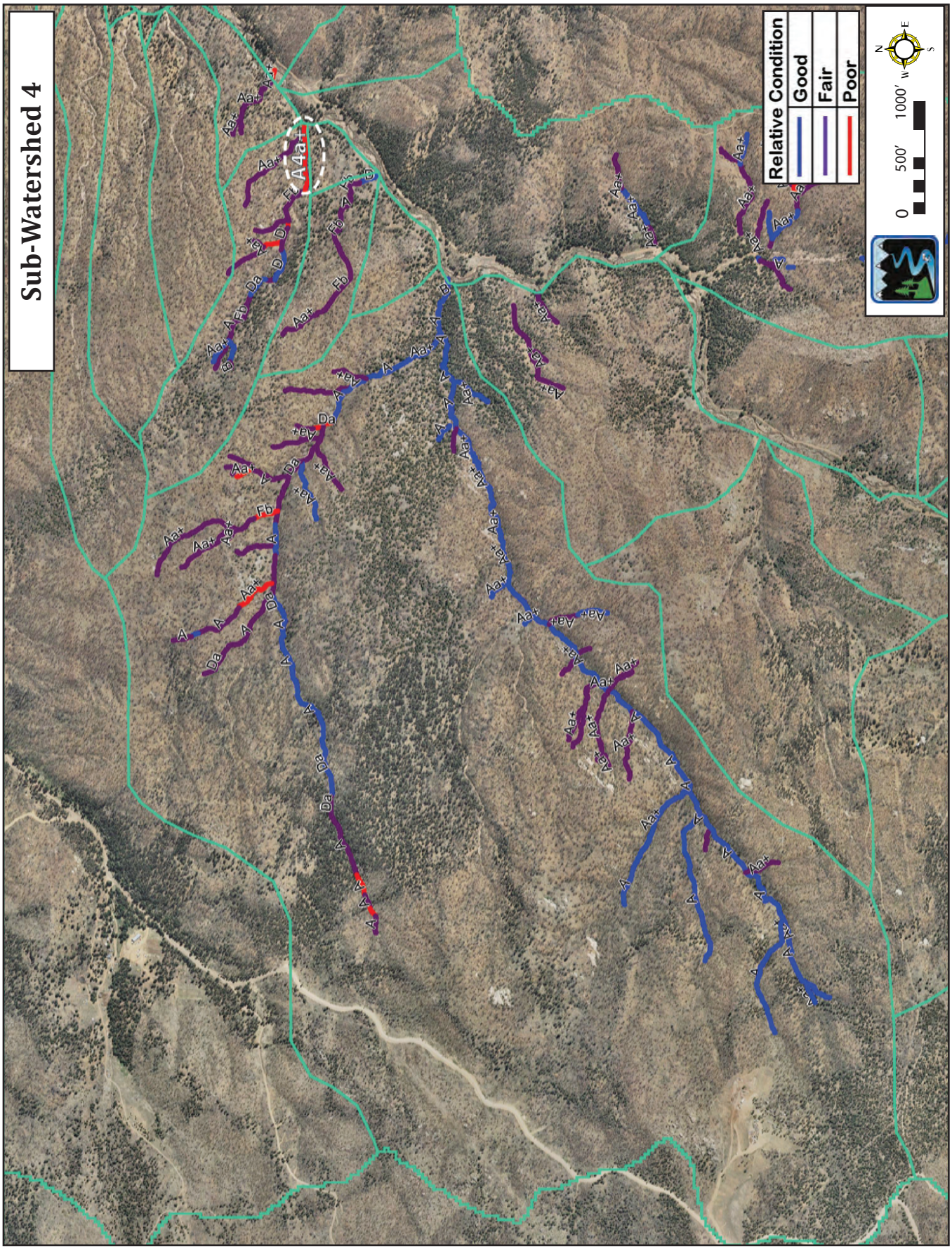


Figure II-73. The location of the A4a+ *Poor* stability stream type in Sub-Watershed 4 within a short alluvial fan that is proposed to be converted to a B4a *Stable* stream type.

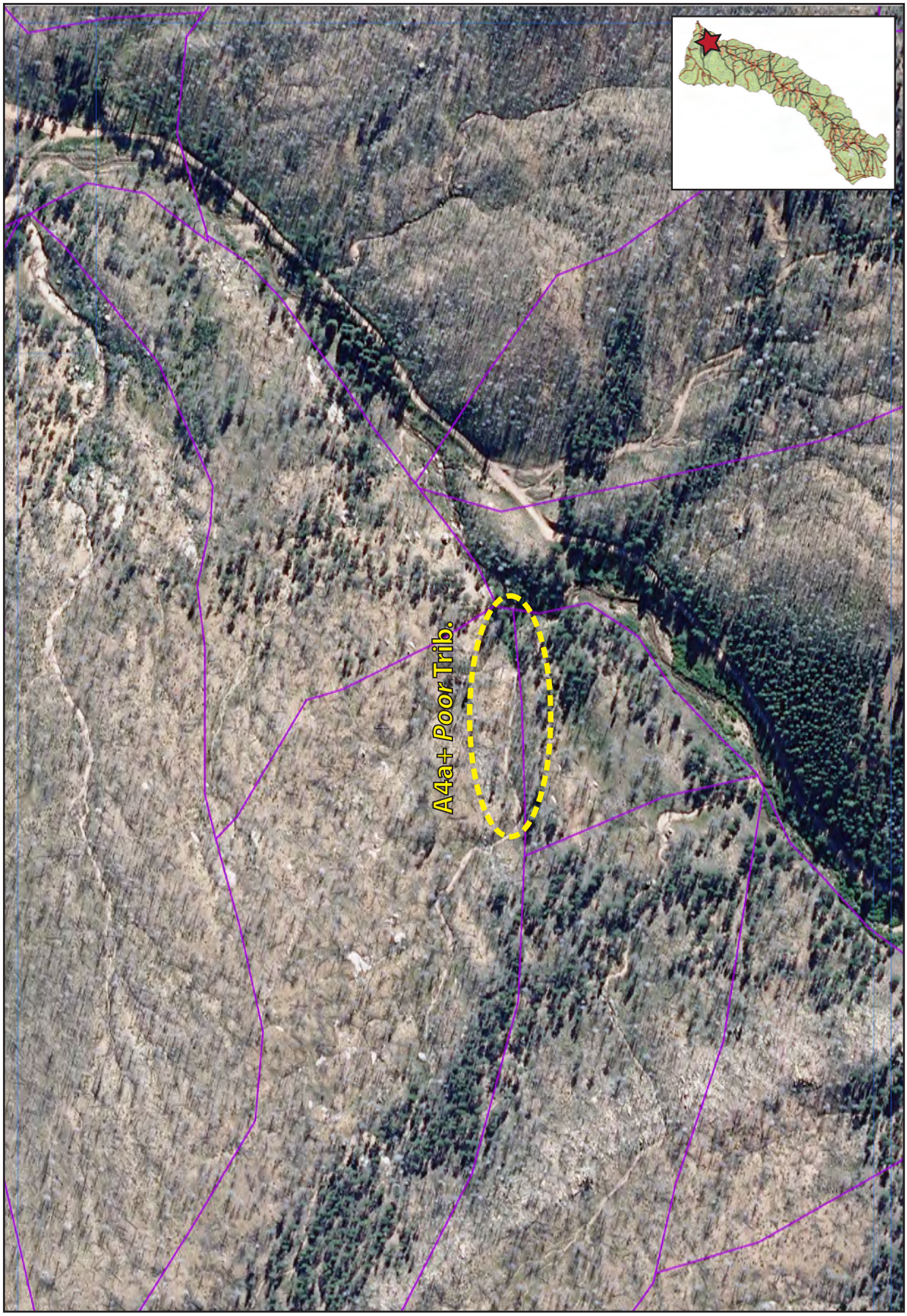


Figure II-74. The *A4a+ Poor* condition tributary that is proposed to be converted to a B4a *Stable* stream type associated with a short alluvial fan in Sub-Watershed 4.

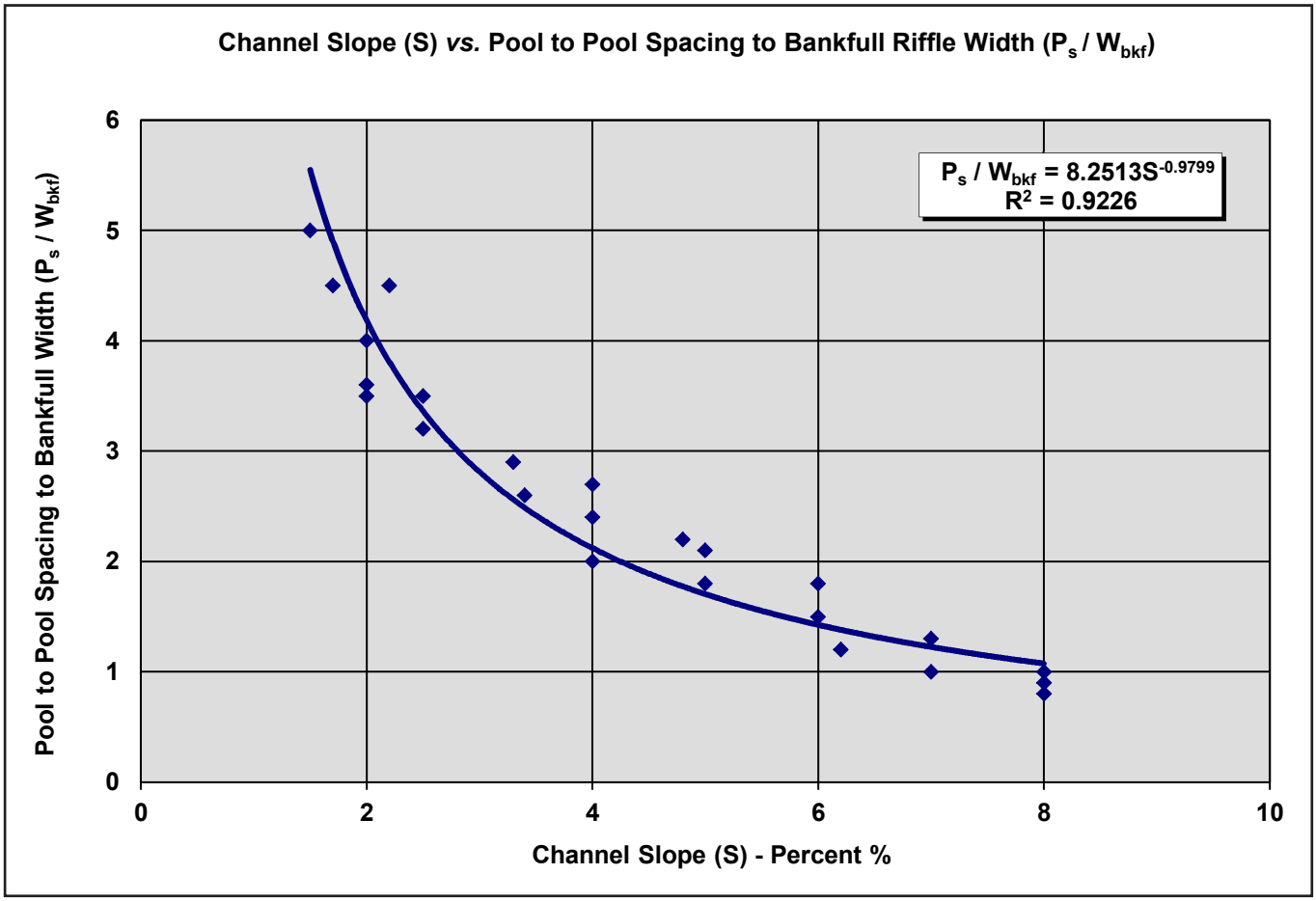


Figure II-75. The ratio of pool-to-pool spacing to bankfull width as a function of channel slope.

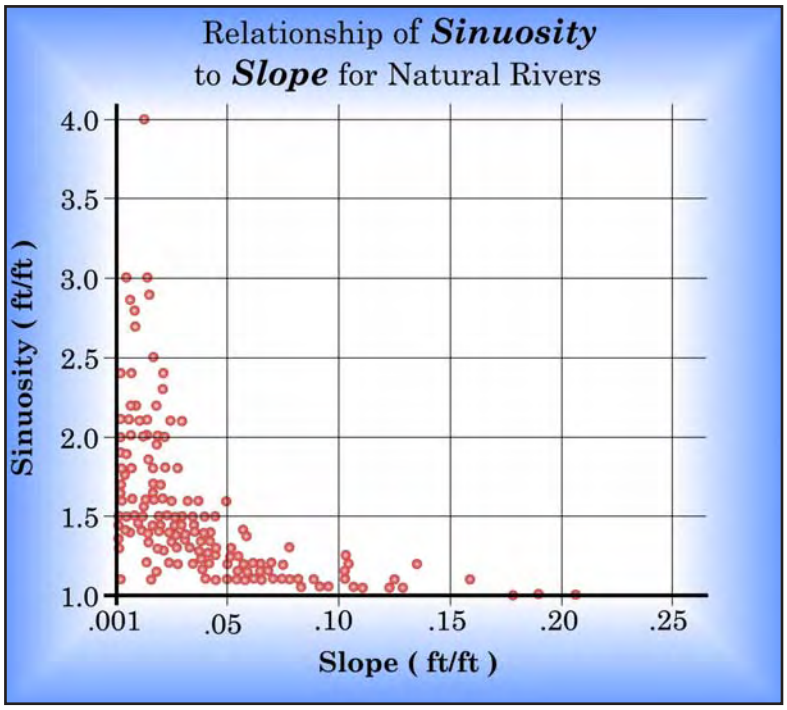


Figure II-76. Relation of sinuosity to slope for natural rivers (Rosgen, 2001b).

Table II-12. The morphological characteristics of the existing, proposed design and reference reaches for the A4a+ *Poor* Tributary to B4a *Stable* stream type conversion within a short alluvial fan – Valley Type III.

Existing Reach Stream & Location:			**A4a+ Poor Tributary to Mainstem Trail Creek North of SW 4**							
Reference Reach Stream & Location:			**B4 Reference Reach, Trail Creek**							
	Entry Number & Variable		**Existing Reach**		**A4a+ Poor Dwn. Rep. Reach**		**Proposed B4a Design Reach**		**Reference Reach**	
	1	Valley Type	**III - Short Fan**		**III - Short Fan**		**III - Short Fan**		**VIII**	
	2	Valley Width							**70**	
	3	Stream Type	**F4b**		**A4a+**		**B4a**		**B4**	
	4	Drainage Area, mi^2	**0.119**		**0.0027**		**0.119**		**14.3**	
	5	Bankfull Discharge, cfs (Q_{bkf})	**2.8**		**0.412**		**2.8**		**32.78**	
Riffle Dimensions	**6**	Riffle Width, ft (W_{bkf})	*Mean:*	**N/A**	*Mean:*	**2.2**	*Mean:*	**5.00**	*Mean:*	**11.8**
			Min:		*Min:*	**1.7**	*Min:*		*Min:*	**9.3**
			Max:		*Max:*	**2.7**	*Max:*		*Max:*	**14.2**
	7	Riffle Mean Depth, ft (d_{bkf})	*Mean:*	**N/A**	*Mean:*	**0.19**	*Mean:*	**0.41**	*Mean:*	**0.75**
			Min:		*Min:*	**0.17**	*Min:*		*Min:*	**0.74**
			Max:		*Max:*	**0.24**	*Max:*		*Max:*	**0.76**
	8	Riffle Width/Depth Ratio (W_{bkf}/d_{bkf})	*Mean:*	**N/A**	*Mean:*	**11.7**	*Mean:*	**12.2**	*Mean:*	**12.60**
			Min:		*Min:*	**9.2**	*Min:*		*Min:*	**12.58**
			Max:		*Max:*	**15.7**	*Max:*		*Max:*	**12.62**
	9	Riffle Cross-Sectional Area, ft^2 (A_{bkf})	*Mean:*	**N/A**	*Mean:*	**0.4**	*Mean:*	**2.05**	*Mean:*	**7.1**
			Min:		*Min:*	**0.3**			*Min:*	**6.9**
			Max:		*Max:*	**0.5**			*Max:*	**7.3**
	10	Riffle Maximum Depth (d_{max})	*Mean:*	**N/A**	*Mean:*	**0.29**	*Mean:*	**0.62**	*Mean:*	**1.13**
			Min:		*Min:*	**0.24**	*Min:*		*Min:*	**1.08**
			Max:		*Max:*	**0.40**	*Max:*		*Max:*	**1.18**
	11	Riffle Maximum Depth to Riffle Mean Depth (d_{max}/d_{bkf})	*Mean:*	**N/A**	*Mean:*	**1.497**	*Mean:*	**1.508**	*Mean:*	**1.508**
			Min:		*Min:*	**1.411**	*Min:*		*Min:*	**1.421**
			Max:		*Max:*	**1.667**	*Max:*		*Max:*	**1.595**
	12	Width of Flood-Prone Area at Elevation of 2 * d_{max}, ft (W_{fpa})	*Mean:*	**N/A**	*Mean:*	**2.9**	*Mean:*	**8.5**	*Mean:*	**16.4**
			Min:		*Min:*	**2.0**	*Min:*	**7.5**	*Min:*	**14.2**
			Max:		*Max:*	**4.0**	*Max:*	**10.0**	*Max:*	**18.5**
	13	Entrenchment Ratio (W_{fpa}/W_{bkf})	*Mean:*	**N/A**	*Mean:*	**1.3**	*Mean:*	**1.7**	*Mean:*	**1.7**
			Min:		*Min:*	**1.2**	*Min:*	**1.5**	*Min:*	**1.5**
			Max:		*Max:*	**1.5**	*Max:*	**2.0**	*Max:*	**2.0**

Table II-12 (page 2). The morphological characteristics of the existing, proposed design and reference reaches for the A4a+ *Poor* Tributary to B4a *Stable* stream type conversion within a short alluvial fan – Valley Type III.

	Entry Number & Variable		Existing Reach	A4a+ Poor Dwn. Rep. Reach	Proposed B4a Design Reach	Reference Reach
Pool Dimensions	**21**	Pool Width, ft (W_{bkfp})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **6.0** *Min:* **3.5** *Max:* **9.0**	*Mean:* **14.0** *Min:* **8.2** *Max:* **21.1**
	22	Pool Width to Riffle Width (W_{bkfp}/W_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.200** *Min:* **0.695** *Max:* **1.792**	*Mean:* **1.190** *Min:* **0.695** *Max:* **1.792**
	23	Pool Mean Depth, ft (d_{bkfp})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.52** *Min:* **0.44** *Max:* **0.57**	*Mean:* **0.80** *Min:* **0.59** *Max:* **1.05**
	24	Pool Mean Depth to Riffle Mean Depth (d_{bkfp}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.180** *Min:* **1.000** *Max:* **1.400**	*Mean:* **1.067** *Min:* **0.787** *Max:* **1.400**
	25	Pool Width/Depth Ratio (W_{bkfp}/d_{bkfp})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **11.5** *Min:* **6.1** *Max:* **20.4**	*Mean:* **17.5** *Min:* **7.8** *Max:* **35.8**
	26	Pool Cross-Sectional Area, ft^2 (A_{bkfp})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **3.1** *Min:* **2.4** *Max:* **2.8**	*Mean:* **8.9** *Min:* **8.5** *Max:* **9.6**
	27	Pool Area to Riffle Area (A_{bkfp}/A_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.522** *Min:* **1.189** *Max:* **1.348**	*Mean:* **1.248** *Min:* **1.189** *Max:* **1.348**
	28	Pool Maximum Depth (d_{maxp})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.00** *Min:* **0.90** *Max:* **1.10**	*Mean:* **1.56** *Min:* **1.33** *Max:* **1.85**
	29	Pool Maximum Depth to Riffle Mean Depth (d_{maxp}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **2.439** *Min:* **2.195** *Max:* **2.683**	*Mean:* **2.080** *Min:* **1.773** *Max:* **2.467**
	30	Point Bar Slope (S_{pb})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.380** *Min:* **0.280** *Max:* **0.400**	*Mean:* **0.290** *Min:* **0.220** *Max:* **0.360**

Table II-12 (page 3). The morphological characteristics of the existing, proposed design and reference reaches for the A4a+ *Poor* Tributary to B4a *Stable* stream type conversion within a short alluvial fan – Valley Type III.

	Entry Number & Variable		Existing Reach		A4a+ Poor Dwn. Rep. Reach		Proposed B4a Design Reach		Reference Reach	
Channel Pattern	72	Linear Wavelength, ft (λ)	*Mean:*	**N/A**	*Mean:*	**N/A**	*Mean:*	**44.2**	*Mean:*	**104.0**
			Min:		*Min:*		*Min:*	**36.9**	*Min:*	**87.0**
			Max:		*Max:*		*Max:*	**54.8**	*Max:*	**129.0**
	73	Linear Wavelength to Riffle Width (λ/W_{bkf})	*Mean:*	**N/A**	*Mean:*	**N/A**	*Mean:*	**8.832**	*Mean:*	**8.832**
			Min:		*Min:*		*Min:*	**7.389**	*Min:*	**7.389**
			Max:		*Max:*		*Max:*	**10.955**	*Max:*	**10.955**
	74	Stream Meander Length, ft (L_m)	*Mean:*	**N/A**	*Mean:*	**N/A**	*Mean:*	**47.6**	*Mean:*	**112.0**
			Min:		*Min:*		*Min:*	**40.1**	*Min:*	**94.5**
			Max:		*Max:*		*Max:*	**57.3**	*Max:*	**135.0**
	75	Stream Meander Length Ratio (L_m/W_{bkf})	*Mean:*	**N/A**	*Mean:*	**N/A**	*Mean:*	**9.512**	*Mean:*	**9.512**
			Min:		*Min:*		*Min:*	**8.025**	*Min:*	**8.025**
			Max:		*Max:*		*Max:*	**11.465**	*Max:*	**11.465**
	76	Belt Width, ft (W_{blt})	*Mean:*	**N/A**	*Mean:*	**13.8**	*Mean:*	**11.5**	*Mean:*	**27.2**
			Min:		*Min:*		*Min:*	**6.2**	*Min:*	**14.6**
			Max:		*Max:*		*Max:*	**25.5**	*Max:*	**60.0**
	77	Meander Width Ratio (W_{blt}/W_{bkf})	*Mean:*	**N/A**	*Mean:*	**6.301**	*Mean:*	**2.306**	*Mean:*	**2.306**
			Min:		*Min:*		*Min:*	**1.237**	*Min:*	**1.237**
			Max:		*Max:*		*Max:*	**5.096**	*Max:*	**5.096**
	78	Radius of Curvature, ft (R_c)	*Mean:*	**N/A**	*Mean:*	**N/A**	*Mean:*	**21.5**	*Mean:*	**50.7**
			Min:		*Min:*		*Min:*	**10.5**	*Min:*	**21.8**
			Max:		*Max:*		*Max:*	**32.3**	*Max:*	**76.0**
	79	Radius of Curvature to Riffle Width (R_c/W_{bkf})	*Mean:*	**N/A**	*Mean:*	**N/A**	*Mean:*	**4.300**	*Mean:*	**4.300**
			Min:		*Min:*		*Min:*	**2.100**	*Min:*	**2.100**
			Max:		*Max:*		*Max:*	**6.454**	*Max:*	**6.454**
	80	Arc Length, ft (L_a)	*Mean:*	**N/A**	*Mean:*	**N/A**	*Mean:*	**16.8**	*Mean:*	**39.6**
			Min:		*Min:*		*Min:*	**4.2**	*Min:*	**10.0**
			Max:		*Max:*		*Max:*	**30.1**	*Max:*	**70.9**
	81	Arc Length to Riffle Width (L_a/W_{bkf})	*Mean:*	**N/A**	*Mean:*	**N/A**	*Mean:*	**3.363**	*Mean:*	**3.363**
			Min:		*Min:*		*Min:*	**0.849**	*Min:*	**0.849**
			Max:		*Max:*		*Max:*	**6.021**	*Max:*	**6.021**
	82	Riffle Length (L_r), ft	*Mean:*	**N/A**	*Mean:*	**N/A**	*Mean:*	**7.5**	*Mean:*	**14.7**
			Min:		*Min:*		*Min:*	**6.5**	*Min:*	**2.7**
			Max:		*Max:*		*Max:*	**14.0**	*Max:*	**28.2**
	83	Riffle Length to Riffle Width (L_r/W_{bkf})	*Mean:*	**N/A**	*Mean:*	**N/A**	*Mean:*	**1.500**	*Mean:*	**1.248**
			Min:		*Min:*		*Min:*	**1.300**	*Min:*	**0.229**
			Max:		*Max:*		*Max:*	**2.800**	*Max:*	**2.395**
	84	Individual Pool Length, ft (L_p)	*Mean:*	**N/A**	*Mean:*	**N/A**	*Mean:*	**15.0**	*Mean:*	**60.1**
			Min:		*Min:*		*Min:*	**10.0**	*Min:*	**23.0**
			Max:		*Max:*		*Max:*	**20.0**	*Max:*	**101.0**
	85	Pool Length to Riffle Width (L_p/W_{bkf})	*Mean:*	**N/A**	*Mean:*	**N/A**	*Mean:*	**3.0**	*Mean:*	**5.104**
			Min:		*Min:*		*Min:*	**2.0**	*Min:*	**1.953**
			Max:		*Max:*		*Max:*	**4.0**	*Max:*	**8.577**
	86	Pool to Pool Spacing, ft (P_s)	*Mean:*	**N/A**	*Mean:*	**N/A**	*Mean:*	**3.5**	*Mean:*	**28.1**
			Min:		*Min:*		*Min:*	**2.5**	*Min:*	**12.2**
			Max:		*Max:*		*Max:*	**4.5**	*Max:*	**47.3**
	87	Pool to Pool Spacing to Riffle Width (P_s/W_{bkf})	*Mean:*	**N/A**	*Mean:*	**N/A**	*Mean:*	**0.700**	*Mean:*	**2.387**
			Min:		*Min:*		*Min:*	**0.500**	*Min:*	**1.039**
			Max:		*Max:*		*Max:*	**0.900**	*Max:*	**4.020**

Table II-12 (page 4). The morphological characteristics of the existing, proposed design and reference reaches for the A4a+ *Poor* Tributary to B4a *Stable* stream type conversion within a short alluvial fan – Valley Type III.

	Entry Number & Variable		Existing Reach	A4a+ Poor Dwn. Rep. Reach	Proposed B4a Design Reach	Reference Reach
Sinuosity and Slope	**88**	Stream Length (SL)	**N/A**	**72.1**	**300**	**514.1**
	89	Valley Length (VL)	**273**	**66.0**	**273**	**455.0**
	90	Valley Slope (S_{val})	**0.1320**	**0.1347**	**0.132**	**0.0264**
	91	Sinuosity (k)	SL/VL: **N/A** VS/S: **N/A**	SL/VL: **1.09** VS/S: **1.09**	SL/VL: **1.10**	SL/VL: **1.13** VS/S: **1.09**
	92	Average Water Surface Slope (S)	**N/A**	**0.1236**	$S = S_{val}/k$ **0.1200**	**0.0242**
Bed Feature Water Surface Facet Slopes and Dimensionless Ratios from Profile	**105**	Riffle Slope (water surface facet slope) (S_{rif})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.1684** *Min:* **0.0790** *Max:* **0.2902**	*Mean:* **0.0340** *Min:* **0.0159** *Max:* **0.0585**
	106	Riffle Slope to Average Water Surface Slope (S_{rif}/S)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.4037** *Min:* **0.6587** *Max:* **2.4182**	*Mean:* **1.4037** *Min:* **0.6587** *Max:* **2.4182**
	107	Pool Slope (water surface facet slope) (S_p)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.0135** *Min:* **0.0005** *Max:* **0.0493**	*Mean:* **0.0027** *Min:* **0.0001** *Max:* **0.0099**
	108	Pool Slope to Average Water Surface Slope (S_p/S)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.1124** *Min:* **0.0041** *Max:* **0.4107**	*Mean:* **0.1124** *Min:* **0.0041** *Max:* **0.4107**
	109	Run Slope (water surface facet slope) (S_{run})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	110	Run Slope to Average Water Surface Slope (S_{run}/S)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	111	Glide Slope (water surface facet slope) (S_g)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	112	Glide Slope to Average Water Surface Slope (S_g/S)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	113	Step Slope (water surface facet slope) (S_s)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **5.2562** *Min:* **4.6116** *Max:* **5.8512**	*Mean:* **1.0600** *Min:* **0.9300** *Max:* **1.1800**
	114	Step Slope to Average Water Surface Slope (S_s/S)	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **43.8017** *Min:* **38.4298** *Max:* **48.7603**	*Mean:* **43.8017** *Min:* **38.4298** *Max:* **48.7603**

Table II-12 (page 5). The morphological characteristics of the existing, proposed design and reference reaches for the A4a+ *Poor* Tributary to B4a *Stable* stream type conversion within a short alluvial fan – Valley Type III.

	Entry Number & Variable	Existing Reach	A4a+ Poor Dwn. Rep. Reach	Proposed B4a Design Reach	Reference Reach
Bed Feature Max Depth Measurements and Dimensionless Ratios from Profile	**115** Riffle Maximum Depth, ft (d_{max})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.58** *Min:* **0.51** *Max:* **0.65**	*Mean:* **1.06** *Min:* **0.93** *Max:* **1.18**
	116 Riffle Maximum Depth to Riffle Mean Depth (d_{max}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.413** *Min:* **1.240** *Max:* **1.573**	*Mean:* **1.413** *Min:* **1.240** *Max:* **1.573**
	117 Pool Maximum Depth, ft (d_{maxp})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.83** *Min:* **0.73** *Max:* **1.01**	*Mean:* **1.52** *Min:* **1.33** *Max:* **1.85**
	118 Pool Maximum Depth to Riffle Mean Depth (d_{maxp}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **2.027** *Min:* **1.773** *Max:* **2.467**	*Mean:* **2.027** *Min:* **1.773** *Max:* **2.467**
	119 Run Maximum Depth, ft (d_{maxr})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	120 Run Maximum Depth to Riffle Mean Depth (d_{maxr}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	121 Glide Maximum Depth, ft (d_{maxg})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	122 Glide Maximum Depth to Riffle Mean Depth (d_{maxg}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	123 Step Maximum Depth, ft (d_{maxs})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	124 Step Maximum Depth to Riffle Mean Depth (d_{maxs}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **N/A** *Min:* *Max:*
	Entry Number & Variable	**Existing Reach**	**A4a+ Poor Dwn. Rep. Reach**	**Proposed B4a Design Reach**	**Reference Reach**
Hydraulics	**127** Estimated Bankfull Mean Velocity, ft/sec (u_{bkf})	**N/A**	**0.78**	**1.4**	**4.7**
	128 Estimated Bankfull Discharge, cfs (Q_{bkf}); Compare with Regional Curve	**2.8**	**0.4**	**2.8**	**32.8**

Table II-12 (page 6). The morphological characteristics of the existing, proposed design and reference reaches for the A4a+ *Poor* Tributary to B4a *Stable* stream type conversion within a short alluvial fan – Valley Type III.

	Entry Number & Variable	Existing Reach	A4a+ Poor Dwn. Rep. Reach	Proposed B4a Design Reach	Reference Reach
Sediment Yield	**Sediment Yield (FLOWSED)**	**Existing Reach**		**Proposed Design Reach**	**Difference in Sediment Yield**
	141 Bedload Sediment Yield (tons/yr)	**180.3**		**33.8**	**146.5**
	142 Suspended Sediment Yield (tons/yr)	**564.1**		**0.7**	**563.4**
	143 Suspended Sand Sediment Yield (tons/yr)	**282.1**		**0.4**	**281.7**
	144 Total Annual Sediment Yield (tons/yr)	**744.4**		**34.5**	**709.9**
Bank Erosion	**Streambank Erosion**	**Existing Reach**	**Representative Reach**	**Proposed Design Reach**	**Reference Reach**
	145 Stream Length Assessed (ft)	**300.0**	**58.0**	**300**	**406.0**
	146 Graph/Curve Used (e.g., Yellowstone or Colorado)	**Colorado**	**Colorado**	**Colorado**	**Colorado**
	147 Streambank Erosion (tons/yr)	**23.55**	**4.55**	**1.45**	**1.96**
	148 Streambank Erosion (tons/yr/ft)	**0.0785**	**0.0785**	**0.0048**	**0.0048**

Bankfull Discharge, Cross-Sectional Area & Mean Velocity

The bankfull discharge and cross-sectional area were determined from regional curves based on a drainage area of *0.119 mi*^{2} resulting in a bankfull discharge of *2.8 cfs* and a cross-sectional area *2.0 ft*^{2}. The corresponding velocity is predicted at *1.4 ft/sec* using the continuity equation as shown in **Worksheet II-21**.

Plan View Alignment & Cross-Section Dimensions

The proposed plan view of the alignment is shown in **Figure II-77**, which follows the proposed stable B4a stream type values developed from scaled dimensionless ratios of the *B4 Reference Reach* with adjustments for sinuosity and slope relations (**Table II-12**). The proposed streambank stabilization structures are also shown on the plan view in **Figure II-77**, in addition to the corresponding cross-section designs.

Longitudinal Profile

The typical longitudinal profile in **Figure II-78** illustrates the depths, slopes, lengths, and spacing of bed features in addition to the placement locations and types of structures for the proposed B4a design reach. These values are derived from **Table II-12** with adjustments for pool-to-pool spacing and step and pool lengths from **Figure II-75**. An existing *vs*. proposed cross-section is also illustrated in **Figure II-78** indicating the shaping of the proposed stream channel and structure placement.

Structures

The proposed structures for streambank stabilization, flow resistance, and grade control are shown in the plan, cross-section, and longitudinal views in **Figure II-77** and **Figure II-78**. The structures include converging rock clusters; the rock and log roller structure; the toe wood structure with sod mats and riparian transplants; and the rock step–pool structure. The materials for these structures will be obtained from on-site sources. Many of the burned logs will be salvaged to use for the rock and log roller structure and toe wood structures. Local rock sources will be used for the converging rock clusters and the rock step–pool structure. Riparian transplants of willow and alder will be salvaged from local donor areas.

Worksheet II-21. The mean velocity estimates for the proposed B4a design reach to be converted from the existing, A4a+ *Poor* condition tributary within Sub-Watershed 4 at the confluence of Trail Creek.

Bankfull VELOCITY & DISCHARGE Estimates

Stream:	**Proposed B4a from A4a+ Poor**	Location:	**Tributary in Sub-Watershed 4**
Date:	**3/15/2011** Stream Type: **B4a**	Valley Type:	**III - Short Alluvial Fan**
Observers:	**Rosgen *et al*.**	HUC:	_ _ _ _ _ _ _ _ _ _ _ _

Input Variables for PROPOSED Design			Output Variables for PROPOSED Design		
Bankfull Riffle Cross-Sectional AREA	**2.05**	**A_{bkf}** (ft^2)	Bankfull Riffle Mean DEPTH	**0.41**	**d_{bkf}** (ft)
Bankfull Riffle WIDTH	**5.0**	**W_{bkf}** (ft)	Wetted PERMIMETER ~ (2 * d_{bkf}) + W_{bkf}	**5.82**	**W_p** (ft)
D_{84} at Riffle	**N/A**	**Dia.** (mm)	D_{84} (mm) / 304.8	**N/A**	**D_{84}** (ft)
Bankfull SLOPE	**0.120**	**S_{bkf}** (ft / ft)	Hydraulic RADIUS A_{bkf} / W_p	**0.35**	**R** (ft)
Gravitational Acceleration	**32.2**	**g** (ft / sec^2)	Relative Roughness R(ft) / D_{84} (ft)	**N/A**	**R / D_{84}**
Drainage Area	**0.119**	**DA** (mi^2)	Shear Velocity $u^* = (gRS)^{½}$	**1.167**	**u*** (ft/sec)

ESTIMATION METHODS	Bankfull VELOCITY		Bankfull DISCHARGE	
1. Friction Factor / Relative Roughness $u = [\ 2.83 + 5.66 * Log\ \{\ R / D_{84}\ \}\ ]\ u^*$		ft / sec		cfs
2. Roughness Coefficient: a) Manning's *n* from Friction Factor / Relative Roughness (Figs. 5-7, 5-8) $u = 1.49*R^{2/3}*S^{1/2} / n$ $n =$		ft / sec		cfs
2. Roughness Coefficient: b) Manning's *n* from Stream Type (Fig. 5-9) $u = 1.49*R^{2/3}*S^{1/2} / n$ $n =$		ft / sec		cfs
2. Roughness Coefficient: c) Manning's *n* from Jarrett (USGS): $u = 1.49*R^{2/3}*S^{1/2} / n$ $n = 0.39*S^{0.38}*R^{-0.16}$ **Note:** This equation is applicable to **steep, step/pool, high boundary roughness, cobble- and boulder-dominated stream systems**; i.e., for Stream Types A1, A2, A3, B1, B2, B3, C2 & E3 $n =$ **0.206**	**1.25**	ft / sec	**2.56**	cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)		ft / sec		cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)		ft / sec		cfs
4. Continuity Equations: a) USGS Gage Data $u = Q / A$ **Return Period for Bankfull Q** $Q =$ **year**		ft / sec		cfs
4. Continuity Equations: b) Regional Curves $u = Q / A$	**1.4**	ft / sec	**2.8**	cfs

Protrusion Height Options for the D_{84} Term in the Relative Roughness Relation (R/D_{84}) – Estimation Method 1

Option 1.	For **sand-bed** channels: Measure 100 **"protrusion heights"** of sand dunes from the downstream side of feature to the top of feature. Substitute the D_{84} sand dune protrusion height in ft for the D_{84} term in method 1.
Option 2.	For **boulder-dominated** channels: Measure 100 **"protrusion heights"** of boulders on the sides from the bed elevation to the top of the rock on that side. Substitute the D_{84} boulder protrusion height in ft for the D_{84} term in method 1.
Option 3.	For **bedrock-dominated** channels: Measure 100 **"protrusion heights"** of rock separations, steps, joints or uplifted surfaces above channel bed elevation. Substitute the D_{84} bedrock protrusion height in ft for the D_{84} term in method 1.
Option 4.	For **log-influenced** channels: Measure **"protrustion heights"** proportionate to channel width of log diameters or the height of the log on upstream side if embedded. Substitute the D_{84} protrusion height in ft for the D_{84} term in method 1.

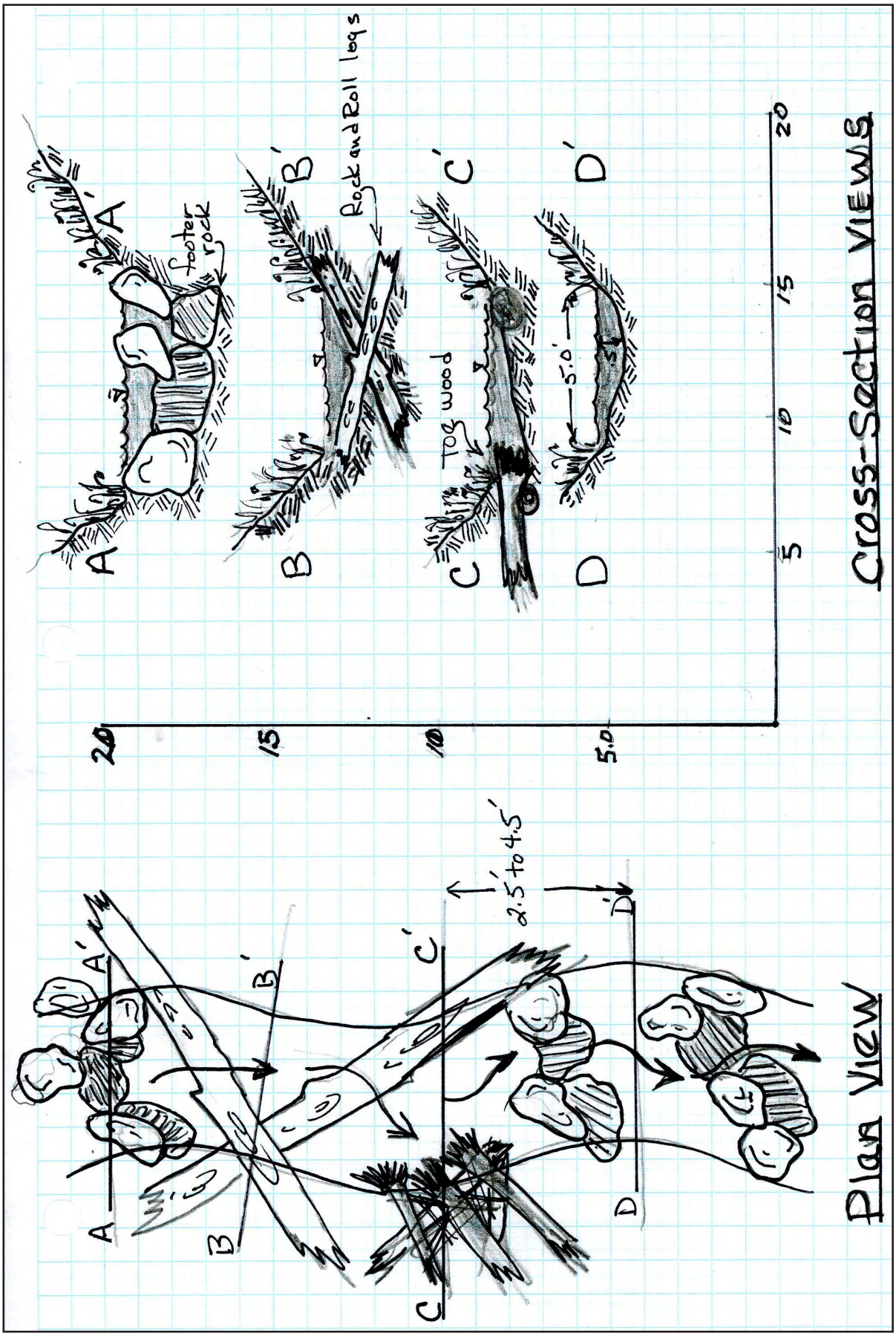


Figure II-77. The proposed B4a alignment, structure placement, and cross-sections converted from the A4a+ *Poor* condition tributary in Sub-Watershed 4

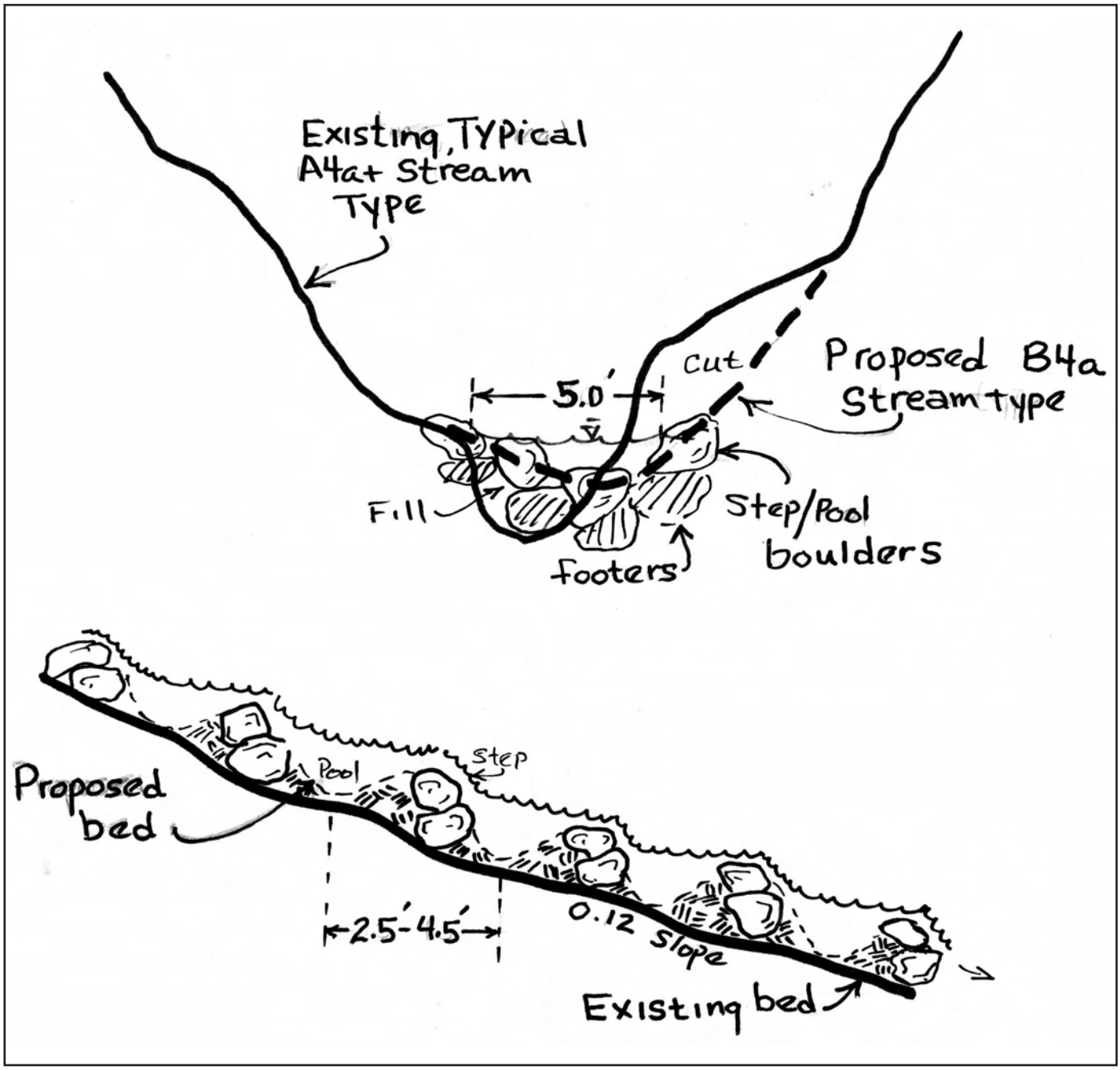


Figure II-78. Typical longitudinal profile for the proposed B4a design reach to be converted from the A4a+ *Poor* condition tributary in Sub-Watershed 4.

Riparian Vegetation

It is a key requirement to re-establish a woody riparian community of willow and alder along this B4a stream type. This is accomplished by transplanting from available nearby donor areas. Native bunch grasses, such as big mountain brome, are recommended for seeding the side slopes. The revegetation is critical for the long-term physical stability of the reach.

Cut & Fill Computations

The cut and fill material is generally balanced by sloping the upper banks and shaping the B4a channel in this stream type conversion. The fill associated with the structures for this size would vary from *25–45 yds*^{3} for the *300 ft* of proposed channel. The anticipated excavation and fill are generally balanced with this design without requiring disposal or end-hauling.

Streambank Erosion

The streambank erosion that is expected for the proposed B4a design reach is *1.45 tons/yr* for *300 ft* of designed channel *vs*. the estimated *23.6 tons/yr* for the existing A4a+ *Poor* tributary (**Table 12**), representing a potential reduction of *22.1 tons/yr* for this reach. These values are based on the extrapolation of annual erosion rates of the *B4 Reference Reach* (*0.0048 tons/yr/ft*) and the *A4a+ Poor Downstream Representative Reach* (*0.0785 tons/yr/ft*). This reduction assumes that the various structures designed and located in **Figure II-77** and **Figure II-78** are implemented, such as the toe wood and rock and log roller structures. These structures have proven to reduce streambank erosion rates in similar designs. These significant reductions in streambank erosion are extremely important as *84%* of the total sediment source of the watershed is from streambank erosion. Thus restoration can not 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.

Flow-Related Sediment

The FLOWSED model indicates that by converting from a "Poor" condition to a "Good" condition throughout the sub-watershed, the flow-related sediment yields would be significantly reduced from *744.4 tons/yr* (**Worksheet II-22a**) to *34.5 tons/yr* (**Worksheet II-22b**) as a result of the restoration. The corresponding potential sediment supply reductions based on converting from "Poor" to "Good" conditions are *146.5 tons/yr* for bedload and *563.4 tons/yr* for suspended sediment, representing a total sediment reduction of *709.9 tons/yr*. These sediment reductions are still assuming a high post-fire runoff response and continued increased stormflow peak runoff. These reductions are also associated with treating the majority of the stream length of the sub-watershed above this reach.

The reductions in sediment supply associated with restoring *300 ft* of the existing A4a+ *Poor* tributary to the proposed B4a *Stable* design reach are *22.1 tons/yr* of streambank erosion, *24.4 tons/yr* of bedload, *93.9 tons/yr* of suspended sediment and *118.3 tons/yr* of total sediment yield reduction. The total sediment yield value includes streambank erosion contributions and streambed sources. The sediment reductions associated with the local channel source sediment for this design scenario are based on sediment yield rates determined from taking the sediment yield values generated from FLOWSED and dividing by the total stream length of potential sediment contributions.

For this scenario, it was determined that approximately *1,800 ft* of tributary reach is potentially contributing sediment. The resultant sediment yield rates were then multiplied by the existing and proposed design reach lengths for this scenario to obtain the local sediment reductions.

The POWERSED model could not be used for this scenario because no existing cross-sections of the A4a+ *Poor* tributary were surveyed. However, a large portion of the *118.3 tons/yr* of flow-related sediment is coming from the streambanks and the bed due to channel incision and advancing headcuts. The potential sediment reductions will be generated by implementing the design structures to greatly reduce the bed and bank erosion. The proposed B4a *Stable* design reach will prevent further channel degradation and will eliminate future advancing headcuts.

Sediment Competence

Based on the small particle sizes and the steeper slopes in the tributary channels in the Trail Creek Watershed, the sediment competence would show excess energy for this proposed design. Thus grade control structure are recommended and designed to add flow resistance and prevent downcutting to counteract the increased shear stress (**Figure II-77** and **Figure II-78**).

Worksheet II-22a. The existing sediment supply at the A4a+ *Poor* reach using the FLOWSED model and generated by using the dimensionless sediment rating curves and bankfull sediment values related to the "Poor" condition.

Stream: **A4a+ Poor Tributary** Location: **Tributary to Mainstem Trail Creek, Sub-Watershed 4** Date: **3/15/11**

Observers: **Rosgen *et al*.** Gage Station #: **Goose Creek Gage** Stream Type: **A4a+** Valley Type: **III**

Equation Type	Equation Source	Equation	Bankfull Discharge (cfs)	Bankfull Bedload Sediment (kg/s)	Bankfull Suspended Sediment (mg/l)
1. Bedload Sediment	"Poor" Pagosa	$y = 0.07176+1.02176x^{2.3772}$	2.8	0.0161	102.86
2. Suspended Sediment	"Poor" Pagosa	$y = 0.0989+0.9213x^{3.659}$			

From Dimensional Flow-Duration Curve							From Sediment Rating Curves				Calculate	Calculate Sediment Yield		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Percentage of Time	Daily Mean Discharge	Mid-Ordinate	Time Increment (percent)	Time Increment (days)	Mid-Ordinate Streamflow	Dimension-less Streamflow	Dimension-less Suspended Sediment Discharge	Suspended Sediment Discharge	Dimension-less Bedload Discharge	Bedload Sediment Discharge	Time Adjusted Streamflow [(5)×(6)]	Suspended Sediment [(5)×(9)]	Bedload Sediment [(5)×(11)]	Suspended + Bedload Sediment [(13)+(14)]
(%)	(cfs)	(%)	(%)	(days)	(cfs)	(Q/Q_{bkf})	(S/S_{bkf})	(tons/day)	(b_s/b_{bkf})	(tons/day)	(cfs)	(tons)	(tons)	(tons)
0%	12.3													
0.10%	10.6	0.05%	0.09%	0.34	11.5	4.092	159.804	508.47	29.175	44.73	3.9	174.45	15.35	189.80
0.25%	9.2	0.08%	0.15%	0.55	9.9	3.525	92.714	254.18	20.499	31.43	5.4	139.16	17.21	156.37
0.50%	7.9	0.13%	0.25%	0.91	8.5	3.049	54.530	129.29	14.534	22.28	7.8	117.97	20.33	138.31
0.75%	6.8	0.13%	0.25%	0.91	7.3	2.620	31.353	63.88	10.157	15.57	6.7	58.29	14.21	72.50
1%	5.8	0.13%	0.25%	0.91	6.3	2.251	18.026	31.55	7.100	10.89	5.8	28.79	9.93	38.72
1.5%	4.2	0.25%	0.50%	1.83	5.0	1.792	7.878	10.98	4.158	6.37	9.2	20.03	11.63	31.66
2%	3.5	0.25%	0.50%	1.83	3.9	1.377	3.066	3.28	2.256	3.46	7.0	5.99	6.31	12.30
3%	3.0	0.50%	1.00%	3.65	3.3	1.167	1.720	1.56	1.547	2.37	11.9	5.70	8.66	14.35
4%	2.7	0.50%	1.00%	3.65	2.8	1.017	1.077	0.85	1.134	1.74	10.4	3.11	6.35	9.46
5%	2.4	0.50%	1.00%	3.65	2.5	0.903	0.732	0.51	0.873	1.34	9.2	1.88	4.88	6.76
10%	1.7	2.50%	5.00%	18.25	2.0	0.725	0.383	0.22	0.547	0.84	37.0	3.94	15.31	19.25
20%	0.9	5.00%	10.00%	36.50	1.3	0.465	0.155	0.06	0.237	0.36	47.5	2.04	13.28	15.32
30%	0.6	5.00%	10.00%	36.50	0.8	0.274	0.107	0.02	0.119	0.18	28.0	0.83	6.64	7.47
40%	0.4	5.00%	10.00%	36.50	0.5	0.187	0.101	0.01	0.091	0.14	19.1	0.54	5.08	5.61
50%	0.3	5.00%	10.00%	36.50	0.4	0.137	0.100	0.01	0.081	0.12	14.0	0.39	4.52	4.91
60%	0.3	5.00%	10.00%	36.50	0.3	0.105	0.099	0.01	0.077	0.12	10.7	0.30	4.28	4.58
70%	0.2	5.00%	10.00%	36.50	0.2	0.082	0.099	0.01	0.074	0.11	8.4	0.23	4.17	4.40
80%	0.2	5.00%	10.00%	36.50	0.2	0.068	0.099	0.01	0.073	0.11	7.0	0.19	4.11	4.30
90%	0.1	5.00%	10.00%	36.50	0.2	0.055	0.099	0.00	0.073	0.11	5.6	0.15	4.07	4.23
100%	0.0	5.00%	10.00%	36.50	0.1	0.027	0.099	0.00	0.072	0.11	2.8	0.08	4.03	4.10
										Annual Totals:	257.4 (cfs) 510.5 (acre-ft)	564.1 (tons/yr)	180.3 (tons/yr)	744.4 (tons/yr)

Worksheet II-22b. The proposed sediment supply at the proposed B4a design reach using the FLOWSED model and generated by using the dimensionless sediment rating curves and bankfull sediment values related to the restored "Good" condition (assuming that the watershed area above this reach is also restored to "Good" conditions).

Stream: **Proposed B4a Stream Type from A4a+ Poor** Location: **Sub-Watershed 4** Date: **3/15/11**

Observers: **Rosgen *et al*.** Gage Station #: **Goose Creek Gage** Stream Type: **B4a** Valley Type: **III**

Equation Type	Equation Source	Equation	Bankfull Discharge (cfs)	Bankfull Bedload Sediment (kg/s)	Bankfull Suspended Sediment (mg/l)
1. Bedload Sediment	"Good/Fair" Pagosa	$y = -0.0113+1.0139x^{2.1929}$	2.8	0.0044	0.4715
2. Suspended Sediment	"Good/Fair" Pagosa	$y = 0.0636+0.9326x^{2.4085}$			

From Dimensional Flow-Duration Curve							From Sediment Rating Curves				Calculate	Calculate Sediment Yield		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Percentage of Time	Daily Mean Discharge	Mid-Ordinate	Time Increment (percent)	Time Increment (days)	Mid-Ordinate Streamflow	Dimension-less Streamflow	Dimension-less Suspended Sediment Discharge	Suspended Sediment Discharge	Dimension-less Bedload Discharge	Bedload Sediment Discharge	Time Adjusted Streamflow [(5)×(6)]	Suspended Sediment [(5)×(9)]	Bedload Sediment [(5)×(11)]	Suspended + Bedload Sediment [(13)+(14)]
(%)	(cfs)	(%)	(%)	(days)	(cfs)	(Q/Q_{bkf})	(S/S_{bkf})	(tons/day)	(b_s/b_{bkf})	(tons/day)	(cfs)	(tons)	(tons)	(tons)
0%	12.3													
0.10%	10.6	0.05%	0.09%	0.34	11.5	4.092	27.825	0.41	22.264	9.40	3.9	0.14	3.23	3.37
0.25%	9.2	0.08%	0.15%	0.55	9.9	3.525	19.458	0.24	16.058	6.78	5.4	0.13	3.71	3.85
0.50%	7.9	0.13%	0.25%	0.91	8.5	3.049	13.732	0.15	11.674	4.93	7.8	0.14	4.50	4.64
0.75%	6.8	0.13%	0.25%	0.91	7.3	2.620	9.551	0.09	8.369	3.53	6.7	0.08	3.23	3.31
1%	5.8	0.13%	0.25%	0.91	6.3	2.251	6.644	0.05	5.995	2.53	5.8	0.05	2.31	2.36
1.5%	4.2	0.25%	0.50%	1.83	5.0	1.792	3.862	0.02	3.630	1.53	9.2	0.05	2.80	2.84
2%	3.5	0.25%	0.50%	1.83	3.9	1.377	2.078	0.01	2.033	0.86	7.0	0.02	1.57	1.59
3%	3.0	0.50%	1.00%	3.65	3.3	1.167	1.416	0.01	1.411	0.60	11.9	0.02	2.18	2.20
4%	2.7	0.50%	1.00%	3.65	2.8	1.017	1.034	0.00	1.040	0.44	10.4	0.01	1.60	1.62
5%	2.4	0.50%	1.00%	3.65	2.5	0.903	0.792	0.00	0.799	0.34	9.2	0.01	1.23	1.24
10%	1.7	2.50%	5.00%	18.25	2.0	0.725	0.493	0.00	0.489	0.21	37.0	0.02	3.77	3.79
20%	0.9	5.00%	10.00%	36.50	1.3	0.465	0.211	0.00	0.178	0.08	47.5	0.01	2.74	2.75
30%	0.6	5.00%	10.00%	36.50	0.8	0.274	0.105	0.00	0.048	0.02	28.0	0.00	0.74	0.74
40%	0.4	5.00%	10.00%	36.50	0.5	0.187	0.080	0.00	0.014	0.01	19.1	0.00	0.22	0.22
50%	0.3	5.00%	10.00%	36.50	0.4	0.137	0.071	0.00	0.002	0.00	14.0	0.00	0.02	0.03
60%	0.3	5.00%	10.00%	36.50	0.3	0.105	0.068	0.00	0.000	0.00	10.7	0.00	0.00	0.00
70%	0.2	5.00%	10.00%	36.50	0.2	0.082	0.066	0.00	0.000	0.00	8.4	0.00	0.00	0.00
80%	0.2	5.00%	10.00%	36.50	0.2	0.068	0.065	0.00	0.000	0.00	7.0	0.00	0.00	0.00
90%	0.1	5.00%	10.00%	36.50	0.2	0.055	0.064	0.00	0.000	0.00	5.6	0.00	0.00	0.00
100%	0.0	5.00%	10.00%	36.50	0.1	0.027	0.064	0.00	0.000	0.00	2.8	0.00	0.00	0.00
									Annual Totals:		257.4 (cfs) / 510.5 (acre-ft)	0.7 (tons/yr)	33.8 (tons/yr)	34.5 (tons/yr)

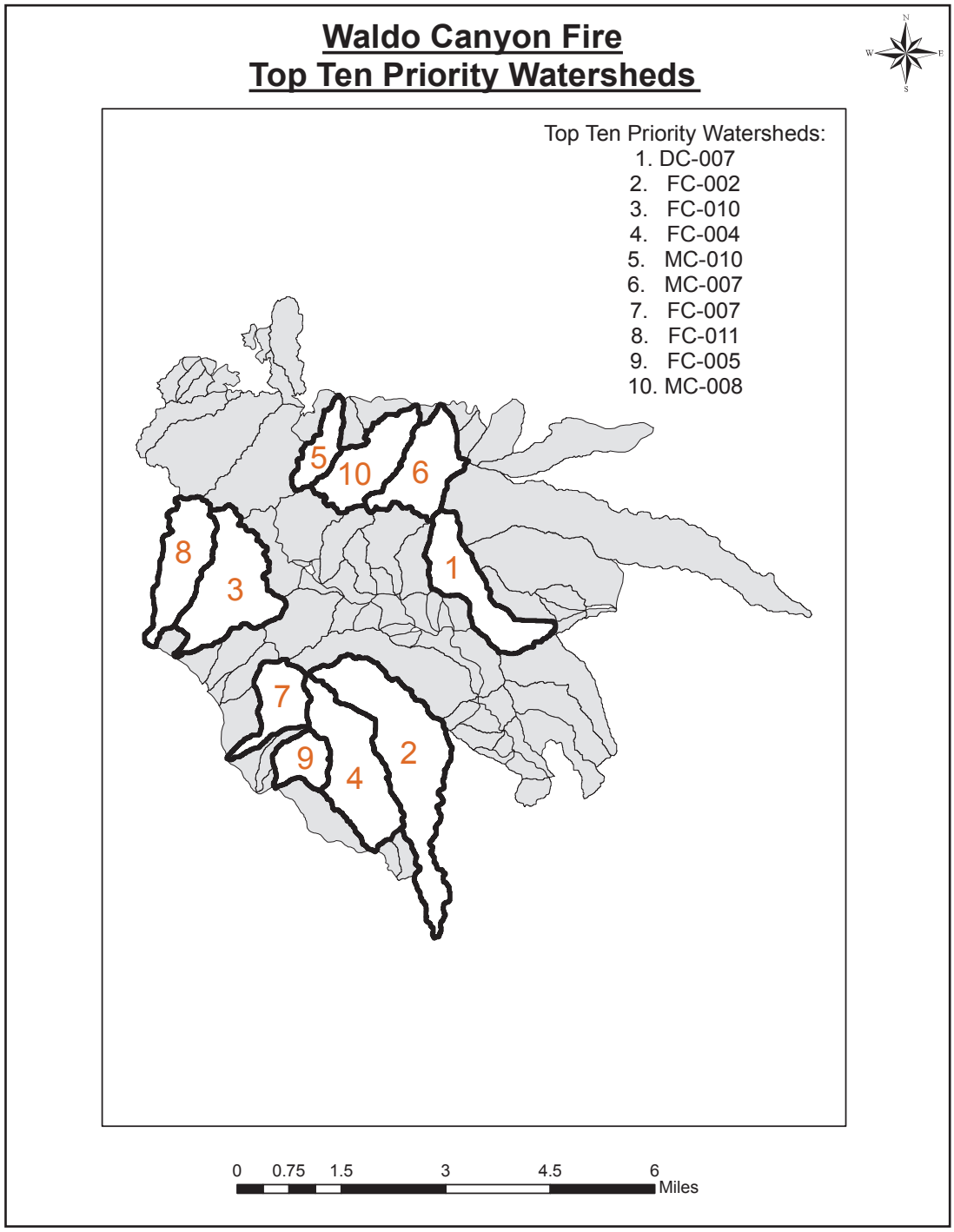
Summary of Tributary A4a+ Poor to B4a Conversion

Numerous A4a+ reaches exist that suffer similar impacts and consequences, yet do not have the detailed assessment as performed for the representative reaches. This scenario is an example of extrapolating the *A4a+ Poor Stability Downstream Representative Reach* stability analysis to the existing A4a+ *Poor* reach condition and extrapolating the dimensionless relations of the *B4 Reference Reach* to develop the design criteria with appropriate adjustments due to the steeper slope. The remaining A4a+ tributary reaches are prime candidates for this conversion scenario that exist in cut-off or "short" alluvial fans, Valley Type III, where designing a D4 braided channel is not an option. If proportionate savings in the sediment supply can result, then restoring similar reaches will help reduce sediment.

Appendix III

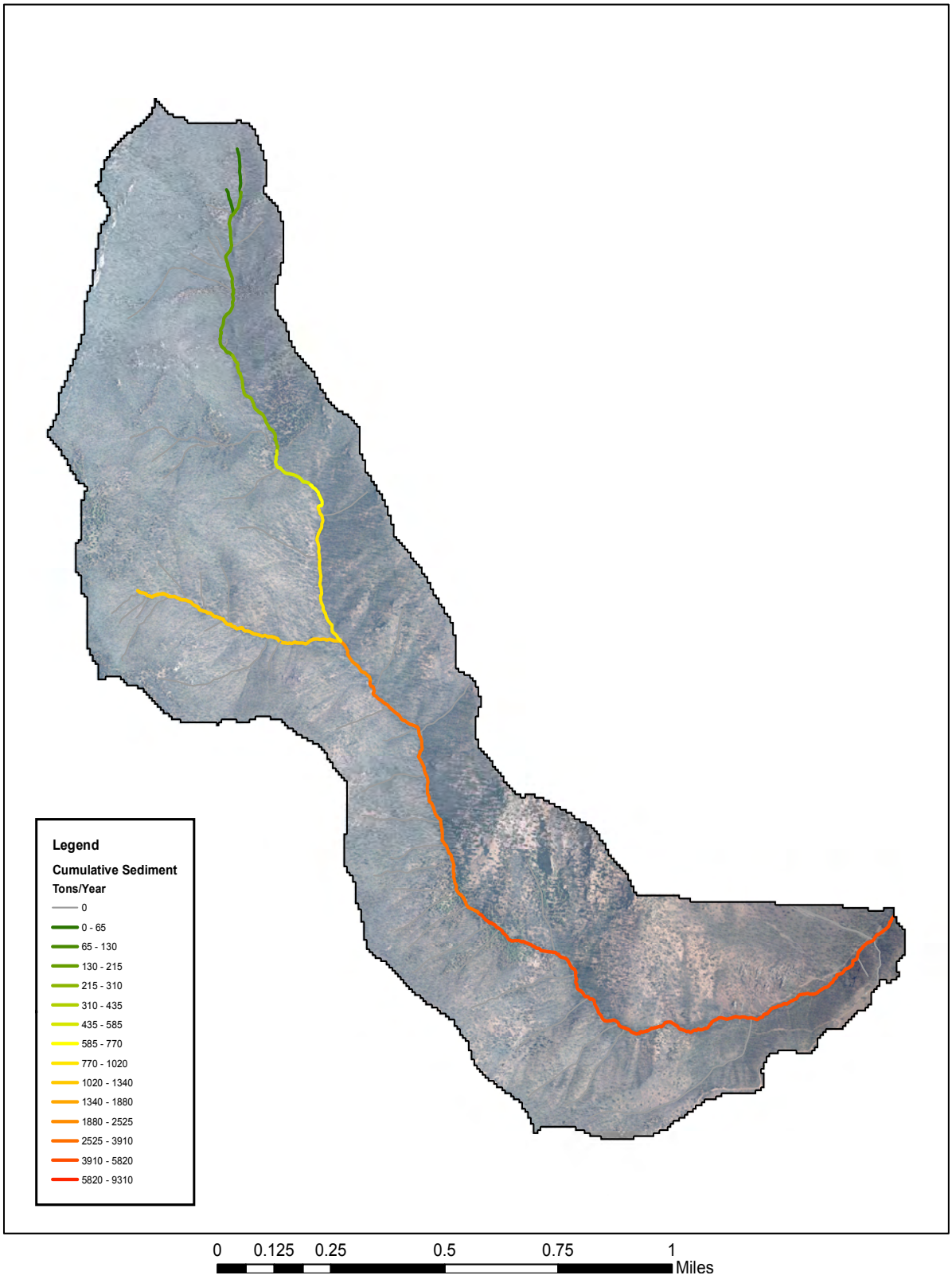
Treatment Potential for the Top Ten Priority Watersheds

Appendix III summarizes the sediment sources and treatment potential for the top ten priority watersheds in the Waldo Canyon Fire. Each watershed summary consists of three maps and two summary tables. The maps summarize cumulative sediment from channel processes, hillslope processes, and treatment potential. The tables summarize hillslope processes and channel processes, including the effectiveness of treatments.

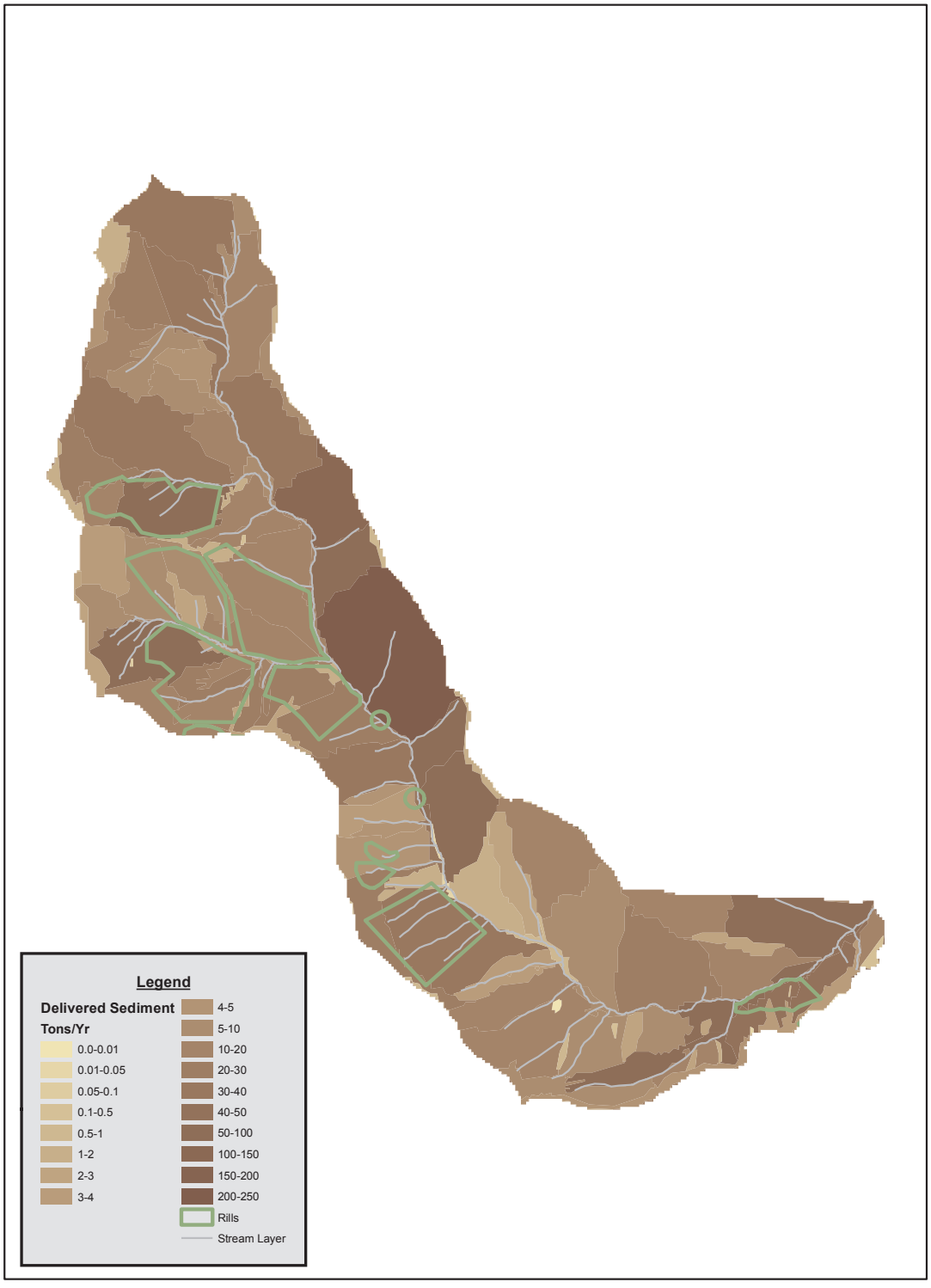


Priority #1: DC-007

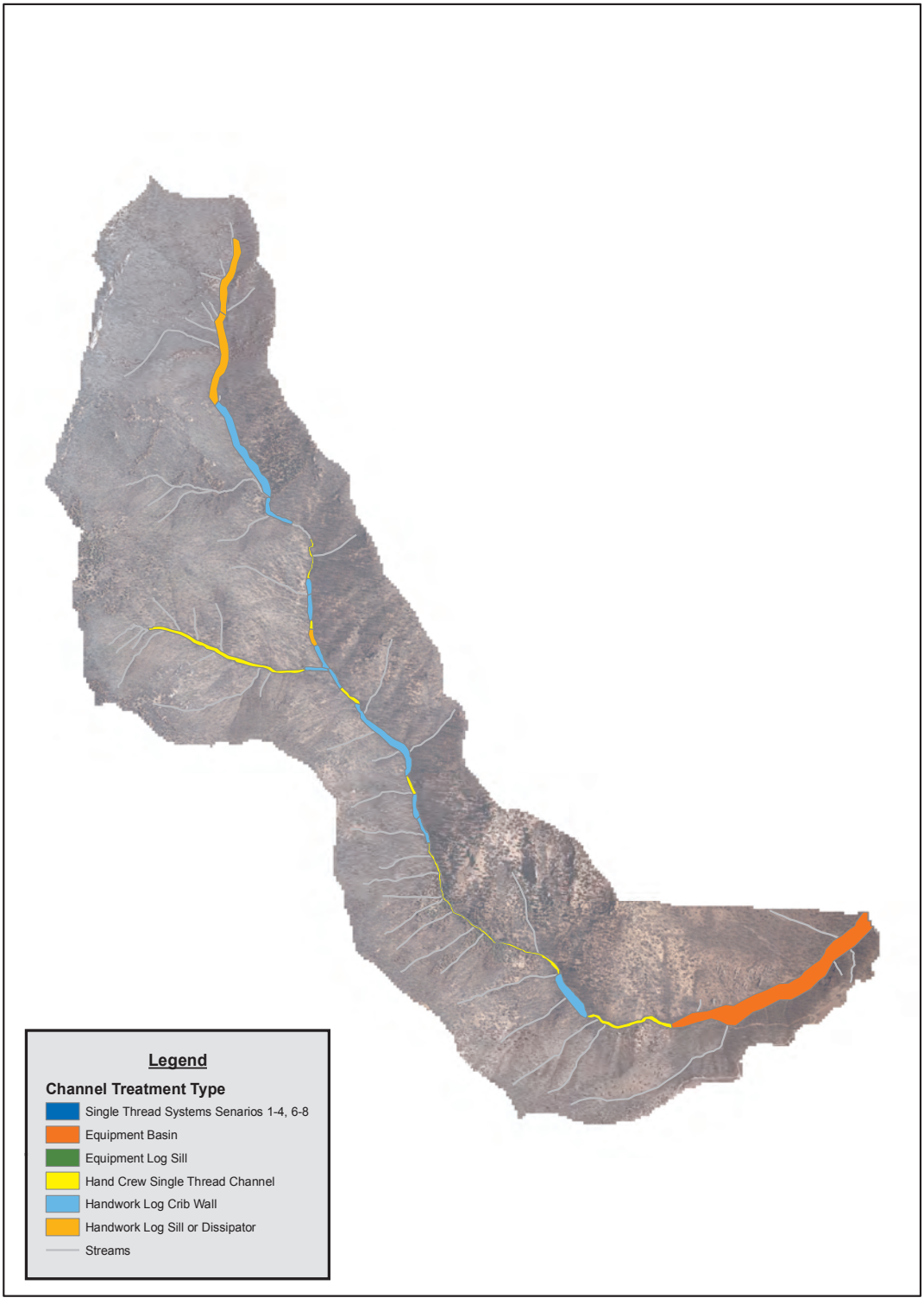
Cumulative Sediment - DC-007



Hillslope Delivered Sediment - DC-007



Treatment Potential - DC-007

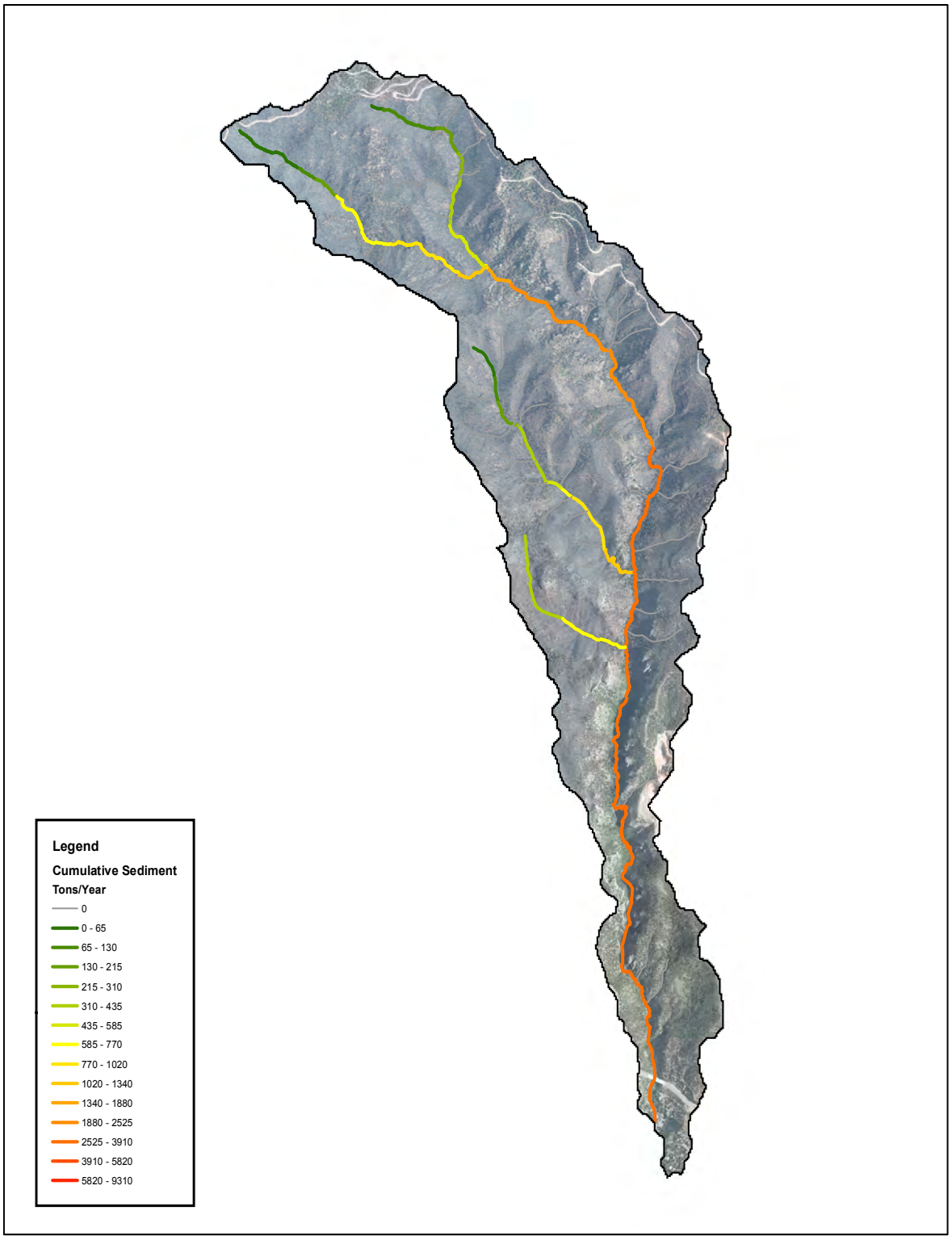


DC-007 – Hillslope Processes – Sub-Watershed Priority #1							
Total Acres	Priority Area (acres)	Priority Area (%)	Total Delivered Sediment (tons/yr)	Delivered Sediment from Priority Area (tons/yr)	Delivered Sediment from Priority Area (%)	Delivered Sediment Reduction (tons/yr)	Delivered Sediment Reduction (%)
823	430	52%	1,815	1,484	81%	1,113	61%

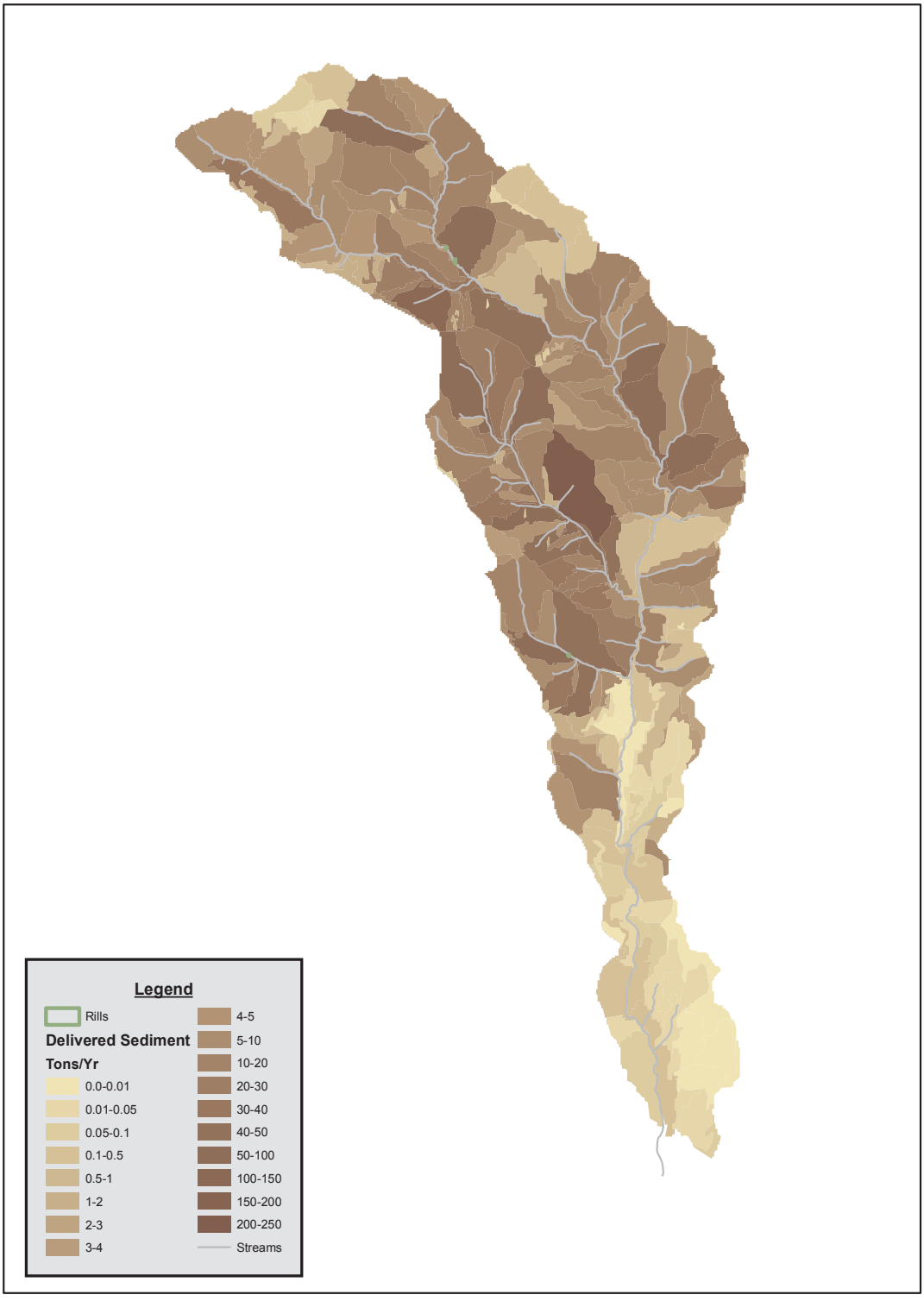
DC-007 – Channel Processes – Sub-Watershed Priority #1			
Total Length (ft)	Total Channel Length Treated (ft)	Reduced Bank Erosion (tons/yr)	Sediment Stored or Stabilized (tons/yr)
55,095	17,347	2,417	30,370

Priority #2: FC-002

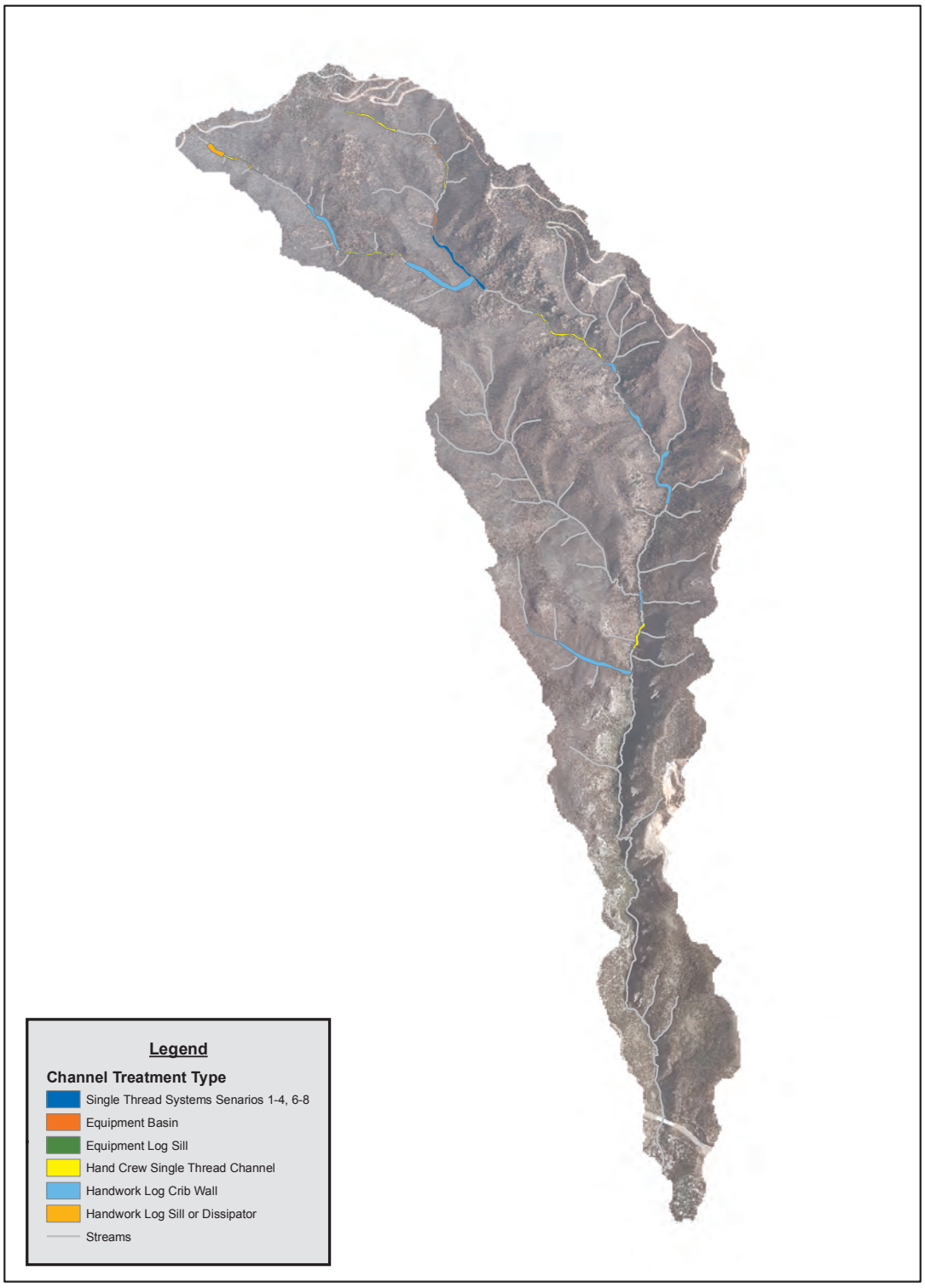
Cumulative Sediment - FC-002



Hillslope Delivered Sediment - FC-002



Treatment Potential - FC-002

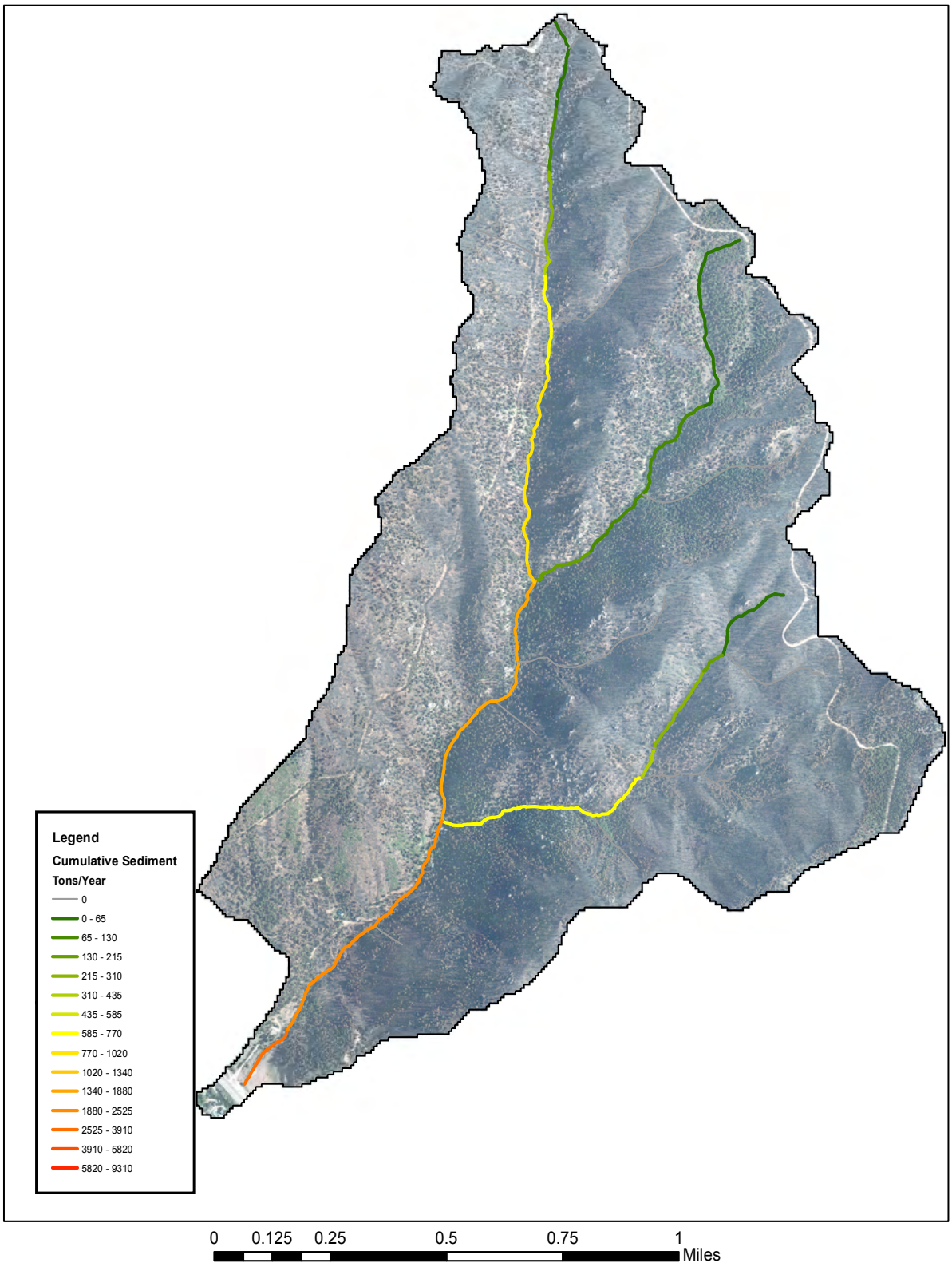


FC-002 – Hillslope Processes – Sub-Watershed Priority #2							
Total Acres	Priority Area (acres)	Priority Area (%)	Total Delivered Sediment (tons/yr)	Delivered Sediment from Priority Area (tons/yr)	Delivered Sediment from Priority Area (%)	Delivered Sediment Reduction (tons/yr)	Delivered Sediment Reduction (%)
1,684	865	51%	2,710	2,519	92%	1,889	69%

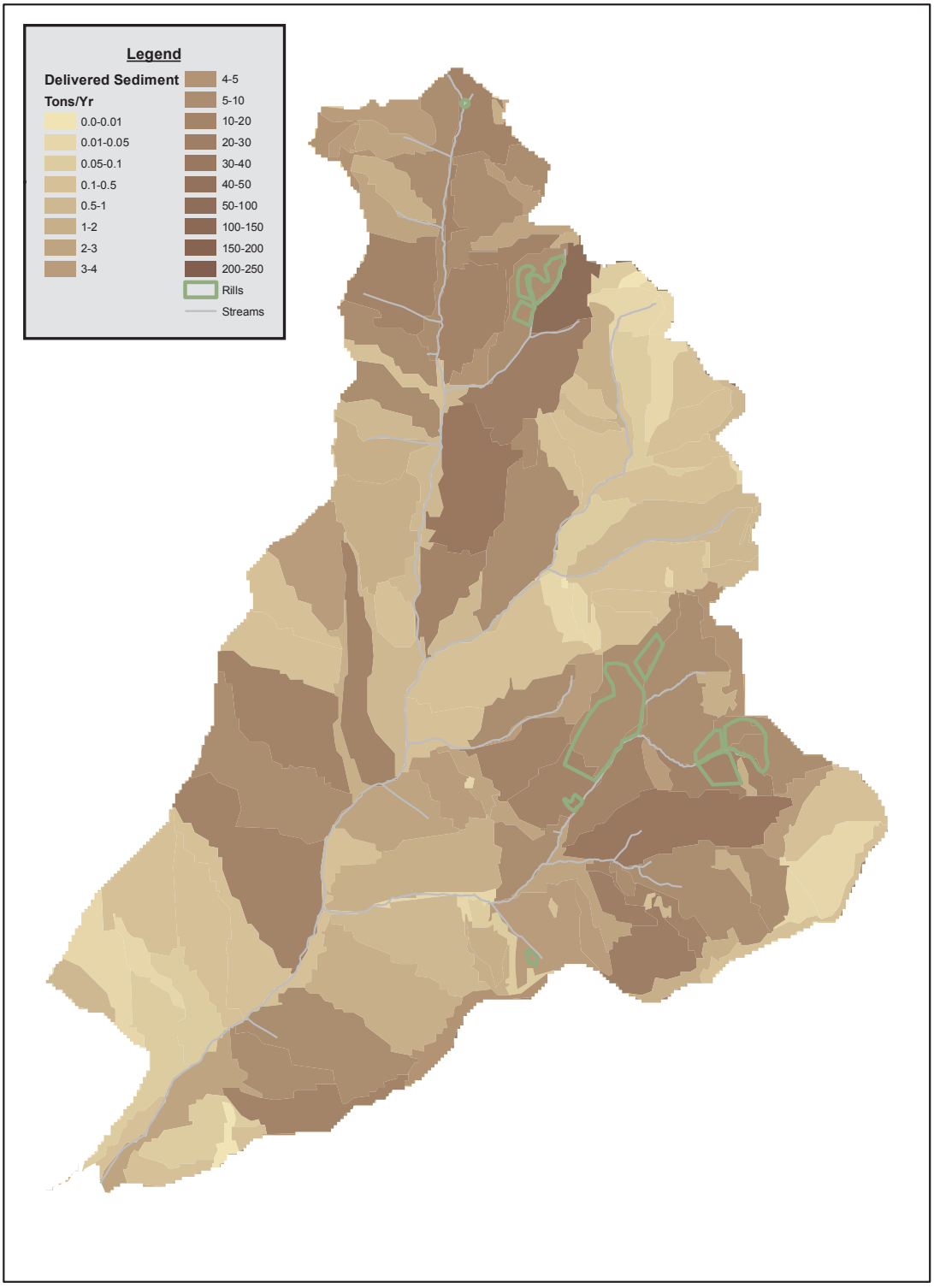
FC-002 – Channel Processes – Sub-Watershed Priority #2			
Total Length (ft)	Total Channel Length Treated (ft)	Reduced Bank Erosion (tons/yr)	Sediment Stored or Stabilized (tons/yr)
83,067	17,346	9,942	23,160

Priority #3: FC-010

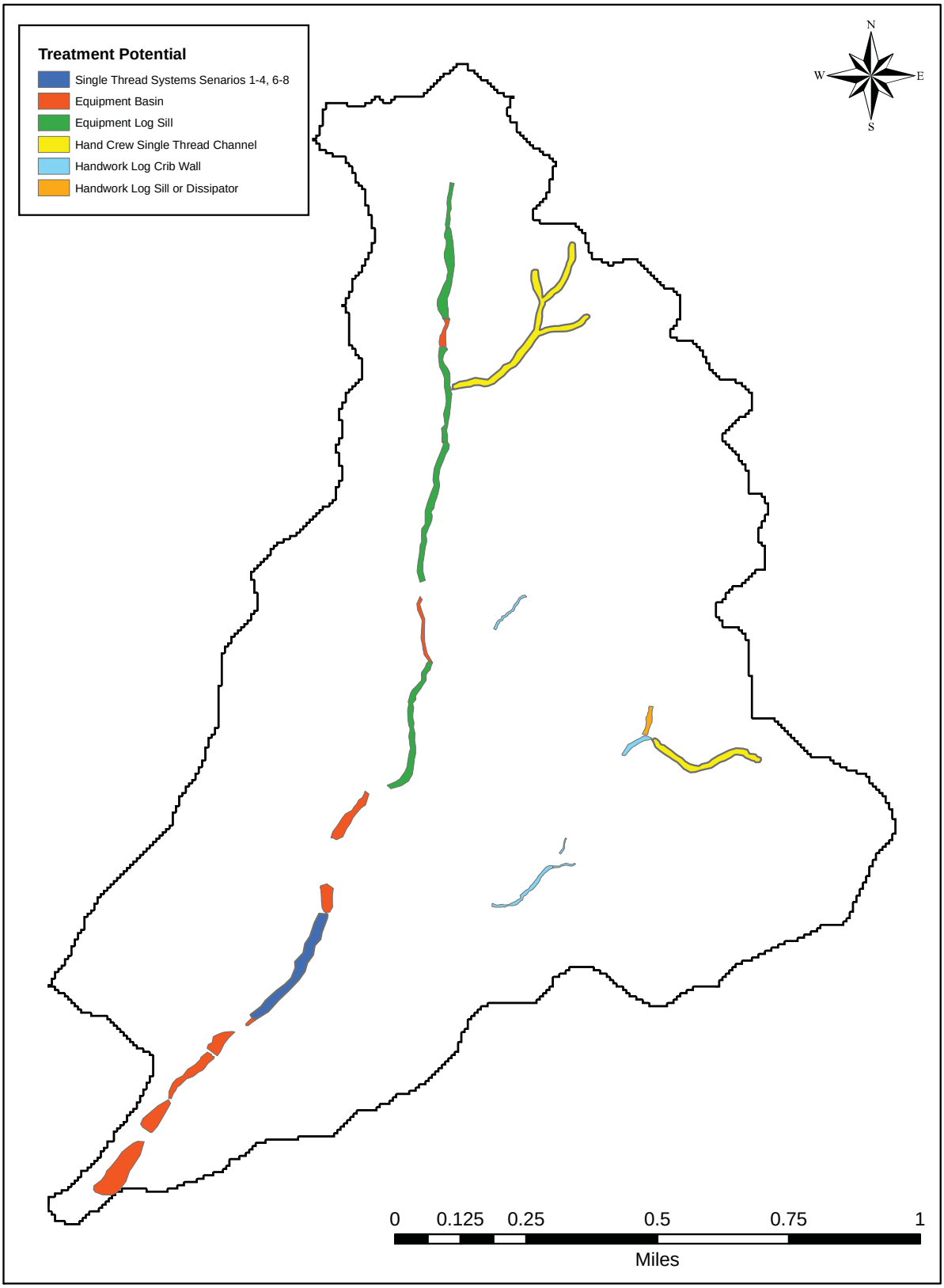
Cumulative Sediment - FC-010



Hillslope Delivered Sediment - FC-010



Treatment Potential - FC-010

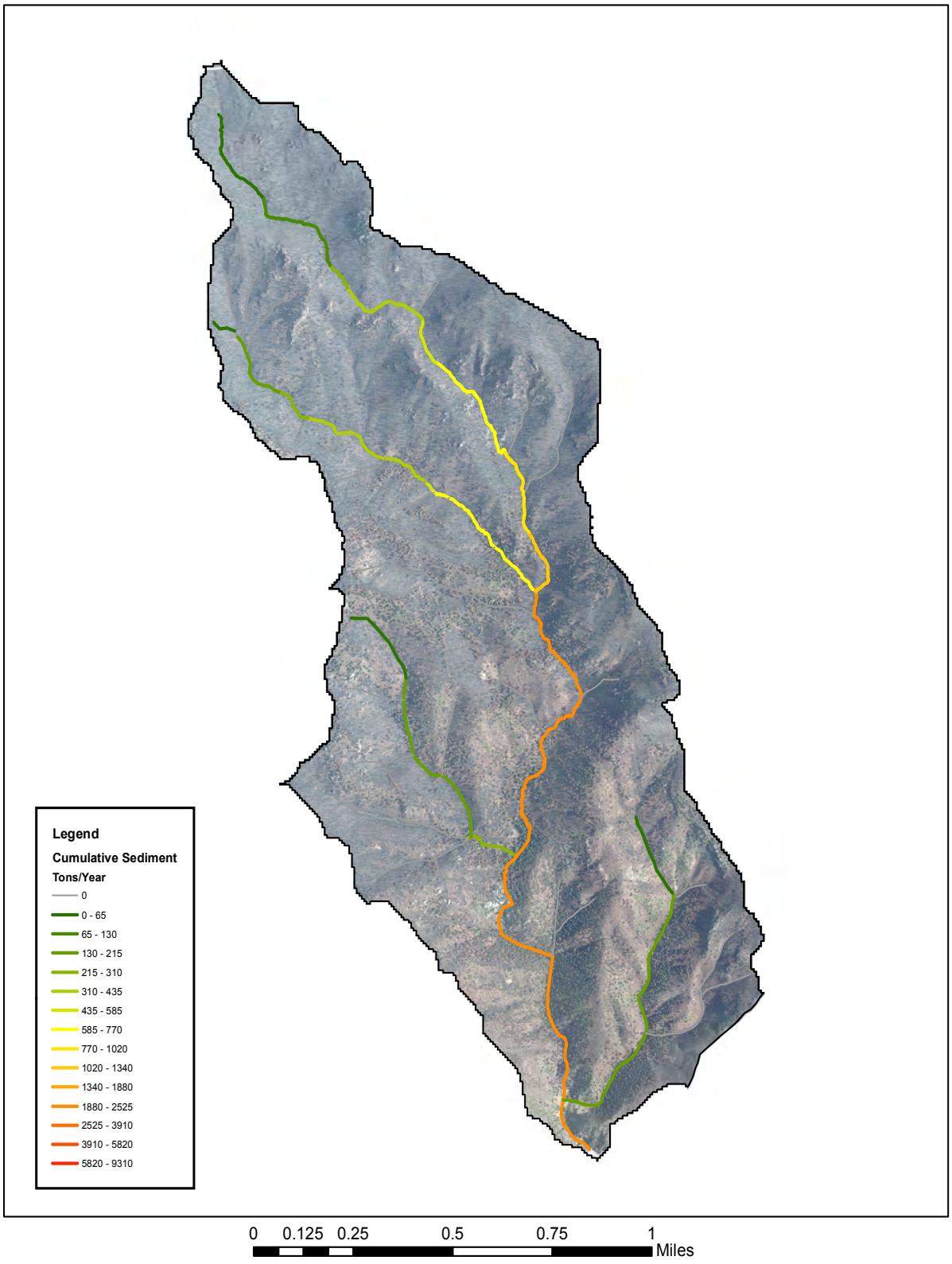


FC-010 – Hillslope Processes – Sub-Watershed Priority #3							
Total Acres	Priority Area (acres)	Priority Area (%)	Total Delivered Sediment (tons/yr)	Delivered Sediment from Priority Area (tons/yr)	Delivered Sediment from Priority Area (%)	Delivered Sediment Reduction (tons/yr)	Delivered Sediment Reduction (%)
1,100	528	48%	625	575	92%	431	69%

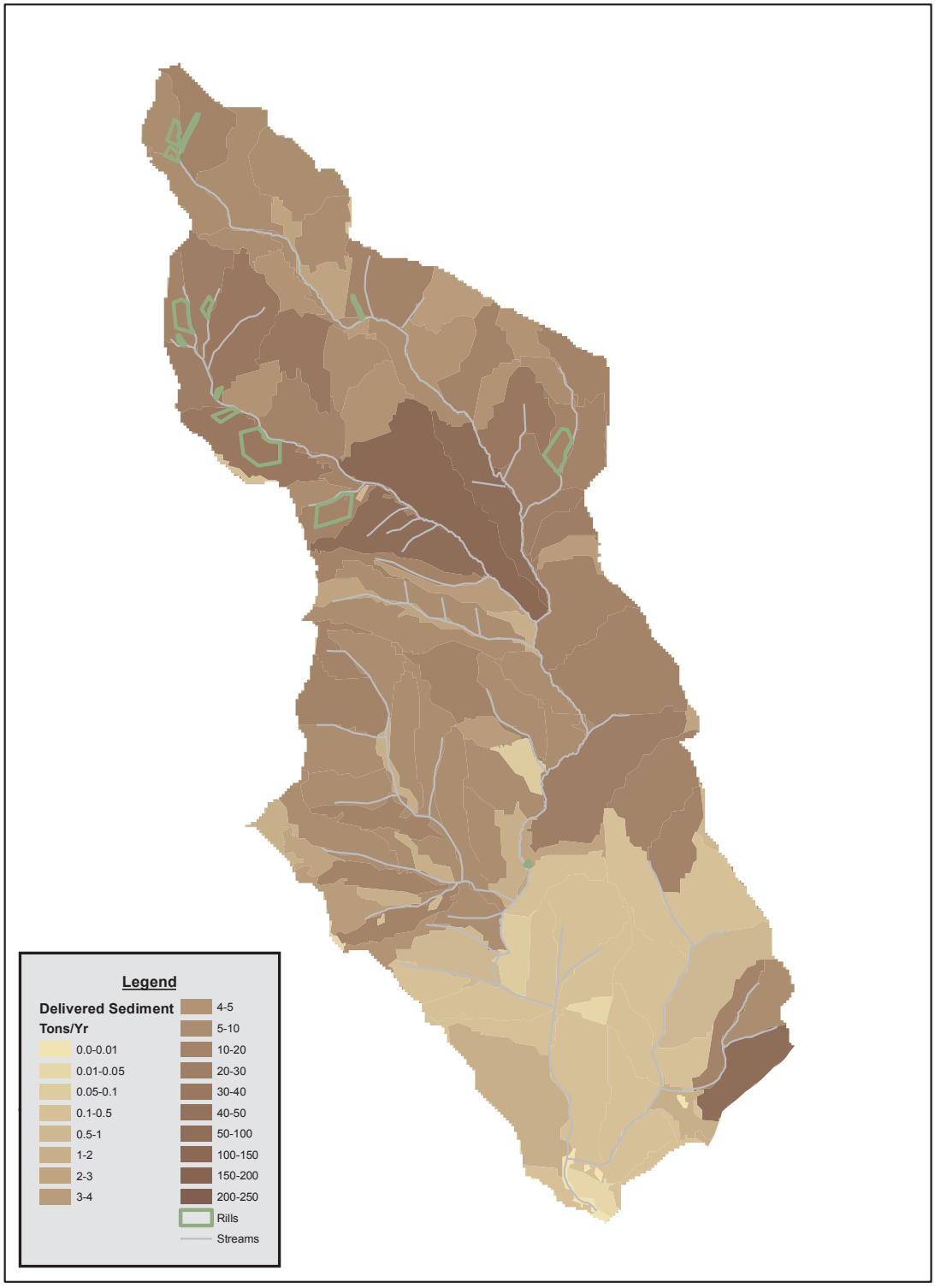
FC-010 – Channel Processes – Sub-Watershed Priority #3			
Total Length (ft)	Total Channel Length Treated (ft)	Reduced Bank Erosion (tons/yr)	Sediment Stored or Stabilized (tons/yr)
39,188	17,266	1,968	27,624

Priority #4: FC-004

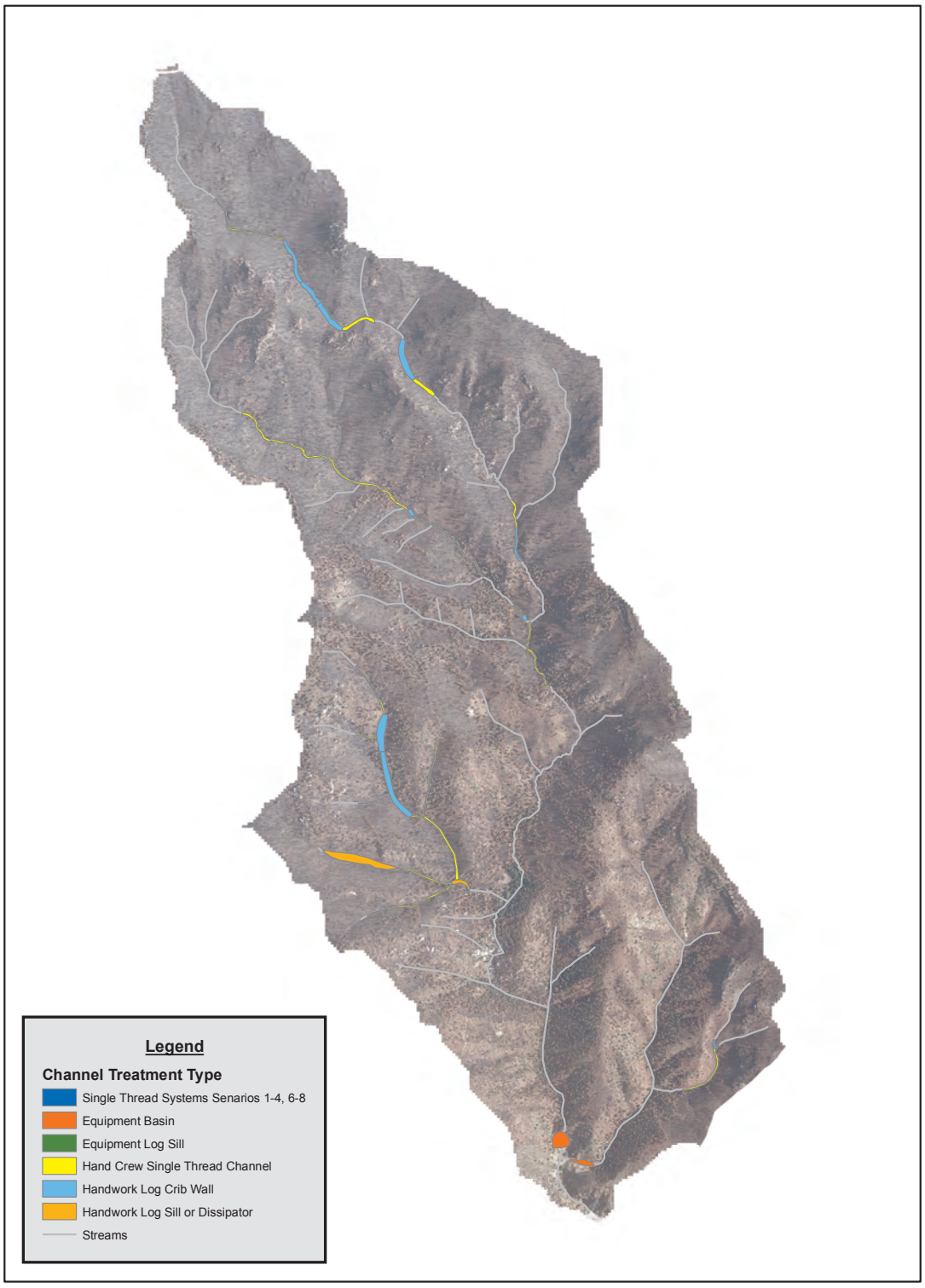
Cumulative Sediment - FC-004



Hillslope Delivered Sediment - FC-004



Treatment Potential - FC-004

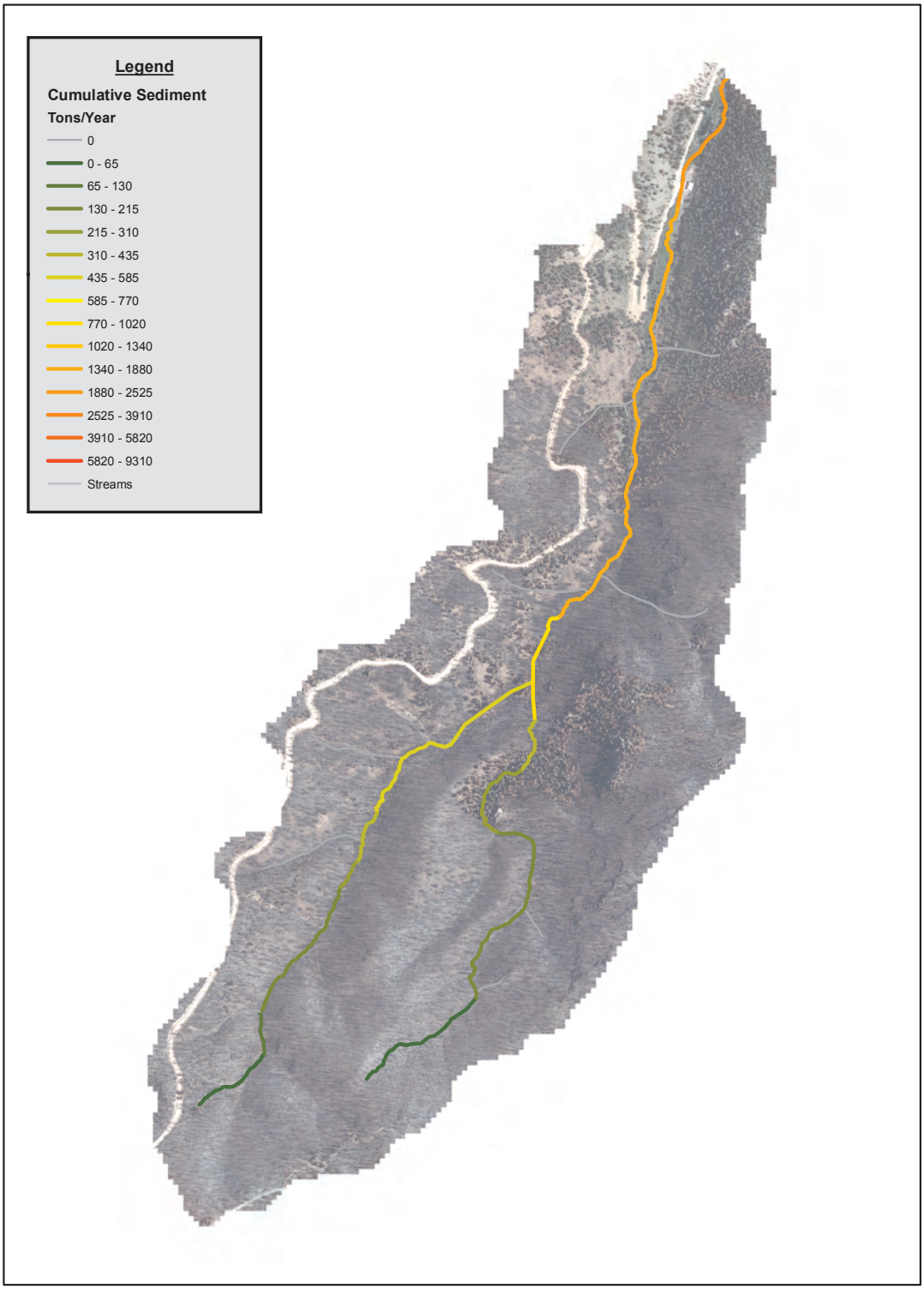


FC-004 – Hillslope Processes – Sub-Watershed Priority #4							
Total Acres	Priority Area (acres)	Priority Area (%)	Total Delivered Sediment (tons/yr)	Delivered Sediment from Priority Area (tons/yr)	Delivered Sediment from Priority Area (%)	Delivered Sediment Reduction (tons/yr)	Delivered Sediment Reduction (%)
1,124	568	50%	1,202	1,041	86%	781	65%

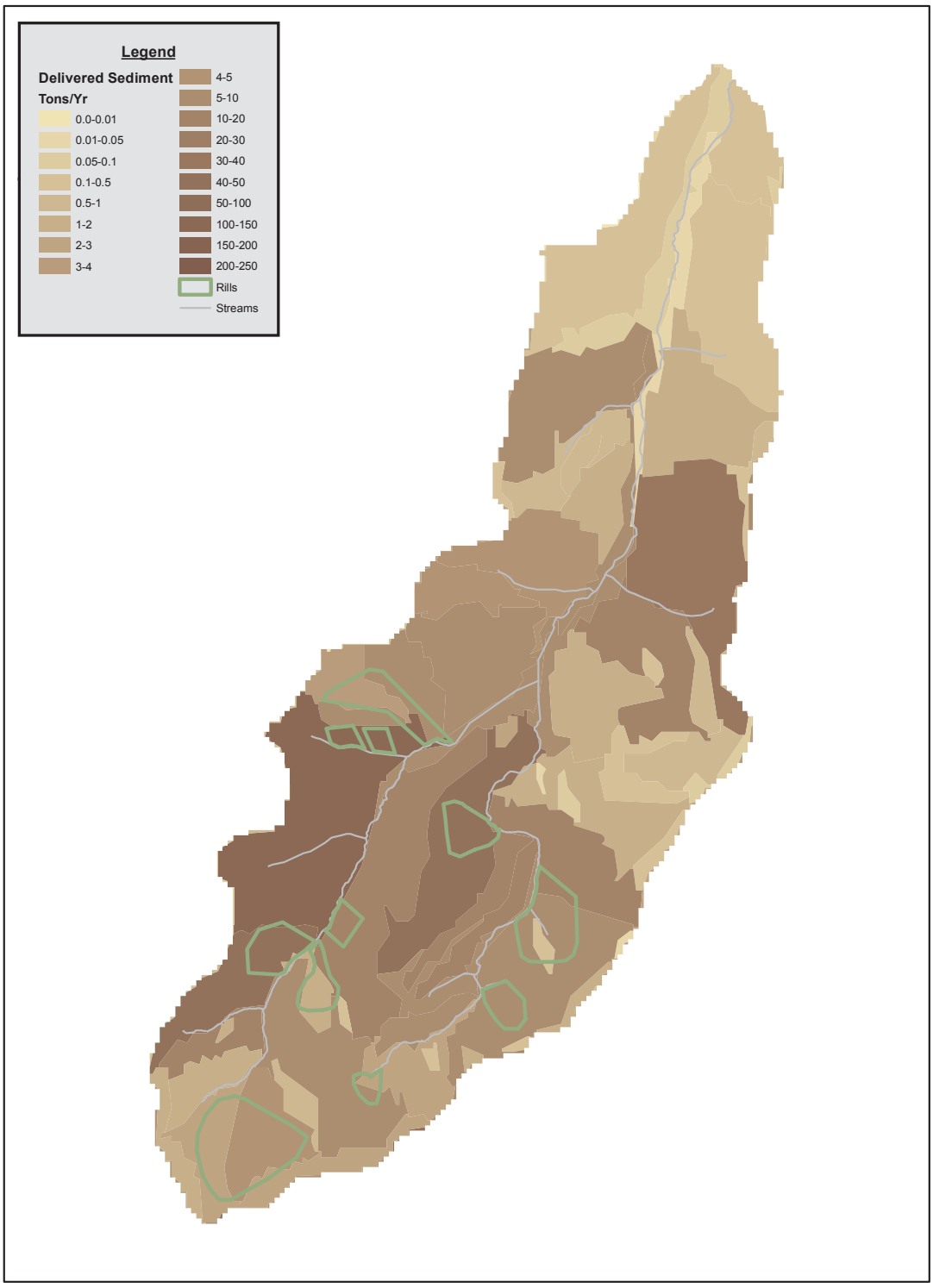
FC-004 – Channel Processes – Sub-Watershed Priority #4			
Total Length (ft)	Total Channel Length Treated (ft)	Reduced Bank Erosion (tons/yr)	Sediment Stored or Stabilized (tons/yr)
62,471	18,494	1,388	11,054

Priority #5: MC-010

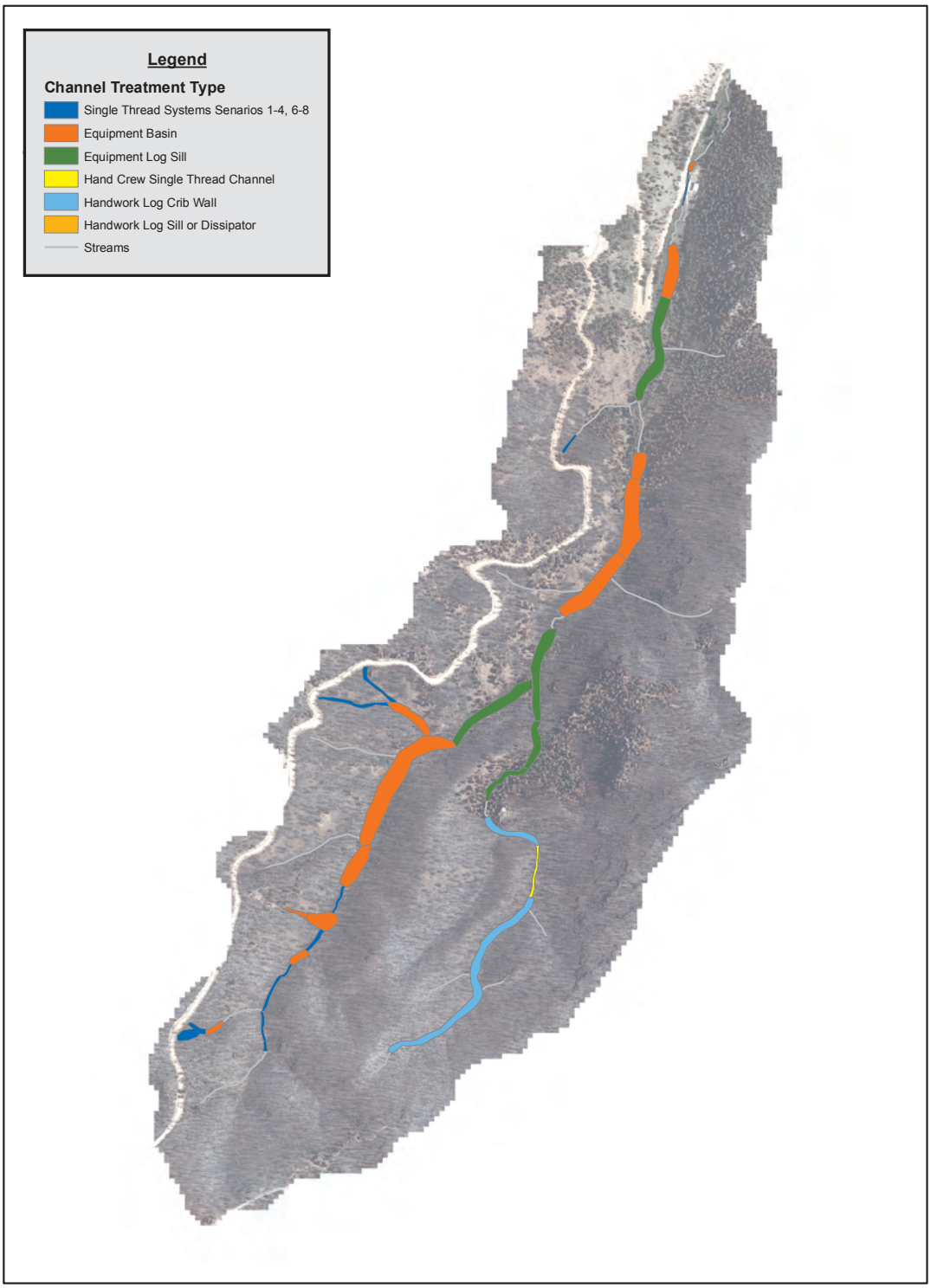
Cumulative Sediment - MC-010



Hillslope Delivered Sediment - MC-010



Treatment Potential - MC-010

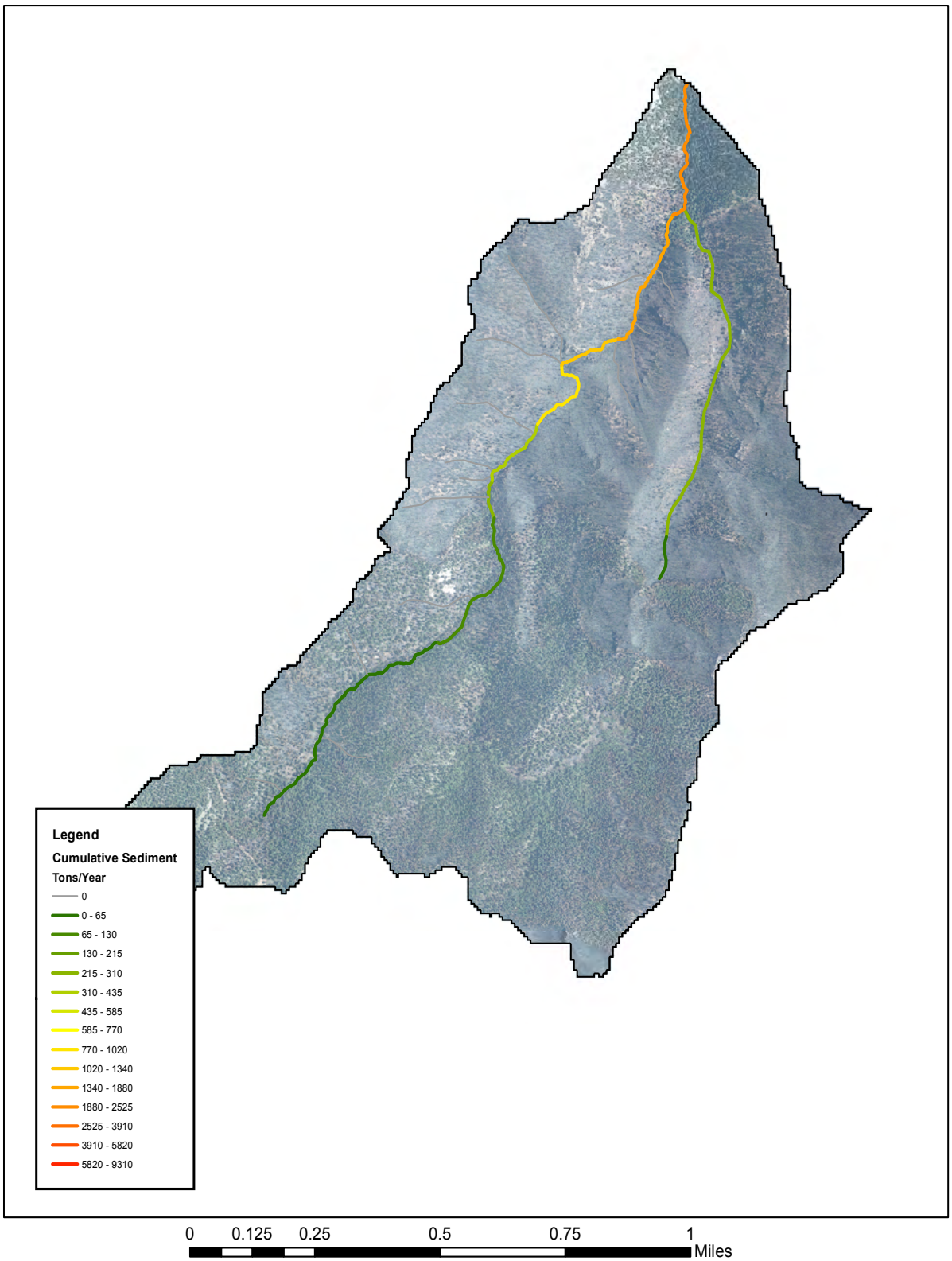


MC-010 – Hillslope Processes – Sub-Watershed Priority #5							
Total Acres	Priority Area (acres)	Priority Area (%)	Total Delivered Sediment (tons/yr)	Delivered Sediment from Priority Area (tons/yr)	Delivered Sediment from Priority Area (%)	Delivered Sediment Reduction (tons/yr)	Delivered Sediment Reduction (%)
308	171	55%	446	410	92%	308	69%

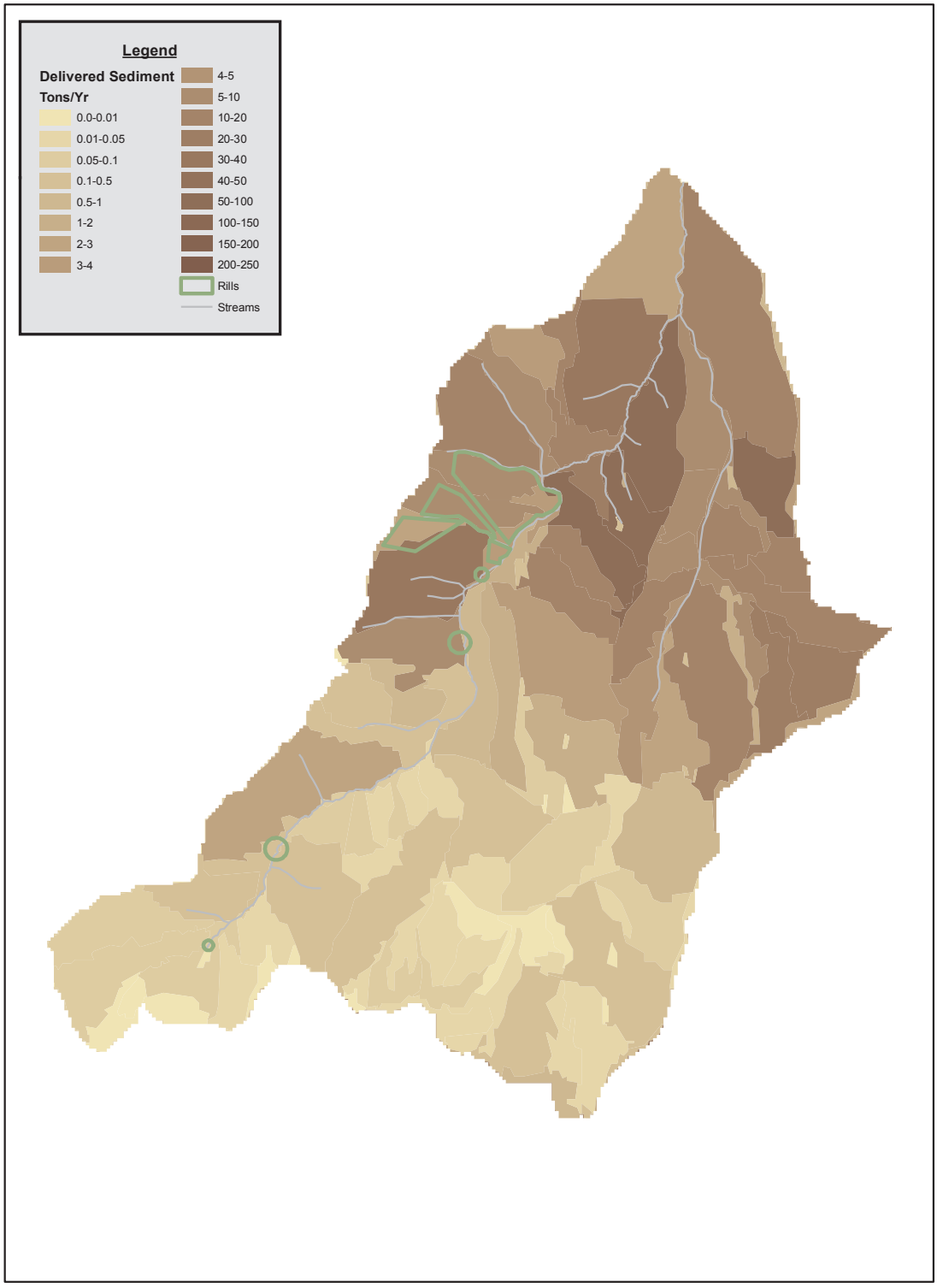
MC-010 – Channel Processes – Sub-Watershed Priority #5			
Total Length (ft)	Total Channel Length Treated (ft)	Reduced Bank Erosion (tons/yr)	Sediment Stored or Stabilized (tons/yr)
17,099	10,054	1,284	44,133

Priority #6: MC-007

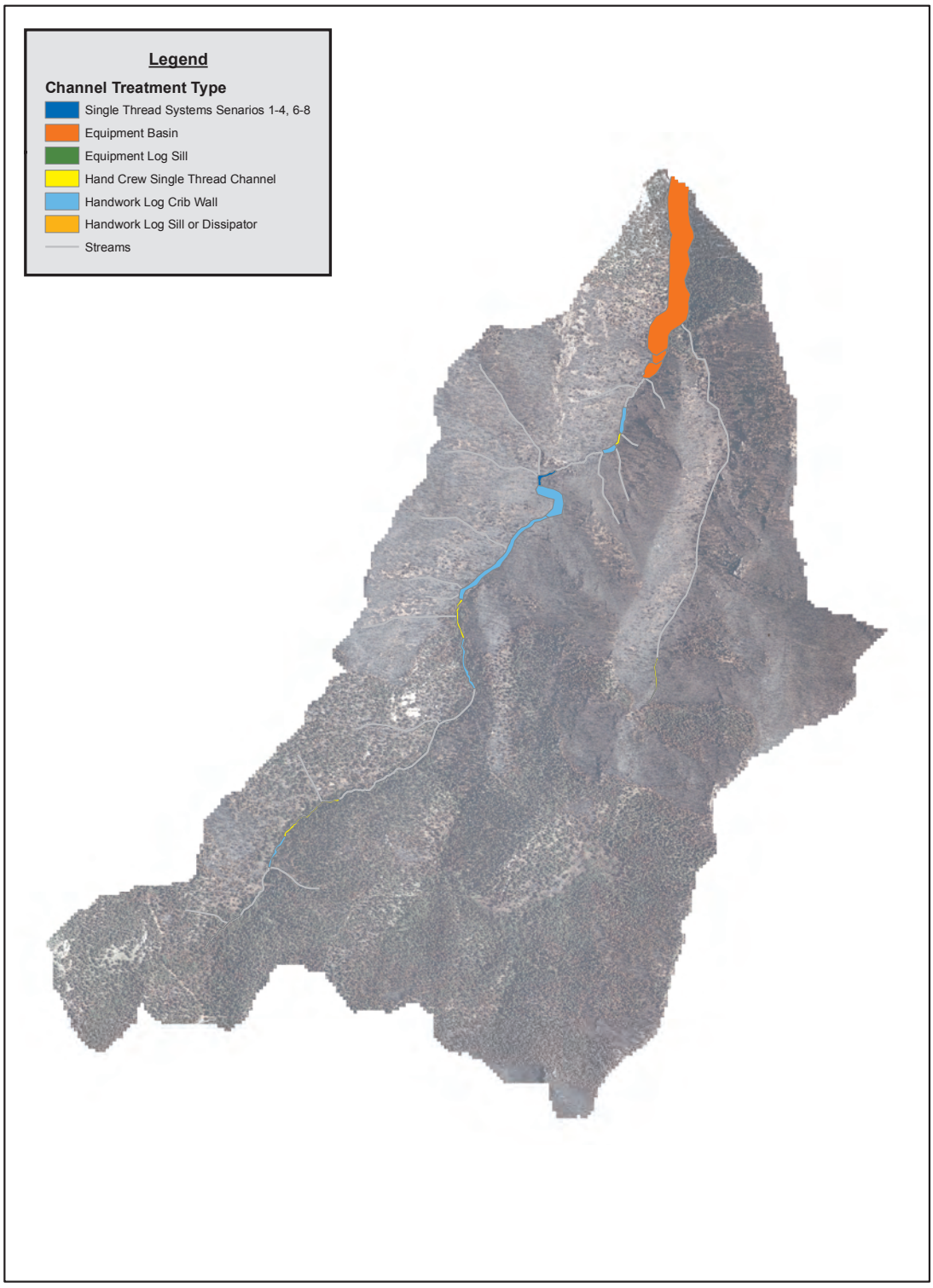
Cumulative Sediment - MC-007



Hillslope Delivered Sediment - MC-007



Treatment Potential - MC-007

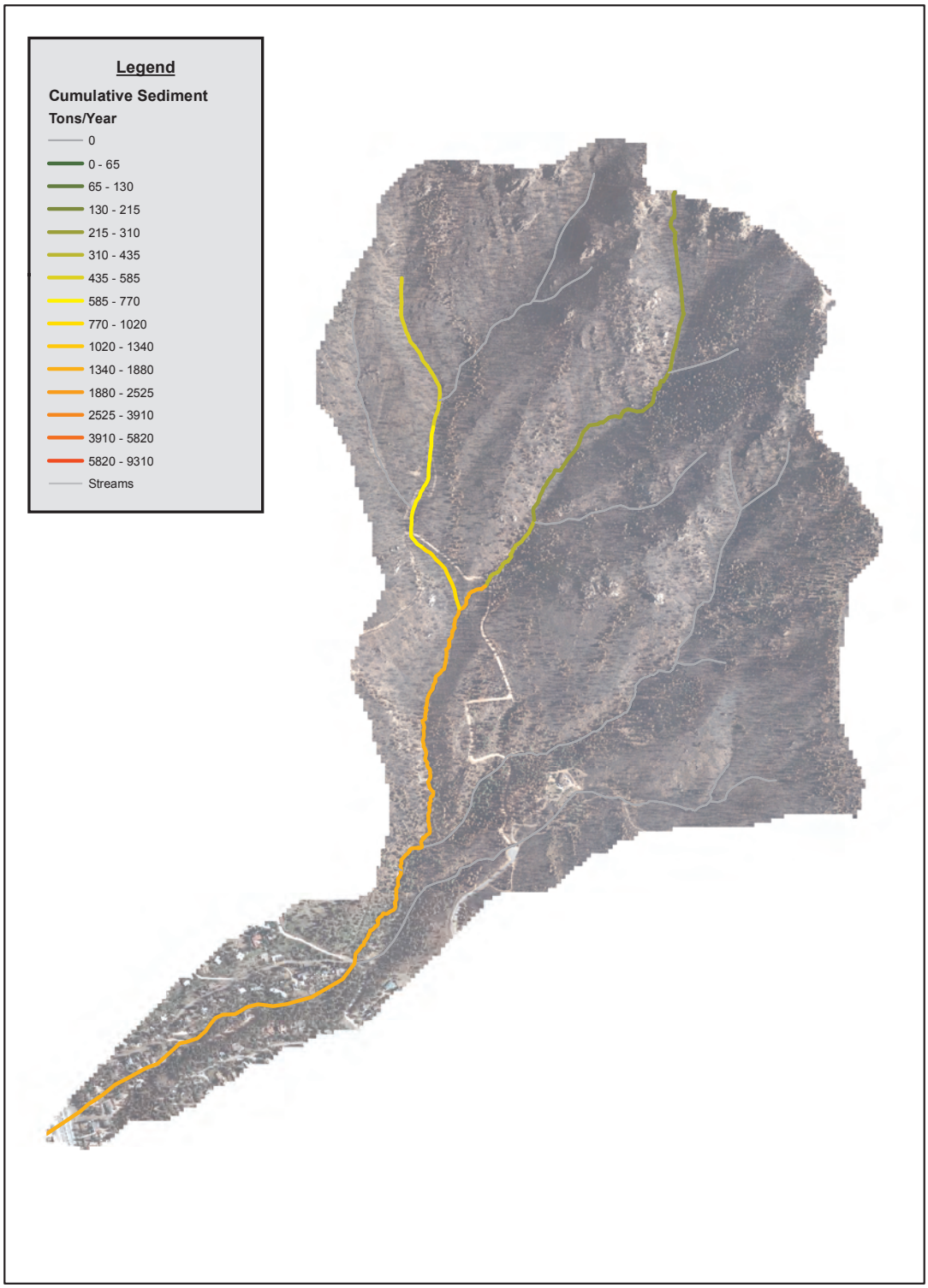


MC-007 – Hillslope Processes – Sub-Watershed Priority #6							
Total Acres	Priority Area (acres)	Priority Area (%)	Total Delivered Sediment (tons/yr)	Delivered Sediment from Priority Area (tons/yr)	Delivered Sediment from Priority Area (%)	Delivered Sediment Reduction (tons/yr)	Delivered Sediment Reduction (%)
729	384	52%	678	670	98%	503	74%

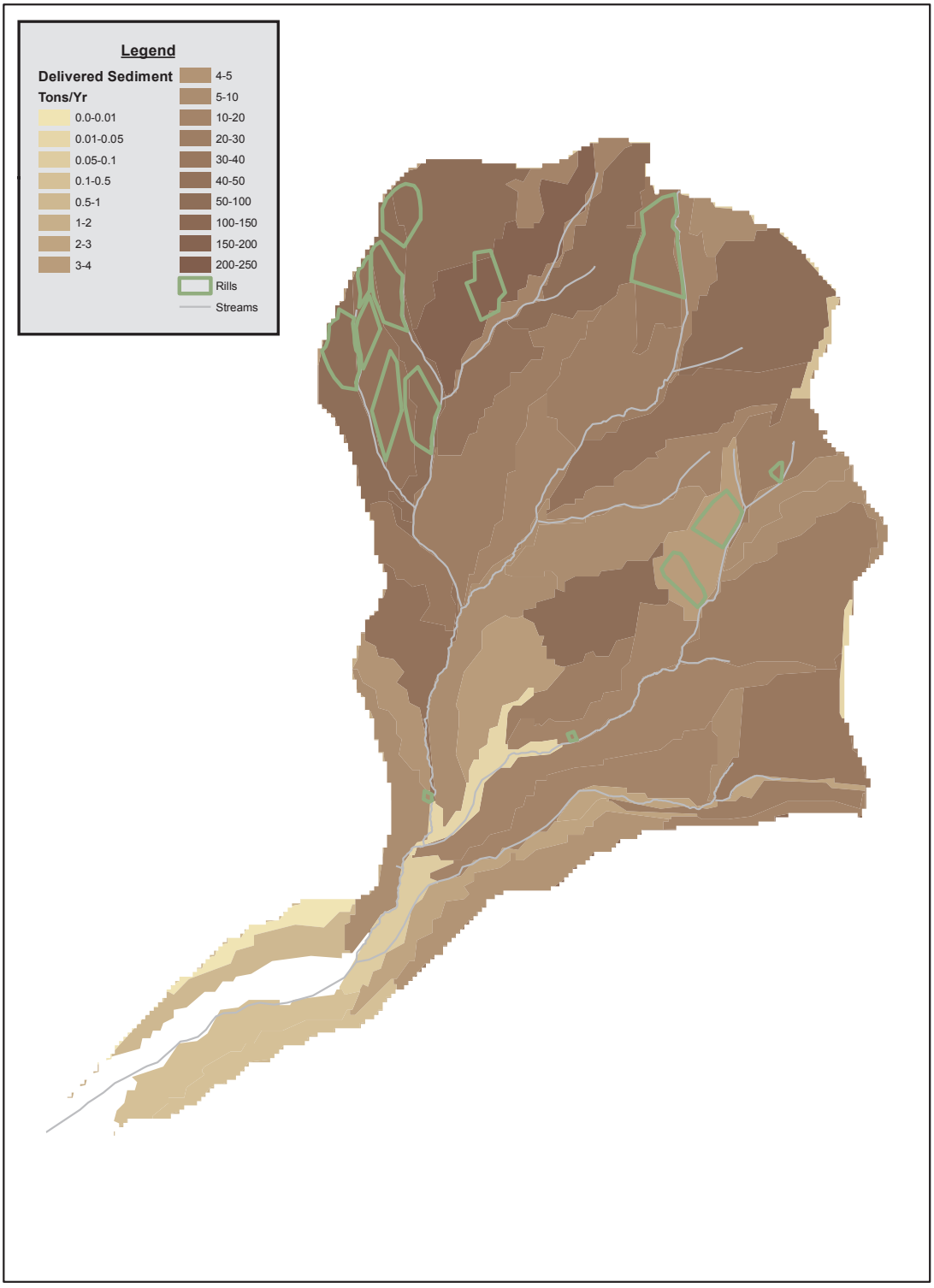
MC-007 – Channel Processes – Sub-Watershed Priority #6			
Total Length (ft)	Total Channel Length Treated (ft)	Reduced Bank Erosion (tons/yr)	Sediment Stored or Stabilized (tons/yr)
24,178	7,079	1,447	13,380

Priority #7: FC-007

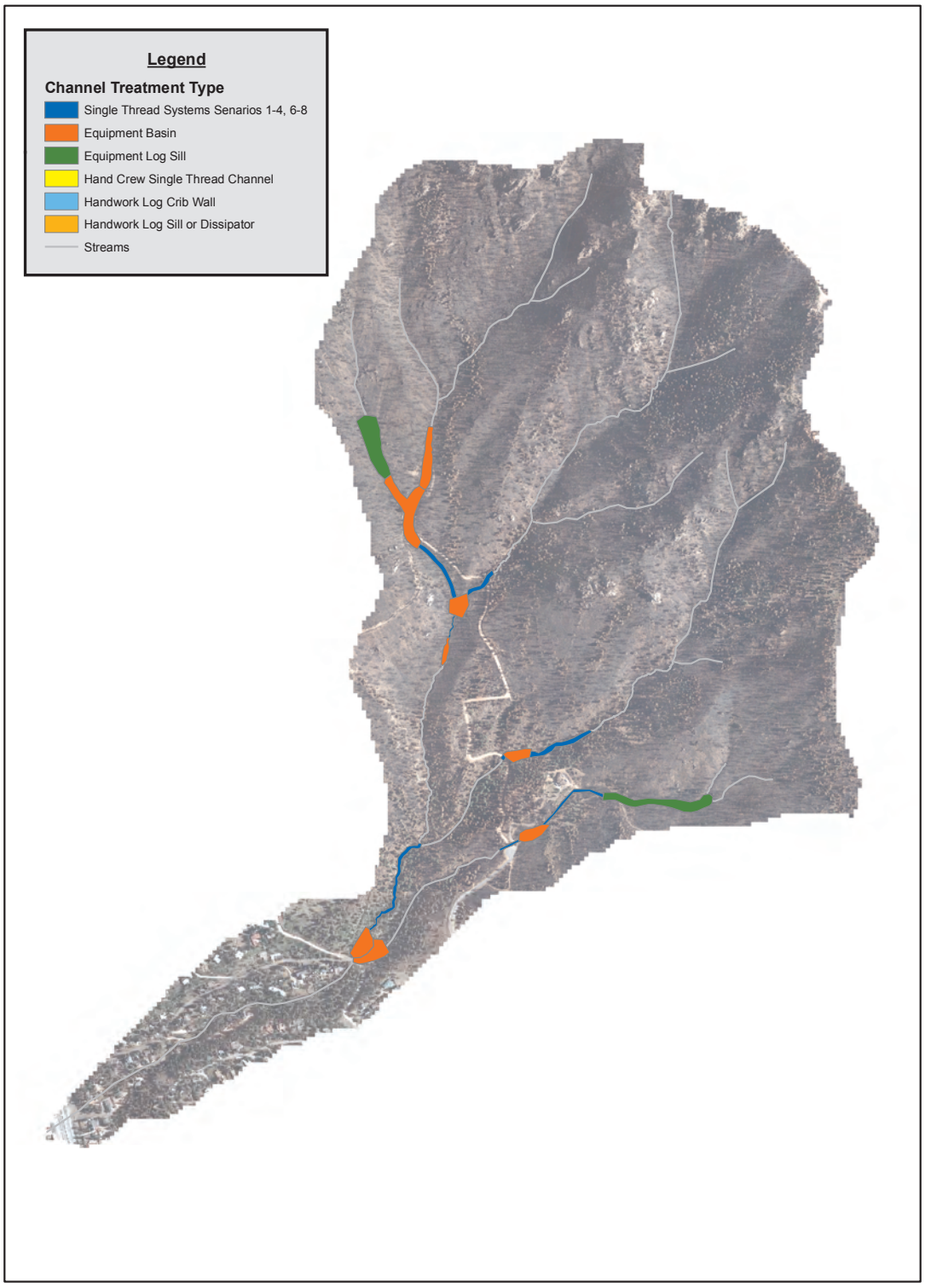
Cumulative Sediment - FC-007



Hillslope Delivered Sediment - FC-007



Treatment Potential - FC-007

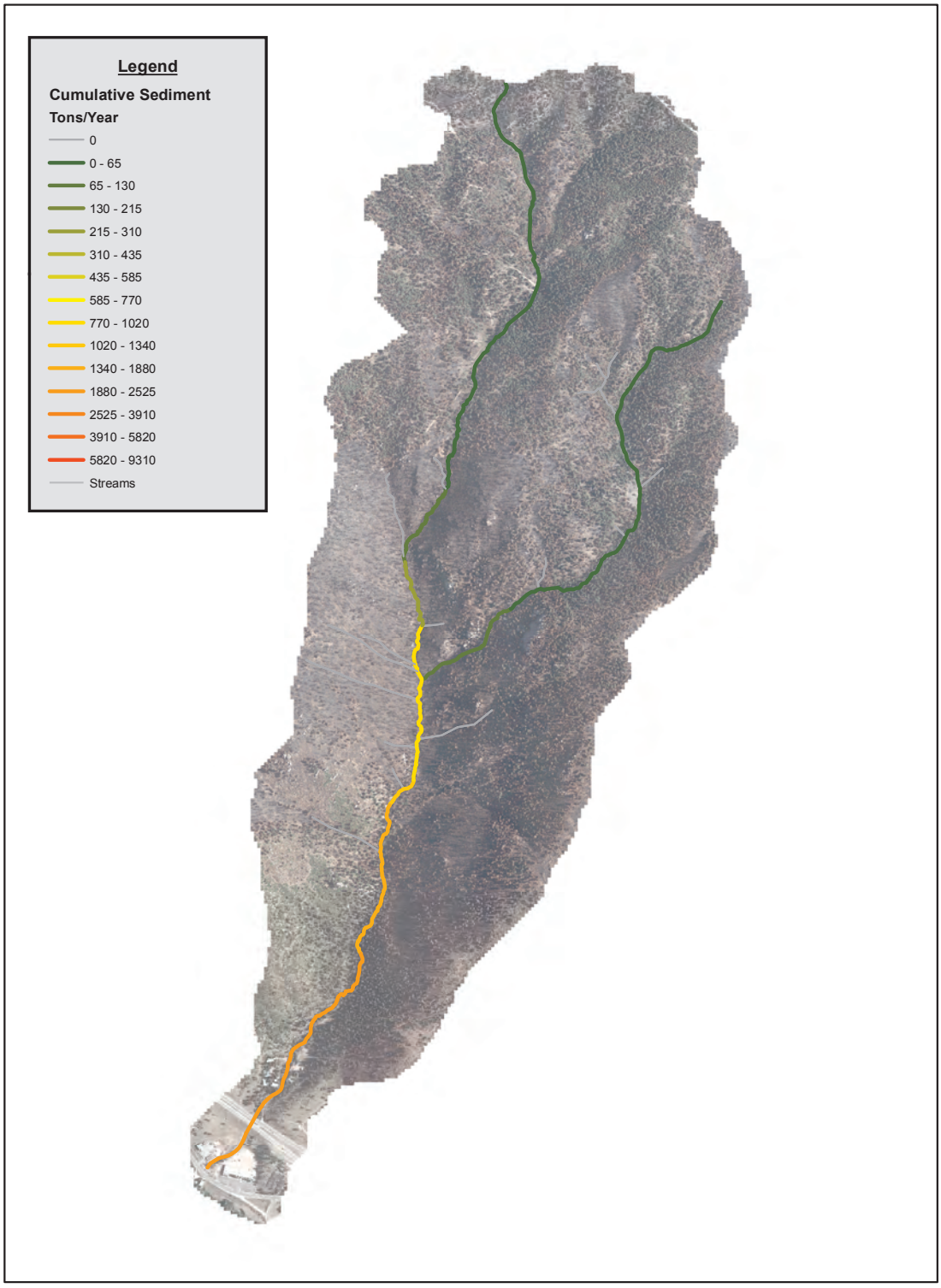


FC-007 – Hillslope Processes – Sub-Watershed Priority #7							
Total Acres	Priority Area (acres)	Priority Area (%)	Total Delivered Sediment (tons/yr)	Delivered Sediment from Priority Area (tons/yr)	Delivered Sediment from Priority Area (%)	Delivered Sediment Reduction (tons/yr)	Delivered Sediment Reduction (%)
475	228	48%	1,199	1,016	84%	762	63%

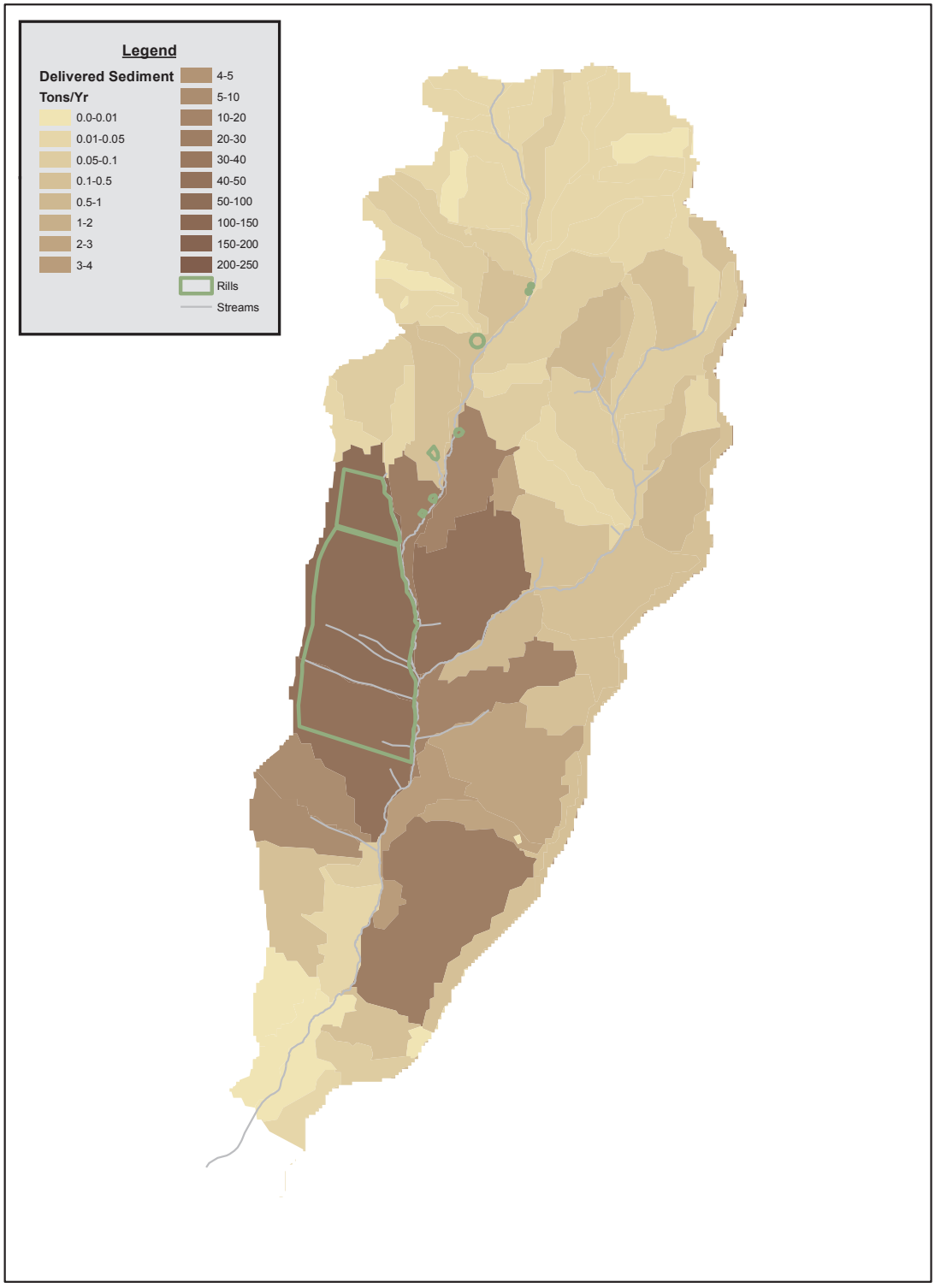
FC-007 – Channel Processes – Sub-Watershed Priority #7			
Total Length (ft)	Total Channel Length Treated (ft)	Reduced Bank Erosion (tons/yr)	Sediment Stored or Stabilized (tons/yr)
29,409	6,641	1,033	16,429

Priority #8: FC-011

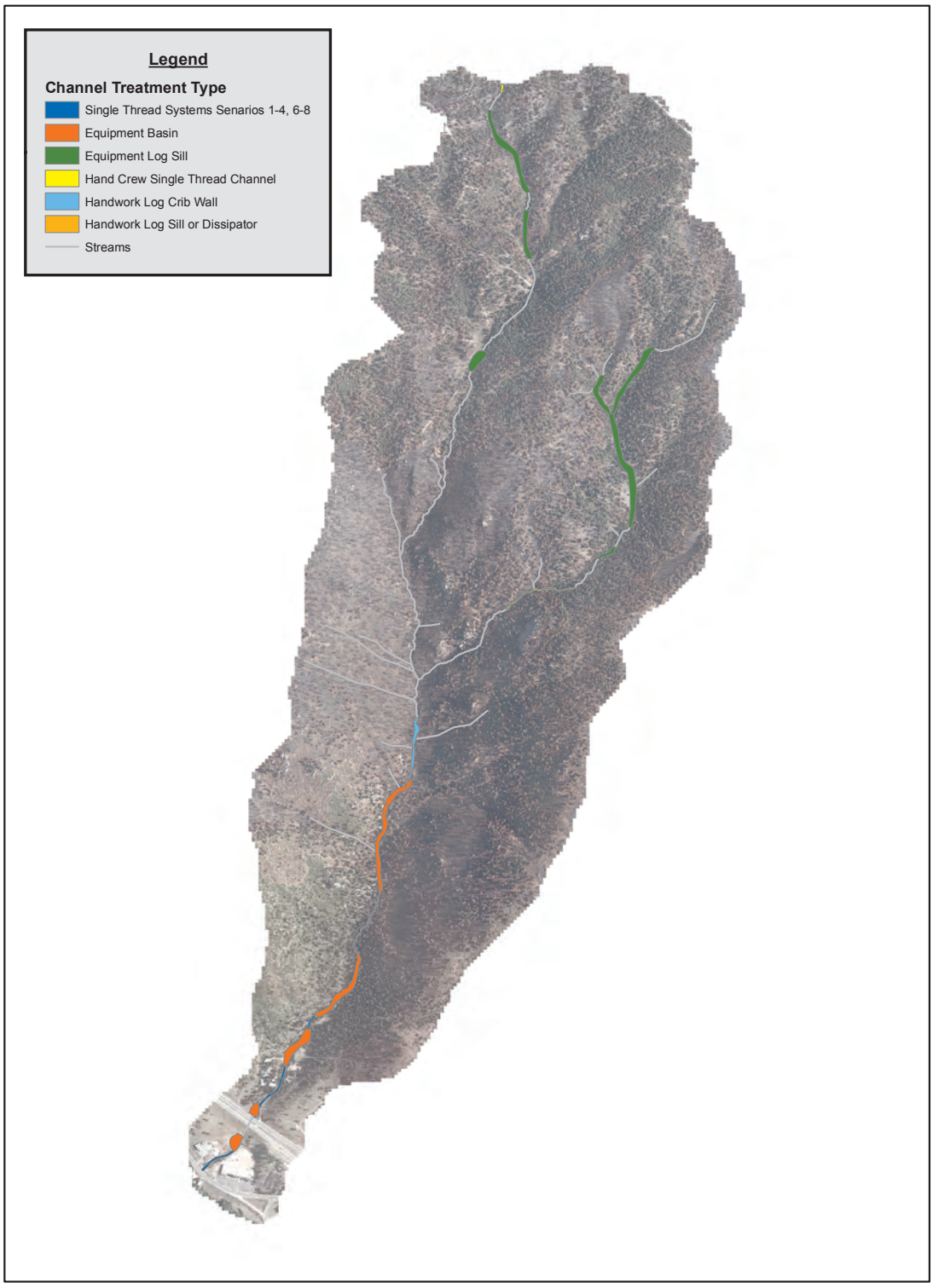
Cumulative Sediment - FC-011



Hillslope Delivered Sediment - FC-011



Treatment Potential - FC-011

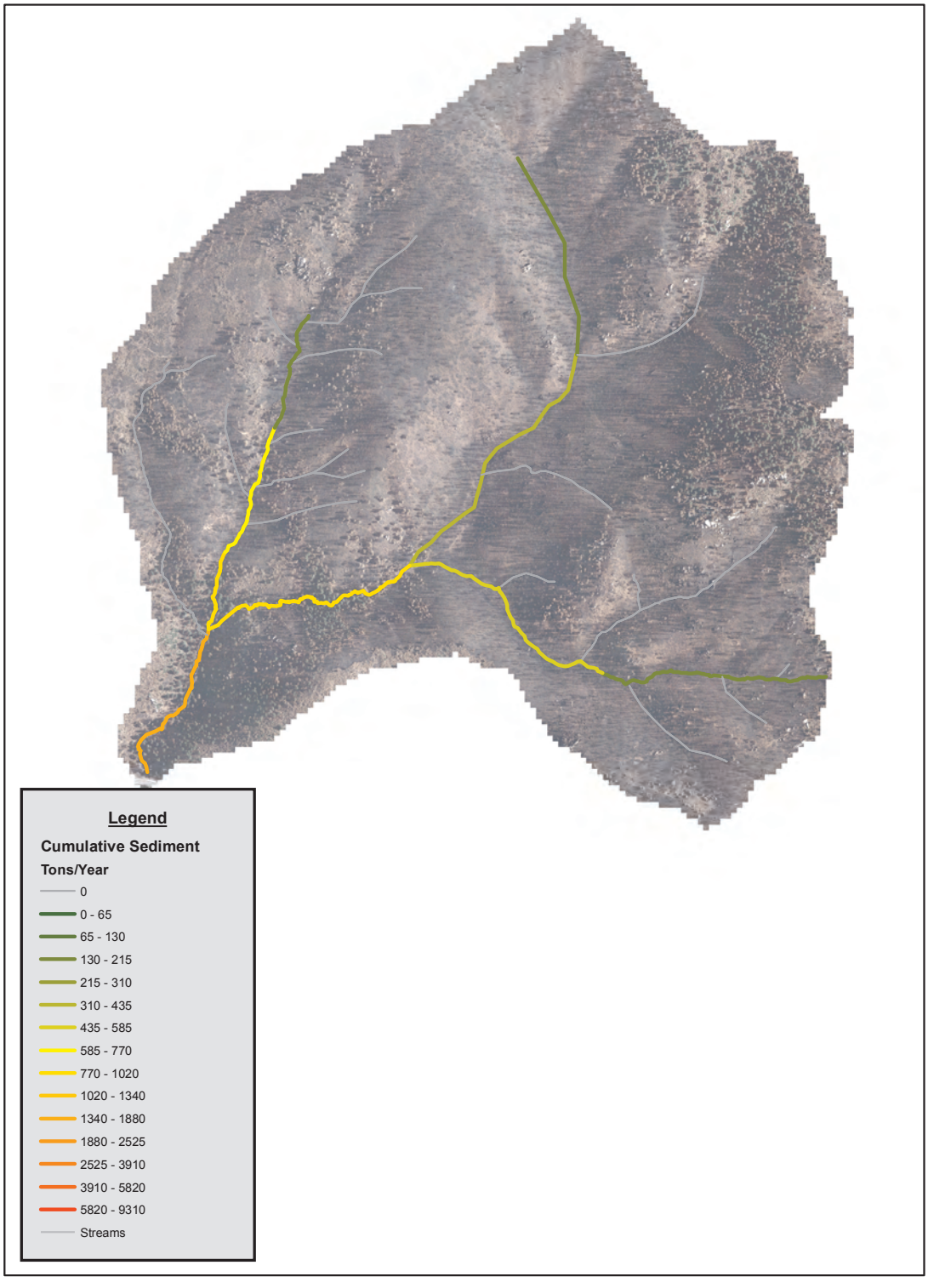


FC-011 – Hillslope Processes – Sub-Watershed Priority #8							
Total Acres	Priority Area (acres)	Priority Area (%)	Total Delivered Sediment (tons/yr)	Delivered Sediment from Priority Area (tons/yr)	Delivered Sediment from Priority Area (%)	Delivered Sediment Reduction (tons/yr)	Delivered Sediment Reduction (%)
718	464	64%	280	278	99%	209	74%

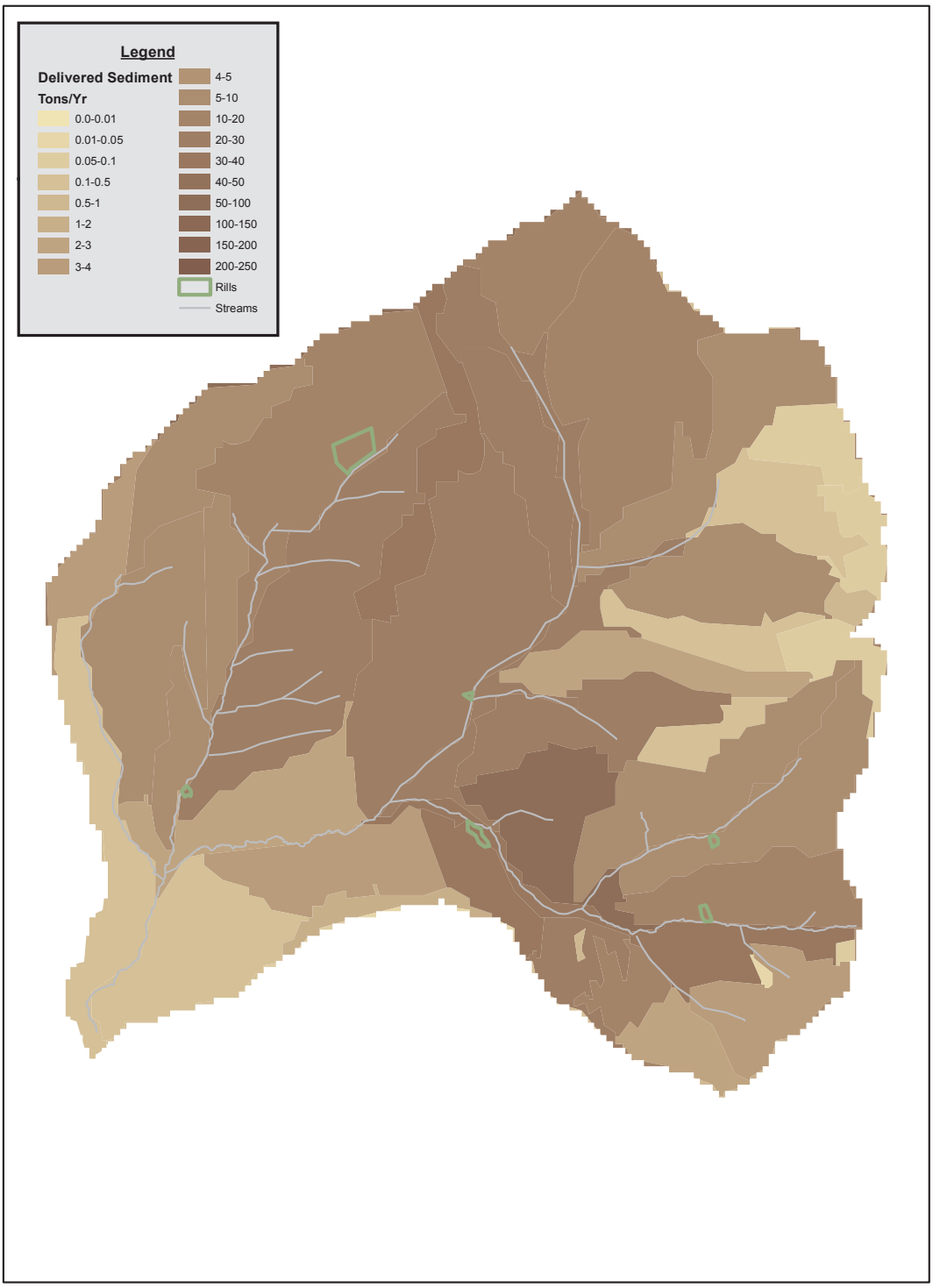
FC-011 – Channel Processes – Sub-Watershed Priority #8			
Total Length (ft)	Total Channel Length Treated (ft)	Reduced Bank Erosion (tons/yr)	Sediment Stored or Stabilized (tons/yr)
26,994	10,557	1,123	20,196

Priority #9: FC-005

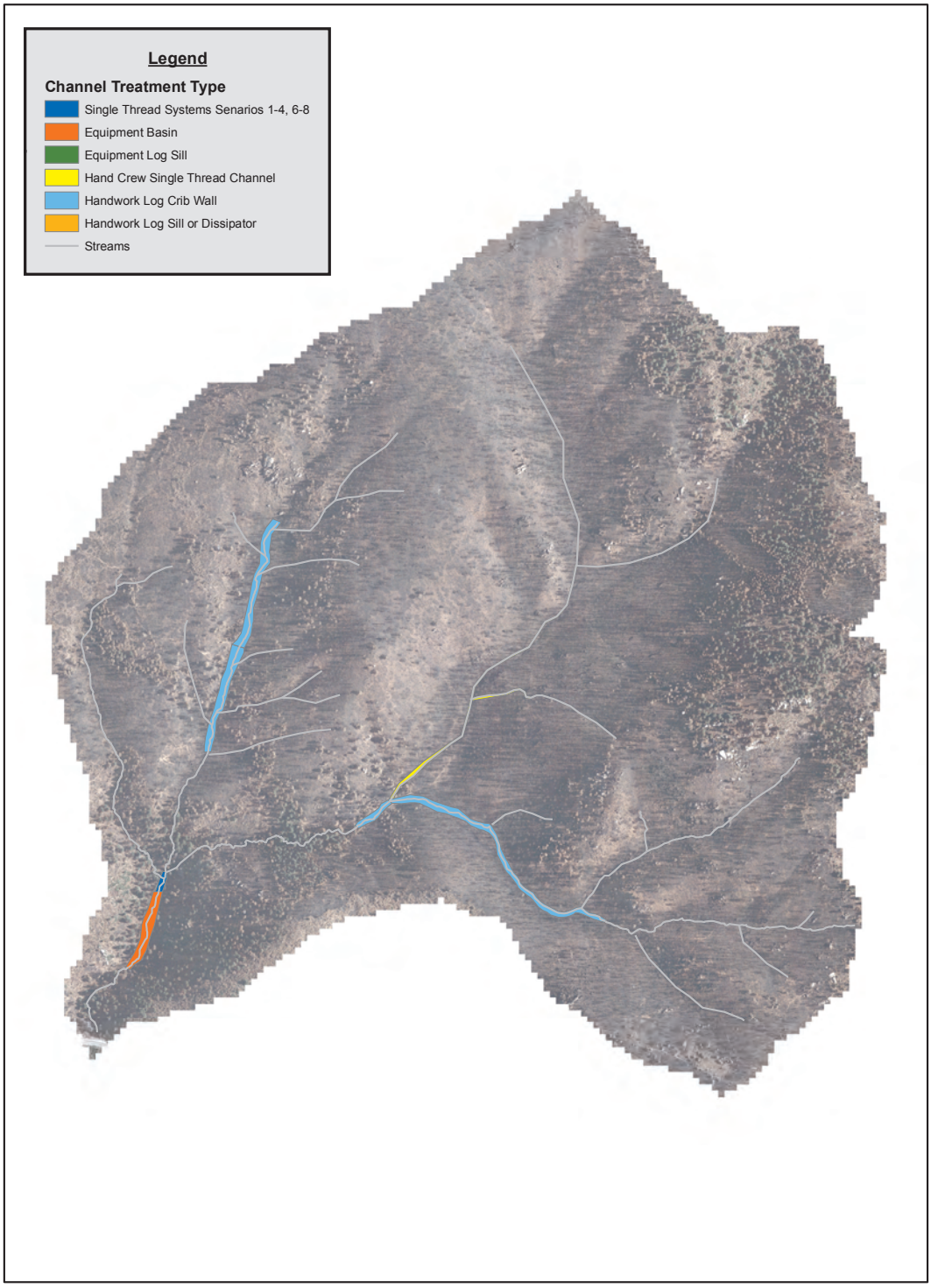
Cumulative Sediment - FC-005



Hillslope Delivered Sediment - FC-005



Treatment Potential - FC-005

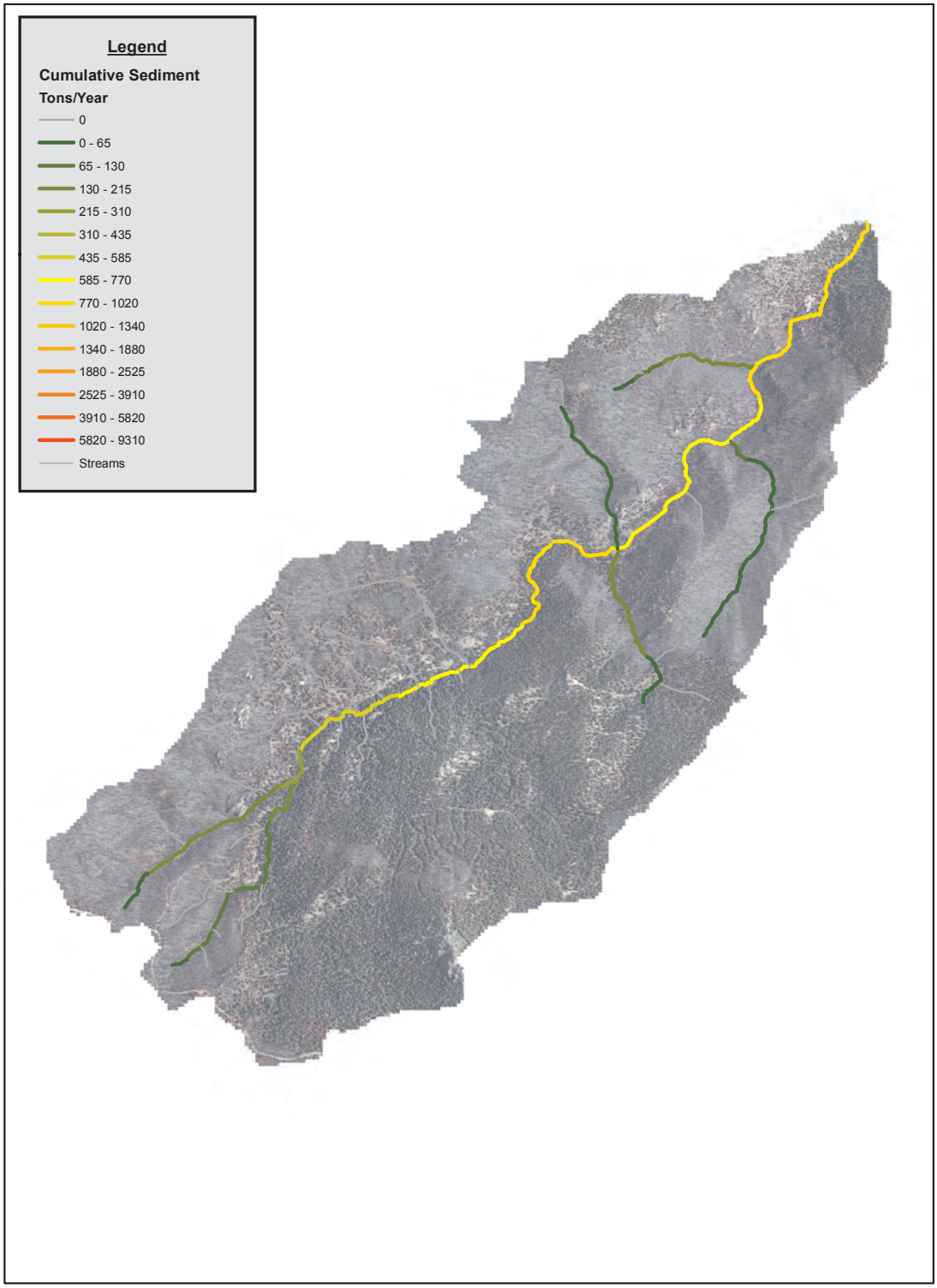


FC-005 – Hillslope Processes – Sub-Watershed Priority #9							
Total Acres	Priority Area (acres)	Priority Area (%)	Total Delivered Sediment (tons/yr)	Delivered Sediment from Priority Area (tons/yr)	Delivered Sediment from Priority Area (%)	Delivered Sediment Reduction (tons/yr)	Delivered Sediment Reduction (%)
336	191	56%	470	422	89%	317	67%

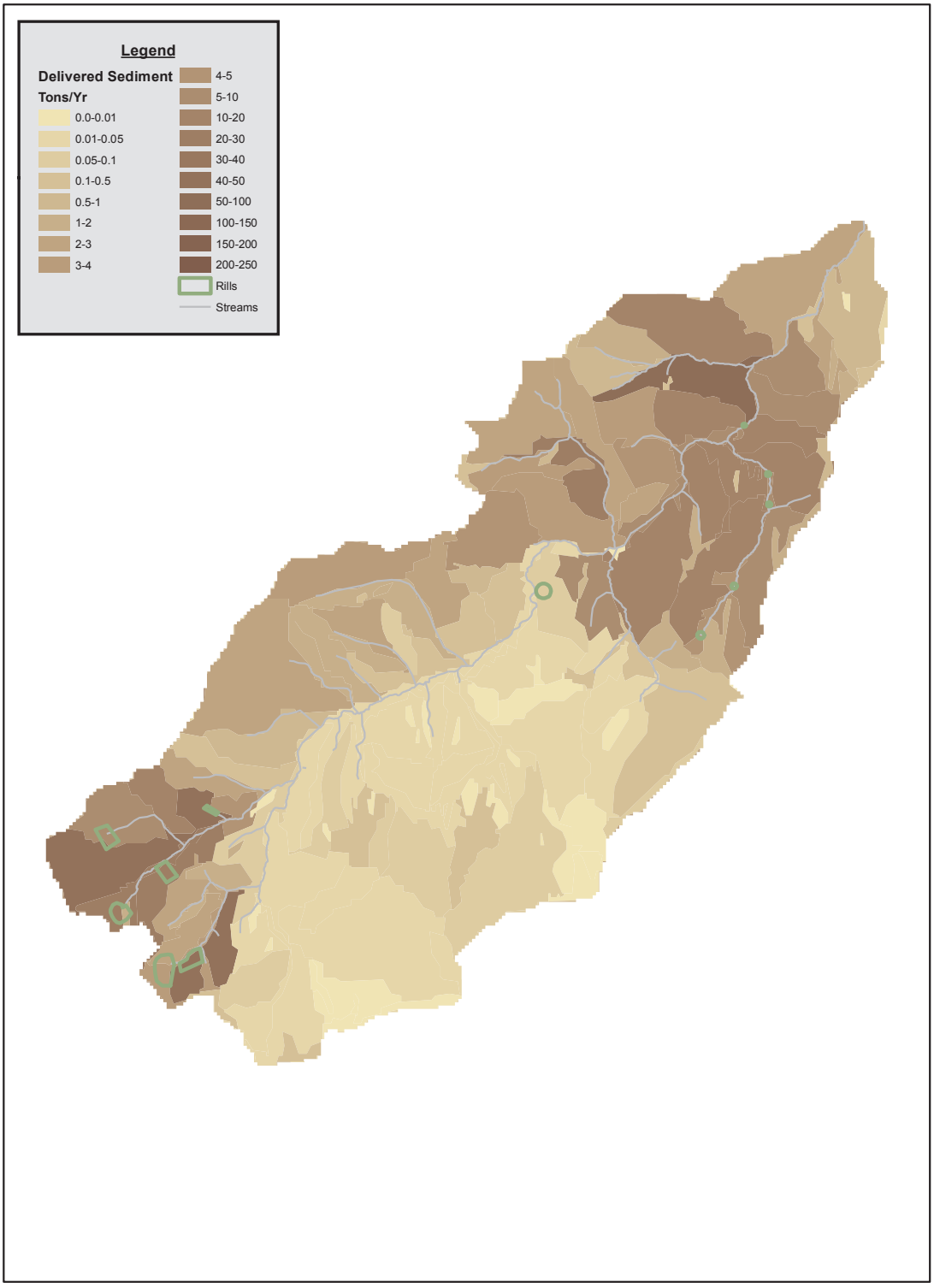
FC-005 – Channel Processes – Sub-Watershed Priority #9			
Total Length (ft)	Total Channel Length Treated (ft)	Reduced Bank Erosion (tons/yr)	Sediment Stored or Stabilized (tons/yr)
22,548	5,602	783	9,267

Priority #10: MC-008

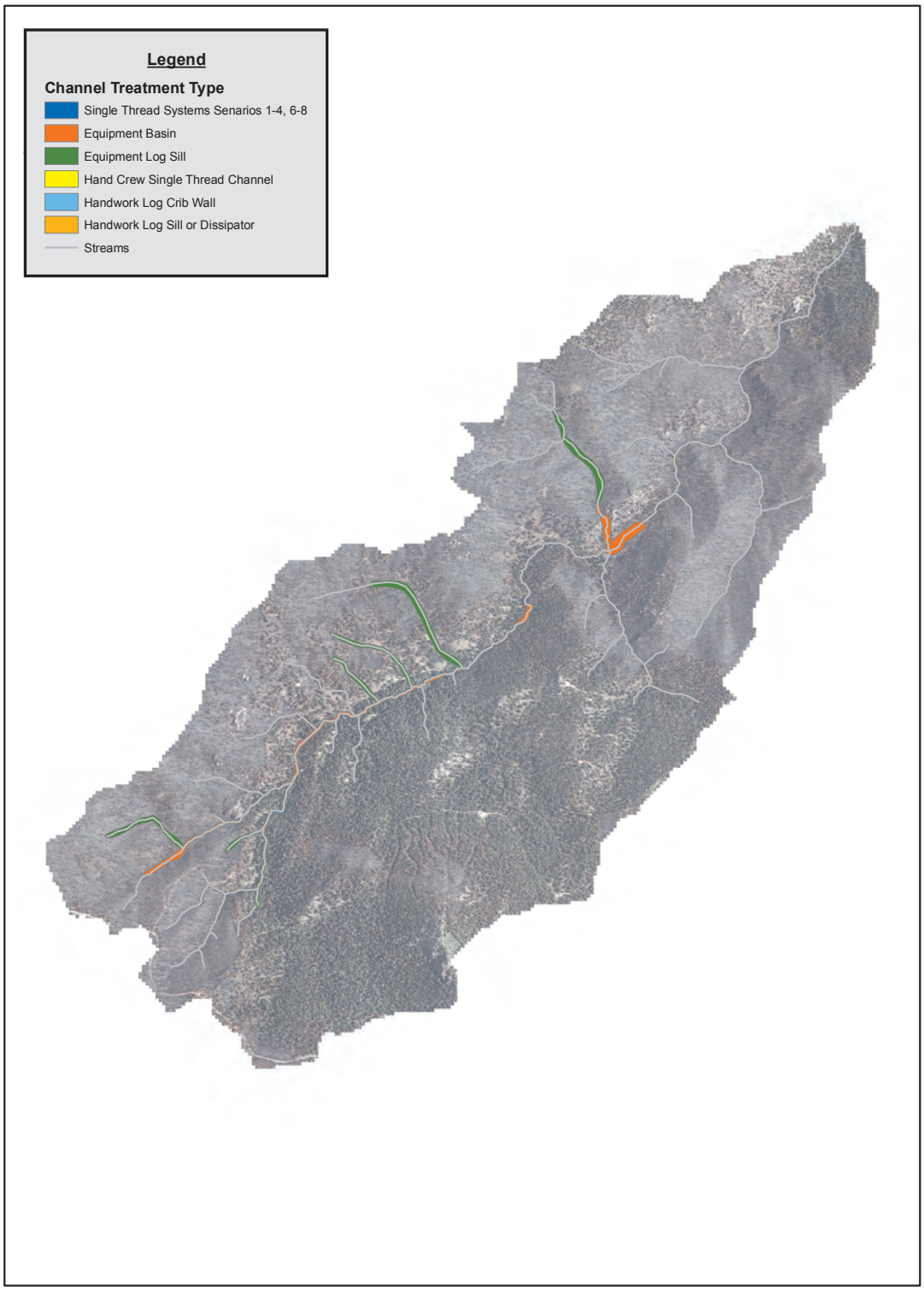
Cumulative Sediment - MC-008



Hillslope Delivered Sediment - MC-008



Treatment Potential - MC-008



MC-008 – Hillslope Processes – Sub-Watershed Priority #10							
Total Acres	Priority Area (acres)	Priority Area (%)	Total Delivered Sediment (tons/yr)	Delivered Sediment from Priority Area (tons/yr)	Delivered Sediment from Priority Area (%)	Delivered Sediment Reduction (tons/yr)	Delivered Sediment Reduction (%)
710	382	53%	486	484	99%	361	74%

MC-008 – Channel Processes – Sub-Watershed Priority #10			
Total Length (ft)	Total Channel Length Treated (ft)	Reduced Bank Erosion (tons/yr)	Sediment Stored or Stabilized (tons/yr)
39,979	13,624	366	30,051