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SWAN RIVER RESTORATION
PRELIMINARY DESIGN PLAN REPORT

March 22, 2013

Prepared for:

Blue River Watershed Group

Prepared in corporation with:

ERC

Forest Service, Department of Agriculture

Town of Breckenridge Open Space & Trails

Summit County Open Space and Trails

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PO Box 1626
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ERC Project # 860-1201

Swan River Restoration
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1.0 INTRODUCTION

1.1 Project Background

The Blue River Watershed Group (BRWG) desired to complete a Preliminary Design Plan (Design Plan Plan) for restoration of the Swan River from the downstream limits approximately at the Tiger Road crossing of Muggins Gulch extending upstream approximately 12,200 feet (2.3 miles) along the center of the valley bottom (herein referred to as "Project Area"). Ecological Resource Consultants, Inc. (ERC) was contracted to develop a Preliminary Design Plan for the Project Area that combined two previously completed concept plans: 1) the Swan River Restoration Plan (October 27, 2009) (herein referred to as "2009 Plan") prepared by Summit County and 2) the Upper Swan River Restoration Plan prepared by the Blue River Watershed Group (ERC, 2012) (herein referred to as "2012 BRWG Concept Plan"). The Project Area is located both on private and public lands. This Preliminary Design Plan has been developed in close coordination with private land owners, Summit County Open Space, the Town of Breckenridge and the US Forest Service.

The total distance of the Project Area as measured along the center of Swan River valley is approximately 12,200 feet located in the Swan River drainage, a major tributary of the Blue River, in Summit County, Colorado. The entire approximately 100-acre Project Area has been extensively disturbed from historic placer mining activities. The stream corridor and valley bottom are relatively devoid of ecological function and the Swan River is highly degraded and channelized. As a result of the dredge material, the Swan River flows subsurface through portions of stream corridor. The project goal is to restore the channel and adjacent areas within the Project Area, returning them to a natural and functional state. Objectives for the Concept Plan included the following:

- Create a natural, stable channel based on existing and anticipated flows and sediment loads,
- Establish instream aquatic habitat including pools, riffles, glides, spawning and rearing areas and promote aquatic macroinvertebrate populations,
- Protect and enhance existing wetlands,
- Restore riparian and floodplain function and habitat by removing dredge piles within the riparian corridor, recontouring banks and establishing vegetation,
- Maintain groundwater return flows seeping into the stream,
- Improve the aesthetics of the area by creating a natural system with sufficient capacity to transport flood flows,
- Remove, regrade and cap remaining dredge piles to reduce erosion and promote upland revegetation,
- Demonstrate stream restoration techniques as a model for on-going efforts to reclaim other stream reaches degraded by historic dredge mining,

- Create a fish barrier structure to eliminate upstream migration of resident non-native brook trout populations and facilitate isolation of the upper Swan River Basin for native cutthroat trout habitat, and
- Account for revised and appropriate road/stream crossings which provide appropriate fish habitat and movement.

This report is similar in nature to the report prepared by ERC as part of the 2012 BRWG Concept Plan. Much of the information presented in the 2012 report is repeated herein with additional, more detailed data and design information.

1.2 2009 Summit County Plan

The 2009 Summit County Plan provided a conceptual plan for restoration for over approximately one mile of stream through 50 acres of land owned by Summit County and the Town of Breckenridge. Similar to this Preliminary Design Plan and the 2012 BRWG Concept Plan, the 2009 Summit County Plan was based on the concept of creating a natural stream corridor; however design elements presented in the 2009 Summit County Plan only provide general restoration properties and do not include the level of detail in either analysis of geomorphologic characteristics or appropriate channel geometry. The 2009 Summit County Plan presents typical templates for proposed stream geometry, but lacks specific design elements including channel widths and design elevations necessary to achieve sustainable restoration.

This Preliminary Design Plan takes basic information presented in the 2009 Summit County Plan to a level that is compatible with the 2012 BRWG Concept Plan including providing preliminary level elevations and appropriate channel widths and geometry for both earlier projects.

1.3 2012 BRWG Concept Plan

The 2012 BRWG Concept Plan was developed by ERC. The 2012 BRWG Concept Plan included restoration of the upper Swan River from the Summit County property line extending approximately 6,900 feet upstream along the valley bottom. The 2012 BRWG Concept Plan called for dredge material to be removed and a meandering stream channel to be created within the confines of the valley. Channel alignment was generally defined to match stream planform observed in natural stream settings. Provisions were made to allow continued use of a majority of the valley across private property by confining channel alignment near the edge of the valley as it crosses this property. The proposed alignment also follows an existing stream segment near the confluence of the North Fork of the Swan River to utilize the stream and riparian area that appear to be properly functioning.

The project also includes plans for creation of a riparian zone generally parallel and extending a minimum of 50 feet on either side of the stream. Uplands would be created from the exterior of the riparian zone and extend outward to match existing vegetation on both sides of the riparian corridor.

2.0 PROJECT AREA

2.1 Location

The Project Area is located in the upper Swan River drainage in Summit County Colorado. It includes approximately 2.3 miles and 100-acres of the surrounding valley bottom. The downstream end of the Project Area is located at Latitude: 39.525735° North, Longitude -105.971660° West and the upstream extent is located at Latitude 39.501191° North, Longitude -105.946749° West. Project Area location maps are provided in **Figure 2.1** and **2.2**.

Figure 2.1. Project Area Location Map.

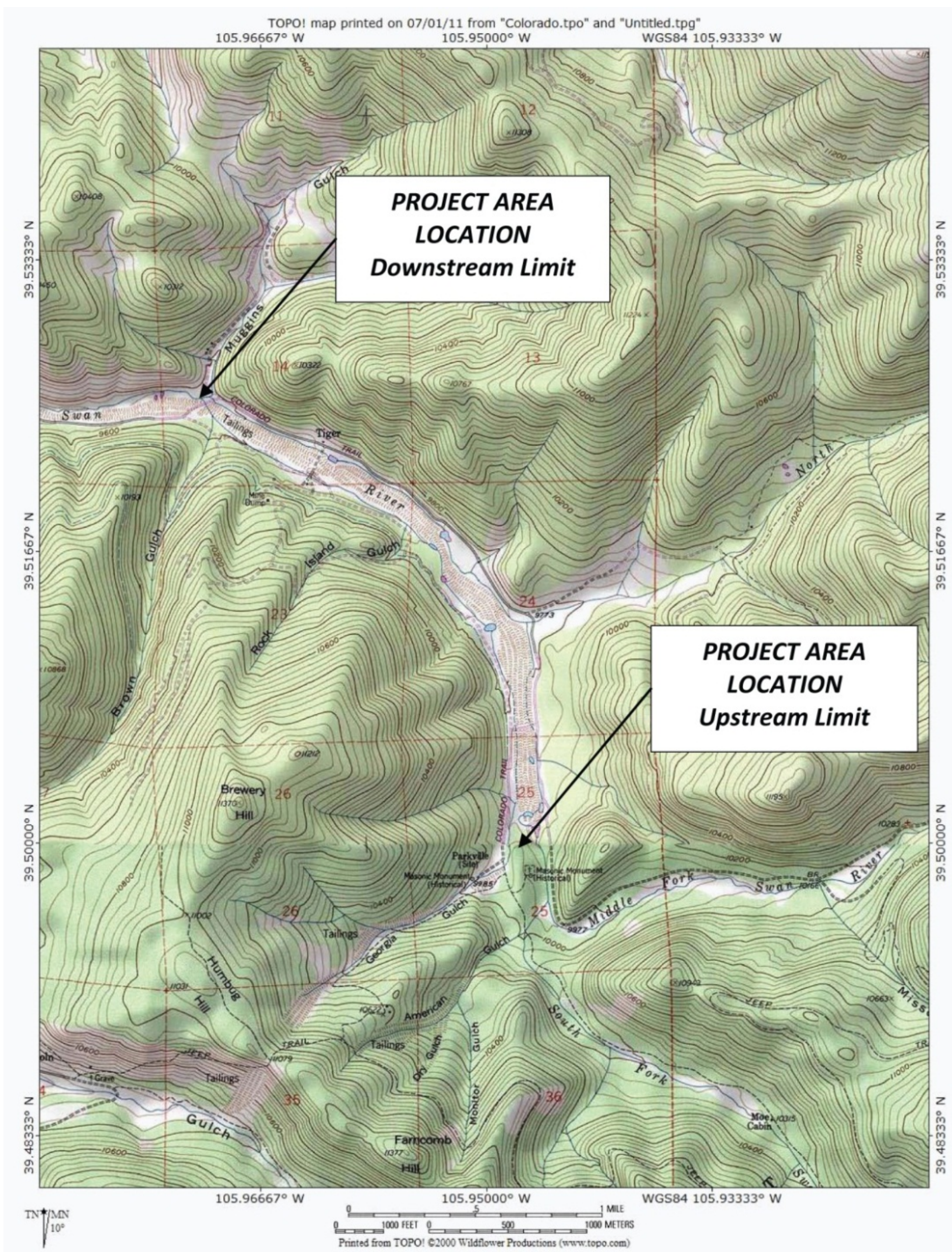
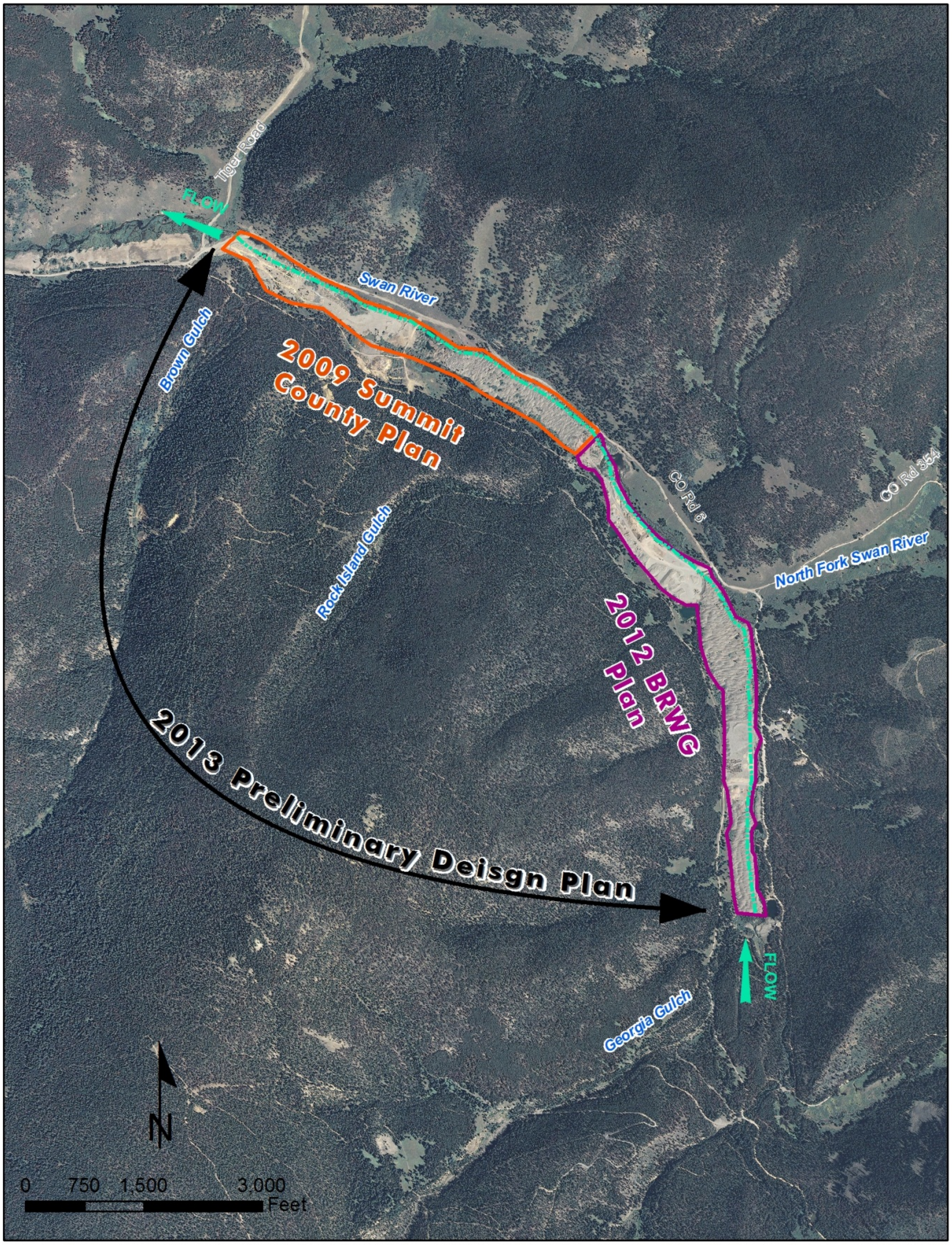


Figure 2.2. Preliminary Design Plan in Relation to the 2009 Summit County Plan and 2012 BRWG Concept Plan.



The Project Area has been historically mined using placer mining techniques. Dredging was completed to an unknown depth throughout the Swan River Valley as well as the nearby Blue River Valley. Dredge spoils remain on the Project Area and typically consist of sand to cobble sized materials left in piles that extend approximately 25 feet above the surrounding valley floor. The entire Project Area is generally devoid of natural vegetation and ecological function as a result of past mining activities. Sporadic pockets of shrubs or young trees may exist near the existing Swan River channel or where groundwater surfaces. In portions of the Project Area, dredge material has been removed or is currently being removed and sold commercially. A majority of the dredge material that has been removed from the valley for commercial purposes was located in the lower portion of the Project Area within the 2009 County Plan area. The stream has been channelized in large part by the mining process and natural riparian areas are minimal to nonexistent throughout the Project Area. Removal of the dredge material and restoration of a natural stream and riparian system are the primary focus of this Preliminary Design Plan. **Figure 2.3** and **Figure 2.4** show historic and present conditions in the project area.

Figure 2.3. Dredges used in the Swan River Valley in the early 1900s.

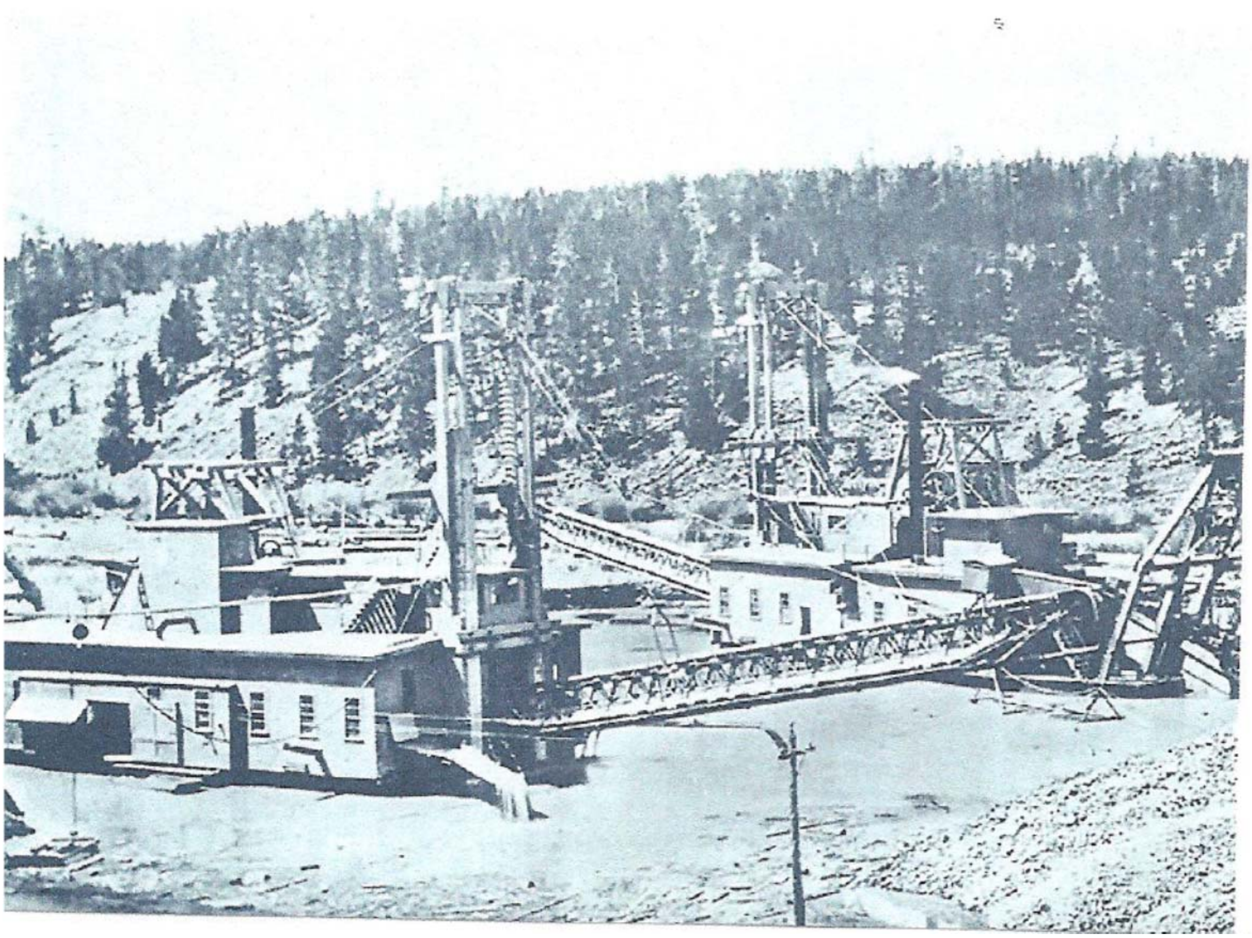


Figure 2.4. Existing Dredge Piles and General Site Characteristics of the Project Area.

3.0 HYDROLOGY

3.1 Surface Water Hydrology

Estimates of flow through the Project Area were completed in order to obtain and understand the magnitude and variability of flows that can be expected. Flow data were then used to estimate appropriate channel properties and define key hydrological design parameters.

No stream gage exists on the Swan River, therefore an evaluation was performed of regional gages and results were used as one method to estimate flows through the Project Area. Regional streamflow gages were evaluated for completeness, proximity to the Project Area and tributary drainage areas. Gages with relatively long, continuous records that are not impacted by diversions in close proximity to the Swan River basin and having tributary areas similar to the Swan River were preferred.

Four local gages were identified and evaluated. They included Keystone Gulch near Dillon (USGS Station 09047700), Snake River near Montezuma (USGS Station 09047500), Rock Creek near Dillon (USGS Station 0905200) and Turkey Creek near Red Cliff (USGS Station 09063400). Data on the four drainages are summarized in **Table 3.1**.

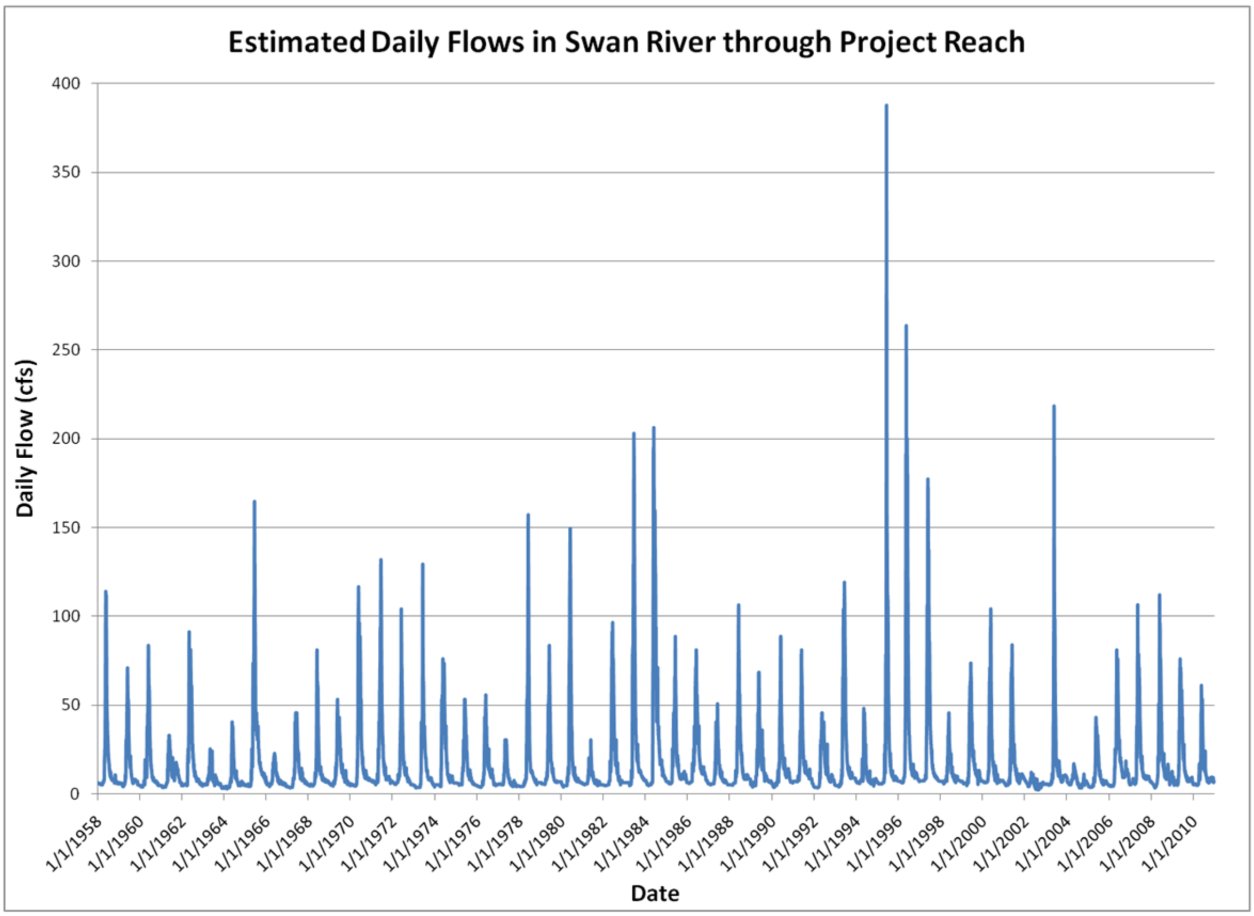
Table 3.1. Local Streamflow Gages.

Gage	Location	Period of Record	Drainage Area	Comments
Keystone Gulch	39° 35' 40" 105° 58' 19" (6.0 miles away)	October 1957 to present	9.10 mi^2	No upstream diversions
Snake River	39° 36' 20" 105° 56' 33" (6.6 miles away)	July 1942 to September 1946, October 1951 to present	57.7 mi^2	Small upstream diversions
Rock Creek	39° 43' 23" 106° 07' 41" (17 miles away)	October 1942 to September 1994	15.8 mi^2	No upstream diversions
Turkey Creek	39° 31' 22" 106° 20' 08" (21.0 miles away)	October 1963 to September 2008	23.8 mi^2	No upstream diversions

Keystone Gulch was selected as likely to be the most representative of the Swan River due to the similar drainage basin sizes, proximity to the site and the orientation of their drainages. Estimates of daily flows at the site were derived using the Keystone Gulch data; bankfull flow estimates were derived using estimates from all four stations for comparison.

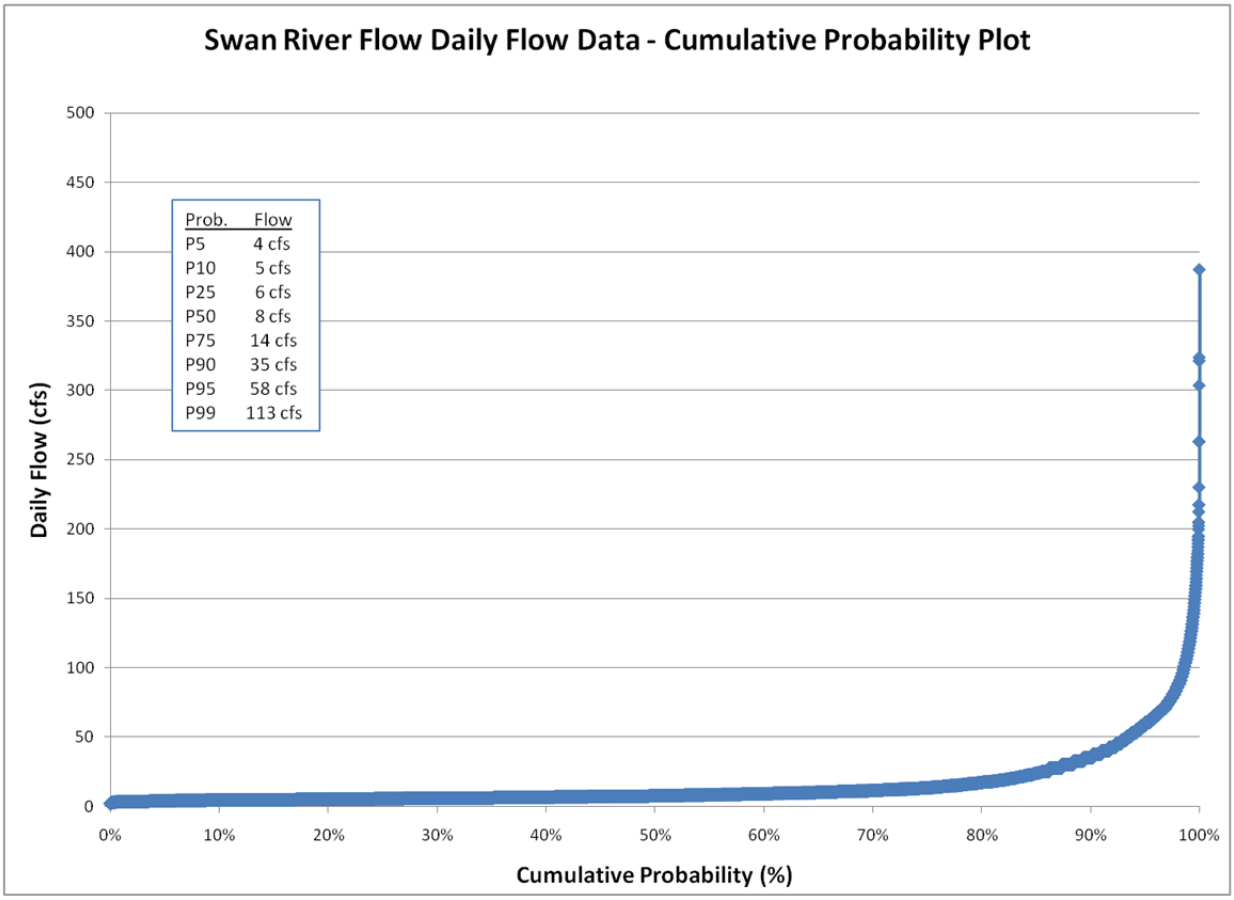
Flow estimates for the Swan River were then made based on available data from Keystone Gulch from 1958 through 2010. Daily flows measured at Keystone Gulch were multiplied by 2.53 to adjust flows from this 9.10 square mile basin to estimate daily flows at the Project Area. Estimated daily flows through the Project Area over this 53 year period of record are shown on **Figure 3.1.** Note that a straight basin adjustment was used for these daily flows. Unlike flood flows where additional adjustment is often used, a straight basin ratio was taken when looking at daily data following the idea that the unit runoff from both basins would be similar.

Figure 3.1. Estimated Daily Swan River Flows.



As would be expected, flows show a definite seasonal trend with peak flows occurring as the result of spring runoff. Flows through the late fall and winter are typically the lowest. A cumulative probability plot of estimated daily flows was developed to quantify the percentage of times flows are less than a given flow magnitude. Results of the flow frequency analysis are shown on **Figure 3.2.**

Figure 3.2. Cumulative Probability Plot – Daily Flows.

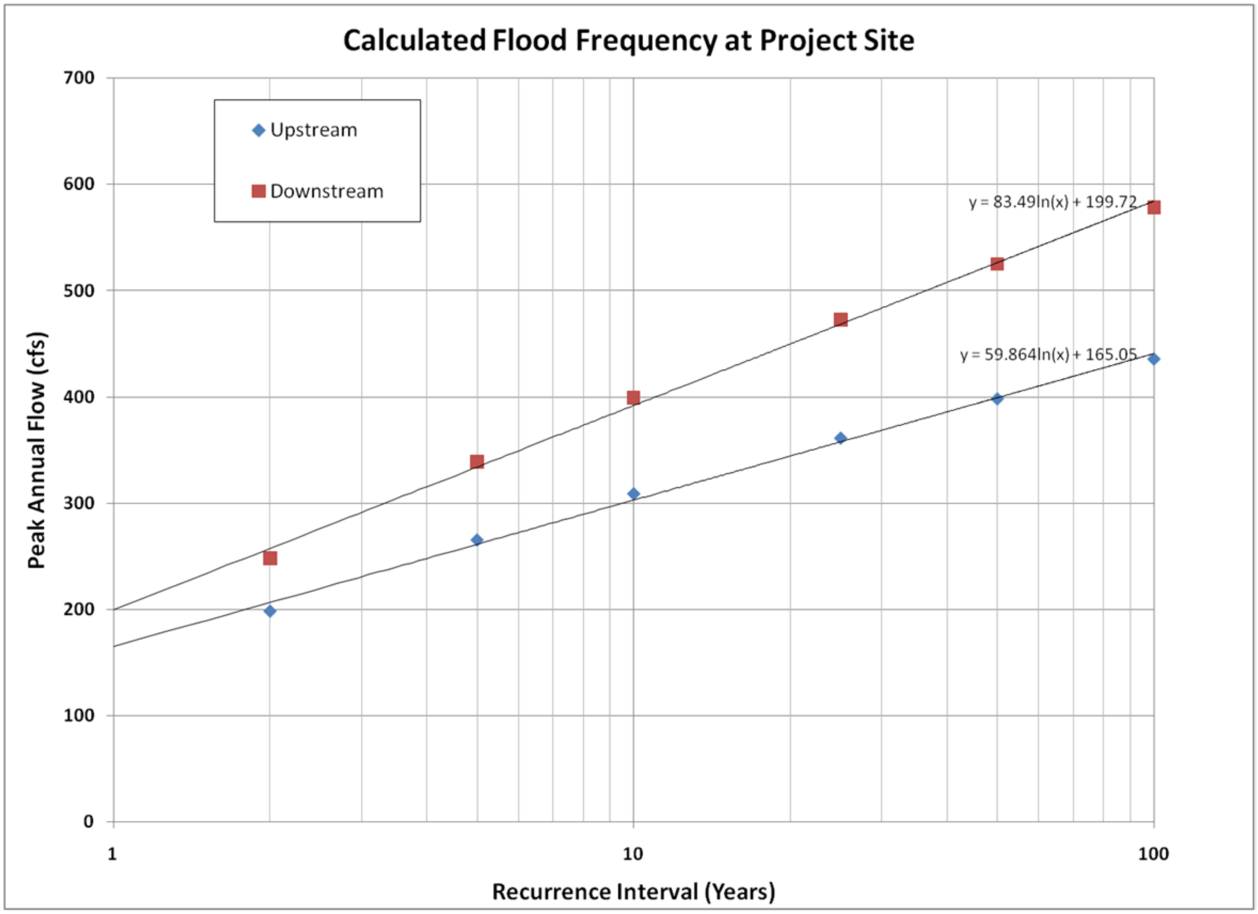


Results indicate that 5% of the time, flows are predicted to be at or below 4 cubic feet per second (cfs) based on extrapolation from the Keystone Gulch gage. Flows are expected to be at or below 8 cfs 50% of the time and at or below 58 cfs 95% of the time. Over the 53 years flows are estimated to range from a low of approximately 2.2 cfs to a high of 390 cfs.

Peak flow estimates for the project site were then made using the regional flood-frequency equations for ungaged stream reaches established by Vaill (2000). Estimates were made at the upstream and downstream project extents for the 2- through 100-year floods using the equations for mountain regions. An estimate of the 1.5-year event was obtained by extrapolation.

Flood flow estimates were used to develop conceptual channel geometries, specifically to estimate bankfull flow. Bankfull flow was assumed to have a recurrence interval of approximately 1.5 years. For the restoration design, the bankfull flow is intended to be the point where bank vegetation will be established. **Figure 3.3** shows the flood flow values calculated by the Vaill method for both the upstream and downstream project reaches, extrapolated to include the 1.5-year flood event. Based on this information, the bankfull flow is assumed to be on the order of 190 cfs – 230 cfs.

Figure 3.3. Estimated Flood Flow Frequencies at the Project Site.



There is an inherent uncertainty in the estimate of bankfull flows at an ungaged location. Errors are greater for the more frequent flood events and range from 59.6% for the 2-year event to 43.4% for the 100-year event (Vaill 2000). A number of checks on this important design input were therefore performed as part of the preliminary design. One check included review of available references to check estimates of larger flows against flow estimates at the other gages. A second check involved field surveys and hydraulic modeling to estimate bankfull flow further downstream on the Swan River.

As a first check on the numbers presented above, peak flows were estimated based on data from Keystone Gulch, the Snake River, Rock Creek and the Turkey Creek gage sites. At each of these locations peak flow estimates contained in the Vaill 2000 report were compiled. The 1.5-year event at each location was extrapolated using probability plotting based on estimated flows. A graph showing plotted flood frequency data for each of the four sites is provided in **Figure 3.4**. Results using these various locations are summarized in **Table 3.2.**

Figure 3.4. Estimated Flood Flow Frequencies at Regional Station.

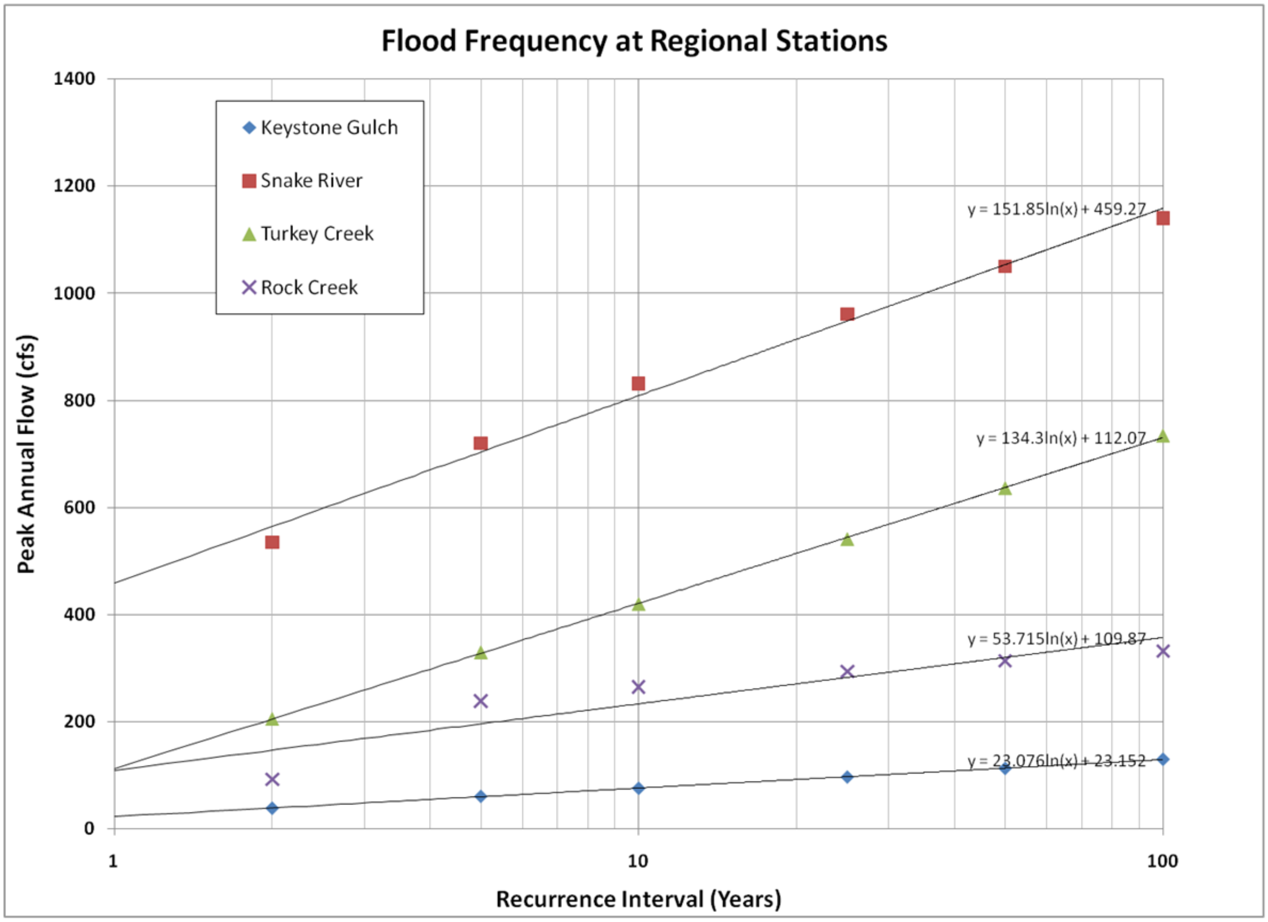


Table 3.2. Comparison of 1.5-Year Flow Estimates at Different Locations.

Site	Area (mi^2)	1.5-Year Flow Estimate (cfs)	Unit 1.5-Year Flow (cfs/mi^2)
Keystone Gulch	9.10	33	3.63
Rock Creek	15.8	132	8.35
Snake River	57.7	521	9.03
Turkey Creek	23.8	167	7.02
Mean	NA	NA	7.01
Median	NA	NA	7.69

Results show a range of unit flows from 3.63 cfs per square mile to 9.03 cfs per square mile with a mean and median of 7.01 cfs per square mile and 7.69 cfs per square mile, respectively. Graphical results suggest that all data except Rock Creek tend to plot well on trend lines. Utilizing the mean and median unit flows presented in the table result in a 1.5-year flow of 102 cfs and 112 cfs, respectively at the upstream end of the project. Unit flow values produce a 1.5-year flow of 160 cfs for the mean value and 176 cfs for the median value at the downstream end of the project.

Estimates of bankfull flow were then made based on physical conditions in a downstream section of the Swan River in an attempt to add certainty to the bankfull flow estimate used in design. This is believed to provide the most accurate estimate of bankfull flow as it is based on physical observations rather than empirical, regional estimates. The Forest Service completed a survey on May 31, 2012 to aid in the evaluation of bankfull flow. The survey was completed on a section of the Swan River near the dredge boat on Summit County Open Space land. The river at this location has a tributary drainage area of 28.9 square miles. Calculations by the Forest Service indicate a bankfull flow of 101 cfs at the dredge boat site. Details of the Forest Service's bankfull flow estimates including a sensitivity analysis is presented in **Appendix B**.

ERC and the Forest Service discussed the field methods employed and results and concluded that given the condition of the site investigated it is likely that there is significant subsurface flow at the dredge boat site that should be considered when estimating actual bankfull flow. The actual quantity of flow that may be conveyed in the subsurface is not practical to quantify from physical measurements. Given the stream size and location, however, it is reasonable to assume that the Swan River would be a perennial stream. As the stream is observed to be dry or nearly dry conditions at different times, it is likely that flows on the order of average baseflows may be occurring subsurface. Adding average baseflows to the bankfull estimate calculated by the Forest Service likely improves the accuracy of the bankfull flow estimate that should be used in the design.

ERC therefore estimate baseflows at the dredge boat site for inclusion with the bankfull flow estimate by the Forest Service. Four different procedures were evaluated. ERC selected a flow of 17 cfs as the baseflow based on the results of this analysis. Details of the baseflow calculations are provided in **Appendix C**. Adding 17 cfs of baseflow to the calculated (surface) bankfull flow of 101 from the Forest Service results in a total bankfull flow estimate of 118 cfs at the dredge boat site.

Estimates of bankfull flow were then made at the project site based on drainage areas following methods suggested by Vaill (2000). The drainage area at the upstream end of the project site and downstream from the North Fork of the Swan, which is the largest tributary along the project length are 14.6 and 22.9 square miles. Using these aerial adjustments results in an estimated bankfull flow of 80 cfs and 103 cfs, respectively for this method.

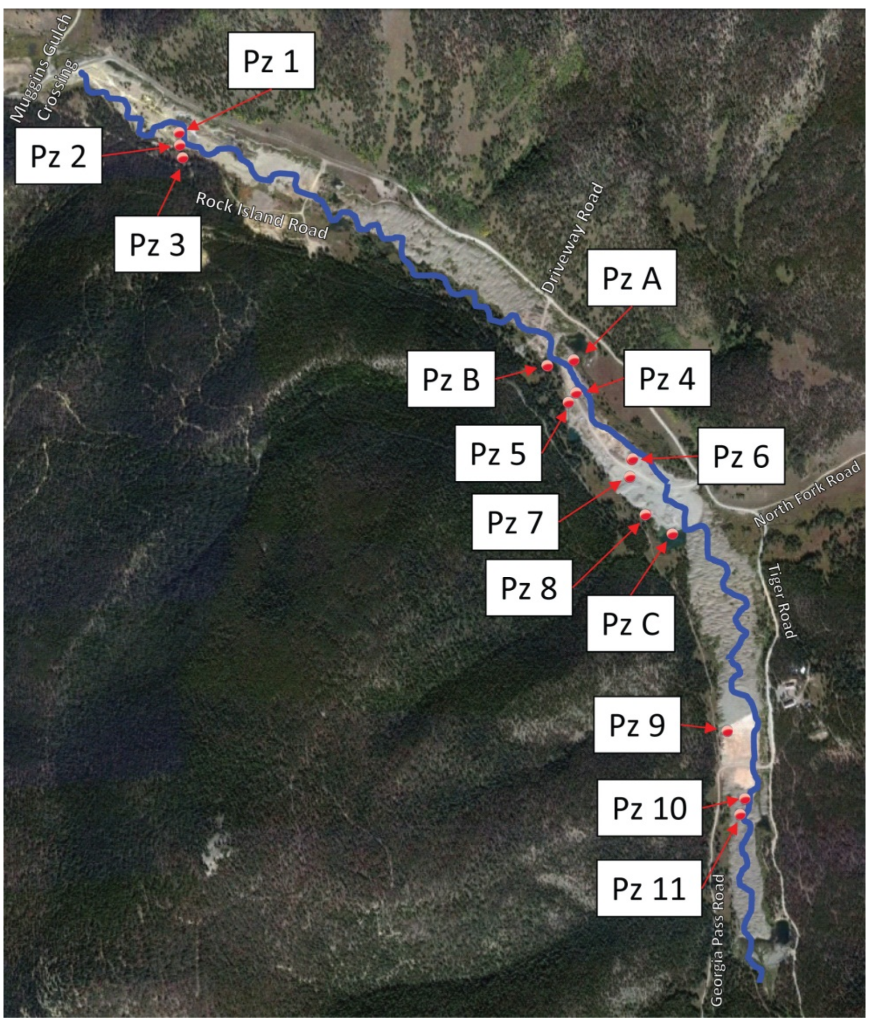
3.1.1 Bankfull Flow Estimates

Estimates of bankfull flow values derived from physical measurements plus baseflows are believed to be the most accurate method available. For this reason bankfull flow estimates at the upstream and downstream ends of the Project Area were assumed to be 80 cfs and 103 cfs, respectively. A bankfull flow value of 80 cfs was used for areas upstream of the North Fork tributary confluence and a value of 103 cfs was used downstream of the North Fork tributary confluence.

3.2 Groundwater Hydrology

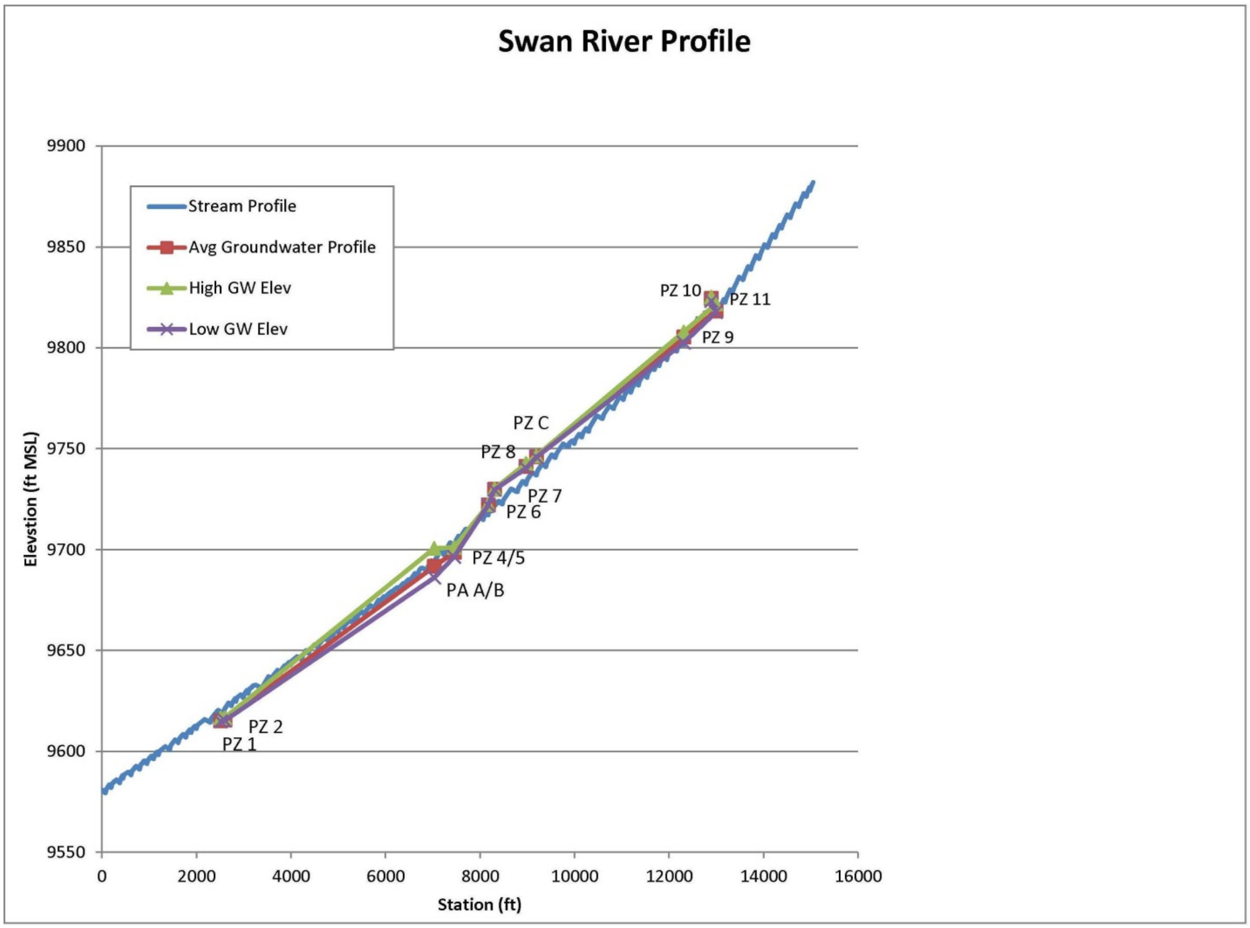
Given that the existing stream runs subsurface through the Project Area, obtaining a better understanding of groundwater levels was an important aspect of the preliminary design process. A series of 14 piezometers were installed by the Everist Materials, LLC and monitored by the Forest Service at locations intended to provide spatial coverage of the Project Area while considering access and current topography created by the dredge piles. The locations where groundwater was measured from piezometers are shown on **Figure 3.5.**

Figure 3.5. Locations of Ground Water Piezometers.



Readings were taken by the Forest Service and consisted of 18 water depth measurements from each of 14 separate piezometers. Measurements were taken approximately weekly between June and November 2012. Raw data were compiled into highest, lowest, and average groundwater elevations in each piezometer over the sample period. These elevations were plotted in profile with the proposed stream elevation by matching piezometers to the closest stream station. This plot is shown in **Figure 3.6**. It should be noted that ERC projected groundwater elevations to the stream location, so some variability is inherent in this figure. Graphs displaying the temporal variation in water levels at the different piezometers are included in **Appendix A**.

Figure 3.6. Groundwater and Stream Profiles.



A comparison of the proposed steam profile with the groundwater levels indicated that in general the two surfaces are quite similar but at certain locations and times the groundwater levels appear to be below the proposed stream bed. This is particularly true in the downstream section of the project in the vicinity of PZ 1 and 2 (near STA 25+00), and PZ 4 and 5 (near STA 74+00). In these locations stream bed elevations are generally 1-4 feet higher than the highest groundwater elevations. In general, groundwater levels appear to be lower than the proposed streambed in the vicinity of piezometers downstream of Driveway Road. Groundwater levels in these piezometers generally showed very minimal variation during the period when data was collected and suggest that average groundwater levels may be approximately 2-6 feet below the proposed streambed at these locations.

Data were compiled to compare the proposed streambed elevation with the range of groundwater elevations observed from the nearest piezometers. High, average and low groundwater levels are compared with stream elevations with differences provided. Results are given in **Table 3.3** and include the difference in completed groundwater and streambed elevation. In this table positive values indicate areas where the streambed is above apparent groundwater while negative values indicate areas where the stream is below the apparent groundwater level. PZ 3 was not included in the analysis because it is approximately 200 feet from the stream and may not accurately reflect groundwater levels in the vicinity of the stream bed.

Table 3.3. Comparison of Stream and Ground Water Elevations.

PZ	STA	Stream El. (ft)	Groundwater El. (ft)			Distance between Stream and Groundwater El. (ft)		
			High	Average	Low	High	Average	Low
1	25+18	9,619.8	9,616.5	9,615.3	9,614.9	3.2	4.5	4.9
2	26+00	9,624.1	9,616.7	9,615.6	9,615.3	7.4	8.5	8.8
A/B	70+35	9,693.2	9,700.6	9,691.7	9686.2	-7.4	1.5	7.0
4/5	74+55	9,702.1	9,701.1	9,698.7	9,696.5	1.0	3.4	5.6
6	81+75	9,717.1	9,722.3	9,722.1	9,722.1	-5.2	-5.0	-5.0
7	83+10	9,722.6	9,730.2	9,729.9	9,729.7	-7.6	-7.3	-7.1
8	89+75	9,732.4	9,742.7	9,741.2	9,740.4	-10.3	-8.8	-8.0
C	91+95	9,736.9	9,746.5	9,746.0	9,745.9	-9.6	-9.1	-9.0
9	12+315	9,801.5	9,807.9	9,805.4	9,802.6	-6.4	-3.9	-1.1
10	12+995	9,816.4	9,821.7	9,818.2	9,817.7	-5.3	-1.8	-1.3
11	12+900	9,822.6	9,825.1	9,824.5	9,823.3	-2.5	-1.9	-0.7

Overall data suggests that groundwater and proposed streambed elevations are generally very similar in the upper portions of the Project Area and groundwater is believed to be below the proposed streambed in the lower reaches. Given that the current plan is to complete restoration of the upper most section first, it is anticipated that the proposed streambed will be very near the groundwater levels for the Reach D work. ERC believes that continued monitoring of groundwater is warranted as it will allow the group to better understand the relationship of these parameters and potentially guide minor design revisions moving forward with future work.

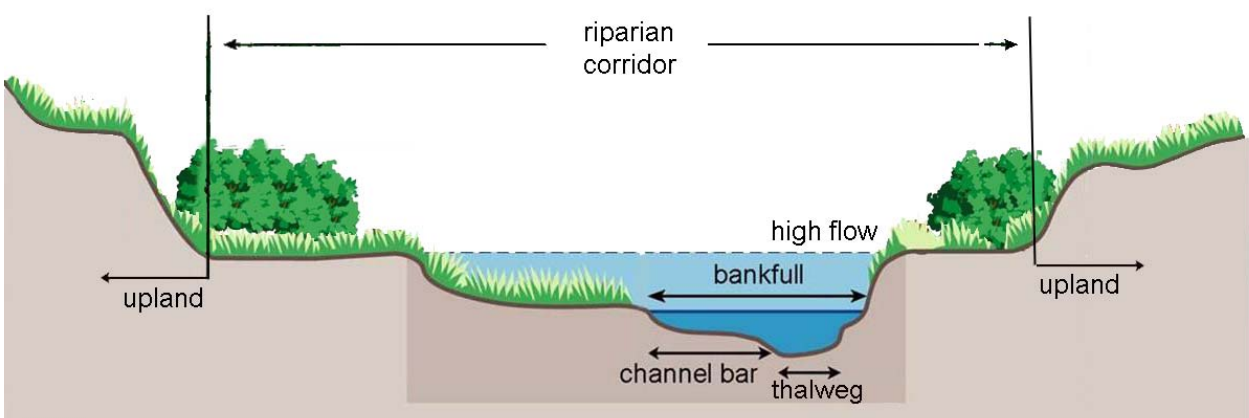
4.0 PRELIMINARY DESIGN PLAN CONCEPTS

4.1 Natural Restoration Concept

A natural based restoration approach was taken for all proposed improvements, whenever possible. The guiding principle of ERC's natural restoration approach is that a restored stream system should mimic a natural channel in appearance and function. Restoring the natural form and function within the stream system will allow lost balance and ecologic benefits to be restored. Like a natural channel, restoration was approached with a design that will allow the stream to migrate in response to flow and sediment loads, but is intended to maintain its basic form without significant aggradation or degradation. This approach, rather than a structural approach to restoration, is of the utmost importance to this project so that the restored resources function holistically and restore the desired natural characteristics throughout the Project Area.

As part of this approach, design concepts considered improvements to the channel and the connection between the stream and adjacent lands. Improvements recommended as part of this Preliminary Design Plan include an appropriately sized channel to convey typical and bankfull flow events, a riparian corridor and transitions into upland areas. A schematic showing the relationship between the stream and adjacent lands considered in this Preliminary Design Plan is presented in **Figure 4.1.**

Figure 4.1. Schematic of Stream and Adjacent Lands in a Natural System.



Natural stream improvements are sustainable, provide natural resource benefits, promote active recreation such as angling and passive recreation such as bird watching and relaxing, and result in a stream corridor that is aesthetically pleasing. ERC's restoration approach incorporates features that would be found in an undisturbed ecosystem and is based on fundamental geomorphologic and reference reach principles. For the project setting, natural restoration includes features such as riffles, bend pools, glides, instream habitat, stable vegetated banks and riparian and upland vegetation.

Structural stream control features such as rock weirs, arches, jetties and vanes that are common to many stream projects, yet are not natural features, were not considered as part of this natural design approach.

4.2 Aquatic Environment

The aquatic environment will be the life-blood of the restored Swan River local ecosystem providing forage, protection, spawning and rearing habitat for fish and other aquatic species as well as the hydrological regime to maintain a riparian community. Many factors contribute to the quality of an aquatic ecosystem. Water quality is probably the single most influential component. Water quality elements such as temperature, pH, dissolved oxygen and suspended solids can determine the productivity of a stream system. From an aquatic standpoint, historic mining activities through the Project Area have left the Swan River relatively devoid of natural features. Slow moving deep pool habitat, steeper, oxygenated riffle sections, slack backwater areas and gravel spawning beds are all important habitat typical of western streams. Instream cover (rocks, undercut banks, logs and debris) and overhead vegetation are imperative to support healthy macroinvertebrate and fish populations. These characteristics are not present through the Project Area and are the focus of the instream habitat features of the Preliminary Design Plan.

Specifically of concern is preservation of a known nearly pure genetic strain of the native cutthroat trout located upstream on the North Fork tributary. The Forest Service has expressed a desire to restore the entire Project Area, through eradication of existing non-native brook trout (*Salvelinus fontinalis*) and creation of fish movement barriers. Today, remaining native cutthroat populations are primarily limited to small headwater streams and lakes within their historic range. The US Department of Agriculture Forest Service 2005 Range-Wide Status of Colorado River Cutthroat (CRCT) states that approximately 21,386miles of stream habitat were identified as having the potential of being historically occupied by CRCT, of which about 13,615 are in Colorado. Currently CRCT occupy only about 1,359 miles of stream in Colorado, of which 46-miles is located in the Blue River Hydrologic Unit Code (HUC) 14010002. Of the total existing CRCT habitat the study further states that only 12.4% is considered excellent in Colorado.

The Preliminary Design Plan focuses on creating a healthy, diverse and self-sustaining aquatic environment which includes specific habitat requirements for native cutthroat trout. As defined by the US Fish and Wildlife Service's Habitat Suitability Indexes (HSI, February 1982), optimal cutthroat trout riverine habitat can be characterized by clear, cold water; a silt-free rocky substrate in riffle-run areas; an approximately 1:1 pool-to-riffle ratio, with areas of slow, deep water; well-vegetated stream banks; abundant instream cover; and relatively stable water flow, temperature regimes, and stream banks.

Cover and overwintering habitat are recognized as essential components of trout streams. Cover for adult trout consists of areas of obscure stream bottom in areas of water greater than 15 centimeters deep with a low velocity of less than 15 centimeters per second. These basic principles serve as the fundamental guidelines for instream aquatic environment developed as part of the Preliminary Design Plan.

One of the initial objectives of this project was to provide a fish barrier structure intended to eliminate upstream migration of resident non-native brook trout populations and facilitate isolation of the upper Swan River Basin for native cutthroat trout habitat. Through discussions with the Forest Service and project proponents throughout the development of this Preliminary Design Plan it was decided that the fish barrier would ideally be located at the existing Tiger Road Crossing of Muggins Gulch.

The barrier will be a drop barrier, taking advantage of the existing grade break from the upstream to the downstream side of the existing Tiger Road crossing. Site surveys indicate that the elevation difference from the invert on the upstream (east) side of the road to the channel invert on the downstream (west) side of the road is currently 7.9 feet (2.4 meters).

The existing grade break across the road was compared with literature values on brook trout jump heights. The highest recorded jump height for brook trout in research reviewed was 73.5 cm (2.41 feet) by brook trout in the 15 – 20+ cm size range in a laboratory setting (Kondratieff 2006). The jump heights recorded in this study were 2.9 – 4.0 times the fish body length, and maximum jump heights were only achieved when downstream plunge pools were at least 40 cm deep (1.6 times their body lengths). Another study indicates the field observation of brook trout passing a 1.2 m waterfall complex (Adams 2000). This 1.2-m-high falls complex was comprised of a 0.5 m high upper step and a 0.7 m high lower step separated by a plunge pool less than 0.2 m deep. It is our opinion that this report is not indicative of a brook trout being able to effectively clear a 1.2 m vertical drop as there was an intermediate step. In addition, no consideration appears to have been given for the downstream tailwater condition. Other reports indicate that other species including brown trout and rainbow trout have maximum jump heights of 2.5 feet, and 2.8 feet, respectively (Saila 2005). Discussions with Matt Kondratieff (2013) from Colorado Parks and Wildlife indicate that the State of Colorado uses a minimum four foot drop height from tailwater depth to crest of the upstream surface. ERC recommends that a vertical depth of at least four feet above the tailwater should be maintained. Maintaining this minimum height and a quality barrier are paramount to the success of the native cutthroat trout restoration goal. The nearly eight (8) feet of vertical separation provided by the Tiger Road crossing therefore is believed to be more than adequate to prevent upstream fish migration into the upper Swan River section even when accounting for a significant tailwater depth.

5.0 CHANNEL MORPHOLOGY

One of the key components of the restoration design was establishing the appropriate geometry for the restored stream. Appropriate channel widths were estimated for the 2012 BRWG Concept Plan based on standard geomorphologic principles and verified by review of "representative conditions" identified within the Project Area. Appropriate channel planform was estimated based on typical properties for the anticipated stable stream type following the Rosgen Classification system (Rosgen 1996).

In addition, ERC completed a HEC-RAS model of the proposed channel configuration to refine initial channel geometry estimates. Channel geometry derived from standard geomorphologic principles as well as information resulting from the more detailed hydraulic modeling are presented in this section.

5.1 Bankfull Channel Width

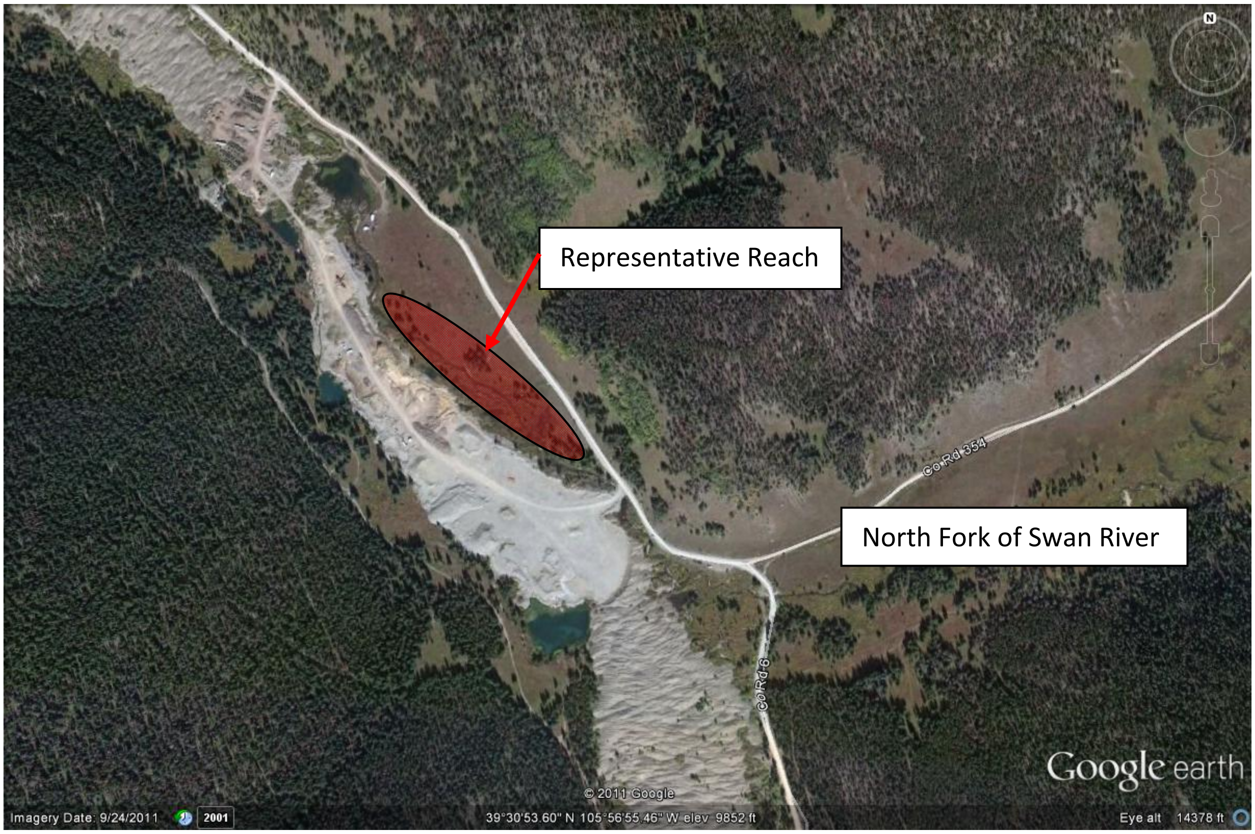
The approximate width for the restored channel was estimated based on observed relationships relating basin area to bankfull width (Leopold 1994), (Rosgen 1996). For the Project Area, bankfull width is the width of the channel where it first starts to overflow into its floodplain. As indicated above, the Swan River through the Project Area has a total tributary area of approximately 22 square miles. Standard regional geomorphologic curves suggest that for this sized basin the active channel should be on the order of 25 - 30 feet wide with a mean depth of approximately 1.5 feet at riffle sections.

Observations of sections of the stream that are currently properly functioning were used as a check against the values estimated using the basin area/width geomorphologic relationships. For this assessment the stretch of the Swan River downstream from the confluence with the North Fork of the Swan River was evaluated. The location of this "representative reach" is shown on **Figure 5.1.**

While this section of stream may or may not have been impacted in the past, it is currently functioning well with stable channel cross sections and profile and a healthy riparian area. As discussed in more detail below, the stream through the representative reach is generally straighter than typical for this type of a valley, which generally relates to narrower cross sections.

Existing bankfull channel widths were measured at five locations within this representative reach by ERC as part of a site investigation in September of 2011. All bankfull measurements ranged from 20 – 25 feet. Measured bankfull widths are within the general range of the widths estimated based on standard geomorphologic data indicating a good relationship between widths estimated from standard geomorphologic principles and those measured in the field. Results lead to the design geometry of 25 foot bankfull width in riffle sections. Bankfull stream widths for the riffles sections and in pool and glide sections (areas between riffles) were then further refined through the use of hydraulic modeling.

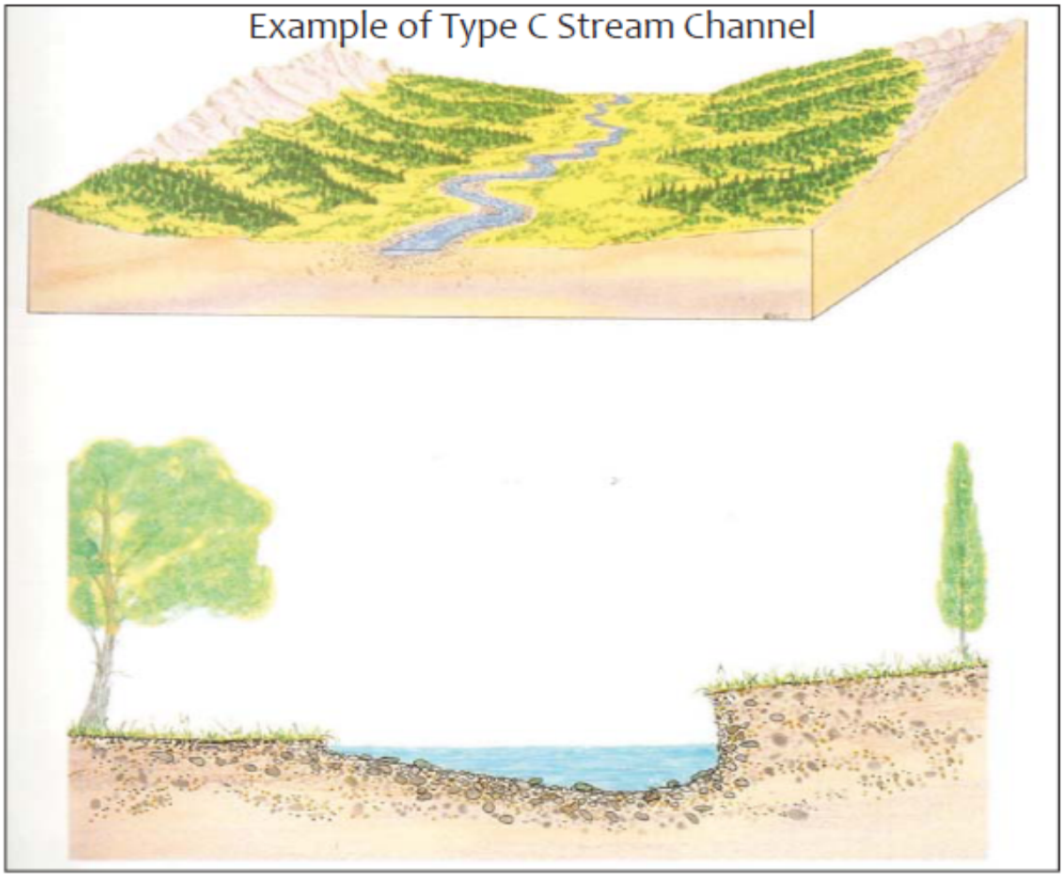
Figure 5.1. "Representative Reach" within Project Area.



5.2 Channel Planform

Channel planform, or shape as observed from above, was estimated based on the stream type that is assumed to be appropriate through the Project Area. As part of this assessment other regional streams were evaluated and it was found, as would be expected, that a majority of healthy streams in this area are single thread systems. Given this and the broad, terraced valleys observed in other segments of the Swan River, ERC believes that a Rosgen Cb Stream Type is an appropriate target for the restored channel segment. A Type Cb stream is a single thread channel alluvial stream, as shown in **Figure 5.2.** It typically includes a meandering planform with point bars and riffle/pool sequences and has a broad, defined floodplain.

Figure 5.2. Schematic of Typical Type C Stream.



Source: Rosgen 1996

Typical published values for stream sinuosity, slope, meander wavelength and entrenchment for Type Cb3 and Cb4 streams are given on **Table 5.1** where “3” and “4” indicate the dominate substrate are cobbles and gravels, respectively.

Table 5.1. Typical Type Cb Stream Properties.

Category	Criteria
Channel Slope	2 % - 3.99%
Pool Spacing	5-7 Times Bankfull Width
Width/Depth Ratio	> 12
Entrenchment Ratio	>2.2
Sinuosity	>1.2

Meander lengths and mean radii of curvature can be approximated from channel width. A mean channel width of 25 feet relates to a meander length of approximately 280 feet and a radius of curvature of approximately 60 feet (Leopold 1992).

The conceptual planform view for the restored stream section was developed based on these general guidelines. By design, not all sections of the proposed stream exactly fit within the criteria of a typical Type Cb stream due to the desire to provide variability in the stream geometry, as one finds in natural stream systems. The proposed stream planform can be seen on **Sheets 1-8** in **Appendix D**. A summary of the average properties measured from the proposed Concept Plan is given on **Table 5.2.**

Table 5.2. Characteristics of Conceptual Level Restoration.

Category	Value
Valley Length (ft)	11,760
Stream Length (ft)	15,055
Stream Sinuosity	1.28
Number of Bend Pools	91
Average Pool Spacing (ft)	165 (6.6 bankfull widths)
Riffle Bankfull Width (ft)	25
Riffle Bankfull Depth (ft)	1.5
Width/Depth Ratio	16.7
Average Channel Slope	2.0%
Floodprone Depth (ft)	3
Floodprone Width (ft)	175
Entrenchment Ratio	7

5.3 Stream Profile

Typically a proposed stream profile would include information on existing and proposed elevations. This effort was limited by the fact that detailed topographic mapping of the full Project Area is not available. ERC completed a limited site survey which included selected point locations along the existing stream channel, at all existing stream crossings, at select locations where groundwater intercepts the surface and at the upstream and downstream ends of the Project Area. This information was supplemented by detailed survey data provided by the Forest Service at the extreme upstream and downstream ends of the Project Area well as two foot contour interval mapping available over the downstream Summit County/Town of Breckenridge property.

The proposed channel profile was developed to match key elevations along the length of the Project Area while establishing new proposed elevations for a majority of the Project Area. Key elevations that were generally matched in the stream profile included the following:

- Upstream culvert invert under Tiger Road at the downstream Project Area limit,
- Road crossing at Rock Island Road,
- Road crossing at the Driveway Road and
- Upstream extent of the Project Area,

Elevations at internal road crossings Rock Island Road and the Driveway Road were maintained in the design not because they provided critical vertical controls for the project but rather because they represent logical breakpoints for the construction reach phasing of the project. In order to construct the project following a phased approach, it will be important to have vertical continuity from one stream reach to another. Establishing these internal crossings as vertical control provides the opportunity to start and end a restoration reach at any of these road crossings.

Through conversations with project sponsors it was decided that the existing elevation at the Georgia Pass Road does not need to be maintained. This elevation was not maintained because the logical breakpoint between reaches in the upstream end of the project is further downstream from the road and lowering the channel in this location makes it feasible to intercept groundwater. For this reason the current culvert elevation at Georgia Pass Road was not maintained in the Preliminary Design Plan.

Proposed channel slopes are illustrated on the plan and profile design drawings in **Appendix D**.

5.4 Hydraulic Modeling

Detailed hydraulic modeling was performed using the proposed plan and profile. Hydraulic modeling was performed for several reasons. First hydraulic model results allowed ERC to evaluate the physical stream geometries that were estimated based on fundamental geomorphologic principles and measures of bankfull channel properties in the reference section. Secondly the hydraulic model results provide insight on anticipated flow characteristics which are helpful for evaluating likely flow velocities and shear stresses. For these reasons, HEC-RAS modeling software was used.

In order to properly model the proposed improvements, the Project Area was divided into two reaches with the first being the portion of the project upstream of the confluence with North Fork tributary and the second being the segment downstream of this point. The differentiation between these two subreaches being that the bankfull flow is greater in the downstream reach than in the upstream reach. The entire Project Area was stationed from 0+00 feet beginning at the downstream end, which corresponds to the crossing of the Swan River by Tiger Run Road. Each individual proposed riffle, pool and glide was incorporated into the model. Pools were located at major river bends with riffles located upstream of bend pools. Glides were located halfway between pools and riffle beginnings. Elevations were assigned to each feature based on the stationing distance from the downstream end. The base of each pool is 2 feet lower than the riffle leading into it and 1.5 feet lower than the elevation at the start of the next riffle beginning downstream. This results in a residual pool depth of 0.5 feet. Glide elevations were set halfway between the elevations of upstream pool and start of the downstream riffle beginning.

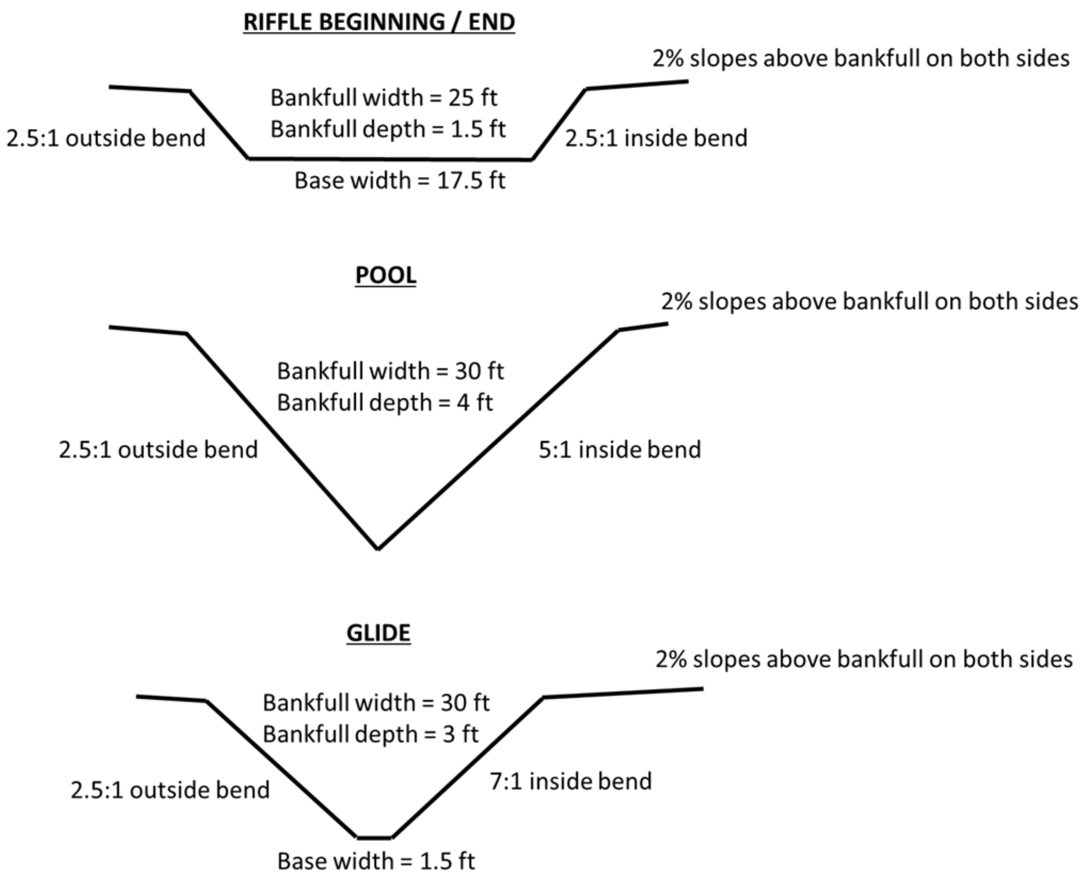
A sensitivity analysis was performed for the Manning's n roughness within the channel. Standard literature suggests a value of 0.04 for the channel (Chow 1959). The survey and calculation of bankfull flow performed by the Forest Service at the dredge boat sites, however, suggest a higher Manning's n value in the range of 0.056 for this stream system. ERC modeled the system assuming Manning's n values ranging from a low of 0.04 to a high of 0.067 (20% greater than the value calculated by the Forest

Service). Average flow depths in riffle sections were found to be more sensitive to roughness values near the lower end of this range than the higher end. Calculated flow depths were generally found to be within 0.2 foot using Manning's n values of 0.056 and 0.067. A value of 0.056 was utilized in the final hydraulic modeling performed for the project.

A total of 371 individual cross-sections were input into the HEC-RAS model. Each cross-section had a uniform geometry based on the type of feature represented. The model was run using the mixed flow regime option; upstream and downstream boundary conditions were set assuming normal flow depth based on the average reach slope. Mixed flow was selected as opposed to subcritical flow as it allowed the resultant flow regime to go supercritical. This was desired as it allowed ERC to identify locations where supercritical flow may occur. Iterative model runs were made and results inspected to determine the appropriate bankfull geometries that would cause the stream banks to approach an overtopping condition at bankfull flow.

Results obtained by the model suggest that the flow depth in the riffles in the upstream and downstream reaches will be in the range of 1.4 – 1.6 feet. Flows were calculated to be subcritical. The cross-sections for each of the features are depicted in **Figure 5.3.**

Figure 5.3. Channel Cross-Section Geometry by Feature.



5.5 Rock Sizing

Channel geometry and flow information allowed ERC to determine rock sizes that are appropriate for different stream components. Given that the intent of the stream is to act as a natural system rather than an engineered channel, rock sizing criteria were set to promote stability in normal flow conditions yet allow for some mobilization in extreme flow conditions. To achieve this goal rocks were sized to provide general stability for flows up to the bankfull conditions. For flows above bankfull conditions it is expected that portions of the bed may mobilize, which is similar to conditions measured in Colorado where bed mobilization typically occurs as flows approach bankfull conditions (Ryan 2002).

RipWin software was used to determine the appropriate design rock size to minimize scour and erosion for each type of stream feature for the bankfull flow. Inputs to RipWin included flow rate, meander radius, cross-section geometry, Manning's n and average slope. The two different bankfull flow rates were used upstream of the confluence with the North Fork and downstream of that point. For meander radii, the smallest radius in each reach was used. Model inputs are shown in **Table 5.3.** Rounded rock was assumed for all calculations given that the available rock consists of rounded river cobble.

Table 5.3. Parameters for RipWin Rock Sizing Software.

Feature Type	Location	Flow rate (cfs)	Smallest Meander Radius (ft)	Cross-Section Geometry			Average Bed Slope
				Left Bank Slope	Bottom Width (ft)	Right Bank Slope	
Riffle (straight)	upstream	80	n/a	2.5:1	17.5	2.5:1	0.0426
	downstream	103	n/a	2.5:1	17.5	2.5:1	0.0299
Riffle (bending)	upstream	80	100	2.5:1	17.5	2.5:1	0.0426
	downstream	103	120	2.5:1	17.5	2.5:1	0.0299
Pool	upstream	80	21	5:1	0	2.5:1	0.0071
	downstream	103	15	5:1	0	2.5:1	0.0065
Glide	upstream	80	21	7:1	1.5	2.5:1	0.0071
	downstream	103	15	7:1	1.5	2.5:1	0.0065

The results of the RipWin analysis are displayed in **Table 5.4.** Rock sizes were rounded to the nearest inch. D_{50} is the rock diameter that is greater than that of 50% of the rocks. With the possible exception of the rock sizes calculated for the outside bends, all material sizes appear to be readily available based on observation of the dredge piles. Larger material for the outside bend appears to be available, but in lesser quantities.

Table 5.4. D50 Rock Size by Feature Type.

UPSTREAM (Q=80 cfs)				
	Riffle Bed	Riffle Side Slope (straight riffle)	Outside Bend Downstream of Riffle (outside bend)	All other sections
D_{50} (in)	2	2	6	1
DOWNSTREAM (Q=103 cfs)				
	Riffle Bed	Riffle Side Slope (straight riffle)	Outside Bend Downstream of Riffle (outside bed)	All other sections
D_{50} (in)	2	2	5	1

Flow velocities produced by the HEC-RAS were also evaluated. As HEC-RAS is a 1-D program, velocities represent average velocities across a given cross section. In one location model results suggested a flow velocity significantly greater than the remainder of the riffles. To account for the high velocity anticipated at this location, the design calls for the use of a modified "step pool". This step pool will utilize larger (D_{50} = 12 inch) rock and a steeper 6:1 slope in place of the standard lower gradient riffle. This single step pool is located at Riffle 21, which is located at approximately Station 34+30.

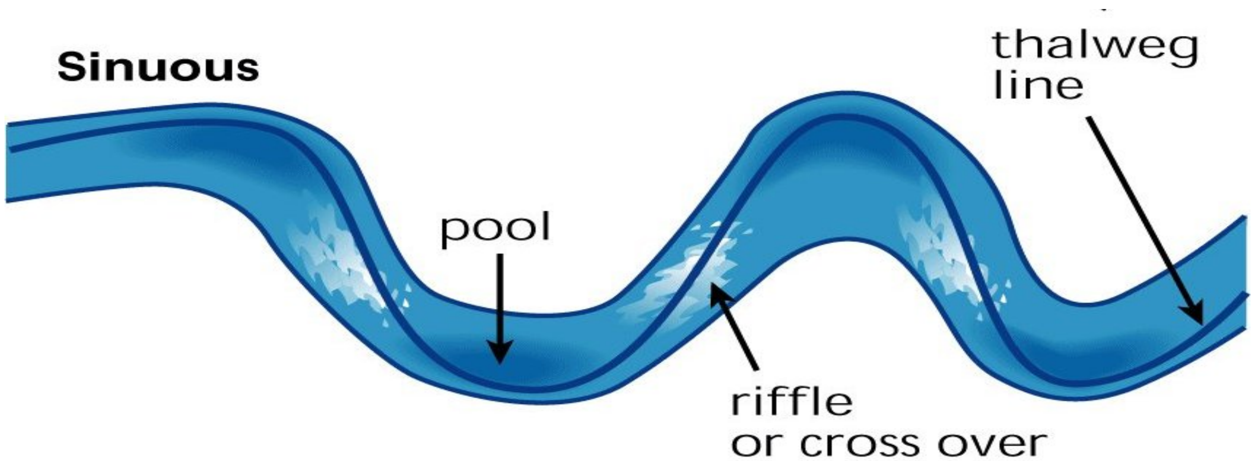
6.0 CONCEPTUAL DESIGN COMPONENTS

The main elements of the Preliminary Design Plan include creating a natural, meandering channel, providing quality instream habitat, stabilizing banks utilizing bioengineering techniques, creating a native riparian terrace and reclaiming upland areas. Methods used to achieve these improvements are discussed in this section of the report.

6.1 Channel Form

A plan view of the proposed channel is presented on **Sheets 2-8** in **Appendix D**. A key element of the proposed channel design is creating a meandering pattern that is in balance with the natural hydrograph. The proposed channel takes on an alignment that is generally meandering through the valley, as shown in **Figure 6.1.** It has an overall sinuosity of 1.28 and follows a non-uniform route to achieve the type of diversity that is observed in natural streams. The straightest section of the planned stream is downstream of the confluence with the North Fork of the Swan River. This section of the stream is proposed to remain in its current alignment. While straighter than a typical Type Cb stream this section of the stream was found to be functioning well with stable banks and established riparian vegetation along the stream corridor. Another section from approximately station 120+00 to 129+00 on the Preliminary Design Plan has been designed straighter than a typical Type Cb stream in order to maximize available usable land at the request of the current landowner. The exact sinuosity may evolve with progressive stages of construction as more is learned and final grading accommodates existing vegetation.

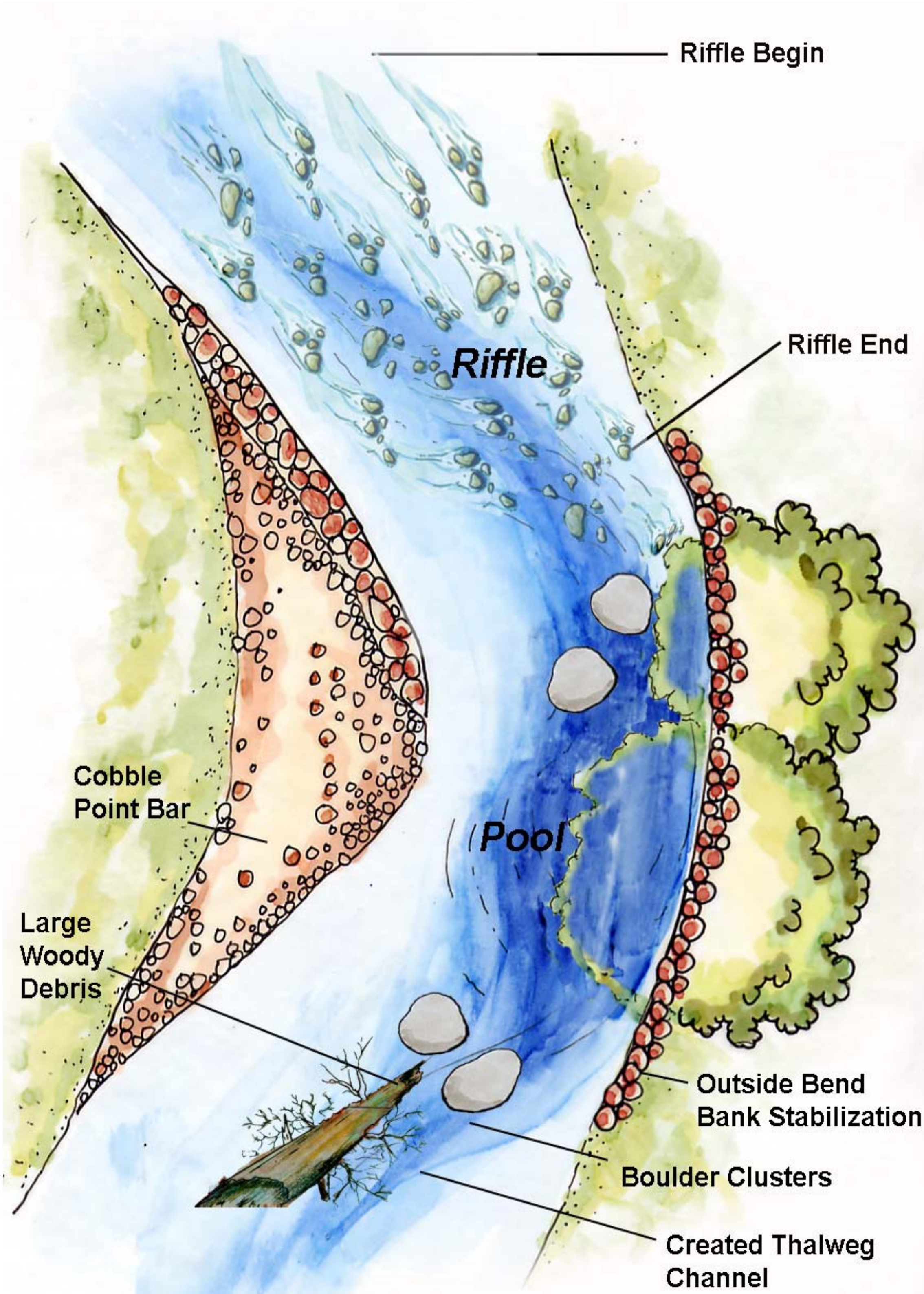
Figure 6.1. Schematic of Meandering Channel with Riffle/Bend Pools.



Type Cb streams are dominated by repeating riffle/bend pool complexes and point bars, as shown in **Figure 6.2.** Riffles are the steeper sections of the stream and generally located upstream from larger channel bends. Riffles are characterized by larger substrate material and swift flows. Pools are located downstream of riffles and are typically at or near the more pronounced bends in the stream. The higher flow velocity of the riffle sections provide energy required to continually scour the pools maintaining quality pool habitat. Glides are located between pools and riffles and generally have a mild adverse slope leading from the end of a pool up to the start of the next riffle. Glides have a well-defined thalweg that contain flow to a defined channel during low flow periods. Schematic templates depicting typical geometries of riffle, pool and glide cross sections are presented on **Sheet 9** of the Preliminary Design Plan.

The Preliminary Design Plan shows the proposed channel meandering through the valley and intercepting and/or impacting some of the limited open water and mature vegetation that exists at some locations. It is anticipated that during further design development and field staking prior to construction the precise alignment may be modified slightly in some locations to preserve existing resources. Final grading will need to be understood and considered when determining which resources can and cannot be protected in the field, but all efforts should be made to preserve vegetation where practical. Vegetation that will be impacted should be salvaged and utilized as part of the revegetation plan whenever possible.

Figure 6.2. Schematic of Riffle/Pool Complex.



6.2 Bank Stabilization

Stabilizing the newly constructed channel banks will be important in maintaining water quality and sustaining the constructed channel. The long-term goal of the restoration work is to create a condition where bank stability is achieved through vegetation. During initial vegetation establishment, however, additional stabilization measures are needed. Restoration concepts are therefore to provide adequate native vegetation along the stream corridor yet supplement this with additional, temporary stabilization measures.

Different levels of stabilization are expected to be required for different shear stresses. In straight sections of the channel and along inside bends, stresses will be relatively low and stabilization requirements will be less. Along outside bends stresses will be highest and additional stabilization measures will be warranted. Two different stabilization concepts were developed to meet these different requirements.

For both conditions, the key to relieving stresses on the banks is allowing flood flows to access its floodplain where flows can then spread out over a larger area. For this reason all banks should be constructed to the bankfull elevation and riparian corridor immediately adjacent to the stream should be gently sloped towards the uplands. This general configuration will allow for the dissipation of energy and activation of the floodplain.

As was observed in the representative reach, existing stream banks consist of a combination of cobbles, gravels and fine material with healthy stands of riparian vegetation were stable at all locations observed. This natural condition should be replicated in the constructed banks.

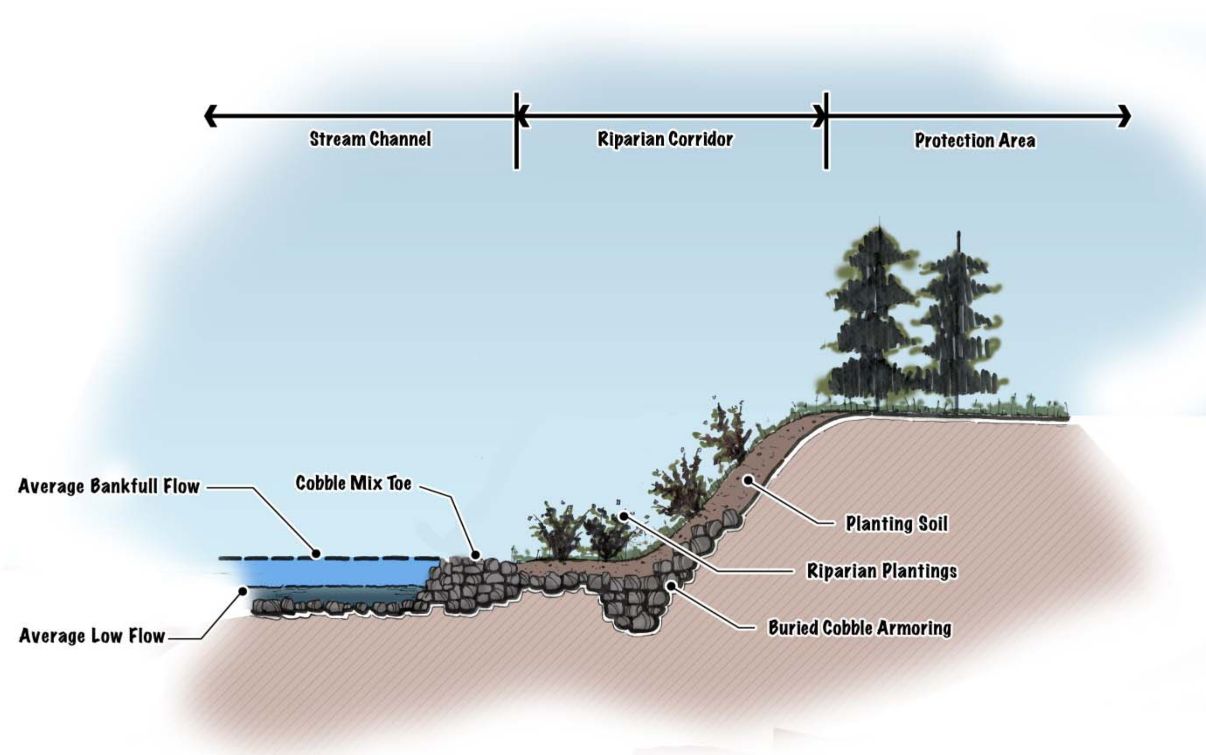
Bank stabilization and riparian corridor development for straight sections and inside bends will include a cobble mix toe with a riparian corridor sloping outward towards the uplands at a maximum 2% grade. Soil growth medium should be placed along these banks, extending 50 feet outward into the riparian corridor, at a minimum six inch depth and seeded using native riparian grasses. A temporary erosion control fabric should be used to cover the soil and protect it during vegetation establishment. This soil growth medium, seed and erosion control fabric is designed to extend for 50 feet on both sides of the channel. Biolog check structures will be installed along the banks perpendicular to flow to help minimize flow velocities that could be encountered during vegetation establishment when the banks are the most susceptible to erosion. The biolog is biodegradable and intended to provide protection only during the initial establishment period.

Bank stabilization and riparian corridor development for outside bends will experience higher stresses and therefore additional protection will be required utilizing native plants rootmass. Outside bends will include two (2) feet of soil growth medium along the bank stabilization bench, extending 4 feet outward from the stream channel edge in order to provide greater rooting depth. Brush layering using native willows (Salix spp.) is planned immediately behind the cobble mix toe. Willow stakes should be harvested locally, properly prepared and layered with a density of six stakes per linear foot of bank. Two staggered rows of #5 native willow shrubs (with fully developed rootballs) will also be planted behind the brush layering to provide additional root mass. This larger sized potted material is recommended to provide more immediate rootmass reinforcement as well as increased survival rate. Combined the brush layering, rooted willows and deeper available rooting depth will promote a more structurally stable and biological diverse outside bend. Typical details of the two proposed bank stabilization techniques are provided on **Sheet 10** of the Preliminary Design Plan. Recommended species list is provided on **Sheet 10** -Table 1.

The Preliminary Design Plan anticipates approximately 8,100 linear feet of outside bend bank stabilization and 22,008 linear feet of straight section and inside bend bank stabilization.

Specific locations may be defined where lateral channel migration should not be allowed. In critical locations the bank can be armored below the surface yet restored to resemble a natural channel. An example of a more structured bank armoring approach that can be utilized if needed is provided on **Figure 6.3.**

Figure 6.3. Schematic of Bank Armoring.



6.3 Riparian Corridor

Riparian corridors refer to the entire ecosystem connected to the stream consisting of the physical channel, banks, wetlands and transitional vegetation communities The Preliminary Design Plan has developed a riparian corridor that is approximately 4-6 times the stream bankfull width, inclusive of the channel itself. This width provides a flood prone area that is consistent with the intended channel type.

Evaluation of aerial photographs, literature review and professional judgment of regional wetland/riparian habitats indicated that prior to significant land disturbance (i.e., dredge operations), the Project Area likely contained suitable elevation, geomorphic setting and climate for montane willow riparian shrubland.

These riparian systems, which are found throughout the region, are located along streams and drainages and typically occur as mosaic of vegetative communities that may be tree or herb dominated in areas but contain diverse shrub components throughout. The hydroperiod for these habitats is highly dependent on snowmelt and geomorphology which largely control the frequency, timing, duration and depth of flooding (Laubhan 2004). The systems consist of temporarily, seasonally and intermittently flooded shrublands comprised of broad-leaved deciduous willow dominated species in the midstory canopy (Lemly and Joe Rocchio 2009) and an understory of herbaceous species including a mix of grasses, forbs, sedges and rushes. These corridors are some of the most biologically diverse habitats having a consistent source of water and providing structural habitat diversity utilized by a wide variety of wildlife. **Figure 6.4** depicts typical reference condition riparian characteristics incorporated into the Preliminary Design Plan. Variability should be expected in hydrologic composition of the final riparian conditions. Some riparian areas are expected to be wetter or drier than others based on surface and groundwater interaction.

Figure 6.4. Photo Examples of Typical Riparian Corridor Reference Condition in Summit County.

This Preliminary Design Plan focuses first on establishing a deeply rooted and dense groundcover dominated by native riparian herbaceous species that are typical to the region such as Nebraska sedge (*Carex nebrascensis),* beaked sedge (*Carex utriculata*), rushes (*Juncus spp*.), common spikerush (*Eleocharis palustris*), fowl managrass *(Glyceria striata),* bluejoint (*Calamagrostis canadensis*), mountain brome (*Bromus marginatus*), streambank wheatgrass (*Elymus laceolatus*), western wheatgrass (*Pascopyrum smithii*) and/or alpine timothy (*Phleum alpinum*). The intent is to quickly establish a groundcover to stabilize soil, minimize establishment of invasive species and promote long-term successional development. To facilitate complete ground coverage and seed bank development the entire riparian corridor would be seeded with specialized riparian seed mix that promotes species diversity, contains locally native species that germinate rapidly and provides complete groundcover over a wide variety of hydrologic conditions.

Second, strategically placed riparian plantings are proposed along the length of the new channel to provide not only bank stability but also increased biomass and structural habitat for the fishery and terrestrial wildlife. Additionally, riparian vegetation provides biomass to the stream (leaf-litter), overhead cover (shading) and increases bug life (terrestrial and aquatic, such as caddis).

Typically, this type of riparian system includes a dense midstory of native shrubs including a variety of tall willows such as Geyer's willow (Salix geyeriana), Drummond willow (*Salix drummondiana*) or park willow (*Salix monticola*), intermixed with serviceberry (*Amelanchier alnifolia*), shrubby cinquefoil (*Pentafloides floribunda*) or bog birch (*Betual glandulosa*). Overstory tree species are not dominant in these riparian shrub communities but may include canopy stands of blue spruce (*Picea pungens*) or quaking aspen (*Populus tremuloides*). Recommended species lists are provided on **Sheet 10** (Table 1 and 2).

Riparian plantings are proposed in two general forms, (1) those associated with outside bend bank stabilization (described in **Section 6.2**) and (2) riparian planting pockets. The Preliminary Design Plan presents the creation of 81 outside bend bank stabilization areas and 105 distinct riparian planting pockets. Preliminary riparian planting pocket locations are shown schematically on **Sheets 2-8** of the Preliminary Design Plan and typical details of the pockets are shown on **Sheet 10**. These details and layouts were used to determine material quantities and estimate costs. It is intended, however, that exact location, size and shape of the pockets will be determined as part of further design development and field conditions during construction.

Riparian planting pockets are intended to create an island effect or a diverse plant community in a relatively small space, as compared to spacing individual species at greater distances. In ecological literature, this type of island habitat has a much higher functional value resulting from increased structural complexity. Significantly more bird species will utilize this type of habitat when compared to an isolated shrub or tree. In addition, the islands typically look more visually natural as compared to an isolated planting. The riparian planting pockets are also typically more successful because they act as a natural windbreak, preventing drying out from wind/sun exposure and are significantly easier to protect and maintain during the critical establishment period.

Each riparian planting pocket should consist of an approximately 25 foot diameter (approximately 500 square foot) randomly and irregularly shaped circle or oval formed along the general contour of the stream channel edge. The pocket will be excavated to a depth of 2 feet, approximately 13 #5 native shrubs installed at 6 foot on-center spacing and one ball-and burlap tree or aspen clump, backfilled with soil growth medium and covered with a 3 inch mulch layer. During the establishment period (2-3 years), the pocket should also be surrounded by wooden snow fencing (or similar) to increase protection of the pocket from wind, wildlife predation and providing minor shading. Routine watering of the entire riparian planting pocket may also be required during the establishment period. A typical detail of a riparian planting pocket is provided on **Sheet 10**.

All proposed plantings and seeding associated with bank stabilization, planting pockets, riparian corridor as well as uplands will need to consider regional availability. While commercial native plant nurseries and seed companies can provide specific species, local plant genetics should be considered. The Project Area provides an ideal opportunity to collect, harvest, salvage, transplant and/or propagate plant materials. Reuse of salvaged on site materials is always preferred over purchasing commercial materials. Many commercial nurseries under a contract-grow agreement can harvest plant materials at a site specific location and complete full propagation and grow-out in a controlled environment until project implementation. Seed stock can be harvested and stored from site specific locations. The timing of project implementation and use of locally native plant material must be strongly considered as part of project planning.

6.4 Aquatic Micro-Habitat

The Preliminary Design Plan incorporates approximately 91 aquatic micro-habitat features, assuming a minimum of one within each glide section of the proposed channel. Because the proposed channel will be constructed through barren land, many instream habitat features that commonly exist in established channels will not be present. While the Preliminary Design Plan focuses primarily on creating instream habitat diversity in the form of riffles-pools-glides and vegetated banks, additional non-structural micro-habitat features have been included to further increase aquatic habitat complexity, diversity and instream biomass. The Preliminary Design Plan incorporates two types of aquatic micro-habitats; (1) boulder clusters and (2) log spurs (large woody debris). These features will be placed in pool and/or glide sections where velocities are low and water is slightly deeper and are intended for habitat cover only and not intended for bank stability or grade control.

(1) Boulder clusters would consist of two to four larger irregularly shaped boulders placed in close proximity creating localized scour holes. Boulders are placed in configuration at differing elevations and spacing to create a diversity of water depths and velocities across the spectrum of typical stream flows.

(2) Log spurs, or what is commonly referred to as large woody debris (LWD), is common in many established rocky mountain streams creating fish habitat and biological diversity. Water flowing over and under LWD during high flow events can result in localized scour pockets or holes for cover habitats for fish. Such features can also trap smaller wood, branches leaves and organic matter that add to the complexity and diversity of aquatic life. These features would generally consist of one or more logs with

a minimum diameter of 1 foot (with or without the rootwad intact) buried into stream channel bank protruding downstream, resting on the bottom of the channel, below the bankfull elevation. The incorporation of these log spurs or LWD are not intended as a structural component of the channel or bank stability but rather as ways to increase instream habitat. Typical details of aquatic micro-habitat are provided on **Sheet 9**.

6.5 Soil Growth Medium

Re-establishing a more natural ecosystem over more than 95-acres in what currently is now barren waste cobble requires extensive amounts of soil growth medium. Detailed analysis of the particle size and or quantity has not been completed within the dredge on the Project Area. The Preliminary Design Plan currently calls for upwards of 35,600 cubic yards of soil growth medium for uplands and over another 33,645 cubic yards associated with the riparian corridor. This is assumed as an minimum and deeper depths of soil growth medium would only result in more ecological benefit. The purchase and import of this quantity of soil growth media has been estimated at approximately $2.07 million dollars or almost 24% of the total project cost based on an assumed unit cost of $30 per cubic yard. While a high quality topsoil or growth medium is essential for the successful long-term establishment of natural vegetation, many options may exist to produce or amend lesser quality materials and obtain the required benefits at a lower cost. The composition of topsoil generally consists of upwards of 45% fine grain mineral particles with less than 5% organic material/nutrients and the remaining 50% comprised of water and air. Substantial cost savings can be incurred by simply amending salvaged fine grained mineral soils during processing of the dredge. Fine grained mineral soils can be amended with wood chips, biosolids and manufactured fertilizers, humates and mycorrhizal inoculations. Large volumes of compost are potentially available locally through the Summit County Resource Allocation Park (Summit County Landfill) (http://www.co.summit.co.us/index.aspx?NID=232). This compost source could serve as an ideal soil amendment for a soil growth medium. Once a project phase has identified potential sources of fine grained materials, either through onsite materials or import, special consideration must be made to the overall characteristics of such materials. In particular, soil texture, pH, salts, percent organic matter and nutrients as well as the presences of potential contaminants are all critical to the performance of the soil mixture and ultimately the success of the restoration. More detailed analysis and consideration beyond the scope of this report will be required when considering the soil growth medium required for restoration implementation.

As part of the Preliminary Design Plan, the costs provided assume the purchase and import of a fine grained soil growth medium and a single application of manufactured fertilizer/humates and mycorrhizal. Future design efforts will need to evaluate more thoroughly the availability and suitability of onsite and offsite materials in order to develop a more cost effective growth media solution.

6.6 Upland Planting

The Preliminary Design Plan depicts upwards of 44.1-acres of upland area that will be reclaimed. These areas will consist of temporary storage areas of dredge material or spoil areas. These areas should be graded to varying and undulating landforms based on material quantities. Generally upland areas should be graded to form naturally appearing varying landforms with stable slopes and capped with a minimum of six inches of unconsolidated soil growth media. All grading should create a smooth transition into both the riparian corridor and the existing natural uplands. The initial focus of the Preliminary Design Plan is to re-vegetate the upland areas with an appropriate native mountain big sagebrush community. These vegetation communities in the area are dominated by a midstory of species such as big sagebrush (*Artemisia tridentate),* rabbitbrush (*Chrysothamnus sp.*) and buffaloberry (*Shepherdia canadensis*). Understory vegetation can include Rocky Mountain fescue (*Festuca saximontana*), Indian ricegrass (*Oryzopsis hymenoides*), mountain brome (*Bromus marginatus),* western wheatgrass (*Pascopyrum smithii) or* Canada wildrye (*Elymus Canadensis).* Initial re-vegetation will need to quickly stabilize soils, increase soil biomass and prevent invasive weed establishment. Once the understory grassland community is well established future restoration efforts can focus on developing a more diverse vegetation community which includes shrubland and forest species based on final topography and landforms. The cost estimate provided associated with upland planting zones includes grading, placement, amendments seeding and mulching of the initial grassland community and does not include establishment of shrubland or forest. A recommended species lists is provided on **Sheet 10** (Table 3).

6.7 Stream and Groundwater Interface

Currently through the Project Area the Swan River is both a gaining and losing stream over individual sections. At some locations surface flows are evident even during times of low flow while the stream is dry with all flows going subsurface at other locations. One of the most important aspects of the planned stream restoration will be to ensure that flow is maintained at the surface and not allowed to go subsurface in the dredge material.

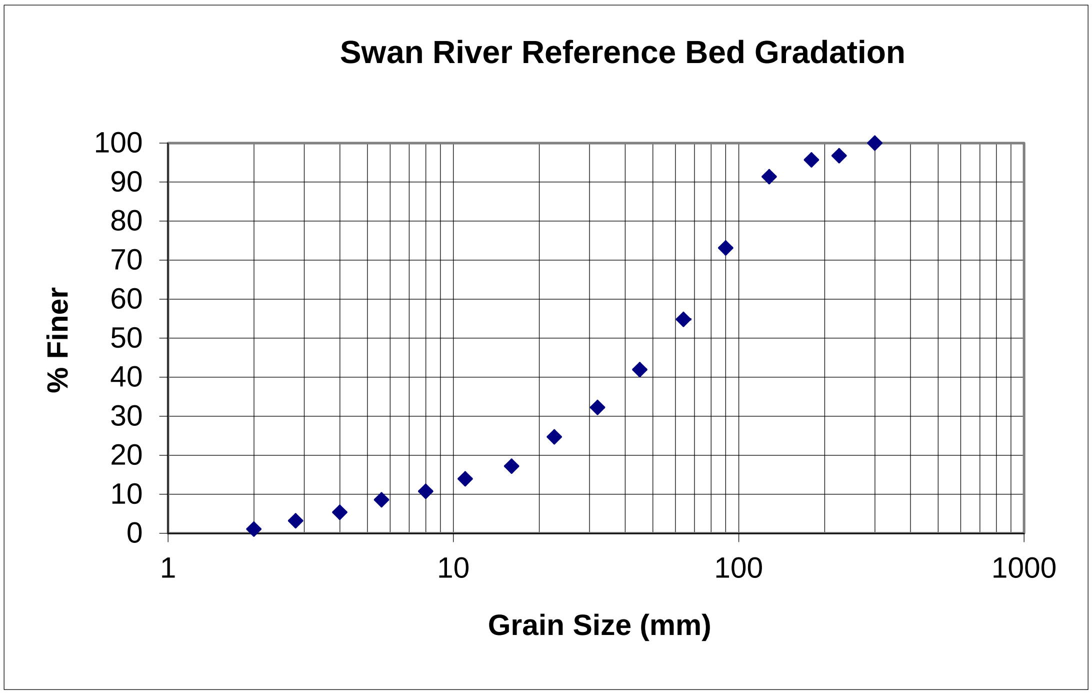
A first step towards this was gaining a better understanding of groundwater levels as they relate to the proposed stream elevation. As discussed in the groundwater section above there are areas where current groundwater is believed to be both above and below the proposed streambed. In areas where the streambed is below the groundwater level, water will tend to stay at the surface and groundwater inflows will make the river a gaining stream. In areas where groundwater is below the proposed streambed, there will be a tendency for the stream to lose water.

In areas where the groundwater is below the proposed streambed it is desired to create a barrier that minimizes surface water loss to the groundwater system. The technique that will be utilized to maintain surface flows is to create a layer below the channel bed that has relatively low permeability. This will be accomplished using natural materials. The low permeability zone is designed to be constructed using a combination of finer material mixed with the smaller portion of dredge material to create a substrate with lower vertical permeability than the surrounding dredge rock. This finer material will help to inhibit vertical migration of the water, maintaining flows at the surface. If the channel is set at an elevation that intercepts the groundwater and fine material underlies the stream, water will remain at the surface. The lower permeability material layer is designed to extend below the active channel and under a portion of the riparian area for a total width of 75 feet. A 1.5 foot thick layer, consisting of a compacted mixture of

3 inch minus material with 20% of the material passing the #200 sieve (fines) is included for this conceptual level design. A typical stream cross section including this low permeability layer is shown on **Sheet 10**.

This material specification was compared with an existing gradation measured by ERC in the stream reach downstream from the Project Area. Results of ERC's stream gradation analysis are shown on **Figure 6.5**.

Figure 6.5. Reference Stream Bed Gradation.



Based on ERC's sampling, the D_{50} of the existing bed material is on the order of 55 mm (2.2 inches). Observations indicated some level of armoring. Following the method of Fuller and Thompson (1907), suggest that soils should have a fines content of between 5% and 15% based on the recommended range of n values in the procedure. Considering that the bed gradation measured by ERC likely overestimates the D_{50} due to armoring, the recommended fines content would be greater than the 5% - 15% range from the Fuller-Thompson method presented above. Use of 20% fines in the low permeability material is therefore believed to be appropriate.

6.8 Road Crossings

Five road crossings were included as part of this Preliminary Design Plan. Crossings included three internal to the project along the Swan River (Rock Island Road, the Driveway Road and Georgia Pass Road) and the crossing of the Swan River at Tiger Road at the downstream end of the Project Area. An additional culvert was also sized for as one will be required for the proposed relocated Muggins Gulch Road crossing.

Road crossings are intended to serve multiple functions. First, they need to be capable of passing peak flow events and second, given the overall project goal of native cutthroat habitat they need to meet fish migration needs. The one exception is the culvert planned for the Tiger Road crossing. As this road crossing is intended to eliminate the upstream migration of brook trout there was no need to size this crossing for passage.

Input from the Forest Service dictated that all crossings where fish passage is required should target a minimum crossing width of 1.5 times the bankfull width. Given the approximately 25 foot calculated bankfull width, a stream crossing width of 40 feet was selected. This would typically necessitate a bridge span crossing rather than a culvert crossing. Bridge spans were therefore assumed for the three crossings of the Swan River internal to the Project Area. A box culvert crossing as assumed for both the Tiger Road and Muggins Gulch crossings. The proposed box culvert at Tiger Road was designed to be 25 feet wide.

The results in **Table 6.1** show recommended crossing sizes determined for Swan River and Muggins Gulch.

Table 6.1. Recommended Culvert Sizing.

Crossing Name	Crossing Type	Crossing Size
Swan River Rock Island Road Driveway Road Georgia Pass Road	Precast Bridge Span	40’ span
Swan River Tiger Road	Box Culvert	4’ rise x 25 foot span
Muggins Gulch	Box Culvert	3’ rise x 6’ span

6.9 Existing Open Water Features

Several existing open water features exist throughout the Project Area. These areas were non-naturally formed from dredge operations consisting of excavated pits now filled with exposed groundwater or impoundments of the existing Swan River. These open water areas vary in depth from a few feet to upwards of possibly 20 feet. Vegetation of these open water features is generally limited to a narrow fringe along the ordinary high water mark. Preservation, enhancement or creation of additional such areas are subject to Colorado water law and US Army Corps of Engineers (USACE) jurisdiction and will require additional consideration during further design development.

On the Preliminary Design Plans these existing open water areas and larger areas of existing vegetation are shown as part of the riparian corridor. In such instances the preservation, incorporation or salvage/transplanting will need to be determined based on more detailed evaluation and construction conditions.

In other instances existing open water features are shown as "reclamation areas". In these areas the design parameters require open water features to be modified and recontoured. More detailed design will be required in such areas however the areas will likely be converted to uplands or may provide opportunity for wetland/riparian development.

6.10 Muggins Gulch Road Crossing

Project proponents have expressed interested as part of the 2009 Summit County Plan and in recent conversations to reconfigure the Tiger Road and Muggins Gulch Road crossings of the Swan River. The intent of this would be to alter the road configurations in order to consolidate what is currently two crossings of the Swan River near Muggins Gulch into a single crossing. As part of this Preliminary Design Plan ERC developed a road alignment that allows for the removal of the western most of these two roads. With the proposed road consolidation eastbound traffic headed to Muggins Gulch would cross the Swan River on Tiger Road before turning left onto a new spur road. The new spur road would cross Muggins Gulch and reconnect with the existing Muggins Gulch Road north of the Swan River. The proposed new road alignment is illustrated on **Sheet 2** of the Preliminary Design Plans.

Construction of this spur road would allow for removal and reclamation of the southern portions of the existing Muggins Gulch Road, which would improve both the Swan River and its riparian habitat.

ERC designed the Muggins Gulch Road to be a 20-foot wide, single lane, low-volume road with a 2-4° outslope. To handle seasonal truck traffic, the minimum curve radius should be 60 feet. The road bed should be made of 6-inch deep crushed rock (1-inch diameter maximum). Cut and fill slopes should not exceed 1:1 and 2:1, respectively. The stream crossing at Muggins Gulch should be sized to for 1.5 times the bankfull width. Topographical analysis revealed that Muggins Gulch is no wider than 4 feet across. This means a 3 feet x 6 feet box culvert will allow passage of 1.5 times bankfull width. The design criteria for the Muggins Gulch road are based on the assumptions and recommendations described in Keller (2003) and Edwards (2011). The location of the proposed new road segment along with the sections of road that can be abandoned and areas reclaimed as well as typical road cross sections are provided on **Sheets 2 and 11** of the Preliminary Design Plans.

6.11 Public Access Easement

Summit County and the Forest Service have been working with private landowners within the Project Area to develop a public access easement along the proposed stream channel. At this point the easement is only preliminary and will need to be finalized in the future. For the purposes of the Preliminary Design Plan the easement has been depicted as 175 feet wide established from the proposed channel centerline extending approximately extending 87.5 feet on either side. The easement will encompass the stream channel as well as portions of the riparian corridor and uplands.

7.0 PROJECT COST ESTIMATES

Cost estimates were developed for the individual elements of the overall Preliminary Design Plan. Costs contained in this Preliminary Design Plan are based on 2013 prices. Estimates were generated from material costs, discussions with contractors, costs for completed stream improvement projects and engineering judgment. These quantities and costs are not all inclusive however should be considered adequate for planning purposes.

Unit construction costs were prepared for each specific Preliminary Design Plan improvement. **Tables 7.2 through 7.5** provide itemized costs for each improvement type by Construction Reach and **Table 7.6** provides overall project quantities and costs.

Major assumptions included in the cost estimates are provided below:

1. Mining activities will include excavation of the dredge material to the approximate subgrade elevation.

2. Restoration costs include final excavation of the stream channel and fine grading at all areas.

3. An 18 inch thick low permeability underliner consisting of a compacted mixture of fine graded materials will be applied for a 75 foot wide area under the stream and riparian areas.

4. Appropriate sized gravel and cobble will be used to create channel beds and banks. It is assumed that this material will be available on site and provided at no cost to the project.

5. Two feet of unconsolidated soil growth medium will be utilized in the riparian corridor adjacent to outside bends. Six inches of unconsolidated soil growth medium will be utilized in the remainder of the riparian corridor within 50 feet on each side of the stream.

6. Six inches of unconsolidated soil growth medium will be utilized within the all upland areas.

7. Road crossings are sized for 1.5 times the bankfull width. Costs for the Tiger Road crossing include monies for protection of the slope below the culvert outlet and additional costs assumed to prevent brook trout migration.

8. Straight sections of the restored channel and inside channel bends will include appropriately sized cobble mix toes with 50 foot wide riparian areas. These riparian areas will have six inches of soil growth medium and will be covered with a biodegradable erosion control fabric. Biologs will be placed along the banks perpendicular to flow to help dissipate overbank flow that may occur during vegetation development.

9. Bank stabilization on outside bends of the restored channel have been designed to promote more robust vegetation development. Appropriately sized cobble mix toes will form the foundation. Two feet of soil will be included on the bank stabilization bench immediately behind the cobble toe extending four feet. Brush layering will be added along the outside banks and two rows of #5 shrubs planted at 6 foot centers will be included along the outside bends.

10. There will be 105 riparian planting pockets dispersed throughout the riparian corridor. Riparian plating pockets will include approximately 37 cubic yards of soil growth medium placed at a minimum unconsolidated depth of two feet, 13 #5 shrubs and one balled and burlapped tree per pocket.

11. Upland area reclamation includes seeding, soil amendments and mulched and crimped.

12. Some existing open water areas will be reclaimed via grading and planting. Details of the specific work required in these areas will be determined in the field. An average per acre cost of $40,000 was assumed for the Reclamation Areas and is intended to include grading, soil and planting.

13. Temporary irrigation and weed control including minor maintenance will be required and is included in the project costs. Temporary irrigation of the bank stabilization areas, riparian planting pockets, riparian corridor and uplands is highly recommended during the establishment period.

14. Monitoring and maintenance will likely be required by the US Army Corps of Engineers and is included in the costs. An adapted management program approach is highly recommended.

15. Water Control identified in the cost estimate will need further evaluation and is highly dependent on restoration sequencing and unknown groundwater elevations. Since dredge removal operations are assumed to leave the surface at Preliminary Design Plan subgrade elevations, groundwater may be exposed for final restoration work in some areas. The cost estimate has assumed a lump sum cost to adequately manage water during restoration construction of the entire project. This cost will need to be further refined based on specific restoration items and groundwater elevations.

16. Costs for mobilization and demobilization were assumed at 5% of construction.

17. Costs for survey and construction management were assumed at 5% of construction.

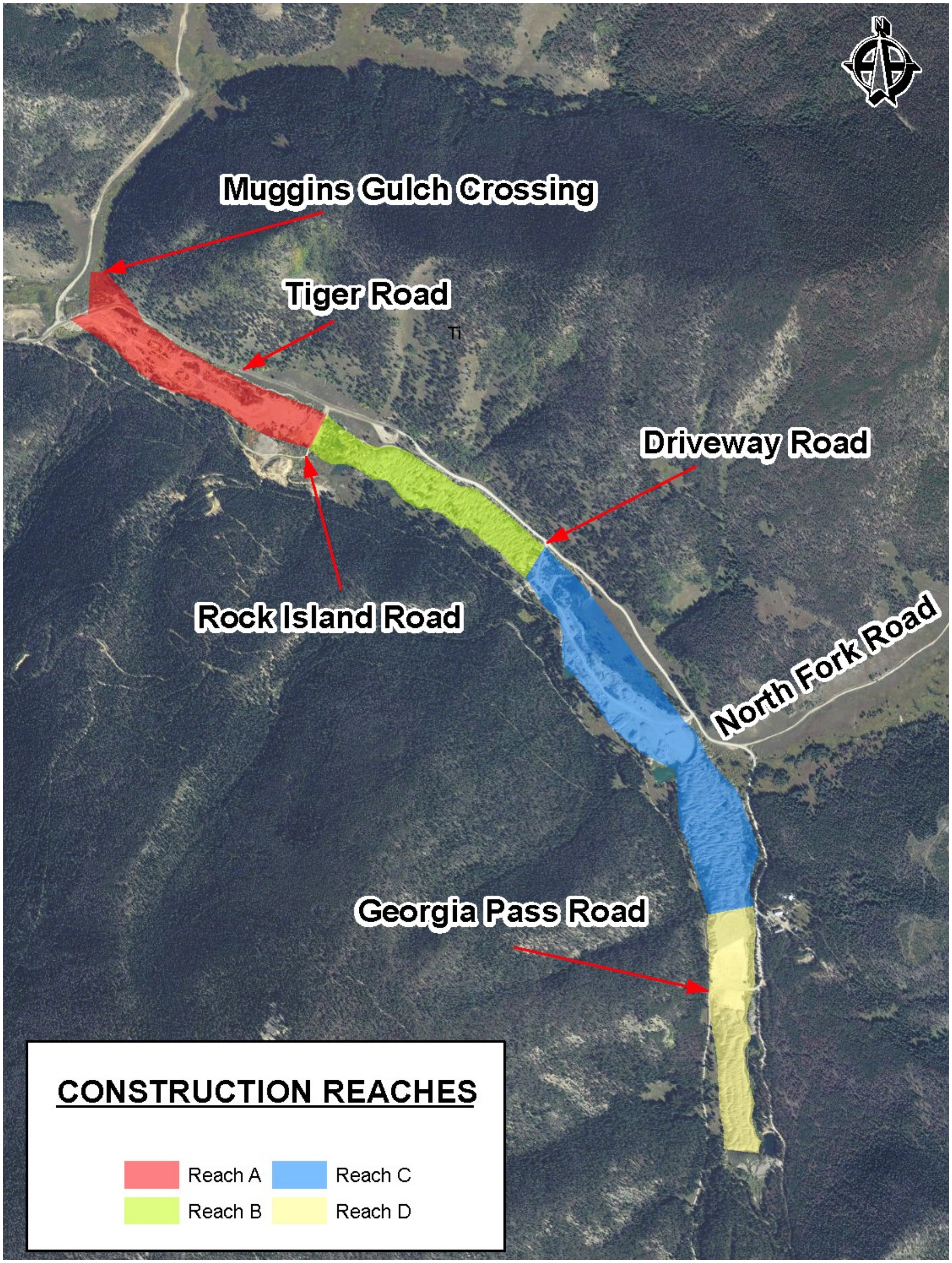
18. A contingency of 10% of construction costs was included in the estimate.

Due to financial, logistical and other constraints the improvements will not be completed at one time. In order to break the project into smaller segments, four different Construction Reaches were defined. Four reaches were assumed, with major road crossings used to delineate three of the reaches. The downstream extent of the upstream most reach was not defined by an existing road but rather by a logical break point based on current dredge material removal. As discussed earlier, constructing different reaches at different times creates a project constraint in that it dictates that the elevation of the upstream and downstream end of each reach must generally match existing conditions in order to avoid a vertical disconnect during construction. The benefit of matching existing grade, however, is that the reaches can be designed to occur in any order. For this report reaches were identified as A through D starting at the downstream end of the project. Different reaches can be implemented in different order desired as financing is available and different lands are ready to be reclaimed. Table 7.1**Table 7.1** shows the approximate stationing and road crossings included when defining each phase**.** A map of the approximate phase locations is shown in **Figure 7.1.**

Table 7.1. Construction Reaches.

Reach	Approximate Stationing	Included Road Crossing
A	0+00 to 32+50	Tiger Rd Muggins Gulch
B	32+50 to 67+50	Rock Island Rd
C	67+50 to 120+00	Driveway Rd
D	120+00 to 150+55	Georgia Pass Rd

Figure 7.1. Approximate Locations of Recommended Construction Reaches



Itemized project costs have been defined for each reach of the work and for the project as a whole. Costs for the individual phases are presented on **Table 7.2**, **Table 7.3**, **Table 7.4** and **Table 7.5.** Based on this budgetary level estimate and the assumptions presented above, it is anticipated that the total cost to complete the full restoration of this area is approximately $8.48 million, as presented on **Table 7.6.**

Table 7.2. Budgetary Level Project Cost Estimates for Reach A.

Item	Unit	Quantity	Unit Cost	Sub-Total
STREAM IMPROVEMENTS				$718,260.00
Excavation - 125 Foot Stream and Riparian Zone	Cubic Yard	11900	$6.00	$71,400.00
Material Sorting & Placement - Fine Material Mixture for Subgrade	Cubic Yard	8900	$8.00	$71,200.00
Fine Grading for Riparian Zone	Acre	13.0	$4,000.00	$52,000.00
Fine Grading - Active Channel	Linear Foot	3200	$12.00	$38,400.00
Material Supply, Sorting and Placement - Material Sizes for Channel Bed and Banks	Cubic Yard	5930	$8.00	$47,440.00
Instream Habitat - Construct Riffle/Bend Pool Sequences	Each	20	$1,000.00	$20,000.00
Instream Micro Habitat Rock Features per Each Sequence	Each	20	$500.00	$10,000.00
Instream Micro Habitat Woody Debris Features per Each Sequence	Each	20	$500.00	$10,000.00
Riparian Planting Soils along 100 foot Riparian Corridor	Cubic Yard	5930	$30.00	$177,900.00
Erosion Control Fabric along 100 foot Riparian Corridor	Square Foot	352000	$0.35	$123,200.00
Bank Stabilization - Outside Bend Extra Mineral Soil	Cubic Yard	510	$30.00	$15,300.00
Bank Stabilization - Outside Bend Vegetation (Brush Layering and Shrubs)	Linear Foot	2300	$31.00	$71,300.00
Temporary Fencing - Outside Bends	Linear Foot	2530	$4.00	$10,120.00
RIPARIAN AND UPLAND PLANTING ZONES				$409,990.00
Riparian Area Seeding	Acre	12.9	$2,500.00	$32,250.00
Riparian Planting Pockets	Each	28	$2,630.00	$73,640.00
Temporary Fencing - Riparian Planting Zone	Linear Foot	2200	$4.00	$8,800.00
Upland Area Fine Grading	Acre	6.6	$2,000.00	$13,200.00
Upland Planting Soil	Cubic Yard	5300	$30.00	$159,000.00
Upland Seeding	Acre	6.6	$3,500.00	$23,100.00
Weed Control, Irrigation and Minor Maintenance	Lump Sum	1	$100,000.00	$100,000.00
MISCELLANEOUS ITEMS				$720,750.00
6' x 3' box culvert (Muggins Gulch proposed road alignment)	Each	1	$21,000.00	$21,000.00
25' x 4' box culvert with downstream armoring for fish migration barrier	Each	1	$141,900.00	$141,900.00
Spoils Piles Grading and Reclamation	Cubic Yard	11900	$3.00	$35,700.00
Road Construction	Lump Sum	1	$13,000.00	$13,000.00
Road Demolition	Lump Sum	1	$25,000.00	$25,000.00
Reclaimed Area	Acre	0	$40,000.00	$0.00
Water Control	Lump Sum	1	$125,000.00	$125,000.00
Construction BMPs	Lump Sum	1	$12,500.00	$12,500.00
Monitoring	Lump Sum	1	$40,000.00	$40,000.00
Project Permitting	Lump Sum	1	$6,250.00	$6,250.00
Construction Mobilization/Demobilization (5% of Construction Subtotal)	Lump Sum	1	$75,100.00	$75,100.00
Construction Survey & Management (5% of Construction Subtotal)	Lump Sum	1	$75,100.00	$75,100.00
Contingency (10% of Construction Subtotal)	Lump Sum	1	$150,200.00	$150,200.00
CONSTRUCTION SUBTOTAL				$1,502,350.00
Total				$1,849,000.00

Table 7.3. Budgetary Level Project Cost Estimates for Reach B.

Item	Unit	Quantity	Unit Cost	Sub-Total
STREAM IMPROVEMENTS				$777,640.00
Excavation - 125 Foot Stream and Riparian Zone	Cubic Yard	12300	$6.00	$73,800.00
Material Sorting & Placement - Fine Material Mixture for Subgrade	Cubic Yard	10000	$8.00	$80,000.00
Fine Grading for Riparian Zone	Acre	12.0	$4,000.00	$48,000.00
Fine Grading - Active Channel	Linear Foot	3600	$12.00	$43,200.00
Material Supply, Sorting and Placement - Material Sizes for Channel Bed and Banks	Cubic Yard	6670	$8.00	$53,360.00
Instream Habitat - Construct Riffle/Bend Pool Sequences	Each	24	$1,000.00	$24,000.00
Instream Micro Habitat Rock Features per Each Sequence	Each	24	$500.00	$12,000.00
Instream Micro Habitat Woody Debris Features per Each Sequence	Each	24	$500.00	$12,000.00
Riparian Planting Soils along 100 foot Riparian Corridor	Cubic Yard	6670	$30.00	$200,100.00
Erosion Control Fabric along 100 foot Riparian Corridor	Square Foot	396000	$0.35	$138,600.00
Bank Stabilization - Outside Bend Extra Mineral Soil	Cubic Yard	490	$30.00	$14,700.00
Bank Stabilization - Outside Bend Vegetation (Brush Layering and Shrubs)	Linear Foot	2200	$31.00	$68,200.00
Temporary Fencing - Outside Bends	Linear Foot	2420	$4.00	$9,680.00
RIPARIAN AND UPLAND PLANTING ZONES				$395,790.00
Riparian Area Seeding	Acre	11.7	$2,500.00	$29,250.00
Riparian Planting Pockets	Each	28	$2,630.00	$73,640.00
Temporary Fencing - Riparian Planting Zone	Linear Foot	2200	$4.00	$8,800.00
Upland Area Fine Grading	Acre	6.2	$2,000.00	$12,400.00
Upland Planting Soil	Cubic Yard	5000	$30.00	$150,000.00
Upland Seeding	Acre	6.2	$3,500.00	$21,700.00
Weed Control, Irrigation and Minor Maintenance	Lump Sum	1	$100,000.00	$100,000.00
MISCELLANEOUS ITEMS				$738,950.00
40-ft precast bridge span	Each	1	$207,200.00	$207,200.00
Spoils Piles Grading and Reclamation	Cubic Yard	12300	$3.00	$36,900.00
Reclaimed Area	Acre	0	$40,000.00	$0.00
Water Control	Lump Sum	1	$125,000.00	$125,000.00
Construction BMPs	Lump Sum	1	$12,500.00	$12,500.00
Monitoring	Lump Sum	1	$40,000.00	$40,000.00
Project Permitting	Lump Sum	1	$6,250.00	$6,250.00
Construction Mobilization/Demobilization (5% of Construction Subtotal)	Lump Sum	1	$77,800.00	$77,800.00
Construction Survey & Management (5% of Construction Subtotal)	Lump Sum	1	$77,800.00	$77,800.00
Contingency (10% of Construction Subtotal)	Lump Sum	1	$155,500.00	$155,500.00
CONSTRUCTION SUBTOTAL				$1,555,030.00
Total				$1,912,380.00

Table 7.4. Budgetary Level Project Cost Estimates for Reach C.

Item	Unit	Quantity	Unit Cost	Sub-Total
STREAM IMPROVEMENTS				$1,065,660.00
Excavation - 125 Foot Stream and Riparian Zone	Cubic Yard	22700	$6.00	$136,200.00
Material Sorting & Placement - Fine Material Mixture for Subgrade	Cubic Yard	14400	$8.00	$115,200.00
Fine Grading for Riparian Zone	Acre	13.0	$4,000.00	$52,000.00
Fine Grading - Active Channel	Linear Foot	5200	$12.00	$62,400.00
Material Supply, Sorting and Placement - Material Sizes for Channel Bed and Banks	Cubic Yard	9630	$8.00	$77,040.00
Instream Habitat - Construct Riffle/Bend Pool Sequences	Each	29	$1,000.00	$29,000.00
Instream Micro Habitat Rock Features per Each Sequence	Each	29	$500.00	$14,500.00
Instream Micro Habitat Woody Debris Features per Each Sequence	Each	29	$500.00	$14,500.00
Riparian Planting Soils along 100 foot Riparian Corridor	Cubic Yard	9630	$30.00	$288,900.00
Erosion Control Fabric along 100 foot Riparian Corridor	Square Foot	572000	$0.35	$200,200.00
Bank Stabilization - Outside Bend Extra Mineral Soil	Cubic Yard	400	$30.00	$12,000.00
Bank Stabilization - Outside Bend Vegetation (Brush Layering and Shrubs)	Linear Foot	1800	$31.00	$55,800.00
Temporary Fencing - Outside Bends	Linear Foot	1980	$4.00	$7,920.00
RIPARIAN AND UPLAND PLANTING ZONES				$869,090.00
Riparian Area Seeding	Acre	12.9	$2,500.00	$32,250.00
Riparian Planting Pockets	Each	29	$2,630.00	$76,270.00
Temporary Fencing - Riparian Planting Zone	Linear Foot	2280	$4.00	$9,120.00
Upland Area Fine Grading	Acre	21.9	$2,000.00	$43,800.00
Upland Planting Soil	Cubic Yard	17700	$30.00	$531,000.00
Upland Seeding	Acre	21.9	$3,500.00	$76,650.00
Weed Control, Irrigation and Minor Maintenance	Lump Sum	1	$100,000.00	$100,000.00
MISCELLANEOUS ITEMS				$928,650.00
40-ft precast bridge span	Each	1	$207,200.00	$207,200.00
Spoils Piles Grading and Reclamation	Cubic Yard	22700	$3.00	$68,100.00
Reclaimed Area	Acre	0	$40,000.00	$0.00
Water Control	Lump Sum	1	$125,000.00	$125,000.00
Construction BMPs	Lump Sum	1	$12,500.00	$12,500.00
Monitoring	Lump Sum	1	$40,000.00	$40,000.00
Project Permitting	Lump Sum	1	$6,250.00	$6,250.00
Construction Mobilization/Demobilization (5% of Construction Subtotal)	Lump Sum	1	$117,400.00	$117,400.00
Construction Survey & Management (5% of Construction Subtotal)	Lump Sum	1	$117,400.00	$117,400.00
Contingency (10% of Construction Subtotal)	Lump Sum	1	$234,800.00	$234,800.00
CONSTRUCTION SUBTOTAL				$2,347,550.00
Total				$2,863,400.00

Table 7.5. Budgetary Level Project Cost Estimates for Reach D.

Item	Unit	Quantity	Unit Cost	Sub-Total
STREAM IMPROVEMENTS				$626,045.00
Excavation - 125 Foot Stream and Riparian Zone	Cubic Yard	7600	$6.00	$45,600.00
Material Sorting & Placement - Fine Material Mixture for Subgrade	Cubic Yard	8500	$8.00	$68,000.00
Fine Grading for Riparian Zone	Acre	8.0	$4,000.00	$32,000.00
Fine Grading - Active Channel	Linear Foot	3050	$12.00	$36,600.00
Material Supply, Sorting and Placement - Material Sizes for Channel Bed and Banks	Cubic Yard	5650	$8.00	$45,200.00
Instream Habitat - Construct Riffle/Bend Pool Sequences	Each	18	$1,000.00	$18,000.00
Instream Micro Habitat Rock Features per Each Sequence	Each	18	$500.00	$9,000.00
Instream Micro Habitat Woody Debris Features per Each Sequence	Each	18	$500.00	$9,000.00
Riparian Planting Soils along 100 foot Riparian Corridor	Cubic Yard	5650	$30.00	$169,500.00
Erosion Control Fabric along 100 foot Riparian Corridor	Square Foot	335500	$0.35	$117,425.00
Bank Stabilization - Outside Bend Extra Mineral Soil	Cubic Yard	400	$30.00	$12,000.00
Bank Stabilization - Outside Bend Vegetation (Brush Layering and Shrubs)	Linear Foot	1800	$31.00	$55,800.00
Temporary Fencing - Outside Bends	Linear Foot	1980	$4.00	$7,920.00
RIPARIAN AND UPLAND PLANTING ZONES				$459,580.00
Riparian Area Seeding	Acre	8.4	$2,500.00	$21,000.00
Riparian Planting Pockets	Each	20	$2,630.00	$52,600.00
Temporary Fencing - Riparian Planting Zone	Linear Foot	1570	$4.00	$6,280.00
Upland Area Fine Grading	Acre	9.4	$2,000.00	$18,800.00
Upland Planting Soil	Cubic Yard	7600	$30.00	$228,000.00
Upland Seeding	Acre	9.4	$3,500.00	$32,900.00
Weed Control, Irrigation and Minor Maintenance	Lump Sum	1	$100,000.00	$100,000.00
MISCELLANEOUS ITEMS				$771,650.00
40-ft precast bridge span	Each	1	$207,200.00	$207,200.00
Spoils Piles Grading and Reclamation	Cubic Yard	7600	$3.00	$22,800.00
Reclaimed Area	Acre	1.4	$40,000.00	$56,000.00
Water Control	Lump Sum	1	$125,000.00	$125,000.00
Construction BMPs	Lump Sum	1	$12,500.00	$12,500.00
Monitoring	Lump Sum	1	$40,000.00	$40,000.00
Project Permitting	Lump Sum	1	$6,250.00	$6,250.00
Construction Mobilization/Demobilization (5% of Construction Subtotal)	Lump Sum	1	$75,500.00	$75,500.00
Construction Survey & Management (5% of Construction Subtotal)	Lump Sum	1	$75,500.00	$75,500.00
Contingency (10% of Construction Subtotal)	Lump Sum	1	$150,900.00	$150,900.00
CONSTRUCTION SUBTOTAL				$1,453,125.00
Total				$1,857,275.00

Table 7.6. Budgetary Level Project Cost Estimates for Entire Project.

Item	Unit	Quantity	Unit Cost	Sub-Total
STREAM IMPROVEMENTS				$3,187,605.00
Excavation - 125 Foot Stream and Riparian Zone	Cubic Yard	54500	$6.00	$327,000.00
Material Sorting & Placement - Fine Material Mixture for Subgrade	Cubic Yard	41800	$8.00	$334,400.00
Fine Grading for Riparian Zone	Acre	46.0	$4,000.00	$184,000.00
Fine Grading - Active Channel	Linear Foot	15050	$12.00	$180,600.00
Material Supply, Sorting and Placement - Material Sizes for Channel Bed and Banks	Cubic Yard	27880	$8.00	$223,040.00
Instream Habitat - Construct Riffle/Bend Pool Sequences	Each	91	$1,000.00	$91,000.00
Instream Micro Habitat Rock Features per Each Sequence	Each	91	$500.00	$45,500.00
Instream Micro Habitat Woody Debris Features per Each Sequence	Each	91	$500.00	$45,500.00
Riparian Planting Soils along 100 foot Riparian Corridor	Cubic Yard	27880	$30.00	$836,400.00
Erosion Control Fabric along 100 foot Riparian Corridor	Square Foot	1655500	$0.35	$579,425.00
Bank Stabilization - Outside Bend Extra Mineral Soil	Cubic Yard	1800	$30.00	$54,000.00
Bank Stabilization - Outside Bend Vegetation (Brush Layering and Shrubs)	Linear Foot	8100	$31.00	$251,100.00
Temporary Fencing - Outside Bends	Linear Foot	8910	$4.00	$35,640.00
RIPARIAN AND UPLAND PLANTING ZONES				$2,134,450.00
Riparian Area Seeding	Acre	45.9	$2,500.00	$114,750.00
Riparian Planting Pockets	Each	105	$2,630.00	$276,150.00
Temporary Fencing - Riparian Planting Zone	Linear Foot	8250	$4.00	$33,000.00
Upland Area Fine Grading	Acre	44.1	$2,000.00	$88,200.00
Upland Planting Soil	Cubic Yard	35600	$30.00	$1,068,000.00
Upland Seeding	Acre	44.1	$3,500.00	$154,350.00
Weed Control, Irrigation and Minor Maintenance	Lump Sum	1	$400,000.00	$400,000.00
MISCELLANEOUS ITEMS				$3,159,800.00
25' x 4' box culvert with downstream armoring for fish migration barrier	Each	1	$141,900.00	$141,900.00
6' x 3' box culvert (Muggins Gulch proposed road alignment)	Each	1	$21,000.00	$21,000.00
40-ft precast bridge span	Each	3	$207,200.00	$621,600.00
Spoils Piles Grading and Reclamation	Cubic Yard	54500	$3.00	$163,500.00
Road Construction	Lump Sum	1	$13,000.00	$13,000.00
Road Demolition	Lump Sum	1	$25,000.00	$25,000.00
Reclaimed Area	Acre	1.4	$40,000.00	$56,000.00
Water Control	Lump Sum	1	$500,000.00	$500,000.00
Construction BMPs	Lump Sum	1	$50,000.00	$50,000.00
Monitoring	Lump Sum	1	$160,000.00	$160,000.00
Project Permitting	Lump Sum	1	$25,000.00	$25,000.00
Construction Mobilization/Demobilization (5% of Construction Subtotal)	Lump Sum	1	$345,700.00	$345,700.00
Construction Survey & Management (5% of Construction Subtotal)	Lump Sum	1	$345,700.00	$345,700.00
Contingency (10% of Construction Subtotal)	Lump Sum	1	$691,400.00	$691,400.00
CONSTRUCTION SUBTOTAL				$6,914,055.00
Total				$8,481,855.00

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APPENDIX A

Ground Water Level Monitoring Data

Table A-1: Piezometer measurements, depth to ground water in feet.

Type	Elevation of Pipe top (ft AMSL)	6/11/ 2012	6/21/ 2012	6/25/ 2012	Added/Cut Pipe (ft)[1]	7/9/ 2012	7/17/ 2012	7/25/ 2012	8/1/ 2012	8/8/ 2012
PZ 1	9620.92	4.40	5.10	5.20	5.55	10.89	11.02	11.21	10.91	11.28
PZ 2	9619.70	3.05	3.50	3.63	5.48	9.23	9.31	9.46	9.27	9.53
PZ 3	9625.25	13.00	13.10	13.10	1.95	14.11	15.01	15.06	14.94	15.12
PZ 4	9711.12	13.20	13.10	13.70	-3.59	10.11	10.11	10.99	10.99	11.01
PZ 5	9713.24	12.10	12.26	12.30	0.00	12.30	12.44	12.51	12.47	12.62
PZ 6	9734.94	12.75	12.73	12.74	-2.94	9.80	9.82	9.85	9.81	9.84
PZ 7	9739.75	9.60	9.67	9.70	1.20	10.90	10.94	11.01	10.99	11.03
PZ 8	9751.76	9.69	9.84	9.11	0.00	10.10	10.19	10.34	10.24	10.45
PZ 9	9822.62	14.74	15.21	15.31	2.10	17.53	17.63	17.96	17.58	18.24
PZ 10	9838.15	16.46	17.73	8.34	0.50	20.33	20.84		20.84	20.88
PZ 11	9845.48	20.64	20.69	20.71	0.00	20.35	20.87	20.80	20.64	
PZ A	9700.62						4.42	4.49	4.51	4.53
PZ B	9695.70							7.13	7.36	7.47
PZ C	9755.29						8.79	9.10	8.85	9.26

1. Pipe length was changed in late June or early July 2012. Subsequent measurements reflect this change.

Table A-1: Piezometer measurements, depth to ground water in feet (con't).

8/14/ 2012	8/28/ 2012	9/6/ 2012	9/10/ 2012	9/17/ 2012	9/27/ 2012	10/3/ 2012	10/9/ 2012	10/18/ 2012	10/22/ 2012	11/26/ 2012
11.31	11.51	11.61	11.49	11.49	11.51	11.54	11.51	11.55	11.55	11.50
9.38	9.72	9.81	9.84	9.80	9.82	9.83	9.88	9.86	9.89	9.85
15.00	15.42	15.53	15.56	15.53	15.53	15.57	15.58	15.56	15.64	15.70
11.02	11.02	11.02	11.03	11.06	11.07	11.05	11.07	11.05	11.06	10.88
12.56	12.98	12.69	12.71	12.70	12.73	12.69	12.77	12.74	12.79	12.73
9.87	9.88	9.88	9.91	9.92	9.93	9.89	9.93	9.91	9.94	9.75
11.03	11.13	11.18	11.19	11.21	11.02	11.19	11.22	11.19	11.24	11.10
10.31	10.81	10.98	11.03	10.99	11.01	11.05	11.06	11.03	11.11	11.38
18.01	21.11	21.98	22.01	21.90	21.89	22.09				
20.94	20.83	20.82	20.87	20.91	20.87	20.91	20.89	20.81	20.89	20.75
21.04	21.04	21.16	21.16	21.13	21.11	21.21	21.12	21.19	21.24	22.18
4.33	4.56	4.62	4.74	4.81	4.87		4.94	5.01	5.03	4.88
7.44	8.96	6.39	9.46	9.50	9.51	9.43	9.55	9.45	9.52	9.32
9.14	9.41	9.33	9.37	9.38	9.38	9.39	9.38	9.41	9.39	9.25

Table A-2: Piezometer measurements, converted to ground water elevation in feet AMSL.

Type	Elevation of Pipe top (ft AMSL)	6/11/ 2012	6/21/ 2012	6/25/ 2012	Added/ Cut Pipe (ft)[1]	7/9/ 2012	7/17/ 2012	7/25/ 2012	8/1/ 2012	8/8/ 2012
PZ 1	9620.92	9616.52	9615.82	9615.72	5.55	9615.58	9615.45	9615.26	9615.56	9615.19
PZ 2	9619.70	9616.65	9616.20	9616.07	5.48	9615.95	9615.87	9615.72	9615.91	9615.65
PZ 3	9625.25	9612.25	9612.15	9612.15	1.95	9613.09	9612.19	9612.14	9612.26	9612.08
PZ 4	9711.12	9697.92	9698.02	9697.42	-3.59	9697.42	9697.42	9696.54	9696.54	9696.52
PZ 5	9713.24	9701.14	9700.98	9700.94	0.00	9700.94	9700.80	9700.73	9700.77	9700.62
PZ 6	9734.94	9722.19	9722.21	9722.20	-2.94	9722.20	9722.18	9722.15	9722.19	9722.16
PZ 7	9739.75	9730.15	9730.08	9730.05	1.20	9730.05	9730.01	9729.94	9729.96	9729.92
PZ 8	9751.76	9742.07	9741.92	9742.65	0.00	9741.66	9741.57	9741.42	9741.52	9741.31
PZ 9	9822.62	9807.88	9807.41	9807.31	2.10	9807.19	9807.09	9806.76	9807.14	9806.48
PZ 10	9838.15	9821.69	9820.42		0.50	9818.32	9817.81		9817.81	9817.77
PZ 11	9845.48	9824.84	9824.79	9824.77	0.00	9825.13	9824.61	9824.68	9824.84	
PZ A	9700.62						9696.20	9696.13	9696.11	9696.09
PZ B	9695.70							9688.57	9688.34	9688.23
PZ C	9755.29						9746.50	9746.19	9746.44	9746.03

1. Pipe length was changed in late June or early July 2012. Subsequent measurements reflect this change.

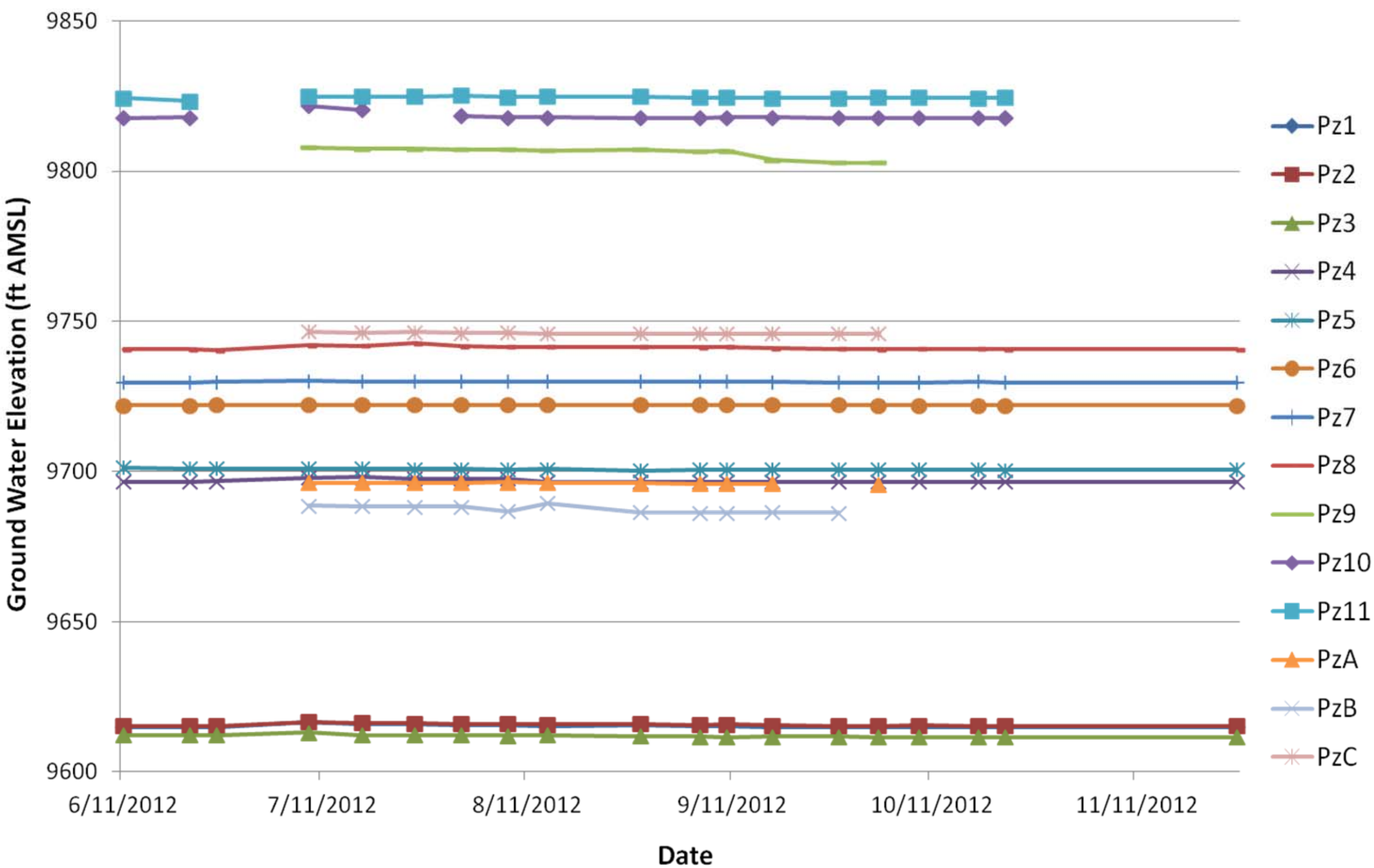
Table A-2: Piezometer measurements, converted to ground water elevation in feet AMSL (con't).

8/14/ 2012	8/28/ 2012	9/6/ 2012	9/10/ 2012	9/17/ 2012	9/27/ 2012	10/3/ 2012	10/9/ 2012	10/18/ 2012	10/22/ 2012	11/26/ 2012
9615.16	9614.96	9614.86	9614.98	9614.98	9614.96	9614.93	9614.96	9614.92	9614.92	9614.97
9615.80	9615.46	9615.37	9615.34	9615.38	9615.36	9615.35	9615.30	9615.32	9615.29	9615.33
9612.20	9611.78	9611.67	9611.64	9611.67	9611.67	9611.63	9611.62	9611.64	9611.56	9611.50
9696.51	9696.51	9696.51	9696.50	9696.47	9696.46	9696.48	9696.46	9696.48	9696.47	9696.65
9700.68	9700.26	9700.55	9700.53	9700.54	9700.51	9700.55	9700.47	9700.50	9700.45	9700.52
9722.13	9722.12	9722.12	9722.09	9722.08	9722.07	9722.11	9722.07	9722.09	9722.06	9722.25
9729.92	9729.82	9729.77	9729.76	9729.74	9729.93	9729.76	9729.73	9729.76	9729.71	9729.85
9741.45	9740.95	9740.78	9740.73	9740.77	9740.75	9740.71	9740.70	9740.73	9740.65	9740.39
9806.71	9803.61	9802.74	9802.71	9802.82	9802.83	9802.63				
9817.71	9817.82	9817.83	9817.78	9817.74	9817.78	9817.74	9817.76	9817.84	9817.76	9817.90
9824.44	9824.44	9824.32	9824.32	9824.35	9824.37	9824.27	9824.36	9824.29	9824.24	9823.31
9696.29	9696.06	9696.00	9695.88	9695.81	9695.75		9695.68	9695.61	9695.59	9695.74
9688.26	9686.74	9689.31	9686.24	9686.20	9686.19	9686.27	9686.15	9686.25	9686.18	9686.38
9746.15	9745.88	9745.96	9745.92	9745.91	9745.91	9745.90	9745.91	9745.88	9745.90	9746.04

Table A-3: Summary of Piezometer measurements.

Name	High GW Elev (ft AMSL)	Low GW Elev (ft AMSL)	Avg GW Elev (ft AMSL)	Standard Deviation (ft)	Range (ft)	Deepest Depth to Water (ft)	Shallowest Depth to Water (ft)	Avg Depth to Water (ft)
PZ 1	9616.52	9614.86	9615.25	0.43	1.66	-0.67	-2.33	-1.06
PZ 2	9616.65	9615.29	9615.65	0.38	1.36	-2.06	-3.43	-2.42
PZ 3	9613.09	9611.50	9611.94	0.39	1.59	8.00	6.41	7.56
PZ 4	9698.02	9696.46	9696.80	0.53	1.56	8.46	6.90	8.11
PZ 5	9701.14	9700.26	9700.66	0.22	0.88	7.08	6.20	6.68
PZ 6	9722.25	9722.06	9722.14	0.06	0.19	7.18	6.99	7.10
PZ 7	9730.15	9729.71	9729.89	0.14	0.44	4.24	3.80	4.06
PZ 8	9742.65	9740.39	9741.20	0.06	2.26	5.98	3.71	5.16
PZ 9	9807.88	9802.63	9805.42	2.17	5.25	13.54	8.29	10.75
PZ 10	9821.69	9817.71	9818.20	1.10	3.98	14.74	10.76	14.25
PZ 11	9825.13	9823.31	9824.47	0.39	1.82	13.77	11.95	12.62
PZ A	9696.29	9695.59	9695.92	0.23	0.70	2.78	2.08	2.45
PZ B	9689.31	9686.15	9687.10	1.16	3.16	7.20	4.04	6.26
PZ C	9746.50	9745.88	9746.04	0.20	0.62	4.66	4.04	4.51

Figure A-1: Time series plot of ground water elevation in feet AMSL.



APPENDIX B

Swan River Bankfull Flow Estimates

Swan River Bankfull Flow Estimates

The intent of this summary is to document the procedure used to estimate bankfull discharge at the bottom end of the project reach for the Swan River restoration project. Since there is considerable divergence between estimates based on local gauges, this analysis is intended to help choose a value within that range.

The general process involved taking a discharge measurement during high flow in order to back calculate a starting roughness value for the stream reach. This starting roughness value was then adjusted, based on stage and relative submergence of bed material, to give a roughness value at bankfull stage. The measured cross section, field-identified bankfull indicators, and measured slope were then used to estimate the discharge at bankfull stage using WinXSPRO, a one-dimensional hydraulic model (Hardy et al. 2005).

On May 31, 2012 we collected a discharge measurement and cross section in the Summit County Open Space land on the Swan River, immediately behind the dredge boat. The discharge at the time was only 13.4 cfs, a very low value for that time of year. The gradient, hydraulic variables from the cross section, along with the discharge value, were fed backwards into Manning's equation to determine the effective flow resistance in the reach (n = 0.080) at that low stage.

This roughness value is expected to decrease as roughness elements become submerged at stages near bankfull, so two empirical equations were used to estimate the decline. Thorne and Zevenbergen (1985), which gave the best prediction of the measured low flow roughness (based partly on D_{84} particle size), suggest a decrease in roughness of approximately 30 percent between low flow stage and bankfull. This resulted in a roughness value of n = 0.056. Both the back-calculated and estimated roughness values are consistent with published data by Hicks and Mason (1998) as well as other measurements we have made in similar gravel-bed streams.

With a 'known' roughness value at bankfull stage, a measured cross section, and a measured slope between bankfull indicators, we calculated the discharge in the Open Space reach as 101 cfs. This measurement was translated upstream to the project reach using the methods suggested by Vaill (1999):

$$Q_P = Q_{OS} (A_P/A_{OS})^{0.69}$$

Where the subscripts OS and P refer to the Open Space reach and Project reach, respectively. Based on drainage areas (estimated from StreamStats) of 28.9 square miles at the Open Space and 23.1 square miles at the bottom of the project reach, the estimated bankfull discharge was about 86 cfs.

There is obvious uncertainty in this estimate, primarily in the measured gradient (mainly due to the short length between identifiable bankfull indicators) and the Manning's roughness. In order to account for this uncertainty, the discharge at the Open Space was recalculated by sampling from probability distributions for both the gradient and roughness within a Monte Carlo simulation.

We assumed normal probability distributions to describe the slope and roughness at bankfull discharge. The measured values were used as the means of the distributions. Since those values could easily be off by 20 percent, the standard deviation of the distribution was assumed to be 20 percent of the mean. While the selection of these standard deviation values could be considered somewhat arbitrary, they appear reasonable and provide some starting point for determining sensitivity and uncertainty in the discharge estimate.

The Monte Carlo simulation was performed with an EXCEL add-on called @Risk. The bankfull discharge was repeatedly calculated with Manning's equation by sampling from the previously described probability distributions. The summary results for 1000 iterations are shown below in Figure 1 and Table 1. The median value at the bottom end of the project reach is approximately 86 cfs, as previously calculated. However, a 90 percent confidence interval could be interpreted as 70.3 to 109.0 cfs. The interquartile range (25^{th} to 75^{th} percentile) could range from 79.1 to 94.8 cfs.

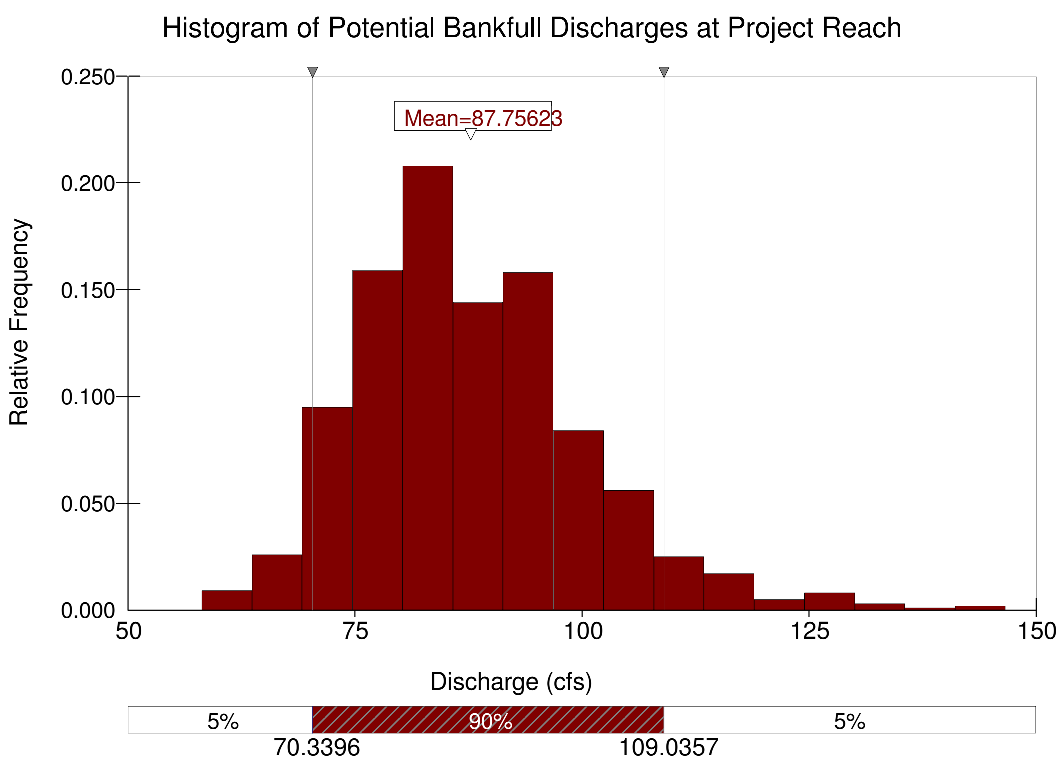


Figure 1. Histogram of 1000 iterations of Manning's equation, generated by sampling from probability distributions for slope and roughness.

Table 1. Summary statistics for 1000 iterations of Manning's equation, generated by sampling from probability distributions for slope and roughness.

Summary Statistics			
Statistic	**Value**	**Percentile**	**Value**
Minimum	58.1	5%	70.3
Maximum	146.6	10%	73.4
Mean	87.8	15%	75.6
Std Dev	12.5	20%	77.1
Variance	157.3	25%	79.1
Skewness	0.8	30%	80.5
Kurtosis	4.4	35%	82.0
Median	86.0	40%	83.0
Mode	82.1	45%	84.4
Left X	70.3	50%	86.0
Left P	5%	55%	87.4
Right X	109.0	60%	89.5
Right P	95%	65%	91.7
Diff X	38.7	70%	93.3
Diff P	90%	75%	94.8
#Errors	0	80%	96.9
Filter Min		85%	100.1
Filter Max		90%	103.4
#Filtered	0	95%	109.0

Hopefully these estimates, along with discussions about subsurface and base flow, will beneficially inform our choice of a design discharges for the Swan River project.

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APPENDIX C

Swan River Base Flow Calculations

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Technical Memorandum

Date: December 10, 2012

To: Troy Thompson

From: James Koehler

Re: Swan River Base Flow Calculations

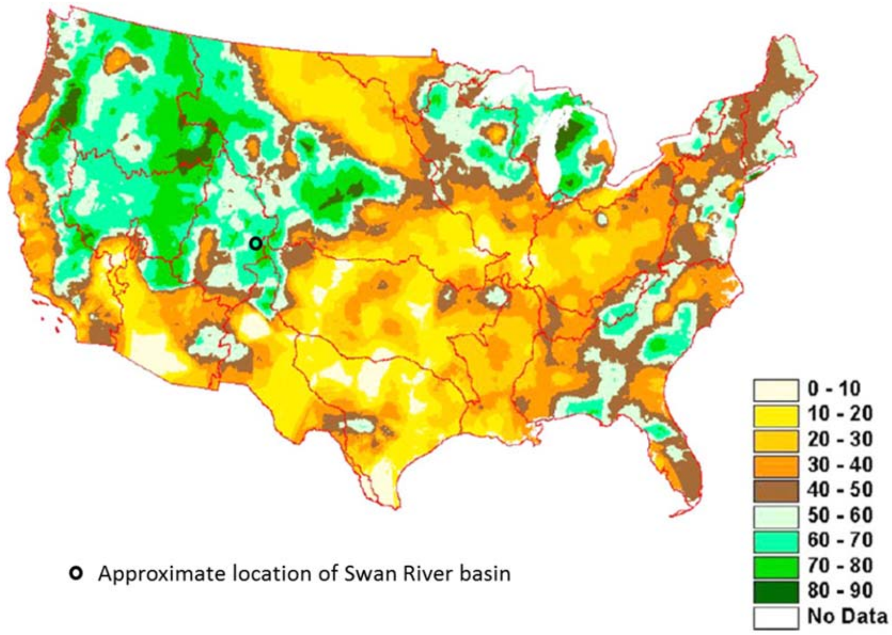
Introduction

The process for determining base flow for the Swan River watershed area involved four techniques: 1) interpolation from a base flow index (BFI) map produced by the USGS, 2) interpolation from a base flow index map produced by Santhi, et al, 3) analytically calculating base flow index and 4) analytically calculating base flow volume. Techniques 3) and 4) used closed-form equations developed by Santhi, et al to describe the relationship between basin characteristics and base flow. These techniques were selected based on their availability, simplicity, and relevance to the problem at hand. Multiple techniques were used to increase the confidence in results if similar values were produced.

USGS Base Flow Index Map

Figure 1 shows a BFI map created by the USGS from a 1-km raster dataset (Wolock). Base flow index is defined as the percentage of total streamflow that can be attributed to ground water discharge, or base flow. The BFI is calculated by dividing base flow by total flow. The map in Figure 1 was developed by interpolating BFI values obtained using a smoothed minima technique to separate base flow from total flow for 8,249 streamflow records. These records spanned an average of 33 years of daily observations. The average observed basin size was 528 km2. Using the map in Figure 1, the BFI in the Swan River watershed can be approximated as 60-70%.

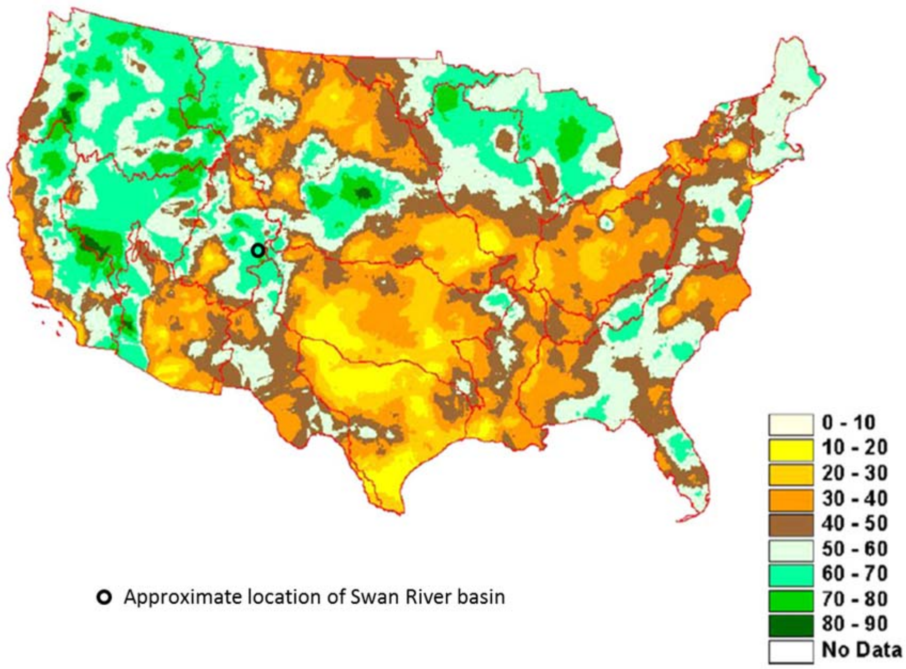
Figure 1: USGS Base Flow Index Map



Santhi, *et* al. (2008) Base Flow Index Map

Figure 2 shows a BFI map created by Santhi, et al. (2008). This map was developed by interpolating BFI values using a digital filtering technique to separate base flow from total flow for nearly 8,600 streamflow records. These gauges were selected from basins of drainage areas of 50-1,000 km2 and consisted of at least 10 years of daily records from low ET months. Using the map in Figure 2, the BFI in the Swan River watershed can be approximated as 60-70%.

Figure 2: Santhi, et al (2008), Base Flow Index Map



Base Flow Equations

Santhi, et al. (2008) used multiple regression techniques to find the most significant relationships between basin characteristics (terrain, geology and climate variables) and base flow (Santhi et a. 2008). These relationships are described by Equations 1 and 2: [1]

$$BFI = 33.5435 + 0.0091*Relief + 0.3034*Sand \qquad (1)$$

where,

BFI = base flow index, in percent
Relief = maximum basin elevation minus minimum basin elevation, in meters
Sand = percentage of sand in soil

$$BF = 60.43 + 0.2145*Relief + 0.4283*(P - PET) \qquad (2)$$

where,

[1] In the article by Santhi, *et al*, the equation for base flow contains a typographical error. ERC confirmed from the lead author, Dr. Santhi Chinnasamy, that the base flow equation presented here as Eqn (2) is correct.

BF = base flow volume, in millimeters
Relief = maximum basin elevation minus minimum basin elevation, in meters
P = annual precipitation, in millimeters
PET = annual potential evaporation, in millimeters

The values used for the parameters in Equations 1 and 2 came from various sources. "Relief" and "Precipitation" were estimated using the USGS Stream Stats program. "Sand" was estimated using the USDA Natural Resources Conservation Service Web Soil Survey. "PET" was estimated by taking an average of estimated lake and pan evaporation values from multiple sources including: Colorado State University, the National Agroforestry Center, the National Oceanic and Atmospheric Administration, and the Western Regional Climate Center. Because the estimates of PET from these sources ranged from 889 mm (35 in) to 1295 mm (51 in), a simple average was taken. The estimated parameters are presented in Table 1.

Table 1: Parameter Values Used in Equations 1 and 2

Parameter	Relief	Sand	P	PET
Value	1037 m	51%	646 mm	1143 mm

Results

The results of the analyses are presented in Table 2. Three of the four methods produced BFI, the percentage of total flow attributed to base flow. BFI is converted to base flow volume by multiplying by the mean annual streamflow. The mean annual streamflow in the Swan River basin is estimated from the USGS Stream Stats program as 29 cubic feet per second (cfs). The estimated base flow shown in Table 2 is the product of estimated BFI and 29 cfs.

Table 2: Results from Four Techniques used to Calculate Base Flow

Technique	**Estimated BFI (%)**	**Estimated Base Flow (cfs)**
Interpolation from USGS Map	65	19
Interpolation from Santhi, *et al* Map	65	19
Calculating BFI from Eqn (1)	58	17
Calculating Base Flow from Eqn (2)	n/a	7

Discussion

The results presented in Table 2 are in general agreement with each other. The base flow calculated using Technique 4 is the outlier based on the sensitivity of Equation 2 to PET, a parameter that is very difficult to accurately determine. However, using the low end of estimates for PET (889 mm), instead of a simple average, yields a base flow of 19 cfs. This provides a high degree of confidence that the base flow in Swan River is in the vicinity of 17 cfs.

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APPENDIX D

Preliminary Design Plan