Design and Consulting Services Group

Submitted to
Wendy and Bill Thompson
Riverside Ranch Company
P.O. Box 826
Kremmling, CO 80459

Submitted by
AECOM
804 Colorado Ave
Suite 201
Glenwood Springs, CO 81601

Riverside Ranch Irrigation Diversion and River Restoration Design Report.

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Design Report.

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AECOM & Golder Associates

Riverside Ranch Irrigation Diversion and River Restoration

Design Report.

Project Manager:

John Sikora, PE, CFM
AECOM

Principal Design Engineer:

Chris Romeyn, PE, CFM
AECOM

Senior Geomorphologist:

Edmund D. Andrews, PhD
AECOM

Senior Ecologist:

Randy Mandel
Golder Associates

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1 Introduction

AECOM contracted with Riverside Ranch, LLLP to develop final engineering and construction drawings for two irrigation diversions and restoration of approximately one mile of the Colorado River through Riverside Ranch. This work was funded by a Colorado Water Conservation Board, Colorado Basin Roundtable grant for $113,000 and a $69,973 match from the owners of Riverside Ranch Company, LLLP. The Grant was administered through Trout Unlimited (TU). This report presents a summary of the engineering performed for this design.

1.1 Project Background

In 2014 a group of ranches (Irrigators of Lands in the Vicinity of Kremmling, or ILVK) and the Colorado Water Conservation Board sponsored a detailed study of approximately 10 miles of the Colorado River that extends from the Colorado's confluence with the Blue River up to the headgate of the K.B. Ditch diversion (Figure 1). The results of this study are presented in the report titled ILVK Upper Colorado River Irrigation and Restoration Assessment Phase 1: K.B. Ditch to Blue River (The Assessment Report). This project investigated the driving forces behind a number of issues related to the Colorado River through this reach. These issues include failing diversion structures, loss of agricultural infrastructure and lands due to stream bank erosion, and loss of aquatic habitat. The results of this study were presented to the CWCB in March, 2015. The Assessment Report outlined a number of different issues for the reach wide instabilities and provided restoration recommendations, conceptual plans and costs for restoration projects throughout the reach. The Assessment Report serves as the Basis of Design for approximately ten miles of the Colorado River.

The Riverside Ranch Irrigation Diversion and River Restoration Project (The Riverside Ranch Project) represents the next phase of work for Riverside Ranch: implementation of the recommendations presented in The Assessment Report. Specifically this study addresses issues from the Highway 9 Bridge to the Riverside Ranch-McElroy Ranch property boundary.

This project improves diversion for the following water rights owned by Riverside Ranch shown in Table 1:

Table 1 Riverside Ranch Water Rights

Water Right Name	DIV	WD	ID	Admin No.		
TA Engle Ditch No 1	5	51	925	34241.18263	449A	10
TA Engle Ditch No 2	5	51	926	34241.18263	449B	2
TA Engle Ditch No 3	5	51	651	34241.18263		4
Thompson Pump No 1	5	51	1148	34241.18263	449D	13.84
Total Diversion						29.84

1.2 Project Goals

The Assessment Report provides a general approach to restoration projects through this reach as follows:

1) Design solutions that preserve and enhance agricultural operations.
2) Design solutions that provide multuiple benefits including improvide aquatic and riparian habitat.
3) Design solutions that are cost effective and use locally available material.
4) Design solutions that limit the use of large boulders in the channel.
5) Design solutions that maintain flood conveyance.
6) Design solutions that limit the use of hard revetment.

7) Design solutions that improve the low flow channel (i.e. narrow).

The specific goals of The Riverside Ranch project are as follows:

1) Increase water surface elevations, particularly for low flows, to improve agricultrual pumping operations at the TA Engle and Thompson Pump No. 1 Consolidated (Thompson Consolidated) diversion locations (Figure 1).
2) Reduce bank erosion through most of the reach.
3) Protect aggricultural facilities (fields and ditches) from continued bank erosion.
4) Improve Aquatic and Riparian Habitat.
5) Reduce low flow temperatures.

1.3 Project Approach

Riverside Ranch's operations are highly dependent on a reliable irrigation water supply. The degraded nature of the Riverside Ranch reach of the Colorado River has made irrigation diversions difficult to impossible in some years due to low minimum flows in the reach. The initial scope for this project involved the use of SRH-2D hydraulic model to model live-bed sediment transport conditions through the project reach in an effort to engineer stable, self-sustaining grade control riffles. The self-sustaining riffles would be constructed out of material that would be mobilized under effective discharge flow conditions and the designed configuration of the riffles would ensure that the material that was transported out of the riffle was replaced from upstream sources.

In 2014 diversion operations on Riverside Ranch were difficult and there was concern that if the winter of 2014 and 2015 was below average Riverside Ranch might not be able to divert at all. Therefore the design and construction of the irrigation diversion structures was a high priority. The project was urgent enough that it could not wait for the CWCB contracting process which would not be completed until spring, too late for the 2015 irrigation season. In the fall of 2014 Bill Thompson contracted with AECOM to design and construct a pilot project riffle grade control structure at the Thompson Consolidated pump. Hydraulic modeling with HEC-RAS indicated that the velocities and shear stresses at the riffle structure would be large enough that large gravel and cobble material, with a D_{50} of 2.5 inches, would be required to prevent the structure from washing away at low to moderate flows. If the bed material on the riffle did become mobile the upstream reach was incapable of replacing the larger size material. This lack of upstream riffle material supply dictated that a self-sustaining riffle could not be used in this reach. Importing the precise gradation of riffle material proved to be too expensive, therefore the decision was made to use a locally sourced alluvium that had a smaller D_{50} and greater sand content to test how it performed. The information gathered during the pilot project, including Acoustic Doppler Current Profiler (ADCP) velocity was used for the final design.

The methods/approach used to reach each of the project goals are as follows:

1) Design an Engineered Grade Control Riffle Structure for each of the two pump stations.
2) Use a combination of encapsulated soil lifts, driven timber walls, and riffle vanes to reduce bank erosion.
3) Protect agricultural infrastructure by softening all slopes to 3:1; building vegetated floodplain benches to provide a buffer between high velocity channel flows and the facilities; and building driven timber walls in critical locations to provide extra bank protection. Convert ditch irrigation to piped irrigation where bank erosion is exacerbated by irrigation return flows saturating the river banks.
4) In addition to the two riffle grade control structures three riffle vanes are proposed for the reach. These vanes are similar in design to one of the wings of the riffle grade control structures. The riffle vanes will redirect flows away from the bank towards the center of the river. They also provide important habitat for aquatic organisms, particularly benthic invertebrates. They also create flow diversity providing areas of slower and faster water and seamlines, which are important for fish habitat.
5) Several vegetated point bars will be used to narrow the low flow channel (Q=150 cfs). These point bars will be constructed out of locally sourced alluvium and planted with native vegetation. In combination with the driven timber walls, these features will narrow the low flow channel through much of the reach. Additionally the installation of a wide variety of riparian plants (particularly willows and cottonwoods) will provide much needed shade throughout the reach.

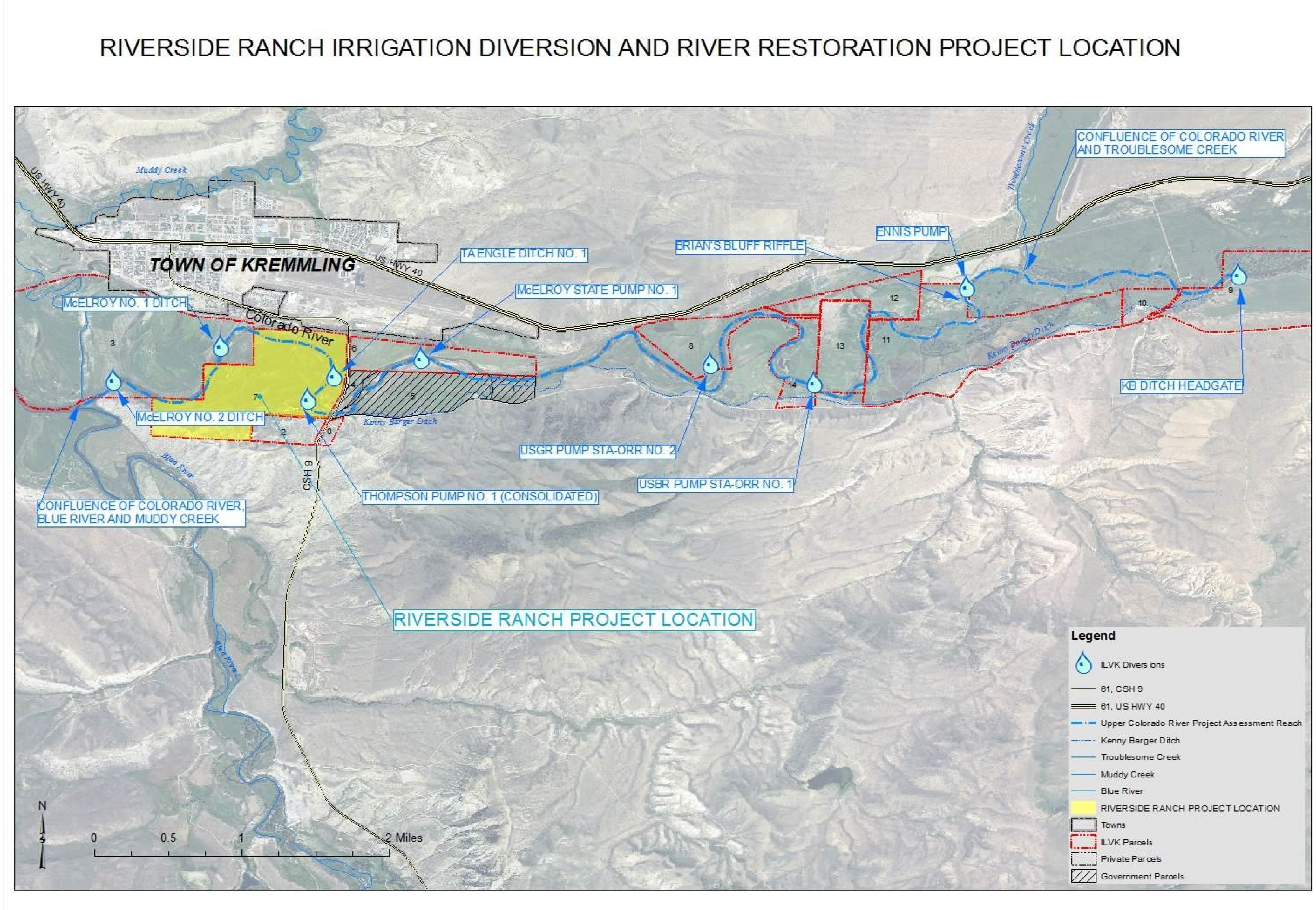

Figure 1. Project Location Map

2 Methods/Results

2.1 Restoration Plan

The attached drawings show the proposed restoration plan. Five different restoration methods will be used throughout the project: Driven Timber Walls, Riffle Vanes, Encapsulted Soil Lifts, Vegetated Point Bars, and Floodplain Benches. Each of these methods is described below.

2.1.1 Driven Timber Wall

There are two sections of the project reach where toe scour is a concern. Large boulders are not available locally and importing them is expensive. For these sections AECOM is proposing a Driven Timber Wall using driven beetle killed timbers to protect against scour. The front face of this structure will be built out of 20-25 foot long, 12-inch diameter beetle killed timbers driven a minimum of 15 feet into the ground. Timber tiebacks will be placed approximately every 10 ft and anchored to driven timer deadmen placed back from the face of the wall into native materials. The resulting 10ft wide bays will be filled with a combination of select locally sourced alluvium and native fill. See construction plans for details.

2.1.2 Riffle Vanes

Riffle vanes are proposed at several key locations: one at the beginning and end of the Driven Timber Wall below the TA Engle drop structure and one at the beginning of the downstream wall. These structures are placed at these locations to decrease velocities along the bank and train the flow towards the centerline of the stream. Additionally, these structures will provide additional habitat for benthic invertebrates and provide flow diversity fish. See construction plans for details.

2.1.3 Encapsulated Soil Lifts

In areas where the bank is over-steepened, but the velocities are not has high, the proposed treatment consists of a combination of select locally sourced alluvium and encapsulated soil lifts. The bull nose of the lift is protected by a coir log placed inside the wrap. There are two layers of fabric, Coir 700 woven fabric protects the soil from impacts while a non-woven coir mat prevents fines from being eroded from the lift. The maximum lift is 1 ft. The wrap is filled with native soil, alluvium and vegetation. See construction details.

2.1.4 Vegetated Point Bars

Point Bars form naturally on the inside of bends. During large flows (e.g. bankfull/effective discharge), these areas can transport significant amounts of sediment, but as the higher flows recede these shallowly sloped point bars see a more rapid decrease in velocity that the centerline of the river or the outside of the bend. There are several locations where the existing point bar is very flat, which results in very shallow depths at low flows. The vegetated point bars are constructed out of select locally sourced alluvium and planted according to the planting plan.

2.1.5 Riffle Grade Control Structures

The riffle grade control structures consist of a core of locally available stone which is embedded into the river bottom a minimum of 3 ft. Locally sourced alluvium is then backfilled downstream against the core to create riffles that are between 1% and 5% in slope. The upstream side is backfilled with the same alluvium to a slope of 1(h):5(v). The wings of the core are keyed into stable bank a minimum of 15 ft. See Construction Drawings for more details.

2.2 Engineering Design

2.2.1 Data Acquisition

The following sections outline the data collected for the Riverside Ranch project.

2.2.1.1 Survey Data

AECOM performed topographic survey for all of the Riverside Ranch reach from above the SH 9 Bridge to downstream of the McElroy / Riverside Ranch property boundary. There were several places where the river was too deep to access with traditional survey equipment. An Acoustic Doppler Current Profiler (ADCP) was used to collect the remaining benthic topography data (Figure 2). The resulting topographic survey is accurate to within +/- 1 ft (Figure 3).

Figure 2 Acoustic Doppler Current Profiler (ADCP) Benthic Survey

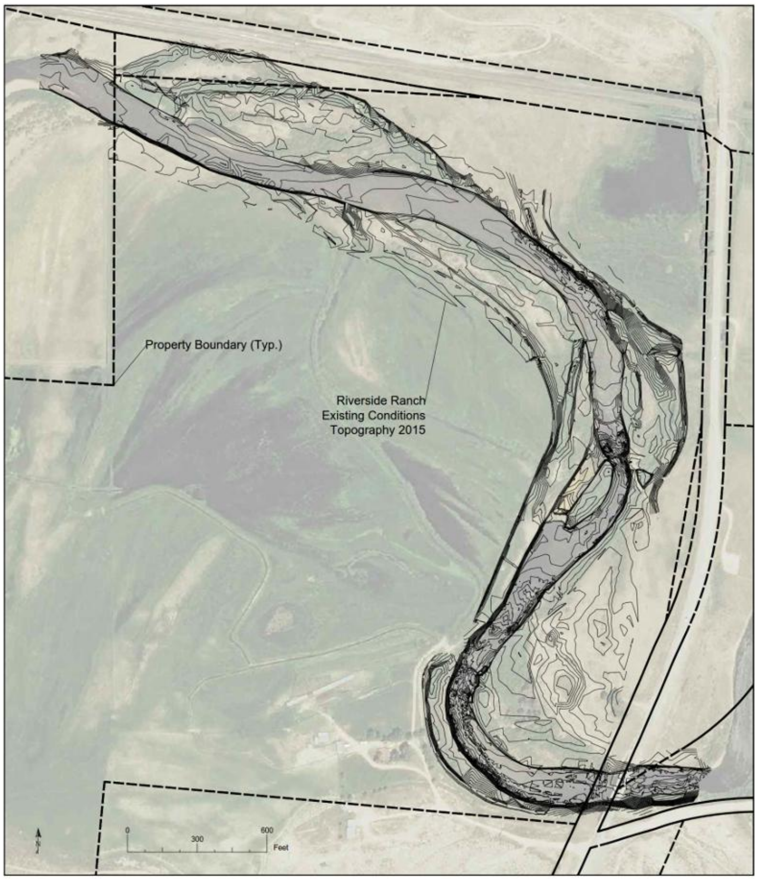

Figure 3 Riverside Ranch Existing Conditions Topography

2.2.1.2 Sediment Data

As previously indicated, the sustainable riffle concept design will not work for this reach due to an insufficient upstream source of replacement sediment. With the option of self-sustaining riffle grade control structures eliminated there was no longer a need for additional sediment samples. Two sediment samples were collected on the Riverside Ranch.

1) At the upstream end of the project reach, just upstream of the SH 9 Bridge.
2) At just downstream of the proposed Thompson Consolidated drop structure location.

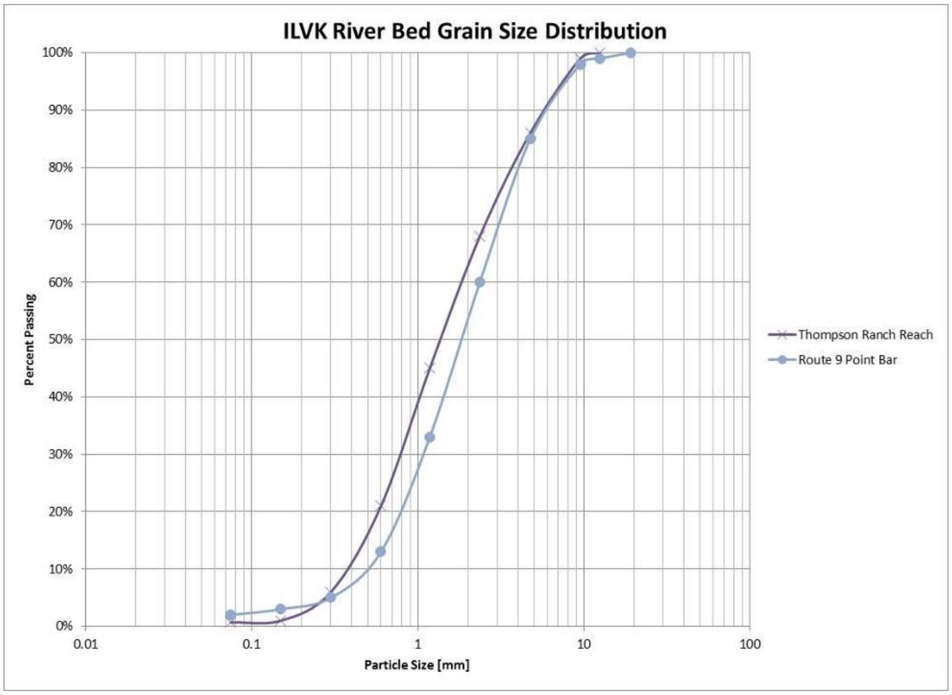

Figure 4. Riverside Ranch River Bed Sediment Gradations

The results of the sediment analysis are presented in Figure 4. A summary of the critical diameters is present in Table 2 and Table 3.

Table 2. Riverside Ranch Bed Material Below Thompson Consolidated

Diameter Class	Diameter [mm]
D_{50}	1.4
D_{65}	2.2
D_{84}	4.5
D_{90}	6.2

Table 3. Riverside Ranch Bed Material above SH 9 Bridge

Diameter Class	Diameter [mm]
D_{50}	1.9
D_{65}	2.8
D_{84}	4.7
D_{90}	6.6

2.2.2 Project Hydrology

The hydrology used for the Riverside Ranch design was adopted from The Assessment Report. A range of flows were considered. The range of expected bankfull flows is from 2200 cfs to 4300 cfs with and average effective discharge of 3500 cfs (see Assessment Report). Flows were selected because they were important from a geomorphic perspective or from an ecological perspective. The future average daily flows from the Denver Water PACSM (see Assessment Report for more detail) were analyzed to develop a flow-duration relationship for the growing season of May 1 to October 1. The results of this analysis is presented in Figure 5.

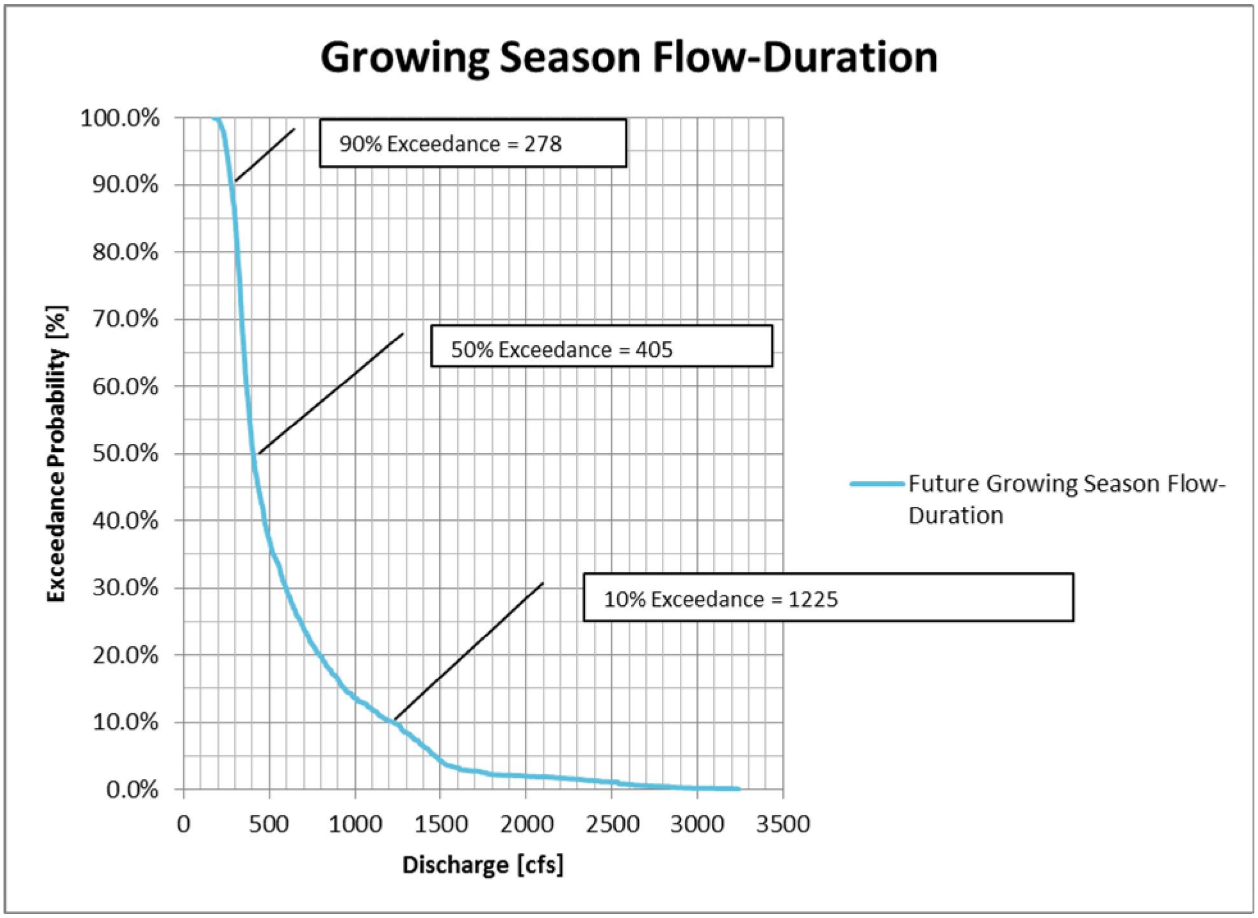

Figure 5. Future Growing Season Flow Duration Relationship.

These growing season flows were used to develop the planting plan. The minimum flow considered was the CWCB minimum flow of 150 cfs. The mean annual peak was used because it was so close to the lower end of the effective discharge estimates. Additional discharges considered were the reach wide effective discharge and the estimated 25-year flood (StreamStats).

Table 4 Design Discharge Summary

Discharge Name	Discharge [cfs]
Instream Flow Minimum	150
90% Growing Season Exceedance Probability	278
50% Growing Season Exceedance Probability	405
10% Growing Season Exceedance Probability	1225
Mean Annual Peak	1860
Effective Discharge	3500
Stream Stats 25-Year Flood	6890

2.2.3 Hydraulic Geometry

The ILVK Colorado River restoration is based on hydraulic relationships developed by Andrews (1984) as presented in The Assessment Report. The Assessment Report presented an analysis of non-dimensional hydraulic geometry for the entire 10 miles of the ILVK Colorado River project. This analysis was performed specifically for the Riverside Ranch project using the sediment data from the Riverside Ranch reach. The analysis considered the range of effective discharges established in the Assessment Report (2200 cfs, 3500 fs, and 4300 cfs).

Table 5. Bankfull Width Estimate based on Andrews 1984.

Veg Type	Condition	Q [cms]	Q [cfs]	D50 [m]	Qbar	W*	W [m]	W [ft]
Thin	Colorado River Future	121.8	4300	0.00144	384815098	62730	90	296
Thick	Colorado River Future	121.8	4300	0.00144	384815098	53750	77	254
Thin	Colorado River Future	99.1	3500	0.00144	313221592	56852	82	269
Thick	Colorado River Future	99.1	3500	0.00144	313221592	48673	70	230
Thin	Colorado River Future	62.3	2200	0.00144	196882143	45536	66	215
Thick	Colorado River Future	62.3	2200	0.00144	196882143	38913	56	184

As explained in The Assessment Report there are many section of the ILVK reach where there is evidence that the channel is narrowing in response to hydromodification. In many locations through the Riverside Ranch reach the water surface width of the effective discharge of 3500 cfs is greater than 296 ft, and in places is as high as 642 ft wide. However, at many cross-section locations much of the cross-section is significantly vegetated and has very little conveyance. An example of this is shown in the HEC-RAS cross-section in Figure 6.

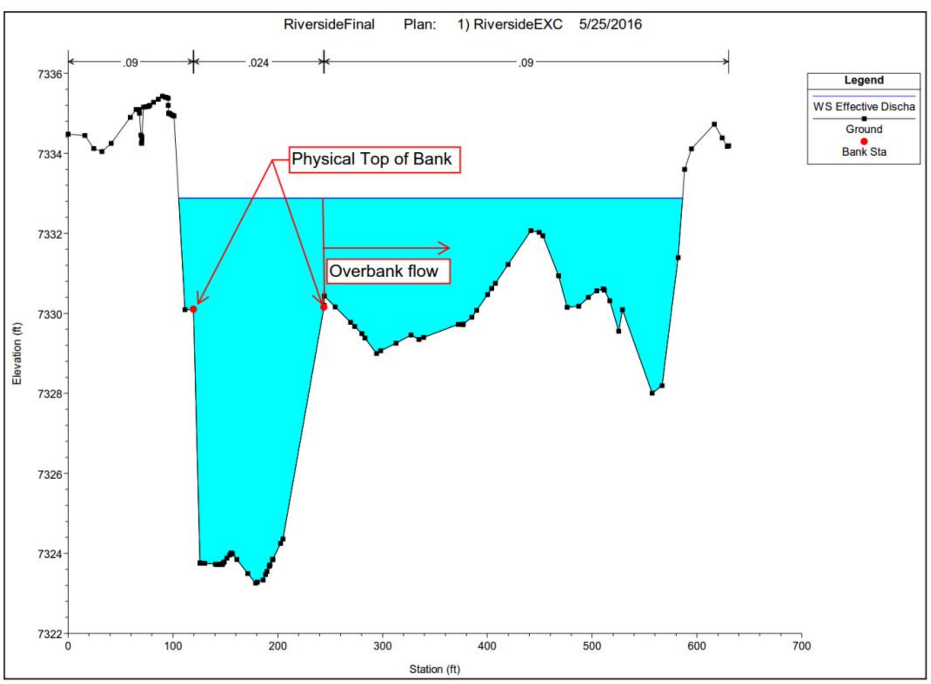

Figure 6. HEC-RAS section showing overbank flow during effective discharge flow of 3500 cfs.

An aerial photograph of the cross-section presented in Figure 6 is presented in Figure 7. The overbank flow section is filled with vegetation and likely contains pocket wetlands. Filling in this right overbank area in an attempt to narrow the width of the Effective Discharge would cause significant negative impacts to the riparian habitat. The proposed design has a limited impact on these well vegetated overbank areas and most of the restoration efforts are concentrated along the active banks.

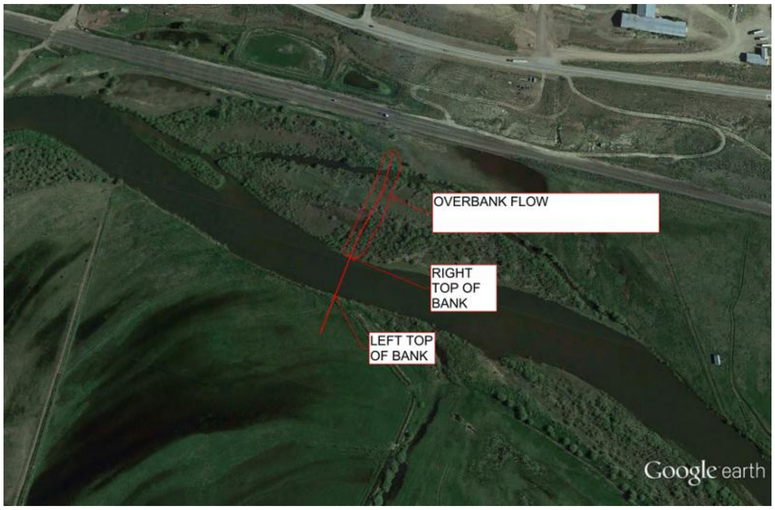

Figure 7. Effective Discharge Overbank Flow

The HEC-RAS model results for the existing conditions shows that for the mean annual peak discharge of 1860 cfs the average flow width is approximately 230 ft, which is closer to the values presented in Table 5. Based on this analysis the proposed design focuses on reducing the width of the active flow events that are less than the mean annual peak and leaving the overbank areas largely undisturbed. Several floodplain benches will provide shade for aquatic habitat.

2.2.4 Hydraulic Modeling

Ranching operations at Riverside Ranch dictated that the design of the riffle grade control structures be accelerated. During the initial design of these structures it became apparent that there was not an adequate supply of adequately sized material coming from the upstream reach to maintain self-sustaining riffle structures. The bed of the Colorado River through this reach is largely sand and small gravels. The velocities of the riffle structures require that much larger material to be stable. A self-sustaining riffle structure at this location is not feasible. Therefore the focus of design for the irrigation diversions became creating stable riffle grade control structures which also provide habitat. The design of the riffle grade control structures was guided by several different hydraulic models including HEC-RAS 1D, FLOW-3D, and HEC-RAS 2D. A brief explanation of each modeling effort is presented below.

2.2.4.1 HEC-RAS

The calibrated HEC-RAS model developed for The Assessment Report was modified for the design of the grade control riffles as well as the proposed bank stabilization. The full ILVK model was used to ensure that upstream and downstream boundaries were consistent. Model resolution was increased with a total of 52 cross-sections used to model conditions along the 5192 ft length of the Riverside Ranch project (Figure 8). This model was used for the preliminary layout of the Thompson grade control riffles as well as bank restoration.

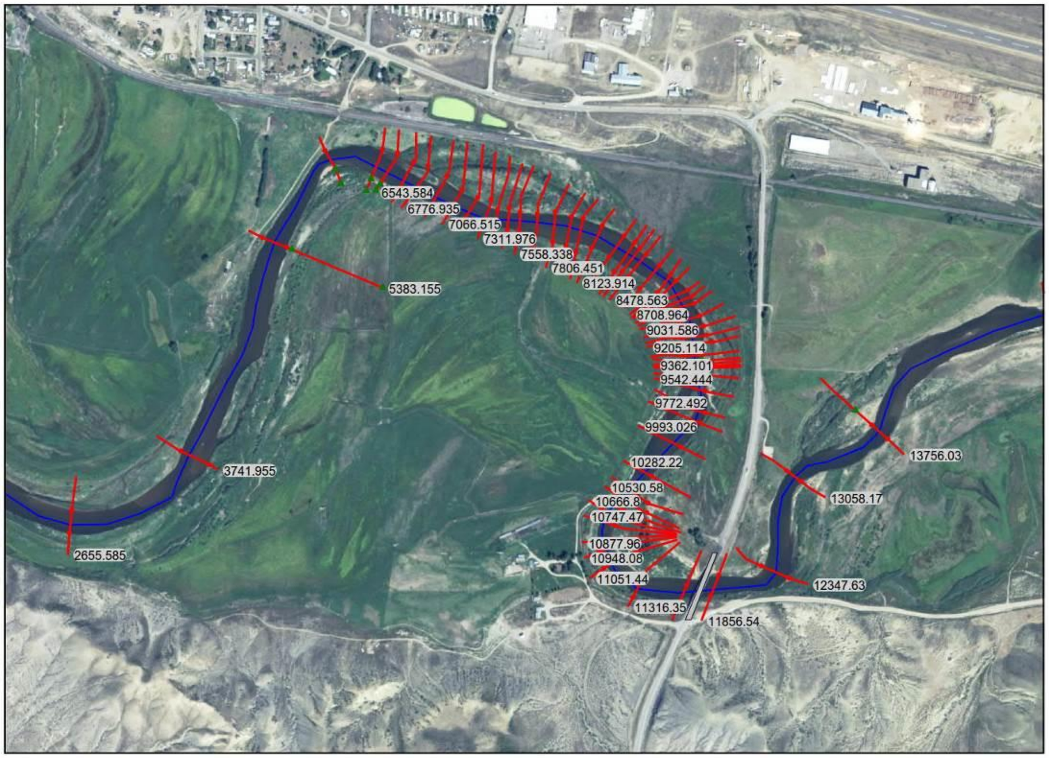

Figure 8 HEC-RAS Cross-Sections

2.2.4.2 FLOW-3D

A three-dimensional Computational Fluid Dynamics (CFD) was conducted for the Colorado River at Riverside Ranch to evaluate the hydraulics in the river with the proposed construction of the riffle control structure for stream bank and grade control.

For the purpose of the analysis, AECOM assessed the hydraulic performance of the proposed riffle as well as the existing condition using the FLOW-3D computer program (version 11.0, Flow Science, Inc. 2016), a commonly used and well-tested, CFD code developed and supported by Flow Science, Inc. of Santa Fe, New Mexico, USA. The program has been used in many open channel hydraulic studies around the world.

One of the major strengths of FLOW-3D for hydraulic analysis is its ability to accurately model problems involving free surface flow. In FLOW-3D, free surfaces are modelled using the Volume of Fluid (VOF) technique, which accurately tracks the fractional face areas and fractional volumes of each element that are blocked by solids/structures as fluid is moving through a computational grid. The program handles transitions between sub-critical and super-critical flow within a single model set up.

The developed CFD model was used to determine the velocity at the design flow of about 2,400cfs. Figure 9 shows the computation flow domain for this model runt. The upstream boundary is approximately 1600 ft upstream of the proposed riffle and the downstream boundary is about 1400 ft downstream from the proposed structure. For the purpose of this modeling, a shallow flow model was used, meaning that the flow is calculated as two-dimensional flow due to the shallow depth at the design flow of 2,400 cfs.

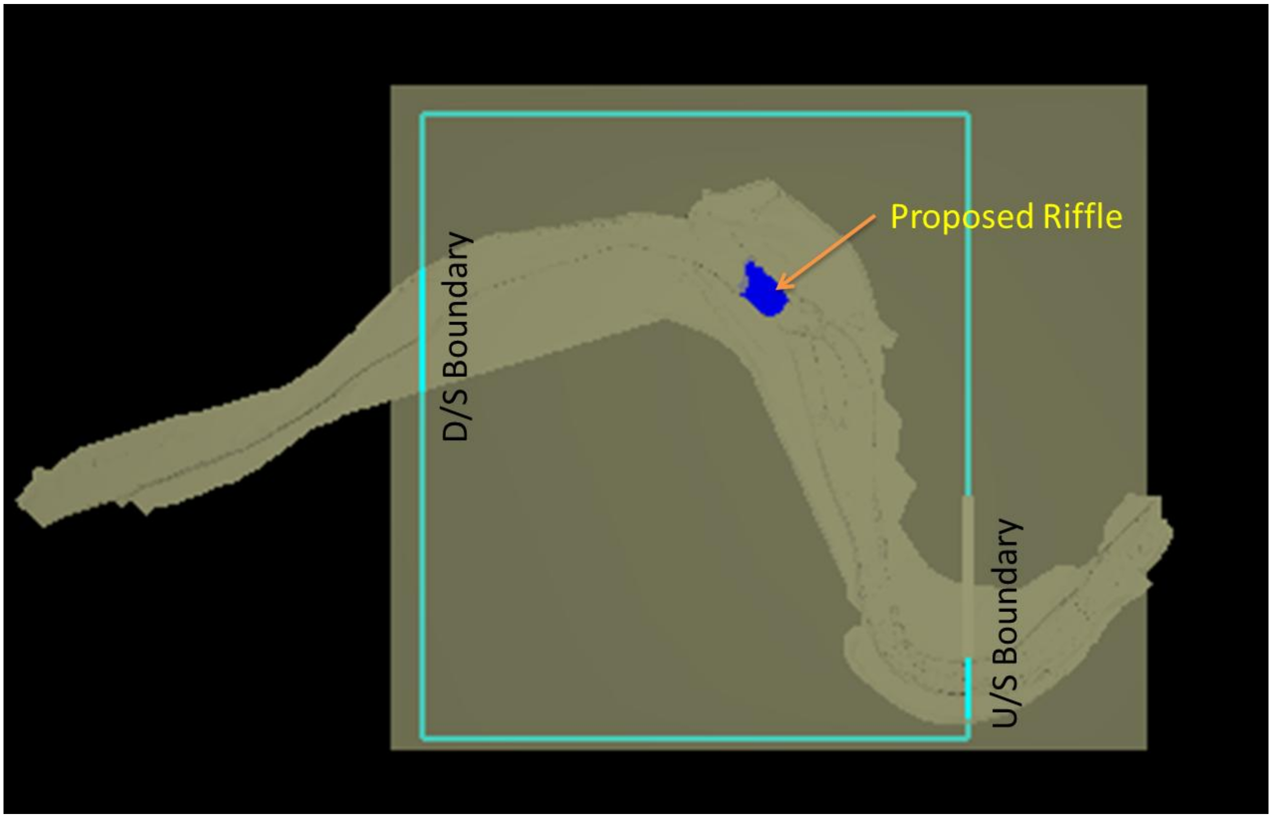

Figure 9 FLOW-3D Model Domain

This flow was simulated using the water surface elevations from the HEC-RAS model. The downstream boundary condition for the model was specified as "outflow" boundary in the FLOW-3D program. The simulated depth average flow velocity for the modeled reach is shown in Figure 10. The modeling results show a maximum flow velocity of about 10.0 ft/s at the downstream toe of the proposed riffle grade control structure.

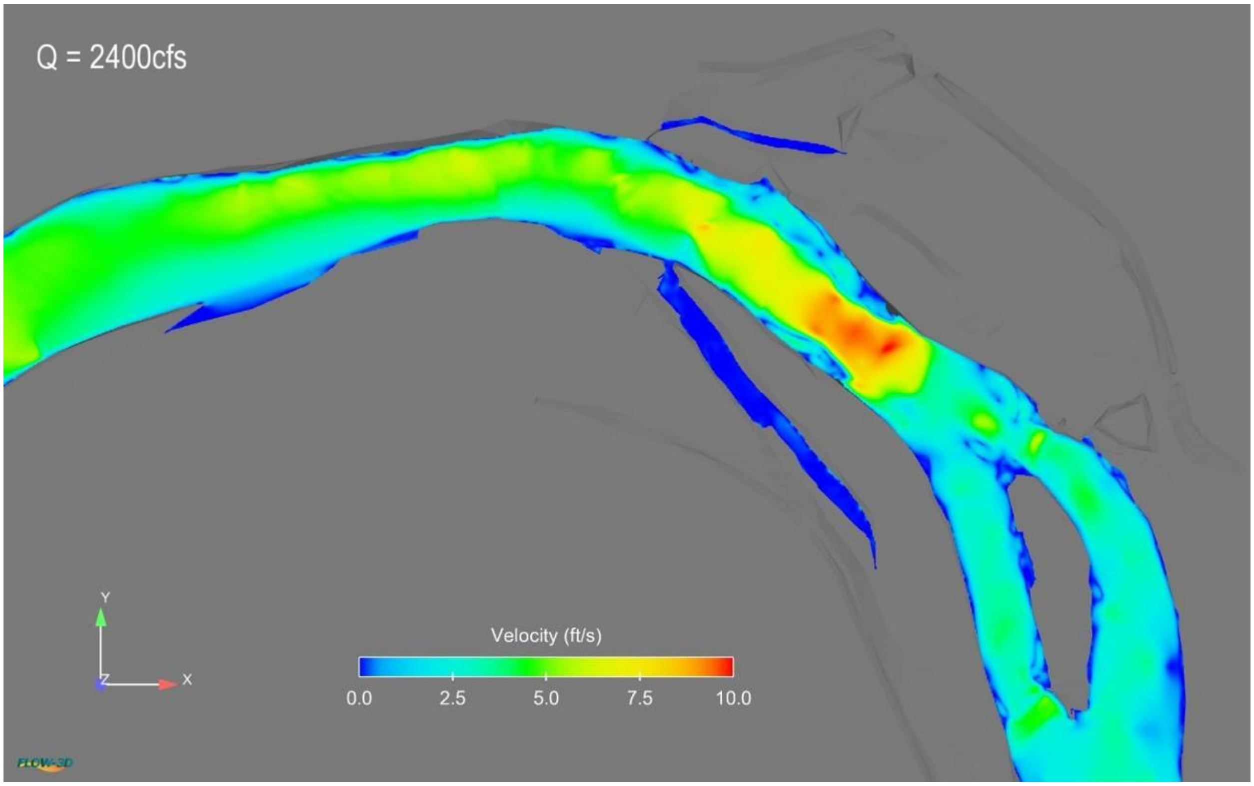

Figure 10 FLOW-3D Results

The results of this analysis were used to adjust the design of the grade control riffle and protect the bank downstream from the accelerated flows. Several iterations of this model were used to refine the placement of the riffle vanes downstream of the TA Engle riffle structure.

2.2.4.3 HEC-RAS-2D

Two-dimensional hydraulic modeling was performed using HEC-RAS 5.0.1 (USACE 2016) for the following discharges:

- 3,500 cfs Effective Discharge under existing conditions,
- 3,500 cfs Effective Discharge under proposed conditions,
- 6,890 cfs 25-Year under existing conditions, and
- 6,890 cfs 25-Year under proposed conditions.

A grid sized of 5 feet was used for both existing and proposed model geometries. Manning's n values of 0.04 and 0.055 were assumed for the main channel and overbank areas, respectively. The downstream boundary condition was assumed to be normal depth for a slope of 0.001. Unsteady flow simulations were performed with constant inflows (3500 cfs or 6890 cfs) as the upstream boundary condition. The following computation settings were used for all four flood scenarios:

- Simulation Duration: 2 hours
- Computation Interval: 3 seconds
- Mapping Output Interval: 5 Minutes
- Hydrograph Output Interval: 5 Minutes
- Detailed Output Interval: 5 Minutes
- Flow Regime: Mixed

Maximum flow velocity grids were developed for each discharge as presented in Figure 11 A through D.
The model results were used to refine the design of the driven timber walls and vegetated point bars.

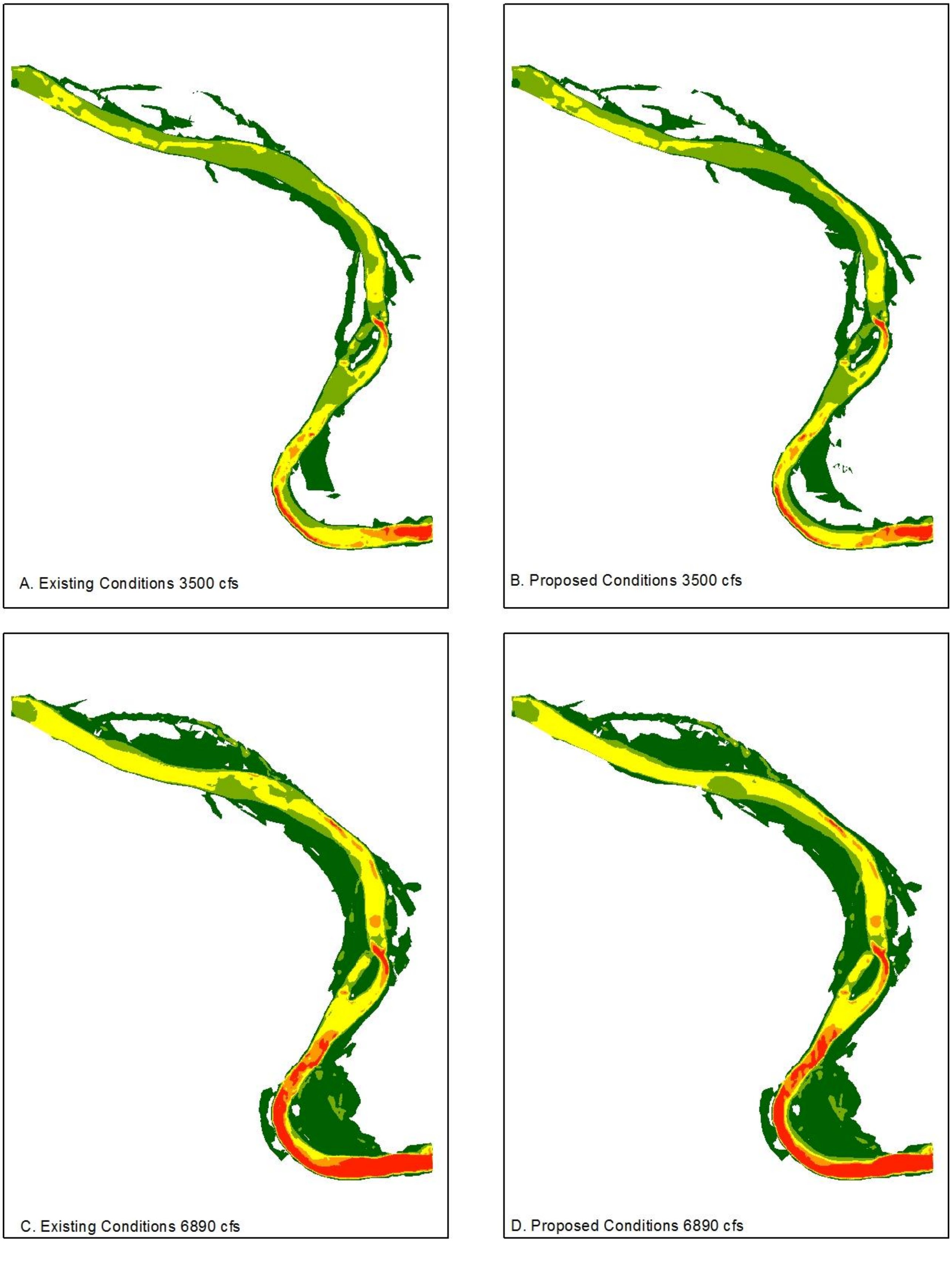

Figure 11. HEC-RAS 2D Results

2.2.5 Driven Timber Wall Engineering

The following sections outline the design of the driven timber walls.

2.2.5.1 Scour Analysis

Contraction scour ($y_{contraction}$) associated with the timber walls for a discharge of 3,500 was estimated to be approximately 2 feet based on the following equation (Laursen 1960):

$$y_{contraction} = y_1 \left[\frac{Q_2}{Q_1}\right]^{6/7} \left[\frac{W_1}{W_2}\right]^{k_1} - y_0$$

Where:

$y_1 = 7.9\ feet$ is the average depth in the main channel at the approach section
$Q_1 = 3{,}500\ cfs$ is the flow in the main channel or floodplain at the approach section
$Q_2 = 3{,}500\ cfs$ is the flow in the main channel or floodplain at the contracted section
$W_1 = 140\ feet$ is the bottom width in the main channel at the approach section
$W_2 = 120\ feet$ is the bottom width in the main channel at the contracted section
$y_0 = 8.2\ feet$ is the average depth in the main channel or floodplain at the contraction section before scour
$k_1 \cong 0.69$ for mostly suspended discharge material

Abutment scour ($y_{abutment}$) associated with the timber walls for a discharge of 3,500 was estimated to be approximately 7.5 feet based on the following equation (Froehlich 1989):

$$y_{abutment} = 2.27 K_1 K_2 L_a^{0.43} y_a^{0.57} Fr^{0.61} + y_a$$

Where:

$K_1 = 1.0$ for a vertical wall
$K_2 = 0.6$ based on angle of attack of approximately 30°
$L_a = 10\ feet$ is the length of abutment projected normal to flow
$y_a = 3\ feet$ is the average depth of flow on the floodplain at the approach section
$Fr = 0.5$ is the Froude number of the floodplain flow at the approach section

Therefore, the total scour associated with the timber walls at a discharge of 3,500 cfs was estimated to be approximately 2.0 feet + 7.5 feet = 9.5 feet.

2.2.5.2 Timber Pile Wall Stability Design

The timber piles were evaluated against uplift during high river flows. Skin friction between the pile and the surrounding soil will provide a downwards force to resist the buoyancy force from the river. The upwards buoyancy force was calculated assuming the top of the pile was submerged 5 feet beneath the water surface of the river. The piles were assumed to be 12 inches in diameter, 20 feet long and driven 15 feet into the ground. An effective friction angle at the interface between the timber pile and the silty sandy soils is assumed to 22.5 degrees. The factor of safety against uplift was calculated to be greater than 2.0.

The timber pile wall was also designed to resist the retained soil. The wall relies on the embedment into the ground for support at the base and a waler/deadman system to support the top. The lateral earth pressure was calculated using a unit weight of 120 pcf and an internal friction angle of 28 degrees and 0 cohesion. Active earth pressure was used when the timbers are resisting the soil and passive earth pressure was used when the timbers are pushing against the soil. The phreatic surface was assumed to be equal on both sides of the wall, at the lower soil elevation.

2.2.5.3 Timber Pile Wall Strength Design

The strength design values and reduction factor used in the calculations are from the National Design Specification for Wood Construction of the American Wood Council – 2015 Edition (NDS).

The loading described in Section 2.2.5.2 create tensions, shears and moments in the piles, walers, tie-backs, and deadmans which are resisted by the capacities of the timbers. Table 6 present the design values from the NDS. These design values were factored using duration, temperature, treatment, bearing and single pile factors, as required, to calculate an allowable design stress.

Table 6. Timber Properties.

Species and Commercial Grade	Bending	Tension Parallel to grain	Shear Parallel to grain	Compression Perpendicular to grain
Spruce-Pine-Fir Post and Timber Grade 2	500 psi	325 psi	125 psi	425 psi

The vertical piles, which will be driven into the riverbed, were designed for bending and shear. The piles will be 20 feet long, with a minimum embedment into the riverbed of 15 feet, and a minimum diameter of 12 inches. The vertical piles will be connected to the horizontal waler with a 5/8 inch diameter lag bolt with a minimum embedment of 6 inches. The walers will be 10 feet long and supported by the tiebacks and were designed for bending and shear. The walers will have a minimum diameter of 14 inches. The connection from the waler to the tiebacks will be a combination of a 4 inch notch and 1 inch diameter all-thread. The tiebacks were designed for tension and have a minimum diameter of 14 inches and supported by a deadman with a minimum diameter of 14 inches. The connection to the deadman will be a combination of a 4 inch notch and 5/8 inch diameter lag bolt with 10 inch minimum embedment.

The assumptions used in the design are as follows:

- The timber strengths are assumed to be of spruce pine fir, however the quality control will likely not be that of dimensional lumber and could have flaws, such as cracks, nots, etc. that could reduce the capacities of the timbers. These variations in the timbers were not accounted for in the design.

- The loads on the timbers that could see during driving them into the riverbed were not addressed in this calculation and are considered means and methods of the contractor.

- It is understood that these timbers will not be treated to reduce the decomposing rate. Even those this increases the allowable design stress the life of the timbers could greatly be reduced due to decomposition.

- It is assumed that the temperature will not be above 100 degrees Fahrenheit.

- No surcharge was accounted for on top of the fill and is assumed that minimal loading will be allowed on the fill area.

- The retained height will not be more than 6.6 feet above the riverbed.

2.3 Planting Plan

The following sections outline the proposed planting plan. See construction drawing set for location details. Percentages refer to the growing season exceedance (e.g. 50% to 10% is land that is wet 50% to 10% of the growing season. In accordance with our conversations and emails, please see the following riparian vegetation specifications for the Riverside Ranch in Kremmling, Colorado. The area is presented as three zones C-14, C-15, and C-16 per the hydrologic area information presented by AECOM on May 31, 2016.

2.3.1 Summarization of Hydrologic Zone by Reach

The following is a summarization of hydrologic zone by reach, including driven timber wall areas:

Table 7 Hydrologic Zones Sheet C-11

Sheet C-14					
hydrology	color code	ecological zone	est. sq. ft.	est ac	
above bankful	red	upland	4,431	0.1	
wet mean peak to bankful	dark green	transitional	40,259	0.92	1.35 (combined)
wet 10% to mean peak	light green	transitional	19,787	0.45	
wet 50% to 10%	light blue	FACW	23,961	0.55	
wet 90% to 50%	dark blue	OBL	6,122	0.14	
Total			94,560	2.17	

Table 8 Hydrologic Zones Sheet C-12

Sheet C-15					
hydrology	color code	ecological zone	est. sq. ft.		
above bankful	red	upland	17,653	0.41	
wet mean peak to bankful	dark green	transitional	11,112	0.26	0.7 combined
wet 10% to mean peak	light green	transitional	19,988	0.46	
wet 50% to 10%	light blue	FACW	14,536	0.33	
wet 90% to 50%	dark blue	OBL	4,221	0.1	
Total			67,510	1.56	

Table 9 Hydrologic Zones Sheet C-13

Sheet C-16					
hydrology	color code	ecological zone	est. sq. ft.		
above bankful	red	upland	411	0.01	
wet mean peak to bankful	dark green	transitional	7,869	0.19	0.38 combined
wet 10% to mean peak	light green	transitional	8,398	0.19	
wet 50% to 10%	light blue	FACW	12,374	0.28	
wet 90% to 50%	dark blue	OBL	3,173	0.07	
Total			32,225	0.74	

2.3.2 Above Bankfull Zones

The following upland seed mix is recommended for the above bankfull zones for each reach:

Table 10 Upland Seed Mix Sheet C-14

C-14 Upland Seed Mix								
Scientific Name	Common Name	Percent of mix	Seed number using 120 seeds/sq ft	Pure Live Seed (PLS) Weight	PLS lb Required/ac per Broadcast Application	PLS lb Required/ac per Drilled Application	Total PLS lb Required per Broadcast Application	Total PLS lb Required per Drilled Application
graminoids								
Bromus marginatus	mountain brome	10	12	104,843	4.99	2.5	0.50	0.25
Elymus elymoides	bottlebrush squirreltail	5	6	160,563	1.63	0.82	0.16	0.08
Elymus lanceolatus ssp. *lanceolatus*	thickspike wheatgrass	20	24	155,350	6.73	3.37	0.67	0.34
Elymus trachycaulus ssp. *trachycaulus*	slender wheatgrass	20	24	147,500	7.09	3.55	0.71	0.36
Koeleria macrantha	junegrass	5	6	2,057,500	0.13	0.07	0.01	0.01
Pascopyron smithii	western wheatgrass	20	24	133,000	7.86	3.93	0.79	0.39
Poa secunda	big bluestem 'Sherman'	15	18	902,500	0.87	0.44	0.09	0.04
Pseudoroegneria spicata	bluebunch wheatgrass	5	6	140,000	1.87	0.94	0.19	0.09
Total		100	120 PLS Seeds/sq ft		31.17 PLS lb	15.62 PLS lb	3.12 PLS lb	1.56 PLS lb

Table 11 Upland Seed Mix Sheet C-15

C-15 Upland Seed Mix								
Scientific Name	Common Name	Percent of mix	Seed number using 120 seeds/sq ft	Pure Live Seed (PLS) Weight	PLS lb Required/ac per Broadcast Application	PLS lb Required/ac per Drilled Application	Total PLS lb Required per Broadcast Application	Total PLS lb Required per Drilled Application
graminoids								
Bromus marginatus	mountain brome	10	12	104,843	4.99	2.5	2.05	1.03
Elymus elymoides	bottlebrush squirreltail	5	6	160,563	1.63	0.82	0.67	0.34
Elymus lanceolatus ssp. *lanceolatus*	thickspike wheatgrass	20	24	155,350	6.73	3.37	2.76	1.38
Elymus trachycaulus ssp. *trachycaulus*	slender wheatgrass	20	24	147,500	7.09	3.55	2.91	1.46
Koeleria macrantha	junegrass	5	6	2,057,500	0.13	0.07	0.05	0.03
Pascopyron smithii	western wheatgrass	20	24	133,000	7.86	3.93	3.22	1.61
Poa secunda	big bluestem 'Sherman'	15	18	902,500	0.87	0.44	0.36	0.18
Pseudoroegneria spicata	bluebunch wheatgrass	5	6	140,000	1.87	0.94	0.77	0.39
Total		100	120 PLS Seeds/sq ft		31.17 PLS lb	15.62 PLS lb	12.78 PLS lb	6.40 PLS lb

Table 12 Upalnd Seed Mix Sheet C-16

C-16 Upland Seed Mix								
Scientific Name	Common Name	Percent of mix	Seed number using 120 seeds/sq ft	Pure Live Seed (PLS) Weight	PLS lb Required/ac per Broadcast Application	PLS lb Required/ac per Drilled Application	Total PLS lb Required per Broadcast Application	Total PLS lb Required per Drilled Application
graminoids								
Bromus marginatus	mountain brome	10	12	104,843	4.99	2.5	0.05	0.03
Elymus elymoides	bottlebrush squirreltail	5	6	160,563	1.63	0.82	0.02	0.01
Elymus lanceolatus ssp. *lanceolatus*	thickspike wheatgrass	20	24	155,350	6.73	3.37	0.07	0.03
Elymus trachycaulus ssp. *trachycaulus*	slender wheatgrass	20	24	147,500	7.09	3.55	0.07	0.04
Koeleria macrantha	junegrass	5	6	2,057,500	0.13	0.07	0.01	0.01
Pascopyron smithii	western wheatgrass	20	24	133,000	7.86	3.93	0.08	0.04
Poa secunda	big bluestem 'Sherman'	15	18	902,500	0.87	0.44	0.01	0.01
Pseudoroegneria spicata	bluebunch wheatgrass	5	6	140,000	1.87	0.94	0.02	0.01
Total		100	120 PLS Seeds/sq ft		31.17 PLS lb	15.62 PLS lb	0.32 PLS lb	0.17 PLS lb

The upland seed recommendations are based on 120 PLS per square foot, as determined on a percentage basis by species to facilitate ecological functionality, to minimize interspecific competition, and to promote proper revegetation. All seed must be labeled as ‘certified’ and should not include the presence of noxious or invasive species prohibited under the Colorado Seed Act (as indicated on the tag by the Colorado Seed Growers Association approved labeling) and all tags must be maintained for documentation. Prior to delivery, seed should be processed by the seed provider on a “gravity-table” to remove non-target seed types, such as yellow sweetclover (*Melilotus officinalis*), alfalfa (*Medicago sativa*), wood sorrel (*Oxalis acetosella*), and other potentially aggressive species. Substitutions will be made thorough consultation with the project designer or their designee. Seed should preferentially be applied through hand broadcast using the presented upland seed mix. Once applied, the seed should raked in, then pressed with a weighted water wheel or similar implement to encourage good soil contact, then covered with wood straw at a rate of approximately 3,000 lb. per acre. Conversely, once the seed has been properly applied to the site, the seed can be protected via HydraCX2 hydromulch with tackifier at an application rate of 2500 lb/ac within 24 hours of seed application.

2.3.3 Wet Mean Peak to Bankfull and Wet 10% to Mean Peak

The following transitional seed mix is recommended for the wet mean peak to bankfull and wet 10% to mean bankfull zones for each reach:

Table 13 Transitional Seed Mix Sheet C-14

C-14 Transitional Seed Mix								
Scientific Name	Common Name	Percent of mix	Seed number using 150 seeds/sq ft	Pure Live Seed (PLS) Weight	PLS lb Required/ac per Broadcast Application	PLS lb Required/ac per Drilled Application	Total PLS lb Required per Broadcast Application	Total PLS lb Required per Drilled Application
herbaceous dicot								
Campanula rotundifolia	harebell	3	4.5	7,250,000	0.03	0.02	0.04	0.03
Cleome serrulata	Rocky Mountain beeplant	3	4.5	87,250	2.25	1.13	3.04	1.53
Helianthus nuttallii	Nuttall's sunflower	3	4.5	217,000	0.9	0.45	1.22	0.61
Sphaeralcea coccinea	scarlet globemallow	3	4.5	318,712	0.62	0.31	0.84	0.42
Solidago canadensis	Canada goldenrod	3	4.5	1,350,000	0.15	0.08	0.20	0.11
graminoids								
Bromus marginatus	mountain brome	10	15	104,843	6.23	3.12	8.41	4.21
Elymus canadensis	Canada wildrye	10	15	103,000	6.34	3.17	8.56	4.28
Elymus elymoides	bottlebrush squirreltail	5	7.5	160,563	2.03	1.02	2.74	1.38
Elymus lanceolatus ssp. *la*	thickspike wheatgrass	15	22.5	155,350	6.31	3.16	8.52	4.27
Elymus trachycaulus ssp. *t*	slender wheatgrass	15	22.5	147,500	6.64	3.32	8.96	4.48
Pascopyron smithii	western wheatgrass	15	22.5	133,000	7.37	3.69	9.95	4.98
Poa secunda	big bluestem 'Sherman'	10	15	902,500	0.72	0.36	0.97	0.49
Pseudoroegneria spicata	bluebunch wheatgrass	5	7.5	140,000	2.33	1.17	3.15	1.58
Total		100	150 PLS Seeds/sq ft		41.92 PLS lb	21.00 PLS lb	56.59 PLS lb	28.35 PLS lb

Table 14 Transitional Seed Mix Sheet C-15

C-15 Transitional Seed Mix								
Scientific Name	Common Name	Percent of mix	Seed number using 150 seeds/sq ft	Pure Live Seed (PLS) Weight	PLS lb Required/ac per Broadcast Application	PLS lb Required/ac per Drilled Application	Total PLS lb Required per Broadcast Application	Total PLS lb Required per Drilled Application
herbaceous dicot								
Campanula rotundifolia	harebell	3	4.5	7,250,000	0.03	0.02	0.02	0.01
Cleome serrulata	Rocky Mountain beeplant	3	4.5	87,250	2.25	1.13	1.58	0.79
Helianthus nuttallii	Nuttall's sunflower	3	4.5	217,000	0.9	0.45	0.63	0.32
Sphaeralcea coccinea	scarlet globemallow	3	4.5	318,712	0.62	0.31	0.43	0.22
Solidago canadensis	Canada goldenrod	3	4.5	1,350,000	0.15	0.08	0.11	0.06
graminoids								
Bromus marginatus	mountain brome	10	15	104,843	6.23	3.12	4.36	2.18
Elymus canadensis	Canada wildrye	10	15	103,000	6.34	3.17	4.44	2.22
Elymus elymoides	bottlebrush squirreltail	5	7.5	160,563	2.03	1.02	1.42	0.71
Elymus lanceolatus ssp. *la*	thickspike wheatgrass	15	22.5	155,350	6.31	3.16	4.42	2.21
Elymus trachycaulus ssp. *t*	slender wheatgrass	15	22.5	147,500	6.64	3.32	4.65	2.32
Pascopyron smithii	western wheatgrass	15	22.5	133,000	7.37	3.69	5.16	2.58
Poa secunda	big bluestem 'Sherman'	10	15	902,500	0.72	0.36	0.50	0.25
Pseudoroegneria spicata	bluebunch wheatgrass	5	7.5	140,000	2.33	1.17	1.63	0.82
Total		100	150 PLS Seeds/sq ft		41.92 PLS lb	21.00 PLS lb	29.34 PLS lb	14.70 PLS lb

Table 15 Transitional Seed Mix Sheet C-16

C-16 Transitional Seed Mix								
Scientific Name	Common Name	Percent of mix	Seed number using 150 seeds/sq ft	Pure Live Seed (PLS) Weight	PLS lb Required/ac per Broadcast Application	PLS lb Required/ac per Drilled Application	Total PLS lb Required per Broadcast Application	Total PLS lb Required per Drilled Application
herbaceous dicot								
Campanula rotundifolia	harebell	3	4.5	7,250,000	0.03	0.02	0.01	0.01
Cleome serrulata	Rocky Mountain beeplant	3	4.5	87,250	2.25	1.13	0.86	0.43
Helianthus nuttallii	Nuttall's sunflower	3	4.5	217,000	0.9	0.45	0.34	0.17
Sphaeralcea coccinea	scarlet globemallow	3	4.5	318,712	0.62	0.31	0.24	0.12
Solidago canadensis	Canada goldenrod	3	4.5	1,350,000	0.15	0.08	0.06	0.03
graminoids								
Bromus marginatus	mountain brome	10	15	104,843	6.23	3.12	2.37	1.19
Elymus canadensis	Canada wildrye	10	15	103,000	6.34	3.17	2.41	1.20
Elymus elymoides	bottlebrush squirreltail	5	7.5	160,563	2.03	1.02	0.77	0.39
Elymus lanceolatus ssp. *la*	thickspike wheatgrass	15	22.5	155,350	6.31	3.16	2.40	1.20
Elymus trachycaulus ssp. *t*	slender wheatgrass	15	22.5	147,500	6.64	3.32	2.52	1.26
Pascopyron smithii	western wheatgrass	15	22.5	133,000	7.37	3.69	2.80	1.40
Poa secunda	big bluestem 'Sherman'	10	15	902,500	0.72	0.36	0.27	0.14
Pseudoroegneria spicata	bluebunch wheatgrass	5	7.5	140,000	2.33	1.17	0.89	0.44
Total		100	150 PLS Seeds/sq ft		41.92 PLS lb	21.00 PLS lb	15.93 PLS lb	7.98 PLS lb

The transitional seed recommendations are based on 150 PLS per square foot, as determined on a percentage basis by species to facilitate ecological functionality, to minimize interspecific competition, and to promote proper revegetation. All seed must be labeled as 'certified' and should not include the presence of noxious or invasive species prohibited under the Colorado Seed Act (as indicated on the tag by the Colorado Seed Growers Association approved labeling) and all tags must be maintained for documentation. Prior to delivery, seed should be processed by the seed provider on a "gravity-table" to remove non-target seed types, such as yellow sweetclover (Melilotus officinalis), alfalfa (Medicago sativa), wood sorrel (Oxalis acetosella), and other potentially aggressive species. Substitutions will be made thorough consultation with the project designer or their designee. Seed should preferentially be applied through hand broadcast using the presented upland seed mix. Once applied, the seed should raked in, then pressed with a weighted water wheel or similar implement to encourage good soil contact, then covered with wood straw at a rate of approximately 3,000 lb. per acre. Conversely, once the seed has been properly applied to the site, the seed can be protected via HydraCX2 hydromulch with tackifier at an application rate of 2500 lb/ac within 24 hours of seed application.

2.3.4 Wet 50% to 10% Zone

The following wetland seed mix and vegetative cuttings are recommended for the wet 50% to 10% zones for each reach:

Table 16 Wet 50% to 10% Seed Mix Sheet C-14

C-14 Wet 50% to 10% Seed Mix								
Scientific Name	Common Name	Percent of mix	Seed number using 150 seeds/sq ft	Pure Live Seed (PLS) Weight	PLS lb Required/ac per Broadcast Application	PLS lb Required/ac per Drilled Application	Total PLS lb Required per Broadcast Application	Total PLS lb Required per Drilled Application
herbaceous dicot								
Campanula rotundifolia	harebell	3	4.5	7,250,000	0.03	0.02	0.02	0.01
Cleome serrulata	Rocky Mountain beeplant	3	4.5	87,250	2.25	1.13	1.24	0.62
Helianthus nuttallii	Nuttall's sunflower	3	4.5	217,000	0.9	0.45	0.50	0.25
Monarda fistulosa	wild bergamot	3	4.5	1,250,625	0.16	0.08	0.09	0.04
Solidago canadensis	Canada goldenrod	3	4.5	1,350,000	0.15	0.08	0.08	0.04
graminoids								
Elymus lanceolatus ssp. *lanceolatus*	thickspike wheatgrass	15	22.5	155,350	6.31	3.16	3.47	1.74
Glyceria striata	fowl mannagrass	10	7.5	170,000	1.92	0.96	1.06	0.53
Juncus arcticus ssp. *littoralis*	mountain rush	5	7.5	6,950,000	0.05	0.03	0.03	0.02
Juncus torreyi	Torrey rush	5	7.5	12,150,000	0.03	0.02	0.02	0.01
Nasella viridula	green needlegrass	15	22.5	152,117	6.44	3.22	3.54	1.77
Pascopyron smithii	western wheatgrass	15	22.5	133,000	7.37	3.69	4.05	2.03
Poa palustris	fowl bluegrass	20	30	2,078,000	0.63	0.32	0.35	0.18
Total		100	150 PLS Seeds/sq ft		26.24 PLS lb/ac	13.16 PLS lb/ac	14.43 PLS lb	7.24 PLS lb

Table 17 Wet 50% to 10% Plant Mix Sheet C-14

C-14 Wet 50% to 10% Plant Mix					
Scientific Name	Common Name	Percent of mix	Plant Materials Type	Propagules/Ac	Total Number of Propagules
Woody Species					
Populus angustifolia	narrowleaf cottonwood	40	4 ft. cutting	1,263	695
Salix bebbiana	Bebb's willow	5	4 ft. cutting	158	87
Salix drummondiana	Drummond's willow	10	4 ft. cutting	316	174
Salix exigua	coyote/sandbar willow	15	4 ft. cutting	474	261
Salix geyeriana	Geyer's willow	15	4 ft. cutting	474	261
Salix monticola	Rocky Mountain willow	15	4 ft. cutting	474	261
Total		100		3,159	1,737

Table 18 Wet 50% to 10% Seed Mix Sheet C-15

C-15 Wet 50% to 10% Seed Mix								
Scientific Name	Common Name	Percent of mix	Seed number using 150 seeds/sq ft	Pure Live Seed (PLS) Weight	PLS lb Required/ac per Broadcast Application	PLS lb Required/ac per Drilled Application	Total PLS lb Required per Broadcast Application	Total PLS lb Required per Drilled Application
herbaceous dicot								
Campanula rotundifolia	harebell	3	4.5	7,250,000	0.03	0.02	0.01	0.01
Cleome serrulata	Rocky Mountain beeplant	3	4.5	87,250	2.25	1.13	0.74	0.37
Helianthus nuttallii	Nuttall's sunflower	3	4.5	217,000	0.9	0.45	0.30	0.15
Monarda fistulosa	wild bergamot	3	4.5	1,250,625	0.16	0.08	0.05	0.03
Solidago canadensis	Canada goldenrod	3	4.5	1,350,000	0.15	0.08	0.05	0.03
graminoids								
Elymus lanceolatus ssp. *lanceolatus*	thickspike wheatgrass	15	22.5	155,350	6.31	3.16	2.08	1.04
Glyceria striata	fowl mannagrass	10	7.5	170,000	1.92	0.96	0.63	0.32
Juncus arcticus ssp. *littoralis*	mountain rush	5	7.5	6,950,000	0.05	0.03	0.02	0.01
Juncus torreyi	Torrey rush	5	7.5	12,150,000	0.03	0.02	0.01	0.01
Nasella viridula	green needlegrass	15	22.5	152,117	6.44	3.22	2.13	1.06
Pascopyron smithii	western wheatgrass	15	22.5	133,000	7.37	3.69	2.43	1.22
Poa palustris	fowl bluegrass	20	30	2,078,000	0.63	0.32	0.21	0.11
Total		100	150 PLS Seeds/sq ft		26.24 PLS lb/ac	13.16 PLS lb/ac	8.66 PLS lb	4.34 PLS lb

Table 19 Wet 50% to 10% Plant Mix Sheet C-15

C-15 Wet 50% to 10% Plant Mix					
Scientific Name	Common Name	Percent of mix	Plant Materials Type	Propagules/Ac	Total Number of Propagules
Woody Species					
Populus angustifolia	narrowleaf cottonwood	40	4 ft. cutting	1,263	417
Salix bebbiana	Bebb's willow	5	4 ft. cutting	158	52
Salix drummondiana	Drummond's willow	10	4 ft. cutting	316	104
Salix exigua	coyote/sandbar willow	15	4 ft. cutting	474	156
Salix geyeriana	Geyer's willow	15	4 ft. cutting	474	156
Salix monticola	Rocky Mountain willow	15	4 ft. cutting	474	156
Total		100		3,159	1,042

Table 20 Wet 50% to 10% Seed Mix Sheet C-16

C-16 Wet 50% to 10% Seed Mix								
Scientific Name	Common Name	Percent of mix	Seed number using 150 seeds/sq ft	Pure Live Seed (PLS) Weight	PLS lb Required/ac per Broadcast Application	PLS lb Required/ac per Drilled Application	Total PLS lb Required per Broadcast Application	Total PLS lb Required per Drilled Application
herbaceous dicot								
Campanula rotundifolia	harebell	3	4.5	7,250,000	0.03	0.02	0.01	0.01
Cleome serrulata	Rocky Mountain beeplant	3	4.5	87,250	2.25	1.13	0.63	0.32
Helianthus nuttallii	Nuttall's sunflower	3	4.5	217,000	0.9	0.45	0.25	0.13
Monarda fistulosa	wild bergamot	3	4.5	1,250,625	0.16	0.08	0.04	0.02
Solidago canadensis	Canada goldenrod	3	4.5	1,350,000	0.15	0.08	0.04	0.02
graminoids								
Elymus lanceolatus ssp. *lanceolatus*	thickspike wheatgrass	15	22.5	155,350	6.31	3.16	1.77	0.88
Glyceria striata	fowl mannagrass	10	7.5	170,000	1.92	0.96	0.54	0.27
Juncus arcticus ssp. *littoralis*	mountain rush	5	7.5	6,950,000	0.05	0.03	0.01	0.01
Juncus torreyi	Torrey rush	5	7.5	12,150,000	0.03	0.02	0.01	0.01
Nasella viridula	green needlegrass	15	22.5	152,117	6.44	3.22	1.80	0.90
Pascopyron smithii	western wheatgrass	15	22.5	133,000	7.37	3.69	2.06	1.03
Poa palustris	fowl bluegrass	20	30	2,078,000	0.63	0.32	0.18	0.09
Total		100	150 PLS Seeds/sq ft		26.24 PLS lb/ac	13.16 PLS lb/ac	7.35 PLS lb	3.68 PLS lb

Table 21 Wet 50% to 10% Plant Mix Sheet C-16

C-16 Wet 50% to 10% Plant Mix					
Scientific Name	Common Name	Percent of mix	Plant Materials Type	Propagules/Ac	Total Number of Propagules
Woody Species					
Populus angustifolia	narrowleaf cottonwood	40	4 ft. cutting	1,263	354
Salix bebbiana	Bebb's willow	5	4 ft. cutting	158	44
Salix drummondiana	Drummond's willow	10	4 ft. cutting	316	88
Salix exigua	coyote/sandbar willow	15	4 ft. cutting	474	133
Salix geyeriana	Geyer's willow	15	4 ft. cutting	474	133
Salix monticola	Rocky Mountain willow	15	4 ft. cutting	474	133
Total		100		3,159	885

The wet 50% to 10% zone seed recommendations are based on 150 PLS per square foot, as determined on a percentage basis by species to facilitate ecological functionality, to minimize interspecific competition, and to promote proper revegetation. All seed must be labeled as ‘certified’ and should not include the presence of noxious or invasive species prohibited under the Colorado Seed Act (as indicated on the tag by the Colorado Seed Growers Association approved labeling) and all tags must be maintained for documentation. Prior to delivery, seed should be processed by the seed provider on a “gravity-table” to remove non-target seed types, such as yellow sweetclover (*Melilotus officinalis*), alfalfa (*Medicago sativa*), wood sorrel (*Oxalis acetosella*), and other potentially aggressive species. Substitutions will be made thorough consultation with the project designer or their designee. Seed should preferentially be applied through hand broadcast using the presented upland seed mix. Once applied, the seed should raked in, then pressed with a weighted water wheel or similar implement to encourage good soil contact, then covered with wood straw at a rate of approximately 3,000 lb. per acre. Conversely, once the seed has been properly applied to the site, the seed can be protected via HydraCX2 hydromulch with tackifier at an application rate of 2500 lb/ac within 24 hours of seed application.

The specified wet 50% to 10% vegetative cuttings should be harvested from pre-identified site-specific collection locations for installation up to two weeks prior to planting, trimmed of side branches and apical growth, then soaked from 5 to 7 days prior to planting. If planting cannot take place prior to spring runoff, willow and cottonwood material should be collected prior to bud break, placed in water, and kept in cold storage for no more than 6 weeks until planting can occur. Target species should include those species in the presented wet 50% to 10% tables. The cutting implementation should incorporate the recommendations presented in the attached “Field Guide for Harvesting Willow and Cottonwood Cuttings” (Giordanengo and Mandel 2015). As highlighted in the field guide, the utilized stakes should be of an adequate length to reach six inches into the low-season water table, with enough stem remaining such that no fewer than 3 to 4 live buds remaining above the ground surface. All stakes should be place in a manner that extends to the stagnant water table to ensure good hydration and to assist with survival. All planting shall take place under the supervision of the Restoration Ecologist to ensure that proper techniques are utilized to maximize survival. Planting locations will be flagged in advance of planting by Restoration Ecologist based on hydrologic zone and species-specific requirements for soil type and hydrology.

2.3.5 Wet 90% to 50% Zones

The following wetland seed mix, vegetative cuttings, and containerized plants are recommended for the wet 90% to 50% zones for each reach:

Table 22 Wet 90% to 50% Seed Mix Sheet C-14

C-14 Wet 90% to 50% Seed Mix								
.	Common Name	Percent of mix	Seed number using 150 seeds/sq ft	Pure Live Seed (PLS) Weight	PLS lb Required/ac per Broadcast Application	PLS lb Required/ac per Drilled Application	Total PLS lb Required per Broadcast Application	Total PLS lb Required per Drilled Application
graminoids								
Calamagrostis canadensis	bluejoint reedgrass	10	15	4,114,584	0.16	0.08	0.02	0.01
Deschampsia caespitosa	tufted hairgrass	30	45	1,812,500	1.08	0.54	0.15	0.08
Glyceria striata	fowl mannagrass	20	30	170,000	7.69	3.84	1.08	0.54
Juncus arcticus ssp. *littoralis*	mountain rush	5	7.5	6,950,000	0.05	0.03	0.01	0.00
Juncus torreyi	Torrey rush	5	7.5	12,150,000	0.03	0.02	0.01	0.01
Poa palustris	fowl bluegrass	30	45	2,078,000	0.94	0.47	0.13	0.07
Total		100	150 PLS Seeds/sq ft		9.95 PLS lb/ac	4.98 PLS lb/ac	1.40 PLS lb	0.70 PLS lb

Table 23 Wet 90% to 50% Plant Mix Sheet C-14

C-14 Wet 90% to 50% Plant Mix					
Scientific Name	Common Name	Percent of mix	Plant Materials Type	Propagules/Ac	Total Number of Propagules
Woody Species					
Salix drummondiana	Drummond's willow	20	3 ft cutting	632	88
Salix exigua	coyote/sandbar willow	25	3 ft cutting	790	111
Salix geyeriana	Geyer's willow	20	3 ft cutting	632	88
Salix monticola	Rocky Mountain willow	20	3 ft cutting	632	88
graminoids					
Carex aquatilis	water sedge	5	tubling	158	22
Carex utriculata	beaked sedge	5	tubling	158	22
Eleocharis palustris	creeping spikerush	5	tubling	158	22
Total		100		3,160	442

Table 24 Wet 90% to 50% Seed Mix Sheet C-15

C-15 Wet 90% to 50% Seed Mix								
Scientific Name	Common Name	Percent of mix	Seed number using 150 seeds/sq ft	Pure Live Seed (PLS) Weight	PLS lb Required/ac per Broadcast Application	PLS lb Required/ac per Drilled Application	Total PLS lb Required per Broadcast Application	Total PLS lb Required per Drilled Application
graminoids								
Calamagrostis canadensis	bluejoint reedgrass	10	15	4,114,584	0.16	0.08	0.02	0.01
Deschampsia caespitosa	tufted hairgrass	30	45	1,812,500	1.08	0.54	0.11	0.05
Glyceria striata	fowl mannagrass	20	30	170,000	7.69	3.84	0.77	0.38
Juncus arcticus ssp. *littoralis*	mountain rush	5	7.5	6,950,000	0.05	0.03	0.01	0.01
Juncus torreyi	Torrey rush	5	7.5	12,150,000	0.03	0.02	0.01	0.01
Poa palustris	fowl bluegrass	30	45	2,078,000	0.94	0.47	0.09	0.05
Total		100	150 PLS Seeds/sq ft		9.95 PLS lb/ac	4.98 PLS lb/ac	1.00 PLS lb	0.51 PLS lb

Table 25 Wet 90% to 50% Plant Mix Sheet C-15

C-15 Wet 90% to 50% Plant Mix					
Scientific Name	Common Name	Percent of mix	Plant Materials Type	Propagules/Ac	Total Number of Propagules
Woody Species					
Salix drummondiana	Drummond's willow	20	3 ft cutting	632	63
Salix exigua	coyote/sandbar willow	25	3 ft cutting	790	79
Salix geyeriana	Geyer's willow	20	3 ft cutting	632	63
Salix monticola	Rocky Mountain willow	20	3 ft cutting	632	63
graminoids					
Carex aquatilis	water sedge	5	tubling	158	16
Carex utriculata	beaked sedge	5	tubling	158	16
Eleocharis palustris	creeping spikerush	5	tubling	158	16
Total		100		3,160	316

Table 26 Wet 90% to 50% Seed Mix Sheet C-16

C-16 Wet 90% to 50% Seed Mix								
Scientific Name	Common Name	Percent of mix	Seed number using 150 seeds/sq ft	Pure Live Seed (PLS) Weight	PLS lb Required/ac per Broadcast Application	PLS lb Required/ac per Drilled Application	Total PLS lb Required per Broadcast Application	Total PLS lb Required per Drilled Application
graminoids								
Calamagrostis canadensis	bluejoint reedgrass	10	15	4,114,584	0.16	0.08	0.01	0.01
Deschampsia caespitosa	tufted hairgrass	30	45	1,812,500	1.08	0.54	0.08	0.04
Glyceria striata	fowl mannagrass	20	30	170,000	7.69	3.84	0.54	0.27
Juncus arcticus ssp. *littoralis*	mountain rush	5	7.5	6,950,000	0.05	0.03	0.01	0.01
Juncus torreyi	Torrey rush	5	7.5	12,150,000	0.03	0.02	0.01	0.01
Poa palustris	fowl bluegrass	30	45	2,078,000	0.94	0.47	0.07	0.03
Total		100	150 PLS Seeds/sq ft		9.95 PLS lb/ac	4.98 PLS lb/ac	0.71 PLS lb	0.37 PLS lb

Table 27 Wet 90% to 50% Plant Mix Sheet C-16

C-16 Wet 90% to 50% Plant Mix					
Scientific Name	Common Name	Percent of mix	Plant Materials Type	Propagules/Ac	Total Number of Propagules
Woody Species					
Salix drummondiana	Drummond's willow	20	3 ft cutting	632	44
Salix exigua	coyote/sandbar willow	25	3 ft cutting	790	55
Salix geyeriana	Geyer's willow	20	3 ft cutting	632	44
Salix monticola	Rocky Mountain willow	20	3 ft cutting	632	44
graminoids					
Carex aquatilis	water sedge	5	tubling	158	11
Carex utriculata	beaked sedge	5	tubling	158	11
Eleocharis palustris	creeping spikerush	5	tubling	158	11
Total		100		3,160	221

The wet 90% to 50% zone seed recommendations are based on 150 PLS per square foot, as determined on a percentage basis by species to facilitate ecological functionality, to minimize interspecific competition, and to promote proper revegetation. All seed must be labeled as ‘certified’ and should not include the presence of noxious or invasive species prohibited under the Colorado Seed Act (as indicated on the tag by the Colorado Department of Agriculture approved labeling) and all tags must be maintained for documentation. Prior to delivery, it is recommended that the seed should be processed by the seed provider on a “gravity-table” to remove non-target seed types, such as yellow sweetclover (Melilotus officinalis), alfalfa (Medicago sativa), wood sorrel (Oxalis acetosella), and other potentially aggressive species. Substitutions will be made thorough consultation with the project designer or their designee. Seed should preferentially be applied through hand broadcast using the presented upland seed mix. Once applied, the seed should raked in, then pressed with a weighted water wheel or similar implement to encourage good soil contact, then covered with wood straw at a rate of approximately 3,000 lb. per acre. Conversely, once the seed has been properly applied to the site, the seed can be protected via HydraCX2 hydromulch with tackifier at an application rate of 2500 lb/ac within 24 hours of seed application.

The specified wet 90% to 50% vegetative cuttings should be harvested as dormant material from pre-identified site-specific collection locations up to two weeks prior to planting, trimmed of side branches and apical growth, then soaked from 5 to 7 days prior to planting. If planting cannot take place prior to spring runoff, willow and cottonwood material should be collected prior to bud break, placed in water, and kept in cold storage for no more than 6 weeks until planting can occur. Target species should include those species in the presented wet 90% to 50% tables. The field implementation of cuttings should incorporate the recommendations presented in the attached “Field Guide for Harvesting Willow and Cottonwood Cuttings” (Giordanengo and Mandel 2015). As highlighted in the field guide, the utilized stakes should be of an adequate length to reach six inches into the low-season water table, with enough stem remaining such that no fewer than 3 to 4 live buds remaining above the ground surface. All stakes should be place in a manner that extends to the stagnant water table to ensure good hydration and to assist with survival. All planting shall take place under the supervision of the Restoration Ecologist to ensure that proper techniques are utilized to maximize survival. Planting locations will be flagged in advance of planting by Restoration Ecologist based on hydrologic zone and species-specific requirements for soil type and hydrology.

Container plants should include those graminoids specified in the 90% to 50% tables. All materials will be purchased through a reputable local nursery with available stock. All containerized plants should be of a 10 cubic inch tubling size to maximize value and rooting depth, while minimizing cost. All plants shall be inspected prior to installation to confirm proper species, source, vigor, and readiness. Depending on availability and site conditions, substitutions will be made through consultation with the project restoration ecologist.

Planting holes for containerized stock should be hand dug to allow deep root penetration for maximum stability. Holes will be dug to the depth of the plant root ball. Holes will be watered before planting, then filled, tamping down the soil to remove air pockets, and watered again immediately. Wood mulch should be installed around all containerized stock. All planting shall take place under the coordination and supervision of the project restoration specialist to help ensure appropriate planting methods are used and that plant survival is maximized. Planting locations will be flagged in advance of planting by restoration ecologist based on hydrologic zone and species-specific requirements for soil type and hydrology.

2.4 404 Permitting

Army Corps 404 Permits are time sensitive and the Riverside Ranch project is part of a larger effort by the ILVK and other stake holders to restore the Colorado River. In addition to the Riverside Ranch project there are restoration and irrigation diversion design projects scheduled for the McElroy Ranch, Shepard's Bend Ranch, Peterson Ranch and Reeder Creek Ranch. Permitting for the project will be undertaken as a larger effort as construction funding becomes available for the reach wide restoration effort.

3 Conclusion

The engineering analysis presented above resulted in the attached engineering drawings for restoration of the Colorado River through Riverside Ranch. The design includes two engineered riffle grade control structures and over a mile of bank bio-stabilization. The riffle grade control structures have been constructed and are performing as designed (Figure 12). The bank bio-stabilization will be constructed when funding is available.

Figure 12. TA Engle Engineered Riffle Grade Control Structure

Figure 13. Pteronarcys Hatch at Thompson ABC Pump Riffle Grade Control Structure

4 Actual Expense Budget

The final actual expense budget was less than the original amount proposed in the grant application due to the elimination of the permitting task. The permitting task was assumed to cost $23,206.00. Thus the final expense budget was $159,794.00. Detailed project invoicing has been submitted to Trout Unlimited.

5 Appendices

Appendix A. References

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Appendix B. Willow and Cottonwood Guide

FIELD GUIDE FOR HARVESTING AND INSTALLING WILLOW AND COTTONWOOD CUTTINGS

John Giordanengo
Synergy Ecological Restoration
www.synergy3.org

Randy Mandel
Golder Associates
www.golderassociates.com

Support for this field guide and training was provided by the Colorado Water Conservation Board and Synergy Ecological Restoration, and is conducted in partnership with Rocky Mountain Flycasters.

June 06, 2015

INTRODUCTION AND PURPOSE

This field guide covers basic techniques for selecting, harvesting, and installing willow and cottonwood cuttings for restoration projects. It also provides a basic understanding of the biology of Salicaceae, the family that includes all willow and cottonwood species. Knowledge of Salicaceae biology can inform plant selection, harvest, and storage methods, and proper techniques can play a key role the success of a diversity of restoration projects, from live staking to advanced bioengineering structures.

IMPORTANCE OF WILLOWS AND COTTONWOODS IN RESTORATION

In arid regions of the Rocky Mountains, willows and cottonwoods provide important wildlife cover for nesting birds and small mammals, and forage for elk, moose, and other herbivores. Willows and other riparian vegetation provide effective soil stabilization through the large web of underground roots that bind soil particles together. The above-ground biomass of riparian vegetation slows water velocities and therefore aids in reducing shear stress along stream banks, road embankments, and other erosion-prone areas. Willows have a number of characteristics that make them resilient to high-velocity flood waters, burial by sediments, long periods of inundation, high winds, and heavy browsing by wildlife. Cottonwoods provide similar benefits, as well as providing structural diversity (i.e., variety of canopy heights) in a riparian habitat. Furthermore, willows and cottonwoods provide essential shade and organic matter inputs to rivers, both of which are critical to the quality of aquatic habitats. Such riparian vegetation also facilitates nutrient uptake of effluents such as nitrates and phosphates.

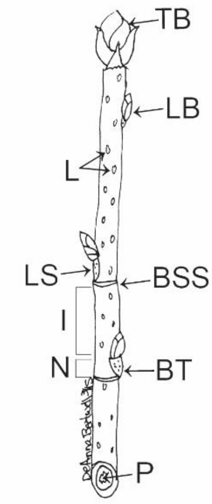
BIOLOGY, BEAVERS, AND BENEFITS

Willows and cottonwoods are deciduous woody plants in the Willow Family (Salicaceae) that typically occur in mesic sites such as riparian areas (i.e., riverside habitats) and other wetland habitats. Willows are classified in the genus Salix, and cottonwoods are in the genus *Populus*. Both willows and cottonwoods have an important feature in their biology that make them excellent candidates for use in ecological restoration.

Willow and cottonwood stems can develop new roots readily from dormant buds and adventitious buds (i.e., buds that develop in an “atypical” place rather than at the branch tip or in leaf axils) when in contact with water or moist soil. This strategy is helpful in habitats where beaver routinely cut and haul willows to construct dams and lodges. Should a stem break loose and flow down river, or become dislodged by a flood, the stems root readily in the muddy riverbanks. And so in the course of riparian restoration we find ourselves following in the footsteps of the beaver. However, incorrect selection of species, as well as improper storage, handling, timing, and installation techniques, can produce widely varying results. This guide provides tips and information to help you improve your chances of success in a riparian restoration project.

APICAL CONTROL IN SHRUBS

All woody plants, including willows and cottonwoods, produce a mix of hormones including auxins, cytokinins, ethylene, and gibberellins. Hormones are substances that are produced in small amounts and influence the growth, development, and differentiation of cells and tissues. The specific ratio and timing of hormone release has strong control over plant growth. One example of this is known as *apical control*, where the top branches of a plant (i.e., apical or terminal buds) have an influence over the lower branches. Apical control occurs widely among willows and cottonwoods, where auxins produced by terminal buds are transported to lateral buds (i.e., buds along the stem below the terminal bud) and adventitious buds to convey a signal to "stay dormant." When the apical bud is removed by a browsing animal or severed by a willow harvester, the hormonal signal from auxin is interrupted, which stimulates the growth of lateral and adventitious buds. In heavily browsed areas, it is the removal of the terminal buds that causes a bushy appearance in both willow and cottonwood stands. Under some conditions, however, and for certain species (e.g., sandbar willow, *Salix exigua*), removal of the terminal bud may not be necessary or desirable to achieve project goals. If a tree-like willow is desired, removing the terminal bud(s) is not recommended.



TB=Terminal Bud; LB=Lateral Bud; BSS=Ring of bud scale scars from previous year's terminal bud; BT=Bundle trace in leaf scar; P=Pith; N=Node; I=Internode; LS=Leaf Scar; L=Lenticels;

USING LIVE CUTTINGS FOR RESTORATION

Thanks to the nature of willow biology, and especially to the presence of adventitious and dormant buds that form roots when wet, live cuttings (poles, stakes, or whips) can be used in a variety of restoration practices. When installed properly and under the right environmental and moisture conditions, live cuttings can develop roots and above-ground shoots rapidly. Survival of these cuttings through the first growing season can range between 45% and 90% of installed cuttings. However, subsequent survival can be highly variable, and three seasons of monitoring is recommended before claiming success or admitting defeat for any willow restoration project. Lack of adequate soil moisture, poor timing, incorrect species choice, and improper selection of willow stems are important factors associated with poor survivorship of cuttings.

Careful attention to harvesting healthy stems, proper stem diameter and age, groundwater hydrology and hydroperiod, depth of installation, and good soil-to-stem contact all contribute to successful restoration projects.

Roots sprouting from adventitious buds after 13 days of soaking. USDA-NRCS, Aberdeen Plant Materials Center

Selecting the Right Materials: Garbage In = Garbage Out

The best willow installation job often fails when the cuttings are not properly selected and stored ahead of time. These simple rules will improve the success of every willow and cottonwood project and help to protect the resource.

Harvest Location: Select a source population as close to your project site as feasible, preferably within the same drainage. Harvest species that occur in the same site conditions (e.g., hydrology, landscape position, elevation) as the conditions of your restoration site. Avoid sourcing plant materials more than 1,000 feet in elevation above or below your restoration site.

Healthy Stems: Always select healthy stems (i.e., "green" wood in cross-section) that are: relatively straight, covered in smooth bark (i.e., not furrowed or damaged), and free of insects, disease, or fungal damage. For most willow and cottonwood species, stems older than 4 years of age produce fewer adventitious buds and are lower in vigor than younger stems. This is especially true for species such as peachleaf willow (*Salix amygdaloides)*, Bebb's willow (*S. Bebbiana*), and many alpine and subalpine species.

Harvest Ethically -- Leave More Than You Take!

Follow ethical harvest guidelines to conserve health of the donor stand:

- **Know before you go! Obtain approval from land owner (public or private) before harvesting. In some cases a permit may be required.**
- **Remove no more than 20% of the branches from any single willow.**
- **Never remove more than 30% of the overall canopy cover from any willow stand.**
- **Harvest stems evenly through the stand (e.g., not from one side of the plant only).**
- **In Preble's Meadow Jumping Mouse Habitat (<7,400' elevation on the Colorado Front Range), and in other sensitive wildlife habitats, more stringent harvest guidelines should be followed.**

HARVESTING AND PREPARATION

Tools: Lopping shears, hand by-pass pruners, small wood saws or brush cutters, twine, labels, buckets, trash cans.

HARVESTING & STORING

Harvest cuttings during the dormant season (i.e., between fall dormancy/leaf abscission and spring bud break):

Select stems ½ to 1¼ inches (between pinky and thumb width) in diameter for most projects. Some projects may require willow stems up to 3 inches in diameter or cottonwoods up to 6 inches in diameter (e.g., posts) where longer or stronger cuttings are required to reach deep groundwater. In this case, cuttings may need to be installed into the soil via pounding, hammer drills, water stingers, augers, or other means.

Cut stems to length, as determined by specific project needs (e.g., depth to late-summer water table, severity of erosion and flood damage). Cuttings can range from 18 inches to 12 feet long depending on depth to groundwater and height of competing vegetation. Remove the cutting with a clean diagonal cut at the base of the stem. The diagonal surface differentiates the rooting end from the above ground portion, and facilitates installation.

Leave the terminal buds and a few upper branches intact until installation. Remove all but the top few lateral (i.e., side) branches by clipping them as close to the stem as possible. Use caution to avoid damaging the stem while trimming the lateral branches. Removing lateral branches assists in transport and storage, helps maintain an appropriate root-to-shoot ratio, and reduces transpiration losses prior to root establishment. Logistically, a trimmed willow cutting is easier to install down a narrow pilot hole.

Bundle cuttings in groups of 50 or 100 by species. Keep bundles cool, moist, and shaded during transportation and on-site storage.

Prior to planting, **soak cuttings** in water for 7-14 days to increase the rate and degree of adventitious root formation. Cuttings can be soaked in buckets, streams, or ponds with well-oxygenated water. Roughly 50 to 80% of the length of the cutting should be in contact with water while soaking. Plants should be weighted down when soaked in a horizontal position. Research shows significant increase in survival for willows that are pre-soaked prior to planting (Tilley and Hoag 2008).

CAUTION – Dangerous Stowaways!

Avoid soaking cuttings in water bodies that may harbor aquatic nuisance species such as New Zealand mudsnail, Eurasian milfoil, chytrid fungus, and other pests that are exotic and known to negatively impact native species. To be safe, soak your cuttings in buckets of tap water or in water from your restoration site.

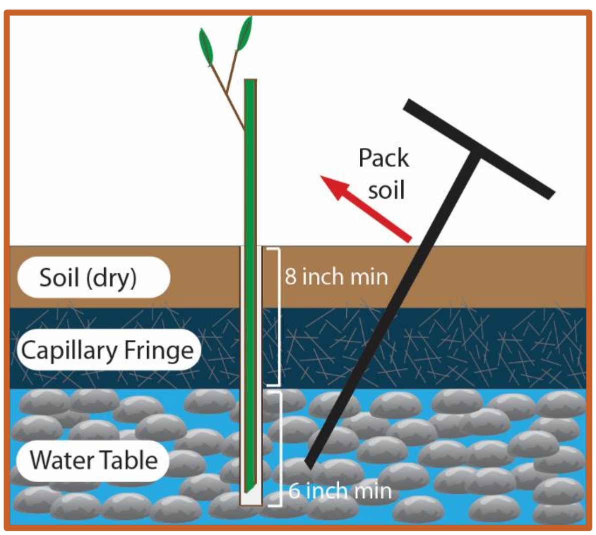
Pre-soaking willow cuttings. (USDA-NRCS, Aberdeen Plant Materials Center)

Tools: planting bars (dibbles), rebar, rubber mallet/mini sledge, post-hole diggers, electric hammer-drills, soil augers, power stingers, shovels, buckets, lopping shears.

Installing Live Cuttings

Location location location. It's as true with willow and cottonwood plantings as it is in real estate: location matters! While a full site analysis and planting location plan is beyond the scope of this field guide, some tips include: (1) previous knowledge of soil moisture, hydrographs, and/or groundwater monitoring well data is extremely helpful; (2) avoid installing cuttings in dense herbaceous wetland communities, as such soils can be anaerobic and difficult for survivorship of fresh adventitious roots; (3) avoid installing cuttings too close to the stream edge, especially in unconsolidated soils, as it is likely the eroding streambank will result in the loss of your planted materials prior to establishment; (4) avoid installing willows too far away from the water, such that the bottom of the cutting and the adjacent buds are not in contact with the low/dry-season groundwater – unless utilizing artificial irrigation.

Optimal time for willow and cottonwood planting varies by region, plant community, and local hydrologic (i.e., stream and groundwater hydrology) regime. Typically, cuttings are installed after spring thaw but before bud break, or in fall after leaves change color and/or drop. If planting in fall, be sure to install cuttings deep enough (i.e., at least 2 feet) to avoid being dislodged from the ground by winter freeze-thaw cycles. In river systems with fairly unaltered flow regimes, planting willows and cottonwoods after peak discharge (i.e, during the receding limb of the hydrograph) is recommended, as long as the timing in that location is prior to bud break. In altered systems, where surface and groundwater elevations are known to drop quickly, early season (i.e., very early spring) planting is recommended.



Pilot holes allow for easier installation without damaging the cuttings. In soft soils, pilot holes may not be necessary. Prepare pilot holes by pounding in rebar or other appropriate tools. Mechanical devices (e.g., stingers or augers) can also be used to prepare deeper holes in difficult soils.

The bottom is of top importance. The bottom 6-8 inches of the cutting should be installed below the expected dry-season water table. **NOTE: Sufficient depth of installation is the most difficult task for any laborer.** Generally, 50-80% of the cutting should is below ground.

TIP: many cuttings are not installed deep enough to reach the low-season groundwater. To adequately address this, ensure that the pilot hole reaches a depth of at least 6 inches into the estimated low-season groundwater.

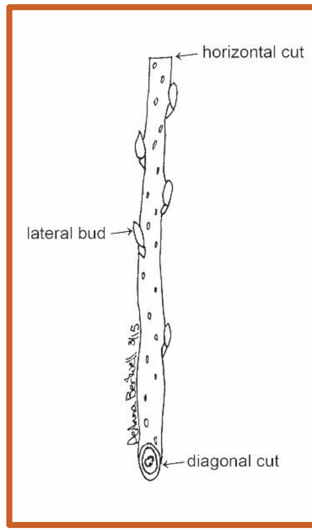
Installing Live Cuttings (continued)

Backfill around cuttings to ensure good soil-to-stem contact (i.e., without air pockets). When installing cottonwood posts or cuttings into pre-augered holes, add a pancake batter-like slurry of soil and water into the hole, allowing sediment to displace any air pockets as water leaches into underlying soil.

NOTE: Willow and cottonwood roots cannot survive in dry air! Tamp your soil around the cuttings to eliminate air pockets.

Important Installation Tips

- Remove the bottom 2-3 inches of the cutting with a clean diagonal cut to "freshen up" the conductive xylem cells prior to installation.
- Be sure upward-facing tips of lateral buds point sky-ward and the diagonally cut end, usually the thicker end of the cutting, is inserted into the ground.
- Custom cut the top of the stem to leave 1-3 feet remaining above ground, so competing plants do not overshadow the cutting during the growing season.
- Cracked, diseased, or mangled cut ends will increase susceptibility to pest damage, decreasing survival rates. If cuttings are damaged from installation, provide a clean diagonal cut just below the damaged surface.
- A minimum of two lateral buds (preferably 3 or more) should be present on portion of stem remaining above the ground.



Cluster Planting

To improve chance of establishment per planting site, install multiple cuttings in a single larger hole (cluster planting, Hoag 2009). Typically, 3 cuttings per hole is sufficient. This is a useful technique in cobble-dominated substrate such as along river banks.

Softwood Cuttings

Softwood cuttings are comprised of the current year's growth. For many non-salicaceae species, softwood cuttings can be used in a nursery setting to propagate container stock. To improve success, follow these tips:

- Perform the snap test to determine if softwood is in an appropriate stage for harvesting.
- Include 6-8 inches of softwood and 6 inches of hardwood with your cutting.
- Place entire cutting in water immediately.
- Remove all but top 3-6 leaves (before harvesting).
- Transport cuttings safely to propagation facility within four hours of harvesting (sooner the better).

GLOSSARY

Adventitious Buds/Roots: buds or roots that develop in an "atypical" place rather than at the branch tip or in leaf axils.

Apical Dominance: The phenomenon whereby the main central stem of a plant grows more strongly and readily than the lateral or side stems.

Bioengineering: Also referred to as "biotechnical slope protection," this is the integration of living woody and herbaceous materials along with organic and inorganic materials to increase the strength and structure of soil.

Buffer: A vegetated area of grass, shrubs, or trees designed to capture and filter runoff from surrounding land uses.

Canopy: The overhead branches and leaves of vegetation.

Capillary Fringe: The distance water is wicked upwards above the water table by capillary action in the soil.

Coir: A woven mat of coconut fibers used for various soil erosion control applications; Biodegrades after a period of a few years.

Fascine: A long bundle of brushwood or cuttings that is typically installed near the toe of the slope, and is used to stabilize stream banks and other slopes.

Leaf Abscission: The process by which a plant sheds some of its parts, such as leaves, spent flowers, secondary twigs, seeds, and ripe fruits.

Live Cuttings: Leafless stem cuttings of woody plant species.

Pilot Hole: A pre-drilled or augered hole in the soil substrate created in advance before installing a live cutting.

Riparian Area: An ecosystem situated between aquatic and upland environments and is characterized by greater soil moisture than adjacent upland areas. Riparian areas are periodically influenced by flooding.

Root-to-Shoot Ratio: **T**he dry weight of root biomass divided by the dry weight of shoot biomass. A plant that has a greater biomass of leaves and stems, compared to the biomass of its roots, would have a low root-to-shoot ratio. A low root-to-shoot ratio is considered an unhealthy condition for many plants.

Stinger: A tool used to create holes to use for planting cuttings from woody species.

Wattle: A sausage-like bundle of plant cuttings used to stabilize stream banks and other slopes.

Xylem: A compound tissue found in vascular plants used to transport water and some nutrients up from its roots to its stem, leaves, and buds.

Recommended Reading and Literature Cited

For advanced techniques and additional detail, refer to the following recommended reading and literature cited.

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Appendix C.
Construction Drawings

About AECOM

AECOM (NYSE: ACM) is a global provider of professional technical and management support services to a broad range of markets, including transportation, facilities, environmental, energy, water and government. With approximately 45,000 employees around the world, AECOM is a leader in all of the key markets that it serves. AECOM provides a blend of global reach, local knowledge, innovation, and collaborative technical excellence in delivering solutions that enhance and sustain the world’s built, natural, and social environments. A Fortune 500 company, AECOM serves clients in more than 100 countries and has annual revenue in excess of $6 billion.

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