PRELIMINARY DESIGN MEMORANDUM

TO:	Tracy Wendt, Sun River Watershed Group
FROM:	Tom Coleman, P.E., Karin Boyd, Tony Thatcher, Robert Sain
DATE:	December 10, 2021
SUBJECT:	Muddy Creek – **Preliminary** Design Documentation

INTRODUCTION

The following memorandum summarizes a preliminary design effort to restore lost functions to a reach of Muddy Creek near Vaughn, Montana. Muddy Creek extends approximately 40 miles upstream from its confluence with the Sun River. Along much of its path, Muddy Creek flows along the eastern margin of the Fairfield Bench, which is a major part of The Sun River Project, a large irrigation project that was originally envisioned and surveyed by the US Government in the late 1800s (Figure 1). Gibson Dam was built on the Sun River in 1929, and Sun River flows have been diverted via Pishkun Canal to irrigate the Fairfield bench ever since the distribution system was initially completed in the late 1930s. Subsequent decades saw massive changes in the hydrology of Muddy Creek, as irrigation return flows entered the small stream, described in August 1869 by General Land Office surveyors as dry. The increased magnitude and duration of flows has driven systemic downcutting of the stream that previously flowed on top of highly erodible fine sediment deposits of Glacial Lake Great Falls. Downcutting was rapid and dramatic, with up to 30 feet of incision into the erodible valley bottom. The historic floodplain is now perched as a high terrace well above the creek.

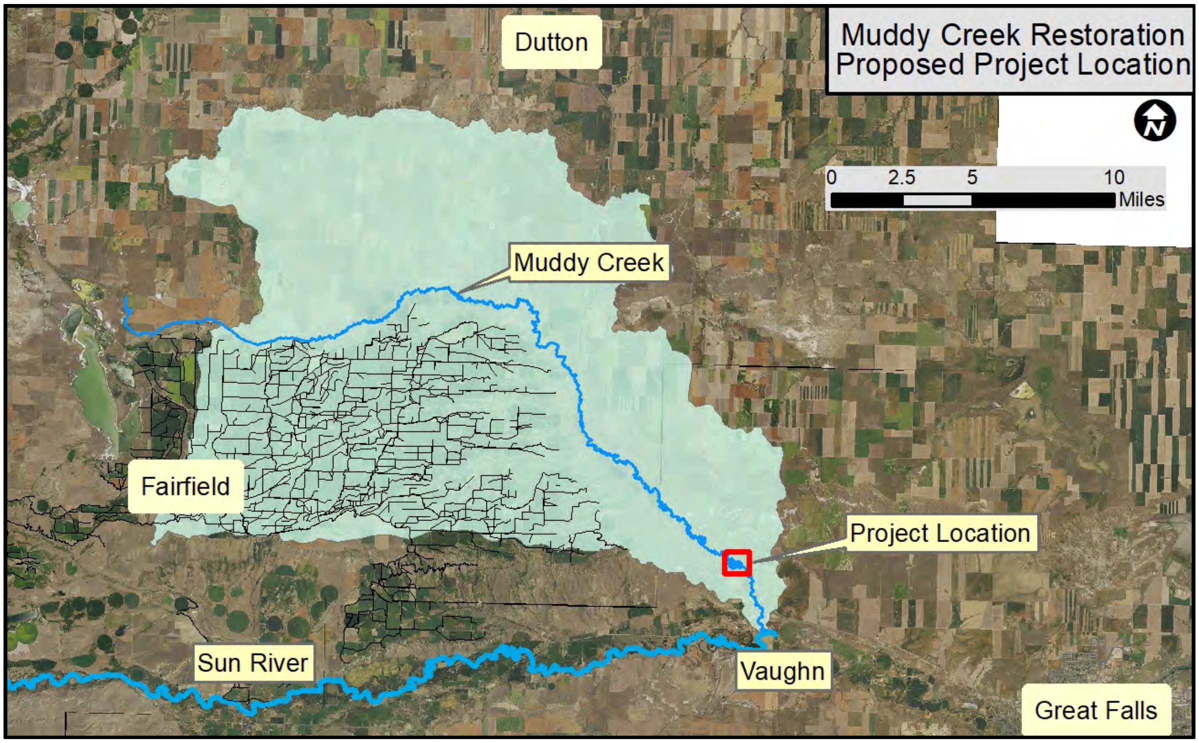


Figure 1. Muddy Creek watershed showing Greenfields irrigation distribution system in black and proposed project location.

In the mid-1990s, the Muddy Creek Conservation District in collaboration with the Cascade Conservation district worked on a project to "stabilize the planform and gradient of the stream". This included two phases of work, the first consisting of work on about four miles of channel beginning about 3 miles upstream of the mouth. This Phase 1 project was anchored by a large rock sill structure built in February 1994 at RM 3.15 to hold gradient at that location (Photo 1). An additional 10 rock grade control structures were built upstream of the sill to accommodate additional downcutting. Although the structures were constructed largely at grade, the additional downcutting caused them to become steep drops, rapidly reaching a cumulative drop of 15 feet as of October 1996. The project also included the construction of over 160 rock barbs over about 8 miles of channel. Several additional bank revetments were built, some of which were designed to prevent meander cutoffs.

Photo 1, April 29, 2021. View downstream showing Muddy Creek drop structure within incised channel.

A review of the stabilization project concluded that, in 1998, the project elements were functioning well, including during ice jams. Reviewers concluded that the grade control structures had stopped headcuts from migrating upstream, which would have caused additional instability and fine sediment production. The group made recommendations at that time for additional grade controls, barbs, longitudinal dikes to control slip failures, cutoff prevention efforts, erosion suppression, and revegetation. Subsequent revegetation efforts in the reach have been largely unsuccessful.

The conclusion that the grade controls remain functional largely remains the case, although they have become increasingly associated with excessive lateral scour and some hillslope failure, increasing their risk of failure in coming years (Photo 2).

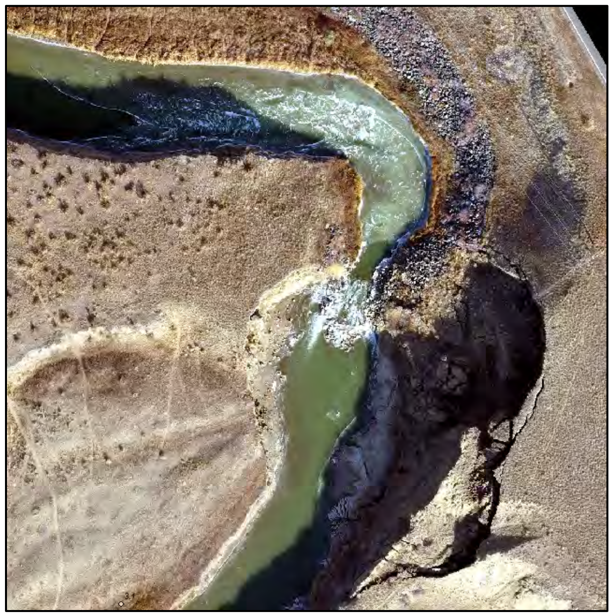


Photo 2, November 2, 2021. Drone image of hillslope destabilization below grade control, Muddy Creek (flow direction is top to bottom).

The mid-1990's grade and bank stabilization efforts on Muddy Creek have proven to be an effective means of arresting additional downcutting and reducing rates of bank erosion. As they were built ~25 years ago, the appear to have met primary project objectives regarding channel stabilization. This largely stabilized condition now can provide a foundation upon additional work can be performed to improve the longevity of that work while adding additional objectives that integrate both stability and ecological function. To achieve this, it is important to consider the current geomorphic condition on the creek in terms of current functions and limitations to those functions.

Current Geomorphic Conditions on Muddy Creek—Grade Stability

As described above, the initial grade control structures are over 25 years old and are showing obvious signs of decay. Although they can be described as "functional," the steep structure profiles and associated high velocity streaming flows create strong lateral eddies that cause bank erosion that threatens their integrity. The structures are also associated with a deep scour pool, downstream of which scoured streambed materials generally settle and form central bars (Photo 3) driving further lateral erosion. The structures were unevenly spaced along the channel but the structure crests generally conform to the average channel gradient. The infrequent structure spacing has created a stepped longitudinal profile where the channel is most closely connected to an inset floodplain surface immediately upstream of each structure and most disconnected immediately downstream of the structures. Barbs that were installed concurrently to the grade controls are mostly still in place and functioning although they are generally associated with a scalloped bank pattern due to eddy erosion between the structures (Photo 4). Herbaceous vegetation has become established on some of the barbs adding additional stability.

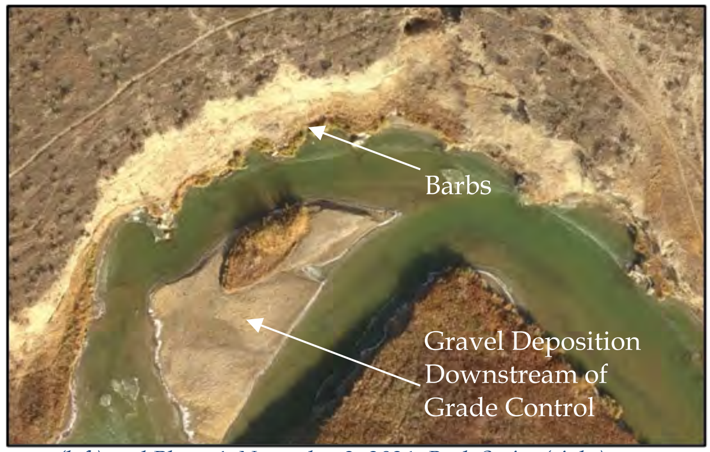


Photo 3, November 2, 2021. Existing Grade Control Structure (left) and Photo 4, November 2, 2021. Barb Series (right)

Any grade control failure in this section of stream would drive additional channel incision, downcutting, floodplain disconnection, and bank erosion. Failure of any one structure would immediately jeopardize the structure upstream. As a result, it is critical that any project on Muddy Creek ensure that the grade control system is functional for a project life that exceeds the current condition. Enhancing grade stability can then provide a primary project foundation upon which additional project elements and ecologically beneficial outcomes can be pursued.

Current Geomorphic Conditions on Muddy Creek—Floodplain Connectivity

A primary aspect of geomorphic function when considering riparian health is the level of connectivity between a channel and its floodplain. Although Muddy Creek has incised deeply below its historic floodplain, it has also developed new "inset floodplain" surfaces adjacent to the channel. Photo 5 shows an example of a large meander tab that is at an elevation below the historic floodplain surface. Although surfaces such as the one shown in Photo 5 appear to provide some connected areas that may be amenable to riparian recovery, many of them slope steeply towards the channel. This indicates that the river was migrating laterally as it was rapidly downcutting, leaving a point bar in its wake. Figure 2 shows a topographic profile through the same meander, and Figure 3 captures the meander topography via a Relative Elevation Model (REM) derived from the Lidar. These images capture how much of the "inset floodplain" is actually an older surface that is over five feet above the creek and thus is substantially disconnected and likely inhospitable to woody riparian colonization.

Another feature that is evident on the photos and figures below is the presence of a steep channel bank where the meander tab meets the active channel. This records the final phase of additional downcutting that occurred once the planform was stabilized. Point bars typically grade smoothly from a bankfull elevation into a channel without any distinct grade break forming a discreet bankline. In this case, the meander core drops steeply to the channel, indicating that the entire meander tab is somewhat disconnected from the creek. This is the case throughout the system (Photo 6), it appears little of the grassed surface that appears as an inset floodplain is actually hydrologically connected to the river and thus capable of supporting riparian functions. Previous work has estimated the effective discharge on Muddy Creek to be about 300 cubic feet per second (CFS). A preliminary HEC RAS model was built with geometry taken from the 2020 Montana Department of Natural Resources and Conservation (MDNRC) LiDAR and a GPS survey conducted by this design team. The model indicates no inundation of inset floodplain surfaces at the effective discharge and the lowest elevation floodplain surfaces just begin to inundate at a flow somewhere between the 5-yr to 10-yr recurrence interval flood.

These observations have been used to develop techniques that will integrate directly with previous work to help the system recover as quickly possible. This includes considering the condition of that previous work.

Photo 5, November 2, 2021. View upstream at RM 3.5 showing inset floodplain surfaces adjacent to channel.

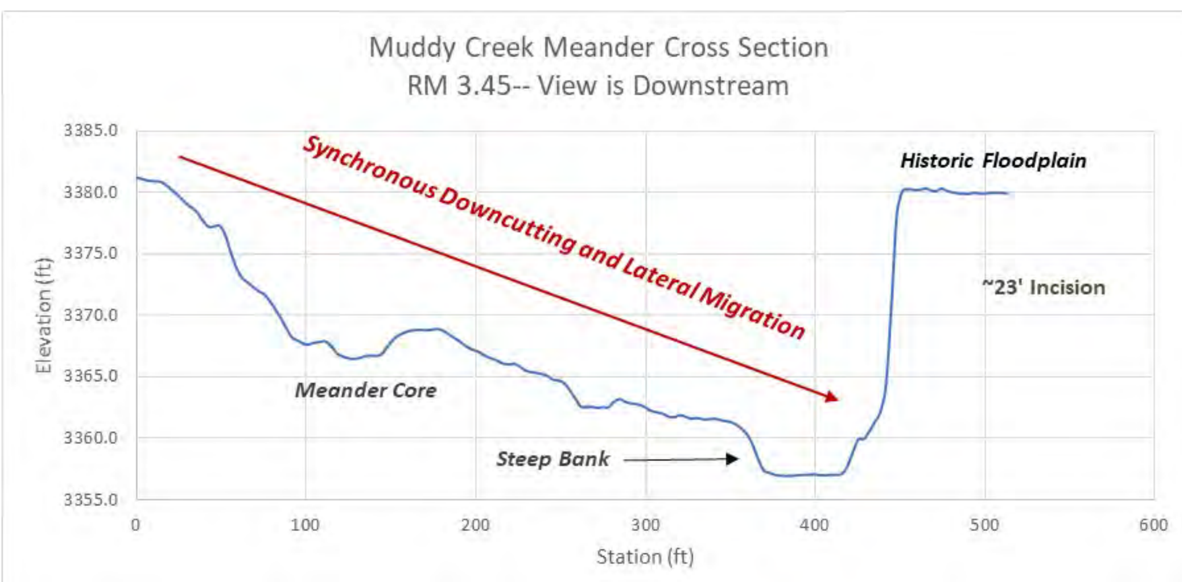


Figure 2. Cross section showing sloping meander core at RM 3.45 showing process of synchronous channel downcutting and migration; note steep left bank on edge of meander tab.

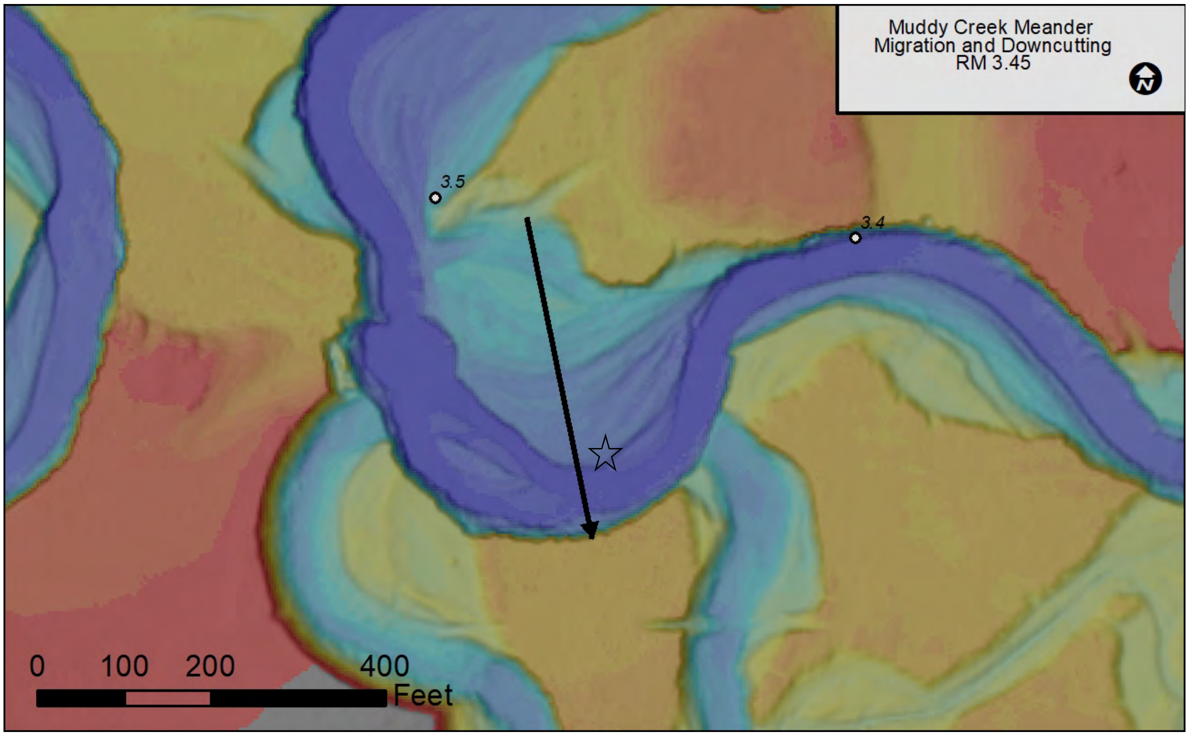


Figure 3. Relative Elevation Model showing sloping point bar surface; note steep edge on channel margin (star).

Photo 6, November 2, 2021. View upstream showing steep channel margins on passive edge and island; preliminary hydraulic modeling shows little hydrologic connectivity between these surfaces and the creek.

Proposed Project Location and Objectives

This project extends from the lowermost rock sill at RM 3.15 for about three miles upstream, in a section of stream that is at risk of grade destabilization and systemic loss of function upstream (See Sheet 2 of the Preliminary Design Drawings). The project is intended to demonstrate the application of modern concepts of riffle-based grade control, flow dispersal via floodplain reconnection, stream power reduction, and habitat renewal in an area that was originally heavily engineered to purely resist the amplified hydraulic forces on the bed and banks. In doing this, benefits are sought to improve complexity and channel structure, reduce sediment production rates, restore vegetation, improve riparian habitat, and expand wetlands and backwaters.

The project reach was selected for the following reasons:

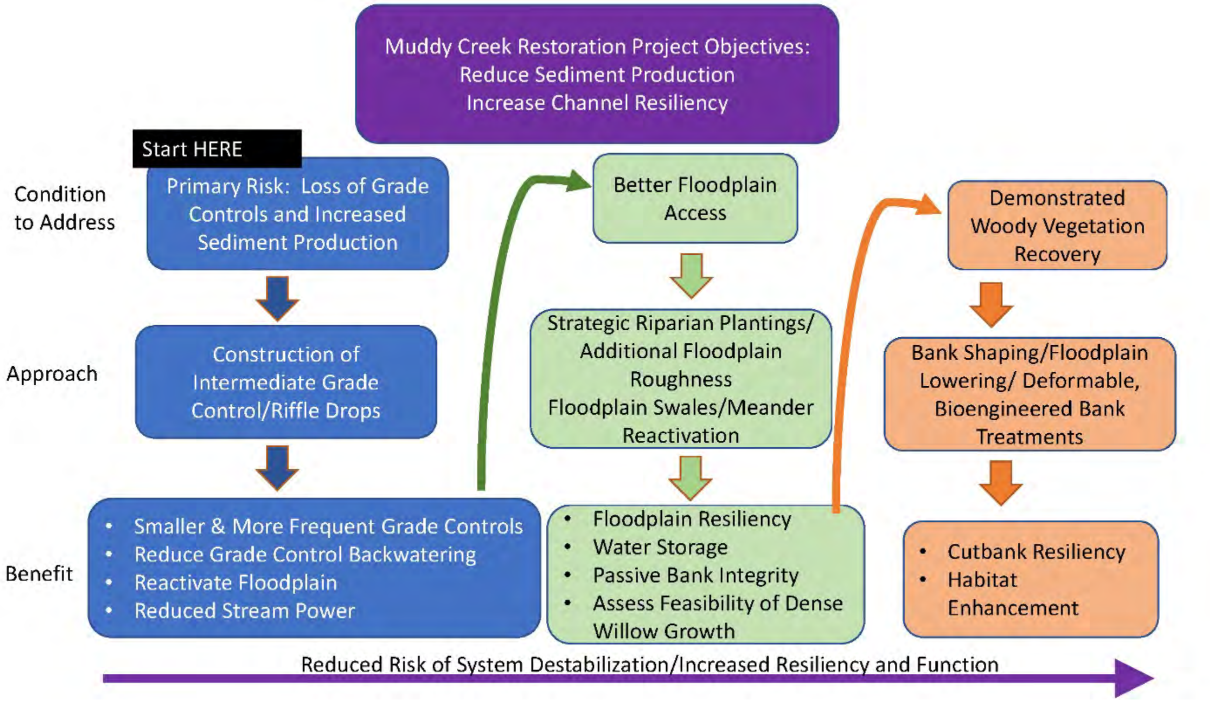
1. There is no evidence that the reach is on any natural trend of geomorphic recovery.
2. Loss of grade controls at this location in the lower segments of the creek will have a cascading effect upstream by creating a new cycle of incision.
3. Channel incision is severe in this reach such that gravitational bank collapse and associated sediment loading is common.
4. Inset floodplain surfaces have locally developed and can be opportunistically reconnected to the creek along the length of the project, serving to expand floodplain access, reduce in-channel stream power, and promote riparian recovery.
5. The reach has an obvious lack of fish habitat including backwater areas for larval and juvenile fish.
6. The range of opportunities allow the demonstration of a variety of restoration methods that can be applied throughout the watershed

The following project objectives were developed during a simultaneous master planning process:

1. Improve long-term grade stability
2. Improve hydrologic connectivity between the creek and adjacent inset floodplain
3. Create geomorphic and hydraulic conditions amenable for woody riparian recovery
4. Demonstrate a series of bank treatments that have the potential to improve bank stability and enhance riparian conditions.
5. Add project elements to improve aquatic and riparian habitats such as floodplain roughness, riparian plantings, topographic complexity etc.

Design Approach

Simultaneous to this project, the Greenfields Irrigation District (GID) is pursuing an irrigation pumpback project that will reduce GID inputs to the Muddy Creek system. Addressing flow inputs simultaneously with stream restoration is a critical aspect of this project. Although the reduction of inputs will reduce the magnitude and/or duration of high flows, this alone will not maintain stability or restore resiliency to Muddy Creek due to the current geomorphic state of the channel. As such, this project is designed to accommodate substantial uncertainty in terms of the future flow regime, while optimizing conditions to re-invigorate natural evolution and the achievement of an equilibrium state under that flow regime. The following general framework flow chart describes the project approach. The foundation for the project is sound grade stabilization in this otherwise vulnerable system. This in turn provides opportunities to increase floodplain access and complexity, conditions that can be capitalized on to promote system resiliency and optimal ecological function in this highly altered environment.



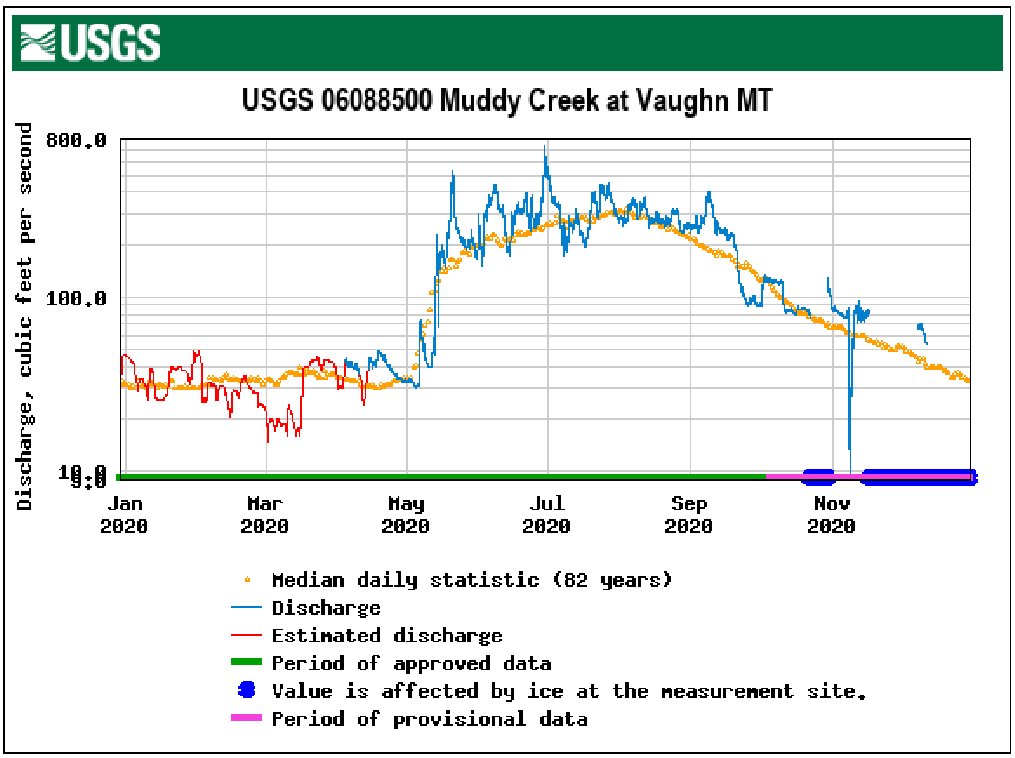
Design Considerations—Hydrology

The current irrigation enhanced hydrologic regime is the primary driver of system degradation on Muddy Creek, as irrigation wastewater flows from the GID significantly alter the natural hydrograph. As the proposed GID pumpback project will complement this effort, it is important to consider the existing and anticipated future hydrologic regime in design. The overall impact of irrigation flow augmentation is summarized in Table 1, which shows the flood frequencies for Muddy Creek calculated from regional regression equations using basin characteristics (considered "pristine") compared with the actual gage record-derived flood frequencies from the Muddy Creek gage near Vaughn (06089000). The results show, for example, that the 2-year flood event on Muddy Creek would be estimated at 176 CFS based on basin characteristics, but the actual flow record indicates a 2-year discharge of 646 CFS, a 267% increase. The relative impact of the augmented flows on flood frequencies decreases with higher flows as one would expect.

Table 1. Estimate flood recurrence discharges based on flow data and basin characteristics (USGS Streamstats).

Flood Frequency	Flow Data-Based (CFS)	Basin Characteristics-Based (CSF)	Difference (CFS)	Difference (%)
2-yr	646	176	470	267%
5-yr	1180	571	609	107%
10-yr	1720	1060	660	62%
25-yr	2700	2150	550	26%
50-yr	3730	3450	280	8%
100-yr	5080	5190	-110	-2%

GID wastewater inputs strongly skew flood magnitudes higher up to the 10-year flow event. Irrigation inputs also increase the duration of high flows through the entire growing season. Graphically, effects of the irrigation wastewater inputs can be seen in a hydrograph of daily median flows through the 82-year period of record. Figure 1 shows the Muddy Creek near Vaughn hydrograph compared to the Sun River near Vaughn, which is less influenced by irrigation returns. The Sun River gage is downstream of Muddy Creek and while the hydrograph is more typical of a natural hydrograph the influence of Muddy Creek can be seen in the summer months. The net effect of the GID inputs is an extended duration high flow condition (often exceeding the basin generated peak) that occurs each year through the entire summer season. As a result, our approach to this project is to improve connectivity while also effectively capitalizing on the benefit of long flow durations during the growing season. This will include integrating pumpback volumes into the hydrologic analysis and modeling those flows accordingly. In addition, substantial variability will be integrated into floodplain surfaces to accommodate flow fluctuations.



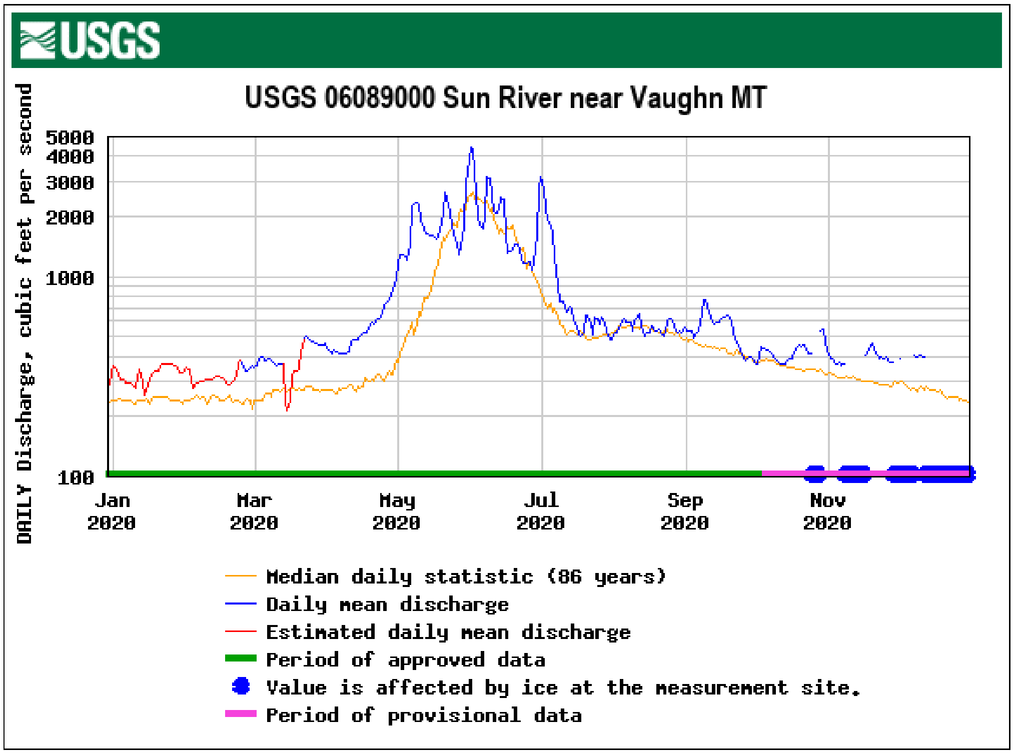


Figure 4. 2020 annual hydrographs for Muddy Creek (top) and Sun River (bottom) showing difference in shape from irrigation augmented system (Muddy Creek) to typical snowmelt runoff pattern (Sun River).

Preliminary Design Elements

Impairments in the Muddy Creek watershed are extensive and watershed scale restoration, as envisioned, in the Muddy Creek Master Plan are costly. Accordingly, the objective of this project is to demonstrate cost effective techniques to be efficient in the use of locally available materials and treatment methods. By way of example, where sod materials are prescribed as a building material, sod will be excavated at the limits of an active floodplain surface so that obtaining materials serves a dual purpose of expanding the floodplain. Further, the plan explores methods to direct dump materials at treatment sites to avoid costly inter-project stockpiling, re-loading, and hauling.

Grade control is the core element of this preliminary restoration plan. Controlling grade protects against future cycles of incision, the largest source of sediment to downstream reaches. Conceptually the plan is to strategically lift the system vertically, narrow it laterally, and lower inset floodplain tabs such that broad floodplain surfaces can be regularly inundated or saturated for a sufficient duration to support riparian vegetation plantings and natural vegetation colonization. Reconnection of a floodplain surface and establishment of riparian vegetation will decrease stream energy during floods and improve system resiliency.

Other design elements are complementary to the grade control and create a platform for system recovery that can only come from a robust riparian community that is naturally regenerated through flood processes. The project seeks to reduced high terrace erosion as vulnerable high terrace banks are common in the project reach and a significant source of sediment to downstream reaches. Multiple Bendway Terrace Toe Protections methods are proposed to demonstrate tools available for future projects and to explore effective and efficiency of each method at scale. Multiple methods also allow for selection of bank treatments that utilize the most locally available materials at the time of construction, which will allow some mitigation of project costs. Where the channel corridor is narrow with little established floodplain; no Terrace Protection measures are proposed to allow for natural corridor expansion and floodplain development.

Deep rooted woody riparian vegetation is sparse throughout the project reach and since riparian vegetation establishment is essential for long term stability and resiliency the project proposes installation of containerized plantings in all treatments. Table 2 summarizes the proposed project treatments. Project Costs are provided in Appendix A as a total reach cost and an approximate cost for each Riffle Control complex (defined as the suite of treatments applied to a reach between two of the existing grade controls). Project treatments are illustrated and further defined on the Preliminary Design Sheets in Appendix B.

Table 2. Proposed project treatments

Type	Treatment	Description	Locations	Objectives	Potential Challenges in Implementation
A	Riffle Grade Controls (RGC)	Place intermittent grade controls (riffle analogs) between rock drops	Typical riffle locations	Contribute to grade stability, increase water surface elevation to improve connectivity, backwater older rock drops, improve fish passage and habitat	Access to site, importing gravel substrate, working in-channel.
B.1	Terrace Toe Protection: Stacked Sod	Use salvaged sod to create bank toe on opposite cutbanks; incorporate live willow cuttings/clumps at slope	Cutbanks	Create bank toe on outer banks to reduce risk of mass failure and improve riparian conditions and system roughness	Access, importing willow clumps, working in active channel
B.2	Terrace Toe Protection: Bankfull Bench	Construct bankfull bench using alluvium and brush, incorporate live willow clumps and cuttings	Cutbanks & Adjacent to riffle grade controls	Create coarse alluvial bench amenable to riparian colonization retain eroded materials from terrace slumps and collapses	Access, importing alluvial material and willows to site
B.3	Terrace Toe Protection: Modified Barbs	Construct discontinuous barbs along eroding terrace toes using oversize alluvium (or quarry rock) and brush matrix secured	Cutbanks	Create stable toe along terrace toes with a discontinuous treatment. Increase system roughness and enourage deposition.	Access, importing alluvial materials to the site. Brush avaiablility.
B.4	Terrace Toe Protection: Existing Terrace Toe	Plant containerized shrubs, trees and live cuttings on existing terrace toe benches	Cutbanks with established toe bench	Stabilize existing floodplain surfaces. Increase system roughness	Access
C.	Floodplain Expansion	Excavate perched floodplain surfaces and scalp sod for use in bank treatments	Meander cores and perched lateral surfaces	Lower perched point bars while salvaging sod for bank treatments.	Access
D.	Floodplain Surface Enhancement	Add complexity to connected floodplain with wood, topographic diversity, riparian plantings	Expanded floodplain areas	Increase floodplain function	Access, importing materials
E.	Meander Reactivation	Raise water surface elevation and excavate perched meander cutoffs to restore connectivity	Perched meanders that are topographically accessible	Add channel length and restore historic wetlands/channel environments	Access
F.	Tributary headcuts	Use detention ponds and bio-swales to slow and attenuate flow, stabilize headcuts with wetsod or wood terracing	Adjacent to Muddy Creek alignment	Eliminate these additional sediment sources to Muddy Creek.	Land use related to fencing and livestock grazing can greatly reduce timeline of

APPENDIX A

ESTIMATED PROJECT COSTS

Project construction costs are shown in the tables below. A total reach cost as well as individual component costs are provided. This project can be completed as one project or in phases with sub-reaches bounded by the existing NRCS grade controls. The work between reaches in not uniform but at this preliminary planning stage the following statistics may be useful in estimating costs for a phases approach:

Cost per lineal foot	=	$75/ft
Cost per Riffle Control Complex	=	$171,500

For planning purposes typical design, permitting & construction oversight costs can be estimated at 20% to 25% of the total project cost.

Work Item	CONSTRUCTION COSTS - RIFFLE GRADE CONTROLS					
	Task	**Unit**	**Unit Cost**	**Quantity**	**Total**	**Comments**
1	**Mobilization**	LS	$ 4,500.00	1	$ 4,500	For all project tasks
2	Haul road improvements, creation and finish grading, GPS enabled	LS	$ 10,150.00	1	$ 10,150	Includes all machinery needed by contractor to get the work completed
3	Excavation, Machinery & Installation, GPS enabled	LS	$ 9,600.00	31	$ 297,600	Includes all machinery needed by contractor to get the work completed
4	Water Management	LS	$ 9,920.00	1	$ 9,920	Notch Existing Grade Control, Pump around systems, coffer dams, and labor to complete
5	Sod - Material Cost	FT^2	$ 0.50	16650	$ 8,325	On-Site Landowner Match
6	Materials (Graded Streambed Mix)	CY	$ 35.00	8,990	$ 314,650	Delivered to project site--350 yards per riffle
7	Willow Cuttings	EA	$ 2.00	9300	$ 18,600	Cut on and off site; Installed on-site during appropriate season
				Task 1 Cost	**$ 663,745**	
	note: LS= lump sum; CY= cubic yards; EA= each; HRS= hourly					

Work Item	CONSTRUCTION COSTS - FLOODPLAIN EXPANSION/EXCAVATION					
	Task	**Unit**	**Unit Cost**	**Quantity**	**Total**	**Comments**
1	Excavation, GPS enabled	CY	$ 6.00	10,671	$ 64,024	Assumes disposal of excavated materials is locally for use in other tasks
2	Sod - Material Cost	FT^2	$ 0.50	35000	$ 17,500	Fill areas on inside bends to expand floodplain (Sheet 5)
3	Containerized Trees	EA	$ 15.00	330.7	$ 4,961	Installed
4	Containerized Shrubs	EA	$ 12.00	992.1	$ 11,905	Installed
5	Large Woody Debris	LS	$ 7,672.24	1	$ 7,672	
				Task 2 Cost	**$ 106,061**	
	note: LS= lump sum; CY= cubic yards; EA= each; HRS= hourly					

Work Item	CONSTRUCTION COSTS - MEANDER REACTIVATION					
	Task	**Unit**	**Unit Cost**	**Quantity**	**Total**	**Comments**
1	Excavation, GPS enabled	CY	$ 10.00	4720	$ 47,200	Includes haul to disposal
2	Riffle Installation	NA	$ -	0	$ -	4 Riffles Included in **Task 1** costs
3	Sod - Material Cost	FT^2	$ 0.50	21000	$ 10,500	Channel plug area
4	Finish Grading	HRS	$ 155.00	80	$ 12,400	Finsihing channel margins and stream bed grading
5	Structural Fill	CY	$ 35.00	500	$ 17,500	
				Task 3 Cost	**$ 87,600**	
	note: LS= lump sum; CY= cubic yards; EA= each; HRS= hourly					

Work Item	CONSTRUCTION COSTS - FLOODPLAIN BENCH TERRACE TOE PROTECTION					
	Task	**Unit**	**Unit Cost**	**Quantity**	**Total**	**Comments**
1	Excavation/Installation GPS enabled	LF	$ 120.00	600	$ 72,000	
2	Sod - Material Cost	FT^2	$ 0.50	12000	$ 6,000	
3	Large Wood/Willow Clumps/Russian Olive	EA	$ 58.00	565	$ 32,770	
4	Small brush	LS	$ 8,000.00	1	$ 8,000	
5	Live Willow Cuttings	EA	$ 2.00	3000	$ 6,000	
6	Containerized Trees	EA	$ 15.00	21	$ 310	Installed
7	Containerized Shrubs	EA	$ 12.00	62	$ 744	Installed
				Task 4 Cost	**$ 124,770**	
	note: LS= lump sum; CY= cubic yards; EA= each; HRS= hourly					

Work Item	CONSTRUCTION COSTS - STACKED SOD BANK TERRACE TOE PROTECTION					
	Task	**Unit**	**Unit Cost**	**Quantity**	**Total**	**Comments**
1	Excavation & Installation GPS enabled	CY	$ 6.00	2992	$ 17,952	Assumes Sod is Delivered to work area from Floodplain Excavation Activities
2	Sod - Material Cost	FT^2	$ 0.50	69300	$ 34,650	
3	Live Willow Cuttings	EA	$ 2.00	4620	$ 9,240	
4	Containerized Trees	EA	$ 15.00	27	$ 398	
5	Containerized Shrubs	EA	$ 12.00	80	$ 955	
				Task 5 Cost	**$ 63,194**	
	note: LS= lump sum; CY= cubic yards; EA= each; HRS= hourly					

Work Item	CONSTRUCTION COSTS - MODIFIED BARB TERRACE TOE PROTECTION					
	Task	**Unit**	**Unit Cost**	**Quantity**	**Total**	**Comments**
1	Excavation & Installation	LS	$ 14,531.25	1	$ 14,531	Assumes 40 foot spacing on structures
2	Materials (Graded Streambed Mix)	CY	$ 35.00	1500	$ 52,500	
3	Timber Posts	EA	$ 15.00	563	$ 8,438	
4	Brush/Small Logs	EA	$ 25.00	562.5	$ 14,063	
5	Containerized Trees	EA	$ 15.00	38	$ 563	
6	Containerized Shrubs	EA	$ 12.00	94	$ 1,125	
7	Live Willow Cuttings	EA	$ 2.00	563	$ 1,125	
				Task 6 Cost	**$ 90,094**	
	note: LS= lump sum; CY= cubic yards; EA= each; HRS= hourly					

Work Item	CONSTRUCTION COSTS - EXISTING TOE BENCH REVEGETATION					
	Task	**Unit**	**Unit Cost**	**Quantity**	**Total**	**Comments**
1	Containerized Trees	EA	$ 15.00	**49**	728	
2	Containerized Shrubs	EA	$ 12.00	**146**	1,748	
3	Live Willow Cuttings	EA	$ 2.00	1410	2,820	
				Task 7 Cost	**5,296**	
	note: LS= lump sum; CY= cubic yards; EA= each; HRS= hourly					

Work Item	CONSTRUCTION COSTS - RIPRAP					
	Task	**Unit**	**Unit Cost**	**Quantity**	**Total**	**Comments**
1	Excavation & Installation	LS	$ 15,500.00	1	$ 15,500	
2	Materials (Angular Quarry Rock Gradation)	CY	$ 80.00	500	$ 40,000	
3	Materials (Pit Run Bedding)	CY	$ 35.00	114	$ 3,990	
				Task 8 Cost	**$ 59,490**	
	note: LS= lump sum; CY= cubic yards; EA= each; HRS= hourly					
				Total Project Cost	**$1,200,251**	

APPENDIX B

PRELIMINARY DESIGN DRAWINGS

SUN RIVER WATERSHED GROUP
MUDDY CREEK RESTORATION DEMONSTRATION PROJECT

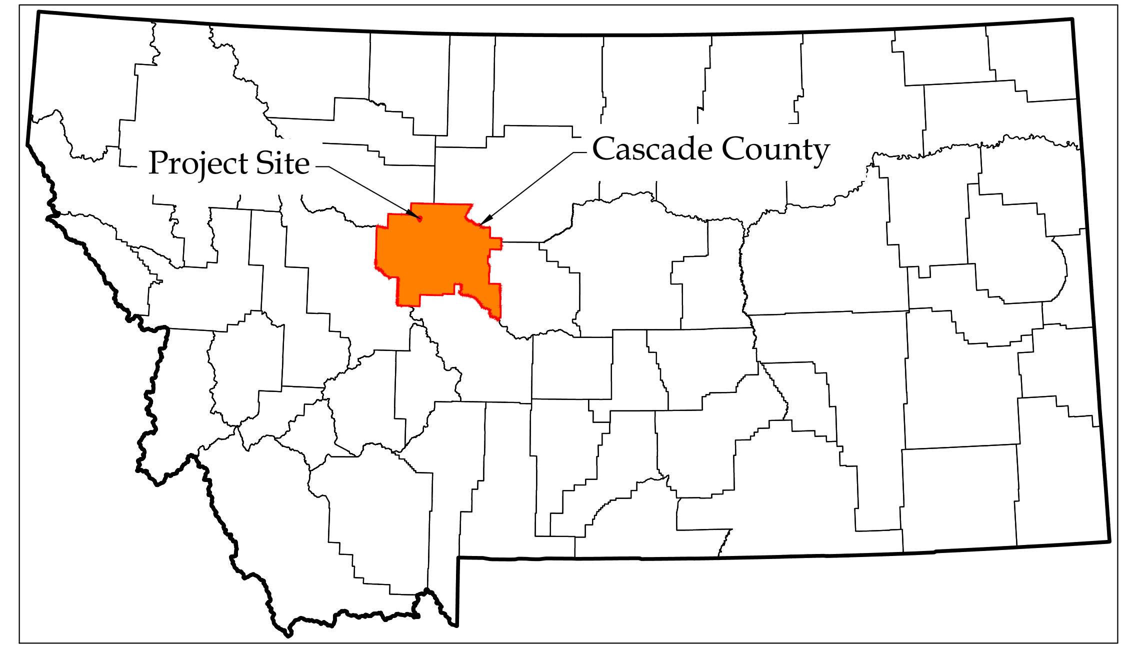
PROJECT LOCATION

LOCATED ON THE BOTHA, ROPE, AND POWELL PROPERTIES, NEAR VAUGHAN, CASCADE COUNTY, MONTANA

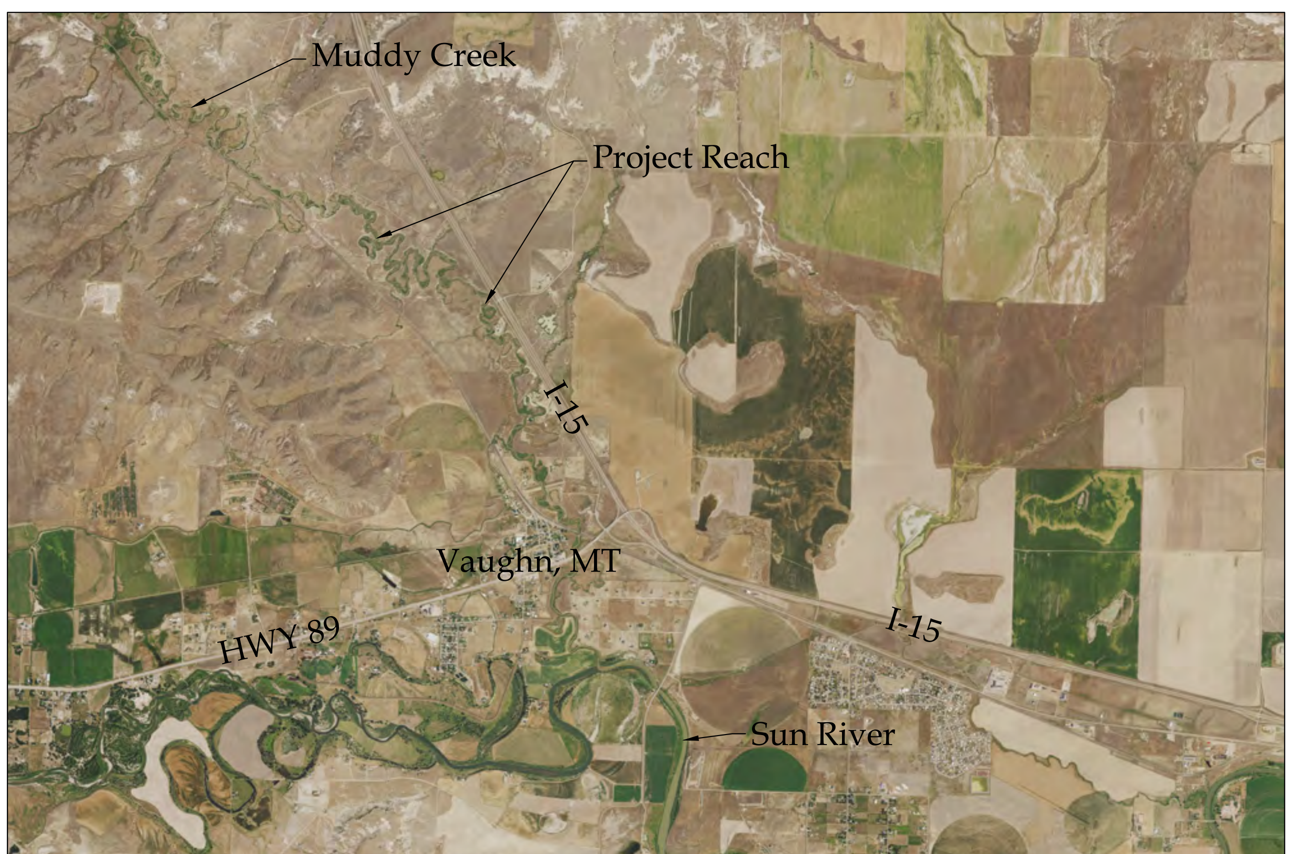
SE NW, NE SW, NW SE, SW SE, SE SE OF SECTION 11 &
NW NE, NE NE OF SECTION 14 &
SW SW OF SECTION 12 &
NW NW OF SECTION 13 ALL IN
TOWNSHIP 21N RANGE 1E

PROJECT CENTROID: LATITUDE = 47° 35' 01" NORTH; LONGITUDE = 111° 33' 52" WEST

PROJECT SPONSOR: SUN RIVER WATERSHED GROUP



VICINITY MAP



AREA MAP
SCALE 1" = 5000'

SHEET INDEX:

DATE: 12/9/2021
SCALE: NA
PROJECT NUMBER: 0221-01

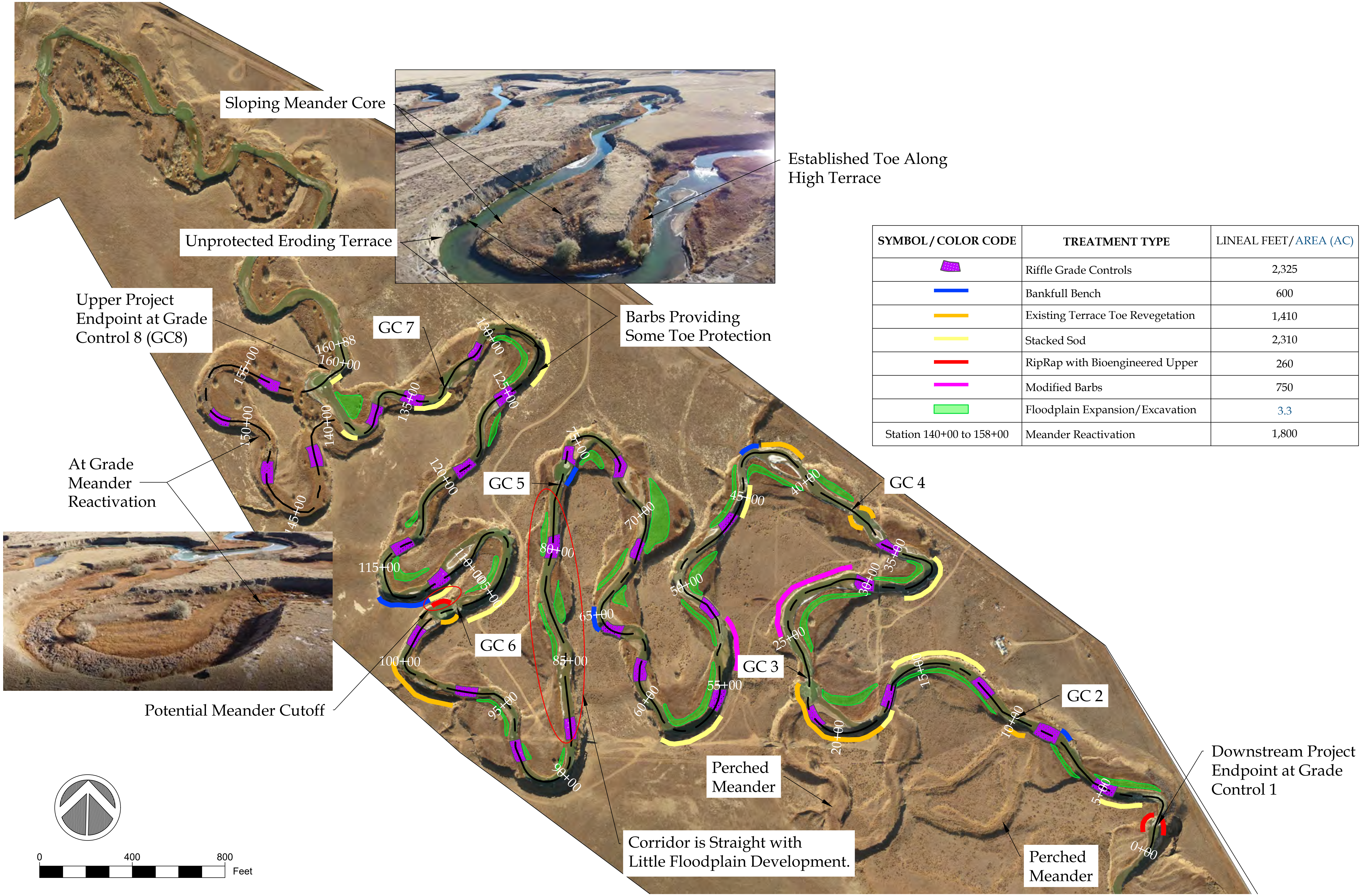
DESIGN TEAM:

PROJECT SPONSOR: SUN RIVER WATERSHED GROUP

PROJECT: MUDDY CREEK RESTORATION
INDEX AND VICINITY MAP

NO.	DATE	REVISIONS	BY	CHK

DRAWN: TC/RS
ENGINEER: TC
CHECKED: KB
APPROVED:



SYMBOL / COLOR CODE	TREATMENT TYPE	LINEAL FEET / AREA (AC)
purple	Riffle Grade Controls	2,325
blue line	Bankfull Bench	600
orange line	Existing Terrace Toe Revegetation	1,410
yellow line	Stacked Sod	2,310
red line	RipRap with Bioengineered Upper	260
magenta line	Modified Barbs	750
green	Floodplain Expansion/Excavation	3.3
Station 140+00 to 158+00	Meander Reactivation	1,800

SHEET 2 OF 10
DATE: 12/10/2021
SCALE: 1" =400'
PROJECT NUMBER: 0221-01

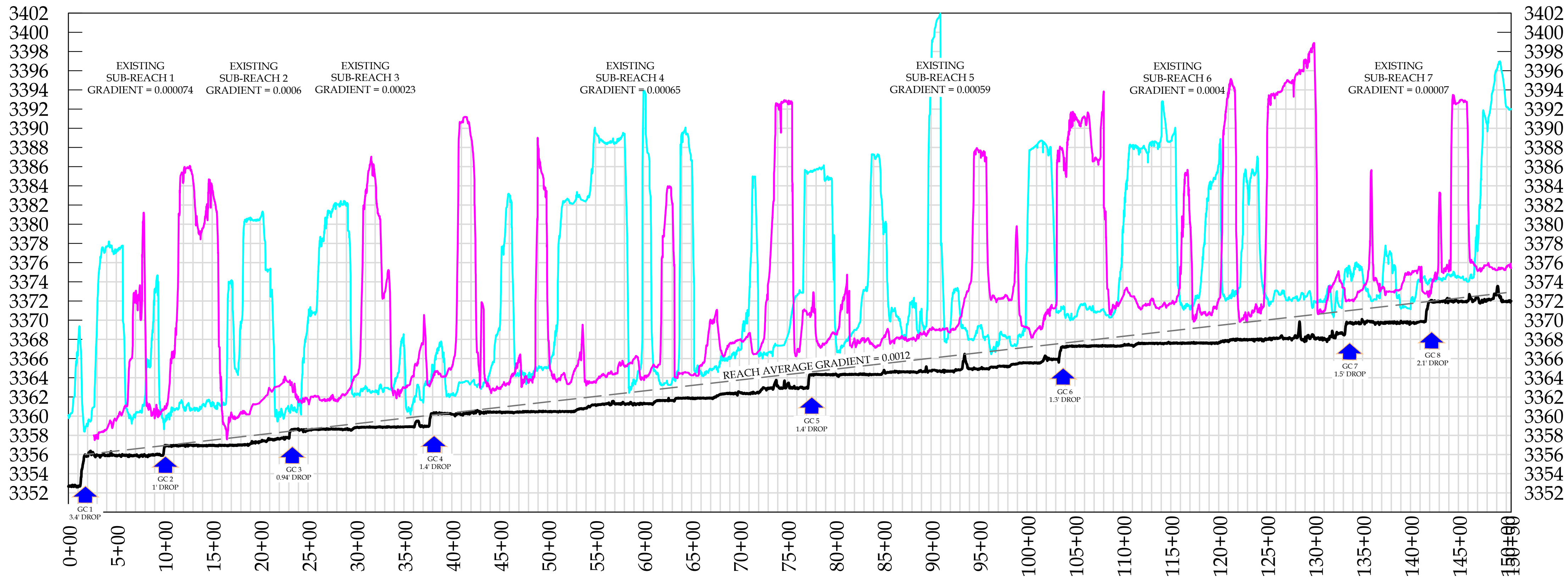
DESIGN TEAM:
RESTORATION ENGINEERING
DTM CONSULTING
Applied Geomorphology
Troutwater Restoration

PROJECT SPONSOR:
SUN RIVER WATERSHED GROUP

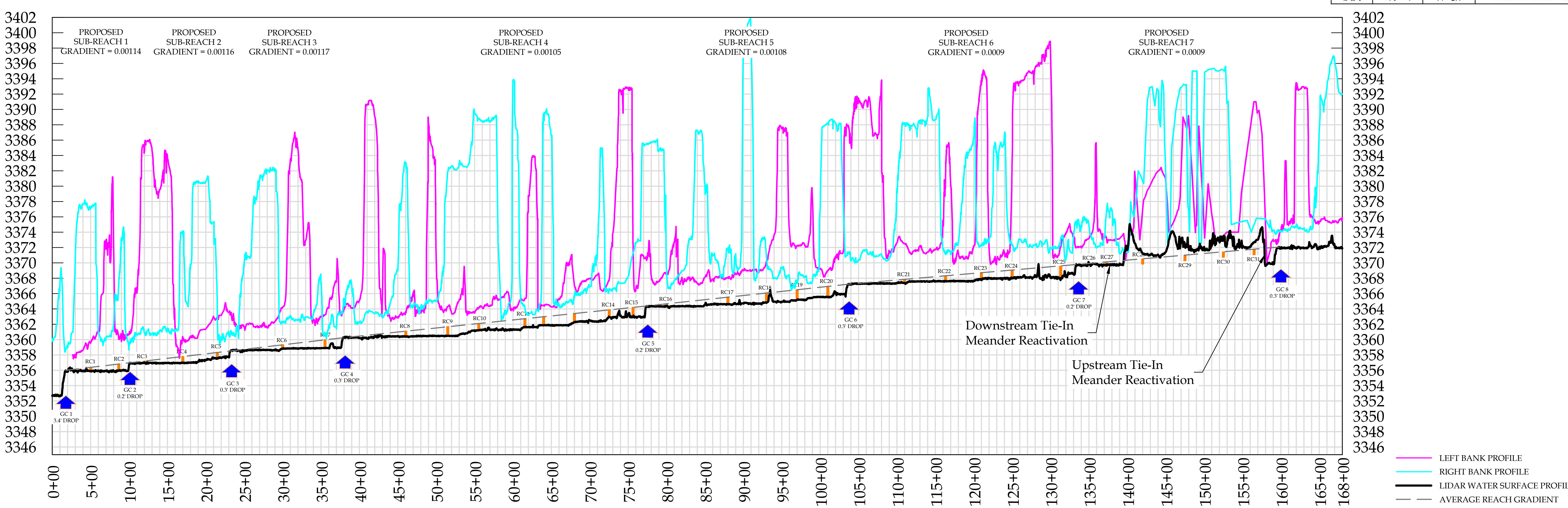
PROJECT:
MUDDY CREEK RESTORATION
PROJECT OVERVIEW

NO.	DATE	REVISIONS	BY	CHK

DRAWN: TC/RS
ENGINEER: TC
CHECKED: KB
APPROVED:



EG LONG PROFILE



PG ALIGNMENT

PRELIMINARY GRADE CONTROL ELEVATIONS

Control	Station	Elevation	Notes
GC 1	1+50	3356	Project Reach Endpoint
RC1	5+00	3356.4	
RC2	8+65	3356.8	
GC 2	10+10	3357	
RC3	12+00	3357.2	
RC4	17+00	3357.8	
RC5	21+50	3358.3	
GC 3	23+25	3358.6	
RC6	30+00	3359.3	
RC7	35+50	3359.9	
GC 4	37+90	3360.2	
RC8	46+00	3361	
RC9	51+50	3361.6	
RC10	55+50	3362.1	
RC11	61+50	3362.7	
RC12	64+00	3363	
RC13	68+00	3363.4	
RC14	72+50	3363.9	
RC15	75+60	3364.2	
GC 5	77+40	3364.4	
RC16	80+00	3364.7	
RC17	88+00	3365.5	
RC18	93+00	3366	
RC19	97+00	3366.5	
RC20	101+00	3366.9	
GC 6	103+60	3367.2	
RC21	111+00	3367.9	
RC22	116+30	3368.3	
RC23	121+00	3368.7	
RC24	125+00	3369	
RC25	131+30	3369.6	
GC 7	133+35	3369.8	
RC26	135+00	3369.9	
RC27	137+25	3370.1	1st Control downstream of meander reactivation
RC28	142+00	3370.5	
RC29	147+50	3371	
RC30	152+50	3371.4	
RC31	156+50	3371.8	
GC 8	160+10	3372.1	1st Control Upstream of meander reactivation

SHEET 3 OF 10
DATE: 12/9/2021
SCALE: NA
PROJECT NUMBER: 0221-01

DESIGN TEAM:

RESTORATION ENGINEERING
DTM CONSULTING
Applied Geomorphology
Trollwater Restoration

PROJECT SPONSOR:

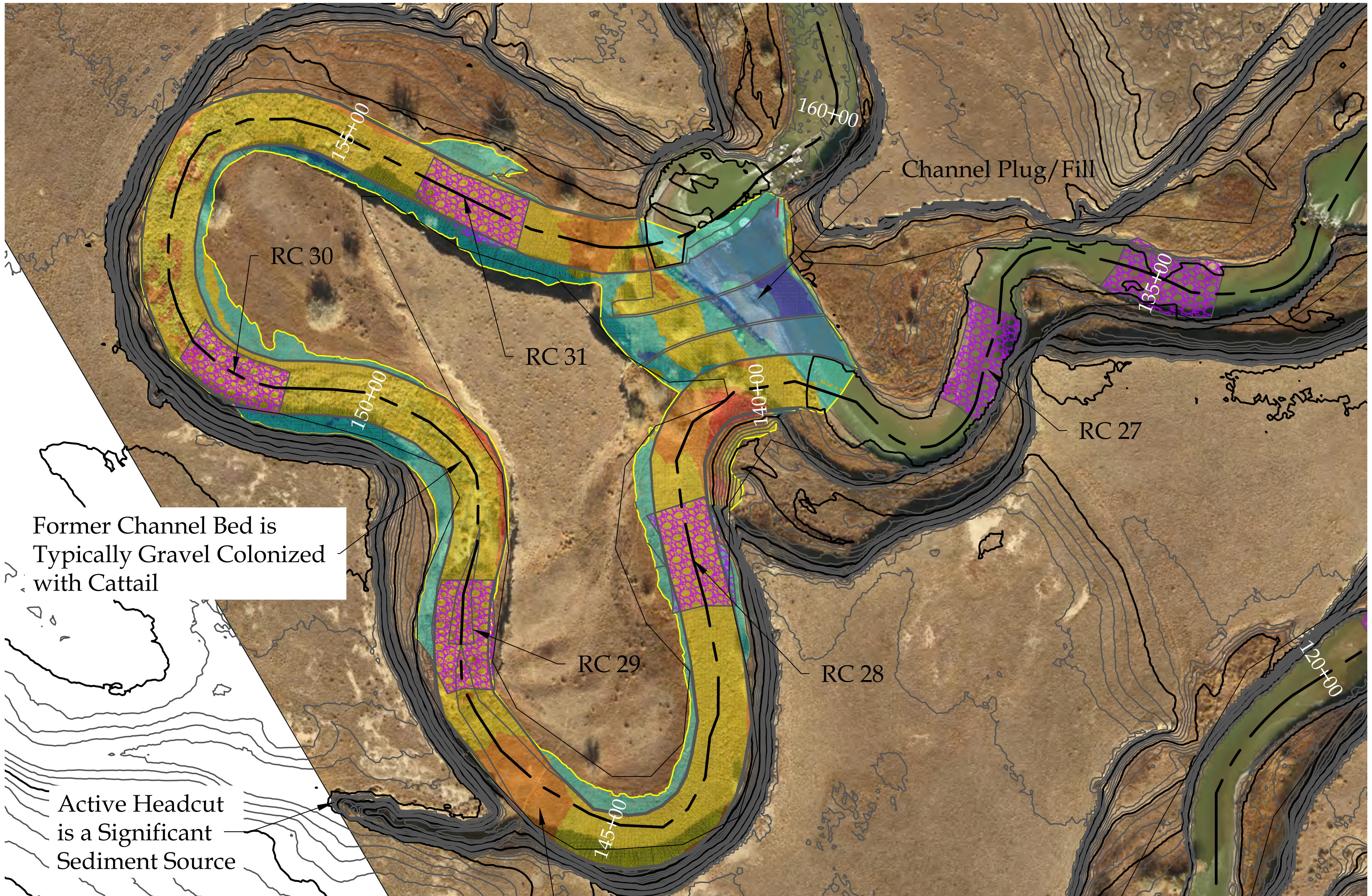
SUN RIVER WATERSHED GROUP

PROJECT:

MUDDY CREEK RESTORATION
EXISTING & PROPOSED LONGITUDINAL PROFILE

NO.	DATE	REVISIONS	BY	CHK

DRAWN:	ENGINEER:	CHECKED:	APPROVED:
TC/RS	TC	KB	



Meander Reactivation Earthwork

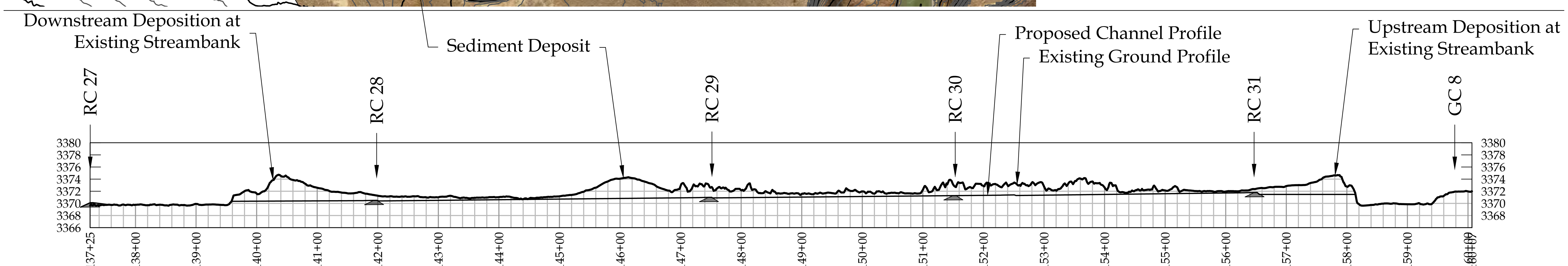
Type	Quantity (YD³)	Notes
Cut - Sod	3,400	Assume 1 Ft Lift
Cut - General	1320	Not Suitable for Structural Fill
Fill - General	1320	From Excavation
Fill - Structural	500	Imported
Fill - Sod	700	Type

Excavation of Channel Will Create Approximately 73,000 FT² / 2,700 YD³ of Wetland Sod For Use As a Building Material In Other Reaches

CUT/FILL COLOR CODES

Color Scheme	Minimum Elev.	Maximum Elev.
	-8	-10
	-6	-8
	-4	-6
	-2	-4
	-0	-2
	0	2
	2	4
	4	6

0 125 250 Feet



RC# - Riffle Controls (Proposed)

MEANDER REACTIVATION LONG PROFILE

SHEET 4 OF 10

DATE: 12/10/2021

SCALE: NA

PROJECT NUMBER: 0221-01

DESIGN TEAM:

PROJECT SPONSOR: SUN RIVER WATERSHED GROUP

PROJECT: MUDDY CREEK RESTORATION MEANDER REACTIVATION

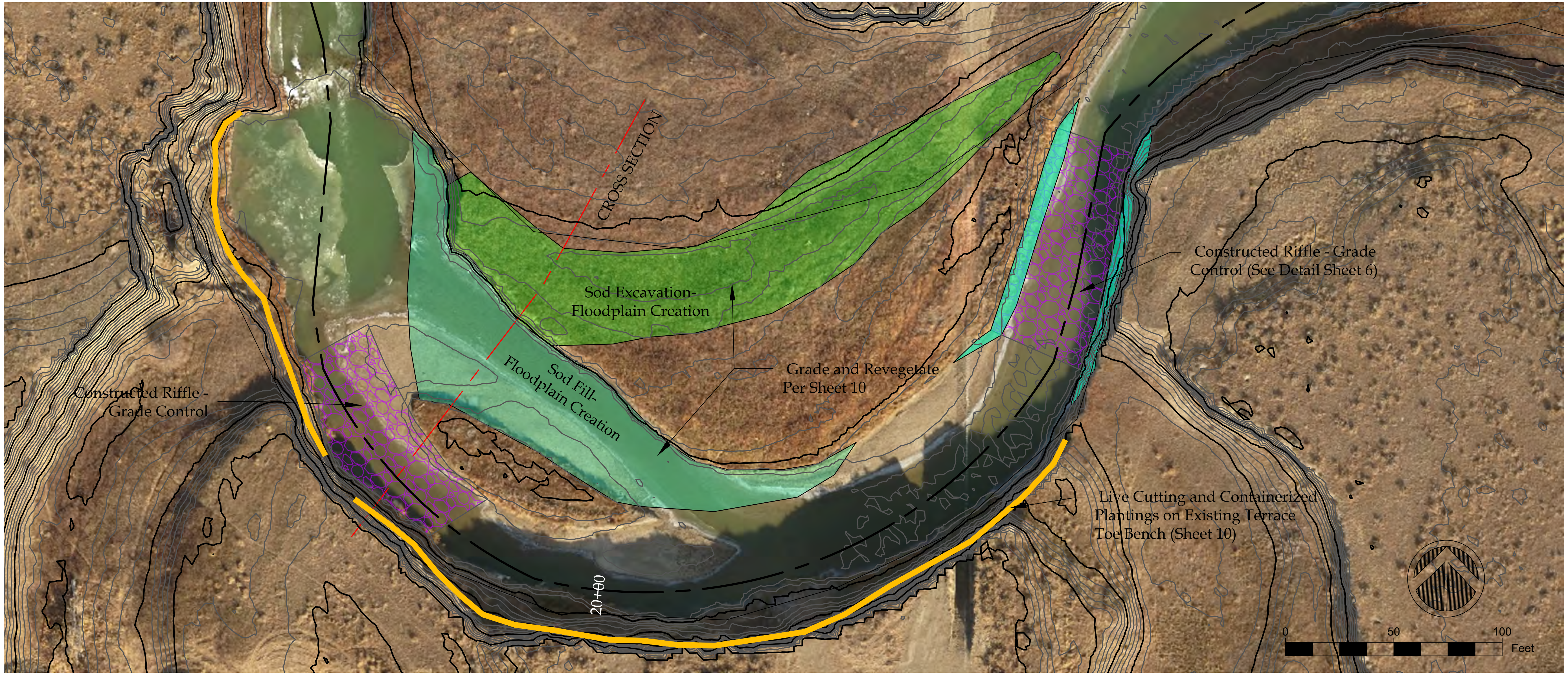
NO.	DATE	REVISIONS	BY	CHK

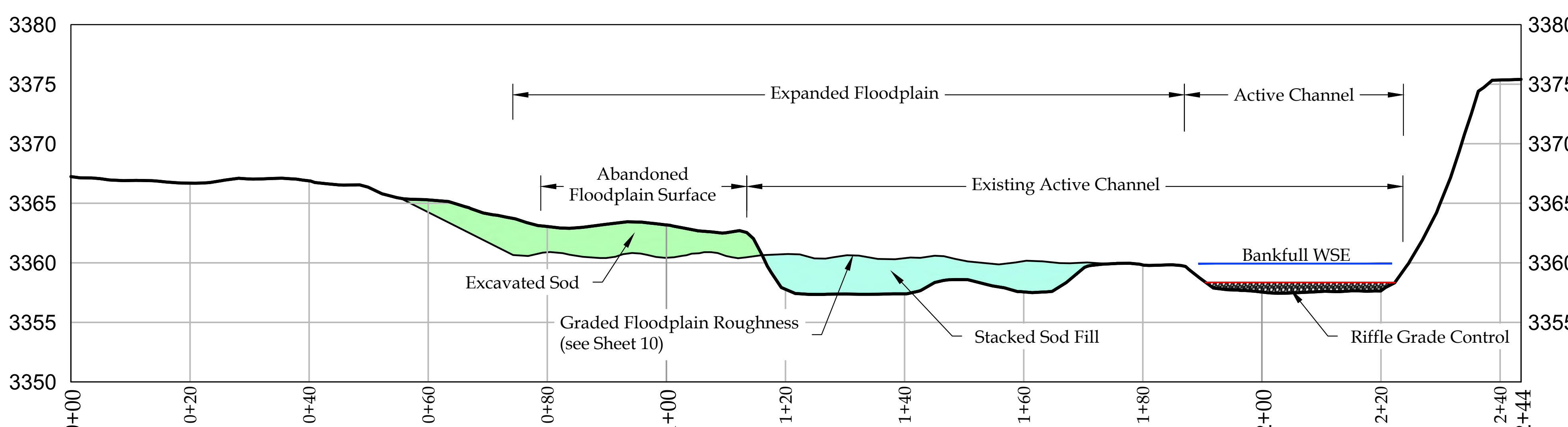
DRAWN: TC/RS

ENGINEER: TC

CHECKED: KB

APPROVED:





CROSS SECTION

SHEET 5 OF 10
DATE: 12/10/2021
SCALE: 1" =25'
PROJECT NUMBER: 0221-01

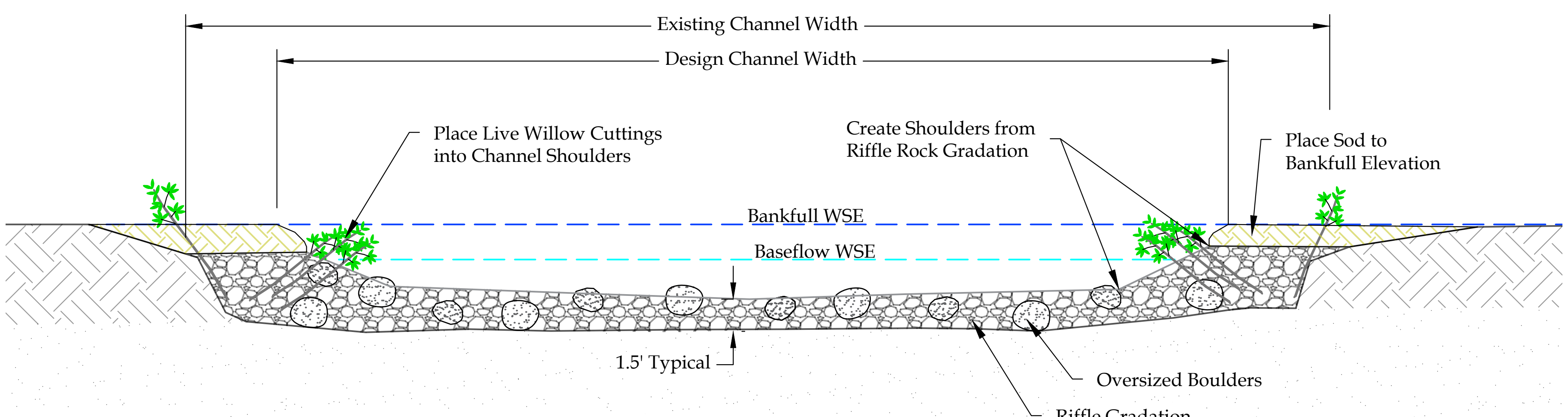
DESIGN TEAM:

PROJECT SPONSOR:
SUN RIVER WATERSHED GROUP

PROJECT:
MUDDY CREEK RESTORATION
RIFFLE / FLOODPLAIN COMPLEX

NO.	DATE	REVISIONS	BY	CHK

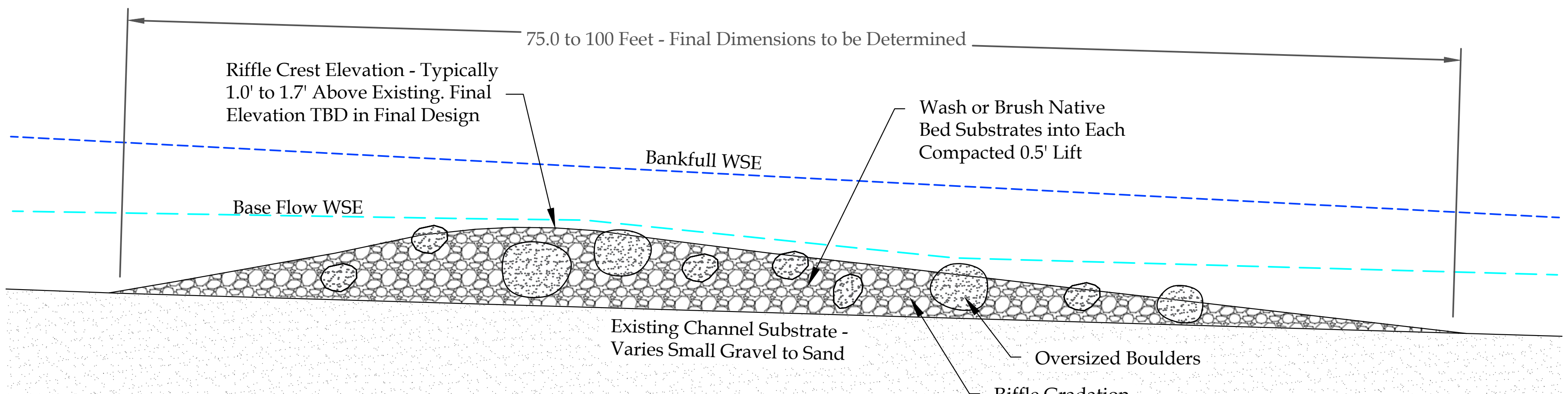
DRAWN: TC/RS
ENGINEER: TC
CHECKED: KB
APPROVED:



CROSS SECTION VIEW

Material Schedule		
Type	Description	Quantity
Oversize Boulders	Up to 18" Glacial/River Rounded	15 Tons
Imported Riffle Material	River Rounded Alluvium	350 CY
Existing Streambed Material	Small Gravel to Sand	5 CY
Live Willow Cuttings	0.5 to 2.5" X 5' Live Stems	300
Sod	Locally Harvested Sod	750 FT²

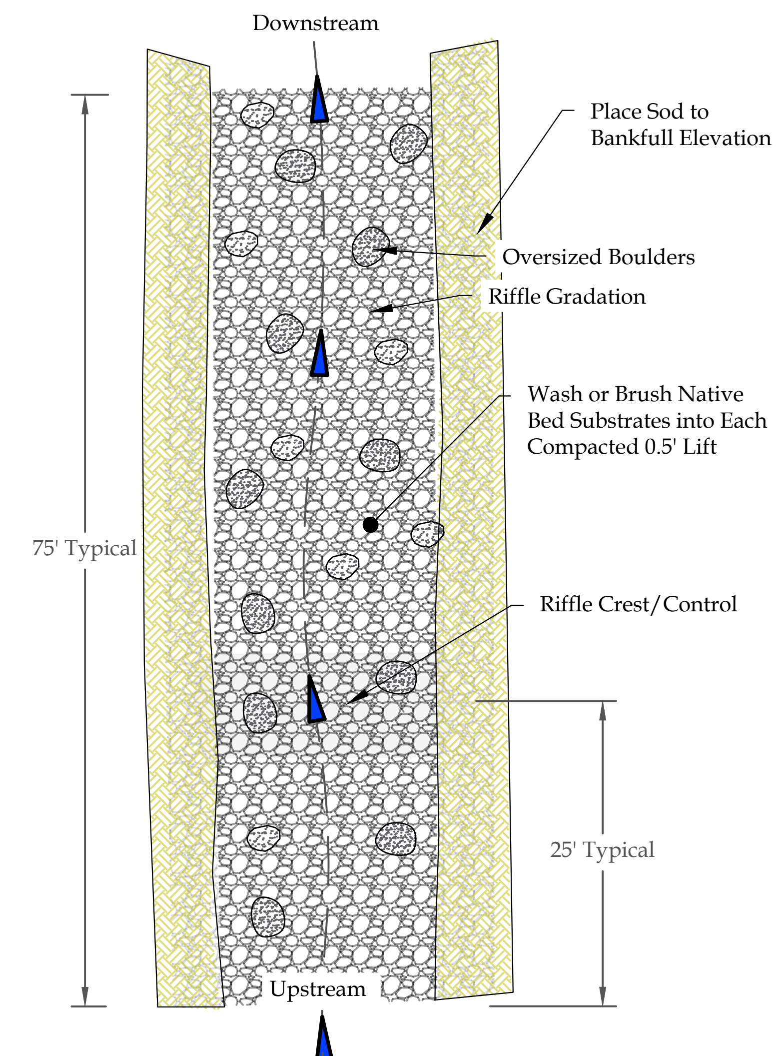
Typical Streambed Gradation	
Size Class	Percent Passing
12"	100
10"	90 - 100
8"	50 - 80
6"	30 - 50
4"	10 - 30
Existing Streambed Material (Gravel/Sand)	0 - 10



PROFILE VIEW

Work Description:
Riffle Grade Controls provide vertical stability and effectively increase (lift) the elevation of the existing streambed to provide connectivity to an existing abandoned floodplain. They also prevent channel incision because they are constructed with an immobile rock gradation. The shape, frequency, geomorphic position, and elevation drop across these structures allows them to behave like a natural riffles. The local water surface slope steepens across the structures at low flows but progressively flattens ('washes out") as water flows increase, eliminating the high energy loss conditions present at the existing grade controls and the associated scour and lateral erosion

Notes:
1. Prepare subgrade to a firm and un-yielding condition
2. Excavate loose riffle sub-grade material from constructed riffle footprint and stockpile.
3. Place boulders on sub-grade in a random array throughout the riffle footprint avoiding a linear un-natural appearance.
4. Fill and compact imported riffle material in 0.5' lifts.
5. Fill interstitial spaces with native streambed material by washing or brushing the materials into the riffle matrix.
6. Repeat compacted lift sequence until design elevations are achieved.
7. The width of the riffle will be determined in final design.
8. Riffle gradation and boulders to be used to construct a stable shoulder at the margins of the constructed riffle.
9. Salvaged sod to be placed on shoulder to complete the bank to the bankfull elevation.
10. Typical structure length will vary form 75' to 100' depending on channel position and final design criteria.
11. Typical structure height at crest preliminarily ranges from 1.0' to 1.7'.
12. Material volume will range form 200 to 400 tons of rock depending on sub-grade quality and structure dimensions.



PLAN VIEW

SHEET 6 OF 10
DATE: 12/8/2021
SCALE: NA
PROJECT NUMBER: 0221-01

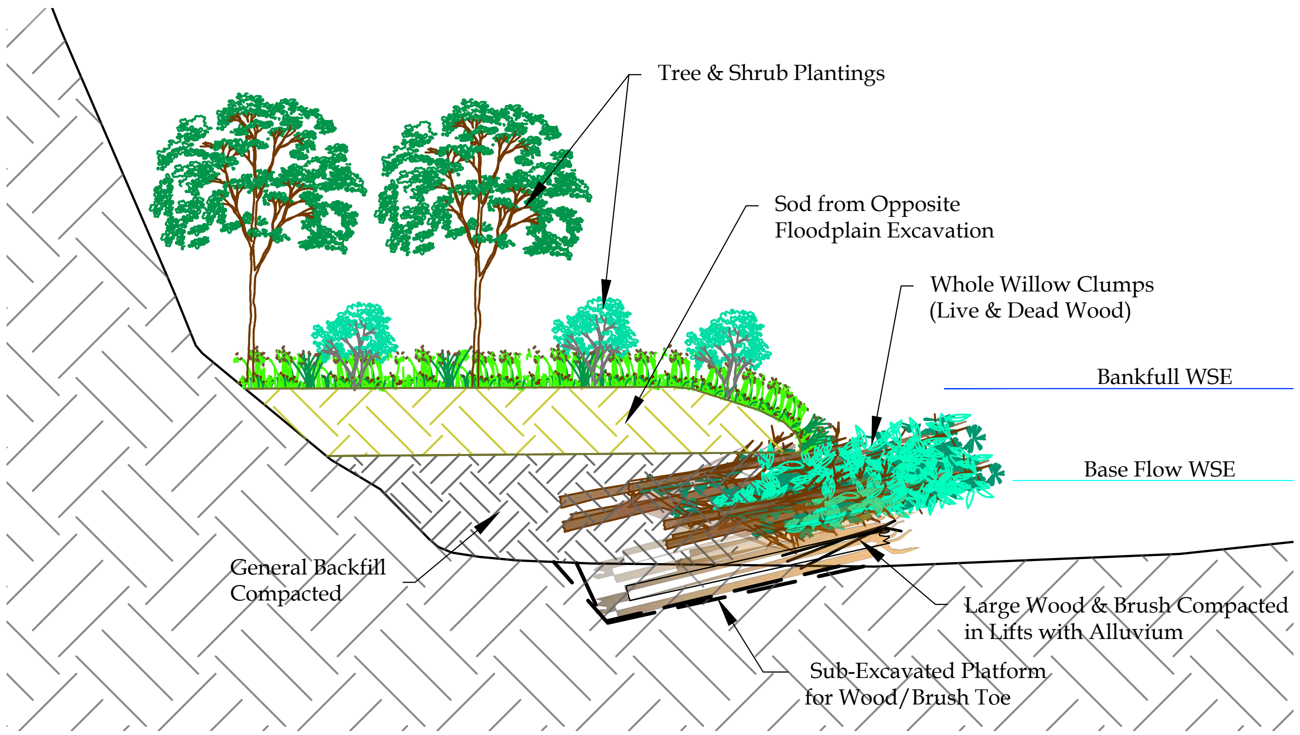
DESIGN TEAM:
RESTORATION ENGINEERING
DTM CONSULTING
Applied Geomorphology
Troutwater Restoration

PROJECT SPONSOR:
SUN RIVER WATERSHED GROUP

PROJECT:
MUDDY CREEK RESTORATION
RIFFLE GRADE CONTROL

NO.	DATE	REVISIONS	BY	CHK

DRAWN: TC/RS
ENGINEER: TC
CHECKED: KB
APPROVED:



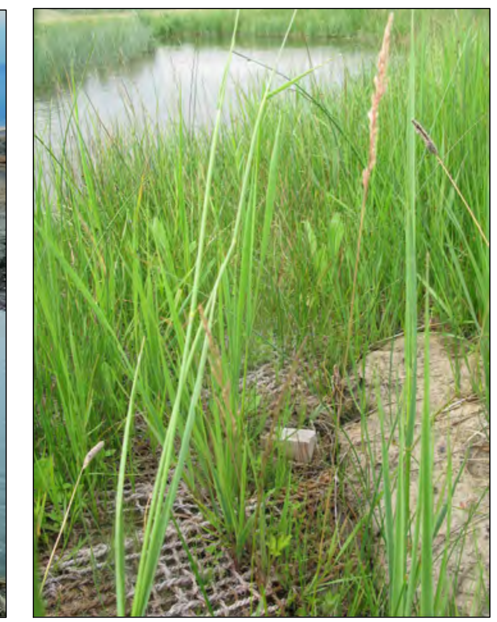
Work Description:

Creation of a bankfull bench at the toe of eroding terraces to prevent future erosion. The bankfull bench serves numerous purposes including; 1) Provides a platform to retain collapsed bank materials from terrace before they are entrained in creek flows, 2) Provides a platform for growing stabilizing riparian vegetation, 3) Increases system roughness, 4) Narrows over-widened cross sections and 4) Improves aquatic habitat. Use of a stabilizing composite wood toe allows for the use of more erodable (locally available) materials to create a bankfull bench. Large wood and willows are not readily available on site but may be available nearby opportunistically thorough maintenance operations on Greenfield Irrigation District (GID) lands, highway roadside ditch maintenance, Christmas tree collections, and selective harvest from health riparian areas in the region.

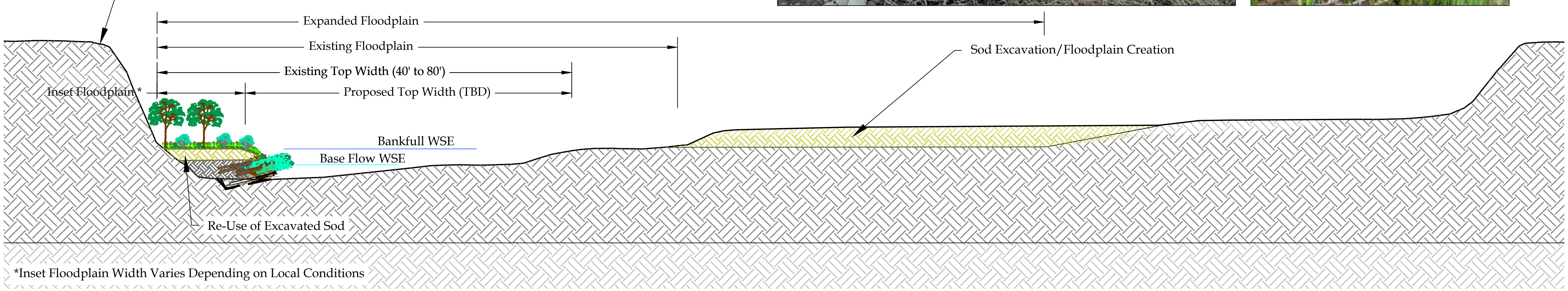
Notes:

1. Sub-excavate streambed to create a platform for wood/brush placement that slopes down in the direction of the terrace.
2. Excavated materials to be placed at toe of terrace to be used as general fill.
3. Construction to occur at low water
4. Notch the downstream grade control to lower the base flow water elevation to make construction from the creek side feasible.
5. Place woody / brush in lifts and compact with alluvium.
6. Backfill bankfull bench with general fill up to top of wood/brush toe.
7. Place sod salvaged from the opposite floodplain to finish the bank up to the bankfull elevation.
8. Incorporate live will clumps and cuttings throughout the toe above the base flow elevation.
9. Create a rough surface on the bankfull bench per the floodplain roughness detail.

TYPICAL MATERIAL			
TYPE	DIMENSIONS	UNITS	QUANTITY
Whole Willow Clumps	TBD	EA	0.2/LF
Dormant Willow Cuttings	TBD	EA	5
Alluvial Backfill	TBD	CY/LF	0.6
Floodplain Backfill	Native	CY/LF	Varies
Sod	Native	CY/LF	Varies
Cottonwood/Russian Olive	TBD	EA	0.5/LF
Containerized Shrubs	TBD	EA	0.2/LF
Containerized Trees	TBD	EA	.1/LF



BIO-ENGINEERED COMPOSITE WOOD/BRUSH
TOE AND INSET FLOODPLAIN



*Inset Floodplain Width Varies Depending on Local Conditions

SHEET 7 OF 10
DATE: 12/8/2021
SCALE: NA
PROJECT NUMBER: 0221-01

DESIGN TEAM:

PROJECT SPONSOR: SUN RIVER WATERSHED GROUP

PROJECT: MUDDY CREEK RESTORATION
TERRACE TOE PROTECTION
BANKFULL BENCH

NO.	DATE	REVISIONS	BY	CHK

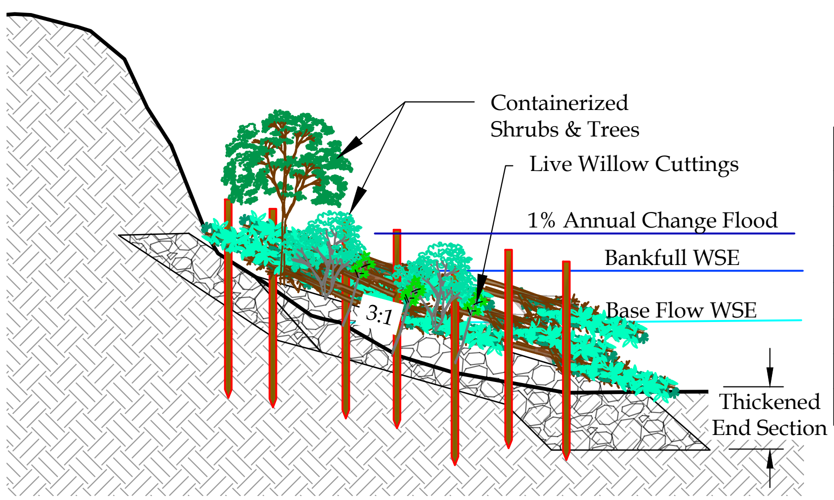
DRAWN: TC/RS
ENGINEER: TC
CHECKED: KB
APPROVED:

Work Description:

Of the 160 barbs installed in the mid-90's, many are still functioning, which is testament to the effectiveness of the treatment. Barbs are also discontinuous treatments so material requirements are lower than other continuous treatments. Rock barbs move the channel thalweg away from the toe of a bank but they can increase velocities in the main channel. In keeping with the project objectives of reducing stream energy an alternative barb plan is proposed as shown on the attached concept drawings. Construction of the original barbs used large blasted quarry rock and were placed with a long-boom trackhoe from the top of 20 to 30 foot terraces. This practice limited the extent of the structures and precision in placement of materials. The proposed structure evision an alternative construction method, alternative materials and modified functionality.

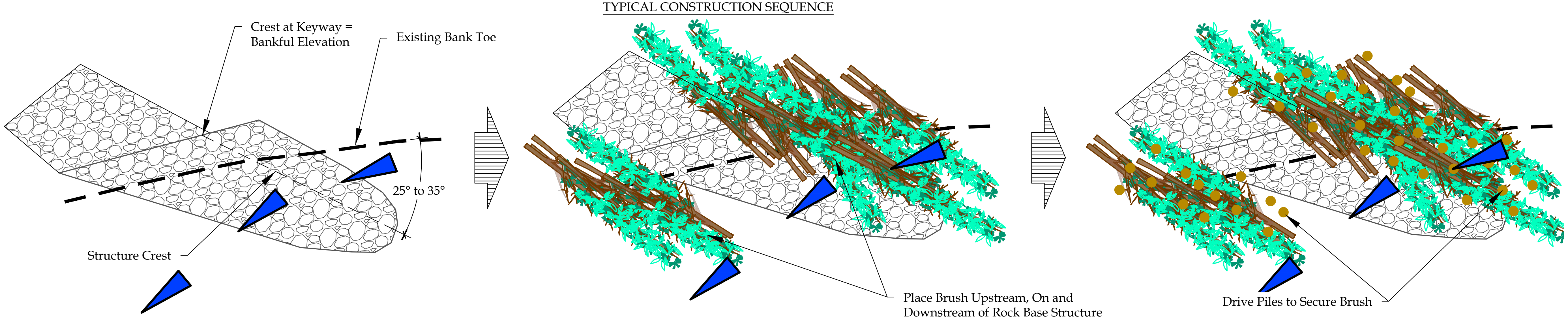
Notes:

1. Construction to occur at low water
2. Notch the downstream grade control to lower the base flow water elevation to make construction from the creek side feasible.
3. Sub-excavate streambed to create a thickened end section
3. End dump cobble/rock gradation from top of terrace at each structure location.
4. Shape structure with trackhoe from the river level
5. Place stacked brush mats upstream, on and downstream of the structures.
6. Drive wood piles to secure brush mattresses.
7. Top of elevations of select piles to exceed the 1% annual chance flood elevation.
8. Incorporate live willow clumps and cuttings throughout the structures.



TYPICAL MATERIAL			
TYPE	DIMENSIONS	UNITS	QUANTITY
Washed Cobble Gradation	18" Minus	CY/Structure	80
Timber Posts	0.5' Dia. X 15'	EA	35
Brush / Small Logs	0.25'-0.5' Dia X 10'	EA	30
Containerized Shrubs	TBD	EA	5
Containerized Trees	TBD	EA	2
Live Willow Cuttings	0.5"-2.5" Dia. X 5'	EA	30

MODIFIED BARB
TYPICAL CONSTRUCTION SEQUENCE



SHEET 8 OF 10
DATE: 12/8/2021
SCALE: NA
PROJECT NUMBER: 0221-01

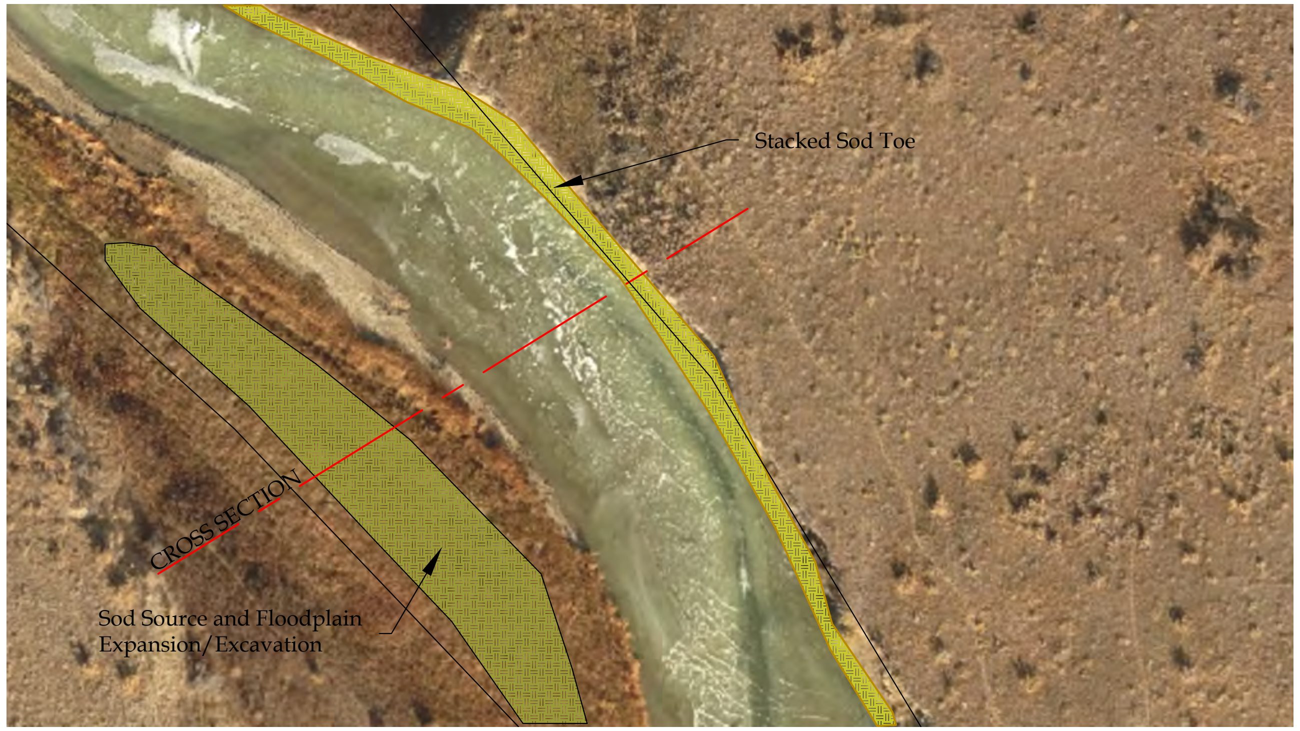
DESIGN TEAM:
RESTORATION ENGINEERING
DTM CONSULTING
Applied Geomorphology
Trailwater Restoration

PROJECT SPONSOR:
SUN RIVER WATERSHED GROUP

PROJECT:
MUDDY CREEK RESTORATION
TERRACE TOE PROTECTION MODIFIED BARB

NO.	DATE	REVISIONS	BY	CHK

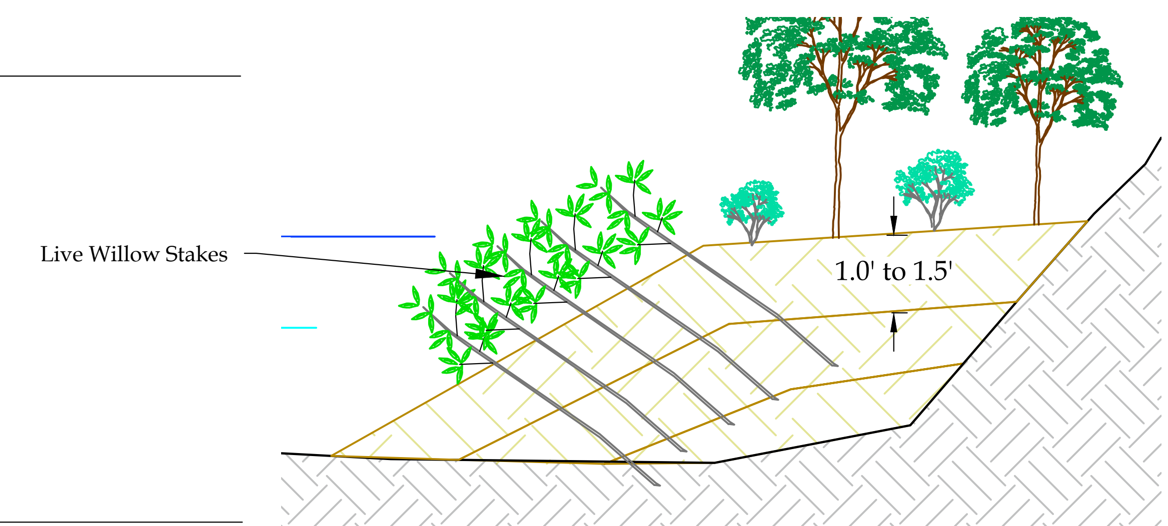
DRAWN: TC/RS
ENGINEER: TC
CHECKED: KB
APPROVED:



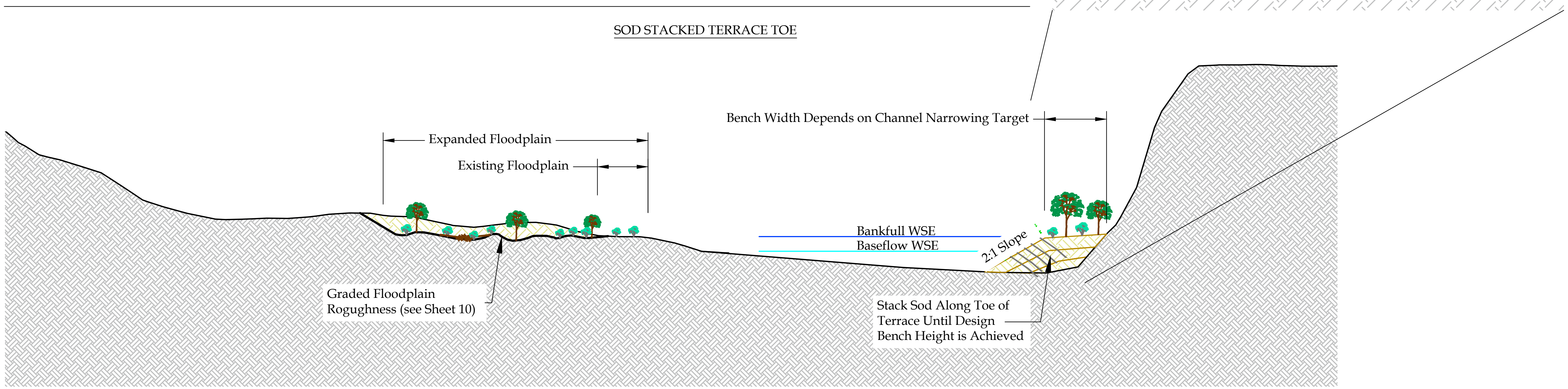
Work Description:
Sod will be a readily available material along the project reach. Muddy Creek is a low energy system and there are numerous examples (analogs) of vegetated toe benches naturally establishing at the base of terrace surfaces. Some of these surfaces appear to be persistent. This method uses a readily available materials that can be placed efficiently so extensive reaches can be treated at a lower costs. Sod is stacked and shaped to create a small bench and gently sloping bank face to facilitate vegetation establishment. Additional sod stabilization can be derived from live staking with shroud line interwoven between stakes or blanketing with Coir mats.

Notes:
1. Notch the downstream grade control to lower the base flow water elevation to make construction from the creek feasible.
2. Complete construction during base flow conditions.
3. Strip sod from excavated floodplain surface, preserving the integrity of the sod to the maximum extent possible.
4. Place and shape sod along toe of opposite terrace bank.
5. Repeat until the deign bank height is achieved.
6. Shape sod to create a gentle bank face slope and flat bankfull bench.
7. Apply stabilization measures (TBD).
8. Grade and revegetate sod borrow area per Sheet X Revegetation and Floodplain Grading.
9. Revegetate stacked sod bench per Sheet X Revegetation and Floodplain Grading.

TYPICAL MATERIAL			
TYPE	DIMENSIONS	UNITS	QUANTITY
Excavation	1' to 1.5' Sod Thickness	CY/ACRE	2,020
Fill	1' to 1.5' Sod	CY/ACRE	4,030
Containerized Shrubs	Quantities on Sheet 10. Revegetation and Floodplain Roughness		
Containerized Trees			



SOD STACKED TERRACE TOE



SHEET 9 OF 10
DATE: 12/8/2021
SCALE: NA
PROJECT NUMBER: 0221-01

DESIGN TEAM: RESTORATION ENGINEERING; DTM CONSULTING; Applied Geomorphology; Trailwater Restoration

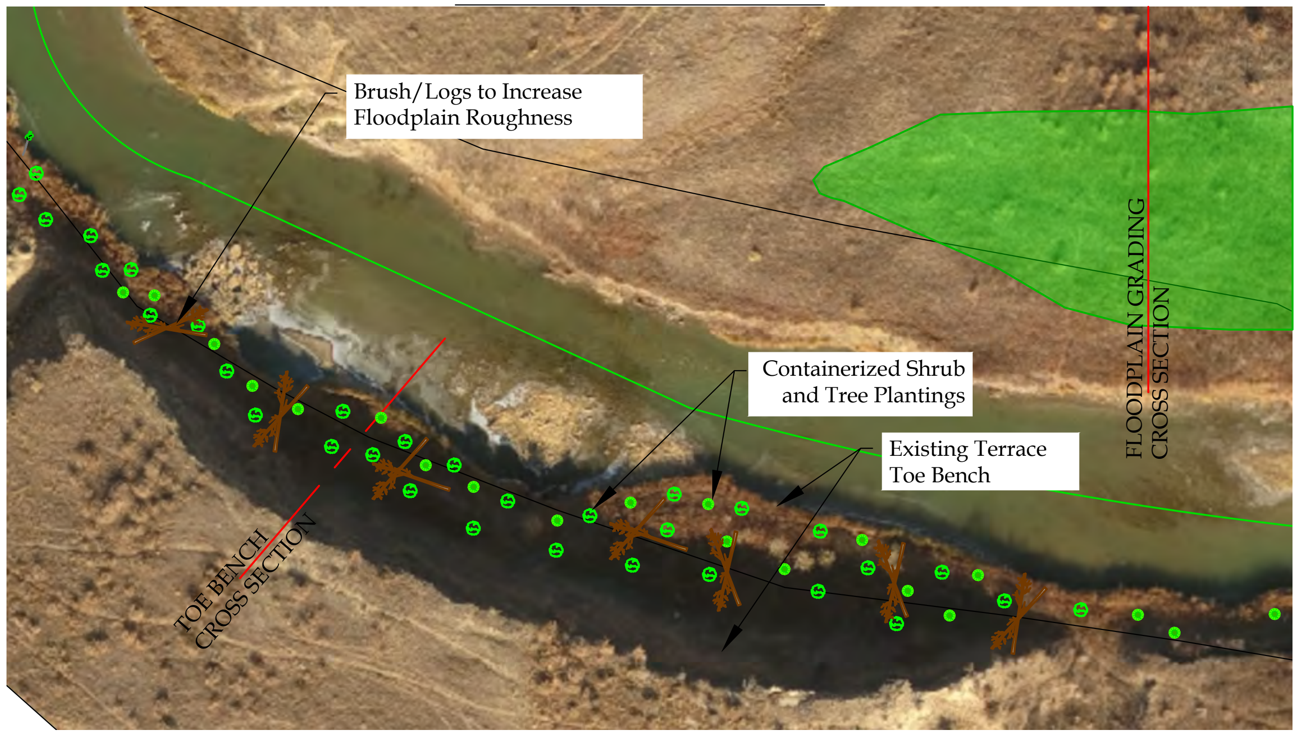
PROJECT SPONSOR: SUN RIVER WATERSHED GROUP

PROJECT: MUDDY CREEK RESTORATION
TERRACE TOE PROTECTION STACKED SOD

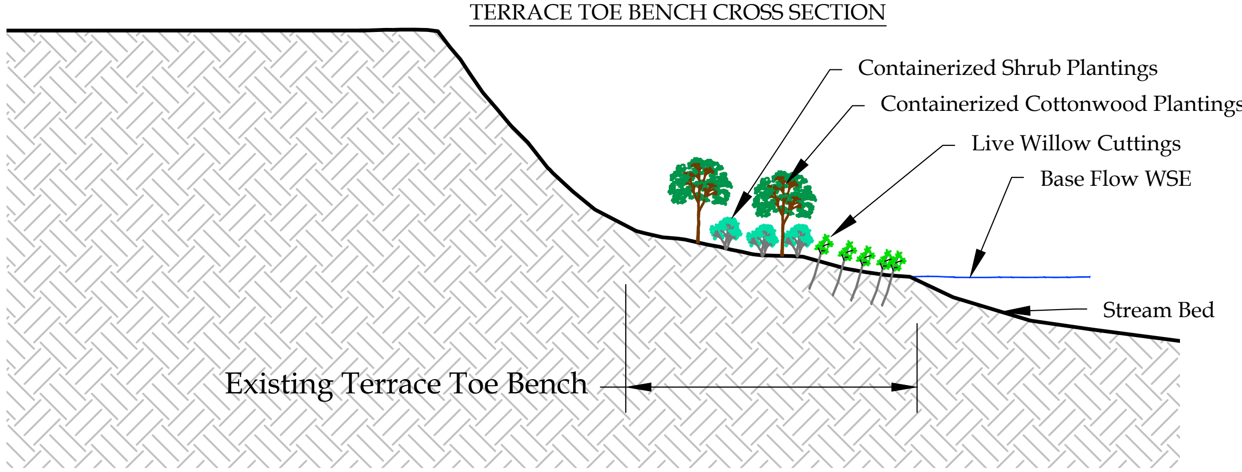
NO.	DATE	REVISIONS	BY	CHK

DRAWN:	ENGINEER:	CHECKED:	APPROVED:
TC/RS	TC	KB	

TERRACE TOE BENCH PLAN VIEW



TERRACE TOE BENCH CROSS SECTION



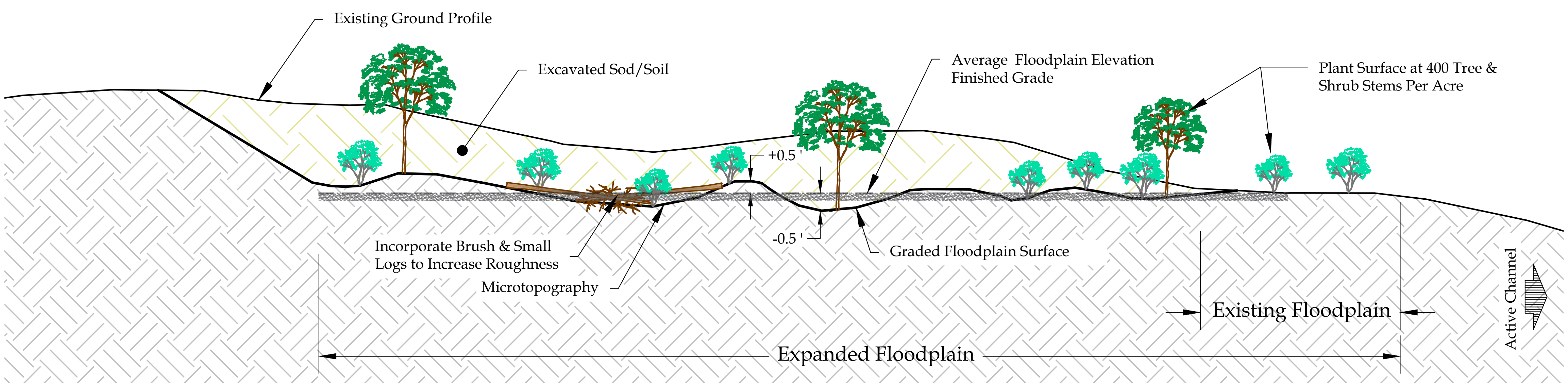
Work Description:
At numerous locations within the project reach, a narrow bench is present along the toe of terraces banks. Benches vary in width and are generally colonized with grass and a few shrubs. These benches will be targeted with live willow cutting and containerized tree and shrub plantings. Stabilizing these existing surfaces with a riparian fringe is a comparatively low cost endeavor to increase system roughness and prevent future erosion of terrace surfaces.

Notes:
1. For containerized planitings auger hole 3X the diameter of the container.
2. Install plant and backfill to the top of the root crown.
3. Mound surplus soil to create a water basin around plant.
4. Water-in plant with several gallons of water
5. Install weed mat.
6. Install browse control.
7. Create a pilot hole with a hand held dibble bar, hydraulic jet, or excavator mounted dibble bar.
8. Insert willow cutting leaving 2 to 3 buds above the ground surface elevation.
9. Water-in cuttings to ensure no air voids are present between the sides of the pilot hole and the cutting.

TYPICAL MATERIAL

TYPE	DIMENSIONS	UNITS	QUANTITY
Dormant Willow Cuttings	4' - 6' X 0.5"-2.5" Dia.	EA	1/LF
Containerized Shrubs	TBD	EA	300/AC
Containerized Trees	TBD	EA	100/AC

FLOODPLAIN GRADING CROSS SECTION



SHEET 10 OF 10
DATE: 12/8/2021
SCALE: NA
PROJECT NUMBER: 0221-01

DESIGN TEAM:
RESTORATION ENGINEERING
DTM CONSULTING
Applied Geomorphology
Trout Water Restoration

PROJECT SPONSOR:
SUN RIVER WATERSHED GROUP

PROJECT:
MUDDY CREEK RESTORATION
REVEGETATION & FLOODPLAIN GADING

NO.	DATE	REVISIONS	BY	CHK

DRAWN: TC/RS
ENGINEER: TC
CHECKED: KB
APPROVED: