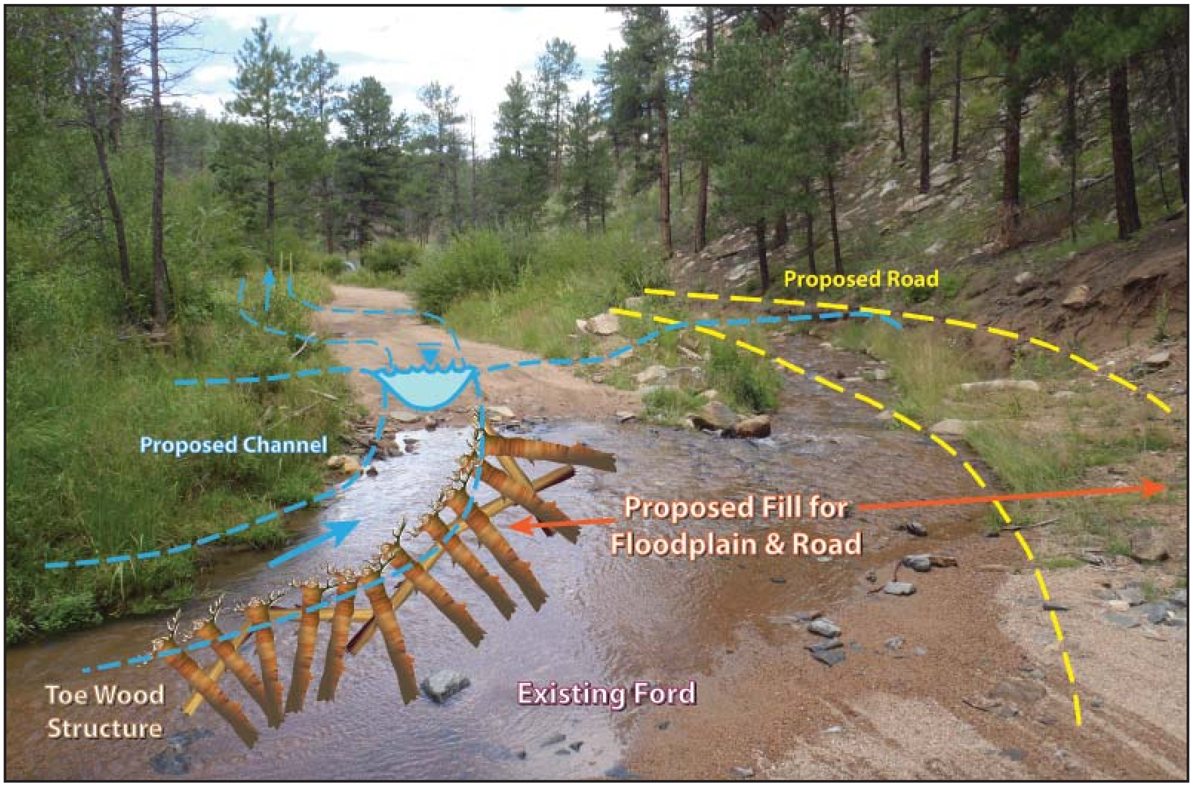
The Trail Creek Watershed Master Plan for Stream Restoration & Sediment Reduction



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Dave Rosgen, Wildland Hydrology
11210 N County Rd 19
Fort Collins, Colorado 80524
Phone: 970.568.0002
E-mail: wildland@wildlandhydrology.com

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The Trail Creek Watershed Master Plan for Stream Restoration & Sediment Reduction

This master plan for restoration is developed for the Trail Creek Watershed to reduce the accelerated sediment yields following the Hayman Fire of 2002. This design relies on the results of a three-phase watershed assessment conducted in 2010 and 2011 by Wildland Hydrology based on the *WARSSS* methodology (*Watershed Assessment and River Stability and Sediment Supply*, Rosgen, 2006/2009). The initial two phases of *WARSSS*, the R*econnaissance Level Assessment (RLA)* and the *Rapid Resource Inventory for Sediment Supply Consequences (RRISSC)*, were conducted on the *186* mi^2 Horse Creek Watershed on the Pike National Forest. The *RLA* and the *RRISSC* assessments identified the Trail Creek Watershed as *High Risk* for disproportionate sediment supply and river impairment. The detailed results of these phases are documented in the report *Horse Creek Watershed RLA and RRISSC Assessments* (Rosgen and Rosgen, 2010).

The third phase of the assessment, the *Prediction Level Assessment (PLA)*, identified the erosional and depositional processes that are disproportionately contributing sediment to the Trail Creek Watershed and quantified the sediment loading by location and process. The results are documented in the report *Trail Creek Watershed Assessment & Conceptual Restoration Plan* (Rosgen, 2011). This assessment report is referenced throughout this document as the "Trail Creek *WARSSS* analysis."

The restoration is directed at design solutions for the identified areas with disproportionately high sediment yields throughout the watershed. Designs will be addressed for typical sediment yield processes for hillslope and channel processes at representative or typical impaired stream type and valley type locations. This plan documents the restoration objectives, priorities, various design scenarios for a diversity of sediment problems, structure designs, and earthwork computations for the various restoration scenarios. 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 Trail Creek Watershed.

Location & Description

The Trail Creek Watershed involves nearly *16* mi^2 of drainage area within the South Platte River drainage in Colorado. The watershed is located in the Granitic geology associated with the Pikes Peak Batholith composed of very erosive grussic granite soils. The confluence of Trail Creek is at West Creek near the community of West Creek. A general vicinity map is shown in **Figure 1**. A more detailed map of the Trail Creek Watershed is shown in the Forest Service map in **Figure 2**. The majority of the watershed was burned during the Hayman Fire in 2002.

The Trail Creek Watershed was delineated into 59 sub-watersheds each given a unique number ID as identified in **Figures 3–6**. Ownership within Trail Creek is predominantly USDA Forest Service, Pike National Forest with some private land inholdings in the upper watershed.

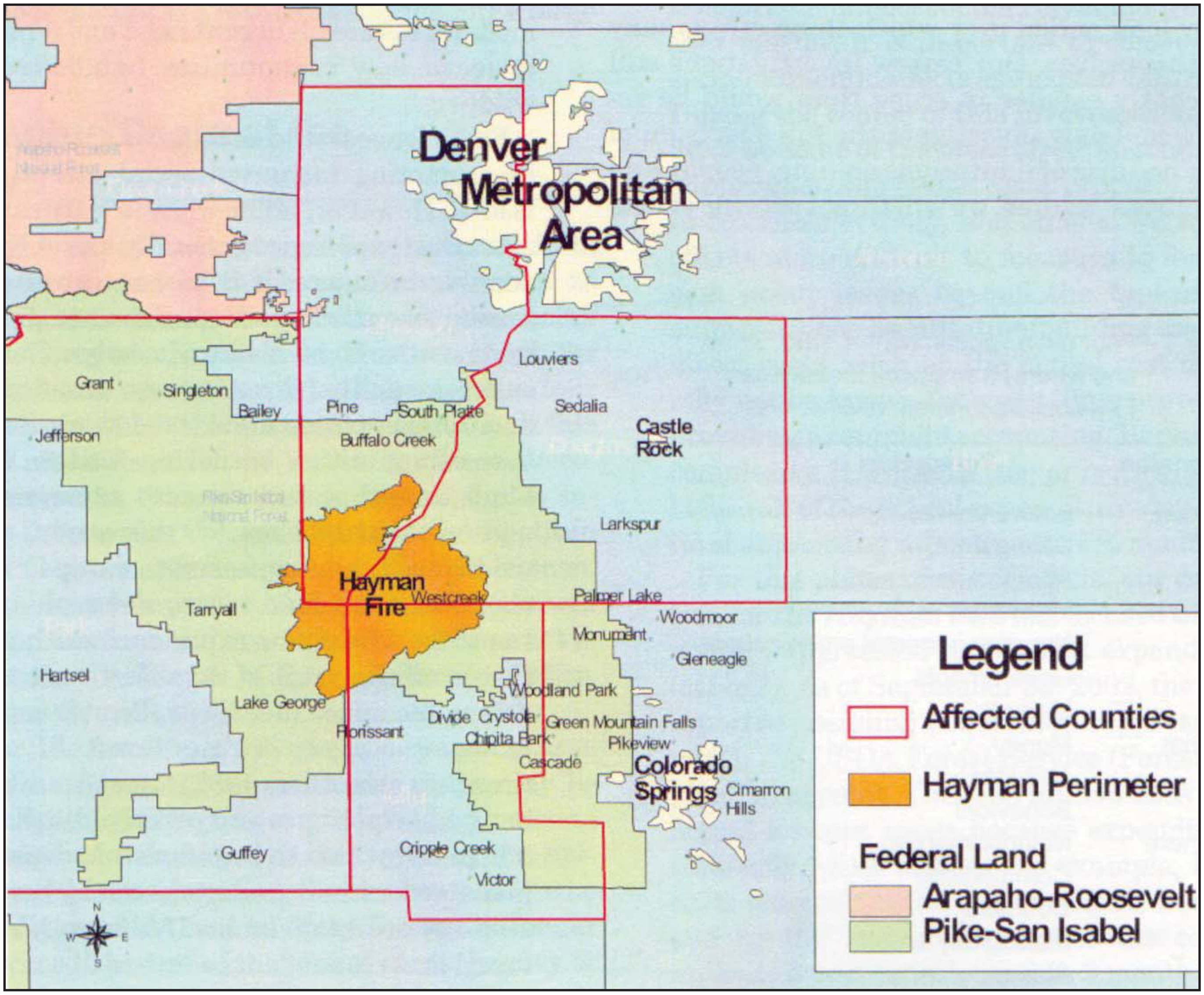


Figure 1. A general vicinity map of the area influenced by the Hayman Fire.

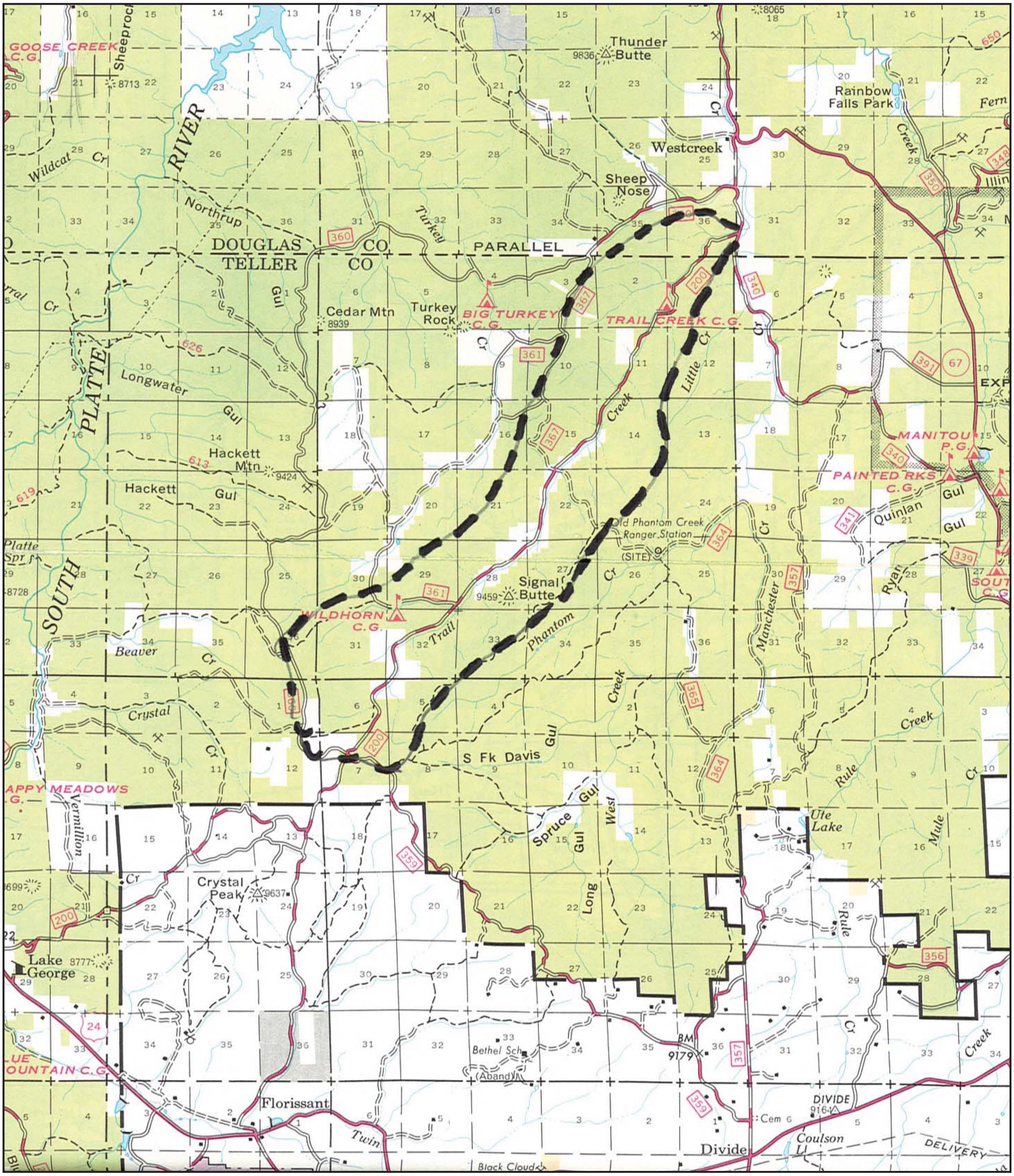


Figure 2. Forest Service map identifying the Trail Creek Watershed.

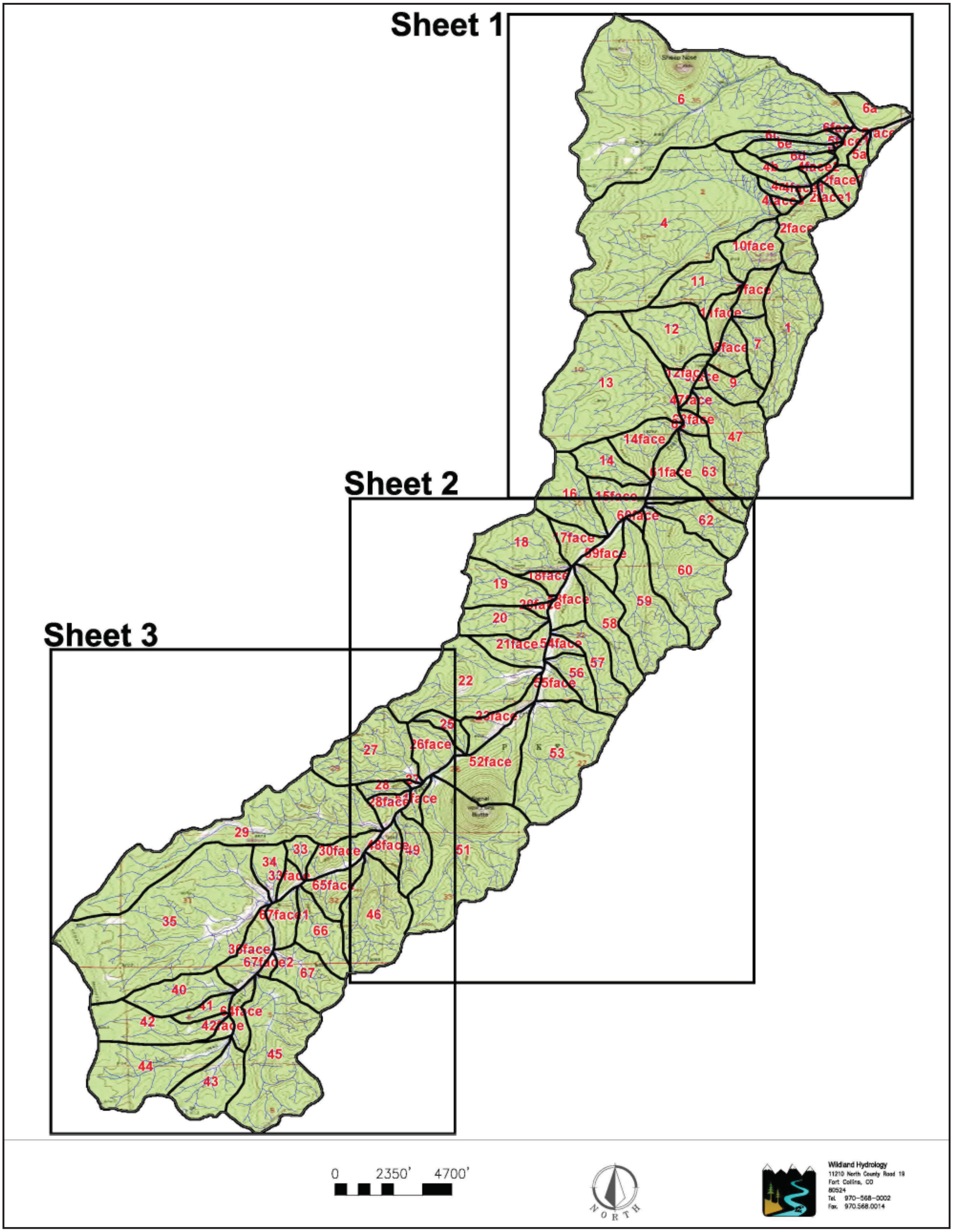


Figure 3. The sub-watershed delineation of the Trail Creek Watershed; the area in "Sheet 1" is depicted in **Figure 4**, the area in "Sheet 2" is depicted in **Figure 5**, and the area in "Sheet 3" is depicted in **Figure 6**.

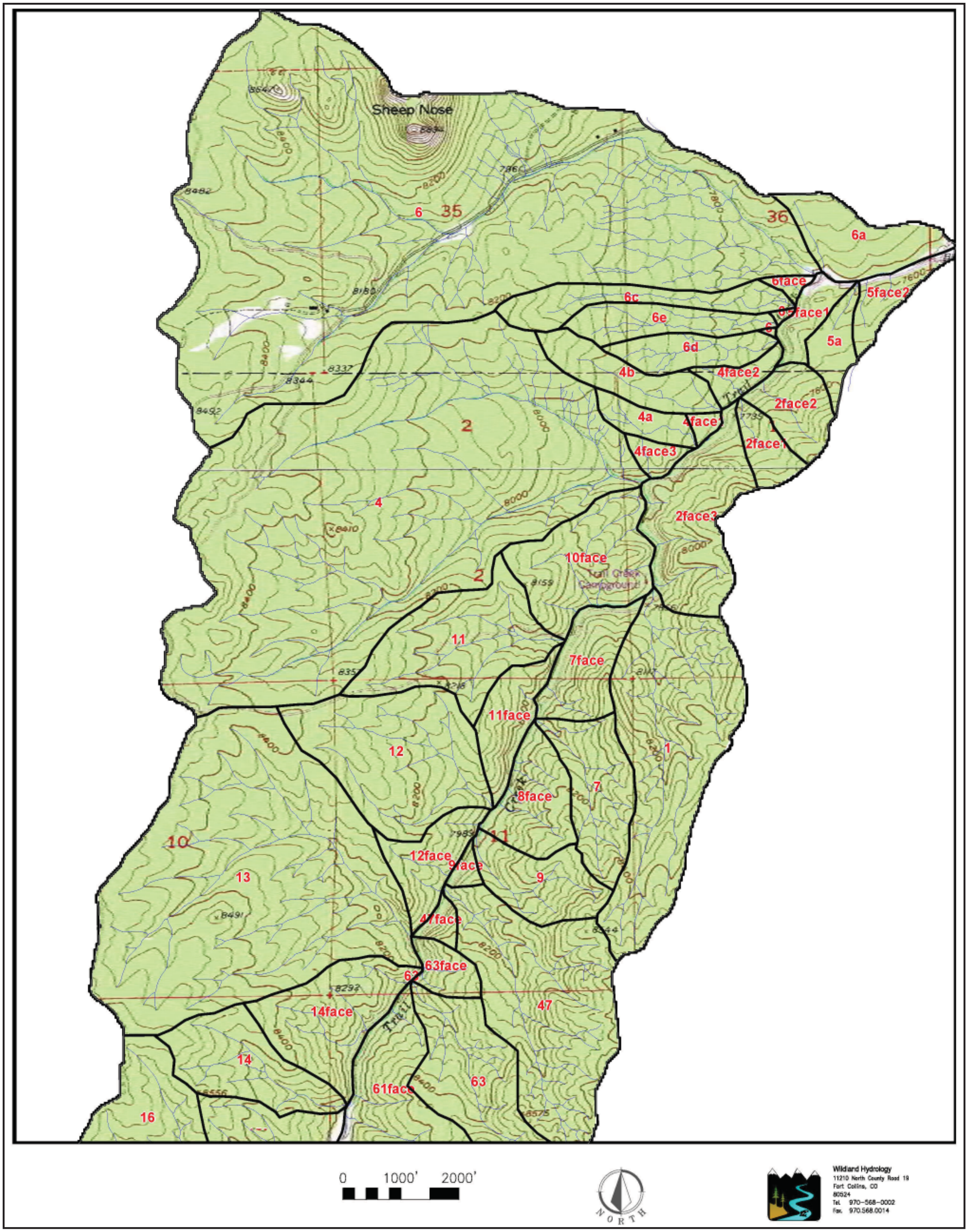


Figure 4. The sub-watershed delineation of the Trail Creek Watershed illustrating the area in "Sheet 1" in **Figure 3**.

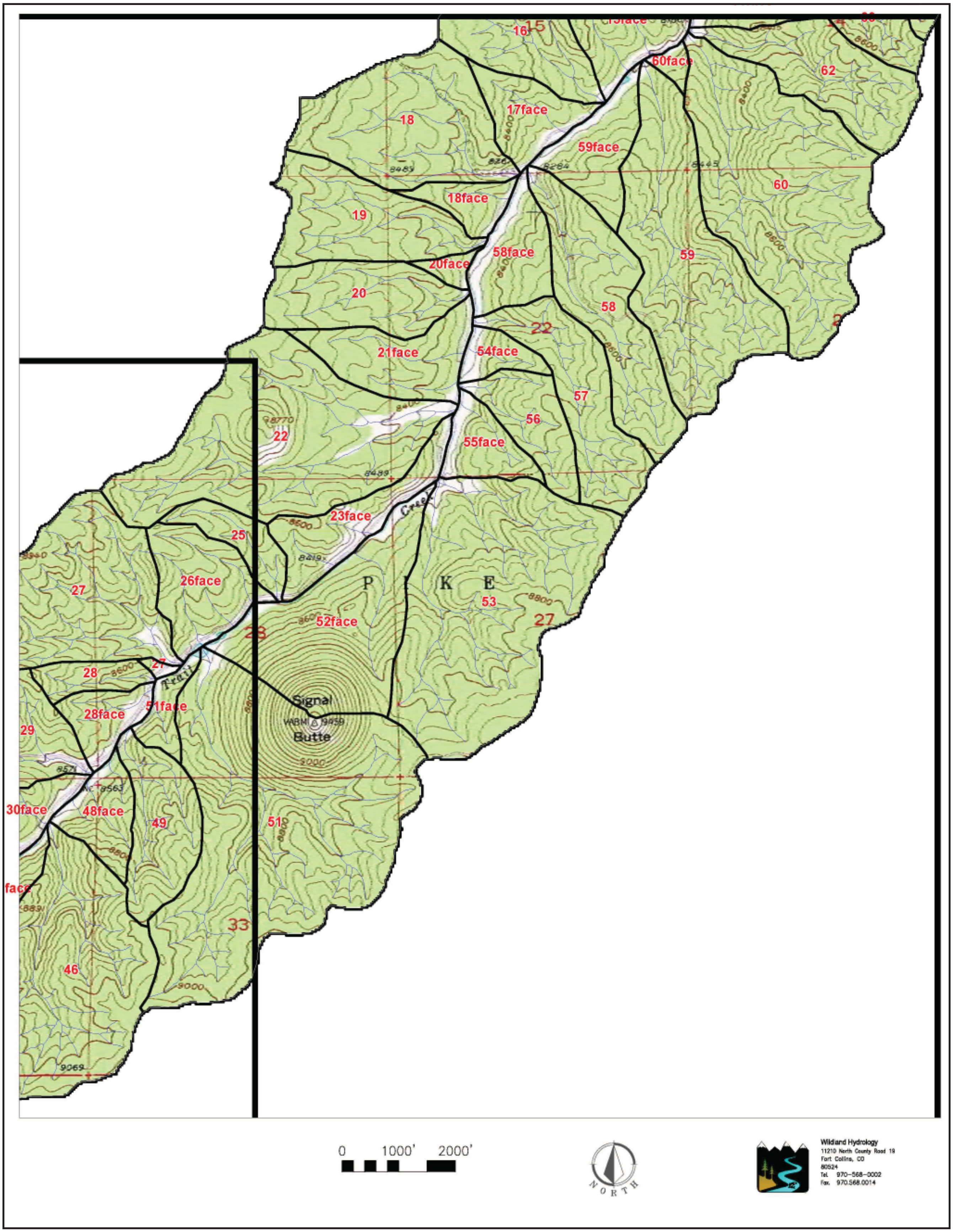


Figure 5. The sub-watershed delineation of the Trail Creek Watershed illustrating the area in "Sheet 2" in **Figure 3**.

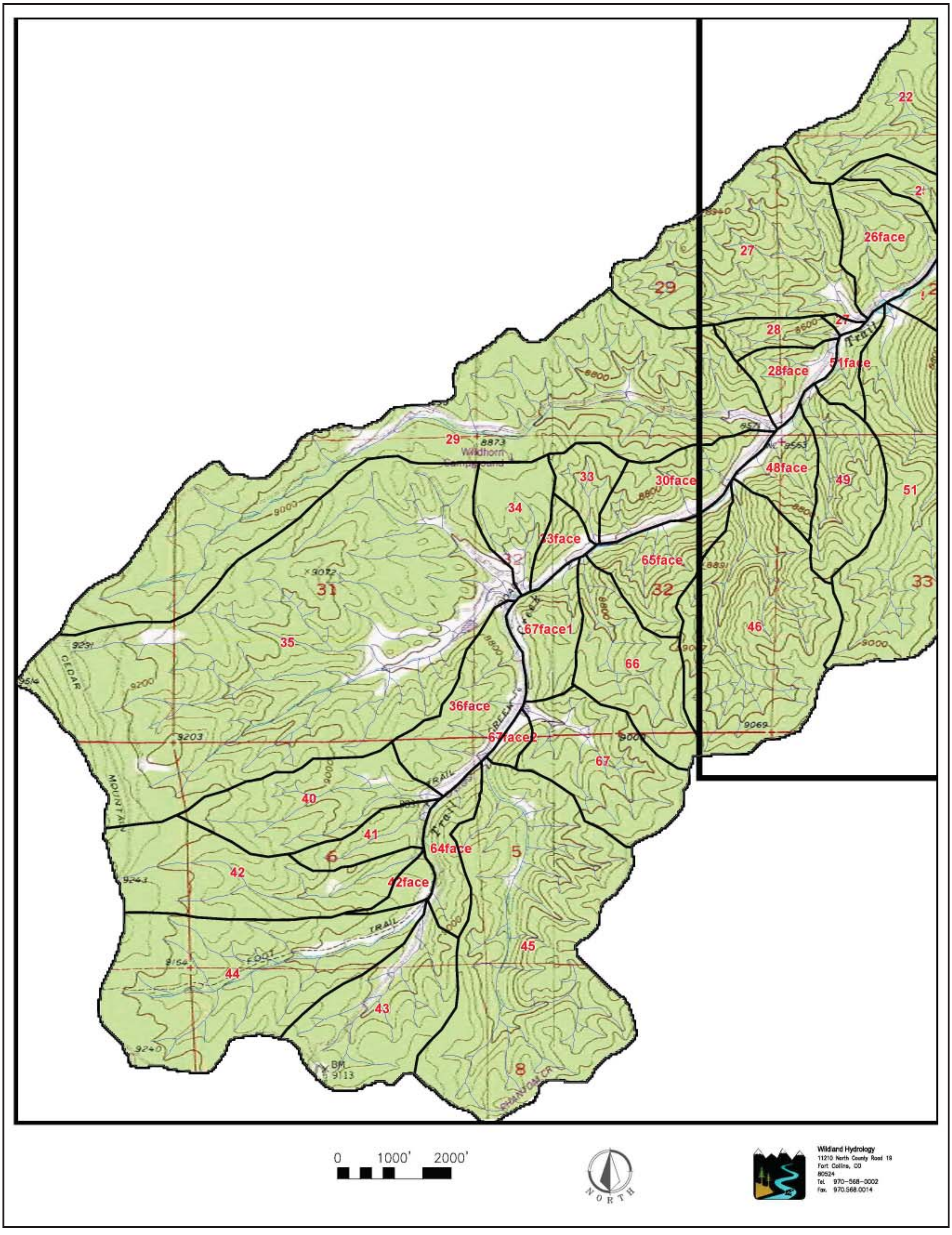


Figure 6. The sub-watershed delineation of the Trail Creek Watershed illustrating the area in "Sheet 3" in **Figure 3**.

Sediment Sources by Process

The *WARSSS* analysis identified and quantified annual sediment yields from hillslope processes (surface erosion and roads and trails), flow-related sediment from a change in hydrology due to the fire, and channel processes, such as streambank erosion, degradation (bed erosion) due to headcuts and incising channels, and the combined sediment yield of 59 individual tributaries and the mainstem Trail Creek. The summary of the sediment budget is shown in **Table 1**.

Various priorities were established for the tributaries based on the magnitude of sediment sources for a variety of land uses that were quantified. The list of priority sub-watersheds is shown in **Table 2** (Trail Creek *WARSSS* analysis, Rosgen, 2011). The 59 sub-watersheds are shown in **Figures 3–6** and their individual descriptions, mapped stream types and conditions, streambank erosion rates, and additional sources of sediment are documented in *Appendix D* of the Trail Creek *WARSSS* analysis (Rosgen, 2011, pp. D-1 to D-138).

Table 1. Summary of the total annual sediment supply by sediment source related to hillslope, hydrology and channel processes (Trail Creek *WARSSS* analysis, Rosgen, 2011).

Sediment Source	Annual Sediment Supply
Hillslope Processes	
Roads & Trails	848 tons/yr
Surface Erosion	2,542 tons/yr
Hydrology	
Pre-Fire Water Yield: Trail Creek watershed	3,689 acre-ft/yr
Post-Fire Water Yield: Trail Creek watershed	6,560 acre-ft/yr
Pre-Fire Flow-related Sediment: Trail Creek Watershed	1,250 tons/yr
Post-Fire Flow-related Sediment: Trail Creek Watershed	20,838 tons/yr
Post-Fire Flow-related Sediment Increase: Trail Creek watershed	19,588 tons/yr
Channel Processes	
Streambank Erosion	18,118 tons/yr

Table 2. The priorities representing the highest sediment supply to lowest and the impairment by sub-watershed.

Sub-watershed ID	Priority
6	1
63	2
18	3
13	4
14	5
62	6
1	7
2	8
53	9
57	10
58	11
60	12
27	13
4	14
59	15
16	16
17	17
30	18
7	19
25	20
29	21
8	22
44	23
49	24
15	25
21	26
36	27
40	28
43	29

Sub-watershed ID	Priority
67	30
65	31
56	32
66	33
19	34
35	35
10	36
11	37
22	38
26	39
33	40
41	41
42	42
46	43
5	44
9	45
20	46
23	47
34	48
47	49
51	50
54	51
55	52
64	53
12	54
45	55
48	56
52	57
28	58

Hillslope Processes

Surface Erosion

The surface erosion contributions were quantified within *100 ft* of either side of drainageways as the erosion rates would have a higher sediment delivery potential to a waterway (conveyance). The surface erosion rates were determined for each of the 59 sub-watersheds and along the main Trail Creek slopes between the tributary confluences. Approximately *12%*, or *2,542 tons/yr*, of the total sediment is related to surface erosion processes. Restoration scenarios to reduce this source are discussed within the *Restoration Plan for Hillslope Processes* section.

Roads & Trails

The sediment yields from the main access road adjacent to Trail Creek throughout the majority of its length and the off-road and trail systems were quantified. Although the acres impacted are small relative to the Trail Creek Watershed area, *848 tons/yr* from roads and trails (approximately *4%* of the total sediment) are contributing to the annual sediment yield. Because the road and trails are presently adjacent to the drainageways, the majority of soil loss is directly routed into the streams. The restoration scenarios for the roads and trails are associated with relocation, stabilization at the toe of fill slopes, and improving or reducing the number of stream crossings. Specific design criteria are presented in the *Restoration Plan for Hillslope Processes* section.

Channel Processes

Reference reaches were established to document the stable dimension, pattern and profile of these reaches stratified by stream type and valley type (see *Appendix A* in Rosgen, 2011, for valley and stream type descriptions, or Rosgen, 1994, 1996). Stability ratings were also obtained to document the existing, stable state. This data is used to extrapolate the dimensionless relations of the reference reach morphology for departure analysis when compared to unstable stream types. Thus the same analysis that is completed for each reference reach is completed for each impaired reach.

Representative reaches were also established within the Trail Creek Watershed to obtain detailed morphological data stratified by stream type and valley type to document the state of the reach. The overall stability conditions of these reaches were determined by analyzing the departure of each representative reach from the potential, stable stream type (reference reach). The results of this analysis were extrapolated to other similar reaches within the sub-watersheds and the mainstem Trail Creek.

The stream types and general stability conditions of the reaches within the sub-watersheds and the mainstem Trail Creek are documented in *Appendix D* of the Trail Creek *WARSSS* analysis (Rosgen, 2011). Streambank erosion rates in *tons/yr/ft* are also mapped for these areas.

The locations of the *reference* and *representative reaches* are identified in **Figure 7**. The detailed morphological characterization and stability analysis for each reference reach is included in *Appendix B* of the Trail Creek *WARSSS* analysis, and the detailed data for each representative reach is included in *Appendix C* (Rosgen, 2011). The fundamental relations of the reference and representative reaches are used to create various restoration scenarios that reflect proposed stream types and the corresponding appropriate dimension, pattern and profile relations.

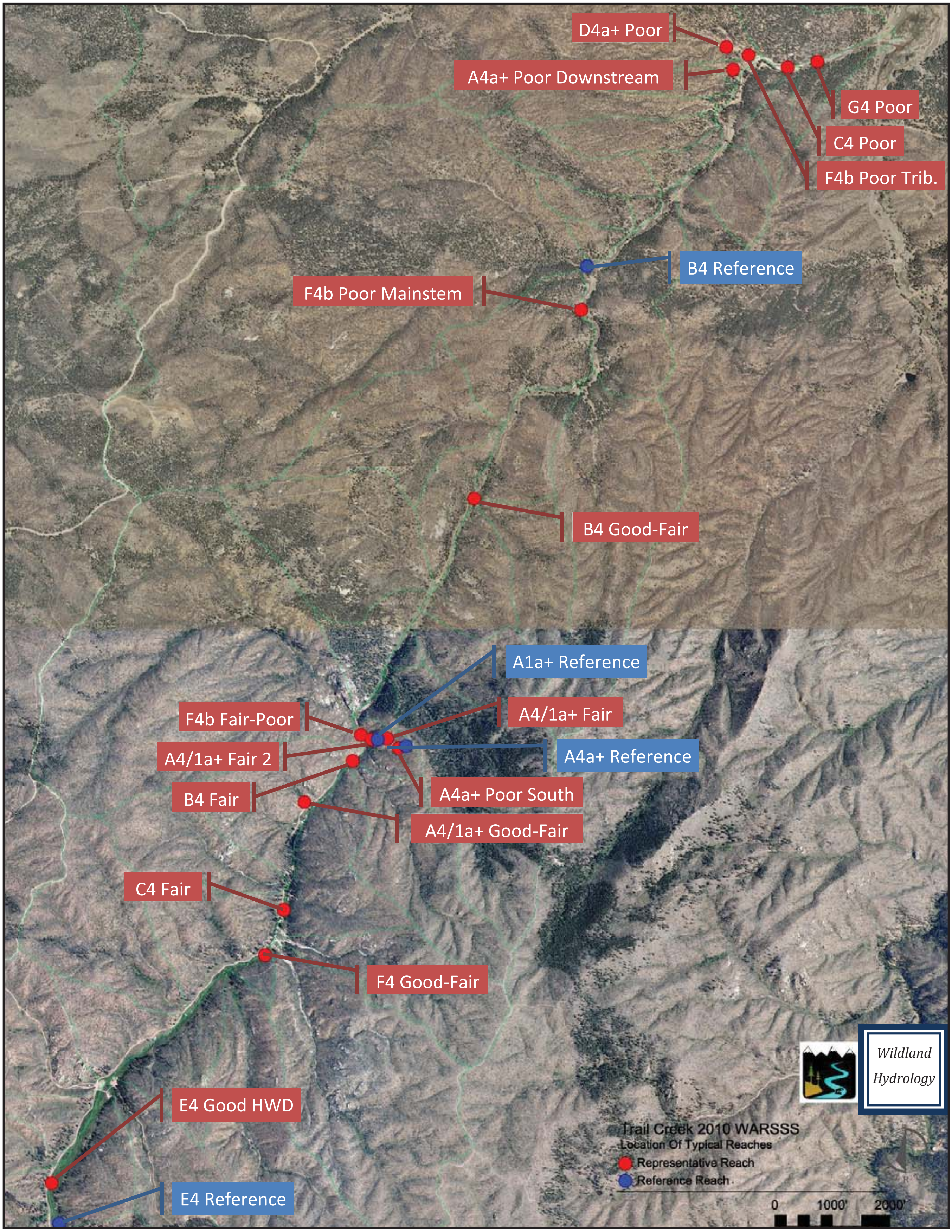


Figure 7. Location of the *reference* and *representative reaches* within the Trail Creek Watershed.

Stream Succession

The use of stream succession in design is dependent on the existing stream type and the stable potential type based on a valley type that matches the boundary conditions and the controlling variables. Stream type succession was used to interpret and predict the potential stable morphological state of the impaired reaches. The resultant stream type conversions of existing, impaired stream types to their stable form within the same valley type are shown in **Table 3** (Trail Creek *WARSSS* analysis, Rosgen, 2011). In addition, "Fair" and "Poor" condition B and C stream types can be converted to their stable condition stream type.

In several scenarios, incised tributaries on alluvial fans (Valley Type III) are presently transporting an accelerated upstream sediment supply to the mainstem Trail Creek. Alluvial fans have a natural function to store sediment from steeper gradient, high sediment supply channels by deposition on the fan surface. This occurs on typical, braided channel, D stream types that induce sediment deposition throughout their longitudinal profile. Several scenarios are to convert some A, F and G stream types to D on such alluvial fans (**Table 3**). Detailed designs for large, active alluvial fans are provided in the *Typical Design Scenarios & Restoration Details for Channel Processes* section.

On short and narrow alluvial fans, B stream types are designed because there is insufficient room for braided channels and sediment storage. The B stream types will not contribute bed and bank material to Trail Creek, but will route what is produced upstream. If the upstream conditions are reflected as a high priority for sediment reduction, then those reaches are also targeted for restoration.

Table 3. Proposed stable stream type conversions for various existing stream types by valley type for Trail Creek and its tributaries.

Existing Stream Type	Existing Valley Type	Proposed Stream Type
A4	III (short fan)	B4a
A4	III (long fan)	D4
D4	VIII	C4
F4b	II	B4
F4b	VIII	B4
F4b	III (long fan)	D4
F4b	III (short fan)	B4
F4	VIII	C4
F4	VIII (confined)	B4c
G4	VIII	B4
G4	III (short fan)	B4
G4	III (long fan)	D4
B4 "Fair" or "Poor"	VIII	Stable B4
C4 "Fair" or "Poor"	VIII	Stable C4

Channel Incision & Headcuts

Many reaches of A and G stream types are associated with active headcutting (degradation) due to the increased peak, stormflow runoff after the fire. Grade control structures are additionally designed for this process as documented in the *Structures in Natural Channel Design* section.

Streambank Erosion

Approximately *82%* of the total sediment yield (*18,118 tons/yr*) is from streambank erosion due primarily to the increased flood peaks (flow-related sediment increase), channel instability, channel encroachment due to roads, and riparian vegetation loss. Although much of this sediment is not delivered to the mouth of Trail Creek, substantial volumes are stored in the channel and made available for subsequent re-entrainment or subjected to channel incision and enlargement. Due to this extensive source, it is of high priority to initiate restoration designs that will significantly reduce this high sediment source. The BANCS model (Rosgen, 2001a, 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
2) Near-Bank Stress (NBS), or the distribution of energy against the streambank

To effectively reduce streambank erosion rates, the *High* and *Extreme* BEHI and NBS variables must be offset. First it is essential to construct the stable dimension, pattern and profile of the potential stream type. Streambank stabilization structures are then used in many instances to buy time to establish the riparian vegetation for the 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.

Restoration Design Approach, Assumptions & 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 Trail Creek *WARSSS* analysis report (Rosgen, 2011). Phases VI–X are discussed in the remainder of this report.

Restoration Assumptions

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

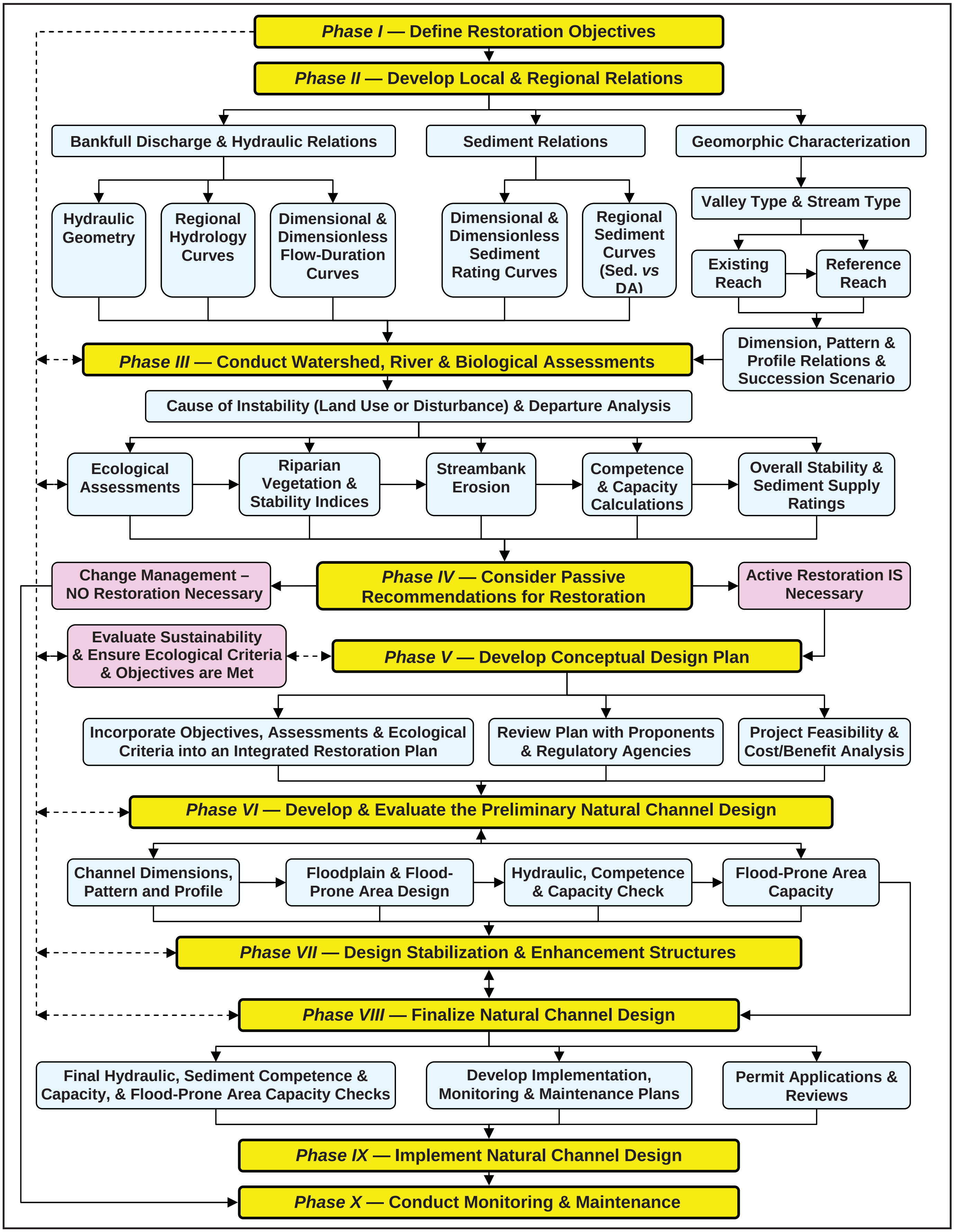
- The design plan will address the sediment sources, land uses, erosional processes and river impairment based on the output of the cumulative effects analysis using *WARSSS*.
- The *WARSSS* procedure will assist in setting restoration priorities based on quantitative determinations of process-specific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

Restoration Objectives

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

1. Reduce sediment supply from disproportionate sources identified by erosional process, land use and specific locations within the watershed
2. Quantify the sediment supply reduction by proposed restoration
3. Develop restoration scenarios that address the cause of impairment
4. Improve fish habitat diversity and function
5. Stabilize streambanks and streambeds
6. Utilize a natural channel design methodology that results in a natural appearance (aesthetics)
7. Accelerate the recovery processes from the Hayman Fire
8. Re-establish a functional riparian corridor
9. Reduce road and trail maintenance
10. Provide for improved recreational opportunities
11. Provide ecological restoration (including birds, fish, mammals and amphibians)
12. Reduce flood stage
13. Accommodate floods and reduce flooding impacts on adjacent road
14. Create cost-effective and low-risk restoration solutions
15. Be complimentary to the central tendency of natural systems
16. Provide a demonstration reach for extrapolation of similar applications
17. Provide an opportunity for research and restoration monitoring

The watershed restoration master plan and design considers the stated objectives and offers a variety of solutions for a wide range of conditions.



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

Riparian Re-establishment

Streambank stabilization and fish habitat enhancement 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. 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. Various structure designs incorporate riparian vegetation and are shown in the following *Structures in Natural Channel Design* section. Supplemental work with hand labor from volunteers can be effective in re-establishing the riparian vegetation.

Structures in Natural Channel Design

The various structures recommended are designed to reduce streambank erosion, provide grade control, dissipate excess energy, prevent headcutting, buy time for riparian vegetation, provide fish habitat enhancement, maintain floodplain connectivity, protect road fills from erosion, and generally reduce sediment supply. The structures listed in **Table 4** are recommended for use in the Trail Creek Watershed restoration for a wide variety of situations and objectives. These structures are particularly adapted to A4, B4 and C4 stream types. The G4 and F4 stream types must be converted to B4, B4c or C4 stream types before structures can be installed. The details of each of the structures in **Table 4** are described in this section.

Table 4. List of structures recommended for use in the Trail Creek Watershed restoration and their primary objectives.

<table>
<tr><th rowspan="2">Structures*</th><th colspan="6">Primary Objectives</th></tr>
<tr><th>Streambank Stabilization: NBS Reduction</th><th>Streambank Stabilization: BEHI</th><th>Habitat (In-stream Cover)</th><th>Grade Control</th><th>Visual (Aesthetics)</th><th>Energy Dissipation</th></tr>
<tr><td>Rock Vane, J–Hook</td><td>✓</td><td></td><td>✓</td><td></td><td>✓</td><td>✓</td></tr>
<tr><td>Root Wad, Log Vane, J–Hook</td><td>✓</td><td></td><td>✓</td><td></td><td>✓</td><td>✓</td></tr>
<tr><td>Rock Cross–Vane</td><td>✓</td><td></td><td>✓</td><td>✓</td><td>✓</td><td>✓</td></tr>
<tr><td>Toe Wood Structure</td><td></td><td>✓</td><td>✓</td><td></td><td>✓</td><td></td></tr>
<tr><td>“Rock & Roll” Log Structure</td><td>✓</td><td></td><td>✓</td><td>✓</td><td></td><td>✓</td></tr>
<tr><td>Rock Step–Pool Structure</td><td>✓</td><td></td><td>✓</td><td>✓</td><td></td><td>✓</td></tr>
<tr><td>Converging Rock Clusters</td><td></td><td></td><td>✓</td><td>✓</td><td></td><td>✓</td></tr>
<tr><td colspan="7">*All structures must be designed to maintain width/depth ratio, sediment transport capacity and the dimension, pattern and profile of the stable form</td></tr>
</table>

Rock Vane, J-hook

Rock vane, J-hook structures are utilized for streambank stabilization, fish habitat and energy dissipation (**Figure 8**). 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 natural rock making it adaptable to ephemeral streams and larger perennial channels. Because the availability of extensive rock is present, the costs associated this structure are reasonable and its appearance in the channel would not be unnatural.

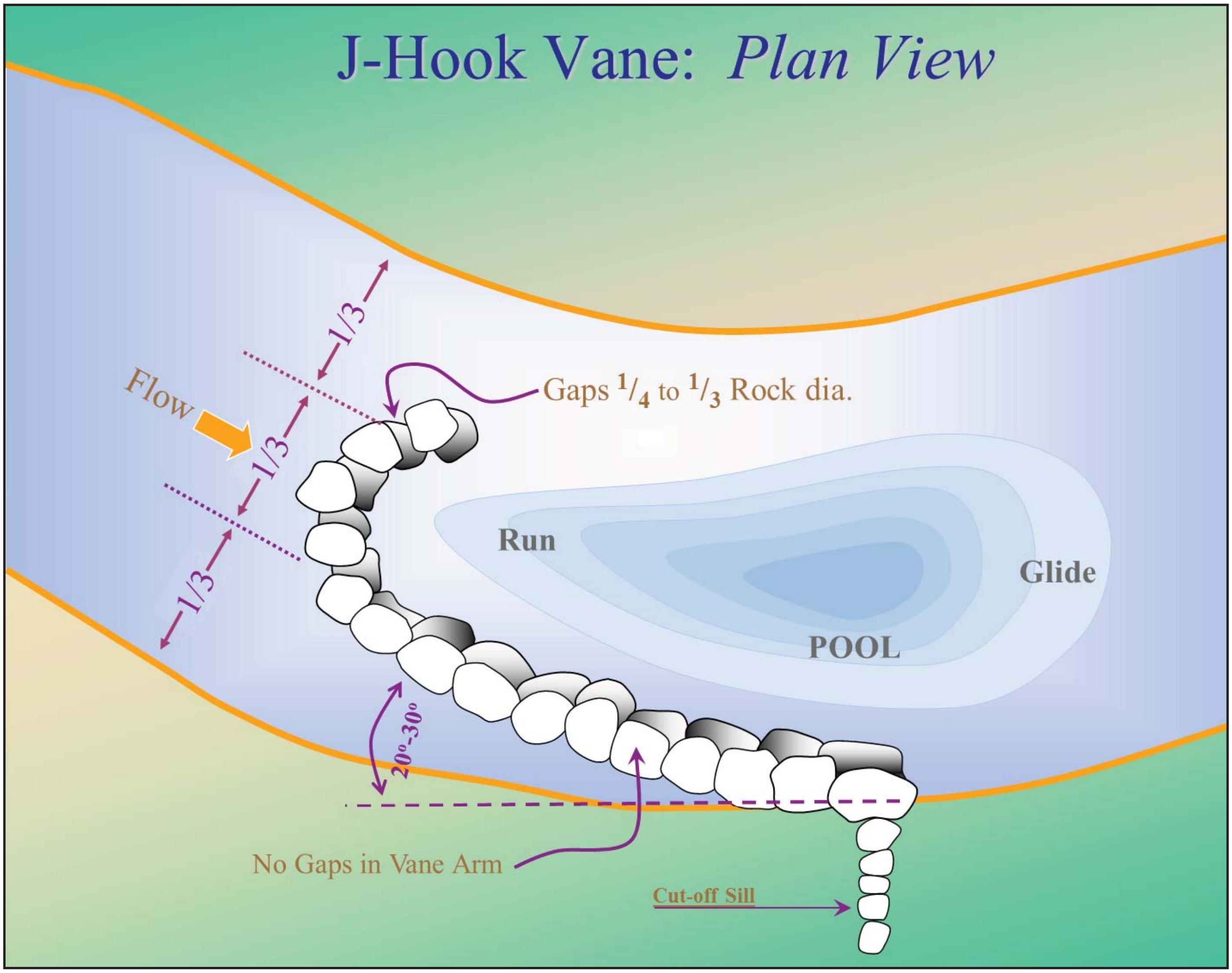


Figure 8. The rock vane, j-hook structure for streambank stabilization, fish habitat and energy dissipation.

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 9**). 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.

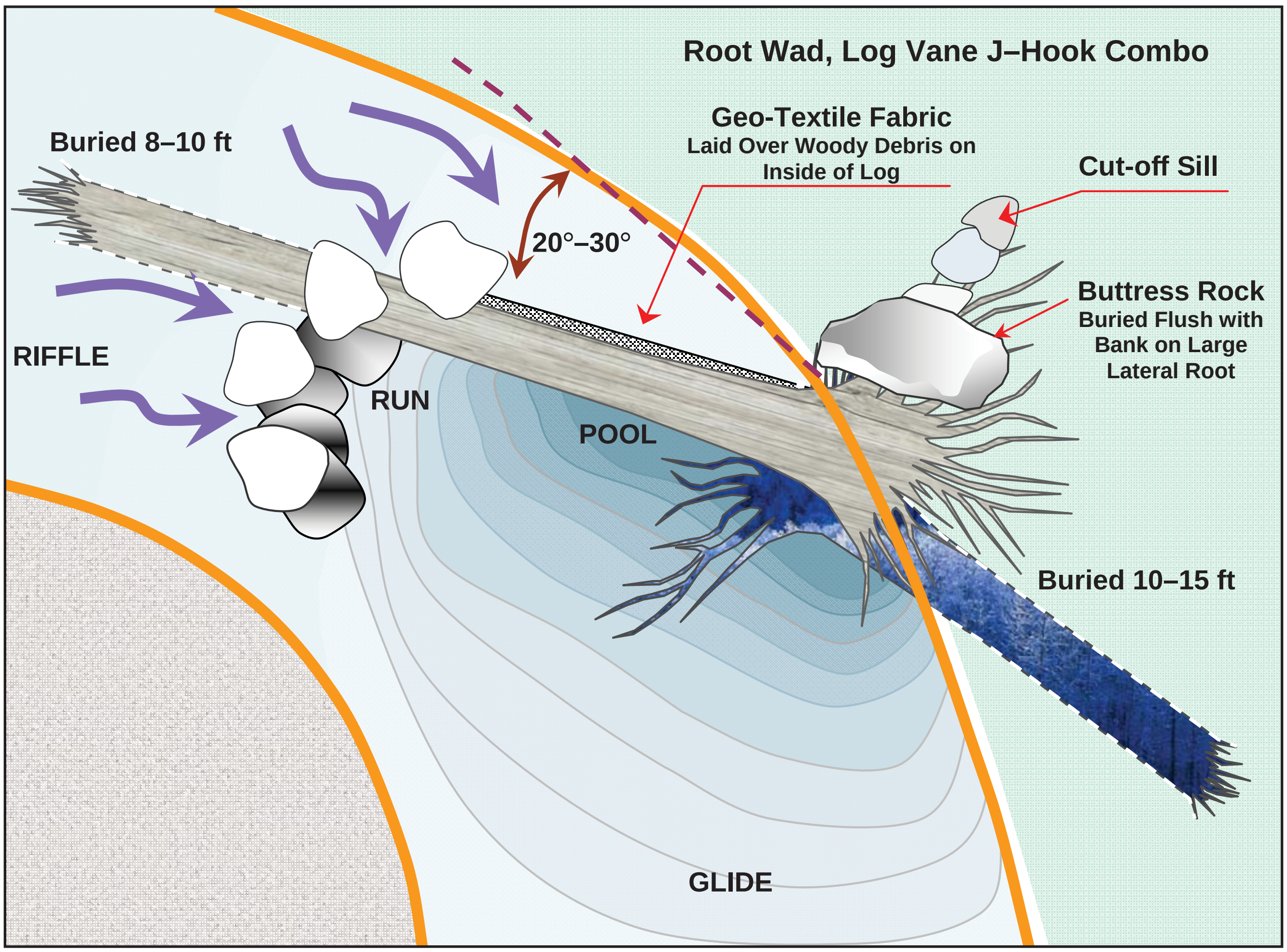


Figure 9. The root wad, log vane, j-hook structure for streambank stabilization, fish habitat and energy dissipation.

Rock Cross-Vane

The rock cross-vane structure illustrated in **Figure 10** 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 11.** The detailed design plan includes a rock cross-vane for the redesigned stream crossing on West Creek road in lower Trail Creek. An implemented cross-vane on the Little Snake River, Colorado, is shown in **Figure 12**.

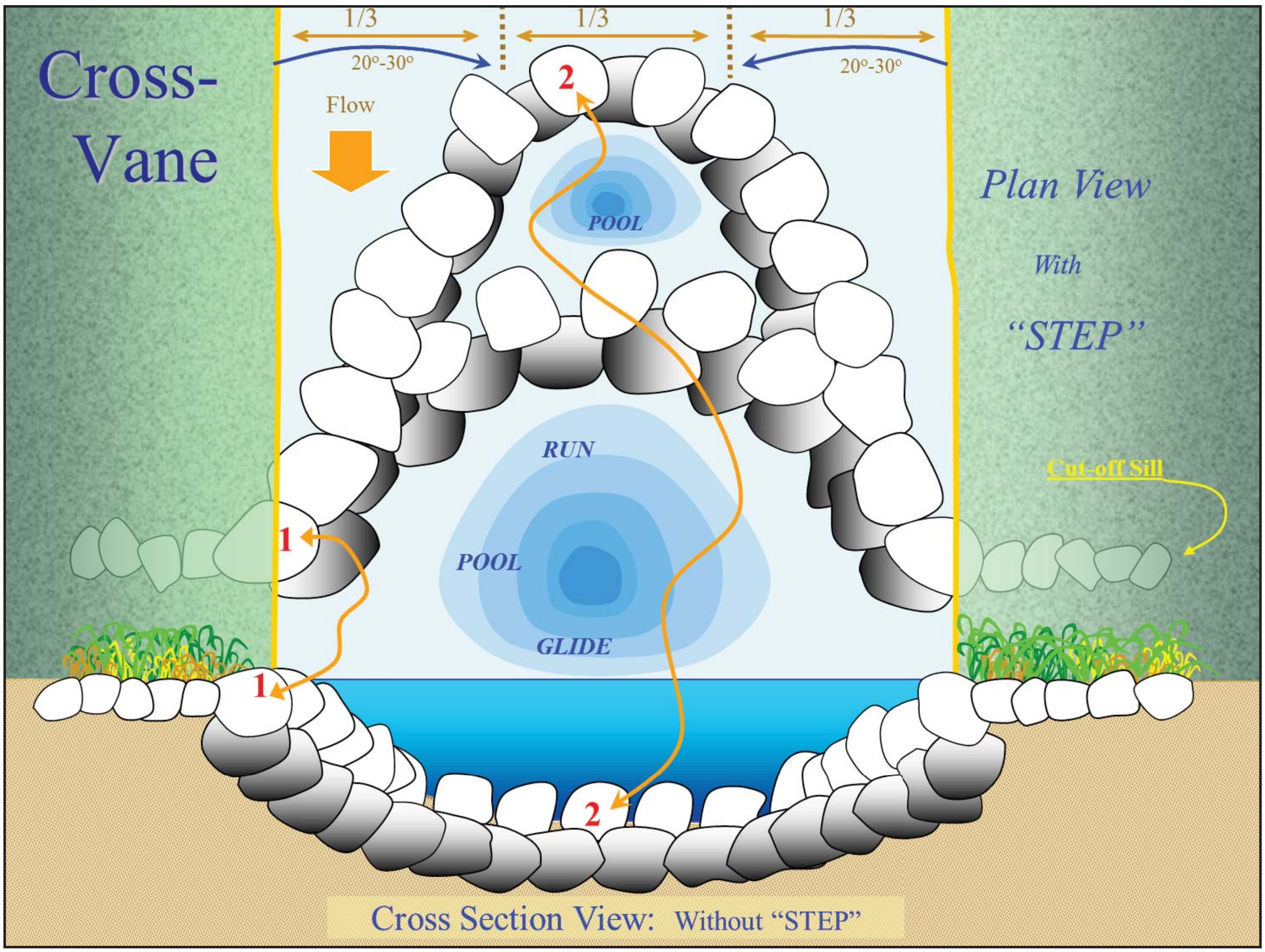


Figure 10. The rock cross-vane structure for grade control, streambank stabilization and fish habitat.

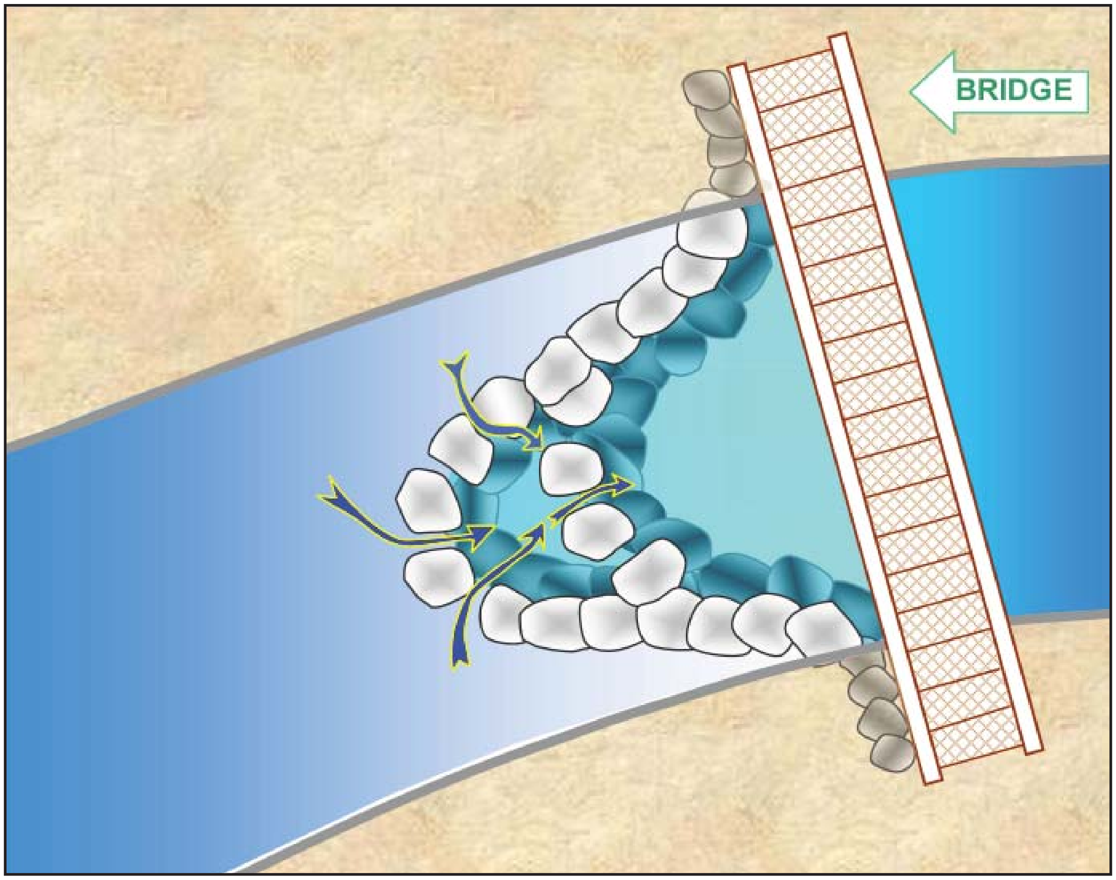


Figure 11. The application of the rock cross-vane for bridge and channel stability (Rosgen, 2001b).

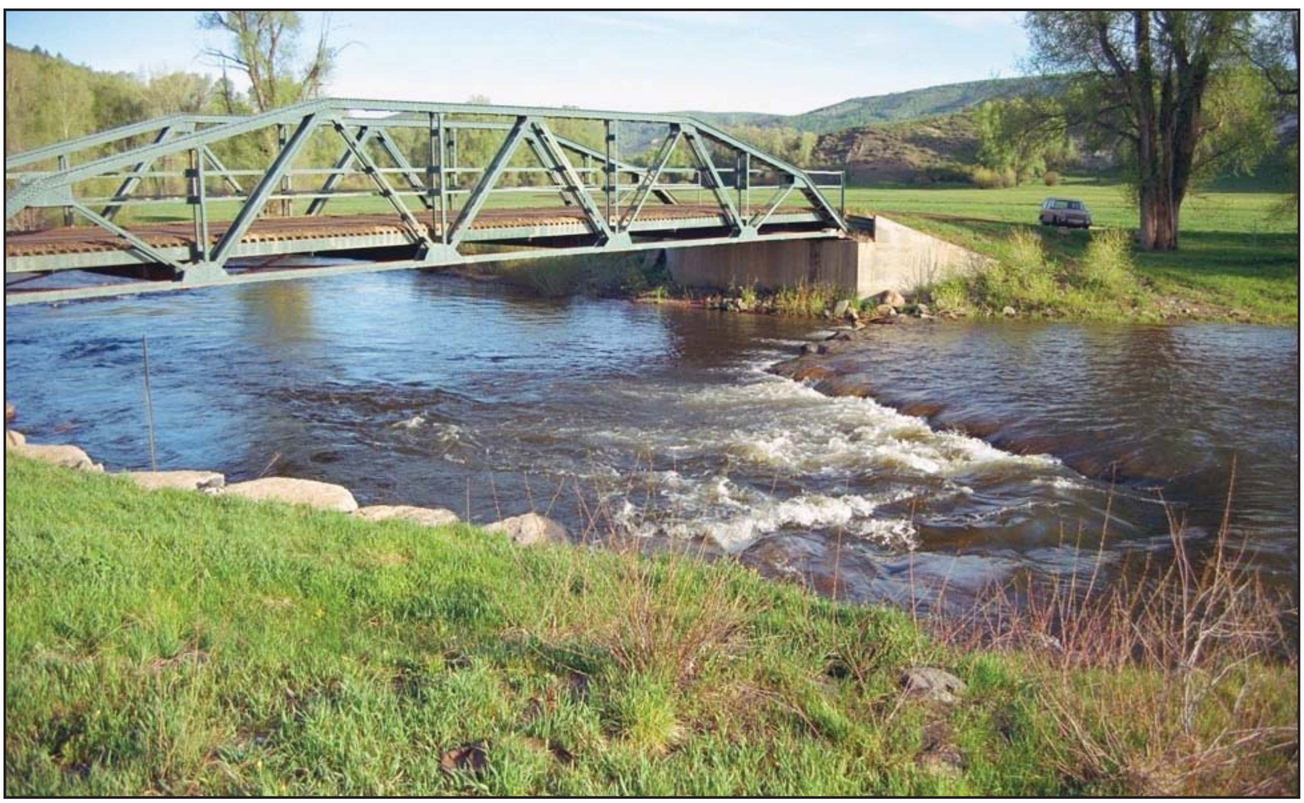


Figure 12. A rock cross-vane at a bridge crossing on the mainstem Little Snake River, Colorado.

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 over-head and in-stream 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. **Figure 13** illustrates the general concepts of the use of the toe wood structure with a constructed bankfull bench in an existing over-wide channel with eroding banks. **Figure 14** illustrates the toe wood placement prior to transplanting sod mats and woody vegetation.

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 15**). Another option uses woody transplants, such as willow, alder, cottonwood or dogwood, instead of the cuttings and sod mats (**Figure 16**). Where sod mats and woody transplants are unavailable, cuttings are used with "burrito" soil lifts as in **Figure 17**.

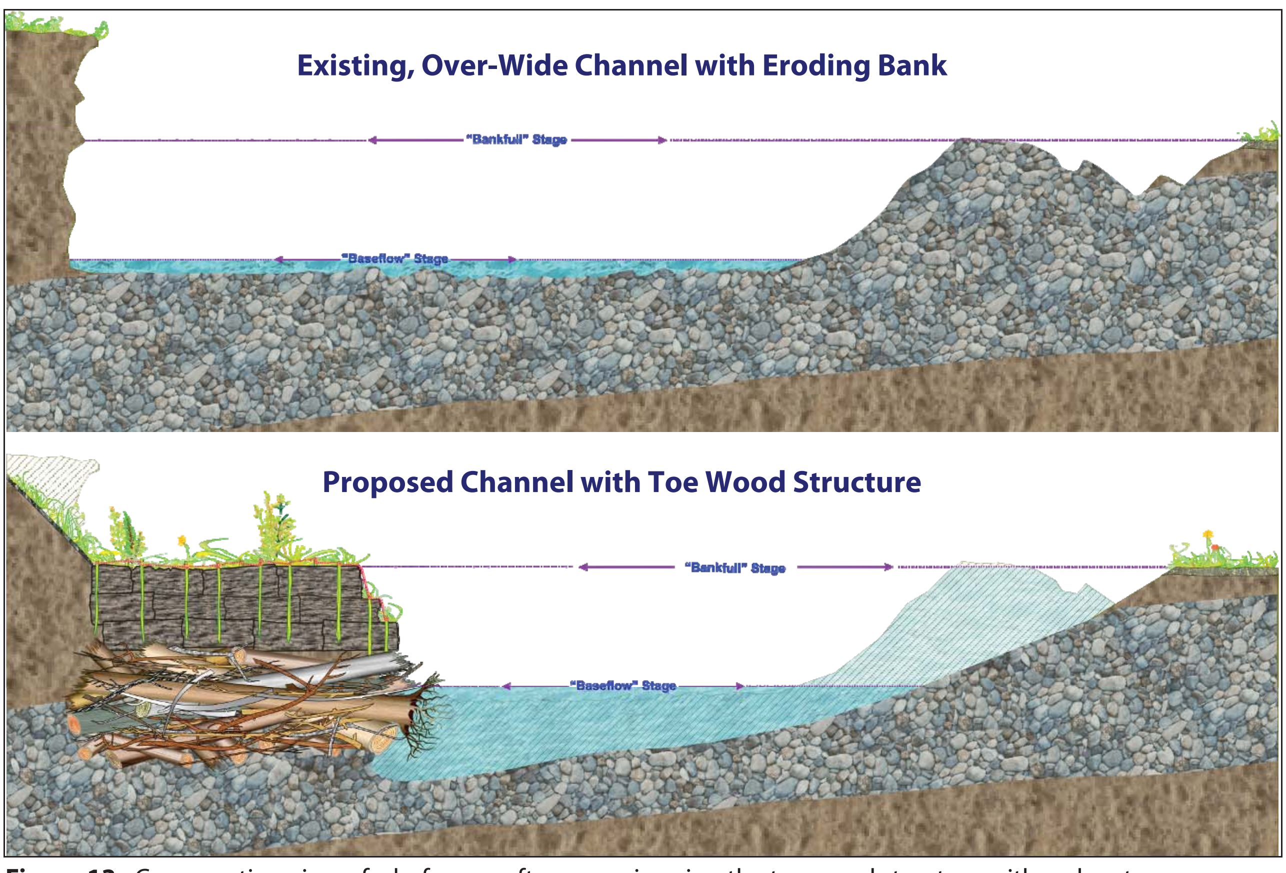


Figure 13. Cross-section view of a before *vs*. after scenario using the toe wood structure with sod mats.

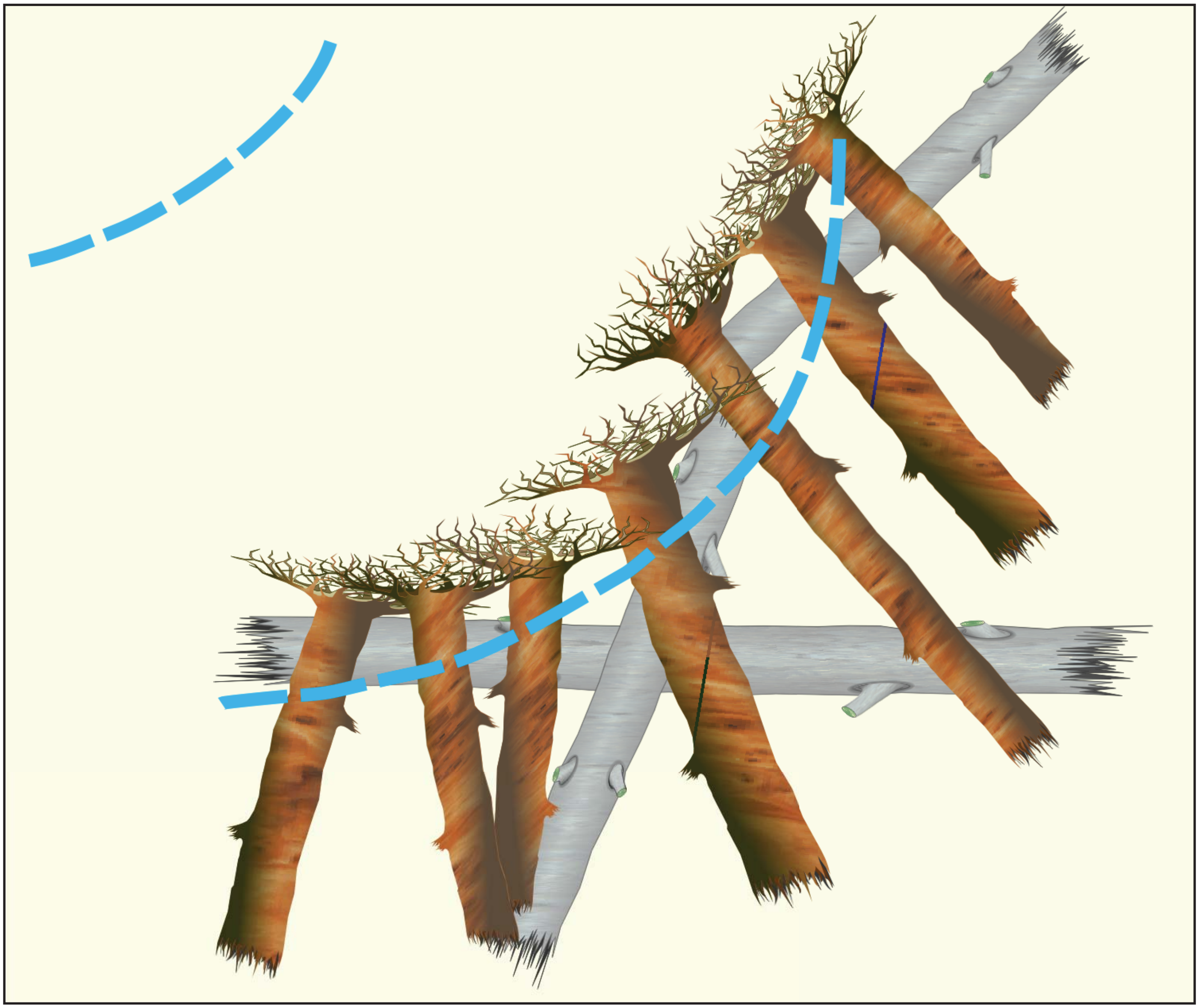


Figure 14. Plan view of toe wood placement prior to transplanting sod mats and woody vegetation (flow is left to right).

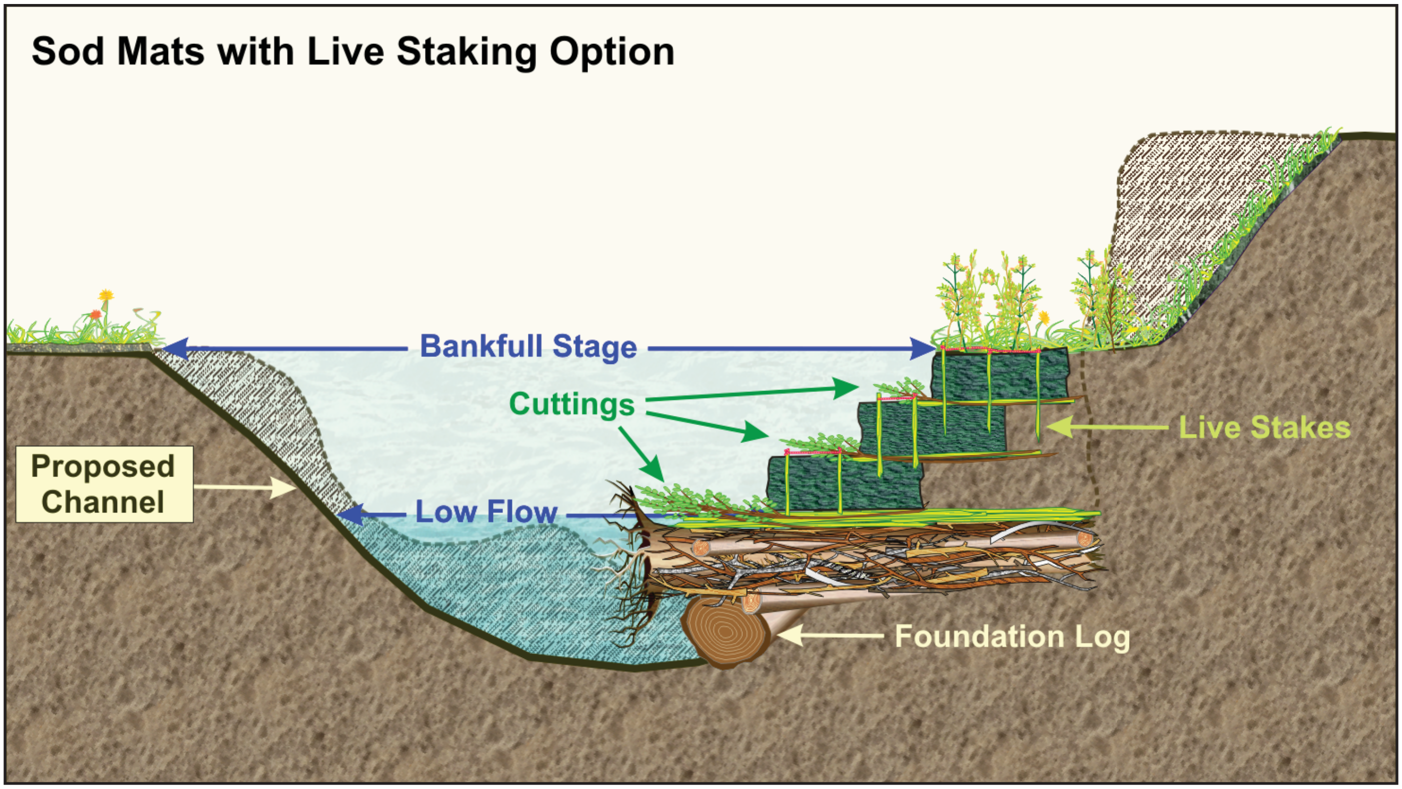


Figure 15. The toe wood structure with cuttings, sod mats and live staking.

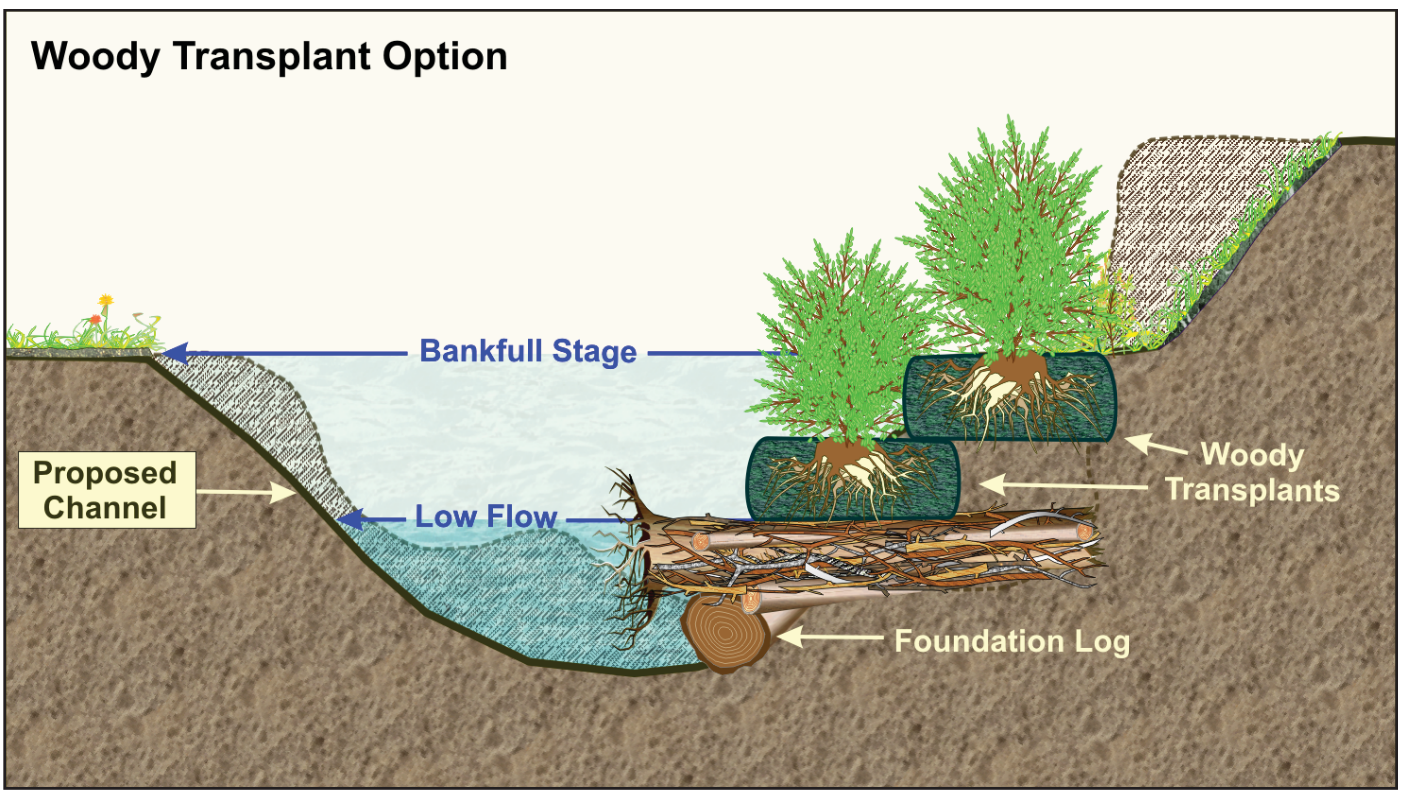


Figure 16. The toe wood structure with woody transplants.

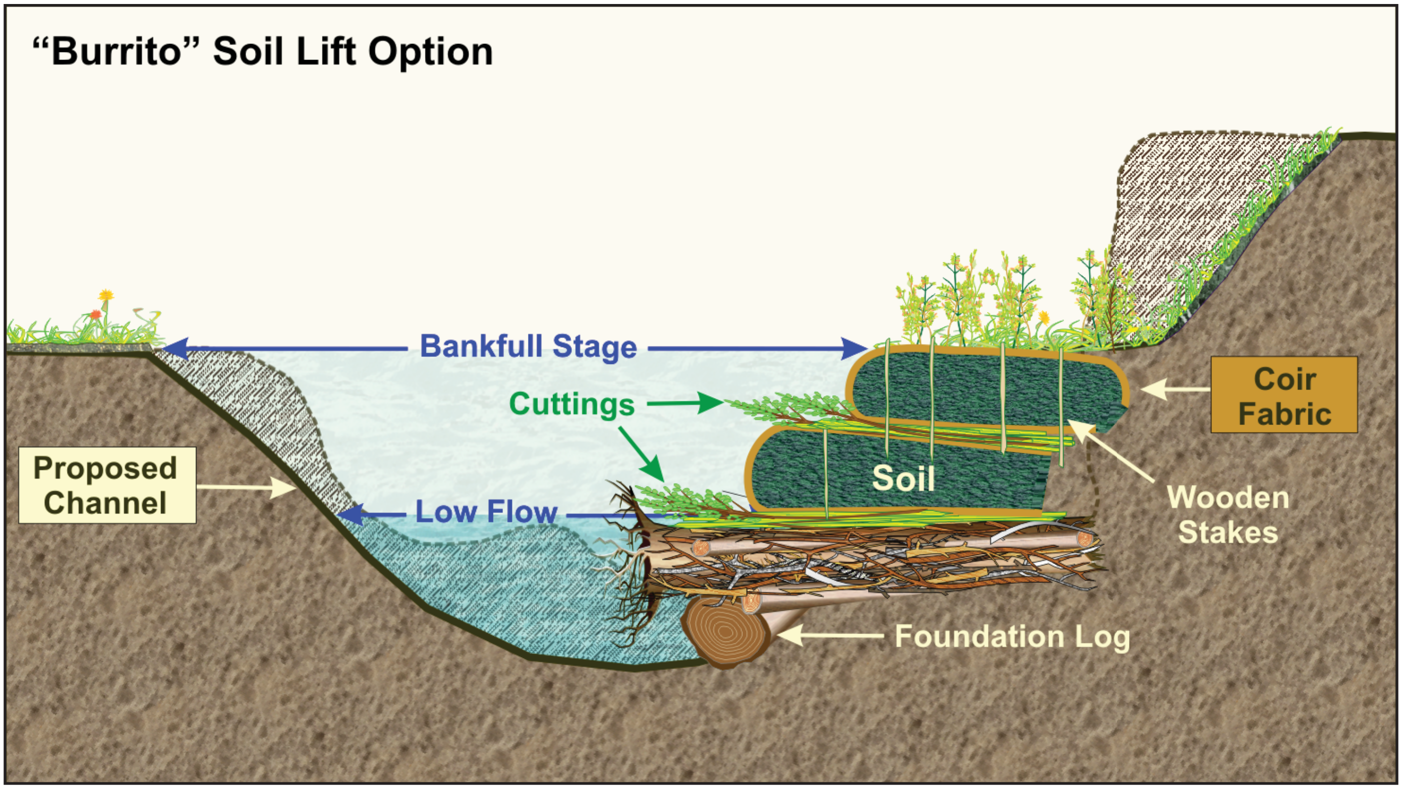


Figure 17. The toe wood structure with cuttings and "burrito" soil lifts.

"Rock & Roll" Log Structures

The "Rock & Roll" log 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 "Rock & Roll" log structure is shown in **Figure 18** as implemented on a Colorado river, and a schematic of the structure is depicted in **Figure 19**.

Figure 18. The "Rock & Roll" log structure implemented on the Roaring Fork of the Little Snake River, Colorado.

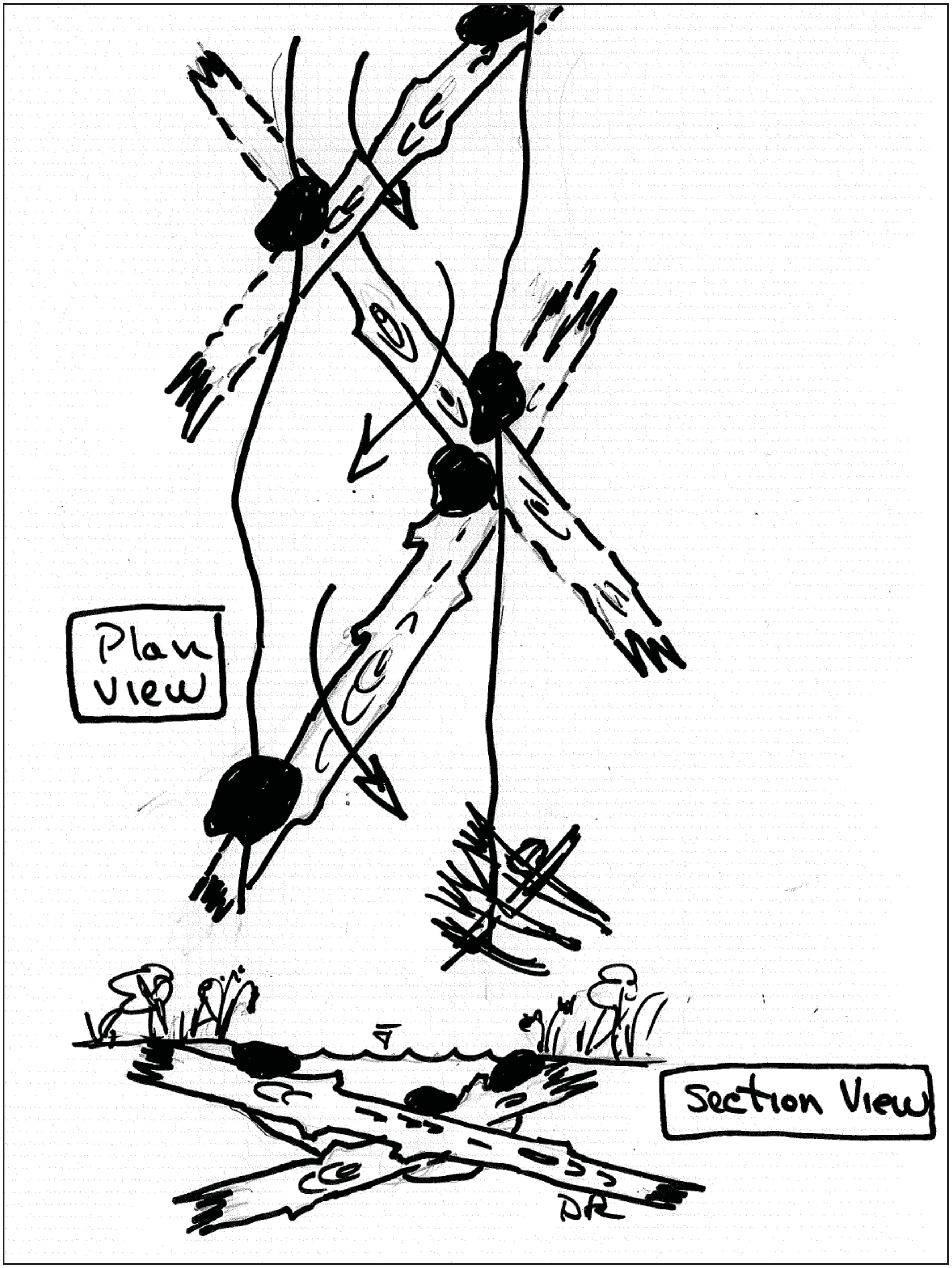


Figure 19. "Rock & Roll" log structure for grade control, energy dissipation, streambank stabilization and fish habitat.

Rock Step–Pool Structure

The 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 20**.

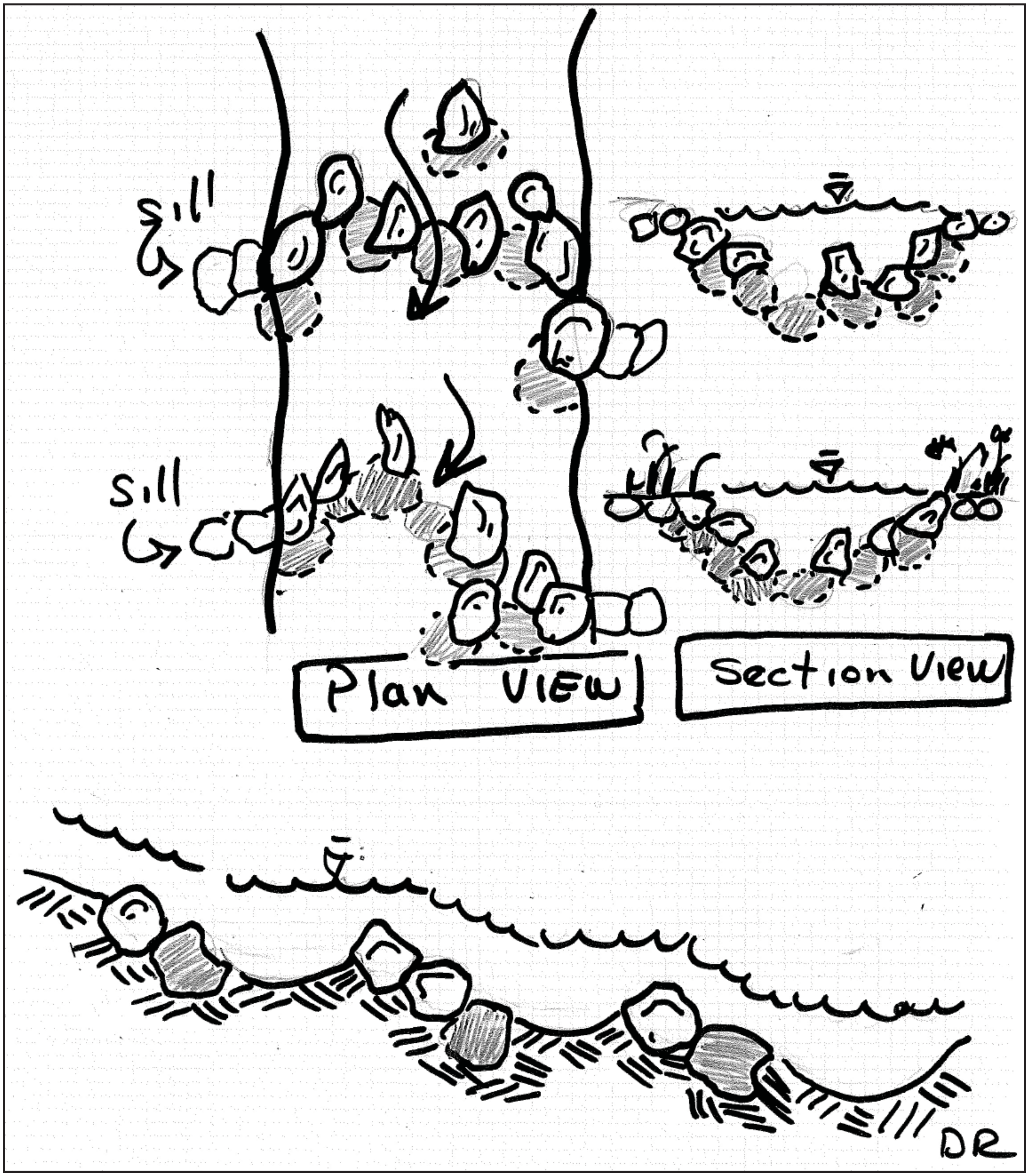


Figure 20. Rock step–pool structures for grade control, energy dissipation, streambank stabilization and fish habitat.

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 21**, and the structure design is illustrated in **Figure 22**.

Figure 21. Converging rock clusters at the head of a riffle as implemented on Ohio Creek, Colorado.

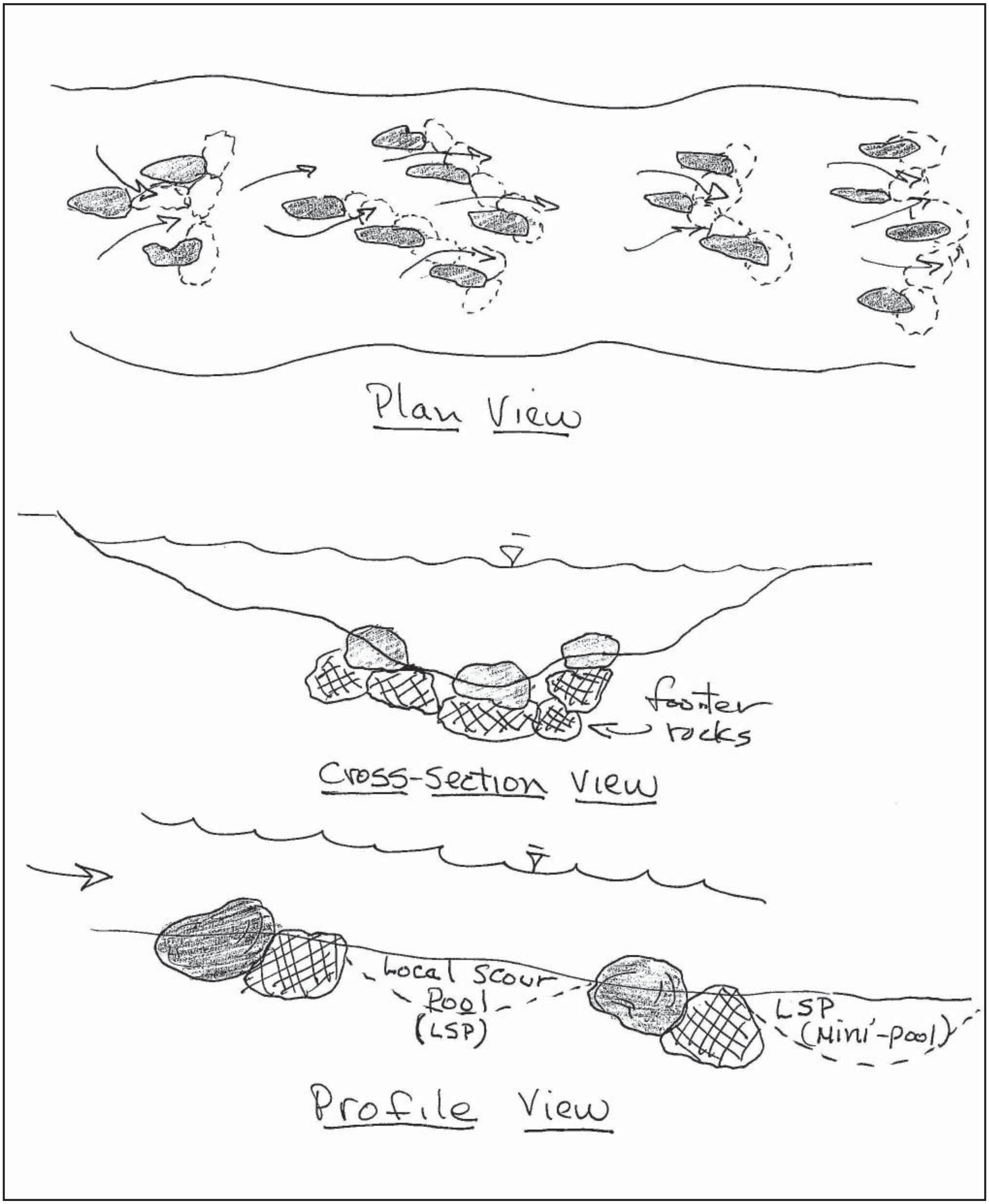


Figure 22. The plan, cross-section and profile views of the converging rock clusters.

Restoration Plan for Hillslope Processes

Surface Erosion

Surface erosion reduction is planned within the *100 foot buffer* to existing streams because this zone has the highest probability of delivered sediment. The highest priorities are also set adjacent to perennial channels. The annual sediment contribution of approximately *2,542 tons/yr* makes this effort worthwhile (*see* Trail Creek *WARSSS* analysis, Rosgen, 2011, for surface erosion contributions by sub-watershed). The following recommendations are designed to reduce this sediment source.

Increase Ground Cover

Because ground cover density is directly related to erosion rates and sediment supply (*see* Trail Creek *WARSSS* analysis, Rosgen, 2011, *Figure 57*, p. 48), any sites with a ground cover density less than *40%* will need treatment. Treatment includes reseeding with a grass hay or straw mulch surface. Adding debris, such as small logs, tops and branches, will also help reduce soil loss transport. The highest priorities for treatment are on slopes adjacent to perennial streams. The locations of the lowest ground cover density based on burn intensity for each sub-watershed are also zones of highest priority for surface erosion contributions.

Construct Bankfull Benches

Where sufficient space allows, constructing a bankfull bench against the toe of the slope is recommended rather than allowing the sediment to be routed directly into the stream channel (**Figure 23**). The bench is most appropriate adjacent to B and C stream types. The materials for the entire bench width and length are generated from borrow sites as illustrated in **Figure 23**. The borrow sites can also be used as a sediment detention basin. It is also necessary to establish vegetation on the bench to add as a potential sediment filter and sediment catch. Native bunchgrasses, such as big mountain brome, are appropriate species for the bench as these sites are not typically in wetland areas. The design requires approximately *89* yds^3 of fill per *100 ft* of constructed bench based on a bench width of *12 ft* and a mean depth of *2.0 ft*. Thus the borrow depression would be sufficiently deep and spaced to provide the needed fill. There is a net balance of cut and fill by design.

Surface Erosion Summary

It is anticipated that at least *50%*, or *1,270 tons/yr*, can be reduced by increasing ground cover to above *65%* and by installing benches and establishing riparian vegetation on stream-adjacent slopes that are contributing to sediment delivery from surface erosion.

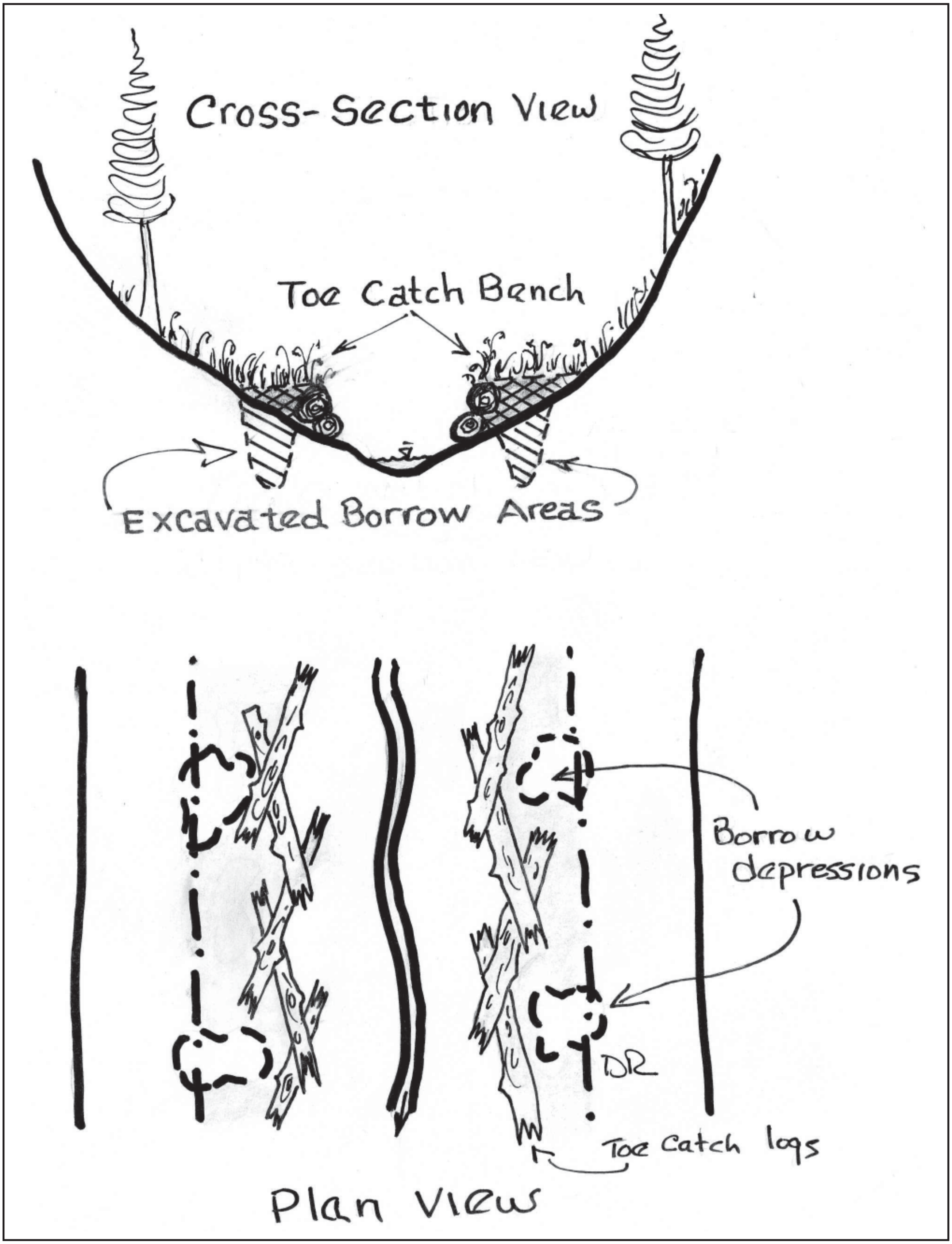


Figure 23. The "toe catch" bankfull bench to decrease surface erosion indicating the borrow depression areas and placement of toe catch logs.

Roads & Trails – The Trail Creek Road

The *WARSSS* assessment indicated that the mainstem Trail Creek road contributes approximately *589.9 tons/yr* of delivered sediment compared to the total of *848 tons/yr* from the trails, off-road 4x4 roads systems and the mainstem Trail Creek road. To reduce sediment sources, the reduction of stream crossings on the Trail Creek road is directly related to the Road Impact Index (RII = road density multiplied by the number of stream crossings by slope position). The following sections discuss the road-related activities and proposed mitigation and stabilization recommendations.

Reduce the Number of Fords (Stream Crossings)

To reduce the delivered sediment and erosional debris from the Trail Creek road directly into Trail Creek, decreasing the *number* of stream crossings is recommended. Relocating the main Trail Creek road in two major locations will potentially reduce six crossings. **Figure 24** depicts the proposed relocation of the road and channel to reduce two stream crossings. Plan and cross-section views comparing the existing road and channel locations *vs*. the proposed road and channel relocations are shown in **Figure 25**. The streambank erosion and sediment supply is very high at this location where the existing channel is undercutting a steep, erodible slope for hundreds of feet. The proposed design positions the channel on the opposite side of the steep slopes and also stabilizes the actively eroding slope. The proposed channel is placed within a floodplain with existing riparian vegetation where the road is presently located. The proposed stream type for this location is a C4 channel (proposed design details for a C4 stream type are included in the *Typical Design Scenario 5: C4 Poor to C4 Stable Conversion* section).

A schematic photograph overlay in **Figure 26** depicts the new location of Trail Creek and the road. The new channel will be excavated and toe wood will be placed as shown (with subsequent fill and vegetation transplants) to stabilize the streambanks from the newly placed fill. The road will be relocated and raised above the floodplain where the channel previously was located. Note the existing toe erosion of the slope from the channel that will be stabilized with the road placement.

The sequencing of the restoration involves excavating and placing structures in the proposed new channel location first, then turning the water into the new channel before placing fill for the new road. The new road location will then have fill placed adjacent to the eroding side slope undercut by Trail Creek. This will counter-buttress the toe of the slope, stabilize the slope, and reduce the existing very high sediment supply in this reach. The fill required for the new road is *3,333 yds*^{3}. The amount of excavation of the new channel currently occupied by the road is *622 yds*^{3}. The fill required to construct the new floodplain is *380 yds*^{3}. The balance of *3,091 yds*^{3} of fill will be end-hauled from the excavation generated from the mouth of lower Trail Creek in the proposed *Typical Design Scenario 1: D4 to C4 Stream Type Conversion*. Any remaining fill from the lower river reach will be placed at the toe of previously eroded alluvial fans in the vicinity. Overall, this proposal eliminates two ford crossings and will greatly reduce the existing streambank erosion.

Insert 11 x 17 Figure 24 Here

Figure 24. The proposed location to eliminate two stream crossings by relocating the Trail Creek road and channel to reduce the existing high sediment supply and streambank erosion.

Insert 11 x 17 Figure 24 Here

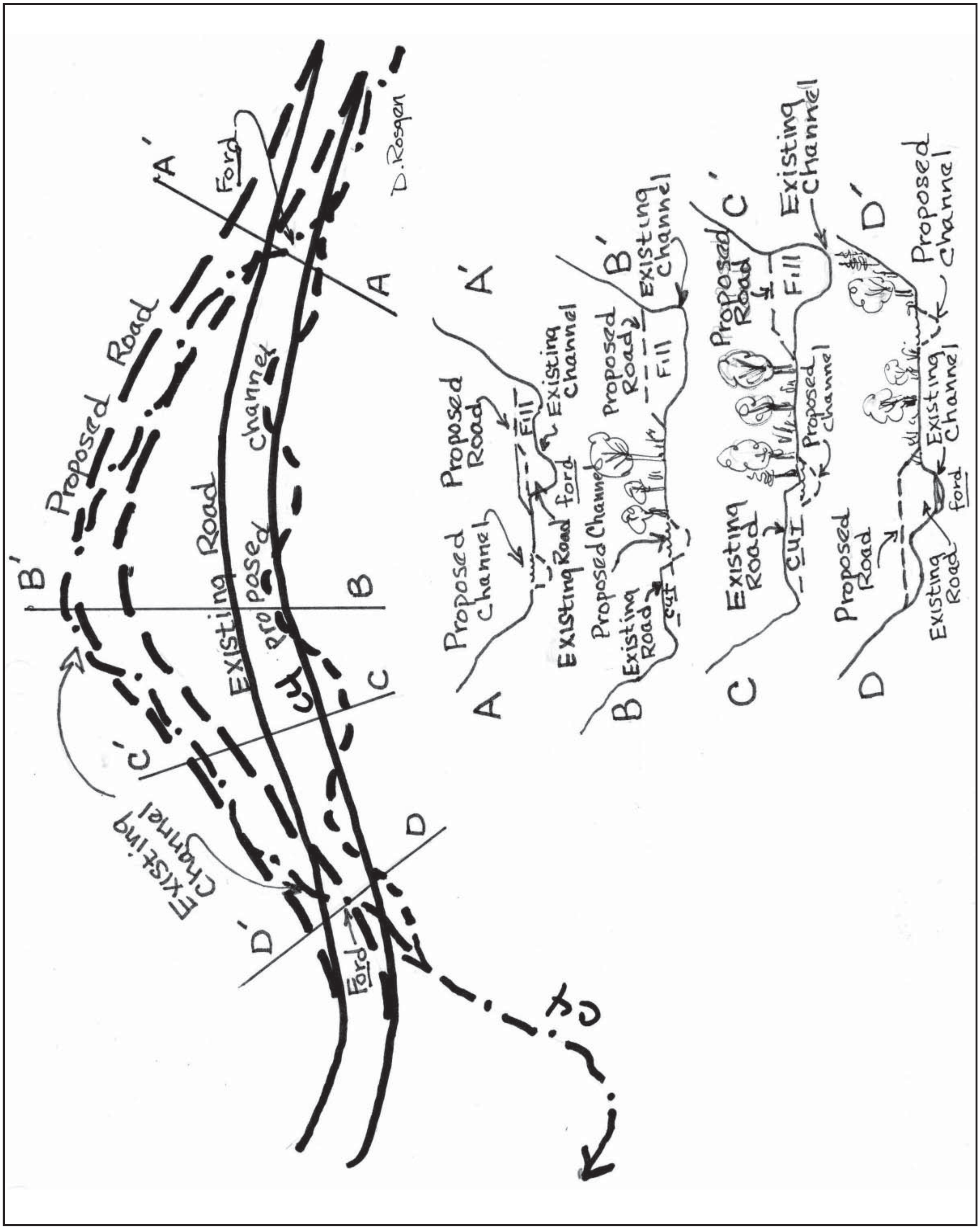


Figure 25. The proposed relocation of the road and channel to eliminate two stream crossings for the location in **Figure 24**.

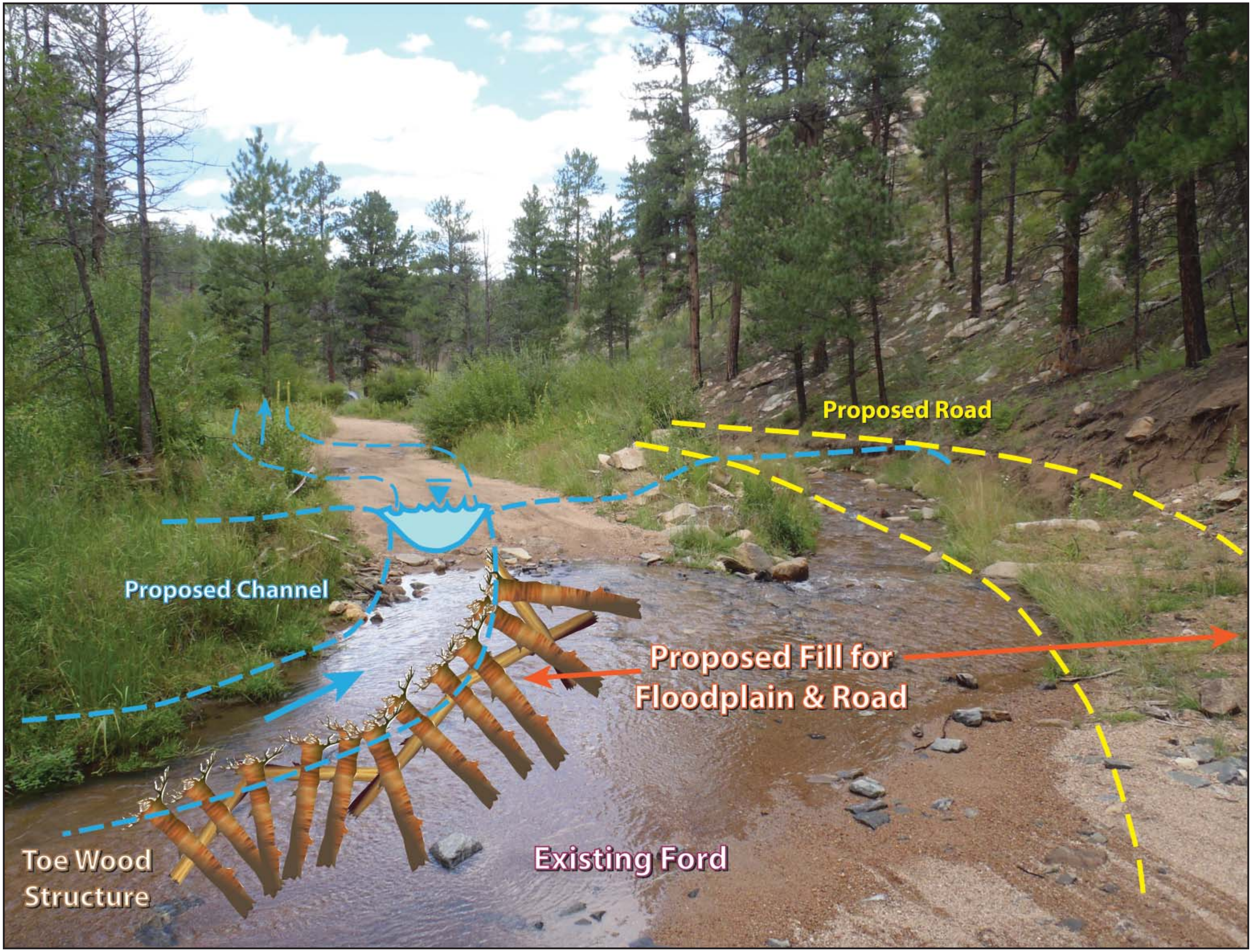


Figure 26. Schematic photo overlay of the proposed stream and road relocations as depicted in **Figure 24**.

Reduce the Number of Fords (Stream Crossings), Continued

The second location relocates the existing Trail Creek to eliminate four crossings. Plan and cross-section views are shown in **Figure 27** and **Figure 28** that compare the existing channel location *vs*. the proposed channel relocation to eliminate the four existing stream crossings. The existing channel is presently an F4b stream type with a high sediment supply and streambank erosion. The proposed stream type for this location is a B4 channel (proposed design details for a B4 channel are included in the *Typical Design Scenario 2: F4 to B4 Stream Type Conversion* section). The existing channel is also undercutting a steep, erodible slope. The proposed design stabilizes the steep slope and positions the channel on the opposite side of the steep slope within existing vegetation and a floodplain alongside the road. The new channel will be excavated and stabilized with toe wood and rock structures. Riparian vegetation will be transported and cuttings will be placed along the new channel.

The sequencing of the restoration is similar to the previous road relocation scenario, and the proposed design will greatly reduce the very high sediment supply in this reach. The proposed rerouting of Trail Creek to reduce four stream crossings will involve approximately *240* yds^3 of fill for the road prism and *266* yds^3 of excavation for the new channel. The cut from the channel will be used to fill the fords along the road.

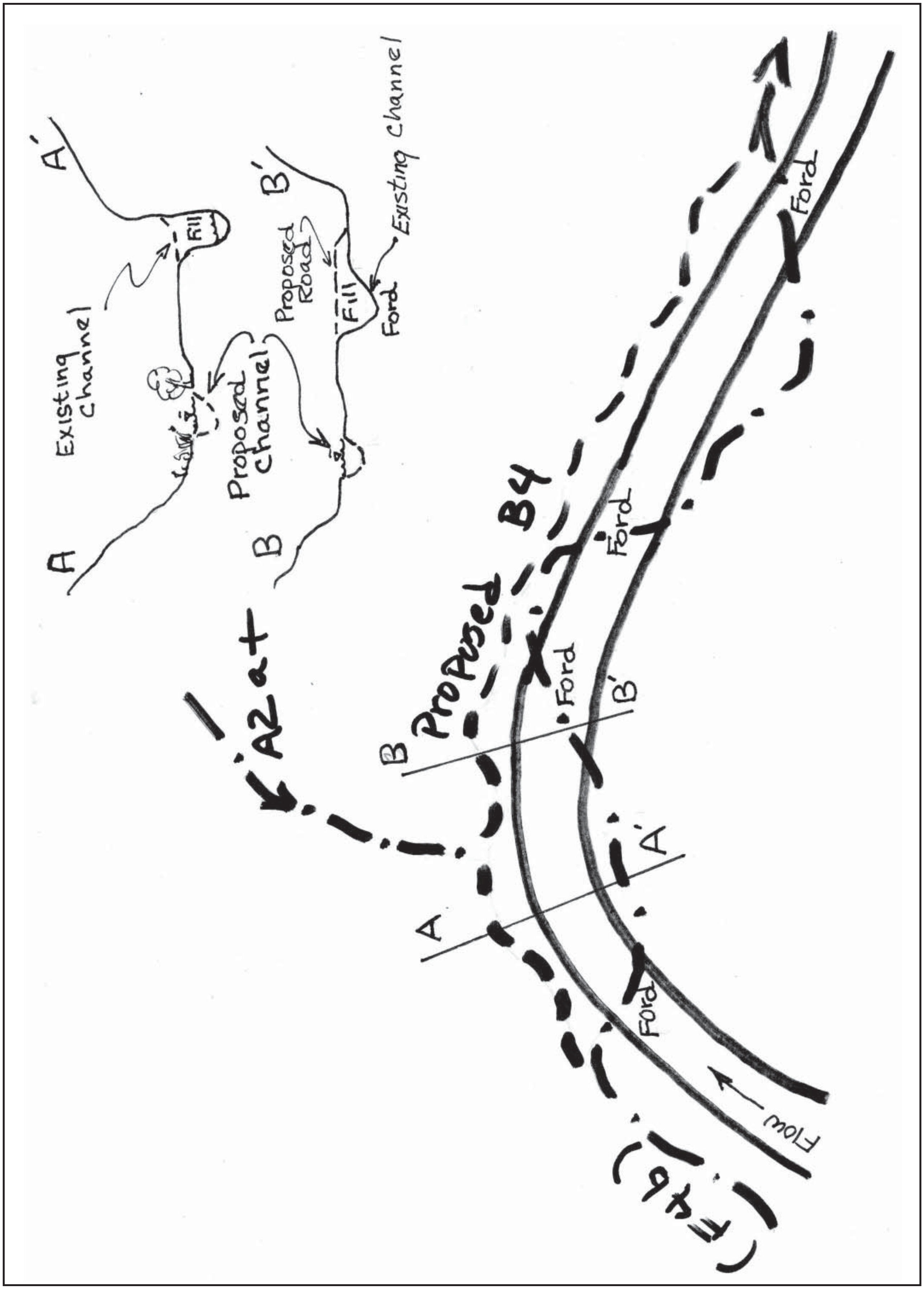


Figure 27. Proposed rerouting of Trail Creek to eliminate four stream crossings for the location in **Figure 28**.

Insert 11 x 17 Figure 28 Here

Figure 28. The proposed location to eliminate four stream crossings by relocating Trail Creek to reduce the existing high sediment supply and streambank erosion.

Insert 11 x 17
Figure 28 Here

Fill Erosion

To reduce the fill erosion along many actively eroding road fill sites that are responsible for direct sediment contributions to Trail Creek, 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) 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 Trail Creek from eroding the fill material

Road Surface & Ditch-Line Erosion

Recommended practices are to surface the road, but being cost-prohibitive for this class of road, alternative techniques to improve the surface drainage are recommended 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 ditch-line surface
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 and sediment deposition

Headcut Channels Intercepted by Road

Recommended practices are to stabilize the channel headward and downslope by step–pool grade control to help stabilize road adjacent channels. This will help reduce the current high maintenance of sediment deposition on the road surface and will prevent "over-steepening" of the channel at the toe of the road.

Increase Maintenance Frequency

Reseeding and grading the road surface to reduce surface rills and maintain drainage features are recommended.

Trail Creek Road Summary

It is anticipated that the aforementioned recommendations can effectively reduce the existing sediment yield from the Trail Creek road by approximately *413 tons/yr*, representing a *70%* sediment reduction.

ORV Roads & Trails

The Trail Creek *WARSSS* analysis contained many locations where, due to the location of the roads and trails that parallel and cross the channels in the Trail Creek Watershed, it is recommended to relocate the majority of these systems away from the drainage proximities. Based on the immediate proximity of the ORV roads and trails to the adjacent channels and their steepness, it would be extremely difficult with a poor likelihood of success to institute sediment mitigation on these systems. The proposed recommendation to reduce the sediment yield is to relocate the high risk roads and trails that are frequently introducing direct sediment. The current road and trail systems in the Trail Creek Watershed are shown in **Figure 29**. The recommended relocations of the high risk systems are shown in the watershed maps in **Figure 30**, **Figure 31**, and **Figure 32**. The proposed ridge routes are available and feasible for these trails without changing their origin or destination sites. This recommendation can reduce nearly *200 tons/yr* of delivered sediment to Trail Creek.

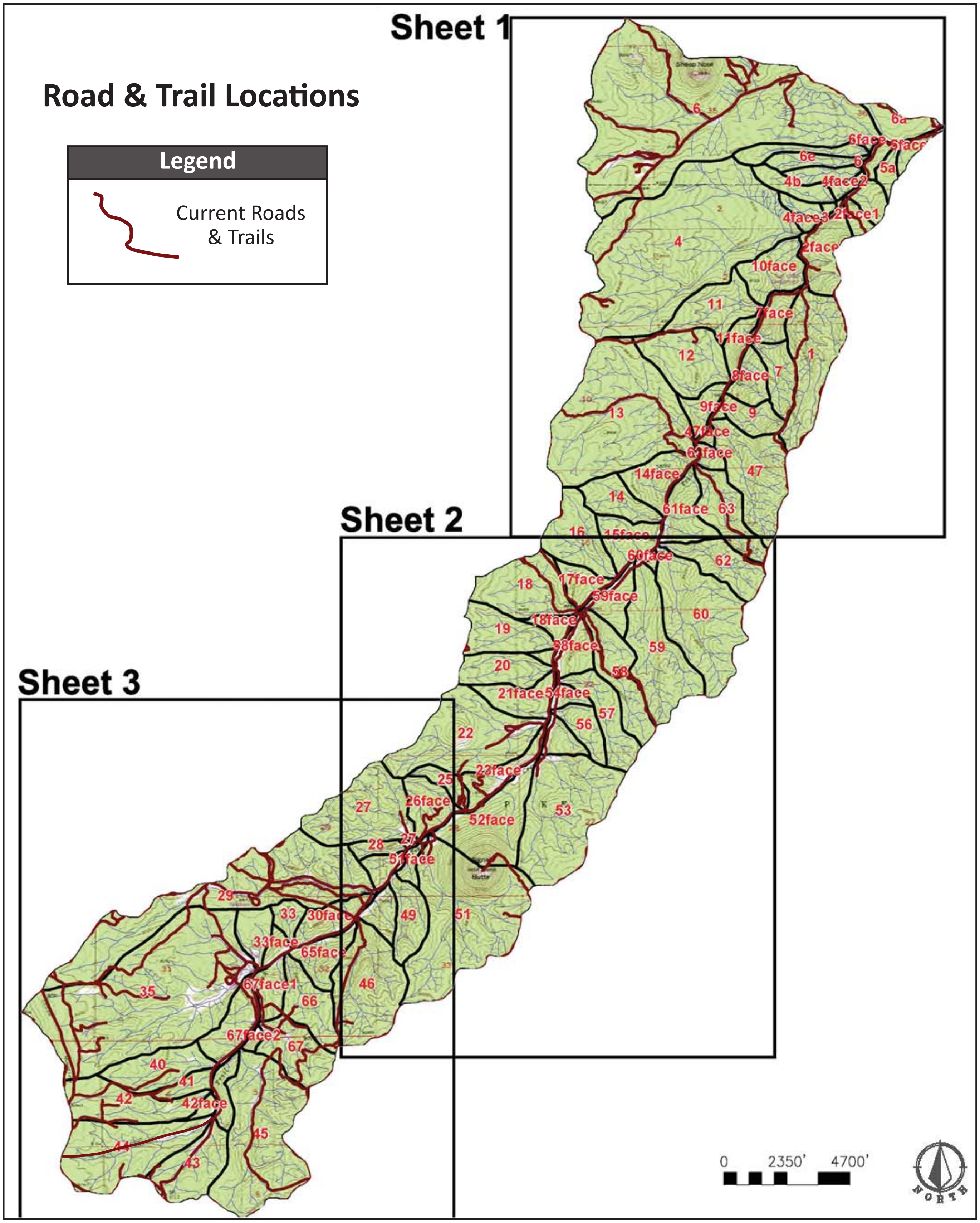


Figure 29. The current road and trail systems in the Trail Creek Watershed; the relocations of the roads and trails for the area in "Sheet 1" are depicted in **Figure 30**, the relocations for the area in "Sheet 2" are depicted in **Figure 31**, and the relocations for the area in "Sheet 3" are depicted in **Figure 32**.

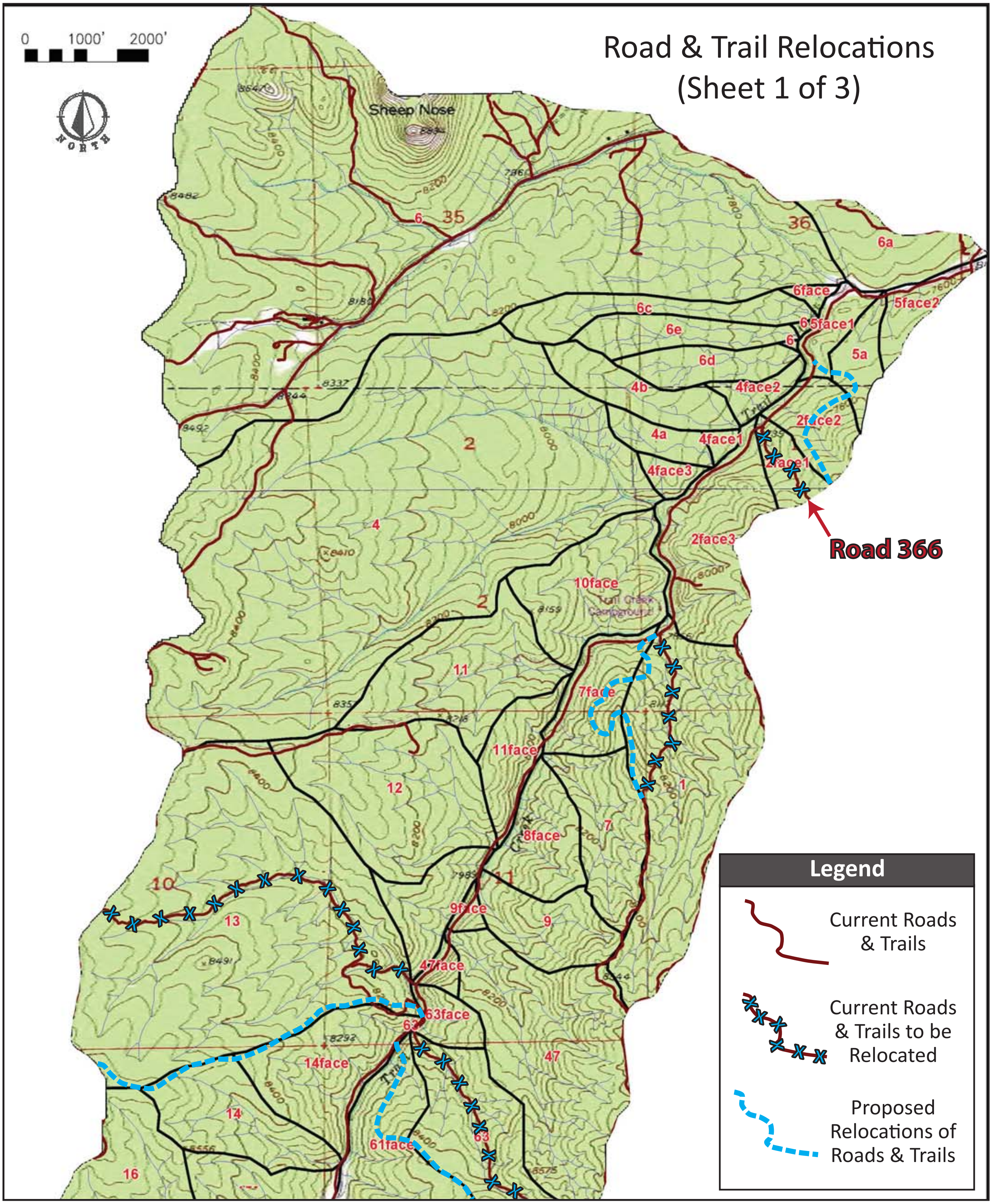


Figure 30. The proposed relocations of the problematic roads and trails illustrating the area in "Sheet 1" in **Figure 29**.

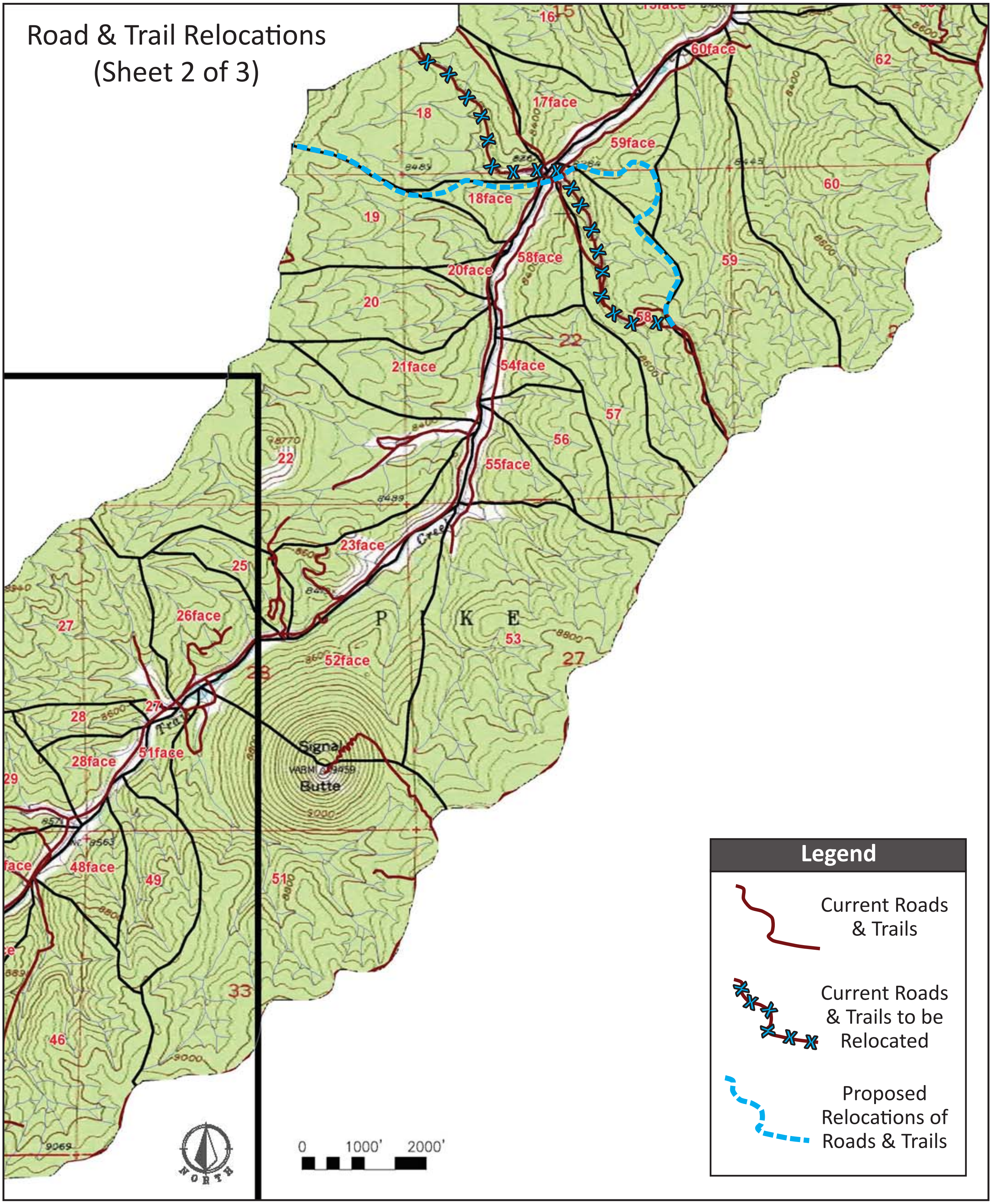


Figure 31. The proposed relocations of the problematic roads and trails illustrating the area in "Sheet 2" in **Figure 29**.

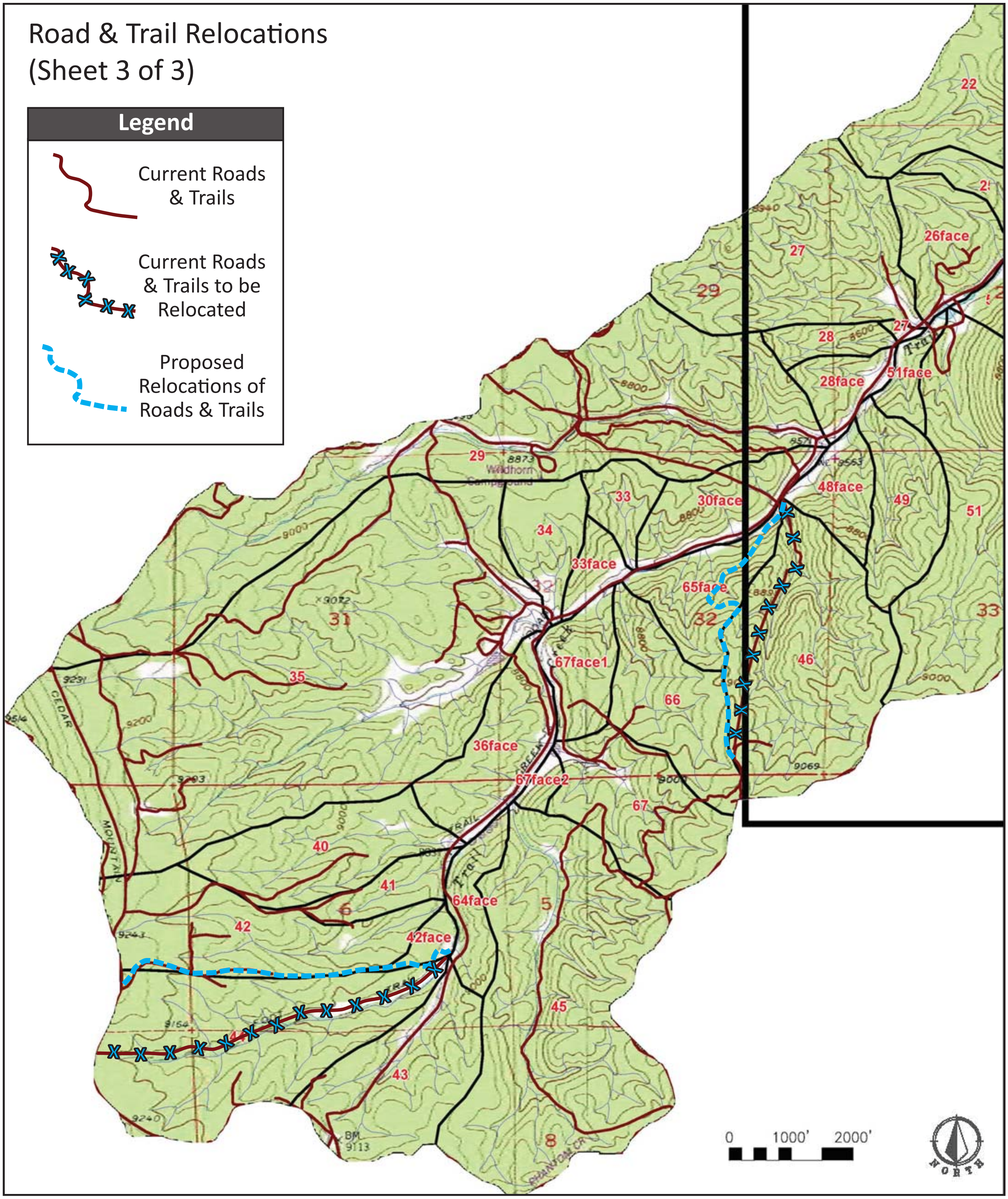


Figure 32. The proposed relocations of the problematic roads and trails illustrating the area in “Sheet 3” in **Figure 29**.

Roads & Trails Summary

If the proposed recommendations related to the main Trail Creek road and the ORV trails and roads are implemented, including the relocations, reduced stream crossings and fill stabilization, it is anticipated that the introduced sediment delivered from roads would decrease by *613 tons/yr*, representing a *72%* reduction. These recommended, mitigative measures are appropriate to be applied to all roads within the watershed, regardless of ownership. Cooperative efforts are most effective if all ownerships and entities work toward a common goal with common solutions to solve the sediment and river impairment problems in the Trail Creek Watershed.

Restoration Plan for Hydrologic Processes

The increase in peak flows due a reduction in evapo-transpiration will continue until a forested stand is re-established. Decades will be required to reach a full hydrologic utilization. Planting coniferous trees on the burned landscape will help accelerate the re-establishment of a forested stand for the potential long-term condition.

Restoration Plan for Channel Processes

Due to high sediment yield results from post-fire, flow-related increases, stream channel restoration and stabilization can be effective to reduce this accelerated sediment supply. The restoration work includes protecting streambeds and streambanks from the increased flows and re-establishing floodplain connectivity where possible. Creating a functioning riparian corridor is also recommended for the long-term stability of stream channels. Fisheries habitat will also be improved with such river restoration and stabilization work. The remainder of the report focuses on the proposed restoration of the stream channels to reduce the accelerated sediment supply by converting unstable stream types to stable stream types and reducing the streambank erosion.

Stream Type Conversion Overview

The Trail Creek *WARSSS* analysis identified the stream succession scenarios of the representative reaches to determine the stable end-point type to use for design. **Table 3** (previously presented) was derived from the analysis and lists the stable stream type conversions for various existing stream types by valley type for the mainstem Trail Creek and its tributaries. This section includes an overview of the stable stream type conversions. Detailed examples of the proposed dimension, pattern and profile for various stream type conversion scenarios are presented in the *Typical Design Scenarios* section in addition to structure and riparian vegetation recommendations.

Converting to a Braided, D4 Stream Type

The natural function of alluvial fans (Valley Type III) is to induce sediment deposition on the fan surface through a braided channel system. The Trail Creek Watershed, however, includes numerous tributary A4, F4 and G4 stream channels that have headcut through the fan, which promote accelerated high sediment transport and streambank and streambed erosion. These headcut stream channels should be converted to braided, D4 stream types on large, long and wide alluvial fans as shown in **Figure 33**. This conversion re-establishes the normal functions of alluvial fans and braided channels to induce sediment deposition on the fan surface rather than routing excess sediment to Trail Creek. Included in this design is the installation of cross-fan sediment detention basins. These basins will store the excess sediment produced from 1st and 2nd order ephemeral streams that are still producing sediment related to post-fire instability. To prevent any headward advancement or gullying from these basins, log sills are installed using native materials (**Figure 33**). The material from the excavation of the sediment detention basins will be used to fill the existing, entrenched channels to the fan surface so that the braided, D4 stream types can effectively disperse flow energy (reduced stream power) and consequently spread the transported sediment on the fan surface through flow convergence and divergence processes related to braided channels.

Converting to a Stable C4 Stream Type

In some instances in Valley Type VIII, braided, D4 stream types are proposed to be converted to single-thread, C4 meandering channels with a floodplain as in **Figure 34**. This stable C4 stream type conversion is the scenario at the mouth of Trail Creek. The current D4 stream type is aggrading and raising flood stages at less than flood-magnitude flows. The very low stage at base flow creates subterranean and discontinuous flows that restrict fish access resulting in an effective migration barrier. If the existing D4 stream type is not converted, the objectives of fisheries access and flood-stage reduction would not be met.

Existing “Poor” condition C4 stream types also occur within the Trail Creek Watershed in a Valley Type VIII that are proposed to be converted to the stable C4 stream type. The proposed conversion to a stable C4 stream type will reduce the high channel source sediment supply by reducing streambank erosion and increasing bed stability.

Converting to a Stable B4 Stream Type

Entrenched and confined G4, F4b and F4 stream types in a Valley Type II or VIII can be converted to B4 stream types. Cross-section views of unstable G4, F4b or F4 stream types converted to the stable B4 stream type are shown in **Figure 35**. The sediment supply related to flow-related sediment increases can effectively be reduced by two to three orders of magnitude as a result of converting to the stable B4 stream type. The sediment reductions are related to reduced streambank erosion, increased bed stability, and the creation of a flood-prone area to help disperse flood flows.

Headcut tributary channels including the A4, F4b, F4 and G4 stream types on short alluvial fans (Valley Type III) can also be converted to B4a or B4 stream types (**Figure 35**) with log or rock step–pools as illustrated in **Figure 36**.

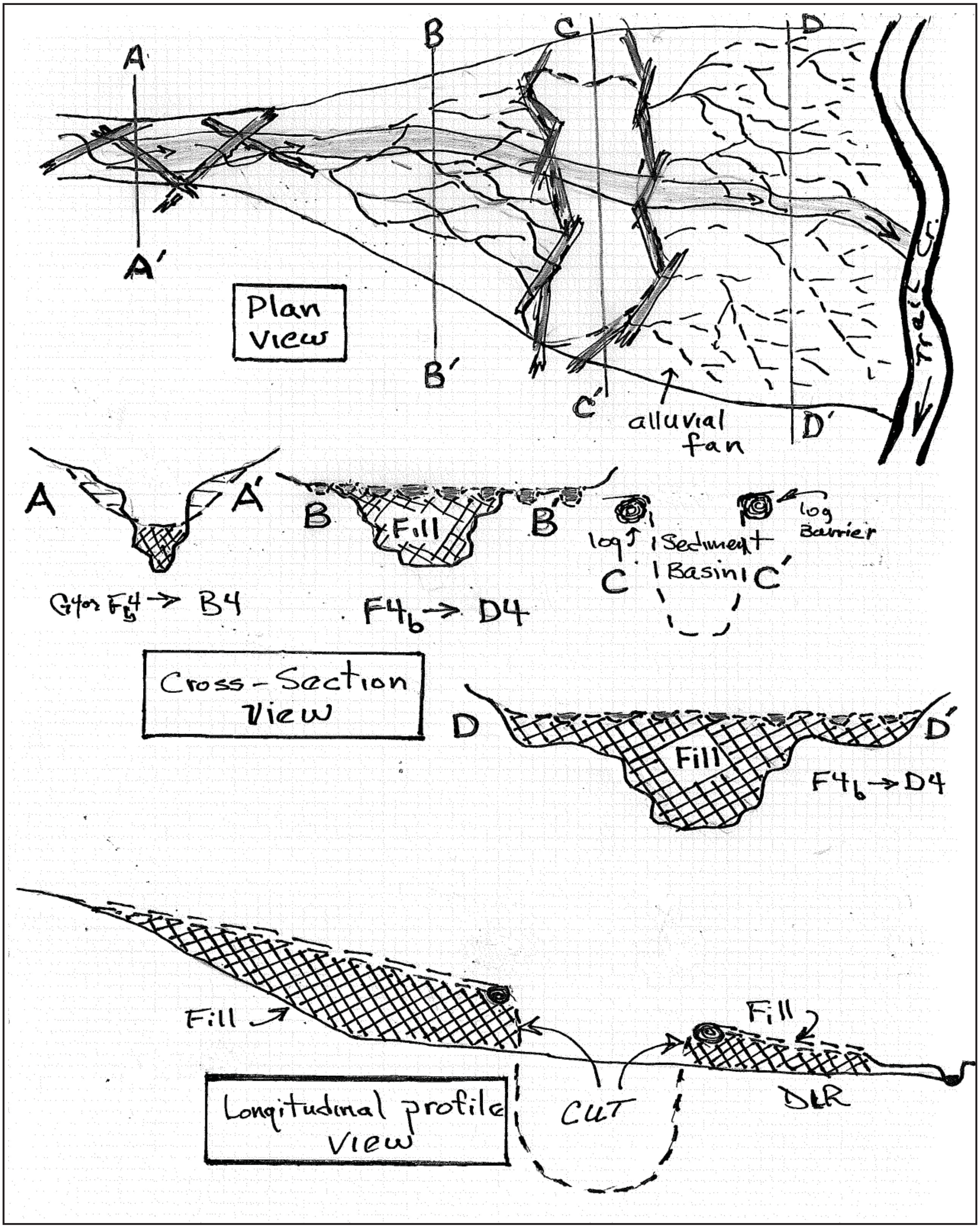


Figure 33. Typical plan, cross-section and profile views of the F4b tributary to D4 stream type conversion on a long and wide alluvial fan (Valley Type III) with a sediment detention basin.

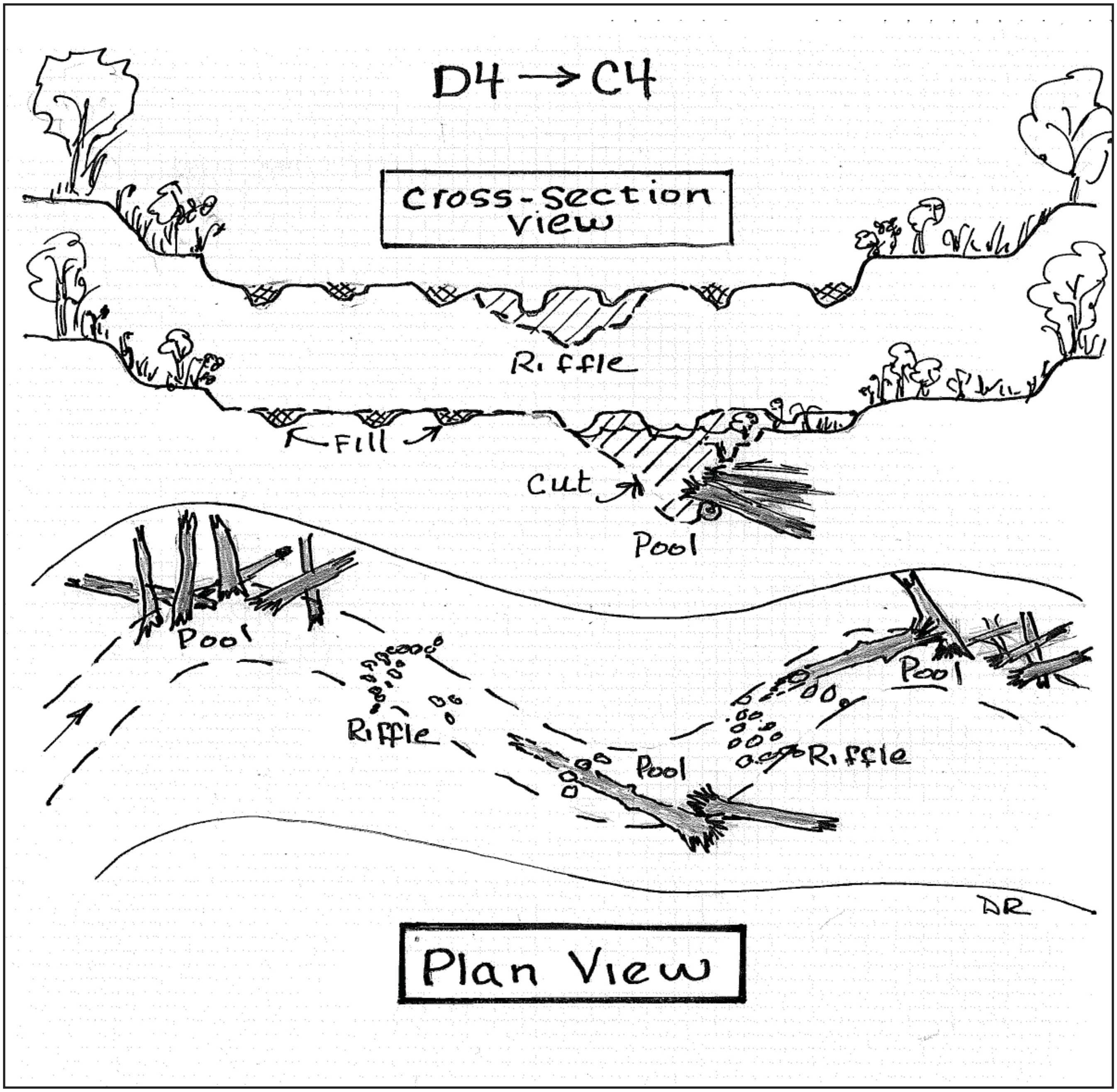


Figure 34. Typical cross-section and plan views illustrating a D4 to C4 stream type conversion in an alluvial fill valley (Valley Type VIII), and the proposed streambank stabilization and fish habitat structures by typical location.

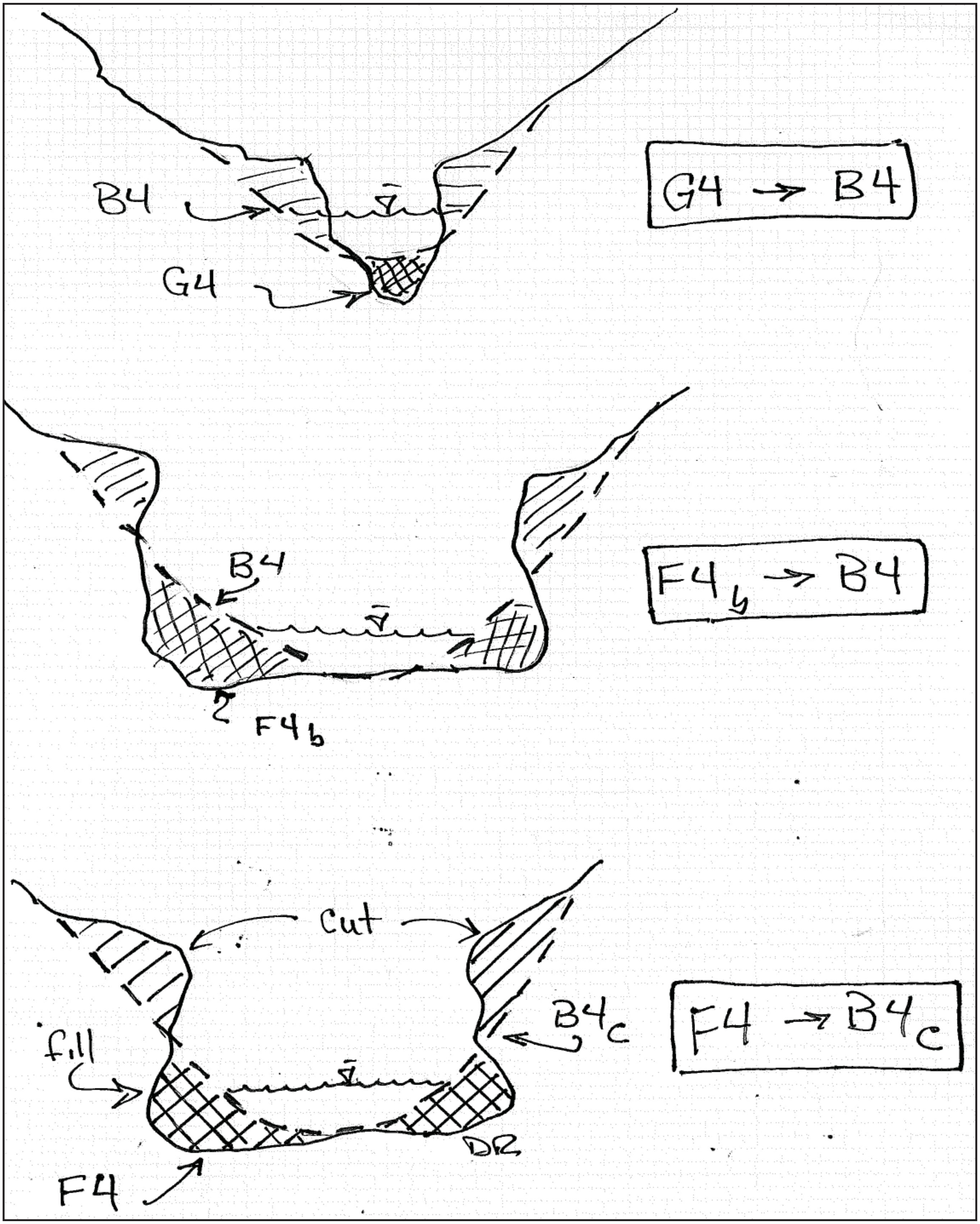


Figure 35. Typical cross-section views of the G4, F4 and F4b stream types converted to B4 or B4c stream types.

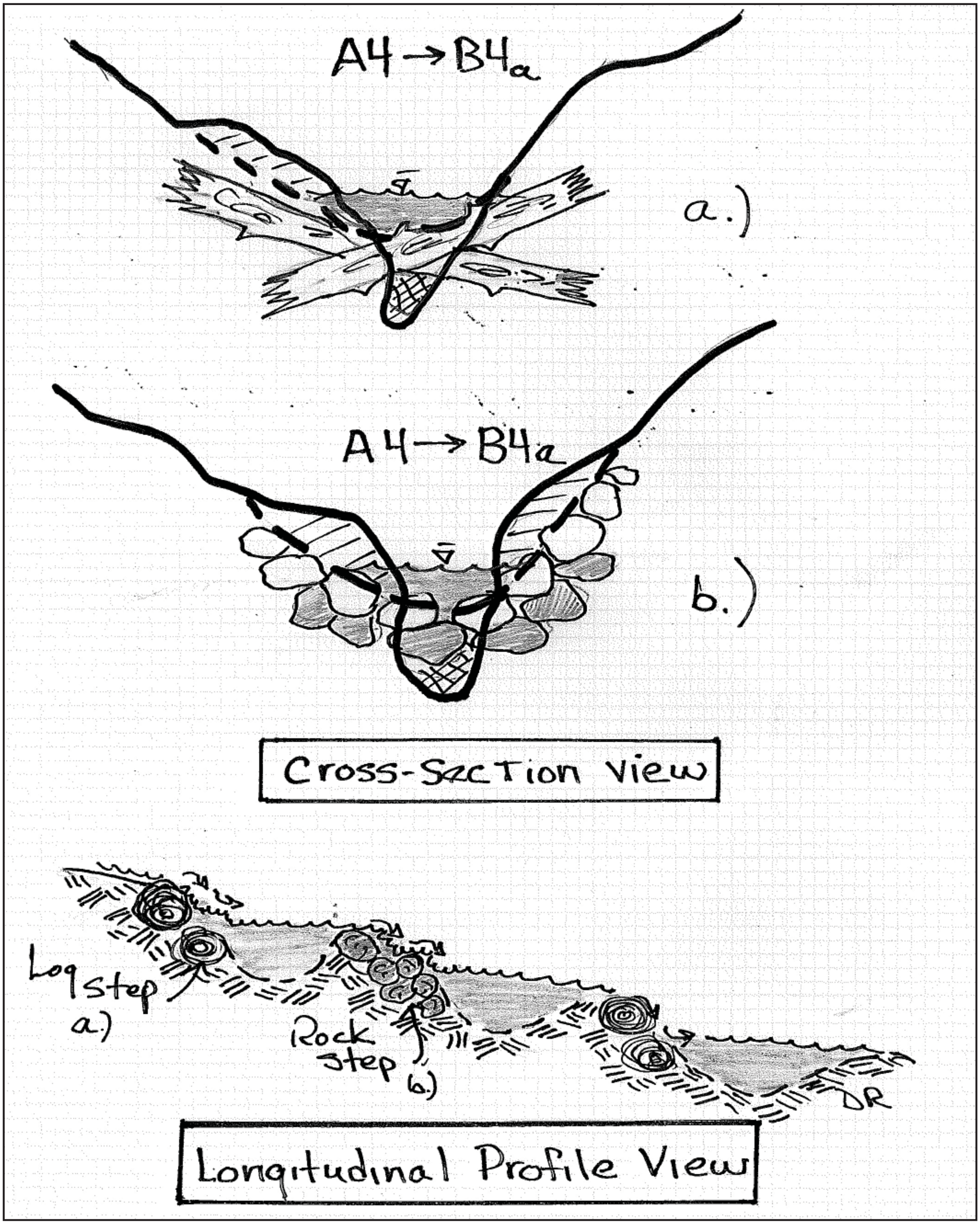


Figure 36. Typical cross-section and profile views of converting tributary A4 to B4a stream types, illustrating step–pool bed features with a.) log step structures and b.) rock step structures.

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. *Reference reach* relations were established to determine departure of the potentially impaired, *representative reaches* and to establish the stable reach relations for design. Because reference reaches are often not the same size as the impaired reaches, the reference reach relations must be scaled. Thus dimensionless relations of the reference reach that represent the stable dimension, pattern and profile are established using bankfull discharge, width, depth, area and slope as the normalization parameters. The established *reference reach* relations for use in the restoration design are documented in *Appendix B* of the Trail Creek *WARSSS* analysis (Rosgen, 2011). 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 normalization parameters.

The impaired reaches by valley and stream type are documented in the *representative reach* summary in *Appendix C* of the Trail Creek *WARSSS* analysis (Rosgen, 2011). This detailed data is used as a typical of a given stability condition for a particular stream type and valley type location. This data represents 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 Trail Creek *WARSSS* analysis by sub-watershed. For example, streambank erosion rates of the *G4 Poor Representative Reach* in a Valley Type VIII 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.

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). Regional curves of bankfull cross-sectional area *vs*. drainage area generally have an excellent correlation coefficient and low variance making it acceptable to determine the proposed channel's cross-sectional area. Relationships of bankfull width and mean depth *vs*. drainage area were not developed because these variables change by stream type for the same discharge because of differing width/depth ratios. Hence, regional curves of bankfull discharge and cross-sectional area were developed for the Trail Creek Watershed as part of the *WARSSS* analysis as shown in **Figure 37** and **Figure 38**.

However, cross-sectional area cannot always be 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 D4 (braided channels). In these instances, reasonable estimates of velocity are required to calculate a corresponding bankfull cross-sectional area using flow. For example, very small streams with *0.2 ft* to *0.3 ft* of bankfull mean depth on slopes between *4%* and *10%* 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 regional curve) is divided by the mean bankfull velocity. Roughness coefficients by stream type, dominant bed-material size, vegetative controlling influences, 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 multiple small channels and associated small mean velocity estimates. Many of these small channels have a very high boundary roughness due to their very shallow depths of their multiple channels. Velocities for streamflows less than *10 cfs* on D4 stream types will average between *0.5* and *1.5 ft/sec*, and thus will require very high cross-sectional areas for small discharges. Many of these D4 stream types are designed to have width/depth ratios greater than 100 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 ($u = Q/A$). 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

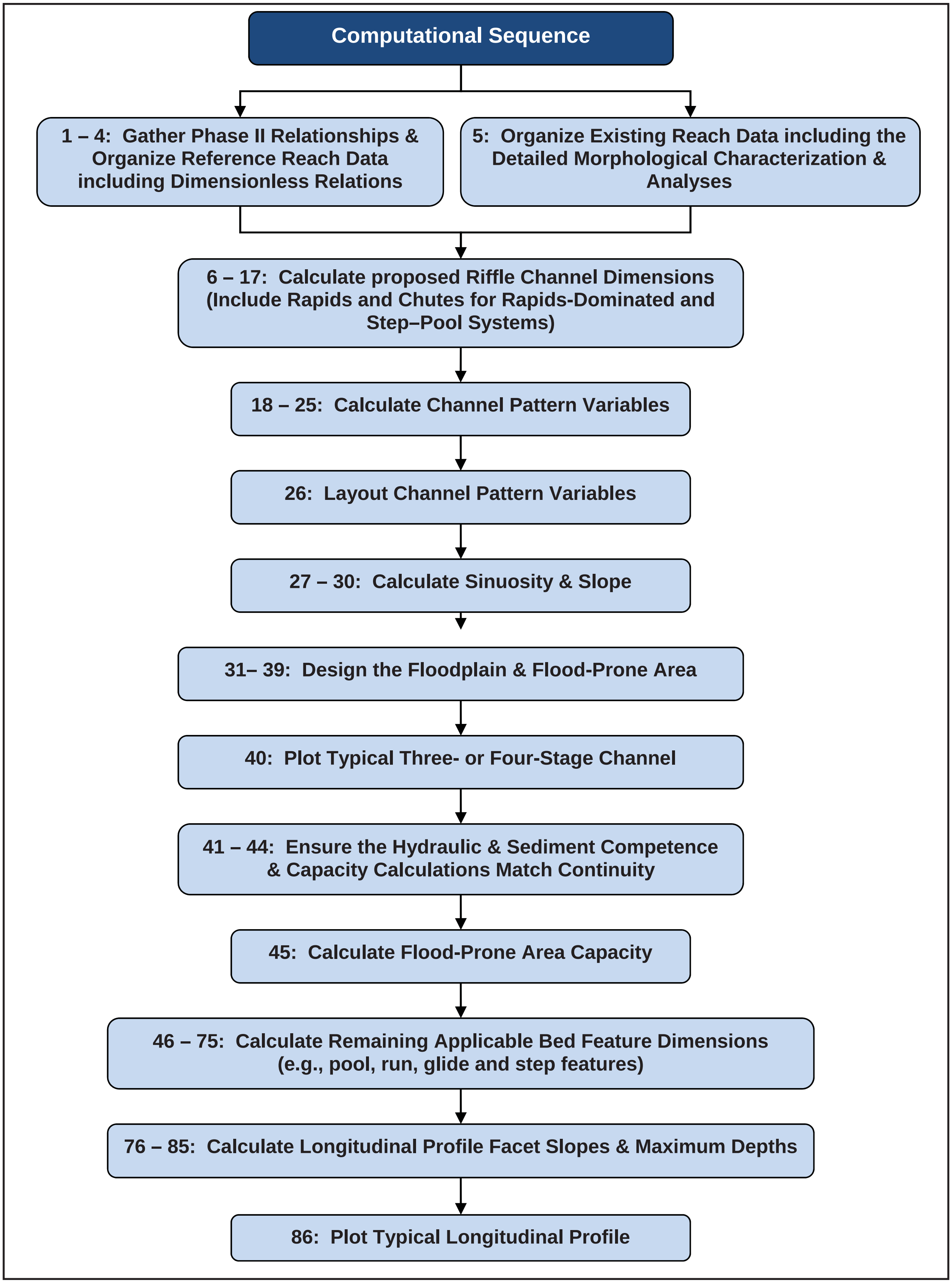
W/d_{ref} = bankfull width/depth ratio from the reference reach

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 meandering pattern determined in NCD and the heterogeneity of bed features are important to dissipate energy and to promote a 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 and competence.

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 Trail Creek Watershed. Because the proposed master plan involves a *watershed* restoration with approximately *178 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 & profile variables for the proposed design reach.

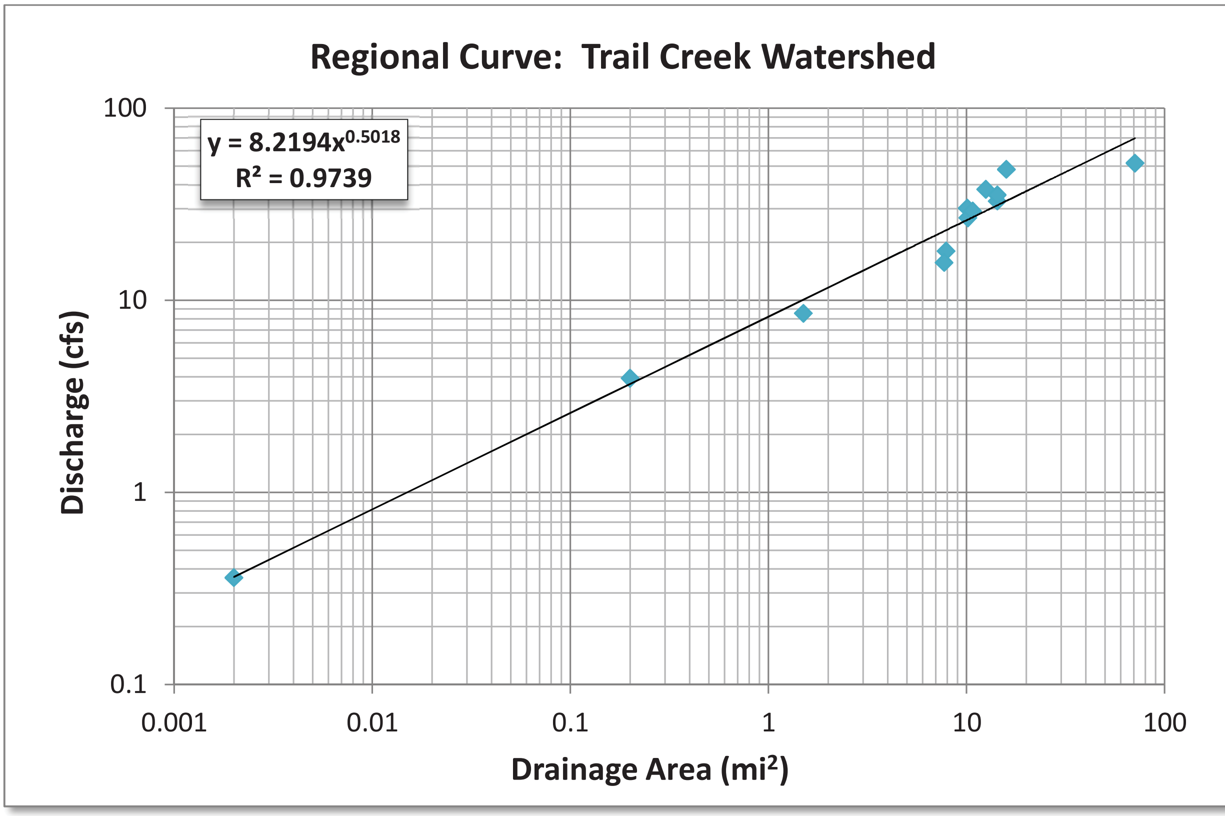


Figure 37. Regional curve for bankfull discharge *vs*. drainage area for the Trail Creek Watershed.

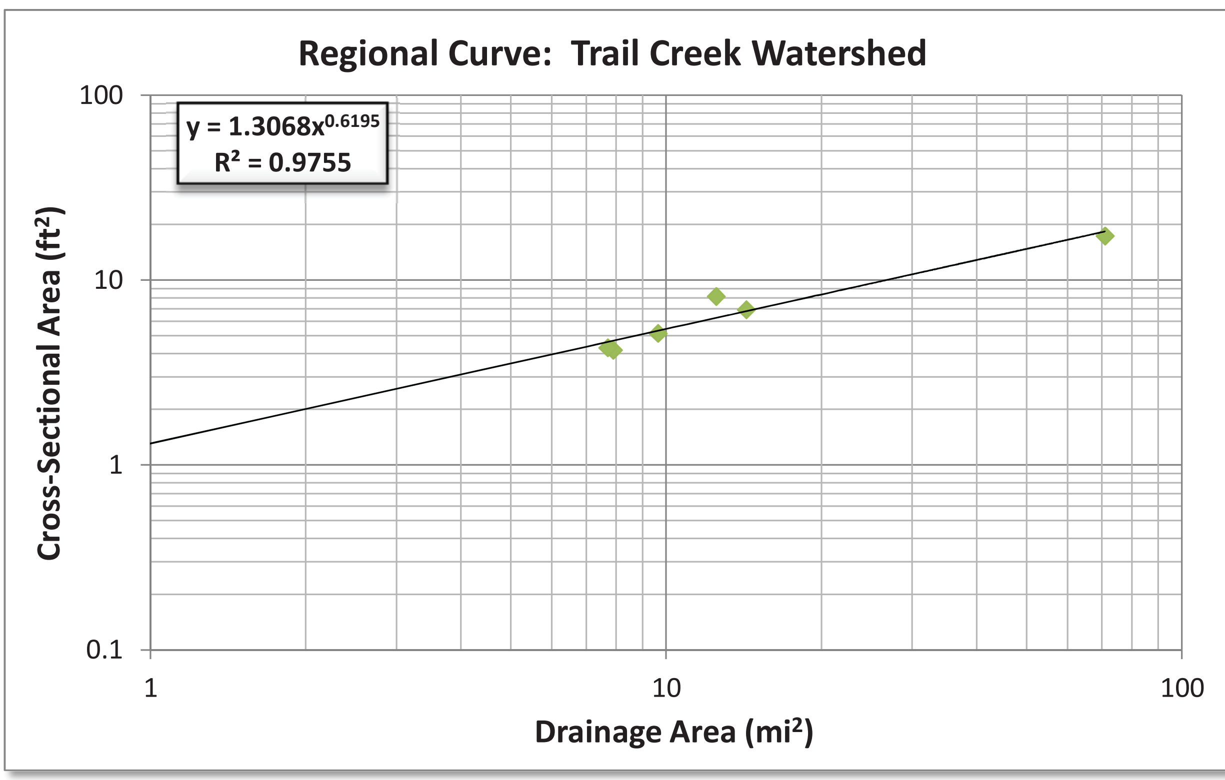


Figure 38. Regional curve for bankfull cross-sectional area *vs*. drainage area for the Trail Creek Watershed.

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 Trail Creek Watershed 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 nine design scenarios shown in **Table 5** were developed to represent the range of stream types and stability conditions that require restoration within the Trail Creek Watershed. 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 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 5**. Each typical design scenario 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 5. The nine typical design scenarios developed to extrapolate to other locations in the Trail Creek Watershed for restoration.

Typical Design Scenarios		
Existing, Impaired Stream Type & Condition	Proposed, Stable Stream Type	Valley Type (VT)
1. D4 Poor	C4	VIII
2. F4 Poor	B4	VIII (confined)
3. G4 Poor	B4	VIII
4. C4 Poor	C4	VIII
5. F4b Poor Tributary	D4	III (large fan)
6. F4b Poor Tributary	B4	III (short fan)
7. A4a+ Poor	A4a+ Step-Pool	I or II
8. A4a+ Poor	D4	III (large fan)
9. A4a+ Poor	B4a	III (short fan)

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, 2001a, 2006/2009, 2011). 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 *178 miles* (*939,840 ft*) of potential sediment contributions in the Trail Creek Watershed, 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. For example, the total annual sediment yield rate for the Trail Creek Watershed associated with a "Good" condition would be approximately *0.0009 tons/yr/ft* compared to a rate of *0.026 tons/yr/ft* associated with a "Poor" condition (three orders of magnitude greater than the "Good" condition). These sediment rates are based on the FLOWSED model that incorporates dimensionless sediment rating curves and bankfull sediment values as explained in the Trail Creek *WARSSS* analysis. For "Good" condition reaches, the FLOWSED model uses the "Good or Fair" dimensionless sediment rating curves and the "Good" bankfull sediment values, which resulted in *844.6 tons/yr* for this condition at the mouth of the Trail Creek Watershed. The "Poor" condition resulted in *24,190.4 tons/yr* for the same location based on the use of "Poor" dimensionless sediment rating curves and "Poor" bankfull sediment values. 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 typical design scenarios 1–4 involve lower mainstem Trail Creek 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 *10 miles* (*55,280 ft*) of channel length of similar condition. The tributary reaches related to the typical design scenarios 6, 7 and 9 utilize the total length of the tributary channels within the associated sub-watershed. The typical design scenarios 5 and 8 that convert A4a+ and F4b stream types to the braided, D4 stream type with sediment detention basins do 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 Trail Creek.

Streambank erosion and 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. A typical, stable rate of *0.0063 tons/yr/ft* of annual streambank erosion has been observed for a "Good" condition C4 stream type. An annual streambank erosion rate of *0.7183 tons/yr/ft* for unstable reaches is typical, representing three orders of magnitude of accelerated erosion rates. The streambank erosion savings related to the proposed design reach, in addition to the savings in flow-related annual sediment yield, are summarized for each of the nine typical design scenarios. Obviously, the more reaches eventually restored, the greater the reductions in annual sediment yield.

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., typical design scenarios 5 and 8: A4a+ and F4b stream types converted to D4 stream types). In these scenarios, 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.

As a reference for all nine typical design scenarios, **Table 6** is presented that summarizes the flow-related sediment and potential sediment reductions, including streambank erosion contributions, for the existing and proposed design reaches. The proposed, braided, D4 stream types do not focus on unit yield reductions but rather compare the sediment storage of the upstream sediment source using both the FLOWSED and POWERSED models.

The following nine typical designs are proposed not only for the locations identified in the following scenarios, but also for other reaches of the same stream type, valley type and stability condition as mapped in *Appendix D* of the Trail Creek *WARSSS* analysis (Rosgen, 2011). The first five scenarios listed in **Table 5** are all located in lower Trail Creek above the mouth; hence, a general discussion of the conceptual restoration for lower Trail Creek is given prior to the detailed individual scenarios.

Table 6. The sediment savings for the nine typical design scenarios comparing the *existing vs. proposed design reaches.*

Typical Design Scenario	Local *Existing* Unit Sediment Yield: Unit Length x Total Length			Local *Proposed* Sediment Yield: Unit Length x Total Length			Sediment Reductions: Local Channel Source Sediment			Streambank Erosion		
	Bedload (tons/yr)	Suspended Sediment (tons/yr)	Total Sediment (tons/yr)	Bedload (tons/yr)	Suspended Sediment (tons/yr)	Total Sediment (tons/yr)	Bedload (tons/yr)	Suspended Sediment (tons/yr)	Total Sediment (tons/yr)	*Existing* (tons/yr)	*Proposed* (tons/yr)	Total Reduction (tons/yr)
1. D4 to C4, VT VIII	41.0	142.2	183.3	1.2	6.0	7.2	39.8	136.3	176.1	287.3	2.8	284.5
2. F4 to B4, VT VIII (confined)	95.4	330.7	426.1	2.7	13.3	16.0	92.7	317.4	410.1	439.1	4.8	434.3
3. G4 to B4, VT VIII	28.2	97.8	126.0	0.8	4.0	4.8	27.4	93.8	121.2	181.1	1.4	179.6
4. C4 *Poor* to C4 *Stable* , VT VIII	30.8	106.7	137.4	0.8	4.0	4.8	30.0	102.7	132.6	14.2	1.9	12.3
6. Tributary F4b to B4, VT III (short fan)	79.4	519.1	598.4	10.5	0.9	11.5	68.8	518.1	587.0	196.5	2.4	194.1
7. Tributary, A4a+ *Poor* to A4a+ *Stable* , VT I	11.9	49.5	61.4	6.9	0.0	6.9	5.0	49.5	54.5	6.2	0.3	5.9
9. Tributary A4a+ to B4a, VT III (short fan)	30.1	94.0	124.1	5.6	0.1	5.8	24.4	93.9	118.3	23.6	1.4	22.1
Totals	**316.7**	**1,339.9**	**1,656.6**	**28.6**	**28.2**	**56.9**	**288.1**	**1,311.7**	**1,599.7**	**1147.8**	**15.1**	**1132.7**

Typical Design Scenario	Annual Storage on Alluvial Fan			Annual Storage in Sediment Detention Basins			Total Storage (Alluvial Fan & Dentention Basins)			Streambank Erosion		
	Bedload (tons/yr)	Suspended Sediment (tons/yr)	Total Sediment (tons/yr)	Bedload (tons/yr)	Suspended Sediment (tons/yr)	Total Sediment (tons/yr)	Bedload (tons/yr)	Suspended Sediment (tons/yr)	Total Sediment (tons/yr)	*Existing* (tons/yr)	*Proposed* (tons/yr)	Total Reduction (tons/yr)
5. Tributary F4b to D4, VT III (long fan)*	1,044	4,117	5,161	20.2	79.6	99.8	1,064.2	4,196.6	5,260.8	132.4	12.8	119.6
8. Tributary A4a+ to D4, VT III (large fan)*	29.9	166.8	196.7	7.0	3.0	10.0	36.9	169.8	206.7	23.6	11.4	12.2
Totals	**1,073.9**	**4,283.8**	**5,357.7**	**27.2**	**82.6**	**109.8**	**1,101.1**	**4,366.4**	**5,467.5**	**156.0**	**24.2**	**131.8**

**It is estimated that 100% of sediment from these tributaries will be stored on the alluvial fan and in the detention basins*

Lower Trail Creek Design Concept

Any restoration plan must first look at the "big picture" that involves local base level and compatible solutions amongst varying stream and valley types. The lower Trail Creek area was selected as an example of integrating various reach types to reach a common set of objectives using various solutions. For example, some of the stream types and conditions in this lower reach are aggrading, while others are degrading. The solutions involve raising local base level by *3–4 ft* in one reach, while in another reach the design requires excavating down *4–5 ft*. This is determined by studying the longitudinal profile over a long distance. The longitudinal profile in **Figure 39** extends through major sediment contributions from an impaired tributary and major headcuts to approximately one-half mile downstream at the mouth of the alluvial fan at the confluence with West Creek. At the uppermost part of the profile, there is a laterally migrating, C4 *Poor* condition stream type that is proposed to be converted to a C4 *Stable* stream type. This reach transitions to an actively incising G4 stream type that is proposed to be converted to a B4 stream type by raising the bed *1–3 ft* to match the local base level and flatten the energy slope to reduce future degradation (**Figure 39**). The longitudinal profile then shows the transition through the existing, entrenched and confined F4 reach downstream of the G4 reach (F4 to B4 stream type conversion) that extends to the lower aggrading reach (D4 to C4 stream type conversion) where bed excavation is required to increase the energy slope.

The lower reach design of the Trail Creek Watershed must also address the active lateral erosion into an alluvial fan and accelerated headcutting with extreme sediment supply of a tributary that is causing major impacts to the mainstem Trail Creek. This tributary is within Sub-Watershed 6 that has been set as the highest priority for restoration of all 59 sub-watershed based on its disproportionately high sediment supply (**Table 2**). Thus, hillslope and channel process restoration must be concurrently implemented based on the design details contained in this report. Stop-gap recommendations are included to help reduce the direct sediment supply into Trail Creek, such as sediment detention basins and the stream type conversion from F4b to D4. The success of the lower watershed restoration is premised on implementing the recommended mitigation to reduce the major sediment in Sub-Watershed 6.

The aggrading and unstable stream crossing of Trail Creek on the West Creek road is also redesigned in conjunction with converting the existing D4 stream type to C4 in this lowest reach. If fish migration is to be encouraged from West Creek, a single-thread, C4 stream type is proposed to increase the depth during low flow periods. In conjunction with a redesigned stream crossing on the West Creek road, the C4 stream type design enhances the fish habitat and increases the stability of the reach by reducing the aggradation and streambank erosion processes.

Plan views of the general restoration design for lower Trail Creek are depicted in **Figures 40–45**. These design sheets include the C4 *Poor* to C4 *Stable*, G4 to B4, F4 to B4, and D4 to C4 stream type and stability conversions, along with the location of the impaired tributary to be converted from an F4b to D4 stream type. The following five typical design scenarios contain the detailed data required for design and implementation starting downstream at the existing D4 stream type and extending upstream. These restoration scenarios include the morphological, sedimentological, hydraulic and biological characteristics that must be addressed to ensure a sustainable design and that specific objectives are met. Specific structure locations along the proposed channel alignment are also included for design implementation.

Last, the vegetated alluvial fan at the confluence of Trail Creek with West Creek is the recommended location where water quality controls can be implemented during restoration as illustrated in **Figure 46**. The turbidity levels can be reduced during construction by dispersing flows over the vegetated surfaces and by implementing sediment detentions ponds (beaver ponds).

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Figure 39 Here

Figure 39. The existing longitudinal profile of lower Trail Creek indicating the new bed elevations, associated slopes and cut and fill requirements of the proposed design.
Figure 40. The master layout view of the sheets corresponding to **Figures 41–45** that depict the general restoration design plan for lower Trail Creek.
Figure 41. The general proposed design for lower Trail Creek for the area depicted in Sheet 1 in **Figure 40**.
Figure 42. The general proposed design for lower Trail Creek for the area depicted in Sheet 2 in **Figure 40**.
Figure 43. The general proposed design for lower Trail Creek for the area depicted in Sheet 3 in **Figure 40**.
Figure 44. The general proposed design for lower Trail Creek for the area depicted in Sheet 4 in **Figure 40**.
Figure 45. The general proposed design for lower Trail Creek for the area depicted in Sheet 5 in **Figure 40**.
Figure 46. The proposed location of a flow diversion for water quality control during construction using the riparian area for natural filtration and sediment detention.

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Figure 39 Here

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

General Description & Morphological Data

This typical design scenario 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 47**). 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 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"* 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 location of the *C4 Reference Reach* is shown in **Figure 7** and the detailed characteristics and stability evaluation are documented in *Appendix B4* of the Trail Creek *WARSSS* analysis (Rosgen, 2011, pp. B4-1 to B4-36).

The resultant proposed dimension, pattern and profile for the stable C4 stream type are documented in **Table 7** 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 47. 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 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.

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 7 (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 7 (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:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**12.5**	*Mean:* *Min:* *Max:*	**24.2**
	39	Run Width to Riffle Width (W_{bkfr}/W_{bkf})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**0.926**	*Mean:* *Min:* *Max:*	**1.308**
	40	Run Mean Depth, ft (d_{bkfr})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**1.38** **1.30** **1.40**	*Mean:* *Min:* *Max:*	**0.62**
	41	Run Mean Depth to Riffle Mean Depth (d_{bkfr}/d_{bkf})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**1.394** **1.313** **1.414**	*Mean:* *Min:* *Max:*	**0.596**
	42	Run Width/Depth Ratio (W_{bkfr}/d_{bkfr})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**9.1**	*Mean:* *Min:* *Max:*	**39.1**
	43	Run Cross-Sectional Area, ft^2 (A_{bkfr})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**17.2**	*Mean:* *Min:* *Max:*	**15.1**
	44	Run Area to Riffle Area (A_{bkfr}/A_{bkf})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**1.293**	*Mean:* *Min:* *Max:*	**0.785**
	45	Run Maximum Depth (d_{maxr})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**2.00**	*Mean:* *Min:* *Max:*	**1.50**
	46	Run Maximum Depth to Riffle Mean Depth (d_{maxr}/d_{bkf})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**2.020**	*Mean:* *Min:* *Max:*	**1.442**
Glide Dimensions	**47**	Glide Width, ft (W_{bkfg})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**14.6** **14.0** **15.0**	*Mean:* *Min:* *Max:*	**22.0**
	48	Glide Width to Riffle Width (W_{bkfg}/W_{bkf})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**1.081** **1.037** **1.111**	*Mean:* *Min:* *Max:*	**1.189**
	49	Glide Mean Depth, ft (d_{bkfg})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**0.80**	*Mean:* *Min:* *Max:*	**0.98**
	50	Glide Mean Depth to Riffle Mean Depth (d_{bkfg}/d_{bkf})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**0.808**	*Mean:* *Min:* *Max:*	**0.942**
	51	Glide Width/Depth Ratio (W_{bkfg}/d_{bkfg})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**18.25**	*Mean:* *Min:* *Max:*	**22.5**
	52	Glide Cross-Sectional Area, ft^2 (A_{bkfg})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**11.6**	*Mean:* *Min:* *Max:*	**21.5**
	53	Glide Area to Riffle Area (A_{bkfg}/A_{bkf})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**0.872**	*Mean:* *Min:* *Max:*	**1.122**
	54	Glide Maximum Depth (d_{maxg})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**1.10**	*Mean:* *Min:* *Max:*	**1.62**
	55	Glide Maximum Depth to Riffle Mean Depth (d_{maxg}/d_{bkf})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**1.111**	*Mean:* *Min:* *Max:*	**1.558**

Table 7 (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:* **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 7 (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 7 (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 7 (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:*	**N/A**	*Mean:*	**0.0156**	*Mean:*	**0.0045**
			Min:		*Min:*	**0.0099**	*Min:*	**0.0029**
			Max:		*Max:*	**0.0189**	*Max:*	**0.0054**
	106	Riffle Slope to Average Water Surface Slope (S_{rif}/S)	*Mean:*	**N/A**	*Mean:*	**1.0205**	*Mean:*	**1.0205**
			Min:		*Min:*	**0.6477**	*Min:*	**0.6477**
			Max:		*Max:*	**1.2341**	*Max:*	**1.2341**
	107	Pool Slope (water surface facet slope) (S_p)	*Mean:*	**N/A**	*Mean:*	**0.0080**	*Mean:*	**0.0023**
			Min:		*Min:*	**0.0028**	*Min:*	**0.0008**
			Max:		*Max:*	**0.0132**	*Max:*	**0.0038**
	108	Pool Slope to Average Water Surface Slope (S_p/S)	*Mean:*	**N/A**	*Mean:*	**0.5250**	*Mean:*	**0.5250**
			Min:		*Min:*	**0.1841**	*Min:*	**0.1841**
			Max:		*Max:*	**0.8636**	*Max:*	**0.8636**
	109	Run Slope (water surface facet slope) (S_{run})	*Mean:*	**N/A**	*Mean:*	**0.0392**	*Mean:*	**0.0113**
			Min:		*Min:*	**0.0230**	*Min:*	**0.0066**
			Max:		*Max:*	**0.0485**	*Max:*	**0.0140**
	110	Run Slope to Average Water Surface Slope (S_{run}/S)	*Mean:*	**N/A**	*Mean:*	**2.5614**	*Mean:*	**2.5614**
			Min:		*Min:*	**1.5000**	*Min:*	**1.5000**
			Max:		*Max:*	**3.1705**	*Max:*	**3.1705**
	111	Glide Slope (water surface facet slope) (S_g)	*Mean:*	**N/A**	*Mean:*	**0.0119**	*Mean:*	**0.0034**
			Min:		*Min:*	**0.0090**	*Min:*	**0.0026**
			Max:		*Max:*	**0.0136**	*Max:*	**0.0039**
	112	Glide Slope to Average Water Surface Slope (S_g/S)	*Mean:*	**N/A**	*Mean:*	**0.7750**	*Mean:*	**0.7750**
			Min:		*Min:*	**0.5909**	*Min:*	**0.5909**
			Max:		*Max:*	**0.8864**	*Max:*	**0.8864**
	113	Step Slope (water surface facet slope) (S_s)	*Mean:*	**N/A**	*Mean:*	**N/A**	*Mean:*	**N/A**
			Min:		*Min:*		*Min:*	
			Max:		*Max:*		*Max:*	
	114	Step Slope to Average Water Surface Slope (S_s/S)	*Mean:*	**N/A**	*Mean:*	**N/A**	*Mean:*	**N/A**
			Min:		*Min:*		*Min:*	
			Max:		*Max:*		*Max:*	

Table 7 (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:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**1.70** **1.41** **1.80**	*Mean:* *Min:* *Max:*	**1.60** **1.40** **1.75**
	116	Riffle Maximum Depth to Riffle Mean Depth (d_{max}/d_{bkf})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**1.717** **1.424** **1.818**	*Mean:* *Min:* *Max:*	**1.534** **1.342** **1.677**
	117	Pool Maximum Depth, ft (d_{maxp})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**3.10** **2.80** **3.50**	*Mean:* *Min:* *Max:*	**2.46** **2.12** **2.95**
	118	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:*	**2.358** **2.038** **2.837**
	119	Run Maximum Depth, ft (d_{maxr})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**2.00** **1.50** **2.20**	*Mean:* *Min:* *Max:*	**1.74** **1.57** **1.95**
	120	Run Maximum Depth to Riffle Mean Depth (d_{maxr}/d_{bkf})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**2.020** **1.515** **2.222**	*Mean:* *Min:* *Max:*	**1.668** **1.505** **1.869**
	121	Glide Maximum Depth, ft (d_{maxg})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**1.10** **1.00** **1.30**	*Mean:* *Min:* *Max:*	**1.55** **1.33** **1.78**
	122	Glide Maximum Depth to Riffle Mean Depth (d_{maxg}/d_{bkf})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**1.111** **1.010** **1.313**	*Mean:* *Min:* *Max:*	**1.486** **1.275** **1.706**
	123	Step Maximum Depth, ft (d_{maxs})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**N/A**
	124	Step Maximum Depth to Riffle Mean Depth (d_{maxs}/d_{bkf})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**N/A**
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 7 (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**
Hydraulics	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**
Sediment Competence	130	Predicted largest moveable particle size (mm) at bankfull shear stress, τ, using the original **Shields** relation	**10.8**	**34**	**24.0**
Sediment Competence	131	Predicted largest moveable particle size (mm) at bankfull shear stress, τ, using the **Colorado** relation	**37.6**	**84**	**70.0**
Sediment Competence	132	Largest particle size to be moved (D_{max}) (mm) (see #126: Particle Size Distribution of Bar Material)	**80**	**80**	**74.0**
Sediment Competence	133	Predicted shear stress required to initiate movement of D_{max} (mm) using the original **Shields** relation	**1.025**	**1.025**	**1.000**
Sediment Competence	134	Predicted shear stress required to initiate movement of D_{max} (mm) using the **Colorado** relation	**0.418**	**0.418**	**0.350**
Sediment Competence	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**
Sediment Competence	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**
Sediment Competence	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**
Sediment Competence	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**
Sediment Competence	139	Bankfull dimensionless shear stress (τ*) (see competence form)	**N/A**	**N/A**	**N/A**
Sediment Competence	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**
Sediment Competence	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 7 (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 7**. Using continuity, the corresponding mean velocity for the proposed design reach is *3.0 ft/sec* as shown in **Worksheet 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 48**, which corresponds with the proposed pattern values developed from the dimensionless ratios of the *C4 Reference Reach* in **Table 7**. The existing cross-section locations of the D4 stream type are also shown in **Figure 48**.

Cross-Section Dimensions

Table 7 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 49**, **Figure 50**, **Figure 51** and **Figure 52**, respectively. A typical schematic of the proposed excavation and shaping of a multi-stage channel and valley cross-section is shown in **Figure 53**. The overlay of the existing D4 cross-section 2+29 *vs*. proposed C4 *riffle* cross-section indicating the cut recommendations is shown in **Figure 54**. Similarly, the existing D4 cross-section 1+28 *vs*. the proposed C4 *pool* cross-section is shown in **Figure 55**. The locations of cross-section 1+28 and cross-section 2+29 are indicated in **Figure 48**.

Longitudinal Profile

The typical longitudinal profile for the proposed C4 design reach is shown in **Figure 56** 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 56**). Additionally, the locations of the cross-section overlays in **Figure 54** and **Figure 55** 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 57**. The rock cross-vane structure (**Figure 10** and **Figure 11**) 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 (**Figure 22**) 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 (**Figure 15** and **Figure 16**).

Worksheet 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**	Valley Type:	**VIII**
Observers:	**Rosgen *et al*.**	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 $\sim (2 * d_{bkf}) + W_{bkf}$	**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 $u^* = (gRS)^{1/2}$	**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 48 Here

Figure 48. 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 48 Here

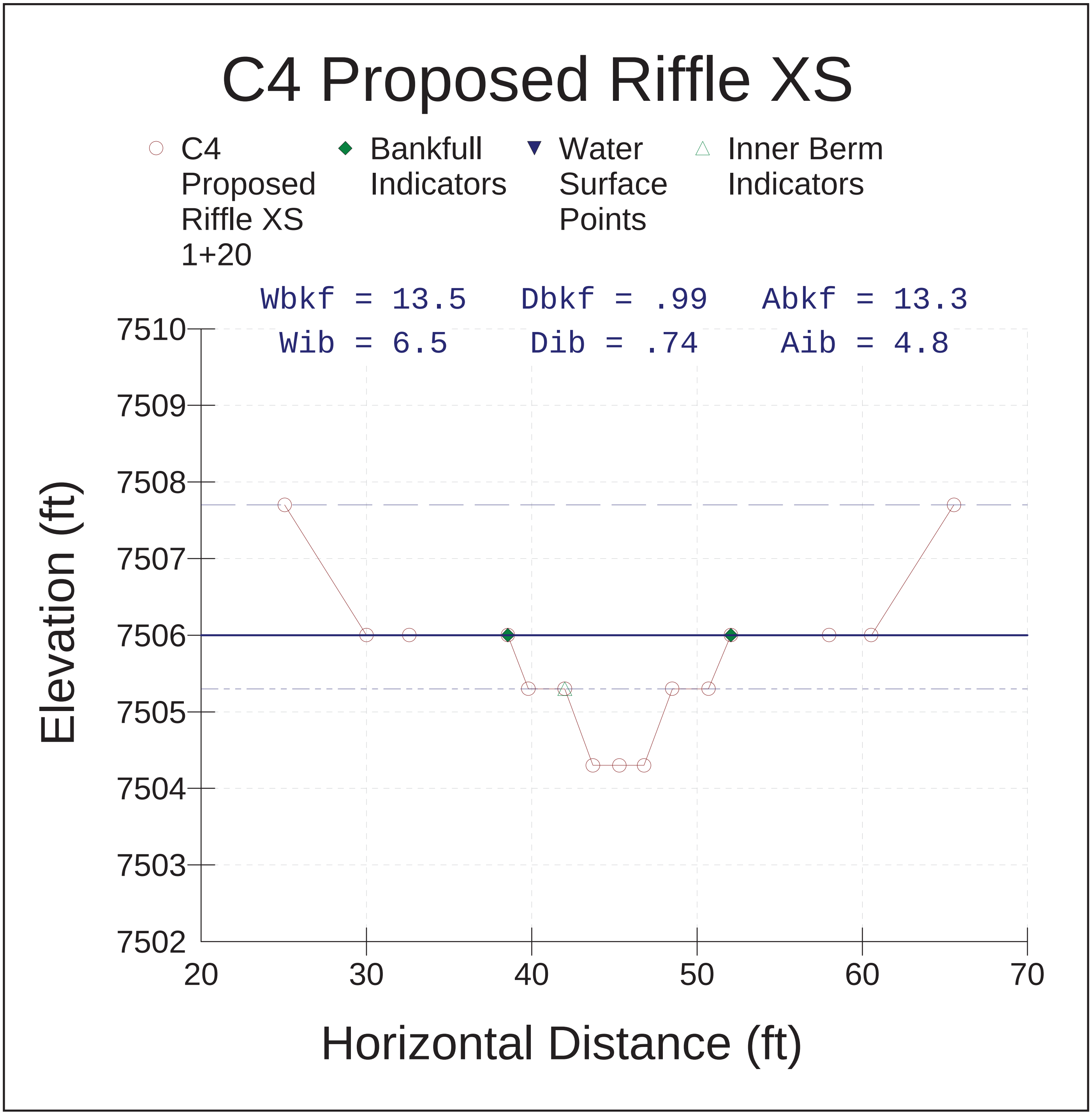

Figure 49. The typical *riffle* cross-section for the proposed C4 reach below the West Creek road.

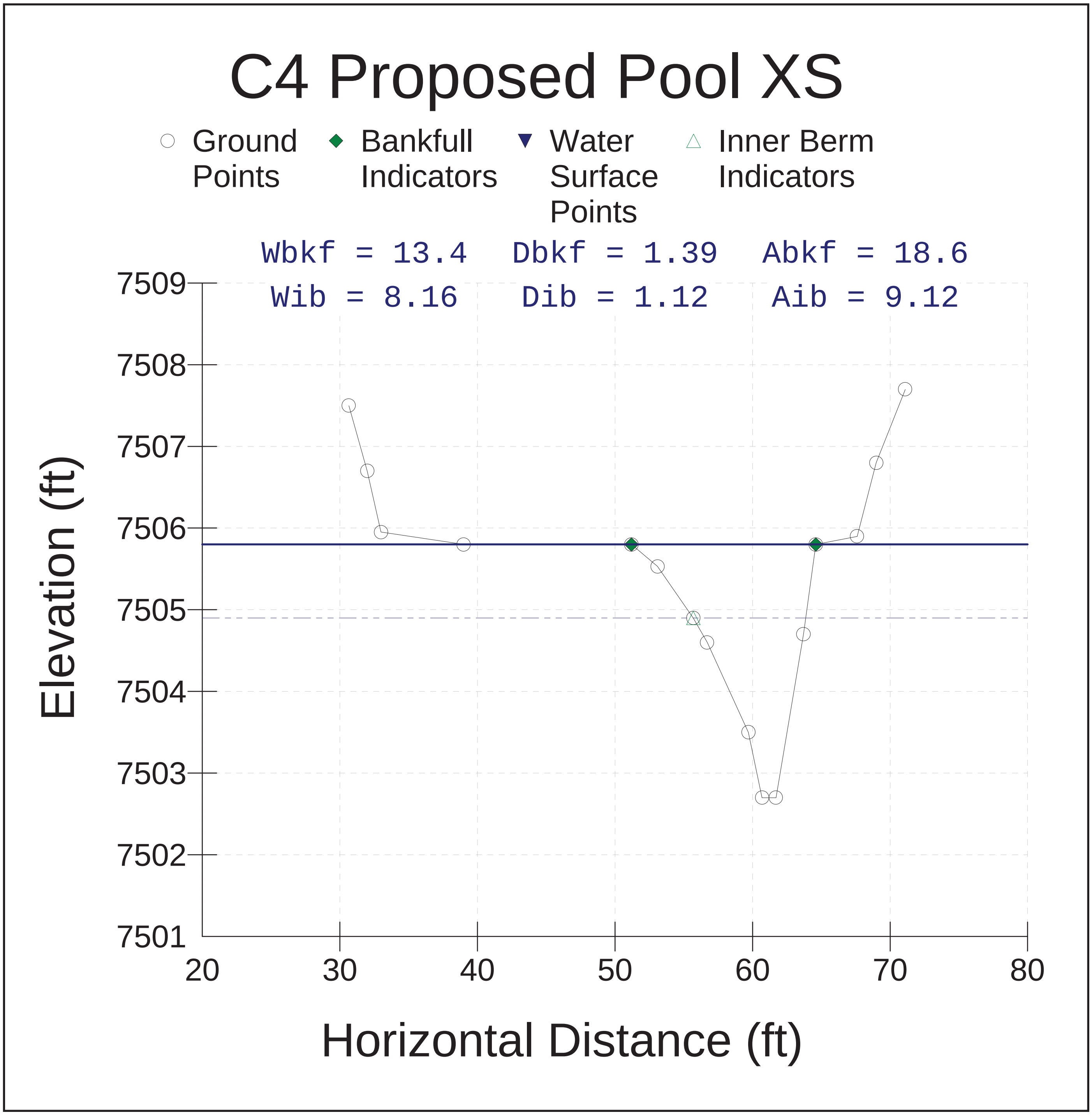

Figure 50. The typical *pool* cross-section for the proposed C4 reach below the West Creek road.

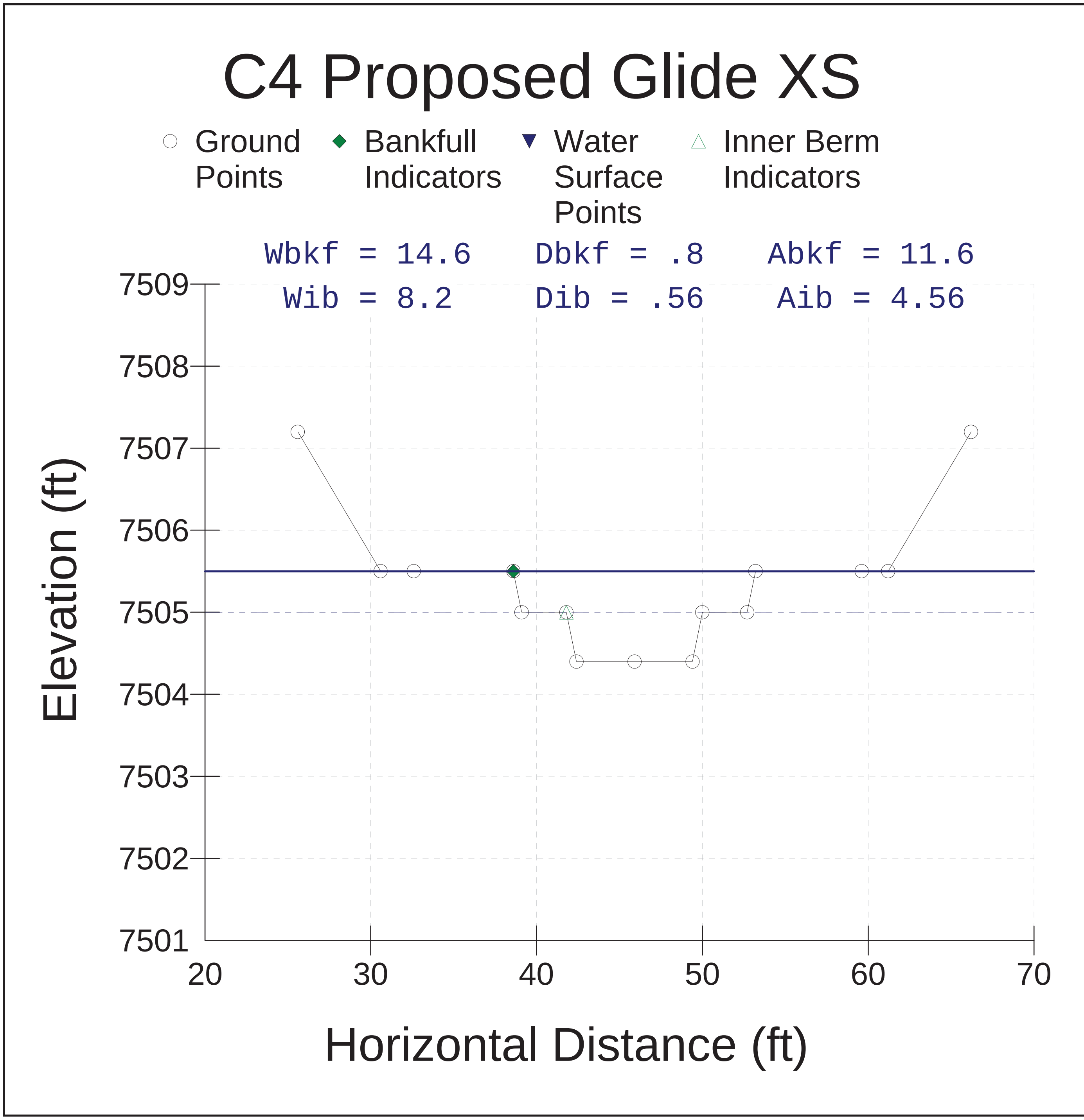

Figure 51. The typical *glide* cross-section for the proposed C4 reach below the West Creek road.

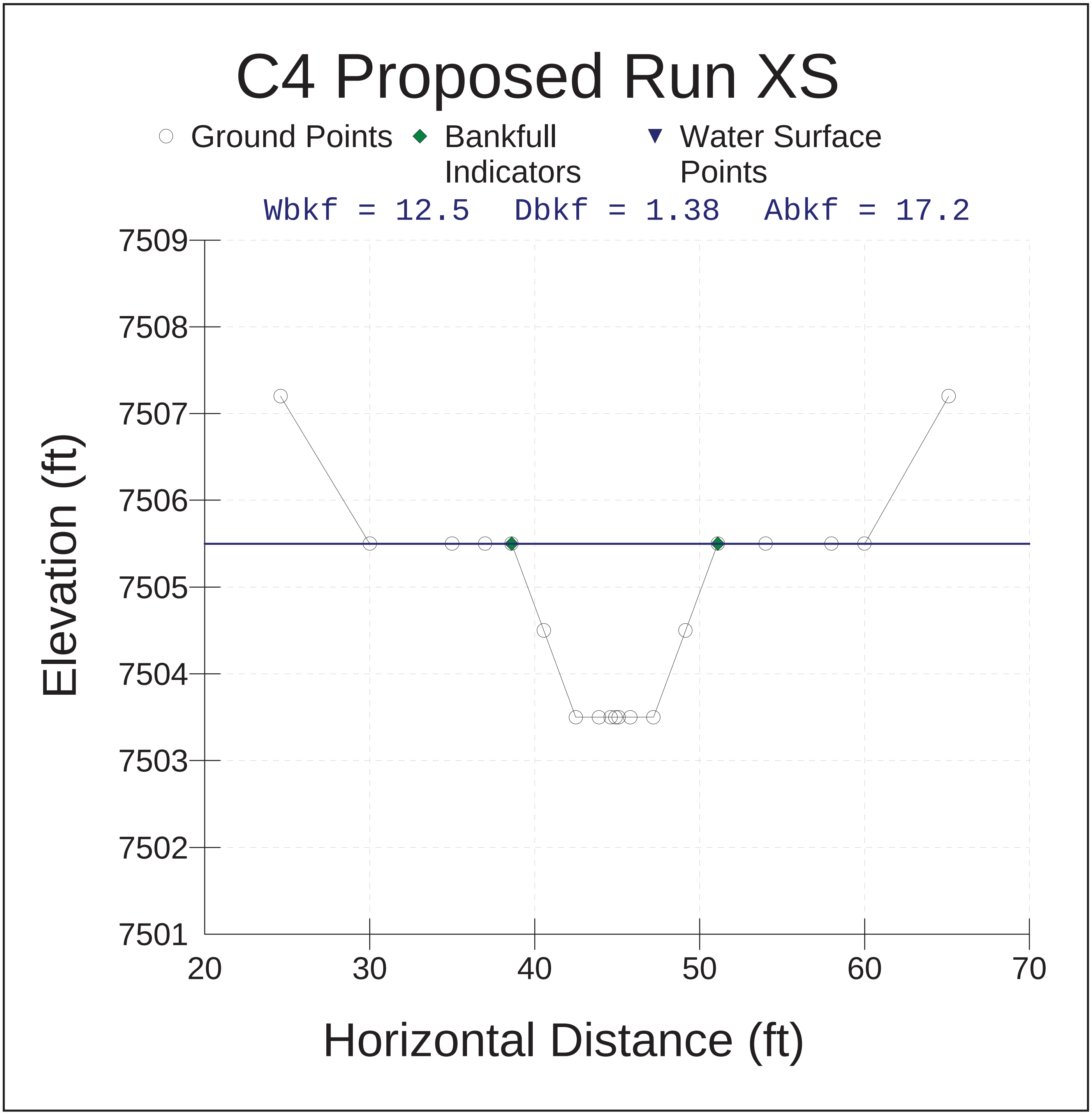

Figure 52. The typical *run* cross-section for the proposed C4 reach below the West Creek road.

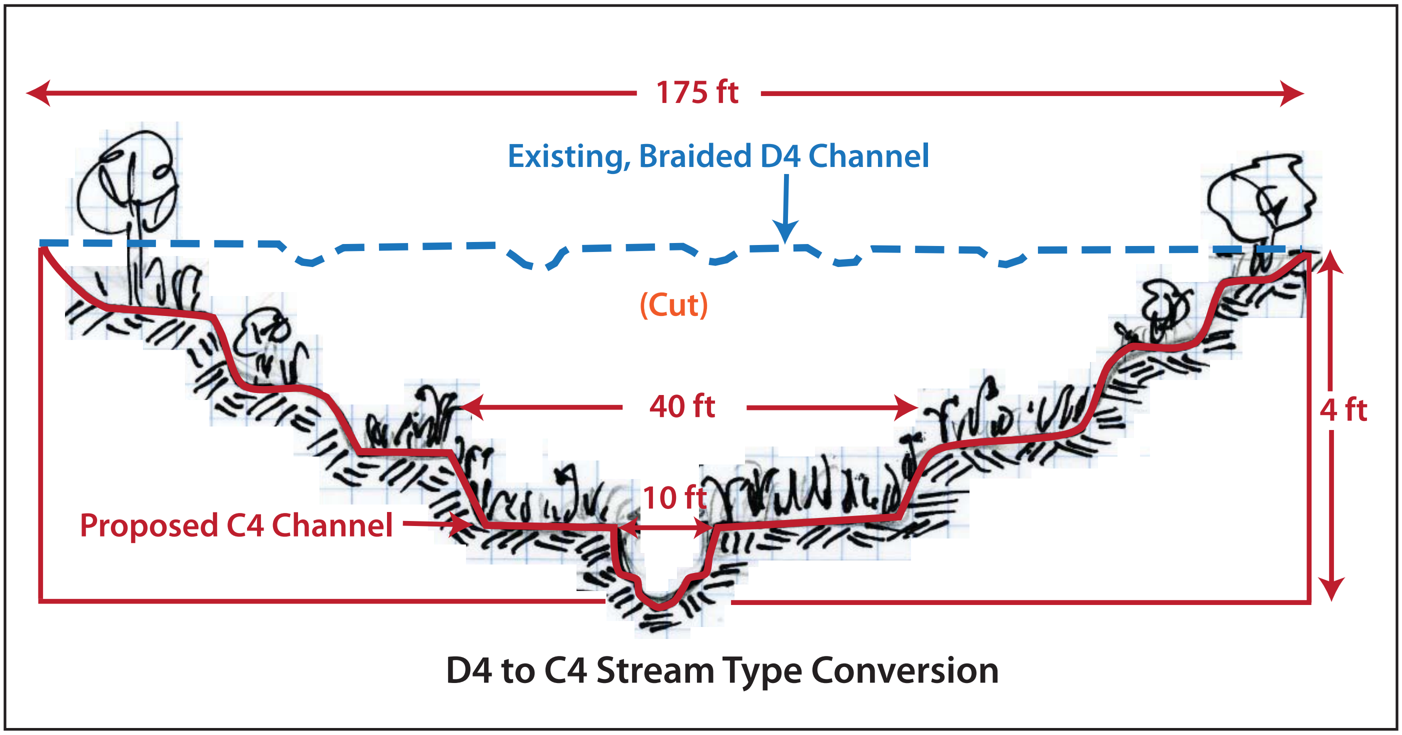

Figure 53. Schematic of the proposed excavation and shaping of a multi-stage channel and valley cross-section for the D4 to C4 stream type conversion below the West Creek road crossing.

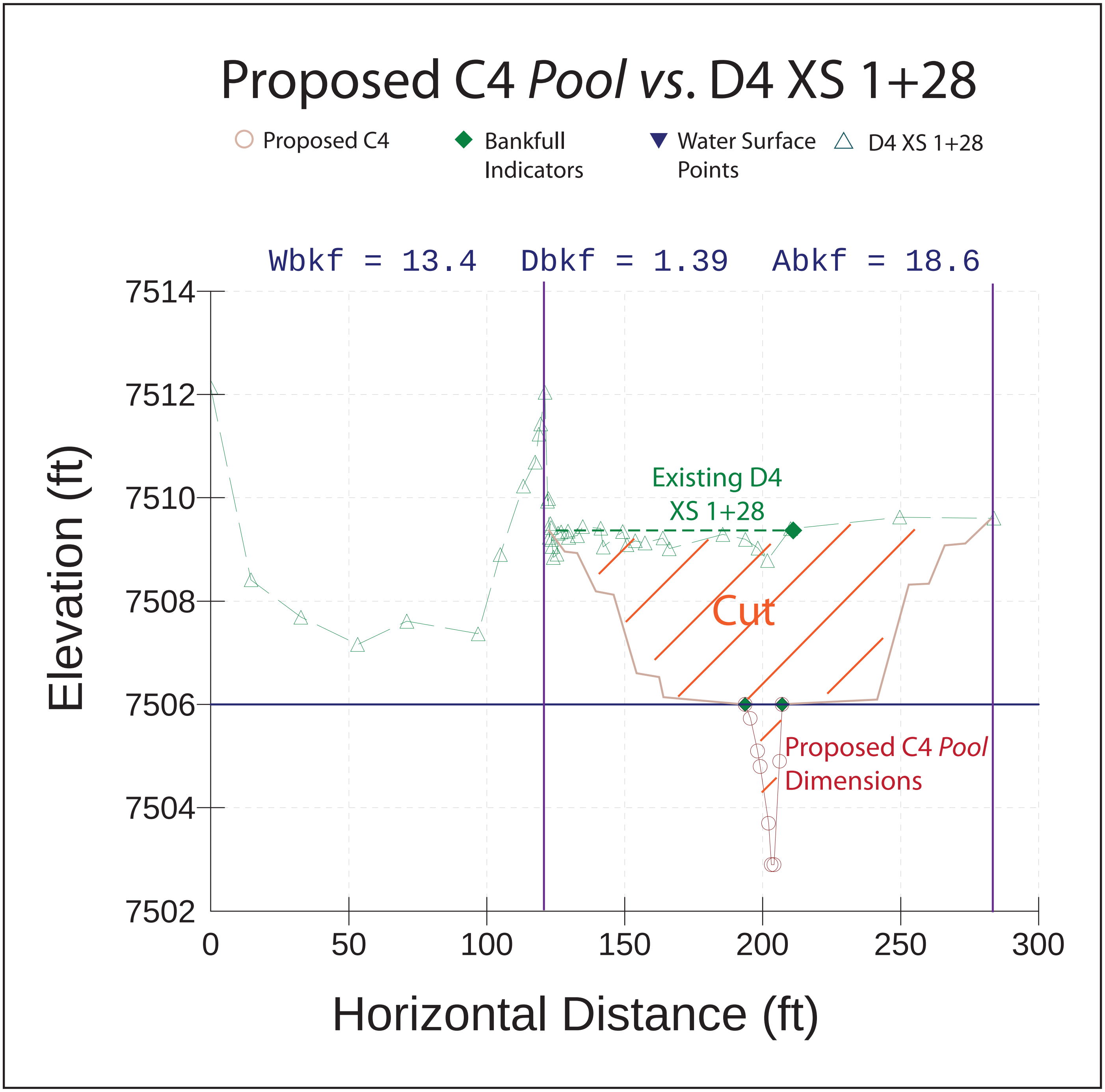

Figure 54. The proposed C4 *pool* cross-section compared to the existing D4 cross-section 1+28 below the West Creek road.

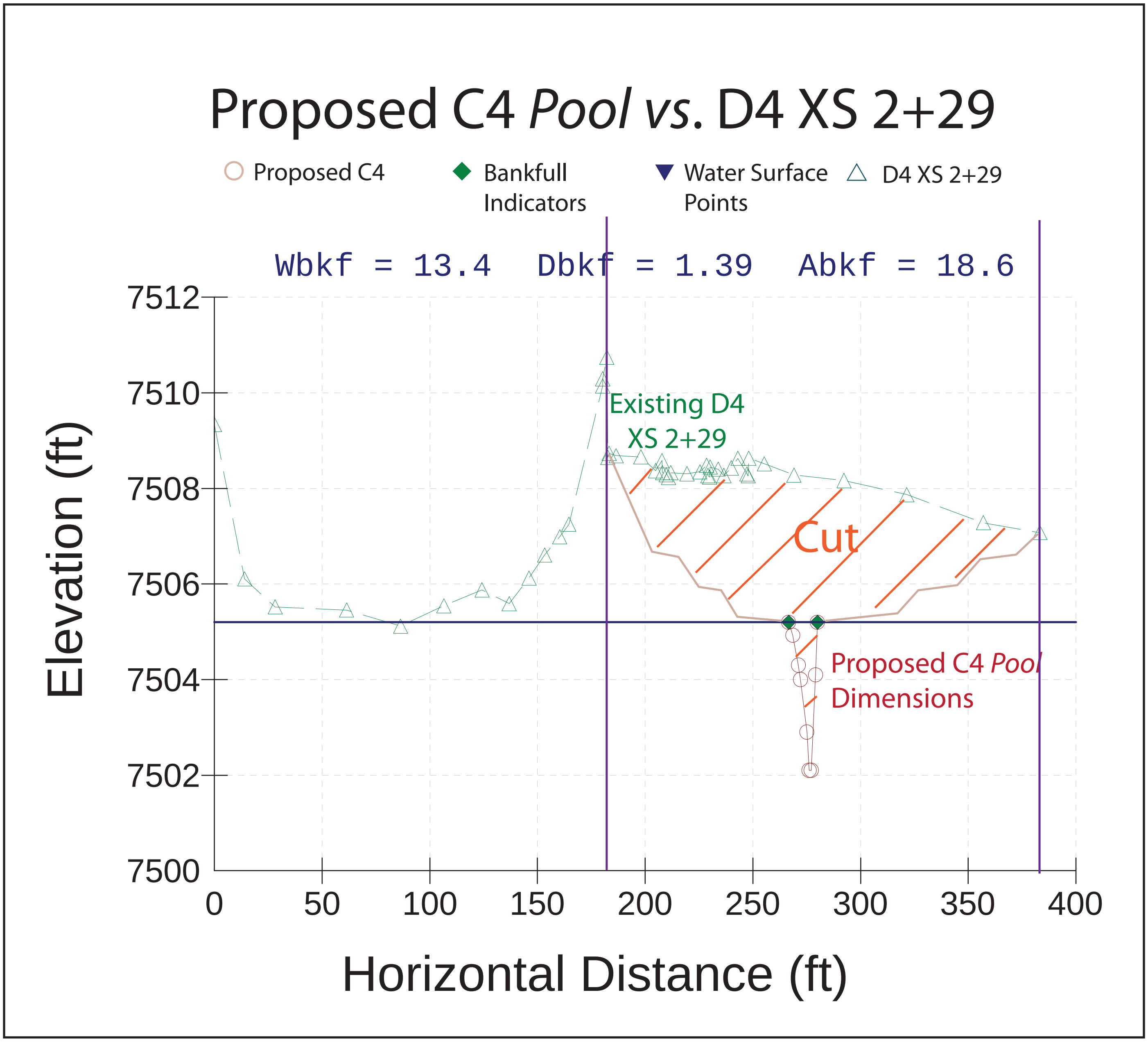

Figure 55. The proposed C4 *pool* cross-section compared to the existing D4 cross-section 2+29 below the West Creek road.

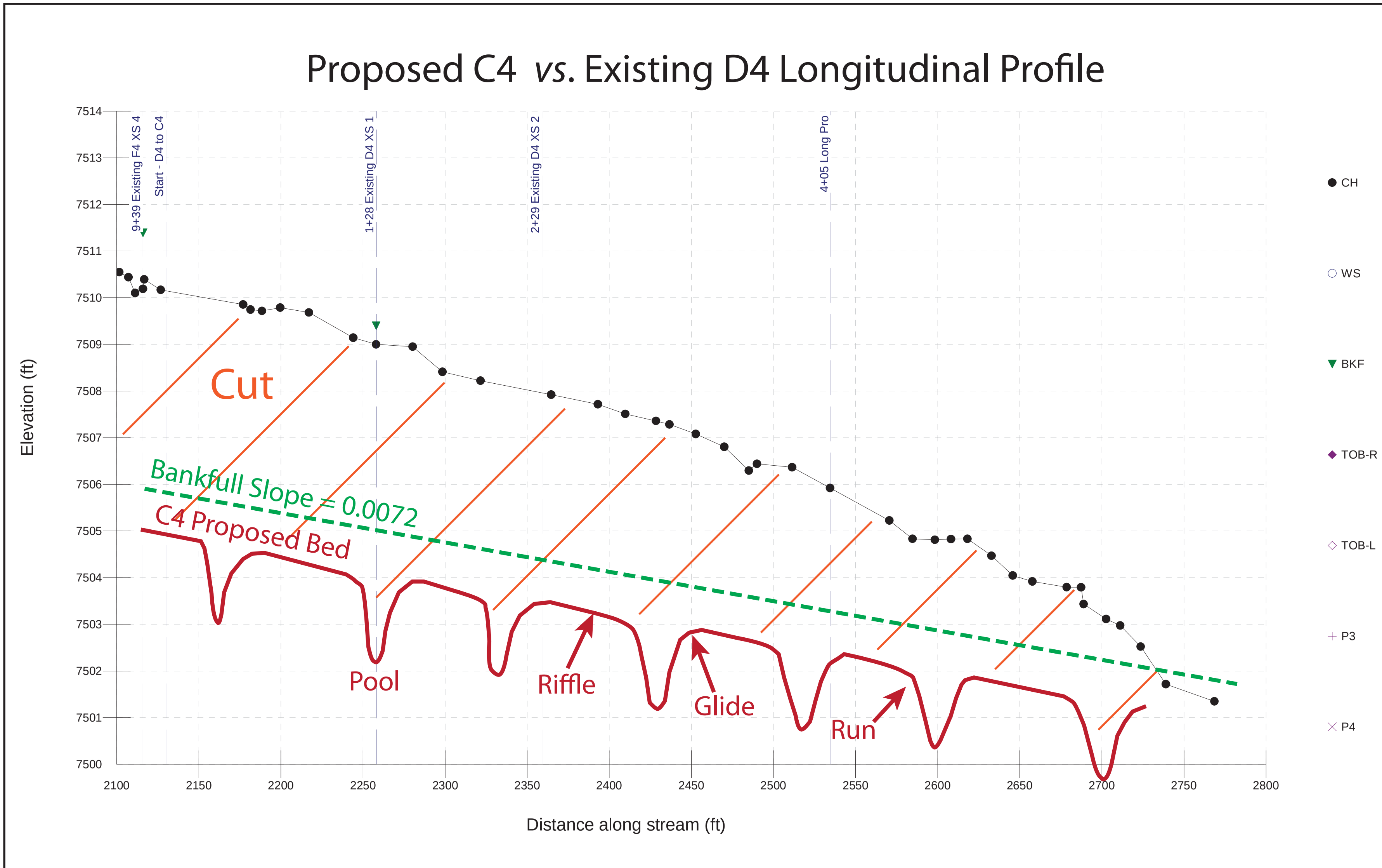

Figure 56. The existing *vs.* proposed design longitudinal profile for the D4 to C4 stream type conversion in Valley Type VIII below the West Creek road, lower Trail Creek.

Insert 11 x 17 Figure 57 Here

Figure 57. Plan view of the alignment for the proposed C4 stream type, including stream stabilization and fish enhancement structures.

Insert 11 x 17 Figure 57 Here

Riparian Vegetation

The exposed cut area within the flood-prone area and multi-stage valley (**Figure 53**) 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 as presented previously in the *Restoration Plan for Hillslope Processes* section of this design (**Figures 24–26**). 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 7**), representing a reduction of *284.5 tons/yr* for this reach (**Table 6**). 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 2a**) to *844.6 tons/yr* (**Worksheet 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 (**Table 6**). 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 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 (**Figure 22**).

Worksheet 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 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 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	$\hat{D}_{50}$	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
0.00720	S	Proposed design bankfull water surface slope (ft/ft)		
0.99	d	Proposed design bankfull mean depth (ft)		
1.65	$\gamma_s - \gamma / \gamma$	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:	
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) τ = predicted shear stress, γ = 62.4, S = proposed design slope	$d = \frac{\tau}{\gamma S}$	
Shields **0.0166**	CO **0.0068**	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				

Stream Crossing Design

The existing, aggraded concrete culvert (*6 ft x 20 ft*) with *12"* culverts on the West Creek road and crossing Trail Creek is shown on the plan view photo overlay in **Figure 57** and in the photographs in **Figure 58** (looking downstream) and **Figure 59** (looking upstream). The proposed redesign of the West Creek road crossing is shown in **Figure 60**. The initial invert of the *10 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 ft* of width compared to the existing design that has *20 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 ft* remains, the box culvert will fill with sediment after the first bankfull runoff event.

The proposed design that has *10 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"* 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 58. The aggrading box culvert (*6 ft x 20 ft*) and the *12″* culverts on the West Creek road (looking downstream).

Figure 59. The existing stream crossing on West Creek road showing the undersized, *12″* culverts and the associated, high width/depth ratio, D4 stream type (looking upstream).

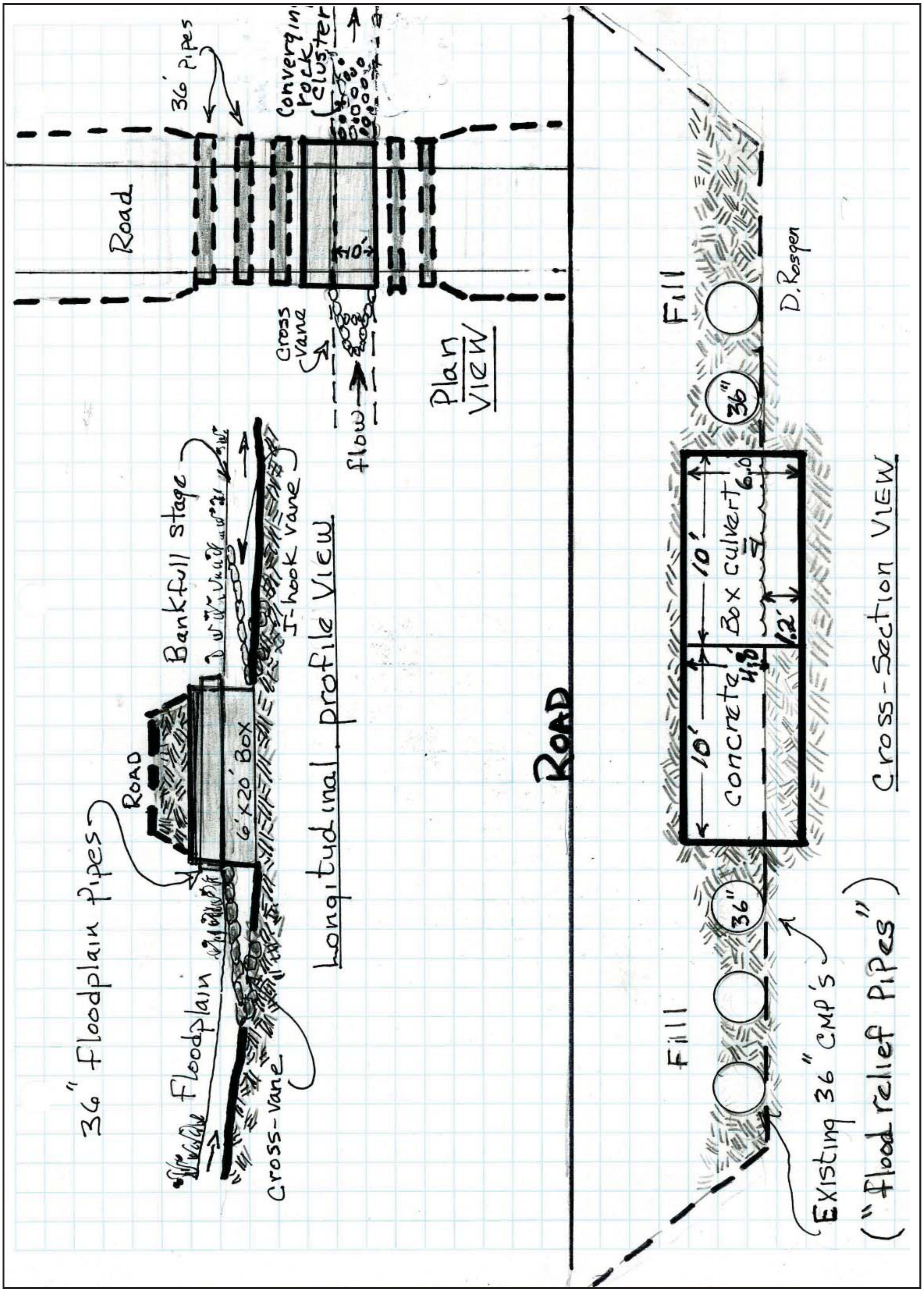

Figure 60. The proposed stream crossing for the West Creek road over Trail Creek based on lowering the base level of the proposed C4 design reach.

Summary of Typical Design Scenario 1: 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:
F4 to B4 Stream Type Conversion (VT VIII)

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* (**Figure 39**). 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 61**). 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 7** and the detailed characteristics and stability evaluation are documented in *Appendix B3* of the Trail Creek *WARSSS* analysis (Rosgen, 2011, pp. B3-1 to B3-36).

The resultant proposed dimension, pattern and profile for the stable B4 stream type are documented in **Table 8** 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 61. The entrenched, high width/depth ratio F4 stream type on lower Trail Creek showing accelerated streambank erosion and excess sediment deposition.

Table 8. 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:* **19.4** *Min:* **12.9** *Max:* **25.2**	*Mean:* **10.4** *Min:* **9.4** *Max:* **11.4**	*Mean:* **11.8** *Min:* **9.3** *Max:* **14.2**
	7	Riffle Mean Depth, ft (d_{bkf})	*Mean:* **0.69** *Min:* **0.62** *Max:* **0.83**	*Mean:* **0.85** *Min:* **0.70** *Max:* **0.90**	*Mean:* **0.75** *Min:* **0.74** *Max:* **0.76**
	8	Riffle Width/Depth Ratio (W_{bkf}/d_{bkf})	*Mean:* **29.5** *Min:* **15.5** *Max:* **40.6**	*Mean:* **12.24** *Min:* **12.0** *Max:* **12.5**	*Mean:* **12.60** *Min:* **12.58** *Max:* **12.62**
	9	Riffle Cross-Sectional Area, ft^2 (A_{bkf})	*Mean:* **12.9** *Min:* **10.6** *Max:* **15.6**	*Mean:* **8.8**	*Mean:* **7.1** *Min:* **6.9** *Max:* **7.3**
	10	Riffle Maximum Depth (d_{max})	*Mean:* **1.22** *Min:* **1.10** *Max:* **1.36**	*Mean:* **1.20** *Min:* **1.00** *Max:* **1.40**	*Mean:* **1.13** *Min:* **1.08** *Max:* **1.18**
	11	Riffle Maximum Depth to Riffle Mean Depth (d_{max}/d_{bkf})	*Mean:* **1.780** *Min:* **1.640** *Max:* **1.940**	*Mean:* **1.412** *Min:* **1.176** *Max:* **1.647**	*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:* **30.7** *Min:* **27.4** *Max:* **32.4**	*Mean:* **22.4** *Min:* **14.6** *Max:* **22.9**	*Mean:* **16.4** *Min:* **14.2** *Max:* **18.5**
	13	Entrenchment Ratio (W_{fpa}/W_{bkf})	*Mean:* **1.5** *Min:* **1.3** *Max:* **1.6**	*Mean:* **2.15** *Min:* **1.4** *Max:* **2.2**	*Mean:* **1.7** *Min:* **1.5** *Max:* **2.0**
Riffle Inner Berm Dimensions	14	Riffle Inner Berm Width, ft (W_{ib})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **6.2** *Min:* **5.2** *Max:* **7.2**	*Mean:* **7.3** *Min:* **5.6** *Max:* **8.8**
	15	Riffle Inner Berm Width to Riffle Width (W_{ib}/W_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.596** *Min:* **0.500** *Max:* **0.692**	*Mean:* **0.616** *Min:* **0.476** *Max:* **0.750**
	16	Riffle Inner Berm Mean Depth, ft (d_{ib})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.52** *Min:* **0.42** *Max:* **0.72**	*Mean:* **0.32** *Min:* **0.20** *Max:* **0.43**
	17	Riffle Inner Berm Mean Depth to Riffle Mean Depth (d_{ib}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.612** *Min:* **0.494** *Max:* **0.847**	*Mean:* **0.427** *Min:* **0.267** *Max:* **0.573**
	18	Riffle Inner Berm Width/Depth Ratio (W_{ib}/d_{ib})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **11.9** *Min:* **7.2** *Max:* **17.1**	*Mean:* **23.6** *Min:* **20.5** *Max:* **32.1**
	19	Riffle Inner Berm Cross-Sectional Area (A_{ib})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **3.9** *Min:* **2.9** *Max:* **4.9**	*Mean:* **2.4** *Min:* **1.3** *Max:* **3.8**
	20	Riffle Inner Berm Cross-Sectional Area to Riffle Cross-Sectional Area (A_{ib}/A_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.438** *Min:* **0.330** *Max:* **0.557**	*Mean:* **0.340** *Min:* **0.180** *Max:* **0.533**

Table 8 (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 8 (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** *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:* **N/A** *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:* **N/A** *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:* **N/A** *Min:* *Max:*	*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:* **N/A** *Min:* *Max:*	*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:* **N/A** *Min:* *Max:*	*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:* **N/A** *Min:* *Max:*	*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:* **N/A** *Min:* *Max:*	*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:* **N/A** *Min:* *Max:*	*Mean:* **2.788** *Min:* **1.192** *Max:* **4.615**	*Mean:* **2.387** *Min:* **1.039** *Max:* **4.020**

Table 8 (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 8 (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 8 (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**
Hydraulics	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**
Sediment Competence	130	Predicted largest moveable particle size (mm) at bankfull shear stress, τ, using the original **Shields** relation	**34.8**	**93**	**84.0**
Sediment Competence	131	Predicted largest moveable particle size (mm) at bankfull shear stress, τ, using the **Colorado** relation	**86.0**	**173**	**180.0**
Sediment Competence	132	Largest particle size to be moved (D_{max}) (mm) (see #126: Particle Size Distribution of Bar Material)	**80**	**80**	**100.0**
Sediment Competence	133	Predicted shear stress required to initiate movement of D_{max} (mm) using the original **Shields** relation	**1.025**	**1.025**	**1.400**
Sediment Competence	134	Predicted shear stress required to initiate movement of D_{max} (mm) using the **Colorado** relation	**0.418**	**0.418**	**0.580**
Sediment Competence	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**
Sediment Competence	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**
Sediment Competence	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**
Sediment Competence	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**
Sediment Competence	139	Bankfull dimensionless shear stress (τ*) (see competence form)	**N/A**	**N/A**	**N/A**
Sediment Competence	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**
Sediment Competence	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 8 (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 cfs* and the proposed bankfull riffle cross-sectional area is *8.8 ft*^{2} as shown in **Table 8**. Using continuity, the corresponding mean velocity for the proposed design reach is *4.55 ft/sec* as shown in **Worksheet 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 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**	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 $\sim (2 * d_{bkf}) + W_{bkf}$	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 $u^* = (gRS)^{1/2}$	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): $u = 1.49*R^{2/3}*S^{1/2} / n$ $n = 0.39*S^{0.38}*R^{-0.16}$ $n =$ N/A **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/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 62** 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 8**). The existing cross-section locations of the F4 stream type are also shown in **Figure 62**.

Cross-Section Dimensions

Table 8 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 62**. 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 63** 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 64**. **Figure 65** 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 66** 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 67** 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 67**). Additionally, the locations of the cross-section overlays in **Figures 63–66** are depicted on the typical longitudinal profile that corresponds with the proposed design bed features.

Insert 11 x 17 Figure 62 Here

Figure 62. 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 62 Here

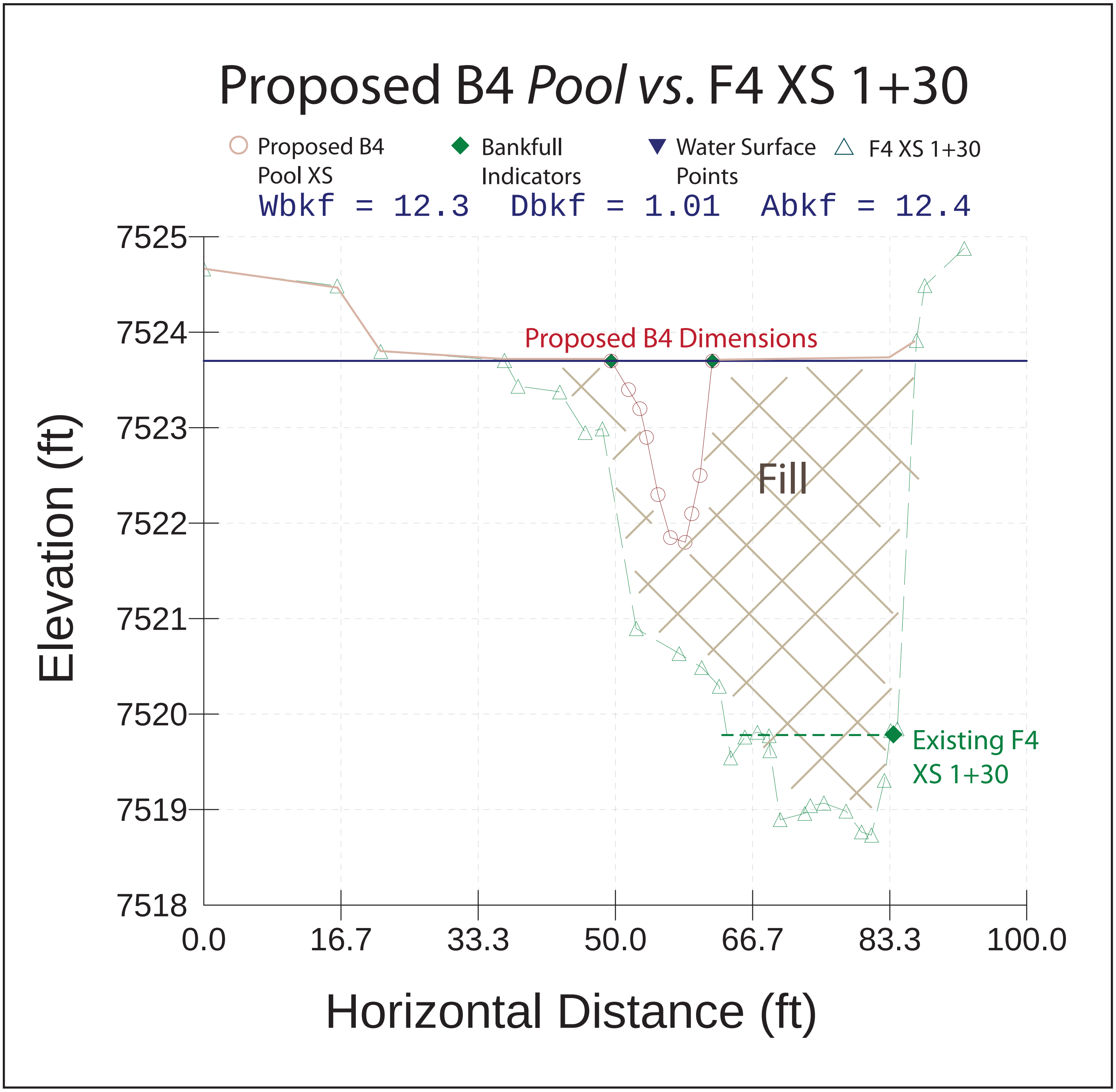

Figure 63. The proposed B4 *pool* cross-section compared to the existing F4 cross-section 1+30, indicating the substantial fill requirements and new bankfull elevation.

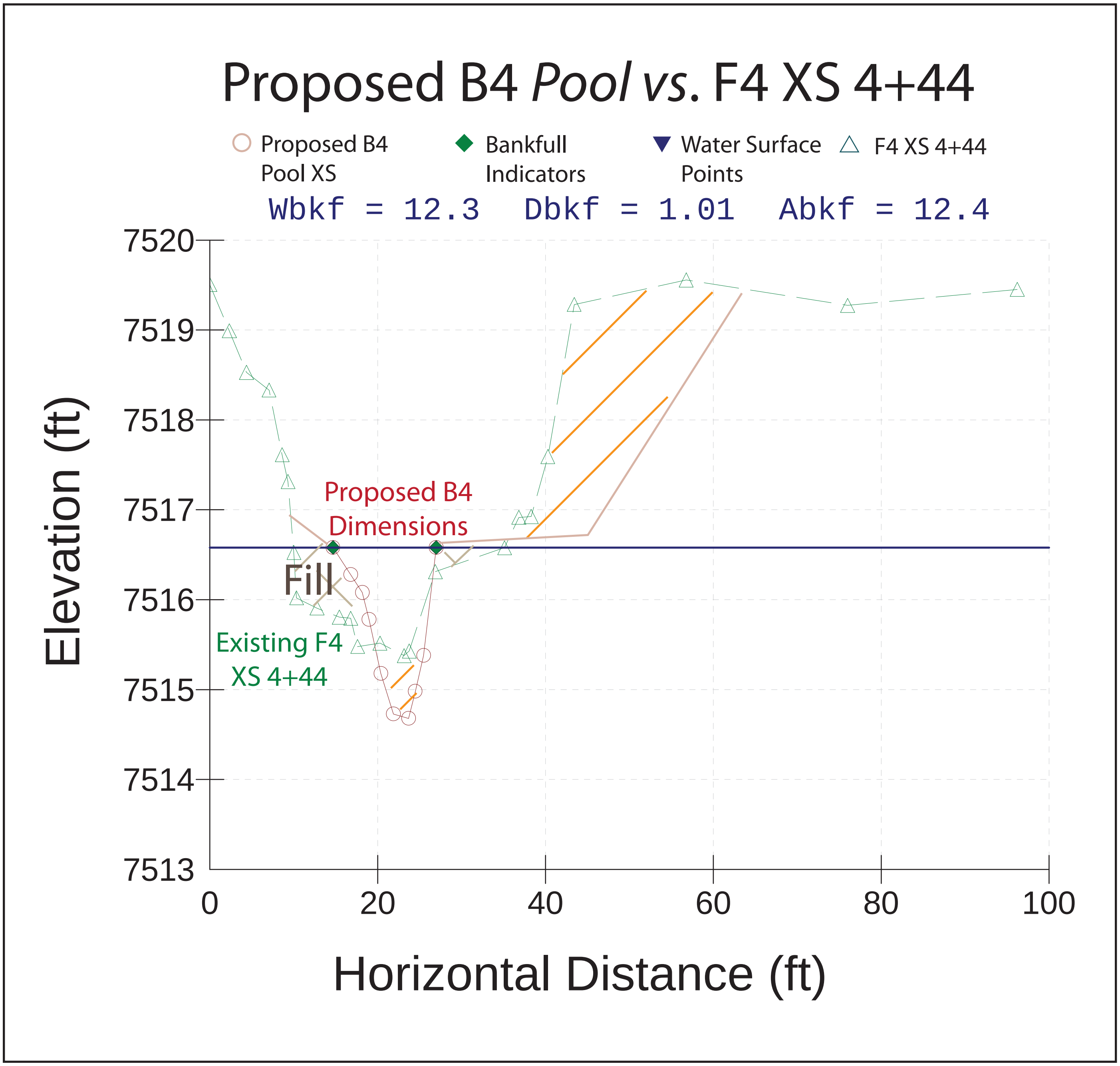

Figure 64. The proposed B4 *pool* cross-section compared to the existing F4 cross-section 4+44, indicating the cut and fill requirements.

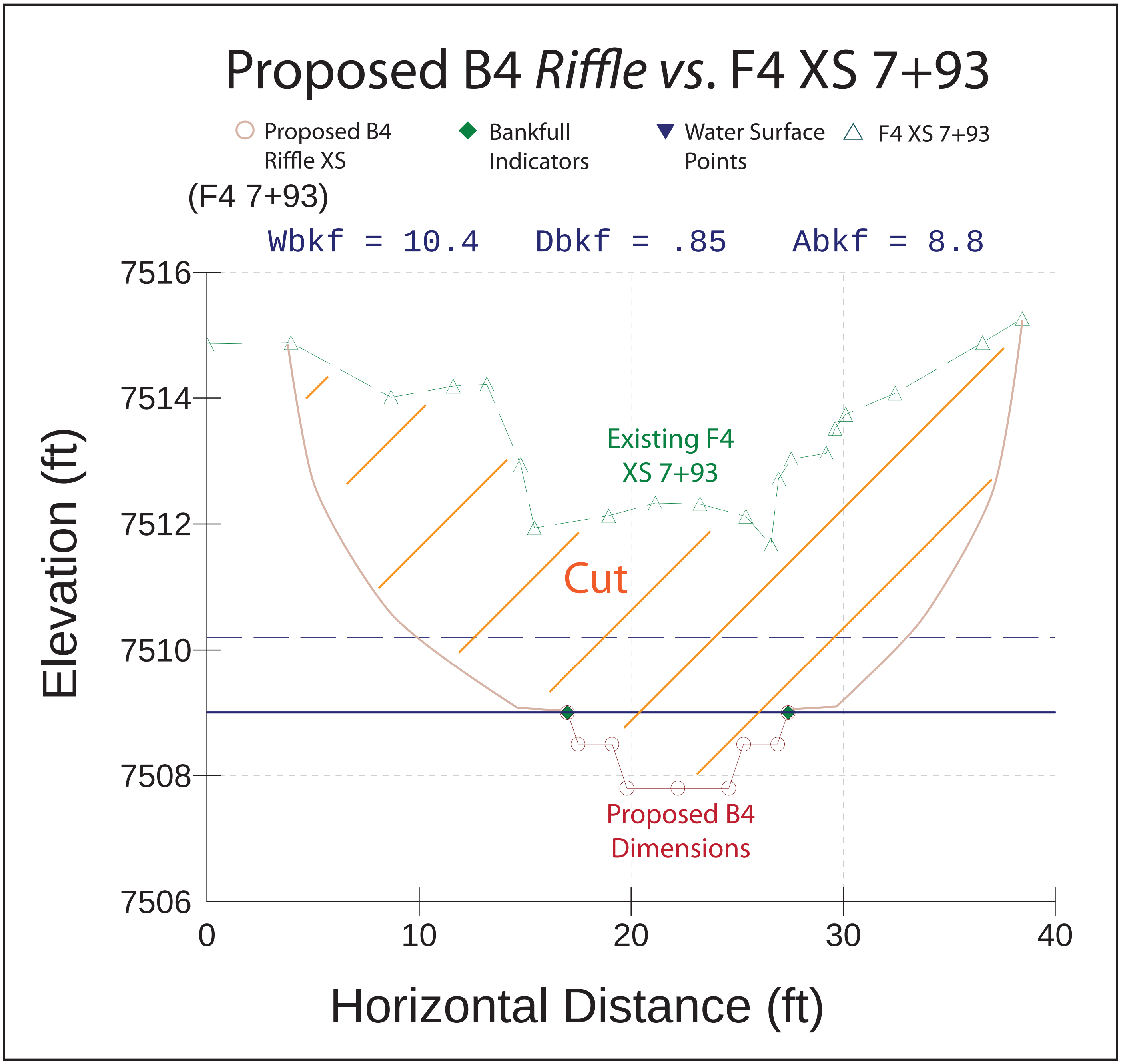

Figure 65. The proposed B4 *riffle* cross-section compared to the existing F4 cross-section 7+93, indicating the substantial excavation required.

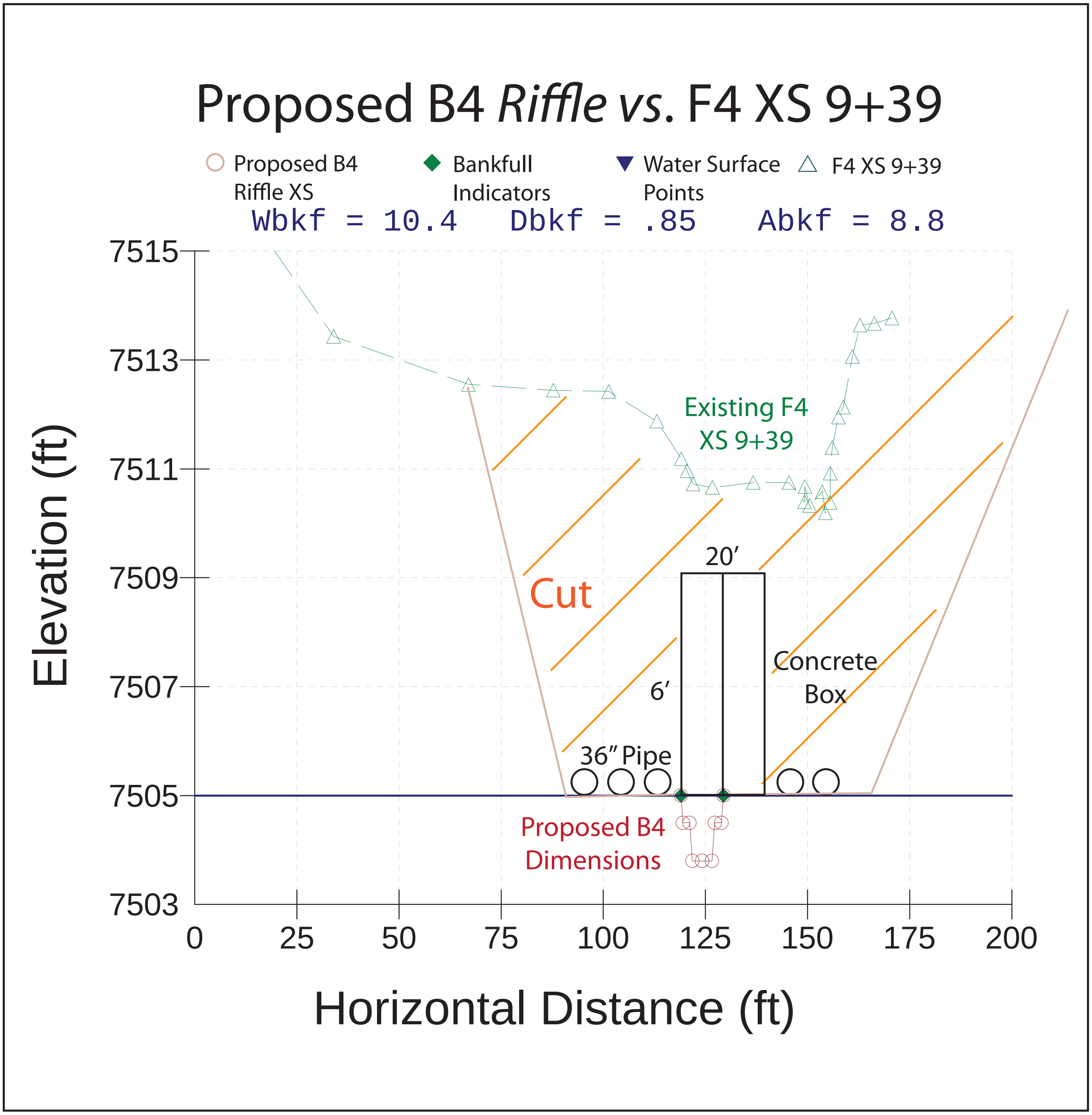

Figure 66. The proposed B4 *riffle* cross-section compared to the existing F4 cross-section 9+39, indicating the substantial excavation required.

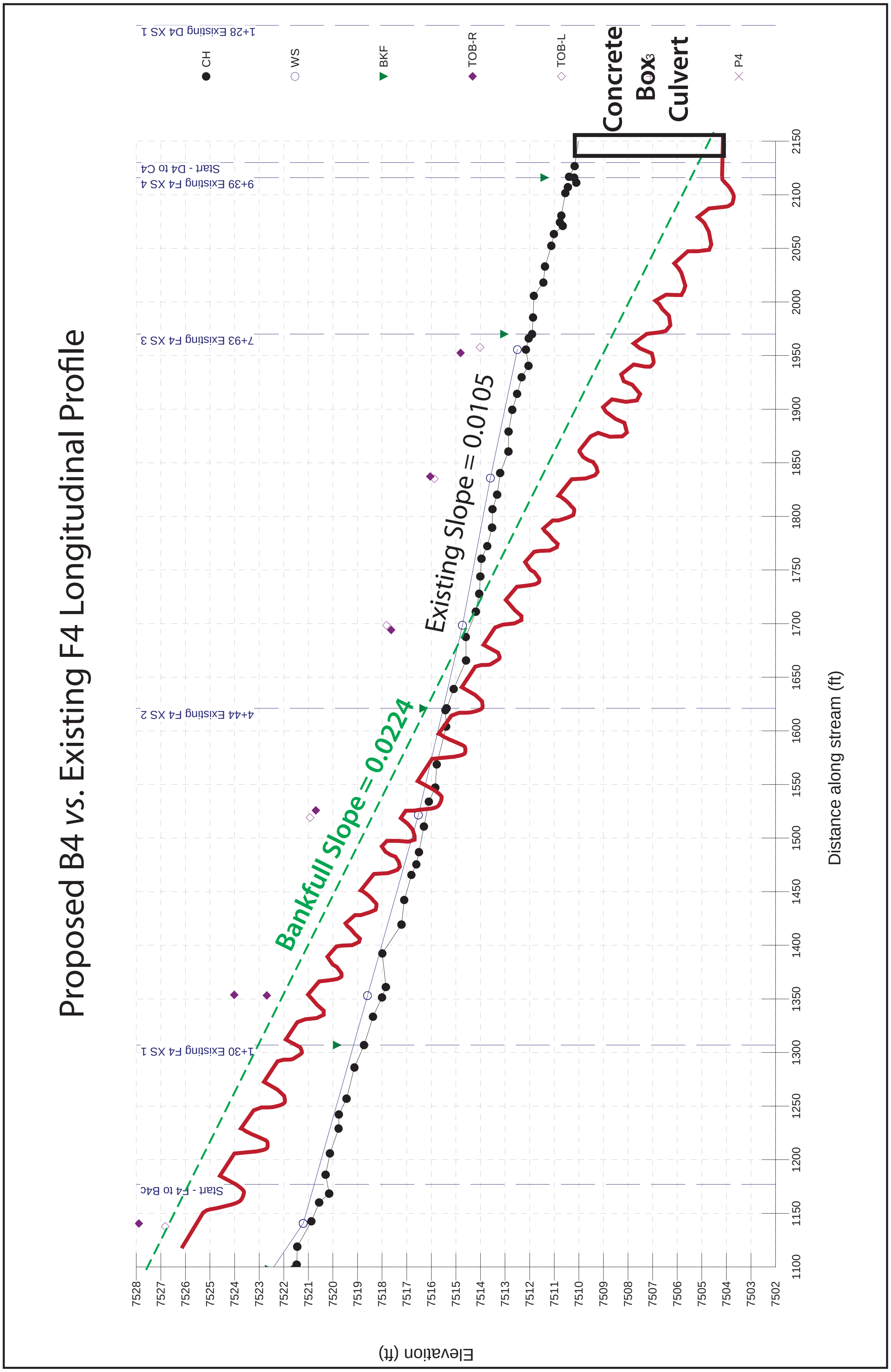

Figure 67. The longitudinal profile comparing the elevations and slopes of the existing F4 *vs.* proposed B4 stream type.

Structures

The proposed streambank stabilization and fish habitat enhancement structures are shown in the plan view layout in **Figure 68**. The rock cross-vane structure (**Figure 10** and **Figure 11**) 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 (**Figure 22**); the root wad, log vane, J-hook (**Figure 9**); the rock vane, J-hook (**Figure 8**); the "Rock & Roll" log structure (**Figure 19**); and the toe wood structure with sod mats and riparian transplants (**Figure 15** and **Figure 16**). 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 68 Here

Figure 68. The proposed plan view layout of the F4 to B4 conversion depicting the stabilization and fish enhancement structures.

Insert 11 x 17 Figure 68 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 8**), 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 68** 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 5a**) to *844.6 tons/yr* (**Worksheet 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 (**Table 6**). 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. This result is confirmed in the overall longitudinal profile for lower Trail Creek as shown in **Figure 39** that indicates the extreme aggradation of the valley in this reach.

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 5-6**); therefore, grade control at the head of each riffle is warranted and recommended. The converging rock clusters and the "Rock & Roll" log structures are designed for grade control, as described previously.

Worksheet 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 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 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	$\hat{D}_{50}$	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
0.0224	S	Proposed design bankfull water surface slope (ft/ft)			
0.85	d	Proposed design bankfull mean depth (ft)			
1.65	$\gamma_s-\gamma/\gamma$	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)	$d = \dfrac{\tau^*(\gamma_s - 1)D_{max}}{S}$	(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)	$S = \dfrac{\tau^*(\gamma_s - 1)D_{max}}{d}$	(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	$d = \dfrac{\tau}{\gamma S}$
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	$S = \dfrac{\tau}{\gamma d}$

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.

The remaining F4 and F4b stream types in the mainstem Trail Creek that exist in confined, Valley Type VIII are prime candidates for this conversion scenario. Numerous F and Fb stream types and conditions are mapped for the mainstem Trail Creek in *Appendix D* of the Trail Creek *WARSSS* analysis (Rosgen, 2011). The calculation of bankfull discharge and cross-sectional area using drainage area from regional curves will allow scaling of the dimensionless ratios using the reference condition B4 stream type as was done for this scenario example. The general procedure to extrapolate this design scenario to other F4 and F4b stream types is included in the *Extrapolation of Typical Scenarios to other Locations* section using the scaling and Natural Channel Design procedure detailed in **Appendix I**.

Typical Design Scenario 3:
G4 to B4 Stream Type Conversion (VT VIII)

General Description & Morphological Data

This typical design scenario 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 7**. The detailed characteristics and stability evaluation of this representative reach are documented in *Appendix C16* of the Trail Creek *WARSSS* analysis (Rosgen, 2011, pp. C16-1 to C16-38). 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 69**. The lower Trail Creek longitudinal profile in **Figure 39** shows the location of the headcut and associated change in slope through this G4 stream type reach. 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 7** and the detailed characteristics and stability evaluation are documented in *Appendix B3* of the Trail Creek *WARSSS* analysis (Rosgen, 2011, pp. B3-1 to B3-36).

The resultant proposed dimension, pattern and profile for the stable B4 stream type are documented in **Table 9** 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 69. 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 9. 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:* **6.4** *Min:* **5.8** *Max:* **9.8**	*Mean:* **10.4** *Min:* **9.4** *Max:* **11.4**	*Mean:* **11.8** *Min:* **9.3** *Max:* **14.2**
Riffle Dimensions	7	Riffle Mean Depth, ft (d_{bkf})	*Mean:* **1.08** *Min:* **0.89** *Max:* **1.29**	*Mean:* **0.85** *Min:* **0.70** *Max:* **0.90**	*Mean:* **0.75** *Min:* **0.74** *Max:* **0.76**
Riffle Dimensions	8	Riffle Width/Depth Ratio (W_{bkf}/d_{bkf})	*Mean:* **7.2** *Min:* **4.5** *Max:* **11.0**	*Mean:* **12.24** *Min:* **12.0** *Max:* **12.5**	*Mean:* **12.60** *Min:* **12.58** *Max:* **12.62**
Riffle Dimensions	9	Riffle Cross-Sectional Area, ft^2 (A_{bkf})	*Mean:* **7.6** *Min:* **6.7** *Max:* **8.7**	*Mean:* **8.8**	*Mean:* **7.1** *Min:* **6.9** *Max:* **7.3**
Riffle Dimensions	10	Riffle Maximum Depth (d_{max})	*Mean:* **1.29** *Min:* **1.15** *Max:* **1.56**	*Mean:* **1.20** *Min:* **1.00** *Max:* **1.40**	*Mean:* **1.13** *Min:* **1.08** *Max:* **1.18**
Riffle Dimensions	11	Riffle Maximum Depth to Riffle Mean Depth (d_{max}/d_{bkf})	*Mean:* **1.203** *Min:* **1.085** *Max:* **1.315**	*Mean:* **1.412** *Min:* **1.176** *Max:* **1.647**	*Mean:* **1.508** *Min:* **1.421** *Max:* **1.595**
Riffle Dimensions	12	Width of Flood-Prone Area at Elevation of 2 * d_{max}, ft (W_{fpa})	*Mean:* **10.0** *Min:* **8.4** *Max:* **12.4**	*Mean:* **22.4** *Min:* **14.6** *Max:* **22.9**	*Mean:* **16.4** *Min:* **14.2** *Max:* **18.5**
Riffle Dimensions	13	Entrenchment Ratio (W_{fpa}/W_{bkf})	*Mean:* **1.4** *Min:* **1.2** *Max:* **1.3**	*Mean:* **2.15** *Min:* **1.4** *Max:* **2.2**	*Mean:* **1.7** *Min:* **1.5** *Max:* **2.0**
Riffle Inner Berm Dimensions	14	Riffle Inner Berm Width, ft (W_{ib})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **6.2** *Min:* **5.2** *Max:* **7.2**	*Mean:* **7.3** *Min:* **5.6** *Max:* **8.8**
Riffle Inner Berm Dimensions	15	Riffle Inner Berm Width to Riffle Width (W_{ib}/W_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.596** *Min:* **0.500** *Max:* **0.692**	*Mean:* **0.616** *Min:* **0.476** *Max:* **0.750**
Riffle Inner Berm Dimensions	16	Riffle Inner Berm Mean Depth, ft (d_{ib})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.52** *Min:* **0.42** *Max:* **0.72**	*Mean:* **0.32** *Min:* **0.20** *Max:* **0.43**
Riffle Inner Berm Dimensions	17	Riffle Inner Berm Mean Depth to Riffle Mean Depth (d_{ib}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.612** *Min:* **0.494** *Max:* **0.847**	*Mean:* **0.427** *Min:* **0.267** *Max:* **0.573**
Riffle Inner Berm Dimensions	18	Riffle Inner Berm Width/Depth Ratio (W_{ib}/d_{ib})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **11.9** *Min:* **7.2** *Max:* **17.1**	*Mean:* **23.6** *Min:* **20.5** *Max:* **32.1**
Riffle Inner Berm Dimensions	19	Riffle Inner Berm Cross-Sectional Area (A_{ib})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **3.9** *Min:* **2.9** *Max:* **4.9**	*Mean:* **2.4** *Min:* **1.3** *Max:* **3.8**
Riffle Inner Berm Dimensions	20	Riffle Inner Berm Cross-Sectional Area to Riffle Cross-Sectional Area (A_{ib}/A_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.438** *Min:* **0.330** *Max:* **0.557**	*Mean:* **0.340** *Min:* **0.180** *Max:* **0.533**

Table 9 (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:* *Min:* *Max:*	**9.6** **8.6** **10.6**	*Mean:* *Min:* *Max:*	**12.3** **7.2** **18.4**	*Mean:* *Min:* *Max:*	**14.0** **8.2** **21.1**
Pool Dimensions	22	Pool Width to Riffle Width (W_{bkfp}/W_{bkf})	*Mean:* *Min:* *Max:*	**1.500** **1.340** **1.660**	*Mean:* *Min:* *Max:*	**1.183** **0.692** **1.769**	*Mean:* *Min:* *Max:*	**1.190** **0.695** **1.792**
Pool Dimensions	**23**	Pool Mean Depth, ft (d_{bkfp})	*Mean:* *Min:* *Max:*	**0.81** **0.67** **0.95**	*Mean:* *Min:* *Max:*	**1.01** **0.85** **1.20**	*Mean:* *Min:* *Max:*	**0.80** **0.59** **1.05**
Pool Dimensions	24	Pool Mean Depth to Riffle Mean Depth (d_{bkfp}/d_{bkf})	*Mean:* *Min:* *Max:*	**0.750** **0.620** **0.880**	*Mean:* *Min:* *Max:*	**1.188** **1.000** **1.412**	*Mean:* *Min:* *Max:*	**1.067** **0.787** **1.400**
Pool Dimensions	**25**	Pool Width/Depth Ratio (W_{bkfp}/d_{bkfp})	*Mean:* *Min:* *Max:*	**11.8** **9.0** **15.8**	*Mean:* *Min:* *Max:*	**12.2** **6.0** **21.6**	*Mean:* *Min:* *Max:*	**17.5** **7.8** **35.8**
Pool Dimensions	**26**	Pool Cross-Sectional Area, ft^2 (A_{bkfp})	*Mean:* *Min:* *Max:*	**7.9** **5.7** **10.0**	*Mean:* *Min:* *Max:*	**12.5** **8.5** **18.0**	*Mean:* *Min:* *Max:*	**8.9** **8.5** **9.6**
Pool Dimensions	27	Pool Area to Riffle Area (A_{bkfp}/A_{bkf})	*Mean:* *Min:* *Max:*	**1.031** **0.749** **1.313**	*Mean:* *Min:* *Max:*	**1.415** **0.966** **2.045**	*Mean:* *Min:* *Max:*	**1.248** **1.189** **1.348**
Pool Dimensions	**28**	Pool Maximum Depth (d_{maxp})	*Mean:* *Min:* *Max:*	**1.51** **1.40** **1.61**	*Mean:* *Min:* *Max:*	**1.90** **1.50** **2.10**	*Mean:* *Min:* *Max:*	**1.56** **1.33** **1.85**
Pool Dimensions	29	Pool Maximum Depth to Riffle Mean Depth (d_{maxp}/d_{bkf})	*Mean:* *Min:* *Max:*	**1.398** **1.296** **1.491**	*Mean:* *Min:* *Max:*	**2.235** **1.765** **2.471**	*Mean:* *Min:* *Max:*	**2.080** **1.773** **2.467**
Pool Dimensions	**30**	Point Bar Slope (S_{pb})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**0.380** **0.280** **0.400**	*Mean:* *Min:* *Max:*	**0.290** **0.220** **0.360**
Pool Inner Berm Dimensions	**31**	Pool Inner Berm Width, ft (W_{ibp})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**8.2** **4.0** **10.0**	*Mean:* *Min:* *Max:*	**4.8** **4.5** **5.1**
Pool Inner Berm Dimensions	32	Pool Inner Berm Width to Pool Width (W_{ibp}/W_{bkfp})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**0.665** **0.325** **0.813**	*Mean:* *Min:* *Max:*	**0.343** **0.320** **0.361**
Pool Inner Berm Dimensions	**33**	Pool Inner Berm Mean Depth, ft (d_{ibp})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**0.90** **0.50** **0.95**	*Mean:* *Min:* *Max:*	**0.31** **0.22** **0.40**
Pool Inner Berm Dimensions	34	Pool Inner Berm Mean Depth to Pool Mean Depth (d_{ibp}/d_{bkfp})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**0.891** **0.495** **0.941**	*Mean:* *Min:* *Max:*	**0.388** **0.275** **0.500**
Pool Inner Berm Dimensions	**35**	Pool Inner Berm Width/Depth Ratio (W_{ibp}/d_{ibp})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**9.1** **4.2** **20.0**	*Mean:* *Min:* *Max:*	**0.9** **0.8** **0.9**
Pool Inner Berm Dimensions	**36**	Pool Inner Berm Cross-Sectional Area (A_{ibp})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**7.36** **3.8** **5.0**	*Mean:* *Min:* *Max:*	**1.5** **1.0** **2.0**
Pool Inner Berm Dimensions	37	Pool Inner Berm Cross-Sectional Area to Pool Cross-Sectional Area (A_{ibp}/A_{bkfp})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**0.591** **0.305** **0.402**	*Mean:* *Min:* *Max:*	**0.172** **0.114** **0.226**

Table 9 (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:
Run Dimensions	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:
Run Dimensions	**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:
Run Dimensions	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:
Run Dimensions	**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:
Run Dimensions	**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:
Run Dimensions	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:
Run Dimensions	**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:
Run Dimensions	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:
Glide Dimensions	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:
Glide Dimensions	**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:
Glide Dimensions	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:
Glide Dimensions	**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:
Glide Dimensions	**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:
Glide Dimensions	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:
Glide Dimensions	**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:
Glide Dimensions	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 9 (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**	*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:*	**14.6**	*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:*	**2.288**	*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:*	**4.6**	*Mean:*	**15.0**	*Mean:*	**14.7**
			Min:	**1.3**	*Min:*	**3.0***	*Min:*	**2.7***
			Max:	**9.1**	*Max:*	**29.0**	*Max:*	**28.2**
	83	Riffle Length to Riffle Width (L_r/W_{bkf}) ***Refers to a Step Length - Not Riffle**	*Mean:*	**0.721**	*Mean:*	**1.442**	*Mean:*	**1.248**
			Min:	**0.204**	*Min:*	**0.288***	*Min:*	**0.229***
			Max:	**1.426**	*Max:*	**2.788**	*Max:*	**2.395**
	84	Individual Pool Length, ft (L_p)	*Mean:*	**7.8**	*Mean:*	**62.0**	*Mean:*	**60.1**
			Min:	**4.1**	*Min:*	**24.0**	*Min:*	**23.0**
			Max:	**11.4**	*Max:*	**103.0**	*Max:*	**101.0**
	85	Pool Length to Riffle Width (L_p/W_{bkf})	*Mean:*	**1.223**	*Mean:*	**5.962**	*Mean:*	**5.104**
			Min:	**0.643**	*Min:*	**2.308**	*Min:*	**1.953**
			Max:	**1.787**	*Max:*	**9.904**	*Max:*	**8.577**
	86	Pool to Pool Spacing, ft (P_s)	*Mean:*	**163.0**	*Mean:*	**29.0**	*Mean:*	**28.1**
			Min:	**7.6**	*Min:*	**12.4**	*Min:*	**12.2**
			Max:	**24.2**	*Max:*	**48.0**	*Max:*	**47.3**
	87	Pool to Pool Spacing to Riffle Width (P_s/W_{bkf})	*Mean:*	**25.549**	*Mean:*	**2.788**	*Mean:*	**2.387**
			Min:	**1.191**	*Min:*	**1.192**	*Min:*	**1.039**
			Max:	**3.793**	*Max:*	**4.615**	*Max:*	**4.020**

Table 9 (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 9 (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.

Group	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 9 (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 9 (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 cfs* and the proposed bankfull riffle cross-sectional area is *8.8* ft^2 as shown in **Table 9**. Using continuity, the corresponding mean velocity for the proposed design reach is *4.55 ft/sec* as shown in **Worksheet 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 70** 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 9**). The existing cross-section locations of the G4 stream type are also shown **Figure 70**.

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 9**. The locations of existing cross-sections are displayed in **Figure 70**. To establish the stable base level and slope, the proposed channel must be placed over new fill in the existing channel. **Figure 71** 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 72**). Additional proposed cross-sections for riffles and pools are shown in the existing *vs*. proposed cross-section overlays in **Figure 73** (*pool*), **Figure 74** (*riffle*), **Figure 75** (*pool*), **Figure 76** (*pool*), **Figure 77** (*riffle*) and **Figure 78** (*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 79** 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 70**. 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 79**. Additionally, the locations of the cross-section overlays in **Figures 71–78** are depicted on the typical longitudinal profile that corresponds with the proposed design bed features.

Worksheet 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 PERIMETER $\sim (2 * d_{bkf}) + W_{bkf}$	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 $u^* = (gRS)^{1/2}$	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): $u = 1.49 * R^{2/3} * S^{1/2} / n$; $n = 0.39 * S^{0.38} * R^{-0.16}$ n = N/A. 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/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 70 Here

Figure 70. 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 70 Here

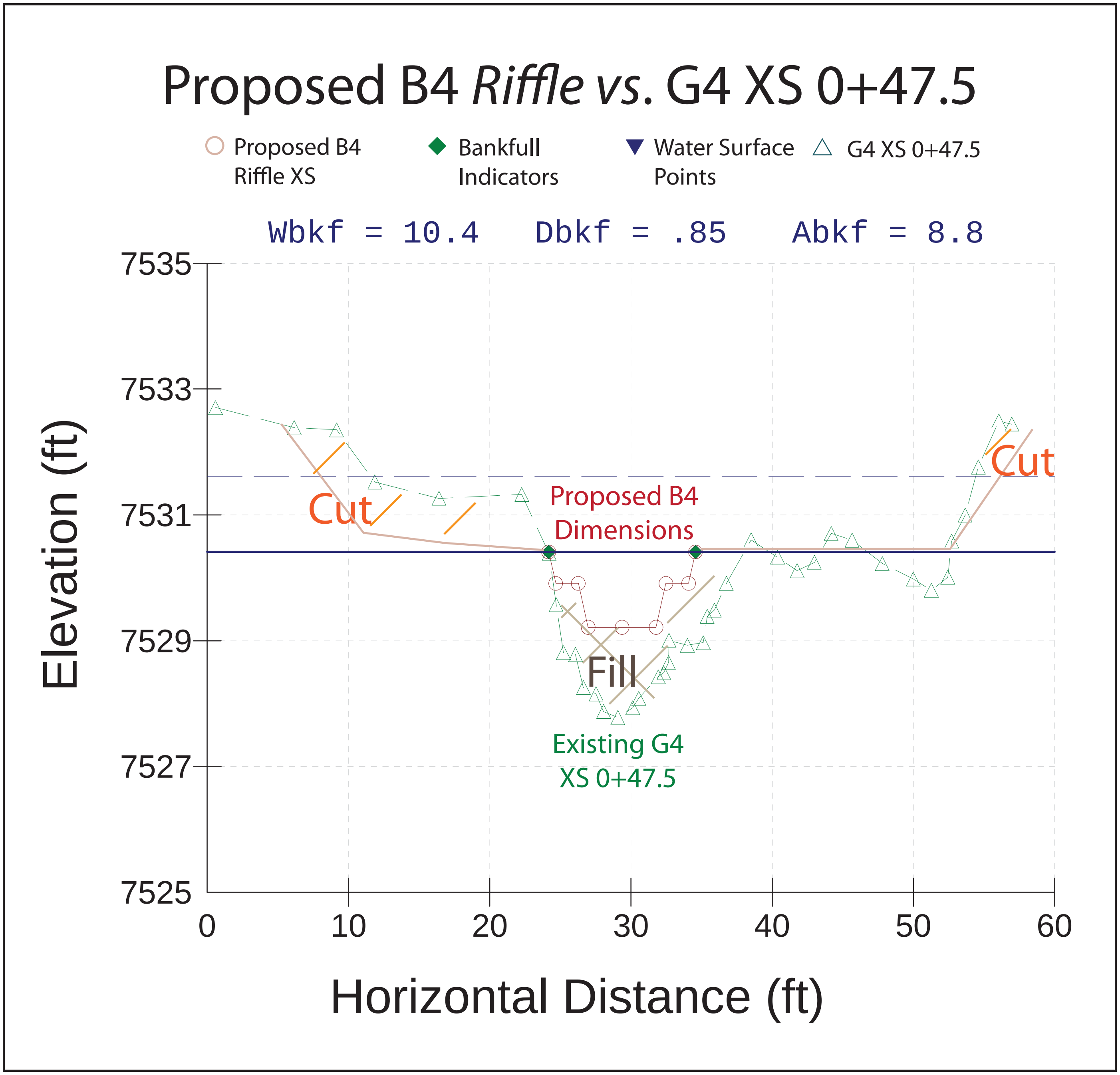

Figure 71. The proposed B4 *riffle* cross-section compared to the existing G4 cross-section 0+47.5, indicating the cut and fill requirements and new bankfull elevation.

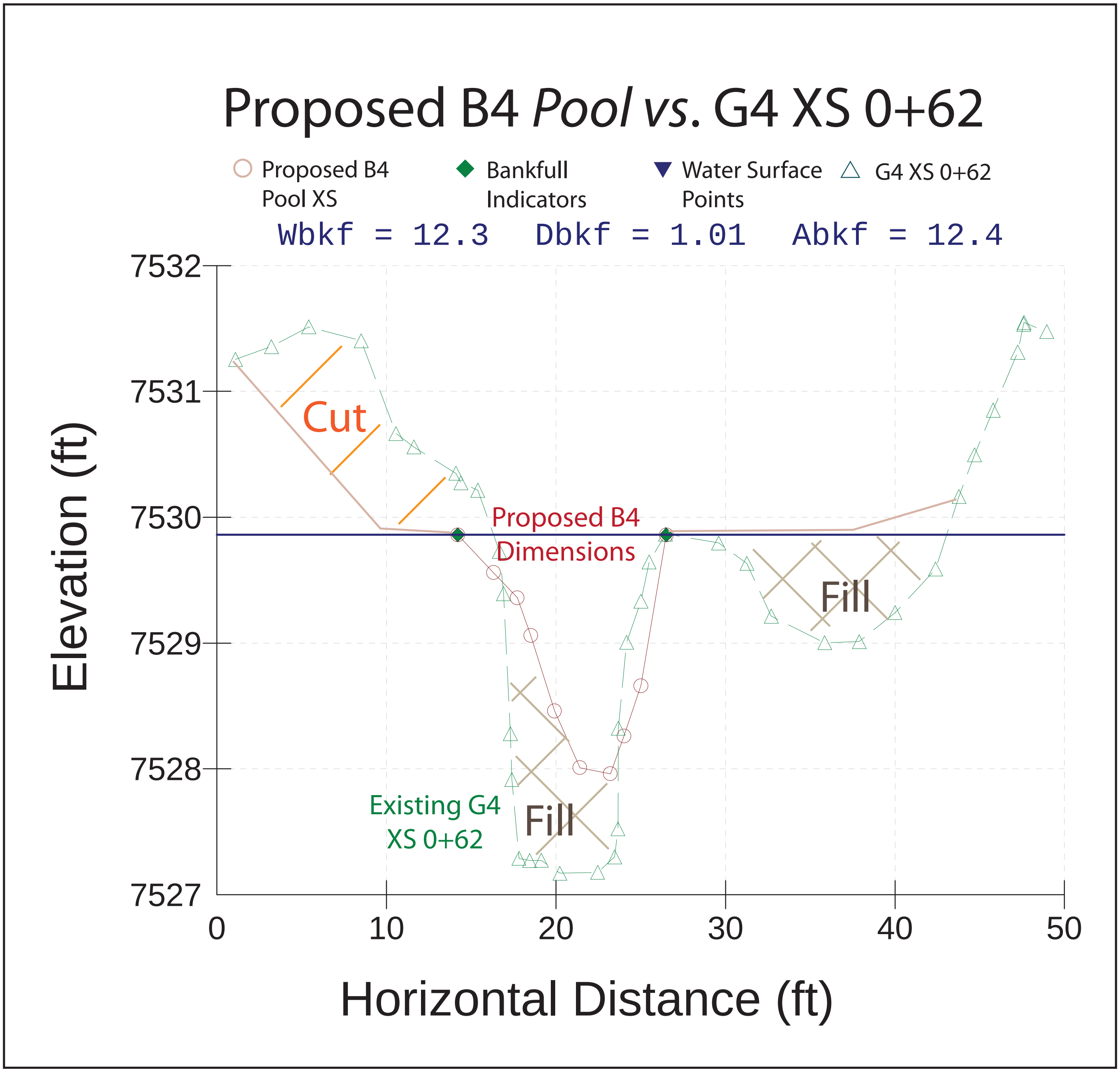

Figure 72. The proposed B4 *pool* cross-section compared to the existing G4 cross-section 0+62, indicating the cut and fill requirements and new bankfull elevation.

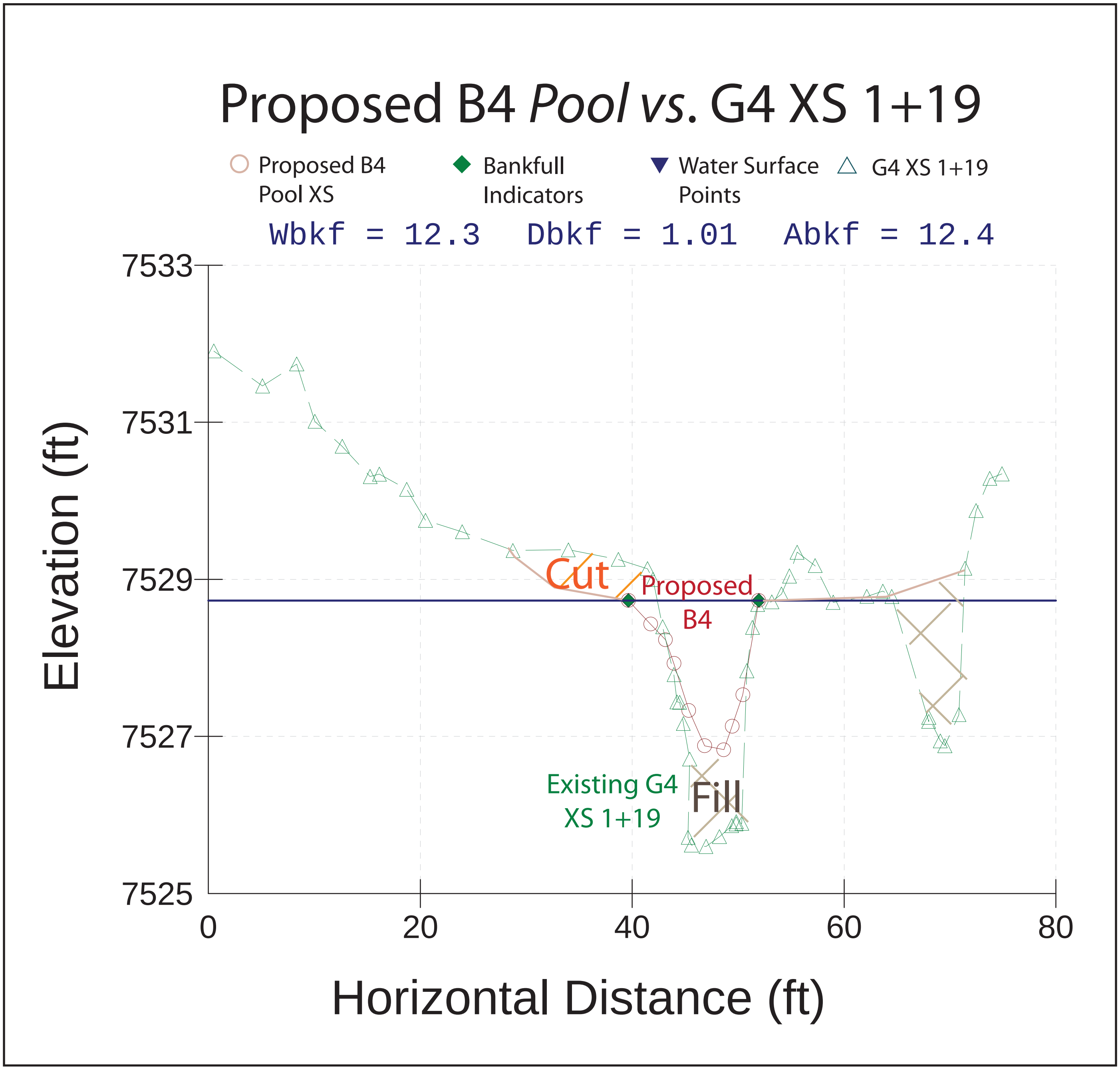

Figure 73. The proposed B4 *pool* cross-section compared to the existing G4 cross-section 1+19, indicating the cut and fill requirements and new bankfull elevation.

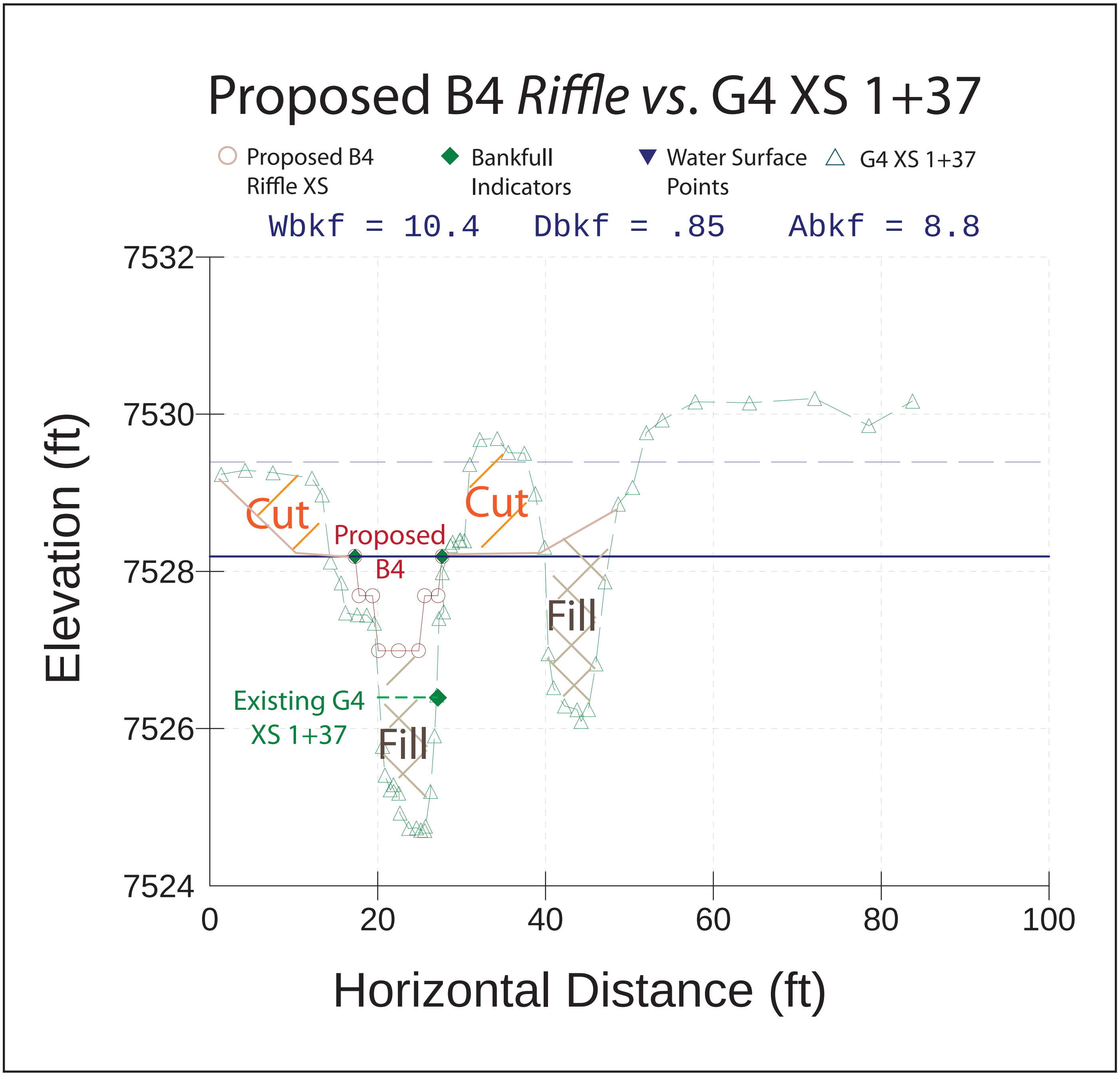

Figure 74. The proposed B4 *riffle* cross-section compared to the existing G4 cross-section 1+37, indicating the cut and fill requirements and new bankfull elevation.

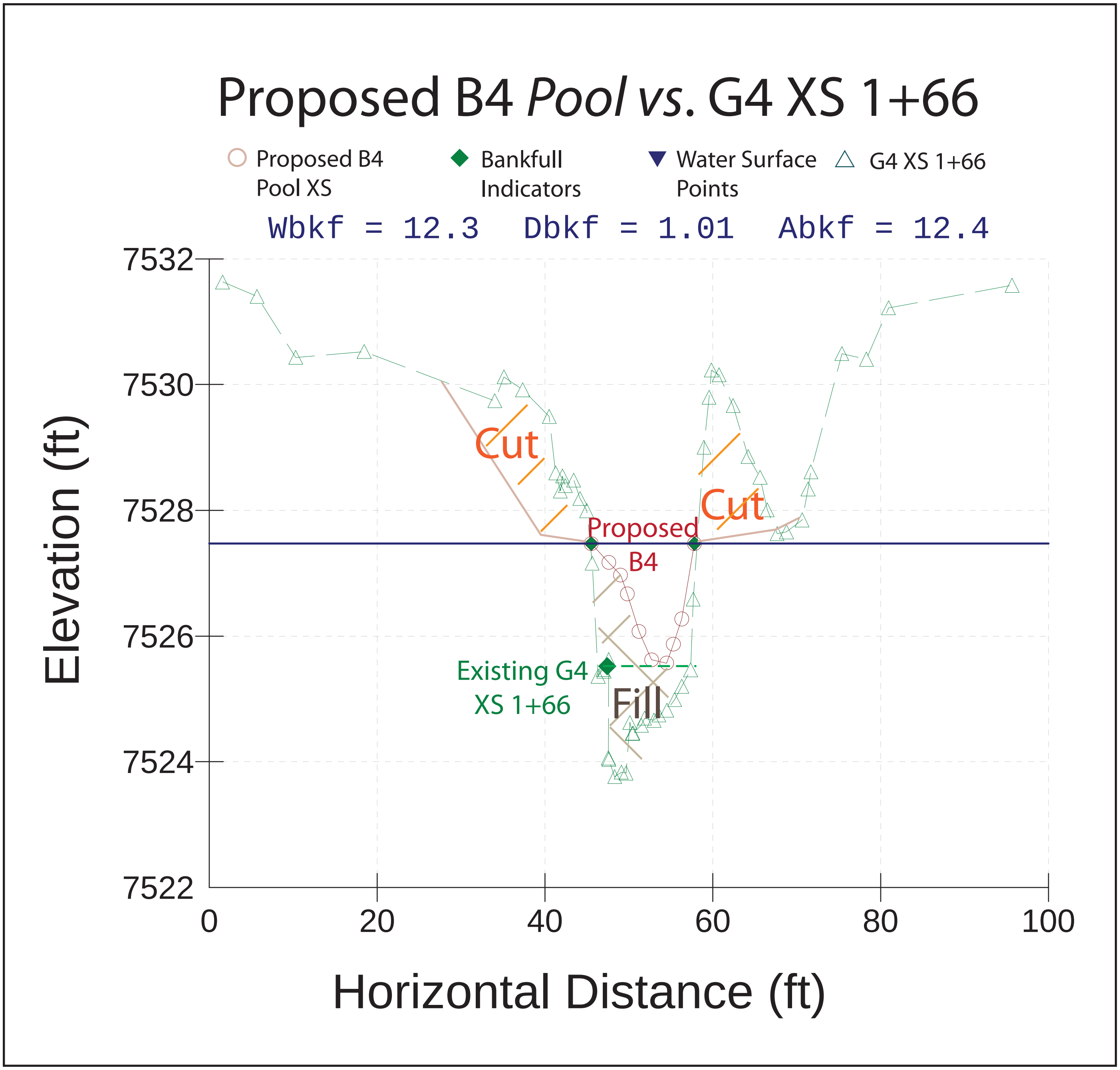

Figure 75. The proposed B4 *pool* cross-section compared to the existing G4 cross-section 1+66, indicating the cut and fill requirements and new bankfull elevation.

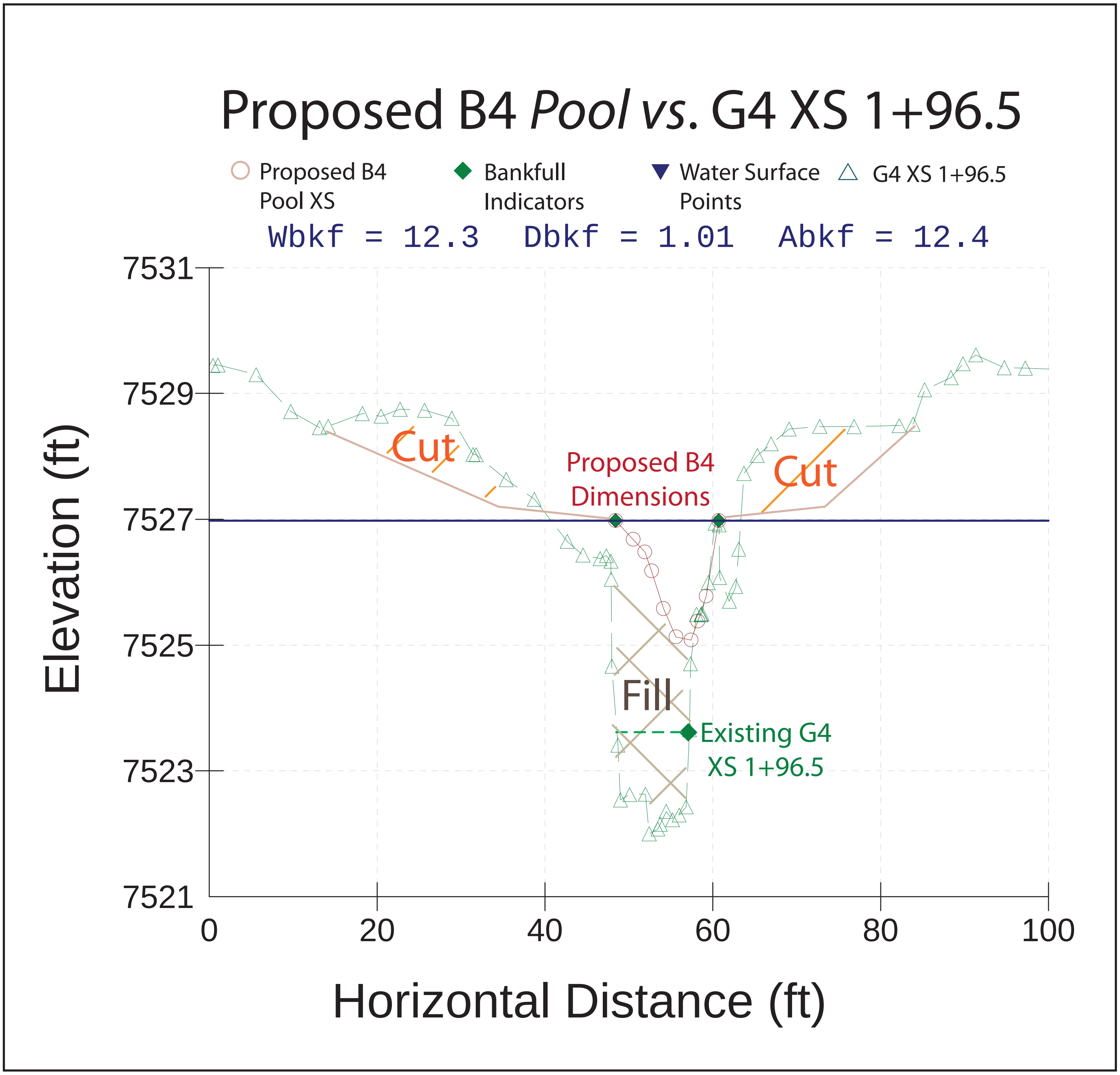

Figure 76. The proposed B4 *pool* cross-section compared to the existing G4 cross-section 1+96.5, indicating the cut and fill requirements and new bankfull elevation.

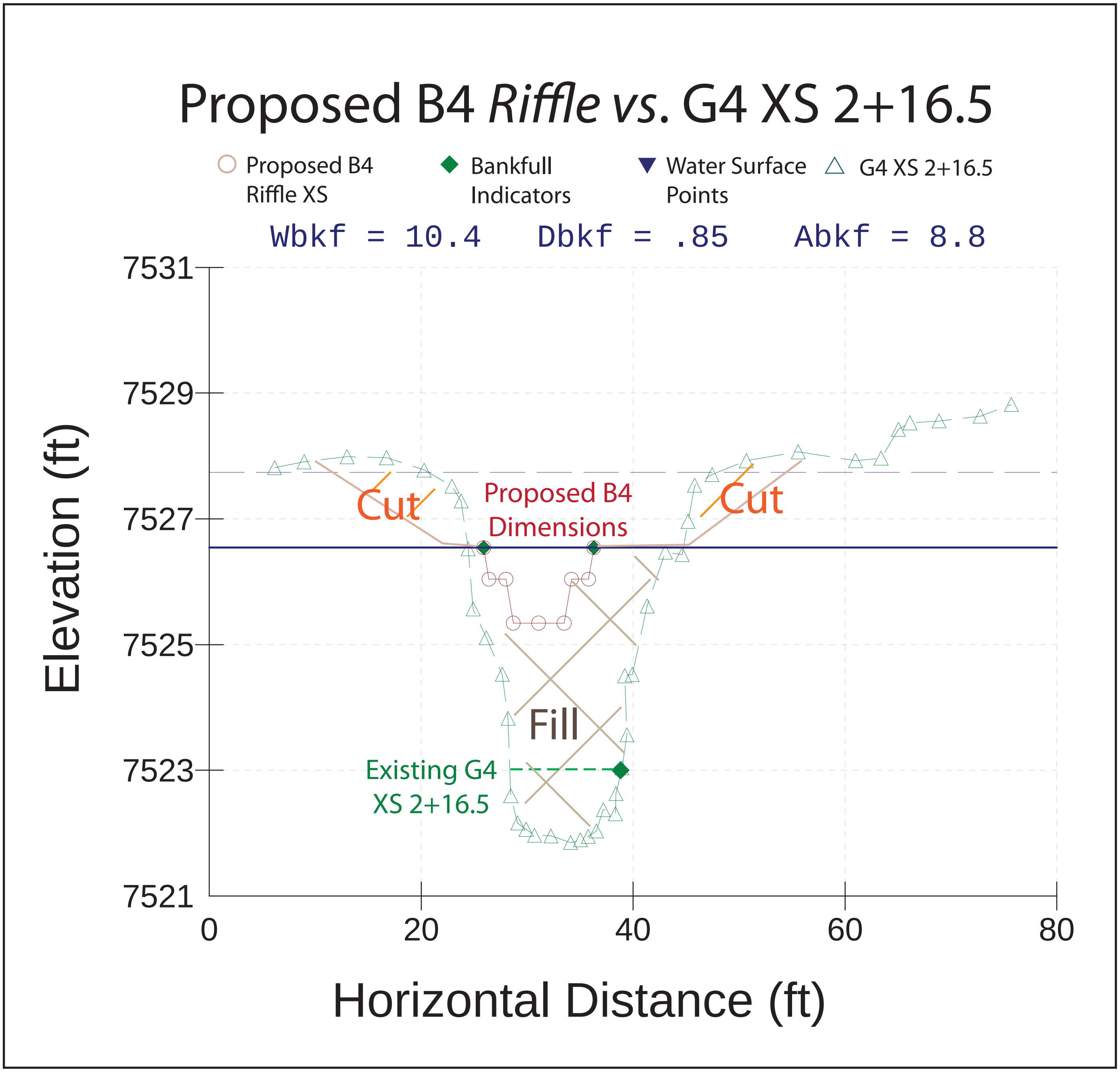

Figure 77. The proposed B4 *riffle* cross-section compared to the existing G4 cross-section 2+16.5, indicating the cut and fill requirements and new bankfull elevation.

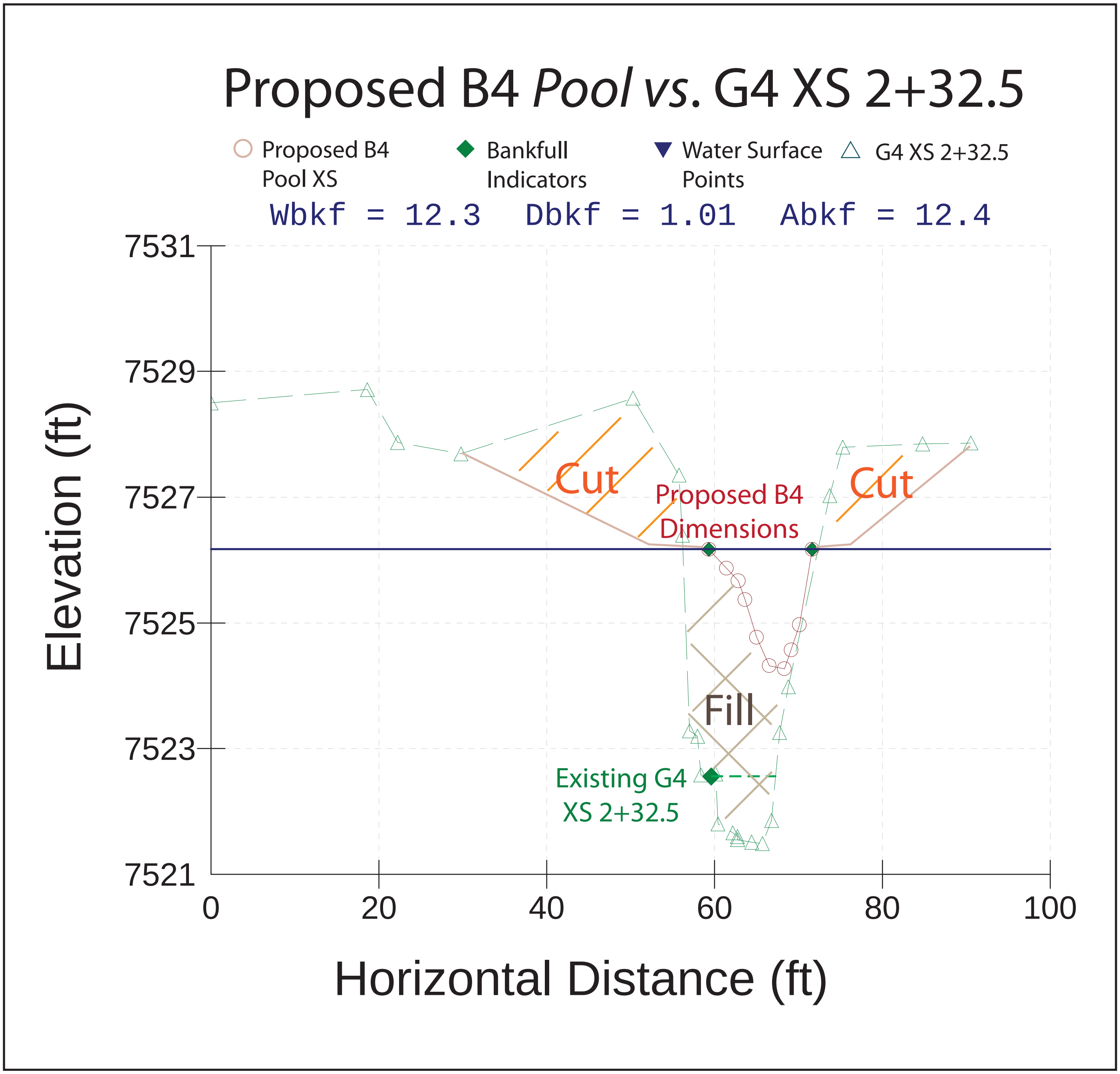

Figure 78. The proposed B4 *pool* cross-section compared to the existing G4 cross-section 2+32.5, indicating the cut and fill requirements and new bankfull elevation.

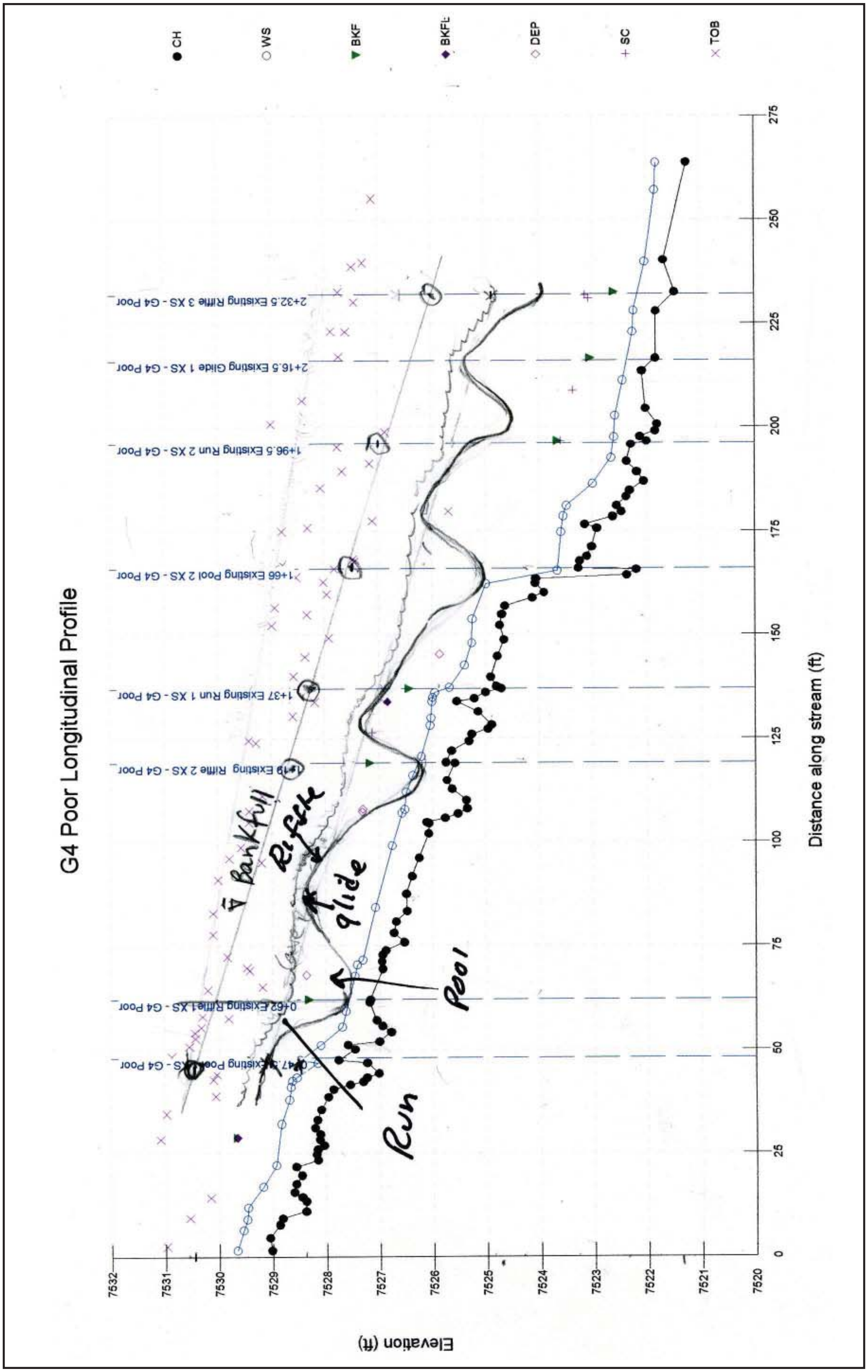

Figure 79. The longitudinal profile comparing the elevations, slopes, and fill requirements of the existing G4 vs. proposed B4 stream type.

Structures

The proposed structures for streambank stabilization, flow resistance, grade control and fish habitat enhancement are shown in the plan view layout in **Figure 80**. The structures include converging rock clusters (**Figure 22**); the root wad, log vane, J-hook (**Figure 9**); the rock vane, J-hook (**Figure 8**); the "Rock & Roll" log structure (**Figure 19**); and the toe wood structure with sod mats and riparian transplants (**Figure 15** and **Figure 16**). 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 80 Here

Figure 80. The proposed plan view layout of the G4 to B4 conversion depicting the stabilization and fish enhancement structures.

Insert 11 x 17 Figure 80 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 9**), 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 80** 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 8a**) to *844.6 tons/yr* (**Worksheet 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 (**Table 6**). 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. The overall longitudinal profile as shown in **Figure 39** indicates extreme aggradation of the channel, then downcutting in the deposition, which confirms the interpretation from the POWERSED model.

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 9**); therefore, grade control at the head of riffles is warranted and recommended. The converging rock clusters and the "Rock & Roll" log structures are designed for grade control, as described previously.

Worksheet 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 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 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	$\hat{D}_{50}$	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	$\gamma_s-\gamma/\gamma$	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) $d = \dfrac{\tau^*(\gamma_s - 1)D_{max}}{S}$	(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) $S = \dfrac{\tau^*(\gamma_s - 1)D_{max}}{d}$	(use D_{max} in ft)
Check: ☐ Stable ☐ Aggrading ☐ Degrading			

Sediment Competence Using Dimensional Shear Stress		
1.278		Bankfull shear stress $\tau = \gamma dS$ (lbs/ft²) (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 $d = \dfrac{\tau}{\gamma S}$
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 $S = \dfrac{\tau}{\gamma d}$
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.

There are numerous locations along the mainstem Trail Creek where gullies are common due to headcuts. This typical design scenario provides a blueprint for these locations with G4 stream types that have similar boundary conditions and controlling variables. The numerous G4 stream types that occur in the mainstem Trail Creek are mapped in *Appendix D* of the Trail Creek *WARSSS* analysis (Rosgen, 2011). Obtaining the corresponding drainage area and verification of Valley Type VIII allow the extrapolation of the proposed design relations by following the procedure included in the *Extrapolation of Typical Scenarios to other Locations* section.

Typical Design Scenario 4: C4 *Poor* to C4 *Stable* Conversion (VT VIII)

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 7**. The detailed characteristics and stability evaluation of this representative reach are documented in *Appendix C9* of the Trail Creek *WARSSS* analysis (Rosgen, 2011, pp. C9-1 to C16-34). 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 lower Trail Creek longitudinal profile (**Figure 39**) shows the location of the headcut below the C4 *Poor* reach and the associated change in slope through the downstream G4 stream type reach. The typical characteristics and minimum vegetative influence associated with active streambank erosion for the existing C4 *Poor* reach are depicted in **Figure 81**. 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 location of the *C4 Reference Reach* is shown in **Figure 7** and the detailed characteristics and stability evaluation are documented in *Appendix B4* of the Trail Creek *WARSSS* analysis (Rosgen, 2011, pp. B4-1 to B4-36).

The resultant proposed dimension, pattern and profile for the stable C4 design reach are documented in **Table 10** 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 10**. Using continuity, the corresponding mean velocity for the proposed design reach is *3.0 ft/sec* as shown in **Worksheet 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 81. 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 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.

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:* **29.0** *Min:* *Max:*	*Mean:* **13.5** *Min:* **12.0** *Max:* **15.0**	*Mean:* **18.5** *Min:* **16.3** *Max:* **19.9**
	7	Riffle Mean Depth, ft (d_{bkf})	*Mean:* **0.48** *Min:* *Max:*	*Mean:* **0.99** *Min:* **0.89** *Max:* **1.09**	*Mean:* **1.04** *Min:* **0.89** *Max:* **1.19**
	8	Riffle Width/Depth Ratio (W_{bkf}/d_{bkf})	*Mean:* **60.5** *Min:* *Max:*	*Mean:* **13.7** *Min:* **11.0** *Max:* **16.9**	*Mean:* **18.1** *Min:* **13.7** *Max:* **21.8**
	9	Riffle Cross-Sectional Area, ft^2 (A_{bkf})	*Mean:* **14.0** *Min:* *Max:*	*Mean:* **13.3**	*Mean:* **19.2** *Min:* **17.3** *Max:* **20.9**
	10	Riffle Maximum Depth (d_{max})	*Mean:* **1.12** *Min:* *Max:*	*Mean:* **1.70** *Min:* **1.55** *Max:* **1.85**	*Mean:* **1.64** *Min:* **1.40** *Max:* **1.81**
	11	Riffle Maximum Depth to Riffle Mean Depth (d_{max}/d_{bkf})	*Mean:* **2.333** *Min:* *Max:*	*Mean:* **1.717** *Min:* **1.566** *Max:* **1.869**	*Mean:* **1.575** *Min:* **1.429** *Max:* **1.724**
	12	Width of Flood-Prone Area at Elevation of 2 * d_{max}, ft (W_{fpa})	*Mean:* **59.0** *Min:* *Max:*	*Mean:* **40.5** *Min:* **29.7** *Max:* **81.0**	*Mean:* **58.8** *Min:* **41.9** *Max:* **69.4**
	13	Entrenchment Ratio (W_{fpa}/W_{bkf})	*Mean:* **2.0** *Min:* *Max:*	*Mean:* **3.0** *Min:* **2.2** *Max:* **6.0**	*Mean:* **3.2** *Min:* **2.2** *Max:* **4.0**
Riffle Inner Berm Dimensions	14	Riffle Inner Berm Width, ft (W_{ib})	*Mean:* **14.4** *Min:* *Max:*	*Mean:* **6.5** *Min:* **5.0** *Max:* **8.0**	*Mean:* **11.4** *Min:* **10.4** *Max:* **12.9**
	15	Riffle Inner Berm Width to Riffle Width (W_{ib}/W_{bkf})	*Mean:* **0.496** *Min:* *Max:*	*Mean:* **0.481** *Min:* **0.370** *Max:* **0.593**	*Mean:* **0.619** *Min:* **0.522** *Max:* **0.668**
	16	Riffle Inner Berm Mean Depth, ft (d_{ib})	*Mean:* **0.35** *Min:* *Max:*	*Mean:* **0.74** *Min:* **0.50** *Max:* **0.90**	*Mean:* **0.57** *Min:* **0.38** *Max:* **0.73**
	17	Riffle Inner Berm Mean Depth to Riffle Mean Depth (d_{ib}/d_{bkf})	*Mean:* **0.729** *Min:* *Max:*	*Mean:* **0.747** *Min:* **0.505** *Max:* **0.909**	*Mean:* **0.537** *Min:* **0.319** *Max:* **0.820**
	18	Riffle Inner Berm Width/Depth Ratio (W_{ib}/d_{ib})	*Mean:* **41.1** *Min:* *Max:*	*Mean:* **8.8** *Min:* **5.6** *Max:* **12.0**	*Mean:* **21.3** *Min:* **17.6** *Max:* **28.7**
	19	Riffle Inner Berm Cross-Sectional Area (A_{ib})	*Mean:* **5.0** *Min:* *Max:*	*Mean:* **4.8** *Min:* **3.2** *Max:* **6.8**	*Mean:* **6.5** *Min:* **4.1** *Max:* **9.4**
	20	Riffle Inner Berm Cross-Sectional Area to Riffle Cross-Sectional Area (A_{ib}/A_{bkf})	*Mean:* **0.358** *Min:* *Max:*	*Mean:* **0.361** *Min:* **0.241** *Max:* **0.511**	*Mean:* **0.349** *Min:* **0.214** *Max:* **0.542**

Table 10 (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 10 (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:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**12.5**	*Mean:* *Min:* *Max:*	**24.2**
	39	Run Width to Riffle Width (W_{bkfr}/W_{bkf})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**0.926**	*Mean:* *Min:* *Max:*	**1.308**
	40	Run Mean Depth, ft (d_{bkfr})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**1.38** **1.30** **1.40**	*Mean:* *Min:* *Max:*	**0.62**
	41	Run Mean Depth to Riffle Mean Depth (d_{bkfr}/d_{bkf})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**1.394** **1.313** **1.414**	*Mean:* *Min:* *Max:*	**0.596**
	42	Run Width/Depth Ratio (W_{bkfr}/d_{bkfr})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**9.1**	*Mean:* *Min:* *Max:*	**39.1**
	43	Run Cross-Sectional Area, ft^2 (A_{bkfr})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**17.2**	*Mean:* *Min:* *Max:*	**15.1**
	44	Run Area to Riffle Area (A_{bkfr}/A_{bkf})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**1.293**	*Mean:* *Min:* *Max:*	**0.785**
	45	Run Maximum Depth (d_{maxr})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**2.00**	*Mean:* *Min:* *Max:*	**1.50**
	46	Run Maximum Depth to Riffle Mean Depth (d_{maxr}/d_{bkf})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**2.020**	*Mean:* *Min:* *Max:*	**1.442**
Glide Dimensions	**47**	Glide Width, ft (W_{bkfg})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**14.6** **14.0** **15.0**	*Mean:* *Min:* *Max:*	**22.0**
	48	Glide Width to Riffle Width (W_{bkfg}/W_{bkf})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**1.081** **1.037** **1.111**	*Mean:* *Min:* *Max:*	**1.189**
	49	Glide Mean Depth, ft (d_{bkfg})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**0.80**	*Mean:* *Min:* *Max:*	**0.98**
	50	Glide Mean Depth to Riffle Mean Depth (d_{bkfg}/d_{bkf})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**0.808**	*Mean:* *Min:* *Max:*	**0.942**
	51	Glide Width/Depth Ratio (W_{bkfg}/d_{bkfg})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**18.25**	*Mean:* *Min:* *Max:*	**22.5**
	52	Glide Cross-Sectional Area, ft^2 (A_{bkfg})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**11.6**	*Mean:* *Min:* *Max:*	**21.5**
	53	Glide Area to Riffle Area (A_{bkfg}/A_{bkf})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**0.872**	*Mean:* *Min:* *Max:*	**1.122**
	54	Glide Maximum Depth (d_{maxg})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**1.10**	*Mean:* *Min:* *Max:*	**1.62**
	55	Glide Maximum Depth to Riffle Mean Depth (d_{maxg}/d_{bkf})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**1.111**	*Mean:* *Min:* *Max:*	**1.558**

Table 10 (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**	*Mean:*	**8.2**	*Mean:*	**12.9**
			Min:		*Min:*		*Min:*	
			Max:		*Max:*		*Max:*	
	57	Glide Inner Berm Width to Glide Width (W_{ibg}/W_{bkfg})	*Mean:*	**N/A**	*Mean:*	**0.562**	*Mean:*	**0.583**
			Min:		*Min:*		*Min:*	
			Max:		*Max:*		*Max:*	
	58	Glide Inner Berm Mean Depth, ft (d_{ibg})	*Mean:*	**N/A**	*Mean:*	**0.56**	*Mean:*	**0.48**
			Min:		*Min:*		*Min:*	
			Max:		*Max:*		*Max:*	
	59	Glide Inner Berm Mean Depth to Glide Mean Depth (d_{ibg}/d_{bkfg})	*Mean:*	**N/A**	*Mean:*	**0.700**	*Mean:*	**0.490**
			Min:		*Min:*		*Min:*	
			Max:		*Max:*		*Max:*	
	60	Glide Inner Berm Width/Depth Ratio (W_{ibg}/d_{ibg})	*Mean:*	**N/A**	*Mean:*	**14.6**	*Mean:*	**26.8**
			Min:		*Min:*		*Min:*	
			Max:		*Max:*		*Max:*	
	61	Glide Inner Berm Cross-Sectional Area (A_{ibg})	*Mean:*	**N/A**	*Mean:*	**4.6**	*Mean:*	**6.2**
			Min:		*Min:*		*Min:*	
			Max:		*Max:*		*Max:*	
	62	Glide Inner Berm Area to Glide Area (A_{ibg}/A_{bkfg})	*Mean:*	**N/A**	*Mean:*	**0.393**	*Mean:*	**0.287**
			Min:		*Min:*		*Min:*	
			Max:		*Max:*		*Max:*	

Table 10 (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 10 (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 10 (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:*	**0.0160**	*Mean:*	**0.0148**	*Mean:*	**0.0045**
			Min:		*Min:*	**0.0094**	*Min:*	**0.0029**
			Max:		*Max:*	**0.0179**	*Max:*	**0.0054**
	106	Riffle Slope to Average Water Surface Slope (S_{rif}/S)	*Mean:*	**1.1034**	*Mean:*	**1.0205**	*Mean:*	**1.0205**
			Min:		*Min:*	**0.6477**	*Min:*	**0.6477**
			Max:		*Max:*	**1.2341**	*Max:*	**1.2341**
	107	Pool Slope (water surface facet slope) (S_p)	*Mean:*	**0.0110**	*Mean:*	**0.0076**	*Mean:*	**0.0023**
			Min:		*Min:*	**0.0027**	*Min:*	**0.0008**
			Max:		*Max:*	**0.0125**	*Max:*	**0.0038**
	108	Pool Slope to Average Water Surface Slope (S_p/S)	*Mean:*	**0.7586**	*Mean:*	**0.5250**	*Mean:*	**0.5250**
			Min:		*Min:*	**0.1841**	*Min:*	**0.1841**
			Max:		*Max:*	**0.8636**	*Max:*	**0.8636**
	109	Run Slope (water surface facet slope) (S_{run})	*Mean:*	**0.0240**	*Mean:*	**0.0371**	*Mean:*	**0.0113**
			Min:		*Min:*	**0.0218**	*Min:*	**0.0066**
			Max:		*Max:*	**0.0460**	*Max:*	**0.0140**
	110	Run Slope to Average Water Surface Slope (S_{run}/S)	*Mean:*	**1.6552**	*Mean:*	**2.5614**	*Mean:*	**2.5614**
			Min:		*Min:*	**1.5000**	*Min:*	**1.5000**
			Max:		*Max:*	**3.1705**	*Max:*	**3.1705**
	111	Glide Slope (water surface facet slope) (S_g)	*Mean:*	**0.0170**	*Mean:*	**0.0112**	*Mean:*	**0.0034**
			Min:		*Min:*	**0.0086**	*Min:*	**0.0026**
			Max:		*Max:*	**0.0129**	*Max:*	**0.0039**
	112	Glide Slope to Average Water Surface Slope (S_g/S)	*Mean:*	**1.1724**	*Mean:*	**0.7750**	*Mean:*	**0.7750**
			Min:		*Min:*	**0.5909**	*Min:*	**0.5909**
			Max:		*Max:*	**0.8864**	*Max:*	**0.8864**
	113	Step Slope (water surface facet slope) (S_s)	*Mean:*	**N/A**	*Mean:*	**N/A**	*Mean:*	**N/A**
			Min:		*Min:*		*Min:*	
			Max:		*Max:*		*Max:*	
	114	Step Slope to Average Water Surface Slope (S_s/S)	*Mean:*	**N/A**	*Mean:*	**N/A**	*Mean:*	**N/A**
			Min:		*Min:*		*Min:*	
			Max:		*Max:*		*Max:*	

Table 10 (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 10 (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
Hydraulics	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
Sediment Competence	130	Predicted largest moveable particle size (mm) at bankfull shear stress, τ, using the original **Shields** relation	30.0	70	24.0
Sediment Competence	131	Predicted largest moveable particle size (mm) at bankfull shear stress, τ, using the **Colorado** relation	80.0	140	70.0
Sediment Competence	132	Largest particle size to be moved (D_{max}) (mm) (see #126: Particle Size Distribution of Bar Material)	110	110	74.0
Sediment Competence	133	Predicted shear stress required to initiate movement of D_{max} (mm) using the original **Shields** relation	1.600	1.391	1.000
Sediment Competence	134	Predicted shear stress required to initiate movement of D_{max} (mm) using the **Colorado** relation	0.660	0.644	0.350
Sediment Competence	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
Sediment Competence	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
Sediment Competence	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
Sediment Competence	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
Sediment Competence	139	Bankfull dimensionless shear stress (τ*) (see competence form)	N/A	N/A	N/A
Sediment Competence	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
Sediment Competence	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 10 (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 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 PERIMETER ~ $(2 * d_{bkf}) + W_{bkf}$	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 $u^* = (gRS)^{1/2}$	0.751	u* (ft/sec)

ESTIMATION METHODS	Bankfull VELOCITY		Bankfull DISCHARGE	
1. Friction Factor / Relative Roughness $u = [2.83 + 5.66 * \text{Log}\{R / D_{84}\}] u^*$	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): $u = 1.49 * R^{2/3} * S^{1/2} / n$ $n = 0.39 * S^{0.38} * R^{-0.16}$ n = N/A. 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/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 82**, which corresponds with the proposed pattern values developed from the dimensionless ratios of the *C4 Reference Reach* in **Table 10**. The existing cross-section locations of the C4 *Poor* condition stream type are also shown in **Figure 82**.

Cross-Section Dimensions

Table 10 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 83**. 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 84**. The locations of cross-section 0+27 and cross-section 1+27.3 are indicated in **Figure 82**. Typical design cross-sections and dimensions are also shown for a *glide* in **Figure 85**, and for a *run* in **Figure 86**.

Longitudinal Profile

The typical longitudinal profile for the proposed C4 *Stable* design reach is shown in **Figure 87** 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 87**). Additionally, the locations of the cross-section overlays in **Figure 83** and **Figure 84** are depicted on the typical longitudinal profile that corresponds with the proposed design bed features.

Insert 11 x 17 Figure 82 Here

Figure 82. 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 82 Here

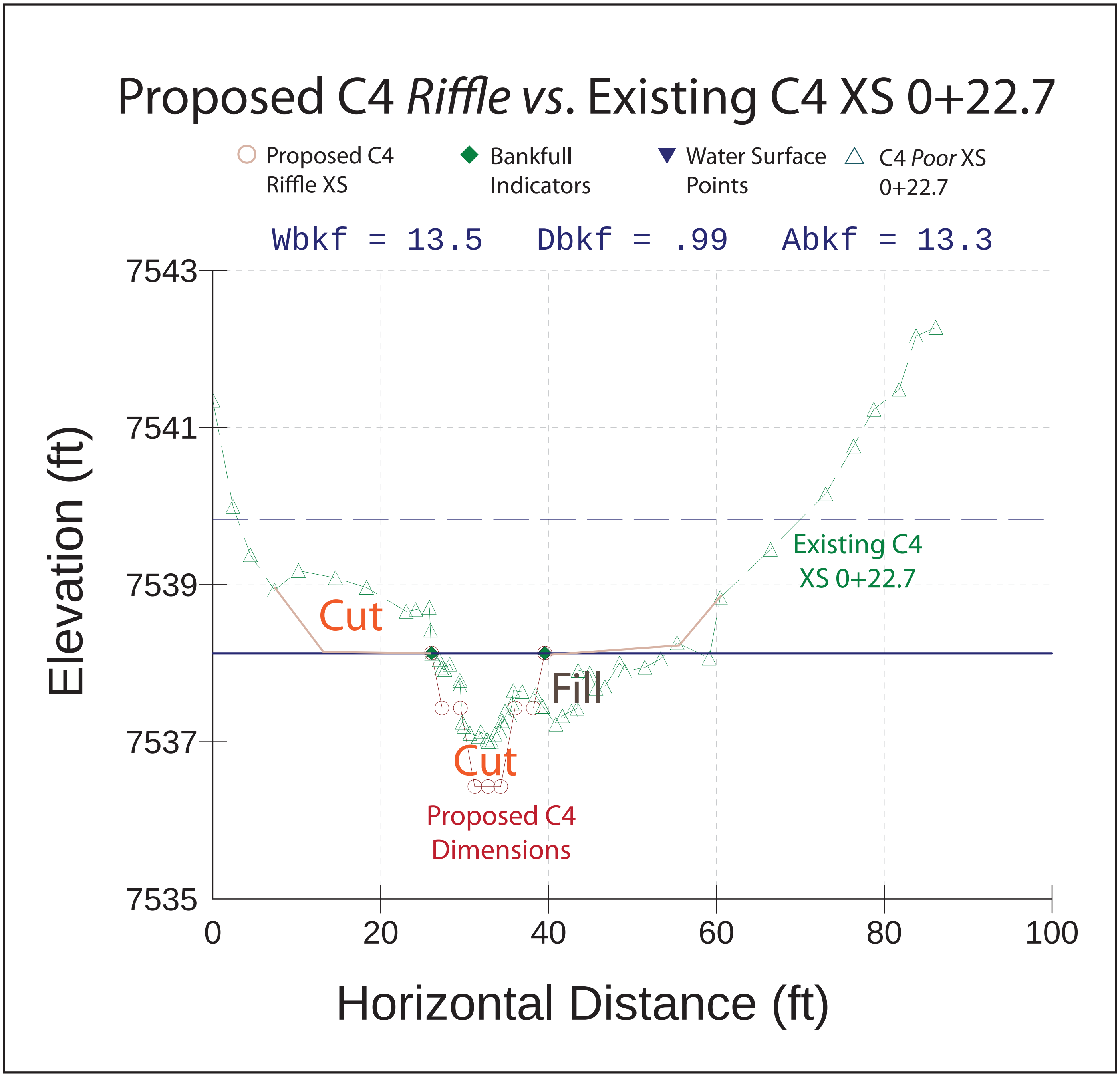

Figure 83. The proposed C4 *Stable riffle* cross-section compared to the existing C4 *Poor* cross-section 0+27 showing the cut and fill recommendations and reconnecting the channel with the floodplain.

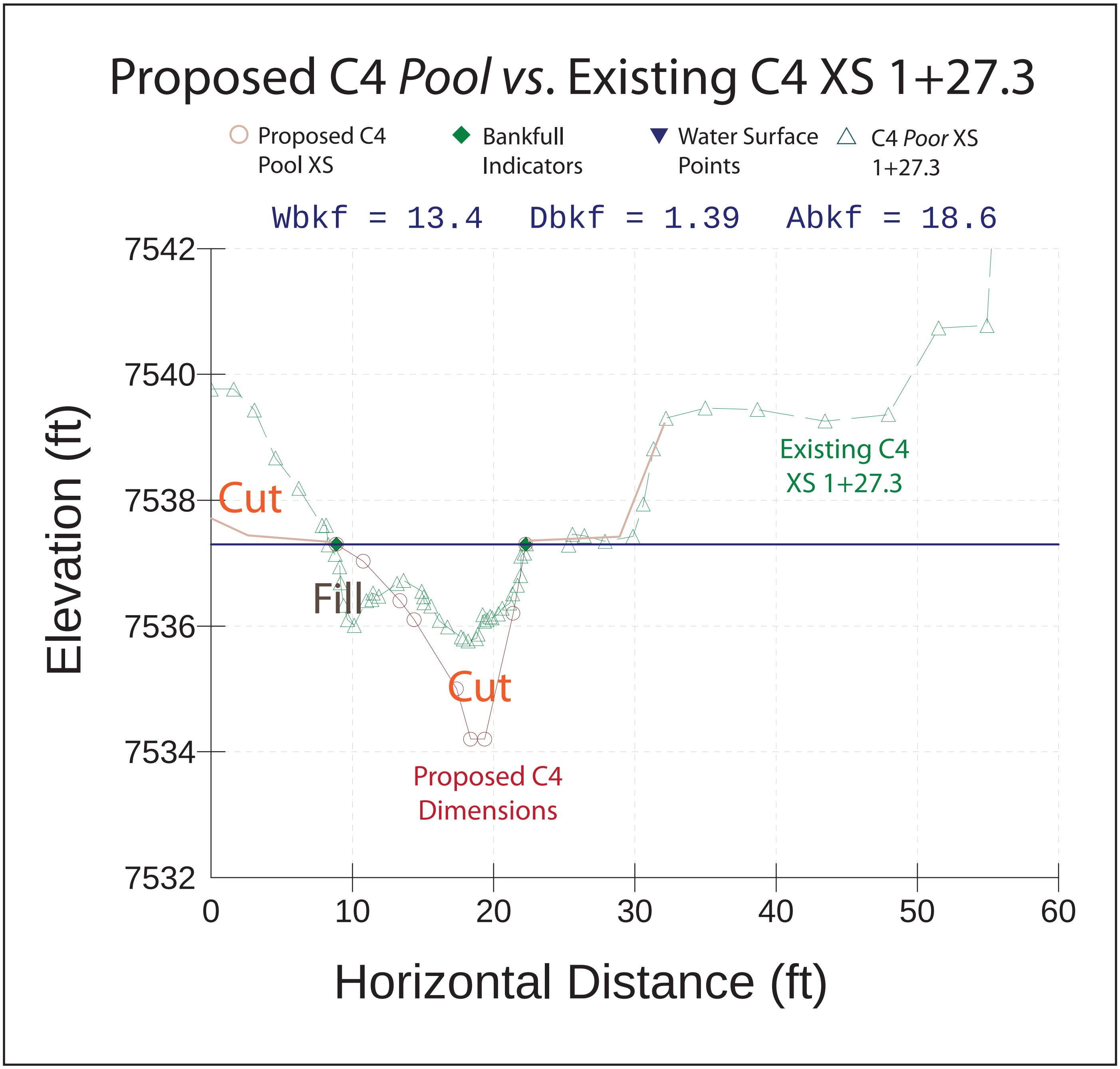

Figure 84. The proposed C4 *Stable pool* cross-section compared to the existing C4 *Poor* cross-section 1+27.3 showing the cut and fill recommendations and reconnecting the channel with the floodplain.

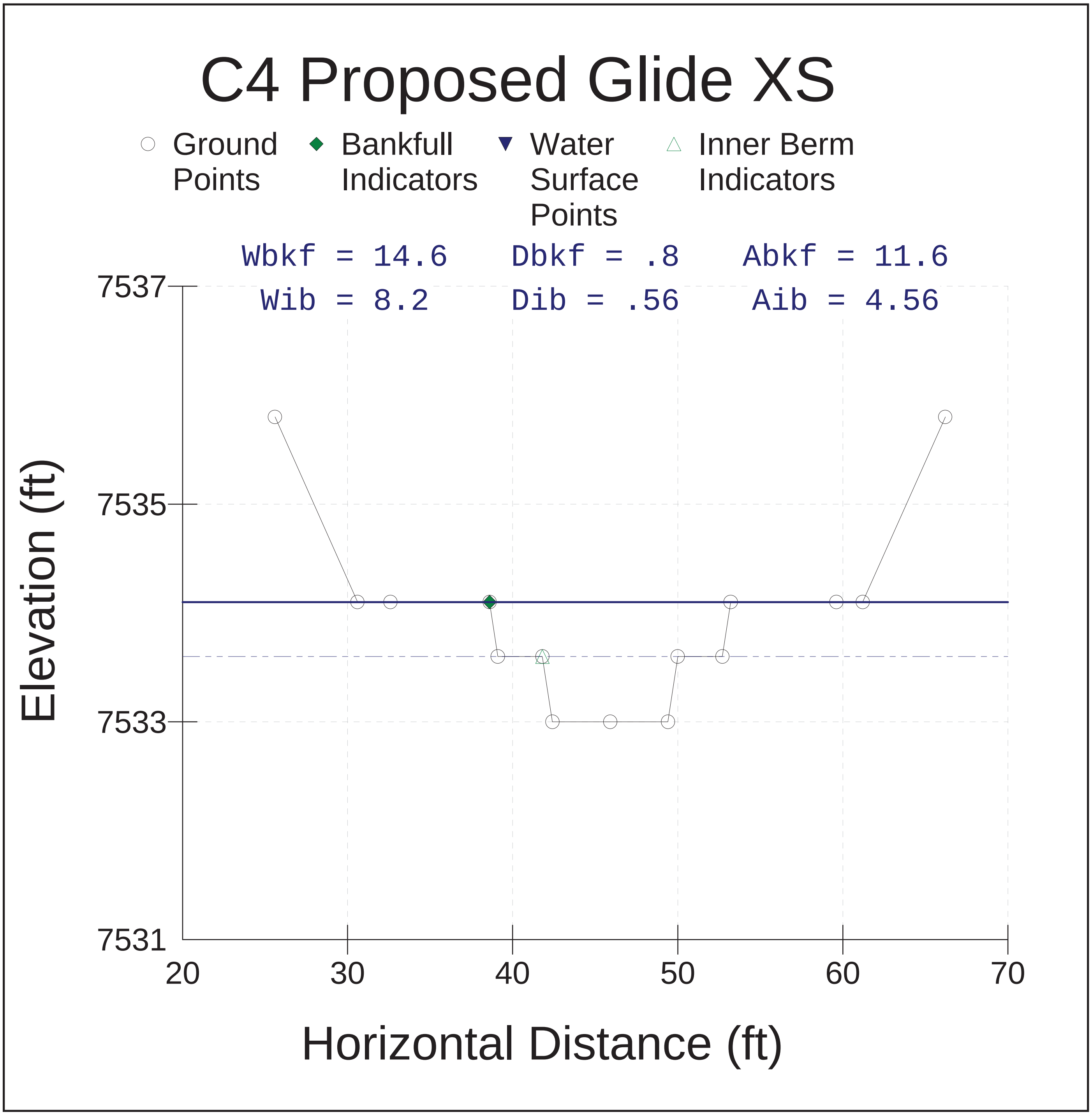

Figure 85. The typical *glide* cross-section for the proposed C4 *Stable* design converted from the existing C4 *Poor* condition stream type.

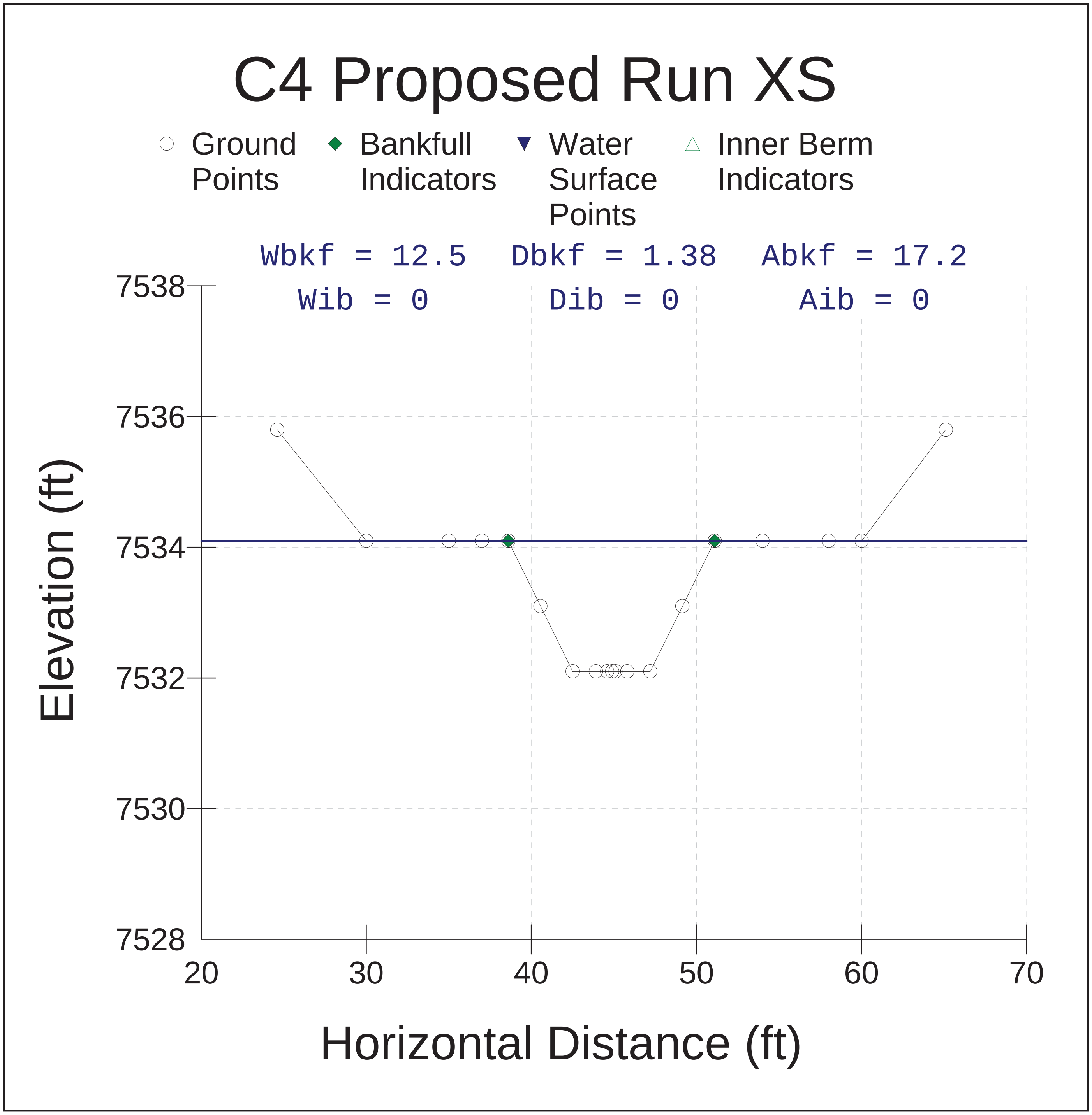

Figure 86. The typical *run* cross-section for the proposed C4 *Stable* design converted from the existing C4 *Poor* condition stream type.

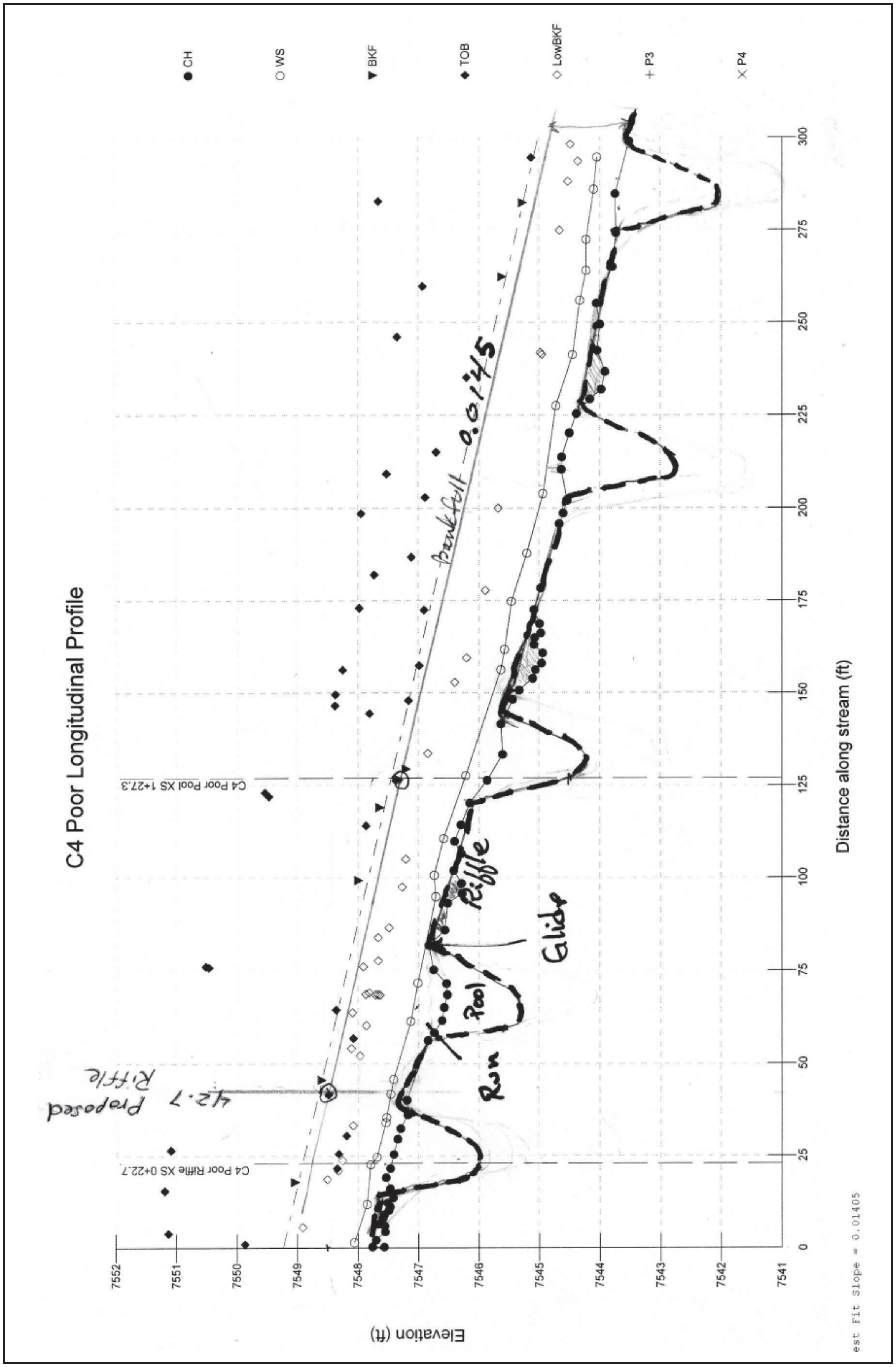

Figure 87. The existing *vs.* proposed design longitudinal profile for the C4 *Poor* to C4 *Stable* conversion in Valley Type VIII.

Structures

The recommended structures for the C4 design reach include converging rock clusters (**Figure 22**); the root wad, log vane, J-hook (**Figure 9**); the rock vane, J-hook (**Figure 8**); and the toe wood structure with sod mats and riparian transplants (**Figure 15** and **Figure 16**). These structures are recommended for streambank stabilization, flow resistance, grade control and fish habitat enhancement as shown on the plan view layout in **Figure 88**. 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 10**), 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 87** 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 88 Here

Figure 88. Plan view of the alignment for the proposed C4 stream type, including stream stabilization and fish enhancement structures.

Insert 11 x 17 Figure 88 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 11a**) to *844.6 tons/yr* (**Worksheet 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 (**Table 6**). 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 87** 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 12**). Converging rock clusters for grade control are designed at the head of riffles to further ensure bed stability.

Worksheet 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 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 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	$\gamma_s - \gamma / \gamma$	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)	$d = \dfrac{\tau^*(\gamma_s - 1)D_{max}}{S}$	(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)	$S = \dfrac{\tau^*(\gamma_s - 1)D_{max}}{d}$	(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) τ = predicted shear stress, γ = 62.4, S = proposed design slope	$d = \dfrac{\tau}{\gamma S}$
Shields **0.0225**	CO **0.0104**	Predicted slope required to initiate movement of measured D_{max} (mm) τ = predicted shear stress, γ = 62.4, d = proposed design depth	$S = \dfrac{\tau}{\gamma d}$
		Check: ☑ Stable ☐ Aggrading ☐ Degrading	

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.

This design scenario can be extrapolated to the various C4 *Poor* condition stream types that exist in the mainstem Trail Creek in a Valley Type VIII. These stream types and conditions are mapped for the mainstem Trail Creek in *Appendix D* of the Trail Creek *WARSSS* analysis (Rosgen, 2011). The general procedure for extrapolation is discussed in the *Extrapolation of Typical Scenarios to other Locations* section. An example of extrapolating this design scenario to locations within lower Trail Creek is presented as follows.

Extrapolation of Design to Lower Trail Creek

Similar conditions persist both upstream and downstream of the impaired *C4 Poor Representative Reach* that are in need of restoration. This typical design scenario is used to demonstrate the extrapolation of the design to these locations with similar conditions but without the detailed representative reach data. This demonstration is important as the restoration of the entire watershed can apply the typical design scenarios without the extensive detail conducted at this representative reach demonstration site. Because reference reach data is established to obtain dimensionless relations and the regional hydrology and sediment curves are developed, it is possible to design and to verify bankfull discharge, bedload and suspended sediment values elsewhere in the Trail Creek Watershed. Approximately *1,940 ft* of impaired C4 stream type exists above and below the C4 *Poor* demonstration reach that will also be designed in a similar manner following the C4 *Poor* to C4 *Stable* conversion scenario.

The objectives of the restoration of the impaired C4 reach are to reduce streambank erosion, improve river stability, enhance fish habitat and diversity, stabilize the toe of slopes and alluvial fans from existing erosion, create habitat for beaver, re-establish floodplain connectivity and reduce localized channel incision. Oxbows are designed on floodplains and interconnected with the river for fish access and off-channel beaver habitat. The material excavated from the oxbows is needed to replace eroded material from the lower one-third of slopes including alluvial fans.

The proposed channel dimensions can be scaled from the *C4 Reference Reach*; however, this reach has the same valley slope and a similar bankfull discharge as the *C4 Poor Representative Reach*. Thus the cross-sections for riffles, runs, pools and glides, in addition to the longitudinal profile shape and slope, are the same as designed in the typical C4 *Poor* to C4 *Stable* design scenario as documented in **Table 10**. The pattern variables are also the same as the proposed C4 *Stable* reach and are shown in the proposed plan view layout in **Figure 41**, **Figure 42** and **Figure 43** as presented in the *Lower Trail Creek Design Concept* section. The impaired C4 condition begins at the proposed station 0+00 in **Figure 41** and continues downstream to the typical design scenario *C4 Poor to C4 Stable* at proposed station 17+00 (**Figure 42**). This typical design scenario is then also extrapolated to the impaired

C4 condition below the demonstration site at proposed station 20+00 and extends to station 22+40, which is the start of the typical design scenario for the G4 to B4 stream type conversion (**Figure 43**).

The design of the plan view layout is to move the active channel away from very high eroding banks against an alluvial fan (**Figure 42**). This will help reduce some high sediment source areas that are presently contributing sediment to the mainstem Trail Creek. The proposed structures are also similar to the proposed C4 stable reach in the typical design scenario and are also depicted in the plan view layouts. The amount of cut and fill will be proportionately calculated assuming similarity of the downstream reach conditions. The proposed cut for *2,000 ft* of channel is *1,853* yds^3 and the fill is estimated at *2,000* yds^3. The material should balance with the cubic yards of added stabilization and enhancement structures. The riparian vegetation plan is also similar to the typical C4 *Poor* to C4 *Stable* design scenario.

The streambank erosion rate reduction for this proposed restoration will potentially reduce the estimated existing erosion from *91.6 tons/yr* to *12.2 tons/yr*. This savings of bank erosion of *79.4 tons/yr* for *1,940 ft* of restored channel is equivalent to *103* yds^3, or ten, 10-yard end dump truck loads of sediment per year.

To obtain material to stabilize and vegetate the toe of slopes including alluvial fans, oxbows will be excavated in parts of abandoned channels and sediment deposition sites. The oxbow locations are shown in **Figure 41** and **Figure 42**. Small interconnected channels will be constructed to provide season-long access to these oxbows. The depth of the oxbows will be *9–14 ft*, except for a *15 ft* wide and shallow (*1.5–2.0 ft*) safety shelf (littoral zone for fisheries). This provides fishing opportunities for recreationists, a greater diversity of habitat and low water refugia. The oxbows also create terrestrial habitat for wildlife, waterfowl and amphibians. Beaver are particularly fond of oxbows and move out of stream channels to establish permanent residence in the oxbows by making their lodge in the submerged banks. The oxbows also help raise the local water table and improve the riparian vegetation community. Beaver also eat the aquatic vascular plants that occupy the shallow areas of the ponds. The deeper sections of the ponds are important to maintain cooler water by exchanges with ground water and to prevent dissolved oxygen depletion problems during plant die off. The four oxbows along this short reach are *30–50 ft* across and comprise of approximately *6,000* ft^2 or *0.14 acres*.

Typical Design Scenario 5:
Tributary F4b to D4 Stream Type Conversion (VT III)

General Description & Morphological Data

This typical design scenario 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 (**Table 2**) 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 89** and located on the general map in **Figure 7**. The detailed characteristics and stability evaluation of this representative reach are documented in *Appendix C16* of the Trail Creek *WARSSS* analysis (Rosgen, 2011, pp. C16-1 to C16-38). 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 the fans within the Trail Creek Watershed 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 Trail Creek
- 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 11**. 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 89. 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 11. 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:* **12.8** *Min:* **11.4** *Max:* **14.9**	*Mean:* **29.0** *Min:* **(3.6 Wbkf for** *Max:* **8 channels)**
	7	Riffle Mean Depth, ft (d_{bkf})	*Mean:* **0.19** *Min:* **0.16** *Max:* **0.24**	*Mean:* **0.29** *Min:* **for each** *Max:* **channel**
	8	Riffle Width/Depth Ratio (W_{bkf}/d_{bkf})	*Mean:* **68.4** *Min:* **47.3** *Max:* **77.4**	*Mean:* **100.0** *Min:* *Max:*
	9	Riffle Cross-Sectional Area, ft^2 (A_{bkf})	*Mean:* **2.4** *Min:* **2.0** *Max:* **2.9**	*Mean:* **8.4**
	10	Riffle Maximum Depth (d_{max})	*Mean:* **0.34** *Min:* **0.27** *Max:* **0.41**	*Mean:* **0.29** *Min:* *Max:*
	11	Riffle Maximum Depth to Riffle Mean Depth (d_{max}/d_{bkf})	*Mean:* **1.752** *Min:* **1.588** *Max:* **2.063**	*Mean:* **1.000** *Min:* *Max:*
	12	Width of Flood-Prone Area at Elevation of 2 * d_{max}, ft (W_{fpa})	*Mean:* **13.9** *Min:* **12.8** *Max:* **15.4**	*Mean:* **N/A** *Min:* *Max:*
	13	Entrenchment Ratio (W_{fpa}/W_{bkf})	*Mean:* **1.1** *Min:* **1.0** *Max:* **1.2**	*Mean:* **N/A** *Min:* *Max:*

Table 11 (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 11 (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
Hydraulics	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
Sediment Competence	130	Predicted largest moveable particle size (mm) at bankfull shear stress, τ, using the original **Shields** relation	43.0	60
Sediment Competence	131	Predicted largest moveable particle size (mm) at bankfull shear stress, τ, using the **Colorado** relation	105.0	126
Sediment Competence	132	Largest particle size to be moved (D_{max}) (mm) (see #126: Particle Size Distribution of Bar Material)	16	16
Sediment Competence	133	Predicted shear stress required to initiate movement of D_{max} (mm) using the original **Shields** relation	0.210	0.219
Sediment Competence	134	Predicted shear stress required to initiate movement of D_{max} (mm) using the **Colorado** relation	0.043	0.047
Sediment Competence	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
Sediment Competence	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
Sediment Competence	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
Sediment Competence	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
Sediment Competence	139	Bankfull dimensionless shear stress (τ*) (see competence form)	N/A	N/A
Sediment Competence	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
Sediment Competence	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 11 (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 cfs* and the proposed bankfull riffle cross-sectional area is *8.7* ft^2 as shown in **Table 11**. 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 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 90** 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 11**). The existing cross-section locations of the F4b tributary are also shown **Figure 90**. Sediment detention (storage) basins designed with log sills to prevent headcuts are also part of the design to store sediment (**Figure 90**). 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 12**. A design sketch in **Figure 91** indicates the cross-section, plan and profile views of the proposed B2 step–pool design.

Worksheet 13. The mean velocity estimates for the proposed D4 reach converted from the existing, F4b stream type.

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 PERIMETER ~ $(2 * d_{bkf}) + W_{bkf}$	**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 $u = [\,2.83 + 5.66 * \text{Log}\,\{R / D_{84}\}\,]\,u^*$	**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 90 Here

Figure 90. 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 90 Here

Table 12. 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

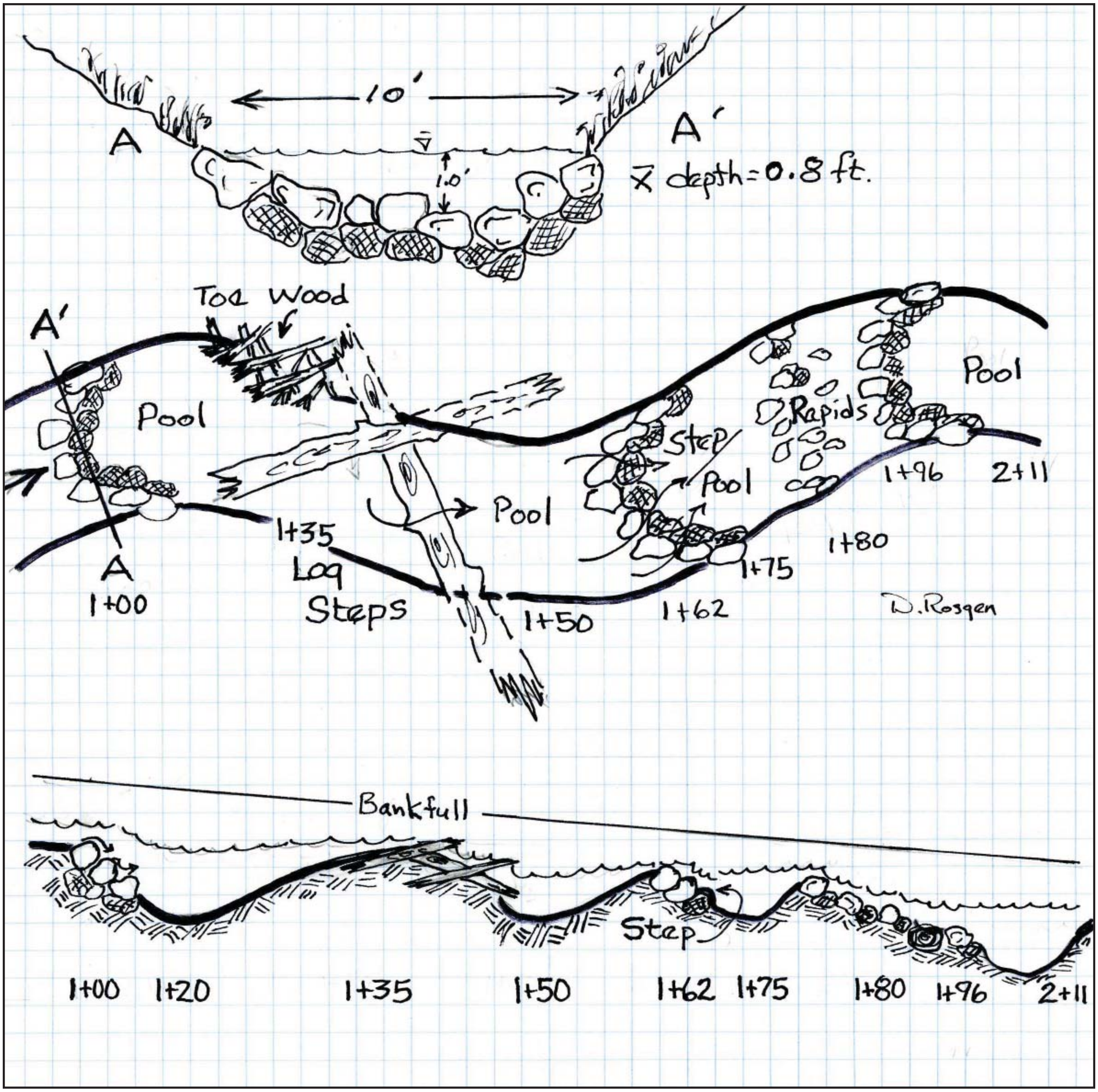

Figure 91. Typical cross-section, plan and profile views of the proposed B2 stream type and associated structures.

Cross-Section Dimensions

The proposed channel dimensions for the multiple-thread, braided D4 stream type are included in **Table 11**. The total designed bankfull width is *29 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 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 90**. **Figure 92** 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 90**. 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 93**. Additional cross-section overlays are also included for the locations associated with the existing F4b cross-section 2+47 (**Figure 94**) and cross-section 2+80 (**Figure 95**). 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 96** 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 90** shows three basins for an extended length of restoration beyond the representative reach displayed in **Figure 96** 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 92–95** are depicted on the typical longitudinal profile in **Figure 96**. The schematic longitudinal profile in **Figure 97** 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 90** and **Figure 97**. 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.

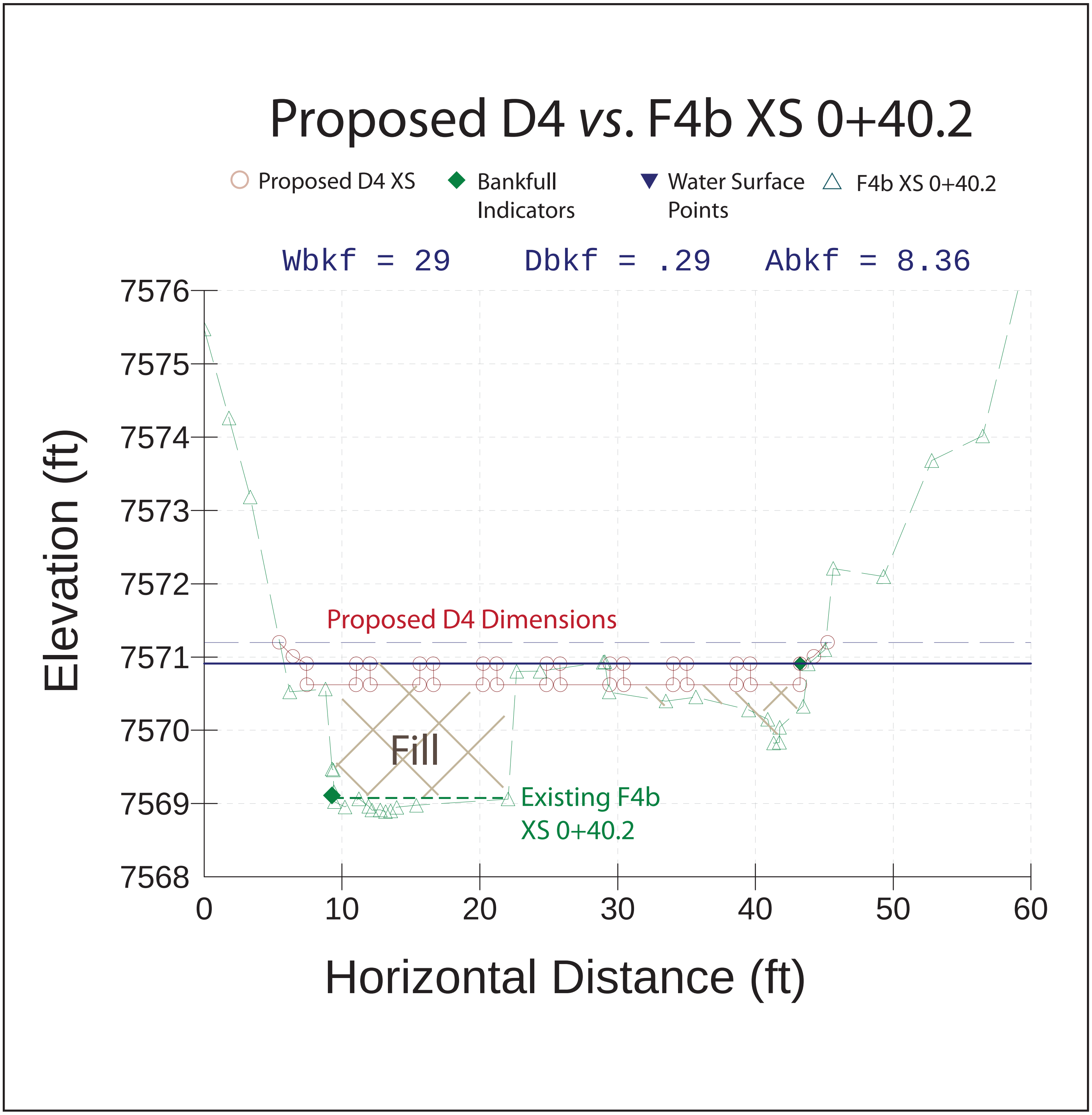

Figure 92. The typical, proposed D4 cross-section dimensions compared to the existing F4b cross-section 0+40.2, indicating the extensive fill requirements and new bankfull elevation.

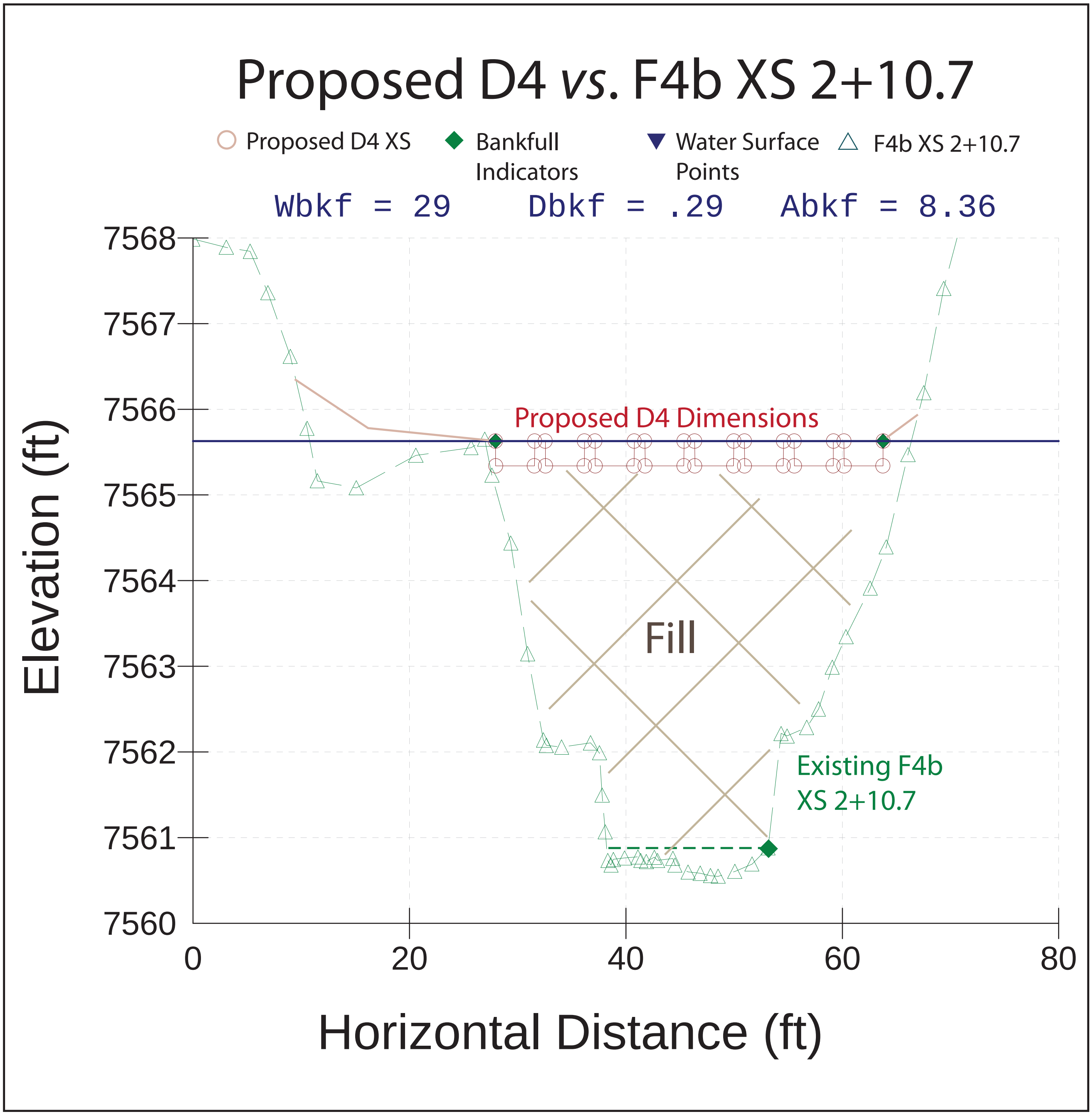

Figure 93. The typical, proposed D4 cross-section dimensions compared to the existing F4b cross-section 2+10.7, indicating the extensive fill requirements and new bankfull elevation.

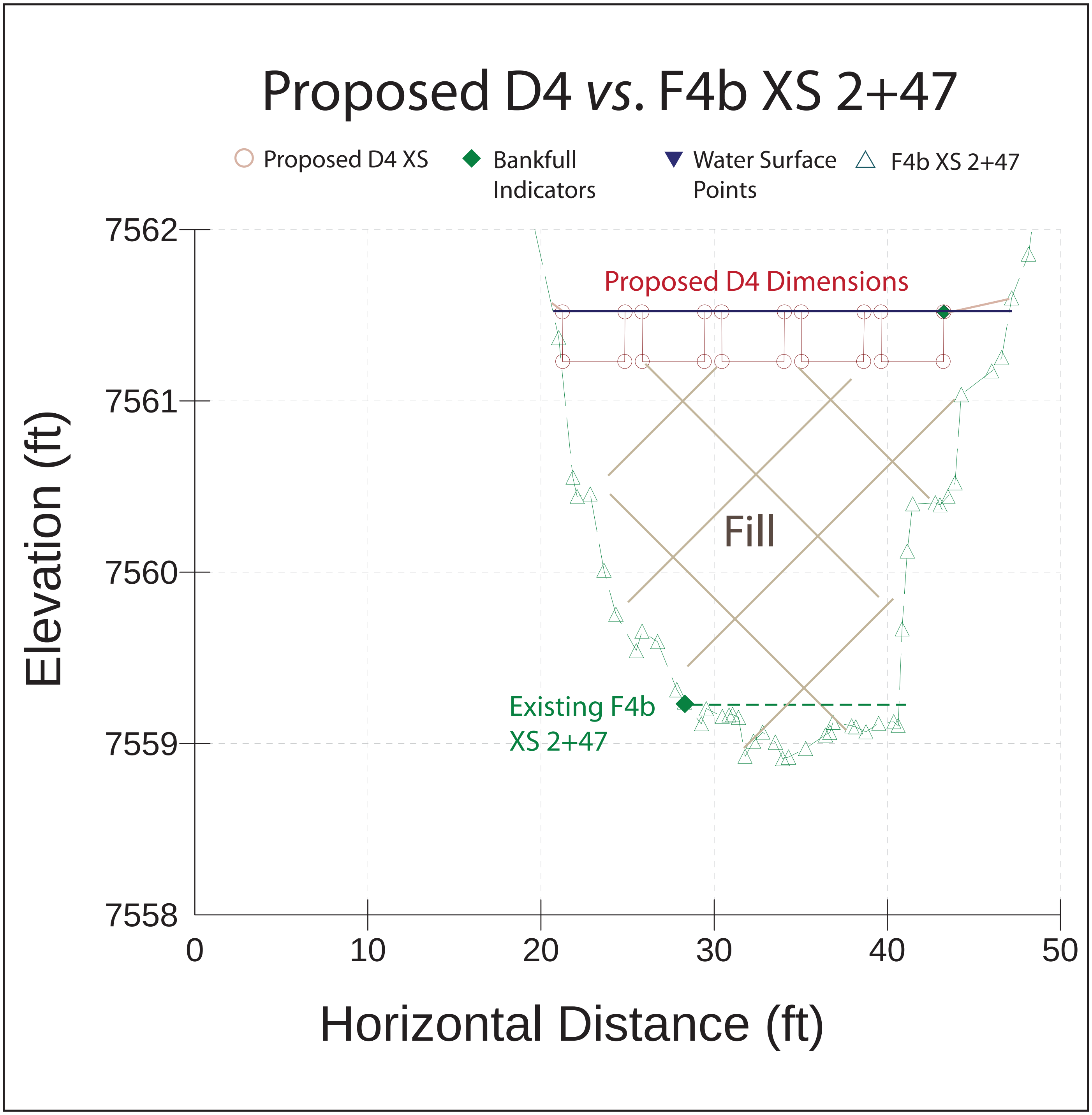

Figure 94. The typical, proposed D4 cross-section dimensions compared to the existing F4b cross-section 2+47, indicating the extensive fill requirements and new bankfull elevation.

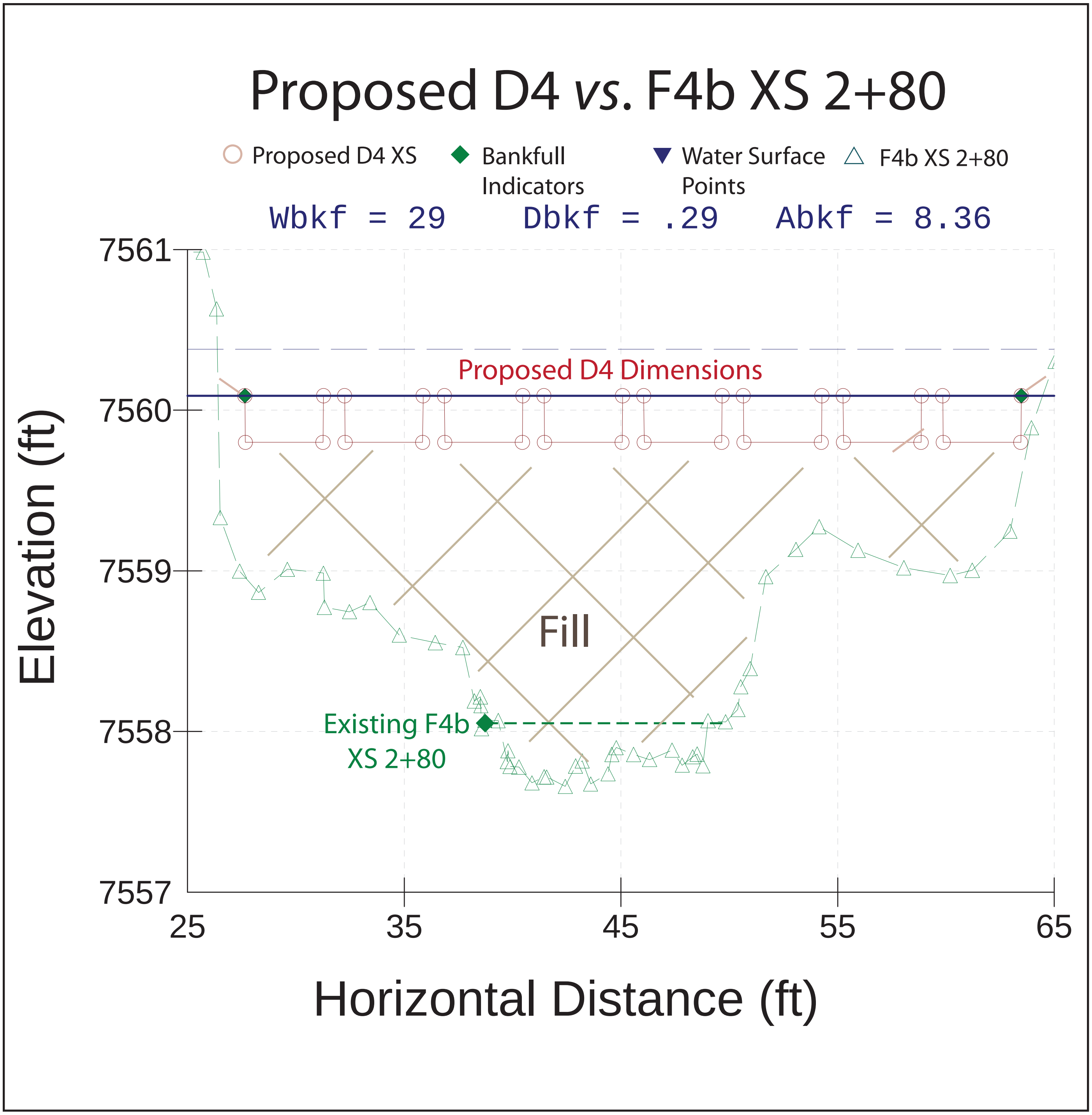

Figure 95. The typical, proposed D4 cross-section dimensions compared to the existing F4b cross-section 2+80, indicating the extensive fill requirements and new bankfull elevation.

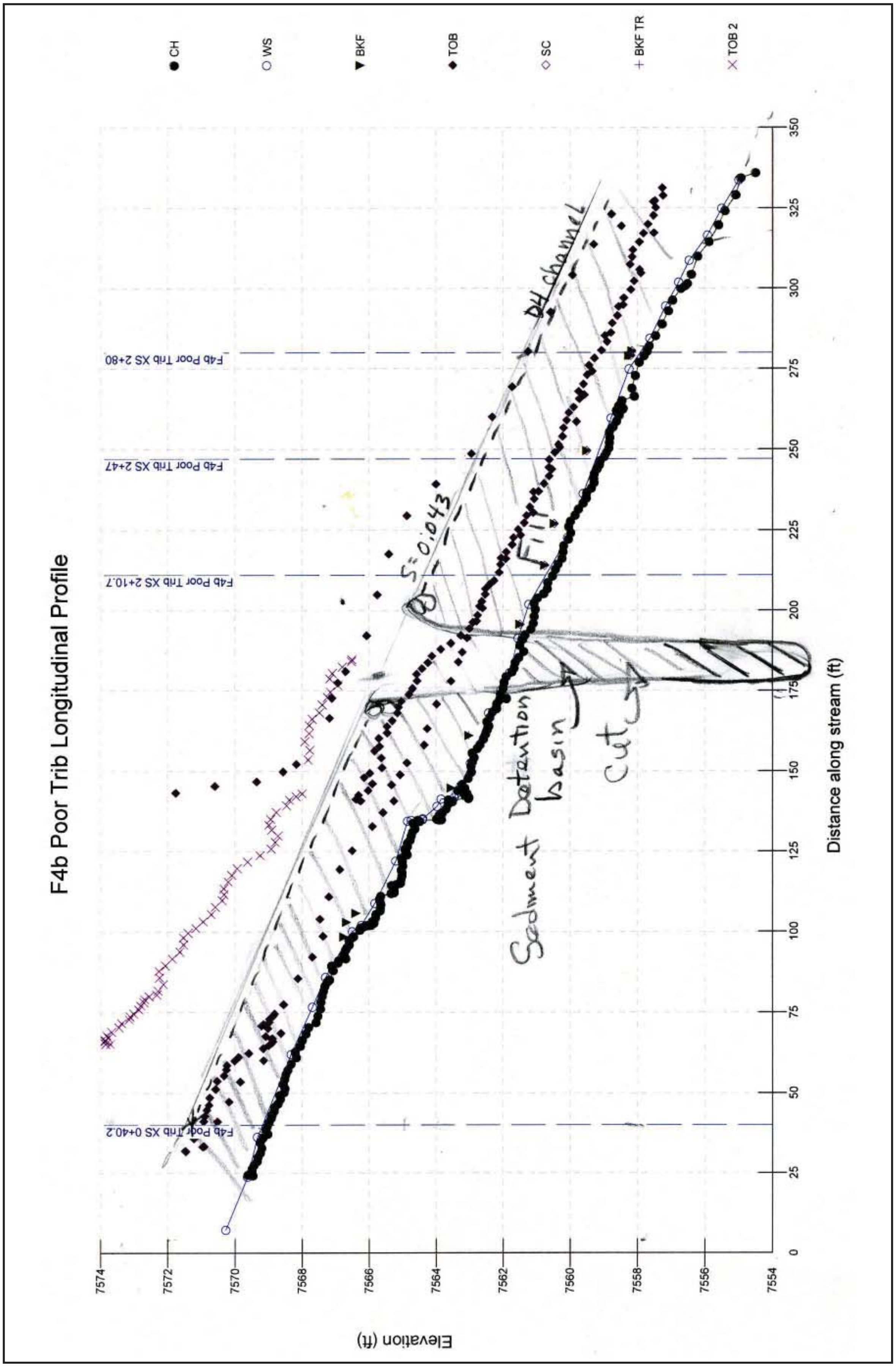

Figure 96. The longitudinal profile showing a sediment detention basin and also comparing the elevations, slopes, and fill requirements of the existing F4b *vs.* proposed D4 stream type.

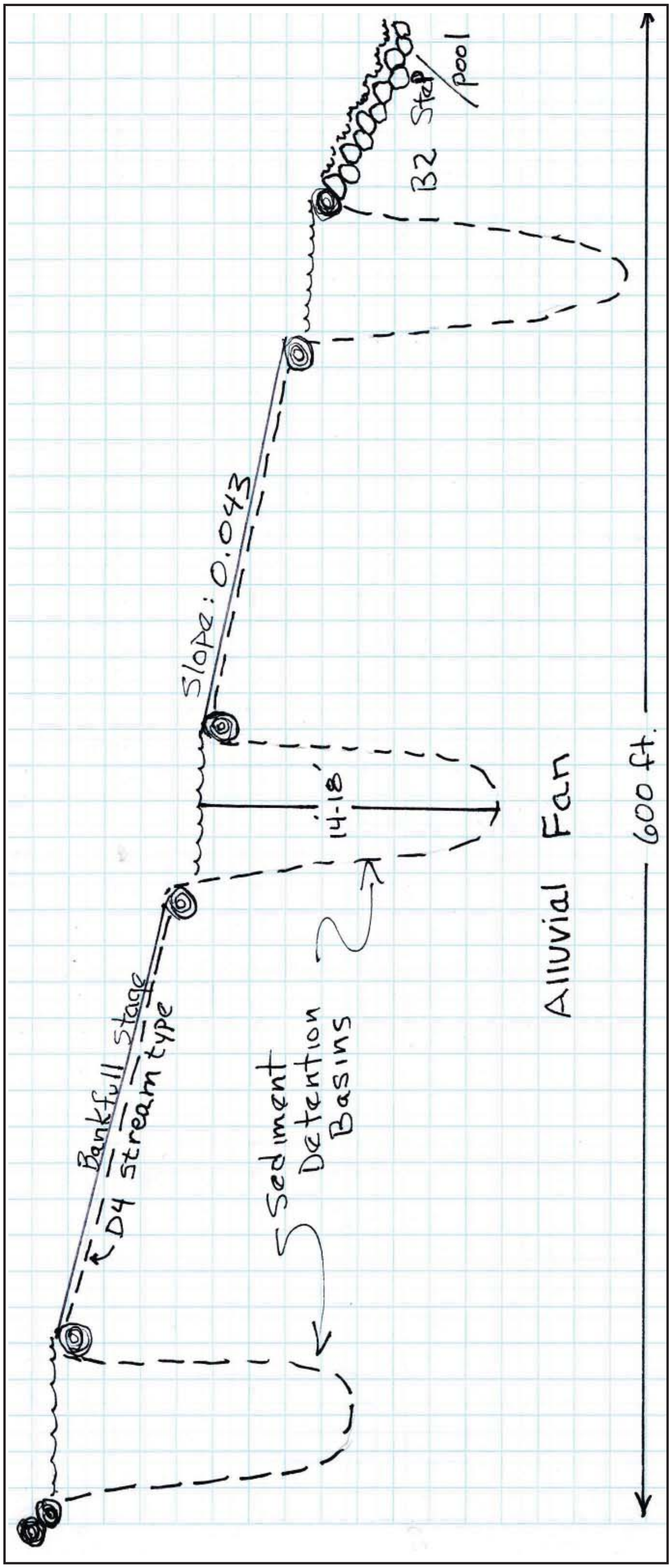

Figure 97. A schematic of the proposed longitudinal profile of the F4b to D4 stream type conversion showing the three sediment detention basins and the designed B2, step–pool channel.

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 11**), 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 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* (**Table 6**). 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 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 90**). 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 90**, **Figure 91** and **Figure 97**).

Worksheet 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, 2011).

Typical Design Scenario 6:

Tributary F4b to B4 Stream Type Conversion (VT III)

General Description & Morphological Data

This typical design scenario 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 98**). This channel is deeply incised, confined and entrenched, and cuts through an alluvial fan as depicted in **Figure 99**. 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 that contains the existing F4b tributary are included in **Table 13**, 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 7** and the morphology and stability evaluation are documented in *Appendix C14* of the Trail Creek *WARSSS* analysis (Rosgen, 2011, pp. C14-1 to C14-34).

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 7** and the detailed characteristics and stability evaluation are documented in *Appendix B3* of the Trail Creek *WARSSS* analysis (Rosgen, 2011, pp. B3-1 to B3-36).

The resultant proposed dimension, pattern and profile for the stable B4 stream type are documented in **Table 14** 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.

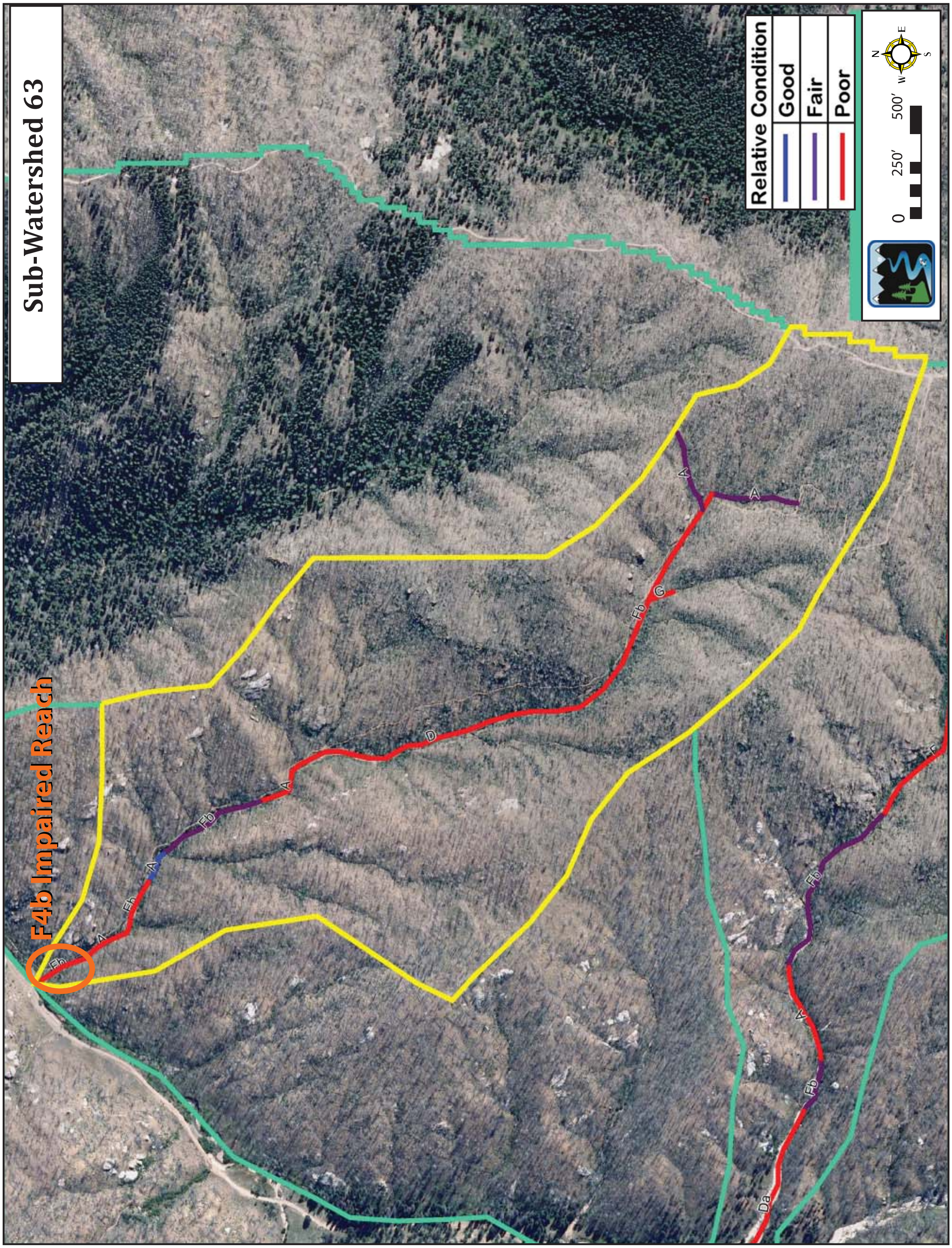

Figure 98. The location of the existing F4b *Poor* impaired tributary at the mouth of Sub-Watershed 63 and the confluence with Trail Creek.

Figure 99. 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 13. The summary of Sub-Watershed 63 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

	High	Moderate	Low	Unburned
Burn Severity (%)	7.2%	90.5%	2.3%	0.0%

	N	NE	E	SE	S	SW	W	NW
Percent of Aspect	29%	7%	0%	0%	0%	0%	20%	43%

	Aa+	A	B	C	D	Da+	E	F	Fb	G
Stream Types (%)	0%	29%	0%	0%	23%	0%	0%	0%	45%	2%

Streambank Erosion

	Good	Fair	Poor
Percent of Stream Conditions	3%	25%	72%

Total Erosion (tons/yr)	1,931

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
Percent of Erosion Categories	0%	0%	0%	29%	34%	2%	35%	0%	0%

Hillslope

Length of Road (ft)	3,750
Total Sediment from Roads (tons/yr)	5.2
Sediment from Surface Erosion (tons/yr)	52
Total Introduced Sediment (tons/yr)	57.2

Hydrology

Zone A			
Q_{bkf} cfs 3.41	DA (mi^2) 0.173		
	Pre-Fire	Post-Fire	Post-Restoration
Water Yield (ac-ft)	372	423	423
Flow-Related Sediment (tons/yr)	12	231	71

N/A			
Q_{bkf} cfs	DA (mi^2)		
	Pre-Fire	Post-Fire	Post-Restoration
Water Yield (ac-ft)			
Flow-Related Sediment (tons/yr)			

N/A			
Q_{bkf} cfs	DA (mi^2)		
	Pre-Fire	Post-Fire	Post-Restoration
Water Yield (ac-ft)			
Flow-Related Sediment (tons/yr)			

N/A			
Q_{bkf} cfs	DA (mi^2)		
	Pre-Fire	Post-Fire	Post-Restoration
Water Yield (ac-ft)			
Flow-Related Sediment (tons/yr)			

N/A			
Q_{bkf} cfs	DA (mi^2)		
	Pre-Fire	Post-Fire	Post-Restoration
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

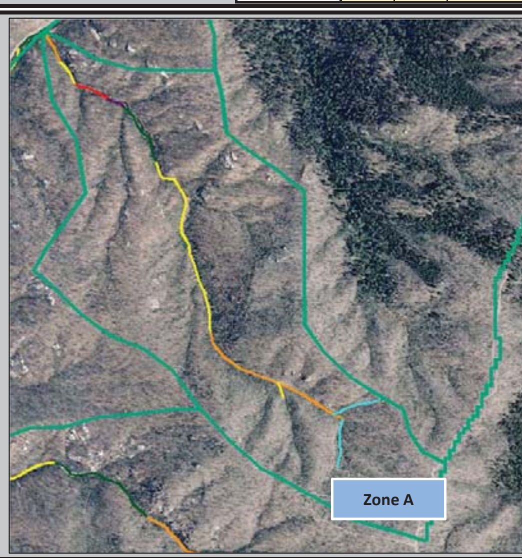

Table 14. The morphological characteristics of the existing, proposed design, reference and representative reaches for the F4b tributary to B4 stream type conversion in a Valley Type III – short alluvial fan.

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 14 (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**	*Mean:*	**N/A**	*Mean:*	**6.0**	*Mean:*	**14.0**
			Min:		*Min:*		*Min:*	**3.8**	*Min:*	**8.2**
			Max:		*Max:*		*Max:*	**9.9**	*Max:*	**21.1**
	22	Pool Width to Riffle Width (W_{bkfp}/W_{bkf})	*Mean:*	**N/A**	*Mean:*	**N/A**	*Mean:*	**1.091**	*Mean:*	**1.190**
			Min:		*Min:*		*Min:*	**0.695**	*Min:*	**0.695**
			Max:		*Max:*		*Max:*	**1.792**	*Max:*	**1.792**
	23	Pool Mean Depth, ft (d_{bkfp})	*Mean:*	**N/A**	*Mean:*	**N/A**	*Mean:*	**0.52**	*Mean:*	**0.80**
			Min:		*Min:*		*Min:*	**0.44**	*Min:*	**0.59**
			Max:		*Max:*		*Max:*	**0.62**	*Max:*	**1.05**
	24	Pool Mean Depth to Riffle Mean Depth (d_{bkfp}/d_{bkf})	*Mean:*	**N/A**	*Mean:*	**N/A**	*Mean:*	**1.180**	*Mean:*	**1.067**
			Min:		*Min:*		*Min:*	**1.000**	*Min:*	**0.787**
			Max:		*Max:*		*Max:*	**1.400**	*Max:*	**1.400**
	25	Pool Width/Depth Ratio (W_{bkfp}/d_{bkfp})	*Mean:*	**N/A**	*Mean:*	**N/A**	*Mean:*	**11.5**	*Mean:*	**17.5**
			Min:		*Min:*		*Min:*	**6.2**	*Min:*	**7.8**
			Max:		*Max:*		*Max:*	**22.4**	*Max:*	**35.8**
	26	Pool Cross-Sectional Area, ft^2 (A_{bkfp})	*Mean:*	**N/A**	*Mean:*	**N/A**	*Mean:*	**3.1**	*Mean:*	**8.9**
			Min:		*Min:*		*Min:*	**2.9**	*Min:*	**8.5**
			Max:		*Max:*		*Max:*	**3.2**	*Max:*	**9.6**
	27	Pool Area to Riffle Area (A_{bkfp}/A_{bkf})	*Mean:*	**N/A**	*Mean:*	**N/A**	*Mean:*	**1.300**	*Mean:*	**1.248**
			Min:		*Min:*		*Min:*	**1.189**	*Min:*	**1.189**
			Max:		*Max:*		*Max:*	**1.348**	*Max:*	**1.348**
	28	Pool Maximum Depth (d_{maxp})	*Mean:*	**N/A**	*Mean:*	**N/A**	*Mean:*	**1.00**	*Mean:*	**1.56**
			Min:		*Min:*		*Min:*	**0.90**	*Min:*	**1.33**
			Max:		*Max:*		*Max:*	**1.10**	*Max:*	**1.85**
	29	Pool Maximum Depth to Riffle Mean Depth (d_{maxp}/d_{bkf})	*Mean:*	**N/A**	*Mean:*	**N/A**	*Mean:*	**2.273**	*Mean:*	**2.080**
			Min:		*Min:*		*Min:*	**2.045**	*Min:*	**1.773**
			Max:		*Max:*		*Max:*	**2.500**	*Max:*	**2.467**
	30	Point Bar Slope (S_{pb})	*Mean:*	**N/A**	*Mean:*	**N/A**	*Mean:*	**0.380**	*Mean:*	**0.290**
			Min:		*Min:*		*Min:*	**0.280**	*Min:*	**0.220**
			Max:		*Max:*		*Max:*	**0.400**	*Max:*	**0.360**

Table 14 (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	Stat	Existing Reach	F4b Poor Trib. Rep. Reach	Proposed Design Reach	Reference Reach
Channel Pattern	**72** Linear Wavelength, ft (λ)	Mean:	N/A	N/A	48.6	104.0
		Min:			40.6	87.0
		Max:			60.3	129.0
	73 Linear Wavelength to Riffle Width (λ/W_{bkf})	Mean:	N/A	N/A	8.832	8.832
		Min:			7.389	7.389
		Max:			10.955	10.955
	74 Stream Meander Length, ft (L_m)	Mean:	N/A	N/A	52.3	112.0
		Min:			44.1	94.5
		Max:			63.1	135.0
	75 Stream Meander Length Ratio (L_m/W_{bkf})	Mean:	N/A	N/A	9.512	9.512
		Min:			8.025	8.025
		Max:			11.465	11.465
	76 Belt Width, ft (W_{blt})	Mean:	N/A	18.3	12.7	27.2
		Min:		14.0	6.8	14.6
		Max:		27.4	28.0	60.0
	77 Meander Width Ratio (W_{blt}/W_{bkf})	Mean:	N/A	1.427	2.306	2.306
		Min:		1.092	1.237	1.237
		Max:		2.136	5.096	5.096
	78 Radius of Curvature, ft (R_c)	Mean:	N/A	N/A	23.7	50.7
		Min:			11.6	21.8
		Max:			35.5	76.0
	79 Radius of Curvature to Riffle Width (R_c/W_{bkf})	Mean:	N/A	N/A	4.300	4.300
		Min:			2.100	2.100
		Max:			6.454	6.454
	80 Arc Length, ft (L_a)	Mean:	N/A	N/A	18.5	39.6
		Min:			4.7	10.0
		Max:			33.1	70.9
	81 Arc Length to Riffle Width (L_a/W_{bkf})	Mean:	N/A	N/A	3.363	3.363
		Min:			0.849	0.849
		Max:			6.021	6.021
	82 Riffle Length (L_r), ft *Refers to a Step Length - Not Riffle	Mean:	N/A	N/A	8.2	14.7
		Min:			1.6*	2.7
		Max:			15.0	28.2
	83 Riffle Length to Riffle Width (L_r/W_{bkf}) *Refers to a Step Length - Not Riffle	Mean:	N/A	N/A	1.500	1.248
		Min:			0.300*	0.229
		Max:			2.800	2.395
	84 Individual Pool Length, ft (L_p)	Mean:	N/A	N/A	28.1	60.1
		Min:			10.7	23.0
		Max:			47.2	101.0
	85 Pool Length to Riffle Width (L_p/W_{bkf})	Mean:	N/A	N/A	5.104	5.104
		Min:			1.953	1.953
		Max:			8.577	8.577
	86 Pool to Pool Spacing, ft (P_s)	Mean:	N/A	N/A	15.0	28.1
		Min:			7.0	12.2
		Max:			26.0	47.3
	87 Pool to Pool Spacing to Riffle Width (P_s/W_{bkf})	Mean:	N/A	N/A	2.788	2.387
		Min:			1.190	1.039
		Max:			4.615	4.020

Table 14 (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 14 (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 14 (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 (FLOWSED)	Existing Reach	Proposed Design Reach	Difference in Sediment Yield
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

		Streambank Erosion	Existing Reach	Representative Reach	Proposed Design Reach	Reference Reach
Bank Erosion	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 14**. Using continuity, the corresponding mean velocity for the proposed design reach is *2.0 ft/sec* as shown in **Worksheet 15**.

Plan View Alignment, Cross-Section Dimensions & Longitudinal Profile

The plan view alignment for the proposed B4 reach is shown in **Figure 100**, which follows the pattern data for the stable B4 stream type developed from dimensionless relations of the *B4 Reference Reach* (**Table 14**).

The proposed B4 channel dimensions are also recorded in **Table 14** 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 100**. The typical proposed riffle and pool cross-sections of the proposed B4 stream type compared to the F4b stream type are illustrated in **Figure 101**.

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 100**).

Structures

The proposed structures for streambank stabilization, flow resistance and grade control are shown in the plan, cross-section and longitudinal views in **Figure 100**. The structures include converging rock clusters (**Figure 22**); the root wad, log vane, J-hook (**Figure 9**); the "Rock & Roll" log structure (**Figure 19**); the toe wood structure with sod mats and riparian transplants (**Figure 15** and **Figure 16**); and the rock step–pool structure (**Figure 20**). 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 & Roll" log 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 101**. 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 15. 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 $\sim (2 * d_{bkf}) + W_{bkf}$	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 $u^* = (gRS)^{1/2}$	0.623	u* (ft/sec)

ESTIMATION METHODS	Bankfull VELOCITY		Bankfull DISCHARGE	
1. Friction Factor / Relative Roughness $u = [2.83 + 5.66 * \text{Log}\{R / D_{84}\}] u^*$		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): $u = 1.49*R^{2/3}*S^{1/2} / n$; $n = 0.39*S^{0.38}*R^{-0.16}$ n = 0.123. 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	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.

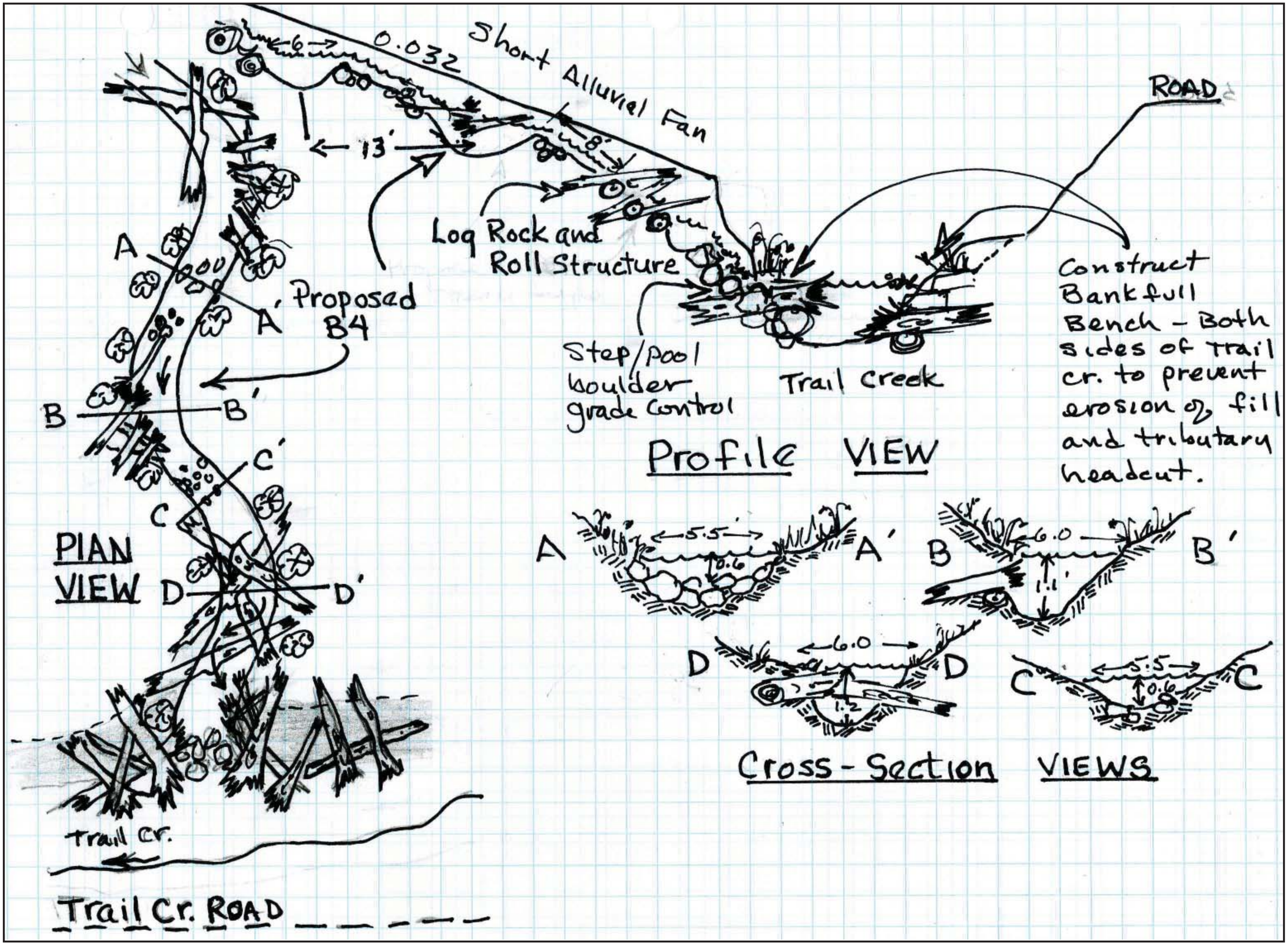

Figure 100. The designed alignment, cross-sections and longitudinal profile for the proposed B4 reach to be converted from the existing F4b *Poor* tributary at the mouth of Sub-Watershed 63 and the confluence of Trail Creek.

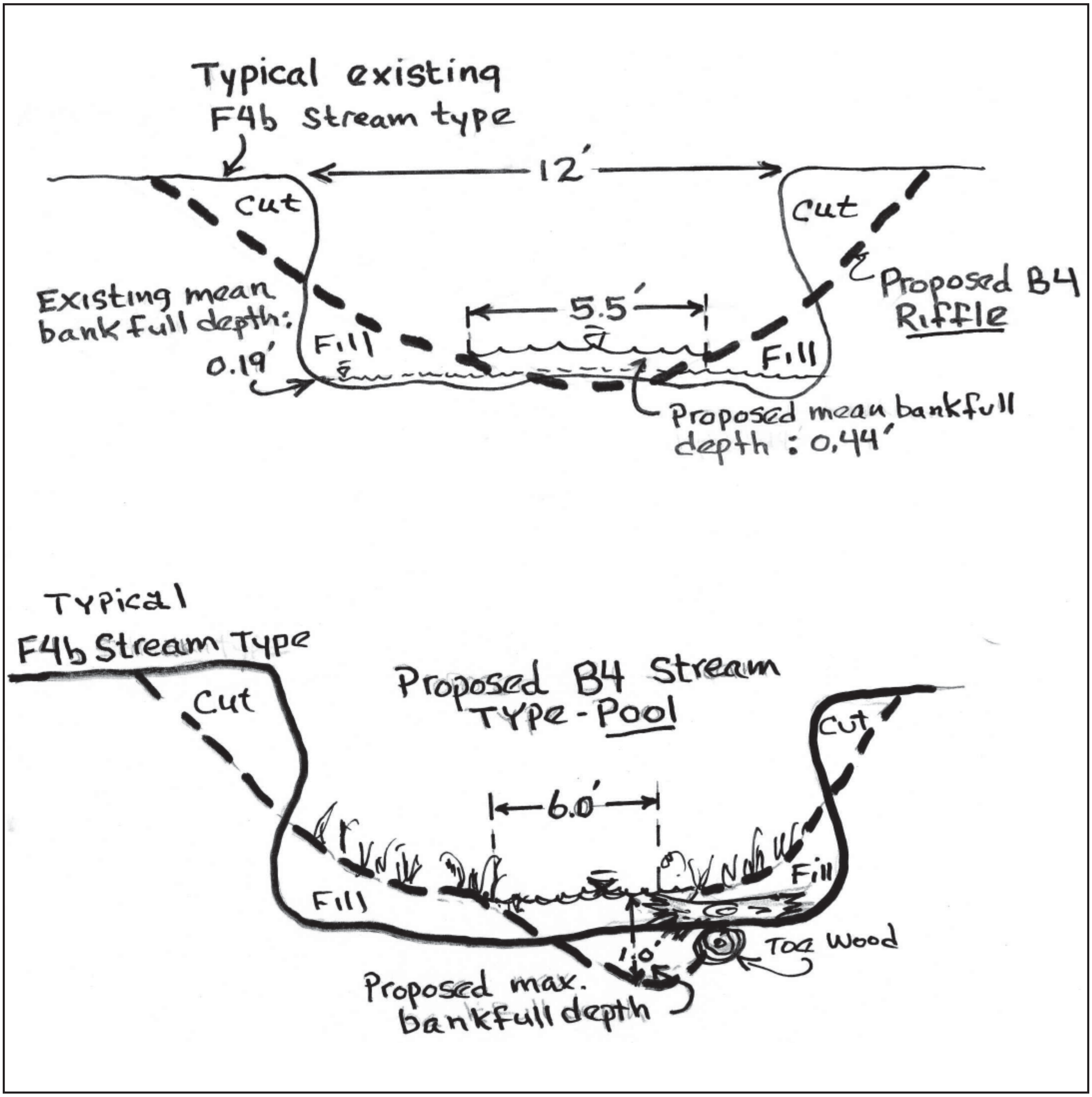

Figure 101. The typical riffle and pool cross-sections for the proposed B4 reach to be converted from the existing F4b tributary at the mouth of Sub-Watershed 63.

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 14**), 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 100** are implemented, such as the toe wood, J-hook and "Rock & Roll" log 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 16a**) to *94.1 tons/yr* (**Worksheet 16b**) 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 (**Table 6**). 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 16a. 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 16b. 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 exist within the Trail Creek Watershed 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 *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 remaining 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 meet the Trail Creek Watershed objective of sediment reduction. The Fb tributaries and associated conditions are mapped by sub-watershed in *Appendix D* of the Trail Creek *WARSSS* analysis (Rosgen, 2011). The calculation of bankfull discharge and cross-sectional area using drainage area from regional curves will allow scaling of the dimensionless ratios using the reference condition B4 stream type as was done for this scenario example. The general procedure to extrapolate this design scenario to other F4b stream types is included in the *Extrapolation of Typical Scenarios to other Locations* section using the scaling and Natural Channel Design procedure detailed in **Appendix I**.

Typical Design Scenario 7:
Tributary A4a+ *Poor* to A4a+ *Stable* Conversion (VT I)

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 102** and located on the general map in **Figure 7**. The detailed characteristics and stability evaluation of this representative reach are documented in *Appendix C4* of the Trail Creek *WARSSS* analysis (Rosgen, 2011, pp. C4-1 to C4-32). 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 103**. 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 7**). The detailed characteristics and stability evaluation of the *A4a+ Reference Reach* are documented in *Appendix B2* of the Trail Creek *WARSSS* analysis (Rosgen, 2011, pp. B2-1 to B2-32).

The resultant proposed dimension, pattern and profile for the stable A4a+ design reach are documented in **Table 15** 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 15**). 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 15**. Using continuity, the corresponding mean velocity for the proposed design reach is *0.5 ft/sec* as shown in **Worksheet 17**.

Figure 102. The deeply incised, confined and entrenched *A4a+ Poor Stability South Representative Reach*.

Figure 103. The advancing headcut in the *A4a+ Poor Stability South Representative Reach*.

Table 15. 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:*	**1.7**	*Mean:*	**2.3**	*Mean:*	**3.0**	
			Min:	**1.4**	*Min:*	**2.0**	*Min:*	**2.3**	
			Max:	**2.0**	*Max:*	**2.6**	*Max:*	**3.6**	
	7	Riffle Mean Depth, ft (d_{bkf})	*Mean:*	**0.20**	*Mean:*	**0.32**	*Mean:*	**0.22**	
			Min:	**0.18**	*Min:*	**0.28**	*Min:*	**0.18**	
			Max:	**0.22**	*Max:*	**0.37**	*Max:*	**0.26**	
	8	Riffle Width/Depth Ratio (W_{bkf}/d_{bkf})	*Mean:*	**8.4**	*Mean:*	**7.2**	*Mean:*	**11.2**	
			Min:	**7.8**	*Min:*	**5.4**	*Min:*	**11.0**	
			Max:	**9.0**	*Max:*	**9.2**	*Max:*	**11.4**	
	9	Riffle Cross-Sectional Area, ft^2 (A_{bkf})	*Mean:*	**0.3**	*Mean:*	**0.736**	*Mean:*	**0.6**	
			Min:	**0.3**			*Min:*	**0.5**	
			Max:	**0.4**			*Max:*	**0.8**	
	10	Riffle Maximum Depth (d_{max})	*Mean:*	**0.40**	*Mean:*	**0.50**	*Mean:*	**0.33**	
			Min:	**0.37**	*Min:*	**0.41**	*Min:*	**0.27**	
			Max:	**0.43**	*Max:*	**0.60**	*Max:*	**0.39**	
	11	Riffle Maximum Depth to Riffle Mean Depth (d_{max}/d_{bkf})	*Mean:*	**2.005**	*Mean:*	**1.558**	*Mean:*	**1.558**	
			Min:	**1.955**	*Min:*	**1.286**	*Min:*	**1.286**	
			Max:	**2.056**	*Max:*	**1.889**	*Max:*	**1.889**	
	12	Width of Flood-Prone Area at Elevation of 2 * d_{max}, ft (W_{fpa})	*Mean:*	**2.40**	*Mean:*	**5.0**	*Mean:*	**5.02**	
			Min:	**1.88**	*Min:*	**3.7**	*Min:*	**3.65**	
			Max:	**2.91**	*Max:*	**5.9**	*Max:*	**5.85**	
	13	Entrenchment Ratio (W_{fpa}/W_{bkf})	*Mean:*	**1.41**	*Mean:*	**1.55**	*Mean:*	**1.55**	
			Min:	**1.35**	*Min:*	**1.53**	*Min:*	**1.53**	
			Max:	**1.47**	*Max:*	**1.58**	*Max:*	**1.58**	

Table 15 (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 15 (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**	*Mean:*	**N/A**	*Mean:*	**N/A**
			Min:		*Min:*		*Min:*	
			Max:		*Max:*		*Max:*	
	73	Linear Wavelength to Riffle Width (λ/W_{bkf})	*Mean:*	**N/A**	*Mean:*	**N/A**	*Mean:*	**N/A**
			Min:		*Min:*		*Min:*	
			Max:		*Max:*		*Max:*	
	74	Stream Meander Length, ft (L_m)	*Mean:*	**N/A**	*Mean:*	**N/A**	*Mean:*	**N/A**
			Min:		*Min:*		*Min:*	
			Max:		*Max:*		*Max:*	
	75	Stream Meander Length Ratio (L_m/W_{bkf})	*Mean:*	**N/A**	*Mean:*	**N/A**	*Mean:*	**N/A**
			Min:		*Min:*		*Min:*	
			Max:		*Max:*		*Max:*	
	76	Belt Width, ft (W_{blt})	*Mean:*	**2.6**	*Mean:*	**4.5**	*Mean:*	**4.5**
			Min:		*Min:*		*Min:*	
			Max:		*Max:*		*Max:*	
	77	Meander Width Ratio (W_{blt}/W_{bkf})	*Mean:*	**1.509**	*Mean:*	**1.500**	*Mean:*	**1.515**
			Min:		*Min:*		*Min:*	
			Max:		*Max:*		*Max:*	
	78	Radius of Curvature, ft (R_c)	*Mean:*	**N/A**	*Mean:*	**N/A**	*Mean:*	**N/A**
			Min:		*Min:*		*Min:*	
			Max:		*Max:*		*Max:*	
	79	Radius of Curvature to Riffle Width (R_c/W_{bkf})	*Mean:*	**N/A**	*Mean:*	**N/A**	*Mean:*	**N/A**
			Min:		*Min:*		*Min:*	
			Max:		*Max:*		*Max:*	
	80	Rapid (Riffle) Length, ft (L_a)	*Mean:*	**N/A**	*Mean:*	**5.1**	*Mean:*	**5.1**
			Min:		*Min:*	**3.5**	*Min:*	**3.5**
			Max:		*Max:*	**6.9**	*Max:*	**6.9**
	81	Rapid (Riffle) Length to Riffle Width (L_a/W_{bkf})	*Mean:*	**N/A**	*Mean:*	**2.200**	*Mean:*	**2.200**
			Min:		*Min:*	**1.500**	*Min:*	**1.500**
			Max:		*Max:*	**3.000**	*Max:*	**3.000**
	82	Step Length (L_r), ft	*Mean:*	**N/A**	*Mean:*	**0.75**	*Mean:*	**0.8**
			Min:		*Min:*	**0.50**	*Min:*	**0.5**
			Max:		*Max:*	**1.00**	*Max:*	**1.0**
	83	Step Length to Riffle Width (L_r/W_{bkf})	*Mean:*	**N/A**	*Mean:*	**0.326**	*Mean:*	**0.326**
			Min:		*Min:*	**0.217**	*Min:*	**0.217**
			Max:		*Max:*	**0.435**	*Max:*	**0.435**
	84	Individual Pool Length, ft (L_p)	*Mean:*	**N/A**	*Mean:*	**2.2**	*Mean:*	**2.2**
			Min:		*Min:*	**1.0**	*Min:*	**1.0**
			Max:		*Max:*	**3.0**	*Max:*	**3.0**
	85	Pool Length to Riffle Width (L_p/W_{bkf})	*Mean:*	**N/A**	*Mean:*	**0.960**	*Mean:*	**0.960**
			Min:		*Min:*	**0.450**	*Min:*	**0.450**
			Max:		*Max:*	**1.300**	*Max:*	**1.300**
	86	Pool to Pool Spacing, ft (P_s)	*Mean:*	**N/A**	*Mean:*	**3.9**	*Mean:*	**3.9**
			Min:		*Min:*	**1.8**	*Min:*	**1.8**
			Max:		*Max:*	**6.0**	*Max:*	**6.0**
	87	Pool to Pool Spacing to Riffle Width (P_s/W_{bkf})	*Mean:*	**N/A**	*Mean:*	**1.700**	*Mean:*	**1.700**
			Min:		*Min:*	**0.800**	*Min:*	**0.800**
			Max:		*Max:*	**2.600**	*Max:*	**2.600**

Table 15 (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 15 (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.

Category	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 15 (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 17. 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 $u^* = (gRS)^{1/2}$	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): $u = 1.49*R^{2/3}*S^{1/2} / n$; $n = 0.39*S^{0.38}*R^{-0.16}$; n = 0.223. 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	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 104**, which follows the reference reach data for the stable A4a+ stream type (**Table 15**). 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 15**. **Figure 104** illustrates the typical cross-sections in relation to the plan view. The typical rapid/chute (riffle) cross-section dimensions are shown in **Figure 105**. 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 106**. Similarly, the overlay of the existing cross-section 1+52.7 *vs*. proposed pool cross-section is shown in **Figure 107**. 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 108**. 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 104**.

Figure 109 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 109** as derived from **Table 15**. 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 106** and **Figure 107**).

Structures

This typical design scenario recommends converging rock clusters (**Figure 22**), "Rock & Roll" log structures (**Figure 19**), and rock step–pool structures (**Figure 20**) for streambank stabilization, energy dissipation and grade control. The location of these recommended structures are illustrated in **Figure 104**, **Figure 108** and **Figure 109**. 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 & Roll" log 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.

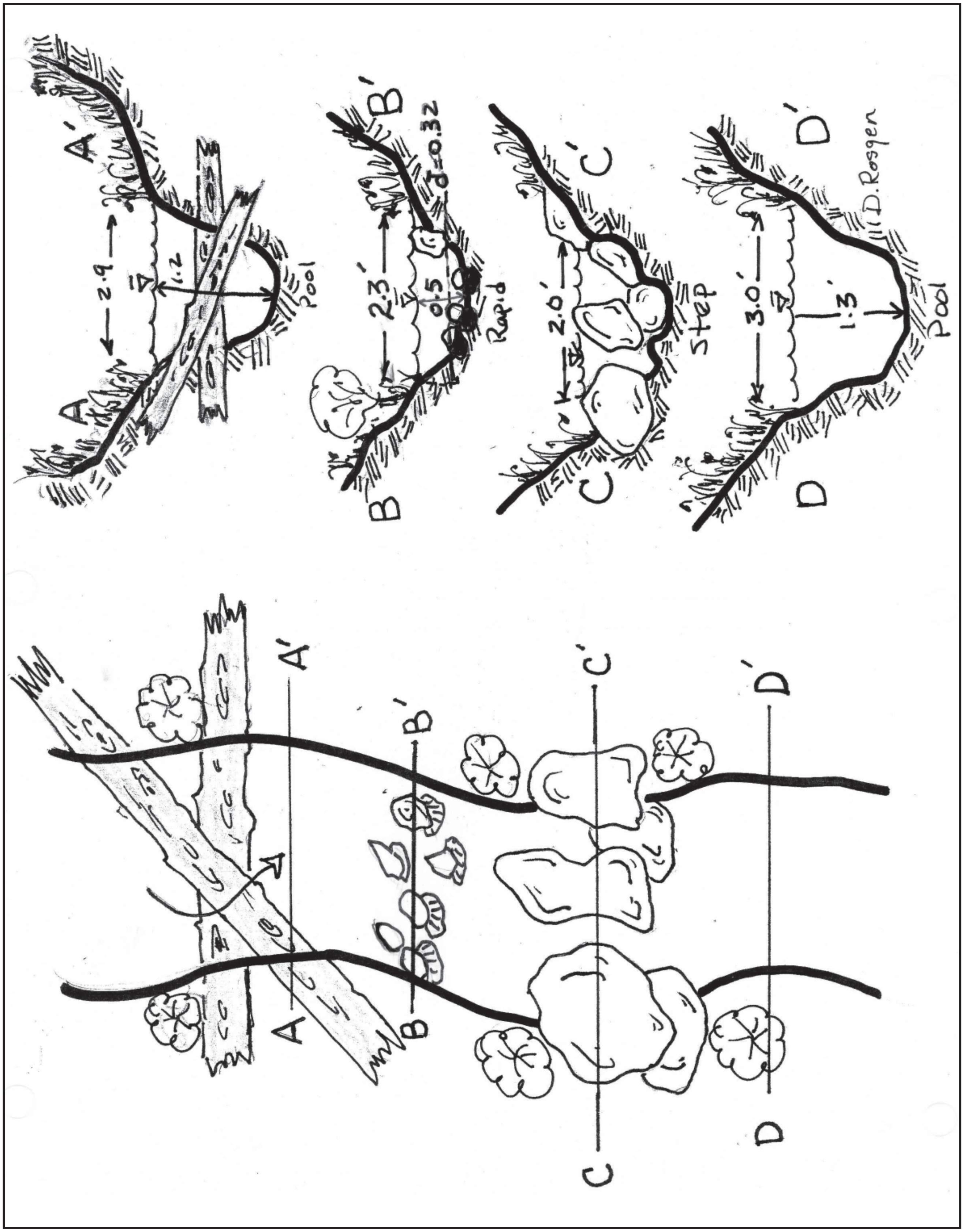

Figure 104. Typical plan view alignment with corresponding cross-section dimensions and structure locations.

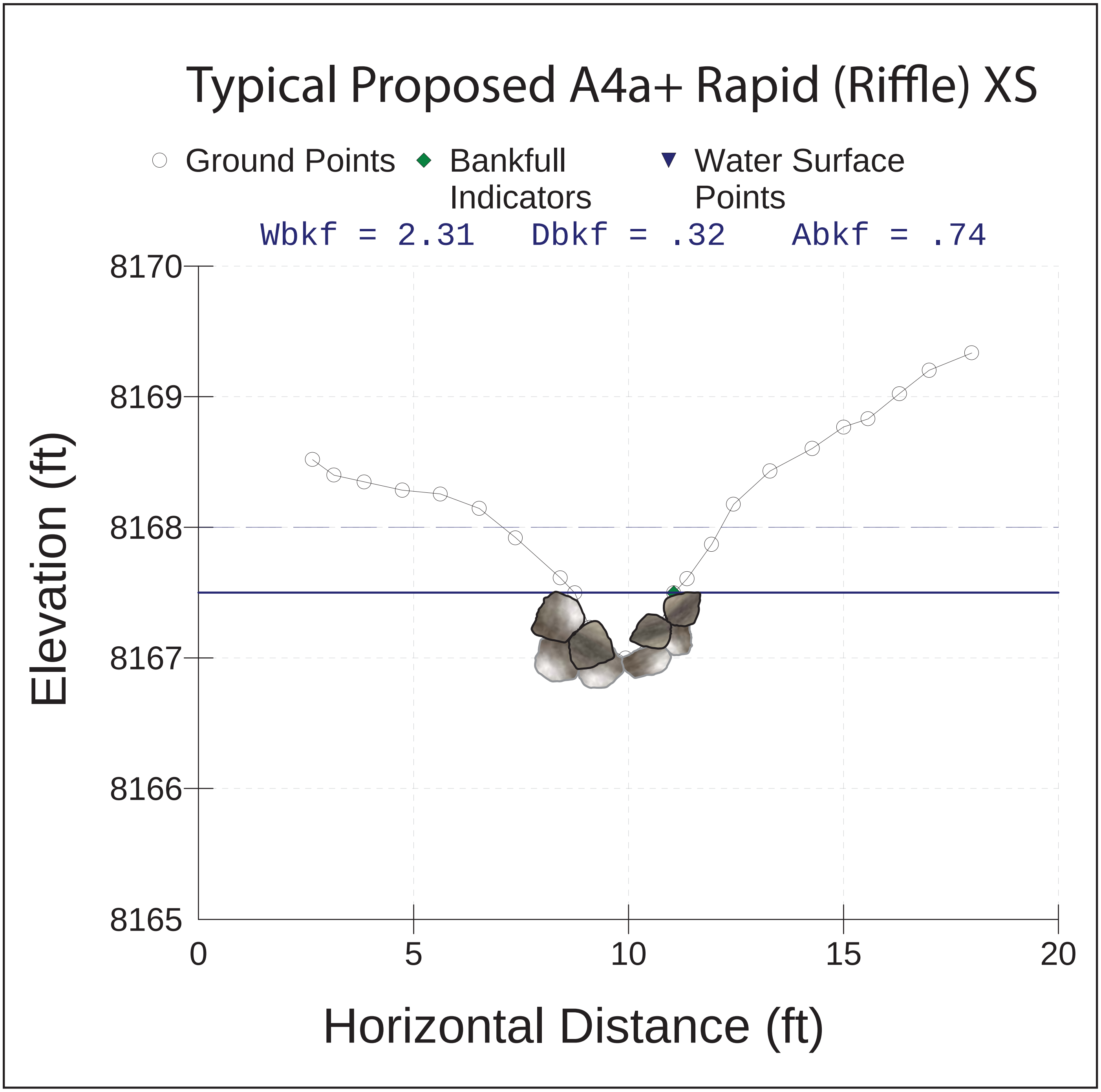

Figure 105. The typical rapid/chute (riffle) cross-section for the proposed A4a+ *Stable* step–pool design.

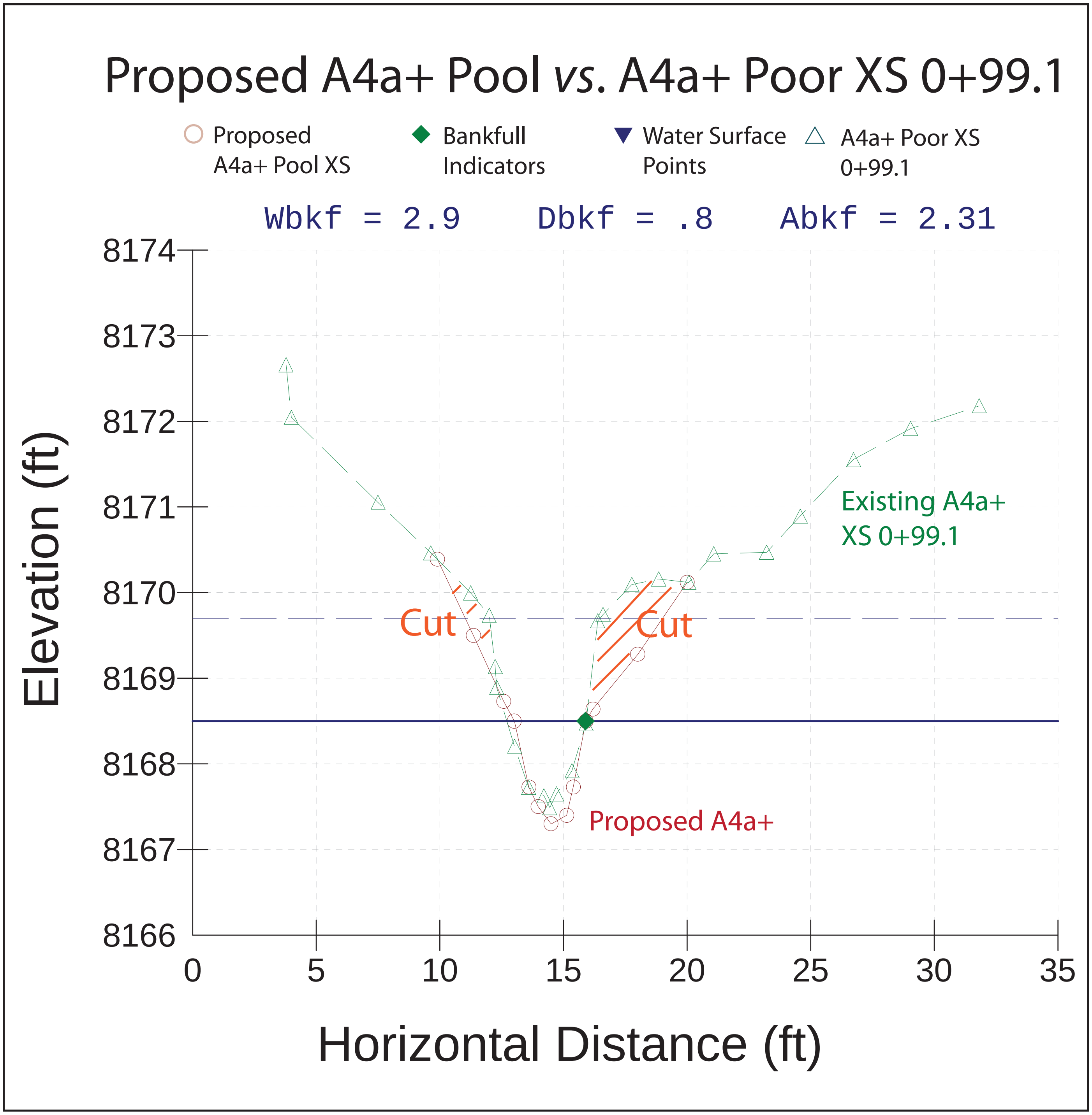

Figure 106. The overlay of the existing cross-section 0+99.1 *vs*. proposed pool cross-section indicating the cut and fill recommendations for the A4a+ *Poor* to A4a+ *Stable* step–pool conversion.

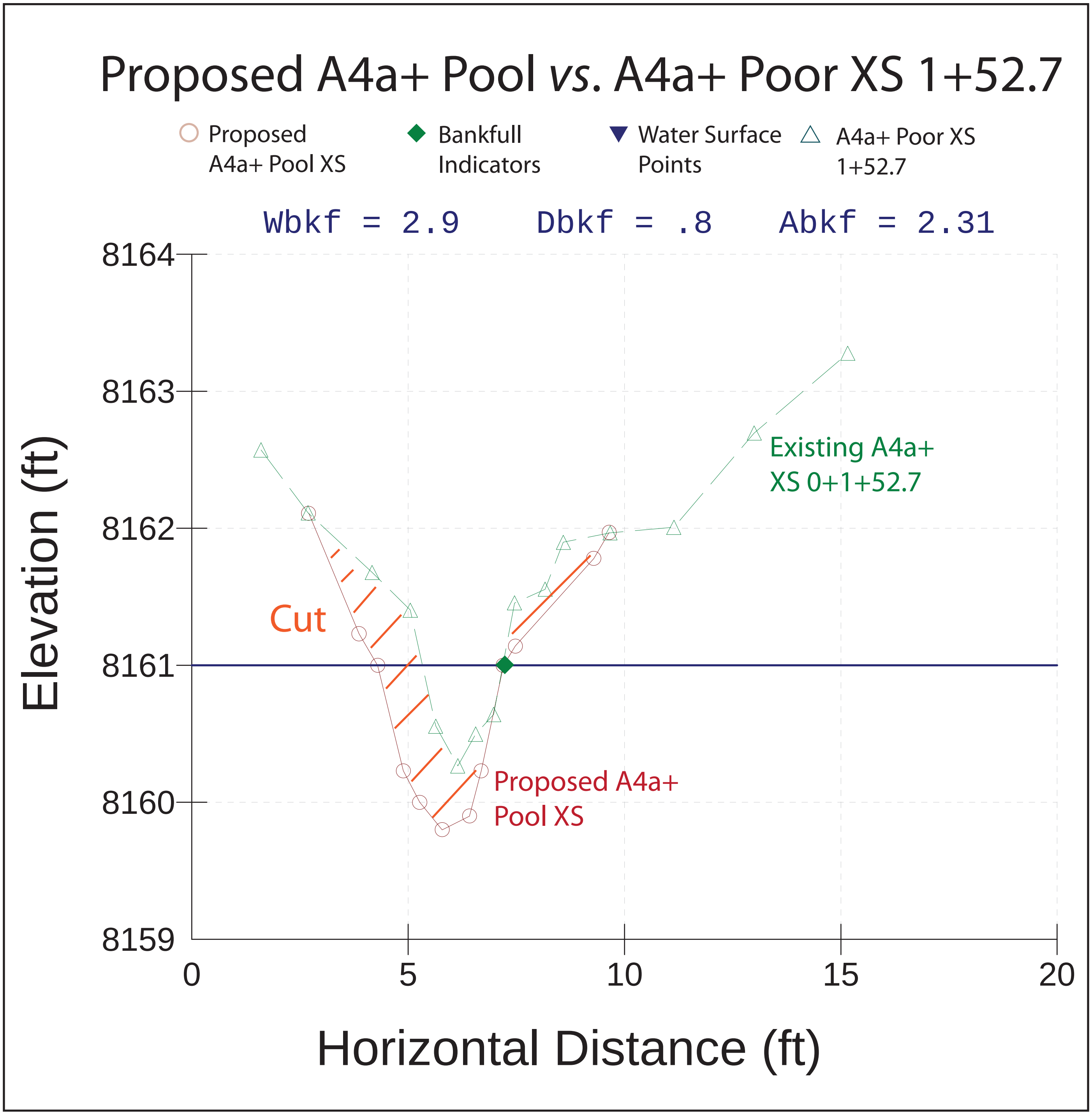

Figure 107. The overlay of the existing cross-section 1+52.7 *vs*. proposed pool cross-section indicating the cut and fill recommendations for the A4a+ *Poor* to A4a+ *Stable* step–pool conversion.

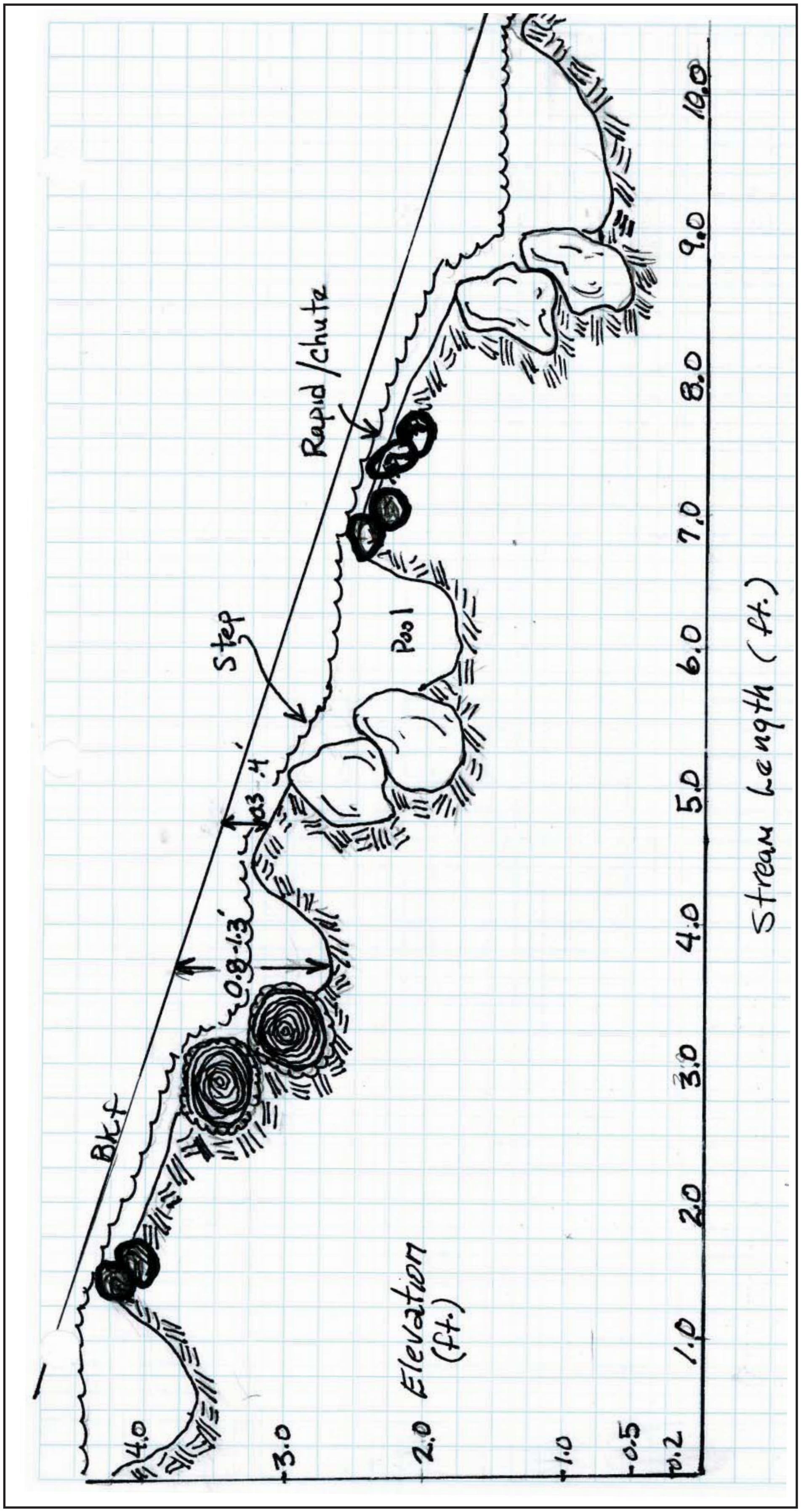

Figure 108. The typical longitudinal profile for *10 ft* of the proposed A4a+ *Stable* step–pool design, including the structure placement and the depths, slopes, lengths and spacing of bed features.

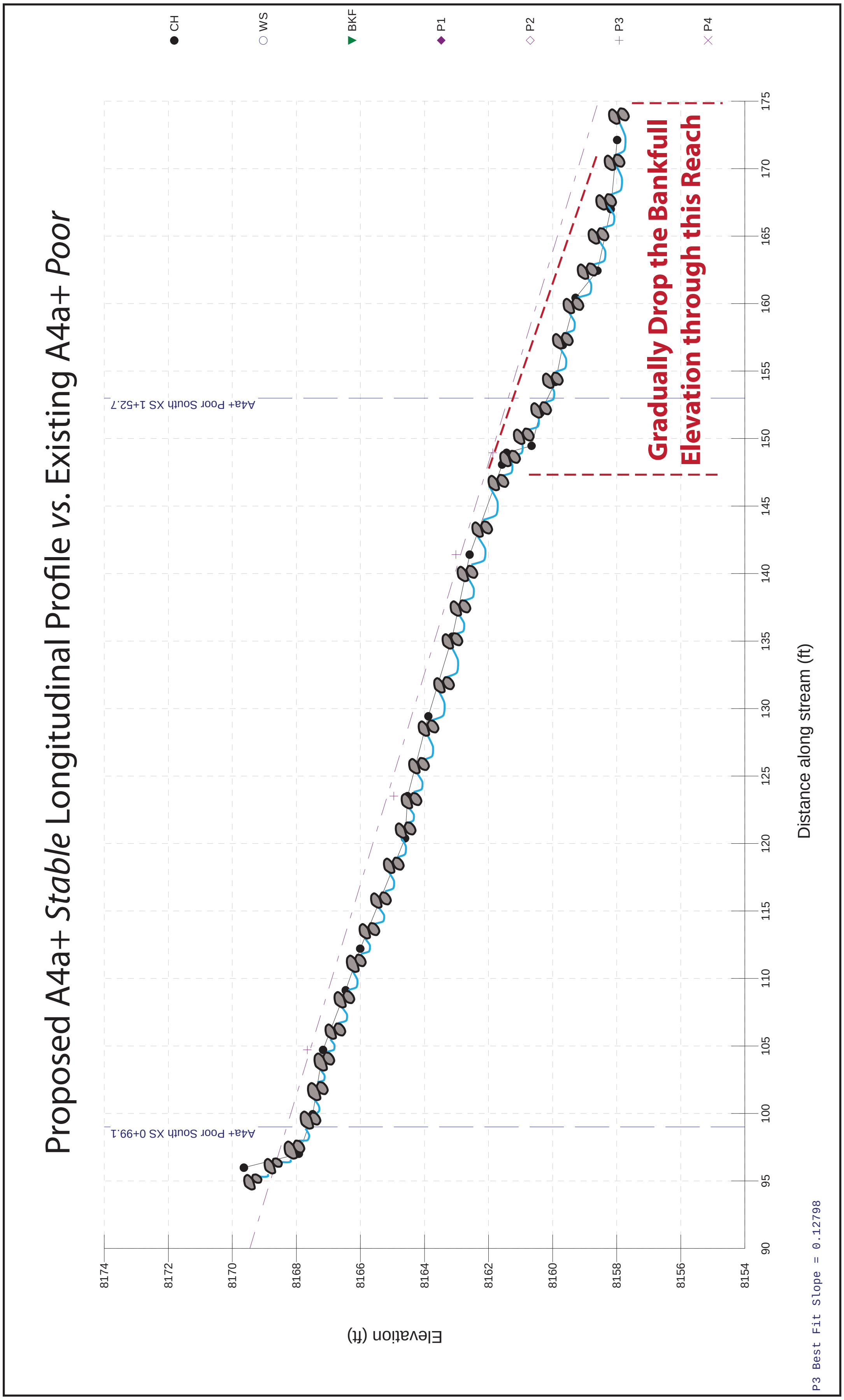

Figure 109. The proposed longitudinal profile compared to the existing *A4a+ Poor South Representative Reach* profile.

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 15**). 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 104** 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 18a**) to *19.6 tons/yr* (**Worksheet 18b**) 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 (**Table 6**). 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 & Roll" log structures as designed in **Figure 104** and **Figure 108**.

Worksheet 18a. 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 18b. 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 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.

Several miles of similar stream systems occur within the Trail Creek Watershed; some of them are small enough to use hand labor, but must still follow consistent restoration criteria. If proportionate savings in the sediment supply can result, then additional design reaches will help meet the overall objective of sediment reduction. The other incising A4a+ *Poor* stream types that are mapped in *Appendix D* of the Trail Creek *WARSSS* analysis (Rosgen, 2011) will follow a similar design, scaled for the local drainage area and corresponding bankfull discharge.

Typical Design Scenario 8:
Tributary A4a+ to D4 Stream Type Conversion (VT III)

General Description & Morphological Data

This typical design scenario 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 7**. The tributary is located at the mouth of a face drainage south of Sub-Watershed 6 as shown in **Figure 110**. The detailed characteristics and stability evaluation of this representative reach are documented in *Appendix C5* of the Trail Creek *WARSSS* analysis (Rosgen, 2011, pp. C5-1 to C5-32). 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 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 111 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. The designed relocation of Trail Creek at this location is included in **Figure 41** in the *Lower Trail Creek Design Concept* section that converts the existing C4 *Poor* condition stream type to its stable form. 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 16**. 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.

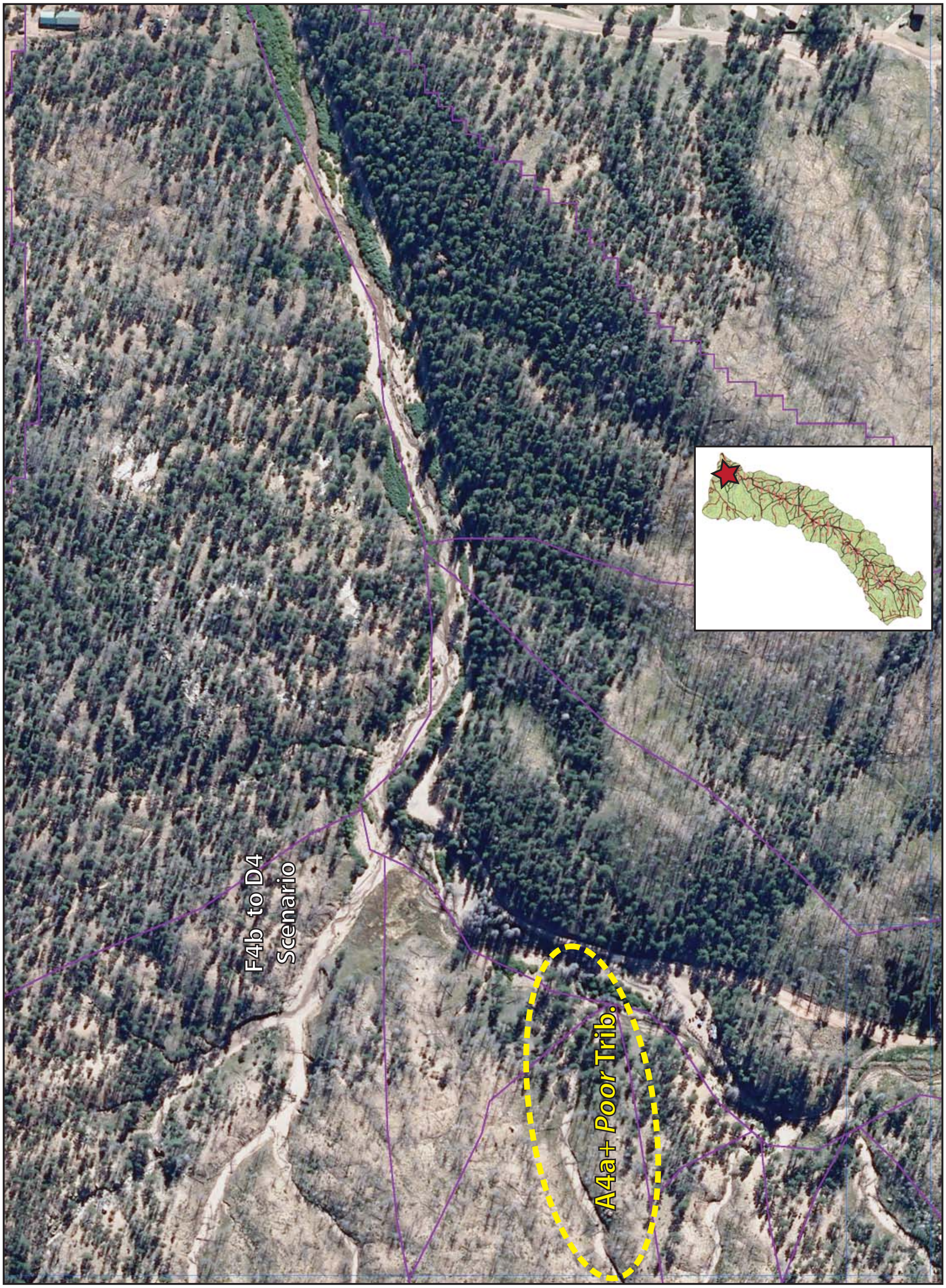

Figure 110. The location of the existing, impaired *A4a+ Poor Stability Downstream Representative Reach* within Sub-Watershed 6.

Figure 111. 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 16. 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:* **2.2** *Min:* **1.7** *Max:* **2.7**	*Mean:* **8.0** *Min:* *Max:*
	7	Riffle Mean Depth, ft (d_{bkf})	*Mean:* **0.19** *Min:* **0.17** *Max:* **0.24**	*Mean:* **0.10** *Min:* *Max:*
	8	Riffle Width/Depth Ratio (W_{bkf}/d_{bkf})	*Mean:* **11.7** *Min:* **9.2** *Max:* **15.7**	*Mean:* **80.0** *Min:* *Max:*
	9	Riffle Cross-Sectional Area, ft^2 (A_{bkf})	*Mean:* **0.4** *Min:* **0.3** *Max:* **0.5**	*Mean:* **0.8**
	10	Riffle Maximum Depth (d_{max})	*Mean:* **0.29** *Min:* **0.24** *Max:* **0.40**	*Mean:* **0.15** *Min:* *Max:*
	11	Riffle Maximum Depth to Riffle Mean Depth (d_{max}/d_{bkf})	*Mean:* **1.497** *Min:* **1.411** *Max:* **1.667**	*Mean:* **1.500** *Min:* *Max:*
	12	Width of Flood-Prone Area at Elevation of 2 * d_{max}, ft (W_{fpa})	*Mean:* **2.9** *Min:* **2.0** *Max:* **4.0**	*Mean:* **N/A** *Min:* *Max:*
	13	Entrenchment Ratio (W_{fpa}/W_{bkf})	*Mean:* **1.3** *Min:* **1.2** *Max:* **1.5**	*Mean:* **N/A** *Min:* *Max:*

Table 16 (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 16 (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* mi^2 for the proposed D4 stream type, the bankfull discharge is *0.412 cfs* and the proposed bankfull riffle cross-sectional area is *0.8* ft^2 as shown in **Table 16**. Using continuity, the corresponding mean velocity for the proposed design reach is *0.52 ft/sec* as shown in **Worksheet 19**.

Plan View Alignment

The design sketch in **Figure 112** 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 16 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 113**. The proposed sediment detention basin is shown in **Figure 114** 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 115**.

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 116**. 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 117** 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 112**.

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 19. 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 $\sim (2 * d_{bkf}) + W_{bkf}$	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): $u = 1.49*R^{2/3}*S^{1/2} / n$; $n = 0.39*S^{0.38}*R^{-0.16}$; n = 0.264. **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	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.

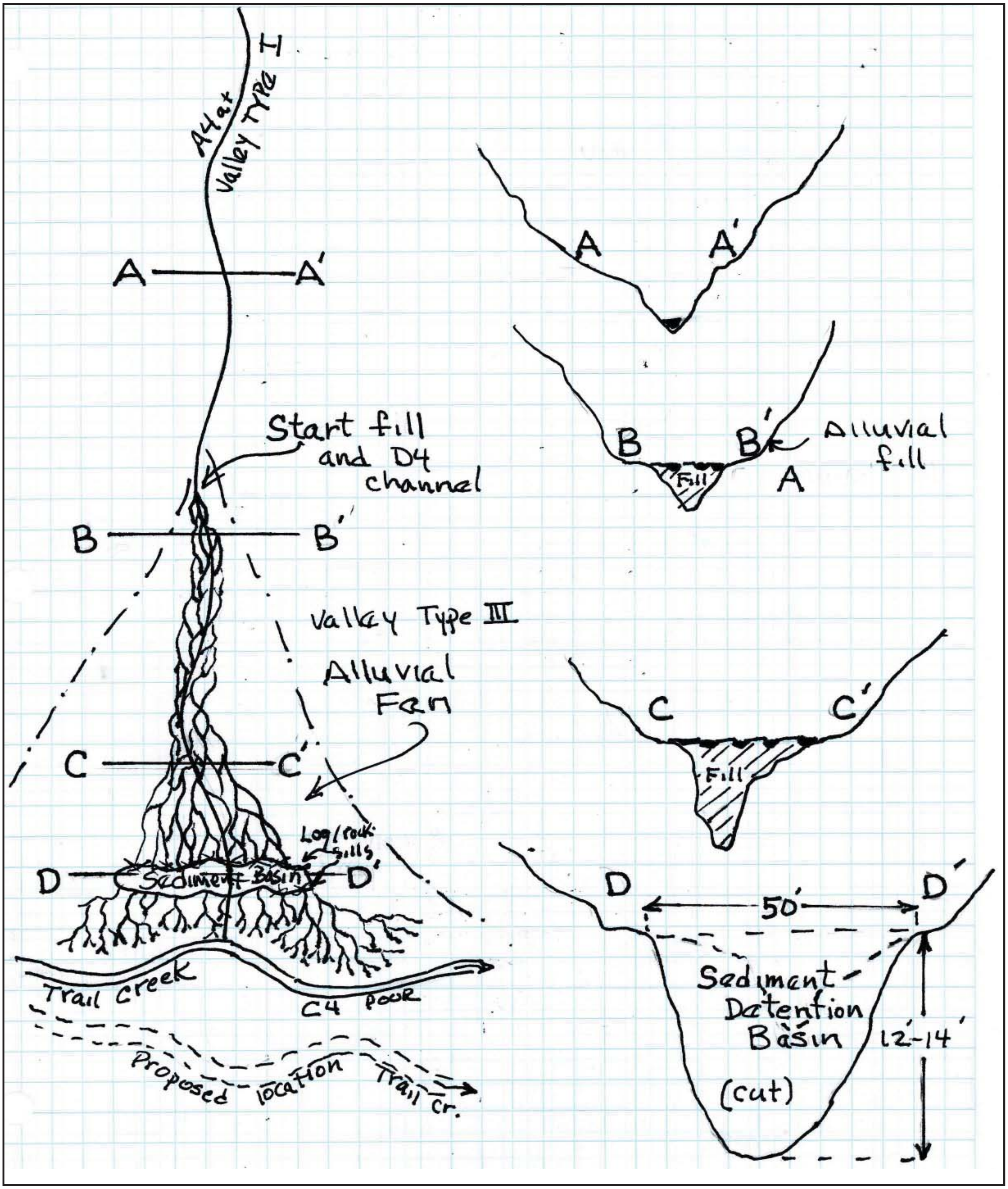

Figure 112. The plan and cross-section views of the proposed A4a+ to D4 stream type conversion with a sediment detention basin, Valley Type III.

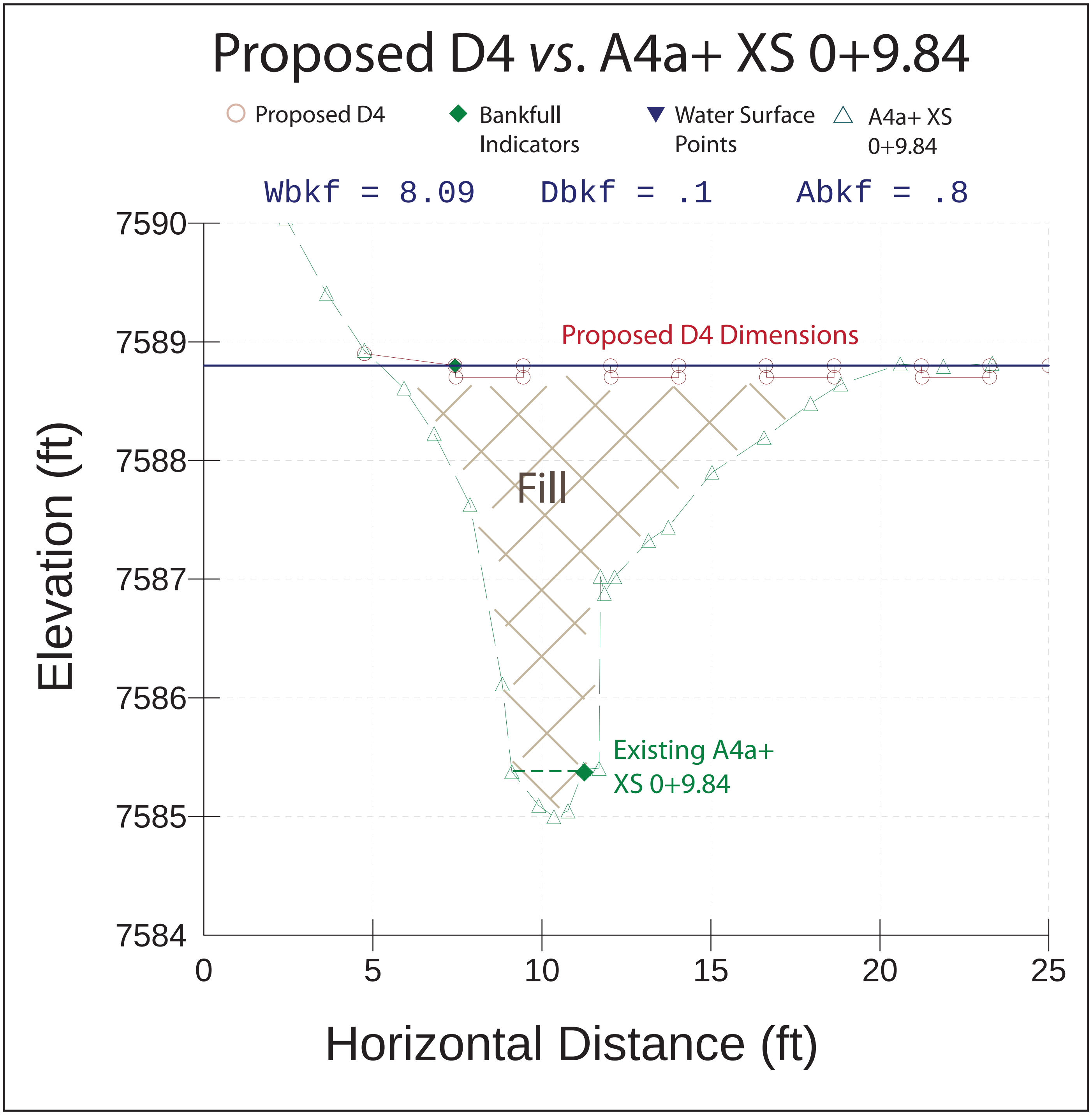

Figure 113. The proposed D4 cross-section *vs.* the existing A4a+ cross-section 0+9.84 indicating the extensive fill requirements.

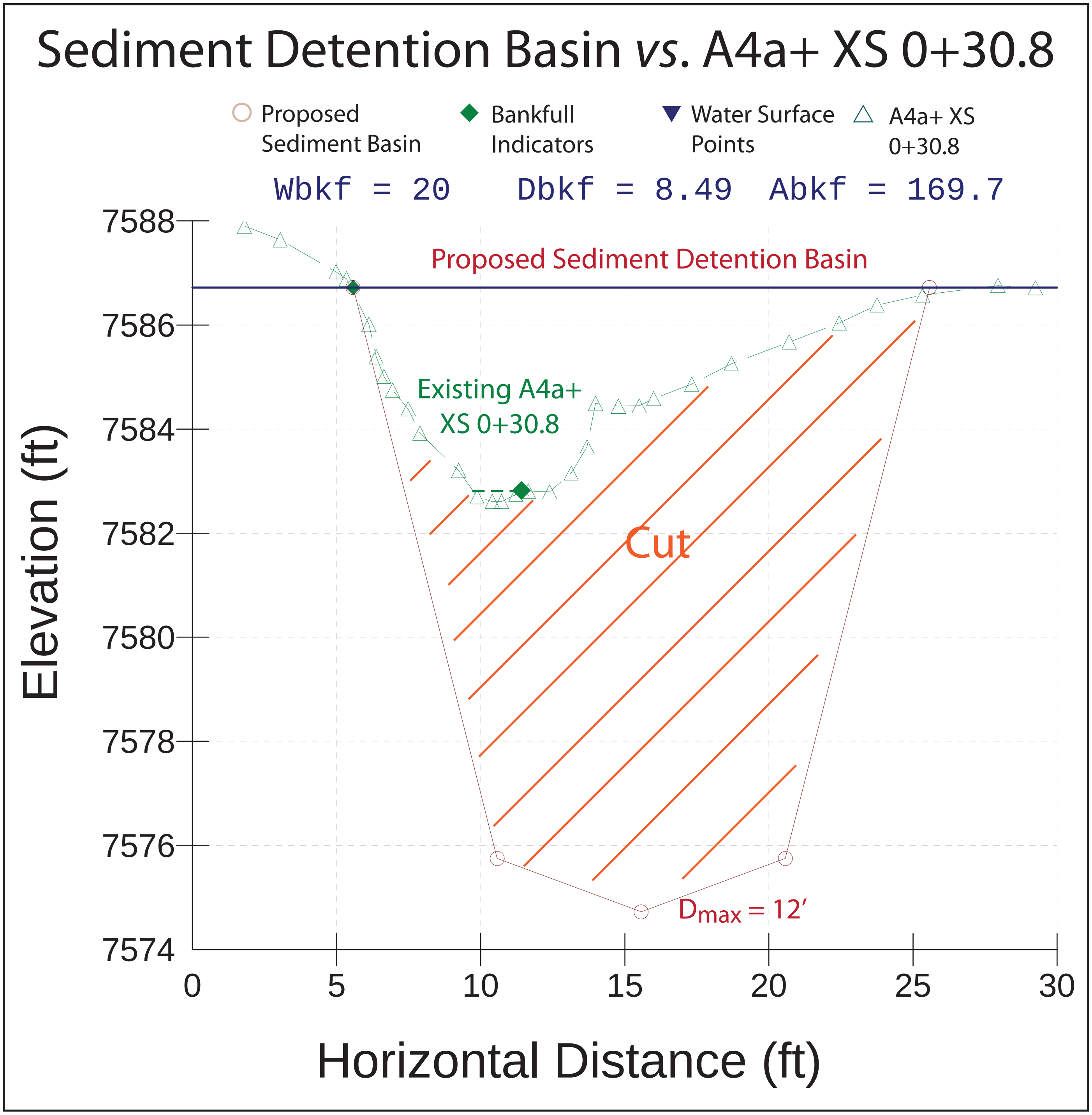

Figure 114. The proposed sediment detention basin located at the existing A4a+ cross-section 0+30.8.

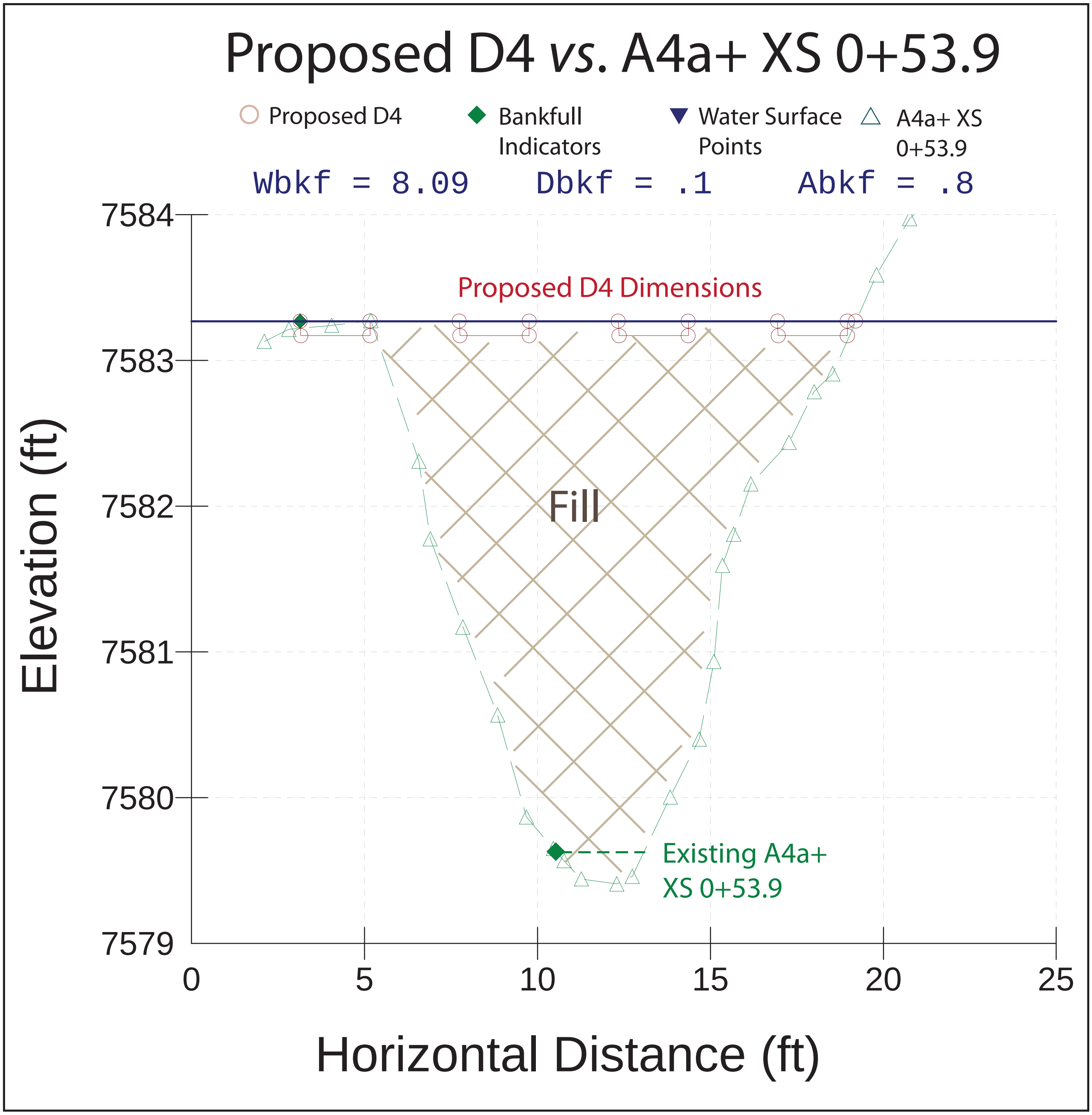

Figure 115. The proposed D4 cross-section *vs*. the existing A4a+ cross-section 0+53.9 indicating the extensive fill requirements.

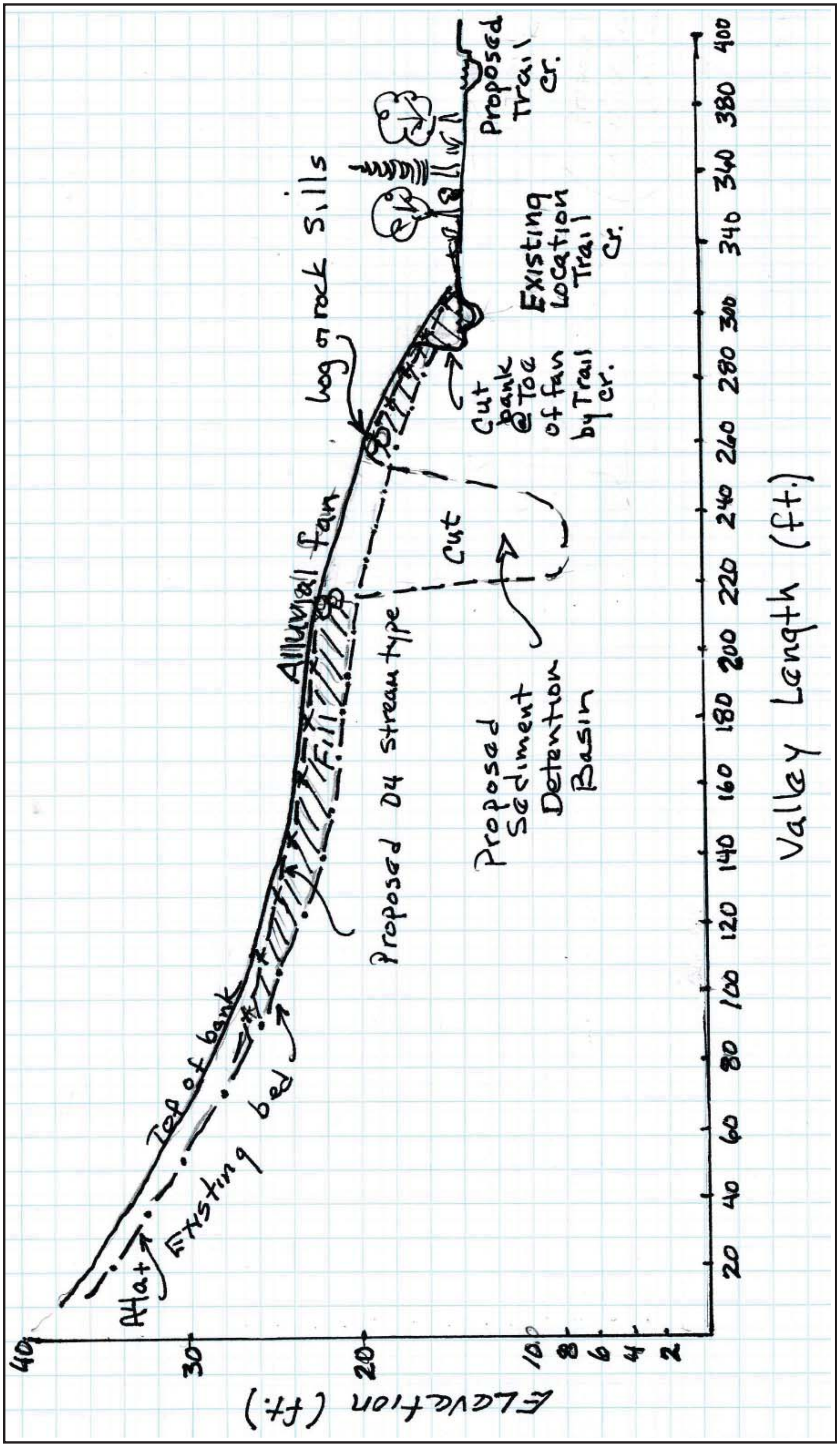

Figure 116. The slope profile of the proposed A4a+ to D4 stream type conversion, Valley Type III, with a sediment detention basin and fill of the fan toe.

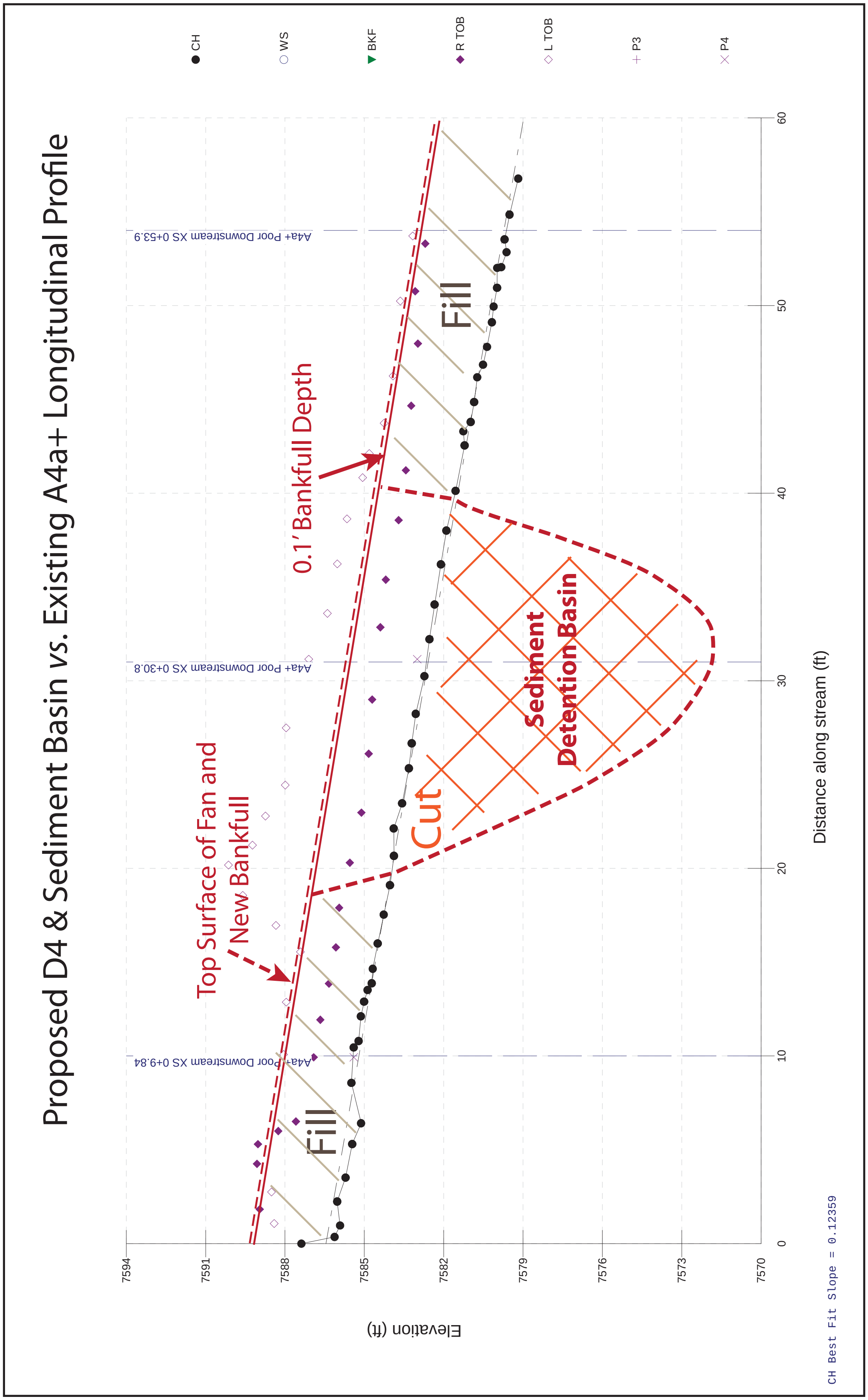

Figure 117. A localized longitudinal profile of the proposed D4 over the existing A4a+ stream type, showing the sediment detention basin.

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 16**), 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 20**). 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} (**Table 6**). 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 20. 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 of the Trail Creek 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 to Trail Creek. 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. The numerous A4a+ reaches and their associated stability conditions are mapped by sub-watershed in *Appendix D* of the Trail Creek *WARSSS* analysis (Rosgen, 2011).

Typical Design Scenario 9:
Tributary A4a+ to B4a Stream Type Conversion (VT III)

General Description & Morphological Data

This typical design scenario 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 (**Figure 118**). The reach begins at the mouth and confluence with Trail Creek and extends upstream approximately *300 ft* in reach length (**Figure 119**). 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 17**. 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 7** and the morphology and stability evaluation are documented in *Appendix C5* of the Trail Creek *WARSSS* analysis (Rosgen, 2011, pp. C5-1 to C5-32).

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 7** and the detailed characteristics and stability evaluation are documented in *Appendix B3* of the Trail Creek *WARSSS* analysis (Rosgen, 2011, pp. B3-1 to B3-36). 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 120**. The sinuosity is also much lower with steeper slopes as shown the relationship in **Figure 121**. 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 17**. 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.

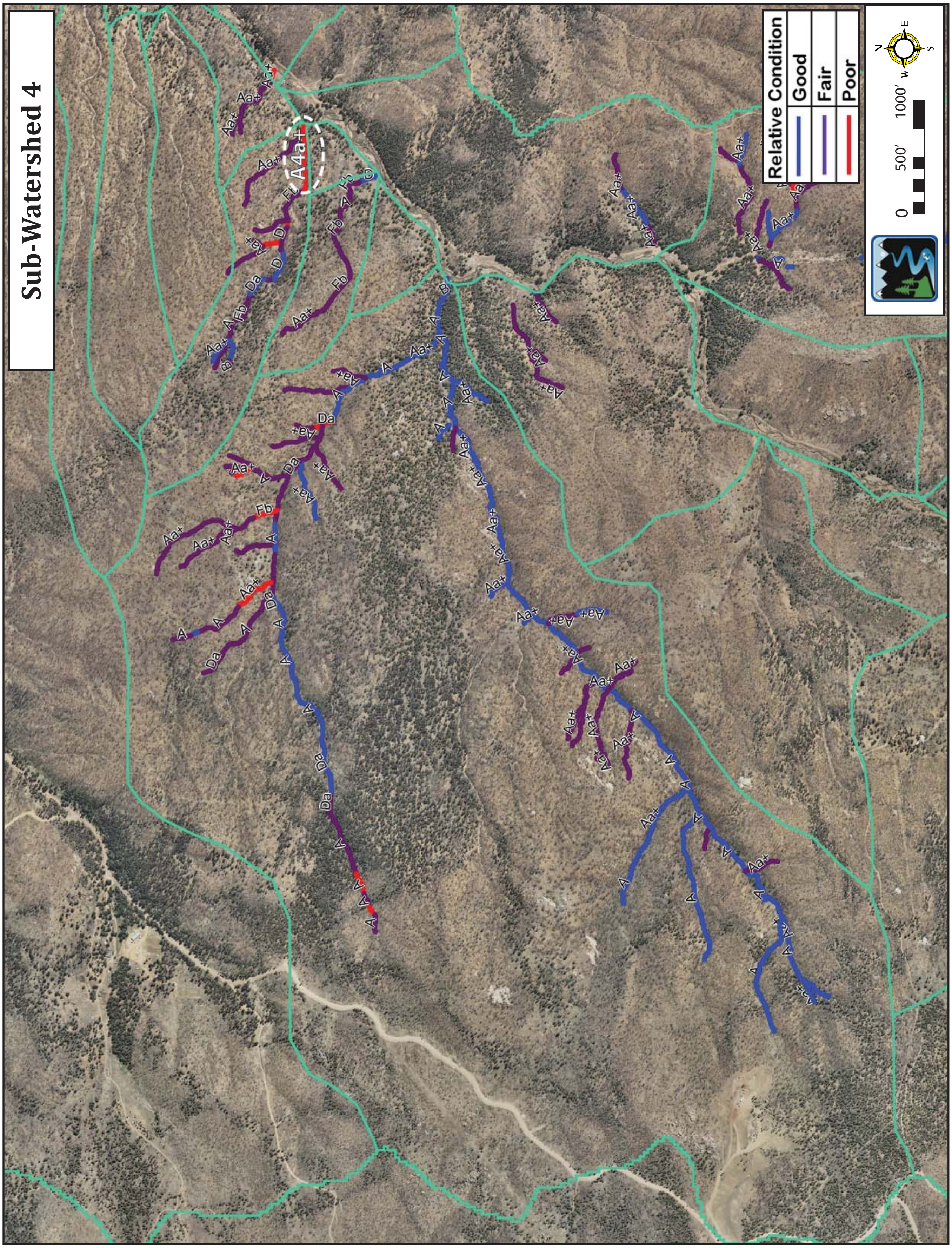

Figure 118. The location of the A4a+ *Poor* stability stream type in Sub-Watershed 4 within a short alluvial fan that is proposed to be converted to a B4a *Stable* stream type.

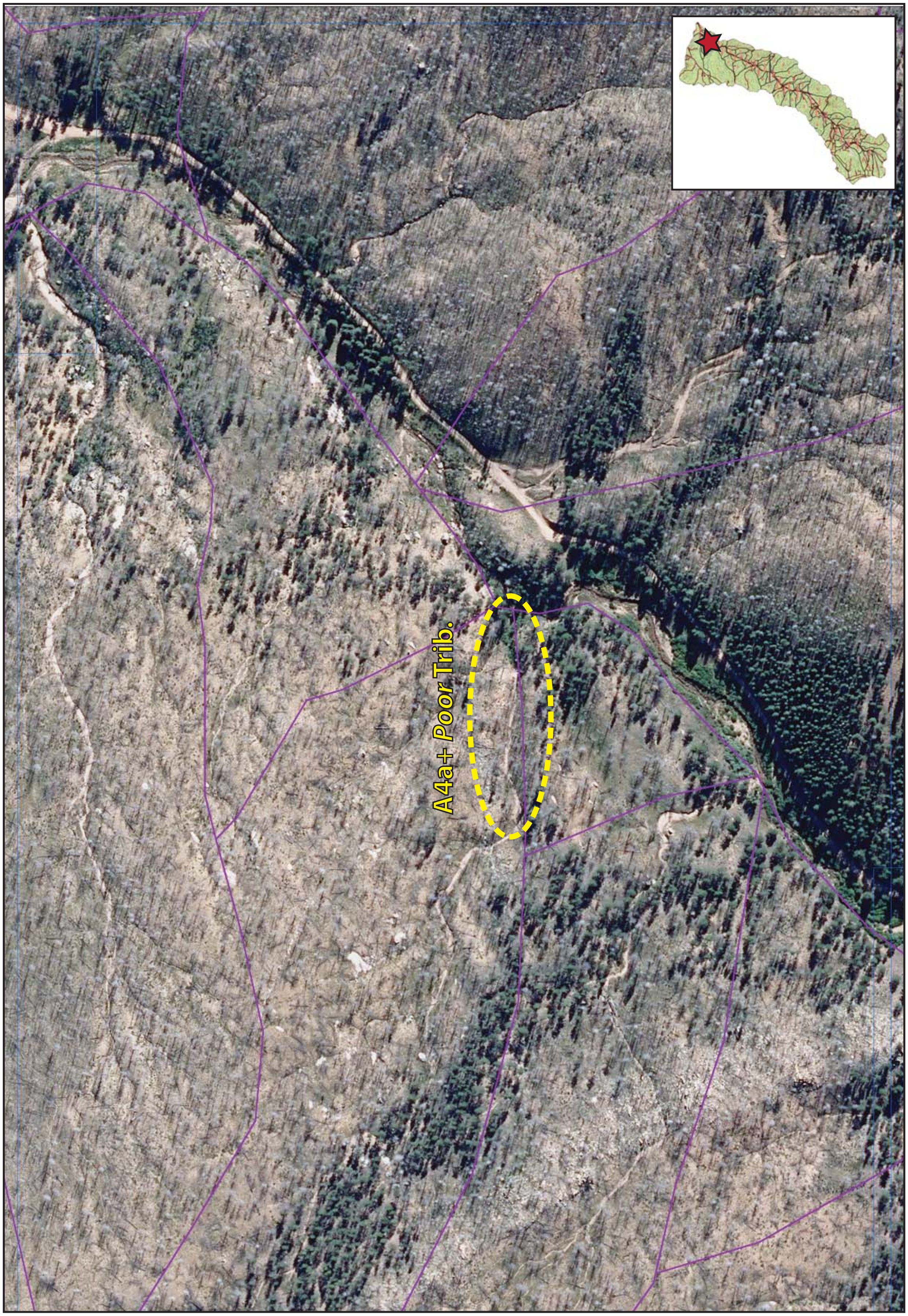

Figure 119. The A4a+ *Poor* condition tributary that is proposed to be converted to a B4a *Stable* stream type associated with a short alluvial fan in Sub-Watershed 4.

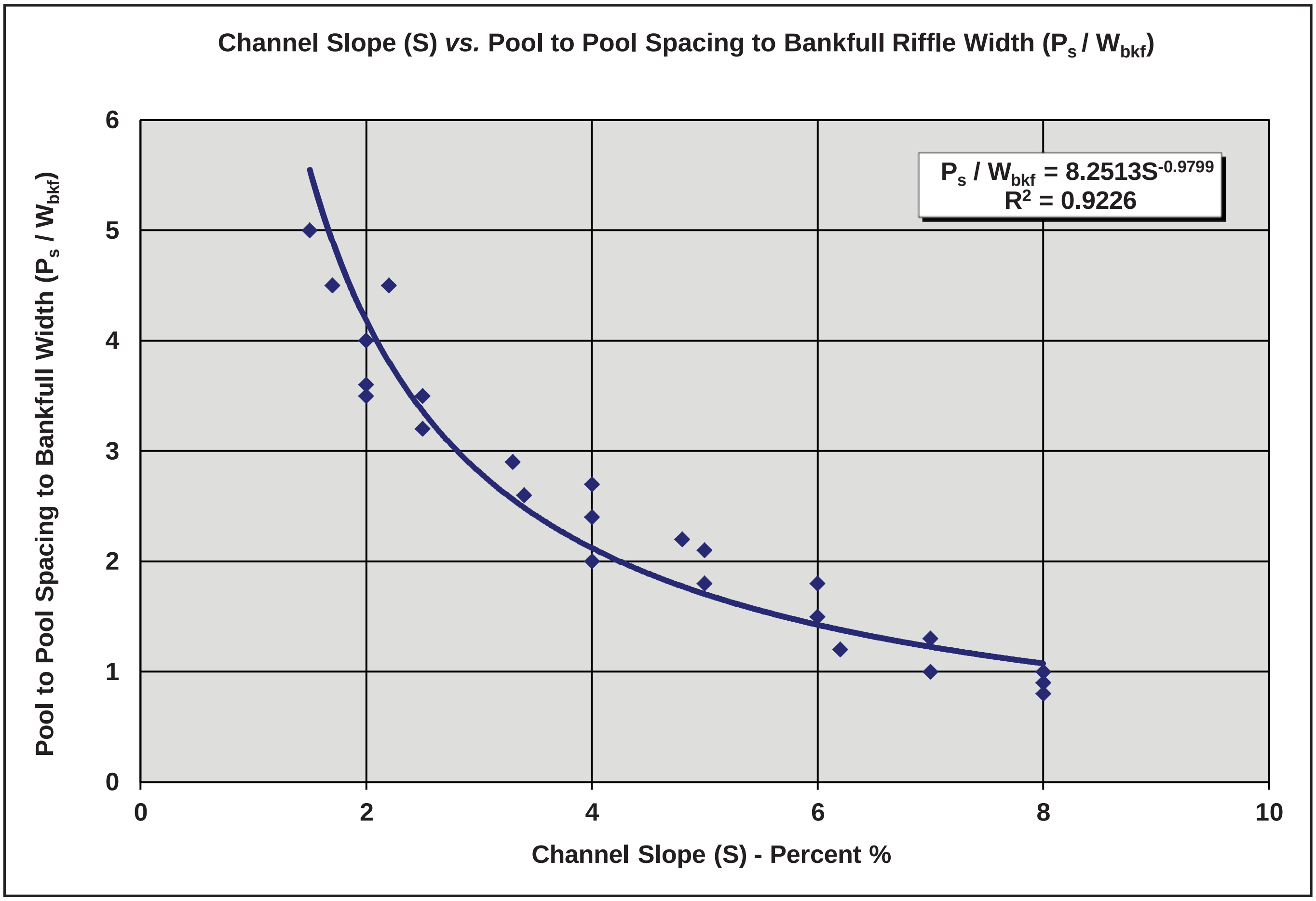

Figure 120. The ratio of pool-to-pool spacing to bankfull width as a function of channel slope.

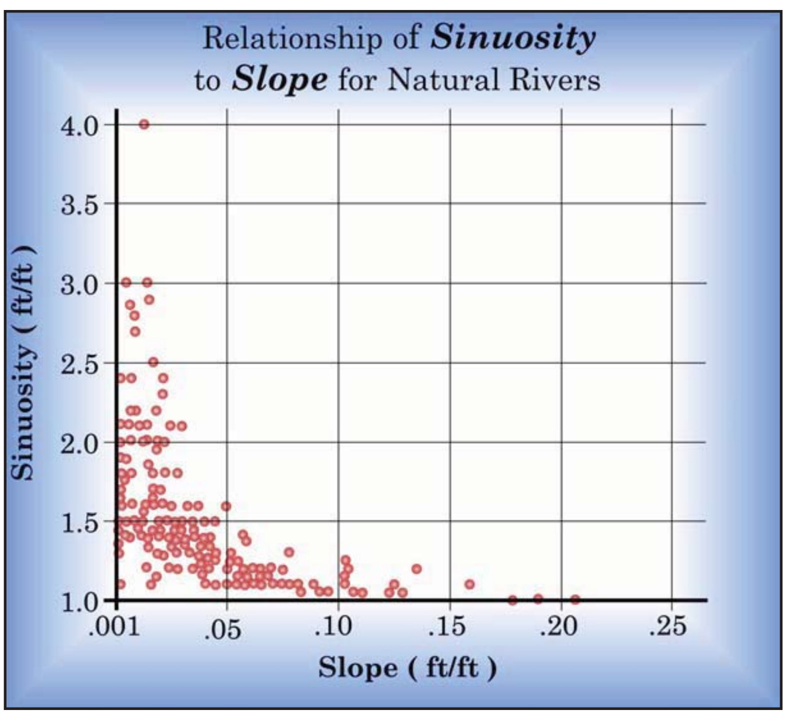

Figure 121. Relation of sinuosity to slope for natural rivers (Rosgen, 2001b).

Table 17. 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** *Min:* *Max:*	*Mean:* **2.2** *Min:* **1.7** *Max:* **2.7**	*Mean:* **5.00** *Min:* *Max:*	*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:* **0.17** *Max:* **0.24**	*Mean:* **0.41** *Min:* *Max:*	*Mean:* **0.75** *Min:* **0.74** *Max:* **0.76**
	8	Riffle Width/Depth Ratio (W_{bkf}/d_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **11.7** *Min:* **9.2** *Max:* **15.7**	*Mean:* **12.2** *Min:* *Max:*	*Mean:* **12.60** *Min:* **12.58** *Max:* **12.62**
	9	Riffle Cross-Sectional Area, ft^2 (A_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.4** *Min:* **0.3** *Max:* **0.5**	*Mean:* **2.05**	*Mean:* **7.1** *Min:* **6.9** *Max:* **7.3**
	10	Riffle Maximum Depth (d_{max})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **0.29** *Min:* **0.24** *Max:* **0.40**	*Mean:* **0.62** *Min:* *Max:*	*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:* **1.497** *Min:* **1.411** *Max:* **1.667**	*Mean:* **1.508** *Min:* *Max:*	*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:* **2.9** *Min:* **2.0** *Max:* **4.0**	*Mean:* **8.5** *Min:* **7.5** *Max:* **10.0**	*Mean:* **16.4** *Min:* **14.2** *Max:* **18.5**
	13	Entrenchment Ratio (W_{fpa}/W_{bkf})	*Mean:* **N/A** *Min:* *Max:*	*Mean:* **1.3** *Min:* **1.2** *Max:* **1.5**	*Mean:* **1.7** *Min:* **1.5** *Max:* **2.0**	*Mean:* **1.7** *Min:* **1.5** *Max:* **2.0**

Table 17 (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:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**6.0** **3.5** **9.0**	*Mean:* *Min:* *Max:*	**14.0** **8.2** **21.1**
	22	Pool Width to Riffle Width (W_{bkfp}/W_{bkf})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**1.200** **0.695** **1.792**	*Mean:* *Min:* *Max:*	**1.190** **0.695** **1.792**
	23	Pool Mean Depth, ft (d_{bkfp})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**0.52** **0.44** **0.57**	*Mean:* *Min:* *Max:*	**0.80** **0.59** **1.05**
	24	Pool Mean Depth to Riffle Mean Depth (d_{bkfp}/d_{bkf})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**1.180** **1.000** **1.400**	*Mean:* *Min:* *Max:*	**1.067** **0.787** **1.400**
	25	Pool Width/Depth Ratio (W_{bkfp}/d_{bkfp})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**11.5** **6.1** **20.4**	*Mean:* *Min:* *Max:*	**17.5** **7.8** **35.8**
	26	Pool Cross-Sectional Area, ft^2 (A_{bkfp})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**3.1** **2.4** **2.8**	*Mean:* *Min:* *Max:*	**8.9** **8.5** **9.6**
	27	Pool Area to Riffle Area (A_{bkfp}/A_{bkf})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**1.522** **1.189** **1.348**	*Mean:* *Min:* *Max:*	**1.248** **1.189** **1.348**
	28	Pool Maximum Depth (d_{maxp})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**1.00** **0.90** **1.10**	*Mean:* *Min:* *Max:*	**1.56** **1.33** **1.85**
	29	Pool Maximum Depth to Riffle Mean Depth (d_{maxp}/d_{bkf})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**2.439** **2.195** **2.683**	*Mean:* *Min:* *Max:*	**2.080** **1.773** **2.467**
	30	Point Bar Slope (S_{pb})	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**N/A**	*Mean:* *Min:* *Max:*	**0.380** **0.280** **0.400**	*Mean:* *Min:* *Max:*	**0.290** **0.220** **0.360**

Table 17 (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 17 (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.

Group	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 17 (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 17 (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**
Sediment Yield	**141** Bedload Sediment Yield (tons/yr)	180.3	33.8		146.5
Sediment Yield	**142** Suspended Sediment Yield (tons/yr)	564.1	0.7		563.4
Sediment Yield	**143** Suspended Sand Sediment Yield (tons/yr)	282.1	0.4		281.7
Sediment Yield	**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**
Bank Erosion	**145** Stream Length Assessed (ft)	300.0	58.0	300	406.0
Bank Erosion	**146** Graph/Curve Used (e.g., Yellowstone or Colorado)	Colorado	Colorado	Colorado	Colorado
Bank Erosion	**147** Streambank Erosion (tons/yr)	23.55	4.55	1.45	1.96
Bank Erosion	**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 21**.

Plan View Alignment & Cross-Section Dimensions

The proposed plan view of the alignment is shown in **Figure 122**, 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 17**). The proposed streambank stabilization structures are also shown on the plan view in **Figure 122**, in addition to the corresponding cross-section designs.

Longitudinal Profile

The typical longitudinal profile in **Figure 123** 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 17** with adjustments for pool-to-pool spacing and step and pool lengths from **Figure 120**. An existing *vs*. proposed cross-section is also illustrated in **Figure 123** 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 122** and **Figure 123**. The structures include converging rock clusters (**Figure 22**); the "Rock & Roll" log structure (**Figure 19**); the toe wood structure with sod mats and riparian transplants (**Figure 15** and **Figure 16**); and the rock step–pool structure (**Figure 20**). 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 & Roll" log 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 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): $u = 1.49 * R^{2/3} * S^{1/2} / n$ $n = 0.39 * S^{0.38} * R^{-0.16}$ $n =$ 0.206 **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	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 "**protrusion 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.

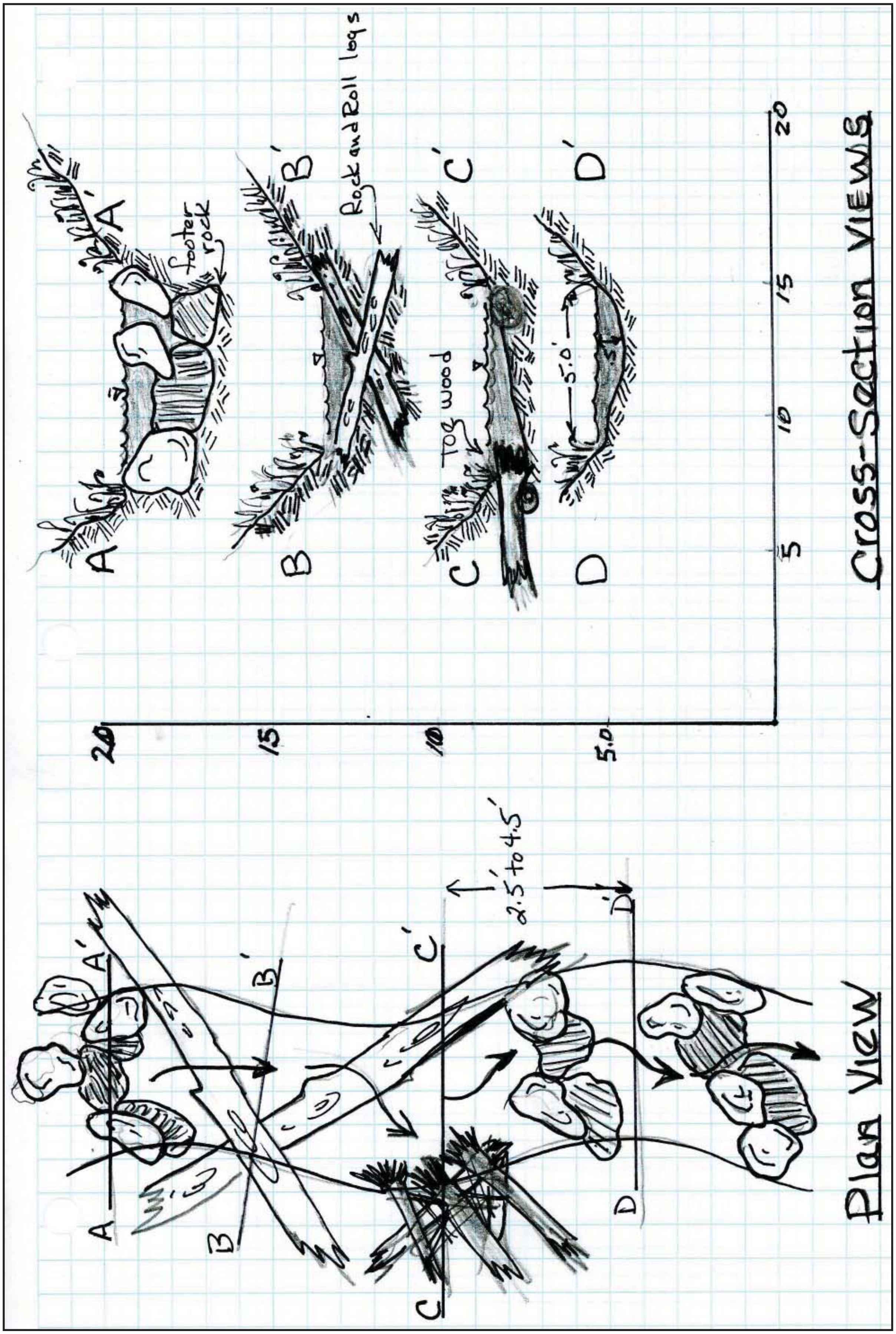

Figure 122. The proposed B4a alignment, structure placement and cross-sections converted from the A4a+ *Poor* condition tributary in Sub-Watershed 4.

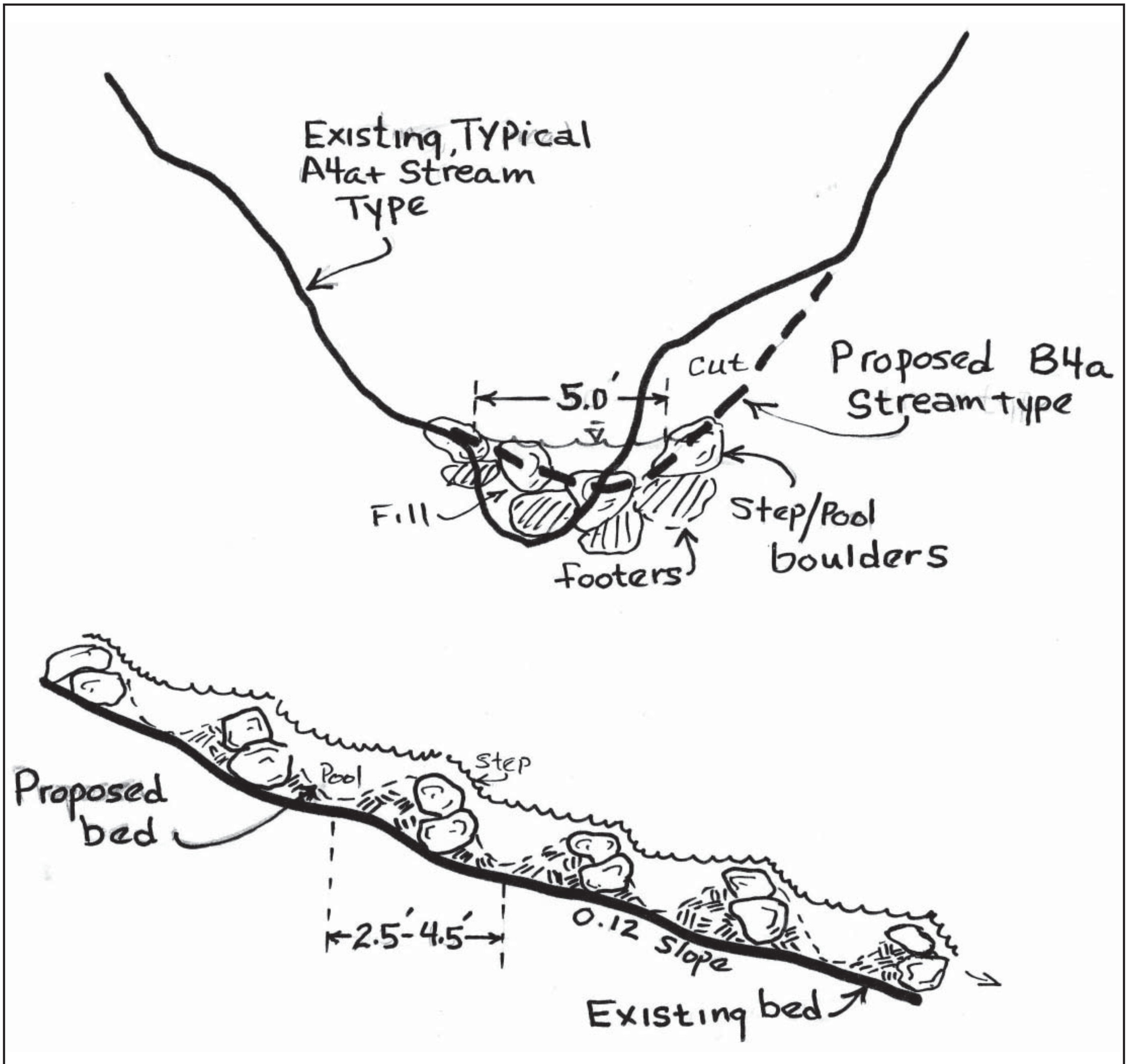

Figure 123. Typical longitudinal profile for the proposed B4a design reach to be converted from the A4a+ *Poor* condition tributary in Sub-Watershed 4.

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 17**), 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 122** and **Figure 123** are implemented, such as the toe wood and "Rock & Roll" log 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 22a**) to *34.5 tons/yr* (**Worksheet 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 (**Table 6**). 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 122** and **Figure 123**).

Worksheet 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	Dimensionless Streamflow	Dimensionless Suspended Sediment Discharge	Suspended Sediment Discharge	Dimensionless 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 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 within the Trail Creek Watershed 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 additional restoring similar reaches will help meet the Trail Creek Watershed objective of sediment reduction. The Aa+ tributaries and associated conditions are mapped by sub-watershed in *Appendix D* of the Trail Creek *WARSSS* analysis (Rosgen, 2011). The calculation of bankfull discharge and cross-sectional area using drainage area from regional curves will allow scaling of the dimensionless ratios using the reference condition B4 stream type as was done for this scenario example. The general procedure to extrapolate this design scenario to other A4a+ *Poor* stream types is included in the *Extrapolation of Typical Scenarios to other Locations* section using the scaling and Natural Channel Design procedure detailed in **Appendix I**.

Extrapolation of Typical Scenarios to other Locations

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 extracting 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 3** that lists the stream type conversion recommendations by valley type. The following discussion provides the general procedure to extrapolate the typical design scenarios and includes the recommendations for the remaining *representative reaches* and stream types and conditions within the Trail Creek Watershed that were not formally addressed with the typical design scenarios.

The reaches that rate "Good-Fair" generally have a good recovery potential without requiring direct intervention. These reaches are a low priority for restoration or stabilization as their sediment contributions are not as significant as those stream types that rate "Fair" to "Poor." The boundary conditions that may affect reach morphology must be examined for the reaches that rate "Fair" condition. Depending on the boundary conditions, these reaches may require spot stabilization of various eroding banks rather than realigning and creating a new channel. The transplants of riparian vegetation on bankfull benches are treatment scenarios that can be especially effective at accelerating the recovery of impaired streams and also reducing the corresponding streambank erosion. For example, the *B4 Fair* and *C4 Fair Representative Reaches* are recovering with vegetation-related stability but have areas with streambank erosion that led to the rating of "Fair". Rather than realign these reaches and disturb the existing riparian vegetation, spot stabilization work is recommended for the streambank erosion sites. However, if channel realignment is necessary for any condition, flexibility must be initiated in the application of dimensionless relations from the reference reach that may not be universal for a variety of boundary conditions.

The reaches that rate "Fair-Poor" or "Poor" that have similar impairments and stream types can apply the appropriate typical restoration scenario as presented. For example, the *F4b Fair-Poor Representative Reach* and the *F4b Poor Mainstem Representative Reach* are both in a confined, Valley Type VIII. It is recommended that these representative reaches are converted to B4 stream types because of the confined valley. The design plan for this stream type conversion is detailed in the previously presented F4 *Poor* to B4 stream type conversion in design scenario 2. The similar application of applying dimensionless ratios from the *B4 Reference Reach* is recommended using the procedure detailed in **Appendix I**.

The *D4a+ Poor Representative Reach*, however, is not recommended for restoration because the reach is located on an actively building alluvial fan, which is the appropriate stream type that can exist. The deposition due to the convergence/divergence bed features is a positive process as it reduces the sediment delivery efficiency to Trail Creek.

G4 *Poor* stream types in a Valley Type III have similar restoration solutions as the F4b *Poor* and A4a+ *Poor* reaches. Within short alluvial fans, the G4 *Poor* reach should be converted to B4, similar to the F4b *Poor* to B4 and A4a+ *Poor* to B4a conversions in the typical design scenarios 6 and 9. However, G4 *Poor* stream types that are cut into long and wide alluvial fans should be converted to D4, similar to the F4b *Poor* to D4 and A4a+ *Poor* to D4 conversions in the typical design scenarios 5 and 8. This conversion provides sediment storage on the fan surface and into sediment settling basins.

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 Trail Creek Watershed, advancing through the design phases will be accelerated. The dimensionless relations from the reference reach must be scaled and normalized to develop the dimensional values of the proposed reach. The drainage area, corresponding bankfull discharge and sediment supply by stability condition are necessary in the extrapolation of relations to apply the design details and principles elsewhere in the watershed. The following is the general procedure to extrapolate the typical design scenarios to locations with similar conditions:

a. Review the stream type and condition as mapped for all locations in *Appendix D* in the Trail Creek *WARSSS* analysis (Rosgen, 2011). Streams with mapped conditions of "Fair", "Fair-Poor" and "Poor" require restoration or stabilization. The "Good-Fair" streams will not require restoration as the succession scenario is trending toward a stable state and the magnitude of instability and corresponding impairment are not as severe.
b. Determine the Valley Type. If a Valley Type III, determine if the alluvial fan is short or large.
c. Determine the appropriate stream type conversion scenario (**Table 3**)
d. Determine the bankfull discharge and cross-sectional area for the proposed design reach using the regional curves (**Figure 37** and **Figure 38**) and continuity to check for reasonableness among velocity, discharge and area
e. Obtain the dimensionless ratios representing the dimension, pattern and profile from the appropriate reference reach in the stream type conversion scenario
f. 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***)
g. Select the appropriate structures for the proposed design reach
h. Layout the proposed cross-sections, pattern and profile over the existing conditions to estimate the extent of excavation and fill requirements
i. Define the riparian vegetation establishment
j. Estimate the costs of the proposed restoration and set priorities for implementation

Overall, the cumulative effects of sediment reduction and meeting restoration objectives simultaneously are the key to this master plan for a watershed-based restoration. Typical conditions by stream type and stability condition are mapped for the *178 miles* of stream channels in the Trail Creek Watershed; the typical design scenarios can be extrapolated to the various stream types and conditions at a given location with details suitable for implementation.

Additional Restoration Recommendations for Various Scenarios & Locations

Headcuts

There are numerous A4a+, A4 and G4 stream types that are actively advancing headward making the upstream reaches susceptible to accelerated sediment supply by both streambed and streambank erosion processes. The headcuts shown in **Figure 124** and **Figure 125** are typical examples of an acceleration of streambed and streambank erosion that can be effectively reduced. The methods to reduce the sediment from these systems include installing rock step–pool structures (**Figure 20**) for grade control as presented in many of the typical design scenarios. Some of the tributaries are sufficiently small enough that hand crews can perform the work. On larger systems, excavators with hydraulic thumbs are recommended. The work will greatly reduce sediment yields and minimize the adverse impacts of post-fire, flow-related sediment.

Figure 124. An actively advancing headcut adding accelerated sediment supply and potentially leading to increased enlargement from post-fire flooding.

Figure 125. An actively advancing headcut adding accelerated sediment supply and potentially leading to increased enlargement from post-fire flooding.

Accelerated Streambank Erosion Sites

Some streams are recovering with vegetation-related stability, but many reaches are still introducing excessive sediment yields from streambank erosion as depicted in **Figures 126–129**. The following design recommendations will accelerate the recovery process and reduce the sedimentation in the sites with accelerated streambank erosion:

1. Construct a bankfull bench
2. Install toe wood structures with sod mats and willow transplants (**Figure 15** and **Figure 16**)
3. Slope the upper bank and reseed to accelerate the recovery process and keep the soil intact

Figure 126. Accelerated streambank erosion on a C4 stream type on Trail Creek.

Figure 127. Accelerated streambank erosion on a C4 stream type on Trail Creek.

Figure 128. Accelerated streambank erosion on a C4 stream type on Trail Creek.

Figure 129. Accelerated streambank erosion on a C4 stream type on Trail Creek.

Road Encroachment & Streambank Road Fill Problems

The Trail Creek road in numerous locations requires an accelerated program of fill stabilization as shown in **Figure 130**. The solution to the problem in **Figure 130** is to relocate the channel so that a floodplain and bankfull bench can buffer the road fill and opposite banks. Incorporating toe wood structures with sod mats is a much cheaper solution than rip-rap bank stabilization methods; the toe wood structure has proven to be an effective bank stabilization structure.

The Trail Creek road 336 located approximately *1.2 miles* above the mouth of Trail Creek is associated with a major road erosion and sedimentation problem. Road 336, as located in **Figure 30**, is within the watercourse of a major drainage that is associated with excess road drainage and road surface gullies with significant sediment transport onto the Trail Creek road and into the mainstem Trail Creek immediately below. A ford crossing exists but is within an entrenched F4b to G4 transition stream type that promotes major road crossing problems. The road surface and fill continue to erode with associated gullies down the road into Trail Creek. The existing road and stream alignment are shown in **Figure 131**.

The recommended restoration for this site is also illustrated in **Figure 131** and described as follows:

1) Relocate the existing road 336 away from the drainage (as relocated onto a ridge route away from stream courses presented in **Figure 30**)
2) Route the Trail Creek road on the abandoned road 336 on the North side of the ford
3) Cross the drainage and place rock over the single-thread, B4 stream type for a stable ford father upstream from its present location
4) Continue the Trail Creek road at the toe of a slope until it connects with the existing road
5) Construct a braided, D4 stream type on the alluvial fan as previously described in the typical design scenario 5
6) Abandon the short section of Trail Creek road and remove the road fill and grade to the fan surface below the new ford
7) Install a sediment detention basin to provide material to fill the entrenched, ephemeral channel to create the D4 stream type and to catch the excess sediment below road 336 that presently exists
8) Convert the existing F4b and G4 stream type (gully) to a stable step–pool, B4 stream type as previously described in the typical design scenarios 2 and 3.

Overall, this proposed restoration for road 336 improves the road alignment, decreases the very steep slope of the existing Trail Creek road grade, and reduces the existing rill, gully and fill erosion causing sediment introduction directly below the road into Trail Creek.

Figure 130. Accelerated streambank erosion due to the road encroachment.

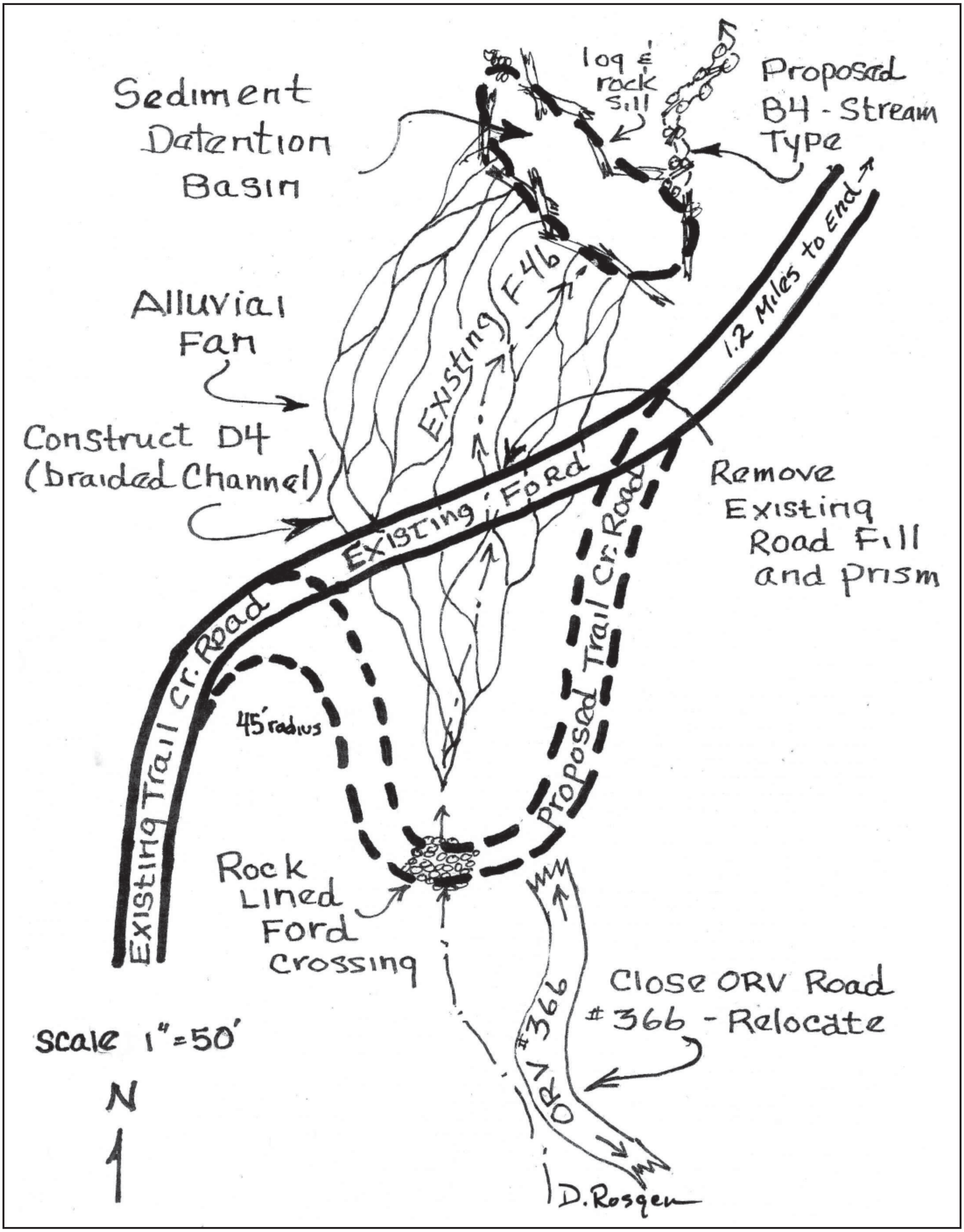

Figure 131. Road 336 relocation to prevent existing road surface and fill erosion in conjunction with converting the F4b to D4 stream type with a sediment detention basin on the alluvial fan and drained by a step–pool, B4 stream type.

Sediment Detention Basins on Alluvial Fans

Sediment detention basins are recommended for the sites with braided, D4 stream types on alluvial fans (**Figure 132**) that deliver significant sediment to Trail Creek. The material excavated for the basin can be used downstream to construct the toe of alluvial fans that have been eroded away as discussed in the following sections.

Figure 132. A braided, D4 stream type on an alluvial fan that is a prime candidate for a sediment detention basin.

Alluvial Fan Reconstruction

Many alluvial fans have been cut into and have become dysfunctional. Many can be rebuilt to help store the erosional debris from upslope. The alluvial fan depicted in **Figure 133** is evidently not functioning and can be rebuilt.

Figure 133. A dysfunctional alluvial fan that is actively eroding and can be readily restored back to naturally store sediment.

Channel Migration into Large Sediment Sources

Priorities can be set where channels are migrating into large sediment sources, such as actively eroding alluvial fans as displayed in **Figure 134**. The solution is to stabilize and relocate the channel away from such slopes. The alluvial fan in **Figure 134** is intended to naturally store sediment from upstream routing; however, the fan is now being eroded by the mainstem channel. These are localized problems that contribute a disproportionate amount of sediment that can be greatly reduced. A debris basin can be constructed in the middle of the fan with the material used to reconstruct the fan as discussed in the previous sections. Sufficient area exists for the channel in **Figure 134** to be relocated in conjunction with constructing a bankfull bench with toe wood structures.

Figure 134. An actively eroding alluvial fan that can be restored by rebuilding the fan, relocating the channel and constructing a bankfull bench with toe wood structures.

Water Quality Control

Sediment control during design implementation can be accomplished by the following measures:

1. Install a flow diversion at the mouth that naturally treats settleable sediment by routing into a wetland and constructed shallow detention basins on the Trail Creek alluvial fan at the confluence with West Creek (**Figure 46**)
2. Route water to by-pass flows where possible using in-channel berms to isolate channel construction, road fill repair and streambank stabilization
3. For road relocations, construct the new channel first, and then route water into the new channel prior to placing fill in the new road relocation
4. Implement construction during low flow periods when it is easier to reduce sediment transport
5. Install sediment detention basins as soon as possible on restoration sites associated with perennial tributaries on alluvial fans (Valley Type III) to trap any sediment generated from new channel construction

Monitoring & Maintenance Plan

Watershed and river assessments leading to restoration involve complex process interactions, making accurate predictions somewhat precarious. Measured data from monitoring that reflects specific processes will continually improve understanding and prediction of sedimentological, hydrological, morphological, and biological process relations. Another great benefit resulting from monitoring is the demonstration of the effectiveness of reduced sediment problems and improved river stability due to management or mitigation, which is the central purpose of watershed and sediment assessments and restoration. The rationale for post-restoration monitoring is to evaluate not only the criteria used, but how well the criteria met the objectives. The following types of monitoring objectives are recommended.

Implementation

Implementation monitoring determines if the design variables, structures and riparian plantings were constructed correctly. The natural variability of stream type morphological data should be used to help evaluate if the dimension, pattern and profile was implemented within the range that matches the natural variability as documented within the dimensionless ratios of the reference reach data. The structures must be evaluated for the design criteria actually installed (e.g., slopes, angles, footer placement and rock sizes). Riparian vegetation success is often evaluated by selected planting methods, species and age classes where appropriate.

Effectiveness

Effectiveness monitoring evaluates if the intended objectives of the restoration were met. Monitoring will also determine if post-runoff channel adjustments following restoration fall within the range of natural variability for dimension, pattern and profile data.

Validation

Validation monitoring evaluates if the predictions match the post-restoration response. This monitoring is directed at the response of post runoff, such as streambank erosion reduction and bed stability *vs*. the predicted response.

Physical & Biological Monitoring

Physical monitoring involves resurveys of cross-sections and longitudinal profiles. Permanent monitoring sites must be established to check both post-restoration construction (implementation) *vs*. post-runoff response (effectiveness). Bank pins and scour chains assist in validating pre- *vs*. post-runoff bank erosion rates and particle entrainment. All of the physical monitoring methods and examples are included in *WARSSS* (Rosgen, 2006/2009).

The biological monitoring should include pre- and post-restoration population estimates and macro-invertebrate inventories. Vegetative mortality and survival plots will establish post-restoration success response.

Maintenance Plan

A maintenance plan is necessary to ensure that the implemented design is successful. The maintenance plan for the Trail Creek Watershed includes the following:

- Survival of the riparian vegetation reestablishment—replanting or seeding may be necessary.
- Structure stability—Post-runoff inspections must be conducted of structures for grade control, bank stabilization and/or fish habitat enhancement. Maintenance needs are assessed and implemented to prevent future failures and to secure proper function.
- The dimension, pattern, and profile of the design reaches must stay within the natural variability or range as depicted in the summary tables within each typical design scenario. Maintenance of these variables is recommended only if the values exceed the design channel ranges.
- Biological maintenance may be necessary to reestablish populations of various age classes or species of fish and food sources.

Overall, monitoring is essential to evaluate if the natural channel design methods, if correctly implemented, meet the stated objectives. Monitoring will also direct any necessary modifications or improvements for future work. It is also important to validate the models used for assessment leading to the design to ensure that predictions are correct in relation to observations.

Summary of Sediment Reductions with the Master Plan

Hillslope Processes

Surface Erosion

Implementing the recommended practices for surface erosion prevention would potentially reduce the sediment introduction from this erosional process by approximately *1,270 tons/yr*. These beneficial recommendations include increasing the ground cover to over *65%* in riparian areas and constructing stable, bankfull bench "catches".

Trail Creek Road

The proposed rerouting of Trail Creek at three locations (**Figures 24–28** and **Figure 131**) associated with eliminating six 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 potentially reduce the sediment yields by approximately *413 tons/yr*.

ORV Roads & Trails

The proposed restoration and rerouting of the existing ORV roads and trails (**Figures 30–32**) would potentially reduce the annual sediment yield by *200 tons/yr*. 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 the new ridge route locations for the roads and trails.

Channel Processes

The sediment reduction potential by implementing the proposed stream restoration design scenarios involving *3,025 ft* of stream channel is approximately *1,600 tons/yr* for 7 of the 9 scenarios (**Table 6**). The remaining two scenarios that convert A4a+ and F4b stream types to D4 stream types with sediment detention basins are related to substantial sediment savings as they would store sediment on alluvial fans and in sediment detention basins rather than route the sediment directly to Trail Creek; the reductions are approximately *1,101 tons/yr* of bedload, *4,367 tons/yr* of suspended sediment and *5,468 tons/yr* of total sediment. In total, over *7,000 tons/yr* of sediment could be kept out of Trail Creek per year based on the implementation of the nine scenarios presented. This represents approximately *29%* of the total annual sediment yield in the Trail Creek Watershed. This reduction involves only channel source sediment and not the hillslope processes. The sediment reductions, however, require implementation of both hillslope and channel process restoration, particularly in Sub-Watershed 6 as the storage capacity of the basins and fans of that drainage could soon be exceeded as previously discussed.

Total Potential Sediment Reductions

The potential sediment reductions associated with implementing the nine typical design scenarios and the recommendations for hillslope processes are presented in **Table 18**. The total potential reduction is approximately *8,853 tons/yr*, representing approximately *37%* of the total annual sediment yield.

Table 18. The potential sediment reductions by implementing the recommendations for hillslope and channel processes.

Total Sediment Contribution Reductions	
Hillslope Processes	
Surface Erosion	*1,270 tons/yr*
Trail Creek Road	*413 tons/yr*
ORV Roads & Trails	*200 tons/yr*
Channel Processes	
The Nine Typical Design Scenarios	*7,000 tons/yr*
Total Potential Reduction	***8,853 tons/yr***

Implementation Sequencing

The sub-watershed priorities for restoration in **Table 2** are used as a general guide for the sequencing of the design implementation. The highest priorities are associated with the highest accelerated sediment supply. Restoring Trail Creek first from the mouth and extending upstream one mile is recommended. The lower Trail Creek restoration will improve fish migration, reduce sediment supply and realign Trail Creek away from the alluvial fans. This realignment will allow the design of D4 stream types of selected high risk tributaries that can utilize the full dimensions of their alluvial fans. The proposed work on the roads, sub-watersheds and trail relocations can all proceed concurrently with the main channel restoration. Beyond the lower mainstem Trail Creek design being implemented first, the remaining priorities for restoration can be implemented in any order.

Discussion & Summary

The Trail Creek Watershed master plan for stream restoration and sediment reduction is the result of a detailed watershed assessment that has directed the proposed restoration to impaired streams. The assessment has also identified the source of impairment including hillslope, 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.

Each of the 17 specific, multiple objectives for this master restoration design for the Trail Creek Watershed are potentially met with the implementation of the various scenarios and locations proposed. The monitoring plan will validate if these objectives were indeed met. Overall, the various restoration scenarios within the Trail Creek watershed 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 2011 to implement these typical designs and to initiate a monitoring plan to provide a demonstration of the methods and associated effectiveness of meeting the stated goals of restoration

These subsequent designs are intended to accelerate the recovery of the Trail Creek Watershed from the adverse impacts of the Hayman fire. The proposed design scenarios and subsequent implementation will potentially direct the future of watershed restoration following large wildfires. The procedures can also be used for other watersheds that are currently impaired due to the Hayman fire in the South Platte Basin. 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 additional understanding of the benefits of restoration in relation to accelerating watershed recovery.

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The Natural Channel Design Procedure

The Trail Creek Watershed master plan for stream restoration and sediment reduction is based on the Natural Channel Design (NCD) methodology as depicted in *Flowchart 1* in the main report (Rosgen, 2007). 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 Trail Creek *WARSSS* analysis report (Rosgen, 2011). 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 VII–X are addressed in the main report, including the stabilization and enhancement structures, the final designs for the typical scenarios, design implementation and the monitoring and maintenance plans.

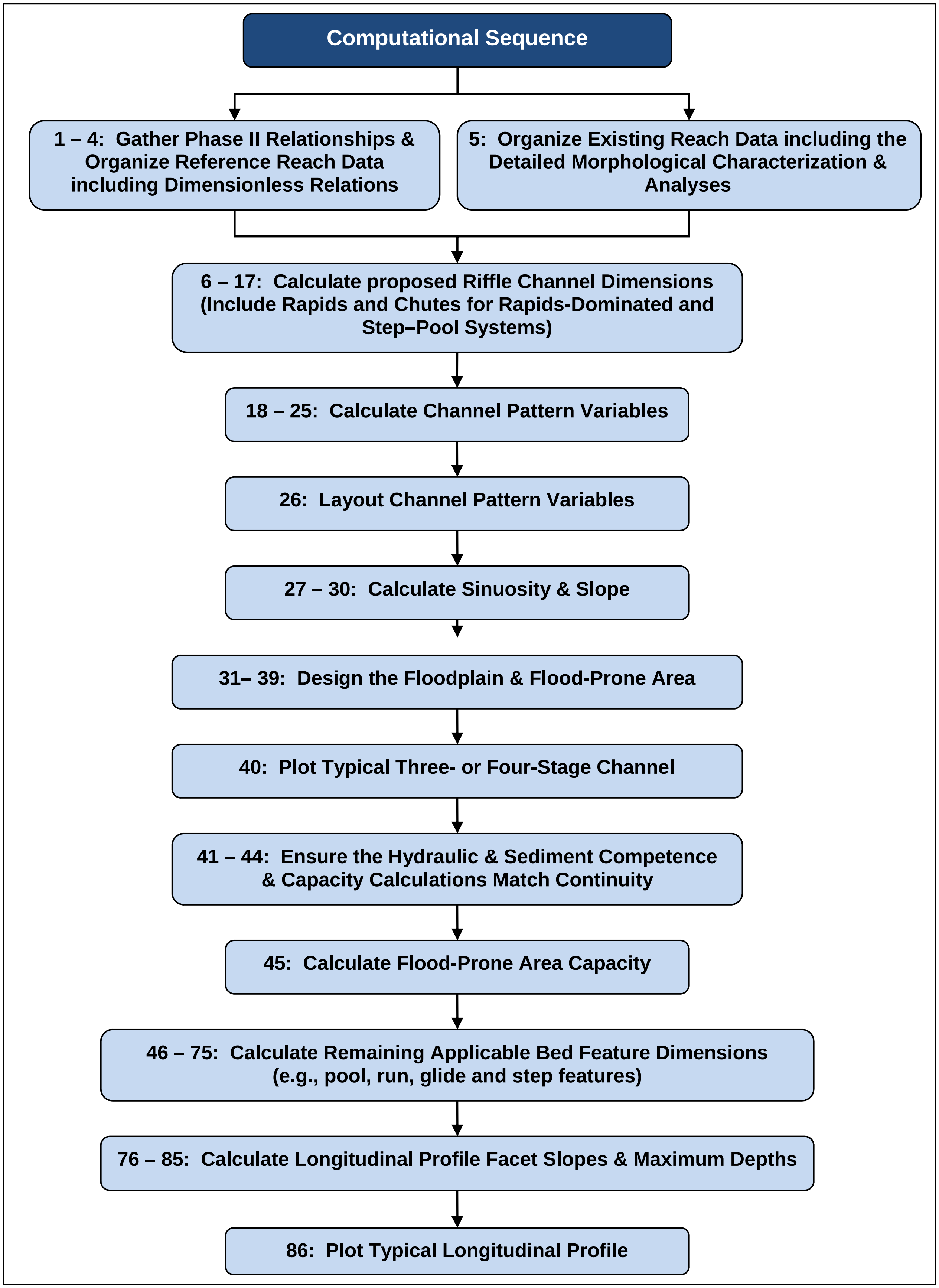
Phase VI — Develop & Evaluate the Preliminary Natural Channel Design

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 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. A key to the development of this design phase is the reference reach data that represents similar potential controlling variables (boundary conditions), including valley type, riparian vegetation and sediment and flow regime. The early sequence calculates the required variables to initially test whether the hydraulic and sediment relations associated with the existing condition 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 for the flexibility in design necessary as boundary conditions and constraints often change or are discovered at this phase. For example, if the valley width was constrained and the entrenchment ratio ranged from *3–5*, using the minimum width/depth ratio value with 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. Adjustments in the dimensionless relations are often required, as a variation in ratios occur in natural laterally constrained river valleys that still exhibit natural stability. If the valley slope was relatively steep associated with a coarse, high bedload sediment supply regime, a large radius of curvature to width ratio would be observed along with and an arc length ratio of *3–4* widths forming a compound pool; these relations need to be reflected in the design. In this case, 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 basic reference reach data ranges and pattern relations will help in determining which combination of values (*mean*, *minimum* or *maximum*) to select.

Computational Sequence

The computational sequence outlined in **Flowchart 1** determines and evaluates the dimension, pattern and profile variables for the preliminary natural channel design. All morphological characteristics are recorded in **Table 1** for the *existing*, *proposed design* and *reference reaches*. References to specific entry items in **Table 1** are included throughout the sequence to locate where to record the proposed design reach variables. A detailed discussion of each procedural sequence follows **Flowchart 1** and **Table 1**.



Flowchart 1. Computational sequence to determine and evaluate the dimension, pattern & profile variables for the preliminary natural channel design.

Table 1. 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			
	2	Valley Width			
	3	Stream Type			
	4	Drainage Area, mi^2			
	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 1. 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 1. 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 ($W_{bkf\,r}$)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	39	Run Width to Riffle Width ($W_{bkf\,r}/W_{bkf}$)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	40	Run Mean Depth, ft ($d_{bkf\,r}$)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	41	Run Mean Depth to Riffle Mean Depth ($d_{bkf\,r}/d_{bkf}$)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	42	Run Width/Depth Ratio ($W_{bkf\,r}/d_{bkf\,r}$)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	43	Run Cross-Sectional Area, ft^2 ($A_{bkf\,r}$)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	44	Run Area to Riffle Area ($A_{bkf\,r}/A_{bkf}$)	*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 ($W_{bkf\,g}$)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	48	Glide Width to Riffle Width ($W_{bkf\,g}/W_{bkf}$)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	49	Glide Mean Depth, ft ($d_{bkf\,g}$)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	50	Glide Mean Depth to Riffle Mean Depth ($d_{bkf\,g}/d_{bkf}$)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	51	Glide Width/Depth Ratio ($W_{bkf\,g}/d_{bkf\,g}$)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	52	Glide Cross-Sectional Area, ft^2 ($A_{bkf\,g}$)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	53	Glide Area to Riffle Area ($A_{bkf\,g}/A_{bkf}$)	*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 1. 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 1. 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 1. 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)		$S = S_{val}/k$	
Flood-Prone Area Dim.	**93**	Flood-Prone Area Width, ft (W_{fpa})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	94	Flood-Prone Area Mean Depth, ft (d_{fpa})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	95	Flood-Prone Area Cross-Sectional Area, ft^2 (A_{fpa})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
Floodplain Dimensions	**96**	Floodplain Width, ft (W_f)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	97	Floodplain Mean Depth, ft (d_f)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	98	Floodplain Cross-Sectional Area, ft^2 (A_f)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
Low Terrace Dim.	**99**	Low Terrace Width, ft (W_{lt})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	100	Low Terrace Mean Depth, ft (d_{lt})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	101	Low Terrace Cross-Sectional Area, ft^2 (A_{lt})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
Degree of Incision	**102**	Low Bank Height (LBH)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	103	Maximum Bankfull Depth (d_{max}) at Same Location as Low Bank Height (LBH) Measurement	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	104	Bank-Height Ratio (LBH/d_{max})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*

Table 1. Morphological characteristics of the existing, proposed design & reference reaches. Page 7/10

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:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	106	Riffle Slope to Average Water Surface Slope (S_{rif}/S)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	107	Pool Slope (water surface facet slope) (S_p)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	108	Pool Slope to Average Water Surface Slope (S_p/S)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	109	Run Slope (water surface facet slope) (S_{run})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	110	Run Slope to Average Water Surface Slope (S_{run}/S)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	111	Glide Slope (water surface facet slope) (S_g)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	112	Glide Slope to Average Water Surface Slope (S_g/S)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	113	Step Slope (water surface facet slope) (S_s)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	114	Step Slope to Average Water Surface Slope (S_s/S)	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*

Table 1. Morphological characteristics of the existing, proposed design & reference reaches. Page 8/10

	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:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	116 Riffle Maximum Depth to Riffle Mean Depth (d_{max}/d_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	117 Pool Maximum Depth, ft (d_{maxp})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	118 Pool Maximum Depth to Riffle Mean Depth (d_{maxp}/d_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	119 Run Maximum Depth, ft (d_{maxr})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	120 Run Maximum Depth to Riffle Mean Depth (d_{maxr}/d_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	121 Glide Maximum Depth, ft (d_{maxg})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	122 Glide Maximum Depth to Riffle Mean Depth (d_{maxg}/d_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	123 Step Maximum Depth, ft (d_{maxs})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
	124 Step Maximum Depth to Riffle Mean Depth (d_{maxs}/d_{bkf})	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*	*Mean:* *Min:* *Max:*
Channel Materials	**125 Particle Size Distribution of Channel Material (Active Bed) or Pavement**			
	D_{16} (mm)			
	D_{35} (mm)			
	D_{50} (mm)			
	D_{84} (mm)			
	D_{95} (mm)			
	D_{100} (mm)			
	126 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}: Largest size particle at the toe (lower third) of bar (mm) or sub-pavement			

Table 1. Morphological characteristics of the existing, proposed design & reference reaches. Page 9/10

Entry Number & Variable			Existing Reach	Proposed Design Reach	Reference Reach
Hydraulics	127	Estimated Bankfull Mean Velocity, ft/sec (u_{bkf})			
Hydraulics	128	Estimated Bankfull Discharge, cfs (Q_{bkf}); Compare with Regional Curve			
Sediment Competence	129	Calculated bankfull shear stress value, lbs/ft^2 (τ)			
Sediment Competence	130	Predicted largest moveable particle size (mm) at bankfull shear stress, τ, using the original **Shields** relation			
Sediment Competence	131	Predicted largest moveable particle size (mm) at bankfull shear stress, τ, using the **Colorado** relation			
Sediment Competence	132	Largest particle size to be moved (D_{max}) (mm) (see #126: Particle Size Distribution of Bar Material)			
Sediment Competence	133	Predicted shear stress required to initiate movement of D_{max} (mm) using the original **Shields** relation			
Sediment Competence	134	Predicted shear stress required to initiate movement of D_{max} (mm) using the **Colorado** relation			
Sediment Competence	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**)			
Sediment Competence	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**)			
Sediment Competence	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**)			
Sediment Competence	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**)			
Sediment Competence	139	Bankfull dimensionless shear stress (τ^*) (see competence form)			
Sediment Competence	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)			
Sediment Competence	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)			

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

	Sediment Yield (FLOWSED)	**Existing Reach**	**Proposed Design Reach**	**Difference in Sediment Yield**
Sediment Yield	**141** Bedload Sediment Yield (tons/yr)			
	142 Suspended Sediment Yield (tons/yr)			
	143 Suspended Sand Sediment Yield (tons/yr)			
	144 Total Annual Sediment Yield (tons/yr)			
	Streambank Erosion	**Existing Reach**	**Proposed Design Reach**	**Reference Reach**
Bank Erosion	**145** Stream Length Assessed (ft)			
	146 Graph/Curve Used (e.g., Yellowstone or Colorado)			
	147 Streambank Erosion (tons/yr)			
	148 Streambank Erosion (tons/yr/ft)			

Computational Sequence 1 – 4: Gather Phase II Relationships & Reference Reach Data

1 — Obtain & Verify Regional Curves

Obtain and verify regional curves of bankfull dimensions and bankfull discharge versus drainage area as developed in Phase II (**Figure 37** and **Figure 38**). The regional curves must be located in the same hydro-physiographic province as that of the existing or proposed design reach. The regional curves are used to determine bankfull discharge and cross-sectional area of the proposed design reach. Regional curves of cross-sectional area versus 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 (reflecting the variation in width/depth ratio).

2 — Obtain Dimensionless Flow-Duration Curves

Obtain the dimensionless flow-duration curves created or acquired in Phase II. This curve is derived from gage site data that represents a similar hydro-physiographic province as the restoration site. A dimensional flow-duration curve is obtained at the gage site and is made dimensionless by dividing all flow values by the mean daily bankfull discharge at the gage site.

Post-fire flow-duration curves were developed from a water yield model that utilized the Goose Creek gage station data as presented in the Trail Creek *WARSSS* analysis (Rosgen, 2011). The flow-duration curves are used in the FLOWSED model to predict the sediment yields for the existing *vs*. proposed reaches as discussed in the typical design scenarios.

3 — Obtain Sediment Relations

The sediment transport capacity of the proposed design reach must be checked using the FLOWSED and POWERSED models, which require measured bankfull stage bedload, suspended and suspended sand concentrations. Regional sediment relations of bankfull bedload and suspended sediment were developed as a function of drainage area for the Trail Creek Watershed as presented in the Trail Creek *WARSSS* analysis (Rosgen, 2011). These regional bankfull sediment curves are delineated by major geologic province and stream stability rating by stream type inferring sediment supply.

4 — Obtain & Organize the Reference Reach Data

Obtain the reference reach data collected in Phase II and in the Trail Creek *WARSSS* analysis (Rosgen, 2011). Be certain to stratify the reference reach by a similar valley type, flow regime, sediment regime, bank type and riparian vegetation type to match boundary conditions that are associated with the controlling variables as the proposed design reach. Complete the *Reference Reach* Column in **Table 1** to organize all morphological characteristics and analyses. The reference reach data represents the dimensionless ratios used to generate design values; thus the dimension, pattern and profile data is critical to be representative of a stable reach.

Computational Sequence 5: Obtain & Organize Existing Reach Data

5 — Obtain & Organize the Existing Reach Data

Complete the *Existing Reach* Column in **Table 1** to organize all morphological characteristics and analyses. Stability assessments conducted on representative reaches can be extrapolated to locations without the detailed assessments given that the stream and valley types are similar. Regardless, basic data is required for existing locations, including the valley slope and boundary conditions.

Computational Sequence 6 – 18: Calculate Riffle Channel Dimensions

6 — Obtain the Drainage Area

Obtain the drainage area (mi^2) for the proposed design reach (Record in **Table 1**, Entry 4).

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

Obtain the bankfull discharge (Q_{bkf}) for the proposed design reach using the determined drainage area and the obtained regional curves (Record in **Table 1**, Entry 5). Determine the corresponding cross-sectional area (A_{bkf}) using the regional curves and checking for reasonabless of the variables using continuity (Record in **Table 1**, Entry 9). **Note:** The cross-sectional area is recorded as the "*mean*" value in Entry 9 and this value is used in remaining computations that involve riffle area. Cross-sectional area can be calculated from continuity ($A_{bkf} = Q_{bkf} / u_{bkf}$) by knowing bankfull discharge and either knowing or estimating the bankfull mean velocity (u_{bkf}). Be sure to check the reasonableness of the mean velocity; generally the bankfull velocity is between *3–5 ft/sec* with an average of *4 ft/sec* for the majority of stream types. The bankfull mean velocity of the proposed design reach will be checked with resistance and roughness relations later in the sequence after riffle channel dimensions and average water surface slope are calculated.

8 — 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 1**, Entry 6):

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

where:

$(W_{bkf} / d_{bkf})_{ref}$ = *mean* reference reach bankfull riffle width/depth ratio

A_{bkf} = *mean* bankfull riffle cross-sectional area of the proposed design reach

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

where:

$(W_{bkf} / d_{bkf})_{ref}$ = *minimum* reference reach bankfull riffle width/depth ratio

A_{bkf} = *mean* bankfull riffle cross-sectional area of the proposed design reach

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

where:

$(W_{bkf} / d_{bkf})_{ref}$ = *maximum* reference reach bankfull riffle width/depth ratio

A_{bkf} = *mean* bankfull riffle cross-sectional area of the proposed design reach

The mean value of the riffle width will be used to convert dimensionless relations that follow. However, the reason for the range in riffle width computations is to provide the designer with some options that occur in nature and to provide an understanding of the range of bankfull riffle widths to be used for monitoring and maintenance criteria. The channel width adjustment following runoff should stay within the range of widths based on natural, stable stream types.

9 — 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 1**, Entry 7):

Mean $d_{bkf} = A_{bkf} / W_{bkf}$ **Equation 4**

where:

A_{bkf} = *mean* bankfull riffle cross-sectional area of the proposed design reach

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

or

Mean $d_{bkf} = W_{bkf} / (W_{bkf} / d_{bkf})_{ref}$ **Equation 5**

where:

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

$(W_{bkf} / d_{bkf})_{ref}$ = *mean* reference reach bankfull riffle width/depth ratio

Minimum $d_{bkf} = A_{bkf} / W_{bkf}$ **Equation 6**

where:

A_{bkf} = *mean* bankfull riffle cross-sectional area of the proposed design reach

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

or

Minimum $d_{bkf} = W_{bkf} / (W_{bkf} / d_{bkf})_{ref}$ **Equation 7**

where:

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

$(W_{bkf} / d_{bkf})_{ref}$ = *maximum* reference reach bankfull riffle width/depth ratio

Maximum $d_{bkf} = A_{bkf} / W_{bkf}$ **Equation 8**

where:

A_{bkf} = *mean* bankfull riffle cross-sectional area of the proposed design reach

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

or

Maximum $d_{bkf} = W_{bkf} / (W_{bkf} / d_{bkf})_{ref}$ **Equation 9**

where:

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

$(W_{bkf} / d_{bkf})_{ref}$ = *minimum* reference reach bankfull riffle width/depth ratio

10 — Calculate Bankfull Riffle Width/Depth Ratio (W_{bkf}/d_{bkf})

Calculate the bankfull riffle width/depth ratio (W_{bkf}/d_{bkf}) for the proposed design reach for the *mean*, *minimum* and *maximum* values (Record in **Table 1**, Entry 8).

Mean $W_{bkf}/d_{bkf} = W_{bkf} / d_{bkf}$ **Equation 10**

where:

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

d_{bkf} = *mean* bankfull riffle mean depth of the proposed design reach

Minimum $W_{bkf}/d_{bkf} = W_{bkf} / d_{bkf}$ **Equation 11**

where:

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

d_{bkf} = *maximum* bankfull riffle mean depth of the proposed design reach

Maximum $W_{bkf}/d_{bkf} = W_{bkf} / d_{bkf}$ **Equation 12**

where:

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

d_{bkf} = *minimum* bankfull riffle mean depth of the proposed design reach

11 — 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 1**, Entry 10):

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

where:

$(d_{max} / d_{bkf})_{ref}$ = *mean* reference reach bankfull riffle maximum depth to bankfull riffle mean depth

d_{bkf} = *mean* bankfull riffle mean depth of the proposed design channel

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

where:

$(d_{max} / d_{bkf})_{ref}$ = *minimum* reference reach bankfull riffle maximum depth to bankfull riffle mean depth

d_{bkf} = *mean* bankfull riffle mean depth of the proposed design channel

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

where:

$(d_{max} / d_{bkf})_{ref}$ = *maximum* reference reach bankfull riffle maximum depth to bankfull riffle mean depth

d_{bkf} = *mean* bankfull riffle mean depth of the proposed design channel

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

The inner berm (Stage 1 of the multi-stage channel design often associated with mean annual discharge and a flow *30–40%* of the bankfull channel) 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 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.

12 — 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 1**, Entry 14):

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

where:

$(W_{ib} / W_{bkf})_{ref}$ = *mean* reference reach riffle inner berm width to bankfull riffle width

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

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

where:

$(W_{ib} / W_{bkf})_{ref}$ = *minimum* reference reach riffle inner berm width to bankfull riffle width

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

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

where:

$(W_{ib} / W_{bkf})_{ref}$ = *maximum* reference reach riffle inner berm width to bankfull riffle width

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

13 — 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 1**, Entry 16):

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

where:

$(d_{ib} / d_{bkf})_{ref}$ = *mean* reference reach riffle inner berm mean depth to bankfull riffle mean depth

d_{bkf} = *mean* bankfull riffle mean depth of the proposed design reach

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

where:

$(d_{ib} / d_{bkf})_{ref}$ = *minimum* reference reach riffle inner berm mean depth to bankfull riffle mean depth

d_{bkf} = *mean* bankfull riffle mean depth of the proposed design reach

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

where:

$(d_{ib} / d_{bkf})_{ref}$ = *maximum* reference reach riffle inner berm mean depth to bankfull riffle mean depth

d_{bkf} = *mean* bankfull riffle mean depth of the proposed design reach

14 — 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 1**, Entry 20):

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

where:

$(A_{ib} / A_{bkf})_{ref}$ = *mean* reference reach riffle inner berm cross-sectional area to bankfull riffle cross-sectional area

A_{bkf} = *mean* bankfull riffle cross-sectional area of the proposed design reach

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

where:

$(A_{ib} / A_{bkf})_{ref}$ = *minimum* reference reach riffle inner berm cross-sectional area to bankfull riffle cross-sectional area

A_{bkf} = *mean* bankfull riffle cross-sectional area of the proposed design reach

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

where:

$(A_{ib} / A_{bkf})_{ref}$ = *maximum* reference reach riffle inner berm cross-sectional area to bankfull riffle cross-sectional area

A_{bkf} = *mean* bankfull riffle cross-sectional area of the proposed design reach

15 — Calculate Riffle Inner Berm Width/Depth Ratio (W_{ib}/d_{ib})

Calculate the riffle inner berm width/depth ratio (W_{ib}/d_{ib}) for the *mean*, *minimum* and *maximum* values (Record in **Table 1**, Entry 18):

$Mean\ W_{ib}/d_{ib} = W_{ib} / d_{ib}$ **Equation 25**

where:

W_{ib} = *mean* riffle inner berm width of the proposed design reach

d_{ib} = *mean* riffle inner berm mean depth of the proposed design reach

Minimum $W_{ib}/d_{ib} = W_{ib} / d_{ib}$ **Equation 26**

where:

W_{ib} = *minimum* riffle inner berm width of the proposed design reach
d_{ib} = *maximum* riffle inner berm mean depth of the proposed design reach

Maximum $W_{ib}/d_{ib} = W_{ib} / d_{ib}$ **Equation 27**

where:

W_{ib} = *maximum* riffle inner berm width of the proposed design reach
d_{ib} = *minimum* riffle inner berm mean depth of the proposed design reach

Vertical Containment

Entrenchment ratio is used to describe the degree of vertical containment of river channels and is defined as the ratio of the flood-prone area width to the bankfull riffle width. Flood-prone area width 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 flood-prone area width will also be used in the flood capacity computations of the proposed design.

16 — Determine Flood-Prone Area Width (W_{fpa}).

Calculate the flood-prone area width (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 1**, Entry 12).

17 — 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 1**, 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**

where:

W_{fpa} = width of the flood-prone area of the proposed design reach
W_{bkf} = bankfull riffle width of the proposed design reach at same location as the width of the flood-prone area (W_{fpa})

Computational Sequence 18 – 25: Calculate Channel Pattern Variables

18 — Calculate Linear Wavelength (λ)

Calculate the linear wavelength (λ) for the proposed design reach for the *mean*, *minimum* and *maximum* values (Record in **Table 1**, Entry 72):

Mean $\lambda = (\lambda / W_{bkf})_{ref} * W_{bkf}$ **Equation 31**

where:

$(\lambda / W_{bkf})_{ref}$ = *mean* reference reach linear wavelength to bankfull riffle width

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

Minimum $\lambda = (\lambda / W_{bkf})_{ref} * W_{bkf}$ **Equation 32**

where:

$(\lambda / W_{bkf})_{ref}$ = *minimum* reference reach linear wavelength to bankfull riffle width

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

Maximum $\lambda = (\lambda / W_{bkf})_{ref} * W_{bkf}$ **Equation 33**

where:

$(\lambda / W_{bkf})_{ref}$ = *maximum* reference reach linear wavelength to bankfull riffle width

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

19 — 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 1**, Entry 74):

Mean $L_m = MLR_{ref} * W_{bkf}$ **Equation 34**

where:

MLR_{ref} = *mean* reference reach Meander Length Ratio = $(L_m/W_{bkf})_{ref}$

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

Minimum $L_m = MLR_{ref} * W_{bkf}$ **Equation 35**

where:

MLR_{ref} = *minimum* reference reach Meander Length Ratio = $(L_m/W_{bkf})_{ref}$

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

Maximum $L_m = MLR_{ref} * W_{bkf}$ **Equation 36**

where:

MLR_{ref} = *maximum* reference reach Meander Length Ratio = $(L_m/W_{bkf})_{ref}$

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

20 — 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 1**, Entry 76):

Mean $W_{blt} = MWR_{ref} * W_{bkf}$ **Equation 37**

where:

MWR_{ref} = *mean* reference reach Meander Width Ratio = $(W_{blt}/W_{bkf})_{ref}$
W_{bkf} = *mean* bankfull riffle width of the proposed design reach

Minimum $W_{blt} = MWR_{ref} * W_{bkf}$ **Equation 38**

where:

MWR_{ref} = *minimum* reference reach Meander Width Ratio = $(W_{blt}/W_{bkf})_{ref}$
W_{bkf} = *mean* bankfull riffle width of the proposed design reach

Maximum $W_{blt} = MWR_{ref} * W_{bkf}$ **Equation 39**

where:

MWR_{ref} = *maximum* reference reach Meander Width Ratio = $(W_{blt}/W_{bkf})_{ref}$
W_{bkf} = *mean* bankfull riffle width of the proposed design reach

21 — 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 1**, Entry 78):

Mean $R_c = (R_c / W_{bkf})_{ref} * W_{bkf}$ **Equation 40**

where:

$(R_c / W_{bkf})_{ref}$ = *mean* reference reach radius of curvature to bankfull riffle width
W_{bkf} = *mean* bankfull riffle width of the proposed design reach

Minimum $R_c = (R_c / W_{bkf})_{ref} * W_{bkf}$ **Equation 41**

where:

$(R_c / W_{bkf})_{ref}$ = *minimum* reference reach radius of curvature to bankfull riffle width
W_{bkf} = *mean* bankfull riffle width of the proposed design reach

Maximum $R_c = (R_c / W_{bkf})_{ref} * W_{bkf}$ **Equation 42**

where:

$(R_c / W_{bkf})_{ref}$ = *maximum* reference reach radius of curvature to bankfull riffle width
W_{bkf} = *mean* bankfull riffle width of the proposed design reach

22 — 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 1**, Entry 80):

Mean $L_a = (L_a / W_{bkf})_{ref} * W_{bkf}$ **Equation 43**

where:

$(L_a / W_{bkf})_{ref}$ = *mean* reference reach arc length to bankfull riffle width
W_{bkf} = *mean* bankfull riffle width of the proposed design reach

Minimum $L_a = (L_a / W_{bkf})_{ref} * W_{bkf}$ **Equation 44**

where:

$(L_a / W_{bkf})_{ref}$ = *minimum* reference reach arc length to bankfull riffle width
W_{bkf} = *mean* bankfull riffle width of the proposed design reach

Maximum $L_a = (L_a / W_{bkf})_{ref} * W_{bkf}$ **Equation 45**

where:

$(L_a / W_{bkf})_{ref}$ = *maximum* reference reach arc length to bankfull riffle width
W_{bkf} = *mean* bankfull riffle width of the proposed design reach

23 — 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 1**, Entry 82):

Mean $L_r = (L_r / W_{bkf})_{ref} * W_{bkf}$ **Equation 46**

where:

$(L_r / W_{bkf})_{ref}$ = *mean* reference reach riffle length to bankfull riffle width
W_{bkf} = *mean* bankfull riffle width of the proposed design reach

Minimum $L_r = (L_r / W_{bkf})_{ref} * W_{bkf}$ **Equation 47**

where:

$(L_r / W_{bkf})_{ref}$ = *minimum* reference reach riffle length to bankfull riffle width
W_{bkf} = *mean* bankfull riffle width of the proposed design reach

Maximum $L_r = (L_r / W_{bkf})_{ref} * W_{bkf}$ **Equation 48**

where:

$(L_r / W_{bkf})_{ref}$ = *maximum* reference reach riffle length to bankfull riffle width
W_{bkf} = *mean* bankfull riffle width of the proposed design reach

24 — 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 1**, Entry 84):

Mean $L_p = (L_p / W_{bkf})_{ref} * W_{bkf}$ **Equation 49**

where:

$(L_p / W_{bkf})_{ref}$ = *mean* reference reach pool length to bankfull riffle width
W_{bkf} = *mean* bankfull riffle width of the proposed design reach

Minimum $L_p = (L_p / W_{bkf})_{ref} * W_{bkf}$ **Equation 50**

where:

$(L_p / W_{bkf})_{ref}$ = *minimum* reference reach pool length to bankfull riffle width
W_{bkf} = *mean* bankfull riffle width of the proposed design reach

Maximum $L_p = (L_p / W_{bkf})_{ref} * W_{bkf}$ **Equation 51**

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

25 — 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 1**, Entry 86):

Mean $P_s = (P_s / W_{bkf})_{ref} * W_{bkf}$ **Equation 52**

where:

$(P_s / W_{bkf})_{ref}$ = *mean* reference reach pool to pool spacing to bankfull riffle width
W_{bkf} = *mean* bankfull riffle width of the proposed design reach

Minimum $P_s = (P_s / W_{bkf})_{ref} * W_{bkf}$ **Equation 53**

where:

$(P_s / W_{bkf})_{ref}$ = *minimum* reference reach pool to pool spacing to bankfull riffle width
W_{bkf} = *mean* bankfull riffle width of the proposed design reach

Maximum $P_s = (P_s / W_{bkf})_{ref} * W_{bkf}$ **Equation 54**

where:

$(P_s / W_{bkf})_{ref}$ = *maximum* reference reach pool to pool spacing to bankfull riffle width
W_{bkf} = *mean* bankfull riffle width of the proposed design reach

Computational Sequence 26: Layout Channel Pattern Variables

26 — 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 27 – 30: Calculate Sinuosity & Slope

27 — 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 1**, Entries 88 and 89).

28 — Calculate Sinuosity (k)

Calculate sinuosity (k) of the proposed design reach (Record in **Table 1**, Entry 91):

$$k = SL / VL \qquad \textbf{Equation 55}$$

29 — Calculate Valley Slope (S_{val})

Calculate valley slope (S_{val}) (Record in **Table 1**, 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:

$$S_{val} = DE / VL \qquad \textbf{Equation 56}$$

30 — Calculate Average Water Surface Slope (S)

Calculate the average water surface slope (S) for the proposed design channel (Record in **Table 1**, Entry 92):

$$S = S_{val} / k \qquad \textbf{Equation 57}$$

Computational Sequence 31 – 32: Design the Flood-prone Area

The first approximation of flood-prone area is determined at an elevation at two times the bankfull riffle maximum depth of the proposed channel. Three-stage channels comprise of just the flood-prone area (Stage 3) while four-stage channels are composed 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.

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 with a low terrace to accommodate the *100-year* or larger flood. Calculations of flood-prone area capacity are necessary in this computational sequence, which may indicate that the active floodplain, low terrace and/or flood-prone area dimensions need to be adjusted.

Floodplains, low terraces and flood-prone areas must be developed for the following various scenarios:

a) For braided rivers converted to meandering channels (D to C Stream Type) in a Valley Type VIII
b) For Priority 1 (Gc to C Stream Type) or Priority 2 (F to C or E Stream Type) restorations that reconnect the channel with floodplain and fluvial features
c) For Priority 3 restorations that convert G to B Stream Types or F to Bc Stream Types
d) Developing flood-prone areas for G or B Stream Types in Valley Type II and for A Stream Types in Valley Types I and II.

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 channel. The flood-prone area width, mean depth and cross-sectional area can then be calculated at this elevation based on the valley dimensions of the existing or proposed condition.

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

Calculate the flood-prone area width (W_{fpa}) for the proposed design channel for the *mean*, *minimum* and *maximum* values. The flood-prone area width is obtained by selecting the flood-prone area elevation at two times the maximum bankfull depth of the proposed channel (Record in **Table 1**, Entry 93).

32 — Calculate Flood-Prone Area Mean Depth (d_{fpa})

Calculate the flood-prone area mean depth (d_{fpa}) for the proposed design channel for the *mean*, *minimum* and *maximum* values (Record in **Table 1**, Entry 94).

33 — Calculate Cross-Sectional Area of Flood-Prone Area (A_{fpa})

Calculate the cross-sectional area of the flood-prone area (A_{fpa}) for the proposed design channel for the *mean*, *minimum* and *maximum* values (Record in **Table 1**, Entry 95).

Floodplain Dimensions (Applicable to Four-Stage Channels, e.g., most commonly C channels in Valley Type VIII)

34 — Calculate Floodplain Width (W_f)

Calculate the floodplain width (W_f) for the proposed design channel for the *mean*, *minimum* and *maximum* values (Record in **Table 1**, Entry 96).

35 — Calculate Floodplain Mean Depth (d_f)

Calculate the mean floodplain depth (d_f) for the proposed design channel for the *mean*, *minimum* and *maximum* values (Record in **Table 1**, Entry 97).

36 — Calculate Floodplain Cross-Sectional Area (A_f)

Calculate the floodplain cross-sectional area (A_f) for the proposed design channel for the *mean*, *minimum* and *maximum* values (Record in **Table 1**, Entry 98).

Low Terrace Dimensions (Applicable to Four-Stage Channels, e.g., most commonly C channels in Valley Type VIII)

37 — Calculate Low Terrace Width (W_{lt})

Calculate the low terrace width (W_{lt}) for the proposed design channel for the *mean*, *minimum* and *maximum* values (Record in **Table 1**, Entry 99).

38 — Calculate Mean Low Terrace Mean Depth (d_{lt})

Calculate the low terrace mean depth (d_{lt}) for the proposed design channel for the *mean*, *minimum* and *maximum* values (Record in **Table 1**, Entry 100).

39 — Calculate Low Terrace Cross-Sectional Area (A_{lt})

Calculate the low terrace cross-sectional area (A_{lt}) for the proposed design channel for the *mean*, *minimum* and *maximum* values (Record in **Table 1**, Entry 101).

Computational Sequence 40: Plot Typical Multi-Stage Channel Dimensions

40 — Plot Typical Multi-Stage Channel Cross-Sections

Plot the typical multi-stage channel cross-sections. Overlaying the proposed cross-section over the existing cross-section is often useful if the proposed channel design is within proximity of the existing channel.

Computational Sequence 41– 44: Ensure the Hydraulic & Sediment Competence & Capacity Calculations Match Continuity

41 — Calculate Bankfull Velocity (u_{bkf})

Calculate the bankfull velocity (u_{bkf}) and corresponding bankfull discharge for the proposed design reach estimated in **Worksheet 1** (Record in **Table 1**, Entries 127 and 128). Check that the estimated bankfull discharge is similar to the bankfull velocity calculated using the continuity equation from regional curves:

$$u = Q / A \text{ (continuity)} \qquad \textbf{Equation 85}$$

42 — Calculate Stream Competence / Entrainment

Calculate the stream competence/entrainment for the proposed design reach using **Worksheet 2** (Record in **Table 1**, Entries 129–139). The competence calculation using **Worksheet 2** uses the design channel's bankfull water surface slope (S) and bankfull mean depth (d_{bkf}) 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 $\hat{D}_{50}$ 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 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 PERMIMETER ~ (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 *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$^{-0.16}$* ***n =*** **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		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 u = Q / A **Return Period for Bankfull Q** **Q =** **year**		ft / sec		cfs
4. Continuity Equations: b) Regional Curves 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.

Worksheet 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) $d = \dfrac{\tau^*(\gamma_s - 1)D_{max}}{S}$	(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) $S = \dfrac{\tau^*(\gamma_s - 1)D_{max}}{d}$	(use D_{max} in ft)
	Check: ☐ Stable ☐ Aggrading ☐ Degrading		

Sediment Competence Using Dimensional Shear Stress		
		Bankfull shear stress $\tau = \gamma d S$ (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) $d = \dfrac{\tau}{\gamma S}$ τ = predicted shear stress, γ = 62.4, S = proposed design slope
Shields	CO	Predicted slope required to initiate movement of measured D_{max} (mm) $S = \dfrac{\tau}{\gamma d}$ τ = predicted shear stress, γ = 62.4, d = proposed design depth
		Check: ☐ Stable ☐ Aggrading ☐ Degrading

43 — Compute Sediment Transport Capacity

Compute sediment transport capacity using the FLOWSED and POWERSED models detailed in Rosgen (2006/2009) for the proposed design reach (Record in **Table 1**, Entries 140–143).

44 — Evaluate the Sediment Competence and 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 items **8** through **43** 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 proposed design's dimension, pattern and profile does not satisfy the sediment competence and/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 and/or capacity indicate 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 45: Calculate Flood-Prone Area Capacity

45 — Calculate Flood-Prone Area Capacity

Calculate flood-prone area capacity. This involves estimating velocity associated with the cross-sectional area and slope of the stream channel and flood-prone area. Determine cross-sectional area of the flood-prone area. Plot the bankfull cross-section and flood-prone area elevation ($2 \times d_{max}$) and width. Use 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 50- and 100-year flood levels based on the proposed design. Use the bankfull channel capacity from computational sequence item 41.

Computational Sequence 46 – 75: Calculate and Plot Remaining Applicable Bed Feature Dimensions

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

46 — 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 1**, Entry 19):

Mean $W_{bkfp} = (W_{bkfp} / W_{bkf})_{ref} * W_{bkf}$ **Equation 86**

where:

$(W_{bkfp} / W_{bkf})_{ref}$ = *mean* reference reach bankfull pool width to bankfull riffle width

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

Minimum $W_{bkfp} = (W_{bkfp} / W_{bkf})_{ref} * W_{bkf}$ **Equation 87**

where:

$(W_{bkfp} / W_{bkf})_{ref}$ = *minimum* reference reach bankfull pool width to bankfull riffle width

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

Maximum $W_{bkfp} = (W_{bkfp} / W_{bkf})_{ref} * W_{bkf}$ **Equation 88**

where:

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

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

47 — 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 1**, Entry 21):

Mean $d_{bkfp} = (d_{bkfp} / d_{bkf})_{ref} * d_{bkf}$ **Equation 89**

where:

$(d_{bkfp} / d_{bkf})_{ref}$ = *mean* reference reach bankfull pool mean depth to bankfull riffle mean depth

d_{bkf} = *mean* bankfull riffle mean depth of the proposed design reach

Minimum $d_{bkfp} = (d_{bkfp} / d_{bkf})_{ref} * d_{bkf}$ **Equation 90**

where:

$(d_{bkfp} / d_{bkf})_{ref}$ = *minimum* reference reach bankfull pool mean depth to bankfull riffle mean depth

d_{bkf} = *mean* bankfull riffle mean depth of the proposed design reach

Maximum $d_{bkfp} = (d_{bkfp} / d_{bkf})_{ref} * d_{bkf}$ **Equation 91**

where:

$(d_{bkfp} / d_{bkf})_{ref}$ = *maximum* reference reach bankfull pool mean depth to bankfull riffle mean depth

d_{bkf} = *mean* bankfull riffle mean depth of the proposed design reach

48 — 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 1**, Entry 24).

Mean $A_{bkfp} = (A_{bkfp} / A_{bkf})_{ref} * A_{bkf}$ **Equation 92**

where:

$(A_{bkfp} / A_{bkf})_{ref}$ = *mean* reference reach bankfull pool cross-sectional area to bankfull riffle cross-sectional area

A_{bkf} = *mean* bankfull riffle cross-sectional area of the proposed design reach

Minimum $A_{bkfp} = (A_{bkfp} / A_{bkf})_{ref} * A_{bkf}$ **Equation 93**

where:

$(A_{bkfp} / A_{bkf})_{ref}$ = *minimum* reference reach bankfull pool cross-sectional area to bankfull riffle cross-sectional area

A_{bkf} = *mean* bankfull riffle cross-sectional area of the proposed design reach

Maximum $A_{bkfp} = (A_{bkfp} / A_{bkf})_{ref} * A_{bkf}$ **Equation 94**

where:

$(A_{bkfp} / A_{bkf})_{ref}$ = *maximum* reference reach bankfull pool cross-sectional area to bankfull riffle cross-sectional area

A_{bkf} = *mean* bankfull riffle cross-sectional area of the proposed design reach

49 — Calculate Bankfull Pool Width/Depth Ratio (W_{bkfp}/d_{bkfp})

Calculate the bankfull pool width/depth ratio (W_{bkfp}/d_{bkfp}) for the proposed design reach for the *mean*, *minimum* and *maximum* values (Record in **Table 1**, Entry 23):

Mean $W_{bkfp}/d_{bkfp} = W_{bkfp} / d_{bkfp}$ **Equation 95**

where:

W_{bkfp} = *mean* bankfull pool width of the proposed design reach

d_{bkfp} = *mean* bankfull pool mean depth of the proposed design reach

Minimum $W_{bkfp}/d_{bkfp} = W_{bkfp} / d_{bkfp}$ **Equation 96**

where:

W_{bkfp} = *minimum* bankfull pool width of the proposed design reach

d_{bkfp} = *maximum* bankfull pool mean depth of the proposed design reach

Maximum $W_{bkfp}/d_{bkfp} = W_{bkfp} / d_{bkfp}$ **Equation 97**

where:

W_{bkfp} = *maximum* bankfull pool width of the proposed design reach
d_{bkfp} = *minimum* bankfull pool mean depth of the proposed design reach

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

Calculate the bankfull maximum pool depth (d_{maxr}) for the proposed design reach for the *mean*, *minimum* and *maximum* values (Record in **Table 1**, Entry 26):

Mean $d_{maxp} = (d_{maxp} / d_{bkf})_{ref} * d_{bkf}$ **Equation 98**

where:

$(d_{maxp} / d_{bkf})_{ref}$ = *mean* reference reach bankfull pool maximum depth to bankfull riffle mean depth
d_{bkf} = *mean* bankfull riffle mean depth of the proposed design channel

Minimum $d_{maxp} = (d_{maxp} / d_{bkf})_{ref} * d_{bkf}$ **Equation 99**

where:

$(d_{maxp} / d_{bkf})_{ref}$ = *minimum* reference reach bankfull pool maximum depth to bankfull riffle mean depth
d_{bkf} = *mean* bankfull riffle mean depth of the proposed design channel

Maximum $d_{maxp} = (d_{maxp} / d_{bkf})_{ref} * d_{bkf}$ **Equation 100**

where:

$(d_{maxp} / d_{bkf})_{ref}$ = *maximum* reference reach bankfull pool maximum depth to bankfull riffle mean depth
d_{bkf} = *mean* bankfull riffle mean depth of the proposed design channel

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

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

Calculate the pool inner berm width (W_{ibp}) for the proposed channel for the *mean*, *minimum* and *maximum* values (Record in **Table 1**, Entry 29):

Mean $W_{ibp} = (W_{ibp} / W_{bkfp})_{ref} * W_{bkfp}$ **Equation 101**

where:

$(W_{ibp} / W_{bkfp})_{ref}$ = *mean* reference reach pool inner berm width to bankfull pool width
W_{bkfp} = *mean* bankfull pool width of the proposed design reach

Minimum $W_{ibp} = (W_{ibp} / W_{bkfp})_{ref} * W_{bkfp}$ **Equation 102**

where:

$(W_{ibp} / W_{bkfp})_{ref}$ = *minimum* reference reach pool inner berm width to bankfull pool width
W_{bkfp} = *mean* bankfull pool width of the proposed design reach

$Maximum\ W_{ibp} = (W_{ibp} / W_{bkfp})_{ref} * W_{bkfp}$ **Equation 103**

where:

$(W_{ibp} / W_{bkfp})_{ref}$ = *maximum* reference reach pool inner berm width to bankfull pool width

W_{bkfp} = *mean* bankfull pool width of the proposed design reach

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

Calculate the pool inner berm mean depth (d_{ibp}) for the proposed channel for the *mean*, *minimum* and *maximum* values (Record in **Table 1**, Entry 31):

$Mean\ d_{ibp} = (d_{ibp} / d_{bkfp})_{ref} * d_{bkfp}$ **Equation 104**

where:

$(d_{ibp} / d_{bkfp})_{ref}$ = *mean* reference reach pool inner berm mean depth to bankfull pool mean depth

d_{bkfp} = *mean* bankfull pool mean depth of the proposed design reach

$Minimum\ d_{ibp} = (d_{ibp} / d_{bkfp})_{ref} * d_{bkfp}$ **Equation 105**

where:

$(d_{ibp} / d_{bkfp})_{ref}$ = *minimum* reference reach pool inner berm mean depth to bankfull pool mean depth

d_{bkfp} = *mean* bankfull pool mean depth of the proposed design reach

$Maximum\ d_{ibp} = (d_{ibp} / d_{bkfp})_{ref} * d_{bkfp}$ **Equation 106**

where:

$(d_{ibp} / d_{bkfp})_{ref}$ = *maximum* reference reach pool inner berm mean depth to bankfull pool mean depth

d_{bkfp} = *mean* bankfull pool mean depth of the proposed design reach

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

Calculate the pool inner berm cross-sectional area (A_{ibp}) for the proposed channel for the *mean*, *minimum* and *maximum* values (Record in **Table 1**, Entry 34):

$Mean\ A_{ibp} = (A_{ibp} / A_{bkfp})_{ref} * A_{bkfp}$ **Equation 107**

where:

$(A_{ibp} / A_{bkfp})_{ref}$ = *mean* reference reach pool inner berm cross-sectional area to bankfull pool cross-sectional area

A_{bkfp} = *mean* bankfull pool cross-sectional area of the proposed design reach

$Minimum\ A_{ibp} = (A_{ibp} / A_{bkfp})_{ref} * A_{bkfp}$ **Equation 108**

where:

$(A_{ibp} / A_{bkfp})_{ref}$ = *minimum* reference reach pool inner berm cross-sectional area to bankfull pool cross-sectional area

A_{bkfp} = *mean* bankfull pool cross-sectional area of the proposed design reach

$Maximum\ A_{ibp} = (A_{ibp} / A_{bkfp})_{ref} * A_{bkfp}$ **Equation 109**

where:

$(A_{ibp} / A_{bkfp})_{ref}$ = *maximum* reference reach pool inner berm cross-sectional area to bankfull pool cross-sectional area

A_{bkfp} = *mean* bankfull pool cross-sectional area of the proposed design reach

54 — Calculate Pool Inner Berm Width/Depth Ratio (W_{ibp}/d_{ibp})

Calculate the pool inner berm width/depth ratio (W_{ibp}/d_{ibp}) for the proposed channel for the *mean*, *minimum* and *maximum* values (Record in **Table 1**, Entry 33):

$Mean\ W_{ibp}/d_{ibp} = W_{ibp} / d_{ibp}$ **Equation 110**

where:

W_{ibp} = *mean* pool inner berm width of the proposed design reach

d_{ibp} = *mean* pool inner berm mean depth of the proposed design reach

$Minimum\ W_{ibp}/d_{ibp} = W_{ibp} / d_{ibp}$ **Equation 111**

where:

W_{ibp} = *minimum* pool inner berm width of the proposed design reach

d_{ibp} = *maximum* pool inner berm mean depth of the proposed design reach

$Maximum\ W_{ibp}/d_{ibp} = W_{ibp} / d_{ibp}$ **Equation 112**

where:

W_{ibp} = *maximum* pool inner berm width of the proposed design reach

d_{ibp} = *minimum* pool inner berm mean depth of the proposed design reach

55 — Determine Point Bar Slope (S_{pb})

Determine the point bar slope (S_{pb}) for the proposed design reach based on the reference reach point bar slope. Record the *mean*, *minimum* and *maximum* values in **Table 1**, Entry 28:

$Mean\ S_{pb} = (S_{pb})_{ref}$ **Equation 113**

where:

$(S_{pb})_{ref}$ = *mean* reference reach point bar slope

$Minimum\ S_{pb} = (S_{pb})_{ref}$ **Equation 114**

where:

$(S_{pb})_{ref}$ = *minimum* reference reach point bar slope

$Maximum\ S_{pb} = (S_{pb})_{ref}$ **Equation 115**

where:

$(S_{pb})_{ref}$ = *maximum* reference reach point bar slope

Run Dimensions (Riffle–Pool Systems)

56 — Calculate Bankfull Run Width (W_{bkfr})

Calculate the bankfull run width (W_{bkfr}) for the proposed design reach for the *mean*, *minimum* and *maximum* values (Record in **Table 1**, Entry 36):

Mean $W_{bkfr} = (W_{bkfr} / W_{bkf})_{ref} * W_{bkf}$ **Equation 116**

where:

$(W_{bkfr} / W_{bkf})_{ref}$ = *mean* reference reach bankfull run width to bankfull riffle width

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

Minimum $W_{bkfr} = (W_{bkfr} / W_{bkf})_{ref} * W_{bkf}$ **Equation 117**

where:

$(W_{bkfr} / W_{bkf})_{ref}$ = *minimum* reference reach bankfull run width to bankfull riffle width

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

Maximum $W_{bkfr} = (W_{bkfr} / W_{bkf})_{ref} * W_{bkf}$ **Equation 118**

where:

$(W_{bkfr} / W_{bkf})_{ref}$ = *maximum* reference reach bankfull run width to bankfull riffle width

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

57 — Calculate Bankfull Run Mean Depth (d_{bkfr})

Calculate the bankfull run mean depth (d_{bkfr}) for the proposed design reach for the *mean*, *minimum* and *maximum* (Record in **Table 1**, Entry 38):

Mean $d_{bkfr} = (d_{bkfr} / d_{bkf})_{ref} * d_{bkf}$ **Equation 119**

where:

$(d_{bkfr} / d_{bkf})_{ref}$ = *mean* reference reach bankfull run mean depth to bankfull riffle mean depth

d_{bkf} = *mean* bankfull riffle mean depth of the proposed design channel

Minimum $d_{bkfr} = (d_{bkfr} / d_{bkf})_{ref} * d_{bkf}$ **Equation 120**

where:

$(d_{bkfr} / d_{bkf})_{ref}$ = *minimum* reference reach bankfull run mean depth to bankfull riffle mean depth

d_{bkf} = *mean* bankfull riffle mean depth of the proposed design channel

Maximum $d_{bkfr} = (d_{bkfr} / d_{bkf})_{ref} * d_{bkf}$ **Equation 121**

where:

$(d_{bkfr} / d_{bkf})_{ref}$ = *maximum* reference reach bankfull run mean depth to bankfull riffle mean depth

d_{bkf} = *mean* bankfull riffle mean depth of the proposed design channel

58 — Calculate Bankfull Run Cross-Sectional Area (A_{bkfr})

Calculate the bankfull run cross-sectional area (A_{bkfr}) for the proposed design reach for the *mean*, *minimum* and *maximum* values (Record in **Table 1**, Entry 41).

Mean $A_{bkfr} = (A_{bkfr} / A_{bkf})_{ref} * A_{bkf}$ **Equation 122**

where:

$(A_{bkfr} / A_{bkf})_{ref}$ = *mean* reference reach bankfull run cross-sectional area to bankfull riffle cross-sectional area

A_{bkf} = *mean* bankfull riffle cross-sectional area of the proposed design reach

Minimum $A_{bkfr} = (A_{bkfr} / A_{bkf})_{ref} * A_{bkf}$ **Equation 123**

where:

$(A_{bkfr} / A_{bkf})_{ref}$ = *minimum* reference reach bankfull run cross-sectional area to bankfull riffle cross-sectional area

A_{bkf} = *mean* bankfull riffle cross-sectional area of the proposed design reach

Maximum $A_{bkfr} = (A_{bkfr} / A_{bkf})_{ref} * A_{bkf}$ **Equation 124**

where:

$(A_{bkfr} / A_{bkf})_{ref}$ = *maximum* reference reach bankfull run cross-sectional area to bankfull riffle cross-sectional area

A_{bkf} = *mean* bankfull riffle cross-sectional area of the proposed design reach

59 — Calculate Bankfull Run Width/Depth Ratio (W_{bkfr}/d_{bkfr})

Calculate the bankfull run width/depth ratio (W_{bkfr}/d_{bkfr}) for the proposed design reach for the *mean*, *minimum* and *maximum* values (Record in **Table 1**, Entry 40):

Mean $W_{bkfr}/d_{bkfr} = W_{bkfr} / d_{bkfr}$ **Equation 125**

where:

W_{bkfr} = *mean* bankfull run width of the proposed design reach

d_{bkfr} = *mean* bankfull run mean depth of the proposed design reach

Minimum $W_{bkfr}/d_{bkfr} = W_{bkfr} / d_{bkfr}$ **Equation 126**

where:

W_{bkfr} = *minimum* bankfull run width of the proposed design reach

d_{bkfr} = *maximum* bankfull run mean depth of the proposed design reach

Maximum $W_{bkfr}/d_{bkfr} = W_{bkfr} / d_{bkfr}$ **Equation 127**

where:

W_{bkfr} = *maximum* bankfull run width of the proposed design reach

d_{bkfr} = *minimum* bankfull run mean depth of the proposed design reach

60 — Calculate Bankfull Run Maximum Depth (d_{maxr})

Obtain the bankfull run maximum depth (d_{maxr}) for the proposed design reach for the *mean*, *minimum* and *maximum* values (Record in **Table 1**, Entry 43):

Mean $d_{maxr} = (d_{maxr} / d_{bkf})_{ref} * d_{bkf}$ **Equation 128**

where:

$(d_{maxr} / d_{bkf})_{ref}$ = *mean* reference reach bankfull run maximum depth to bankfull riffle mean depth

d_{bkf} = *mean* bankfull riffle mean depth of the proposed design channel

Minimum $d_{maxr} = (d_{maxr} / d_{bkf})_{ref} * d_{bkf}$ **Equation 129**

where:

$(d_{maxr} / d_{bkf})_{ref}$ = *minimum* reference reach bankfull run maximum depth to bankfull mean riffle depth

d_{bkf} = *mean* bankfull riffle mean depth of the proposed design channel

Maximum $d_{maxr} = (d_{maxr} / d_{bkf})_{ref} * d_{bkf}$ **Equation 130**

where:

$(d_{maxr} / d_{bkf})_{ref}$ = *maximum* reference reach bankfull run maximum depth to bankfull riffle mean depth

d_{bkf} = *mean* bankfull riffle mean depth of the proposed design channel

Glide Dimensions (Riffle–Pool Systems)

61 — Calculate Bankfull Glide Width (W_{bkfg})

Calculate the bankfull glide width (W_{bkfg}) for the proposed design reach for the *mean*, *minimum* and *maximum* values (Record in **Table 1**, Entry 45):

Mean $W_{bkfg} = (W_{bkfg} / W_{bkf})_{ref} * W_{bkf}$ **Equation 131**

where:

$(W_{bkfg} / W_{bkf})_{ref}$ = *mean* reference reach bankfull glide width to bankfull riffle width

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

Minimum $W_{bkfg} = (W_{bkfg} / W_{bkf})_{ref} * W_{bkf}$ **Equation 132**

where:

$(W_{bkfg} / W_{bkf})_{ref}$ = *minimum* reference reach bankfull glide width to bankfull riffle width

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

Maximum $W_{bkfg} = (W_{bkfg} / W_{bkf})_{ref} * W_{bkf}$ **Equation 133**

where:

$(W_{bkfg} / W_{bkf})_{ref}$ = *maximum* reference reach bankfull glide width to bankfull riffle width

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

62 — Calculate Bankfull Glide Mean Depth (d_{bkfg})

Calculate the bankfull glide mean depth (d_{bkfg}) for the proposed design reach for the *mean*, *minimum* and *maximum* values (Record in **Table 1**, Entry 47):

Mean $d_{bkfg} = (d_{bkfg} / d_{bkf})_{ref} * d_{bkf}$ **Equation 134**

where:

$(d_{bkfg} / d_{bkf})_{ref}$ = *mean* reference reach bankfull glide mean depth to bankfull riffle mean depth

d_{bkf} = *mean* bankfull riffle mean depth of the proposed design channel

Minimum $d_{bkfg} = (d_{bkfg} / d_{bkf})_{ref} * d_{bkf}$ **Equation 135**

where:

$(d_{bkfg} / d_{bkf})_{ref}$ = *minimum* reference reach bankfull glide mean depth to bankfull riffle mean depth

d_{bkf} = *mean* bankfull riffle mean depth of the proposed design channel

Maximum $d_{bkfg} = (d_{bkfg} / d_{bkf})_{ref} * d_{bkf}$ **Equation 136**

where:

$(d_{bkfg} / d_{bkf})_{ref}$ = *maximum* reference reach bankfull glide mean depth to bankfull riffle mean depth

d_{bkf} = *mean* bankfull riffle mean depth of the proposed design channel

63 — Calculate Bankfull Glide Cross-Sectional Area (A_{bkfg})

Calculate the bankfull glide cross-sectional area (A_{bkfg}) for the proposed design reach for the *mean*, *minimum* and *maximum* values (Record in **Table 1**, Entry 50):

Mean $A_{bkfg} = (A_{bkfg} / A_{bkf})_{ref} * A_{bkf}$ **Equation 137**

where:

$(A_{bkfg} / A_{bkf})_{ref}$ = *mean* reference reach bankfull glide cross-sectional area to bankfull riffle cross-sectional area

A_{bkf} = *mean* bankfull riffle cross-sectional area of the proposed design reach

Minimum $A_{bkfg} = (A_{bkfg} / A_{bkf})_{ref} * A_{bkf}$ **Equation 138**

where:

$(A_{bkfg} / A_{bkf})_{ref}$ = *minimum* reference reach bankfull glide cross-sectional area to bankfull riffle cross-sectional area

A_{bkf} = *mean* bankfull riffle cross-sectional area of the proposed design reach

Maximum $A_{bkfg} = (A_{bkfg} / A_{bkf})_{ref} * A_{bkf}$ **Equation 139**

where:

$(A_{bkfg} / A_{bkf})_{ref}$ = *maximum* reference reach bankfull glide cross-sectional area to bankfull riffle cross-sectional area

A_{bkf} = *mean* bankfull riffle cross-sectional area of the proposed design reach

64 — Calculate Bankfull Glide Width/Depth Ratio (W_{bkfg}/d_{bkfg})

Calculate the bankfull glide width/depth ratio (W_{bkfg}/d_{bkfg}) for the proposed design reach for the *mean*, *minimum* and *maximum* values (Record in **Table 1**, Entry 49):

Mean $W_{bkfg}/d_{bkfg} = W_{bkfg} / d_{bkfg}$ **Equation 140**

where:

W_{bkfg} = *mean* bankfull glide width of the proposed design reach

d_{bkfg} = *mean* bankfull glide mean depth of the proposed design reach

Minimum $W_{bkfg}/d_{bkfg} = W_{bkfg} / d_{bkfg}$ **Equation 141**

where:

W_{bkfg} = *minimum* bankfull glide width of the proposed design reach

d_{bkfg} = *maximum* bankfull glide mean depth of the proposed design reach

Maximum $W_{bkfg}/d_{bkfg} = W_{bkfg} / d_{bkfg}$ **Equation 142**

where:

W_{bkfg} = *maximum* bankfull glide width of the proposed design reach

d_{bkfg} = *minimum* bankfull glide mean depth of the proposed design reach

65 — Calculate Bankfull Glide Maximum Depth (d_{maxg})

Obtain the bankfull glide maximum depth (d_{maxg}) for the proposed design reach for the *mean*, *minimum* and *maximum* values (Record in **Table 1**, Entry 52):

Mean $d_{maxg} = (d_{maxg} / d_{bkf})_{ref} * d_{bkf}$ **Equation 143**

where:

$(d_{maxg} / d_{bkf})_{ref}$ = *mean* reference reach bankfull glide maximum depth to bankfull riffle mean depth

d_{bkf} = *mean* bankfull riffle mean depth of the proposed design channel

Minimum $d_{maxg} = (d_{maxg} / d_{bkf})_{ref} * d_{bkf}$ **Equation 144**

where:

$(d_{maxg} / d_{bkf})_{ref}$ = *minimum* reference reach bankfull glide maximum depth to bankfull riffle mean depth

d_{bkf} = *mean* bankfull riffle mean depth of the proposed design channel

Maximum $d_{maxg} = (d_{maxg} / d_{bkf})_{ref} * d_{bkf}$ **Equation 145**

where:

$(d_{maxg} / d_{bkf})_{ref}$ = *maximum* reference reach bankfull glide maximum depth to bankfull riffle mean depth

d_{bkf} = *mean* bankfull riffle mean depth of the proposed design channel

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

66 — Calculate Glide Inner Berm Width (W_{ibg})

Calculate the glide inner berm width (W_{ibg}) for the proposed design reach for the *mean*, *minimum* and *maximum* values (Record in **Table 1**, Entry 54):

Mean $W_{ib} = (W_{ibg} / W_{bkfg})_{ref} * W_{bkfg}$ **Equation 146**

where:

$(W_{ibg} / W_{bkfg})_{ref}$ = *mean* reference reach glide inner berm width to bankfull glide width

W_{bkfg} = *mean* bankfull glide width of the proposed design reach

Minimum $W_{ib} = (W_{ibg} / W_{bkfg})_{ref} * W_{bkfg}$ **Equation 147**

where:

$(W_{ibg} / W_{bkfg})_{ref}$ = *minimum* reference reach glide inner berm width to bankfull glide width

W_{bkfg} = *mean* bankfull glide width of the proposed design reach

Maximum $W_{ib} = (W_{ibg} / W_{bkfg})_{ref} * W_{bkfg}$ **Equation 148**

where:

$(W_{ibg} / W_{bkfg})_{ref}$ = *maximum* reference reach glide inner berm width to bankfull glide width

W_{bkfg} = *mean* bankfull glide width of the proposed design reach

67 — Calculate Glide Inner Berm Mean Depth (d_{ibg})

Calculate the glide inner berm mean depth (d_{ibg}) for the proposed reach for the *mean*, *minimum* and *maximum* values (Record in **Table 1**, Entry 56):

Mean $d_{ibg} = (d_{ibg} / d_{bkfg})_{ref} * d_{bkfg}$ **Equation 149**

where:

$(d_{ibg} / d_{bkfg})_{ref}$ = *mean* reference reach glide inner berm mean depth to bankfull glide mean depth

d_{bkfg} = *mean* bankfull glide mean depth of the proposed reach

Minimum $d_{ibg} = (d_{ibg} / d_{bkfg})_{ref} * d_{bkfg}$ **Equation 150**

where:

$(d_{ibg} / d_{bkfg})_{ref}$ = *minimum* reference reach glide inner berm mean depth to bankfull glide mean depth

d_{bkfg} = *mean* bankfull glide mean depth of the proposed reach

$Maximum\ d_{ibg} = (d_{ibg} / d_{bkfg})_{ref} * d_{bkfg}$ **Equation 151**

where:

$(d_{ibg} / d_{bkfg})_{ref}$ = *maximum* reference reach glide inner berm mean depth to bankfull glide mean depth

d_{bkfg} = *mean* bankfull glide mean depth of the proposed reach

68 — Calculate Glide Inner Berm Cross-Sectional Area (A_{ibg})

Calculate the glide inner berm cross-sectional area (A_{ibg}) for the proposed reach for the *mean*, *minimum* and *maximum* values (Record in **Table 1**, Entry 59):

$Mean\ A_{ibg} = (A_{ibg} / A_{bkfg})_{ref} * A_{bkfg}$ **Equation 152**

where:

$(A_{ibg} / A_{bkfg})_{ref}$ = *mean* reference reach glide inner berm cross-sectional area to bankfull glide cross-sectional area

A_{bkfg} = *mean* bankfull glide cross-sectional area of the proposed design reach

$Minimum\ A_{ibg} = (A_{ibg} / A_{bkfg})_{ref} * A_{bkfg}$ **Equation 153**

where:

$(A_{ibg} / A_{bkfg})_{ref}$ = *minimum* reference reach glide inner berm cross-sectional area to bankfull glide cross-sectional area

A_{bkfg} = *mean* bankfull glide cross-sectional area of the proposed design reach

$Maximum\ A_{ibg} = (A_{ibg} / A_{bkfg})_{ref} * A_{bkfg}$ **Equation 154**

where:

$(A_{ibg} / A_{bkfg})_{ref}$ = *maximum* reference reach glide inner berm cross-sectional area to bankfull glide cross-sectional area

A_{bkfg} = *mean* bankfull glide cross-sectional area of the proposed design reach

69 — Calculate Glide Inner Berm Width/Depth Ratio (W_{ibg}/d_{ibg})

Calculate the glide inner berm width/depth ratio (W_{ibg}/d_{ibg}) for the proposed reach for the *mean*, *minimum* and *maximum* values (Record in **Table 1**, Entry 58):

$Mean\ W_{ibg}/d_{ibg} = W_{ibg} / d_{ibg}$ **Equation 155**

where:

W_{ibg} = *mean* glide inner berm width of the proposed design reach

d_{ibg} = *mean* glide inner berm mean depth of the proposed design reach

$Minimum\ W_{ibg}/d_{ibg} = W_{ibg} / d_{ibg}$ **Equation 156**

where:

W_{ibg} = *minimum* glide inner berm width of the proposed design reach

d_{ibg} = *maximum* glide inner berm mean depth of the proposed design reach

Maximum $W_{ibg}/d_{ibg} = W_{ibg} / d_{ibg}$ **Equation 157**

where:

W_{ibg} = *maximum* glide inner berm width of the proposed design reach
d_{ibg} = *minimum* glide inner berm mean depth of the proposed design reach

Step Dimensions (Step–Pool Systems)

70 — Calculate Bankfull Step Width (W_{bkfs})

Calculate the bankfull step width (W_{bkfs}) for the proposed design reach for the *mean*, *minimum* and *maximum* (Record in **Table 1**, Entry 61):

Mean $W_{bkfs} = (W_{bkfs} / W_{bkf})_{ref} * (W_{bkf})$ **Equation 158**

where:

$(W_{bkfs} / W_{bkf})_{ref}$ = *mean* reference reach bankfull step width to bankfull riffle width
W_{bkf} = *mean* bankfull riffle width of the proposed design reach

Minimum $W_{bkfs} = (W_{bkfs} / W_{bkf})_{ref} * (W_{bkf})$ **Equation 159**

where:

$(W_{bkfs} / W_{bkf})_{ref}$ = *minimum* reference reach bankfull step width to bankfull riffle width
W_{bkf} = *mean* bankfull riffle width of the proposed design reach

Maximum $W_{bkfs} = (W_{bkfs} / W_{bkf})_{ref} * (W_{bkf})$ **Equation 160**

where:

$(W_{bkfs} / W_{bkf})_{ref}$ = *maximum* reference reach bankfull step width to bankfull riffle width
W_{bkf} = *mean* bankfull riffle width of the proposed design reach

71 — Calculate Bankfull Step Mean Depth (d_{bkfs})

Calculate the bankfull mean step depth (d_{bkfs}) for the proposed design reach for the *mean*, *minimum* and *maximum* values (Record in **Table 1**, Entry 63):

Mean $d_{bkfs} = (d_{bkfs} / d_{bkf})_{ref} * (d_{bkf})$ **Equation 161**

where:

$(d_{bkfs} / d_{bkf})_{ref}$ = *mean* reference reach bankfull step mean depth to bankfull riffle mean depth
d_{bkf} = *mean* bankfull riffle mean depth of the proposed design reach

$Minimum\ d_{bkfs} = (d_{bkfs} / d_{bkf})_{ref} * (d_{bkf})$ **Equation 162**

where:

$(d_{bkfs} / d_{bkf})_{ref}$ = *minimum* reference reach bankfull step mean depth to bankfull riffle mean depth

d_{bkf} = *mean* bankfull riffle mean depth of the proposed design reach

$Maximum\ d_{bkfs} = (d_{bkfs} / d_{bkf})_{ref} * (d_{bkf})$ **Equation 163**

where:

$(d_{bkfs} / d_{bkf})_{ref}$ = *maximum* reference reach bankfull step mean depth to bankfull riffle mean depth

d_{bkf} = *mean* bankfull riffle mean depth of the proposed design reach

72 — Calculate Bankfull Step Cross-Sectional Area (A_{bkfs})

Calculate the bankfull step cross-sectional area (A_{bkfs}) for the proposed design reach for the *mean*, *minimum* and *maximum* values (Record in **Table 1**, Entry 66):

$Mean\ A_{bkfs} = (A_{bkfs} / A_{bkf})_{ref} * (A_{bkf})$ **Equation 164**

where:

$(A_{bkfs} / A_{bkf})_{ref}$ = *mean* reference reach bankfull step cross-sectional area to bankfull riffle cross-sectional area

A_{bkf} = *mean* bankfull riffle cross-sectional area of the proposed design reach

$Minimum\ A_{bkfs} = (A_{bkfs} / A_{bkf})_{ref} * (A_{bkf})$ **Equation 165**

where:

$(A_{bkfs} / A_{bkf})_{ref}$ = *minimum* reference reach bankfull step cross-sectional area to bankfull riffle cross-sectional area

A_{bkf} = *mean* bankfull riffle cross-sectional area of the proposed design reach

$Maximum\ A_{bkfs} = (A_{bkfs} / A_{bkf})_{ref} * (A_{bkf})$ **Equation 166**

where:

$(A_{bkfs} / A_{bkf})_{ref}$ = *maximum* reference reach bankfull step cross-sectional area to bankfull riffle cross-sectional area

A_{bkf} = *mean* bankfull riffle cross-sectional area of the proposed design reach

73 — Calculate Bankfull Step Width/Depth Ratio (W_{bkfs}/d_{bkfs})

Calculate the bankfull step width/depth ratio (W_{bkfs}/d_{bkfs}) for the proposed design reach for the *mean*, *minimum* and *maximum* values (Record in **Table 1**, Entry 65):

$Mean\ W_{bkfs}/d_{bkfs} = W_{bkfs} / d_{bkfs}$ **Equation 167**

where:

W_{bkfs} = *mean* bankfull step width of the proposed design reach

d_{bkfs} = *mean* bankfull step mean depth of the proposed design reach

Minimum $W_{bkfs}/d_{bkfs} = W_{bkfs} / d_{bkfs}$ **Equation 168**

where:

W_{bkfs} = *minimum* bankfull step width of the proposed design reach

d_{bkfs} = *maximum* bankfull step mean depth of the proposed design reach

Maximum $W_{bkfs}/d_{bkfs} = W_{bkfs} / d_{bkfs}$ **Equation 169**

where:

W_{bkfs} = *maximum* bankfull step width of the proposed design reach

d_{bkfs} = *minimum* bankfull step mean depth of the proposed design reach

74 — Calculate Bankfull Step Maximum Depth (d_{maxs})

Obtain the bankfull step maximum depth (d_{maxs}) for the proposed design reach for the *mean*, *minimum* and *maximum* values (Record in **Table 1**, Entry 68):

Mean $d_{maxs} = (d_{maxs} / d_{bkf})_{ref} * d_{bkf}$ **Equation 170**

where:

$(d_{maxs} / d_{bkf})_{ref}$ = *mean* reference reach bankfull step maximum depth to bankfull riffle mean depth

d_{bkf} = *mean* bankfull riffle mean depth of the proposed design channel

Minimum $d_{maxs} = (d_{maxs} / d_{bkf})_{ref} * d_{bkf}$ **Equation 171**

where:

$(d_{maxs} / d_{bkf})_{ref}$ = *minimum* reference reach bankfull step maximum depth to bankfull riffle mean depth

d_{bkf} = *mean* bankfull riffle mean depth of the proposed design channel

Maximum $d_{maxs} = (d_{maxs} / d_{bkf})_{ref} * d_{bkf}$ **Equation 172**

where:

$(d_{maxs} / d_{bkf})_{ref}$ = *maximum* reference reach bankfull step maximum depth to bankfull riffle mean depth

d_{bkf} = *mean* bankfull riffle mean depth of the proposed design channel

Plot Typical Bed Feature Cross-Sections

75 — Plot Typical Cross-Sections

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

Computational Sequence 76 – 85: Calculate Longitudinal Profile Facet Slopes & Maximum Depths

Bed Feature Facet Slopes

76 — 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 (Record in **Table 1**, Entry 105):

Mean $S_{rif} = (S_{rif} / S)_{ref} * S$ **Equation 173**

where:

$(S_{rif} / S)_{ref}$ = *mean* reference reach riffle facet slope to average water surface slope

S = average water surface slope of proposed design reach

Minimum $S_{rif} = (S_{rif} / S)_{ref} * S$ **Equation 174**

where:

$(S_{rif} / S)_{ref}$ = *minimum* reference reach riffle facet slope to average water surface slope

S = average water surface slope of proposed design reach

Maximum $S_{rif} = (S_{rif} / S)_{ref} * S$ **Equation 175**

where:

$(S_{rif} / S)_{ref}$ = *minimum* reference reach riffle facet slope to average water surface slope

S = average water surface slope of proposed design reach

77 — 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 1**, Entry 107):

Mean $S_p = (S_p / S)_{ref} * S$ **Equation 176**

where:

$(S_p / S)_{ref}$ = *mean* reference reach pool facet slope to average water surface slope

S = average water surface slope of proposed design reach

Minimum $S_p = (S_p / S)_{ref} * S$ **Equation 177**

where:

$(S_p / S)_{ref}$ = *minimum* reference reach pool facet slope to average water surface slope

S = average water surface slope of proposed design reach

Maximum $S_p = (S_p / S)_{ref} * S$ **Equation 178**

where:

$(S_p / S)_{ref}$ = *maximum* reference reach pool facet slope to average water surface slope

S = average water surface slope of proposed design reach

78 — Calculate Run Facet Slope (S_{run})

Calculate the run slope (S_{run}) (water surface facet slope) for the proposed design reach for the *mean*, *minimum* and *maximum* values (Record in **Table 1**, Entry 109):

Mean $S_{run} = (S_{run} / S)_{ref} * S$ **Equation 179**

where:

$(S_{run} / S)_{ref}$ = *mean* reference reach run facet slope to average water surface slope

S = average water surface slope of proposed design reach

Minimum $S_{run} = (S_{run} / S)_{ref} * S$ **Equation 180**

where:

$(S_{run} / S)_{ref}$ = *minimum* reference reach run facet slope to average water surface slope

S = average water surface slope of proposed design reach

Maximum $S_{run} = (S_{run} / S)_{ref} * S$ **Equation 181**

where:

$(S_{run} / S)_{ref}$ = *maximum* reference reach run facet slope to average water surface slope

S = average water surface slope of proposed design reach

79 — Calculate Glide Facet Slope (S_g)

Calculate the glide slope (S_g) (water surface facet slope) for the proposed design reach for the *mean*, *minimum* and *maximum* values (Record in **Table 1**, Entry 111):

Mean $S_g = (S_g / S)_{ref} * S$ **Equation 182**

where:

$(S_g / S)_{ref}$ = *mean* reference reach glide facet slope to average water surface slope

S = average water surface slope of proposed design reach

Minimum $S_g = (S_g / S)_{ref} * S$ **Equation 183**

where:

$(S_g / S)_{ref}$ = *minimum* reference reach glide facet slope to average water surface slope

S = average water surface slope of proposed design reach

$Maximum\ S_g = (S_g / S)_{ref} * S$ **Equation 184**

where:

$(S_g / S)_{ref}$ = *maximum* reference reach glide facet slope to average water surface slope

S = average water surface slope of proposed design reach

80 — Calculate Step Facet Slope (S_s)

Calculate the step slope (S_s) (water surface facet slope) for the proposed design reach for the *mean*, *minimum* and *maximum* values (Record in **Table 1**, Entry 113):

$Mean\ S_s = (S_s / S)_{ref} * S$ **Equation 185**

where:

$(S_s / S)_{ref}$ = *mean* reference reach step facet slope to average water surface slope

S = average water surface slope of proposed design reach

$Minimum\ S_s = (S_s / S)_{ref} * S$ **Equation 186**

where:

$(S_s / S)_{ref}$ = *minimum* reference reach step facet slope to average water surface slope

S = average water surface slope of proposed design reach

$Maximum\ S_s = (S_s / S)_{ref} * S$ **Equation 187**

where:

$(S_s / S)_{ref}$ = *maximum* reference reach step facet slope to average water surface slope

S = average water surface slope of proposed design reach

Bed Feature Maximum Depths

81 — 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 1**, Entry 115):

$Mean\ d_{max} = (d_{max} / d_{bkf})_{ref} * d_{bkf}$ **Equation 188**

where:

$(d_{max} / d_{bkf})_{ref}$ = *mean* reference reach bankfull riffle maximum depth to bankfull riffle mean depth

d = *mean* bankfull riffle mean depth of the proposed design reach

$Minimum\ d_{max} = (d_{max} / d_{bkf})_{ref} * d_{bkf}$ **Equation 189**

where:

$(d_{max} / d_{bkf})_{ref}$ = *minimum* reference reach bankfull riffle maximum depth to bankfull riffle mean depth

d = *mean* bankfull riffle mean depth of the proposed design reach

Maximum $d_{max} = (d_{max} / d_{bkf})_{ref} * d_{bkf}$ **Equation 190**

where:

$(d_{max} / d_{bkf})_{ref}$ = *maximum* reference reach bankfull riffle maximum depth to bankfull riffle mean depth

d = *mean* bankfull riffle mean depth of the proposed design reach

82 — 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 1**, Entry 117):

Mean $d_{maxp} = (d_{maxp} / d_{bkf})_{ref} * d_{bkf}$ **Equation 191**

where:

$(d_{maxp} / d_{bkf})_{ref}$ = *mean* reference reach bankfull pool maximum depth to bankfull riffle mean depth

d_{bkf} = *mean* bankfull riffle mean depth of the proposed design reach

Minimum $d_{maxp} = (d_{maxp} / d_{bkf})_{ref} * d_{bkf}$ **Equation 192**

where:

$(d_{maxp} / d_{bkf})_{ref}$ = *minimum* reference reach bankfull pool maximum depth to bankfull riffle mean depth

d_{bkf} = *mean* bankfull riffle mean depth of the proposed design reach

Maximum $d_{maxp} = (d_{maxp} / d_{bkf})_{ref} * d_{bkf}$ **Equation 193**

where:

$(d_{maxp} / d_{bkf})_{ref}$ = *maximum* reference reach bankfull pool maximum depth to bankfull riffle mean depth

d_{bkf} = *mean* bankfull riffle mean depth of the proposed design reach

83 — Calculate Bankfull Run Maximum Depth (d_{maxr})

Calculate the bankfull run maximum depth (d_{maxr}) for the proposed design channel for the *mean*, *minimum* and *maximum* values (Record in **Table 1**, Entry 119):

Mean $d_{maxr} = (d_{maxr} / d_{bkf})_{ref} * d_{bkf}$ **Equation 194**

where:

$(d_{maxr} / d_{bkf})_{ref}$ = *mean* reference reach bankfull run maximum depth to bankfull riffle mean depth

d_{bkf} = *mean* bankfull riffle mean depth of the proposed design reach

Minimum $d_{maxr} = (d_{maxr} / d_{bkf})_{ref} * d_{bkf}$ **Equation 195**

where:

$(d_{maxr} / d_{bkf})_{ref}$ = *minimum* reference reach bankfull run maximum depth to bankfull riffle mean depth

d_{bkf} = *mean* bankfull riffle mean depth of the proposed design reach

Maximum $d_{maxr} = (d_{maxr} / d_{bkf})_{ref} * d_{bkf}$ **Equation 196**

where:

$(d_{maxr} / d_{bkf})_{ref}$ = *maximum* reference reach bankfull run maximum depth to bankfull riffle mean depth

d_{bkf} = *mean* bankfull riffle mean depth of the proposed design reach

84 — Calculate Bankfull Glide Maximum Depth (d_{maxg})

Calculate the bankfull glide maximum depth (d_{maxg}) for the proposed design reach for the *mean*, *minimum* and *maximum* values (Record in **Table 1**, Entry 121):

Mean $d_{maxg} = (d_{maxg} / d_{bkf})_{ref} * d_{bkf}$ **Equation 197**

where:

$(d_{maxg} / d_{bkf})_{ref}$ = *mean* reference reach bankfull glide maximum depth to bankfull riffle mean depth

d_{bkf} = *mean* bankfull riffle mean depth of the proposed design reach

Minimum $d_{maxg} = (d_{maxg} / d_{bkf})_{ref} * d_{bkf}$ **Equation 198**

where:

$(d_{maxg} / d_{bkf})_{ref}$ = *minimum* reference reach bankfull glide maximum depth to bankfull riffle mean depth

d_{bkf} = *mean* bankfull riffle mean depth of the proposed design reach

Maximum $d_{maxg} = (d_{maxg} / d_{bkf})_{ref} * d_{bkf}$ **Equation 199**

where:

$(d_{maxg} / d_{bkf})_{ref}$ = *maximum* reference reach bankfull glide maximum depth to bankfull riffle mean depth

d_{bkf} = *mean* bankfull riffle mean depth of the proposed design reach

85 — Calculate Bankfull Step Maximum Depth (d_{maxs})

Calculate the maximum step depth (d_{maxs}) for the proposed design reach for the *mean*, *minimum* and *maximum* values (Record in **Table 1**, Entry 123):

Mean $d_{maxs} = (d_{maxs} / d_{bkf})_{ref} * d_{bkf}$ **Equation 200**

where:

$(d_{maxs} / d_{bkf})_{ref}$ = *mean* reference reach bankfull step maximum depth to bankfull riffle mean depth

d_{bkf} = *mean* bankfull riffle mean depth of the proposed design reach

Minimum $d_{maxs} = (d_{maxs} / d_{bkf})_{ref} * d_{bkf}$ **Equation 201**

where:

$(d_{maxs} / d_{bkf})_{ref}$ = *minimum* reference reach bankfull step maximum depth to bankfull riffle mean depth

d_{bkf} = *mean* bankfull riffle mean depth of the proposed design reach

$$\text{Maximum } d_{maxs} = (d_{maxs} / d_{bkf})_{ref} * d_{bkf}$$ **Equation 202**

where:

$(d_{maxs} / d_{bkf})_{ref}$ = *maximum* reference reach bankfull step maximum depth to bankfull riffle mean depth

d_{bkf} = *mean* bankfull riffle mean depth of the proposed design reach

Computational Sequence 86: Plot Typical Longitudinal Profile

86 — Plot Typical Longitudinal Profile

Plot a typical longitudinal profile of the proposed design reach.

Computational Sequence 87: Prepare a Riparian Vegetation Plan

87 — Prepare a Riparian Vegetation Plan

Prepare a vegetation plan compatible with native plants, soil and site conditions. Make recommendations on vegetative maintenance and management for long-term solutions.

Summary

The nine typical design scenarios utilized the procedures detailed in this appendix 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 stream types and conditions are mapped for the *178 miles* of stream channels in the Trail Creek Watershed in *Appendix D* of the Trail Creek *WARSSS* analysis (Rosgen, 2011).